Product User Guide – HIRS FDR Release 1

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DCR = Document Change Request

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1 Introduction

1.1 Purpose and Scope

The purpose of this guide is to provide users with detailed information about the first EUMETSAT release of re-calibrated Level 1c brightness temperatures for three generations of HIRS instruments, onboard the operational polar-orbiting Metop satellites (HIRS-4) and NOAA satellites (HIRS/4, HIRS/3, HIRS/2), to be used as consistent input to climate analyses. A subset of this record, consisting of HIRS data collected by satellites TIROS-N, NOAA-06, and Metop-B, was produced with support from the European Union Copernicus Climate Change Service (C3S). As shown hereafter, the data records of all HIRS instruments were reprocessed consistently with each other. The overall data record is hereinafter referred to as HIRS Fundamental Data Record (FDR) Release 1. The FDR covers more than 40 years of data from 29 October 1978 until 31 December 2020.

This guide provides:

1. An overview of the data record;
2. Scientific details on the definition and generation of the data record;
3. Information on characteristics, applicability and limitations of the product;
4. Technical details on the format and the ordering of the data record, as well as information on the mechanisms to provide feedback.

1.2 Reference Documents

Reference documents contain additional information related to this document. The list of reference documents is provided in section 11.

1.3 Acronyms and Abbreviations

Acronym	Meaning
ATBD	Algorithm Theoretical Baseline Document
C3S	Copernicus Climate Change Service
CF	Climate and Forecast
DOI	Digital Object Identifier
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA5	ECMWF ReAnalysis 5
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FDR	Fundamental Data Record
FCDR	Fundamental Climate Data Record
FIDUCEO	Fidelity and uncertainty in climate data records from Earth Observations
HIRS	High Resolution Infrared Sounder
LW	Longwave
NEDT	Noise Equivalent Differential Temperature
NWP	Numerical Weather Prediction
SRF	Spectral Response Function
SW	Shortwave

Acronym	Meaning
UMARF	Unified Meteorological Archive & Retrieval Facility
WMO	World Meteorological Organization

2 Background

HIRS instruments have been providing information on tropospheric temperature and humidity [RD 1, RD 2], clouds [RD 3], and ozone [RD 4] since late 1970s. The quality of the historical and later operational satellite data that have been assimilated over the years into Numerical Weather Prediction (NWP) models is not optimal for the use in today's climate applications (such as reanalyses), for several reasons. For example, the strict timeliness requirements have led NWP centers to miss the acquisition of some observations. In addition, the procedures for quality control and calibration have improved over time. As a result, the quality of the complete HIRS calibrated data record can be improved by reprocessing and by making updates to, for example, the metadata, the quality flags, and/or the instrument calibration.

The operational HIRS calibration algorithm has undergone several improvements [RD 5] as follows. The calibration algorithm that was first used for HIRS/2 (until NOAA-14) introduced artefacts in the middle of a superswath, which is the sequence between two complete calibration cycles. The subsequent calibration algorithm (V3.0), which has been operational since 1998 from NOAA-15 onwards, removed these artefacts. This later algorithm was based on the assumption that the instrument gain does not change significantly during a 24-hour period and thus a 24-hour average slope (inverse of gain) was used for calibrating all data during the period. This assumption becomes invalid when the instrument background flux changes significantly and rapidly (for a detailed explanation of this effect see Cao et al., 2007 [RD 5]), causing errors in the Level 1b radiance data, by as much as 3K. This finding led to the development of a new version (V4.0, [RD 5]). This new algorithm takes into account the variations in the thermal environment of the HIRS instrument.

The HIRS FDR Release 1 is based on the V4.0 calibration method described by Cao et al., 2007 [RD 5]. This method was implemented in the NWP-SAF software ATOVS and AVHRR processing Package [RD 8] (AAPP). This software was consistently used to recalibrate and reprocess data from all HIRS instruments onboard TIROS-N, NOAA-06 to NOAA-19, Metop-A, and Metop-B.

3 Data Record Overview

General	Data record name	HIRS FDR Release 1
	Data record digital identifier	DOI: 10.15770/EUM_SEC_CLM_0026
	Data record short description	Contains calibrated radiances as brightness temperature [K], noise equivalent differential temperature [K], geolocation, sensing time, viewing geometries, and quality information.
	Record type	Fundamental Data Record
Coverage	Spatial coverage	Global
	Temporal coverage	1979 – 2020
	Temporal frequency	14 Orbits per day, twice daily coverage.
Instrument	Instruments names	High Resolution Infrared Sounder (HIRS)
	Instruments descriptions	HIRS is a 20 channel cross-track scanning infrared radiometer onboard NOAA's and EUMETSAT's polar orbiting satellites. Among the 20 spectral channels, there are 12 longwave channels (669–1529 cm−1), 7 shortwave channels (2188–2657 cm−1), and 1 visible channel (0.69 μm).
Instrument Data	Input data	HIRS L1b data files from NOAA/CLASS
	Output data	HIRS Level 1c brightness temperatures in NetCDF format.
	Format	The products are provided in NetCDF4 format
Access	EUMETSAT Data Centre	The dataset is available from EUMETSAT Data Centre (https://eoportal.eumetsat.int/)
	Delivery	ftp push

4 Product Definition

This section provides an overview of the HIRS FDR Release 1 in terms of instrument details, data file specifications such as names, data volumes and format, and the specific product content, including metadata.

4.1 HIRS Instruments and data

The HIRS FDR Release 1 comprises in total three different instruments (HIRS/2 on TIROS-N and NOAA-06 to NOAA-14, HIRS/3 on NOAA-15, -16, and -17, and HIRS/4 on NOAA-18, -19, and Metop-A and -B). Each instrument is a cross-track scanning infrared radiometer with 19 infrared channels and one visible channel, operating on a polar orbiting meteorological satellite, sun-synchronously orbiting above the Earth at about 830 km altitude.

The HIRS instruments have different spatial resolution: HIRS/2 and HIRS/3 circular field-of-views are approximately 20 km diameter at nadir, whereas HIRS/4 field-of-views are smaller (10 km diameter). This spatial resolution at nadir (expressed as a diameter of the field-of-view or footprint) decreases towards the edge of the swath (as the sizes of the field-of-views gradually increase).

The data files provide brightness temperatures for the Earth view measurements (that is, not for calibration views), radiometric noise of the instrument at 280 K (derived using cold and warm calibration views), and quality flags.

The main characteristics of the three HIRS instruments are summarised in Table 1. The channels' central wavelengths are given in Table 2.

Table 1: Summary of the instrument characteristics of the three HIRS models. Swath widths were calculated based on a satellite height of 830 km and assuming spherical earth of radius 6371km.

Characteristic	HIRS/2	HIRS/3	HIRS/4
Optical Field of View	1.25 degrees	1.3 degrees (LW) 1.4 degrees (SW)	0.69 degrees
Earth Scan Angle	±49.5 degrees from nadir	±49.5 degrees from nadir	±49.5 degrees from nadir
Pixels per scan line	56	56	56
Sampling interval	1.8 degrees	1.8 degrees	1.8 degrees
Scan rate	6.4 seconds	6.4 seconds	6.4 seconds
Earth Swath	2232 km	2240 km	2204 km
IFOV size	17.4 km at nadir	20.3 km (1.4 degrees IFOV) at nadir 18.9 km (1.3 degrees IFOV) at nadir	10 km at nadir

Table 2: Summary of the central wavelength (in μm) for each spectral channel of the different HIRS instruments (HIRS/2, HIRS/3, and HIRS/4). These numbers are for information summary purposes only, as some flight models differed from these general specifications. For numerical exploitation of this information, users are directed to refer to the data, attribute "wavenumber" (see example in Appendix B). LW channels are 1-12, SW channels are 13-19, and channel 20 is in the visible part of the spectrum.

Channel	HIRS/2	HIRS/3	HIRS/4
1	14.97	14.96	14.96
2	14.71	14.71	14.70
3	14.48	14.49	14.49
4	14.19	14.23	14.23
5	13.94	13.97	13.97
6	13.65	13.64	13.64
7	13.36	13.35	13.35
8	11.10	11.11	11.11
9	9.71	9.71	9.71
10	8.21	12.47	12.47
11	7.31	7.33	7.33
12	6.73	6.52	6.52
13	4.57	4.57	4.57
14	4.53	4.53	4.53
15	4.47	4.47	4.47
16	4.41	4.45	4.45
17	4.24	4.13	4.13
18	3.98	3.98	3.98
19	3.77	3.76	3.76
20	0.69	0.69	0.69

4.2 File Specifications

Data files for the HIRS FDR Release 1 are provided in NetCDF-4 format. The following subsections provide an overview of the filename definition, on the file size, and on how to visualise the data.

4.2.1 Filenames

The filenames of the data files include information on the instrument, product level, spacecraft, sensing start time, sensing end time, and dataset release. Sensing times are actually the start and end time of the measurements covered in the file. The file naming conventions used for the NetCDF-4 files are shown in Table 3.

Table 3: File names used for the Level 1c HIRS FDRs, corresponding to the NetCDF format.

Naming convention Level 1c MHS –NetCDF
FDR_<level>_<instr>_<sat>_<start_time>_<end_time>_<release>.nc
Example
FDR_L1C_HIRS4_METOPA_20061121154526_20061121172640_R01.0.nc

where:

<level>	data level = L1C
<inst>	instrument ID (e.g., HIRS4 for the 4th version of the HIRS sensor)
<sat>	satellite ID (e.g., METOPA for Metop-A)
<start_time>	sensing start time (YYYYMMDDHHMMSS)
<end_time>	sensing end time (YYYYMMDDHHMMSS)
<release>	FDR release number

4.2.2 File Sizes

Single NetCDF-4 granules cover an orbit from equator-to-equator and have sizes of about 6 MB. The approximate size of the whole data record is about 4.9 Terabyte. Details on the data volumes are given in Table 4, and are provided per instrument and per year.

Table 4: Data volume is given for all HIRS data per satellite and year in Gigabytes (GB). Numbers are split over two tables and are rounded to the closest integer.

Satellite	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
TIROS-N	5	37	2																			
NOAA-6		18	37	36	36	7																
NOAA-7				14	37	36	37	3														
NOAA-8						24	17															
NOAA-9								31	37	38	32											
NOAA-10									4	38	37	38	37	27								
NOAA-11											6	38	35	38	38	38	38	11		18	38	
NOAA-12														11	38	38	36	38	38	38	36	
NOAA-14																		36	38	39	39	38
NOAA-15																						38

Satellite	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	TOTAL
TIROS-N																						**44**
NOAA-6																						**134**
NOAA-7																						**127**
NOAA-8																						**41**
NOAA-9																						**138**
NOAA-10																						**181**
NOAA-11																						**298**
NOAA-12																						**273**
NOAA-14	38	38	38	38	36	35	23															**436**
NOAA-15	34	39	39	39	39	39	39	36	39	16									6.5	39	39	**397**
NOAA-16		39	39	39	39	39	39	38	39	39	38	39	38	39	17							**521**
NOAA-17			19	39	39	39	39	39	39	39	38	39	38	7								**414**
NOAA-18						22	38	39	39	39	38	39	38	39	38	39	39	39	39	39	39	**597**
NOAA-19										29	38	39	38	39	38	39	39	39	39	39	39	**455**
Metop-A							4	37	38	39	38	38	38	39	38	39	39	39	39	38	38	**541**
Metop-B														37	38	39	39	39	38	39	38	**307**
TOTAL																						**4904**

4.2.3 File Visualisation

Commonly known NetCDF viewers and NetCDF image-processing software can be used for visualisation of the NetCDF-4 files. Among others the files can be viewed with HDFview (version 2.13 or later), Ncview (version 2.1.7 or later), Panoply (version 4.7.0 or later), and processed with IDL (version 8.0 or later) and NetCDF-4 python (version 1.2.4) on python (version 2.6 or later).

4.3 Product Contents

This subsection provides a detailed description of the file content. This includes the metadata conventions, the measurement data, and the global attributes. Appendix B provides a complete example of the file metadata.

Metadata conventions

Metadata follow the CF (Climate and Forecast) convention and the Attribute Convention on Data Discovery (ACDD). Each variable is defined with the attributes standard name, units, and fill_value. The attribute ancillary_variables links other datasets, e.g. the Noise Equivalent Differential Temperature (NEDT), to the file containing the brightness temperature. Any data available on a pixel basis has attribute coordinates. These attributes directly link the pixel to a latitude and longitude information. Quality bitmasks are provided with flag_mask and flag_meaning attributes. More detail on these is provided at the end of this section. The global attributes include the WMO identifiers, defining the instrument and the satellite (Table 5).

Table 5: Overview of the instrument and satellite identifiers used in the FDR according to the WMO definition[1].

Satellite	Instrument name	WMO instrument id.	WMO satellite id.
TIROS-N	HIRS/2	605	708
NOAA-6	HIRS/2	605	706
NOAA-7	HIRS/2	605	707
NOAA-8	HIRS/2	605	200
NOAA-9	HIRS/2	605	201
NOAA-10	HIRS/2	605	202
NOAA-11	HIRS/2	605	203

[1] COMMON CODE TABLE C–5: Satellite identifier and COMMON CODE TABLE C–8: Satellite instruments.

Satellite	Instrument name	WMO instrument id.	WMO satellite id.
NOAA-12	HIRS/2	605	204
NOAA-14	HIRS/2	605	205
NOAA-15	HIRS/3	606	206
NOAA-16	HIRS/3	606	207
NOAA-17	HIRS/3	606	208
NOAA-18	HIRS/4	607	209
NOAA-19	HIRS/4	607	223
Metop-A	HIRS/4	607	4
Metop-B	HIRS/4	607	3

Variables available

The variables in the Level 1C NetCDF files include measurements and associated information. Details of the measurement datasets are presented in Table 6.

The FDR files contain brightness temperatures of the Earth view measurements, warm and cold NEDT, and metadata, such as geolocation (copied from Level 1b files), viewing geometry (copied from Level 1b files), and quality flags.

Table 6: Variables in the NetCDF files of the HIRS FDRs. Dimensions of arrays are indicated in square brackets: scanline number is denoted by 'time', scan position is denoted by 'x', and channel number is denoted by 'channel'.

Measurement data set	Long name
latitude	latitude (in degrees north) [time,x]
longitude	longitude (in degrees east) [time,x]
btemps	toa brightness temperature in Kelvin [channel, time, x]
satellite_azimuth_angle	sensor_azimuth_angle [time,x]
satellite_zenith_angle	sensor_zenith_angle [time,x]
solar_azimuth_angle	solar_azimuth_angle [time,x]
solar_zenith_angle	solar_zenith_angle [time,x]
warmnedt	warm target noise equivalent temperature difference [time, x]
coldnedt	cold target noise equivalent temperature difference [time, x]
instrtemp	instrument_temperature [time, x]
chanqual	Sensor specific bitmask for quality channel [channel, time]
dataqual	Sensor specific bitmask for data quality [time, x]
qualind	Sensor specific bitmask for quality indicator [time]
scanqual	Sensor specific bitmask for Scan line quality [time]
scalti	Satellite altitude [time]

Global attributes

The global attributes in the Level 1C NetCDF describe the data and give useful information about their content and production. The global attributes are listed in Appendix B (Table 9).

Quality Flags

The data files comprise four quality bitmasks, addressing different categories of issues as shown in Table 7. Note the quality flags for bad calibration cycles (chanqual) are only set for the calibration scan lines but not for the Earth view scanlines. This information has to be taken into account by the user when analysing the data, depending on the application at hand (see examples in the validation report [RD 7]).

Table 7: Meaning of the quality flags, as defined in AAPP documentation[2] [RD 8]

Quality flag	Bit	Description
dataqual	**quality control word for the data in each field of view**	
	0	set if all channels missing
	20-1	bit n set to 1 if brightness temperature in channel n is physically unreasonable or has not been calculated due to calibration problems
	30	set if secondary calibration used
	31	spare
scanqual	**scan line quality flags**	
	0-3	spare
	4	Earth location questionable. Fails
	5	Earth location questionable. Only marginal agreement with reasonableness check
	6	Earth location questionable because of questionable time code (see time problem flags above)
	7	not Earth located because of bad time
	8-9	spare
	10	uncalibrated due to instrument mode
	11	some uncalibrated channels of this scan. See channel indicators
	12	scan line was calibrated but with marginal PRT data
	13	scan line was not calibrated because of bad or insufficient PRT data
	14	scan line was calibrated using fewer than the preferred number of scan lines because of proximity to start or end of data set or to a data gap
	15	scan line was not calibrated because of bad time
	20	start of a sequence that apparently repeats scan times that have been previously accepted
	21	this record starts a sequence that is inconsistent with previous times (i.e., there is a time discontinuity). This may or may not be associated with a spacecraft clock update. (see bit 26 below)
	22	time field is bad and can't be inferred from the previous good time
	23	time field is bad but can probably be inferred from the previous good time
	24-31	spare
qualind	**quality indicator bit field In all of the following, the statement is true if the bit is on.**	
	0-24	spare
	25	instrument status changed with this scan
	26	first good time following a clock update
	27	no Earth location
	28	no calibration
	29	data gap precedes this scan
	30	time sequence error detected with this scan
	31	do not use scan for product generation
chanqual	**quality flag for each channel, with the channel indices to be read in the order 1, 3, 4, 6, 16, 15, 10, 11, 20, 13, 8, 18, 5, 14, 17, 19, 2, 7, 9, 12. (all bits off implies a good calibration)**	
	0	some QC tests could not be applied
	1	space views failed NEDC test
	2	BB views failed NEDC test
	3	calibration slope value came from the HCF
	4	calibration marginal
	5	calibration failed
	6-31	spare

[2] Except for the channel ordering of variable 'chanqual', which was found to differ from AAPP documentation (https://nwp-saf.eumetsat.int/site/forums/topic/order-of-hirs-channels-possibly-swapped-for-the-channel-quality-flag/); the modified wording in this table reflects this finding.

5 Product Generation

This section provides an overview of the generation process of the data record. Figure 1 summarises the data processing in a simplified sketch.

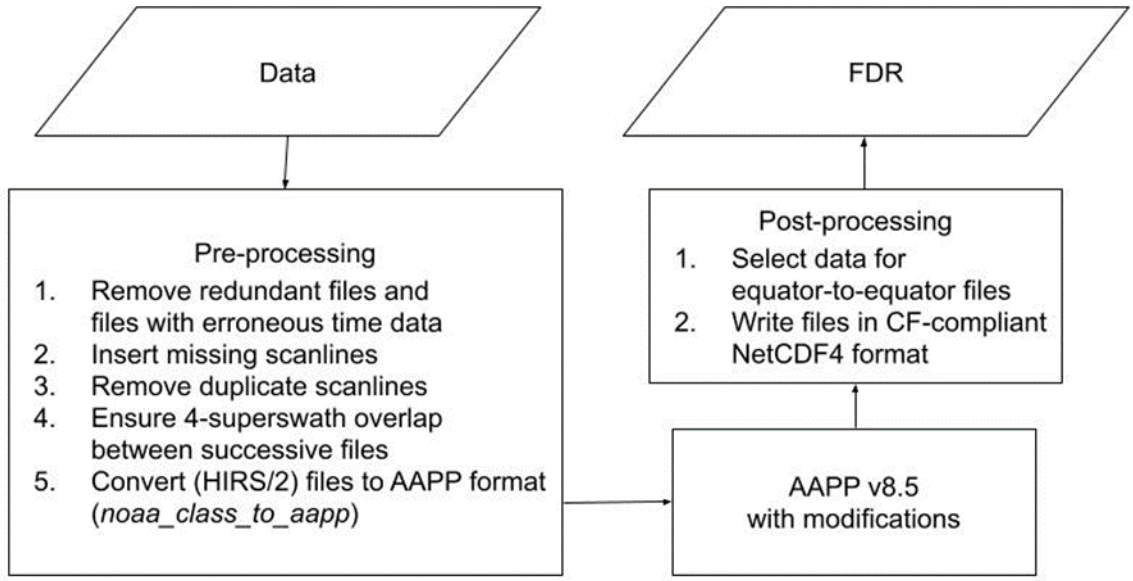

Figure 1 Processing steps from Level 1b HIRS data to Level 1c HIRS FDR. The modifications to AAPP v8.5 software are described in the ATBD [RD 6].

The processing scheme for the HIRS FDR uses python3. The HIRS Level 1b data was pre-processed to allow optimal calibration by the core of the processing, using a modified version of the ATOVS and AVHRR Pre-processing Package (AAPP, version 8.5). A detailed description of the AAPP software can be found in [RD 8]. Parts of the utilized calibration algorithm in AAPP were modified, mostly to enable processing of HIRS/2 data. Lastly a post-processing step reformats the data to its final form. A detailed description of these steps and modifications applied to the AAPP software can be found in the HIRS FDR Release 1 ATBD [RD 6].

6 Dataset Description

In this section, the HIRS FDR Release 1 is described in terms of temporal and spatial coverage and the instrument noise information is introduced.

6.1 Coverage

The HIRS FDR Release 1 consists of approximately 14 files per day per satellite. Each file is covering one full orbit from equator to equator. Table 8 summarises the temporal coverage of each HIRS instrument and the full data record.

Table 8: List of satellites, instruments, and main years of operation.

Satellite	Instrument	Operational Years	Number of years
TIROS-N	HIRS/2	1978 - 1980	3
NOAA-06	HIRS/2	1979 - 1983	5
NOAA-07	HIRS/2	1981 – 1985	5

NOAA-08	HIRS/2	1983 – 1984	2
NOAA-09	HIRS/2	1985 - 1988	4
NOAA-10	HIRS/2	1986 - 1991	6
NOAA-11	HIRS/2	1988 - 1998	10
NOAA-12	HIRS/2	1981 - 1998	8
NOAA-14	HIRS/2	1995 - 2006	12
NOAA-15	HIRS/3	1999 - 2020	14
NOAA-16	HIRS/3	2001 - 2014	14
NOAA-17	HIRS/3	2002 - 2013	12
NOAA-18	HIRS/4	2005 – 2020	16
NOAA-19	HIRS/4	2009 – 2020	12
Metop-A	HIRS/4	2006 – 2020	15
Metop-B	HIRS/4	2013 - 2020	9
TOTAL		**1978 - 2020**	**144**

Further, the 14 orbits each day provide an almost full spatial coverage of the Earth as shown in Figure 2. Each day, the Earth is observed once at daytime and once at night-time (descending node and ascending node). Figure 2 shows the brightness temperatures of channel 8, which primarily measures emission in the thermal window. The white areas around latitudes 20°S and 20°N represent locations that are not observed by the HIRS instrument on this particular day due to its scanning pattern. These gaps change their positions along longitudes on any particular day.

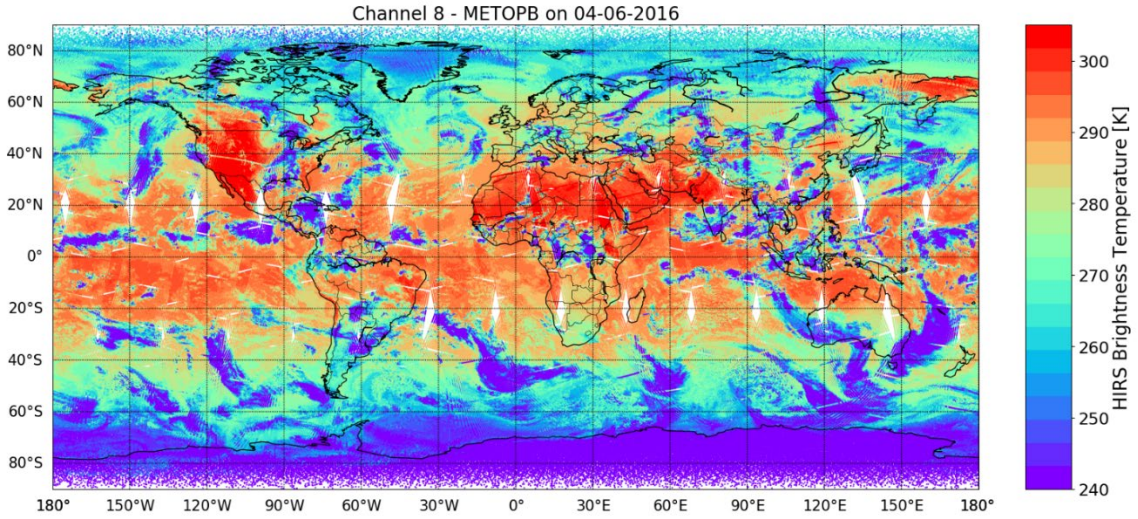

Figure 2: Example map of one day of HIRS brightness temperatures (channel 8 at 11 µm) collected from Metop-B (04-06-2016).

6.2 Uncertainty characterisation

The HIRS FDR Release 1 contains noise estimates based on the calibration measurements. The variability in the calibration measurements (counts) of a stable and known target is considered as the signal to noise ratio of the sensor. For any change in measurement signal that is lower than this variability, differentiation between noise and signal is impossible without carrying out additional spatial or temporal averaging. The variability in the measured count values is first converted into radiance and then it is converted to K at a reference temperature of 280 K. Because the calibration measurements are performed with respect to a cold target and a warm target, two corresponding NEDT values are available. Because the warm calibration target temperature is close to the Earth scene temperature, the warm NEDT is used to describe the

sensor noise level. Figure 3 shows the times series of the warm NEDT for channel 8. It is clear from the figure that the instrument noise for this particular channel is within its specifications for most sensors. Major exceptions for this are NOAA-12 in the later years, NOAA-18 over most of its lifetime, and NOAA-19 and Metop-A in the end of their time series. The use of NEDT along with the quality-controlled brightness temperature enables a user to filter out bad quality data.

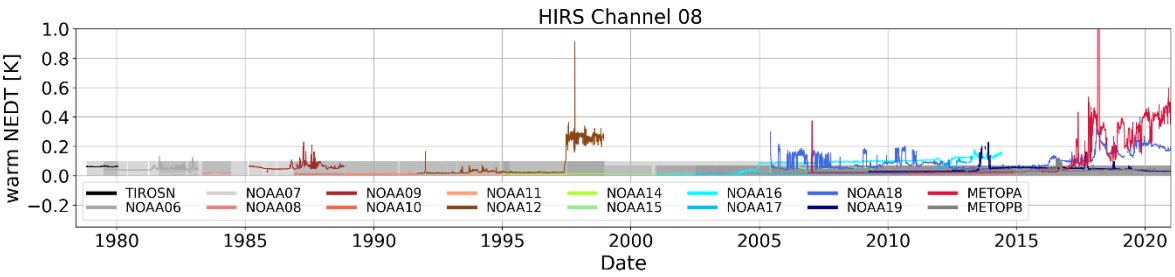

Figure 3: Time series of the channel 8 NEDT for all HIRS instruments of the FDR. The grey shaded area shows the specifications for each sensor.

The validation report presents examples on how to use the quality flags in combination with the NEDT and on how to remove noisy data (e.g. section 3.2.2 in the validation report).

7 Quality Evaluation

7.1 Validation

The HIRS FDR Release 1 has been technically and scientifically validated [RD 7]. The technical validation involved the following criteria:

- Basic checks of the data record, ensuring all the products are present and readable and that the metadata available is complete and consistent with the re-processing system configuration;
- Basic monitoring of the geophysical information in the products to ensure that they are within the ranges expected;

The scientific validation of the HIRS FDR Release 1, presented in the Validation Report [RD 7], involved the following criteria:

- Time series analysis of the HIRS brightness temperatures and comparison to original brightness temperatures;
- Comparison to simulated observations;

The results show a clear improvement of the HIRS FDR compared to the operationally processed data (original data). This can be expressed by (1) less noise and higher stability in the time series of the brightness temperatures especially for NOAA-18 and (2) higher stability of the calibration on the short time range especially within a super swath. These factors considered together make this HIRS FDR more consistent and more accurate than the operationally processed data (original data).

The analysis of the bias within a calibration cycle clearly shows improvements in the HIRS FDR for the HIRS/2 sensors. Although this improvement may not be visible when looking at aggregated mean statistics, the impact on single pixel data is significant. Therefore, it is

expected that this improvement will have considerable impact on downstream (level 2 and 3) products.

7.2 Improvements over operational data

The main improvements of the FDR over the operational data are:

- More than one calibration cycle is used to compute the calibration slope and offset, which reduces strong variations in the calibration coefficients between two calibration cycles or within a superswath;
- The instrument self-emission is considered and a model for computing its impact is implemented;
- The NEDT, as a measure of the instrument noise, is computed and provided for every pixel for all HIRS instruments. This feature was introduced in AAPP v7.1 in November 2015, but a reprocessing of all HIRS data with this or later versions of AAPP has not been done till the realisation of the present data record;
- The data quality control has been updated and applied consistently throughout the FDR.

7.3 Limitations and Known Issues

The FDR exhibits some limitations and known issues:

- The FDR does not correct for inter-satellite biases.
- Periods of increased noise remain, with NEDT out of specifications for NOAA-9, -12, -16, -18, -19, and Metop-A. Note, the NEDT on pixel level enables additional quality control.
- Several days have missing data files, due to voluntary exclusion from the data record. Two main reasons lead to this exclusion. First, known problems with the calibration algorithm result in wrongly calibrated data, and, second, unsuccessful occurrences of calibration result in missing values for almost the full data file. Badly calibrated data are excluded following a visual inspection and unsuccessful calibrated orbit files are excluded by applying a threshold to the data [RD 6].

  Due to known problems with the calibration, the following data are excluded from the FDR:
  - TIROS-N on 30.10.1978 and 31.10.1978;
  - NOAA-6 on 12.07.1979, 13.07.1979, and 17.12.1982;
  - NOAA-7 on 31.12.1984;
  - NOAA-12 on 11.01.1992 – 14.01.1992;
  - NOAA-14 on 30.09.2006 and 01.10.2006;
  - NOAA-15 on 25.10.2000 – 08.12.2000 and 30.05.2009 – 14.06.2009.

  Due to unsuccessful calibration, the following data are excluded from the FDR:
  - NOAA-6 on 08.04.1985 – 15.11.1986;
  - NOAA-8 on 01.07.1985 – 14.10.1985;
  - NOAA-15 on 15.06.2009 – 13.12.2015.

Generally, some periods have been identified to show reduced quality especially in the longwave channels. This is mostly related to problems with the filter wheel. These periods are:

- NOAA-12 after summer 1997;
- Metop-A after 2015;
- NOAA-18 most of its lifetime;
- NOAA-19 after July 2013;

- NOAA-16 after 2004;
- NOAA-9 especially after fall 1986.
-

These periods show an increased NEDT, where daily mean NEDT is out of specifications (see Table 3). However, the user can use the updated NEDT to filter out all pixels, which NEDT is actually above a certain threshold.

8 Product Ordering

Access to the data record is granted to all users without charge and without conditions of use. To access data, you need to be registered with the EUMETSAT Data Centre. When registered, you can order the data through a written request send to EUMETSATs helpdesk.

8.1 Register with the Data Centre

Do this to register with the EUMETSAT Data Centre:

1 Register in the EUMETSAT EO-Portal (*https://eoportal.eumetsat.int/*) by clicking on the New User – Create New Account tab;
2 After finalisation of the registration process, an e-mail is sent to the e-mail address entered in the registration. Click the confirmation link in the e-mail to activate your account;
3 Login and subscribe to the Data Centre Service by going to the Service Subscription Tab and selecting Data Centre Service. Follow instructions issued from the web page to add needed information.

8.2 Order Data

The data record described in this product user guide can be ordered via the EUMETSAT User Service Helpdesk in Darmstadt, Germany. Please send a written request to this helpdesk, email *ops@eumetsat.int*, indicating the data record that you want to order including its Digital Object Identifier (DOI) number (these are on the front page of this document).

Further information on data ordering and delivery can be found under "Satellites / How to access our data" at www.eumetsat.int.

If you have more questions or support issues, please contact the User Service Helpdesk directly via e-mail: *ops@eumetsat.int*

8.3 Data Policy

Access to the archive of products described in this product user guide is granted to all users without charge and without conditions on use if a licence agreement has been signed. For the full EUMETSAT data policy, please refer to: https://www.eumetsat.int/legal-framework/data-policy

9 Product Support and feedback

For enquiries and/or feedback concerning the products described in this product user guide, please contact the EUMETSAT User Service Helpdesk by email: *ops@eumetsat.int.*

10 Product Referencing

The products described in this product user guide are provided with a unique Digital Object Identifier (DOI) number, which is given at the top of this document as well as in the *doi* global attribute of each netCDF file. Please cite this DOI when referring to the products described in this document.

11 Reference Documents

Number	*Document Name*
RD 1.	Shi, L., J.L. Matthews, S.-P. Ho, Q. Yang, and J.J. Bates (2016) Algorithm Development of Temperature and Humidity Profile Retrievals for Long-Term HIRS Observations. *Remote Sens.* 2016, **8**(4), 280, https://doi.org/10.3390/rs8040280
RD 2.	Matthews, J.L., and L. Shi (2019) Intercomparisons of Long-Term Atmospheric Temperature and Humidity Profile Retrievals. *Remote Sens.* 2019, **11**, 853, https://doi.org/10.3390/rs11070853
RD 3.	Kolat, U., P. Menzel, E. Olson, and R. Frey (2013) Very high cloud detection in more than two decades of HIRS data. *J. Geophys. Res. Atmos.*, **118**, 3278– 3284, https://doi.org/10.1029/2012JD018496
RD 4.	Ma, X.-L., W.L. Smith and H.M. Woolf (1984) Total Ozone from NOAA Satellites—A Physical Model for Obtaining Measurements with High Spatial Resolution. *J. Clim. Applied Meteorol.*, **23** (9), pp. 1309-1314, https://doi.org/10.1175/1520-0450(1984)023%3C1309:TOFNSP%3E2.0.CO;2
RD 5.	Cao, C., K. Jarva, and P. Ciren (2007) An Improved Algorithm for the Operational Calibration of the High-Resolution Infrared Radiation Sounder. *J. Atmos. Ocean. Tech.*, **24**(2), 169-181, February 2007, https://doi.org/10.1175/jtech2037.1
RD 6.	Algorithm Theoretical Baseline Document - HIRS FDR Release 1,EUM/OPS/DOC/20/1204897
RD 7.	Validation Report - HIRS FDR Release 1, EUM/OPS/DOC/20/1179880
RD 8.	Atkinson, N. (2020) AAPP User Guide, NWPSAF-MO-UD-036. https://nwp-saf.eumetsat.int/site/download/documentation/aapp/NWPSAF-MO-UD-036_Userguide.pdf

Appendix A Header of a HIRS FDR NetCDF File

List of variables names corresponding to the NetCDF format.

```
netcdf FDR_L1C_HIRS4_METOPA_20061121154526_20061121172640_R01.0 {
dimensions:
    channel = 20 ;
    x = 56 ;
    time = 950 ;
variables:
    int64 channel(channel) ;
     channel:long_name = "channel number" ;
     channel:units = "dimensionless" ;
    int64 x(x) ;
     x:long_name = "scan position" ;
     x:units = "dimensionless" ;
    float btemps(time, x, channel) ;
     btemps:_FillValue = -999.f ;
     btemps:units = "K" ;
     btemps:long_name = "Brightness temperature of METOPA" ;
     btemps:standard_name = "toa_brightness_temperature" ;
     btemps:ancillary_variables = "warmnedt coldnedt" ;
     btemps:coordinates = "longitude latitude" ;
    int64 chanqual(time, channel) ;
     chanqual:long_name = "Sensor specific bitmask for quality channel" ;
     chanqual:standard_name = "status_flag" ;
     chanqual:description = "Channel quality: see AAPP Formats document" ;
    float coldnedt(time, channel) ;
     coldnedt:_FillValue = -999.f ;
     coldnedt:units = "mK" ;
     coldnedt:long_name = "cold target noise equivalent temperature difference" ;
     coldnedt:Reference_Temperature = "280K" ;
    int64 dataqual(time, x) ;
     dataqual:long_name = "Sensor specific bitmask for data quality" ;
     dataqual:standard_name = "status_flag" ;
     dataqual:description = "Data quality: see AAPP Formats document" ;
     dataqual:coordinates = "longitude latitude" ;
    float instrtemp(time) ;
     instrtemp:_FillValue = -999.f ;
     instrtemp:units = "K" ;
     instrtemp:long_name = "instrument temperature" ;
    int64 qualind(time) ;
     qualind:long_name = "Sensor specific bitmask for quality indicator" ;
     qualind:standard_name = "status_flag" ;
     qualind:description = "Quality indicator: see AAPP Formats document" ;
    float scalti(time) ;
     scalti:_FillValue = -999.f ;
     scalti:units = "km" ;
     scalti:long_name = "satellite altitude" ;
    int64 scanqual(time) ;
     scanqual:long_name = "Sensor specific bitmask for Scan line quality" ;
     scanqual:standard_name = "status_flag" ;
     scanqual:description = "Scan line quality: see AAPP Formats document" ;
    int scnlin(time) ;
     scnlin:long_name = "scanline number" ;
    float warmnedt(time, channel) ;
     warmnedt:_FillValue = -999.f ;
     warmnedt:units = "mK" ;
     warmnedt:long_name = "warm target noise equivalent temperature difference" ;
     warmnedt:Reference_Temperature = "280K" ;
```

```
    double time(time) ;
      time:_FillValue = -1. ;
      time:long_name = "time" ;
      time:units = "seconds since 1970-01-01" ;
      time:calendar = "proleptic_gregorian" ;
    float latitude(time, x) ;
      latitude:_FillValue = -999.f ;
      latitude:units = "degrees_north" ;
      latitude:long_name = "latitude" ;
      latitude:standard_name = "latitude" ;
    float longitude(time, x) ;
      longitude:_FillValue = -999.f ;
      longitude:units = "degrees_east" ;
      longitude:long_name = "latitude" ;
      longitude:standard_name = "latitude" ;
    float satellite_azimuth_angle(time, x) ;
      satellite_azimuth_angle:_FillValue = -999.f ;
      satellite_azimuth_angle:units = "degree" ;
      satellite_azimuth_angle:long_name = "sensor azimuth angle" ;
      satellite_azimuth_angle:standard_name = "sensor_azimuth_angle" ;
      satellite_azimuth_angle:valid_range = 0LL, 360LL ;
      satellite_azimuth_angle:coordinates = "longitude latitude" ;
    float satellite_zenith_angle(time, x) ;
      satellite_zenith_angle:_FillValue = -999.f ;
      satellite_zenith_angle:units = "degree" ;
      satellite_zenith_angle:long_name = "sensor zenithg angle" ;
      satellite_zenith_angle:standard_name = "sensor_zenith_angle" ;
      satellite_zenith_angle:valid_range = 0LL, 180LL ;
      satellite_zenith_angle:coordinates = "longitude latitude" ;
    float solar_azimuth_angle(time, x) ;
      solar_azimuth_angle:_FillValue = -999.f ;
      solar_azimuth_angle:units = "degree" ;
      solar_azimuth_angle:long_name = "solar azimuth angle" ;
      solar_azimuth_angle:standard_name = "solar_azimuth_angle" ;
      solar_azimuth_angle:valid_range = 0LL, 360LL ;
      solar_azimuth_angle:coordinates = "longitude latitude" ;
    float solar_zenith_angle(time, x) ;
      solar_zenith_angle:_FillValue = -999.f ;
      solar_zenith_angle:long_name = "solar zenith angle" ;
      solar_zenith_angle:units = "degree" ;
      solar_zenith_angle:standard_name = "solar_zenith_angle" ;
      solar_zenith_angle:valid_range = 0LL, 180LL ;
      solar_zenith_angle:coordinates = "longitude latitude" ;

// global attributes:
      :site = "NSS" ;
      :satht_hectometres = 8330 ;
      :startorbit = 468 ;
      :endorbit = 469 ;
      :wmosatid = "4" ;
      :coldnedt_average_mK = "807, 182, 111, 93, 65, 63, 60, 23, 45, 55, 94, 101, 27,
      23, 22, 21, 32, 42, 30, 0" ;
      :warmnedt_average_mK = "795, 190, 107, 92, 68, 64, 59, 22, 46, 54, 94, 97, 20, 18,
      17, 17, 27, 31, 26, 0" ;
      :title = "EUMETSAT HIRS Fundamental Data Record Release 1" ;
      :title_short_name = "HIRS_L1C_FDR" ;
      :keywords = "ATMOSPHERIC EMITTED RADIATION, OUTGOING LONGWAVE RADIATION,
      BRIGHTNESS TEMPERATURE" ;
      :licence = "Copyright by EUMETSAT" ;
```

```
      :summary = "This file is part of the recalibrated HIRS data record based on
      consistent calibration algorithm. The reprocessing has been performed at EUMETSAT
      in 2020. The used software is a modification of the NWPSAF AAPP 8.4 software." ;
      :doi = "10.15770/EUM_SEC_CLM_0026" ;
      :conventions = "CF-1.6" ;
      :Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
      :data_format_type = "NetCDF4" ;
      :keyword_vocabulary = "ACDD - GCMD Science Keywords" ;
      :Standard_name_vocabulary = "CF-1.6, v58" ;
      :naming_authority = "EUMETSAT" ;
      :processing_software_version = "1.0; AAPP version 8.4" ;
      :internal_git_commit_number = "GITLAB@EUMETSAT:USC_Climate/LEO/AAPP.git; Tag:
      V1.2_Release1" ;
      :centre = "GOVERNMENT AGENCIES-NON-US>GERMANY>DE/EUMETSAT>European Organisation
      for the Exploitation of Meteorological Satellites" ;
      :creator_email = "USC Climate Team c/o EUMETSAT ops <ops@eumetsat.int>" ;
      :creator_name = "EUMETSAT" ;
      :creator_url = "http://www.eumetsat.int" ;
      :institution = "EUMETSAT" ;
      :processing_centre = "EUMETSAT processing facility; CDR Production Environment" ;
      :processing_level = "L1C" ;
      :producer_agency = "EUMETSAT" ;
      :product_type = "Brightness temperature" ;
      :wmoinstrid = "607" ;
      :instrument_model = "4" ;
      :instrument_name = "HIRS" ;
      :platform_long_name = "Earth Observation Satellites>METOP>METOP-A>Meteorological
      Operational Satellite - A" ;
      :platform_type = "spacecraft" ;
      :no_scanlines = 950LL ;
      :no_missing_scanlines = 0 ;
      :date_created = "2020-10-08T09:24:15Z" ;
      :temporal_coverage_start = "2006-11-21T15:45:26Z" ;
      :temporal_coverage_end = "2006-11-21T17:26:40Z" ;
      :geospatial_lat_min = -89.8462f ;
      :geospatial_lat_max = 89.6522f ;
      :geospatial_lon_min = -179.9356f ;
      :geospatial_lon_max = 179.9443f ;
      :band_correction_offset = "0.00125, 0.00742, 0.01901, 0.01776, 0.01953, 0.01982,
      0.02114, 0.06415, 0.03918, 0.01598, 0.07343, 0.11363, 0.01703, 0.01818, 0.01857,
      0.01758, 0.03020, 0.04938, 0.28027" ;
      :band_correction_slope = "0.99999, 0.99997, 0.99991, 0.99992, 0.99991, 0.99991,
      0.99991, 0.99977, 0.99987, 0.99994, 0.99982, 0.99974, 0.99997, 0.99997, 0.99997,
      0.99997, 0.99995, 0.99993, 0.99962" ;
      :wavenumber = " 668.6600,  679.1800,  689.7000,  701.9900,  716.4700,  731.7100,
      748.8200,  898.5900, 1028.5000,  800.9300, 1361.9000, 1530.1000, 2189.7000,
      2212.3000, 2237.6001, 2245.6001, 2418.8999, 2516.1001, 2663.7000" ;
      :period = 101.35 ;
      :filename = "FDR_L1C_HIRS4_METOPA_20061121154526_20061121172640_R01.0.nc" ;
}
```

Appendix B Global Attributes of a HIRS FDR NetCDF File

Table 9: Global attributes of the NetCDF files

Name	Value
licence	"Copyright by EUMETSAT"
institution	"EUMETSAT"
title	"EUMETSAT HIRS Fundamental Data Record Release 1"
title_short_name	"HIRS_L1C_FDR"
doi	"10.15770/EUM_SEC_CLM_0026"
keywords	"ATMOSPHERIC EMITTED RADIATION, OUTGOING LONGWAVE RADIATION, BRIGHTNESS TEMPERATURE"
summary	"This file is part of the recalibrated HIRS data record based on consistent calibration algorithm. The reprocessing has been performed at EUMETSAT in 2020. The used software is a modification of the NWPSAF AAPP 8.4 software."
conventions	"CF-1.6"
Metadata_Conventions	"Unidata Dataset Discovery v1.0"
data_format_type	"NetCDF4"
keyword_vocabulary	"ACDD – GCMD Science Keywords"
Standard_name_vocabulary	"CF-1.6, v58"
naming_authority	"EUMETSAT"
processing_software_version	"1.0; AAPP version 8.4";
internal_git_commit_number	"GITLAB@EUMETSAT:USC_Climate/LEO/AAPP.git; Tag: V1.2_Release1" (or V1.3 Release2 for TIROSN to NOAA12)
Centre	"GOVERNMENT AGENCIES-NON-US>GERMANY>DE/EUMETSAT>European Organisation for the Exploitation of Meteorological Satellites"
creator_email	"USC Climate Team c/o EUMETSAT ops <ops@eumetsat.int>"
creator_name	"EUMETSAT"
creator_url	"http://www.eumetsat.int"
processing_centre	"EUMETSAT processing facility; CDR Production Environment"
processing_level	"L1C"
producer_agency	"EUMETSAT"
product_type	"Brightness temperature"
wmoinstrid	See Table 5
instrument_model	This indicates the instrument version operating on the platform (e.g., 4 for HIRS/4)
instrument_name	"HIRS"
platform_long_name	e.g. "Earth Observation Satellites>METOP>METOP-B > Meteorological Operational Satellite – B"
platform_type	"spacecraft"
wmosatid	See Table 5
site	e.g. "NSS"
startorbit	Orbit number of the first observation in the dataset
endorbit	Orbit number of the last observation in the dataset
no_scanlines	Number of scanlines in the file
no_missing_scanlines	Number of identified missing scanlines
period	Length of one orbit in minutes
date_created	e.g. „2019-02-01T18:20:16Z" (YYYY-MM-DDTHH:mm:SSZ)
temporal_coverage_start	e.g. „2010-12-31T08:03:29Z" (YYYY-MM-DDTHH:mm:SSZ)
temporal_coverage_end	e.g. „2010-12-31T09:44:49Z" (YYYY-MM-DDTHH:mm:SSZ)

geospatial_lat_min	e.g. -89.9387
geospatial_lat_max	e.g. 89.8446
geospatial_lon_min	e.g. -179.9989
geospatial_lon_max	e.g. 179.999
band_correction_offset	Offset of the band correction coefficient
band_correction_slope	Slope of the band correction coefficient
wavenumber	Central wavenumber for each channel
coldnedt_average_mK	Orbit mean cold NEdT
warmnedt_average_mK	Orbit mean warm NEdT
satht_hectometres	Orbit altitude
filename	filename