Monitoring soil moisture from space; a European perspective

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Climate Change

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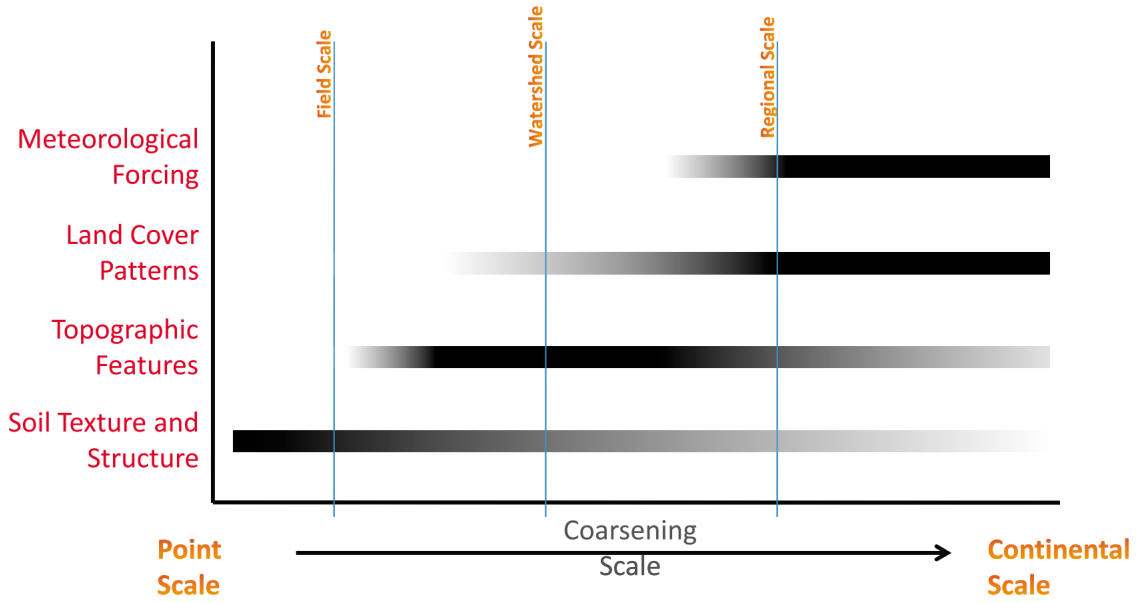
Soil Moisture

- Key variable of the hydrological cycle
- Approximately 75% of land precipitation globally enters the soil → soil moisture will determine whether precipitation infiltrates or runs off the soil.
- Soil moisture is highly variable spatially and temporally - controlled by different drivers depending on the scale



Crow et al., 2012 (Reviews of Geophysics)

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Soil Moisture

Important for

- Hydrology: provides almost all the water that enters groundwater reservoirs (recharge), water supply
- Meteorology: evapotranspiration (partition of available energy into sensible and latent heat exchange)
- Climate Studies
- Agriculture: provides all the water for natural and cultivated agriculture, important for irrigation scheduling, insects & diseases, de-nitrification, etc.

Users:

- Meteorologists
- Hydrologists
- Climatologists
- Water resources managers
- Forest managers
- Agriculture monitoring
- Researchers
- Extremes monitoring (landslide, drought, flooding)
- Rainfall estimation

etc.

Key variable of the water cycle → we need to monitor it continuously and globally

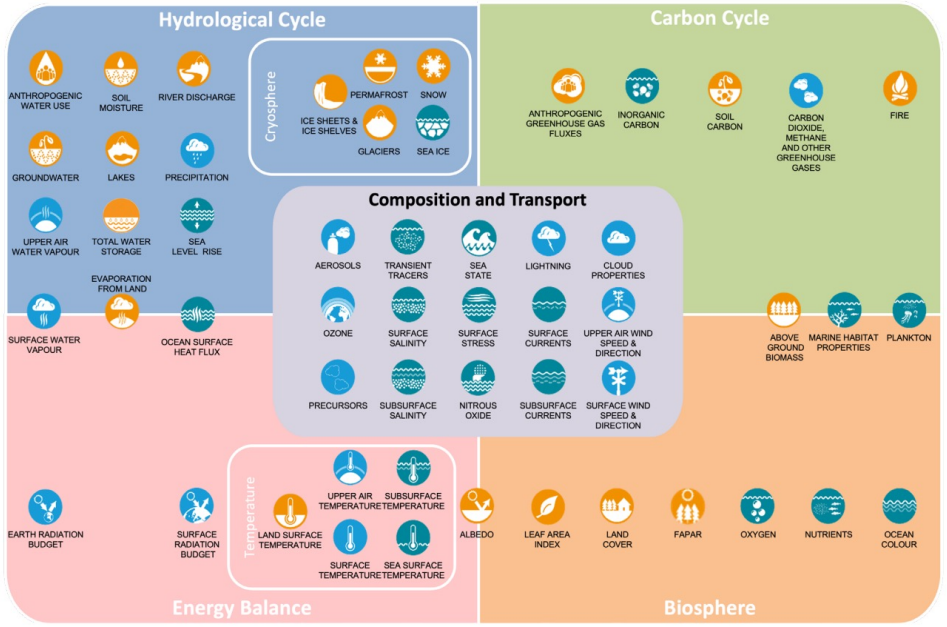

Figure 2. Essential Climate Variables and the climate cycles (See section 2.4). Many ECV contribute to understanding several different cycles – this only indicates the main links.

ECVs belong to three panel domains: ● Atmosphere ECVs (AOPC); ● Ocean ECVs (OOPC); ● Terrestrial ECVs (TOPC)

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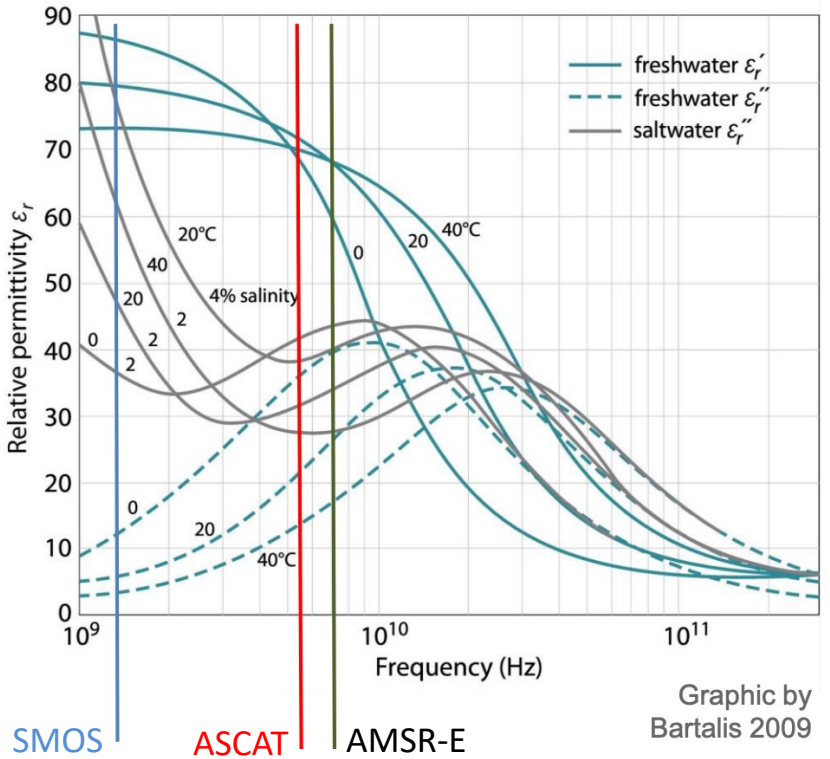
Microwaves domain

- Ground-based measurements of soil moisture are generally sparse and unavailable at many locations, often short term.
- Microwave remote sensing offers all-weather (but the densest and precipitating cloud cover), day-round measurement capability
- Microwave measurements are sensitive to
  - Dielectric properties – Water
  - Geometric structure – Roughness
  - Vegetation (High penetration into vegetation and soil; penetration depth is deeper for lower microwave frequencies)
- Longer wavelengths beneficial
- Basis of microwaves remote sensing of soil moisture is the contrast between the dielectric constant of water (80) and dry soils (<5), producing strong contrast in emissivity

Dielectric properties of water at microwave frequencies



Graphic by Bartalis 2009

SMOS L-band: 1.4 GHz

ASCAT C-band: 5.2 GHz

AMSR-E C-band: 6.9 GHz

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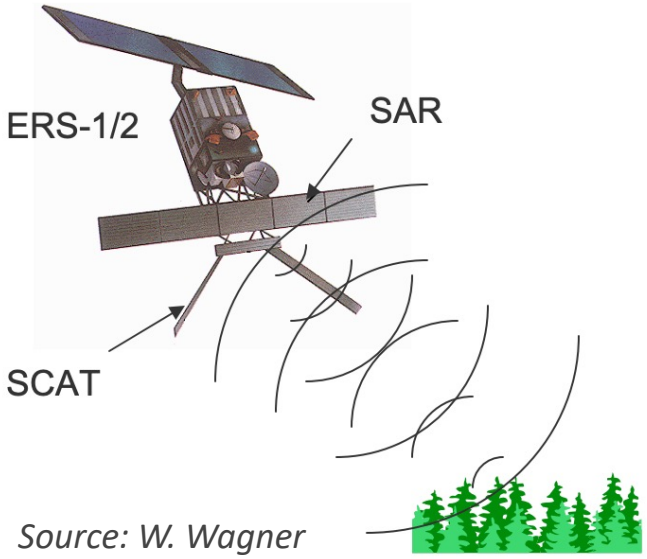
Microwaves remote sensing - measuring principles

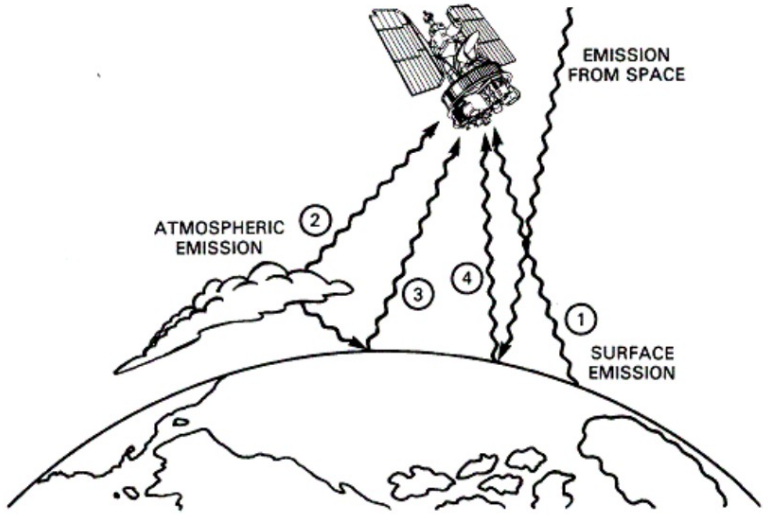
- **Radars** emit pulses of energy, then detects and measure the energy scattered back from the surface (how reflective the Earth surface is)
- **Radiometers** measure the self-emission of the Earth's surface

Active Sensors



Source: W. Wagner

Passive Sensor



If soil moisture ↑ soil reflectivity (backscatter) ↑ and emissivity ↓

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Active remote sensing – European C-Band Scatterometers (~ 5.2 GHz)

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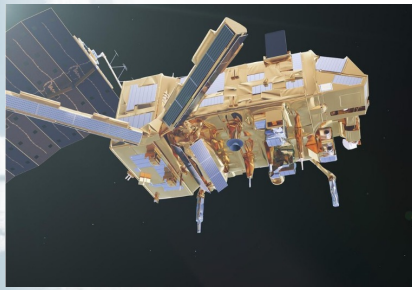
AMI Scaterometer

ERS-1: 1991-2000
ERS-2: 1995-2011
Resolution: 50 km
Daily global coverage: 41%
2002: first global SM dataset



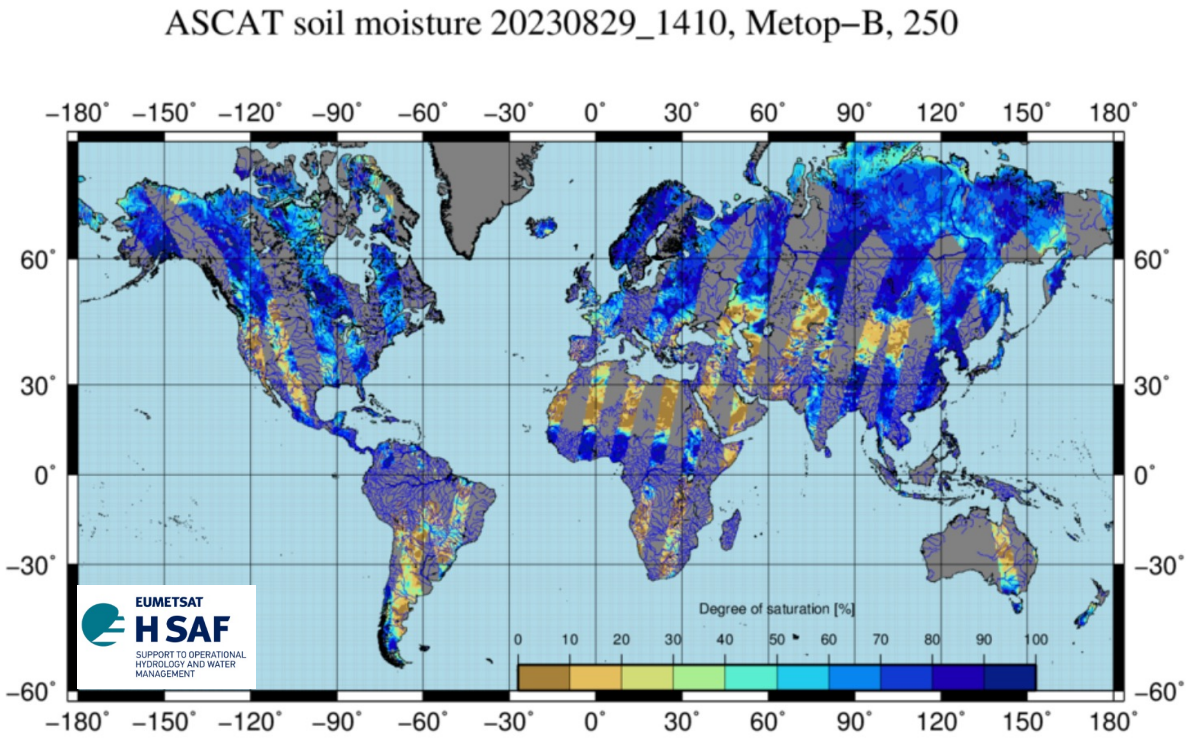
ASCAT

METOP-A: 2006-2021
METOP-B: 2012-present
METOP-C: 2018-present
Resolution: 25 km
Daily global coverage: 82%
2008: first oper SM service

SCA

METOP-SG-B1: 2025
METOP-SG-B2: 2032
METOP-SG-B3: 2039
Resolution: 12.5 km
Daily global coverage: 88%

Profile of soil moisture content obtained by filtering surface soil moisture time series with an exponential function



Several products (NRT, offline, data records) produced and distributed by EUMETSAT's H-SAF

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Passive remote sensing – European L-band radiometers (1.4 GHz)

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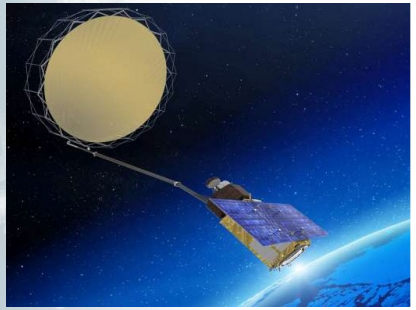
SMOS

SMOS: 2010-present
Resolution: ~35 km at center FOV
Global land coverage 3 days

SMAP

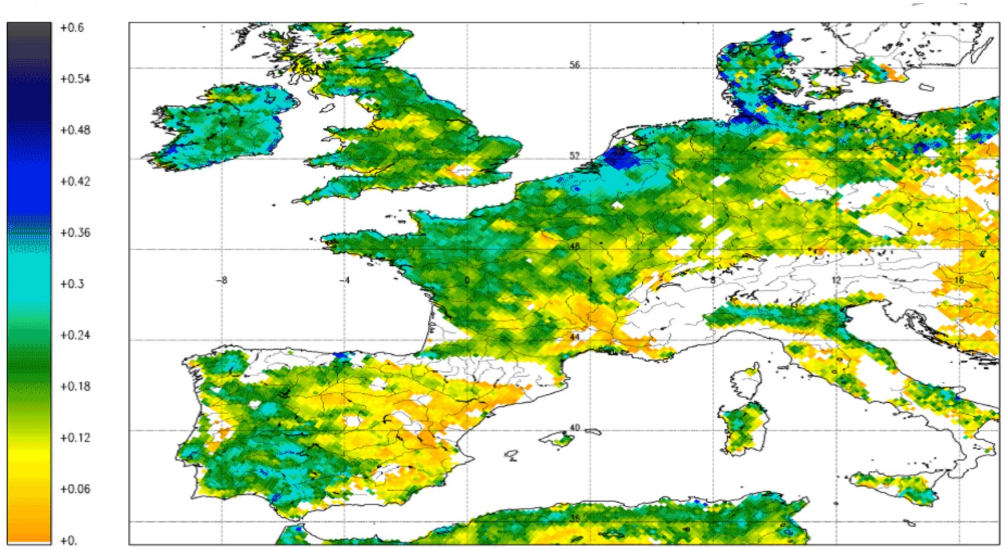
SMAP: 2015-present
Resolution: ~40 km
Global land coverage 3 days



CIMR

CIMR: 2028/2029
Resolution: L-band (60 km);
C/X-bands (15 km)
Daily global coverage 95%

Volumetric soil moisture (m^3/m^{-3}) based on SMOS observations



esa CESBIO

ESA SMOS dissemination centre distributes SMOS L1&L2 products

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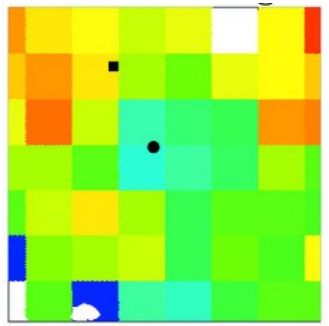
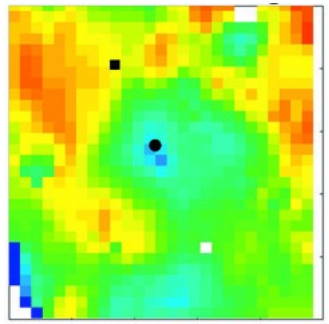
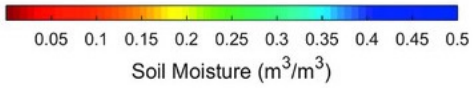
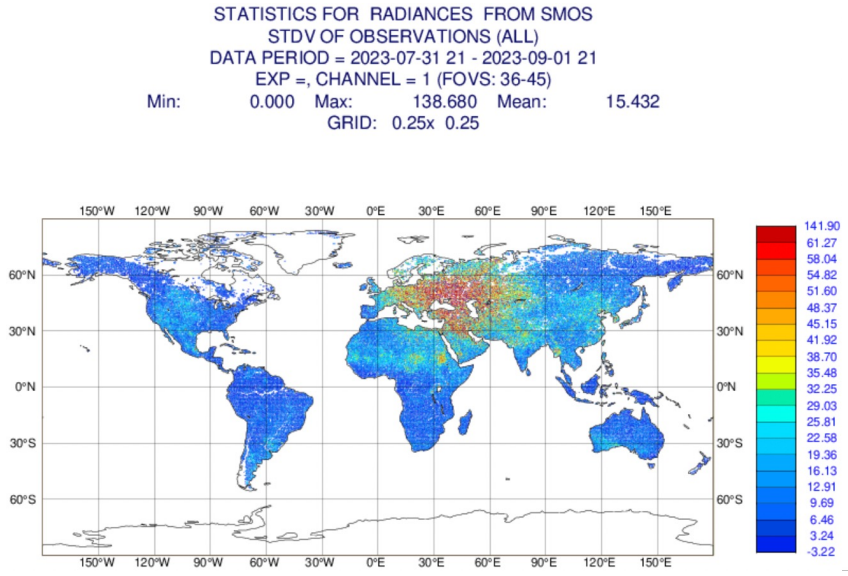
Active vs passive

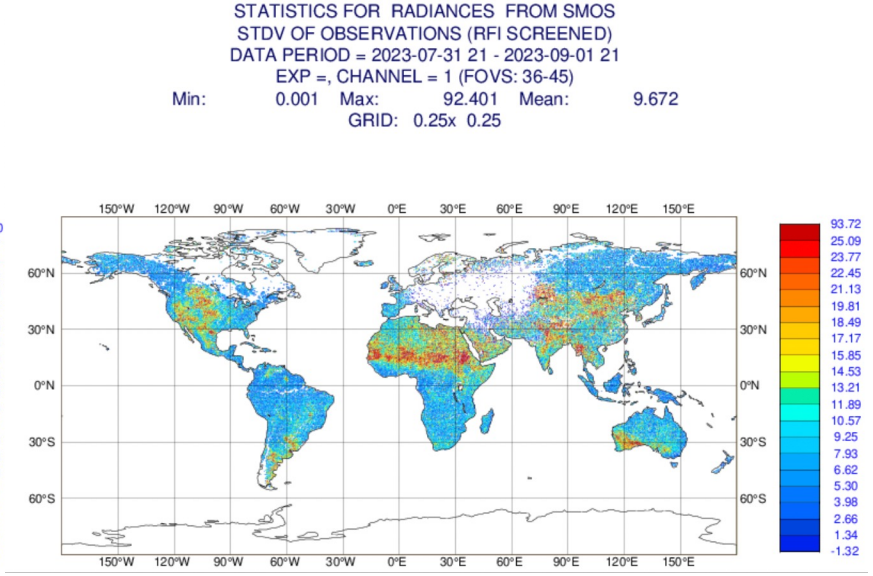
- Active measurements are more sensitive to surface roughness and vegetation structure. However, they are less affected by surface temperature (above 0°C) and have higher spatial resolution
- Low frequencies passive measurements have higher penetration depth, best sensitivity to soil moisture, but could be affected by RFI.











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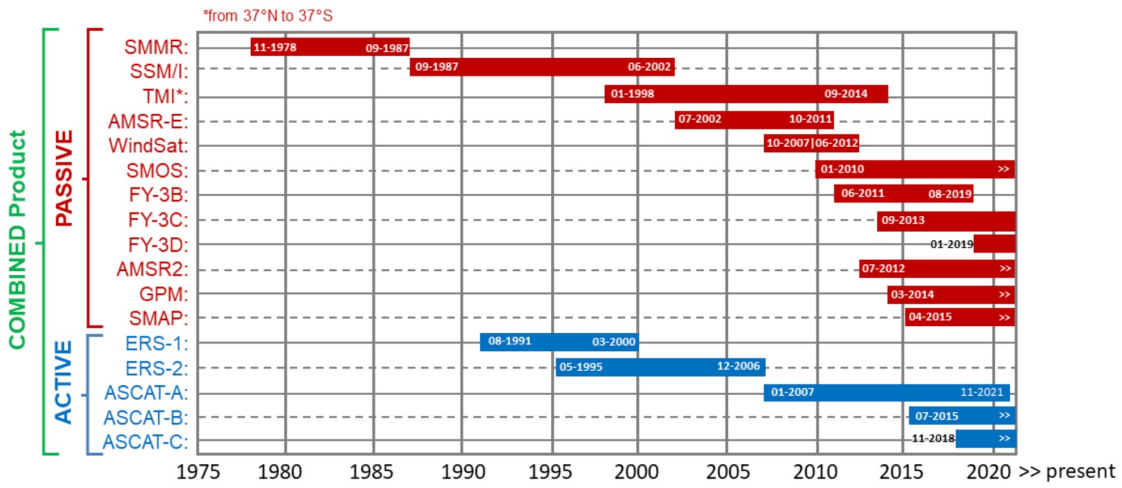
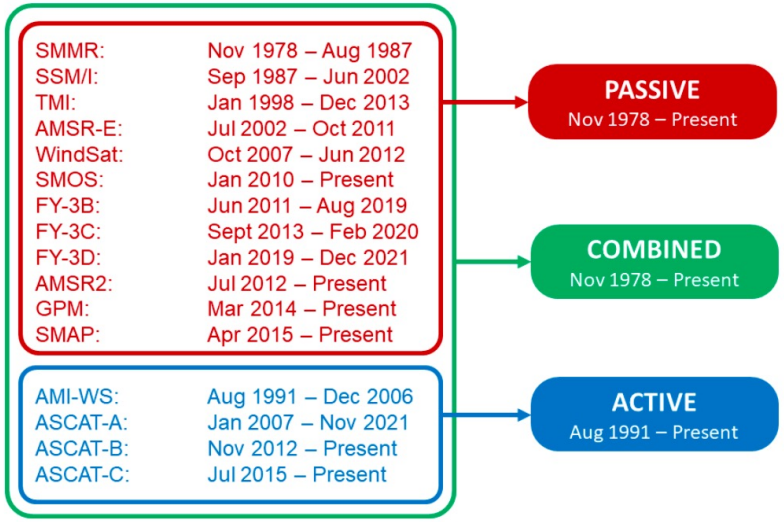
Multi-sensor fused active/passive soil moisture

A combination of active and passive measurements can overcome some of the shortfalls of active or passive only data.

→ ESA-CCI Soil Moisture has developed developed a multi-sensor fused product

Sensors and merging periods for the C3S soil moisture product





Credits: TUWien / EODC

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C3S Soil moisture data services

Clima
Chang

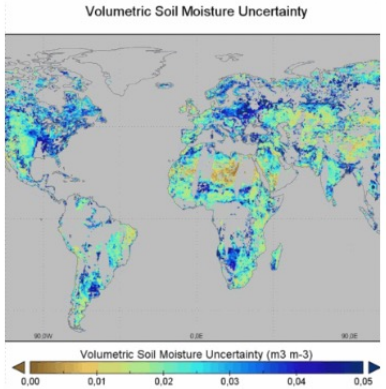
Soil moisture gridded data from 1978 to present

Overview | Download data | Quality assessment | Documentation

This dataset provides estimates of **soil moisture** over the globe from a large set of satellite sensors. It is based on the ESA Climate Change Initiative soil moisture version 03.3 and represents the current state-of-the-art for satellite-based soil moisture climate data record production, in line with the "Systematic observation requirements for satellite-based products for climate" as defined by GCOS (Global Climate Observing System). Data are on a regular latitude/longitude grid expectedly with gaps in space and time.

When dealing with satellite data it is common to encounter references to Climate Data Records (CDR) and interim-CDR (ICDR). For this dataset, both the ICDR and CDR parts of each product were generated using the same software and algorithms. The CDR is intended to have sufficient length, consistency, and continuity to detect climate variability and change. The ICDR provides a short-delay access to current data where consistency with the CDR baseline is expected but was not extensively checked. The dataset contains the following products: "active", "passive" and "combined". The "active" and "passive" products were created by using scatterometer and radiometer soil moisture products, respectively. The "combined" product results from a blend based on the two previous products.

This dataset is produced on behalf of the Copernicus Climate Change Service (C3S).



DATA DESCRIPTION	
Data type	Gridded
Projection	Regular latitude-longitude grid
Horizontal coverage	Global
Horizontal resolution	0.25° x 0.25°
Temporal coverage	1978 to present
Temporal resolution	Daily, 10-day, Monthy
File format	NetCDF
Conventions	Climate and Forecast (CF) Metadata Convention v1.8
Versions	v201706: First release of the dataset. Equivalent to CCI version 3. v201812: Algorithm updates (merging, signal to noise ratio gap filling, uncertainties, masking), sensor updates (SMOS included). Equivalent to CCI version 4. v201912: Temporal extension of v201812 to 2019-12-31, updates in passive data pre-processing. Equivalent to CCI version 3. v202012: Algorithm updates (passive sensors processing, matching, sensor updates (SMAP included). Equivalent to CCI version 5.
Update frequency	ICDR: produced on a 10-day cycle with a 10-day latency. CDR: annual. Both updated in the CDS with a 25 days latency.

MAIN VARIABLES		
Name	Units	Description
Surface soil moisture	%	Content of liquid water in a surface soil layer of 2 to 5 cm depth expressed as the percentage of total saturation.
Volumetric soil moisture	$m^3\ m^{-3}$	Content of liquid water in a surface soil layer of 2 to 5 cm depth expressed as m^3 water per m^3 soil.

- Data providers: EODC, TU Wien & VanderSat
- Long-term datasets (1978 up to present)
- 0.25° x 0.25° active/passive only and merged active/passive microwave soil moisture
- Daily, decadal and monthly data files
- Updated CDRs with latest research
- Independent quality assurance
- Comprehensive documentation

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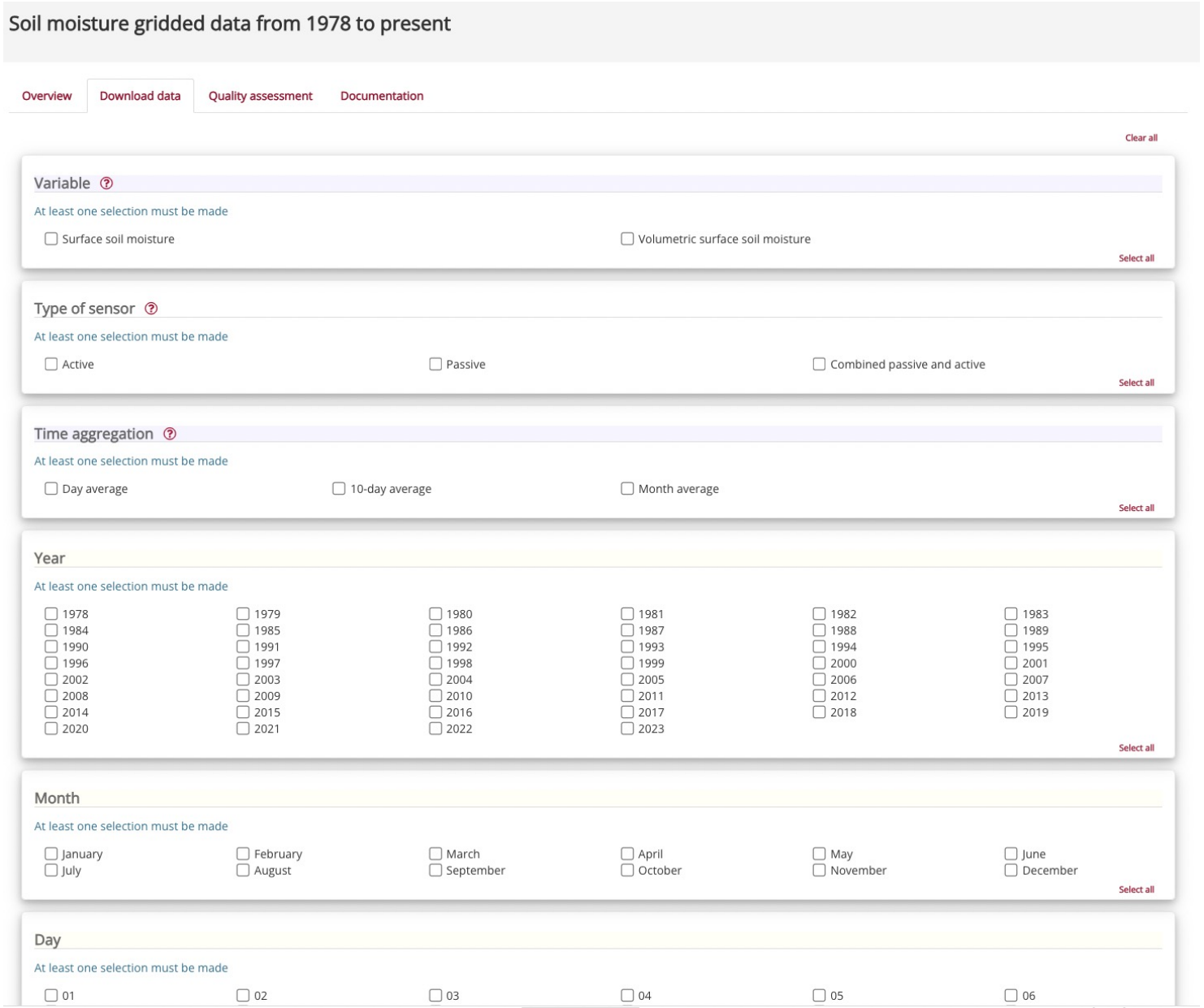

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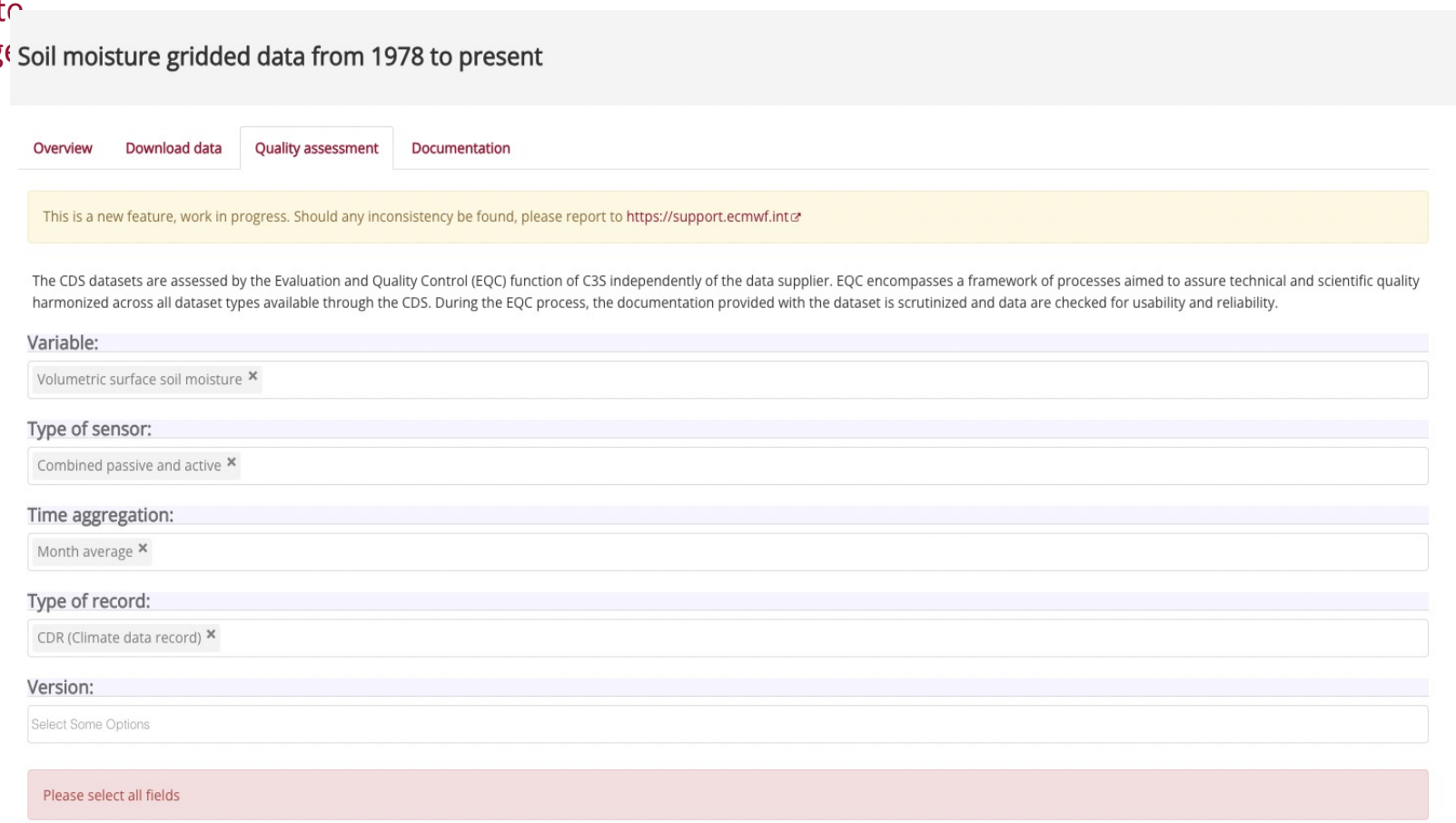

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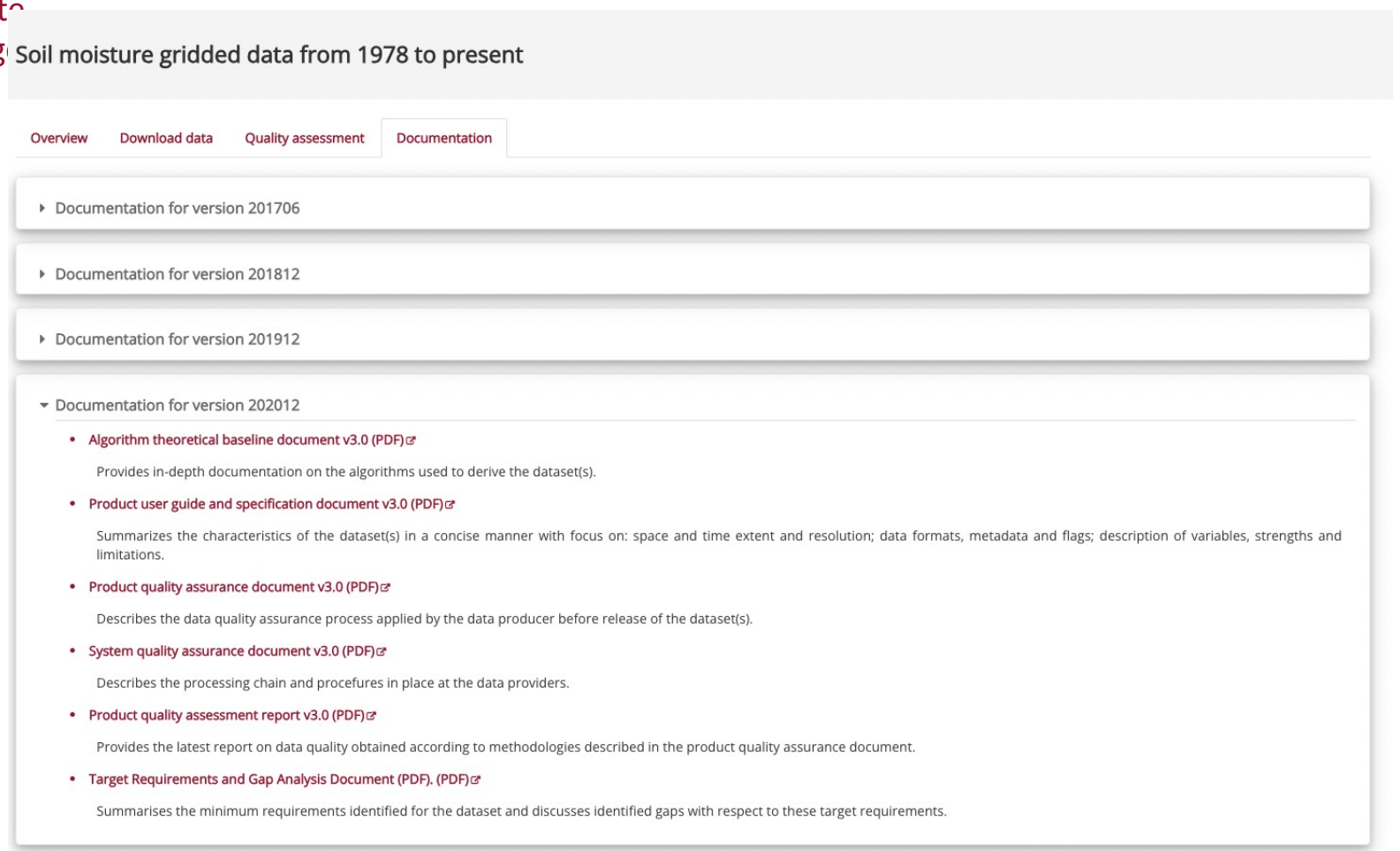

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Monitoring the quality of the data

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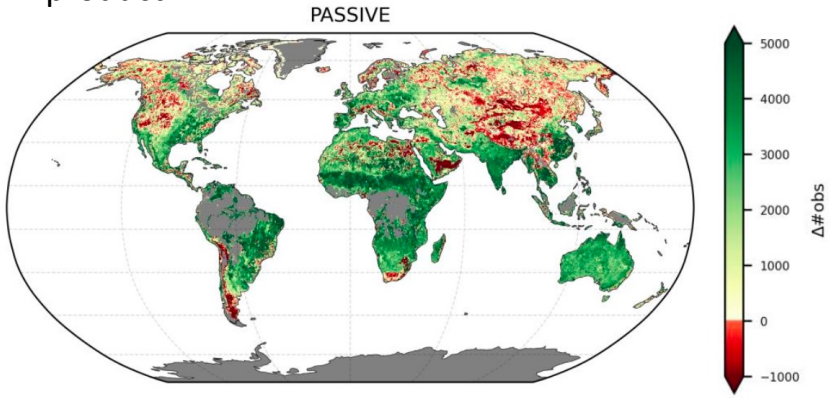
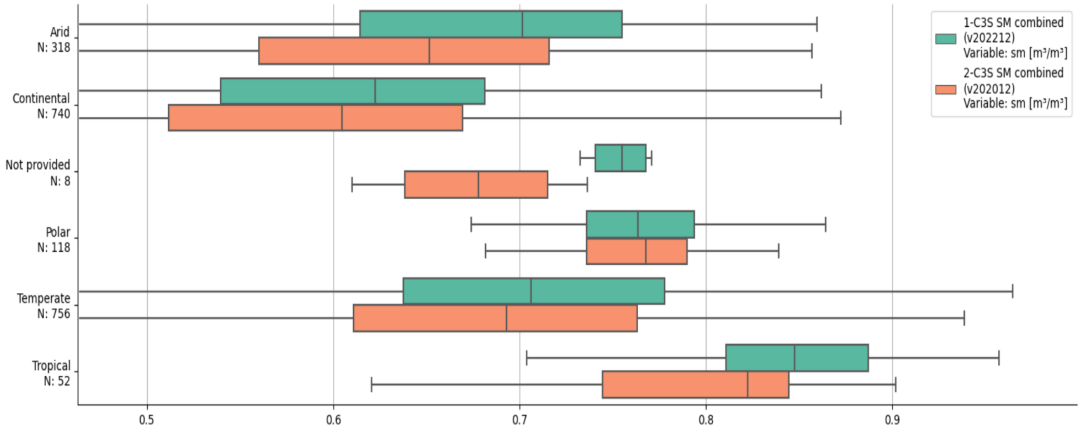
Change in number of observations (daily) in C3S SM v202212 compared to v202012 in the period after 1991-01-01 for the PASSIVE product

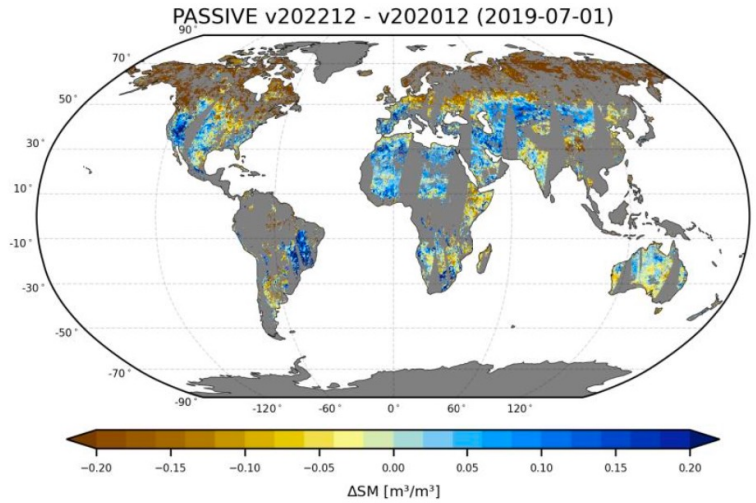


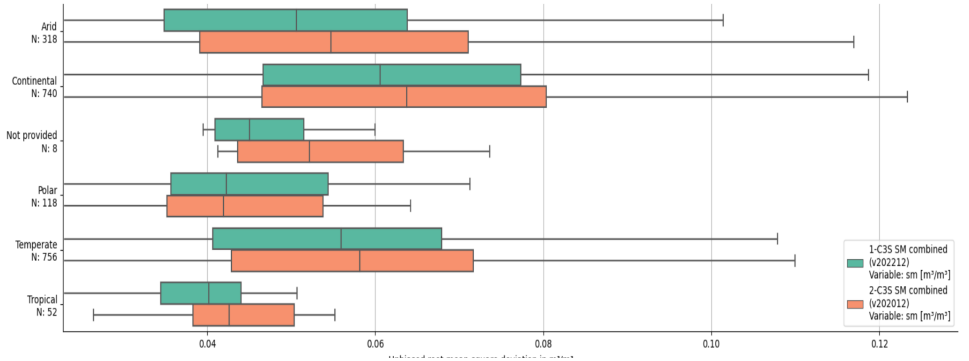
Absolute values of SM(combined product) and ISMN for different climate classes in 0-10 cm depth.



Correlation (Pearson's)

Absolute difference in soil moisture between C3S SM v202212 and v202012 for PASSIVE product on 2019-07-01.





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Credits: TUWien / EODC

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Summary & final remarks

- Soil moisture is a key Essential Climate Variable of the hydrological cycle, critical for many types of users. As such, we have to monitor it globally and continuously.

- Microwaves remote sensing (in particular L-band) are the most sensitive to soil moisture variations. However, its retrieval and interpretation is complex and requires expertise.

- In Europe there exist a rich legacy of research, industry and exploitation of microwave remote sensing signal, which allows us to build long, consistent Climate Data Records of soil moisture.

- C3S offers soil moisture services, including access to up-to-date data records, documentation oriented to all type of users, data viewer, training material, etc.

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Thank you for your attention

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