VIENNA UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF GEODESY AND GEOINFORMATION
RESEARCH GROUPS PHOTOGRAMMETRY & REMOTE SENSING

Bernhard **Bauer-Marschallinger**

http://land.copernicus.eu/global/

Soil Moisture @ Copernicus

Satellite-based Soil Moisture Data within the Copernicus Global Land Service

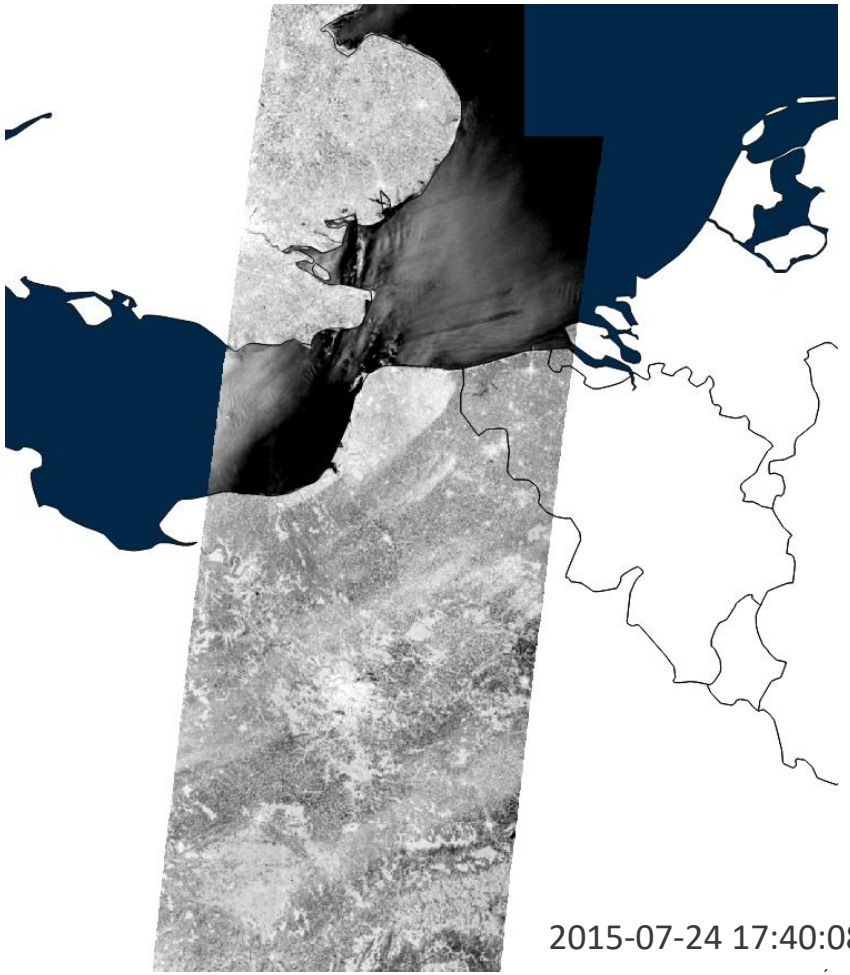
Virtual Workshop
2020-07-14

The **Copernicus User Uptake project** is financed by the European Commission under the FPA no.: 275/G/GRO/COPE/17/10042

Framework Partnership Agreement for Copernicus User Uptake

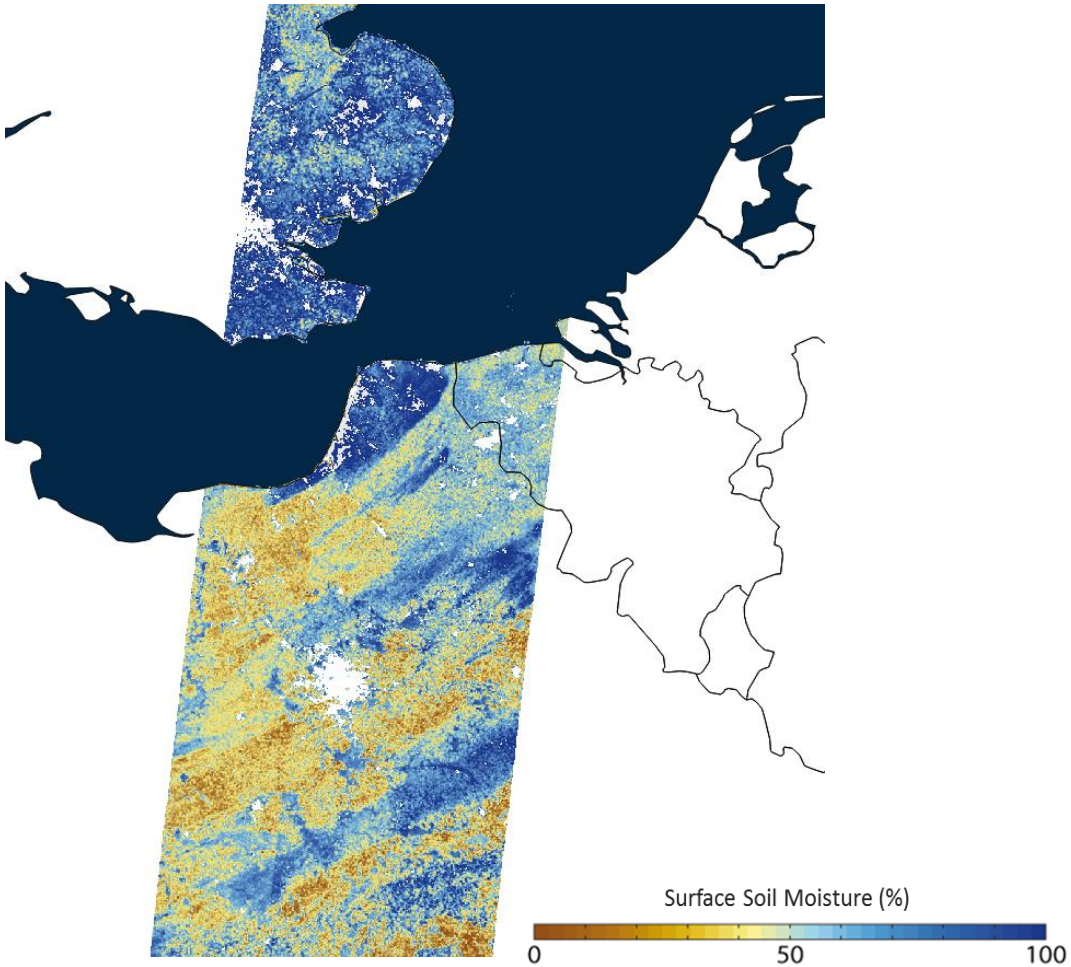
Soil Moisture from Satellite Radar Sensors!?

Satellite Radar backscatter in dB



2015-07-24 17:40:08

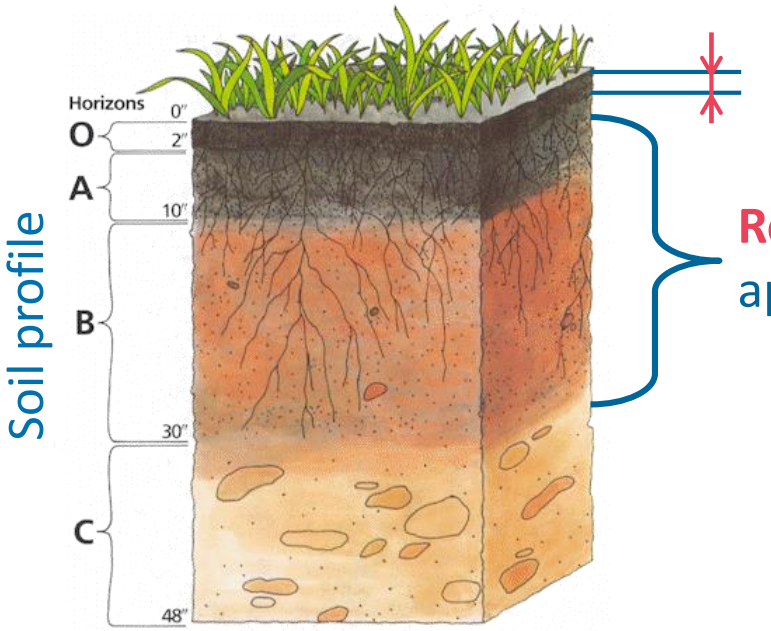
Soil Moisture in %



Overview for Today

- Soil Moisture & Satellite Radar
- TU Backscatter Model @ Copernicus
- Soil Moisture Products @ Copernicus
    - ASCAT SWI
    - SSM1km
    - SWI1km
  - Product Usage & Access
  - Quality Assessment & Validation
  - Known Issues & Conclusions

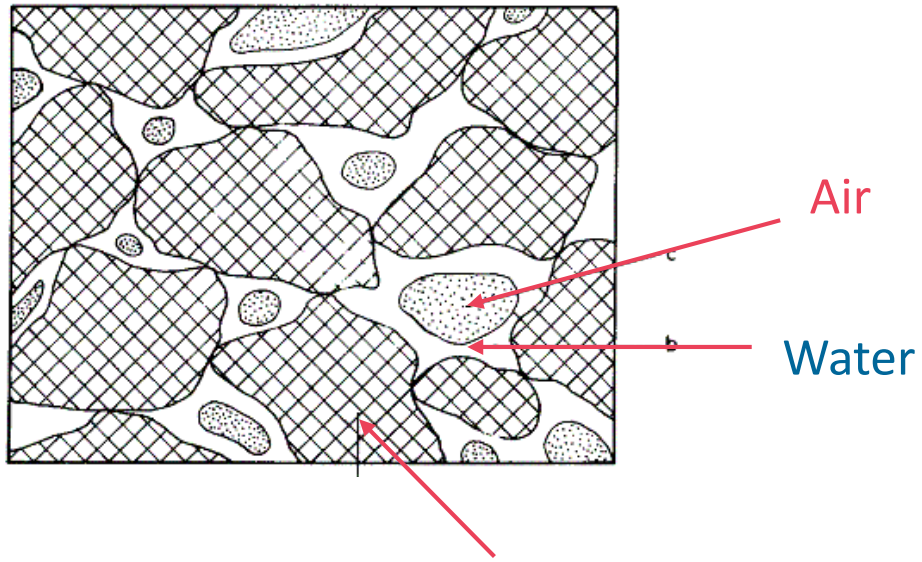
Soil Moisture



Thin, **remotely sensed surface** soil layer

Root zone: layer of interest for most applications

Cross-section of a soil

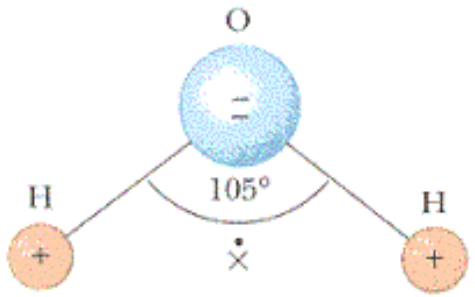


Approaches to Remote Sensing of Soil Moisture

- Measurement principles
  - No direct measurement of soil moisture possible, only indirect techniques
- Optical to Mid-Infrared (0.4 – 3 μm)
  - Change of "colour"
  - Water absorption bands at 1.4, 1.9 and 2.7 μm
- Thermal Infrared (7-15 μm)
  - Indirect assessment of soil moisture through its effect on the surface energy balance (temperature, thermal inertia, etc.)
- Microwaves (1 mm – 1 m)
  - Change of dielectric properties

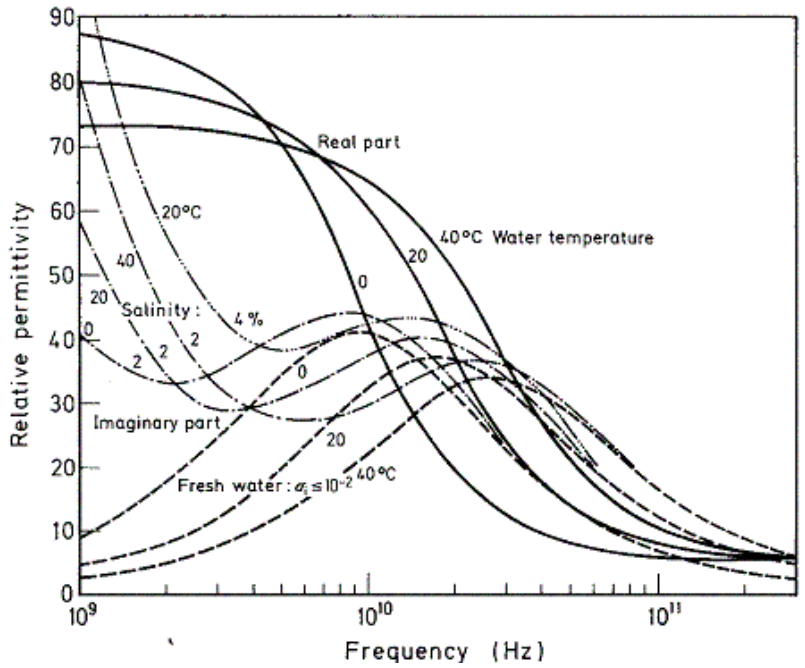
Microwaves & Water

- Microwaves (1 mm – 1 m wavelength)
  - All-weather, day-round measurement capability
  - Very sensitive to soil water content below relaxation frequency of water (< 10 GHz)
  - Penetrate vegetation and soil to some extent
    - Penetration depth increases with wavelength



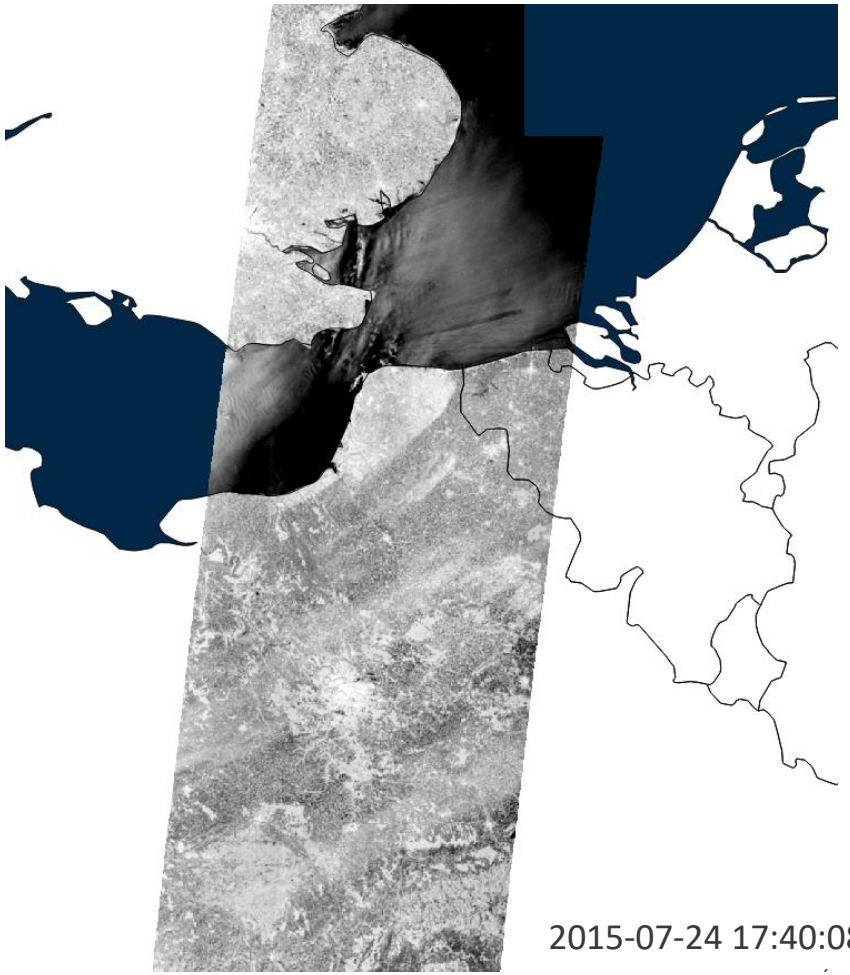
The dipole moment of water molecules causes “orientational polarisation”
→ a high dielectric constant

Dielectric constant of water



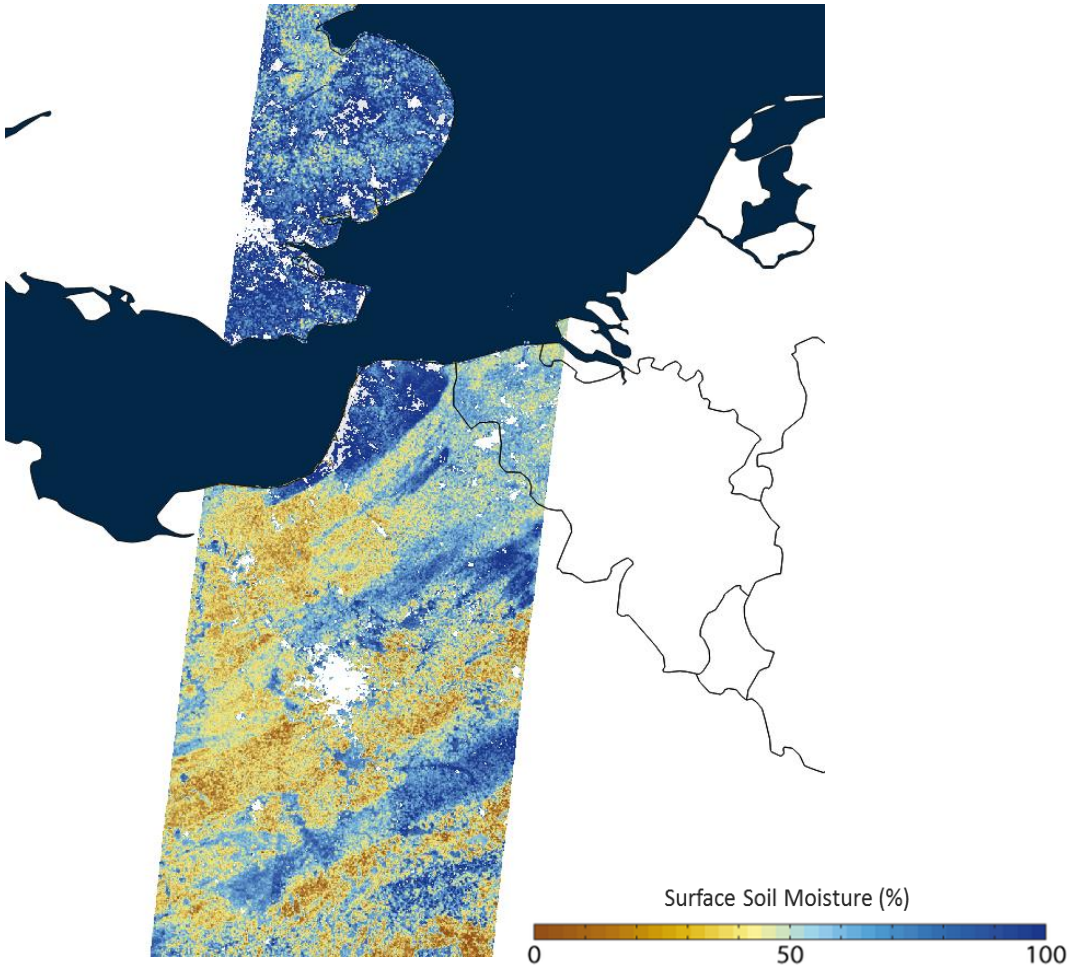
Soil Moisture from Satellite Radar Sensors!

Satellite Radar backscatter in dB

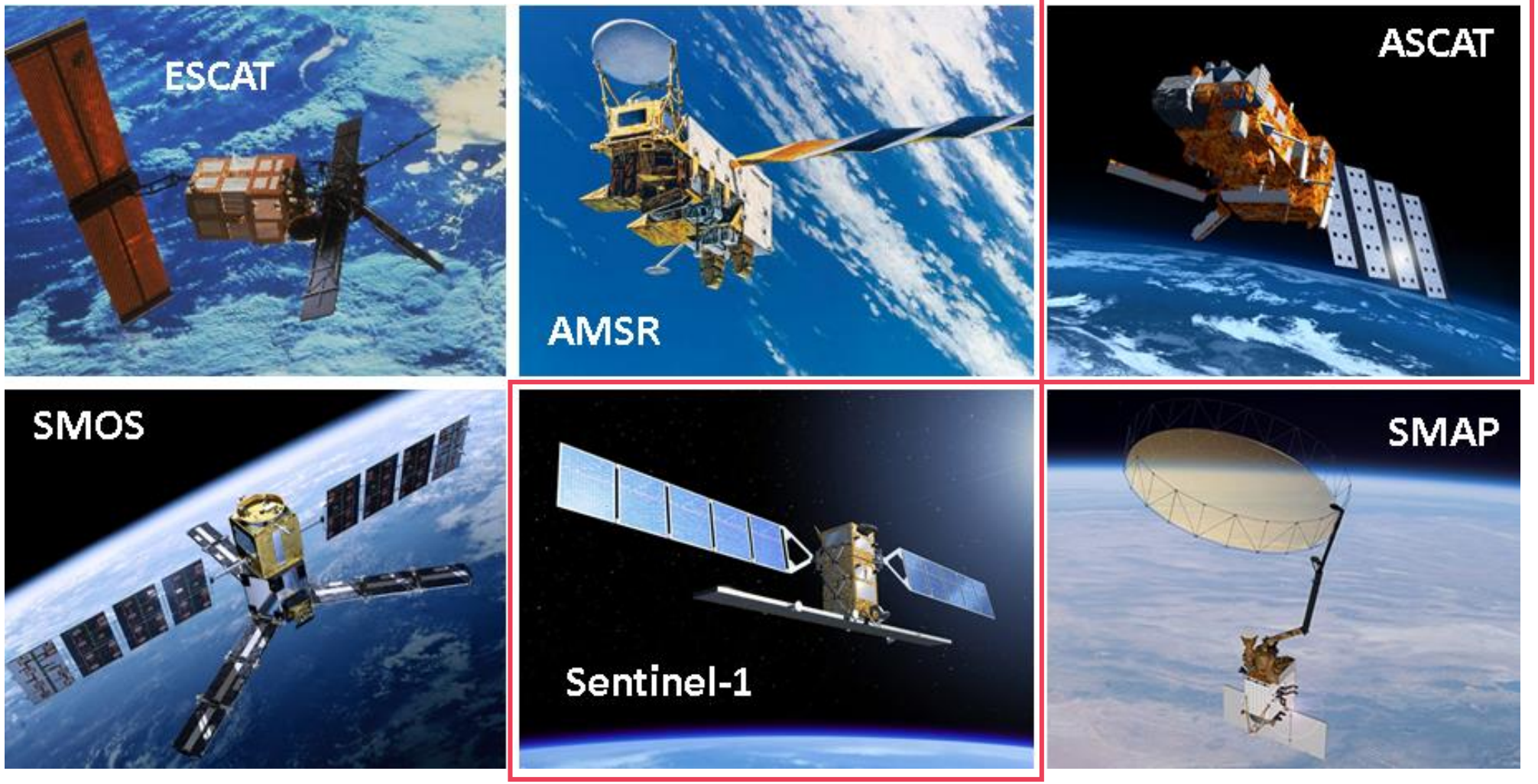


2015-07-24 17:40:08

Soil Moisture in %



Microwave Satellites used for Soil Moisture Retrieval

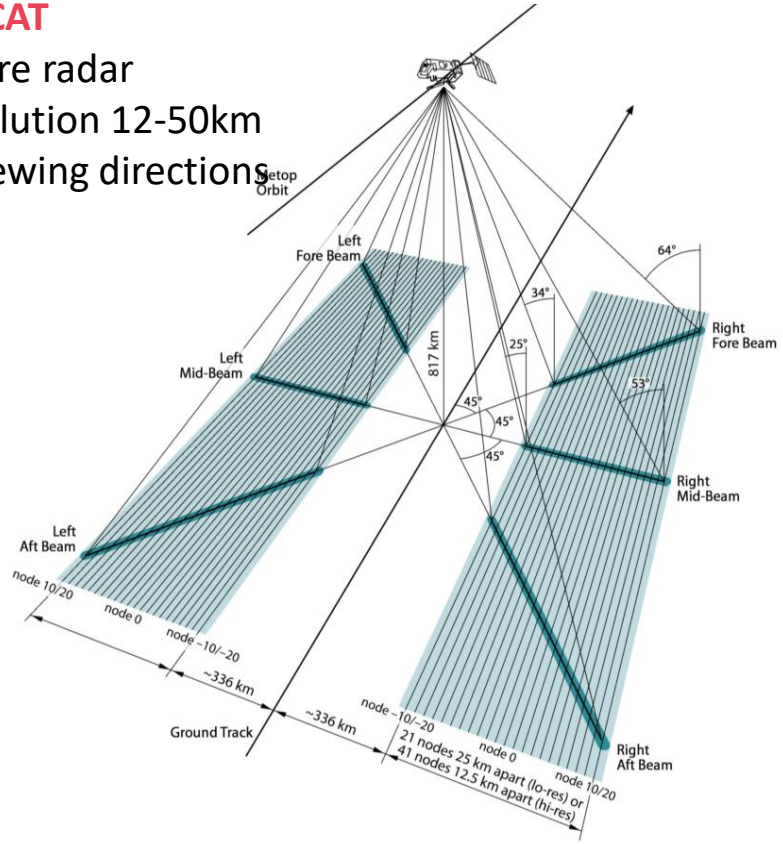


Measurement Concept

- Side-looking radars
  - measuring the backscatter coefficient σ^0 (sigma0), in [dB]

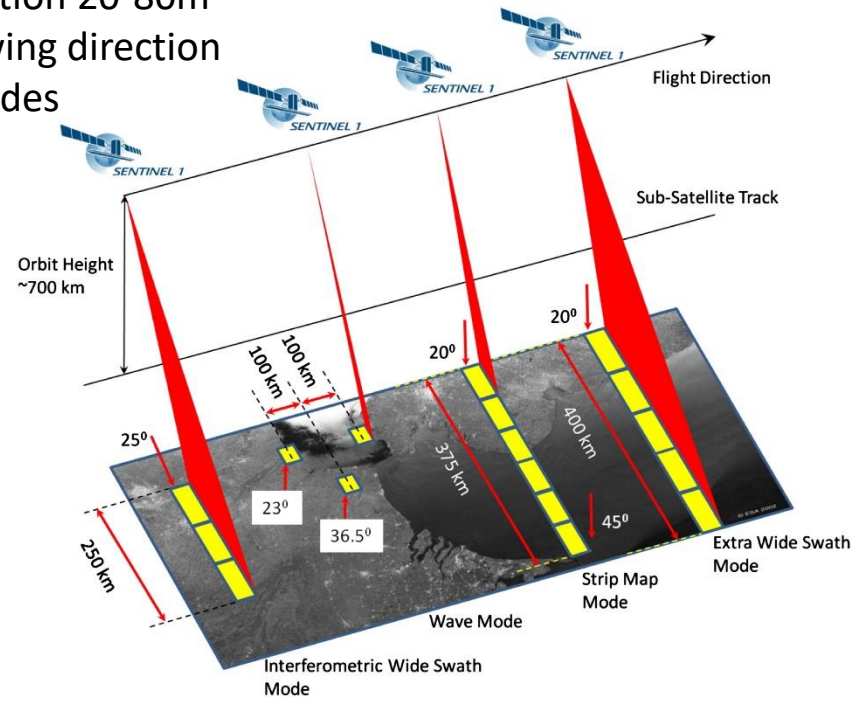
METOP ASCAT

Real aperture radar
Coarse resolution 12-50km
Multiple-viewing directions
One mode



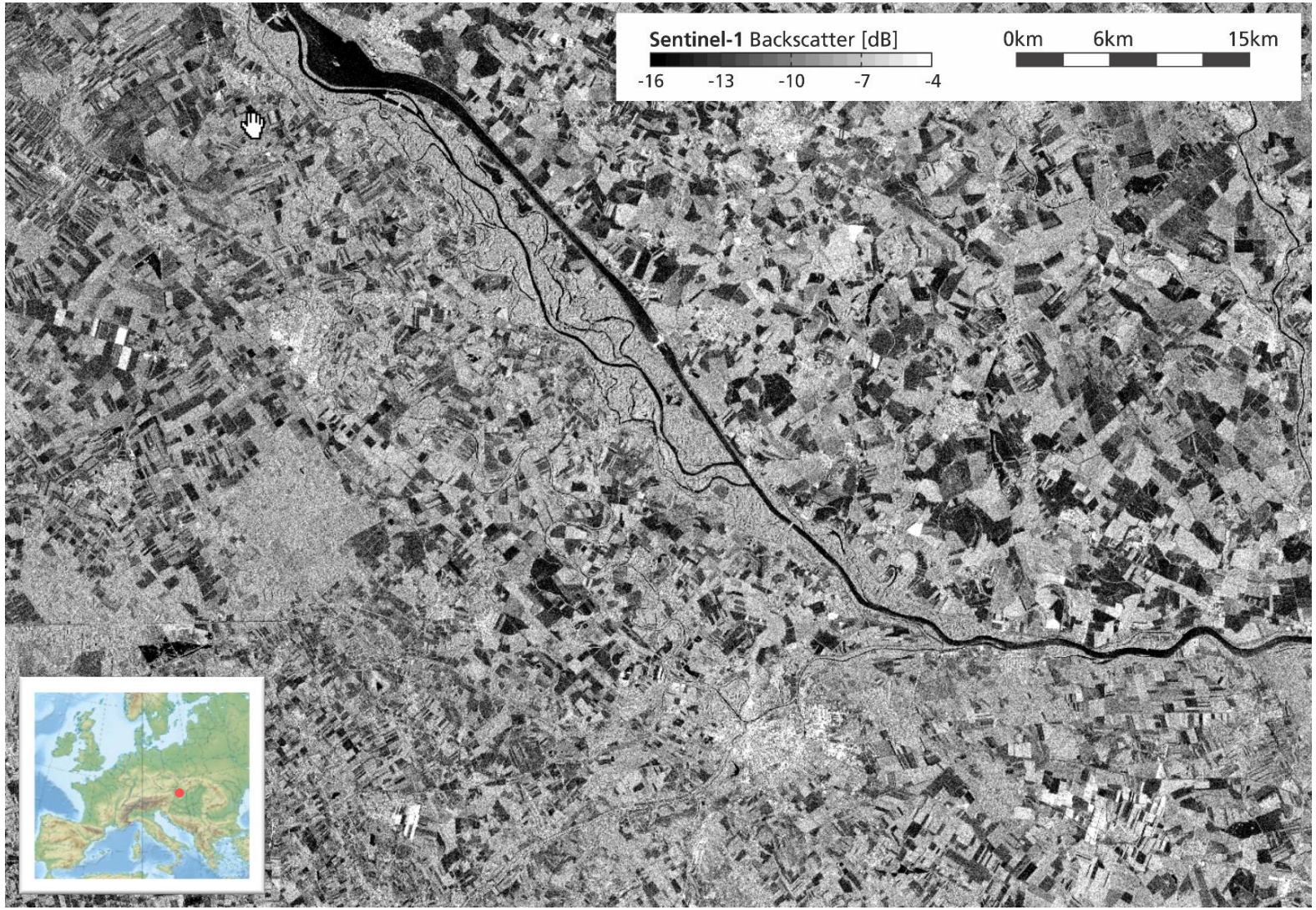
Sentinel-1 CSAR

Synthetic aperture radar
Fine resolution 20-80m
Single-viewing direction
Several modes



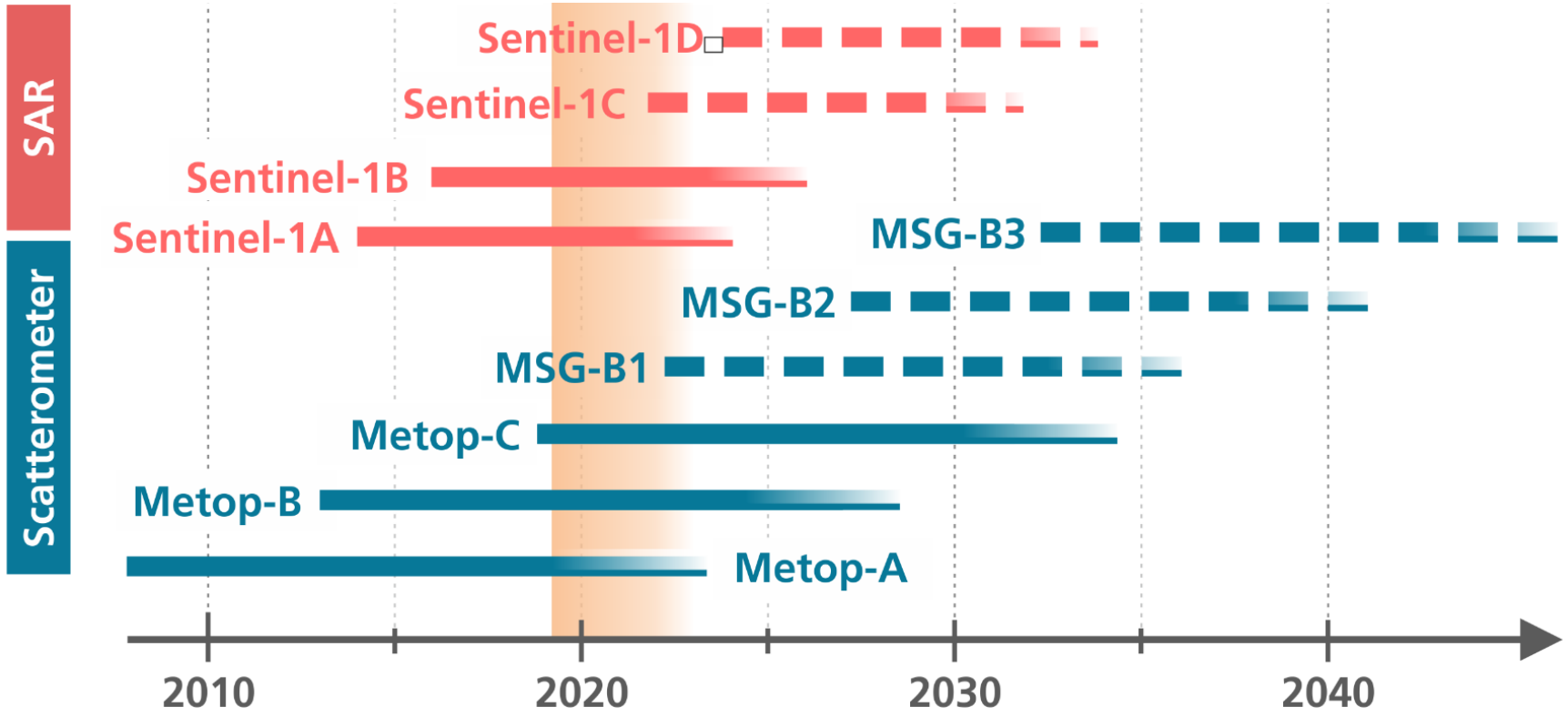
Radar Imagery

- Spaceborne radar
  - independent from weather and daylight
  - different processes observable than with optical sensors
- Scatterometers
  - e.g. ASCAT
  - 1-50km resolution
  - 1-2 days coverage
- SAR
  - e.g. Sentinel-1
  - 10-100m resolution
  - 2-14 days coverage
  - TBs of raw data per day

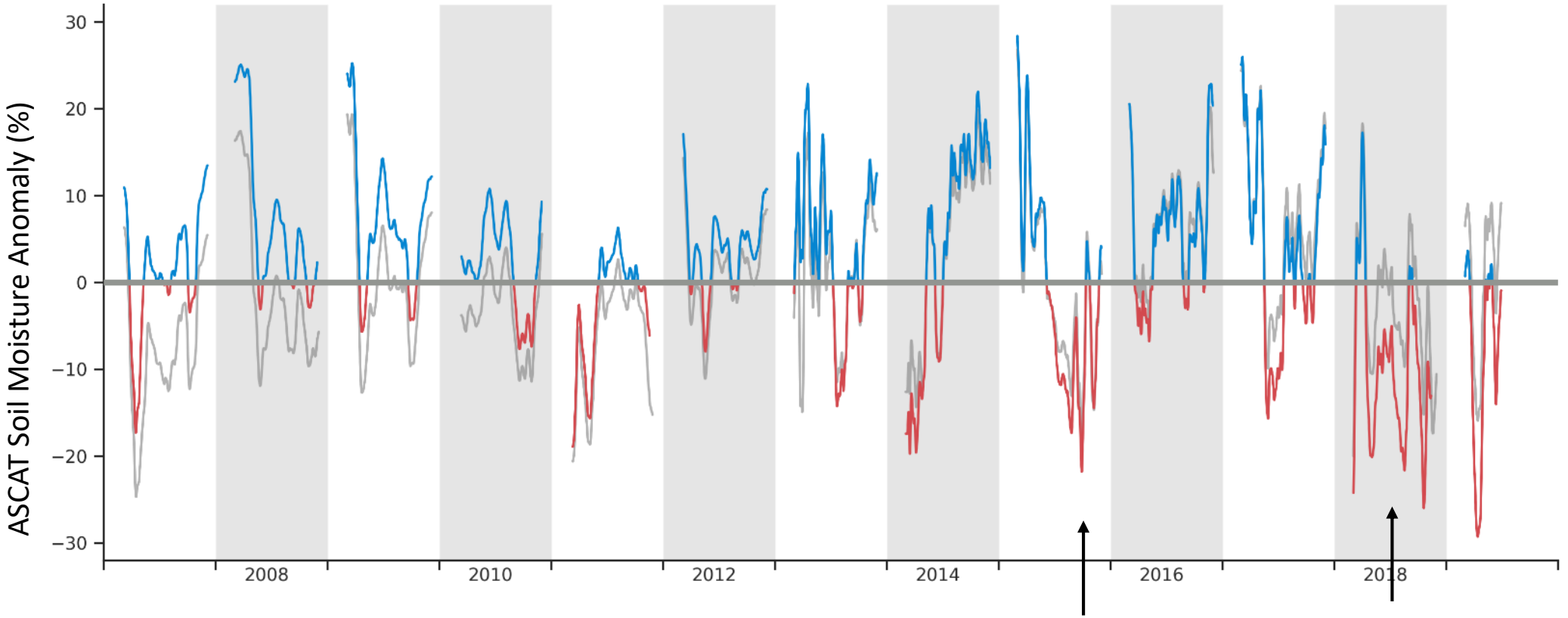


Sentinel-1 SAR + ASCAT for Soil Moisture

- proven capability for SM monitoring
  - building upon previous C-band missions (e.g. ERS-1/2 or Envisat ASAR, ~5GHz ~5cm)
  - high radiometric accuracy & stability
  - long prospect for mission continuity (min. until 2030s)



Drought Monitoring with ASCAT Soil Moisture Data

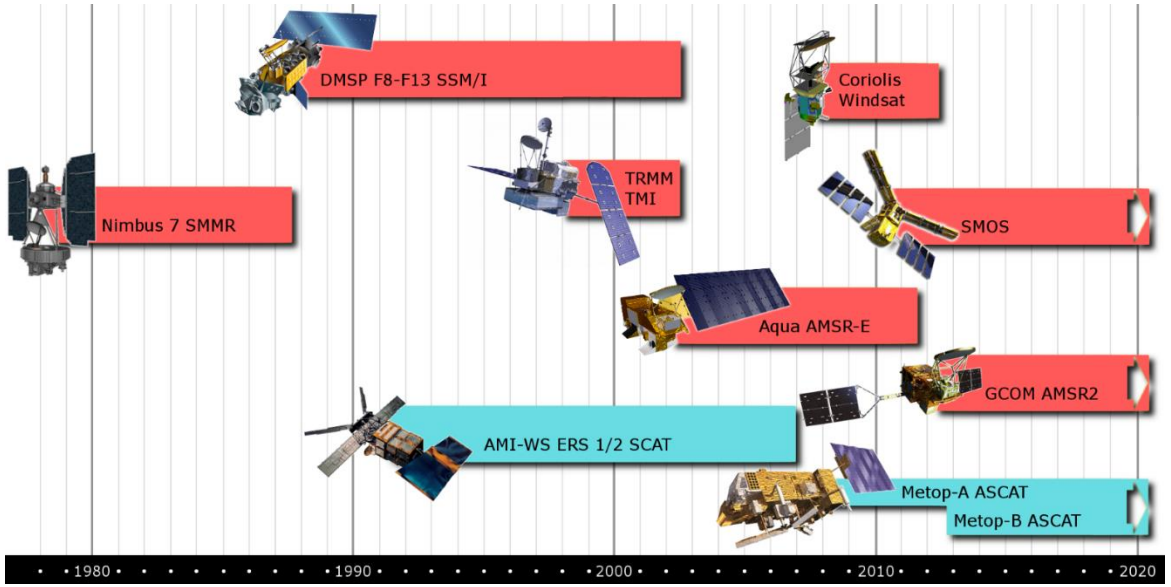


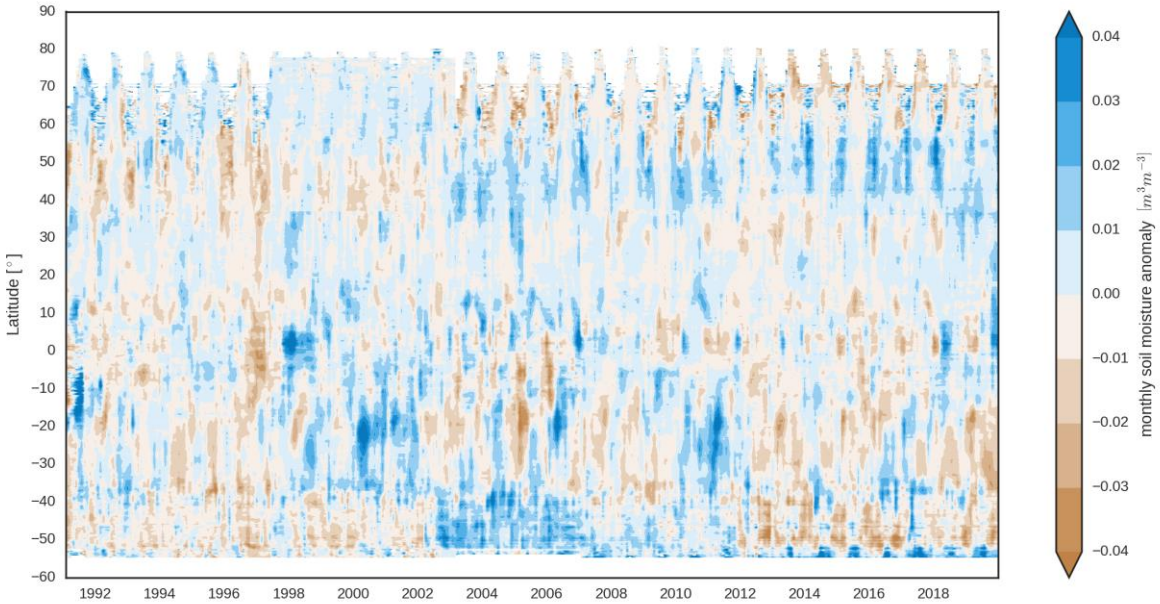
Drought-index derived from ASCAT soil moisture data over Offenhausen, Upper Austria.
Grey line: without correcting for land cover changes and RFI.

→ ESA CCI SM

v04.7 is the latest publicly available ESA CCI SM dataset spanning the period 1978-2019

http://www.esa-soilmoisture-cci.org





Input data products

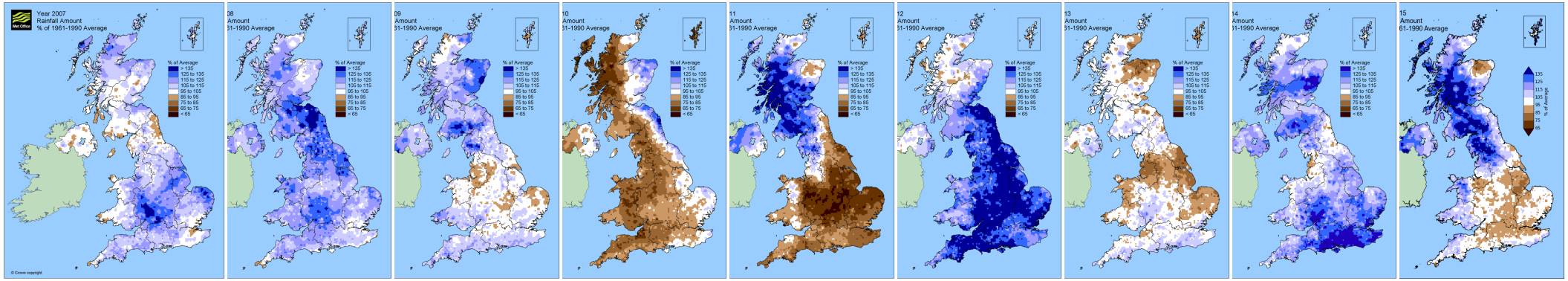
- 11 active and passive microwave L2 products
- L-, C-, X-, Ku-band
- Resolution: ~25-100 km
- Revisit time: 1-7 days

Merged ESA CCI Soil Moisture

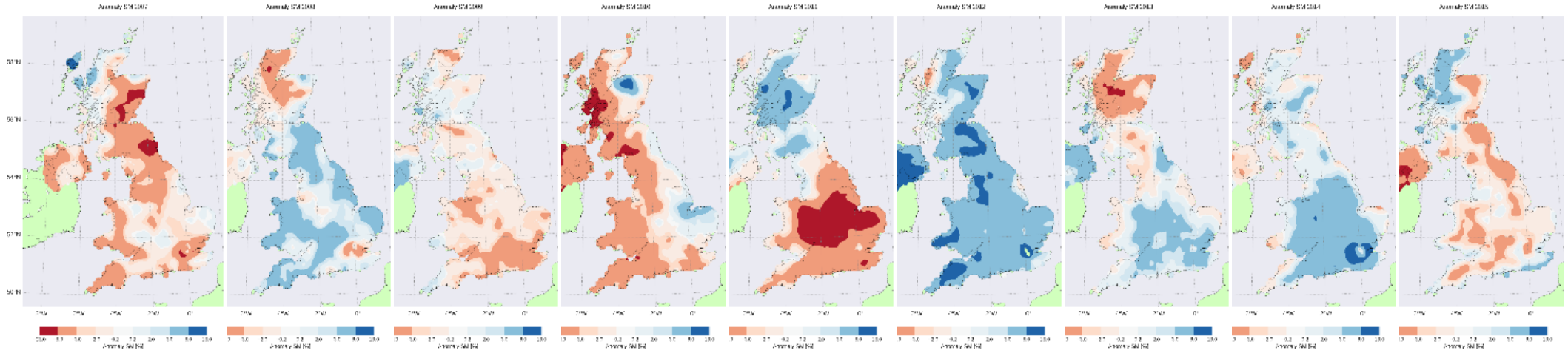
- 0.25° resolution
- Daily product
- Period 1978-2019 (PASSIVE and COMBINED), 1991-2019 (ACTIVE)

ASCAT Soil Moisture

UK MetOffice Precipitation anomalies (1961-1990)



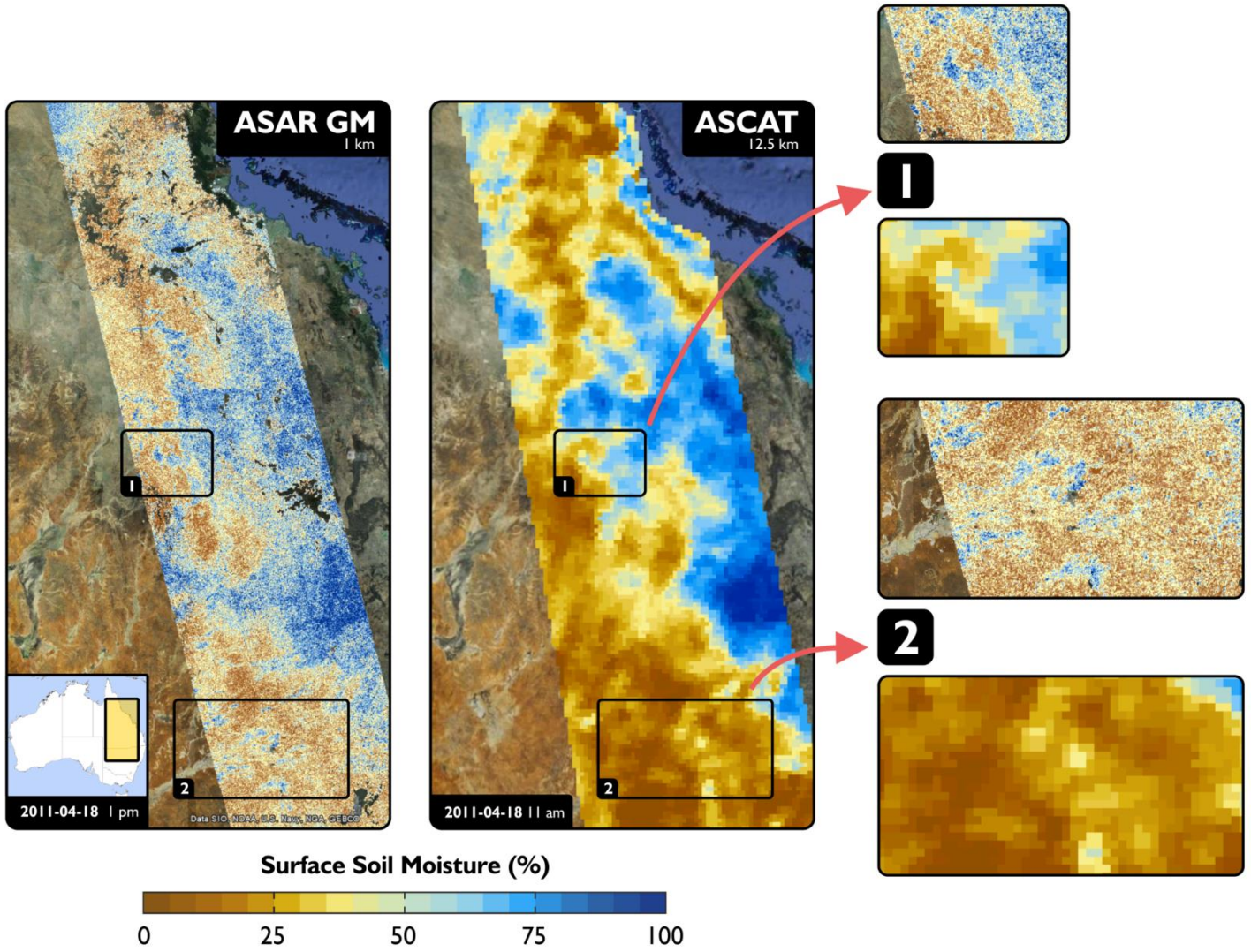
ASCAT Soil Moisture anomalies (2007-2015)



2007 2008 2009 2010 2011 2012 2013 2014 2015

SAR Soil Moisture

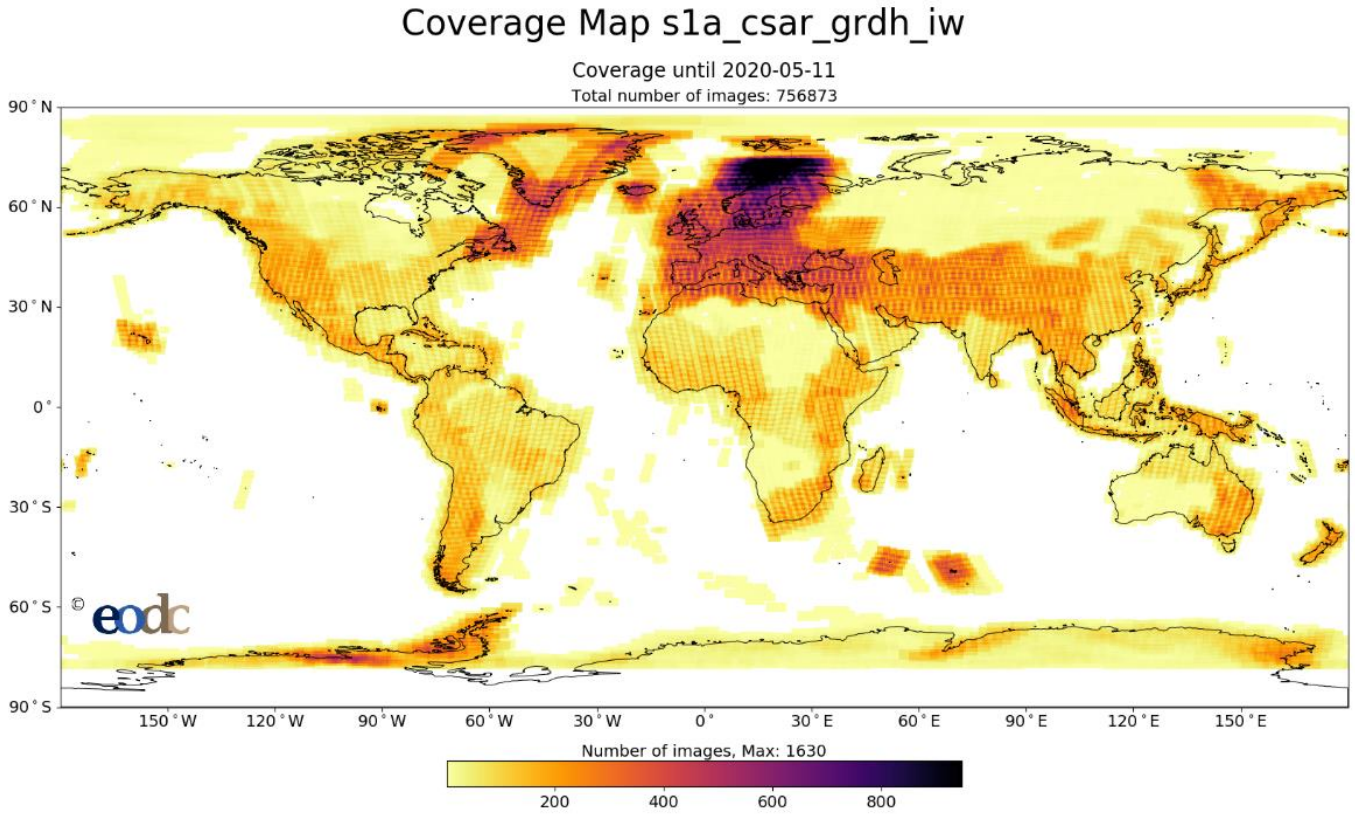
- Motivation:
  - „Old“ example over Queensland, Australia

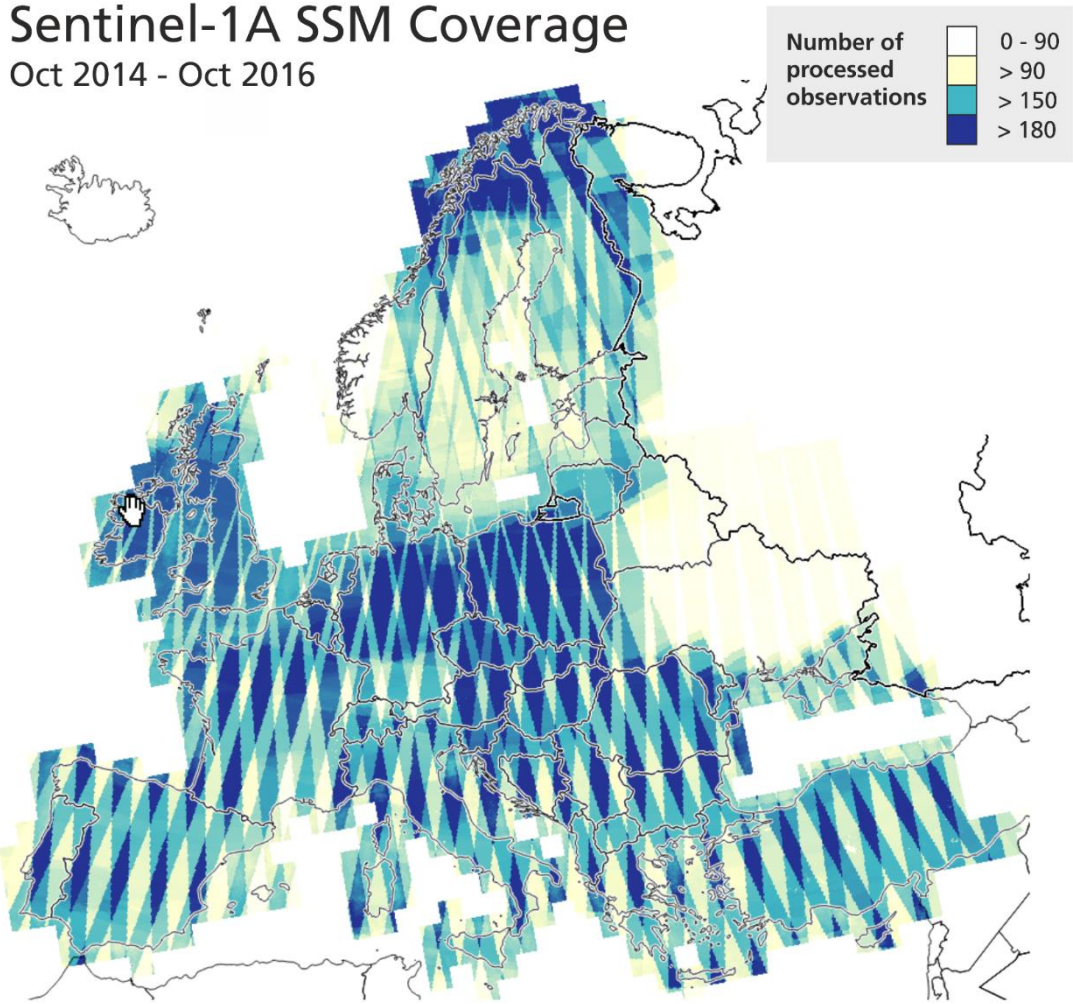


Sentinel-1 Synthetic Aperture Radar (SAR)

(video too big to store)

Sentinel-1 Coverage

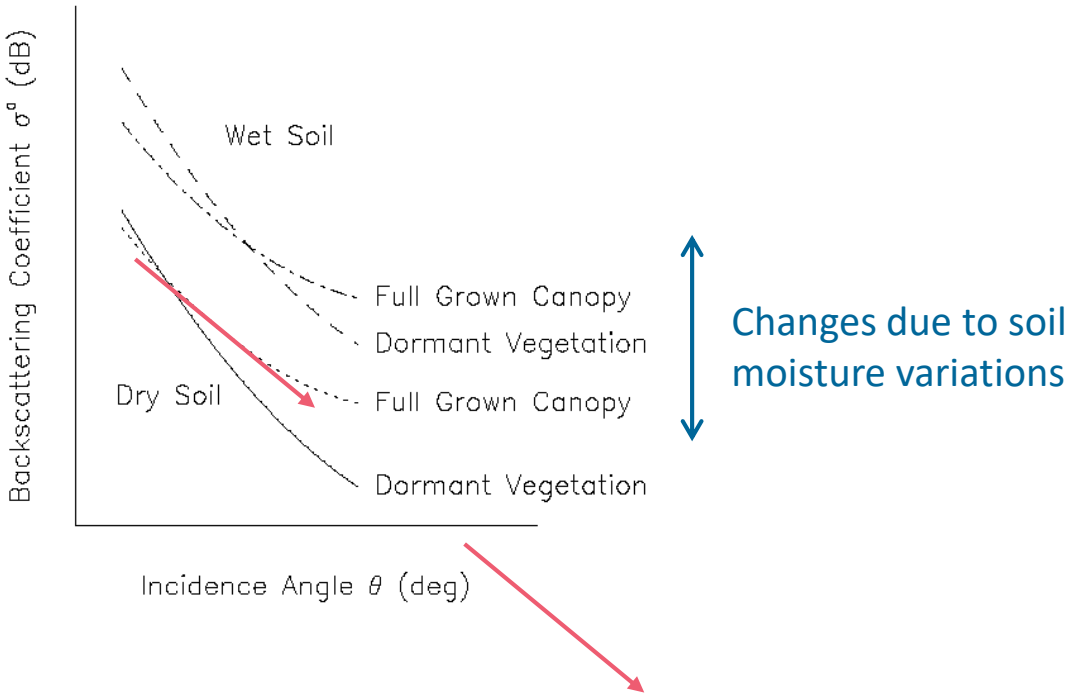




TU Backscatter Model @ Copernicus SM

TU Wien Backscatter Model (in short)

- Motivated by physical models and empirical evidence
  - Formulated in decibels (dB) domain
  - Linear relationship between backscatter (in dB) and soil moisture
  - Empirical description of incidence angle behaviour



TU Wien Change Detection Approach

- Formulated in 1996-98 out of the need to circumvent the lack of adequate backscatter models

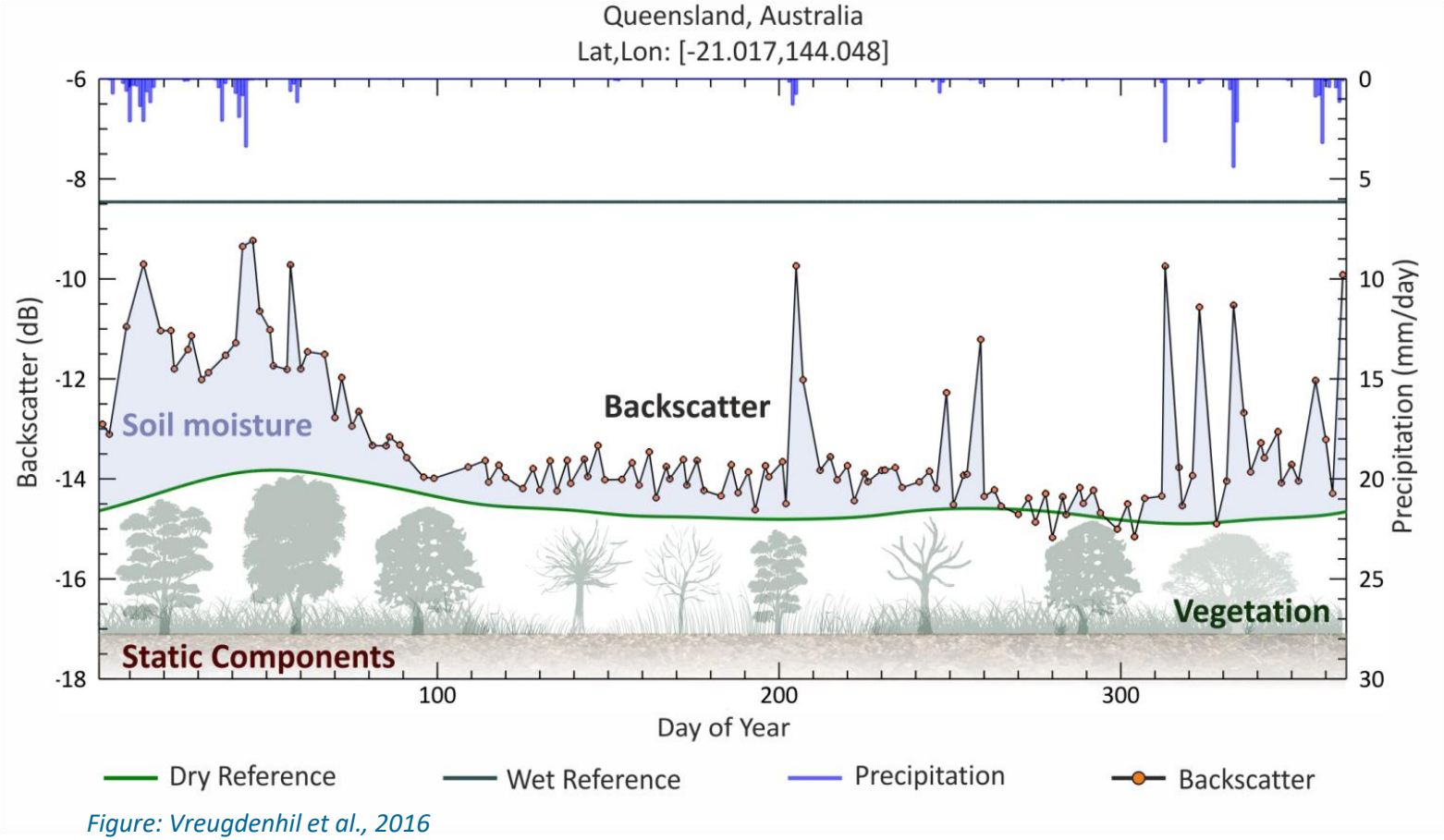
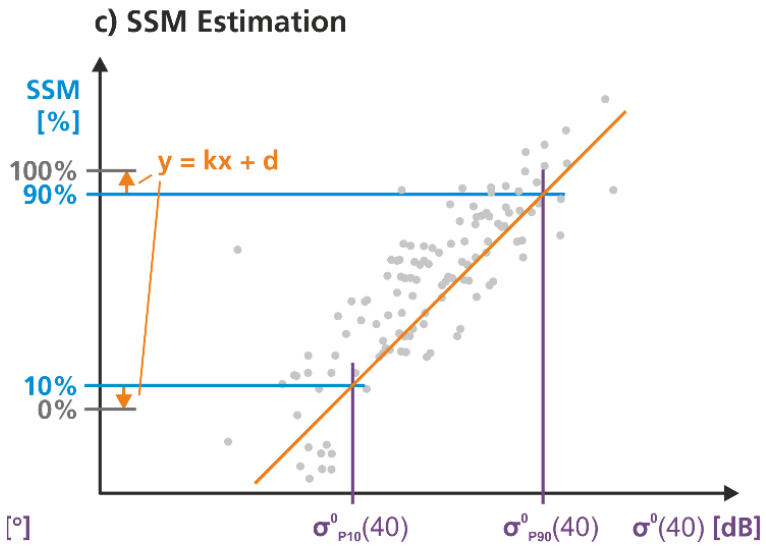


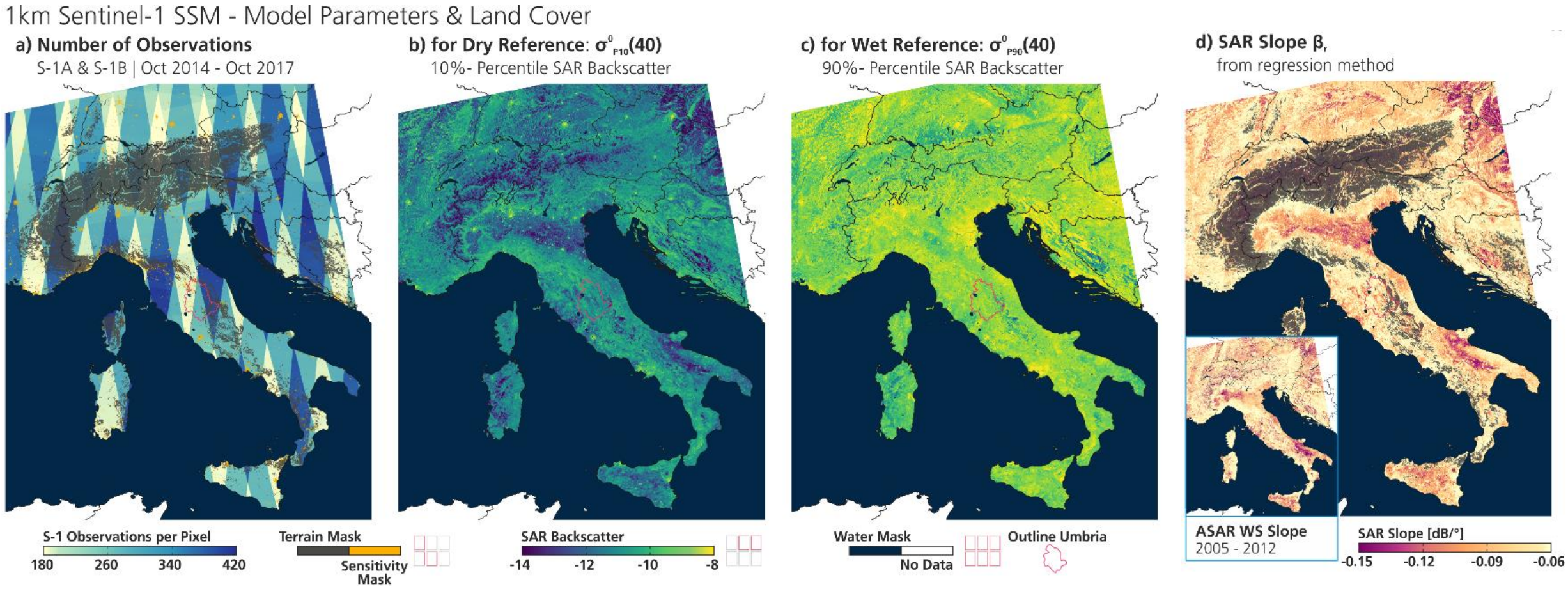
Figure: Vreugdenhil et al., 2016

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



Change Detection Model Parameters for S-1 SSM

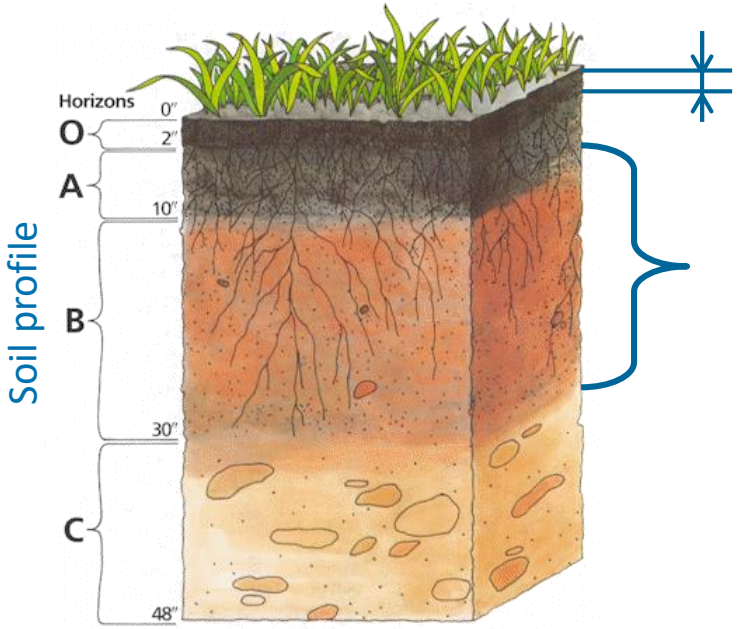
- heterogenous coverage does not affect S-1 parameters



Soil Water Index

Soil Water Index (SWI)

- method developed in 1999, well-established for e.g. ASCAT SSM
- estimates moisture in soil profile (~1cm – ~1m) through temporal filtering
  - = models Surface SM percolating downwards into deeper soils over time
  - = transforms local SSM history to (e.g. daily) SWI values
  - „**T-value**“ governs filter length ~ soil layer depth of SWI-value (T = 2, 5, 10, 15, 20, 40, 60, 100)



Thin, remotely sensed surface soil layer

Root zone: layer of interest for most applications

Wagner, W., G. Lemoine, H. Rott (1999) A Method for Estimating Soil Moisture from ERS Scatterometer and Soil Data, Remote Sensing of Environment, 70, 191-207.

SCATSAR-SWI

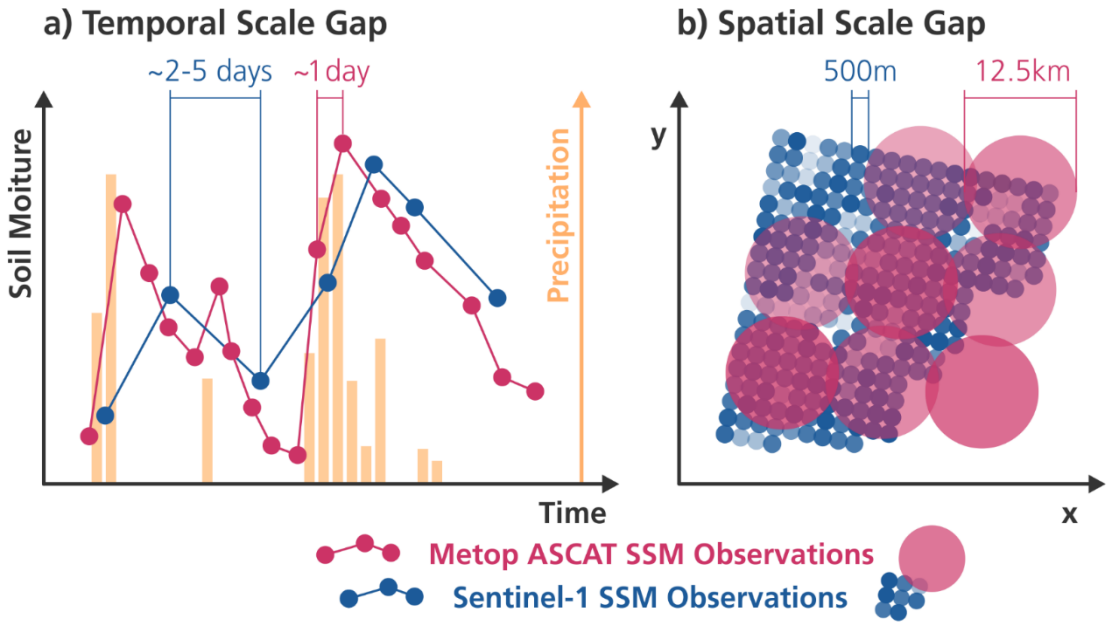
- merge SSM from ASCAT & Sentinel-1 to a joint SSM datacube
- per 500m pixel: temporal filtering of the joint SSM history
- → we get beneficial data fusion
  - high temporal frequency
  - SM dynamics at 1km-scale

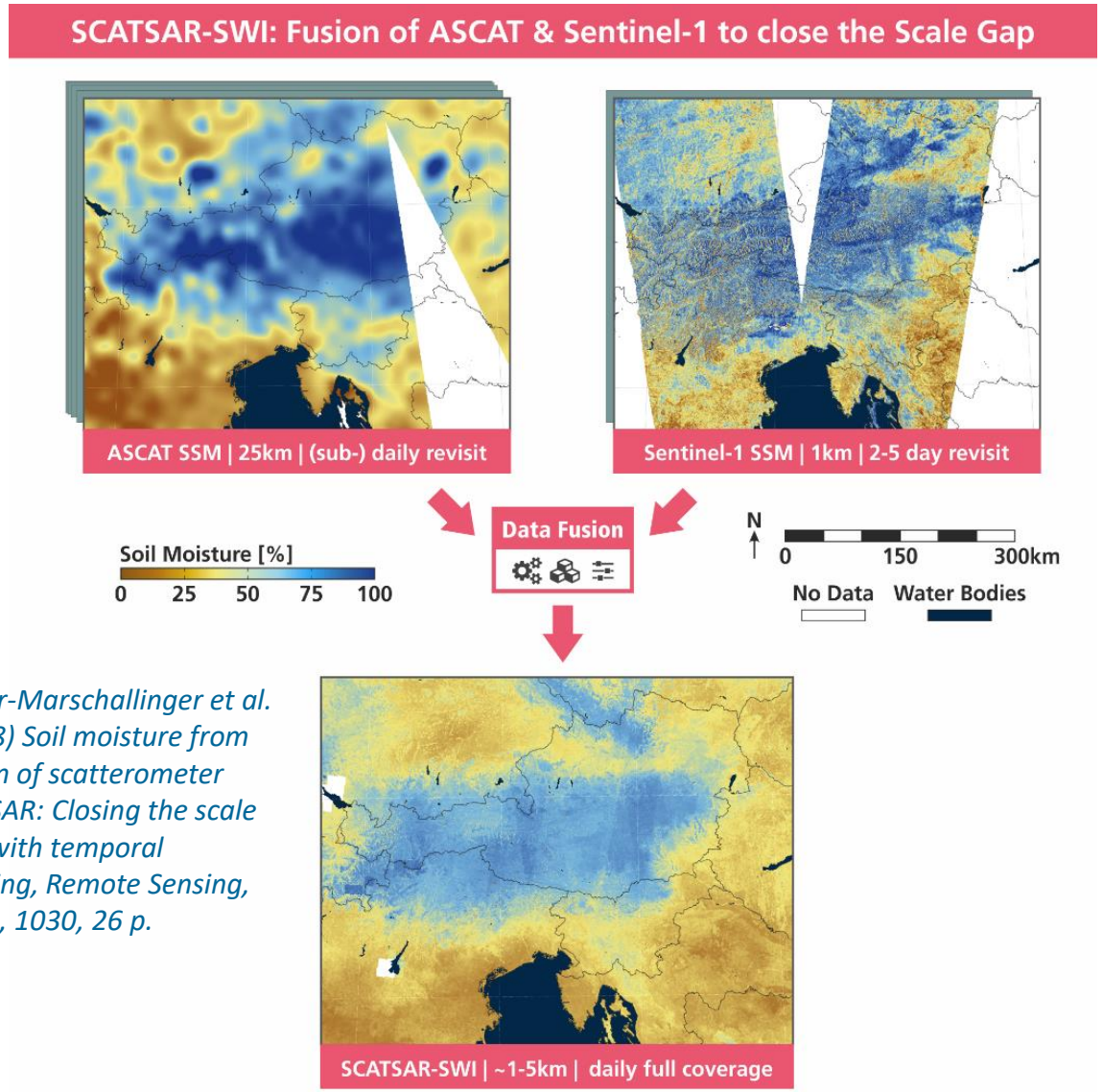
25km ASCAT SSM 1km Sentinel-1 SSM

$$SWI_T(t_n) = \frac{\sum_i^n SSM(t_i) e^{-\frac{t_n - t_i}{T}}}{\sum_i^n e^{-\frac{t_n - t_i}{T}}}$$

SCATSAR-SWI: Data Fusion with SWI

- soil moisture data from microwave sensors feature
  - either a high temporal frequency
    - *50km – 10km ←→ daily, sub-daily*
  - or a high spatial resolution
    - *10m – 1km ←→ weeks, some days*

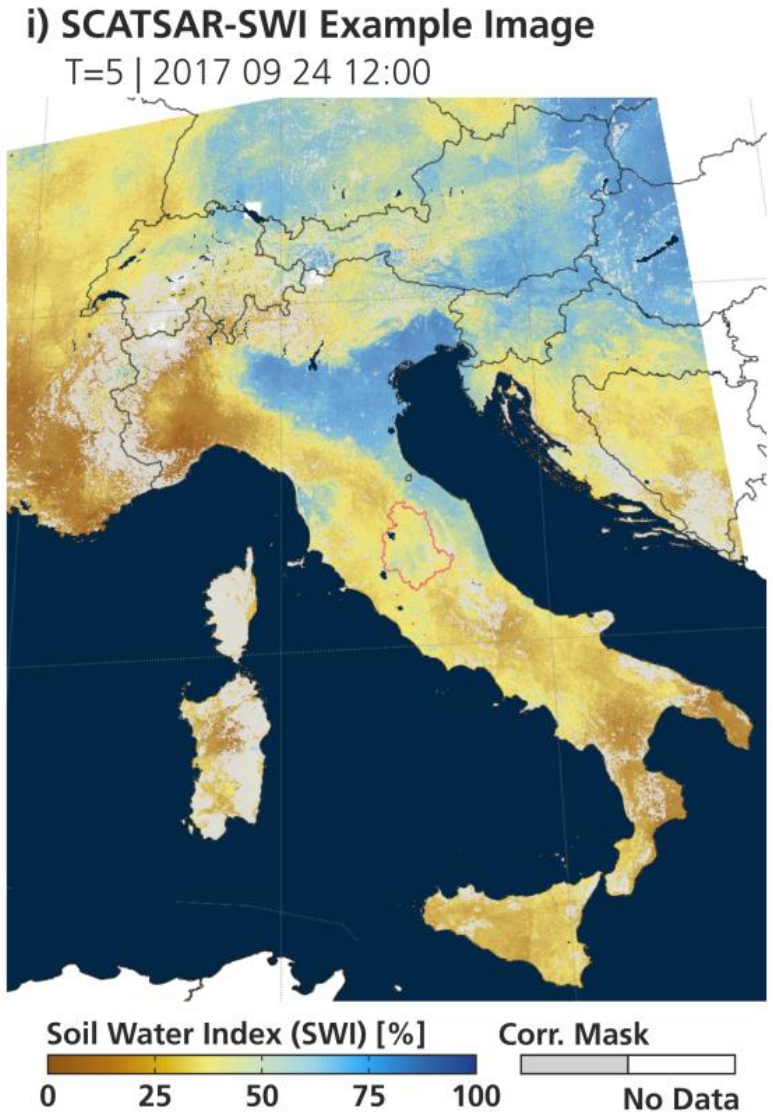




Bauer-Marschallinger et al. (2018) Soil moisture from fusion of scatterometer and SAR: Closing the scale gap with temporal filtering, Remote Sensing, 10(7), 1030, 26 p.

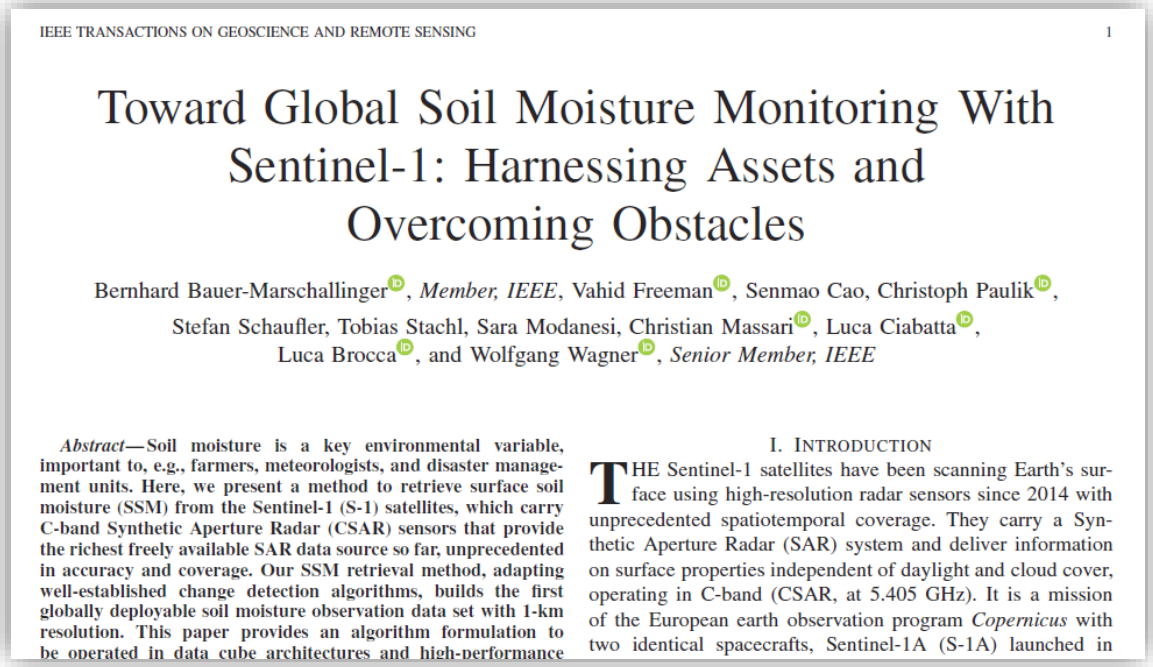
SCATSAR-SWI Example

- vs Land Cover



Publications on Methods & Evaluation

- Methods, Data, Algorithms
- Evaluations over Italy
  - SM Data Cubes: 2015-2017



IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING 1

Toward Global Soil Moisture Monitoring With Sentinel-1: Harnessing Assets and Overcoming Obstacles

Bernhard Bauer-Marschallinger, *Member, IEEE*, Vahid Freeman, Senmao Cao, Christoph Paulik, Stefan Schaufler, Tobias Stachl, Sara Modanesi, Christian Massari, Luca Ciabatta, Luca Brocca, and Wolfgang Wagner, *Senior Member, IEEE*

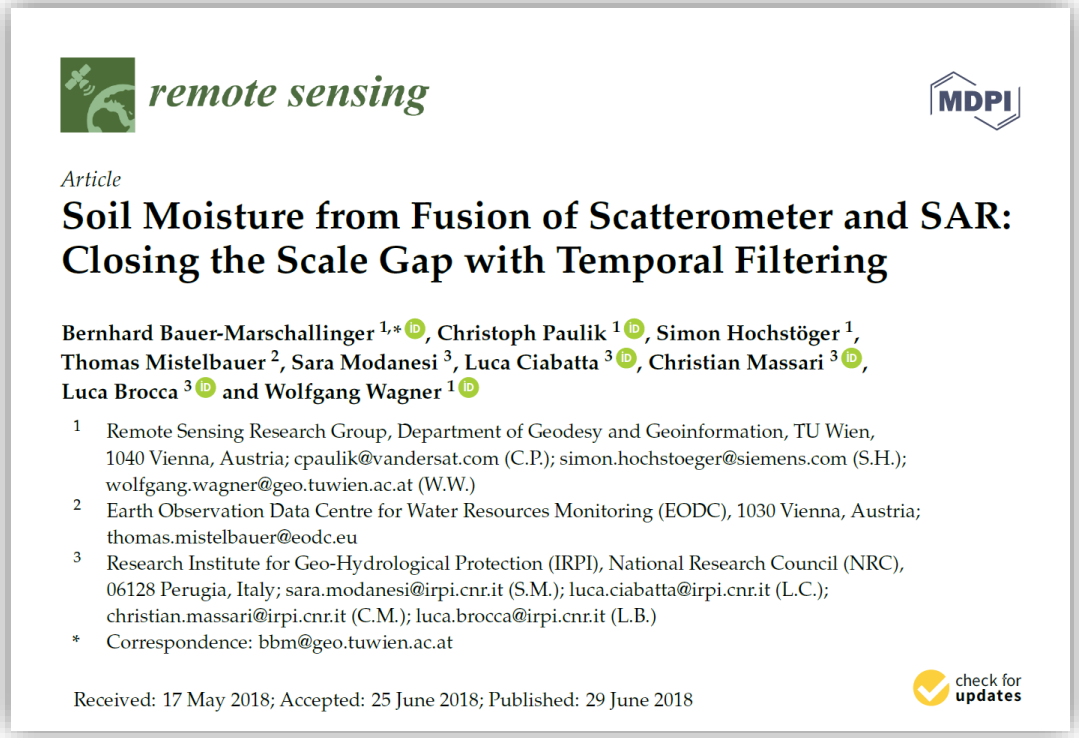
Abstract— Soil moisture is a key environmental variable, important to, e.g., farmers, meteorologists, and disaster management units. Here, we present a method to retrieve surface soil moisture (SSM) from the Sentinel-1 (S-1) satellites, which carry C-band Synthetic Aperture Radar (CSAR) sensors that provide the richest freely available SAR data source so far, unprecedented in accuracy and coverage. Our SSM retrieval method, adapting well-established change detection algorithms, builds the first globally deployable soil moisture observation data set with 1-km resolution. This paper provides an algorithm formulation to be operated in data cube architectures and high-performance

I. Introduction

THE Sentinel-1 satellites have been scanning Earth's surface using high-resolution radar sensors since 2014 with unprecedented spatiotemporal coverage. They carry a Synthetic Aperture Radar (SAR) system and deliver information on surface properties independent of daylight and cloud cover, operating in C-band (CSAR, at 5.405 GHz). It is a mission of the European earth observation program *Copernicus* with two identical spacecrafts, Sentinel-1A (S-1A) launched in

Sentinel-1 SSM → SSM1km

Bauer-Marschallinger, B., Naeimi, V., Cao, S., Paulik, C., Schaufler, S., Stachl, T., Modanesi, S., Ciabatta, L., Massari, C., Brocca, L. & Wagner, W. (2018). Toward Global Soil Moisture Monitoring with Sentinel-1: Harnessing Assets and Overcoming Obstacles. IEEE Transactions on Geoscience and Remote Sensing (57), 520 – 539. doi:10.1109/TGRS.2018.2858004



remote sensing MDPI

Article

Soil Moisture from Fusion of Scatterometer and SAR: Closing the Scale Gap with Temporal Filtering

Bernhard Bauer-Marschallinger [1,*], Christoph Paulik [1], Simon Hochstöger [1], Thomas Mistelbauer [2], Sara Modanesi [3], Luca Ciabatta [3], Christian Massari [3], Luca Brocca [3] and Wolfgang Wagner [1]

1 Remote Sensing Research Group, Department of Geodesy and Geoinformation, TU Wien, 1040 Vienna, Austria; cpaulik@vandersat.com (C.P.); simon.hochstoeger@siemens.com (S.H.); wolfgang.wagner@geo.tuwien.ac.at (W.W.)
2 Earth Observation Data Centre for Water Resources Monitoring (EODC), 1030 Vienna, Austria; thomas.mistelbauer@eodc.eu
3 Research Institute for Geo-Hydrological Protection (IRPI), National Research Council (NRC), 06128 Perugia, Italy; sara.modanesi@irpi.cnr.it (S.M.); luca.ciabatta@irpi.cnr.it (L.C.); christian.massari@irpi.cnr.it (C.M.); luca.brocca@irpi.cnr.it (L.B.)
* Correspondence: bbm@geo.tuwien.ac.at

Received: 17 May 2018; Accepted: 25 June 2018; Published: 29 June 2018

check for updates

SCATSAR-SWI → SWI1km

Bauer-Marschallinger, B., Paulik, C., Mistelbauer, T., Hochstöger, S., Modanesi, S., Ciabatta, L., Massari, C., Brocca, L. & Wagner, W. (2018). Soil Moisture from Fusion of Scatterometer and SAR: Closing the Scale Gap with Temporal Filtering. Remote Sensing, 10(7), 1030. doi:10.3390/rs10071030

Soil Moisture Products @ Copernicus

The Copernicus Global Land Service (CGLS)

http://land.copernicus.eu/global/

Copernicus Global Land Service
Providing bio-geophysical products of global land surface

CGLS: Copernicus Global Land Service

- The CGLS provides a large number of data products on energy, water and vegetation variables
  - **freely accessible**
  - **in Near-Real-Time (NRT)**
  - **global/continental coverage**
  - **harmonised and co-formatted**

EUMETSAT H SAF Support to Operational Hydrology and Water Management → Copernicus Europe's eyes on Earth

- ASCAT SWI V3
  - SWI derived from H SAF Metop ASCAT SSM observations
  - describing the wetness of the soil along profile (~1cm – 1m)
  - global, since 2007, ~25km resolution
- Two new 1km soil moisture (SM) products
  - based on Sentinel-1 CSAR & Metop ASCAT scatterometer ob
  - Surface Soil Moisture from Sentinel-1
    - named **SSM1km**
  - SCATSAR Soil Water Index from fused Sentinel-1 + ASCAT
    - named **SWI1km**

Sentinel-1

Copernicus Global Land Service
Providing bio-geophysical products of global land surface

Copernicus Europe's eyes on Earth

Theme	Variable
Vegetation	Fraction of photosynthetically active radiation absorbed by the vegetation
	Fraction of green vegetation cover
	Leaf Area index
	Normalized Difference Vegetation Index
	Vegetation Condition Index
	Vegetation Productivity Index
	Dry Matter Productivity
	Burnt Area
	Soil Water Index
	Surface Soil Moisture
Energy	Land Surface Temperature
	Top Of Canopy Reflectance
	Surface Albedo
Water	Water Bodies
	Lake Surface Water Temperature
	Lake Water Quality
Cryosphere	Lake Ice Extent
	Snow Cover Extent
	Snow Water Equivalent

ASCAT-based SWI Products (12.5 km)

12.5km Soil Moisture

- **SWI V3 product** (Operational Status)
  - for **basic users** in hydrology and agriculture with **large-scaled scope**
  - well evaluated and stable performance
  - **8 depth layers (T-values)**, including quality information (=quality flag, **QFLAG**)
    - QFLAG: describing the SSM data density contributing to SWI-values
  - Freeze/Thaw layer for masking frozen conditions (=surface state flag, **SSF**)
  - daily, on a 0.1° grid SWI V3 product (~12.5km)
  - netCDF4 format

- **SWI10 product** (Operational Status)
  - 10 day average SWI product- **compatible to other decadal products**
  - Same format and grid as SWI V3 version
  - netCDF4 format

- **SWI TS product** (quasi Operational Status)
  - Time Series product
  - for **advanced and scientific users** doing time series analysis
  - provides data in time-series-optimized format
  - **updated half-yearly**
  - on a discrete global grid (point-wise, ~12.5km)
  - netCDF4 format

- **SWI-Static Layers**
  - can be used for masking regions where SWI retrieval is difficult or not possible
    - Dense Forests, Water Bodies, Complex Topography
  - Discrete Global Grid (DGG) layer for SWI TS product
  - Correlation Information (CI) Layers describing agreement with reanalysis model
    - per year: correlation between daily SWI and GLDAS-Noah model

Sentinel-1 & ASCAT –based products (1km)

1km Soil Moisture

- **SSM1km** (Operational Status)
  - for basic users in hydrology and agriculture, **requiring more spatial detail**
  - senses effects from **small-scale rainfalls** and **irrigation activities**
  - Surface Soil Moisture (~top 5cm)
  - ingesting high-resolution SAR data from Sentinel-1
  - daily image, on a 1km grid
    - no full coverage at each day
    - actual frequency over European locations: 1.5-4 days
  - Product masks, which identify and exclude areas that the SSM algorithm does not apply or does not make sense such as
    - inland water, urban areas and strong topography
  - netCDF4 format

- **SCATSAR-SWI** (Operational Status)
  - ingesting SSM from Sentinel-1 and ASCAT → SWI at 1km!
  - For users as European and national institutions, research institutions for weather forecast, crop monitoring, climate studies.
  - **high spatio-temporal detail**
  - same format and grid as SSM1km: daily & 1km
    - regularily full coverage at each day
  - **8 depth layers (T-values),** including quality information (quality flag, **QFLAG)**
  - Freeze/Thaw layer for masking frozen conditions (surface state flag, **SSF**, at 12.5km res.)

ASCAT SWI

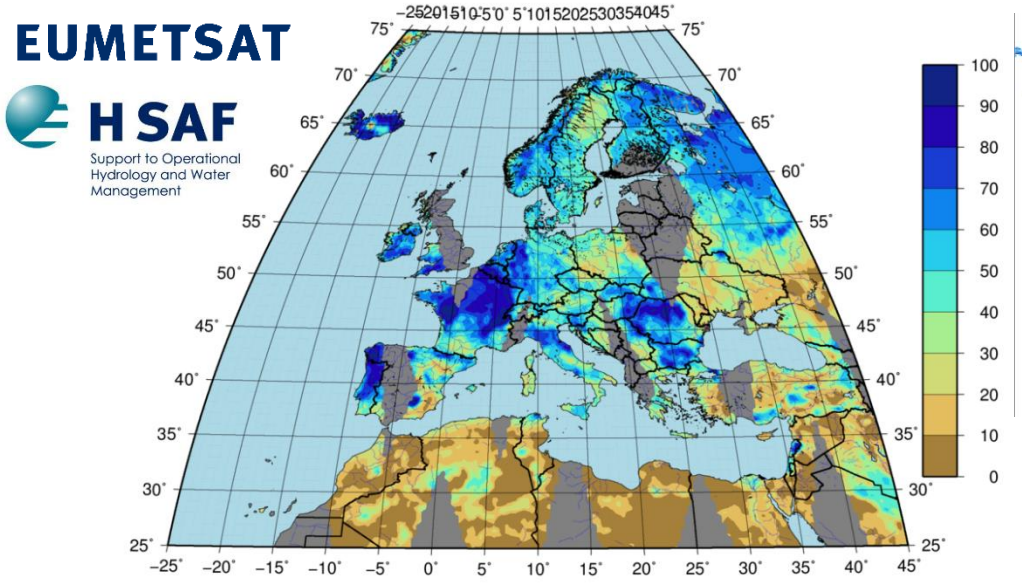
Coarse-scale SM since 2007

(global)

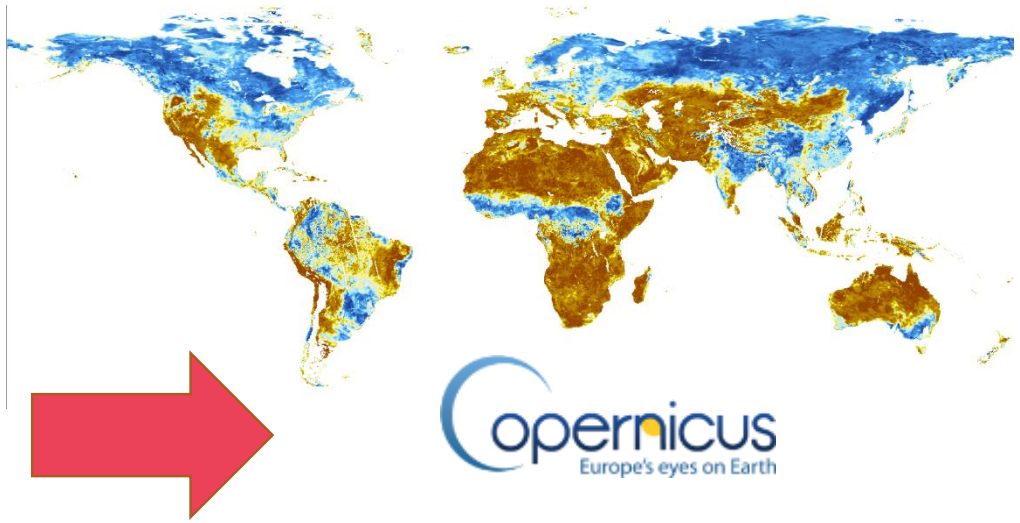
ASCAT Soil Water Index (SWI)

- since 2007 (current version “V3”)
- describing the wetness of the soil along profile (~1cm – 1m)
- derived from surface soil moisture (SSM) time series
- input: Metop ASCAT microwave radar observations (H-SAF SSM)

H-SAF H101/16/104 SSM products

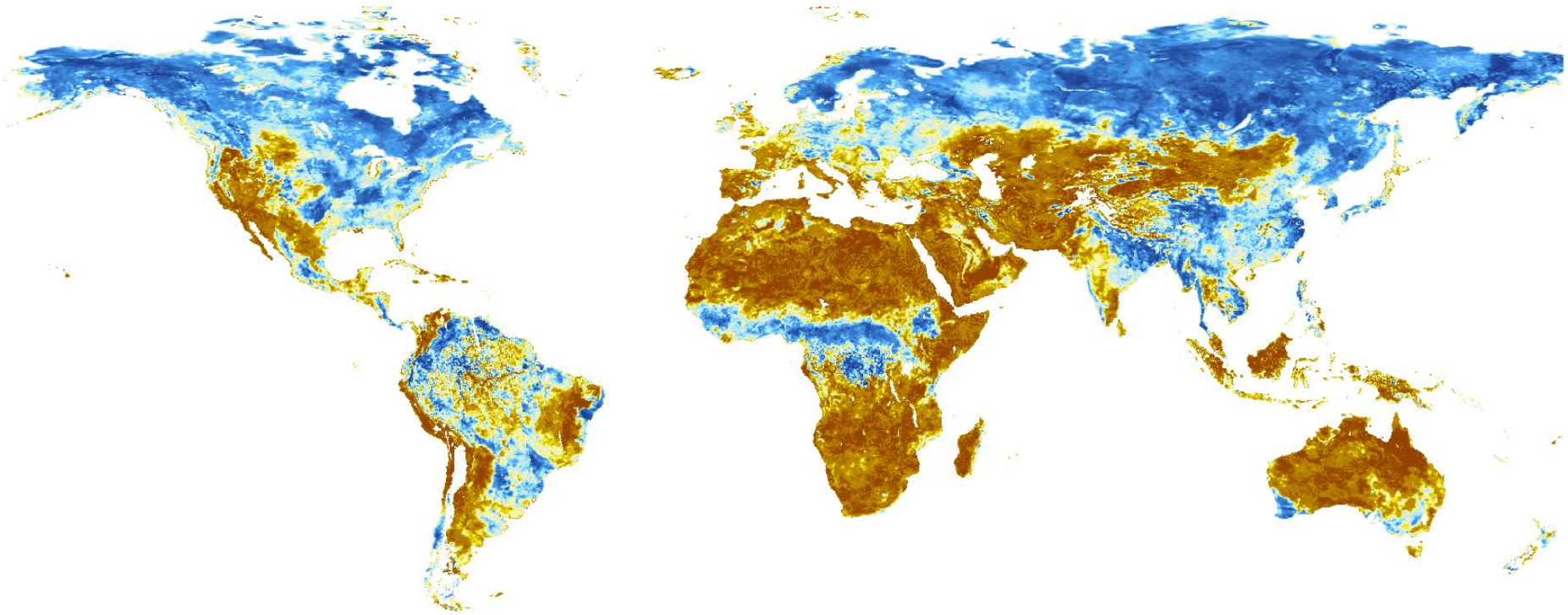


Copernicus SWI V3 product



SWI V3 product

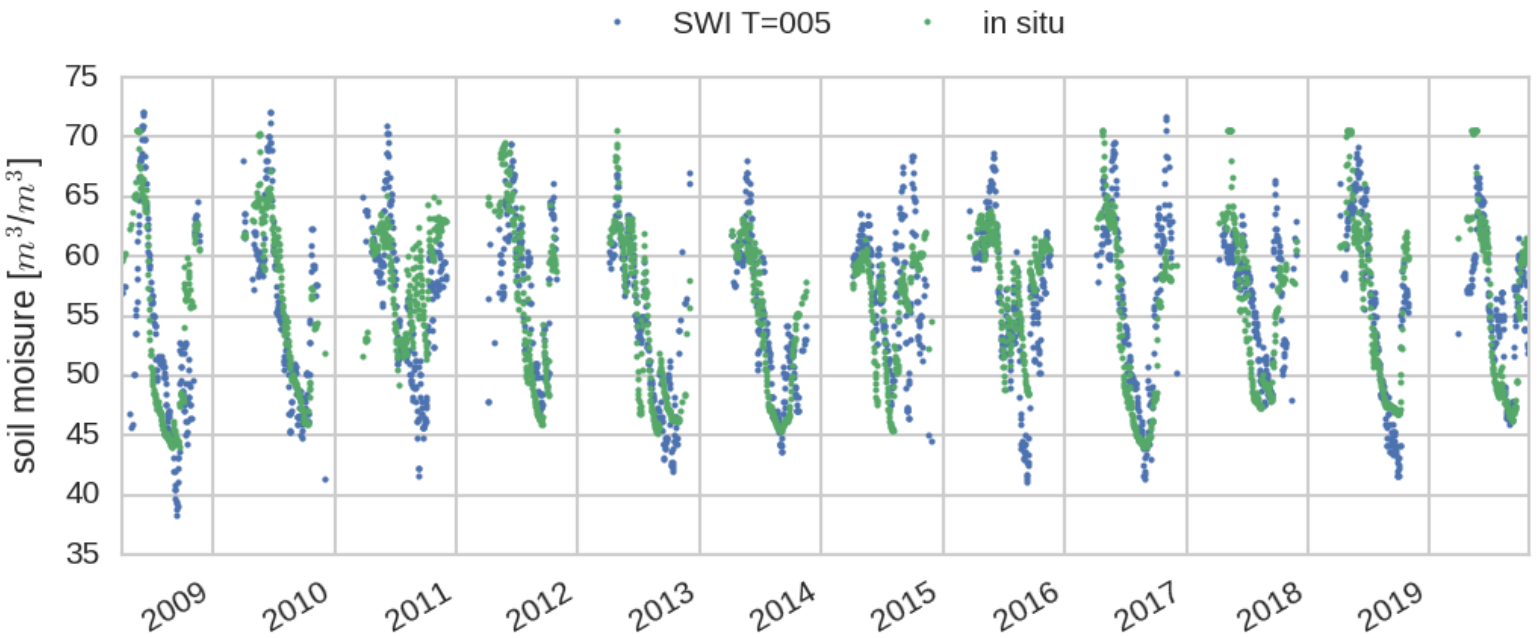
- 8x depth layers (T-values)
  - 8x SWI layers
  - 8x Quality Flag layers
    - quality information = SSM data density for SWI value
- 1x Surface State Flag (SSF)
  - Freeze/Thaw layer for masking frozen conditions
- netCDF4 format
- daily, on a 0.1° grid



SWI TS product

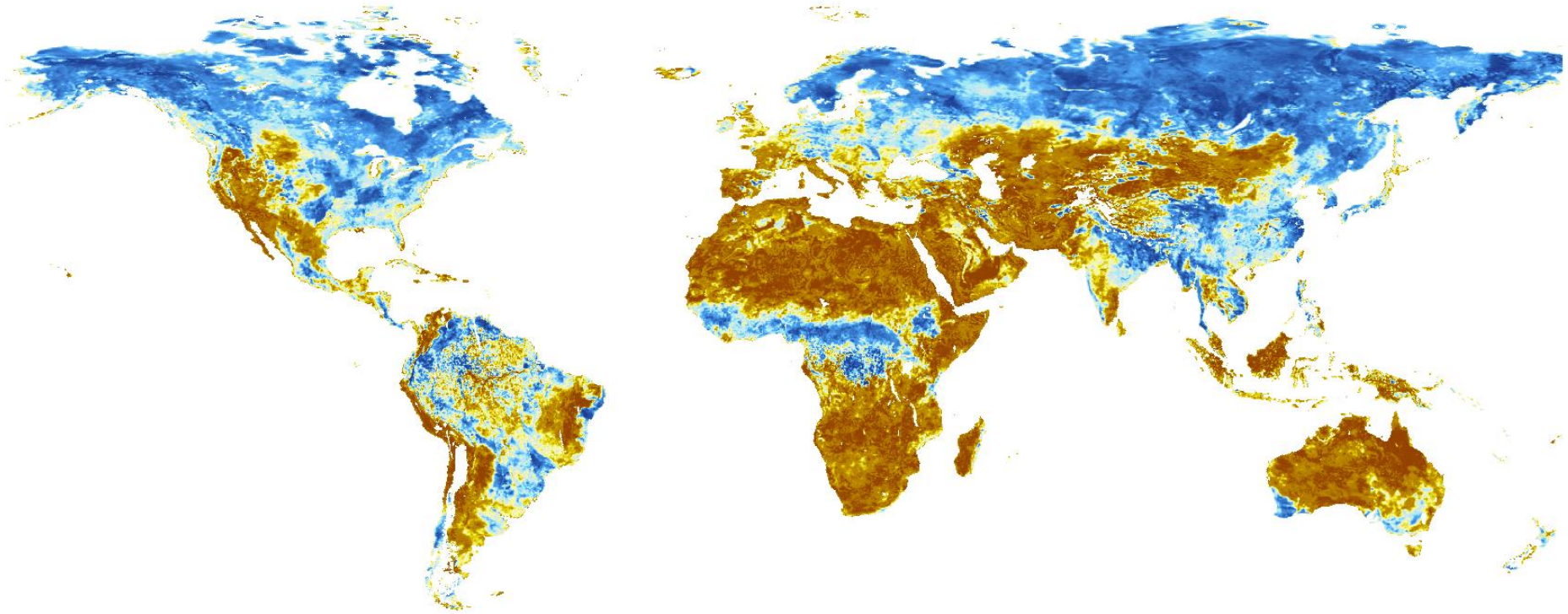
- Provides data in time-series-optimized format
  - Product for advanced users doing time series analysis
- On a Discrete Global Grid (DGG, point-wise)
  - in cell-based format

SWI and in-situ data for SNOTEL-station “Crab Creek”



SWI10 product

- 10 day averaged SWI product – compatible to other decadal products
- same format and grid as SWI V3



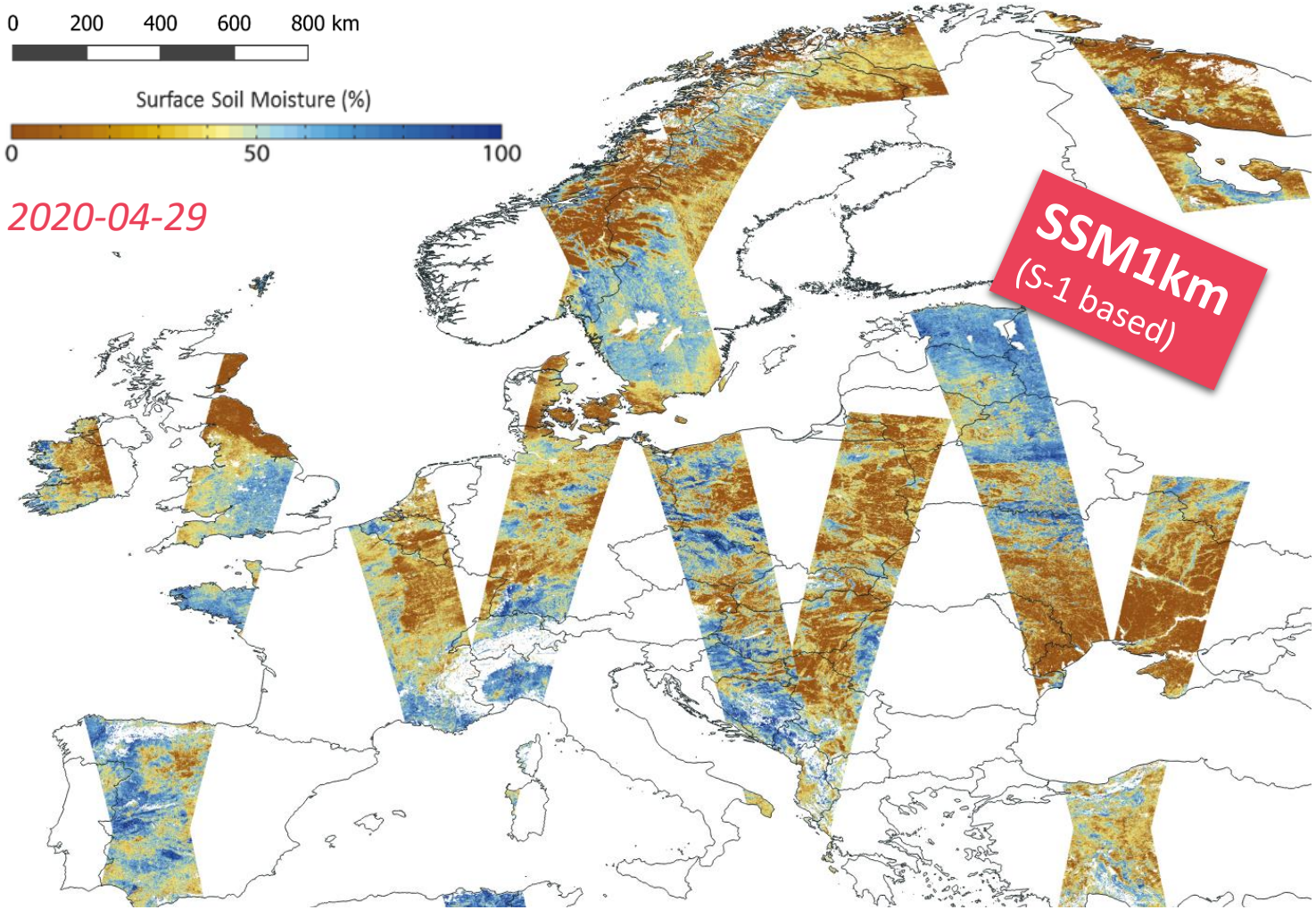
SSM1km

1km SM from Sentinel-1 since 2015

(Europe, global to come in 2021)

SSM1km Product

- Sentinel-1 SSM @ Copernicus Global Land Service
  - currently over Europe
  - launched December 2018
  - 2021: ramp-up to global
- **SSM1km**
  - Surface Soil Moisture
  - Version 1.1.1
  - over Europe
  - 2015-NRT
  - Parameter Baseline 2015-2018
  - daily composite images (orbits)
    - 1.5 – 4 days coverage
  - 1/112° ~ 1km sampling
    - **~2-5 km effective resolution**
  - with masks & noise layer



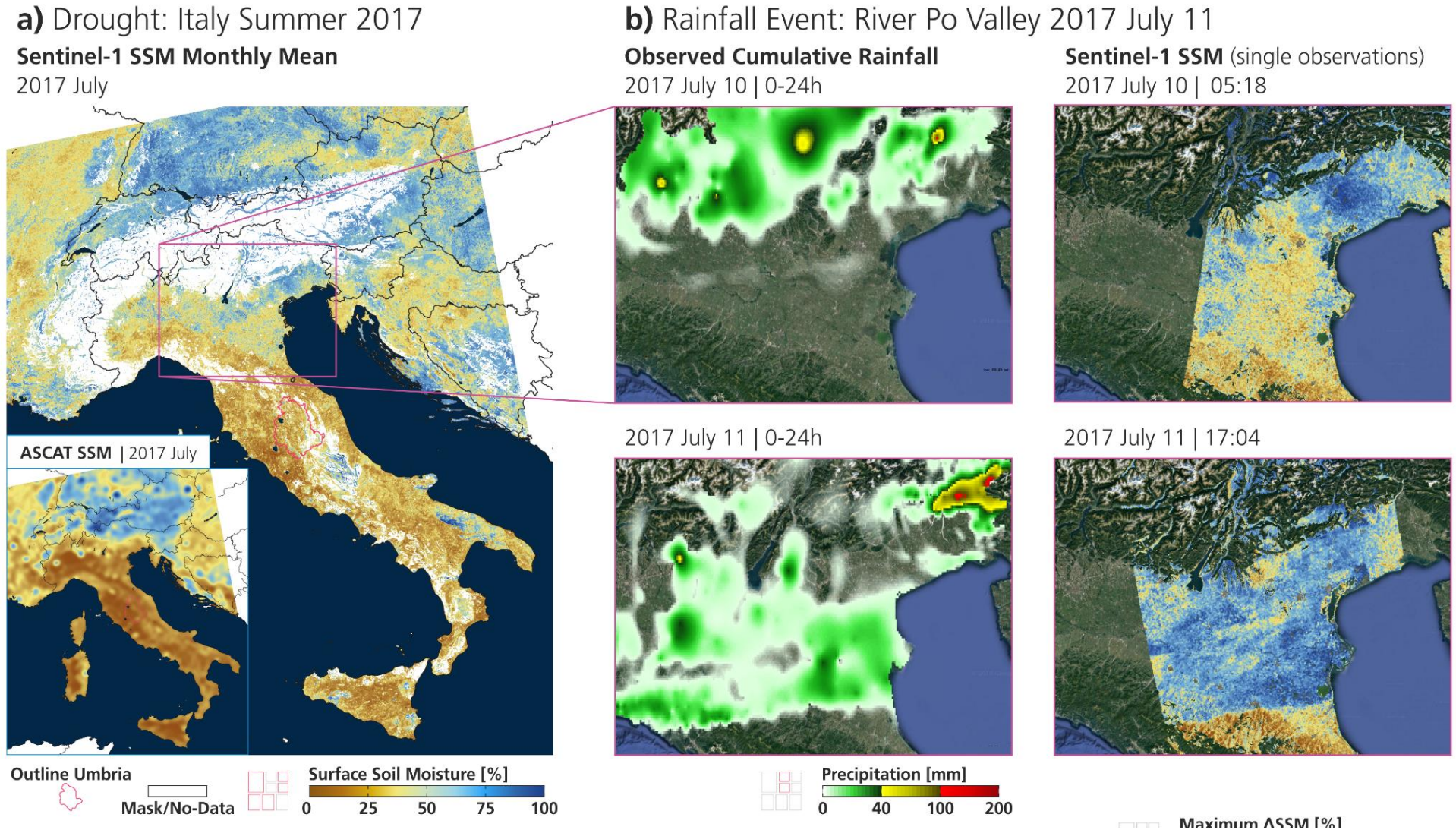
Dry spring 2020 over Europe: Beginning wet relief in late April with scattered rainfalls over the continent. SSM1km composite (ascending + descending overpasses) product from 2020-04-29

SSM1km – day to day Coverage

(GIF-animiation too big to store)

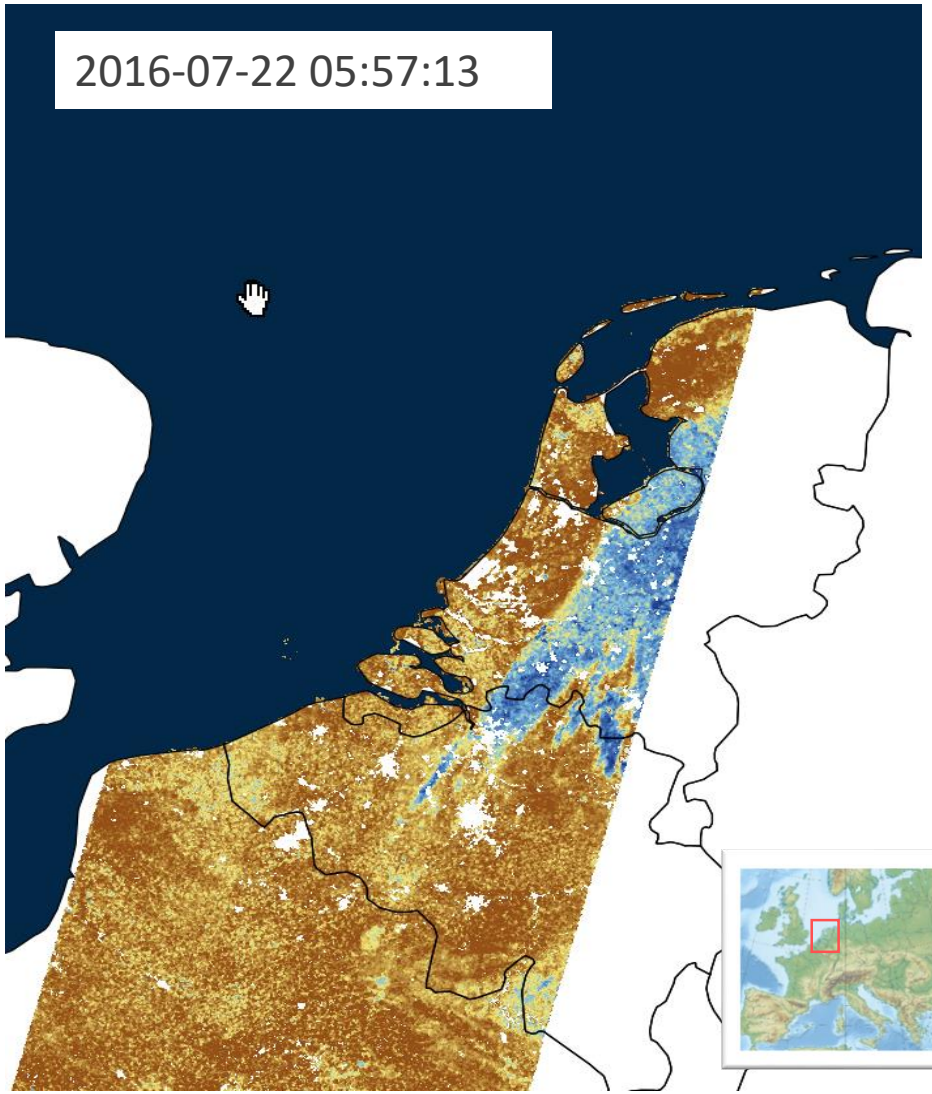
(Quicklooks)

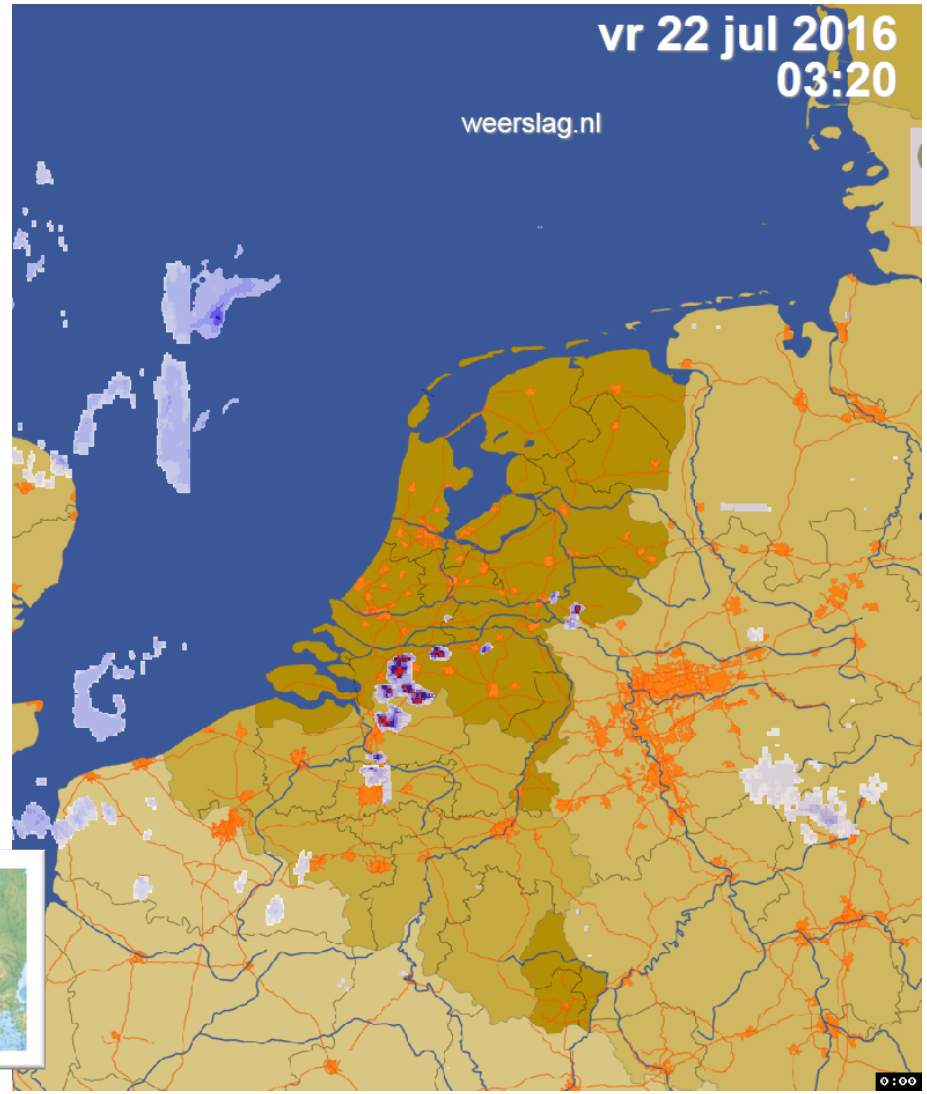
SSM1km: example results over Italy



Bauer-Marschallinger, B., Freeman, V., Cao, S., Paulik, C., Schaufler, S., Stachl, T., Modanesi, S., Massari, C., Ciabatta, L., Brocca, L. & & Wagner, W. (2018). Toward global soil moisture monitoring with Sentinel-1: Harnessing assets and overcoming obstacles. IEEE Transactions on Geoscience and Remote Sensing, 57(1), 520-539.

Eye Candy





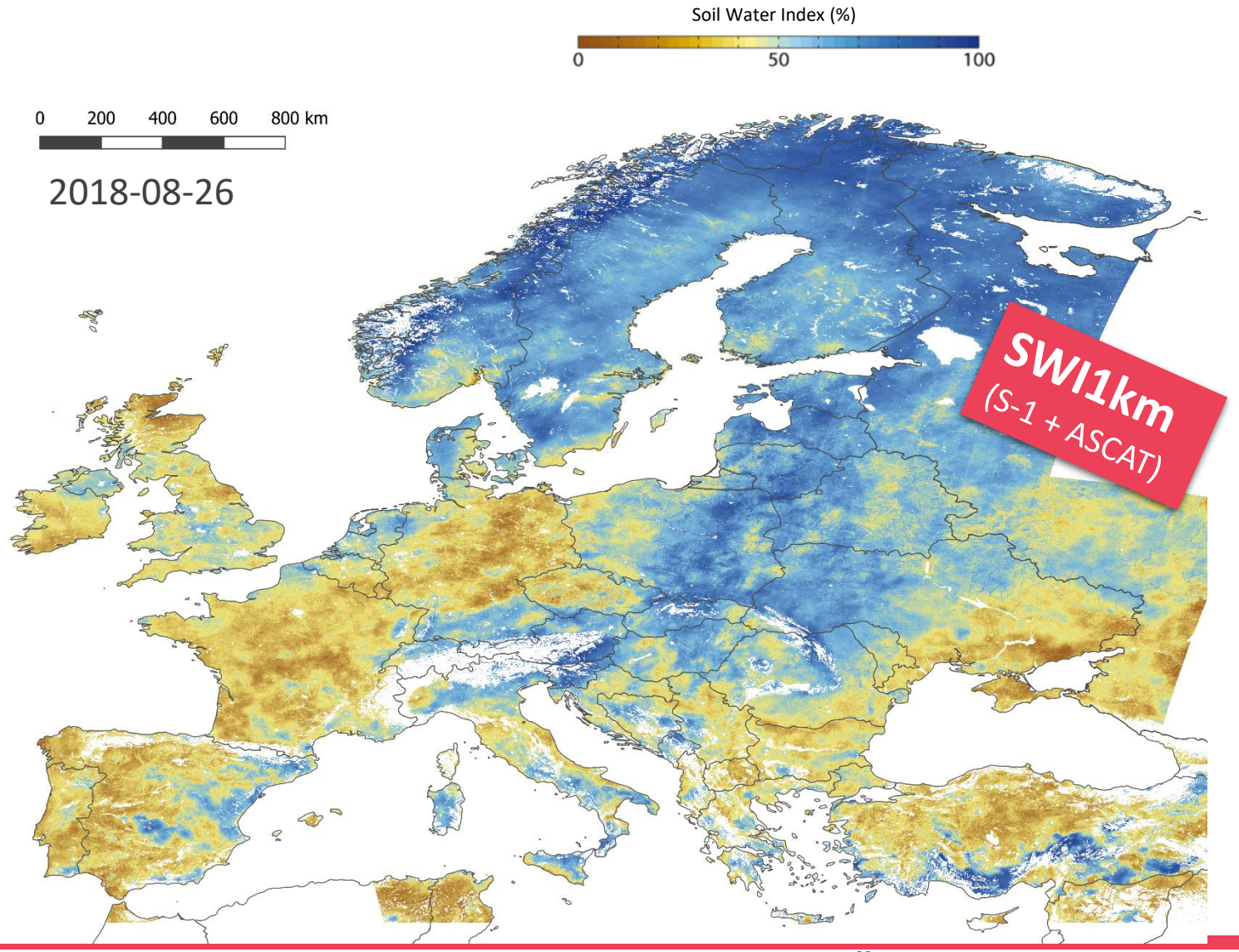
SWI1km

1km SM from Sentinel-1+ASCAT since 2015

(Europe, global to come in 2021)

SWI1km Product

- S-1 SSM + ASCAT @ Copernicus Global Land Service
  - currently over Europe
  - launched April 2019
  - 2021: ramp-up to global
- **SWI1km**
  - uses SCATSAR-SWI algorithm
  - Soil Water Index: 8 depth levels
    - T-Values: 2, 5, 10, 15, 20, 40, 60, 100
  - Version 1.0.1
  - over Europe
  - 2015-NRT
  - Parameter Baseline 2015-2018
  - daily full coverage images
  - 1/112° ~ 1km sampling
    - **~2-10 km effective resolution**
  - with Freeze/Thaw Masking

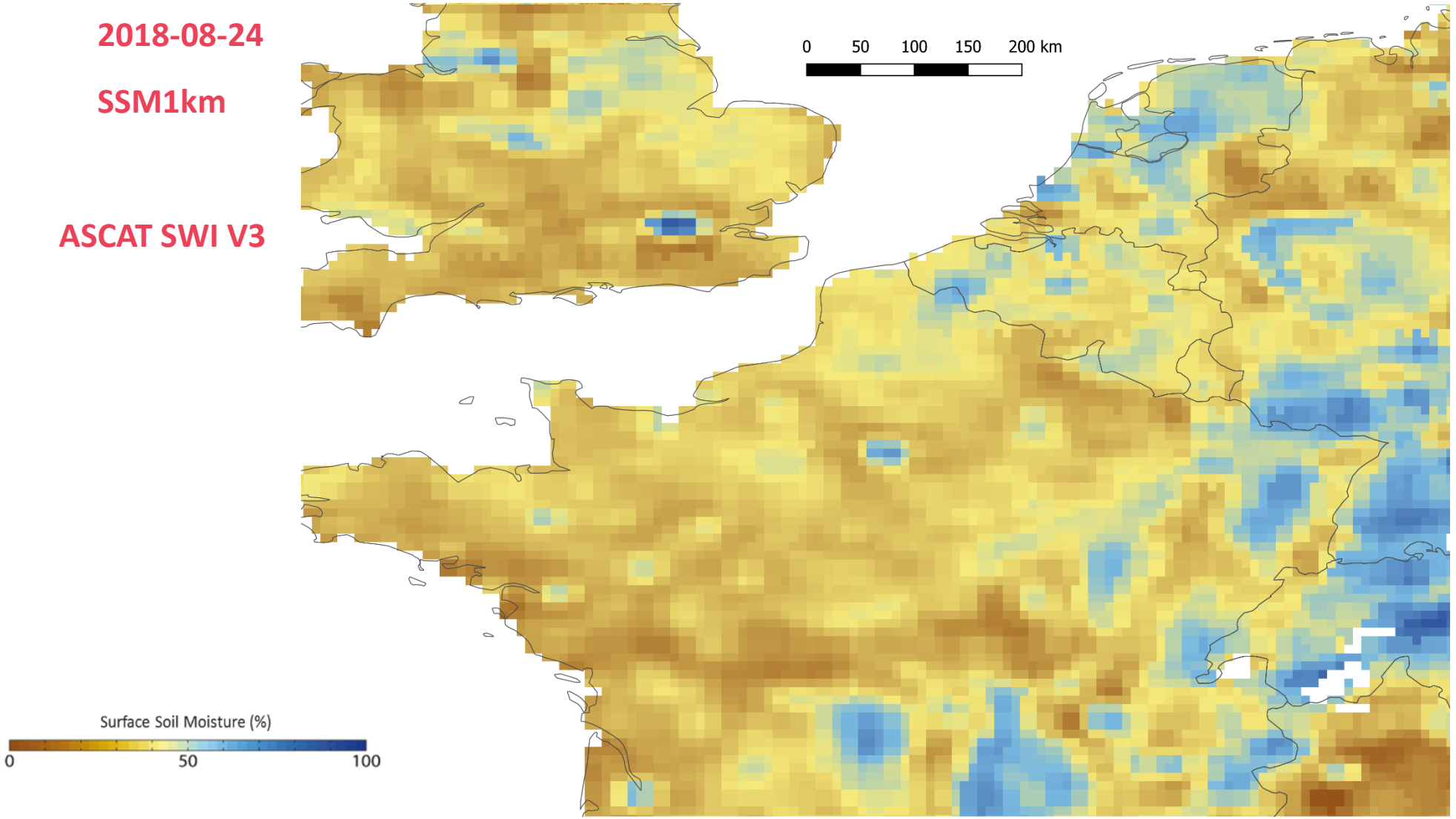


Spatial Resolution: Product Comparison

2018-08-24

SSM1km

ASCAT SWI V3



SWI1km – daily product

- – Detail for Spring 2019
  - over Italy
- retreating SSF-masking
- permanent topogrophy masking

(GIF-animiation too big to store)

SWI1km – daily product

- Heat wave 2019 over Europe

(GIF-animiation too big to store)

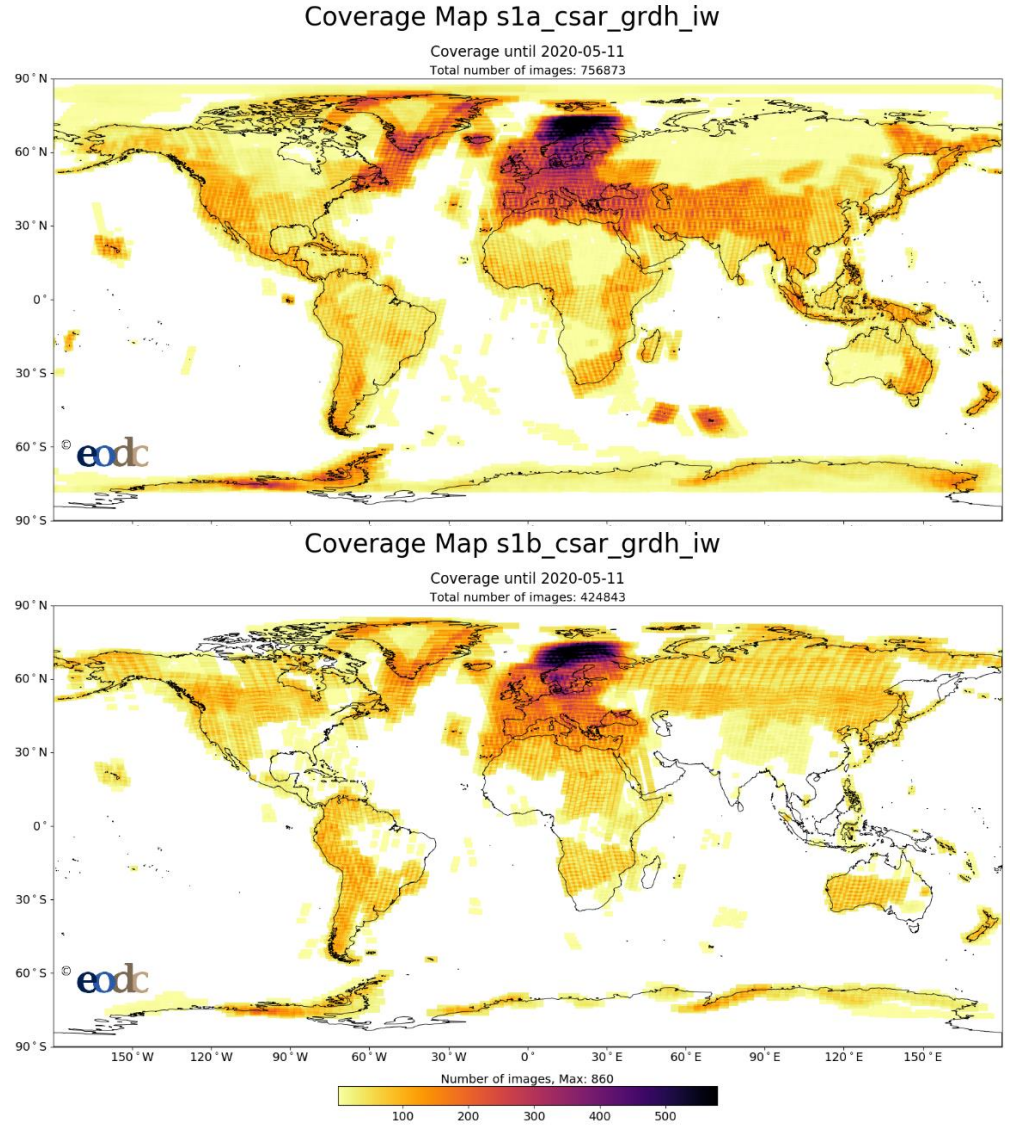
Dry and hot summer 2019 over Europe: Very dry conditions in July and September, with relief in early October (SWI1km product from 2020-07 to 2020-10)

CGLS SM: Service Continuation and Extension

- Service continuation in current Framework until 2021
- **Proposed** Service Adaptions for upcoming Framework (2021-25):
  a) Operational NRT service extension to global coverage
  b) Product resolution enhancement to 300m
  c) Integration of Sentinel-1C observations
- to be evaluated: impact of coverage/frequency on product robustness over non-European areas
  - stable model parameters rely on complete caption of local variability
    - …was achieved over Europe within data period 2015-2018

Total number of at EODC ingested Sentinel-1 IW GRDH products available for CGLS Soil Moisture production (full misison period)

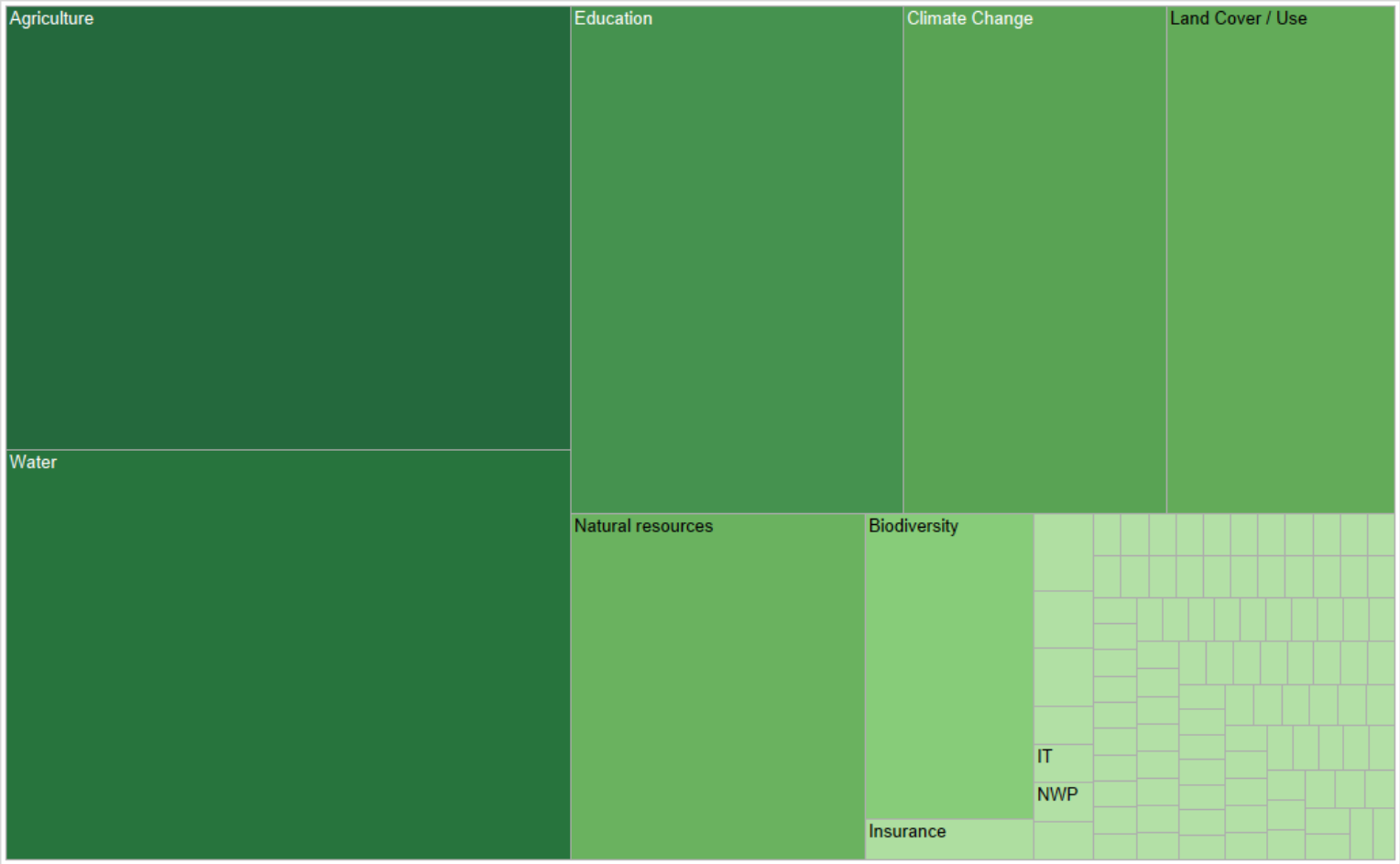
Top: Sentinel-1A
Bottom: Sentinel-1B

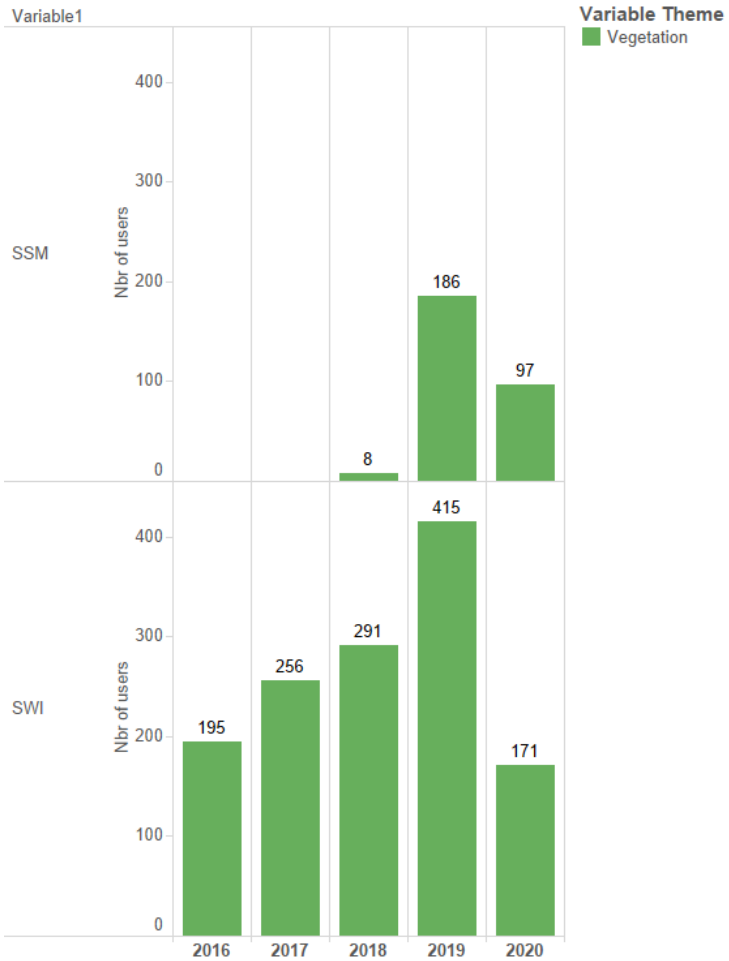


Product Usage & Access

- show QGIS example
- show panoply example (NASA‘s tool for netcdf)
  - https://www.giss.nasa.gov/tools/panoply/

Main Application Domains & Active Downloaders





Note: these figures (up to Q1 2020) are increasingly incomplete due to emergence of mirrors (redistributors) at national and EU levels

Use Cases Portal

- https://land.copernicus.eu/global/use-cases

Product Portfolio & Access

- https://land.copernicus.eu/global/products

Home | Products | Use cases | Product Access | Viewing | Library | Get Support

Overview of the product portfolio

The Copernicus Global Land Service reliably provides a set of biophysical variables which describe the state and the evolution of the vegetation, the energy budget, the water cycle and the cryosphere over the land surface at global scale.

The below tables show the availability of the latest major version, **in near-real time**. For more details on the definition, quality, development or version history of the products, as well as the available archive (time series), please visit the individual product pages.

From medium to high resolution

Theme	Variable	Spatial Resolution Moderate 100m
Vegetation	Land Cover	In production

From coarse to medium resolution

Theme	Variable	Spatial Resolution Coarse >=1km	 Medium 300m
Vegetation	Fraction of photosynthetically active radiation absorbed by the vegetation	In production	In production
	Fraction of green vegetation cover	In production	In production
	Leaf Area index	In production	In production
	Normalized Difference Vegetation Index	In production	In production
	Vegetation Condition Index	In production	
	Vegetation Productivity Index	In production	
	Dry Matter Productivity	In production	In production
	Burnt Area	In production	In production
	Soil Water Index	In production	
	Surface Soil Moisture	In production	

Soil Water Index

The Soil Water Index quantifies the moisture condition at various depths in the soil. It is mainly driven by the precipitation via the process of infiltration. Soil moisture is a very heterogeneous variable and varies on small scales with soil properties and drainage patterns. Satellite measurements integrate over relative large-scale areas, with the presence of vegetation adding complexity to the interpretation.

The soil moisture, up to 5cm soil depth, is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).

The Soil Water Index is provided:

- over Europe, with 1km resolution, based on Surface Soil Moisture from Sentinel-1 C-band SAR (SSM product) and EUMETSAT H SAF Metop ASCAT surface soil moisture.
- at global scale, with 0.1 degree or 12.5km resolution, based on the same Metop ASCAT soil moisture observations.

SWI product updates

Order processing has caught up
Tue, 09 Jun 2020
Temporary delay in the processing of large orders
Fri, 29 May 2020
Temporary delay and maintenance window for 1km Surface Soil Moisture and Soil Water Index production
Tue, 26 May 2020
Read more or Subscribe

Soil Water Index characteristics

SWI 1km Europe | SWI 0.1 degree Global

Access | Algorithm | Quality | Application | Technical | Documents | Gallery

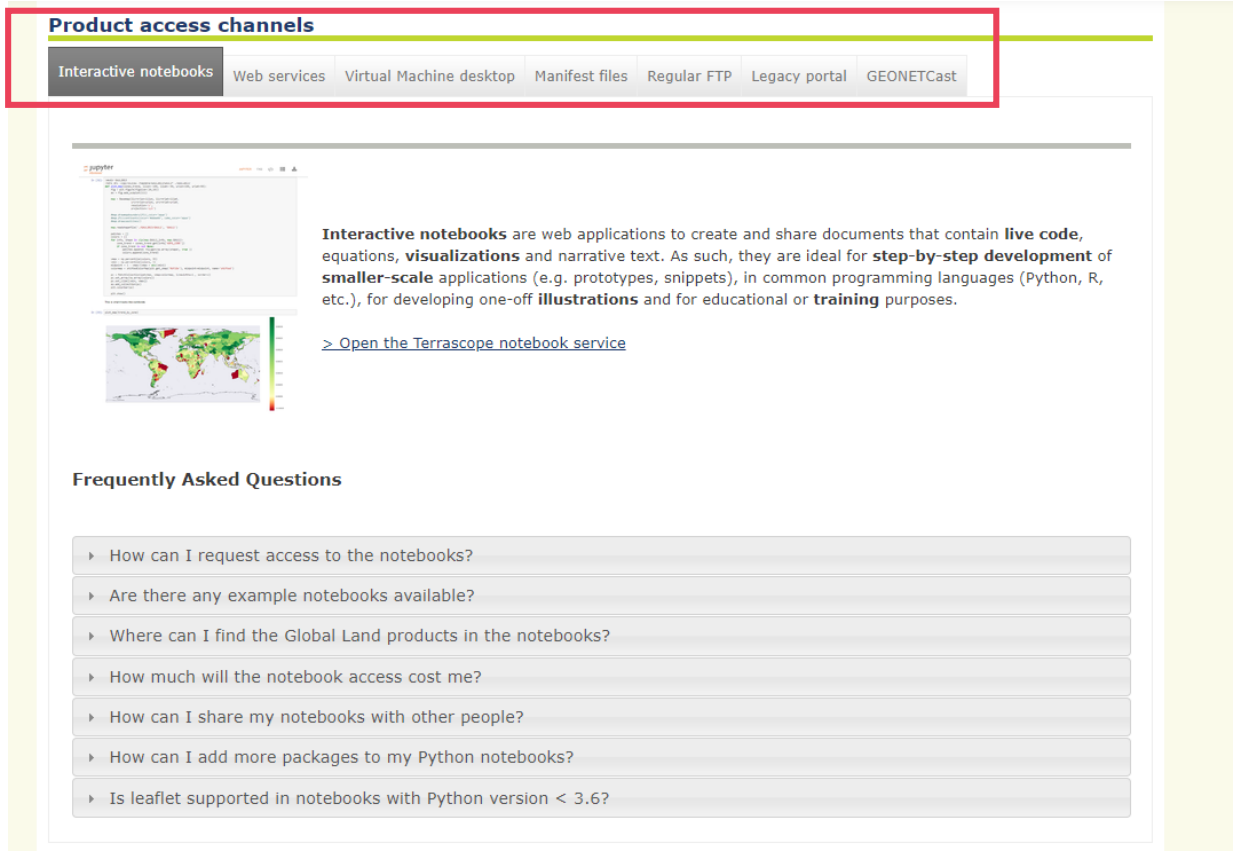
Product version	Access	Sensor	Temporal coverage	Spatial information	Timeliness
1	Product portal	Sentinel-1 C-SAR and Metop ASCAT	Jan 2015 - present	Europe, 1km	Within 2 days after observation

Different Ways to Access the Products

https://land.copernicus.eu/global/access

Are you looking for…

- a sample product to try
- netCDF4 or GeoTIFF format
- whole area or subset
- mirror copy of entire archive
- standing order for upcoming products
- cloud access, i.e. without download



⇒ Try different access channels with FAQ and/or tutorial(s)

⇒ Not all (50+ !) product collections available on all channels (but this is improving)

Recent Work on Access Options

Under development:

- Sample R and Python code to download & read products, with Jupyter notebook examples
- See https://github.com/cgls

For questions, feedback, use case or code to share:

- Help desk https://land.copernicus.eu/global/contact

- show where to find documents
  - https://land.copernicus.eu/global/products/ssm
  - https://land.copernicus.eu/global/products/swi

Quality Assessment & Validation

Internal & External Studies

Product Maturity & Quality

- Independent panel's quality classification:
  => demonstration, pre-op, ops status

Development stages

Global Land Service products are classified in **four development stages** defined as follows. The promotion (bottom-to-top progress) or demotion is announced in the Product News section of this website and via the Global Land mailing list.

Development stage	Description	Lead-in requirement(s)	Product availability	Quality control
Operational	Products with documented, non-relevant limitations that largely satisfy the applicable user requirements and/or are considered mature.	• Qualification by independent review board • Full quality assessment	All users	• Routine monitoring via statistics to verify temporal stability • Regular quality assessment • Can be part of cross-cutting validation
Pre-operational	Products with documented limitations that can satisfy the majority of the applicable requirements and/or have been considered useful for distribution to the mainstream users.	• Qualification by independent review board • Limited quality assessment	All users	• Routine monitoring via statistics to verify temporal stability
Demonstration	Products with a limited commitment on the quality or availability, but are still considered useful for users to test and provide feedback.	• Brief technical and scientific verification by consortium • Full set of documentation, except validation report	All users	
In development	Products that are in internal development.		Within service consortium	

SWI & SSM are products with "Operational" status

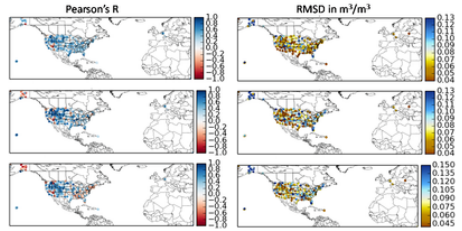
- Regular validation & quality assessment
  - Scientific Quality Evaluation (SQE) Reports
  - Validation Repots (VR)

Soil Water Index characteristics

SWI 1km Europe | SWI 0.1 degree Global

Access | Algorithm | Quality | Application | Technical | Documents | Gallery

The quality of the daily (SWI) and 10-day (SWI10) Soil Water Index version 3 products, with 0.1degree resolution, was assessed by comparison with global Land Surface Models output (GLDAS Noah) and with in-situ measurements provided by the International Soil Moisture Network (ISMN). The Pearson correlation coefficient of the SWI-TS product at T=1 with the upper layer soil moisture from the GLDAS Noah model is provided in the Correlation Information (CI) static layer. The details of the analysis and results can be found in the Validation Report.



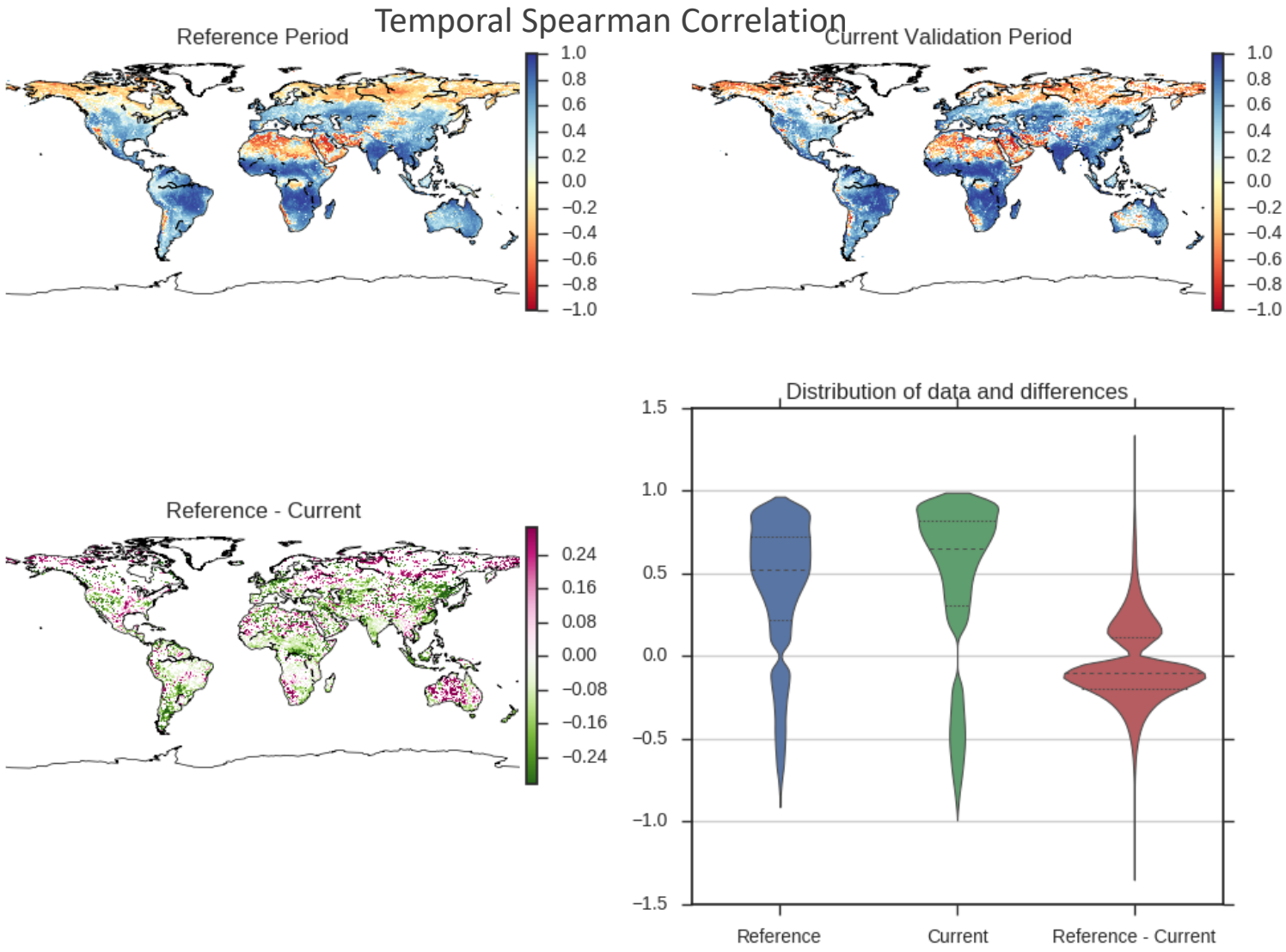
Maps of Pearson's correlation coefficient (left) and RMSD (right) for T=1 (top), T=20 (center) and T=100 (bottom) between SWI-V3 and in-situ ISMN data during the period April 2013-April 2014.

The accuracy assessment is updated every year using the most recent ground reference data available (Figure Below). The results obtained on the 2018 SWI products are presented in the 2018 Validation Report.

See Validation Reports

ASCAT SWI

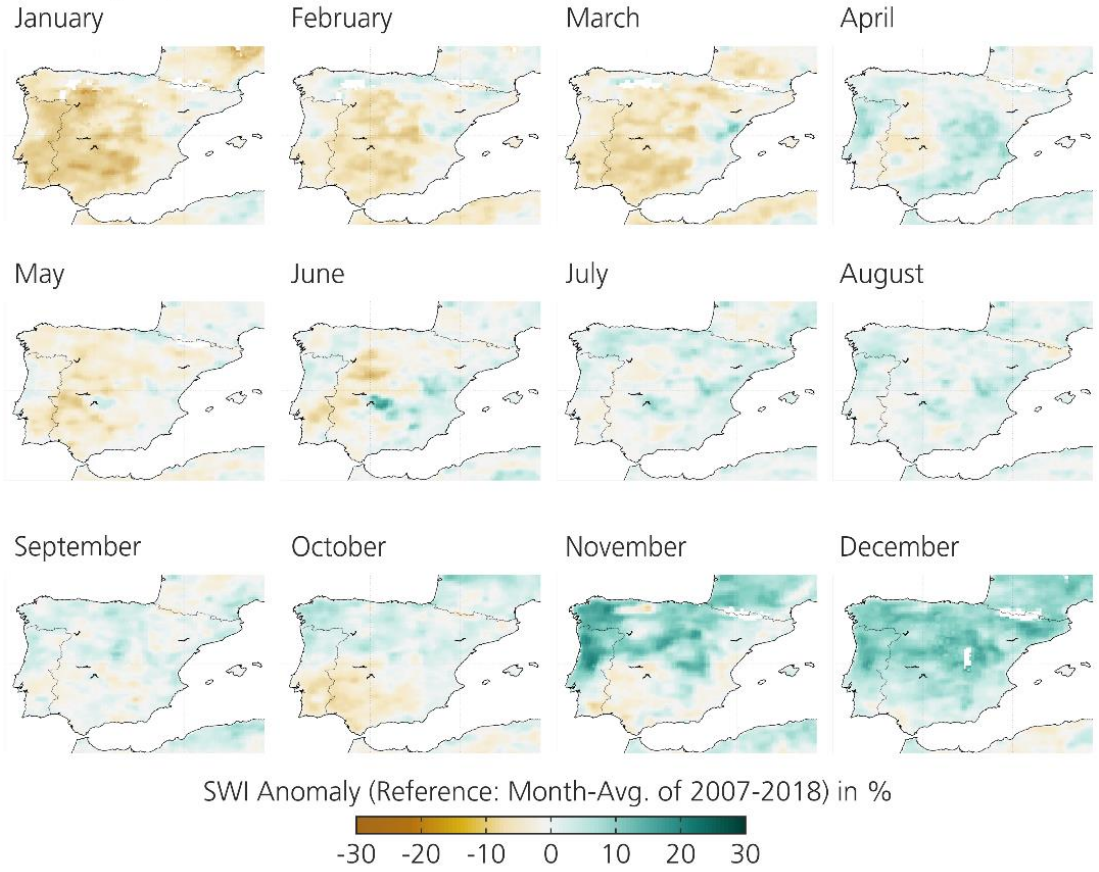
- Scientific Quality Evalution
  - (SQE Report 2019)
- annual validation against
  - global re-analysis data
    - GLDAS Land Surface Models
  - in-situ stations
    - ISMN (International Soil Moisture Network)
- regional studies (next slides)



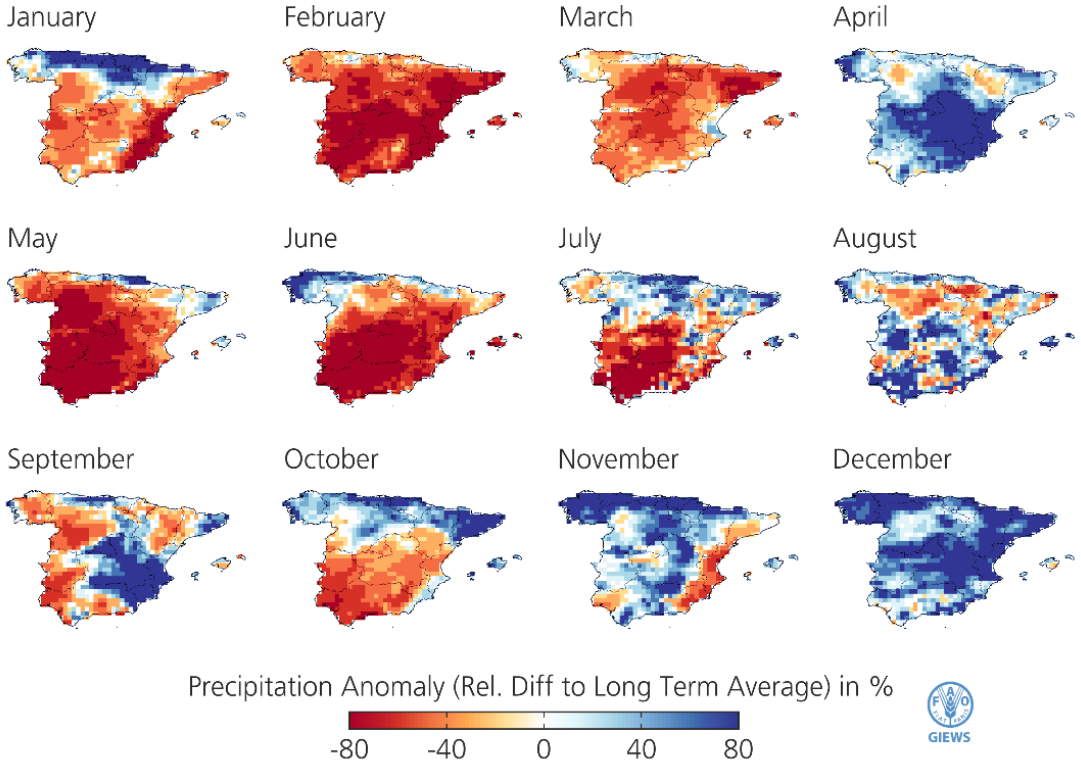
SQE Report: ASCAT SWI vs Rainfall Anomalies in 2019

Spain

SWI10 (T=1) Anomalies

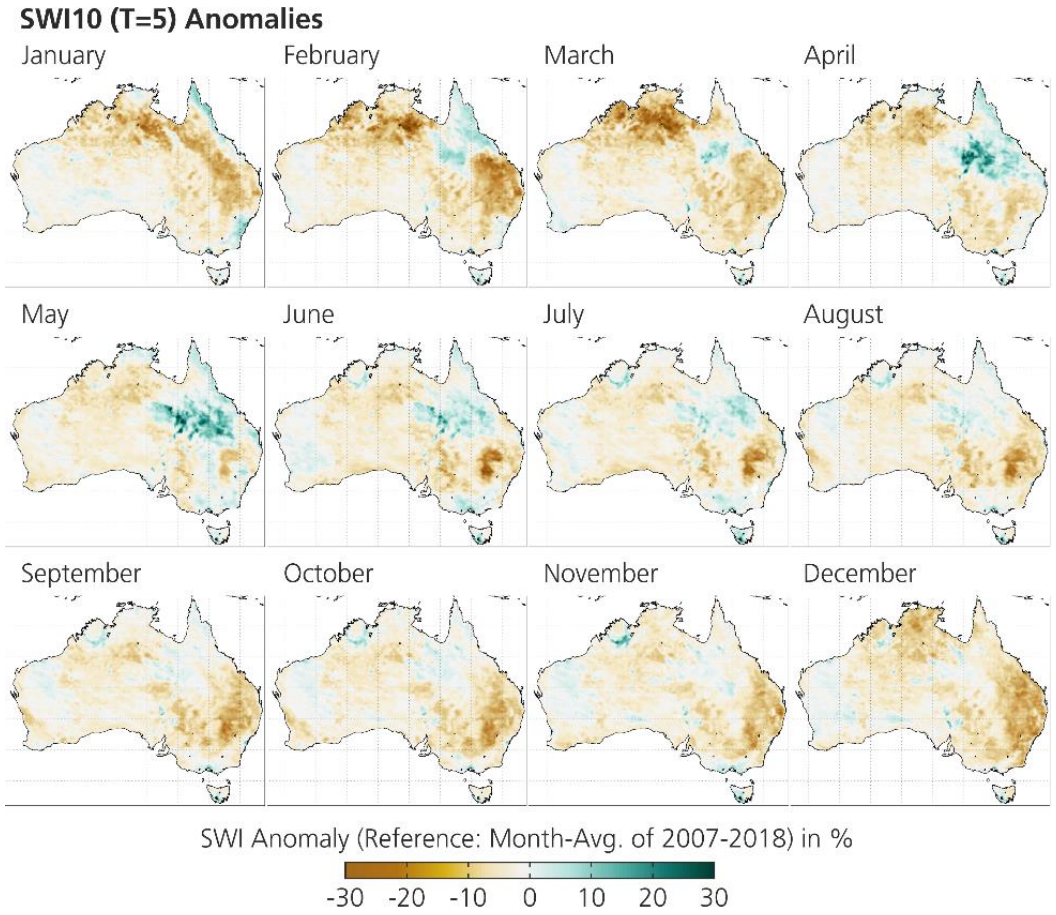


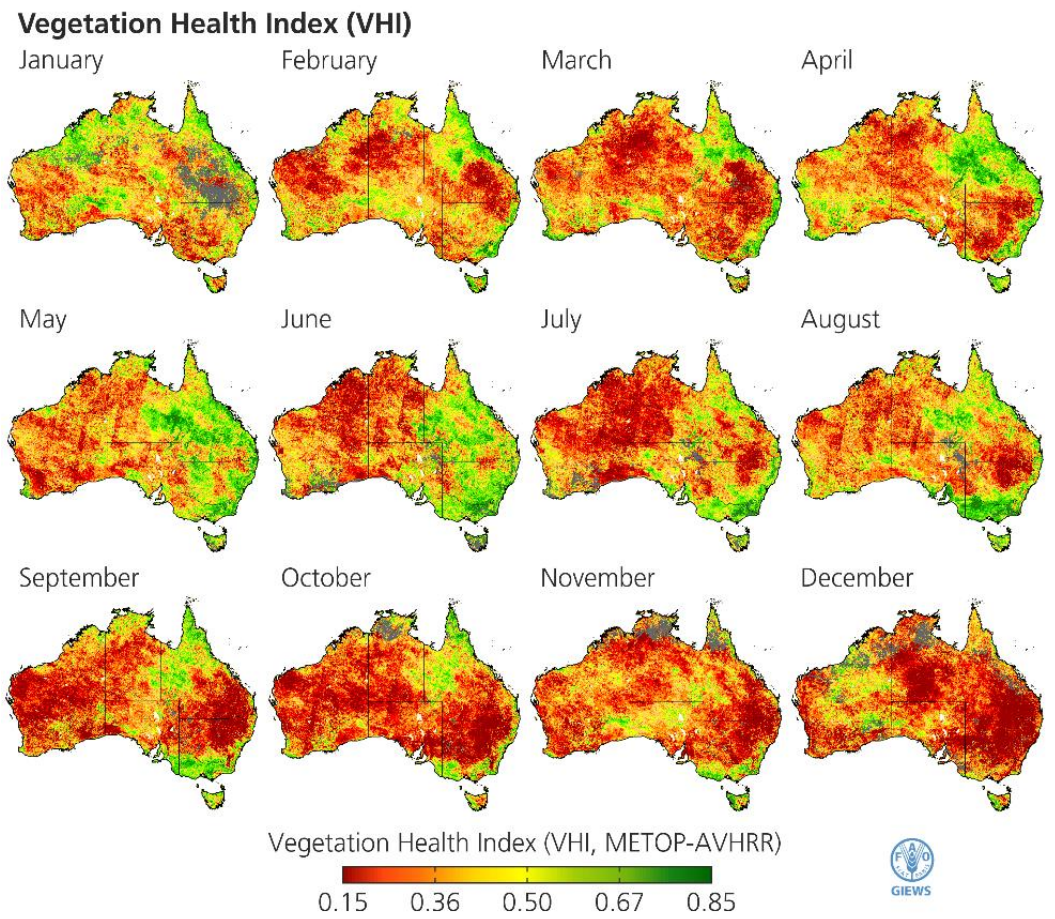
Rainfall Anomalies



SQE Report: ASCAT SWI vs Vegetation Health in 2019

Australia

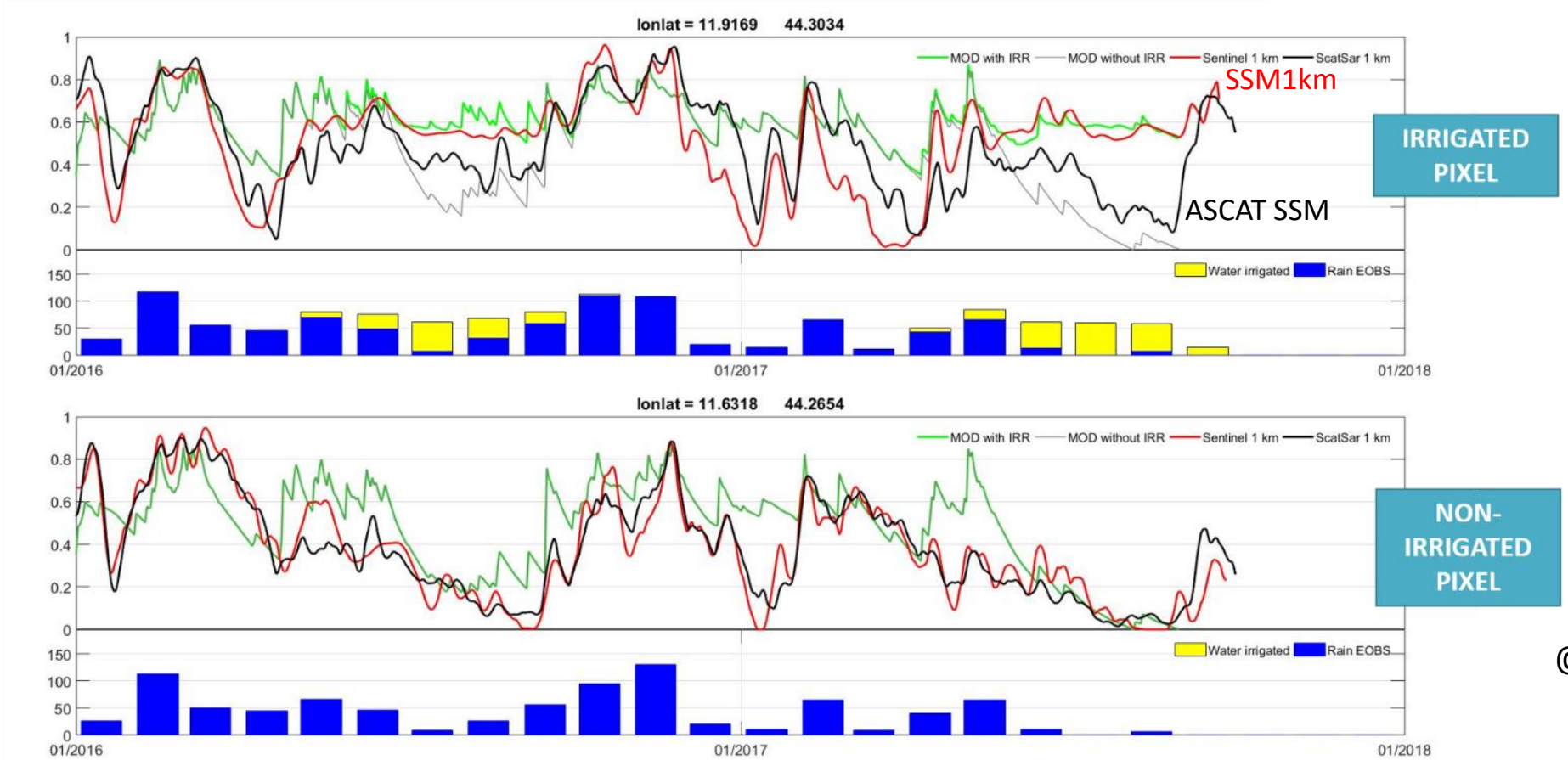




SSM1km: Added-Value of SAR Signal

- contrary to other satellite products: **irrigation** impacts are visible!

ROMAGNA (ITALY)



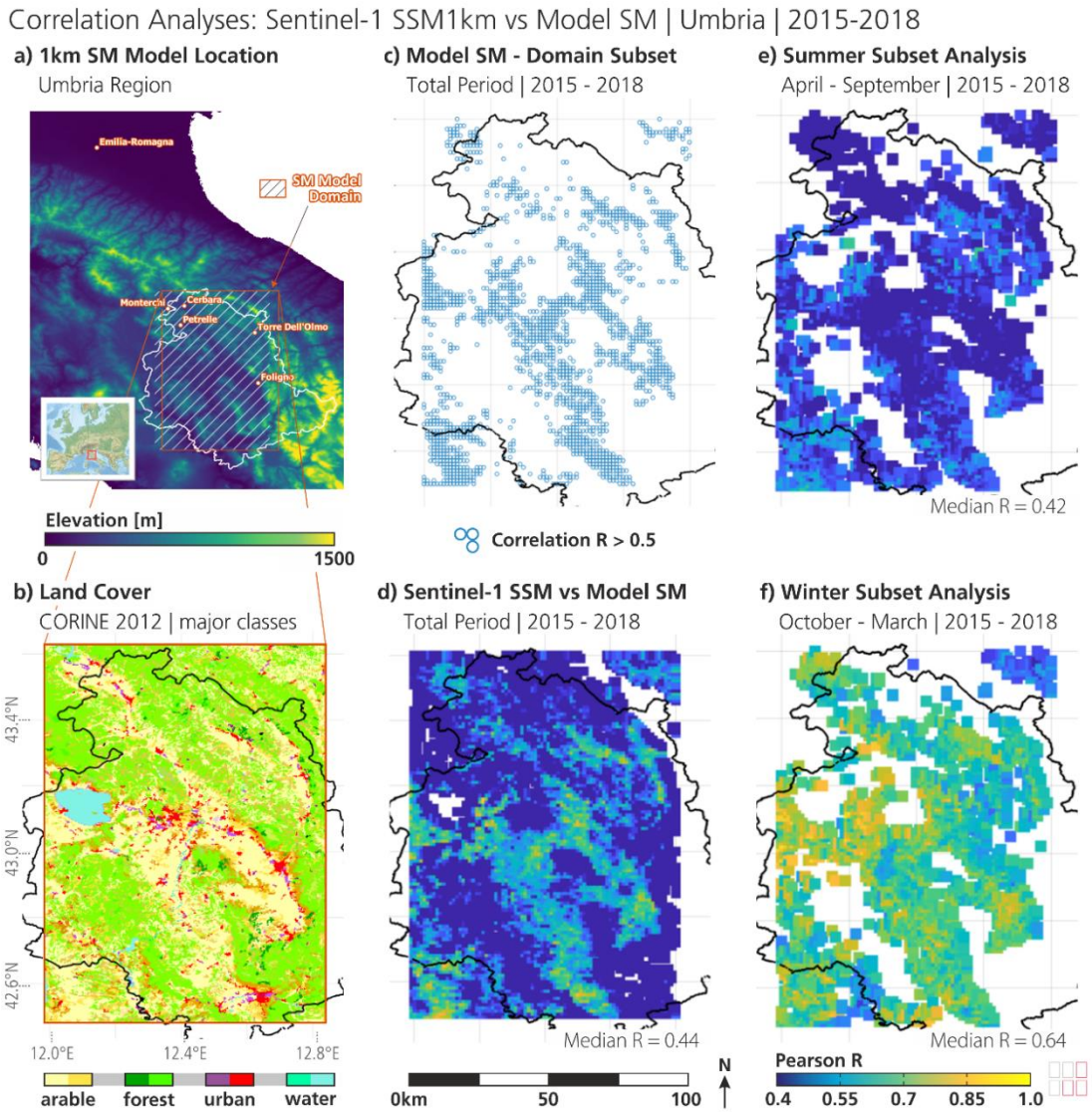
IRRIGATED PIXEL

NON-IRRIGATED PIXEL

© irpi

SSM1km vs 1km-SM-Model

- comparison against 1km SM model over Umbria
  - good quality over lowlands/agricultural areas
  - no reliable signal over forests (…C-band!)
- vegetation dynamics troubling SSM retrieval
  - higher scores for winter than for summer period
  - need for dynamic vegetation correction!

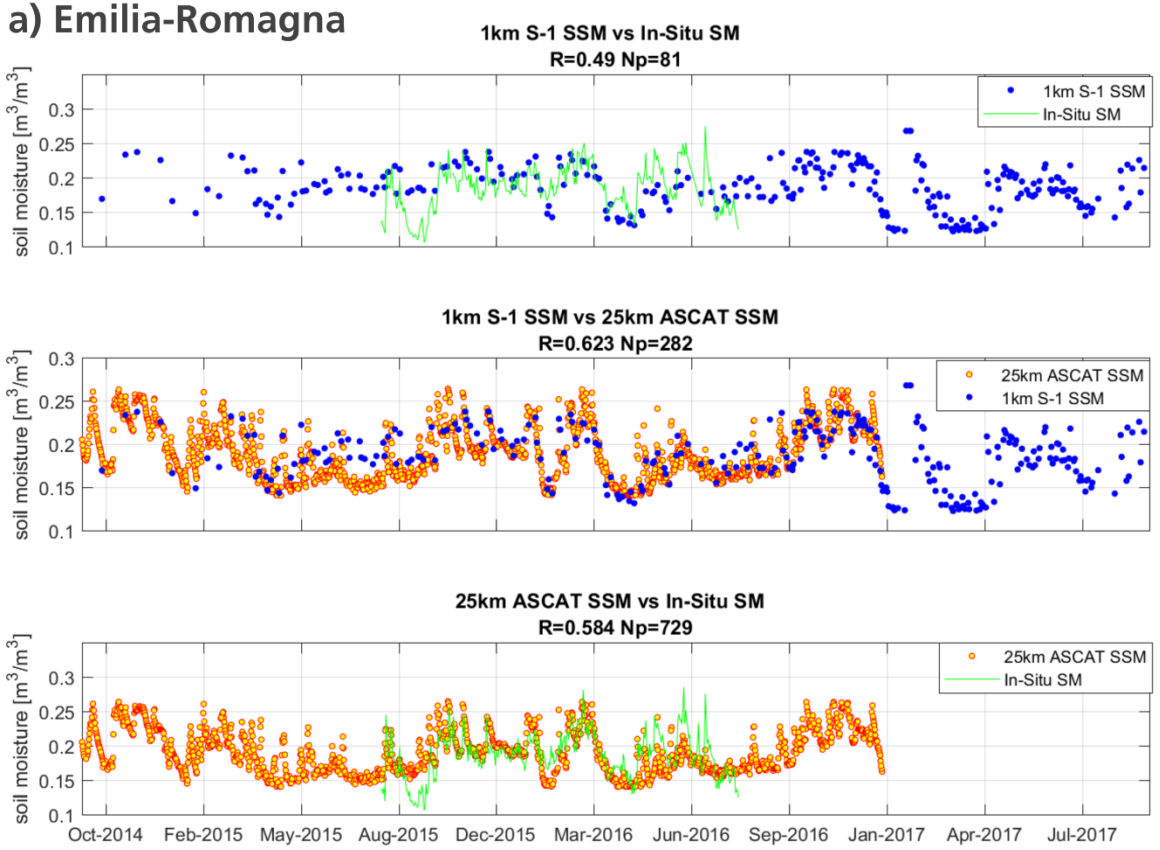


SSM1km Time Series

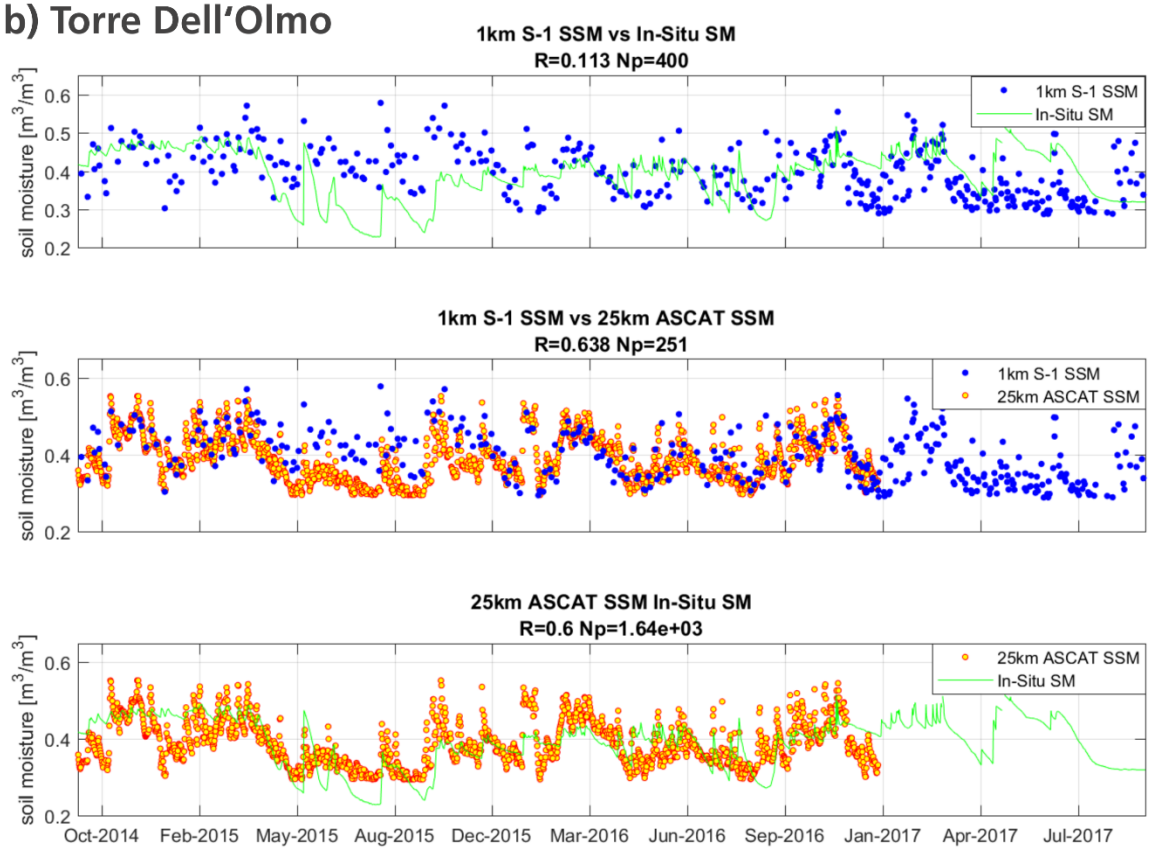
- From publications
  - **good** agreement over lowland
  - **bad** agreement over hills/forest

Sentinel-1 SSM1km vs. In-Situ SM and ASCAT SSM

a) Emilia-Romagna

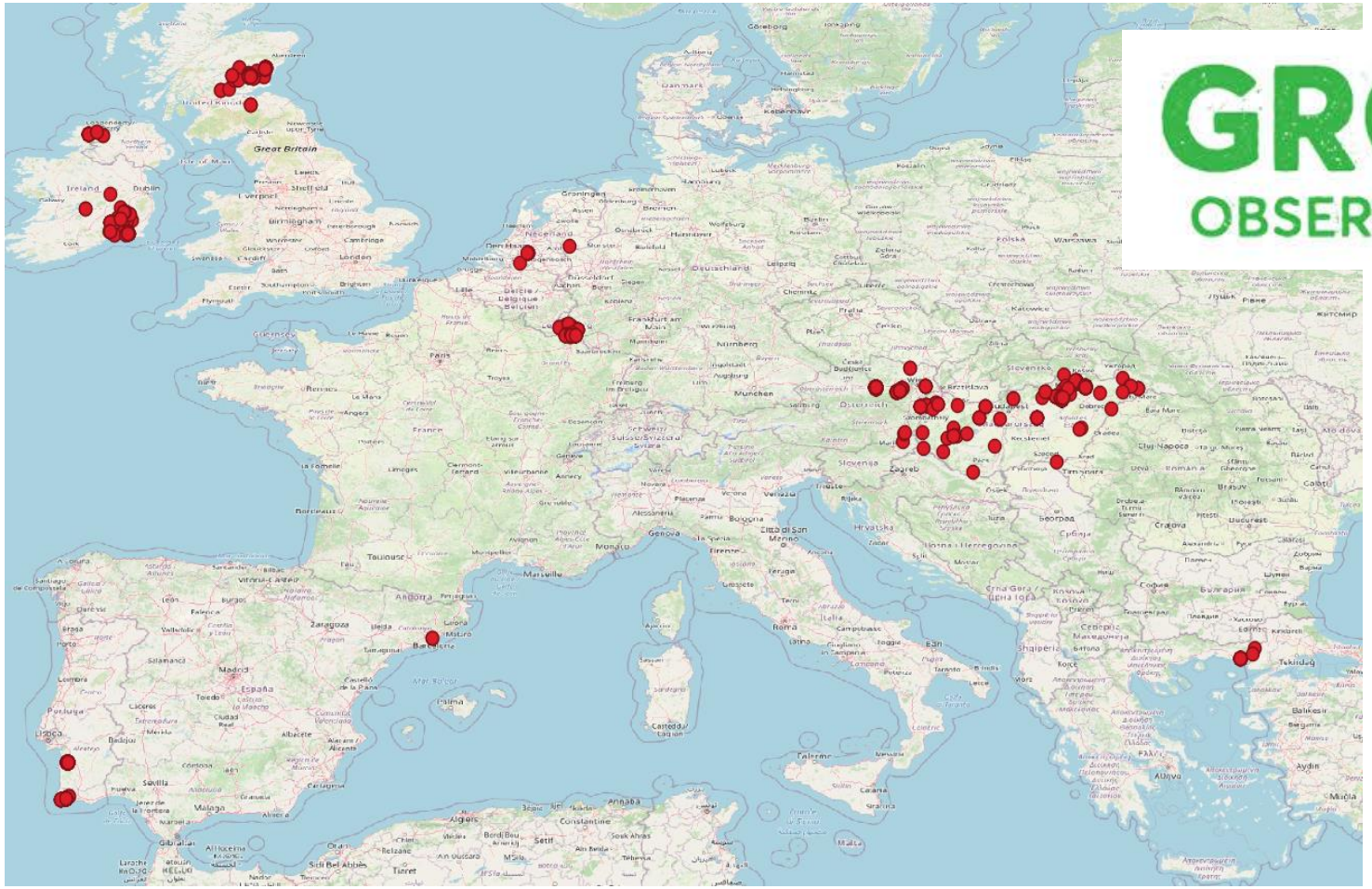


b) Torre Dell'Olmo



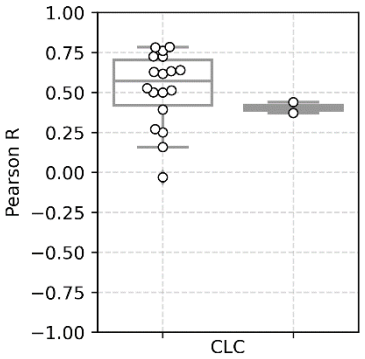
SSM1km vs GROW Observatory

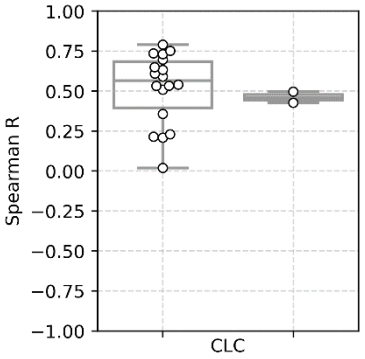
- GROW Observatory = citizen scientist's observatory



GROW OBSERVATORY

https://growobservatory.org/

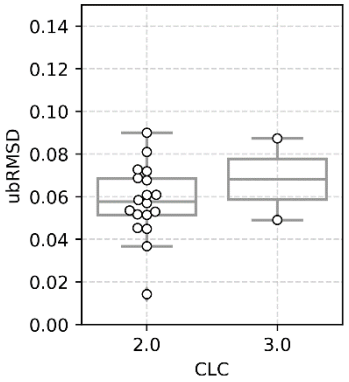




Temporal Correlation

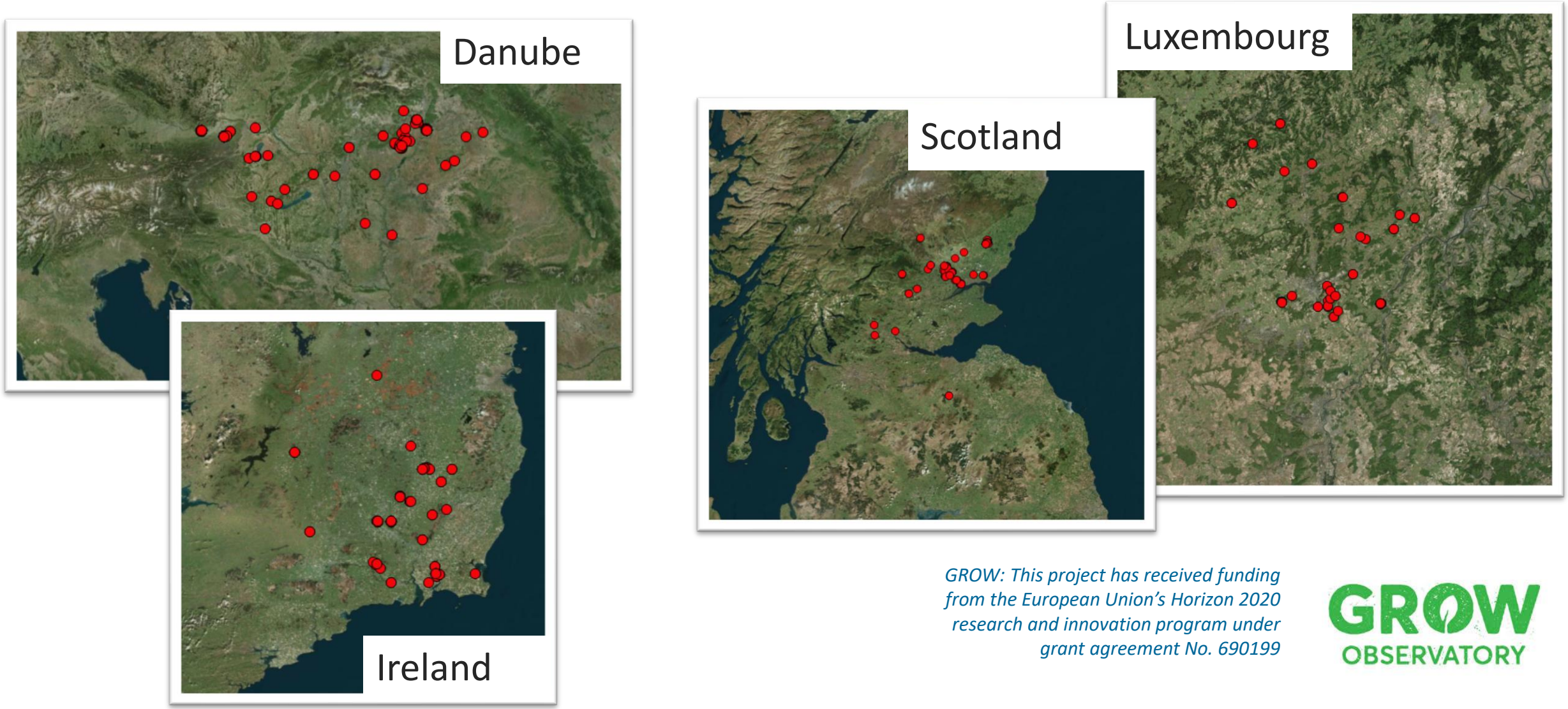
2017-19

per Land Cover Class



Agri Forest

GROW: Dense Networks: Spatial Correlation

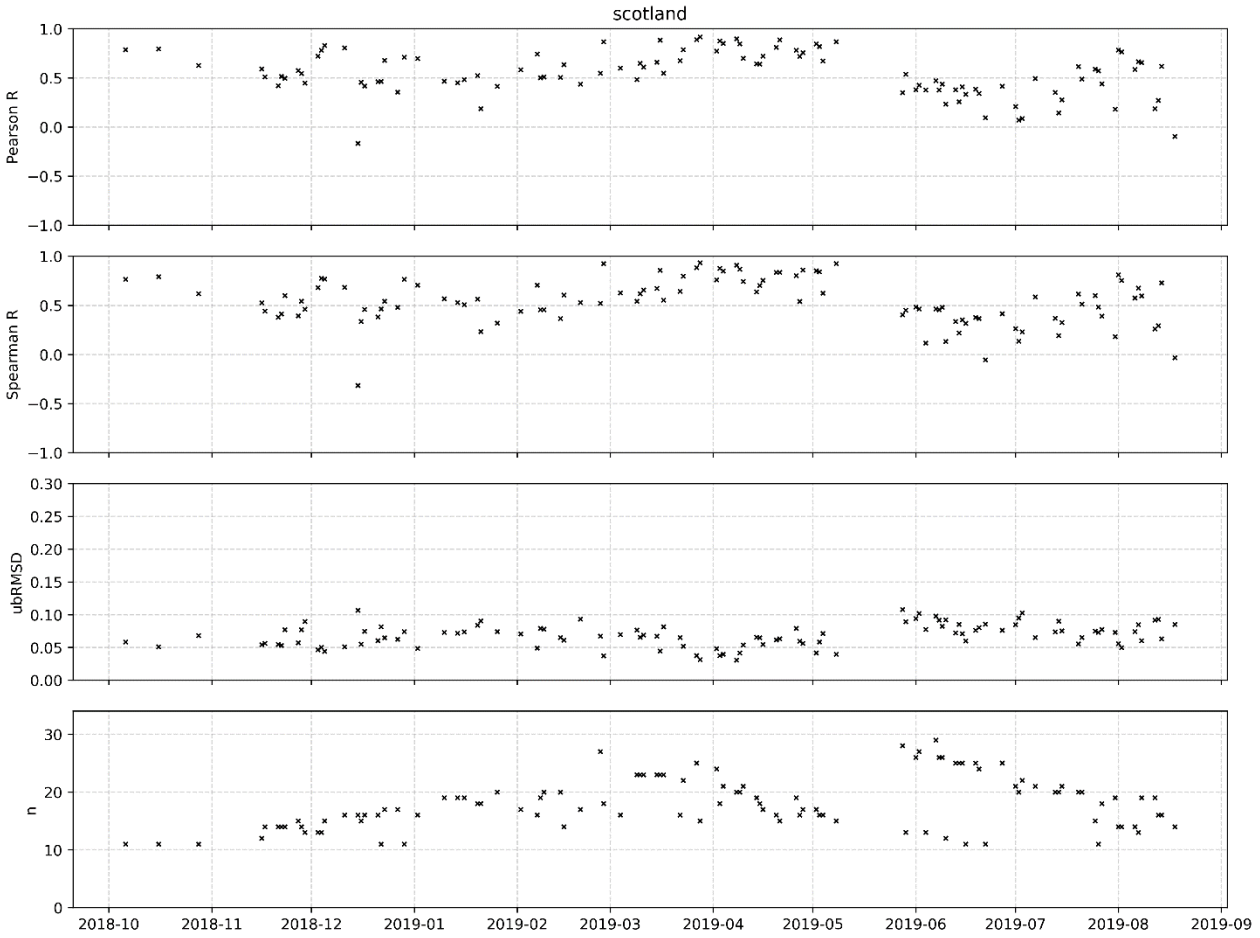


GROW: This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 690199

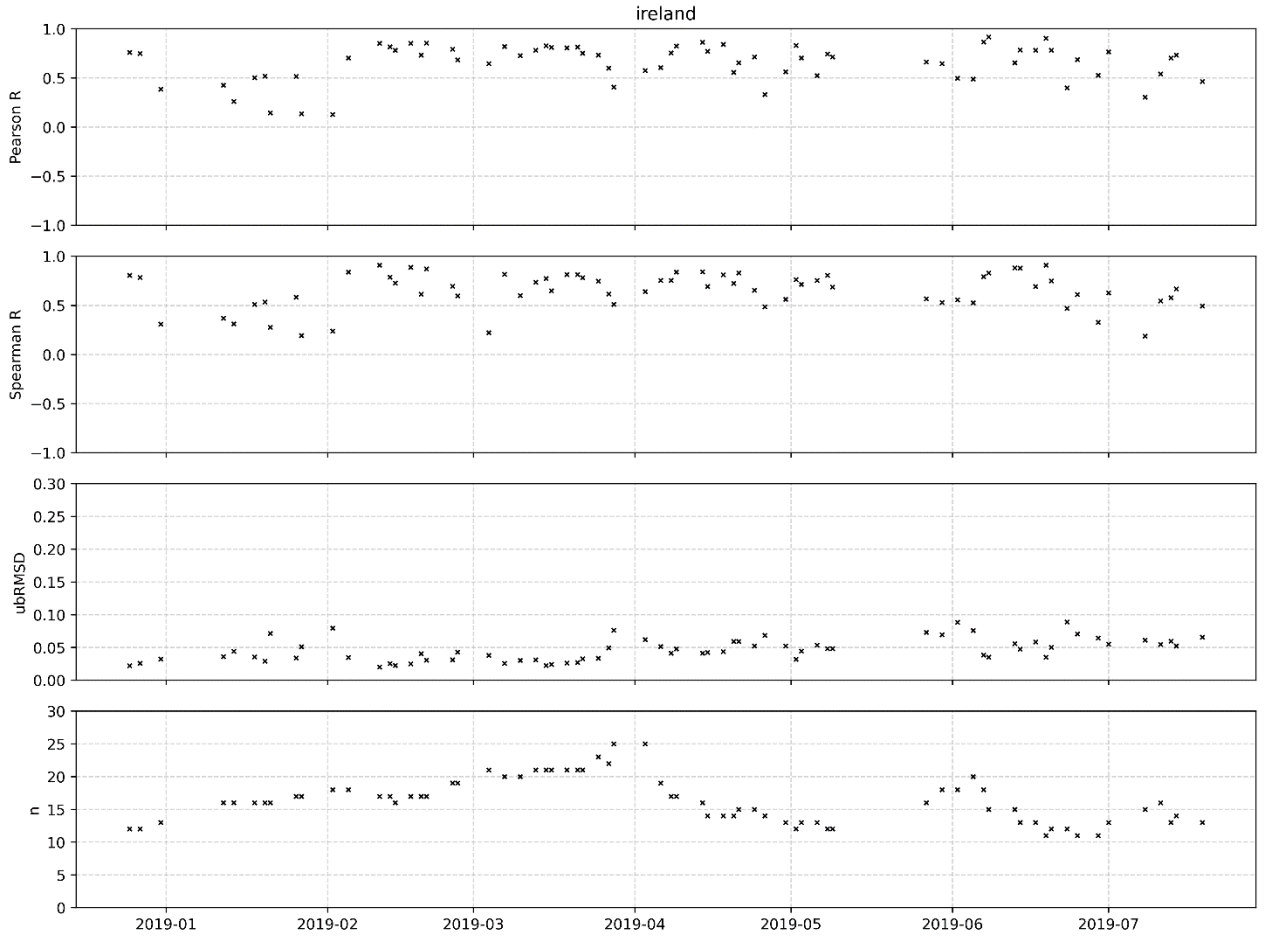
GROW OBSERVATORY

GROW: Spatial Correlation

Scotland

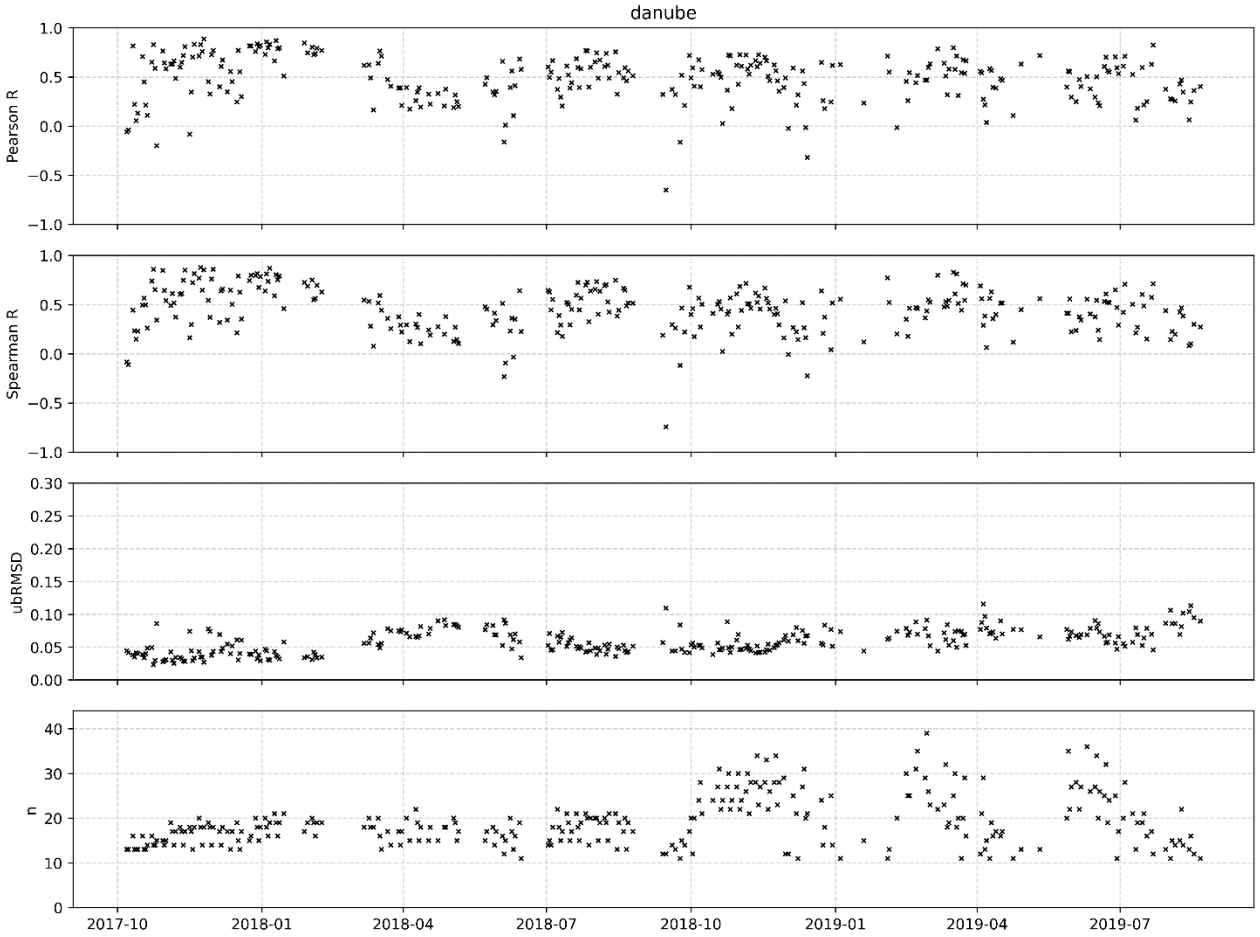


Ireland

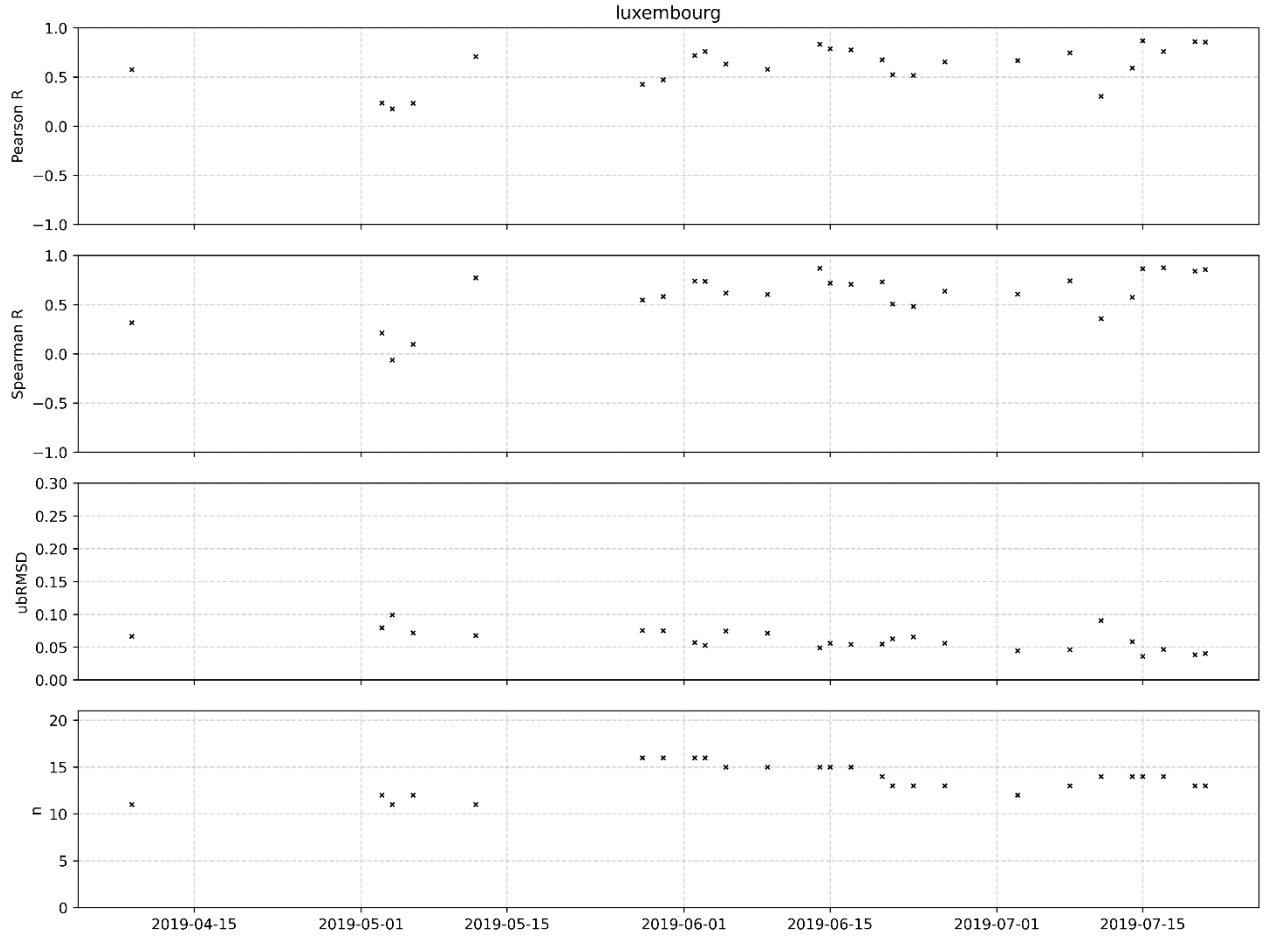


GROW: Spatial Correlation

Danube



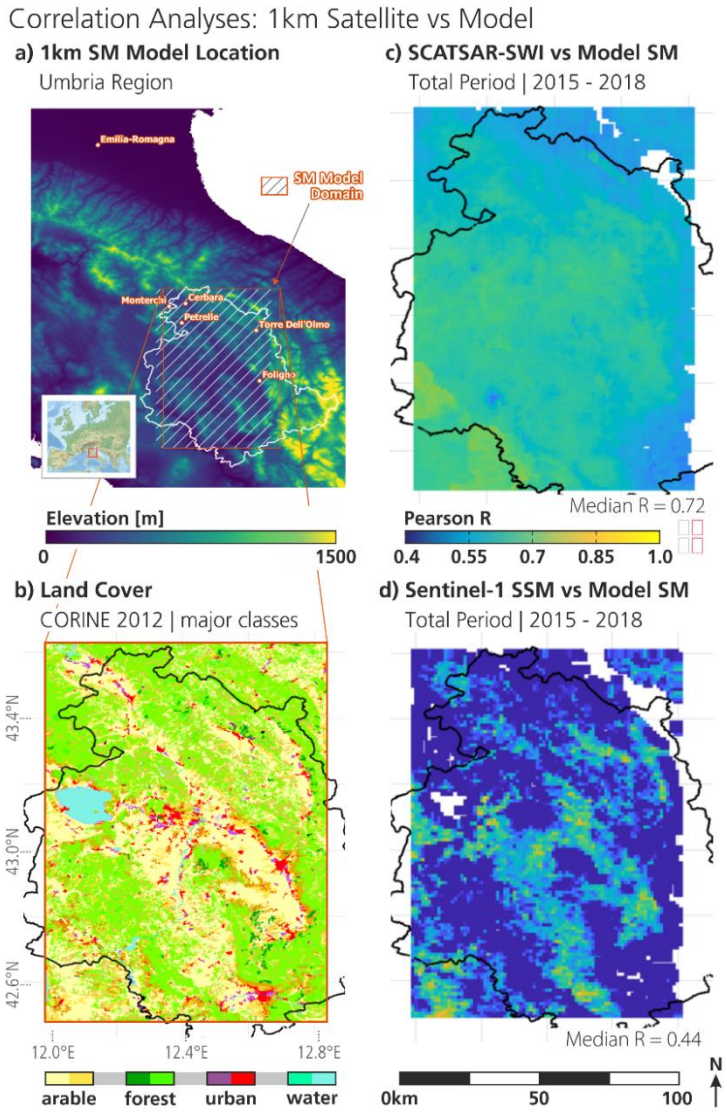
Luxembourg

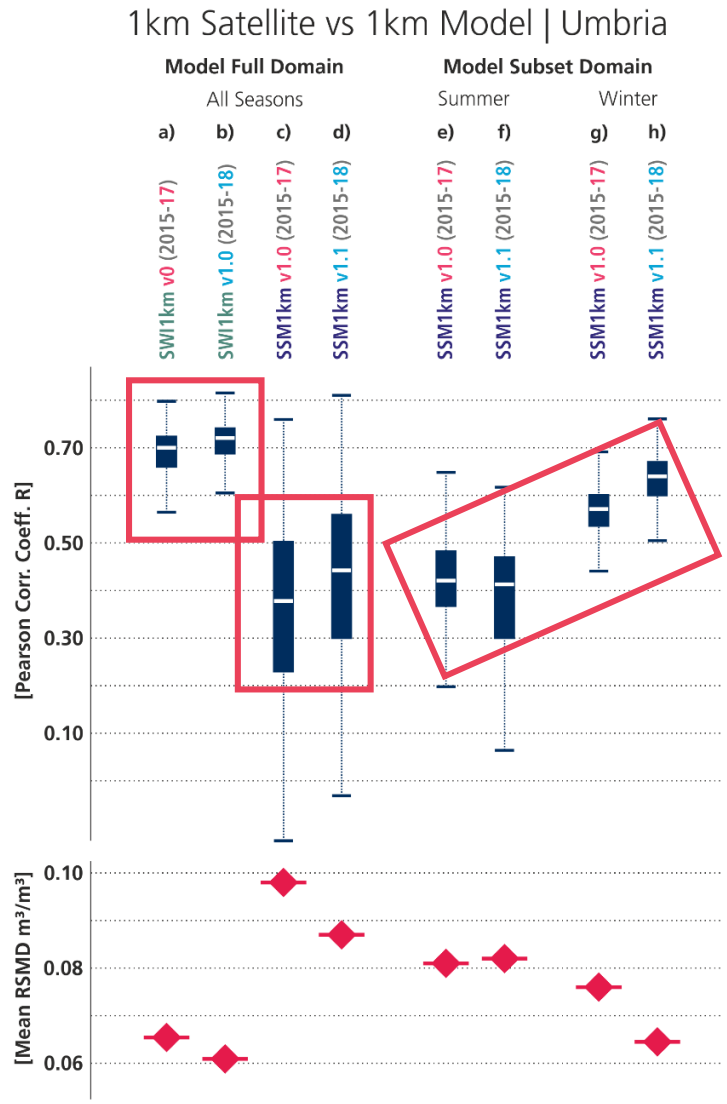


SWI1km vs 1km-SM-Model

Summary

- comparison against 1km SM model over Umbria
  - metrics very similar to the 25km ASCAT SWI





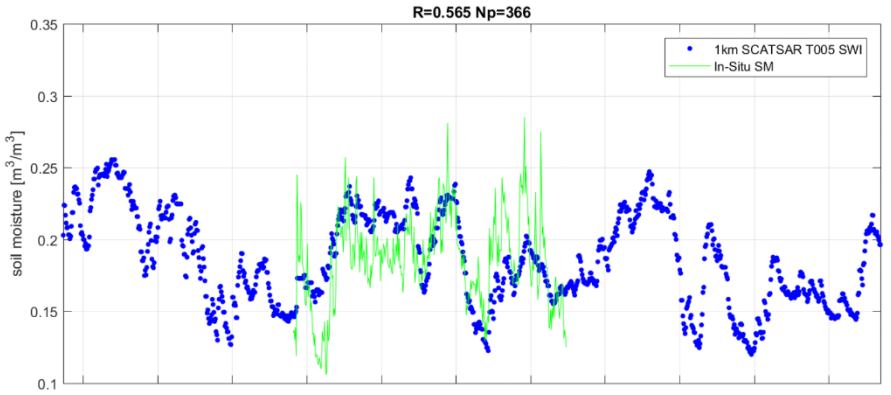
SWI1km Time Series

- (also from publications)
- SCATSAR data fusion appear to work
  - Sentinel-1 parametrisation can improve the signal
  - ASCAT signal quality preserved in SWI1km

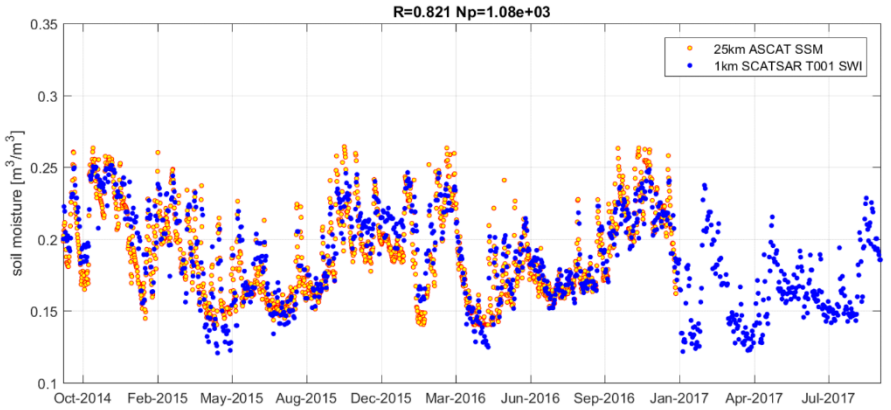
SCATSAR SWI1km vs. In-Situ SM and ASCAT SSM

a) Emilia-Romagna

SCATSAR-SWI (T-Value=5) vs. In-Situ SM (COSMOS station)

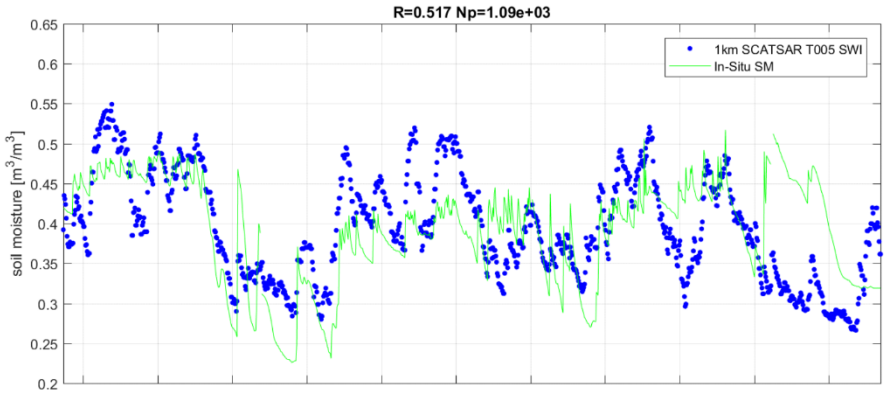


SCATSAR-SWI (T-Value=1) vs. ASCAT SSM (top 5cm)

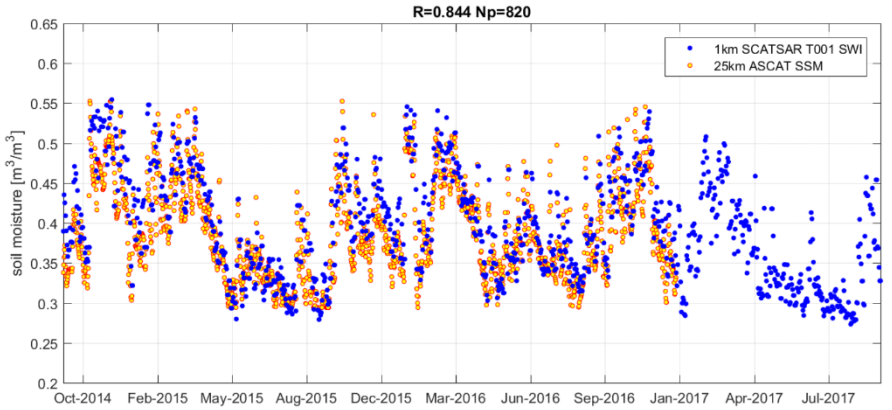


b) Torre dell'Olmo

SCATSAR-SWI (T-Value=5) vs. In-Situ SM (10cm depth)

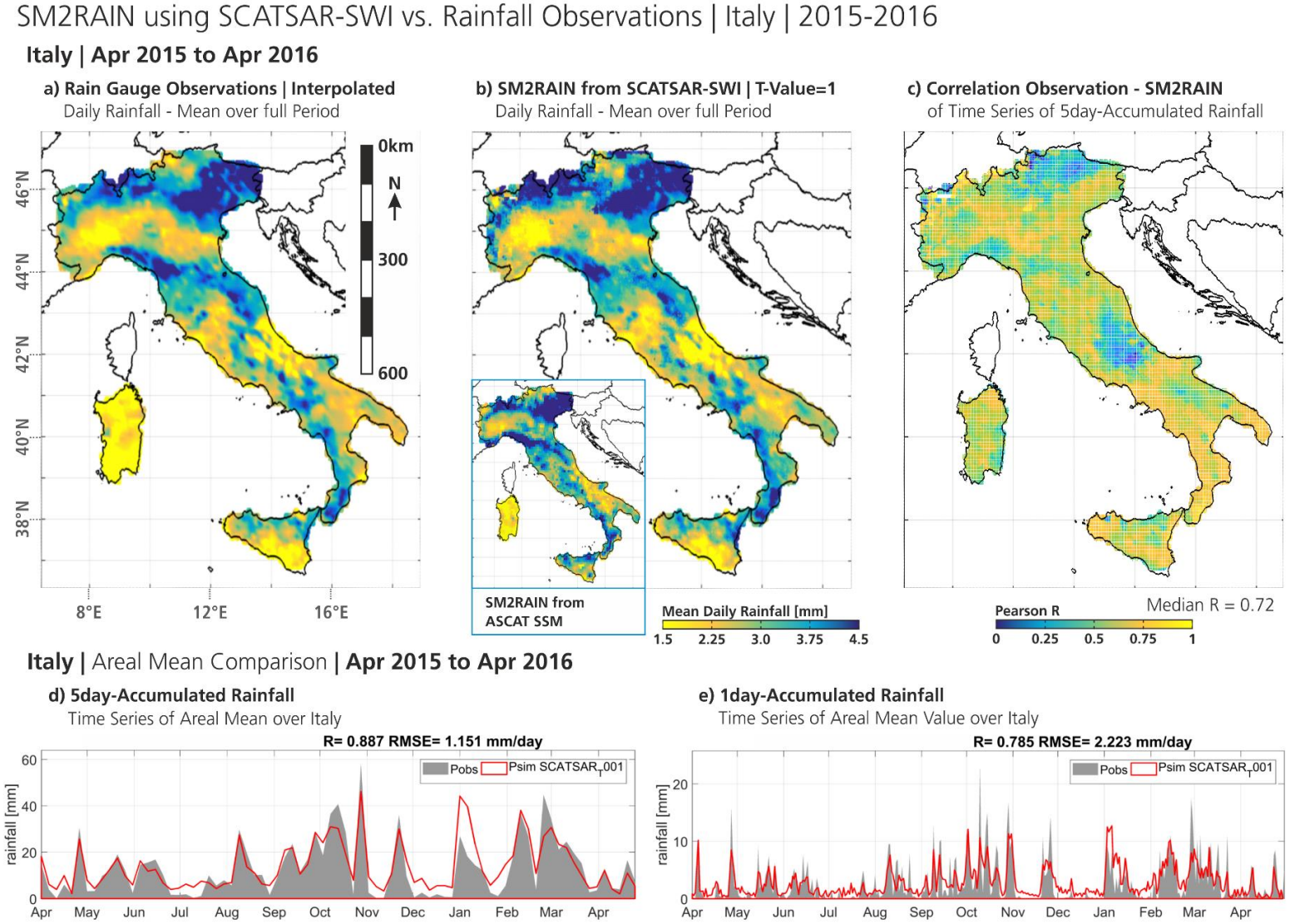


SCATSAR-SWI (T-Value=1) vs. ASCAT SSM (top 5cm)



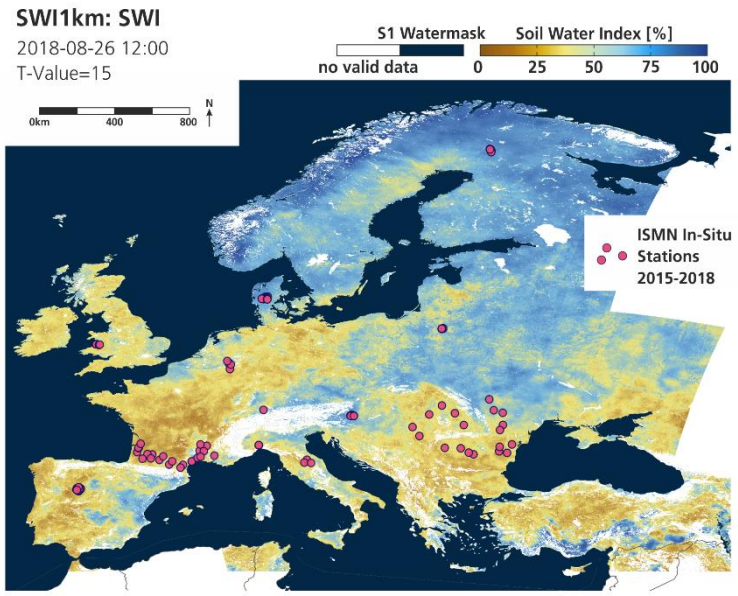
SWI1km for Rainfall Estimation: SM2RAIN Approach

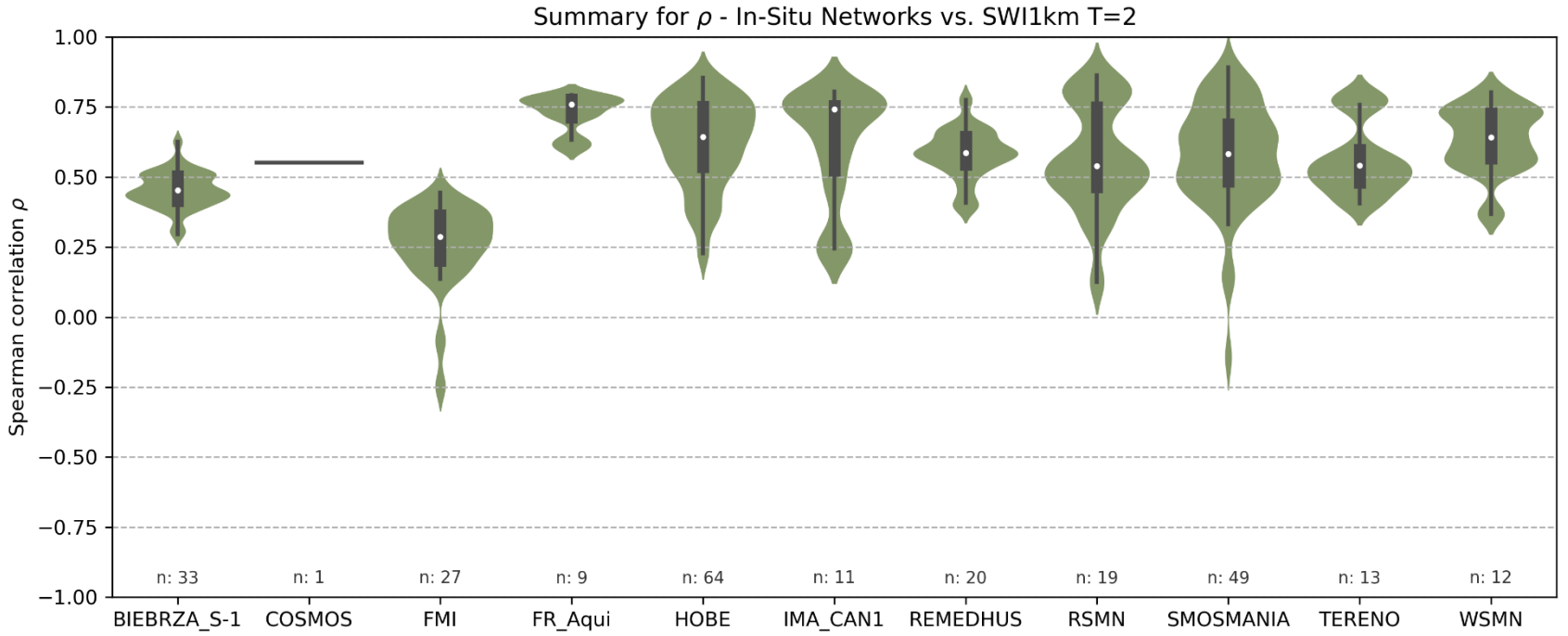
- (also from publications)
- SWI1km signal can be used for rainfall estimation
  - high agreement with interpolated observations
- 5-day accumulated rainfall shows very good agreement
- 1-day accumulated rainfall is underestimated
  - temporal frequency not enough?



SWI1km vs In-Situ (ISMN)

- Validation Report https://land.copernicus.eu/global/sites/cgls.vito.be/files/products/CGLOPS1_QAR_SWI1km-

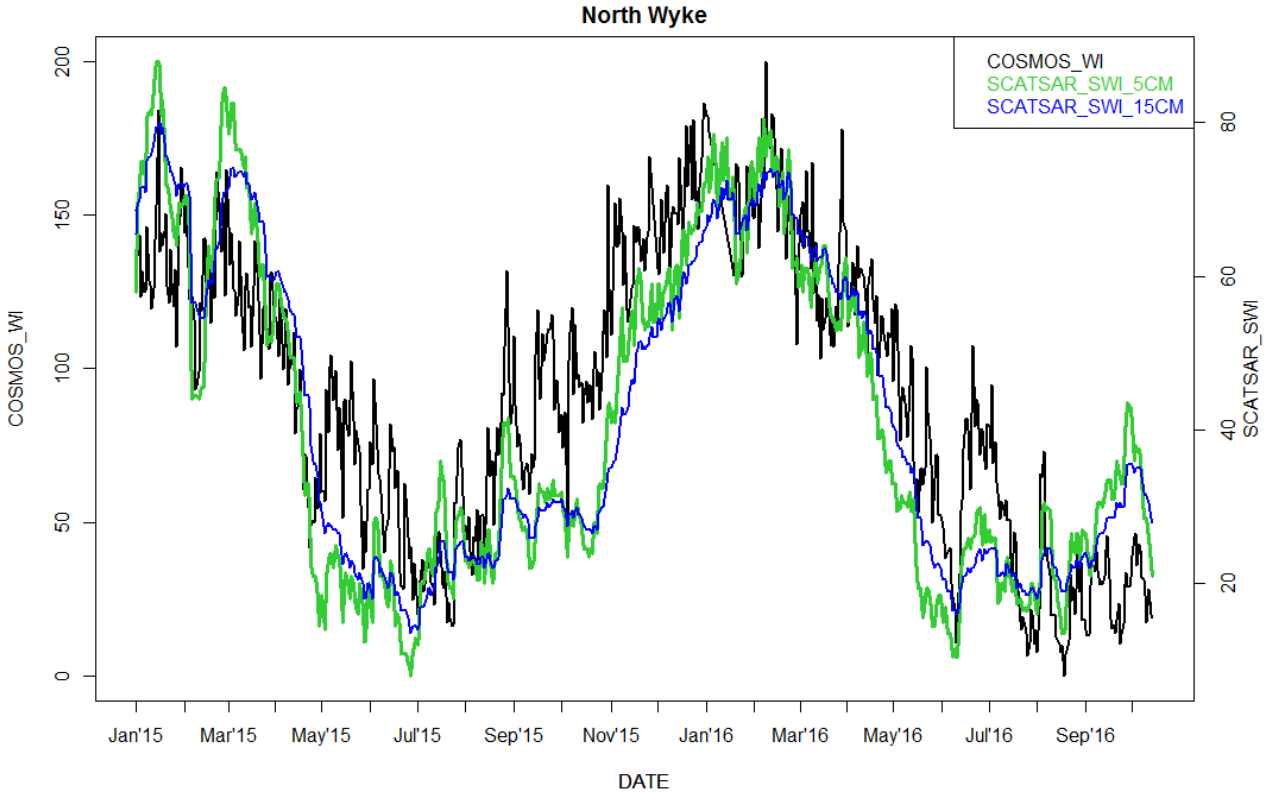


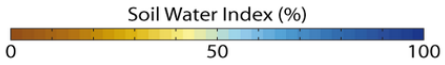


SWI1km: Early Example over UK

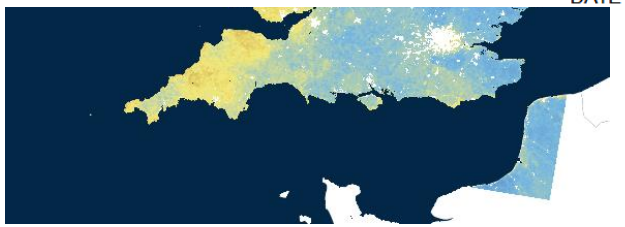
- Set of COSMOS TS provided by CEH UK

CEH UK
COSMOS Stations





2015-05-04 | T020



2015-11-07 | T020

2016-10-13 | T005

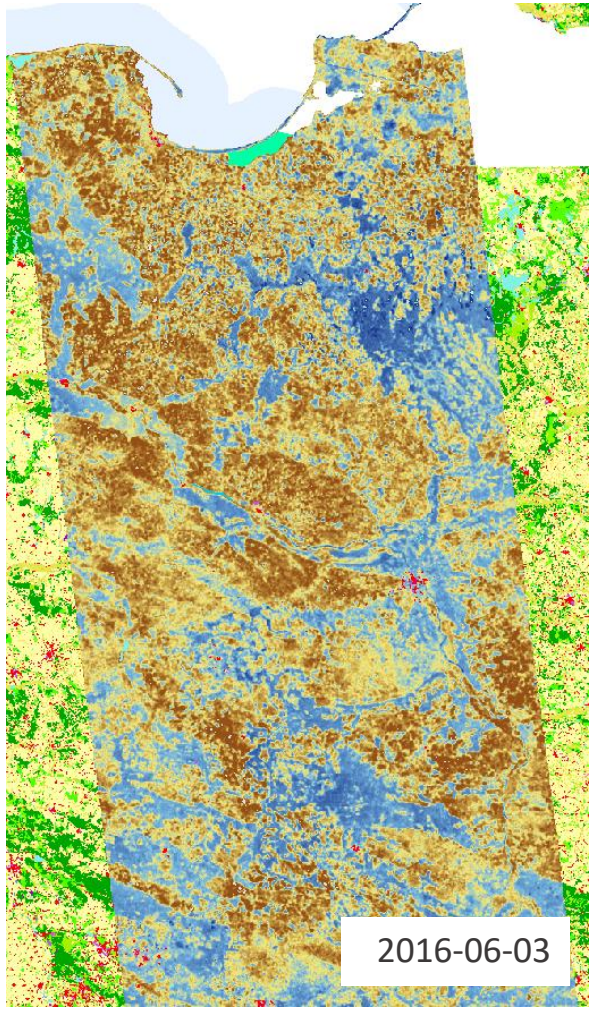
Known Issues & Conclusions

SSM1km

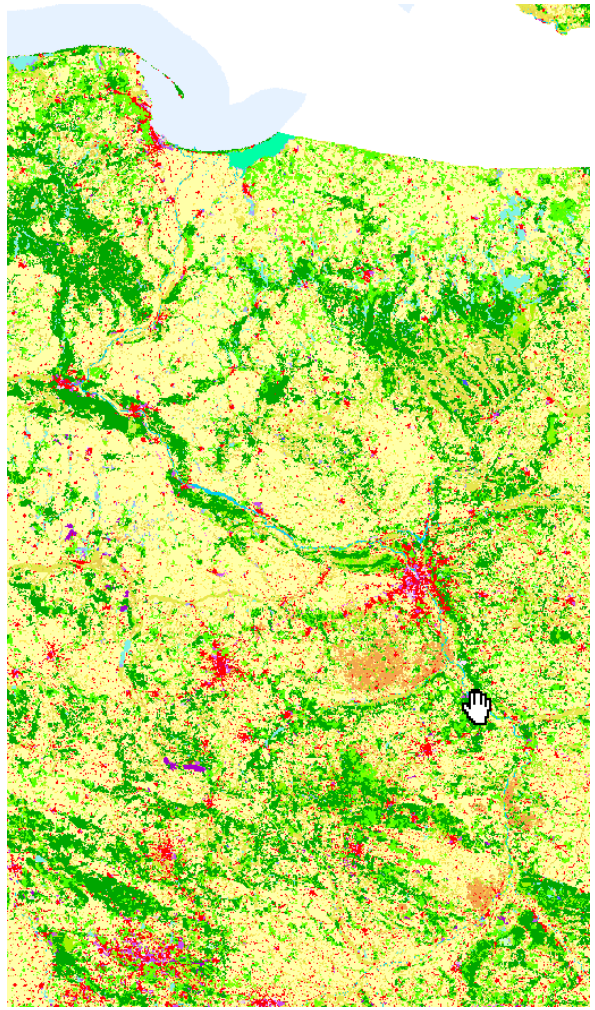
SSM1km: Vegetation Biases

- SSM Algorithm currently does not take **vegetation dynamics** into account.
- problems through unknown…
  - vegetation density
  - vegetation water content
- help through using…?
  - using Sentinel-1 VH-polarised data
    - VH/VV sensitive to Vegetation Optical Depth (VOD)
  - separate seasonal/monthly/weekly parameters
    - dry, wet, slope

Sentinel-1 SSM

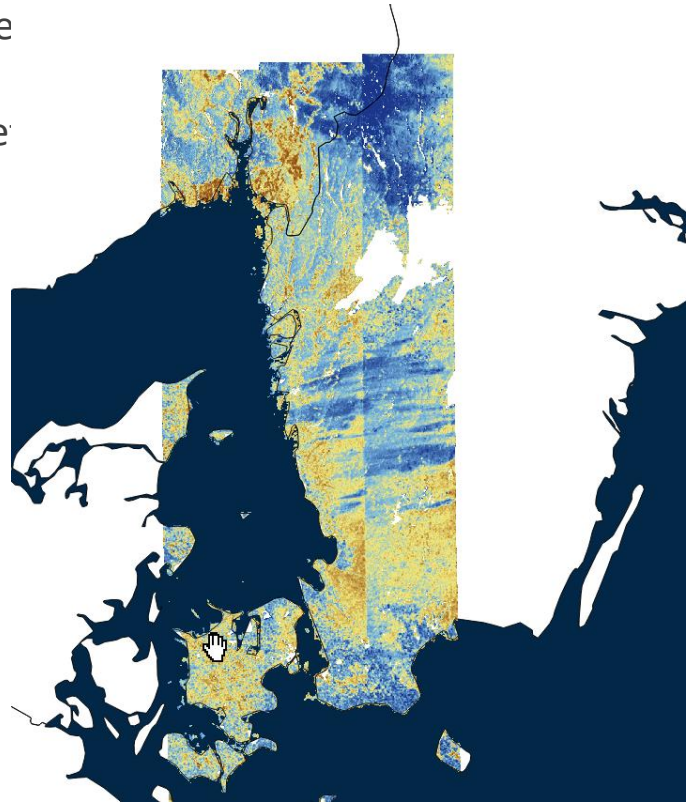


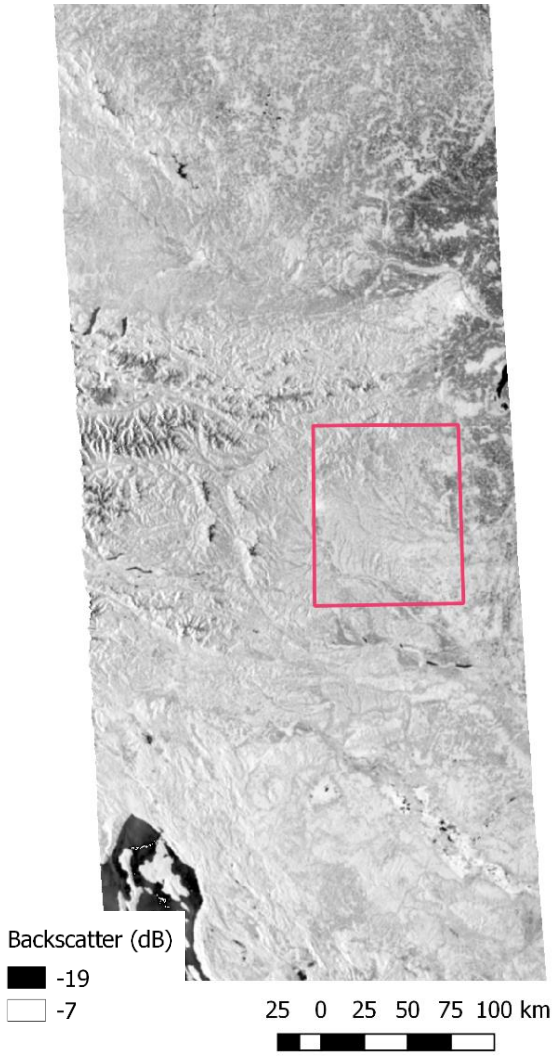
CORINE Land Cover

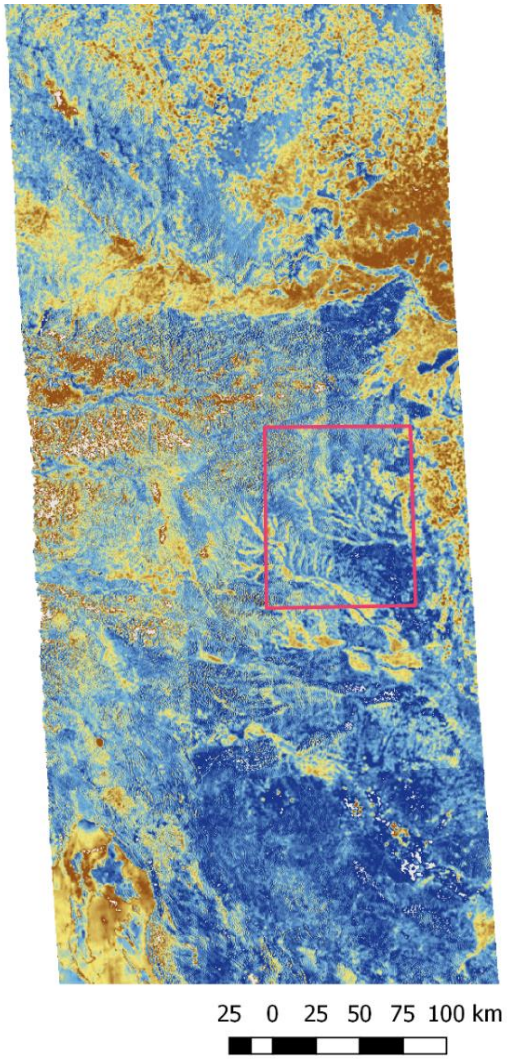


SSM1km: Subswath-Striping

- We see striping effects along sub-swath sections in SAR images.
  - bad calibration in raw Level1 data (GRD-images)
  - some orbits are more affected
  - problems tends to ge better
- Hardly be seen in backscatter, but SSM algorithm sensitive to this issue



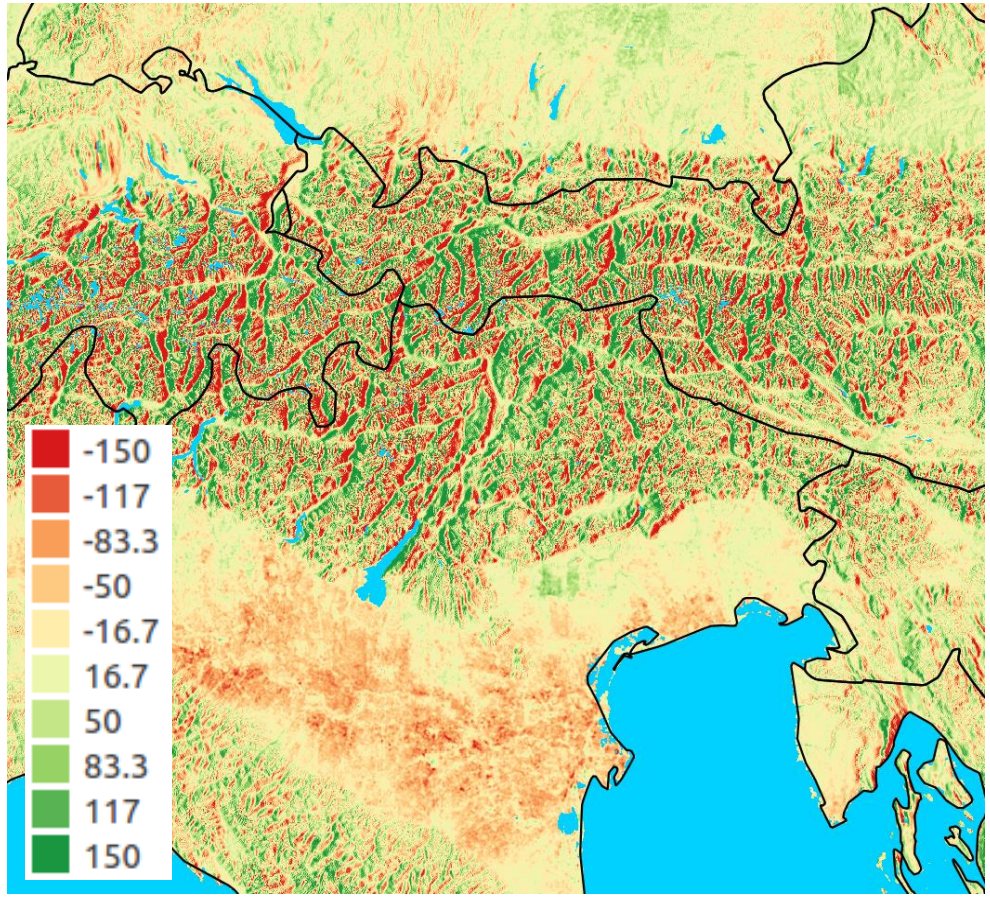


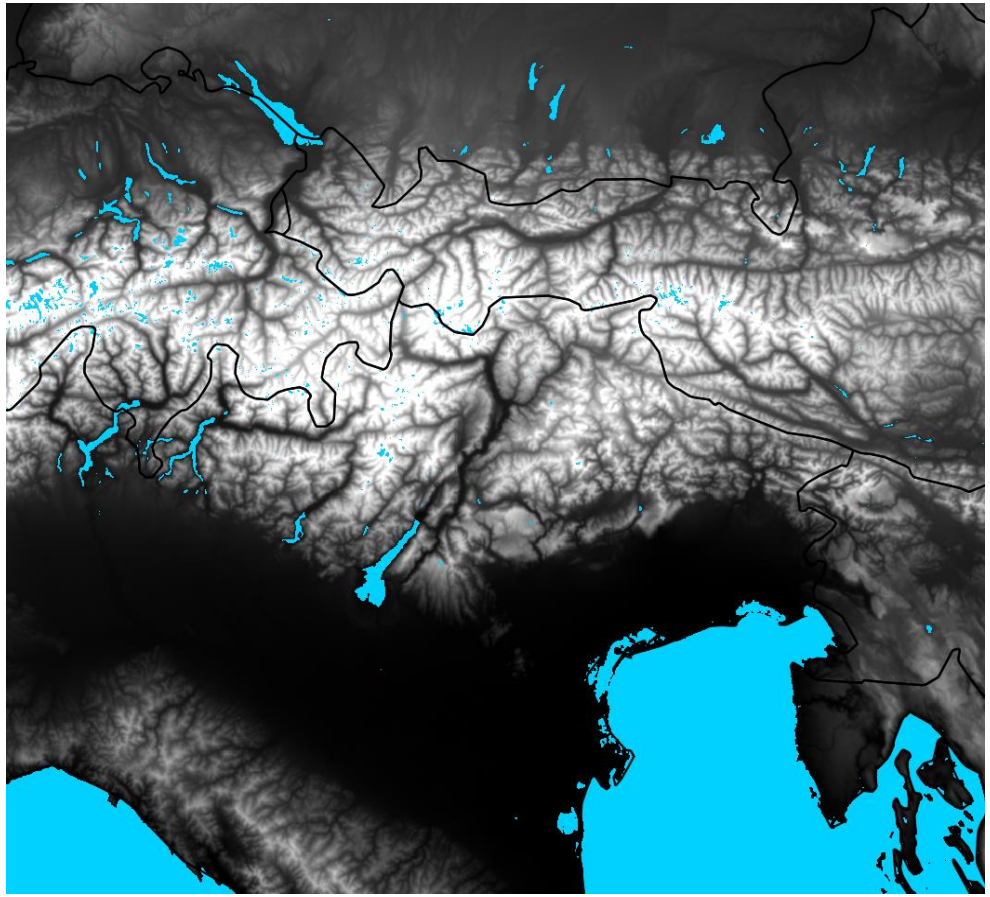


SSM1km: Azimuthal Biases

- Strong topography is challenging for SAR models…

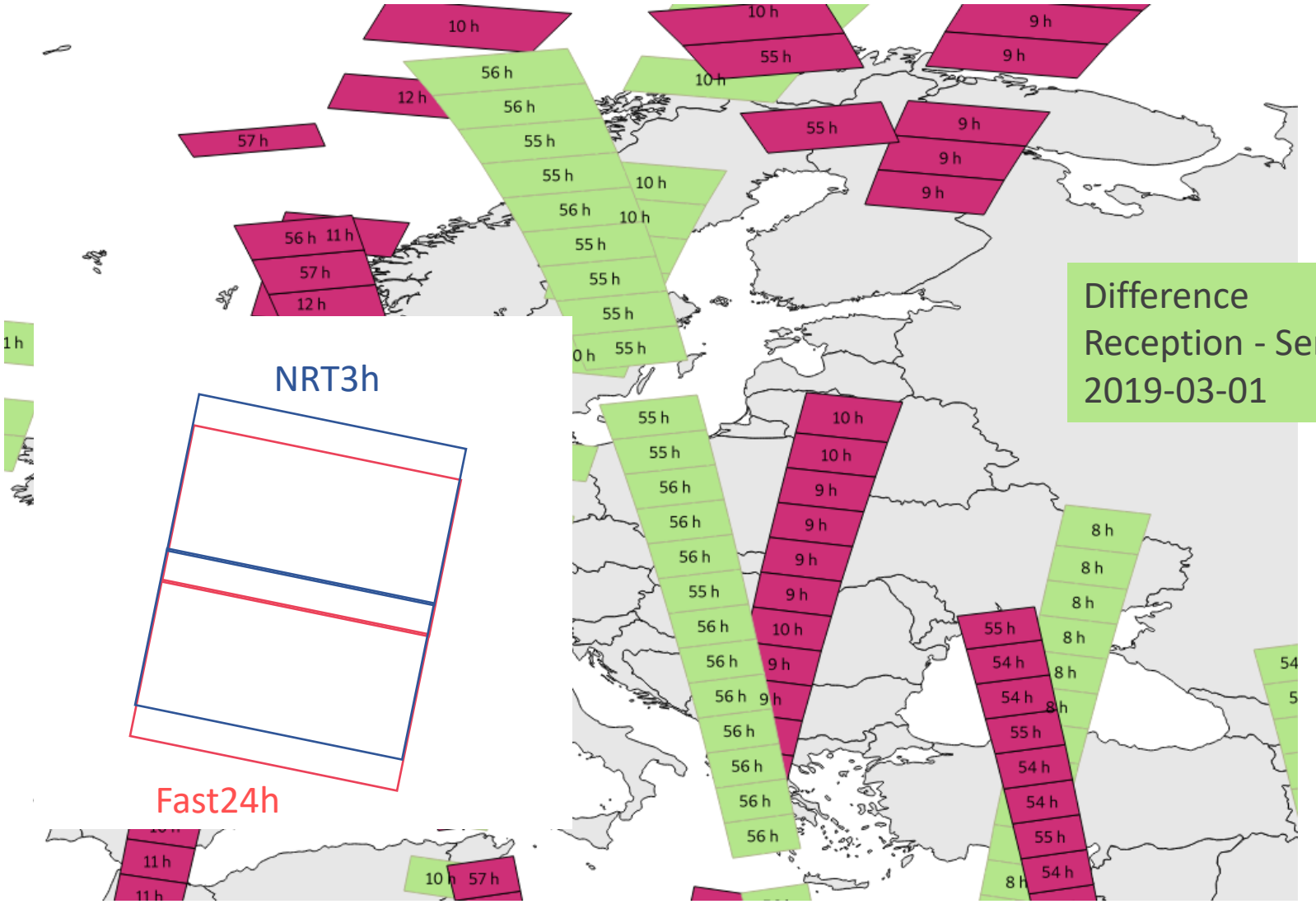
Mean S-1A Backscatter: Descending – Ascending





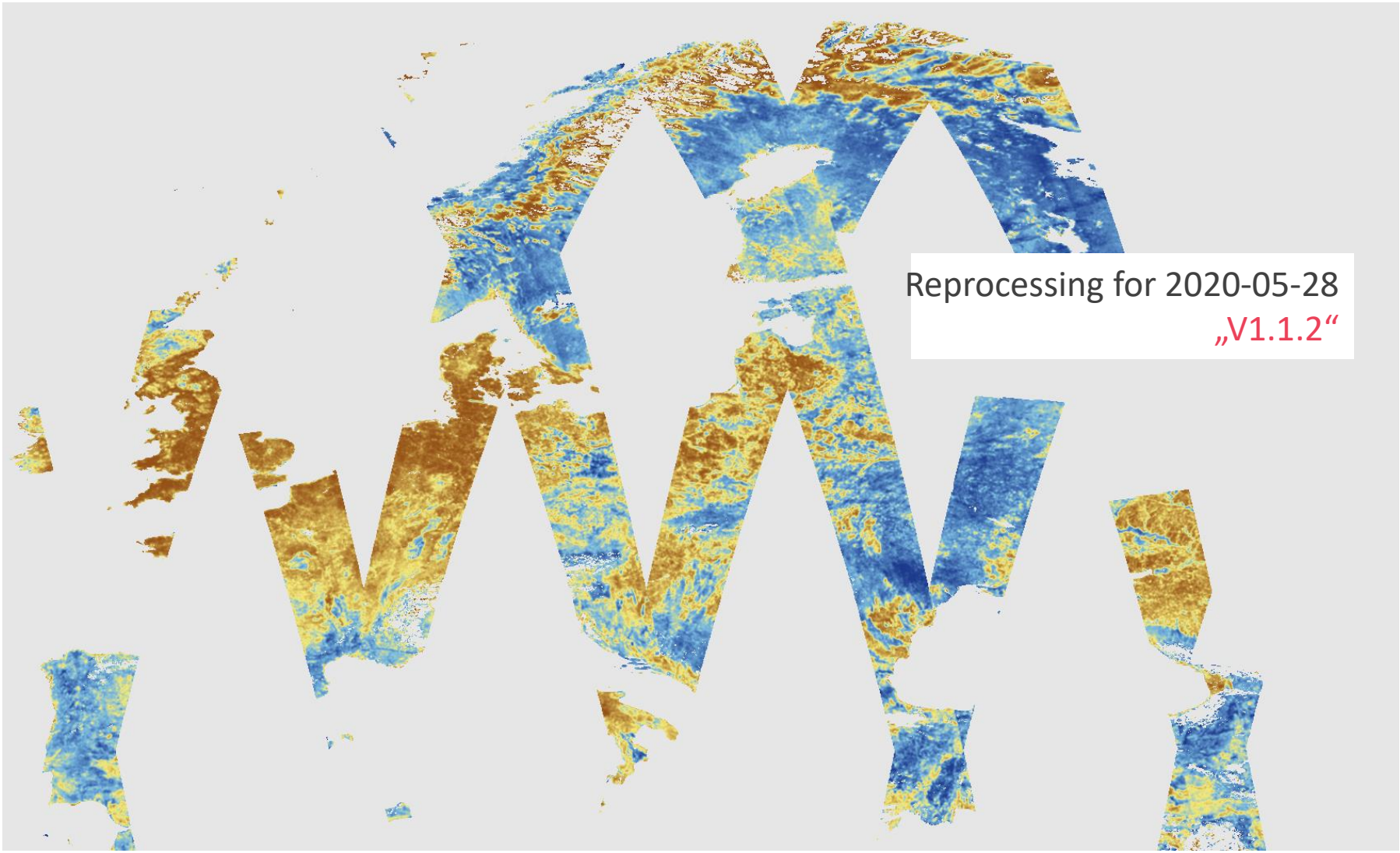
SSM1km: Data Gaps in NRT – Timeliness Issue

- Timeliness of S-1 IWGRD data showed some erratic behaviour
  - Different timeliness-categories, which (partially) overlap
    - *NRT3h (Europe + polar)*
    - *Fast24h (global)*
  - Getting unique data is complex
  - Troubling the building up of consistent data cube (reprocessing!)
  - NRT daily product: for time-being, we switched to 2-day-delay
- Problem appears to be improving, but needs further understanding
  - Right now: 5,5h delay between sensing and reception at EODC
  - Via EODC's "Hub-Watchter"
    - *collectin from multiple Hubs*



SSM1km: Data Gaps

- NRT product sometimes shows gaps
- → Reprocessing
  - different „Production Run Number“!



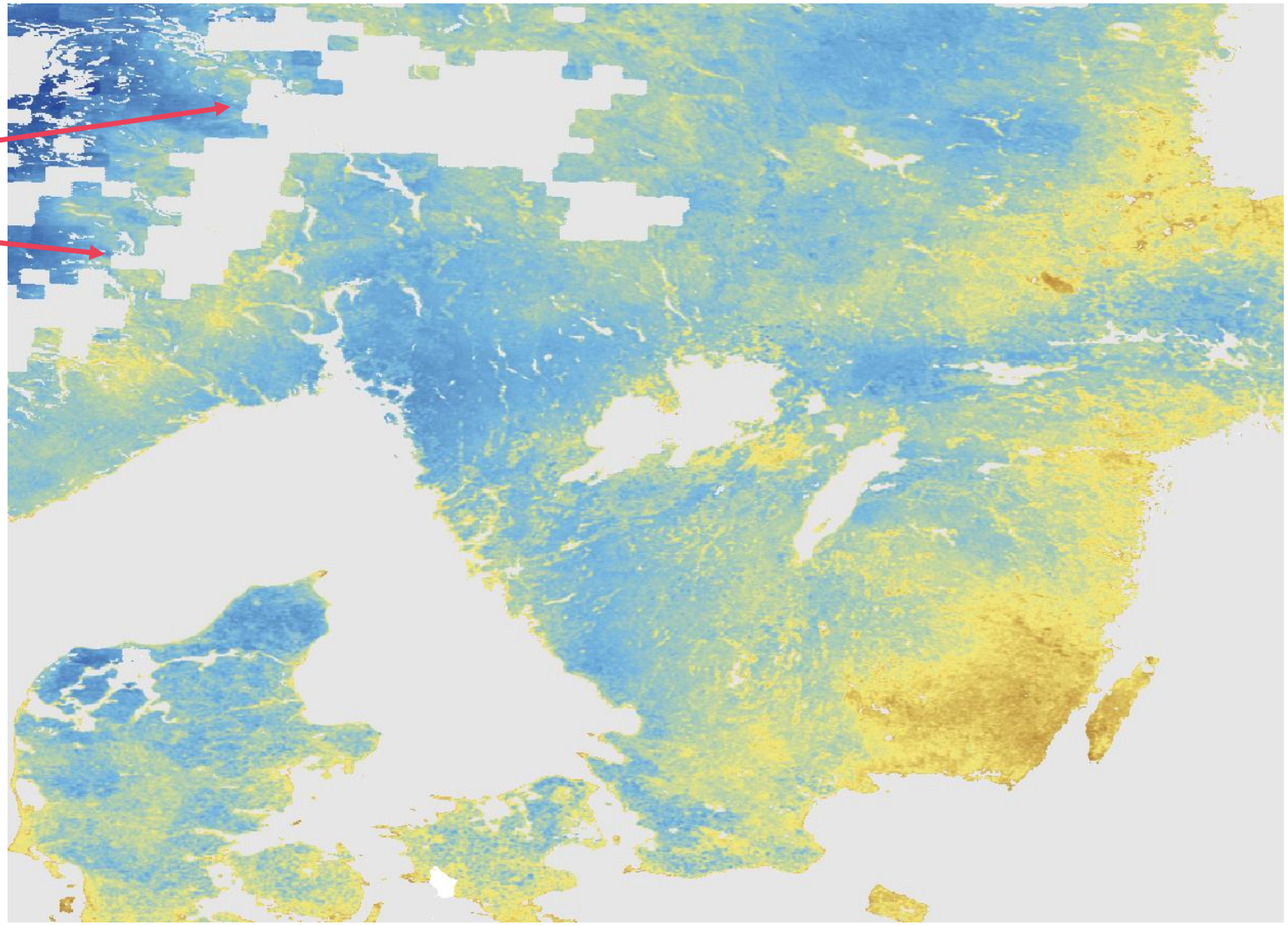
Conclusions on SSM1km

- Based adapted change detection algorithm (used for Envisat ASAR and Metop ASCAT)
- 1km product that exploits the high-resolution SAR signal
- no full daily coverage over operated areas
- **main deficit**: missing dynamic vegetation correction
  - wrongly attributing parts of „agricultural“ dynamics (plant stature, water content) to SM dynamics
    - we see biases during growing season
- but: in contrast to coarse-scale products: it captures effects from **small-scaled rainfall events** or **irrigation**
  - of course only when overpassed by orbit

SWI1km

SWI1km: SSF-Flagging

- Currently: freeze/thaw detection is done on 25km ASCAT grid
  - based on coarse radar signal
  - box-shaped SSF-mask



- → migrate the SSF-calculation to 1km-scale
- → include signals from NRT products on snow cover & soil temperatures
  - higher accuracy
  - more dependencies
- → include SFF also in SSM1km product

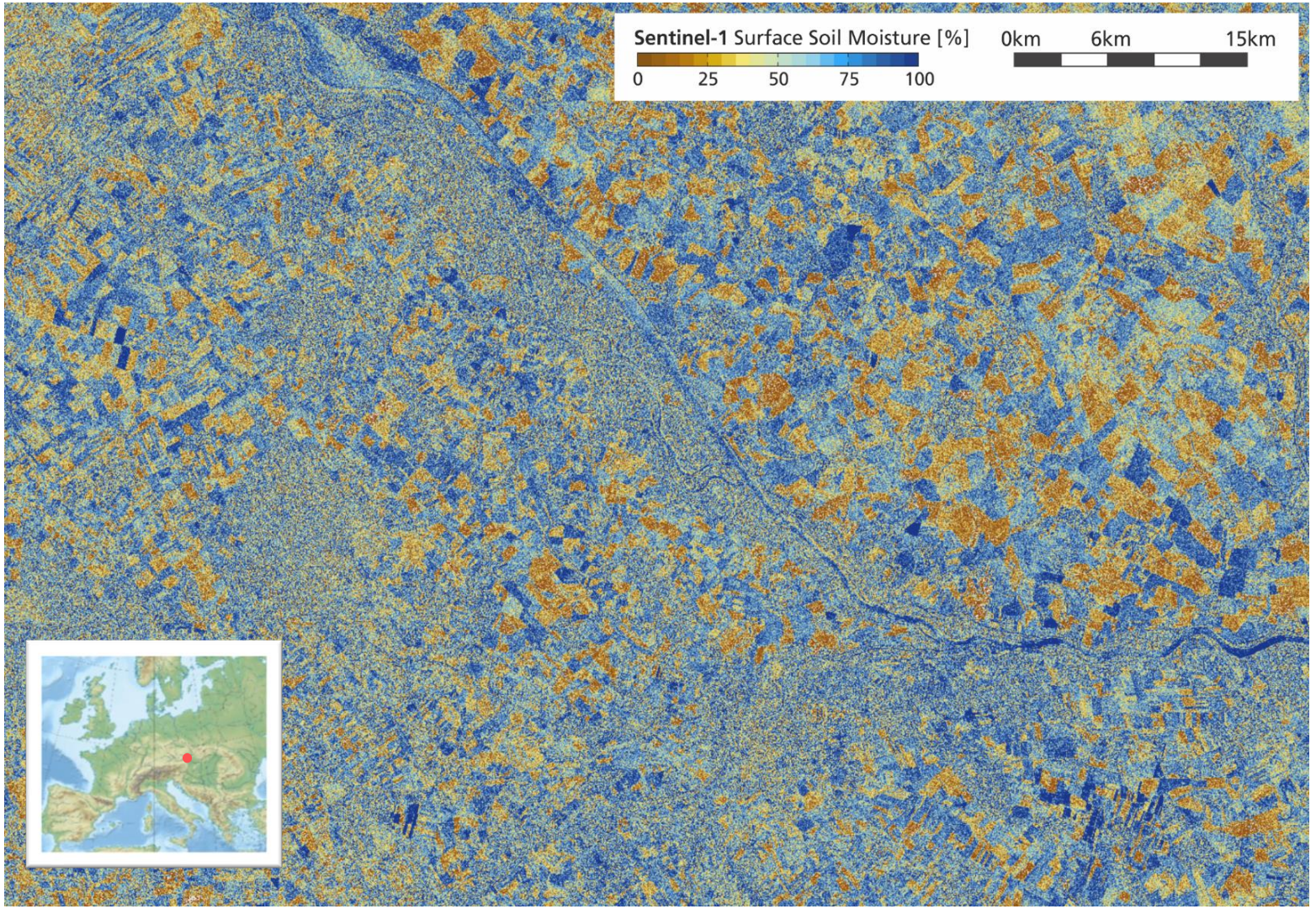
Conclusions on SWI1km

- uses the SWI-temporal-filtering approach → fusing a joint SSM history of two sensors
- **full daily coverage** over operated areas
- successfully integrates temporal dynamics of ASCAT & spatial patterns of Sentinel-1
  - good agreement with model data (and in-situ)
  - common caveats of ASCAT around coasts or cities are rectified through the SAR parametrisation
- at the current setup, SCATSAR-SWI1km temporal signal is dominated by SCAT
  - as ASCAT has a much higher observation frequency
  - → SAR signal is included only in an attenuated fashion
    - rainfall / irrigations signals are damped
- nevertheless: **rainfall estimates** via SM2RAIN already well reproduce ground observations

Additional Material

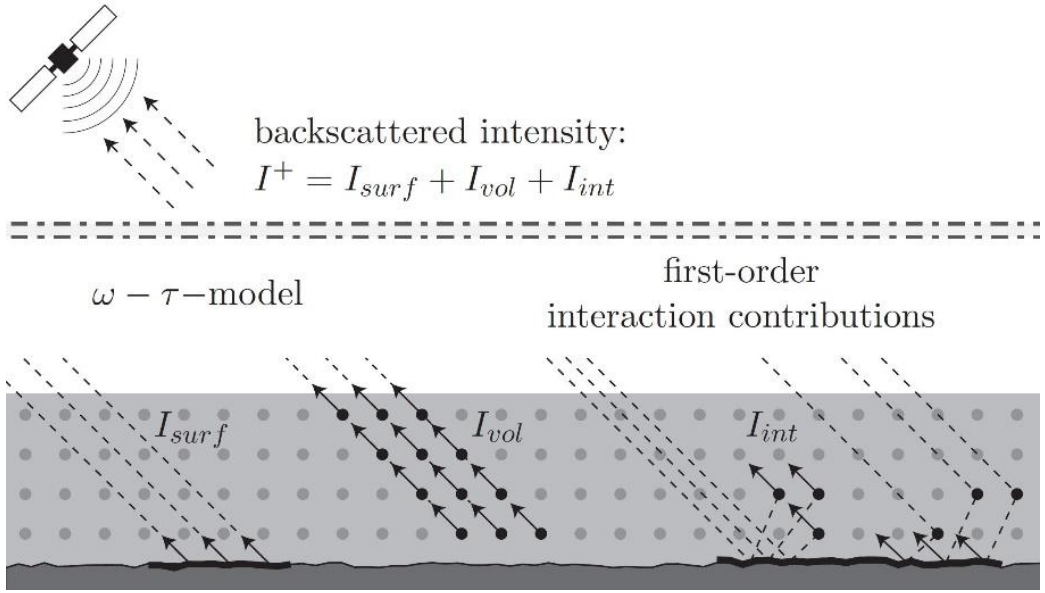
Sentinel-1 IW Mode: 20m SAR Image

- at field scale, SAR backscatter is sensitive to
  - vegetation
    - water content
    - crop row orientation
    - current geometry
    - size and density
    - wind bending?
  - soil
    - soil moisture
    - roughness
    - tillage
- very high complexity
  - **SAR-modelling at 20m is a tough job**
  - change detection models are not scalable



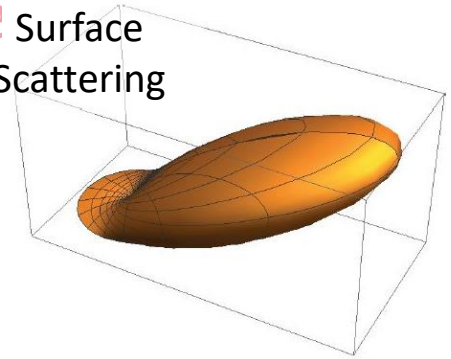
RT1: a New Theoretical Backscatter Model

- Radiative transfer theory
- Modelling of bi-static scattering
  - Mono-static backscatter as a special (simple) case
- Generalised phase functions for modelling surface-volume interactions
- Will become open source

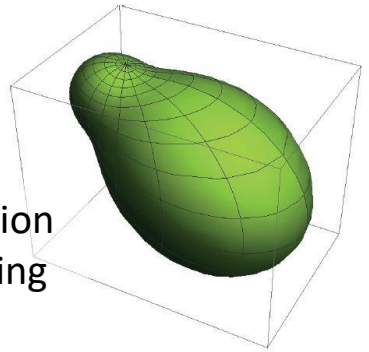


Exemplary Phase Functions for

Surface Scattering



Vegetation Scattering



Quast, R., W. Wagner (2016) An analytical solution for first-order scattering in bistatic radiative transfer interaction problems of layered media, Applied Optics, 55(20), 5379-5386.