H-SAF PRODUCTS APPLICATION
SOIL MOISTURE FOR HYDROLOGICAL RISK MANAGEMENT

Rome, 13-16/11/2018

H-SAF root-zone soil moisture products

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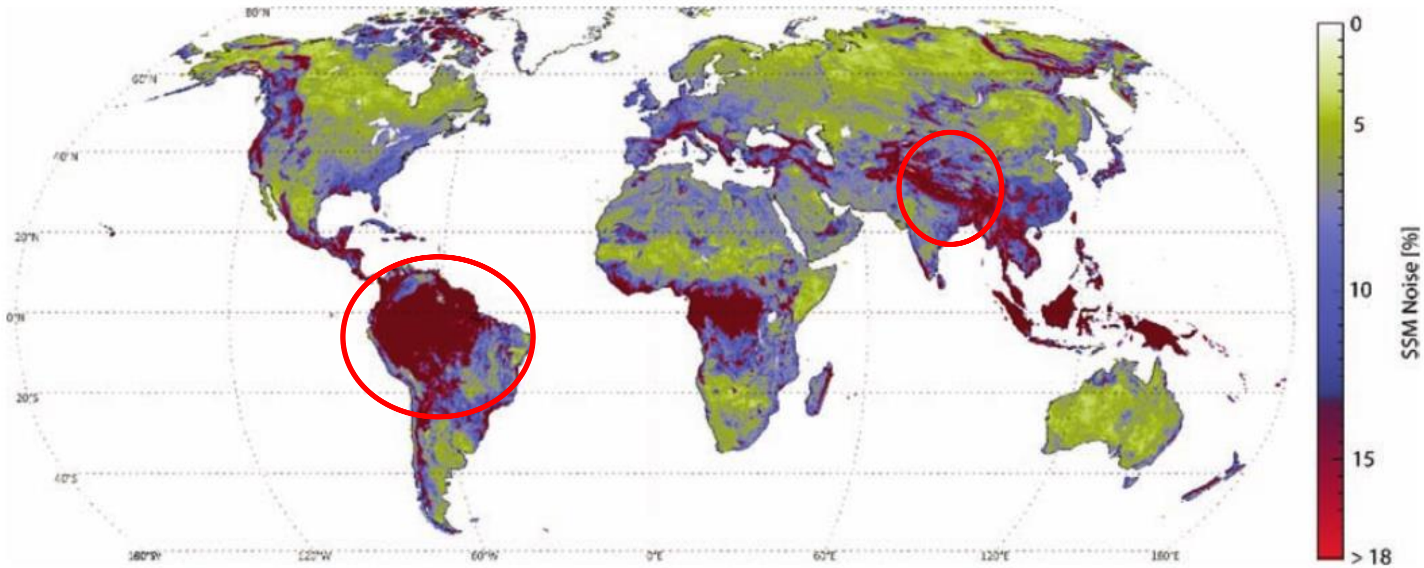
Section 1

Introduction to data assimilation

ASCAT-derived observations

- Satellite derived global observations from the Advanced Scatterometer (ASCAT) measure the top few centimetres of soil;
- Soil moisture derived from C-band low-frequency microwave signal using the change detection technique (Wagner *et al*., 1999; Bartalis *et al*., 2007)
- ASCAT-derived surface soil moisture (SSM) observations are generally quite accurate (Unbiased RMSE of ~ 0.04 m^3/m^3 according to Brocca et al. (2010));
- However, the frequency of the observations is limited by the temporal sampling of the satellite swath (~ every 2 days in midlatitudes);
- Observations are not able to detect frozen soil moisture content and are unreliable in highly vegetated regions (e.g. Amazon rainforest) and mountainous regions (e.g. Himalayas).

ASCAT observation accuracy



Estimate of noise (%) in ASCAT-derived observations. From Figure 6 of Wagner et al (2013). Based upon the methods presented in Naiemi et al. (2009).

- Most areas have a high signal-to-noise ratio. But observations in highly vegetated regions and mountainous regions are noisy.

Land surface models

- Land surface models (LSMs) provide continuous and spatially complete estimates of root-zone soil moisture and other land related variables e.g. snow. They are forced by atmospheric variables, notably precipitation and radiative forcing;

- The atmospheric forcing for LSMs typically comes from reanalyses or a Numerical Weather Prediction forecast;

- The land surface models require parameterizations (e.g. soil texture, vegetation type), which are not always accurate;

- Errors in root-zone soil moisture from LSMs are significant in some regions due to model errors and/or errors in the atmospheric forcing.

H-TESSEL land surface model

- 8 vegetation tiles
- 7 soil textural types (H-TESSEL)

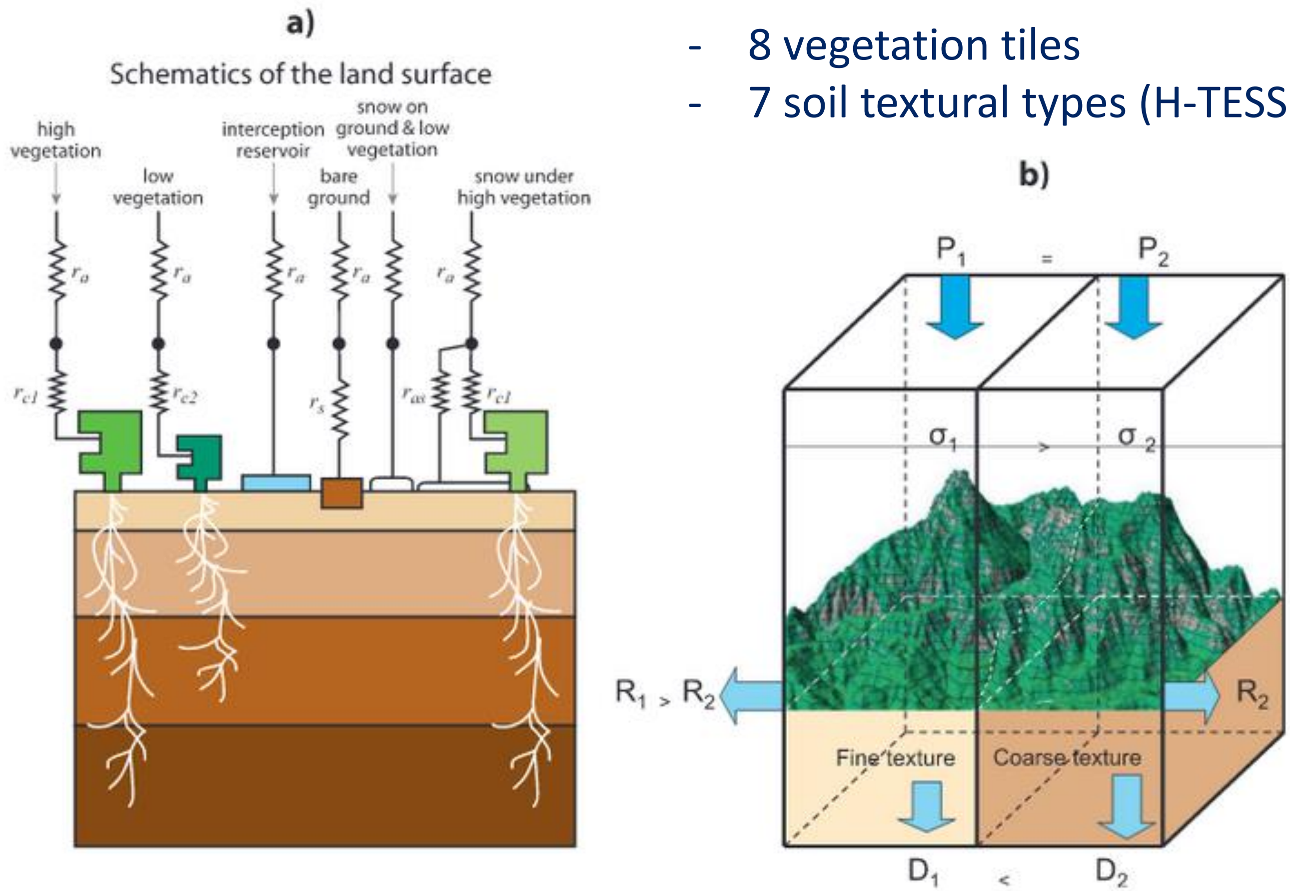


Figure 1: Schematic representation of the structure of (a) TESSEL land-surface scheme and (b) spatial structure added for H-TESSEL. From Balsamo *et al* (2009).

Data assimilation

- Data assimilation (DA) aims to optimally combine observations with a model simulation, by weighting them according to their respective uncertainties;

- The ASCAT-derived SM observations are accurate in most regions, but can only observe the top few centimetres of soil. Also they are unreliable in certain areas and not frequent enough for some operational applications.

- The LSM ensures a continuous and complete global coverage of root-zone soil moisture, but suffers from model/forcing errors;

- The DA algorithm assimilates the ASCAT-derived SSM observations into the LSM, enabling the ASCAT observations to improve the entire root-zone soil moisture profile (0-1 m), while maintaining a continuous and complete global coverage.

Section 2

NRT root-zone soil wetness index product (H14)

H14 NRT root-zone SWI

- H14 is the near-real-time (NRT) root-zone soil wetness index (SWI) product at 25 km resolution and is bounded between 0 (residual soil moisture) and 1 (saturation);

- H14 consists of global daily (00 UTC) grib files of the four model layers and a quality control flag (since October 2018). It has a latency of 12-36 hours;

- H14 is produced by assimilating a near-real-time (NRT) ASCAT-A/B derived SSM product from EUMETCAST (H16) into the H-TESSEL LSM using a simplified Extended Kalman Filter (SEKF, de Rosnay et al, (2012)). It is run independently of the ECMWF NWP system.

- Additionally, H14 assimilates observations of 2m temperature and humidity, which ensures consistency between the land surface and the near-surface atmospheric conditions.

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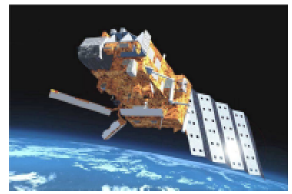
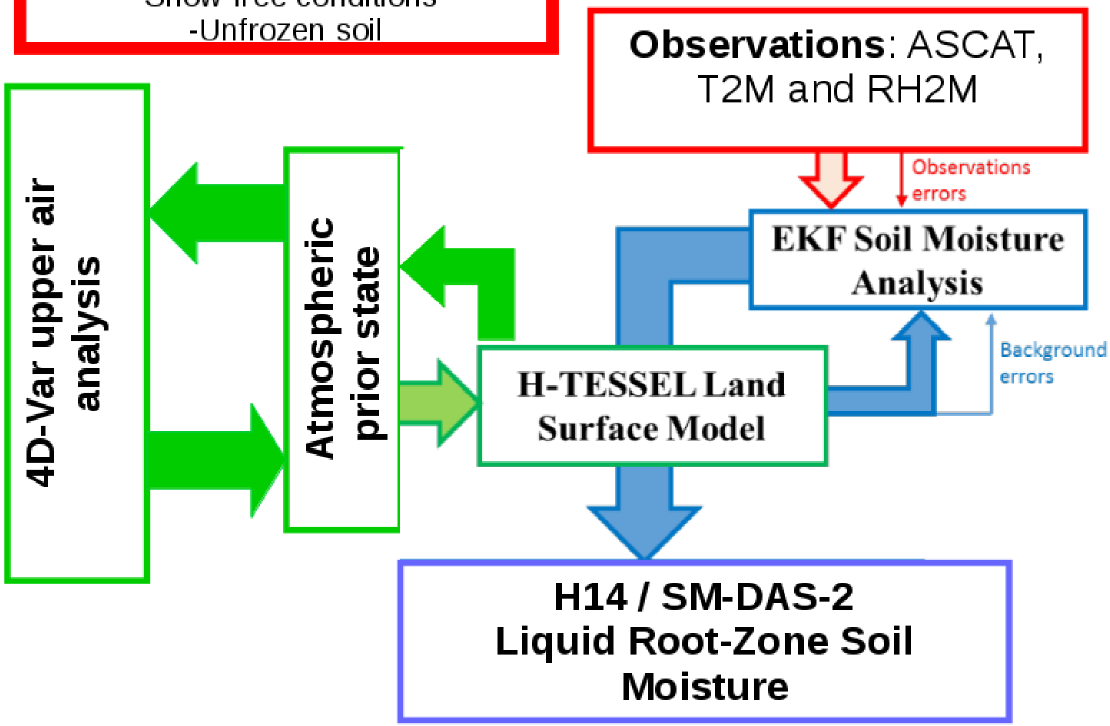
H14 data assimilation

Quality contol
Use data when:
- Topographic complexity ≤ 20
- Wetland fraction ≤ 15
- Noise level ≤ 8
- Snow-free conditions
- Unfrozen soil





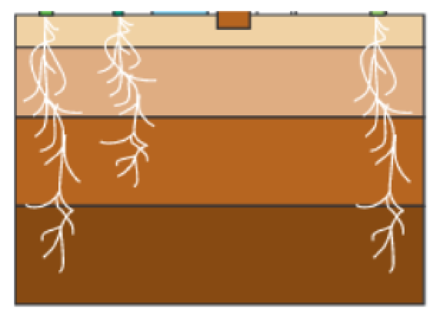
Simplified EKF analysis

$$\mathbf{x}^a(t_i) = \mathbf{x}^b(t_i) + \mathbf{K}_i\left[\mathbf{y}^o(t_i) - \mathcal{H}_i(\mathbf{x}^b)\right],$$

$$\mathbf{K}_i = \left[\mathbf{B}^{-1} + \mathbf{H}_i^T\mathbf{R}^{-1}\mathbf{H}_i\right]^{-1}\mathbf{H}_i^T\mathbf{R}^{-1},$$

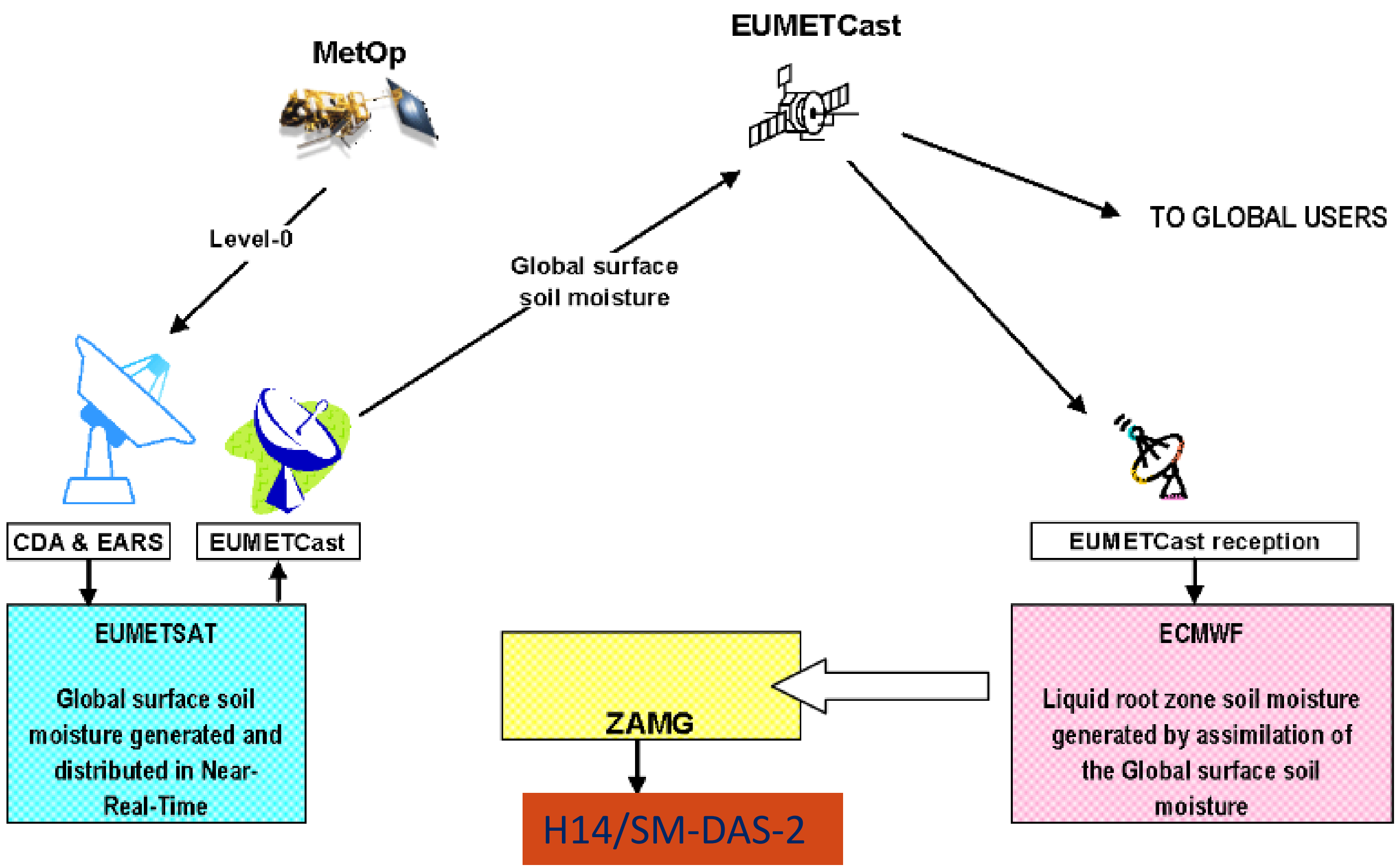
$$\mathbf{H}_{mn,i} = \frac{\mathcal{H}_{m,i}(\mathbf{x}^b + \delta\mathbf{x}_n^b) - \mathcal{H}_{m,i}(\mathbf{x}^b)}{\delta x_n}.$$

SM analysed over first 3 layers in H-TESSEL:
Layer 1: 0-7 cm
Layer 2: 7-28 cm
Layer 3: 28-100 cm
Layer 4 (not analysed): 100-289 cm



- 12 hour assimilation windows
- Produced daily at 00 UTC (12-36 hour latency)

H14 production chain



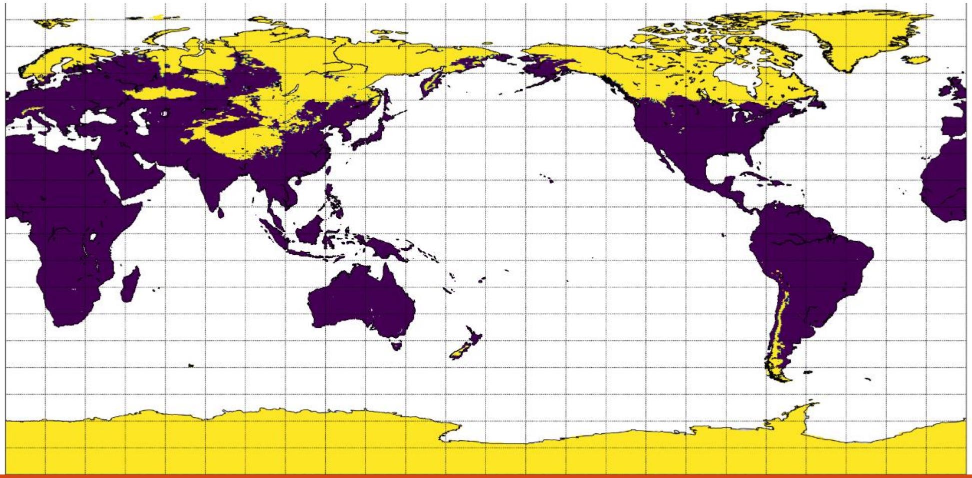
H14 quality control

- The assimilated ASCAT-derived SSM observations (H16) already undergo a rigorous quality control screening (see Sebastian Hahn's presentation)

- On 4/10/18, a quality control flag was introduced for H14, which identifies grid points where there is a risk of frozen conditions (modelled soil temperature in any layer < 4°C):

QC code:
1 = normal;
2 = risk of frozen conditions;
3 = outside nominal range (0-1)

H14 QC flag for 04/10/18



Purple=normal conditions, Yellow=risk of frozen conditions

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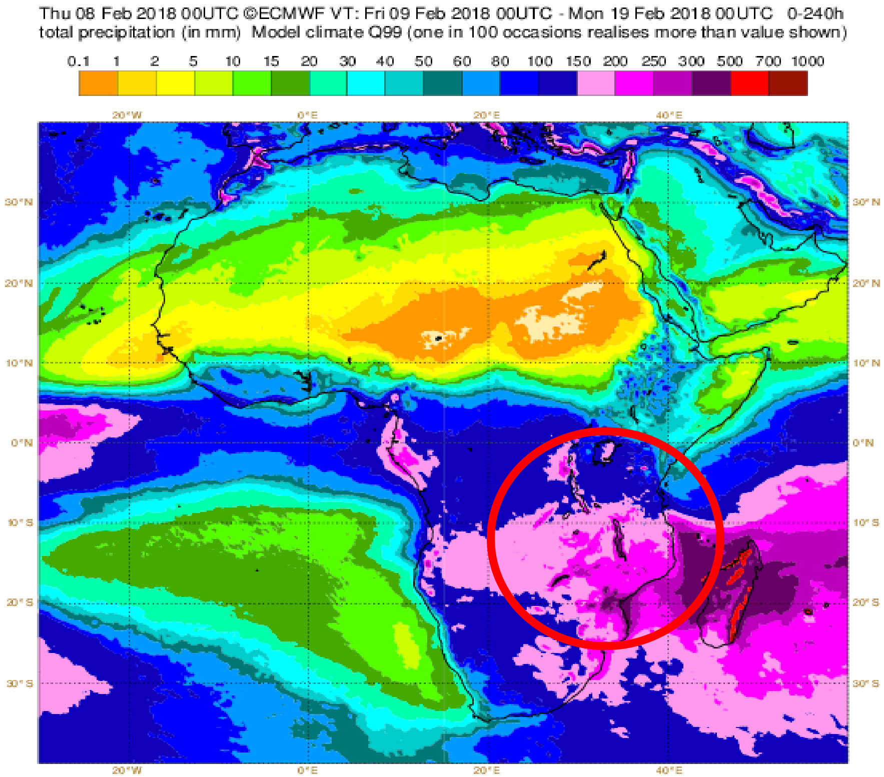
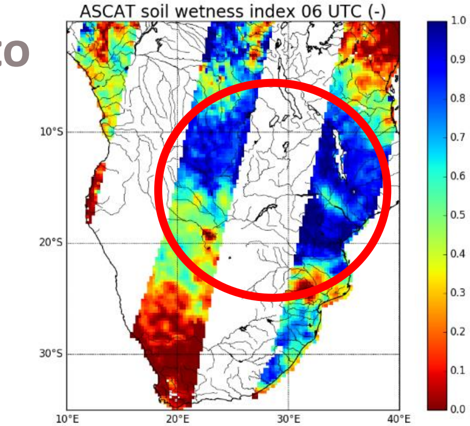
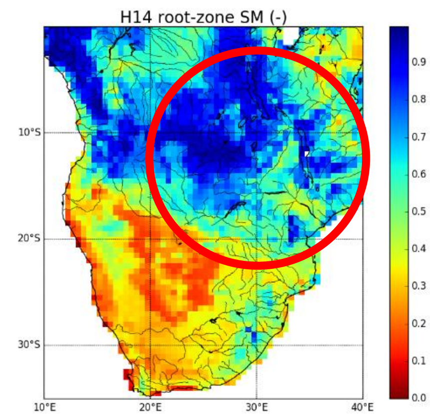
Case study that illustrates the ability of ASCAT to monitor soil moisture in extreme conditions



ECMWF predicts heavy rains in southern Africa (north of Okavango delta) 9/2/18-19/2/18



ASCAT **surface** soil wetness index (12/2/2018)



H14 **Root zone** soil moisture after heavy rains (19/2/18)

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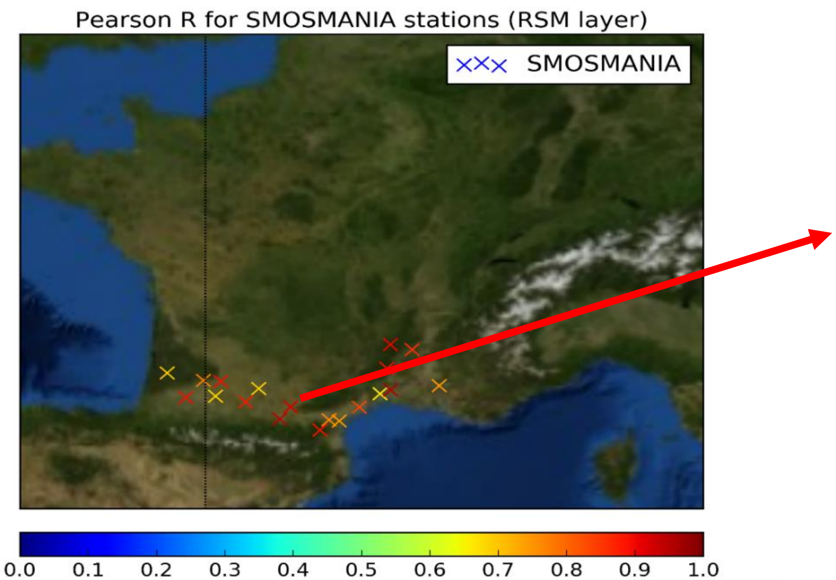
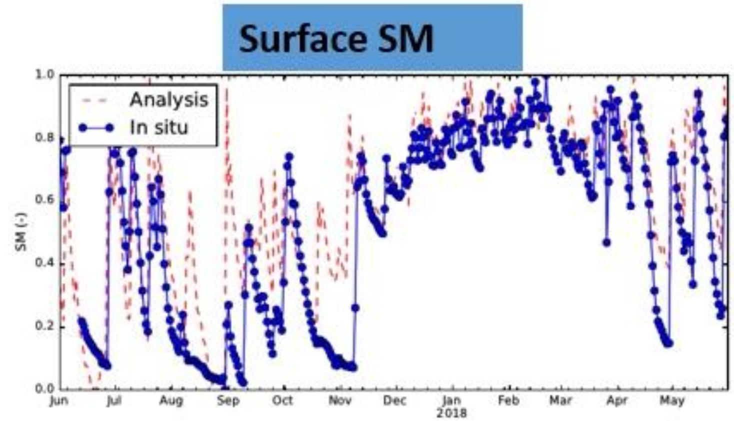
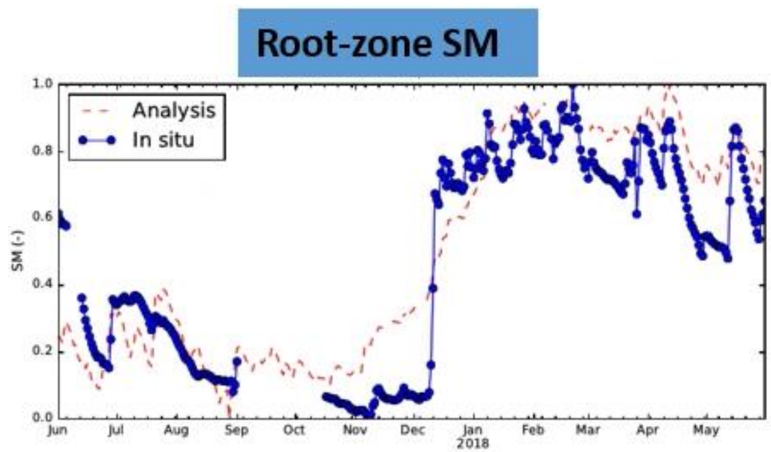
H14 validation

- H14 surface layer (0-7 cm) and root-zone layer (0-100 cm) validated using in situ observations from the US and France from the international soil moisture network (ISMN, Dorigo et al., 2011);
- Latest annual validation (06/2017-05/2018) of H14 performed using 300 observations;
- Average correlation coefficient (h14 vs in situ) = 0.64 (0.70) for surface (root-zone) SM;
- Average RMSD (approximated in volumetric) = 0.07 (0.04) m^3/m^3 for surface (root-zone) SM.





Accuracy requirements for product SM-DAS-2 [R]			
Unit	**Threshold**	**Target**	**Optimal**
Dimensionless	0.50	0.65	0.80



H14 applications

- Example applications:

- Used to validate soil moisture in SCHEME hydrological model at IRM, Belgium (Baguis and Roulin, 2017) and operational hydrological model at NIMH Sofia, Bulgaria (Artinyan, 2012);

- Used to initialize SM in rainfall-runoff model, which was then shown to provide skilful flood prediction over Italy (Massari et al., 2015);

- Validation of evapotranspiration satellite-derived products in central-eastern Europe (Struzik and Kępińska-Kasprzak, 2016);

Section 3

Data record root-zone soil wetness index product (H27/H140)

H27/H140 data record products

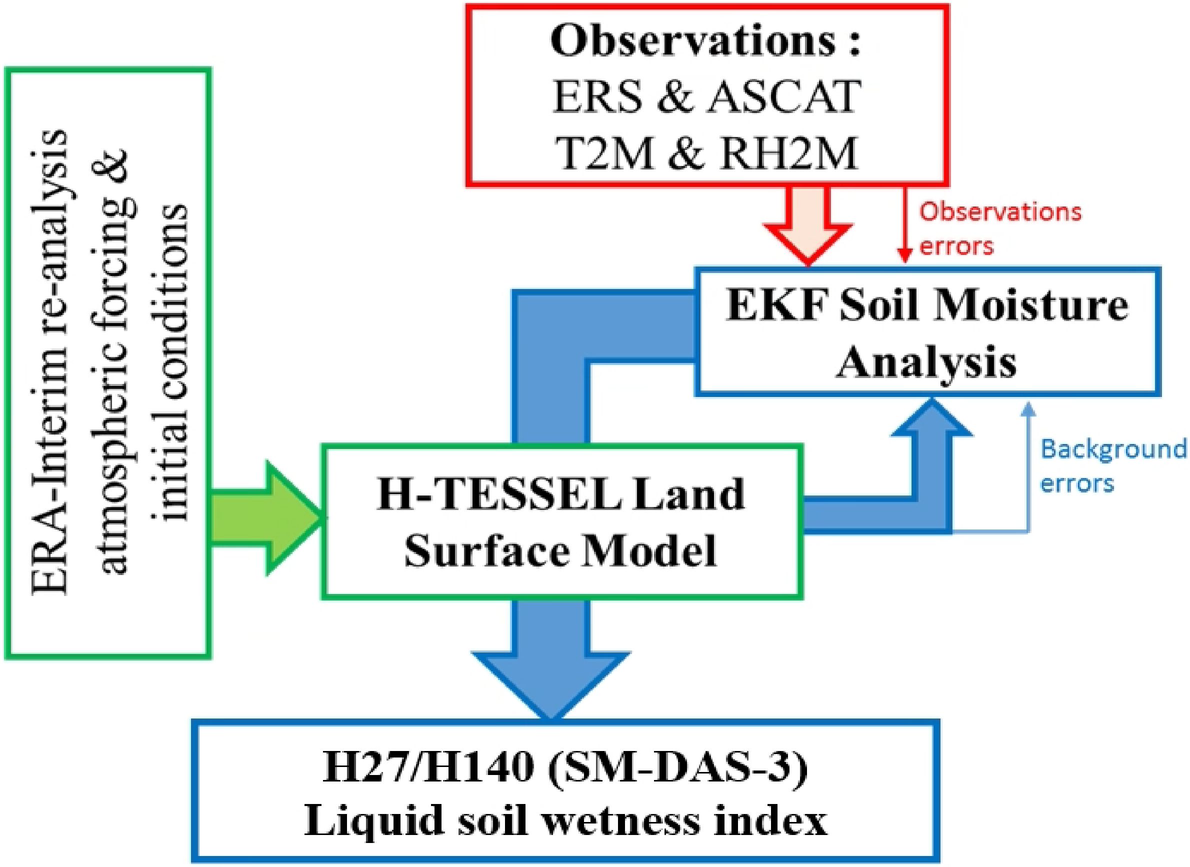
- H27/H140 are the root-zone soil wetness index (SWI) data record products (1992-2016) at 16 km resolution. H27 covers the period (1992-2014) and H140 covers the period (2015-2016);

- H27/H140 consist of global daily (00 UTC) grib files of the four model layers;

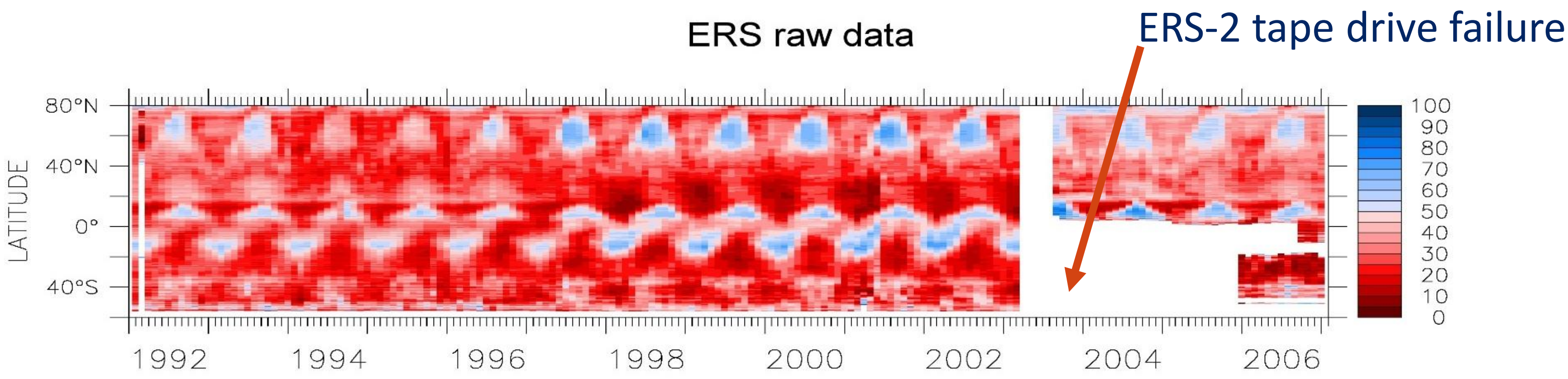
- H27/H140 are produced by assimilating a reprocessed version of ERS-scatterometer (1992-2006) from TuWien and ASCAT-A SSM observations from EUMETCAST (2007-2016), as well as SLV observations (1992-2016).

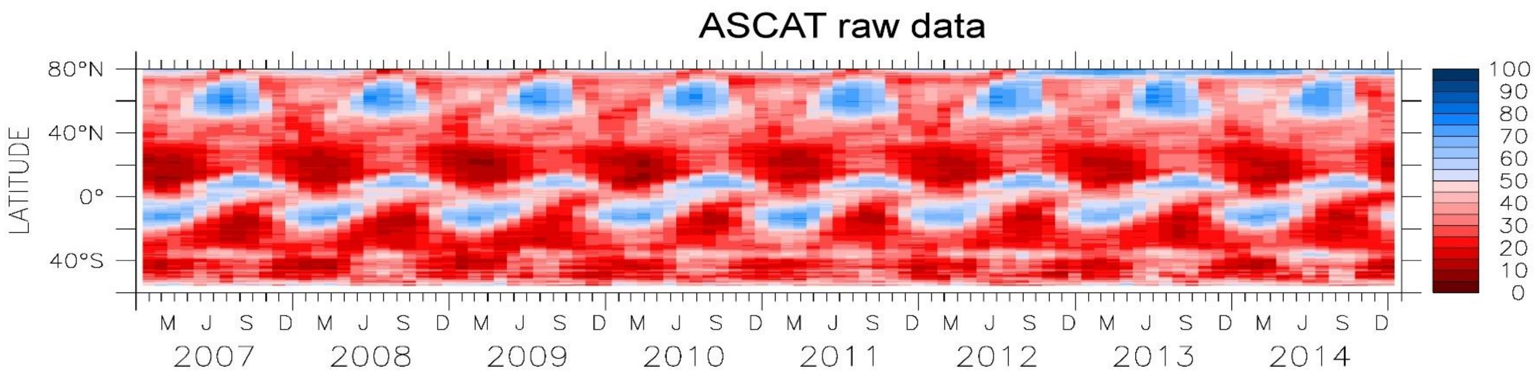
- H27/H140 use an offline version of the ECMWF LDAS with ERA-interim atmospheric forcing.

H27/H140 data assimilation



Scatterometer data coverage



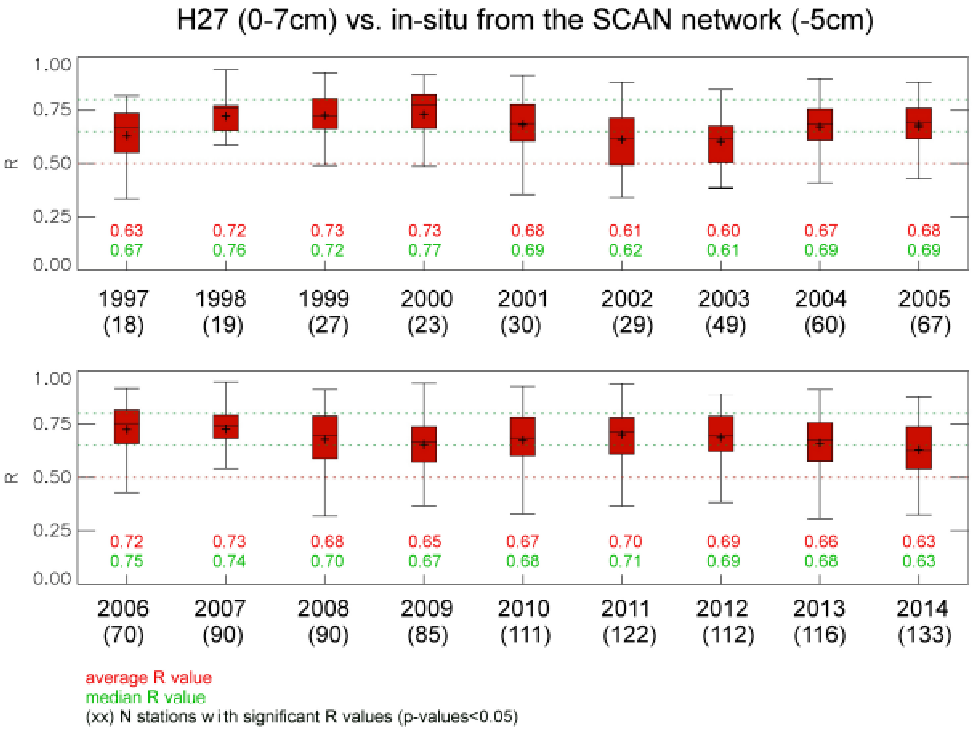


Longitudinal monthly mean of satellite derived surface soil moisture from the ERS-1/2 (top) and ASCAT-A (bottom) over 1992-2006 and 2007-2014, respectively.

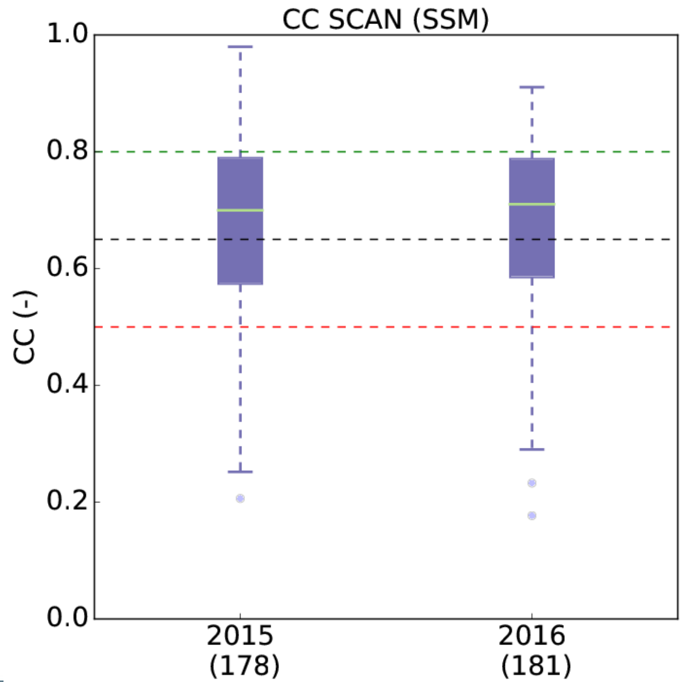
H27/H140 validation

- Validation using in situ observations from the SCAN network in the US (available from 1997).

Accuracy requirements for product SM-DAS-3 [R]			
Unit	**Threshold**	**Target**	**Optimal**
Dimensionless	0.50	0.65	0.80



H140 (0-7cm) vs in situ from SCAN



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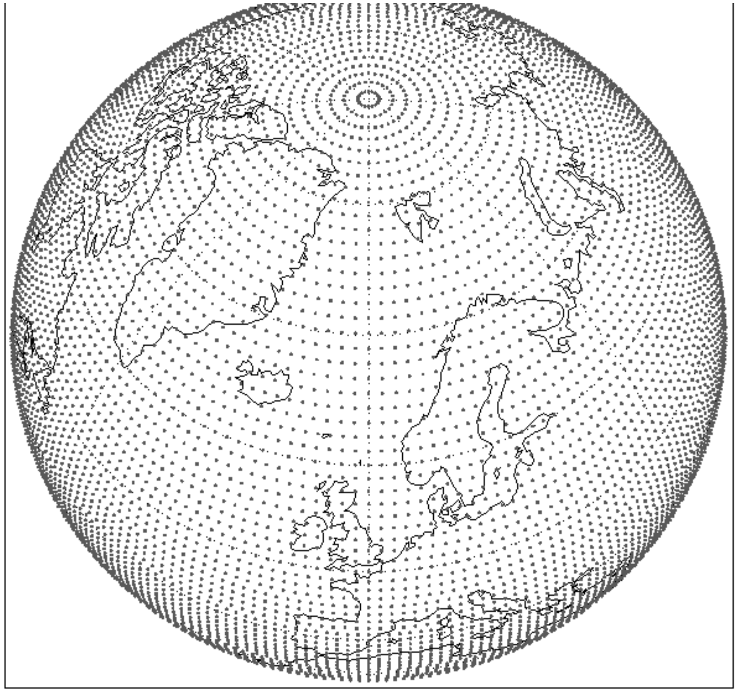
Section 4

Format and documentation

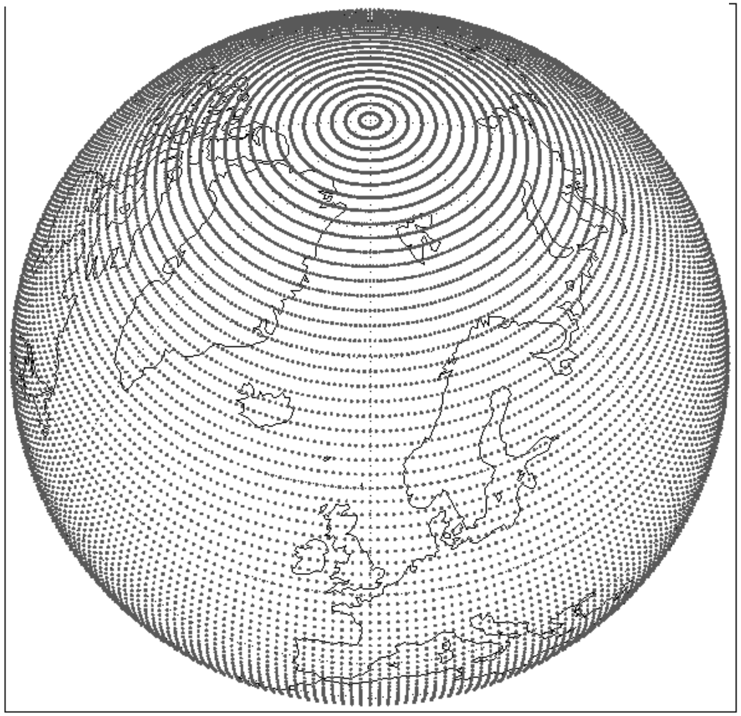
Format

- H14 is available in grib format on a linear reduced Gaussian grid (T799~25 km resolution);
- H27/H140 are available in grib format (T1279~16 km resolution).
- The reduced Gaussian grid maintains approximately equidistant grid-point distances between the poles and the equator (unlike regular lat/lon grid):

Reduced Gaussian grid:



Regular lat/lon grid:



For more info, see https://confluence.ecmwf.int/display/FCST/Gaussian+grids

Download and documentation

- H14, H27 and H140 (soon to be released) daily grib files can be downloaded via the H-SAF ftp: ftp://ftphsaf.meteoam.it/products

The documentation can be found via http://hsaf.meteoam.it/user-documents.php:

- Product user manual
- Algorithm theoretical baseline document
- Product validation report

Section 5

Summary and future products

Summary

- The ECMWF land data assimilation system combines SSM observations with a land surface model in order to improve the root-zone soil moisture profile.

- The H14 NRT root-zone SWI product assimilates ASCAT-A/B derived SSM observations and SLV observations into the H-TESSEL LSM at ECMWF. It uses a NRT atmospheric forecast to force the LSM, but is run independently of the NWP system. H14 is available daily at 25 km resolution (since 2012);

- H27/H140 data record SWI products assimilate reprocessed ERS-scatterometer (1992-2006) and ASCAT-A SSM observations (2007-2016), as well as SLV observations. (1992-2016). The offline H-TESSEL LSM is forced by the ERA-interim reanalysis. They are available at 16 km resolution.

- The products are available to download on the H-SAF ftp in grib format (H140 is soon to be released).

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Table of current products

NRT and data record RSM products

Product name	Type	Period	Obs assimilated	DA system	Resolution	QC flags
H14	NRT	2012 onwards	ASCAT-A/B SSM products	Regular updates of ECMWF LDAS (38R1-45R1)	25 km	**Yes since 4/10/18 (1=normal, 2=frozen risk, 3=outide nominal range)**
H27	Data record	1992-2014	ERS 1/2 (1992-2006) and ASCAT-A (2007-2014) reprocessed SSM	41R1 of ECMWF LDAS	16 km	**None**
H140	Data record	2015-2016	ASCAT-A (2015-2016) reprocessed SSM	43R3 of ECMWF LDAS	16 km	**None**

Future products

- **NRT** from **ASCAT-A/B assimilation: H26** (expected from June 2019) with 10 km resolution.

- **NRT** from **EPS-SGA assimilation: H76** (expected from June 2019) with 10 km resolution.

- **Data record** from **ASCAT-A assimilation**: **H141** (next year release) with 10 km resolution. A yearly release of the data record will follow.

- **Data record** with **EPS-SGA assimilation**: **H77** (expected 2022) with 10 km resolution. A yearly release will follow.

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Thank you for your attention