

# EUMETSAT Satellite Application Facility on Climate Monitoring

The EUMETSAT  
Network of  
Satellite  
Application  
Facilities



## Product User Manual

### **Fundamental Climate Data Record of SMMR / SSMI / SSMIS Brightness Temperatures**

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## Applicable documents

Reference	Title	Code
AD 1	Memorandum of Understanding between CM SAF and the Max-Planck Institute for Meteorology and Meteorological Institute, University of Hamburg	
AD 2	Cooperation Agreement	
AD 3	CM SAF Product Requirements Document	SAF/CM/DWD/PRD/2.4

## Reference documents

Reference	Title	Code
RD 1	Algorithm Theoretical Basis Document Fundamental Climate Data Record of SSM/I Brightness Temperatures	SAF/CM/DWD/ATBD/FCDR_SSMI/1.3
RD 2	Product User Manual Fundamental Climate Data Record of SSM/I Brightness Temperatures	SAF/CM/DWD/PUM/FCDR_SSMI/1.1
RD 3	Validation Report Fundamental Climate Data Record of SSM/I Brightness Temperatures	SAF/CM/DWD/VAL/FCDR_SSMI/1.0
RD 4	Algorithm Theoretical Basis Document Fundamental Climate Data Record of SSMIS Brightness Temperatures	SAF/CM/DWD/ATBD/FCDR_SSMIS/1.1
RD 5	Validation Report Fundamental Climate Data Record of SMMR / SSM/I / SSMIS Brightness Temperatures	SAF/CM/DWD/VAL/FCDR_MWI/1.4
RD 6	Algorithm Theoretical Basis Document Fundamental Climate Data Record of SMMR Brightness Temperatures	SAF/CM/DWD/ATBD/FCDR_SMMR/1.1
RD 7	Product User Manual Fundamental Climate Data Record of SSMIS Brightness Temperatures	SAF/CM/DWD/PUM/FCDR_SSMIS/1.4

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## I Preface

### I-1 The EUMETSAT SAF on Climate Monitoring

The importance of climate monitoring with satellites was recognized in 2000 by EUMETSAT Member States when they amended the EUMETSAT Convention to affirm that the EUMETSAT mandate is also to “contribute to the operational monitoring of the climate and the detection of global climatic changes”. Following this, EUMETSAT established within its Satellite Application Facility (SAF) network a dedicated centre, the SAF on Climate Monitoring (CM SAF, <http://www.cmsaf.eu/>).

The consortium of CM SAF currently comprises the Deutscher Wetterdienst (DWD) as host institute, and the partners from the Royal Meteorological Institute of Belgium (RMIB), the Finnish Meteorological Institute (FMI), the Royal Meteorological Institute of the Netherlands (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI), the Meteorological Service of Switzerland (MeteoSwiss), and the Meteorological Service of the United Kingdom (UK MetOffice). Since the beginning in 1999, the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) has developed and will continue to develop capabilities for a sustained generation and provision of Climate Data Records (CDR’s) derived from operational meteorological satellites.

In particular the generation of long-term data sets is pursued. The ultimate aim is to make the resulting data sets suitable for the analysis of climate variability and potentially the detection of climate trends. CM SAF works in close collaboration with the EUMETSAT Central Facility and liaises with other satellite operators to advance the availability, quality and usability of Fundamental Climate Data Records (FCDRs) as defined by the Global Climate Observing System (GCOS). As a major task the CM SAF utilizes FCDRs to produce records of Essential Climate Variables (ECVs) as defined by GCOS. Thematically, the focus of CM SAF is on ECVs associated with the global energy and water cycle.

The CM SAF data sets can serve applications related to the new Global Framework of Climate Services initiated by the WMO World Climate Conference-3 in 2009. CM SAF is supporting climate services at national meteorological and hydrological services (NMHSs) with long-term data records but also with data sets produced close to real time that can be used to prepare monthly/annual updates of the state of the climate. Both types of products together allow for a consistent description of mean values, anomalies, variability, and potential trends for the chosen ECVs. CM SAF ECV data sets also serve the improvement of climate models both at global and regional scale.

A catalogue of all available CM SAF products is accessible via the CM SAF webpage, <http://www.cmsaf.eu/>. Here, detailed information about product ordering, add-on tools, sample programs and documentation is provided.

### I-2 Introduction

This CM SAF Product User Manual (PUM) provides information on the Fundamental Climate Data Record (FCDR) of Microwave Brightness Temperatures from the conical scanning microwave sensors Special Sensor Microwave/Imager (SSM/I), Special Sensor Microwave Imager/Sounder (SSMIS) and Scanning Multichannel Microwave Radiometer (SMMR). This third release is a continuation of the SSM/I and SSMIS FCDR (Fennig et al., 2015). As the SSM/I part remains unchanged since the first release (Fennig et al., 2013), it is included here as an integral part of this third release.

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The predecessors of this data record and the data processor suite have originally been developed at the Max-Planck Institute for Meteorology (MPI-M) and the University of Hamburg (UHH) for the Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data (HOAPS, <http://www.hoaps.org/>) climatology. HOAPS is a compilation of climate data records for analysing the water cycle components over the global oceans derived from satellite observation (Andersson et al. 2011). The main satellite instrument employed to retrieve the geophysical parameters is the SSM/I and much work has been invested to process and carefully homogenize all SSM/I instruments onboard the Defence Meteorological Satellite Program (DMSP) platforms F08, F10, F11, F13, F14 and F15 (Andersson et al., 2010).

In order to derive reliable long term trend estimates of the global water cycle parameters it is strictly necessary to carefully correct for all known problems and deficiencies of the SSM/I radiometers as well as to inter-calibrate and homogenise the different instruments. Moreover, all applied corrections need to be clearly documented to provide a complete calibration traceability for a Fundamental Climate Data Record (FCDR). Following these recommendations, CM SAF released a first edition of the microwave radiance FCDR comprising just the SSM/I brightness temperatures in 2013, freely available from the web user interface (<http://wui.cmsaf.eu/>; Fennig et al., 2013). This FCDR has already been used in the ESA CCI Sea ice project and will also be used in the upcoming reanalysis ERA5.

In order to further extend the Thematic Climate Data Records (TCDRs) like the HOAPS data record in time, the SSM/I successor instrument SSMIS has to be used from 2009 onwards. A second edition of the combined SSM/I and SSMIS FCDR has been successfully released by CM SAF in 2015 (Fennig et al., 2015), covering the time period from 1987 to 2013. The SSMIS sensors on-board F16, F17, and F18 have now been reprocessed for this third FCDR release:

- The SSMIS inter-calibration has been updated.
- Deficiencies in the reflector emissivity correction are rectified.
- The time period is extended by two additional years compared to the previous release to cover the SSMIS period until end of 2015.

The CM SAF FCDR is a completely reprocessed data record, thus ensuring a maximum in homogeneity by applying a common processing scheme and inter-calibration model for all observations. Among others, known instrument issues like sunlight intrusions, moonlight intrusions, and reflector emissivity have been accounted for and the brightness temperatures have been carefully inter-calibrated to the predecessor SSM/I instrument series, allowing a seamless continuation of existing TCDRs. The inter-calibration method, developed for the SSMIS FCDR, explicitly includes all possible surface types to account for the entire natural distribution of brightness temperatures from radiometric cold scenes (rain-free ocean) to radiometric warm scenes (vegetated land surfaces). This ensures a broad range of applications of this FCDR not only for oceanic, but also for sea-ice and land surfaces.

This third microwave radiance FCDR release now also provides data records from the Scanning Multichannel Microwave Radiometer on board Nimbus-7 for the time period from 1978 to 1987. As the original raw data records are not available, the Nimbus-7 SMMR Pathfinder Level 1B Brightness Temperatures data record, available from NSIDC (Njoku, 2003), are used to generate the SMMR FCDR.

It is important to keep in mind that the three microwave radiometers SMMR, SSM/I and SSMIS are completely differently designed instruments and not just one sequential instrument series. While the SSMIS does provide a continuation of the basic SSM/I observed frequencies (19, 22, 37 GHz), the SMMR contains SSM/I like channels at 18 GHz, 21 GHz and 37 GHz. However, it is not expected

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that all instruments give identical brightness temperatures per se. A combination of all individual data records with an inter-sensor calibration can thus be defined as a FCDR for a specific frequency, spanning the complete time period. Otherwise, also a sensor specific FCDR can be defined, providing consistent data records for one sensor type. This leads to the potential paradigm, that a FCDR can be defined in two ways:

- with a primary aim as the consistency across sensors with sensor calibration being a secondary consideration, or
- with a focus on accuracy on each sensor data record independently with consistency diagnosed rather than constraint.

In order to aim for one data set able to fulfil both paradigms, one important feature of this FCDR is the flexibility to use the same data record with or without inter-calibration. The brightness temperatures, corrected for instrument anomalies, and the inter-calibration offsets are provided as separate layers in each data file, allowing the users to individually choose whether to apply the correction (adding the offsets) or not. In this sense, the first, still unchanged version of the Microwave Imager Radiance FCDR (CM-150), covering the SSM/I plus the updated SSMIS and the newly generated SMMR data records form together the third release (CM-12002), defined as a combined FCDR with optimal sensor calibration and consistency.

## II SSM/I

The SSM/I component of this combined FCDR remains unchanged compared to first release and therefore also the corresponding documents ATBD [RD 1], Product User Manual [RD 2], and Validation Report [RD 3] are still applicable to the SSM/I data record part. These documents are easily accessible from the SSM/I FCDR DOI summary webpage [[http://dx.doi.org/10.5676/EUM\\_SAF\\_CM/FCDR\\_SSMI/V001](http://dx.doi.org/10.5676/EUM_SAF_CM/FCDR_SSMI/V001)] and at [www.cmsaf.eu/docs](http://www.cmsaf.eu/docs). Access to the SSM/I data records is given also through the DOI webpage.

## III SSMIS

The technical description and the Product User Manual of the SSMIS component of this combined FCDR (V003) are available as individual, instrument specific ATBD [RD 4] and PUM [RD 7], respectively. The latest validation report [RD 5] for this release covers the SMMR and SSMIS data records.

## IV SMMR

This part of the document focuses on the SMMR, starting with a brief technical description of the instrument and then provides information on the file format as well as on the data access. Details on the implementation of the processing chain and individual processing steps are available in the corresponding SMMR Algorithm Theoretical Basis Document [RD 6]. Basic accuracy requirements are defined in the product requirements document [AD 3]. A detailed validation of the SMMR FCDR is available in the Validation Report [RD 5].

### IV-1 The SMMR Instrument

A detailed description of the SMMR is given in Gloersen and Barath (1977) and Madrid et al. (1978). Hence, only a short summary of essential information is given here.

Two SMMR instruments were operated on board Nimbus-7 and SEASAT. While only about three month of data from the SEASAT mission exist, the SMMR on Nimbus-7 delivered a data record covering nearly 8 years from October 25, 1978 until August 20, 1987.

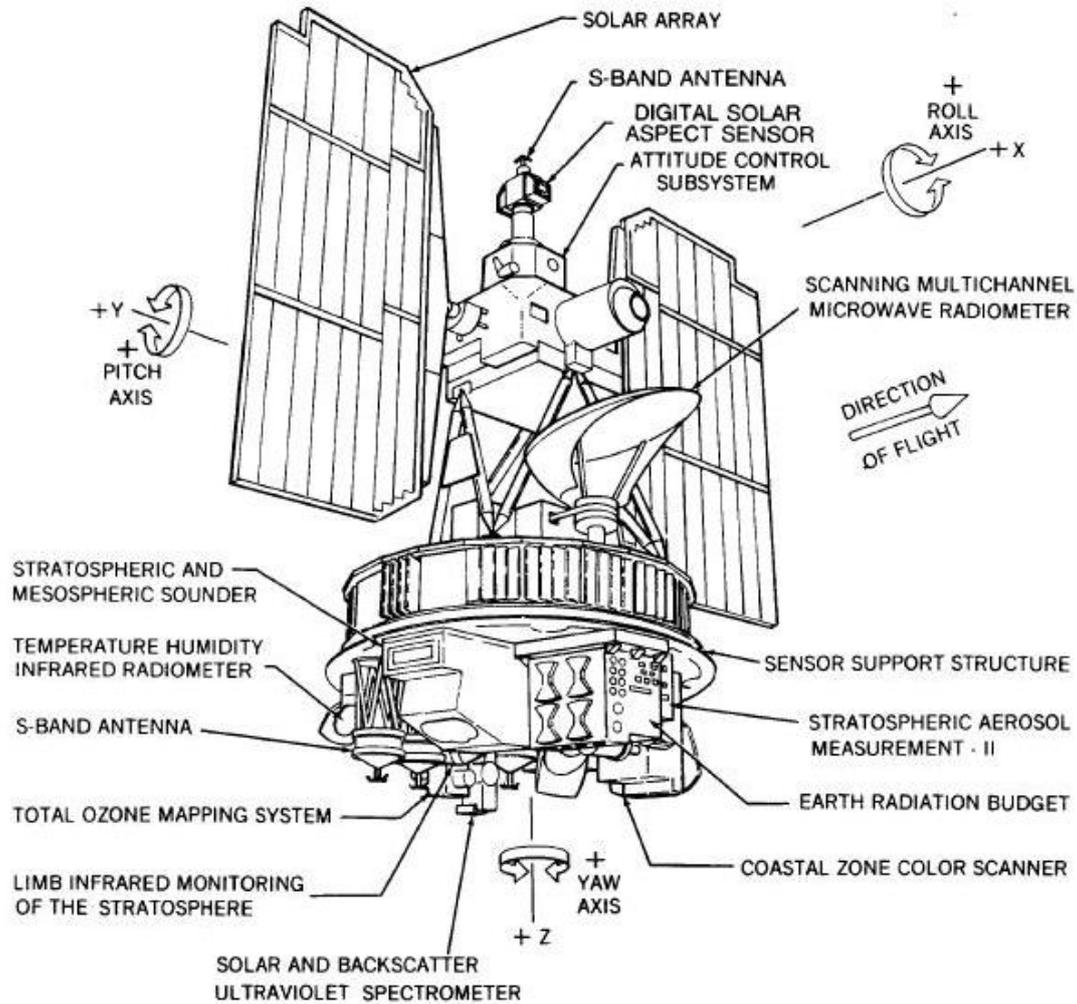


Figure 1: Nimbus 7 Observatory (from Nimbus 7 Users Guide; Madrid, 1978).

The Nimbus-7 spacecraft operated in a sun-synchronous orbit with an inclination of 99° and an average altitude of 955 km. This configuration results in an orbital period of about 104 minutes and provided approximately 14 orbits per day. There are 8 instruments mounted on the platform. Figure 1 shows a diagram of the Nimbus-7 observatory and the locations of the instruments. The SMMR was mounted on the forward side in direction of flight. Due to power limitations only one instrument operated full time. The SMMR instrument operated most of the time on a 50% duty cycle: one day "on" followed by one day "off."

The SMMR was a ten-channel radiometer, measuring microwave radiation from the Earth's atmosphere and surface in five frequencies at vertical and horizontal polarization (see Table 7). Six radiometers are integrated in the instrument, fed by one multispectral feedhorn. While the four radiometers operating at the lower frequencies (6.6 – 21 GHz) measure alternating polarizations each half-scan, the other two at 37 GHz measure continuously vertical and horizontal polarization. A schematic of the SMMR is shown in Figure 2.

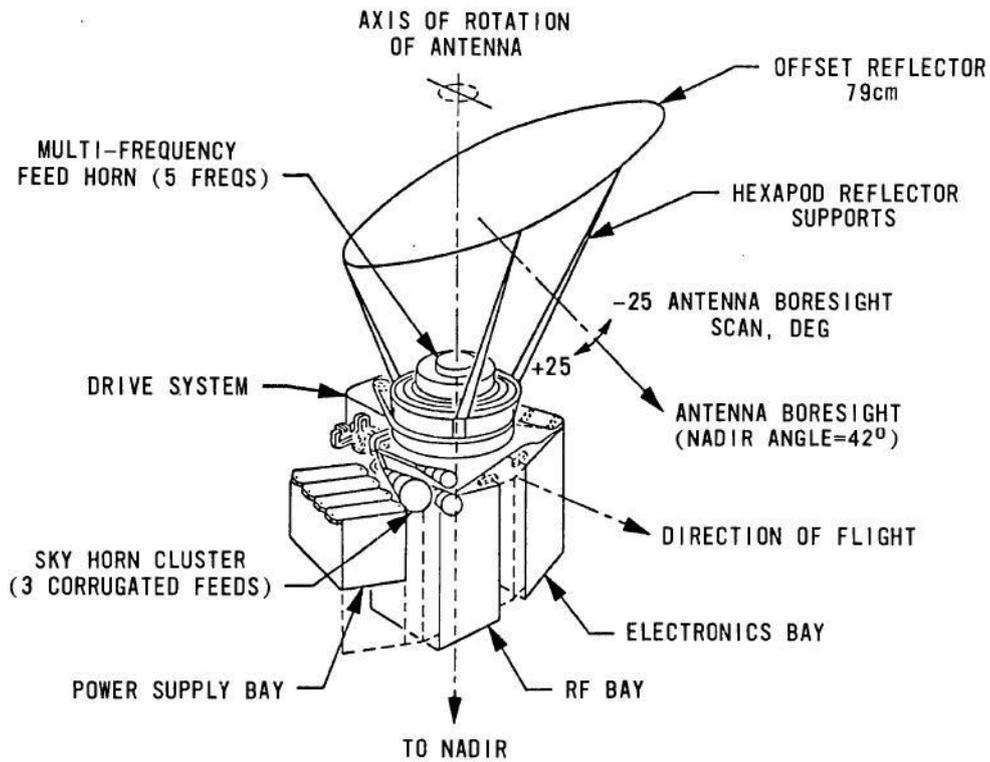


Figure 2: SMMR Instrument configuration (from Nimbus 7 Users Guide, 1978).

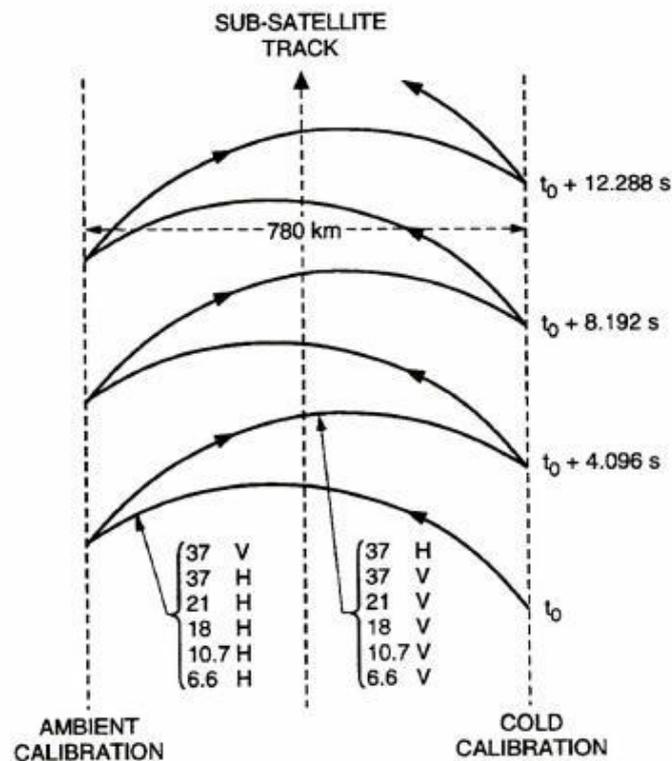


Figure 3: SMMR schematic scan pattern (from Njoku et al., 1998).

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The instruments antenna consists of an offset parabolic reflector and the multi-frequency feed assembly. The reflector was mounted at a nadir angle of 42°, which results in an average Earth incidence angle (EIA) of 50.3°. The antenna rotates ±25°, centred about the sub-satellite track, which results in a 780 km wide swath at the Earth's surface. The scan velocity varied sinusoidally, being fastest at 0° azimuthal scan angle and slowest at the scan edges. A complete scan was accomplished after 4.096 seconds. Cold space is used as the cold reference target, viewed directly through one of three cold-sky calibration horns. The warm calibration target is at the instruments ambient temperature.

The SMMR was observing the Earth surface with a reflector that scanned by oscillating about the vertical axis between azimuth angles of 25 degrees. Separate radiometers were used for vertical and horizontal polarizations only at 37 GHz. The channels at other frequencies used a single radiometer time-shared between vertical and horizontal polarizations. On the first half of each scan cycle (from right to left), these radiometers measured at vertical polarization while on the second half of the scan cycle (from left to right) horizontal polarization was measured (see Figure 3). The 37 GHz vertical and horizontal polarizations were measured on both halves of the scan cycle. This original scan and FOV resolution is not provided in the level 1B data files. Instead all observations were interpolated to the 37 GHz positions with 47 scan positions for each half-scan. This geolocation remains unchanged in the FCDR data processing. A full scan line will therefore consist of 94 usable FOVs,

#### **IV-1.1 Instrument operation**

Acquisition of Nimbus-7 SMMR data commenced at midnight of October 25, 1978. The SMMR operated continuously during a three-week checkout period from start-up until November 16, 1978, at which time it began alternate-day operation. This was the normal mode of operation of the SMMR for most of its mission, as dictated by power sharing constraints among instruments on the spacecraft. Under normal operations the SMMR was turned on near midnight GMT (corresponding to a descending node equator crossing near 0° longitude) and turned off at approximately the same time the following day, in a continuing sequence. A special operations period occurred from April 3 to June 6, 1986, during which the SMMR was switched on and off more frequently, with "off" periods averaging 75 minutes and "on" periods averaging 30 minutes. The antenna scan mechanism was turned off permanently on August 20, 1987 for safety reasons, marking the end of the scanning SMMR data set (Njoku, 1998).

#### **IV-2 Product definition**

The CM SAF FCDR from SMMR brightness temperatures consists of daily collections of all observations from each sensor. All sensor specific data available in the input raw data records are provided as well as additional information like quality control flags and inter-sensor calibration offsets. The SMMR FCDR is available for the time period from October 1978 until August 1987.

The SMMR FCDR daily data files provide all available 10 SMMR channels (see Table 7) in the common resolution defined in the Pathfinder Level 1B data record. During the reprocessing procedures the spacecraft position is recomputed using a new set of Nimbus-7 orbit parameters. This information is used to filter the original Level 1B data record. The new spacecraft altitude plus latitude and longitude of the sub-satellite point are provided in the FCDR data files. The FCDR processor also applies an along-scan correction for the 37 GHz channels and derives sensor health statistics (for more details see the ATBD, RD 6). Only the SSM/I-like channels at 18, 21, and 37 GHz are then inter-calibrated to the F08 instrument, which itself is inter-calibrated to the F11 reference sensor. This inter-calibration offset is available as an additional layer in the data files. However, the non-SSM/I channels are not inter-calibrated and thus inter-calibration offsets are not provided.

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### IV-3 Data format description

The CM SAF FCDR is provided as NetCDF (Network Common Data Format) files version 4 (<http://www.unidata.ucar.edu/software/netcdf/>). The data files are conforming to the NetCDF Climate and Forecast (CF) Metadata Convention version 1.6 (<http://cf-pcmdi.llnl.gov/>) and NetCDF Attribute Convention for Dataset Discovery version 1.3.

All SMMR FCDR product files are swath based and built following the same design principles. The record dimension of the data files is the scan integer time measured in seconds since 1<sup>st</sup> January 1970. Each file contains all possible scans for one complete day regardless of their quality and status. Missing scans are marked as missing and all sensor data are set to undefined in this case. If the SMMR is operating at alternate days, orbits at the end of the day are completed and the file ends with the last scan from this orbit.

The users are advised to read and apply the supplied quality control flags *qc\_scan*, *qc\_channel*, *qc\_fov*, and *qc\_status* in order to filter incorrect and erroneous observations. The *qc\_status* flag is the original scan status word from the level 1B data files. The quality control procedure and thresholds are described in the ATBD [RD 4]. An example how to read and apply the quality control flags is given in Appendix B. The meanings of the flags are summarized in Table 3, Table 4, Table 5 and Table 6 (all in Appendix A).

In order to provide a common file format for all sensors, the observations are provided in a logical data group. This scene data group provides the geolocation variables similar to the SSMIS scene groups. The scene across scan coordinate is an index array to the global across scan coordinate and the scene channel is an index array to the global channel coordinate. The quality control flag and bit values are numbered using the global channel coordinate.

Calibration data records (instrument temperature readings and calibration counts) and spacecraft related variables are also available in separate logical data groups. This flexible format design allows it to provide the different microwave conical scanning instrument data in one logical format.

Brightness temperatures and inter-sensor offsets are archived as separate variables to allow the corrections to be added as required by the users. Only the SSM/I related channels are inter-calibrated. The other SMMR channels are provided without inter-calibration offsets. The brightness temperatures *tb* are the values after the along-scan correction is applied. An example how to read the temperatures and how to apply the offsets is given in Appendix B.

Daily mean values, e.g. noise equivalent temperature, have a fixed dimension *date* of size 1.

#### IV-3.1 Data file contents

A common NetCDF file consists of groups, dimensions, variables, and attributes. These components can be used together to capture the meaning of data and relations among data. The variables are grouped into logical data groups. Global attributes are summarized in Table 1 and possible variable attributes in Table 2 (both in Appendix A). The following variables (thematically sorted) are available in the FCDR data files:

##### Global Coordinate variables

*date*

Validity date [days since 1970-01-01 00:00:00 UTC]  
Fixed dimension [1]

*time*

Scan start time [seconds since 1970-01-01 00:00:00 UTC]  
Record dimension

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*across\_track*

FOV across track position  
Fixed dimension [94]

*channel*

Channel number  
Fixed dimension [10]

*nread*

General reading number  
Fixed dimension [3]

*nchar*

General character length  
Fixed dimension [50]

**Global variables**

*central\_freq*

Frequencies of the corresponding channel number.

*polarization*

Polarization of the corresponding channel number.

*channel\_name*

String representation of the corresponding channel number.

*tfrac*

Scan micro seconds [ $10^{-6}$  s]  
dimension [*time*]  
To get the exact scan time add this to *time* coordinate.

*rev*

Revolution number  
dimension [*time*]

*qc\_status*

level-1B scan status word [bit mask]  
dimensions [*time*]  
All bits set to 0 indicates normal condition. See Table 6 for bit meanings.

*qc\_scan*

Scanline quality control [bit mask]  
dimensions [*time*]  
All bits set to 0 indicates normal condition. See Table 3 for bit meanings.

*qc\_channel*

Channel quality control [bit mask]  
dimensions [*time, channel*]  
All bits set to 0 indicates normal condition. See Table 4 for bit meanings.

*rotation*

instrument rotational speed [rpm]  
dimension [*date*]

**Data group 'platform'**

This group contains spacecraft related variables.

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*salt*

Altitude of spacecraft [km]  
dimension [*time*]

*slat*

Latitude of spacecraft sub satellite point [degree\_north]  
dimension [*time*]

*slon*

Longitude of spacecraft sub satellite point [degree\_east]  
dimension [*time*]

*roll*

Spacecraft roll angle [degree]  
dimension [*time*]

*pitch*

Spacecraft pitch angle [degree]  
dimension [*time*]

*yaw*

Spacecraft yaw angle [degree]  
dimension [*time*]

*ecliptic*

angular position of the spacecraft measured along its orbit from the point of closest approach to the sun [degree]  
dimension [*time*]

### **Data group ‘calibration’**

This group contains SSMIS calibration related variables.

*cal\_horn*

calibration horn coordinate  
fixed dimensions [3]

*switch\_temp*

Dicke switch temperature [K]  
dimension [*time, channel*]

*cal\_horn\_temp*

Calibration horn temperature [K]  
dimension [*time, cal\_horn*]

*feedhorn\_temp*

Antenna feedhorn temperature [K]  
dimension [*time*]

*feedhorn\_wg\_temp*

Feedhorn waveguide temperature [K]  
dimension [*time, channel*]

*cal\_horn\_wg\_temp*

Calibration horn waveguide temperature [K]  
dimension [*time, channel*]

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*hotc*

Hot load reading [count]  
dimensions [*time, channel*]

*colc*

Cold load reading [count]  
dimensions [*time, channel*]

*trhl*

Hot load temperature [K]  
dimensions [*time, channel*]

*slope*

Calibration slope [K/count]  
dimensions [*time, channel*]

*hotc\_var*

variance of hot load reading [count<sup>2</sup>]  
dimensions [*date, channel*]

*colc\_var*

variance of cold load reading [count<sup>2</sup>]  
dimensions [*date, channel*]

*trhl\_var*

variance of hot load temperature [K<sup>2</sup>]  
dimension [*date, channel*]

*nedt*

noise equivalent temperature [K]  
dimensions [*date, channel*]

### **Feedhorn data group 'scene\_env'**

These data groups contain SMMR FOV sensor variables.

*scene\_channel*

Group channel coordinate (index to global *channel*)  
fixed dimension length 10

*scene\_across\_track*

Group across track coordinate (index to global *across\_track*)  
fixed dimension length 94

*lat*

FOV latitude [degree\_north]  
dimensions [*time, scene\_across\_track*]

*lon*

FOV longitude [degree\_east]  
dimensions [*time, scene\_across\_track*]

*laz*

FOV local azimuth angle [degree\_east]  
dimension [*time, scene\_across\_track*]

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*eia*

Earth incidence angle [degree]  
dimension [*time, scene\_across\_track*]

*refl\_sun\_angle*

Reflected sun footprint angle [degree]  
dimension [*time, scene\_across\_track*]

*sft*

FOV surface types  
dimensions [*time, scene\_across\_track*]  
Possible types are: water (0), land (1), coast (2)

*qc\_fov*

Field of view quality control [bit mask]  
dimensions [*time, scene\_across\_track*]  
All bits set to 0 implies acceptable data. See Table 5 for bit meanings.

*tb*

Brightness temperature [K]  
dimensions [*time, scene\_channel, scene\_across\_track*]

*ical*

Brightness temperature inter-calibration offset [K]  
dimensions [*time, scene\_channel, scene\_across\_track*]

#### IV-4 Assumptions and Limitations

The inter-sensor calibration method used here to correct the SMMR brightness temperatures (see RD 6) does not account for an absolute radiometric offset. The inter-calibration target is the SSM/I aboard DMSP F08, which is inter-calibrated to the SSM/I F11 and acts as a transfer standard. Therefore, any absolute offset in the F11 TBs will be transferred to the other radiometers. However, one reason to choose the F11 as the reference target was its good performance when validating against collocated in-situ wind speed measurements from buoy observations. This should at least minimize the remaining absolute error in the brightness temperature data record.

The inter-sensor calibration is determined over ocean because of a lower variability, smaller diurnal cycle and better behaved error characteristics in the modelled brightness temperatures. Scene dependence is accounted for, assuming no systematic instrument related errors at the warm calibration target. Therefore the quality of the inter-calibration is expected to be better over ocean than over land and sea-ice. Also, it is assumed that the inter-sensor differences can be characterized as a linear problem and the derived correction coefficients can be used over land and ice as well.

The inter-sensor calibration does not account for radiometric differences due to frequency shifts, EIA variations, or overpass time differences. The brightness temperatures are corrected to be physically consistent with the SSM/I observations. During the level 1B processing various corrections were applied to the antenna temperatures. Although these corrections might not be optimal or even incorrect, it is not possible to revert the original uncorrected temperatures.

No EIA normalization offsets are provided for the SMMR. As the mean EIA changes significantly in 1986, the true EIA should always be used to account for the impact in the observed brightness temperatures. The true EIA is available for each FOV in the 'scene\_env' data group (see also section IV-3.1). A detailed discussion of the EIA variation can be found in section IV-1 of the accompanying Validation Report [RD 5].

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A special operations period occurred from April 3 to June 6, 1986, during which the SMMR was switched on and off more frequently, with "off" periods averaging 75 minutes and "on" periods averaging 30 minutes. This results in a severely limited coverage and can also lead to a reduced quality of the calibration for the first scans after the instrument is switched on.

A number of limitations arise from the SMMR calibration problems. Francis (1987) provided a thorough analysis of these instrument related deficiencies, which are summarized here as follows:

### **Polarization Mixing**

Due to the scan geometry the polarization vector relative to the Earth surface rotates with increasing scan angle and horizontally and vertically polarized radiation is mixed. Also leakages in the radiometer switches lead to polarization mixing.

### **Sunlight intrusions**

During certain portions of the orbit, sunlight intrusions into the cold sky calibration occur. A quality status flag indicates this condition.

### **In-orbit variation of instrument temperatures**

A warming trend over the first three orbits after the instrument is switched on can be observed when it is in alternate day operation mode. A quality status flag indicates this condition.

### **Attitude variations**

Anomalies in the spacecraft attitude control system are observed. Amongst others, abrupt changes occur when the attitude control is switched from the daytime to the night-time system. These anomalies translate to anomalies in the observed EIA and therefore lead to uncertainties in the brightness temperatures.

### **Component degradation**

Some channels are affected by continuous drifts in the brightness temperatures that can only be explained by drifts in the radiometer components over the life time. This affects mainly the 21 GHz channels. Although a correction was applied in the Level 1B processing to remove this effect, a significant artificial drift might still be observed in the final FCDR. This might compromise the suitability of this data record for climate trend analysis applications if the affected SMMR channels are utilised.

### **Sun glitter reflection**

During certain portions of the daytime orbit, the observed brightness temperatures at the lower frequencies (6.6 and 10 GHz) are contaminated by reflected solar radiation from the surface.

### **Faraday rotation**

Faraday rotation by the ionosphere is adding an additional polarization mixing during daytime observations. This affects mainly the 6.6 GHz channels.

## **IV-5 Data ordering via the Web User Interface (WUI)**

The internet address <http://wui.cmsaf.eu/> allows direct access to the CM SAF data ordering interface. On this webpage a detailed description how to use the interface for product search and ordering is given. We refer the user to this description since it is the central and most up to date documentation. However, some of the key features and services are briefly described in the following sections.

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Further user service including information and documentation about CM SAF and the CM SAF products are available from the CM SAF home page (<http://www.cmsaf.eu/>).

#### **IV-5.1 Product ordering process**

You need to be registered and logged in to order products. A login is provided upon registration, all products are delivered free of charge (Please note the copyright disclaimer given in section IV-7). After the selection of the product, the desired way of data transfer can be chosen. This is either via a temporary ftp account (the default setting), or by CD/DVD or email. Each order will be confirmed via email, and the user will get another email once the data have been prepared. If the ftp data transfer was selected, this second email will provide the information on how to access the ftp server.

#### **IV-5.2 Contact User Help Desk staff**

In case of questions the contact information of the User Help Desk (e-mail address [contact.cmsaf@dwd.de](mailto:contact.cmsaf@dwd.de)) are available via the CM SAF home webpage (<http://www.cmsaf.eu/>) or the home page of the Web User Interface (<http://wui.cmsaf.eu/>).

#### **IV-5.3 User Problem Report**

Users of CM SAF products and services are encouraged to provide feedback on the CM SAF products and services to the CM SAF team. Users can either contact the User Help Desk (see section IV-5.2) or use the “User Problem Report” page. A link to the “User Problem Report” is available either from the CM SAF home page (<http://www.cmsaf.eu/>) or the Web User Interface (<http://wui.cmsaf.eu/>).

#### **IV-5.4 Service Messages / log of changes**

Service messages and a log of changes are also accessible from the CM SAF homepage (<http://www.cmsaf.eu/>) and provide useful information on product status, versioning and known deficiencies.

### **IV-6 Feedback**

#### **IV-6.1 User feedback**

Users of CM SAF products and services are encouraged to provide feedback on the CM SAF product and services to the CM SAF team. We are keen to learn of what use the CM SAF data are. So please feedback your experiences as well as your application area of the CM SAF data.

EUMETSAT CM SAF is an user driven service and is committed to consider the needs and requirements of its users in the planning for product improvements and additions. Please provide your feedback e.g. to our User Help Desk (e-mail address [contact.cmsaf@dwd.de](mailto:contact.cmsaf@dwd.de)).

#### **IV-6.2 Specific requirements for future products**

Beside your general feedback you are cordially invited to provide your specific requirements on future products for your applications. Please provide your requirements e.g. to our staff or via our User Help Desk (e-mail address [contact.cmsaf@dwd.de](mailto:contact.cmsaf@dwd.de)).

#### **IV-6.3 User Workshops**

CM SAF is organizing training workshops on a regular basis in order to facilitate the use of our data. Furthermore, through our regular (approximately every four years) user’s workshop we revisit our product baseline. Your participation in any of these workshops is highly appreciated. Please

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have a look at on the CM SAF home web page (<http://www.cmsaf.eu/>) to get the latest news on upcoming events.

#### IV-7 Copyright and Disclaimer

The user of CM SAF data agrees to respect the following regulations:

#### IV-8 Copyright

All intellectual property rights of the CM SAF products belong to EUMETSAT. The use of these products is granted to every interested user, free of charge. If you wish to use these products in publications, presentations, web pages etc., *EUMETSAT's copyright credit must be shown by displaying the words "copyright (year) EUMETSAT" on each of the products used.*

##### IV-8.1 Acknowledgement and Identification

When exploiting EUMETSAT/CM SAF data you are kindly requested to acknowledge this contribution accordingly and make reference to the CM SAF, e.g. by stating "The work performed was done (i.a.) by using data from EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF)". It is highly recommended to clearly identify the product version used. An effective way to do this is the citation of CM SAF data records via the digital object identifier (DOI). All information can be retrieved through (<http://www.cmsaf.eu/DOI/>). The DOI for this data set is provided on the title page of this document.

##### IV-8.2 Re-distribution of CM SAF data

Please do not re-distribute CM SAF data to 3<sup>rd</sup> parties. The use of the CM SAF products is granted free of charge to every interested user, but we have an essential interest to know how many and what users the CM SAF has. This helps to ensure of the CM SAF operational services as well as its evolution according to users needs and requirements. Each new user shall register at CM SAF in order to retrieve the data.

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## IV-10 Glossary

ATBD	Algorithm Theoretical Baseline Document
CM SAF	Satellite Application Facility on Climate Monitoring
CDOP	Continuous Development and Operations Phase
DMSP	Defense Meteorological Satellite Program
DWD	Deutscher Wetterdienst (German MetService)
ECV	Essential Climate Variable
EIA	Earth Incidence Angle
EPS	European Polar System
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record
FMI	Finnish Meteorological Institute
FOV	Field of view
GCOS	Global Climate Observing System
HOAPS	The Hamburg Ocean Atmosphere Fluxes and Parameters from Satellite data
KNMI	Koninklijk Nederlands Meteorologisch Instituut
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information System
NOAA	National Oceanic & Atmospheric Administration
PRD	Product Requirement Document
PUM	Product User Manual
QC	Quality Control
RMIB	Royal Meteorological Institute of Belgium
SAF	Satellite Application Facility
SMHI	Swedish Meteorological and Hydrological Institute
SMMR	Scanning Multichannel Microwave Radiometer
SSM/I	Special Sensor Microwave Imager
SSMIS	Special Sensor Microwave Imager Sounder
TA	Antenna Temperature
TB	Brightness Temperature
TDR	Temperature Data Records

## IV-11 Appendix A

Table 1: Global NetCDF attributes.

Name	Description
title	dataset title
summary	short description of the data file content
Conventions	conventions followed, "CF-1.6,ACDD-1.3 " for all files
netcdf_library_version	NetCDF library version used
institution	institution where the data was produced
project	The name of the project responsible for originating this data.
creator_name	Creator institution of this data.
creator_url	URL contact information for the creator of this data
creator_email	email contact information for the creator of this data
references	references that describe the data or methods used to produce it
id	Digital Object Identifier (DOI)
source	original data source
cdm_data_type	data type, "swath" for all files
keywords_vocabulary	Controlled vocabulary used for keywords.
keywords	A comma-separated list of key words.
standard_name_vocabulary	The name and version of the controlled vocabulary from which variable standard names are taken.
filename	original filename
time_coverage_start	temporal coverage start of the data [ISO8601 date]
time_coverage_end	temporal coverage end of the data [ISO8601 date]
geospatial_lat_units	latitude attributes unit
geospatial_lat_min	latitude bounding box minimum
geospatial_lat_max	latitude bounding box maximum
geospatial_lon_units	longitude attributes unit
geospatial_lon_min	longitude bounding box minimum
geospatial_lon_max	longitude bounding box maximum
revolution_coverage_start	revolution coverage start of the data [revolution since launch]
revolution_coverage_end	evolution coverage end of the data [revolution since launch]
platform_vocabulary	Controlled vocabulary used for platform.
platform	platform name
platform_identifier	platform sequential number [e.g. 7]
wmo_satellite_identifier	WMO code: satellite identifier
instrument_vocabulary	Controlled vocabulary used for instrument.
intrument	Instrument name, "SMMR"
wmo_instrument_identifier	WMO code: instrument identifier

scanlines_count	total number of scan-lines in the data file
scanlines_missing_count	number of missing scan-lines in the data file
scanlines_coverage_percent	fraction of available scans in the data file
product_version	FCDR version number
format_version	NetCDF layout version number.
tdr_software_rev_num	Level1 TDR software revision number.
date_created	date on which the data was created [ISO8601 date]
date_modified	date on which the data was modified [ISO8601 date]
history	provides an audit trail for modifications to the original data

Table 2: Attributes assigned to variables.

Name	Description
long_name	long descriptive name
standard_name	standard name that references a description of a variable's content in the CF standard name table
units	physical unit [udunits standards]
C_format	format string that should be used for C applications to print values for this variable
FORTRAN_format	format string that should be used for FORTRAN applications to print values for this variable
valid_min	smallest valid value of a variable
valid_max	largest valid value of a variable
_FillValue	This number represent missing or undefined data.
flag_masks	list of bit fields expressing Boolean or enumerated flags
flag_meanings	descriptive words for each flag value
compress	Records dimensions which have been compressed by gathering.

Table 3: Scanline quality control bit meanings [*qc\_scan*].

Bit	Meaning	Description
1	missing	Complete scanline is missing in raw data record.
2	geolocation_error	Geolocation is erroneous.
3	calibration_temperature_error	Calibration temperature readings are erroneous.
4	possible_smoothed_calibration_interference	Calibration can be affected by smoothing in Level 1a data
5	all_tb_values_missing	Scanline is available but all TBs are undefined

Table 4: Channel quality control bit meanings [*qc\_chan*].

Bit	Meaning	Description
1	calibration_hotload_error	Hot load readings erroneous.
2	calibration_coldload_error	Cold load readings erroneous
3	calibration_agc_error	Gain control settings are erroneous.
4	out_of_bounds_error	Too many FOVs are out of bounds.
5	defective	Channel is defective.

Table 5: FOV quality control bit meanings [*qc\_fov*].

Bit	Meaning	Description
1	TB_V6_out_of_bounds	TB at 6.6 GHz vpol is out of bounds.
2	TB_H6_out_of_bounds	TB at 6.6 GHz hpol is out of bounds.
3	TB_V10_out_of_bounds	TB at 10 GHz vpol is out of bounds.
4	TB_H10_out_of_bounds	TB at 10 GHz hpol is out of bounds.
5	TB_V18_out_of_bounds	TB at 18 GHz vpol is out of bounds.
6	TB_H18_out_of_bounds	TB at 18 GHz hpol is out of bounds.
7	TB_V21_out_of_bounds	TB at 21 GHz vpol is out of bounds.
8	TB_H21_out_of_bounds	TB at 21 GHz hpol is out of bounds.
9	TB_V37_out_of_bounds	TB at 37 GHz vpol is out of bounds.
10	TB_H37_out_of_bounds	TB at 37 GHz hpol is out of bounds.

Table 6: Scan status bit meanings [*qc\_status*].

Bit	Meaning	Description
1	possible_loss_of_data_quality_in_level_1A	Possible loss of data quality in level 1A processing (flag passed from input TAT data).
2	period_of_initialization_of_calibration	Scan is in period of initialization of calibration and engineering data running averages. Brightness temperature calibrations may be less reliable during this period.
3	calibration_temperature_error	One or more of the instrument component temperatures used in the radiometric calibrations has deviated by more than +/- 3K from its running average value in the previous scan. The accuracy of the brightness temperature calibrations in this scan may be reduced.
4	spacecraft_attitude_error	Pitch, roll, or yaw error value is greater than +/- 0.95 degrees. This indicates an anomalous spacecraft attitude variation.
5	spacecraft_attitude_missing	The spacecraft attitude information and EIA is not available.
6	sun_in_cold_horn_period	Scan is in the "sun-in-the-cold-horn" period. Cold calibration counts have been interpolated and brightness temperature calibration accuracy may be reduced.

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## IV-12 Appendix B

The following pseudo code can be used as a reference to read the valid brightness temperatures and to apply the inter-calibration offsets. This is not a valid source code but should assist in writing reading procedures.

### Read and apply inter-sensor calibration offsets

```
tb      = netcdf_read ('tb')
ical    = netcdf_read ('ical')
pos     = where (ical eq ical@_Fillvalue or tb eq tb@_Fillvalue)
ical[pos] = NAN
tb[pos]  = NAN
tb      = tb + ical
```

### Read and apply quality scanline and channel control flags

```
; Read and apply qc_scan flag
qc      = netcdf_read ('qc_scan')
pos     = where (qc ne 0)
tb[pos,*,*] = NAN

; Read and apply qc_channel flag (set flagged values to undefined)
chn     = netcdf_read ('scene_channel')
qc      = netcdf_read ('qc_channel')
for c=0, dimsize(chn)-1 do
  pos   = where (qc[chn[c]] ne 0)
  tb[pos,c,*] = NAN
end for
```

### Read and apply FOV control flags

Here we set all TBs at one FOV to undefined if one channel in the group is out of bounds.

```
time = netcdf_read ('time')
qc   = netcdf_read ('qc_fov')
for t = 0, dimsize(time)-1
  pos = where (qc[t,*] ne 0)
  tb[t,*,pos] = NAN
endfor
```

### IV-13 Appendix C

Table 7: Nimbus-7 SMMR characteristics (Nimbus-7 Users Guide, Madrid et al. 1978).

Channel	1,2	3,4	5,6	7,8	9,10
Frequency [GHz]	6.6	10.69	18.00	21.00	37.00
Bandwidth [Mhz]	250	250	250	250	250
Integration time [ms]	126	126	62	62	30
3-dB beamwidth [deg]	4.2	2.6	1.6	1.4	0.8
FOV resolution [km]	148x95	91x59	55x41	46x30	27x18
Sensitivity [K]	0.9	0.9	1.2	1.5	1.5
Absolute accuracy [K]	<2	<2	<2	<2	<2