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

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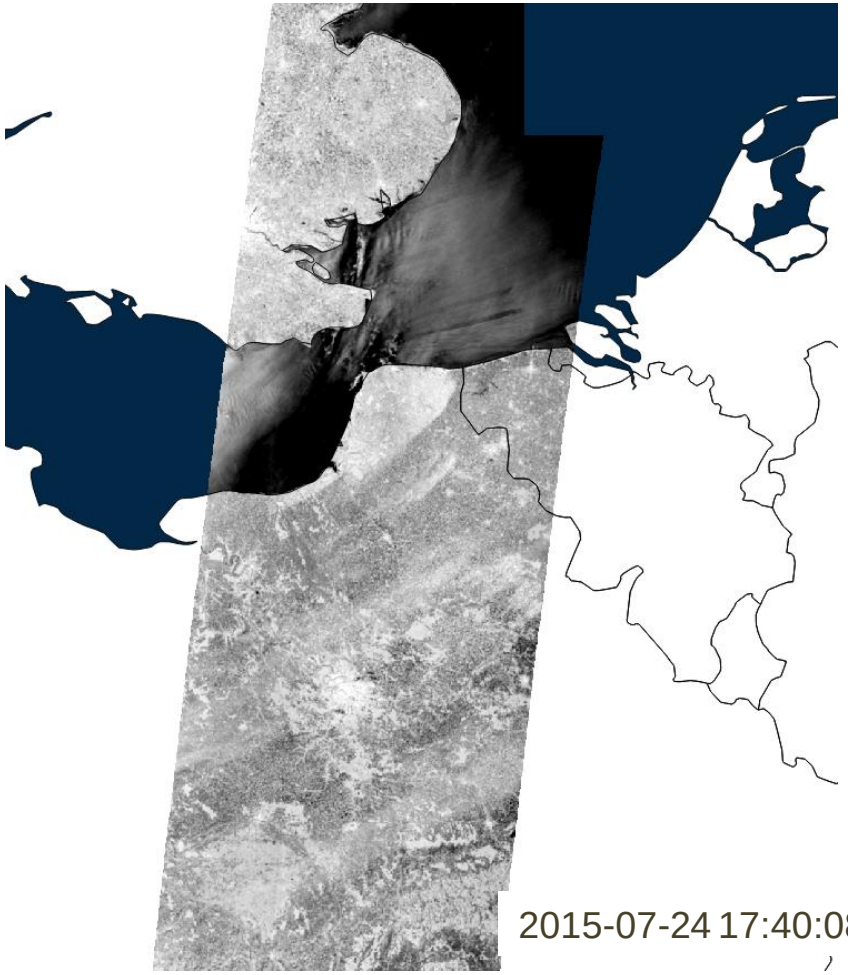
Soil Moisture @ Copernicus

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

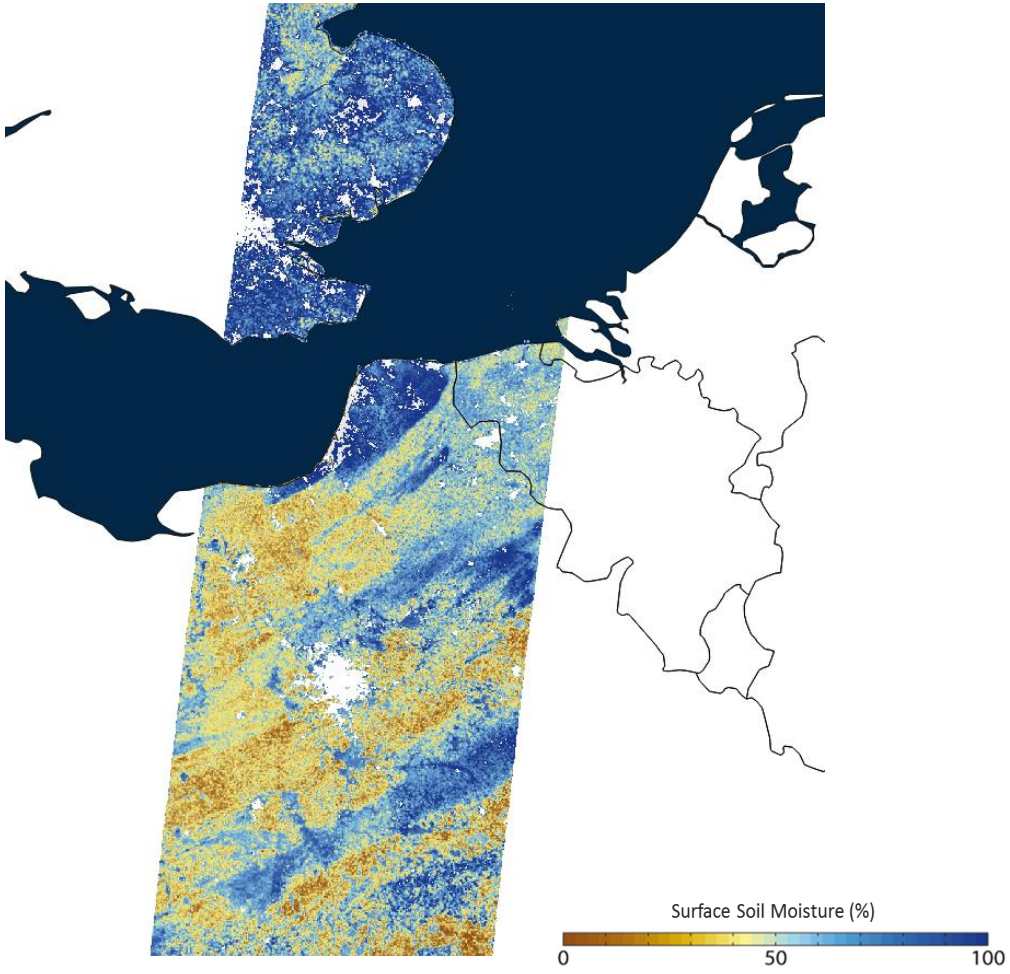
http://land.copernicus.eu/global/

Soil Moisture from Satellite Radar Sensors!?

Satellite Radar backscatter in dB



Soil Moisture in %



Overview

1. Physical Basis for Soil Moisture Remote Sensing
2. Current SM Products in Copernicus – example Droughts observed
3. Access & Usage
4. CGLS Data
5. New SM Products in Copernicus – 1km

Physical Basis

Soil Moisture

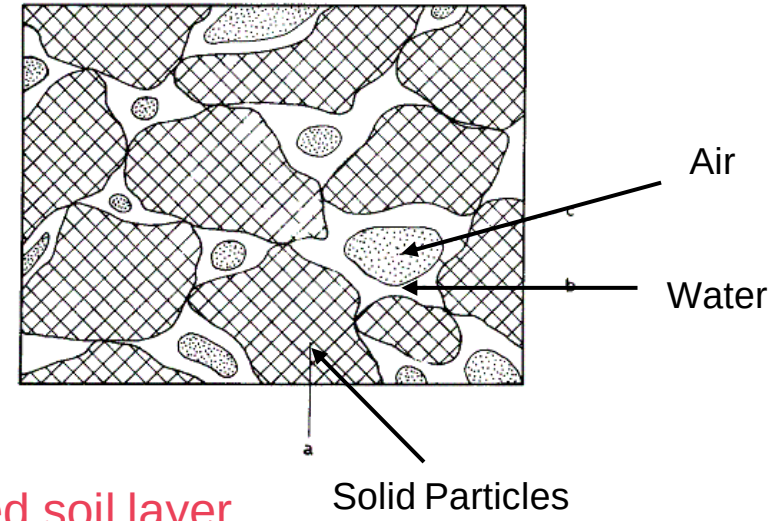
- Definition, e.g.

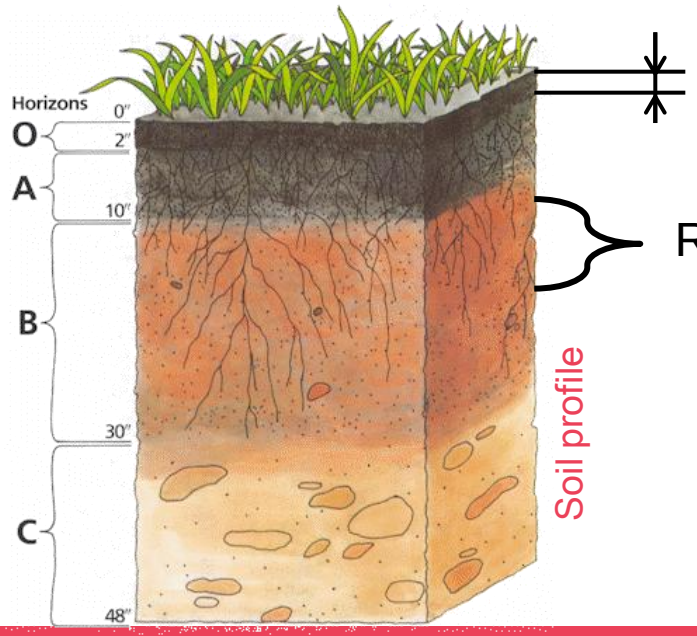
$$\theta = \frac{\text{Water Volume } (\text{m}^3)}{\text{Total Volume } (\text{m}^3)}$$

- Average

$$\langle \theta \rangle = \frac{1}{Area \cdot Depth} \int_{Area} \int_{Depth} \theta(x, y, z) dz dx dy$$

Cross-section of a soil





Thin, remotely sensed soil layer

Root zone: layer of interest for most applications

Approaches to Remote Sensing of Soil Moisture

- Remote sensing - measurement principles
  - No direct measurement of soil moisture possible, only indirect techniques
  - BUT: strengths of remote sensing: extensive & global & repeating & cheap observations

- Optical to Mid-Infrared (0.4 – 3 μm)
  - Change of "colour"
  - Water absorption bands at 1.4, 1.9 and 2.7 μm

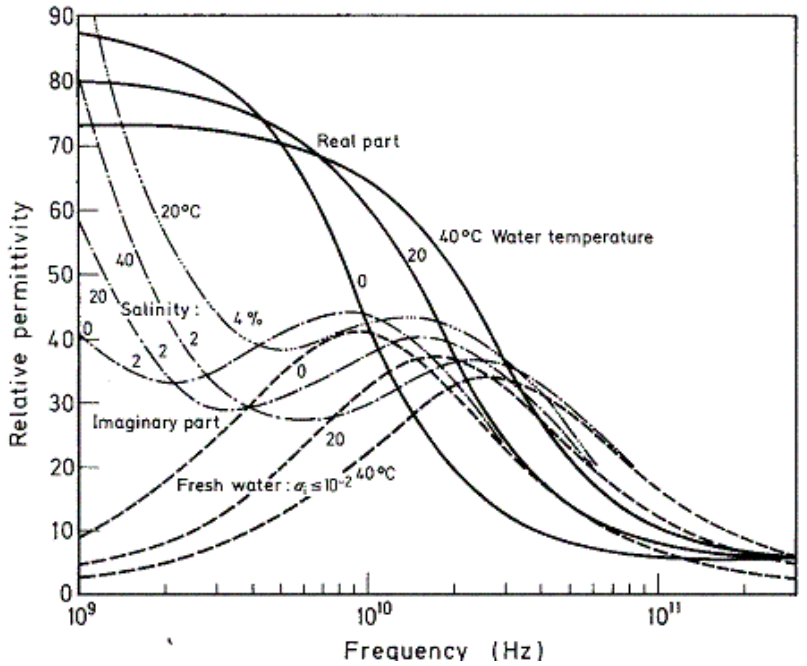
- Thermal Infrared (7-15 μm)
  - Indirect assessment of soil moisture through its effect on the surface energy balance (temperature, thermal inertia, etc.)

- Microwaves (1 mm – 1 m)
  - Change of dielectric properties

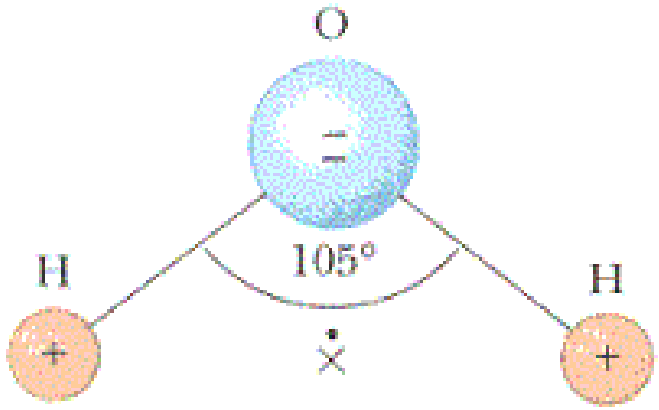
Microwave Satellites used for Soil Moisture Retrieval

Microwaves and 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*



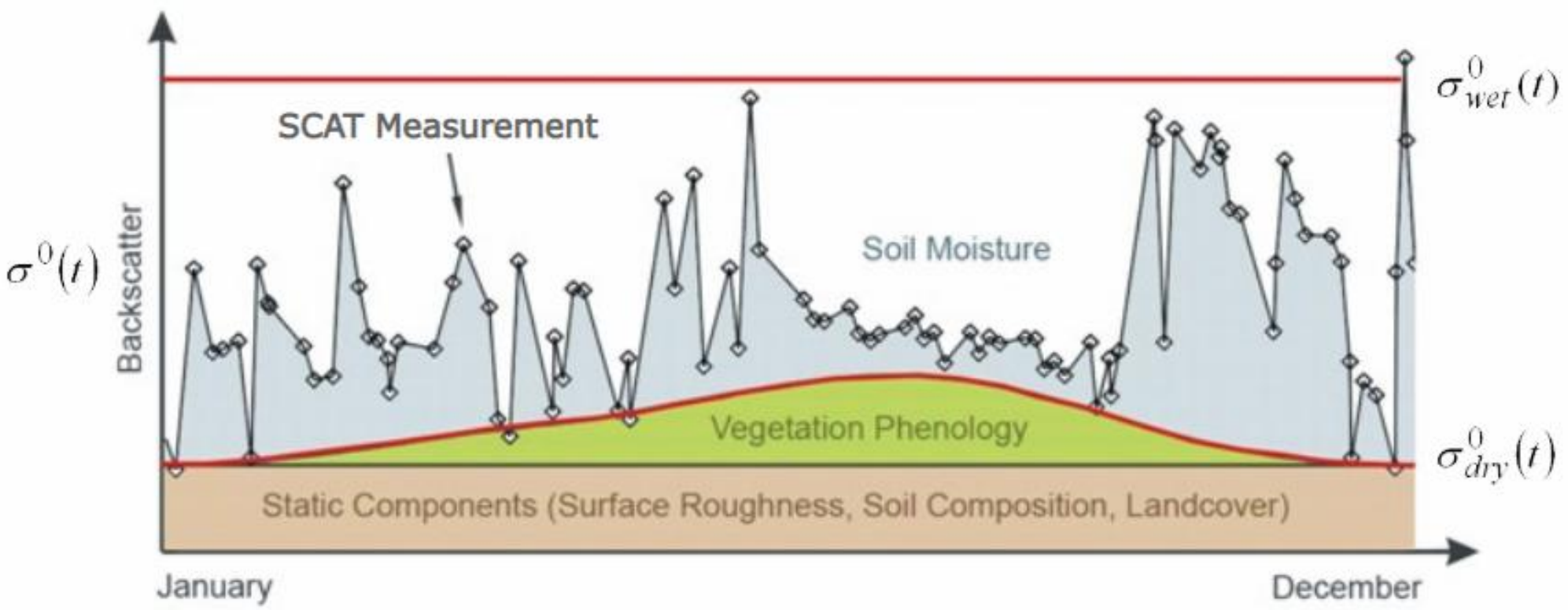
Dielectric constant of water



The dipole moment of water molecules causes “orientational polarisation”, i.e. a high dielectric constant

SM Retrieval Model

- Change Detection: attribute changes in backscatter to changes in soil moisture
  - ~linear relationship
  - no auxilliary data required in the model

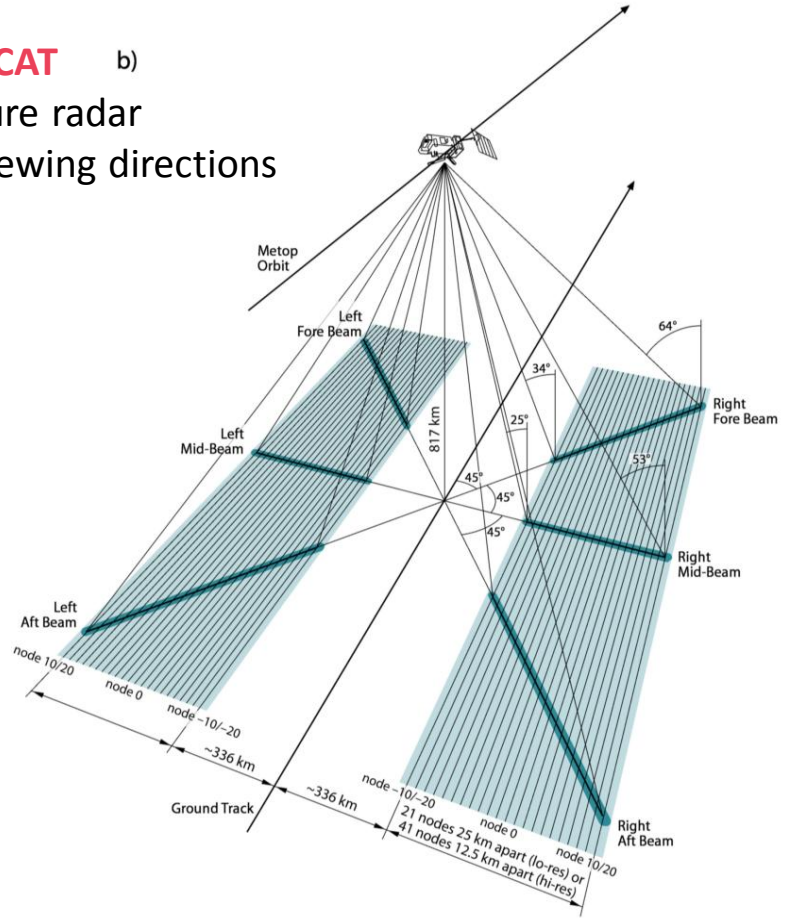


Measurement Concept

- Side-looking radars measuring the backscatter coefficient σ^0 [dB]

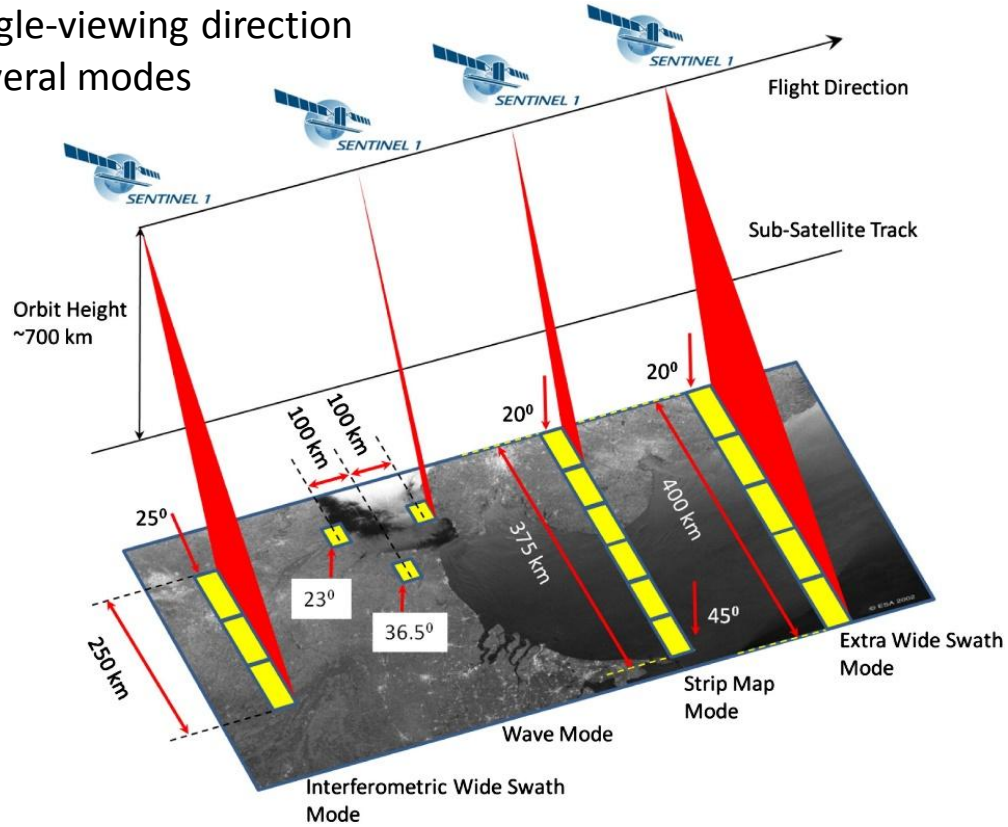
METOP ASCAT

Real aperture radar
Multiple-viewing directions
One mode



Sentinel-1 SAR

Synthetic aperture radar
Single-viewing direction
Several modes



Current SM Products @ Copernicus

ASCAT Soil Water Index

Soil Moisture products in Copernicus - 12.5km Soil Moisture

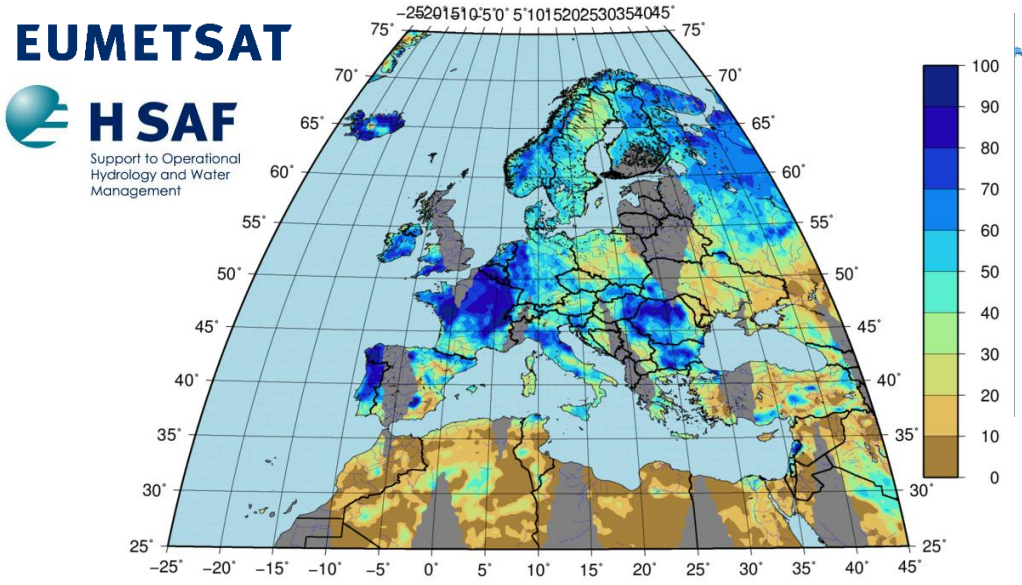
- **SWI V3 product** (Operational Status)
  - for **basic users** in hydrology and agriculture with **large-scaled scope**
  - well evaluated and stable performance
  - daily, on a 0.1° grid SWI V3 product (~12.5km)
  - recently: migrate from HDF5 to netCDF4 format
- **SWI10 product** (Operational Status)
  - 10 day average SWI product- **compatible to other decadal products**
  - Same format and grid as SWI V3 version
  - recently: migrate from HDF5 to netCDF4 format
- **SWI TS product** (quasi Operational Status)
  - 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)
  - in netCDF4
  - version will be renamed to V3.1.x in order to be consistent with daily SWI.

- **SWI-Static Layers**
  - masking regions where SWI retrieval is difficult or not possible
  - new in 2018: Correlation Information (CI) Layers
    - » describing agreement with reanalysis model

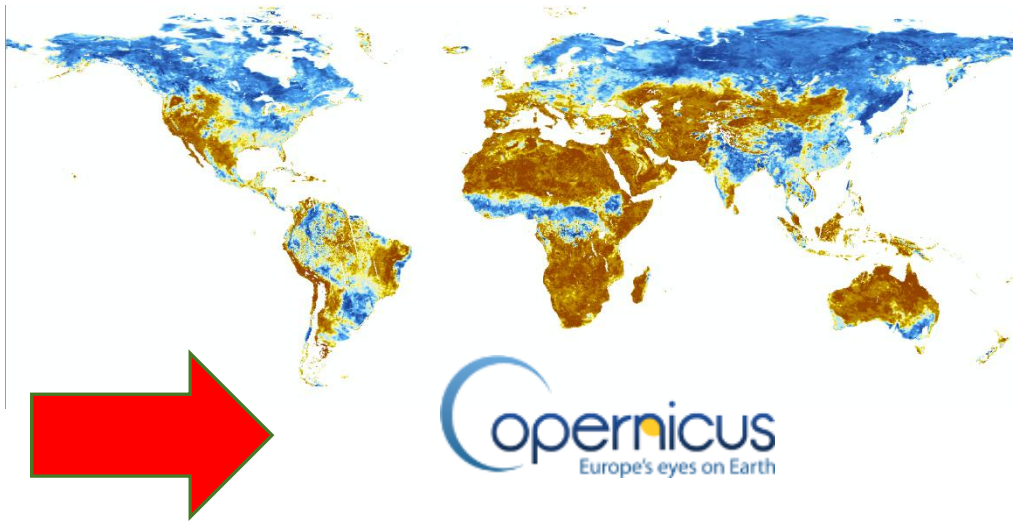
ASCAT Soil Water Index (SWI)

- since 2007
- 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

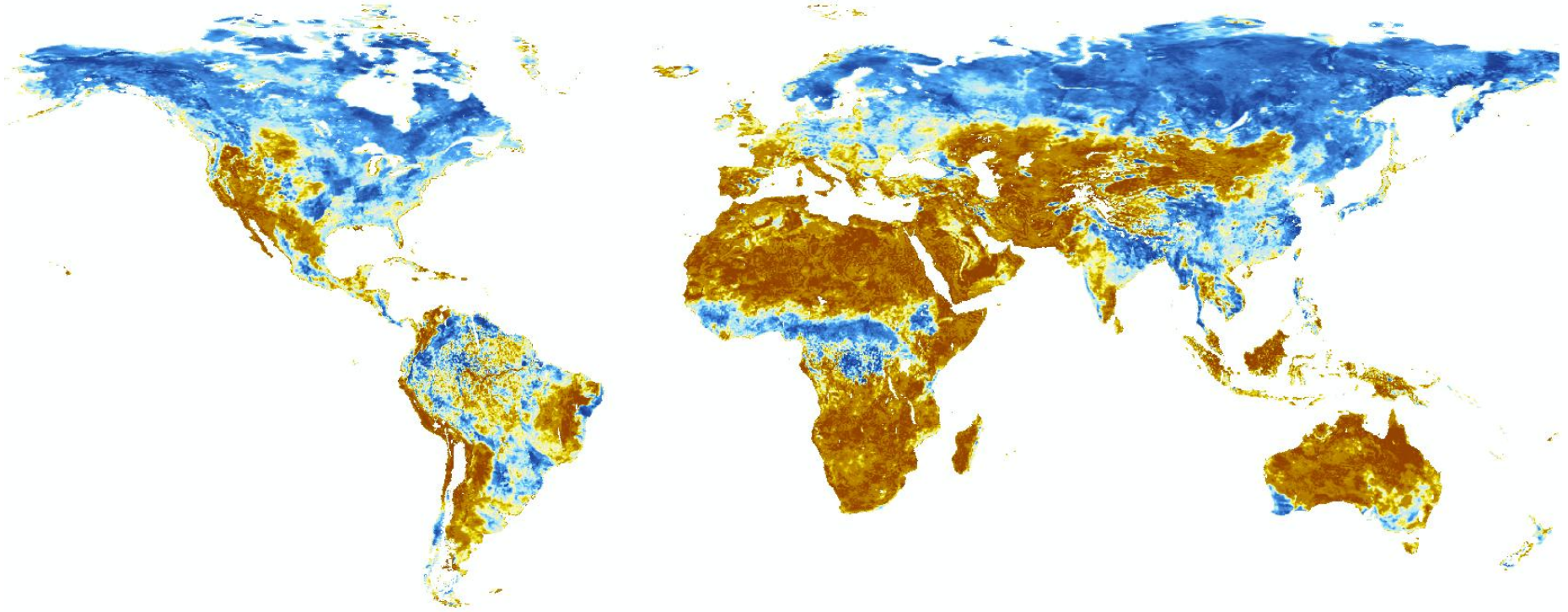


Copernicus SWI V3 product



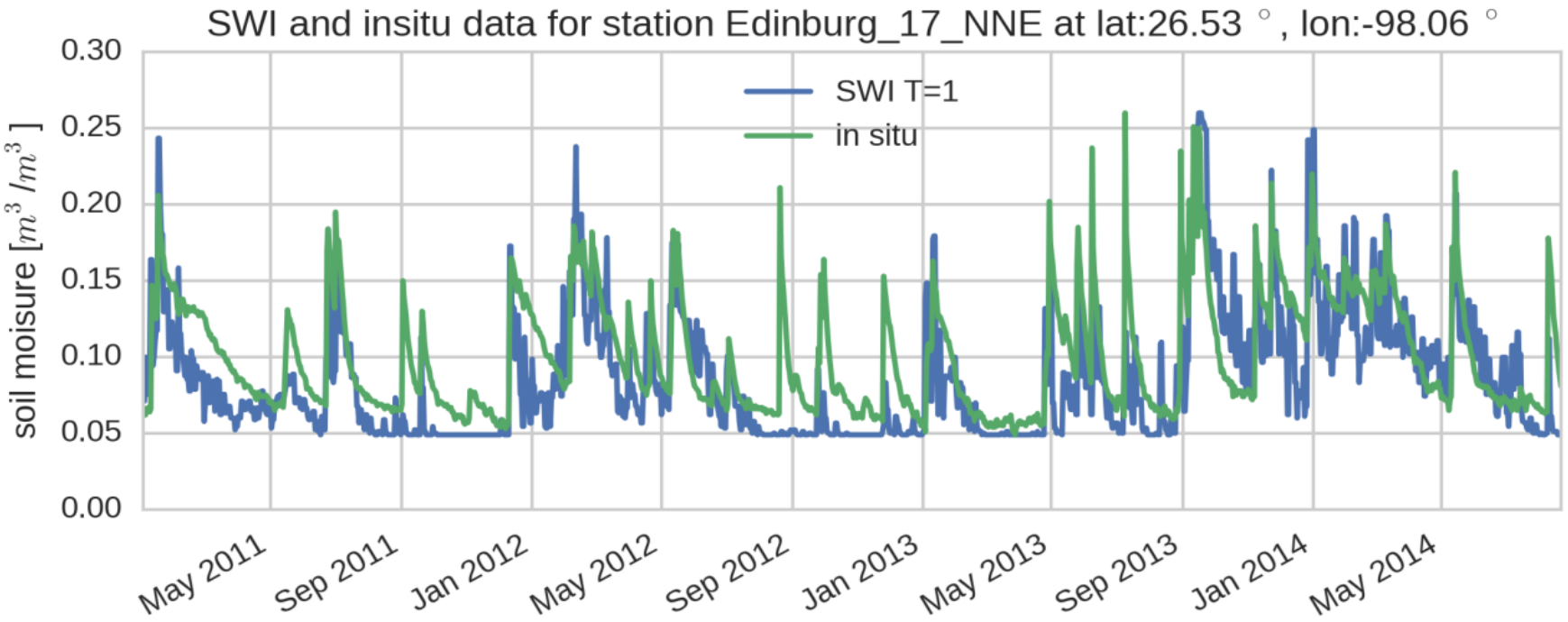
SWI V3 product

- 8 depth layers (T-values), including quality information (=quality flag)
- Freeze/Thaw layer for masking frozen conditions (=surface state flag)
- planned: migrate from HDF5 to netCDF4 format
- daily, on a 0.1° grid



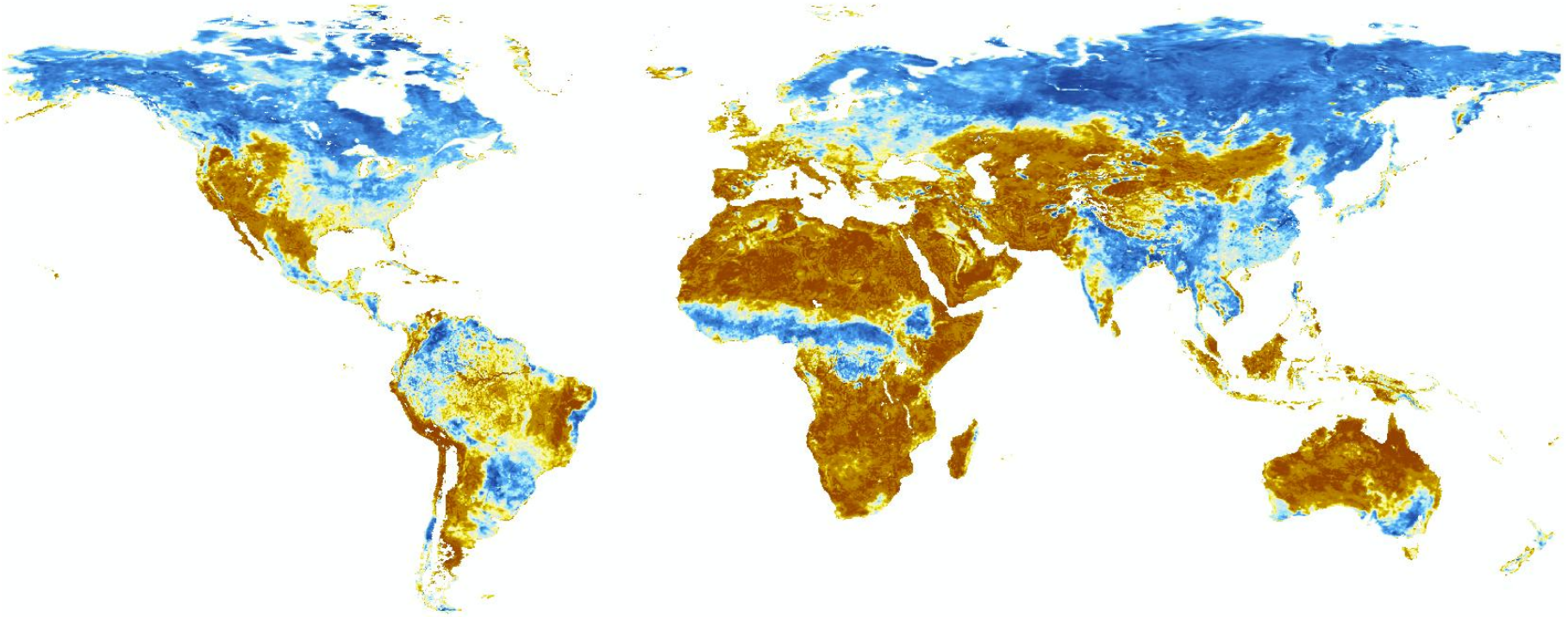
SWI TS product

- Provides data in time-series-optimized format
  - On a discrete global grid (point-wise)
  - Product for advanced users doing time series analysis



SWI 10 product

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



SWI Product use cases – past drought in central America

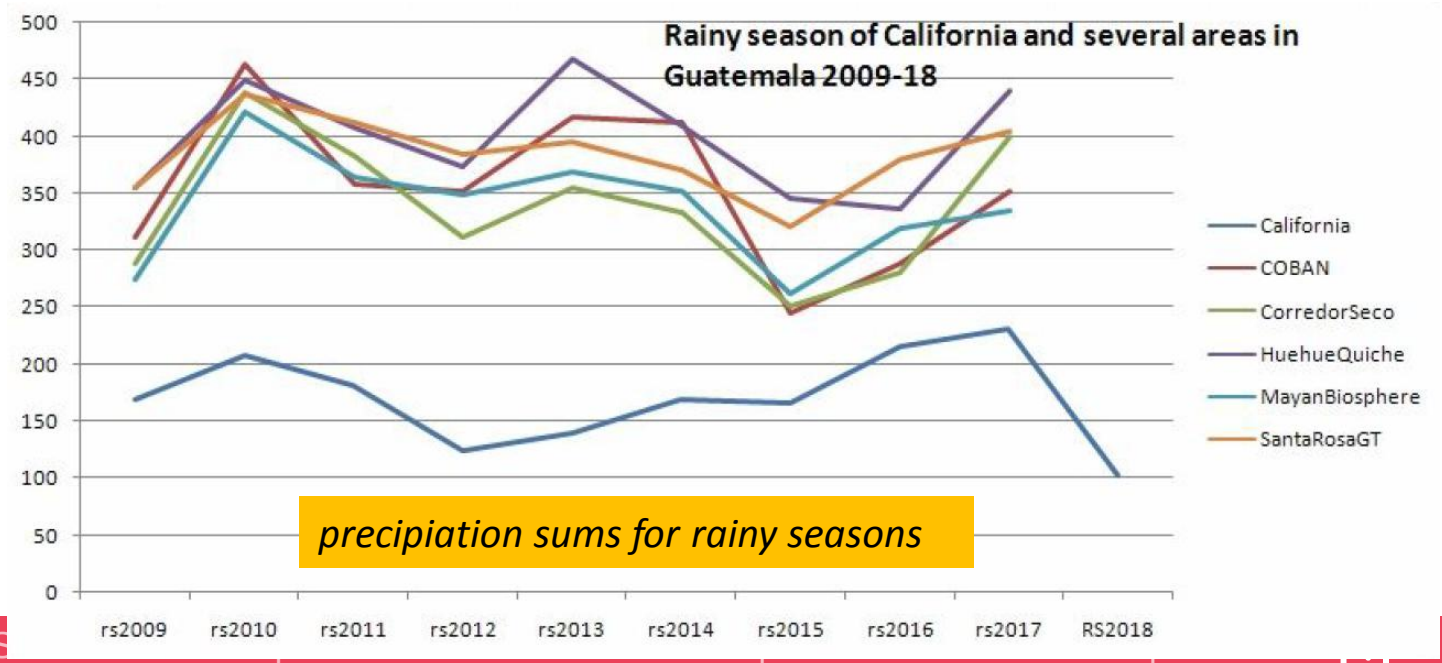
- Assessment of Drought Damage to agriculture in Guatemala, El Salvador, Honduras and Nicaragua

Coffee rust after water scarcity

Fernando Roque

https://metricst.info/

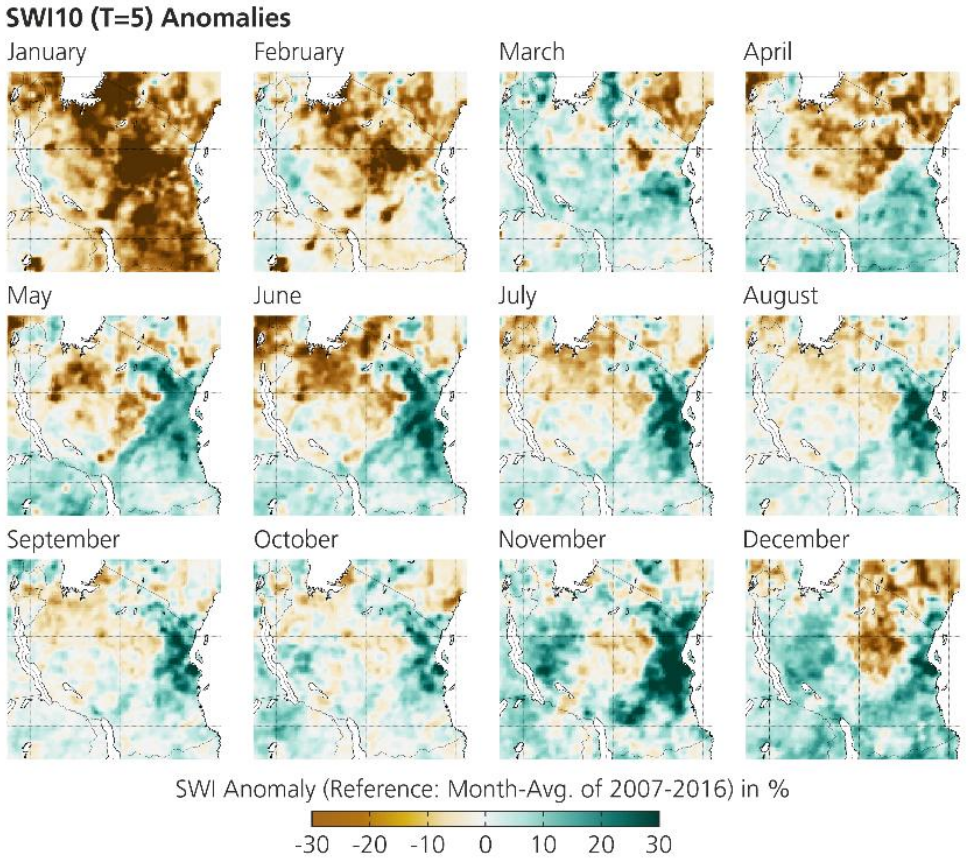
- Local Researchers found evidencein the SWI10 for the drought crisis 2014-16 in Central America („Mayan Biosphere“)
- Weak rainy seasons caused damage to maize, beans and coffee cultures

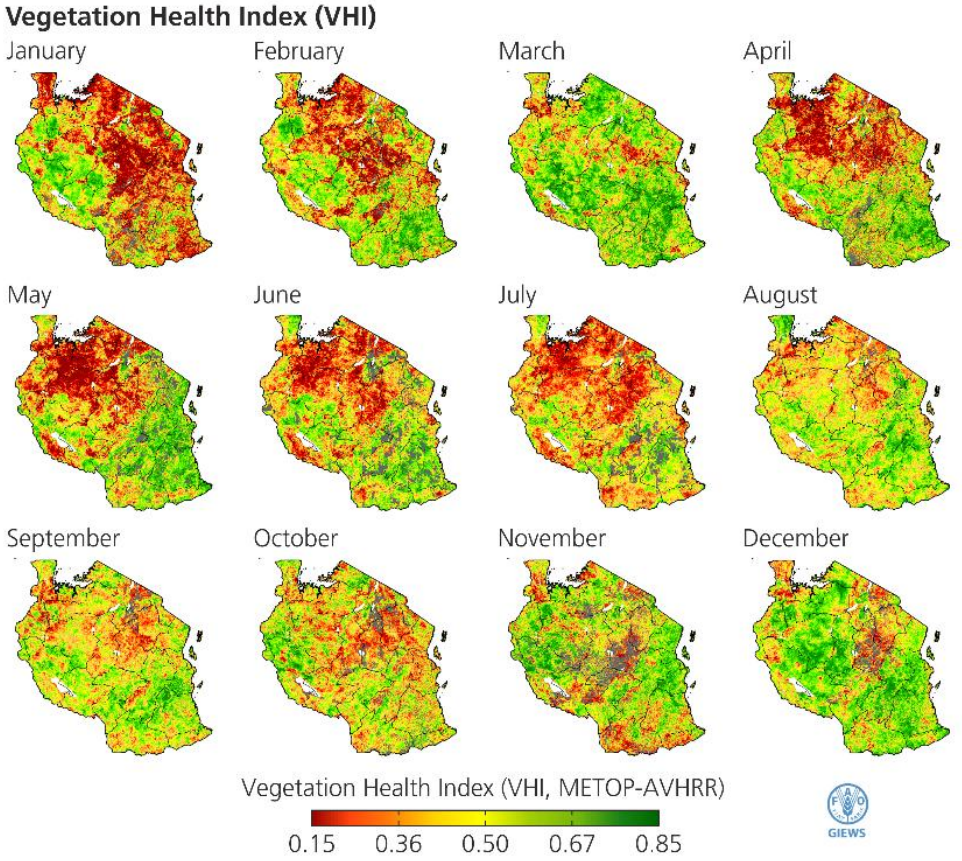


ASCAT SWI sees 2017 drought in East Africa

- Regional analysis for 2017 on ongoing drought East Africa
  - Good qualitative agreement with Vegetation Health Index over Uganda, Tanzania, Kenya, and over large parts of Somalia and Ethiopia + California

Tanzania





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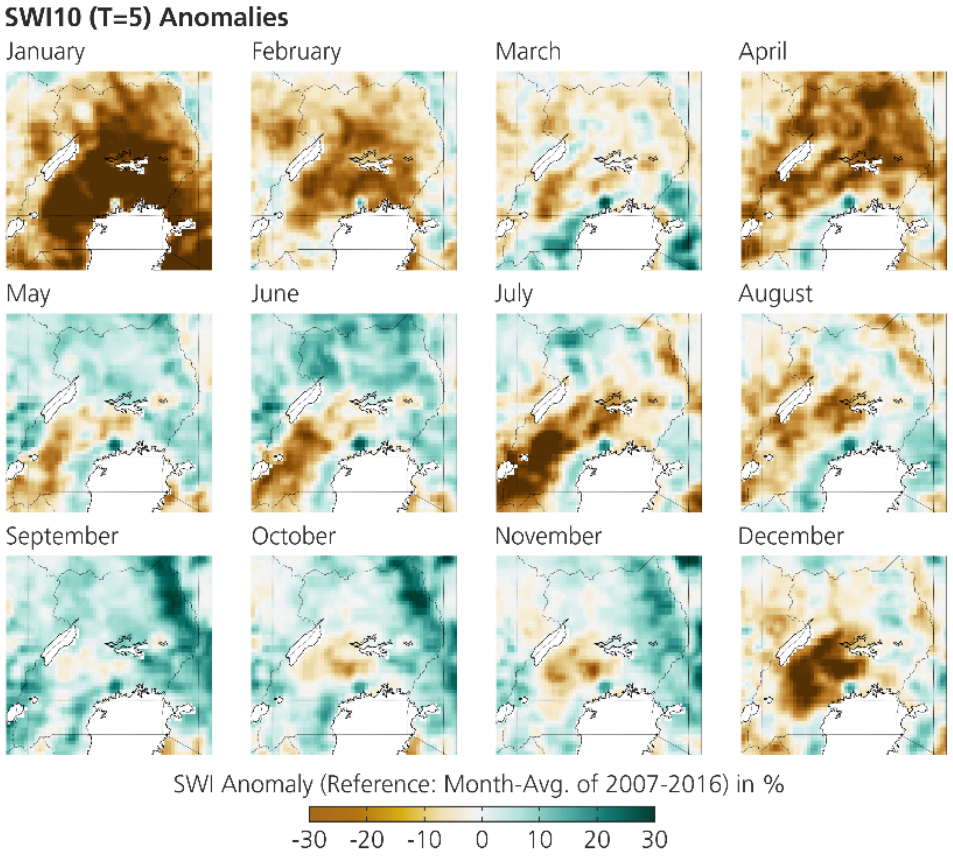
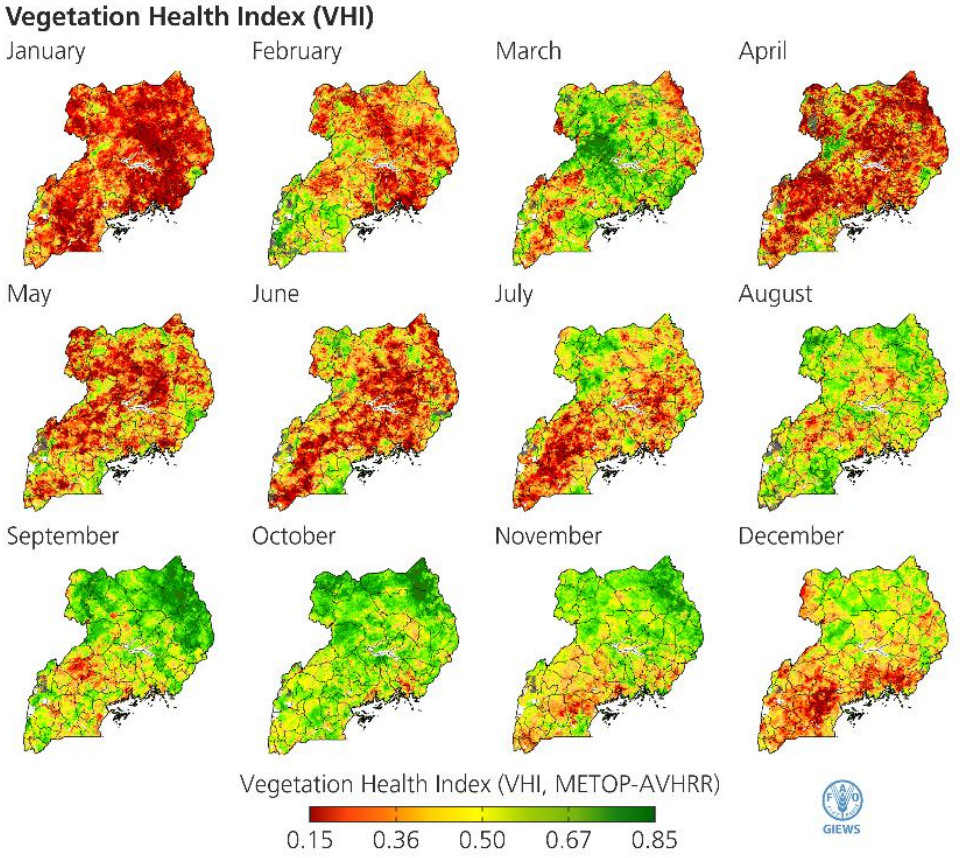
Uganda

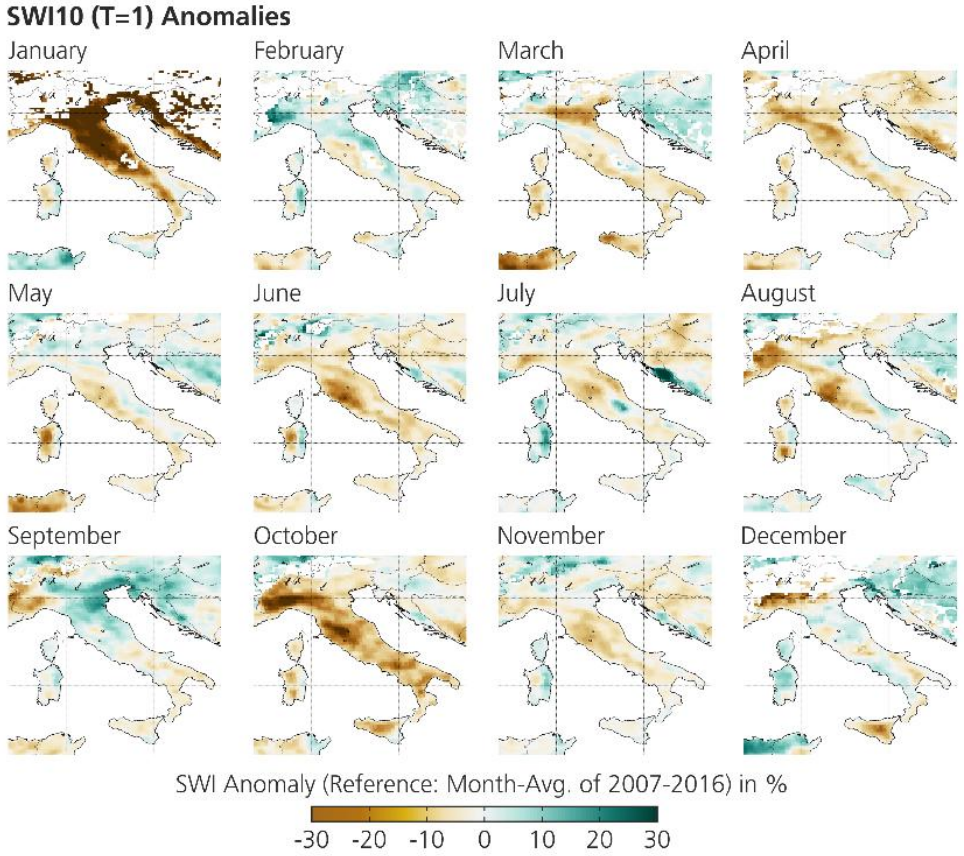


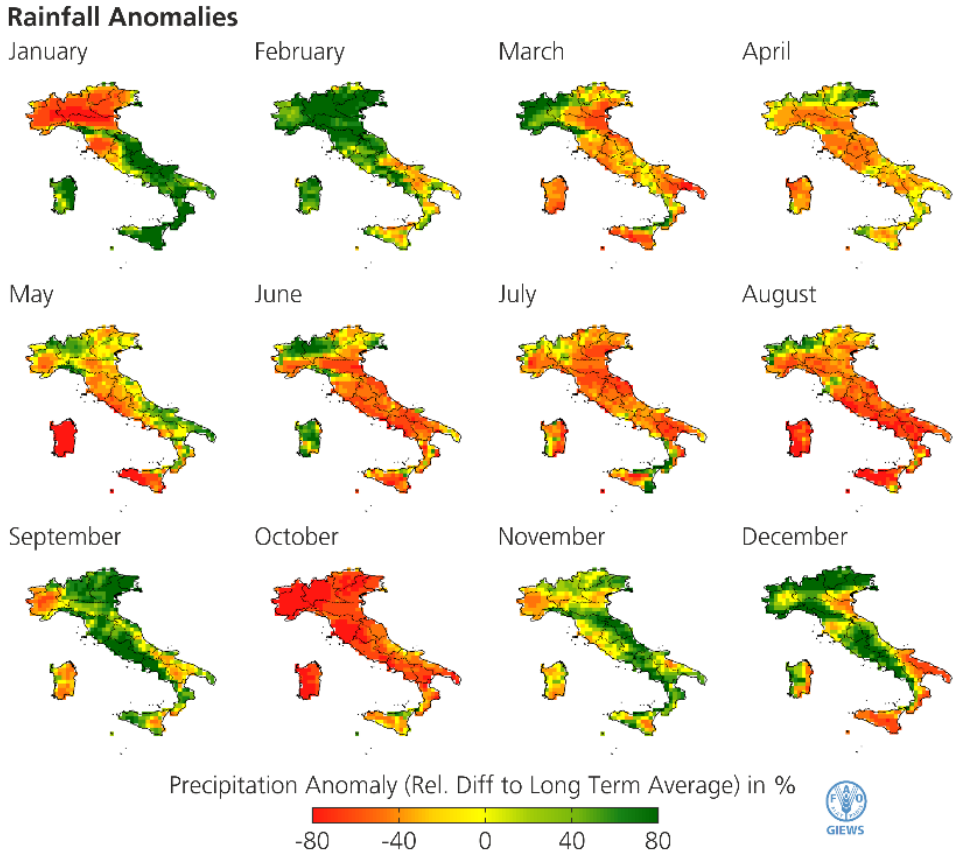


ASCAT SWI sees 2017 dry spell in Italy

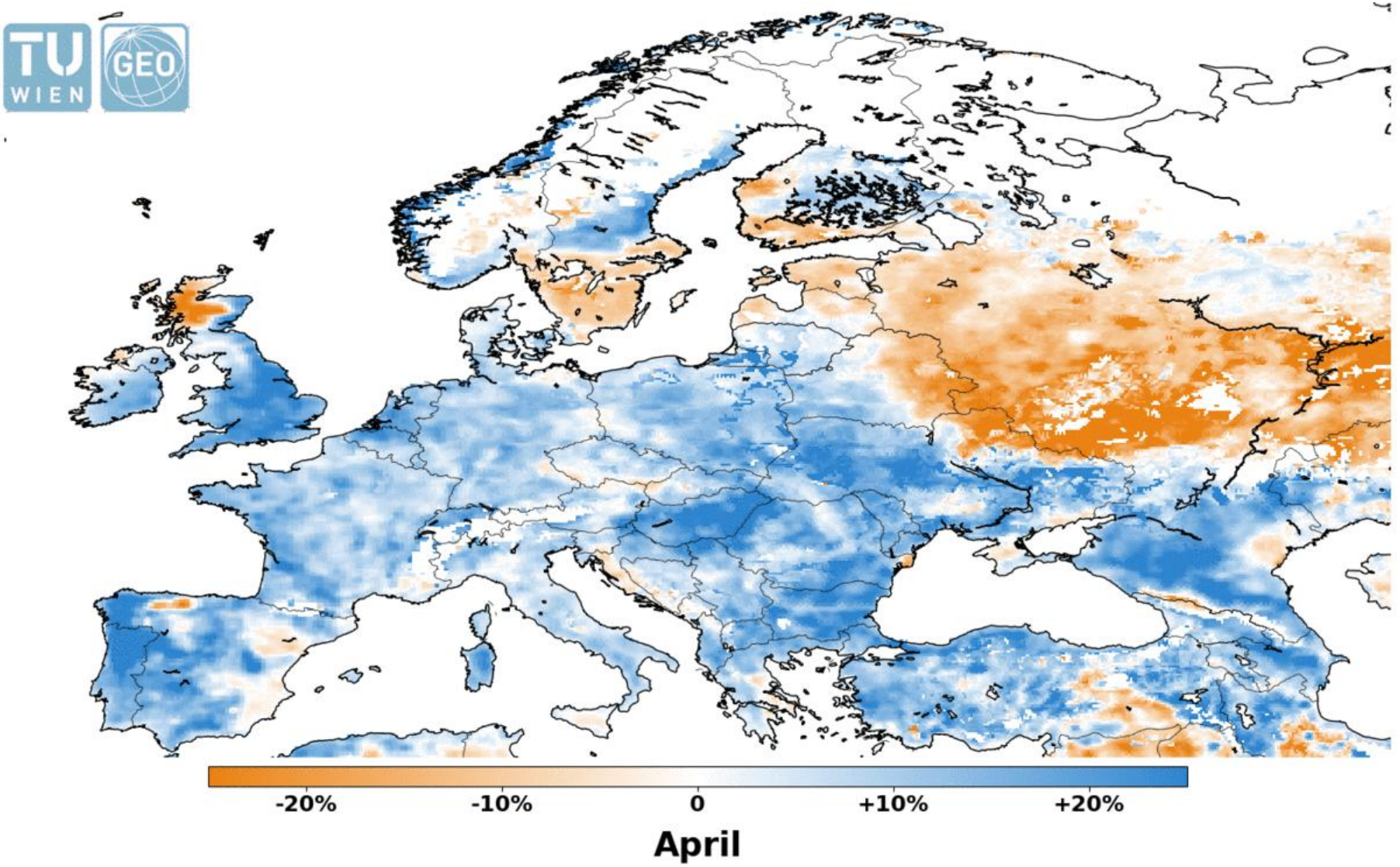
- Regional analysis on dryness over Italy in 2017
  - Also good qualitative agreement with rainfall anomalies during summer and fall - but also with discrepancies

Italy





ASCAT-SWI: 2018 Anomalies in Europe

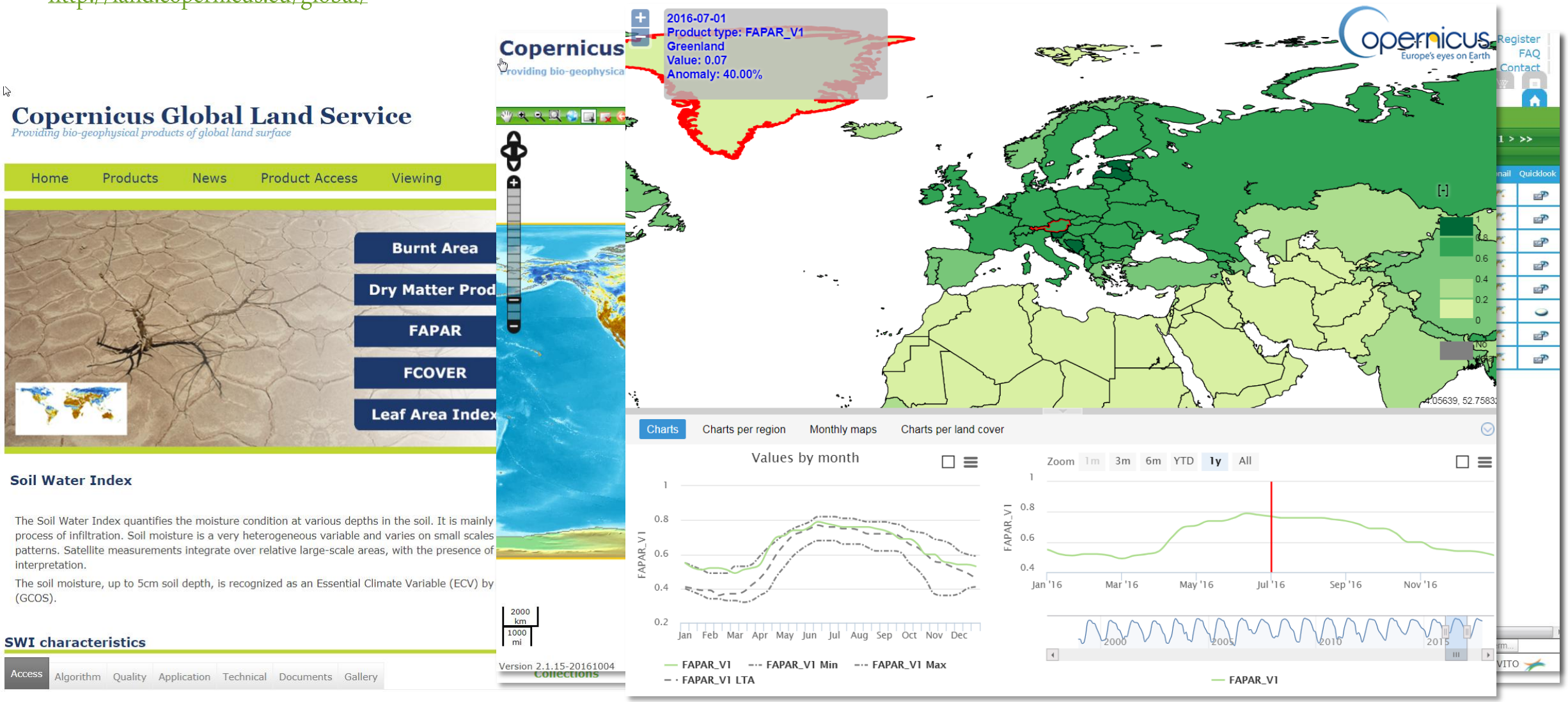


Access & Usage

at Copernicus Global Land Service

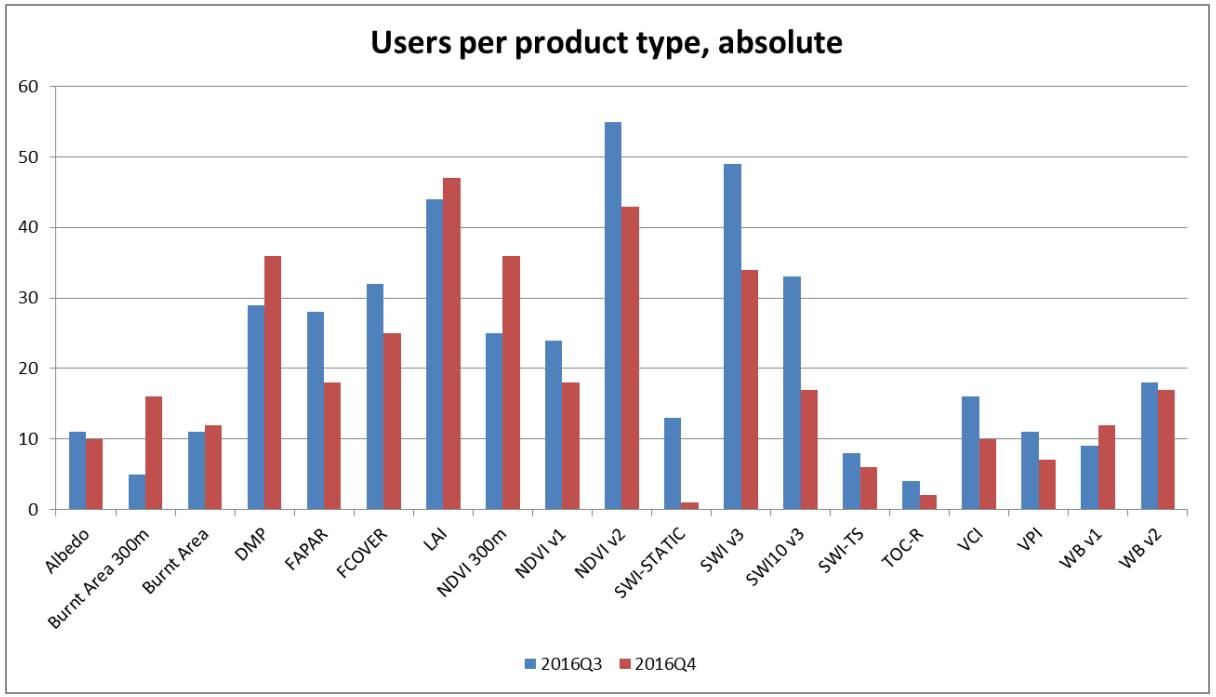
Access to Copernicus GLS

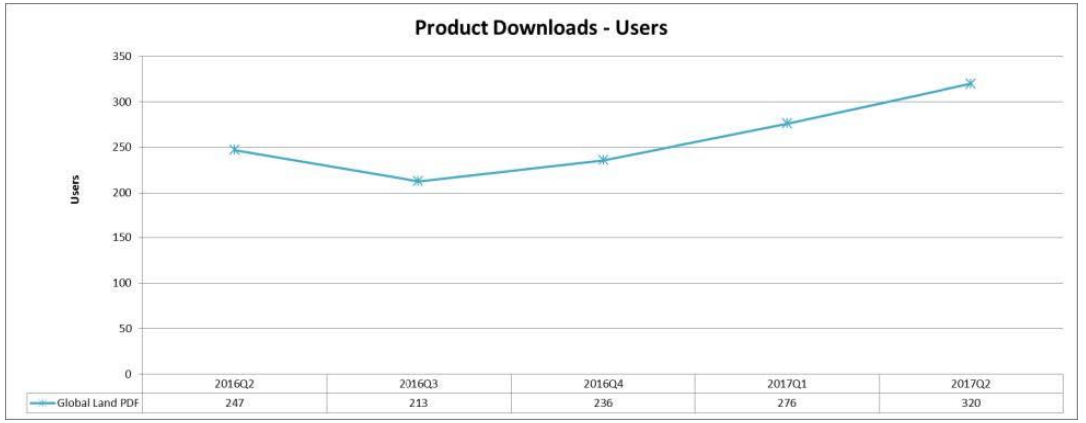
- http://land.copernicus.eu/global/

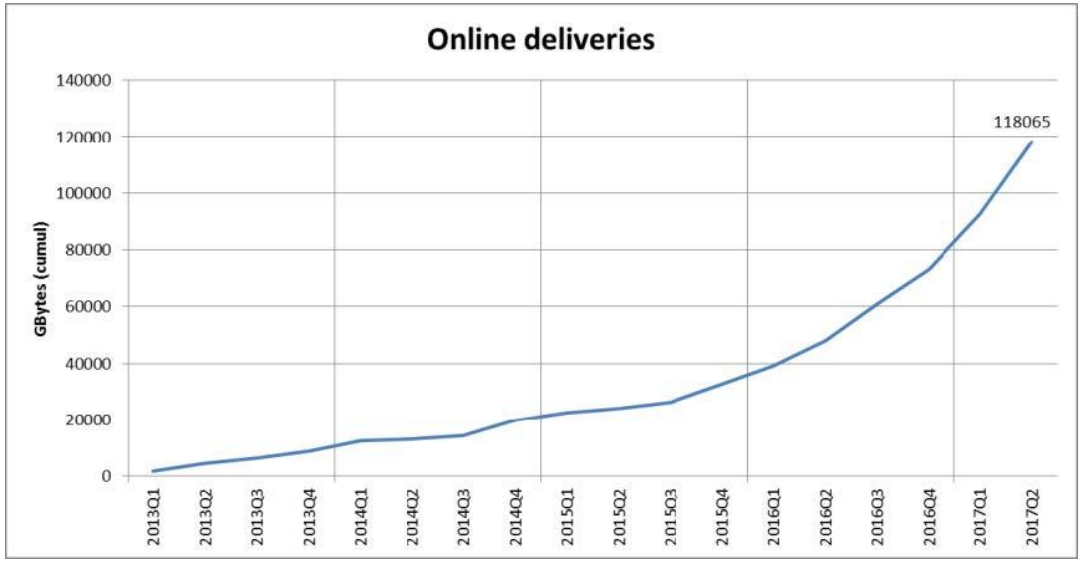


Growing Usage

- 25 TB data provided to 320 users out of 73 countries in 2017/Qu2
- ~2000 registered users
- SWI: daily distribution 100% succesfull and on-time in 2017







netCDF?

- UNIDATA: "NetCDF is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data."
- format widely used in meteorology, geosciences, etc.
- allows many options
- easy to use...
  - **panoply:** stand-alone app: https://www.giss.nasa.gov/tools/panoply/
  - **python**: interface via netcdf4-package: http://unidata.github.io/netcdf4-python/
  - supported also by suites like **MATLAB, QGIS, ArcGIS**

CGLS Data

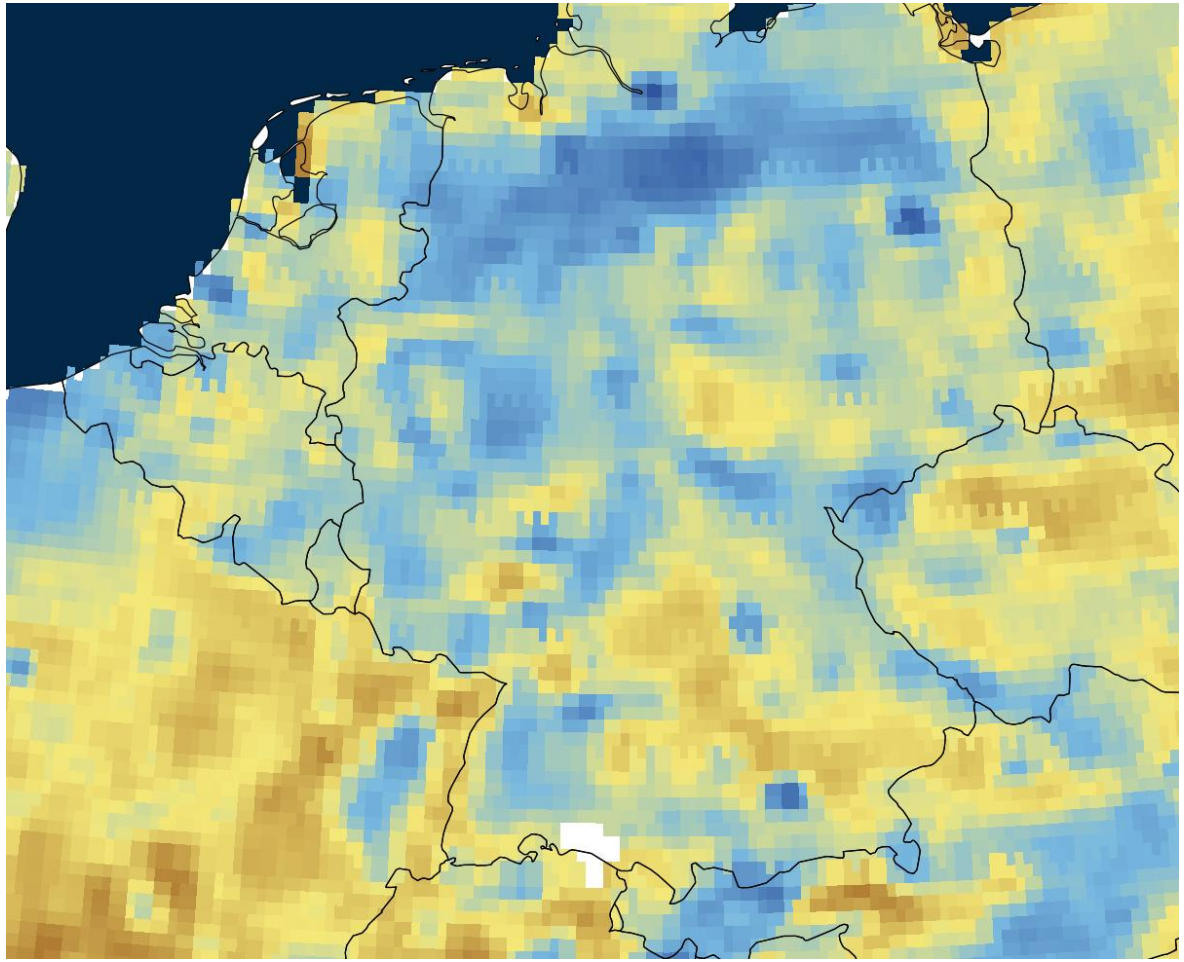
Live show on SM-data

New 1km Products @ Copernicus

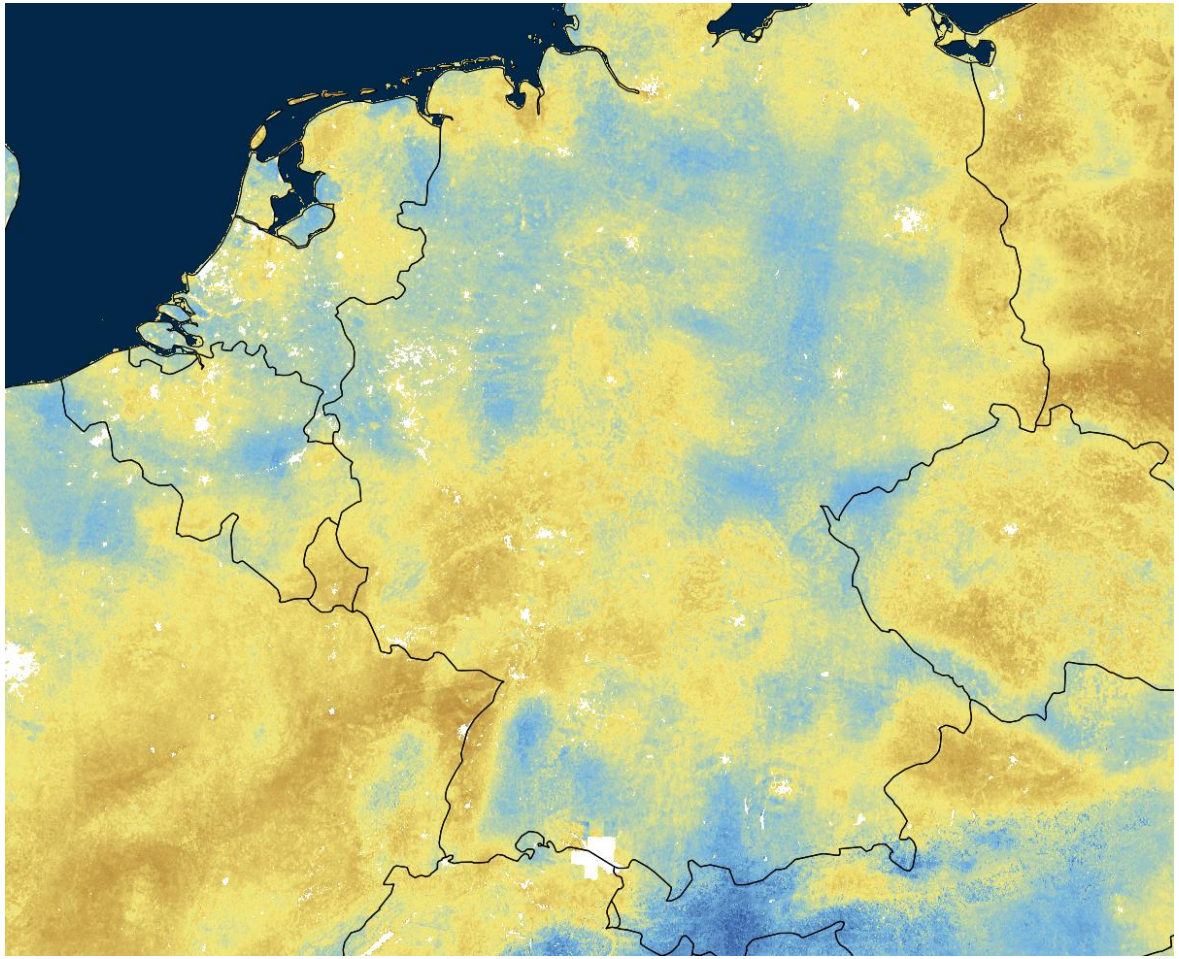
Make use of Sentinel-1 SAR

SWI: 0.1° vs 1km

ASCAT SWIV3 | 0.1° ~ 12.5km



SCATSAR SWI | 1km



why 1km products?

- high spatial resolution is demanded/expected/needed
  - management in agriculture (wine growing, horticulture, irrigation, …)
  - meteorological models
- Currently, Soil Water Index (SWI) with 0.1° spatial resolution
- Sentinel-1 satellite mission enables operational soil moisture production at 1km
  - meets the resolution of other Copernicus products
- SSM/SWI from Sentinel-1
  - same physical observation techniqe and retrieval methode as ASCAT
  - = migration of method used in Copernicus to new data source

Upcoming 1km SM products in CGLS

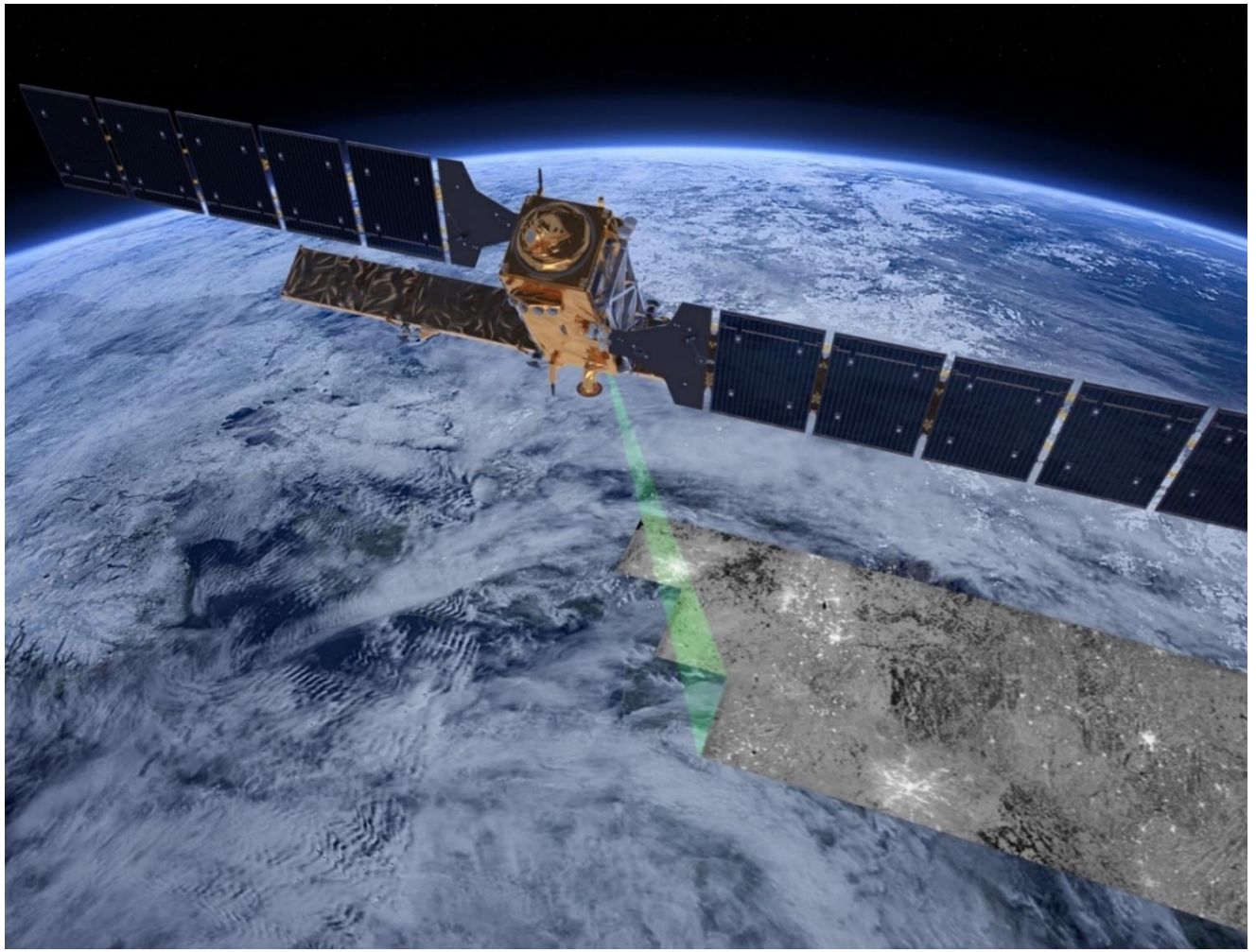
Soil Moisture products in ramp-up 2018 – 1km Soil Moisture

- SSM1km (towards pre-operational, public beta release ~Dec 2018)
  - 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 satellites
  - daily image, on a 1km grid
    - *no full coverage at each day*
    - *actual frequency over European locations: 1.5-4 days*
  - netCDF4 format
- SCATSAR-SWI (towards pre-operational, public beta release ~Dec 2018)
  - ingesting SSM from Sentinel-1 and ASCAT → SWI at 1km!
  - **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.)

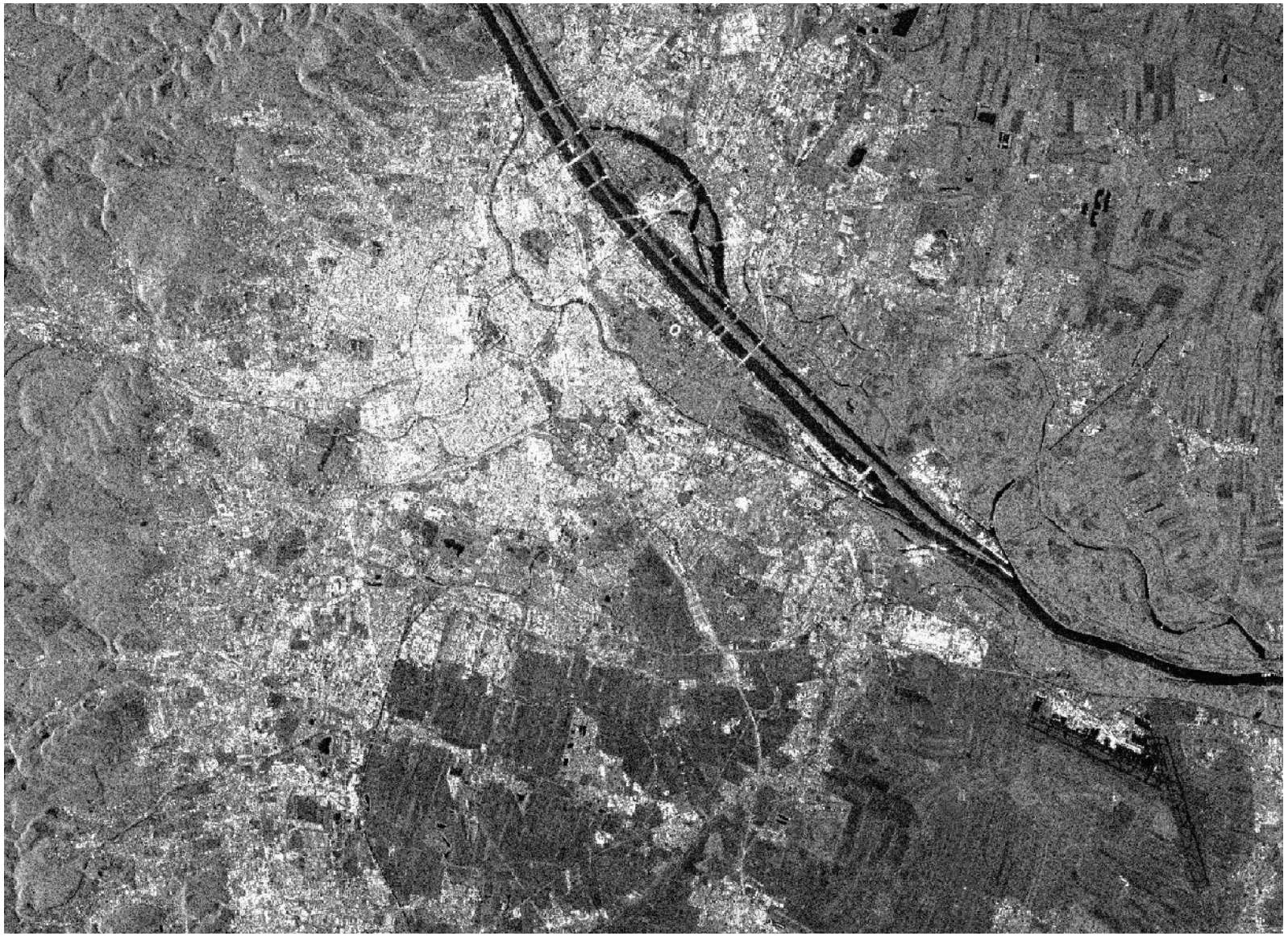
- Both are currently in preparation towards operations
  - Taking up 2016/2017 Evolution activities
  - Dec 2018: data available over Europe
  - 2019: rolling out to global coverage

Sentinel-1 SAR Mission

- C-band SAR satellites succeeding ERS- and Envisat missions
  - Sentinel-1A launched Apr 2014
  - Sentinel-1B launched Apr 2016
- active microwave sensor
  - independent from weather and daylight
  - topography, vegetation, water bodies, soil moisture
- high spatio-temporal resolution
  - 20m
  - 3-6 days (global)
  - 1.5-4 days (over Europe)
- Big Data remote sensing
  - 1 TB raw data per day

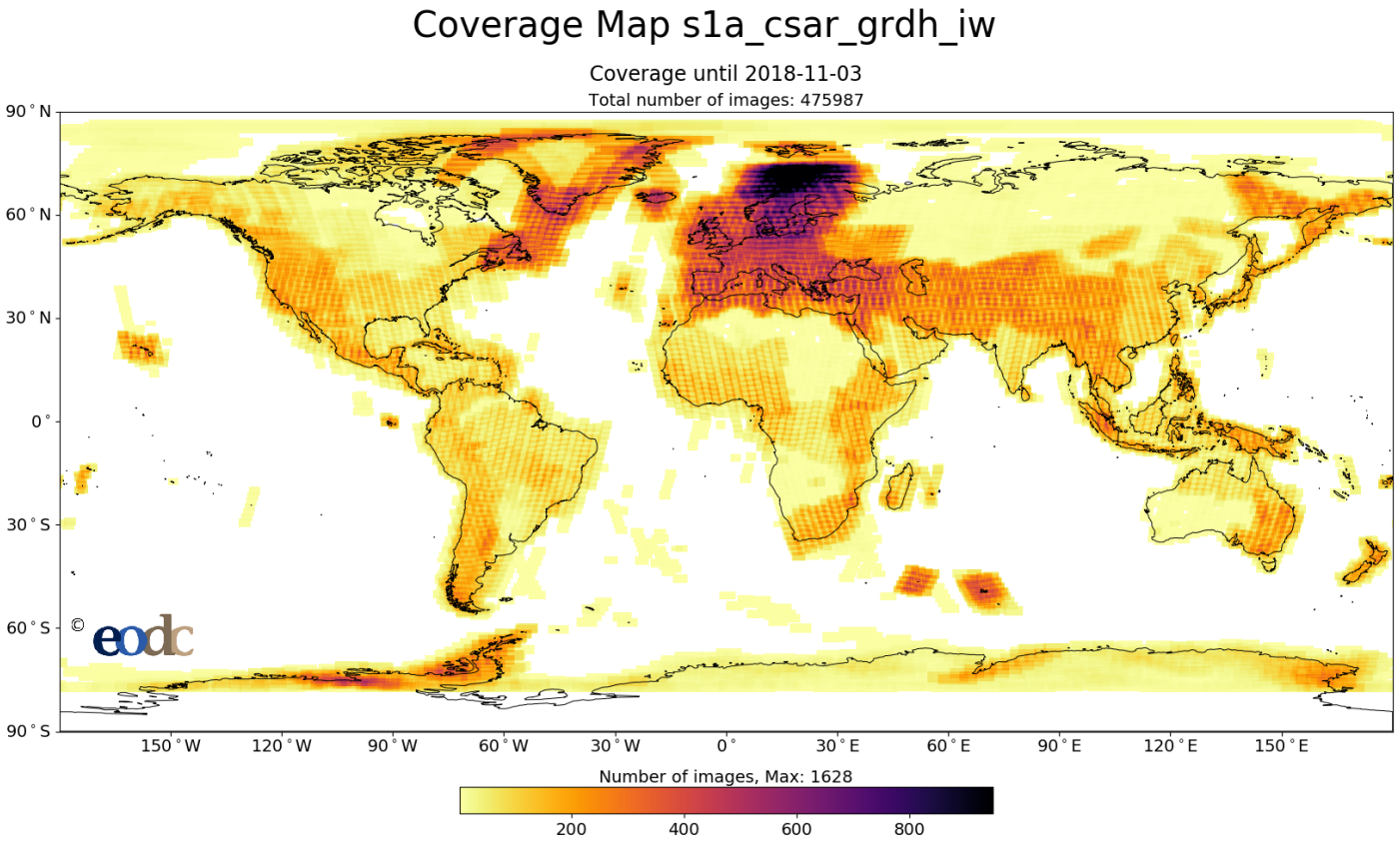


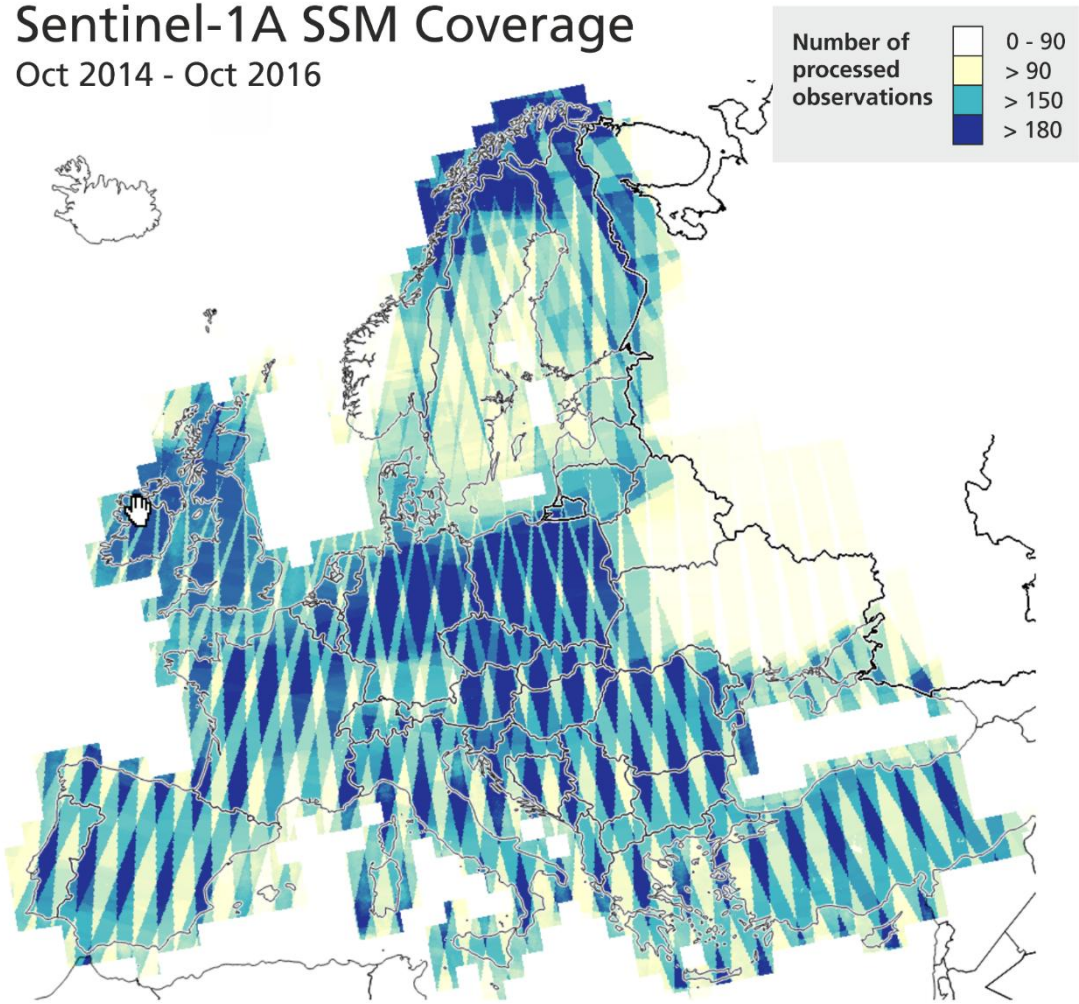
Sentinel-1 - Spatial Resolution



Sentinel-1 Image of Vienna 15/03/2015 Orbit 5045

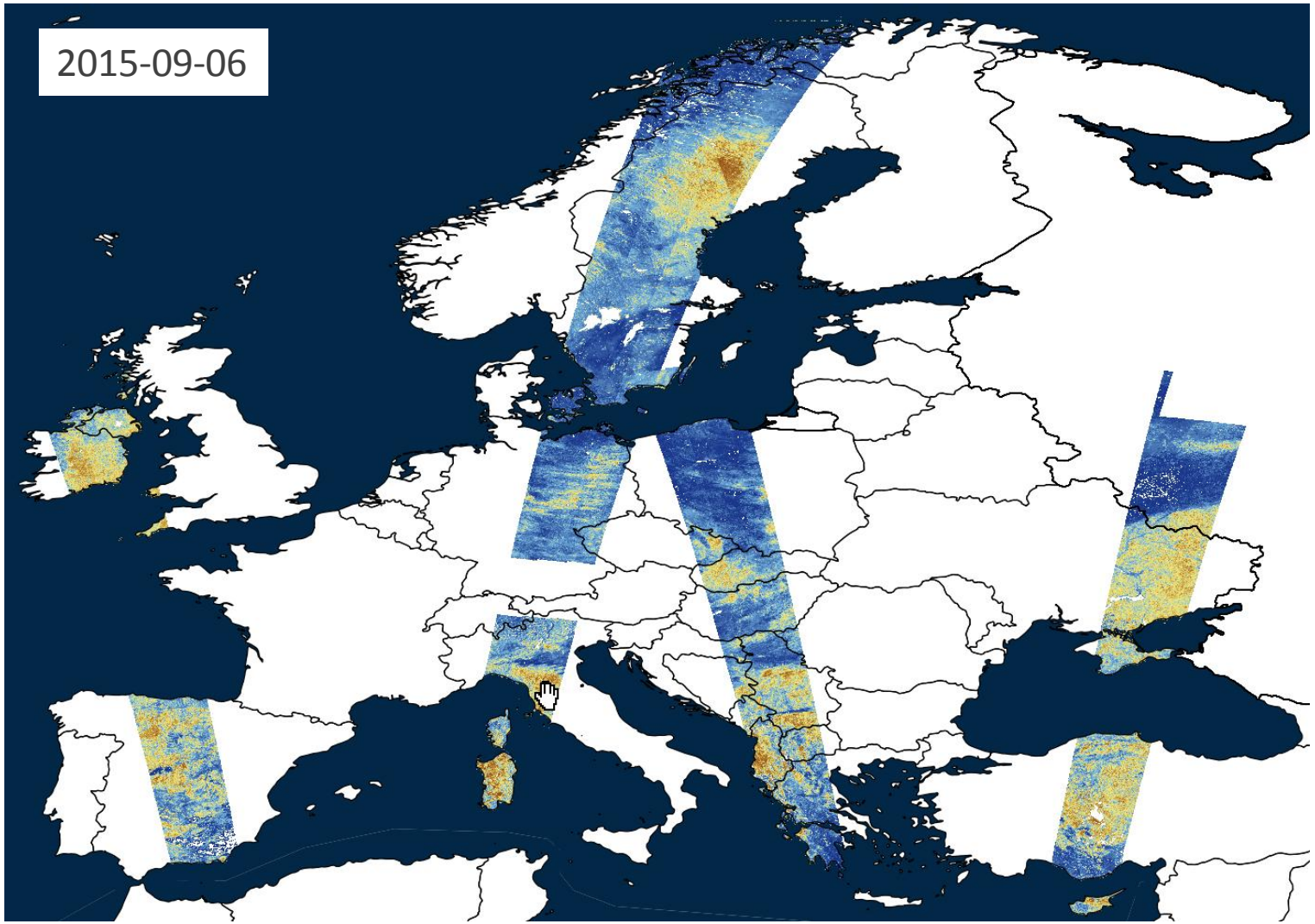
Sentinel-1 - Coverage



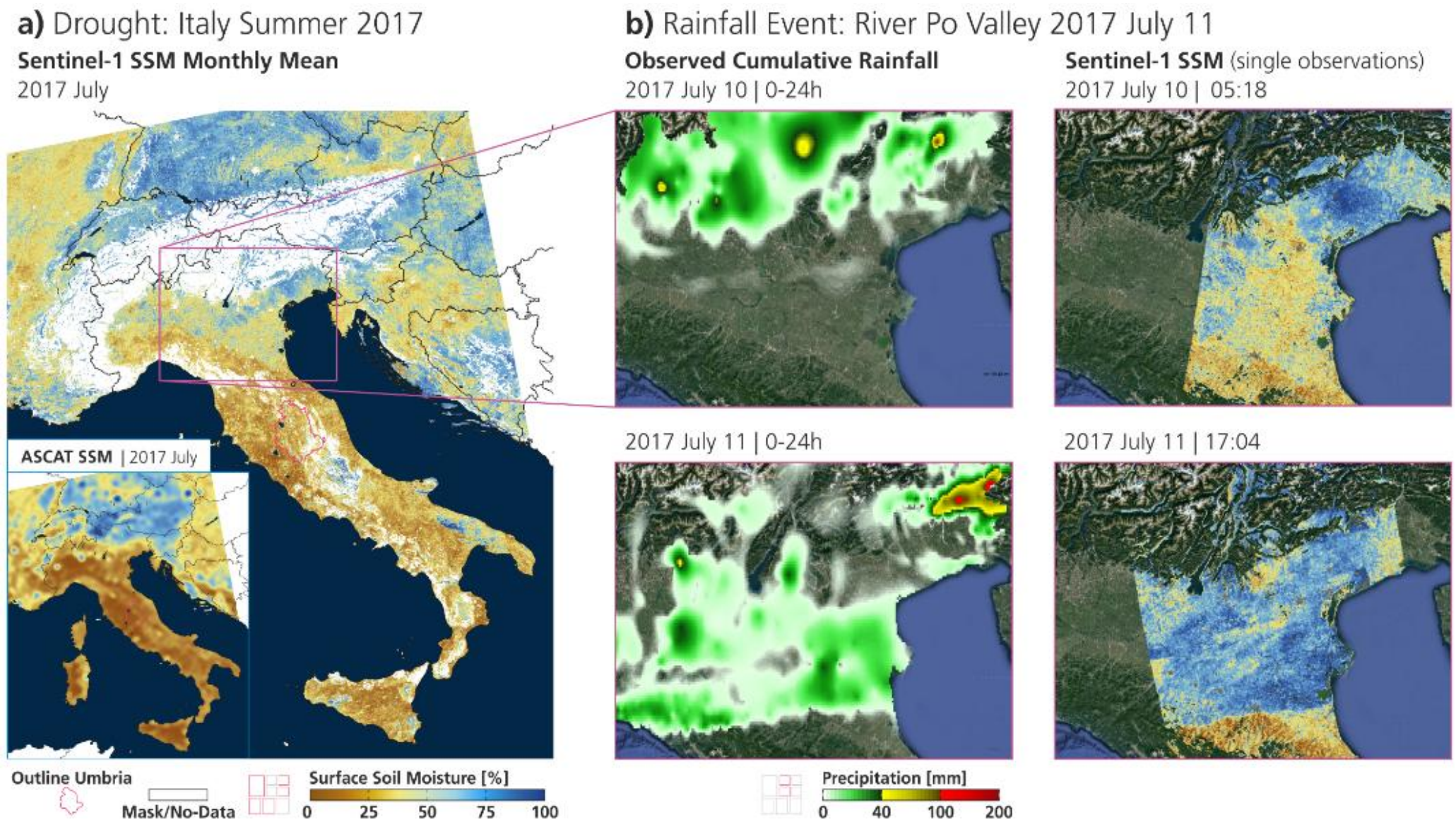


Sentinel-1 SSM @ Copernicus

- S-1 SSM @ Copernicus Global Land Operations - 1km Collection
  - Currently towards pre-operational
  - public launch end of year
- SSM1km-V1
  - Version 1
  - over Europe
  - since 2015
  - daily composite images (orbits)
  - 1/112° ~ 1km
  - with masks & noise



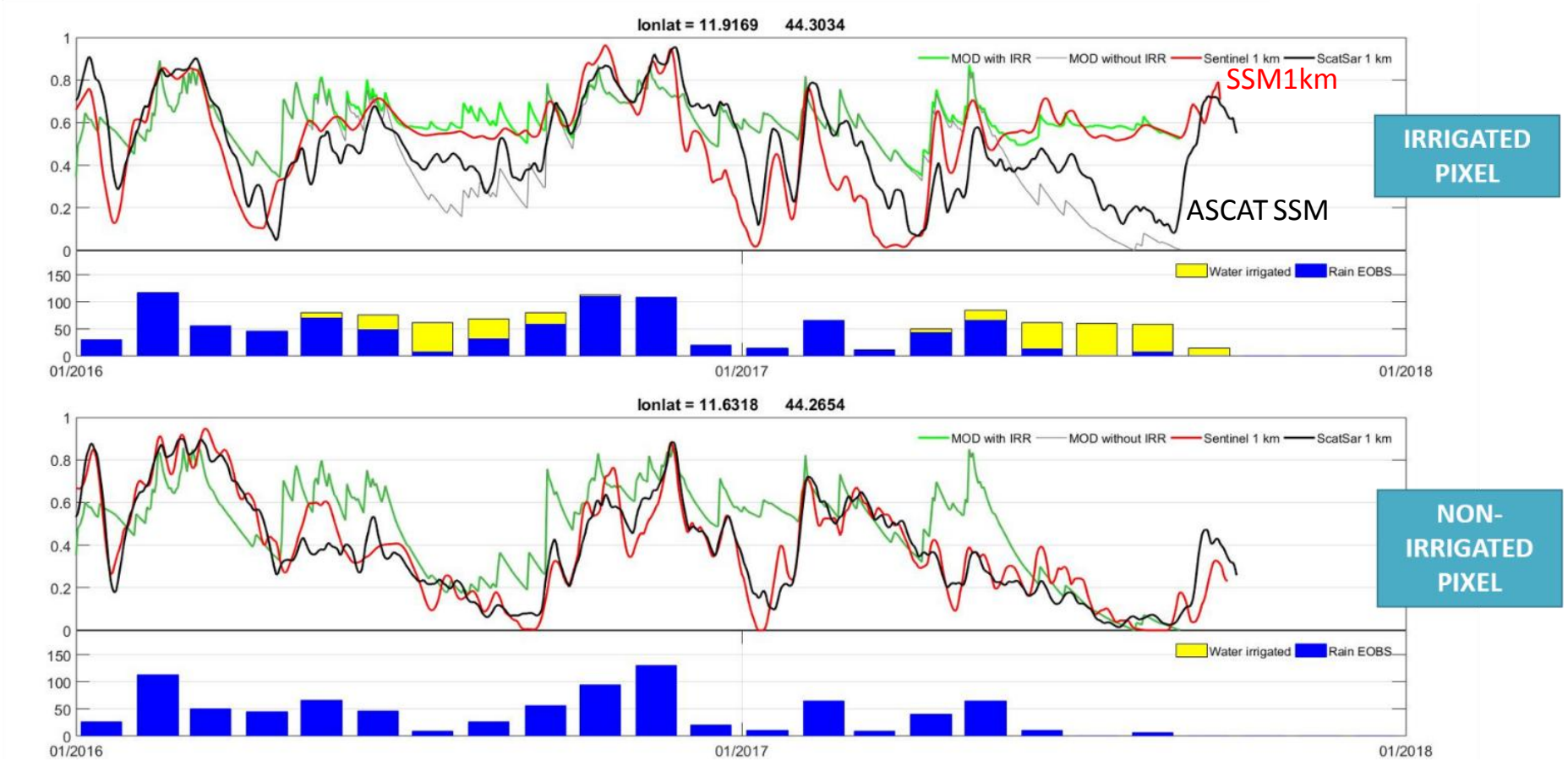
Sentinel-1 SSM: Examples



Sentinel-1 SSM: Examples

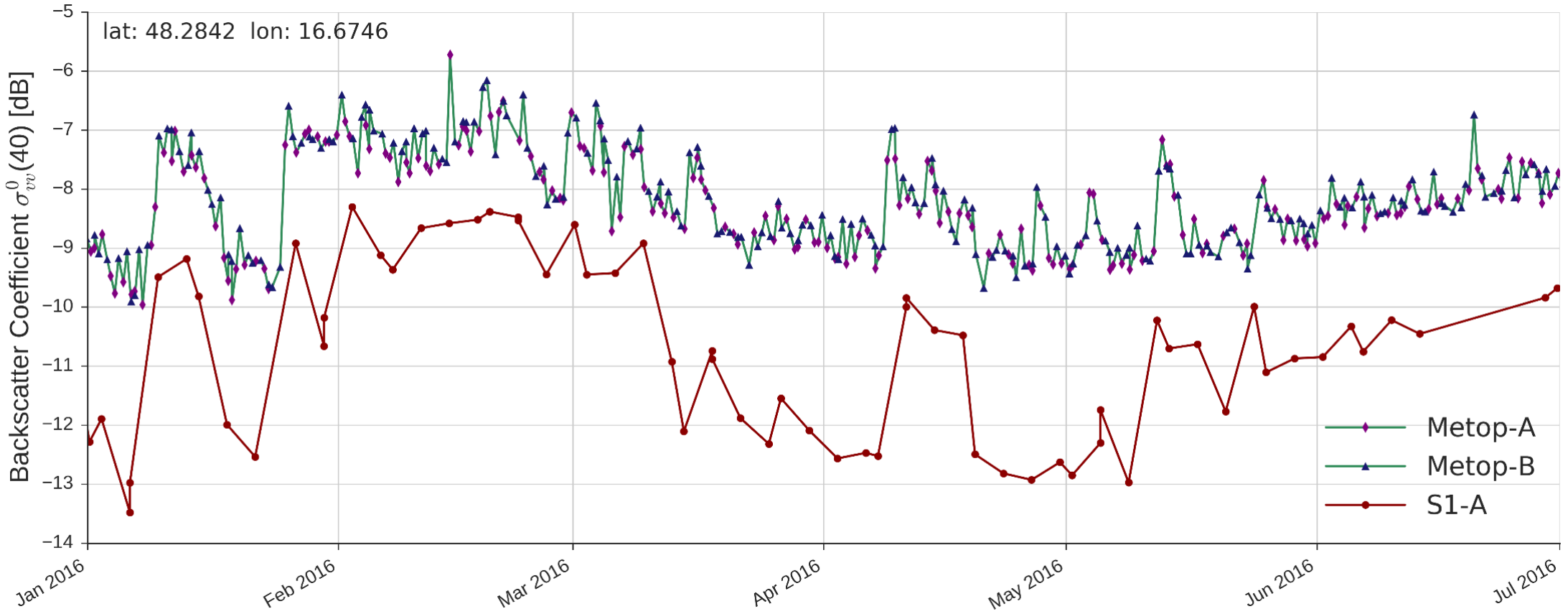
- contrary to other satellite products: irrigation impacts are visible!

ROMAGNA (ITALY)



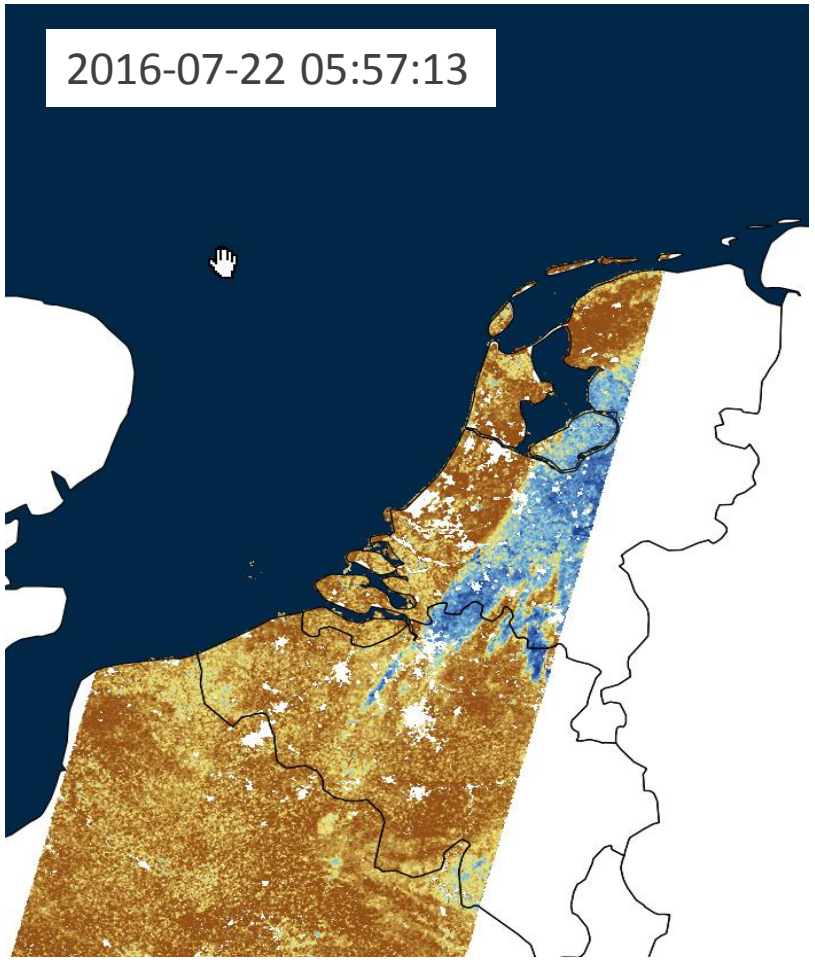
Sentinel-1 SSM: Potential Biases

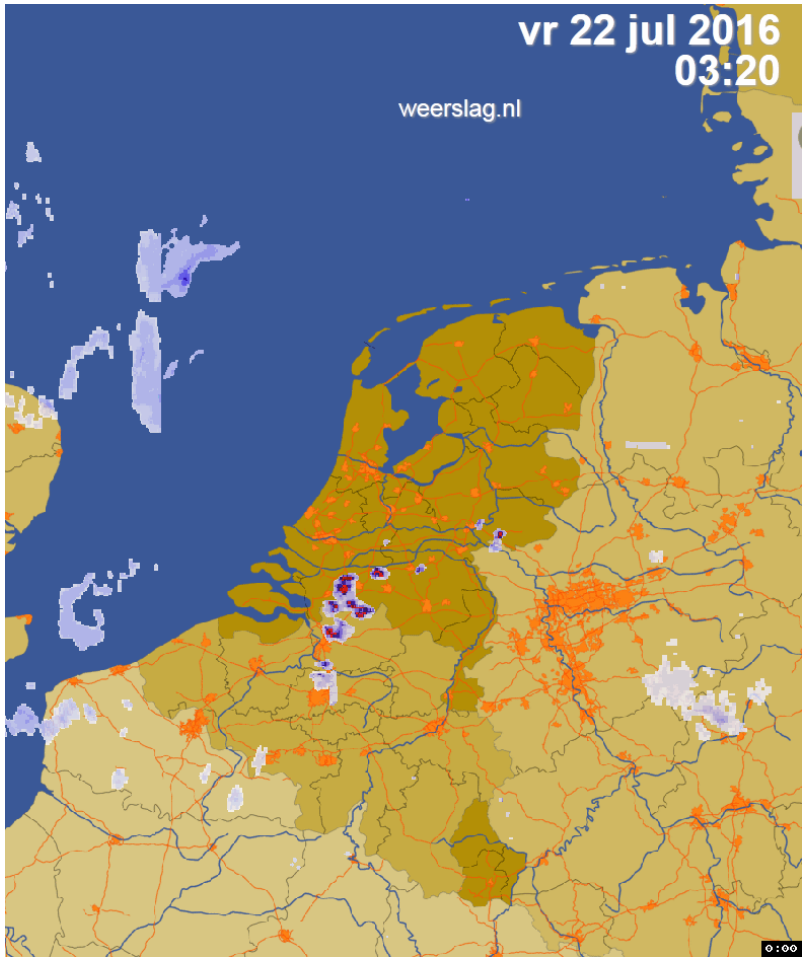
- ASCAT versus Sentinel-1
  - Normalised VV backscatter time series over an agricultural region east of Vienna (Marchfeld) for the months January to June 2016.



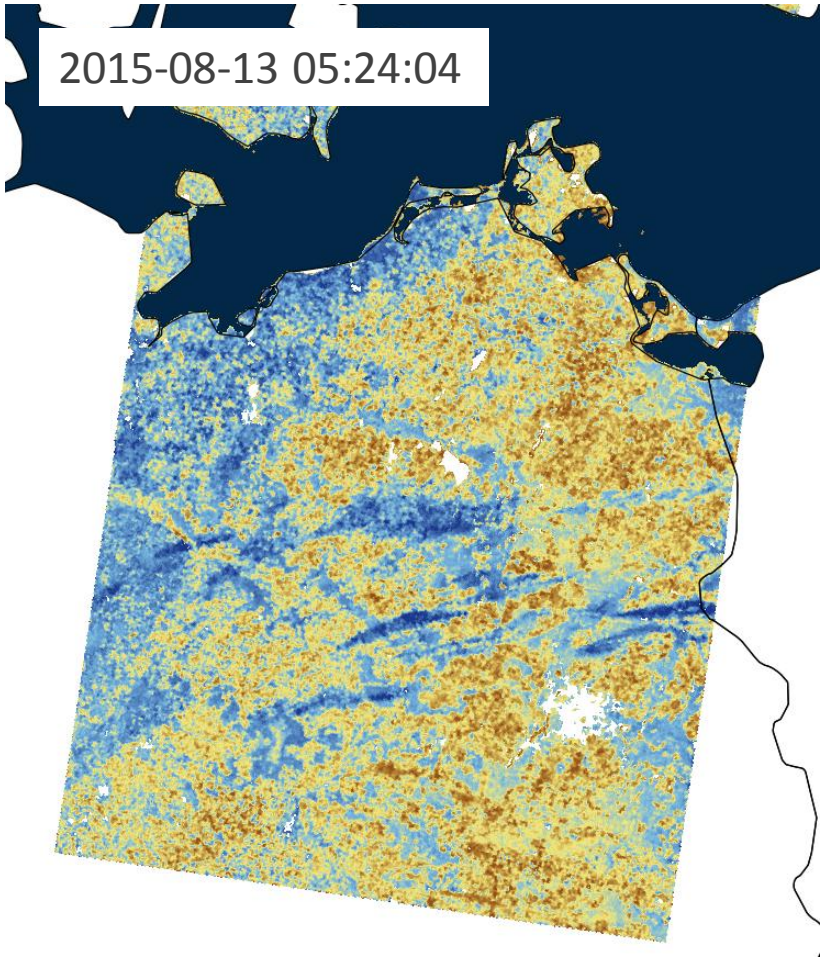
Rainy Days @ Sentinel-1 SSM

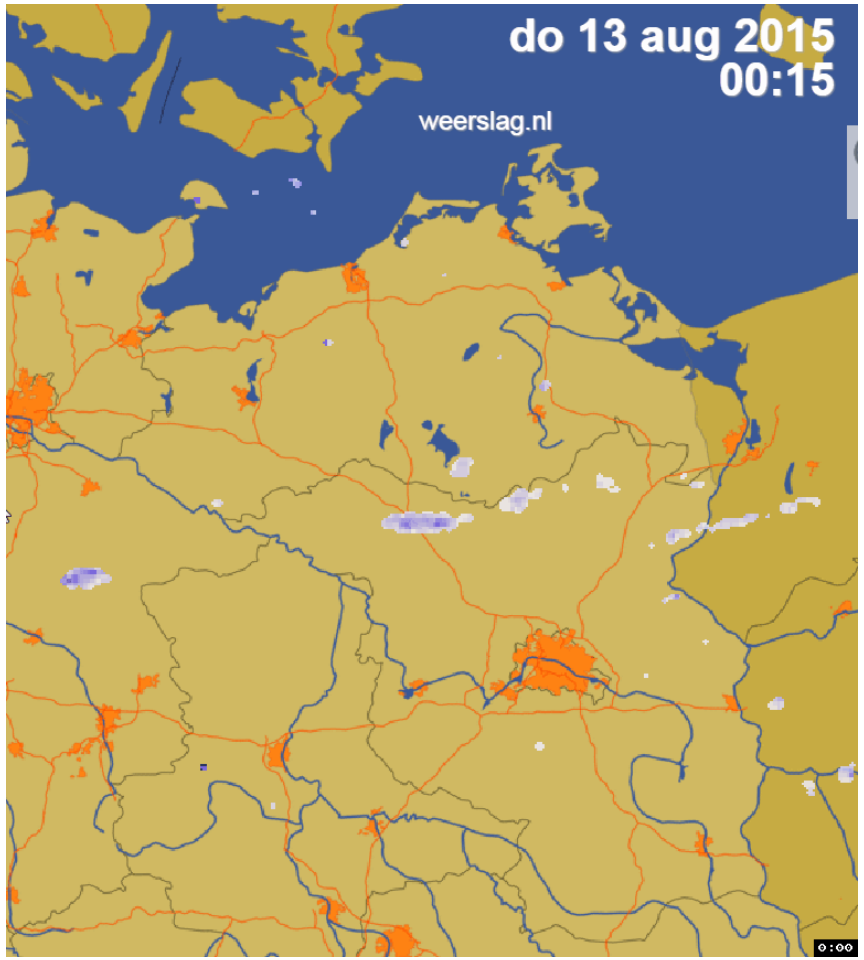
Rainfall events „precipitate“ into 1km SSM product.





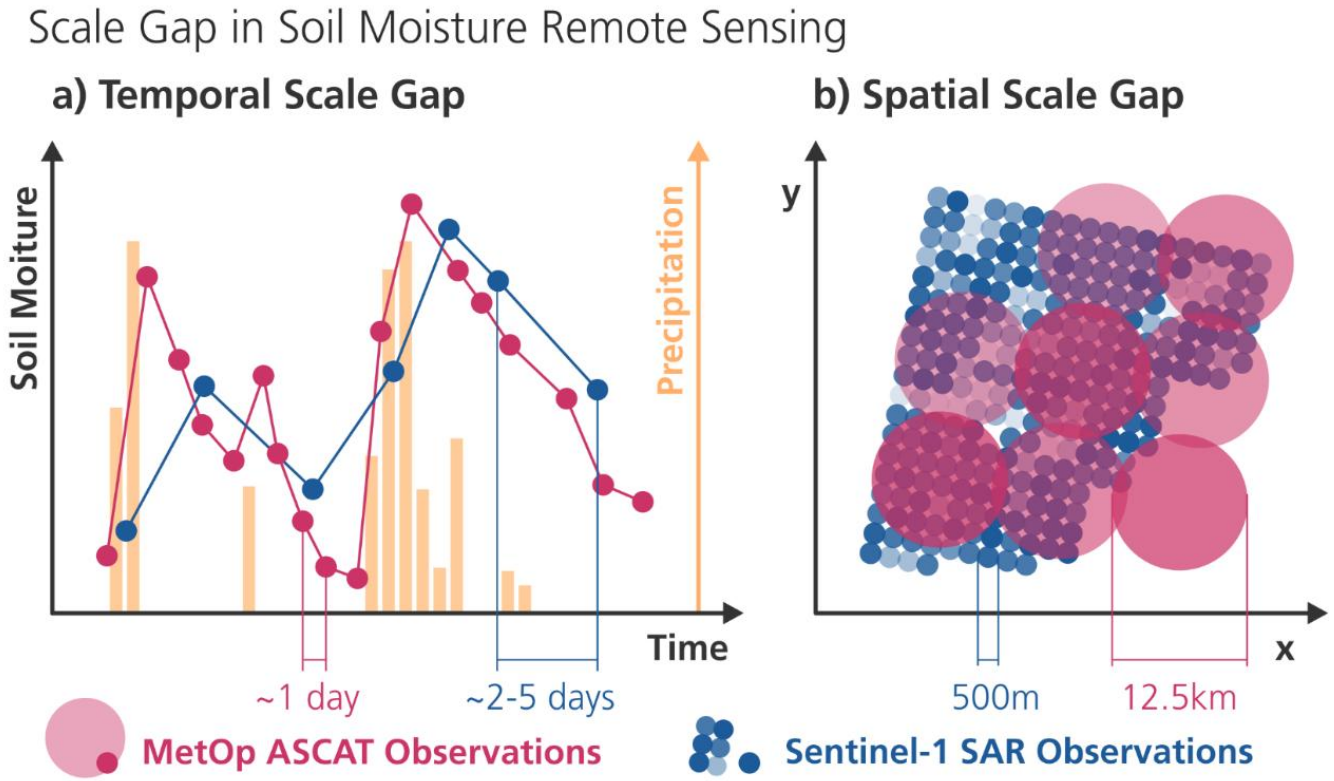
Rainy Days @ Sentinel-1 SSM



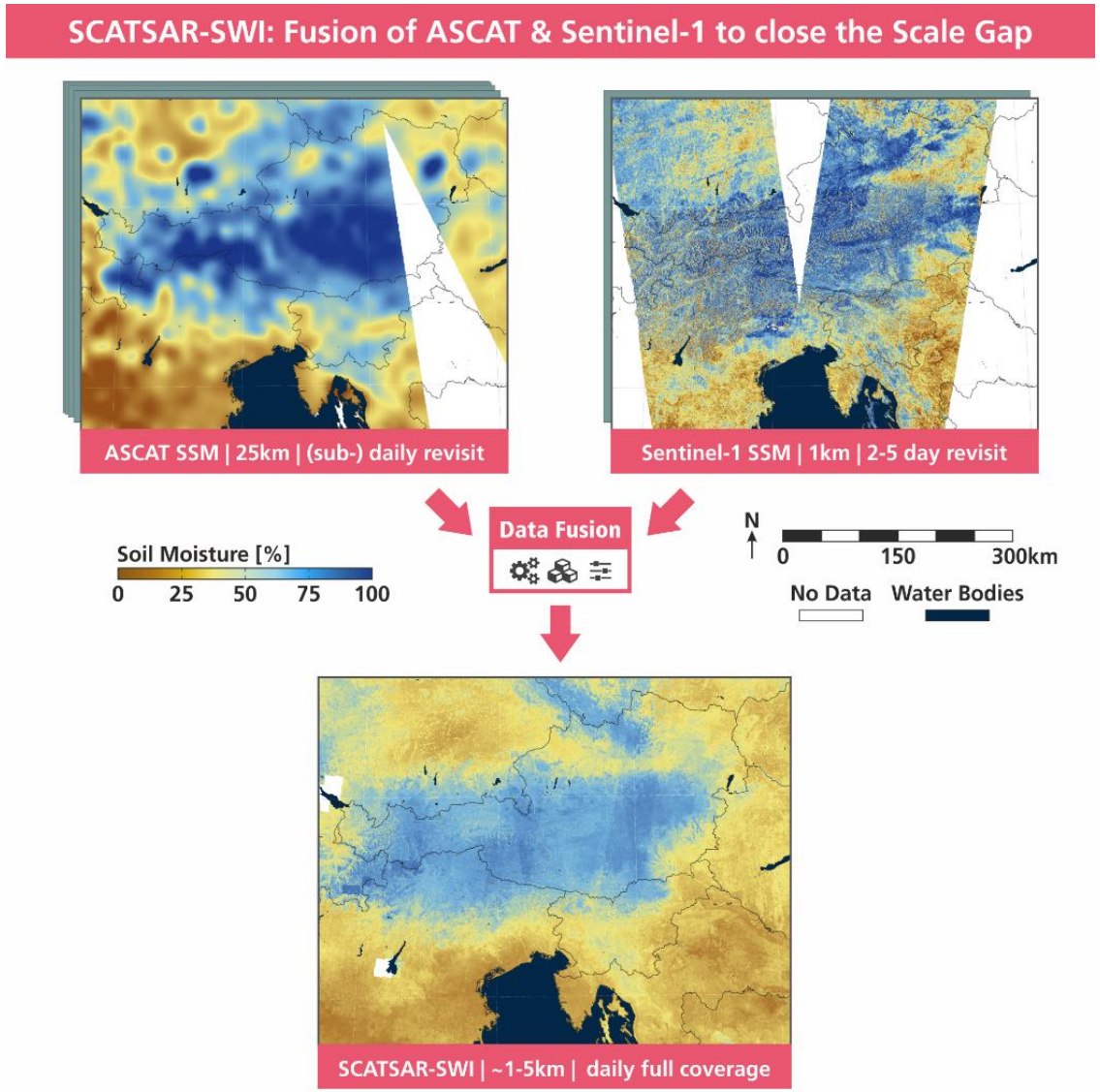


SCATSAR-SWI: Combining ASCAT & Sentinel-1

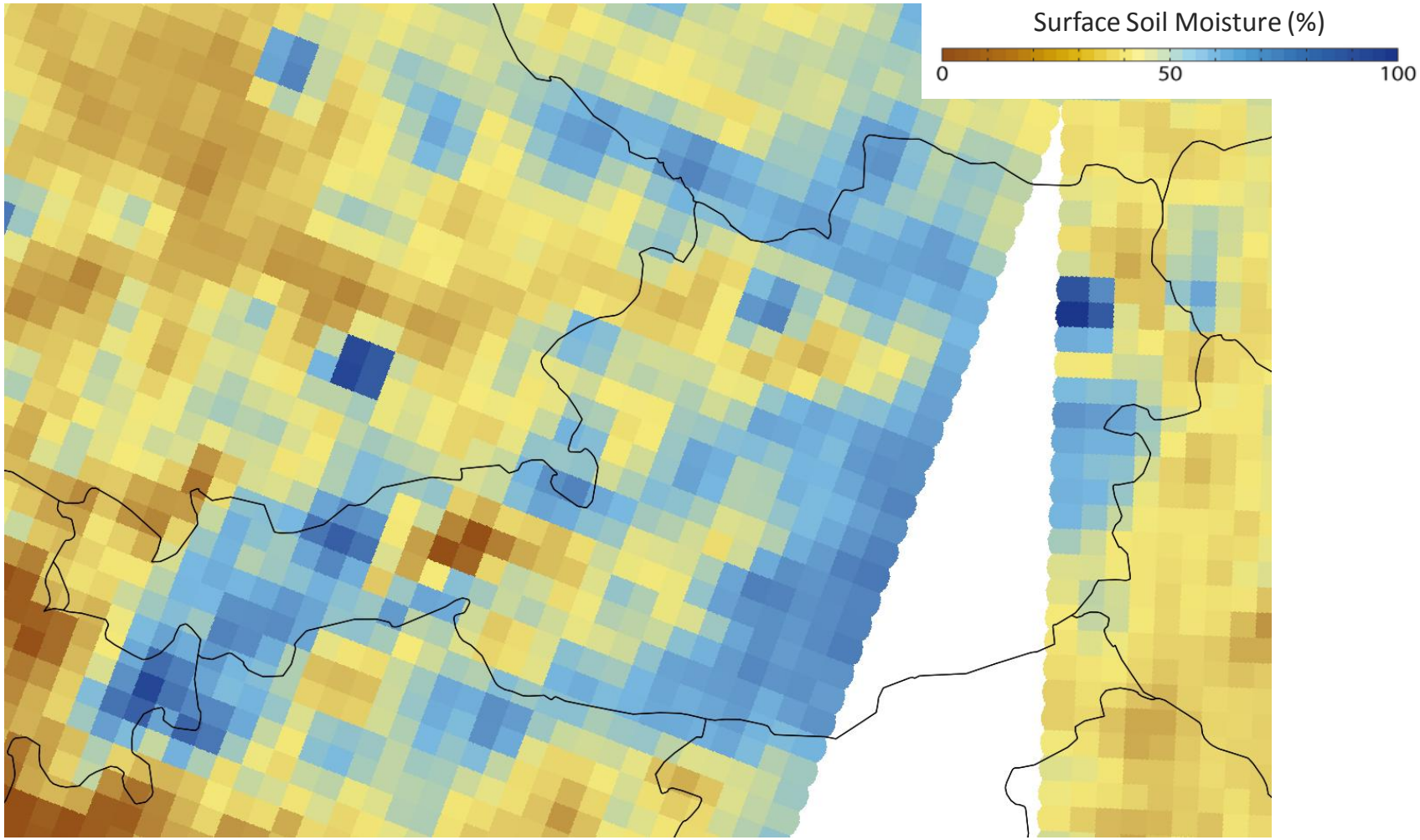
- Scale Problem: in remote sensing, a single system can provide either high resolution in space OR time:
- → Fusion of data from different scales / spectral domains
  - *optical/thermal*
  - *SAR/scatterometer*
- → our approach: SCATSAR-SWI
  - combination of ASCAT and Sentinel-1 soil moisture
    - *fused SCATSAR-SWI product*



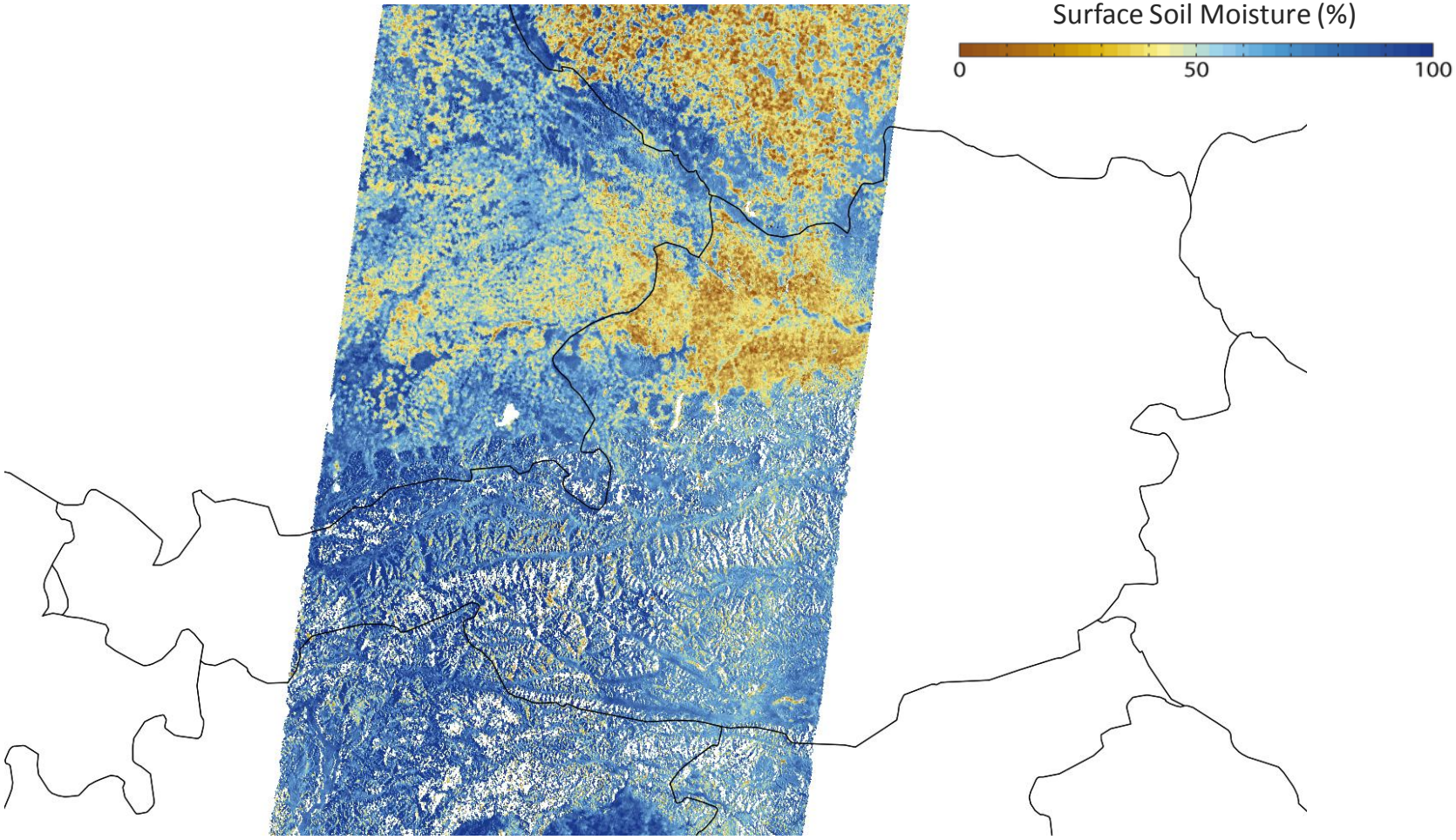
SCATSAR-SWI: Combining ASCAT & Sentinel-1



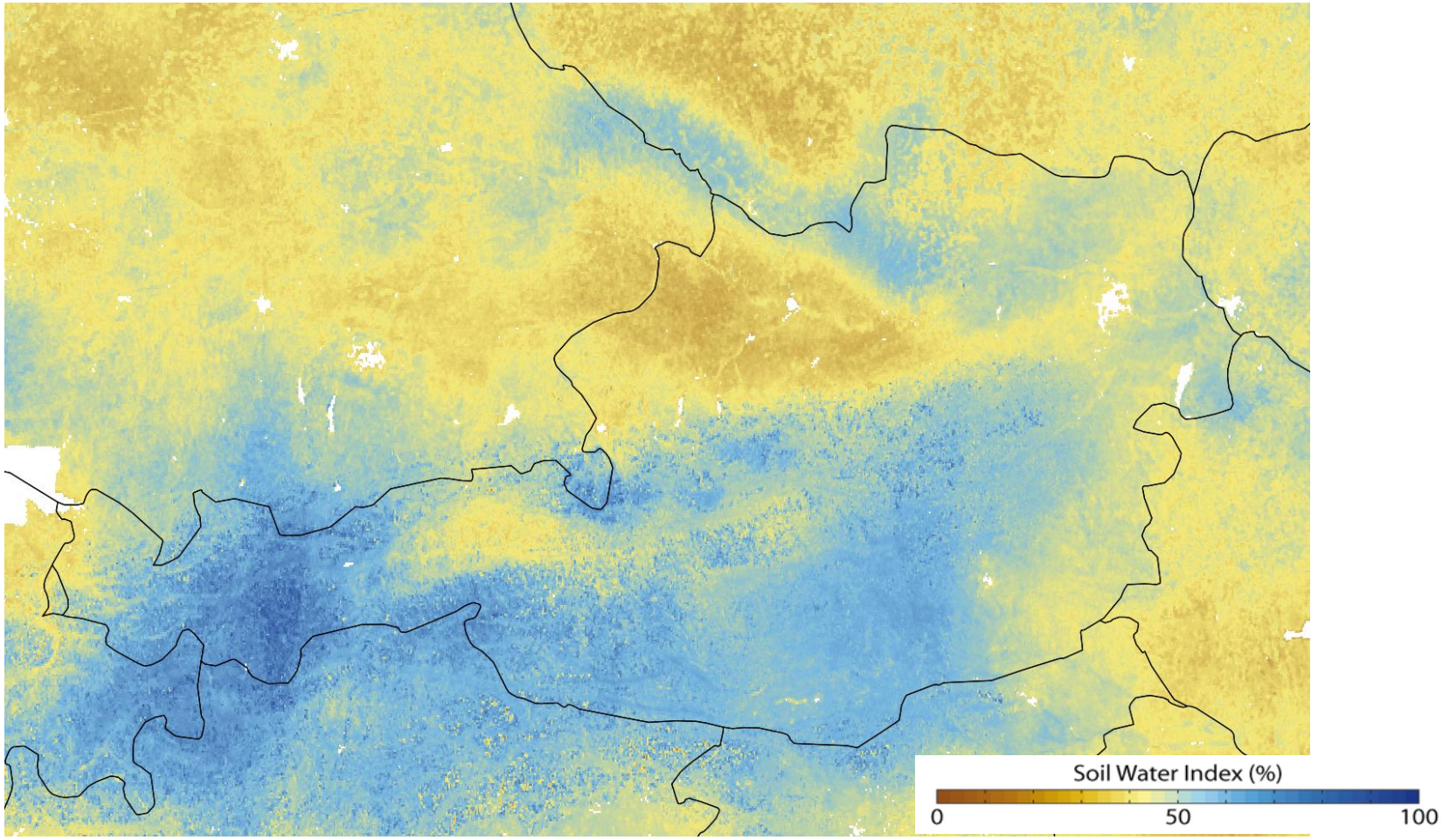
ASCAT SSM - detail



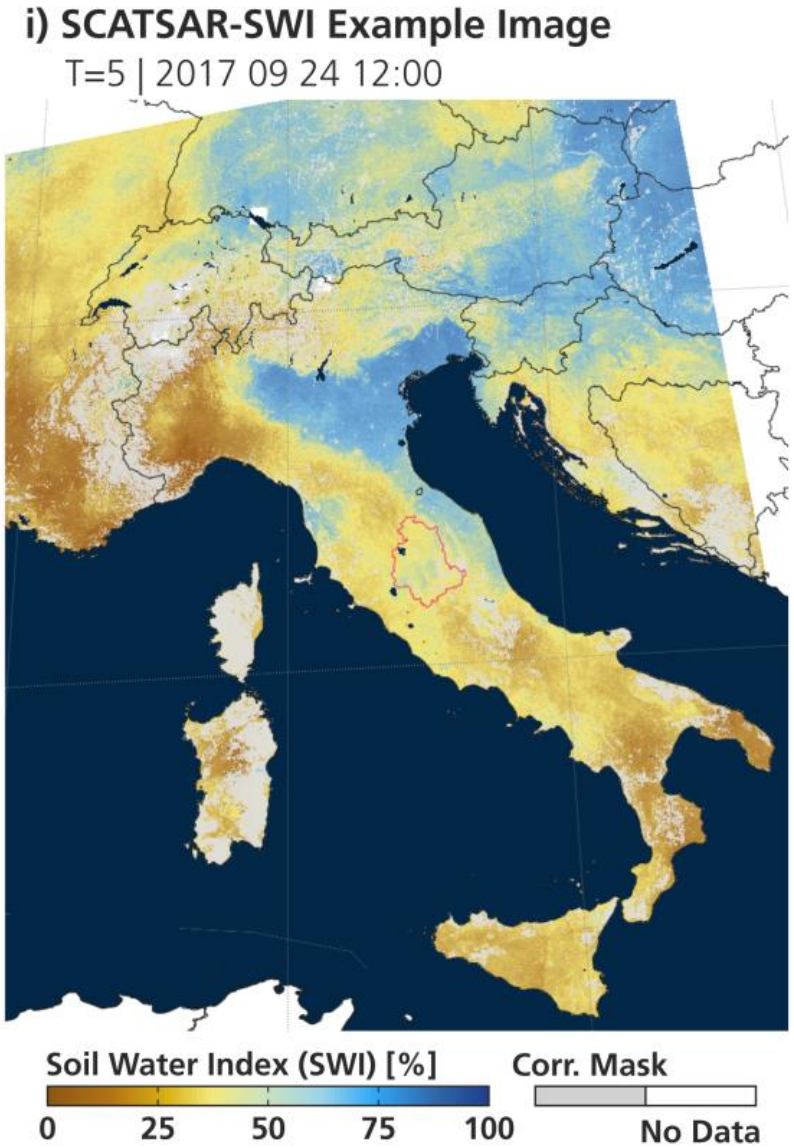
Sentinel-1 SSM - detail



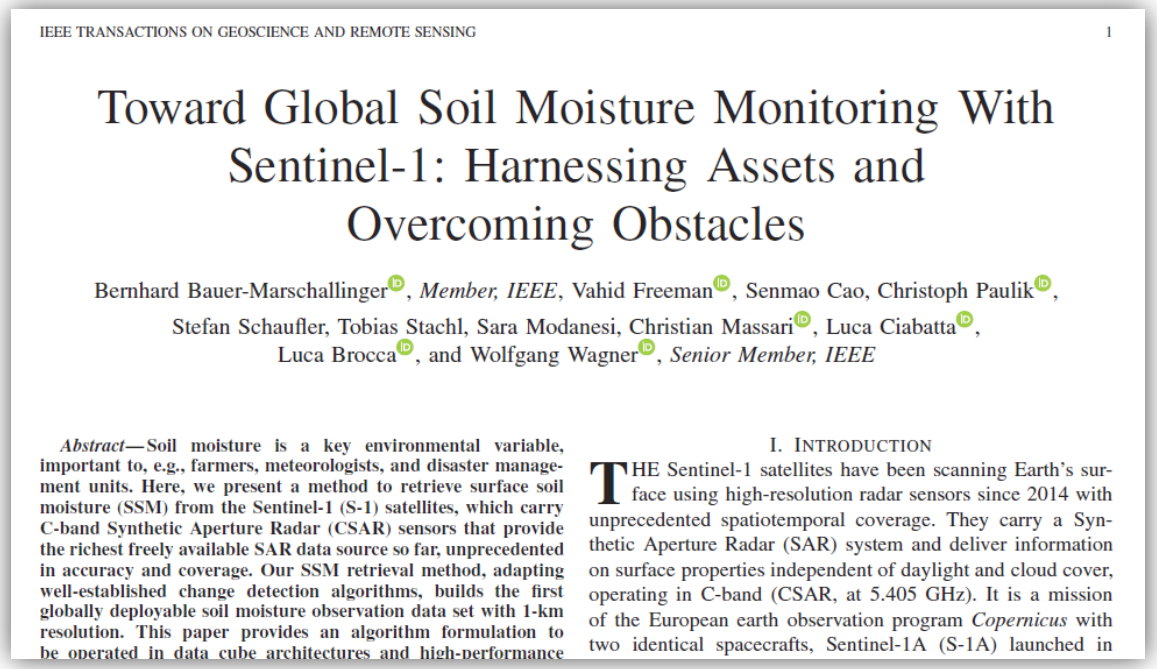
SCATSAR-SWI - detail



SCATSAR-SWI example image over Italy



Recent Publications



IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING 1

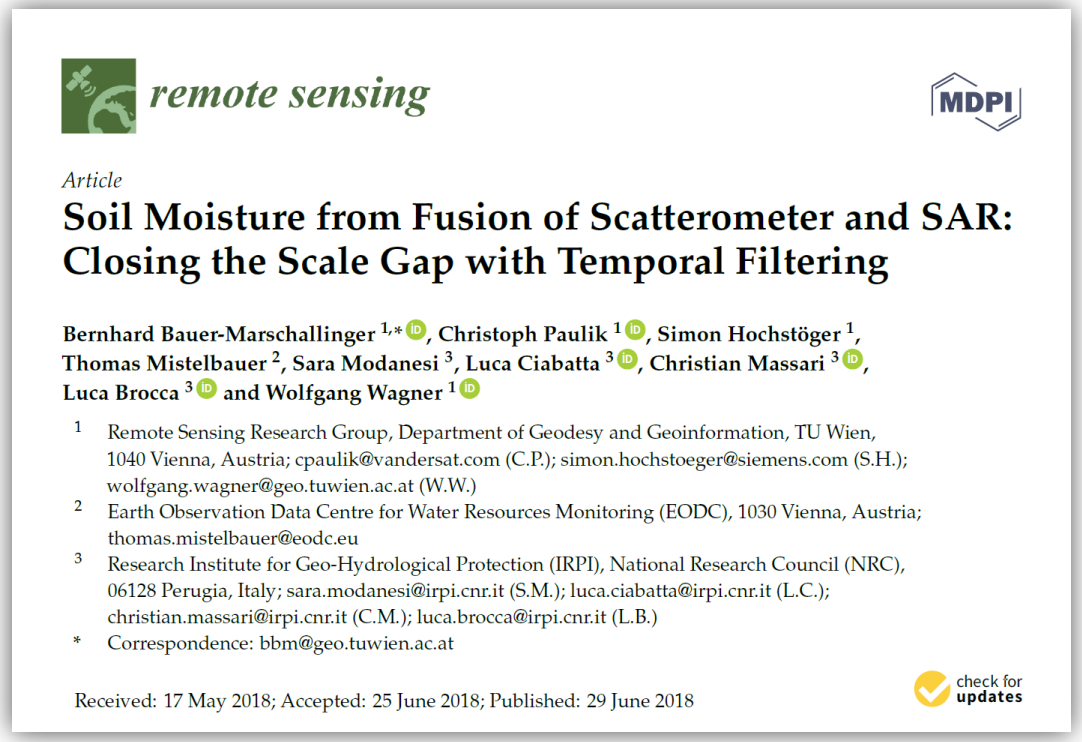
Toward Global Soil Moisture Monitoring With Sentinel-1: Harnessing Assets and Overcoming Obstacles

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



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]

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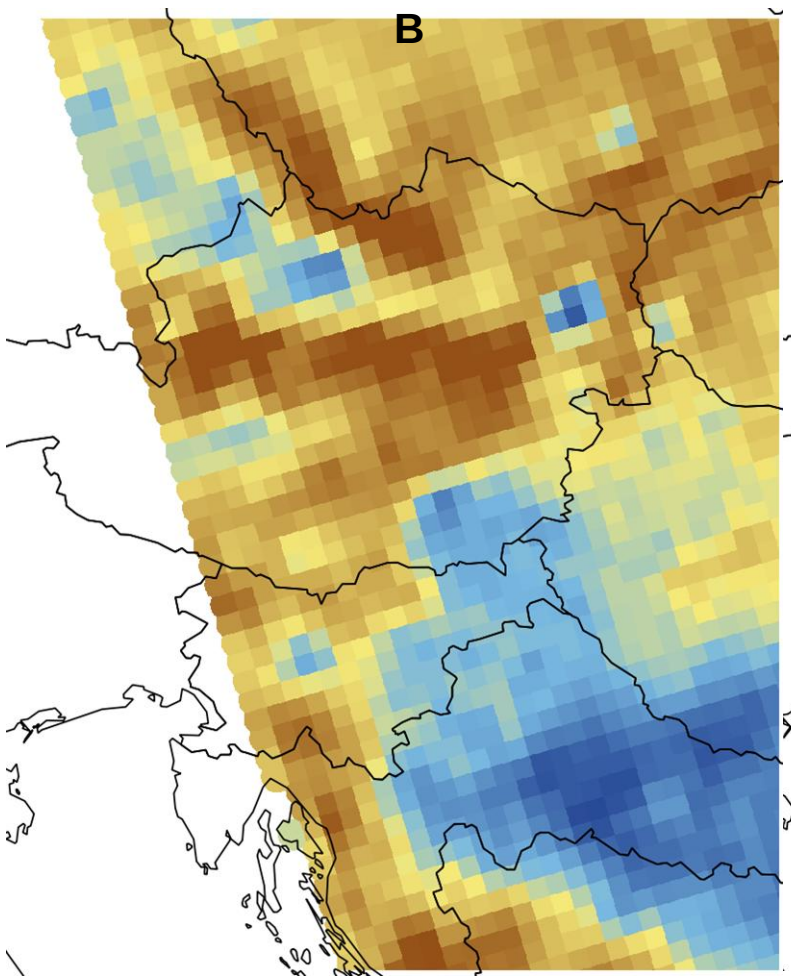
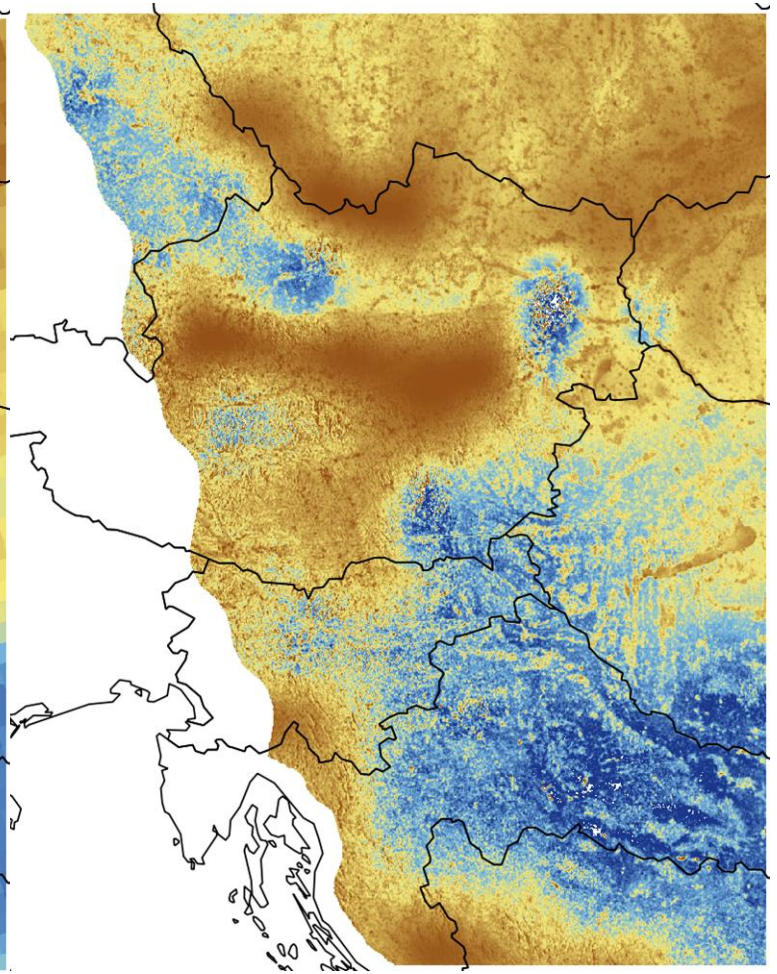
check for updates

Outlook: ~1km ASCAT SSM from SAR-Disaggregation

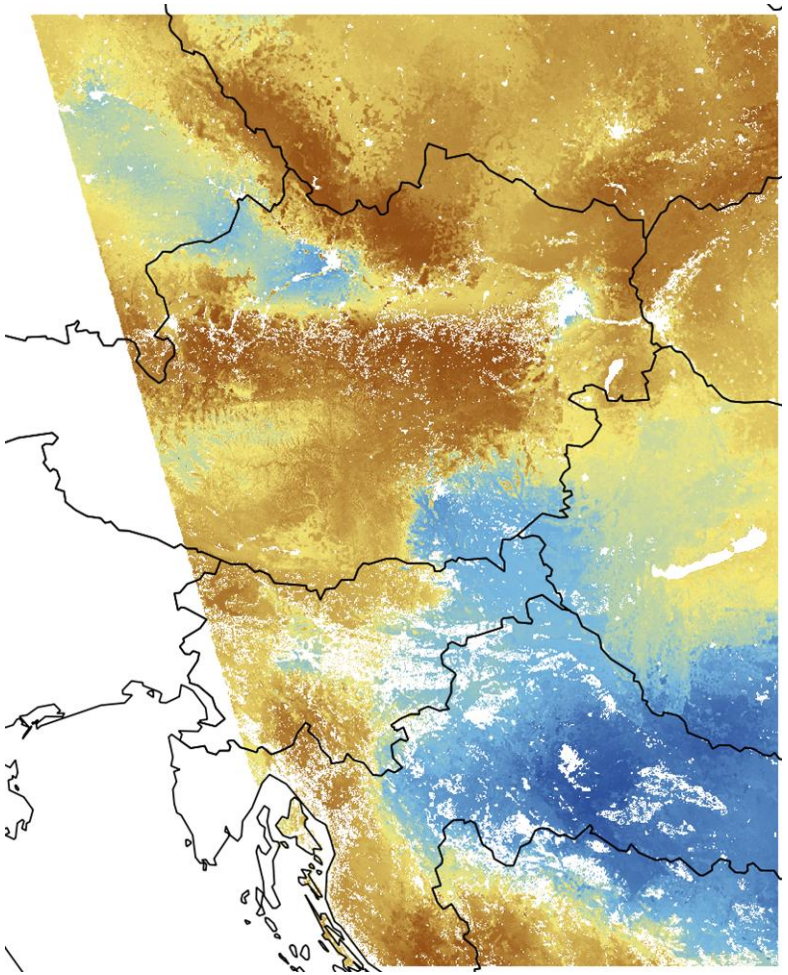
2018-03-21 19:09:00 METOP-B



H SAF H16



H SAF H08 (old)



New directional resampling approach (new)

Thank you for the attention!

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