MSG Meteorological Products Extraction Facility Algorithm Specification Document

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Document Change Record

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1.0	4/12/96	-	First Issue
1.2	4/7/97	EUM/MSG/DCN/070 and EUM/MSG/DCN/074	The two DCNs cover the changes of the document from Issue 1.0 to Issue 1.2
2.0	16/3/98	EUM/MSG/DCN/085	See DCN for details
2.1	8/4/98	EUM/MSG/DCN/104	See DCN for details
2.2	19/6/98	EUM/MSG/DCN/143	CLM product added, see DCN for details.
2.3	2/3/98	EUM/MSG/DCN/163	See DCN for details
2.5	17/09/02	EUM/OPS-MSG/DCN/03/0014	See DCN for details – EUM/OPS-MSG/DCN/03/0014
2.6	01/06/04		Reflects MSG MPEF Release 13.9
2.7	21/11/05		Reflects MSG MPEF Release 14.2
2.8	06/06/06		As detailed in AR 14307.2: §5.2.1 - First paragraph rephrased for better clarity. §5.2.3 - Table "STATIC APPLICATION DATA - THRESHOLDS AND PARAMETERS", first parameter: “thresH” --> “threshold”. Figure 5-1 SCE Processing: typo “contine” --> “continue”. §5.3.2.6 – 2 typos on page: “M-X” --> “MAX”. §5.4 – Second table: Scenes types values “1 to 96” expanded to list each value with meaning. §6.3.2.5 – Many instances of typo “then a threshold” --> “than a threshold”. §6.4.1 – Second table: Scenes types entry added to reference or list each value with meaning.
v3	02/07/07		New products added: §20 DIV Divergence & §21 FIR Fire. Corresponding references added to §3.1 & §3.2.2. Figure 2-3 updated to include all current products. §7 AMV: Extensive updates reflecting

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			new version 1.8, including height assignment and target optimisation, addition of Recursive Filter Function and Upper Level Divergence. §18.2.2 Table 18-1 provided with number/caption. §3.2.1 Corrections to titles: World Meteorological Organisation → World Meteorological Organization Global Precipitation Centre Project → Global Precipitation Climatology Project International Satellite Cloud Climatology Programme → International Satellite Cloud Climatology Project Products SCE, CLA, CDS, TH, SST, TOZ, CRM: Table 'Prec'/'Acc' column values for sun and satellite zenith angles, which were variously 0.01, 0.1 or 1, corrected to 10^{-6} (in most cases). CLAI and CTH image products: Mention of GRIB-2 encoding added. Calculation of image size corrected from 1238 to 1237 pixels (§6.4.3 for CLAI, §8.4 for CTH). Appendix C: Acronyms added: EBBT, GSDPC, ICSU, WRCP.
v3A	15/11/07		§5 Scenes Analysis: Many updates made throughout the section (for version 1.8). §6.3.2.3 & §10.3.2: Multiplication sign in formulae changed from 'x' to '*' for consistency.
v3B	27/12/07		New product added: §22 MPE Multi-Sensor Precipitation Estimate. Corresponding references added to §3.1 & §3.2.2, and updates to §1.2 and Figure 2-3. All references to Requirements Spec documents FRS and FMRS removed by either deleting or replacing by suitable alternative as necessary. Acronym list updated to add many new entries used in body text; a few others corrected, or expanded in body text instead.
v4	16/05/08	EUM/MSG/AR/17182.3 EUM/MSG/AR/17598.2 (with EUM/MSG/AR/14950.4) EUM/MSG/AR/17715.2	§5 SCE Scenes Analysis: Updates to channel availability criteria, and to threshold tests for sunglint and scattering angle, and addition of high viewing angles. §6 CLA Cloud Analysis: §6.3.3 Algorithm Description for Final

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			CLA clarified; §6.4.1 Extra value 3 for 'semi-transp_flag' of Intermediate CLA Product; §6.4.2 In table for Final CLA Product, 'total cloud amount' replaced by 'effective cloud amount' (AR 17182). §10 ASR All Sky Radiance product added. §14 TH Tropospheric Humidity: 'Missing' setting if cloudy (AR 17598); 'number of cloudy pixels' changed to 'percentage of cloudy pixels'; addition of quality indicators; some typos.
v4A	01/11/08	ECP 814 EUM/MSG/AR/18113	§16.3.2.2.2 Cross Satellite Cal section updated. §2: Mention added of RSS, with new section 2.2 inserted and updates to sections 2.1, 2.2.2.2, 3.2.2, 5.3.1, 5.3.2.1, 7.3.1, 19.2.2. Acronym list: RSS added. §6 CLA: Some values in table in §6.2.2 corrected. In §6.4.1 first table updated to correct values and remove entries 'cloud phase' and 'semi-transparency flag'; second table split into two and second part rewritten to better describe CLA_int_quality_flag. §10.3.1: Step bulleted list numbering corrected. §22 FIR: Extensive updates for new Fire algorithm.
v4B	02/12/08	EUM/MSG/AR/18587, EUM/MSG/AR/18603	CRM product now derived every 2 h between 06 & 20 UTC, not just at noon, so text updates required in §3.2.2 (CRM para), §5.3.2.7, §20.3.1 and §20.3.2.2. AMV updates in release 14.8 require document updates to: §7.2.3 - new parameters in two new tables, also existing param 'max_pres_diff' moved to new table. §7.3.2.6 - sentence update. §7.3.3.2.1 - addition of encoding filter description (new section).
v4C	13/11/09	ECP 899, AR 18745, AR 19113, AR 19273	§4 RTM: Extensive table and descriptive updates resulting from replacement of SYNSATRAD model by RTTOV, including removal of semi-transparency
v5	16/11/09		§7 AMV: Further updates to tables for Static Application Data and Final Product.

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
v5A	22/02/11	ECP 974, AR 19824	New chapters inserted after Scenes Analysis, for BDRF Table and NDVI Product. NDVI references added to §3.1 & §3.2.2, Figure 2-3 and Acronyms list. TOZ: Algorithm description of final product (now §20.3.2) updated to add also option to use current repeat cycle. Also final product segment size is now 3x3 not 32x32 pixels. GII/RII: GII segment size change – update to table Value entry and to sentence on horizontal resolution (§21.2.2).
v5B	01/09/11	STM_DOCET_73 (after OPS_ECPD_235)	Updates to §20 TOZ & §21 GII (TOZ now generated as by-product of GII). §7.4.2 updated for NDVI encoded product generation.
v6	31/07/12	TBC	Update to § 27 for new Volcanic ash Detection and retrieval product generation specifications.
v6A	09/07/12		Update to §9 for change in AMV algorithm. Specifically, Sections 9.3.2.5.9 through 9.3.2.5.15 were removed. Section 9.3.2.5 replaced them.
v6B	09/08/12		Formatting changes to match current specifications for document template
v6C	09/09/12		New version added for configuration control of document.
v7	28/03/13	Related ECP (ECR220)	New sections 9.3.2.5.8 and 9.3.2.5.9 added. Previous sections 9.3.2.5.8 and 9.3.2.5.9 moved to new sections 9.3.2.5.10 and 9.3.2.5.11
v7A	20/03/14	Changes to AMV Height Assignment Algorithm	9.3.2.5.6 Inversion Height Assignment text changed 9.3.2.5.11 section added (Forecast Best-Fit Pressure) Added text to new section 9.3.2.5.12 9.3.3.1.2 Changed algorithm specifications for Spatial Consistency Test 9.3.3.1.7 Added text to Image Correlation Test 9.4.2 Appended text to Final AMV Product section
v7B	23/10/15	Related ECP (ECR 535), ECPD 544	Sections 9.3.2.6 and 9.4.2. changed with new text to describe AMV algorithm. 2.3.2.1 Added the new RTM 2-path transmission table to the list of RTM output tables. 3.3 Removed reference to 'IR' in RTM, since the new RTM includes solar affected channels. Chapter 4 the solar channels are added in the description of the RTM, since the new version of RTTOV processes solar and IR channels. 4.2 Updated the version of RTTOV and the coefficients file used in the RTM. 4.2 The SYNSATRAD specific input parameters are removed from Tables 3, 4, 5, and 6. Table 7 is added to include the input parameters required for the 2-path transmission table.

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			4.3.1 Added the solar affected channels processed by the RTM and added the 2-path transmission table to the list of generated RTM tables. 4.3.2.3 Added description of the 2-path transmission table. 4.4. Added table 11 detailing the output in the 2-path transmission table. 4.5 Ammended the test data and test results. 4.7 Updated the references for the RTTOV 11 documents and the MPEF validation test report. 4.8 Removed SYNSATRAD specific Mnemonic descriptions from the Symbols and Description table. Added new chapter 18 to describe the OCA product. 9.3.2.5.1 Added text to introduction defining height assignment and the OCA product 9.3.2.5.3 Revised text describing pixels of the “cold branch” used to calculate pressure 9.3.2.5.5 Added text for height assignment 9.3.2.5.9.1 Appended text at end of the section describing EBBT pressure based on CCC using all pixels. 9.3.2.5.11.2 Changed text defining the temporary solution adapted for EBBT pressure. Section 9.4.2 Corrections to Notes in table and appendage of text at the end of the table.

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1 INTRODUCTION

1.1 Purpose and Scope of the Specification

This document is the Algorithm Specification Document (ASD) for the Meteosat Second Generation (MSG) Meteorological Products Extraction Facility (MPEF).

The purpose of this document is to describe the scientific algorithms which will be used to extract the Meteorological Products from the pre-processed Level 1.5 image data acquired by the Spinning Enhanced Visible and Infra Red Imager (SEVIRI) on board the MSG series of satellites.

SEVIRI produces images in twelve spectral channels, in the Visible (VIS), Near InfraRed (NIR) and InfraRed (IR, along with water vapour (WV)) part of the spectrum covering the following channels: VIS 0.6µm, VIS 0.8µm, NIR 1.6µm, IR 3.9µm, WV 6.2µm, WV 7.3µm, IR 8.7µm, IR 9.7µm, IR 10.8µm, IR 12.0µm, IR 13.4µm and High Resolution Visible (HRVIS) channel. The imaging yields a resolution of 3 km (at satellite nadir) and 1 km for the HRVIS channel. Further information on the SEVIRI instrument and the Level 1.5 image data can be found in [RD1]. This document should be understood by anyone with a basic university level understanding of Mathematics. A background in either Meteorology or Remote Sensing is also required in order to understand the more detailed scientific requirements.

This document provides detailed scientific requirements for the algorithms; however, the requirements will need some interpretation by the contractor in order for the algorithms to be implemented.

This document describes the algorithms in sufficient detail to ensure that their implementation is scientifically correct, but does not attempt to impose an overall software design.

1.2 Document Structure

This document contains the following sections:

Chapter 1	Describes the purpose and scope of the document, lists any open issues or assumptions which have been made in the production of this specification, provides an overview of the MPEF, defines the applicable and reference documents and identifies how requirements are specified in the remainder of the document.
Chapter 2	Contains an introduction to the Product Generation function of the MPEF and explains the terminology used in the document. The Product Generation sub-functions are also described.
Chapter 3	Contains an introduction to the MPEF products and the algorithms required to generate them. It also provides information on the algorithm prototyping and on how to interpret the algorithm specifications.
Chapters 4	Contain the specifications for the individual algorithms.

1.3 Purpose of the MPEF

The MPEF is a part of the MSG Ground Segment, its primary function is the generation of Meteorological Products from the Level 1.5 image data supplied by the Image Processing Facility (IMPF). The products are then quality controlled and encoded prior to being passed to the Data Acquisition and Dissemination Facility (DADF) for delivery to users. Additionally, the products generated by the MPEF are transferred to the MSG Unified Meteorological Archive and Retrieval Facility (UMARF) for online and off-line retrieval.

1.4 Related Documents

1.4.1 Applicable Documents

The applicable documents for this specification are referenced in the individual algorithm specifications, as defined in Section 3.4.

1.4.2 Reference Documents

The following documents are the reference documents for this specification. Where referred to in the text these are referenced using the form RD.n, where n is the appropriate number from the list below.

RD.1	Level 1.0 and Level 1.5 Image Data Characteristics,	EUM/MSG/TEN/068, Issue 1.1, 2/7/96.
RD.2	Radiances to Brightness Temperature Conversion,	EUM/OPS/TEN/05/2556
RD.3	Conversion from Radiance to Reflectance for SEVIRI Warm Channels	EUM/MSG/TEN/05/2986

1.5 Identification of Requirements in this Document

This document concentrates on the lower level requirements imposing the use of specific algorithms for the product generation. Requirements are not explicitly numbered. The following formatting has identifies tasks that contain mandatory requirements:

The word '**<u>shall</u>**' (in bold and underlined) indicates that the function/task is mandatory.

1.6 Acronyms/Abbreviations and Terms used in this Document

A list of words or expressions with a specific meaning in the context of this document can be found in 0, and are also described in Section 2.1.1. Where relevant, such terms are indicated by *italics* in text. A list of acronyms and abbreviations used in this document is below. On first use in a section, an acronym or abbreviation will be spelled out.

Example: Development of the Rapid Scanning Service (RSS) will continue in the future.

Acronym	***Meaning***
A&R	Analysis and Reporting
AES	Aerosol Properties Over Sea Product
AMV	Atmospheric Motion Vectors Product
AMVI	Atmospheric Motion Vectors Image Products
AOT	Aerosol Optical Thickness
AQC	Automatic Quality Control
ASD	Algorithm Specification Document
ASR	All Sky Radiances Product
AVHRR	Advanced Very-High Resolution Radiometer
BDRF	Bi-Directional Reflectance Function
BUFR	Binary Universal Form for the Representation of meteorological data

Acronym	Meaning
CAL	Calibration Support Product
CDP	Collocated Data Point
CDS	Climate Data Set Product
CLA	Cloud Analysis Product
CLAI	Cloud Analysis Image Product
CLM	Cloud Mask Product
CMS	Centre de Métorologie Spatiale (of Météo-France, in Lannion)
CRM	Clear Sky Reflectance Map Product
CSICC	Cross Satellite Instantaneous Calibration Coefficient
CSOCC	Cross Satellite Operational Calibration Coefficient
CSR	Clear Sky Radiances Product
CTH	Cloud Top Height Product
DADF	Data Acquisition and Dissemination Facility
DCP	Data Collection Platforms
DIV	Divergence Product
DMSP	Defense Meteorological Satellite Program (of USA)
EBBT	Equivalent Black Body Temperature
ECMWF	European Centre for Medium-range Weather Forecasting
EMD	External Meteorological Data
EPS	EUMETSAT Polar System
EPS	EUMETSAT Polar System
ESA	European Space Agency
EUMETCast	EUMETSAT's data distribution system, which multicasts meteorological and environmental data and products to the user community via telecommunication satellites
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FFT	Fast Fourier Transform
FIR	Active Fire Monitoring Product
FOV	Field Of View
FSD	Foreign Satellite Data (e.g. in Low Earth Orbit)
FTP	File Transfer Protocol
GII	Global Instability Index Product
GMS	Geostationary Meteorological Satellite (of Japan)
GOES	Geostationary Operational Environmental Satellite
GPCP	Global Precipitation Climatology Project
GRIB	General Regularly-distributed Information in Binary form (WMO standard for exchanging gridded data; GRIB Edition 2 (GRIB-2) is current version)
GSDPC	Geostationary Satellite Data Processing Centre
GTS	Global Telecommunication System
HPI	GPCP High Resolution Precipitation Index Product

Acronym	*Meaning*
ICAO	International Civil Aviation Organization
ICSU	International Council for Science
IDS	ISCCP Data Set Product
IGBP	International Geosphere-Biosphere Programme
IR	Infrared (channels of SEVIRI)
ISCCP	International Satellite Cloud Climatology Project
LEO	Low Earth Orbit
LSD	Local Standard Deviation
LST	Land Surface Temperature (product of Land Surface Analysis SAF)
LUT	Look-Up Table
M&C	Monitoring and Control
MODIS	Moderate Resolution Imaging Spectroradiometer
MOP	Meteosat Operational Programme
MPE	Multi-sensor Precipitation Estimate Product
MPEF	Meteorological Products Extraction Facility
MQC	Manual Quality Control
MSG	Meteosat Second Generation
MTP	Meteosat Transition Programme
NDVI	Normalised Difference Vegetation Index Product
NIR	Near Infrared (NIR1.6 channel of SEVIRI)
NOAA	National Oceanic and Atmospheric Administration (also the series of LEO satellites operated by this organisation)
NRT	Near Real Time
NTC	Normalised Total Contribution
NTCC	Normalised Total Cumulative Contribution
NWP	Numerical Weather Prediction
OCC	Operational Calibration Coefficient
OCA	Optimal Cloud Analysis
PB	Processing Box
PNG	Portable Network Graphics (image format)
PQM	Product Quality Monitoring
QI	Quality Index
RFF	Recursive Filter Function
RII	Regional Instability Index Product
RMS	Root Mean Square
RSM	Radiance Sampling Method
RSS	Rapid Scanning Service
RTM	Radiative Transfer Model
RTTOV	Radiative Transfer model for TOVS

Acronym	*Meaning*
SAFNWC	SAF to support Nowcasting and Very Short-Range Forecasting
SCC	Satellite Calibration Centre
SCE	Scenes Analysis Product
SD	Standard Deviation
SEVIRI	Spinning Enhanced Visible and InfraRed Imager (on MSG satellites)
SNR	Signal-to-Noise Ratio
SPC	Sector Processing Centre
SSM/I	Special Sensor Microwave Imager (instrument on the US DMSP polar satellites)
SSP	Sub-Satellite Point
SST	Sea Surface Temperature Product
STC	Semi-Transparency Correction
TBC	To be confirmed
TBD	To be defined
TH	Tropospheric Humidity Product
TIROS	Television and InfraRed Observation Satellite (US polar satellite series)
TOA	Top of Atmosphere
TOVS	TIROS Operational Vertical Sounder
TOZ	Total Ozone Product
UMARF	Unified Meteorological Archive and Retrieval Facility (also known as EUMETSAT Archive or EUMETSAT Data Centre)
UTC	Coordinated Universal Time
VAS	VISSR Atmospheric Sounder (GOES instrument)
VICC	Vicarious Instantaneous Calibration Coefficient
VIS	Visible (VIS0.6, VIS0.8, HRVIS channels of SEVIRI)
VISSR	Visible and Infrared Spin Scan Radiometer (GOES instrument)
VOCC	Vicarious Operational Calibration Coefficient
VOL	Volcanic Ash Detection Product
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WV	Water Vapour (WV6.2, WV7.3 channels of SEVIRI)

2 INTRODUCTION TO PRODUCT GENERATION

2.1 Introduction

This chapter provides an introduction to the MPEF Product Generation function. The descriptions in this chapter are applicable to both the standard operational service as well as to the Rapid Scanning Service (RSS) (see Section 2.2).

The product generation task can be further subdivided into a number of functions, namely:

- Data Preparation (on- and off-line)
- Application Data Preprocessing
- Product Processing
- Product Verification
- Calibration Support

Description of these major functions are included in Section 2.3.

2.1.1 Terminology

The following general terms have a specific meaning when used in this document. As such, their specific meanings should be thoroughly understood when reading this document. Most of these terms are also defined in 0 at the end of the document, but are repeated here for clarity. Although both types of data are described below, this document concentrates mainly on the application data.

Term	***Meaning***
Data	‘Data’ is used in a generic sense in this document to refer to all types of ‘information’ which may be required in order for the MPEF or its scientific algorithms to operate. The term ‘data’ may thus refer to input/output products, databases, data files, individual parameters, control data, monitoring data etc.
Application Data	The scientific data required for, and produced by, the scientific algorithms, e.g. all input data, the products, intermediate products.
System Data	These data are required by the facility to allow it to operate.
Algorithm	A ‘self contained’ routine which inputs data, performs certain processing and then outputs data, e.g. Scenes Analysis. An algorithm may generate a product or may generate intermediate results required by subsequent processes.
Product	A product may be classed as a collection of parameters which are generated by an algorithm(s) and which are supplied to an external facility. For all products it will be possible to specify the destination(s).
Intermediate Product	Any intermediate results or product which is generated during processing which is not disseminated to users but is required to generate another product. These products may be required to be stored in the UMARF.
Processing Segment	A ‘segment’ of size n by n level 1.5 image pixels, where n is configurable and product-specific.
Superpixel	A processing segment made up of nominally 3 by 3 level 1.5 image pixels.
Synoptic scale	Providing a horizontal accuracy of 100 km or better, this corresponds nominally to a processing segment of between 16 × 16 and 32 × 32 level 1.5 image pixels.

2.2 Rapid Scanning Service

In addition to the operational service with a 15-minute image frequency, a Rapid Scanning Service (RSS) is provided, using the backup spacecraft when available. This service provides a 5-minute image frequency over a limited area, from 15° N to 70° N (approximately). Due to hardware limitations, the MPEF RSS processing area is further limited from 35° N to 70º N (approximately). The following MPEF products are produced for the rapid scan area:

Product	*Frequency*	*Comments*
AMV	20 minutes	AMV Channel 2 (VIS 0.8) and 9 (IR 10.8) only
CSR	15 minutes	
MPE	5 minutes	
FIR	5 minutes	
GII	5 minutes	Segment size is 3 × 3 pixels

The basic approach for RSS is to apply the same product algorithm as for the normal scanning. For products where this is not the case, the differences are described in the respective product section below.

After a planned hardware upgrade, the full RSS image area will be processed and more AMV channels and the Divergence product will be added.

It is emphasised that the MSG MPEF Rapid Scanning Service is on trial basis, with outstanding issues to be clarified in an ongoing process. The main purpose with the trial service is to make it possible for users to gain experience of the products.

2.3 Product Generation Functions

This section contains a description of all the MPEF functions relating to the Product Generation function.

Figure 1 shows the relationship of these functions in terms of the application data flows. This diagram is concerned solely with the scientific flows rather than the system data-related flows like Monitoring and Control.

To implement the scientific functionality to produce the required results, functions have been subdivided into a number of algorithms. However, it should be noted that the grouping of the algorithms into these functional groups should not be considered to be a design constraint.

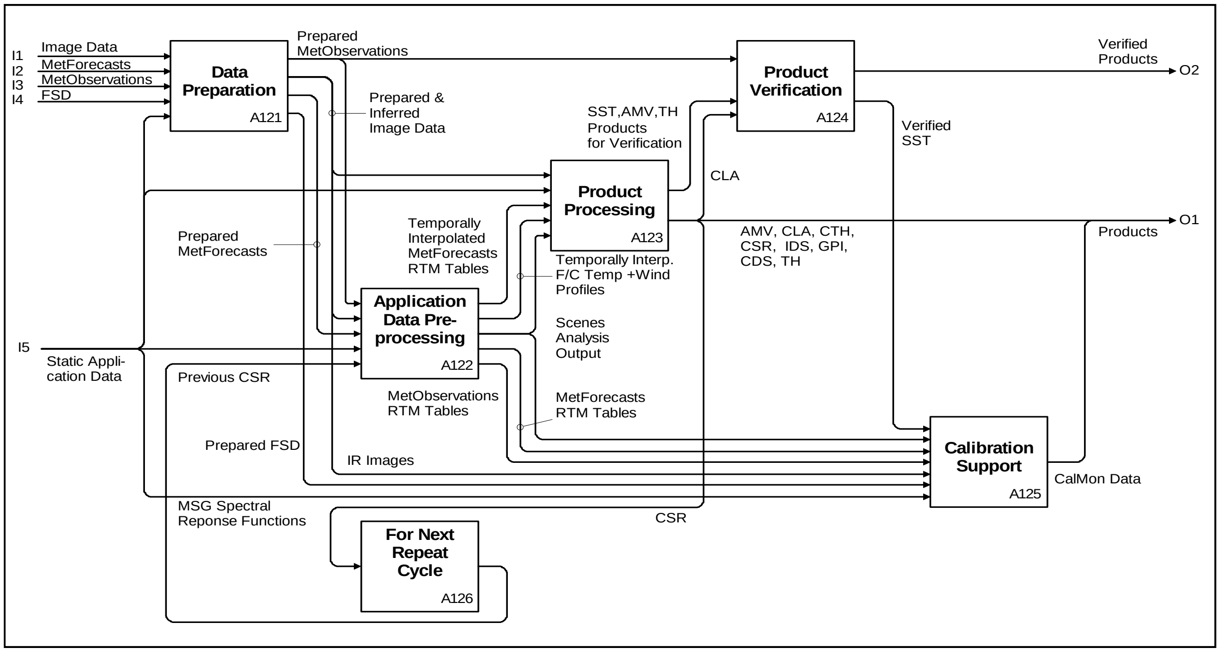

Figure 1: Product Generation Application Data Flow Diagram

2.3.1 Data Preparation

Data Preparation is split into the online and off-line functions described below:

Online Data Preparation	This involves the preprocessing of the near-real-time level 1.5 image data supplied by the IMPF, formatting the Foreign Satellite Data (FSD) and the decoding and reformatting of the External Meteorological Data (EMD) (i.e. forecast and observation data) supplied by the DADF. The dynamic application data required by the subsequent algorithms are derived from these input data.

Off-line Data Preparation	This covers the tailoring of the static application data sets for the MPEF processing. Examples of these data sets are background surface data, coastline data or spectral response curves for the SEVIRI channels. All these data sets are held under configuration control.

2.3.2 Application Data Preprocessing

Application data preprocessing involves the generation of data which are required by many of the subsequent algorithms. There are two major processes which must be performed, radiation modelling and scenes analysis Figure 2 shows the application data flows for these functions.

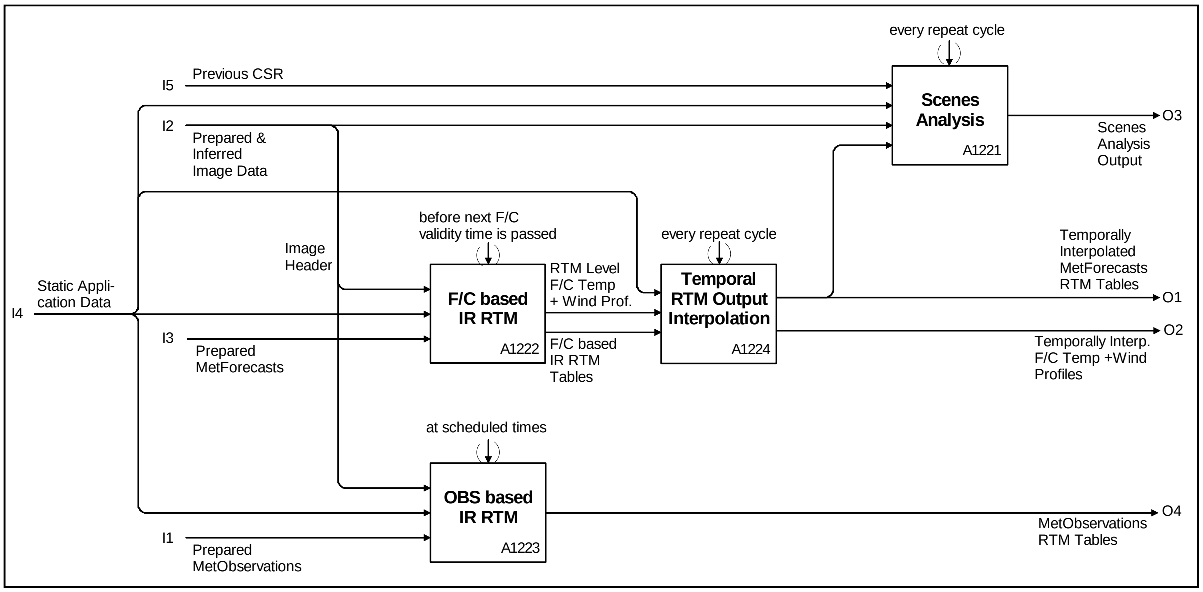

Figure 2: Application Data Preprocessing Data Flows Diagram

2.3.2.1 Radiation Modelling

Radiation Modelling is the process of modelling the radiative state of the atmosphere under a range of atmospheric states and satellite viewing angles.

The Radiative Transfer Model (RTM) is used for all SEVIRI channels. The IR RTM will be able to calculate the IR channel radiance at the top of the atmosphere (TOA) in the direction of the satellite taking these factors into account:

- the absorption and re-emission of the infrared radiance by different atmospheric gases;
- the emissivity of the surfaces (clouds and earth surfaces);
- the influence of clouds at different levels on the infrared radiation.

The solar RTM will be able to calculate the 2-path transmittances in all channels affected by solar radiation, taking into account:

- the absorption of radiance by different atmospheric gases and discounting extinction by molecular scattering (Rayleigh);

The radiative transfer calculation will include the spectral response function for each of the SEVIRI channels given above.

It is assumed that the specified IR radiation model is used to support both the near-real-time product generation and the calibration support processing.

For the support of product generation, the RTM will use forecast data. The forecast data are provided nominally on a 1° by 1° grid for 31 atmospheric levels requiring the RTM to produce results for all grid points within the EMD processing area for cloud-free cases and assuming opaque clouds at a configurable number of levels, nominally 15.

The RTM produces the following output tables for product generation support:

- atmospheric correction tables
- semi-transparency correction tables
- tropospheric humidity generation tables
- contribution function tables.
- two-path transmission tables.

For calibration support, meteorological observations data will be used in the IR RTM processing. The output of the RTM based on meteorological observation data will contain results only at the location of the observations. The RTM produces the following output tables for calibration support:

- vicarious calibration tables.

2.3.2.2 Scenes Analysis

Several products which are derived from the MSG image data require information on the type of scene contained within a pixel. While some products are derived from cloudy pixels (e.g. Cloud Top Height), others are derived from clear pixels only (e.g. Clear Sky Radiances). For calibration monitoring and vicarious calibration, it is very important that the pixels of selected Earth targets are really cloud-free. Thus the classification of the pixels within the image, i.e. Scenes Analysis, is a critical process within the MPEF.

The main function of Scenes Analysis is to identify whether a pixel contains clouds or not. In this process, pixels partially covered by clouds or covered with semi-transparent clouds will also be marked as cloudy. Pixels identified as clear will contain the information of the surface type (taken from the surface type mask), except for pixels which are identified by the algorithm as snow-covered or ice-covered, which will be marked accordingly.

Scenes Analysis is based on currently operational threshold techniques and includes functionality that uses the data of the previous image as a prediction for the current image. Additionally, use is also made of spatial information (maximum, minimum, mean, standard deviation). The threshold technique makes optimal use of the spectral information provided for each pixel for all twelve channels.

The Scenes Analysis result is produced on a pixel basis for the whole MPEF processing area.

2.3.3 Product Processing

This function is responsible for the generation of the meteorological products. The data which have been produced by the Data Preparation and Application Data Preprocessing functions are used as input, with further calculations performed using these data in order to derive the meteorological products.

Figure 3 shows the top-level breakdown into the product generation algorithms. The diagram shows the MPEF application data flows, the inputs, outputs and interactions between these algorithms. These diagrams are concerned solely with the scientific flows rather than the system data-related flows, for example monitoring and control (M&C).

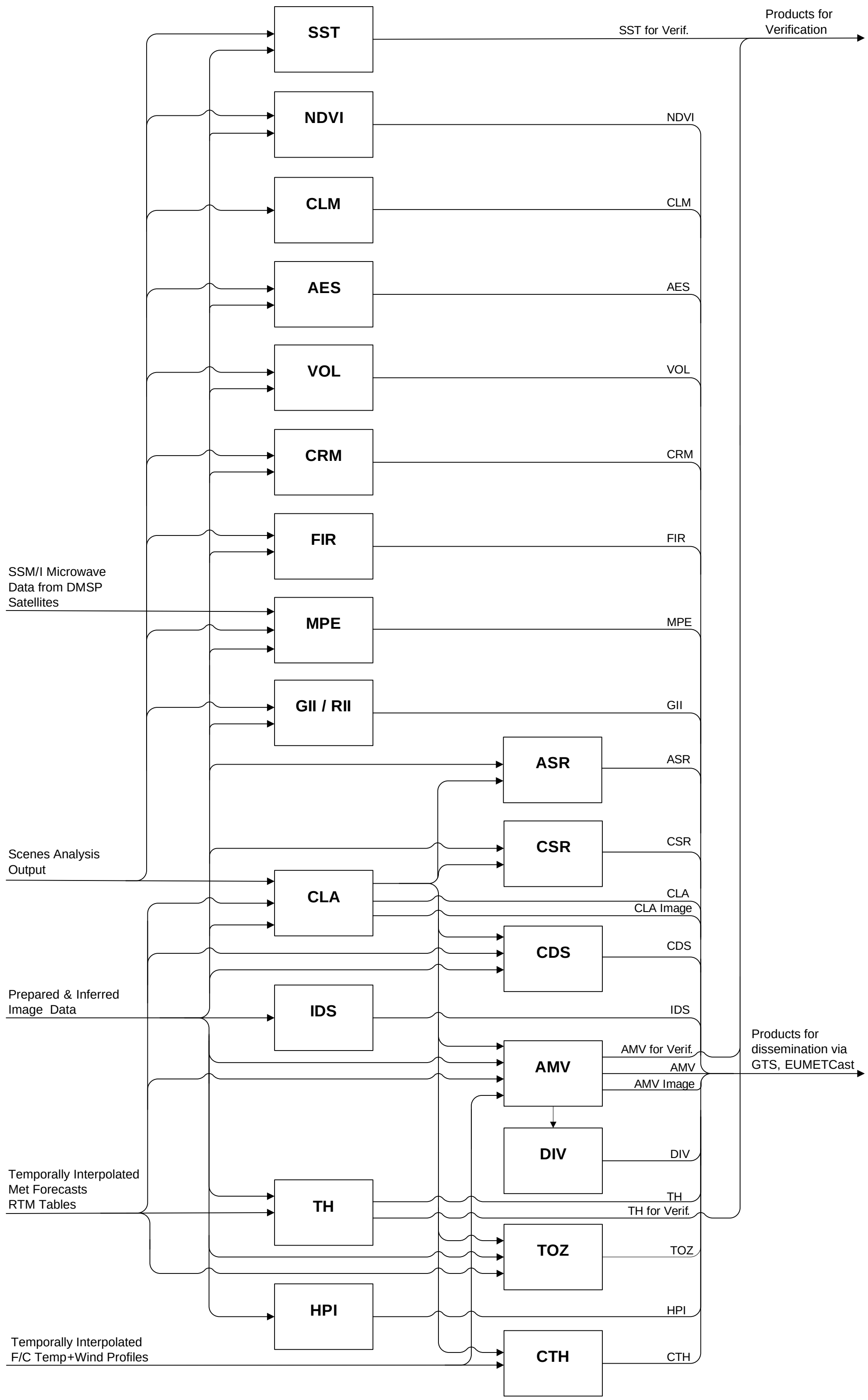

Figure 3: Product Processing Application Data Flow Diagram (Inter-algorithm interfaces) ***Note****: Static application data input, which applies to all products, has been omitted from this diagram.*

Disseminated products are produced at varying horizontal scales. These horizontal scales are product-specific and configurable, and are defined by means of the product-specific processing segment,, e.g. synoptic scale (nominally between 16 × 16 and 32 × 32 Level 1.5 image pixels) or superpixel scale (nominally 3 × 3 Level 1.5 image pixels). Table 1 shows the approximate number of pixels within the MPEF processing area for various different processing segment sizes.

By implication, once the processing segment size is specified, the level 1.5 image pixels which are contained in each segment (line and column numbers) and the physical location of each segment, (corners and centre), in terms of latitude and longitude, are fixed.

Processing Segment Size	*# nominal segments*	*# HRVIS segments*
Pixels	9274440	54473190
3 pixels by 3 pixels	1030493	6052577
32 pixels by 32 pixels	9058	53197
1° by 1°	14217	14217

Table 1: Processing Segments in the MPEF Processing Area

The products have different dissemination frequencies which are published on the EUMETSAT website:

Access to Data/ Meteosat Meteorological Products/Product Schedule

Due to the repeat cycle concept of MSG, the products to be disseminated are not extracted at 'fixed' times but will be extracted from the repeat cycle(s) which are closest to the required UTC. However, the products may be extracted from more repeat cycles, with only those relating to the required dissemination times actually being disseminated.

2.3.4 Product Verification

Some products have their quality verified and continuously monitored using independent meteorological data (as radiosonde observations) and/or forecast data. The methods are further described in the respective product descriptions below and the results are stored in a database within the EUMETSAT ground segment.

2.3.5 Calibration Support

Calibration Support is composed of two main areas which are described below:

- Calibration Monitoring for both VIS/NIR and IR channels
- Absolute Calibration for both VIS/NIR and IR channels

2.3.5.1 Calibration Monitoring - IR Channels

Level 1.0 data received from the satellite and the Primary Ground Station are transformed into level 1.5 data which are radiometrically and geometrically corrected. This task is performed operationally by the IMPF. Part of the process of radiometrically transforming the data from level 1.0 to level 1.5 involves calibration of the IR SEVIRI channels using the on-board black body. MPEF receives the level 1.5 data in the form of corrected counts and a set of calibration coefficients which are used to transform the counts to radiances valid at the top of the atmosphere (TOA), convolved with the spectral response function of each spectral channel.

The radiometric accuracy of the level 1.5 data has to be assured over the lifetime of the satellite.

Calibration monitoring will involve the extraction of statistical data (bias and RMS) describing the difference between the measured level 1.5 radiances (for clear sky cases) and the radiances calculated from external data (such as observations or other satellites and meteorological forecasts), in order to detect whether any changes are required to the calibration coefficients.

The results from calibration monitoring will be sent to the IMPF; results include a flag indicating whether a change to the calibration coefficients currently being used is required.

2.3.5.2 Absolute Calibration - IR Channels

Absolute Calibration is responsible for deriving absolute calibration coefficients for the eight infrared channels of MSG:

- IR3.9
- WV6.2
- WV7.3
- IR8.7
- IR9.7
- IR10.8
- IR12.0
- IR13.4

This is done independently from the on-board calibration. The output of this process consists of tables describing the temporal evolution of the Absolute Calibration Coefficient. This information is provided to the IMPF for further processing.

The Absolute Calibration Coefficients are calculated as a weighted mean of the Vicarious Operational Calibration Coefficient, derived using forecast data, meteorological observations, and the Cross Satellite Operational Calibration Coefficient derived from Foreign Satellite Data.

2.3.5.3 Calibration Support - Solar (VIS/NIR) Channels

The solar radiation modelling required to support the calibration monitoring and absolute calibration of the SEVIRI VIS/NIR channels is not part of the MSG MPEF processing.

There is no on-board calibration foreseen on MSG for the VIS channels, unlike for the IR channels,

The calibration coefficients and monitoring information for the VIS/NIR channels and different surface types are transferred off-line to the MSG MPEF from whence they will be transferred online to the IMPF, together with the IR calibration monitoring results.

2.3.5.4 Calibration Campaigns

A calibration campaign is planned as early as possible after an MSG satellite launch. The campaign will cover the calibration of the thermal IR channels and the VIS and NIR channels. The results will be used to verify the pre-launch calibration of the SEVIRI channels and will provide a reference for the operational calibration and the MPEF calibration monitoring. The calibration campaigns will use level 1.5 image data from the DADF or the UMARF. There is no functionality required in the MSG MPEF to support the calibration campaigns.

3 ALGORITHMS AND PRODUCTS

This chapter provides further information on the products themselves and the algorithms which are required to generate them. It also provides information on the structure of the algorithm specifications and how to interpret them.

3.1 Overview

There are two types of algorithms which are specified in this document – those which have been prototyped and those which have not.

The algorithms which have been prototyped are those for which there is a high scientific content. Where the existing MOP or MTP algorithms have required significant modifications, or completely new algorithms have been developed, prototyping has been used to ensure that these new or modified algorithms are scientifically valid, can produce the expected results, and can meet the required accuracy criteria.

The remaining algorithms, which have not been prototyped, perform much simpler, non-scientific tasks like reformatting of data, and thus do not need the same level of investigation and testing as the former category.

The current issue of the ASD covers the specifications of the following products to be generated by the MPEF. These products form the baseline for the MSG MPEF development:

- Atmospheric Motion Vectors (AMV)
- Cloud Analysis (CLA)
- Cloud Analysis Image (CLAI)
- Cloud Top Height (CTH)
- Clear Sky Radiances (CSR)
- Climate Data Set (CDS)
- High Resolution Precipitation Index (HPI)
- ISCCP Data Set (IDS)
- Tropospheric Humidity (TH)
- Calibration Monitoring Data (CAL)

Furthermore, specifications for other products are also included in the current issue of the ASD. These products will be used in the internal product generation process, but will not be distributed to the end-users. If the baseline changes it **shall** be required to distribute these products as well:

- Sea Surface Temperature (SST)

The following products are new and have been added to the ASD during the course of the MPEF development:

- Aerosol Properties Over Sea (AES)
- All Sky Radiances (ASR)
- Cloud Mask (CLM)
- Clear Sky Reflectance Map (CRM)
- Divergence (DIV)

- Active Fire Monitoring (FIR)
- Global Instability Index (GII) / Regional Instability Index (RII)
- Multi-Sensor Precipitation Estimate (MPE)
- Total Ozone (TOZ)
- Volcanic Ash Detection (VOL)
- Normalised Difference Vegetation Index (NDVI)
- Optimal Cloud Analysis (OCA)

The Atmospheric Motion Vectors Image (AMVI) product has been removed from baseline MPEF product generation. The AMVI product can still be generated as an output of AMV product generation, but it is expected that this will not be scheduled to take place in the future.

Most MPEF products are required to be disseminated in a particular format, e.g. BUFR, as defined by the World Meteorological Organization (WMO). Where this is required it has been indicated in the relevant specifications of the ASD. Product formats are explicitly specified in these cases in order to provide continuity with those products which are currently operational, to ensure minimum disruption for the users. However, the formatting and encoding of the products is not explicitly described in this document.

3.2 Summary Description of MPEF Products

3.2.1 Baseline Products

In this section, top-level descriptions of the baseline products are provided.

Atmospheric Motion Vectors (AMV)

Motion in the atmosphere can be derived from satellite images by the tracking of clouds and other atmospheric constituents, e.g. water vapour patterns and ozone. The product derived from tracking these atmospheric motions on a synoptic scale (100 km or better) using MSG imagery is the Atmospheric Motion Vectors (AMV) product.

The product is based on the measurement of clouds or atmospheric constituents displacement between two or more consecutive images. The displacement is derived by means of matching a target area containing the tracer to the search area, and an interpolation in the matching surface.

The height at which the vector is measured is defined by the temperature of the tracer and converted to a pressure level via the forecast temperature-to-pressure profile of the atmosphere. Corrections for semi-transparent clouds, atmospheric absorption and cloud base for low-level clouds are also considered.

The AMV baseline product will be derived continuously from five spectral SEVIRI channels. The derivation of vectors from other channels, e.g. Ozone and further IR channels, is considered as Future Enhancements.

It is the intention that the AMV Image Products will not be generated as part of MPEF baseline product generation. It will however be possible if required to produce AMV Image Products from the AMV product containing bit map images with wind vectors derived for low, medium and high-level height bands (one image per band) together with coastlines on the MSG projection.

The AMV product generation, and especially the matching, which is based on cross-correlation, is the main contributor to overall processing load requirements. The AMV product is a key product and is required on a routine basis for the data assimilation process of numerical forecast models.

Cloud Analysis (CLA)

The Cloud Analysis product is based on the Scenes Analysis results and will provide on a synoptic scale (i.e. 100 km or better) information about cloud cover, cloud top temperature, cloud top pressure and cloud type and phase. As with the Scenes Analysis processing, the CLA product is based on a threshold technique.

The CLA product includes the height assignment of the identified clouds and the correction for semi-transparent clouds.

A CLA Image product will be derived from the intermediate CLA product and will contain information about the identified cloud type for cloudy pixels and the surface type for clear pixels.

The CLA product will also provide internally input to the AMV, CTH and CDS products and needs therefore to be continuously derived at pixel resolution. The distribution of the product to the end-users will be nominally at three-hourly intervals and with a reduced resolution described in the CLA product description below.

Cloud Top Height (CTH)

The CTH product, based on a subset of the information derived during the cloud analysis processing, is an image-based product which indicates the height of the highest cloud within a superpixel of size 3×3 pixels.

The CTH product will provide a vertical resolution equivalent to 300 meter height-bands.

Clear Sky Radiances (CSR)

The CSR product is a subset of the information derived during the Scenes Analysis processing. The product provides the radiances for a subset of the MSG channels averaged over all pixels within a processing segment which has been identified as ‘clear’, except for channel WV6.2 where the CSR is also derived for areas containing low-level clouds. The accuracy of the product depends mainly on the accuracy of the calibrated image data and the accuracy of the scenes analysis processing.

The product will provide valuable input to numerical weather prediction models. The horizontal resolution will be on synoptic scale (100 km or better).

Tropospheric Humidity (TH)

The TH product provides estimates of the relative humidity in the troposphere on a synoptic scale (i.e. 100 km or better). Due to the fact that MSG will have two channels providing information about the water vapour content in the troposphere and one IR channel highly affected by the low-layer humidity, the TH product will be derived in the form of a mean layer tropospheric humidity, providing the mean relative humidity in at least two layers. The following MSG channels are used to derive mean-layer humidities:

- with channel WV6.2, the mean layer relative humidity nominally between 600 hPa and 300 hPa, upper tropospheric humidity (UTH)
- with channel WV7.3, the mean layer relative humidity between nominally 850 hPa and 600 hPa, mid-tropospheric humidity (MTH)

The TH product is needed as input for numerical models and as a climatological product.

Climate Data Set (CDS)

The CDS product provides statistical information of the classified clusters in pre-defined processing segments of the image. The Scenes Analysis, providing the input to the CDS, provides information on pixel resolution. The CDS product will provide the results on a synoptic scale, e.g. 32 × 32 pixel segments.

The CDS product is not disseminated in real-time but is provided by means of off-line retrieval by the UMARF.

High Resolution Precipitation Index (HPI)

The High Resolution Precipitation Index product is primarily generated to support the Global Precipitation Climatology Project (GPCP). In the framework of this project, the supporting center (MPEF) is acting as a "Geostationary Satellite Data Processing Centre (GSDPC)". The HPI product provides BBT class histograms (three per hour) to support the estimation of the accumulated convective precipitation for the box bounded by ±40° of latitude and ± 50° of longitude from the SSP on a 1° by 1° grid.

The GPCP HPI product is not disseminated in real-time. The non-real-time delivery is done in accordance with the WMO/ICSU Global Precipitation Climatology Project rules.

It is assumed that MSG will support GPCP (as during MOP and MTP) although the HPI product extraction method and the amount of requested data may be modified.

ISCCP Data Set (IDS)
The IDS has to support the International Satellite Cloud Climatology Project (ISCCP) of the World Climate Research Programme (WCRP) of the WMO. In this programme satellite data in different forms is collected. The IDS product has to provide three data formats: the AC-data, the B1-data and the B2-data. The AC-data are satellite data of all channels of a satellite in full resolution, including navigation and calibration information. The AC-data have to be recorded in coordination with an overpass of polar-orbiting meteorological satellites for geographical areas of about 2000 km x 2000 km. The AC-data set has to be recorded approximately five times per month. The B1-data are a reduced data set for the whole MSG field of view with a nominal resolution of 10 km. The reduction is achieved by averaging and sampling. The B2-data are a further compressed data set derived from B1-data by further sampling the data to a nominal 30-km spacing. It is assumed that MSG will support ISCCP (as during MOP and MTP) although the amount of requested data may be modified. The IDS product is not disseminated in real-time. The non-real-time delivery is done in accordance with the ISCCP requirements.

3.2.2 New Products

This section provides a top-level description of the new products which have been added during the course of the MPEF development is provided.

Aerosol Properties Over Sea (AES)
The AES intermediate product,, generated every repeat cycle, consists of the optical thickness for the three visible channels and the Angström coefficient, for every pixel over sea. The retrieval is based on pre-calculated look-up tables. A daily product is also derived by temporally and spatially averaging the intermediate products over processing segments.

All Sky Radiances (ASR)
The ASR product is (as with CSR) a subset of the information derived during the Scenes Analysis processing. The product provides brightness temperatures for the MSG infrared channels averaged over all pixels within a processing segment and in six separate categories: all pixels, clear pixels, cloudy pixels, and low-, mid- and high-level cloud pixels.

Cloud Mask (CLM)
The Cloud Mask product is an image-based product derived from the Scenes Analysis results and provides information about the cloud contamination and non-static surface types (i.e. snow/ice cover) on a pixel basis for every repeat cycle.

Clear Sky Reflectance Map (CRM)

The Clear Sky Reflectance Map product is an image-based product derived from the Scenes Analysis results. It shows the remote sensing reflectance (uncorrected for atmospheric or viewing angle reflection effects) that would be seen by the satellite in the visible and near infrared channels over a cloud-free Earth. The product is derived from a set of seven-day averages of cloud-free pixels of images corresponding to daily times of every two hours between 06:00 and 20:00 UTC, for the full visible disc except for the polar regions.

Divergence (DIV)

The Divergence product is derived directly from the Atmospheric Motion Vector results for the WV6.2 channel. It describes the convergence and divergence in the upper troposphere on a 1^o x 1^o grid and is produced at hourly intervals. The product is particularly applicable for showing the development of tropical convective cells, i.e. small-scale divergence.

Active Fire Monitoring (FIR)

The Active Fire Monitoring product, which is in full pixel resolution, displays information on the presence of fire within a pixel. It has been developed primarily for detecting and quantifying biomass burning in Africa. Generated every image, the product compares the brightness temperatures of the IR3.9, 8.7 and 10.8 channels over cloud-free land areas and assigns a 'fire-free' status or a 'potential' (i.e. possible) or 'probable' fire status to each pixel. The algorithm used is based on threshold values and will be further developed.

Global Instability Index (GII) / Regional Instability Index (RII)

The air mass analysis mission is a new mission for MSG. The Global Instability Index product (along with the computationally identical Regional Instability Index product) is considered as an example of such a product to be provided with priority. However, operational retrieval of temperature and humidity profiles and derived instability parameters have been performed since 1987 from the GOES VAS instrument.

The GII Statistical Retrieval algorithm has been developed as a prototype, and demonstrated on the basis of existing satellite data. It is assumed that the method will use SEVIRI information from the lower and mid troposphere and the earth's surface. The results from the cloud analysis will also be needed.

The product is required at better resolution than synoptic scale in order to provide a representative sample of the geographic distribution of instability areas. It should be noted that there is probably no 'global' index which will serve as a successful predictor for different regions. Therefore the production of several indices will be required to ensure a forecast with high performance.

Multi-Sensor Precipitation Estimate (MPE)

The Multi-Sensor Precipitation Estimate product provides estimated instantaneous rain rates in full pixel resolution. The algorithm is based on a combination of MSG images from the IR10.8 channel and passive microwave data from the SSM/I instrument on the US DMSP polar satellites. The product is most suitable for convective precipitation, and is intended mainly for areas with poor radar coverage (especially in Africa and Asia).

Total Ozone (TOZ)

The Total Ozone product makes use of the new SEVIRI Ozone IR 9.7 µm channel and of the other IR and WV channels of SEVIRI. The Total Ozone product is derived as an intermediate TOZ product (TOZ_{int}) on a pixel basis for each repeat cycle and as a final TOZ product (TOZ_{fin}), which will be distributed to the end-users. The final TOZ summarises the intermediate TOZ information for a TOZ processing segment.

Volcanic Ash Detection (VOL)

The VOL product is an image-based product in full pixel resolution that displays information on the presence of volcanic ash within a cloudy pixel. The algorithm is applied in areas within 5° of known active volcanoes, and applies a series of reflectance ratio tests for visible channels and brightness temperature differences for infrared in order to detect thin/thick ash clouds and hotspots.

Normalised Difference Vegetation Index (NDVI)

The NDVI product is derived as part of the Scenes Analysis processing, based on visible and near-infrared reflectances from channels VIS0.6 and VIS0.8. It is an image-based product in full pixel resolution that displays information on vegetative cover and its seasonal variation. The product is encoded in HDF5 format, both daily and weekly (the latter being an accumulation of daily data).

3.2.3 Additional Products

In this section, a top-level description of the additional products is provided.

Sea Surface Temperature (SST)

The SST product currently derives for every repeat cycle, for all pixels identified as clear ocean by the Scenes Analysis algorithm, an estimate of the sea surface temperature. It is foreseen that this product be used in the calibration support process and may also be used off-line to monitor the performance of the Scenes Analysis algorithm.

If required the repeat cycle-based data could be segmented into the required horizontal scale and averaged over a given time period for dissemination as an SST product.

3.3 Prototyping

In order to support the specification of the algorithms, prototyping has been performed for a subset of the baseline algorithms which are considered as critical for the development of the MPEF.
For the following algorithms, the specifications in this document are based on prototype software and test data sets:

- Radiative Transfer Model (RTM)
- Scenes Analysis (SCE)
- Cloud Analysis (CLA)
- Atmospheric Motion Vectors (AMV)
- Tropospheric Humidity (TH)
- Global Instability Index (GII)
- Sea Surface Temperature (SST)

The detailed descriptions of the prototype software and of the test data available for each of these algorithms are included in the relevant algorithm specifications later in this document.
The use of simulated SEVIRI test data for prototyping is problematic as some of the spectral channels have not been operated on board a geostationary satellite or are only available at a reduced horizontal resolution. The test data used during the prototyping came from the following satellites/instruments: Meteosat, GOES-8/VISSR, GOES-8/VAS and NOAA/AVHRR. Test data from the NIR 1.6 µm and the IR 8.7 µm channel have not been explored yet.

3.4 Structure and Interpretation of the Algorithm Specifications

Each algorithm specification in this document contains seven sections. A brief description of the purpose of each of these sections follows.

1. Algorithm Configuration Information

Provides information about the algorithm; its name, identifier and version.

2. Inputs

Describes all the input data required by the algorithm. All inputs are listed in a tabular form together with their source. An example of the input data table is shown below together with some notes on the usage of each column. No guidance concerning the format of the input data are given, unless these are already fixed by an external source, e.g. format of the Level 1.5 image data from the IMPF.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Precision*	*Accuracy*	*Resolution*	*Source*
Name	Note 1	Note 2	Note 3	Note 3	Note 4	Note 4	Note 5	Text description

Note 1 The Mnemonic for the parameter may be used in preference to the full name in the specification to improve clarity particularly in scientific formulae. The parameters should be referred to using only their full name or mnemonic in order to avoid confusion.

Note 2 The Units which are specified are those to which the parameters are required to be converted for the relevant scientific equations to be valid.

Note 3 The Min and Max columns provide the expected minimum and maximum values for the inputs in the units as given, where these are available.

Note 4 The Accuracy column specifies the accuracy to which a parameter should be calculated, while the Precision column specifies the number of decimal places to which the parameter should be supplied, both columns supplied in the units given, where these are available.

Note 5 The required Resolution of the parameter, on a pixel basis or processing segment basis or a superpixel basis, is given where appropriate.

3. Algorithm Functional Specification

Provides all the information about what the algorithm does and gives all the formulae necessary to calculate the required parameters. Where an established scientific technique is available to perform a function, a reference to the relevant literature / prototype software is given rather than distilling the scientific content of the technical paper or complex code into the specification. This section also gives details of the Automatic Quality Control (AQC) functionality required.

The section covers also the product verification/check against meteorological observations and forecast data where appropriate.

4. Outputs

Describes all the output data generated by the algorithm. All outputs are listed in a tabular form, together with their destination. Again no guidance concerning the format of the output data are given, unless these are already fixed by an external source. The definition of the mnemonic, units, min, max, accuracy, precision and resolution columns are the same as for the input data. The source column is replaced by a column specifying the destination of the outputs.

5. Prototyping and Testing

If the algorithm has been prototyped this provides an overview of the prototyping activities together with any caveats concerning the implementation of the algorithm.

This section also provides information about the test data and expected results which will be supplied with the prototype algorithm in order to fully test its scientific functionality. No test data or expected results are supplied with algorithms which have not been prototyped.

6. Future Enhancements

This section describes any potential product improvements which can be expected to be included in the algorithm in a later release.

7. References

Gives all the scientific references used in the definition of the algorithm. All references **shall** be treated as Applicable Documents.

4 IR RADIATIVE TRANSFER MODEL

4.1 Algorithm Configuration Information

No specific information on configuration.

4.1.1 Algorithm Name

IR Radiative Transfer Model (RTM)

4.1.2 Algorithm Identifier

EUM_MSG_RTM_A001

4.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	S. A. Tjemkes	RTM Baseline
1.1	16/5/97	S. A. Tjemkes	TBD resolved, errors corrected.
1.2	1/7/97	S. A. Tjemkes	Some functionality descoped and clarifications/simplifications added.
1.3	8/12/97	H. K. Wilson	Requirements Analysis clarification points added.
1.4	11/3/98	H. K. Wilson	Peer Group Review changes added.
1.5	12/08/02	S. J. Fowler	Surface emissivity added.
1.6	18/09/09	J. D. Jackson	SYNSATRAD replaced by RTTOV. Removed the semi-transparency and spectroscopic tables.
1.7	13/10/15	J. D. Jackson	Upgraded the version of RTTOV from 9.3 to 11.2. New 2-path visible transmission tables added.

4.2 Inputs

RTTOV 11.2 LBLRTM coefficients file (refer to NWPSAF-MO-UD-016 in Section 4.7).

The tables on the following pages detail each input.

THERMODYNAMIC INPUT PARAMETERS FOR THE ATMOSPHERIC CORRECTION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Pressure	p	hPa	0	1050	10^{-2}	10^{-3}	Forecast
Temperature	T	K	0	400	1	1	Forecast
Water vapour mixing ratio	q_{h20}	kg/kg	-	$50\ 10^{-3}$	10^{-7}	10^{-8}	Forecast
Ozone volume mixing ratio	m_{o3}	kg/kg	-	-	-	-	Forecast
Satellite viewing angle	θ	°	0	90	10^{-1}	10^{-1}	Level 1.5 image data
Number of pressure levels	Z	-	0	100	1	1	Forecast
Minimum water vapour mixing ratio	q_{h2o}^{min}	kg/kg	0	$20\ 10^{-3}$	10^{-7}	10^{-8}	Set-up

Table 2: IR Radiative Transfer Model: Thermodynamic input parameters for the Atmospheric Correction Tables

THERMODYNAMIC INPUT PARAMETERS FOR THE TROPOSPHERIC HUMIDITY CORRECTION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Pressure	p	hPa	0	1050	10^{-2}	10^{-3}	Forecast
Temperature	T	K	0	400	1	1	Forecast
Ozone volume mixing ratio	m_{o3}	kg/kg	-	-	-	-	Forecast
Water vapour relative humidity	RH	%	0	100	1	1	Set-up
Pressure threshold parameter	THR1	hPa	0	<THR2	10^{-2}	10^{-3}	Set-up
Pressure threshold parameter	THR2	hPa	>THR1	1050	10^{-2}	10^{-3}	Set-up
Minimum water vapour mixing ratio	q_{h2o}^{min}	kg/kg	0	$20\ 10^{-3}$	10^{-7}	10^{-8}	Set-up
Satellite viewing angle	θ	°	0	90	10^{-1}	10^{-1}	Level 1.5 image data
Number of pressure levels	Z	-	0	100	1	1	Forecast

Table 3: IR Radiative Transfer Model: Thermodynamic input parameters for the Tropospheric Humidity Correction Tables

THERMODYNAMIC INPUT PARAMETERS FOR THE VICARIOUS CALIBRATION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Pressure	p	hPa	0	1050	10^{-2}	10^{-3}	Observations
Temperature	T	K	0	400	1	1	Observations
Water vapour mixing ratio	q_{h20}	kg/kg	-	$20\ 10^{-3}$	10^{-7}	10^{-8}	Observations
Ozone volume mixing ratio	m_{o3}	kg/kg	-	-	-	-	Observations
Satellite viewing angle	θ	°	0	90	10^{-1}	10^{-1}	Level 1.5 image data
Number of pressure levels	Z	-	0	100	1	1	Forecast

Table 4: IR Radiative Transfer Model: Thermodynamic input parameters for the VICARIOUS Calibration Tables.

THERMODYNAMIC INPUT PARAMETERS FOR THE CONTRIBUTION FUNCTION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Pressure	p	hPa	0	1050	10^{-2}	10^{-3}	Forecast
Temperature	T	K	0	400	1	1	Forecast
Water vapour Mixing ratio	q_{h20}	kg/kg	-	$20\ 10^{-3}$	10^{-7}	10^{-8}	Forecast
Ozone volume mixing ratio	m_{o3}	kg/kg	-	-	-	-	Forecast
Satellite viewing angle	θ	°	0	90	10^{-1}	10^{-1}	Level 1.5 image data
Number of pressure levels	Z	-	0	100	1	1	Forecast

Table 5: IR Radiative Transfer Model: Thermodynamic input parameters for the Contribution Function Tables

THERMODYNAMIC INPUT PARAMETERS FOR THE TWO-PATH TRANSMISSION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Pressure	p	hPa	0	1050	10^{-2}	10^{-3}	Forecast
Temperature	T	K	0	400	1	1	Forecast
Water vapour Mixing ratio	q_{h20}	kg/kg	-	$20\ 10^{-3}$	10^{-7}	10^{-8}	Forecast
Ozone volume mixing ratio	m_{o3}	kg/kg	-	-	-	-	Forecast
Satellite viewing angle	θ	°	0	90	10^{-1}	10^{-1}	Level 1.5 image data
Number of pressure levels	Z	-	0	100	1	1	Forecast

Table 7: IR Radiative Transfer Model: Thermodynamic input parameters for the 2-Path Transmission Tables

4.3 Algorithm Functional Specification

4.3.1 Overview

This algorithm is responsible for calculating the radiances at the top of the atmosphere and various level based radiance and transmission quantities in the eight IR channels of MSG (IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0, and IR13.4) propagating into the direction of the satellite, under a range of atmospheric conditions. In addition the algorithm is responsible for calculating the two-path transmission for solar-affected channels (VIS0.6, VIS0.8, NIR1.6, and IR3.9).

The output of the Radiative Transfer Model consists of tables describing synthetic radiances/transmittances in the IR and visible channels, which will be used for various other algorithms. These tables are as follows:

- Atmospheric Correction Tables
- Tropospheric Humidity Generation Tables
- Vicarious Calibration Tables
- Contribution Function Tables
- Two-Path Transmission Tables

The tables are generated using the Radiative Transfer Model for different atmospheric situations. The Atmospheric Correction Tables, Tropospheric Humidity Generation Tables, Vicarious Calibration Tables for the window channels (IR3.9, IR8.7, IR10.8 and IR12.0), Contribution Function Tables, and Two-Path Transmission Tables **shall** be based on the forecast data.

The forecast model grid has a nominal horizontal resolution of 1° x 1°. Furthermore, nominally 30 levels at fixed pressure values are used to describe the vertical state of the atmosphere, plus the values at the surface and 2 metres above the surface. These data arrive nominally twice a day. Each forecast has a base time (t_o), and contains a number of forecast predictions, e.g. (t_o+6h, t_o+12h, t_o+18h, t_o+24h, t_o+30h). The generation of the radiation tables is driven by the arrival of the forecast data.

The Vicarious Calibration Tables are calculated for the absorber channels (WV6.2, WV7.3, IR 9.7, and IR13.4) and **shall** be based on observations by radiosondes. These Vicarious Calibration Tables **shall** be based on all available observations, subject to quality control within a cut-off time, defined by a set-up parameter, after the observational time.

Further details of the Vicarious Calibration Process can be found in Chapter 19.

The *Contribution Function Tables* **shall** be based on Radiative Transfer calculations for clear sky scenes. These calculations **shall** adopt the surface state and vertical distribution of temperature and radiative active gases as specified by the forecast profiles for each point of the original forecast grid. The spectral response functions of the channels and the satellite viewing angle **shall** be taken into account. The Two-Path Transmission Tables for the solar affected channels **shall** use the solar zenith angle at the forecast grid point and time in addition to the satellite zenith angle to define the two-path geometry.

4.3.2 Algorithm Description

The following steps **shall** be performed:

- Meteorological Data Preparation,
- Radiative Transfer Calculations for IR and solar channels,
- Radiation Table Generation.

4.3.2.1 Meteorological Data Preparation

The following tasks **shall** be performed:

1. The meteorological profiles from either the forecast model or the observations are used to describe the vertical structure of the atmosphere at specific pressure levels, defined by set-up parameters in the atmosphere. The vertical distribution of radiative active gases other than water vapour and ozone **shall not** be specified, but the default values in RTTOV are assumed. The specific humidity at each level **shall** exceed a minimum threshold defined by a set-up parameter. The data describing the vertical structure of the atmosphere are supplemented by data describing the surface properties, like surface temperature, surface emissivity, 2 m water vapour and 2 m temperature.
2. The observation profiles **shall** be filtered according to their completeness. Only profiles with at least 10 levels which reach at least from 850 hPa to 300 hPa **shall** be used. From the highest observation level to the highest RTM level a linear interpolation is performed. At the highest RTM level the temperature **shall** be 205 K and the water vapour mixing ratio **shall** be 0.

4.3.2.2 Radiative Transfer Calculations

The following tasks for the Radiative Transfer Calculations **shall** be performed:

1. The atmosphere temperature structure **shall** be described by a finite number of levels (nominally 32). The number of these levels and the actual position are defined by set-up parameters.
2. The vertical distribution of water vapour and ozone **shall** be described by a finite number of levels. These levels coincide with the levels at which the temperature profile is described.
3. The following RTTOV output is used to generate the RTM tables for each solar channel:
    1. Transmittance from TOA to each standard pressure level to TOA along combined sun-surface-satellite path.
4. The following RTTOV output is used to generate the RTM tables for each IR channel:
    1. Clear sky radiance.
    2. Radiance at the top of atmosphere (TOA) when a black cloud is at each standard pressure level.
    3. Radiance emitted by a black cloud at each pressure level except the surface.
    4. Above-cloud upwelling atmospheric radiance for each pressure level down to the surface.
    5. Above-cloud downwelling atmospheric radiance for each pressure level down to the surface.
    6. Transmittance from each standard pressure level to top of atmosphere.
    7. Transmittance from each standard pressure level to the surface.

4.3.2.3 Radiation Table Generation

1. **Atmospheric Correction Tables**

   The Atmospheric Correction Tables represent the radiance in the eight IR channels, emitted by an opaque cloud at each of the standard pressure levels. The fast radiative transfer model (RTTOV) calculates the emitted upwelling and downwelling radiance from above and below an opaque cloud using the transmission of each layer. The transmission of each layer is determined by the atmospheric state vector and predictors based on the LBLRTM. These parameters, including the transmission of the layers and the emissivity values used to determine the surface contribution, are included in the atmospheric correction table.

   The radiances **shall** be based on radiative transfer calculations for clear sky and opaque cloud scenes at any of the standard levels. For the clear sky scene, the calculations **shall** adopt the surface state and the vertical distribution of temperature and radiative active gases as specified by the forecast profiles for each of the original forecast grids. For the opaque cloud scenes, the vertical distribution of temperature and radiative active gases **shall** be taken from the forecast model for each of the original forecast grid points, with an opaque cloud inserted at the standard levels between the surface and top of atmosphere, nominally 31 levels. The spectral response functions of the channels and the satellite viewing angle **shall** be taken into account.

2. **Tropospheric Humidity Generation Tables**

   The Tropospheric Humidity Generation Tables represent the synthetic radiances for the WV6.2 and WV7.3 channels for each of the original forecast grids under specific clear sky atmospheric conditions. The synthetic radiances **shall** be based on radiative transfer calculations. The spectral response function of WV6.2 and WV7.3, and the satellite viewing angle **shall** be taken into account. The radiative transfer calculations make certain assumptions concerning the atmospheric profiles. The temperature profile used is the forecast one. The vertical distribution of radiative gases other than water vapour **shall** be the same as specified by the forecast profiles for each of the original forecast grid points. The forecast specific humidity profile is not used. Instead, the radiative transfer calculations for these two channels **shall** be made with two synthetic specific humidity profiles. In both profiles the variation of specific humidity with height in the layers between the surface and a threshold (defined by a set-up parameter) **shall** be calculated from the assumption that the relative humidity in these layers is constant. Two values, defined by set-up parameters, **shall** be adopted for this constant relative humidity. For levels above another threshold (defined by set-up parameter) the specific humidity **shall** be taken to be constant as defined by a set-up parameter for both profiles. For the levels between the two height thresholds the variation of the specific humidity **shall** be based on an interpolation between the specific humidity value at the second threshold level and the value at first threshold level. This interpolation **shall** be based on the assumption that the specific humidity depends on the third power of pressure, but **shall** **not** be less than the constant value above the first threshold.

3. **Vicarious Calibration Tables**

   The Vicarious Calibration Tables represent the radiance in the Water Vapour channels, the Ozone channel and the Carbon Dioxide channel, at the top of the atmosphere, propagating in the direction of the satellite. These radiances **shall** be based on radiative transfer calculations for particular clear sky scenes. The calculations **shall** adopt the surface state and the vertical distribution of temperature and radiative active gases as specified by observed profiles. The spectral response functions of the channels and the satellite viewing angle **shall** be taken into account.

4. Two-Path Transmission Tables

The Two-Path Transmission Tables represent the transmission from the TOA to each standard pressure level and back to TOA in the solar affected channels. The two-path transmission is determined by the fast radiative transfer model (RTTOV) using the forecast data provided along with the satellite and calculated solar viewing angles. In addition to the two-path transmission the calculated path-length for each grid point **shall** be provided. The solar angle **shall** be limited to 70 degrees.

5. Contribution Function Tables

The Contribution Function Tables **shall** contain as a function of pressure the normalised total contribution function and the normalised total cumulative contribution function for radiation propagating upwards towards the satellite for each of the eight infrared channels.

The Contribution Function **shall** be based on radiative transfer calculations for clear sky scenes. These calculations **shall** adopt the surface state and the vertical distribution of temperature and radiative active gases as specified by the forecast profiles for each of the original forecast grids. The spectral response functions of the channels and the satellite viewing angle **shall** be taken into account.

The generation of the Contribution Function tables for each of the eight infrared channels **shall** include the following steps:

1) At the upper boundary of the highest layer the total atmospheric transmission for radiation propagating in the upward direction towards the satellite **shall** be set to a value defined by a set-up parameter.
2) At the lower boundary of each layer, the total atmospheric transmission for radiation propagating in the upward direction towards the satellite **shall** be calculated as the product of the total atmospheric transmission for radiation propagating in the upward direction towards the satellite at the upper boundary of that layer and the transmission for radiation propagating in the upward direction towards the satellite of that layer.
3) At each level, the cumulative contribution function for radiation propagating in the upward direction towards the satellite **shall** be calculated as the product of the upwelling radiance of radiation propagating in the upward direction towards the satellite and the total atmospheric transmission for radiation propagating in the upward direction towards the satellite.
4) At each level, the contribution function for radiation propagating in the upward direction towards the satellite **shall** be calculated as the derivative of the cumulative contribution function for radiation propagating in the upward direction towards the satellite and the natural logarithm of pressure.
5) At each level, the total cumulative contribution function for radiation propagating in the upward direction towards the satellite covering the spectral region of the particular channel **shall** be calculated as the arithmetic mean of the cumulative contribution function for radiation propagating in the upward direction towards the satellite, weighted with the spectral response function.

6) At each level, the total contribution function of radiation propagating in the upward direction towards the satellite covering the spectral region of the particular channel **shall** be calculated as the arithmetic mean of the contribution function for radiation propagating in the upward direction towards the satellite, weighted with the spectral response function.
7) At each level, the normalised total cumulative contribution function for radiation propagating in the upward direction towards the satellite covering the spectral region of the particular channel **shall** be calculated as the ratio of the total cumulative contribution function for radiation propagating in the upward direction towards the satellite covering the spectral region of the particular channel and the total radiance at the top of the atmosphere of radiation propagating in the upward direction towards the satellite covering the spectral region of the particular channel.
8) At each level, the normalised total contribution function of radiation propagating in the upward direction towards the satellite **shall** be calculated as the ratio of the total contribution function of radiation propagating in the upward direction towards the satellite and the maximum value of the total contribution function of radiation propagating in the upward direction towards the satellite.

4.3.3 Physical Principles

For a detailed description of the RTTOV algorithms, refer to the RTTOV 11 Science and Validation Plan (NWPSAF-MO-TV-032).

4.3.4 Automatic Quality Control (AQC)

No AQC checks are required.

4.4 Outputs

The tables that follow detail each table to be produced. Each table **shall** be produced:

ATMOSPHERIC CORRECTION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***To***
Radiance at top of the atmosphere	$\Im^{\uparrow}_{3.8}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	SCE, AMV, CAL, CLA, CDS
Clear sky and opaque cloud at standard levels, including position, zenith angle	$\Im^{\uparrow}_{6.2}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
on the original forecast grid within the EMD processing area	$\Im^{\uparrow}_{7.3}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{8.7}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{9.7}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{10.8}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{12.0}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{13.4}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
Radiance at bottom of atmosphere	$\Im^{\uparrow}_{3.8}(p_b, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	SCE, AMV, CAL, CLA, CDS
Clear sky and black cloud at standard levels, including position, zenith angle	$\Im^{\uparrow}_{6.2}(p_b, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
on the original forecast grid within the EMD processing area	$\Im^{\uparrow}_{7.3}(p_b, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{8.7}(p_b, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{9.7}(p_b, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{10.8}(p_b, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	

ATMOSPHERIC CORRECTION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***To***
	$\Im^{\uparrow}_{12.0}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{13.4}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
Downwelling atmospheric radiance from above a black cloud at each of the standard pressure levels	$\Im^{\downarrow}_{3.8}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	OCA
Black cloud at each standard pressure level	$\Im^{\downarrow}_{6.2}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
on the original forecast grid within the EMD processing area	$\Im^{\downarrow}_{7.3}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\downarrow}_{8.7}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\downarrow}_{9.7}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\downarrow}_{10.8}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\downarrow}_{12.0}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\downarrow}_{13.4}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
Upwelling atmospheric radiance from above a black cloud at each of the standard pressure levels	$\Im^{\uparrow}_{3.8}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	OCA
Black cloud at each standard pressure level	$\Im^{\uparrow}_{6.2}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
on the original forecast grid within the EMD processing area	$\Im^{\uparrow}_{7.3}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{8.7}(p_b,\mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	

ATMOSPHERIC CORRECTION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***To***
	$\Im^{\uparrow}_{9.7}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{10.8}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{12.0}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{13.4}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
Upwelling atmospheric radiance from below a black cloud at each of the standard pressure levels	$\Im^{\uparrow}_{3.8}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	OCA
Black cloud at each standard pressure level	$\Im^{\uparrow}_{6.2}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
on the original forecast grid within the EMD processing area	$\Im^{\uparrow}_{7.3}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{8.7}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{9.7}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{10.8}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{12.0}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{13.4}(p_b,\mu)$	mWm^{-2}sr^{-1}(cm^{-1})$^{-1}$	0	-	-	-	
Transmission to top of atmosphere from each standard pressure level	$\Gamma^{\uparrow}_{v3.8}(p_b,\mu)$	-	0	1	-	-	OCA
on the original forecast grid within the EMD processing area	$\Gamma^{\uparrow}_{v6.2}(p_b,\mu)$	-	0	1	-	-	

ATMOSPHERIC CORRECTION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***To***
	$\Gamma^{\uparrow}_{v7.3}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\uparrow}_{v8.7}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\uparrow}_{v9.7}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\uparrow}_{v10.8}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\uparrow}_{v12.0}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\uparrow}_{v13.4}(p_b,\mu)$	-	0	1	-	-	
Transmission to surface from each standard pressure level	$\Gamma^{\downarrow}_{v3.8}(p_b,\mu)$	-	0	1	-	-	OCA
on the original forecast grid within the EMD processing area	$\Gamma^{\downarrow}_{v6.2}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\downarrow}_{v7.3}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\downarrow}_{v8.7}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\downarrow}_{v9.7}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\downarrow}_{v10.8}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\downarrow}_{v12.0}(p_b,\mu)$	-	0	1	-	-	
Emissivity at the surface	-	-	0	1	-	-	OCA

Table 6: IR Radiative Transfer Model: Atmospheric Correction Tables

TROPOSPHERIC HUMIDITY GENERATION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***To***
Radiance at top of the atmosphere	$\Im^{\uparrow}_{6.2}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	TH
for two values of relative humidity on the original forecast grid within the EMD processing area	$\Im^{\uparrow}_{7.3}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	

Table 7: IR Radiative Transfer Model: Tropospheric Humidity Generation Tables

VICARIOUS CALIBRATION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***To***
Radiance at top of the atmosphere	$\Im^{\uparrow}_{6.2}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	CAL
	$\Im^{\uparrow}_{7.3}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{9.7}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	
	$\Im^{\uparrow}_{13.4}(p_t, \mu)$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	

Table 8: IR Radiative Transfer Model: Vicarious Calibration Tables

CONTRIBUTION FUNCTION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***To***
Normalised total contribution function and total cumulative contribution function as a function of pressure (for all the standard pressure levels provided by the ECMWF as defined by the set-up parameter) for all eight IR channels, i	NTC_i, $NTCC_i$	-	0	1	10^{-3}	10^{-4}	AMV

Table 9: IR Radiative Transfer Model: Contribution Function Tables

TWO-PATH TRANSMISSION TABLES							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***To***
Path-Length	l	-	2	6.787 (note 1)	-	-	OCA
2-Path Transmission	$\Gamma^{\downarrow\uparrow}_{\nu_{0.6}}(p_b,\mu)$	-	0	1	-	-	
on the original forecast grid within the EMD processing area	$\Gamma^{\downarrow\uparrow}_{\nu_{0.8}}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\downarrow\uparrow}_{\nu_{1.6}}(p_b,\mu)$	-	0	1	-	-	
	$\Gamma^{\downarrow\uparrow}_{\nu_{3.8}}(p_b,\mu)$	-	0	1	-	-	

Table 11: IR Radiative Transfer Model: 2-Path Transmission Tables. (Note 1: This is a function of the maximum angles permitted in the calculation. The maximum solar angle is currently 70 degrees and the maximum satellite angle currently is 75 degrees).

4.5 Prototyping and Testing

This section describes the prototyping activities, highlighting the major problems which were encountered with this development.

4.5.1 Prototyping

4.5.1.1 Installation

Installation details are described in the documentation provided by the supplier.

4.5.2 Test Data

An internal EUMETSAT validation was performed comparing different MPEF products generated using the MPEF RTM using RTTOV 9.3 and RTTOV 11.2.

4.5.3 Test Results

For a detailed description of the internal EUMETSAT validation, refer to the product validation report (EUM/TSS/REP/14/781236).

4.6 Future Enhancements

No future enhancements are currently foreseen.

4.7 References

Reference	*Title*	*Date*	*Author(s)*
Int. J. Remote Sensing, Vol 19, No 14, 2753 – 2774	Classification-based emissivity for land surface temperature measurement from space	1998	W.C. Snyder, W, Wan, Y. Zang and Y.Z. Feng
J. Atmos. Oceanic. Tech. Vol 13, No. 1, 126 – 141	Wind speed effects on Sea Surface Emission and Reflection from the Along Track Scanning Radiometer	1996	Watts, P.D., Allen, M.R., Nightingale, T.J.
NWPSAF-MO-UD-028	RTTOV v11 Users Guide	2014	J Hocking, P Rayer, D Rundle, R Saunders.
NWPSAF-MO-TV-032	RTTOV 11 Science and Validation Plan	2013	R Saunders
EUM/TSS/REP/14/781236	MPEF Release 2.1 Validation Test Report	2014	S Joro

4.8 Symbols and Definitions

A list of all variables used in this algorithm, together with their meanings and units, is in the table below.

Mnemonic	*Parameter*	*Units*
ν	Wavenumber	cm^{-1}
μ	cos θ	-
θ	Satellite viewing angle	degree
θ_{Sol}	Solar zenith angle	degree
p	Pressure	hPa
p_b	Pressure at lower boundary	hPa
p^o	Reference pressure	hPa
p^1	Reference pressure	hPa
$\Im^{\uparrow}$	Total upward propagating radiance	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$
$\Im^{\downarrow}$	Total downward propagating radiance	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$
$I_\nu^{\uparrow}$	Upward propagating radiance	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$
$I_\nu^{\downarrow}$	Downward propagating radiance	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$
Γ_ν	Transmission	-
$\Gamma_\nu^{\downarrow\uparrow}$	2-Path Transmission	-
ε_ν	Surface emissivity	-
B_ν	Planck function	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$
T	Temperature	K
T_{sfc}	Surface temperature	K
q_i	Mixing ratio of the *i*th radiative active gas	$kg\ kg^{-1}$
NTC	Normalised Total Contribution Function	-
NTCC	Normalised Total Cumulative Contribution Function	-
l	Path Length	-

5 SCENES ANALYSIS

5.1 Algorithm Configuration Information

No specific information on configuration.

5.1.1 Algorithm Name

Scenes Analysis (SCE).

5.1.2 Algorithm Identifier

EUM_MSG_SCE_A001

5.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	H.-J. Lutz	SCE Baseline
1.1	26/5/97	H.-J. Lutz	Updated for the resolution of AMV and CLA TBDs.
1.2	2/7/97	H.-J. Lutz	Additional tests added to improve the robustness of the algorithm to give greater confidence in the classification of a pixel as cloudy or clear.
1.3	8/12/97	H. K. Wilson	Kick-off clarification points added, Requirements Analysis clarification points added.
1.4	11/3/98	H. K. Wilson	Peer Group Review changes added.
1.5	15/1/99	H.-J. Lutz	Detailed Design Phase changes added.
1.6	31/1/02	H.-J. Lutz	Changes added, according to ECPs 297, 298, 299.
1.7	25/7/05	T. Heinemann	Updated according to AR 10973.
1.8	7/09/07	O. Samain	Updated according to AR 10095, 15892, 16003 and ECP 804.
1.9	05/05/08	O. Samain	Updated for specific channel availability criteria and threshold test applications.

5.2 Inputs

5.2.1 Image and Preprocessing Data (Dynamic Application Data)

The main input of the Scenes Analysis algorithm is the level 1.5 data from all MSG channels. The image data **shall** be available in the form of reflectances (%) for the VIS/NIR channels, and in the form of equivalent black body brightness temperatures (EBBT) in kelvin (K) for the IR/WV channels. For information on the derivation of the EBBT and of the reflectances, see Table 10 and Table 11, also the EUMETSAT website:

Access to Data > Meteosat Meteorological Products > Calibration > Meteosat Second Generation

Additionally, the Scenes Analysis algorithm **shall** use data from a subset of channels from the previous repeat cycle. The following table defines the input data required from the level 1.5 image data.

LEVEL 1.5 IMAGE DATA AND DATA DERIVED FROM THE IMAGE DATA								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Resolution***	***Source***
Reflectances for channels VIS0.6, VIS0.8, NIR1.6, IR3.9_sol, HRVIS	$REFL_{channel}$	%	0	150	0.1	0.1	pixel	Derived from level 1.5 image data
EBBTs for channels IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4	$EBBT_{Ichannel}$	K	170	350	0.1	0.1	pixel	Derived from level 1.5 image data
Local mean, minimum, maximum and standard deviation on a 3 x 3 pixel segment for channels VIS0.6, VIS0.8, NIR1.6, IR3.9, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4, WV6.2, WV7.3, HRVIS	mn_REFL/EBBT max_REFL/EBBT min_REFL/EBBT std_REFL/EBBT	-	-	-	-	-	pixel	Derived from level 1.5 image data
Reflectances of the previous repeat cycle for channels VIS0.6, VIS0.8	$prev\_REFL_{channel}$	%	0	120	0.1	0.1	pixel	Derived from previous level 1.5 image data
EBBTs of the previous repeat cycle for channels: IR3.9, IR10.8, IR12.0	$prev\_EBBT_{Ichannel}$	K	170	350	0.1	0.1	pixel	Derived from previous level 1.5 image data
Start times of current and previous repeat cycle	start_current_image start_previous_image	mins	-	-	1	1	-	Derived from level 1.5 image data
Solar Zenith Angle	sol_zenith	degrees	0	90	0.1	0.1	pixel	Derived from level 1.5 image data
Satellite Observing Angle	sat_zenith	degrees	0	90	0.1	0.1	pixel	Derived from level 1.5 image data
Relative azimuth angle sun/sat	sol_sat_azimuth	degrees	0	360	0.1	0.1	pixel	Derived from level 1.5 image data
Line radiometric quality flag (per channel)	LRQF_channel	-	-	-	-	-	image line	Level 1.5 data header

Table 10: Scenes Analysis Product: Input data required from the level 1.5 image data

5.2.2 Data from other MPEF Algorithms (Dynamic Application Data)

The Scenes Analysis algorithm **shall** use data from other MPEF algorithms, as defined in the following table:

DATA FROM OTHER MPEF ALGORITHMS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Resolution***	***Source***
Scenes Analysis Data from previous repeat cycle	prev_scene_type	-	0	255	1	1	pixel	SCE of previous repeat cycle
Clear sky reflectances from previous repeat cycle for channels: VIS0.6, VIS0.8, NIR1.6	prev_CSR_REFL	%	0	150	0.1	0.1	CSR processing segment	CSR intermediate product of previous repeat cycle
Clear sky brightness temperatures from previous repeat cycle for channels: IR3.9, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4, WV6.2, WV7.3	prev_CSR_EBBT	K	230	350	0.1	0.1	CSR processing segment	CSR intermediate product of previous repeat cycle
Forecast brightness temperatures for channels: IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4	for_EBBTchannel	K	230	350	0.1	0.1	pixel	RTM
MSG Clear Sky Reflectance Map, for channels: VIS0.6, VIS0.8, NIR1.6, IR3.9_sol	MRMchannel	%	0	100	0.1	0.1	pixel	SCE - clear sky reflectances image, updated multiple times per day
Mean solar zenith, satellite zenith and relative azimuth angle for the Clear Sky Reflectance Map	MRM_sol_zenith MRM_sat_zenith MRM_rel_azi	degrees degrees degrees	0 0 0	90 90 360	0.1 0.1 0.1	0.1 0.1 0.1	pixel pixel pixel	SCE - clear sky reflectances image, updated multiple times per day

Table 11: Scenes Analysis Product: Data from other MPEF algorithms

5.2.3 Static Application Data

The static application data used by the Scenes Analysis algorithm **shall** consist of the following:

- pixel-based map of surface-type. The surface types are as follows:
- evergreen needle-leaf forest, evergreen broadleaf forest, deciduous needle-leaf forest, deciduous broadleaf forest, mixed deciduous forest, closed shrubland, open shrubland, woody savannah, savannah, grassland, permanent wetland, cropland, urban, crop/natural vegetation mosaic, permanent snow/ice, barren/desert, water bodies, tundra and mixed land/water (land pixels containing small rivers or lakes)
- pixel-based map of surface elevation
- pixel-based map containing the distance of each pixel to the nearest coast (in km)
- spectral albedo tables for channels VIS0.6, VIS0.8, NIR1.6, IR3.9 and for each surface type
- the normalised bi-directional reflectance functions (BDRF) for each surface type; the normalisation is with respect to the spectral bi-hemispherical albedo
- static thresholds
- static parameters for the different mathematical expressions used in the algorithm

The static data sets needed for the Scenes Analysis processing are summarised in the following tables, one for surface information including spectral properties of the different surface types and one for SCE thresholds and SCE parameters.

The tables that follow detail the static application data that shall be produced.

STATIC APPLICATION DATA - SURFACE DATA/SPECTRAL PROPERTIES								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Resolution***	***Source***
Surface elevation	elevation	m	0	8900	100	100	pixel	Static data
Surface-Type-Map	surface_type_map	-	0	99	1	1	pixel	Static data
Nearest Coast Map	Nearest_coast		0	1000	1	1	pixel	Static data
Spectral albedo for each surface type, for channels: VIS0.6, VIS0.8, NIR1.6 and IR3.9	clim_alb	%	0	100	0.1	0.1	-	Static data
Normalised bi-directional reflectance function for each surface type, for channels: VIS0.6, VIS0.8, NIR1.6 and IR3.9	norm_BDRF	-	0	1.5	0.01	0.01	-	Static data

Table 12: Scenes Analysis Product: Static Application Data Produced, Surface Data Spectral Properties

STATIC APPLICATION DATA –AND PARAMETERS THRESHOLDS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Pre***	***Acc***	***Res***	***Source***
Solar zenith threshold for normalisation	SZ_normalize	degrees	0	90	1	1	-	Static data
Solar zenith threshold for day	SZ_day	degrees	0	90	1	1	-	Static data
Solar zenith threshold for night	SZ_night	degrees	0	100	1	1	-	Static data
Nominal repeat cycle duration	rc_nom_dur	mins	0	15	0.5	0.5	-	Static data
Static SCE thresholds:								
Max temperature difference between CSR EBBT in channel IR10.8 and the forecast EBBT in step 1	max_temp_diff	K	-20	20	0.1	0.1	-	Static data
Search area size for clear pixels in step 1	m1	pixel	0	32	1	1	-	Static data
Search area enlargement factor in step 1	nenl		1	4	1	1	-	Static data

STATIC APPLICATION DATA –AND PARAMETERS THRESHOLDS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Pre***	***Acc***	***Res***	***Source***
Time threshold for maximum start time difference between two repeat cycles for step 1	max_time	minutes	0	360	1	1	-	Static data
Search area size for CSR in step 1	m2	pixel	0	32	1	1	-	Static data
Max SD for step 1	std_max_{chan}	K	0	20	0.1	0.1	-	Static data
Reflectance and temperature thresholds - step 3	refl_min	%	0	150	0.1	0.1	-	Static data
	temp_min	K	170	350	0.1	0.1	-	Static data
	temp_max	K	170	350	0.1	0.1	-	Static data
Threshold to determine max start time difference between two repeat cycles for step 4	max_num	-	0	6	1	1	-	Static data
Reflectance threshold for step 4	VIS_change	%	0	150	0.1	0.1	-	Static data
Temperature value to determine the IR threshold in step 4	step4_temp	K	170	350	0.1	0.1	-	Static data
Thresholds for tests 1a to 1d	refl_test1a_add_max_{land,coast,sea}	%	0	50	0.1	0.1	-	Static data
	refl_test1b_add_max_{land,coast,sea}	%	0	50	0.1	0.1	-	Static data
	refl_test1b_add_min_{land,coast,sea}	%	0	50	0.1	0.1	-	Static data
	refl_test1c_add_max_{land,coast,sea}	%	0	50	0.1	0.1	-	Static data
	refl_test1c_add_min_{land,coast,sea}	%	0	50	0.1	0.1	-	Static data
	refl_test1d_add_max_{land,coast,sea}	%	0	50	0.1	0.1	-	Static data
	refl_test1d_add_min_{land,coast,sea}	%	0	50	0.1	0.1	-	Static data
Thresholds for tests 2a to 2f	$a_{0,max1,2a}$ to $a_{0,max1,2f}$	-	-	-	-	-	-	Static data
	$a_{0,max2,2a}$ to $a_{0,max2,2f}$	-	-	-	-	-	-	Static data

STATIC APPLICATION DATA –AND PARAMETERS THRESHOLDS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Pre***	***Acc***	***Res***	***Source***
	$a_{0,min1,2a}$ to $a_{0,min1,2f}$	-	-	-	-	-	-	Static data
	$a_{0,min2,2a}$ to $a_{0,min2,2f}$	-	-	-	-	-	-	Static data
	$a_{1,max1,2a}$ to $a_{1,max1,2f}$	-	-	-	-	-	-	Static data
	$a_{1,max2,2a}$ to $a_{1,max2,2f}$	-	-	-	-	-	-	Static data
	$a_{1,min1,2a}$ to $a_{1,min1,2f}$	-	-	-	-	-	-	Static data
	$a_{1,min2,2a}$ to $a_{1,min2,2f}$	-	-	-	-	-	-	Static data
Thresholds for tests 3a to 3d	temp3a_{land, coast, sea}_{min, max}	K	0	50	0.1	0.1	-	Static data
	temp3b_{land, coast, sea}_{min, max}	K	0	50	0.1	0.1	-	Static data
	temp3c_{land, coast, sea}_{min, max}	K	0	50	0.1	0.1	-	Static data
	temp3d_{land, coast, sea}_{min, max}	K	0	50	0.1	0.1	-	Static data
Correction for diurnal temperature cycle	Dtc_corr_fac(Surface type)	K	0	50	0.1	0.1	-	Static data
Correction for forecast grid surface type	Undef_corr_min	K	0	50	0.1	0.1	-	Static data
Maximum cloud temperature	temp_cloud_max_sea	K	0	500	1	1	-	Static data
	temp_cloud_max_land	K	0	500	1	1	-	Static data
Minimum surface temperature	temp_clear_min_sea	K	0	500	1	1	-	Static data
	temp_clear_min_land	K	0	500	1	1	-	Static data
Thresholds for tests 4a to 4j	$a_{0,4a}$ to $a_{0,4k}$	-	-	-	-	-	-	Static data
	$a_{1,4a}$ to $a_{1,4k}$	-	-	-	-	-	-	Static data
	$a_{2,4a}$ to $a_{2,4k}$	-	-	-	-	-	-	Static data
	$b_{0,4a}$ to $b_{0,4k}$	-	-	-	-	-	-	Static data
	$b_{1,4a}$ to $b_{1,4k}$	-	-	-	-	-	-	Static data

STATIC APPLICATION DATA –AND PARAMETERS THRESHOLDS								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Pre*	*Acc*	*Res*	*Source*
	$b_{2,4a}$ to $b_{2,4k}$	-	-	-	-	-	-	Static data
	$c_{0,4d}$ to $c_{2,4d}$	-	-	-	-	-	-	Static data
	test4d_lat_limit	-	0	90	0.1	0.1	-	Static data
Thresholds for tests 5a to 5h	test5a_{land, sea}	%	0	50	0.1	0.1	-	Static data
	test5b_{land, sea}	%	0	50	0.1	0.1	-	Static data
	test5c_{land, sea}	%	0	50	0.1	0.1	-	Static data
	test5d_{land, sea}	%	0	50	0.1	0.1	-	Static data
	test5e_{land, sea}	K	0	50	0.1	0.1	-	Static data
	test5f_{land, sea}	K	0	50	0.1	0.1	-	Static data
	test5g_{land, sea}	K	0	50	0.1	0.1	-	Static data
	test5h_{land, sea}	K	0	50	0.1	0.1	-	Static data
Coefficients to derive thresholds for test6	c1_vis_{06, 08} c2_vis_{06, 08}	K %	- -	- -	- -	- -	- -	Static data Static data
Temperature threshold for test7	tempsnow0	K	170	280	0.1	0.1		Static data
	Tempsnow1	K	-100	100	0.1	0.1		Static data
	Tempsnow2	K	-100	100	0.1	0.1		Static data
	Tempsnow3	K	-100	100	0.1	0.1		Static data
	Tempsnow4	K	-100	100	0.1	0.1		Static data
	Reflsnow1	%	0	100	0.1	0.1		Static data
	Reflsnow2	%	100	100	0.1	0.1		Static data
	Reflsnow3	%	100	100	0.1	0.1		Static data

STATIC APPLICATION DATA –AND PARAMETERS THRESHOLDS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Pre***	***Acc***	***Res***	***Source***
Threshold to define sunglint conditions	sgl_criteria	degrees	0	90	0.1	0.1	-	Static data
Max time difference for updating Clear Sky Reflectance Map	map_max_time	hours	0	6	0.25	0.25	-	Static data
Elevation EBBT	elevation_EBBT	m	0	10000	1	1	-	Static data
Temperature gradient (K/km)	temp_elev_corr	K	0	50	0.1	0.1	-	Static data
Time interval	time_int	minutes	0	360	1	1	-	Static data
Min number of tests required for AQC	MinTestRequired	-	1	100	1	1	-	Static data
Distance to Coast	DistCoast	pixel	0	3712	1	1		Static data
Near coast temperature adjustment over ocean (array for all 8 IR channels)	TempAdjustWater	K	-100	100	0.1	0.1		Static data
Near coast temperature adjustment over land (array for all 8 IR channels)	TempAdjustLand	K	-100	100	0.1	0.1		Static data
Maximum difference between sun and viewing zenith angle	MaxScatAngle	degrees	0	180	1	1	-	Static data
Latest Clear Sky Reflectance Map (CRM) of the day.	CrmHourHigh	hours	0	24	0	24	-	Static data
First CRM of the day.	CrmHourLow	hours	0	24	0	24	-	Static data
Noon definition	CrmNoon	hours	0	24	12	12	-	Static data
Time step for multiple CRM per day	CrmUpdateStep	hours	0	24	2	2	-	Static data
Temperature below which the correction for cold desert surfaces applies	ColdSurfCorrTstart	K	0	500	0.1	0.1	-	Static data
Slope for the cold surface correction	ColdSurfCorrTslope	K/K	0	1	0.1	0.1	-	Static data
Maximum for the cold surface correction	ColdSurfCorrMax	K	0	10	0.1	0.1	-	Static data

Table 13: Scenes Analysis Product: Static application data and parameters thresholds

Note: All static application data specified in the above tables **shall** be configurable.

5.3 Algorithm Functional Specification

5.3.1 Overview

Several products which are derived from the MSG image data require information on the type of scene contained within a pixel. While some products are derived from cloudy pixels like Cloud Top Height (CTH), Atmospheric Motion Vectors (AMV), others are derived from clear pixels only (Clear Sky Radiances (CSR), for example). For calibration monitoring and vicarious calibration, it is very important that the pixels of selected Earth targets are really cloud-free. Thus the classification of the pixels within a segment, like Scenes Analysis, is a critical process within the MPEF.

The main function of the Scenes Analysis algorithm is to identify whether a pixel contains clouds or not. In this process, pixels partially covered by clouds or covered with semi-transparent clouds will be marked as cloudy pixels. The algorithm can also identify if the pixel is clear with confidence. In some situations when it is difficult to decide between clear and cloudy, the result of the algorithm may be 'unknown'. Pixels identified as clear will contain the information of the surface type which comes from the surface type map. In the case of snow or ice covered pixels, specific checks are used to avoid false cloud detection.

The concept of the Scenes Analysis algorithm is based on a threshold technique, which has been prototyped using AVHRR and GOES data. The algorithm is performed nominally on a pixel basis, however this **shall** be configurable. The following steps are performed for the Scenes Analysis. These are shown graphically in Figure 4.

Step 1	**Prediction of the clear sky brightness temperature:** Predict the clear sky brightness temperature for channels IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0 and IR13.4 by using the Scenes Analysis results, the measured EBBTs and the clear sky radiances product of the previous repeat cycle and by using the output tables of the RTM.

Step 2	**Solar zenith angle check:** Check the solar zenith angle data for each pixel to determine the local time, i.e. day, dawn/dusk and night. This defines the channels and the threshold tests which are required to be used in the following steps

Step 3	**Channel availability and quality check:** Check channel availability and quality for each pixel using the information from the data preparation to determine which of the channels can be used, i.e. which of the threshold tests can be applied.

Step 4	**Data comparison with previous repeat cycle:** Compare the data of the current repeat cycle with the data from the previous repeat cycle for some channels, to determine if the data have changed. If no change (within given boundaries) is detected, it is assumed that the Scenes Analysis algorithm will provide the same result as the previous run, therefore the previously identified scene can be used and all other steps skipped. This step **shall** have the possibility to be disabled.

Step 5	**Threshold determination:** Determine the thresholds to be used for each of the tests of the scenes type identification.
Step 6	**Scenes type identification:** Identify the scenes type using threshold tests.

The **threshold technique** is based on the concept of comparing the image data with thresholds which mark the border between the physical signal (i.e. EBBT and reflectance) of a pixel without clouds and a pixel containing clouds. The Scenes Analysis algorithm can also use the data of the previous image as a prediction for the current image. Also, spatial information (maximum, minimum, mean, standard deviation) is used to supplement the Scenes Analysis process. The threshold technique makes optimal use of the spectral information provided for each pixel with the measurements in all twelve channels. The following threshold tests **shall** be used as a baseline in the Scenes Analysis algorithm:

Test	*Specification*
Test1a	reflectance test using channel VIS0.6
Test1b	reflectance test using channel VIS0.8
Test1c	reflectance test using channel NIR1.6
Test1d	reflectance test using channel IR3.9_sol
Test2a	reflectance difference test VIS0.8/VIS0.6
Test2b	reflectance difference test NIR1.6/VIS0.6
Test2c	reflectance difference test IR3.9_sol/VIS0.6
Test2d	reflectance difference test NIR1.6/VIS0.8
Test2e	reflectance difference test IR3.9_sol/VIS0.8
Test2f	reflectance difference test IR3.9_sol/NIR1.6
Test3a	temperature test using channel IR3.9
Test3b	temperature test using channel IR8.7
Test3c	temperature test using channel IR10.8
Test3d	temperature test using channel IR12.0
Test4a	temperature difference IR10.8 – IR3.9
Test4b	temperature difference IR10.8 – IR6.2
Test4c	temperature difference IR10.8 – IR7.3
Test4d	temperature difference IR10.8 – IR8.7
Test4e	temperature difference IR10.8 – IR12.0
Test4f	temperature difference IR10.8 – IR13.4
Test4g	temperature difference IR12.0 – IR3.9
Test4h	temperature difference IR12.0 – IR6.2
Test4i	temperature difference IR12.0 – IR7.3
Test4j	temperature difference IR12.0 – IR8.7
Test4k	temperature difference IR12.0 – IR13.4
Test5a	standard deviation of channel HRVIS for *n* x *n* processing segment (*n* is nominally 9)

Test	Specification
Test5b	standard deviation of channel VIS0.6 for *n* x *n* processing segment (*n* is nominally 3)
Test5c	standard deviation of channel VIS0.8 for *n* x *n* processing segment (*n* is nominally 3)
Test5d	standard deviation of channel NIR1.6 for *n* x *n* processing segment (*n* is nominally 3)
Test5e	standard deviation of channel IR3.9 for *n* x *n* processing segment (*n* is nominally 3)
Test5f	standard deviation of channel IR8.7 for *n* x *n* processing segment (*n* is nominally 3)
Test5g	standard deviation of channel IR10.8 for *n* x *n* processing segment (*n* is nominally 3)
Test5h	standard deviation of channel IR12.0 for *n* x *n* processing segment (*n* is nominally 3)
Test6	cloud test for sunglint conditions using channels IR3.9 and IR10.8
Test7	snow and ice test – during day

Table 14: Scenes Analysis, Threshold tests

During the lifetime of the satellite the algorithm may be updated, e.g. using more of the spectral channels or including additional/disabling existing threshold tests, using the portable application module concept (Future Enhancement). Therefore it is required that the algorithm **shall** be designed and implemented in such a way that these enhancements can be easily added.

Set-up parameters **shall** define which of the above tests are overall enabled, enabled over sea only, enabled over land only, or overall disabled. In addition, the map indicating the distance of each pixel to the nearest coast is used to select specific threshold parameters (when available) or to disable tests that are not reliable along the coastlines.

The conditions under which each of these tests should be applied are described in the algorithm description. At the beginning of the cloud threshold tests, each pixel is first assumed to be unknown.

The results of Scenes Analysis are quality checked for every pixel. For these quality checks, counters indicating the number of individual tests reporting ‘cloud’, ‘clear’ or ‘unknown’ are used to provide a quality mark indicating the confidence in the Scenes Analysis results.

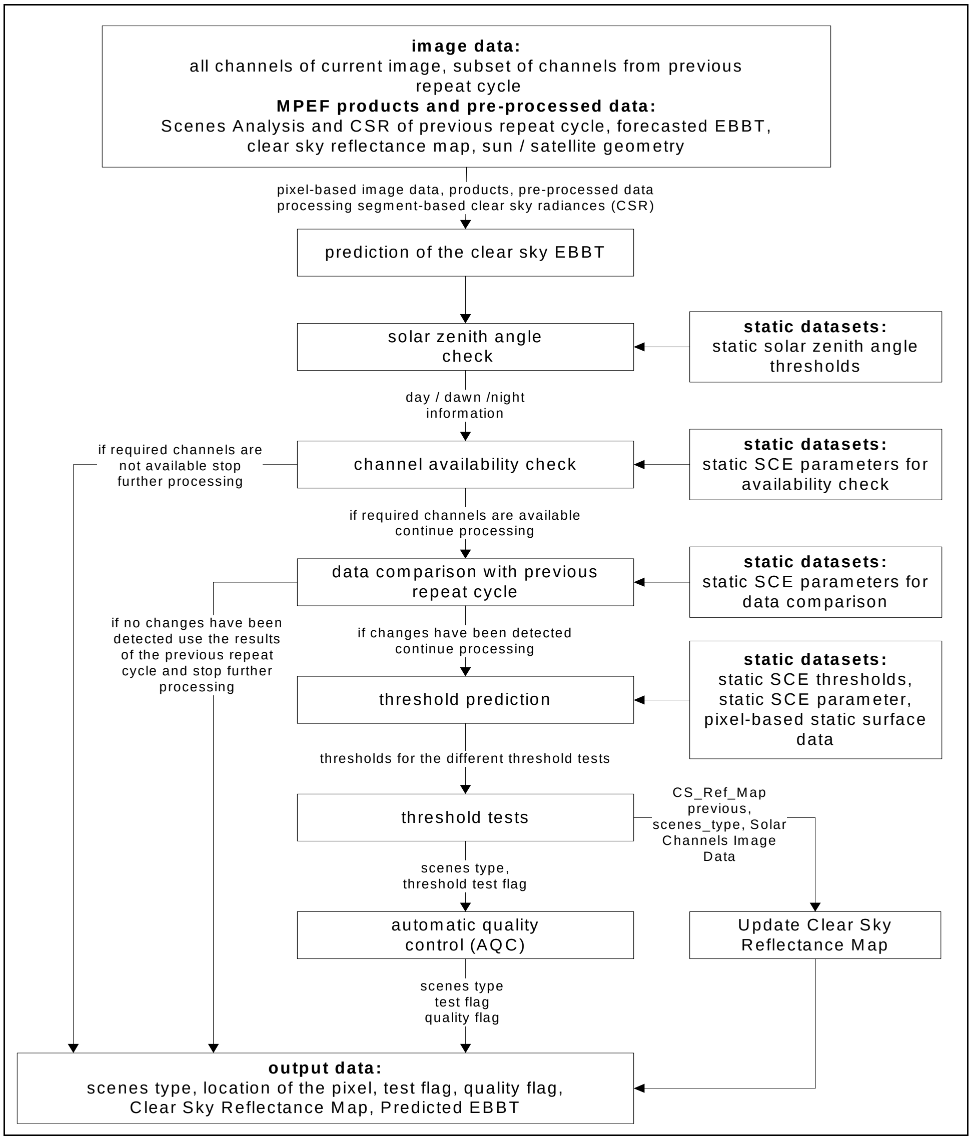

Figure 4: Scenes Analysis SCE Processing

5.3.2 Algorithm Description

The Scenes Analysis algorithm is performed in six steps, which are described in detail below. These steps **shall** be performed for each pixel. All static application data, e.g. thresholds, parameters and constants, **shall** be configurable.

The outcome of the third step (channel availability and quality check), the fourth step (data comparison with previous repeat cycle) and each threshold test of the sixth step **shall** be marked with a flag indicating its result. This flag is called hereafter the test flag.

For all threshold tests, the test flag **shall** be able to reflect four conditions, i.e. ‘test failed’, ‘cloud detected’, ‘clear scene’ or ‘unknown scene’. Finally, the post-processing step of updating of the Clear Sky surface Reflectance Map is described.

5.3.2.1 Step 1: Prediction of Clear Sky EBBT

For tests Test3a–Test3d (temperature tests) and for use by the CLA and AMV height assignment, the clear sky brightness temperature (EBBT) **shall** be determined for channels IR3.9, WV6.3, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0 and IR13.4. The predicted EBBT ($EBBT_{pred}$) **shall** be in units of kelvin (K). The predicted EBBT **shall** be derived as follows:

- The scenes type from the previous repeat cycle **shall** be used to find within an *m1* x *m1* pixel segment surrounding the current pixel location the three closest clear pixels. The EBBT values of these pixels **shall** be averaged for each of the above-defined channels from the previous repeat cycle. If the current pixel is located over land, only clear pixels with a land surface type **shall** be used. Similarly for the sea pixels. The difference in starting time between the previous and the current repeat cycle **shall** **not** exceed *max_time*. If not enough clear pixels can be found as required above or if the time difference exceeds the threshold, the Clear Sky Radiances product of the previous repeat cycle **shall** be used.
- The Clear Sky Radiances product of the previous repeat cycle is derived on an *m2* x *m2* pixel segment. The CSR value with its location closest to the current pixel location **shall** be selected. The difference in starting time between the previous and the current repeat cycle **shall** **not** exceed *max_time*. The distance between the location of the CSR value and the current pixel location **shall** **not** exceed *m2+1* pixels. The standard deviation provided with the CSR **shall** **not** exceed *std_max*. The clear sky radiance **shall** be converted to clear sky equivalent black body brightness temperature (EBBT).
- Additionally, the Scenes Analysis algorithm **shall** use forecast EBBT derived from the radiative transfer model, interpolated in time (to image frequency intervals representing the expected nominal time of the repeat cycle) and space (to the pixel location). If the surface elevation of the pixel is larger than *elevation_EBBT*, the forecast clear sky EBBT of channels IR3.9, IR8.7, IR10.8 and IR12.0 **shall** be corrected by subtracting *(pixel_elevation – elevation_EBBT) * temp_elev_corr / 1000.*

If the clear pixel averaging method or the CSR cannot be applied (as described above), or if the difference between their value and the forecast EBBT is larger than *max_temp_diff*, the forecast EBBT **shall** be used if it is valid for the whole image. Otherwise, the algorithm **shall** repeat this step with *max_time=max_time+time_int* and by enlarging the search area size by a factor of *nenl.*

- The predicted EBBT for the above-specified channels **shall** be stored for later use in the Cloud Analysis (CLA) and Atmospheric Motion Vector (AMV) algorithms. Pixels for which the predicted EBBT is not derived **shall** be set to a default value.
- In addition to the above, a predicted coldest EBBT for each pixel **shall** be derived from the radiative transfer model, interpolated in time (to image frequency intervals representing the expected nominal time of the repeat cycle). The values **shall** be derived from the surrounding gridpoint with the coldest forecast EBBT in channel IR10.8.

5.3.2.2 Step 2: Solar Zenith Angle Check

The Scenes Analysis algorithm **shall** use information about the elevation of the sun in the form of the solar zenith angle for each pixel. According to the solar zenith angle the local time of the day for a single pixel **shall** be identified as the following:

- day, if the solar zenith angle is lower than or equal to a threshold (*SZ_day*)
- night, if the solar zenith angle is greater than or equal to a threshold (*SZ_night*)
- dawn/dusk (i.e. either dawn or dusk), if the solar zenith angle is between the two above thresholds (*SZ_day, SZ_night*)

5.3.2.3 Step 3: Check Channel Availability and Quality

For an optimal performance of the Scenes Analysis algorithm all MSG channels should be available including the statistical information (i.e. mean, max, min, standard deviation) of *n* x *n* pixel matrices derived for each pixel of all channels, where *n* is configurable and is nominally 3. As a minimum, two channels out of the following **shall** be available:

- during daytime: two out of (VIS0.6/VIS0.8/NIR1.6/IR8.7/IR10.8/IR12.0).
- at dawn/dusk and during night: two out of IR3.9/IR8.7/IR10.8/IR12.0.

The line radiometric quality flag of the level 1.5 data header **shall** be checked for each channel, and all pixels in a line flagged as 'suspect' or 'do not use' for this channel **shall** **not** be used.

Additionally the data **shall** be checked for unrealistic values, i.e. temperatures below a minimum threshold (*temp_min*) and above a maximum threshold (*temp_max*), and reflectances below a minimum threshold (*refl_min*) and above a maximum threshold (*refl_max*).

Where the channels are not available any tests using these channels cannot be performed and **shall** be disabled via the updating of the test enable/disable set-up parameters.

If the minimum channels required, as stated above, are not available or if they are showing unrealistic values, then:

- the scenes type **shall** be set to a default value stating 'no scene identified, data not available'
- the test flag for this test **shall** be set to a value stating 'no scene identified, data not available'
- the quality flag **shall** be set to a default value
- the following steps **shall** be skipped.

5.3.2.4 Step 4: Data Comparison with Previous Image

The current and previous image data in the form of EBBT/reflectances **shall** be compared in certain of the channels for each pixel to verify whether there has been a significant change in the data. This check **shall** accept differences in starting time between the current and the previous repeat cycle of up to a value *max_num*. The difference is defined as

$$n = (start\_current\_image - start\_previous\_image)/rc\_nom\_dur$$

Provided the most recent previous repeat cycle has a value of n smaller than or equal to *max_num* then the absolute difference between the current and the previous image data is calculated for a subset of the channels:

Absolute difference = ABS(current - previous)

As a minimum, two channels out of the following (VIS0.6, VIS0.8, IR3.9, IR10.8, IR12.0) **shall** be used for this check. If channel IR3.9 is available, it **shall** be one of these two channels because of its sensitivity to any changes of the scene. During dawn/dusk and night channels VIS0.6 and VIS0.8 **shall** **not** be used for this check. The selection of the channels to be used for the check **shall** be configurable.

For channels VIS0.6 and VIS0.8 a static threshold (*VIS_change*) **shall** be used for this check.

For channels IR3.9, IR10.8 and IR12.0 the following formula **shall** be applied:

IR_threshold = (n +1) * *step4_temp*

where: n = (start_current_image - start_previous_image) / nominal repeat cycle duration

As stated above, if n is larger than *max_num* these tests **shall** **not** be performed and the algorithm **shall** continue with the next step.

If no change has been detected in all channels used for this check (i.e. if the absolute differences are smaller than the thresholds), then:

- the value of prev_scene_type for the pixel **shall** be used
- the test flag for this test **shall** be set to a value identifying the above and the test flags of the previous threshold tests **shall** be used
- the quality flag from the previous AQC **shall** be used
- the subsequent processing steps **shall** be skipped

5.3.2.5 Step 5: Threshold Determination

For each of the threshold tests, the thresholds have to be determined. There are both static and dynamic thresholds. Static thresholds are fixed physical values which are valid nominally for the lifetime of the satellite. Dynamic thresholds are physical values which are changing (with a different timescale) during the lifetime of the satellite and therefore need to be updated frequently.

THRESHOLD DETERMINATION FOR TEST1A, TEST1B, TEST1C AND TEST1D

For Test1a, Test1b, Test1c and Test1d (reflectance tests) the algorithm **shall** use a pixel-based reflectance map to determine the reflectance for each pixel, for channels VIS0.6, VIS0.8, NIR1.6, and IR3.9_sol. The reflectance maps **shall** be updated on a weekly basis by using clear sky reflectances observed in channels VIS0.6, VIS0.8, NIR1.6 and IR3.9_sol for each of the pixels.

As these maps are only valid for a few specific times of the day (i.e. specific sun/satellite geometries) the algorithm **shall** correct the read value for the specific angle dependency by using look-up tables describing the bi-directional reflectance function (BDRF) dependency related to the solar zenith angle, the satellite zenith angle and the relative azimuth angle (sun/satellite) and to the surface type, and **shall** interpolate the BDRF values from the closest triple of angles (solar zenith, satellite zenith and relative azimuth) to the current pair of angles, using a linear interpolation. The determined reflectance for each of the three channels **shall** be derived by using the relationship:

$REFL_{i,c} = REFL_{i,m} * BDRF_{i,c} / BDRF_{i,m}$

where

- $REFL_{i,c}$ is the predicted clear sky reflectance in channel i for the current image c in %.
- $REFL_{i,m}$ is the clear sky reflectance in channel i from the Clear Sky Reflectance Map (CRM) m in %. If multiple CRM per day are available, then the correct CRM to be used is the one whose time stamp is equal to:

$$CrmHourLow + \left[Int\left(\frac{t_c - CrmHourLow - 1/4}{CrmUpdateStep} \right) + 1 \right] \times CrmUpdateStep \qquad \text{Equation 1}$$

if $t_c \le CrmNoon$

or

$$CrmHourHigh - \left[Int\left(\frac{CrmHourHigh - t_c - 1/4}{CrmUpdateStep} \right) + 1 \right] \times CrmUpdateStep$$ *Equation 2*

if $t_c > CrmNoon$

where:

t_c	is the time of the current image in hours

So, for example, for a time step of 2 hours, at 09:30 UTC the 10:00 UTC CRM **shall** be used, whereas at 17:00 UTC the 16:00 UTC CRM **shall** be used.

In the case that a given CRM is not available, the CRM at noon **shall** be used instead.

- $BDRF_{i,c}$ is the normalised bi-directional reflectance function value for channel i valid for the sun/satellite geometry at pixel location for the current image c.
- $BDRF_{i,m}$ is the normalised bi-directional reflectance function value for channel i valid for the sun/satellite geometry at pixel location of the Clear Sky Reflectance Map m.

How this map is derived is described in Section 5.3.2.7. If no Clear Sky Reflectance Map is available, climatological albedo values, *clim_alb*, valid for the different surface types, for each of channel VIS0.6, VIS0.8, NIR1.6 and IR3.9_sol, and for each month of the year, **shall** be used. The reflectance value will be derived by multiplying the albedo with the BDRF valid for the sun/satellite geometry at pixel location for the current image. The final threshold **shall** be derived as follows:

$THR\_TEST1A\_MAX_i = REFL_{i,c} + refl\_test1a\_add\_max$

$THR\_TEST1A\_MIN_i = REFL_{i,c} + refl\_test1a\_add\_min$

$THR\_TEST1B\_MAX_i = REFL_{i,c} + refl\_test1b\_add\_max$

$THR\_TEST1B\_MIN_i = REFL_{i,c} + refl\_test1b\_add\_min$

$THR\_TEST1C\_MAX_i = REFL_{i,c} + refl\_test1c\_add\_max$

$THR\_TEST1C\_MIN_i = REFL_{i,c} + refl\_test1c\_add\_min$

$THR\_TEST1D\_MAX_i = REFL_{i,c} + refl\_test1d\_add\_max$

$THR\_TEST1D\_MIN_i = REFL_{i,c} + refl\_test1d\_add\_min$

THRESHOLD DETERMINATION FOR TEST2A – TEST2F

For *test_index* = Test2a to Test2f the thresholds **shall** be derived as follows:

$THR\_TEST(test\_index)\_MAX1 = a_{0,,max1,test\_index} + REFL_{meas,0.6} * a_{1,max1,test\_index}$

$THR\_TEST(test\_index)\_MAX2 = a_{0,max2,test\_index} + REFL_{meas,0.6} * a_{1,max2,test\_index}$

$THR\_TEST(test\_index)\_MIN1 = a_{0,min1,test\_index} + REFL_{meas,0.6} * a_{1,min1,test\_index}$

$THR\_TEST(test\_index)\_MIN2 = a_{0,min2,test\_index} + REFL_{meas,0.6} * a_{1,min2,test\_index}$

where $REFL_{meas,y}$ is the measured reflectance in channel y. The coefficients $a_{0,xx,yy}$ and $a_{1,xx,yy}$ are different for land and sea.

THRESHOLD DETERMINATION FOR TEST3A TO TEST3D

For Test3a to Test3d (temperature test) the clear sky brightness temperature (EBBT) **shall** be determined for channels IR3.9, IR8.7, IR10.8 and IR12.0. The thresholds **shall** be determined from the predicted EBBT ($EBBT_{pred}$), which are derived in step 1 and which **shall** be in addition adjusted for the following cases:

If the surface type of the pixel is land and different from the ones of the grid points (e.g. small islands):

$EBBT_{pred} = EBBT_{pred} + TempAdjustLand$

If the surface type of the pixel is water and different from the ones of the grid points (e.g. small lakes/rivers):

$EBBT_{pred} = EBBT_{pred} + TempAdjustWater$

If the pixel is within *DistCoast* of a coastline then:

$EBBT_{pred} = EBBT_{pred\ coldest}$

The final thresholds **shall** be derived as follows (with coefficient *test_index* = 3a to 3d):

For sea:

THR_TEST(*test_index*)_MAX = MIN(*T_cloud_max*,($EBBT_{pred}$ – *temp(test_index)_sea_max*)

THR_TEST(*test_index*)_MIN = MIN(*T_cloud_max*, MAX(*T_clear_min*, ($EBBT_{pred}$ – *temp(test_index)_sea_min* – *test3_corr_min*)))

For land:

THR_TEST(*test_index*)_MAX = MIN(*T_cloud_max*,($EBBT_{pred}$ – *temp(test_index)_land_max*))

THR_TEST(*test_index*)_MIN = MIN(*T_cloud_max*, MAX(*T_clear_min*, ($EBBT_{pred}$ – *temp(test_index)_land_min* – *test3_corr_min*)))

with *test3_corr_min* = *Elev_corr* + *Undef_corr* + *DTC_corr* + *Cold_surf_corr*

and where: *T_cloud_max* is the maximum cloud temperature

T_clear_min is the minimum surface temperature

Elev_corr takes into account the decrease of temperature with altitude and is defined as:

*Elev_corr = pixel_elevation * temp_elev_corr / 1000*

where:

pixel_elevation is the elevation (in metres) taken from the pixel-based map of surface elevation

temp_elev_corr is the altitude temperature gradient in kelvin/km.

Undef_corr is given a value of 6 when the RTM forecast grid point surface type does not match with pixel surface, and is null otherwise.

DTC_corr is a term to prevent false cloud detection near sunrise. It **shall** be calculated as follows:

If $(t_{sunrise} - 3 < t_{image} < t_{sunrise} + 3)$ then

$$DTC\_corr = DTC\_corr\_fac \times \left[\Delta T_{interp} - \Delta T(t_{image}) + 0.5\right] \times \left[3 - ABS(t_{image} - 1 - t_{sunrise})\right]$$

else $DTC\_corr = 0$

with: $\Delta T(t_{image}) = DTC\_corr \left\{1 - \cos\left[(t_{image} - t_{sunrise}) \times \pi / 12\right]\right\} / 2$,

$$\Delta T_{interp} = \frac{\{1-\cos[(t_{forecast1}-t_{sunrise})\times\pi/12]\}\times(t_{forecast2}-t_{image}) + \{1-\cos[(t_{forecast2}-t_{sunrise})\times\pi/12]\}\times(t_{image}-t_{forecast1})}{2\times(t_{forecast2}-t_{forecast1})}$$

where: t_{image} is the image timestamp in hours

$t_{forecast1}$ and $t_{forecast2}$ are the RTM forecast times used to interpolate the pixel EBBT

$t_{sunrise}$ is apparent sunrise UTC time

For more details about how this correction is derived, see Appendix A in *Cloud Detection for MSG - Algorithm Theoretical Basis Document*.

Cold_surf_corr is a term to prevent false cloud detection for cold desert surfaces at night, when the forecast surface temperature is overestimated:

$$Cold\_surf\_corr = \begin{cases} 0 \text{ if } T_{forecast}(10.8) \geq T_0 \\ \text{else} \\ Min(ColdSurfCorrMax, (T_{forecast}(10.8) - T_0) * ColdSurfCorrTslope) \end{cases}$$

with $T_0 = ColdSurfCorrTstart - Pixel\_elevation * Temp\_elev\_corr$

THRESHOLD DETERMINATION FOR TEST4A TO TEST 4J

For Test4a to Test 4j (temperature difference tests) the following static thresholds **shall** be derived:

THR_TEST4A_MAX = $a_{0,4a}$+ $EBBT_{pred,10.8}$* $a_{1,4a}$+ $EBBT_{pred,3.9}$* $a_{2,4a}$ – *test4a_corr_max*

THR_TEST4A_MIN = $b_{0,4a}$+ $EBBT_{pred,10.8}$* $b_{2,4a}$+ $EBBT_{pred,3.9}$* $b_{2,4a}$ – *test4a_corr_min*

THR_TEST4B = $a_{0,4b}$ + $EBBT_{pred,10.8}$ * $a_{1,4b}$ + $EBBT_{pred,6.2}$* $a_{2,4b}$ – *DTC_corr*

THR_TEST4C = $a_{0,4c}$ + $EBBT_{pred,10.8}$ * $a_{1,4c}$ + $EBBT_{pred,7.3}$* $a_{2,4c}$ – *DTC_corr*

THR_TEST4D_MIN = $a_{0,4d}$ + $EBBT_{pred,10.8}$ * $a_{1,4d}$ + $EBBT_{pred,8.7}$* $a_{2,4d}$ – *DTC_corr*

THR_TEST4D_MAX1 = $b_{0,4d}$ + $EBBT_{pred,10.8}$ * $b_{1,4d}$ + $EBBT_{pred,8.7}$* $b_{2,4d}$

THR_TEST4D_MAX2 = $c_{0,4d}$ + $EBBT_{pred,10.8}$ * $c_{1,4d}$ + $EBBT_{pred,8.7}$* $c_{2,4d}$

THR_TEST4E = $a_{0,4e}$ + $EBBT_{pred,10.8}$ * $a_{1,4e}$ + $EBBT_{pred,12.0}$* $a_{2,4e}$

THR_TEST4F = $a_{0,4f}$ + $EBBT_{pred,10.8}$ * $a_{1,4f}$ + $EBBT_{pred,13.4}$* $a_{2,4f}$ + *test4f_corr* – *DTC_corr*

THR_TEST4G_MAX = $a_{0,4g}$ + $EBBT_{pred,12.0}$* $a_{1,4g}$ + $EBBT_{pred,3.9}$* $a_{2,4g}$

THR_TEST4G_MIN = $b_{0,4g}$ + $EBBT_{pred,12.0}$ * $a_{1,4g}$ + $EBBT_{pred,3.9}$* $b_{2,4g}$

THR_TEST4H = $a_{0,4h}$ + $EBBT_{pred,12.0}$ * $a_{1,4h}$ + $EBBT_{pred,6.2}$* $a_{2,4h}$

THR_TEST4I = $a_{0,4i}$ + $EBBT_{pred,12.0}$ * $a_{1,4I}$ + $EBBT_{pred,7.3}$* $a_{2,4I}$

THR_TEST4J = $a_{0,4j}$ + $EBBT_{pred,12.0}$ * $a_{1,4j}$ + $EBBT_{pred,8.7}$* $a_{2,4j}$

THR_TEST4K = $a_{0,4k}$ + $EBBT_{pred,12.0}$ * $a_{1,4k}$ + $EBBT_{pred,13.4}$* $a_{2,4k}$

where $EBBT_{pred, nnn}$ is the predicted clear sky EBBT of channel nnn as derived in step1 and *DTC_corr* is a correction to prevent false cloud detection at sunrise (see previous section).

test4a_corr_min is used to correct the thresholds at daytime for the solar reflection in channel IR3.9. This term **shall** be calculated as follows:

For water bodies: *test4a_corr_min* = MIN(0, *sunglint_angle* * 0.3 - 15)

$test4a\_corr\_max = 0$

For other surface types: $test4a\_corr\_min = -$ Climate_albedo(surface_type)*0.3

$test4a\_corr\_max = -$ Climate_albedo(surface_type)*0.3

test4f_corr is a correction term for the emissivity effects over bare and low vegetated soils. It **shall** be set to -2 for barren/desert, grasslands and open shrublands and to 0 for other surface types.

The coefficients a_0, a_1, a_2, b_0, b_1, b_2 **shall** be different for day/night and land/sea (i.e. day/sea, day/land, night/sea, night/land).

THRESHOLD DETERMINATION FOR TEST5A TO TEST5H

For Test5a to Test5h (standard deviation) the thresholds **shall** be set as follows:

For sea: THR_TEST5A = *test5a_sea*
THR_TEST5B = *test5b_sea*
THR_TEST5C = *test5c_sea*
THR_TEST5D = *test5d_sea*
THR_TEST5E = *test5e_sea*
THR_TEST5F = *test5f_sea*
THR_TEST5G = *test5g_sea*
THR_TEST5H = *test5h_sea*

For land: THR_TEST5A = *test5a_land*
THR_TEST5B = *test5b_land*
THR_TEST5C = *test5c_land*
THR_TEST5D = *test5d_land*
THR_TEST5E = *test5e_land*
THR_TEST5F = *test5f_land*
THR_TEST5G = *test5g_land*
THR_TEST5H = *test5h_land*

THRESHOLD DETERMINATION FOR TEST6

The threshold **shall** be determined by using the following relationship:

$$THR\_TEST6 = \text{maximum of } c1 \text{ and } c1 * REFL_{VIS0.8} / c2$$

where $REFL_{VIS0.8}$ is the measured reflectance in channel VIS0.8 in units of %. If channel VIS0.8 is not available channel VIS0.6 **shall** be used instead with different coefficients c_1, c_2.

THRESHOLD DETERMINATION FOR TEST7

The thresholds **shall** be determined only for day and dawn/dusk.

For night no thresholds are derived, since the test is not applied during night.

The thresholds are directly taken from the set-up parameters list.

5.3.2.6 Step 6: Scenes Type Identification

All tests for each local time type, i.e day, dawn/dusk or night, **shall** be performed independently of each other. Each test **shall** be enabled/disabled by a set-up parameter. Several test counters **shall** be used on each pixel to calculate the following numbers:

Test_count	for the total number of tests actually used on that pixel
Max_clear_count	for the total number of tests that *may* actually report 'clear'
Cloud_count	for the total number of tests reporting 'cloudy'
Clear_count	for the total number of tests reporting 'clear'
Unknown_count	for the total number of tests reporting 'unknown'

The threshold tests **shall** be performed as specified below.

DESCRIPTION OF THE THRESHOLD TESTS

For each test used, *Test_count* **shall** be incremented by one.

TEST1A to TEST1D

If it is day (not dawn/dusk), *Max_clear_count* **shall** be incremented by one for each of the tests used in this group.

If the reflectance in channel VIS0.6 is larger than THR_TEST1A_MAX, then the test flag for this test **shall** be set indicating 'cloud detected' and the number of tests reporting 'cloudy' **shall** be incremented by one.

Else, if it is not dawn or dusk and if the reflectance in channel VIS0.6 is less than THR_TEST1A_MIN, then the test flag for this test **shall** be set indicating 'clear detected' and the number of tests reporting 'clear' **shall** be incremented by one.

If none of these conditions are fulfilled, then the test flag for that test **shall** be set indicating 'unknown' and the number of tests reporting 'unknown' **shall** be incremented by one.

TEST1B to TEST1D **shall** be applied similarly.

TEST2A to TEST2F

Max_clear_count **shall** be incremented by one for each of the tests used in this group.

If the difference VIS0.6-VIS0.8 is larger than THR_TEST2A_MAX1 OR lower than THR_TEST2A_MIN1, then the test flag for that test **shall** be set indicating 'cloud detected', and the number of tests reporting 'cloudy' **shall** be incremented by one.

Else, if the difference VIS0.6-VIS0.8 is lower than THR_TEST2A_MAX2 AND larger than THR_TEST2A_MIN2, then the test flag for this test **shall** be set indicating 'clear detected' and the number of tests reporting 'clear' **shall** be incremented by one.

If none of these conditions are fulfilled, then the test flag for that test **shall** be set indicating 'unknown' and the number of tests reporting 'unknown' **shall** be incremented by one.

TEST2B to TEST2F **shall** be applied similarly.

TEST3A to TEST3D

Max_clear_count **shall** be incremented by one for each of the tests used in this group.

If the brightness temperature in channel IR3.9 is smaller than THR_TEST3A_MIN, then the test flag for that test **shall** be set to 'cloud detected' and the number of tests reporting 'cloudy' **shall** be incremented by one.

Else, if the brightness temperature in channel IR3.9 is larger than THR_TEST3A_MAX, then the test flag for that test **shall** be set to 'clear detected' and the number of tests reporting 'clear' **shall** be incremented by one.

If none of these conditions are fulfilled, then the test flag for that test **shall** be set indicating 'unknown' and the number of tests reporting 'unknown' **shall** be incremented by one.

TEST3B to TEST3D **shall** be applied similarly.

TEST4A

If it is daytime, *Max_clear_count* **shall** be incremented by one when this test is used.

If the difference IR10.8-IR3.9 is larger than THR_TEST4A_MAX during night OR smaller than THR_TEST4A_MIN, then the test flag for that test **shall** be set indicating 'cloud detected' and the number of tests reporting 'cloudy' **shall** be incremented by one.

Else, if it is daytime and IR10.8-IR3.9 is larger than THR_TEST4A_MAX, then the test flag for that test **shall** be set to 'clear detected' and the number of tests reporting 'clear' **shall** be incremented by one.

If none of these conditions are fulfilled, then the test flag for that test **shall** be set indicating 'unknown' and the number of tests reporting 'unknown' **shall** be incremented by one.

TEST4B, TEST4C, TEST4F and TEST4H to TEST4K

If the difference IR10.8-IR6.2 is lower than THR_TEST4B_MIN, then the test flag for that test **shall** be set indicating 'cloud detected' and the number of tests reporting 'cloudy' **shall** be incremented by one.

Else, the test flag for that test **shall** be set indicating 'unknown' and the number of tests reporting 'unknown' **shall** be incremented by one.

TEST4C, TEST4F and TEST 4H to TEST4K **shall** be applied similarly.

TEST4D

If the difference IR10.8-IR8.7 is lower than THR_TEST4D_MIN, then the test flag for that test **shall** be set indicating 'cloud detected' and the number of tests reporting 'cloudy' **shall** be incremented by one.

If the pixel latitude is larger than threshold_*4D_lat_limit* AND the difference IR10.8-IR8.7 is larger than THR_TEST4D_MAX1, then the test flag for that test **shall** be set indicating 'cloudy' and the number of tests reporting 'cloudy' **shall** be incremented by one (case of fog or low stratus).

If the pixel latitude is lower than threshold_*4D_lat_limit* AND the pixel surface type is barren/desert, then *Max_clear_count* **shall** be incremented by one and the following test issued: If the difference IR10.8-IR8.7 is larger than THR_TEST4D_MAX2, then the test flag for that test **shall** be set to 'clear detected' and the number of tests reporting 'clear' **shall** be incremented by one.

If none of these conditions are fulfilled, then the test flag for that test **shall** be set indicating 'unknown' and the number of tests reporting 'unknown' **shall** be incremented by one.

TEST4G

If the difference IR12.0-IR3.9 is larger than THR_TEST4G_MAX OR smaller than THR_TEST4G_MIN, then the test flag for that test **shall** be set indicating 'cloud detected' and the number of tests reporting 'cloudy' **shall** be incremented by one.

Else, the test flag for that test **shall** be set indicating 'unknown' and the number of tests reporting 'unknown' **shall** be incremented by one.

TEST5A to TEST5H

These tests **shall** **not** be applied to n x n pixel areas which contain a mixture of land and sea pixels.

If the standard deviation in channel HRVIS is larger than THR_TEST5A and the measured reflectance in channel HRVIS is higher than the mean value of the n x n pixel array, then the test flag for that test **shall** be set indicating ‘cloud detected’ and the number of tests reporting ‘cloudy’ **shall** be incremented by one.

Else, the test flag for that test **shall** be set indicating ‘unknown’ and the number of tests reporting ‘unknown’ **shall** be incremented by one.

TEST5B to TEST5D **shall** be applied similarly.

If the standard deviation in channel IR3.9 is larger than THR_TEST5E and the measured brightness temperature in channel IR3.9 is smaller than the mean value of the n x n pixel array, then the test flag for that test **shall** be set indicating ‘cloud detected’, and the number of tests reporting ‘cloudy’ **shall** be incremented by one.

Else, the test flag for that test **shall** be set indicating ‘unknown’ and the number of tests reporting ‘unknown’ **shall** be incremented by one.

TEST5F to TEST5H **shall** be applied similarly.

TEST6

If the difference IR3.9-IR10.8 is larger than THR_TEST6, then the test flag for that test **shall** be set indicating ‘cloud detected’, and the number of tests reporting ‘cloudy’ **shall** be incremented by one.

Else, the test flag for that test **shall** be set indicating ‘unknown’ and the number of tests reporting ‘unknown’ **shall** be incremented by one.

SCENE DETERMINATION

The final scene type is obtained by using the counters defined at the beginning of the section. In addition, the two following numbers **shall** be used:

- ***Clear% = (Clear_count / Max_clear_count) * 100***
- ***Cloud% = (Cloud_count / Test_count) * 100***

If *Clear_count* is larger than 0 AND *Cloud_count* is null, then the scenes type **shall** be set to the surface type and the quality index set to 10.

If *Clear_count* is null AND *Cloud_count* is null, then the scenes type **shall** be set to the surface type and the quality index set to 30.

If *Clear_count* is larger than 0 AND *Cloud_count* larger than 0, then the following checks **shall** be done:

> If *Clear%* is larger than *Cloud%* is AND *Clear_count* is larger than or equal to *Cloud_count*, then scenes type **shall** be set to the surface type and the quality index set to 40.
>
> Else, if *Cloud%* is larger than *Clear%*, then the scenes type **shall** be set to ’cloudy’ and the quality index set to 60.
>
> If none of these two conditions are fulfilled, then the scenes type **shall** be set to ’unknown’ and the quality index set to 50.

If *Clear_count* is null AND *Cloud_count* is larger than 0 AND *Unknown_count* is larger than 0, then the scenes type **shall** be set to ’cloudy’ and the quality index set to 90.

If *Clear_count* is null AND *Cloud_count* is larger than 0 AND *Unknown_count* is null, then the scenes type **shall** be set to ’cloudy’ and the quality index set to 100.

TEST7

Test7 **shall** be applied after the Scene determination, since this test will change the overall quality index. This test will reset cloudy pixels to the value clear (ice and snow cover) if a clear snow- or ice-covered surface has been falsely classified as cloud.

The test **shall** be applied only at day or dawn/dusk conditions as follows:

Calculate the normalised snow index (NSI) as follows:

NSI = (REFL0.6 – REFL1.6) / (REFL0.6 + REFL1.6)

At daytime, if the pixel is cloud covered according to one of the tests above,

and if the reflectance in channel VIS06 is smaller than a threshold *ReflSnow1,*

and if the normalised snow index is larger than a threshold ReflSnow2,

and if the predicted EBBT of channel IR10.8 is lower than a threshold TempSnow0,

and if the measured EBBT of channel IR10.8 is greater than the predicted EBBT for that channel plus a threshold TempSnow1,

and if the difference EBBT10.8-EBBT12.0 is greater than a threshold TempSnow2, then:

Reset the Scene Type to 'clear snow land' if pixel is on land or to 'clear ice water' if the pixel is on water. Set the test flag of this test to 'snow detected' and set the overall quality flag to 25%.

At dawn/dusk, if the pixel is cloud covered according to one of the tests above,

and if the normalised snow index is larger than a threshold ReflSnow3,

and if the predicted EBBT of channel IR10.8 is lower than a threshold TempSnow0,

and if the measured EBBT of channel IR10.8 is greater than the predicted EBBT for that channel plus a threshold TempSnow3,

and if the difference EBBT10.8-EBBT12.0 is greater than a threshold TempSnow4, then:

Reset the Scene Type to 'clear snow land' if pixel is on land, or to 'clear ice water' if the pixel is on water. Set the test flag of this test to 'snow detected' and set the overall quality flag to 25%.

APPLICATION OF THE THRESHOLD TESTS

The threshold tests described above **shall** be performed independently. They **shall** be used in the following context:

- First, the scenes type **shall** be set to 'unknown'.
- **For day pixels** the following tests **shall** be applied (see exceptions below):

TEST1A to TEST1D, TEST2A to TEST2F, TEST3A to TEST3D, TEST4A to TEST4K, TEST5A to TEST5H, TEST7.

- **For dawn and dusk pixels** the following tests **shall** be applied (see exceptions below):

TEST1A to TEST1D, TEST2A to TEST2F, TEST3A to TEST3D, TEST4A to TEST4K, TEST5A to TEST5H, TEST7.

TEST1A to TEST1D **shall** be disabled if a Clear Sky Reflectance Map with a valid value is not available (climatological albedo is not accurate enough).

TEST4A **shall** not be applied over sea.

TEST1A to TEST1D **shall** **not** be applied if the viewing angle from the satellite is higher than 55º (to avoid strong backscattering / "hot spot" situations).

- **For day, dawn and dusk pixels** the following exceptions **shall** be applied:

Sunglint

If the following sunglint criteria are fulfilled:

- the pixel is located over water surfaces (i.e. lake or ocean)
- ABS(COS^{-1}(COS(sol_zenith)*COS(sat_zenith) – SIN(sol_zenith)*SIN(sat_zenith) *COS(relative azimuth)) is smaller than a threshold *sgl_criteria*

then TEST1A to TEST1D, TEST2A to TEST2F, TEST3A, TEST4G, and TEST5A to TEST 5G **shall** be disabled and TEST6 **shall** be enabled.

Scattering angle

If the angle between the sun and the satellite directions is higher than *max_scat_angle* over land and *max_scat_angle* – 10º over sea, then the following tests **shall** be disabled:

TEST1A to TEST1D, TEST3A, TEST4A, and TEST5A to TEST5H.

High viewing angles

If the satellite viewing angle is higher than 55º, then the following tests **shall** be disabled:

TEST1A to TEST1D.

- **For night pixels** the following tests **shall** be applied:

TEST3A to TEST3D, TEST4A to TEST4K, TEST5E to TEST5H. However, Test4A **shall** be disabled at night if the surface type is barren/desert, grassland or open shrubland.

- **For all time conditions** the following tests **shall** be excluded if the pixel is closer than *DistCoast* to the nearest coastline:

  TEST1A to TEST1D, TEST2A to TEST2F, TEST4A, TEST4G, TEST5A to TEST5H.

5.3.2.7 Update of the Clear Sky Reflectance Map

This post-processing function **shall** update existing CRM files and create new CRM files. New CRM files for each CRM derivation time (every two hours between 06:00 and 20:00 UTC) **shall** be created daily. For the other CRM time stamps new CRM files **shall** be created twice a week, on Sundays and Wednesdays. The time stamps for which CRM files are created and updated are the full hours, starting from *CrmHourLow* to *CrmHourHigh* every *CrmUpdateSteps* hours.

For the two closest repeat cycles (these **shall** be within *map_max_time* hours) of each CRM time stamp the files are updated.

For each pixel the reflectance value for each of channels VIS0.6, VIS0.8, NIR1.6 and IR3.9_sol for clear scenes **shall** be collected for a period of seven days and averaged, i.e. clear sky reflectance of channel VIS0.6, VIS0.8, NIR1.6 and IR3.9_sol for that pixel.

For each pixel the mean solar zenith angle and the mean relative azimuth angle (sun/satellite) at the CRM time stamp at the SSP for that seven-day period **shall** be determined.

If a pixel has no clear scene in that seven-day period the value of the previous seven-day period **shall** be used. If that value is not available, the value **shall** be set to a default invalid value.

5.3.3 Automatic Quality Control (AQC)

The Scenes Analysis algorithm is designed in a way that there is a high confidence in the determination of a pixel to be clear or cloud contaminated. Therefore the automatic quality control (AQC) **shall** be applied to all pixels. The AQC **shall** provide a quality index (QI) for each pixel, which is a number ranging between 0% and 100%. The number 0% has the meaning of 0% confidence for cloud contamination (i.e. 100% confidence clear) and the number 100% has the meaning of 100% confidence for cloud contamination. The QI **shall** be derived as detailed in the Scene determination section in §5.3.2.6. The following table summarises the possible values for the scene type and QI:

Case	*Scene Type*	*Quality Index*
Scenes analysis not performed	0	0
Clear, high confidence	Surface type map	10
Clear, confidence	Surface type map	30
Clear, low confidence	Surface type map	40
Unknown	Unknown scene	50
Cloud, low confidence	Cloud	60
Cloud, confidence	Cloud	90
Cloud, high confidence	Cloud	100

5.4 Outputs

The results of the Scenes Analysis algorithm (i.e. scenes type) **shall** be provided per pixel as follows:

- for pixel with no image data available, the scenes type **shall** be set to a default value stating 'no scenes identified, missing image data'.
- for pixel identified as clear, the scenes type **shall** be set either to the value of the surface type (including the surface type 'snow/ice'), or to a value stating 'sunglint'.
- for pixels identified as cloudy, the scenes type **shall** be set to a value stating 'cloudy'.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Scenes type	scenes_type	-	0	255	1	1	CLA, CAL, SST, SCE, GII
Predicted EBBTs for all IR channels	pred_EBBT_chan	K	170	350	0.1	0.1	CLA, AMV
SCE test flag	test_flag	-	-	-	-	-	CLA, SCE_{next}
SCE quality index	QI	%	0	100	1	1	All products
Clear Sky Reflectance Map	csr_map	% × 10	0	1500	1	1	SCE next

Table 15: Scenes Analysis algorithm Pixels identified as cloudy

Parameter	*Value*	*Meaning*
Scenes type	0	No scenes identified, missing input data
	1	Evergreen needleleaf forest
	2	Evergreen broadleaf forest
	3	Deciduous needleleaf forest
	4	Deciduous broadleaf forest
	5	Mixed forest
	6	Closed shrublands
	7	Open shrublands
	8	Woody savannahs
	9	Savannahs

Parameter	*Value*	*Meaning*
	10	Grasslands
	11	Permanent wetlands
	12	Croplands
	13	Urban and built-up
	14	Cropland mosaics
	15	Permanent snow/ice
	16	Bare soil and rocks
	17	Water bodies
	18	Tundra
	19	Mixed land/water
	20 to 49	(Spare)
	50	Unknown scene
	51 to 96	(Spare)
	97	Snow/ice over land
	98	Snow/ice over water (ocean)
	99	Clear sunglint
	100	Cloudy

Table 16: Scenes Analysis algorithm: Scenes type values

SCENE TEST FLAG

Each test result **shall** be stored using 2 bits and coded as following:

Value (binary)	*Test result*
0 (00)	Clear
1 (01)	Unknown
2 (10)	Cloud
3 (11)	Test failed

The test flags **shall** be written into a 2-bytes integer from right to left according to the position given in the table here below (i.e., Test 1A is at the right end, or lowest binary exposure). To limit the size of the test flag file, only the results of the tests currently used are stored.

Nb	*Position*	*Test*	*Nb*	*Position*	*Test*
1	0	1A	9	16	4D
2	2	1B	10	18	4F
3	4	1C	11	20	5C
4	6	2A	12	22	5G
5	8	3C	13	24	7
6	10	4A	14	26	Unused
7	12	4B	15	28	Unused
8	14	4C	16	30	Unused

5.5 Prototyping and Testing

This section describes the prototyping activities, highlighting the major problems which were encountered with this development.

5.5.1 Prototyping

The prototyping activities provide information about the scientific background for the Scenes Analysis algorithm and verify that the algorithm is scientifically correct. The scientific background of the prototype is mainly based on existing algorithms, i.e. APOLLO, SCANDIA and the model used at CMS in France. References are listed in Section 5.7. Additionally new ideas have been included, e.g. using the data from the previous repeat cycle as a first guess for the current image.

5.5.2 Test Data

The major problem is to simulate the MSG channels. The prototype uses existing data from:

- GOES-8/Imager, which helps to simulate channels VIS0.6, IR3.9, WV6.2, IR10.8 and IR12.0 on a similar horizontal resolution as MSG.
- GOES-8/Sounder, which helps to simulate channels VIS0.8, IR3.9, WV6.2, WV7.3, IR9.7, IR10.8, IR12.0 and IR13.4 on a lower horizontal resolution. During prototyping and testing only these channels have been used and the other 'MSG' channels have been regarded as missing.
- AVHRR, which helps to simulate channels VIS0.6, VIS0.8, IR3.9, IR10.8 and IR12.0 on a higher horizontal resolution than MSG. The new generation of AVHRR will also provide an NIR1.6 channel in the near future.

The surface type map was only available in the form of a land-sea mask. Also the surface albedo was only specified for land (16% albedo) and ocean (8%). A more detailed global surface type map, with 18 different surface types on a 0.167° grid resolution, is provided with the test data together with the spectral albedo for the different surface types. The surface temperature analysis is made available as part of the External Meteorological Data.

5.5.3 Test Results

Tests have been performed for several slots of the GOES-8 images. For one slot the results from each single threshold test and the final cloud mask are available. For the other slots the results are only available in the form of the final cloud mask.

5.6 Future Enhancements

The following Future Enhancements **shall** be foreseen in the algorithm design as indicated above:

- Inclusion of additional tests, adding new AQC checks or disabling existing tests or AQC checks.
- Use of a pixel-based surface emissivity map.
- Use of level 1.5 image data from additional spectral channels.

5.7 References

Reference	*Title*	*Date*	*Author(s)*
Int. J. of Remote Sensing, Vol. 9, pp. 123-150	An improved method for detecting clear sky and cloudy radiances from AVHRR data	1988	Saunders, R.W. and Kriebel, K.T.
Remote Sensing of Environ., Vol. 46, pp. 246-267	Automatic cloud detection applied to NOAA-11/AVHRR imagery	1993	Derrien, M. et al.
SMHI Reports Meteorology and Climatology, No. 67, Jan 1996	Cloud classifications with the SCANDIA model	1996	Karlson, K.-G.

6 BDRF TABLE GENERATION

6.1 Introduction

The Bi-Directional Reflectance Function (BDRF) describes for a surface the ratio of the reflected radiance L to the incident irradiance I, for a given wavelength λ and geometry.

$$\rho(\lambda,\theta_s,\theta_v,\varphi) = \frac{\pi.L(\lambda,\theta_v,\varphi)}{I(\lambda,\theta_s).\cos(\theta s)}$$ *Equation 3*

where θ_s, θ_v and ϕ are respectively the source zenith angle, the view zenith angle and the relative azimuth angle. Provided as a static data table, the BDRF is used in MPEF by the SCE algorithm (see under Sections 5.3.2.4 and 5.3.2.5) for calculating the expected top-of-atmosphere reflectance, and by the NDVI algorithm (described in Chapter 7) to attenuate the effect of the solar zenith angle variability.

This chapter explains how this BDRF table is generated.

6.2 Semi-empirical BDRF Model

An analytic reflectance model is used to represent the BDRF, whose values are finally extracted to write the static tables for a sampling of geometries. Many different models are available (Maignan *et al.*, 2004). The Ross/Roujean semi-empirical kernel model (Roujean *et al.,*1992, also used by the LAND-SAF for BDRF and albedo determination) has been selected, with the advantage of being linear, and so easy to invert against observations.

The model has three terms representing respectively the isotropic, geometric (shading effects) and volumic (multiple reflections) contributions. A fourth specular reflection term has been added for the reflectance over water and deserts.

$$\rho = k_0 + k_1.f_1^{geo}(\theta_s,\theta_v,\varphi) + k_2 f_2^{vol}(\theta_s,\theta_v,\varphi) + k_3 f_3^{spec}(\theta_s,\theta_v,\varphi)$$ *Equation 4*

where:

$$f_1^{geo} = \frac{1}{2\pi}\left[(\pi-\varphi)\cos\varphi + \sin\varphi\right]\tan\theta_s\tan\theta_v - \frac{1}{\pi}\left[\tan\theta_s + \tan\theta_v + \Delta(\theta_s,\theta_v,\varphi)\right]$$

$$\Delta = \sqrt{\tan^2\theta_s + \tan^2\theta_v - 2\tan\theta_s\tan\theta_v\cos\varphi}$$

$$f_2^{vol} = \frac{4}{3\pi}\frac{1}{\cos\theta_s + \cos\theta_v}\left[\left(\frac{\pi}{2}-\xi\right)\cos\xi + \sin\xi\right] - \frac{1}{3}$$

$$\cos\xi = \cos\theta_s\cos\theta_v + \sin\theta_s\sin\theta_v\cos\varphi$$

$$f_3^{spec} = \frac{1.25 - 0.25\cos(2\theta_s)}{1 + \dfrac{sgl}{S_0}}$$

$$\cos(sgl) = \cos\theta_s\cos\theta_v - \sin\theta_s\sin\theta_v\cos\varphi$$

$$S_0 = 0.1 + 0.002\times\theta_s \quad \text{(with } \theta_s \text{ in degrees; } S_0 \text{ will be in radians)}$$

k_0, k_1, k_2, k_3 are the model variables, for a given wavelength and surface type.

In the expressions for $(\pi-\varphi)$, $\left(\frac{\pi}{2}-\xi\right)$ and $\frac{sgl}{S_0}$ note that the angles φ, ξ, sgl and S_0 are expressed in radians.

6.3 Model inversion

Clear-sky observations for each surface type are accumulated by collecting several archived clear-sky reflectance maps (see Chapter 23), at different times of the year, in order to get a sufficient angular sampling.

These observations are used to invert the BDRF model using a standard least squares regression technique. This method, however, does not work properly for deserts, because this surface type covers in fact many different soil types, with different reflectance levels. So for deserts, the model variables have been defined empirically. A similar manual fitting was performed for water bodies, the goal being here to mimic the modelled sea reflectance from P.D. Watts' study on aerosols for an optical thickness of 0.2 (see references in Section 6.5).

The following tables show the retrieved model variables for each channel surface type:

Channel 1				
Surface type	***K0***	***K1***	***K2***	***K3***
Evergreen needleleaf forest	0.133	0.004	0.119	0
Evergreen broadleaf forest	0.112	0.001	0.115	0
Deciduous needleleaf forest	0.139	0.004	0.131	0
Deciduous broadleaf forest	0.117	0.003	0.117	0
Deciduous mixed forest	0.095	0.001	0.152	0
Closed shrubland	0.143	0.008	0.140	0
Open shrubland	0.224	0.007	0.098	0
Woody savannah	0.114	0.001	0.133	0
Savannah	0.139	0.004	0.102	0
Grassland	0.189	0.007	0.068	0
Permanent wetland	0.143	0.008	0.134	0

Channel 1				
Cropland	0.151	0.005	0.092	0
Urban	0.150	0.006	0.107	0
Crop vegetation	0.139	0.005	0.096	0
Permanent snow	0.407	0.022	–0.066	0
Barren deserts	0.200	0	0.050	0.10
Water bodies	0.080	0.027	0.005	0.65
Tundra	0.100	0	0.050	0

Table 17: BDRF Table Generation: the retrieved model variables for Channel 1

Channel 2				
Surface type	***K0***	***K1***	***K2***	***K3***
Evergreen needleleaf forest	0.240	0.016	0.050	0
Evergreen broadleaf forest	0.224	0.016	0.044	0
Deciduous needleleaf forest	0.250	0.014	0.049	0
Deciduous broadleaf forest	0.223	0.015	0.049	0
Deciduous mixed forest	0.212	0.013	0.080	0
Closed shrubland	0.210	0.018	0.081	0
Open shrubland	0.261	0.017	0.049	0
Woody savannah	0.216	0.015	0.061	0
Savannah	0.216	0.014	0.064	0
Grassland	0.242	0.016	0.038	0
Permanent wetland	0.214	0.017	0.087	0
Cropland	0.222	0.012	0.063	0
Urban	0.214	0.015	0.069	0
Crop vegetation	0.227	0.015	0.052	0
Permanent snow	0.386	0.036	–0.073	0
Barren deserts	0.250	0	0.050	0.10
Water bodies	0.060	0.027	0.005	0.70
Tundra	0.100	0	0.050	0

Table 18: BDRF Table Generation: the retrieved model variables for Channel 2

Channel 3				
Surface type	***K0***	***K1***	***K2***	***K3***
Evergreen needleleaf forest	0.243	0.026	–0.017	0
Evergreen broadleaf forest	0.202	0.018	0.008	0
Deciduous needleleaf forest	0.237	0.023	–0.015	0
Deciduous broadleaf forest	0.237	0.021	-0.010	0
Deciduous mixed forest	0.204	0.023	0.029	0
Closed shrubland	0.247	0.027	0.000	0
Open shrubland	0.366	0.027	–0.021	0
Woody savannah	0.216	0.019	0.015	0
Savannah	0.262	0.023	–0.015	0
Grassland	0.322	0.025	–0.054	0
Permanent wetland	0.216	0.022	0.047	0
Cropland	0.273	0.024	–0.022	0

Channel 3				
Surface type	***K0***	***K1***	***K2***	***K3***
Urban	0.253	0.026	0.002	0
Crop vegetation	0.255	0.023	–0.018	0
Permanent snow	0.225	0.031	–0.071	0
Barren deserts	0.250	0	0.050	0.10
Water bodies	0.040	0.027	0.005	0.73
Tundra	0.100	0	0.050	0

Table 19: BDRF Table Generation: the retrieved model variables for Channel 3

6.4 Table generation

As the f_i functions require intensive calculations, for every pixel, the reflectance values are stored in a static table, in which the entries are the surface type, the sun zenith angle, the view zenith angle and the relative azimuth angle. The sampling resolutions for the latter are respectively 10°, 10° and 30°.

6.5 References

Reference	***Title***	***Date***	***Author(s)***
Remote Sensing of Environment , 90 (2004) 210–220	Bidirectional reflectance of Earth targets: Evaluation of analytical models using a large set of spaceborne measurements with emphasis on the Hot Spot	2004	F. Maignan, F.-M. Bréon, R. Lacaze
Journal of Geophysical Research, vol. 97, pp. 20,455 – 20,468	A bi-directional reflectance model of the earth's surface for the correction of remote sensing data	1992	J.L. Roujean, M. Leroy, P.Y. Deschamps
RAL/TN/EUM/004	Aerosol Properties derived from Meteosat Second Generation Observations	2000	P.D. Watts, M.R. Allen, C.T. Mutlow
EUM/OPS/TEN/10/1901	BDRF function for MSG MPEF	2010	O. Samain

7 NORMALISED DIFFERENCE VEGETATION INDEX (NDVI) PRODUCT GENERATION

7.1 Algorithm Configuration Information

7.1.1 Algorithm Name

Normalised Difference Vegetation Index (NDV)

7.1.2 Algorithm Identifier

EUM_MSG_NDV_A001

7.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	01/01/11	O. Samain	NDVI Baseline

7.2 Inputs

The Normalised Difference Vegetation Index (NDVI) generation is technically part of the Scenes Analysis processing. For more technical information on the processing of input data, see Chapter 5.

7.3 Algorithm Functional Specification

7.3.1 Overview

The NDVI is an indicator of the photosynthetic activity of the vegetation. It varies between zero (deserts) and 1 (dense vegetation).

7.3.2 Algorithm Description

The NDVI is defined as the following ratio:

$$NDVI = \frac{R(NIR) - R(VIS)}{R(NIR) + R(VIS)}$$ *Equation 5*

where R(VIS) is the reflectance in the 0.6 µm channel and R(NIR) the reflectance in the 0.8 µm channel.

Usually, this formula applies to top-of-canopy reflectances, i.e. corrected for atmospheric transmission effects for low orbit sensors. In the case of MSG, top-of-atmosphere reflectances are used. The consequences are greater distortions due to high view zenith angles and changing sun zenith angles during the year. To reduce these distortions, a corrected NDVI is calculated instead:

$$NDVIcor = \frac{R_{cor}(NIR) - R_{cor}(VIS)}{R_{cor}(NIR) + R_{cor}(VIS)}$$

$$\text{where } R_{cor} = R_{mes} \times \frac{BDRF(0,0,0,suface\_type)}{BDRF(\theta_s,\theta_v,\varphi,suface\_type)}$$ *Equation 6*

R_{mes} is the actual top-of-atmosphere reflectance and θ_s, θ_v and ϕ are respectively the sun zenith angle, the view zenith angle and the relative azimuth angle. The BDRF function refers to the BDRF table described in Chapter 6.

7.3.3 Automatic Quality Control (AQC)

There is no automatic quality control mechanism in the algorithm. However, the number of accumulations in the generated product can be used as a quality indicator. A higher number indicates that the calculated NDVI is more accurate.

7.4 Outputs

7.4.1 Daily product

The NDVI daily product is generated by incremental update at each repeat cycle, every time a new clear-sky observation is available for a given pixel.

The output file contains the following fields:

- Minimum NDVI for the day
- Maximum NDVI for the day
- Mean NDVI
- Number of accumulations

7.4.2 Encoded product

The daily NDVI product is encoded in HDF5 format.

In addition, a so-called 10-day NDVI product is generated, also in HDF5, by accumulating the data of the daily product. This product is generated for every month according to the following scheme:

- Day 1–10
- Day 11–20
- Day 21 – end of month

7.5 Future Enhancements

No future enhancements are foreseen.

7.6 References

None

8 CLOUD ANALYSIS PRODUCT GENERATION

8.1 Algorithm Configuration Information

8.1.1 Algorithm Name

Cloud Analysis (CLA)

8.1.2 Algorithm Identifier

EUM_MSG_CLA_A001

8.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	H.-J. Lutz	CLA Baseline
1.1	26/5/97	H.-J. Lutz	TBDs resolved, bid clarification points added, errors corrected.
1.2	1/7/97	H.-J. Lutz	Clarifications added and updates as a result of the improvements to the SCE algorithm.
1.3	8/12/97	H. K. Wilson	Requirements Analysis clarification points added.
1.4	13/3/98	H. K. Wilson	Peer Group Review changes added.
1.5	15/1/99	H.-J. Lutz	Detailed Design Phase changes added.
1.6	31/1/02	H.-J. Lutz	Updated according to ECP 295.
1.7	25/7/05	J. Gustafsson	Added inversion height assignment.

8.2 Inputs

8.2.1 Image and Preprocessing Data (Dynamic Application Data)

The Cloud Analysis algorithm uses the level 1.5 data from all MSG channels. As defined below, the image data **shall** be available in the form of equivalent black body brightness temperatures (EBBT) (unit K) for all IR/WV channels and in the form of reflectances (unit %) for all VIS/NIR channels.

LEVEL 1.5 IMAGE DATA AND DATA DERIVED FROM THE IMAGE DATA								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Reflectances for channels VIS0.6, VIS0.8, NIR1.6, HRVIS, IR3.9_sol	$REFL_{channel}$	%	0	150	0.1	0.1	pixel	Derived from level 1.5 data
EBBTs for channels: IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4	$EBBT_{Ichannel}$	K	170	350	0.1	0.1	pixel	Derived from level 1.5 data
Radiances for channels: IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4	$Rad_{Ichannel}$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	pixel	Derived from level 1.5 data
Local mean, minimum, maximum and standard deviation on a 3 x 3 pixel segment for channels VIS0.6, VIS0.8, NIR1.6, IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4	mn_REFL/EBBT max_REFL/EBBT min_REFL/EBBT std_REFL/EBBT	- - - -	- - - -	- - - -	- - - -	- - - -	pixel pixel pixel pixel	Derived from level 1.5 data Derived from level 1.5 data Derived from level 1.5 data Derived from level 1.5 data
Solar Zenith Angle	sol_zenith	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from level 1.5 data
Satellite Zenith Angle	sat_zenith	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from level 1.5 data
Relative azimuth angle sun/sat	sol_sat_azimuth	degrees	0	360	0.1	0.1	pixel	Derived from level 1.5 data

Table 20: Cloud Analysis algorithm: Level 1.5 Image Data and Data Retrieved from the Image Data

8.2.2 Data from other MPEF Algorithms (Dynamic Application Data)

The Cloud Analysis algorithm uses data from other MPEF algorithms, as defined in the following table:

DATA FROM OTHER MPEF ALGORITHMS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Scenes Type	scenes_type	-	-	-	-	-	pixel	SCE
Predicted clear sky temperatures for all IR channels	pred_EBBT_chan	K	170	350	0.1	0.1	pixel	SCE
SCE quality index	QI	-	0	100	10	10	pixel	SCE
Scenes Type	prev_scenes_type	-	0	100	-	-	pixel	CLA int previous
Cloud Phase	prev_cld_phase	-	0	3	-	-	pixel	CLA int previous
Cloud Top Temperature	prev_cld_ctt	K	170	300	0.1	0.1	pixel	CLA int previous
Cloud Top Height	prev_cld_cth	hPa	100	1050	50	1	pixel	CLA int previous
Cloud Optical Thickness	prev_cld_opt	-	0	200	1	1	pixel	CLA int previous
Effective Cloud amount	prev_cld_neff	%	0	100	1	1	pixel	CLA int previous
Forecast EBBTs for all IR channels including calculations for semi-transparency and different cloud layers	$for\_EBBT_{ch.}\_clear$ $for\_EBBT_{ch.}\_cloud$ $for\_EBBT_{ch.}\_semi$	K K K	230 200 200	350 300 320	0.1 0.1 0.1	0.1 0.1 0.1	pixel pixel pixel	Derived from RTM output Derived from RTM output Derived from RTM output
Forecast radiances for all IR channels including calculations for semi-transparency and different cloud layers	$for\_Rad_{ch.}\_clear$ $for\_Rad_{ch.}\_cloud$ $for\_Rad_{ch.}\_semi$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0 0 0	- - -	- - -	- - -	pixel pixel pixel	Derived from RTM output Derived from RTM output Derived from RTM output
Tropopause Height	trop_ht	hPa	0	1030	1	1	pixel	Derived from Forecast
Forecast temperature profiles on the pressure levels of the ECMWF model	for_prof	K	170	350	0.1	0.1	pixel	Derived from Forecast

Table 21: CLA Algorithm: Dynamic Application Data

8.2.3 Static Application Data

The static application data used by the Cloud Analysis algorithm consists of the following:

- static thresholds
- static parameters for the different mathematical expressions used in the algorithm

STATIC DATA SETS - THRESHOLDS AND PARAMETERS								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Pre.*	*Acc.*	*Res*	*Source*
Solar Zenith Thresholds	SZ_thresh	degrees	0	100	1	1	-	Set-up
CLA processing segment size	ps_size	pixel	1	64	1	1	-	Set-up
Min number of pixels to be included in final product	min_cld_pixel	-	1	1024	1	1	-	Set-up
Sub-level for final CLA	sub_levels	hPa	25	200	25	25	-	Set-up
Min pixels for image product	min_ima_pixels	-	1	25	1	1	-	Set-up
Max time delay allowed	max_hours	hours	0	6	0.25	0.25	-	Set-up
Max delay in repeat cycles	max_cycles	-	0	24	1	1	-	Set-up
Temperature difference allowed in step 2	step2_temp	K	0	5	0.1	0.1	-	Set-up
Lower Pressure limit for band	low_level_cloud_pressure	hPa	600	900	25	25	-	Set-up
Mid-level Pressure limit for band	high_level_cloud_pressure	hPa	300	600	25	25	-	Set-up
VIS threshold for step 2	VIS_change	%	0	10	0.1	0.1	-	Set-up
Repeat cycle nominal duration	rc_nom_dur	mins	0	15	0.5	0.5	-	Set-up
Max difference VIS0.6 -VIS0.8 Threshold	THR_D1VIS_PCMAX	%	-50	50	0.1	0.1	-	Set-up
Min difference VIS0.6 -VIS0.8 Threshold	THR_D1VIS_PCMIN	%	-50	50	0.1	0.1	-	Set-up
EBBT Difference Threshold IR3.9-IR10.8 Fog	THR_D1IR_FOG_DAY	K	-20	20	0.1	0.1	-	Set-up
EBBT SD IR10.8 Threshold Cumulus	THR_STDIR108_CUM	K	0	50	0.1	0.1	-	Set-up
EBBT SD IR10.8 Threshold Altocumulus/Altostratus	THR_STDIR108_AC	K	0	50	0.1	0.1	-	Set-up

STATIC DATA SETS - THRESHOLDS AND PARAMETERS								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Pre.*	*Acc.*	*Res*	*Source*
Reflectance Threshold VIS0.6	THR_VIS06_NS	%	0	150	0.1	0.1	-	Set-up
EBBT Difference Threshold IR10.8-IR12.0 Nimbostratus	THR_D2IR_NS	K	-20	20	0.1	0.1	-	Set-up
EBBT Difference Threshold IR3.9-IR10.8 Cumulonimbus	THR_D1IR_CB1	K	-20	20	0.1	0.1	-	Set-up
EBBT SD IR10.8 Threshold Cumulonimbus	THR_IR108_CB	K	0	50	0.1	0.1	-	Set-up
EBBT Difference Threshold IR3.9-IR10.8 Partly Cloudy	THR_D1IR_PC	K	-50	50	0.1	0.1	-	Set-up
EBBT Difference Threshold IR3.9-IR10.8 Fog Night	THR_D1IR_FOG_NIGHT	K	-50	50	0.1	0.1	-	Set-up
Intermediate QA check EBBT threshold	Int_QA_thresh_1	K	-50	50	0.1	0.1	-	Set-up
Intermediate QA check height threshold	Int_QA_thresh_2	hPa	-50	50	0.1	0.1	-	Set-up
Minimum number. of values from LUT to be used for interpolation for cloud optical thickness	nmin	-	0	10	1	1	-	Set-up
Emissivity correction factor for cloud top height	rat_cor_6.2/7.3/13.4	-	0	2	0.01	0.01	-	Set-up
Maximum effective cloud amount	neff_max	%	100	150	1	1	-	Set-up
Minimum effective cloud amount for opaque clouds	neff_min	%	0	100	1	1	-	Set-up
Coefficients for derivation of cloud top height	a_0, a_1, a_2, a_3	-	0	1	0.01	0.01	-	Set-up
Coefficients for derivation of cloud top temperature	b_0, b_1, b_2, b_3	-	0	1	0.01	0.01	-	Set-up
Coefficients for derivation of effective cloud amount	c_0, c_1, c_2, c_3	-	0	1	0.01	0.01	-	Set-up
Vertical interpolation interval for forecast profiles	vertical_int	hPa	1	100	1	1	-	Set-up
Optical Thickness Look up Table	OT_lut	-	-	-	-	-	-	Set-up
Threshold for Cloud Phase test	temp_ice_max	K	170	350	0.1	0.1	-	Set-up
Threshold for Cloud Phase test	temp_ice_min	K	170	350	0.1	0.1	-	Set-up
Minimun difference between predicted and measured EBBT in ch. 10.8 (or 12.0), ch. 6.2, 7.3 and 13.4	DiffBase, Diff62, Diff73, Diff134	K	-100	100	0.1	0.1	-	Set-up

STATIC DATA SETS - THRESHOLDS AND PARAMETERS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Pre.***	***Acc.***	***Res***	***Source***
Standard deviation threshold EBBT ch. 6.2, 7.3, 13.4	Std62, Std73, Std134	K	0	100	0.1	0.1	-	Set-up
Cloud phase ratio threshold	CloudPhRat1, CloudPhRat2	-	0	100	0.1	0.1	-	Set-up
Cloud phase difference for IR10.8-IR3.9, IR10.8-IR8.7, IR10.8-IR12.0	CloudPhTdiff1, 2, 3, 4 CloudPhTdiff5, 6, 7, 8	K	-100	100	0.1	0.1	-	Set-up
Cloud phase maximum and minimum EBBT	CloudPhT1, CloudPhT2, CloudPhT3, CloudPhT4,	K	170	350	0.1	0.1	-	Set-up
Semi-transparency ratio threshold	SemiTrRat1, SemiTrRat2	-	0	100	0.1	0.1	-	Set-up
Standard deviation threshold EBBT ch. 10.8 for semi-transparency	SemiTrStdDev1, SemiTrStdDev2	K	0	100	0.1	0.1	-	Set-up
Semi-transparency EBBT difference for IR10.8-IR3.9, IR10.8-IR8.7, IR10.8-IR12.0	SemiTrTdiff1, 2, 3, 4 SemiTrTdiff5, 6, 7, 8	K	-100	100	0.1	0.1	-	Set-up
Inversion height correction level set-up parameters	inv_C1	-	0	1	1	1	-	Set-up
	inv_C2	-	0	1	1	1	-	Set-up
	inv_C3	-	0	1	1	1	-	Set-up
Inversion height correction surface offset	inv_surf_offset	-	0	100	1	1	-	Set-up
Inversion height correction inversion magnitude	inv_magnitude	-	-10	10	0.1	0.1	-	Set-up
Inversion height correction max inversion level	inv_low_FC_pres_thres	-	100	1100	1	1	-	Set-up
Inversion height correction max AMV level	inv_low_AMV_pres_thres	-	100	1100	1	1	-	Set-up

Table 22: CLA Product: Static Data Sets-Thresholds and Parameters

Note: All static data shall be configurable.

8.3 Algorithm Functional Specification

8.3.1 Overview

The Cloud Analysis (CLA) algorithm generates cloud information for every repeat cycle and for every pixel determined as cloudy in the Scenes Analysis of the same repeat cycle. For the cloudy pixels the scenes type provided by the SCE algorithm is updated in this algorithm to provide the detailed cloud type. Additional cloud information such as cloud phase, cloud optical thickness, cloud top temperature and cloud height estimations, including a semi-transparency correction, are produced. This information is used as an intermediate CLA product within MPEF, to support the generation of the Atmospheric Motion Vectors (AMV) product and others. The final CLA product, which will be distributed to the end-users, summarises the CLA information for a CLA processing segment. A third kind of CLA product, the CLA image product, will be distributed to end-users in GRIB-2 data format, providing, on a CLA image processing segment basis, the scenes type.

The following general requirements **shall** be applied:

- The intermediate CLA product **shall** update the scenes type for cloudy pixels with the detailed cloud type; it **shall** also derive additional cloud information in the form of cloud phase, cloud top temperature and cloud top height on a pixel basis for every repeat cycle. It **shall** also include a flag for semi-transparent clouds / partly cloudy pixels for the VIS channels and the IR channels, and according to the semi-transparency/partly cloudiness an effective cloud amount for every pixel.
- The final CLA product **shall** derive cloud information on a CLA processing segment in the form of the overall cloud cover, and for at least three cloud level bands (low-level, mid-level, high-level) the cloud type, the cloud phase for every cloud type, the cloud cover for every cloud type, the cloud top temperature and height for every cloud type.

The final CLA product and the CLA image product for the CLA processing segments **shall** be generated using the intermediate CLA product which has been produced for the repeat cycle which is closest to the required extraction time(s) of the final CLA product and the CLA image product.

Currently ten cloud **types** are specified:

Level	*Type*
low-level cloud	Fog or Stratus
low-level cloud	Cumulus or Stratocumulus
low-level cloud	unknown type
mid-level cloud	Nimbostratus
mid-level cloud	Altocumulus or Altostratus
mid-level cloud	unknown type
high-level cloud	Cumulonimbus
high-level cloud	Cirrus
high-level cloud	unknown type
unknown cloud type	

Four cloud **phases** are specified:

- water phase
- ice phase
- mixed phase
- unknown phase

The CLA algorithm **shall** first generate the intermediate CLA product for every pixel and for every repeat cycle as shown in Figure 5 and described below:

Step 1	**Scenes type check:** Check whether the scenes type provided by the Scenes Analysis has been identified as clear or cloudy.
Step 2	**Solar zenith angle check:** Check the solar zenith angle data for every pixel to determine the local time, i.e. day, dawn and night. This is to define the channels to be used in the following steps and to define the tests to be used later.
Step 3	**Comparison with previous repeat cycle:** Use the current and previous image data from a subset of the channels to detect if the image data have changed significantly. If there has been no significant change the results of the previous intermediate CLA product can be used.
Step 4	**Threshold prediction:** Currently the algorithm uses only static thresholds. For Future Enhancements using additional MSG channels which may require more complex threshold predictions, this functionality **shall** be foreseen.
Step 5	**Cloud type, cloud phase, semi-transparency identification, cloud top height, cloud top temperature, and effective cloud amount estimation:** Identify the cloud phase; identify whether the clouds are semi-transparent, partly cloudy or opaque; derive the cloud top height, the cloud top temperature, the effective cloud amount; and identify the cloud type on a pixel basis.

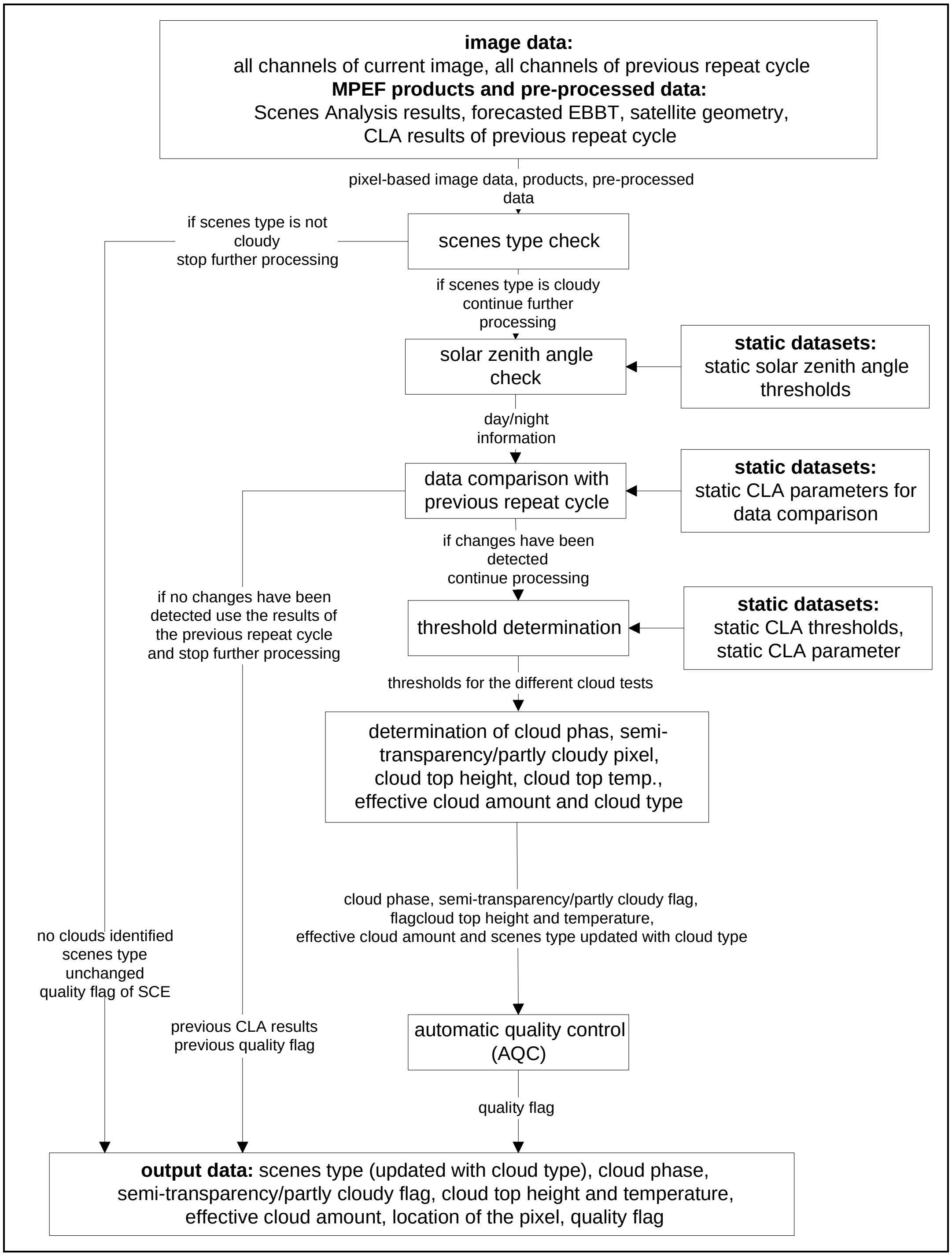

Figure 5: CLA Processing

8.3.2 Algorithm Description for Intermediate CLA

In the following, the steps listed above are described in detail. All static application data, thresholds, parameters and numbers mentioned below **shall** be configurable. The algorithm for the intermediate CLA **shall** be performed for every pixel.

8.3.2.1 Step 1: Scenes Type Check

The CLA algorithm **shall** use the scenes type information provided by the Scenes Analysis and check whether it states clear or cloudy scene. If the scene has been identified as clear, the following steps **shall** be skipped. Otherwise, the scenes type **shall** be updated according to the findings of the cloud type tests specified below in Step 5.

8.3.2.2 Step 2: Solar Zenith Angle Check

The CLA Analysis algorithm **shall** use information about the elevation of the sun in the form of the solar zenith angle for every pixel. According to the solar zenith angle the local time of the day for a single pixel **shall** be identified as:

- day, if the solar zenith angle is lower than a threshold (*SZ_thres*)
- night, if the solar zenith angle is greater than or equal to a threshold (*SZ_thres*)

8.3.2.3 Step 3: Data Comparison with Previous Repeat Cycle

The current and previous image data in the form of EBBT/reflectances **shall** be compared for channels VIS0.6 (day only), VIS0.8 (day only), NIR1.6 (day only), IR3.9, IR8.7, IR10.8, IR12.0 for each pixel to verify whether there has been a significant change in the data. This check **shall** accept differences in starting time between the current and the previous repeat cycle of up to *max_hours*.

This is done by calculating the absolute difference between the current and the previous image data for a subset of the channels:

absolute difference = ABS(current - previous)

For channels VIS0.6, VIS0.8 and NIR1.6 a static threshold (*VIS_change*) **shall** be used for this check.

For the remaining IR channels the following formula **shall** be applied:

IR_threshold = (n +1) * *step2_temp*

with: n = (start_current_image - start_previous_image) /*rc_nom_dur*

If n is larger than *max_cycles* these tests **shall** **not** be performed and the algorithm **shall** continue with the next step.

If no change has been detected in all channels used for this check (i.e. if the absolute differences are smaller than the thresholds), then:

- the value of prev_scenes_type for the pixel **shall** be used
- the quality flag from the previous AQC **shall** be used
- the subsequent processing steps **shall** be skipped

8.3.2.4 Step 4: Threshold Prediction

Currently, the CLA Analysis algorithm uses only static thresholds for the determination of the cloud type, cloud phase and the semi-transparency identification, according to the time of the day. But Future Enhancements (e.g. use of additional channels) may have the need to introduce more complex functions to predict the thresholds.

8.3.2.5 Step 5: Cloud Type, Cloud Phase, Semi-Transparency Identification, Cloud Top Height, Cloud Top Temperature and Effective Cloud Amount Estimation

The cloud type and cloud phase **shall** be identified using threshold tests, which depend on the availability of the input channels, and on the time of the day. In the following sections the threshold tests are defined depending on the local time of the day.

8.3.2.5.1 Description of the Tests to be applied for Daytime Pixels

1. Cloud Phase Test

The cloud phase **shall** first be set to unknown phase.

If the ratio REFL1.6 / REFL0.6 is larger than a threshold *ClouPhRat1,* or

if the EBBT difference IR10.8-IR8.7 is smaller than a threshold *CloudPhTdiff1,* or

if the EBBT difference IR10.8-IR12.0 is smaller than a threshold *CloudPhTdiff2,* or

if the EBBT of IR10.8 is larger than a threshold *CloudPhT1,* then:

The cloud phase **shall** be set to water phase.

Otherwise, if the ratio REFL1.6 / REFL0.6 is smaller than a threshold *ClouPhRat2,* or

if the EBBT difference IR10.8-IR8.7 is larger than a threshold *CloudPhTdiff3,* or

if the EBBT difference IR10.8-IR12.0 is larger than a threshold *CloudPhTdiff4,* or

if the EBBT of IR10.8 is smaller than a threshold *CloudPhT2* , then:

The cloud phase **shall** be set to ice phase.

Otherwise the cloud phase **shall** be set to mixed phase.

2. Semi-Transparency Test

The semi_transp_flag **shall** initially be set to a default flag stating opaque.

If the cloud phase is set to water phase then:

If the standard deviation in channel IR10.8 is larger than a threshold *SemiTrStdDev1,* and

if the ratio REFL0.8/REFL0.6 is between the thresholds *SemiTrRat1* and *SemiTrRat2,* or

if the EBBT difference IR10.8-IR3.9 is smaller than a threshold *SemiTrTdiff1,* or

if the EBBT difference IR10.8-IR12.0 is larger than a threshold *SemiTrTdiff2*, then:

The semi-transparency flag **shall** be set to partly cloudy.

Otherwise:

If the EBBT difference IR10.8-IR8.7 is smaller than a threshold *SemiTrTdiff3,* or

if the EBBT difference IR10.8-IR12.0 is smaller than a threshold *SemiTrTdiff4*, then:

The semi-transparency flag **shall** be set to semi-transparent.

3. Cloud top height, cloud top temperature and effective cloud amount estimation

A detailed description of the derivation of the cloud top height, cloud top temperature and effective cloud amount is given in Section 8.3.2.6.

4. Cloud Type Test

Low-level clouds:	If the pressure of the cloud top height is higher than *low_level_cloud_pressure*, then: • The scenes type **shall** be set to low-level cloud. • If the EBBT-difference IR3.9-IR10.8 is larger than a threshold (*THR_D1IR_FOG_DAY*), then the scenes type **shall** be set to fog/stratus. • Otherwise, if the standard deviation of the EBBT in channel IR10.8 is larger than a threshold (*THR_STDIR108_CUM*), then the scenes type **shall** be set to Cumulus/Stratocumulus.

Mid-level clouds:	If the pressure of the cloud top height is higher than high_level_cloud_pressure, and lower than low_level_cloud_pressure, then: • The scenes type shall be set to mid-level cloud. • If the standard deviation in channel IR10.8 is larger than a threshold (THR_STDIR108_AC), then the scenes type shall be set to Altocumulus/Altostratus. • Otherwise, if the reflectance in channel VIS0.6 is larger than a threshold (THR_VIS06_NS) and if the EBBT-difference IR10.8-IR12.0 is smaller than a threshold (THR_D2IR_NS), then the scenes type shall be set to Nimbostratus.

High-level clouds:	If the pressure of the cloud top height is lower than *high_level_cloud_pressure*, then: • The scenes type **shall** be set to high-level cloud. • If the EBBT-difference IR3.9-IR10.8 is larger than a threshold (*THR_D1IR_CB1*) and if the standard deviation of channel IR10.8 is larger than a threshold *THR_IR108_CB*), then the scenes type **shall** be set to Cumulonimbus. If the cloud_phase is equal to ice phase and if the scenes type is not Cumulonimbus, then: • The scenes type **shall** be set to Cirrus.

8.3.2.5.2 Description of the Tests to be applied for Night-time Pixels

1. Cloud Phase Test

The cloud phase **shall** first be set to unknown phase.

If the EBBT difference IR10.8-IR8.7 is smaller than a threshold *CloudPhTdiff5,* or

if the EBBT difference IR10.8-IR12.0 is smaller than a threshold *CloudPhTdiff6,* or

if the EBBT of IR10.8 is larger than a threshold *CloudPhT3,* then:

The cloud phase **shall** be set to water phase.

Otherwise, if the EBBT difference IR10.8-IR8.7 is larger than a threshold *CloudPhTdiff7,* or

if the EBBT difference IR10.8-IR12.0 is larger than a threshold *CloudPhTdiff8,* or
if the EBBT of IR10.8 is smaller than a threshold *CloudPhT4* , then:
The cloud phase **shall** be set to ice phase.

Otherwise the cloud phase **shall** be set to mixed phase.

2. Semi-Transparency Test

The semi_transp_flag **shall** initially be set to a default flag stating opaque.
If the cloud phase is set to water phase then:

If the standard deviation in channel IR10.8 is larger than a threshold *SemiTrStdDev2,* and
if the EBBT difference IR10.8-IR3.9 is smaller than a threshold *SemiTrTdiff5,* or
if the EBBT difference IR10.8-IR12.0 is larger than a threshold *SemiTrTdiff6*, then:
The semi-transparency flag **shall** be set to partly cloudy.

Otherwise:

If the EBBT difference IR10.8-IR8.7 is smaller than a threshold *SemiTrTdiff7,* or
if the EBBT difference IR10.8-IR12.0 is smaller than a threshold *SemiTrTdiff8*, then:
The semi-transparency flag **shall** be set to semi-transparent.

3. Cloud top height, cloud top temperature and effective cloud amount estimation

A detailed description of the derivation of the cloud top height, cloud top temperature and effective cloud amount is given in Section 8.3.2.6.

4. Cloud Type Test

Low-level clouds:	If the pressure of the cloud top height is higher than *low_level_cloud_pressure*, then: • the scenes type **shall** be set to low-level cloud • if the EBBT-difference IR3.9-IR10.8 is smaller than a threshold (*THR_D1IR_FOG_NIGHT*), then the scenes type **shall** be set to fog/stratus. • otherwise if the standard deviation of the EBBT in channel IR10.8 is larger than a threshold (*THR_STDIR108_CUM*), then the scenes type **shall** be set to Cumulus/Stratocumulus.

Mid-level clouds:	If the pressure of the cloud top height is higher than high_level_cloud_pressure, and lower than low_level_cloud_pressure, then: • the scenes type shall be set to mid-level cloud • if the standard deviation in channel IR10.8 is larger than a threshold (THR_STDIR108_AC), then the scenes type shall be set to Altocumulus/Altostratus • if the EBBT-difference IR10.8-IR12.0 is smaller than a threshold (THR_IR_NS), then the scenes type shall be set to Nimbostratus.

High-level clouds:	If the pressure of the cloud top height is lower than *high_level_cloud_pressure*, then: • the scenes type **shall** be set to high-level cloud • if the EBBT-difference IR3.9-IR10.8 is larger than a threshold (*THR_IR108D1IR_CB*) and if the standard deviation of channel IR10.8 is larger than a threshold (*THR_D1IR_CB2*), then the scenes type **shall** be set to Cumulonimbus If the cloud_phase is equal to ice phase and if the scenes type is not Cumulonimbus, then: • the scenes type shall be set to Cirrus.

8.3.2.6 Cloud Top Height, Cloud Top Temperature and Effective Cloud Amount Estimation

This function **shall** derive the cloud top temperature (in kelvin), the cloud top height (in hPa) and the effective cloud amount (in %).

The cloud top height, the cloud top temperature and the effective cloud amount **shall** be determined on a pixel basis for all pixels flagged as cloudy as follows:

- Interpolate the data provided by the RTM (which already has been horizontally interpolated) in the vertical to fixed *vertical_int* hPa pressure levels between the tropopause and the surface.
- Extract the level with the smallest difference of measured and calculated radiances in channel IR10.8 between the tropopause and the surface (i.e. lowest possible cloud level). Extract: the pressure of that level, i.e. the cloud top height in hPa ($PCLH_0$), the temperature of that level, i.e. the cloud top temperature in kelvin ($TCTH_0$) and set the effective cloud amount of the level to 100% ($NEFF_0$). If the extracted level is equal to the surface and if the cloud is flagged as opaque in the cloud analysis, the cloud height **shall** be set to the pressure of the closest level above the surface, the cloud top temperature **shall** be set to the predicted temperature of that level, the effective cloud amount **shall** be set to 100%, the cloud type **shall** be reset to fog/stratus and the following steps **shall** be skipped.
- Calculate the difference between the measured radiance of channel IR10.8 and the predicted clear sky radiance of that channel ($RADDIF_{10.8,\ measured}$). If channel IR10.8 is not available channel IR12.0 **shall** be selected instead.
- Calculate the difference between the measured radiance of channel IR13.4 and the predicted clear sky radiance of that channel. ($RADDIF_{13.4,\ measured}$)
- Calculate the difference between the measured radiance of channel WV6.2 and the predicted clear sky radiance of that channel. ($RADDIF_{6.2,\ measured}$)
- Calculate the difference between the measured radiance of channel WV7.3 and the predicted clear sky radiance of that channel. ($RADDIF_{7.3,\ measured}$)
- Calculate the following ratios:

$$RATIO_1 = rat\_cor\_13.4 * RADDIF_{13.4,\ measured} / RADDIF_{10.8,\ measured}$$
$$RATIO_2 = rat\_cor\_6.2 * RADDIF_{6.2,\ measured} / RADDIF_{10.8,\ measured}$$
$$RATIO_3 = rat\_cor\_7.3 * RADDIF_{7.3,\ measured} / RADDIF_{10.8,\ measured}$$

where

rat_cor_13.4, rat_cor_6.2, rat_cor_7.3 are correction factors given in a static data set. These correction factors depend on the cloud phase.

- Calculate the difference between the calculated radiance (from the RTM) of channel IR10.8 and the predicted clear sky radiance of that channel for all pressure levels between the tropopause and the lowest possible cloud level. ($RADDIF_{10.8,\ calculated}$ (p))
- Calculate the difference between the calculated radiance (from the RTM) of channel IR13.4 and the predicted clear sky radiance of that channel for all pressure levels between the tropopause and the lowest possible cloud level. ($RADDIF_{13.4,\ calculated}$ (p))
- Calculate the difference between the calculated radiance (from the RTM) of channel WV6.2 and the predicted clear sky radiance of that channel for all pressure levels between the tropopause and the lowest possible cloud level. ($RADDIF_{6.2,\ calculated}$ (p))
- Calculate the difference between the calculated radiance (from the RTM) of channel WV7.3 and the predicted clear sky radiance of that channel for all pressure levels between the tropopause and the lowest possible cloud level. ($RADDIF_{7.3,\ calculated}$ (p))
- Calculate the following ratios for each pressure level between the tropopause and the lowest possible cloud level:

  $RATIO_1$ (p) = *rat_cor_13.4* * $RADDIF_{13.4,\ calculated}$ (p) / $RADDIF_{10.8,\ calculated}$ (p)

  $RATIO_2$ (p) = *rat_cor_6.2* * $RADDIF_{6.2,\ calculated}$ (p) / $RADDIF_{10.8,\ calculated}$ (p)

  $RATIO_3$ (p) = *rat_cor_7.3* * $RADDIF_{7.3,\ calculated}$ (p) / $RADDIF_{10.8,\ calculated}$ (p)

  where *rat_cor_13.4, rat_cor_6.2, rat_cor_7.3* are correction factors given in a static data set. These correction factors depend on the cloud phase.
- For each of the three channel combinations find the level ($L_{CLD,1}$, $L_{CLD,2}$, $L_{CLD,3}$) between the tropopause and the lowest possible cloud level with the best agreement (minimum difference) between the ratio with measured radiances (i.e. $RATIO_1$, $RATIO_2$, $RATIO_3$) and the ratio with calculated radiances (i.e. $RATIO_1$ (p) , $RATIO_2$ (p) , $RATIO_3$ (p).
- For each of the three channel combinations extract the pressure of that level, i.e. the cloud top height in hPa ($PCTH_{1,\ 2,\ 3}$).
- For each of the three channel combinations extract the temperature of that level, i.e. the cloud top temperature in kelvin ($TCTH_{1,\ 2,\ 3}$).
- For each of the three channel combinations the effective cloud amount (NEFF in units of %) is derived as follows:
  - Extract the difference between the calculated radiance and the clear sky radiance in channel 10.8 at the derived cloud level ($RADDIF_{10.8\ ,\ calculated,\ lcld}$).
  - Derive the effective cloud amount by building the following ratio:

  $NEFF_{1,\ 2,\ 3}$ = 100 * $RADDIF_{10.8\ ,\ measured}$ / $RADDIF_{10.8,\ calculated,\ LCLD,\ 1,\ 2,\ 3}$

  If the effective cloud amount is larger than *neff_max*, it **shall** be reset to *neff_max*.

  If the effective cloud amount is smaller than *neff_min* and if the semi_transp_flag is set to opaque, the semi_transp_flag **shall** be reset to semi-transparent/partly cloudy.

The final product output for the cloud top height, the cloud top temperature and the effective cloud amount will be derived as follows:

- If the cloud phase is set to ice phase or to mixed phase and if the EBBT measured in channel IR10.8 or channel IR12.0 is colder than the predicted EBBT by a threshold *DiffBase*, then the cloud top parameters **shall** be derived as follows:

  Cloud top height, PCTH = $a_0 + a_1$ * $PCTH_1 + a_2$ * $PCTH_2 + a_3$ * $PCTH_3$

Cloud top temperature, $TCTH = b_0 + b_1 * TCTH_1 + b_2 * TCTH_2 + b_3 * TCTH_3$

Effective cloud amount, $NEFF = c_0 + c_1 * NEFF_1 + c_2 * NEFF_2 + c_3 * NEFF_3$

The coefficients in the above equations **shall** be set as follows:

- A flag for channel WV6.2 is set to true, if the channel available and if the measured EBBT in the channel is colder than the predicted EBBT by a threshold *Diff62* and if the standard deviation of the EBBT in the channel is larger than a threshold *Std62*.
- The same check **shall** be applied to channels WV7.3 and IR13.4.
- If for all three channels the flag is set to true, the pre-set coefficients from the set-up data set **shall** be used to derive the cloud top height, the cloud top temperature and the effective cloud amount.
- Otherwise the following procedure **shall** be applied:

  - All coefficients are set to 0.

  - If the flag for channel IR13.4 is set to true, its relevant coefficients are set to 1.0.

  - Otherwise if the flag for channel WV7.3 is set to true, its relevant coefficients are set to 1.0.

  - Otherwise if the flag for channel WV6.2 is set to true, its relevant coefficients are set to 1.0.

  - Otherwise the opaque cloud top values ($PCTH_0$, $TCTH_0$, $NEFF_0$) are used instead.

- Otherwise, if the cloud phase is not set to ice phase or to mixed phase and if the EBBT measured in channel IR10.8 or channel IR12.0 is not colder than the predicted EBBT by a threshold DiffBase:

  The cloud top height, PCTH, **shall** be set to $PCTH_0$.

  The cloud top temperature, TCTH, **shall** be set to $TCTH_0$.

  The effective cloud amount, NEFF, **shall** be set to $NEFF_0$.

For all cloud top heights, PCTH, with a pressure bigger than inv_low_AMV_pres_thres (nominally 600 hPa) the inversion height assignment **shall** be performed. The inversion height assignment **shall**:

1. Extract the minimum forecast temperature (min_temp) and maximum forecast temperature (max_temp) between inv_low_FC_pres_thres (nominally 700 hPa) and the layer closest to the surface pressure plus inv_surf_offset (nominally 40 hPa).
2. Extract the pressure corresponding to min_temp (pres_of_min_temp) and pressure corresponding to max_temp (pres_of_max_temp).
3. If temp_grad (max_temp – min_temp) > inv_magnitude (nominally 0 K) then

   inv_pres = (inv_C1 * pres_of_min_temp + inv_C2 * pres_of_max_temp) / (inv_C1 + inv_C2) + inv_C3

   and

   inv_temp = (inv_C1 * min_temp + inv_C2 * max_temp) / (inv_C1 + inv_C2) + inv_C3

   where inv_C1, inv_C2 and inv_C3 are set-up parameters.
4. If steps 2 and 3 were successful, then reset PCTH to inv_pres as new cloud top height and temperature to inv_temp as new cloud top temperature.

8.3.3 Algorithm Description for the Final CLA Product

In the following the determination of the final CLA product, which **shall** be disseminated, is described in detail. The final CLA product **shall** be derived on a CLA processing segment of size *CLA_ps_size* using the pixel-based results of the intermediate CLA product. The following parameters **shall** be derived on this CLA processing segment:

- For every CLA processing segment the total effective cloud amount **shall** be calculated by summing the effective cloud amount of every pixel in the segment, and by dividing by the total number of pixels. If fewer than *min_cld_pixels* cloudy pixels can be found for the whole segment then default values **shall** be provided indicating 'no clouds'.
- The effective cloud amount for each cloud type and for each sub-level **shall** be calculated similarly.
- The mean cloud top height, the mean cloud top temperature and the mean optical thickness **shall** be determined for each cloud type in each sub-level.

8.3.4 Algorithm Description for the CLA Image Product

In the following the determination of the CLA image product, which **shall** be disseminated, is described. The CLA image product **shall** be derived on a CLA image processing segment basis using the pixel-based information of the intermediate CLA product. Depending on the extracted information, this image **shall** either provide the most significant surface type if the number of clear pixels is greater than *min_ima_pixels* (i.e. surface type for majority of pixels in the segment) if the segment is clear, or otherwise it **shall** provide the most significant cloud type (i.e. cloud type for majority of pixels in the segment) if the segment is cloudy. Currently 21 surface types (as specified for the Scenes Analysis algorithm) and 10 cloud types (as specified above) are used.

8.3.5 Automatic Quality Control (AQC)

8.3.5.1 Intermediate CLA Product

The following automatic quality control steps **shall** be applied only for the intermediate CLA product. It **shall** be applied to the cloud top height estimation.

The AQC **shall** be performed as follows:

Spatial Consistency AQC check for the cloud top height

For each pixel all surrounding neighbouring pixels **shall** be checked for the cloud top height. If the neighbouring pixels have the same cloud type as the investigated one, if the measured EBBTs are within *int_QA_thresh_1* kelvin and the derived cloud top height is within *int_QA_thresh_2* hPa, the CLA intermediate quality flag **shall** be set indicating 'cloud_top_height related parameters, good quality' else it **shall** be set to 'cloud_top_height related parameters, bad quality'.

Spatial Consistency AQC check for the cloud type

For each pixel all surrounding neighbouring pixels **shall** be checked for the cloud type. If none of the neighbouring pixels has the same cloud type as the investigated one, the CLA intermediate quality flag **shall** be set indicating 'cloud_type, bad quality'.

8.3.5.2 Final CLA Product

The following automatic quality control steps **shall** be applied only for the final CLA product. It **shall** be applied for each cloud type identified in the CLA processing segment, the cloud top temperature of that cloud type and the cloud height of that cloud type.

The AQC **shall** be performed as follows:

- If any pixel comprising the Final Product processing segment has CLA_int_quality flag in the Intermediate Product flagged as 'Cloud Type poor quality', the CLA_quality_flag in the Final Product will be flagged as 'Cloud Type poor quality' for that processing segment.
- If any pixel comprising the Final Product processing segment has a value for the cloud_top_temp in the Intermediate Product which differs by more than Int_QA_thres_1 from the mean cloud top temperature of the relevant cloud type, the CLA_quality_flag in the Final Product will be flagged as 'Cloud Top Temperature poor quality' for that processing segment.
- If any pixel comprising the Final Product processing segment has a value for the cloud_top_pressure in the Intermediate Product which differs by more than Int_QA_thres_2 from the mean cloud top pressure of the relevant cloud type, the CLA_quality_flag in the Final Product will be flagged as 'Cloud Top Pressure poor quality' for that processing segment.
- An average value of the SCE quality flag **shall** be derived from all cloudy pixels in the Final Product processing segment. If this average value indicates a confidence greater than 90% the CLA_quality_flag in the Final Product will be flagged as 'Cloud Dectection confidence >90%' for that processing segment. If this average value is between 70% and 90% the CLA_quality_flag in the Final Product will be flagged as 'Cloud Dectection confidence 70% - 90%' for that processing segment. If this average value is below 70% the CLA_quality_flag in the Final Product will be flagged as 'Cloud Dectection confidence <70%' for that processing segment.

8.4 Outputs

Three types of products **shall** be generated, i.e. the intermediate CLA product, the final CLA product and the CLA image product.

8.4.1 Intermediate CLA Product

This product **shall** be used for further internal MPEF processing (e.g. AMV) and **shall** be provided on a pixel basis for every repeat cycle.

INTERMEDIATE CLA PRODUCT							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***To***
Scenes type	scenes_type	-	0	110	-	-	AMV, CDS, CSR, CLA_{ima}, CLA_{final}, CLA_{next}
Cloud top temperature	cloud_top_temp	K	170	300	1	1	CLA_{final}, CLA_{next}
Cloud top pressure	cloud_top_pressure	hPa	100	1050	50	1	AMV, CTH, CLA_{final}, CLA_{next}
Effective cloud amount	cloud_amount_eff	%	0	100	1	1	AMV, CLA_{final}, CLA_{next}
SCE quality index	QI	-	0	100	10	10	CSR
CLA intermediate quality flag	CLA_int_quality_flag	-	-	-	-	-	AMV, CLA_{next}

Table 23: Intermediate Cloud Product, Components

Parameter	***Value***	***Meaning***
scenes_type	0 – 100	See details in Section 5.4
	101	Fog or Stratus
	102	Cumulus or Stratocumulus
	103	Low-level unknown cloud
	104	Nimbostratus
	105	Altocumulus or Altostratus
	106	Mid-level unknown cloud
	107	Cumulonimbus
	108	Cirrus
	109	High-level unknown cloud
	110	Unknown cloud

Parameter	***Bit No.***	***Meaning***	***Value***	***Meaning***
CLA_int_quality_flag	Bits 0-1	Cloud phase	0 1 2 3	Unknown Water Ice Mixed
	Bits 2-3	SCE quality flag		
	Bit 4	Cloud type quality	0 1	Good Bad
	Bit 5	Cloud height quality	0 1	Good Bad
	Bits 6-7	Semi-transparency flag	0 1 2 3	Opaque Partly cloudy Semi-transparent Semi-transparency correction failed / not processed

8.4.2 Final CLA Product

This product **shall** be provided on CLA processing segment basis for the required extraction times.

Parameter	*Value*	*Meaning*
CLA_quality_flag	Bit 0 : 1	Cloud Type poor quality
	Bit 1 : 1	Cloud Top Temperature poor quality
	Bit 2 : 1	Cloud Top Height poor quality
	Bit 3 : 1	Cloud Determination 100% confidence (from SCE quality flag)
	Bit 4 : 1	Cloud Determination 75% confidence (from SCE quality flag)
	Bit 5 : 1	Cloud Determination 50% confidence (from SCE quality flag)

Table 24 that follows presents the Final CLA Product Parameters.

FINAL CLA PRODUCT							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***To***
Total effective cloud amount	tot_eff_cloud_amount	%	0	100	1	1	Final CLA
Total cloud amount of all low-level clouds	cloud_amount_llc	%	0	100	1	1	
All cloud types of low-level cloud	$cloud\_type_i\_llc$	-	-	-	-	-	
Cloud amount of every low-level cloud type	$cloud\_amount\_type_i$	%	0	100	1	1	
Cloud phase of every low-level cloud type	$cloud\_phase\_type_i$	-	-	-	-	-	
Mean cloud top temperature of every low-level cloud type	$cloud\_top\_temp\_type_i$	K	170	300	1	1	
Mean cloud top height of every low-level cloud type	$cloud\_top\_height\_type_i$	hPa	100	1050	50	1	
Cloud amount of all mid-level clouds	cloud_amount_mlc	%	0	100	1	1	
All cloud types of mid-level clouds	$cloud\_type_i\_mlc$	-	-	-	-	-	
Cloud amount of every mid-level cloud type	$cloud\_amount\_type_i$	%	0	100	1	1	
Cloud phase for every mid-level cloud type	$cloud\_phase\_type_i$	-	-	-	-	-	
Mean cloud top temperature of every mid-level cloud type	$cloud\_top\_temp\_type_i$	K	170	300	1	1	
Mean cloud top height of every mid-level cloud type	$cloud\_top\_height\_type_i$	hPa	100	1050	50	1	
Cloud amount of all high-level-clouds	cloud_amount_hlc	%	0	100	1	1	
All cloud types of high-level clouds	$cloud\_type_i\_hlc$	-	-	-	-	-	
Cloud amount of every high-level cloud type	$cloud\_amount\_type_i$	%	0	100	1	1	
Cloud phase of every high-level cloud type	$cloud\_phase\_type_i$	-	-	-	-	-	
Mean cloud top temperature of every high-level cloud type	$cloud\_top\_temp\_type_i$	K	170	300	1	1	
Mean cloud top height of every high-level cloud type	$cloud\_top\_height\_type_i$	hPa	100	1050	50	1	
CLA quality flag	CLA_quality_flag	-	-	-	-	-	

Table 24: Final CLA Product Parameters

8.4.3 CLA Image Product

This product **shall** be provided on a CLA image processing segment basis in the form of a GRIB Edition 2 encoded product for the required extraction times. The segment size is 3 × 3 pixels of the original intermediate CLA product. Since the latter contains 3712 × 3712 pixels, the area of CLAI containing actual information is given by:

3712 ÷ 3 = 1237.3 = 1237 (rounded down) thus: 1237 × 1237 pixels.

The product **shall** contain for every segment the scenes type.

CLA IMAGE PRODUCT							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***To***
Scenes type	scenes_type	-	-	-	-	-	CLA_{image}

8.5 Prototyping and Testing

The prototyping software is available for deriving the cloud type, cloud phase and the semi-transparency flag.
The inclusion of the semi-transparency correction, the cloud optical thickness, cloud top temperature and the cloud top height calculations is a Future Enhancement.

8.6 Future Enhancements

The following Future Enhancements **shall** be foreseen in the algorithm design:

- Use of level 1.5 image data from additional channels
- Dynamic threshold prediction

8.7 References

None

9 ATMOSPHERIC MOTION VECTORS PRODUCT GENERATION

9.1 Algorithm Configuration Information

9.1.1 Algorithm Name

Atmospheric Motion Vectors (AMV)

9.1.2 Algorithm Identifier

EUM_MSG_AMV_A001

9.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	K. Holmlund	AMV Baseline
1.1	26/5/97	K. Holmlund	TBDs resolved, bid clarification points added, errors corrected.
1.2	1/7/97	K. Holmlund	Clarifications added and improvement to the AQC checks added.
1.3	8/12/97	H. K. Wilson	Kick-off clarification points added, Requirements Analysis clarification points added.
1.4	20/3/98	H. K. Wilson	Peer Group review comments added.
1.5	15/1/99	H.-J. Lutz	Detailed Design Phase changes added.
1.6	04/12/01	K. Holmlund	Target extraction and height assignment (ECP290).
1.7	25/7/05	A. de Smet, G. Dew, J. Gustafsson	Various updates, mainly to height assignment.
1.8	27/3/07	A. de Smet, G. Dew, J. Gustafsson	Various updates including height assignment and target optimisation. Addition of Recursive Filter Function and Upper Level Divergence.
1.9	02/12/08	J. Gustafsson	Addition of Encoding Filter. Addition of two parameters for use in final vector derivation.
1.10	27/10/09	A. de Smet	Description of AMV Inversion Height Assignment rewritten to reflect actual implementation (AR 18745). Updates to both output tables with respect to introduction of land-sea flag (AR 19113) and to remove two duplicate entries.

9.2 Inputs

The Atmospheric Motion Vector (AMV) generation **shall** use the Level 1.5 image data from all spectral channels selected by the AMV channel selection table. Initially, the AMV is extracted from the following spectral channels:

- VIS 0.8
- IR 10.8
- WV 6.2
- WV 7.3
- HRVIS

AMV extraction is also possible from the VIS0.6 channel, but this option is currently switched off. The use of other channels, i.e. IR8.7 and IR9.7, **shall** be possible as a future enhancement.

The AMV **shall** use clear-sky radiances tables that relate the effect of opaque cloud at different heights to the radiances in the eight IR channels and atmospheric correction tables provided by the RTM. This information **shall** be provided to the AMV as EBBTs. It is foreseen that the RTM **shall** provide the clear sky contribution functions for the selected IR channels. This RTM table **shall** in the AMV retrieval be used as a continuous function interpolated in time and space to the gravity centre of the target. This implies that, as the table is provided only at discrete levels, the table values **shall** also be interpolated in height, when necessary.

The results from the RTM and the Cloud Analysis **shall** be used to define the suitability of the channels to provide good displacement vectors at all locations, image enhancement and height assignment for each tracer. The AMV **shall** also use the forecast temperature profiles for height assignment. Finally, the AMV requires an ensemble of AMV set-up parameters (static application data) to control the different processes.

9.2.1 Image and Preprocessing Data (Dynamic Application Data)

The dynamic input is time-dependent and is different for each repeat cycle. The implementation **shall** make all data available for all the extractions performed, i.e. for every specified channel. The table is specific for the baseline configuration. For future enhancements, also the possibility to include further channels (e.g. IR9.7 and IR8.7) **shall** be anticipated

LEVEL 1.5 DATA AND DATA DERIVED FROM THE IMAGE DATA							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Source***
Local mean and local standard deviation data from the currently processed channel	ima_stat_dat	-	-	-	-	-	Derived from level 1.5 image data
HRVIS level 1.5 image data	HRVIS_ima_dat	%	0	150	0.1	0.1	Level 1.5 image data
VIS0.6 level 1.5 image data	VIS06_ima_dat	%	0	150	0.1	0.1	Level 1.5 image data
VIS0.8 level 1.5 image data	VIS08_ima_dat	%	0	150	0.1	0.1	Level 1.5 image data
NIR1.6 level 1.5 image data	NIR16_ima_dat	%	0	150	0.1	0.1	Level 1.5 image data
IR3.9 level 1.5 image data	IR38_ima_dat	K	170	350	0.1	0.1	Level 1.5 image data
IR8.7 level 1.5 image data	IR87_ima_dat	K	170	350	0.1	0.1	Level 1.5 image data
IR9.7 level 1.5 image data	IR97_ima_dat	K	170	350	0.1	0.1	Level 1.5 image data
IR10.8 level 1.5 image data	IR108_ima_dat	K	170	350	0.1	0.1	Level 1.5 image data
IR12.0 level 1.5 image data	IR120_ima_dat	K	170	350	0.1	0.1	Level 1.5 image data
IR13.4 level 1.5 image data	IR134_ima_dat	K	170	350	0.1	0.1	Level 1.5 image data
WV6.2 level 1.5 image data	WV62_ima_dat	K	170	350	0.1	0.1	Level 1.5 image data
WV7.3 level 1.5 image data	WV73_ima_dat	K	170	350	0.1	0.1	Level 1.5 image data
Radiances for channels: IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4	$Rad_{Ichannel}$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	Derived from level 1.5 image data

Table 25: AMV Product Level 1.5 Data and Data Derived from the Image Data

9.2.2 Data from other MPEF Algorithms (Dynamic Application Data)

DATA FROM OTHER MPEF ALGORITHMS							
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Source*
Pressure, temperature and wind forecast profiles	temp_prof	-	-	-	-	-	Forecast
Tropopause Height	trop_ht	hPa	0	1030	1	1	Derived from Forecast
Atmospheric Correction Table	RTM_acc_tab	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	RTM
Semi-Transparency Correction Table	RTM_stc_tab	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	RTM
Contribution Function Tables	NTC, NTCC	-	0	1	10^{-3}	10^{-4}	RTM
Scenes Type	scenes_type	-	-	-	-	-	CLA intermediate
Cloud Phase	cloud_phase	-	-	-	-	-	CLA intermediate
Cloud Top Height	cl_top_ht	hPa	100	1050	50	1	CLA intermediate
Predicted EBBTs for all IR channels	pred_EBBT_chan	K	170	350	0.1	0.1	SCE

Table 26: AMV Product: Data from other MPEF Algorithms

9.2.3 Static Application Data

The static application data input controls the complete AMV process. These data are changed infrequently during operations but **shall** be configurable.

The static application data used by the AMV algorithm **shall** consist of the following:

- Pixel-based map of surface-type
- Pixel-based map of distance to nearest coastline
- Pixel-based description of processing area
- Static parameters for different mathematical expressions and channel instrument characteristics
- Set-up parameters specific to the AMV processing algorithm

The static input **shall** be specified separately for every baseline channel used for the extraction of displacement vectors. The same approach **shall** also be adapted for the channels foreseen as Future Enhancements.

STATIC APPLICATION DATA – SURFACE DATA							
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Source*
Surface-Type-Map	Surface_type_map	-	0	99	1	1	Static data
Nearest coast distance	Nearest_coast_dist	km	0	10000	-	-	Static data
Processing_area	Proc_area	pixels	0	10000	-	-	Static data

STATIC APPLICATION DATA – OTHER							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Source***
Mathematical expressions, channel specific constants	Alg_data	-	-	-	-	-	Static data

STATIC APPLICATION DATA (PER CHANNEL USED FOR AMV PROCESSING)								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
AMV channel ID	AMV_chan_id	-	1	12	1	1	-	Static
AMV channel selection table	AMV_chan_tab	-	-	-	-	-	-	Static
Flag indicating method to be used for scenes analysis	AMV_use_dynamic_scenes	-	0	1	-	-	-	Static
Minimum cluster size (pixels) in dynamic scenes analysis	cluster_min_size	pixels	1	1024	-	-	pixel	Static
Minimum 3-point histogram frequency	his_min_freq	-	5	10	-	-	-	Static
Gaussian point 2 histogram offset	his_off_coeff1	-	1	10	-	-	-	Static
Gaussian point 3 histogram offset	his_off_coeff2	-	1	10	-	-	-	Static
Number of histogram bins	n_hist_bin	-	10	200	-	-	-	Static
Maximum number of clustered scenes	n_cloud_clusters	-	1	20	-	-	-	Static
Histogram analysis maximum number of cycles	max_class_cycles	-	1	4	-	-	-	Static
Minimum acceptable no. of occurrences of histogram peaks	min_peak_occ	-	1	10	-	-	-	Static
Histogram analysis minimum difference in peak mean to avoid merging	peak_min_diff	-	1	10	-	-	-	Static
Histogram analysis minimum difference in peak std to avoid merging	peak_std_diff	-	1	10	-	-	-	Static
Minimum scene distance	min_scene_dist	K	0	100	0.1	0.1	-	Static
Minimum number of pixels for a valid scene	min_sce_size	pixels	1	2^{32-1}	1	1	pixel	Static
Computation grid	grid_distance	pixels	1	2^{32-1}	1	1	pixel	Static

STATIC APPLICATION DATA (PER CHANNEL USED FOR AMV PROCESSING)								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Maximum target overlap	max_tar_overlap	pixels	1	2^{32-1}	1	1	pixel	Static
Minimum tracer size	min_tracer_size	pixels	1	2^{32-1}	1	1	pixel	Static
Minimum standard deviation	min_sd	K	0	100	0.1	0.1	-	Static
Minimum number of pixels with high standard deviation	min_num_high_sd	pixels	1	2^{32-1}	1	1	pixel	Static
Cloud target size	Cl_tar_size	pixels	1	2^{32-1}	1	1	pixel	Static
Clear sky target size	CS_tar_size	pixels	1	2^{32-1}	1	1	pixel	Static
Cloud search area size	Cl_sar_size	pixels	1	2^{32-1}	1	1	pixel	Static
Clear sky search area size	CS_sar_size	pixels	1	2^{32-1}	1	1	pixel	Static
Target optimisation area	tar_opt_area	pixels	1	2^{32-1}	1	1	pixel	Static
Target extraction method	tar_ex_met	-	0	7	1	1	-	Static
Target extraction scheme	tar_extraction	-	0	7	1	1	-	Static
Flag to define application of coastal check	lcoast_flag	Logica	false	true	-	-	-	Static
Apply image enhancement	l_enhance	-	no	yes	-	-	-	Static
Matching method	Mm	-	0	7	1	1	-	Static
Scene limit factor	cl_lim	-	0.0	300.0	0.01	0.01	-	Static
Tracer masking type	TM	-	0	1	-	-	-	Static
Contrast factor	CF	-	0.0	300.0	0.01	0.01	-	Static
Flag indicating cloud coverage for the WV channels	wv_cloud_type	-	0	2	-	-	-	Static
SCM regression factor for large contrast	SCM_RF_L	-	0.0	1000.0	0.01	0.01	-	Static
SCM regression factor for small contrast	SCM_RF_S	-	0.0	1000.0	0.01	0.01	-	Static
SCM regression offset for large contrast	SCM_RO_L	K	0.0	1000.0	0.01	0.01	-	Static
SCM regression offset for small contrast	SCM_RO_S	K	0.0	1000.0	0.01	0.01	-	Static

STATIC APPLICATION DATA (PER CHANNEL USED FOR AMV PROCESSING)								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Temperature threshold for SCM selection	SCM_T	K	0	350	0.01	0.01	-	Static
Apply low pass filtering	FFT_low	-	no	yes	-	-	-	Static
Refinement of displacement	n_fit	-	0	255	1	1	-	Static
Number of cycles used to generate final product	N_gen	-	0	96	1	1	-	Static
Minimum quality for targets after one cycle	first_cycle_min_qi	-	0	1	0.01	0.01	-	Static
Minimum quality for targets after more than one cycle	new_cycle_min_qi	-	0	1	0.01	0.01	-	Static
Set-up parameters for AQC Forecast Consistency test	AQC_FC_A	-	0	1	0.01	0.01	-	Static
	AQC_FC_B	-	0	1	0.001	0.001	-	Static
	AQC_FC_C	-	0	10	0.1	0.1	-	Static
	AQC_FC_D	-	0	10	0.1	0.1	-	Static
Set-up parameters for AQC Temporal Vector Consistency test	AQC_TC_A	-	0	1	0.01	0.01	-	Static
	AQC_TC_B	-	0	1	0.001	0.001	-	Static
	AQC_TC_C	-	0	10	0.1	0.1	-	Static
	AQC_TC_D	-	0	10	0.1	0.1	-	Static
Maximum pressure difference to surrounding vectors	AQC_SC_max_pp	hPa	0	1100	0.1	0.1	-	Static
Set-up parameters for AQC Spatial Vector Consistency test	AQC_SC_A	-	0	1	0.01	0.01	-	Static
	AQC_SC_B	-	0	1	0.001	0.001	-	Static
	AQC_SC_C	-	0	10	0.1	0.1	-	Static
	AQC_SC_D	-	0	10	0.1	0.1	-	Static
Local consistency distance weight flag	lc_dist_weight	Logica	false	true	-	-	-	Static
Number of best matches for local consistency	N_best_lc	-	1	100	1	1	-	Static
Set-up parameters for AQC Spatial Height Consistency test	AQC_HC_A	-	0	1	0.01	0.01	-	Static

STATIC APPLICATION DATA (PER CHANNEL USED FOR AMV PROCESSING)								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
	AQC_HC_B	-	0	100	1	1	-	Static
	AQC_HC_C	-	0	10	1	1	-	Static
Set-up parameters for AQC Temporal Speed Consistency test	AQC_TSC_A	-	0	1	0.01	0.01	-	Static
	AQC_TSC_B	-	0	1	0.001	0.001	-	Static
	AQC_TSC_C	-	0	10	0.1	0.1	-	Static
	AQC_TSC_D	-	0	10	0.1	0.1	-	Static
Set-up parameters for AQC Temporal Direction Consistency test	AQC_TDC_A	-	0	100	0.1	0.1	-	Static
	AQC_TDC_B	-	0	100	0.1	0.1	-	Static
	AQC_TDC_C	-	0	100	0.1	0.1	-	Static
	AQC_TDC_D	-	0	100	0.1	0.1	-	Static
	AQC_TDC_E	-	0	100	0.1	0.1	-	Static
Set-up parameters for AQC Temporal Height Consistency test	AQC_TPC_A	-	0	1	0.001	0.001	-	Static
	AQC_TPC_B	-	0	1	0.001	0.001	-	Static
	AQC_TPC_C	-	0	1	0.01	0.01	-	Static
	AQC_TPC_D	-	0	100	1	1	-	Static
Set-up parameters for AQC Inter-Channel Consistency	AQC_IC_A	-	0	1	0.001	0.001	-	Static
	AQC_IC_B	-	0	1	0.001	0.001	-	Static
	AQC_IC_C	-	0	1	0.01	0.01	-	Static
	AQC_IC_D	-	0	100	1	1	-	Static
	ic_low_press	hPa	0	1100	1	1	-	Static
	ic_min_spd	m/s	0	100	1	1	-	Static

STATIC APPLICATION DATA (PER CHANNEL USED FOR AMV PROCESSING)								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
	low_ic_check_dist	km	0	200	1	1	-	Static
	ic_press_diff	hPa	0	1100	1	1	-	Static
Set-up parameters for AQC Image Correlation test	AQC_HA_A	-	0	1	0.001	0.001	-	Static
	AQC_HA_B	-	0	1	0.001	0.001	-	Static
	AQC_HA_C	-	0	1	0.01	0.01	-	Static
	AQC_HA_PP	-	0	100	1	1	-	Static
Weight of forecast consistency test final quality mark	AMV_Q_Weights_forecast	-	-	-	-	-	-	Static
Weight of image correlation test in final quality mark	AMV_Q_Weights_ha	-	-	-	-	-	-	Static
Weight of inter-channel consistency test in final quality mark	AMV_Q_Weights_ic	-	-	-	-	-	-	Static
Weight of spatial height test in final quality mark	AMV_Q_Weights_shc	-	-	-	-	-	-	Static
Weight of spatial vector test in final quality mark	AMV_Q_Weights_swc	-	-	-	-	-	-	Static
Weight of temporal vector consistency test in final quality mark	AMV_Q_Weights_tc	-	-	-	-	-	-	Static
Weight of temporal direction consistency test in final quality mark	AMV_Q_Weights_tdc	-	-	-	-	-	-	Static
Weight of temporal height consistency test in final quality mark	AMV_Q_Weights_tpc	-	-	-	-	-	-	Static
Weight of temporal speed consistency test in final quality mark	AMV_Q_Weights_tsc	-	-	-	-	-	-	Static
Weight of height assignment consistency test in final quality mark	AMV_Q_Weights_hac	-	-	-	-	-	-	Static
Weights of intermediate temporal vector tests in final product	N_Gen_AQC_Weights_tc						-	Static
Weights of intermediate temporal direction tests in final product	N_Gen_AQC_Weights_tdc						-	Static
Weights of intermediate image correlation tests in final product	N_Gen_AQC_Weights_tha						-	Static

STATIC APPLICATION DATA (PER CHANNEL USED FOR AMV PROCESSING)								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Weights of intermediate temporal pressure tests in final product	N_Gen_AQC_Weights_tpc						-	Static
Weights of intermediate temporal speed tests in final product	N_Gen_AQC_Weights_tsc						-	Static
AMV Verification vector set-up parameter	pr_vec	hPa	0	10	1	1	-	Static
AMV Verification pressure set-up parameter	pr_pres	hPa	0	1100	1	1	-	Static
AMV Verification temperature set-up parameter	pr_temp	K	0	100	1	1	-	Static
Parameter to indicate whether CLA quality is to be used	AMV_use_CLA_quality	-	-	-	-	-	-	Static
Width of bands for mean and SD calculation	AMV_merge_pressure	hPa	0	100	1	1	-	Static
Maximum number of cloudy pixels allowed in CS target	CS_max_cloud_pix	pixels	1	2^{32-1}	1	1	pixel	Static
Percentage of surface scene type which must be present in a suitable target	tar_sel_bckg_frac	%	0	100	1	1	target area	Static
Maximum difference allowed between repeat cycles for primary targets	max_ptarget_age	minutes	0	360	1	1	-	Static
Minimum number of intermediate AMVs to be used for deriving the final AMV vector	min_derivations	-	0	10	1	1	-	Static
Set-up parameters for AMV AQC temporal test search area	A1	-	0	1000	0.01	0.01	-	Static
	A2	-	0	1000	0.01	0.01	-	Static
	B1	-	0	1000	0.01	0.01	-	Static
	B2	-	0	1000	0.01	0.01	-	Static
	A1_p	-	0	1000	0.01	0.01	-	Static
	A2_p	-	0	1000	0.01	0.01	-	Static
	B1_p	-	0	1000	0.01	0.01	-	Static
	B2_p	-	0	1000	0.01	0.01	-	Static
	prev_gen_pp	hPa	0	1000	1	1	-	Static

STATIC APPLICATION DATA (PER CHANNEL USED FOR AMV PROCESSING)								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Speed threshold for low-quality winds	speed_threshold	m/s	0	1000	1	1	-	Static
Pressure threshold for low-level winds	low_level_pressure_ threshold	hPa	0	1000	1	1	-	Static

Table 27: AMV Product Static Application Data (per channel used for AMV processing)

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Minimum number of consecutive neighbouring cloud-free pixels inside the sampling window	n_clear	pixels	1	25	1	1	pixel	Static
Maximum time difference between image data and oldest upgrading of the cloud-free radiance data set	dif_time_cfr	Hours	0	24	0.25	0.25	-	Static
Minimum distance (in km) to coast lines	dist_coast	km	0	100	1	1	-	Static
Number of interpolation points in the pressure domain	m_levels	-	1	1000	1	1	-	Static
Number of image lines of the target sampling window	Ibox	-	1	96	1	1	pixel	Static
Number of image columns of the target sampling window	Jbox	-	1	96	1	1	pixel	Static
Default number of image columns to move the sampling window inside the target	Jstep	-	1	15	1	1	pixel	Static
Default number of image lines to move the sampling window inside the target	Istep	-	1	15	1	1	pixel	Static
Minimum number of consecutive neighbouring cloudy pixels inside the sampling window	n_cloud	pixels	1	25	1	1	pixel	Static
Flag for representative radiances of cloud classes	iflag_cloud_class	-	0	1	-	-	-	Static
Flag for representative radiances of cloud-free classes	iflag_clear_class	-	0	1	-	-	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Minimum fraction of the target area occupied by the cloud-free pixels	t_clear	%	0	100	1	1	target area	Static
Minimum fraction of sampled cloudy pixels inside the target to process class	f_class	%	0	100	1	1	target area	Static
Flag for averaging cloudy radiances inside the sampling window	iflag_cloudy	-	0	1	-	-	-	Static
Flag for averaging clear radiances inside the sampling window	iflag_clear	-	0	1	-	-	-	Static
Flags for setting the mechanism to select valid samples used for the regression analysis	iflag_dif_IRWV iflag_snr_IRWV iflag_lsd_IRWV	- - -	0 0 0	1 1 1	- - -	- - -	- - -	Static
Maximum fraction of cloudy pixels for weighted mean radiance inside sampling window	f_sample	%	0	100	1	1	sampling window	Static
Max. fraction of cloud-free pixels for weighted mean radiance inside sampling window	f_clear	%	0	100	1	1	sampling window	Static
Noise Equivalent Radiance (NEδR) of channel IR10.8 @Tref=300 K	nedr_ir10.8	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	2	0.001	0.001	-	Static
Noise Equivalent Radiance (NEδR) of channel IR12.0 @Tref=300 K	nedr_ir12.0	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	3	0.001	0.001	-	Static
Noise Equivalent Radiance (NEδR) of channel IR13.4 @Tref=250 K	nedr_ir13.4	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	10	0.001	0.001	-	Static
Noise Equivalent Radiance (NEδR) of channel WV6.2 @Tref=250 K	nedr_wv6.2	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	1	0.001	0.001	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Noise Equivalent Radiance (NEδR) of channel WV7.3 @Tref=250 K	nedr_wv7.3	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	1	0.001	0.001	-	Static
Weight for Semi-Transparency Correction with IR10.8 + WV6.2	iflag_iSTC_wv6.2	-	0	1	-	-	-	Static
Weight for Semi-Transparency Correction with IR10.8 + WV7.3	iflag_iSTC_wv7.3	-	0	1	-	-	-	Static
Weight for IR/WV Ratioing with IR10.8 + WV6.2	iflag_iIRWV_wv6.2	-	0	1	-	-	-	Static
Weight for IR/WV Ratioing with IR10.8 + WV7.3	iflag_iIRWV_wv7.3	-	0	1	-	-	-	Static
Weight for IR/WV Two Channel Ratioing with IR10.8+WV6.2+ WV7.3 using cloud class representative radiances	iflag_iIRWV_2wv_rr	-	0	1	-	-	-	Static
Weight for IR/WV Two Channel Ratioing with IR10.8+WV6.2+ WV7.3 using sample radiances	iflag_iIRWV_2wv_sr	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR10.8 using cloud class representative radiances	iflag_iCO2ABS_ir10.8_rr	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR10.8 using sample radiances and arithmetic averaging	iflag_iCO2ABS_ir10.8_sr_ arithmt	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR10.8 using sample radiances and histogram analysis	iflag_iCO2ABS_ir10.8_sr_ histgrm	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR10.8 using sample radiances and cumulative histogram analysis	iflag_iCO2ABS_ir10.8_sr_ cumhist	-	0	1	-	-	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Weight for CO2 Absorption Method with IR13.4+IR12.0 using cloud class representative radiances	iflag_iCO2ABS_ir12.0_rr	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR12.0 using sample radiances and arithmetic averaging	iflag_iCO2ABS_ir12.0_sr_arithmt	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR12.0 using sample radiances and histogram analysis	iflag_iCO2ABS_ir12.0_sr_histgrm	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR12.0 using sample radiances and cumulative histogram analysis	iflag_iCO2ABS_ir12.0_sr_cumhist	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR10.8+IR12.0 using cloud class representative radiances	iflag_iCO2ABS_irwv_rr	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR10.8+IR12.0 using sample radiances and arithmetic averaging	iflag_iCO2ABS_irwv_sr_arithmt	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR10.8+IR12.0 using sample radiances and histogram analysis	iflag_iCO2ABS_irwv_sr_histgrm	-	0	1	-	-	-	Static
Weight for CO2 Absorption Method with IR13.4+IR10.8+IR12.0 using sample radiances and cumulative histogram analysis	iflag_iCO2ABS_irwv_sr_cumhist	-	0	1	-	-	-	Static
Weight for Clear-sky EBBT height assignment method	iflag_ClearSky_EBBT	-	0	1	-	-	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Weight for Clear-sky maximum NTC height assignment method	iflag_ClearSky_MaxNTC	-	0	1	-	-	-	Static
Weight for Clear-sky NTCC HL height assignment method	iflag_ClearSky_NTCC_HL	-	0	1	-	-	-	Static
Weight for Clear-sky NTCC LL height assignment method	iflag_ClearSky_NTCC_LL	-	0	1	-	-	-	Static
Minimum relative humidity for good chance of clouds	rh_crit	%	0	100	1	1	-	Static
Maximum pressure difference between cloud top and top of boundary layer	dp_BL	hPa	0	1000	10	10	-	Static
Minimum pressure at top of boundary layer	p_crit_bl	hPa	0	1000	10	10	-	Static
Maximum. pressure difference between surface and cloud top	dp_SUF	hPa	0	1000	10	10	-	Static
Cloud base pressure threshold	Pcbpt	hPa	0	1000	10	10	-	Static
Pressure scaling factor	Psc_10.8	hPa	0	1000	10	10	-	Static
Amplitude factor of the correction (for pressure at cloud base)	K_10.8	-	0	10	0.1	0.1	-	Static
Pressure scaling factor	Psc_12.0	hPa	0	1000	1	1	-	Static
Amplitude factor of the correction (for pressure at cloud base)	K_12.0	-	0	10	0.1	0.1	-	Static
Flag for critical parameter to Semi-Transparency Correction	iflag_out_STC	-	0	1	-	-	-	Static
Minimum SNR of contrast in WV6.2, in Semi-Transparency Correction	snr_crit_wv6.2_STC	-	0	1000	1	1	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Minimum SNR of contrast in WV7.3, in Semi-Transparency Correction	snr_crit_wv7.3_STC	-	0	1000	1	1	-	Static
Minimum SNR of contrast in IR10.8, in Semi-Transparency Correction	snr_crit_ir10.8_STC	-	0	1000	1	1	-	Static
Minimum contrast of WV6.2, in Semi-Transparency Correction	dif_crit_wv6.2_STC	-	0	100	1	1	-	Static
Minimum contrast of WV7.3, in Semi-Transparency Correction	dif_crit_wv7.3_STC	-	0	100	1	1	-	Static
Minimum contrast of IR10.8, in Semi-Transparency Correction	dif_crit_ir10.8_STC	-	0	100	1	1	-	Static
Flag for critical parameter in IR/WV Ratioing	iflag_out_IRWV	-	0	1	-	-	-	Static
Minimum SNR of contrast in WV6.2, in IR/WV Ratioing	snr_crit_wv6.2_IRWV	-	0	1000	1	1	-	Static
Minimum SNR of contrast in WV7.3, in IR/WV Ratioing	snr_crit_wv7.3_IRWV	-	0	1000	1	1	-	Static
Minimum SNR of contrast in IR10.8, in IR/WV Ratioing	snr_crit_ir10.8_IRWV	-	0	1000	1	1	-	Static
Minimum contrast of samples in WV6.2, in IR/WV Ratioing	dif_crit_wv6.2_IRWV	-	0	100	1	1	-	Static
Minimum contrast of samples in WV7.3, in IR/WV Ratioing	dif_crit_wv7.3_IRWV	-	0	100	1	1	-	Static
Minimum contrast of samples in IR10.8, in IR/WV Ratioing	dif_crit_ir10.8_IRWV	-	0	100	1	1	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Minimum local SD of samples in WV6.2, in IR/WV Ratioing	lsd_crit_wv6.2_IRWV	-	0	-	1	1	-	Static
Minimum local SD of samples in WV7.3, in IR/WV Ratioing	lsd_crit_wv7.3_IRWV	-	0	-	1	1	-	Static
Minimum local SD of samples in IR10.8, in IR/WV Ratioing	lsd_crit_ir10.8_IRWV	-	0	-	1	1	-	Static
contrast in WV6.2, in IR/WV Ratioing	dif_cont_wv6.2_IRWV	-	0	100	1	1	-	Static
contrast in WV7.3, in IR/WV Ratioing	dif_cont_wv7.3_IRWV	-	0	100	1	1	-	Static
contrast in IR10.8, in IR/WV Ratioing	dif_cont_ir10.8_IRWV	-	0	100	1	1	-	Static
Minimum fraction of valid samples of target sampling window in IR/WV Ratioing	f_crit_samples_IRWV	%	0	100	1	1	sampling window	Static
Proportion of pixels required for merged IR/WV	f_crit_pixels_IRWV	%	0	100	1	1	-	Static
Minimum number of pixels for merged IR/WV	n_crit_merged_IRWV	-	0	-	1	1	-	Static
Critical correlation coefficient in IR/WV ratioing	crit_corr_IRWV	-	0	1	-	-	-	Static
Flag for critical parameters in IR/WV Two Channel Ratioing	iflag_out_2WV	-	0	1	-	-	-	Static
Confidence for different slopes, in IR/WV Two Channel Ratioing	conf_dif_slopes_2WV	%	0	100	1	1	-	Static
Critical ratio of slopes, in IR/WV Two Channel Ratioing	crit_rat_2WV	-	0	1	0.01	0.01	-	Static
Minimum fraction of valid samples of target sampling window in IR/WV Two Channel Ratioing	f_crit_samples_2WV	%	0	100	1	1	sampling window	Static
Minimum SNR of IR13.4 contrast, in CO2 Absorption Method	snr_crit_ir13.4_CO2ABS	-	0	100	1	1	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Minimum SNR of IR10.8 contrast, in CO2 Absorption Method	snr_crit_ir10.8_CO2ABS	-	0	100	1	1	-	Static
Minimum SNR of IR12.0 contrast, in CO2 Absorption Method	snr_crit_ir12.0_CO2ABS	-	0	100	1	1	-	Static
Minimum contrast of samples in IR13.4, in CO2 Absorption Method	dif_crit_ir13.4_ CO2ABS	-	0	100	1	1	-	Static
Minimum contrast of samples in IR10.8, in CO2 Absorption Method	dif_crit_ir10.8_ CO2ABS	-	0	100	1	1	-	Static
Minimum contrast of samples in IR12.0, in CO2 Absorption Method	dif_crit_ir12.0_ CO2ABS	-	0	100	1	1	-	Static
Minimum fraction of valid samples of target sampling window in CO2 Absorption Method	f_crit_samples_CO2ABS	%	0	100	1	1	-	Static
Histogram smoothing factor	his_smoothing_factor	hPa	0	1000	1	1	-	Static
Minimum number of sampled CO2 pressures to be used	his_min_n_samples	-	0	10000	1	1	sampling window	Static
Minimum inflexion CO2	his_min_infl_slope	-	0	1	0.001	0.001	-	Static
Width of pressure histogram bins for analysis of sampled CO_2 pressures	his_bin_width	hPa	0	1000	1	1	-	Static
Offset i(1) in CO_2 sampled pressure histogram analysis	his_i1	hPa	0	1000	1	1	-	Static
Offset i(2) in CO_2 sampled pressure histogram analysis	his_i2	hPa	0	1000	1	1	-	Static
Offset i(3) in CO_2 sampled pressure histogram analysis	his_i3	hPa	0	1000	1	1	-	Static
Offset j(1) in CO_2 sampled pressure histogram analysis	his_j1	hPa	0	1000	1	1	-	Static
Offset j(2) in CO_2 sampled pressure histogram analysis	his_j2	hPa	0	1000	1	1	-	Static
Offset j(3) in CO_2 sampled pressure histogram analysis	his_j3	hPa	0	1000	1	1	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Offset k(1) in CO2 sampled pressure histogram analysis	his_k1	hPa	0	1000	1	1	-	Static
Offset k(2) in CO2 sampled pressure histogram analysis	his_k2	hPa	0	1000	1	1	-	Static
Offset k(3) in CO_2 sampled pressure histogram analysis	his_k3	hPa	0	1000	1	1	-	Static
Window width for analysis of CO2 sampled pressures	his_win_width	hPa	0	1000	1	1	-	Static
Minimum pressure to start the analysis of the sampled CO2 pressures	his_min_pressure	hPa	0	1000	1	1	-	Static
Step size in CO2 pressure histogram analysis	his_win_step	hPa	1	50	1	1	-	Static
Minimum RTM radiance contrast for lowest level	crit_con_rtm_13.4	-	0	100	1	1	-	Static
Minimum RTM radiance contrast for lowest level	crit_con_rtm_12.0	-	0	100	1	1	-	Static
Minimum RTM radiance contrast for lowest level	crit_con_rtm_10.8	-	0	100	1	1	-	Static
Standard error of cloud-free outgoing radiance in channel x	sigma_rsuf (x)	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	-5	5	0.001	0.001	-	Static
Standard error of black cloud outgoing radiance in channel x at level P_c	sigma_rbcd (x)	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	-5	5	0.001	0.001	-	Static
Pressure threshold for applying the Inversion Height Assignment	inv_height_thres						-	Static
Minimum pressure difference between surface and bottom of inversion layer	inv_surface_offset						-	Static
Minimum pressure (highest level) for bottom of inversion layer	inv_pressure_thres						-	Static
Minimum strength of temperature inversion, i.e. minimum temperature difference between top and bottom of inversion layer	inv_magnitude_thres						-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Atmospheric level to start the search for temperature inversion layers	start_pressure						-	Static
Parameters in the derivation of the inversion height assignment	inv_c1						-	Static
	inv_c2						-	Static
	inv_c3						-	Static
Thresholds for the NTCC to derive the three single level heights in clear sky areas	NTCC_LL NTCC_N NTCC_HL	- - -	0 0 0	100 100 100	0.001 0.001 0.001	0.0001 0.0001 0.0001	- - -	Static
Threshold in derivation of clear-sky height standard deviation according to NTCC_N method	NTCC_threshold		0.01	0.5	-	-	-	Static
Threshold in derivation of clear-sky height standard deviation according to MaxNTC method	NTC_threshold	-	0.5	1.0	-	-	-	Static
Fraction of coldest pixels to be used for clear-sky EBBT height assignment	frac_cs_ebbt	%	0	100	1	1	target area	Static
Minimum fraction of clear-sky pixels in a clear-sky target	min_cs_fraction	%	0	100	1	1	target area	
Flag indicating use of sequential height assignment	iflag_sequence_ha	-	0	1	-	-	-	Static
Temperature threshold for the CO2 method in sequential height assignment	temp_thresh_co2	K	0	1000	-	-	-	Static
Pressure threshold for the IR/WV method in sequential height assignment	height_thresh_irwv	hPa	0	1000	-	-	-	Static
Pressure threshold for the STC method in sequential height assignment	height_thresh_stc	hPa	0	1000	-	-	-	Static

STATIC APPLICATION DATA FOR HEIGHT ASSIGNMENT								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Temperature threshold for the STC 6_2 method in sequential height assignment	temp_thresh_stc6_2	K	0	1000	-	-	-	Static
Temperature threshold for the STC 7_3 method in sequential height assignment	temp_thresh_stc7_3	K	0	1000	-	-	-	Static
Temperature threshold for the IRWV 6_2 method in sequential height assignment	temp_thresh_irwv6_2	K	0	1000	-	-	-	Static
Temperature threshold for the IRWV 7_3 method in sequential height assignment	temp_thresh_irwv7_3	K	0	1000	-	-	-	Static
Critical correlation coefficient for IRWV regression analysis	crit_corr_IRWV_1	-	0	1	-	-	-	Static
Critical correlation coefficient for IRWV regression analysis	crit_corr_IRWV_2	-	0	1	-	-	-	Static

Table 28: AMV Product: Static Application Data for Height Assignment

STATIC APPLICATION DATA FOR RECURSIVE FILTER FUNCTION								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Analysis field latitude interval	rff_delta_lat	degrees	1	10	1	1	-	Static
Analysis field longitude interval	rff_delta_lon	degrees	1	10	1	1	-	Static
Forecast field pseudo latitude interval	rff_pseudo_density_lat	degrees	1	10	1	1	-	Static
Forecast field pseudo longitude interval	rff_pseudo_density_lon	degrees	1	10	1	1	-	Static
Apply stagger to forecast field longitude sampling	rff_stagger	-	No	Yes	-	-	-	Static
Height re-adjustment best fit weight in direction	rff_weight_direction	-	1	10000	-	-	-	Static
Height re-adjustment best fit weight in pressure	rff_weight_pressure	-	1	10000	-	-	-	Static

STATIC APPLICATION DATA FOR RECURSIVE FILTER FUNCTION								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Height re-adjustment best fit weight in speed	rff_weight_speed	-	1	10000	-	-	-	Static
Height re-adjustment best fit weight in temperature	rff_weight_temp	-	1	10000	-	-	-	Static
Height re-adjustment best fit weight in velocity	rff_weight_velocity	-	1	10000	-	-	-	Static
Initial First Pass Dimensionality of Analysis	rff_initial_firstpass_dim	-	1	3	-	-	-	Static
Initial First Pass forecast weight	rff_initial_firstpass_fc_ weight	-	0	1	-	-	-	Static
Initial First Pass No. of Iterations	rff_initial_firstpass_no_ iterations	-	1	10	-	-	-	Static
Initial First Pass No. of Smoothing Passes	rff_initial_firstpass_no_ smoothing_passes	-	1	10	-	-	-	Static
Initial First Pass Quality Exponent	rff_initial_firstpass_quality_exp	-	1	10.0	-	-	-	Static
Initial First Pass Radius of Influence	rff_initial_firstpass_radius_influence	km	1	1000	-	-	-	Static
Initial First Pass Radius Scale Factor	rff_initial_firstpass_radius_scale_factor	-	1	100	-	-	-	Static
Initial First Pass Control Fit of Analysis to Data	rff_initial_firstpass_rf	-	0.0	1.0	-	-	-	Static
Initial First Pass Error Tolerance	rff_initial_firstpass_ tolerance	m/s	0	10000	-	-	-	Static
Initial First Pass Vertical Coupling	rff_initial_firstpass_vert_ coup	km	1	1000	-	-	-	Static
Initial Second Pass Dimensionality of Analysis	rff_initial_secondpass_dim	-	1	3	-	-	-	Static
Initial Second Pass forecast weight	rff_initial_secondpass_fc_ weight	-	0	1	-	-	-	Static
Initial Second Pass No. of Iterations	rff_initial_secondpass_no_ iterations	-	1	10	-	-	-	Static
Initial Second Pass No. of Smoothing Passes	rff_initial_secondpass_no_ smoothing_passes	-	1	10	-	-	-	Static
Initial Second Pass Quality Exponent	rff_initial_secondpass_ quality_exp	-	1	10.0	-	-	-	Static

STATIC APPLICATION DATA FOR RECURSIVE FILTER FUNCTION								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Initial Second Pass Radius of Influence	rff_initial_secondpass_ radius_influence	km	1	1000	-	-	-	Static
Initial Second Pass Radius Scale Factor	rff_initial_secondpass_ radius_scale_factor	-	1	100	-	-	-	Static
Initial Second Pass Control Fit of Analysis to Data	rff_initial_secondpass_rf	-	0.0	1.0	-	-	-	Static
Initial Second Pass Error Tolerance	rff_initial_secondpass_ tolerance	m/s	0	10000	-	-	-	Static
Initial Second Pass Vertical Coupling	rff_initial_secondpass_ vert_ coup	km	1	1000	-	-	-	Static
Main Analysis Dimensionality of Analysis	rff_ main _dim	-	1	3	-	-	-	Static
Main Analysis forecast weight	rff_ main _fc_ weight	-	0	1	-	-	-	Static
Main Analysis No. of Iterations	rff_ main _no_ iterations	-	1	10	-	-	-	Static
Main Analysis No. of Smoothing Passes	rff_ main _no_ smoothing_passes	-	1	10	-	-	-	Static
Main Analysis Quality Exponent	rff_ main _quality_exp	-	1	10.0	-	-	-	Static
Main Analysis Radius of Influence	rff_ main _radius_influence	km	1	1000	-	-	-	Static
Main Analysis Radius Scale Factor	rff_main_radius_ scale_factor	-	1	100	-	-	-	Static
Main Analysis Control Fit of Analysis to Data	rff_ main _rf	-	0.0	1.0	-	-	-	Static
Main Analysis Error Tolerance	rff_ main _ tolerance	m/s	0	10000	-	-	-	Static
Main Analysis Vertical Coupling	rff_ main _vert_ coup	km	1	1000	-	-	-	Static
Final Analysis Dimensionality of Analysis	rff_ final_dim	-	1	3	-	-	-	Static
Final Analysis forecast weight	rff_ final _fc_ weight	-	0	1	-	-	-	Static
Final Analysis No. of Iterations	rff_ final _no_ iterations	-	1	10	-	-	-	Static
Final Analysis No. of Smoothing Passes	rff_ final _no_ smoothing_passes	-	1	10	-	-	-	Static
Final Analysis Quality Exponent	rff_ final _quality_exp	-	1	10.0	-	-	-	Static

STATIC APPLICATION DATA FOR RECURSIVE FILTER FUNCTION								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Final Analysis Radius of Influence	rff_ final _radius_influence	km	1	1000	-	-	-	Static
Final Analysis Radius Scale Factor	rff_ final _radius_ scale_factor	-	1	100	-	-	-	Static
Final Analysis Control Fit of Analysis to Data	rff_ final _rf	-	0.0	1.0	-	-	-	Static
Final Analysis Error Tolerance	rff_ final _ tolerance	m/s	0	10000	-	-	-	Static
Final Analysis Vertical Coupling	rff_ final _vert_ coup	km	1	1000	-	-	-	Static

Table 29: AMV Product: Static application data for recursive filter function

STATIC APPLICATION DATA FOR ENCODING FILTER (PER CHANNEL)								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Minimum average forecast consistency	qual_forecast	%	0	100	-	-	-	Static
Minimum number of AMVs with QI (exFC) > qual_qi	qual_num_good	-	0		-	-	-	Static
Maximum number of AMVs with pressure < qual_pressure	qual_num_high	-	0		-	-	-	Static
Pressure threshold for qual_num_high	qual_pressure	hPa	0		-	-	-	Static
Quality threshold for qual_num_good	qual_qi	%	0	100	-	-	-	Static
Minimum average vector consistency	qual_vector	%	0	100	-	-	-	Static
Minimum proportion of AMVs with QI (exFC) > qual_qi related to total for channel. For HRV and VIS only low levels are considered.	qual_proportion	%	0	100				Static

Table 30: AMV Product: Static application for encoding filter

STATIC APPLICATION DATA FOR AMV AVERAGING								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
Maximum pressure difference between different intermediate vector heights	max_pres_diff	hPa	0	200	-	-	-	Static
Maximum direction difference between different intermediate vector heights	max_dir_diff	°	0	360	-	-	-	Static
Maximum speed difference between different intermediate vector heights	max_speed_diff	m/s	0		-	-	-	Static

Table 31: AMV Product: Static application data for AMV averaging

9.3 Algorithm Functional Specification

9.3.1 Overview

The following steps **shall** be performed in order to derive one single displacement vector for one channel for the intermediate AMV product. These are described in more detail in the following sections:

1. Target selection
2. Image data preparation
3. Image enhancement
4. Derivation of target displacement
5. Height assignment

This algorithm initially derives the Atmospheric Motion Vectors intermediate product for three out of every four repeat cycles for all specified channels over the processing area.

It **shall** extract all possible targets within each image and find the position of the same targets in the following image. The primary targets **shall** be centralised around the locations of the end position of the successfully tracked targets from the previous cycle. It **shall** additionally complement these targets with new targets extracted by the target selection scheme. Only targets with a quality higher than *first_cycle_min_qi* (nominally 0)–in the case that the target has been tracked only over one cycle, or *new_cycle_min_qi* (nominally 0)–in the case that the target has been tracked over two or more cycles, **shall** be kept for further processing. The target selection will be initialised on an equidistant grid specified by *grid_distance*.

The target position **shall** be optimised within the target search area to gain maximum contrast within the target area. Specific targets **shall** be enhanced to increase contrast with respect to lower level scenes. The vectors successfully extracted with cloud targets **shall** be assigned a height corresponding to the temperature at which the cloud is radiating. The other vectors **shall** be assigned a height related to a representative layer of the displacement.

Finally, all vectors **shall** be subjected to an Automatic Quality Control (AQC) for both the intermediate and final products where appropriate. The information derived from a single repeat cycle **shall** be an intermediate product.

The final AMV product **shall** be generated at scheduled times. It **shall** be based on intermediate AMV products, where the number of intermediate products which **shall** be used is specified by the set-up parameter *N_Gen* which is nominally three (3).

In the nominal case, intermediate products are generated with time stamps of 15, 30 and 45 minutes into the synoptic hour. The final product is generated with a time stamp of 45 minutes into the synoptic hour. This means that, for example, for the 15-minute time stamp intermediate product, each target is selected from the image data (scan) starting at 0 minutes. The target displacement is extracted from the image data (scan) starting at 15 minutes into the synoptic hour. Then everything is shifted forward one repeat cycle for the next intermediate product. No intermediate products are generated at the 0-minute synoptic time. In effect, four images are used each hour to generate three intermediate products and a final product. The Rapid Scanning Service (RSS) similarly uses three intermediate products to form a final product three times an hour, with time stamps of 15, 35 and 55 minutes into the synoptic hour. The AMV processing flow is shown graphically in Figure 6. The target optimisation, being a complex process, is shown separately in Figure 7.

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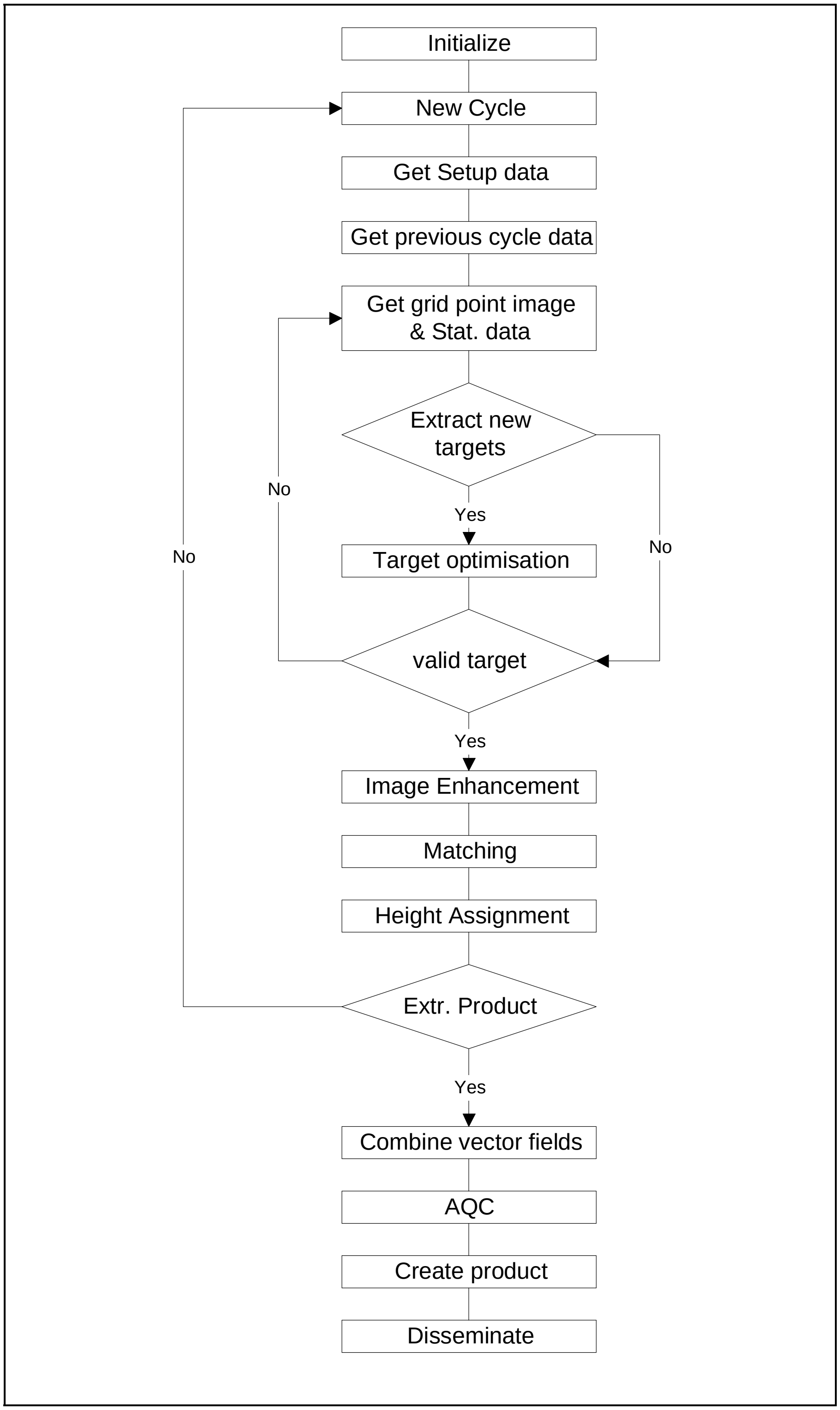

Figure 6: AMV Processing

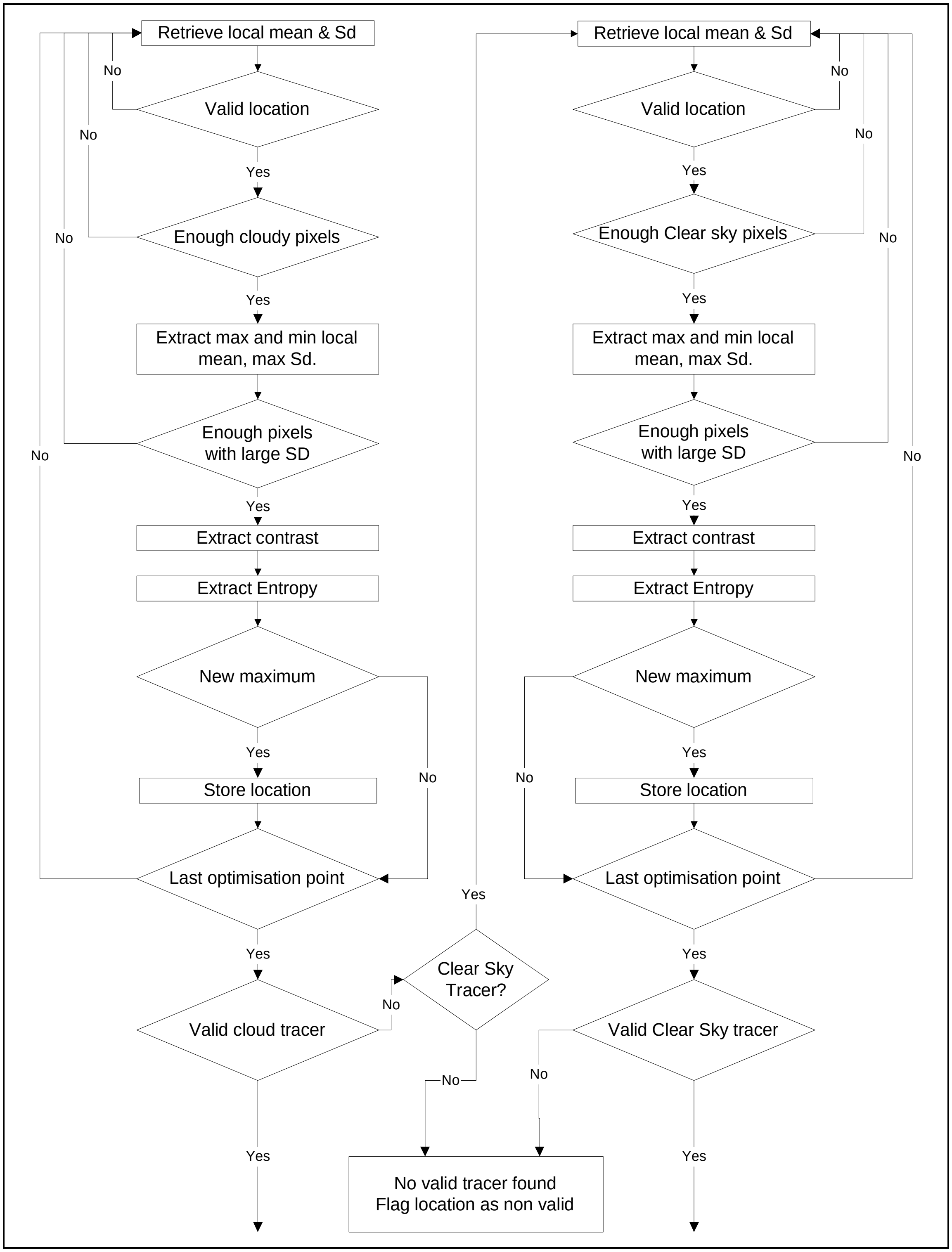

Figure 7: AMV Processing - Target Optimisation

9.3.2 Algorithm Description

9.3.2.1 Target Selection

The main inputs for the target selection are the image data in all the specified channels and the scenes type provided by Scenes Analysis. Further inputs are set-up parameters controlling the actual selection procedure and the vectors derived during the previous cycle.

The target size **shall** be specified separately for each channel and target type by *Cl_tar_size* (nominally 24 and for HRVIS 32) and *CS_tar_size* (nominally 32). Two types of targets **shall** be used to derive the baseline products: clouds and moisture features. The use of ozone targets **shall** be foreseen as a Future Enhancement. The targets **shall** be extracted in two separate steps. The primary targets **shall** be the targets extracted from the previous extraction cycle so that the target position will be located at the best position indicated by the matching surface (in the case of cross correlation at the maximum correlation value). Primary targets **shall** only be valid if they are derived from a repeat cycle within *max_ptarget_age* of the current repeat cycle. In addition, primary targets for VIS and HRVIS channels **shall** only be valid for solar zenith angles less than (nominally) 87 degrees.

The secondary targets **shall** be extracted at an equidistant grid specified *grid_distance* (nominally 24 and for HRVIS 32). The search for the optimum secondary target in the vicinity of each grid point **shall** be limited to an optimisation area and it **shall** also take into account the positions of the already identified targets. This **shall** be controlled by *tar_opt_area* (nominally 48 and for HRVIS 64), which defines the optimisation area size and *max_tar_overlap* (nominally 288) which defines the acceptable target overlap in total pixels. Secondary targets for VIS and HRVIS channels **shall** only be valid for solar zenith angles less than (nominally) 87 degrees.

The concept of target and search areas is shown in Figure 8.

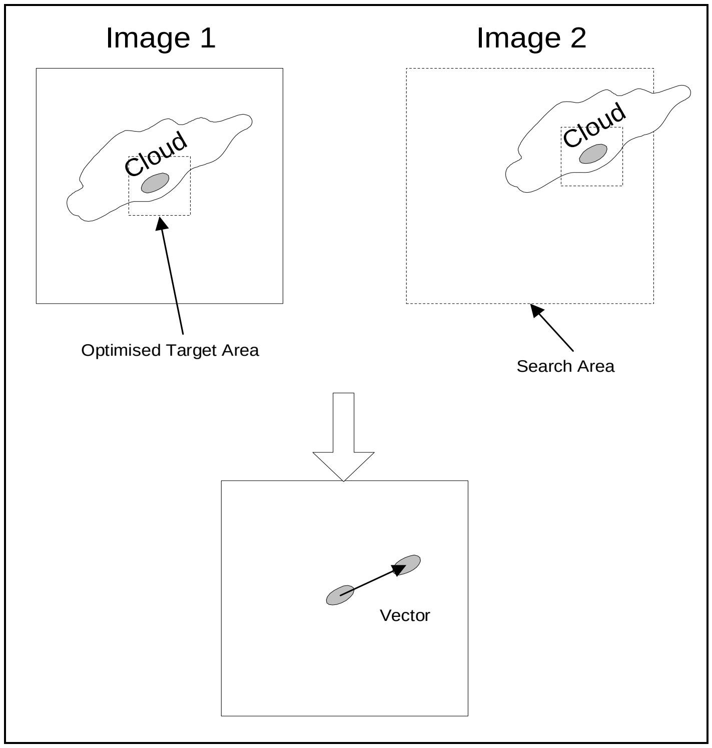

Figure 8: Target and Search Areas

The optimisation of the target position **shall** extract the location within the optimisation area at which the contrast within the target area and/or entropy is maximised. Entropy (E) is defined as follows:

$$E = \sum_{i=1}^{N} P_i \times 2 \log P_i$$

Equation 7

where P_i is the probability that a pixel has the value i.

This **shall** further be controlled with a selection based on the cumulative histogram of the local standard deviation. The selection between maximum contrast and maximum entropy **shall** be selected by setting *tar_ex_met* (nominally 1= maximum contrast).

The target optimisation process is illustrated graphically in Figure 9.

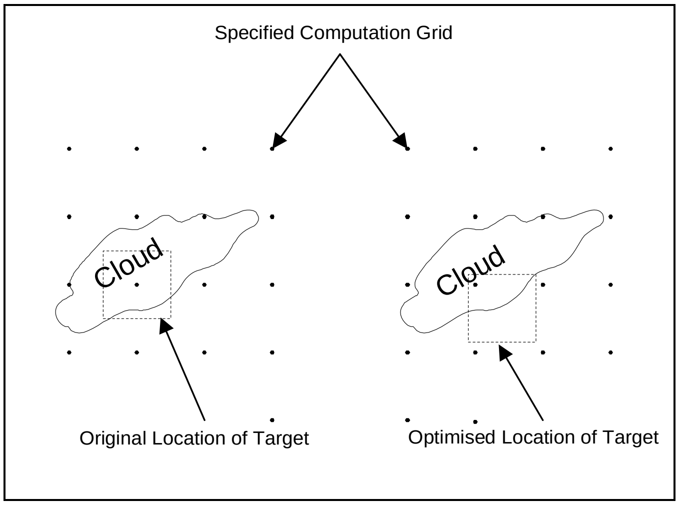

Figure 9 Target Optimisation

The following steps **shall** be performed in order to find a suitable target:

1. Use *Cl_tar_size*
2. Retrieve local means and local standard deviations (computed over 3 × 3 pixels) for each location in the target search area.
3. For all possible locations within the target search area: the primary target locations are defined by the vector of the previous extraction having a quality greater than *new_cycle_min_qi* (nominally 0.0).
4. Control that the current location is valid–the overlap with previously identified targets must be less than *max_tar_overlap*. For each valid location, continue with steps 4 to 12. If the location is invalid, skip to the next location.
5. a) In the case of *Cl_tar_size*, check the number of cloudy pixels for all locations. For the water vapour channels, the definition of which cloud layers contribute to the final number of cloudy pixels should be defined by *wv_cloud_type* (nominally 2 for WV6.2 and WV7.3). The possible values of *wv_cloud_type* are = 0, 1, 2 and correspond to all cloud layers (0), high cloud only (1), high and medium cloud only (2). For all other channels all cloud layers contribute to the definition of the number of cloudy pixels. (If a pixel does not contribute to a cloudy target, it will automatically be considered to contribute to a clear sky target.) If the number of cloudy pixels in the location is less than *min_tracer_size* (nominally 50), skip to next location.

   b) In the case of *CS_tar_size*, the location **shall** be skipped if it contains more than *CS_max_cloud_pix* (nominally 50 for WV channels and -1 for other channels) cloud pixels. The parameters are set to ensure that nominally clear sky targets can only be generated for the water vapour channels.
6. Derive maximum local mean, minimum local mean, maximum local standard deviation, and number of pixels with a local standard deviation greater than *min_sd* for each of these possible target locations.
7. Check that more than *min_num_high_sd* number of pixels have a standard deviation larger than *min_sd*.

8. Extract the contrast as the local standard deviation at the target centre.
9. Extract the entropy.
10. Find position of maximum contrast/entropy within the target optimisation area.
11. Check that the background location is valid. This **shall** be carried out using the *Surface_type_map.* A set-up flag *lcoast_flag* is used to determine which location is valid. It can take the following values:
    0 = Any background is valid: land, sea or coast.
    1 = Land or sea but no coastline, where e.g.

$$\frac{(100 * MAX(number\_of\_seapixels, number\_of\_landpixels))}{(number\_of\_seapixels + number\_of\_landpixels)} \geq tar\_sel\_bckg\_frac \quad \text{Equation 8}$$

    (*tar_sel_bckg_frac* nominally has a value of 100 %).
    2 = Land only (set *tar_sel_bckg_frac* to a value of 100 %) or land/coastline (set *tar_sel_bckg_frac* to a value of 0%).
    3 = Sea only (set *tar_sel_bckg_frac* to a value of 100 %) or sea/coastline (set *tar_sel_bckg_frac* to a value of 0 %).
    4 = Coast only (set *tar_sel_bckg_frac* to a value of 100 %).

    Number_of_seapixels and *number_of_landpixels* **shall** be determined from the static land/sea-mask, where any pixel location containing sea or water is assigned to *number_of_seapixels*. The nominal values for *lcoast_flag* and *tar_sel_bckg_frac* are 1 and 100 % respectively.
12. Determine the centre position of the target.
13. Compute the mean and standard deviation of all scenes for all channels within the target area, using only the pixels within the target area.
14. If a successful optimum location was found then return. Use *Cl_tar_size* (nominally 24) and *Cl_sar_size* for matching.
15. If no location contains enough cloudy pixels then if *CS_tar_size* is greater than zero, re-compute steps 2 to 13 using *CS_tar_size* (and step 5b rather than 5a).
16. Compute the number of cloudy pixels for the final location. If the total number is greater than *min_tracer_size* , skip return and identify the location with no valid target and proceed to next grid point.
17. If the number of cloudy pixels is less than *min_tracer_size* then return. Use *CS_tar_size* and *CS_sar_size* for matching.

The following four alternative target extraction schemes **shall** be implemented:

1. The primary targets are always used and are always complemented by the secondary targets.
2. The primary targets are always used and the secondary targets **shall** be extracted only from the first image of a new generation cycle.
3. As 1) except no primary targets are extracted from the first image of a new generation cycle.
4. As 3) except secondary targets **shall** be extracted only from the first image of a new generation cycle.

It **shall** be possible to select the extraction scheme with the appropriate setting of *tar_extraction* (nominally 4). The target optimisation will provide the position of the optimised target location for the follow-on processes together with a flag stating the validity of the location. The target area and search area of the matching **shall** be centred at the location-optimised location.

9.3.2.2 Image Data Preparation

9.3.2.2.1 Introduction

The purpose of the Image Data Preparation task is to combine the information provided by CLA into scenes relevant to the AMV. This is required at two stages of the overall processing:

a) Prior to Image Enhancement (see Section 9.3.2.3)

b) Prior to Height Assignment (see Section 9.3.2.5)

In item a), the image data preparation shall be performed after the target selection with the optimised target. However, it will only be performed for those AMV channels in which image enhancement is applied. Its aim is to provide the AMV Image Enhancement with suitable scene mean and standard deviations derived from the target area (prior to target displacement).

In b) the image data preparation shall be performed after the derivation of target displacement, and will be performed on the displaced target area (i.e. in the new target position) for all AMV channels. The aim is to provide the AMV height assignment with relevant scenes derived from the displaced target area.

The main inputs for the Image Data Preparation are the image data in all the specified channels, the scenes type, and the additional cloud information from CLA. Further inputs are the set-up parameters controlling the actual procedure.

There are two alternative schemes for Image Data Preparation which can be selected by a set-up parameter *AMV_use_dynamic_scenes*. One separates the data into fixed bands (0) and the other uses a dynamic clustering scheme based on histogram analysis (1). The nominal value for *AMV_use_dynamic_scenes* is 0.

9.3.2.2.2 Cloud Clustering Based on Fixed Bands

For image data preparation prior to image enhancement, the process **shall** perform the following steps for the AMV processing channel:

1. The process **shall** loop over all pixels within the target area. If *AMV_use_CLA_quality* is true then only use pixels where the CLA quality is good, otherwise (nominal case) use all pixels. The process **shall** compute the mean, standard deviation, and mean pressure for all channels of all scenes containing pixels of the same cloud phase in bands of *AMV_merge_pres* hPa (nominally 200 hPa).
2. The process **shall** compare the computed means for all successfully classified scenes. Cloud scenes **shall** **not** be compared to surface scenes. Identify the two scenes with the smallest mean pressure difference. If the difference is smaller than *min_scene_dist* (nominally 2 hPa) the two scenes **shall** be reclassified to provide a new combined scene type.
3. If a reclassification was performed in step 2, then re-compute the means and standard deviation of the new reclassified scene and then go back to step 2.
4. Count the numbers of pixels belonging to each scene type. Only scene types containing more than *min_sce_size* (nominally 20) pixels **shall** be considered to be valid.

If the image data preparation has identified more than two valid cloud scenes, the two coldest cloud scenes **shall** be extracted, with the remaining ones discarded.

All surface pixels are combined into a single surface scene and the mean and standard deviation computed.

For image data preparation prior to height assignment, the above steps are carried out with the following exceptions:

a) No means and standard deviations are calculated – the aim is to assign each pixel to a particular scene.
b) All valid cloud scenes shall be used – there is no filtering to the two coldest cloud scenes.

9.3.2.2.3 Cloud Clustering Based on Histogram Analysis

Surface scenes **shall** be merged to create a single surface scene.

The clustering of cloud pixels **shall** be performed through an algorithm based on histogram analysis of the cloud top height (as provided by the CLA algorithm). No distinction is made between cloud phases.

A future enhancement **shall** be to consider separate histogram analyses of opaque and semi-transparent scenes.

The total number of clustered scenes extracted by the clustering algorithm **shall** **not** exceed *n_cloud_clusters* (nominally 6). The smallest clusters will be removed to achieve this end.

The cloudy pixels **shall** individually be assigned to one of *n_hist_bin* (nominally 100) histogram bins, to provide a histogram of cloud top heights.

The histogram analysis **shall** be performed to detect peaks as follows:

- From the original histogram submitted to histogram analysis, a secondary 'smoothed' histogram **shall** be constructed where each bin contains the average of three adjacent bins.
- For each histogram bin in the 'smoothed' histogram, two additional bins **shall** be selected at offsets defined by set-up parameters *hist_off_coeff1* (nominally 1) and *hist_off_coeff2* (nominally two).
- Three sets of offsets **shall** be defined: i(ii), j(ii),k(ii), ii=1,3 where nominally

  $i(1) = 0,\quad j(1) = hist\_off\_coeff1,\quad k(1) = hist\_off\_coeff2$

  $i(2) = 0,\quad j(2) = 2 \times hist\_off\_coeff1,\quad k(2) = 2 \times hist\_off\_coeff2$

  $i(3) = 0,\quad j(3) = 3 \times hist\_off\_coeff1,\quad k(3) = 3 \times hist\_off\_coeff2$

- Using the values of the three selected bins (x_i, x_j and x_k) and their corresponding frequencies of occurrence (f_i, f_j and f_k), for all cases in which the combined three-point frequency exceeds *hist_min_freq* (nominally 5), the mean (x_0), the standard deviation (σ) and the peak frequency (f_0) of the Gaussian curve that fits these values **shall** be calculated according to the following formulae:

$x_0 = [x_i^2 \times \log(f_j/f_k) - x_j^2 \times \log(f_i/f_k) + x_k^2 \times \text{logf}(f_i/f_j)] / 2 \times [x_i \times \log(f_j/f_k) - x_j \times \log(f_i/f_k) + x_k \times \text{logf}(f_i/f_j)]$ $\sigma^2 = [(x_j- x_0)^2 - (x_i- x_0)^2] / 2 \times \log(f_i/f_j)$ $f_0 = f_i \times \exp(x_i- x_0)^2/ 2\sigma^2$	*Equation 9*

- Where valid values of these quantities can be found, they **shall** be stored and x_0 **shall** be assumed to define a peak in the histogram.
- Once the entire 'smoothed' histogram has been processed, peaks (values of x_0) that are detected fewer than *min_peak_occ* (nominally 2) times **shall** be discarded unless no other peak has been found.
- Peaks that are too close to each other (defined by the thresholds *peak_mean_diff* (nominally 2) and *peak_std_diff* (nominally 2)) **shall** be merged together.
- For each peak found at least *min_peak_occ* times, average values of x_0, σ and f_0 **shall** be calculated.

The peaks detected by the histogram analysis **shall** be assumed to correspond to particular clustered scenes.

Pixel values for a particular clustered scene **shall** be assumed to conform to a normal distribution such that the peaks detected by the histogram analysis **shall** be assumed to correspond to peak values of a Gaussian curve. This means that for each cloud cluster, all contributing histogram bins are truncated to ensure the individual bin frequencies lie under or on a Gaussian curve.

The clustered scenes extracted by the histogram analysis **shall** be characterised by the peak value, the mean value and the standard deviation of the corresponding Gaussian curve.

If the number of pixels in the cluster is less than *cluster_min_size* (nominally 20), the cluster **shall** be removed.

After performing the histogram analysis, individual pixels **shall** be assigned to the clustered scene that has the nearest mean value. The assignment of pixels to clustered scenes **shall** be performed through a number of iterations, limited by *max_class_cycles* (nominally 1), until no further reassignment is required.

An individual pixel **shall** only be assigned to a clustered scene if it lies within three standard deviations of the cluster mean value.

Pixels that cannot be assigned to a cluster **shall** be set to 'unclassified'.

At each iteration in the assignment of pixels to clusters; the mean and standard deviation of each cluster **shall** be re-calculated according to the values of the pixels that have been assigned to it.

At each iteration, if the number of pixels in the cluster is less than *cluster_min_size*, the cluster **shall** be removed.

Prior to Image Enhancement

In the case of image data preparation prior to image enhancement, if there are more than two cloud scenes left at the end of the cluster analysis, the two coldest scenes **shall** be extracted.

Prior to Height Assignment

For image data preparation prior to height assignment, a further check will be carried out to modify (and filter out for WV channels) low-level scenes analysis as follows. If all cloud scenes have a (CLA determined) mean pressure above *low_level_pressure_threshold* (nominally 600 hPa) then for WV channel winds they will be ignored and the number of cloud scenes for the target **shall** be set to zero (WV targets are not expected at these low levels), otherwise (for other channels) they are merged in the following way. If there are fewer than three cloud scenes, all scenes are merged into a single scene. If there are three or more scenes, all scenes excepting the warmest are merged into a single scene. All cloud scenes left at the end of the analysis **shall** be retained. A flag **shall** be set to define the scenes status of the target for use in the height assignment methodology: either undefined, low level, low level (with merging), or medium-high level.

9.3.2.3 Image Enhancement

9.3.2.3.1 Introduction

The image enhancement **shall** use the image data extracted at the location around the optimised target position and the scenes data output from the Image Data Preparation (see Section 9.3.2.2). The mean count and standard deviation, as derived by the Image Data Preparation process, **shall** be applied equally to the target and the search area.

The image enhancement **shall** be performed only for specific channels defined by *l_enhance*. Nominally it **shall** **not** be used for any channel. The image enhancement **shall** increase the contrast between the selected target and possible lower level surfaces. The image enhancement type will be specified by the number of relevant scenes. The number of relevant scenes **shall** be defined as the sum of the number of relevant cloud scenes and a maximum of one (the warmest) surface type.

The following methods **shall** be applied for enhancement of cloud tracers:

- In single scene cases: Pixel masking.
- In areas with two scenes: Linear or non-linear histogram enhancement.
- In multi-layered scenes (three or more scenes) the Spatial Coherence Method (SCM) **shall** be applied.

The use of CLA information and histogram enhancement for image enhancement in cloud-free areas is a Future Enhancement.

9.3.2.3.2 Single Scene Case

The target **shall** be specified by the scene limit counts which are defined by the following:

$$C^{cl}_{\min} = \overline{C^{cl}} - cl\_\lim \bullet \sigma \quad \textit{and}$$
$$C^{cl}_{\max} = \overline{C^{cl}} + cl\_\lim \bullet \sigma, \quad \textit{where}$$
$$\overline{C^{cl}} = \textit{Mean count of scene}$$

Equation 10

cl_lim is the scene limit factor and σ is the standard deviation of the pixels belonging to the scene.

A given pixel of the target or search area **shall** be masked if its radiance (count value) is less than the minimum limit count of the tracer $C^{cl}_{\min}$ or bigger than the maximum count $C^{cl}_{\max}$, otherwise it retains its original value. The masking function **shall** be specified as the following:

$$C^{cl}_{\min d} \leq C \leq C^{cl}_{\max} \Rightarrow C_{new} = C$$
$$C < C^{cl}_{\min}, C > C^{cl}_{\max} \Rightarrow C_{new} = TM \bullet C_{random}$$

Equation 11

where TM is a set-up parameter (0 or 1) and C_{random} is a random value generated between $C^{cl}_{\min}$ and $C^{cl}_{\max}$. If TM is 0 the pixel value = 0 and it **shall not** be used in the correlation computations.

The information about the number of masked pixels in the target area, the number of masked pixels in the search area and the number of cloud layers **shall** be made available for the Automatic Quality Control procedures.

9.3.2.3.3 Two Scene Case

If the target area contains two scenes the following transformation **shall** be performed:

$$C < C^{coldcl}_{\min} \Rightarrow C_{new} = TM \bullet C_{random}$$
$$C^{coldcl}_{\min} \leq C < \overline{C^{coldcl}} \Rightarrow C_{new} = C$$
$$\overline{C^{coldcl}} \leq C < \overline{C^{warmcl}} \Rightarrow C_{new} = \overline{C^{coldcl}} + \frac{(C - \overline{C^{coldcl}})^{CF}}{(\overline{C^{warmcl}} - \overline{C^{coldcl}})^{CF-1}}$$
$$C \geq \overline{C^{warmcl}} \Rightarrow C_{new} = \overline{C^{warmcl}}$$

Equation 12

where:

$\overline{C^{coldcl}}$ = mean count of the colder scene

$\overline{C^{warmcl}}$ = mean count of the warmer scene

$C^{coldcl}_{\min} = \overline{C^{coldcl}} - cl\_lim \bullet \sigma_{cold}$

σ_{cold} = standard deviation of cold scene

cl_lim = scene limit factor

CF = contrast factor

$C^{coldcl}_{\min} \leq C_{random} \leq \overline{C^{warmcl}}$

9.3.2.3.4 Multi-layered Scenes

THREE SCENES

The aim of the image filtering is to enhance the highest cloud tracer suitable for tracking in the target area. The spatial coherence filtering **shall** be applied in cases with three scene types (that is, at least two cloud layers) in a segment. The multispectral image analysis provides the mean counts (C_1, C_2 and C_3) for the three scenes, but they **shall** be modified during the target selection procedure to represent a mean derived only from the cloud points present in the target area. At present a simple parabolic function best suited to fit the arch-like relationship between local standard deviation σ(C) and local mean count C_{lm}(C) is used (Schmetz et al., 1993). Outside the two scenes C^i and C^j the arch **shall** be set to 0; between the two scenes C^i and C^j the arch **shall** be described by the function:

$$\sigma(C) = \frac{-4 \bullet \sigma_{top_{ij}}}{(\overline{C^i} - \overline{C^j})^2} \bullet (C_m(C) - \overline{C^i}) \bullet (C_m(C) - \overline{C^j})$$

Equation 13

where:

C_m(C)	is the local mean value attributed to the pixel with the satellite radiance C
σ(C)	is the local standard deviation attributed to the same pixel
σ_{top}	is the maximum standard deviation corresponding to the top of the arch

σ_{topij} is parameterised as a piecewise linear function of the brightness-temperature difference ΔT between $\overline{C^i}$ and $\overline{C^j}$, which in a three-scene case **shall** be defined by:

$$\Delta T^{12} = T(C^2) - T(C^1)$$
$$\Delta T^{13} = T(C^3) - T(C^1)$$
$$\Delta T^{23} = T(C^3) - T(C^2)$$

and

$$\sigma_{top_{ij}} = SCM\_RF\_S \cdot \Delta T^{ij} + SCM\_RO\_S \quad if \; ABS(\Delta T^{ij}) \le SCM\_T$$
$$\sigma_{top_{ij}} = SCM\_RF\_L \cdot \Delta T^{ij} + SCM\_RO\_L \quad if \; ABS(\Delta T^{ij}) > SCM\_T$$

Equation 14

where:

(i,j)	= (1,2), (1,3) or (2,3)
T(C^i)	= the temperature in kelvin attached to the average count of the scene C^i

and

SCM_RF_S = Regression factor for small temperature differences
SCM_RO_S = Regression offset for small temperature differences
SCM_RF_L = Regression factor for large temperature differences
SCM_RO_L = Regression offset for large temperature differences
SCM_T = Temperature threshold

which are given by the set-up configuration.

Principally, the image filtering **shall** project all counts into a basic radiometric range, defined as the range between $\overline{C^1}$ and $\overline{C^3}$. There **shall** be seven different cases identified, which are addressed sequentially (case 0 to 6) and **shall** only be applied at the first valid occasion. These cases are, in the order they **shall** be applied:

$$\begin{aligned}
&case\,0: \quad C < \overline{C}^1_{\min} \Rightarrow C_{new} = TM \bullet C_{random} \\
&case\,1: \quad C < \overline{C}^1 \Rightarrow C_{new} = C \\
&case\,2: \quad C > \overline{C^3} \Rightarrow C_{new} = \overline{C^3} \\
&case\,3: \quad \sigma(C) > \sigma_{13}(C) \Rightarrow C_{new} = C \\
&case\,4: \quad \sigma(C) < \sigma_{12}(C) \Rightarrow C_{new} = \frac{\overline{C^3} - \overline{C^1}}{\overline{C^2} - \overline{C^1}}\left(C - \overline{C^1}\right) + \overline{C^1} \\
&case\,5: \quad \sigma(C) < \sigma_{23}(C) \Rightarrow C_{new} = \overline{C^3}
\end{aligned}$$

Equation 15

Case 6: For this case, the pixels are within the basic radiometric range between $\overline{C^1}$ and $\overline{C^3}$ and are assumed to contain information from all three scenes. Here, in addition to scaling with fractional cloud amount (which is the principal in *case 4*), a scaling with local standard deviations **shall** be performed:

$$\begin{aligned}
&C_{new} = \frac{\sigma_{13}(C) - \sigma(C)}{\sigma_{13}(C) - \sigma'(C)}\left[\frac{\overline{C^3} - \overline{C^1}}{\overline{C^2} - \overline{C^1}}\left(C' - \overline{C^1}\right) + \overline{C^1}\right] + \frac{\sigma(C) - \sigma'(C)}{\sigma_{13}(C) - \sigma'(C)} C, \quad where \\
&C \le \overline{C^2} \Rightarrow \sigma'(C) = \sigma_{12}(C), C' = C, \quad and \\
&C > \overline{C^2} \Rightarrow \sigma'(C) = \sigma_{23}(C), C' = \overline{C^2}
\end{aligned}$$

Equation 16

where σ(C) is the local standard deviation as computed over 3 × 3 pixels and $\sigma_{ij}(C)$ describes the arch between the scenes i and j where (i,j) take the values (1,2), (1,3) and (2,3).

$C^1{}_{\min} \le C_{random} \le \overline{C}^3$.

FOUR OR MORE SCENES

If the data preparation has identified more than three valid scenes for the target area, the results for the two coldest clouds and the warmest surface scene as identified by the Image Data Preparation process **shall** be used. The image enhancement as described in the three-scenes case **shall** then be utilised.

9.3.2.3.5 Cloud-free Areas (WV and/or Ozone Tracers)

In the baseline set-up there is no enhancement of clear sky targets. The introduction of an image enhancement for clear sky areas **shall** be foreseen as a Future Enhancement.

9.3.2.4 Derivation of Target Displacement

9.3.2.4.1 Introduction

The derivation of the target displacement **shall** utilise the image data at locations centralised around the locations provided by the target selection scheme. For the channels specified for image enhancement the data **shall** be provided by the image enhancement scheme. The derivation of the target displacement **shall** be performed for every obtained pair of consecutive images. It will be based on the derivation of a matching surface derived by matching the selected target within the defined search area in the next image. The matching **shall** be performed by a matching algorithm selected by the parameter *mm*. The following three alternative matching methods **shall** be implemented as a baseline: Cross Correlation (CC) in time domain, Sum of Squared Distances (SSD) and Cross Correlation in the Fourier domain (CCF). Only one method will be used operationally as specified by *mm*. It **shall** be possible to introduce additional matching methods.

The parameter *mm* can be used to specify separate tracking techniques for cloud and clear sky targets. The set-up parameter options are:

1. cross-correlation spatial (CC) for all targets;
2. cross-correlation Fourier (CCF) for all targets;
3. Euclidean distance (SSD) for all targets;
4. CC for cloud and SSD for clear sky;
5. CCF for cloud and SSD for clear sky.

The nominal value is 2 for non-WV channels and 5 for WV channels.

9.3.2.4.2 Perform Matching

The matching process is the core of the AMV task. This is both from a mathematical point of view, because it is the basic scheme retained for the measurement of the tracers displacement, and also from a computational load point of view – it represents probably the most time-consuming operation of all the meteorological products. For these reasons, a detailed mathematical definition is presented here, followed by three alternative suggestions for implementing this operation.

a) Cross Correlation in the time domain

The correlation used for AMV extraction **shall** be based on the classical formula defining the correlation coefficient CC between two random variables T and S:

$$CC = \frac{E\{(T - \overline{T}) \bullet (S - \overline{S})\}}{\sigma_T \bullet \sigma_S} = \frac{E\{T \bullet S\} - E\{T\} \bullet E\{S\}}{\sigma_T \bullet \sigma_S} \qquad \textit{Equation 17}$$

Assuming a square target size with a side length of N_T, the total number of pixels used to compute one correlation value is $N = N_T^2$. If we identify the pixels within the target area with (i,j) and the target location within the search area with (n,m), such that the target is always fully contained within the search area, then $T_{i,j}$ and $S_{n+i,m+j}$ **shall** uniquely define pixel count values within the target and search areas. The expression for the CC **shall** then be expanded by:

$$E\{T\} = \overline{T} = \frac{1}{N_T^2} \bullet \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} T_{i,j}$$ *Equation 18*

$$E\{S\}_{n,m} = \overline{S}_{n,m} = \frac{1}{N_T^2} \cdot \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} S_{n+i,m+j}$$ *Equation 19*

$$E\{T \bullet S\}_{n,m} = \frac{1}{N_T^2} \bullet \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} T_{i,j} \bullet S_{n+i,m+j}$$ *Equation 20*

$$\sigma_T = \sqrt{\frac{1}{N_T^2} \cdot \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} (T_{i,j} - \overline{T})^2}$$

$$\sigma_{S\,n,m} = \sqrt{\frac{1}{N_T^2} \cdot \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} (S_{n+i,m+j} - \overline{S}_{n,m})^2}$$ *Equation 21*

In order to improve the correlation quality, two actions **shall** be foreseen: first the enhancement of the target area and the search area pixels. The second improvement is the introduction of masked pixels both in the target and the search areas (see image enhancement). Masking a pixel means that this pixel **shall** be completely ignored by the correlation, i.e. it doesn't contribute to any of the above terms. As both the target area and the search area contain masked pixels, only the pixels which are simultaneously not masked in both areas **shall** contribute to the correlation. Therefore N_T^2 has to be replaced by N, which is the total number of pixels contributing to the correlation.

b) The Fast Fourier Transform implementation

Implementing convolutions or correlations in the frequency domain using Fast Fourier Transform (FFT) is a classical solution for reducing the computational load. The larger the arrays having to be correlated, filtered or convolved, the more efficiently these can be implemented. The problem in the present case resides in the space variability of the correlated arrays, due to the masked pixels. This implies an extra analysis of the problem in order to get a fast solution.

First, when considering the set of formulae defined in a), the following correlation products (marked *), appear, where MT and MS are the masking functions:

$$E\{T \bullet S\}_{n,m} = \frac{[\,(MT \bullet T) * (MS \bullet S)\,]_{n,m}}{H_{n,m}}$$ *Equation 22*

$$E\{T\}_{n,m} = \overline{T}_{n,m} = \frac{[\,(MS) * (MT \cdot T)\,]_{n,m}}{H_{n,m}}$$ *Equation 23*

$$E\{S\}_{n,m} = \overline{S}_{n,m} = \frac{[\,(MS \bullet S) * (MT)\,]_{n,m}}{H_{n,m}}$$ *Equation 24*

$$\sigma_{T\,n,m} = \sqrt{E\{T^2\}_{n,m} - E\{T\}^2_{n,m}}$$ *Equation 25*

$$= \sqrt{\frac{[(MT \cdot T^2) * (MS)]_{n,m}}{H_{n,m}} - \frac{[(MT \cdot T) * (MS)]^2_{n,m}}{H^2_{n,m}}}$$ *Equation 26*

$$\sigma_{S\,n,m} = \sqrt{E\{S^2\}_{n,m} - E\{S\}^2_{n,m}}$$ *Equation 27*

$$= \sqrt{\frac{[(MS \cdot S^2) * (MT)]_{n,m}}{H_{n,m}} - \frac{[(MS \cdot S) * (MT)]^2_{n,m}}{H_{n,m}}}$$ *Equation 28*

$$\text{and:} \quad H_{n,m} = [\,MS * MT\,]_{n,m}$$ *Equation 29*

These formulae can be completely rewritten using the partial convolutions H, A, B, C, D, E defined as follows:

$$\begin{aligned} H &= MT * MS \\ A &= MT \bullet T * MS \\ B &= MS \bullet S * MT \\ C &= MS \bullet S * MT \bullet T \\ D &= MT \bullet T^2 * MS \\ E &= MS \bullet S^2 * MT \end{aligned}$$ *Equation 30*

The correlation surface CC can then be expressed as a function of these arrays:

$$CC = \frac{C - A \bullet B / H}{\sqrt{\left(D - A^2/H\right) \bullet \left(E - B^2/H\right)}}$$ *Equation 31*

The correlation surface **shall** be defined as a scalar combination of the elements of the six partial correlations H, A, B, C, D and E. An algorithm implementing these partial convolutions in the frequency domain **shall** perform the following steps:

1. Generate and format the six basic arrays: MS, MT, MS.S, MT.T, MS.S^2 and MT.T^2.
2. Perform six two-dimensional FFTs on these arrays.
3. Perform six array multiplications in the frequency domain, in order to obtain the spectra of H, A, B, C, D and E.
4. Perform six two-dimensional inverse FFTs, the result being the arrays H, A, B, C, D and E.
5. Compute the correlation surface array as a scalar combination of the partial convolution arrays.

This method **shall** deliver all the correlation coefficients in full resolution.

It **shall** be possible to define a low pass filtering function as specified by *FFT_low* to be applied to the correlation coefficients for later improvements.

c) Sum of Squared Distances

The Sum of Squared Distances (SSD) is equivalent to the squared Euclidean distance or norm. Using the same assumptions and definitions as for cross correlation, the normalised SSD can then be expressed by:

$$\overline{SSD}_{n,m} = \frac{1}{N_T^2} \bullet \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} \left(S_{n+i,m+j} - T_{i,j} \right)^2 \qquad \textit{Equation 32}$$

As for CC in the time and Fourier domains, the impact of masking has to be taken into account. In these cases N_T^2 **shall** be replaced by N, which is the total number of pixels contributing to the correlation, and the difference **shall** only be computed when both $S_{n+i,m+i}$ and $T_{i,j}$ are non-zero.

9.3.2.4.3 Derivation of Displacement

The matching surface **shall** be considered as valid, and computed, only for relative positions of target and search areas (nominally 80 × 80 pixels, for HRVIS nominally 96 × 96 pixels) such that the target area is always completely included in the search area. The positions in the output arrays corresponding to invalid cross correlation positions **shall** be set to zero in all the result arrays. The point corresponding to zero relative displacement **shall** be the centre of the output surfaces. The matching surface **shall** be made available for further processing.

The extracted matching surface **shall** be used to derive a sub-grid location of the best fit position. This **shall** be done with a polynomial fit in the vicinity of the best fit location within the matching surface. The fitting **shall** utilise the *n_fit* locations around the maximum for the extraction, where *n_fit* is a set-up parameter. Based on the extracted maximum correlation value (or minimum distance) at a sub-grid accuracy, the measured displacement as a function of pixels **shall** be converted to longitude and latitude positions as defined by the central location of the target in the image pair.

In the second step the distance between the two latitude/longitude locations **shall** be derived and an ‘instantaneous’ wind speed and direction **shall** be computed from these locations.

The latitude/longitude assigned to the intermediate AMV **shall** be the centre of the displaced target area. The displaced target area found from the matching algorithm **shall** be used for the height assignment.

9.3.2.5 Height Assignment

9.3.2.5.1 Introduction

This section describes the retrieval of cloud heights for high, medium and low-level clouds, and the height assignment of clear-sky tracers.

The height assignment **shall** be based on information from the Scenes Analysis (SCE) product (see Section 5), as well as on the Cloud-Top Height (CTH) values derived by the Cloud Analysis (CLA) product. See Section 8. Besides this, a height assignment based on the newly-developed Optimal Cloud Analysis (OCA) product **shall** be provided.

The AMV algorithm **shall** be flexible, allowing for any changes to the underlying height assignment product that is selected. This will accommodate use of the most accurate and best-validated methods in the cloud-height assignment field. All the pixel-based information derived by Scenes Analysis, Cloud Analysis and Optimal Cloud Analysis (OCA) **shall** be made available.

The height assignment **shall** be performed for every target requested by the AMV.

The cross-correlation contribution (CCC) method **shall** be implemented, and **shall** be available for every class of cloudy pixels inside each target, during operations.

The cloud classes and single cloud-free class **shall** be derived as specified in the Image Data Preparation (see section 9.3.2.2).

9.3.2.5.2 Cross-Correlation Contribution (CCC) Method

This CCC method **shall** be applied by default to all cloudy and clear-sky targets.

The degree of matching between pixel counts *a* and *b* between the two images A and B **shall** be given by the following two-dimensional cross-correlation coefficient:

$$CC(m,n) = \frac{1}{M \cdot N} \sum_{i=1}^{M} \sum_{j=1}^{N} \frac{a_{i+m,j+n} - \bar{a}(m,n)}{\sigma_a(m,n)} \cdot \frac{b_{ij} - \bar{b}}{\sigma_b}$$

Equation 33

where (m,n) represents the (lines, elements) displacement of the target box in image B from the initial position in the first image A.

The correlation coefficient $CC(m,n)$ is normalized to values between -1 (mirror structures) and +1 (identical structures). The symbols $\bar{a}$ and σ_a represent the average and the standard deviation of the count value *a* in image A, respectively (correspondingly for *b* in image B).

Values M and N correspond to the box size, nominally 32 × 32 for HRVIS and 24 × 24 for all other channels. According to Büche et al. (2006), the correlation coefficient can also be written as follows:

$$CC(m,n) = \sum_{i,j}^{M,N} CC_{ij}(m,n)$$ *Equation 34*

where the symbol CC_{ij} expresses how much the individual pairs of pixels (i,j) and ($i+m$,$j+n$) contribute to the total correlation coefficient of the pair $a(m,n)$ and b within the target boxes in the two images. Usually, coldest and warmest pixels in the target box contribute the most to $CC(m,n)$. In the case of a clear distinction between cold and warm scenes within the target box, the relative individual pixel contributions, $\mathbf{CC_{ij}}$, present a clear 'C-shaped' distribution, as shown in Figure 10. The distance between the two branches corresponds to the contrast of the structures within the target area. Several pixels have a negative $\mathbf{CC_{ij}}$, which generally corresponds to pixels that have very different radiative properties but the same position within the two target boxes in the image 1 and image 2. Appearance and/or decay of clouds between image 1 and 2 generally induce such negative CC_{ij}. Pixels that contribute the most to $CC(m,n)$ are defined as those that have CC_{ij} greater than the average CC_{ij}, $<CC_{ij}>$, represented by the dashed blue line on Figure 10.

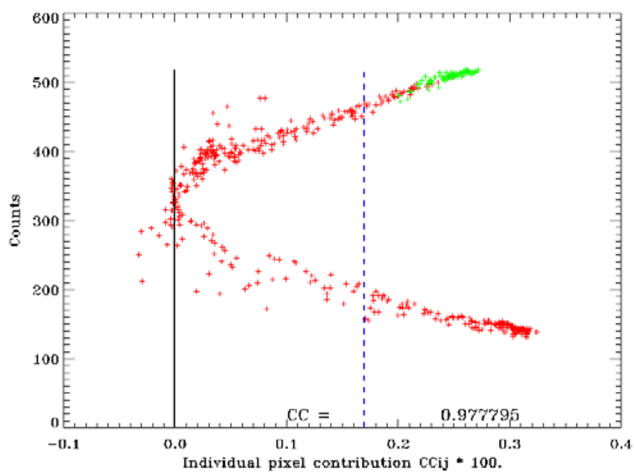

Figure 10: Infrared counts as a function of the individual pixel contribution

9.3.2.5.3 Cloudy Targets in Infrared and Water Vapor Channels

The height assignment of the AMVs **shall** be computed using a cloud height product, which gives an estimation of the cloud-top height for all the cloudy pixels. In the current operational algorithm, the cloud height information provided by the SCE and CLA products **shall** be used.

The AMV pressure P **shall** be calculated as the average cloud-top height (CTH) pressure of the selected pixels, weighted by their individual contribution to the correlation coefficient, CC_{ij}:

$$P = \frac{\sum_{\substack{cold\_branch \\ CC_{ij} > CCij\_thr}} CC_{ij} \cdot CTH_{ij}}{\sum_{\substack{cold\_branch \\ CC_{ij} > CCij\_thr}} CC_{ij}}$$

Equation 35

At first, the value of *CCij_thres* **shall** be dynamically set to the average CC_{ij}, $<CC_{ij}>$, calculated using the pixels present within the target area. If no cold pixels satisfy this condition, then the value of *CCij_thres_def* **shall** be set to 0. When the target area contains very large and homogeneous cloudy layers, it may happen that no cold pixels have a CC_{ij} greater than the average $<CC_{ij}>$. In such case all pixels of the cold branch with a CC_{ij} greater than 0 **shall** be used to calculate the pressure.

For AMVs derived using infrared or water vapour channels, only the pixels of the 'cold branch' of Figure 10 (those with a count value smaller than the average count value within the target area) that have a successful CTH value and a CC_{ij} value greater than *CCij_thres* shall be selected to calculate the pressure.

A weighted pressure standard deviation, σ_P, **shall** be calculated accordingly, and associated to the pressure *P*, using the same set of pixels. This standard deviation gives information on the variability present within the target box, and **shall** be given in hPa. The pressure standard deviation **shall** be given by the following:

$$\sigma_P = \sqrt{\frac{\sum_{\substack{cold\_branch \\ CC_{ij} > CCij\_thr}} CC_{ij} \cdot (CTH_{ij})^2}{\sum_{\substack{cold\_branch \\ CC_{ij} > CCij\_thr}} CC_{ij}} - P^2}$$

Equation 36

9.3.2.5.4 Cloudy Targets in Visible Channels

As for the infrared channels, the cross-correlation contribution process uses the contrast of the pixels present within the target box, and the same kind of plot as that in Figure 11: Height Assignment in Clear-sky areas can be produced considering the visible radiance as a function of the individual pixel contribution.

In the visible part of the spectrum the scattering of photons on cloud particles dominates the radiative transfer processes. Therefore the cloud tops which correspond to pixels having the smallest radiance in the IR or WV channels correspond now to the pixels which have the largest reflectance in the visible channels.

For AMVs derived using visible channels, only the pixels of the 'warm branch' of Figure 11.
(i.e. those with a count value larger than the average count value within the target area) that have a successful CTH value and a CC_{ij} value greater than *CCij_thres* **shall** be selected to calculate the pressure.

The pressure **shall** then be computed as follows:

$$P = \frac{\sum\limits_{\substack{warm\_branch \\ CC_{ij} > CCij\_thr}} CC_{ij} \cdot CTH_{ij}}{\sum\limits_{\substack{warm\_branch \\ CC_{ij} > CCij\_thr}} CC_{ij}}$$

Equation 37

A pressure standard deviation **shall** be computed for the visible channels in a similar way to that described in section 9.3.2.5.3 for the IR and WV channels:

$$\sigma_P = \sqrt{\frac{\sum\limits_{\substack{warm\_branch \\ CC_{ij} > CCij\_thr}} CC_{ij} \cdot (CTH_{ij})^2}{\sum\limits_{\substack{warm\_branch \\ CC_{ij} > CCij\_thr}} CC_{ij}} - P^2}$$

Equation 38

9.3.2.5.5 OCA Height for Cloudy Targets in Infrared, Water Vapour and Visible Channels

As mentioned in 9.3.2.5.1, a height assignment based on the cloud height information provided by the OCA product **shall** be provided. The process **shall** be identical to that described in 9.3.2.5.3, replacing the CLA cloud-top height (CTH) pressure by that from the OCA product.

9.3.2.5.6 Analysis of Results and Derivation of Final Cloud Height

9.3.2.5.6.1 Analysis of the Results

The output from each retrieval technique **shall** consist of:

1. Method_Applied and Method_Success flags.
2. For each of the classes of cloudy pixels with successful results:

   For each estimate:

   - The derived cloud-top pressure
   - Confidence provided by the statistical analysis
   - Cloud-top pressure standard deviation
   - Fraction of pixels associated with the cloud-top estimate
   - Mean cloud-top temperature
   - Cloud-top temperature standard deviation

To evaluate the final results of the CCC method with the forecast profile, the cloud-top mean pressure of every class of estimates **shall** be compared with the atmospheric pressure at the top of every layer whose relative humidity exceeds a critical value *rh_crit*. If there is such a layer in the range of one RMS of the estimated cloud-top mean pressure, then the following parameters **shall** be calculated:

(1) Absolute value of the following ratio: difference between the estimated cloud-top mean pressure and the forecast pressure at the top of that atmospheric layer of high humidity, divided by the forecast pressure at the top of the layer.

(2) Ratio between the root mean square (RMS) of the respective class of estimates of the cloud-top pressure and the thickness of that same atmospheric layer of high humidity.

The evaluation of the final results, as described above by splitting the results into two groups, at present has no direct impact on the wind information written out to the products. Its usefulness will be reviewed as a Future Enhancement.

9.3.2.5.6.2 Derivation of the Final Cloud Height

The final cloud height **shall** be that corresponding to the CCC method. The values for pressure standard deviation, temperature and temperature standard deviation **shall** be those corresponding to the CCC method.

9.3.2.5.7 Inversion Height Assignment

The inversion height assignment algorithm **shall** be applied to infrared and visible channel targets only. For the WV channels a different approach **shall** be used (see 9.3.3.1.7).

For all targets with a final pressure, *fin_pres*, bigger than *inv_height_thres* (nominally 600 hPa) the inversion height assignment **shall** be performed. The inversion height assignment **shall**:

1. Find the temperature *T-bottom* (and corresponding pressure *P-bottom*) at the bottom of the inversion layer. The bottom of the inversion layer is defined as the lowest level (index j) at which T(j) < T(j+1). The search for *T-bottom* will fail if *P-bottom* is not between *inv_height_thres* and the surface pressure + *inv_surface_offset* (this parameter has a nominal value of 40 hPa). In that case quit the inversion height assignment, without changing *fin_pres*.
2. Find the temperature *T-top* (and corresponding pressure *P-top*) at the top of the inversion layer. The top of the inversion layer is defined as the lowest level (index j) above the bottom of the inversion layer at which T(j) > T(j+1). The search for *T-top* will fail if *P-top* is smaller than *inv_height_thres*. In that case quit the inversion height assignment, without changing *fin_pres*.
3. If (*T-top* - *T-bottom*) > *inv_magnitude_thres* (nominally 0 K) then

   inv_pres = (*inv_c1* * *P-bottom* + *inv_c2* * *P-top*) / (*inv_c1* + *inv_c2*) + *inv_c3*

   where nominally *inv_c1* = 1, *inv_c2* = 0 and *inv_c3* = 0. Otherwise, quit the inversion height assignment, without changing *fin_pres*.
4. If *inv_pres* > *fin_pres* then define *inv_pres* as height of the AMV.

9.3.2.5.8 Cloud Base Height Assignment

The cloud-base height assignment **shall** not be applied within the AMV algorithm as of this release.

9.3.2.5.9 Window Channel IR EBBT Method Based on CCC Pixels

The window channel IR EBBT method **shall** be applied to all representative radiance cloud classes, based only on those pixels used by the Cross-Correlation Contribution (CCC) method. Nominally, for non-WV channels the $R^{Cd}_{IR10.8}$ **shall** be converted into the respective EBBTs. For WV channels the R^{Cd}_{WV} **shall** be converted.

The associated pressure P_c **shall** be derived from the atmospheric profile data. The uncertainty σ_{pc} (and the corresponding σ_t) in the height assignment **shall** be defined by the following:

$$\sigma_{pc} = \sqrt{(P_c - P_{\sigma-})^2 + (P_c - P_{\sigma+})^2}$$ *Equation 39*

where $P_{\sigma-}$ and $P_{\sigma+}$ are the pressure associated with ($R^{Cd}_x + \sigma^{Cd}_x$) and ($R^{Cd}_x - \sigma^{Cd}_x$) respectively.

9.3.2.5.9.1 Low-level Cloudy Water Vapour Winds

It may happen that a pressure is found at low levels associated to an AMV extracted from the water vapour 6.3 µm or 7.3 µm channels. Such cases are not realistic because only the high and mid levels of the troposphere can be seen using the water vapour channels. These cases correspond to targets that have been identified as cloudy because low-level clouds are present in the target boxes, but the AMVs correspond to the motion of water vapour features located at higher levels in the troposphere, above the low clouds. So, if an AMV is extracted from a water vapour channel and its pressure is larger than a given threshold, then the EBBT pressure based on CCC using all pixels (not only cloudy) **shall** be used (see 9.3.2.5.11.2). The following prescribed thresholds **shall** be used for WV cloudy AMVs: 450 hPa for the 6.2 µm channel, and 650 hPa for the 7.3 µm channel.

9.3.2.5.10 Low-level AMV Correction

Whenever there is a temperature inversion and the EBBT pressure computed is larger than the corrected AMV pressure, then the EBBT pressure based on CCC pixels **shall** be used. This prevents that pixels whose height was inversion-corrected upwards in the atmosphere during the CLA process contribute to the low-level AMV having an artificially too high altitude. Thus, winds associated to clouds below the inversion layer effectively remain below the inversion layer.

9.3.2.5.11 Height Assignment in Clear Sky Areas

9.3.2.5.11.1 Normalized contribution RTM methods

Height assignment for clear sky targets **shall** be carried out only for the WV6.2 and WV7.3 channels. It **shall** use the normalised total contribution (NTC) and the normalised total cumulative contribution (NTCC) tables provided by the RTM for these channels. Three single level heights **shall** be estimated.

The first height, P_{maxNTC}, **shall** be defined as the level at which NTC reaches a maximum (i.e. equals 1). The second height, P_{NTCC_N}, **shall** be defined as the level at which NTCC exceeds the value NTCC_N (nominally 50 %). The difference $\Delta P = (P_{NTCC\_N} - P_M)$ defines the reliability of the single level height and **shall** also be provided as an output.

The representative layer thickness, P_{LT}, is defined by $P_{LT} = P_{NTCC\_LL} - P_{NTCC\_HL}$, where P_{NTCC_LL} and P_{NTCC_HL} are defined as the levels where the NTCC assumes the values NTCC_LL (nominally 10 %) and NTCC_HL (nominally 90 %).

This process is shown graphically in Figure 11.

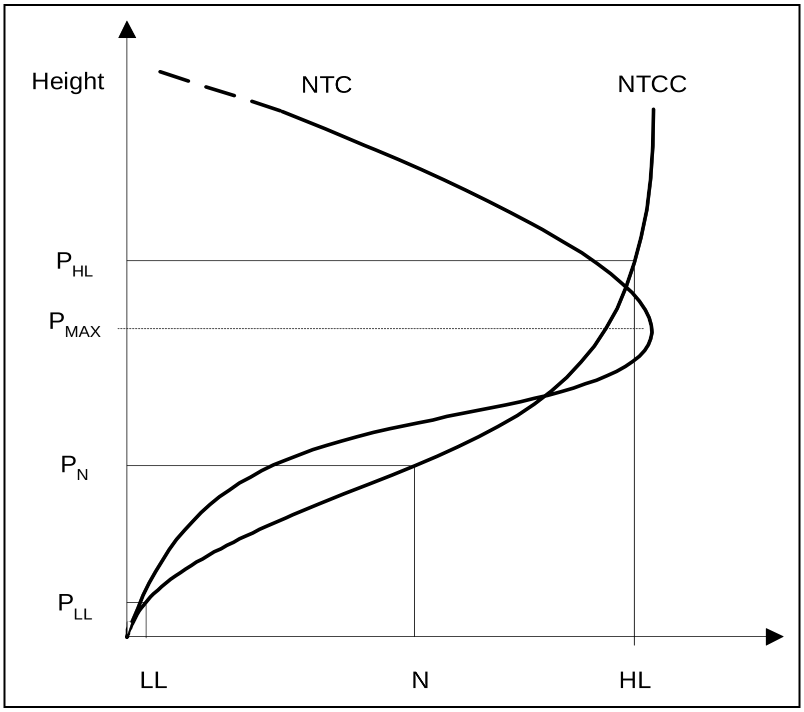

Figure 11: Height Assignment in Clear-sky areas

A third height, $P_{wv,EBBT}$, is derived from the average EBBT of the coldest water vapour pixels in the clear sky cluster. The number of pixels from which the average EBBT is derived is determined by the fraction *frac_cs_ebbt* (nominally 30% of the total cluster size).

All derived heights, i.e. P_{maxNTC}, P_{NTCC_N}, P_{LT}, P_{NTCC_LL} and P_{NTCC_HL} as well as $P_{wv,EBBT}$, **shall** be saved for further processing.

The final height associated with the target **shall** be computed in one of two ways. If *iflag_sequence_ha* = 0, a weighted mean of the three single level heights **shall** be computed, using set-up parameter values for *iflag_ClearSky_MaxNTC, iflag_ClearSky_NTCC_N* and *iflag_ClearSky_EBBT* (nominally all 1). If *iflag_sequence_ha* = 1 (nominal value), the final height **shall** be set to P_{NTCC_N} .

9.3.2.5.11.2 CCC Method Using Water Vapour Brightness Temperature

The EBBT pressure based on CCC (described in 9.3.2.5.9) **shall** be computed for all clear-sky water vapour winds. All pixels within the target box **shall** be considered–not only cloudy pixels.

9.3.2.5.12 Forecast Best-Fit Pressure

A forecast best-fit pressure value **shall** be computed, based on the algorithm used at the Met Office.

First, the forecast speed and direction profiles at the wind location, *FcstWindSpeed* and *FcstWindDirection*, **shall** be extracted. Then, the U and V components of the forecast profile **shall** be computed as follows:

$$FcstWindU_i = FcstWindSpeed_i \cdot \cos(270 - FcstWindDirection_i);$$

$$FcstWindV_i = FcstWindSpeed_i \cdot \sin(270 - FcstWindDirection_i);$$

where *i* represents each forecast level.

The minimum and maximum forecast speeds within a prescribed range of the wind pressure, *PresDiff* (currently set to 150 hPa), **shall** be computed, namely *WindMinSpeed* and *WindMaxSpeed*. Then, the forecast level with the pressure closest to the computed wind pressure, *ClosestLevel*, **shall** be found.

The U and V components of the wind **shall** be computed as follows:

$$WindU = WindSpeed \cdot \cos(270 - WindDirection);$$

$$WindV = WindSpeed \cdot \sin(270 - WindDirection).$$

Then, the vector difference between the wind and the forecast **shall** be computed at all levels:

$$VecDiff_i = \sqrt{(WindU - FcstWindU_i)^2 + (WindV - FcstWindV_i)^2} \quad \text{Equation 40}$$

The best-fit level, *BestFitLevel*, is the forecast level for which the vector difference is minimal. If the best-fit level is the first level in the forecast profile, $P3$ is smaller than *TopPres* (currently set to 100 hPa), or $V2$ equals $V1$ or $V3$, where:

$$P1 = FcstPressure(BestFitLevel-1); \quad V1 = VecDiff(BestFitLevel-1);$$
$$P2 = FcstPressure(BestFitLevel); \quad V2 = VecDiff(BestFitLevel);$$
$$P3 = FcstPressure(BestFitLevel+1); \quad V3 = VecDiff(BestFitLevel+1);$$

then, the best-fit pressure **shall** be set to $P2$. Otherwise, a parabolic fit **shall** be used in order to find the best-fit pressure:

$$BestFitPressure = P2 - 0.5\frac{(P2-P1)^2(V2-V3)-(P2-P3)^2(V2-V1)}{(P2-P1)(V2-V3)-(P2-P3)(V2-V1)} \quad \text{Equation 41}$$

The U and V components of the best-fit level **shall** be computed using a linear interpolation as follows:

$$BestFitU = FcstWindU_{below} \cdot (1 - Prop) + FcstWindU_{above} \cdot Prop;$$
$$BestFitV = FcstWindV_{below} \cdot (1 - Prop) + FcstWindV_{above} \cdot Prop;$$

where:

$$P2 < BestFitPressure \Rightarrow \begin{cases} LevelBelow = BestFitLevel - 1; \\ LevelAbove = BestFitLevel; \\ Prop = (BestFitPressure - P1)/(P2 - P1); \end{cases}$$

$$P2 \geq BestFitPressure \Rightarrow \begin{cases} LevelBelow = BestFitLevel; \\ LevelAbove = BestFitLevel + 1; \\ Prop = (BestFitPressure - P2)/(P3 - P2). \end{cases} \quad \text{Equation 42}$$

$$P2 < BestFitPressure \Rightarrow \begin{cases} LevelBelow = BestFitLevel - 1; \\ LevelAbove = BestFitLevel; \\ Prop = (BestFitPressure - P1)/(P2 - P1); \end{cases}$$

$$P2 \geq BestFitPressure \Rightarrow \begin{cases} LevelBelow = BestFitLevel; \\ LevelAbove = BestFitLevel + 1; \\ Prop = (BestFitPressure - P2)/(P3 - P2). \end{cases}$$

Equation 43

Finally, the computed best-fit pressure **shall** be used only if *BestFitLevel* is not 0, the minimum vector difference, *MinVecDiff*, is smaller than 4.0 m/s, and the vector difference is larger than *MinVecDiff* + 2 m/s outside of the band *BestFitPressure* ± 100 hPa. Otherwise, the wind **shall** be marked as poorly constrained, and the best-fit pressure value **shall not** be used.

9.3.2.6 Derivation of the Final Vector

The derivation of the final vector **shall** be based on the *N_gen* Intermediate Products, where *N_gen* is nominally three. Vectors originating from the same target **shall** be combined to provide a final vector. The combination **shall** take into account all possible single repeat cycle vectors. It **shall** also take into consideration the impact of possible reduced scan configurations. The total number of vectors used to derive the final vector **shall** be transferred to the follow-on processes.

There are two alternative methods available for computing the final vector. These are selected by the set-up parameter *iflag_sequence_ha* (nominally 1).

- Weighted Mean (*iflag_sequence_ha* = 0)
- Sequential Method (*iflag_sequence_ha* = 1)

For the weighted mean, the combination **shall** be linear, providing an average speed and direction maintained during the specified generation cycle. The location **shall** be the average location of the target location in each cycle used to generate the final vector. The height and temperature **shall** be the arithmetic mean of the coldest scene within the target area. This applies to both cloud and clear-sky targets. Only targets based on at least *min_derivations* **shall** be used.

For the Sequential Method, for each cloud target, an arithmetic mean **shall** be used to calculate the height estimate for the final vector, using the intermediate components associated with the most frequently occurring height assignment method. Prior to the introduction of the CCC method, if, for example, components 1 and 3 were obtained using the EBBT method, and component 2 by the CO_2 method, only components 1 and 3 were used for the final vector. Now, because there is only one height assignment method (i.e. CCC), all components **shall** be used. Any of the component heights which are not within *max_pres_diff* (nominally 50 hPa), *max_dir_diff* (nominally 20°) or *max_speed_diff* (nominally 10 m/s) of at least one of the others **shall** **not** be considered (and both **shall** be ignored if this happens when there are only two components remaining). If the number of components left is less than *min_derivations*, the final vector **shall** **not** be calculated.

For clear-sky targets, an arithmetic mean of the coldest scene within the target area **shall** be computed for the final vector height, as for the weighted mean method.

The temperature, speed, direction and position associated with the final vector **shall** be an arithmetic mean of the components used for calculating the height.

As a temporary solution, the pressure value corresponding to the CCC method **shall** be stored in component 6 of the array of height assignment methods to be written to the AMV BUFR file, as part of the AMV Final Product. Additionally, the pressure plus one standard deviation **shall** be stored in component 8 of the mentioned array as an indication of the height error.

As a temporary solution, the pressure value corresponding to the forecast best-fit **shall** be stored in component 19 of the array of height assignment methods in the AMV Intermediate Product. Besides, it **shall** be stored in component 10 of the array of height assignment methods to be written to the AMV BUFR file, as part of the AMV Final Product.

As a temporary solution, the pressure value corresponding to the use of the OCA cloud-top height **shall** be stored in component 18 of the array of height assignment methods in the AMV Intermediate Product. Besides, it **shall** be stored in component 3 of the array of height assignment methods to be written to the AMV BUFR file, as part of the AMV Final Product. Additionally, the OCA pressure plus one standard deviation **shall** be stored in component 5 of the mentioned array as an indication of the height error.

As a temporary solution, the EBBT pressure based on CCC of WV clear-sky and low-level cloudy AMVs **shall** be stored in component 17 of the array of height assignment methods in the AMV Intermediate Product. Besides, it **shall** be stored in component 9 of the array of height assignment methods to be written to the AMV BUFR file, as part of the AMV Final Product.

9.3.3 Automatic Quality Control (AQC)

The Automatic Quality Control **shall** apply a set of tests to the extracted vectors. Each test **shall** provide a normalised output value such that they can be linearly combined to obtain a final quality estimate of each of the vectors, or be used as a multiplicator on the obtained final quality estimate. This final reliability estimate **shall** form the basis of further evaluation of the vectors and **shall** be disseminated together with the vectors. A selection mechanism **shall** be introduced, which prevents vectors with a quality less than a specified threshold from being disseminated. In the following, some relevant tests are described, but the AQC **shall** provide the flexibility to easily introduce new tests: this is considered a future enhancement.

9.3.3.1 AQC for Intermediate AMV Product

9.3.3.1.1 Forecast Consistency Test

This process **shall** generate the quality mark $M_{forecast}$, which is a measure of the consistency of the forecast AMV.

To do this, the vector difference of the AMV vector and the forecast vector interpolated to the same location and pressure level **shall** be computed.

The computation **shall** be done for all AMV vectors in every intermediate AMV product, according to the following equation:

$$M_{forecast}(i) = 1 - \left(\tanh\left(\frac{|S(x,y) - F(x,y)|}{\max(AQC\_FC\_A \cdot |S(x,y) + F(x,y)| / 2, AQC\_FC\_B) + AQC\_FC\_C} \right) \right)^{AQC\_FC\_D}$$

where AQC_FC_A to AQC_FC_D are set-up parameters included in the static data file.

All interpolated forecast wind directions **shall** be derived by interpolating the u and v components, then calculating the resultant direction.

9.3.3.1.2 Spatial Consistency Check

This process **shall** generate the quality mark M_{SWC} which is a measure of the spatial vector consistency of the AMV.

The process **shall** also generate the quality mark M_{SHC} which is a measure of the spatial height consistency of the AMV.

To calculate the spatial vector consistency, the AMV values **shall** be compared with the AMVs computed at the neighbouring grid points.

The quality mark **shall** be computed against all vectors within the height threshold, *AQC_SC_max_pp*, for which ELL_DIST < 1, where:

$$ELL\_DIST = (X/A)^2 + (Y/B)^2$$

where:

$$A = A1 + WindSpeed \cdot A2;$$
$$B = B1 + WindSpeed \cdot B2;$$
$$X = WindDist \cdot \cos(WindAngle);$$
$$Y = WindDist \cdot \sin(WindAngle);$$

and *WindSpeed* is the reference wind speed. In order to compute the distance between the reference wind and the test wind locations, and the angle of the line containing both locations with respect to the reference wind direction (*WindDist* and *WindAngle*, respectively), the following vectors **shall** be defined first (see Figure 12):

$$VectorC(1) = \cos(WindLat) \cdot \cos(WindLon);$$
$$VectorC(2) = \cos(WindLat) \cdot \sin(WindLon);$$
$$VectorC(3) = \sin(WindLat);$$
$$VectorE(1) = \cos(TestLat) \cdot \cos(TestLon);$$
$$VectorE(2) = \cos(TestLat) \cdot \sin(TestLon);$$
$$VectorE(3) = \sin(TestLat);$$
$$VectorV(1) = -\sin(WindLon);$$
$$VectorV(2) = \cos(WindLon);$$
$$VectorV(3) = 0.0;$$

where: *WindLon* and *WindLat* are the longitude and latitude, respectively, of the reference wind, and *TestLon* and *TestLat* are the longitude and latitude, respectively, of the test wind.

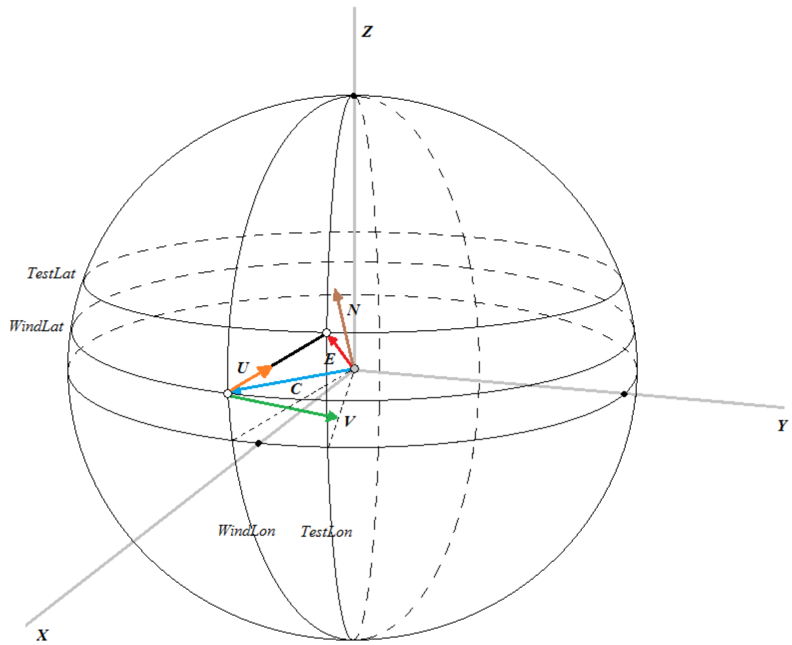

Figure 12: Reference wind and test wind locations with auxiliary vectors (assuming Earth Radius = 1, for clarity).

If the difference in latitude for the reference and test winds is smaller than a given threshold (10^{-6} rad), then the vector from the reference wind location to the test wind location **shall** be:

$$VectorU = \begin{cases} VectorV, & \text{if } TestLon \geq WindLon; \\ -VectorV, & \text{if } TestLon < WindLon. \end{cases}$$ *Equation 42*

Otherwise:

$$VectorU = \frac{VectorN \times VectorC}{|VectorN \times VectorC|};$$ *Equation 43*

where the auxiliary vector *VectorN* is:

$$VectorN = VectorC \times VectorE.$$

Then, the angle formed by *VectorU* with respect to the reference wind direction **shall** be computed as:

$$WindAngle = PsiAngle - WindDir,$$

where *WindDir* is the reference wind direction and $PsiAngle = \text{acos}(VectorU \cdot VectorV)$ is the angle between *VectorU* and the local parallel.

The distance between the reference wind and the test wind locations **shall** finally be computed as the great-circle distance between the two wind locations:

$$WindDist = EarthRadius \cdot \mathrm{acos}(VectorC \cdot VectorE).$$

The individual quality marks **shall** be calculated according to the following equation:

$$M_{SWC_{i,j}} = 1 - \left(\tanh \left(\frac{|S(x,y) - S(x-i, y-j)|}{\max(AQC\_SC\_A \cdot |S(x,y) + S(x-i, y-i)| / 2, AQC\_SC\_B) + AQC\_SC\_C} \right) \right)^{AQC\_SC\_D}$$

where AQC_SC_A to AQC_SC_D are set-up parameters included in the static data file.

If *lc_dist_weight* is false (default value) the final quality mark **shall** be a linear average of the *N_best_lc* (nominally 2) nearest matches.

If *lc_dist_weight* is true the final quality mark **shall** be the distance-weighted average of the *N_best_lc* individual marks:

$$M_{SWC} = \frac{1}{1 / \sum ELL\_DIST} \left(\sum \frac{1}{ELL\_DIST} M_{SWC_{i,j}} \right) \quad \text{Equation 44}$$

If no wind vectors are found the quality mark M_{SWC} **shall** be set to zero.

To calculate the spatial height consistency, the AMV values **shall** be compared with all neighbouring AMV vectors within the height threshold of the current segment, according to the following equation:

$$M_{SHC} = 1 - \left(\tanh \left(\frac{abs(P(x,y) - P(x-i, y-j))_{MIN}}{AQC\_HC\_A \cdot P(x,y) + AQC\_HC\_B} \right) \right)^{AQC\_HC\_C} \quad \text{Equation 45}$$

where AQC_HC_A to AQC_HC_C are set-up parameters included in the static data file.

9.3.3.1.3 Temporal Vector Consistency Test

This process **shall** generate the quality mark M_{TC} which is a measure of the temporal consistency of the AMV.

To calculate M_{TC}, the AMV **shall** be compared with the AMV from the preceding Intermediate AMV Product having the same Target ID.

For new targets within an intermediate AMV, the AMV **shall** be compared with the AMV from the preceding intermediate AMV product within *prev_gen_pp* (nominally 50 hPa) and within the smallest *prev_gen_ell* = $(X/(A\_p))^2 + (Y/(B\_p))^2$

where:

A_p	= A1_p + spd*(A2_p)
B_p	= B1_p + spd*(B2_p)
X, Y	are as for the Spatial Consistency Test, except that d_lat and d_lon are based on the backward propagation of the target into the previous cycle.

If no preceding Intermediate AMV Product is available, the quality mark shall be computed against the Final AMV of the previous AMV Product not older than one hour.

$$M_{TC}(i) = 1 - \left(\tanh\left(\frac{|S(x,y) - S_N(x,y)|}{\max(AQC\_TC\_A \cdot |S(x,y) + S_N(x,y)|/2, AQC\_TC\_B) + AQC\_TC\_C} \right) \right)^{AQC\_TC\_D}$$

where AQC_TC_A to AQC_TC_D are set-up parameters included in the static data file.

9.3.3.1.4 *Temporal Speed Consistency Test*

This process shall generate the quality mark M_{TSC} which is a measure of the speed consistency of the AMV.

To do this, the AMV shall be compared with the AMV from the preceding Intermediate AMV Product in the same way as the Temporal Vector Test above:

$$M_{TSC} = 1 - \left(\tanh\left(\frac{\left||S(x,y)| - |S_N(x,y)|\right|}{\max(AQC\_TSC\_A \cdot (|S(x,y)| + |S_N(x,y)|)/2, AQC\_TSC\_B) + AQC\_TSC\_C} \right) \right)^{AQC\_TSC\_D}$$

where AQC_TSC_A to AQC_TSC_D are set-up parameters included in the static data file.

9.3.3.1.5 *Temporal Direction Consistency Test*

This process shall generate the quality mark M_{TDC} which is a measure of the direction consistency of the AMV.

To do this, the AMV shall be compared with the AMV from the preceding Intermediate AMV Product in the same way as the Temporal Vector Test above:

$$M_{TDC} = 1 - \left(\tanh\left(\frac{|DIR(x,y) - DIR_N(x,y)|}{(AQC\_TDC\_A \cdot e^{-vel/AQC\_TDC\_B}) + AQC\_TDC\_C \cdot vel + AQC\_TDC\_D} \right) \right)^{AQC\_TDC\_E}$$

where AQC_TSC_A to AQC_TSC_D are set-up parameters included in the static data file and

$$vel = \frac{|S(x,y)| + |S_N(x,y)|}{2}$$

Equation 44

9.3.3.1.6 Temporal Pressure Consistency Test

This process **shall** generate the quality mark M_{TPC} which is a measure of the temporal height consistency of the AMV.

To do this, the AMV **shall** be compared with the AMV from the preceding Intermediate AMV Product in the same way as the Temporal Vector Test in 9.3.3.1.3 above:

$$M_{TPC} = 1 - \left(\tanh\left(\frac{\left\| P(x,y) \right| - \left| P_{-1}(x,y) \right\|}{\max(AQC\_TPC\_A \cdot (\left| P(x,y) \right|), AQC\_TPC\_B) + AQC\_TPC\_C} \right) \right)^{AQC\_TPC\_D}$$

where AQC_TPC_A to AQC_TPC_D are set-up parameters included in the static data file.

9.3.3.1.7 Image Correlation Test

This process **shall** generate the quality mark M_{HAC} which is a measure of the correlation cc(ir,wv) between the IR10.8 and WV6.2 channels. The quality mark **shall** be computed as follows:

$$M_{HAC} = \left(\tanh\left(\frac{MAX(AQC\_HA\_A, cc(ir,wv))}{AQC\_HA\_B} \right) \right)^{AQC\_HA\_C} \quad \text{Equation 47}$$

where AQC_HA_A to AQC_HA_C are set-up parameters included in the static data file.

The test is applied to mid-low level cloud winds. If the pressure of the corresponding AMV > AQC_HA_PP, then

$$M_{HAC} = 1 - M_{HAC}$$

else

$$M_{HAC} = 1$$

The above test is also applied to clear sky winds using the above main formula for M_{HAC} and setting

$$M_{HAC} = M_{HAC} - 1$$

For the WV channels, the quality mark **shall** be set to zero in case the pressure is above certain prescribed threshold: 450 hPa for the 6.2 µm channel, and 650 hPa for the 7.3 µm channel.

9.3.3.1.8 Inter-Channel Consistency Check

All winds with pressure greater than *ic_low_pres* (default 600 hPa) and a minimum speed of *ic_min_spd* (default 20 m/s) shall be compared to all winds within *low_ic_check_dist* (nominally 100 km). Against these vectors, if the pressure difference is greater than *ic_pres_diff* (nominally 100 hPa) the following test shall be performed:

$$M_{IC} = \left(\tanh\left(\frac{\left| S(x,y) - S_N(x,y) \right|}{\max\left(AQC\_IC\_A \cdot \left(\left| S(x,y) + S_N(x,y) \right| / 2 \right), AQC\_IC\_B\right) + AQC\_IC\_C} \right) \right)^{AQC\_IC\_D}$$

where AQC_IC_A, AQC_IC_B, AQC_IC_C and AQC_IC_D are set-up parameters.

The final quality of the low-level vectors **shall** be multiplied with this test value. If no suitable collocated clear sky winds are available, the test value returned **shall** be 1.

Note: *The inter-channel consistency check is neither applied nor evaluated in the above form, but will be considered as a Future Enhancement.*

9.3.3.1.9 Final Quality

The Final Quality Value (QI) for AMVs in the Intermediate AMV product **shall** be calculated as a weighted mean of the forecast, four temporal and two spatial consistency tests, multiplied by the image correlation test. The weights **shall** be defined by the set-up parameters AQC_Q_Weights_*. This normalised value **shall** be the final quality indicator which is attached to the AMV. The final quality indicator is always in the range 0 to 1, because of the way in which the individual quality marks have been defined.

9.3.3.2 AQC for the Final AMV Product

Similar consistency tests **shall** be used for the AMV Final Product.

For the ***forecast consistency test***, the vector difference between the AMV final vector and the forecast vector interpolated to the same location and pressure level **shall** be computed, using the same set-up parameters as for the Intermediate Product AQC.

The quality values for the ***spatial consistency tests*** are calculated using the surrounding AMVs in the Final AMV Product itself, using the same set-up parameters as for the Intermediate Product AQC.

For the individual ***temporal consistency tests*** on speed, direction, vector and height, the quality values for the AMVs in the Final AMV Product **shall** be based on the corresponding quality values for the AMVs in the Intermediate AMV Products used to form the Final AMV. The Final value **shall** be calculated as a weighted mean of the contributing Intermediate values. The weights **shall** be defined by the corresponding set-up parameters N_Gen_AQC_Q_Weights_*(1-3), where (1-3) indicates the intermediate AMV product. Values for the first intermediate AMV product are never used in the averaging for the temporal tests.

For the ***image correlation test***, the quality **shall** be calculated in the same way as for the temporal tests above, but the first intermediate AMV product value is now included in the averaging.

The **Final Quality Value (QI)** for AMVs in the Final AMV product is calculated in the same way as described for AMVs in the Intermediate AMV Product above. An additional Final Quality Value which excludes the forecast consistency **shall** also be calculated. This is provided for users requesting a product as independent as possible from the input forecast.

Both quality values **shall** also be modified to reduce the quality of slow winds. If AMV wind speed, wind_spd < *speed_threshold* (nominally 2.5 m/s), then the Final Quality Value is multiplied by the factor, wind_spd/speed_threshold.

9.3.3.2.1 AMV Encoding Filter

An encoding filter is applied to the Final AMV Product to prevent very bad products being sent to users. The filter is tuned in such a way as to prevent dissemination only for extremely bad cases, occurring only a few times a year, in most cases as a result of spacecraft manoeuvres or other image deficiencies. The following values are calculated and checked against a threshold:

- Minimum average vector consistency should be > *qual_vector* (nominally = 50, for channel WV6.2 = 40).
- Minimum average forecast consistency should be > *qual_forecast* (nominally = 30, for channel IR10.8 = 40).
- Minimum proportion of AMVs with QI (exFC) > *qual_qi* (nominally 80%) should be > *qual_proportion* (nominally 20%).
- Minimum number of AMVs with QI (exFC) > *qual_qi* (nominally 80%) should be > *qual_num_good* (nominally = 500, for the VIS channels = 10, and for HRV channel = 20).
- Maximum number of AMVs with pressure < *qual_pressure* (nominally 130 hPa, for the VIS and HRV channels = 10 hPa) should be < *qual_num_high* (nominally = 100, for the VIS and HRV channels = 9999).
- For RSS the parameter *qual_num_good* is nominally set to 100 for channels WV6.2, WV7.3 and IR10.8.

If any of the above tests fails, the number of AMVs passing AQC (per channel) is set to 0 and the AMV channel is not encoded.

9.3.4 Recursive Filter Function AQC Scheme

The AQC scheme described in the previous section has been used as the standard EUMETSAT QI. The Recursive Filter Function (RFF) has been developed as an alternative AQC. It was originally developed at UW–CIMSS (University of Wisconsin - Co-operative Institute for Meteorological Satellite Studies). It is an objective 3D recursive filter analysis of the derived AMVs. The RFF application is described in detail by Hayden et al (1995 and 1996). A three-dimensional background field is created and modified at regular latitude/longitude grid points and pressure levels in several analyses using the AMV wind (velocity component) data and (for the EUMETSAT RFF) the ECMWF forecast field. The background field is smoothed along three dimensions and each grid point/level has a degree of local influence on the smoothing, based on the quality of the analysis at each grid point. The quality of the analysis is essentially composed from a comparison of the AMVs with the background field and is dependent on pre-selected error tolerances. Where the quality analysis is low, for example where the AMV data and background field are significantly different, the local influence is small and information from other grid points is smoothed in. Where the quality analysis is high, smoothing from other grid points is small. Within each analysis, corrections to the background field are built up in several passes with increasingly rigorous quality control, beginning with coarse error tolerances and characteristic spatial scales, which are refined with successive passes. After a number of analyses (using the AMV and forecast field data), a best-fit of each AMV to the modified background field is carried out to provide an adjusted height. A further analysis of the background field is subsequently carried out using the adjusted AMV heights and a final quality indicator is assigned to the AMV based on the quality of neighbouring analysis and the fit of the AMV to the data.

The analysis field has a latitude and longitude grid spacing of *rff_delta_lat* and *rff_delta_lon* (nominally 1 degree) and pressure levels corresponding to those used for the input forecast and RTM data. The forecast field is sampled at nominally every fourth grid point in longitude and every second point in latitude (*rff_pseudo_density_lon* = 4, *rff_pseudo_density_lat* = 2), and (nominally (*rff_stagger* = 1)) staggered in longitude.

There are five main processing steps:

1. Initial Analysis
2. Main Analysis
3. Height Re-adjustment
4. Final Analysis
5. Calculation of Final Quality Flag

9.3.4.1 Initial Analysis

This consists of two analyses of the wind field. It is the effective initialisation of the analysis field as only the forecast data is used. In the first analysis the characteristic spatial scale and error tolerances are independently set to constant values applicable at all heights (respectively *rff_initial_firstpass_radius_influence* = 100 km and *rff_initial_firstpass_tolerance* = 9999.0 m/s).

The vertical coupling (a characteristic scaling of the vertical dimension) is set to *rff_initial_firstpass_vert_coup* (nominally 50 km). There is a single iteration (*rff_initial_firstpass_no_iterations* = 1*)* of the analysis and *rff_initial_firstpass_no_smoothing_passes* (nominally 10) smoothing passes.

In the second analysis there are *rff_initial_secondpass_no_iterations* (nominally 5) iterations, each with *rff_initial_secondpass_no_smoothing_passes* (nominally 3) smoothing passes. The characteristic scale is larger and height dependent (*rff_initial_secondpass_radius_influence* = 600 km at lowest level) and reduces with subsequent iterations (*rff_initial_secondpass_radius_scale_factor* = 18, between initial and final iterations). The vertical coupling is set to *rff_initial_secondpass_vert_coup* (nominally 375 km). The tolerance is as for the first analysis (i.e. very large), however reduces with subsequent iterations.

9.3.4.2 Main Analysis

This is carried out using the AMV wind data and a down-weighted forecast field (*rff_main_fc_weight* = 0.125). The initial error tolerances are based on statistical differences (height dependent) between the AMV observations and the analysis field and constrained to lie between the standard deviation of the difference and a pre-assigned (height dependent) tolerance (*rff_main_tolerance* = 5.0 m/s at lowest level). The error tolerances are necessarily very much lower than in the initial analysis, and are reduced over successive iterations (*rff_main_radius_scale_factor* = 18). The characteristic spatial scale and vertical coupling follows the same pattern as for the previous analysis. The number of iterations and smoothing passes are nominally 5 and 3 (*rff_main_no_iterations, rff_main_no_smoothing*_passes) respectively.

9.3.4.3 Height Re-Adjustment

After the Main Analysis, the AMV re-adjusted height is calculated by minimising a variation penalty function in speed, direction, velocity, pressure, temperature between the AMV wind and the analysis field. The weights assigned to the penalty function are as follows:

- *rff_weight_speed,*
- *rff_weight_dirn,*
- *rff_weight_vel,*
- *rff_weight_pres*
- *rff_weight_temp* (nominally 1000, 1000, 2100 and 10 respectively).

9.3.4.4 Final Analysis

A final analysis is carried out using the AMV wind data with the adjusted AMV heights and the down-weighted forecast data. The same number of iterations and smoothing passes are used as for the main analysis. The error tolerances are calculated as for the main analysis. The characteristic spatial scale is calculated as for the main analysis, but the absolute values are lower:
(*rff_final_radius_influence* = 200 km at lowest level).
The vertical coupling is also reduced to *rff_final_vert_coup* (nominally 125 km).

9.3.4.5 Calculation of Final Quality Flag

On completion of the analysis, the final RFF Quality Indicator is determined by a final pass of the quality analysis with stricter quality control. This means the quality exponent parameter (which controls the fit of the analysis to the data) and tolerance are set to half those of the final analysis (the characteristic spatial scale is left unchanged). The final (unsmoothed) quality value is extracted for each AMV and forecast point, and the quality field at each grid point built up in a single iteration with three smoothing passes. This field is then normalised to the maximum value and interpolated to each AMV observation point. The final RFF quality value is calculated as the square root of the product of this interpolated value and the final (unsmoothed) quality value of the wind.

9.3.5 Monitoring of the Product Quality

The quality of the final product **shall** be continuously monitored. The monitoring **shall** be based on the Final Quality Mark. The data **shall** be sorted into classes according to the Final Quality Mark, and for each group statistics against collocated radiosondes as well as NWP vector fields **shall** be computed. For this purpose certain selected variables **shall** be written into a database located in the facility itself. The selection of these variables is a continuous activity which has to be based on experience.

9.3.5.1 AMV Verification

The satellite-derived AMVs **shall** be compared to independent measurements such as observations by radiosondes and forecast wind profiles. The information collected by the verification **shall** be stored in a database located in the facility itself. This **shall** include all the information described below for the successful collocations and the corresponding AMV vector and quality information. The comparison **shall** take into account all observations or forecast profiles within the MSG processing area. For each AMV only those observations will be considered that are within a distance of 250 km (in horizontal sense) and 50 hPa (in vertical sense) of the AMV position. For radiosonde and forecast profiles the best fit height level **shall** be derived. The best fit level **shall** be specified as the level at which the following function reaches its minimum:

$$BSTFIT = \left(\frac{S(x,y)-F(x,y,p)}{pr\_vec}\right)^2 + \left(\frac{P(x,y)-p}{pr\_pres}\right)^2 + \left(\frac{T(x,y)-T(p)}{pr\_temp}\right)^2$$

Equation 45

where:

S(x,y)	S(x,y) is the AMV vector
F(x,y,p)	is the collocated (e.g. forecast, radiosonde) vector at height p
P(x,y)	is the AMV height
p	is the collocated (e.g. forecast, radiosonde) pressure
T(x,y)	is the AMV temperature
T(p)	is the collocated (e.g. forecast, radiosonde) temperature at height p
	pr_vec, pr_pres and pr_temp are set-up parameters

For forecast data, the BSTFIT value **shall** be calculated at intervals of 5 hPa from the surface to the tropopause. At levels where no forecast data are available a linear interpolation of pressure **shall** be performed. The interpolation **shall** be done in the speed and direction domain where direction **shall** be derived via the u and v components at the nearest levels above and below the missing level. For radiosonde data the BSTFIT value **shall** be calculated only at the observation profile heights.

The following information **shall** be stored for every AMV in the verification database:

- Spacecraft number, date and time for collocation.
- The AMV vector information: band, type, latitude, longitude, speed, direction, height, temperature and layer thickness.
- The collocated forecast information: forecast latitude, forecast longitude, forecast information at first level below AMV and at first level above AMV comprising: forecast speed, forecast direction, forecast pressure and forecast temperature.
- The AMV quality information: final quality mark, forecast quality mark, temporal vector quality mark, temporal speed quality mark, temporal direction quality mark, temporal height quality mark, spatial vector quality mark, spatial height quality mark, inter-channel quality mark, image correlation quality mark.
- The collocated observation information: observation type, observation quality, observation time, station identifier, latitude, longitude, pressure, temperature, speed, direction.
- The derived Best Fit information for the collocated radiosonde and forecast observations, comprising for both: best fit speed, best fit direction, best fit height, and best fit temperature.
- Additional information such as wind method; target type; horizontal, vertical and time separations between AMV and radiosonde; and a flag labelling the nearest observation to every AMV.

9.4 Outputs

The outputs in the following two tables **shall** be produced. Tables include outputs for both intermediate and final AMV product:

9.4.1 Intermediate AMV Product

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Channel identifier	chan_id	-	1	12	1	1	AMV Intermediate Header
Processing Segment Columns	Proc_width	pixels	1	2^{32}-1	1	1	
Processing Segment Rows	Proc_height	pixels	1	2^{32}-1	1	1	
Cloud Target Area Columns	Cloud_t_width	pixels	1	2^{32}-1	1	1	
Cloud Target Area Rows	Cloud_t_height	pixels	1	2^{32}-1	1	1	
Clear sky Target Area Columns	Clear_t_width	pixels	1	2^{32}-1	1	1	
Clear sky Target Area Rows	Clear_t_height	pixels	1	2^{32}-1	1	1	
Cloud Search Area Columns	Cloud_s_width	pixels	1	2^{32}-1	1	1	
Cloud Search Area Rows	Cloud_s_height	pixels	1	2^{32}-1	1	1	
Clear sky Search Area Columns	Clear_s_width	pixels	1	2^{32}-1	1	1	
Clear sky Search Area Rows	Clear_s_height	pixels	1	2^{32}-1	1	1	
No. Vectors in Product	N_vec	-	0	2^{32}-1	1	1	
For each AMV:							AMV Intermediate Body
Target ID	Tgt_Id	°	-	-	-	-	
Latitude	lat	°	-90	90	0.001	0.001	
Longitude	lon	°	-180	180	0.001	0.001	
Vector speed	spd	ms^{-1}	0	500	0.1	0.1	
Direction	dir	°	0	360	0.1	0.1	
Temperature Uncorrected	Temp_uncor	K	170	300	0.1	0.1	
Height Uncorrected	Pres_uncor	hPa	100	1050	50	1	

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Correction Method	Corr_method	-	0	5	-	-	
Temperature	temp	K	170	300	0.1	0.1	
Height	pres	hPa	100	1050	50	1	
Value of best matching	Match_val	-	-1	1	-	-	
Best Match Row Offset	Row_Offset	pixels	1	2^{32}-1	1	1	
Best Match Column Offset	Col_Offset	pixels	1	2^{32}-1	1	1	
Overall reliability	OR	-	0	100	1	1	
Estimated height error	pp_err	hPa	0	200	1	1	
Cloud target	cloud_target	-	0	1	-	-	
Applied image enhancement	tar_enh	-	0	1	-	-	
No. pixels in coldest EBBT class	tar_pix	pixels	0	65532	1	1	
Fraction of land pixels in target area	land_frac	%	0	100	1	1	
Results from each quality test	qc_res	-	0	1	-	-	
Height Assignment Method	HA_mthd	-	1	19	1	1	
For each height assignment method coldest EBBT scene:							
Pressure	tar_press	hPa	0	1100	0.1	0.1	
Pressure standard deviation	tar_press_sigma	hPa	0	1100	0.1	0.1	
Uncorrected temperature	tar_uc_temp	K	170	350	0.01	0.01	
Corrected temperature	tar_temp	K	170	350	0.01	0.01	
Corrected temperature standard deviation	tar_temp_sigma	K	0	350	0.1	0.1	
Confidence of estimate (forecast consistency)	height_rel	-	0	100	0.01	0.01	
Fraction of pixels used	height_pix	%	0	100	0.01	0.01	

Table 32: List of required outputs for the Intermediate AMV Product

9.4.2 Final AMV Product

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Channel identifier	chan_id	-	0	12	1	1	AMV Final Header
Centre Frequency	Frequency	Hz	0	10^{11}	10^3	10^3	
Bandwidth	Frequency	Hz	0	10^{11}	10^3	10^3	
Processing Segment Columns	Proc_width	pixels	1	2^{32}-1	1	1	
Processing Segment Rows	Proc_height	pixels	1	2^{32}-1	1	1	
Segment Size Columns	Seg_width	m	1	2^{32}-1	1	1	
Segment Size Rows	Seg_height	m	1	2^{32}-1	1	1	
Correlation Method	Corr_method	-	0	10	1	1	
No. Vectors in Product	N_vec	-	0	2^{32}-1	1	1	
No. Vectors passing AQC threshold	N_aqc	-	0	2^{32}-1	1	1	
No. cycles	N_cyc	-	1	10	1	1	
For each cycle:	Cyc_time	secs	0	2^{32}-1	1	1	
Product Time	Prod_time	Year, Day, Month, Hour	-	-	-	-	
Start Time	Start_time	Hour, Minute, Sectond	-	-	-	-	
End Time	End_time	Hour, Minute, Second	-	-	-	-	
For each AMV:							AMV Final Body
Latitude	lat	°	-90	90	0.001	0.001	
Longitude	lon	°	-180	180	0.001	0.001	
Vector speed	spd	ms^{-1}	0	500	0.1	0.1	

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Direction	dir	°	0	360	0.1	0.1	
Temperature	temp	K	170	300	0.1	0.1	
Height	pres	hPa	100	1050	50	1	
Overall reliability	OR	-	0	100	1	1	
Overall reliability excluding forecast	OR_ex_fcast	-	0	100	1	1	
Estimated height error	pp_err	hPa	0	100	1	1	
Results from each quality test	qc_res	-	0	1	-	-	
Channel Identifier	chan_id	-	1	12	1	1	
RFF Quality Indicator	RFF	-	0	100	1	1	
Satellite Zenith	Sat_zen	°	0	90	0.1	0.1	
Cloud target	Cloud_target	logical	false	true	-	-	
Height consistency	H_cons	-	0	1	-	-	
Wind method	Wind_mthd	-	1	10	1	1	
Fraction of land pixels in target area	land_frac	%	0	100	1	1	
Land-sea flag	land_sea_flag	-	0	3	1	1	
For each wind intermediate component:							
Direction	dir	°	0	360	0.1	0.1	
Speed	spd	ms^{-1}	0	500	0.1	0.1	
For each Height Assignment method:							
Pressure	pres	hPa	100	1050	50	1	
Pressure SD	pres_sd	hPa	0	100	1	1	
Temperature	temp	K	170	300	0.1	0.1	
Temperature SD	temp_sd	K	0	100	1	1	

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
For each Height Assignment method written to BUFR:							
BUFR Code	BUFR_code	-	0	14	-	-	
Pressure	pres	hPa	100	1050	50	1	
Temperature	temp	K	170	300	0.1	0.1	

Table 33: List of required outputs for the Final AMV Product

Note: As mentioned in Section 9.3.2.6, the pressure value corresponding to the CCC method shall be temporarily stored in component 6 of the array of height assignment methods to be written to the AMV BUFR file. Additionally, the pressure plus one standard deviation shall be stored in component 8 of the mentioned array as an indication of the height error.

Note: As mentioned in Section 9.3.2.6, the pressure value corresponding to the forecast best-fit **shall** be stored in component 19 of the array of height assignment methods in the AMV Intermediate Product. Besides, it **shall** be stored in component 10 of the array of height assignment methods to be written to the AMV BUFR file.

Note: As mentioned in Section 9.3.2.6, the pressure value corresponding to the use of the OCA cloud-top height **shall** be stored in component 18 of the array of height assignment methods in the AMV Intermediate Product. Besides, it **shall** be stored in component 3 of the array of height assignment methods to be written to the AMV BUFR file, as part of the AMV Final Product. Additionally, the OCA pressure plus one standard deviation **shall** be stored in component 5 of the mentioned array as an indication of the height error.

Note: As mentioned in Section 9.3.2.6, the EBBT pressure of WV clear-sky and low-level cloudy AMVs **shall** be stored in component 17 of the array of height assignment methods in the AMV Intermediate Product. Besides, it **shall** be stored in component 9 of the array of height assignment methods to be written to the AMV BUFR file, as part of the AMV Final Product.

9.5 Future Enhancements

The following future enhancements **shall** be foreseen in the design of the algorithm:

- The use of the other channels, e.g. IR8.7 and IR9.7. These channels will be used in a similar fashion to the IR10.8 channel.
- The use of ozone tracers.
- Image enhancement: The incorporation of new channels and new characteristics implies a redefinition of the suitable algorithms. The possibility for new approaches also has to be taken into account. The use of CLA information and the image enhancement of clear sky targets will also be investigated.
- AQC checks: Additional AQC checks may be introduced.

9.6 References

Reference	*Title*	*Date*	*Author(s)*
NOAA Technical Memorandum NESS 78	Satellite derived sea-surface temperatures from NOAA spacecraft	6/76	Brower, Robert L., Gohrband, H.S., Pichel, W.G., Signore, T.L. and Walton, C.C.
Journal of Applied Meteorology, Vol. 32, No. 7	Operational Cloud-Motion Winds from Meteosat Infrared Images	7/93	Schmetz, Johannes, Holmlund, Kenneth et al.
Journal of Applied Meteorology, Vol. 32, No. 9	A comparison of Several Techniques to Assign Heights to Cloud Tracers	9/93	Nieman, Stephen J., Schmetz, Johannes, Menzel, W. Paul
Third International Wind Workshop	Normalised Quality Indicators for EUMETSAT Cloud-Motion Winds	6/96	Holmlund, Kenneth
Journal of Applied Meteorology, Vol 34	Recursive Filter Objective Analysis of Meteorological Fields: Applications to NESDIS Operational Processing	1/95	Hayden, Christopher M., Purser R. James
NOAA Technical Memorandum NESDIS 43	A Primer for Tuning the Automated Quality Control System and for Verifying Satellite-Measured Drift Winds	7/96	Hayden, Christopher M., Nieman, Steven J.

10 CLOUD TOP HEIGHT PRODUCT GENERATION

10.1 Algorithm Configuration Information

10.1.1 Algorithm Name

Cloud Top Height (CTH)

10.1.2 Algorithm Identifier

EUM_MSG_CTH_A001

10.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	H.-J. Lutz	CTH Baseline
1.1	24/6/97	H. K. Wilson	Use of quality flag from intermediate CLA rather than final CLA.
1.2	25/7/05	G.Dew	Revised description of fog indicator.

10.2 Inputs

The following data **shall** be available for the CTH product generation.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Scenes type	scenes_type	-	-	-		-	pixel	Intermediate CLA product
Cloud top height	cloud_top_height	hPa	100	1050	50	1	pixel	Intermediate CLA product
Quality flag	quality_flag	-	0	255	1	1	pixel	Intermediate CLA product
Pressure levels of ICAO standard atmosphere	pressure	hPa	100	1020	1	1	-	Set-up parameters
Height of pressure levels of ICAO standard atmosphere	height	m	0	1800 0	1	1	-	Set-up parameters
Size of the CTH processing segment	ps_size	pixels	0	64	1	1	-	Set-up parameter
Minimum number of pixels	min_pixels	pixels	1	25	1	1	-	Set-up parameter
Coefficients to derive height bands	a1	-	0	10	1	1	-	Set-up parameter
	a2	-	0	1000	50	50	-	Set-up parameter
Maximum % of bad pixels allowed in a CTH processing segment	max_bad	%	0	100	1	1	-	Set-up parameter

Table 34: Data required for production of CTH Product

10.3 Algorithm Functional Specification

10.3.1 Overview

The CTH product is an image-based GRIB Edition 2 encoded product which indicates the height of the highest cloud on a CTH processing segment basis, as defined by *ps_size*. This product is intended for use in aviation meteorology. The following requirements **shall** apply:

- The CTH product **shall** provide the height of the highest cloud for a CTH processing segment with a vertical resolution of 300 metre height bands, hereafter called cth_height_band.
- The CTH product **shall** provide information about fog in the CTH processing segment.

10.3.2 Algorithm Description

10.3.2.1 Product Preparation

For the repeat cycle closest to the required extraction time of the CTH product, the scenes type and cloud_top_height of the pixel-based intermediate CLA product output **shall** be used to derive the CTH product. The data **shall** be grouped into CTH processing segments, which are defined by means of the *ps_size* in the set-up parameters. The CTH processing segments **shall** cover the whole MPEF processing area. All of the following steps **shall** be performed for each of the CTH processing segments.

10.3.2.2 Extraction of the Cloud Top Height

Within each CTH processing segment, the scenes type **shall** be checked. If all pixels are clear, the cth_height_band **shall** be set to a default value (e.g. 0) indicating 'no cth_height_band derived, no clouds in processing segment'. If at least *min_pixels* pixels in the CTH processing segment contain a cloud, the highest cloud **shall** be extracted, i.e. the lowest value of the cloud_top_height (in units of hPa) within the CTH processing segment. This value **shall** then be used to derive the cth_height_band as follows:

- Using the ICAO standard atmosphere (*pressure* and *height*) determine the pressure levels and their corresponding heights for which the cloud_top_height values are greater than (p_n and Z_n) and less than (p_{n+1} and Z_{n+1}). As a Future Enhancement the ICAO standard atmosphere will be replaced by forecast profiles.
- Using these values convert the cloud_top_height to geometrical height as follows:
  $Z_{CTH} = Z_n + ((\ln(\text{cloud\_top\_height}) - \ln(p_n)) \times (Z_{n+1} - Z_n)) / (\ln(p_{n+1}) - \ln(p_n))$
- To derive the final cth_height_band, use the truncated whole number of the following expression: $\text{cth\_height\_band} = a1 + (Z_{CTH} / a2)$

10.3.2.3 Derive the Amount of Fog in the CTH Processing Segment

One method of determining this would be to use the scenes type information to determine fog pixels, then the CTH_quality_flag can be set indicating 'fog/low stratus'. However, the precise method of extracting fog information is a Future Enhancement, and hence the CTH_quality_flag **shall** by default be set to 0 (i.e. no fog).

10.3.3 Automatic Quality Control (AQC)

Use the quality_flag from the intermediate CLA for the cloudy pixels identified within the CTH processing segment, which indicates the quality of the cloud top height for these pixels. If more than *max_bad* percent of the cloudy pixels within the CTH processing segment indicate poor quality for the cloud top height, then the CTH_quality_flag for the segment **shall** be set to 'height poor quality'.

10.4 Outputs

The following data **shall** be produced for each CTH processing segment in the form of a GRIB Edition 2 encoded product, a six-bit image plus two bits of quality information.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Height band of the cloud top height of the highest cloud	cth_height_band	-	0	63	1	1	CTH product
CTH quality flag	CTH_quality_flag	-	0	3	1	1	CTH product

Table 35: Data produced for each CTH Processing Segment

Parameter	*Bit*	*Meaning*
CTH_quality_flag	Bit 0:1	Fog in CTH segment
	Bit 1:1	Poor Quality Height estimation

The CTH image itself has a size that is a multiple of 64, and is given by the equation:
((MPEF_MAX_IMG_WIDTH / CTHSetupParameters%ps_size + 63) / 64)

where:

MPEF_MAX_IMG_WIDTH	= 3712
CTHSetupParameters%ps_size	= 3

This results in an image size of 1280 × 1280 pixels. The image area containing actual information is given by:

MPEF_MAX_IMG_WIDTH/CTHSetupParameters%ps_size = 3712/3 = 1237.3 = 1237

This is rounded down to 1237 × 1237 pixels.

10.5 Prototyping and Testing

No prototype software and test data are available for this product.

10.6 Future Enhancements

The following Future Enhancements **shall** be foreseen in the algorithm design:

- The use of forecast data, pressure, temperature and specific humidity, rather than a standard atmosphere.
- The provision of additional information, e.g. cloud type.
- The provision of height information in more than 6 bits.

10.7 References

None

11 CLEAR SKY RADIANCES PRODUCT GENERATION

11.1 Algorithm Configuration Information

11.1.1 Algorithm Name

Clear Sky Radiances (CSR)

11.1.2 Algorithm Identifier

EUM_MSG_CSR_A001

11.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	H.-J. Lutz	CSR Baseline
1.1	2/7/97	H. K. Wilson	Updated to provide additional inputs for the modified SCE algorithm.
1.2	9/12/97	H. K. Wilson	Requirements Analysis clarification points added.
1.3	02/10/01	H.-J. Lutz	Replaced Quality Flag by Quality Index

11.2 Inputs

11.2.1 Dynamic Application Data

As an input, level 1.5 image data of all channels for every repeat cycle **shall** be available for the CSR processing in the form of radiances, or reflectances and brightness temperatures. Also the CSR product results from the previous repeat cycle and the scenes type information from the Scenes Analysis of the current repeat cycle **shall** be available.

See Table 36 that follows:

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
Scenes type	scenes_type	-	0	255	1	1	pixel	CLA int
Radiances/reflectances/ brightness temperatures from all channels	$RAD_{channel}$ $REFL_{channel}$ $EBBT_{channel}$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ % K	0	-	-	-	pixel	Derived from Level 1.5 image data
CSR from previous repeat cycle	$prev\_CSR_{channel}$	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ % K	0	-	-	-	CSR processing segment	CSR prev
Solar Zenith angle	sol_zenith	degree	0	180	0.01	0.01	pixel	Derived from level 1.5 image header data

Table 36: Dynamic Application Data required for CSR Product

11.2.2 Static Application Data

The following static application data **shall** be required:

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Size of the CSR processing segment	ps_size	pixel	1	64	1	1	-	Set-up parameter
Day/night check threshold	sol_zenith_day	degree	0	180	1	1	-	Set-up parameter
Number of required clear pixels threshold	min_clear_pixel	pixels	0	1024	1	1	-	Set-up parameter
AQC temporal check threshold for channel group	$AQC\_temporal_{group}$	-	-	-	-	-	-	Set-up parameters
AQC SD check threshold for channel group	AQC_SD_{group}	-	-	-	-	-	-	Set-up parameters
Data type for output (EBBT/REFL or radiance)	OutDataType	-	-	-	-	-	-	Set-up parameters
Coefficients A, B, C for quality index cloud fraction (array of 11 each)	AFrac, BFrac, Cfrac	-	-	-	-	-	-	Set-up parameters
Coefficients A, B, C for quality index standard deviation (array of 11 each)	AStd, BStd, CStd	-	-	-	-	-	-	Set-up parameters

Table 37: Static Application Data required for CSR Product

11.3 Algorithm Functional Specification

11.3.1 Overview

The Clear Sky Radiances product (CSR) provides radiances (in $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$), or reflectances (in %) and brightness temperatures (in K), averaged over cloud-free pixels on a processing segment of size as defined by ps_size, for all MSG channels except HRVIS. Within the MPEF the intermediate CSR product which is derived for every repeat cycle is used as an input for the Scenes Analysis for the following repeat cycle and it is used as an input for calibration monitoring. The final CSR product is the intermediate product which was produced from the repeat cycle closest to the required extraction time. It can be used by the end-users to derive several other meteorological products on that scale, i.e. SST, LST, radiation budget components.

The following general requirements **shall** be applied for the CSR product:

- As defined with the switch 'Data type for output' in the set-up data set, the CSR product **shall** provide radiances (in $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$) or reflectances (in %), averaged over all cloud-free pixels on a CSR processing segment basis for the solar channels VIS0.6, VIS0.8 and NIR1.6, and for the infrared channels WV7.3, IR3.9, IR8.7, IR9.7, IR10.8, IR12.0 and IR13.4, and the CSR product **shall** provide radiances (in $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$) or brightness temperatures (in K) on a CSR processing segment averaged over all cloud-free pixels and all pixels covered by a low-level cloud for channel WV6.2.
- The algorithm **shall** be able to derive the CSR product for HRVIS; this is seen as a Future Enhancement. The CSR product for the HRVIS **shall** be able to be derived on two different processing segment scales, one which is collocated with the other solar channels (e.g. nominally 96 × 96 HRVIS pixels) and one with e.g. 32 × 32 HRVIS pixels, to maintain the nominal high resolution differences.

The algorithm is described in detail in the next section. The processing of the algorithm which **shall** be applied to the data from every repeat cycle is as follows:

Step 1	**Image segmentation:** Divide the image data into CSR processing segments.

Step 2	**Extraction of clear pixels within the processing segments:** Use the scenes type information from Cloud Analysis to extract the clear pixels and the pixels with low-level clouds within the processing segment. If the number of clear pixels, hereafter called clear_IR_pixels, is lower than a threshold, *min_clear_pixel*, the following steps will be skipped for all channels, except channel WV6.2. If the number of clear and low-level cloud pixels, hereafter called clear_WV6.2_pixels, is lower than the same threshold (*min_clear_pixel*), then the following steps will also be skipped for channel WV6.2.

Step 3	**Solar zenith angle check:** Use the solar zenith angle to determine whether the clear pixels have day or night conditions. If the number of clear pixels under day conditions, hereafter called clear_VIS_pixels, is smaller than *min_clear_pixel* the following steps will be skipped for the solar channels.

Step 4	**Determination of the CSR:** Determine the CSR for each processing segment by averaging the radiances/brightness temperatures of channel WV6.2 for all clear_WV6.2_pixels and of the other infrared channels for all clear_IR_pixels, and by averaging the radiances/reflectances of the solar channels for all clear_VIS_pixels with day conditions.

Step 5	**Determination of the location of the derived CSR:** Determine the centre of the clear pixels within the processing segment. This defines the location of the derived CSR information, for each CSR processing segment.

11.3.1.1 Algorithm Description

The above listed steps **shall** be performed for each repeat cycle. They are described in detail in the following sections. All static application data used in the algorithm (i.e. static thresholds, parameters) **shall** be configurable.

11.3.1.2 Step 1: Image Segmentation

For each repeat cycle the level 1.5 image data **shall** be divided into CSR processing segments, which are defined by means of ps_size in the set-up parameters, hereafter called CSR processing segment. The CSR processing segments **shall** cover the MPEF processing area. All of the following steps **shall** be performed for each of the CSR processing segments.

11.3.1.3 Step 2: Extraction of Clear Pixels within the CSR Processing Segments

The scenes type provided by the Cloud Analysis **shall** be used to determine how many pixels in the CSR processing segment are clear (clear_IR_pixels) and how many are clear or covered by a low-level cloud (clear_WV6.2_pixels). For all IR channels except WV6.2 the following check **shall** be applied:

If clear_IR_pixels is lower than a threshold (*min_clear_pixel*), a default value **shall** be set for these channels and the quality flag **shall** be set indicating 'no CSR derived for IR channels, insufficient number of clear pixels' and the following steps **shall** be skipped.

For channel WV6.2 the following check **shall** be applied:

If clear_WV6.2_pixels is lower than a threshold (*min_clear_pixel*), a default value **shall** be set for this channel and the quality flag **shall** be set indicating 'no CSR derived for WV channels, insufficient number of clear pixels' and the following steps **shall** be skipped.

The percentage of the clear pixels (or clear and low-level cloud pixels for WV6.2) within the CSR processing segment used to determine the CSR **shall** be calculated.

11.3.1.4 Step 3: Solar Zenith Angle Check

If the number of clear_IR_pixels is greater than *min_clear_pixel*, for all clear pixels within the processing segment, the solar zenith angle data (sol_zenith) **shall** be used to determine whether it was acquired during day or night, i.e. if the sol_zenith is lower than a threshold (*sol_zenith_day*), it is day (clear_VIS_pixels) else it is night. If clear_VIS_pixels is smaller than a threshold (*min_clear_pixel*), then the CSR **shall** **not** be derived for the solar channels. A default value **shall** be set for the CSR product and the quality flag **shall** be set indicating 'no CSR derived for the VIS channels, insufficient number of clear daytime pixels' and the following steps **shall** be skipped for these channels.

The percentage of the clear VIS pixels within the CSR processing segment **shall** be calculated.

11.3.1.5 Step 4: Determination of the CSR

For the infrared channels except channel WV6.2 the CSR **shall** be derived by averaging the radiances or brightness temperatures over all pixels identified as clear_IR_pixels within the CSR processing segment.

For channel WV6.2 the CSR **shall** be derived by averaging the radiances or brightness temperatures over all pixels identified as clear_WV6.2_pixels within the CSR processing segment.

For the solar channels the CSR **shall** be derived by averaging the radiances or reflectances over all pixels identified as clear_VIS_pixels within the CSR processing segment.

The standard deviation of the radiances/reflectances/brightness temperatures of all the clear pixels contributing to the CSR in each processing segment **shall** be calculated for each channel.

11.3.1.6 Step 5: Determination of the Location of the CSR

Because the clear pixels in a processing segment are not uniformly distributed and they may not be representative of the mid-point of a segment, the location of the centre of the used pixels **shall** be derived for each processing segment. This **shall** be performed by calculating the arithmetic mean of the line and element position of all pixels used to derive the CSR and by converting the line and element to latitude and longitude. This latitude and longitude **shall** determine the location of the derived CSR for that processing segment. This location **shall** be determined separately for the solar channels, and channel WV6.2, and the other infrared channels.

The final CSR product for dissemination **shall** be the intermediate CSR product which is extracted from the repeat cycle closest to the required dissemination time.

11.3.2 Automatic Quality Control (AQC)

The automatic quality control (AQC) of the CSR product consists of the Quality Index and an AQC flag providing information about the temporal and spatial consistency of the results. The Quality Index of the CSR product **shall** be determined for each channels as follows:

$QI_{chan} = (QIFrac_{chan} * QIStd_{chan}) / 100.0$

where:

$$QIFrac_{chan} = ((tanh((percentClearPixels**CFrac_{chan}) / BFrac_{chan})) ** AFrac_{chan}) * 100.$$
$$QIStd_{chan} = ((tanh(BStd_{chan} / (StandardDeviation_{chan} ** CStd_{chan}))) ** AStd_{chan}) * 100.$$

In addition to the quality index, the temporal and spatial consistency of the product **shall** be determined as follows:

- The temporal consistency check **shall** compare the CSR results of the current repeat cycle for each processing segment and each of the channels with the results of the previous repeat cycle. If the highest difference for each channel group between the two results exceeds a threshold, $AQC\_Temporal_{group}$, the quality flag **shall** be set indicating 'poor quality, temporal check' for that processing segment and channel group. The thresholds are channel group dependent.

The spatial consistency check **shall** consist of determining whether there are land and water pixels in the same processing segment, using the scenes type. If there are mixed pixels in a segment, the quality flag **shall** be set indicating 'poor quality, spatial check' for that processing.

11.4 Outputs

The following list of output parameters **shall** be generated per CSR processing segment for both the final and the intermediate CSR products.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
$CSR_{channel\_1}$ $CSR_{channel\_2}$ $CSR_{channel\_N}$		$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ … $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0 0 … 0	- - … -	- - … -	- - … -	CSR final & intermediate products
Location of the CSR for the solar channels (lat/lon)	CSR_VIS_lat CSR_VIS_lon	degree degree	-90° -180°	90° 180°	0.1 0.1	0.1 0.1	CSR final & intermediate products
Location of the CSR for channel WV6.2 (lat/lon)	CSR_WV6.2_lat CSR_WV6.2_lon	degree degree	-90° -180°	90° 180°	0.1 0.1	0.1 0.1	CSR final & intermediate products
Location of the CSR for the IR channels (lat/lon)	CSR_IR_lat CSR_IR_lon	degree degree	-90° -180°	90° 180°	0.1 0.1	0.1 0.1	CSR final & intermediate products
Quality flag	CSR_quality_flag	-	-	-	-	-	CSR final & intermediate products
Percentage of clear pixels contributing to the CSR for each segment for each channel	frac_clear	%	0	100	0.1	0.1	CSR final & intermediate products
SD of clear pixels contributing to CSR for each segment for each channel	sd_pixels_{chan}	-	-	-	-	-	CSR final & intermediate products

Table 38: Output parameters per CSR Processing Segment for both final and intermediate CSR products

Parameter	*Value*	*Meaning*
CSR_quality_flag	Bit 0: 1	No CSR derived for VIS channels, insufficient number of clear day pixels
	Bit 1: 1	No CSR derived for WV channels, insufficient number of pixels
	Bit 2: 1	No CSR derived for IR channels, insufficient number of pixels
	Bit 3: 1	AQC Temporal Check failed for VIS channels
	Bit 4: 1	AQC Temporal Check failed for WV channels
	Bit 5: 1	AQC Temporal Check failed for IR channels
	Bit 6: 1	AQC Spatial Check failed
	Bit 7: 1	AQC SD Check failed for VIS channels
	Bit 8: 1	AQC SD Check failed for WV channels
	Bit 9: 1	AQC SD Check failed for IR channels

Table 39: CSR Quality Flags and Bit breakdown

11.5 Prototyping and Testing

No prototyping activities are foreseen for the CSR product.

11.6 Future Enhancements

The following enhancements **shall** be foreseen in the algorithm design:

- Derivation of CSR for HRVIS.

11.7 References

None.

12 ALL SKY RADIANCES PRODUCT GENERATION

12.1 Algorithm Configuration Information

12.1.1 Algorithm Name

All Sky Radiances (ASR)

12.1.2 Algorithm Identifier

EUM_MSG_ASR_A001

12.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	08/04/2008	H-J. Lutz, O. Samain	ASR Baseline

12.2 Inputs

12.2.1 Dynamic Application Data

As an input, level 1.5 image data of all channels for every repeat cycle **shall** be available for the ASR processing in the form of brightness temperatures. Also, the ASR product results from the previous repeat cycle and the scenes type information from the Scenes Analysis of the current repeat cycle **shall** be available.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
Scenes type	scenes_type	-	0	255	1	1	pixel	CLA int
Reflectance, radiances and brightness temperatures from all channels	$EBBT_{channel}$	% $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ or kelvin	0	-	-	-	pixel	Derived from Level 1.5 image data
ASR from previous repeat cycle	$prev\_ASR_{channel}$	% $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ or kelvin	0	-	-	-	ASR processing segment	ASR prev
Solar Zenith angle	sol_zenith	degree	0	180	0.01	0.01	pixel	Derived from Level 1.5 image header data

Table 40: ASR Product: Dynamic Application Data

12.2.2 Static Application Data

The following static application data **shall** be required:

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Size of the ASR processing segment	ps_size	Pixel	1	64	1	1	-	Set-up parameter
Day/night check threshold	sol_zenith_day	Degree	0	180	1	1	-	Set-up parameter
Minimum number of pixels under day conditions	min_day_pixel	%	0	100	1	1	-	Set-up parameter
Minimum number of valid pixels for IR/WV channels for ASR subproduct xy (array of 6)	Min_valid_pixel	%	0	100	1	1	-	Set-up parameters
Minimum number of valid pixels for VIS channels for ASR subproduct xy (array of 6)	Min_valid_VIS_pixel	%	0	100	1	1	-	Set-up parameters
Coefficients A, B, C for quality index cloud fraction (array of 11 times 6 each)	AFrac, BFrac, Cfrac	-	-	-	-	-	-	Set-up parameters
Coefficients A, B, C for quality index standard deviation (array of 11 times 6 each)	AStd, BStd, CStd	-	-	-	-	-	-	Set-up parameters

Table 41: ASR Product Static Application Data required

12.3 Algorithm Functional Specification

12.3.1 Overview

The All Sky Radiances product (ASR) provides brightness temperatures (in K) for the infrared channels, averaged over the following categories:

- **ASR-all** using all pixels within a segment
- **ASR-clear** using all clear pixels within a segment
- **ASR-cloudy** using all cloudy pixels within a segment
- **ASR-low** using all low-level cloud pixels within a segment
- **ASR-mid** using all mid-level cloud pixels within a segment
- **ASR-high** using all high-level cloud pixels within a segment

The intermediate ASR product is derived for every repeat cycle and the final ASR product is the intermediate product which was produced from the repeat cycle closest to the required extraction time. The size of the processing segment is defined by a setup parameter *ps_size*. It can be used by the end-users to derive several other meteorological products on that scale, i.e. SST, LST, radiation budget components.

For the visible channels, the ASR product provides missing values. Radiance or reflectance values **shall** be provided for these channels as a future enhancement.

The algorithm **shall** also be able to derive the ASR product for HRVIS; this is seen as a Future Enhancement. The ASR product for the HRVIS **shall** be able to be derived on two different processing segment scales, one which is collocated with the other solar channels (e.g. nominally 96 × 96 HRVIS pixels) and one with 32 × 32 HRVIS pixels, to maintain the nominal high resolution differences.

The algorithm is described in detail in the next section. The processing of the algorithm which **shall** be applied to the data from every repeat cycle is as follows:

Step 1 Image segmentation
Step 2 Solar zenith angle check
Step 3 Extraction of valid pixels for the ASR sub-products within the processing segments
Step 4 Determination of the ASR
Step 5 Determination of the location of the derived ASR

12.3.1.1 Algorithm Description

The above listed steps **shall** be performed for each repeat cycle. They are described in detail in the following sections. All static application data used in the algorithm (i.e. static thresholds, parameters) **shall** be configurable.

12.3.1.2 Step 1: Image Segmentation

For each repeat cycle the level 1.5 image data **shall** be divided into processing segments, which are defined by means of *ps_size* in the set-up parameters, and which are hereafter called ASR processing segments. The ASR processing segments **shall** cover the MPEF Processing Area. All of the following steps **shall** be performed for each of the ASR processing segments.

12.3.1.3 Step 2: Solar Zenith Angle Check

The solar zenith angle **shall** be used to determine whether the clear pixels have day or night conditions. A pixel is regarded as "under day conditions" if the solar zenith angle is smaller than the threshold *solzen_day*. The number of pixels under day conditions **shall** be given as a percentage of the total number of pixels. If the number of pixels under day conditions is smaller than *min_day_pixel*, the following steps **shall** be skipped for the VIS channels and the ASR product **shall** set a value stating "number of valid pixels under day conditions in the segment smaller than *min_day_pixel*".

12.3.1.4 Step 3: Extraction of valid pixels for ASR sub-products within ASR Processing Segments

The scenes type provided by the Cloud Analysis **shall** be used to extract the valid pixels for the ASR sub-products within the processing segments, as follows:

- All pixels within a segment for sub-product ASR-all
- All clear pixels within a segment for sub-product ASR-clear
- All cloudy pixels within a segment for sub-product ASR-cloudy
- All low-level cloud pixels within a segment for sub-product ASR-low
- All mid-level cloud pixels within a segment for sub-product ASR-mid
- All high-level cloud pixels within a segment for sub-product ASR-high

For each of the sub-products the number of valid pixels, hereafter called valid_pixel_xy (xy stands for the sub-products) is calculated as a percentage (%) of the total number of pixels. In addition to that, the solar zenith angle is used to determine how many valid pixels have day conditions, hereafter called valid_VIS_pixels_xy, which is also given as a percentage of the total number of pixels.

12.3.1.5 Step 4: Determination of the ASR

If the percentage valid_pixels_xy (xy stands for the sub-products) for the IR/WV channel is larger than or equal to the threshold *min_valid_pixel_xy*, the ASR sub_product **shall** be calculated for all IR/WV channels. In addition, if the percentage valid_VIS_pixels_xy is larger than or equal to the threshold *min_valid_VIS_pixels_xy*, the ASR sub-product **shall** be calculated for the VIS channels.

The ASR sub-products are generated for each processing segment per channel using all pixels which are valid for the channel and the sub-product. The following values are determined per segment and channel:

- Mean brightness temperatures
- Standard deviation of the brightness temperatures
- Brightness temperatures maximum value
- Brightness temperatures minimum value

Otherwise, if the percentage valid_pixels_xy for the IR/WV channel is smaller than *min_valid_pixel_xy*, the values of the sub-product is set to a value indicating "percentage of valid pixels in the segment is smaller than *min_valid_pixel_xy* for product xy".

The same is applied to the VIS channels, i.e. if the percentage valid_VIS_pixels_xy is smaller than *min_valid_VIS_pixel_xy*, the value of the sub-product is set to a value indicating "percentage of valid pixels in the segment is smaller than *min_valid_pixel_xy* for product xy".

With the land-sea mask, the percentage of sea pixels within each segment is determined.

12.3.1.6 Step 5: Determination of the location of the derived ASR

The centre of the processing segment **shall** be regarded as the location of the ASR product. The location **shall** be given as latitude and longitude.

The centre of the processing segment **shall** be regarded as the location of the ASR product. The location **shall** be given as latitude and longitude.

12.3.1.7 Automatic Quality Control (AQC)

The automatic quality control (AQC) of the ASR product consists of the Quality Index and an AQC flag providing information about the temporal and spatial consistency of the results. The Quality Index of the ASR product **shall** be determined for each channel and ASR sub-product (*xy*) as follows:

$$QI = (QI_{Frac} \cdot QI_{Std}) / 100$$ *Equation 46*

where:

$$QI_{Frac} = 100 \times \left[TANH\left(Percent\_clear\_pixels^{C_{Frac}} / B_{Frac} \right) \right]^{A_{Frac}}$$ *Equation 47*

$$QI_{Std} = 100 \times \left[TANH\left(\frac{B_{Std}}{Standard\_deviation^{C_{Std}}} \right) \right]^{A_{Std}}$$ *Equation 48*

and where A_{Frac}, B_{Frac}, C_{Frac}, A_{Std}, B_{Std}, C_{Std} are specific for each channel.

12.4 Outputs

The following list of output parameters **shall** be generated per ASR processing segment for both the final and the intermediate ASR products.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
ASR mean values for the 11 channels and 6 sub-products	$ASR_{chan, subproduct}$	% $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ or kelvin	0	-	-	-	ASR final and intermediate products
Standard deviation for the 11 channels and 6 sub-products	$STD_{chan, subproduct}$	% $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ or kelvin	0	-	-	-	ASR final and intermediate products
Centre location of the ASR segment (lat/lon)	ASR_lat ASR_lon	degree degree	-90 -180	90 180	0.1 0.1	0.1 0.1	ASR final and intermediate products
Quality flags	$QI_{chan, sub-product}$ $QIFracv_{chan, subproduct}$ $QIStd_{chan, subproduct}$	- - -	- - -	- - -	- - -	- - -	ASR final and intermediate products
Percentage of clear pixels in the segment	ASR_clear	%	0	100	0.1	0.1	ASR final and intermediate products
Percentage of cloudy pixels in the segment	ASR_cloudy	%	0	100	0.1	0.1	ASR final and intermediate products
Percentage of low-level cloud pixels in the segment	ASR_low	%	0	100	0.1	0.1	ASR final and intermediate products
Percentage of mid-level cloud pixels in the segment	ASR_mid	%	0	100	0.1	0.1	ASR final and intermediate products
Percentage of high-level cloud pixels in the segment	ASR_high	%	0	100	0.1	0.1	ASR final and intermediate products

Table 42: Output parameters per ASR processing segment for both final and intermediate ASR products

12.5 Prototyping and Testing

No prototyping activities are foreseen for the ASR product.

12.6 Future Enhancements

The following enhancements **shall** be foreseen in the algorithm design:

- The derivation of reflectance / radiance values for the visible channels
- The derivation of ASR for HRVIS.

12.7 References

None.

13 CLIMATE DATA SET PRODUCT GENERATION

13.1 Algorithm Configuration Information

13.1.1 Algorithm Name

Climate Data Set (CDS)

13.1.2 Algorithm Identifier

EUM_MSG_CDS_A001

13.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	R. Schraidt	CDS Baseline
1.1	24/6/97	H. K. Wilson	Clarifications added and errors corrected

13.2 Inputs

13.2.1 Dynamic Application Data

See Table 43 on following page:

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Image data (cha_tbp_CDS)	image_i	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	2^{10}-1	1	1	pixel	Derived from level 1.5 data
Scenes Type	scenes_type	-	-	-	-	-	pixel	CLA intermediate
Semi-transparency flag	st_flag	-	-	-	-	-	pixel	CLA intermediate
Effective Cloud Amount	cloud_amount	%	0	100	1	1	pixel	CLA intermediate
Cloud Top Temperature	cloud_top_temp	K	170	300	0.1	0.1	pixel	CLA intermediate
Atmospheric correction tables for channel	atm_corr_j	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	pixel	RTM
Sun zenith angle	sun_zen	degrees	0	180	0.1	0.1	pixel	Derived from level 1.5 data
Spacecraft zenith angle	sat_zen	degrees	0	90	0.01	0.01	pixel	Derived from level 1.5 data
Sun/spacecraft azimuth difference	sunsat_azi	degrees	0	360	0.1	0.1	pixel	Derived from level 1.5 data

Table 43: Climate Data Set: Dynamic Application Data inputs

13.2.2 Static Application Data

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
CDS segment structure	seg_struct_CDS	-	-	-	-	-	-	Set-up
CDS processing area	proc_area_CDS	-	-	-	-	-	-	Set-up
Channels to be processed	cha_tbp_CDS	-	-	-	-	-	-	Set-up
Channels to be corrected	cha_tbc_CDS	-	-	-	-	-	-	Set-up
Scene types	sce_typ	-	-	-	-	-	-	Set-up
Sunglint threshold	sun_glnt_tresh	°	0	90	0.1	0.1	-	Set-up
Minimum cluster size threshold	clust_tresh	pixels	1	1024	-	-	-	Set-up

Table 44: Climate Data Set: Static Application Data inputs

13.3 Algorithm Functional Specification

13.3.1 Overview

This algorithm is responsible for the generation of the Climate Data Set. The product contains results of the image pixel classification process, which is performed by Scenes Analysis and Cloud Analysis, together with calibration tables for the processed image channels, navigation information and sun and spacecraft position angles. As a baseline all spectral channels are to be processed.

The classification process determines which scenes (sea or land surfaces, types of clouds) are likely to have produced the radiation measured by the satellite. This is done on a pixel-by-pixel basis. To reduce the amount of information the processed images are segmented according to the CDS Processing Segment structure (the segments being of synoptic scale, e.g. 32 × 32 pixels) and the pixels of a segment that are classified as belonging to the same scene type are combined into a cluster from which statistical information is derived which is finally put into the CDS product.

13.3.2 Algorithm Description

The following steps **shall** be performed in order to derive the CDS product:

Step 1	Derive CDS processing segment results.

For each CDS processing segment contained in the processing area of the CDS product perform the following processing steps:

A. Remove all pixels of type 'Unknown' from further processing.

B. Using the st_flag separate the pixels of each cloud type into two sub-types, opaque and semi-transparent.

C. For all possible surface types and all possible cloud sub-types calculate the mean and the standard deviation in all the requested channels (*cha_tbp_CDS*) from the uncorrected pixels classified (by Cloud Analysis) with the given scene type and count the number of pixels within the cluster.

D. Remove all clusters with the number of pixels smaller than a threshold (*clust_tresh*) from further processing.

E. For each surface type and for each IR channel requested for correction (*cha_tbc_CDS*), use the cluster pixel mean count to calculate the atmospheric absorption corrected mean count as follows:

1. Derive from the TOA radiance a surface temperature by interpolating the RTM Atmospheric Correction Table.
2. Convert the surface temperature to channel surface radiance by applying the channel-specific Planck function..
3. Convert the channel surface radiance to an atmospheric absorption corrected count value by inverse calibration.
4. Set mean effective cloud amount to 0.

F. For the cloud sub-types, derive from the CLA effective cloud amount the mean effective cloud amount.

G. For each cloud sub-type and for each IR channel requested for correction (*cha_tbc_CDS*), calculate the mean count corrected for atmospheric absorption and potentially corrected for semi-transparency as follows:

1. Calculate the mean cloud_top_temp from the intermediate CLA product.
2. Convert the cloud_top_temp to channel radiance.
3. Convert the IR channel radiance to a corrected count value.

H. Calculate the latitude and the longitude of the centre (in terms of pixels) of the processing segment.

I. Get the zenith angles and the difference of the azimuth angles of the sun and the spacecraft at the centre of the segment for the time when the centre is scanned.

J. Calculate whether the segment centre fulfils the sunglint condition, i.e. might be affected by sunglint. If the following condition is satisfied, the segment may be affected by sunglint:

sun_glnt_tresh > arccos[cos(*sun_zen*) * cos(*sat_zen*) - (sin(*sun_zen*) * sin(*sat_zen*) * cos(*sunsat_azi*))]

K. Store the calculated values, together with the segment row and column numbers and the scene classification identifiers, into the CDS product.

Step 2	For the IR and WV channels used for the CDS product generation, calculate tables that convert the IR pixel counts to temperatures by calibrating each possible pixel count (0, ... , 2^{10}-1) to its channel TOA radiance and transforming the radiance to a temperature by means of the channel-specific Planck function. ***Note:*** Applying the count/temperature conversion tables to uncorrected pixel counts provides EBBTs. Applying them to corrected counts results in surface temperatures (sea, land or cloud top).

Step 3	Construct the CDS product header as described in the reference.

13.3.3 Automatic Quality Control (AQC)

No AQC check is required; the input data are already quality-controlled.

13.4 Outputs

The following data **shall** be output:

Note: The format guide given in Section 13.7 is intended as a reference only, the format information contained within it will need to be modified to incorporate the differences between the MTP and MSG satellites, e.g. increased number of channels, different satellite-specific information.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Count/Temp Conversion Table	C_T_tables	counts, K	-	-	-	-	CDS
Per segment:							
Segment row number	row	-	0	3712	1	1	
Segment column number	column	-	0	3712	1	1	
Latitude of segment centre	lat	°	–90	90	0.1	0.1	
Longitude of segment centre	lon	°	–180	180	0.1	0.1	
Sun zenith angle (segment centre)	sun_zen_c	°	0	180	0.1	0.1	
Spacecraft zenith angle	sc_zen_c	°	0	90	0.1	0.1	
Sun/spacecraft azimuth difference	az_diff	°	0	360	0.1	0.1	
Sunglint indicator	sunglint	-	-	-	-	-	
No. of scene clusters in segment	no_scenes	-	0	64	1	1	
Per scene cluster in segment:							
No. of pixels in cluster	no_pixs	pixels	1	1024	1	1	
Mean effective cloud amount	mean_ec	%	0	100	1	1	
Per channel to be processed:							
Mean pixel count	mean_count	counts	0	-	1	1	
SD of cluster pixel counts	sd_count	counts	0	-	-	-	
Per channel to be corrected:							
Corrected mean pixel count	c_mean_count	counts	0	-	1	1	

Table 45: Climate Data Set: Required outputs parameter definition

13.5 Prototyping and Testing

No prototype software and test data are available for this product.

13.6 Future Enhancements

No Future Enhancements are planned.

13.7 References

Reference	*Title*	*Date*	*Issue*	*Author(s)*
EUM FG 4	The Meteosat Archive, Format Guide No. 4, Climate Data Set (CDS), Open MTP Format	02/96	1.0	

14 HIGH RESOLUTION PI PRODUCT GENERATION

14.1 Algorithm Configuration Information

14.1.1 Algorithm Name

High Resolution Precipitation Index (HPI)

14.1.2 Algorithm Identifier

EUM_MSG_HPI_A001

14.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	R. Schraidt	GPI Baseline
1.1	12/6/97	H. K. Wilson	Specification updated in line with latest GPCP requirements, clarifications added and errors corrected.
1.2	25/7/05	A. Koch	Output table split into two tables with additions.

14.2 Inputs

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Processing area definition as lat/lon boundaries	proc_area_HPI	degree	40	65	1	1	-	Set-up
PI segment structure as equal angle lat/lon areas	seg_struct_HPI	degree	0	1	0.1	0.1	-	Set-up
Number of EBBT histogram classes	no_hist_HPI	-	0	24	1	1	-	Set-up
EBBT histogram class thresholds	T_thresh_HPI	K	180	280	1	1	-	Set-up
Scaling factor	scal_fact	-	10000	10000	1	1	-	Set-up
Backup parameter	backup_HPI	-	0	1	-	-	-	Set-up
IR channel to be processed	cha_tbp_HPI	-	1	12	-	-	-	Set-up
EBBT image data (cha_tbp_HPI)	EBBT_ima	K	180	280	0.1	0.1	pixel	Derived from level 1.5 image data

Table 46: High Resolution Precipitation Index Product Inputs

14.3 Algorithm Functional Specification

14.3.1 Overview

This algorithm is responsible for the generation of the precipitation index data set EUMETSAT have to provide to the Global Precipitation Climatology Project (GPCP).

The distribution of water in the atmosphere, its transport and its diurnal and seasonal change play an important role in the Earth's weather and climate. Precipitation is a meteorological parameter which is important in climatological studies, general circulation studies and for the validation of numerical weather prediction (NWP) models. Because there is rather limited information about the amount and distribution of precipitation in many regions, the use of satellite data can provide the required information.

The precipitation index generation is based on the relationship between the channel TOA radiance equivalent black body temperature (EBBT) of clouds and convective rainfall. The idea of this relationship is that clouds with cold cloud tops are convective rain-bearing clouds. This means that cloudy pixels colder than a configurable threshold temperature are counted because they are assumed to contribute to rainfall. The scheme is a cloud indexing method based on the pixel values of an IR channel.

The default HPI processing area covers a box bounded by ± 40° of latitude and ± 50° of longitude from the SSP. It is segmented into equal angle latitude/longitude areas where the default size of a processing segment is $1^{o} \times 1^{o}$ latitude/longtitude.

Precipitation Index (HPI) values for the different HPI processing segments are currently derived from satellite infrared image data for the synoptic hours (every three hours starting with 03:00 UTC). For MSG, this frequency will remain unaltered. Per run of the HPI Product Generation task an HPI data set is generated. All HPI data sets of a day are put into the Final HPI product providing a temporal and spatial distribution of the precipitation indices of the day. The precipitation indices are based on the black body temperatures (EBBT) being equivalent to the IR pixel counts of a particular IR channel (nominally the IR10.8µm channel). In addition to the precipitation indices, the final HPI product contains also per processing segment the EBBT mean for each individual run (intermediate product)) and the variance of the EBBT means of the individual runs of the day.

The precipitation indices are derived as EBBT class histograms over each processing segment by assigning the pixels of the processing segment to the EBBT classes according to their EBBT value. The number of pixels in the cold EBBT classes are indicative of the likelihood of precipitation.

14.3.2 Algorithm Description

The following steps shall be performed in order to derive the HPI product:

Step 1	At the first run of the HPI product of a day (nominally 03:00 UTC, i.e. the repeat cycle covering 02:45 to 03:00 UTC), initialise the accumulative PI product regardless of whether an image is available for processing or not.

Step 2	At the last run of the HPI product of a day (nominally 00:00 UTC the following day), produce the final HPI product even if no processable image or backup image is available.

Step 3	Process the level 1.5 image data from the processing cycle that matches the requested image recording time. If that image is not available or of bad quality, process a backup image as specified by the backup parameter. The backup parameter specifies the number of images before the nominal extraction time than can be used for backup purposes. The most recently available image should be used. If the backup image is not available or of bad quality, mark in the product header the HPI data set as missing and issue an error message, otherwise mark in the product header the availability of the HPI data set with the time of the used image.

Step 4	Perform HPI product data set generation. For each HPI processing segment contained in the processing area of the HPI product: A. For each pixel in the processing segment increase the histogram count of that EBBT class which corresponds to the pixel's EBBT value. B. Calculate the mean and the variance of the EBBT values of all pixels in the processing segment. C. Divide the number of pixels in each EBBT class by the total number of pixels in the processing segment and multiply the quotient by the scaling factor (*scal_fact*).

Step 5	Generate the final HPI product. After completion of the generation of the last HPI data set of the day and even if the last accumulation was not possible: A. Put all HPI data sets of the day into the Final HPI product.

14.3.3 Automatic Quality Control (AQC)

The header of the HPI product **shall** indicate which intermediate HPI products could not be produced due to missing/bad quality images.

14.4 Outputs

The following data, for intermediate and final products, **shall** be output:

14.4.1 Intermediate Product

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
HPI Header:							HPI Intermediate
Nominal Year of Product	HPI_year	Year	1996	2020	1	1	
Nominal Day of the Year	HPI_day	Day	0	366	1	1	
Nominal Repeat Cycle of Product	HPI__nom_rc	-	1	96	1	1	
For each latitude and longitude:							
For each EBBT histogram class as defined by the set-up parameter:							
HPI count	HPI_count	-	-	-	-	-	

Parameter	Mnemonic	Units	Min	Max	Prec	Acc	To
Mean of the EBBT values	EBBT_mean	K	170	300	0.1	0.1	
SD of the EBBT values	EBBT_SD	K	0	-	-	-	

Table 47: High Resolution Precipitation Index Intermediate Product outputs

14.4.2 Final Product

Parameter	Mnemonic	Units	Min	Max	Prec	Acc	To
HPI Header:							HPI Final
Nominal Year of Product	HPI_year	Year	1996	2020	1	1	
Nominal Day of the Year	HPI_day	Day	0	366	1	1	
Nominal Repeat Cycle of Product	HPI__nom_rc	-	1	96	1	1	
Size of data records	HPI_rec_size	Bytes	0	50000	1	1	
Number of data records (including header)	HPI_rec_no	-	0		1	1	
Number of repeat cycles collected	HPI_rc_used	-	0	96	1	1	
Number of repeat cycles missing	HPI_rc_missing	-	0	96	1	1	
Repeat cycles collected (array of 96 values, detailing which rc were used, nominally 12, 24, 36, 48, 60, 72, 84, 96)	HPI_rc_missing	-	1	96	-	-	
Per intermediate HPI product:							
For each latitude and longitude:							
For each EBBT histogram class defined by set-up parameter:							
HPI count	HPI_count	-	-	-	-	-	
Mean of the EBBT values	EBBT_mean	K	170	300	0.1	0.1	
SD of the EBBT values	EBBT_SD	K	0	-	-	-	

Table 48: High Resolution Precipitation Index Final Product outputs

14.5 Prototyping and Testing

The MTP MPEF HPI software (currently operational) is available as a prototype.

14.6 Future Enhancements

The redefinition of the HPI product in cooperation with the GPCP may be required.

14.7 References

None

15 ISCCP DATA SET PRODUCT GENERATION

15.1 Algorithm Configuration Information

15.1.1 Algorithm Name

ISCCP Data Set (IDS)

15.1.2 Algorithm Identifier

EUM_MSG_IDS_A001

15.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	R. Schraidt	IDS Baseline
1.1	12/6/97	H. K. Wilson	Clarifications added and errors corrected.

15.2 Inputs

See Table 49 on following page.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Source*
Image data (channel i)	ima_dat_i	10 bit counts	0	2^{10}-1	1	1	Level 1.5 Image Data
Image header	ima_head	-	-	-	-	-	Level 1.5 Image Data
Recording time (AC)	rec_tim_AC	UTC	0	23:59	-	-	Schedule
Backup image (AC)	bck_up_AC	-	0	6	1	1	Set-up
Channels to be processed(AC)	cha_tbp_AC	-	1	12	1	1	Set-up
Starting line (channel j; AC)	stt_lin_j_AC	-	1	max_j	1	1	Set-up
Starting pixel (channel j; AC)	stt_pix_j_AC	-	1	max_j	1	1	Set-up
Number of lines (channel j; AC)	no_lin_j_AC	-	1	max_j	1	1	Set-up
Number of pixels (channel j; AC)	no_pix_j_AC	-	1	max_j	1	1	Set-up
Number of pixels averaged (ch j; AC)	pix_avr_j_AC	-	1	-	1	1	Set-up
Averaging method (ch j; AC)	avr_mth_j_AC	-	0= linear	1= RMS	-	-	Set-up
Bits per pixel (ch j; AC)	bit_pix_j_AC	-	8	10	1	1	Set-up
Subsampling factor (ch j; AC)	spl_fac_j_AC	-	1	-	1	1	Set-up
Recording time (B1)	rec_tim_B1	UTC	0	23:59	-	-	Schedule
Backup image (B1)	bck_up_B1	-	0	6	1	1	Set-up
Channels to be processed(B1)	cha_tbp_B1	-	1	12	1	1	Set-up
Starting line (channel j; B1)	stt_lin_j_B1	-	1	max_j	1	1	Set-up
Starting pixel (channel j; B1)	stt_pix_j_B1	-	1	max_j	1	1	Set-up
Number of lines (channel j; B1)	no_lin_j_B1	-	1	max_j	1	1	Set-up
Number of pixels (channel j; B1)	no_pix_j_B1	-	1	max_j	1	1	Set-up
Number of pixels averaged (ch j; B1)	pix_avr_j_B1	-	1	-	1	1	Set-up
Averaging method (ch j; B1)	avr_mth_j_B1	-	0= linear	1= RMS	-	-	Set-up

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Source*
Bits per pixel (ch j; B1)	bit_pix_j_B1	-	8	10	1	1	Set-up
Subsampling factor (ch j; B1)	spl_fac_j_B1	-	1	-	1	1	Set-up
Recording time (B2)	rec_tim_B2	UTC	0	23:59	-	-	Schedule
Backup image (B2)	bck_up_B2	-	0	6	1	1	Set-up
Channels to be processed(B2)	cha_tbp_B2	-	1	12	1	1	Set-up
Starting line (channel j; B2)	stt_lin_j_B2	-	1	max_j	1	1	Set-up
Starting pixel (channel j; B2)	stt_pix_j_B2	-	1	max_j	1	1	Set-up
Number of lines (channel j; B2)	no_lin_j_B2	-	1	max_j	1	1	Set-up
Number of pixels (channel j; B2)	no_pix_j_B2	-	1	max_j	1	1	Set-up
Number of pixels averaged (ch j; B2)	pix_avr_j_B2	-	1	-	1	1	Set-up
Averaging method (ch j; B2)	avr_mth_j_B2	-	0= linear	1= RMS	-	-	Set-up
Bits per pixel (ch j; B2)	bit_pix_j_B2	-	8	10	1	1	Set-up
Subsampling factor (ch j; B2)	spl_fac_j_B2	-	1	-	1	1	Set-up

Table 49: ISCCP Data Set Input:

15.3 Algorithm Functional Specification

15.4 Overview

This algorithm is responsible for the generation of the three data sets (AC, B1 and B2) EUMETSAT has to provide, in its combined role of Meteosat operator and as a Sector Processing Centre (SPC), to the International Satellite Cloud Climatology Project (ISCCP) which is part of the World Climate Research Programme (WCRP) of the World Meteorological Organization (WMO).

The objectives of the Meteosat Sector Processing Centre are as follows:

- To obtain satellite orbital information and calibration data from Meteosat.
- To acquire the full resolution satellite digital data (A-data) from Meteosat in real-time.
- To provide samples of full IR resolution data (the AC-data) for geographical areas of about 2000 km × 2000 km. About 60 samples of these data, with navigation and calibration data appended, are required each year for each satellite, for the purpose of periodically calculating inter-satellite normalisation parameters (BC-data). The inter-calibration calculations are performed at the Satellite Calibration Centre (SCC). The times and the geographical areas of the 60 samples are chosen to produce observations coincident with the overflight of polar orbiters. The coordinates of these samples are supplied by the SCC to each SPC.
- To provide samples of reduced resolution data (the B1-data) for the full FOV disc. These data sets, with navigation and calibration data appended, are to be produced for the synoptic hours (every three hours starting with 00:00 UTC) and are processed at the Global Processing Centre (GPC) and archived at the ISCCP Central Archive (ICA). The reduction of the resolution of the data is achieved by first averaging (linear mean or RMS) the visible channel pixel counts to the resolution of the infrared channel pixel counts and then reducing the IR channel resolution by sub sampling the pixels to a nominal resolution of about 10 km spacing at the sub-satellite point.
- To provide samples of further reduced resolution data (the B2-data) for the full FOV disc. These data sets, with navigation and calibration data appended, are to be produced for the synoptic hours (every three hours starting with 00:00 UTC) and are processed at the Global Processing Centre and archived at the ISCCP Central Archive. The reduction of the resolution of the data is achieved by further sub sampling the pixels of the B1-data to a nominal resolution of about 30 km spacing at the sub-satellite point.

15.4.1 Algorithm Description

The IDS Product Generation has to follow the rules and specifications of the International Satellite Cloud Climatology Project. The algorithm description concentrates therefore mainly on the generic product structure. The detailed product structure <u>shall</u> be as defined in the reference document listed below, e.g. the construction of the data header block. As a baseline all MSG channels <u>shall</u> be used.

The following steps <u>shall</u> be performed in order to derive the IDS AC, B1 or B2 Product:

Step 1	Process the level 1.5 image data from the repeat cycle that matches the requested image recording time. If that image is not available or of bad quality, process the backup image as specified by the backup parameter. The backup parameter specifies the number of images before and after the extraction time than can be used for backup purposes. The most recently available image should be used; if this is not available the next available image (after the current time) should be used. If the backup image(s) is not available or of bad quality, do not produce an IDS product but issue an error message.
Step 2	Construct the Data Block Header.
Step 3	Extract for each channel to be processed the required image pixels as specified by the starting line, starting pixel, number of lines to be processed and pixels per line.
Step 4	Average the VIS channel pixels as specified by the number of pixels to be averaged and the averaging method.
Step 5	Reduce the number of bits per pixels if required.
Step 6	Subsample the IR channel resolution pixels according to the specified sub sampling factor.

15.4.2 Automatic Quality Control (AQC)

The following checks shall be performed.

15.4.2.1 Image Availability Check

If a backup image was used set bit 0 of the IDS_QB to one.

15.4.2.2 Image Quality Check

If the quality bits in the image file header indicate that the IMPF could not produce a high quality image, e.g. due to rectification problems, bit 1 of the IDS_QB shall be set to one.

15.4.2.3 Lost Lines Check

If lines of the area to be processed are not available, bit 2 of the IDS_QB shall be set to one.

15.5 Outputs

The following data **shall** be produced, as defined in the reference document or specified below.

Note: The format guide given in Section 15.8 is intended as a reference only, the format information contained within it will need to be modified to incorporate the differences between the MTP and MSG satellites, e.g. increased number of channels, different satellite-specific information.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
IDS AC Product							IDS AC Product
IDS B1 Product							IDS B1 Product
IDS B2 Product							IDS B2 Product
IDS Quality flag	IDS_quality_flag	-	-	-	-	-	All IDS products

Table 50: ISCCP Data Set Outputs

Parameter	*Value*	*Meaning*
IDS_quality_flag	Bit 0: 0	Requested image used
	Bit 0: 1	Backup image used
	Bit 1: 0	Image quality good
	Bit 1: 1	Image quality not good
	Bit 2: 0	No image lines lost
	Bit 2: 1	Some image lines lost

Table 51: ISCCP Data Set parameter to Bit value

15.6 Prototyping and Testing

No prototype software and test data are available for this product.

15.7 Future Enhancements

The redefinition of the IDS product in co-operation with the ISCCP may be required.

15.8 References

Reference	*Title*	*Date*	*Issue*	*Author(s)*
EUM FG 3	The Meteosat Archive, Format Guide No. 3, ISCCP Data Set (IDS), Open MTP Format	02/96	1.0	

16 TROPOSPHERIC HUMIDITY PRODUCT GENERATION

16.1 Algorithm Configuration Information

16.1.1 Algorithm Name

Tropospheric Humidity (TH)

16.1.2 Algorithm Identifier

EUM_MSG_TH_A001

16.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	M. Gube	TH Baseline
1.1	13/3/98	H. K. Wilson	Peer Group review changes added.
1.2	05/05/08	O. Samain	Several parameter updates or additions (including AR 17598).

16.2 Inputs

16.2.1 Dynamic Application Data

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
EBBT for WV6.2 channel	$EBBT_{WV6.2}$	K	170	300	0.1	0.1	pixel	Derived from level 1.5 image data
EBBT for WV7.3 channel	$EBBT_{WV7.3}$	K	170	300	0.1	0.1	pixel	Derived from level 1.5 image data
Satellite Zenith Angle	Satzen	Degree	0	90	10^{-6}	10^{-6}	pixel	Derived from level 1.5 image data
Predicted EBBT 5% Humidity for WV6.2 channel	$EBBT_{5\_WV6.2}$	K	170	300	0.1	0.1	pixel	RTM
Predicted EBBT 40% Humidity for WV6.2 channel	$EBBT_{40\_WV6.2}$	K	170	300	0.1	0.1	pixel	RTM
Predicted EBBT 5% Humidity for WV7.3 channel	$EBBT_{5\_WV7.3}$	K	170	300	0.1	0.1	pixel	RTM
Predicted EBBT 40% Humidity for WV7.3 channel	$EBBT_{40\_WV7.3}$	K	170	300	0.1	0.1	pixel	RTM
Scenes Type	scenes_type	-	-	-	-	-	pixel	CLA
Radiosonde Observations	rad_obs	-	-	-	-	-	-	Observations

Table 52: Tropospheric Humidity Product: Inputs, dynamic application data

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
EBBT Threshold	EBBT_thresh	K	170	300	1	1	-	Set-up Parameter
TH Upper Threshold	TH_u	%	0	>TH_l	1	1	-	Set-up Parameter
TH Lower Threshold	TH_l	%	0	<TH_u	1	1	-	Set-up Parameter
TH Processing segment size	ps_size	pixels	1	-	1	1	-	Set-up Parameter
TH level threshold 1	TH_level_1	hPa	100	400	50	50	-	Set-up Parameter
TH level threshold 2	TH_level_2	hPa	300	700	50	50	-	Set-up Parameter
TH level threshold 3	TH_level_3	hPa	600	900	50	50	-	Set-up Parameter
Number of valid levels for WV6.2	NLEV6.2	-	1	-	1	1	-	Set-up Parameter
Number of valid levels for WV7.3	NLEV7.3	-	1	-	1	1	-	Set-up Parameter
Level spacing for WV6.2	DP6..2	hPa	1	-	1	1	-	Set-up Parameter
Level spacing for WV7.3	DP7.3	hPa	1	-	1	1	-	Set-up Parameter
Verification area	ver_area	pixels	1	-	1	1		Set-up Parameter
Min Number of pixels for verification	min_ver_pix	pixels	1	-	1	1	-	Set-up Parameter

Table 53: Tropospheric Humidity Product: Inputs, static application data

16.3 Algorithm Functional Specification

16.3.1 Overview

The function of this algorithm is to derive a relative humidity (in %) measure for each of the two water vapour channels on a TH processing segment scale as defined by *ps_size*. The WV6.2 channel will produce an upper tropospheric humidity which is the mean layer relative humidity between *TH_level_1*, nominally 300 hPa, and *TH_level_2*, nominally 600 hPa. The WV7.3 channel will produce a mid-tropospheric humidity which is the mean layer relative humidity between *TH_level_2*, nominally 600 hPa, and *TH_level_3*, nominally 850 hPa. The product is generated for the repeat cycle closest to the required extraction time for the TH product.

The algorithm involves the following steps:

- A relative humidity measure for each of the two water vapour channels is derived on a pixel basis. The algorithm does not use any scenes analysis type of information, i.e. it is applied in identical fashion to cloudy and cloud-free areas. In practice, clouds are identified by the algorithm itself, as it produces unrealistically high (>> 100%) humidities over regions of high or medium high clouds (see Section 16.3.3.1). Also, there might be pixels where the retrieval algorithm produces an unrealistically low (< 0%) humidity which is clearly a failure of the algorithm and could be due to e.g. wrong input data (see Section 16.3.3.2).
- The pixel humidities are used to produce an average measure of humidity, where this average corresponds to a scale of approximately 100 km. As the small scale (pixel) based data are always calculated first, the averaging method can be easily adjusted to consider a different scale. It should already be noted at this point that the average humidity is a 'clear sky' humidity, i.e. is derived for areas which are free of medium-high and high clouds. The algorithm also provides information concerning the number of 'cloudy' pixels within the

considered area, where the term 'cloudy' pixel refers to a pixel where the humidity retrieval algorithm has produced a value of greater than or equal to *TH_u*, nominally 100%. Also the number of pixels where the algorithm has completely failed, i.e. has produced a relative humidity of *TH_l* nominally 0% or less, are provided.

- Finally, the product verification is performed (after the product has been disseminated), comparing the calculated humidities with radiosonde measurements.

16.3.2 Algorithm Description

The following seven steps **shall** be performed in order to derive the relative humidity for each of the two channels. For each pixel:

Step 1	If $EBBT_{WV6.2}$ is less than *EBBT_thresh* then set $TH_{WV6.2}$ to a default value, i.e. *TH_l*, and skip the remaining processing steps for this channel. If $EBBT_{WV7.3}$ is less than *EBBT_thresh* then set $TH_{WV7.3}$ to a default value, i.e. *TH_l*, and skip the remaining processing steps for this channel.

Step 2	Calculate the cosine of the satellite zenith angle: $Q = \cos(satzen)$

Step 3	Calculate XL_5 and XL_{40}, where log is the logarithm in base 10: $XL_5 = \log\left(\frac{5.}{Q}\right)$ $XL_{40} = \log\left(\frac{40.}{Q}\right)$

Step 4	Calculate A and X for each of the WV channels: $A_{wv6.2} = \frac{(EBBT_{40\_WV6.2} - EBBT_{5\_WV6.2})}{(XL_{40} - XL_5)}$ $A_{wv7.3} = \frac{(EBBT_{40\_WV7.3} - EBBT_{5\_WV7.3})}{(XL_{40} - XL_5)}$ $X_{WV6.2} = XL_{40} - \frac{(EBBT_{40\_WV6.2} - EBBT_{WV6.2})}{A_{wv6.2}}$ $X_{WV7.3} = XL_{40} - \frac{(EBBT_{40\_WV7.3} - EBBT_{WV7.3})}{A_{wv7.3}}$

Step 5	Calculate the Tropospheric Humidity for each of the WV channels, $TH_{WV6.2}$ and $TH_{WV7.3}$: $TH_{WV6.2} = Q \times 10^{X_{WV6.2}}$ $TH_{WV7.3} = Q \times 10^{X_{WV7.3}}$

Step 6	Perform the AQC checks specified below.

Step 7	Average the pixel-based TH values for each TH processing segment as follows: • An average clear sky humidity **shall** be computed according to $U(clear\,sky) = \sum U(pixel)^* / N(pixel)^*$ where *U(pixel)** denotes the pixel humidity if this value is above *TH_l* and below *TH_u*; *N(pixel)** denotes the number of pixels which meet this criterion. The summation goes over the *ps_size* by *ps_size* number of pixels. • The percentage of 'cloudy' pixels **shall** be computed according to $Percent\_cloud = 100 \times \frac{\sum(pixels\ with\ THU\_u\ humidity)}{ps\_size^2}$ The summation goes over the *ps_size* by *ps_size* number of pixels. • The number of 'algorithm failure' pixels **shall** be computed according to $N(fail) = \sum(number\ of\ pixels\ with\ THU\_l\ humidity)$ The summation goes over the *ps_size* by *ps_size* number of pixels.

16.3.3 Automatic Quality Control (AQC)

For all the pixel-based values of Tropospheric Humidity which have been calculated, the following checks **shall** be performed.

16.3.3.1 Upper Limit Check

If the value of Tropospheric Humidity for a channel is greater than or equal to *TH_u* then the value of Tropospheric Humidity for that pixel **shall** be set to *TH_u*.

16.3.3.2 Lower Limit Check

If the value of Tropospheric Humidity for a channel is less than or equal to *TH_l* then the value of Tropospheric Humidity for that pixel **shall** be set to *TH_l*.

16.3.3.3 Quality Indicators

For each processed segment, and for the two WV channels, a quality flag is calculated as follows:

$$QCFlag = 100 - Percent\_cloud - 100 \times N(fail) / ps\_size^2 \quad \text{Equation 49}$$

16.3.4 Verification of TH

The satellite-derived humidities $TH_{WV6.2}$ and $TH_{WV7.3}$ **shall** be compared to independent humidity measurements by radiosondes. This **shall** be done separately for the two humidities. The information generated by the verification **shall** be included in the TH product header, and **shall** include all the values of mean radiosonde humidity for the successful radiosonde collocations and the corresponding calculated TH values.

The comparison **shall** take into account all radiosondes within the MSG processing area. However, in order to be actually used for comparison any radiosonde **shall** fulfil the following criteria:

A. For verification of $TH_{WV6.2}$:

1. The radiosonde **shall** be at a distance of less than or equal to *ver_area* pixels from the centre of the corresponding TH segment centre.
2. The radiosonde **shall** have valid humidity measurements in at least a number of *NLEV6.2* layers between *TH_level_1* and *TH_level_2*.
3. The individual measurements within the layer of *TH_level_1* and *TH_level_2* **shall** be evenly spread over that layer. In order to ensure this, individual measurements **shall** lay at least *DP6.2* hPa apart. At least *NLEV6.2* individual measurements **shall** meet this criterion.
4. The radiosonde **shall** be in an area with no high or medium high cloud. For this, a square area **shall** be defined of side *ver_area* pixels, consisting of a fixed number of pixels, with its centre pixel located at the pixel of the radiosonde ground station. From this square area, all pixels which according to the scenes type from Cloud Analysis are determined as free of medium high and high clouds **shall** be selected. The total number of these cloud-free (with respect to medium high and high clouds) pixels **shall** exceed *min_ver_pix*.

If the radiosonde meets all these requirements, it **shall** be considered a valid comparison target for $TH_{WV6.2}$. A mean radiosonde humidity $RTH_{WV6.2}$ **shall** then be computed as the arithmetic mean over all humidity measurements taken between *TH_level_1* and *TH_level_2*.

B. For verification of $TH_{WV7.3}$:

1. The radiosonde **shall** be at a distance of less than or equal to *ver_area* pixels from the centre of the corresponding TH segment centre.
2. The radiosonde **shall** have valid humidity measurements in at least a number of *NLEV7.3* layers between *TH_level_2* and *TH_level_3*.
3. The individual measurements within the layer of *TH_level_2* and *TH_level_3* **shall** be evenly spread over that layer. In order to ensure this, individual measurements **shall** lay at least *DP7.3* hPa apart. At least *NLEV7.3* individual measurements **shall** meet this criterion.
4. The radiosonde **shall** be in a cloud-free area. For this, a square area **shall** be defined of side *ver_area*, consisting of a fixed number of pixels, defined by a set-up parameter, with its centre pixel located at the pixel of the radiosonde ground station. From this square area, all pixels which according to the scenes type from Cloud Analysis are determined as cloud-free **shall** be selected. The total number of these cloud-free pixels **shall** exceed *min_ver_pix*.

If the radiosonde meets all these requirements, it **shall** be considered a valid comparison target for $TH_{WV7.3}$. A mean radiosonde humidity $RTH_{WV7.3}$ **shall** then be computed as the arithmetic mean over all humidity measurements taken between TH_level_2 and TH_level_3.

16.4 Outputs

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Tropospheric Humidity for WV6.2 channel, clear sky	$TH_{WV6.2}$	%	TH_l	TH_u	0.1	0.1	TH product
Tropospheric Humidity for WV7.3 channel, clear sky	$TH_{WV7.3}$	%	TH_l	TH_u	0.1	0.1	TH product
Percentage of 'cloudy' pixels for WV6.2 channel	$Percent\_cloud_{WV6.2}$	%	0	100	0.1	0.1	TH product
Percentage of 'cloudy' pixels for WV7.3 channel	$Percent\_cloud_{WV7.3}$	%	0	100	0.1	0.1	TH product
Number of 'algorithm fail' pixels for WV6.2 channel	$NFAIL_{WV6.2}$	-	0	1024	1	1	TH product
Number of 'algorithm fail' pixels for WV7.3 channel	$NFAIL_{WV7.3}$	-	0	1024	1	1	TH product
TH Segment Centre Latitude	c_lat	°	–90	90	0.01	0.01	TH product
TH Segment Centre Longitude	c_lon	°	–180	180	0.01	0.01	TH product
Quality indicator for channel 6.2	$QCFlag_{WV6.2}$	%	0	100	0.1	0.1	TH product
Quality indicator for channel 7.3	$QCFlag_{WV7.3}$	%	0	100	0.1	0.1	TH product
Verification Results							TH Product Header

Table 54: Tropospheric Humidity Product: outputs

Note: For the BUFR-encoded product, in the case that the percentage of cloud is 100, the Tropospheric Humidity values are set to 'missing'.

16.5 Prototyping and Testing

This section describes the prototyping activities, highlighting the major problems which were encountered with this development.

16.5.1 Prototyping

This algorithm is simple and thus was easy to prototype. The test data used are described below.

16.5.2 Test Data

The following files are required as test data:

Test file wvimage.dat: this is an ASCII file which contains one line (2500 values) of Meteosat-5 WV channel brightness temperatures (in K), in format 10F6.1. These values correspond to $EBBT_{WV}$ in the input table, where the actual channel information (6.2 or 7.3) is omitted as the same formulae apply to either channel.

The following constants were also used:

$EBBT_{5\_WV}$ = 258.8 K

$EBBT_{40\_WV}$ = 240.6 K

SATZEN = 0° (i.e. Q = 1.)

EBBT_thresh = 170.0 K

TH_u = 100 %

TH_l = 0%

16.5.3 Test Results

The test results for the image files described in 16.5.2 are available as uthout.dat. This is an ASCII file which contains the corresponding 2500 humidity values (in per cent, rounded to the next integer), format 19I5.

16.6 Future Enhancements

The use of the intermediate CLA for the generation of the TH is a future enhancement.

16.7 References

None

17 SEA SURFACE TEMPERATURE PRODUCT GENERATION

17.1 Algorithm Configuration Information

17.1.1 Algorithm Name

Sea Surface Temperature (SST)

17.1.2 Algorithm Identifier

EUM_MSG_SST_A001

17.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	H.-J. Lutz	SST Baseline
1.1	12/6/97	H. K. Wilson	TBD resolved, errors corrected.
1.2	13/3/98	H. K. Wilson	Peer Group Review changes added.
1.3	25/7/05	J. Gustafsson	Parameter reset to force use of day formulae at night as well. Added smoothing of pixel values.

17.2 Inputs

17.2.1 Dynamic Application Data

As an input, level 1.5 image data of subset of channels (as listed in the following table) for every repeat cycle **shall** be available for the SST processing in the form of equivalent black body brightness temperatures (EBBT). Also the SST product results from the previous repeat cycle and the scenes type information from the Scenes Analysis of the current repeat cycle **shall** be available.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Scenes type	scenes_type	-	0	255	1	1	pixel	Scenes Analysis
EBBT of channels IR3.9, IR8.7, IR10.8, IR12.0	$EBBT_{channel}$	K	170	350	0.1	0.1	pixel	Derived from Level 1.5 image data
SST from previous repeat cycle	prev_SST	K	260	350	0.1	0.1	pixel	SST product from previous repeat cycle
Solar zenith angle	sol_zenith	degree	0	180	10^{-6}	10^{-6}	pixel	Derived from level 1.5 data
Satellite zenith angle	sat_zenith	degree	0	90	10^{-6}	10^{-6}	pixel	Derived from level 1.5 data

Table 55: Sea Surface Temperature Product inputs

17.2.2 Static Application Data

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*Source*
Day/night check threshold	SZ_day	degrees	0	90	1	1	-	Set-up parameter
AQC temporal check threshold	SST_temporal	kelvin	0	20	1	1	-	Set-up parameter
AQC spatial check threshold	SST_spatial	kelvin	0	20	1	1	-	Set-up parameter
Minimum allowed pixels in segment	M	-	1	1024	1	1	-	Set-up parameter
AQC spatial check area size	n	-	1	32	1	1	-	Set-up parameter
AQC maximum SST threshold	SST_MAX	kelvin	300	350	1	1	-	Set-up parameter
AQC minimum SST threshold	SST_MIN	kelvin	260	280	1	1	-	Set-up parameter
SST Parameters	A_0 - A_n	-	-	-	-	-	-	Set-up parameters
	B_0 - B_n	-	-	-	-	-	-	Set-up parameters
	C_0 - C_n	-	-	-	-	-	-	Set-up parameters
	D_0 - D_n	-	-	-	-	-	-	Set-up parameters

Table 56: Sea Surface Temperature Product: Static Application Data

17.3 Algorithm Functional Specification

17.3.1 Overview

The Sea Surface Temperature product (SST) provides a temperature estimate (in kelvin) for the skin surface of the ocean on a pixel basis. This product will be used for calibration monitoring and product verification purposes.

17.3.2 Algorithm Description

The following steps **shall** be applied for every pixel.

17.3.2.1 Scenes Type Check

The scenes type of every pixel as derived from the Scenes Analysis algorithm **shall** be checked. If the scenes type is not water (ocean) the SST **shall** be set to a default and the SST quality flag **shall** be set indicating 'no SST derived, scenes type is not water (ocean)' and the following steps **shall** be skipped and the processing **shall** start with the next pixel.

17.3.2.2 Solar Zenith Angle Check

If the scenes type is water (ocean) the solar zenith angle **shall** be checked against a threshold. If the solar zenith angle is larger than a threshold (*SZ_day*), then the pixel has night conditions, else it has day conditions.

17.3.2.3 SST Processing

17.3.2.3.1 Day Conditions

For pixels with day conditions the following two formulae **shall** be applied:

$T_{day-1} = A_0 + A_1*T_{IR10.8} + A_2(T_{IR10.8} - T_{IR12.0}) + A_3(T_{IR10.8} - T_{IR12.0})*((1/COS(sat\_zenith))-1)$

$T_{day-2} = B_0 + B_1*T_{IR12.0} + B_2(T_{IR10.8} - T_{IR12.0})*((1/COS(sat\_zenith))-1) +$
$(B_3 + B_4*T_{IR10.8} + B_5*T_{IR12.0}) * (B_6 + B_7*T_{IR12.0}) / (B_8 + B_9*T_{IR10.8} + B_{10}*T_{IR12.0})$

where $T_{IR10.8}$ and $T_{IR12.0}$ are the EBBT in channel IR10.8 and IR12.0

The SST itself **shall** be derived as follows:

$$T_{SST} = C_0 + C_1*T_{day-1} + C_2*T_{day-2}$$

17.3.2.3.2 Night Conditions

For pixels with night conditions the following three formulae are applicable:

$T_{night-1} = A_0 + A_1*T_{IR10.8} + A_2*((1/COS(sat\_zenith))-1) +$
$(A_3 + A_4*T_{IR10.8} + A_5*T_{IR12.0}) * (A_6 + A_7*T_{IR10.8}) / (A_8 + A_9*T_{IR3.9} + A_{10}*T_{IR12.0})$

$T_{night-2} = B_0 + B_1*T_{IR10.8} + B_2*((1/COS(sat\_zenith))-1) +$
$(B_3 + B_4*T_{IR3.9} + B_5*T_{IR10.8}) * (B_6 + B_7*T_{IR10.8}) / (B_8 + B_9*T_{IR3.9} + B_{10}*T_{IR10.8})$

$T_{night-3} = C_0 + C_1*T_{IR12.0} + C_2(T_{IR10.8} - T_{IR12.0})*((1/COS(sat\_zenith))-1) +$
$(C_3 + C_4*T_{IR10.8} + C_5*T_{IR12.0}) * (C_6 + C_7*T_{IR12.0}) / (C_8 + C_9*T_{IR10.8} + C_{10}*T_{IR12.0})$

The SST itself may be derived as follows:

$T_{SST} = D_0 + D_1*T_{night-1} + D_2*T_{night-2} + D_3*T_{night-3}$

Note: The current EUMETSAT set-up does not differentiate between day and night, so the 'day formulae' previously given are used also during hours of darkness.

17.3.2.3.3 Smoothing

To make the radiative noise less apparent when viewing the product, an averaging of the pixel value is applied. Each pixel has its SST value replaced by the local mean value, calculated from the 3 × 3 pixel segment, if the mean is made up of at least *k* values. The impact is that the spatial test (in 17.3.3 below) is disabled, and there is an increased risk of including pixels contaminated by land or cloud.

17.3.3 Automatic Quality Control (AQC)

The automatic quality control (AQC) of the SST product consists of three tests. The SST product shall be quality controlled with a spatial and a temporal consistency check, and with a climatological test.

If an SST is derived for both the pixel of the current repeat cycle and of the previous repeat cycle, then apply the temporal consistency check. This check shall compare the SST result of the current repeat cycle for each pixel with the result of the previous repeat cycle. If the absolute difference between the two values exceeds a threshold, *SST_temporal*, the quality flag shall be set indicating 'poor quality, temporal check' for that pixel.

If in an *n* × *n* pixel segment the SST has been derived for at least *m* pixels, then the spatial consistency check shall be applied. This check shall compare the SST result of each pixel with the averaged SST of the *n* × *n* pixel segment. If the absolute difference between the mean SST and the pixel value exceeds a threshold, *SST_spatial*, the quality flag shall be set indicating 'poor quality, spatial check' for that pixel.

The SST shall also be checked against a minimum climatological temperature threshold (*SST_MIN*) and against a maximum climatological temperature threshold (*SST_MAX*). If the SST is lower than the minimum threshold, the quality flag shall be set indicating 'bad quality, value lower than *SST_MIN*'. If the SST is higher than the maximum threshold, the quality flag shall be set indicating 'bad quality, value higher than *SST_MAX*'.

17.3.4 SST Verification

No SST verification is required.

17.4 Outputs

The following list of output parameters **shall** be generated per pixel.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Res*	*To*
Sea surface temperature	SST	kelvin	270	320	0.1	0.1	pixel	SST Intermediate Product
SST Quality flag	SST_quality_flag	-	-	-	-	-	pixel	SST Intermediate Product

Table 57: Sea Surface Temperature Product: output parameters

Parameter	*Value*	*Meaning*
SST_quality_flag	Bit 0: 1	No SST derived, scenes type not water (ocean)
	Bit 1: 1	AQC Temporal Check poor quality
	Bit 2: 1	AQC Spatial Check poor quality
	Bit 3: 1	SST Bad Quality - less than SST_MIN
	Bit 4: 1	SST Bad Quality - SST_MAX exceeded

Table 58: Sea Surface Temperature Product: Parameter and bit value

17.5 Prototyping and Testing

This section describes the prototyping activities, highlighting the major problems which were encountered with this development.

17.5.1 Prototyping

The prototyping activities provide information about the scientific background for the SST algorithm and verify that the algorithm is scientifically correct. The scientific background of the prototype is mainly based on existing algorithms.

17.5.2 Test Data

The major problem is to simulate the MSG channels. The prototype uses existing data from GOES-8/VISSR, which helps to simulate channels IR3.9, IR10.8 and IR12.0 on a similar horizontal resolution as MSG. The scenes type information comes from the Scenes Analysis algorithm.

17.5.3 Test Results

Tests have been performed for several slots of the GOES-8 images. The results are available for each of these slots.

17.6 Future Enhancements

No future enhancements are currently foreseen.

18 OPTIMAL CLOUD ANALYSIS PRODUCT GENERATION

18.1 Algorithm Configuration Information

18.1.1 Algorithm Name

Optimal Cloud Analysis (OCA)

18.1.2 Algorithm Identifier

EUM_MSG_OCA_A001

18.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	14/10/15	J. Jackson	OCA baseline

18.2 Inputs

18.2.1 Dynamic Application Data

The OCA algorithm uses the Scenes actual EBBT and reflectance derived from the level 1.5 image data, and the modelled radiance and transmittance from the radiative transfer model (RTM). As defined in the following table, the scenes type information, forecast data, clear sky reflectance map, satellite and solar zenith angles for the current repeat cycle **shall** be available.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
Actual reflectances for visible channels.	$REFL_{channel}$	%	0	150	0.1	0.1	pixel	Scenes Analysis.
Actual brightness temperatures for infrared channels.	$EBBT_{channel}$	K	170	350	0.1	0.1	pixel	Scene Analysis.
Atmospheric correction tables.	rtm_acc_tab	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	1 degree	Derived from the RTM.
Visible 2-path transmission tables.	rtm_vis_tab	-	0	100	10^{-6}	10^{-6}	1 degree	Derived from the RTM.
Forecast temperature profiles on the RTM standard pressure levels.	for_temp	K	170	350	0.1	0.1	1 degree	Derived from the Forecast data.
Forecast pressure profiles on the RTM standard pressure levels.	for_prof	hPa	0	1030	1	1	1 degree	Derived from the Forecast data.
Scenes type	scenes_type	-	0	255	1	1	pixel	Scenes Analysis.
Solar zenith angle	sol_zen	Degrees	0	90	10^{-6}	10^{-6}	pixel	Angles Data, derived from Level 1.5 image data.
Satellite zenith angle	sat_zen	Degrees	0	90	10^{-6}	10^{-6}	pixel	Angles Data, derived from Level 1.5 image data.
Solar-satellite relative azimuth	rel_azi	Degrees	0	180	10^{-6}	10^{-6}	pixel	Angles Data, derived from Level 1.5 image data.
Clear sky reflectance maps	crm	%	0	100	0.1	0.1	pixel	Scenes - clear sky reflectances image, updated multiple times per day.

Table 59: OPTIMAL CLOUD ANALYSIS Dynamic Application Data

18.2.2 Static Application Data

All static application data and set-up data **shall** be configurable.

STATIC APPLICATION DATA FOR PHYSICAL RETRIEVAL SCHEME				
Parameter	***Mnemonic***	***Units***	***Value***	***Source***
Surface Type	surface_type_map	-	-	Static data
Processing area mask	Proc_area	pixels	-	Static data
Spectral characteristics of the SEVIRI channels.	SEVIRI_Chan	-	-	Static data
Cloud Radiative Properties (Water)	CRP_water	-	-	Static-data
Cloud Radiative Properties (Ice)	CRP_ice	-	-	Static-data
Pixel Emissivity Maps (one for each month of the year)	Emissivity_tables	-	-	Static-data
Run Type for OCA model	RunType	-	2	Set-up
Satellite ID	SatID	-	3	Set-up
Max. Satellite Zenith Angle	MaxSatZen	degrees	75.0	Set-up
Max. Solar Zenith Angle	MaxSolZen	degrees	80.0	Set-up
Sunset Angle	Sunset	degrees	90.0	Set-up
First pixel number to process	IndX0	-	1	Set-up
First image line number to process	IndY0	-	1	Set-up
Last pixel number to process	IndX1	-	3712	Set-up
Last image line number to process	IndY1	-	3712	Set-up
Temperature threshold to detect phase change to water	PhaseTWater	K	268.0	Set-up
Temperature threshold to detect phase change to ice.	PhaseTIce	K	243.0	Set-up
Equivalent Model Parameter Noise term for surface reflectance.	EqMPNRs	-	0	Set-up
Equivalent Model Parameter Noise term for cloud homogeneity.	EqMPNHomog	-	2	Set-up
Equivalent Model Parameter Noise term for the channels spatial alignment.	EqMPNCoReg	-	2	Set-up
Cloud Type	CloudType	-	2	Set-up
Invert Marquardt starting value	Mqstart	-	0.01	Set-up
Invert Marquardt step size	Mqstep	-	10.0	Set-up
Max. iterations of Invert Marquardt	Maxiter	-	8	Set-up
Max. number of phase changes	Maxphase	-	3	Set-up
The size of the cost function decrease, below which convergence is said to occur.	Ccj	-	1.0	Set-up

Table 60: Optimal Cloud Analysis Static Application Data

18.3 Algorithm Functional Specification

18.3.1 Overview

Optimal Cloud Analysis (OCA) was so named to describe the approach taken to the estimation of cloud properties from the MSG SEVIRI instrument. The approach justifies the description *optimal* from two of its characteristics; firstly that all measurements and all important cloud parameters are dealt with *simultaneously* and secondly that the formal technique of *optimal estimation* (OE) is employed to obtain a solution. The simultaneity characteristic aims to ensure that all information in a measurement is effectively extracted; the corollary of which is that all effects on a measurement are modelled. The OE framework aims to ensure that measurements and any prior information may be given appropriate weight in the solution depending on error characteristics whether instrumental or from modelling sources.

18.3.2 Algorithm Description

The OCA algorithm is based on the following components:

1. A model of a cloudy atmosphere defined by a set of variable - '**state**' - parameters:
   x = Cloud Optical Thickness (COT), Cloud Effective Radius (CRE), Cloud Top Pressure (CTP), Cloud Fraction (CFR), Cloud Phase (CPHS), Skin Temperature (TS) and a set of fixed - '**model**' - parameters
   b = Atmospheric temperature and gaseous constituents, surface properties etc. Uniquely, the cloud phase, is not a continuous variable and takes one of only two values.
2. A fast radiative transfer model (**RTM**) which, when operated on the state and model parameters, estimates the values of the imager measurements **y**. The operation is denoted by **y**(**x**,**b**).
3. Models of **errors** in the measurements and the 'prior to retrieval' values of the state parameters.
4. A penalty or '**cost**' function, J, which describes the 'distance' (weighted mismatch) between measurements, prior state and the state estimate.
5. A technique to minimise the penalty function.

The algorithm is able to alter the state parameters but the model parameters remain fixed.

A major and frequent occurance is the presence of **cloud at multiple levels** which corresponds poorly to the assumed model and results in poor estimates (especially of CTP). However, put briefly, the value minimised cost (as listed in numbers 4 and 5 above) in these cases is very often large so that they can be identified. In identified multi-layer cloud pixels the minimisation algorithm is re-run with altered constraints, (see Section 18.3.3) such that infrared radiative transfer appropriate to a two-layer cloud system is approximated. Solar-affected channels cannot be used in these cases. The retrieved state can then be interpreted, with help from the first single layer attempt, as the parameters of a two-layer cloud system.

18.3.3 Variable Cloud State Parameters (x)

The basic (single layer) OCA model cloud consists of a single layer of zero geometric depth, an optical depth (COT) defined at 0.55 μm and of single phase (ice or water, CPHS). The particle size distribution within the cloud is represented by an effective radius (CRE) and the temperature 'distribution' within the cloud is the ambient temperature at the cloud top pressure (CTP). Finally, the pixel is assumed to be fractionally cloud covered (CFR). [A further parameter is the skin temperature (TS) of the underlying surface, not strictly part of the cloud, which is included because of the strong dependence of almost all TIR channels in some cloud conditions.]

Prior to the retrieval operation we may have some information on the values of the state parameters, known as *a priori*, prior or background information, **x**a. The OE methodology allows us to formally include this information by defining a prior cost function using ***x**a* and the covariance of the errors in **x**a, **S**a. It is the nature of clouds that we actually have little prior knowledge of the state parameters in the observed pixel. Certainly for COT, CRE and CTP there is no information available; **S**a elements for these parameters are therefore set to a high value (1e+8). For CFR, as discussed earlier, we make the assumption that the cloud detection algorithm has deduced the presence of cloud accurately and further that the cloud cover is complete. **S**a for CFR is therefore set an effective zero value (1e-8). This is tantamount to removing CFR from the state vector and is a (somewhat false) constraint that will be revisited as the scheme becomes better tuned and/or applied to instruments with more channels (=information, e.g. MTG-FCI). TS is currently the only variable with genuine prior information available. For ocean pixels a relatively low error of 1.0 K is assumed, for land a higher error, ~5.0 K.
For the re-run **multi-layer cloud** cases COT, CRE, and CTP continue to represent optical depth, effective radius and pressure, but now for the upper cloud layer. CFR remains constrained to unity, but TS is given a higher prior error estimate (~20 K) and is initialised to the mid-lower troposphere (~700 hPa) temperature. By these means it crudely but effectively models now not the skin temperature but the temperature of an underlying cloud layer. As said, there is no possibility of such a simple model for the solar reflectance channels and these are disabled here. Some post-processing of the result of this new minimisation is performed to extend the description: the original single layer COT (=approximately upper+lower) is used with the new value (=upper layer) to determine the COT of the lower layer and this can be used to estimate lower layer cloud IR transparency and convert the lower layer temperature into a cloud pressure.

18.3.4 Fixed Model Parameters (b)

Within OCA, only the cloud parameters are retrieved; therefore assumptions are made about atmospheric humidity, temperature, aerosol concentration, ozone concentration, surface emissivity, reflectivity etc. Values for these so called ‘model’ parameters are derived, for the quickly varying parameters from Numerical Weather Prediction (NWP) sources and for the more static parameters from available climatology and datasets. They are therefore of the highest quality and accuracy available in near real time but nevertheless errors remain. Part of the ‘optimality’ of the OCA scheme comes from appropriate weighting of the measurements in the retrieval.

18.3.5 The Measurements (y)

The measurement vector, **y**m, constitutes all the single pixel measurements from the sensor; thus 11 for SEVIRI. The values are “solar angle uncorrected” reflectance for wavelengths to 3 µm and brightness temperatures thereafter. The measurements are weighted in the retrieval by their errors, (**S**y). It is important to note that the definition of error here refers to the ability of the forward model to reproduce the measurements since this defines how close a fit is expected. Thus the error should in principle include:

- instrument noise
- channel co-registration effects
- effects of deviations from the OCA cloud model
- effects of errors in ancillary model parameters

The algorithm includes of all of the measurements, however channels that are difficult to model (e.g. 3.9 µm) or visible channels during poor illumination conditions or in two-layer retrievals are removed by the model by setting the channel error covariance value to a high level (∞).

18.3.6 Radiative Transfer Model

The RTM needs to be very fast to achieve real time processing of high resolution imagery and this is achieved with a) the use of lookup tables (LUTs) which store computationally intensive cloud radiative properties, b) pre-calculated atmospheric radiative effects and transmissions at NWP forecast grid resolution and c) a simple three layer (below cloud, cloud, and above cloud) radiative transfer integration.

18.3.7 Cost Function

The 'cost' or 'distance' function, J, which defines the OCA algorithm method is the sum of two parts: the measurement cost (J_m) and the prior cost (J_a).

Given a current estimate of the state **x**, Jm is the weighted squared difference of the observed measurements, **y**m, and the values **y**(**x**) (the estimated measurements). The weights are given by the expected errors in the measurements. Formally, this is written:

$$\mathbf{J_m = (y_m - y(x))^T S_y^{-1}(y_m - y(x))} \qquad \textit{Equation 50}$$

Similarly, J_a is the weighted squared difference of the prior values of the state, $\mathbf{x}_a$, and **x**; the weights being the expected errors in the prior values.

$$\mathbf{J_a = (x - x_a)^T S_a^{-1} (x - x_a))} \qquad \textit{Equation 51}$$

A high *J* value therefore indicates that the current state is in disagreement with either the measurements or the prior information or both. At the minimum value of J, the state has been found which gives best agreement with both the prior estimate and the measurements. This is the meaning of the statistical 'optimality' of the OCA method.

18.3.8 Minimising the Cost Function

Minimisation of the cost function involves a 'descent' algorithm which, starting from 'first guess' estimates of the state parameters, $\mathbf{x_0}$, takes successive steps (or 'iterations'), δ**x**, that reduce the cost until either the cost is acceptably small, the cost reduction becomes insignificant, or the iteration limit is exceeded.

Although it is not proven, experience suggests that the cost functions found with MSG SEVIRI measurements and the OCA cloud model state definition are relatively 'well behaved'. This means that there are generally few instances of multiple minima or other complex features that would require the use of sophisticated search algorithms to find the true minimum. OCA therefore operates a straightforward Levenberg-Marquardt descent algorithm which combines steepest descent and Newtonian methods.

Steepest descent (SD) involves stepping in the direction in *x*-space that is in the steepest 'downhill' direction, **-J'** = $-\partial$**J**/ ∂**x** . Such steps will always be in the correct direction although as the length of the step is not determined and may be too far (stepping past the minimum) or too short (needing many iterations). **Newtonian descent** (ND) on the other hand uses a step that is Newton's root finding method for the equation **J'=0** which is the condition expected at any minimum. The step is thus **-J'/J"** and, if **J** is a quadratic function of **x**, as it would be if all errors are purely normal and the RT is linear in **x**, then one step finds exactly the minimum. It is because the RT is not in practice completely linear that these two descent methods are combined with a mechanism to alter the balance between them. Thus the Levenberg-Marquardt step is given by

$$\delta \mathbf{x} = -(\mathbf{J}'' + \alpha \mathbf{I})^{-1} \mathbf{J}'$$	*Equation 54*

where the control variable α is varied to shift between SD and ND; α very small is equivalent to ND. Adjustment of α is made according to the success of the last step made: if the step is successful (i.e. lowers the value of **J**) then α is reduced (by e.g. a factor of 10) because it is assumed the minimum is nearer and the problem more linear. If the step is unsuccessful in that the value of J would increase, the step is not made and α is increased.

Steps that would lead to a parameter leaving its physically valid bounds (e.g. CTP greater than surface pressure) are generally modified so that the parameter is restricted to the bounding value (surface pressure in this case). An exception is the bounds check on CRE where over-stepping in two of the four possible cases is taken to imply that the current cloud phase (water or ice) is incorrect and the phase is changed and the minimisation re-initialised. A phase change is made when a step to CRE larger than the water phase upper limit (e.g. ~23 microns) is taken to imply the cloud phase is more likely to be ice and, similarly, when a step to CRE less than the ice phase lower limit (~10 microns) is taken to imply the cloud phase is more likely to be water. Figure 13 is taken from reference document R1 is the logic scheme used to implement the Levenburg-Marquardt. The central column is essentially the Levenburg-Marquardt loop; the branching to the left and right sides implement phase change and multi-layer cloud treatments respectively.

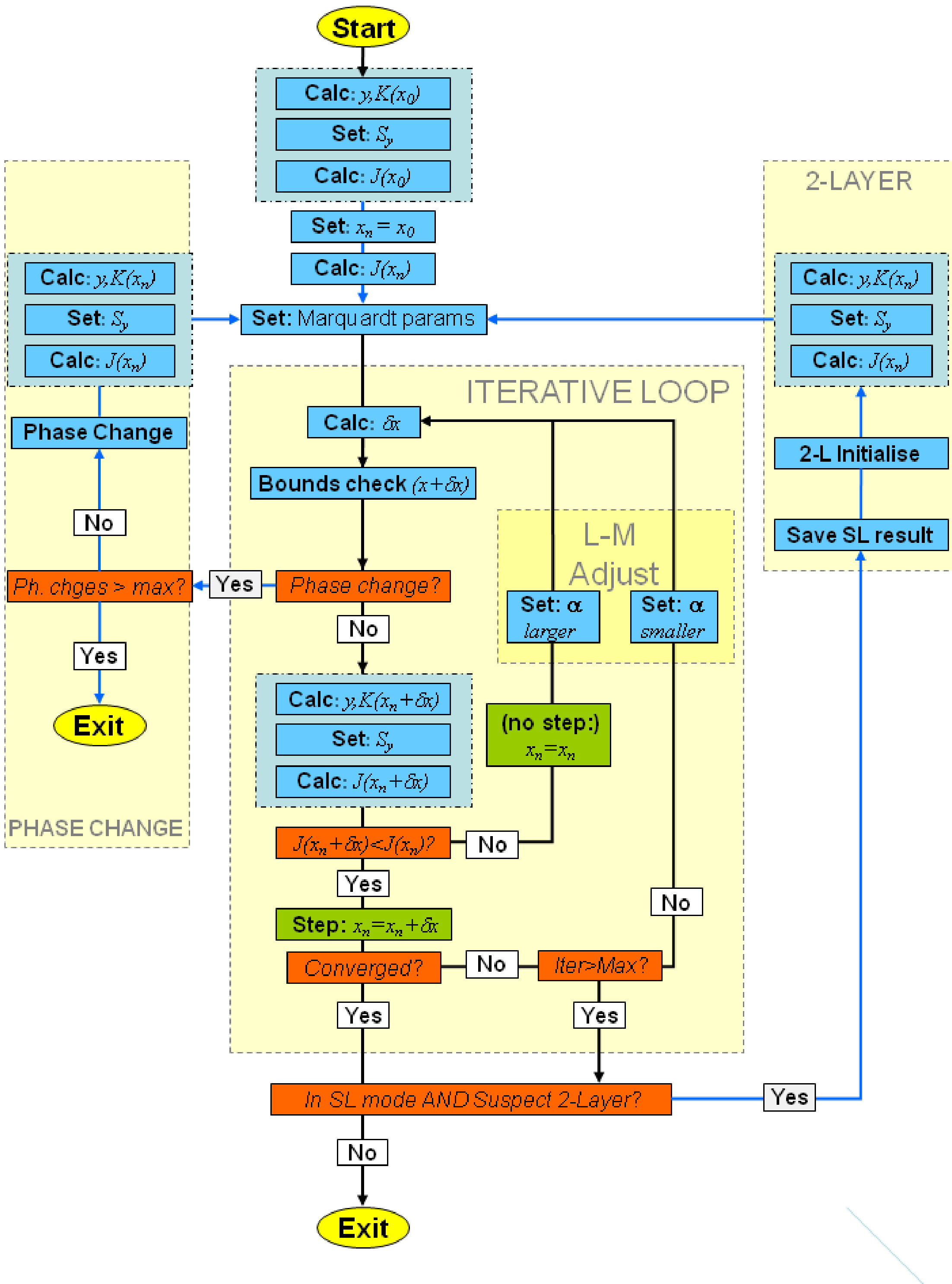

Figure 13: The OCA cost minimisation scheme (taken from R2).

18.3.9 Processing mask

The OCA algorithm is applied to all SEVIRI pixels within the processing area. The OCA algorithm is only applied to pixels classified as clouds by the Scenes algorithm.

18.4 Outputs

18.4.1 Final Product

The following data **shall** be produced for the OCA product for every pixel:

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*To*
Latitude	Latitude	degrees	–90	90	0.1	OCA Final Product
Longitude	Longitude	degress	–180	180	0.1	
Quality Flag	Quality_Flag	-	0	255	1	
Cloud Phase	Phase	-	0	3	1	
Cost	Jm	-	0	-	1	
Upper Layer Cloud Optical Depth	ULTau	-	–1.0	2.4	0.01	
Upper Layer Cloud Top Pressure	ULCtp	hPa	50	1060	0.01	
Upper Layer Cloud Particle Size	ULCre	µm	1	180	0.1	
Upper Layer Error in Calculated Optical Depth	ULSnTau	-	0	-	0.01	
Upper Layer Error in Calculated Cloud Top Pressure	ULSnCtp	hPa	0	-	0.01	
Upper Layer Error in Calculated Particle Size	ULSnCre	µm	0	-	0.1	
[1]Lower Layer Cloud Optical Depth	LLTau	-	–1.0	2.4	0.01	
[1]Lower Layer Cloud Top Pressure	LLCtp	hPa	50	1060	0.01	
[1]Lower Layer Error in Calculated Optical Depth	LLSnTau	-	0	-	0.1	
[1]Lower Layer Error in Calculated Cloud Top Pressure	LLSnCtp	hPa	0	-	0.01	

[1] Lower Layer Cloud products are only present when the 2-layer re-run has been performed–when the Cloud Phase parameter = 3.

18.4.2 Encoded Products

The fields of the intermediate product are encoded into a single file in the GRIB 2 format. The Latitude, Longitude, Row, Column, and Quality Flag values are omitted from the encoded product. The file is compressed with complex packing using the NCEP GRIB2 encoder. Finally an MPEF_PRODUCT_HEADER (of size 172 bytes) and the XRINT_NonImage_Data_Header (of size 4 bytes) is pre-appended to the encoded OCA product.

18.5 Future Enhancements

The most likely significant future enhancement will be to replace the *ad hoc* 2 layer cloud modelling currently implemented with a full description – that is extension of the state vector to explicitly include parameters from both layers and the consequent extension of the OCA fast radiative transfer model. The latter will probably be approached in two steps with the somewhat simpler infrared channels in the first enhancement.

18.6 References

	Reference	*Title*	*Date*	*Author(s)*
R1	EUM/MTG/DOC/11/0654	MTG-FCI: ATBD for Optimal Cloud Analysis Product.	2011	Philip Watts
R2	J. Geophys. Res., **116**, D16203, doi:10.1029/2011JD015883	Retrieval of two-layer cloud properties from multispectral observations using optimal estimation	2011	P. D. Watts, R. Bennartz, and F. Fell

19 CALIBRATION SUPPORT

19.1 Algorithm Configuration Information

19.1.1 Algorithm Name

IR and VIS Calibration Support

19.1.2 Algorithm Identifier

EUM_MSG_CAL_A001

19.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	26/11/96	S. A. Tjemkes	CAL Baseline
1.1	20/5/97	H. K. Wilson	TBDs resolved, bid clarification points added, editorial errors corrected.
1.2	1/7/97	S. A. Tjemkes	Descoping and simplification of Cross Satellite Calibration.
1.3	9/12/97	H. K. Wilson	Requirements Analysis clarification points added.
1.4	13/3/98	H. K. Wilson	Peer Group Review changes added, algorithm simplified.
1.5	25/7/05	T. Heinemann	Updates according to ARs 9271, 9492, 10164, 11264, 11596.
1.6	15/09/08	T. Heinemann	Updated according to ECP 814.

19.2 Inputs

The tables on the following pages list the input parameter specifications for these specific calibration instances:

Calibration Monitoring
Absolute Calibration of Windows Channels
Absolute Calibration of Water Vapour Channels
Absolute Calibration of Ozone Channel
Determination of the Vicarious Calibration Constants
Cross-Satellite Calibration

INPUT PARAMETERS FOR CALIBRATION MONITORING							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Scenes type	CLDMSK	-	-	-	-	-	SCE
Number of pixels in the search area	CMPSA	-	0	1089	1	1	Set-up
Minimum number of clear sky pixels in the search area	CMNCR	-	0	1089	1	1	Set-up
Observed radiances	OBSRAD	$mWm^{-2}sr^{-1} (cm^{-1})^{-1}$	0	-	-	-	Derived from level 1.5 data
Atmospheric Correction Table	CALRAD	$mWm^{-2}sr^{-1} (cm^{-1})^{-1}$	0	-	-	-	RTM
Number of geographical regions	CMNGEO	-	0	-	-	-	Set-up
Position of geographical regions	CMPGEO	-	-	-	-	-	Set-up
Distance to nearest coastline	coastdist	km	0	1000	1	1	Set-up
Channel-dependent threshold parameter	CMTRS	-	0	100	10^{-1}	10^{-2}	Set-up
Mean radiance difference reference per channel	$cm\_mean\_rad_{chan}$	-	-	-	-	-	Set-up
Calibration Monitoring tolerance threshold per channel	cm_tol_{chan}	-	0	-	-	-	Set-up

Table 61: Input parameters for calibration monitoring

INPUT PARAMETERS FOR ABSOLUTE CALIBRATION OF WINDOWS CHANNELS							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Scenes Type	CLDMSK	-	-	-	-	-	SCE
Number of pixels in the search area	ACPSA	-	0	1089	1	1	Set-up
Minimum number of clear sky pixels in the search area	ACNCR	-	0	1089	1	1	Set-up
Observed digital counts	OBSCNT	counts	0	-	-	-	Level 1.5 data
Level 1.5 space counts	SPACNT	counts	0	-	-	-	Level 1.5 data
Atmospheric Correction Table	CALRAD	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	RTM
Channel-dependent threshold parameter	ACTRS	-	0	100	10^{-1}	10^{-2}	Set-up
Distance to nearest coastline	coastdist	km	0	1000	1	1	Set-up

Table 62: Input parameters for Absolute Calibration of windows channels

INPUT PARAMETERS FOR ABSOLUTE CALIBRATION OF WATER VAPOUR CHANNELS							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Scenes type	CLDMSK	-	-	-	-	-	SCE
Pressure	p	hPa	0	1050	10^{-2}	10^{-3}	Observations
Temperature	T	K	170	350	10^{-1}	10^{-2}	Observations
Water vapour relative humidity	RH	%	0	100	1	1	Observations
Cut-off time	ACCUT	hours	0	24	1	1	Set-up
Minimum relative humidity	ACMINRH	%	0	100	1	1	Set-up
Max. relative humidity	ACMAXRH	%	0	100	1	1	Set-up
Minimum observations	ACMINOBS	-	0	1089	1	1	Set-up
Maximum cloudiness	ACMAXCLD	%	0	100	1	1	Set-up
Number of pixels in the search area	ACPSA	-	0	1089	1	1	Set-up
Minimum number of clear sky pixels in the search area	ACNCR	-	0	1089	1	1	Set-up
Observed digital counts	OBSCNT	counts					Level 1.5 data
Level 1.5 space counts	SPACNT	counts	0				Level 1.5 data
Vicarious Calibration Table	CALRAD	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$					RTM
Channel-dependent threshold parameter	ACTRS	-	0	100	10^{-1}	10^{-2}	Set-up

Table 63: Input parameters for absolute calibration of water vapour channels

INPUT PARAMETERS FOR ABSOLUTE CALIBRATION OF OZONE CHANNEL							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Scenes type	CLDMSK	-	-	-	-	-	SCE
Pressure	p	hPa	0	1050	10^{-2}	10^{-3}	Observations
Temperature	T	K	170	350	10^{-1}	10^{-2}	Observations
Water vapour relative humidity	RH	%	0	100	1	10^{-1}	Observations
Ozone mixing ratio	m_{o3}	kg/kg	0	-	-	-	Observations
Cut-off time	ACCUT	hours	0	24	1	1	Set-up
Minimum observations	ACMINOBS	-	0	1089	1	1	Set-up
Maximum cloudiness	ACMAXCLD	%	0	100	1	1	Set-up
Number of pixels in the search area	ACPSA	-	0	1089	1	1	Set-up
Minimum number of clear sky pixels in the search area	ACNCR	-	0	1089	1	1	Set-up
Observed digital counts	OBSCNT	counts	0	-	-	-	Level 1.5 data
Level 1.5 space counts	SPACNT	counts	0	-	-	-	Level 1.5 data
VICARIOUS CALIBRATION TABLE	CALRAD	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	RTM
Channel-dependent threshold parameter	ACTRS	-	0	100	10^{-1}	10^{-2}	Set-up

Table 64: Input parameters for absolute calibration of ozone channel

INPUT PARAMETERS FOR INCLUSION IN PRODUCT HEADER							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
On-board black body calibration data	BB_CAL	-	-	-	-	-	LEVEL 1.5 IMAGE DATA

Table 65: Input parameters for inclusion in product header

INPUT PARAMETERS FOR DETERMINATION OF THE VICARIOUS CALIBRATION CONSTANTS							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Averaging time period outside eclipse season	TIMPEROUT	hours	0	24	1	1	Set-up
Averaging time period inside eclipse season	TIMPERIN	days	0	24	1	1	Set-up
Channel-dependent threshold parameter	VOCCTRS	-	0	100	10^{-1}	10^{-2}	Set-up

Table 66: Input parameters for determination of the vicarious calibration constants

INPUT PARAMETERS FOR CROSS SATELLITE CALIBRATION							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
MSG observed counts	GEOOBS	counts	0	-	-	-	Level 1.5 data
MSG space counts	GEOSPC	counts	0	-	-	-	Level 1.5 data
Clear Sky FSD, (LEO) radiances, geometrically corrected and absolutely calibrated	LEOOBS	$mWm^{-2}sr^{-1}(cm^{-1})^{-1}$	0	-	-	-	FSD
Minimum number of clear sky pixels in target area	CCGEONCR	-	0	-	-	-	Set-up
Third degree polynomial coefficients a(0), a(1), a(2), a(3)	POLCOEF	-	-	-	-	-	Set-up
Number of pixels in target area	CCPTA	-	0	4356	1	1	Set-up
Viewing angle difference	VIEWDIFF	°	0	90	1	1	Set-up
Channel-dependent threshold parameter	CCTRS1	-	0	100	10^{-1}	10^{-2}	Set-up
Channel-dependent threshold parameter	CCTRS2	-	0	100	10^{-1}	10^{-2}	Set-up
Distance threshold	DISTTHRS	km	0	1000	1	1	Set-up
Observation time difference	OBSTIMDIFF	seconds	0	1800	1	1	Set-up

Table 67: Input parameters for cross satellite calibration

INPUT PARAMETERS FOR ABSOLUTE CALIBRATION							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Weighting functions for	abs_cal_wt_vicc	-	0	1	-	-	SET-UP
Absolute calibration Calculation	abs_cal_wt_xsat	-	0	1	-	-	Set-up
Vicarious calibration tolerance threshold per channel	vic_tol_{chan}	-	0	-	-	-	Set-up
Cross-sat. calibration tolerance threshold per channel	$xsat\_tol_{chan}$	-	0	-	-	-	Set-up
Quality flag weights per channel	$qf\_wt\_cm_{chan}$ $qf\_wt\_vic_{chan}$ $qf\_wt\_xsat_{chan}$	-	0	1	-	-	Set-up
Quality flag thresholds per channel	$qf\_upper\_thr_{chan}$ $qf\_lower\_thr_{chan}$	-	0	1	-	-	Set-up
Operational calibration coefficient per channel	OCC_{chan}	-	-	-	-	-	Level 1.5 data

Table 68: Input parameters for absolute calibration

INPUT PARAMETERS FROM OFF-LINE ABSOLUTE CALIBRATION OF VIS/NIR CHANNELS							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Acc***	***Prec***	***Source***
Quality flag for Level 1.5 data	QF_{chan}	-	-	-	-	-	Set-up
Used reference data flag	rdf_{chan}	-	-	-	-	-	Set-up
Absolute calibration method flag	ABC_flag_{chan}	-	-	-	-	-	Set-up
Absolute cal. weight (Vic. Cal)	$AC\_wt\_vic_{chan}$	-	-	-	-	-	Set-up
Abs calibratoin weight (Xsat. Cal)	$AC\_wt\_xsat_{chan}$	-	-	-	-	-	Set-up
Absolute calibration coefficients for channels VIS0.6, VIS0.8, NIR1.6, HRVIS	VIS_CC_{chan}	-	-	-	-	-	Set-up
Estimated accuracy of absolute calibration	ACC_{chan}	-	-	-	-	-	Set-up
Bias from calibration monitoring	$BIAS_{chan}$	-	-	-	-	-	Set-up
RMS from calibration monitoring	RMS_{chan}	-	-	-	-	-	Set-up
Space count	$Space\_cnt_{chan}$	-	-	-	-	-	Set-up

Table 69: Input parameters from off-line absolute calibration of VIS/NIR channels

19.3 Algorithm Functional Specification

19.3.1 Overview

The main task of the Calibration Support is the monitoring of the radiometric accuracy of the level 1.5 data of the eight infrared channels, namely IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0 and IR13.4. A further application of the algorithm is to provide absolute calibration coefficients for the eight infrared channels, which can be used as a backup in the event of failure of the on-board calibration. Additionally, the VIS/NIR calibration coefficients, which are generated off-line in the algorithm prototyping environment, are also incorporated in this algorithm. The calibration coefficients for all the SEVIRI channels are then supplied to the IMPF.

The output of the Calibration Monitoring process is data describing the temporal evolution of the relation between the level 1.5 data and calculated radiances. These latter radiances are calculated using meteorological data from the forecast model. These data **shall** be generated for every repeat cycle.

The output of the Absolute Calibration task consists of the temporal evolution of the instantaneous calibration relation between the digital counts and reference radiances. These reference radiances are either calculated by the Radiative Transfer Model using meteorological observations or taken from observations by instruments mounted on a space-borne platform in a Low Earth Orbit (LEO), e.g. FSD. The generation of the Absolute Calibration **shall** be determined by the availability of the required input data.

The on-board black body calibration information **shall** also be included in the product header for the CAL products sent to the UMARF.

The enhancement of the calibration monitoring of the window channels using the SST product and independent observations is a Future Enhancement.

19.3.2 Algorithm Description

19.3.2.1 Calibration Monitoring

For the Calibration Monitoring the following tasks **shall** be performed:

1. A valid target point **shall** be defined as any grid point of the forecast model not over land areas with a minimum distance to the nearest coastline exceeding a threshold defined by a set-up parameter, within the EMD processing area.
2. For each valid target point, a search area **shall** be defined, as a square area, consisting of a fixed number of pixels, defined by a set-up parameter, with its centre pixel located at the grid point of the forecast model.
3. For each of the search areas, all pixels which according to the Scenes Analysis are determined as being clear, **shall** be selected.
4. If the total number of clear sky pixels in the valid target area does not exceed a threshold specified by a set-up parameter, this target area **shall** be removed from further processing.
5. For each of the valid target points and each of the eight infrared channels, a local mean observed clear sky radiance and the associated local standard deviation **shall** be calculated from the level 1.5 data converted into radiances (units: $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$) over all clear sky pixels in the corresponding search area.

6. For each of the valid target areas, and each of the eight infrared channels, a calculated clear sky radiance **shall** be extracted from the *Atmospheric Correction Tables* generated by the Radiative Transfer Model.
7. For each of the eight IR channels and each of the valid target areas, the local radiance difference between the local mean observed clear sky radiance and the calculated clear sky radiance **shall** be calculated. For each of the eight IR channels a mean radiance difference and its associated standard deviation **shall** be calculated from all local radiance differences. For each of the eight IR channels, a reference value for the mean radiance difference **shall** be defined by a set-up parameter. For each of the eight IR channels a tolerance threshold **shall** be defined by a set-up parameter.

   For each of the eight IR channels, the following tests **shall** be implemented in order to set the radiance quality flag for that channel:

   a. If the absolute difference between the mean radiance difference and the reference value is less than or equal to the standard deviation associated with the mean radiance difference, or
   b. when the mean radiance difference is smaller than the reference value and the mean radiance difference reduced by the standard deviation associated with the mean radiance difference is larger than the reference value reduced by the tolerance value, or
   c. when the mean radiance difference is larger than the reference value and the mean radiance difference increased by the standard deviation associated with the mean radiance difference is smaller than the reference value increased by the tolerance value, then:

      The radiance quality flag **shall** be set indicating that according to the Calibration Monitoring the operational calibration produces acceptable results.

   If conditions a, b and c do not apply, then:

   d. When the mean radiance difference is smaller than the reference value and the absolute difference between the mean radiance difference and the reference reduced by the tolerance value is less than or equal to the standard deviation associated with the mean radiance difference, or
   e. when the mean radiance difference is larger than the reference value and the absolute difference between the mean radiance difference and the reference increased by the tolerance value is less than or equal to the standard deviation associated with the mean radiance difference, then:

      The radiance quality flag **shall** be set indicating that according to the Calibration Monitoring the operational calibration produces suspect results, but that improvements are not required.

   If conditions a, b, c, d, and e do not apply, then the radiance quality flag **shall** be set indicating that according to the Calibration Monitoring the operational calibration produces non-acceptable results.
8. The implementation of the Calibration Monitoring **shall** be such that the comparison between the radiance difference and the reference value can be applied to all valid target areas in geographical areas specified by user-defined set-up parameters, over a time period specified by a user-defined set-up parameter.

19.3.2.2 Absolute Calibration Coefficient

This algorithm is responsible for deriving absolute calibration coefficients for the eight infrared channels of MSG, i.e. IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0 and IR13.4, independently of the on-board calibration. The output of this algorithm consists of tables which (when used as a time series) can be used to describe the temporal evolution of the Absolute Calibration Coefficient. This information is provided to the IMPF for further processing.

The calibration coefficients for the VIS/NIR channels are generated off-line and **shall** be read into this algorithm and output together with the IR calibration coefficients.

The Absolute IR Calibration Coefficients **shall** be calculated as a weighted mean of the Vicarious Operational Calibration Coefficient and the Cross Satellite Operational Calibration Coefficient using weights determined by set-up parameters.

The implementation of the Absolute Calibration **shall** be such that the analysis can be applied to all valid target areas in geographical areas specified by user-defined set-up parameters, over a time period specified by a user-defined set-up parameter.

19.3.2.2.1 Vicarious Operational Calibration Coefficient

The determination of the Vicarious Operational Calibration Coefficient **shall** be done in two steps. First the Vicarious Instantaneous Calibration Coefficient (VICC) is calculated for each channel. From these in the second step the Vicarious Operational Calibration Coefficient (VOCC) **shall** be calculated. The actual procedure to calculate the VOCC no longer depends on the eclipse season.

The monitoring VICC of all IR channels, except the IR9.7 channel, **shall** be based on meteorological data from the forecast model, supplemented with Sea Surface Temperature Data. For the calculation of the VICC of these monitoring channels the following tasks **shall** be performed:

1. A valid target point **shall** be defined as any grid point of the forecast model not over land areas with a minimum distance to the nearest coastline exceeding a threshold defined by a set-up parameter, within the EMD processing area.
2. For each valid target point a search area **shall** be defined, as a square area, consisting of a fixed number of pixels, defined by a set-up parameter, with its centre pixel located at the grid point of the forecast model.
3. For each of the search areas, all pixels which according to the Scenes Analysis are determined as being clear, **shall** be selected.
4. If the total number of clear sky pixels in the valid target area does not exceed a threshold specified by a set-up parameter, this valid target area is removed from further processing.
5. For each of the valid target points, and each of the monitoring channels, the arithmetic mean observed digital count **shall** be calculated from the observations given by the level 1.5 data in digital counts of all clear sky pixels in the corresponding search area.
6. For each of the valid target areas, and each of the IR channels, the local VICC defined as the ratio between the clear sky radiance extracted from the *Atmospheric Correction Tables* generated by the Radiative Transfer Model and the mean observed clear sky digital count corrected for the level 1.5 space count, **shall** be calculated.
7. For each of the monitoring channels, a first-guess VICC and its standard error **shall** be calculated from the local VICC for all valid target areas.

8. Each local VICC for which the absolute difference between the local VICC and the first-guess VICC exceeds a threshold, **shall** be removed from further processing. This test **shall** be done for each of the monitoring channels. The threshold **shall** be taken as proportional to the standard error of the first-guess VICC; the proportional factor **shall** be determined by a set-up parameter.
9. For each of the monitoring channels, the VICC **shall** be calculated as the arithmetic mean over all remaining local VICCs.

In addition, VICCs of the strongly absorbing water vapour channels, WV6.2, **shall** be calculated based on actual radiosonde ascents. These observations are done twice a day, at midnight and midday. The vicarious calibration **shall** be based on all available observations, subject to quality control within a cut-off time determined by a set-up parameter after the observational time. For the derivation of the VICC of these channels the following tasks **shall** be performed:

1. A valid target point **shall** be defined as a location where an actual radiosonde observation exists.
2. Valid target points where the corresponding radiosonde observations do not meet the following quality control criteria **shall** be removed from further processing:
   - Radiosonde observations **shall** be within the external meteorological data processing area.
   - The radiosonde bulletins **shall** be merged in order to provide a single profile per station.
   - Radiosonde observations **shall** have an average relative humidity in excess of a threshold value defined by a channel-dependent set-up parameter.
   - Radiosonde observations **shall** have a minimum number of observations within the sensitivity range of the channel, determined by a channel-dependent set-up parameter.
   - The observed cloudiness given by the associated surface observations **shall** **not** exceed a threshold determined by a set-up parameter.
   - The observed relative humidity **shall** **not** exceed a threshold defined by a set-up parameter.
3. For each valid target point a search area **shall** be defined, as a square area, consisting of a fixed number of pixels, defined by a set-up parameter, with its centre pixel located at the position of the observation.
4. For each of the search areas, all pixels which according to the Scenes Analysis are determined as being clear, **shall** be selected.
5. If the total number of clear sky pixels in the target area does not exceed a threshold specified by a set-up parameter, this target area is removed from further processing.
6. For each of the valid target points and each of the water vapour channels, the arithmetic mean observed digital count **shall** be calculated from the observations given by the level 1.5 data in digital counts of all clear sky pixels in the corresponding search area.
7. For each of the valid target areas and each of the water vapour channels, the local VICC defined as the ratio between the clear sky radiance extracted from the *Absolute Calibration Tables* for the water vapour channels generated by the Radiative Transfer Model and the mean observed clear sky digital count corrected for the level 1.5 space count, **shall** be calculated.
8. For each of the water vapour channels, a first-guess VICC and its standard error **shall** be calculated from the local VICC for all valid target areas.

9. Each local VICC for which the absolute difference between the local VICC and the first-guess VICC exceeds a threshold, **shall** be removed from further processing. This test **shall** be done for each of the water vapour channels. The threshold **shall** be taken as proportional to the standard error of the first-guess VICC; the proportional factor **shall** be determined by a set-up parameter.
10. For each of the water vapour channels, the VICC **shall** be calculated as the arithmetic mean over all remaining local VICCs.

The VICC of the ozone channel, IR9.7, **shall** be based on ozonesonde ascents. These observations are done nominally once a week. The VICC **shall** be based on all available observations, subject to quality control within a cut-off time determined by a set-up parameter after the observational time. For the derivation of the VICC of this channel the following tasks **shall** be performed:

1. A target area **shall** be defined as any grid point where an actual ozonesonde observation exists.
2. Target areas where the corresponding ozonesonde observations do not meet the following quality control criteria **shall** be removed from further processing:
   - Ozonesonde observations **shall** be within the external meteorological data processing area.
   - Ozonesonde observations **shall** have a minimum number of observations within the sensitivity range of the channel, determined by a set-up parameter.
   - The observed cloudiness given by the associated surface observations **shall** **not** exceed a threshold determined by a set-up parameter.
3. For each valid target a search area **shall** be defined, as a square area, consisting of a fixed number of pixels, defined by a set-up parameter, with its centre pixel located at the position of the observation.
4. For each of the search areas, all pixels which according to the Scenes Analysis are determined as being clear, **shall** be selected.
5. If the total number of clear sky pixels in the target area does not exceed a threshold specified by a set-up parameter, this target area is removed from further processing.
6. For each of the valid target areas, the arithmetic mean observed digital count **shall** be calculated from the observations given by the level 1.5 data in digital counts of the ozone channel of all clear sky pixels in the corresponding search area.
7. For each of the valid target areas, the local VICC defined as the ratio between the clear sky radiance extracted from the *Absolute Calibration Tables* for the ozone channel generated by the Radiative Transfer Model and the mean observed clear sky digital count corrected for the level 1.5 space count, **shall** be calculated.
8. A first-guess VICC and its standard error **shall** be calculated from the local VICC for all valid target areas.
9. Each local VICC for which the absolute difference between the local VICC and the first-guess VICC exceeds a threshold **shall** be removed from further processing. The threshold **shall** be taken as proportional to the standard error of the first-guess VICC; the proportional factor **shall** be determined by a set-up parameter.
10. The VICC **shall** be calculated as the arithmetic mean over all remaining local VICCs.

For each of the eight infrared channels, the VOCC **shall** be based on the VICCs.

For the channel WV6.2 the VOCC should be based only on VICCs derived from observations.

For the channel IR3.9 the contribution of reflected sunlight to the signal at the satellite does not allow the use of images with a daylight component for the vicarious calibration which is based on IR radiative transfer. Therefore only the VICCs derived in the three repeat cycles around local midnight are used to calculate the VOCC for this channel.

For each channel the following tasks **shall** be performed:

1. A first-guess VOCC and its standard error **shall** be calculated as the arithmetic mean over each VICC within a time period determined by a set-up parameter.
2. Each VICC within this time period for which the absolute difference between the VICC and the first-guess VOCC exceeds a threshold, **shall** be removed from further processing. This threshold **shall** be taken as proportional to the standard error of the first-guess VOCC; the proportional factor **shall** be determined by a set-up parameter. If fewer than three VICCs are available this criterion is not applied.
3. A VOCC, i.e. the arithmetic mean over all valid VICCs and its associated standard deviation, **shall** be calculated.
4. A monitoring of the operational calibration coefficient **shall** be implemented in a similar way as described for the monitoring of the radiances. In particular, the following steps **shall** be implemented:

For each of the eight IR channels a tolerance threshold **shall** be defined set by a set-up parameter. For each of the eight IR channels, the following tests **shall** be implemented in order to set an Operational Calibration Coefficient (OCC) quality flag for that channel:

a. If the absolute difference between the VOCC and the OCC is less than or equal to the standard deviation associated with the VOCC, or

b. when the VOCC is smaller than the OCC, and the VOCC reduced by its standard deviation is larger than the OCC reduced by the tolerance value, or

c. when the VOCC is larger than the OCC, and the VOCC increased by its standard deviation is smaller than the OCC increased by the tolerance value, then:

A quality flag **shall** be set indicating that according to the vicarious calibration method the operational calibration produces acceptable results.

If conditions a, b and c do not apply, then:

d. when the VOCC is smaller than the OCC, and the absolute difference between the VOCC and the OCC reduced by the tolerance value is less than or equal to the standard deviation associated with the VOCC, or

e. when the VOCC is larger than the OCC, and the absolute difference between the VOCC and the OCC increased by the tolerance value is less than or equal to the standard deviation associated with the VOCC, then:

A quality flag **shall** be set indicating that according to the vicarious calibration method the operational calibration produces suspect results, but that improvements are not required.

If conditions a, b, c, d and e do not apply, then a quality flag **shall** be set indicating that according to the Vicarious Calibration Method the operational calibration produces non-acceptable results.

19.3.2.2.2 Cross-Satellite Operational Calibration Coefficient

The cross satellite calibration **shall** be done for each foreign satellite independently.

The determination of the Cross Satellite Operational Calibration Coefficient **shall** be done in two steps. First, the appropriate foreign satellite data **shall** be transferred to MPEF and if necessary decoded. The most suitable foreign satellite overpass for the specified repeat cycle **shall** be selected and only data from this satellite **shall** be used for this repeat cycle. As a second step, the Cross Satellite Instantaneous Calibration Coefficient (CSICC) **shall** be calculated.

For each of the eight infrared channels, namely IR3.9, WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0 and IR13.4, for which suitable foreign satellite data are available, the following tasks **shall** be performed:

1. A valid target area **shall** be defined as an area consisting of a finite number of foreign satellite pixels determined by a set-up parameter.
2. For each valid target area, all pixels of the corresponding MSG channel, which meet the following criteria, **shall** be selected:
   - The MSG observation **shall** be determined as being clear according to the Scenes Analysis.
   - The great circle difference between the centre of the target area and the position of the MSG pixel **shall** be less than a threshold defined by a set-up parameter.
   - The difference between the MSG observational time, defined by the average acquisition time of the level 1.0 data line, and the FSD observational time **shall** **not** exceed a threshold defined by a set-up parameter.
   - The difference between the viewing angle of the MSG observation and the mean viewing angle of the foreign satellite observations within the valid target area **shall** **not** exceed a threshold defined by a set-up parameter.
3. If the total number of selected MSG pixels in the target area does not exceed a threshold specified by a set-up parameter, this target area **shall** be removed from further processing.
4. If the standard deviation of the selected pixels exceeds a threshold defined by a set-up parameter, this target area **shall** be removed from further processing.
5. For each of the valid target areas, the local mean observed MSG digital count and its standard error **shall** be calculated from the instantaneous MSG observations given by the level 1.5 data in digital counts of all clear sky pixels in the valid target area.
6. For each of the valid target areas, the local mean foreign satellite clear sky radiance observation and its standard error **shall** be calculated from the individual foreign satellite clear sky observations within the target area.
7. For each of the valid target areas, the local mean foreign satellite clear sky observations **shall** be corrected for the difference in spectral response function between the foreign satellite channel and the corresponding MSG channel, using a second order polynomial, with constants defined by set-up parameters or an appropriate spectral convolution.
8. For each of the valid target areas, the local CSICC defined as the ratio between the local mean foreign satellite clear sky radiance (corrected for the spectral response functions) and the local mean MSG clear sky digital count (corrected for the level 1.5 space count) **shall** be calculated.
9. A first-guess CSICC and its standard error **shall** be calculated from the local CSICC for all valid target areas.

10. Each local CSICC for which the absolute difference between the local CSICC and the first-guess CSICC exceeds a threshold **shall** be removed from further processing. The threshold **shall** be taken as proportional to the standard error of the first-guess CSICC; the proportional factor **shall** be determined by a set-up parameter. The other CSICCs **shall** be stored as Cross Calibration Operational Calibration Coefficients (CSOCC) in the calibration data.
11. A monitoring of the operational calibration coefficient **shall** be implemented in a similar way as described for the monitoring of the radiances. In particular, the following steps **shall** be implemented:

For each of the eight IR channels a tolerance threshold **shall** be set by a set-up parameter. For each of the eight IR channels, the following tests **shall** be implemented in order to set an Operational Calibration Coefficient (OCC) quality flag from the Cross Satellite Operational Calibration Method for that channel:

a. If the absolute difference between the CSOCC and the OCC is less than or equal to the standard deviation associated with the CSOCC, or
b. when the CSOCC is smaller than the OCC and the CSOCC reduced by its standard deviation is larger than the OCC reduced by the tolerance value, or
c. when the CSOCC is larger than the OCC and the CSOCC increased by its standard deviation is smaller than the OCC increased by the tolerance value, then:

   A quality flag **shall** be set indicating that according to the cross-satellite calibration method the operational calibration produces acceptable results.

If conditions a, b and c do not apply, then:

d. When the CSOCC is smaller than the OCC and the absolute difference between the CSOCC and the OCC reduced by the tolerance value is less than or equal to the standard deviation associated with the CSOCC, or
e. when the CSOCC is larger than the OCC and the absolute difference between the CSOCC and the OCC increased by the tolerance value is less than or equal to the standard deviation associated with the CSOCC, then:

   A quality flag **shall** be set indicating that according to the cross-satellite calibration method the operational calibration produces suspect results, but that improvements are not required.

If conditions a, b, c, d, and e do not apply, then a quality flag **shall** be set indicating that according to the cross-satellite calibration method the operational calibration produces non-acceptable results.

The implementation of the Cross Satellite Calibration Method **shall** be such that for each channel a comparison between the local CSICC and the OCC can be applied to all valid target areas in geographical areas specified by user-defined set-up parameters, over a time period specified by a user-defined set-up parameter.

19.3.2.2.3 Inclusion of VIS/NIR Calibration Coefficients

The solar calibration monitoring and the derivation of calibration coefficients for the three visible SEVIRI channels will be performed outside the operational MPEF processing. The results of this process, namely the VIS/NIR calibration coefficients, **shall** be input via a static data file and output along with the IR calibration coefficients as defined above.

19.3.3 Automatic Quality Control (AQC)

An Overall Quality Flag for each channel **shall** be set using the quality flags set by the cross-satellite calibration method, the vicarious calibration method and the calibration monitoring method. This **shall** be done according to the following steps. For each of the three methods, the quality flag **shall** be transformed into a numerical quality equivalent, namely 0, 0.5 and 1.0 for the quality flags 'non-acceptable', 'suspect' and 'acceptable' respectively. The numerical equivalent of the Overall Quality Flag **shall** be calculated as a linear weighted mean of the numerical quality equivalents, with the understanding that the weights for the three methods **shall** be set by set-up parameters, and the linear summation of these three weights **shall** be equal to unity. The Overall Quality Flag **shall** be set depending on the value of its numerical equivalent according to the following rules:

a. If the numerical equivalent of the Overall Quality Flag is smaller than or equal to a lower threshold value, set by a set-up parameter, nominal value 0.33, then the Overall Quality Flag **shall** be set to 'non-acceptable'.

b. If the numerical equivalent of the Overall Quality Flag is larger than or equal to an upper threshold value, set by a set-up parameter, nominal value 0.66, then the Overall Quality Flag **shall** be set to 'acceptable'.

c. If condition *a* and condition *b* do not apply then the Overall Quality Flag **shall** be set to 'suspect'.

19.4 Outputs

The following data **shall** be output:

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Satellite ID	SAT_ID	-	1	3	1	1	CAL Header
Date and Time of Repeat Cycle	CAL_RC_DATE	YYYYMMDDHHMMSS	-	-	-	-	CAL Header
Abs Cal Performed flag per channel	ABS_CAL_PERF	-	FALSE	TRUE	-	-	CAL Header
Applicable Date/Time for Abs Calibration per channel	CAL_DATE	YYYYMMDDHHMMSS	-	-	-	-	CAL Header
Cal Mon Quality flag per channel	CM_QF	-	-	-	-	-	CAL Header
Vicarious Operational Calibration Coefficient per channel	VOCC	-	-	-	-	-	CAL Header
Vic Cal Quality flag per channel	VICC_QF	-	-	-	-	-	CAL Header
Cross-Satellite Operational Calibration Coefficient per channel	CSOCC	-	-	-	-	-	CAL Header
Xsat Cal Quality flag per channel	XSAT_QF	-	-	-	-	-	CAL Header
Cal Data for IMPF, per channel:							
Quality Flag for Level 1.5 data	QF	-	-	-	-	-	CAL Header
Used Reference Data Flag	rdf	-	-	-	-	-	CAL Header
Absolute Calibration Method Flag	ABC_flag	-	-	-	-	-	CAL Header
Abs Cal Weight (Vic. Cal)	AC_wt_vic	-	0	1	-	-	CAL Header
Abs Cal Weight (Xsat. Cal)	AC_wt_xsat	-	0	1	-	-	CAL Header
Absolute Calibration Coefficients	CC	-	-	-	-	-	CAL Header
Estimated Accuracy of Absolute Calibration	ACC	-	-	-	-	-	CAL Header
Bias from Calibration Monitoring	BIAS	-	-	-	-	-	CAL Header
RMS from Calibration Monitoring	RMS	-	-	-	-	-	CAL Header
Space Count	Space_cnt	Counts	0	-	-	-	CAL Header

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
BB Cal Data:							
On-board Black body calibration Data	BB_CAL	-	-	-	-	-	CAL Header
VICC History Data:							
VICC Calibration Time	OLD_TIME	YYYYMMDDHHMMSS	-	-	-	-	CAL Header
VICC Calibration Type	VICC_TYPE	-	-	-	-	-	CAL Header
Old VICCs	OLD_VICC	-	-	-	-	-	CAL Header
Cal Mon Data, per collocation:							
Collocation latitude	col_lat	degrees	-90	90	0.01	0.01	CAL
Collocation longitude	col_lon	degrees	-180	180	0.01	0.01	CAL
Collocation box size (N-S)	col_size	pixels	1	-	-	-	CAL
Collocation box size (E-W)	col_size	pixels	1	-	-	-	CAL
Collocation time	C_TIME	-	-	-	-	-	CAL
Collocation channel	C_CHAN	-	-	-	-	-	CAL
Mean Observed radiance (SEVIRI)	OBS_RAD	-	-	-	-	-	CAL
Mean Calculated radiance (from RTM)	CALC_RAD	-	-	-	-	-	CAL
Local Difference	LOCAL_DIFF	-	-	-	-	-	CAL
Abs Cal Data, per collocation:							
For all VICCs used to calculate the VOCCs, per VICC:							
Collocation latitude	col_lat	degrees	-90	90	0.01	0.01	CAL
Collocation longitude	col_lon	degrees	-180	180	0.01	0.01	CAL
Collocation box size (N-S)	col_size	pixels	1	-	-	-	CAL
Collocation box size (E-W)	col_size	pixels	1	-	-	-	CAL
Collocation time	C_TIME	-	-	-	-	-	CAL
Collocation channel	C_CHAN	-	-	-	-	-	CAL

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Mean Observed radiance (SEVIRI)	OBS_RAD	-	-	-	-	-	CAL
Mean Calculated radiance (from Met Obs)	CALC_RAD	-	-	-	-	-	CAL
Local VICC	LOCAL_VICC	-	-	-	-	-	CAL
For all CSICCs used to calculate theCSOCCs, per CSICC:							
Collocation latitude	col_lat	degrees	–90	90	0.01	0.01	CAL
Collocation longitude	col_lon	degrees	–180	180	0.01	0.01	CAL
Collocation box size (N-S)	col_size	pixels	1	-	-	-	CAL
Collocation box size (E-W)	col_size	pixels	1	-	-	-	CAL
Collocation time	C_TIME	-	-	-	-	-	CAL
Collocation channel	C_CHAN	-	-	-	-	-	CAL
Mean Observed radiance (SEVIRI)	OBS_RAD	-	-	-	-	-	CAL
Mean Observed radiance (from FSD)	FSD_RAD	-	-	-	-	-	CAL
Local CSICC	LOCAL_CSICC	-	-	-	-	-	CAL

Table 70: Calibration Support required outputs

19.5 Prototyping and Testing

No prototyping activity was carried out for this algorithm.

19.6 Future Enhancements

No future enhancements are currently foreseen.

19.7 References

None.

20 CLOUD MASK PRODUCT GENERATION

20.1 Algorithm Configuration Information

20.1.1 Algorithm Name

Cloud Mask (CLM)

20.1.2 Algorithm Identifier

EUM_MSG_CLM_A001

20.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	14/5/98	H.-J. Lutz	CLM Baseline
1.1	31/8/98	H.-J. Lutz	Clarification of the option of the CLM.
1.2	9/9/2002	S. S. Elliott	Redefinition of CLM content, and change of format to GRIB Edition 2. See EUM/MSG/ECP/328.

20.2 Inputs

The Cloud Mask algorithm **shall** use the following data:

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
Scenes type	scenes_type	-	0	255	1	1	pixel	SCE
SCE quality flag	AQC_flag	%	0	100	1	1	pixel	SCE

20.3 Algorithm Functional Specification

20.3.1 Overview

The purpose of the Cloud Mask Product (CLM) is to provide information about the cloud contamination for each pixel for every repeat cycle. The CLM Product is a GRIB Edition 2 encoded product and **shall** provide the following information per pixel:

Classification of pixel type as one of the following:

- clear sky over water
- clear sky over land
- cloud
- no data

The CLM Product **shall** be derived from the existing information produced on a pixel basis for every repeat cycle by the Scenes Analysis (SCE) algorithm.

20.3.2 Algorithm Description

20.3.2.1 Cloud Mask Product

The value for the *cloud_mask* **shall** be generated as follows:

- If the *scenes_type* is 'cloudy', then the *cloud_mask* **shall** be set to 'cloud'.
- If the *scenes_type* is 'clear with sunglint', then the *cloud_mask* **shall** be set to 'clear sky over water'.
- If the *scenes_type* is 'snow/ice over land', then the *cloud_mask* **shall** be set to 'clear sky over land'.
- If the *scenes_type* is 'snow/ice over water', then the *cloud_mask* **shall** be set to 'clear sky over water'.
- If the *scenes_type* is 'water', then the *cloud_mask* **shall** be set to 'clear sky over water'.
- If the *scenes_type* is one of the surface types, then the *cloud_mask* **shall** be set to 'clear sky over land'.
- If the *scenes_type* is 'no scenes identified, missing input data', then the *cloud_mask* **shall** be set to 'no data'.

20.3.3 Automatic Quality Control (AQC)

Not required as already performed as part of Scenes Analysis.

20.4 Outputs

The following data **shall** be produced for the cloud mask product for every pixel in the form of a GRIB Edition 2 encoded product.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Cloud Mask	cloud_mask	-	0	3	1	1	CLM

The parameter value is defined in code table 4.217 of GRIB Edition 2. A specific entry (7) was added to code table 4.2 (Product Discipline 3, Parameter Category 0) to specify cloud mask data.

Parameter	*Value*	*Meaning*
Cloud Mask	0	Clear sky over water
	1	Clear sky over land
	2	Cloud
	3	No data

20.5 Prototyping and Testing

CLM extraction has been extensively tested during the Post-Acceptance Support phase of the project.

20.6 Future Enhancements

None

20.7 References

None

21 TOTAL OZONE PRODUCT GENERATION

21.1 Algorithm Configuration Information

21.1.1 Algorithm Name

Total Ozone (TOZ)

21.1.2 Algorithm Identifier

EUM_MSG_TOZ_A001

21.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
Draft A	04/01/99	F. Karcher	TOZ Draft Baseline
1.0	15/01/99	H.-J. Lutz	TOZ Baseline
2.0	25/07/05	R. Swifte	Replacement algorithm
3.0	29/10/09	J. D. Jackson L. van de Berg	Removed some obsolete parameters from the static application data table, and removed the description for the AQC (Automatic Quality Control) in the intermediate product. See the Updated Product Enhancement section.
4.0	02/02/11	J. D. Jackson	Addition of current repeat cycle method as alternative option for final product derivation. Final product segment size is now 3 × 3 not 32 × 32 pixels.
5.0	17/06/11	J. D. Jackson	Replacement algorithm.

21.2 Inputs

The Total Ozone generation is technically part of the Global Instability Indexing processing. For more technical information on the processing of input data, see Chapter 22.

21.3 Algorithm Functional Specification

21.3.1 Overview

The scientific principle of the Total Ozone algorithm is described in "ATBD for the MSG GII/TOZ Product" (see Section 21.7 for full reference). TOZ is generated as a by-product of GII using the same algorithm, but the TOZ output is then produced as a separate product.

21.3.2 Algorithm Description of the Final TOZ Product

In the following the determination of the final TOZ product is described.

The final TOZ product **shall** be derived on a TOZ processing segment (nominally 3 × 3 pixels).

For each repeat cycle and each processing segment the total ozone **shall** be calculated.

21.3.3 Automatic Quality Control (AQC)

For each segment and each repeat cycle the following parameters **shall** be calculated:

21.3.3.1 AQC for the Final Total Ozone Product

AQC Flag Quality	*Description*
0-7	Reserved.
8	Insufficient pixels (not processed).
9	First guess good (ozone retrieval using optimal estimation is not necessary; ozone forecast data is used to determine the total ozone).
10	High cloud (not processed).
11	Successful retrieval (ozone retrieved using the optimal estimation method).
12	Bad retrieval (unable to retrieve the ozone using the optimal estimation method).

21.3.3.2 Processing Segment Type

Segment Type	*Description*
0	Cloudy
1	Clear
2	Unknown
3	Insufficient pixels to classify
4	Outside processing area

21.3.3.3 Pixel Count within the Processing Segment

Pixel Count	*Description*
0-9	The number of pixels within the segment that are used to classify the segment as either clear, cloudy or unknown (i.e. if the segment is classified as clear, then cloudy and unknown pixels are rejected in the processing). If the number of pixels classified as either clear or cloudy is greater than a configurable threshold, the segment is processed; unknown segments **shall** **not** be processed.

21.4 Outputs

21.4.1 Output of the Final TOZ Product

The following data **shall** be produced for the final TOZ product for every processing segment:

FINAL TOZ PRODUCT							
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Total Ozone	TOZ_{fin}	Dobson	0	600	1	10	
PixelCount	Number of Pixels used	1	0	9	1	1	
SegType	Segment Type	-	0	4	1	1	
AQC Flag	Quality indicator	-	8	12	1	1	
Seg Row No	Segment Row	-	1	3712	1	1	
Seg Col No	Segment Column	-	1	3712	1	1	
Latitude	Lat	degrees	–90	90	0.001	0.001	
Longitude	Lon	degrees	–180	180	0.001	0.001	

Table 71: Final TOZ Product required output

21.5 Prototyping and Testing

A complete set of input data and output data will be available at Météo-France to be used as test data and test results.

21.6 Future Enhancements

The following Future Enhancements **shall** be foreseen in the design of the algorithm:

- The resolution of the forecast data **shall** be improved, thereby improving the first guess of the ozone data within the segment.

The enhancements will not change the TOZ product generation. They will be studied as tasks designed in the framework of the Ozone SAF.

21.7 References

Reference	*Title*	*Date*	*Author(s)*
Study on the exploitation of the ozone channel on MSG for the extraction of wind information, report for contract EUM/CO/96/439/MPe, p. 5-17	Review of literature on total ozone algorithms using the nadir emission in the 9.7 micron ozone channel	1998	Karcher, F. and Blaison, D.
Study on the exploitation of the ozone channel on MSG for the extraction of wind information, report for contract EUM/CO/96/439/MPe, p. 29-42	The effect of clouds on the TOVS total ozone determination	1998	Karcher, F.
Study on the exploitation of the ozone channel on MSG for the extraction of wind information, report for contract EUM/CO/96/439/MPe, p. 43-104	Total ozone algorithms for geostationary orbiting satellites	1998	Karcher, F, Meyer, J.-P. and Armand, P.
EUM/OPS/TEN/05/0266	Algorithm theoretical baseline for the total ozone retrievals from SEVIRI observations using optimal estimation method	2005	Tjemkes, S. A.
EUM/MET/DOC/11/0247	ATBD for the MSG GII/TOZ Product	2011	König, Marianne

22 GLOBAL AND REGIONAL INSTABILITY INDICES PRODUCTS GENERATION

22.1 Algorithm Configuration Information

The Global and Regional Instability Indices products (GII and RII respectively) are derived using the same algorithm. In addition, the total ozone is retrieved as part of the GII Optimal Estimation (OE) framework and is used to generate the TOZ (total ozone) product. The GII and RII products are described together in this chapter, whilst the TOZ product is detailed in Chapter 21. The difference in product derivation is determined by the resolution, which is a configurable parameter (segment size) in the algorithm. RII, being regional, is computed over a configurable regional area at a higher resolution than both GII and TOZ, which are always computed over the full disc. The TOZ product is a by-product of the GII algorithm, and is therefore always generated at the same resolution as the GII product.

22.1.1 Algorithm Name

Global Instability Index (GII)
Regional Instability Index (RII)

22.1.2 Algorithm Identifier

EUM_MSG_GII_A001

22.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	27/11/00	S.J. Turner	GII Baseline
1.1	08/03/01	S.J. Turner	Update to GII intermediate and final product averaging methods
1.2	16/09/01	M. Koenig	Complete change of output
1.3	06/12/01	S.J. Turner	Minor modifications to GII section during its inclusion to ASD 2.5
1.4	14/01/02	S.J. Turner	Minor corrections
1.5	01/07/05	A. Yildirim	Major change in the algorithm implementation.
1.6	29/10/09	J. Jackson	Addition of three LPW (Layer Precipitable Water) content parameters to the GII intermediate and BUFR product. Improvement to the segment scene type classification added to improve the emissivity calculation.
1.7	17/06/11	J. Jackson	The TOZ product is generated as part of the GII OE framework. The SEVIRI ozone channel and ozone forecast data are added into the OE framework of GII. The pixel emissivity maps are used and replace the previous LUT method. RTTOV upgrade to handle arbitrary number of profile levels is removed from the Future Enhancements list. The version of RTTOV used can already handle an arbitrary number of profiles. Addition of the "ATBD for the MSG GII/TOZ Product" to the reference list.

22.2 Inputs

22.2.1 Dynamic Application Data

The GII/RII algorithm uses the Scenes Actual EBBT that is derived from the level 1.5 data from every repeat cycle from the MSG channels. As defined in the following table, the image data **shall** be available in the form of equivalent black body brightness temperatures (EBBT). The scenes type information from the Scenes Analysis of the current repeat cycle **shall** also be available. It is expected that the latitude and longitude will be derived from the pixel line and column using the geostationary projection transformation. M and D **shall** be derived from the nominal repeat cycle start time in the Level 1.5 header.

Dynamic Application Data for Physical Retrieval Scheme								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Res***	***Source***
EBBT of channels WV6.2, WV7.3, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4 from cloud-free areas (GII, RII, and TOZ), and cloudy areas (TOZ only)	$EBBT_{channel}$	K	170	350	0.1	0.1	pixel	Actual EBBT data in Scenes Analysis
Scenes type	scenes_type	-	0	255	1	1	pixel	Scenes Analysis
Month of year	M	months	1	12	1	1	pixel	Level 1.5 header
Day of month	D	days	1	31	1	1	pixel	Level 1.5 header
UTC Time of day (time of line scan)	H	hours	0	23	1	1	pixel	Level 1.5 header
	M	minutes	0	59	1	1	pixel	Level 1.5 header
Latitude	Lat	degree	-90	90	0.001	0.001	pixel	Level 1.5 data
Longitude	Long	degree	-180	180	0.001	0.001	pixel	Level 1.5 data
Satellite zenith angle (assuming sub-satellite position 0°N and 0°E)	sat_zenith	degree	0	90	0.01	0.01	pixel	Level 1.5 data

Table 72: GII and RII Product dynamic application data for physical retrieval scheme

22.2.2 Static Application Data

The static application data in the following table **shall** be specified separately for each instability index to be calculated.

Static Application Data for Physical Retrieval Scheme				
Parameter	***Mnemonic***	***Units***	***Value***	***Source***
Error covariance matrix for ECMWF forecasts for temperature, humidity and ozone				Static data
Instrument noise in the seven channels used				Static data
Bias Correction for Ch5 (See ***Note***)	chan5_bias	K	0.05	Set-up
Bias Correction for Ch6	chan6_bias	K	-0.07	Set-up
Bias Correction for Ch7	chan7_bias	K	0.00	Set-up
Bias Correction for Ch8	chan8_bias	K	0.00	Set-up
Bias Correction for Ch9	chan9_bias	K	-0.05	Set-up
Bias Correction for Ch10	chan10_bias	K	-0.07	Set-up
Bias Correction for Ch11	chan11_bias	K	1.60	Set-up
Threshold for the cloudiness	cloudthresh	%	50	Set-up
Maximum iteration	Max_iter		6	Set-up
Root Mean Square to define convergence	Rms_thres	K	2	Set-up
RTTOV coefficients for MSG				Static data
Atmospheric pressure level to derive layer precipitable water content	lpw_first_pres	hPa	500	Set-up
Atmospheric pressure level to derive layer precipitable water content	lpw_second_pres	hPa	850	Set-up
Pixel Emissivity Maps				Static data

Table 73: GII and RII Product Static Application Data for Physical Retrieval Scheme

Note: The channel bias correction values shown in this table are for MSG-2 (= Meteosat-9). The values are satellite-dependent and may also vary with time.

All static application data and set-up data **shall** be configurable.

The imaging radiometer instrument on board the MSG satellite is known as SEVIRI (Spinning Enhanced Visible and Infrared Imager). This instrument provides full disc Earth scans from MSG's nominal position over the Greenwich meridian in 11 channels of the visible, near-infrared and infrared spectrum. The 12th channel is a high-resolution visible channel with a sampling distance which is three times higher than that of the other 11 channels, and its images only cover a certain section of the Earth's disc. SEVIRI scans the full Earth disc at 15-minute intervals (or five minutes for RSS), and the sampling rate of individual picture elements is 3 km at the sub-satellite point. The more frequent and comprehensive data collected by MSG will also aid weather forecasters in the fast recognition and successful prediction of dangerous weather phenomena such as thunderstorms, which is an important contribution to the nowcasting community. As a support in this area, Air Mass Analysis has been defined as an MSG mission, with the objective to monitor the thermodynamic characteristics of the troposphere using the SEVIRI channels that are responsive in the atmospheric window, water vapour and carbon dioxide absorption bands. The GII is produced at a horizontal resolution of approximately 9 km and the RII at 3 km (at the sub-satellite point). The GII and RII products are distributed via EUMETCast.

The spectral characteristics of the SEVIRI channels are as follows:

Channel	*Band*	*Frequency at Centre (µm)*	*Spectral Coverage (98-99% of Energy) (µm)*	*Noise Specification*
HRV	High resolution visible	(0.75)	Broadband (peak 0.6 – 0.9)	1.07 W/m 2 sr µm
VIS0.6 VIS0.8	Visible	0.635 0.81	0.56 – 0.71 0.74 – 0.88	0.53 W/m 2 sr µm 0.49 W/m 2 sr µm
IR1.6	Near-Infrared	1.64	1.59 – 1.78	0.25 W/m 2 sr µm
IR3.9 IR8.7 IR10.8 IR12.0	Atmospheric Window	3.92 8.70 10.80 12.00	3.48 – 4.36 8.30 – 9.10 9.80 – 11.80 11.00 – 13.00	0.35 K at 300 K 0.28 K at 300 K 0.25 K at 300 K 0.37 K at 300 K
WV6.2 WV7.3	Water Vapour	6.25 7.35	5.35 – 7.15 6.85 – 7.85	0.75 K at 300 K 0.75 K at 300 K
IR9.7	Ozone	9.66	9.38 – 9.94	1.50 K at 250 K
IR13.4	CO2	13.4	12.40 – 14.40	1.80 K at 270 K

Table 74: Spectral characteristics of the SEVIRI channels

22.3 Algorithm Functional Specification

22.3.1 Overview

The Global Instability Index (GII) and Regional Instability Index (RII) products use MSG-SEVIRI observed brightness temperatures plus some additional data to generate indices of atmospheric instability for nowcasting of severe weather.

Two different methods exist for the generation of instability indices:

1. Statistical Retrieval method
2. Physical Retrieval method

Only the Physical Retrieval method will be described here.

The processing of the GII/RII Physical Retrieval scheme involves repeating an identical calculation for each instability index to be calculated. The number of instability indices (n) to be calculated **shall** be variable and **shall** be configurable via the Static Application Data. The following eight indices **shall** be initially defined and set up as part of the baseline GII/RII product:

- K Index (KI)
- KO Index (KO)
- Lifted Index (LI)
- Maximum Buoyancy (MB)
- Precipitable Water Content Index (TPW)
- Layer Precipitable Water (LPW) content between the TOA and 500 hPa
- Layer Precipitable Water content between 500 hPa and 850 hPa
- Layer Precipitable Water content between 850 hPa and the surface

For simplicity, the four instability indices (KI, KO, LI and MB), TPW and LPW will all be referred to as 'instability indices'.

The instability indices are defined as follows:

- Lifted Index LI = $T^{obs} - T^{lifted\ from\ surface}$ at 500 hPa
- K Index KI = $(T^{obs(850)} - T^{obs(500)}) + TD^{obs(850)} - (T^{obs(700)} - TD^{obs(700)})$
- KO Index KO = $0.5 * (\theta_e^{obs(500)} + \theta_e^{obs(700)} - \theta_e^{obs(850)} - \theta_e^{obs(1000)})$
- Maximum Buoyancy MB = $\theta_e^{obs(maximum\ between\ surface\ and\ 850)} - \theta_e^{obs(minimum\ between\ 700\ and\ 300)}$

where:

T^{obs}	is the observed temperature
TD^{obs}	is the observed dew point temperature
θ_e^{obs}	is the observed equivalent potential temperature
	all at the indicated pressure level (in hPa)

22.3.2 Physical Retrieval Average Pixel-Based GII/RII Algorithm Description

The pixel-based GII/RII algorithm initially works independently on each pixel of the image. The following steps **shall** be performed on every pixel of the image.

22.3.2.1 Scenes Type Checks

22.3.2.1.1 Clear Sky Check

Instability cannot be derived for cloudy cases because the state of the lower troposphere, which is essential to all indices of instability, is shielded for the SEVIRI channels. Therefore, only cloud-free pixels **shall** be used.

The GII/RII algorithm **shall** use scenes type information provided by the Scenes Analysis to check whether it states that the pixel is clear or cloudy. All brightness temperatures for cloud-free pixels in a segment **shall** be averaged. If the scene has been identified as clear, the algorithm steps in the following sections **shall** be performed. Otherwise:

- If the segment is covered more than 50 % with clouds, GII/RII **shall** be set to a default value of –999.
- If the scenes type is 'no scenes identified/missing input data' the GII/RII **shall** be set to a default value of –999.

If the segment is identified as not clear the following steps **shall** be skipped and the processing **shall** start with the next segment.

22.3.2.1.2 Land/Sea Check

The scenes type of every pixel as derived from the Scenes Analysis algorithm **shall** be checked.

If the *scenes_type* is water (ocean) the *land_sea* flag **shall** be set to 2 indicating sea. If the *scenes_type* is **not** water (ocean) the *land_sea* flag **shall** be set to 1 indicating land.

22.3.2.1.3 Emissivity Calculations

The emissivity is read for each processed pixel within the segment, from the monthly pixel emissivity maps. The average emissivity is used for segment processing.

22.3.2.2 Time Calculations

For every clear sky pixel, time information **shall** be converted into continuous and periodic phase angles within the year and the day.

The time of year **shall** be calculated as a continuous phase angle φ_{year} from the month (*M*) and day (*D*). The local time of day **shall** be calculated as a continuous phase angle φ_{day} from the longitude (*Long*) and UTC (in hours (*H*) and minutes (*m*) of the exact time the respective image line was scanned).

The following formulae **shall** be applied:

$$\varphi_{year} = \frac{\pi}{180}\left(30.0(M-1)+0.985D\right)$$ *Equation 52*

$$\varphi_{day} = \frac{\pi}{180}\left(15H+\frac{24}{360}Long+0.25m\right)$$ *Equation 53*

22.3.2.3 EBBT Bias Adjustment

For each channel, the EBBT bias (nominally 0) **shall** be added to the EBBTs for each clear sky pixel to create bias-adjusted EBBTs as follows:

$$EBBT\_adj_{channel} = EBBT_{channel} + bias_{channel}$$ *Equation 54*

22.3.3 Physical Retrieval Method

The physical retrieval **shall** reconstruct a temperature, humidity and ozone profile from the satellite-observed radiances or brightness temperatures of a given set of channels and a first-guess profile. Within the retrieval, the profile is modified until its simulated outgoing radiance field at the top of the atmosphere matches the satellite observations, or in practice, until its difference from the observations is minimal. The retrieval thus needs some kind of forward model to simulate the brightness temperatures.

The core of the retrieval is the profile adjustment step (Ma et al. 1999, or Rodgers 1976):

$$\mathrm{x}_{n+1} = \mathrm{x}_0 + (\mathbf{S}_x^{-1} + \mathbf{K}_n^T \cdot \mathbf{S}_\varepsilon^{-1} \cdot \mathbf{K}_n)^{-1} \times \mathbf{K}_n^T \cdot \mathbf{S}_\varepsilon^{-1}\left[\mathrm{T_B} - \mathrm{T}_{B,n} + \mathbf{K}_n \cdot (\mathrm{x}_n - \mathrm{x}_0)\right]$$ *Equation 55*

where:

x	= state vector (atmospheric profile, together with a lower boundary condition)
n	= iteration step; n=0 denotes background profile
T_B	= observed brightness temperature
$T_{B,n}$	= simulated brightness temperature for profile of iteration step n
$\mathbf{S}_x$	= error covariance matrix of background
$\mathbf{K}_n$	= Jacobian matrix at iteration step n
$\mathbf{S}_\varepsilon$	= error covariance matrix of observed brightness temperatures and of radiation model

22.3.4 Automatic Quality Control (AQC)

For each GII/RII processing segment, a unique quality indicator **shall** be defined which is applicable to all instability indices:

AQC = 100 - (Percentage of Cloudy Pixels contained within this Segment)

The range of the AQC is 50 % to 100 %, as any segment which has more than 50% of cloudy pixels is not processed. A segment with AQC of 100 % is of very good quality as there is no cloud contamination, whereas an AQC of 50 % is of poor quality as the cloud contamination is at the maximum allowed.

22.3.5 Radiation Model

The RTTOV model is used to compute brightness temperatures at the satellite level for a given atmospheric profile. This model is also used to compute the weighting function matrix (K_n) which is usually referred to as Jacobians. The radiation model is called *rttov_direct* and outputs the modelled brightness temperatures *ebbt* and also the associated radiances. These two outputs are one-dimensional arrays, containing the modelled temperatures/radiances for the seven MSG channels.

22.4 Outputs

The following data **shall** be produced for the GII/RII product for every pixel, except for the following parameters which are valid for the whole image:

- Segment width (the processing segment width)
- Segment height (the processing segment height)

Note: As already mentioned, the TOZ product is generated as a by-product of GII. TOZ output is provided as a separate product as described under Section 21.4.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
KI index	Ki_index	°C	-	-	-	-	Final GII/RII product
KO index	Ko_index_{fin}	K	-	-	-	-	
Lifted index	Li_index_{fin}	K	-	-	-	-	
Maximum Buoyancy index	Mb_index	K	-	-	-	-	
Total Precipitable Water	TotalPrepWater	mm	-	-	-	-	
Layer Precipitable Water (TOA→500 hPa)	lpw1	mm	-	-	-	-	
Layer Precipitable Water (500 hPa→850 hPa)	lpw2	mm	-	-	-	-	
Layer Precipitable Water (850 hPa→BOA)	lpw3	mm	-	-	-	-	
Segment quality	SegQuality	-	-	-	-	-	
Pixel Row in product	Row	-	0	3712	1	1	
Pixel Column in product	Column	-	0	3712	1	1	
Latitude	Latitude	degrees	–90	90	0.1	0.1	
Longitude	Longitude	degrees	–180	180	0.1	0.1	
Satellite Zenith Angle	SatZenith	degrees	0	180	0.1	0.1	

Table 75: GII/RII product outputs

22.5 Future Enhancements

This future enhancement **shall** be considered in the design of GII/RII: The generation of new instability indices (in addition to the baseline set).

22.6 References

Reference	*Title*	*Date*	*Author(s)*
EUM/MET/DOC/04/0155	GII- Physical Retrieval Algorithm Description	June 2004	König, Marianne
EUMETSAT Technical Memorandum No.9	Atmospheric Instability Parameters Derived from MSG SEVIRI Observations	January 2002	König, Marianne
EUM/CO/98/646/JKK	Development of Operational Algorithms for the Retrieval of Instability Indices from MSG	July 2000	Fuhrhop R., Erdmann A., Czekala H., Simmer C.
J. Appl. Meteor., 38, 501-513.	A nonlinear physical retrieval algorithm – its application to the GOES-8/9 sounder.	1999	MA, X.L., SCHMIT, T.J.. SMITH, W.L.
Rev. Geophys. Spac. Phys., 14, 609-624.	Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation.	1976	Rodgers, C.D.
EUM/MET/DOC/11/0247	ATBD for the MSG GII/TOZ Product	2011	König, Marianne

23 CLEAR SKY REFLECTANCE MAP

23.1 Algorithm Configuration Information

23.1.1 Algorithm Name

Clear Sky Reflectance Map (CRM)

23.1.2 Algorithm Identifier

EUM_MSG_CRM_A001

23.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	25/7/05	T. Heinemann	CRM Baseline
1.1	02/12/08	R. Swifte	CRM now derived every 2 hours between 06 and 20 UTC, not just at noon.

23.2 Inputs

The Clear Sky Reflectance Map algorithm **shall** use the following data:

LEVEL 1.5 IMAGE DATA AND DATA DERIVED FROM THE IMAGE DATA								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
Scenes type	scenes_type	-	0	255	1	1	pixel	SCE
Reflectances for channels VIS0.6, VIS0.8, NIR1.6, IR3.9_sol, HRVIS	$REFL_{channel}$	%	0	150	0.1	0.1	pixel	Derived from level 1.5 image data
Solar zenith angle	sol_zenith	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from level 1.5 image data
Satellite observing angle	sat_zenith	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from level 1.5 image data
Relative azimuth angle sun/satellite	sol_sat_azimuth	degrees	0	360	0.1	0.1	pixel	Derived from level 1.5 image data

23.3 Algorithm Functional Specification

23.3.1 Overview

The Clear Sky Reflectance Map describes the reflection that would be seen from the satellite in the visible and near infrared MSG channels over a cloud-free Earth. No atmospheric correction and no surface reflection correction according to the viewing angle is applied. Therefore, the CRM corresponds to the so-called remote sensing reflectance. It is derived every two hours between 06:00 and 20:00 UTC for the complete visible disc except for the polar regions, and except for sun zenith angles higher than 70 degrees.

23.3.2 Algorithm Description

23.3.2.1 Clear Sky Reflectance Map Product

The CRM product contains the remote sensing reflectance for cloud-free pixels of the MSG channels VIS0.6, VIS0.8, NIR1.6 and NIR3.9. In addition, the sun zenith angle and the azimuthal difference between sun and viewing direction, as well as the number of accumulations, are given for each pixel. If the number of accumulations is 0 the reflection values are taken from a previous CRM. The product is encoded in the GRIB-2 data format.

23.3.2.2 Update of the Clear Sky Reflectance Map

For each pixel the reflectance value for each of channels VIS0.6, VIS0.8, NIR1.6 and IR3.9_sol for clear scenes **shall** be collected for a period of seven days for each specific daily derivation time and averaged, i.e. clear sky reflectance of channel VIS0.6, VIS0.8, NIR1.6 and IR3.9_sol for that pixel.

For each pixel the mean solar zenith angle and the mean relative azimuth angle (sun/satellite) for each specific daily derivation time at the SSP for that seven-day period **shall** be determined. If a pixel has no clear scene in that seven-day period the value of the previous seven-day period **shall** be used. If that value is not available, the value **shall** be set to a default invalid value.

23.3.3 Automatic Quality Control (AQC)

Not required. This is already performed as part of Scenes Analysis.

23.4 Outputs

The following data **shall** be produced for the CRM product for every pixel in the form of a GRIB Edition 2-encoded product.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Reflectances for channels VIS0.6, VIS0.8, NIR1.6, IR3.9_sol	$REFL_{channel}$	%	0	150	0.1	0.1	SCE next
Solar zenith angle	sol_zenith	degrees	0	90	0.1	0.1	SCE next
Relative azimuth angle sun/satellite	sol_sat_azimuth	degrees	0	360	0.1	0.1	SCE next
Number of accumulations	no_accum	-	0	14	1	1	SCE next

Table 76: Clear Sky Reflectance Map required outputs

23.5 Prototyping and Testing

Since the Clear Sky Reflectance Map is produced as part of Scenes Analysis, details of prototyping and testing are included in the appropriate Scenes Analysis Section 5.5.

23.6 Future Enhancements

The following future enhancements **shall** be foreseen in the algorithm design above:

- Increase temporal frequency of product generation.

23.7 References

None

24 DIVERGENCE PRODUCT GENERATION

24.1 Algorithm Configuration Information

24.1.1 Algorithm Name

Divergence (DIV)

24.1.2 Algorithm Identifier

EUM_MSG_DIV_A001

24.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	21/03/07	A. de Smet	DIV Baseline
1.1	27/10/09	A. de Smet	Updated according to AR 19273.

24.2 Inputs

24.2.1 Data From Other MPEF Algorithms (Dynamic Application Data)

The divergence algorithm **shall** use the following data from the AMV Final product.

DATA FROM OTHER MPEF ALGORITHMS							
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Source*
AMV latitude	latitude	degrees	-60	60	0.01	0.01	AMV Final Product
AMV longitude	longitude	degrees	-60	60	0.01	0.01	AMV Final Product
AMV speed	speed	m/s	0	100	0.01	0.01	AMV Final Product
AMV direction	direction	degrees	0	360	0.01	0.01	AMV Final Product
AMV pressure	height	hPa	100	400	0.01	0.01	AMV Final Product
AMV QI, excluding F/C consistency	qi_excl	%	0	100	1	1	AMV Final Product

Table 77: Divergence Product: dynamic application data from other MPEF algorithms

24.2.2 Static Application Data

The static application data **shall** define the following:

- The rectangular processing grid
- The atmospheric layer from which the AMV data should be used
- Static parameters for the mathematical expressions used in the algorithm

STATIC APPLICATION DATA							
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Source***
min latitude	DIV_min_latitude	degrees	–60	60	0.1	0.1	Static data
max latitude	DIV_max_latitude	degrees	–60	60	0.1	0.1	Static data
min longitude	DIV_min_longitude	degrees	–60	60	0.1	0.1	Static data
max longitude	DIV_max_longitude	degrees	–60	60	0.1	0.1	Static data
delta latitude	DIV_delta_lat	degrees	0.1	5.0	0.1	0.1	Static data
delta longitude	DIV_delta_lon	degrees	0.1	5.0	0.1	0.1	Static data
min pressure	DIV_min_pressure	hPa	100	400	0.1	0.1	Static data
max pressure	DIV_max_pressure	hPa	100	700	0.1	0.1	Static data
critical distance	DIV_crit_distance	km	0	1000	0.1	0.1	Static data
critical QI	DIV_crit_QI	%	0	100	1	1	Static data
minimum QI	DIV_min_QI	%	0	100	1	1	Static data
mode	DIV_mode	-	0	1	1	1	Static data

Table 78: Divergence Product: Static Application Data

The static data **shall** be defined in the AMV product static data files and **shall** be configurable.

24.3 Algorithm Functional Specification

24.3.1 Overview

The Divergence product represents the two-dimensional horizontal divergence of the atmospheric velocity field. In Cartesian coordinates it is simply written as follows:

$$Divergence = \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}$$ *Equation 56*

In a latitude-longitude coordinate frame, which is the basis for the algorithm, this becomes:

$$Divergence = \frac{1}{R_e . \cos\phi} \times \left[\frac{\partial U}{\partial \lambda} + \frac{\partial}{\partial \phi}(V.\cos\phi) \right]$$ *Equation 57*

where:

R_e	= Earth's radius
φ	= latitude
λ	= longitude

The algorithm generates divergence values on a latitude-longitude processing grid. It uses as input data the Atmospheric Motion Vectors (AMVs) from the final AMV product for a prescribed atmospheric layer. It will therefore have a frequency of one product per hour.

The product **shall** be generated for the water vapour 6.2 micron channel only (channel 5). It **shall** in principle be possible however to derive divergence products from any spectral channel for which AMV data are available.

24.3.2 Algorithm Description

The algorithm breaks down into the following steps:

Step 1	Read the AMVs from the WV6.2 final AMV product. Ignore AMVs that have an overall quality less than *DIV_min_QI*. Moreover, consider only those AMVs having a final pressure in the range [*DIV_min_pressure* , *DIV_max_pressure*].
Step 2	For each remaining AMV, convert its wind speed and direction to U and V wind components.
Step 3	Define a rectangular processing grid in a latitude-longitude coordinate frame.
Step 4	Apply a Barnes interpolation to the U and V wind components, as well as to the AMV quality (the one excluding the forecast consistency) and the AMV wind speed. This will map the U, V, quality and wind speed values onto the grid points. In data-sparse areas the grid point values will remain undefined; the U, V, quality and wind speed values **shall** be set to a pre-defined 'missing data' value (currently 999.9) for these cases. Refer to Borde (Section 24.7 References) for an introduction to the Barnes interpolation scheme.
Step 5	Calculate the divergence at each grid point, applying the discrete version of Equation 2. If one or more of the U and V components that are used in the calculation have an undefined value, the divergence value itself **shall** become undefined as well. The value **shall** then be set to 999.9.

24.3.3 Automatic Quality Control (AQC)

There **shall** be a quality indicator for each grid point. The value of this indicator **shall** result from the Barnes interpolation of the AMV quality values, as described in Section 24.3.2.

24.4 Outputs

The data in data **shall** be produced for the divergence product in the form of a GRIB Edition 2- encoded product.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
min latitude	DIV_min_latitude	degrees	–60	60	0.1	0.1	DIV
maximum latitude	DIV_max_latitude	degrees	–60	60	0.1	0.1	DIV
minimum longitude	DIV_min_longitude	degrees	-60	60	0.1	0.1	DIV
maximum longitude	DIV_max_longitude	degrees	–60	60	0.1	0.1	DIV
delta latitude	DIV_delta_lat	degrees	0.1	5.0	0.1	0.1	DIV
delta longitude	DIV_delta_lon	degrees	0.1	5.0	0.1	0.1	DIV
minimum pressure	DIV_min_pressure	hPa	100	400	0.1	0.1	DIV
maximum pressure	DIV_max_pressure	hPa	100	700	0.1	0.1	DIV
critical distance	DIV_crit_distance	km	0	1000	0.1	0.1	DIV
critical QI	DIV_crit_QI	%	0	100	1	1	DIV
minimum QI	DIV_min_QI	%	0	100	1	1	DIV
mode	DIV_mode	-	0	1	1	1	DIV
minimum divergence	min_divergence	10^{-6} s^{-1}	–250	250	2	1	DIV
divergence	divergence	10^{-6} s^{-1}	–250	250	2	1	DIV
quality	quality	%	0	100	1	1	DIV
wind speed	windspeed	m/s	0	102	0.4	0.4	DIV

Table 79: Divergence Product: Outputs

24.5 Prototyping and testing

The derivation of the Divergence product has been extensively tested with the Meteorological Division (MET) prototype, as well as on the MPEF validation systems.

24.6 Future Enhancements

No enhancements are currently foreseen.

24.7 References

Reference	*Title*	*Date*	*Author(s)*
J. Appl. Meteor., 3, 396-409	A technique for maximizing details in numerical weather map analysis	1964	Barnes, S.L.
EUM/MET/REP/05/0163	Upper Level Divergence Product Algorithm Description	2005	Borde, Régis.
EUM/OPS/REP/07/0100	Product Validation Report No. 12	2007	de Smet, Arthur.

25 ACTIVE FIRE MONITORING PRODUCT GENERATION

25.1 Algorithm Configuration Information

25.1.1 Algorithm Name

Active Fire Monitoring Product (FIR)

25.1.2 Algorithm Identifier

EUM_MSG_FIR_A001

25.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	30/03/07	A. Yildirim	FIR Baseline
2.0	1/11/08	O. Samain	New FIR algorithm, as specified by EUM/MPEF/DOC/08/0195

25.2 Inputs

25.2.1 Dynamic Application Data

The main input to the Active Fire Monitoring algorithm is the Level 1.5 data from the MSG IR channels. The image data **shall** be available in the form of either equivalent black body brightness temperatures (EBBT) in kelvin (K), or radiances.

LEVEL 1.5 IMAGE DATA AND DATA DERIVED FROM THE IMAGE DATA								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
EBBT of channels IR3.9, IR8.7, IR10.8	$EBBT_{channel}$	K	170	350	0.1	0.1	pixel	Derived from Level 1.5 image data
Reflectances for channel VIS0.6	$REFL_{channel}$	%	0	150	0.1	0.1	pixel	Derived from level 1.5 image data
Standard deviation on a 3 × 3 pixel segment for channels IR3.9, IR10.8	std_EBBT	K	-	-	-	-	pixel	Derived from Level 1.5 image data
Solar zenith angle	sol_zenith	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from Level 1.5 image data
Satellite zenith angle	sat_zenith	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from Level 1.5 image data
Relative azimuth angle sun/satellite	sol_sat_azimuth	degrees	0	360	0.1	0.1	pixel	Derived from Level 1.5 image data
Scene quality	scene_quality	-	0	100	1	1	pixel	Scenes Analysis

Table 80: Active Fire Monitoring Product: Level 1.5 image data

Note: The scene quality is derived by the SCE algorithm (H.J. Lutz, 2007) and represents the probability of cloudiness.

25.2.2 Static Application Data

STATIC APPLICATION DATA - SURFACE DATA								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Resolution***	***Source***
Surface Type Map	surface_type_map	-	0	99	1	1	pixel	Static data
Nearest Coast Map	Nearest_coast	-	0	1000	1	1	pixel	Static data
Emissivity Tables (for each month of the year)	Emissivity_tables	-	0	1	0.01	0.01	pixel	Static data

Table 81: Active Fire Monitoring Product: static application data

The pixel-based land-sea mask /surface type map consists of 17 different land surface types and one ocean/open water surface type. This map has been derived from the International Geosphere-Biosphere Programme (IGBP) surface type map (Loveland and Belward, 1997).

The emissivity tables are created with data from the Global Infrared Land Surface Emissivity project, using MODIS sensor data. The baseline fit method (Seemann et al., 2007), based on a conceptual model developed from laboratory measurements of surface emissivity, is applied to fill in the spectral gaps between the six emissivity wavelengths available in the MOD11 product (more information at http://cimss.ssec.wisc.edu/iremis/). The data are then sampled spatially onto the nominal SEVIRI rectified image grid and averaged over the individual SEVIRI spectral response functions.

25.3 Algorithm Functional Specification

25.3.1 Overview

The Active Fire Monitoring product has been developed for detecting and quantifying biomass burning in Africa.

25.3.2 Algorithm Description

The basic principles of the FIR algorithm are similar to those already in use for other instruments like the GOES-8 3.9 µm IR channel (Weaver and Purdom, 1995), AVHRR (Giglio et al., 1999) and MODIS (Giglio et al., 2003).

The FIR algorithm is only applied to land surfaces with a scene quality lower than or equal to 70, which means that off-shore oil burning fires, fires on small islands (e.g. active volcanoes which also fall under the "hot spot" category) or fires hidden by thick clouds are not monitored by the algorithm. Bare soil land surfaces (deserts) are also excluded from the processing.

For the remaining valid pixels, the FIR algorithm uses the following four criteria to check for potential fire and fire pixels:

- Brightness temperature of channel IR3.9
- Standard deviation of channel IR3.9
- Brightness temperature difference of channel IR3.9 and IR10.8
- Standard deviation of channel IR10.8

The brightness temperature of channel IR3.9 picks up hot spots caused by the fire. The other MSG channels are less sensitive to hot spots. In this test, simple fixed temperature thresholds are used, which are different for day and night (see Section 25.3.2.2).

The standard deviation of channel IR3.9 over 3×3 pixels around a central hot spot is used to identify the real hot spot versus the natural (heated) background temperature of the surface.

As channel IR10.8 is much less sensitive to hot spots, the brightness temperature of IR10.8 will not be as high as the brightness temperature in channel IR3.9. This means that the brightness temperature difference of channels IR3.9 and IR10.8 is also higher than for non-fire pixels.

The reduced sub-pixel fire sensitivity of IR10.8 is furthermore used to correct for miss-classified fire pixels. Pixels that have passed the first three of the above tests can also be missed clouds, highly variable surface types or highly variable terrain elevation. The correction is done by using the standard deviation of channel IR10.8, which will be relatively low in fire regions because the fire pixels have similar brightness temperatures to the surrounding non-fire areas.

The standard deviation is calculated on a 3 × 3 pixel array around each MSG pixel. Water and cloud pixels are excluded from the calculation of the standard deviation. The standard deviation tests are abandoned if fewer than three pixels can be used for the calculation.

The first requirement is to select all pixels which are '*potential*' fire pixels. This first component is often a trade-off between computation speed/overhead and increased false detections on the one hand, and underestimation of fire activity and biomass burning on the other. If the conditions for selecting potential fire pixels are conservative, fewer pixels will be returned, which will reduce the prevalence of false detections whilst benefiting from reduced processing time. On the other hand, if the conditions are quite liberal then a greater number of pixels will be returned, which has the inverse effect by increasing computational overhead and the likelihood of false detections.

The approach adopted in this algorithm is to identify 'potential' fire pixels using a liberal approach since an earlier comparison between SEVIRI and MODIS suggests SEVIRI misses approximately 40% of the fires which MODIS detects. Given this, it was deemed more important to increase the sensitivity of the algorithm so that smaller fires could be detected whilst attempting to reduce false detections.

25.3.2.1 Description of the Threshold Tests

The algorithm distinguishes between potential fires and fires. Pixels with a lower confidence in their results are defined as 'potential fires', those with a higher confidence are defined as 'fires'. The main criteria for defining potential fires and fires are different threshold settings. 'Potential' fires means here that it cannot be stated with absolute certainty that there is a fire within that respective pixel. The thresholds are day- and night-dependent for both potential fire and fire cases.

25.3.2.2 Derivation of the Thresholds

The first step is to generate the predicted clear sky brightness temperatures per channel, per repeat cycle and per pixel from the RTM output. Because of the fact that the RTM uses emissivity values of 1 for all grid points, the given top of the atmosphere clear sky radiance has to be corrected with the given (pixel-based) land surface emissivity. This is performed as follows:

The given top of atmosphere radiance (R_{TOA}), total transmittance (τ_s), surface skin radiance (R_{SFC}) and the downward radiance (R_{DN}) at surface level have to be interpolated in space and time to the given repeat cycle time and the pixel location. The atmospheric contribution (R_{ATM}) to the clear sky radiance is calculated (for each channel) as follows:

$$R_{ATM} = R_{TOA} - R_{SFC} * \tau_s$$

The corrected clear sky radiance (R_{COR}) uses the emissivity ε at pixel location and is calculated as:

1. For channel IR3.9

$$R_{COR} = R_{ATM} + \varepsilon_{3.9} * R_{SFC} * \tau_s + (1 - \varepsilon_{3.9}) * R_{DN} * \tau_s + (1 - \varepsilon_{3.9}) * R_{SOL} * COS(MIN(90, SZEN)) * \tau_s * \tau_s$$

   where R_{SOL} is the top of atmosphere solar irradiance of channel IR3.9, which is 4.883 (mW/(m^2 sr (cm)$^{-1}$)).

2. For channel IR10.8

$$R_{COR} = R_{ATM} + \varepsilon_{10.8} * R_{SFC} * \tau_s + (1 - \varepsilon_{10.8}) * R_{DN} * \tau_s$$

The derived radiances R_{COR} for channels IR3.9 and IR10.8 are converted to brightness temperatures (T_{pred_39} , T_{pred_108}). The thresholds are derived as follows:

Threshold1	$= T_{pred\_39} + a1 + a2 \times SIN(MIN(szmax, sat\_zenith))$
Threshold2	$= MAX(a3, a3 + (sat\_zenith – a4) \times a5)$
Threshold3	$= (T_{pred\_39} - T_{pred\_108}) + a6 + a7 \times SIN(MIN(szmax, sat\_zenith))$
Threshold4	$= a8$
Threshold5	$= T_{pred\_39} + b1 + b2 \times SIN(MIN(szmax, sat\_zenith))$
Threshold6	$= MAX(b3, b3 + (sat\_zenith – b4) \times b5)$
Threshold7	$= (T_{pred\_39} - T_{pred\_108}) + b6 + b7 \times SIN(MIN(szmax, sat\_zenith))$

The coefficients used above are listed in the following table. It should be noted that the coefficients a6, a7, b6 and b7 are set to zero and can be regarded as placeholders for later improvements.

Thresholds coefficients		
Coeff	***Day***	***Night***
szmax	70	70
a1	5	0
a2	5	5
a3	2	2
a4	60	60
a5	0.25	0.25
a6	0	0
a7	0	0
a8	4	4
b1	10	5
b2	5	5
b3	4	4
b4	60	60
b5	0.25	0.25
b6	0	0
b7	0	0

Note: "Day" is defined with a local solar zenith angle lower than szmax and "night" with a solar zenith angle of higher than 90º. For solar zenith angles between szmax and 90º the thresholds are linearly interpolated.

25.3.2.3 Application of the Threshold Tests

The FIR algorithm will be applied if the following conditions are met:

- Pixel is land
- Pixel is at least 5 km away from the nearest coastline/lake
- During day the reflectance in channel VIS0.6 is smaller than 30%
- The sunglint angle is larger than 3º
- The Scene Quality is lower than or equal to 70

The algorithm contains the following tests:

Test 1: T_{39} is greater than threshold1
Test 2: $StdDev_{39} – StDev_{108}$ is greater than threshold2
Test 3: $T_{39} – T_{108}$ is greater than threshold3
Test 4: $StdDev_{108}$ is less than threshold4
Test 5: T_{39} is greater than threshold5
Test 6: $StdDev_{39} – StDev_{108}$ is greater than threshold6
Test 7: $T_{39} – T_{108}$ is greater than threshold7

where:

T_{39}, T_{108}	are the brightness temperatures of channels IR3.9, IR10.8
$StdDev_{39}$, $StDev_{108}$	are the temperature standard deviations calculated on a 3 × 3 pixels box for the same channels, respectively.

Then the tests are applied as follows:

IF (Test 5 AND Test 6 AND Test 7) THEN
    The result is set to *fir_val = probable_fire*
ELSE IF (Test1 AND Test2 AND Test3 AND Test4) THEN
    The result is set to *fir_val = possible_fire*
ELSE
    The result is set to *fir_val = no_fire*
END

In order to provide diagnostic information on which test is true, the final value, coded on a one-byte integer, is calculated as follows:

$$Fire\_output = fir\_val + Test1*4 + Test2*2^3 + Test3*2^4 + Test5*2^5 + Test6*2^6 + Test7*2^7$$

25.3.3 Automatic Quality Control (AQC)

There is no automatic quality control mechanism in the algorithm. The algorithm itself is based on a simple threshold algorithm. After excluding cloudy, desert/bare soil and sea pixels, the remaining land pixels are checked to see if they meet any of the threshold criteria and then they are assigned either fire-free, possible fire or probable fire status. Validation and verification of the fire pixels are done by some users (the Met services in Portugal and Turkey) by comparison against surface observations.

25.4 Outputs

The EUMETSAT FIR product produces two types of output – one is an image-based product generated in GRIB Edition 2 format, and the other is in ASCII format. Both output products are disseminated to the end-users via FTP and EUMETCast. These products can be retrieved from the following FTP address:

ftp://ftp.eumetsat.int/pub/OPS/out/simon/FIRE/

25.4.1 GRIB-2 Encoded Product

The following data **shall** be produced for each pixel for the FIR GRIB-2 encoded product according to WMO FM 92-XIII GRIB Code Table 4.223 - Fire detection indicator:

Code figure	*Meaning*
0	**No fire detected**
1	Possible fire detected
2	Probable fire detected
3	Missing

25.4.2 ASCII-coded Product

For the ASCII-coded text file, the following table **shall** be generated **only** for Possible Fires and Probable Fires:

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Pixel Row	Row	-	0	3712	1	1	
Pixel Column	Col	-	0	3712	1	1	
Latitude	Lat	°	–90	90	0.001	0.001	
Longitude	Lon	°	–180	180	0.001	0.001	
FIR Value		ASCII	-	-	-	-	

Table 82: Active Fire Monitoring Product: ASCII-Coded table requirements

An example of a FIR ASCII text-coded file is given below:

```
Data from EUMETSAT, Satellite: MET09, Date: 2007/05/28 19:45Z

Row:  940  Col:  925  Lat: -26.996 Lon:  30.846 *** Probable fire ***
Row:  941  Col:  922  Lat: -26.967 Lon:  30.953 *** Probable fire ***
Row: 1527  Col: 1239  Lat:  -9.070 Lon:  17.287 *** Probable fire ***
Row: 1570  Col:  994  Lat:  -7.946 Lon:  24.672 *** Probable fire ***
Row: 2331  Col: 3491  Lat:  14.396 Lon: -60.969     Possible fire
Row: 2332  Col: 3492  Lat:  14.431 Lon: -61.078     Possible fire
Row: 2333  Col: 3492  Lat:  14.463 Lon: -61.099     Possible fire
Row: 2336  Col: 3491  Lat:  14.556 Lon: -61.075     Possible fire
Row: 2356  Col: 3489  Lat:  15.190 Lon: -61.340 *** Probable fire ***
Row: 2388  Col: 3479  Lat:  16.187 Lon: -61.201 *** Probable fire ***
```

25.5 Future Enhancements

The current fire monitoring algorithm is able to detect most of the existing active fires with a minimum of false alarms. The validation of the algorithm is still ongoing and may lead to some further improvements of the algorithm.

In particular, some of the remaining problems listed below need to be solved, namely:

- Mixed water (river/lake/coast) and land scenes
- Non-homogeneous land surfaces
- Dusk and dawn periods with rapidly changing IR3.9 values

An example of the limitations of fire monitoring algorithms is given by Morisette et al. (2005).

25.6 References

Reference	*Title*	*Date*	*Author(s)*
Int. J. of Remote Sensing, Vol. 20, No. 10, pp. 1947-1985	Evaluation of global fire detection algorithms using simulated AVHRR infrared data	1999	Giglio L., J.D. Kendall, C.O. Justice
Remote Sensing of Environment, Vol. 87, pp. 273-282	An Enhanced Contextual Fire Detection Algorithm for Modis	2003	Giglio L., J. Descloitres, C.O. Justice, Y.J. Kaufman
Int. Journal of Remote Sensing, Vol. 18, No. 15, p. 3289	The IGBP-DIS global 1 km land cover data set, DISCover: first results	1997	Loveland T.R. and Belward A.S.
EUMETSAT Technical Memorandum No. 4	Cloud processing for Meteosat Second Generation	1999	Lutz H.J.
EUMETSAT, EUM/MET/REP/07/0132	Cloud Detection for MSG – Algorithm Theoretical Basis Document (ATBD)	2007	Lutz H.J.
Int. Journal of Remote Sensing, Vol. 26, No. 19, pp. 4239-4264	Validation of the MODIS active fire product over Southern Africa with ASTER data	2005	Morisette J.T., L. Giglio, I. Csiszar, C.O. Justice
Weather and Forecasting, Vol. 10, pp. 803-808	Observing Forest Fires with the GOES-8, 3.9 µm Imaging Channel	1995	Weaver J.F. and J.F. Purdom
EUMETSAT, EUM/MET/DOC/08/0195	Algorithm Implementation Document for the Active Fire Detection Algorithm	2008	Lutz H.J.
J. Appl. Meteor. Climatol., Vol. 47, 108-123	Development of a Global Infrared Land Surface Emissivity Database for Application to Clear Sky Sounding Retrievals from Multi-spectral Satellite Radiance Measurements	2008	Seemann, S.W., E. E. Borbas, R. O. Knuteson, G. R. Stephenson, H.-L. Huang

26 MULTI-SENSOR PRECIPITATION ESTIMATE PRODUCT GENERATION

26.1 Algorithm Configuration Information

26.1.1 Algorithm Name

Multi-Sensor Precipitation Estimate Product (MPE)

26.1.2 Algorithm Identifier

EUM_MSG_MPE_A001

26.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	30/11/07	T. Heinemann, O. Samain	MPE Baseline

26.2 Inputs

The main inputs to the MPE algorithm are as follows (deriving from two separate satellite sources):

- Level 1.5 data from the MSG IR10.8 channel.
- Microwave imager data from the SSM/I instruments on board the polar-orbiting satellites of the US Defense Meteorological Satellite Program (DMSP).
- Outputs from the Scenes Analysis (SCE).

26.2.1 Dynamic Application Data

As defined in the following table, the MSG IR10.8 image data **shall** be available in the form of equivalent black body brightness temperatures (EBBT) in kelvin (K).

LEVEL 1.5 IMAGE DATA AND DATA DERIVED FROM THE IMAGE DATA								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
EBBT of channel IR10.8	$EBBT_{channel}$	K	170	350	0.1	0.1	pixel	Derived from Level 1.5 image data
Scene type	scene_type	-	0	255	1	1	pixel	Scenes Analysis

Table 83: Multi-Sensor Precipitation Product dynamic application data

EXTERNAL DATA								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
SSM/I rain rate	R_SSMI	mm/h	0	100	0.1	0.1	SSM/I pixel	Derived from SSM/I image data

Table 84: Multi-Sensor Precipitation Product external data

26.2.2 Static Application Data

STATIC APPLICATION DATA – SETUP PARAMETERS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Resolution***	***Source***
Minimum time difference from the collocation reference time for the retrieval of SSM/I data *Or* Minimum time difference from the rain-rate generation reference time for the histogram accumulation	Delta_Tlf	seconds	0	10000	1	1	-	Static data
Maximum time difference from the collocation reference time for the retrieval of SSM/I data *Or* Maximum time difference from the rain-rate generation reference time for the histogram accumulation.	Delta_Tlp	seconds	0	10000	1	1	-	Static data
Collocation box size in latitude	Dlat	-	0	180	0.1	0.1	-	Static data
Collocation box size in longitude	Dlon	-	0	180	0.1	0.1	-	Static data
Processing area size in latitude	Max_Lat_Diff	-	0	180	0.1	0.1	-	Static data
Processing area size in longitude	Max_Lon_Diff	-	0	180	0.1	0.1	-	Static data
Maximum rain rate	Max_Rainrate	mm/h	0	100	0.1	0.1	-	Static data
Minimum rain rate	Min_Rainrate	mm/h	0	100	0.1	0.1	-	Static data
Minimum number of observations inside collocation box to build a LUT	Minpoints	-	0	100	1	1	-	Static data
Rain rate histogram minimum value	Rbin1	mm/h	0	100	0.1	0.1	-	Static data
Rain rate histogram maximum value	Rbin2	mm/h	0	100	0.1	0.1	-	Static data
Rain rate histogram increment	Rstep	mm/h	0	100	0.1	0.1	-	Static data
Brightness temperature histogram minimum value	Tbin1	K	0	1000	0.1	0.1	-	Static data
Brightness temperature histogram maximum value	Tbin2	K	0	1000	0.1	0.1	-	Static data

STATIC APPLICATION DATA – SETUP PARAMETERS								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Resolution***	***Source***
Brightness temperature histogram increment	Tstep	K	0	100	0.1	0.1		
Time offset between reference and the processing time	Time_Delay	seconds	0	10000	1	1	-	Static data
Maximum brightness temperature for accepting MSG observations	Tmax	K	0	1000	0.1	0.1	-	Static data
Threshold value for the percentage of null rain rate elements in a LUT, before assigning a complete zero-rain LUT	Zerohist	-	0	100	0.1	0.1	-	Static data
Threshold below witch SSM/I rain rates are forced to zero	Zerorain	mm/h	0	100	0.1	0.1	-	Static data

Table 85: Multi-Sensor Precipitation Product: Static application dat

26.3 Algorithm Functional Specification

26.3.1 Overview

The MPE algorithm processes MSG data from channel IR10.8 in near real-time (or some time later in the event of delayed processing) and derives instantaneous rain rates at full MSG pixel resolution. As additional input, external satellite data from the SSM/I instrument on board the DMSP satellite series **shall** be required from up to 24 hours before the acquisition time of the MSG image. The scientific background of the algorithm is described in detail in the reference documents in Section 25.6 (Heinemann et al, 2002 & 2003).

26.3.2 Algorithm Description

26.3.2.1 Structure of Processing

The algorithm consists of two independent steps: the collocation of SSM/I and MSG data, and the product generation on the basis of the collocated data sets. In the framework of MPEF these two steps are realised by two activities of the MPE software unit, namely the 'CoLoc' activitiy and the 'ProdGen' activity. The CoLoc activity includes the acquisition and the decoding of the SSM/I data files as well as the calculation of rain rates from the SSM/I data at the original SSM/I resolution.

26.3.2.2 Data Retrieval

SSM/I data for the period between `Delta_Tlp-x` minutes and `Delta_Tlf` minutes before the reference time of the CoLoc activity are retrieved via a link to an external data directory. It **shall** be insured that no duplicated data are used in the processing.

The decoded and calibrated data **shall** be converted to rain rates using the formulae described in the reference documents in Section 0 (Ferraro 1997, Turk et al 1999). Rain rates **shall not** be derived for SSM/I pixels which are flagged as *coast* or *degraded*.

26.3.2.3 Collocation Data Retrieval

A temporal and spatial collocation **shall** be done in a time span from `Delta_Tlp` minutes to `Delta_Tlf` minutes before the reference time of the CoLoc activity. In the case of delayed processing `Delta_Tlp` can also be negative. In this time span the rain rates of SSM/I pixels which are in the MPE processing area are stored together with averaged brightness temperatures (EBBT) of MSG pixels, representing the same geographical area as the SSM/I pixel. The time difference between the measurement of the SSM/I data and the MSG pixel **shall** be smaller than 10 minutes. The real pixel sensing time and not the image time stamp of the MSG image is relevant in this context. Each collocated data point (CDP) consists of the geographical location of the centre of the SSM/I pixel (latitude and longitude), the rain rate derived from SSM/I data and the collocated average MSG EBBT. The CDPs are stored in intermediate data files. The processing area is defined relative to the rectification point by the parameters `Max_Lat_Diff` and `Max_Lon_Diff`.

26.3.2.4 Product Generation

Definition of processing boxes: For the product generation the MSG image is divided into processing boxes (PBs) which are equally spaced in latitude and longitude. The size of the boxes in latitude and longitude **shall** be determined by the parameters `Dlat` and `Dlon`, respectively. The processing area (see above) is filled with PBs without gaps.

Calculation of look-up tables: The CDPs from the intermediate files **shall** be read for the time span from `Delta_Tlp` minutes to `Delta_Tlf` minutes before the reference time of the ProdGen activity. For each PB the corresponding CDPs are identified. A histogram-matching technique is used to derive look-up tables, describing the relation between MSG EBBT and SSM/I rain rate for each single PB. The matching **shall** be done for the EBBT range from `Tbin1` to `Tbin2` with a step of `Tstep`, and for the rain-rate range from `Rbin1` to `Rbin2` with a step of `Rstep`. From high to low rain rates the cumulated histogram for rain rates is calculated at the defined rain-rate steps. In addition, the cumulated histogram is calculated for the EBBTs from low to high temperatures at the respective temperature steps. For each histogram value of the cumulated rain-rate histogram, the corresponding value of the cumulated temperature histogram is searched. The corresponding EBBT is assigned to the rain rate of the cumulated rain-rate histogram. In this way, a set of (`Rbin2-Rbin1`)/`Rstep`+1 pairs of EBBT and rain rate are derived for each PB. These data are stored in look-up tables (LUTs).

Estimation of instantaneous rain rates: The image for channel IR10.8 is read for the reference time of the ProdGen activity. This step can be done either in real-time or delayed. For a given pixel, the rain-rate estimation **shall** be performed only if the scene type is cloudy. Otherwise, the rain rate **shall** be set to zero.

For each pixel of the image, the geographical location is calculated. Then the corresponding PB and its surrounding eight PBs are identified. At the edge of the processing area the number of surrounding PBs can be smaller. The LUTs of the (up to nine) PBs are used to determine rain rates for the pixel EBBTs. The final rain rate R is determined as a weighted mean of the (up to nine) pixel rain rates r_i:

$$R = \frac{\sum_{i=1}^{9} w_i r_i}{\sum_{i=1}^{9} w_i} \qquad \textit{Equation 58}$$

The weights w_i are derived from the distance between the location of the pixel and the location of the mid-points of the nine PBs:

$$\text{If } \left| lat_i - lat_{pix} \right| < dlat \text{ and } \left| lon_i - lon_{pix} \right| < dlon$$

then:

$$w_i = \left(\sqrt{(lat_i - lat_{pix})^2 + (lon_i - lon_{pix})^2} \right)^{-1}$$ *Equation 59*

else:

$$w_i = 0$$

26.3.3 Automatic Quality Control (AQC)

For each processing box, there are two Quality Indicators (QIs): a standard deviation and a correlation coefficient. MSG rain rates are first derived from the EBBTs using the LUTs for each CDP. These values are then compared to the initial SSM/I rain rates, by calculating their standard deviation and correlation coefficient.

The correlation coefficient can be used to identify areas where the confidence in the rain retrieval is not sufficient. For instance, if the correlation is less than 0.4 then the MPE product is no longer suitable for locating rain pattern correctly. The standard deviation is useful for estimating the accuracy of the SSM/I rain rates themselves.

26.4 Outputs

The following data **shall** be output:

26.4.1 Intermediate Product

The derived rain rates for each pixel **shall** be written to the intermediate output files, as well as the latest QIs (from the last collocation process), for each processing box.

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*To*
Estimated rain rate	R	mm/h	0	100	0.1	0.1	-
Standard deviation	Stdev	mm/h	0	100	0.1	0.1	-
Correlation coefficient	Correl	-	–1	1	0.1	0.1	-

26.4.2 GRIB-2 Encoded Product

The previous data **shall** be produced for each pixel for the MPE GRIB-2 encoded product according to WMO FM 92-XIII GRIB Code Table 4.2.

26.5 Future Enhancements

The following future enhancements **shall** be foreseen in the algorithm design:

- Use of the WV6.2 channel to discriminate between cirrus (not producing rain) and high-level cumulonimbus (producing rain).
- Replacement of core algorithm by a *morphing* scheme.

26.6 References

Reference	Title	Date	Author(s)
Proceedings of the second international Precipitation Working Group (IPWG) meeting, Madrid, Spain, September 2002	The Eumetsat multi-sensor precipitation estimate (MPE)	2002	Heinemann, T., A. Latanzio
Proceedings of the EUMETSAT users conference , Weimar, Germany, 2003	The EUMETSAT Multi Sensor Precipitation Estimate (MPE): Concept and Validation	2003	Heinemann, T. and J. Kerényi
In: Microwave Radiometry and Remote Sensing of the Earth's Surface and Atmosphere, P. Pampaloni and S. Paloscia Eds., VSP Int. Sci. Publ., 353-363	Meteorological applications of precipitation estimation from combined SSM/I, TRMM and infrared geostationary satellite data	1999	Turk, F. J., G. D. Rohaly, J. Hawkins, E. A. Smith, F. S. Marzano, A. Mugnai and V. Levizzani

27 AEROSOL PROPERTIES OVER SEA PRODUCT GENERATION

27.1 Algorithm Configuration Information

27.1.1 Algorithm Name

Aerosol Properties Over Sea (AES)

27.1.2 Algorithm Identifier

EUM_MSG_AES_A001

27.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	11/05/09	O. Samain	AES baseline

27.2 Inputs

27.2.1 Dynamic Application Data

The main input to the AES algorithm is the Level 1.5 data from the MSG VIS channels, in the form of top of atmosphere reflectances.

LEVEL 1.5 IMAGE DATA AND DATA DERIVED FROM THE IMAGE DATA								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
Reflectances for channels VIS0.6, VIS0.8 and NIR1.6	$REFL_{channel}$	%	0	150	0.1	0.1	pixel	Derived from level 1.5 image data
Solar zenith angle	sol_zenith	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from Level 1.5 image data
Satellite zenith angle	sat_zenith	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from Level 1.5 image data
Relative azimuth angle sun/satellite	sol_sat_azimuth	degrees	0	360	0.1	0.1	pixel	Derived from Level 1.5 image data
Scene type	scene_type	-	0	100	1	1	pixel	Scenes Analysis
Scene quality	scene_quality	-	0	100	1	1	pixel	Scenes Analysis

Table 86: Aerosol Properties Over Sea Product: Dynamic application data

The scene quality is derived by the SCE algorithm (H.J. Lutz, 2007) and represents the probability of cloudiness.

27.2.2 Static Application Data

STATIC APPLICATION DATA – SURFACE DATA								
Parameter	***Mnemonic***	***Units***	***Min***	***Max***	***Prec***	***Acc***	***Resolution***	***Source***
Look-up table for channel VIS0.6	AESLUTChan1	-	-	-	-	-	-	Static data
Look-up table for channel VIS0.8	AESLUTChan2	-	-	-	-	-	-	Static data
Look-up table for channel NIR1.6	AESLUTChan3	-	-	-	-	-	-	Static data
Nearest coast map	Nearest_coast	-	0	1000	1	1	pixel	Static data

Table 87: Aerosol Properties Over Sea Product: Static application data-surface data

27.3 Static Application Data Setup Parameters

STATIC APPLICATION DATA – SETUP PARAMETERS	
Parameter	***Mnemonic***
Maximum scene quality	MaxCloudQuality
Maximum satellite zenith angle	MaxSatZen
Maximum solar zenith angle	MaxSolZen
Maximum distance to coast	MaxDistCoast
Maximum sunglint angle	MaxSunglintAngle
Minimum valid Angström coefficient	MinAngstCoeff
Maximum valid Angström coefficient	MaxAngstCoeff
Size in pixels of the final product	FinalSegmentSize
Maximum valid AOT value for channel 1 for the final product generation	FinalMaxAOTChan1
Maximum valid AOT value for channel 2 for the final product generation	FinalMaxAOTChan2
Maximum valid AOT value for channel 3 for the final product generation	FinalMaxAOTChan3

27.4 Algorithm Functional Specification

27.4.1 Overview

The AES retrieval algorithm is based on the work of Alexander Ignatov from NOAA. He developed similar algorithms for AVHRR and MODIS and also generated the look-up tables for SEVIRI. The theoretical background of his work is described in Ignatov and Stowe, 2002. See Section 26.7.

27.4.2 Algorithm Description

After reading in the image data (channels 1, 2 and 3, i.e. VIS0.6, VIS0.8 and NIR1.6 respectively), the related auxiliary data (latitude, longitude, solar zenith, satellite zenith, relative azimuth, look-up tables) and the Scene type and quality, the retrieval algorithm is applied only if:

- The Scene type is clear water and the scene quality is equal to or lower than *MaxCloudQuality*
- The *SunglintAngle* is lower than *MaxSunglintAngle*, where:

$$SunglintAngle = \left|ACOS(anglecos - anglesin)\right| \times \left[1 - 0.5\left(1 - \left|COS(SolZenAngle)\right|\right)\right]$$

with:

$$anglecos = COS(SolZenAngle) \times COS(SatZenAngle)$$

$$anglesin = SIN(SolZenAngle) \times SIN(SatZenAngle) \times COS(SatSunAzim)$$

- The solar zenith angle is lower than *MaxSolZen*
- The satellite viewing angle is lower than *MaxSatZen*

The aerosol optical thickness (AOT) for each channel is derived by a multi-dimensional interpolation of the look-up table values from *AESLUTChan1*, *AESLUTChan2* and *AESLUTChan3* (two-dimensional and one-dimensional three-point Langrangian interpolation). The table entries are the solar zenith angle, the satellite viewing angle, the relative azimuth angle and the reflectance for the respective channel.

The Angström coefficient (or exponent), which expresses the spectral dependence of AOT with the wavelength of incident light, is calculated as follows:

$$AngstCoeff = -0.5 \times \left[\frac{\log\left(\frac{AOT08}{AOT06}\right)}{\log\left(\frac{0.810}{0.635}\right)} + \frac{\log\left(\frac{AOT16}{AOT08}\right)}{\log\left(\frac{1.640}{0.810}\right)} \right]$$

Equation 60

where

AOT06, AOT08 and AOT16 are the respective AOTs for channels VIS0.6, VIS0.8 and NIR1.6.

Results for which $AngstCoeff$ is less than $MinAngstCoeff$ or greater than $MaxAngsCoeff$ are discarded.

27.4.3 Final product

The intermediate product is generated every repeat cycle at pixel resolution. The final product consists of a daily average (from 00:00 to 23:45 UTC) and a spatial average over $FinalSegmentSize \times FinalSegmentSize$ segments.

Filtering is applied to reject noisy values and artefacts:

First, optical thickness values are rejected IF (AOT0.6 > *FinalMaxAOTChan1*
OR AOT0.8 > *FinalMaxAOTChan2*
OR AOT1.6 > *FinalMaxAOTChan3*)

Secondly, the average *AOTMean* and standard deviation *AOTStd* are calculated for each channel and segment with the values satisfying the previous criteria. The mean is then recalculated by rejecting the data for which:

$$\left|AOTValue - AOTMean\right| > 3 \times (AOTStd + 0.005)$$

Equation 61

27.4.4 Automatic Quality Control (AQC)

There is no automatic quality control mechanism in the algorithm. The use of look-up tables does not allow the generation of uncertainty values. Instead, the *scene_quality* is provided as quality indicator of the input data.

27.5 Outputs

27.5.1 Final Product

Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Format*
Segment row number	SegRowNo	-	0	3712	-	-	Short Int
Segment column number	SegColNo	-	0	3712	-	-	Short Int
Segment latitude	Latitude	°	-90	90	0.01	0.01	Real
Segment longitude	Longitude	°	-180	180	0.01	0.01	Real
Aerosol optical thickness for channels 0.6, 0.8 and 1.6	AOTValues	-	0	10	0.1	0.1	Real(3)
Angström coefficient	AngstCoeff	-	0	3	0.1	0.1	Real
Quality indicator	Quality	%	0	100	1	1	Real

Table 88: Aerosol Properties Over Sea Product: Outputs, final product

27.5.2 Encoded Product

The AES final product is encoded in GRIB Edition 2 format. The specific GRIB codes for AES (Code Table 4.2, Product Discipline 3, Parameter Category 1) are defined in the following table:

Code Figure	*Meaning*
14	Aerosol optical thickness at 0.635 µm
15	Aerosol optical thickness at 0.810 µm
16	Aerosol optical thickness at 1.640 µm
17	Angström coefficient

27.6 Future Enhancements

This process also derives optical depth values over small water bodies like rivers and lakes. For an optimal product, such non-ocean pixels should be removed from the product, which is difficult with the existing cloud mask. We should consider the production of such an "open ocean mask" for this product (not available in MPEF at the moment).

27.7 References

Reference	*Title*	*Date*	*Author(s)*
J. Atmos. Sci., 59, 313-334	Aerosol retrievals from individual AVHRR channels. Part I: Retrieval algorithm, and transition from Dave to 6S RTM	2002	Ignatov and Stowe

28 VOLCANIC ASH DETECTION AND RETRIEVAL PRODUCT GENERATION

28.1 Algorithm Configuration Information

28.1.1 Algorithm Name

Volcanic Ash Detection (VOL)

28.1.2 Algorithm Identifier

EUM_MSG_VOL_A001

28.1.3 Algorithm Specification Version History

Version	*Date*	*Modified By*	*Description*
1.0	10/05/09	O. Samain	VOL baseline
2.0	5/03/12	T. Hultberg	Quantitative ash properties retrieval added

28.2 Inputs

28.2.1 Dynamic Application Data

The main input to the VOL algorithm is the Level 1.5 data from the MSG channels, in the form of top-of-atmosphere reflectances for VIS0.6 and IR3.9 and brightness temperatures for IR3.9, IR8.7, IR10.8 and IR12.0.

LEVEL 1.5 IMAGE DATA AND DATA DERIVED FROM THE IMAGE DATA								
Parameter	*Mnemonic*	*Units*	*Min*	*Max*	*Prec*	*Acc*	*Resolution*	*Source*
Reflectances for channels VIS0.6 and IR3.9	$REFL_{channel}$	%	0	150	0.1	0.1	pixel	Derived from level 1.5 image data
Brightness temperatures for channels IR3.9, IR8.7, IR10.8 and IR12.0	$EBBT_{channel}$	K	0	500	0.1	0.1	pixel	Derived from SCE processing.
Solar zenith angle	sol_zen	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from Level 1.5 image data
Satellite zenith angle	sat_zen	degrees	0	90	10^{-6}	10^{-6}	pixel	Derived from Level 1.5 image data

Table 89: Volcanic Ash Detection and Retrieval Product: Inputs, dynamic application data

28.2.2 Static Application Data

STATIC APPLICATION DATA –THRESHOLD COEFFICIENTS AND LOOKUP TABLE	
Parameter	***Mnemonic***
Thresholds coefficients a*	$a_{\{1A,\ 2A,\ 3A,\ 3B,\ 4A\}}$
Thresholds coefficients b*	$b_{\{1A,\ 2A,\ 3A,\ 3B\}}$
Thresholds coefficients c*	$c_{\{1A,\ 2A,\ 3A,\ 3B\}}$
Ash cloud optical depth lookup table	lut_aod
Ash effective particle radius lookup table	lut_radius

Table 90: Volcanic Ash Detection and Retrieval Product: Static application data

28.3 Algorithm Functional Specification

28.3.1 Overview

The volcanic ash cloud detection algorithm is based on the work of the SAFNWC, and of Jochen Kerkmann (EUMETSAT) and Fred Prata (Norwegian Institute for Air Research). It is based on a combination of threshold tests, depending on the time of day and channel availability. For pixels where volcanic ash is detected, a volcanic ash retrieval algorithm is applied. This algorithm is based on the work of Fred Prata (Norwegian Institute for Air Research) under a EUMETSAT study contract.

28.3.2 Processing mask

The ash detection algorithm is applied to all SEVIRI pixels in the processing area. The ash retrieval algorithm is only applied to pixels in which ash was detected.

28.3.3 Algorithm Description

28.3.4 Ash detection

After reading in the image data, the related auxiliary data (latitude, longitude, solar zenith and static datasets), the processing performs the following steps for each pixel:

Step 1	Check the solar zenith angle for day (sol_zen < 80°), night (sol_zen > 90°) or twilight (between 80° and 90°), to select the thresholds and tests.

Step 2	Calculate the following test flags: Test1A = $(T8.7 - T10.8) > a_{1A} + b_{1A} \times T_{PCS,8.7} + c_{1A} \times T_{PCS,10.8}$ **Test2A** = $(T12.0 - T10.8) > a_{2A} + b_{2A} \times T_{PCS,12.0} + c_{2A} \times T_{PCS,10.8}$ **Test3A** = $(T3.9 - T10.8) > a_{3A} + b_{3A} \times T_{PCS,3.9} + c_{3A} \times T_{PCS,10.8}$ **Test3B** = $(T3.9 - T10.8) < a_{3B} + b_{3B} \times T_{PCS,3.9} + c_{3B} \times T_{PCS,10.8}$ **Test4A** = $(Refl3.9 / Refl0.6) > a_{4A}$ with ($T_{PCS,chan}$) denoting the predicted clear sky brightness temperature in channel *chan* derived from the ECMWF forecast with the radiative transfer model.

Step 3	Apply the following tests:

Test Condition	*Test Logic*	*Result*
Night or Twilight ($sol\_zen >= 80$)	Test 1A *AND* Test2A *AND* Test3A *AND* Test3B	**Ash**
Day ($sol\_zen < 80$)	Test1A *AND* Test2A *AND* Test4A	**Ash**

Step 4	If the result of the tests is Ash and (T12.0 - T10.8) > 0.5**,** the pixel is considered to be potentially ash-contaminated.

28.3.5 Ash retrieval

The ash retrieval algorithm is applied to the pixels which were classified as potentially ash contaminated by the ash detection algorithm above. The inputs to the ash retrieval algorithm are as follows:

- the satellite zenith angle, ***sat_zen***
- the measured brightness temperature in channels IR10.8 and IR12.0, **T10.8** and **T12.0**
- an estimate of the surface skin temperature, $\mathbf{Ts} = \mathbf{T_{PCS,12.0}}$, taken as the predicted clear sky brightness temperature in channel IR12.0
- an estimate of the ash cloud top temperature, **Tc**, obtained from the minimum measured brightness temperature in channel IR12.0 of potentially ash contaminated pixels within a neighbourhood of the current pixel, as further detailed below.

For the estimation of the ash cloud top temperature, the 3712 × 3712 image is divided into 128 × 128 blocks of size 29 × 29 pixels each.

1. Determine the minimum value of T12.0 for potentially ash contaminated pixels within each block.
2. Within each block set Tc to the minimum value of T12.0 in a region of 15 × 15 blocks centered around the current block

From the satellite zenith angle and T10.8 compute a water vapour correction term as

$$\Delta T_{wv} = \min\{1/\cos(sat\_zen), 3\} \times \exp[6 \times (T10.8/320) - 6]$$

The water vapour corrected T10.8 minus T12.0 difference is now computed as

$$\mathbf{TD} = T10.8 - T12.0 - \Delta T_{wv}$$

Given the values of sat_zen, Tc, Ts, T10.8 and TD, the ash cloud optical depth, *aod*, and effective particle radius, *radius*, are looked up in two tables dimensioned as follows:

where:

DIM1	= 12 Satellite zenith angle intervals ( ]82.97..78.98],]78.98..7427], ...,]13.52..0]) degree
DIM2	= 21 Tc ([200..205[, [205..210[, ..., [300 305[ ) K
DIM3	= 17 Ts ( ]220..225],]225..230], ...,]300 305]) K
DIM4	= 200 T10.8 (200.5, 201, ..., 300) K
DIM5	= 100 TD (–0.1, -0.2, ..., -10) K

These tables have been derived by inversion of the tables of T10.8 and T12.0 for varying ash cloud optical depth and effective particle radius provided by Fred Prata.

A further result of the VOL processing is the total ash mass loading, *M*, expressed in kg /m^{-2}, which is related to optical depth and particle radius according to the following:

$$M = 4/3 \times rho \times 1e\text{-}6 \times radius \times aod \times \cos(sat\_zen)/Qext$$

Where rho = 2.6e + 6 g/m^3 is the density of silicate and Qext is the extinction efficiency depending on the radius via a lookup table. Finally, the ash cloud top height (in km) is derived as (Ts-Tc) / 7.

28.4 Outputs

28.4.1 Intermediate Product

The results are stored in as three floats and a one byte quality flag for every pixel, as detailed in the following table:

Data type	*Value*	*Dimension*
float	Volcanic_ash_height	3712 × 3712
byte	Volcanic_ash_height_quality	3712 × 3712
float	Volcanic_ash_loading	3712 × 3712
float	Volcanic_ash_effective_radius	3712 × 3712

28.4.2 Encoded Products

28.4.2.1 NetCDF Product

The fields of the intermediate product are encoded in a single file with netCDF 3 format. The file is compressed with bzip2 and finally an MPEF_PRODUCT_HEADER (of size 172 bytes) is pre-appended to arrive at the VOLEncProduct.

28.4.2.2 Text Product

The VOL product is encoded in ASCII format, one line being written for each pixel for which has been detected. In addition, Common Alert Protocol (CAP) messages are generated by identifying areas where volcanic plumes are present. For each area, a PNG image is produced showing thick and thin ashes. The IR channel at 8.7µm is used as background.

28.5 Future Enhancements

Refinement of the ash detection and improvements to the ash cloud top height product are anticipated.

28.6 References

Reference	*Title*	*Date*	*Author(s)*
Contract EUM/CO/10/4600000775/MK	Volcanic information derived from satellite data	2011	Fred Prata
Technical note	EVOSS products specification	2011	EVOSS project team.

APPENDIX A: OPEN ISSUES TO BE DECIDED OR TO BE CONFIRMED

28.7 Issues To Be Decided (TBD)

None

28.8 Issues To Be Confirmed (TBC)

None

APPENDIX B: GLOSSARY OF TERMS USED IN THIS DOCUMENT

Term	***Definition***
algorithm	'Self contained' routine which inputs data, performs certain processing and then outputs data, e.g. Scenes Analysis. An algorithm may generate a product or may just generate data required by subsequent processes.
configurable	A parameter which is modifiable at run-time (by means of the static data database management utilities) without the need for code modifications.
dynamic	Data which are updated on a regular basis, e.g. for every repeat cycle, for a predictable time or for a predictable repeat cycle (every sixth cycle for example).
EMD processing area	Defined as a 67-degree geocentric angle around the sub-satellite point. This is slightly larger than the area to be used to generate the products themselves in order to allow for correct interpolation at the edges of the MPEF processing area.
intermediate product	Any product which is generated during processing which is not disseminated to users but is required to generate another product.
MPEF processing area	Defined as 65 degrees geocentric angle around the sub-satellite point.
processing segment	A 'segment' of size n by *n* level 1.5 image pixels, where *n* is configurable and product-specific.
product	A product may be classed as a collection of parameters which are generated by an algorithm(s) and which are supplied to an external facility.
static	Data which are considered to be unchanging or only infrequently requiring update (with the frequency being monthly or longer).
superpixel	A processing segment made up of nominally 3 by 3 level 1.5 image pixels.
synoptic scale	Providing a horizontal accuracy of 100 km or better, this corresponds nominally to a processing segment of between 16×16 and 32×32 level 1.5 image pixels.

APPENDIX C: APPLICABLE DOCUMENTS NOT IN THE PUBLIC DOMAIN

This annex lists any applicable documents listed in the Reference section of each Algorithm Specification which are *not* currently available in the public domain.

Reference	*Title*	*Date*	*Author(s)*
None			