Surface Soil Moisture Products and Algorithm Description

Sebastian Hahn

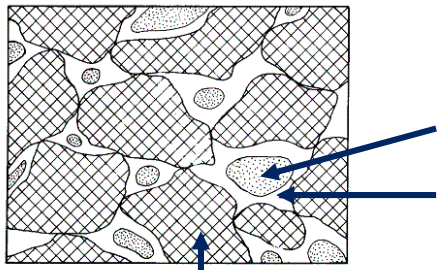
Department of Geodesy and Geoinformation (GEO), TU Wien
http://www.geo.tuwien.ac.at/

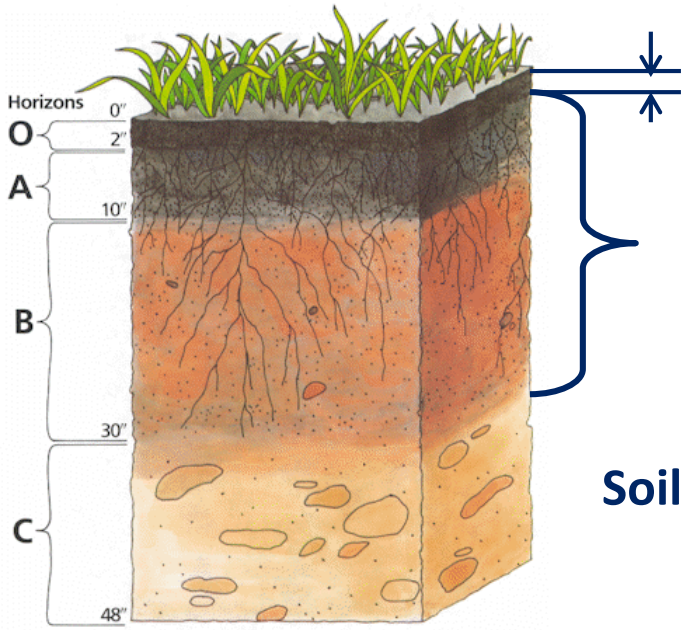
Soil Moisture

- Volumetric definition

$$\theta = \frac{V_w}{V_w + V_s + V_a}$$

Cross-section of a soil





Thin, remotely sensed soil layer

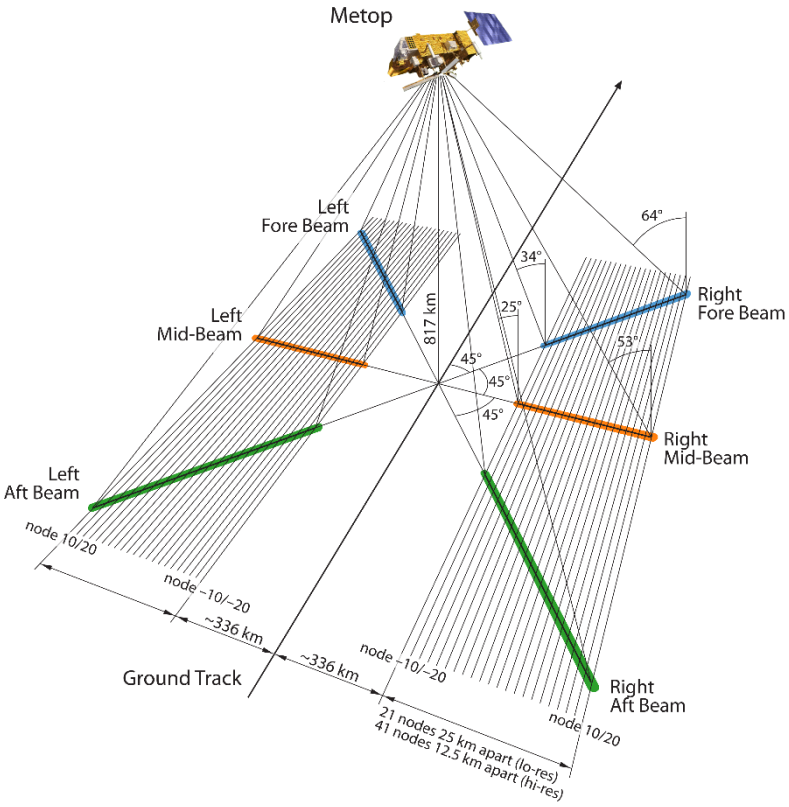
Root zone: layer of interest for most applications

Soil profile

Advanced Scatterometer (ASCAT) on boad 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 %

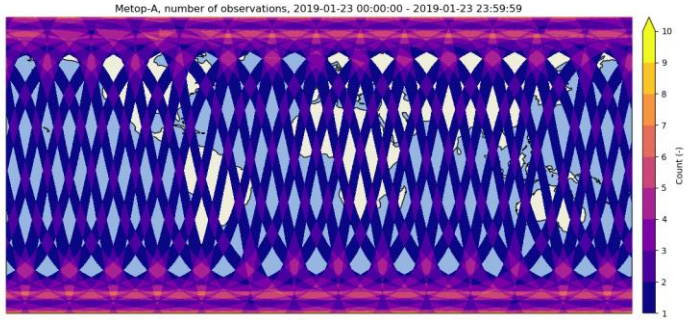
- Metop-A (Oct. 2006 – ongoing)
- Metop-B (Sep. 2012 – ongoing)
- Metop-C (Nov. 2018 – ongoing)



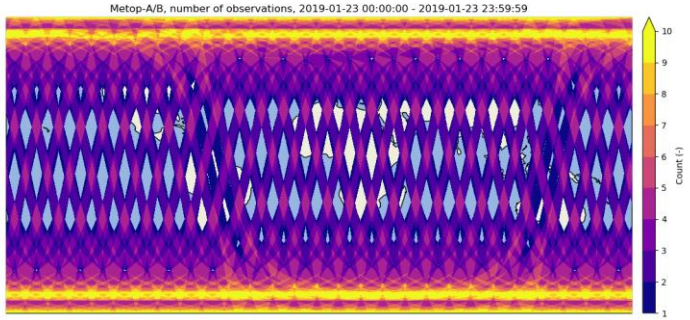
Figa-Saldana, et al., The advanced scatterometer (ASCAT) on the meteorological operational (MetOp) platform: A follow on for European wind scatterometers, Canadian Journal of Remote Sensing, 28(3), 404–412 (2002). http://dx.doi.org/10.5589/m02-035

Spatial coverage of ASCAT

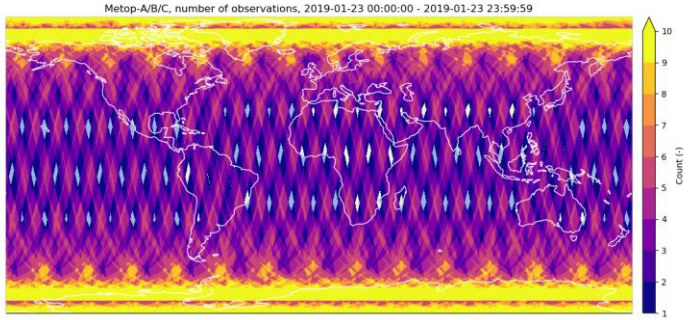
Metop-A

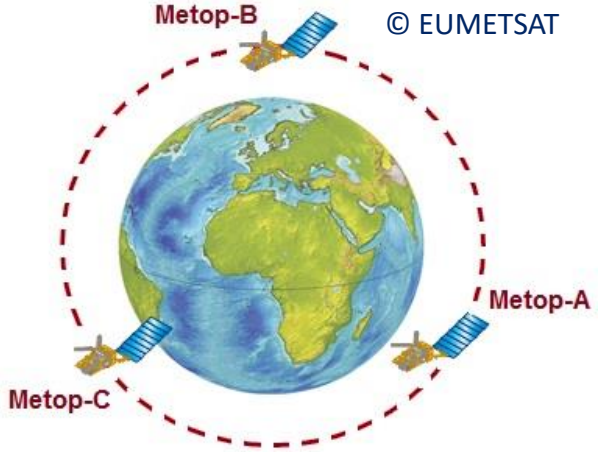


Metop-A
Metop-B



Metop-A
Metop-B
Metop-C





- The series of Metop satellites fly in a “tri-star” constellation
- Metop-A will be put in a drift-orbit and presumably remain operational until 2021

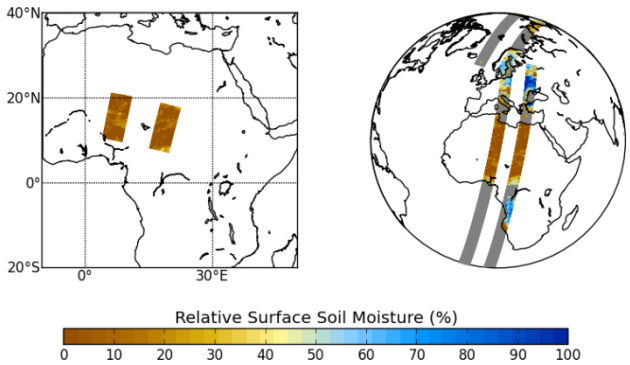
H SAF ASCAT Surface Soil Moisture

- **ASCAT SSM Near Real-Time (NRT) products**
  - NRT products for ASCAT on-board Metop-A, Metop-B, Metop-C
  - Swath orbit geometry
  - Available 130 minutes after sensing
  - Various spatial resolutions
    - 25 km spatial sampling (50 km spatial resolution)
    - 12.5 km spatial sampling (25-34 km spatial resolution)
    - 0.5 km spatial sampling (1 km spatial resolution)
    - 6.25 km spatial sampling (15-20 km spatial resolution)

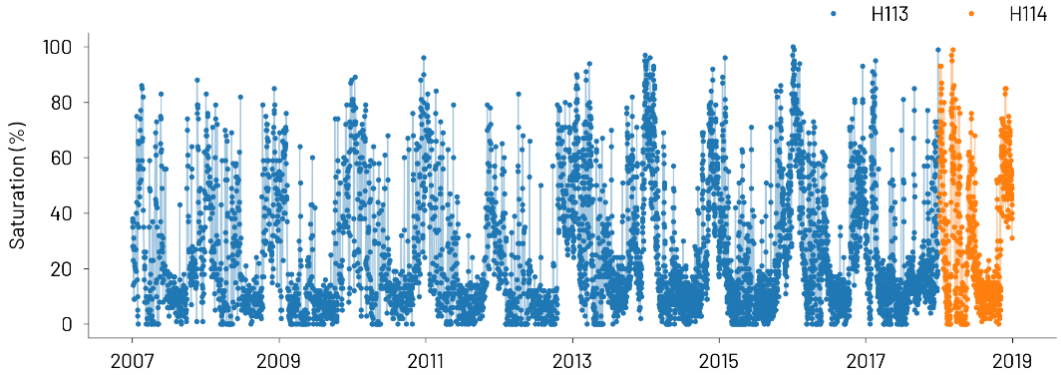
- **ASCAT SSM Climate Data Record (CDR) and Offline (CDR Extension) products**
  - ASCAT Level 1b data merged for all Metop satellites
  - Time series format located on an Earth fixed DGG (WARP5 Grid)
  - 12.5 km spatial sampling (25-34 km spatial resolution)
  - Re-processed every year
  - Extensions computed until new release

H SAF ASCAT Surface Soil Moisture

- **ASCAT SSM Near Real-Time (NRT) products**



- **ASCAT SSM Climate Data Record (CDR) and Offline (CDR Extension) products**

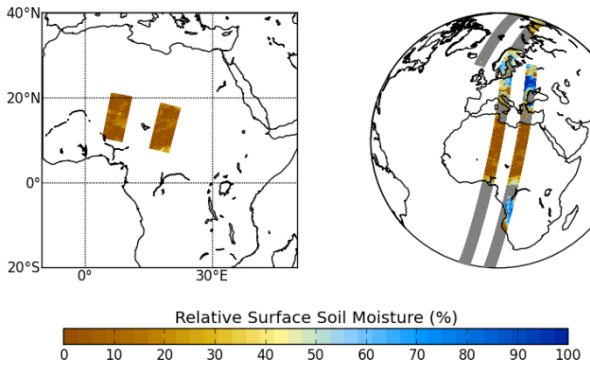


H SAF ASCAT Surface Soil Moisture

- **ASCAT SSM Near Real-Time (NRT) products**

BUFR
~3 min. swath

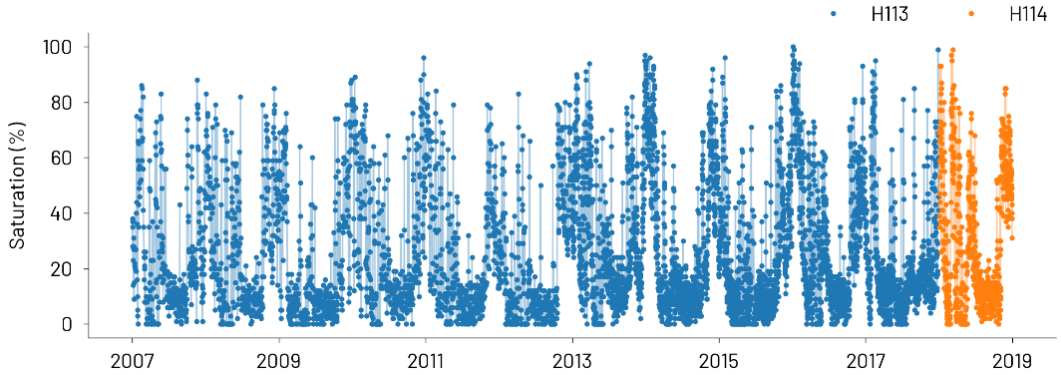
EUMETCast
H SAF FTP



BUFR
EPS Native
NetCDF
~101 min. swath

EUMETSAT Archive
(except H08)

- **ASCAT SSM Climate Data Record (CDR) and Offline (CDR Extension) products**



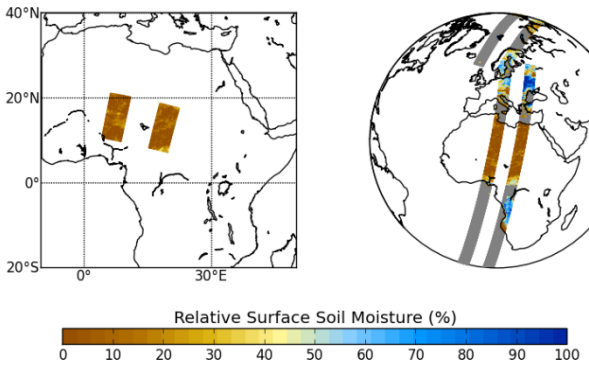
NetCDF
Time series format

H SAF FTP

H SAF ASCAT Surface Soil Moisture

- **ASCAT SSM Near Real-Time (NRT) products**

EUMETCast
H SAF FTP



EUMETSAT Archive
(except H08)

Different filenaming between H SAF FTP and EUMETCast/Archive

- Metop-A ASCAT NRT 25 km sampling (H102) = Metop-A ASCAT Level 2 SMO
- Metop-A ASCAT NRT 12.5 km sampling (H101) = Metop-A ASCAT Level 2 SMR
- Metop-B ASCAT NRT 25 km sampling (H103) = Metop-B ASCAT Level 2 SMO
- Metop-B ASCAT NRT 12.5 km sampling (H16) = Metop-B ASCAT Level 2 SMR

H SAF ASCAT Surface Soil Moisture

- **ASCAT SSM Near Real-Time (NRT) products**

Metop-A
- 25 km spatial sampling - H102
- 12.5 km spatial sampling - H101

Metop-B
- 25 km spatial sampling - H103
- 12.5 km spatial sampling - H16
- 0.5 km spatial sampling - H08 (Europe only)

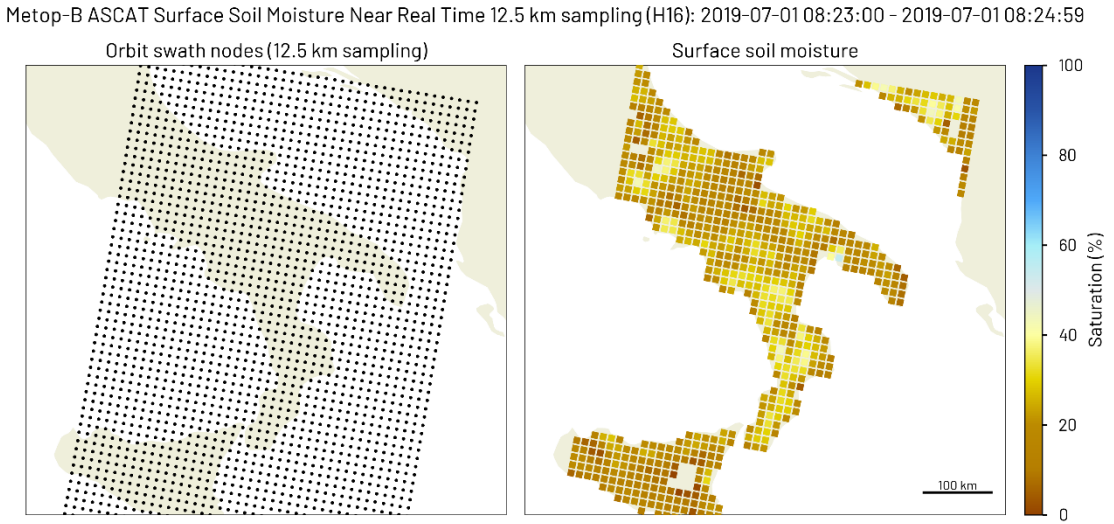
Metop-C
- 25 km spatial sampling - H105
- 12.5 km spatial sampling - H104

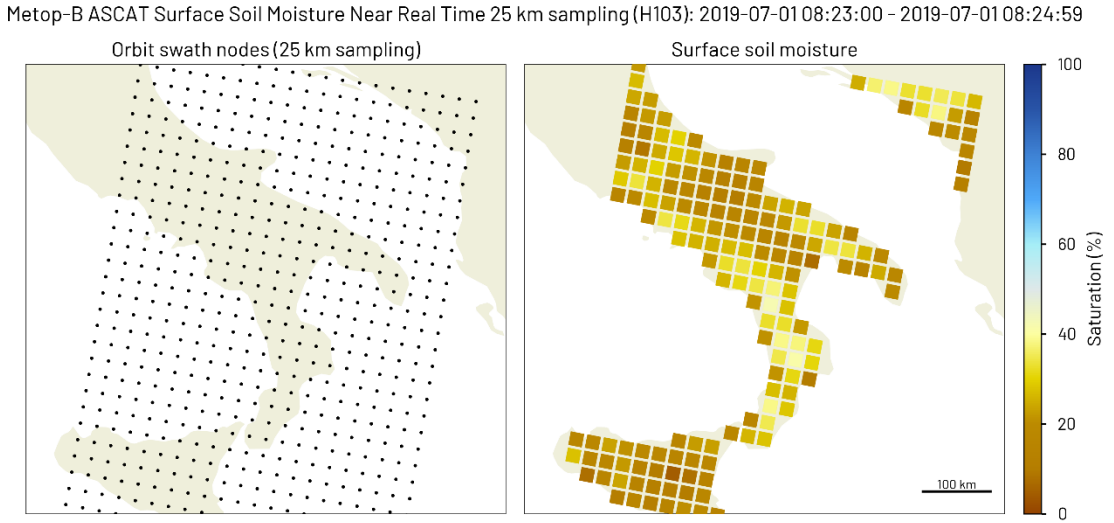
Metop-A, Metop-B, Metop-C
- 6.25 km spatial sampling - H122
- 1 km spatial sampling - H28

- **ASCAT SSM Climate Data Record (CDR) and Offline (CDR Extension) products**

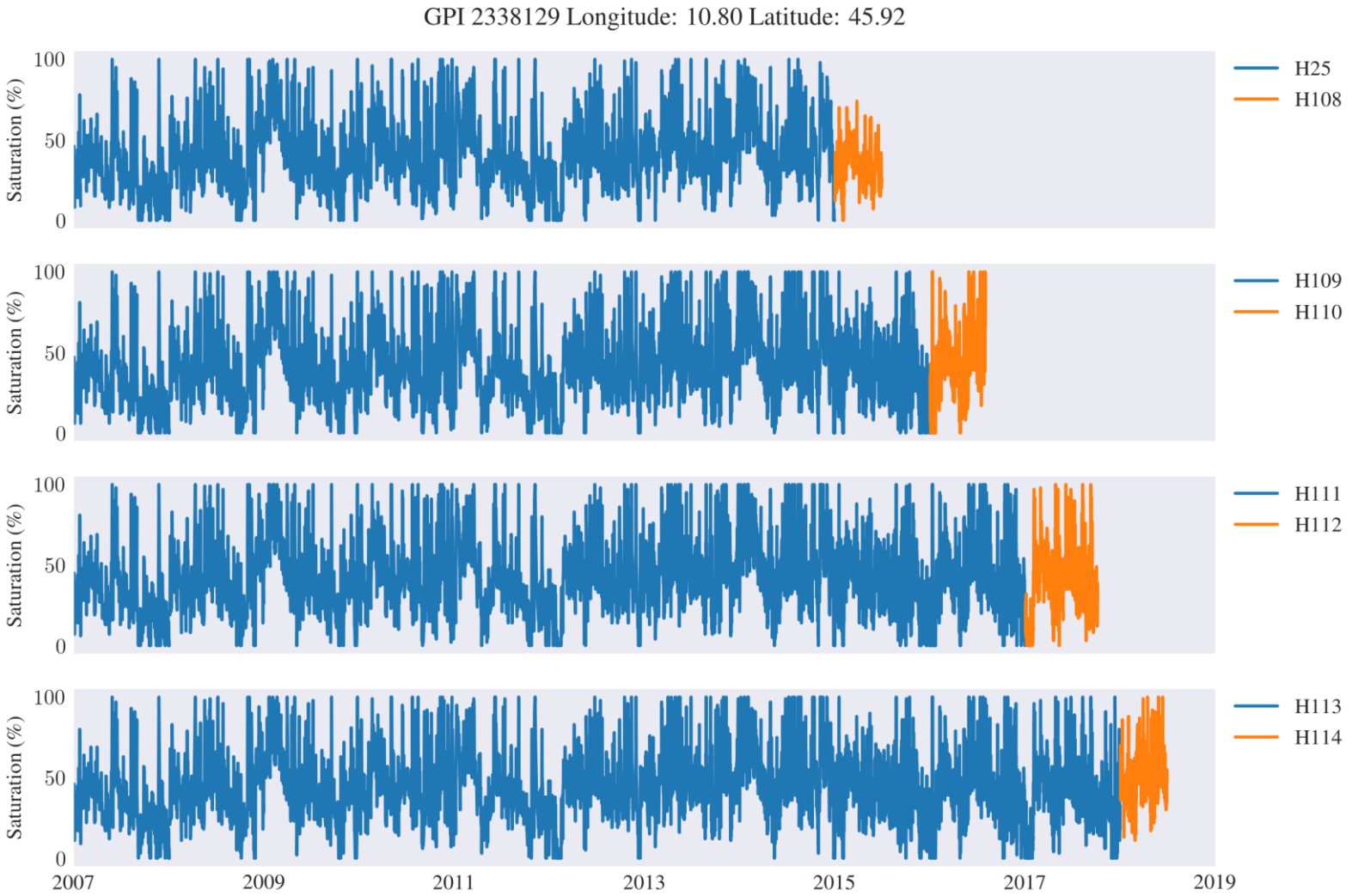
Metop-A, Metop-B, Metop-C
- Metop ASCAT DR2015 SSM time series 12.5 km sampling - H25 (Extension H108)
- Metop ASCAT DR2016 SSM time series 12.5 km sampling - H109 (Extension H110)
- Metop ASCAT DR2017 SSM time series 12.5 km sampling - H111 (Extension H112)
- Metop ASCAT DR2018 SSM time series 12.5 km sampling - H113 (Extension H114)
- Metop ASCAT DR2019 SSM time series 12.5 km sampling - H115 (Extension H116)
- Metop ASCAT DR2020 SSM time series 12.5 km sampling - H117 (Extension H118)

ASCAT SSM NRT products (12.5 km and 25 km sampling)

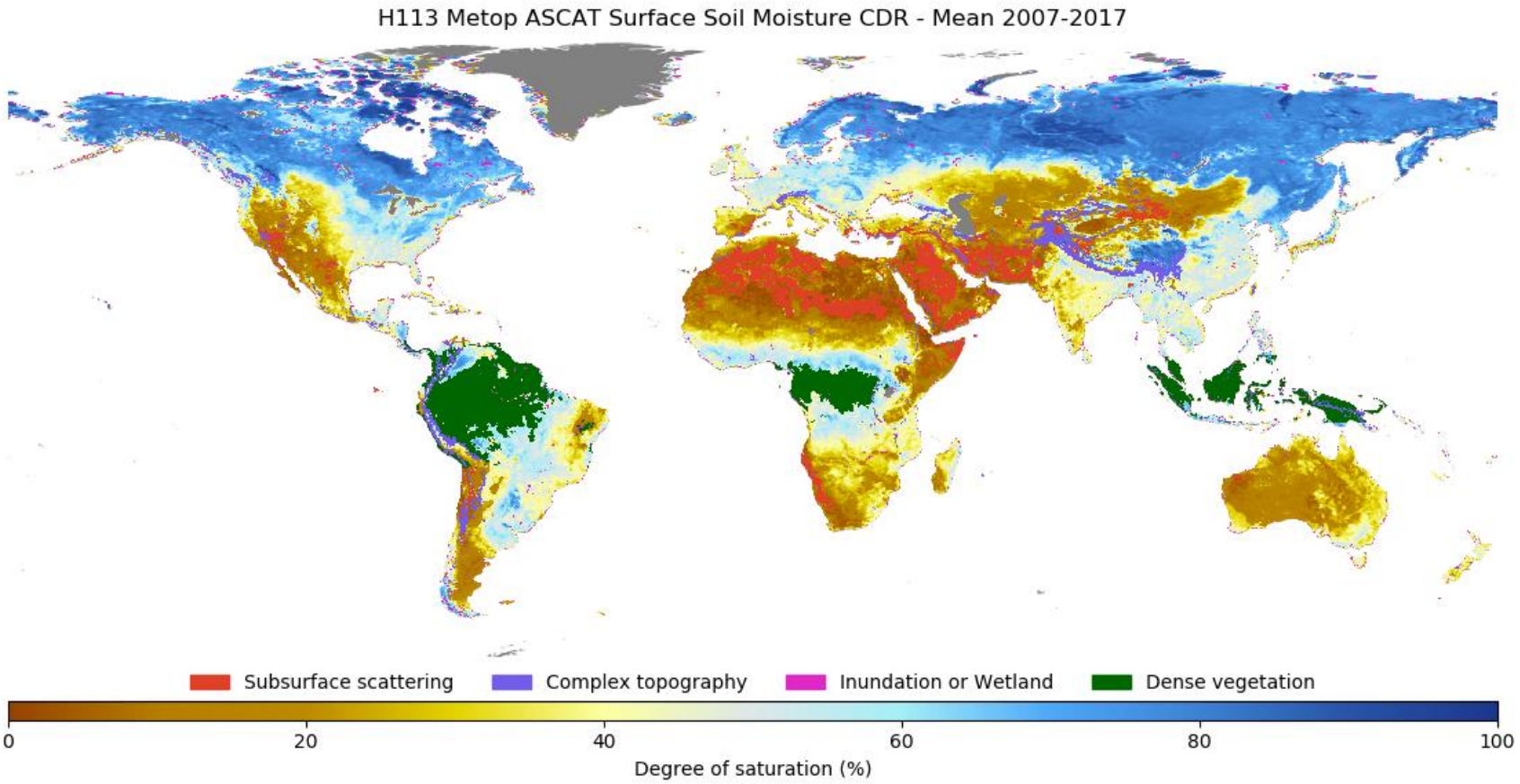




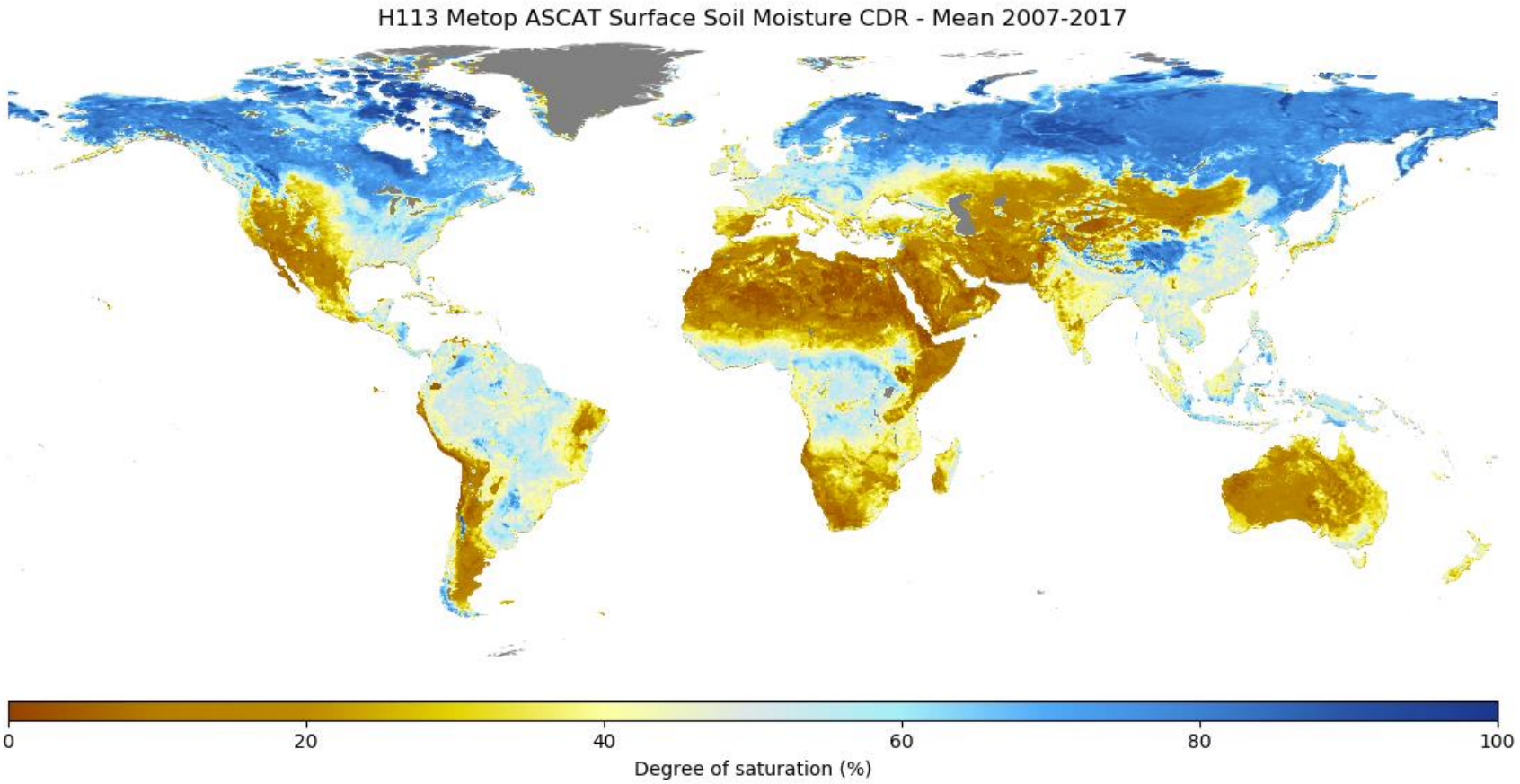
Metop ASCAT Surface Soil Moisture CDR



Metop ASCAT Surface Soil Moisture DR2018 (H113)

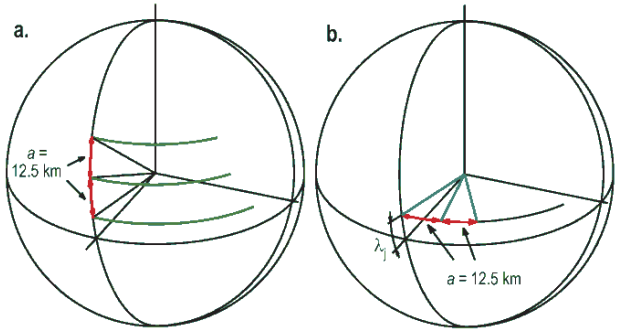


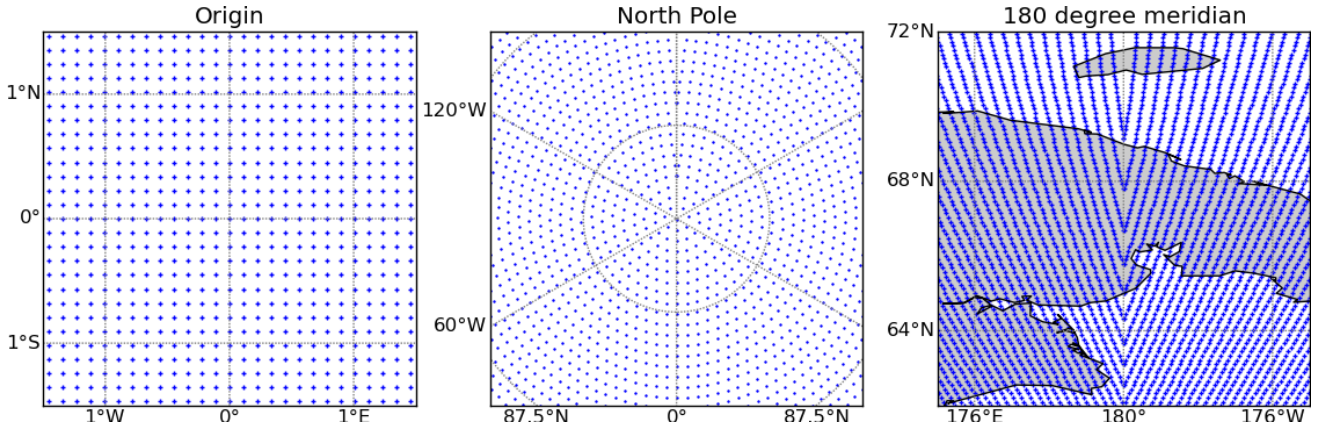
Metop ASCAT Surface Soil Moisture DR2018 (H113)



WARP5 Grid

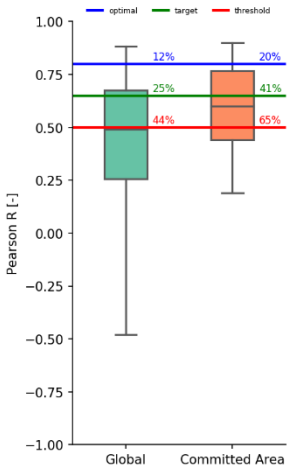
- Discrete Global Grid (DGG) construction and properties
  - Number of grid points: 3,264,391 (839,826 over land)
  - Equidistant 12.5 km sampling
  - Discontinuity on Anti-Meridian
  - Unique ID for each point
    - Grid Point Index (GPI)

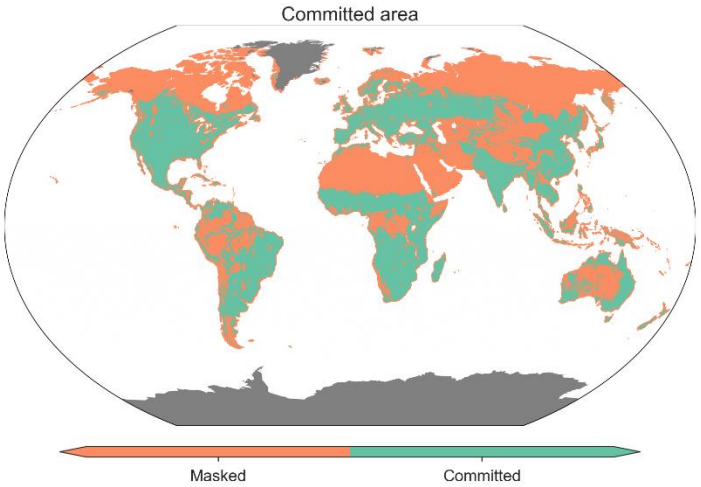


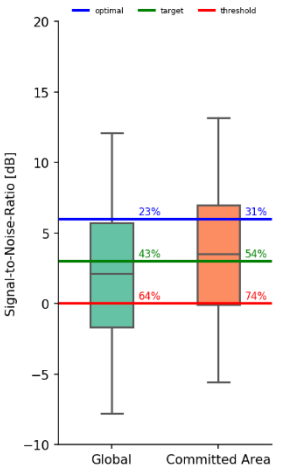


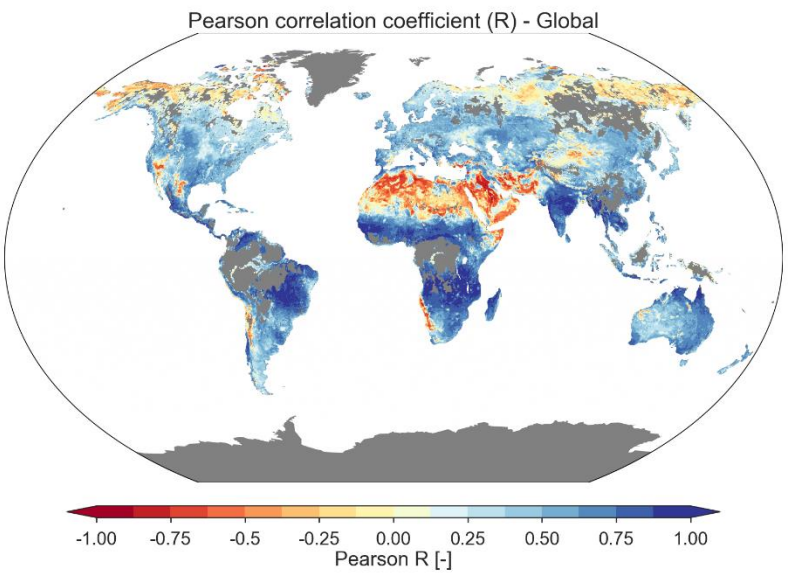
https://www.geo.tuwien.ac.at/dgg/

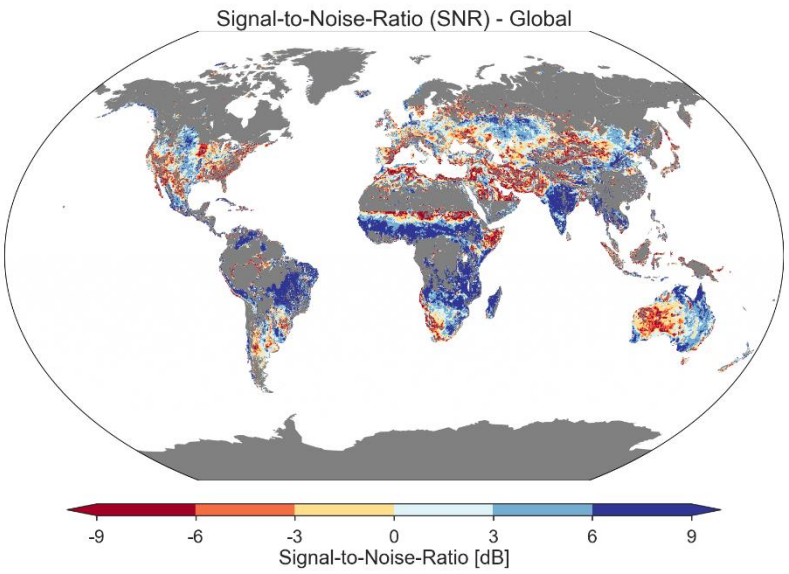
Metop ASCAT SSM DR2018 (H113) Product Validation











Metop ASCAT SSM DR2014 – Citation example

H SAF (2017): ASCAT Surface Soil Moisture CDR2014 time series 12.5 km sampling – Metop (H25), EUMETSAT SAF on Support to Operational Hydrology and Water Management, DOI: 10.15770/EUM_SAF_H_0001. http://dx.doi.org/10.15770/EUM_SAF_H_0001

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  year = 2017,
  note = {{EUMETSAT SAF on Support to Operational Hydrology and Water Management}},
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}
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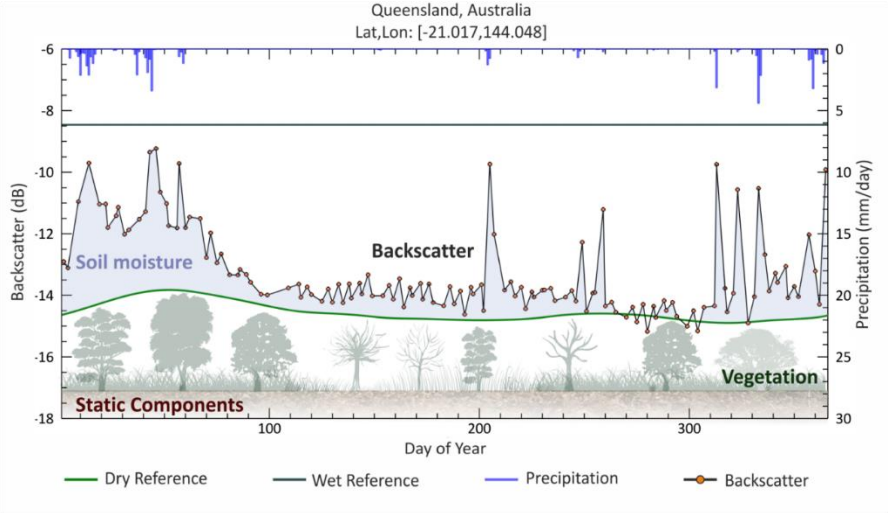
https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:H25

Algorithm & CDR/NRT Production Systems

- H SAF EUMETSAT TU Wien Surface Soil Moisture Algorithm
  - WARP - Climate Data Record Production System (TU Wien)
    - Products: H25/H108, H109/H110, H111/H112, H113/H114, H115/H116
    - Computation of empirical model parameters
  - WARP NRT - Near Real-Time Production System (EUMETSAT)
    - Products: H16, H101, H102, H103, H104, H105
    - Applying pre-computed model parameters
- H SAF EUMETSAT TU Wien Soil Moisture Disaggregation Algorithm
  - WARP H - Downscaling Parameter Production System (TU Wien)
    - Computation of downscaling parameter
  - WARP H NRT - Near Real-Time Production System (ZAMG)
    - Products: H08
    - Applying pre-computed downscaling parameter

TU Wien Model

- Formulated in 1996-1998 out of the need to circumvent the lack of adequate backscatter models
- Accounts indirectly for surface roughness and land cover



Vreugdenhil, M., et al., Analyzing the vegetation parameterization in the TU-wien ASCAT soil moisture retrieval, IEEE} Transactions on Geoscience and Remote Sensing, 54(6), 3513–3531 (2016). http://dx.doi.org/10.1109/tgrs.2016.2519842

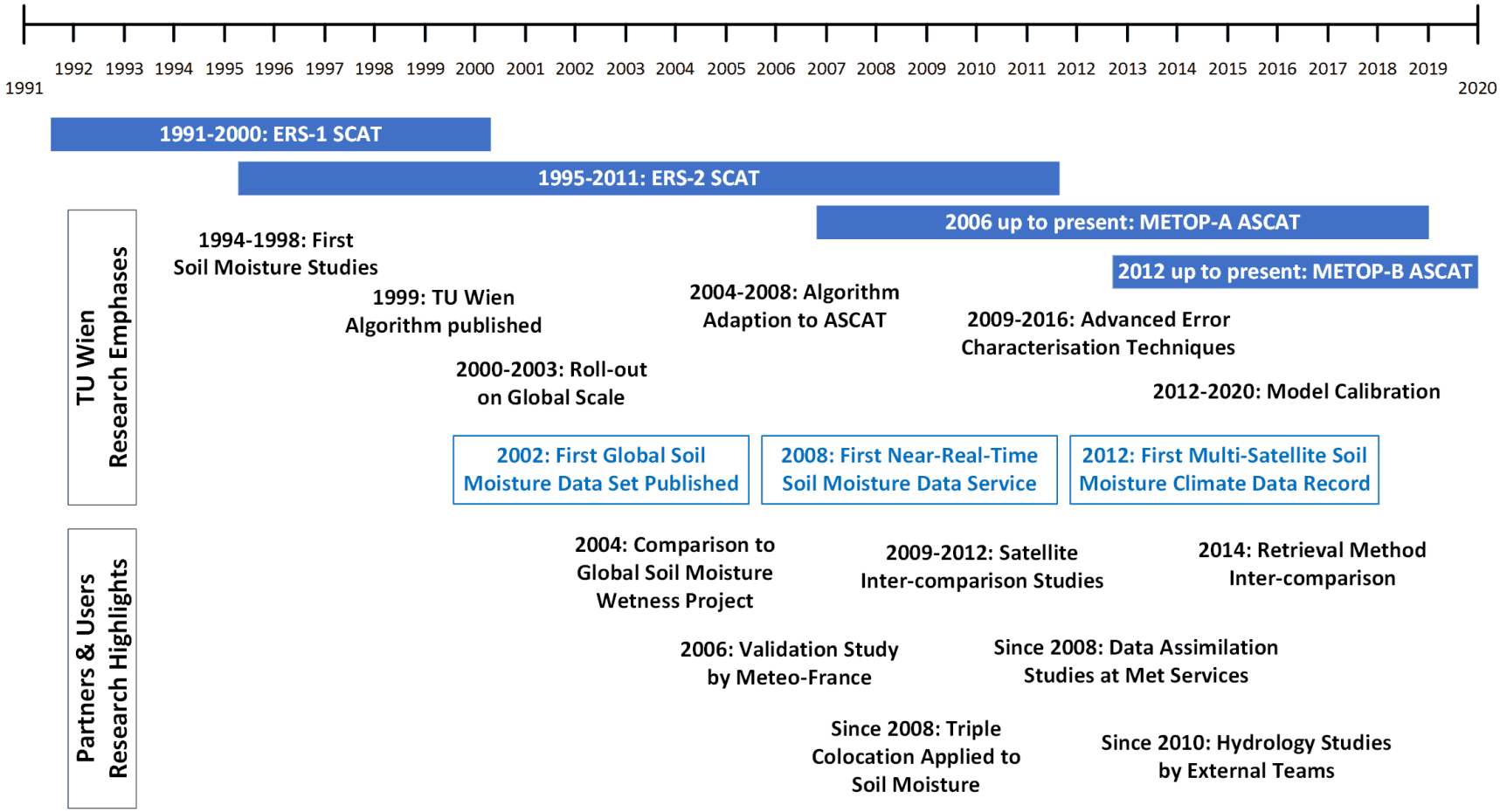
Wagner, W., et al., A method for estimating soil moisture from ERS scatterometer and soil data, Remote Sensing of Environment, 70(2), 191–207 (1999). http://dx.doi.org/10.1016/S0034-4257(99)00036-X

Wagner, W., et al., Monitoring soil moisture over the canadian prairies with the ERS scatterometer, IEEE} Transactions on Geoscience and Remote Sensing, 37(1), 206–216 (1999). http://dx.doi.org/10.1109/36.739155

Wagner, W., et al., A study of vegetation cover effects on ERS scatterometer data, IEEE} Transactions on Geoscience and Remote Sensing, 37(2), 938–948 (1999). http://dx.doi.org/10.1109/36.752212

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

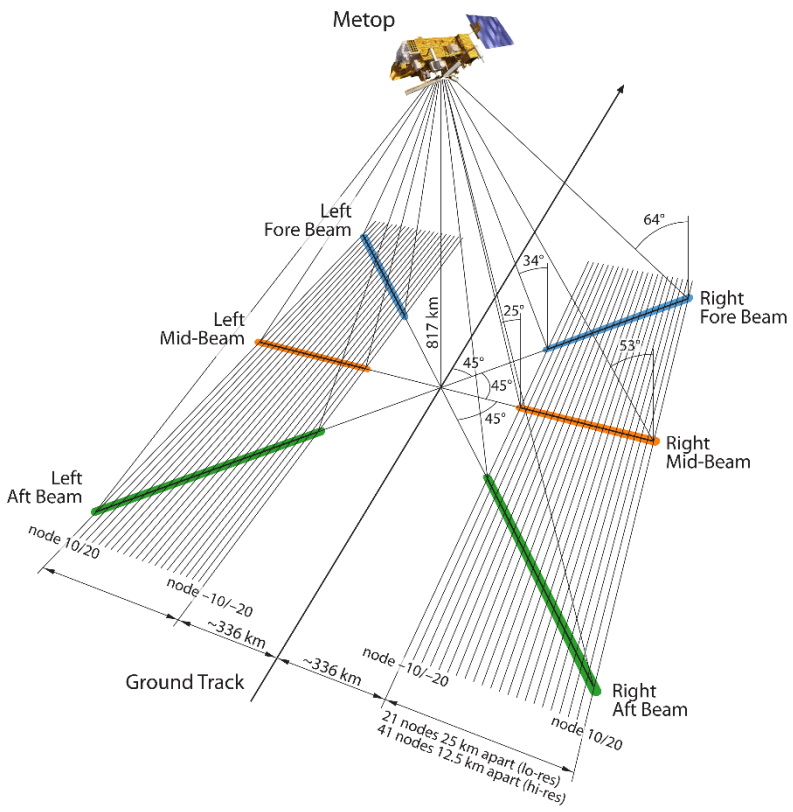
Soil Moisture Retrieval History

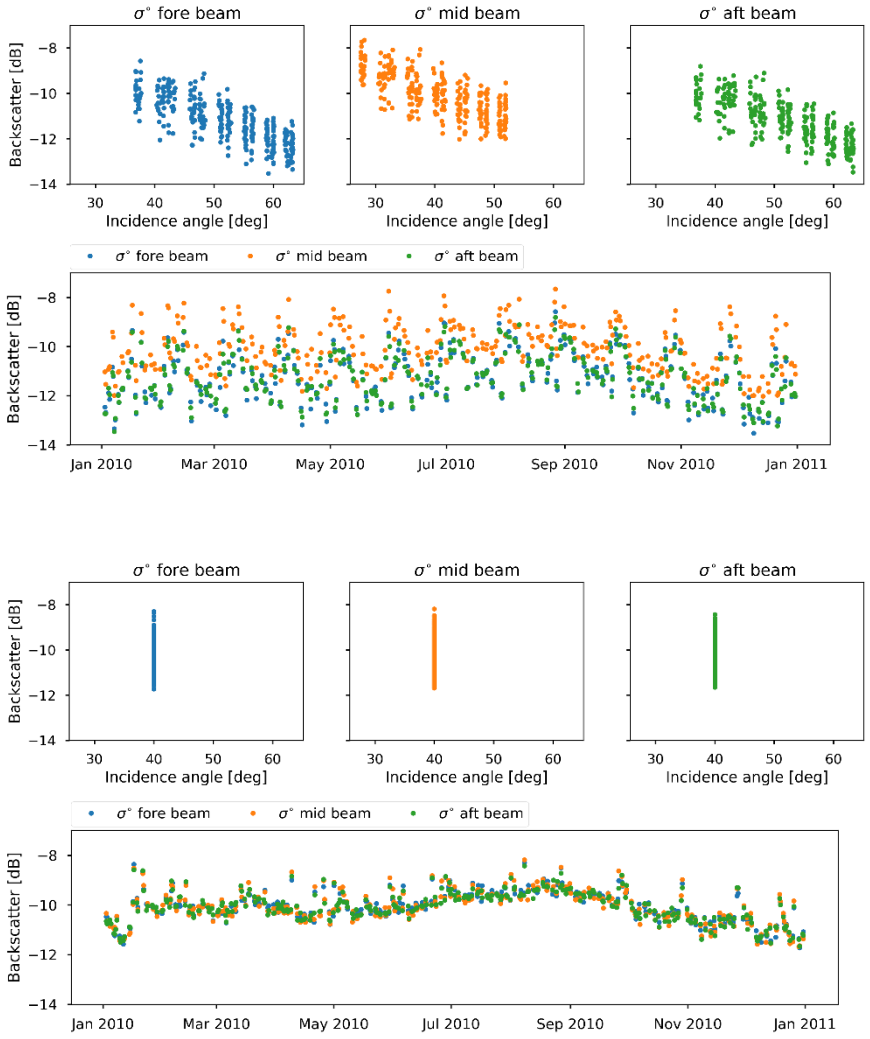


Working hypothesis for ASCAT soil moisture retrieval

- Information about absolute soil moisture content comes from **soil maps**, not the satellite
- ASCAT SM data are not fundamentally different to passive microwave SM products (e.g. SMOS, SMAP). Nonetheless, for ASCAT we have always stressed that the information content lies in the **relative variation** of the observations
  - This has resulted in a disparate treatment of ASCAT and SMOS data in the literature
    - ASCAT data have often been referred to as soil moisture index
    - ASCAT users approached the problem with less expectations
- ASCAT soil moisture data are represented in **degree of saturation**
  - Ranging between 0-1 or 0-100 % (i.e. completely dry - saturated soil)
  - Dry and wet reference values are extracted from multi-year time series
  - **Conversion to absolute values possible if soil porosity and soil moisture residual content are known**

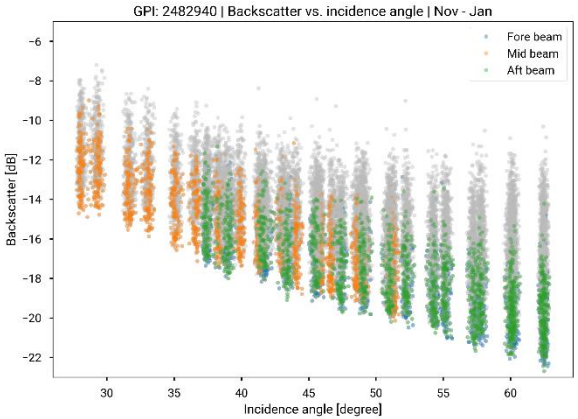
ASCAT geometry, backscatter vs incidence angle

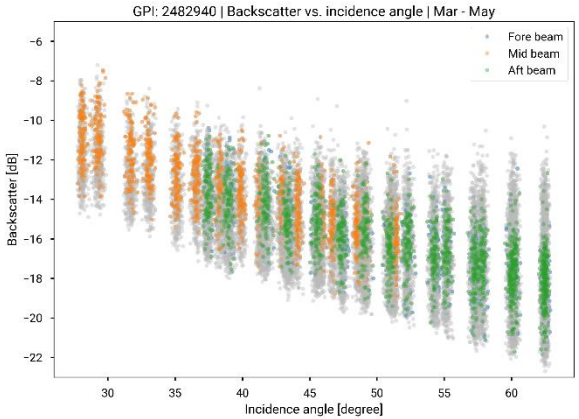


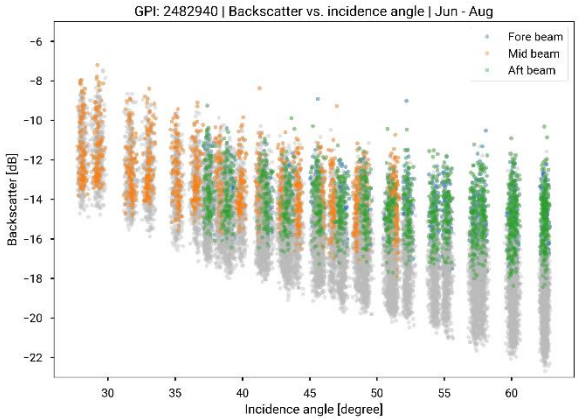


Incidence angle dependency of backscatter

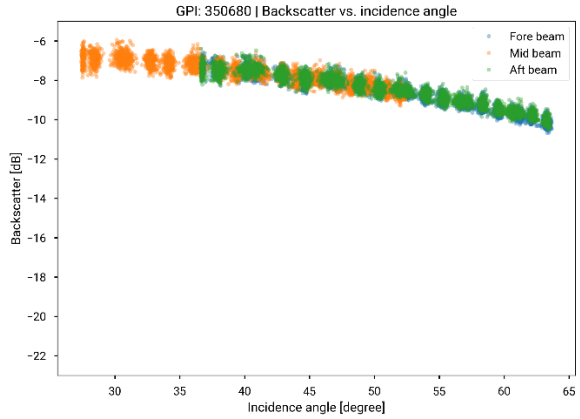
- Incidence angle characteristics change over time

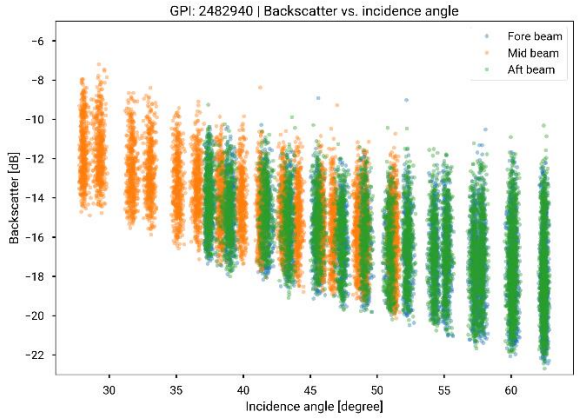


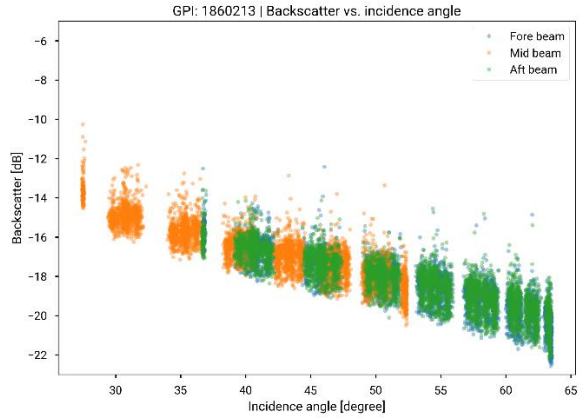




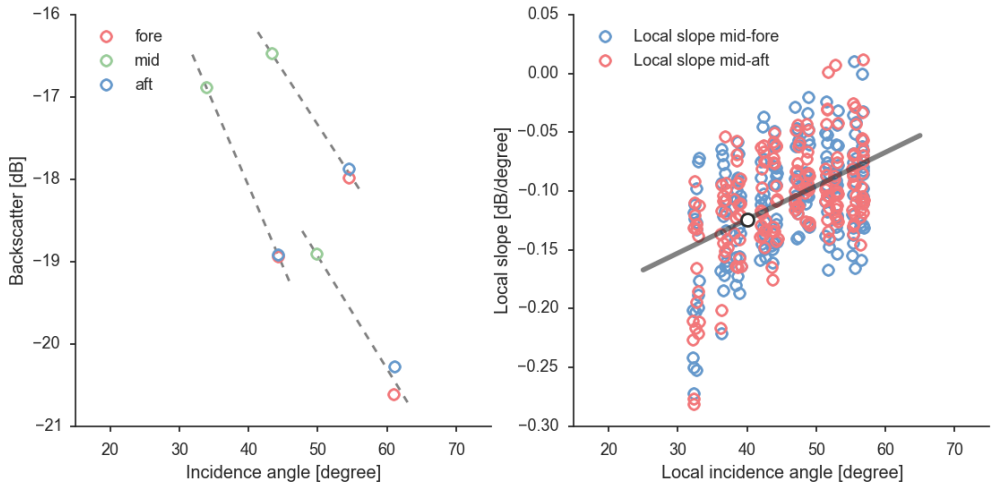
- And depend on location (land cover, vegetation , topography

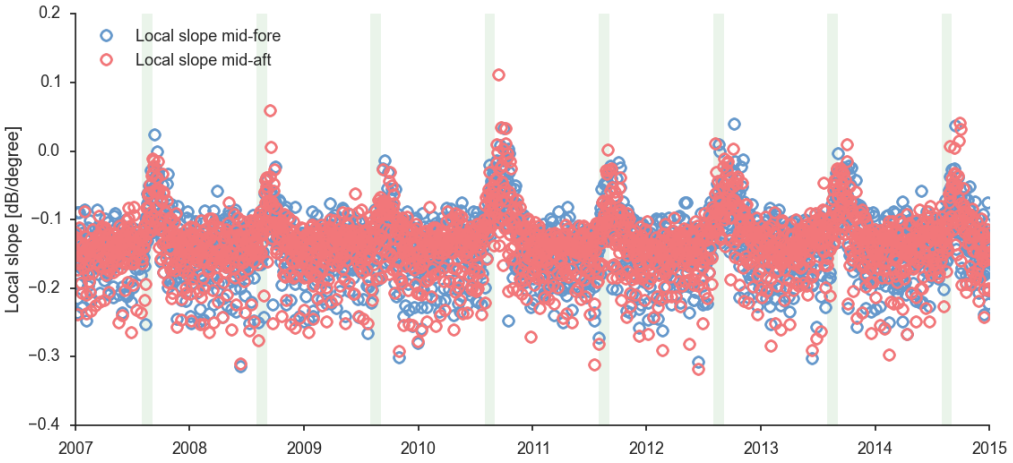






Estimation of Slope & Curvature parameters





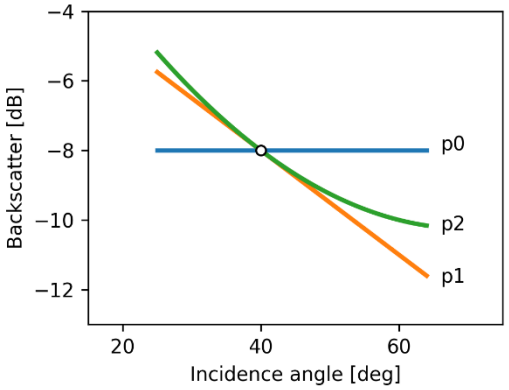
- Local slope is estimated for each backscatter triplet

$$\sigma'(\theta_{local}) = \frac{\sigma^0_{Mid} - \sigma^0_{Fore/Aft}}{\theta_{Mid} - \theta_{Fore/Aft}}$$

- A time window (42 days) contains many local slope values and a local linear regression is used to estimate slope and curvature for each day of year

Hahn, S., et al., Dynamic characterization of the incidence angle dependence of backscatter using metop ASCAT, IEEE} Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(5), 2348–2359 (2017). http://dx.doi.org/10.1109/jstars.2016.2628523

Incidence angle normalization of backscatter



$$y = c + b \cdot x + a \cdot x^2$$

$$\sigma_\theta^0(t) = \sigma_r^0(t) + \sigma_r'(t) \cdot (\theta - \theta_r) + 0.5 \cdot \sigma_r''(t) \cdot (\theta - \theta_r)^2$$

Backscatter at a common reference angle $\sigma_r^0(t)$ can be converted to an arbitrary incidence angle $\sigma_\theta^0(t)$ using slope $\sigma_r'(t)$ and curvature $\sigma_r''(t)$.

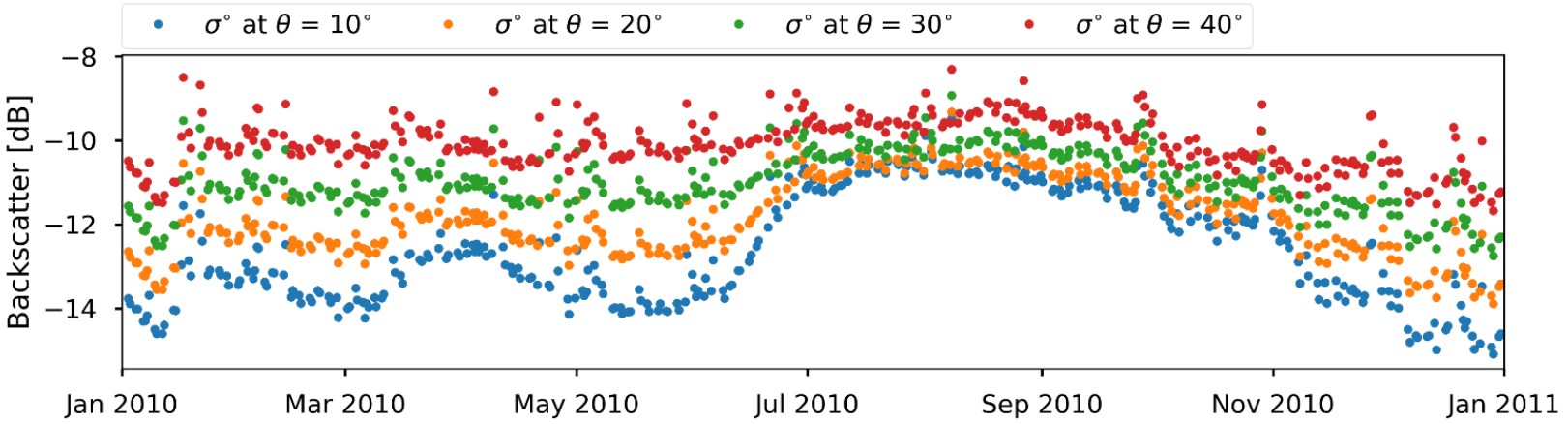
Naeimi, V., et al., An improved soil moisture retrieval algorithm for ers and metop scatterometer observations, IEEE} Transactions on Geoscience and Remote Sensing, 47(7), 1999–2013 (2009). http://dx.doi.org/10.1109/tgrs.2008.2011617

$$c = y - b \cdot x - a \cdot x^2$$

$$\sigma_r^0(t) = \sigma_\theta^0(t) - \sigma_r'(t) \cdot (\theta - \theta_r) - 0.5 \cdot \sigma_r''(t) \cdot (\theta - \theta_r)^2$$

Backscatter at an arbitrary incidence angle $\sigma_\theta^0(t)$ can be converted to any common incidence angle $\sigma_r^0(t)$ using slope $\sigma_r'(t)$ and curvature $\sigma_r''(t)$.

Incidence angle normalization of backscatter



Naeimi, V., et al., An improved soil moisture retrieval algorithm for ers and metop scatterometer observations, IEEE} Transactions on Geoscience and Remote Sensing, 47(7), 1999–2013 (2009). http://dx.doi.org/10.1109/tgrs.2008.2011617

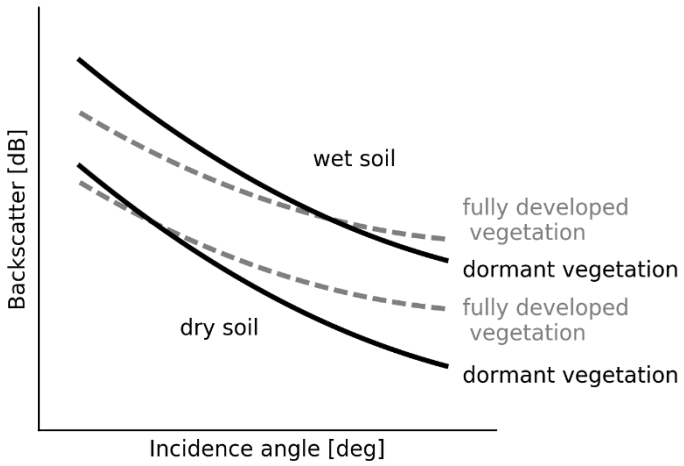
$$c = y - b \cdot x - a \cdot x^2$$

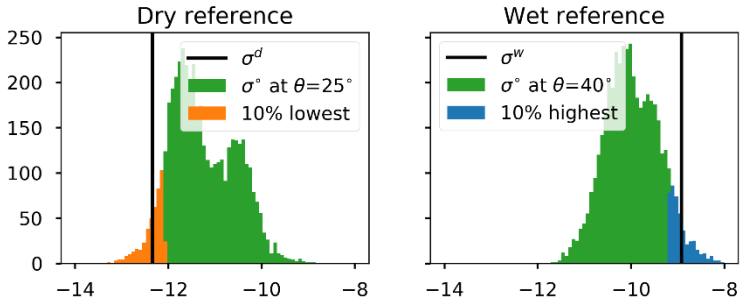
$$\sigma_r^0(t) = \sigma_\theta^0(t) - \sigma_r'(t) \cdot (\theta - \theta_r) - 0.5 \cdot \sigma_r''(t) \cdot (\theta - \theta_r)^2$$

Backscatter at an arbitrary incidence angle $\sigma_\theta^0(t)$ can be converted to any common incidence angle $\sigma_r^0(t)$ using slope $\sigma_r'(t)$ and curvature $\sigma_r''(t)$.

Estimation of Dry & Wet backscatter reference

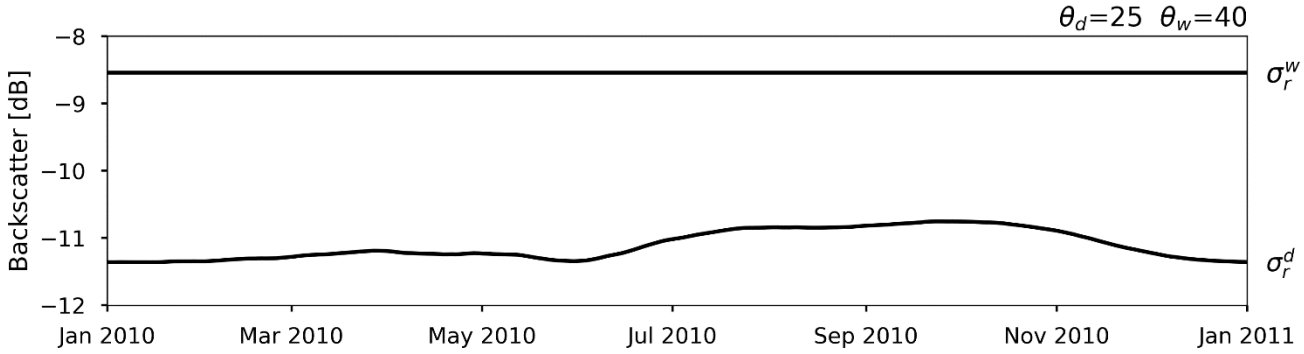
Cross-over angle concept





Estimation of dry and wet backscatter reference at dry and wet cross-over angle

$$\sigma_r^0(t) = \sigma_\theta^0(t) - \sigma_r'(t) \cdot (\theta - \theta_r) - 0.5 \cdot \sigma_r''(t) \cdot (\theta - \theta_r)^2$$

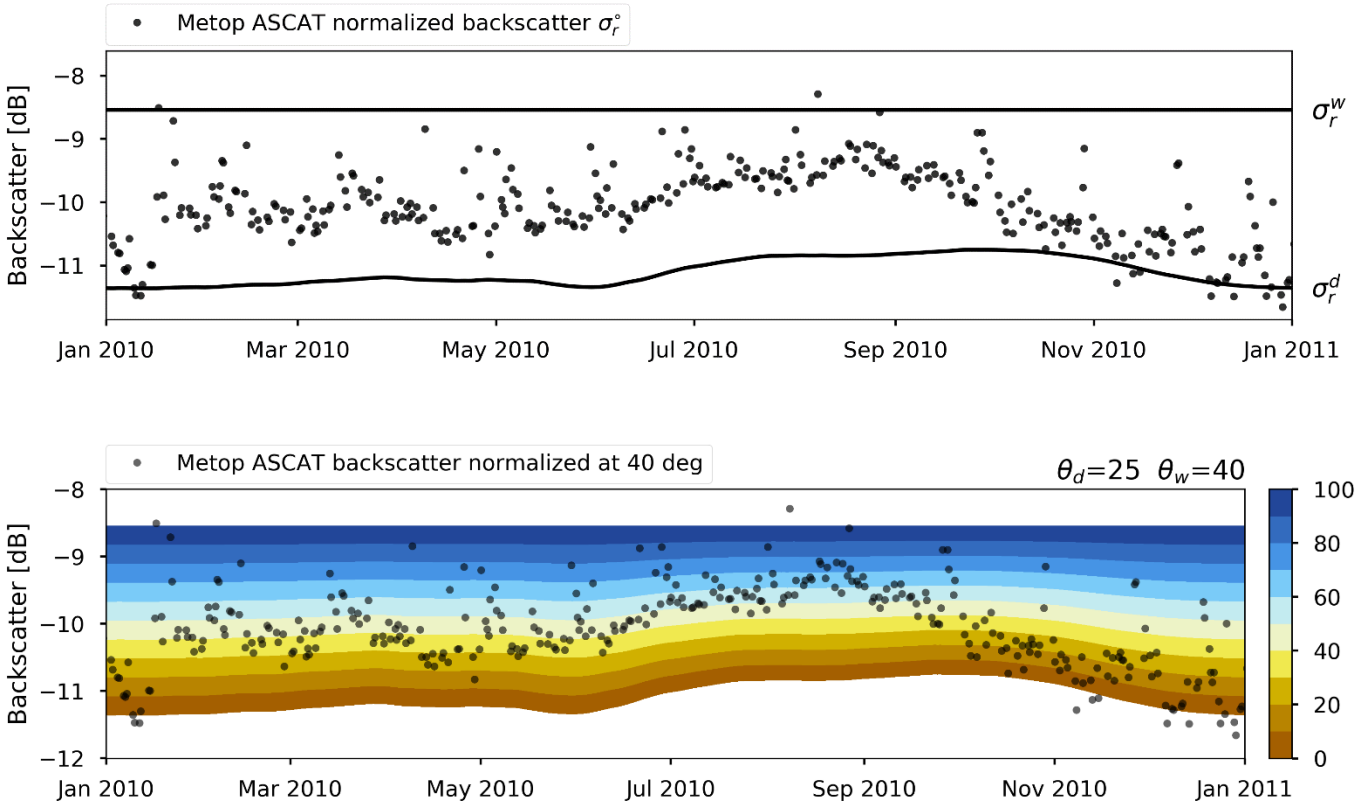


wet reference

dry reference

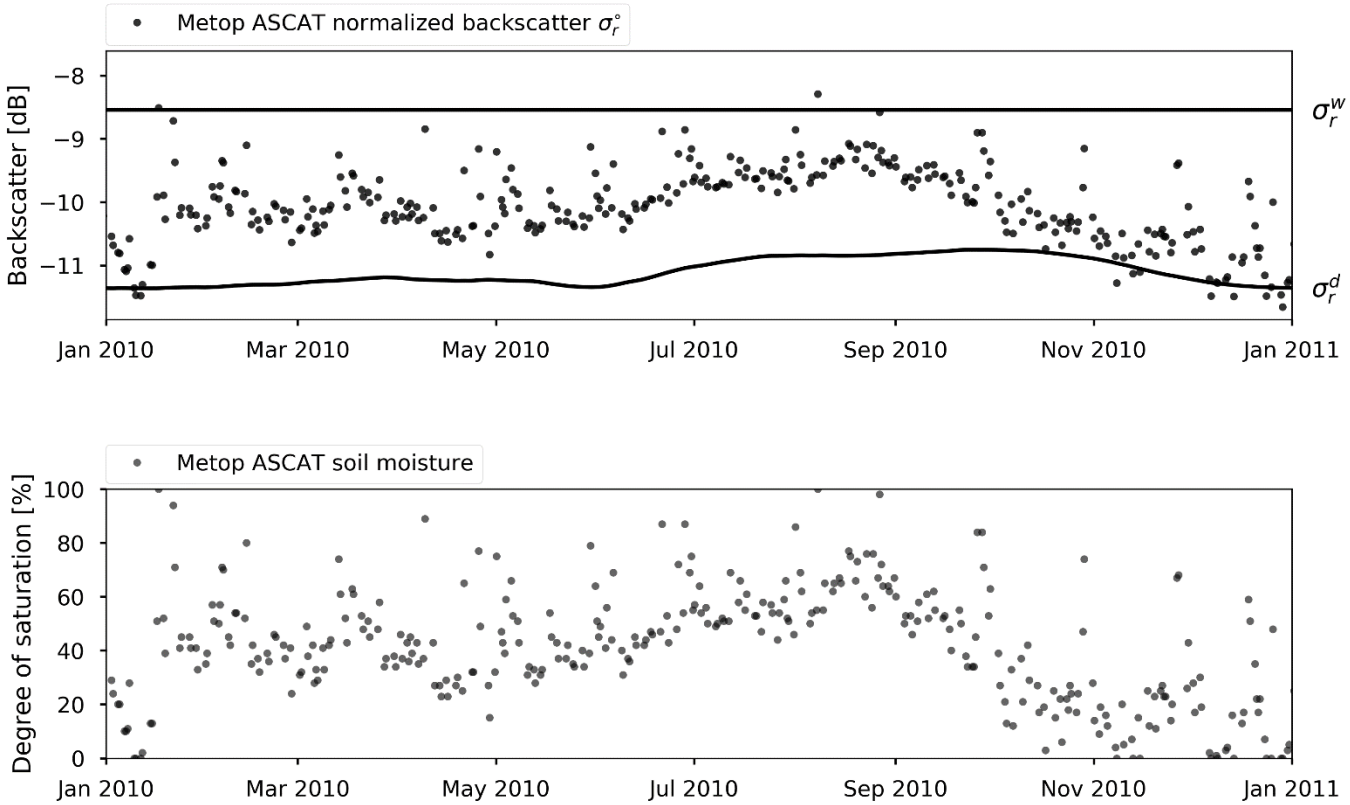
Soil Moisture Retrieval – Change Detection

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



Soil Moisture Retrieval – Change Detection

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

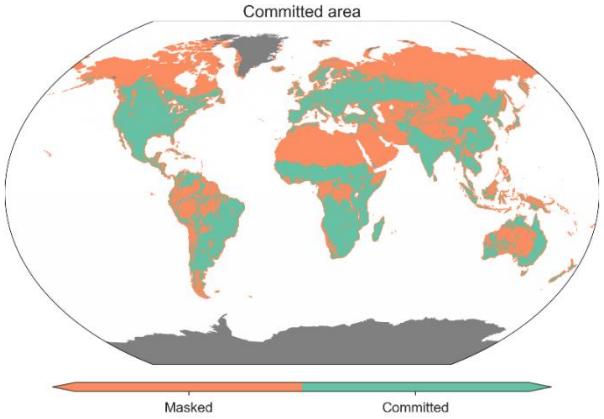


Limitation and caveats

- Soil moisture retrieval is not possible over
  - Urban areas, concrete and rock
  - Water bodies and inundation
  - Frozen or snow covered soil
  - Under forests and dense shrubs

- Soil moisture data quality varies in space and time because of
  - Vegetation water content and structure
  - Sub-surface scattering in dry areas
  - Topographic effects

- Data quality described by uncertainty estimates and additional flags
  - Uncertainty estimates from error propagation
  - Advisory flags (e.g. frozen soil probability, snow cover probability)



Wagner, W., et al., The ASCAT Soil Moisture Product: A Review of its Specifications, Validation Results, and Emerging Applications, Meteorologische Zeitschrift, 22(1), 5–33 (2013). http://dx.doi.org/10.1127/0941-2948/2013/0399

Brocca, L., et al, 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 (2017). http://dx.doi.org/10.1109/JSTARS.2017.2651140

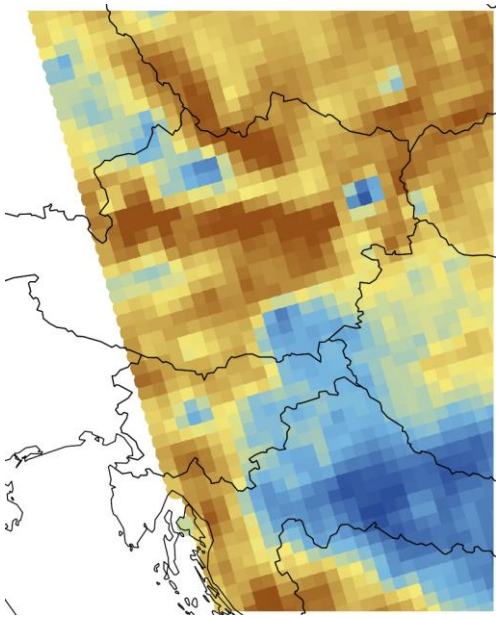
Soil Moisture Disaggregation Algorithm

- Disaggregation method is based on the concept of temporal stability of soil moisture
  - Given temporally stable soil moisture patterns, time-invariant relationships can be used for estimating regional soil moisture from point scale measurements (“upscaling”)
- The time-invariant relationship is derived from local and averaged (=regional) backscatter from ENVISAT ASAR, which are called downscaling parameter
  - Temporal persistence of soil moisture should be reflected in the spatio-temporal behavior of backscatter
- The downscaling parameter are applied to ASCAT SSM NRT

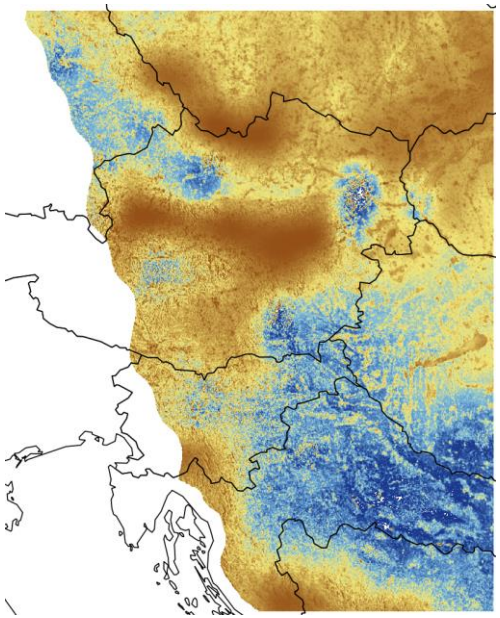
Wagner, W. et al., Temporal stability of soil moisture and radar backscatter observed by the advanced synthetic aperture radar (ASAR), Sensors, 8(2), 1174–1197 (2008). http://dx.doi.org/10.3390/s80201174

Disaggregated Metop ASCAT NRT SSM

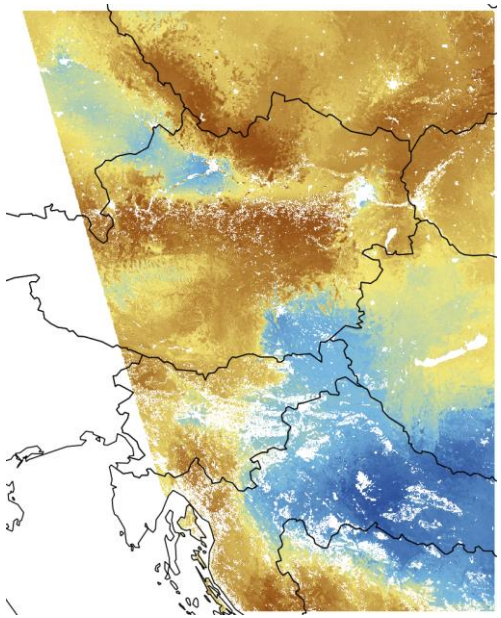
- H08 - 0.5 km spatial sampling (BUFR, NetCDF) based on Metop-B
- H28 - 1 km spatial sampling (NetCDF) based on Metop-A/B/C



H16 - 12.5 km sampling



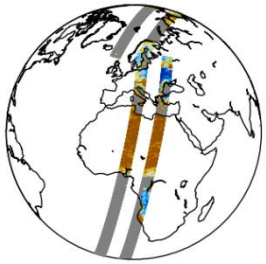
H08 - 0.5 km sampling



H28 - 1 km sampling

Summary & Outlook

- **ASCAT SSM Near Real-Time (NRT) products**

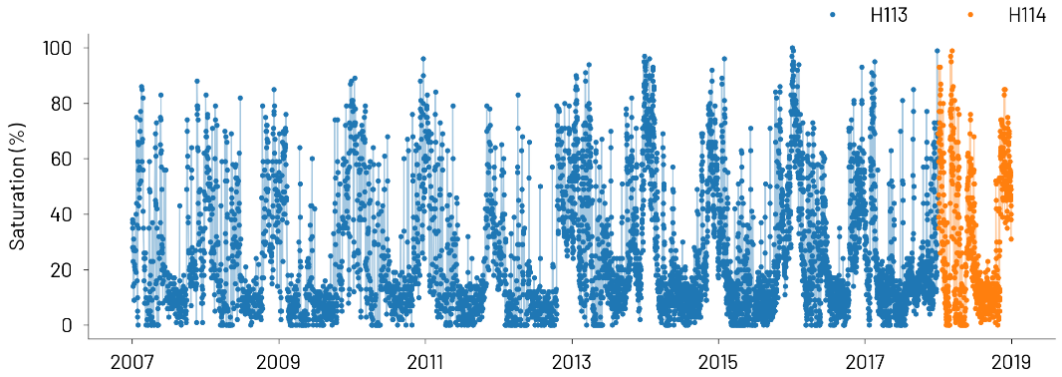


Metop-C
- 25 km spatial sampling - H105
- 12.5 km spatial sampling - H104

Metop-A, Metop-B, Metop-C
- 6.25 km spatial sampling - H122
- 1 km spatial sampling - H28

Metop-SG SCA
- 6.25 km spatial sampling
- 12.5 km spatial sampling

- **ASCAT SSM Climate Data Record (CDR) and Offline (CDR Extension) products**



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- Product User Manual (PUM) Soil Moisture Data Records, Metop ASCAT Soil Moisture Time Series, Tech. Rep. Doc. No: SAF/HSAF/CDOP3/PUM, v0.8, 2018.
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