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.

Table of Contents

Table of Figures

Table of Tables

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.

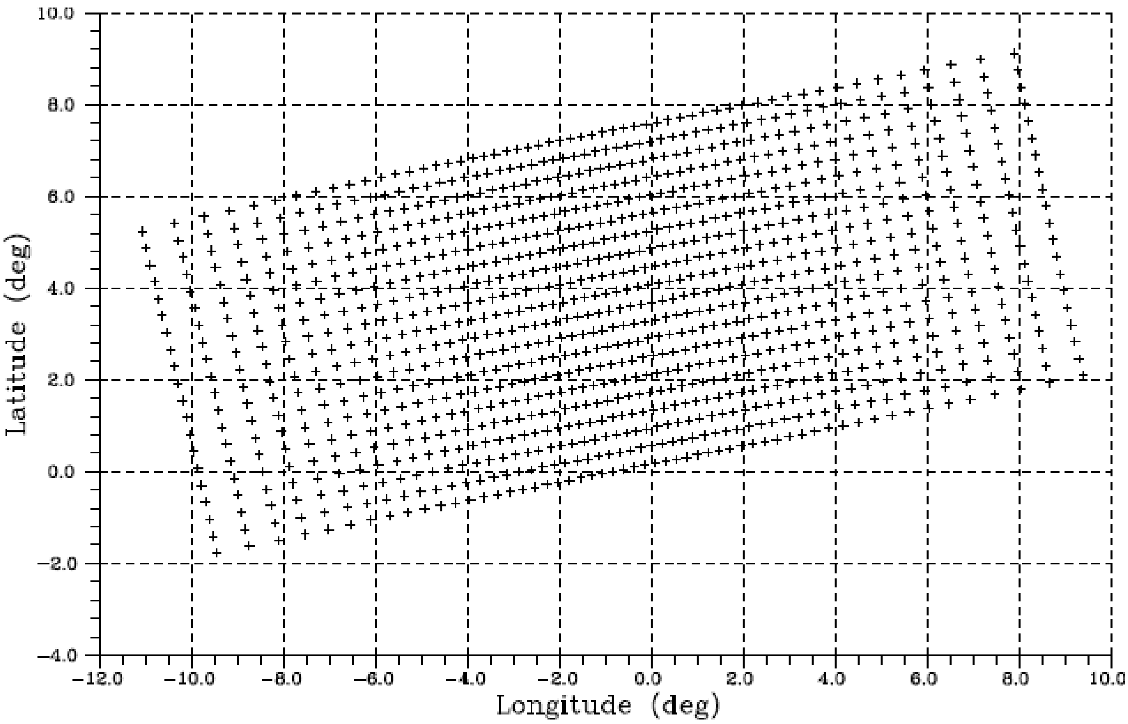

Figure 1: IFOV on-ground projection of HIRS/4 (at the equator in ascending track).

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.

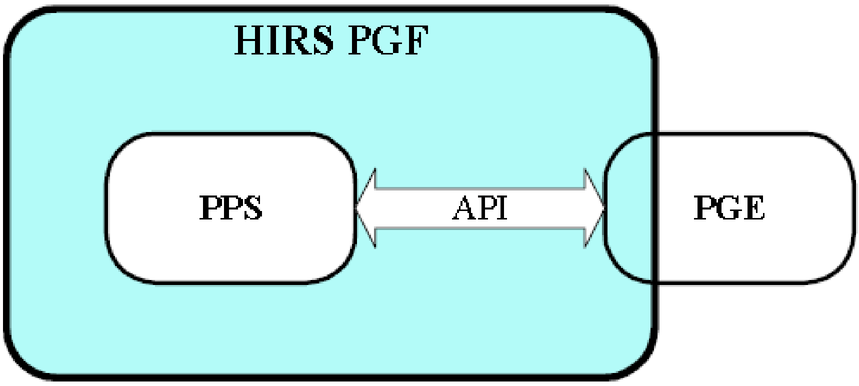

Figure 2: System Context

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.	

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.

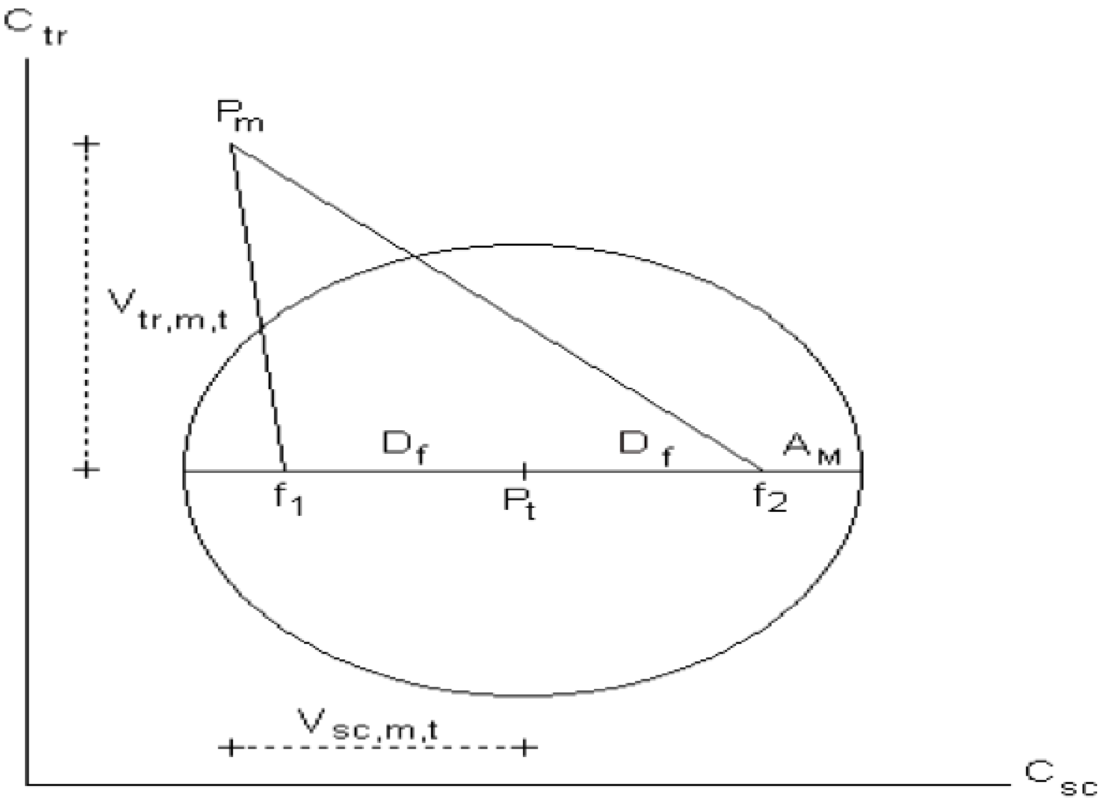

Figure 7: Collocation with target pixel fov ellipse

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

$$D_{m,f1} + D_{m,f2} \leq A_M$$ ***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 $mod(L_t - L_{s,t} + R_t , R_t) = 0$ 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

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

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.

$$R_s = a_0 + a_1 C_s + a_2 C_s^{\,2} \qquad \textit{Equation 87}$$

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:

$$A_s = a_0 + a_1 C_s \qquad \textit{Equation 88}$$

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
$B(v,T)$	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
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
$\Phi(LUT)$	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