

Monitoring soil moisture from space; a European perspective



Climate Change

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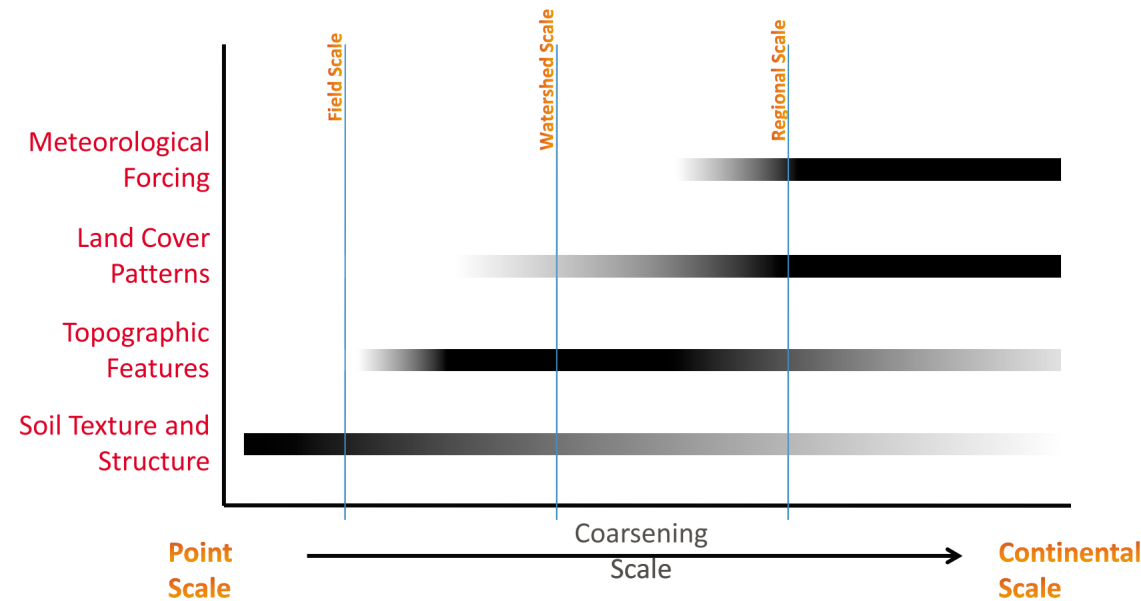




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Soil Moisture

- 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

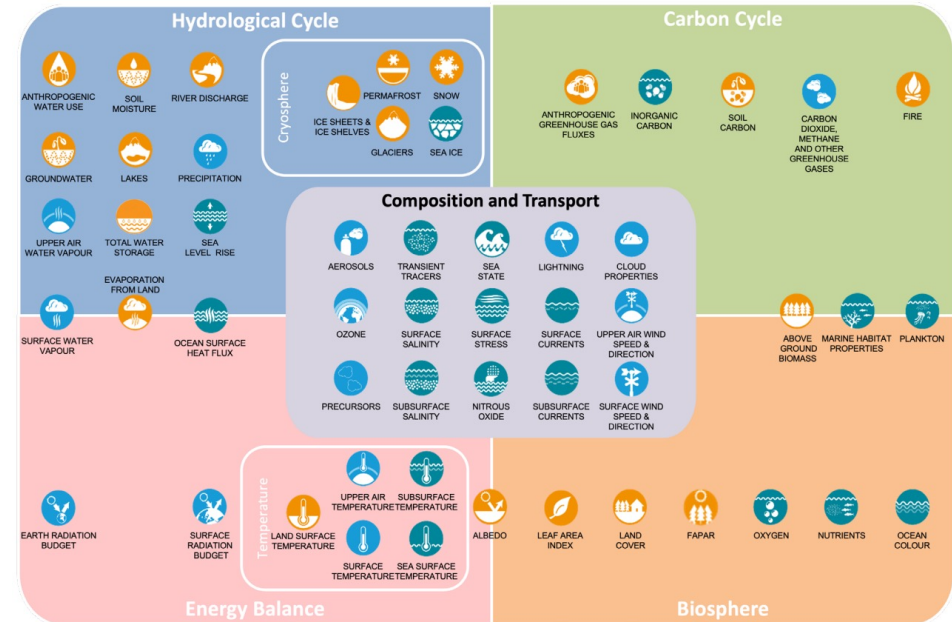


Figure 2. Essential Climate Variables and the climate cycles (See section 2.4). Many ECV contribute to understanding several different cycles – this only indicates the main links.



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

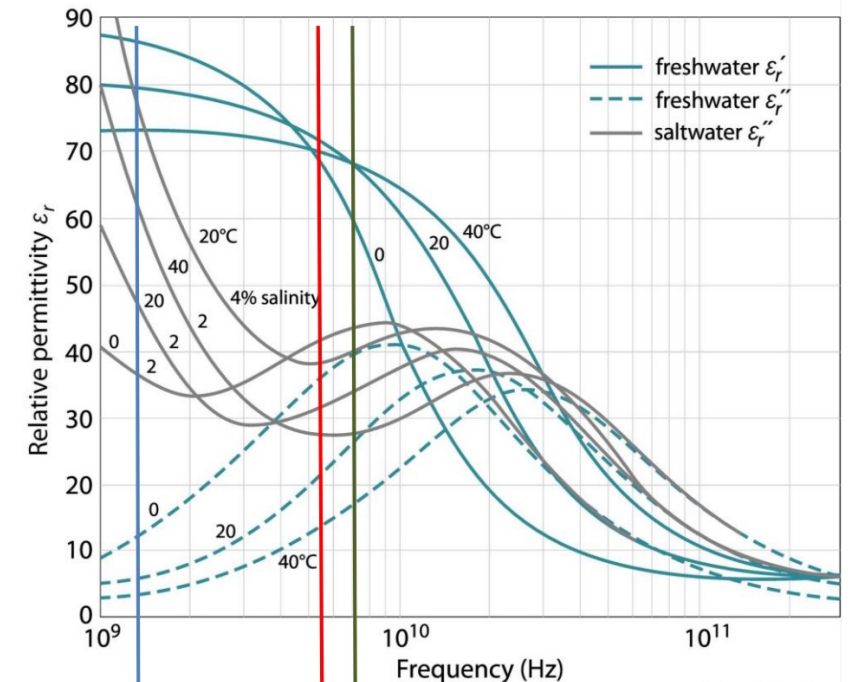


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Microwaves domain

- 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



SMOS
L-band:
1.4 GHz

ASCAT
C-band:
5.2 GHz

AMSR-E
C-band:
6.9 GHz

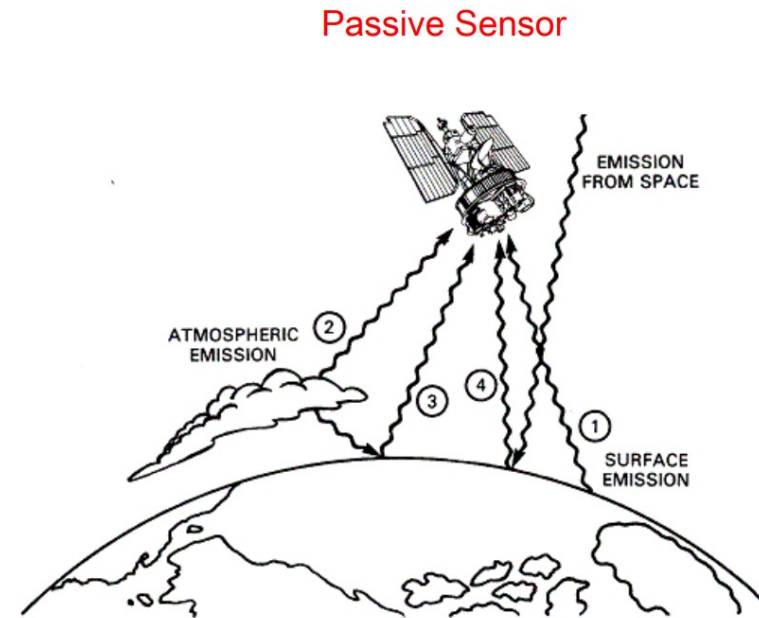
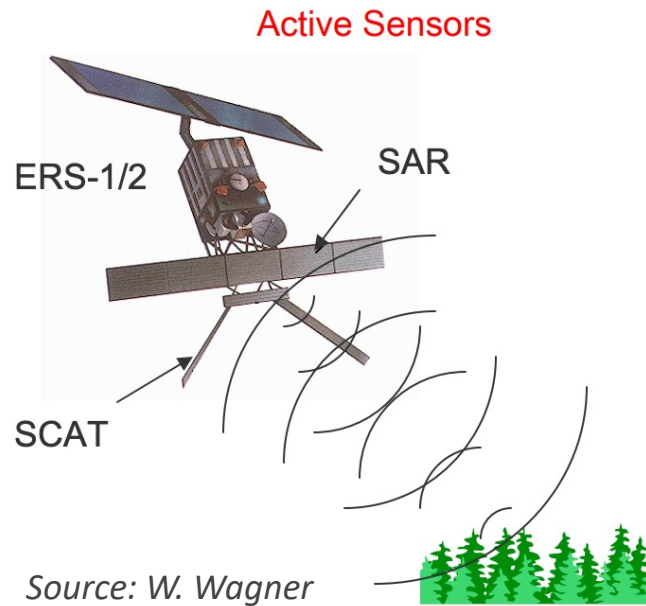
Graphic by
Bartalis 2009



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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



If soil moisture \uparrow soil reflectivity (backscatter) \uparrow and emissivity \downarrow



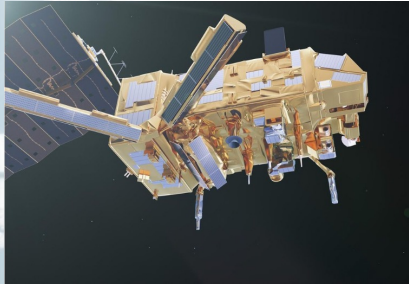
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Active remote sensing – European C-Band Scatterometers (~ 5.2 GHz)



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

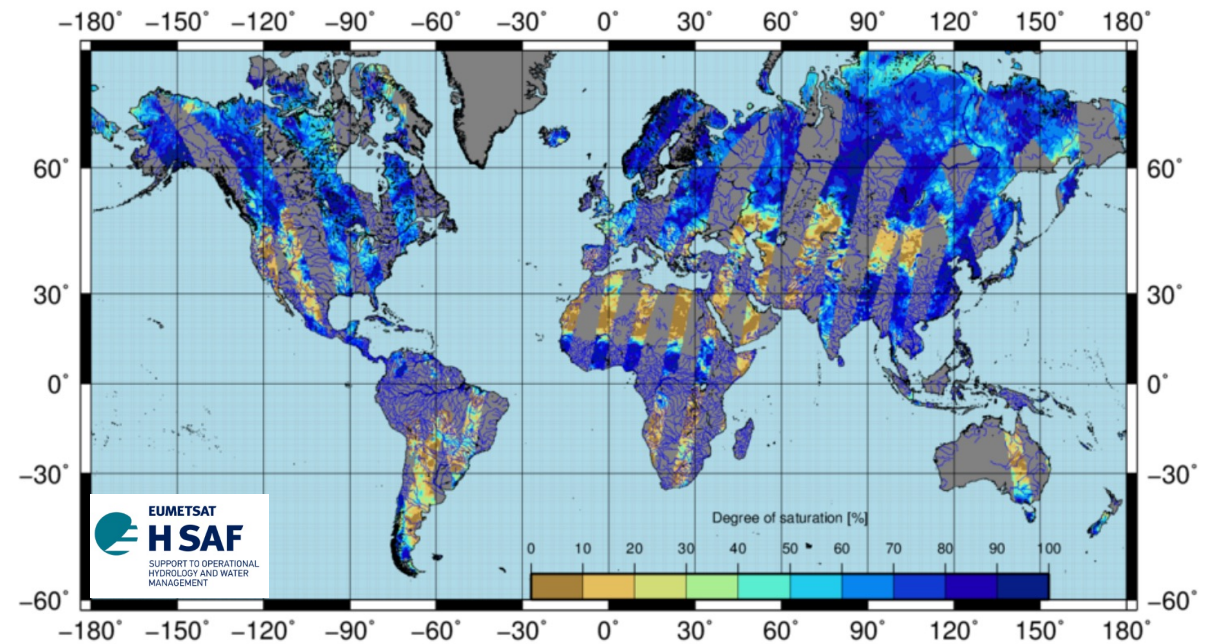


SCA

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

ASCAT soil moisture 20230829_1410, Metop-B, 250



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)



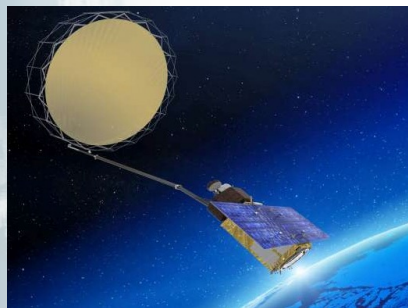
SMOS

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



SMAP

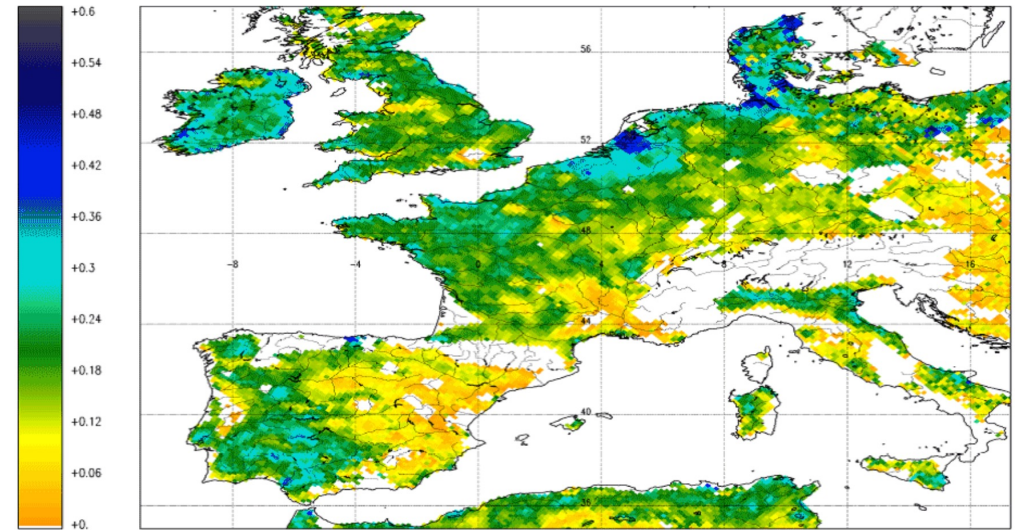
SMAP: 2015-present
Resolution: ~40 km
Global land coverage 3 days



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



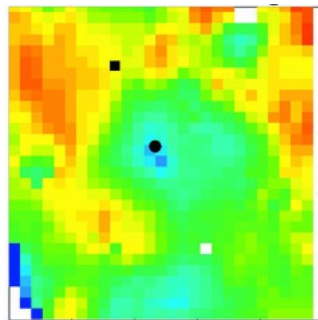
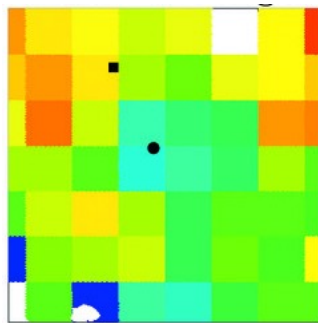
ESA SMOS dissemination centre distributes SMOS L1&L2 products





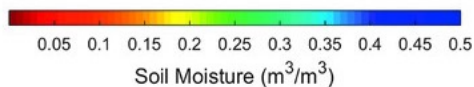
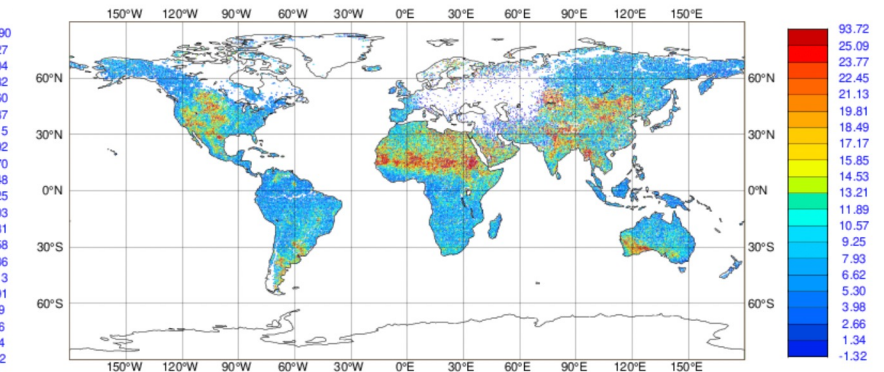
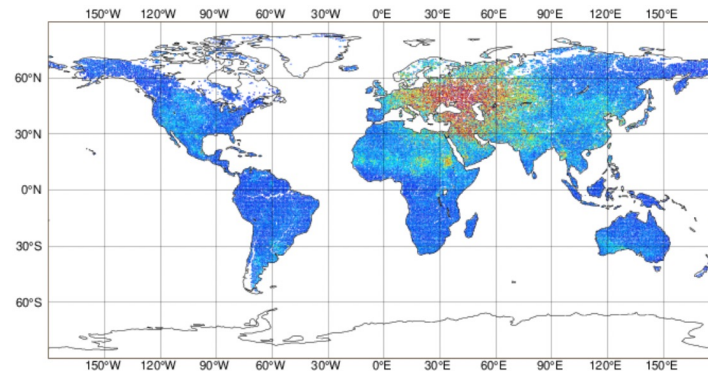
Active vs passive

- 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.



STATISTICS FOR RADIANCES FROM SMOS
STDV OF OBSERVATIONS (ALL)
DATA PERIOD = 2023-07-31 21 - 2023-09-01 21
EXP =, CHANNEL = 1 (FOVS: 36-45)
Min: 0.000 Max: 138.680 Mean: 15.432
GRID: 0.25x 0.25

STATISTICS FOR RADIANCES FROM SMOS
STDV OF OBSERVATIONS (RFI SCREENED)
DATA PERIOD = 2023-07-31 21 - 2023-09-01 21
EXP =, CHANNEL = 1 (FOVS: 36-45)
Min: 0.001 Max: 92.401 Mean: 9.672
GRID: 0.25x 0.25





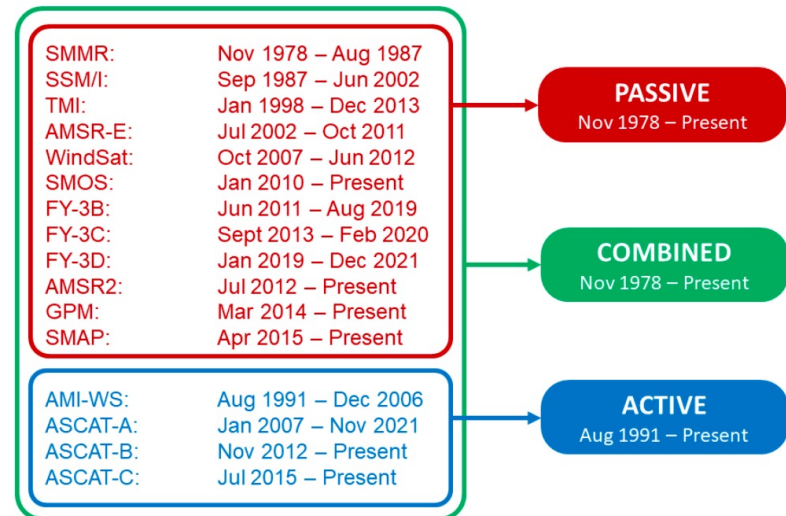
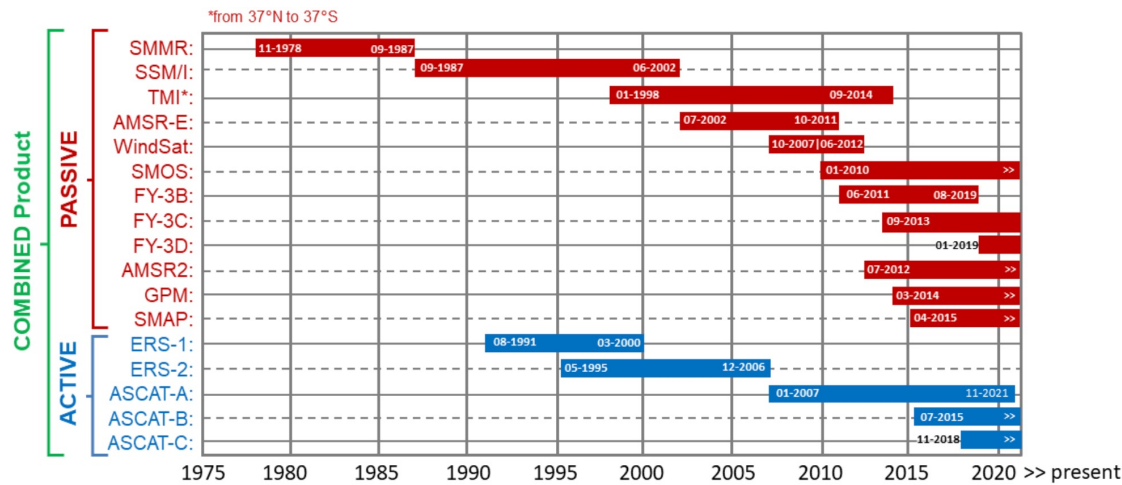
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Multi-sensor fused active/passive soil moisture

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

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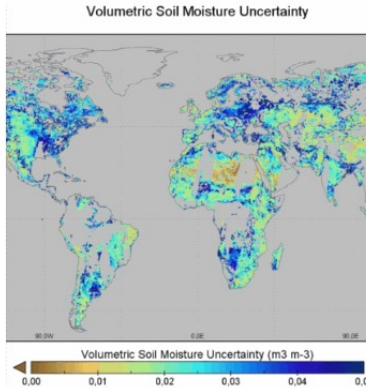
Soil moisture gridded data from 1978 to present

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, Monthly
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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C3S Soil moisture data services

Soil moisture gridded data from 1978 to present

Overview | **Download data** | Quality assessment | Documentation

Clear all

Variable ⓘ
At least one selection must be made

Surface soil moisture Volumetric surface soil moisture Select all

Type of sensor ⓘ
At least one selection must be made

Active Passive Combined passive and active Select all

Time aggregation ⓘ
At least one selection must be made

Day average 10-day average Month average Select all

Year
At least one selection must be made

<input type="checkbox"/> 1978	<input type="checkbox"/> 1979	<input type="checkbox"/> 1980	<input type="checkbox"/> 1981	<input type="checkbox"/> 1982	<input type="checkbox"/> 1983
<input type="checkbox"/> 1984	<input type="checkbox"/> 1985	<input type="checkbox"/> 1986	<input type="checkbox"/> 1987	<input type="checkbox"/> 1988	<input type="checkbox"/> 1989
<input type="checkbox"/> 1990	<input type="checkbox"/> 1991	<input type="checkbox"/> 1992	<input type="checkbox"/> 1993	<input type="checkbox"/> 1994	<input type="checkbox"/> 1995
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<input type="checkbox"/> 2014	<input type="checkbox"/> 2015	<input type="checkbox"/> 2016	<input type="checkbox"/> 2017	<input type="checkbox"/> 2018	<input type="checkbox"/> 2019
<input type="checkbox"/> 2020	<input type="checkbox"/> 2021	<input type="checkbox"/> 2022	<input type="checkbox"/> 2023		

Select all

Month
At least one selection must be made

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<input type="checkbox"/> July	<input type="checkbox"/> August	<input type="checkbox"/> September	<input type="checkbox"/> October	<input type="checkbox"/> November	<input type="checkbox"/> December

Select all

Day
At least one selection must be made

<input type="checkbox"/> 01	<input type="checkbox"/> 02	<input type="checkbox"/> 03	<input type="checkbox"/> 04	<input type="checkbox"/> 05	<input type="checkbox"/> 06
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Soil moisture gridded data from 1978 to present

Overview Download data **Quality assessment** Documentation

This is a new feature, work in progress. Should any inconsistency be found, please report to <https://support.ecmwf.int>

The CDS datasets are assessed by the Evaluation and Quality Control (EQC) function of C3S independently of the data supplier. EQC encompasses a framework of processes aimed to assure technical and scientific quality harmonized across all dataset types available through the CDS. During the EQC process, the documentation provided with the dataset is scrutinized and data are checked for usability and reliability.

Variable:

Volumetric surface soil moisture ✕

Type of sensor:

Combined passive and active ✕

Time aggregation:

Month average ✕

Type of record:

CDR (Climate data record) ✕

Version:

Select Some Options

Please select all fields

- Data providers: EODC, TU Wien & VanderSat
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Soil moisture gridded data from 1978 to present

Overview Download data Quality assessment Documentation

- ▶ Documentation for version 201706
- ▶ Documentation for version 201812
- ▶ Documentation for version 201912
- ▼ Documentation for version 202012
 - [Algorithm theoretical baseline document v3.0 \(PDF\)](#) 
Provides in-depth documentation on the algorithms used to derive the dataset(s).
 - [Product user guide and specification document v3.0 \(PDF\)](#) 
Summarizes the characteristics of the dataset(s) in a concise manner with focus on: space and time extent and resolution; data formats, metadata and flags; description of variables, strengths and limitations.
 - [Product quality assurance document v3.0 \(PDF\)](#) 
Describes the data quality assurance process applied by the data producer before release of the dataset(s).
 - [System quality assurance document v3.0 \(PDF\)](#) 
Describes the processing chain and procedures in place at the data providers.
 - [Product quality assessment report v3.0 \(PDF\)](#) 
Provides the latest report on data quality obtained according to methodologies described in the product quality assurance document.
 - [Target Requirements and Gap Analysis Document \(PDF\)](#), [\(PDF\)](#) 
Summarises the minimum requirements identified for the dataset and discusses identified gaps with respect to these target requirements.

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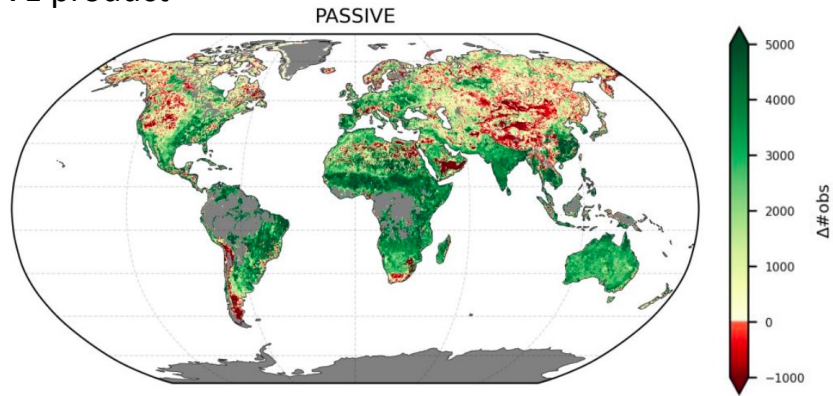
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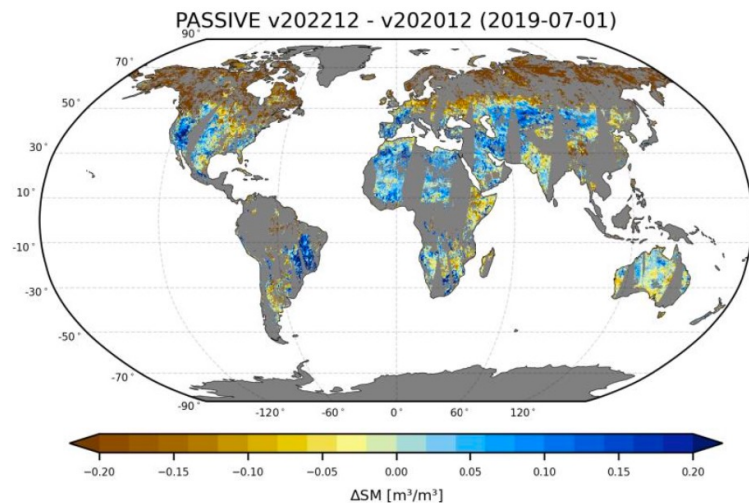
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Monitoring the quality of the data

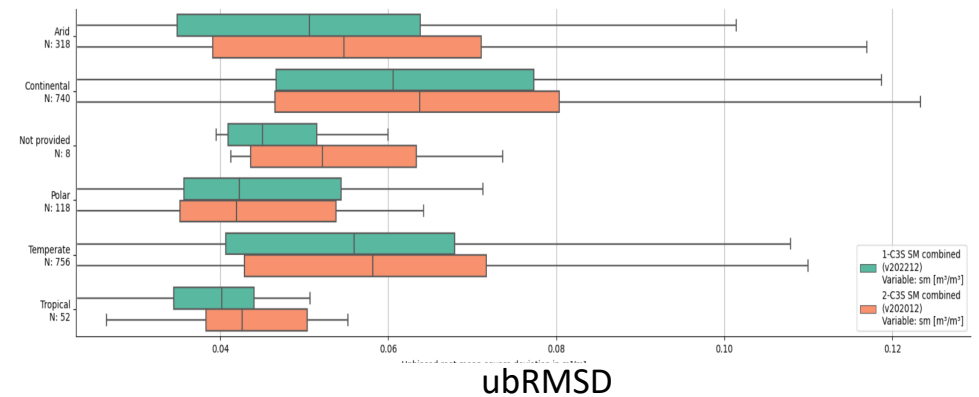
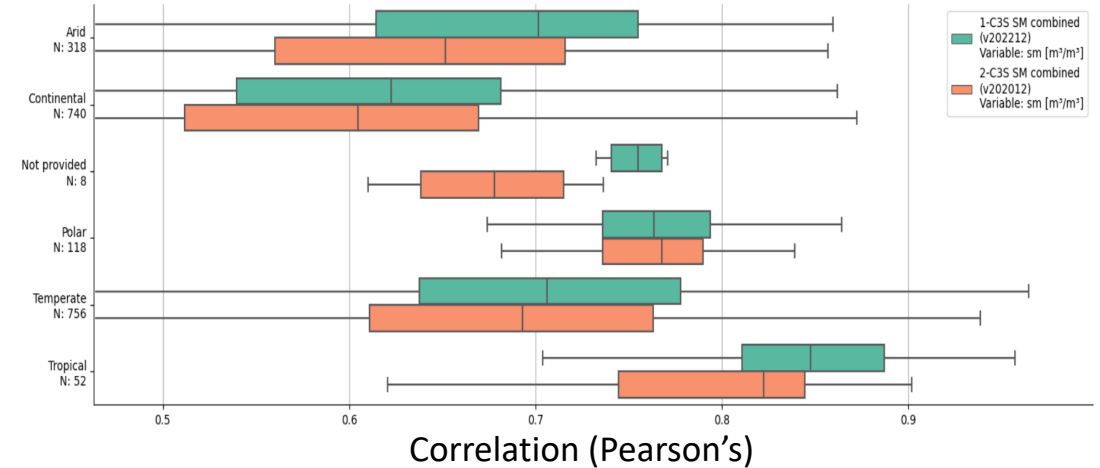
Change in number of observations (daily) in C3S SM v202212 compared to v202012 in the period after 1991-01-01 for the PASSIVE product



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



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



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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