Copernicus Climate Change Service

Product User Guide

Fundamental Climate Data Record of Microwave Humidity Sounder

Issued by: EUMETSAT
Date: 19/10/2020
REF.: C3S_311b Task 1.1 D1.1, D1.2, D1.3
Service contract: 2016/C3S_311b _EUMETSAT

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Product User Guide

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List of Abbreviations

AAPP	ATOVS and AVHRR Pre-processing Package
ACDD	Attribute Convention on Data Discovery
AMSU	Advanced Microwave Sounding Unit
ATBD	Algorithm Theoretical Basis Document
ATOVS	Advanced TIROS Operational Vertical Sounder
ATMS	Advanced Technology Microwave Sounder
AVHRR	Advanced very-high-resolution radiometer
bb	Shortcut for black body in the quality flag names
C3S	Copernicus Climate Change Service
calib	Shortcut for calibration in the quality flag names
CDS	Climate Data Store
DOI	Digital Object Identifier
DSV	Deep Space View
ECMWF	European Centre for Medium-range Weather Forecast
ERA5	ECMWF ReAnalysis 5
FCDR	Fundamental Climate Data Record
FIDUCEO	Fidelity and uncertainty in climate data records from Earth Observations
GCOS	Global Climate Observing System
geoloc	Shortcut for geolocation in the quality flag names
MHS	Microwave Humidity Sounder
MWHS	MicroWave Humidity Sounder
OBCT	On-Board Calibration Target
PRT	platinum resistance thermometer
RFI	RadioFrequencyInterference
RTTOV	Radiative Transfer for TOVS
SAPHIR	Sondeur Atmosphérique du Profil d'Humidité Intertropical par Radiométrie
SARR	Search and Rescue Repeater
SNPP	Suomi National Polar-orbiting Partnership
susp	Shortcut for suspicious in the quality flag names
STX	Station Transmission Assembly

1 INTRODUCTION

1.1 Purpose and Scope

Within Task 1.1 in C3S_311b [AD1], EUMETSAT provides Fundamental Climate Data Records (FCDRs) of level 1c brightness temperatures from microwave humidity sounder instruments on board polar-orbiting operational weather satellites as consistent input to the C3S reanalysis. These FCDRs are referred to as the *C3S microwave sounder FCDRs,* which consists of:

1. Release 2 for the Microwave Humidity Sounder (MHS) on Metop A and Metop B satellites;
2. Release 1 for the Advanced Technology Microwave Sounder (ATMS) on Suomi National Polar-orbiting Partnership (SNPP) satellite;
3. Release 1 for the MicroWave Humidity Sounder (MWHS) on FY-3A, FY-3B, and FY-3C satellites;

The C3S microwave sounder FCDRs cover the period 31/10/2006 until 31/12/2018.

Three documents provide information essential for users to understand and to use the C3S microwave sounder FCDRs:

- Algorithm Theoretical Baseline Description (ATBD), which describes the methods and algorithms used to generate the product;
- Quality Evaluation Report, which provides information on the accuracy, precision, and stability of the product;
- Product User Guide (this document), which summarises the other documents, informs on applications and limitations, and introduces the format in which the product is available.

1.2 Structure of the Document

This document has the following structure:

Section 1	Introduction describing purpose and scope of this product user guide
Section 2	Background information on the product
Section 3	Product definition summarises the temporal and spectral content and the volume of the data
Section 4	Product features summarises the validation results as well as known issues and the applicability
Section 5	Product generation outlines details on the data record generation
Section 6	Product access informs on the data ordering
Section 7	Product support and feedback
Section 8	Product referencing
Section 9	Acknowledgements
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Appendix	Metadata NetCDF File

1.3 Applicable documents

AD1.	Draft Multi-Annual Implementation Plan 2016 - 2021. C3S_311b D9.2

1.4 Reference Documents

RD 1.	C3S_311b Task1.1 ATBD (version 1.0)
RD 2.	C3S_311b Task1.1 Quality Evaluation Report (version 1.0)
RD 3.	FIDUCEO project description, www.fiduceo.eu (assessed on 4 June 2019)
RD 4.	FIDUCEO Report D2.2 (MW): Report on the MW FCDR uncertainty (version 1.0)
RD 5.	FIDUCEO Product User Guide – Microwave FCDR release 4.1, 2019 (*in preparation*)
RD 6.	Chen, K., S. English, N. Bormann, and J. Zhu, 2015: Assessment of FY-3A and FY-3B MWHS Observations. Wea. Forecasting, 30, 1280–1290,https://doi.org/10.1175/WAF-D-15-0025.1
RD 7.	M. Dowell, P. Lecomte, R. Husband, J. Schulz, T. Mohr, Y. Tahara, R. Eckman, E. Lindstrom, C. Wooldridge, S. Hilding, J.Bates, B. Ryan, J. Lafeuille, and S. Bojinski, 2013: Strategy Towards an Architecture for Climate Monitoring from Space. Pp. 39.
RD 8.	S. Gu, Y. Guo, Z. Wang and N. Lu, "Calibration Analyses for Sounding Channels of MWHS Onboard FY-3A," in IEEE Transactions on Geoscience and Remote Sensing, vol. 50, no. 12, pp. 4885-4891, Dec. 2012. doi: 10.1109/TGRS.2012.2214391
RD 9.	H. Jieying, Z. Shengwei and W. Zhenzhan, "Advanced Microwave Atmospheric Sounder (AMAS) Channel Specifications and T/V Calibration Results on FY-3C Satellite," in IEEE Transactions on Geoscience and Remote Sensing, vol. 53, no. 1, pp. 481-493, Jan. 2015. doi: 10.1109/TGRS.2014.2324173
RD 10.	NASA GES DISC (2018), Data Product User Guide for S-NPP Sounder Science Investigator-led Processing System (SIPS) ATMS Level 1B Products, product version 2.0, software version 2.5,
RD 11.	EUMETSAT Data Policy (link to pdf, assessed on 4 June 2019)
RD 12.	EUMETSAT, MHS Level 1 Product Generation Specification (EUM.EPS.SYS.SPE.990006), Version 6.0
RD 13.	Lambrigtsen, B.H., Algorithm Theoretical Basis Document – NASA L1B: Advanced Technology Microwave Sounder, Version 1, July 2014
RD 14.	Monarrez, Ruth, NASA Advanced Technology Microwave Sounder (ATMS) Level 1B Data Product User Guide, Product Version 2.11, 08/2019
RD 15.	WMO (2017): "Manual on Codes", Vol I.2, WMO No. 306
RD 16.	WMO Data processing levels, http://www.wmo.int/pages/prog/sat/dataandproducts_en.php (assessed on 25.06.2019)
RD 17.	ATOVS and AVHRR Pre-processing Package (AAPP) User Guide (2019), NWPSAF-MO-UD-036, Version8.3
RD 18.	Lawrence H., N. Bormann, Q. Lu, A.Geer and S. English, An evaluation of FY-3C MWHS-2 at ECMWF (link to pdf, assessed on 25 June 2019)
RD 19.	M. Schreier, B. Lambrigtsen, E. Fetzer, " Advanced Technology Microwave Sounder (ATMS) Assessment Report for Suomi National Polar-orbiting Partnership (SNPP)

	Sounder Science Investigator-led Processing System (SIPS) Data Level 1", 2018, NASA JPL
RD 20.	Wang Zhenzhan, Zhang Shengwei and Li Jing, "Thermal/vacuum calibration of microwave humidity sounder on FY-3B satellite",Strategic Study of Chinese Academy of Engineering,2013,15(10):33-46.

1.5 Definitions

The following definitions are used throughout the document.

Data levels (RD 16):

- Level 1A: Instrument counts with geolocation and calibration information attached but not applied
- Level 1B: Geolocation and calibration information applied to the instrument counts
- Level 1C: Instrument specific. For example, 1b radiance data converted to brightness temperature (for infrared sensors)

Products types:

- Operational data - are Level 1 data provided by the space agency responsible for operating the sensor in space;
- Fundamental Climate Data Record [RD 7] – The term FCDR denotes a well-characterised, long-term data record, usually involving a series of instruments, with potentially changing measurement approaches, but with overlaps and calibrations sufficient to allow the generation of products that are accurate and stable, in both space and time, to support climate applications. FCDRs are typically calibrated radiances, brightness temperatures, backscatter of active instruments, or radio occultation bending angles. FCDRs also include the ancillary data used to calibrate them. The term FCDR has been adopted by GCOS and can be considered as an international consensus definition.

2 BACKGROUND

In support to global reanalyses using Numerical Weather Prediction (NWP) models, satellite data used as input for the data assimilation schemes need to be improved in quality. This quality is not optimal because of the high timeliness that is required to deliver the data for operational weather forecast. This is reflected in missing observations and insufficient quality control. For the use in reanalysis, the quality of the satellite data is analysed and in most cases can be improved, e.g., by updating meta data, instrument calibration, inter-satellite calibration etc.

A major needed data record for global reanalysis is from passive microwave sounding around the 183 GHz water vapour absorption line that provides information on the atmospheric humidity in the upper atmosphere. Microwave humidity sounding sensors were flown on several satellites in the past and are part of the payload of operational satellites in polar orbit since 1998.

Within the EU project Fidelity and uncertainty in climate data records from Earth Observations (FIDUCEO) [RD 3] a first release of the Microwave humidity sounder data record has been prepared and is available from EUMETSAT. It consists of time series from three different instruments:

- MHS (NOAA18, NOAA19, Metop A, Metop B);
- AMSU-B (NOAA 15, NOAA 16, NOAA 17);
- SSMT/2 (DSMP F11, F12, F14, F15).

The main feature of these FCDRs is the provision of uncertainties describing the errors in the individual measurements.

The methods to generate the C3S microwave sounder FCDRs build upon the methods developed and used in FIDUCEO. Uncertainties are determined applying the same methodology and quality checks and pixel flagging was adopted. The FCDR releases to C3S extend the data delivered by FIDUCEO to new instruments and extends the MHS data in time for the Metop mission.

3 PRODUCT DEFINITION

In this section, an overview on the C3S microwave sounder FCDRs is provided in terms of its physical structure, data file specifications such as names, data volumes and format, and the specific product content including metadata.

3.1 Physical Structure

The C3S microwave sounder FCDRs comprises in total four different instruments (MHS, MWHS/1, MWHS/2, and ATMS) operating on six satellites. Each instrument is a cross track scanning microwave humidity sounder, operating on a polar orbiting meteorological satellite. Each satellite orbits the earth in about 830km on a sun-synchronous orbit. The instruments have a comparable spatial resolution of about 16km at nadir, but have a varying swath width from 2310km (MHS) to 2660km (MWHS) (see also section 4.1). The data files provide brightness temperatures for the earth view field of views with their associated uncertainties and quality flags.

The FCDR comprises observations around the water vapour absorption band at 183.31GHz. Depending on the instrument, the absorption band is measured at three (MHS, MWHS/1) or five (ATMS, MWHS/2) spectral channels. The instruments use the heterodyne principle, which provides two passbands around the central frequency (more information can be found in RD 5). One exception is MHS, which provides only the upper side for the 183.31 ± 7 GHz channel at 190.31 GHz. Apart from that, the instruments only differ slightly by their passband width, their polarisation, and the number of channels around 183.31 GHz. The main characteristics of the data in the C3S microwave sounder FCDRs are summarised in Table 1.

Although the instruments observe at other frequencies as well, the C3S microwave sounder FCDR data intentionally, only include observations at the 183.31 GHz water vapour absorption band. Therefore and to keep the file size low, any other channel from ATMS and MWHS/2 has been excluded. For the other two instruments, MWHS/1 and MHS, only two additional channels exist and these are included. For MHS, channel 1 and 2 are processed using the FIDUCEO methodology, but their quality was not evaluated.

For MWHS/1, channel 1 and 2 were copied from the operational L1C data files and the uncertainties are set to a specific value indicating they were not derived.

For further information on the instruments and satellites, the authors refer to the further documentation from the data providers:

- MHS: [RD 12]
- ATMS: [RD 13], [RD 14] (Appendix A), [RD 19]
- MWHS: [RD 8], [RD 9], [RD 20]

Table 1: List of instruments, satellites, time coverage, and spectral properties of the FCDR dataset. (*) for MHS, only 183+7GHz is observed, for the other sensors this channel also observes both passbands. (**) H stands for horizontal polarized and V for vertical polarized.

Sensor	Platform	re-processing period	183.31GHz channels (H/V**) / Max Bandwidth [MHz]				
			±1	±1.8	±3	±4.8	±7
MHS*	Metop A	31-10-2006 to 31-12-2018	✓(H) / 250	✗	✓(H) / 500	✗	✓*(V) / 1100
	Metop B	01-04-2013 to 31-12-2018	✓(H) / 250	✗	✓(H) / 500	✗	✓*(V) / 1100
MWHS /1	FY-3A	01-07-2008 to 04-05-2014	✓(V) / 500		✓(V) / 1000		✓(V) / 2000
	FY-3B	18-11-2010 to 31-12-2018	✓(V) / 500		✓(V) / 1000		✓(V) / 2000
MWHS /2	FY-3C	30-09-2013 to 31-12-2018	✓(H) / 500	✓(H) / 700	✓(H) / 1000	✓(H) / 2000	✓(H) / 2000
ATMS	S-NPP	10-12-2011 – 31-12-2018	✓(H) / 500	✓(H) / 1000	✓(H) / 1000	✓(H) / 2000	✓(H) / 2000

3.2 File Specifications

Data files for the individual microwave sounder FCDRs are provided in NetCDF4 format. The following subsections provide an overview on the filename definition, on the file size, and on how to visualise the data.

3.2.1 Filenames

The filenames of the data files include information on the instrument, product level, spacecraft, start sensing time, end sensing time, processor version, and dataset release. Sensing times are actually the start and end time of the measurements covered in the file. The file naming conventions used for the NetCDF4 files are shown in Table 2.

Table 2: File names used for the level 1c *C3S Microwave Humidity Sounders FCDRs*, corresponding to the NetCDF format.

Naming convention Level 1c MHS –NetCDF
C3S_FCDR_<level>_<instr>_<sat>_<start_time>_<end_time>_<version>_<release>.nc
Example name Level 1c MHS –NetCDF
C3S_FCDR_L1C_MHS_METOPA_20061101224433_20061102002553_V1.0_R02.0.nc

where:

<level> level version (e.g. L1A, L1B, L1C)

<inst> instrument ID (e.g., MHS for the microwave humidity sounder instrument)

<sat> satellite ID (e.g., METOPA for Metop-A)

<start_time> sensing start time (e.g., 20101231094452)

<end_time> timestamp characterizing sensing end time

<version> code referring to processor version used to process the data

<release> code referring to FCDR release number

3.2.2 File Sizes

Single NetCDF4 granules cover an orbit from equator-to-equator and have sizes varying around 25 MB. The approximate size of the complete instruments FCDRs is about four Terra Byte. Table 3 provides the data volumes per year and per satellite in GB.

Table 3: Size of the level 1c C3S FCDRs in NetCDF4 format in GB.

Satellite	Instr.	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Metop-A	MHS	8	73	67	77	77	77	75	78	66	78	78	78	77	**909**
Metop-B	MHS								59	77	77	78	78	76	**445**
FY3A	MWHS/1			31	83	79	83	83	82	26					**467**
FY3B	MWHS/1					10	83	81	83	83	83	84	84	83	**674**
FY3C	MWHS/2								29	118	103	122	119	117	**608**
SNPP	ATMS						7	117	119	119	119	118	117	117	**833**
Total		**8**	**73**	**98**	**160**	**166**	**250**	**356**	**450**	**489**	**460**	**480**	**476**	**470**	**3936**

3.2.3 File Visualisation

Commonly known NetCDF viewers and NetCDF image processing software can be used for visualisation of the NetCDF4 files. Among others the files can be viewed with HDFview (version 2.13 or later), Ncview (version 2.1.7 or later), Panoply (version 4.7.0 or later), and processed with IDL (version 8.0 or later) and netcdf4-python (version 1.2.4) on Python (version 2.6 or later).

3.3 Product Contents

The FCDRs contain information on the earth view observed brightness temperature with their associated uncertainties, the NEΔT, and metadata, such as geolocation, viewing geometry, and quality control variables.

The uncertainties are provided as independent, structured, and common uncertainty. Uncertainty is independent if it is uncorrelated to the uncertainty for any other measurements taken by the instrument. Uncertainty is structured when it is correlated in space and time. Within the FIDUCEO project, a spatial scale of 300 scanlines [RD 4] has been evaluated to be useful for the computation of the structured uncertainty. Uncertainty is common if it appears in all measurements and during the entire lifetime of the instrument, e.g., by using the same calibration target for all measurements. More information on the different types of uncertainties can be found in the FIDCUEO project documentation [RD 5] and in the ATBD [RD 1].

The following paragraphs provide a detailed overview on the file content. This includes the metadata conventions, the measurement datasets, and the global attributes. Appendix A provides a complete example of the file metadata is given.

Metadata conventions

Metadata follow the CF (Climate Forecast) convention and the Attribute Convention on Data Discovery (ACDD). Each variable is defined with the attributes standard name, units, and fill_value. The attribute ancillary_variables links other datasets, e.g. the uncertainty, to the file containing the brightness temperature. Any data, available on pixel basis, consist of the attribute coordinates, which directly link the pixel to a latitude and longitude information. Quality bitmasks are provided with flag_mask and flag_meaning attributes. More detail on these is provided at the end of this section. In the global attributes, the unique WMO identifiers define the instrument and satellite (Table 4).

Table 4: Overview on the instrument and satellite IDs used in the FCDR according to the WMO definition in [RD 15][1].

WMO instrument id	Instrument name	WMO satellite id	Satellite name
203	MHS	3	METOP-B
		4	METOP-A
936	MWHS/1	520	FY-3A
		521	FY-3B
953	MWHS/2	522	FY-3C
621	ATMS	224	Suomi NPP

Measurement Datasets

The level 1C NetCDF files comprise of the following measurement data sets, presented in Appendix B, Table 6. Each measurement data sets has a set of attributes, supporting the reading of the data.

Global attributes

Global attributes describe the data and give useful information about their content and production. The global attributes are listed in Appendix C, Table 7.

Quality Flags

The data files comprise four quality bitmasks, which address different categories of issues within the data, their calibration, and their transmission. They are compiled generally from two sources, the level 1a data file, and the data processing. From the level 1a data file, where available, information on issues with the data transmission to ground, the geolocation, and the time stamp are utilised. During the data processing, quality flags are generated for most processing steps, which are accumulated to the data quality flags presented in the level 1b output file. Appendix D provides a detailed overview on the included quality bits and their meaning. This table is adapted from the [RD 5].

4 PRODUCT FEATURES

This section provides an overview of the scientific data available in the C3S microwave sounder FCDRs. The subsections inform on the spatial and temporal characteristics,

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

summarises the validation results, and express the applicability including known limitations and issues.

4.1 Spatial and Temporal Characteristics

Each data file covers one satellite orbit, from equator going southwards to back to equator. The four instruments that are included in the C3S microwave sounder FCDRs differ slightly in their spatial and temporal characteristics. The main characteristics of the instruments are summarised in Table 5. The varying swath width affects the spatial coverage of the different instruments.

The satellites, on which the instruments are operating, have a polar, sun-synchronous orbit with about 14.2 orbits per day. Each orbit can be separated in two nodes, the ascending and descending node, of which one observes mostly at night-time and one at day-time. The spatial coverage over 24 hours is nearly global. Because the swath widths vary slightly from 2310km to 2660 km among the instruments, a single node does not provide a complete global coverage. A gap between two orbits appears close to the equator, as shown for MHS on Metop-A in Figure 1. The next node, providing observations 12 hours apart, fills such gaps. Towards the poles, at latitudes higher than 60°N and S, the Earth the coverage is better and orbits start to overlap.

Table 5 Spatial and temporal characteristics of the instruments [RD 18].

Instr.	IFOV nadir	Pixels / Scan	Scan rate	swath
MHS	16 km	90	8/3 seconds	2310 km
MWHS/1	15 km	98	8/3 seconds	2660 km
MWHS/2	16 km	98	8/3 seconds	2660 km
ATMS	16 km	96	8/3 seconds	2580 km

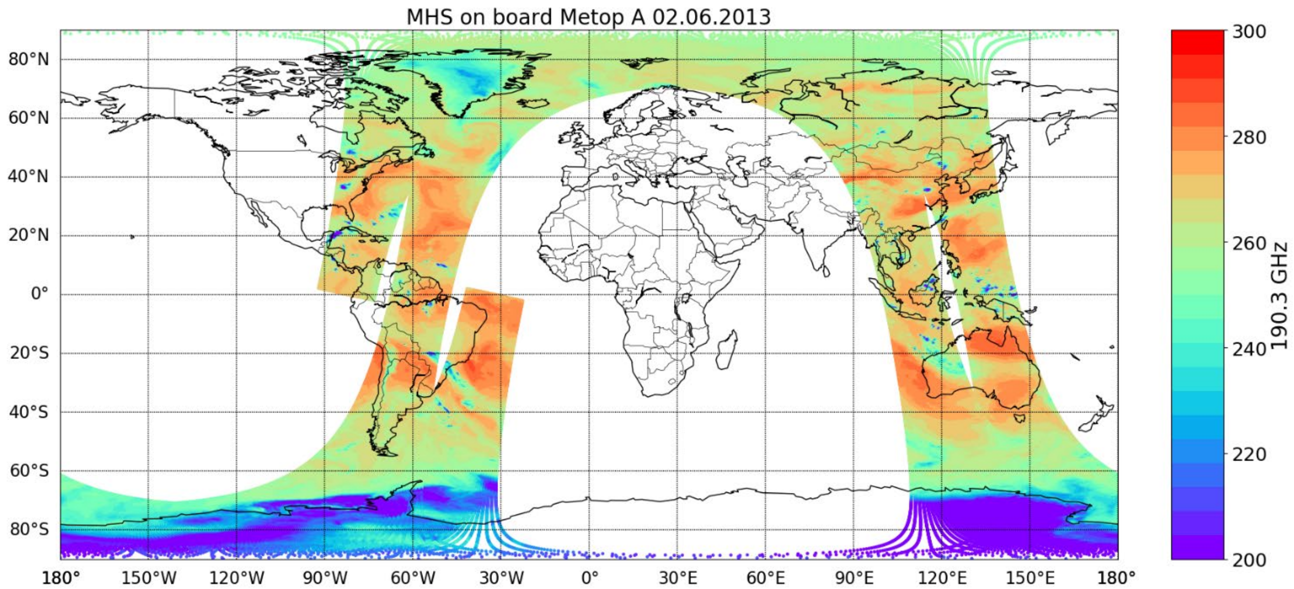

Figure 1 Channel 5 brightness temperature for two consecutive orbits of MHS on board of Metop A on 02.06.2013 between 11:36 UTC and 14:59 UTC.

To visualise the impact of the swath width on the global coverage, Figure 2 shows the ascending and descending node from all observations over 24 hours that indicates the different spatial samplings for the single instruments. The figures show the brightness temperature for the 183.31 ± 7 GHz channel on 2 June 2013 (2 June 2016 for MWHS2 on FY-3C).

4.2 Validation

This section overviews the methods applied for scientifically validation of the C3S microwave sounder FCDR. The results of the validation work are presented in the Quality Evaluation Report [RD 2]. Please note there is no official reference document that provides requirements for the C3S microwave sounder FCDR product.

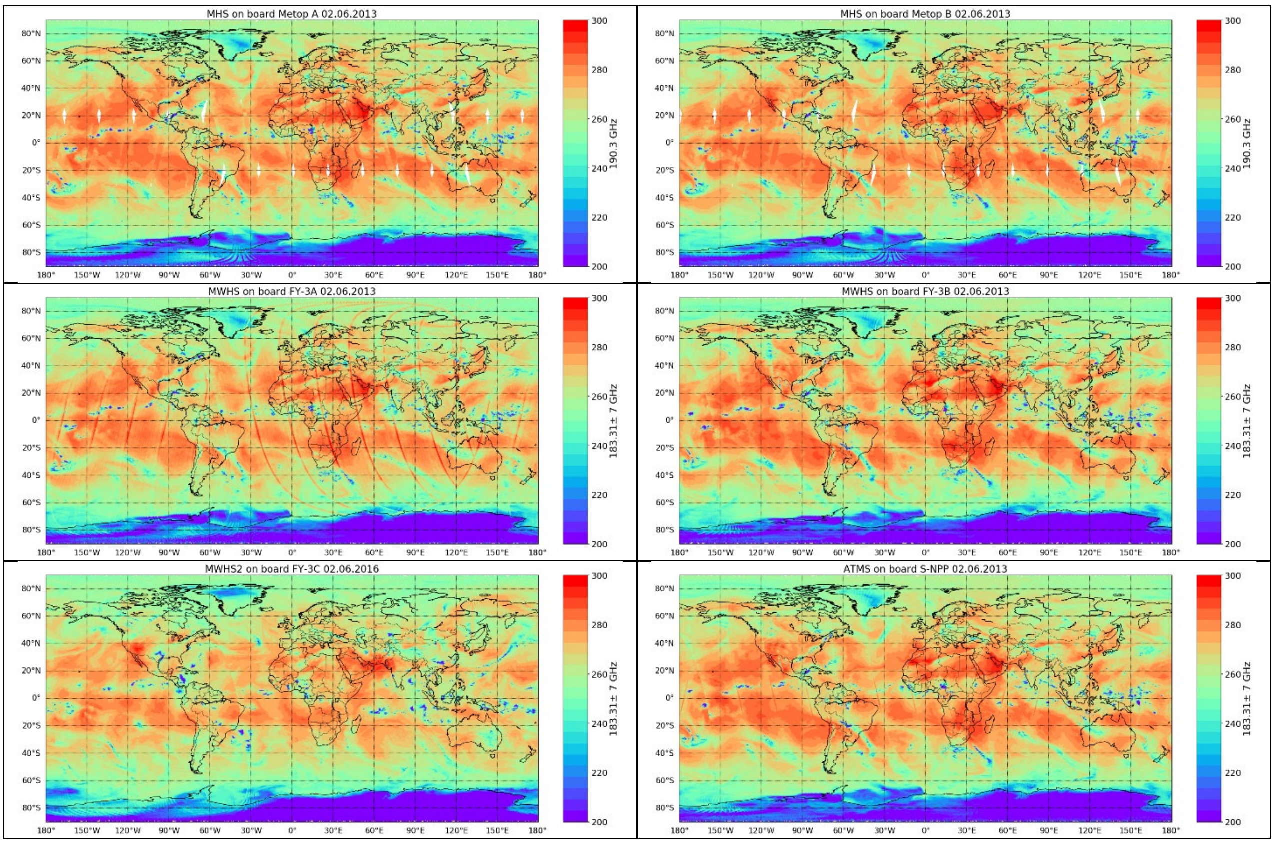

Figure 2 Spatial coverage of the individual instruments over 24 hours. From top left to bottom right: MHS/Metop A, MHS/Metop B, MWHS/FY-3A, MWHS/FY-3B, MWHS2/FY-3C, ATMS/SNPP. Shown is the brightness temperature at 183.31 ± 7 GHz.

4.3 Quality Evaluation and Known Issues

This section summarises the validation work presented in the Quality Evaluation Report [RD 2].

The validation results suggest that the FCDRs for Metop A and B are of very good quality. Through the analysis of double-differences calculated using simulated TOA BTs based on ERA-5 atmospheric profiles, Metop A and B are found to agree almost exactly, except for the 183.31±7 GHz channel where there is a small offset (~0.1 K). Virtually no difference is found between the Metop B FCDR and the operational Metop B L1c product with differences amounting to just a few hundredths of a K, which are negligible. The agreement between the Metop A FCDR and operational L1c product is also very good, with both mean differences and standard deviations of ~0.1 K (FCDR warmer). Both Metop A and B show remarkable stability with respect to the simulated BTs and show no discontinuities.

The results for S-NPP are also very good. However, there appears to be a very stable but systematic difference between the FCDR and the operational BTs of ~1.4 to ~1.9 K (FCDR warmer), depending on the channel. There is also a significant discontinuity at high latitudes in 2016, where the mean difference between the FCDR and operational data reduces, such that the global standard deviation increases from <0.5 K to nearly 3 K. However, analysis of the FCDR with respect to the simulations and operational data suggest that the FCDR is very stable with time at all latitudes between ±60°.

Both Metop A and B, and S-NPP demonstrate good agreement with the simulated data. Some non-zero and varying agreement between the FCDRs and the simulations is expected as differences in the atmospheric states between the ERA5 reanalysis and the true atmosphere observed by the satellites will also influence the agreement between the two data sets. However, mean differences between the FCDRs and the simulations between ±60° latitude (higher latitudes are excluded from this particular analysis) are generally within ±1 K with standard deviations of around 1.5 – 2.5 K. The analysis of double differences suggests that the zonal mean differences between Metop A and B, and S-NPP, do not exceed ±1 K. This apparently good agreement is also confirmed through the analysis of SNOs. There are no SNOs between Metop A and B, but the analysis of SNO pairs for Metop A or B with S-NPP indicates that the mean differences and their standard deviations are consistently within ~1 K. However, it should be noted that the SNO analysis for these sensor pairs is restricted to very high latitudes and do not include assessment of the S-NPP 183.31±1.8 GHz and 183.31±4.5 GHz channels. Collectively, these results suggest that the systematic difference between the FCDR and operational data for S-NPP may be due to the operational data, rather than the FCDR. An independent assessment of these FCDRs using SAPHIR further confirms the quality of the Metop A, B and S-NPP FCDR data. It should be noted that the frequencies of the SAPHIR channels do not match those of Metop A, B and S-NPP exactly, so some differences are expected. Mean differences are within ±1 K, with the exception of the SAPHIR/S-NPP 183.31±7 GHz channel (183.31±6.6 GHz for SAPHIR), which is -2.1 K, while the standard deviations range between 1.5 and 2.7 K.

The validation results suggest that the FY-3A, -B, and -C FCDRs are of lower quality than those for Metop A, B and S-NPP. However, this comparative low quality is likely to originate from the L1a data rather than from the processing of the FCDRs, as there is good agreement between the FCDRs and operational data sets, particularly for FY-3B and FY-3C. For these sensors, the agreement between the FCDRs and operational data is generally within a few tenths of a K. However, for FY-3A, the FCDR is 0.5 to 1 K colder than the operational data, with standard deviations of up to ~1.7 K depending on the channel. Comparisons between the FY-3 FCDRs and simulations also present some large and variable differences. In particular, FY-3C is highly erratic for the 183.31±3 GHz and 183.31±4.5 GHz channels, with the mean differences varying by several K, and sometimes abruptly. The FY-3A and -3B time series are consistently cold compared with the simulated TOA BTs and have a tendency for negative trends with time. Despite these larger mean differences, it is notable that the standard deviations of the differences are quite stable and similar to those obtained for Metop A, B and S-NPP. All the FY-3 FCDRs have significant discontinuities. For FY-3A, these occur in 2009 and mid-2012. The FY-3A FCDR also exhibits discontinuities with respect to the operational data in May and September 2013. For FY-3B, there are discontinuities at the end of 2010, in the second half of 2011, the second half of 2012, and in the first half of 2017. There is also a discontinuity present in the FCDR with respect to the operational data at the end of 2016. For FY-3C, there are discontinuities in 2013, 2015 and in early 2018, in addition to a 6-month anomaly in the middle of 2016. A discontinuity with respect to the operational FY-3C data is also identified in mid-2014.

Results for the SNO analyses confirm the relatively poor performance of the FY-3 FCDRs compared with Metop A, B and S-NPP. SNO pairs that include one of the FY-3 FCDRs tend to have the largest mean differences and standard deviations. With exception of the 183.31±3 GHz channel on FY-3C, the SNO analysis indicates that FY-3A, -B and -C is generally warmer than Metop A, B and S-NPP (note that the 183.31±1.8 GHz and 183.31±4.5 GHz channels are not assessed in the SNO analysis). The FY-3 sensors also appear to have a BT-dependent response, i.e. for a 1 K change in true BT, the observed FY-3 BTs do not necessarily change by 1K; this issue seems to be particularly bad for the FY-3B. This response is frequently non-linear and appears in all three channels assessed. The SNO analysis also suggests some variation in the BT differences with time, which may, at least in part, be a result of this BT-dependent response. In some cases, this variation has an annual cycle. In general, Metop A, B and S-NPP do not appear to have a significant BT-dependent response and/or show a variation in BT differences with time, but there are exceptions. For example, there is a weak non-linear dependency of the S-NPP minus Metop B BT differences on S-NPP BT for both the 183.31±3 GHz and 183.31±7 GHz channels and the time series for these channels has an annual cycle with amplitude of 0.5-1 K.

A BT-dependent response in the FY-3A observations may also be responsible for the weak annual cycle in the agreement between the FY-3A FCDR and operational BT data. There are annual cycles in this comparison both in the NH tropics and at high latitudes that appear to be linked to changes in cloud frequency and intensity that are associated with the ITCZ and mid-to-high latitude storms. Similar annual cycles are also present in the comparisons between the FCDRs and simulated BTs, although these are much more intense with larger BT variations. In this case, any annual cycles may also be due to failures in the cloud screening applied to the observations to make them consistent with the simulated BTs. A decreasing intensity of these annual cycles with channel sounding height and a negative skew in the lowest-sounding channels at 183.31±7.0 GHz and 190.31 GHz is further evidence to support this theory. BTs over clouds that are not transparent at 183 GHz are cold, which will result in a cold tail in the distribution of differences where cloud contamination occurs.

One of the main benefits of the FCDRs over the operational L1c data is in the provision of well-characterised uncertainties and detailed QC information. The validation results suggest that the uncertainties on the FCDRs are underestimated, particularly for the FY-3 sensors. The total uncertainties for all the FCDRs are typically <1 K but based on the results presented here, it seems likely that the errors frequently exceed this limit. There are four separate QC flags provided with the FCDRs, each of which indicate different issues within the data. Using the QC flags together generally results in up to 10% of the data being rejected, although this varies slightly with each FCDR. Use of the QC flags appears to remove bad data points successfully, resulting in a data set with lower noise.

Finally, the validation has highlighted anomalies in the FY-3 operational L1c data at 17°N and 0.5°N. These latitudes are where the operational data start and finish and where there is a disruption in the operational calibration, which is averaged over a sequence of scan lines. These anomalies are not present in the FCDR due to a more consistent approach to the averaging required for the calibration.

4.4 Applicability

The C3S microwave humidity sounder FCDRs provide brightness temperature observations on the atmospheric humidity, especially in the middle and upper troposphere. As the observations come with associated uncertainties, that according to the validation results are reasonable, the data provide the opportunity to propagate instrument related uncertainty into retrieval and data assimilation schemes.

The prime application areas for the data are:

1. The assimilation to Numerical Weather Production models for global reanalysis. The data might be too large scale to have any impact on regional reanalysis activities;
2. Generation of climate data records, e.g. of upper or free tropospheric humidity, preferably with retrieval schemes that offer means for error propagation. The quality of the retrieved parameters including uncertainty may make the data fit for applications such as climate feedback analysis, in particular using the MHS and ATMS data. Data series may be too short for trend analysis although the stability of the brightness temperature record is found to be good enough for MHS and ATMS data to be close to GCOS requirements. In any case, the propagated instrument uncertainty and retrieval uncertainty should be propagated into trend computations.

According to the validation results Metop MHS and SNPP ATMS data can be used with confidence, FY MWHS data from all satellites must be used with care.

5 PRODUCT GENERATION

This section provides an overview on the generation process of the data record. It describes the algorithm, the dynamic and static input, and the setup of the reprocessing environment. Figure 3 summarises the data processing in a simplified sketch.

5.1 Data Processing

The processing scheme for the C3S microwave sounder FCDRs has been developed using Python 3. The processing does not follow single-orbit-processing logic. Instead, it interprets data from polar orbiting satellites as a stream of measurements and uses time as continuous coordinate along which the processing is performed. The processing scheme overview in Figure 3 illustrates this.

The FCDR consist of level 1 input data from different sensors, which are available in different data formats. The data include instrument Earth counts, calibration counts, viewing geometry information, and geolocation data. For MWHS/1, this information is stored with the calibrated brightness temperature in one L1C file. The data format differs between the agencies providing the data, and covers NetCDF4, HDF5, as well as binary files. For each instrument, a dedicated reader has been prepared which reads the data, collects required coefficients, and merges all information into a common variable design, which interfaces with the upper level software module. More information is provided in the appendix of [RD 1].

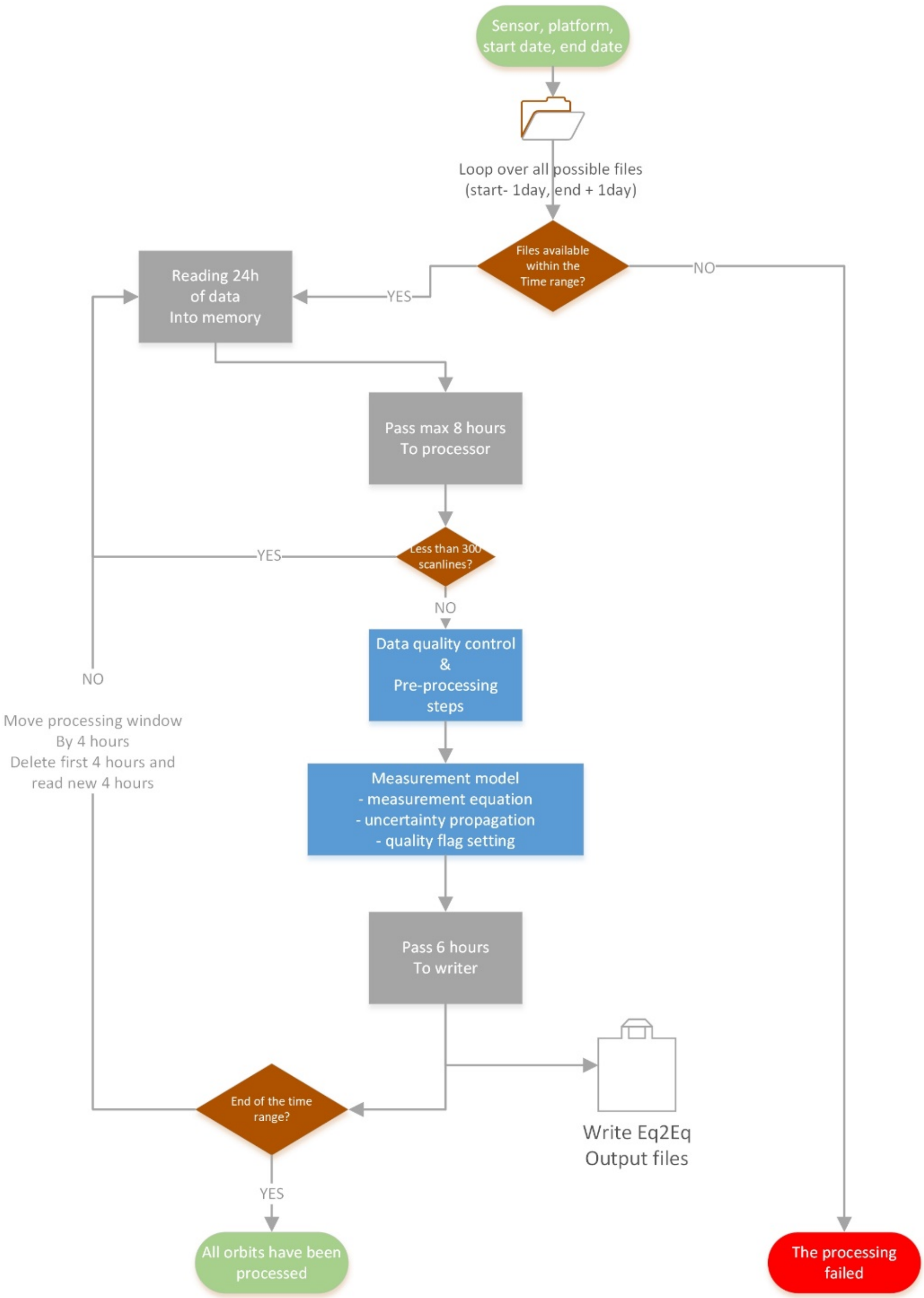

Figure 3 Schematic representation of the workflow in the processing algorithm.

The central approach of the algorithm is the execution of the measurement model. This model represents the instrument by the measurement equation and all effects causing errors in the measurements are considered in a way that for each effect and combination of effects the uncertainty is determined. In addition, a rigorous quality control is performed and compiled into informative quality flags. The processing scheme provides on output calibrated brightness temperatures with associated combined uncertainty estimates and quality flags as level 1c data files.

The operational processing of the individual sensors is based on different instrument calibration approaches. For example, ATMS is calibrated at NASA JPL in brightness temperature space [RD 14], while the other sensors are calibrated in the radiance space [e.g. RD 12]. The processing scheme has a measurement equation adapted for each instrument to reflect this. Other processing steps, described above, are applied in a similar manner to all sensors, ensuring a homogeneous processing and quality control over the different sensors.

The ATBD [RD 1] provides more information.

5.2 Updates in version 1.1

This release of the data record has been updated to version 1.1 in May 2020. The updates comprised of additional channel data for completeness and bug fixes as reported by users. Note that the additional channel data did not undergo a comprehensive validation as was done for the 183 GHz band.

- For MHS, the FIDUCEO processing algorithm has been applied to all additional channels;
- For ATMS, reprocessed data provided by NOAA has been added until 08.03.2017 and the operational data afterwards;
- For MWHS and MWHS-2, data have been inserted from the operational L1C files;
- The independent, structured, and common uncertainties for the added channels of ATMS, MWHS, and MWHS-2 have been set to fill_value;
- As above, the variable "quality_issue_pixel_bitmask" for these added channels have been set to 0. Because for these channels the brightness temperatures has not been processed, no quality information could be derived from the processing.

- The NEDT has been added for all channels, if available in the operational data:
  - For MWHS/2, no NEDT is available in the operational data;
  - For MWHS no NEDT is available in the operational data. However, the NEDT of the two additional channels were taken from the processing, as done for MHS;
  - As described in the ATBD [RD 1], the NEDT is calculated based on the Allan deviation of the calibration counts.

Bug fixes are:

- The platform and solar azimuth angles were reported with values outside of the expected value range, which are now corrected. These angles have now been copied from the input data;

- For MHS, no solar azimuth angle is available in the input data and, thus, is set to fill_value;
- The attribute "valid_range" has been added to the geolocation and viewing geometry variables.

All these changes are reflected in Appendix A.

6 PRODUCT ACCESS

Access to the data records is granted to all users without charge. The data can be accessed in two manners:

1 The data are accessible via the Copernicus Climate Data Store (CDS) and are available from the Copernicus Climate Change Service (C3S) website: https://climate.copernicus.eu.
2 The data are accessible via the EUMETSAT Data Centre after accepting the EUMETSAT Data Policy [RD 11]. To access the data from EUMETSAT, you need to register with the EUMETSAT Data Centre. When registered, you can order the data through a written request send to EUMETSAT's helpdesk (*ops@eumetsat.int*).

6.1 Register with the Data Centre

To register with the EUMETSAT Data Centre:

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

6.2 Order Data

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

- 10.15770/EUM_SEC_CLM_0033 for the MHS FCDR;
- 10.15770/EUM_SEC_CLM_0034 for the ATMS FCDR, and
- 10.15770/EUM_SEC_CLM_0035 for the MWHS FCDR.

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

7 PRODUCT SUPPORT AND FEEDBACK

For enquiries or feedback concerning the product described in this product user guide, the CDS offers Help & Support functionality. Alternatively, the user can contact the EUMETSAT User Service Helpdesk by email: *ops@eumetsat.int.*

8 PRODUCT REFERENCING

The data record described in this product user guide has a unique DOI, which is also given in the *doi* global attribute of each NetCDF file. In addition, the product's filename provides a unique identifier for each data granule, which is also contained in the *title* global attribute of the NetCDF files.

9 ACKNOWLEDGEMETS

The C3S microwave sounder FCDR has been prepared within the Copernicus Climate Change Service in cooperation with EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF). We highly acknowledge especially the work on the validation of the FCDR described in the Quality Evaluation Report that was performed by the CM SAF partner UK Met Office.
We further acknowledge Mathias Schreier from NASA JPL, who provided calibration coefficients for ATMS and the ATMS L1a data, NOAA CLASS for providing the MHS data, and the CMA/NSMC for providing MWHS/1&2 L1a and L1c data.

Appendix A Metadata netCDF File

```
netcdf C3S_FCDR_L1C_MHS_METOPA_20160602134325_20160602152445_V1.1_Release2 {
dimensions:
   y = 2282 ;
   x = 90 ;
   channel = 5 ;
variables:
   float latitude(y, x) ;
           latitude:_FillValue = -999.f ;
           latitude:standard_name = "latitude" ;
           latitude:units = "degrees_north" ;
           latitude:long_name = "latitude" ;
           latitude:valid_range = -90LL, 90LL ;
   float longitude(y, x) ;
           longitude:_FillValue = -999.f ;
           longitude:standard_name = "longitude" ;
           longitude:units = "degrees_east" ;
           longitude:long_name = "longitude" ;
           longitude:valid_range = -180LL, 180LL ;
   ubyte quality_pixel_bitmask(y, x) ;
           quality_pixel_bitmask:long_name = "Bitmask for quality per pixel" ;
           quality_pixel_bitmask:standard_name = "status_flag" ;
           quality_pixel_bitmask:flag_masks = "1, 2, 4, 8, 16, 32, 64, 128" ;
           quality_pixel_bitmask:flag_meanings  =  "invalid  use_with_caution  invalid_input
invalid_geoloc invalid_time sensor_error padded_data incomplete_channel_data" ;
           quality_pixel_bitmask:description  =  "issue  related  to  the  input  data  and  the
geolocation,  such  as  invalid  geolocation,  invalid  time  variable,  or  if  the  input  data  are
flagged" ;
           quality_pixel_bitmask:coordinates = "latitude longitude" ;
   float btemps(channel, y, x) ;
           btemps:_FillValue = -999.f ;
           btemps:standard_name = "toa_brightness_temperature" ;
           btemps:units = "K" ;
           btemps:ancillary_variables    =    "u_independent_btemps    u_structured_btemps
u_common_btemps" ;
           btemps:long_name = "Brightness temperature of METOPA" ;
           btemps:coordinates = "latitude longitude" ;
   float instrtemp(y) ;
           instrtemp:_FillValue = -999.f ;
           instrtemp:units = "K" ;
           instrtemp:long_name = "instrument temperature" ;
   ushort scnlin(y) ;
           scnlin:long_name = "scanline number in original file" ;
   float satellite_azimuth_angle(y, x) ;
           satellite_azimuth_angle:_FillValue = -999.f ;
           satellite_azimuth_angle:standard_name = "sensor_azimuth_angle" ;
           satellite_azimuth_angle:units = "degree" ;
           satellite_azimuth_angle:long_name = "satellite azimuth angle" ;
           satellite_azimuth_angle:valid_range = -180LL, 180LL ;
           satellite_azimuth_angle:description  =  "original  variable  name:  Local  azimuth
angle" ;
           satellite_azimuth_angle:coordinates = "latitude longitude" ;
   float satellite_zenith_angle(y, x) ;
           satellite_zenith_angle:_FillValue = -999.f ;
           satellite_zenith_angle:standard_name = "sensor_zenith_angle" ;
           satellite_zenith_angle:units = "degree" ;
           satellite_zenith_angle:long_name = "satellite zenith angle" ;
           satellite_zenith_angle:valid_range = 0LL, 180LL ;
           satellite_zenith_angle:coordinates = "latitude longitude" ;
   float solar_azimuth_angle(y, x) ;
           solar_azimuth_angle:_FillValue = -999.f ;
           solar_azimuth_angle:standard_name = "solar_azimuth_angle" ;
           solar_azimuth_angle:units = "degree" ;
```

```
            solar_azimuth_angle:long_name = "solar azimuth angle" ;
            solar_azimuth_angle:valid_range = -180LL, 180LL ;
            solar_azimuth_angle:coordinates = "latitude longitude" ;
    float solar_zenith_angle(y, x) ;
            solar_zenith_angle:_FillValue = -999.f ;
            solar_zenith_angle:standard_name = "solar_zenith_angle" ;
            solar_zenith_angle:units = "degree" ;
            solar_zenith_angle:long_name = "solar zenith angle" ;
            solar_zenith_angle:valid_range = 0LL, 180LL ;
            solar_zenith_angle:coordinates = "latitude longitude" ;
    float u_independent_btemps(channel, y, x) ;
            u_independent_btemps:_FillValue = -999.f ;
            u_independent_btemps:standard_name = "toa_brightness_temperature
independent_uncertainty" ;
            u_independent_btemps:long_name =
"uncertainty_of_toa_brightness_temperature_independent_effects" ;
            u_independent_btemps:units = "K" ;
            u_independent_btemps:description = "Uncertainty of the TOA brightness
temperature. Contains all considered independent effects of uncertainty." ;
            u_independent_btemps:coordinates = "latitude longitude" ;
    float u_structured_btemps(channel, y, x) ;
            u_structured_btemps:_FillValue = -999.f ;
            u_structured_btemps:standard_name = "toa_brightness_temperature
structured_uncertainty" ;
            u_structured_btemps:long_name =
"uncertainty_of_toa_brightness_temperature_structured_effects" ;
            u_structured_btemps:units = "K" ;
            u_structured_btemps:description = "Uncertainty of the TOA brightness temperature.
Contains all considered structured effects of uncertainty." ;
            u_structured_btemps:coordinates = "latitude longitude" ;
    ushort channel(channel) ;
            channel:long_name = "channel number" ;
            channel:units = "dimensionless" ;
            string channel:frequencies_GHz = "89, 150, 183.31± 1, 183.31± 3, 183.31± 7" ;
            channel:original_channel_number = 1LL, 2LL, 3LL, 4LL, 5LL ;
    ushort x(x) ;
            x:long_name = "scan position" ;
            x:units = "dimensionless" ;
    uint y(y) ;
            y:long_name = "scanline number" ;
            y:units = "dimensionless" ;
    ubyte quality_issue_pixel_bitmask(channel, y, x) ;
            quality_issue_pixel_bitmask:long_name = "Bitmask for quality issues per pixel
and channel" ;
            quality_issue_pixel_bitmask:standard_name = "status_flag" ;
            quality_issue_pixel_bitmask:flag_masks = "1,2,4,8,16" ;
            quality_issue_pixel_bitmask:flag_meanings = "susp_calib_DSV susp_calib_OBCT
no_calib_bad_DSV no_calib_bad_OBCT bad_data_earthview" ;
            quality_issue_pixel_bitmask:description = "issue related to the calibration
target measurement or earth view measurement, such as no sufficient number of valid
calibration counts" ;
            quality_issue_pixel_bitmask:coordinates = "latitude longitude" ;
    ubyte data_quality_bitmask(y, x) ;
            data_quality_bitmask:long_name = "Sensor specific bitmask for quality per pixel"
;
            data_quality_bitmask:standard_name = "status_flag" ;
            data_quality_bitmask:flag_masks = "1, 2, 4, 8, 16, 32" ;
            data_quality_bitmask:flag_meanings = "moon_check_fails no_calib_bad_prt
no_calib_moon_intrusion susp_calib_bb_temp susp_calib_prt susp_calib_moon_intrusion" ;
            data_quality_bitmask:description = "issue related to the calibration target, such
as moon intrusion or bad PRT measurements" ;
            data_quality_bitmask:coordinates = "latitude longitude" ;
    ubyte quality_scanline_bitmask(y, x) ;
            quality_scanline_bitmask:long_name = "Bitmask for quality per scanline" ;
            quality_scanline_bitmask:standard_name = "status_flag" ;
            quality_scanline_bitmask:flag_masks = "1,2,4,8,16,32" ;
```

```
            quality_scanline_bitmask:flag_meanings         =          "STX1_transmitter_on
STX2_transmitter_on    STX3_transmitter_on    STX4_transmitter_on    SARR_A_transmitter_on
SARR_B_transmitter_on" ;
            quality_scanline_bitmask:description = "issue related to the transmission of the
data." ;
            quality_scanline_bitmask:coordinates = "latitude longitude" ;
   float u_common_btemps(channel, y, x) ;
            u_common_btemps:_FillValue = -999.f ;
            u_common_btemps:standard_name = "toa_brightness_temperature common_uncertainty"
;
            u_common_btemps:long_name                                                     =
"uncertainty_of_toa_brightness_temperature_common_effects" ;
            u_common_btemps:units = "K" ;
            u_common_btemps:description = "Uncertainty of the TOA brightness temperature.
Contains all considered common effects of uncertainty." ;
            u_common_btemps:coordinates = "latitude longitude" ;
   float warmnedt(y, channel) ;
            warmnedt:_FillValue = -999.f ;
            warmnedt:long_name = "warm target noise equivalent temperature difference" ;
            warmnedt:units = "mK" ;
            warmnedt:Reference_Temperature = "280K" ;
   float coldnedt(y, channel) ;
            coldnedt:_FillValue = -999.f ;
            coldnedt:long_name = "cold target noise equivalent temperature difference" ;
            coldnedt:units = "mK" ;
            coldnedt:Reference_Temperature = "280K" ;
   float time(y) ;
            time:_FillValue = -999.f ;
            time:long_name = "time" ;
            time:units = "seconds since 2016-06-02T13:43:25" ;
            time:calendar = "proleptic_gregorian" ;

// global attributes:
            :licence = "Copyright EUMETSAT / C3S 2019. Licensed under Copernicus data
                        policy.";
            :institution = "EUMETSAT" ;
            :title = "Microwave Humidity Sounder FCDR processed within the Copernicus
                      Climate Change Service" ;
            :title_short_name = "MicrowaveHumiditySounderFCDR" ;
            :keywords = "ATMOSPHERIC EMITTED RADIATION, OUTGOING LONGWAVE RADIATION,
                        BRIGHTNESS TEMPERATURE" ;
            :summary = "This dataset is produced within the Copernicus Climate Change Service.
                       The EUM_MW_HUM_SOUNDER_Reprocessing_Processor v1.0 is based on the
                       methodology developed in the EU FIDUCEO project." ;
            :conventions = "CF-1.6" ;
            :Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
            :data_format_type = "NetCDF4" ;
            :keyword_vocabulary = "ACDD - GCMD Science Keywords" ;
            :Standard_name_vocabulary = "CF-1.6, v58" ;
            :naming_authority = "EUMETSAT" ;
            :processing_software_version = "EUM_MW_HUM_SOUNDER_Reprocessing_Processor v1.0";
            :internal_git_commit_number =
            "GITLAB@EUMETSAT:USC_Climate/LEO/Microwave_Sounders/MicroWave_FCDR.git;
            Tag: V1.0_Release1" ;
            :centre = "GOVERNMENT AGENCIES-NON-US>GERMANY>DE/EUMETSAT>European Organisation
for the Exploitation of Meteorological Satellites" ;
            :creator_email = "USC Climate Team c/o EUMETSAT ops <ops@eumetsat.int>" ;
            :creator_name = "EUMETSAT" ;
            :creator_url = "http://www.eumetsat.int" ;
            :processing_centre = "EUMETSAT processing facility; CDR Production Environment";
            :processing_level = "L1C" ;
            :producer_agency = "EUMETSAT" ;
            :product_type = "Brightness temperature" ;
            :wmoinstrid = "203" ;
            :instrument_model = "1" ;
            :instrument_name = "MHS" ;
```

```
          :platform_long_name = "Earth Observation Satellites>METOP>METOP-A>Meteorological
                                  Operational Satellite - A" ;
          :platform_type = "spacecraft" ;
          :wmosatid = "4" ;
          :site = "NSS" ;
          :startorbit = "49921" ;
          :endorbit = "49923" ;
          :granule_name = "2395140183.NSS.MHSX.M2.D16154.S1320.E1500.B4992122.SV.gz,
                         2395190103.NSS.MHSX.M2.D16154.S1459.E1640.B4992223.SV.gz" ;
          :period = "101.4" ;
          :date_created = "2019-04-09T00:08:52Z" ;
          :temporal_coverage_start = "2016-06-02T13:43:25Z" ;
          :temporal_coverage_end = "2016-06-02T15:24:45Z" ;
          :geospatial_lat_min = -89.9557 ;
          :geospatial_lat_max = 89.8199 ;
          :geospatial_lon_min = -179.9408 ;
          :geospatial_lon_max = 179.9669 ;
          :wavenumber = "2.96872, 5.236956, 6.114597, 6.114597, 6.348092" ;
          :source = "NOAA/CLASS" ;
          :doi = "10.15770/EUM_SEC_CLM_0033" ;
          :no_scanlines = "2282" ;
          :band_correction_offset = "0, 0, 0, 0.0015, 0" ;
          :band_correction_slope = "1, 1, 1, 1.00025, 1" ;
          :history = "Compared to the first version we have: (1) included the non-183GHZ
           BTs, if available (source are operational L1C data files; except MHS; for ATMS
          until 08.03.2017 SDR files reprocessed by NOAA are used); (2) added the NEDT from
          the same source as the BTs; (3) updated the Azimuth angle; (3) included the
          variable attribute valid_range" ;
}
```

Appendix B Measurement Datasets

Table 6: Measurement data sets in the NetCDF files of the C3S Microwave Humidity Sounder FCDRs. Scanline number is denoted by *y*, scan position is denoted by *x*, and channel number is denoted by *channel*.

Measurement data set	Long name
latitude	latitude (in degrees north) [y,x]
longitude	longitude (in degrees east) [y,x]
btemps	toa brightness temperature in Kelvin [channel, y, x]
satellite_azimuth_angle	sensor_azimuth_angle [y,x]
satellite_zenith_angle	sensor_zenith_angle [y,x]
solar_azimuth_angle	solar_azimuth_angle [y,x]
solar_zenith_angle	solar_zenith_angle [y,x]
u_independent_btemps	uncertainty_of_toa_brightness_temperature_independent_effects (in Kelvin)[channel, y, x]
u_structured_btemps	uncertainty_of_toa_brightness_temperature_structured_effects (in Kelvin) [channel, y, x]
u_common_btemps	uncertainty_of_toa_brightness_temperature_common_effects (in kelvin) [channel, y, x]
warmnedt	warm target noise equivalent temperature difference [y, channel]
coldnedt	cold target noise equivalent temperature difference [y, channel]
instrtemp	instrument_temperature [y, x]
quality_issue_pixel_bitmask	bitmask for quality issues per pixel and channel [channel, y, x]
data_quality_bitmask	sensor specific bitmask for quality per pixel [y, x]
quality_pixel_bitmask	bitmask for quality per pixel [y, x]
quality_scanline_bitmask	Bitmask for quality per scanline [y, x]

Appendix C Global Attributes

Table 7: Global attributes of the NetCDF files of the C3S Microwave Humidity Sounder FCDRs.

Name	Value
licence	"Copyright EUMETSAT / C3S 2019. Licensed under Copernicus data policy."
institution	"EUMETSAT"
title	"Microwave Humidity Sounder FCDR processed within the Copernicus Climate Change Service"
title_short_name	"MicrowaveHumiditySounderFCDR"
doi	"10.15770/EUM_SEC_CLM_0033" MHS "10.15770/EUM_SEC_CLM_0034" ATMS "10.15770/EUM_SEC_CLM_0035" MWHS/1 and MWHS2
keywords	"ATMOSPHERIC EMITTED RADIATION, OUTGOING LONGWAVE RADIATION, BRIGHTNESS TEMPERATURE"
summary	"This dataset is produced within the Copernicus Climate Change Service. The EUM_MW_HUM_SOUNDER_Reprocessing_Processor v1.0 is based on the methodology developed in the EU FIDUCEO project."
Conventions	"CF-1.6"
Metadata_Conventions	"Unidata Dataset Discovery v1.0"
data_format_type	"NetCDF4"
keyword_vocabulary	"ACDD - GCMD Science Keywords"
Standard_name_vocabulary	"CF-1.6, v58"
naming_authority	"EUMETSAT"
processing_software_version	"EUM_MM_HUM_SOUNDER_Processor v1.0.0-beta";
internal_git_commit_number	" GITLAB@EUMETSAT: USC_Climate/LEO/Microwave_Sounders/MicroWave_FCDR.git; Tag: V1.0_Release1"
Centre	"GOVERNMENT AGENCIES-NON-US>GERMANY>DE/EUMETSAT>European Organisation for the Exploitation of Meteorological Satellites"
creator_email	"USC Climate Team c/o EUMETSAT ops <ops@eumetsat.int>"
creator_name	"EUMETSAT"
creator_url	"http://www.eumetsat.int"
processing_centre	"EUMETSAT processing facility; CDR Production Environment"
processing_level	"L1C"
producer_agency	"EUMETSAT"
product_type	"Brightness temperature"
wmoinstrid	See Table 4
instrument_model	This indicates the instrument version operating on the platform
instrument_name	"MHS" / "MWHS/1" / "MWHS/2" / "ATMS"
platform_long_name	e.g. "Earth Observation Satellites>METOP>METOP-A > Meteorological Operational Satellite - A"
platform_type	"spacecraft"
wmosatid	See Table 4
site	"NSS" / "NSMC" / not provided for ATMS
startorbit	Orbit number of the first observation in the dataset
endorbit	Orbit number of the last observation in the dataset
granule_name	List of input granule files to the dataset

Name	Value
scnlin	Number of scanlines in the file
misscnlin	Number of identified missing scanlines
period	Length of one orbit in minutes
date_created	e.g. „2019-02-01T18:20:16Z" (YYYY-MM-DDTHH:mm:SSZ)
temporal_coverage_start	e.g. „2010-12-31T08:03:29Z" (YYYY-MM-DDTHH:mm:SSZ)
temporal_coverage_end	e.g. „2010-12-31T09:44:49Z" (YYYY-MM-DDTHH:mm:SSZ)
geospatial_lat_min	e.g. -89.9387
geospatial_lat_max	e.g. 89.8446
geospatial_lon_min	e.g. -179.9989
geospatial_lon_max	e.g. 179.999
temprad_offset	Offset of the band correction coefficient
temprad_slope	Slope of the band correction coefficient
wavenumber	e.g. "2.96872, 5.236956, 6.114597, 6.114597, 6.348092"
source	"NOAA/CLASS" / "CMA/NSMC/FengYun Satellite Data Center" / "NASA/GES_DISC"
processing_software_version	"EUM_MW_HUM_SOUNDER_Reprocessing_Processor v1.0"

Appendix D Quality Flags

Table 8 Meaning of the applied FIDUCEO [RD 5] quality flags.

Quality flag	Bit	Flag Name	Description
quality_issue_pixel_bitmask	**informs on issues with the calibration and earth view pixel counts**		
quality_issue_pixel_bitmask	1	susp_calib_DSV	Bad DSV data, adjacent scanlines had to be used for calibration; or less than 4 DSV could be used for calibration. This includes the case of partial moon contamination; or less than 7 scanlines have been used to get the weighted average of the current one. None of those issues impacts the final calibration significantly
quality_issue_pixel_bitmask	2	susp_calib_OBCT	Bad OBCT data for this scanline. Adjacent scanlines had to be used for calibration; or less than 4 OBCT views could be used for calibration; or less than 7 scanlines have been used to get the weighted average of the current one. None of those issues impacts the final calibration significantly.
Quality_issue_pixel_bitmask	4	no_calib_bad_DSV	Bad DSV data for this scanline. Too far away from good scanlines. Calibration impossible.
Quality_issue_pixel_bitmask	8	no_calib_bad_OBCT	Bad OBCT data for this scanline. Too far away from good scanlines. Calibration impossible.
Quality_issue_pixel_bitmask	16	bad_data_earthview	Bad data from Earth views.
Data_quality_bitmask	**informs on issues with the calibration targets**		
data_quality_bitmask	1	moon_check_fails	The check for moon intrusion failed. Hence no valid DSV data. If set, "invalid_input" is also set.
Data_quality_bitmask	2	no_calib_bad_prt	All PRT measruements are bad. Usable data further away than 5 scan lines. Calibration impossible. If set, "sensor_error" is also set.
Data_quality_bitmask	4	no_calib_moon_intrusion	Moon intrusion detected. Moon contaminates all four DSV. If set, "sensor_error" and "invalid_input" is also set.
Data_quality_bitmask	8	susp_calib_bb_temp	Less than the full number of PRT sensors has been used for calibration. An unaccounted for temperature gradient might be missed. If set, "use_with_caution" is also set.
Data_quality_bitmask	16	susp_calib_prt	PRT data from adjacent scan lines had to be used; or less than the full number of PRT sensors has been used for calibration; or fewer scan lines have been used to get the weighted average of the current one. None of those issues impacts the final calibration significantly.
Data_quality_bitmask	32	susp_calib_moon_intrusion	Moon intrusion detected. At least one DSV could be used for calibration. If set, "use_with_caution" is also set.
Quality_pixel_bitmask	**informs on issues with the geolocation and input data**		
quality_pixel_bitmask	1	invalid	General flag for invalid data. Set to TRUE if any of the following is set: invalid_input, invalid_geoloc, invalid_time, sensor_error, padded_data or any sensor specific flag that indicates invalid data.
Quality_pixel_bitmask	2	use_with_caution	Input data flags set that indicate potential errors. Set to TRUE if one or more of the original sensor data flags indicate possible (but usually not critical) problems or if data in a single channel is not useable. Definition of this flag combination in sensor specific section.

Quality flag	Bit	Flag Name	Description
Quality_pixel_bitmask	4	invalid_input	Input data invalid flag. Set to TRUE if a combination of the original sensor data flags indicates unuseable data. Definition of this flag combination in sensor specific section.
Quality_pixel_bitmask	8	invalid_geoloc	Flag is raised if the geolocation or viewing-geometry data of this pixel is not valid.
Quality_pixel_bitmask	16	invalid_time	Flag is raised if the acquisition time data of the pixel is not valid.
Quality_pixel_bitmask	32	sensor_error	Flag is raised if the measurement data or sensor status data is not valid.
Quality_pixel_bitmask	64	padded_data	Pixel contains fill value or repeated data; the corresponding measurement data is stored in the previous/next orbit file. Usually this data originates from correlation-calculations overlapping orbit-file boundaries.
Quality_pixel_bitmask	128	incomplete_channel_data	Flag is raised if data for one or more channels is incomplete.
Quality_scanline_bitmask	**informs on issues with the transmission of the data**		
quality_scanline_bitmask	1	STX1_transmitter_on	STX1 transmitter is on. Might cause Radio Frequency Interference. Uncertainty component u_common is increased.
Quality_scanline_bitmask	2	STX2_transmitter_on	STX2 transmitter is on. Might cause Radio Frequency Interference. Uncertainty component u_common is increased.
Quality_scanline_bitmask	4	STX3_transmitter_on	STX3 transmitter is on. Might cause Radio Frequency Interference. Uncertainty component u_common is increased.
Quality_scanline_bitmask	8	STX4_transmitter_on	STX4 transmitter is on. Might cause Radio Frequency Interference. Uncertainty component u_common is increased.
Quality_scanline_bitmask	16	SARR_A_transmitter_on	SARR_A transmitter is on. Might cause Radio Frequency Interference. Uncertainty component u_common is increased.
Quality_scanline_bitmask	32	SARR_B_transmitter_on	SARR_B transmitter is on. Might cause Radio Frequency Interference. Uncertainty component u_common is increased.

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