Prepared by:

Christoph Reimer, TU Wien, Department of Geodesy and Geoinformation, Research Group Remote Sensing E120.1

Change register

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Document Approval

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Raffaele Crapolicchio

Digitally signed by Raffaele Crapolicchio
DN: email=raffaele.crapolicchio@serco.com,cn=Raffaele Crapolicchio,o=Serco spa,c=IT
Date: 2017.11.17 12:10:55 +0100
Signed with DigiSigner Free!

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1 Introduction

The Product User Manual (PUM) summarizes the product lineage and format of the ERS ESCAT surface soil moisture time series product. A general introduction of the purpose of the document followed by an overview of the surface soil moisture products concerned by this document are describe. An extensive description of the ESCAT instrument and Level 1 product processing is outlined in Section 2. The product lineage and description are discussed in section 3 and section 4, followed by information about product validation (section 5) and product availability in Section 6). References to technical reports and journal articles are summarized at the end of the document in Section 7.

In the framework of the SCIRoCCo project several soil moisture products, with different spatial resolution, format (e.g. time series, swath orbit geometry) are generated and distributed to users. A list of available soil moisture products, as well as other SCIRoCCo products (such as wind vector fields) can be looked up on the SCIRoCCo website [http://scirocco.sp.serco.eu/]. The following Table 1.1 gives an overview of the instances of soil moisture products related to this PUM.

ID	Product Name
ERS2-ASPS-N-SSM-Ts	ERS-2 ESCAT nominal resolution SSM time series (12.5 km sampling)
ERS2-ASPS-H-SSM-Ts	ERS-2 ESCAT high resolution SSM time series (12.5 km sampling)

Table 1.1: List of soil moisture products related to this PUM.

1.1 Scope

The Product User Manual (PUM) is intended to provide a detailed description of the main product characteristics, format, validation activities and availability.

The PUM contains:

- Product introduction: principle of sensing, satellites utilized, instrument(s) description, highlights of the algorithm, architecture of the products generation chain, product coverage and appearance
- Main product characteristics: Spatial resolution and sampling, observing cycle and time sampling
- Overview of the product validation activity: validation strategy, global statistics, product characterization
- Basic information on product availability: access modes, description of the code, description of the file structure

Although reasonably self-standing, the PUM's rely on other documents for further details [RD-1, RD-2].

Targeted audience

This document mainly targets:

1. Remote sensing experts interested in soil moisture from active microwave data sets.
2. Users of the remotely sensed soil moisture data sets.

1.2 Applicable and Reference Documents

Applicable Documents

The following documents are related to this document:

ID	Reference	Document Title	Issue	Date
AD-1				
AD-2				
AD-3				

Reference Documents

The following documents provide further reference information:

ID	Reference	Document Title	Issue	Date
RD-1	SCI-TNO-16-0044-v02	Algorithm Theoretical Baseline Document (ATBD)	v0.2	-
RD-2	SCI-RPT-16-0046-v02	Product Validation Report (PVR)	v0.2	-
RD-3	SCI-TNO-16-0045-v02	WARP 5 grid	v0.2	-

	unit	ERS-1	ERS-2
Repeat cycle	[orbits]	43 501 2411	501
	[days]	3 35 168	35
Orbits/day	-	14.333 14.314 14.351	14.314
Ground velocity	[km/s]	7	
LMT at ascending node	-	22:15	22:30
Spacecraft mass	[kg]	2384	2516
SCAT payload mass	[kg]	1100	

Table 2.1: ERS-1/2 mission parameter overview.

2 ESCAT on-board the European Remote Sensing Satellites

On 17 July 1991, ESA launched the first European Remote Sensing (ERS) satellite from the Kourou launch site in French Guiana [Vass et al., 1992]. ERS-1 was the major forerunner of the present European satellites for environmental monitoring, with development and predecessor studies dating back to the early seventies [ESA, 2013]. The ERS-1 payload carried an array of instruments for environmental monitoring of land, water, ice and atmosphere. The centrepiece of the ERS-1 payload was the Active Microwave Instrument (AMI), combining the functionality of a Synthetic Aperture Radar (SAR) and a wind scatterometer (ESCAT). Other instruments on-board were a Radar Altimeter, an Along-Track Scanning Radiometer, a Precise Range and Range-Rate equipment and a Laser Retro-Reflector. The system was designed for a nominal lifetime of 3 years, but it was not until March 2000, that ERS-1 mission ended after 9 years of excellent service due to a failure in the on-board attitude control system. Already on 21 April 1995 the follow-on mission ERS-2 was launched, equipped with an almost identical payload as ERS-1, but with an additional sensor on-board for atmospheric ozone research. In July 2011, after 16 years in space, ERS-2 was decommissioned and removed from its operational orbit, comprising, together with ERS-1, a scatterometer data archive of 20 years of Earth backscatter measurements. Both satellites were brought into an elliptical sun-synchronous orbit at approximately 785 km altitude and 98.5° inclination. Consequently, the nominal orbit period was approximately 100 minutes, with an ascending node (crossing of the Equator northwards) time of 22:15 local mean time (LMT) for ERS-1 and of 22:30 LMT for ERS-2 respectively. A standard orbit repeat cycle of 35 days was appointed for both satellites, supplemented with two additional repeat cycles of 3 and 168 days specifically dedicated to ERS-1. An overview of mission relevant parameters is given in Table 2.1.

2.1 Functional Description

As already mentioned, the Active Microwave Instrument (AMI) was the center-piece of the ERS payload. It was designed as a multi-mode RADAR, operating at a frequency of 5.3 GHz (C-band), by combining the functionality of a high resolution SAR and a low resolution wind scatterometer (ESCAT) [Attema, 1991]. AMI SAR operations were performed in two distinct modes: image and wave. In wind mode, AMI was configured as a wind scatterometer to provide backscatter measurements of the Earth's surface. The image and wind mode were mutually exclusive due to the high power consumption and data rate required for high resolution SAR image acquisition. Nevertheless, AMI could operate in a wind/wave mode, in which wind and wave mode were operated sequentially, enabling simultaneous characterization of the wind and wave fields over the oceans. Measurements in wind mode were acquired with three sideways looking, vertically polarized (VV) fan-beam antennas, one looking perpendicular to the right with respect to the satellite track (mid-beam), one looking forward at 45° angle (fore-beam) and one looking backward at 135° angle (aft-beam) illuminating a 500 km wide swath (see Figure 2.1). The transmitter unit of the scatterometer generated a rectangular radio frequency pulse with a duration of 130 μs for the fore- and aft-beam and of 70 μs for the mid-beam antenna. The three antennas were operated in sequences of 32 radio frequency pulses each, starting with the Fore-beam antenna. The pulse repetition frequency was chosen to be 98 Hz for the side antennas and 115 Hz for the mid antenna, resulting in a total repeat cycle length of 940.84 ms referred to as FMA sequence. Four FMA sequences last 3.763 s, which correspond to approximately 25 km along the ground track of the satellite. During each beam sequence of 32 pulses, 4 internal calibration pulses and 28 noise signals were measured [Lecomte, 1998]. The internal calibration pulse was a replica of the transmitted pulse fed into the receiver chain. The aim was to monitor the power of the transmitted pulse and the receiver gain to guarantee instrument stability during the mission, hence the term internal calibration. Noise measurements were necessary to account for thermal radiation superimposing the received echo signal to improve the signal-to-noise ratio. An analogue to digital converter (ADC) was used to sample the echo signal, the internal calibration pulses and the noise measurements at 30 kHz. A sampling of the received echo signal at 30 kHz corresponds to a across track resolution of approximately 32.4 km at 18° and 14 km at 45.5° incidence angle for the mid-beam.

	unit	ESCAT
Frequency	[GHz]	5.3
Wavelength	[cm]	5.66
Chirp rate	[kHz/ms]	-
Polarisation	-	VV
Peak Power Pulse	[W]	4800
Pulse Duration	[μs]	70 (mid) 130 (fore/aft)
PRF	[Hz]	115 (mid) 98 (fore/aft)
Incidence Angle	[deg]	18-47 (mid) 25-59 (fore/aft)
Antenna Angle	[deg]	45 (fore) 0 (mid) -45 (aft)
Swath width	[km]	500
Swath offset	[km]	200
Radiometric Res.	[%]	6.5 - 7.0

Table 2.2: Overview of ESCAT technical parameters.

2.2 Ground Processing

On-board tape recorders were used to store the sampled echo signals, the internal calibration pulses and the noise measurements after various on-board processing steps. These data packages were down-linked to ground stations for further on-ground processing, along with external data (orbit and attitude information) and characteristics of the instrument, in order to achieve the required system performance. In a first step, the signal is processed to improve the signal-to-noise ratio and to correct for transmitter and receiver chain fluctuations (internal calibration). Subsequently, the power echo samples were converted to the normalized radar cross section, σ^0, by utilizing predetermined normalization factors. The normalization factors were defined as the power at the input equal to a uniform reference backscatter coefficient of unity on the Earth's surface. These normalisation factors are a function of changing geometry along the orbit for a given antenna provided as Look-Up-Tables. In a further processing step, a spatial filter was applied to the σ^0 samples to increase the radiometric resolution and achieve the desired point target response along a grid of nodes, representing the entire swath. Calculation of the position of each node in the swath was based on the Mid-beam antenna. The central node position of the swath was determined at the intersection of the Mid-beam bore-sight direction with the Earth's surface. From this central node, more nodes are computed at every 25 km arc distance towards the near and far edge of the swath, along a perpendicular oriented line with respect to the satellite ground track. This is repeated after 4 FMA sequences, corresponding to an along track node interval of 25 km. Once the node positions within the swath were determined, the σ^0 samples located within a certain area around a node were averaged in along and across-track direction using a so-called Hamming function for each antenna beam. The aim of this function is to apply weights to various σ^0 samples, according to their distance to the regarded node. Ultimately, each node in the swath holds a σ^0 value of each antenna beam referred to as σ^0-triplet. This processing step is of major importance, due to the fact that it impacts the characteristic of the σ^0 values and particularly the final spatial resolution of the product. A detailed discussion about the on-ground processing steps of ERS-1/2 ESCAT data packages can be found in Lecomte [1998] and Neyt et al. [2002].

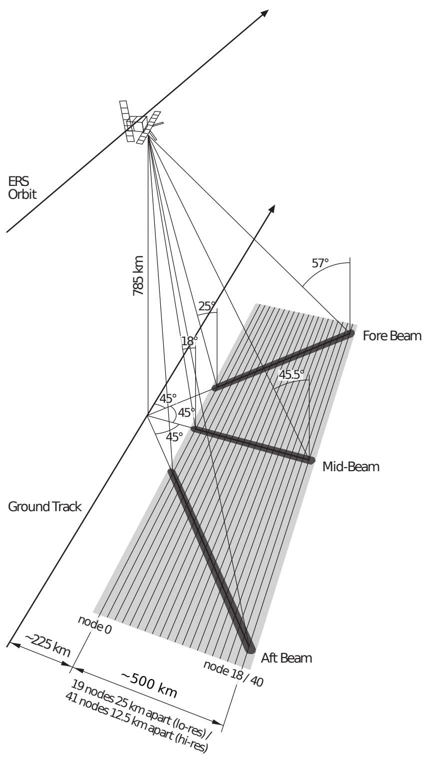

Figure 2.1: Instrument configuration and resulting orbit grid representation (swath) of ERS ESCAT adopted from Bartalis [2009].

Release Date	WARP Version	Level 1 Input Data	Temporal Coverage	Spatial Coverage
2002	WARP 4.0	ERS-1/2 ESCAT Wind Fields	1991-2000	global
2007	WARP 5.0	ERS-1/2 ESCAT Wind Fields and ERS-2 ESCAT fast delivery UWI	1991-2007	global, regional from 2001 onwards
2015	WARP 5.6	ERS-2 ESCAT ASPS nominal resolution	1996-2011	global, regional from 2003 onwards
2015	WARP 5.6	ERS-2 ESCAT ASPS high resolution	1996-2011	global, regional from 2003 onwards

Table 3.1: Overview of ERS-1/2 ESCAT soil moisture products produced by TU Wien. Products highlighted in red have been produced in the framework of the SCIRoCCo project.

3 Product lineage

Surface soil moisture records are derived from the backscatter coefficient σ° measured by the scatterometer (ESCAT) on-board the European Remote Sensing (ERS) satellites using the TU Wien soil moisture retrieval algorithm Naeimi et al. [2009]; Wagner et al. [1999]. In the TU Wien algorithm, long-term records of backscatter measurements are used to model the incidence angle dependency of backscatter, which allows a normalization to a common reference incidence angle ($\theta_r = 40$). The relative surface soil moisture estimates range between 0% and 100% and are derived by scaling the normalized backscatter between the lowest/highest backscatter values corresponding to the driest/wettest soil conditions. Soil moisture is represented in degree of saturation S_d, but can be translated from relative (%) to absolute volumetric units (m^3m^{-3}) using porosity information (see **Eq. 4-1**).

The soil moisture retrieval algorithm is implemented in a software called the WAter Retrieval Package (WARP). ERS ESCAT Level 1b data sets with a spatial sampling of 12.5 km, high resolution, and 25 km, nominal resolution, are used to retrieve relative surface soil moisture information. Except surface temperature data, used for training a freeze-thaw detection algorithm, and a static climate classification map (used for the determination of the wet correction) no external data is required for the retrieval. A detailed description of the TU Wien soil moisture retrieval algorithm together with a description of the derivation of the model parameters can be found in the Algorithm Theoretical Baseline Document (ATBD) [RD-1]. Three distinct ERS ESCAT soil moisture products have been released since the launch of ERS-1 in 1991 and ERS-2 in 1995, created by TU Wien, Department of Geodesy and Geoinformation, Research Group Remote Sensing (see Table 3.1). The released datasets are classical research products funded through several ESA projects with irregular release dates.

4 Product description

4.1 Product parameters

The Level 2 soil moisture product is composed of several parameters (geophysical parameters, flags, geolocation information, etc.). The following subsections will give an overview of all relevant Level 2 parameters and flags.

Level 2 Soil Moisture parameters

The Level 2 parameters represent new variables which have been derived from the respective Level 1b product. The following table summarizes these parameters.

Name	Scaling factor	Units	Type	Byte size	NaN
SM	-	%	int8	1	127
SM_NOISE	-	%	int8	1	127
SSF	-	-	int8	1	127

Table 4.1: Overview of Level 2 parameters included in the ERS ESCAT soil moisture time series product.

Surface soil moisture and its noise The surface soil moisture estimate (SM) represents the topmost soil layer (< 5 cm) and is given in degree of saturation S_d, ranging from 0% (dry) to 100% (wet). S_d can be converted into (absolute) volumetric units m^3m^{-3} with the help of soil porosity information.

$$\Theta = p \cdot \frac{S_d}{100} \quad \text{Eq. 4-1}$$

where Θ is absolute soil moisture in m^3m^{-3}, p is porosity in m^3m^{-3}. As it can be seen in **Eq. 4-1**, the accuracy of soil porosity is as much as important as the relative soil moisture content. An estimate of the uncertainty of soil moisture is given in the parameter soil moisture noise (SM_NOISE) and its unit is degree of saturation in %. Surface soil moisture and its noise have been rounded to full integer values (e.g. original value of 2.3% or 6.7% is rounded to 2% or 7% final value).

Surface state flag The surface state flag (SSF) indicates the surface conditions: unknown, unfrozen, frozen, temporary melting/water on the surface or permanent ice. The flag is intended to help filtering soil moisture values derived under frozen soil conditions.

Geo-location and satellite parameters

The geo-location and satellite parameters

Table 4.2: Overview of geo-location and satellite parameters.

Name	Scaling factor	Units	Type	Byte size
LOCATION_ID	-	-	int64	8
ROW_SIZE	-	-	int64	8
LATITUDE	-	Degrees North	float32	4
LONGITUDE	-	Degrees East	float32	4
TIME	-	Days since 1900-01-01 00:00:00 UTC	float64	8
ORBIT_DIR	-	-	char(1)	1
SAT_ID	-	-	char(1)	1

Location ID The location id (LOCATION_ID) is a unique identifier for a single grid point (GP) of the WARP5 grid [RD-3]. It is also often called Grid Point Index (GPI).

Row size The number of observations per GP is indicated by the row size (ROW_SIZE) or in other words the length of the time series per GP. This parameter is needed to extract the time series of a certain GP.

Latitude The latitude (LATITUDE) position of the GP in degrees north.

Longitude The longitude (LONGITUDE) position of the GP in degrees east.

Time The time parameter (TIME) represents the time stamp for the measurements. It is defined as the days since 1900-01-01 00:00:00 UTC (e.g. 1900-01-01 00:00:00 UTC + 39081.2494791667 = 2007-01-01 05:59:15 UTC).

Orbit direction The orbit direction (ORBIT_DIR) indicates the movement of the spacecraft through the plane of reference. The ascending direction (A) represents a movement north through the plane of reference, and the descending (D) south through the plane of reference.

Satellite id The satellite id (SAT_ID) represents the sensor's platform identification (ERS-1=1, ERS-2=2).

Processing flags

These flags indicate several conditions of interest if a certain bit has been set. A bit is set when it has value 1 and not set when it has value 0.

Table 4.3: Processing and correction field.

Name	Scaling factor	Units	Type	Byte size
PROC_FLAG	-	-	uint8	1

Processing flags (PROC_FLAG) are set to flag the reason for a soil moisture value not being provided in the product and/or that the soil moisture value has been modified after the retrieval for a different reason.

- *Bit 1 set:* Original soil moisture larger than or equal to -50% but less than 0%, value set to 0% artificially.
- *Bit 2 set:* Original soil moisture larger than or equal to 100% but less than 150%, value set to 100% artificially.
- *Bit 3 set:* Original soil moisture lower than -50%, value set to NaN.
- *Bit 4 set:* Original soil moisture larger than 150%, value set to NaN.
- *Bit 5 set:* Normalized backscatter is out of limits or dry/wet reference is NaN. Soil moisture set to NaN.
- *Bit 6-8 set:* Reserved for future use.

4.2 Product limitations and caveats

Product limitations and caveats are discussed in detail in the ATBD [RD-1].

4.3 Spatial resolution and sampling

The spatial resolution of the products is about 25 km × 25 km (high resolution) or 50 km × 50 km (nominal resolution) geo-referenced on the WARP5 grid [RD-3]. The WARP5 grid represents a discrete global grid

(DGG) with a grid spacing of 12.5 km. The location of the points can be viewed interactively with the tool DGG Point Locator [http://rs.geo.tuwien.ac.at/dv/dgg].

4.4 File format

File naming

The product is provided as time series stored in NetCDF-4. All files follow the NetCDF Climate and Forecast (CF) Metadata Conventions version 1.6 [Eaton et al., 2011]. The grid points are organized in cells, in order to reduce the number of files. The cell size is defined as 5° × 5° and does contain up to 2000 grid points, mainly depending on latitude. The cell number and the number of grid points per cell are shown in Figure 4.1. A look-up containing GPI cell number, longitude and latitude can be found in this file: `TUW_WARP5_grid_info_<version>.nc` available on the SCIRoCCo FTP site. The file naming of these soil moisture time series products is: `<cell>.nc`

Time series storage format

The time series are stored in the contiguous ragged array representation defined by the NetCDF Climate and Forecast (CF) Metadata Conventions [Eaton et al., 2011]. The time series parameters (like soil moisture, soil moisture noise) are associated with the coordinate values `time(obs)`, `lat(i)` and `lon(i)`, where `i` indicates which time series. The time series `i` comprises the following data elements:

`row_start(i) to row_start(i) + row_size(i)-1`

where

`row_start(i) = 0 if i = 0`

`row_start(i) = row_start(i-1) + row_size(i-1) if i > 0`

The variable `row_size` is the count variable containing the length of each time series feature. It is identified by having an attribute with name sample_dimension whose value is name of the sample dimension (obs in this case). The auxiliary location parameters `lat` and `lon` are GPI variables.

Example

An example of the NetCDF variables is shown in the Listing 1. The NetCDF files can also be easily read using the open source python package Pytesmo[1] (Toolbox for the Evaluation of Soil Moisture Observations). For more information (installation instructions, documentation, examples and links to the source code) please consult the Pytesmo website[2]).

[1] https://github.com/TUW-GEO/pytesmo
[2] http://rs.geo.tuwien.ac.at/validation_tool/pytesmo/docs/index.html

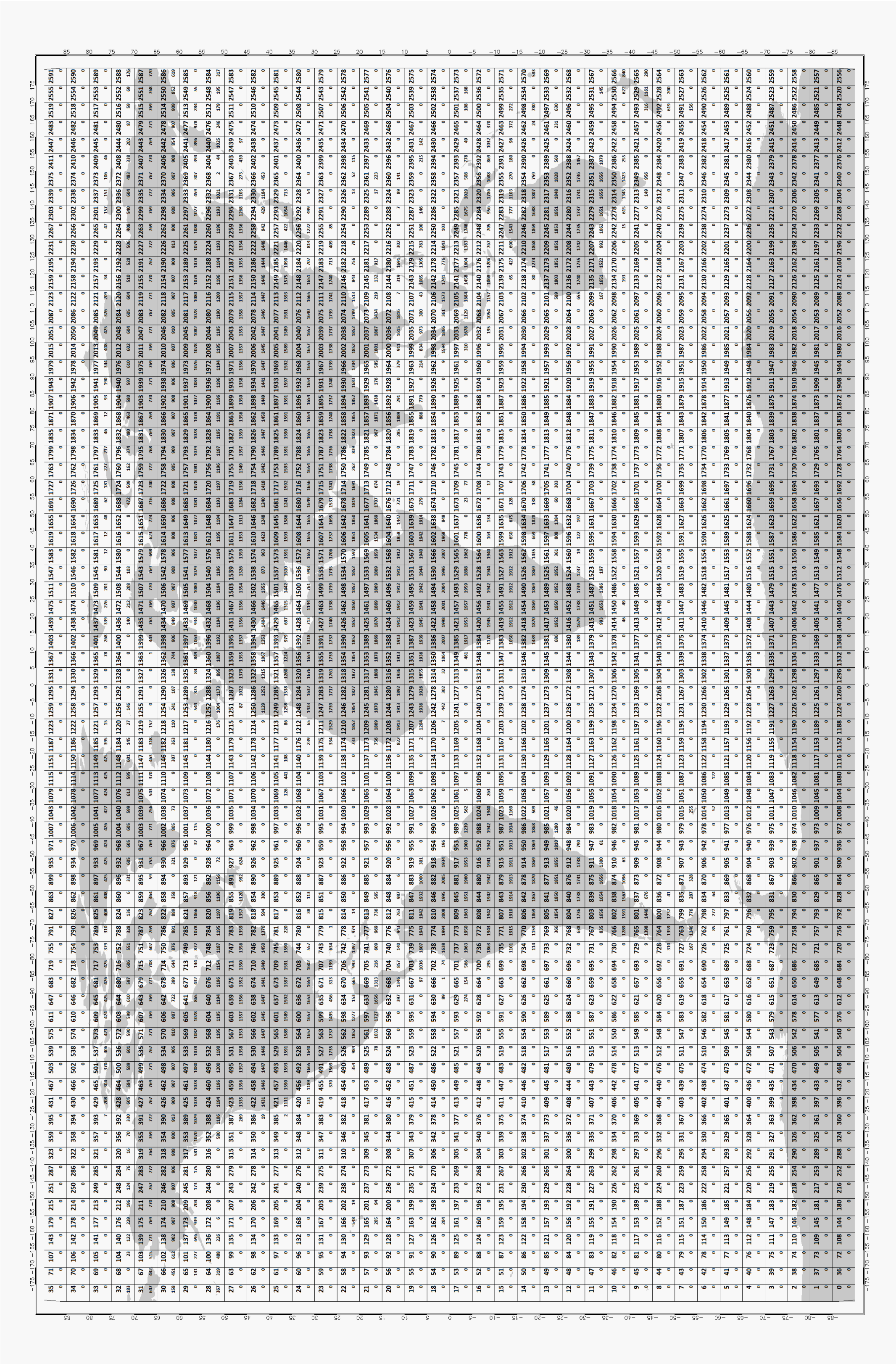

Figure 4.1: 5° × 5° cell partitioning of the grid points. The upper number in each cell represents the cell number and the lower number the number of grid points in this cell.

Listing 1: Example of NetCDF variables and dimension for cell 28.

```
dimensions:
  locations = 4 ;
  obs = UNLIMITED ; // (21827 currently)
variables:
  int64 row_size(locations) ;
    row_size:long_name = "number of observations at this location" ;
    row_size:sample_dimension = "obs" ;
  float lon(locations) ;
    lon:units = "degrees_east" ;
    lon:long_name = "location longitude" ;
    lon:standard_name = "longitude" ;
    lon:valid_range = -180., 180. ;
  float lat(locations) ;
    lat:units = "degrees_north" ;
    lat:long_name = "location latitude" ;
    lat:standard_name = "latitude" ;
    lat:valid_range = -90., 90. ;
  float alt(locations) ;
    alt:units = "m" ;
    alt:long_name = "vertical distance above the surface" ;
    alt:standard_name = "height" ;
    alt:axis = "Z" ;
    alt:positive = "up" ;
  int64 location_id(locations) ;
  string location_description(locations) ;
  double time(obs) ;
    time:units = "days since 1900-01-01 00:00:00" ;
    time:long_name = "time of measurement" ;
    time:standard_name = "time" ;
  byte proc_flag(obs) ;
    proc_flag:long_name = "processing flag" ;
    proc_flag:name = "proc_flag" ;
    proc_flag:flag_meanings = "sensitivity_to_soil_moisture_below_1dB
      soil_moisture_noise_above_50" ;
    proc_flag:flag_masks = 1b, 2b ;
    proc_flag:coordinates = "time lat lon alt" ;
    proc_flag:valid_range = 0b, 3b ;
  byte corr_flag(obs) ;
    corr_flag:long_name = "correction flag" ;
    corr_flag:name = "corr_flag" ;
    corr_flag:flag_meanings = "soil_moisture_set_to_0_it_was_between_0_and_-25
      soil_moisture_set_to_100_it_was_between_100_and_125
```

```
      soil_moisture_set_to_nan_it_was_below_-25
      soil_moisture_set_to_nan_it_was_above_125 wet_correction_applied
      soil_moisture_set_to_nan_backscatter_not_usable" ;
    corr_flag:flag_masks = 1b, 2b, 4b, 8b, 16b, 32b ;
    corr_flag:coordinates = "time lat lon alt" ;
    corr_flag:valid_range = 0b, 63b ;
  byte sm(obs) ;
    sm:long_name = "soil moisture" ;
    sm:name = "sm" ;
    sm:units = "%" ;
    sm:missing_value = 127b ;
    sm:coordinates = "time lat lon alt" ;
    sm:valid_range = 0b, 100b ;
  ubyte sat_id(obs) ;
    sat_id:long_name = "satellite id" ;
    sat_id:flag_values = 1b, 2b, 3b, 4b, 5b ;
    sat_id:name = "sat_id" ;
    sat_id:flag_meanings = "ers-1, ers-2, metop-a, metop-b, metop-c" ;
    sat_id:missing_value = 127b ;
    sat_id:coordinates = "time lat lon alt" ;
    sat_id:valid_range = 1b, 5b ;
  byte ssf(obs) ;
    ssf:name = "ssf" ;
    ssf:flag_meanings = "unknown unfrozen frozen_temporary
      melting_water_on_the_surface permanent_ice" ;
    ssf:coordinates = "time lat lon" ;
    ssf:valid_range = 0b, 4b ;
    ssf:long_name = "surface state flag" ;
    ssf:flag_values = 0b, 1b, 2b, 3b, 4b ;
    ssf:missing_value = 127b ;
  byte dir(obs) ;
    dir:name = "dir" ;
    dir:flag_meanings = "ascending descending" ;
    dir:coordinates = "time lat lon" ;
    dir:valid_range = 0b, 1b ;
    dir:long_name = "orbit direction" ;
    dir:flag_values = 0b, 1b ;
    dir:missing_value = 127b ;
  byte sm_noise(obs) ;
    sm_noise:long_name = "soil moisture noise" ;
    sm_noise:name = "sm_noise" ;
    sm_noise:units = "%" ;
    sm_noise:missing_value = 127b ;
    sm_noise:coordinates = "time lat lon alt" ;
    sm_noise:valid_range = 0b, 100b ;
```

5 Product validation

Information about product verification and validation can be found in the PVR (Product Validation Report) [RD-2].

6 Product availability

6.1 Download

The soil moisture data records are available via FTP. Download details are available after registering at ESA data portal website [https://earth.esa.int]. If you need help with respect to data access please contact the ESA EO portal helpdesk [https://earth.esa.int/web/guest/contact-us] and for questions about the product itself please contact the TU Wien support [remote.sensing@geo.tuwien.ac.at].

6.2 Conditions of use

ERS ESCAT soil moisture products have been produced in the framework of the ESA funded project SCIRoCCo and are disseminated under ESA Data Policy. They are available for all users free of charge after registration.

7 References

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