# Soil Moisture Remote Sensing

Mariette Vreugdenhil and Wolfgang Preimesberger

23/11/2022

# Topics

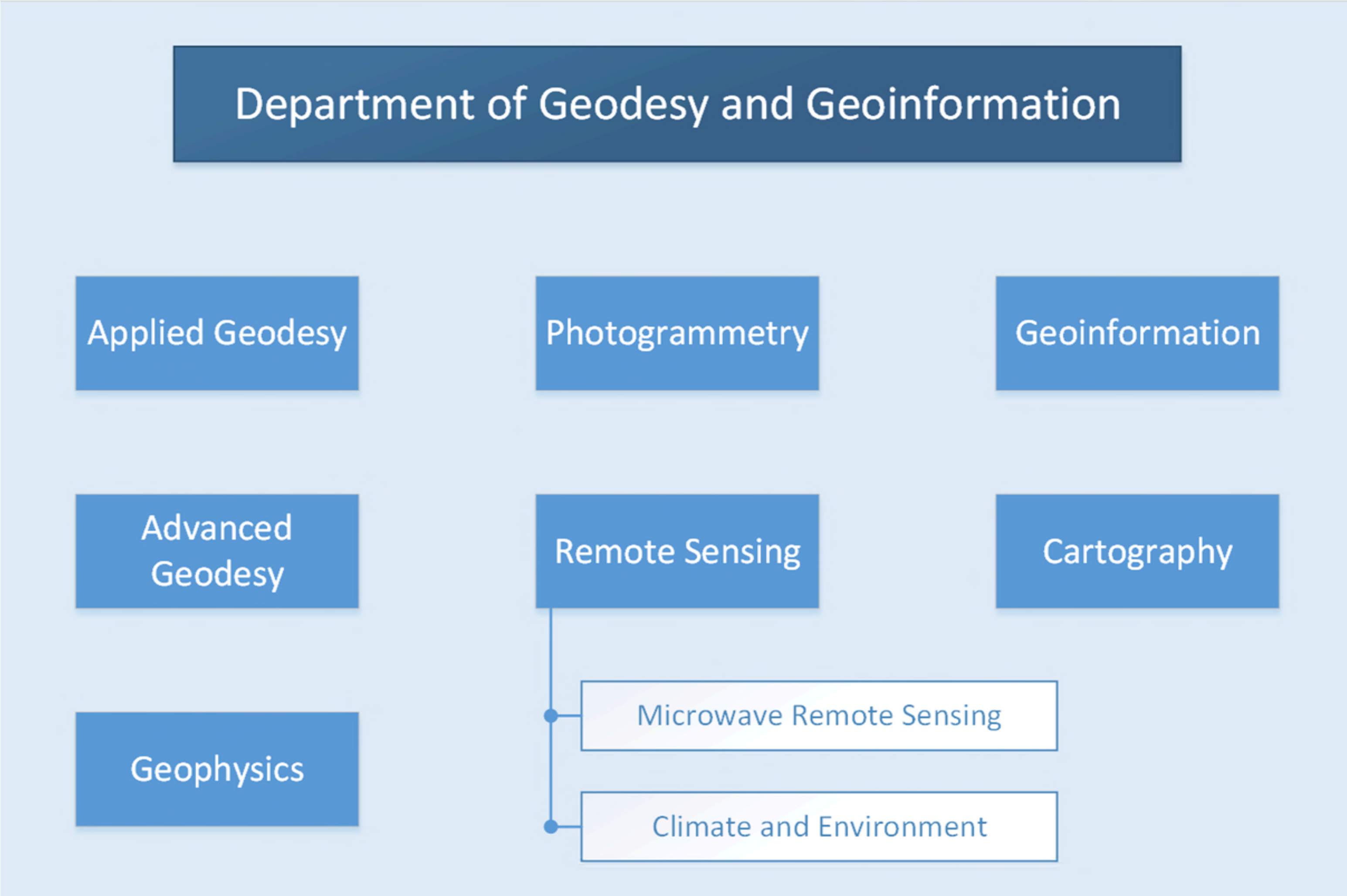
Introduction

Satellite data sources

Applications

Validation and Quality Assurance

# GEO Department



# What Has Happened So Far?

esa

1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

1991-2000: ERS-1 SCAT

1995-2011: ERS-2 SCAT

2006 up to present: METOP-A ASCAT

2012 up to present: METOP-B ASCAT

## TU Wien Research Emphases

1994-1998: First Soil Moisture Studies

1999: TU Wien Algorithm published

2000-2003: Roll-out on Global Scale

2004-2008: Algorithm Adaption to ASCAT

2009-2016: Advanced Error Characterisation Techniques

2012-2020: Model Calibration

2002: First Global Soil Moisture Data Set Published

2008: First Near-Real-Time Soil Moisture Data Service

2012: First Multi-Satellite Soil Moisture Climate Data Record

## Partners & Users Research Highlights

2004: Comparison to Global Soil Moisture Wetness Project

2009-2012: Satellite Inter-comparison Studies

2014: Retrieval Method Inter-comparison

2006: Validation Study by Meteo-France

Since 2008: Data Assimilation Studies at Met Services

Since 2008: Triple Colocation Applied to Soil Moisture

Since 2010: Hydrology Studies by External Teams

# About me

| | |
|---|---|
| 2005-2011 | B.Sc. and M.Sc. Earth Sciences – VU University Amsterdam, The Netherlands |
| 2012-2016 | PhD Remote Sensing TU Wien, Vienna, Austria |
| | *with Wolfgang Wagner and Gunter Bloeschl* |
| | Assessing vegetation dynamics from spaceborne active microwave backscatter observations |
| 2016-……… | PostDoc and Senior Scientist (since 2018) at TU Wien |
| 2018-2021 | ESA Living Planet Fellowship |
| | Sentinel-1 for high resolution monitoring of vegetation dynamics |
| 2020-now | World Bank, Development Agency projects |
| | Drought monitoring with microwave soil moisture |

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 54, NO. 6, JUNE 2016

Analyzing the Vegetation Parameterization in the TU-Wien ASCAT Soil Moisture Retrieval

Mariette Vreugdenhil, Wouter A. Dorigo, Wolfgang W... Richard A. M. de Jeu, Sebastian Hahn, and Ma...

2240 IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 10, NO. 5, MAY 2017

Assessing Vegetation Dynamics Over Mainland Australia With Metop ASCAT

Mariette Vreugdenhil, Sebastian Hahn, Thomas Melzer, Bernhard Bauer-Marschallinger, Christoph Reimer, Wouter Arnoud Dorigo, and Wolfgang Wagner, *Senior Member, IEEE*

Open Access | Article

**Sensitivity of Sentinel-1 Backscatter to Vegetation Dynamics: An Austrian Case Study**

by Mariette Vreugdenhil, Wolfgang Wagner, Bernhard Bauer-Marschallinger, Isabella Pfeil, Irene Teubner, Christoph Rüdiger and Peter Strauss

2348 IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 10, NO. 5, MAY 2017

Dynamic Characterization of the Incidence Angle Dependence of Backscatter Using Metop ASCAT

Sebastian Hahn, Christoph Reimer, Mariette Vreugdenhil, Thomas Melzer, and Wolfgang Wagner, *Senior Member, IEEE*

Check for updates

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Microwave remote sensing for agricultural drought monitoring: Recent developments and challenges

Mariette Vreugdenhil[1*†], Isabella Greimeister-Pfeil[1†], Wolfgang Preimesberger[1], Stefania Camici[2], Wouter Dorigo[1], Markus Enenkel[3], Robin van der Schalie[4], Susan Steele-Dunne[5] and Wolfgang Wagner[1]

ELSEVIER

Remote Sensing of Environment
Volume 191, 15 March 2017, Pages 215-231

Validation of SMAP surface soil moisture products with core validation sites

# Introduction

# Approaches to Remote Sensing of Soil Moisture

Optical to Mid-Infrared (0.4 – 3 μm)

Change of "colour"

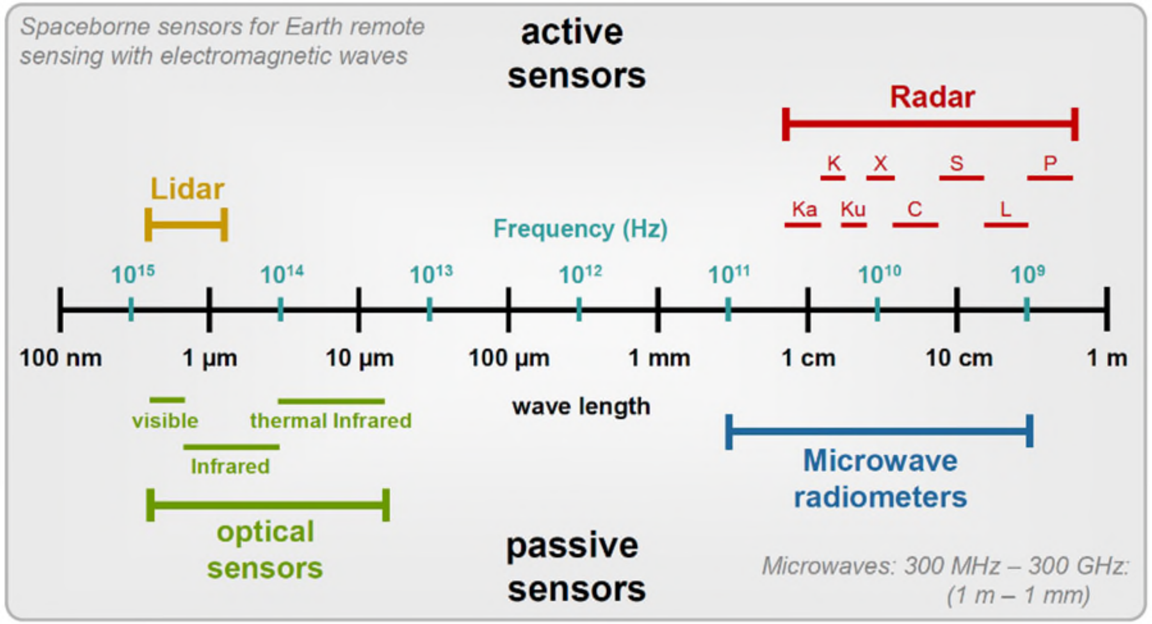
Water absorption bands at 1.4, 1.9 and 2.7 μm

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




https://earth.esa.int/documents/10174/642943/6-LTC2013-SAR-Moreira.pdf

# Active Microwave Sensors

create their own electromagnetic energy

**Observable**: Backscattering coefficient $\sigma^0$

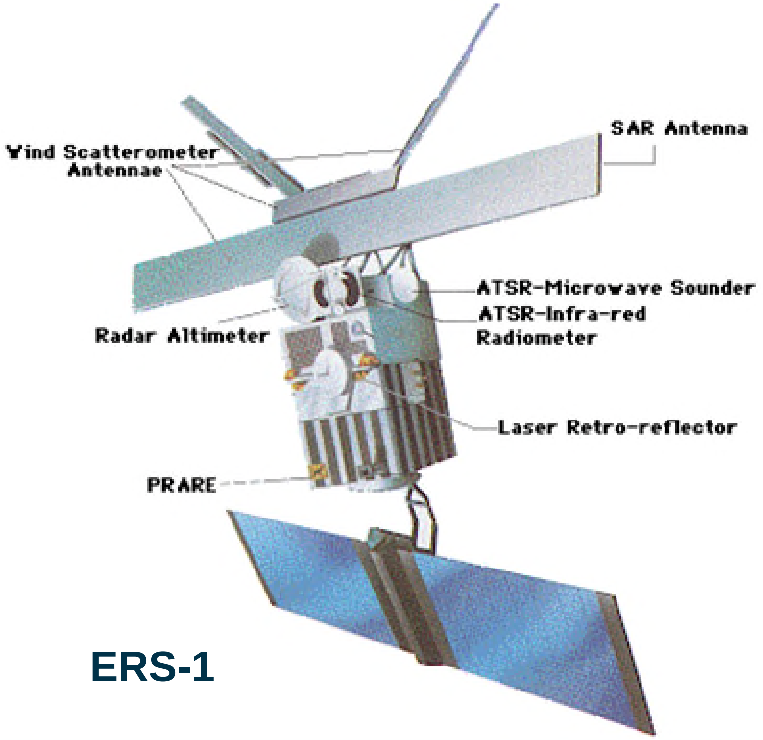
a measure of the reflectivity of the Earth surface

Sensors

- Altimeters
- Side-looking real aperture radar
- Scatterometer (SCAT)
- Synthetic Aperture Radar (SAR)

Sensitive to roughness and vegetation

High spatial resolution




ERS-1

# Passive Microwave Sensors

record reflected or emitted energy from the Earth surface

**Observable**: Brightness temperature

$T_B = eT_s$, where e is the emissivity and $T_s$ is the surface temperature

Sensors

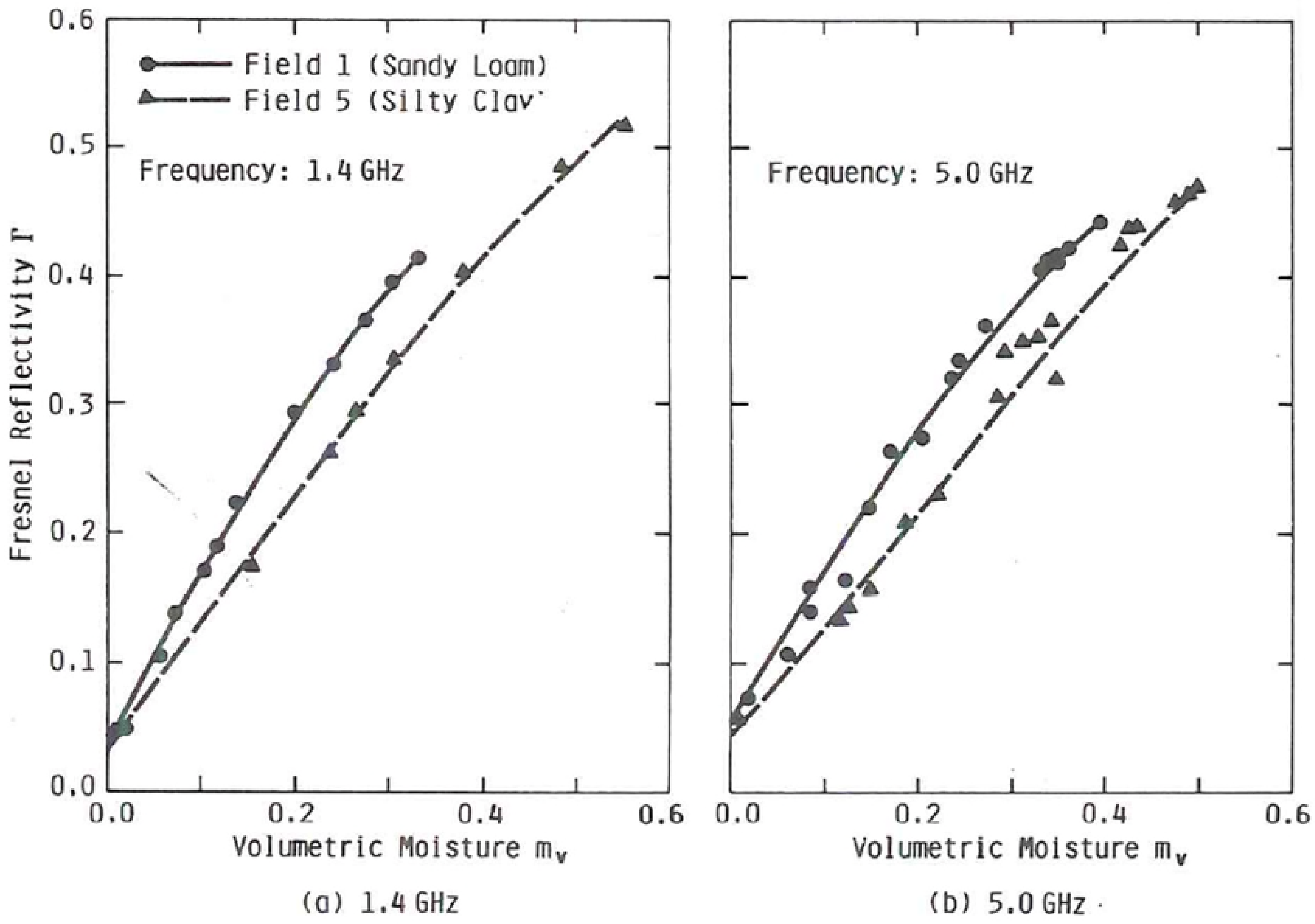
Microwave radiometers

Less sensitive to structural effects

Dependent on land surface temperature

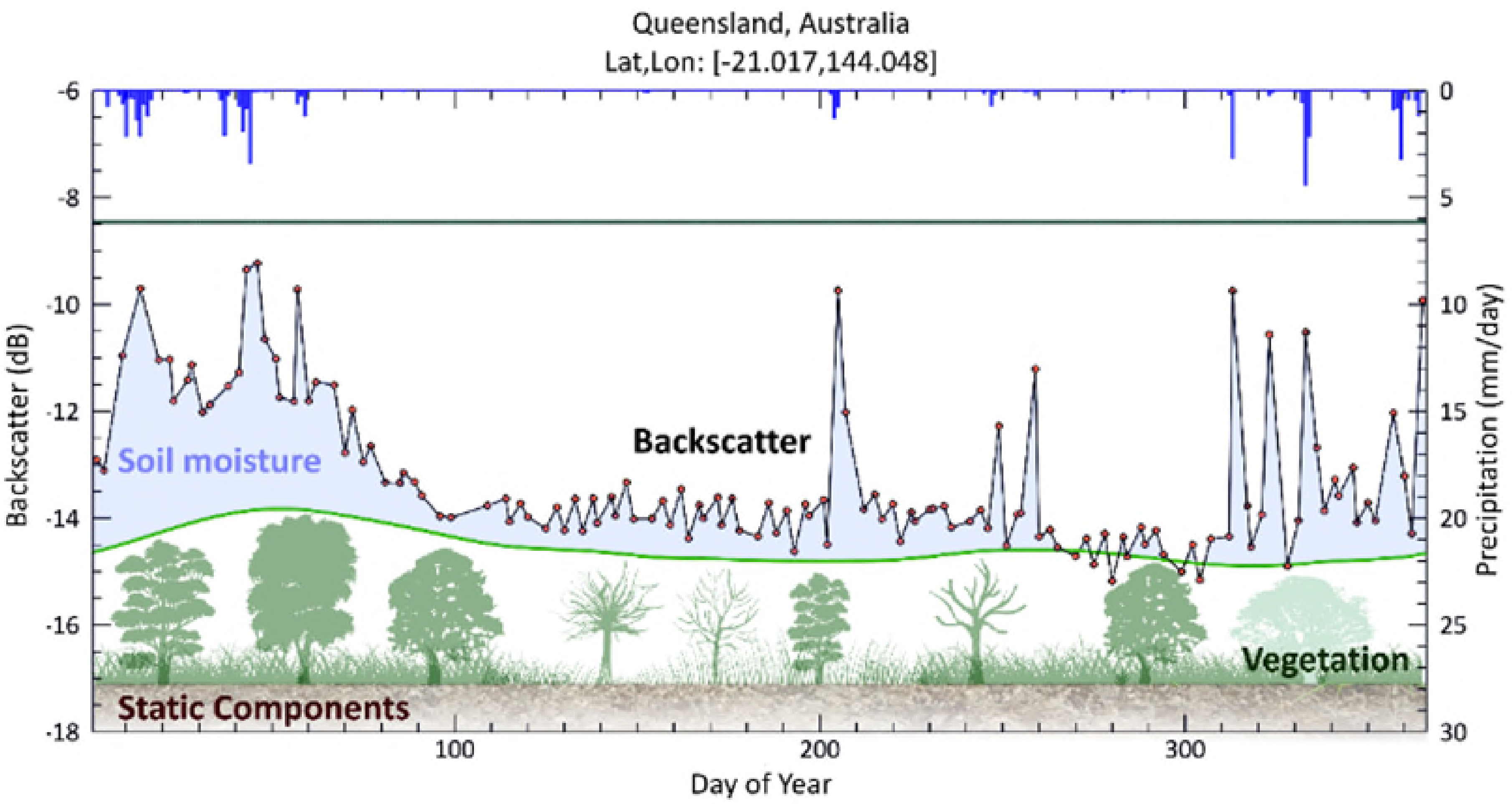
# Active and Passive Sensing of Soil Moisture

Kirchhoff's law: $e = 1 - r$ where $r$ is the reflectivity




From F.T.Ulaby, R.K.Moore, A.K.Fung: *Microwave Remote Sensing: Active and Passive Vol.1,* Artech House (1981)

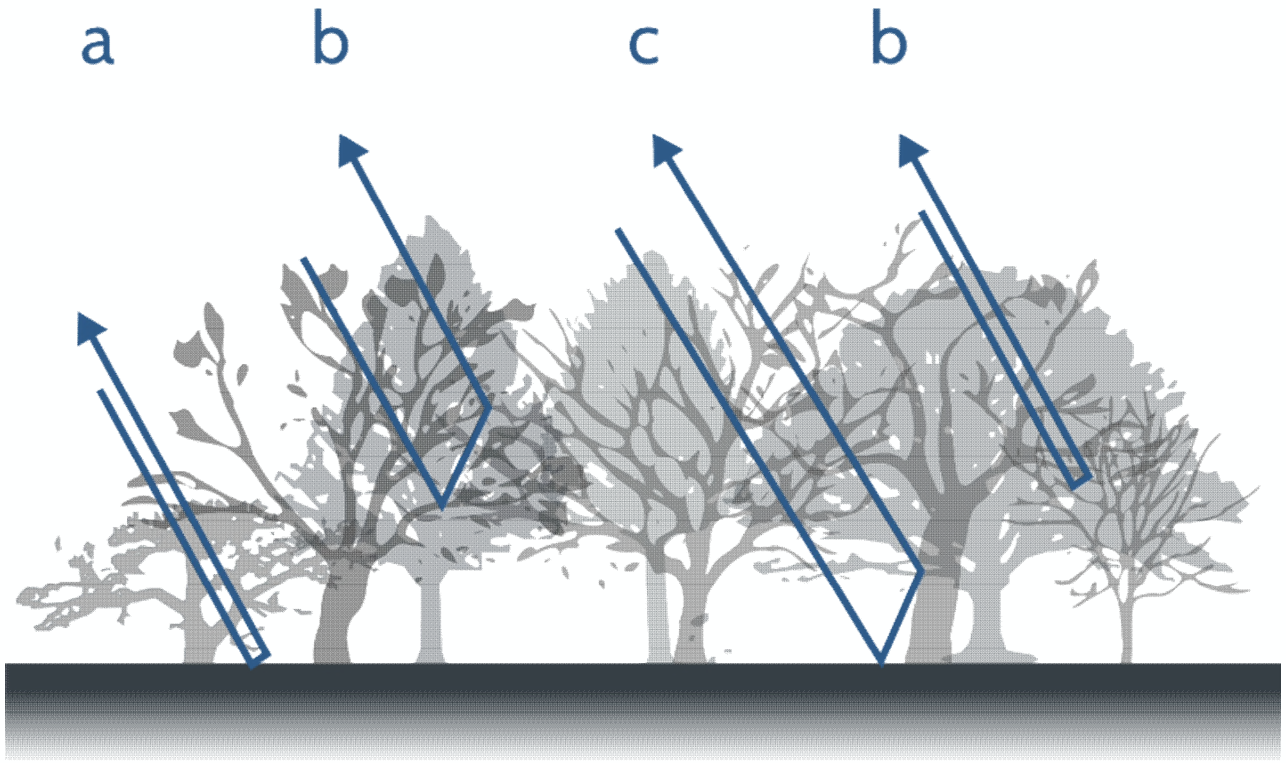
# Active and Passive Sensing of Soil Moisture




*Graphic by M. Vreugdenhil, TU Wien*

# Example for a vegetated surface

$$\sigma° = \sigma°_{Surface} + \sigma°_{Volume} + \sigma°_{Interaction}$$

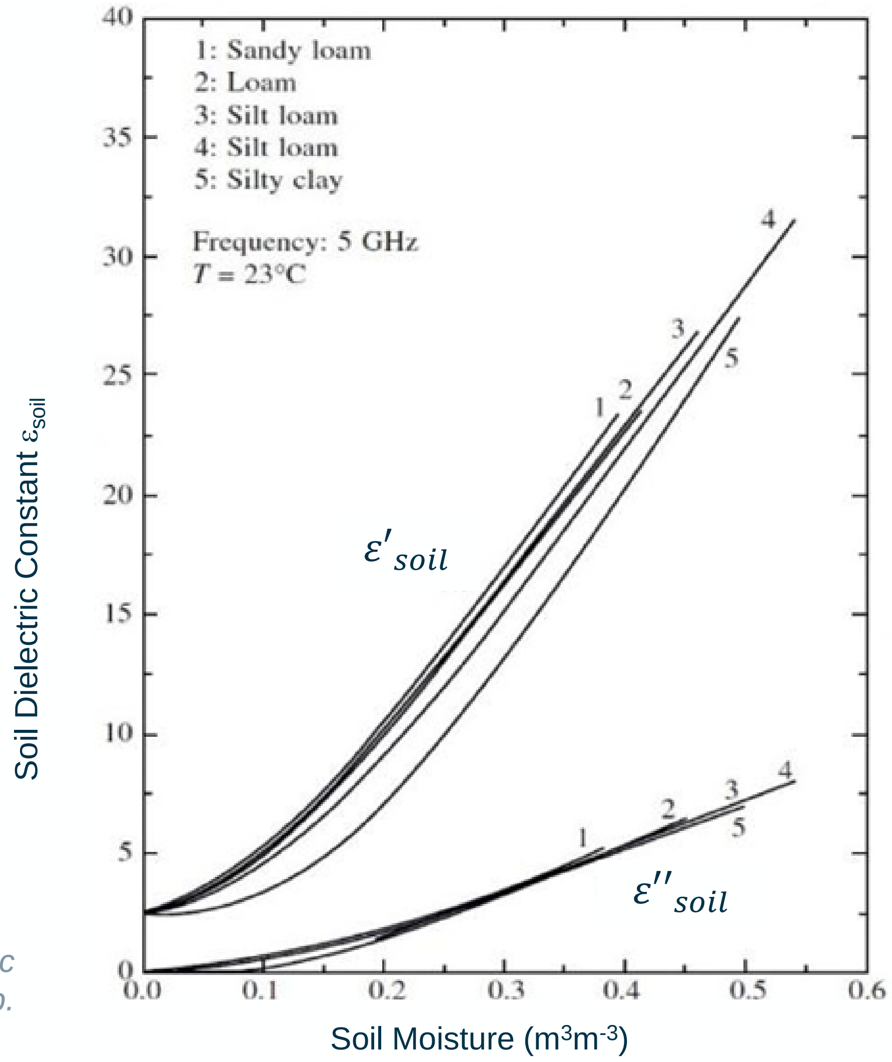



Graphic by M. Vreugdenhil, TU Wien

# Soil Contribution

Soil scattering and emission is principally driven by

- Soil dielectric constant
  - Soil moisture
  - Texture




*Behari (2005) Microwave dielectric behaviour of wet soils, Springer, 164 p.*

# Linear relation for soil moisture?

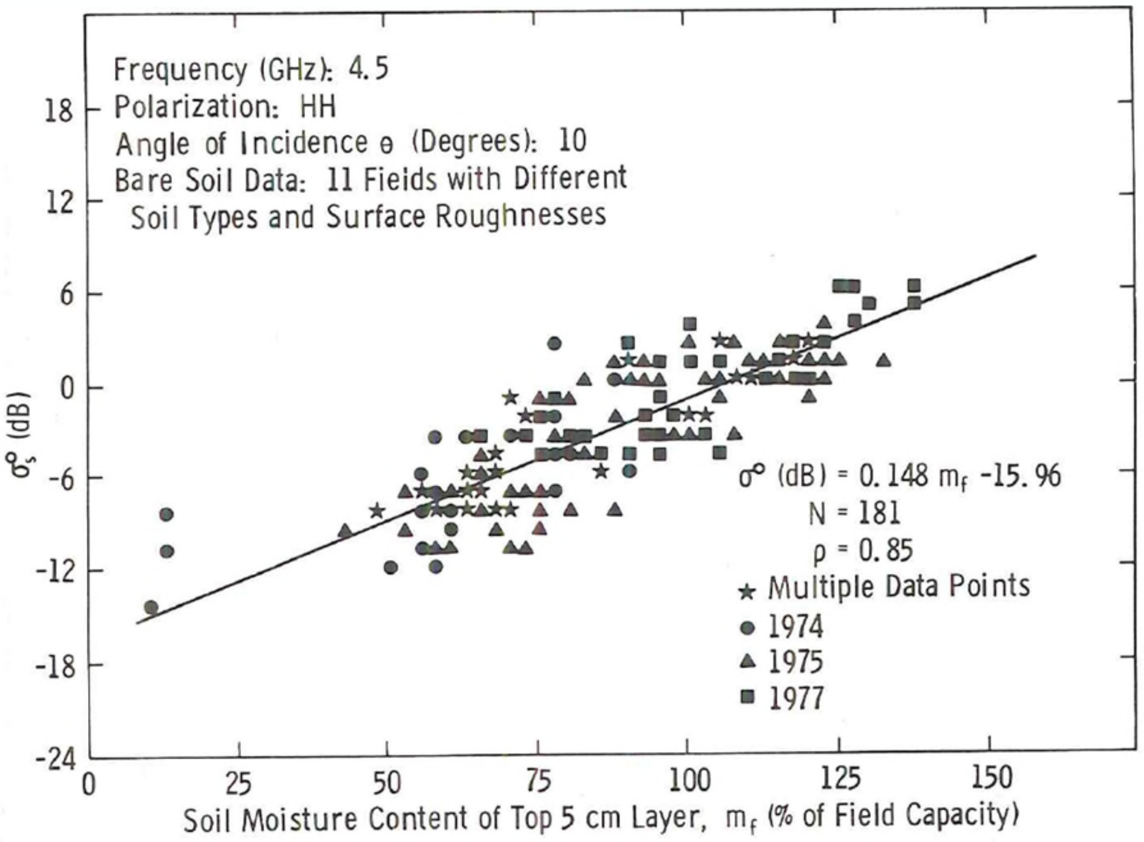
$$\sigma^0_{soil}[dB] = A + Bm_v$$

$$\sigma^0_{soil}[m^2m^{-2}] = 10^{\frac{A+Bm_v}{10}} = e^{\frac{ln10(A+Bm_v)}{10}} = ae^{bm_v}$$

$m_v$ = soil moisture

A = dry soil backscatter

B = sensitivity

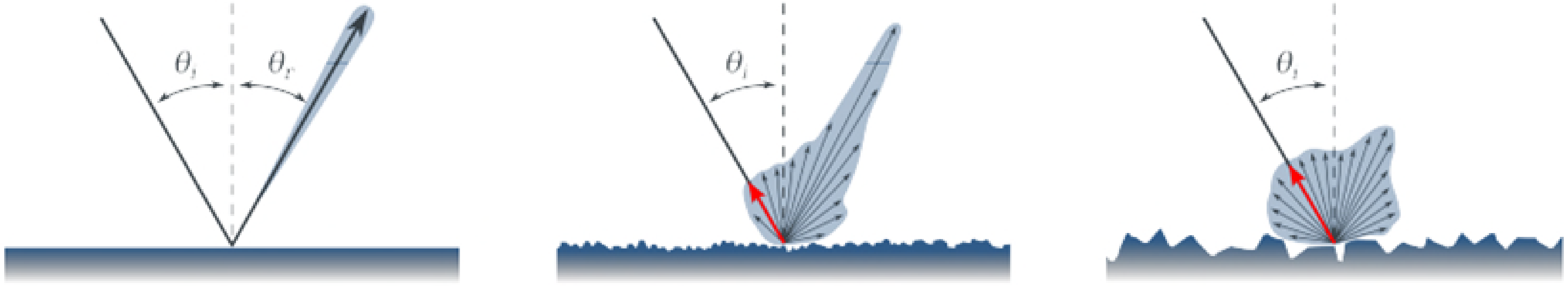


# Soil Contribution

Soil scattering and emission is principally driven by

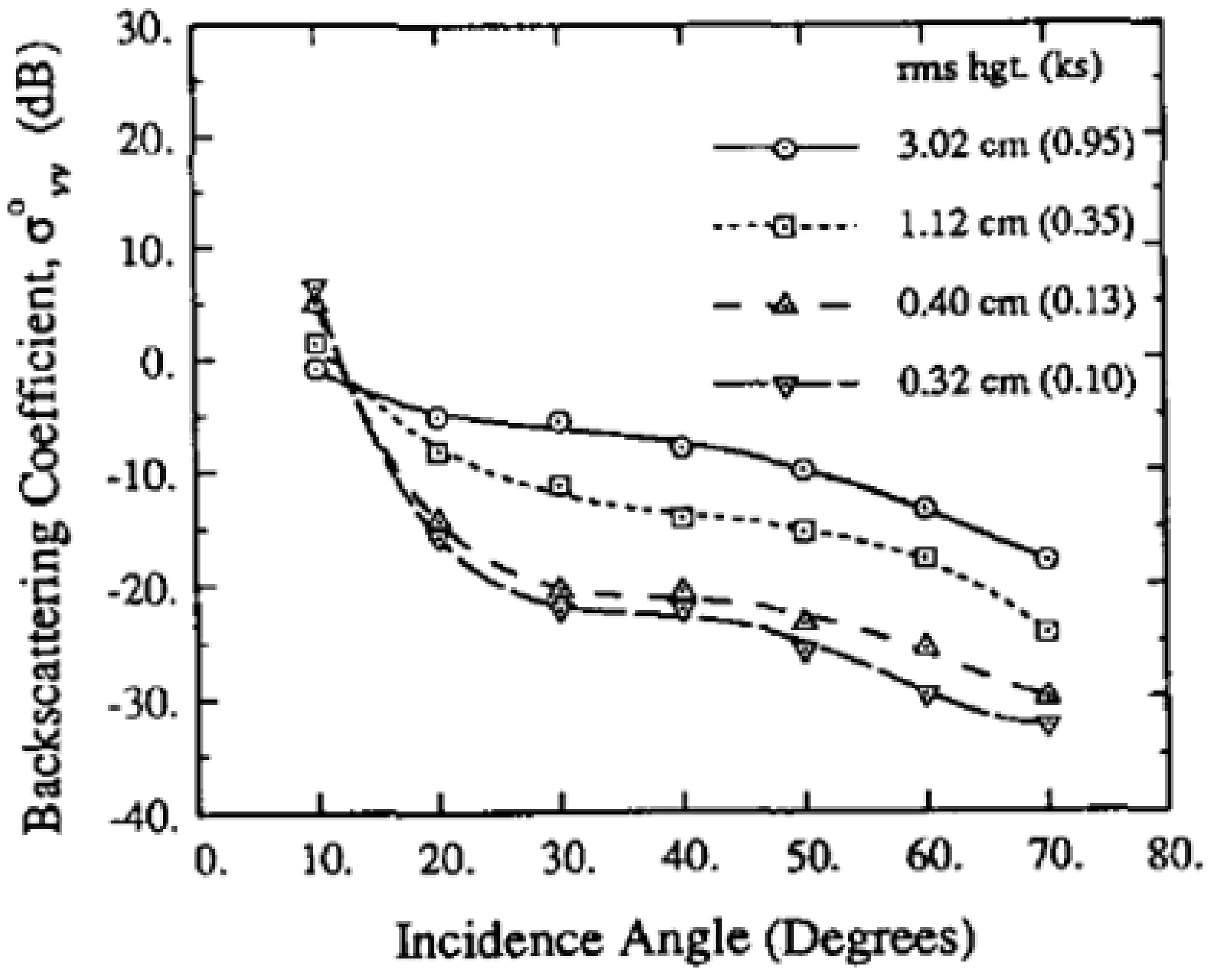
- Soil dielectric constant
  - Soil moisture
  - Texture
- Soil surface “roughness”
  - Relative to wavelength
  - Dependent on soil moisture

*Graphic by M. vreugdenhil, TU Wien*



# Soil Contribution

Roughness affects the distribution of the scattered energy



# Soil Contribution

Many models exist to describe surface roughness

Geometric Optics Model

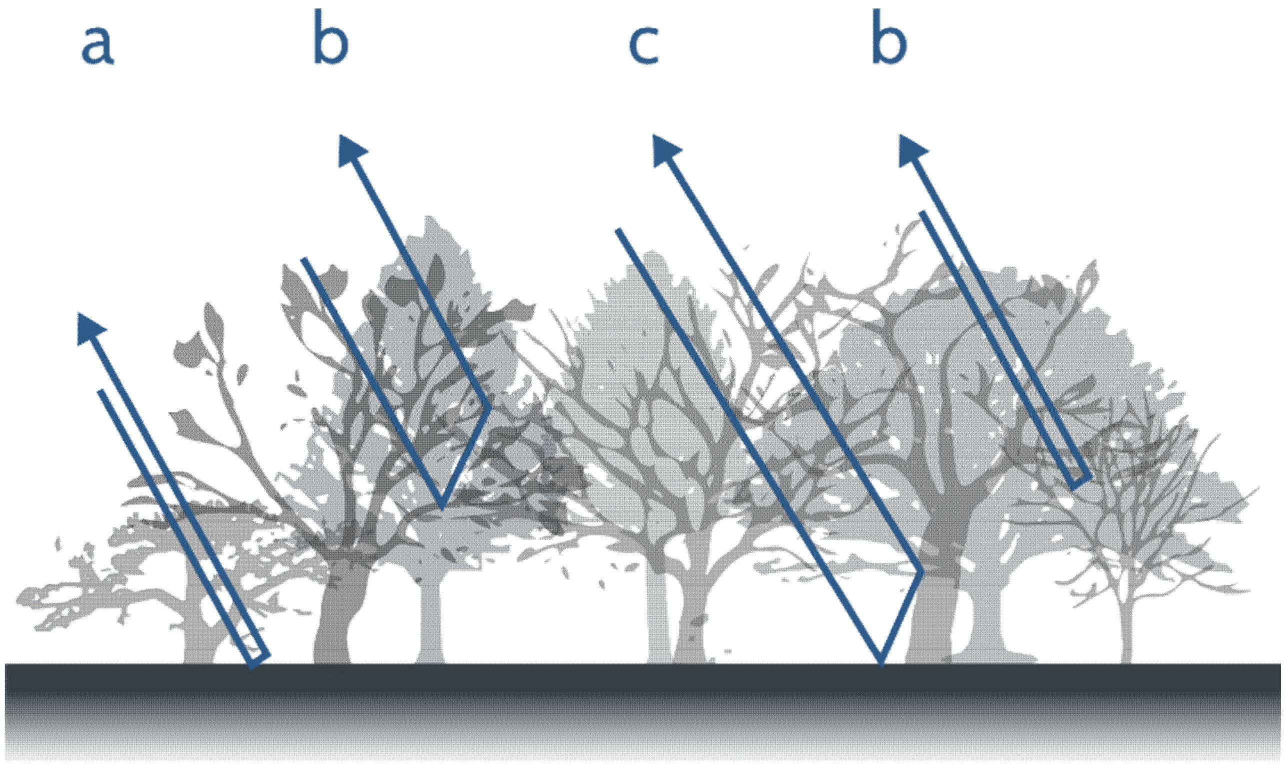
Small Perturbations Model

Integral Equation Model

Approximations must be made – How do you quantify roughness?

# Example for a vegetated surface

$$\sigma° = \sigma°_{Surface} + \sigma°_{Volume} + \sigma°_{Interaction}$$



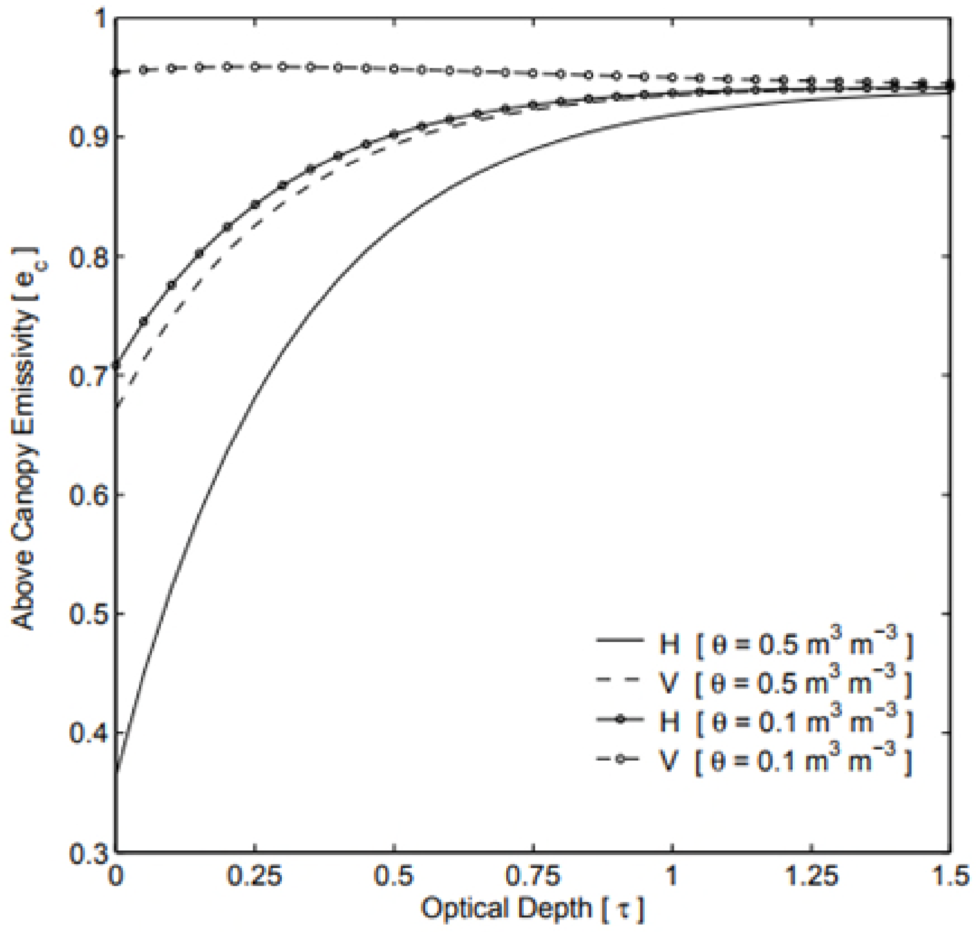

Graphic by M. Vreugdenhil, TU Wien

# Vegetation attenuation

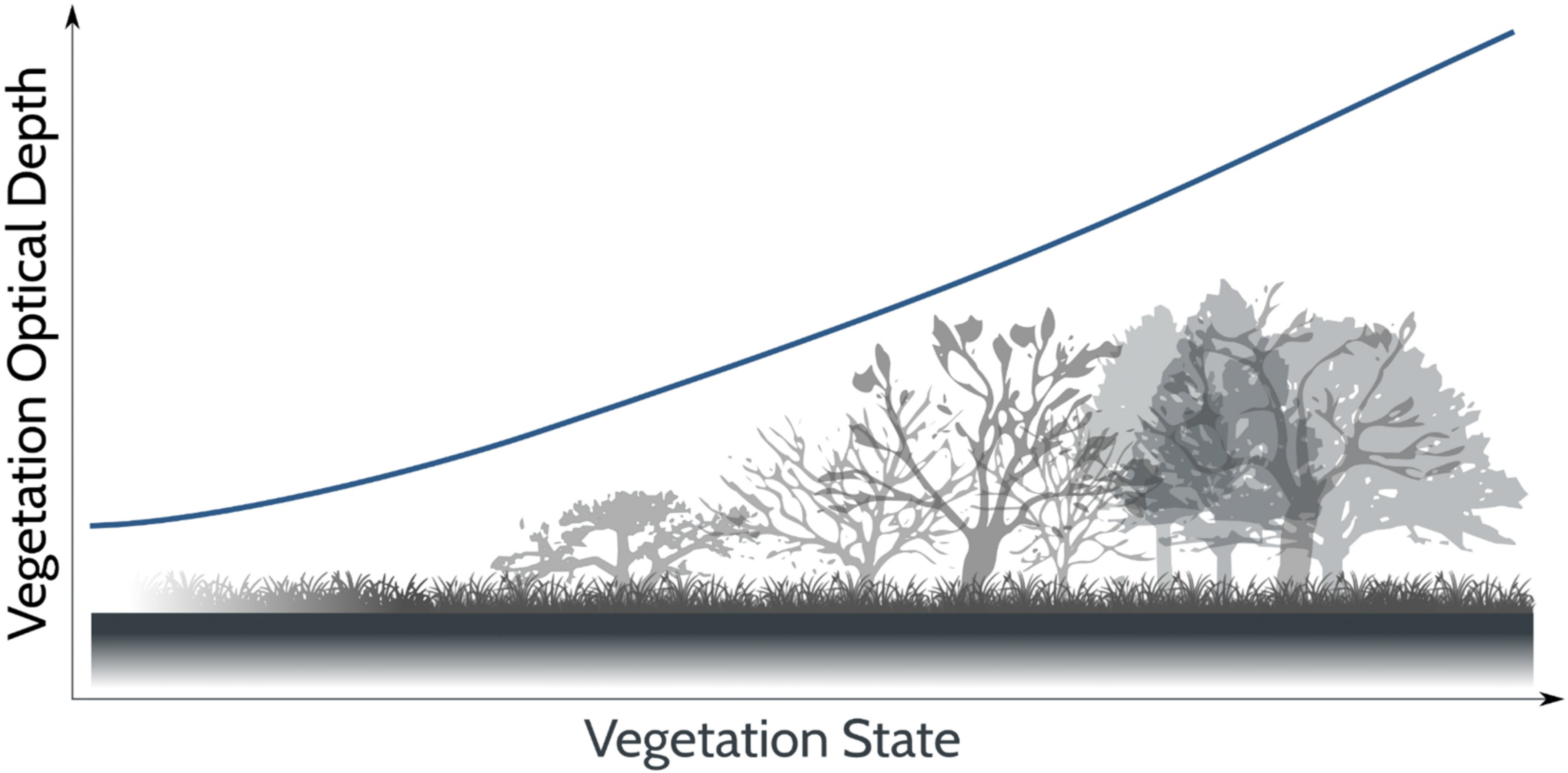
The effect of the vegetation optical depth on the emissivity. At H-polarization,

the sensitivity of the above canopy emissivity is severely reduced at an optical depth of about 0.7.

*de Jeu, R. A. M. (2003). Retrieval of Land Surface Parameters using Passive Microwave Remote Sensing. [PhD-Thesis - Vrije Universiteit Amsterdam].*



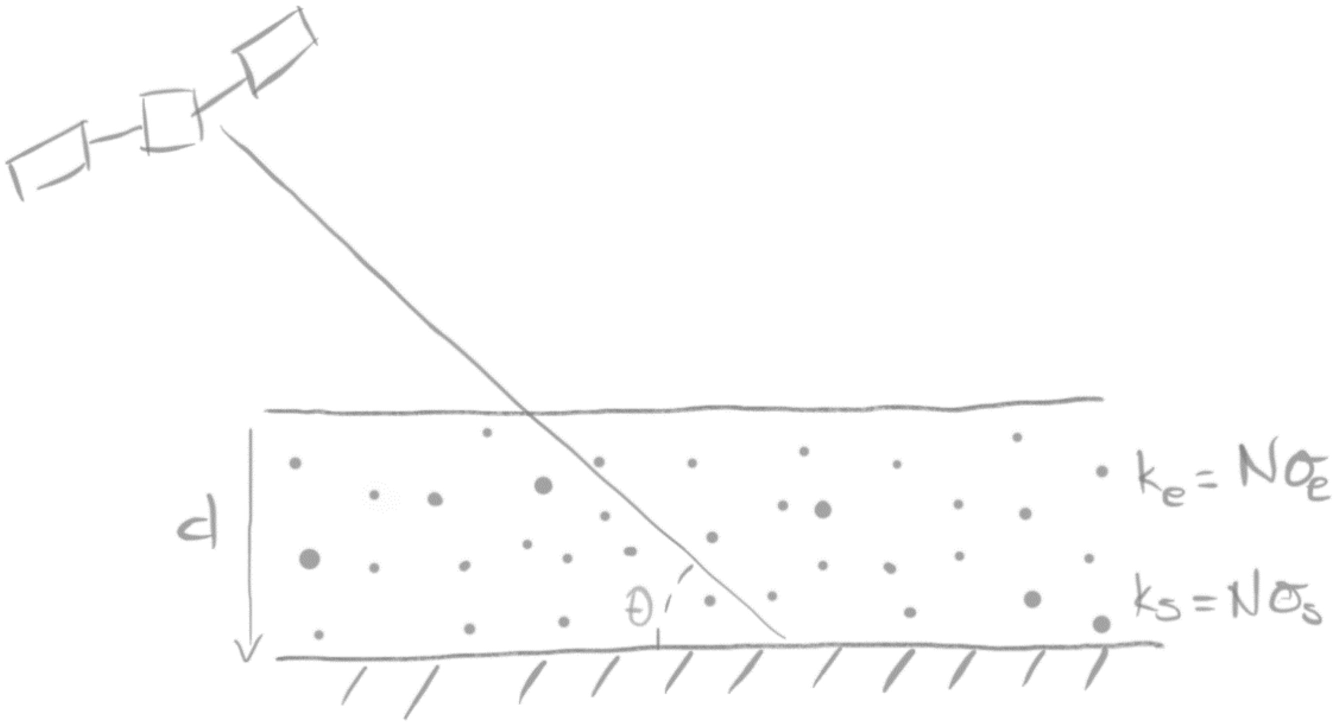
# Vegetation Optical Depth



# Example for a vegetated surface

## Water cloud model ($\omega - \tau$ model)

$$\sigma°(\theta) = \sigma°_s(\theta)e^{\frac{-2\tau}{cos\theta}} + \omega cos\theta\left(1 - e^{\frac{-2\tau}{cos\theta}}\right)$$




$$k_s = N\sigma_s$$

$$k_e = N\sigma_e$$

$\omega = \frac{k_s}{k_e}$ Single Scattering Albedo

$\tau = ked$ Vegetation Optical Depth

*Graphic by M. Vreugdenhil, TU Wien*

# Parsimonious models - water cloud model

$$\sigma°(\theta) = \sigma°_s(\theta)e^{\frac{-2\tau}{cos\theta}} + \omega cos\theta\left(1 - e^{\frac{-2\tau}{cos\theta}}\right)$$

Remember bare soil backscatter:

$$\sigma°(\theta) = \left(\frac{k_s}{2ke}\right)\left[1 - e^{-\frac{2ked}{cos\theta}}\right]cos\theta + \sigma°_s(\theta)e^{-\frac{2ked}{cos\theta}}$$

$$\sigma°_s = ae^{bm_v}$$

$$\sigma°(\theta) = \left(\frac{k_s}{2ke}\right)\left[1 - e^{-\frac{2ked}{cos\theta}}\right]cos\theta + acos\theta e^{bm_v - \frac{2ked}{cos\theta}}$$

# Parsimonious models - water cloud model

$$\sigma°(\theta) = \left(\frac{k_s}{2ke}\right)\left[1 - e^{-\frac{2ked}{cos\theta}}\right]cos\theta + acos\theta e^{bm_v - \frac{2ked}{cos\theta}}$$

$$C = \frac{N\sigma_b}{2N\sigma_e} = \frac{k_s}{2ke} = \frac{\omega}{2}$$

*C* is related to the extinction and scattering of the particles

$$DW \cong 2N\sigma_e = 2k_e$$

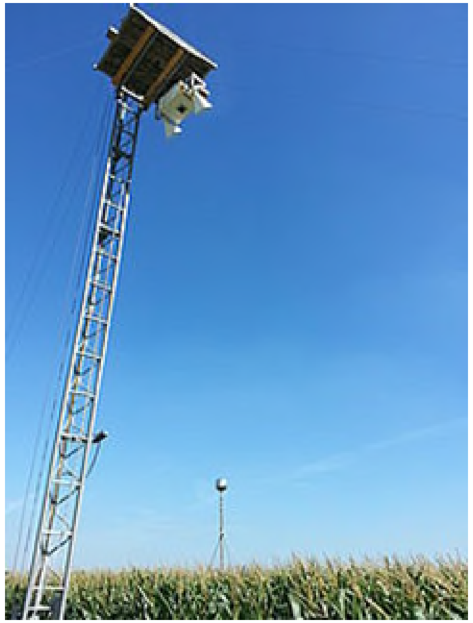
$$2k_e d = 2\tau$$

*D* is related to the extinction of the particles:

$$\sigma°(\theta) = Ccos\theta\left(1 - e^{\frac{-DWd}{cos\theta}}\right) + acos\theta e^{bm_v \frac{-DWd}{cos\theta}}$$

# Parsimonious models - water cloud model

How do we calibrate, *a*, *b*, *C* and *D*?



Radar over corn field. Courtesy of S.C. Steele-Dunne, TU Delft

TABLE I. Summary of ground truth data for the 1974 radar cross section data. *W* is the volumetric water content of the canopy; *h* is the canopy height; $m_s$ is the soil moisture content.

| Date | $W$ (kg/m$^3$) | $h$ (m) | $m_s$ (kg/m$^3$) |
|---|---|---|---|
| *Alfalfa* | | | |
| May 22 | 1.353 | .17 | 280 |
| June 14 | 3.488 | .43 | 330 |
| June 24 | 3.091 | .55 | 230 |
| June 28 | 2.000 | .55 | 170 |
| July 5 | 2.456 | .55 | 300 |
| July 10 | 4.000 | .11 | 150 |
| July 17 | 2.138 | .29 | 20 |
| July 23 | 3.111 | .45 | 30 |
| Aug. 12 | 2.671 | .73 | 160 |
| *Corn* | | | |
| May 20 | .693 | .30 | 240 |
| May 24 | 1.503 | .40 | 260 |
| May 30 | 2.268 | .58 | 120 |
| June 5 | 2.358 | .88 | 100 |
| June 13 | 4.968 | 1.25 | 340 |
| June 26 | 3.447 | 2.3 | 80 |
| July 1 | 3.825 | 2.6 | 70 |
| July 8 | 3.960 | 2.6 | 300 |
| July 11 | 4.410 | 2.6 | 150 |
| July 16 | 3.366 | 2.6 | 60 |
| July 22 | 4.338 | 2.6 | 40 |
| Aug. 5 | 2.124 | 2.6 | 70 |
| Aug. 15 | 0.891 | 2.7 | 260 |
| Sept. 5 | 1.359 | 2.7 | 290 |
| Sept. 19 | 0.522 | .33 | 100 |
| *Milo* | | | |
| July 12 | 2.200 | .30 | 60 |
| July 18 | 4.200 | .46 | 30 |
| July 25 | 6.000 | .71 | 30 |
| Aug. 1 | 25.600 | .77 | 30 |
| Aug. 7 | 7.500 | .92 | 260 |
| Aug. 19 | 11.900 | .92 | 120 |
| Aug. 21 | 11.600 | .92 | 70 |
| Aug. 29 | 6.400 | 1.12 | 310 |
| Sept. 17 | 5.300 | 1.17 | 170 |
| *Wheat* | | | |
| May 21 | 5.760 | .90 | 360 |
| May 27 | 5.600 | .96 | 400 |
| May 31 | 5.520 | .96 | 310 |
| June 6 | 4.240 | .96 | 350 |
| June 10 | 4.160 | .96 | 360 |
| June 17 | 2.550 | .96 | 20 |
| June 21 | 1.040 | .84 | 310 |
| June 25 | 0.880 | .32 | 210 |

# Parsimonious models - water cloud model

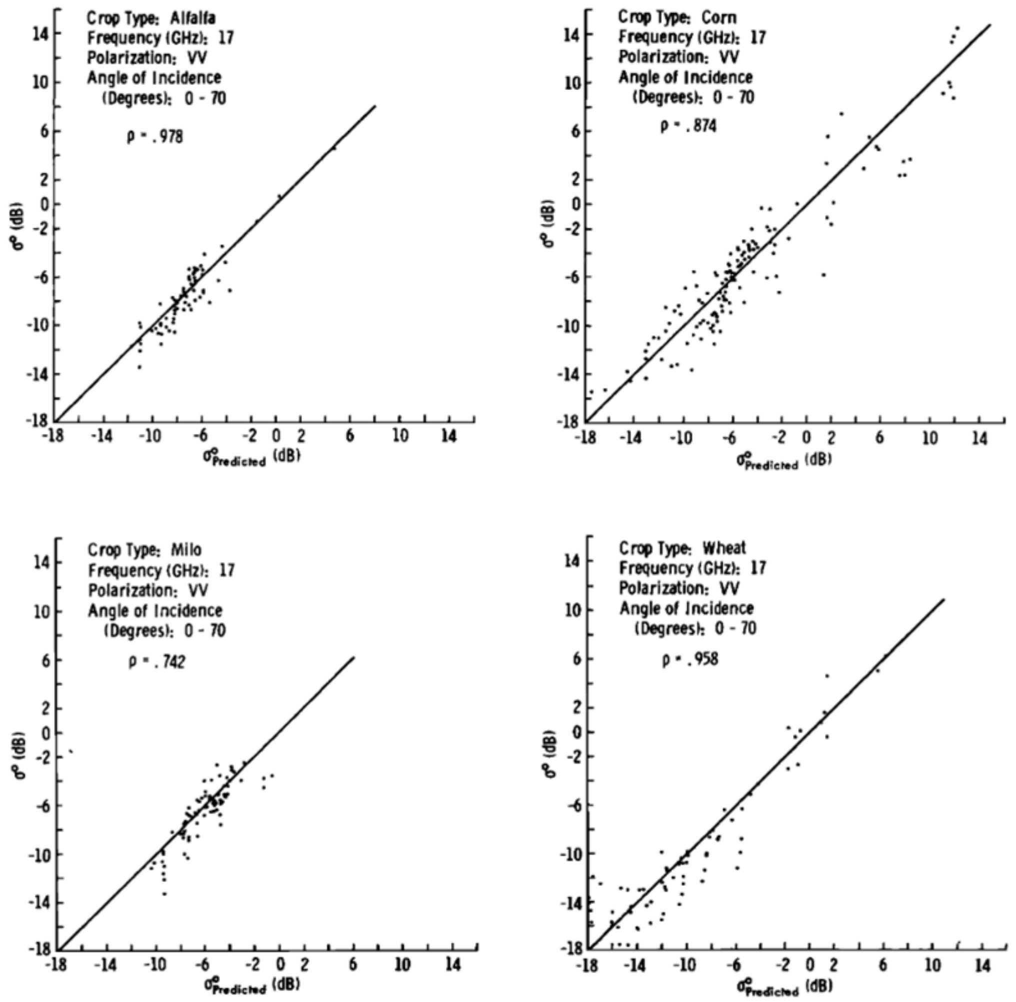
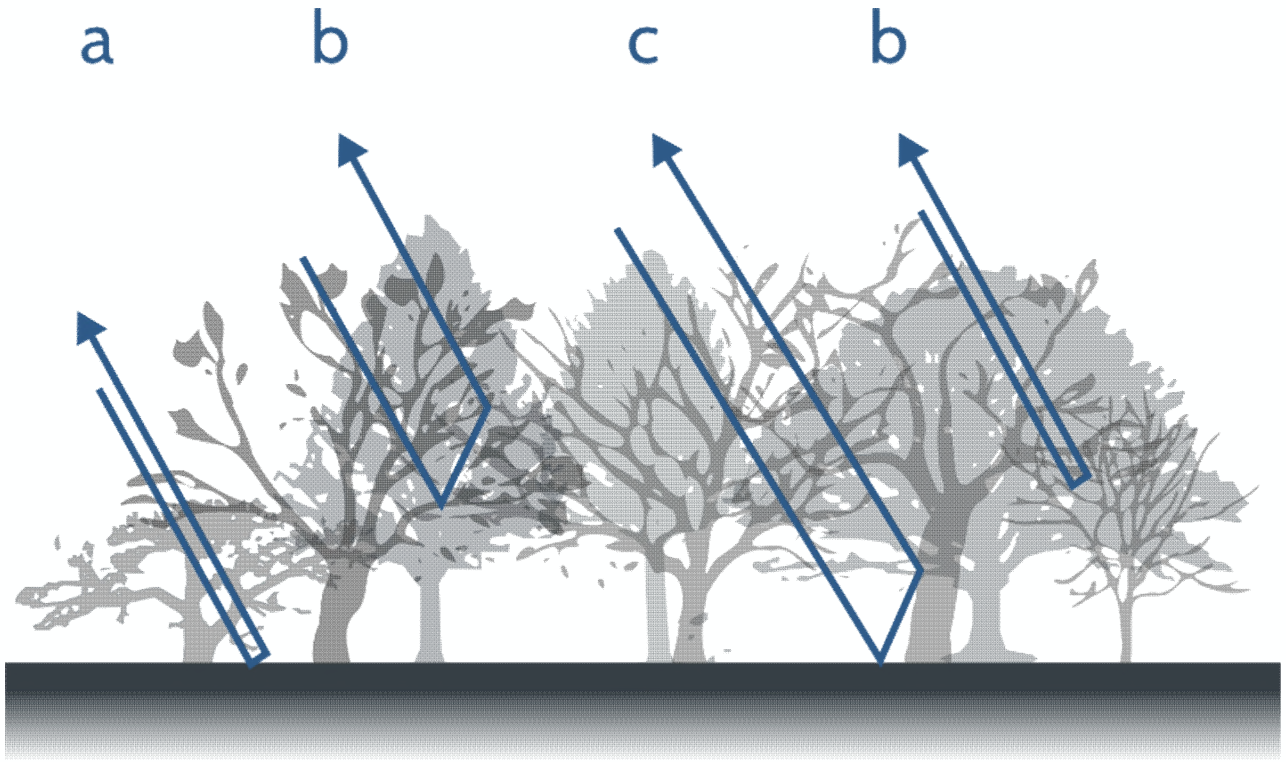



Fig. 2. Measurements versus model predictions of σ° for alfalfa, corn, milo, and wheat.

## Radiative transfer model – passive systems

$$T_b = (e_r T_s) e^{\frac{-\tau}{\cos\theta}} + (1-\omega)T_c\left(1 - e^{\frac{-\tau}{\cos\theta}}\right) + (1-\omega)T_c\left(1 - e^{\frac{-\tau}{\cos\theta}}\right)(1 - er)e^{\frac{-\tau}{\cos\theta}}$$




*Graphic by M. Vreugdenhil, TU Wien*

# Land parameter retrieval method

Nonlinear iterative forward modelling procedure

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 39, NO. 8, AUGUST 2001 1643

A Methodology for Surface Soil Moisture and Vegetation Optical Depth Retrieval Using the Microwave Polarization Difference Index

Manfred Owe, Richard de Jeu, and Jeffrey Walker

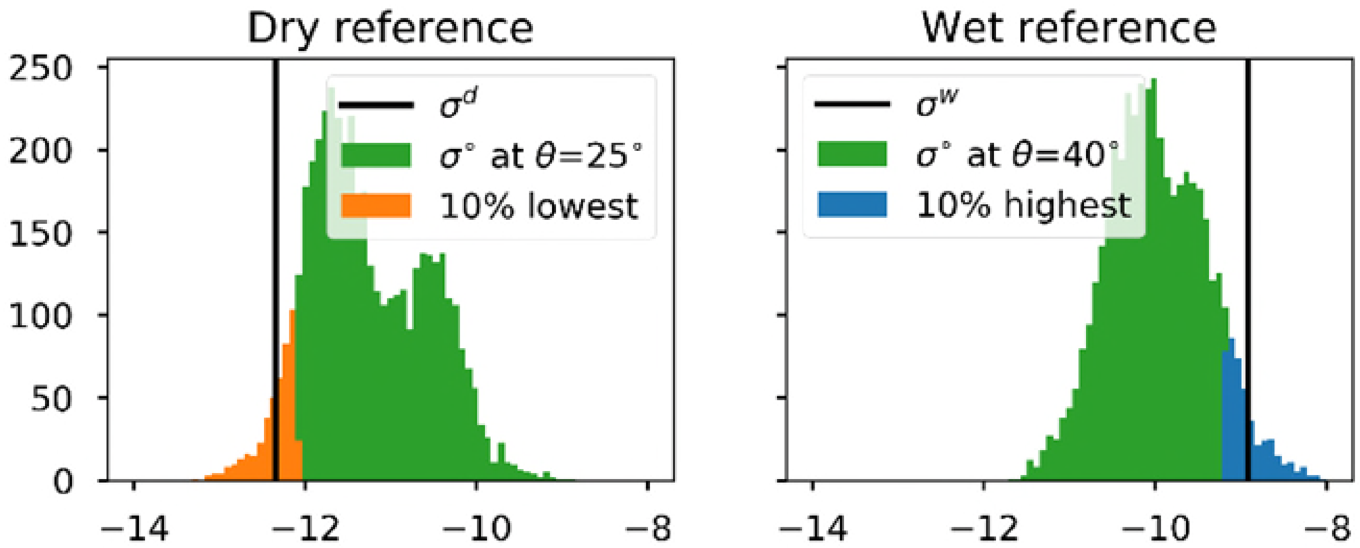
$$T_b = (e_r T_s) e^{\frac{-\tau}{cos\theta}} + (1-\omega) T_c \left(1 - e^{\frac{-\tau}{cos\theta}}\right) + (1-\omega) T_c \left(1 - e^{\frac{-\tau}{cos\theta}}\right)(1 - er) e^{\frac{-\tau}{cos\theta}}$$

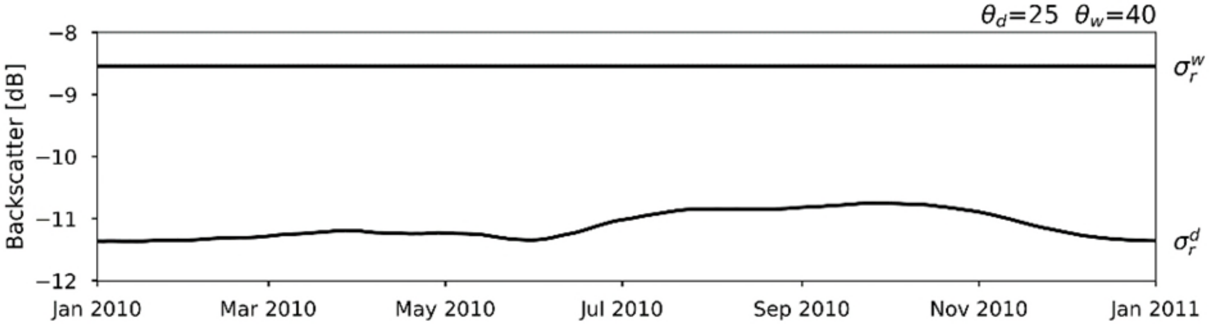
Single scattering albedo and temperature are known

**Optimizing transmissivity** $\Gamma = \text{transmissivity} = e^{-\tau/cosu}$ **and emissivity** $e_r$

Dielectric mixing model to obtain **soil moisture** from emissivity

## Change detection method – Active systems




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

*Graphics by S. Hahn, TU Wien*

# Where do retrievals go wrong?

Low signal-to-noise ratio (known from error propagation)

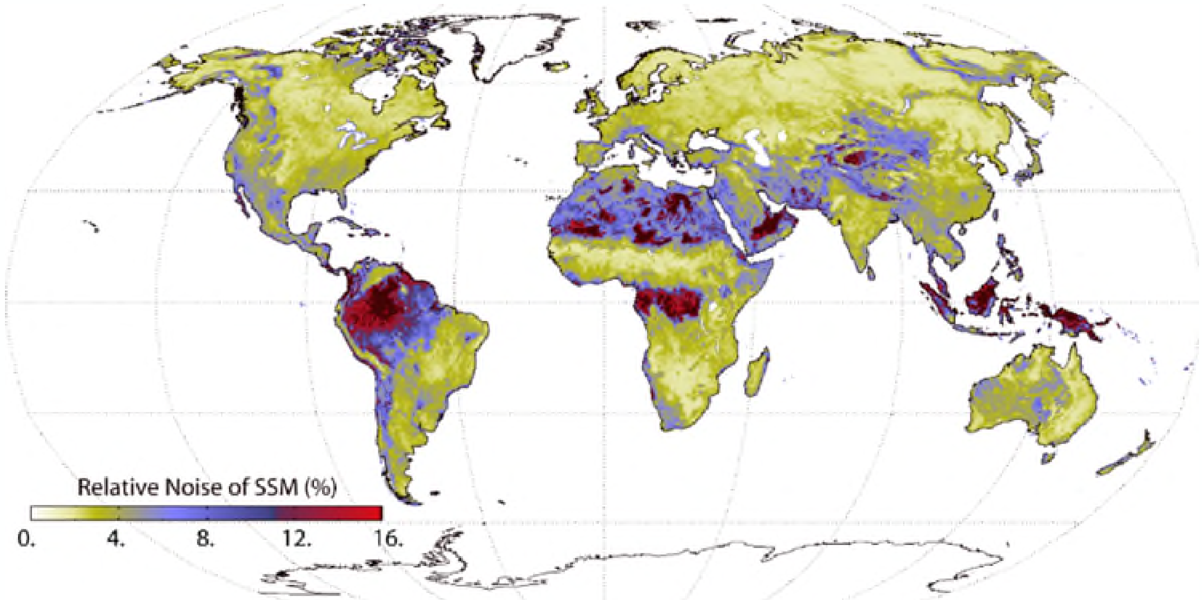
- Vegetation
- Mountainous regions
- Urban areas

Where does the model fail?

- Frozen ground
- Snow cover
- Water surfaces

Known issues

- Changes in land cover (urban sprawl, deforestation, etc.)
- Radio frequency interference
- Sub-surface soil scattering




Graphics by S. Hahn, TU Wien

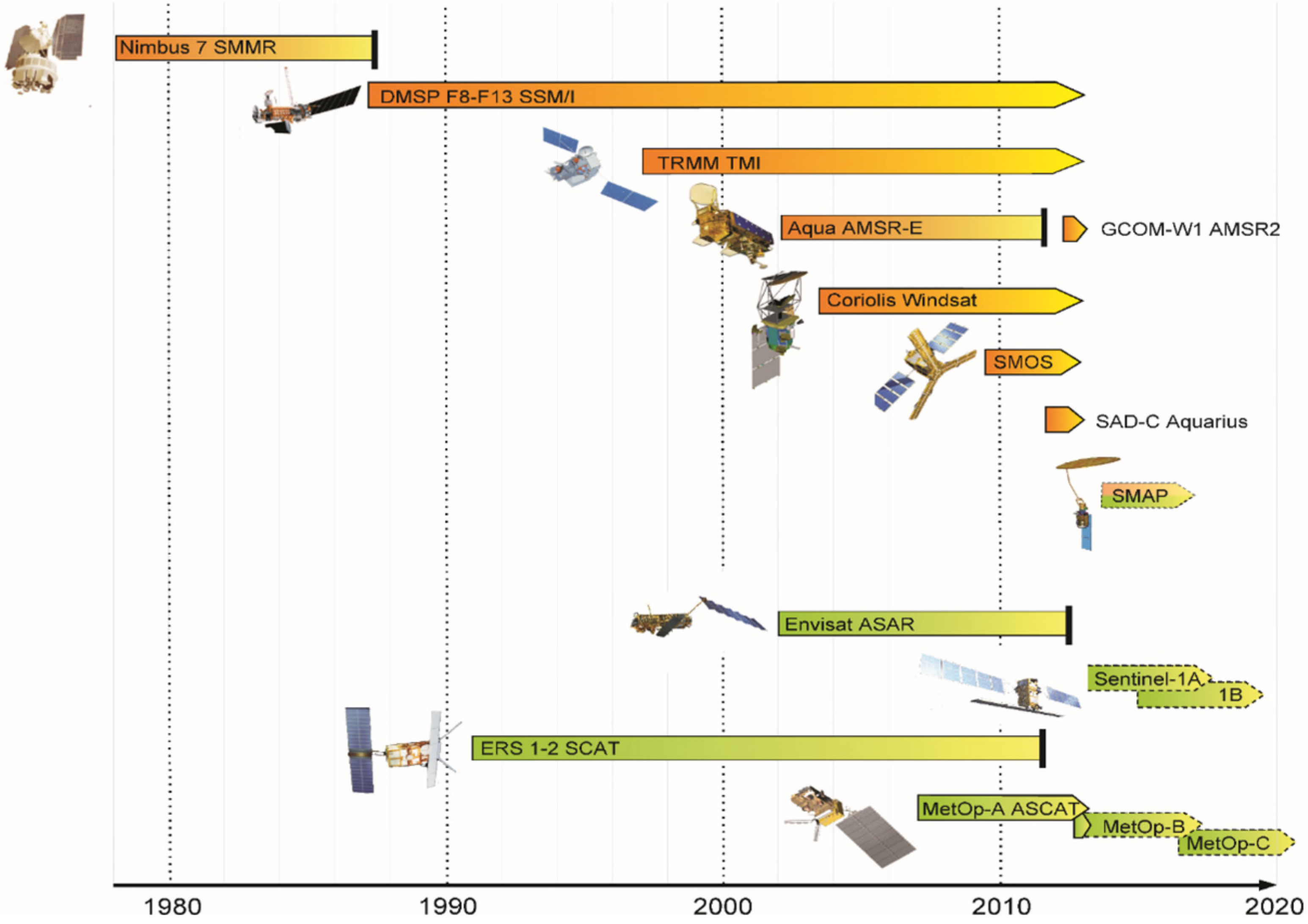
# SATELLITE DATA SOURCES

# Microwave Remote Sensing Satellites






# Active and Passive Microwave Missions



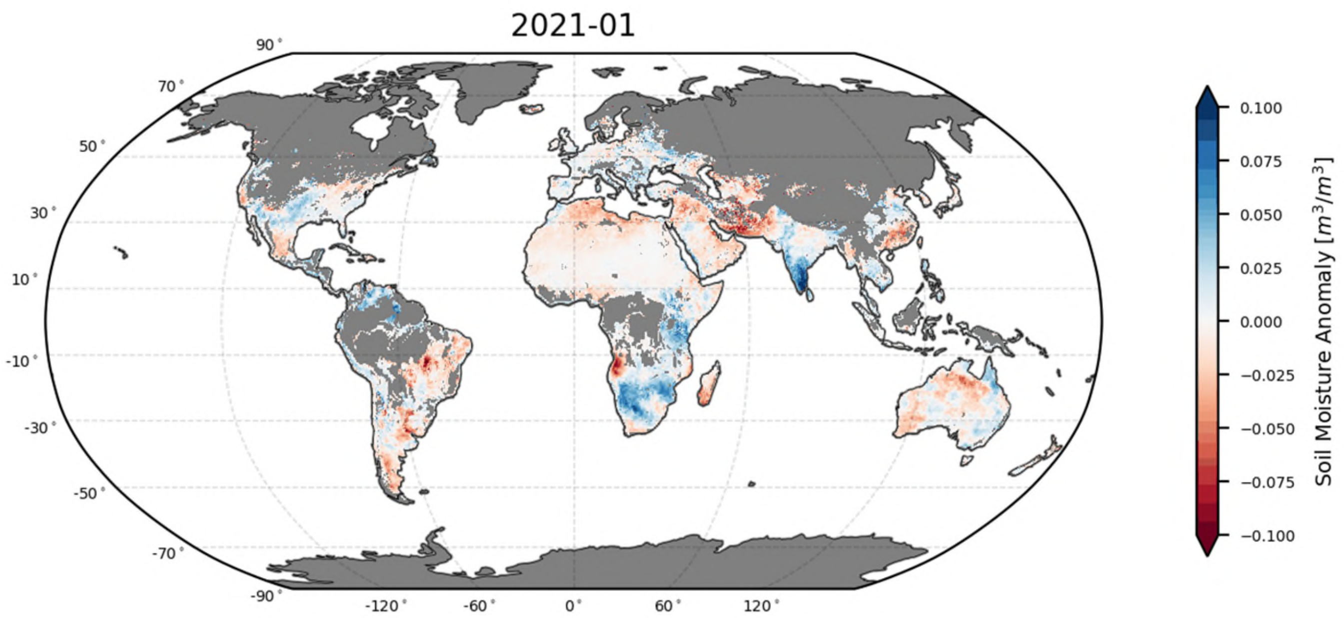
# Operational Soil Moisture Products

| Satellite / Product | Temp. Cov. | Temp. res. | Latency | Spatial sampling | Spatial coverage | Organisation | Access |
|---|---|---|---|---|---|---|---|
| ESA CCI SSM | 1978- | 1-2 d | Year | 0.25° | Global | ESA | Free |
| C3S SSM | 1978 | 10 d | 10d | 0.25° | Global | Copernicus | Free |
| H SAF ASCAT SSM CDR | 2007- | 1-2 d | Year | 12.5 km | Global | EUMETSAT H SAF | Free |
| H SAF ASCAT SSM NRT | 2007- | 1-2 d | 1 d | 12.5 km | Global | EUMETSAT H SAF | Free |
| CGLS ASCAT SWI | 2007- | Daily | 3 d | 0.1° | Global | CGLS | Free |
| SMOS L2 SSM | 2010- | 1-2 d | 1 d | 36 km | Global | ESA | Free |
| SMAP L3 SSM | 2015- | 1-2 d | 1 d | 36 km | Global | NASA | Free |
| SMAP L4 RZSM | 2015- | Daily | 7 d | 9 km | Global | NASA | Free |
| CGLS S-1 SSM | 2015- | 3-24 d | 1 d | 0.5 km | Europe | CGLS | Free |
| CGLS SCATSAR SWI | 2015- | 1-2 d | 3 d | 0.5 km | Europe | CGLS | Free |
| VanderSat | 2002- | Daily | | 100m | request | VanderSat | Paid |

# ESA CCI Soil Moisture?

**ESA CCI Soil Moisture** (ECV, 2010) as a successful response to the need for independent, consistent, observation based and multi-decadal climate data records, having:

- 12000+ registered users
- 100+ publications per year
- Benchmark in BAMS State of the Climate



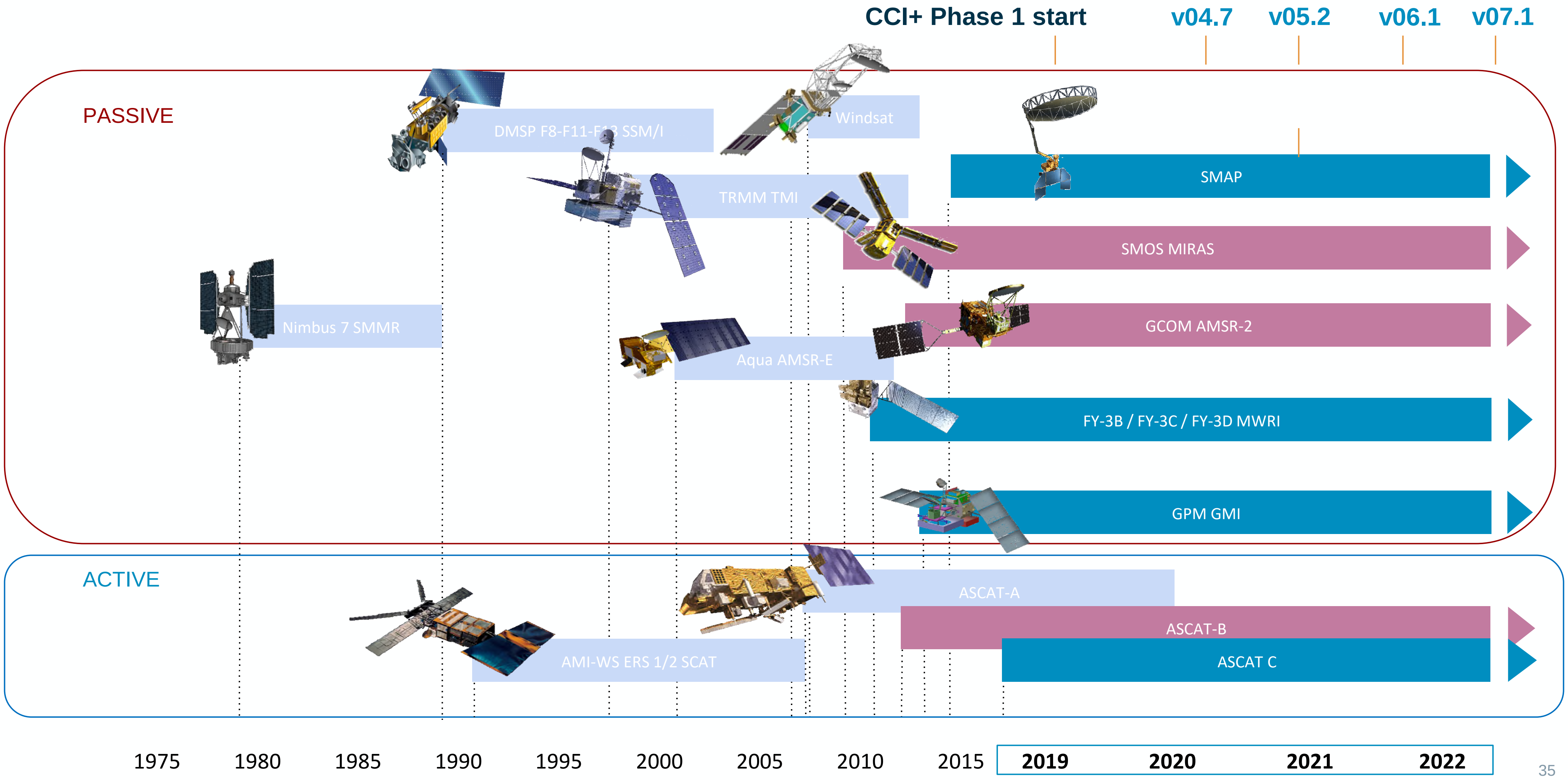

soil moisture cci

**A collaboration between**

TU WIEN, GEO, planet., eodc, ETH zürich, INRAE, KU LEUVEN, CESBIO, METEO FRANCE, VanderSat

# Development of the climate data record

- Operational, updated
- Before CCI+ Phase 1
- Added with CCI+ Phase 1




**Version 7.1 is now available!**

# Scientific Evolution

**Extension**, increase robustness by adding and updating satellites

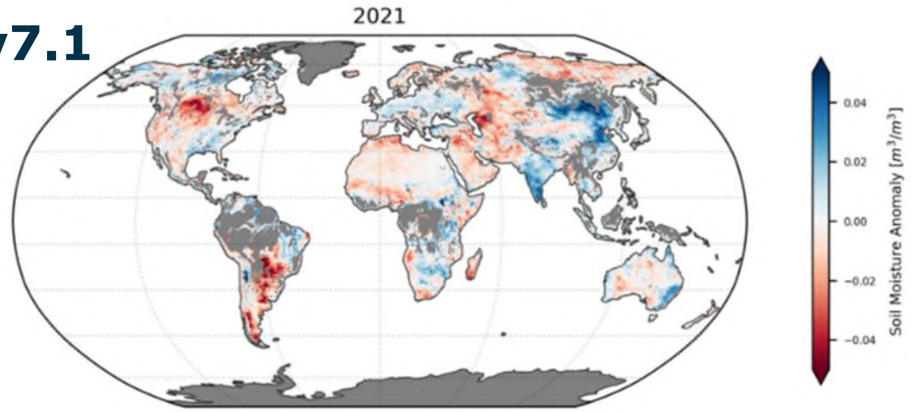
**Consistency**, improve merging and calibration on all levels

**Model independency**, remove impact from LSM where possible

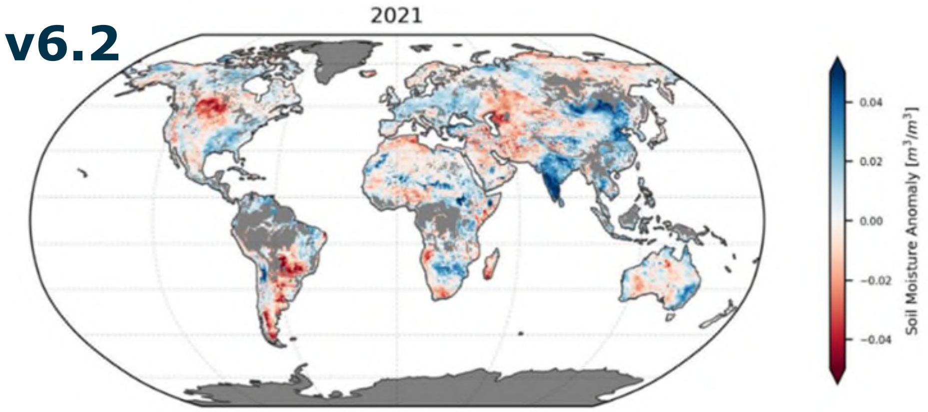
**Skill**, best reflect actual conditions by improving retrieval algorithms

**Understand**, both the strengths and weaknesses of the datasets

**v7.1**




**v6.2**




Soil Moisture anomalies derived from the ESA CCI SM (2 versions) using the 1991-2020 reference period

# C3S Soil Moisture (C3S)

NRT

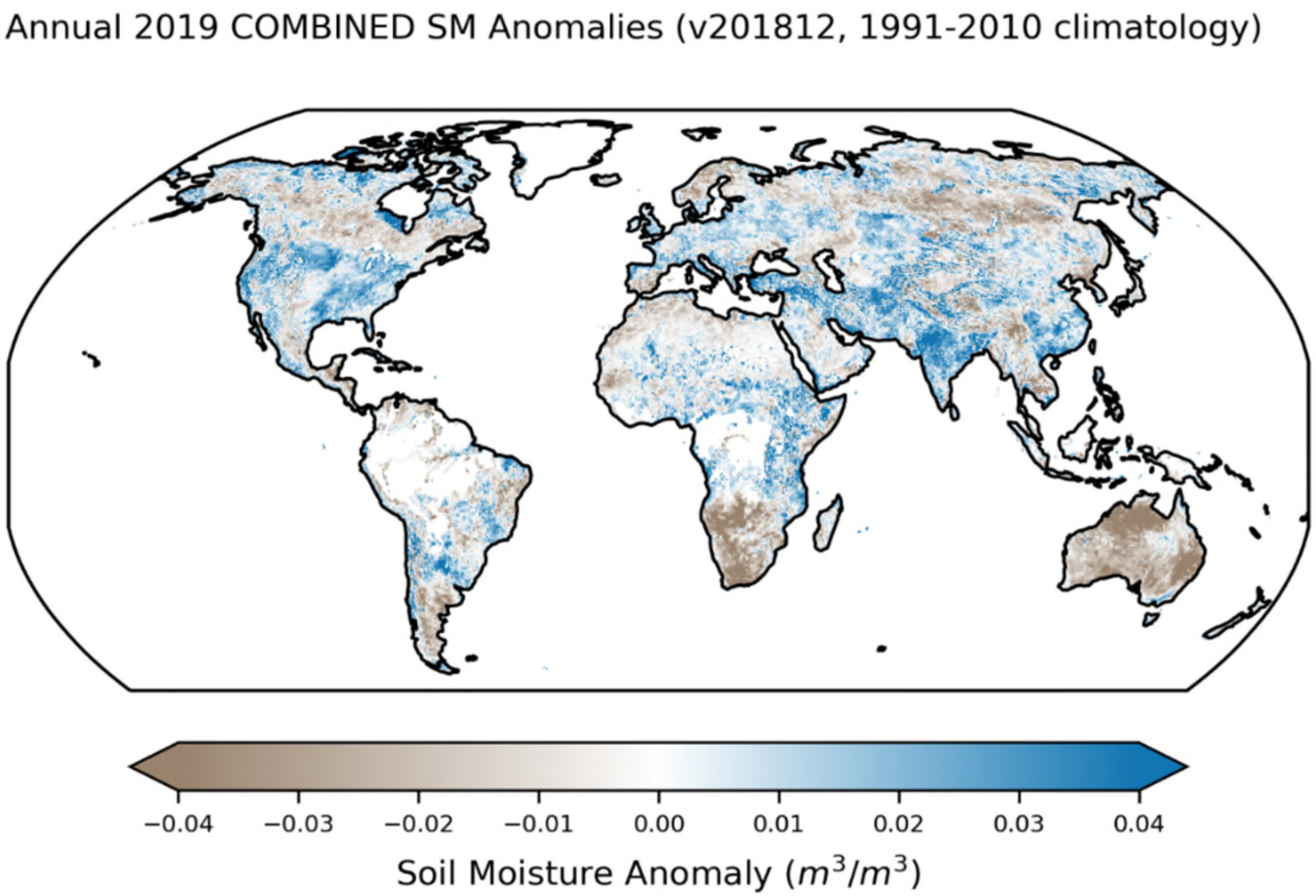
**updated dekadal**

Latency 10 days

1978 – now

0.25°

daily, dekadal, monthly




Climate Change Service

http://climate.copernicus.eu/

# European C-Band Scatterometer Series

**AMI Scatterometer**

Frequency: 5.3 GHz
Polarisation: VV

Resolution: 50 km
Daily coverage: <40%

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

**METOP ASCAT**

Frequency: 5.255 GHz
Polarisation: VV

Resolution: 25 km
Daily coverage: 82%

**Satellites**
METOP-A: 2006
METOP-B: 2012
METOP-C: 2018

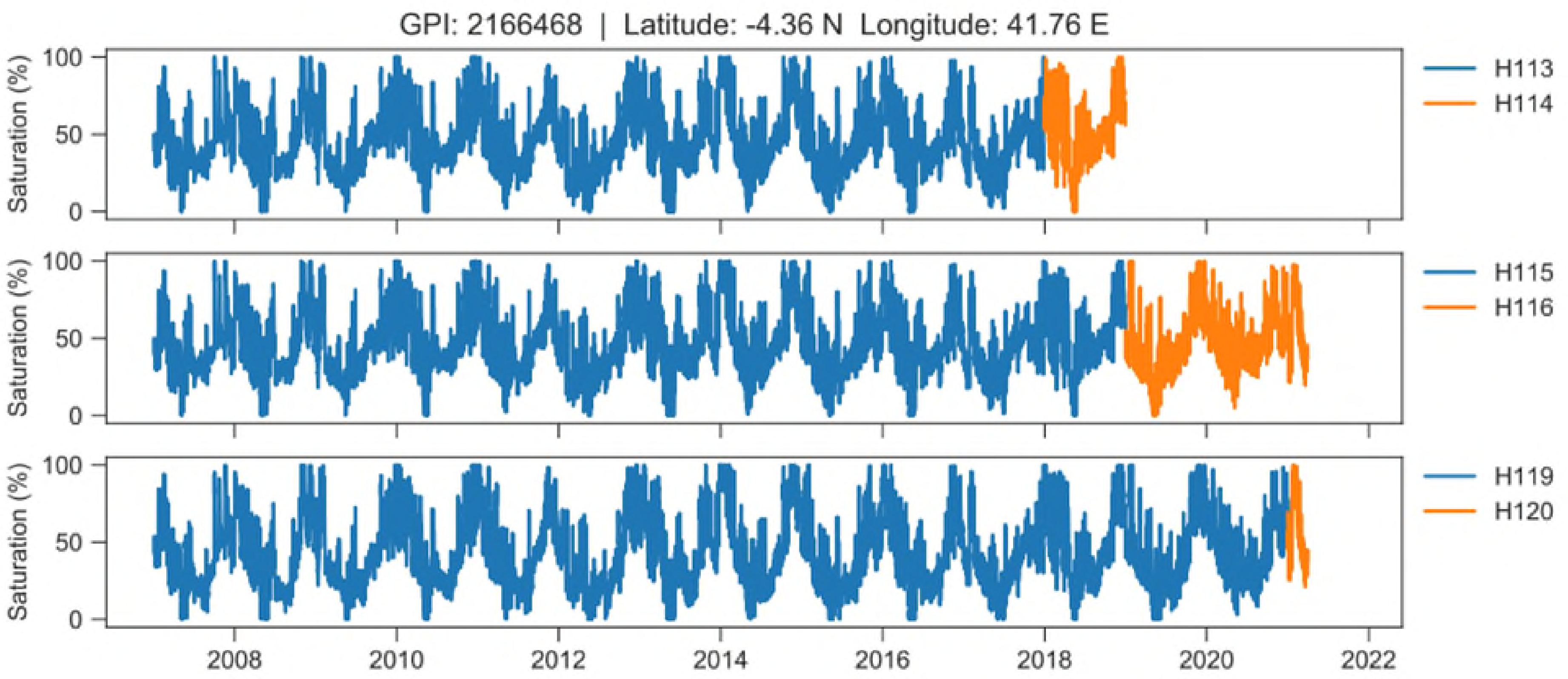
**METOP-SG SCA**

Frequency: 5.355 GHz
Polarisation: VV + VH + HH

Resolution: ~12.5 km
Daily coverage: ~88%

**Satellites**
METOP-SG-B1: 2022
METOP-SG-B2: 2030

# ASCAT Data Record Time Series




EUMETSAT H SAF

# ASCAT NRT Surface Soil Moisture

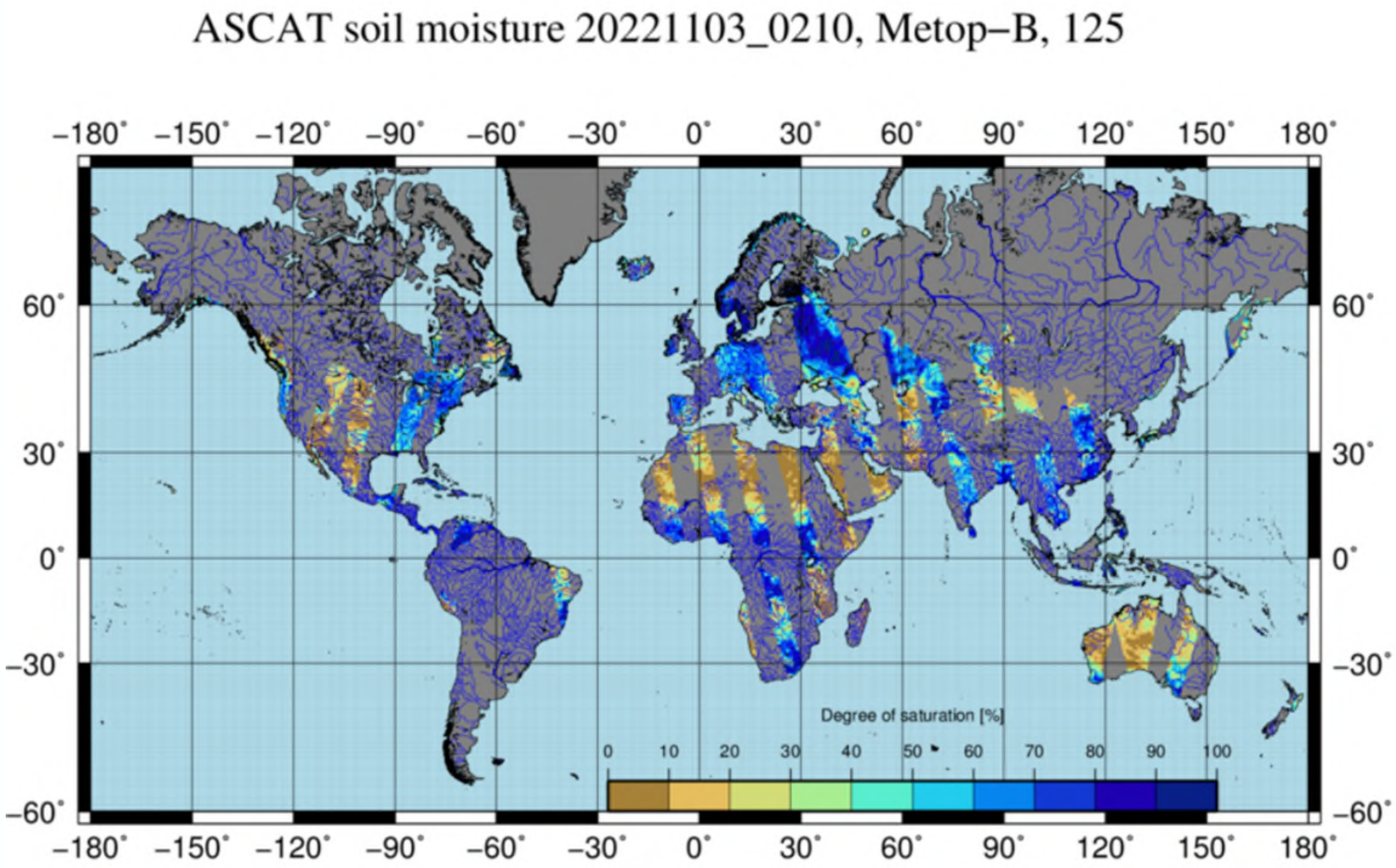
NRT

**Latency 2 hours**

2007 – now

12.5km

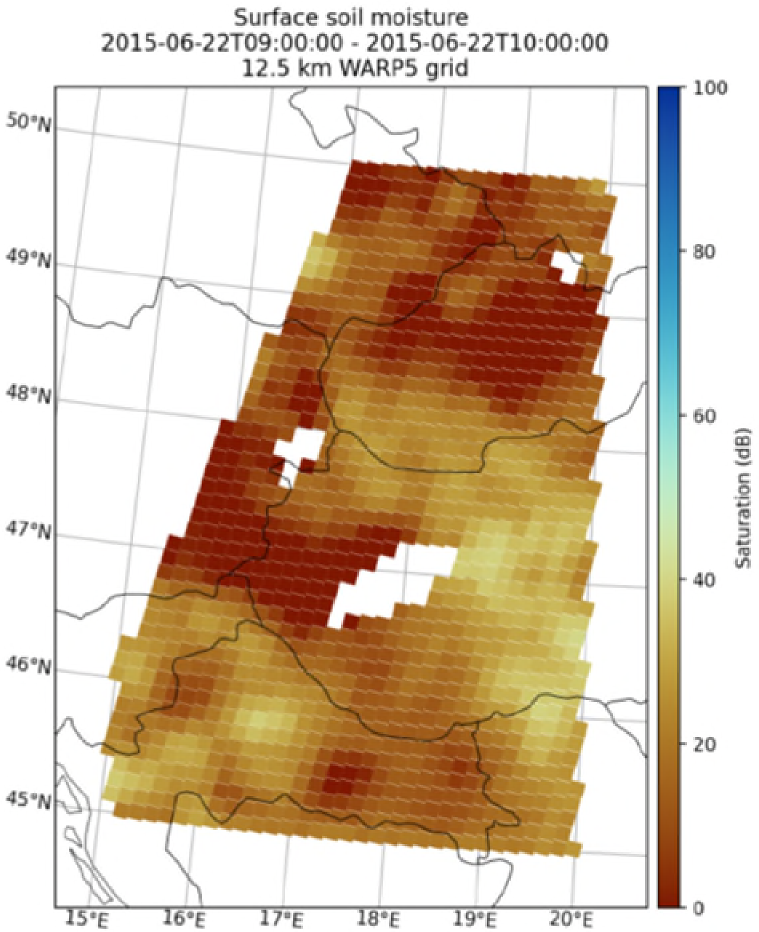
Sub-daily

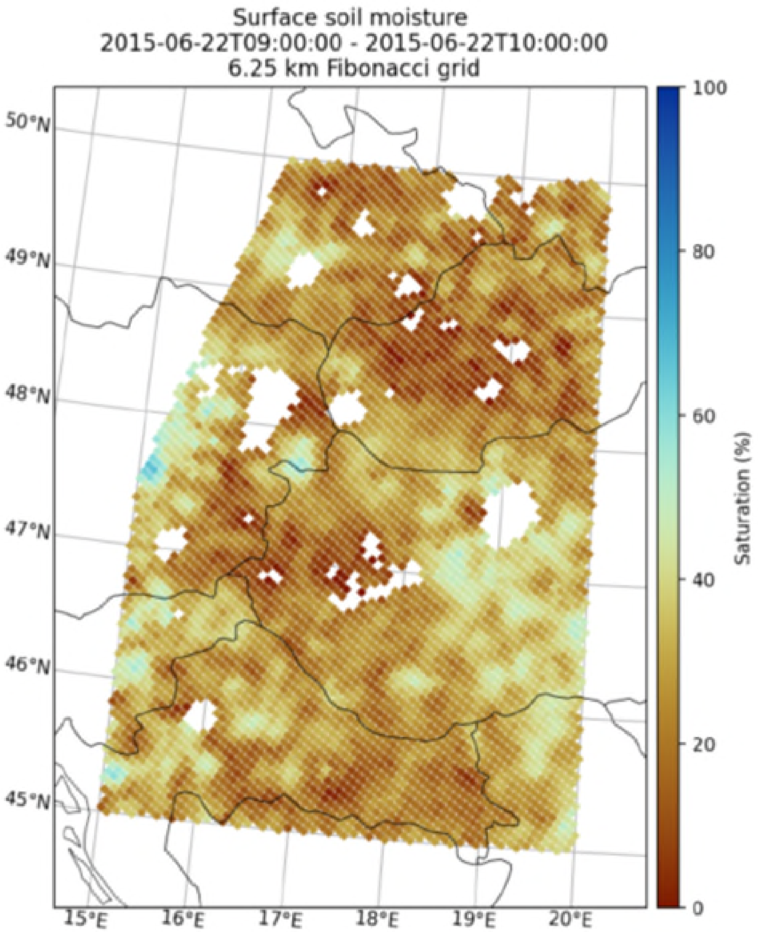



http://hsaf.meteoam.it/soil-moisture.php?tab=5

EUMETSAT H SAF

ASCAT SSM NRT **6.25 km** – Metop-B/C (H122, Q2 2023)



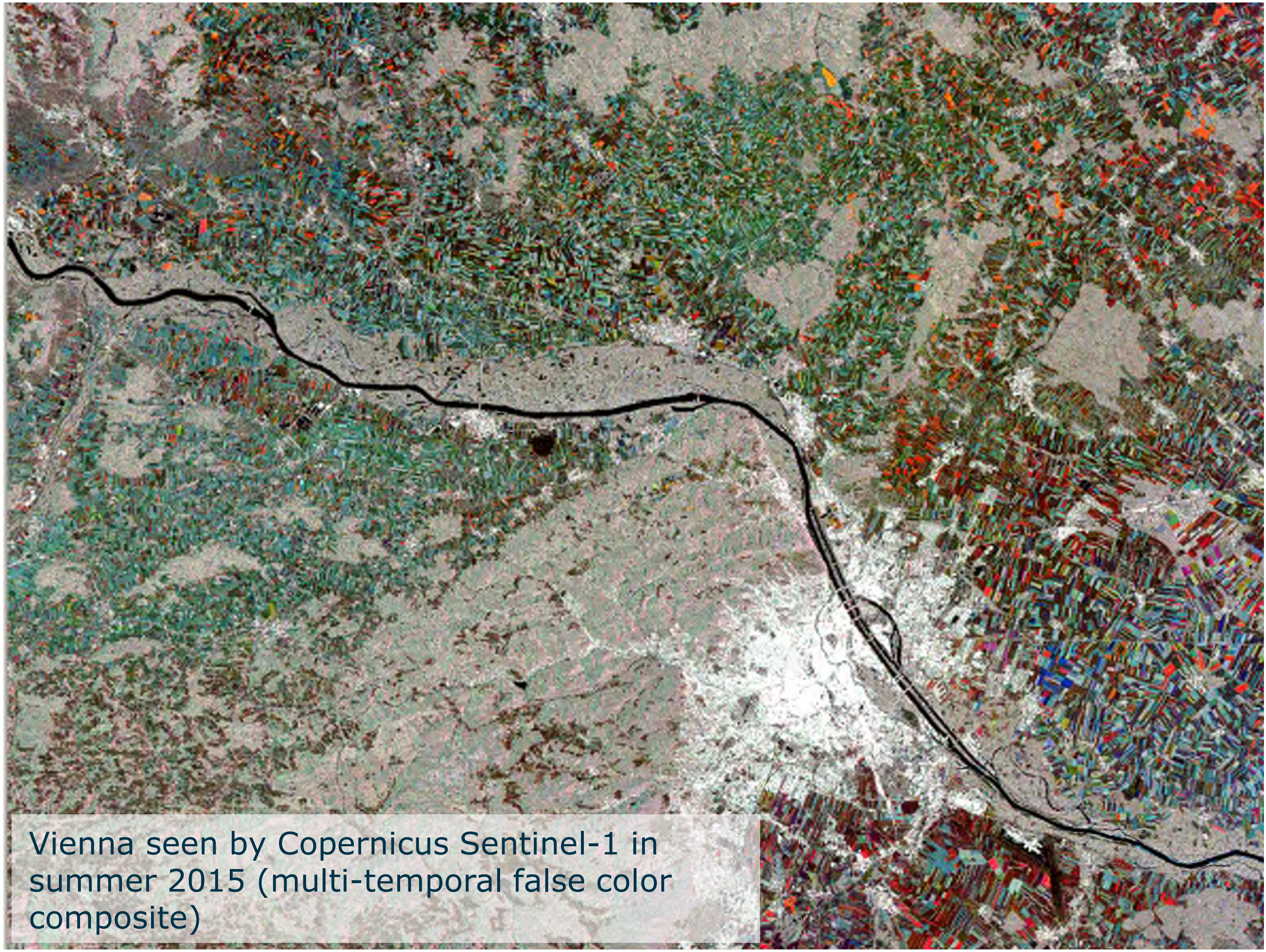



# Sentinel-1 – A Game Changer

C-band SAR satellite

High spatio-temporal coverage

- Spatial resolution 20-80 m
- Temporal resolution < 3 days over Europe with 2 satellites



Vienna seen by Copernicus Sentinel-1 in summer 2015 (multi-temporal false color composite)

# Copernicus Global Land Service

Copernicus Global Land

1 km Sentinel-1 SSM for Europe

1 km ASCAT/Sentinel-1 SWI data for Europe

NRT

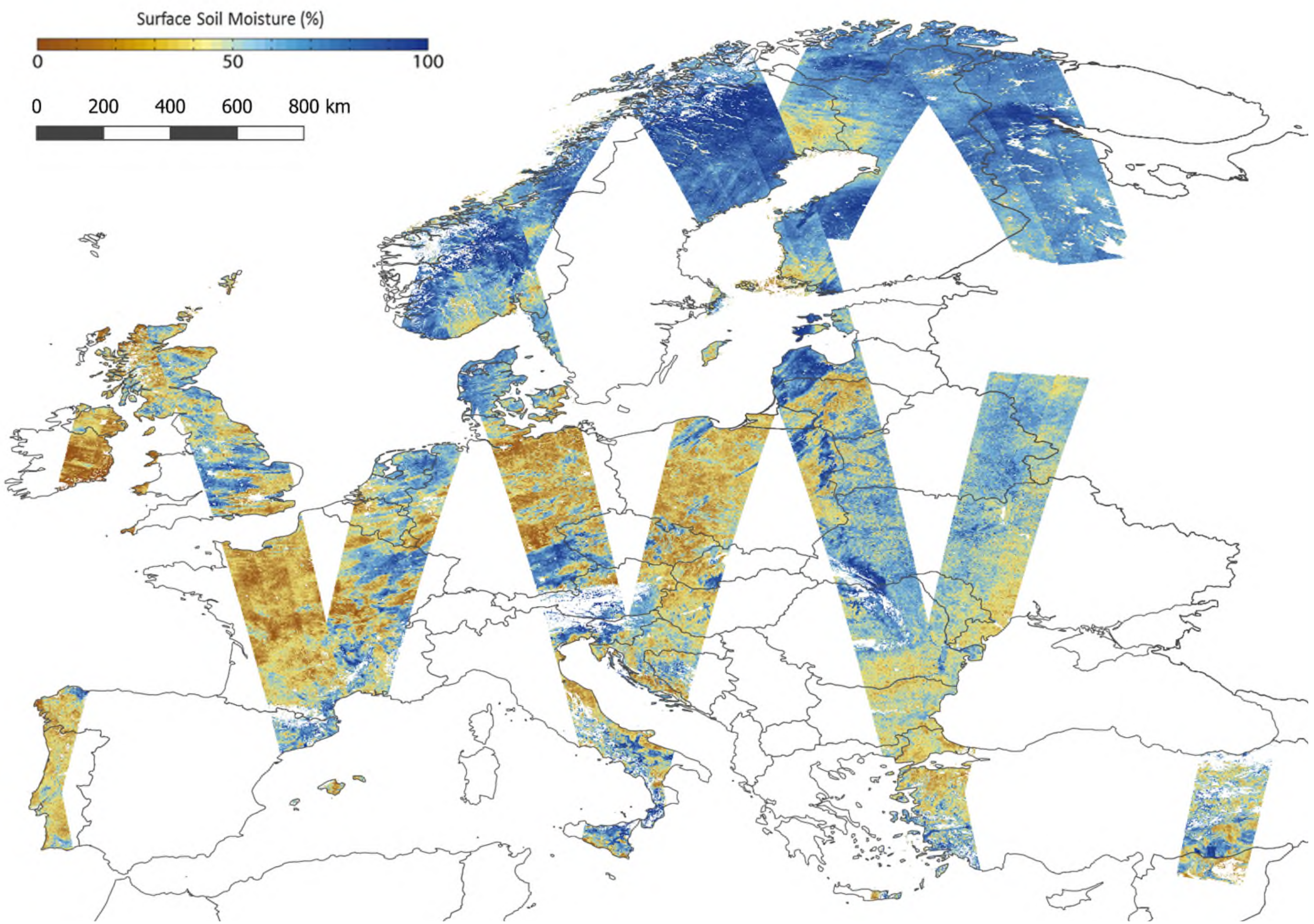
**Daily**

**Latency 24-48 hours**

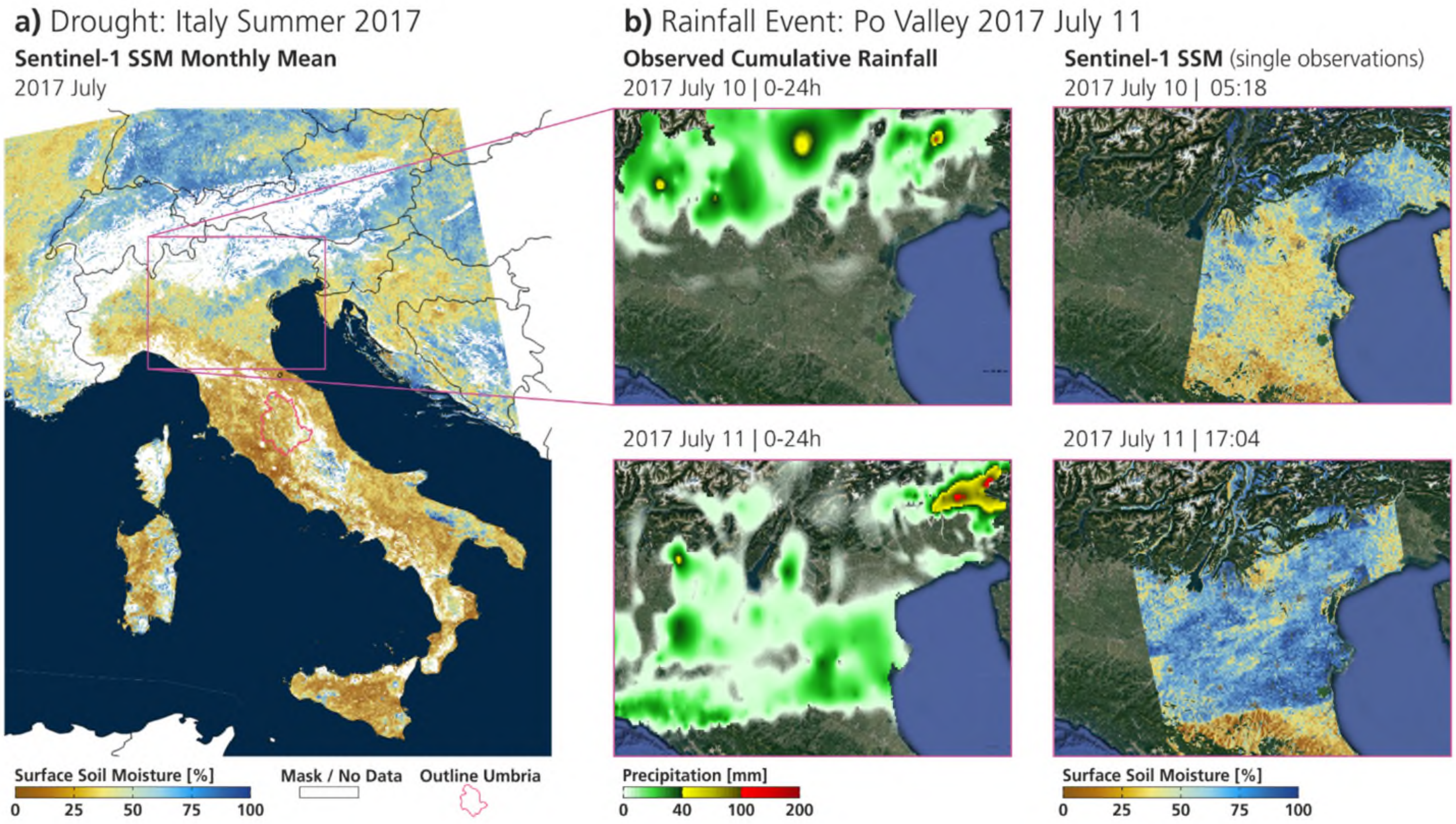
2015 – now

**500m**

1-4 days

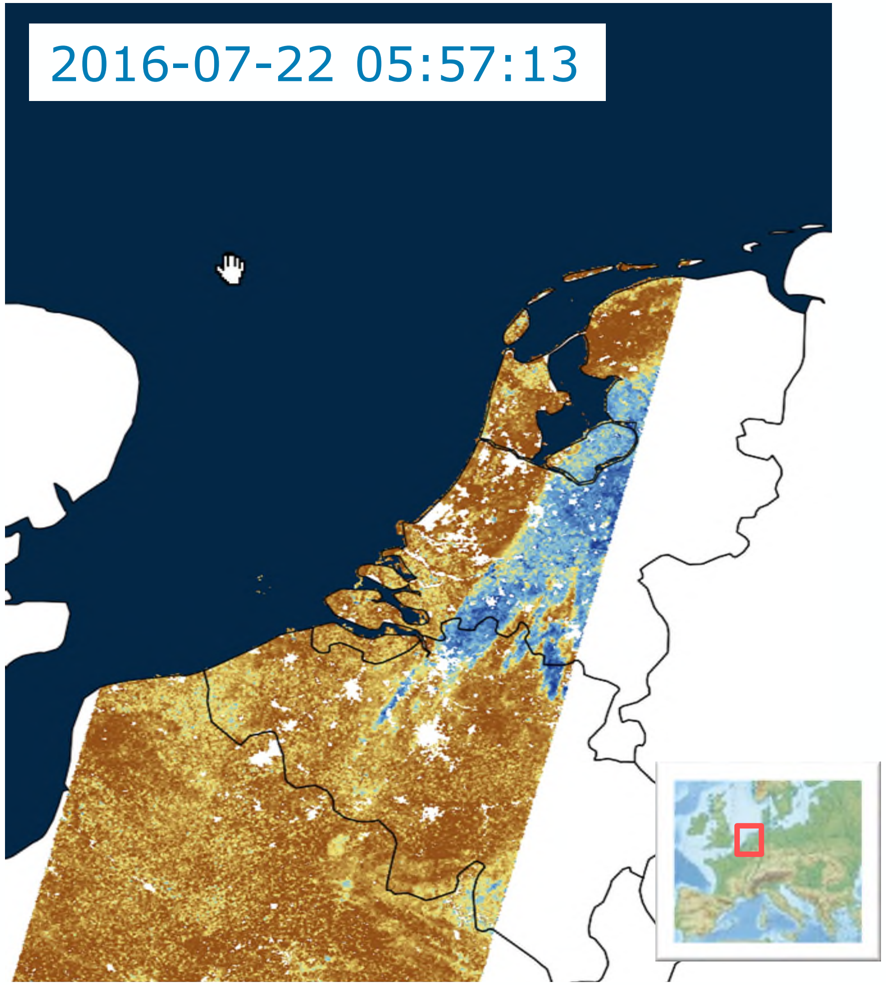


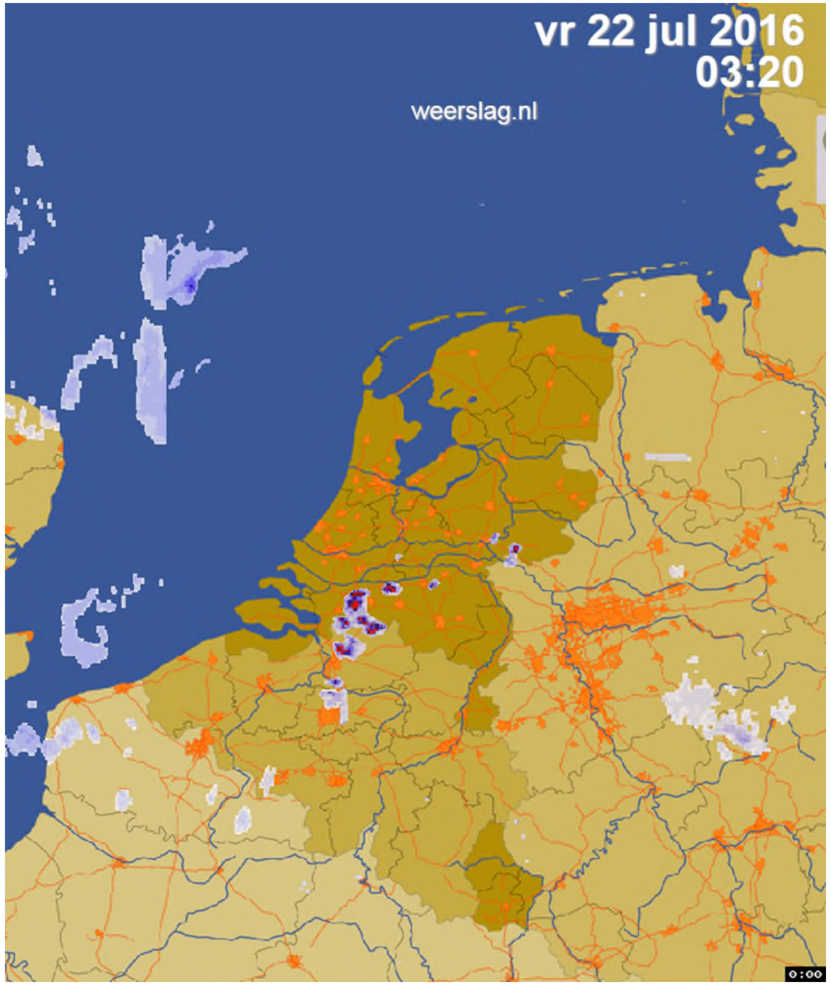
# Sentinel-1 Soil Moisture




*Bauer-Marschallinger et al., 2018, Towards Global Soil Moisture Monitoring with Sentinel-1: Harnessing Assets and Overcoming Obstacles“, in* IEEE Transactions on Geoscience and Remote Sensing

# Sentinel-1 Soil Moisture & Precipitation Radar




*Graphic by B. Bauer-Marschallinger, TU Wien*

# VALIDATION AND QUALITY ASSURANCE

# Quality assurance of EO SM products

Estimating **systematic** and **random** errors through analytical comparison to reference data

Validation can be done using:

- Field campaigns
- In situ networks
- Model data
- Satellite products

Common metrics:

Pearson correlation coefficient

Unbiased Root Mean Square Difference

Remote Sensing of Environment 244 (2020) 111806

Contents lists available at ScienceDirect

Remote Sensing of Environment

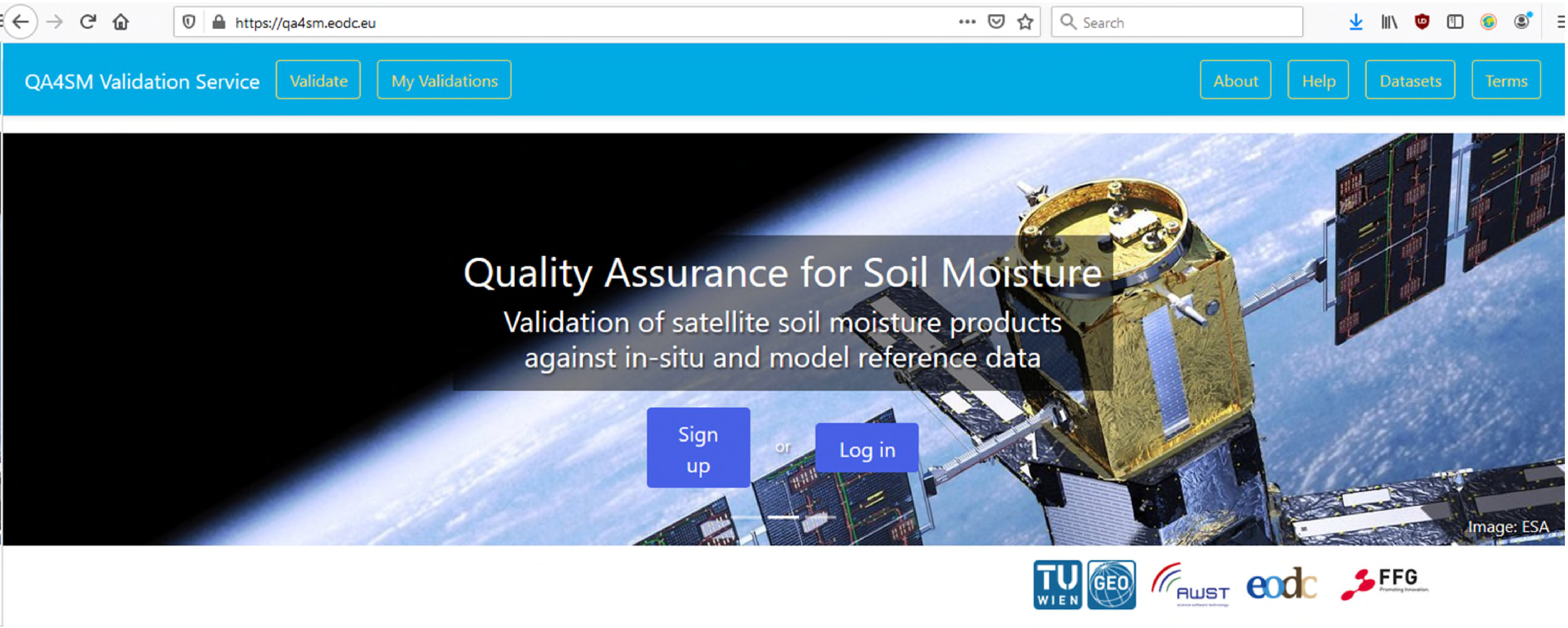
journal homepage: www.elsevier.com/locate/rse

ELSEVIER

Review

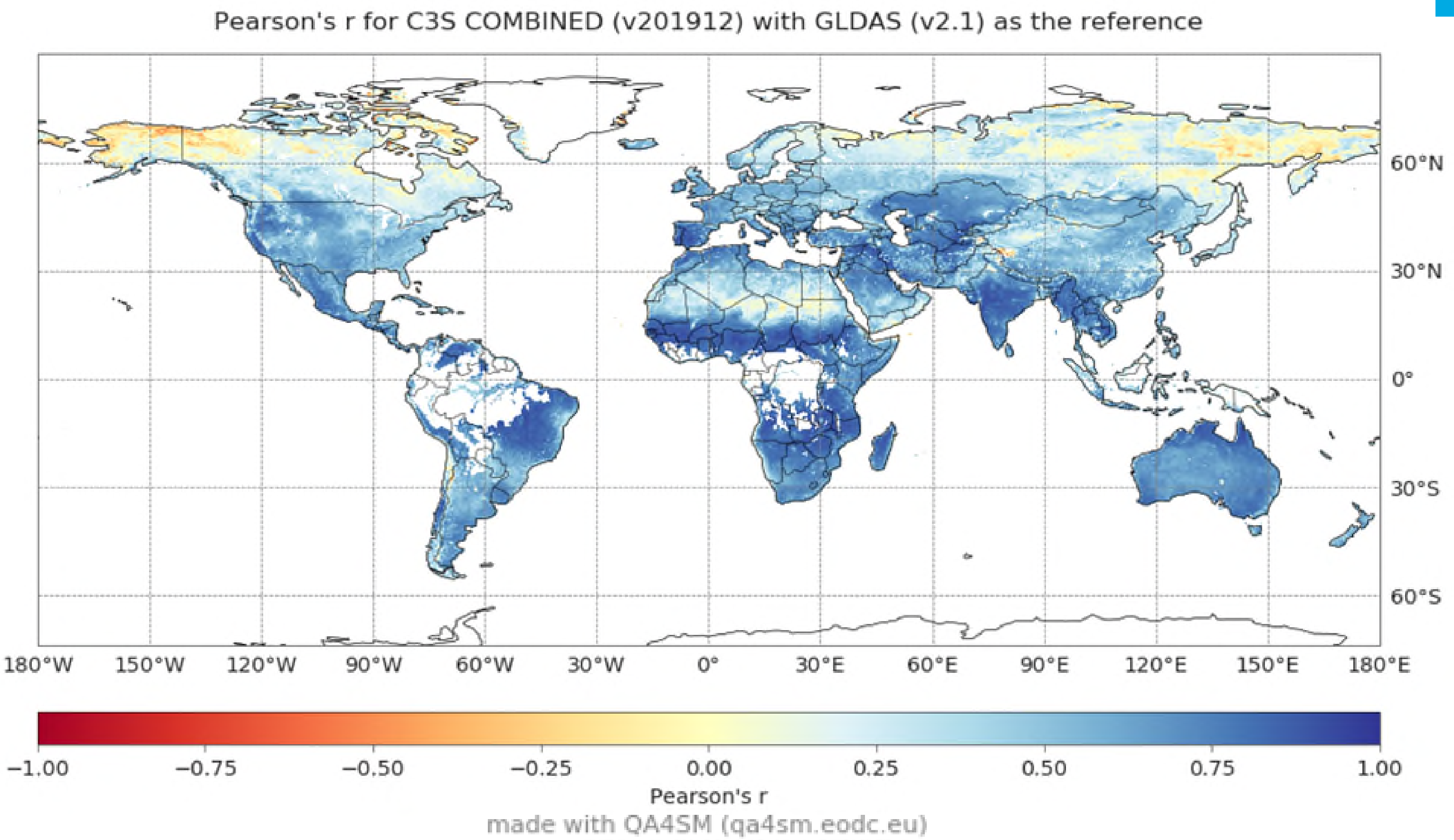
Validation practices for satellite soil moisture retrievals: What are (the) errors?

A. Gruber[a,*], G. De Lannoy[a], C. Albergel[b], A. Al-Yaari[c], L. Brocca[d], J.-C. Calvet[b], A. Colliander[e], M. Cosh[f], W. Crow[f], W. Dorigo[g], C. Draper[h], M. Hirschi[i], Y. Kerr[j], A. Konings[k], W. Lahoz[l], K. McColl[m], C. Montzka[n], J. Muñoz-Sabater[o], J. Peng[p], R. Reichle[q], P. Richaume[j], C. Rüdiger[r], T. Scanlon[g], R. van der Schalie[s], J.-P. Wigneron[t], W. Wagner[g]


https://qa4sm.eodc.eu
Search
QA4SM Validation Service
Validate
My Validations
About
Help
Datasets
Terms
Quality Assurance for Soil Moisture
Validation of satellite soil moisture products against in-situ and model reference data
Sign up
or
Log in
Image: ESA

## Using http://qa4sm.eodc.eu

QA4SM Validation Service




Correlation (Pearson) of the C3S v201912 COMBINED product with GLDAS v2.1 (covering the time period 2000-01-01 to 2019-12-31)

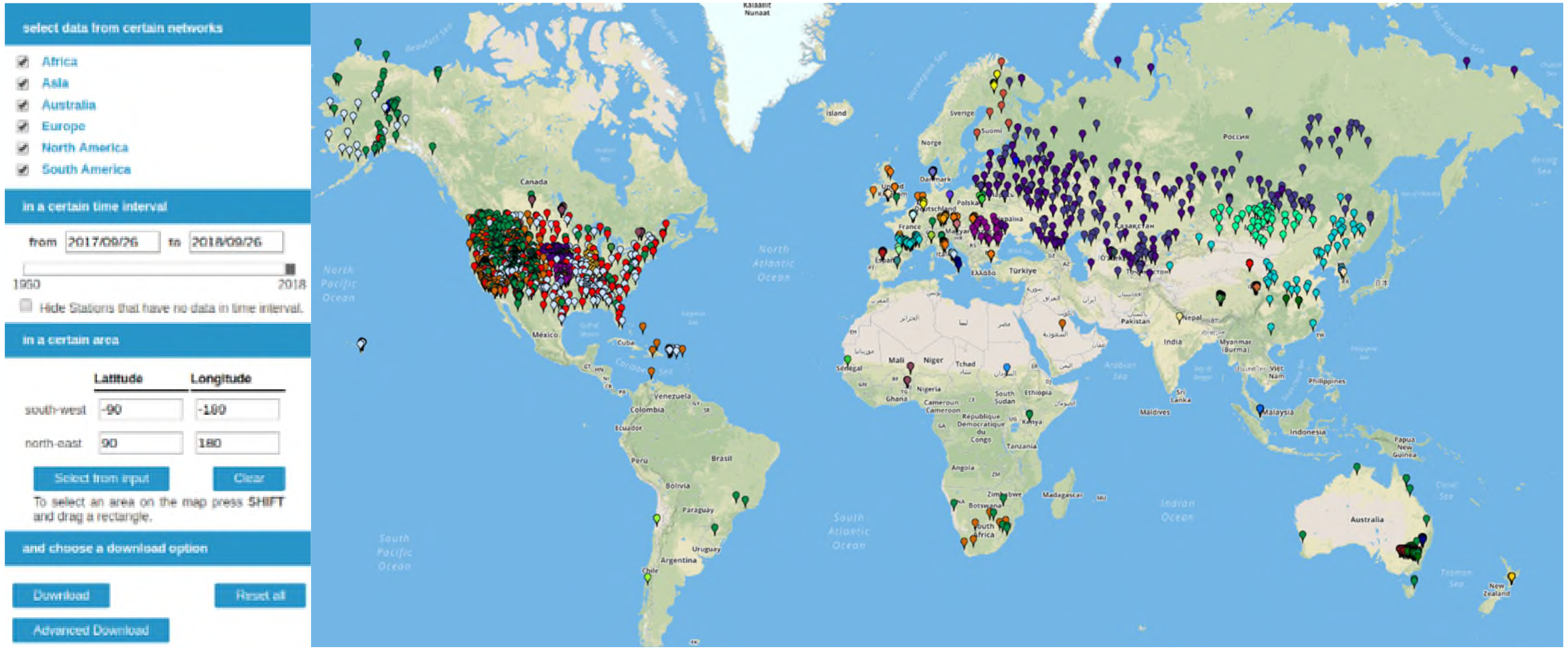
GitHub

pytesmo a Python Toolbox for the Evaluation of Soil Moisture Observations

# International Soil Moisture Network

63 networks

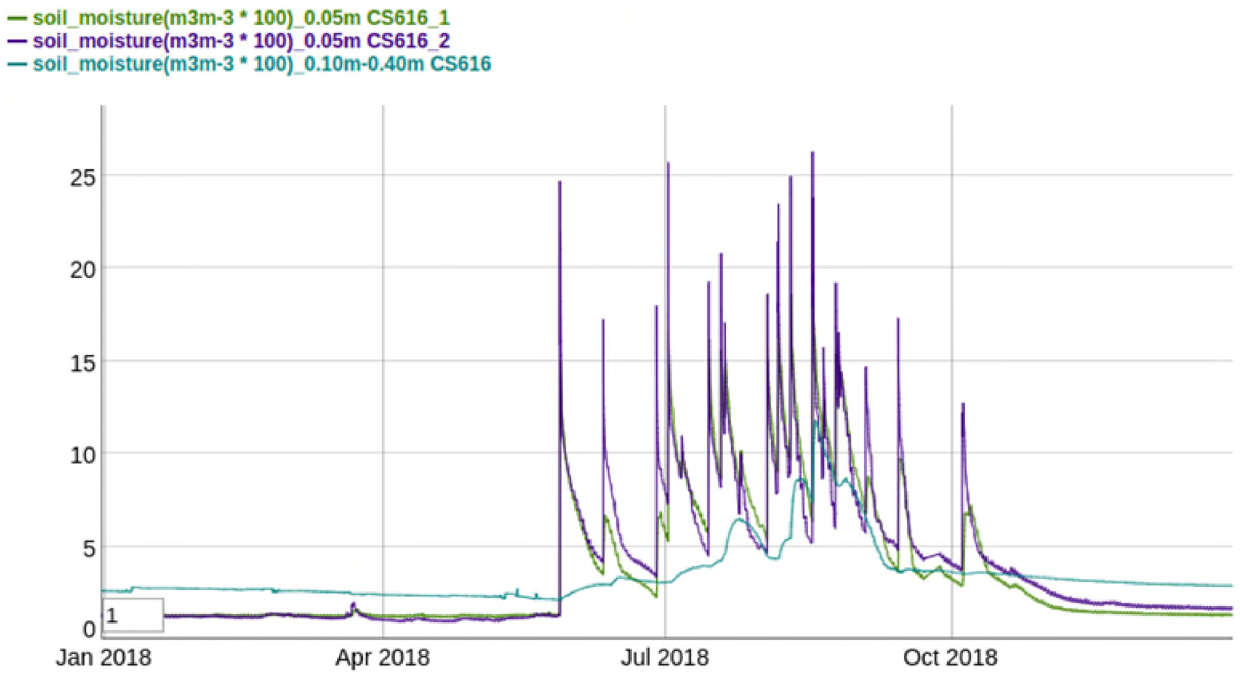
2631 stations




https://ismn.geo.tuwien.ac.at/en/

# International Soil Moisture Network

**Dataviewer Station: Tondikiboro from: 2017/12/31 to: 2018/12/31**




Drag an area vertical or horizontal to zoom in. Double click to zoom to whole date range.

**Select variables to show in graph**

soil_moisture(m3m-3 * 100)_0.05m CS616_1 ▾
soil_moisture(m3m-3 * 100)_0.05m CS616_2 ▾
soil_moisture(m3m-3 * 100)_0.10m-0.40m CS616 ▾

To see more data change the time interval on the left an press refresh.

Refresh Close

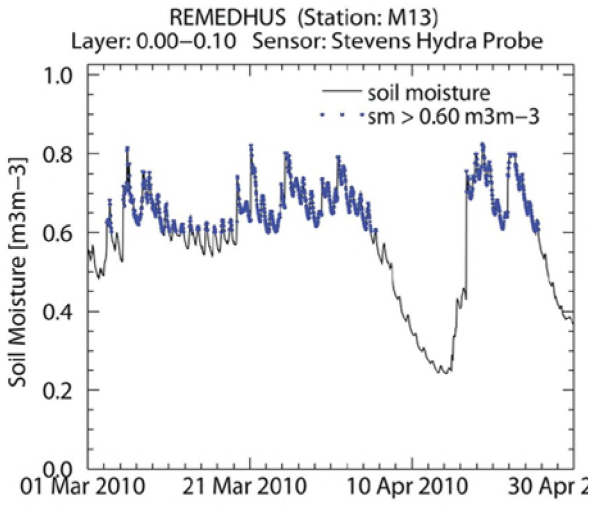
**https://ismn.geo.tuwien.ac.at/en/**

# International Soil Moisture Network

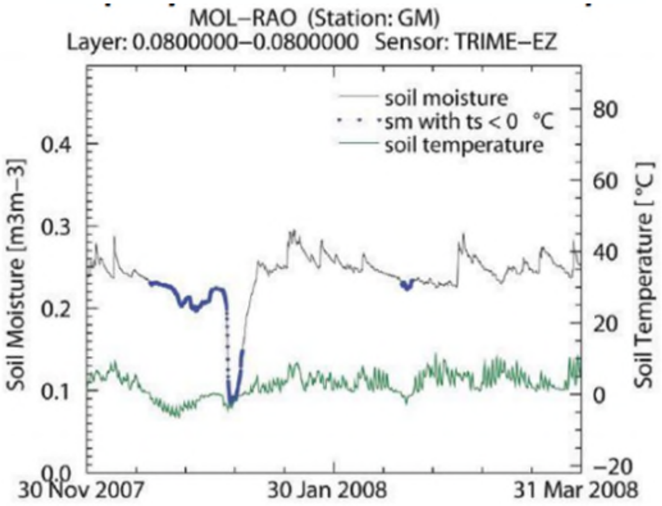
- Keeping flags from provider (rarely provided)
- quality flag added to each measurement (CEOP standards)

| Flag category | Flag values | Definition |
|---|---|---|
| C | C01 - C03 | Threshold based flags for all variables used in the ISMN (soil moisture, soil temperature, temperature air, etc.) |
| D | D01 - D10 | Questionable /dubious |
| M | | Parameter value missing OR derived parameter can not be computed |
| G | | Good |

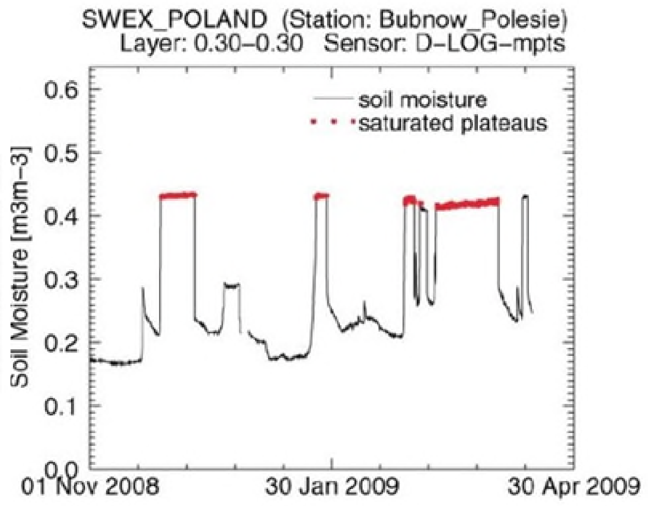
**1) Geophysical Dynamic Range**




**2) Geophysical Consistency**



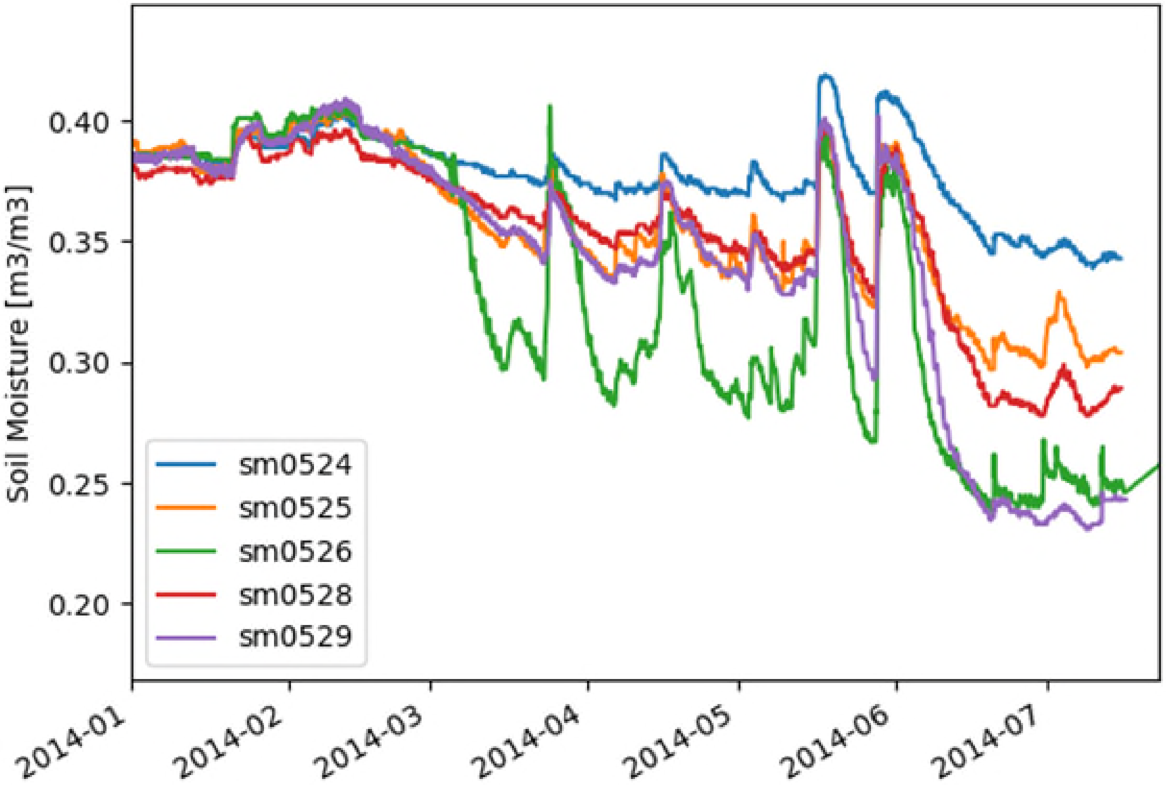

**3) Spectrum Based**

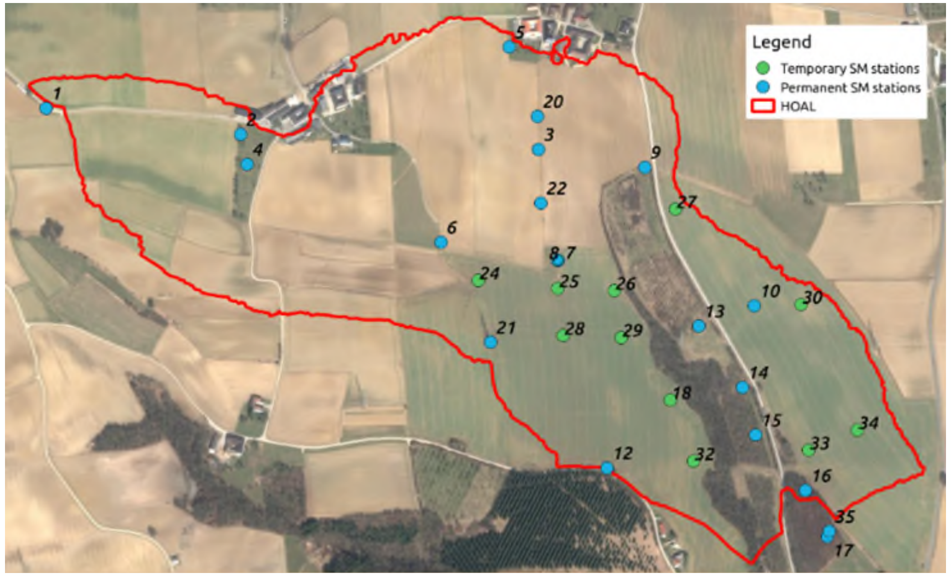


# Representativeness of In Situ Data?

Soil moisture can vary within one field with the same land cover

Temporal stability concept

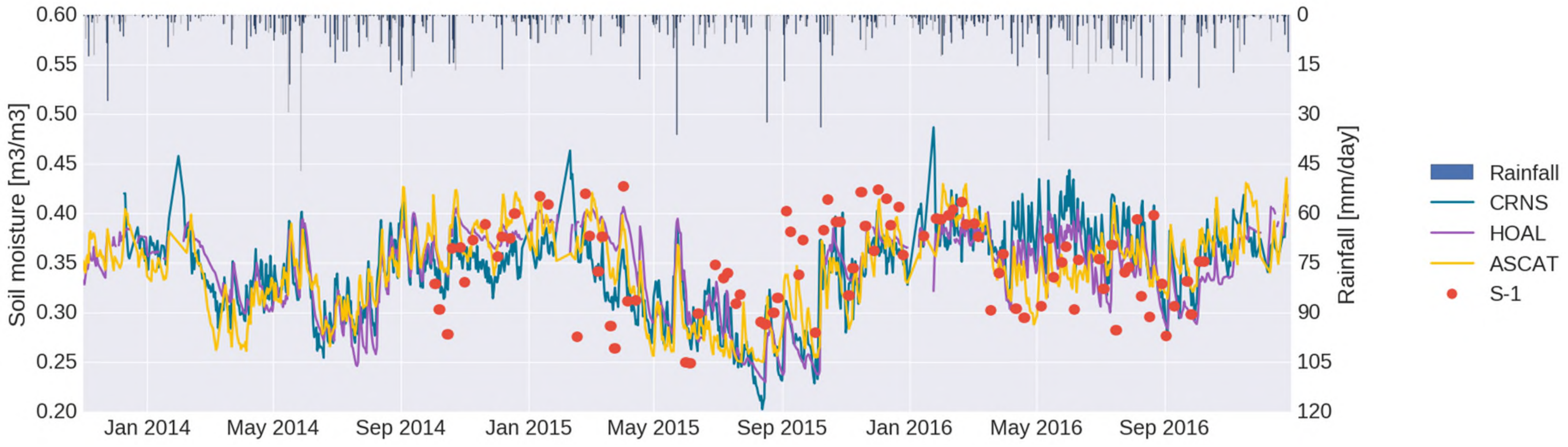



HOAL Soil Moisture Network, Petzenkirchen, Austria

Vienna Doctoral Programme on Water Resource Systems

# Validation with In Situ Soil Moisture Data over HOAL




CRNS: Cosmic Ray Neutron Sensor
HOAL: Catchment average of 31 TDT measurements
ASCAT: 25 km ASCAT soil moisture retrievals (yellow)
S-1: 1 km Sentinel-1 soil moisture retrievals

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Hydrological Open Air Laboratory (HOAL) in Petzenkirchen, Austria

Vienna Doctoral Programme on Water Resource Systems

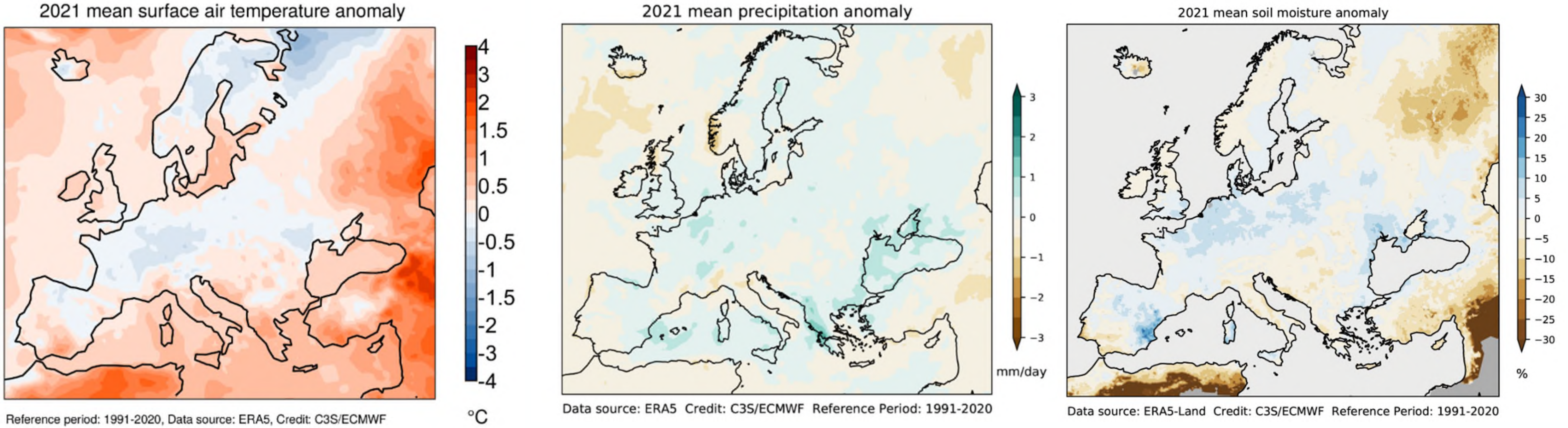


*Graphic by M. Vreugdenhil, TU Wien*

# EXAMPLES AND APPLICATIONS

# European State of the Climate 2021- C3S

esa



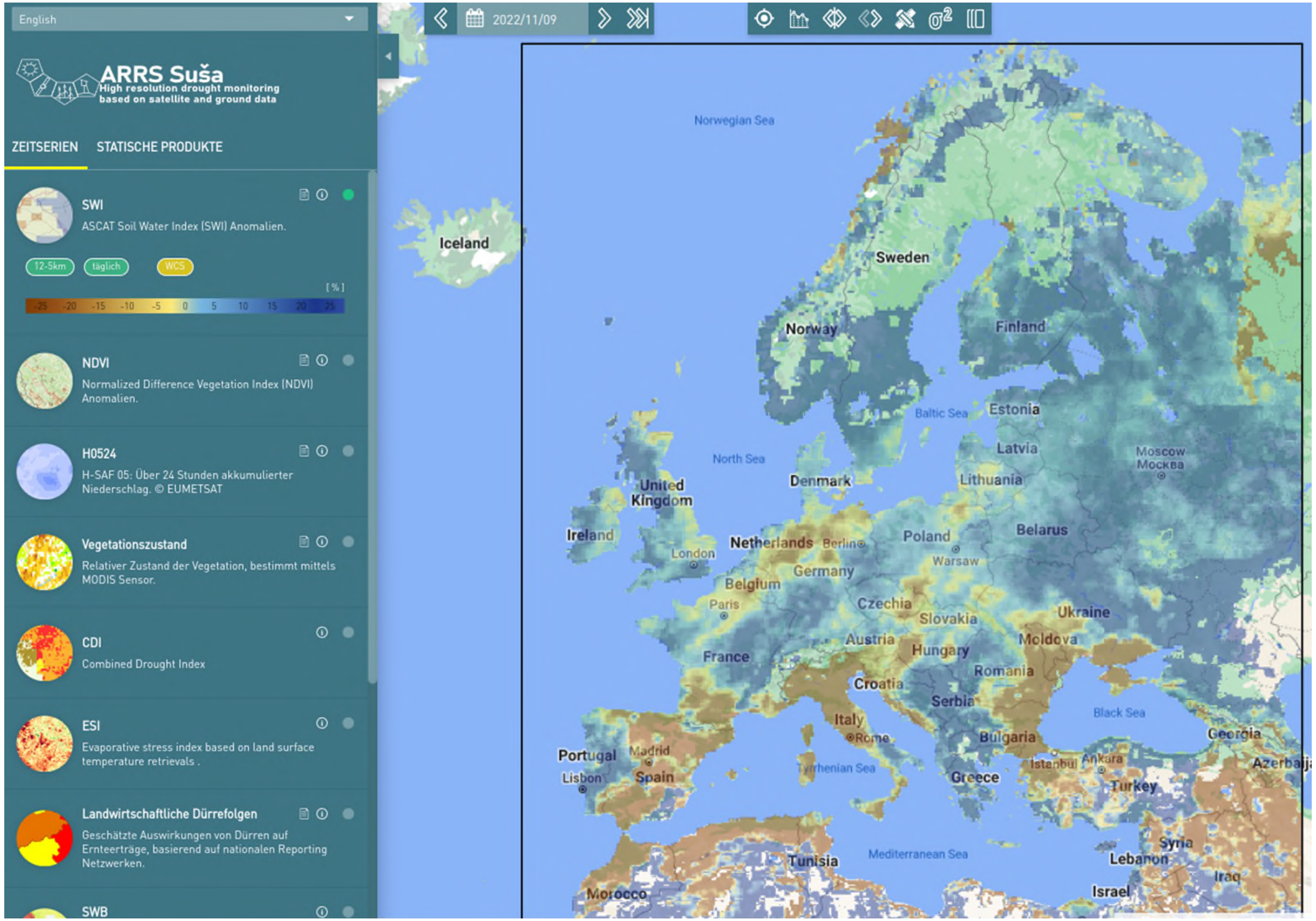

Anomalies of modelled temperature and precipitation, and satellite soil moisture anomalies for 2021.

Climate Change Service

http://climate.copernicus.eu/

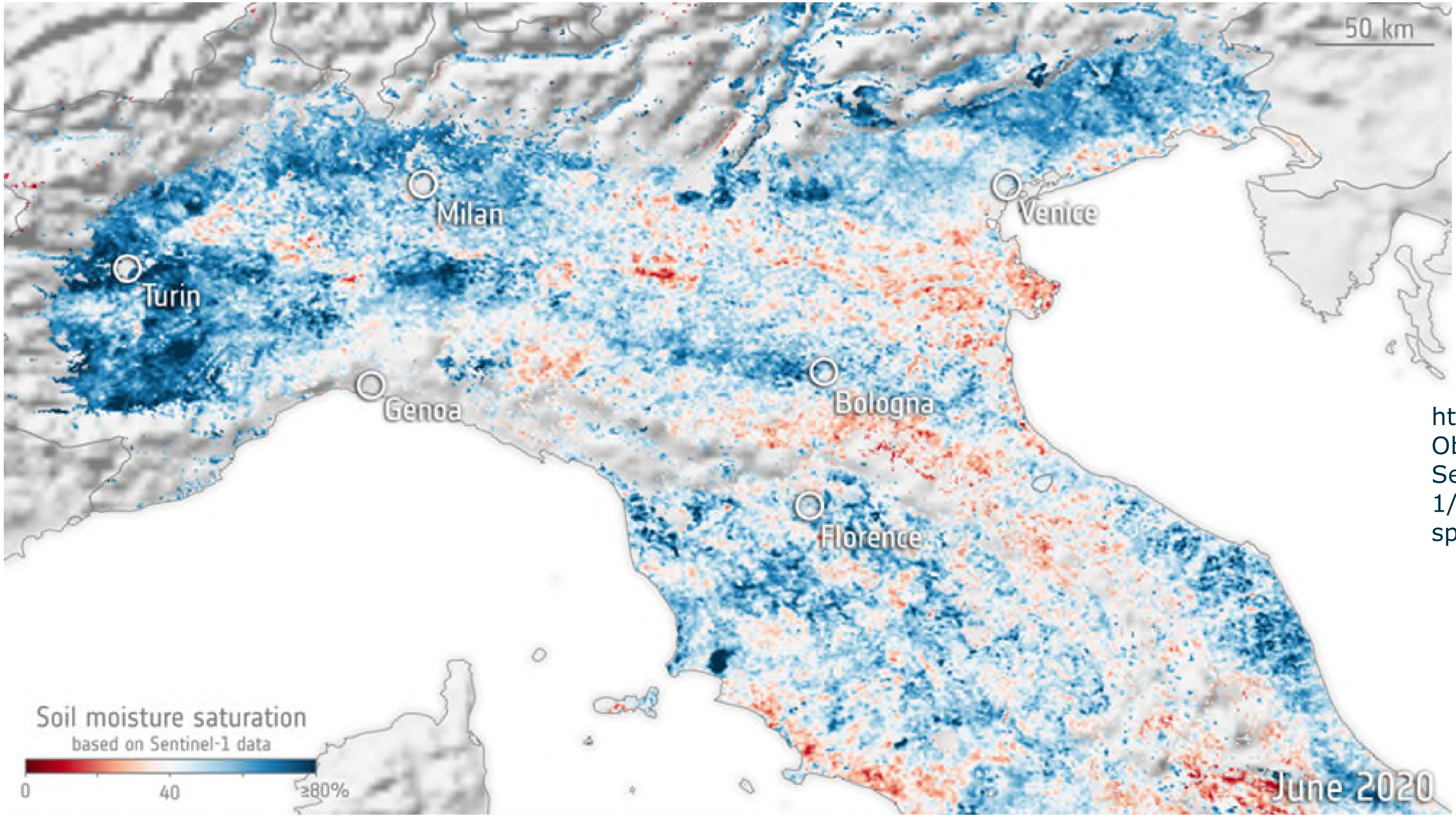
# Drought monitoring

droughtwatch.eu



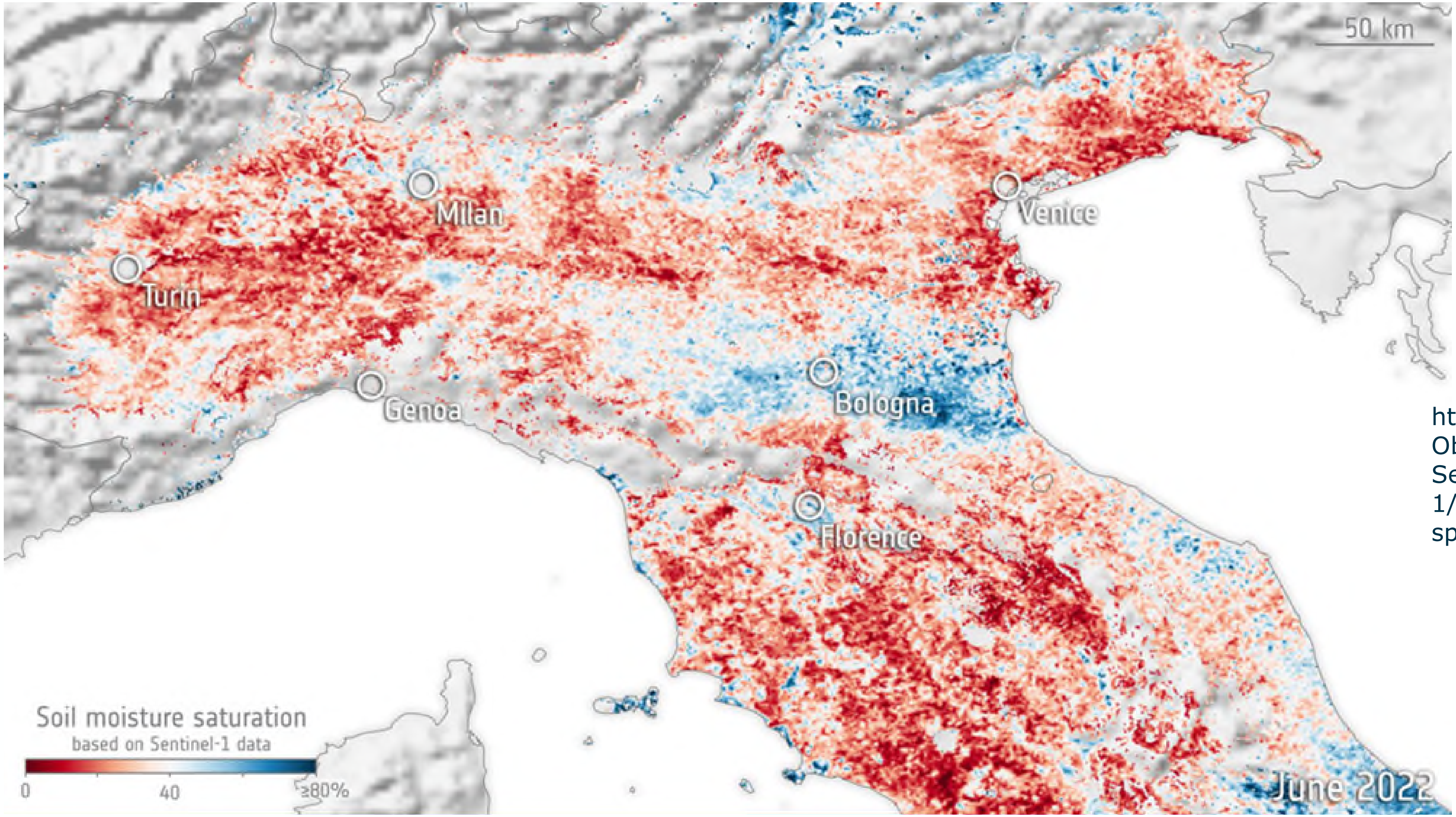

Interreg
Danube Transnational Programme
DriDanube

# Drought monitoring



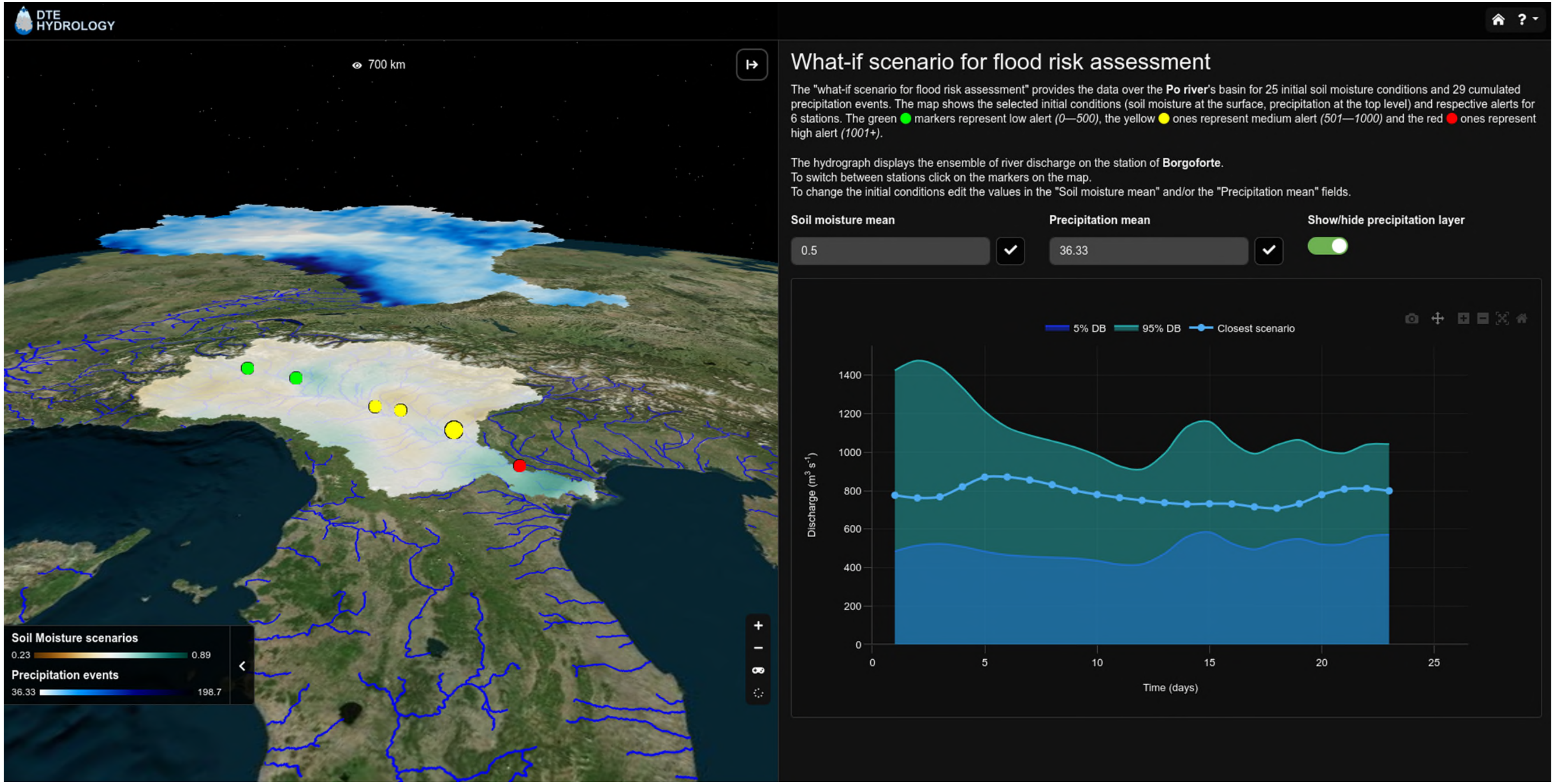

https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-1/Zooming_in_on_drought_from_space

# Drought monitoring



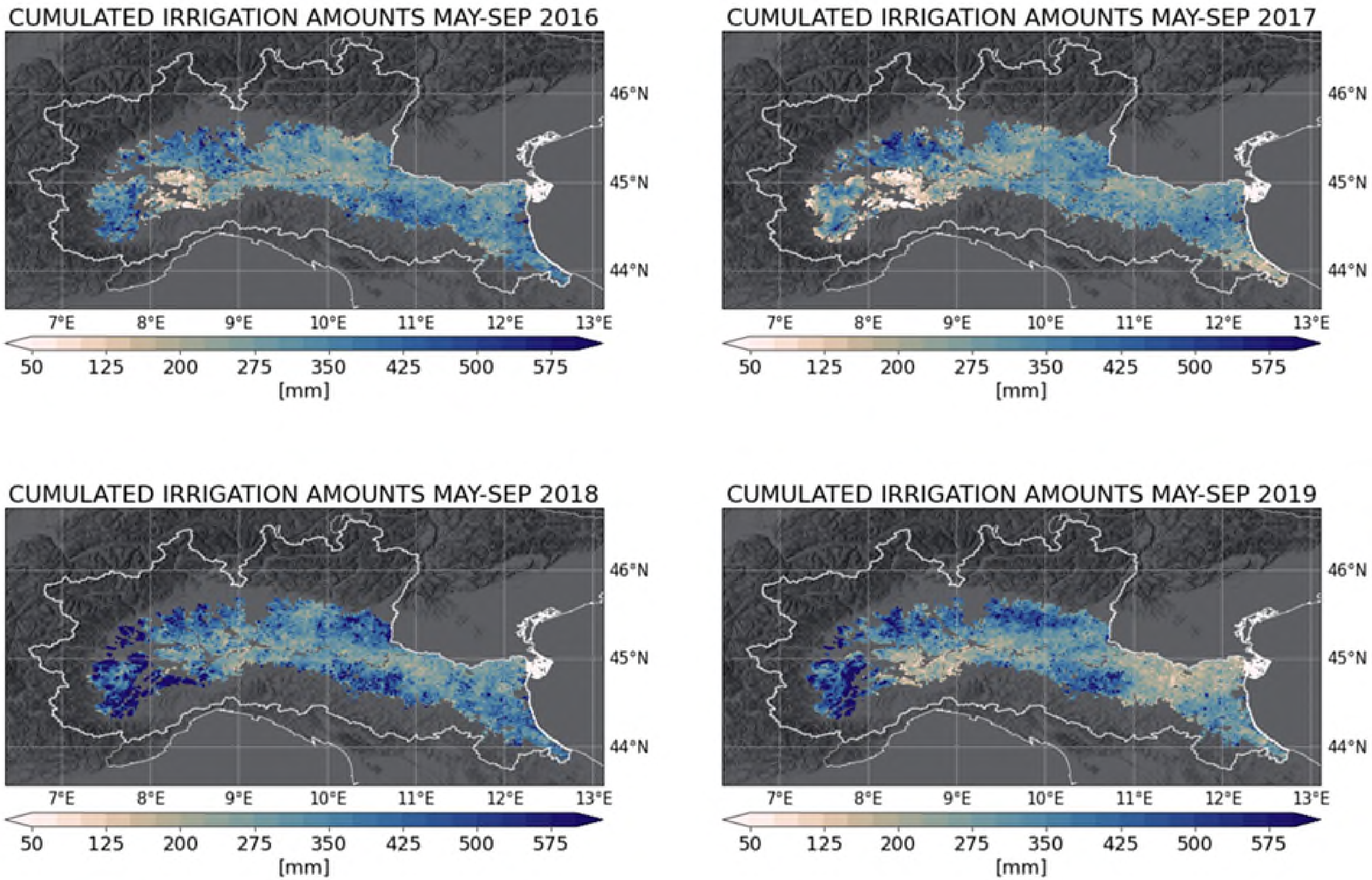

https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-1/Zooming_in_on_drought_from_space

# Digital Twin Earth



# Sentinel-1 for irrigation monitroing

Jacopo Dari –Friday

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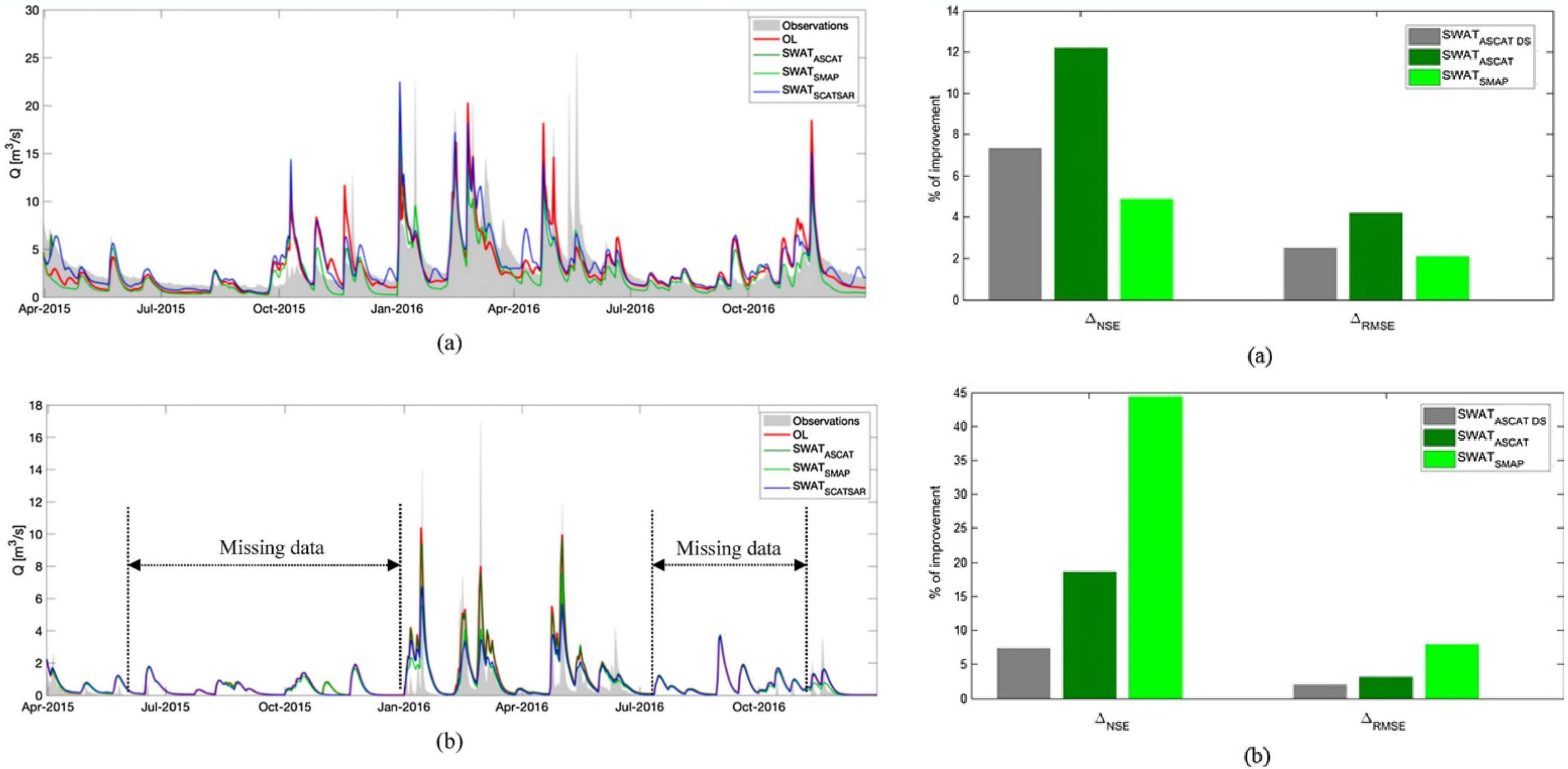
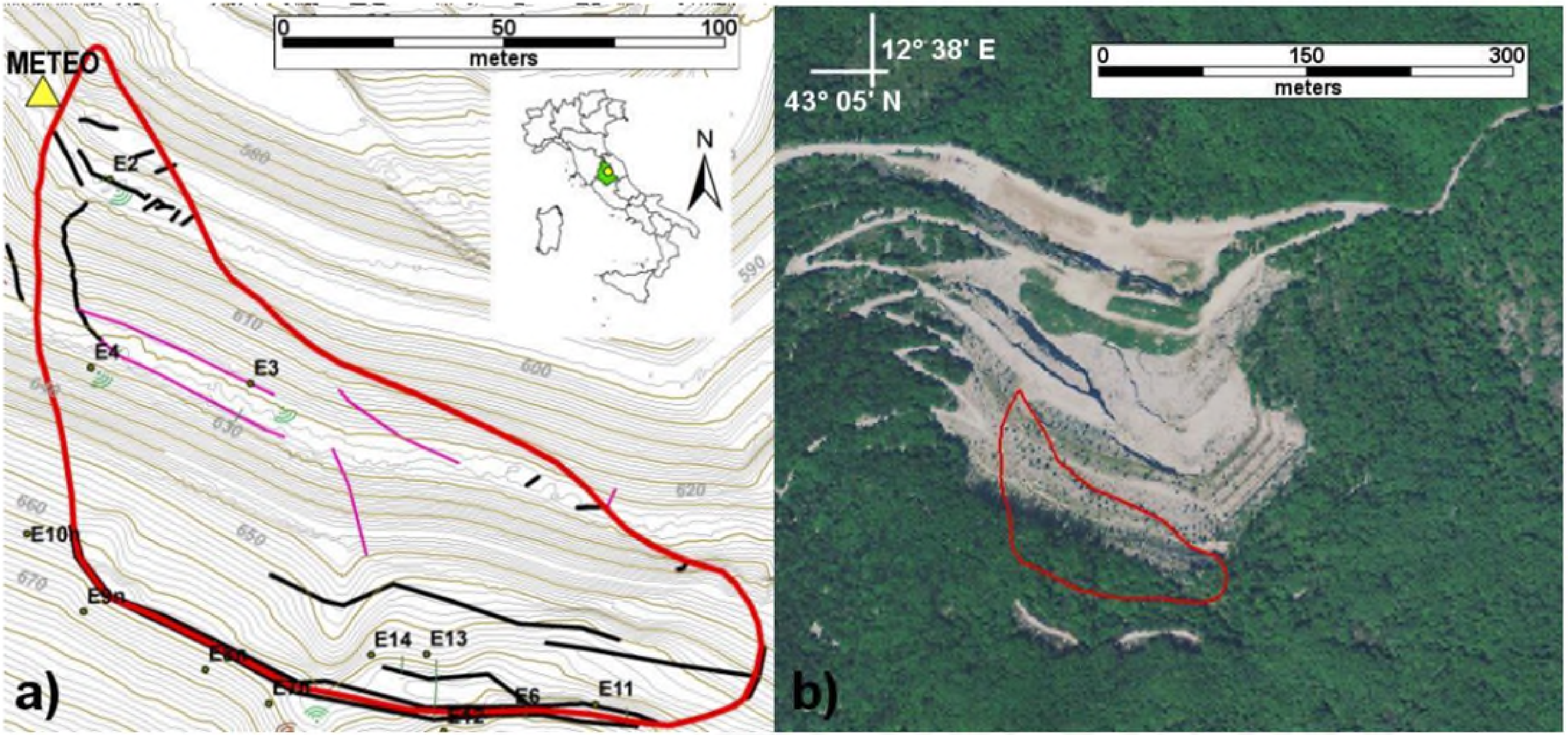
# Temporal sampling important




Discharge and improvements of statistics for two catchments in Umbria, Italy. Azimi et al., 2020 JoH.

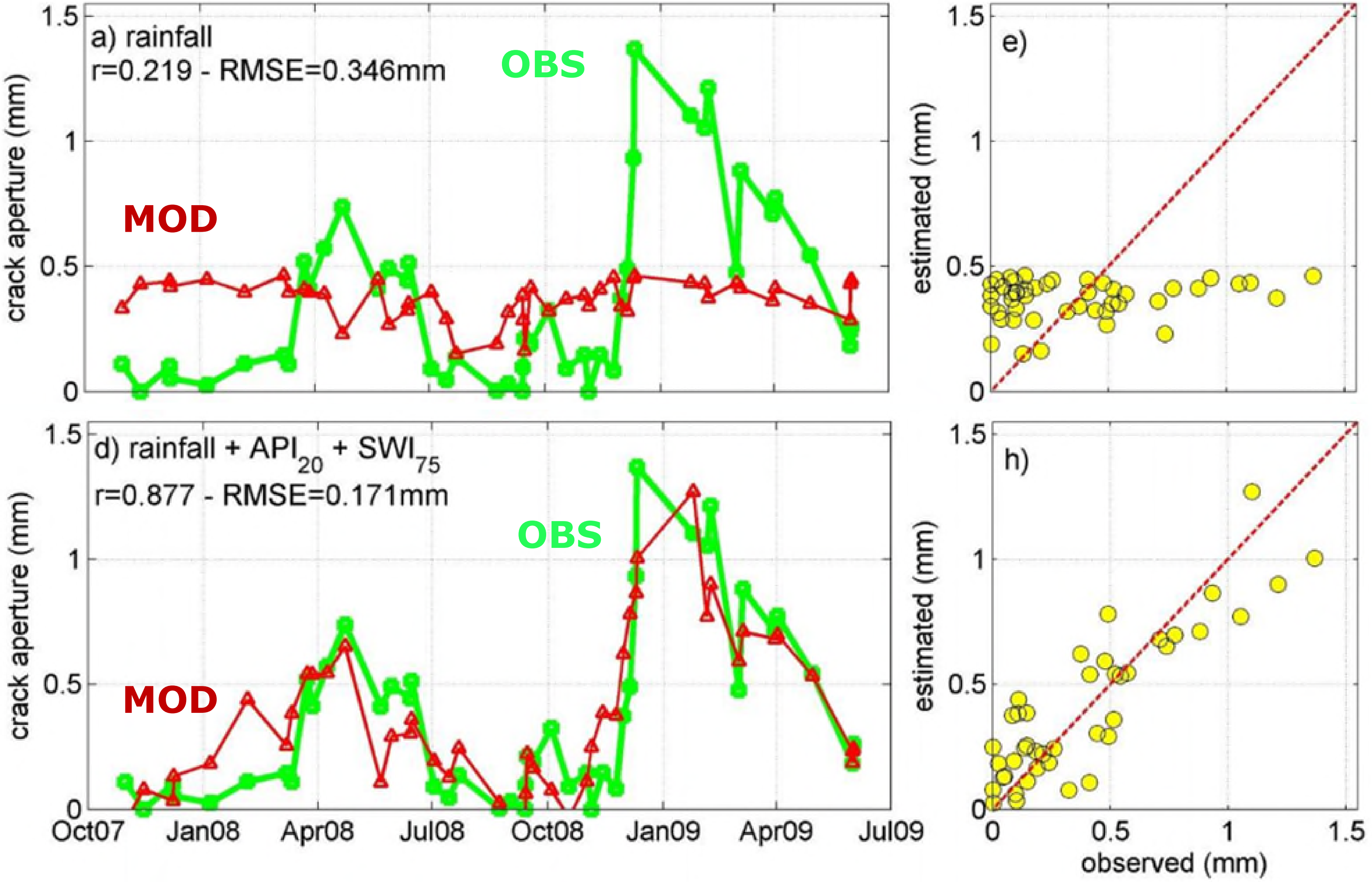
# Landslide monitoring

Torgiovannetto Landslide in Central Italy



# Landslide Monitoring

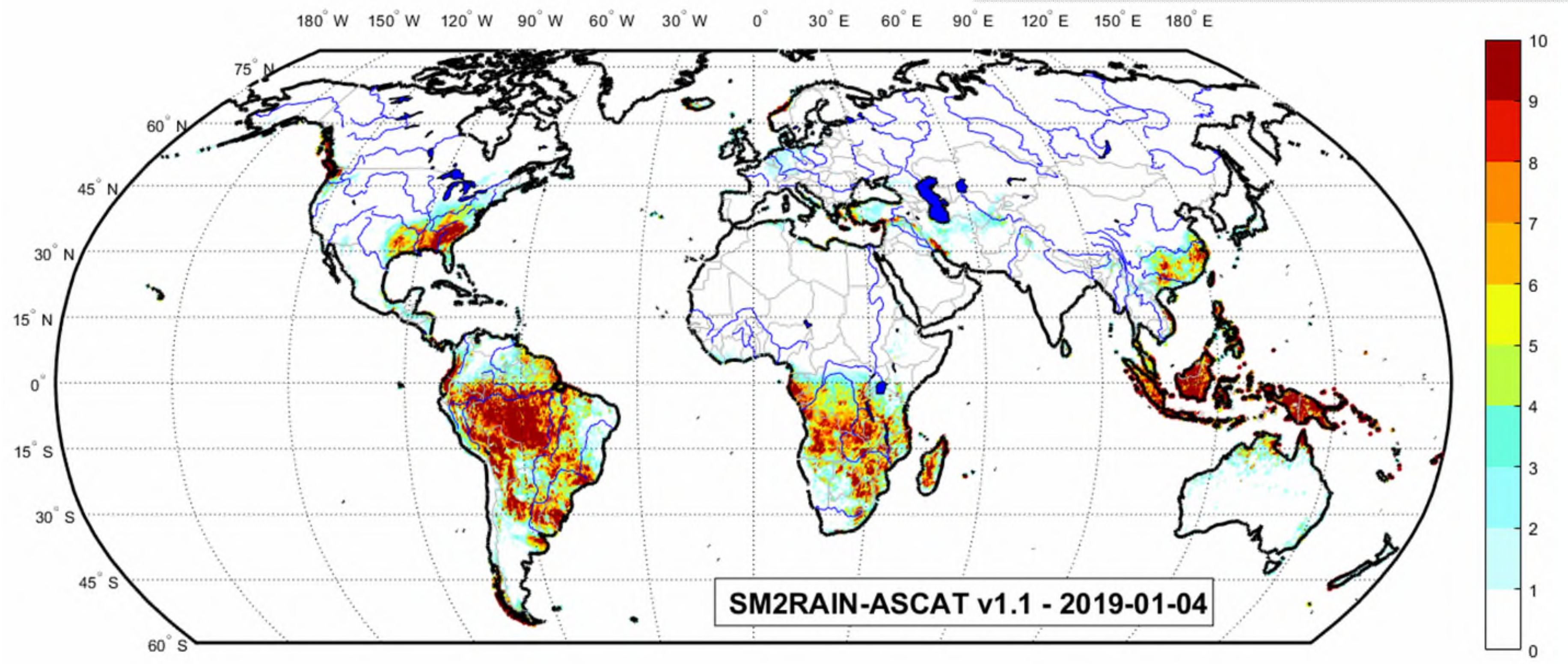
Comparison between observed (circles) and estimated (triangles) crack aperture of the Torgiovannetto Landslide in Central Italy from the beginning to the end of the selected rainfall events.




Brocca et al. (2012) Improving Landslide Forecasting Usi
Data: A Case Study of the Torgiovannetto Landslide in Central Italy, Remote Sensing, 4(5), 1232-1244.

# SM2Rain ASCAT Daily Rainfall Data

Freely available @ Zenodo
https://zenodo.org/record/2591215




DOI 10.5281/zenodo.2591215

Brocca et al. (2019) SM2RAIN-ASCAT (2007–2018): global daily satellite rainfall from ASCAT soil moisture, Earth Syst. Sci. Data, in press.

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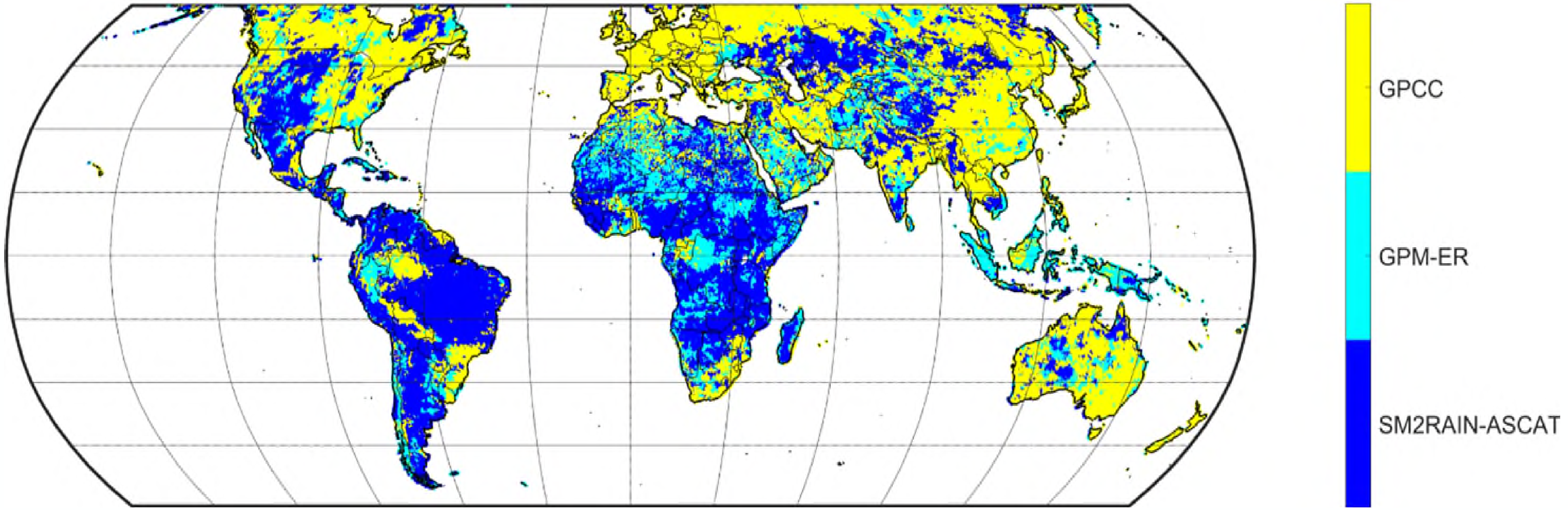
# SM2Rain ASCAT vs GPM vs GPCC




Best performing rainfall product based on the results of a triple collocation analysis according to Brocca et al. (2019).

- GPCC = gauge-based Global Precipitation Climatology Centre data set
- GPM = Integrated Multi-Satellite Retrievals for Global Precipitation Measurement

irpi
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# Exercise

## Mybinder link

Read and analyze CGLS Sentinel-1 and C3S soil moisture data

Trend analysis

ISMN comparison and validation

Outlook on drought analysis

Thank you for your attention!