Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 1/24

EUMETSAT Satellite Application Facility on
Support to Operational Hydrology and Water Management
http://hsaf.meteoam.it/

Product User Manual (PUM)

H141 and H142

Soil Wetness Index in the roots region
Data Record and Offline extension

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Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 2/24

Revision History

Revision	Date	Author(s)	Description
0.1	2019/05/07	David Fairbairn and Patricia de Rosnay	First draft.
0.2	2019/11/06	David Fairbairn and Patricia de Rosnay	(i) Revised Table 4.1 to provide the correct producers and references of the H141 input scatterometer SSM products; (ii) The product name is now included in the title of the document; (iii) A discussion of the quality control screening of the input scatterometer data has been added to section 4; (iv) The compression used for netCDF is mentioned in 5.2.1; (v) An example of how to cite the product has been added in section 7.2.
0.3	2020/03/12	David Fairbairn and Patricia de Rosnay	Included descriptions of offline extension H142

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 3/24

Table of Contents

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 4/24

List of Tables

List of Figures

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 5/24

List of Acronyms

ASAR Advanced Synthetic Aperture Radar (on Envisat)

ASAR GM ASAR Global Monitoring

ASCAT Advanced Scatterometer

ATBD Algorithm Theoretical Baseline Document

BUFR Binary Universal Form for the Representation of meteorological data

DORIS Doppler Orbitography and Radiopositioning Integrated by Satellite (on Envisat)

ECMWF European Centre for Medium-range Weather Forecasts

ERS European Remote-sensing Satellite (1 and 2)

ESA European Space Agency

EUMETCast EUMETSAT's Broadcast System for Environment Data

EUMETSAT European Organisation for the Exploitation of Meteorological Satellites

FTP File Transfer Protocol

H SAF SAF on Support to Operational Hydrology and Water Management

HTESSEL Hydrology Tiled ECMWF Scheme of Surface Exchanges over Land

LDAS Land Data Assimilation System

Météo France National Meteorological Service of France

Metop Meteorological Operational Platform

NRT Near Real-Time

NWP Numerical Weather Prediction

PRD Product Requirements Document

PUM Product User Manual

PVR Product Validation Report

SAF Satellite Application Facility

SEKF Simplified Extended Kalman Filter

SSM Surface soil moisture

SWI Soil Wetness Index

TU Wien Technische Universität Wien (Vienna University of Technology)

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 6/24

WARP Soil Water Retrieval Package

WARP H WARP Hydrology

WARP NRT WARP Near Real-Time

ZAMG Zentralanstalt für Meteorologie und Geodynamic (National Meteorological Service of Austria)

![EUMETSAT H SAF logo]

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 7/24

1. Executive summary

The Product User Manual (PUM) summarizes the product lineage and format of the H141 root zone soil moisture profile index data record for 1992-2018. The 10 km resolution H141 product is generated by assimilating scatterometer derived surface soil moisture observations into an offline land data assimilation system. The output files are provided daily in two different file types with different formats: a cubic octahedral reduced Gaussian grid in GRIB format and a regular lat/lon grid in netCDF format. The offline extension of H141 (called H142) is valid for 2019-2021 and has the same output format.

A general introduction of the purpose of the document (section 2) is followed by a description of the root zone soil wetness index data record (section 3). The product lineage and structure/format of the product are discussed in sections 4 and 5 respectively. This is followed by information about product validation (section 6) and product availability (section 7). A conclusion is given in section 8. References to technical reports and journal articles are summarized in section 9. More information about the organisational structure of H SAF can be found in the Appendix.

2. Introduction

2.1. Purpose of the document

The Product User Manual (PUM) is intended to provide a detailed description of the main Product characteristics, format, validation activities and availability. Each 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 operational characteristics: Spatial resolution and sampling, observing cycle and time sampling, timeliness;

- 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 PUMs rely on other documents for further details. Specifically:

- Algorithm Theoretical Baseline Document (ATBD) for extensive details on the algorithms;

- Product Validation Report (PVR), for a full recount of the validation activity, both the evolution and the latest results.

2.2. Targeted audience

This document mainly targets:

- Hydrology and water management experts

![EUMETSAT H SAF logo]

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 8/24

- Operational hydrology and Numerical Weather Prediction communities

- Users of remotely sensed soil moisture for a range of applications (e.g. climate modelling validation, trend analysis)

2.3. H SAF soil moisture products

In the framework of the H SAF project several soil moisture products, with different timeliness (e.g. near real time products and data records), spatial resolution, format (e.g. time series, swath orbit geometry, global image) or the representation of the water content in various soil layers (e.g. surface, root-zone), are generated on a regular basis and distributed to users. A list of all available soil moisture products, as well as other H SAF products (such as precipitation or snow) can be looked up on the H SAF website (hsaf.meteoam.it). More general information about H SAF can be found in the Appendix. This document describes the production chain of the H141 root zone soil wetness data record product and its offline extension (H142).

3. Description of the root-zone soil wetness data record H141

3.1. Principal of the product

The H141 production chain uses an offline sequential Land Data Assimilation System (LDAS) based on an Simplified Extended Kalman Filter (SEKF) method, as in [1]. The SEKF constitutes the central component of the H141 production chain. The HTESSEL Land Surface Model is used to propagate in time and space the soil moisture information through the root zone, accounting for physiographic information (soil texture, orography), meteorological conditions and land surface processes such as soil evaporation and vegetation transpiration [2–4]. H141 is a root zone soil moisture product derived from ERS/SCAT and Metop ASCAT-A/B surface soil moisture (SSM) observations over from 1992 to 2018. Its offline extension H142 assimilates Metop ASCAT-A/B/C from 2019 to 2021 and is updated at a yearly frequency. The retrieval approach for both products relies on an offline, sequential Land Data Assimilation System (LDAS). The ERS1/2 observations are assimilated from 1992 to 2006, the ASCAT-A observations for 2007-2021, ASCAT-B for 2015-2021 and ASCAT-C from 2019-2021. Although the acquisition period of the ERS2 scatterometer extended until September 2011, the ASCAT-A/B data is assimilated instead of ER2 data after 2007 since each ASCAT sensor gives more than twice the coverage (almost daily) of that provided by the ERS scatterometers [5]. The H141 production chain also assimilates screen level parameters close to the surface (2-metre temperature and relative humidity) to ensure consistency of the retrieved Scatterometer root zone and the near surface observed weather conditions. The land surface model is driven by ERA5 atmospheric fields [6]. Figure 3.1 illustrates the H141 LDAS production suite. The H142 production suite is equivalent to H141, except that ASCAT-C is assimilated from 2019 onwards.

3.2. Main characteristics

H141 is produced at a horizontal resolution of about 10km on four vertical layers in the soil: surface to 7 cm, 7 cm to 28 cm, 28 cm to 100 cm, and 100 cm to 289 cm. H141 relies on a data assimilation approach that propagates the information in time and space (on the vertical dimension in the root zone). Therefore, it allows a global update of the root zone soil moisture

H SAF
EUMETSAT

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
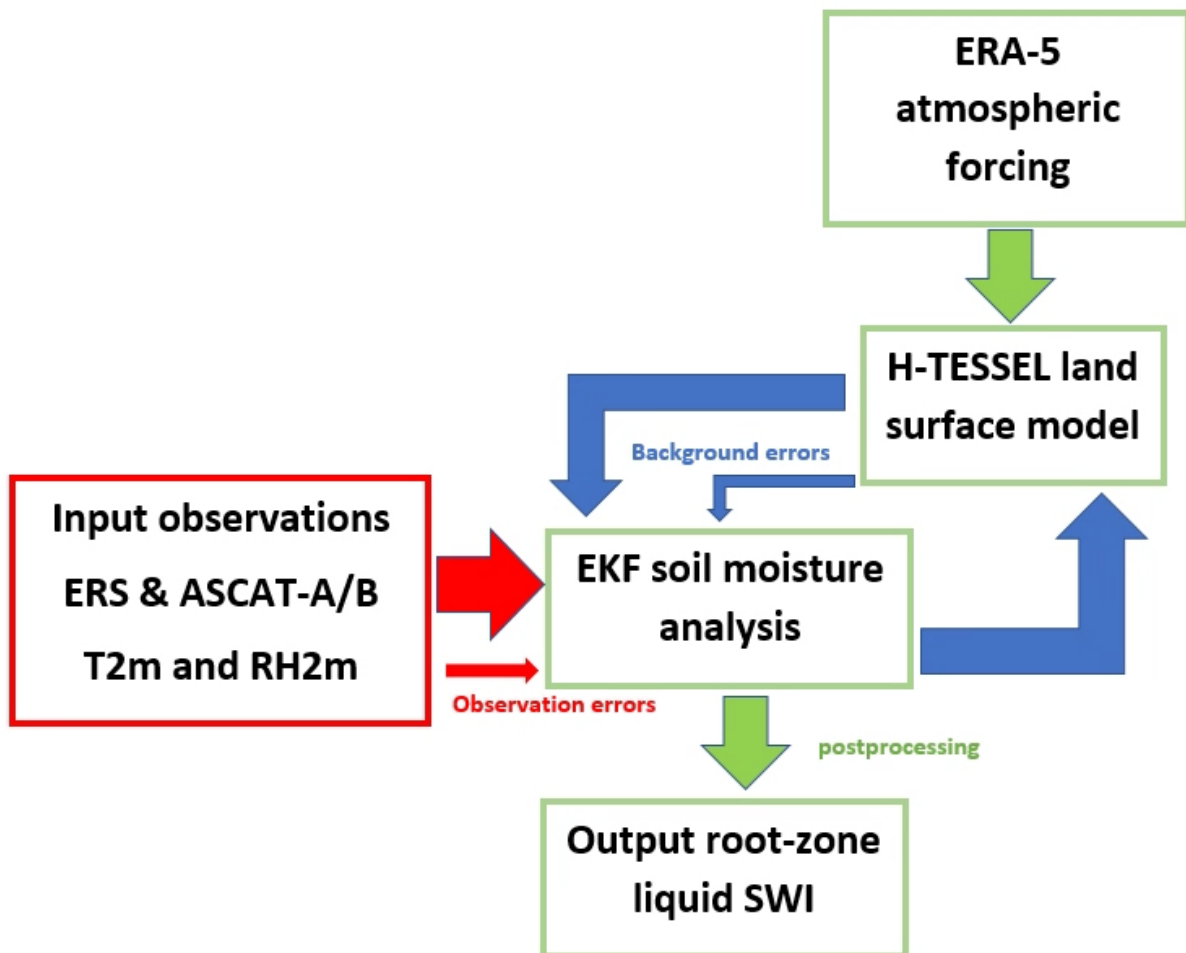Issue/Revision: 0.3
Date: 2020/03/12
Page: 9/24

Figure 3.1: Illustration of the H141 root zone soil moisture production chain based on ERS-1/2 and ASCAT-A/B satellite derived surface soil moisture data assimilation.

![EUMETSAT HSAF logo]

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 10/24

states using surface soil moisture (SSM) derived from the aforementioned scatterometer products. H141 is a daily product valid at 00UTC. The soil moisture in the model and in the data assimilation process is in volumetric units. Prior to data assimilation, the SSM scatterometer derived observations are rescaled to match the model soil moisture climatology (described in the Algorithm Theoretical Baseline Document, ATBD, [7]) and in the process they are effectively converted to volumetric units. However, the H141 root-zone soil moisture product is expressed as a liquid SWI, with units between 0 (residual soil moisture) and 1 (saturation), representing the lower and upper soil moisture limits. After data assimilation, a post-processing step is required to convert the volumetric soil moisture analysis into the SWI. It is computed using the soil texture (as defined by the FAO/United Nations Educational, Scientific and Cultural Organization (UNESCO) Digital Soil Map of the world [8]), the residual and saturated soil moisture, and the fraction of liquid water content (the fraction of water that is not frozen) on each grid point and each soil layer. Having the units of H141 as a liquid SWI is consistent with all the other ASCAT soil moisture products that are available for the surface (e.g. H14 and H101). Furthermore, It is relevant to various applications and can be combined with different hydrological models (e.g. [9]).

4. Product lineage

H141 is the first historically consistent scatterometer derived root zone soil moisture profile database for 1992-2018. It is a unique reprocessed satellite-based root zone soil moisture data record. The products result from data assimilation, which enables the propagation of surface soil moisture information observed by scatterometers (ERS 1/2 and ASCAT-A/B) to the root zone, taking into account ERA5 atmospheric fields used to force the offline LDAS. This makes the H141 products particularly relevant for operational hydrology applications.

Scatterometer surface soil moisture products from ERS-1/2 (from 1992 to 2006) Active Microwave Instruments (AMI), the ASCAT-A from 2007 to 2018 and ASCAT-B from 2015-2018 are used as the main input of the H141 production chain. ASCAT-A/B and (2019-2021) and ASCAT-C (October 2019 to 2021) are the main inputs to the offline extension H142. Table 6.1 below gives the details on the scatterometers SSM products used as input for the H141 production suite. As shown in Table 6.1 there is no overlap between ERS1/2 and ASCAT-A/B observations used to produce H141. In the ECMWF H141 algorithm the input scatterometer SSM products are assimilated in the H141 LDAS which propagates the scatterometer SSM information in space on the soil vertical profile and in time at a daily time scale. The main components of the data assimilation system are the SEKF, a land surface model and input data re-processing. A detailed description of the ECMWF H141 LDAS algorithm can be found in the ATBD [7].

A quality control is applied to filter input ERS 1/2 and ASCAT-A/B/C SSM observations so that only observations with a noise level lower than 15% are used. The quality control also rejects ERS 1/2 and ASCAT-A/B/C SSM observation for pixels with a water fraction larger than 15% and with a topographic complexity larger than 20%, as well as observations in frozen soil and/or snow covered surface conditions. When no observations are assimilated, the root zone soil moisture entirely relies on the HTESSEL land surface model, which ensures physically based soil moisture evolution when there are gaps in the scatterometer observations.

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 11/24

Table 4.1: H141 (1992-2018) and H142 (2019-2021) input scatterometer SSM products.

	Scaterrometer SSM product used in H141 data record		
Period	Sensor	Producer	Reference
04-2014 to 12-2021	ASCAT-A (03/2014 to 12/2021), ASCAT-B (01/2015 to 12/2021) and ASCAT-C (10/2019 to 12/2021) 25 km sampling	EUMETSAT CAF	ASCSMO02: ASCAT-A/B/C 25 km swath grid product distributed by CAF. (https://vnavigator.eumetsat.int/product/EO:EUM:DAT:METOP:SOMO25). Equivalent to H SAF level 2 surface soil moisture products H102 (Metop-A 25 km sampling), H103 (Metop-B 25 km sampling) and H105 (Metop-C 25 km sampling).
01-2007 to 03-2014	ASCAT-A 25 km sampling	TU Wien	H107: H SAF soil moisture data record reprocessed level 2 surface soil moisture.
01-1992 to 12-2006	ERS 1/2 AMI 50 km sampling	TU Wien	ERS-1/2 AMI WARP 5.5 R1.1: ERS-1/2 AMI 50km Soil moisture time series product. Produced as part of the Scirroco project (https://earth.esa.int/documents/) 700255/2925769/SCI-PRE-2015-0001-v-01-SM_reprocessing_TUW.pdf) using the Water Retrieval Package (WARP) version 5.5.

![EUMETSAT H SAF logo]

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 12/24

5. Product structure and format

5.1. Introduction

The H141 and H142 output data are provided at approximately 10 km resolution in two different formats in order to cater for the needs of different users. The model and data assimilation are performed on a cubic octahedral reduced Gaussian grid ($T_{CO}1279$), which has approximately equidistant grid points between the equator and the poles i.e. the number of latitude points reduces closer to the poles. Daily files in GRIB edition 1 format are provided for the soil moisture analysis (valid at 00 UTC) on the original $T_{CO}1279$ grid, giving four fields of global SWI (one for each soil layer). Additionally, the same fields are provided as a single netCDF file on a 0.1 degree regular lat/lon grid (created by interpolating the $T_{CO}1279$ grid points onto a regular lat/lon grid). The $T_{CO}1279$ GRIB files cheaper to store than the regular lat/lon netCDF files, partly because they have fewer latitude points near the poles and partly because missing values (e.g. over the oceans) are not stored explicitly. While many standard software packages are still better adapted to read in and plot data from regular lat/lon grids in netCDF format than irregular grids in GRIB format, increasingly software providers such as Python are developing tools to read in and plot the native reduced Gaussian grids directly. Thus it was decided to provide the data in both formats for the benefit of different users. The output data formats are described and demonstrated in the following section.

5.2. Output data formats

5.2.1. Global map grid

The $T_{CO}1279$ grid (also referred to as O1280) has a quasi-regular grid spacing in distance at each latitude. The grid is symmetrical at the equator with no latitude row at either the pole or at the Equator. The centred first pixel is at longitude 0 and latitude 89.947 and the points are equally spaced along each line of latitude. The precise location of each latitude row and the number of reduced Gaussian grid longitude points are given on the ECMWF website [1]. The total number of $T_{CO}1279$ grid points for a global map of H141 is 6,599680. Information about the $T_{CO}1279$ grid is given in Table 5.1. One grib file has a size of about 26 mb. The grib files are zipped into monthly .tar.gz files of between 70 and 80 mb per month. Users are required to unzip these files prior to reading the data from the GRIB files.

The netCDF files are provided on a 0.1 degree regular lat/lon grid. They use the same grid information as in Table 5.1. Without compressing the data, the netCDF files would be expensive to store (about 100 mb per file). Therefore, they are stored as compressed netCDF4 files with a size of only about 13 mb. The data can be read directly from the compressed netCDF4 files using software that is compatible with netCDF4 e.g. Python, Matlab.

5.2.2. File naming

For H141 on $T_{CO}1279$, the file naming convention is: h141_YYYYMMDDHH_TCO1279.GRIB with YYYY the year, MM the month, DD the day of month, HH valid time UTC (Coordinated Universal Time). The product is available daily at 00UTC. Similarly for the H141 netCDF files, the naming convention is h141_YYYYMMDDHH_R01.nc, where "R01" stands for "0.1 degree

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[1]https://confluence.ecmwf.int/display/FCST/Introducing+the+octahedral+reduced+Gaussian+grid

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 13/24

Table 5.1: H141 grid information

H SAF attribute name	Type	Size	Value
latitudeOfFirstGridPointInDegrees	Real	6	89.947
longitudeOfFirstGridPointInDegrees	Real	1	0
laitutudeOfLastGridPointInDegrees	Real	7	-89.947
longitudeOfFirstGridPointInDegrees	Real	6	359.93
"dataDate"	String	8	"yyyymmdd"
"dataTime"	String	1	"hh"
"dataTime"	String	1	"hh"

Table 5.2: H141 GRIB and netCDF file parameters

H SAF attribute name	Type	Size	Value
table2Version	Real	3	228
Variables	Real	2	40, 41, 42, 43
MissingValue	Real	4	9999
bitsPerValue	Real	2	24
"dataTime"	String	1	"hh"
numberOfValues	Real	7	"Number of values"

regular lat/lon". The offline extension product (H142) has the same naming convention, but with "h142" replacing "h141".

5.2.3. Product parameters

For H141 $T_{CO}1279$ GRIB files each contain four messages, one for each soil layer, using the GRIB parameters 40, 41, 42, and 43 of the table version 228. These parameters describe the SWI in the soil layer 1 (0-7cm), layer 2 (7-28cm), layer 3 (28-100 cm) and layer 4 (100-289 cm), respectively. They are exclusively used for the H SAF root zone products (as originally defined in the Second Continuous Development and Operations Phase, CDOP-2). The same variables and table versions are included in the netCDF files. Table 5.2 shows the parameters of the H141 product, which is also valid for H142.

5.3. Examples

An example of the GRIB data for the first layer is shown below for 31 January 2010. The GRIB files can be easily opened using the GRIB API package [2].

GRIB listing

```
#==============    MESSAGE 1 ( length=6423418 )          ==============
GRIB {
  editionNumber = 1;
```

---
[2] https://software.ecmwf.int/wiki/display/GRIB/Documentation

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 14/24

```
table2Version = 228;
# European Centre for Medium-Range Weather Forecasts (common/c-1.table)
centre = 98;
generatingProcessIdentifier = 255;
# SWI1 Soil wetness index in layer 1  (dimensionless)
indicatorOfParameter = 40;
# Surface  (of the Earth, which includes sea surface)
indicatorOfTypeOfLevel = 1;
level = 0;
# Forecast product valid at reference time + P1  (P1>0)
timeRangeIndicator = 0;
# Unknown code table entry (GRIB1/0.ecmf.table)
subCentre = 0;
paramId = 228040;
#-READ ONLY- cfNameECMF = unknown;
#-READ ONLY- cfName = unknown;
#-READ ONLY- cfVarNameECMF = swi1;
#-READ ONLY- cfVarName = swi1;
#-READ ONLY- units = dimensionless;
#-READ ONLY- nameECMF = Soil wetness index in layer 1;
#-READ ONLY- name = Soil wetness index in layer 1;
decimalScaleFactor = 0;
dataDate = 20100131;
dataTime = 0;
# Hour (stepUnits.table)
stepUnits = 1;
stepRange = 0;
startStep = 0;
endStep = 0;
#-READ ONLY- marsParam = 40.228;
# MARS labelling or ensemble forecast data (GRIB1/localDefinitionNumber.98.table)
localDefinitionNumber = 1;
# Research department (mars/class.table)
marsClass = 2;
# Analysis (mars/type.table)
marsType = 2;
# Atmospheric model (mars/stream.table)
marsStream = 1025;
experimentVersionNumber = h141;
perturbationNumber = 0;
numberOfForecastsInEnsemble = 0;
shortName = swi1;
GDSPresent = 1;
bitmapPresent = 1;
numberOfVerticalCoordinateValues = 0;
Ni = MISSING;
Nj = 2560;
latitudeOfFirstGridPointInDegrees = 89.947;
longitudeOfFirstGridPointInDegrees = 0;
earthIsOblate = 0;
uvRelativeToGrid = 0;
latitudeOfLastGridPointInDegrees = -89.947;
longitudeOfLastGridPointInDegrees = 359.93;
iDirectionIncrement = MISSING;
iDirectionIncrementInDegrees = MISSING;
N = 1280;
iScansNegatively = 0;
```

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 15/24

```
 jScansPositively = 0;
 jPointsAreConsecutive = 0;
 #-READ ONLY- alternativeRowScanning = 0;
 global = 1;
 #-READ ONLY- numberOfDataPoints = 6599680;
 #-READ ONLY- numberOfValues = 1864408;
 }
```

An example of the netCDF file header data is shown below using the standard netCDF software package from UCAR [3].

netCDF headers

```
netcdf h141_2010013100_R01 {
dimensions:
        lon = 3600 ;
        lat = 1801 ;
        time = UNLIMITED ; // (1 currently)
variables:
        float lon(lon) ;
                lon:standard_name = "longitude" ;
                lon:long_name = "longitude" ;
                lon:units = "degrees_east" ;
                lon:axis = "X" ;
        float lat(lat) ;
                lat:standard_name = "latitude" ;
                lat:long_name = "latitude" ;
                lat:units = "degrees_north" ;
                lat:axis = "Y" ;
        double time(time) ;
                time:standard_name = "time" ;
                time:units = "hours since 2010-1-31 00:00:00" ;
                time:calendar = "proleptic_gregorian" ;
                time:axis = "T" ;
        float var40(time, lat, lon) ;
                var40:table = 228 ;
                var40:_FillValue = -9.e+33f ;
                var40:missing_value = -9.e+33f ;
        float var41(time, lat, lon) ;
                var41:table = 228 ;
                var41:_FillValue = -9.e+33f ;
                var41:missing_value = -9.e+33f ;
        float var42(time, lat, lon) ;
                var42:table = 228 ;
                var42:_FillValue = -9.e+33f ;
                var42:missing_value = -9.e+33f ;
        float var43(time, lat, lon) ;
                var43:table = 228 ;
                var43:_FillValue = -9.e+33f ;
                var43:missing_value = -9.e+33f ;
```

The GRIB files can be read in and plotted directly using the new metview-python package developed by ECMWF. Download instructions, documentation and examples can be found on

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[3] https://www.unidata.ucar.edu/software/netcdf/netcdf-4/newdocs/netcdf/NetCDF-Utilities.html

H SAF
EUMETSAT

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 16/24

GitHub [4]. Two metview-python scripts below plot examples of the root-zone SWI over Europe on 31/01/2010 and a time series of root-zone SWI averaged over Europe from 2001 to 2010. The corresponding output plots are shown in Figure 5.1. The regular lat/lon netCDF files can be plotted using most standard graphics packages (e.g. Python, Matlab). Various examples of how to read in and plot root-zone SWI maps and time series from regular lat/lon netCDF files using Python are demonstrated in the H SAF training Exercise 2, which is available to download from the website [5].

Example metview-python plotting script (from GRIB file) of root-zone SWI (31/01/2010):

```
import metview as mv
import numpy as np
from scipy import linalg as LA
import pylab as pl

#plot map over Europe
############################################################################################
fs =mv.read(''h141_2010013100_TCO1279.grib'')

#Setup a contour plot with min/max values
cont_pc = mv.mcont(
    legend        = "on",
    contour_line_colour = "black", contour_highlight = "off",
    contour_max_level = 1.0, contour_min_level = 0.0,
    contour_shade = "on", contour_grid_value_height=0.5,
    contour_shade_colour_method = "palette", contour_shade_method = "area_fill",
    contour_shade_palette_name= "eccharts_red_blue2_10")

my_legend = mv.mlegend(legend_text_font_size=0.5)

# shaded land to make the points stand out more
grey_land_shading = mv.mcoast(
    map_coastline_land_shade        = "on",
    map_coastline_land_shade_colour = "grey",
    map_grid_latitude_increment     = 10,
    map_grid_longitude_increment    = 10,
    map_grid_colour                 = "charcoal"
)

#Extraxt European domain
area_view = mv.geoview(
    map_area_definition = 'corners',
    area = [30,-20.0,65,20],
    coastlines = grey_land_shading
)

#Extract root-zone SWI values by depth-integrating the first 3 layers:
RZSM = fs[0]
RZSM = RZSM.set_values(fs.values()[0]*0.07 + fs.values()[1]*0.21\
                    + fs.values()[2]*0.72)
```

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[4]https://github.com/ecmwf/metview-python
[5]http://hsaf.meteoam.it/training-courses.php

EUMETSAT

H SAF

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 17/24

```
#Save plot output
mv.setoutput(mv.png_output(output_name = 'RZSM_plot_Europe.png'))

dw = mv.plot_superpage(pages = mv.mvl_regular_layout(area_view,1,1,1,1))

#Make plot
mv.plot(dw[0], RZSM, cont_pc, my_legend,
mv.mtext(text_font_size=0.7,text_justification="left",\
text_line_1 = ''Root-zone SWI over Europe( 31/01/2010)''))
```

Example metview-python plotting script (from GRIB file) of root-zone SWI time series over Europe (2001-2010):

```
import metview as mv
import numpy as np
from scipy import linalg as LA
import pylab as pl
import pandas as pd

#Create Pandas dataframe for time series of the first three SWI layers
analysis_period = ["2001-01-01",''2010-12-31'']
data_range = pd.date_range(analysis_period[0], analysis_period[1])
SM_df_layer=pd.DataFrame(pl.empty((data_range.size,3),data_range))

#Geographical area with which to average SWI [upper lon, lower lon, upper lat, lower lat]
area = [30,-25,72,46]

#Read in and average root-zone SWI over Europe over the time series
for days, d in zip(data_range,range(len(data_range))):

  fs = mv.read("/h141_"+str(days.year)+\
  '%02d'%(days.month)+'%02d'%(days.day)+'00_TCO1279.grib')

  fs0 = mv.read(data=fs,param='40.228'); SM_df_layer.ix[d,0] = mv.integrate(fs0, area)
  fs1 = mv.read(data=fs,param='41.228'); SM_df_layer.ix[d,1] = mv.integrate(fs1, area)
  fs2 = mv.read(data=fs,param='42.228'); SM_df_layer.ix[d,2] = mv.integrate(fs2, area)

#Generate root-zone SWI time series by depth-integrating first 3 layers
RZSM_time_series=SM_df_layer.ix[:,0]*0.07 + SM_df_layer.ix[:,1]*0.21\
              + SM_df_layer.ix[:,2]*0.72

#Change time series array to correct index
RZSM_time_series.index=data_range

#Plot SWI time series and save
RZSM_time_series.plot(); pl.title(''H141 SWI averaged over Europe'');
pl.xlabel('Time'); pl.ylabel('SWI'); pl.savefig('H140_time_series_Europe.png',dpi=300)
```
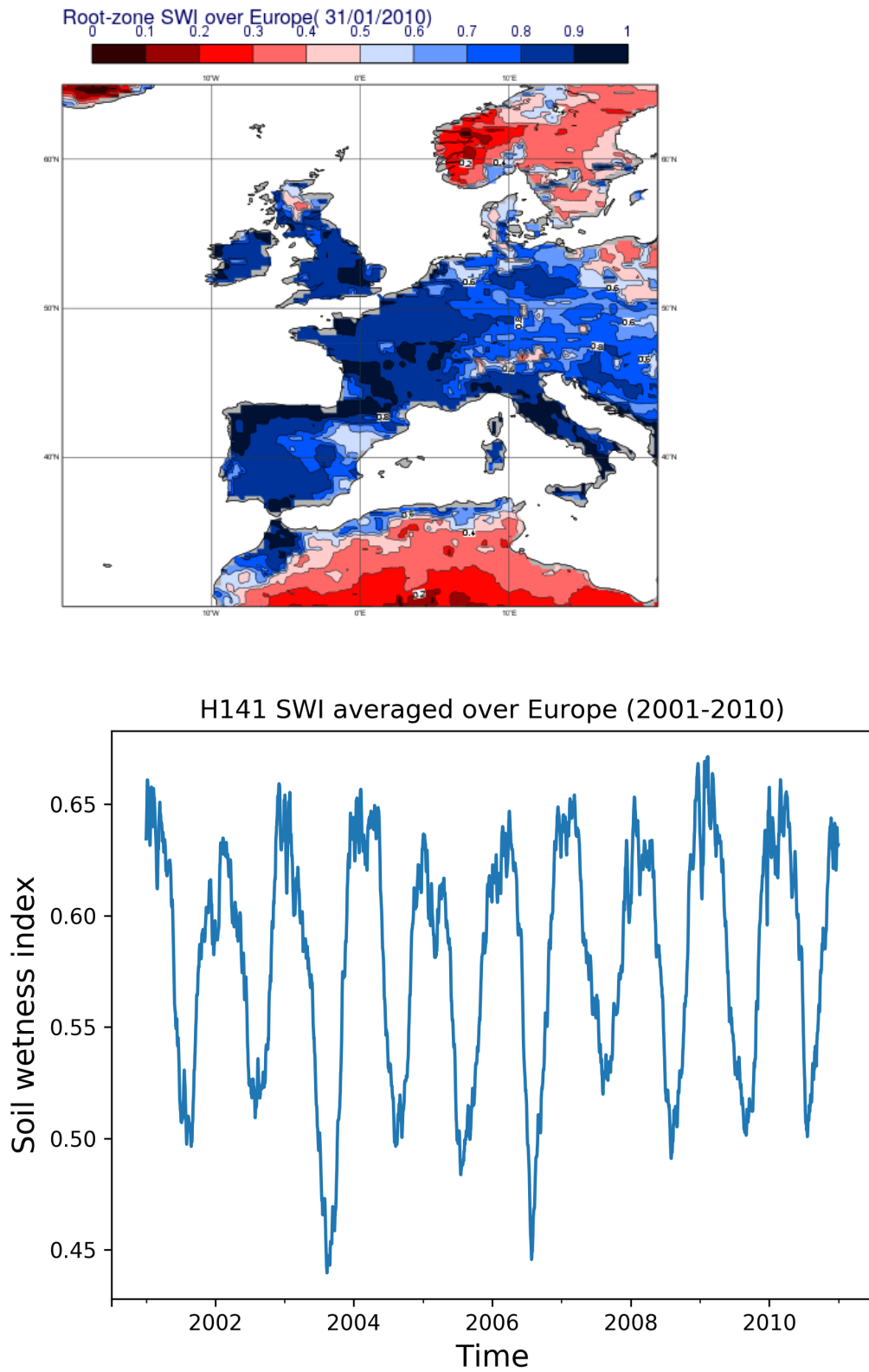
EUMETSAT

H SAF

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 18/24

Figure 5.1: Plot of the root-zone SWI for 31 January 2010 (top) and time series for 2001-2010 (bottom).

H SAF

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 19/24

Table 6.1: Performance requirements for products H14 and H141 [CC]

Unit	Threshold	Target	Optimal
Dimensionless	0.5	0.65	0.8

It is important to consider that the ASCAT-A/B SSM products are swath-based, whereas H141 and H142 (like H14) are daily gridded products with a global coverage. The root zone soil wetness generation relies on land data assimilation, which ensures the ASCAT information is propagated in space and time, even when there are gaps in ASCAT-A/B/C observations. So, the land surface model component ensures the soil wetness evolution until the next ASCAT-A/B observations are available. In some areas the ASCAT-A/B/C SSM observations are seasonally or permanently not available. It is the case over tropical forests, mountainous areas, in frozen or in snow covered conditions. In these conditions the production of the root zone soil moisture entirely relies on the land surface model which ensures physically-based soil moisture evolution in the absence of ASCAT-A/B/C observations.

6. Validation

Following the previous data record (H27/H140) approach, H141 is assessed using the temporal correlation against ground measurements. Additional metrics, including the anomaly correlation coefficient, the root-mean-square error and the bias are also considered. Furthermore, the previous data record product H27/H140 is used as a benchmark to validate the performance of H141 over the period when the data records overlap (1992-2016). Table 6.1 presents the soil wetness index user requirements originally adopted in the H SAF Second Continuous Development and Operations Phase CDOP-2 and also used for the near-real-time (NRT) product (H14) and the H141 data record in the third development phase (CDOP-3). Details and results regarding the validation can be found in the Product Validation Report [10]. The performance of the H142 offline extension is not validated since is assumed to be comparable to H141.

7. Product availability

7.1. Download

The soil moisture data records are available via FTP. The H141 data record and H142 extension products can be found in the "products" directory. The H141 product is already available for 1992-2018. The H142 product is released at a yearly frequency at the start of each year. For example, the 2019 extension will be available in the first quarter of 2020. Download details are available after registering at the H SAF website[6]. If you need help, please contact the H SAF user helpdesk[7].

7.2. Conditions of use and citations

All H SAF products are owned by EUMETSAT, and the EUMETSAT SAF Data Policy applies. They are available for all users free of charge. Users should recognize the respective roles of EU-

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[6]http://hsaf.meteoam.it

[7]us_hsaf@meteoam.it

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 20/24

METSAT, the H SAF Leading Entity and the H SAF Consortium when publishing results that are based on H SAF products. EUMETSAT's ownership and intellectual property rights into the SAF data and products is best safeguarded by simply displaying the words "© EUMETSAT" under each of the SAF data and products shown in a publication or website. The H141 data record should be cited as [11] (the DOI will be confirmed shortly).

8. Conclusion

The H141 data record product consists of a unique historically consistent scatterometer derived root zone soil wetness index database over the period 1992-2018. Its offline product H142 will extend the H141 data record to the end of the CDOP-3 (2019-2021), at a yearly frequency. The products result from data assimilation which enables the propagation of the surface soil moisture information observed by scatterometers (ERS 1/2 and ASCAT-A/B/C) to the root zone, taking into account the consistency with ERA5 atmospheric fields used to force the offline LDAS.

The 10 km resolution H141 product is provided daily as a soil wetness index across the four root-zone layers. It is provided in two different file formats: 1) An octahedral reduced Gaussian grid ($T_{CO}1279$) in GRIB format, which has approximately equidistant grid points between the equator and the poles, and 2) a regular lat/lon grid in netCDF format. Both files are compressed to reduce the storage requirements. Most standard software packages are better suited to reading in netCDF with regular lat/lon grids than GRIB files with irregular grids. Nevertheless, recently ECMWF has developed the metview-python software package that can handle the GRIB files directly. For the benefit of the different users, both file types are provided. Examples of reading and plotting the data are provided or referenced in this document.

More information about the data assimilation theory can be found in the H141 algorithm theoretical baseline document [7]. A comprehensive validation against in situ measurements can be found in the product validation report [10], which demonstrates that the product fulfills its performance requirements.

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Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 21/24

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EUMETSAT
H SAF

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 22/24

Appendices

A. Introduction to H SAF

H SAF is part of the distributed application ground segment of the "European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)". The application ground segment consists of a Central Application Facilities located at EUMETSAT Headquarters, and a network of eight "Satellite Application Facilities (SAFs)", located and managed by EUMETSAT Member States and dedicated to development and operational activities to provide satellite-derived data to support specific user communities (see Figure A.1):
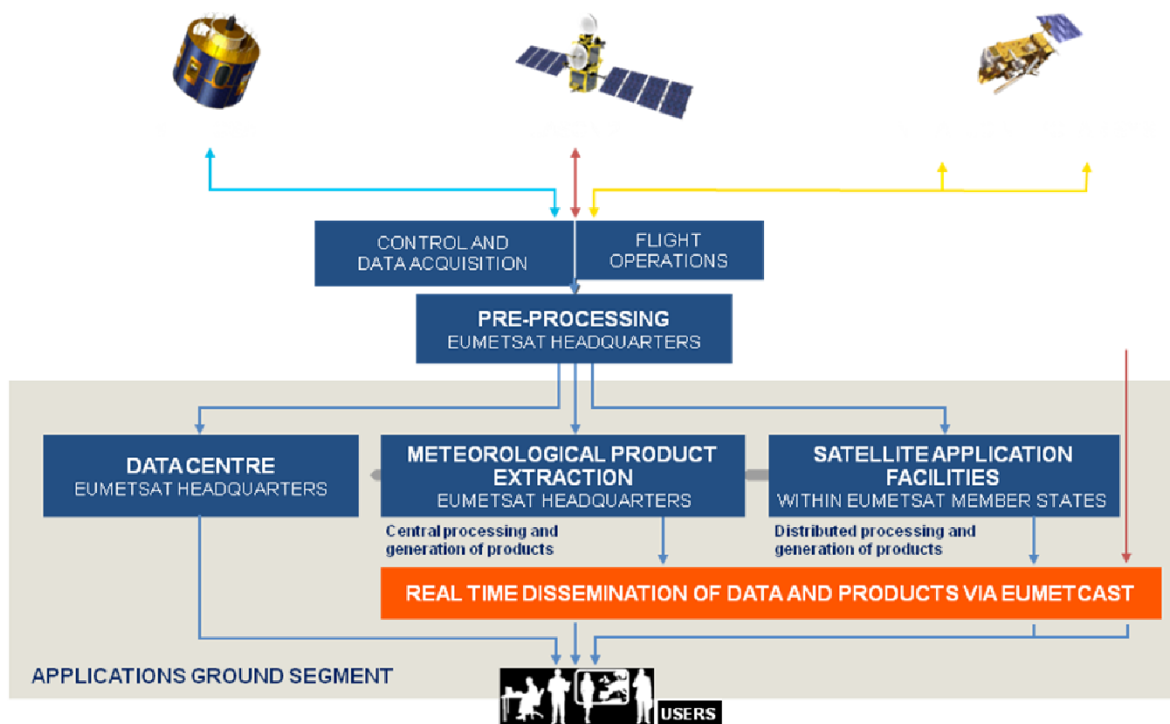

Figure A.1: Conceptual scheme of the EUMETSAT Application Ground Segment.

Figure A.2 here following depicts the composition of the EUMETSAT SAF network, with the indication of each SAF's specific theme and Leading Entity.

B. Purpose of the H SAF

The main objectives of H SAF are:

a) to provide new satellite-derived products from existing and future satellites with sufficient time and space resolution to satisfy the needs of operational hydrology, by generating, centralizing, archiving and disseminating the identified products:

- precipitation (liquid, solid, rate, accumulated);
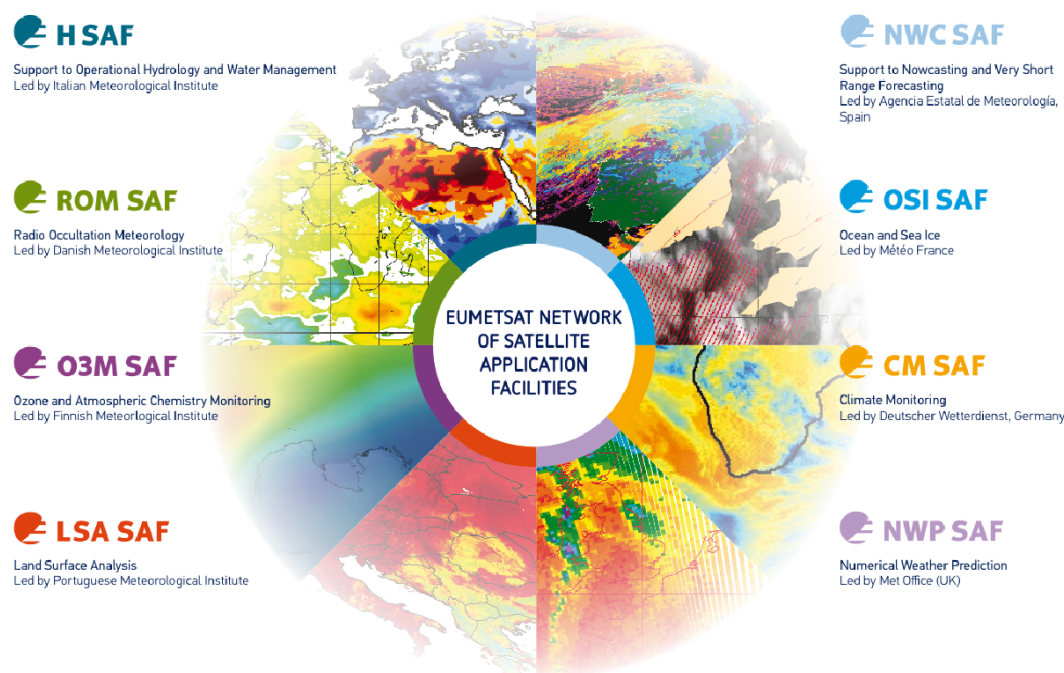- soil moisture (at large-scale, at local-scale, at surface, in the roots region);

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 23/24

Figure A.2: Current composition of the EUMETSAT SAF Network.

- snow parameters (detection, cover, melting conditions, water equivalent);

b) to perform independent validation of the usefulness of the products for fighting against floods, landslides, avalanches, and evaluating water resources; the activity includes:

- downscaling/upscaling modelling from observed/predicted fields to basin level;
- fusion of satellite-derived measurements with data from radar and raingauge networks;
- assimilation of satellite-derived products in hydrological models;
- assessment of the impact of the new satellite-derived products on hydrological applications.

C. Products / Deliveries of the H SAF

For the full list of the Operational products delivered by H SAF, and for details on their characteristics, please see H SAF website hsaf.meteoam.it. All products are available via EUMETSAT data delivery service (EUMETCast[1]), or via ftp download; they are also published in the H SAF website[2].

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

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[1]http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/index.html
[2]http://hsaf.meteoam.it

Product User Manual (PUM)
H141 and H142

Doc.No: SAF/HSAF/CDOP3/PUM/
Issue/Revision: 0.3
Date: 2020/03/12
Page: 24/24

D. System Overview

H SAF is lead by the Italian Air Force Meteorological Service (ITAF MET) and carried on by a consortium of 21 members from 11 countries (see website: hsaf.meteoam.it for details)

Following major areas can be distinguished within the H SAF system context:

- Product generation area

- Central Services area (for data archiving, dissemination, catalogue and any other centralized services)

- Validation services area which includes Quality Monitoring/Assessment and Hydrological Impact Validation.

Products generation area is composed of 5 processing centres physically deployed in 5 different countries; these are:

- for precipitation products: ITAF CNMCA (Italy)

- for soil moisture products: ZAMG (Austria), ECMWF (UK)

- for snow products: TSMS (Turkey), FMI (Finland)

Central area provides systems for archiving and dissemination; located at ITAF CNMCA (Italy), it is interfaced with the production area through a front-end, in charge of product collecting. A central archive is aimed to the maintenance of the H SAF products; it is also located at ITAF CNMCA.

Validation services provided by H SAF consists of:

- Hydrovalidation of the products using models (hydrological impact assessment);

- Product validation (Quality Assessment and Monitoring).

Both services are based on country-specific activities such as impact studies (for hydrological study) or product validation and value assessment. Hydrovalidation service is coordinated by IMWM (Poland), whilst Quality Assessment and Monitoring service is coordinated by DPC (Italy): The Services activities are performed by experts from the national meteorological and hydrological Institutes of Austria, Belgium, Bulgaria, Finland, France, Germany, Hungary, Italy, Poland, Slovakia, Turkey, and from ECMWF.