HIRS 4 Level 1 Product Generation Specification

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Document Change Record

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
Issue 3 Draft A	15 Nov 2000		Re-structuring of the Document. Original in Framemaker
Issue 3 Draft B	1 June 2001		Section 1.1: Removed note about "Reprocessing"
			Section 1.4: Replaced MHS with HIRS and added algorithm state to Warm Start Parameters
			Section 1.5.2 Added HIRS Flight Operations Manual (TBD)
			Section 2.2.2, - Table 5: *AVHRR Scenes Analysis Data* replaced by *AVHRR L1b Data* - Table 6: Level 0 Product formatted according to AD3 instead of AD4
			Section 2.3.1 - Clarified phrasing on operational modes - Removed summary section on supported platforms, channel failure, and automated operation. These are treated by requirements in section 3.1 and in the CGSRD.
			Section 2.3 - removed "extensively" from "revised and developed." - removed the sentence saying instrument operational modes were not a part of the requirements set. - removed "scenario diagram" section (2.3.1)
			2.3.2.1.1 - subsumed into the general-case notes in Section 2.3.1.1 2.3.2.1.2 - subsumed into the general-case notes in Section 2.3.1.1 2.3.2.2.1.1 - subsumed into Section 2.3.1.1 2.3.2.2.1.2 - subsumed into Section 2.3.1.1
			2.3.2.3.1, 2, 3, and 4 - subsumed into Section 2.3.1.2
			2.3.2.3.1.1 and 2.3.2.3.1.2 subsumed into 2.3.1.2.1
			2.3.2.4.1.1 and 2.2.4.1.2 subsumed into 2.3.2.3.1
			Section 2.3.2 - Removed split mission from degraded operations section - Added TBD to HIRS instrument modes

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			Section 2.3.3 - Added sentence about possible though not guaranteed access to warm-start parameters to Backlog processing section - Noted that the operational scenario for backlog processing was equivalent to that for nominal processing, as seen from the processor viewpoint. Therefore removed sections 2.3.4.1 on states and 2.3.4.2 which was simply a reference
			Section 2.3.4 - modified “it is possible to use a different version of the product algorithms or auxiliary data or configuration data than those which are either currently being used operationally or were in use at the time when the data being reprocessed was current.” by including reference to aux data. - removed paragraph stating “extensive revision” and replaced with sentence noting section might be extended. - moved information from section 2.3.5.2 up to this section. - noted explicitly that a user-configurable switch can be set to determine whether cold-start or, if applicable warm-start parameters have been generated, warm-start parameters are to be used for reprocessing.
			2.3.4.1 - compacted information contained in this section; removed redundant concepts already adequately treated earlier.
			2.3.5.2 - moved non-redundant information from this section to Section 2.3.4 ; removed remnants of section due to their redundancy.
			Section 2.2.1 - moved text describing the processing performed by the PGF to Section 2.3.1
			Section 2.2.1 - moved text describing the processing performed by the PGF to Section 2.3.1
			Section 2.3.2.1 - moved to 2.2.1.1
			Section 2.3.1 - removed remark on contractor’s responsibility for timing apportionment.
			Removed section 2.4 - operational scenario to requirements traceability matrix.
			Section 3 - removed references to MHS and replaced with HIRS. Removed headings 3.3 and 3.4 – traceability matrices.
			Section 3.1.1 - Added note on assumed instrument L0 data input format
			Section 3.1.2.4 - Modified AVHRR/3 Scenes Analysis input to L1B input. - Added requirements for clarification
			Section 3.1.1 - Added note on assumed instrument L0 data input format

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			Section 3.1.2.4 - Modified AVHRR/3 Scenes Analysis input to L1B input. - Added requirements for clarification
			Section 3.2.2.2 - Replaced in requirements L0 with L0/1A/1B
			Section 4 - Added note explaining scan line and pixel numbering convention Removed section 4.3 - trace matrix
			Section 4.1.2 - Added telescope to secondary mirror for better reference HIRS instrument documents
			Section 4.1.2.2 Changed head line - Changed setting of calibration coefficients from zero to default values
			Section 4.1.2.4.2.1 - added “band correction factors” for clarification
			Section 4.1.2.4.2.2 - added “n appropriately chosen” for equation 10
			Section 4.1.2.4.4.1 - removed note in front of“check calibration mode parameter 1” - clarified calibration processing at dump boundaries
			Section 4.1.3.4 - Removed references to SADT diagram
			Section 4.1.4 - replaced TBW with specifications
			Annexes B and C: noted that these are TBD.
5.0	27 Feb 2002		Removed Annexes B and C
			Section 4.1.2.4.1 - 5 PRTs instead of 4
			Section 4.1.4 - generalised instrument mapping algorithm to be applicable also for sounder onto sounder mapping and resolved TBCs and corrected some errors
			Annex A – updated
5/1	5 June 2002		DCN # EUM.EPS.SYS.DCR.0 2.107 Throughout: minor editorial changes.
			Removed section 1.2 Document Evolution
			Section 1.2.1 is now 1.2 and changed in this CGS KO to CGS CDR
			Section 1.3 - added details.
			Section 1.4 - clarified definitions.
			Section 1.5.2 - clarified reference documents.
			Section 2.2.1.1 – removed.
			Section 2.2.2 - updated tables 5 and 6; removed table 7
			Section 2.3 - removed paragraphs dealing with processor states.
			Section 2.3.1 - defined instrument modes according to [RD3].

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			Section 2.3.1.1 - removed text dealing with processor states.
			Section 2.3.1.2 - clarified that level 1a processing is performed only if HIRS is in nominal operation mode and added Digital Surface Type Model and a few minor changes
			Section 2.3.1.2.1 - removed
			Section 2.3.1.3.1 - removed
			Section 2.3.1.4.1 - removed last sentence
			Section 2.3.2 - replaced last paragraph by reference to section 4.1.2.4.4.1
			Section 2.3.4.1 - removed
			Section 2.3.5 - updated table 8 and removed a few entries from it
			Section 3.1 - replaced MHS with HIRS; clarified HIRS-PGF.3.1-0030, 0040, 0050, 0080, 0100, 0130; removed 0150 to 0230
			Section 3.1.1.1 - removed timeliness from 0010 and 0050; removed 0040
			Section 3.1.2.1 - scenes analysis data by l1b data to be consistent with other parts; removed comment from 0010
			Section 3.1.2.2 - replaced brightness temp. by measured radiance in 0020 since counts are calibrated to radiances; removed timeliness from 0080; calibrated to radiances; removed timeliness from 0080;
			Section 3.1.2.3 - removed “Others TBD”.
			Section 3.1.2.4 - minor changes.
			Section 3.1.3 - removed 0030.
			Section 3.2.2.1.1 - removed
			Section 3.2.2.2 - removed “Others TBD” from 0020; removed timeliness from 0030 and 0060
			Section 4.1.1 – removed
			Section 4.1.2.4.1 - corrected equation 4
			Section 4.1.2.4.3 - removed TBCs
			Section 4.1.3 - removed TBCs; clarified reference to document specifying the navigation algorithm
			Annexes: Removed “source” column in variable table.
5/2	14 March 2003		DSN: EUM.EPS.SYS.DCR.03.069 Changes to the NOAA 24-hour calibration section. Clarification of some flag setting procedures during calibration. Minor changes throughout.
			Section 2.3.1. Moved sentence in paragraph 3 concerning cloud coverage to previous level 1a paragraph.
			Section 2.3.2. Changed reference to section 4.1.2.4.4.1 to 4.1.1.4.4.1.

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			At the end of paragraph 3 in section 4, inserted "Except for the case of flags which are passed directly through from the level 0 data stream, where no other specification of the setting of a flag bit is identifiable from a combined reading and analysis of this document and the descriptions and/or names of the flag bits in its associated PFS (AD4), the flag bits shall not be set, and where no other specification of the setting of a flag bit with a name or description in the PFS including the word 'some,' is identifiable in this document or its associated PFS, then the word 'some' in the bit name or description is to be taken to mean 'more than zero,' and where bits are indicated as not used in the PFS, these bits are not to be set"
			Section 4.1.1.2. Included description of instrument mode calibration flag and referenced 'Spare Calibration Coefficients' (default values).
			Section 4.1.1.4.1. Added paragraph describing PRT max-min limit test.
			Section 4.1.1.4.1. Added paragraph describing how CALIBRATION_QUALITY and SCAN_LINE_QUALITY flags are set for marginal and insufficient PRT data.
			Section 4.1.1.4.3. Added description of how to set CALIBRATION_QUALITY and SCAN_LINE_QUALITY flags for marginal and no good space/warm target counts. Also included threshold description.
			Section 4.1.1.3.1, first note. Removed statement regarding casual moon correction. This needs to be addressed separately at a later date.
			Section 4.1.1.4.4.1, paragraph 3. Added in instantaneous intercept coefficients to be passed to 24 hours averaging function.
			Section 4.1.1.4.4.1, paragraph 3. Clarified text referring to currently processed scan line of the previous calibration cycle.
			Section 4.1.1.4.4.1, paragraph after second note. Added appropriate SCAN_LINE_QUALITY flag (bit 14) description and expanded partial calibration cycles description.
			Section 4.1.1.4.4.1, bullet 2. Added text to describe how QUALITY_INDICATOR flag (bit 29) set for next scan line to show previous line missing.
			Section 4.1.1.4.4.1, bullet 4. Changed text concerned to 'When complete calibration scan lines are missing, the instantaneous calibration coefficients for that line cannot be calculated but the earth scan lines may still be calibrated as follows:
			Section 4.1.1.4.4.1, bullet 4.2. Added text to describe how to set SCAN_LINE_QUALITY (bit 14) flag.

Issue / Revision	Date	DCN. No	Changed Pages / Paragraphs
			Section 4.1.1.4.4.1, bullet 4.3. Added description of how to set SCAN_LINE_QUALITY (bit 11) flag.
			Section 4.1.1.4.4.1, section concerning baffle temperature calculation per scan line. Inserted equation and text to describe baffle temperature conversion procedure.
			Section 4.1.1.4.4.1, section concerning baffle temperature calculation per scan line. Inserted text describing baffle temperature limits check.
			Section 4.1.1.4.1.1, 'Calculate IR Calibration Coefficients (NOAA)' section. Inserted equations for a1' and a0' plus explanation of how these should be used to calibrate the earth data. The previous non-prime values are used only for the calculation of the 24 hour our calibration coefficients of the next calibration cycle.
			Section 4.1.1.4.1.1, equation 20. Replaced a 0 with a 0' plus corrected supporting text.
			Section 4.1.1.4.1.1, text just before equation 20. Added reference.
			Section 4.1.1.4.1.1, equation 21. Replaced a 0 with a 0'.
			Section 4.1.1.4.1.1, equation 22. Replaced a 0 with a0'.
			Section 4.1.1.4.1.1, last paragraph. Added text to say if both intercepts or baffle temperatures are missing, then flag bit 11 in SCAN_LINE_QUALITY.
			Section 4.1.2.2. Corrected text (grammatical).
			Section 4.1.3.2.3. Changed 'zarget' to 'target'.
			Section 4.1.3.2.5. Changed all instances of variable Ptr,t,m to L,tr,t,m and corrected in Annex symbol table.
			Section 4.1.3.2.6. Added description of DL,m.
			Section 4.1.3.2.6. Removed DL,m.
			The following symbols and definitions were added to the table in the Annex: A '0 prime intercept calibration coefficient A '0, n ,ic prime intercept calibration coefficient for scan line n, cycle ic. A '1 prime slope calibration coefficient. Ntcs threshold number of cold space counts. Ntwt threshold number of warm target counts.
Issue 5: Revision 3	10 June 2013	EPS Docet 228	Added function HIES-PGF-3.1.2.2-0160 in the Calibration Coefficients section. Also added section 4.1.1.5 to describe the algorithms to calculate the Noise Equivalent Radiance (NEdT). Added Table 8 to show the calculated values for Metop-A. Updated the List of Tables and TOC to reflect new pagination.
V6	17 September 2013		Document transcribed to Word format from Framemaker, retaining original Reference Number.

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1 INTRODUCTION

1.1 Purpose and Scope

This Product Generation Specification (PGS) specifies the requirements for the Metop and NOAA HIRS/4 instrument Product Generation Function (PGF).

1.2 Document Structure

Section	*Contents*
1	This introduction.
2	A short overview of the HIRS/4 Instrument and outlines the operational modes of the HIRS/4 PGF. It also introduces the HIRS/4 PGF as a component in a larger system.
3	Contains the requirements on the PGF
4	Contains the scientific and mathematical algorithm specifications that support the requirements.
Appendix A	Lists the symbols used in Section 4.

1.3 Applicable Documents

The instrument product generation function is a constituent of the CGS. Therefore, unless otherwise specified, all the requirements of the Core Ground Segment Requirements Document (CGSRD) [AD 1] apply to this product generation function. In case of conflict between these product generation function requirements and Core Ground Segment Requirements Document (CGSRD) requirements, the latter shall take precedence. For the definitions used in this document, including the reference frames to be used, see the Mission Conventions Document (MCD) [AD 5], and the Product Conventions Document [AD 6].

No.	*Document Title*	*EUMETSAT Reference*
AD 1	EPS Core Ground Segment Requirements Document	EPS/CGS/REQ/95327
AD 2	Product Processing Software to Product Generation Element IRD	EPS/GGS/IRD/980255
AD 3	EPS Generic Product Format Specification	EPS/GGS/SPE/96167
AD 4	HIRS/4 Level 1 Product Format Specification	EPS/MIS/SPE/97230
AD 5	EPS Mission Convention Document	EPS/GGS/SPE/990002
AD 6	EPS Product Convention Document	EPS/SYS/TEN/990007

1.4 Reference Documents

No.	*Document Title*	*Reference*
RD 1	NOAA KLM USER'S GUIDE	http://www2.ncdc.noaa.gov/docs/klm/html
RD 2	AVHRR/3 Level 1 Product Generation Specification	EPS/SYS/SPE/990004
RD 3	HIRS/4 Instrument Interface Control Document	MO-IC-MMT-HI-0001

1.5 Definitions of Terms Used

Term	*Definition*
HIRS Operational Mode	An operational mode of the HIRS Instrument.
PGF Operational Mode	An operational mode of the HIRS PGF.
Warm Start Parameters	A set of parameters that are re-estimated regularly to best approximate the status of the spacecraft and the algorithm, e.g. calibration history, at a given moment in time. These are required to be stored and can be loaded in case of NRT processing, backlog processing and reprocessing.
Ancillary Data	Refers to the HIRS/4 instrument housekeeping data.
Auxiliary Data	This encompasses any non-HIRS data needed to carry out the PGF's tasks. Auxiliary Data includes but is not limited to AVHRR L1B data.

1.6 Abbreviations and Acronyms Used in this Document

Term	*Definition*
BB	Black Body
CFI	Customer Furnished Items
CGS	EPS Core Ground Segment
CGSRD	EPS CGS Requirements Document
FOV	Field of View
FD	Flight Dynamics
LOS	Line-of-Sight
LSB	Least Significant Bit
LUT	Look-Up-Table
M&C	Monitor and Control
MTF	Modulation Transfer Function
MTTR	Mean Time To Recovery
NIR	Near Infrared
NRT	Near Real Time

1.7 Identification of Algorithm-Related Requirements

DES	Design Constraints
FUNCT	Functional Requirements
INT	Interface Requirements
MMI	Man-Machine Interface Requirements
PERF	Performance (including Accuracy) Requirements
RES	Resource Usage Requirements
RAMS	Reliability, Availability, Maintainability and Safety Requirements
TEST	Testing Requirements

The numbering of the requirements follows the following convention:

MHS-PGF-<SECTION NUMBER>-NNNN TYPES

where:

MHS identifies the instrument;
PGF stands for PGF requirement;
<SECTION NUMBER> is the complete section label (up to 6 levels of indentation);
NNNN is the number of the requirement (reset to 0010 at each section,);
TYPES indicate the relevant types of the requirement, according to the list above.

2 SYSTEMS AND OPERATIONS CONCEPT

2.1 Instrument Description and Rationale

The High Resolution Infrared Radiation Sounder/4 (HIRS/4) is a further development of the HIRS/3 instrument, which flies on the NOAA KLM series satellites. HIRS/4 together with the Advanced Microwave Sounding Unit-A (AMSU-A), the complementary Microwave Humidity Sounder (MHS) and the Advanced Very High Resolution Radiometer (AVHRR/3) form the Advanced TIROS Operational Vertical Sounder (ATOVS) instrument package. HIRS/4 instruments will fly on the Metop and NOAA satellites of the Initial Joint Polar System (IJPS).

The HIRS/4 instrument measures the incident radiation primarily in the infrared region of the spectrum in 19 channels including both long wave (6.5-15 micrometers) and shortwave (3.7-4.6 micrometers) regions, and it also has one channel in the visible (0.69 micrometers). The objective of the ATOVS instruments is to provide global coverage of atmospheric temperature and humidity profiles.

The instrument is composed of a single telescope and a rotating wheel with 20 filters. The energy received by the telescope is separated by a dichroic beam splitter into long wave (greater than 6.4 μm) and shortwave (less than 6.4 μm) energy, controlled by field stops. The shortwave energy is passed through a second dichroic beam splitter to separate the visible channel. At each of the scan mirror positions, all 20 filter segments are sampled. There are separate sensors for the visible, shortwave and long wave IR energy. The shortwave and visible optical paths have a common field stop, the long wave path has an identical but separate field stop.

If the IR channels data appear to be effected by contamination of the sensors the IR channel cooler can be heated up to 300 K. During such a decontamination campaign, HIRS IR scans are not produced. The HIRS/4 data are recorded together with the other instrument data on board the satellite and dumped to diverse ground stations when commanded accordingly. The data are transferred from there to EUMETSAT's CGS for processing.

2.1.1 Spectral Characteristics of HIRS/4

The following table summarises the spectral characteristics of HIRS/4.

Channel	*Centre Wave number (cm^{-1})*	*Centre Frequency. (μm)*	*Half Bandwidth (cm^{-1})*	*Anticipated Max. Scene Temp (K)*	*Specified NEΔN ($mW/m^2/sr/cm^{-1}$)*
1	668.5 ± 1.3	14.959	3.0 + 1/-.5	280	3.00
2	680.0 ± 1.8	14.706	10.0 + 4/-1	265	0.67
3	690.0 ± 1.8	14.493	12.0 + 6/-0	240	0.50
4	703.0 ± 1.8	14.225	16.0 + 4/-2	250	0.31
5	716.0 ± 1.8	13.966	16.0 + 4/-2	265	0.21
6	733.0 ± 1.8	13.643	16.0 + 4/-2	280	0.24
7	749.0± 1.8	13.351	16.0 + 4/-2	290	0.20
8	900.0 ± 2.7	11.111	35.0 ± 5.0	330	0.10
9	1030.0 ± 4.0	9.709	25.0 ± 3.0	270	0.15
10	802.0 ± 2.0	12.469	16.0 + 4/-2	300	0.15
11	1365.0 ± 5.0	7.326	40.0 ± 5.0	275	0.20
12	1533.0 + 2/-6	6.523	55.0 ± 5.0	255	0.20
13	2188.0 ± 4.4	4.570	23.0 ± 3.0	300	0.006
14	2210.0 ± 4.4	4.525	23.0 ± 3.0	290	0.003
15	2235.0 ± 4.4	4.474	23.0 ± 3.0	280	0.004
16	2245.0 ± 4.4	4.454	23.0 ± 3.0	270	0.004
17	2420.0 ± 4.0	4.132	28.0 ± 3.0	330	0.002
18	2515.0 ± 5.0	3.976	35.0 ± 5.0	340	0.002
19	2660.0 ± 9.5	3.759	100.0 ± 15.0	340	0.001
20	14500 ± 220	0.690	1000 ± 150.0	100 % Alb	0.10 % A

Table 1: HIRS/4 Spectral Characteristics

2.1.2 Sampling Characteristics of HIRS/4

HIRS/4 is an across-track scanning system with a rotating mirror and a scan range of ± 49.5° with respect to the nadir direction. The instantaneous field of view (IFOV) of each channel is approximately 0.69 degree, leading to a circular IFOV size close to 10.0 km at nadir for a nominal altitude of 833 km ± 19 km. The major difference between HIRS/3 and HIRS/4 is that HIRS/3 has an instantaneous field of view size close to 20 km. Each scan line takes 6.4 seconds to complete. At the end of the scan line, the mirror rapidly returns to its home position (8 retrace steps of 100 m/sec each) and the scanning pattern is repeated. There are 56 Earth-view samples per scan for a swath width of ± 1080.35 km (sampling time of 100.0 ms). The sampling angular interval is approximately 31.42 milliradians (1.8 degree). The distance between two consecutive scans is approximately equal to 42.15 km.

The HIRS/4 instrument can be commanded by a Calibration Enable command to automatically enter a calibration mode every 256 seconds (every 40 scan cycles). If the instrument is commanded by the Calibration Disable command not to perform calibration scans then normal Earth scans are produced instead of calibration scans.

When the instrument is in the calibration mode, the mirror rapidly slews to a space-view position and performs measurements in all channels for the equivalent time of one complete scan line. Due to the time required to bring the mirror into space-view position the first eight scan steps are not usable; this reduces the number of usable space scan steps to 48. Next, the mirror is moved to a position where it views the warm calibration target and data are taken for the equivalent time of 56 scan steps. Upon completion of the calibration mode, the mirror continues its motion to its home position, where it begins a normal Earth scan. The total calibration sequence is equivalent to two scan lines (no Earth data are acquired during this period). Therefore there will be two lines of calibration data followed by 38 lines of Earth view data–forming a so-called calibration cycle.

The calibration repeatability is specified to be better than 0.3 K and the inter-channel accuracy better than 0.2 K. HIRS/4 also has an on-board cold target as the previous instrument version. However, on HIRS/2 it was found that the cold on-board target did not improve the calibration and was not used in the ground processing. Therefore, on HIRS/4 only the warm on-board target is planned to be used in the operational calibration sequence. The second target view is only selectable by command, resulting in a third calibration scan line. Cold on-board target calibration values are disregarded by the HIRS/4 instrument calibration process if they appear in the scan data.

Characteristics	*Value*	*Unit*
Scan type	Step and dwell	
Scan direction	West to East (northbound)	
Scan rate	6.4	second (s)
Sampling interval	100.0	millisecond (ms)
Sampling interval	1.8	degrees
Pixel s/scan	56	
Retrace steps	8	
Bits/pixel	13	bit
Swath	± 49.5	degrees
Swath width	± 1080.35	kilometre (km)
IFOV	0.69	degrees
IFOV shape (nadir)	circular	
IFOV size (nadir)	10	kilometre (km)
IFOV size (edge) – across track	33.27	kilometre (km)
IFOV size (edge) – along track	17.03	kilometre (km)
Scan separation	42.15	kilometre (km)

Table 2: Scanning Characteristics of HIRS

The following figure shows the location of the centre of the IFOV on-ground projections when the satellite is at the equator, in ascending track and for the full-swath width.

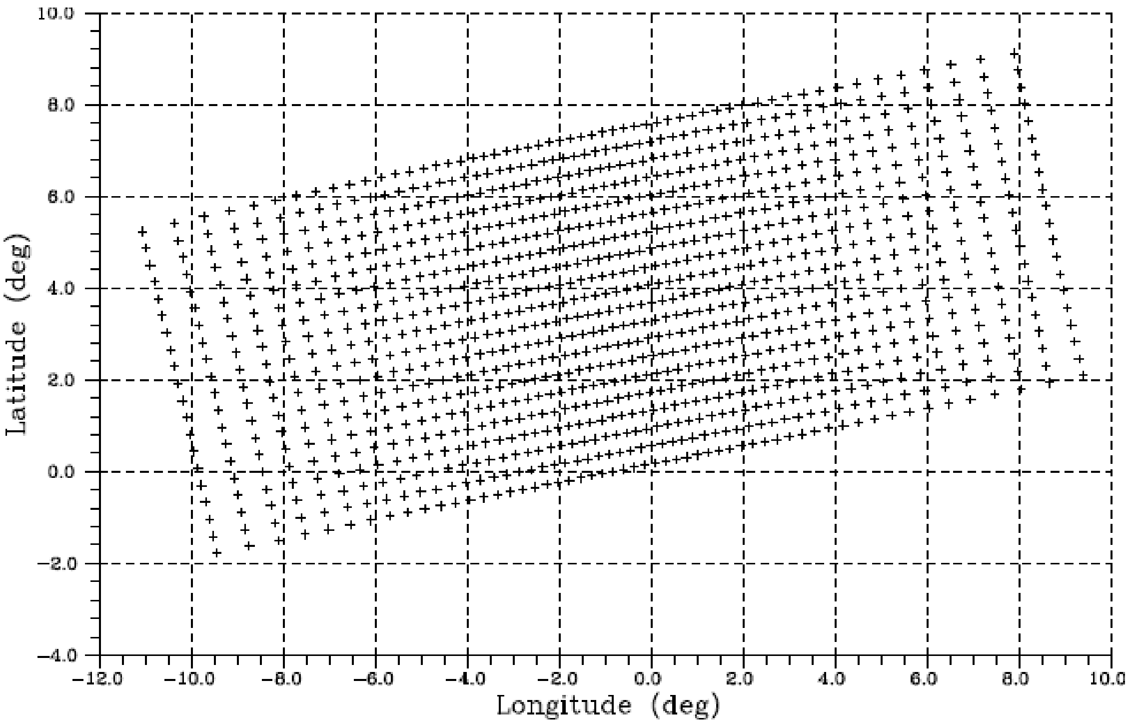

Figure 1: IFOV on-ground projection of HIRS/4 (at the equator in ascending track).

The instrument data are stored on board the satellite until they can be dumped down to a ground station. The dumps are of variable length depending on the number and the location of the ground stations and the orbit/earth surface relation. The dumps are the data units from which the data products are generated. Consequently, the data products are of variable length.

2.2 System Concept

The HIRS PGF shall support all the modes of operations identified in [AD 1].

This section outlines the Operational Modes of HIRS PGF.

2.2.1 System Context

Processing will be performed by Product Processing Software (PPS). The System Context diagram for the HIRS PPS is shown in Figure 2. This figure also depicts the scope of the HIRS PGF.

Note: This document also enumerates which services the PGE has to provide to the HIRS PPS.

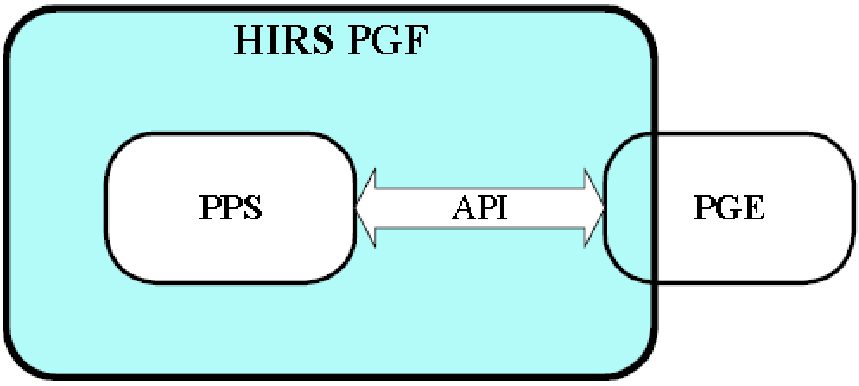

Figure 2: System Context

The PPS makes use of the API provided by the PGE as its only means of external communication. This isolates it from the environment.

The PPS makes use of the PGE services through a dedicated API [AD 2].

The PGE framework also provides a consistent and complete set of services to enable the execution of PPS embedded in this PGE framework both within the CGS and as a stand-alone facility, as a PGE-emulator, to support instrument processor development.

The single use of the API makes the PPS portable between environments that provide the same API together with all the necessary functions to provide the API-services. The PPS requires the API-services provided by the PGE as a prerequisite for its execution .In addition the PPS follows a number of rules established by the PGE on coding rules, invocation procedures, and program structure. The relevant requirements are specified in [AD 2]. This document further clarifies the requirements on the PGE API.

The PGE provides the PPS with all basic functionality to enable it to perform its processing task. In particular support in the following areas is expected to be provided:

Data flow control - to satisfy the PPS's data requests:

- Operational software status and error reporting management
- Control parameters for the PPS. This includes environmental information that is required by the PPS (G/S-1/2, time, machine etc.).
- PPS characterisation information management

Note: This can include, but is not limited to, information on the completeness of the processing of a dump that could be sent to the M and C.

The PGE will provide support services to, for example, replace and restrict the OS services in order to isolate the PPS from the general computational environment and to provide other widely-used functionality, such as the following:

- Orbit propagator function (including orbit and attitude interpolation)
- Earth location utilities (pointing, navigation, co-ordinate conversion)
- Conversion functions (time, location)
- Interpolation functions (space, time)
- Mathematical utilities
- Statistical utilities
- Meteorological, earth and geophysical models and utilities
- Geometric event prediction (celestial bodies position, day/night transition etc.)
- Access to a subset of satellite telemetry
- Access to a Digital Terrain Model.

2.2.2 Major Interfaces

Interface name	***Description***
HIRS/4 Level 0 dataflow	Operational scan mode HIRS/4 Level 0 data in a line by line manner such that there is no difference in the format regardless whether the data are provided by a MetOp or NOAA satellite. RS/4 measurement data (Digital A data) and the instrument ancillary data (Analog and Digital B Telemetry data).
AVHRR/3 Level 1b Data	These are provided by the AVHRR/3 product generation function for the derivation of the cloud coverage data in HIRS/4 level 1a and 1b product.
Auxiliary Data	Corresponds to all data that are required from the G/S and that are not present in the Level 0 data. These are typically all derived information (orbit, attitude, AVHRR L1B data, etc.).
Configuration Parameters	Indicates to the Product Generation Function the version of the static parameters (these are indicated as the user-configurable parameters) that are to be used for the processing. They define, together with the version of the installed processing S/W, the configuration of the processing that is used to derive the products.

Table 3: Input Dataflows for HIRS PGF

Interface name	Description
Level 0 Product	Corresponds to the Level 0 products formatted as defined in the EPS Generic Product Format Specification [AD 3].
Level 1a Product	Corresponds to the Level 1a products formatted as defined in the corresponding HIRS/4 Product Format Specifications [AD 4]
Level 1b Product	Corresponds to the Level 1b products formatted as defined in the corresponding HIRS/4 Product Format Specifications [AD 4]
Reporting Information	Corresponds to the compiled reporting information produced by the product generation function (on the received data, on the instrument performance, on the quality of the processing and on the performance of the mission) that are transferred to the reporting function of the Core Ground Segment. ***Note:*** the information includes also all quality information required by the offline Quality Control function of the CGS.
Monitoring Information	Contains all regular monitoring information on the product generation function, providing the G/S M and C function with the information on the status of the instrument, data, processing functions, processing platforms, and links. In addition, the information contains also all events and command acknowledgements raised by the product generation function.

Table 4: Output Dataflows for HIRS PGF

2.3 Operations Concept

This section describes scenarios pertaining to the operation of the HIRS PGF during the mission lifetime. The PGF can be in one of the following four operational modes:

- nominal operations mode,
- degraded operations mode,
- backlog processing mode,
- reprocessing mode

Section 2.3.5 maps the HIRS PGF Operational Modes to the HIRS Instrument Operational Modes. This section is intended to clarify the relationship between the HIRS PGF and the HIRS Instrument.

2.3.1 Nominal Operation Mode

The HIRS PGF generates the following Level 0, 1a, and 1b Products for the Metop / NOAA spacecraft:

- HIRS_xxx_00_Mnn / HIRS_xxx_00_Nnn,
- HIRS_xxx_1A_Mnn / HIRS_xxx_1A_Nnn,
- HIRS_xxx_1B_Mnn / HIRS_xxx_1B_Nnn

The HIRS Level 1a processing includes the navigation of the HIRS pixels and the calculation of the calibration coefficients for the 19 infrared channels and the provision of (pre-launch determined) calibration coefficients for the visible channel. This information is appended to the HIRS Level 1a data, but the calibration coefficients are not applied. In addition, cloud coverage information in the HIRS pixels FOV is derived from AVHRR L1B data.

The HIRS Level 1b processing includes the application of the calibration coefficients to the Earth view counts to retrieve the radiances for all IR channels and reflectance factors for the one visible channel. Under nominal operations all data of the continuously operated 20 channels of the HIRS/4 instrument will be processed by the PGF, which will support the processing of data from the Metop 1 and 2, NOAA-N, N' satellites1– the level 0/1a/1b products are expected to be extracted 24-hours/day under fully-automated operations throughout the full mission time of the EPS programme. In case of failure of one or more channels, the Instrument Product Generation function will process the remaining channels' data and produce degraded mode products which will be flagged accordingly. No interpolation and/or replacement of missing data with simulated data will be performed. The handling of the majority of these types of 'foreseeable' anomalies is internal to the PGF and will not require specific commanding from the PGE.

The HIRS Instrument has following modes of operation (see [RD3]):

- OFF Mode;
- Heater Mode (for out gassing and decontamination);
- Measurement Mode with Calibration Enabled (nominal mode);
- Measurement Mode with Calibration Disabled (non-nominal mode);
- Continuous Step Mode (degraded mode);
- Inert Mode (contingency mode).

Only when the HIRS/4 instrument is in its nominal mode the PGF will run in its nominal operations mode and generate Level 1a and 1b products. In nominal operation the instrument is operated in a pattern called the 'calibration cycle', and is commanded to automatically enter the calibration mode once every 256 seconds (every 40 scan cycles) to view the cold space and the warm on-board target, the result is the production of two calibration lines followed by 38 lines of nominal earth scans.

It should be noted that although HIRS/4 has an on-board cold target the instrument is not intended to be operated in the extended calibration mode. Should this, nevertheless, be the case, then the calibration cycles will contain one Earth scan line less. These additional calibration scan values are not used by the HIRS/4 instrument calibration process.

2.3.1.1 LEVEL 0 PROCESSING

The level 0 processing is performed for all data, independent of the mode of operation of the instrument.

Level 0 processing consists of the following processes:

- data acceptance and validation;
- combining these data, and quality flags resulting from the combining these data, and quality flags resulting from their checking, in a form that can both be passed to Level 1a Processing as input, and be provided for the formatting of the Level 0 product as described in [AD 3].

The following operations occur during Level 0 processing:

- perform generic checks on data used in processing as per [AD1]
- perform the specific HIRS Level 0 checks
- flag corrupted, missing or duplicate data
- If data quality degradation is detected (for example, if validation checks fail to meet the quality requirements) raise notification events (severity is user-configurable)
- check validity, timeliness and completeness of the Auxiliary Data sets used in processing
- correlate Auxiliary Data sets to the HIRS Level 0 data
- extract the information to be appended to HIRS Level 0 Products
- if Auxiliary Data are invalid or missing, initialise the appended information to default values. Also raise notification events (whose severity is user-configurable)
- accumulate data to perform trend analysis and derive the updated model parameters for the platform/ instrument
- provide the data required for the HIRS Level 0 Product formatting as per [AD3]
- in case of successful/unsuccessful completion of processing as well as the production of any processing outputs, raise events of user-configurable severity.

2.3.1.2 Level 1A Processing

Level 1a processing is performed if and only if the HIRS/4 instrument is in nominal operations mode, which is measurement mode with calibration enabled.

Level 1a processing consists of the following:

- data acceptance and validation;
- navigation of the HIRS/4 pixels;
- calculation of the IR channel calibration coefficients;
- derivation of cloud coverage data from the AVHRR level 1B data supplied by the AVHRR PGF.

The navigation and calibration information are appended to the Level 1a product but the calibration is not applied to the instrument counts. The data acceptance and validation processing step checks all the auxiliary data which are required for the processing to ensure that the data are not corrupted/missing and that the data are correct.

Channel-specific quadratic calibration relations are used to convert the numerical counts returned by the instrument into measured in-band radiances for the 19 infrared channels and a linear calibration to convert counts to reflectance factors for the visible channel. The quadratic coefficients a^2 for the calibration of the thermal channels are determined before launch and are never changed, as are the coefficients for the visible channel calibration.

The intercept and slope calibration coefficients for the thermal channels are determined from the scan lines of the cold space and the warm on-board blackbody target. In nominal scan mode the calibration target scans are performed every 256 seconds–the cold space scan line followed by the black body scan line and 38 Earth scan lines.

The purpose of the navigation processing step is to compute the Earth location in geodetic coordinates (longitude, latitude) of each pixel. Azimuth and zenith angles with reference to the local vertical and north direction at the ground measurement location are computed, as well as solar zenith and azimuth angles.

The following functions are used to perform this task:

- a time handling and processing function which performs the processing of the data using the OBT/UTC correlation data (PGE service);
- an orbit propagator, initialised either with a predicted state vector or with the on-board provided state vector (via PGE service);
- a satellite attitude model to provide the attitude of the platform (via PGE service);
- an instrument viewing model to express the location of the intersection of each optical ray of the considered field of view with the Earth ellipsoid;
- an Earth model for the computation of the navigation (via PGE service);
- a Digital Elevation Model to annotate pixels with surface altitude (via PGE service);
- a Digital Surface Type Model to annotate pixels with surface type (via PGE service).

Cloud coverage is derived for each HIRS/4 Earth scan pixel from the AVHRR/3 level 1B data of the AVHRR pixels contained in the HIRS/4 FOV footprint and are appended to the HIRS/4 level 1a and level 1b products.

2.3.1.3 LEVEL 1B PROCESSING

The Level 1b processing applies the calibration coefficients calculated by the level 1a processing step to convert the instrument counts to in-band radiances in the case of the 19 thermal channels and reflectance factors in the case of the visible channel. The counts are thus replaced by their corresponding physical value.

2.3.1.4 SUPPORT FUNCTIONS

The following list of generic functions is part of the HIRS PGF Specification although the PGE actually supports them. This section also presents the purpose of these functions.

Level 0 data & other input data check & validation	This function is foreseen to provide the isolation of the algorithm and scientific function from the received HIRS Level 0 and input data by validating these before passing them on to the subsequent processing stages. Occurrences of abnormal situations will raise the corresponding events and log/reports. Although the general communication-level checks may be performed using generic PGE services, the validation of the HIRS Level 0 data is instrument-specific.
Instrument status/mode identification:	This function derives the actual mode and state of the instrument from the instrument telemetry and logs / reports this information.
Usage of M &C services:	The PGF uses the generic M&C service of the PGE to receive commands and to output log and monitoring information.
On-line quality control functions:	The purpose of the function is to provide all required statistics on the supported mission and product generation function performance regarding the product quality. On-line quality also implies checks and filtering of outliers in the course of the calibration process (gross limit checks of counts and temperatures, sigma and 2-sigma filtering) as well as consistency check across scan lines.
Parameter estimation function:	The purpose of this function is primarily to re-estimate in Near-Real Time the values of some basic parameters of the models used by the processing. These parameters correspond to the time-varying parameters of the modelled instrument aspect, the gain variation that are not covered by the nominal calibration process.
Generation and compiling of reporting information:	The PGF generates information that will be used for the generation of reports on the Instrument and Mission performance. The PGF compiles all the generated information and makes this reporting information available for the purpose of routine or specific reporting.

2.3.1.4.1 Quality Control

The On-line Quality Control function is a critical part of the near real time processing. Under this function data are checked in near real time to produce quality information which is then disseminated as part of the product itself.

2.3.1.4.2 Reporting

The reporting function collects information about the processing and product extraction and “parcels” it up ready for transmission to an entity external to the PGF, the M&C subsystem, the Cal/Val Facility.

2.3.2 Degraded Operations

This section discusses processing in the case of missing channels and calibration target problems.

Each calibration cycle, the processor usually derives instantaneous calibration coefficients from the mean of the cold space counts and the warm calibration target counts. However, all the expected data may not be available. In such cases, the processing has to follow one of several degraded-processing branches. If some of the cold space or warm calibration target counts are missing, then the processing function must calculate instantaneous calibration coefficients from the remaining counts. It then applies them to the earth scan data. If all the counts for a calibration scan line are missing, however, the PGF cannot do this. It switches to a (temporary) degraded processing mode, which is described in Section 4.1.1.4.4.1.

2.3.3 Backlog Processing

Data are processed as for Nominal Operation Mode, the only difference being that the timeliness requirements for the data no longer apply as the products are not disseminated in real time to Users but are only archived in the UMARF. The conditions for the PGF to enter backlog processing mode are specified in [AD1]. From the point of view of the PGF, processing is equivalent whether it is in backlog mode or in nominal mode. Thus the scenario for processing in Backlog mode is equivalent to that for Nominal mode (see above, Section 2.3.1). Note in particular that the PGF may or may not have access to warm-start parameters, depending both on whether a sufficiently long history has been built up and whether the user-configurable switch (mentioned above) has been set to load warm-start or cold-start parameters.

2.3.4 Reprocessing

Again data are processed as for the Nominal Operations Mode, the only differences being these three:

- the timeliness requirements for the data no longer apply as the products are not disseminated in real time to Users but are only archived in the UMARF;
- historical data are used which may be extracted from the UMARF;
- it is possible to use a different version of the product algorithms or auxiliary data or configuration data than those which are either currently being used operationally or were in use at the time when the data being reprocessed was current.

Reprocessing covers the situations in which data that has previously been processed is processed again, either because the auxiliary data and/or configuration parameters have been changed, or because the software that implements the PGF has been changed.

Data for reprocessing may be interactively selected; as the data to be reprocessed may cover a large number of dumps, the interactive selection shall be able to identify ranges of dumps for reprocessing, along with all applicable auxiliary data and configuration parameters.

Note: As with the backlog and nominal modes, a user-configurable switch can be set to determine whether cold-start or, if applicable, warm-start parameters have been generated. If so, warm-start parameters are to be used.

2.3.5 Summary of the HIRS PGF Operational Modes

Table 7 summarises the Operational Situations the HIRS Instrument may go across versus the Operational Modes of the HIRS PGF.

Operational Situation	*Operational Mode*	*Expected Behaviour*	*Impact on Product*
Nominal NRT Processing	Nominal Operations	Fully nominal product extraction	Nominal quality products
Nominal Backlog Processing	Backlog Processing	Fully nominal product extraction	Nominal quality products
Nominal Reprocessing	Reprocessing	Fully nominal product extraction but based on historical input data “re-injected” via the normal external interfaces. Possibility of modified algorithm version (for product improvement) or same algorithm version. Possibility of loading initial condition for warm start reprocessing.	Nominal quality products
HIRS/4 not in measurement mode with calibration enabled	Nominal Operations Backlog Processing Reprocessing	Since not both measurement and calibration scan data are available no L1 product is generated	No L1 product derived
Manoeuvre	Nominal Operations Backlog Processing	Reprocessing Proper pixel navigation is not possible since orbit and attitude information is obsolete	No L1 product derived
Missing Level 0 data	Nominal Operations Backlog Processing Reprocessing	1. If no Level 0 data for a dump period is available then no Level 1 products are to be produced. 2. If parts of the Level 0 data for a dump period are missing then degraded L1 products are produced containing information on which parts are missing	1. Not derived 2. Degraded and flagged as such
Corrupted Level 0 data	Nominal Operations Backlog Processing Reprocessing	Processing identifies and flags the corrupted data. Processing continues as specified, output products are of degraded quality.	Degraded and flagged as such
Invalid or missing auxiliary data (and/or Instrument TM, G/S aux data)	Nominal Operations Backlog Processing Reprocessing	The processing continues in degraded mode using either interpolated, previous or default side-information (this is case-by case) as per requirements).	Degraded and flagged as such

Operational Situation	*Operational Mode*	*Expected Behaviour*	*Impact on Product*
Missing Channels	Nominal Operations Backlog Processing Reprocessing Degraded Operations	Processing uses a reduced algorithm (to the extent specified) and flags the results as degraded, otherwise the processing enters the relevant Degraded Operations Mode.	Degraded and flagged as such
Invalid/Missing Calibration Scan Lines	Nominal Operations Backlog Processing Reprocessing	No calibration update – older calibration results applied.	Degraded and flagged as such

3 REQUIREMENTS

3.1 Functional and Performance Requirements

The requirements in this section apply to the entirety of the product generation function and derive directly from the basic requirements on the mission this product generation function is supporting.

Note: this instrument-specific functionality is in addition to the generic functions identified in [AD 1]:

HIRS-PGF.3.1-0010	**FUNCT, PERF, INT**
The PGF shall generate Level 0/1a/1b products from input data acquired by the following Instruments and Platforms configurations: 1. Metop-1/HIRS Instrument 2. Metop-2/HIRS Instrument 3. NOAA-N/HIRS Instrument (N=18) 4. NOAA-N´/HIRS Instrument (N=19) ***Note:*** The HIRS/4 instrument is not been scheduled to fly on MetOp-3.	

HIRS-PGF.3.1-0020	**INT**
The HIRS PGF shall generate Level 0/1a/1b products compliant with [AD 4].	

HIRS-PGF.3.1-0030	**FUNCT, INT**
The HIRS PGF shall be able to ingest any HIRS Level 0/1a product and create higher level Products from it.	

HIRS-PGF.3.1-0040	**FUNCT, INT**
The outputs of the PGF shall be formatted as per [AD3], [AD4] and [AD1].	

HIRS-PGF.3.1-0050	**FUNCT, PERF**
The HIRS PGF shall process the HIRS Level 0 data and generate Level 0 products. When the HIRS instrument is in nominal operational mode–in measurement mode with calibration enabled, the HIRS PGF shall generate Level 1a and 1b products of nominal quality.	

HIRS-PGF.3.1-0060	**FUNCT, PERF**
The PGF shall process the HIRS acquired data and generate Level 0/1a/1b products in a degraded manner in the following Operational Situations of the HIRS Instrument: 1. Continuous operation with missing channels 2. Continuous operation with degraded pointing	

HIRS-PGF.3.1-0070	**FUNCT, INT**
The PGF shall support the reception, acceptance and validation of any Auxiliary Data required in the Level 0/1a/1b processing. ***Note:*** This includes but is not limited to instrument TM, G/S auxiliary data, and other products.	

HIRS-PGF.3.1-0080	**INT**
The HIRS PGF shall be able to process any Auxiliary Data identified in this document as being used by it.	

HIRS-PGF.3.1-0090	**FUNCT**
The HIRS PGF shall support the following Operational Modes in compliance with [AD 1]: 1. Nominal Operations Mode 2. Degraded Operations Mode 3. Backlog Processing Mode 4. Reprocessing Mode	

HIRS-PGF.3.1-0100	**DES, INT**
The HIRS PGF shall use the PGE generic API as per [AD 1] to interface with its environment.	

HIRS-PGF.3.1-0110	**FUNCT, DES**
All parameters used for processing shall be user-configurable and S/C and instrument/channel specific.	

HIRS-PGF.3.1-0120	**FUNCT, DES**
The HIRS/4 Level 1 Products generation algorithms shall be implemented as specified in Chapter 3 and detailed in Chapter 4 ***Note:*** Chapter 3 gives the high-level requirements for each function and Chapter 4 gives the detailed scientific implementation details.	

HIRS-PGF.3.1-0125	**FUNCT, PERF**
The level 1 products generated by the HIRS PGF shall contain all scan lines of the current dump and those scan lines from the previous dump (if they were made available to the CGS), including the space and warm target scan lines, that are part of the calibration cycle at the beginning of the current dump.	

HIRS-PGF.3.1-0130	**FUNCT, PERF**
The HIRS PGF shall process the level 0 data and produce products in a degraded manner in the following cases, if applicable: 1. Missing, corrupt, or duplicate instrument L0 or TM data 2. Missing, corrupt, or duplicate auxiliary data	

HIRS-PGF.3.1-0140	**FUNCT, PERF**
A product shall be considered complete if all the required data content (as per [AD 4]) was produced nominally and the complete product made available for dissemination.	

3.1.1 Level 0 Processing

In addition to the generic checks identified in the CGSRD [AD 4], this function performs the instrument specific acceptance and checking of the input data.

Its purpose is to accept the level 0 data and to perform all checks required to validate the input data before passing them further on to the algorithmic functions. Finally, the function correlates the level 0 data with the auxiliary data and extracts the relevant information for the calibration & navigation processing.

Note: The function must be able to cope with all the different Metop spacecraft and with the NOAA platforms, including the handling of the different data formats. The specifications in Chapter 4 assume that the HIRS instrument data are provided as complete scan lines presented in a format being independent of the involved satellite, whether METOP and NOAA.

HIRS-PGF.3.1.1-0010	**FUNCT**
The HIRS L0 processing shall consist of: 1. Reception and Validation of the HIRS Level 0 data; 2. Reception and Validation of the Auxiliary Data.	

3.1.1.1 DATA RECEPTION AND VALIDATION

This function encompasses the check and validation of the HIRS/4 level 0 dataflow from the instrument. The generic checks identified in [AD 1] are followed by the verification against the expected instrument/S/ C configuration and a check for operational scan mode (other data are not processed). This is followed by a coarse data quality check.

The function also receives any required additional information (typically the relevant instrument TM and the auxiliary data), validates them and relates them to the HIRS/4 level 0 dataflow. The function also extracts the mode/state of the instrument.

HIRS-PGF.3.1.1.1-0010	**FUNCT, INT**
The function shall validate the HIRS/4 Level 0 dataflow by checking at least the following aspects: 1. S/C & Instrument identification against the expected configuration; 2. Instrument is in operational scan mode; 3. Time coherency (monotonous, increasing) of the HIRS/4 level 0 data (note this applies also for backlog/reprocessing); 4. Correct sequence of the received data;	

HIRS-PGF.3.1.1.1-0020	**FUNCT, INT**
The function shall perform coarse quality checks on the received HIRS/4 level 0 data, and in particular detect the following: 1. Data corruption resulting in contiguous sequences of same binary values; 2. Data corruption resulting in an sudden (one line to next) change in the line histogram; 3. Abnormal gradients (above an user-configurable threshold) 4. Histogram anomalies (empty bins, stuck bits).	

HIRS-PGF.3.1.1.1-0030	**FUNCT, PERF**
HIRS/4 Level 0 data detected as corrupted or missing shall be identified/flagged as such, allowing the subsequent processing to handle these data without impacting processing of the remaining data.	

HIRS-PGF.3.1.1.1-0050	**FUNCT, PERF**
The Auxiliary Data shall be checked at least for the following: 1. Validity; 2. Completeness.	

HIRS-PGF.3.1.1.1-0060	**FUNCT, INT**
The Auxiliary Data sets shall be correlated to the HIRS Level 0 data to assess whether they can be used for processing the latter. As a minimum, the time correlation shall be performed.	

3.1.2 Level 1a Processing

This function performs the processing of the appended calibration data, using the information from the instrument on-board calibration cycles, the HIRS/4 level 0 data and the information/parameters from on-ground characterisation. The first operation is to validate the received on-board calibration information by verifying the consistency with previous calibration occurrences (if available). The purpose is to avoid corrupted calibration information to propagate through the whole product generation function and the subsequent product extraction.

In addition to the above, this function generates the navigation data to be attached to the products. It uses the validated spacecraft orbit parameters, an Earth model and a model of the instrument/platform to derive the geodetic latitude/longitude coordinates for every HIRS/4 pixel.

HIRS-PGF.3.1.2-0010	**FUNCT**
The HIRS L1a processing shall consist of the following: 1. Data Reception and Validation; 2. Calibration Coefficients Calculation; 3. Navigation Processing; 4. Cloud Coverage Determination.	

3.1.2.1 DATA RECEPTION AND VALIDATION

This function receives AVHRR/3 l1b data from the AVHRR/3 product generation function and checks them for configuration and time consistency.

HIRS-PGF.3.1.2.1-0010	**FUNCT, INT**
The function shall validate the AVHRR/3 scenes analysis data by checking at least the following aspects: 1. S/C and Instrument identification against the expected configuration; 2. Time coherency of the data (note this applies also for backlog/reprocessing); 3. Correctness & completeness of the received data; 4. Correct sequence of the received data.	

3.1.2.2 CALIBRATION COEFFICIENTS CALCULATION

This function receives all extracted information required to perform the calibration processing. It first validates the content of this information, then derives all the calibration parameters needed for the creation of the level 1a appended information.

HIRS-PGF.3.1.2.2-0010	**FUNCT, INT**
The calculation of the calibration coefficients shall consist of the following steps: 1. Scan Mode Check; 2. Calibration Coefficients determination.	

HIRS-PGF.3.1.2.2-0020	**PERF**
The calibration algorithm shall be implemented such that measured (in band) radiance and reflectance factor values are not affected in their 10^{-3} digits by rounding.	

HIRS-PGF.3.1.2.2-0030	**FUNCT, PERF**
All the input data to the on-line calibration processing shall be validated with respect to the source of the data, the data content and the completeness of the information before being used to perform the calibration processing.	

HIRS-PGF.3.1.2.2-0040	**FUNCT, PERF**
The on-line validation of the input data shall include at least the checking of the time consistency with previously validated calibration inputs, if available.	

HIRS-PGF.3.1.2.2-0050	**FUNCT, PERF**
The input data for the calibration shall undergo a gross limit check against user-configurable limits to eliminate outliers.	

HIRS-PGF.3.1.2.2-0060	**FUNCT, PERF**
The processed calibration information shall be checked for consistency with previously generated calibration values for the same instrument/platform, if available.	

HIRS-PGF.3.1.2.2-0070	**FUNCT, PERF**
The following occurrences shall give rise to an event of user-configurable severity: 1. Successful completion of the on-line calibration processing; 2. Successful completion of the Level 1a processing for the corresponding dump; 3. Any failure occurred in the course of the calibration processing.	

HIRS-PGF.3.1.2.2-0080	**FUNCT**
The function shall produce reporting information on the performance of the calibration and HIRS/4 level 1a production, including the following: 1. Information on the on-board calibration events 2. Resulting calibration values; 3. Information on completeness of the produced HIRS/4 level 1a data;	

HIRS-PGF.3.1.2.2-0090	**FUNCT**
If the calibration cycle of the HIRS/4 instrument is enabled the function shall create the calibration parameters for each of the 19 thermal channels for all received Earth scan lines, otherwise skip the calibration step.	

HIRS-PGF.3.1.2.2-0100	**FUNCT**
Cold on-board target scan lines shall be ignored and not be used for calibration.	

HIRS-PGF.3.1.2.2-0110	**FUNCT**
It shall be possible to start the calibration process in a cold mode, without using information from the previous 24-hour period.	

HIRS-PGF.3.1.2.2-0120	**FUNCT**
It shall be possible to start the calibration in a warm mode using the recently saved calibration state vector.	

HIRS-PGF.3.1.2.2-0130	**FUNCT**
The calibration parameters shall be saved as a calibration state vector at the beginning of each calibration cycle and after the 24-hour averaging.	

HIRS-PGF.3.1.2.2-0140	**FUNCT**
Which algorithm alternatives are to be applied shall be controlled by user-configurable mode parameters.	

HIRS-PGF.3.1.2.2-0150	**FUNCT**
The Calibration Coefficients shall be generated as specified in 4.1.1.	

HIRS-PGF.3.1.2.2-0160	**FUNCT**
This function shall calculate the values for the Noise Equivalent Delta Radiance (NEΔR). It comprises the following steps: 1. Use the scan line calibration information to check the completeness and reliability of the space view and the warm target view counts. 2. Using the warm target counts, the cold space counts and the internal warm target temperature, this function shall calculate the Noise-Equivalent radiance for each of the nineteen IR HIRS channels. 3. The information of the *NEΔN*-value is written into the array NEDN_VALUE. 4. The actual NEΔN -value is checked against a predefined threshold. If it exceeds the threshold, a corresponding flag should be set in the 'CALIBRATION_QUALITY' bit field.	

3.1.2.3 NAVIGATION

The navigation function performs the creation of the navigation data of each observation pixel. The navigation data produced are as follows:

- geodetic latitude;
- geodetic longitude;
- Solar zenith angle;
- Satellite zenith angle;
- Solar azimuth angle;
- Satellite azimuth angle;
- Surface elevation;
- Surface type;

The respective reference frames of the MetOp and NOAA S/C have to be used [AD 3].

HIRS-PGF.3.1.2.3-0010	**FUNCT, PERF, DES**
The function shall use the generic orbit and attitude services of the PGE to perform the navigation processing.	

HIRS-PGF.3.1.2.3-0020	**FUNCT, PERF**
The function shall perform the full navigation processing for a user-configurable density of pixels and lines, every pixel and every line are default.	

HIRS-PGF.3.1.2.3-0030	**FUNCT**
The Navigation shall be performed as specified in 4.1.2.	

3.1.2.4 DETERMINE CLOUD COVERAGE

This function determines for each HIRS/4 pixel the percentage of clear AVHRR pixels within the FOV ellipses of the HIRS/4 pixels. This information is derived from the AVHRR/3 level 1B data, which tell for each AVHRR/3 pixel whether it is clear or cloudy. The percentage of clear AVHRR pixels of a HIRS/4 pixel is the ratio of the number of clear AVHRR/3 pixels to the total number of the AVHRR/3 pixels within the FOV ellipse of the HIRS/4 pixel. The mapping of the AVHRR/3 pixels onto the FOV ellipse of the HIRS/4 pixels shall be done by deriving and applying a look up table as specified in Chapter 4.

HIRS-PGF.3.1.2.4-0005	**FUNCT, PERF, DES**
It shall be possible to request or to skip the execution of the function by means of a user-configurable Cloud Coverage Request.	

HIRS-PGF.3.1.2.4-0010	**FUNCT, PERF, DES**
The function shall use the AVHRR/3 level 1B data to derive the cloud coverage within the FOV ellipse of every HIRS/4 Earth scan pixel.	

HIRS-PGF.3.1.2.4-0015	**FUNCT, PERF, DES**
The function shall be capable of mapping high resolution METOP AVHRR/3 level 1B data as well as low resolution NOAA AVHRR/3 level 1B data into the FOV ellipse of every HIRS/4 Earth scan pixel.	

HIRS-PGF.3.1.2.4-0020	**FUNCT, PERF**
If the AVHRR/3 level 1B data is not available after a configurable amount of time after the reception of the corresponding HIRS/4 scan line then the determination of the cloud coverage for that HIRS/4 scan line shall be skipped and default values be put into the HIRS/4 products. ***Note:*** This is to avoid the timeliness of the HIRS/4 products to be jeopardised by missing or late AVHRR/3 level 1b data.	

HIRS-PGF.3.1.2.4-0030	**FUNCT**
The cloud coverage shall be determined as specified in 4.1.3.	

HIRS-PGF.3.1.2.4-0040	**FUNCT, PERF, DES**
The frequency of creating the look-up table for the cloud coverage determination shall be user-configurable.	

3.1.3 Level 1b Processing

From the received Level 1a data and the auxiliary data, this function produces the level 1b data. The counts of the Earth scan pixels are calibrated by means of the calibration relations and the calculated calibration coefficients into physical quantities, i.e. measured radiances for the thermal channels and reflectance factors (percentage albedo) for the one visible channel. The function also produces the appropriate level 1b appended information, which is a constituent of the Level 1b product.

Like any other function, it generates statistics on the processing being performed and provides monitoring information to the M&C interfacing function.

HIRS-PGF.3.1.3-0010	**FUNCT, PERF**
The function shall derive the level 1b data from the level 1a data by using the following information: 1. Appended level 1a data, in particular the derived calibration parameters 2. The on-ground characterised data, made available as configurable databases (e.g. pre-launch defined calibration coefficients).	

HIRS-PGF.3.1.3-0020	**FUNCT, RAMS, DES, PERF**
It shall be possible to configure the level 1b processing function such that the transformation to Level 1b is as follows: 1. Applying the level 1a derived information only if this information is indicated as valid; in the absence of valid information, user-configurable default values shall be applied and the level 1b shall be flagged as such.	

HIRS-PGF.3.1.3-0020	**FUNCT**
The Calibration Coefficients shall be applied as specified in 4.2.1 and 4.2.2.	

3.2 Characteristics Requirements

3.2.1 Interfaces Requirements

Section removed

3.2.2 Monitoring and Reporting Requirements

3.2.2.1 Monitoring Requirements

This section covers the radiometric quality assessment. The radiometric quality assessment consists of the production of a detailed set of radiometric characteristics of the data for each detector/channel, this for different imaged scenes during the dump (Day/night sides, Calibration target viewing, etc.). Geometric quality control is not performed for the HIRS/4 instrument. The produced information will be used to generate detailed quality statistics for analysis purposes. This information (subset) will also be used for reporting on the mission performance/product accuracy. In addition, the derived accuracy information will be post-processed via trend analysis. The Quality Control function will also support the off-line analysis functionality. These MMIs allow analysis of all data received and produced by the product generation function and the extracted quality information. The following specifications address user-configurable parameters defining the windows/locations used for the extraction of radiometric statistics.

HIRS-PGF.3.2.2.1-0010	**FUNCT**
Each subfunction of the product generation function shall monitor its performance and raise events of user-configurable severity on the occurrence of: 1. Any abnormal instrument behaviour being detected; 2. Any occurrence and transition to/from a degraded mode of product generation; 3. Any non-nominal operation of the function; 4. Any occurrence likely to affect the product quality.	

3.2.2.2 Reporting Requirements

This function gathers all the reporting information produced by the different sub-functions of the product generation function and generates the input data for the CGS reporting function. Both the reporting inputs and the full quality information are transferred to the CGS for centralised mission reporting and off-line analysis.

HIRS-PGF.3.2.2.2-0010	**FUNCT, MMI**
All reporting shall be performed in accordance with [AD 1].	

HIRS-PGF.3.2.2.2-0020	FUNCT, MMI
The function shall provide all required near real-time data to the PGE to support the MMI functionality of the CGS in accordance with [AD 1] with the following instrument specific aspects: 1. Representation of the HIRS/4 level 0/1A/1B dataflow for all of the channels of the instrument, with superimposed indication of missing and corrupted data;	

HIRS-PGF.3.2.2.2-0030	FUNCT, MMI
The function shall extract or generate information on the received data (both HIRS and auxiliary data) for the purpose of reporting. These shall include: 1. Parameters describing the validity of the received data; 2. Completeness information on the received data.	

HIRS-PGF.3.2.2.2-0040	FUNCT, INT
The product generation function shall have the capability to select any of the following parameters (user-configurable) for forwarding to the CGS M and C function for routine monitoring: 1. Any parameter derived from the contents of the pixel data contained in the level 0/1A/1B data stream (raw counts for a given pixel, calibrated radiance for a given pixel, averaging counts over a target view, gain value, offset value.) 2. Any parameter of the product generation function software itself (which shall include all statistics developed in the course of processing).	

HIRS-PGF.3.2.2.2-0050	FUNCT, INT
The function shall provide all required near real time data to the PGE to support the MMI functionality of the CGS in accordance with [AD 1] with the following instrument specific aspects: 1. Identified mode and mode transitions of the instrument; 2. Display of a user-configurable subset of the instrument telemetry; 3. Display each channel in a map projection in user-configurable pseudo colours; 4. Display of multi spectral images of up to three channels at level 1a and level 1b; 5. Display of multi spectral images with flexible colour coding, including pseudo true colours;	

HIRS-PGF.3.2.2.2-0060	**FUNCT, PERF**
The function shall produce reporting information on: 1. Completeness of the produced 0/1a/1b data; 2. Validity of the processing to level 0/1a/1b;	

4 SCIENTIFIC AND MATHEMATICAL SUPPORTING INFORMATION

The instrument data do not contain explicit scan line numbers and pixel numbers. Nevertheless, for convenience of referencing, line and pixel numbers are used in the specifications of this chapter. They are defined by following convention.

Line numbers of a satellite data dump are an uninterrupted sequence of increasing integers, which are dependent on the scanning time of the lines. Which number is assigned to the first complete line of a dump is arbitrary; 1 might be convenient. Missing scan lines are identified by inappropriate jumps in the scanning times of existing lines.

The pixels of a scan line are numbered in the sequence of their scanning times starting with 1 for the first pixel of a line. A consequence of this definition is that HIRS pixels are counted from left to right and AVHRR pixels from right to left when looking in satellite track direction.

Except for the case of flags which are passed directly through from the level 0 data stream, where no other specification of the setting of a flag bit is identifiable from a combined reading and analysis of this document and the descriptions and/or names of the flag bits in its associated PFS (AD4), the flag bits shall not be set, and where no other specification of the setting of a flag bit with a name or description in the PFS including the word 'some,' is identifiable in this document or its associated PFS, then the word 'some' in the bit name or description is to be taken to mean 'more than zero,' and where bits are indicated as not used in the PFS, these bits are not to be set.

4.1 Level 1a Processing

4.1.1 Calibration Coefficients Calculation

This function uses the validated HIRS/4 level 0 dataflow and the instrument characteristics to produce the calibration information for each of the 19 thermal channels and the one visible channel of the HIRS/4 instrument. It outputs the calibration parameters, which will be appended to the level 1a products and used by the subsequent level 1b processing.

The HIRS/4 IR channels calibration processing is based on a two-point calibration scheme, using a warm on-board target[1] of known temperature and a deep space view.

Note: Two on-board targets at different temperatures are available on HIRS instruments (temperature measurements are performed for both targets). However, on HIRS/2 it was found that the cold on-board target did not improve the calibration and was largely not used in the ground processing. Therefore, on HIRS/4 only the warm on-board target is planned to be used in the operational calibration sequence. The view of the second cold on-board target is only selectable by command.

The measured (in-band) scene radiance, R_s, is determined from the raw scene count, C_s, using a quadratic calibration relation:

$$R_s = a_0 + a_1 C_s + a_2 C_s^2 \qquad \textbf{Equation 1}$$

where a_2 is assumed to be an unchanging characteristic of the channel that is determined on ground, a_1 is the slope (the inverse receiver gain), and a_0 is an intercept. The slope and intercept are based on the cold space and warm internal target counts collected once every 40 scan lines and their respective estimated radiances.

The calibration algorithm for the visible HIRS/4 consists of a linear equation. The visible channel counts C_s are mapped onto reflectance factors (percentage albedo) A_s according to following formula:

$$A_s = a_0 + a_1 C_s \qquad \textbf{Equation 2}$$

The coefficients a_0 and a_1 are determined pre-launch and are rarely changed.

The HIRS/4 instrument measures all radiation falling on the detector; that means not only the radiation from the scanned scenes but also the radiation emanating from the parts of the instrument and satellite the sensors see (see [RD 1]). To minimise false fluctuations in the signals, the instrument temperature is carefully controlled, so that most optical components experience temperature changes very slowly with respect to the times between calibration cycles (256 seconds–every 40 scan lines). However, the baffle (identified as the secondary mirror/telescope) behaves differently. It is a blackened light material which is subject to short-term temperature changes from emission or blackbody radiation and absorption of incident radiation from the internal blackbody source (about 280 K), space (2.73 K), and the variable earth views (about 200 K-300 K plus reflected sunlight). The result is that the contribution by the baffle affects all measurements on a time scale of seconds. Therefore, the baffle temperature is measured every scan line and the calibration of the instrument channels accounts for its effect.

The calibration of the 19 thermal channels is performed by applying the same algorithm to the data from the 19 channels. The differences in the calibration of the thermal channels are defined by the channel specific algorithm parameters. Note that the algorithm is specified in this document only once in a generic way. The formulae do not explicitly express their channel dependence by a channel index.

The calibration activities depend on the current status of the scan and the history of the calibration process:

- If the calibration cycle of the HIRS/4 instrument is disabled by the Calibration Disable command the calibration of the Earth scan lines cannot be performed and calibration has to be skipped.
- Whenever new cold space and warm target scan lines arrive, instantaneous calibration coefficients, that is intercept $a_{0,ic+1}$ and slope $a_{1,ic+1}$, are calculated. Two different algorithms are specified. Which one is to be applied is controlled by a calibration mode parameter (parameter 2).

- The new instantaneous calibration coefficients and the previous ones are interpolated to scan line specific coefficients $a_{0,n}$ and $a_{1,n}$, which are to be applied to the corresponding scan lines of the previous calibration cycle. Two different interpolation methods are specified. Which one is to be applied is controlled by the calibration mode parameter 1. The first method is a linear interpolation, the second one uses additionally the corresponding baffle temperature T_s and a calibration intercept correction factor b_1 of the previous 24-hour period as described under the next bullet.
- Every 24 hours, the instantaneous calibration intercepts coefficients $a_{0,ic+1}$ together with the corresponding baffle temperatures $T_{s,0,ic+1}$ of the previous 24-hour period are used to derive a calibration intercept correction factor b_1 to be used for the calculation of the calibration intercept coefficient $a_{0,n}$ per Earth scan line n during the following 24-hour period. Additionally, the mean $a_{1,j}$ of the instantaneous calibration slope coefficients $a_{1,ic+1}$ of the previous 24-hour period j is calculated to be used as the calibration slope coefficient during the following 24-hour period.
- If the HIRS/4 instrument product generation function is started in the cold mode then $a_{1,j}$ and b_1 of the previous 24-hour period are not available or not used intentionally. A cold start calibration algorithm allows the derivation of $a_{1,j}$ and b_1 to be used for a degraded calibration of the Earth scan lines of the cold start period. Due to their definition, the coefficients converge to the coefficients to be used for the following 24-hour period.

4.1.1.1 CHECK SCAN STATUS

This function organises the calibration process depending on its history and the scan status of the HIRS/4 instrument:

- If the HIRS/4 Instrument Calibration Mode flag in the HIRS/4 data changes from Enabled to Disabled or if it is set to Disabled from the beginning on the calibration of the Earth scan lines cannot be performed and calibration is skipped.
- If the HIRS/4 Instrument Calibration Mode flag in the HIRS/4 data changes from Disabled to Enabled or the HIRS/4 data processing starts without calibration history or in the cold start mode–that can be requested by the user–the calibration of the Earth scan lines commences with Cold Start Calibration.
- If the HIRS/4 Instrument Calibration Mode flag in the HIRS/4 data is set to Enabled, and if the 24-hour history of the previous 24-hour period is available, then the calibration of the Earth scan lines of the most recent calibration cycle commences when the next cold space and warm target scan lines arrive.
- At the end of a 24-hour period, the 24-hour averaging is performed if more than a configurable number N of calibration cycles were available during that period. If the calibration process was running in cold start mode it switches to the routine calibration mode. If the number of available calibration cycles was less then N then the calibration process switches to the cold start calibration mode.

4.1.1.2 Skip IR Calibration Coefficients Calculation

When no instrument calibration is performed the Earth scan lines of the IR channels cannot be calibrated. The calibration coefficients to be appended to the products are set to default values (which are written into the level 1a MDR "spare calibration coefficient" fields). The scan lines are then flagged accordingly by setting bit 10 of the SCAN_LINE_QUALITY field in the level 1a MDR.

Calibration of the IR channel counts is performed using the default values. The scan lines that contain normally the instrument calibration scan lines contain now Earth scan lines.

Nevertheless, since the calibration coefficients for the one visible channel are determined pre-launch the coefficients are added to the HIRS/4 level 1a product and reflectance factor values are calculated for the HIRS/4 level 1b product.

4.1.1.3 Cold Start Calibration

Case 1: The calibration mode parameter 1 is set to “NOAA”:
The cold start calibration process is mainly identical to the routine calibration process. The only difference between them is that the averaged coefficients from the 24 hours averaging are not available. To overcome this lack of information an averaging step is inserted before the calculation of the IR Calibration Intercepts per Scan Line. The averaging step takes the instantaneous calibration coefficients that have been calculated since the beginning of the cold start calibration phase and applies the same formulae as the 24 hours averaging to derive the coefficients $a_{1,j}$ and b_1.
The coefficients $a_{1,j}$ and b_1 are not constant for the next 24 hours but can vary during the cold start calibration phase.

Case 2: The calibration mode parameter 1 is set to “AAPP”:
No specific cold start processing need be performed.

4.1.1.4 Derive Instantaneous Calibration Coefficients

When the cold space and the warm target scan lines of the next calibration cycle arrive the following processing steps are performed:

- The current temperature of the satellite’s warm target at the time of its scan is derived from the warm target Platinum Resistance Thermometer counts of the current scan line and x scan lines before and after. If x#0, then x Earth scan lines of the new calibration cycle are required.
- The warm target temperature is converted to the measured radiance according to Planck’s law.
- The means of the cold space counts and the warm target counts are calculated.
- The mean of the cold space counts is related to the radiance of the cold space (a user-configurable constant) and the mean of the warm target counts is related to the calculated warm target radiance according to Equation 13. From the resulting two equations the instantaneous calibration coefficients $a_{0,ic+1}$ and $a_{1,ic+1}$ are derived.

If one or both calibration scan lines are missing instantaneous calibration coefficients cannot be derived. This impacts the derivation of the IR channel intercept calibration coefficients per scan line value.

4.1.1.4.1 Calculate Warm Target Temperature

The internal warm target has five Platinum Resistance Thermometers (PRTs). Five readings are taken from each PRT at each scan line. The counts $C_{k,m}$ of the warm target scan line are averaged over the five readings of the warm target scan line and x scan lines before and after for each PRT k to obtain an average count,

$$\tilde{C}_k = \frac{1}{5(2x+1)} \sum_{m=1}^{5(2x+1)} C_{k,m}$$

$$x \in \{0, 1, 2\}, x \text{ is user configurable}$$

Equation 3

The counts, $C_{k,m}$, are subject to a maximum-minimum test; if the difference between the maximum and minimum counts is greater than a user-configurable threshold, the count furthest from the mean is removed and the process repeated. Scan lines in a calibration cycle where one or more PRT count values have been removed are flagged as such using bit 0 in the CALIBRATION_QUALITY field and bit 12 in the SCAN_LINE_QUALITY field of the Level 1a MDR. If the number of readings for the PRT falls below a user-configurable threshold, the PRT is removed from the temperature calculation. If the number of remaining PRTs falls below a user-configurable threshold, then the radiance cannot be calculated. If this results in the scan lines not being calibrated then they are flagged by setting bit 3 in the CALIBRATION_QUALITY field and bit 13 in the SCAN_LINE_QUALITY field of the Level 1a MDR.

The mean counts $\tilde{C}_k$ for each PRT are transformed to temperatures, T_k, using a fourth order polynomial with coefficients that are determined pre-launch and depend on the manufacturers supplied values.

$$T_k = \sum_{j=0}^{4} f_{k,j} \cdot \tilde{C}_k^{\ j}$$

Equation 4

By averaging the five PRT temperatures, the internal warm target temperature is obtained:

$$T_{wt} = \frac{\sum_{j=1}^{5} w_i \cdot T_i}{\sum_{j=1}^{5} w_i}$$ **Equation 5**

The weights w_i are characterised before launch ($w_i = 1$ if the respective PRT is good, 0 if not usable).

4.1.1.4.2 Calculate Warm Target Radiance

Below there are two methods specified for converting the warm target temperature T_{wt} into measured (inband) radiance for each of the 19 thermal channels. Which method the calibration process applies is controlled by the user-configurable mode parameter 2.

4.1.1.4.2.1 Method 1

For each of the 19 thermal HIRS/4 channels a channel dependent effective temperature T^*_{wt} is derived from the warm target temperature T_{wt} according to the following:

$$T^*_{wt} = b + c \cdot T_{wt}$$ **Equation 6**

with channel-dependent coefficients *b* and *c*, the so-called band correction factors.

The measured (in-band) warm target radiance R_{wt} is calculated from the effective temperature T^*_{wt} using Planck's law at the central wave number v_c.

$$R_{wt} = B(v_c, T^*_{wt})$$ **Equation 7**

The channel-dependent coefficients *b* and *c* and the central wave number v_c of the thermal channels are determined (before launch) such that they implicitly reflect the filtering effect of the channels' spectral response functions.

4.1.1.4.2.2 Method 2

The warm target temperature T_{wt} is converted into measured (in-band) radiance for each of the 19 thermal channels using the Planck function assuming that the radiance measured in a particular channel from a blackbody target at the temperature *T* is the weighted average of the Planck function over the spectral response function of the instrument in this spectral channel:

$$R(T) = \frac{\int_{\nu_1}^{\nu_2} B(\nu, T) \cdot \Phi(\nu) \cdot d\nu}{\int_{\nu_1}^{\nu_2} \Phi(\nu) \cdot d\nu} \quad \textbf{Equation 8}$$

where:

ν is the wave number (in cm^{-1}),

ν_1 and ν_2 are the lower and upper spectral limits of the channel,

Θ is the channel specific spectral response function,

and $B(\nu, T)$ is the Planck function defined by:

$$B(\nu, T) = \frac{2hc^2\nu^3}{e^{\frac{hc\nu}{kT}} - 1} = \frac{C_1 \cdot \nu^3}{e^{\frac{C_2 \cdot \nu}{T}} - 1} \quad \textbf{Equation 9}$$

where:

$h = 6.626\ 068\ 76 * 10^{-34}$ J s, Planck constant

$c = 299\ 792\ 458$ m s^{-1}, velocity of light in vacuum

$k = 1.380\ 650\ 30 * 10^{-23}$ J K^{-1}, Boltzmann constant

The constants are as follows:

$C_1 = 2hc^2 = 1.191035768*10^{-5}$ mW/(m^2 sr cm^{-4}) and

C_2= hc/k = 1.43876912 K/cm^{-1}.

Radiances are expressed in mW/(m^2 sr cm^{-1}).

The equation for radiance is used in the discretised form with n appropriately chosen:

$$R(T) = \frac{\sum_{i=1}^{n} B(v_i, T) \cdot \Phi(v_i) \cdot \Delta v}{\sum_{i=1}^{n} \Phi(v_i) \cdot \Delta v}$$

Equation 10

To improve the performance of the algorithm, look-up tables (LUT) may be constructed from this equation, giving radiances as a function of the temperature at every tenth of degree K between 180 K and 320 K. These tables could be used to convert the warm target temperature, T_{wt}, to measured (in-band) radiance R_{wt} for each channel.

$$R_{wt} = R(T_{wt})$$

Equation 11

A view of cold space is made for 48 out of the 56 samples during one scan line. Measurements that are deemed not to be free from scan mirror movement errors and other unsatisfactory conditions are not averaged. Samples 1 to 8 are unusable, since the mirror is moving at this time to the space target. The average cold space counts are computed over these 48 samples. For the internal warm target, all 56 samples are usable and are entered into processing. Additionally those measurements that fall outside of the 3 interval of the set of measurements are not averaged, and the relevant "marginal space view" or "marginal blackbody" flag bit in the CALIBRATION _QUALITY field in the MDR-1A record is set. If the number of valid measurements is below a user-configurable threshold, then the "no good counts" bit of the CALIBRATION _QUALITY field in the MDR-1A record are set.

$$\overline{C}_{cs} = \frac{1}{M}\sum_{i=1}^{M} C_{cs,i} \qquad N_{tcs} < M \leq 48$$

$$\overline{C}_{wt} = \frac{1}{N}\sum_{i=1}^{N} C_{wt,i} \qquad N_{twt} < N \leq 56$$

Equation 12

Note: The channel counts might not be arranged in the sequence of the channel numbering (See [RD 1] chapter 8.3.1.5)

Note: The most significant bit of the 13 bit HIRS/4 counts is to be interpreted as a sign bit (0 = negative) and the counts have to be reformatted to signed integers before their usage in calibration. (See [RD 1] chapter 8.3.1.5).

4.1.1.4.3 Calculate Instantaneous IR Calibration Coefficients

The first two coefficients of the quadratic calibration relation, the slope and the intercept, are determined by relating the cold space radiance (assumed to be constant) to the mean cold space count and the warm target radiance to the mean warm target counts for the new calibration cycle*, ic+1*:

$$R_{cs} = const = a_{0,ic+1} + a_{1,ic+1}\overline{C}_{cs} + a_2\overline{C}_{cs}^2$$

$$R_{wt} = a_{0,ic+1} + a_{1,ic+1}\overline{C}_{wt} + a_2\overline{C}_{wt}^2$$

Equation 13

Since a_2 is known the slope and the intercept become:

$$a_{1,ic+1} = \frac{R_{wt} - R_{cs} - a_2(\overline{C}_{wt}^2 - \overline{C}_{cs}^2)}{\overline{C}_{wt} - \overline{C}_{cs}}$$

$$a_{0,ic+1} = R_{cs} - a_{1,ic+1}\overline{C}_{cs} - a_2\overline{C}_{cs}^2$$

Equation 14

Note: No calibration coefficients calculation need be performed for the HIRS/4 visible channel (channel 20) since the intercept and the slope of the linear calibration function are deemed not to change. This is determined pre-launch.

4.1.1.4.3.1 Derive Calibration Coefficients per Scan Line /old cycle

For each Earth scan line n of the previous calibration cycle calibration coefficients a0,n and a1,n for each thermal channel are derived. Two different methods are specified. Which method is to be applied is controlled by the mode parameter 1.

Case 1: *The calibration mode parameter 1 is set to "AAPP"*

Linear Interpolation is applied to derive scan line specific calibration coefficients for each scan line of the previous calibration cycle from the previous and the new instantaneous calibration coefficients.

Case 2: *The calibration mode parameter 1 is set to "NOAA"*

The interpolation of the instantaneous calibration coefficients to the individual scan lines corrects additionally for the effect of the variations in the baffle temperature. The temperature correction takes into account the temperature of the baffle at the middle of the scan line (of the previous calibration cycle) that is currently being processed, the temperature at the beginning of this cycle and at the beginning of the new cycle. A temperature difference derived from these values is mapped onto an intercept correction value by applying the interception correction factor b1 valid for the current 24-hour period. At the beginning of the new calibration cycle *ic+1*, the baffle temperature $T_{s,0,ic+1}$ and the corresponding instantaneous intercept coefficient are passed on to the 24 hours Averaging function for calculating the interception correction factor b_1.

Check Calibration Mode Parameter 1

Depending on the calibration mode parameter 1 either the AAPP method of calculating Earth scan-line specific calibration coefficients is applied–or the NOAA method.

Calculate IR Calibration Coefficients (AAPP)

For each Earth scan line n between the calibration scan lines of the previous calibration cycle *ic* and the new one *ic+1* Earth scan line specific calibration coefficients $a_{0,n}$ and $a_{1,n}$ are calculated.

If, due to non-nominal operation, the scan line to be processed is a cold black body scan line rather than an Earth scan line then the scan line is to be flagged as a non-Earth scan line and the calibration of the scan line to be skipped.

The Earth scan line specific calibration coefficients are calculated as follows:

$$a_{i,n} = w_1 \cdot a_{i,ic} + w_2 \cdot a_{i,ic+1}$$ **Equation 15**

with

$a_{i,ic}$ and $a_{i,ic+1}$ = instantaneous calibration coefficients from the previous and the new calibration cycle

and the weights w1 and w2 calculated according to:

$$w_1 = \frac{sp_{ic+1} - n + 0.5}{sp_{ic+1} - sp_{ic}}$$

$$w_2 = 1 - w_1$$ **Equation 16**

with:

sp_{ic} and sp_{ic+1} = line numbers of the space scans of the previous and the new calibration cycle

n = Earth scan line number.

***Note**:* Equation 16 assumes the line numbers of the calibration and Earth scans contiguously numbered. Actually relevant is that the Earth scan lines are correctly positioned relatively to the two consecutive calibration scan line pairs used for their calibration. Consequently, for the nominal case one could set e.g. $spic+1$ = 41, $spic$ = 1 and let n run from 3 to 40. Nevertheless, equation 16, as formulated, has the advantage to cover also the degraded cases specified below.

***Note**:* The interpolation is to the middle of the Earth scan line. Partial calibration cycles at the beginning of a dump are complemented by the data of the previous dump. If the required data of the previous dump are not available then the partial calibration cycle at the beginning of the dump is treated like the partial calibration cycle at the end of a dump: Earth scan line specific calibration coefficients are determined by extrapolation of the two instantaneous coefficients derived from the two contiguous correct calibration scans closest to the boundary of the dump (no loss of calibration scan lines being assumed) by applying the above two formulae. Calibration coefficients calculated by extrapolation are flagged accordingly by setting bit 14 in the SCAN_LINE_QUALITY field of the Level 1a MDR.

Following cases of missing data of a dump are treated specifically:

1. Missing pixels in an Earth scan line (value = 0) are not processed. The available pixels are processed normally. The scan line is flagged as incomplete.
2. Missing Earth scan lines are left out from the products. The lines are not padded. The product is flagged as having lost lines.
3. Missing pixels in a calibration scan line are left out from the calculation of the instantaneous calibration coefficients.
4. When complete calibration scan lines are missing then instantaneous calibration coefficients cannot be calculated but the earth scan lines can still be calibrated as follows:
   4.1 This case is treated similarly to the partial calibration cycles if the closest two instantaneous calibration coefficients can be calculated.
   4.2 If only one closest instantaneous calibration coefficients set is available (but not the closest two) then this instantaneous calibration coefficients set is applied to the Earth scan lines of the calibration cycle and the lines are flagged accordingly by setting bit 14 of the SCAN_LINE_QUALITY field in the L1a MDR.
   4.3 If both the preceding and the succeeding calibration scan lines are missing then the available (if any) Earth scan lines are calibrated using the most recent calibration coefficients and are flagged accordingly by setting bit 11 in the SCAN_LINE_QUALITY field of the Level 1a MDR.

Calculate the Baffle Temperature /new cycle

The temperature of the baffle of the secondary mirror/telescope at the begin of the new calibration cycle is calculated by applying the formulae given in Equation 17 using the temperature measured at the end of the cold space calibration line and at the end of the last Earth scan line of the previous calibration cycle.

Calculate the Baffle Temperature per Scan Line /old cycle

If, due to non-nominal operation, the scan line to be processed is a cold black body scan line rather than an Earth scan line then the scan line is to be flagged as a non-Earth scan line and calibration of the scan line to be skipped.

Earth scan lines are to be calibrated as follows.

The calibration intercept varies as a function of the baffle temperature at each scan line. The baffle temperature is obtained from the counts as per Equation 17.

$$T_{s,n} = \sum_{j=0}^{4} f_{s,j} \cdot C_s^j$$

Equation 17

If the baffle temperature exceeds either of two user-configurable high and low thresholds then it is invalid and not used.

The baffle temperature at scan line *n* is linearly interpolated to the midpoint of the radiometric data at beam position 28.5 using the relation

$$T'_{s,n} = T_{s,n-1} + 0.4609(T_{s,n} - T_{s,n-1})$$

Equation 18

where $T_{s,n}$ is the baffle temperature at scan line *n*, and $T_{s,n-1}$ is the baffle temperature at the previous scan line.

For the first scan line of a dump or if the previous scan line is missing, the interpolated value is

$$T'_{s,n} = T_{s,n} - 0.5391(T_{s,n+1} - T_{s,n})$$

Equation 19

If the following scan line is also missing, the baffle temperature of line *n* is not interpolated resulting in

$$T'_{s,n} = T_{s,n}$$

Equation 20

Calculate IR Calibration Coefficients (NOAA)

For the NOAA calibration, modified 'prime' instantaneous calibration coefficients are used which take into account the thermal fluctuations experienced by the secondary mirror telescope. These coefficients a'_0 and a'_1 are used to calculate the radiances as follows:

$$R_s = a'_0 + a'_1 C_s + a_2 C_s^2$$

Equation 21

The coefficients a'_0 and a'_1 are defined by:

$$a'_1 = \bar{a}_{1,j}$$
$$a'_0 = R_{cs} - a'_1 \overline{C}_{cs} - a_2 \overline{C}_{cs}^2$$

Equation 22

where $\bar{a}_{1,j}$ is the 24-hour calibration coefficient as described in Section 4.1.1.4.4.2 . For each calibration cycle, both types of instantaneous calibration coefficients (a_0 a_1 a'_0 a'_1) are calculated. The non-prime coefficients are saved and used to calculate the 24-hour coefficients for use in the next 24-hour period (see Section 4.1.1.4.4.2). The prime calibration coefficients are used to convert counts to radiances for each scan line in the current 24-hour period. The instantaneous prime calibration intercept coefficients, a'_0, of the 19 infrared channels are interpolated at each scan line using the baffle temperatures and the 24-hour calibration coefficients calculated in the previous
24- hour period as given in Equation 20.

$$a'_{0,n,ic} = a'_{0,0,ic} + \frac{n}{40}(a'_{0,0,ic+1} - a'_{0,0,ic}) + b_1\left[(T'_{s,n,ic} - T'_{s,0,ic}) - \frac{n}{40}(T'_{s,0,ic+1} - T'_{s,0,ic})\right]$$

Equation 23

where $a'_{0,0,ic}$ is the intercept from the two point calibration of calibration cycle *ic, a'* $_{0,n,ic}$ is the interpolated intercept calibration coefficient for scan line *n* in cycle *ic* and $T'_{s,n,ic}$ is the interpolated baffle temperature for the scan line n in calibration cycle *ic*. The calibration intercept correction factor b_1 is derived from the instantaneous calibration intercepts and the baffle temperatures of the previous 24-hour period (see Section 4.1.1.4.4.2).

Note: the slope instantaneous calibration coefficient a'_1 is constant for a given 24-hour period (as it is simply the average of all the slope instantaneous calibration coefficients of the previous 24 hours) and therefore can be used as expressed previously for each scan line without the need for any interpolation.

For partial calibration cycles at the beginning of a dump, the intercepts are computed by complementing the incomplete calibration cycle with the data from the previous dump. However, if previous data are not available, then extrapolation back from the next calibration is performed using:

$$d_{0,n,ic} = d_{0,0,ic+1} + b_1(T'_{s,n,ic} - T'_{s,0,ic+1})$$

Equation 24

For partial calibration cycles at the end of a dump the intercepts will be computed according to:

$$d_{0,n,ic} = d_{0,0,ic} + b_1(T'_{s,n,ic} - T'_{s,0,ic})$$

Equation 25

Missing data in a dump is treated similarly to the AAPP calibration method. Note that for the NOAA calibration the cases 4.1 and 4.2 need not be distinguished and in both cases NOAA's partial calibration cycle method is to be applied.

If both intercepts or baffle temperatures are missing the calibration coefficients cannot be calculated for the current calibration cycle. The calibration process calibrates the counts in this case using the most recent valid calibration coefficients and flags the data by setting bit 11 in the SCAN_LINE_QUALITY field of the Level 1a MDR.

4.1.1.4.3.2 24 hours Averaging

Check Calibration Mode Parameter 1

If the calibration mode parameter 1 is set to "AAPP" then this processing step is skipped.

If the calibration mode parameter is set to "NOAA" then the processing proceeds as follows: At the end of each 24-hour period, an average calibration slope coefficient is derived for each IR channel from the instantaneous calibration slope coefficients of the previous 24 hours.

Additionally, a calibration intercept correction factor is calculated for each IR channel. They are derived from the instantaneous calibration intercept coefficients and the baffle temperatures at the middle of the cold space scan lines of the previous 24 hours.

These averaged values are used for calibration during the next 24 hours. But, if the number of the instantaneous calibration coefficients of the previous 24 hours, N_j, is less than a configurable threshold, then the averaging is not performed and the calibration process switches to Cold Start Calibration.

Calculate Mean IR Calibration Slope Coefficients

The instantaneous calibration slope coefficients of all calibration cycles of the previous 24-hour period are averaged to provide a mean calibration slope for the following 24-hour period. Changes in slopes over 24 hours are assumed to be negligible, varying by only about 1 part in 8000 over an orbit. Those instantaneous calibration slope coefficients that fall outside of the 3σ interval of the set are not averaged.

$$\bar{a}_{1,j} = \frac{1}{N_j} \sum_{ic=1}^{N_j} a_{1,ic}$$ ***Equation 26***

where:

$\bar{a}_{1,j}$ is the mean calibration slope for the 24-hour period *j*,

ic is the index on the calibration cycle within the 24-hour period *j*,

N_j is the number of averaged calibration cycles for 24-hour period *j*,

and $a_{1,ic}$ is the instantaneous calibration slope coefficient computed from the two point calibration for calibration cycle *ic*.

Calculate IR Calibration Intercept Factors

The linear variation of the intercept as a function of the baffle temperature over a 24-hour period is determined by a least squares fit to the equation:

$$a_{0,ic} = b_0 + b_1 T'_{s,ic}$$ ***Equation 27***

where

$a_{0,ic}$ is the intercept for calibration cycle *ic*,

$T'_{s,ic}$ is the baffle temperature at the middle of the cold space scan line,

and b_0 and b_1 are the unknown coefficients.

Only the values of those calibration cycles are used for the square fit where the temperature does not fall outside of the 3 interval of the whole 24-hour set of temperatures.

4.1.1.5 The Algorithm to Calculate the Noise Equivalent Radiance

Every 40 scan lines, the HIRS is commanded into a calibration mode where, during a complete scan line cycle, the instrument looks for two successive scan lines on the space view (scan line encoder position 68) target followed by the internal warm target (scan encoder position 156). The value for *NEΔN* is calculated for each channel and each scan line using the standard deviation of the warm target view counts generated during the internal warm target view of the antenna. For the internal warm target, all 56 samples are usable and are entered into processing.

The standard deviation of the warm target counts for a distinct scan line is given by:

$$\sigma_{wt} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(C_{wti} - \bar{C}_{wt})^2} \qquad \text{with N=56}$$

Equation 28

Where the average of the warm target counts is given by (see Equation 12):

$$\sigma_{wt} = \frac{1}{N}\sum_{i=1}^{N} C_{wti} \qquad \text{with N=56}$$

Equation 29

The *NEΔN* for HIRS channels $i \in [1,19]$ or otherwise labelled H01-H19, for a calibration cycle k is given by the fraction of the standard deviation and the gain of this scan line:

$$NE\Delta N_k^{\,i} = \left[\sigma_{wt}^{\,i}\,\frac{B_\nu^i(T_{wt}) - B_\nu^i(T_{SPACE})}{\overline{C_{wt}^i} - \overline{C_{CS}^i}}\right]_k$$

Equation 30

where

σ_{wt}^i is the standard deviation of the internal warm target counts for one calibration cycle

$B_\nu^i(T_{wt}) - B_\nu^i(T_{SPACE})$ is the channel radiance difference between the IWT view [Eq 9] and the space view. Note that $B_\nu(T_{SPACE})$ is set to zero for all channels. ν is the channel centre frequency in [cm^{-1}] for a specific HIRS channel as given in the calibration parameter data set.

T_{wt} is the averaged IWT temperature or the averaged calibrated PRT temperature as Equation 5.

$\overline{C_{wt}^i} - C_{CS}^i$ is the count difference (averaged counts per scan line) between the internal warm target view and the space target view.

The following is just for information, but not for implementation. It is intended to give users advice how to convert the Noise Equivalent Radiance *NEΔN* into Noise-equivalent temperature *NEΔT*. The *NEΔT* is calculated by dividing the value of *NEΔN* by the first derivative of the Planck function at a distinct temperature (usually T_0=300 K), denoted as:

$$\frac{\partial B_{\nu}^{i}(T_0)}{\partial T_0} \qquad NEDT_k^i = \frac{NE\Delta N_k^i}{\frac{\partial B_{\nu}^{i}(T_0)}{\partial T_0}}$$

Equation 31

where:

The derivates of the Planck equation at a constant temperature for each of the infrared HIRS channels are constant values which can be calculated explicitly for each HIRS infrared channel frequency. As an example, the calculated values for Metop-A are given below in Table 8.

HIRS Channel	*Channel Frequency V [cm-1]*	*Derivative of the Planck Equation @ 300K [mW/m2/ster/cm-k/K]*	*Band correction Offset b*	*Band correction slope c*
H01	668.66	1.674	0.001249	0.99999
H02	679.18	1.687	0.007424	0.99997
H03	689.70	1.699	0.019006	0.99991
H04	701.99	1.711	0.017762	0.99992
H05	716.47	1.724	0.019533	0.99991
H06	731.71	1.735	0.019816	0.99991
H07	748.82	1.745	0.021136	0.99991
H08	898.59	1.714	0.064148	0.99977
H09	1028.50	1.558	0.039184	0.99987
H010	800.93	1.757	0.015975	0.99994
H0111	1361.90	0.957	0.073425	0.99982
H012	1530.10	0.679	0.113630	0.99974
H013	2189.70	0.120	0.017029	0.99997
H014	2212.30	0.113	0.018179	0.99997
H015	2237.60	0.104	0.018575	0.99997
H016	2245.60	0.102	0.017578	0.99997
H017	2418.90	0.060	0.030204	0.99995
H018	2516.10	0.044	0.049378	0.99993
H019	2663.37	0.027	0.280270	0.99962

4.1.2 Navigation

4.1.2.1 Satellite Clock Error Estimate

The satellite clock error estimate is required to correct the On Board Time before converting it to UTC. With this the along track error of the sub satellite point is corrected. The clock error is specified in [AD 5].

4.1.2.2 Get Satellite Orbit State and Position

From the flight dynamics function, the satellite position, velocity and attitude is obtained and interpolated to the precision of the time increment specified in [AD4]. In addition, the orbit state vector is provided for the start time of the orbit. The flight dynamics information is specified in [AD 5].

4.1.2.3 Calculate Zenith and Azimuth Angles

From astronomical and satellite orbit information the satellite zenith angle, azimuth angle, the solar zenith angle and azimuth angle and also the relative azimuth angle are calculated. The algorithms are specified in **[**RD 2**].**

4.1.2.4 Add Earth Parameters

From the Earth information database specified in [AD5] terrain elevation is calculated for the HIRS/4 Fields of View. Together with terrain type information this information is put into the appended part of the Level 1a and Level 1b products.

4.1.3 Determine Cloud Coverage

If the Cloud Coverage Request is set to "NO" then the cloud coverage determination is skipped and default values are used for the products.

4.1.3.1 Introduction

The determination of the cloud coverage means here to determine which AVHRR pixels fall into the field of view (fov) ellipses of the HIRS pixels and calculate from the cloudy/clear information given for each AVHRR pixel in the AVHRR level 1b data set the percentage of the clear AVHRR pixels.

The cloud coverage algorithm can therefore be regarded as consisting of two separate steps, collocation and calculation of the percentage of the clear AVHRR pixels within the HIRS fov ellipses.

The collocation process makes several simplifying assumptions: The Earth is spherical and non-rotating.

The satellite's orbit is a circle, the geopotential is homogeneous and the satellite's angular speed is therefore constant.

The attitude of the satellite is nominal–roll, pitch and yaw angles are zero (apart from when METOP is in yaw steering mode). The yaw steering mode of the METOP satellites is not taken into account since the yaw angle varies slowly between its small extremes of ± 3.95 degrees during a full orbit wherefore it has only a marginal impact on the collocation and the roll and pitch angles vary only a little around 0 degrees (±0.05 and ± 0.16 degrees respectively).The scanning geometry of the AVHRR and HIRS instruments is nominal.

The convergence of the scan lines in limb direction due to the spherical surface of the Earth is not taken into account.

Due to these simplifications the mapping geometry shows a repetitive structure since every 32 seconds $R_m = 192$ complete AVHRR scan lines are produced and in the same time period $R_t = 5$ complete HIRS scan lines. The idea is to produce a look up table (LUT) for this period that describes for each HIRS pixel fov ellipse which AVHRR pixels of which AVHRR scan line collocate with the HIRS fov ellipse. This static look up table is then repetitively applied to the satellite data dump when calculating the cloud coverage parameters. Mapping errors due to a relative mispointing between the AVHRR and the HIRS instruments can be compensated by applying empirically determined adjustments of the scan angles and the scanning times to each of the pixels of a HIRS scan line. This mechanism allows to easily correct for such scanning geometry problems like, for example, the one encountered with NOAA16 where the HIRS pixels are displaced by about one HIRS pixel relative to the other instruments.

Note: Mapping from a lower onto a higher resolution instrument grid requires for each of the target lines covered by the same mapping line a set of corrections, e.g. mapping AMSU-A onto MHS may require up to 4 correction sets.

Note: A prerequisite for the LUT method is that the AVHRR and the HIRS instrument operate in the AVHRR synchronisation mode. If this is not the case the scanning times might shift away from each other so that the look up table might not be applicable for longer time intervals. One can cope with this non-nominal situation by repeating the LUT creation more often as long as the shift is smooth and slow. Therefore the frequency of the LUT creation shall be user-configurable.

Note: The algorithm for mapping the AVHRR fov grid onto the HIRS fov grid has been generalised to allow for any ATOVS instrument grid to be mapped onto any other one (except AVHRR). When the mapping algorithm is to be used for another pair of ATOVS instruments replace “AVHRR” by “mapping instrument” and “HIRS” by “target instrument”. In the specification mention is made where the generalised algorithm requires processing steps not needed for the AVHRR to HIRS mapping. These mapping algorithm extensions are needed for the ATOVS level 2 processing and are referenced in the corresponding PGS. That they are specified here (for convenience in the specification work) does not impose any implementation constraint.

Note: The time interval of 32 seconds for the definition of a repetitive mapping structure for AVHRR onto HIRS is convenient for the other pairs of ATOVS instruments as well since during that time exactly 4 AMSU-A lines and 12 MHS lines will be scanned.

4.1.3.2 Create Look-Up Table

In the following specification of the look up table creation algorithm 6 different coordinate systems are distinguished to describe the location of a scan pixel:

1. **Dump target grid =** (P_t, L_t) , $1 \le P_t \le N_t$, $L_1, t \le L_t$
   with

   L_t = (number of) a target instrument (HIRS) scan line in a satellite data dump

   $L_{1,t}$ = (number of) first (complete) target line in dump

   P_t = (number of) a pixel in scan line L_t

   N_t = number of pixels in a target scan line (HIRS = 56)

2. **Dump Mapping Grid** = (P_m, L_m) , $1 \le P_m \le N_m$, $L_{1,m} \le L_m$
   with

   L_m = (number of) a mapping instrument (AVHRR) scan line in a satellite data dump

   $L_{1,m}$ = (number of) first (complete) mapping line in dump

   P_m = (number of) a pixel in scan line L_m

   N_m = number of pixels in a mapping scan line (AVHRR = 2048)

3. **LUT Target Grid** = (P_t, l_t) , $1 \le P_t \le N_t$, $L_{s,t} \le l_t \le L_{e,t}$
   with

   l_t = (number of) a target instrument (HIRS) scan line in a satellite data dump used for the LUT creation

   $L_{s,t}$ = (number of) target line where the LUT creation starts

   $L_{e,t}$ = (number of) target line where the LUT creation ends

4. **LUT Mapping Grid**= (P_m, l_m) , $1 \le P_m \le N_m$, $L_{s,m} \le l_m \le L_{e,m}$
   with

   l_m = (number of) a mapping instrument (AVHRR) scan line in a satellite data dump used for the LUT creation

   $L_{s,m}$ = (number of) mapping line where the LUT creation starts

   $L_{e,m}$ = (number of) mapping line where the LUT creation ends

5. **Collocation System 1** = α_{sc}, time)
   with

   α_{sc} = scan angle of the pixel

   time = time (relative to the scan time of the first pixel (P_t =1) of $L_{1,t}$) of scanning a pixel

6. **Collocation System 2** = (C_{sc}, C_{tr})
   with

   C_s = position of the pixel in scan direction in km with positive values to the right of the track and negative values to the left

   C_{tr} = position of a pixel in track direction in km with position of first pixel (P_t = 1) of $L_{1,t}$ being 0

The relationship between these coordinate systems is illustrated by the following figure (the dotted lines and their annotations can be disregarded in this context).

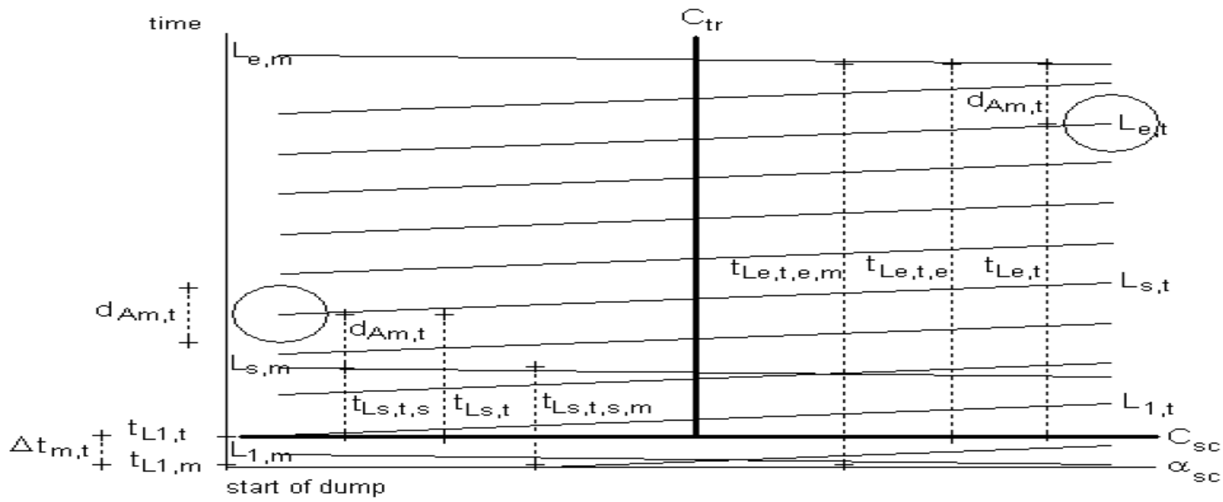

Figure 3: Relationship between coordinate systems

Note: The figure is illustrative only and not scaled in any sense. The AVHRR instrument scans from right to left with respect to the track direction whereas the HIRS instrument scans from left to right.

To be able to decide whether a mapping pixel collocates with a target pixel one has to express the positions of the pixels, which are originally given in their instrument specific (pixel number, line number) coordinates, in a common coordinate system. Since both instruments, AVHRR and HIRS, scan perpendicular to the satellite's yaw direction the time of scanning a pixel and its scanning angle (Earth centre, spacecraft, pixel) can be used as position parameters that are common to both. Since distances between pixels of the two involved instruments need be calculated this common coordinate system is not appropriate. Therefore the time is transformed into a distance in track direction and the scan angle into a distance of the pixel to the nadir at the time of scanning the pixel.

4.1.3.2.1 Calculate Ellipse Parameters

A preparatory step for the collocation is the calculation of the ellipse parameters of the *fov*s of the HIRS pixels of one HIRS scan line. Since the scanning geometry is assumed to be symmetrical to the nadir it is sufficient to calculate the parameters for the pixels on one side of the track.

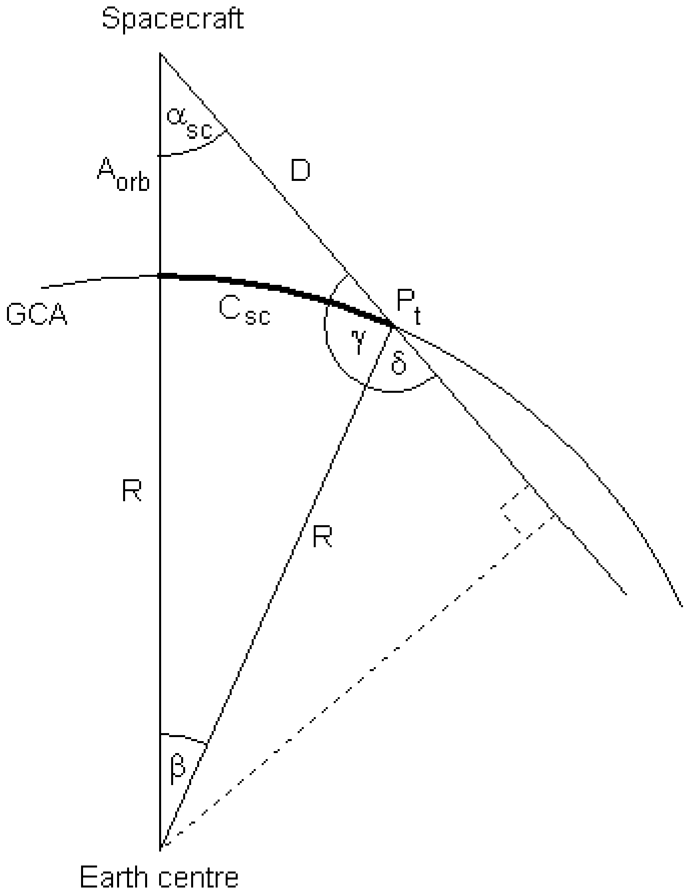

Figure 4: Location of a scan pixel on Earth's surface

The scan angle α_{sc} of a pixel defines the distance of the pixel from the satellite's nadir. This distance is viewed from the Earth's centre under the angle β. β can be calculated as follows.

The HIRS instrument (and as well AVHRR) steps from one scanning position to the next with a constant step angle α_{st} such that the nadir position falls exactly between the two centre pixels so that we can calculate the scanning angle of pixel P_t

$$\alpha_{sc} = \left(\left(\frac{N_t}{2} - P_t \right) + 0.5 \right) \cdot \alpha_{st}$$

Equation 33

Note: The scan angle correction $\Delta\alpha_{sc}$ at pixel P_t is not taken into account here since it describes the relative offset between the mapping and the target instrument and not the deviation of the centre of the scan line from the nadir position.

According to the Sine rule we get from α_{sc} together with the radius R of the Earth and the altitude A_{orb} of the orbit of the spacecraft above the Earth's surface

$$\sin\delta = \frac{R + A_{orb}}{R} \cdot \sin\alpha_{sc}$$ ***Equation 34***

then

$$\gamma = 180 - \mathrm{asin}(\sin\delta)$$ ***Equation 35***

and

$$\beta = 180 - (\alpha_{sc} + \gamma)$$ ***Equation 36***

Applying the above calculation steps to the scanning angles of the far and close ends of the fov ellipse characterized by their "scanning angles"

$$\alpha_{sc,f} = \alpha_{sc} + \frac{1}{2} \cdot \alpha_{co,x} \quad and \quad \alpha_{sc,c} = \alpha_{sc} - \frac{1}{2} \cdot \alpha_{co,x}$$ ***Equation 37***

with $\alpha_{co,x}$ being the expanded scanning cone angle and α_{co} the target instrument scanning cone angle and x_t a configurable target fov expansion factor (to be chosen specifically for the instrument pair involved in the mapping to ensure a reasonable averaging of mapping pixel values for each target pixel, e.g. = 1 for mapping AVHRR onto HIRS) according to

$$\alpha_{co,x} = \alpha_{co} \cdot x_t$$ ***Equation 38***

we get the corresponding viewing angles β_f and β_c (see figure below) that allow us to calculate the great circle arc (GCA) length A_M of the major axis of the fov ellipse of pixel P_t

$$A_M = R \cdot (\beta_f - \beta_c) \cdot \frac{\pi}{180}$$ ***Equation 39***

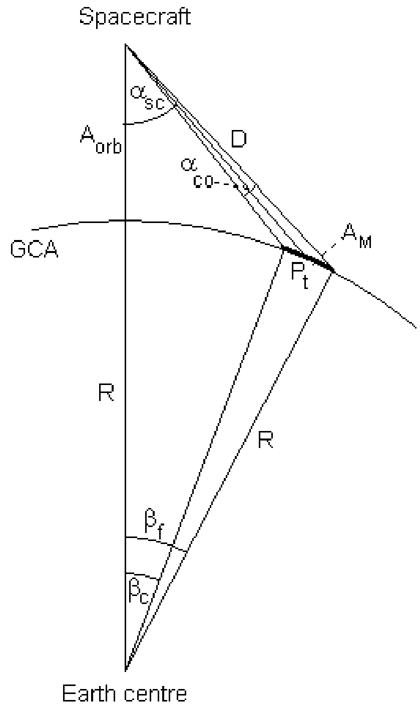

Figure 5: Length of major axis of the fov ellipse of pixel P_t

The length of the minor axis A_m of the fov ellipse of pixel P_t we get by calculating the scanning beam half width W in the tangential plane to Earth in pixel P_t in track direction and projecting W onto the Earth surface in direction of the Earth's centre as following figure shows:

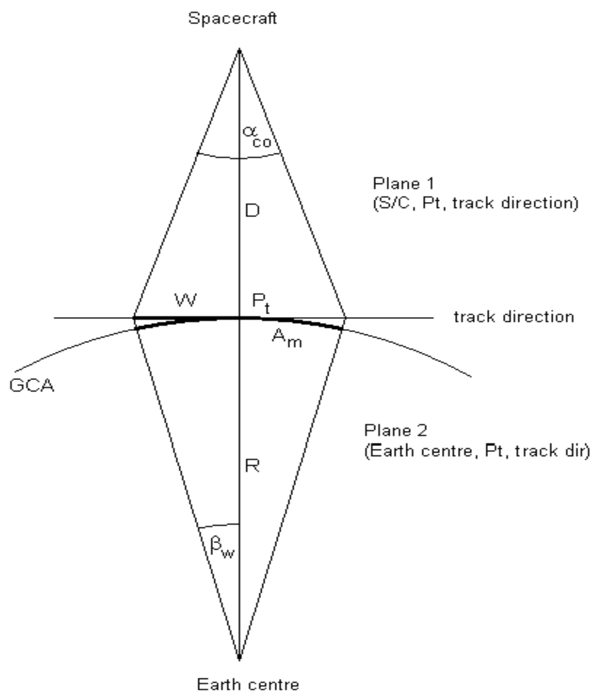

Figure 6: Length of minor axis of the fov ellipse of pixel Figure Pt

According to figure 4 and the Sine rule we get for the distance D of pixel P_t to the spacecraft:

$$D = R \cdot \frac{\sin\beta}{\sin\alpha_{sc}}$$	***Equation 40***

The scanning beam half width W and its corresponding Earth centre viewing angle β_W is derived from D according to:

$$W = D \cdot \tan\frac{\alpha_{co}}{2}$$	***Equation 41***

$$\beta_W = arc\tan\frac{W}{R}$$	***Equation 42***

and then the GCA length of the minor axis of the fov ellipse of pixel P_t:

$$A_m = R \cdot 2 \cdot \beta_W \cdot \frac{\pi}{180}$$	***Equation 43***

Finally we get the eccentricity e of the ellipse and the distance D_f of the foci from the centre of the ellipse

$$e = \sqrt{1 - \left(\frac{A_m}{A_M}\right)^2}$$	***Equation 44***

$$D_f = \frac{A_M}{2} \cdot e$$	***Equation 45***

4.1.3.2.2 Select LUT Instruments Grids

The choice of the start line $L_{s,t}$ of the LUT target grid within the satellite data dump can be quite arbitrary. Nevertheless, it should be chosen such that the fov ellipse (plus a margin) of the first pixel P_t of $L_{s,t}$ is fully contained in the dump mapping grid. With the number of target lines in LUT ($=R_t=5$ for HIRS) we get the end line of the LUT target grid:

$$L_{e,t} = L_{s,t} + R_t - 1$$	***Equation 46***

It is sufficient to make a rough estimate of the range of lines of the mapping instrument required for the LUT creation. The start line $L_{s,m}$ and the end line $L_{e,m}$ of the LUT mapping grid within the satellite data dump are calculated by subtracting from the time $t_{Ls,t}$ of scanning the first pixel of $L_{s,t}$ and adding to the time of scanning the last pixel of $L_{e,t}$ the time $d_{Am,t}$ the spacecraft needs to fly over a track distance of the size of the minor axis A_m of the fov ellipse of the first pixel of L_s,t to get $t_{Ls,t,s}$ and $t_{Le,t,e}$ and adding to these times the difference $\Delta t_{m,t}$ of the scan times of the first pixels of $L_{1,m}$ and $L_{1,t}$ to convert them to times relative to the start of $L_{1,m}$. Dividing the $L_{1,m}$ relative times by the scan duration $d_{L,m}$ of a mapping line results in the required mapping lines $L_{s,m}$ and $L_{e,m}$. These calculations are illustrated in figure 4.

$$t_{Ls,t} = (L_{s,t} - L_{1,t}) \cdot d_{L,t}$$ ***Equation 47***

with $d_{L,t}$ = duration of scanning a target line including the retrace steps.

$$d_{Am,t} = \frac{d_{orb}}{2\pi} \cdot \frac{A_m}{R}$$ ***Equation 48***

with d_{orb} = duration of an orbit of the spacecraft.

$$t_{Ls,t,s} = t_{Ls,t} - d_{Am,t}$$ ***Equation 49***

$$t_{Ls,t,s,m} = t_{Ls,t,s} - \Delta t_{m,t}$$ ***Equation 50***

$$L_{s,m} = \frac{t_{Ls,t,s,m}}{d_{L,m}}$$ ***Equation 51***

The mapping line $L_{e,m}$ is calculated in an analogous way:

$$t_{Le,t} = (L_{e,t} + 1 - L_{1,t}) \cdot d_{L,t}$$ ***Equation 52***

Note: $t_{Le,t}$ is actually not the time of scanning the last pixel of $L_{e,t}$ but of the first pixel of the following line which is even a saver choice.

$$t_{Le,t,e} = t_{Le,t} + d_{Am,t}$$ ***Equation 53***

$$t_{Le,t,e,m} = t_{Le,t,e} - \Delta t_{m,t}$$ ***Equation 54***

$$L_{e,m} = \frac{t_{Le,t,e,m}}{d_{L,m}}$$ ***Equation 55***

4.1.3.2.3 Locate LUT Target Pixels

The next step is to calculate for each pixel of the LUT target grid its location in the (C_{sc}, C_{tr}) coordinate system. The following algorithm has been generalised to the extent that it can also be used to locate the LUT mapping pixels. The subscript i indicates which instrument's data are to be located, with i = m for the mapping instrument and i = t for the target instrument. Three parameter values differ for the two instruments:

mapping instrument: $\Delta t_{i,t} = \Delta t_{m,t} \neq 0$; $\Delta\alpha_{sc,i} = \Delta\alpha_{sc,m} = 0$; $\Delta t_{sc,i} = \Delta t_{sc,m} = 0$

target instrument: $\Delta t_{i,t} = \Delta t_{t,t} = 0$; $\Delta\alpha_{sc,i} = \Delta\alpha_{sc,t}$ and $\Delta t_{sc,i} = \Delta t_{sc,t}$ are applied.

with

$\Delta\alpha_{sc,t}$ = correction of the scan angle of the target instrument pixel P_t to compensate for the relative mispointing between the mapping and the target instrument

$\Delta t_{sc,t}$ = correction of the scanning time of the target instrument pixel P_t

Note: These correction values need be defined for each pixel Pt of the target scan line since they might differ slightly from pixel to pixel.

Calculate scan position coordinate C_{sc}

Since we assume nominal scanning geometry, nominal attitude parameters and simplified orbit and Earth parameters the position of a pixel in scan direction is determined by its corrected scan angle (nadir at the time of scanning the pixel (Earth centre), spacecraft, pixel).

The nadir position $P_{N,i}$ within a scan line of instrument *i* is

$$P_{N,i} = \frac{1}{2} \cdot N_i + 0.5$$ ***Equation 56***

with N_i = number of pixels per scan line of instrument *i*.

The corrected scan angle $\alpha_{sc,i,c}$ of pixel P_i of instrument i is defined as follows:

$$\alpha_{sc,i,c} = D_{sc,i} \cdot (P_i - P_{N,i}) \cdot \alpha_{st,i} + \Delta\alpha_{sc,i}$$ ***Equation 57***

with

$D_{sc,i}$ = scan direction of instrument i being +1 for left to right (in track direction) and -1 for right to left

$\alpha_{st,t}$ = step angle of instrument *i*.

Note: The scan angle is defined for both instruments such that it is negative for pixels left to the track and positive for pixels right to the track.

According to figure 5 and the formulae given in chapter 4.1.4.2.1 we get for the angle β_i (spacecraft, Earth centre, P_i)

$$\beta_i = 180 - \alpha_{sc,i,c} - \left(180 - \operatorname{asin}\left(\frac{R + A_{orb}}{R} \cdot \sin\alpha_{sc,i,c}\right)\right)$$ ***Equation 58***

and derive finally the GCA distance $C_{sc,i}$ of P_i from nadir at the time of scanning P_i

$$C_{sc,i} = \beta_i \cdot \frac{\pi}{180} \cdot R$$ ***Equation 59***

Calculate track position coordinate C_{tr}

The track position $C_{tr,i}$ of a pixel Pi depends on its corrected scanning time $t_{Pi,c}$ and the angular speed of the spacecraft. We get $t_{Pi,c}$ (relative to $T_{L1,t}$) by

$$t_{Pi,c} = \Delta t_{i,t} + (L_i - 1) \cdot d_{L,i} + (P_i - 1) \cdot d_{Pi} + \Delta t_{sc,i}$$ ***Equation 60***

with

$d_{L,i}$ = scan direction of instrument i being +1 for left to right (in track direction) and -1 for right to left

$d_{P,t}$ = step angle of instrument i.

and the position $C_{tr,i}$ of the pixel in track direction by

$$C_{tr,i} = t_{Pi,c} \cdot \frac{2\pi}{d_{orb}} \cdot R$$ ***Equation 61***

with d_{orb} = duration of an orbit of the spacecraft.

4.1.3.2.4 Locate LUT Mapping Pixels

Now we calculate for each pixel of the LUT mapping grid its location in the (C_{sc} , C_{tr}) coordinate system as we have done it for the LUT target grid.

4.1.3.2.5 Calculate Dump Mapping Grid Coordinates of LUT Target Pixels

The first piece of information required for LUT are the dump mapping grid coordinates for each LUT target pixel P_t, –the target pixel position expressed in mapping line number and mapping pixel number units (with fractional digits).

Calculate scan direction coordinate $P_{sc,t,m}$

Dividing the corrected target pixel scan angle by the step angle $\alpha_{st,m}$ of the mapping instrument, we get the dump mapping grid position in scan direction of the LUT target pixel

$$P_{sc,t,m} = P_{N,m} + D_{sc,m} \cdot \frac{\alpha_{sc,t,c}}{\alpha_{st,m}}$$ ***Equation 62***

Calculate track direction coordinate $L_{tr,t,m]}$

The dump mapping grid position in track direction of the LUT target pixel we get by converting the corrected scan time (relative to $t_{L1,t}$) of P_t to the time relative to $t_{L1,m}$, removing thereof the time to scan from the mapping line start to $P_{sc,t,m}$ to get the start time $t_{L,t,m}$ of a virtual mapping line that collocates with P_t and dividing this time by the duration of scanning a mapping line.

$$t_{L,t,m} = t_{Pt,c} - \Delta t_{m,t} - (P_{sc,t,m} - 1) \cdot d_{Pm}$$ ***Equation 63***

$$L_{tr,t,m} = \frac{t_{L,t,m}}{d_{L,m}} + 1$$ ***Equation 64***

Note: "1" needs to be added since the line counting starts with 1.

4.1.3.2.6 Determine Mapping Pixels in Target *fov* Ellipses

To find out which mapping pixels of the LUT mapping grid collocate with the fov ellipses of the pixels of the LUT target grid one defines for each target pixel a rough, big enough search area around its fov ellipse and checks for every mapping pixel of the search area whether it lies within the ellipse.

Define search area

The maximum search area is as follows:

$$L_{s,m,t} = L_{s,m}$$ ***Equation 65***

$$L_{e,m,t} = L_{e,m}$$ ***Equation 66***

$$P_{s,m,t} = 1$$ ***Equation 67***

$$P_{e,m,t} = N_m$$ ***Equation 68***

At least for the mapping of AVHRR pixels onto a sounder (HIRS) grid should the search area be optimised in order to improve the performance of the algorithm. Improved start and end mapping lines of the search area can be obtained by subtracting from respectively adding to the $L_{tr,t,m}$ coordinate of the target pixel the half length of the minor ellipse axis plus additional two lines and adding $\Delta t_{m,t}$ expressed in number of mapping lines

$$L_{s,m,t} = INT\left(\frac{C_{tr,t} - \frac{1}{2} \cdot A_m}{D_{L,m}} - \frac{\Delta t_{m,t}}{d_{L,m}}\right) - 2$$ ***Equation 69***

$$L_{e,m,t} = INT\left(\frac{C_{tr,t} + \frac{1}{2} \cdot A_m}{D_{L,m}} - \frac{\Delta t_{m,t}}{d_{L,m}}\right) + 2$$ ***Equation 70***

with INT(x) being the integer part of number x and $D_{L,m}$ is the distance between two successive scan lines in km.

For all the lines between $L_{s,m,t}$ and $L_{e,m,t}$ improved searching start and end pixels can be obtained by

$$P_{s,m,t} = \left(\textit{first mappixel left of} \left(C_{sc,t} + \frac{1}{2} \cdot A_M \right) \right) - 5$$ **Equation 71**

$$P_{e,m,t} = \left(\textit{first mappixel left of} \left(C_{sc,t} - \frac{1}{2} \cdot A_M \right) \right) + 5$$ **Equation 72**

Check for collocation

If the sum of the distances of a point from the two focal points of a ellipse is greater than the major axis of the ellipse then the point lies outside the ellipse as following figure illustrates.

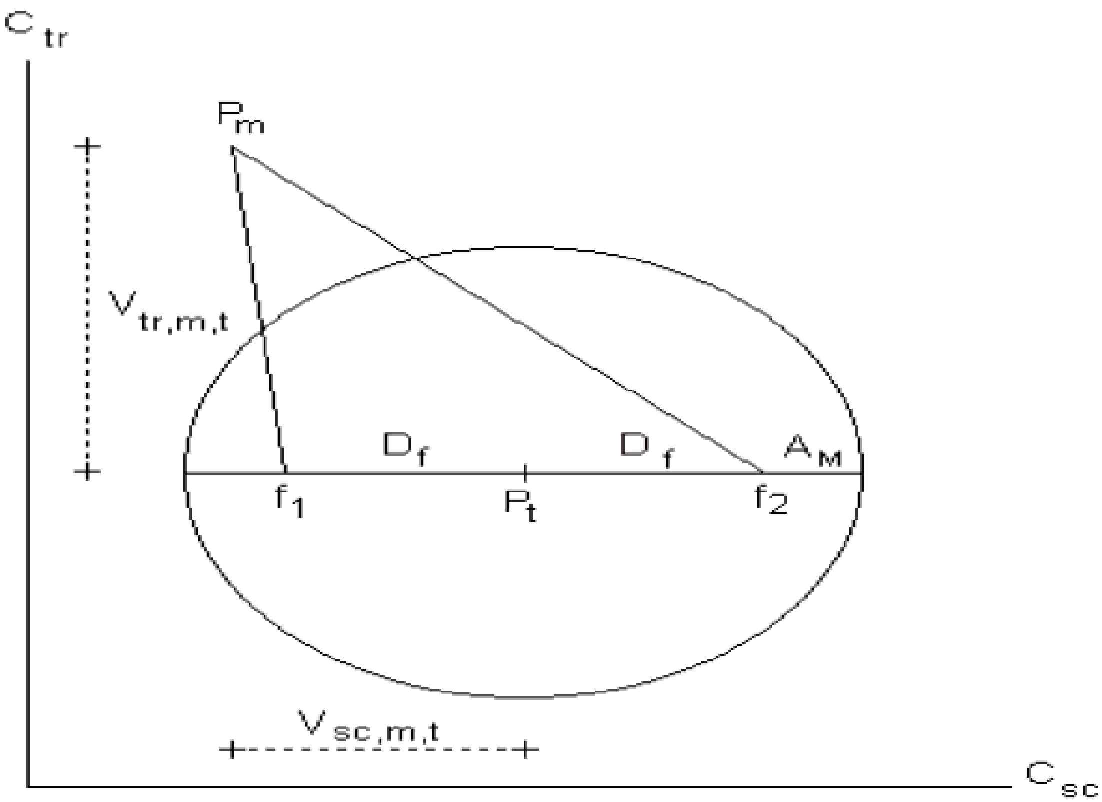

Figure 7: Collocation with target pixel fov ellipse

For the calculation of the distances of the mapping pixel P_m from the two focal points of the fov ellipse of P_t we need the components of the vector from P_t to P_m in scan and track direction, $V_{sc,m,t}$ and $V_{tr,m,t}$ respectively, in the (C_{sc} , C_{tr}) coordinate system

$$V_{sc,m,t} = C_{sc,m} - C_{sc,t}$$ **Equation 73**

$$V_{tr,m,t} = C_{tr,m} - C_{tr,t}$$

Equation 74

For the distances of P_m from the two focal points of the fov ellipse of P_t we get

$$D_{m,f1} = \sqrt{(V_{sc,m,t} - D_f)^2 + (V_{tr,m,t})^2}$$

Equation 75

$$D_{m,f2} = \sqrt{(V_{sc,m,t} + D_f)^2 + (V_{tr,m,t})^2}$$

Equation 76

The mapping pixel P_m lies inside the fov ellipse of the target pixel P_t if

$$D_{m,f1} + D_{m,f2} \le A_M$$

Equation 77

4.1.3.2.7 Store Collocation Information in LUT

For each LUT target pixel P_t store into LUT which mapping pixels P_m lie in the (expanded) fov ellipse of P_t , in following manner:

- position ($P_{sc,t,m}$, $L_{tr,t,m}$) of P_t in the LUT Mapping Grid
- number of pixels P_m collocated with the P_t fov ellipse for each collocated P_m
- position (P_m , l_m) of P_m in the LUT Mapping Grid

Due to the many AVHRR pixels that collocate with a sounder instrument fov ellipse their position information could be stored in a more condensed way such as follows:

the number of LUT mapping lines l_m collocated with P_t
for each LUT mapping line lm collocated with P_t

- the number of the mapping line
- the number of the first collocated pixel P_m of the mapping line
- the number of the last collocated pixel P_m of the mapping line

Note: The following has been specified here for the sake of the ATOVS Level 2 Processing. Reference to here is made in the corresponding PGS.

Assigning mapping instrument values to the target pixels P_t is done for AVHRR simply by averaging the values of the AVHRR pixels that collocate with the P_t fov ellipse. For assigning a value to the P_t pixels when mapping a sounder's data interpolation becomes necessary. To support the interpolation following values should be put in LUT per P_t:

$V_{sc,m,t}$

$V_{tr,m,t}$

weight

Four different weight functions are foreseen to be applied by the ATOVS level 2 processor:

- Nearest neighbour
- Bi-linear interpolation
- Spatial averaging with Gaussian weights
- Spatial averaging with linear weights

Nearest neighbour weights

The nearest neighbour is determined by the minimum of the distances $D_{m,t}$ of the pixels P_m collocated with the P_t fov ellipse.

$$D_{m,t} = \sqrt{V_{sc,m,t}^{\;2} + V_{tr,m,t}^{\;2}}$$

Equation 78

The weight factor of the nearest neighbour is 1; all other collocated P_m get 0.

Bi-linear interpolation weights

The dump mapping grid forms a parallelogram grid when represented in the (C_{sc},C_{tr}) collocation system. Since the angle between the track direction and the direction of a scan line does not deviate much from 90 degrees the weights might be calculated as if the dump mapping grid formed a rectangular grid.

The weight factors are to be calculated for the four mapping pixels P_m that form the parallelogram in which P_t lies.

Spatial averaging with Gaussian weights

Per P_m collocated with the P_t fov ellipse we first calculate an intermediate value according to

$$I_{Pm,Pt} = e^{-\frac{1}{2}\cdot\left(\frac{D_{m,t}}{A_m \cdot f_\sigma}\right)^2}$$

Equation 79

with a factor f_σ to derive from the major ellipse axis a value for σ of the Gaussian function.

From the intermediate values we derive the actual weights for each P_m

$$W_{P_m,P_t} = \frac{I_{P_m,P_t}}{\sum_{P_m} I_{P_m,P_t}}$$

Equation 80

Spatial averaging with linear weights

Per P_m collocated with the P_t fov ellipse we first calculate an intermediate value according to

$$I_{Pm,\,Pt} = A_m \cdot f_D - D_{m,\,t}$$

Equation 81

with a factor f_D to derive from the major ellipse axis a distance such that all $I_{Pm,Pt}$ are positive.
From the intermediate values we derive the actual weights for each P_m

$$W_{P_m,\,P_t} = \frac{I_{P_m,P_t}}{\sum_{P_m} I_{P_m,P_t}}$$

Equation 82

With these weights one can assign a mapping instrument value $V_{m,Pt}$ to P_t by calculating a weighted mean from the instrument values V_{Pm} of all pixels P_m collocated with the P_t fov ellipse

$$V_{m,\,P_t} = \sum_{P_m} W_{P_m,\,P_t} \cdot V_{P_m}$$

Equation 83

4.1.3.3 Collocate Mapping Pixels and Target fov Ellipses

To find out which pixels P_m of the dump mapping grid collocate with which fov ellipses of the pixels P_t of the dump target grid we determine for each line L_t of the dump target grid which line $L_{t,LUT}$ of the LUT target grid corresponds to it. The look-up table LUT tells us for each pixel $P_{t,LUT}$ of $L_{t,LUT}$ which LUT mapping grid lines $L_{m,LUT}$ and which pixels $P_{m,LUT}$ of them collocate with the fov ellipse of $P_{t,LUT}$. This information we relate to the dump mapping grid to get the dump mapping grid lines L_m and their pixels P_m which collocate with the fov ellipse of pixel P_t.

$$L_{t,\,LUT} = mod(L_t - L_{s,\,t} + R_t, R_t) + 1$$

Equation 84

If $(L_t - L_{s,t}) \geq 0$ or $(L_t - L_{s,t}) < 0$ and $\mathrm{mod}(L_t - L_{s,t} + R_t\,,\, R_t\,) = 0$ then

$$L_m = L_{m,\,LUT} + INT\left(\frac{L_t - L_{t,\,LUT}}{R_t}\right) \cdot R_m$$

Equation 85

If $(L_t - L_{s,t}) < 0$ and mod $(L_t - L_{s,t} + R_t,\ R_t) > 0$ then

$$L_m = L_{m,LUT} + INT\left(\frac{L_t - L_{t,LUT} - R_t}{R_t}\right) \cdot R_m$$ **Equation 86**

with INT(x) being the integer part of number x.

4.1.3.4 Calculate Percentage of Clear AVHRR Pixels

For all HIRS pixels in the satellite data dump the percentage of clear AVHRR pixels within the HIRS fov ellipses is derived from the AVHRR Level 1B data. AVHRR pixels are excluded from this calculation if both the following are true:

- QC flag is not okay
- surface type is not the one of the HIRS pixel (if this check is requested through a user-configurable parameter).

The remaining AVHRR pixels within the HIRS pixel fov ellipse are counted and as well the number of clear pixels among them. From this data the percentage of clear AVHRR pixels within HIRS fov ellipse is calculated. If there are no clear AVHRR pixels or no valid AVHRR pixels at all in a HIRS fov ellipse the percentage of the clear AVHRR pixels is set to a default value.

Note: To calculate the percentage of the clear AVHRR pixels for the pixels of the first HIRS line of a satellite data dump it might be necessary to make use of the AVHRR L1B data from the end of the previous dump.

If no previous dump is available then the statistical parameters shall be derived from the data of the current dump only and flagged as incomplete.

4.2 Level 1b Processing

4.2.1 Calibrate IR Earth Scan Counts to Radiances

For each scene count of scan line *n* of calibration cycle *ic* of the current 24-hour period *p*, the corresponding measured (in-band) radiance R_s is computed using Equation 82.

$$R_s = a_0 + a_1 C_s + a_2 {C_s}^2$$ **Equation 87**

where the coefficients are the Earth scan line specific calibration coefficients determined during the HIRS/4 Level 1a product processing.

4.2.2 Calibrate VIS Earth Scan Counts to Reflectance Factors

For each scene count of scan line n of calibration cycle *ic*, the corresponding reflectance factors (per cent albedo) A_s is computed from the following:

$$A_s = a_0 + a_1 C_s$$ **Equation 88**

The coefficients are determined before launch and are rarely changed.

APPENDIX A: LIST OF EQUATION PARAMETERS

These are derived from the processing steps detailed above. The following table presents the list of the parameters, coefficients and intermediate values used to translate the earth view counts into calibrated radiances and albedo percentages for the HIRS/4 instrument.

Symbol	*Description*
a_0	intercept of calibration equation
a_1	slope of calibration equation (inverse receiver gain)
a'_0	intercept of calibration equation obtained using 24-hour coefficients (after NOAA).
$a'_{0,n,ic}$	intercept of calibration equation obtained using 24-hour coefficients (after NOAA) for scan line n, calibration cycle *ic*.
a'_1	slope of calibration equation (inverse receiver gain) obtained using 24-hour coefficients (after NOAA).
$\bar{a}_{1,j}$	mean calibration slope for the 24-hour period *j*
a_2	second order term of calibration equation
α_{co}	scanning cone angle of the target instrument
$\alpha_{co.x}$	expanded scanning cone angle of the target instrument
A_m	GCA length of minor axis of fov ellipse of P_t
A_M	GCA length of major axis of fov ellipse of P_t
A_{orb}	(mean) altitude of the orbit of the spacecraft above Earth's surface
A_s	Scene percent albedo
α_{sc}	scan angle (Earth centre, S/C, pixel) of pixel P_t
$\alpha_{sc,i,c}$	corrected scan angle of P_i , i = mapping or target
$\alpha_{st,i}$	scanning step angle of instrument i, i = mapping or target
β	angle (S/C, Earth centre, pixel) of pixel P_t
$B(\nu,T)$	Planck function
b, c	coefficients for the computation of the modified temperature of the warm target (band correction coefficients)
b_0	constant of least squares regression of intercept a_0 vs temperature T'_s
b_1	intercept correction factor: first order constant of least squares regression of intercept a_0 versus temperature T'_s
β_c	angle (S/C, Earth centre, close A_M point) of pixel P_t
β_f	angle (S/C, Earth centre, far A_M point) of pixel P_t
B_W	viewing angle of W from centre of Earth
C_1	first radiation constant
C_2	second radiation constant
$\bar{C}_{cs}$	averaged cold space counts (average of 48 scenes)
$C_{cs,i}$	cold space counts for scene *i*
$\tilde{C}_k$	warm target PRT counts for PRT *k*, reading number *m*

Symbol	*Description*
$\tilde{C}_{km}$	warm target PRT counts for PRT *k*, reading number *m*
C_s	earth view counts
$C_{sc,i}$	position of pixel P_i in scan direction (in km) with positive values to the right of the track and negative values to the left, *i* = mapping or target
$C_{tr,i}$	position of pixel P_i in track direction (in km) with position of first pixel of $L_{1,t}$ being 0, i = mapping or target
$\bar{C}_{wt}$	averaged warm internal target counts (average of 56 scenes)
$C_{wt,i}$	warm internal target counts for scene *i*
δ	90° - angle (Earth centre, pixel, S/C) of pixel P_t
D	distance of S/C to pixel Pt
d_{Am}	duration of the S/C overflight over a track distance of length A_m of the first pixel P_t of a target scan line
$\Delta\alpha_{sc,i}$	correction of scan angle per pixel P_i , i = mapping or target, being 0 for i = m
D_f	distance of a focal point from the centre of the fov ellipse of P_t
d_j	conversion coefficients for instrument reference temperature (TBC)
$d_{L,i}$	duration of scanning a line of instrument i including the retrace steps, i = mapping or target
$D_{L,m}$	distance of 2 consecutive mapping lines (km)
$D_{m,fi}$	distance between P_m and focal point f_i , i = 1,2 of the fov ellipse of P_t
$D_{m,t}$	distance between P_m and P_t
Dn	spectral discretisation for the radiance computation
d_{orb}	duration of an orbit of the spacecraft
d_{Pi}	duration of stepping from one pixel P_i of instrument i to the next, i = mapping or target
$D_{sc,i}$	scan direction of instrument i, i = mapping or target, (looking in track direction) +1 = left to right (HIRS), -1 = right to left (AVHRR)
$\Delta t_{i,t}$	$= t_{L1,i} - t_{L1,t}$, i = mapping or target
$\Delta t_{sc,i}$	correction of scanning per pixel P_i , i = mapping or target, being 0 for i = m
e	eccentricity of fov ellipse of P_t
Φ*(LUT)*	instrument spectral response function (discretised)
f_D	factor to derive maximum distance from AM for the the linear spatial averaging
$f_{k,j}$	polynomial coefficients for the conversion of the PRT temperature
fov	field of view of a scan spot
f_σ	factor to derive σ from A_M for Gaussian spatial averaging
γ	angle (Earth centre, pixel, S/C) of pixel Pt
GCA	great circle arc on (spherical) Earth
H	instrument reference temperature counts (TBC)
ic	calibration cycle index (ic=1,Nj)
$I_{Pm,Pt}$	intermediate value for calculating a weight factor for P_m for its mapping onto P_t
j	24- hour period index

Symbol	Description
k	warm target PRT index (k = 1 to 4)
$L_{1,i}$	(number of) first line of instrument i of a satellite dump, i = mapping or target
$L_{e,i}$	(number of) the scan line of instrument i where the LUT creation ends, i = mapping or target
$L_{e,m.t}$	(number of) end mapping line of search area around P_t
L_i	(number of) a scan line of instrument i, i = mapping or target
$L_{i,LUT}$	scan line of instrument i, i = mapping or target, used for LUT creation
$L_{s,i}$	(number of) the scan line of instrument i where the LUT creation starts, i = mapping or target
$L_{s,m,t}$	(number of) start mapping line of search area around P_t
LUT	look up table
m	number of readings for PRT k (m = 1 to 5)
n	scan line index (n = 0,..,39) of calibration cycle
v_1, v_2	lower and upper spectral limits of the channels
v_c	central wave number of each channel
N_i	number of pixels per scan line of instrument i, i=mapping or target
N_j	Number of calibration cycles in 24 hour our period j
N_{tcs}	Threshold number of valid calibration measurements for cold space
N_{twt}	Threshold number of valid calibration measurements for warm target
$P_{e,m,t}$	end mapping pixel of search area around Pt
P_i	(number of) a pixel within a scan line of instrument i, i = mapping or target
$P_{i,LUT}$	pixel of scan line of instrument i, i = mapping or target, used for LUT creation
$P_{N,i}$	nadir position within scan line of instrument i, i = mapping or target
$P_{s,m,t}$	start mapping pixel of search area around Pt
$P_{sc,t,m}$	dump mapping grid position in scan direction of LUT target pixel P_t
$L_{tr,t,m}$	dump mapping grid position in track direction of LUT target pixel P_t
R	radius of Earth
R_i	number of lines of instrument i, i = mapping or target, within the 32-second repetition interval (HIRS=5, AVHRR=192)
R_s	calibrated radiances
R_{wt}	computed radiance of the warm internal target
S/C	spacecraft
σ_1	standard deviation of the calibration slope
σ_b	standard deviation of linear regression for b_1
T^*_{wt}	modified estimated temperature of the internal warm target
T_k	estimated temperature for PRT k
T_s	secondary mirror (baffle) temperature
$T_{s,n}$	secondary mirror (baffle) temperature for scan line n
T'_s	interpolated secondary mirror (baffle) temperature
$T'_{s,n}$	interpolated secondary mirror (baffle) temperature for scan line n

Symbol	***Description***
$t_{L,t,m}$	start time of a virtual mapping line collocating with P_t (relative to $t_{L1,t}$)
$t_{L1,i}$	time of scanning first pixel line $L^{1,i}$, i = mapping or target
$t_{Le,t}$	time of last pixel of line $L_{e,t}$ (relative to $t_{L1,t}$)
$t_{Le,t,e}$	time of end of fov ellipse (last A_m point) of last pixel of line $L_{e,t}$ (relative to $t_{L1,t}$)
$t_{Le,t,e,m}$	$t_{Les,t,e}$ relative to $t_{L1,m}$
$t_{Ls,t}$	time of first pixel of line $L_{s,t}$ (relative to $t_{L1,t}$)
$t_{Ls,t,s}$	time of start of fov ellipse (first A_m point) of first pixel of line $L_{s,t}$ (relative to $t_{L1,t}$)
$t_{Ls,t,s,m}$	$t_{Ls,t,s}$ relative to $t_{L1,m}$
$t_{Pi,c}$	corrected time of scanning P_i , i = mapping or target, (relative to $t_{L1,t}$)
T_s	secondary mirror (baffle) temperature
T_{wt}	estimated temperature of the internal warm target
$V_{m,Pt}$	mapping instrument value assigned to P_t
V_{Pm}	mapping instrument value at P_m
$V_{sc,m,t}$	scan direction component of the vector from P_t to P_m
$V_{tr,m,t}$	track direction component of the vector from P_t to P_m
W	half scan cone width in tangential plane of P_t in track direction
w_k	PRT weights for the computation of the warm target temperature
$W_{Pm,Pt}$	weight factor for P_m for its mapping onto P_t
x_t	target fov expansion factor