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Product User Guide

Fundamental Climate Data Record of Microwave Humidity Sounder SSM/T-2 Release 2

Issued by:	EUMETSAT
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Product User Guide

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List of Abbreviations

ACDD	Attribute Convention on Data Discovery
ATBD	Algorithm Theoretical Basis Document
C3S	Copernicus Climate Change Service
CDS	Climate Data Store
CF	Climate and Forecast
CM-SAF	Climate Monitoring Satellite Application Facility
DOI	Digital Object Identifier
ECMWF	European Centre for Medium-range Weather Forecast
ERA5	ECMWF ReAnalysis 5
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record
FIDUCEO	Fidelity and uncertainty in climate data records from Earth Observations
GLOB	Glare obstruction bracket
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite data
IFOV	Instantaneous Field-Of-View
NEDT	Noise Equivalent Delta Temperature
SSM/I	Special Sensor Microwave/Imager
SSM/T-2	Special Sensor Microwave-Humidity
TWP	Total water path
WVP	Water vapour path

1 INTRODUCTION

1.1 Purpose and Scope

Within the optional Task 7.5 in C3S_311b [AD1], EUMETSAT provides Fundamental Climate Data Records (FCDRs) of level 1c antenna temperatures from Special Sensor Microwave Humidity Sounder (SSM/T-2 [RD 1]). Data in the FCDR are antenna temperatures, and not brightness temperatures that would have been obtained after correction for the antenna pattern, because the antenna pattern for the SSM/T-2 instruments is unknown. The FCDR cover the period July 1994 until December 2004.

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 [RD 2];
- Quality Evaluation Report, which provides information on the accuracy, precision, and stability of the product [RD 3];
- 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 access informs on the data ordering
Section 6 Product support and feedback
Section 7 Product referencing
Section 8 Acknowledgements
Appendix Metadata NetCDF File

1.3 Applicable documents

AD1.	C3S_311b Implementation Plan 2020 EUMETSAT-D9.3_v2, EUM/OPS/PLN/19/1065006

1.4 Reference Documents

RD 1.	Galin, I., D.H. Brest, and G.R. Martner, 1993: The DMSP SSM/T-2 microwave water-vapor profiler. SPIE Proc. 1935, 189-198, doi:10.1117/12.152603.
RD 2.	T. Hanschmann, V. O. John, P. Poli, M. Grant, and Jörg Schulz, 2020: Algorithm Theoretical Basis Document (ATBD) - Fundamental Climate Data Record of Microwave Humidity Sounder SSM/T-2 Release 2, Copernicus Climate Change Service, Task 7.5, Deliverable 7.8.
RD 3.	Poli, P., T. Hanschmann, V. O. John, M. Grant, and Jörg Schulz, 2020: Quality Evaluation Report - Fundamental Climate Data Record of Microwave Humidity Sounder SSM/T-2 Release 2, Copernicus Climate Change Service, Task 7.5, Deliverable 7.8.
RD 4.	FIDUCEO project description: https://research.reading.ac.uk/fiduceo
RD 5.	Andersson, A., K. Fennig, C. Klepp, S. Bakan, H. Graßl, and J. Schulz, 2010: The Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data – HOAPS-3. Earth Syst. Sci. Data, 2, 215-234, doi:10.5194/essd-2-215-2010. DOI: 10.5676/EUM_SAF_CM/HOAPS/V002
RD 6.	Hans, I. M. Burgdorf, and E. Woolliams, 2019b: Product user guide – Microwave FCDR release 4.1. Technical Report. FIDUCEO project. http://cedadocs.ceda.ac.uk/1415/
RD 7.	Buehler, S. A., Kuvatov, M., Sreerekha, T. R., John, V. O., Rydberg, B., Eriksson, P., and Notholt, J.: A cloud filtering method for microwave upper tropospheric humidity measurements, Atmos. Chem. Phys., 7, 5531–5542, https://doi.org/10.5194/acp-7-5531-2007, 2007.
RD 8.	EUMETSAT Data Policy (link to pdf, assessed on 4 June 2019)
RD 9.	WMO (2017): "Manual on Codes", Vol I.2, WMO No. 306
RD 10.	WMO Data processing levels, http://www.wmo.int/pages/prog/sat/dataandproducts_en.php (assessed on 25.06.2019)

2 BACKGROUND

Within the EU project FIDelity and Uncertainty in Climate data records from Earth Observations (FIDUCEO) [RD 4] a first release of the SSM/T-2 microwave humidity sounder data record has been prepared by University of Hamburg, Germany and is already available from EUMETSAT. The second release presented here incorporates additional meteorological and quality information. This includes rain, water vapour path, total water path, surface type, and cloud and surface flags based on retrievals using Special Sensor Microwave/Imager (SSM/I) measurements, which were flown together with the SSM/T-2 instruments. These retrievals were materialised as part of the Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite data record (HOAPS) [RD 5], produced by EUMETSAT CM-SAF.

The product user guide of the FCDR Release 1 [RD 6] contains a detailed description on how to use the antenna temperatures and their metrologically traceable uncertainties. As those parameters are unchanged in the second release, we are not repeating the information available in [RD 6] here and only provide a description of the use of the added parameters.

3 PRODUCT DEFINITION

In this section, an overview on the SSM/T-2 FCDR 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 FCDR consists of measurements from four SSM/T-2 instruments which is a 5-channel microwave sounder mounted on DMSP satellites F11, F12, F14, and F15 [RD 1]. The instrument scans the surface across-track (28 pixels), and features a resolution of 48 to 88 km at nadir, depending on the channel frequency. The instrument operates five channels, the two channels at 91.665 GHz and 150 GHz are sensitive to the surface, but can also be affected by clouds of liquid water or ice, and rainfall. The essential value of this instrument for climate monitoring lies in the three other channels. These channels are positioned in the 183 GHz water band, at 183.31±1.0 GHz, 183.31±3.0 GHz, and 183.31±7.0 GHz (Table 1). These channels are double-sideband symmetric about the water vapour line. Their data provide information about the distribution of water vapour in the troposphere, which is an important climate variable due its capability to absorb the outgoing longwave radiation. The channel closest to the centre of the line is sensitive to upper-tropospheric humidity, and the other two channels are gradually more sensitive to humidity located lower in the troposphere. Available records for this instrument start in 1994, and end in 2005.

Table 1: SSM/T-2 channel characteristics.

FCDR channel number	RTTOV channel number	Channel frequency [GHz]	Instantaneous Field-Of-View (IFOV) size at nadir [km]	NEDT (K)	Nominal polarization orientation at nadir
4	1	91.655 ± 1.25	88	0.6	Horizontal
5	2	150.00 ± 1.25	54	0.6	Horizontal
2	3	183.31 ± 1.00	48	0.8	Horizontal
1	4	183.31 ± 3.00	48	0.6	Horizontal
3	5	183.31 ± 7.00	48	0.6	Horizontal

3.2 File Specifications

Data files 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 SSM/T-2 FCDR in NetCDF format.

Naming convention C3S_FCDR_<level>_<instr>_<sat>_<start_time>_<end_time>_<release>.nc **Example name** C3S_FCDR_L1C_SSMT2_F11_19941101224433_19941102002553_R02.0.nc

where:

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

<inst> instrument name (e.g., SSMT2)

<sat> satellite name (e.g., F11)

<start_time> sensing start time (e.g., 19941231094452)

<end_time> timestamp characterizing sensing end time

<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 3 MB. The approximate size of the complete instruments FCDRs is about 170 Giga Byte. Table 3 provides the data volumes per year and per satellite in GB.

Table 3: Size in GB of the SSM/T-2 FCDR Release 2 in NetCDF4 format.

Sat-ellite	*Instr.*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*Total*
F11	SSM/T-2	4.4	2.3											**6.7**
F12	SSM/T-2	0.6	1.4	6.9	8.0	9.6	8.7	0.7	0.1					**35.6**
F14	SSM/T-2				8.9	13.3	12.9	11.3	14.1	11.7	4.8	6.8	0.4	**83.8**
F15	SSM/T-2							10.7	14.9	10.4	5.2	3.3	1.0	**44.6**
Total		**5.0**	**3.7**	**6.9**	**16.8**	**22.9**	**21.5**	**22.5**	**28.9**	**22.0**	**10.0**	**10.3**	**0.5**	**170.5**

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 FCDR files contain information on the Earth view observed antenna temperature (the variable in the data file is still called "tb" refers to brightness temperature. This is to have a consistency naming convention for all the microwave humidity sounding

FCDRs) with their associated uncertainties, and metadata, such as geolocation, and quality control variables, all unchanged from the Release 1 of FCDR (except for additional flagging of contaminated pixels due to an on-board glare obstruction bracket). In addition, Release 2 includes collocated information on rain, total water path, water vapour path, surface type, and channel dependent cloud flags based on rain and total water path. Satellite zenith and azimuth angles are also added.

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.

Metadata conventions

Metadata follow the CF (Climate and Forecast) convention and the Attribute Convention on Data Discovery (ACDD). Each variable is defined with the attributes standard name, units, and fill_value. The attribute ancillary_variables links other datasets, e.g. the uncertainty, to the file containing the antenna 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.

Measurement Datasets

The level 1C NetCDF files comprise of 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.

Geophysical Data and Flags

This category includes rain, total water path, water vapour path, and surface type from HOAPS, as well as a channel-dependent cloud flag (based on rain and total water path from the HOAPS dataset). This flag is called ‘cloud_flag’; if non-zero (and non-missing), cloud and rain may affect the quality of the antenna temperature.

Quality Flags

On top of the quality flags available in the FCDR Release 1, Release 2 includes a flag indicating scan positions for which Earth views are believed to be affected by the glare obstruction bracket (GLOB) on board the satellite. This flag is the bit number 5 (‘bad_data_earthview’) of ‘quality_issue_pixel_bitmask’; if non-zero, the GLOB may affect the quality of the antenna temperature.

4 PRODUCT FEATURES

This section provides an overview of the scientific data available in the FCDR. The subsections inform on the spatial and temporal characteristics, summarises the validation results, and express the applicability including known limitations and issues.

4.1 Spatial and Temporal Characteristics

The satellites, on which the instruments are operating, fly in a polar, sun-synchronous orbit with about 14.2 orbits per day. Each orbit can be separated in two nodes, the ascending, mostly observing at night-time, and the descending node, mostly observing at day-time. Each data file covers one satellite orbit, from equator going southwards back to the equator. The spatial coverage over 24 hours is nearly global as shown in Figure 1.

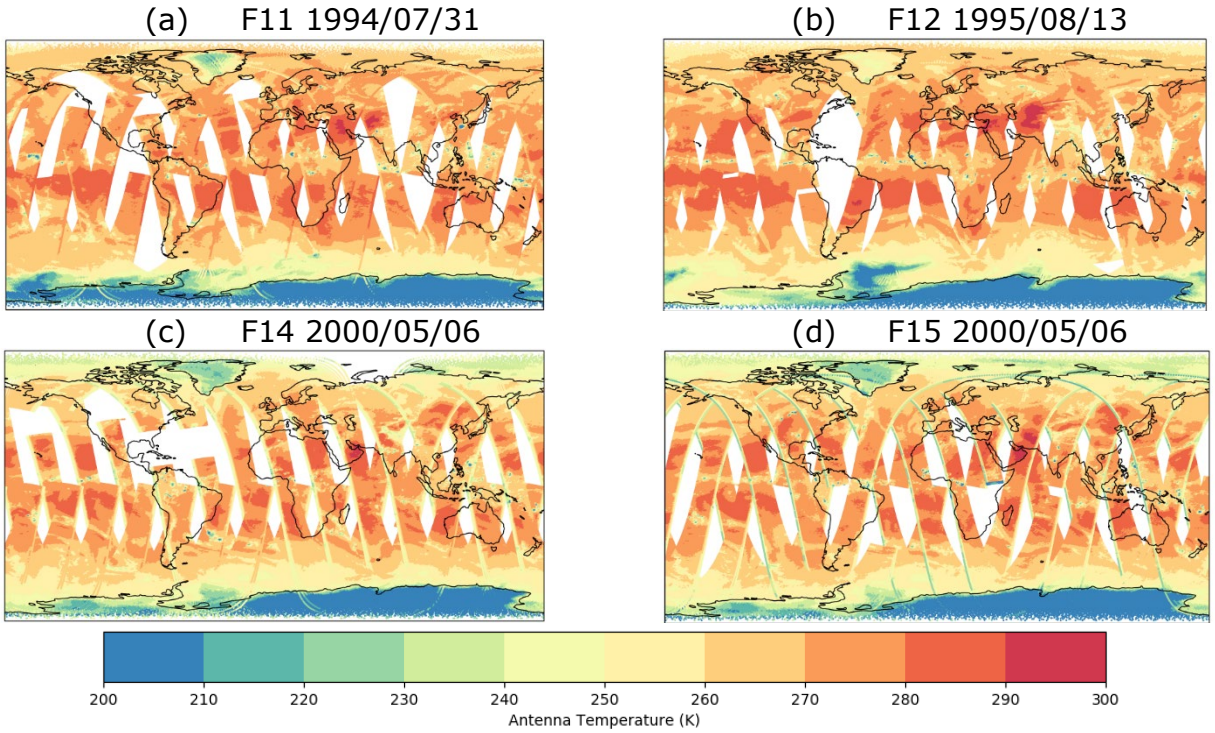

Figure 1 Spatial coverage of the individual instruments over 24 hours, for the antenna temperature at 183.31 ± 7 GHz. Note the first row shows different dates, but the bottom row shows identical dates.

4.2 Additional parameters included

As described in detail in [RD 2] SSM/T-2 measurements were collocated with HOAPS data to assist users with exploitation of the antenna temperature data contained in the FCDR. The following subsections provide details on the added parameters.

4.2.1 Surface Type

The HOAPS data provides surface classifications for SSM/I pixels as shown in Table 4. Surface type can be very useful, for example, for assigning appropriate surface

emissivity values in radiative transfer simulations. Figure 2 shows an example for surface classifications.

Table 4: Surface type classification in HOAPS

Surface type value	Surface type meaning
0	Water
1	Land
2	Coast
3	Coast2
11	Sea-ice
12	Sea-ice edge

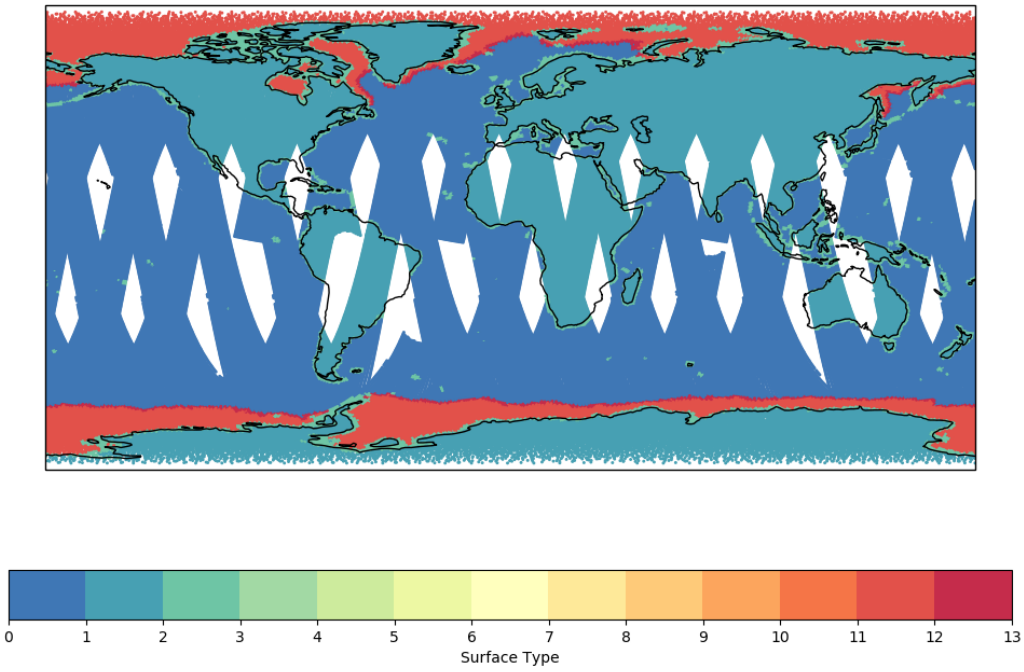

Figure 2: Surface type information contained in the SSM/T-2 FCDR, collocated from HOAPS, for an entire day of data (DMSP F15 on 2000/05/06).

4.2.2 Precipitation

HOAPS utilises a neural network algorithm to determine precipitation rate from SSM/I brightness temperatures. The basic principle behind the retrieval is that emission and scattering of cloud and rain particles increases brightness temperature at low frequencies and decreases brightness temperature at high frequencies relative to the radiometrically cold sea surface. The retrievals are only performed for measurements over ice-free ocean surface, an example is shown in Figure 3. The precipitation information is used for deriving cloud flags.

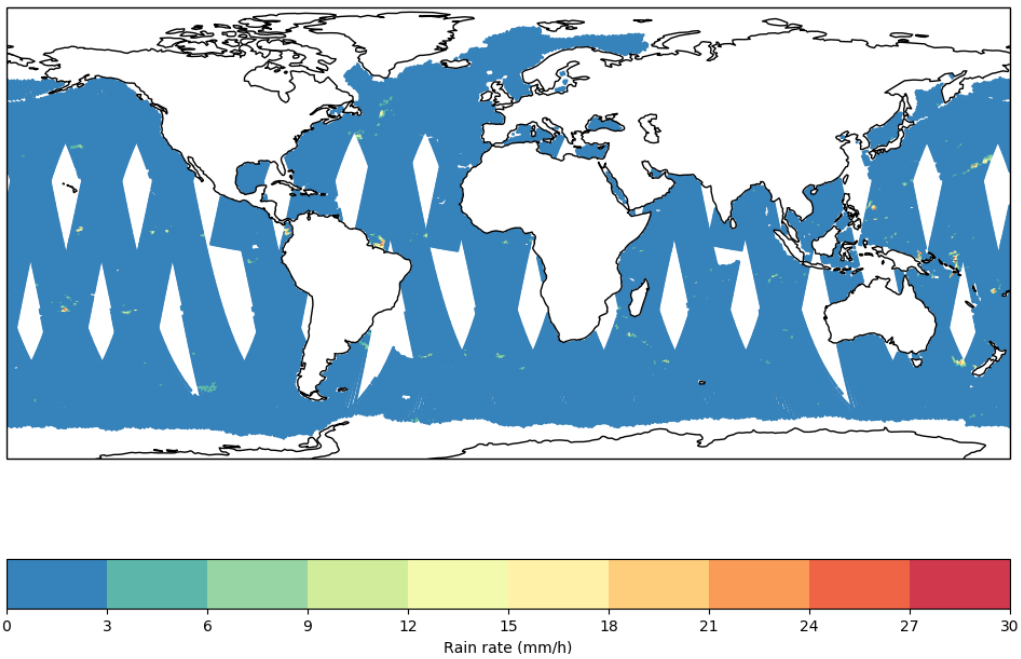

Figure 3: Precipitation estimate contained in the SSM/T-2 FCDR collocated from HOAPS, for the same data files as shown in previous figure.

4.2.3 Total Water path

The HOAPS Total Water Path (TWP) is the sum of liquid and ice water path in the atmosphere, and thus represents liquid and ice clouds. Its validation is inherently difficult, and this parameter is only used here to help detect cloud occurrence. An example of the geographic distribution of TWP is shown in Figure 4. TWP is also used for the derivation of cloud flags.

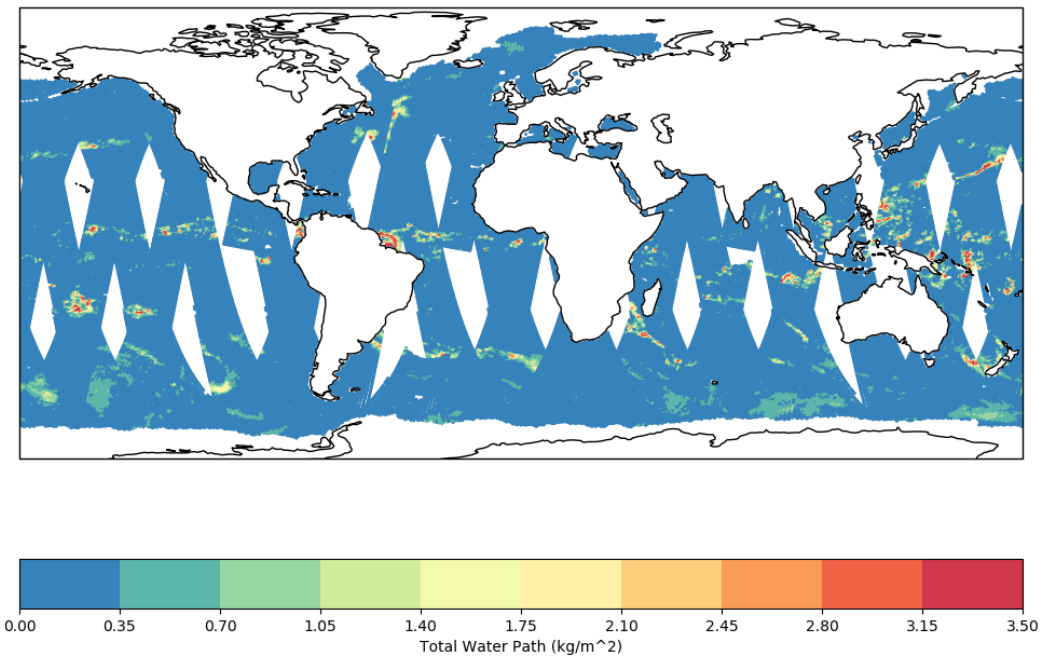

Figure 4: Total water path information contained in the SSM/T-2 FCDR, collocated from HOAPS, for the same data files as shown in previous figure.

4.2.4 Water Vapour Path

Water Vapour Path (WVP) is the column-integrated water vapour in the atmosphere that is retrieved using a 1D-Var method. Figure 5 shows an example of the geographic distribution of WVP. As expected, the tropical areas show higher values of WVP compared to the mid-latitudes. WVP is not used further in deriving any flags. However, users will be able to identify dry atmospheres using this variable. In dry conditions, water vapour sounding channels can be contaminated by a signal from the surface and such measurements could be filtered out using WVP thresholds as shown in [RD 7].

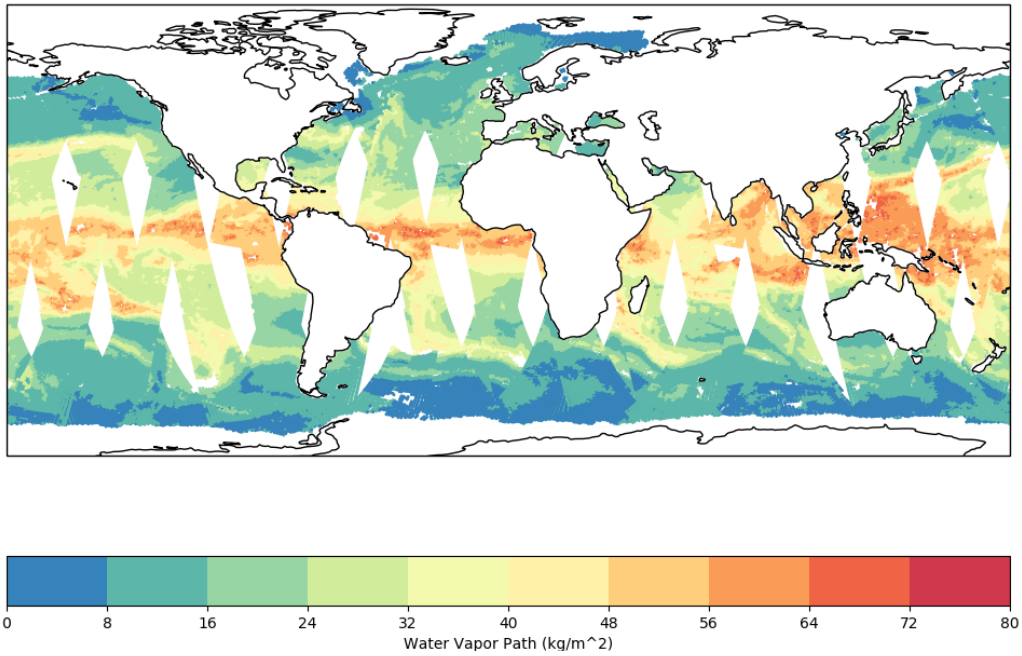

Figure 5: Water vapour path contained in the SSM/T-2 FCDR, for the same data files as shown in previous figure.

4.2.5 Cloud Flag

The cloud flag is derived based on thresholds, which were defined according to the sensitivity study results described in [RD 2]. These thresholds are reminded here for completeness.

Table 5 shows the channel dependent thresholds for rain rate and TWP for a pixel to qualify as cloud contaminated. The thresholds are derived based on departures of the clear-sky simulations from the observations.

Table 5: Threshold applied to the rain rate and the TWP to identify cloud-contaminated measurements.

Channel frequency [GHz]	Rain rate threshold [mm/h]	TWP threshold [kg/m2]
91.655 ± 1.25	4.5	0.15
150.00 ± 1.25	0	0.25
183.31 ± 1.00	1.5	1.2
183.31 ± 3.00	0.5	0.3
183.31 ± 7.00	0	0.2

Rain, liquid, and ice water can cause scattering of the microwave radiation, depending on their particle size and the measured frequency. Whenever a collocated SSM/I rain rate or TWP value exceeds the threshold, the corresponding SSM/T-2 measurement is flagged as cloudy.

If the channel-dependent cloud flag is non-zero (and non-missing), indicates that cloud and/or rain may affect the quality of the antenna temperature.

4.3 Quality Evaluation and Known Issues

Results of the validation work and known issues are presented in the Quality Evaluation Report [RD 3].

Known limitations of this FCDR Release 2 include:

- (Unchanged from Release 1) Data in the FCDR are antenna temperatures, and not brightness temperatures that would have been obtained after correction for the antenna pattern, because the antenna pattern for the SSM/T-2 instruments is unknown.
- (Unchanged from Release 1) Satellite F11, channel 5 (150 GHz) measurements were not valid and are hence missing in the FCDR.
- (Unchanged from Release 1) Spectral response function information (frequencies and weights) is missing in the FCDR because specific details of the instrument characteristics are not known.
- (Unchanged from Release 1) Quality scanline bitmask is not set in the FCDR, because there was no particular reason to discard single scanlines in the processing beyond the reasons for flagging bad data using the other quality information elements.
- The HOAPS retrievals and the corresponding cloud/surfa flags are only available over ice-free ocean.

4.4 Applicability

The SSM/T-2 FCDR provides antenna 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.

A recommended set of quality flags to be applied by users when exploiting the data is presented in the Quality Evaluation Report [RD 3], section 5.3.3.a. In section 5.3.3.b, additional application criteria are recommended for users interested in exploiting data only from scenes that are not contaminated by rain and clouds.

In general, the prime application areas for the SSM/T-2 antenna temperature data are:

1. The assimilation into Numerical Weather Prediction models and for global reanalysis. The data might be too large scale to have any (further) impact on regional reanalysis (after assimilation into a global reanalysis);
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 or comparison with climate model simulations. Data series may be too short for trend analysis alone, although the

stability of the antenna temperature record is found to be good enough. In any case, the propagated instrument uncertainty and retrieval uncertainty should be propagated into trend computations.

5 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 8]. 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 to EUMETSAT's helpdesk (*ops@eumetsat.int*).

5.1 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.

5.2 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_0050

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

6 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.*

7 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.

8 ACKNOWLEDGEMETS

We acknowledge EUMETSAT Climate Monitoring Satellite Application Facility (CM SAF) for providing the HOAPS dataset.

Appendix A Metadata netCDF File

```
netcdf C3S FCDR L1C SSMT2 F14 20050105064508 20050105075456 R02.0 {
dimensions:
            y = UNLIMITED ; // (526 currently)
            x = 28 ;
            channel = 5 ;
            delta_y = 7 ;
            delta x = 90 ;
            string16 = 16 ;
variables:
            float latitude(y, x) ;
                        latitude:_FillValue = -999.f ;
                        latitude:standard name = "latitude" ;
                        latitude:long name = "latitude" ;
                        latitude:units = "degree north" ;
                        latitude:description = "Latitude for each pixel in every scanline." ;
                        latitude:valid_range = -90L, 90L ;
            float longitude(y, x) ;
                        longitude: FillValue = -999.f ;
                        longitude:standard name = "longitude" ;
                        longitude:long name = "longitude" ;
                        longitude:units = "degree east" ;
                        longitude:description = "Longitude for each pixel in every scanline." ;
                        longitude:valid_range = -180L, 180L ;
            ushort quality pixel bitmask(y, x) ;
                        quality pixel bitmask: FillValue = 255US ;
                        quality pixel bitmask:standard name = "status flag" ;
                        quality pixel bitmask:long name = "Bitmask for quality per pixel" ;
                        quality_pixel_bitmask:flag_masks = 1US, 2US, 4US, 8US, 16US, 32US, 64US, 128US
            ;
                        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:coordinates = "latitude longitude" ;
            ushort data quality bitmask(y, x) ;
                        data_quality_bitmask:_FillValue = 255US ;
                        data quality bitmask:standard name = "status flag" ;
                        data quality bitmask:long name = "Sensor specific bitmask for quality per
            pixel" ;
                        data quality bitmask:flag masks = 1US, 2US, 4US, 8US, 16US, 32US ;
                        data_quality_bitmask:flag_meanings = "N/A no_calib_bad_prt N/A
            susp_calib_bb_temp susp_calib_prt N/A " ;
                        data quality bitmask:coordinates = "latitude longitude" ;
            ubyte quality scanline bitmask(y) ;
                        quality scanline bitmask: FillValue = 255UB ;
                        quality scanline bitmask:standard name = "status flag" ;
                        quality_scanline_bitmask:long_name = "Bitmask for quality per scanline" ;
                        quality_scanline_bitmask:flag_masks = 1UB, 2UB, 4UB, 8UB, 16UB, 32UB ;
                        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" ;
            short scanline origl1b(y) ;
                        scanline_origl1b:_FillValue = -32768s ;
                        scanline_origl1b:long_name = "Original_Scan_line_number" ;
                        scanline origl1b:description = "Original scan line numbers from corresponding
            l1b records." ;
            ubyte scanline map to origl1bfile(y) ;
                        scanline map to origl1bfile: FillValue = 255UB ;
                        scanline_map_to_origl1bfile:long_name = "Indicator of original file" ;
                        scanline_map_to_origl1bfile:description = "Indicator for mapping each line to
            its corresponding original level 1b file.\\nSee global attribute \"source\" for the
            filenames. 0 corresponds to 1st listed file, 1 to 2nd file." ;
            float channel correlation matrix independent(channel, channel) ;
                        channel_correlation_matrix_independent:_FillValue = -999.f ;
                        channel_correlation_matrix_independent:long_name =
            "Channel error correlation matrix independent effects" ;
                        channel correlation matrix independent:units = "1" ;
                        channel correlation matrix independent:description = "Cross-Channel error
            correlation matrix for independent effects. " ;
            float channel_correlation_matrix_structured(channel, channel) ;
                        channel_correlation_matrix_structured:_FillValue = -999.f ;
```

```
            channel correlation matrix structured:long name                                =
"Channel error correlation matrix structured effects" ;
            channel_correlation_matrix_structured:units = "1" ;
            channel correlation matrix structured:description   =   "Cross-Channel   error
correlation matrix for structured effects. " ;
float channel correlation matrix common(channel, channel) ;
            channel correlation matrix common: FillValue = -999.f ;
            channel_correlation_matrix_common:long_name                                    =
"Channel error correlation matrix common effects" ;
            channel correlation matrix common:units = "1" ;
            channel correlation matrix common:description    =    "Cross-Channel    error
correlation matrix for common effects." ;
float cross line correlation coefficients(delta y, channel) ;
            cross_line_correlation_coefficients:_FillValue = -999.f ;
            cross line correlation coefficients:long name                                  =
"cross line correlation coefficients" ;
            cross line correlation coefficients:units = "1" ;
            cross line correlation coefficients:description  =  "Correlation  coefficients
per channel for scanline correlation. Note that only the structured effects are taken into
account.  The  correlation  for  the  independent  effects  is  zero  by  definition  and  the
correlation for the common effects is 1 for all scan lines and orbits." ;
float cross element correlation coefficients(delta x, channel) ;
            cross element correlation coefficients: FillValue = -999.f ;
            cross element correlation coefficients:long name                               =
"cross element correlation coefficients" ;
            cross_element_correlation_coefficients:units = "1" ;
            cross element correlation coefficients:description = "Correlation coefficients
per channel for correlation within a scanline. Note that this is a rough estimation as
only the structured effects are taken into account. The correlation for the independent
effects  is  zero  by  definition  and  the  correlation  for  the  common  effects  is  probably
variable within one scan line." ;
float RAIN(y, x) ;
            RAIN: FillValue = -999.f ;
            RAIN:standard name = "lwe precipitation rate" ;
            RAIN:long name = "Rain Rate" ;
            RAIN:units = "mm/h" ;
            RAIN:source = "HOAPS4-S / CMSAF" ;
            string RAIN:comment = "A. Andersson, K. Fennig, C. Klepp, S. Bakan, H. Graßl,
and J. Schulz; Earth Syst. Sci. Data; 2010; Vol 2; 215-234" ;
            RAIN:coordinates = "latitude longitude" ;
float TWP(y, x) ;
            TWP: FillValue = -999.f ;
            TWP:standard_name = "atmosphere_cloud_condensed_water_content" ;
            TWP:long name = " Total Water Path" ;
            TWP:units = "kg/m^2" ;
            TWP:source = "HOAPS4-S / CMSAF" ;
            TWP:comment  =  "P.Bauer,P.Schluessel;  J.Geophys.Res.;  1993;  Vol  98;  No  D11;
20,737-20,759; formula 11" ;
            TWP:coordinates = "latitude longitude" ;
float WVP(y, x) ;
            WVP: FillValue = -999.f ;
            WVP:standard name = "atmosphere water vapor content" ;
            WVP:long name = "Water Vapor Path" ;
            WVP:units = "kg/m^2" ;
            WVP:source = "HOAPS4-S / CMSAF" ;
            WVP:comment = "1D-Var: Algorithm Theoretical Baseline Document HOAPS version
4.0; 2017" ;
            WVP:coordinates = "latitude longitude" ;
float SURFACE(y, x) ;
            SURFACE:_FillValue = -999.f ;
            SURFACE:long_name = "surface type" ;
            SURFACE:units = "1" ;
            SURFACE:source = "HOAPS4-S / CMSAF" ;
            SURFACE:flag meanings = "water land coast coast2 sea ice sea ice edge" ;
            SURFACE:flag masks = 0.f, 1.f, 2.f, 3.f, 11.f, 12.f ;
            SURFACE: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:long name = "sensor zenith angle" ;
            satellite zenith angle:units = "degree" ;
            satellite_zenith_angle:valid_range = 0L, 180L ;
            satellite_zenith_angle:coordinates = "latitude longitude" ;
float satellite_azimuth_angle(y, x) ;
```

```
                        satellite azimuth angle: FillValue = -999.f ;
                        satellite azimuth angle:standard name = "sensor azimuth angle" ;
                        satellite_azimuth_angle:long_name = "sensor azimuth angle" ;
                        satellite azimuth angle:units = "degree" ;
                        satellite azimuth angle:valid range = -180L, 180L ;
                        satellite azimuth angle:coordinates = "latitude longitude" ;
            double time(y) ;
                        time:_FillValue = -1. ;
                        time:long name = "time" ;
                        time:units = "seconds since 1970-01-01" ;
                        time:calendar = "proleptic gregorian" ;
            float tb(y, x, channel) ;
                        tb: FillValue = -999.f ;
                        tb:standard_name = "toa_brightness_temperature" ;
                        tb:units = "K" ;
                        tb:long name = "Brightness temperature of SSM/T2 F14" ;
                        tb:ancillary variables = "u independent tb u structured tb u common tb" ;
                        tb:channel frequency GHz  =  "183.31pm3,  183.31pm1,  183.31pm7,  91.665pm1.25,
            150.0pm1.25" ;
                        tb:coordinates = "latitude longitude" ;
            float cloud flag(y, x, channel) ;
                        cloud flag: FillValue = -999.f ;
                        cloud flag:units = "1" ;
                        cloud flag:long name = "cloud flag for SSM/T2 F14" ;
                        cloud flag:description = "the flag is based on the RAIN and TWP information
            from HOAPS4-S / CMSAF" ;
                        cloud flag:flag meanings = "clear cloud" ;
                        cloud flag:flag masks = 0.f, 1.f ;
                        cloud flag:coordinates = "latitude longitude" ;
            ubyte quality issue pixel bitmask(y, x, channel) ;
                        quality_issue_pixel_bitmask:_FillValue = 255UB ;
                        quality issue pixel bitmask:standard name = "status flag" ;
                        quality issue pixel bitmask:long name = "Bitmask for quality issues per pixel"
            ;
                        quality issue pixel bitmask:description = "the flag is based on the RAIN and
            TWP information from HOAPS4-S / CMSAF" ;
                        quality_issue_pixel_bitmask:flag_meanings  =  "susp_calib_DSV  susp_calib_IWCT
            no calib bad DSV no calib bad IWCT bad data earthview" ;
                        quality issue pixel bitmask:flag masks = 1UB, 2UB, 4UB, 8UB, 16UB ;
                        quality issue pixel bitmask:coordinates = "latitude longitude" ;
            float u independent tb(y, x, channel) ;
                        u independent tb: FillValue = -999.f ;
                        u_independent_tb:long_name  =  "independent  uncertainty  of  toa  brightness
            temperature" ;
                        u independent tb:units = "K" ;
                        u independent tb:description = "Uncertainty of the TOA brightness temperature.
            Contains all considered independent effects of uncertainty." ;
                        u independent tb:coordinates = "latitude longitude" ;
            float u_structured_tb(y, x, channel) ;
                        u_structured_tb:_FillValue = -999.f ;
                        u structured tb:long name  =  "structured  uncertainty  of  toa  brightness
            temperature" ;
                        u structured tb:units = "K" ;
                        u_structured_tb:description = "Uncertainty of the TOA brightness temperature.
            Contains all considered structured effects of uncertainty." ;
                        u_structured_tb:coordinates = "latitude longitude" ;
            double u common tb(y, x, channel) ;
                        u common tb: FillValue = -999. ;
                        u common tb:long name = "common uncertainty of toa brightness temperature" ;
                        u_common_tb:units = "K" ;
                        u_common_tb:description  =  "Uncertainty  of  the  TOA  brightness  temperature.
            Contains all considered common effects of uncertainty." ;
                        u common tb:coordinates = "latitude longitude" ;
            char channel(channel, string16) ;
                        channel:unit = "GHz" ;
                        channel:long_name = "frequency" ;
                        channel:description = "pm is plus minus" ;

// global attributes:
                        : NCProperties = "version=1|netcdflibversion=4.6.1|hdf5libversion=1.10.2" ;
                        :Conventions = "CF-1.9" ;
                        :institution = "EUMETSAT" ;
                        :source           =           "NSS.SMT2.S8.D05005.S0545.E0717.B4002930.NS.gz
            NSS.SMT2.S8.D05005.S0721.E0906.B4003031.NS.gz " ;
```

```
                    :title = "SSM/T2 FCDR with added cloud flags based on collocated HOAPS4 data
          processed within the Copernicus Climate Change Service" ;
                    :history = "This data record is based on the FIDUCEO FCDR data (Release 1;
          doi:10.15770/EUM SEC CLM 0046). all quantities are unchanged, but reformatted. This version
          comprise several additional variables based on collocations to the CMSAF HOAPS dataset
          (Version 4; doi:10.5676/EUM SAF CM/HOAPS/V002)." ;
                    :licence = "Copyright EUMETSAT / C3S 2020. Licensed under Copernicus data
          policy." ;
                    :naming authority = "EUMETSAT" ;
                    :wmoinstrid = "907" ;
                    :doi = "10.15770/EUM SEC CLM 0050" ;
                    :wmosatid = "247" ;
                    :Metadata Conventions = "Unidata Dataset Discovery v1.0" ;
                    :data_format_type = "NetCDF4" ;
                    :keyword vocabulary = "ACDD - GCMD Science Keywords" ;
                    :Standard name vocabulary = "CF-1.9 v74" ;
                    :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" ;
                    :platform type = "spacecraft" ;
                    :band correction offset = "-0.00347, -0.00039, -0.01881, -0.00136, -0.00082" ;
                    :band correction slope = "1.00027, 1.00003, 1.00146, 1.00021, 1.00008" ;
                    :date created = "2020-09-12T12:48:31Z" ;
                    :temporal_coverage_start = "2005-01-05T06:45:08Z" ;
                    :temporal coverage end = "2005-01-05T07:54:56Z" ;
                    :geospatial lat min = -66.54f ;
                    :geospatial lat max = 88.32f ;
                    :geospatial lon min = -179.95f ;
                    :geospatial lon max = 180.05f ;
                    :title_short_name = "SSMT2_FCDR_incl_cloudflags" ;
                    :keywords  =  "ATMOSPHERIC  EMITTED  RADIATION,  OUTGOING  LONGWAVE  RADIATION,
          BRIGHTNESS TEMPERATURE" ;
                    :platform long name    =    "Earth    Observation    Satellites>DMSP    (Defense
          Meteorological Satellite Program)>DMSP 5D-2/F14>Defense Meteorological Satellite Program-
          F14" ;
                    :instrument_name = "SSM/T-2" ;
                    :site = "NSS" ;
                    :no scanlines = "526" ;
}
```

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]
tb	toa antenna temperature in Kelvin [channel, y, x]
satellite_azimuth_angle	sensor_azimuth_angle [y,x]
satellite_zenith_angle	sensor_zenith_angle [y,x]
u_independent_tb	uncertainty_of_toa_antenna_temperature_independent_effects (in Kelvin)[y, x, channel]
u_structured_tb	uncertainty_of_toa_antenna_temperature_structured_effects (in Kelvin) [y, x, channel]
u_common_tb	uncertainty_of_toa_antenna_temperature_common_effects (in kelvin) [y, x, channel]
warmnedt	warm target noise equivalent temperature difference [y, x]
coldnedt	cold target noise equivalent temperature difference [y, x]
instrtemp	instrument_temperature [y, x]
quality_issue_pixel_bitmask	bitmask for quality issues per pixel and channel [y, x, channel]
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]
cloud_flag	Cloud flag [y, x, channel]
SURFACE	Surface type [y, x]
WVP	Water Vapor Path [y, x]
RAIN	Rain rate [y, x]
TWP	Total Water Path [y, x]

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