ESA Water Cycle and Hydrology Science Cluster

European Space Agency

Diego Fernandez Prieto

GEWEX Space Agencies Day

0707/2024

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Need for an urgent and collective response…

Need for science as the bedrock for sustainable solutions…

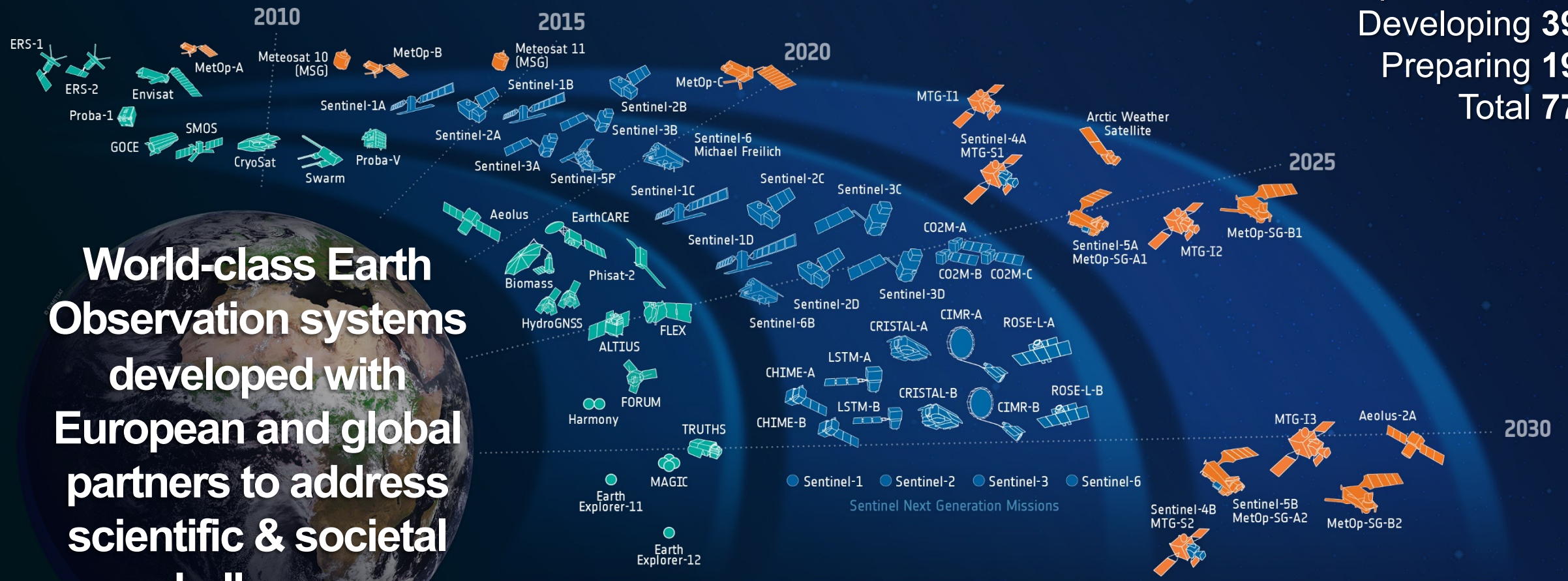
*The unique set of **grand challenges** that humankind is facing require more than ever that scientists advance their understanding of the planet, its processes and its interactions with human activities and translate that knowledge into novel solutions for society.*

ESA UNCLASSIFIED – For Official Use

ESA's Earth Observation Missions

Satellites

Heritage **06**
Operational **13**
Developing **39**
Preparing **19**
Total **77**



World-class Earth Observation systems developed with European and global partners to address scientific & societal challenges

Science esa Copernicus European Union Meteorology EUMETSAT

©ESA 2023

Copernicus Space Component – Evolution

PROGRAMME OF THE EUROPEAN UNION

co-funded with esa

CHIME

Copernicus Hyperspectral Imaging Mission for the Environment

soil properties
crop health
raw materials
biodiversity
water quality

ROSE-L

L-band Radar Observing System

geohazards
polar ice
forest management
food security
maritime surveillance

LSTM

Land Surface Temperature Monitoring

sustainable agriculture
water resources management
drought
urban heat islands

CIMR

Copernicus Imaging Microwave Radiometer

sea-ice concentration
sea-surface temperature
polar maritime security
global ocean and cryosphere
soil moisture and vegetation

CO2M

Copernicus Anthropogenic Carbon Dioxide Monitoring

carbon dioxide and methane from human activity

CRISTAL

Copernicus Polar Ice and Snow Topography Altimeter

sea-ice thickness
ice sheets and glaciers
snow
polar oceanography
coastal and inland waters

Food Security and Water Management

Monitoring Land and Natural Resources

Combatting Climate Change

Safeguarding the Arctic

Copernicus Sentinel Expansion Missions

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ESA Earth Explorer Missions

cryosat
ICE

goce
GRAVITY FIELD

smos
WATER

swarm
MAGNETIC FIELD

aeolus
WIND

earthcare
CLOUD AND AEROSOL

biomass
FOREST CARBON

flex
PHOTOSYNTHESIS

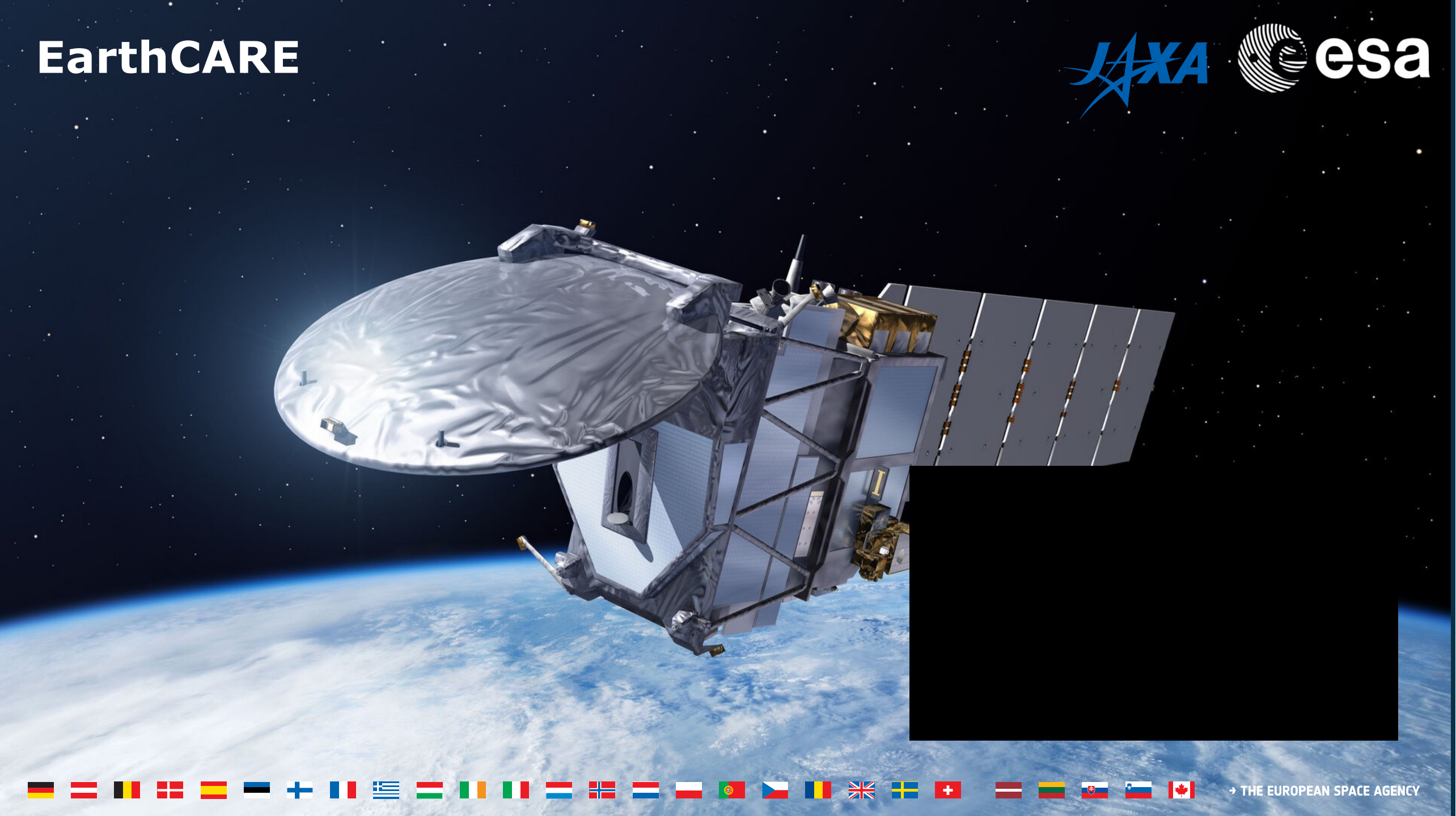
forum
THERMAL RADIATION

harmony
SURFACE DYNAMICS

EE11

EE12

EarthCARE



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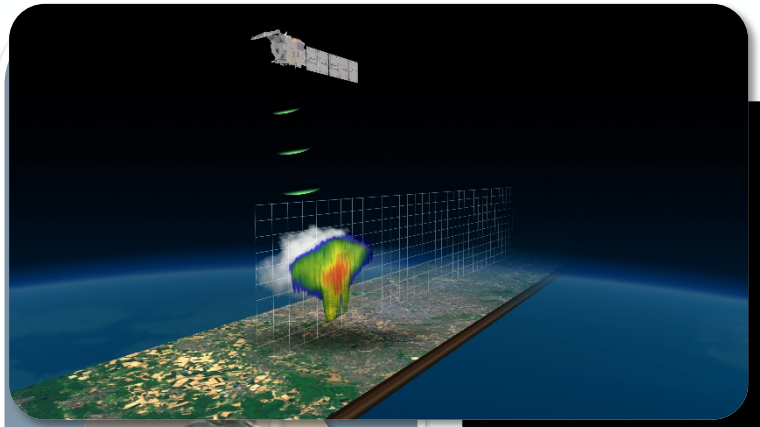
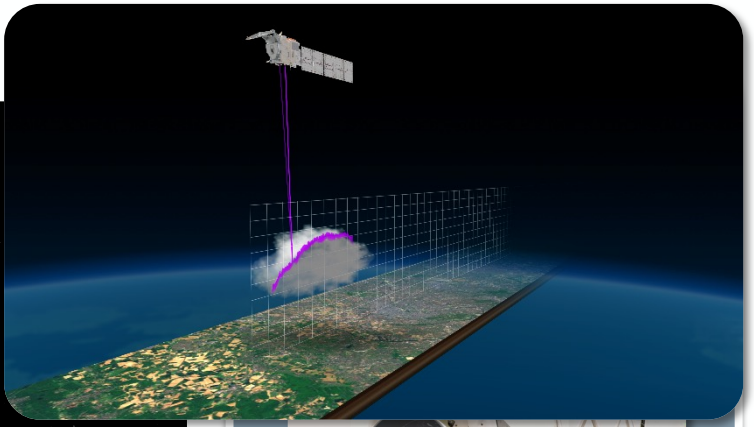
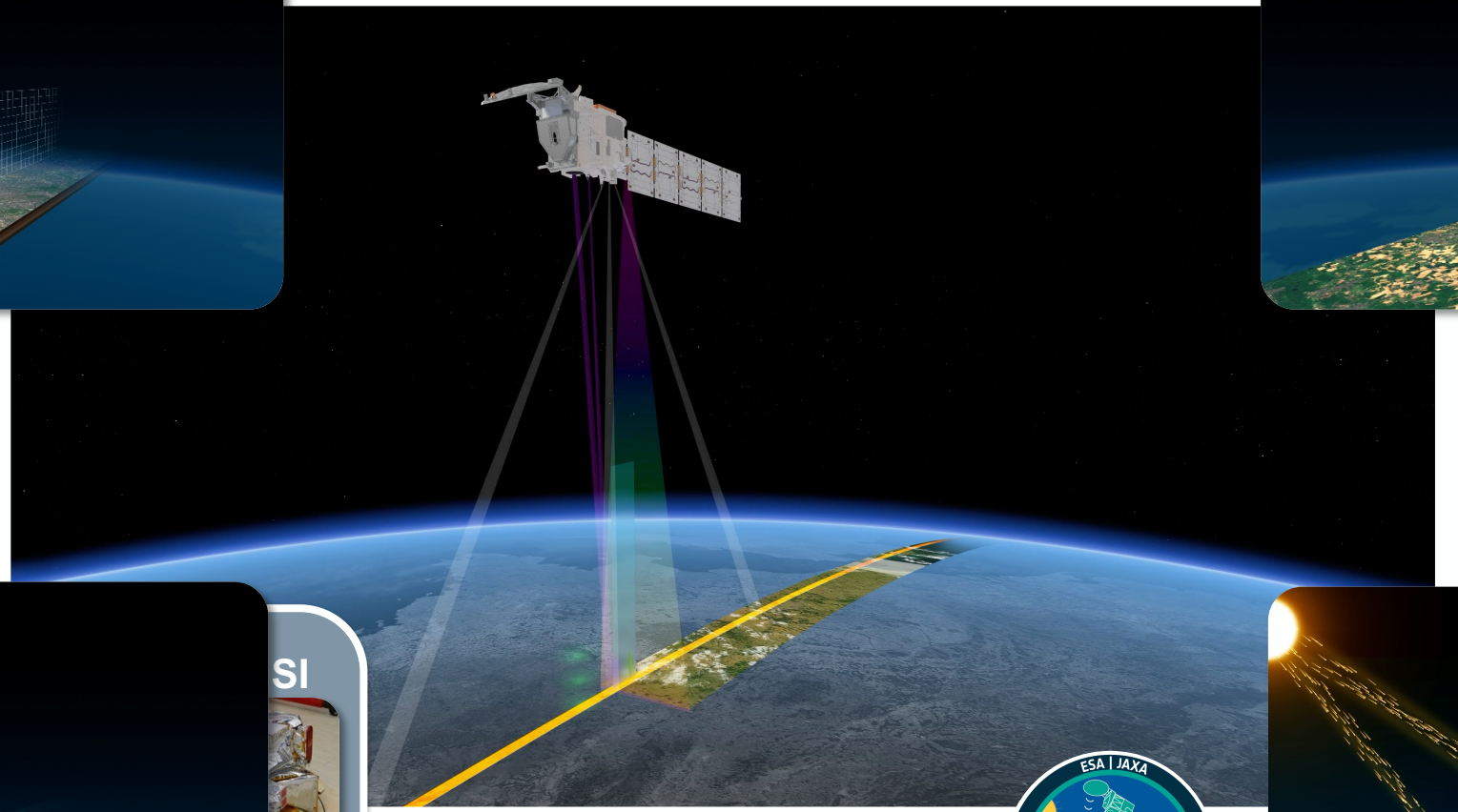
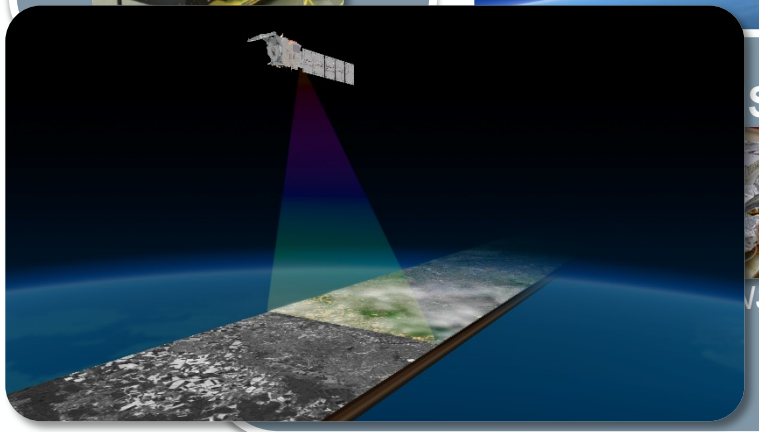
EarthCARE: Earth Cloud and Radiation Explorer









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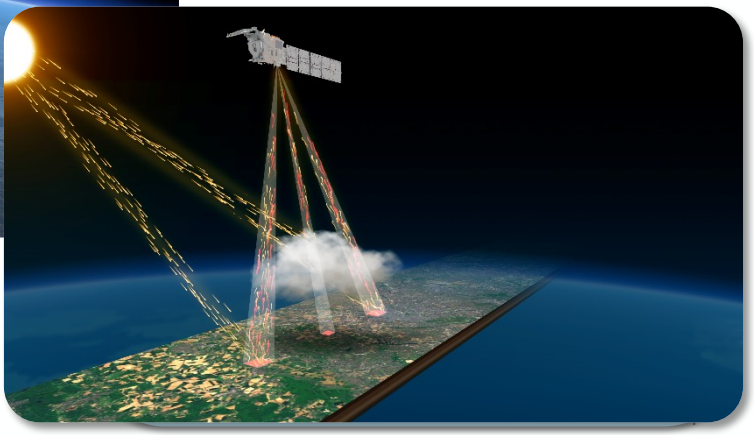
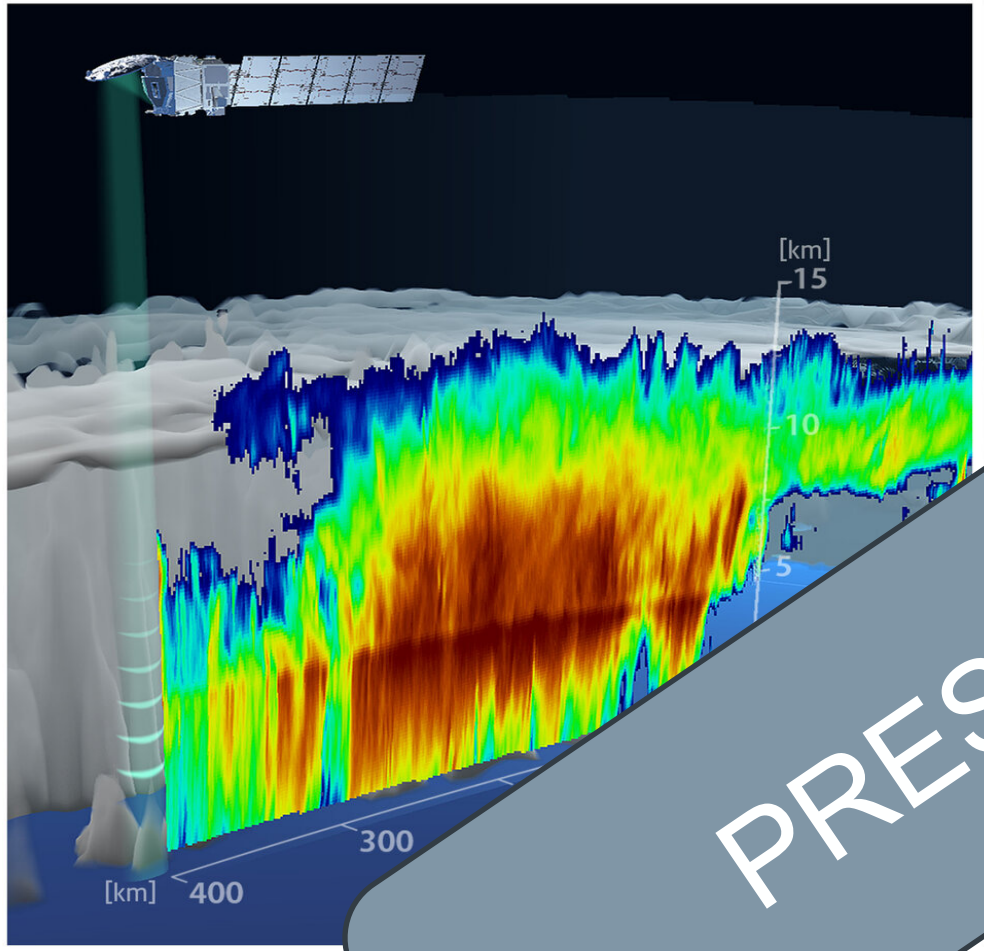
VS)

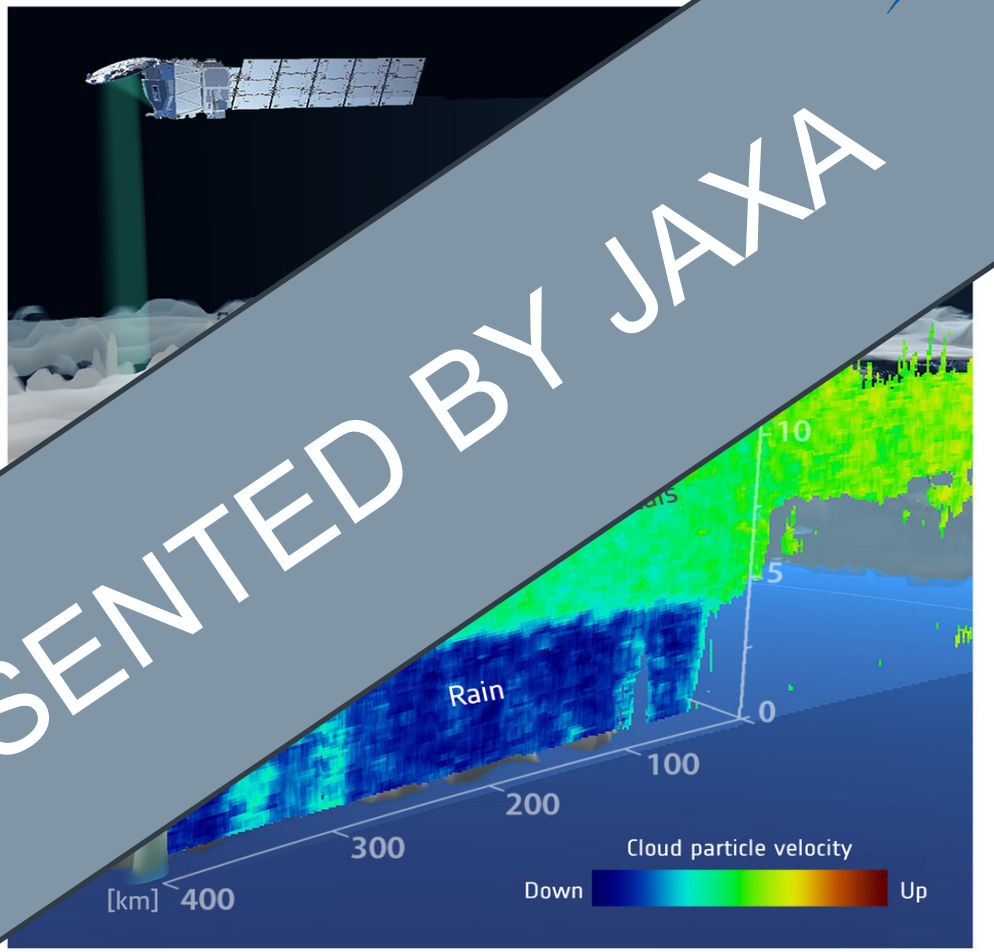


First CPR results from JAXA

PRESENTED BY JAXA



Vertically-resolved c
measured as radar re
cloud is in its centre.



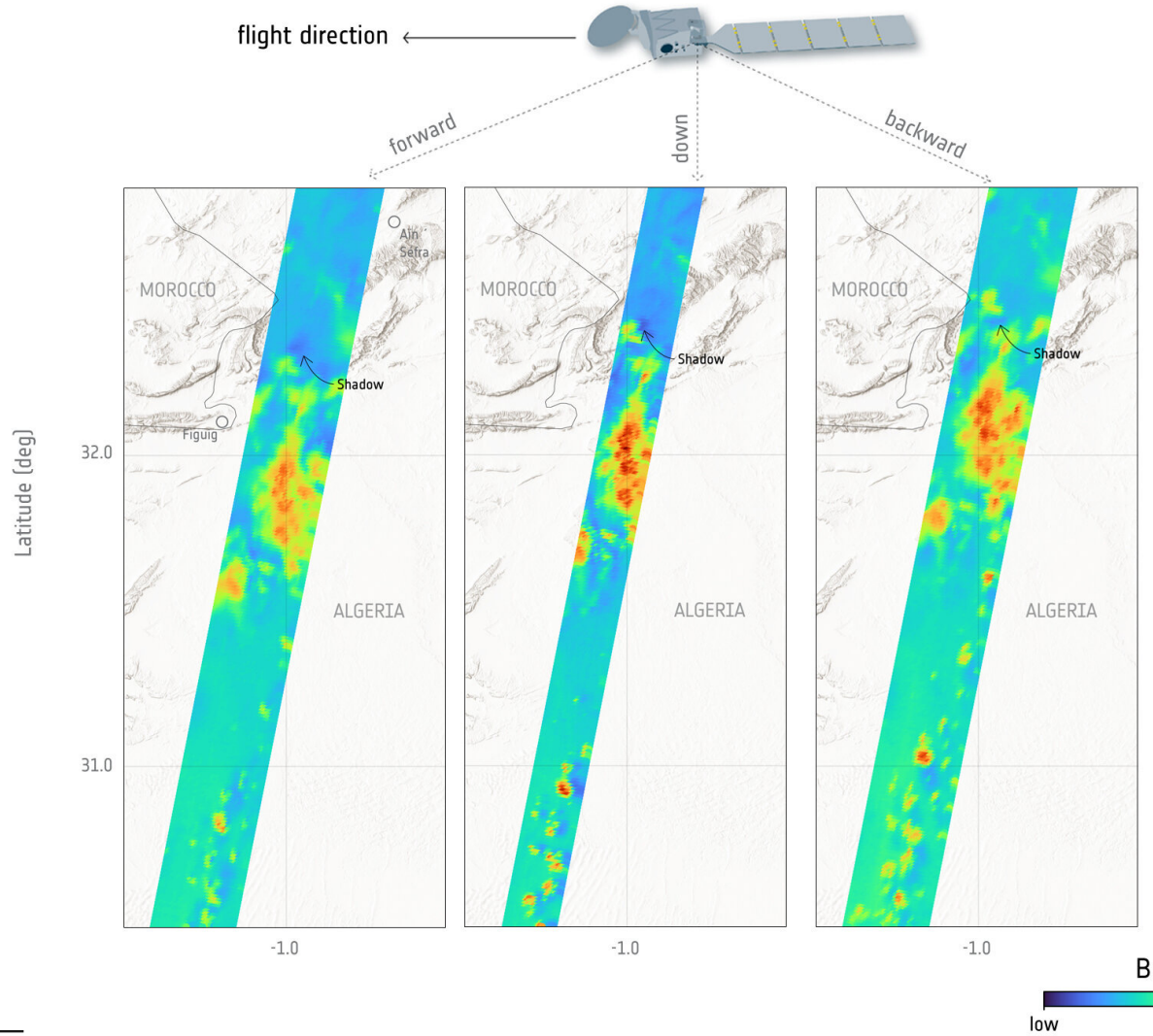
Cloud particle velocities: on top, ice crystals and snowflakes with little vertical motion. Clear boundary at an altitude of around 5 km, which is where the ice and snow melt, forming water droplets falling as rain.

s its Doppler
ility, a unique
ent from space, to
he vertical speed and
tion of the ice, snow and rain.

This detailed information about the density, particle distribution and velocity within the cloud allows scientists to distinguish the cloud constituents and better understand its physics.

Conventionally, these data can only be obtained by cloud radar on the ground or on aircraft. These methods can only measure limited areas, but CPR in EarthCARE now allows cloud structure to be measured uniformly across of the entire planet.

EarthCARE's broadband radiometer first results



The data was taken on 18 June, just a few hours after the broadband radiometer started its measurements.

The image zooms into the Atlas Mountains where thunder clouds tower 10 km into the atmosphere. The broadband radiometer's three different viewing angles capture the clouds from slightly different positions.

This can be seen in the apparent positions of the cloud's shadows relative to the clouds. This combination of viewing angles is the instrument's strength – one view only would not fully reveal the sunlight or the thermal radiation being reflected or emitted by cloud and other features. The view from multiple angles gathers information about the directional distribution of the energy that is seen at the top of the atmosphere.

Major events since EarthCARE Launch

Launch

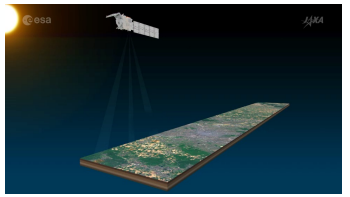
28 May 2024
22:20 UTC

Acquisition of Signal

28 May 2024

End of LEOP

29 May 2024

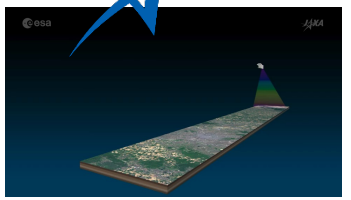


BBR in Measurement

18 June 2024

BBR "First Light"

27 June 2024



MSI in Measurement

0X June 2024

ATLID in Measurement

mid July 2024

Beg. Aug. '24

Deployment Solar Arrays

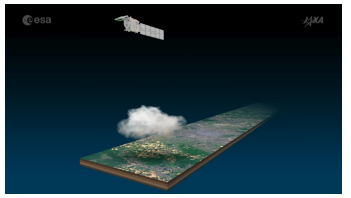
28 May 2024

Deployment CPR Reflector

29 May 2024

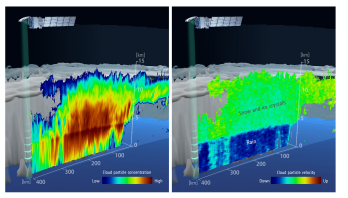
CPR in Measurement

18 June 2024



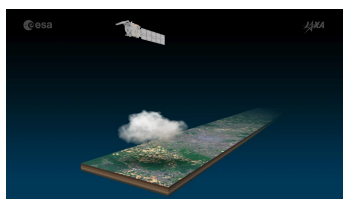
CPR "First Light"

27 June 2024

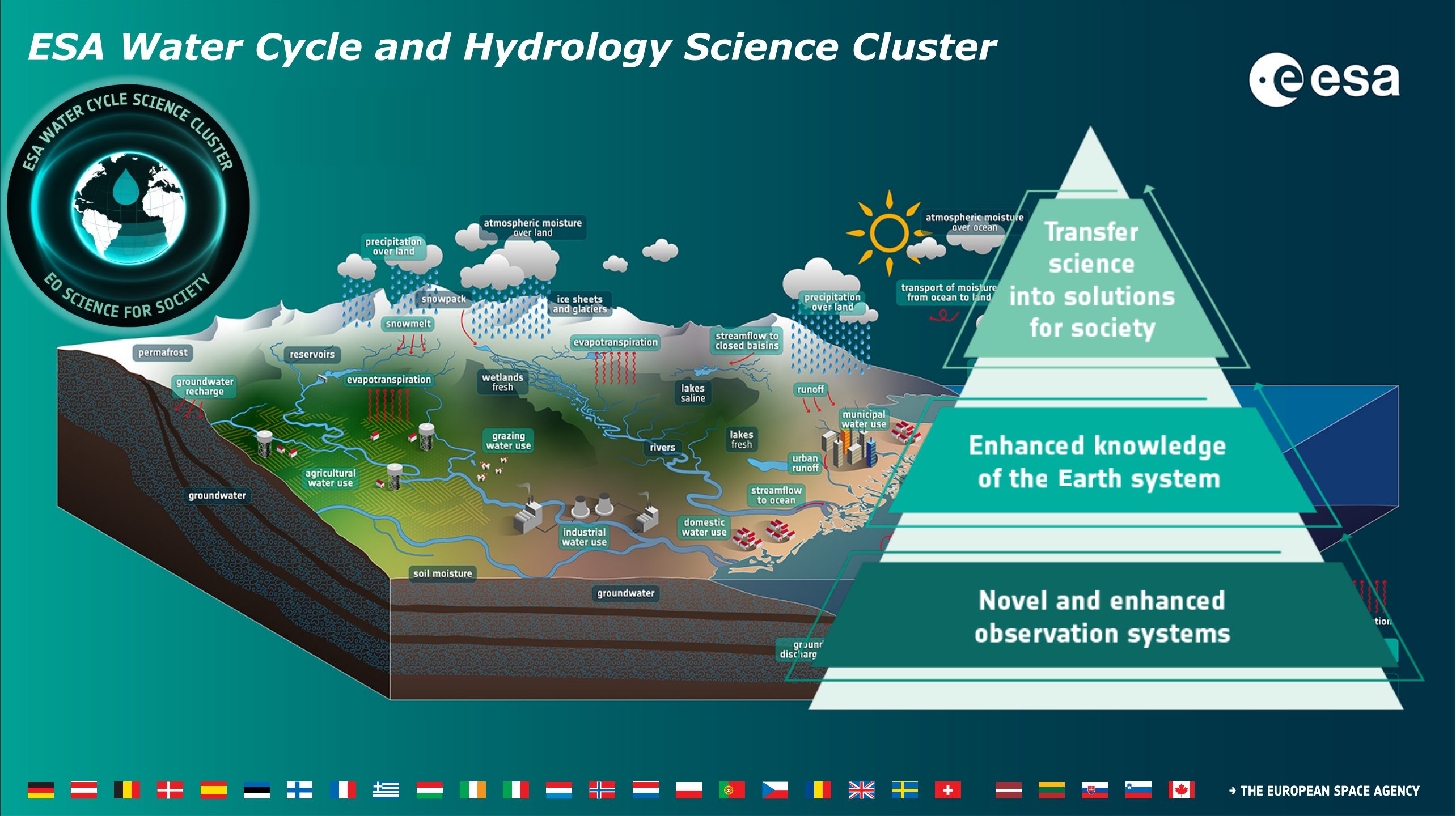


ATLID in Measurement

mid July 2024

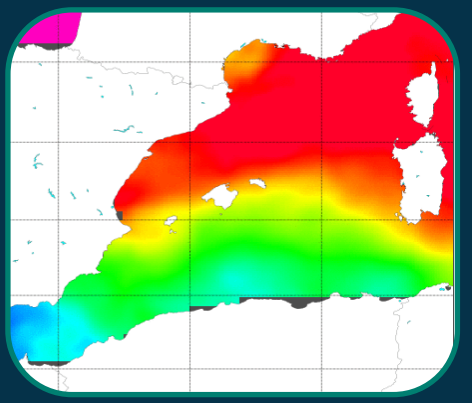


ESA Water Cycle and Hydrology Science Cluster

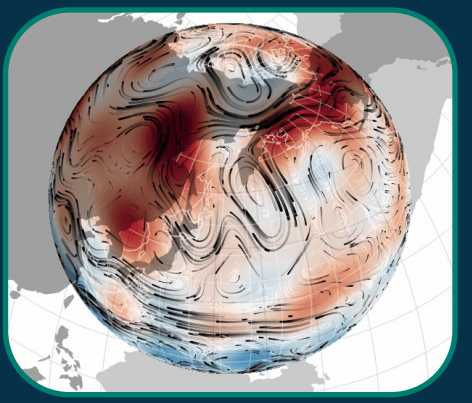


Pushing the frontiers of science

Engaging the community



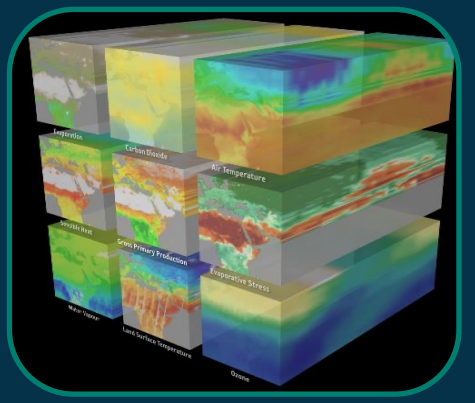
New methods & observation products



Advancing Earth System Science

Advanced simulations & predictability

Training and Education

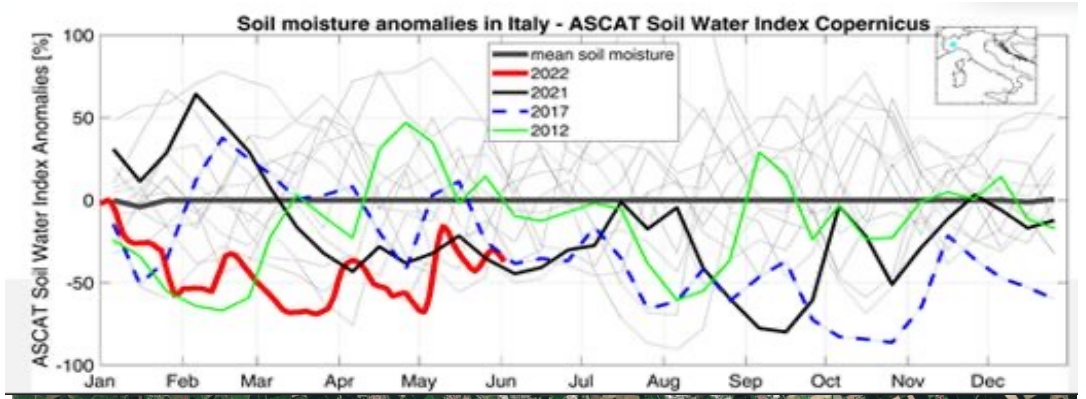


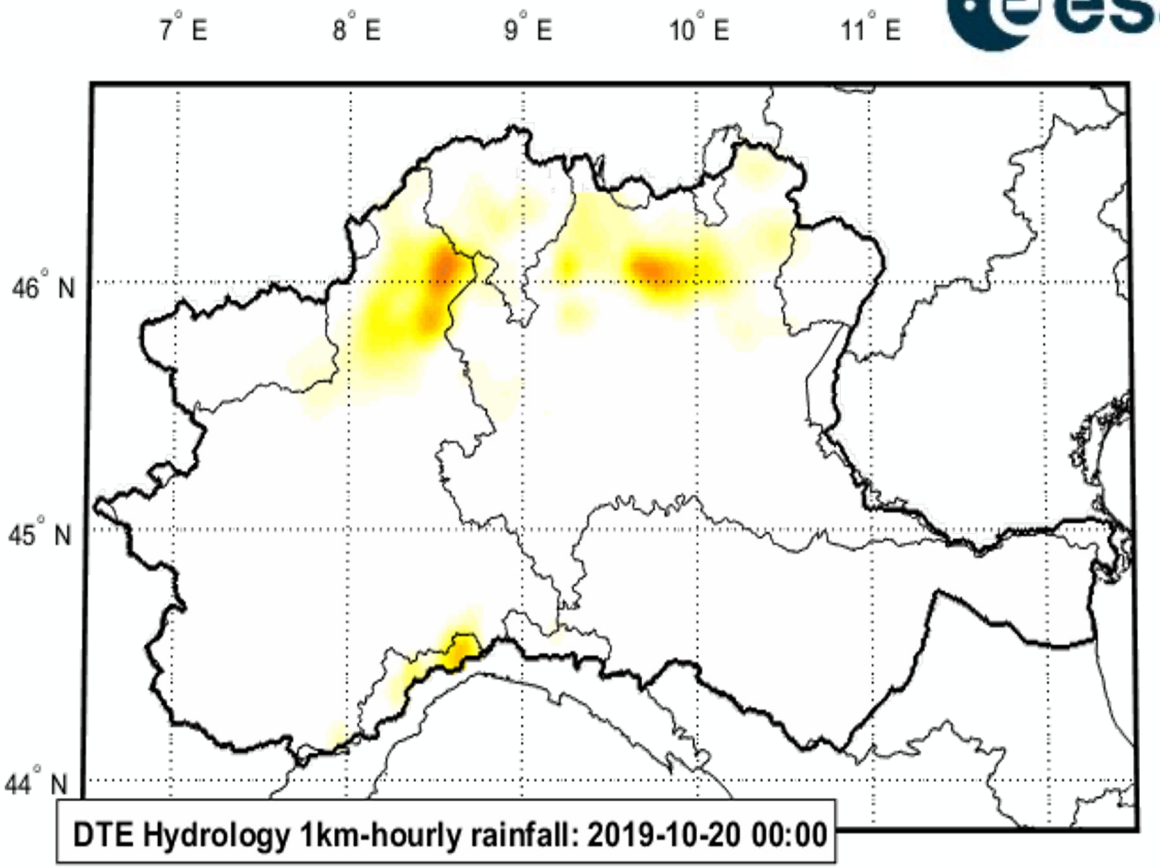
Open Science Tools/Virtual Labs

Scientific Campaigns

Transfer to future missions

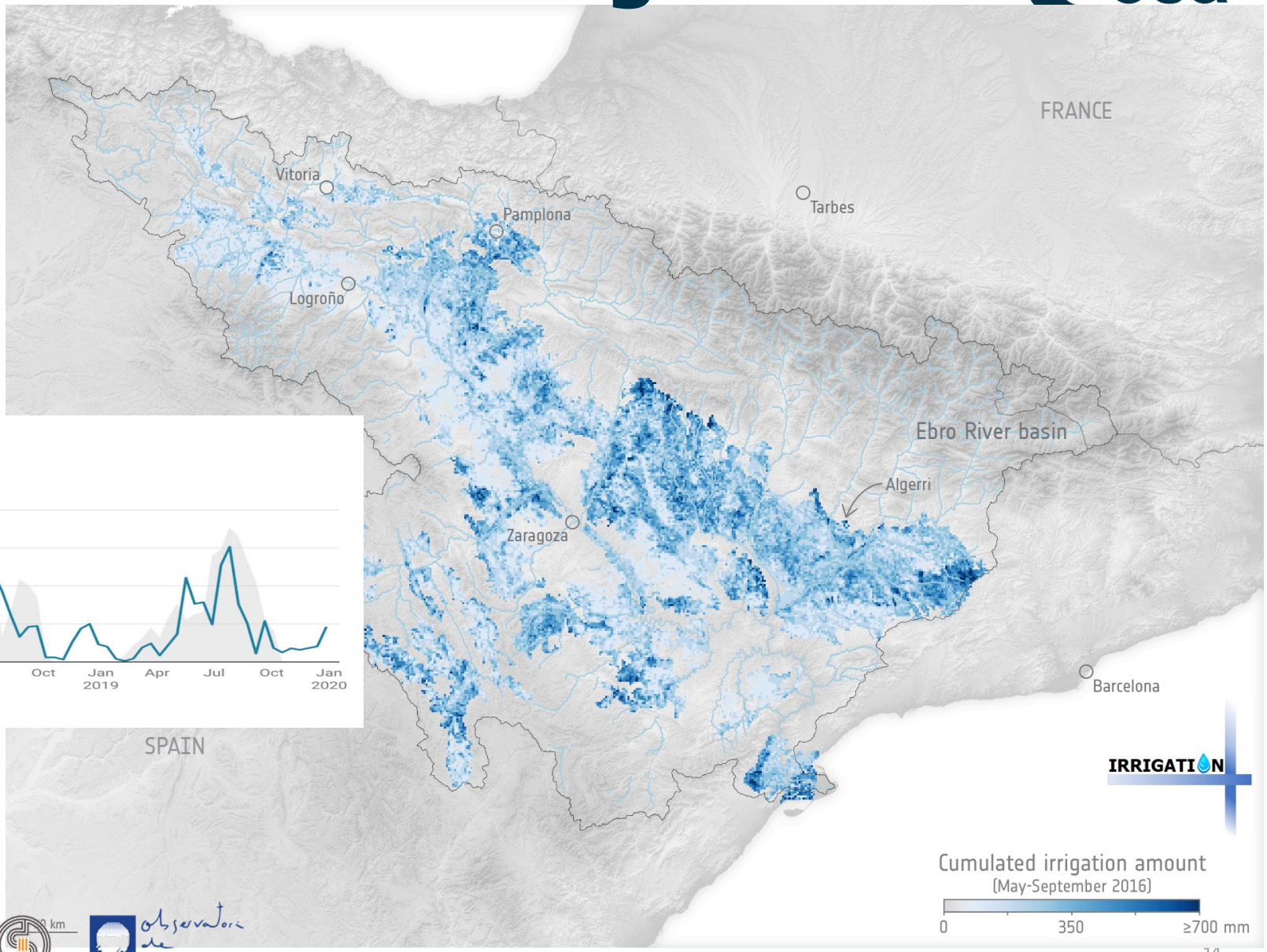
Advancing EO for Hydrology

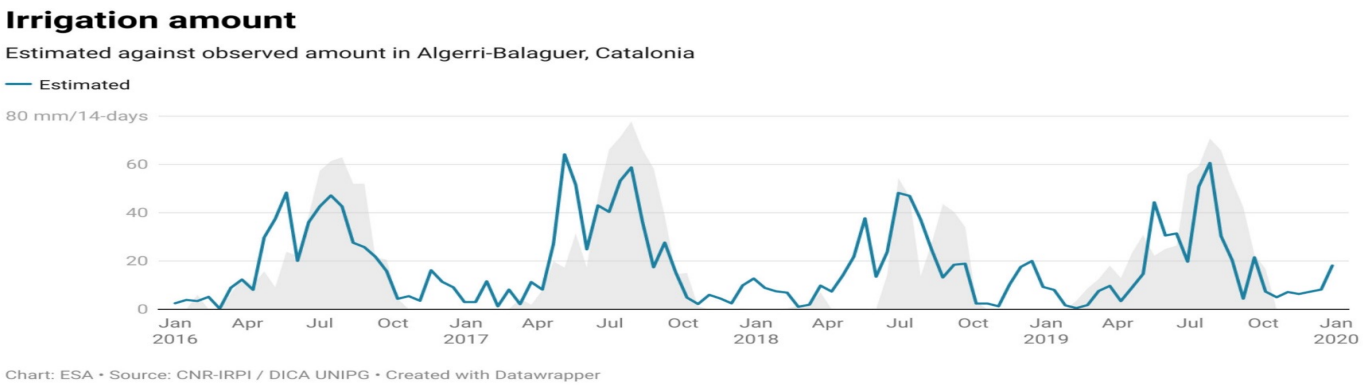




How much water is used for irrigation?

Irrigation is the major water consumer (70%), but irrigation data are absent. Through Sentinel-1 first attempts to obtain irrigation water use from space have been carried out in the ESA **Irrigation+** project.





https://esairrigationplus.org/

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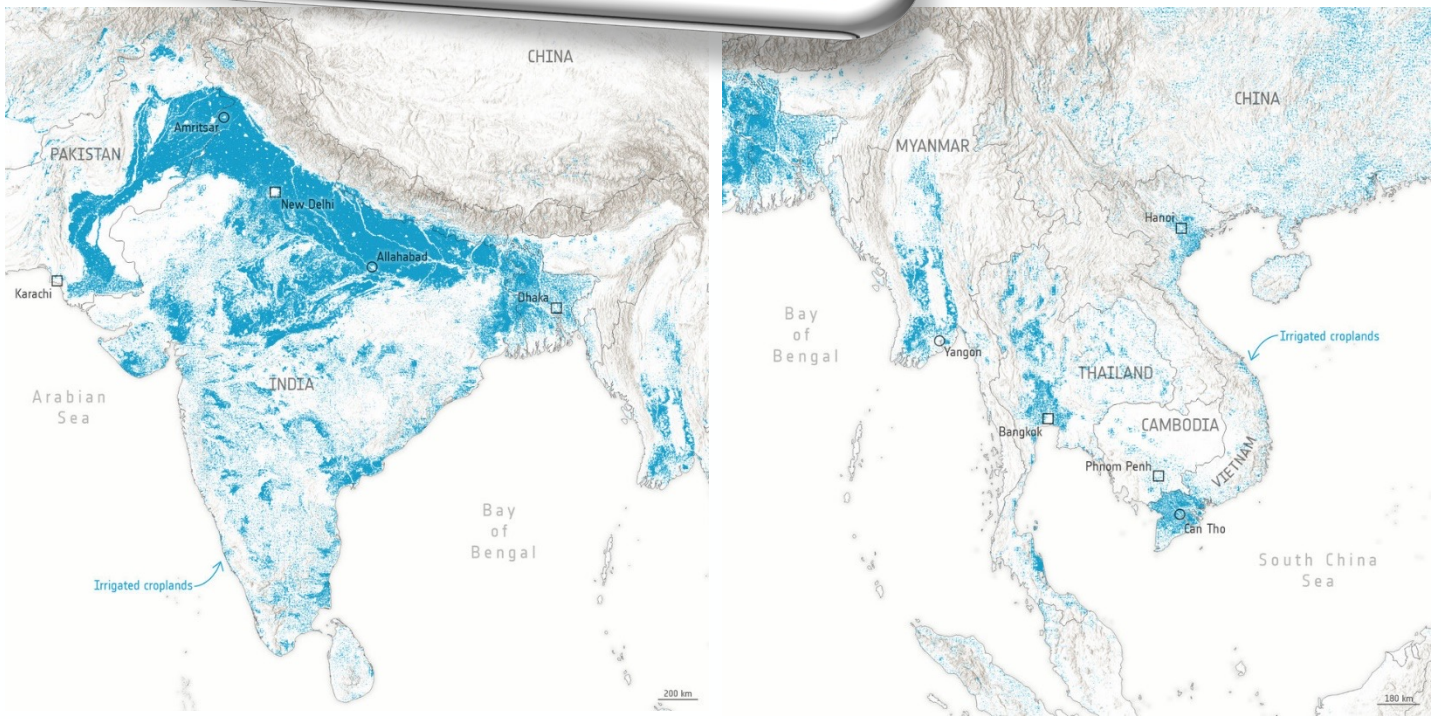
Major community Paper: IRRIGATION IN THE EARTH SYSTEM (IRRIGATION+ project)

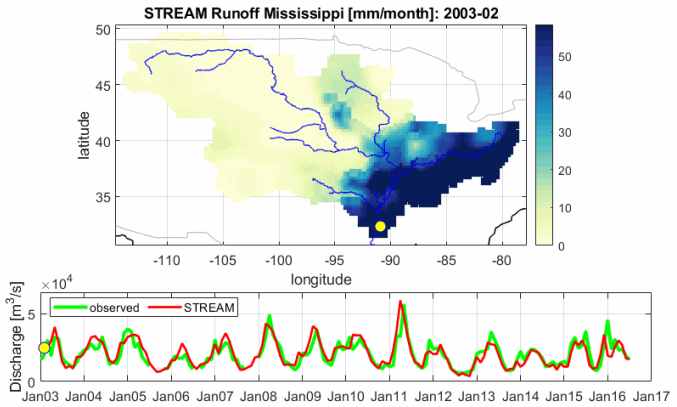
Irrigation in the Earth system, *Nature Reviews Earth & Environment* ***volume 4****, pages435–453 (2023*

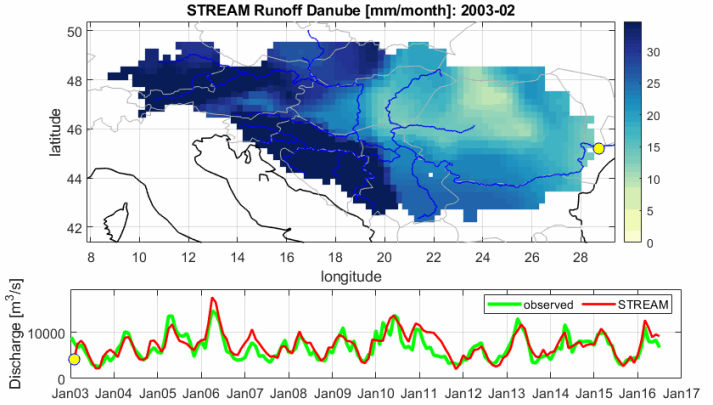


Irrigation accounts for ~70% of global freshwater withdrawals and ~90% of consumptive water use, driving myriad Earth system impacts.

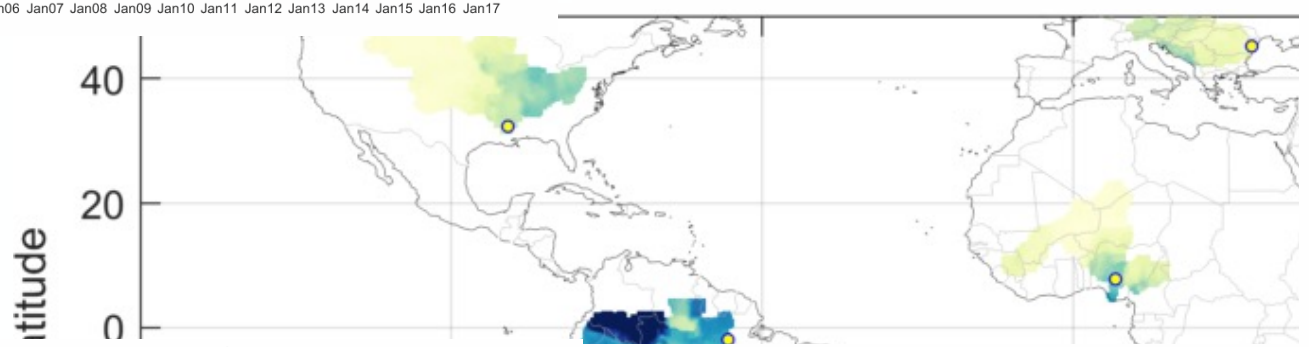
This Review summarize how irrigation impacts key components of the Earth system: e.g., modified surface energy balance and biogeochemical cycling; shift from sensible to latent heat fluxes, and resulting land–atmosphere feedbacks, reduce regional growing season surface temperatures by ~1–3 °C but conversely exacerbates moist heat stress; enhance cropland carbon uptake; but contribute to elevated methane fluxes in rice systems and mobilize nitrogen loading to groundwater.

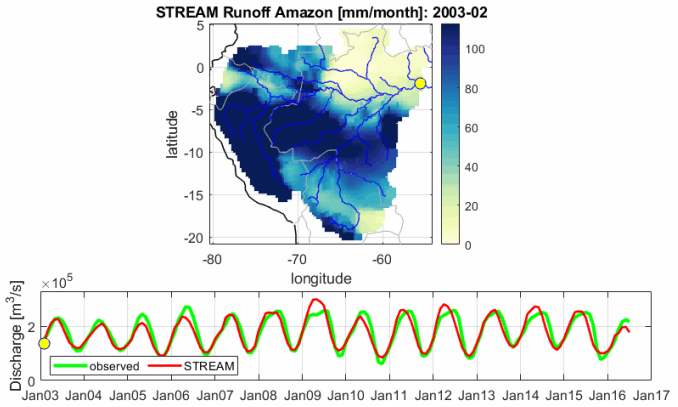
Global Runoff and River Discharge

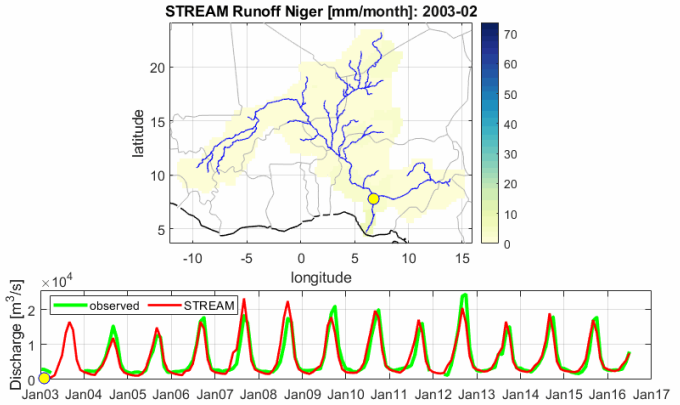


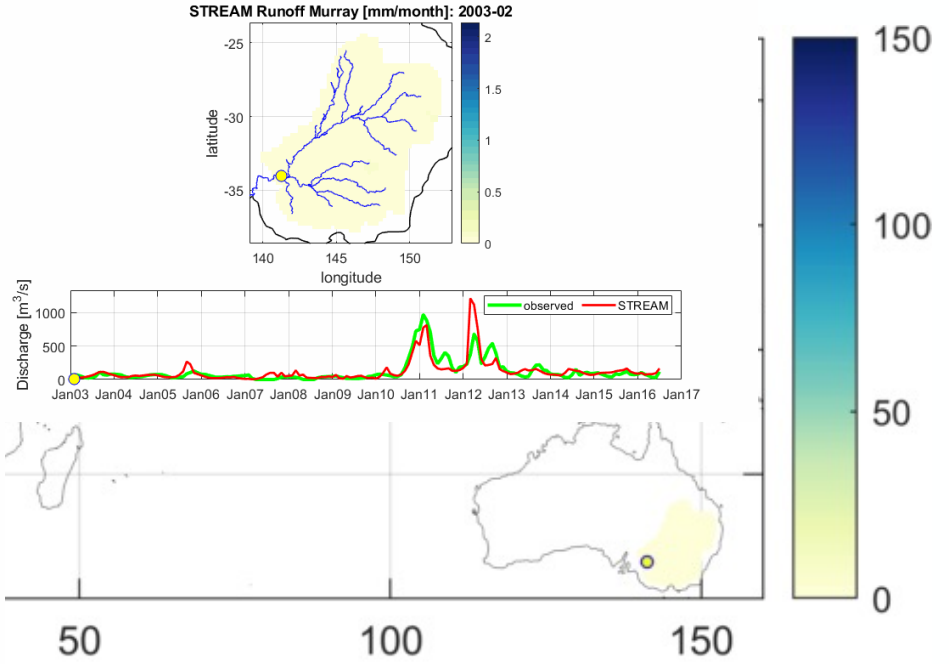


STREAM-NEXT will develop long-term independent global-scale runoff and river discharge to investigate the impact of climate change on runoff and to reconstruct past flood\drought events relevant for water resources management

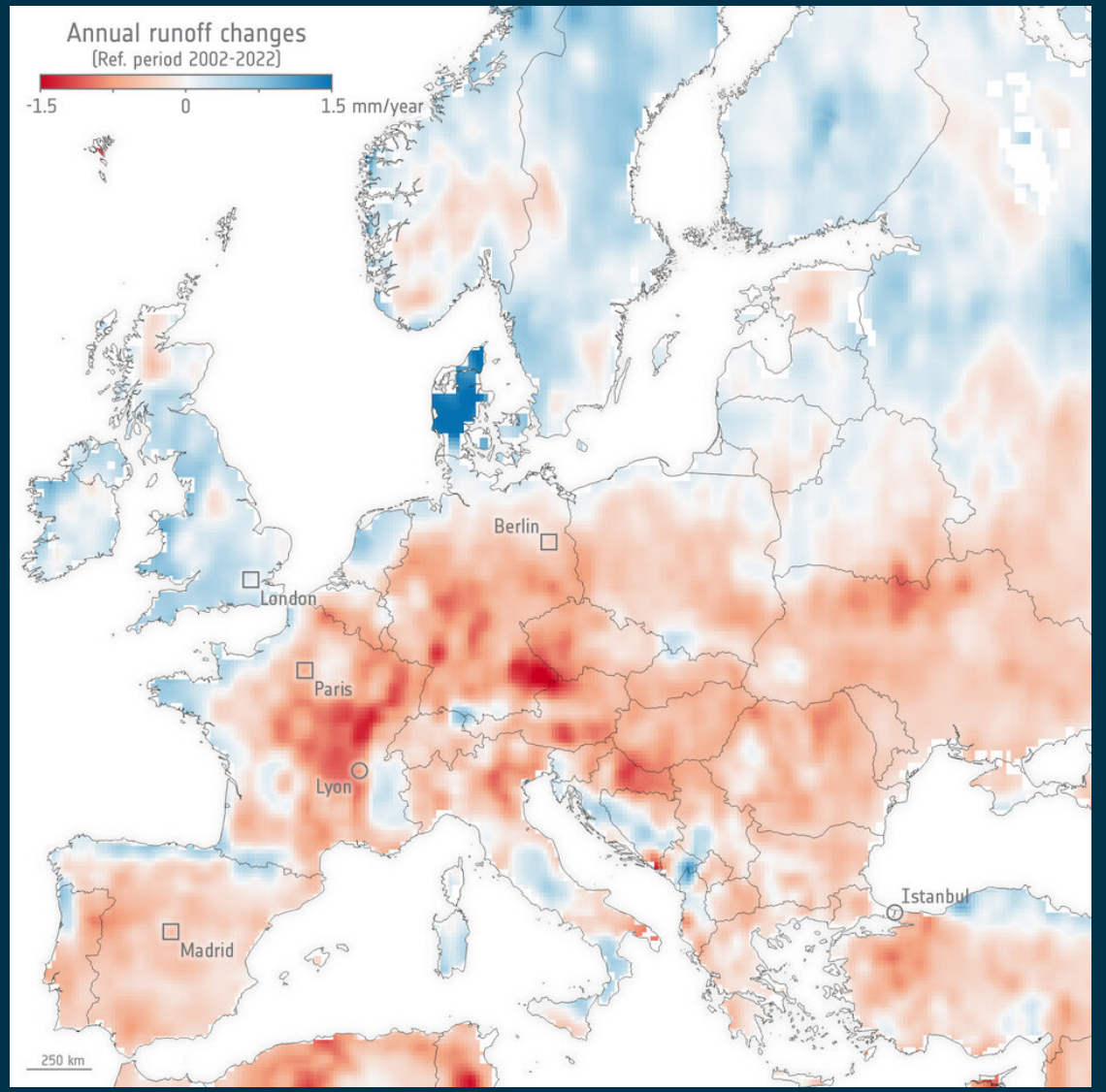








New experiments run-off pan-European product



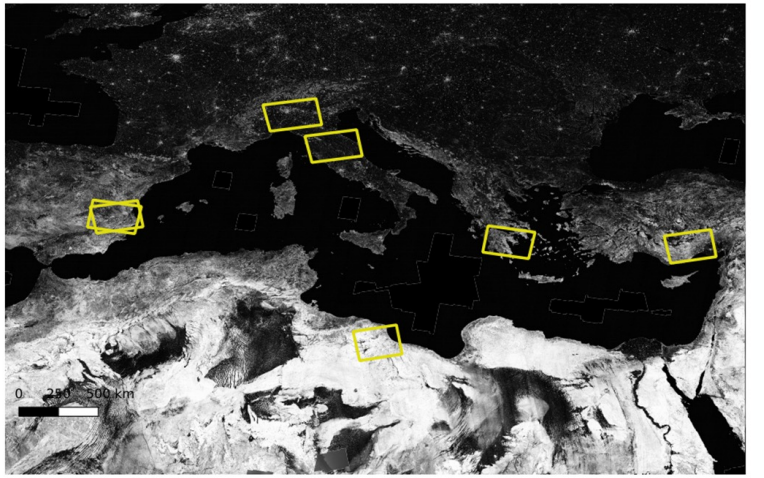
Runoff occurs when there is precipitation, but the soil is saturated and has lost its capacity to soak up any more water. The water is then forced to flow over land or through channels until it reaches a stream or a river.

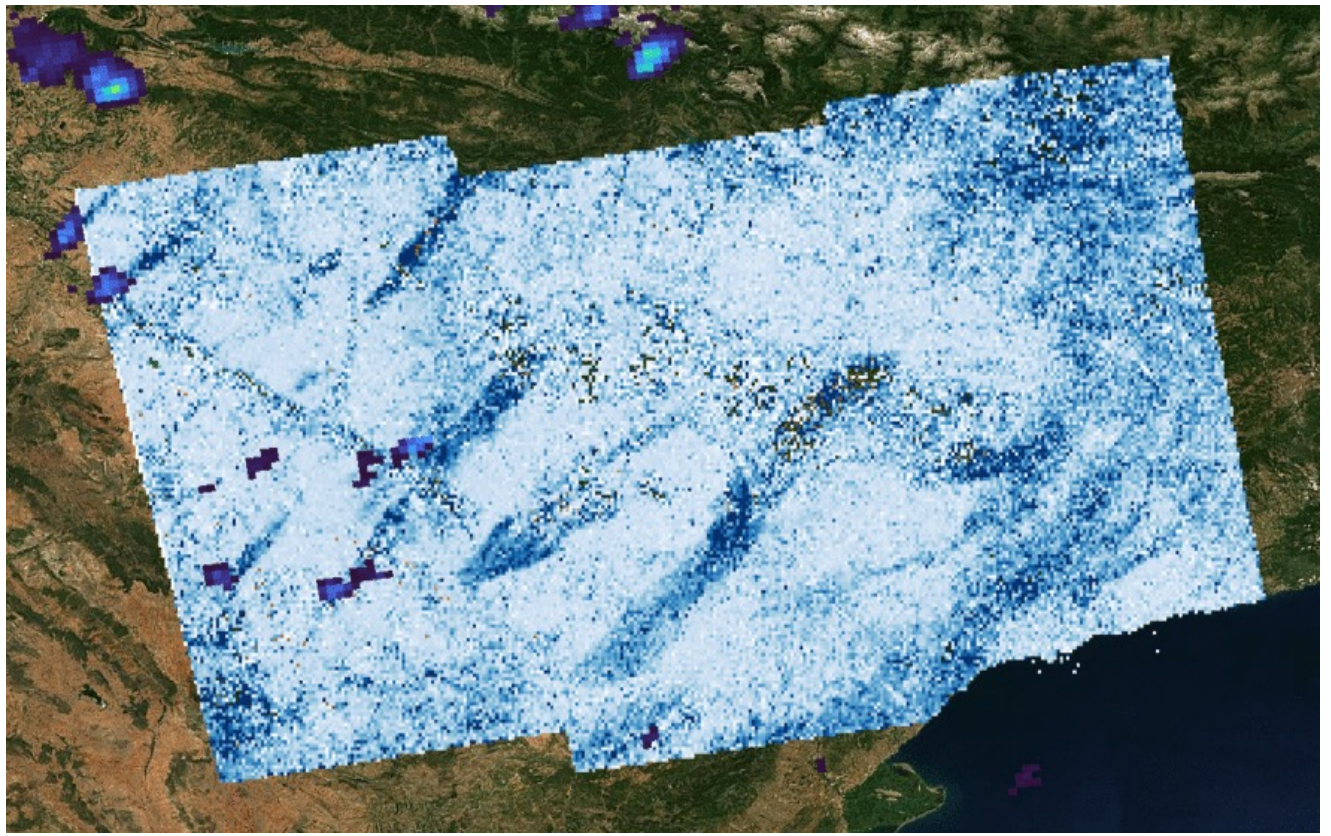
Run-off is typically obtained by using hydrological or land-surface models. Hydrologists are always looking for ways of reducing uncertainties so as to improve runoff estimates.

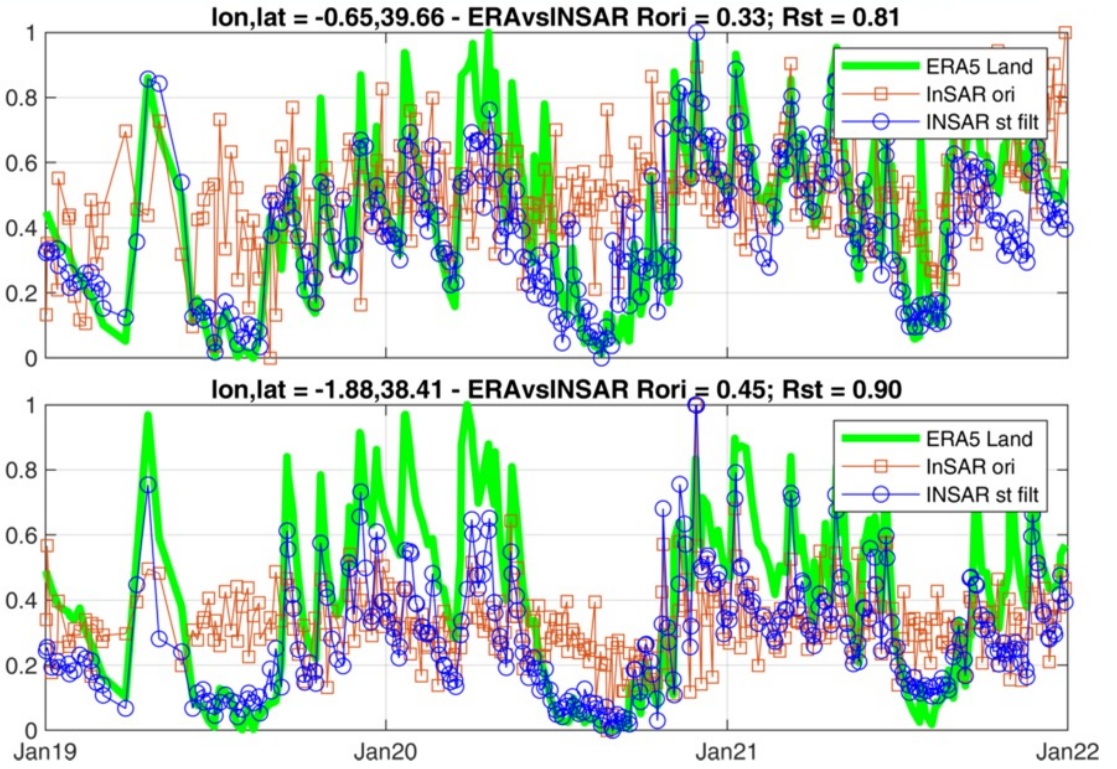
ESA's Stream, Ridesat address this issue by using satellite data including soil moisture and groundwater storage change from GRACE and GRACE follow-on. The map shows annual runoff trend over 20 years, between 2002 and 2022.

HR soil moisture from InSAR

In the **DEMETRAS** project we are developing high resolution soil moisture products from interferometric SAR (InSAR) applied to Sentinel-1 observations. Validation results are highly promising.



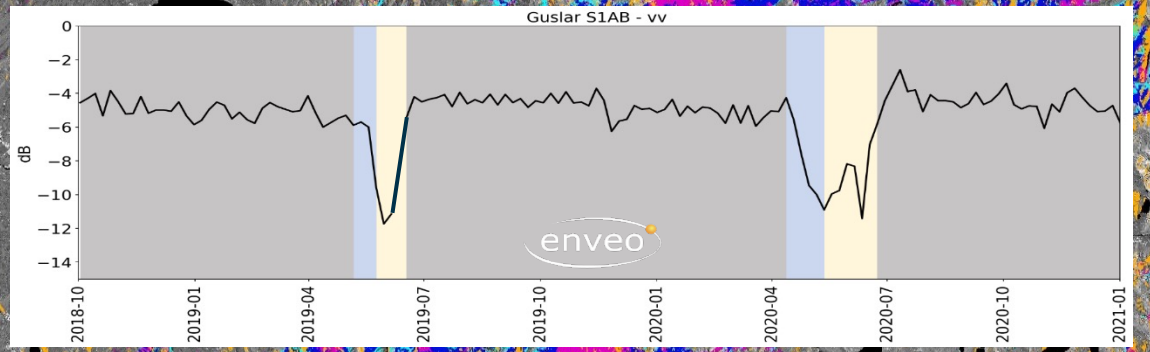


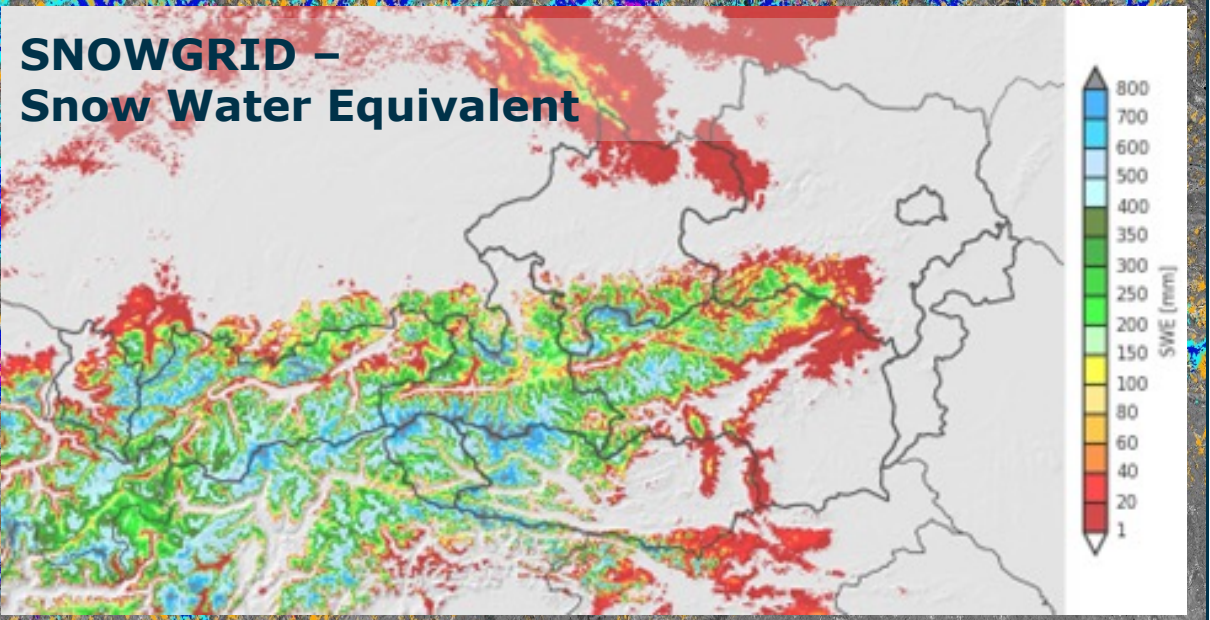


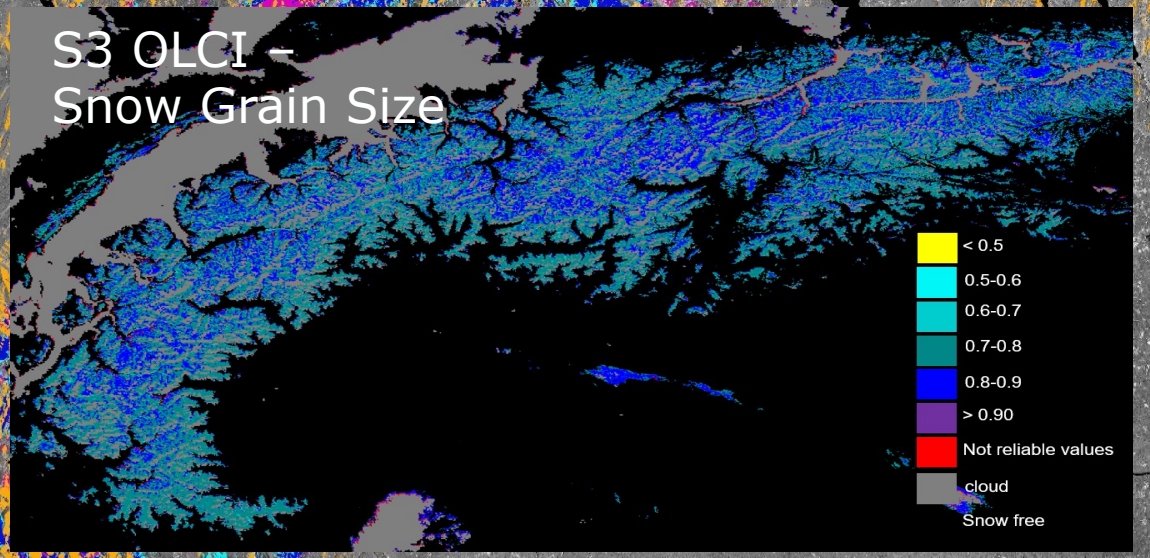
CNR irpi remote sensing

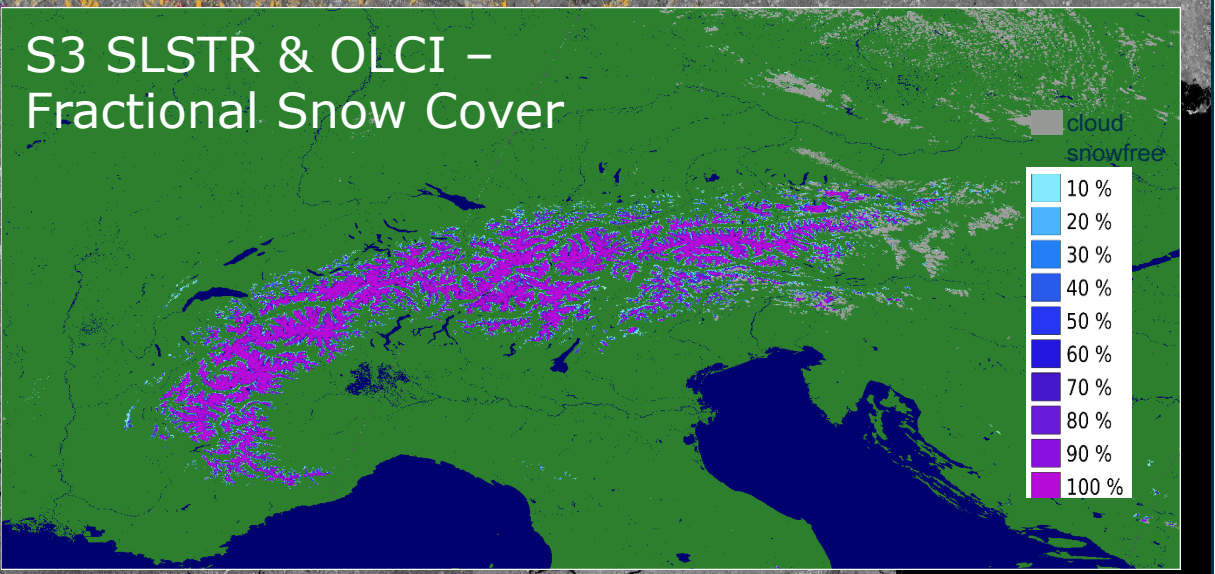
Advancing on physical snow parameters:

- Snow area extent
- Snow surface albedo & grain size
- Snowmelt area extent & melt phase
- Snow water equivalent & snow depth

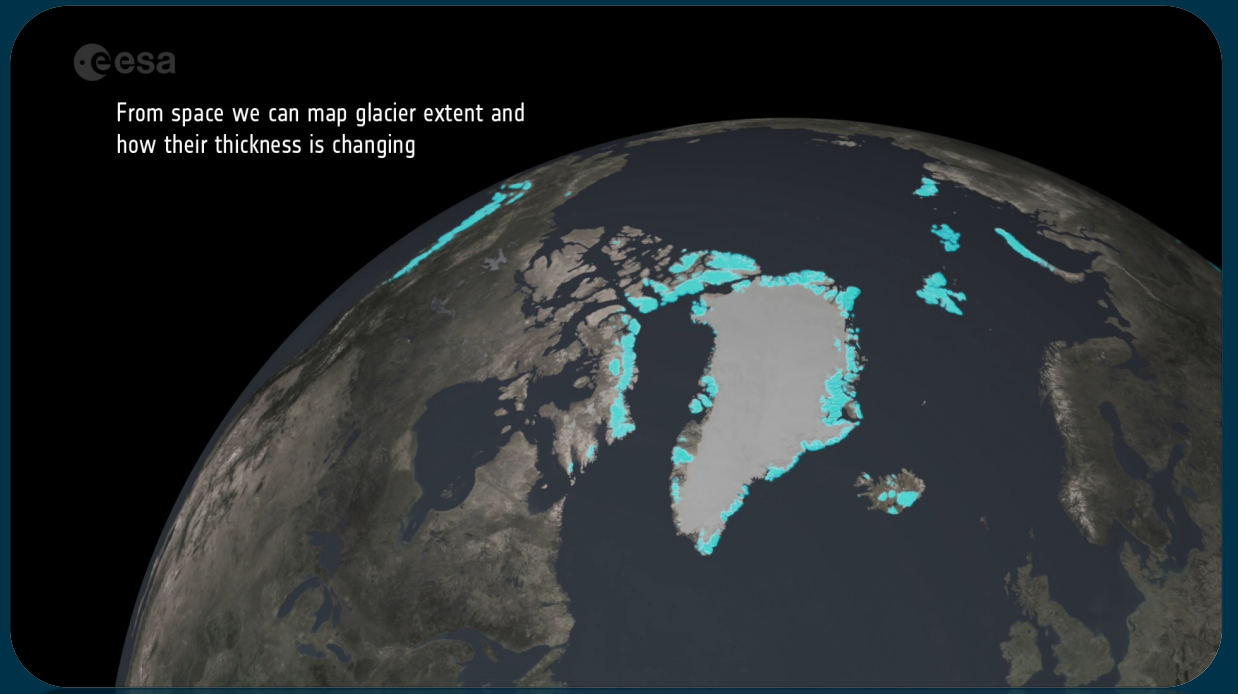


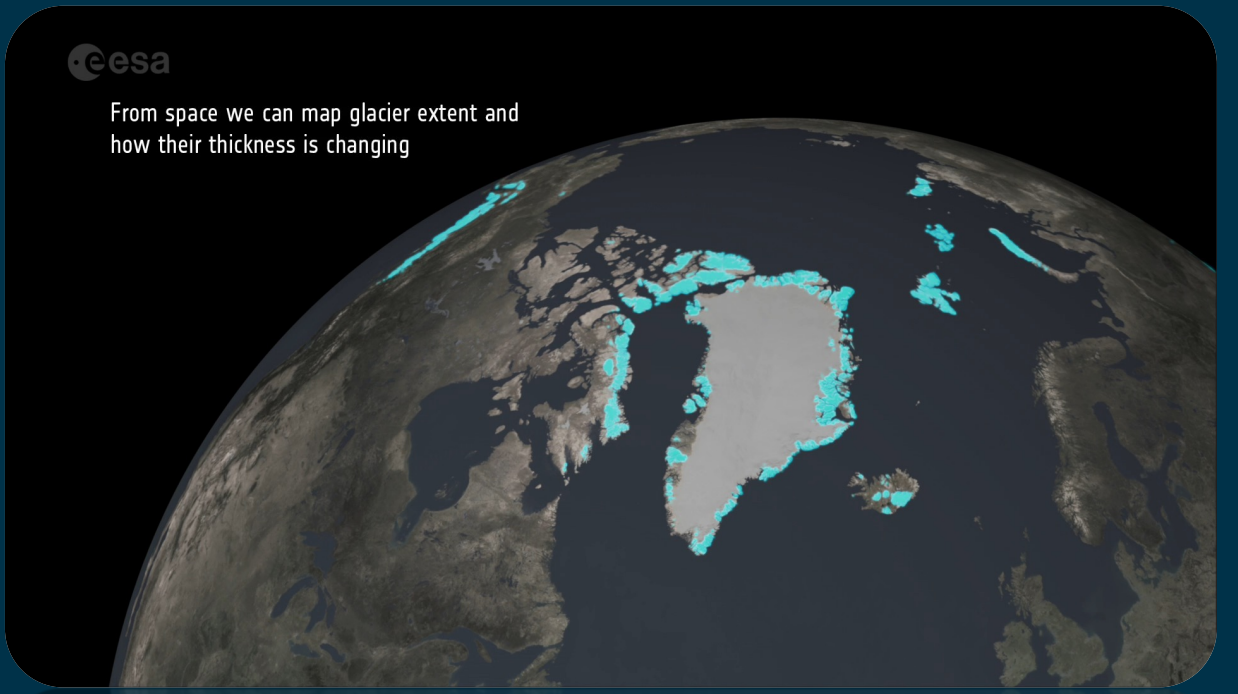




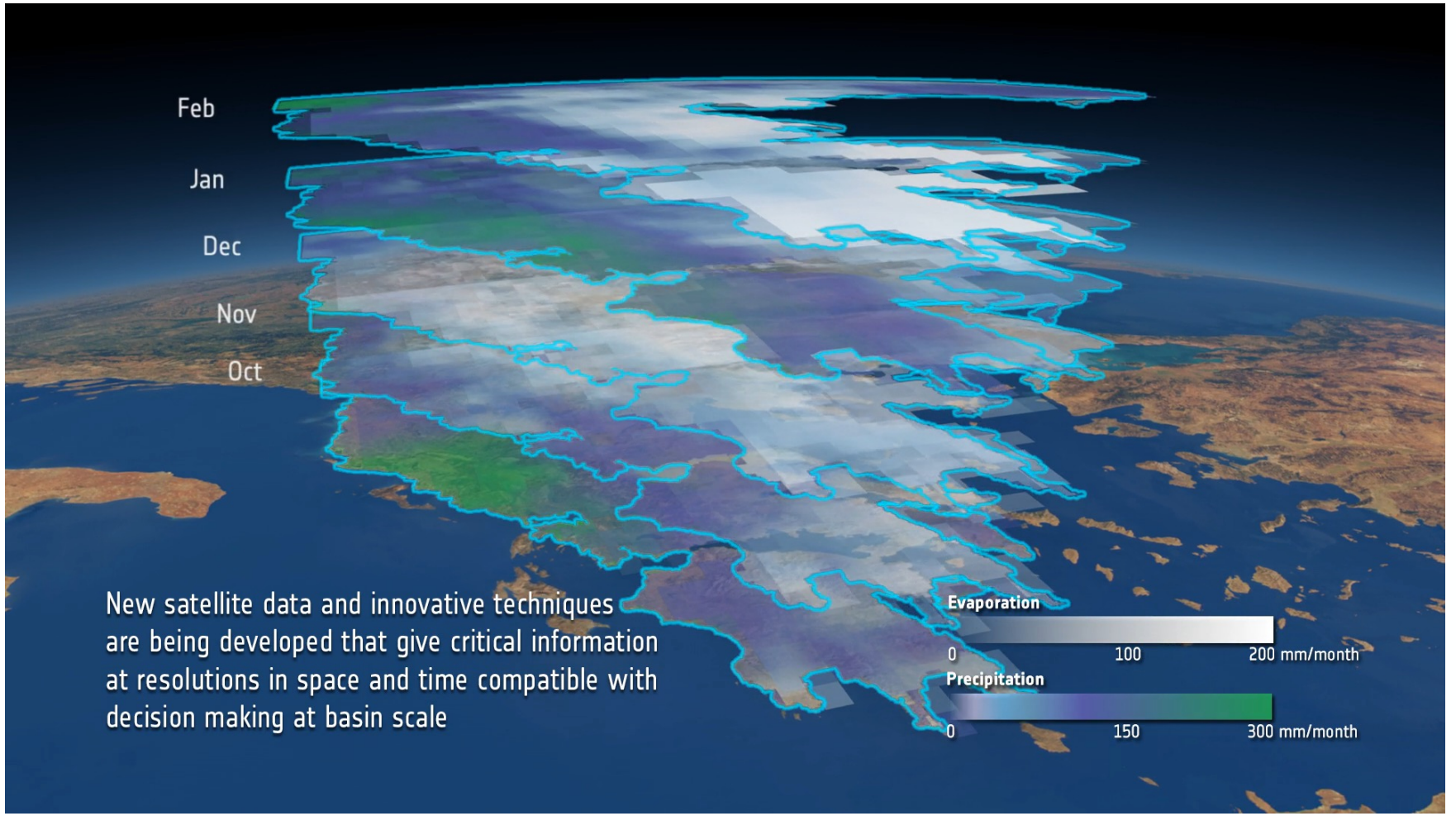


Glaciers and the Water Towers of the World…..

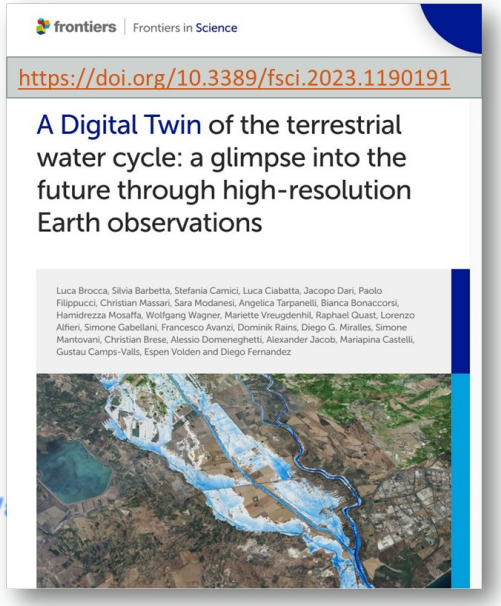




Digital Twin Earth and 4DMED Hydrology



4DMED Hydrology focus on the terrestrial water cycle highlighting the huge potential of high-resolution Earth Observation products for predicting hydrological extremes (flood, landslide and drought) and water resources management

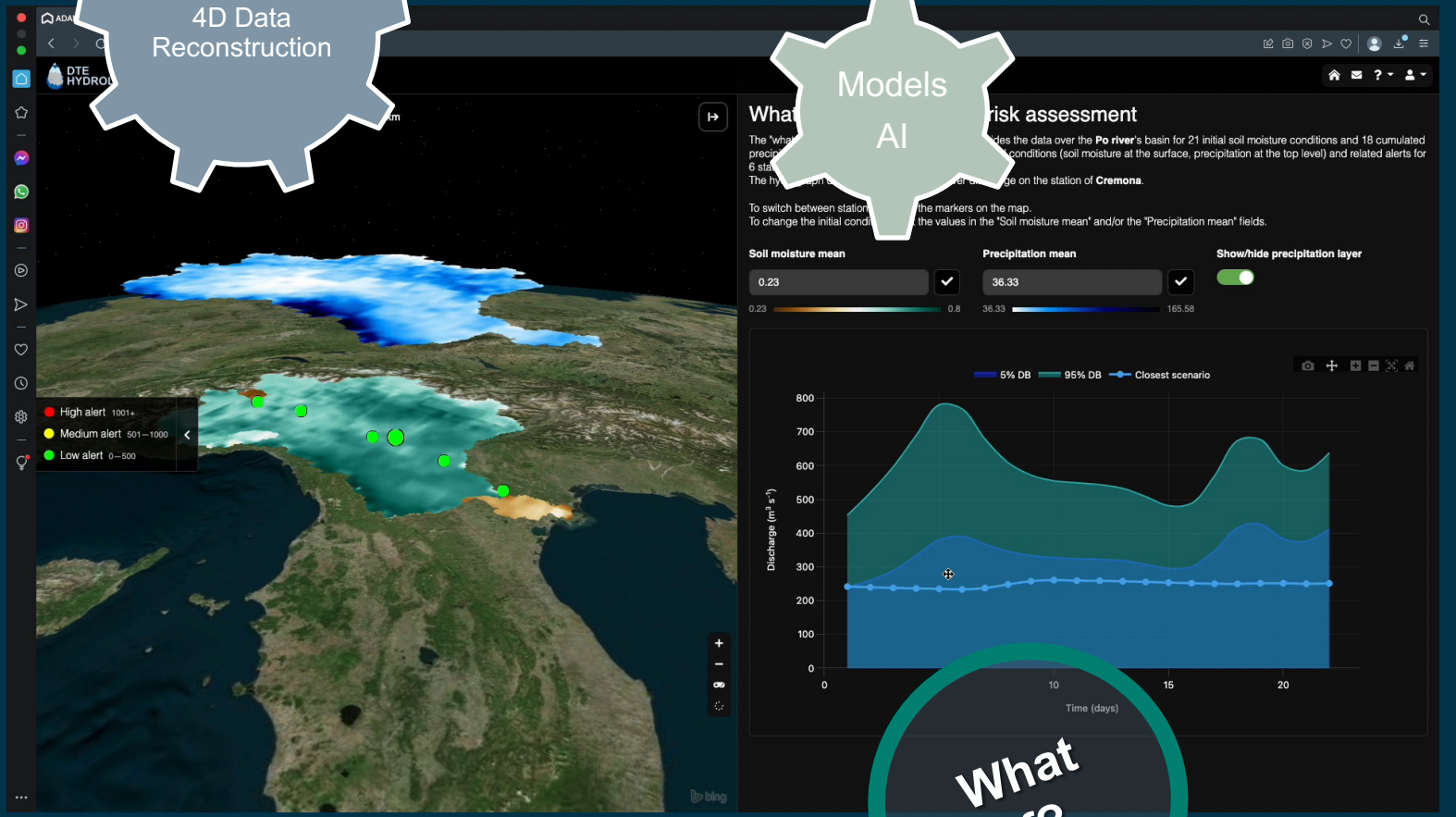


An Example: DTE-Hydrology

Past, Present and Future

4D Data Reconstruction

Models AI



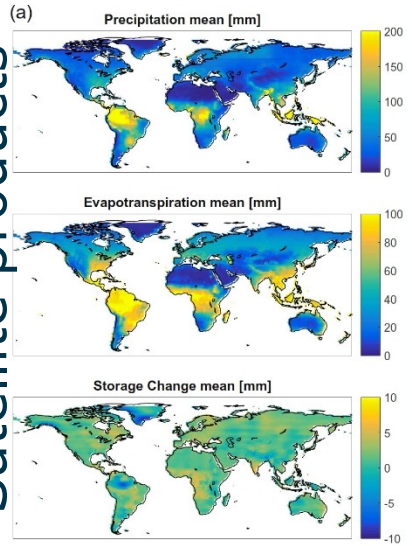
What if?

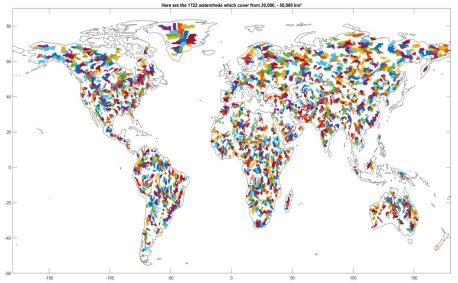
Wat if scenario based on an historical reconstruction of the hydrological cycle at 1Km resolution Hourly for the last 7 years.

AI for Water Cycle

DATABASES

Satellite products



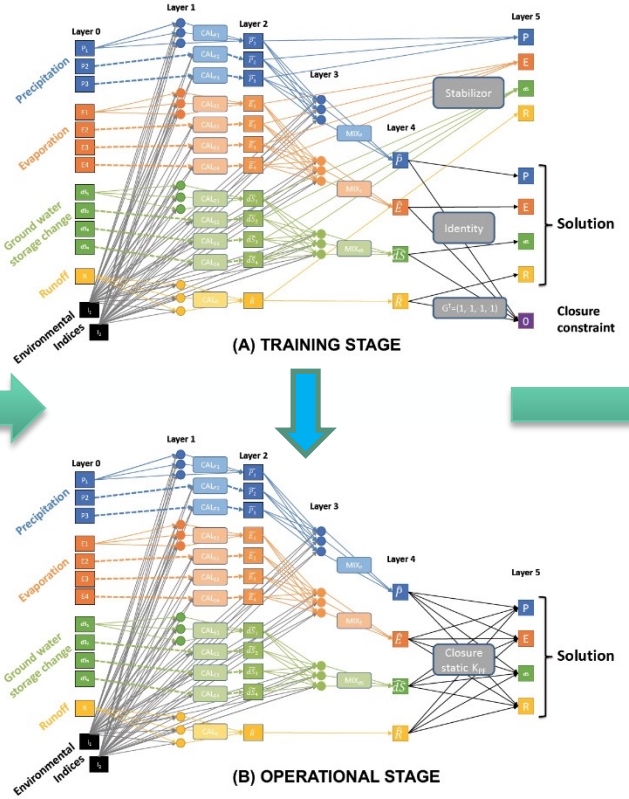


Over 2000 basins in the world

Water cycle budget closure over 2000 basins

Optimal Interpolation

TRAINING DATABASE

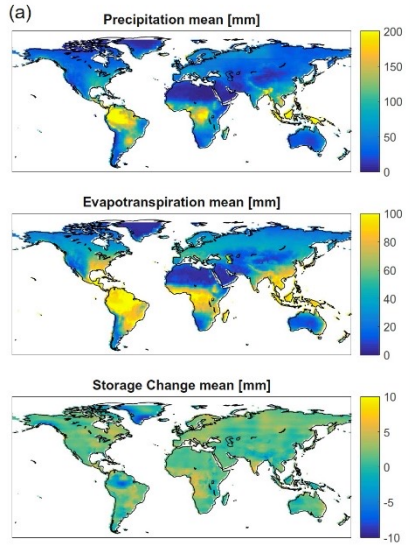


Physical constraints are included in the NN architecture

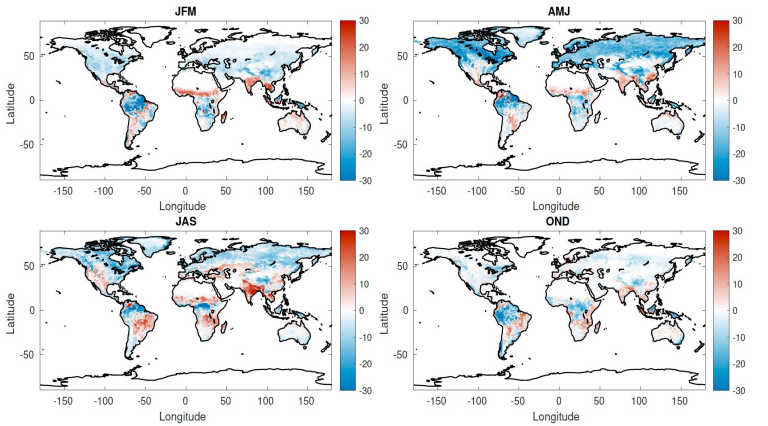
Aires et Pellet 2024
METHODOLOGY

NEURAL NETWORK

Refined water cycle monitoring
With uncertainty analysis



Heberger et al. 2024 (in rev.)
GLOBAL RESULTS



Hascoet et al. 2024
GLOBAL BIAS CORRECTION OF EVAPORATION

AI4Science -Extreme events

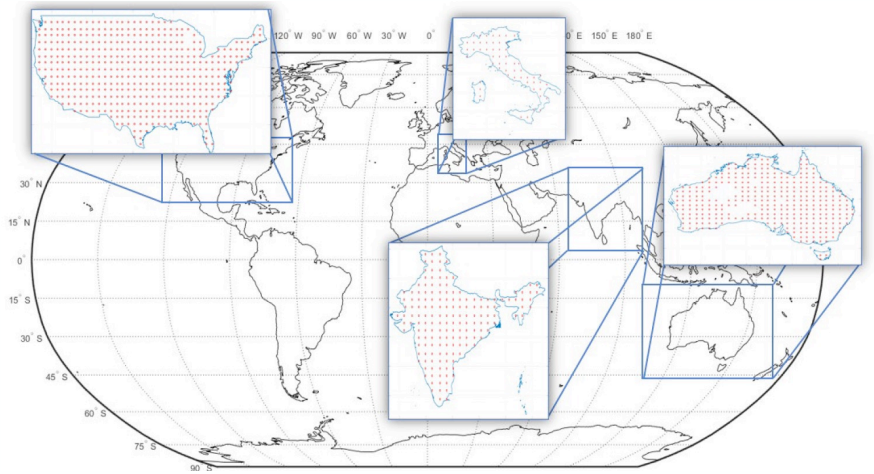
Objectives:

1. Advance understanding of extreme hydro-meteorological extremes
2. Develop new explainable AI Methods suitable for extreme events
3. Produce outcomes transferrable

3 Activities KO in 2022

extrAIM

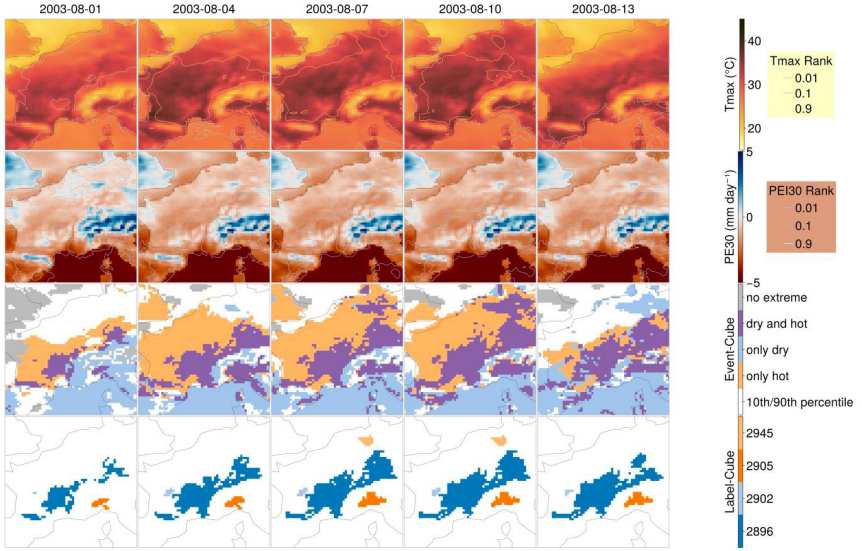
AI-enhanced uncertainty quantification of satellite-derived hydroclimatic extremes



merged precipitation products, developed by implementing the three ML algorithms in two different training strategies with uncertainties.

DeepExtremes

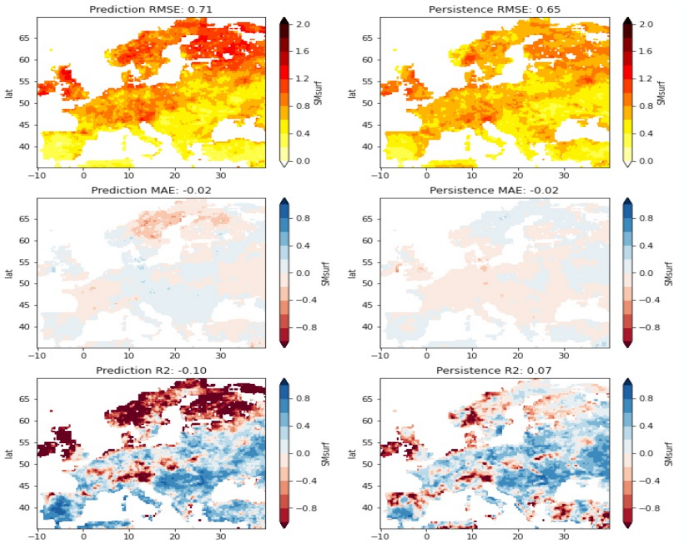
Explainable earth surface forecasting under Compound Climate Extremes



Produced global data cube of labelled dry and hot extreme events (1950-2022) with ancillary data

AI4Drought

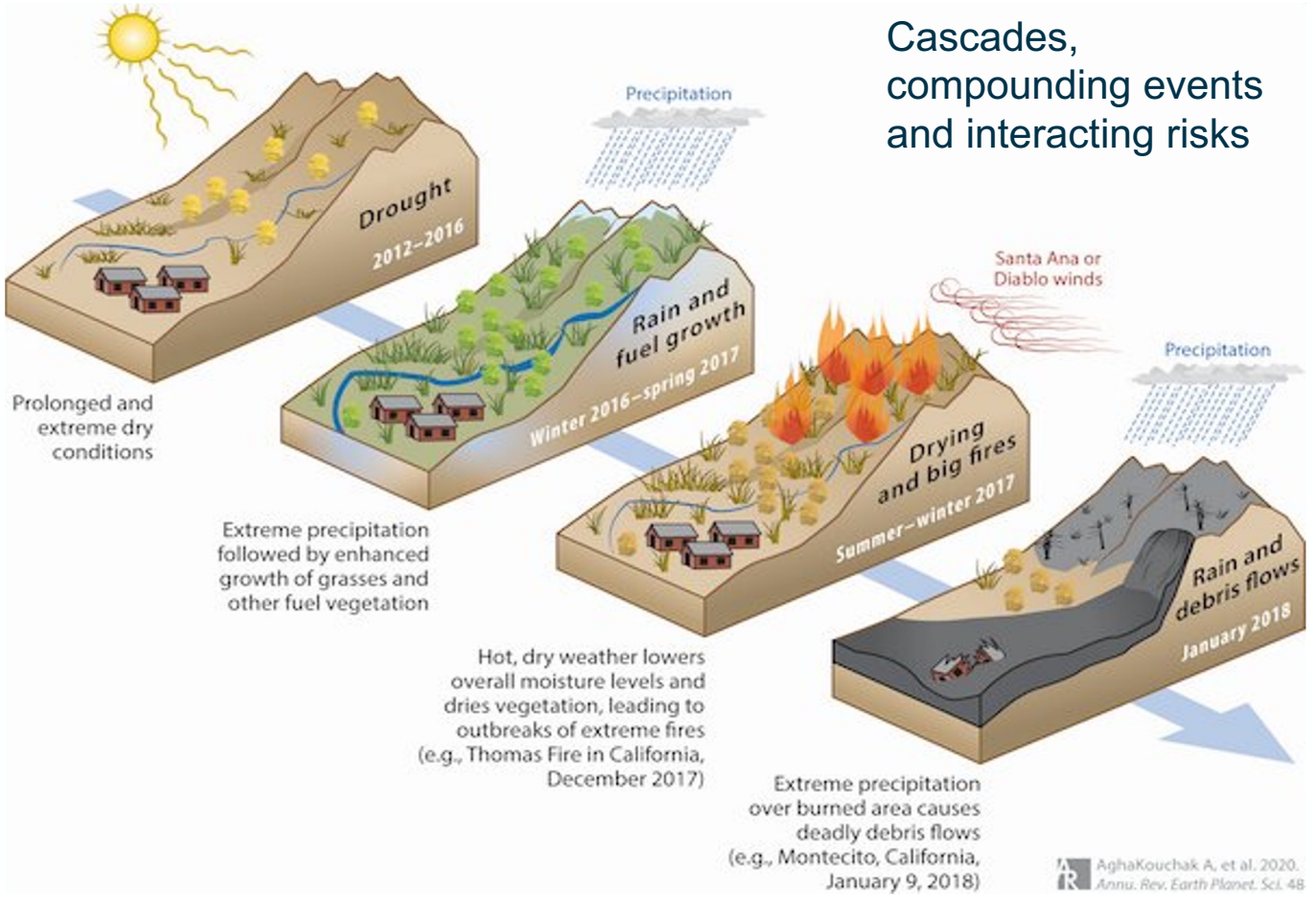
Explainable Artificial Intelligence for Droughts



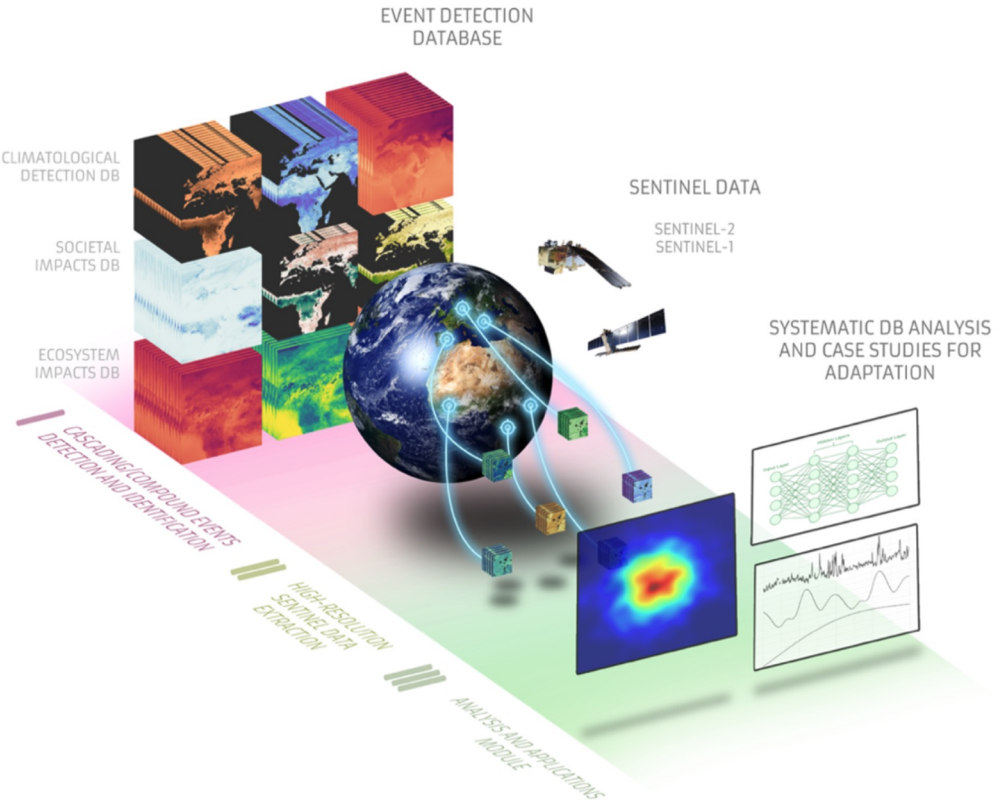
Seasonal drought prediction in Europe combining remote sensing and climate simulations with AI

FIXED CALL FOR PROPOSALS FOR CLIMATE ADAPTATION, EXTREMES, MULTI-HAZARDS AND GEO-HAZARDS SCIENCE

Adaptation and Resilience to Climate Extremes and Multi-hazard Events



Cascades, compounding events and interacting risks



develop an EO-based framework to assess the biophysical and socio-economic impacts of cascading multi-hazard extreme events from a variety of angles and scales

Next Earth Explorer Mission

esa

P-band synthetic aperture radar, the Biomass mission is designed to deliver crucial information about the state of our forests and how they are changing, and to further our knowledge of the role forests play in the carbon cycle.

Fluorescence Explorer will yield information about the health of the world's plants to improve our understanding of how carbon moves between plants and the atmosphere and how photosynthesis affects the carbon and water cycles.

FORUM's observations of the far-infrared will close the gap between the microwave and mid-infrared spectral range. For the first time the full spectral range in the Earth system is accessible through TOA observations.

Harmony involves two satellites in formation with Copernicus Sentinel-1 quantify the processes that govern the exchange of momentum, heat and moisture between the ocean surface and the air above driving weather patterns and climate.

EE12

EE11

harmony
SURFACE DYNAMICS

forum
THERMAL RADIATION

flex
PHOTOSYNTHESIS

biomass
FOREST CARBON

swarm
MAGNETIC FIELD

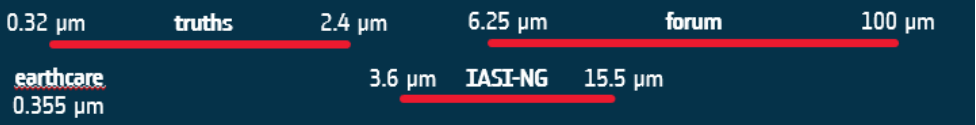
aeolus
WIND

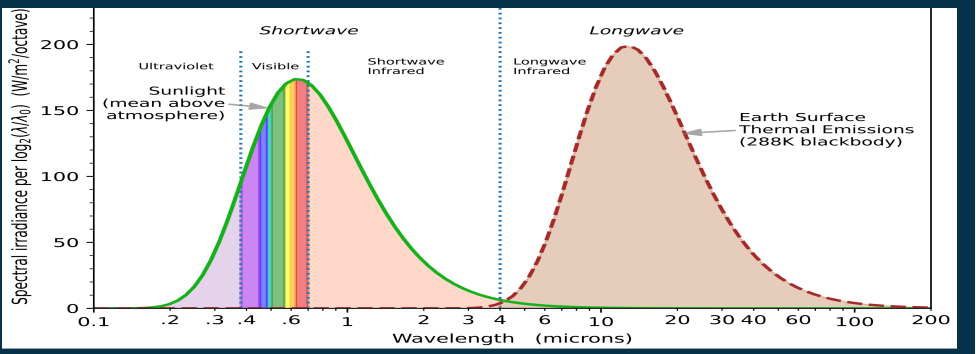
earthcare
CLOUD AND AEROSOL

FORUM

Earth Explorer 9 FORUM's observations of the far-infrared will close the gap between the microwave and mid-infrared spectral range.

With this, for the first time the full spectral range in the Earth system is accessible through top-of-atmosphere observations.





Selection of Earth Explorer 11 Candidate Mission

Cairt First limb-sounder with imaging Fourier-transform infrared technology in space short for changing-atmosphere infrared tomography – understanding the links between climate change, atmospheric chemistry and dynamics in the altitude range of about 5 to 115 km.
It would focus on the processes that couple atmospheric circulation, composition and regional climate change.

Wivern is short for wind velocity radar nephoscope – would provide the first measurements of wind within clouds and precipitation systems. It would also deliver profiles of rain, snow and ice water. Carrying a dual-polarisation, conically scanning, 94 GHz Doppler radar with an 800 km swath, the mission would improve forecasts of hazardous weather and provide new insights into severe storms.

harmony

aeolus
WIND

earthcare
CLOUD AND AEROSOL

biomass
FOREST CARBON

Selection of Earth Explorer 12 Mission Ideas to enter Phase 0

ECO:

measuring the difference between incoming solar radiation and outgoing earth's radiation

CryoRad:

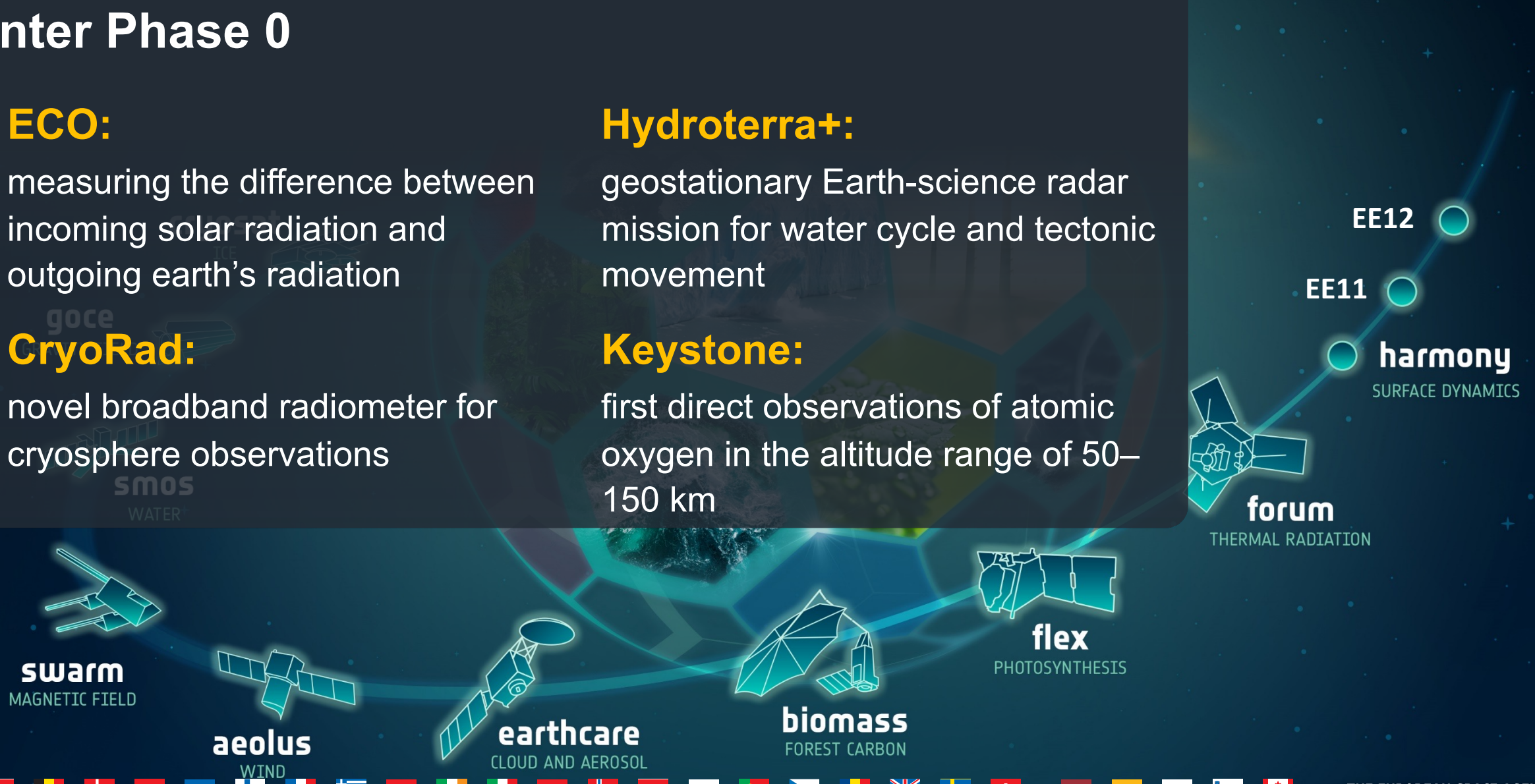
novel broadband radiometer for cryosphere observations

Hydroterra+:

geostationary Earth-science radar mission for water cycle and tectonic movement

Keystone:

first direct observations of atomic oxygen in the altitude range of 50–150 km



Mass-Change and Geosciences International Constellation

The Mass-Change and Geosciences International Constellation (MAGIC) is a planned National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) joint venture. The mission will consist of four satellites, operating in pairs, and will measure fluctuations in Earth's gravitational field, building upon the success of similar missions such as the Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission, the Gravity Recovery and Climate Experiment (GRACE) and its follow-on mission, GRACE-FO.

Opportunities:

Aiming at improved spatial resolution • Revealing finer scale aspects of the natural and human-influenced water cycle • Better separation of comingled signals (e.g., snowy mountain adjacent to dry plains) • Water budget closure over smaller river basins

Improved temporal resolution • More accurate water budget closure • Data more useful for operational applications…

Longer data record • Distinguishing climate change impacts on TWS from natural variations • Testing the theory that global warming increases the intensity of droughts and rainfall…

The new ESA Earth System Science Hub

A new science facility in ESRIN to boost the scientific output of ESA and its MSs through networking and partnerships, offering ESA as a hub for scientific cooperation, exchange of ideas and promoting a community response to major science challenges

Come to visit and work with us us in ESA ESRIN center