H SAF Soil Moisture Products, Quality Assessment and Case Studies

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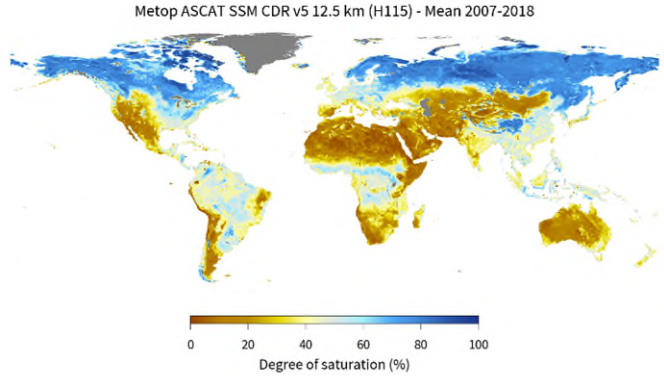
Overview

- H SAF soil moisture products are available
  - at different timeliness
    - Near Real Time (NRT) - shortly after sensing (approx. 130 min)
    - Offline - regular updated data sets (not in NRT, but e.g. daily, monthly)
    - Data Records (DR) - consistent long term data sets
  - at various spatial resolution
    - 1-5 km, 10 km, 25 km, 50 km
  - globally
    - except downscaled SSM products (Europe only)
  - in two product groups
    - Surface Soil Moisture (SSM): topmost soil layer (1-2 cm)
    - Root Zone Soil Moisture (RZSM): 4 layer with thicknesses 0.07, 0.21, 0.72 and 1.89 m

- Soil moisture cluster
  - ZAMG (Cluster leader)
    - Operations of SSM NRT products
  - TU Wien
    - Development of SSM products, SSM DR generation
  - ECMWF
    - Operations and development of all RZSM products

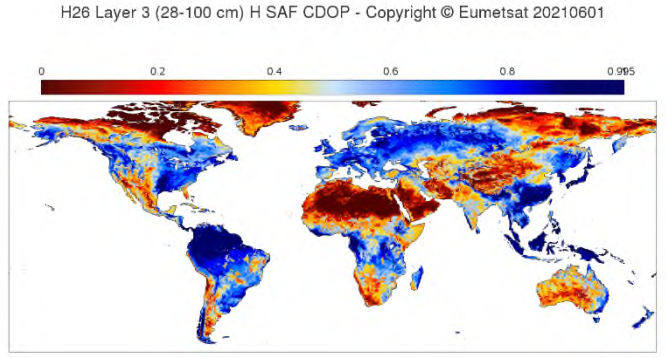
H SAF Surface Soil Moisture and Root-Zone Soil Moisture products

- Surface Soil Moisture (SSM) products
  - Input: Backscatter observations from the Advanced Scattermeter (ASCAT) on-board the series of Metop satellites
  - Method: Semi-empirical change detection algorithm (Wagner et al. 1999)
  - Unit: Degree of saturation (0% - dry, 100% - wet)
  - Spatial resolution: 25 km, 50 km
    - Downscaled SSM products: 1-5 km
  - Vertical resolution: top SM content, 0-2 cm



SM Mean 2007-2018 based on ASCAT SSM CDR v5 12.5 km (SM data not masked)

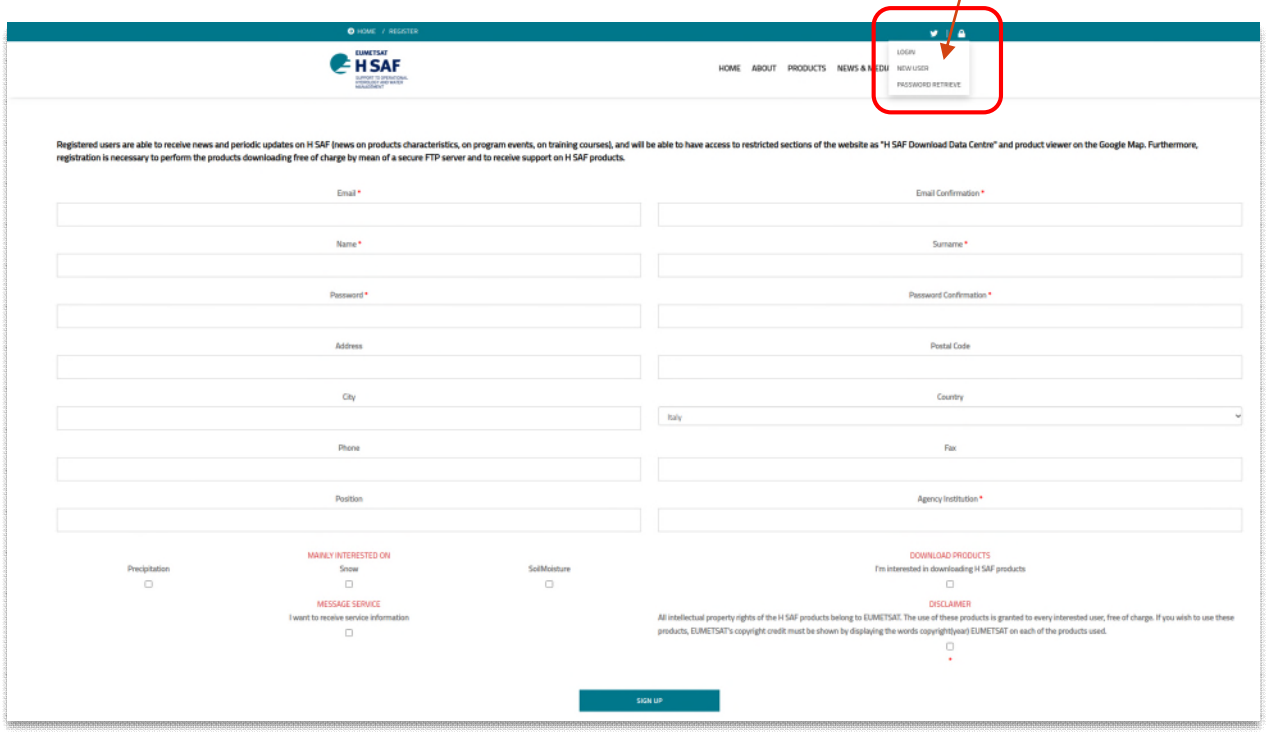
- Root Zone Soil Moisture (RZSM) products
  - Input: H SAF SSM, 2m temperature
  - Method: Data assimilation using a Simplified Extended Kalman Filter (SEKF) into a land surface model
  - Unit: Liquid water content
  - Spatial resolution: 10 km, 25 km
  - Vertical resolution: 4 layers (0-7 cm, 7-28 cm, 28-100 cm, 100-289 cm)



Soil wetness index layer 3 (28-100 cm) based on RZSM-ASCAT-NRT-10km

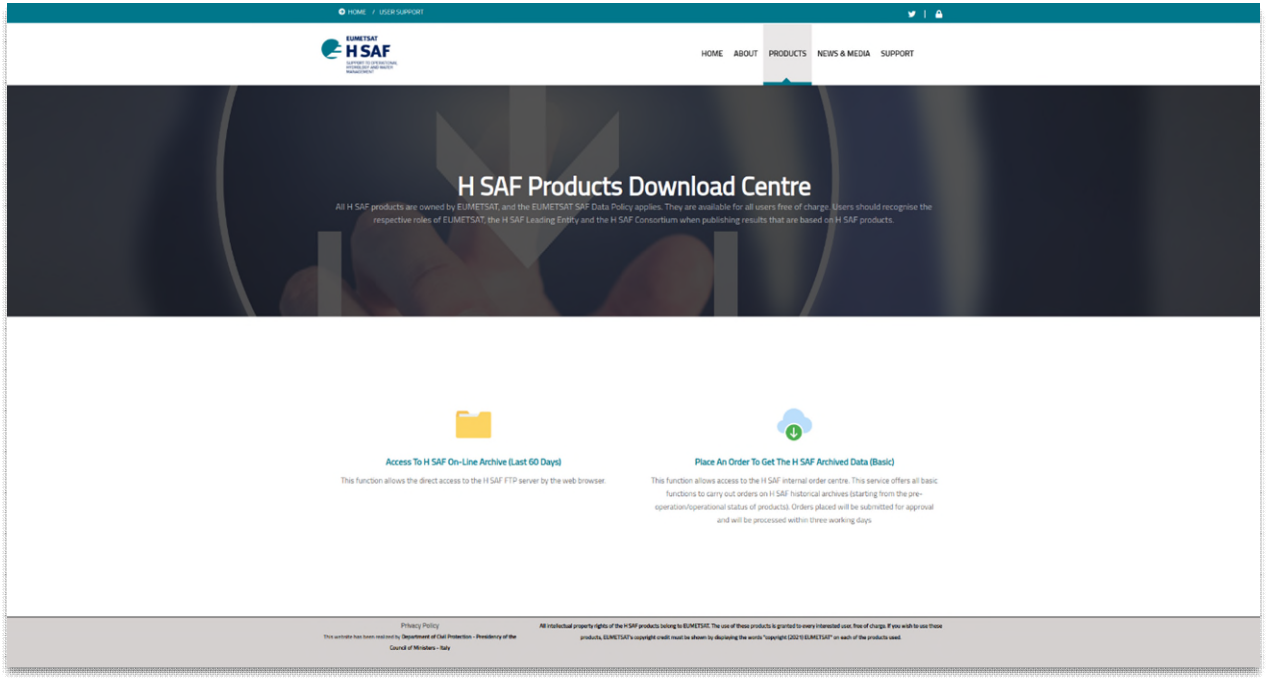
How to access and download H SAF products

- Visit http://h-saf.eumetsat.int/ and fill your details at the user registration page
- Registered H SAF users are able to
  - Receive news and periodic updates on events, training courses, etc.
  - Order and download H SAF products



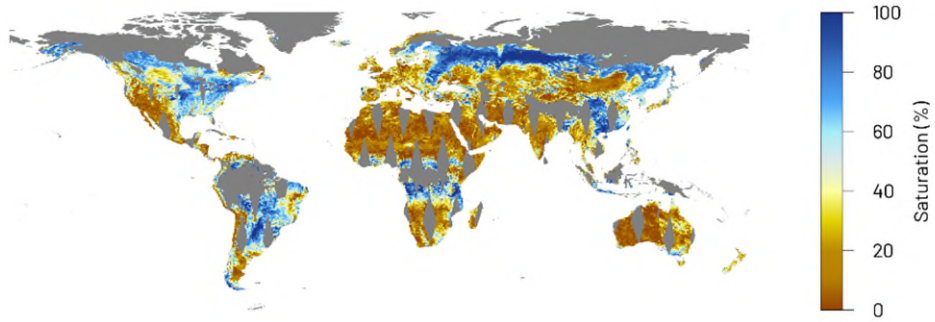
How to access and download H SAF products

- H SAF near real-time (NRT) products can be **downloaded via FTP for the last 60 days**
- Older products (or large data sets) need to be ordered

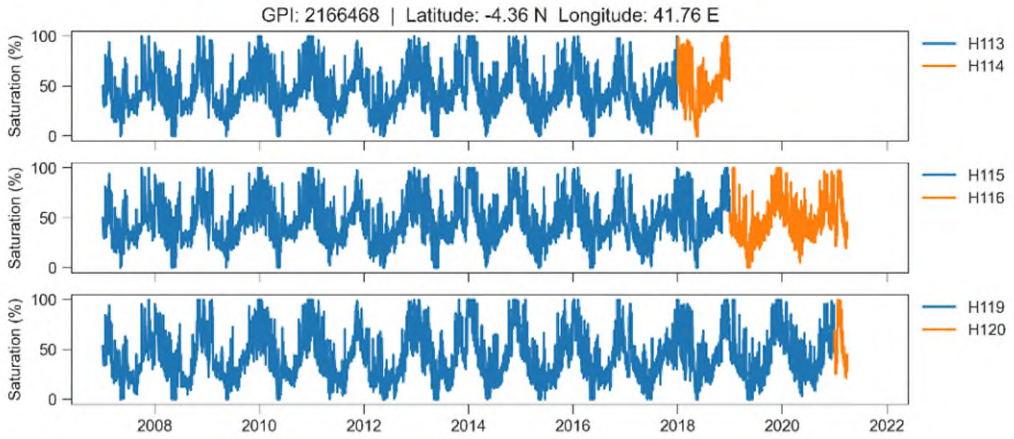


H SAF Surface Soil Moisture (SSM) products

- NRT products
  - ASCAT-B NRT SSM 12.5 km (H16)
  - ASCAT-B NRT SSM 25 km (H103)
  - ASCAT-C NRT SSM 12.5 km (H104)
  - ASCAT-C NRT SSM 25 km (H105)
  - ASCAT NRT SSM 6.25 km (H122)
- Downscaled NRT products
  - ASCAT DIS SSM (H08)
  - ASCAT DIS SSM V2 (H28)
- Data record products
  - ASCAT SSM CDR v5 12.5 km (H115)
  - ASCAT SSM CDR v7 12.5 km (H119)
- Offline products
  - ASCAT SSM CDR v5 Extension (H116) – Extension of H115
  - ASCAT SSM CDR v7 Extension (H120) – Extension of H119



Metop-B ASCAT NRT SSM 12.5 km example - 24 hours.



Time series example of SSM CDR products.

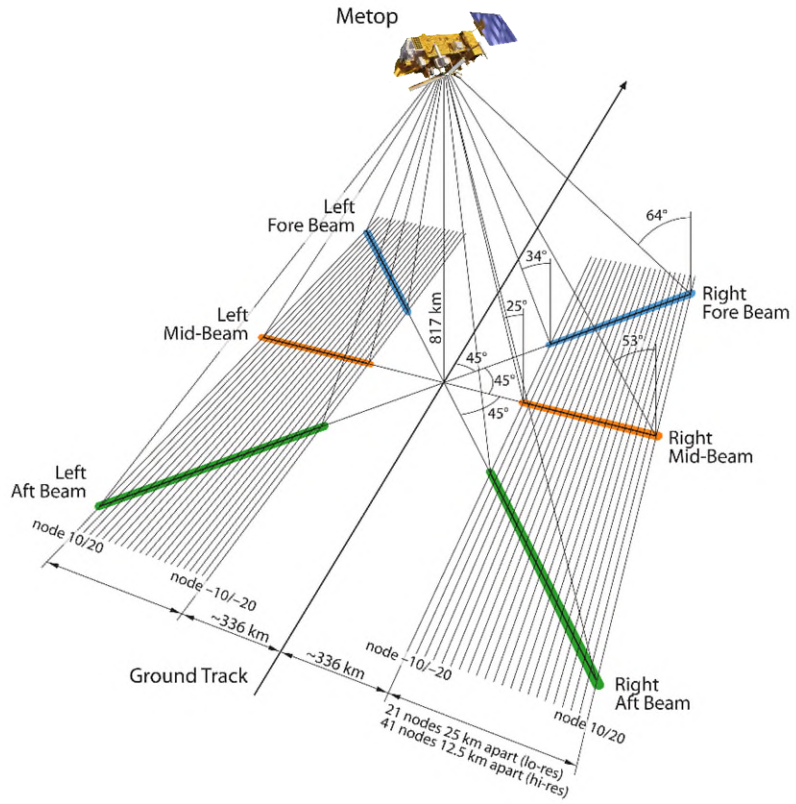
Operational/released

Operational/released by the end of CDOP3

Advanced Scatterometer (ASCAT) on-board Metop

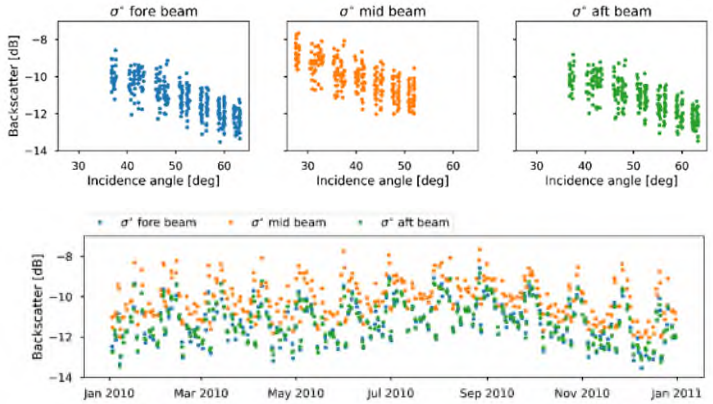
- Sensor characteristics
  - Active microwave scatterometer
  - Frequency: C-band, 5.255 GHz
  - Polarisation: VV
  - Spatial Resolution: 25 km/50 km
  - Antennas: 2 x 3
  - Swath: 2 x 500 km
  - Multi-incidence: 25-65°
  - Daily global coverage: 82 %

- Satellites
  - Metop-A (Oct. 2006 – Nov. 2021)
  - Metop-B (Sep. 2012 – ongoing)
  - Metop-C (Nov. 2018 – ongoing)

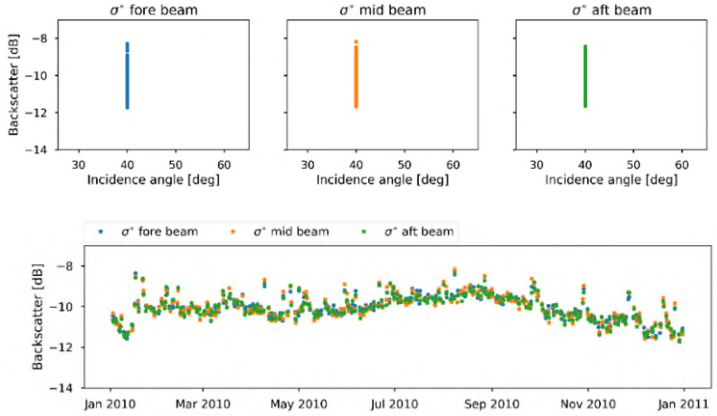


Figa-Saldana, et al., The advanced scatterometer (ASCAT) on the meteorological operational (MetOp) platform: A follow on for European wind scatterometers, Canadian Journal of Remote Sensing, 28(3), 404–412 (2002). http://dx.doi.org/10.5589/m02-035

Original backscatter observations

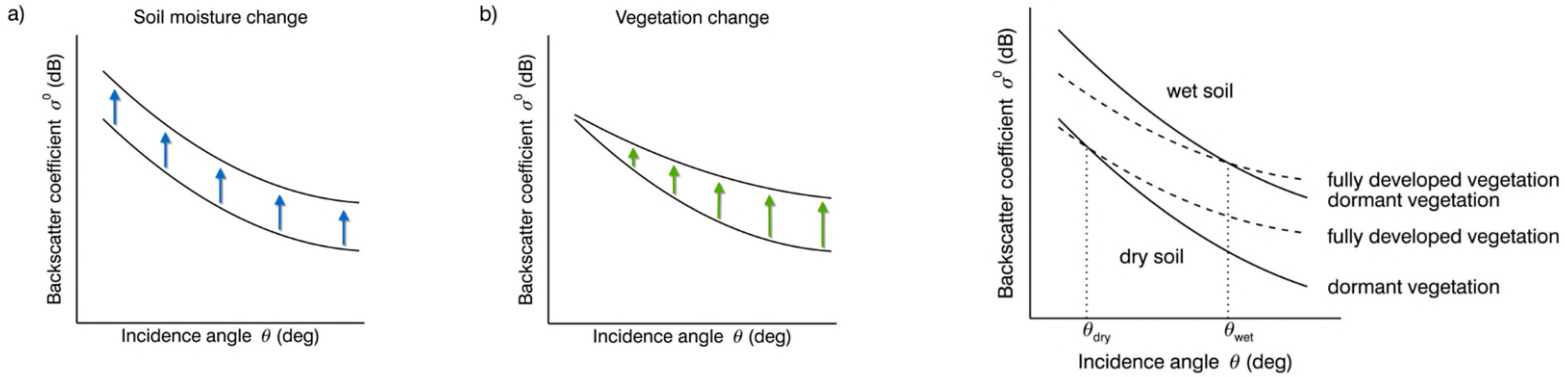


After incidence angle normalization



Backscatter vs. incidence angle over vegetated soil surface

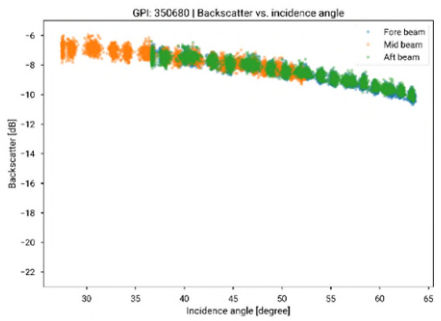
- Backscatter shows a strong dependency on incidence angle
  - With the exception of dense forests, backscatter decreases from near to far range
  - Behaviour is moderated by land surface properties (soil moisture, roughness, biomass, etc.)



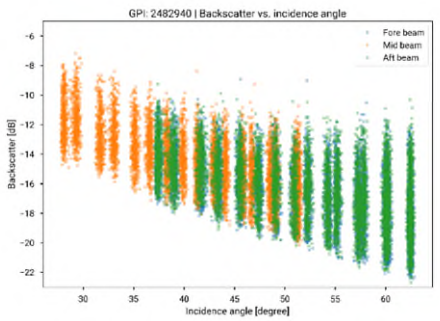
Wagner, W., Lemoine, G., Borgeaud, M., & Rott, H. (1999). A study of vegetation cover effects on ERS scatterometer data. IEEE Transactions on Geoscience and Remote Sensing, 37(2), 938–948. http://dx.doi.org/10.1109/36.752212

Changes in backscatter with land cover and season

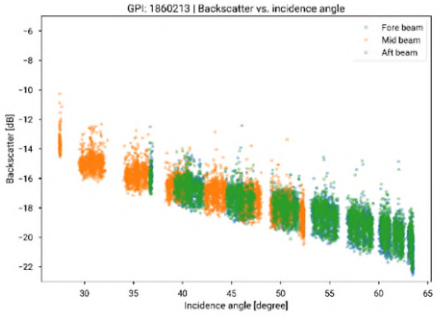
Tropical forest



Agriculture/Grassland



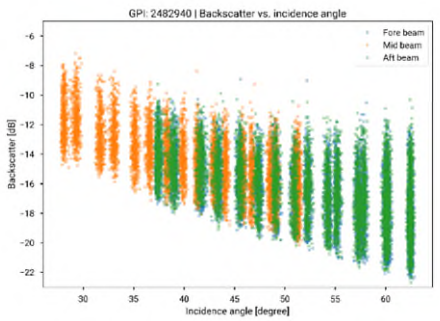
Bare Ground & Low Vegetation



Changes in backscatter with land cover and season

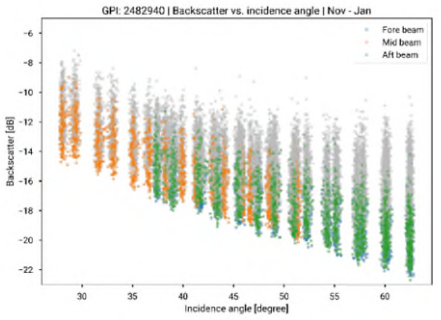
Tropical forest

Agriculture/Grassland

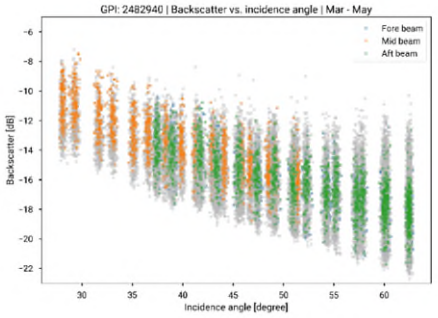


Bare Ground & Low Vegetation

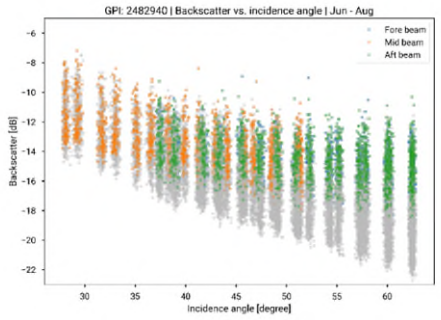
Winter



Spring



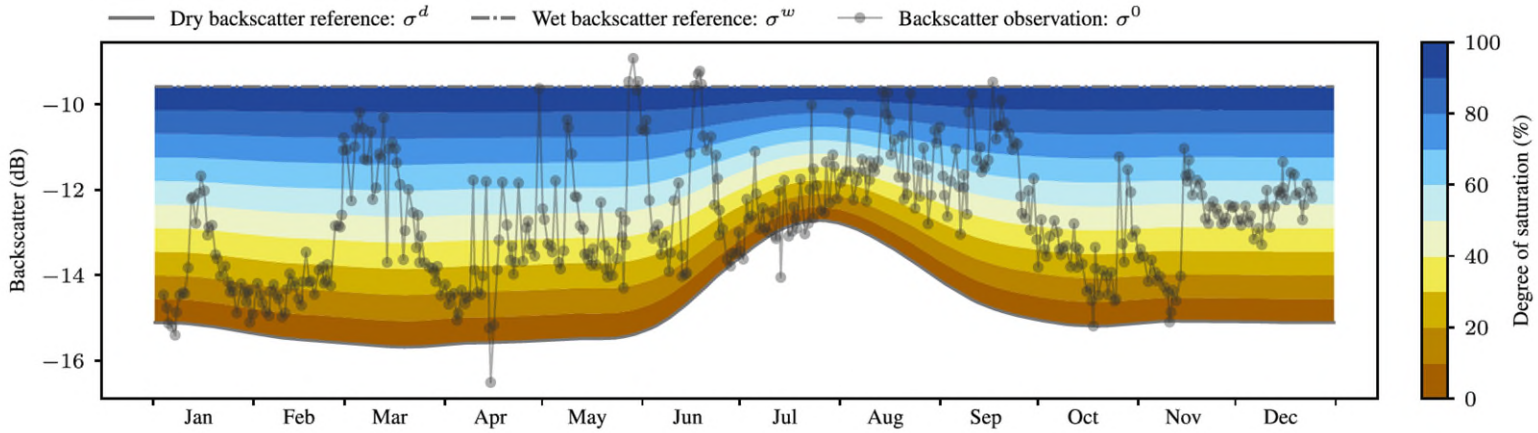
Summer



Soil moisture retrieval

- Soil moisture can be estimated with different types of models
  - Semi-empirical backscatter models using iterative optimization techniques
  - Machine learning
  - **Change detection**

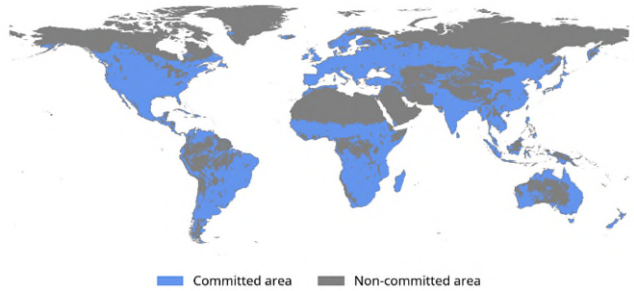
$$m_s(t) = \frac{\sigma^0(t) - \sigma^0_{dry}(t)}{\sigma^0_{wet}(t) - \sigma^0_{dry}(t)}$$



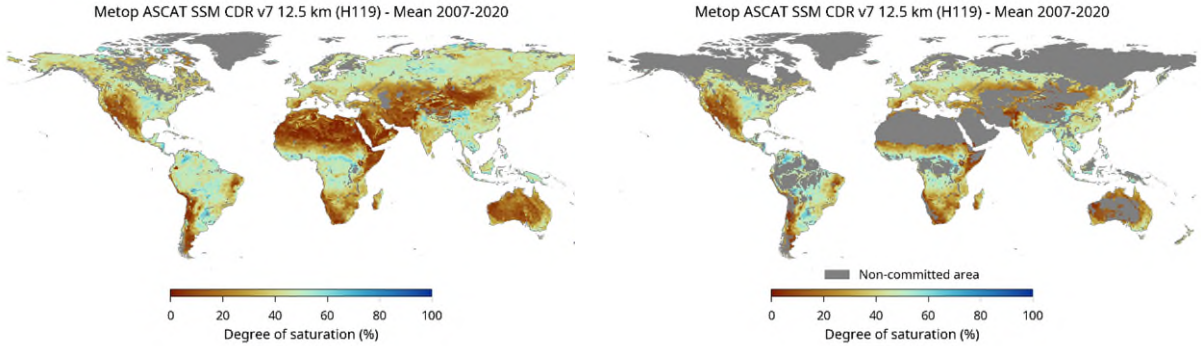
Hahn et al. (2021). Improving ASCAT soil moisture retrievals with an enhanced spatially variable vegetation parameterization. IEEE Transactions on Geoscience and Remote Sensing, 59(10), 8241–8256. http://dx.doi.org/10.1109/tgrs.2020.3041340

Soil moisture retrieval: limitation and caveats

- Interfering factors are
  - Dense forest
  - Snow cover
  - Frozen soil
  - Open water
  - Topographic complex area
- Most suited under following conditions
  - Low to moderate vegetation regimes
  - Unfrozen soil and no snow
  - Low to moderate topographic variations
  - No wetlands and coastal areas.
- Nonetheless, the SSM estimates are computed but flagged
  - Users can decide about masking inaccurate soil moisture values using enclosed advisory and quality flags, as well as external information.



Committed area for ASCAT SSM products.



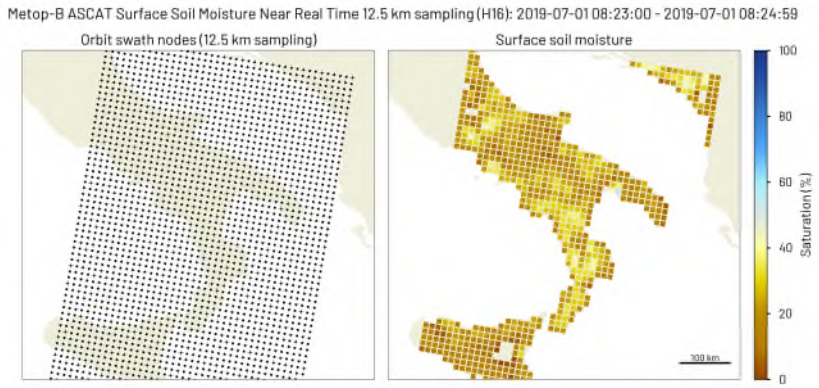
ASCAT SSM CDR v7 12.5 km (H119) – Mean 2007-2020.

H SAF SSM product format

- File format
  - BUFR (Binary Universal Form for the Representation of meteorological data)
    - Binary data format designed to be portable, compact, and universal maintained by WMO
  - NetCDF (Network Common Data Format)
    - Self-describing, machine-independent data format that support the creation, access, and sharing of array-oriented scientific data

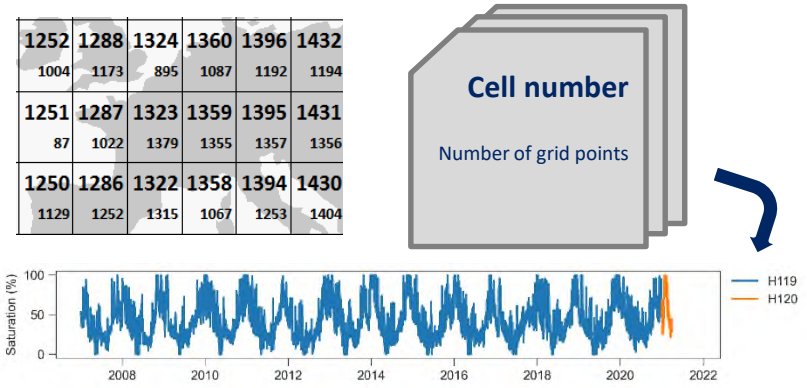
- Data format

ASCAT SSM NRT 12.5 and 25 km



3 min PDU (Processing Distribution Unit) files in orbit geometry.

ASCAT SSM CDR 12.5 km



5x5 degree files containing multiple grid point time series.
(Grid point locator: https://dgg.geo.tuwien.ac.at/)

Quality assessment of ASCAT SSM CDR v5 12.5 km (H115)

- Reference data sets
  - CCI Passive Soil Moisture v4.4
  - Noah Global Land Data Assimilation System (GLDAS) v2.1

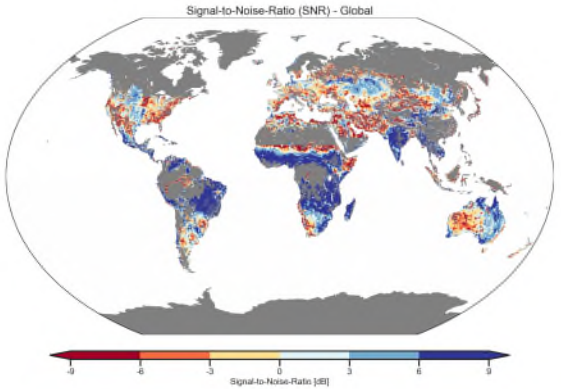
- Masking invalid soil moisture observations
  - Surface State Flag (SSF) - part of the ASCAT SSM DR product
  - Soil temperature & Snow Water Equivalent (SWE) - provided by Noah GLDAS

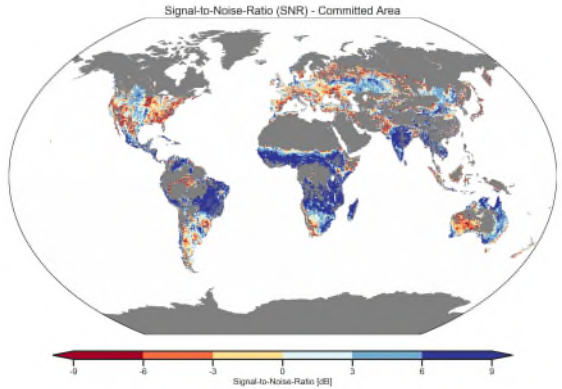
- Keep in mind
  - Find spatial and temporal neighbours (define space and time window)
  - Mismatch of representativeness (i.e. temporal, spatial and/or vertical resolution)

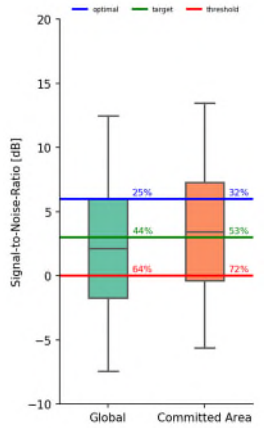
- Validation metrics
  - Signal-to-Noise Ratio (SNR) using Triple Collocation
    - Threshold: 0 dB, Target: 3 dB, Optimal: 6 dB
  - Pearson Correlation Coefficient (R)
    - Threshold: 0.5, Target: 0.65, Optimal: 0.8

Quality assessment of ASCAT SSM CDR v5 12.5 km (H115)

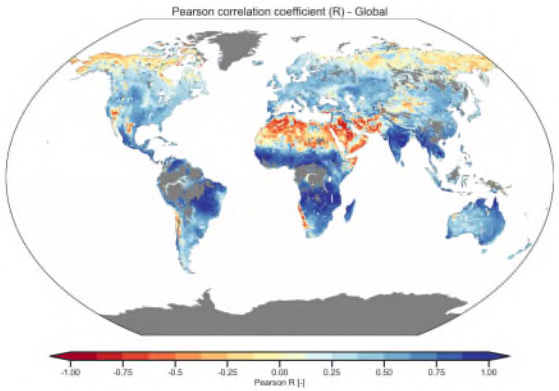
- Signal-to-Noise Ratio (SNR)

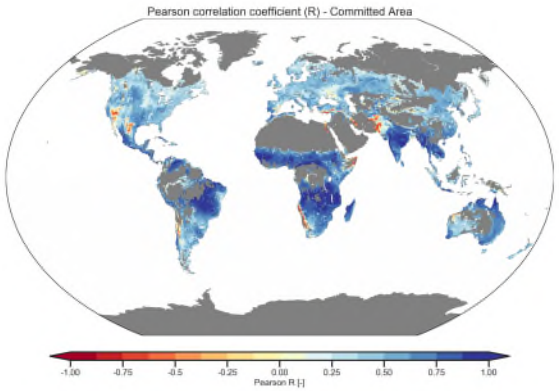


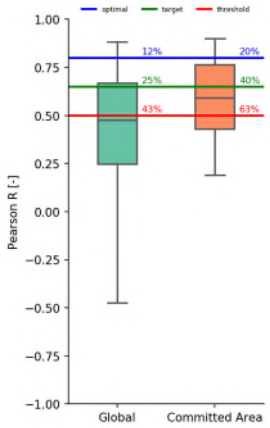




- Pearson Correlation Coefficient (R)

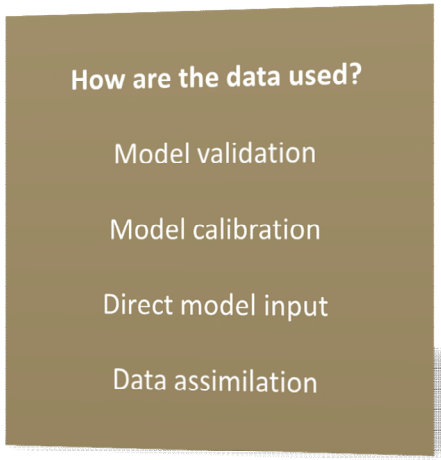


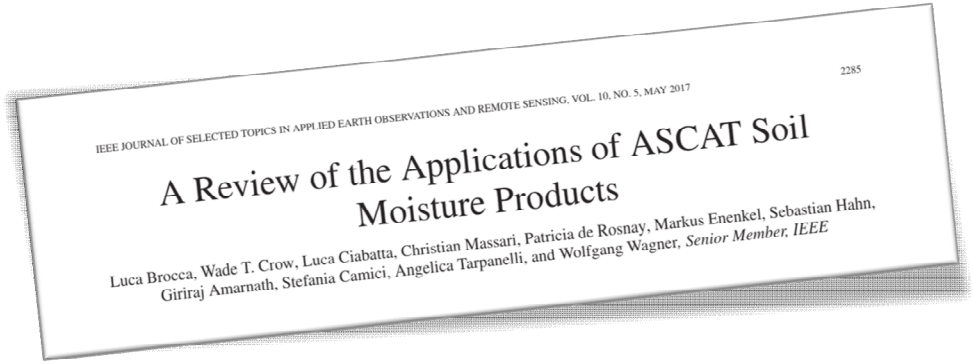




Use cases of satellite soil moisture products

- Runoff forecasting
- Numerical Weather Prediction
- Vegetation monitoring
- Agricultural monitoring
- Tree-Ring studies
- Landslide monitoring
- Epidemiological prediction
- Climate studies
- Ground water modelling
- Drought monitoring
- Rainfall estimation
- etc.



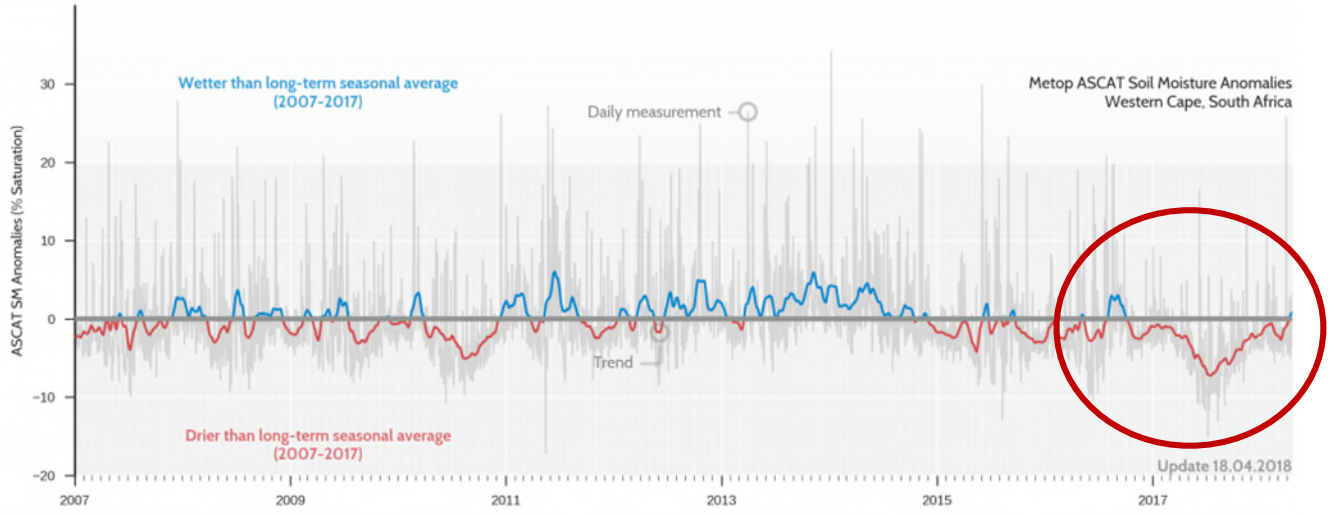


Brocca et al. (2017). A review of the applications of ASCAT soil moisture products. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(5), 2285–2306. http://dx.doi.org/10.1109/JSTARS.2017.2651140

Case study: How satellites can help detect impending droughts

- According to the UN Global Report on Food Crises 2018, climate related shocks were the main drivers of food insecurity in 23 countries in 2017, affecting more than 39 million people

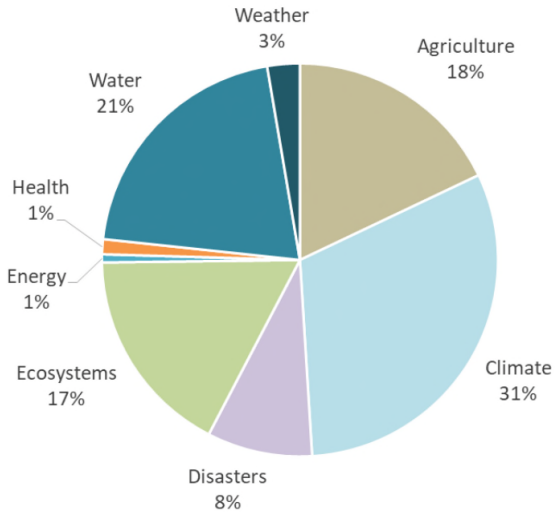
- Soil moisture anomalies in the Western Cape province
  - The impact of drought in South Africa's Western Cape province received international attention
  - The drought led to unprecedented water restrictions in the province, including a daily limit of 50l per person and severe curtailment of water use for agriculture and industry

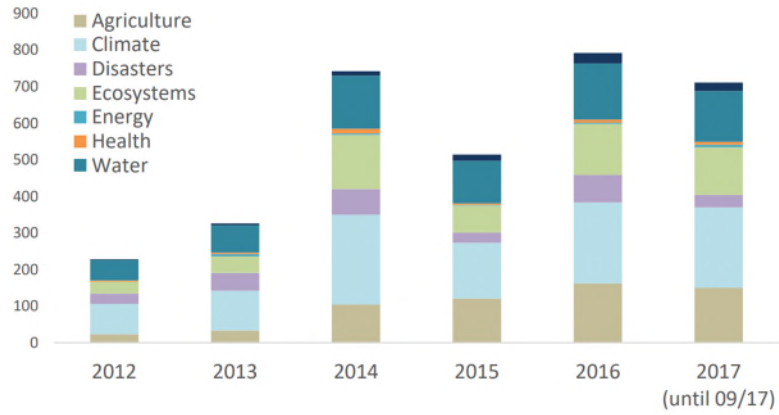


https://www.eumetsat.int/science-blog/how-satellites-can-help-detect-impending-droughts

- Copernicus Global Land
  - Daily 0.1° Soil Water Index (SWI)
  - 1 km ASCAT/Sentinel-1 SWI data over Europe

- CCI + C3S
  - Long-term (1978 up to present) 0.25° active-only and
  - merged active/passive microwave soil moisture data





ESA CCI SM user statistics as of Sep 2017 (presented at CCI SM Workshop 2017).

European C-band Scatterometer Series

AMI Scatterometer

Frequency: 5.3 GHz
Polarisation: VV

Resolution: 50 km
Daily coverage: < 40%

Satellites
ERS-1: 1991 – 2000
ERS-2: 1995 – 2011

Metop ASCAT

Frequency: 5.255 GHz
Polarisation: VV

Resolution: 25-34 km
Daily coverage: 82%

Satellites
Metop-A: 2006 – 2021
Metop-B: 2012 – ongoing
Metop-C: 2018 – ongoing

Metop-SG SCA

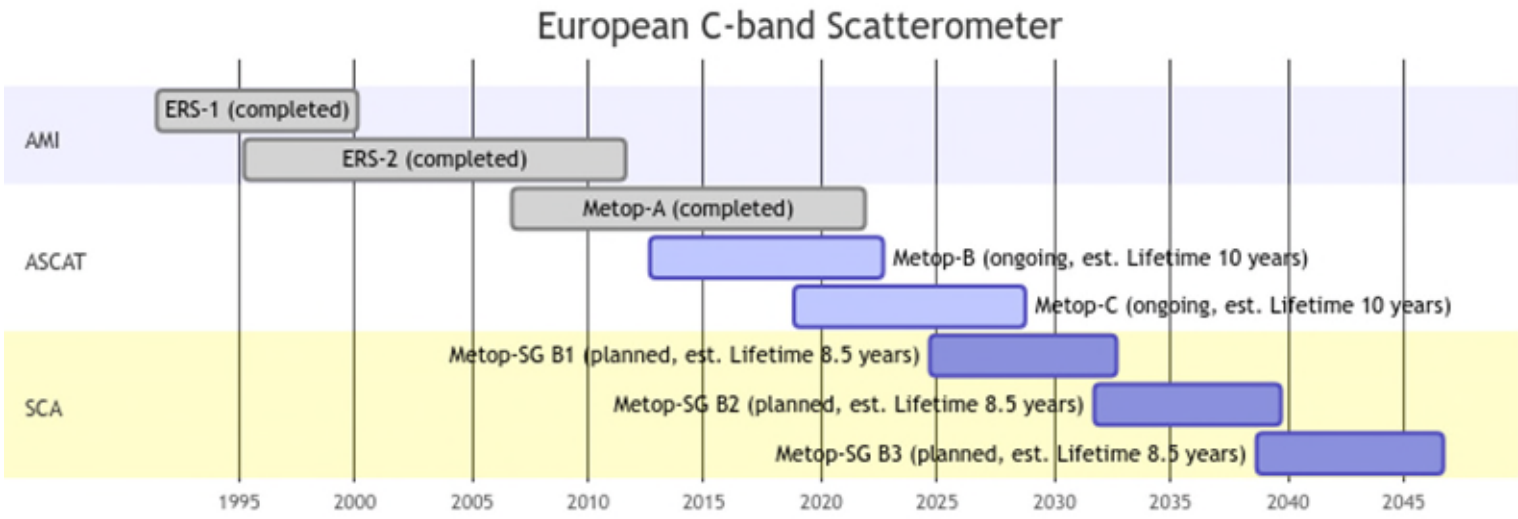
Frequency: 5.355 GHz
Polarisation: VV + VH + HH

Resolution: approx. 12.5 km
Daily coverage: approx. 88%

Satellites
Metop-SG-B1: 2025
Metop-SG-B2: 2032
Metop-SG-B3: 2039

European C-band Scatterometer Series





Overview of Root Zone Soil Moisture (RZSM) products

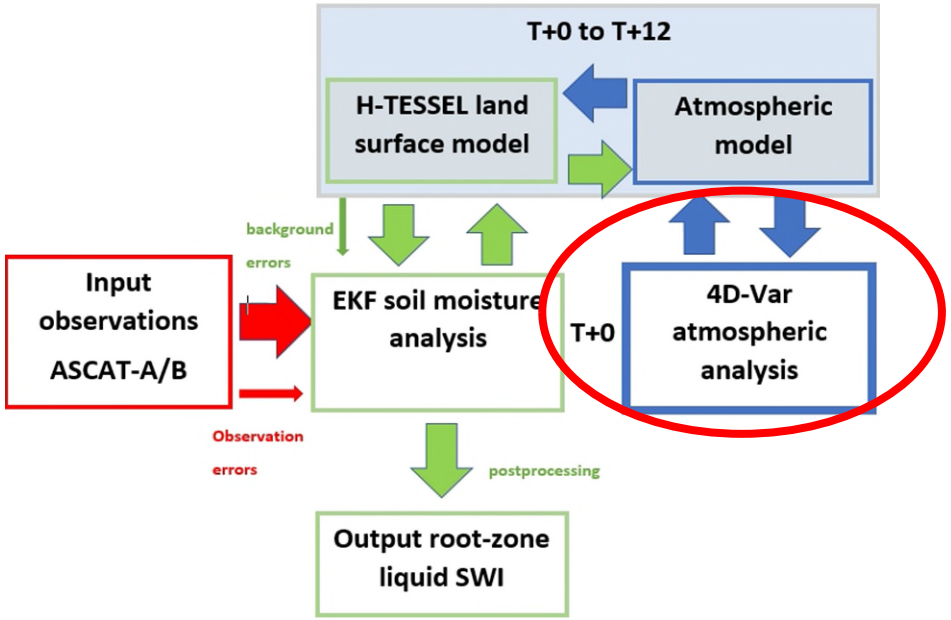
- NRT products
  - 25 km resolution ASCAT-A/B assimilation (SM-DAS-2, H14) – latency 12-36h
  - 10 km resolution ASCAT-A/B/C assimilation (RZSM-ASCAT-NRT-10km, H26) – latency 12h*
- Data record products
  - 10 km resolution ERS-SCAT and ASCAT-A/B assimilation, 1992-2018 (RZSM-DR2019-10km, H141)
- Offline products
  - Extension of the data record at a yearly frequency and assimilation of ASCAT-C, 2019-2021 (RZSM-DR-EXT-10km, H142)

Operational
Operational by the end of CDOP3
*Operational Readiness Review completed

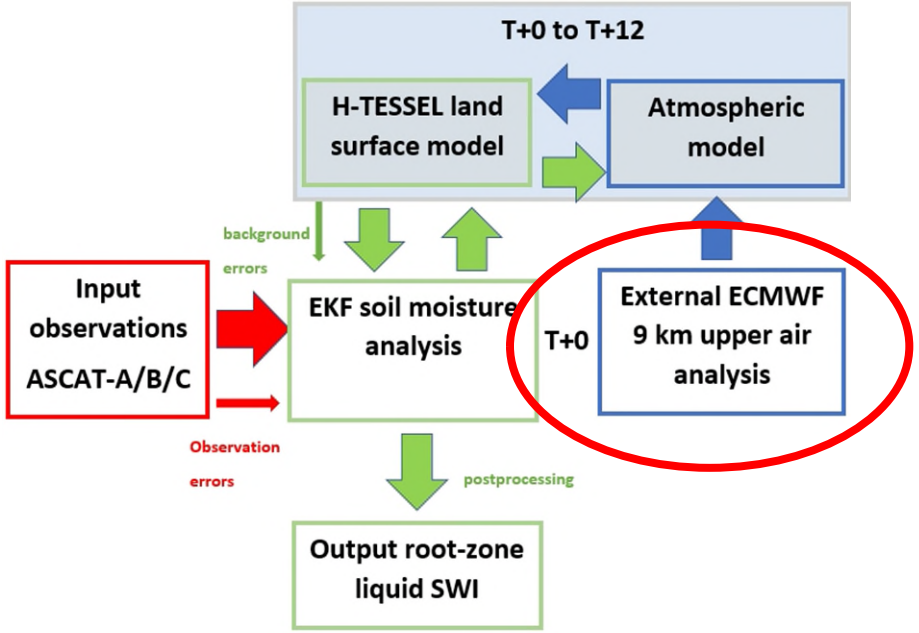
New NRT Root Zone Soil Moisture product (H26)

- New NRT RZSM product (RZSM-ASCAT-NRT-10km - H26) with a higher spatial resolution (10 km vs 25 km) and improved timeliness (12h vs 36h) has been developed
- Transition to stand-alone surface analysis - evaluated by Fairbairn et al., 2019

RZSM-DAS-2 product (H14)



New RZSM-ASCAT-NRT-10km product (H26)



Data assimilation method (RZSM-ASCAT-NRT-10km - H26)

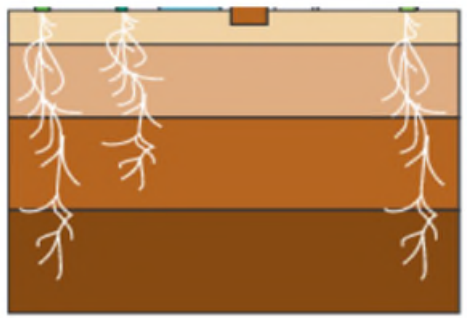
- SEKF based on de Rosnay et al., (2013), but with ensemble of data assimilations (EDA) Jacobians replacing finite differences
- **B** is diagonal, with background-error standard deviation 0.01 m^3m^{-3} for each layer
- **R** is diagonal, with observation-error standard deviation 0.025 m^3m^{-3} for ASCAT-derived SSM

Simplified EKF analysis

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

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

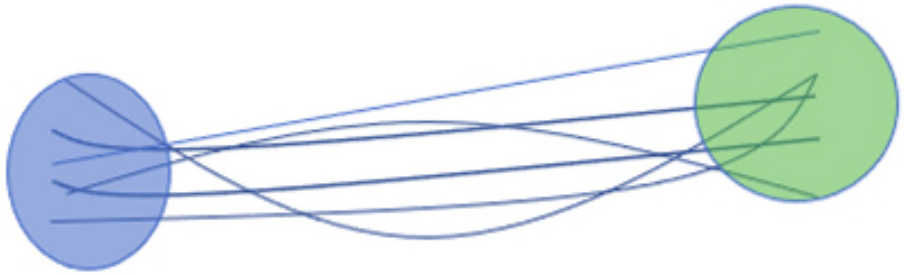
SM analysed over first 3 layers in H-TESSEL:
Layer 1: 0-7 cm
Layer 2: 7-28 cm
Layer 3: 28-100 cm
Layer 4 (not analysed): 100-289 cm



Data assimilation method (RZSM-ASCAT-NRT-10km - H26)

- Jacobian elements H_{ij} for analysis variable j and observation i calculated using EDA spread:

$$H_{ij} = \frac{cov(\mathcal{H}_i(\mathbf{x}^{eda}), \mathbf{x}_j^{eda})}{var(\mathbf{x}_j^{eda})} \cdot c_j$$



Simplified EKF analysis

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

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

SM analysed over first 3 layers in H-TESSEL:

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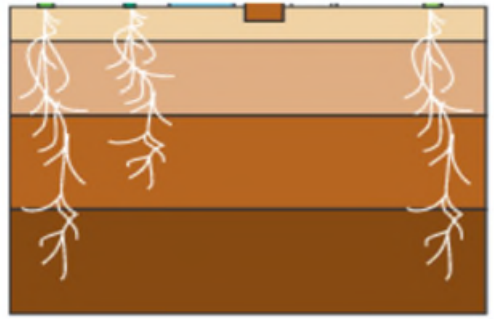


CDF matching bias correction

- SEKF method assumes observations are unbiased with respect to model climatology – designed to correct random errors rather than systematic errors;
- ECMWF employs a linear CDF matching (Scipal et al., 2008): first two moments of the observation CDF are rescaled to match the model equivalent
- Slope *B* and intercept *A* calculated from standard deviations and means of model *x* and observations *y* over climatological period (typically 5 years or more):

$$B = \frac{\sigma_x}{\sigma_y}$$

$$A = \bar{x} - B\bar{y},$$

- Rescaled scatterometer observations ($\hat{y}$):

$$\hat{y} = A + B.y$$

- Seasonal CDF matching employed using 3-month moving average (Draper et al., (2009); Barbu et al., (2014))

- By design, CDF matching converts units of ASCAT from soil wetness index to volumetric.

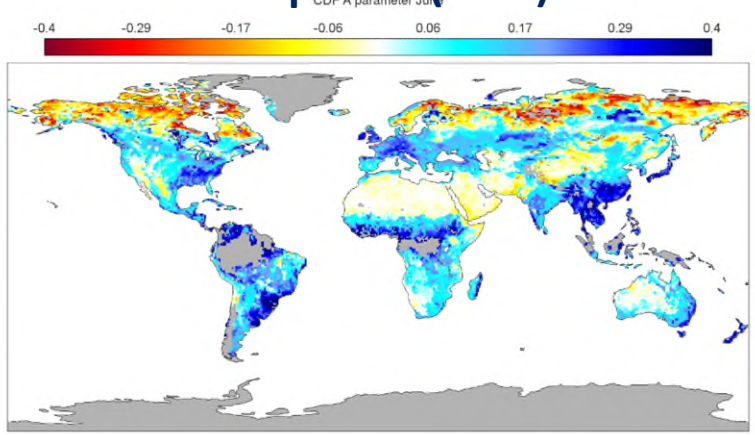
CDF matching bias correction

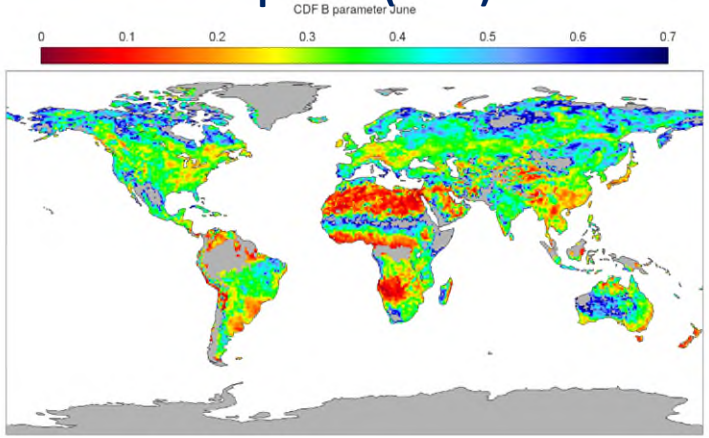
- CDF matching parameters in H141 based on ERA-Interim, ERS/SCAT (1992-1999) and ASCAT-A (2007-2009) data
- Recalibrated parameters using ERA5 and ASCAT-A/B data from 2009 to 2018 reduced bias

A param (June):

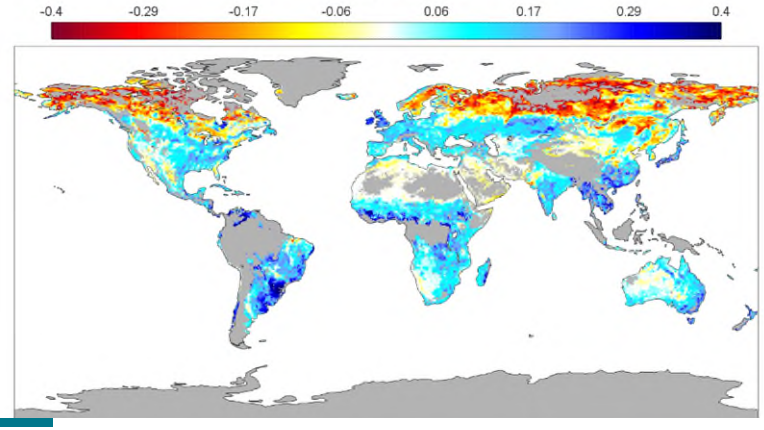
B param (June):

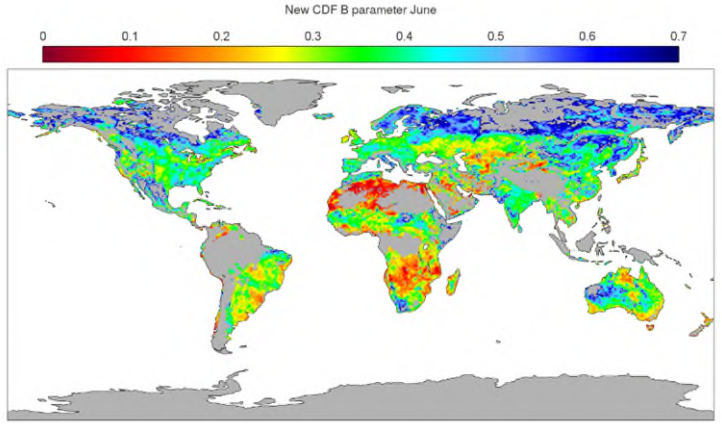
Current:



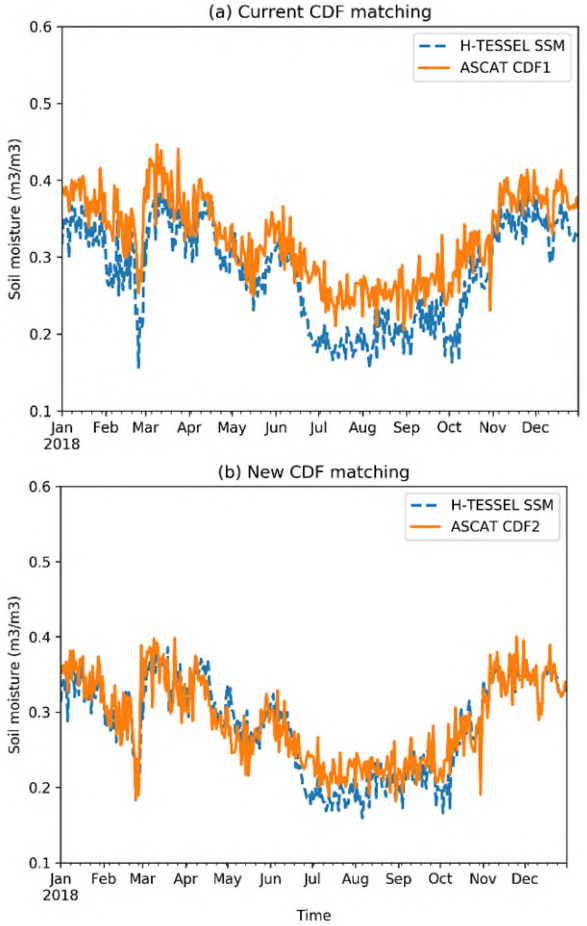


New:





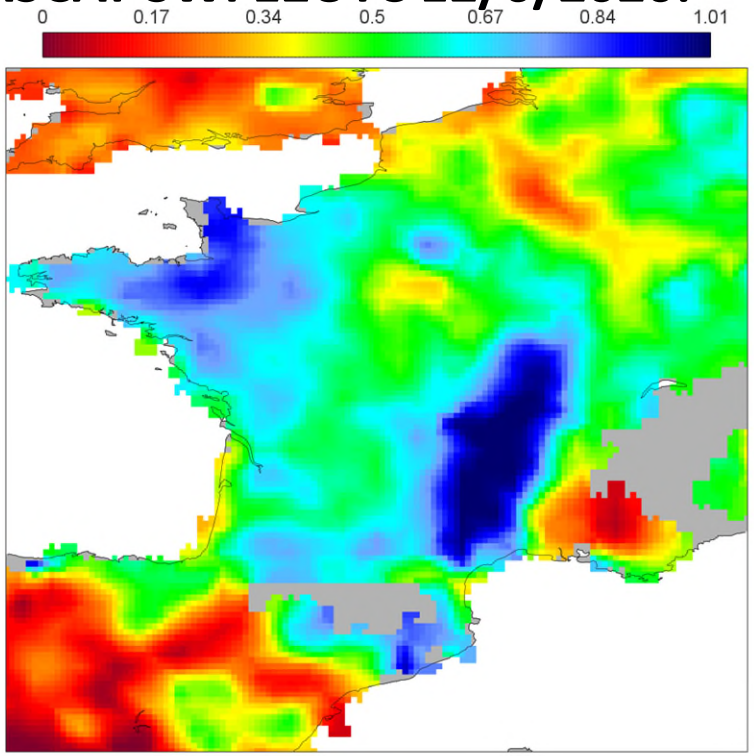
Average SSM over Europe:



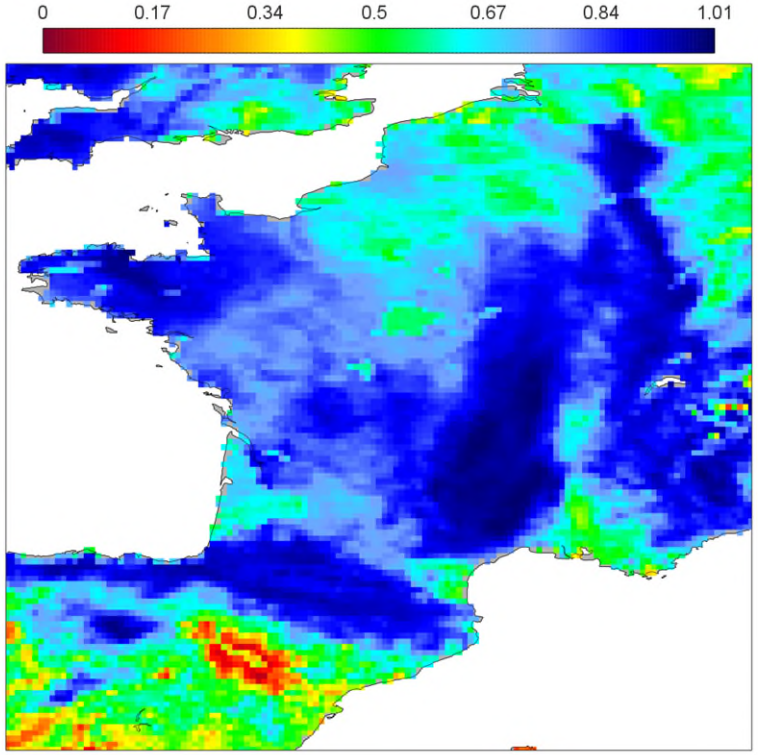
Case study - Floods in France, 2020

- Storm passed southern France on 12th June 2020
- Timeline of heavy precipitation reflected in ASCAT-derived SWI
- Saturated conditions in H26 layer 3 SWI (28-100 cm depth) at time of flooding

ASCAT SWI 12UTC 12/6/2020:



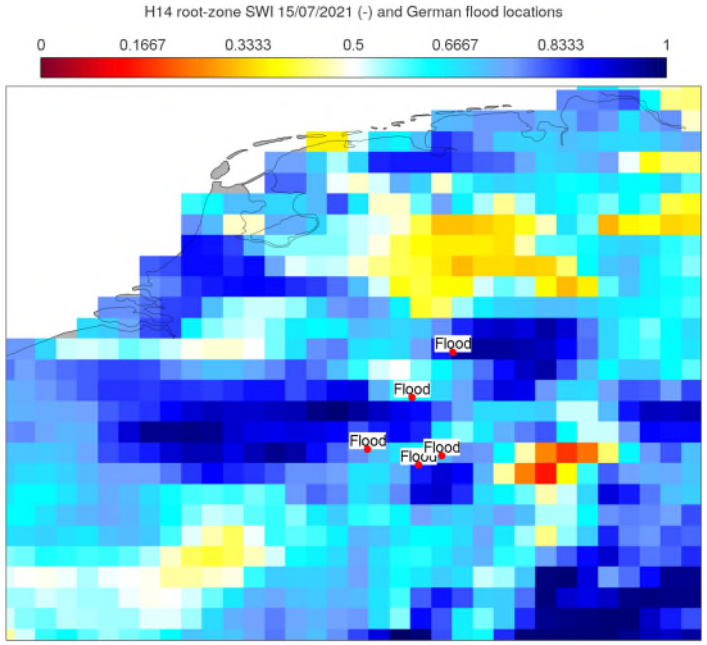
H26 layer 3 SWI 00UTC 13/6/2020:



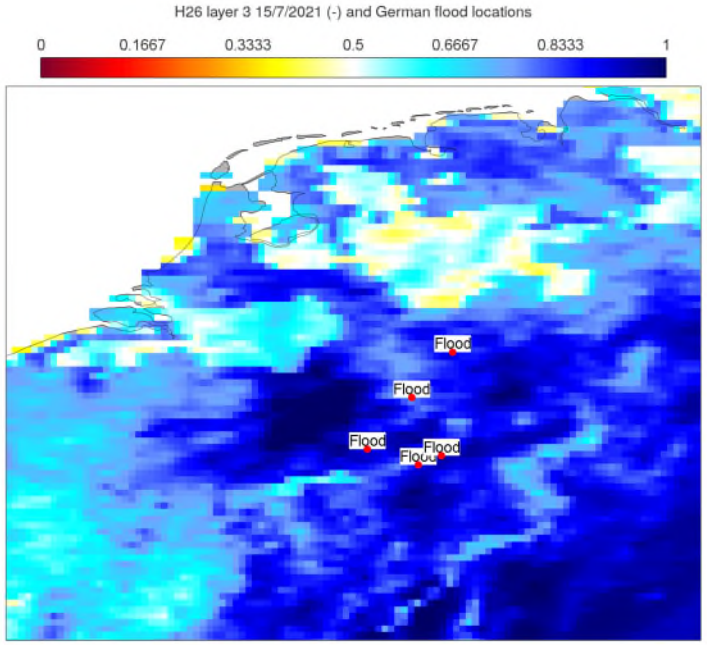
Case study – Floods in Germany, 2021

- By 15/07/21, soil moisture in flooded areas was completed saturated
- RZSM-ASCAT-NRT-10km (H26) (right) captures better detail of saturated soil conditions than RZSM-DAS-2 (H14) (left)

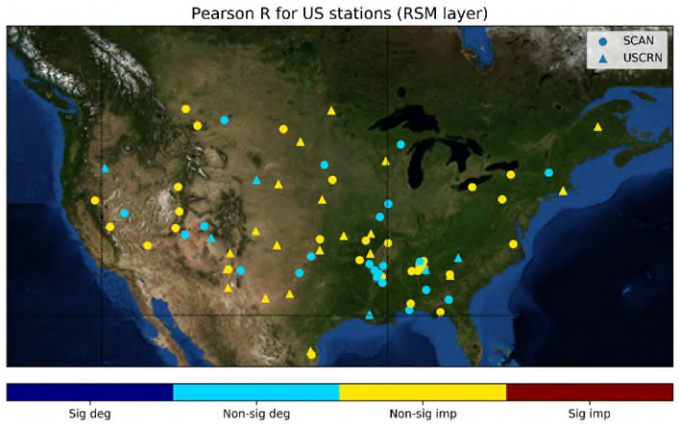
H14 layer 3 SWI 00UTC 15/7/2020

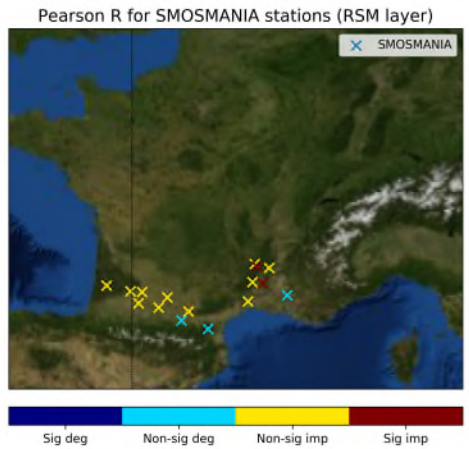


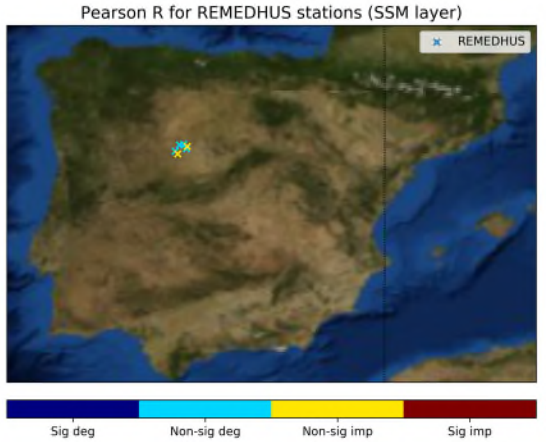
H26 layer 3 SWI 00UTC 15/7/2020



Validation using in situ SM networks from the international SM network (Dorigo et al., 2011) over USA, France and Spain (1/6/18-31/5/19):







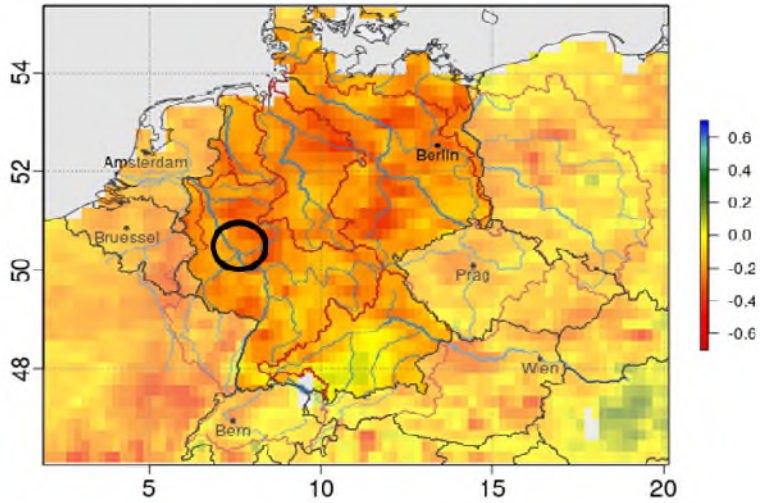
RZSM-ASCAT-NRT-10km improves on SM-DAS-2

	SM-DAS-2 (25 km res)	RZSM-ASCAT-NRT-10km (10 km res)
CC (-) (anomaly)	0.70 (0.50)	**0.77 (0.55)**
RMSD (m3/m3)	0.039	**0.034**

Comparison of NRT products with Lysimeter field data

- Lysimeter field near the city of Koblenz/Germany, at River Rhine Island Niederwerth (50.394 Lon, 7.603 Lat)
- Four weighable Lysimeters (depth = 2m, volume = 2 m^3) with characteristic soil types of the LARSIM-ME* region: alluvial clay, loess loam, high flood sand and loamy pumice
- In addition four non weighable Lysimeters

SWI_0-100-Anomaly
September 2019



Validation by Peter Krahe and Asta Kunkel from German federal institute of hydrology (BAFG)

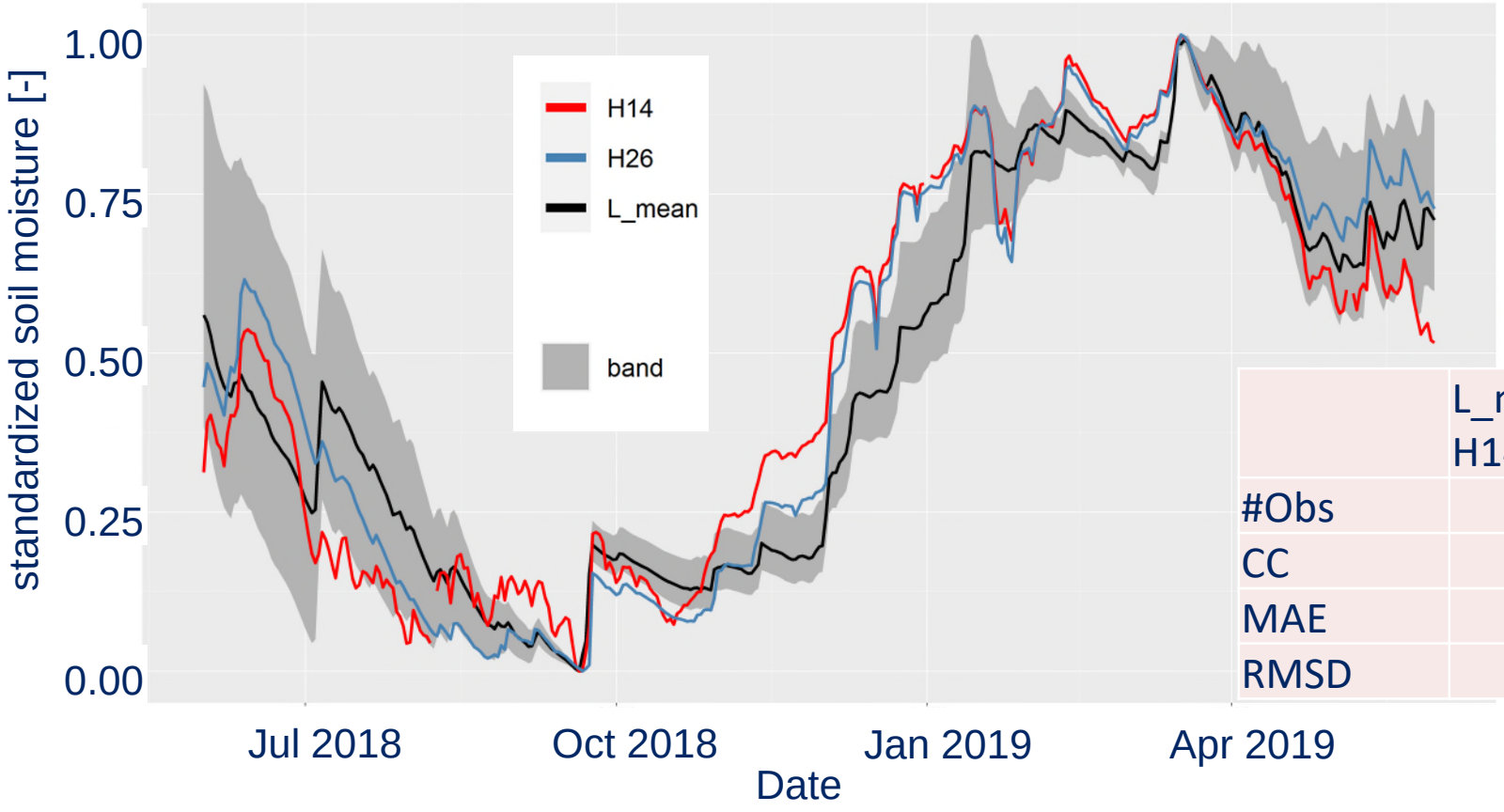
Lysimeter validation method

- Comparison period: June 2018 – May 2019
- Standardization of Lysimeter weights using max/min values
- Aggregation of NRT products (SMI 0 – 100 cm) over 2654 km² LARSIM-ME catchment (region surrounding Lysimter field)
- Standardization of aggregated SM-DAS-2 & RZSM-ASCAT-NRT-10km using max/min values
- Performing standard statistics defined by H SAF soil moisture group: CC, RMSD, bias

Validation by Peter Krahe and Asta Kunkel from German federal institute of hydrology (BAFG)

Comparison of SWI time series

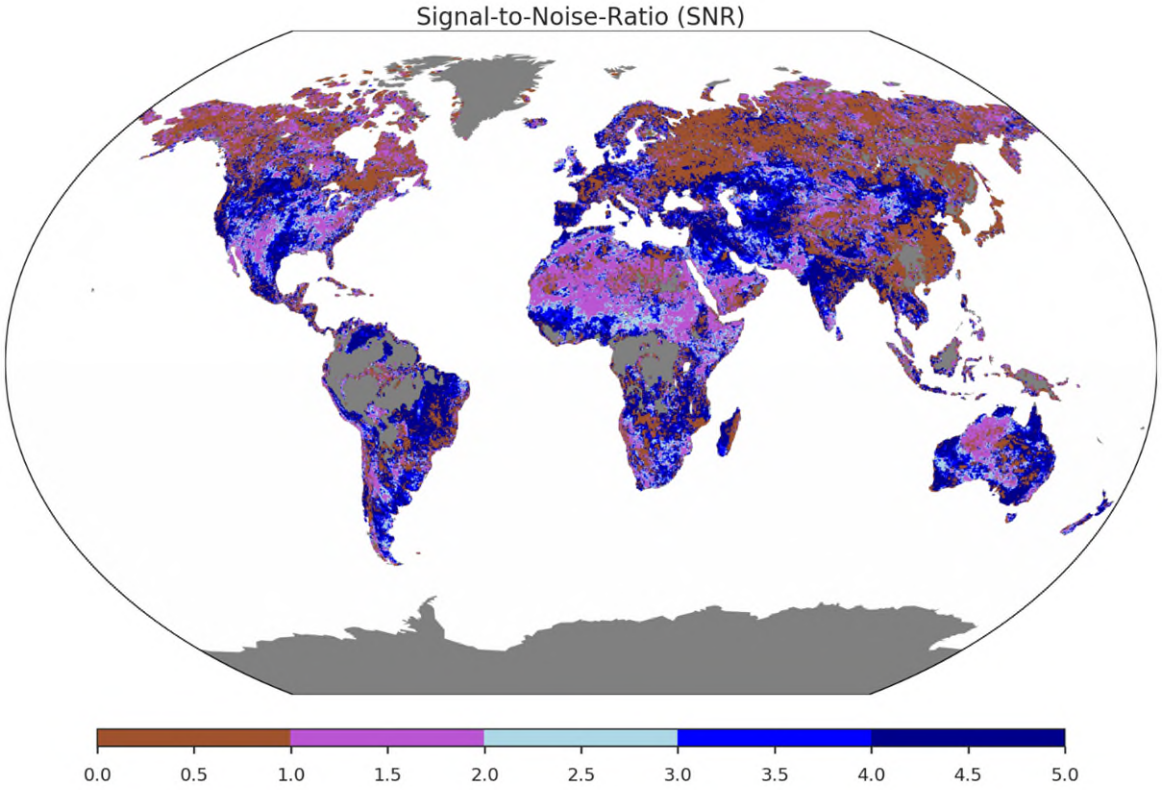
- H14 (SM-DAS-2) & H26 (RZSM-ASCAT-NRT-10km) SWI (0 – 100 cm, regional average near Lysimeter)
- Standardized Lysimeter weights: mean (L_mean) as well as Min and Max (band) of four Lysimeters

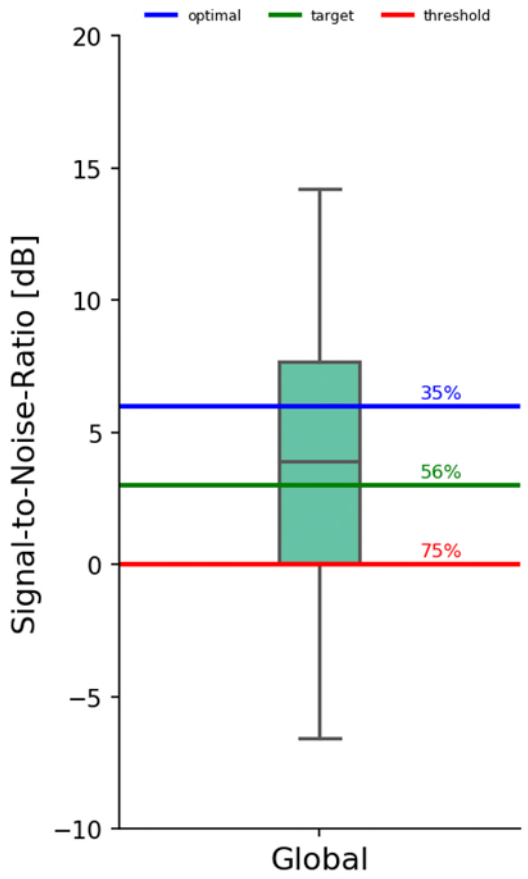


	L_mean - H14	L_mean - H26
#Obs	362	365
CC	0.935	**0.967**
MAE	0.087	**0.07**
RMSD	0.11	**0.089**

Triple colocation validation of surface layer

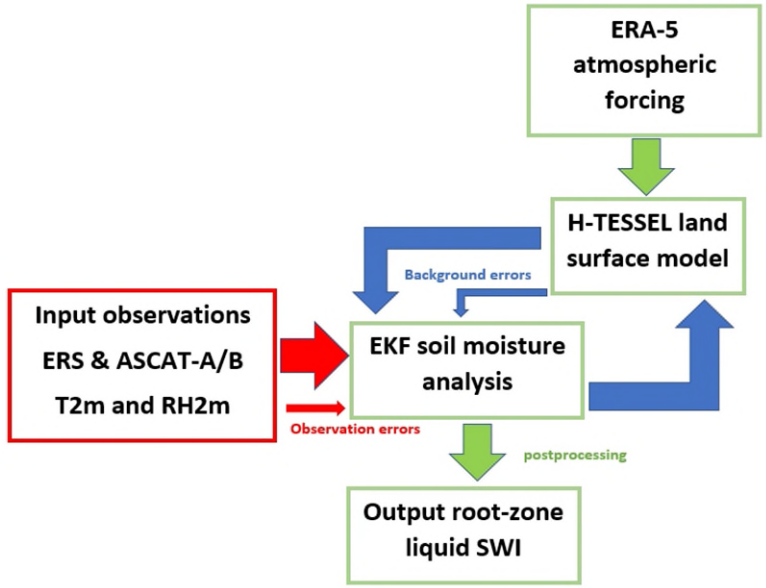
- RZSM-ASCAT-NRT-10km layer 1 (top 7 cm) compared with NOAH Global Land Data Assimilation System (GLDAS, Rodell et al., 2004) and the European Space Agency Climate Change Initiative (ESA CCI) passive soil moisture dataset (Wagner et al., 2012).

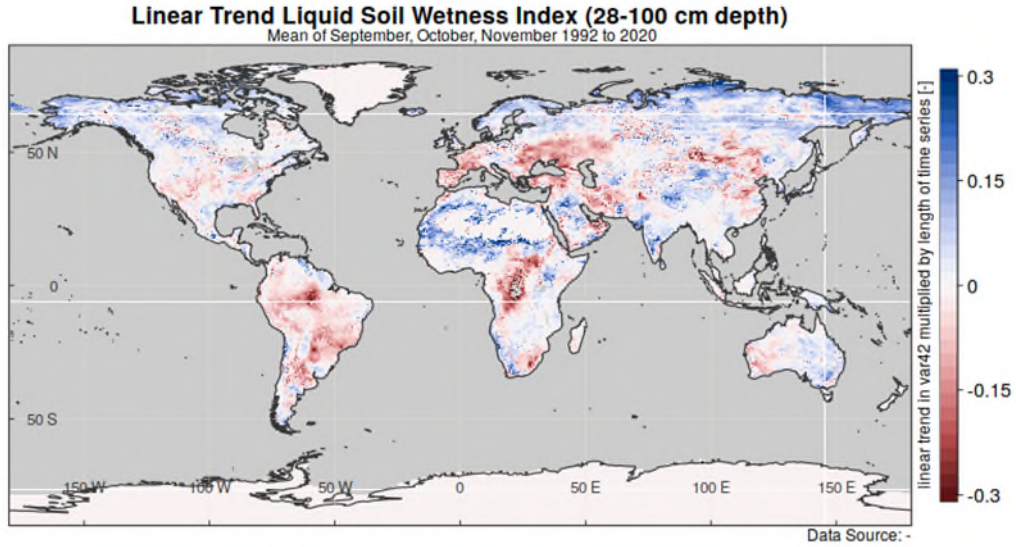


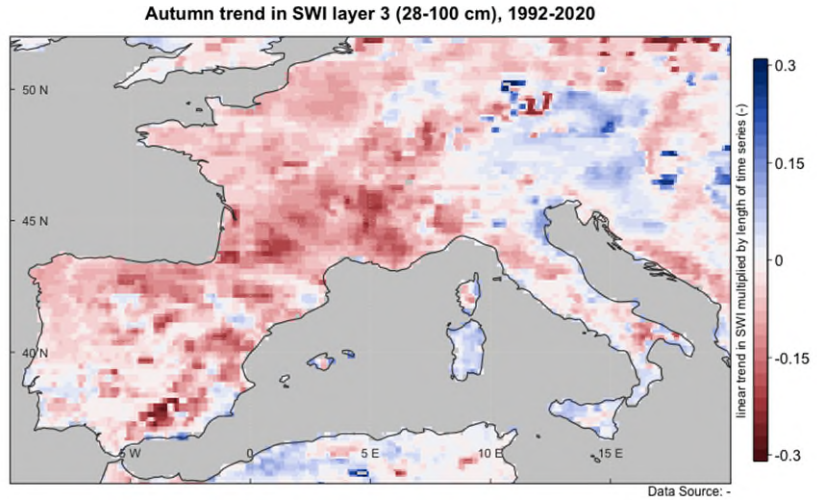


Validation by H SAF colleagues at the CIMA research foundation, Italy.

Exploring trends for H SAF ASCAT root-zone soil moisture data records





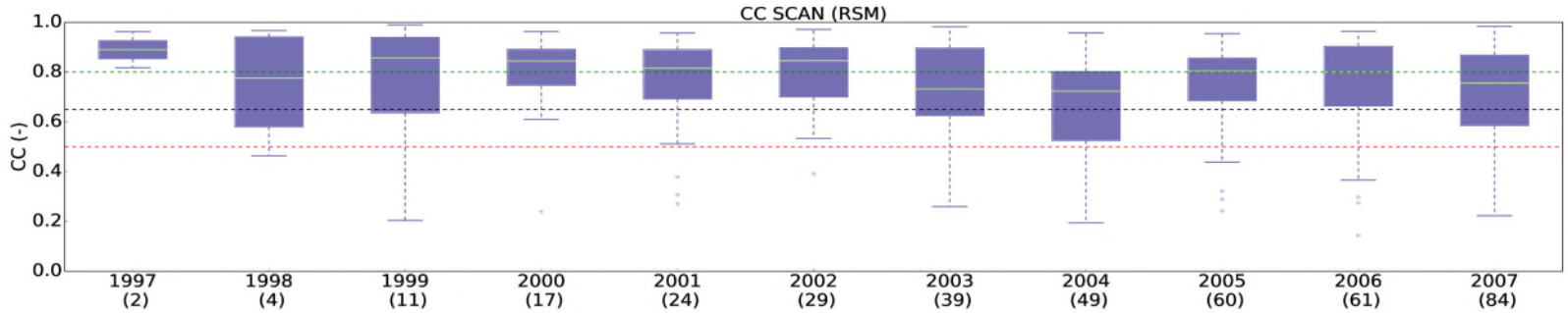


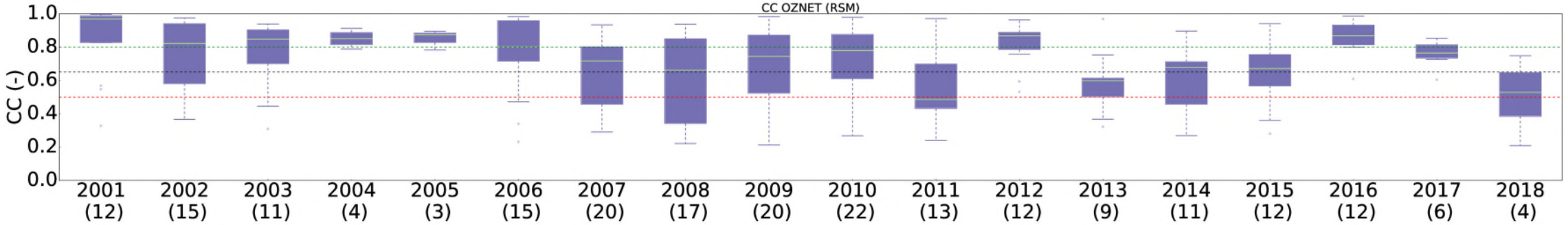
- RZSM-DR2019-10km (CDR): Daily from 1992-2018 (at 00 UTC)
- RZSM-DR-EXT-10km (ICDR): Extension of RZSM-DR2019-10km from 2019-2020
- SWI provided over 4 layers (0-7, 7-28, 28-100 and 100-289 cm depth) at 0.1° spatial sampling

Data record validation

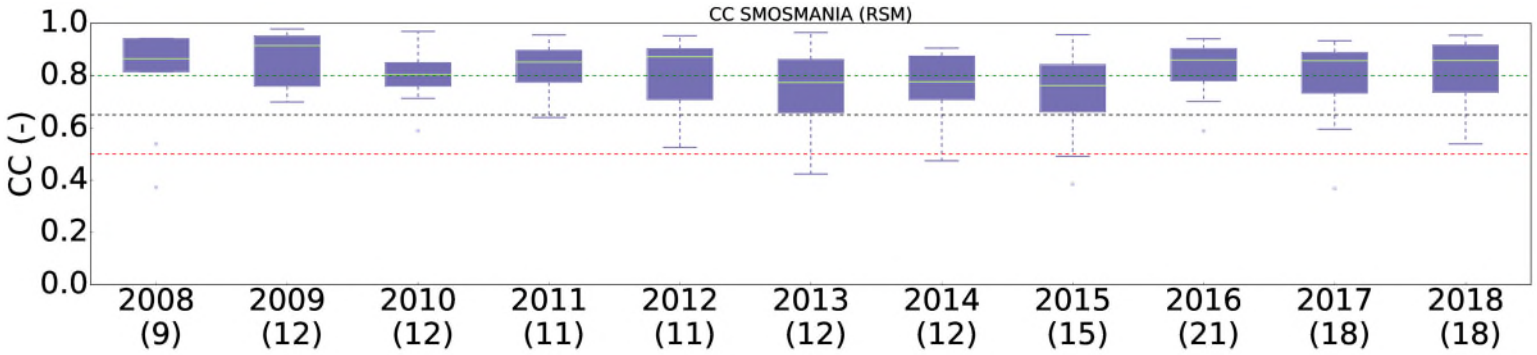
RZSM validated annually with in situ data from networks in four countries:

(1) SMOSMANIA (France)
(2) USCRN/SCAN/SNOTEL (US)
(3) REMEDHUS (Spain)



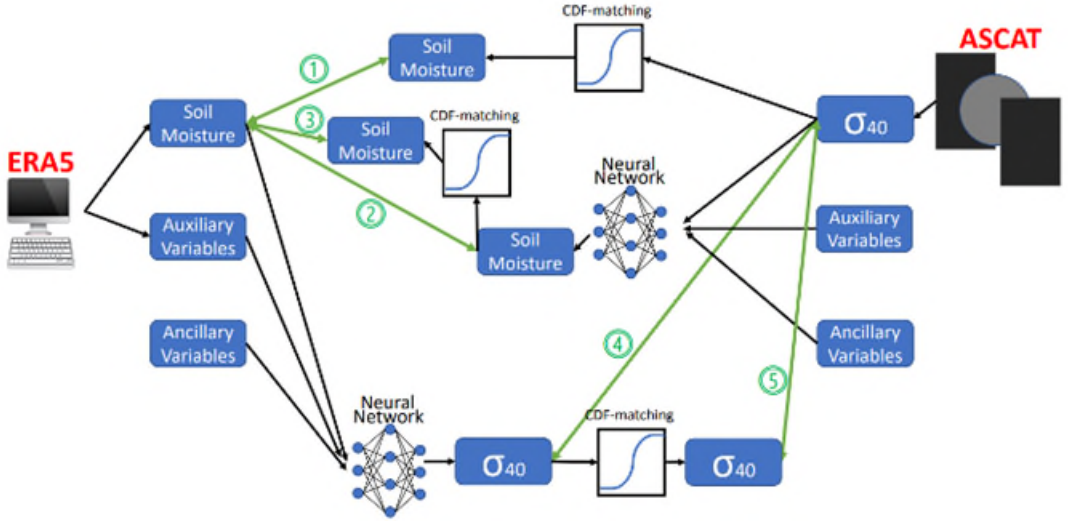


Good overall performance, with CC>0.65 over most stations



- EUMETSAT 2nd generation (EPS-SG) scatterometer derived SSM data to be assimilated in future root-zone SM products – higher spatial sampling (12.5 km) than current ASCAT (25 km).
- Exploring neural network derived SSM for assimilation
- Adaptive SSM bias correction

Aires et al, QJRMS, 2021



Session 5 talk from Filipe Aires about NN developments

Summary and outlook

- H SAF Soil Moisture products are available in NRT, Offline and as a Data Record (DR)
  - Surface Soil Moisture (SSM) and Root Zone Soil Moisture (RZSM) products
  - At various spatial resolution (1-5 km, 10 km, 25 km, 50 km)
  - Globally available (except downscaled SSM products, only covering Europe)

- Coming in the next phase CDOP-4 (Mar. 2022 – Feb. 2027)
  - Continuation of CDOP-3 NRT SSM and RZSM products
  - New NRT products based on Metop-SG SCA
    - SCA SSM NRT 6.25 km (H80), SCA SSM NRT 12.5 km (H81), 2025
    - RZSM-SCA-NRT-10km (H76), EPS-SG SCA assimilation, 2025
    - RZSM-SCA-NN-NRT-10km (H88), EPS-SG SCA assimilation via Neural Network (NN), 2025
  - New Data Record products
    - SCAT-ASCAT-SCA DR v1 12.5 km (H137), 1992-2026
    - ASCAT SSM DR v1 6.25 km (H129), ASCAT SSM DR v1 12.5 km (H131), 2007-2026
    - SCA SSM DR v1 6.25 km (H125), SCA SSM DR v1 12.5 km (H126), 2025-2026
    - RZSM-SCAT-ASCAT-CDOP-4-CDR-10km (H145), 1992-2022
    - RZSM-SCAT-ASCAT-SCA-CDR-10km (H77), 1992-2025
    - RZSM-SCAT-ASCAT-SCA-NN-CDR-10km (H91) , 1992-2025

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