

Course introduction and ESA & the Water Cycle

Espen Volden
Green Solutions Division
Climate Action, Sustainability and Science Department
ESA Earth Observation Programmes Directorate

EUROPEAN SPACE AGENCY

15th Advanced Training Course on Land Remote Sensing: The Water Cycle

7–11 September 2026
University of Perugia, Italy

Consiglio Nazionale delle Ricerche

CNR irpi

unipg
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Content

- Course introduction
- ESA & Earth Observation
- Developing new applications and science
- Opportunities for young scientists

Why does ESA organise LTC26?

ESA does a number of R&D activities in support of remote-sensing based applications related to the water cycle

- Some inside ESA
- Mostly outside with European universities, research institutes, companies, user organisations, …

⇒ Need to ensure there will be competent experts to participate in these activities in the future

⇒ More generally, need to ensure that there will be competent experts in Europe to use the data from the operating ESA and Copernicus satellites, and those we are developing and will launch in the coming years

Objectives

- Training the **next generation of scientists and professionals** on remote sensing for the water cycle
    - Explaining the **theoretical principles, processing algorithms, data products** and their **use**
    - Introducing **tools & methods** for the exploitation of EO satellite data, in particular Sentinels
    - Stimulating and supporting the use of EO data for **science and operational applications** related to hydrology and the water cycle
- Facilitating **networking**

Who is behind the course?

Organising Committee

Jacopo Dari
University of Perugia

Magdalena Fitrzyk
RSAC c/o ESA

Francesco Leopardi
University of Perugia

Irene Renis
Serco c/o ESA

Angelica Tarpanelli
CNR-IRPI

Espen Volden
ESA

TRAINING COURSE ON REMOTE SENSING - WATER CYCLE | September 7 - 11, 2026

	Monday		Tuesday	Wednesday	Thursday	Friday
9:00 - 9:20	**Welcome by UNIPG and ESA** Prof F. Ubertini (UNIPG) E. Volden (ESA)	9:00 - 9:55	**Soil Moisture** L. Brocca (CNR)	**Field Trip** C. Massari (CNR)	**Runoff & Discharge** A. Tarpanelli and S. Camici (CNR)	**TWS/ Water Budget closure** M. Tourian (Univ. of Stuttgart)
9:20 - 9:50	**Introduction to the course and ESA Activities** E. Volden (ESA)					
09:50 - 10:50	**Status of current and future ESA and Copernicus Missions** ESA Mission Managers\Scientists	9:55 - 10:50	**Precipitation** L. Brocca (CNR)			
10:50 - 11:10	Break	10:50 - 11:10	Break		Break	
11:10 - 12:10	**Altimetry** M. Tourian (Univ. of Stuttgart)	11:10 - 13:00	**Soil Moisture** L. Ciabatta (CNR)		**Evaporation** R. Guzinski (DHI)	**TWS/ Water Budget closure** M. Tourian (Univ. of Stuttgart)
12:10 - 13:30	**Optical introduction** F. Ramoino (SERCO)					
13:30 - 15:00	Lunch	13:00 - 14:30	Lunch		Break	
15:00 - 16:20	**SAR introduction** M. Fitrzyk (RSAC)	14:30 - 16:20	**Snow** C. Marin (EURAC)		**Runoff & Discharge** P. Filippucci (CNR)	**AWU** J. Dari (UNIPG)
16:20 - 16:40	Break	16:20 - 16:40	Break		Break	Closure
16:40 - 18:00	PhD Activities	16:40 - 18:30	**Snow** V. Premier (EURAC)		**Evaporation** R. Guzinski (DHI)	
18:00 - 19:30	Ice Breaker					

Theory	Aula Magna
Practical	Aula X
Other	Aula Magna


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on Land Remote Sensing:
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delle Ricerche
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EUROPEAN SPACE AGENCY
ELEVATING THE FUTURE OF EUROPE IN SPACE

THROUGH EUROPEAN COOPERATION
AND WITH INTERNATIONAL PARTNERS

23 MEMBER STATES
4 associate members
1 cooperating state

6500 ESA WORKFORCE

IMPLEMENTS
60%
OF THE EUROPEAN SPACE BUDGET

150+
missions delivered
30+
missions upcoming

2026 BUDGET
€8.26B

€15
per European



→ THE EUROPEAN SPACE AGENCY

ESA Membership

23 Member States

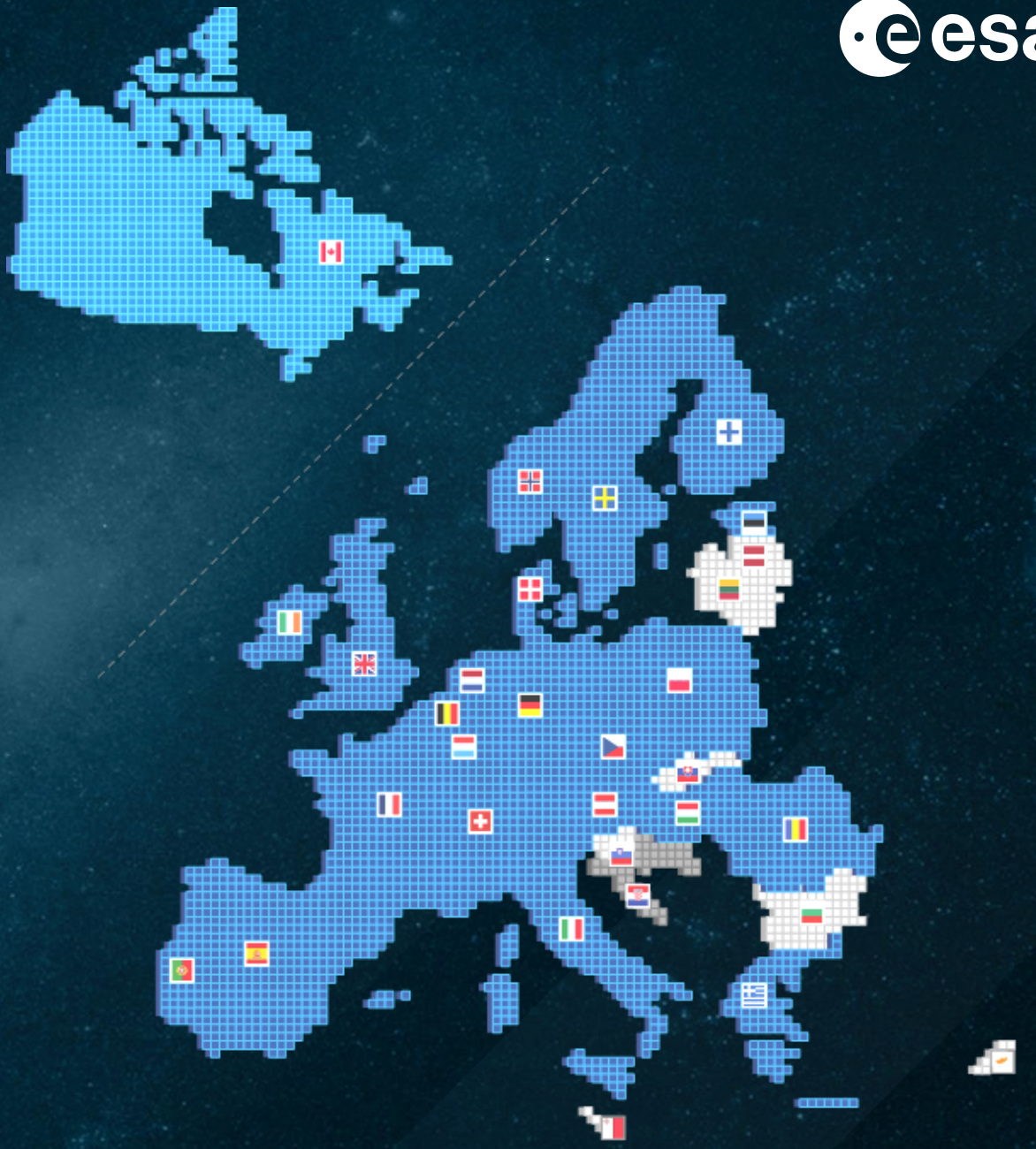
Austria
Belgium
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Luxembourg
Netherlands
Norway
Poland
Portugal
Romania
Spain
Slovenia
Sweden
Switzerland
United Kingdom

3 Associate Members

Slovakia, Latvia, Lithuania

Cooperation Agreements

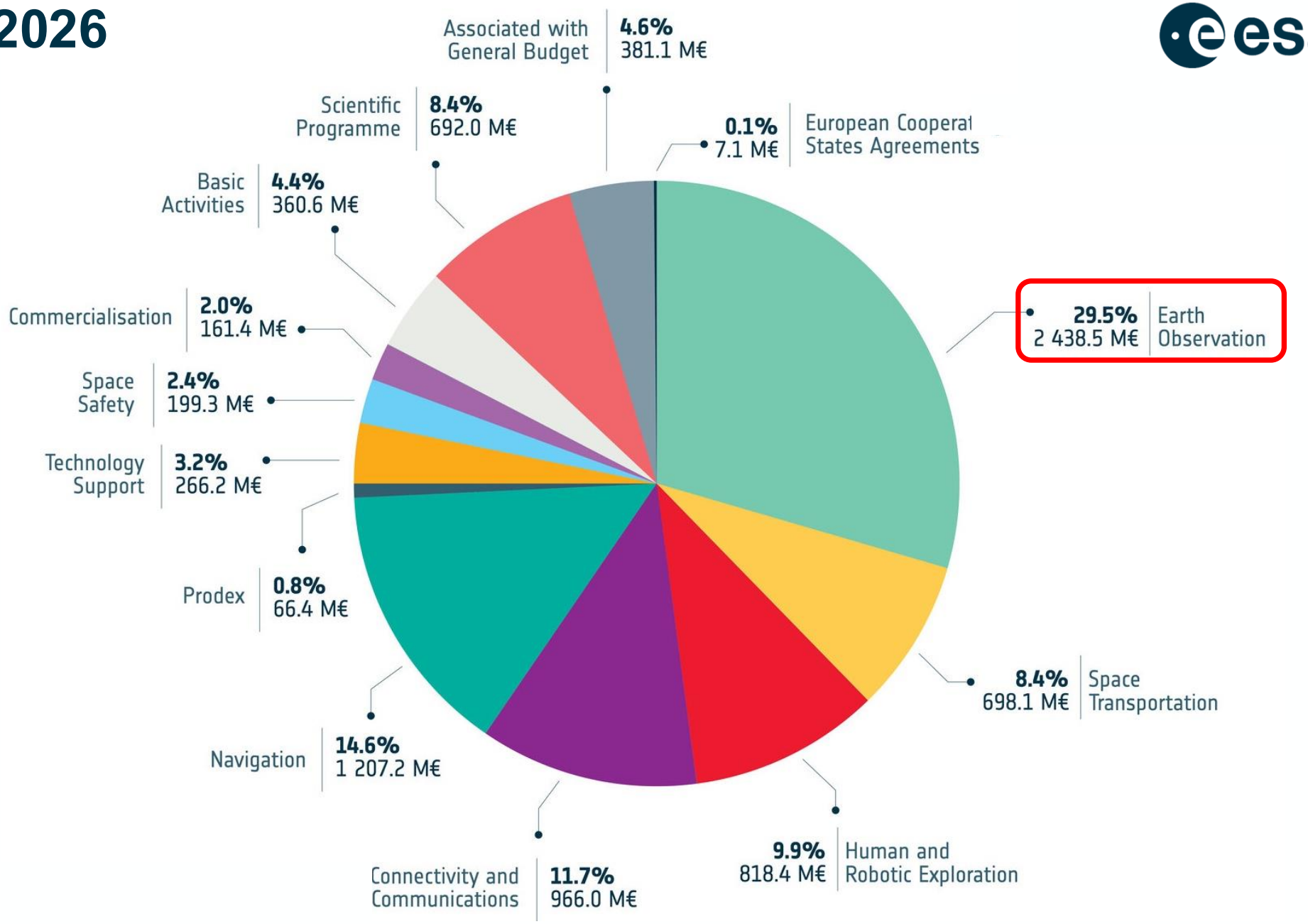
4 other European States + Canada





→ THE EUROPEAN SPACE AGENCY

ESA Budget for 2026

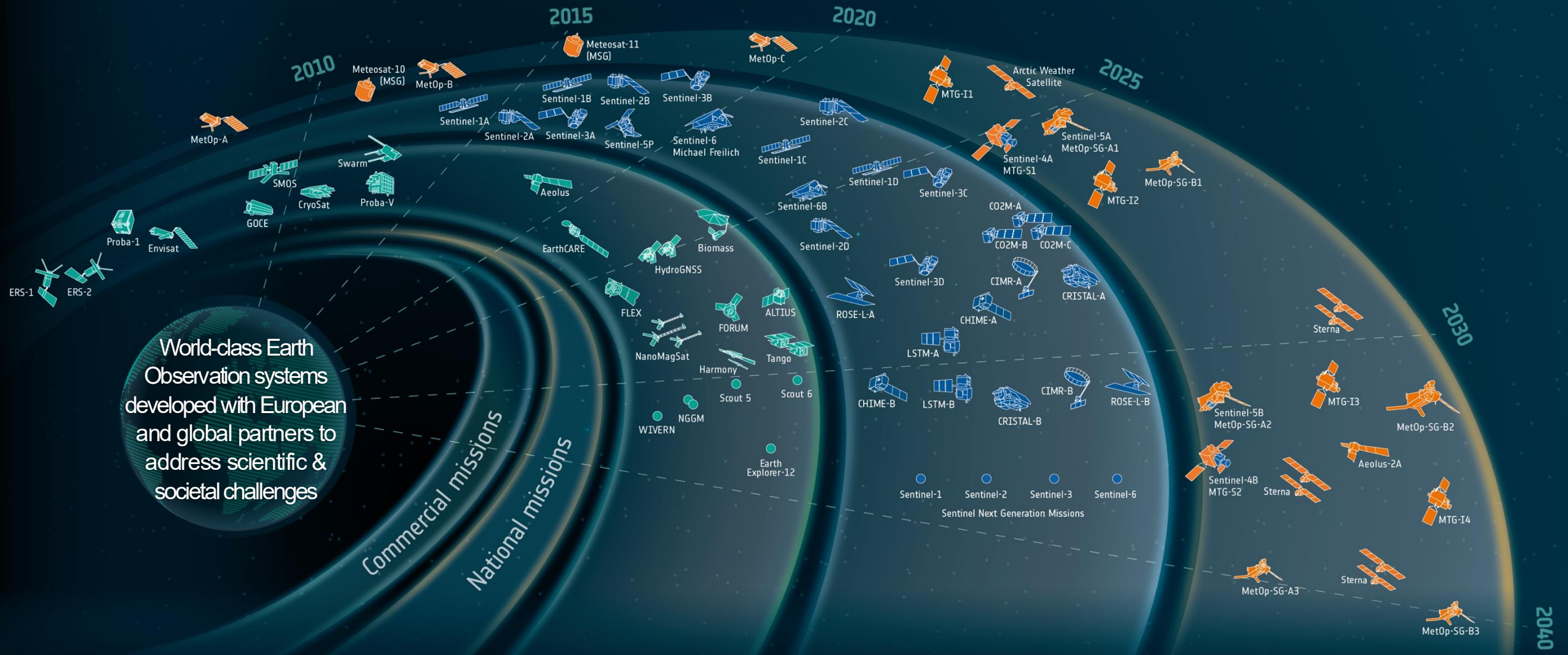


TOTAL
8.26 B€

* Includes activities implemented for other institutional partners

ESA's Earth Observation Missions

Satellites**: Heritage **08** / Operational **24** / Developing **38** / Preparing **39** / Total **109



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FutureEO: Mission Preparation, Development & Earth Action

esa

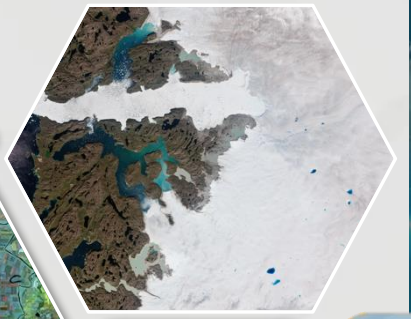
World-class science benefitting society



GHG detection

Crop mapping





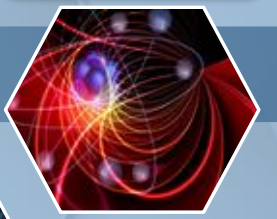
Land & sea ice monitoring

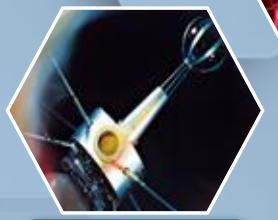
Mission preparation activities

Campaigns



Mission definition





Innovative tech.



New EO concepts







FUTURE
EO

Mission development & mgmt. activities

Scout 2nd Cycle



WIVERN (2030s)





Harmony (2029)



NGGM (2032)

EARTH ACTION

Defining our priorities along the following verticals:



1. Earth System and Climate Science



2. Enabling Policies

Transversal Elements Supporting All FutureEO Activities:



A. Industrial Strategy & Competitiveness



B. Disruptive Innovation & Digital Enablement



C. Knowledge Exchange & Capacity Building



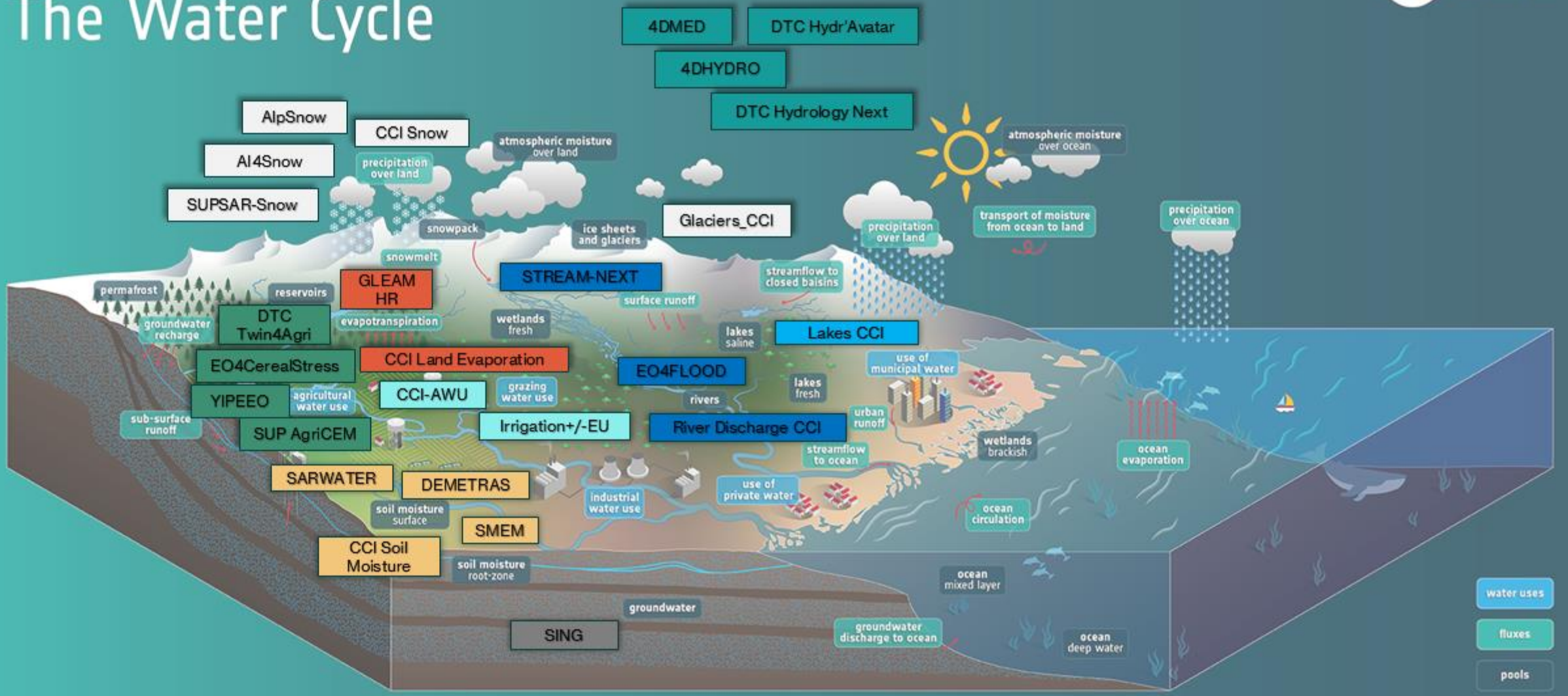
D. Partners & Cooperation

Earth Observation for Sustainable Water Resource Management

- Policy Applications on Water Resources and Freshwater Ecosystems
- Hydrology Science
- Climate and ECVs
- Sentinel User Preparation (SUP)
- Global Development Assistance



The Water Cycle



SDG Target 6.6: Protect and Restore Water-Related Ecosystems

WorldWater

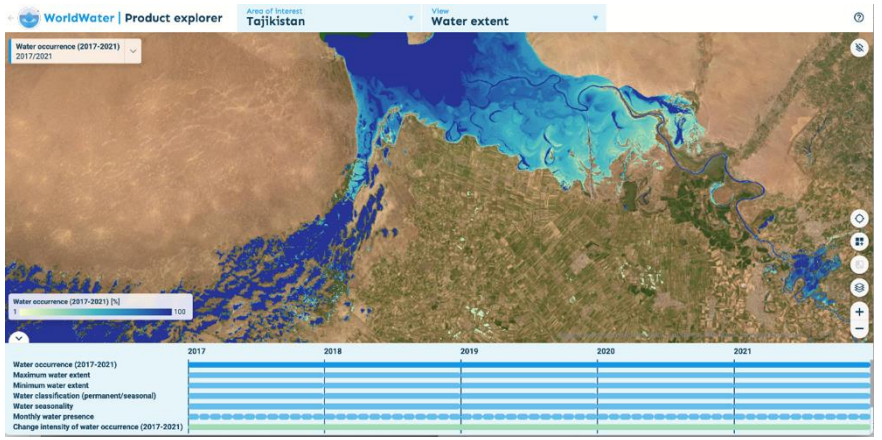
EO-based solutions for monitoring of the dynamics of surface waters

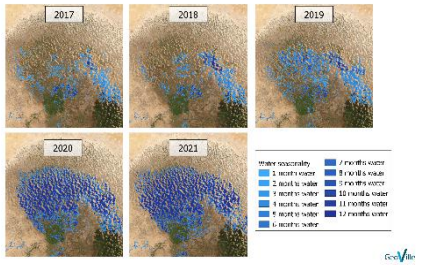
6 CLEAN WATER AND SANITATION

SDG Indicator 6.6.1
Change in the extent of water-related ecosystems over time

EO-based solutions for National Wetland Inventories

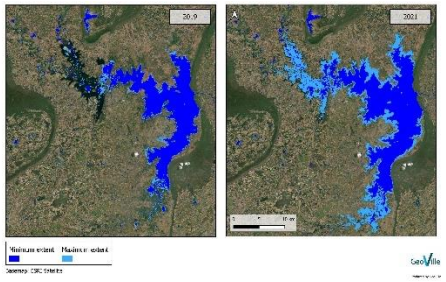
EO4WI
WETLAND INVENTORIES



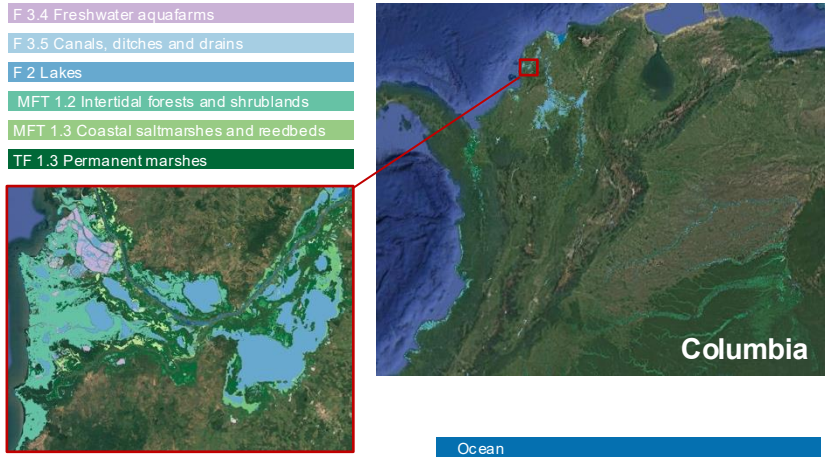


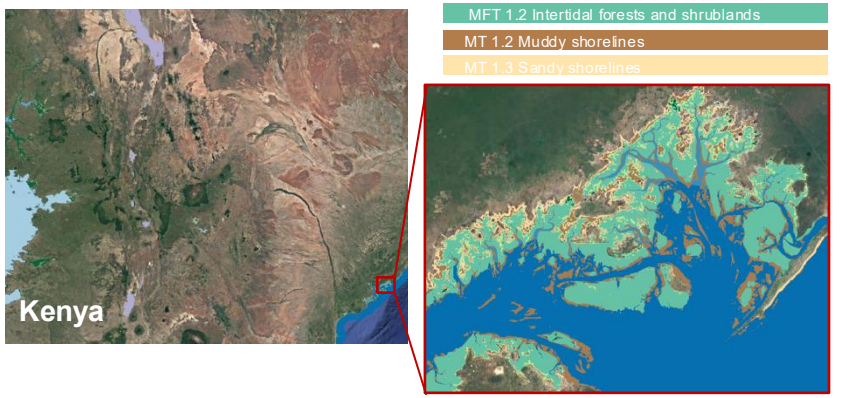
Water frequency,
Niger, Diffa, Northern Lake Chad

Surface Water Min-Max extent,
Thailand, Ubolratana reservoir

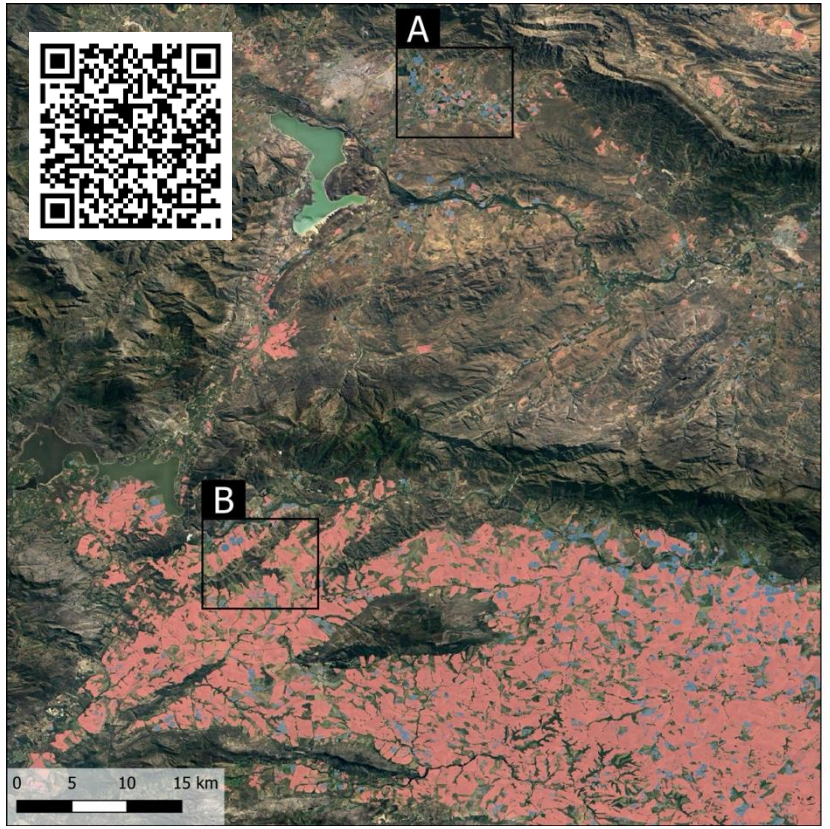


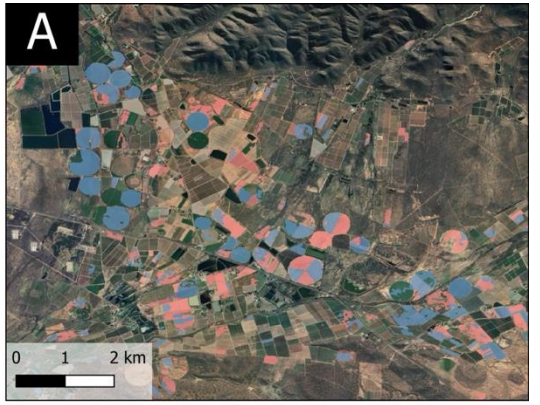
Support
UNEP and Ramsar Secretariat
(custodians of SDG Indicator 6.6.1
on changes over time
in water-related ecosystems)
for the development of monitoring
guidelines, datasets, and tools
to **advance the use of**
Earth Observation
for the monitoring, assessment and
management of water-related
ecosystems.

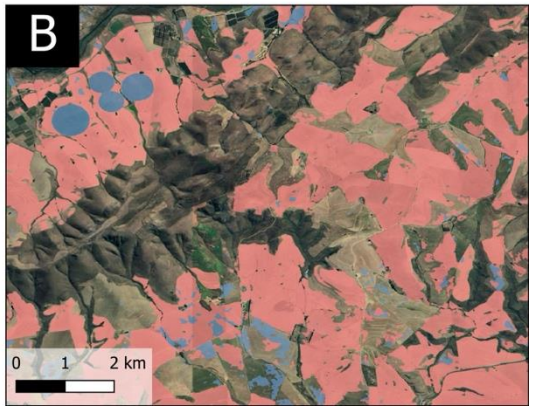




WorldCereal Irrigation products







Western Cape, South Africa

Irrigated | Rainfed

https://esa-worldcereal.org/en

Assessing sub-parcel and season-specific agricultural water consumption

Global, 10m resolution, seasonal irrigated area product available for the year 2021

Recent FAO report highlights overall excellent agreement with agricultural statistics

Flexible, cloud-based processing system that allows anyone to generate high-resolution (10m) cropland and crop type maps tailored to a user-defined region, season and crop types of interest.

Customized irrigated area mapping currently not supported

WorldCereal

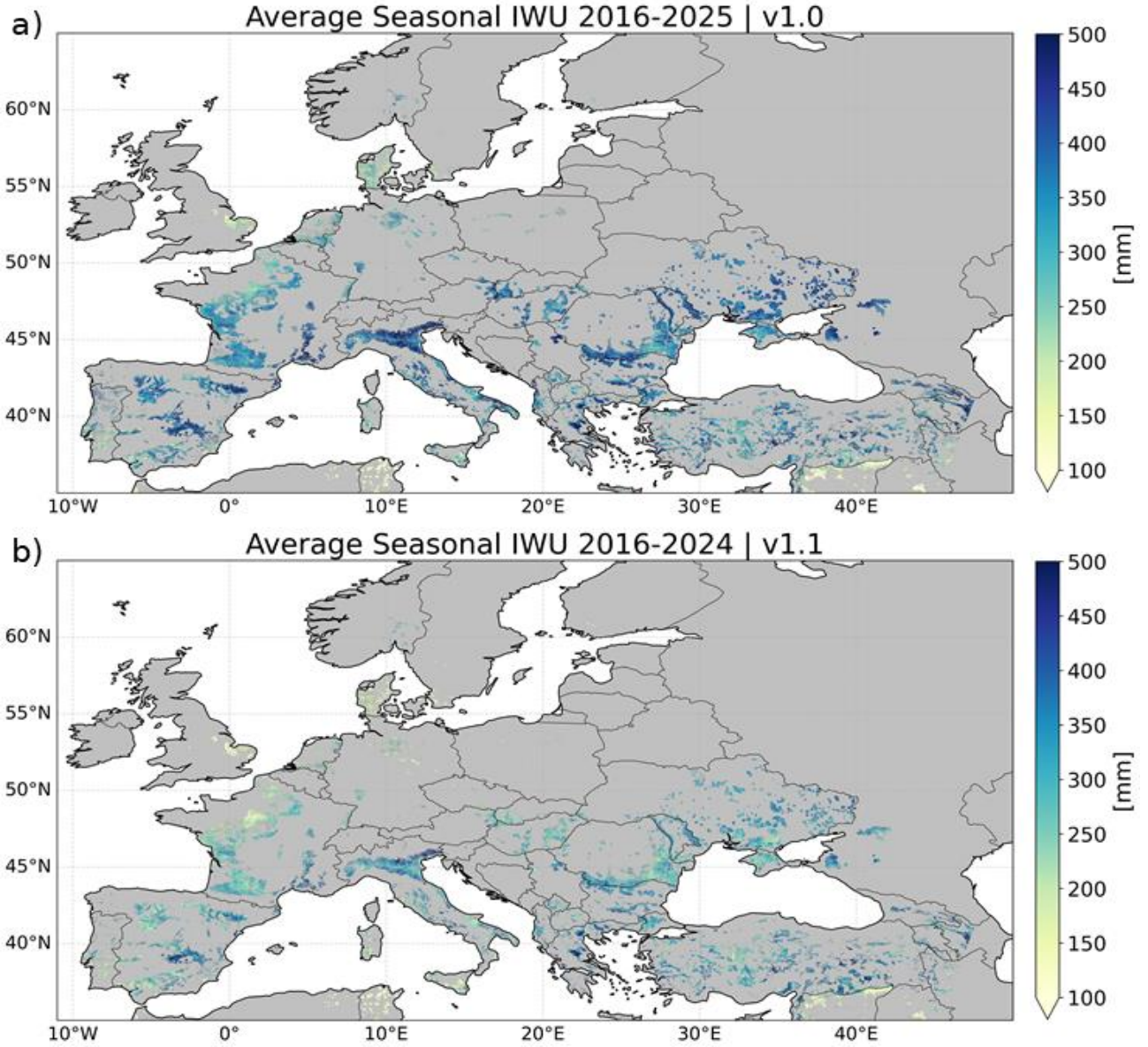
Irrigation-EU

Two European scale IWU data sets (v1.0 and v1.1)

- Spatial resolution: 1 km
- Temporal aggregation: bi-weekly
- Period: 2016-2025 (v1), 2016-2024 (v1.1). V1 relies on Sentinel-1 soil moisture and rainfall and potential evaporation from ERA5-Land. In v1.1, potential evaporation from GLEAM v4.2b is used instead.

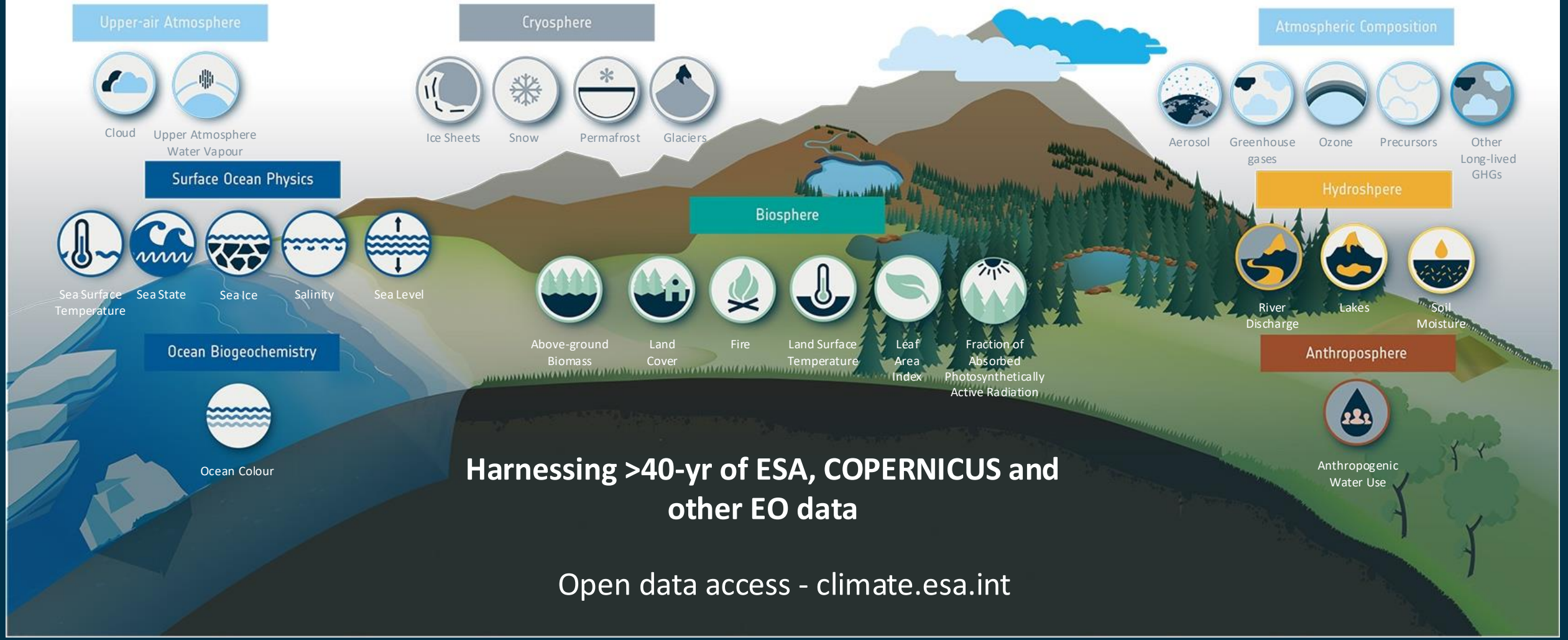
IWU-SMinv v1.0 and v1.1 are available at
https://zenodo.org/records/21473561

Preprint:
https://doi.org/10.21203/rs.3.rs-10602968/v1



ESA's Climate Change Initiative (CCI)

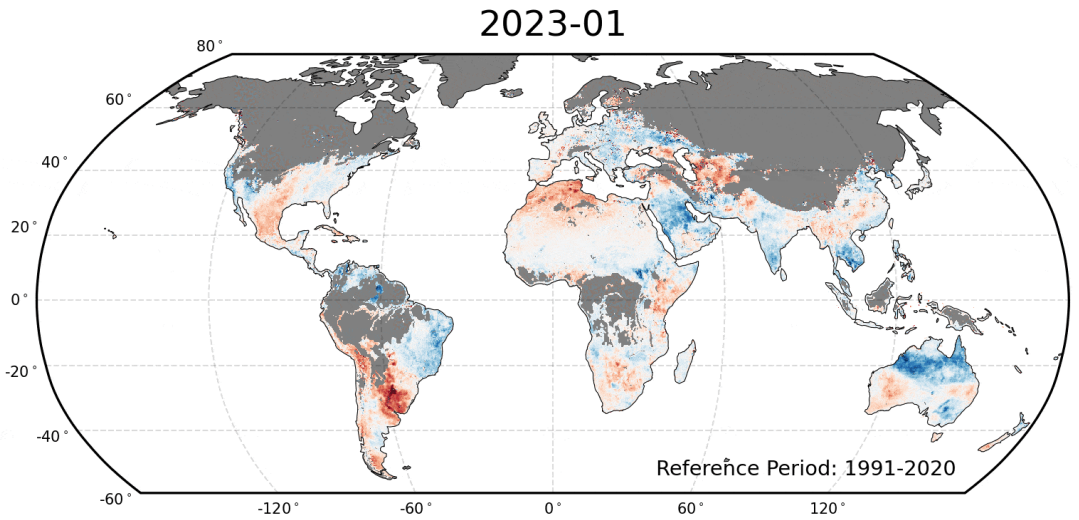
GCOS defined **55** Essential Climate Variables | **36** benefit from space observations
27 generated by ESA Climate Change Initiative | ~20 transferred to operational climate services



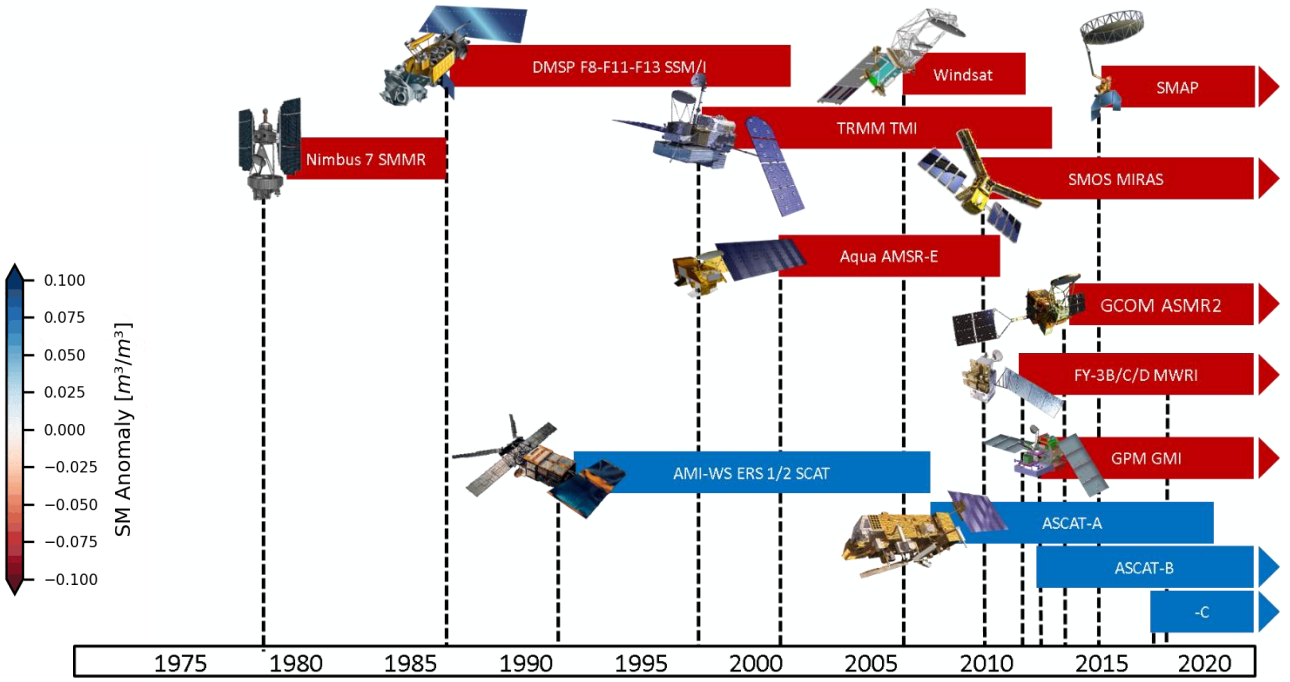
ESA'S CCI: SOIL MOISTURE ECV

- Annually algorithmically updated global climate data record of soil moisture spanning > 40-yr
- 3 separate soil moisture products derived from active, passive and combined (active + passive) sensors
- 14 public releases to date

https://climate.esa.int/en/projects/soil-moisture/



Soil moisture anomalies for the year 2023 derived from the ESA CCI COMBINED v09.0 product



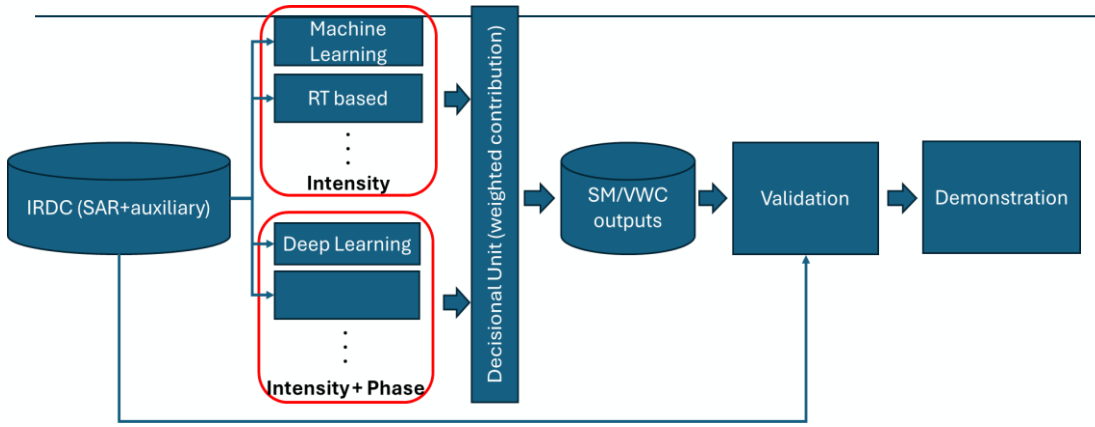
ESA CCI soil moisture v09.1 products utilize 5 active and 12 passive microwave sensors

V09.1 (1979-2023), already available at:

https://climate.esa.int/en/projects/soil-moisture/

Now generated operationally via C3S

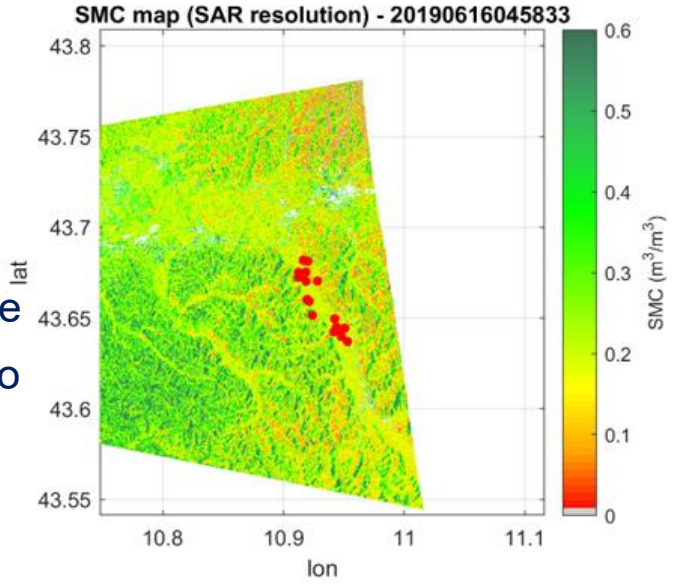
SUPSAR Soil Moisture Ensemble Method (SMEM)

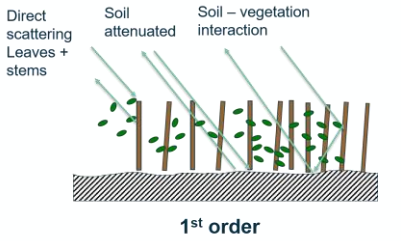


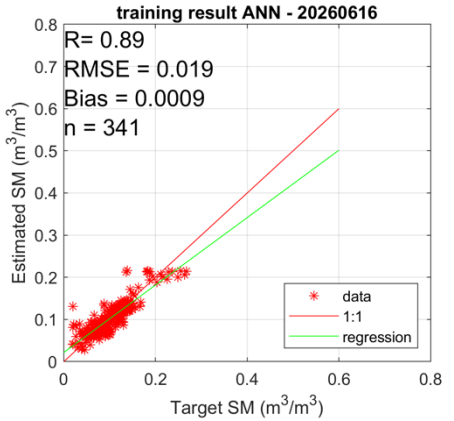
- **SMEM core → ensemble approach,** combining machine/deep learning and physically based algorithms
- **SMEM scope →** predict soil moisture (SM) and vegetation water content (VWC) from multifrequency (L + C + X) SAR observations at high resolution and improved accuracy, including challenging targets as dense vegetation, arid surfaces and complex orography
- **SMEM goal →** define a **roadmap** for SAR-based SM/VWC retrievals

Project in bullets

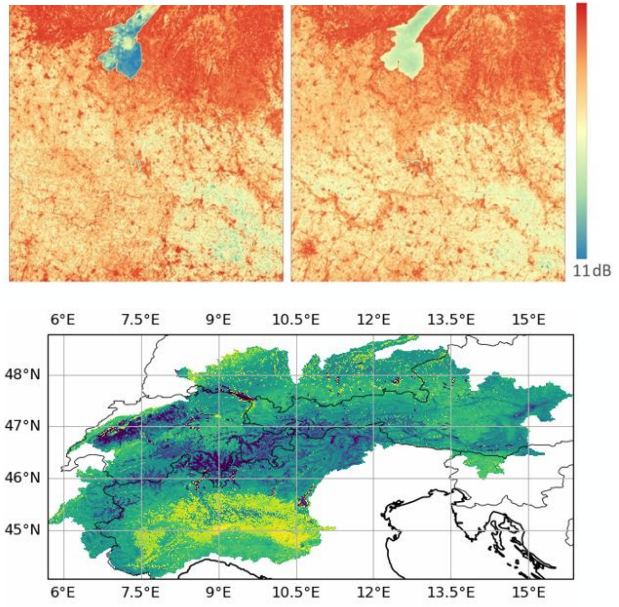
- **KO →** Sept 2025, duration 2 years
- **Test/validation →** 5 areas representative of dense vegetation, arid surfaces, complex orography
- **Demonstration →** Po Valley supersite
- **Stakeholder engagement →** Bolzano Province, CIMA, CNR-IRPI, ARPAE
- **Dissemination →** preliminary results presented so far at FRINGE, SPIE, SMAP Workshop, URSI GASS



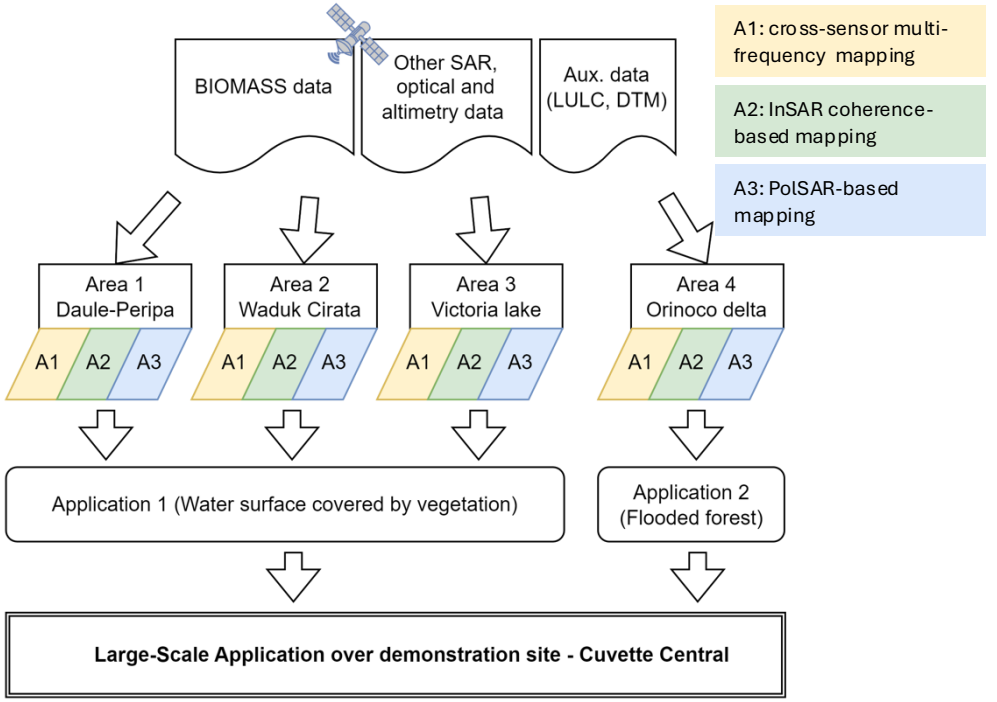


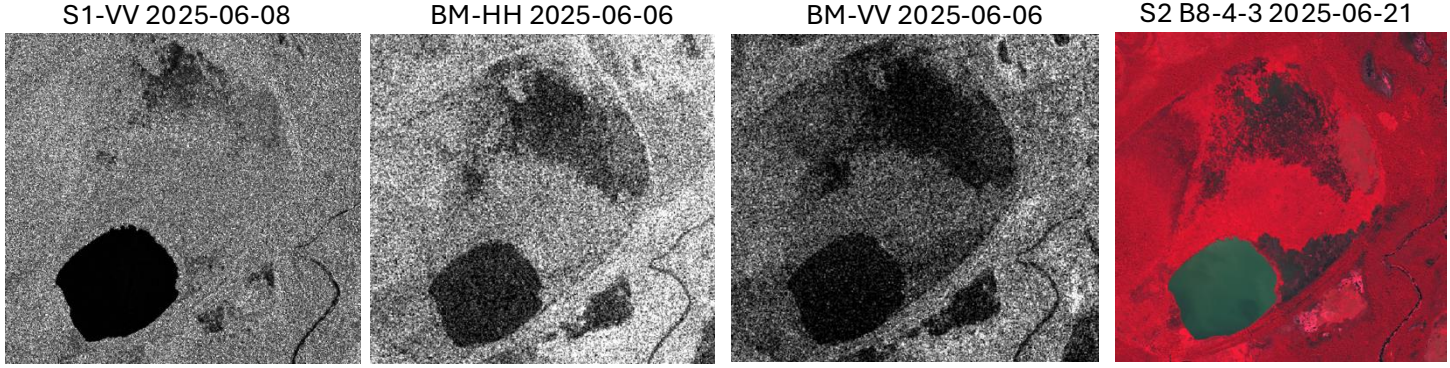


Sensitivity SAOCOM/S-1 vs SM



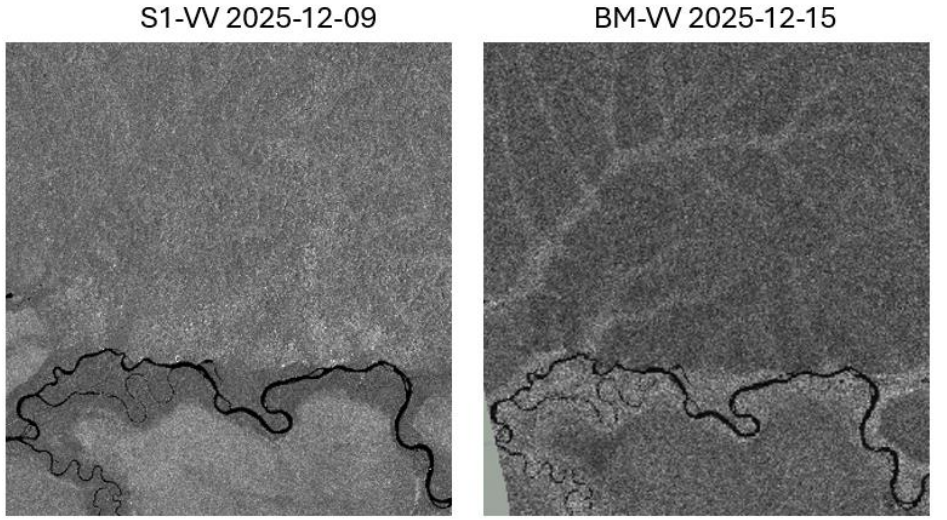
BIOAQUA aims to exploit the unique **P-band SAR capabilities** of ESA's BIOMASS mission to improve the detection, mapping, and characterization of water surfaces and flooded vegetation in tropical environments where current satellite observations face significant limitations. Duration: 12 months.





Same area, but different interpretation possible from Sentinel-1, BIOMASS and Sentinel-2 in this example from the Amazonian basin

By combining BIOMASS data with **complementary** multi-frequency SAR, optical, and hydrological observations, the project will **develop** and **validate innovative methodologies** for monitoring **flooded forests, wetlands, and floating vegetation**, advancing our understanding of the interactions between hydrology, vegetation structure, and ecosystem dynamics.



Sentinel-1 and BIOMASS observe different behaviors in this part of the Congo River Basin.

BIOAQUA will deliver **openly documented** methodologies, processing workflows, validation datasets, and prototype products for mapping open water, flooded forests, wetlands, and floating vegetation from BIOMASS and complementary satellite missions. These outputs will provide the hydrology and Earth Observation communities with new tools and reference datasets to improve the monitoring of inundation dynamics, water resources, and vegetation-water interactions in complex tropical environments.

The outputs from the BIOAQUA project will help enhance the scientific knowledge linked to water mapping of tropical forest in the « cuvette centrale » of the Congo River Basin, which is still lacking precision. In this frame, BIOMASS can bring new insights of unprecedented value.

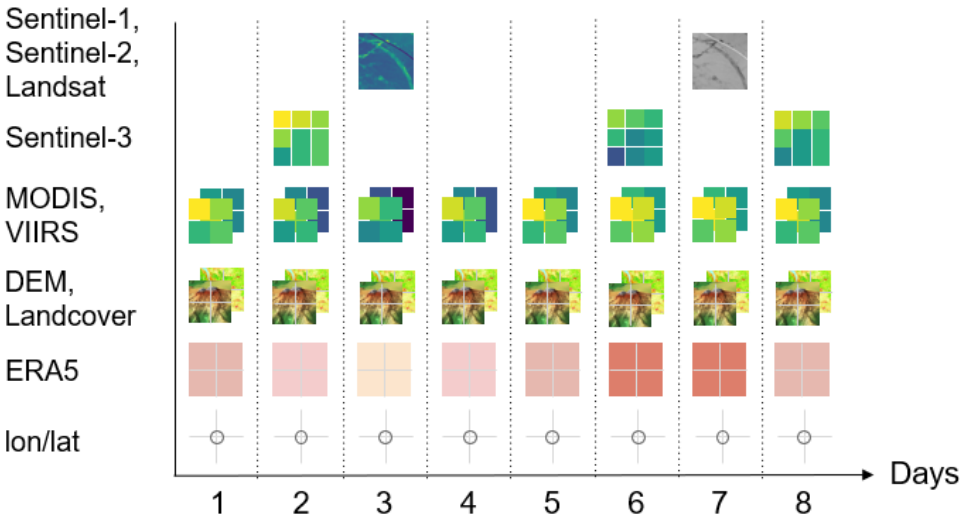
For any question, please contact cfatras@groupcls.com (Project Manager)

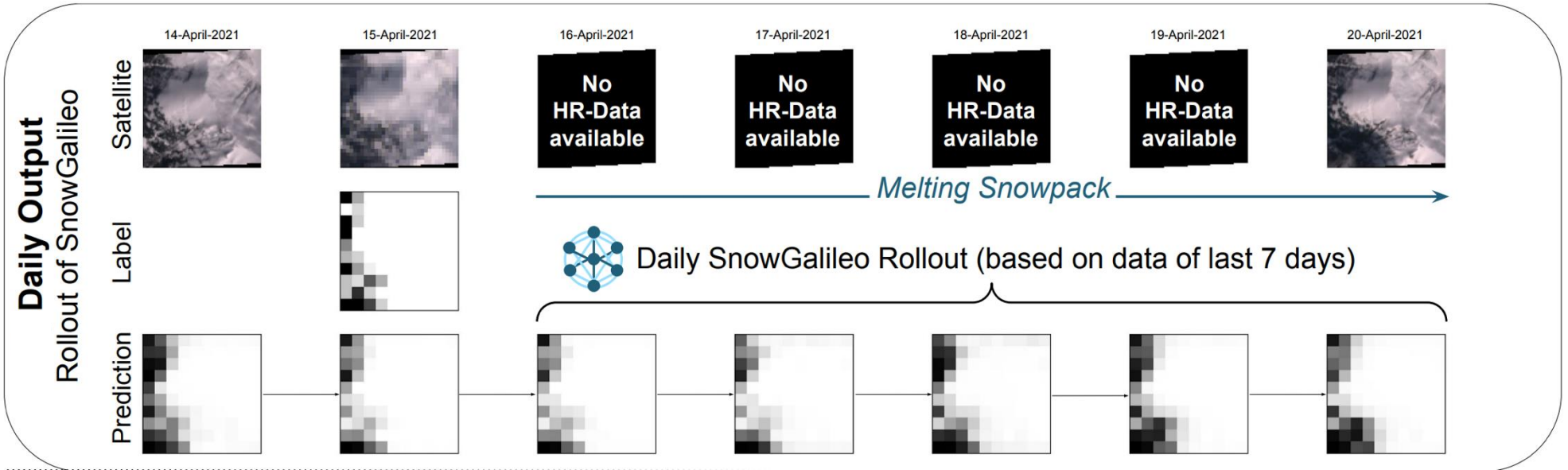
ESA Contract No. 4000152793

AI4SNOW

Development of SnowGalileo:

- Based on an **Earth Foundation Model,** SnowGalileo enables daily, 100m fractional snow cover mapping through multi-sensor fusion
- **SnowGalileo** combines a large number of remote sensing products with different spatial and temporal resolutions
- **State-of-the-art performance:** mean RMSE **0.112**, outperforming all baseline methods
- **Comprehensive evaluation** under cloud cover and limited high-resolution observations





Contract : 4000143295/23/I-DT- AI4Science

Physical snow parameters:

- Snow area extent
- Snow melt extent
- Snow albedo and grain size
- Snow water equivalent

AlpSnow was a science activity within ESA's Alpine Regional Initiative.

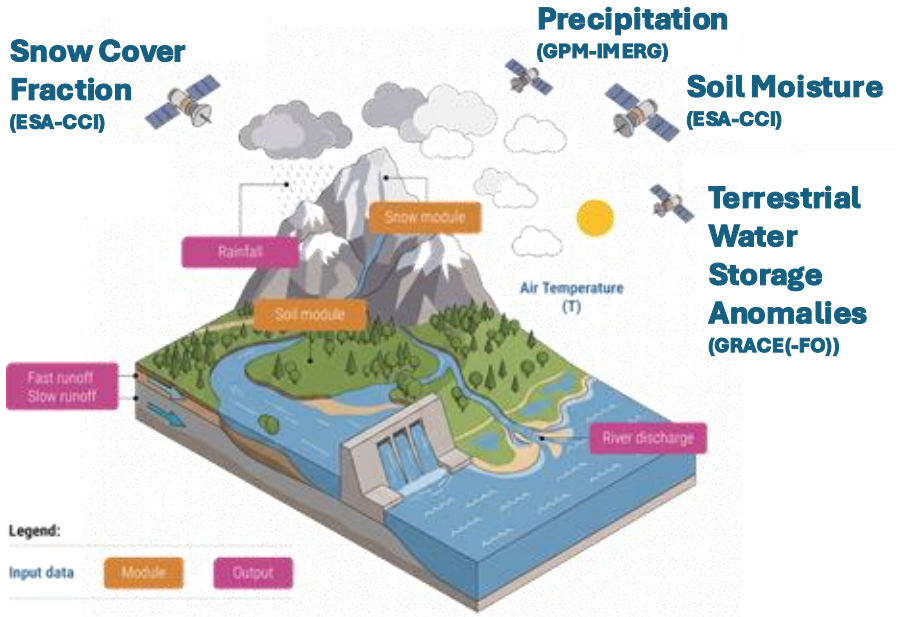
- The project developed and implemented innovative, satellite-based products for serving scientific and operational needs in Alpine environment.
- The activities focused on advancements in the measurement of extent and physical properties of seasonal snow and on the integration of EO-based snow cover information in snow process and hydrological models.
- The new products are designed to support regional operational priorities in hydrology and water management, as well as science, by fostering the use of EO-based products.
- The physical relation of C-band VV and VH backscatter and physical snow properties is investigated within a study (CCN1)
- Building on the project achievements for the Alps, a followon activity for the generation and evaluation of snow product time series in other mountainous regions worldwide is ongoing (CCN2). The work supports the Common Observing Period Experiment (COPE) of the International Network for Alpine Research Catchment Hydrology (INARCH).

Baseline project period: 2021 – 2024; CCN1: 2023 – 2026; CCN2: 2024-2026

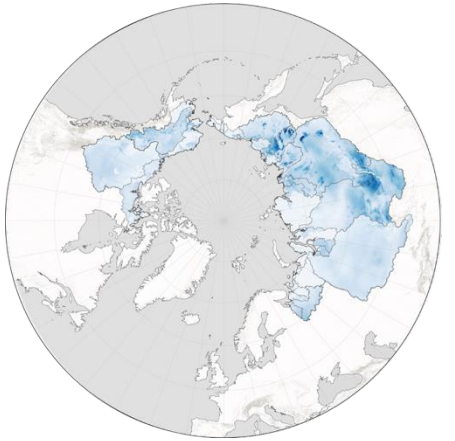
STREAM-NEXT
Global satellite-based runoff and river discharge

Long-term independent **daily** gridded (0.25°x 0.25°) runoff and river discharge estimates at the global scale using **exclusively satellite observations** for the time interval 2003-2022

STREAM model

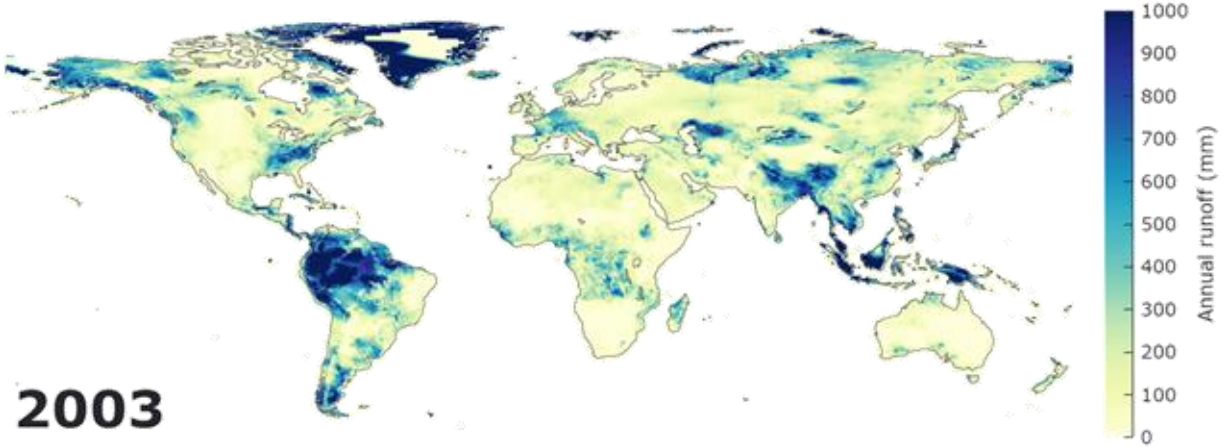


Pan-Arctic annual runoff



Zenodo dataset:

Global annual runoff

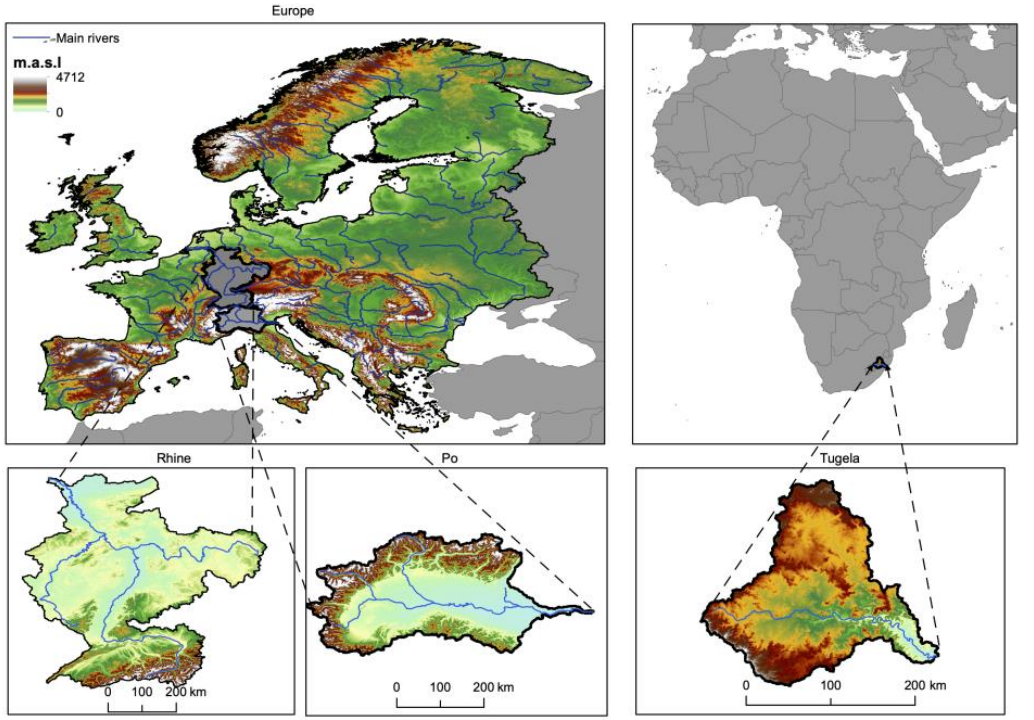


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Hyper-resolution Earth observations and land-surface modeling for a better understanding of the water cycle

4DHydro (May 2023 – Sept 2025) aimed to:

- Understand uncertainty in existing EO and LSM/HM data sets.
- Improve tECVs datasets at 1 km spatial resolution.
- Combine EO products and LSM/HMs models to improve simulations at high spatial and temporal resolutions.
- Enhance the ability of end-users and decision-makers to extract and manipulate existing and future data.
- Derive a solid scientific basis to assist the EU Destination Earth initiative.



Outputs on https://4dhydro.eu/

- Open Science Catalog with EO datasets
- LSM/HM experiments
- 6 papers and more information

UFZ Helmholtz Centre for Environmental Research
UK Centre for Ecology & Hydrology
Deltares Enabling Delta Life
TU Wien Technische Universität Wien Vienna | Austria
eurac research
Utrecht University
irpi
WATERJADE value in every drop
Jülich Forschungszentrum
Università di Trento
CzechGlobe
ES Group
Universitat Politècnica de València

EO4FLOOD

The project aims to demonstrate the maturity of satellite products for implementing a robust and reliable forecasting framework capable of providing timely and accurate predictions of flood events.

It is based on three main pillars:

Development of an Advanced Open Earth Observation Dataset (EO4FLOOD dataset)

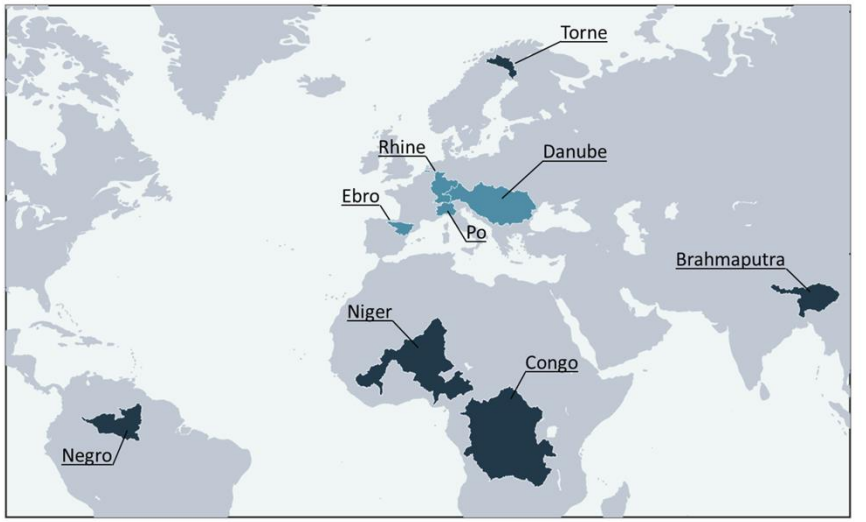
→ Dataset available on Zenodo **https://zenodo.org/records/17787732**

Utilization of the EO4FLOOD Dataset in Flood Forecasting Models

→
- Role of EO forcings
- Contribution of EO for model calibration/validation
- Impact of data assimilation of EO on forecasts

Demonstration of the EO Data and Models' Utility for Science and Society

→
- Impact of dam in the river regime
- Land use change impact in flood
- Population trends, flood dynamics and impact on flood exposure

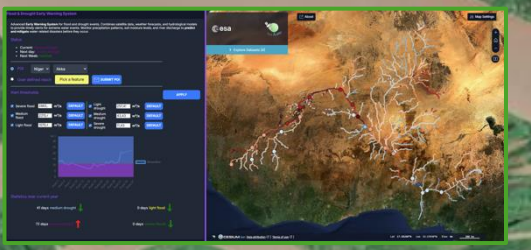


EO4FLOOD

SCAN ME

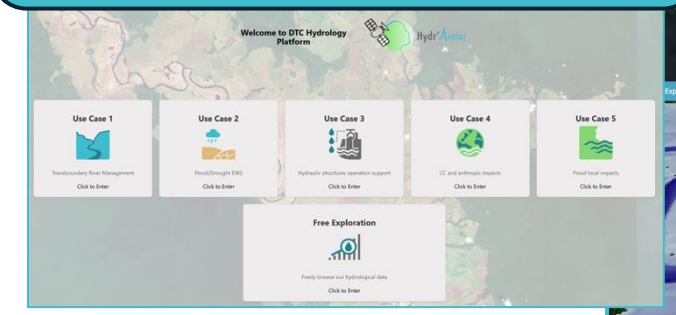
Contact:
angelica.tarpanelli@cnr.it

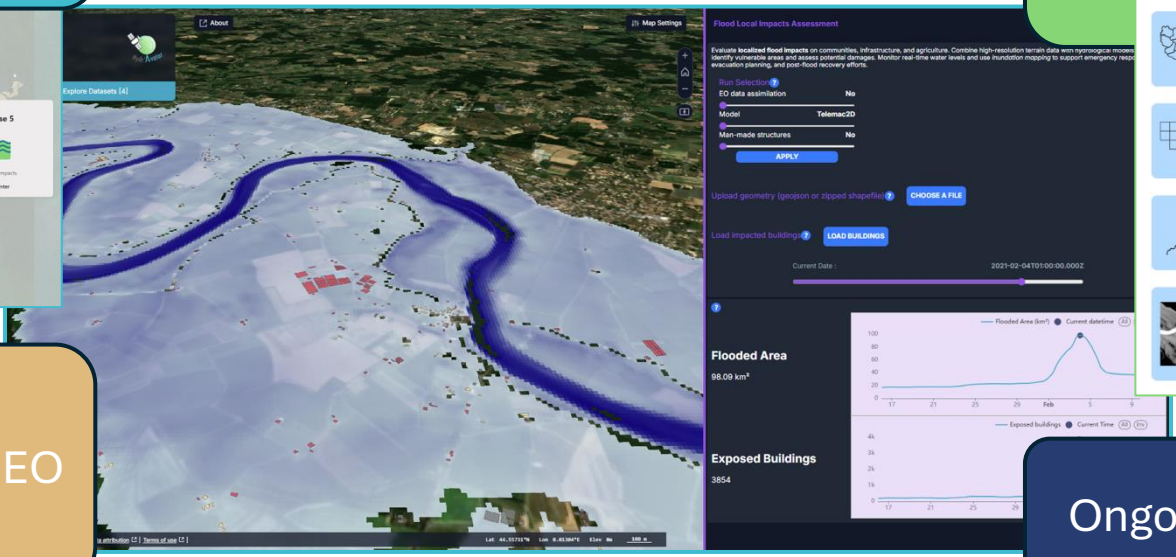
Hydr'Avatar : *a digital twin of hydrological systems using multi-complexity modelling and advanced EO datasets*



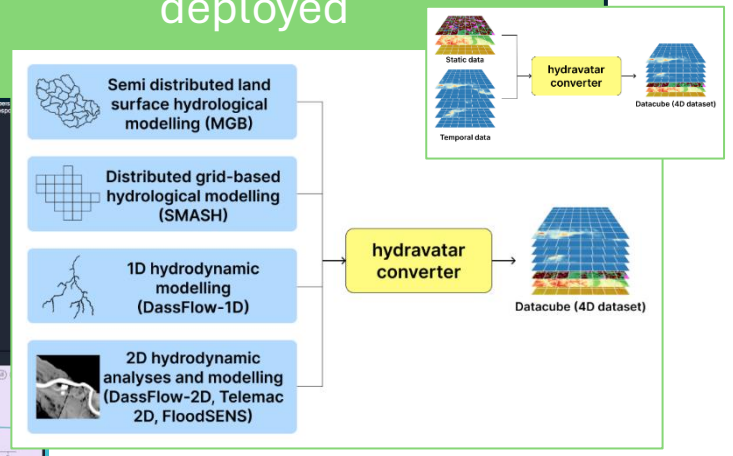
Project's status update

Use Cases refined with stakeholders, and interactive interface and what-if scenarios deployed





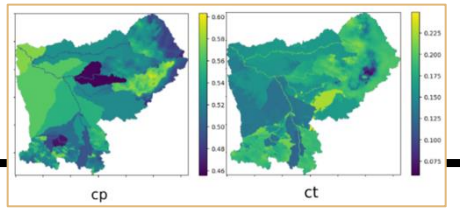
Data curation and preparation, model dockerized and codes deployed



Continuous scientific developments on the use of EO for hydro-hazards

Ongoing integration in DestinE

- Breakthrough EO data assimilation in basin hydrology
- Breakthrough EO data use and assimilation in 2D shallow water models
- **Advancing Conceptual Hydrological-Hydraulic-AI Hybrid model for a better use of multi-sourced obs.**



Hydrology model parameters (SMASH, GR like) calibration by hydraulic backpropagation of WSE observations on the Garonne basin, differentiable H&H chain SMASH-DassFlow 1D, 50k cells (Ettalbi et al. In prep)

<u>Publications:</u>

- Ettalbi et al (in prep), Garonne.
- Pujol et al. (under review), French Guyane.
- Montazem et al. (in prep), global.

3D rendering of flood model on Garonne (Schumann et al.)



Digital Twin Earth Hydrology

Reconstructing the Global Water Cycle

PHASE 1: DATA INPUTS & RETRIEVAL



Multi-Source Data Acquisition: Harvesting rew data from Earth Observation satellites, in-situ sensors, and atmospheric Reanalysis.

Retrieval Algorithms: Advanced algorithms process rew signals into high-quality geophysical variables.

High-Resolution Mapping: Targets 1 km spatial & 1 day/ 1 hour temporal resolution for unprecedented detail.



https://www.openaccessgovernment.org/article/the-digital-twin-earth-for-hydrology-a-paradigm-shift-in-water-management/209171/

Brocca et al. (2024 FSCI) https://doi.org/10.3389/fsci.2023.1190191

PHASE 2: THE DTE HYDROLOGY DATACUBE 2.0



PHASE 3: ANALYTICAL LAYER & MODELING

Integrated Hydrological Modeling: Detacube variables feed into a suite of models to simulate real-world water behavior.



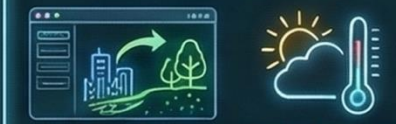
Improving the "New" Water Cycle: Including human factors like irrigation significantly improves the model performance, especially for summer low-flow representation

Uncertainty & Reliability: Toward probabilistic digital twins offering a range of outcomes rather than a single answer



PHASE 4: DECISION SUPPORT & IMPACT

WHAT-IF SCENARIOS (LONG-TERM PLANNING)



Simulate long-term impacts, e.g., land-use changes on flood risks.

MONITORING (CURRENT STATUS)



Track current environmental status, e.g., drought monitoring.

Landslide & Flood Prediction: Predicting landslide probability (Italy) and flood risk (Rhine, Zambia, central America)

Water Resource Management: Helping authorities (e.g., Po river Basis) manage irrigation and reservoir levels during scarcity.

DTE Hydrology

Digital Twin Earth Hydrology

https://platform.dtehydrology.org/

The platform

Fully integrated in Destination Earth Platform

Datasets

- DTE Hydrology Datacube Explorer
  Visit DTE Hydrology Datacube Explorer

Available Case Studies

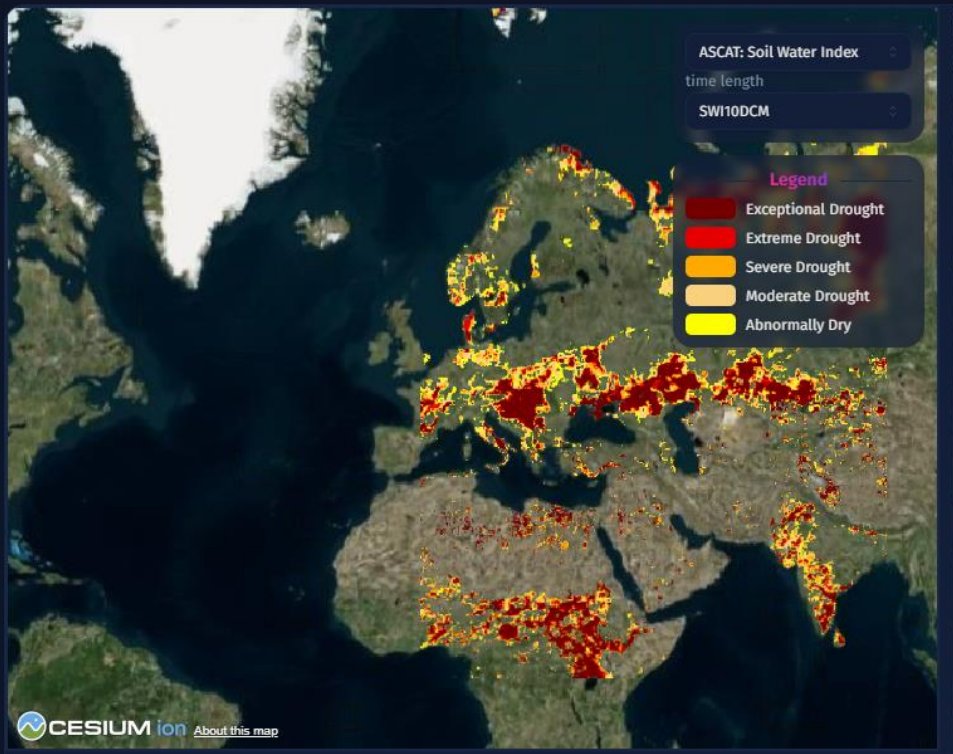
- European Drought Monitor
  Visit European Drought Monitor
- Landslides Catalogue - Italica (Italy)
  Visit Landslides Catalogue - Italica (Italy)
- What-if scenario for landslides prediction (Italy)
  Visit What-if scenario for landslides prediction (Italy)
- Landslide preoperational service (Italy)
  Visit Landslide preoperational service (Italy)
- What-if for flood risk prediction (Rhine)
  Visit What-if for flood risk prediction (Rhine)
- What-if for water resources management (Po river)
  Visit What-if for water resources management (Po river)
- What-if scenario for flood risk assessment (Po river)
  Visit What-if scenario for flood risk assessment (Po river)
- Flood forecasting system
  Visit Flood forecasting system
- Flood risk prediction
  Coming Soon ...

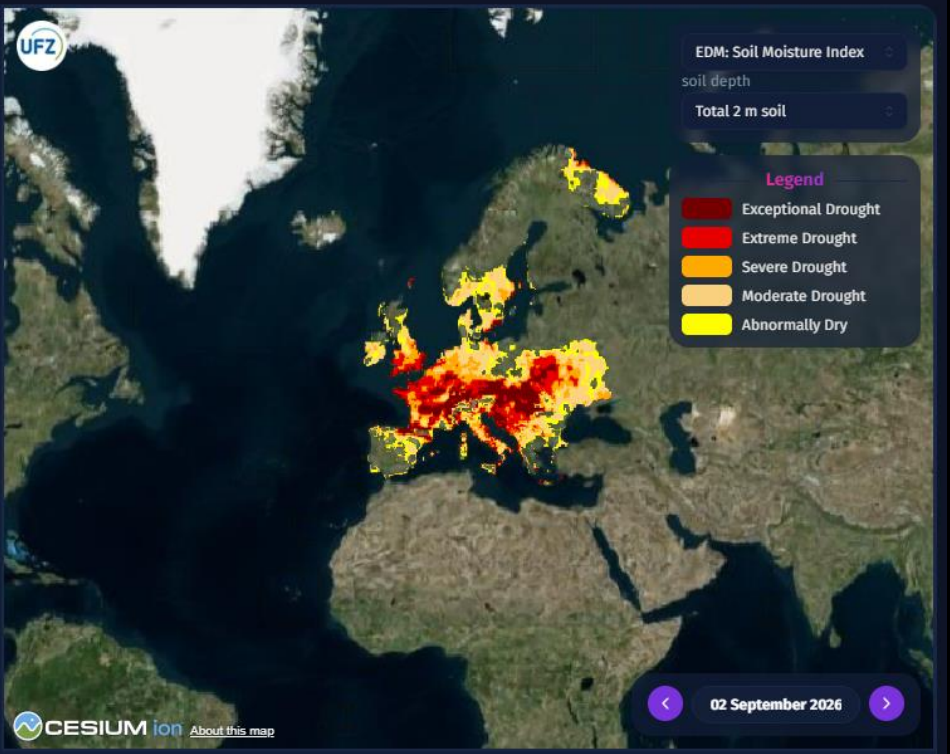
9	10	12
Areas	*Cases*	*Partners*

European Drought Monitor

The European Drought Monitor (EDM) is an experimental end-to-end model chain that produces the European drought status using the Soil Moisture Index (SMI), with plans to extend to multiple indices. The EDM is powered by the mesoscale Hydrological Model (mHM) at its core. The model based near-real-time drought maps with a 1-day delay are made available to support fast monitoring of European droughts and flash droughts. Furthermore, EO-powered EDM will ensure enhanced accuracy, utilizing EO data for model verification across soil moisture, evapotranspiration, total water storage anomalies, reservoir levels and extents, and irrigation water use, among others.

Registered and logged-in users can unlock advanced capabilities to load drought status based on ASCAT EO soil moisture products and compare with EDM drought status map at multiple soil depths simultaneously.





Map details

The map shows the 5 drought classes based on the soil moisture index (SMI) at different soil depths (e.g., top 10cm). The "exceptional drought" is when the soil moisture at the location falls under 2% of the soil moisture history (1974-2023); the similar thresholds for remaining classes are 5% for "extreme drought", 10% for "severe drought", 20% for "moderate drought", and 30% for "abnormally dry".

Destination Earth — Funded by the European Union — Implemented by ECMWF esa EUMETSAT

DTE Hydrology

STEM Education, Living Planet Fellowship, MOOCs, Advanced Training





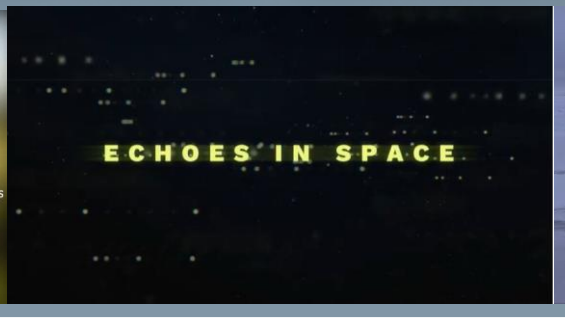


Advanced Courses Organised every year

Living Planet Fellowship Calls every year











Massive Online Open Courses

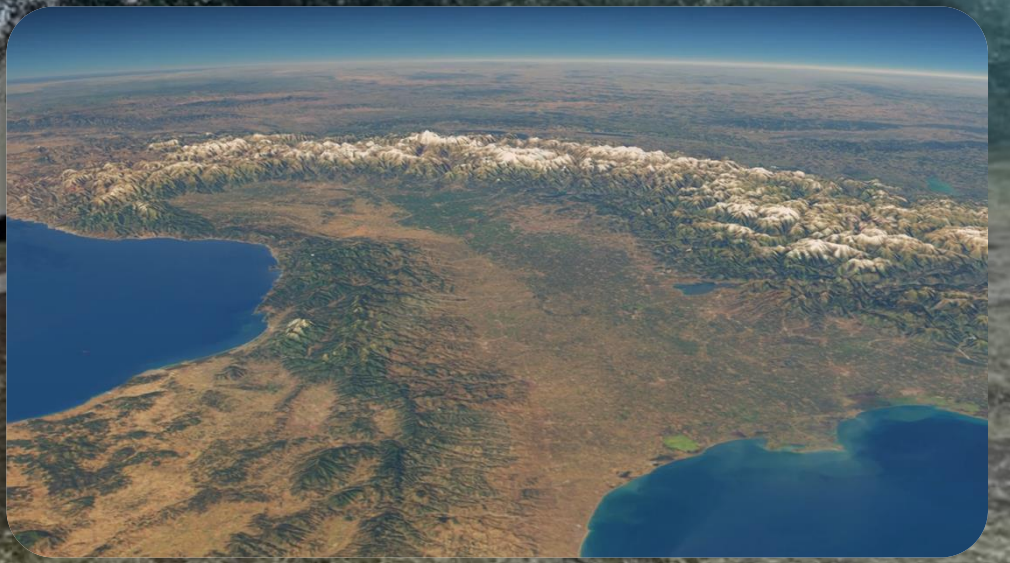
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Science Hub

Provides opportunities for **collaborative research** on Earth system science

- Boosting the Agency's and its Member States' scientific output
- Maximising the scientific impacts of the missions
- Advancing the scientific basis of **Digital Twins** of the Earth





https://www.hydrospace2027.org/



Thanks!

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