Water Management:

Challenges and Capabilities for Evolution of the Copernicus Space Component

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Some of the Many Water Challenges

- Inland/ Coastal/Ocean Water quality Monitoring
- Pollution/Wastewater management
- Eutrophication/Harmful Algal Blooms (HABs)
- Invasive Species/Biodiversity
- Waterborne diseases

- Ground Water recharge/abstraction and quality management
- Irrigation Management
- Flood Risk Management

- Climate change challenges: water availability (droughts)
- Extreme Events/Emergency response (Flooding)

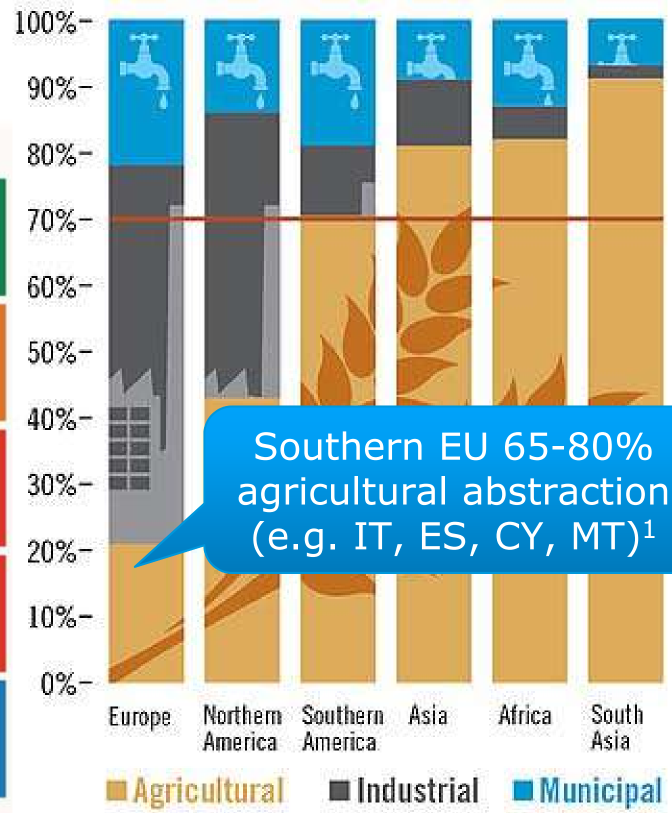
Global Risk: Water Supply

Top 5 Global risks in terms of impact

WEF Global Risk Report 2016

WORLD ECONOMIC FORUM

2012	2013	2014	2015	2016
Major systemic financial failure	Major systemic financial failure	Fiscal crises	Water crises	Failure of climate-change mitigation and adaptation
Water supply crises	Water supply crises	Climate change	Rapid and massive spread of infectious diseases	Weapons of mass destruction
Food shortage crises	Chronic fiscal imbalances	Water crises	Weapons of mass destruction	Water crises
Chronic fiscal imbalances	Diffusion of weapons of mass destruction	Unemployment and underemployment	Interstate conflict with regional consequences	Large-scale involuntary migration
Extreme volatility in energy and agriculture prices	Failure of climate-change mitigation and adaptation	Critical information infrastructure breakdown	Failure of climate-change mitigation and adaptation	Severe energy price shock



Southern EU 65-80% agricultural abstraction (e.g. IT, ES, CY, MT)[1]

[1]Agriculture & Sustainable Water Management in the EU, EC 2017

Some EU policies and Conventions in relation to Water Management and Wetlands

- EU Water Framework Directive (WFD)
  - Water over-abstraction – WFD requires controls of abstraction
  - WFD requires water pricing for services such as irrigation
- EU Marine Strategy Framework Directive (MSFD)
  - Sustainable management of natural marine and coastal resources
  - Protection of marine biodiversity
  - N.E. Atlantic (OSPAR), Baltic (HELCOM), Black Sea, Mediterranean (Barcelona)
- UN Sustainable Development Goals
  - SDG 6 - Ensure availability and sustainable management of water and sanitation for all
  - SDG 14 - Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- UNFCCC / UNCCD – climate change resilience
  - Managing water scarcity
  - Adaptation/Sustainable water management practices
- RAMSAR
  - Conservation of Wetlands Biodiversity Conservation

Assets / Capabilities

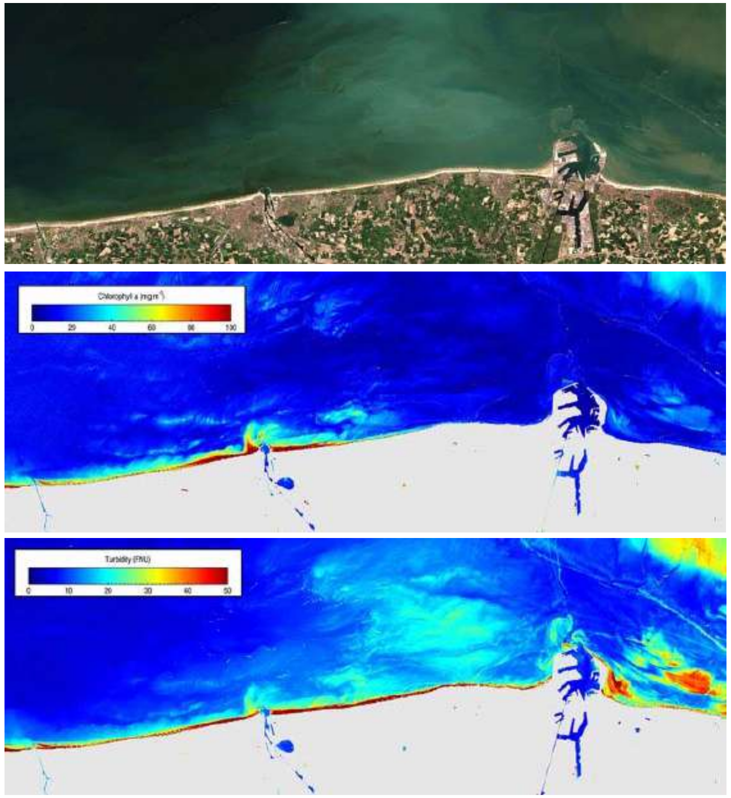
- Optical sensors (at varying spatial/spectral resolution and sampling)
  - Sentinel-2 MSI
  - Sentinel-3 OLCI / SLSTR
- All weather imaging sensors (at varying spatial res./temporal sampling and frequency)
  - Passive Microwave Radiometer
  - SAR (Sentinel-1)
  - Scatterometers (see EUM presentation)
- Geodetic / Metrological sensors
  - Altimetry (S-3, CryoSat, S-6)
  - InSAR
  - Gravimetry

Copernicus Sentinels

	**Sentinel 1** (A/B/C/D) **SAR Imaging**	All weather, day/night applications, interferometry
	**Sentinel 2** (A/B/C/D) **Multispectral Imaging**	Land applications: urban, forest, agriculture, … Continuity of Landsat, SPOT
	**Sentinel 3** (A/B/C/D) **Ocean & Global Land Monitoring**	Wide-swath ocean colour, vegetation, sea/land surface temperature, altimetry
	**Sentinel 4** (A/B) **Geostationary Atmospheric**	Atmospheric composition monitoring, pollution; instrument on MTG satellites
	**Sentinel 5** (A/B/C) & Precursor **Low-Orbit Atmospheric**	Atmospheric composition monitoring; instrument on MetOp-SG satellites
	**Sentinel 6 / Jason-CS** (A/B) **Radar Altimeter**	Ocean Altimetry reference mission

Sentinel-2 and -3: Coastal Water Quality

- Sentinel-2 (13 bands; 10-60m SSD) 6d revisit products complement Sentinel-3 (21 bands 300m SSD) 2d revisit products, capturing near-shore plankton blooms (harmful or non-harmful) at higher spatial res.
- Example shows Chl and Turbidity (clarity) during a near-shore non-toxic algal bloom (*phaeocystis globosa*) close to Ostend, BE
- Sentinel data allow coastal water quality measurements to complement ship-based or in-situ measurements
- Algal bloom monitoring relevant to fishermen, aquaculture and public health officials
- Enables routine monitoring to meet requirements of European Commission's Water Framework and Marine Strategy Framework Directives.

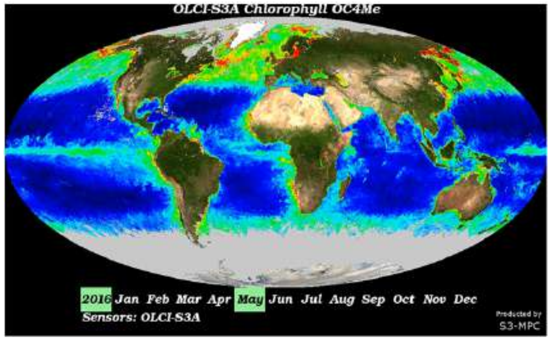


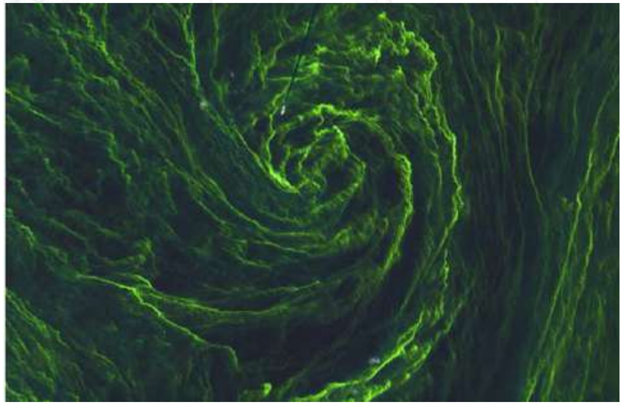
contains modified Copernicus Sentinel-2A data (2016), processed by RBINS

Sentinel-2/-3 Harmful Algal Blooms & Anoxia/Hypoxia

- Severe Baltic environmental problems led to HELCOM (1974): Helsinki Convention for the Protection of the Marine Environment of the Baltic Sea Area
- The loads of many polluting substances, toxins and nutrients since reduced, but legacy pollution slows recovery
- Deep-water anoxia/hypoxia and cyanobacterial blooms remain extensive, and climate change threatens the advances made

- Potential for Ecosystem-based management, based on use of satellite data from Copernicus Sentinel-2 and -3 in conjunction with other satellites.





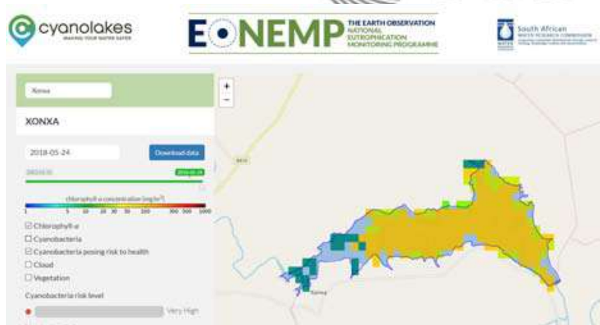
Sentinels: Lake Water Quality

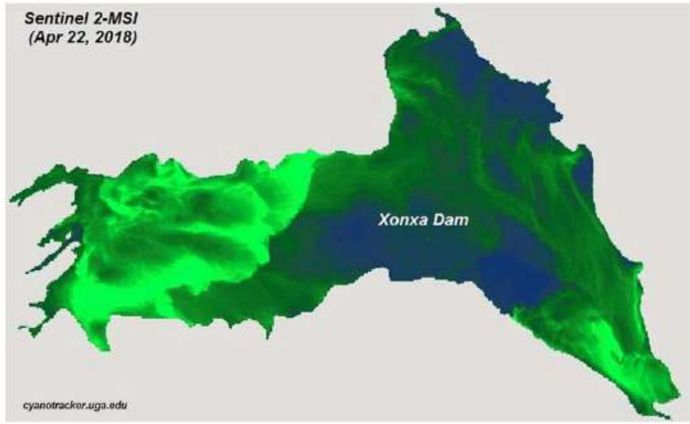
Toxic blue-green algae blooms in lakes (cyanobacteria)

Influenced by:

- Eutrophication
- Warm temperatures
- farming practices: fertilizers/nutrients in runoff water
- Wastewater treatment plant discharge (nitrogen/phosphorus) / effluent

- Sentinel-2 and -3 data used in a variety of lake monitoring apps and services
- http://www.cyanolakes.com/realtime/
- http://cyanotracker.uga.edu/satellite-images-2/





Spatio-temporal variability of bloom pattern in Xonxa Dam, South Africa using recent #Sentinel2 scenes

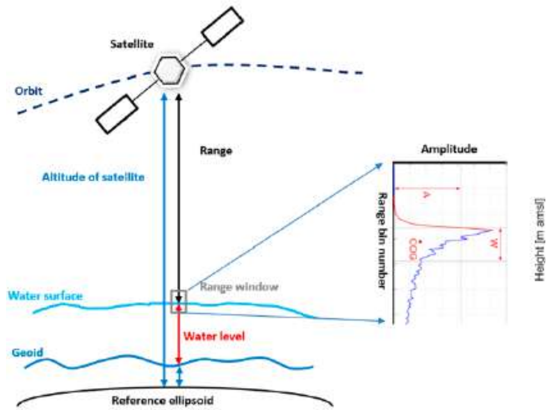
Sentinel- river and lake level monitoring

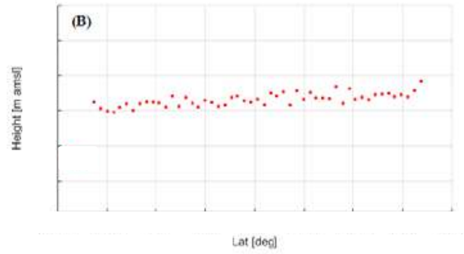
Water Level in lakes recognised as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS)

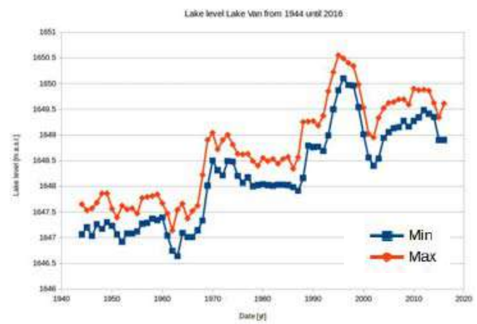
- Water Level measured in height (m) above the geoid
- Measurements accurate to cm with radar altimeters
- Main limitation: only water bodies located along the satellite's ground tracks can be monitored (quality of measurement dependent on surrounding topography/vegetation)

Water Level is computed as time series:

- over lakes
- over rivers, at the intersections of the river network with the satellite ground tracks



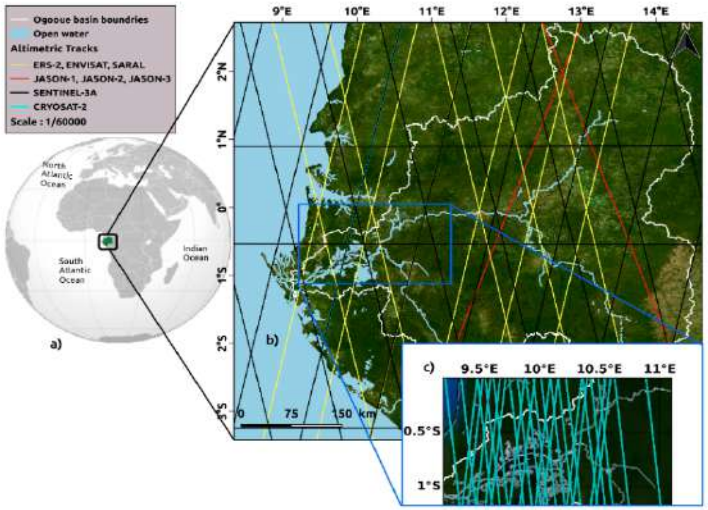


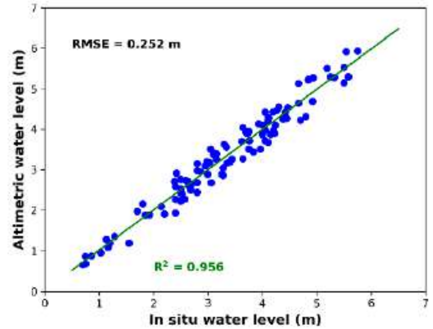


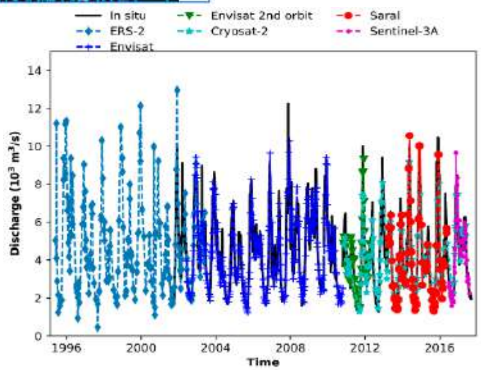
River monitoring

Current altimetry data can be used for virtual river gauging stations – at points where altimeter orbits cross the river

- SAR data from S-1 beneficial to develop a river mask to filter outliers; otherwise classification of waveforms needed
- Use of S-3 (SRAL) in conjunction with Jason; CryoSat (SIRAL); SARAL(AltiKa); HY-2A
- Root mean square error (RMSE) between 30 - 5 cm using special data handling strategies
- Data integrated into hydrologic models for water level and discharge measurements



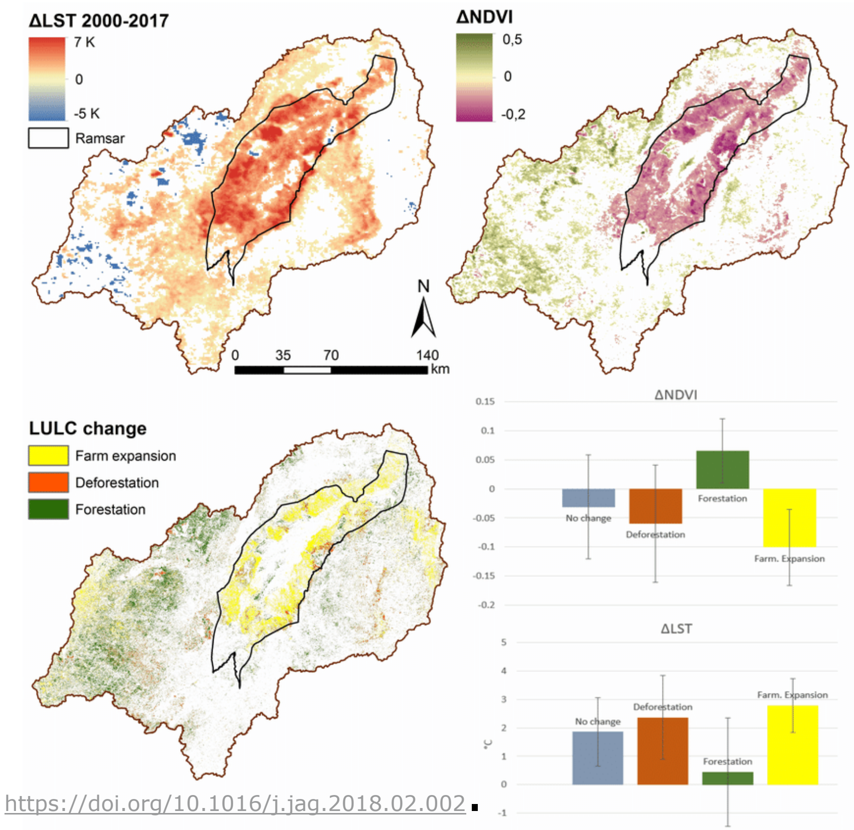




See: Bogning et al (2018), https://doi.org/10.3390/rs10020350

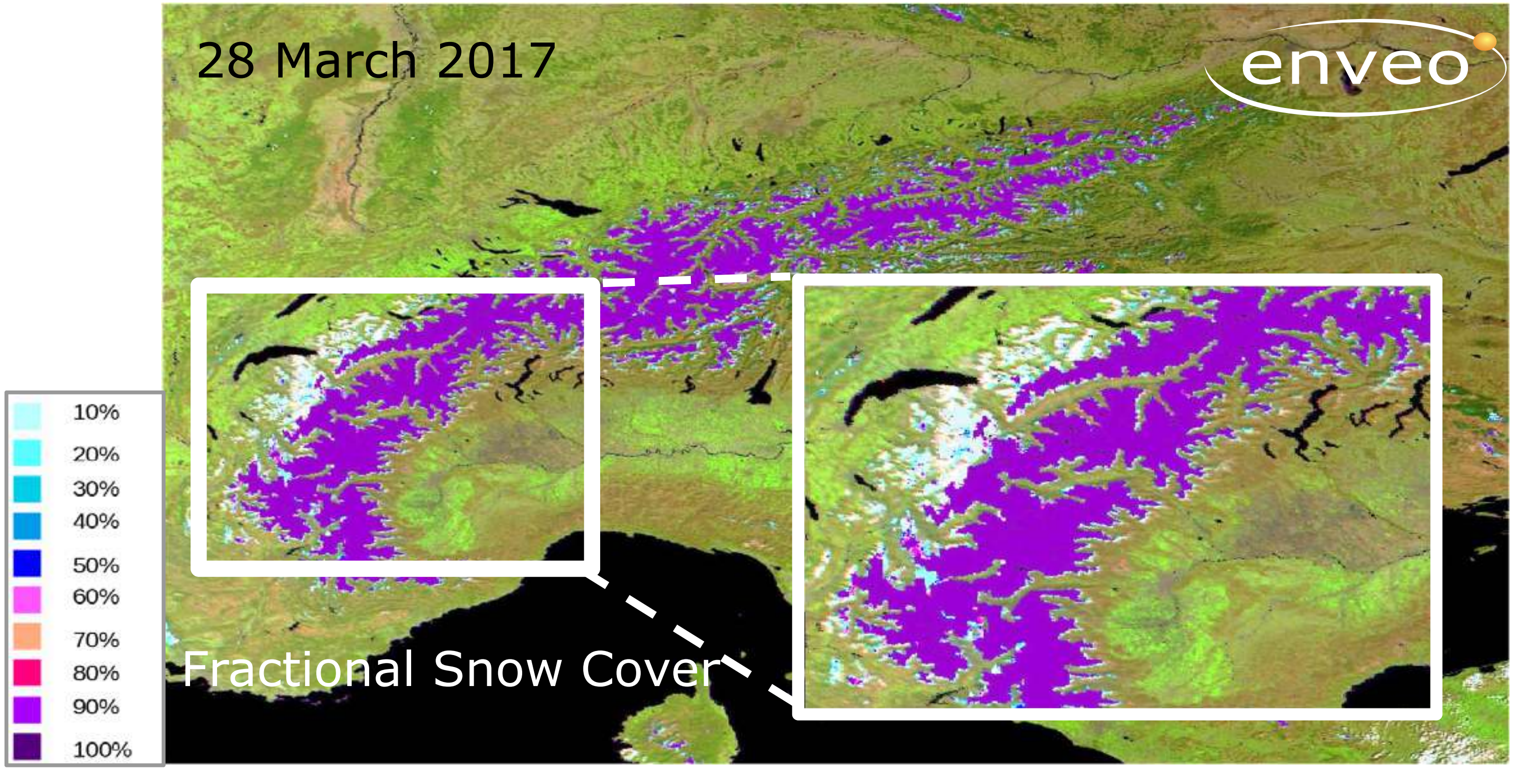
RAMSAR – Wetlands Conservation

- Kilombero catchment wetland region in Tanzania
- Satellite Based Wetlands Observation Service (SWOS) – example showing use of Optical Multispectral and LST observations
- Agricultural expansion on wetlands changes water/energy fluxes and increases LST
- Variation of LST and NDVI in Kilombero for the period 2000-2017 to chart LULC change map.
- ΔLST and ΔNDVI are grouped into the LULC change classes in the lower right charts.
- Wetland experiencing major land conversions to agriculture during the last two decades



Muro et al (2018) https://doi.org/10.1016/j.jag.2018.02.002

Fractional Snow Cover - Sentinel-3 SLSTR



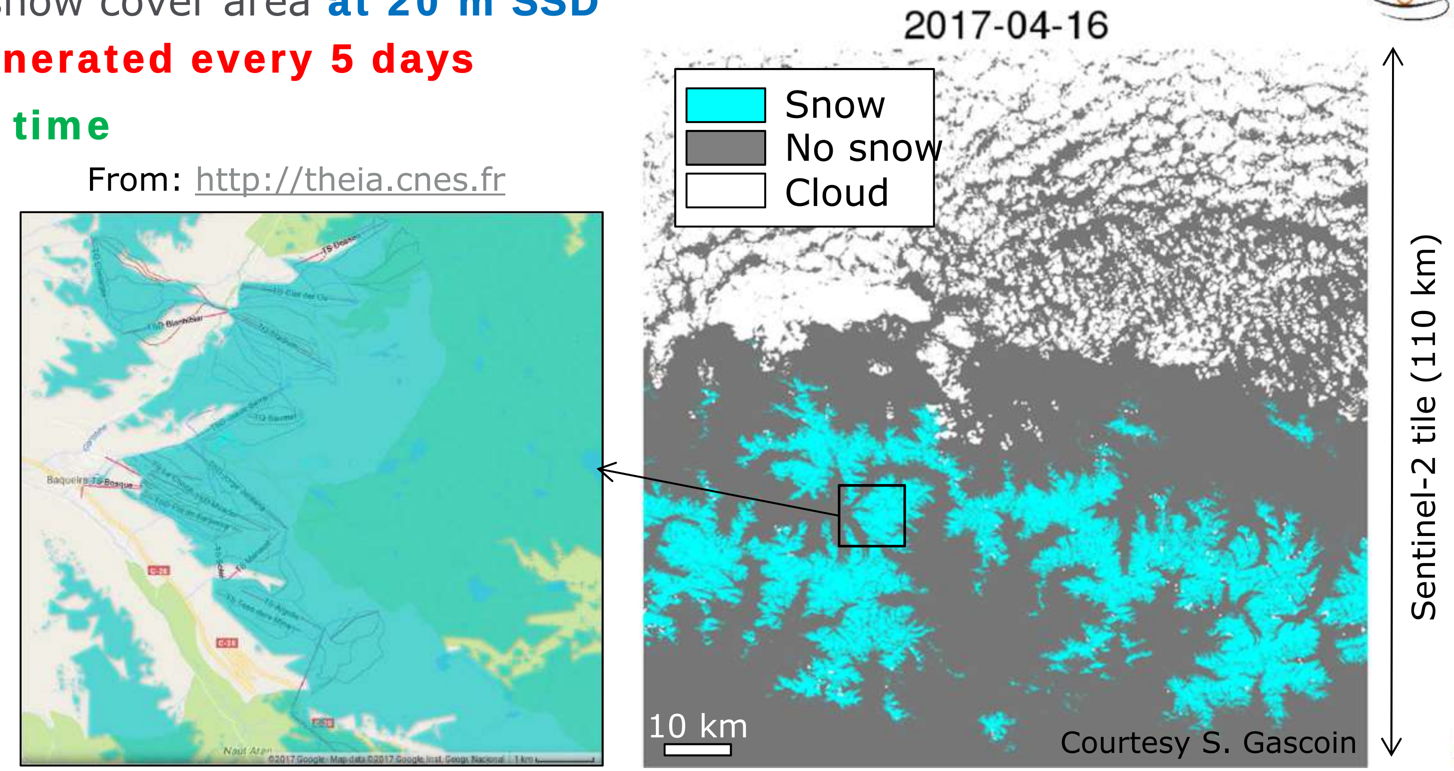
Theia Alpine Snow Product: Sentinel-2

Maps of the snow cover area **at 20 m SSD**

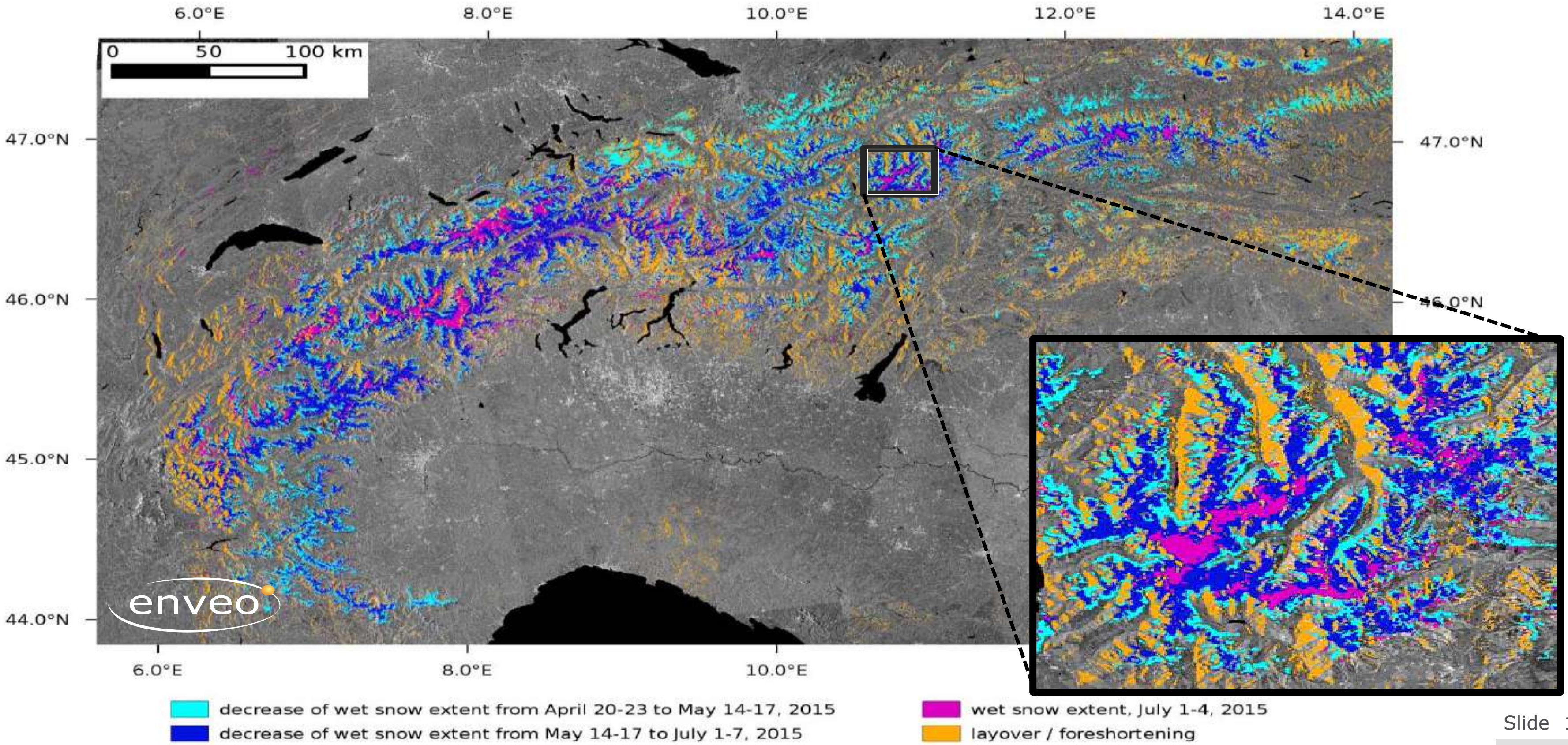
Products generated every 5 days

in near-real time

From: http://theia.cnes.fr

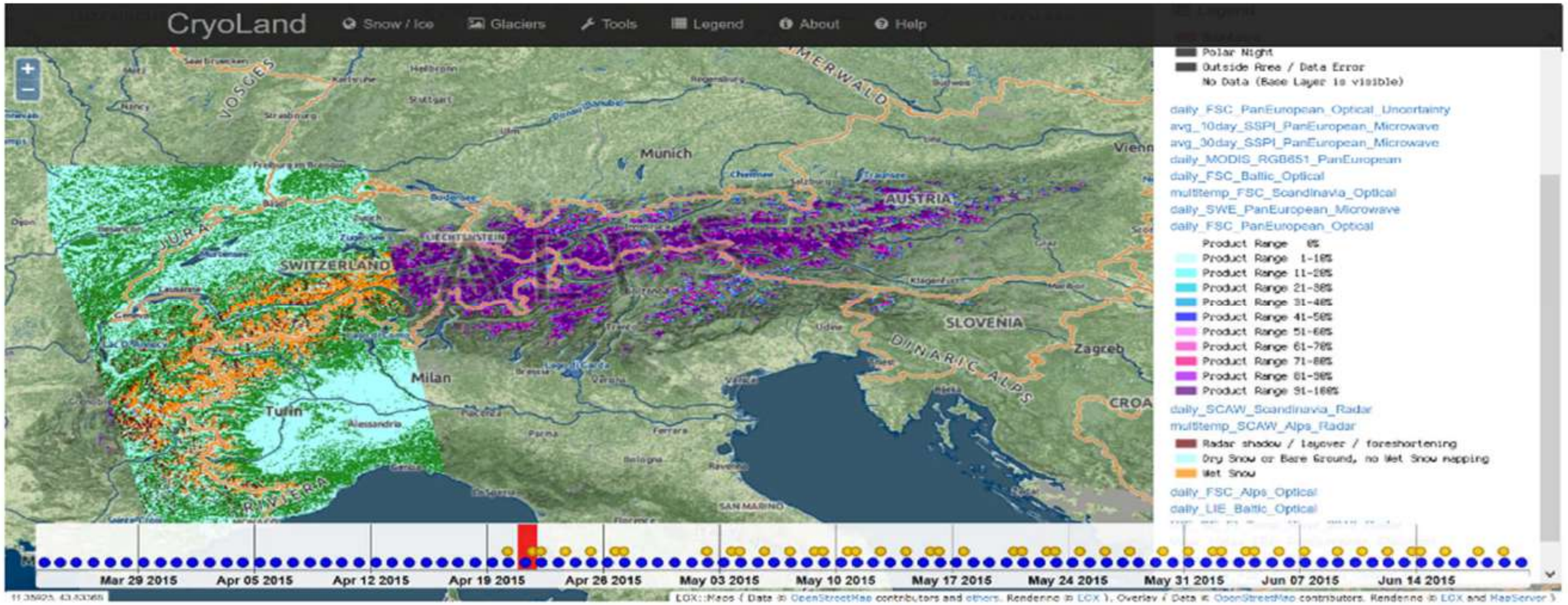


Mountain Wet Snow Maps - Sentinel-1



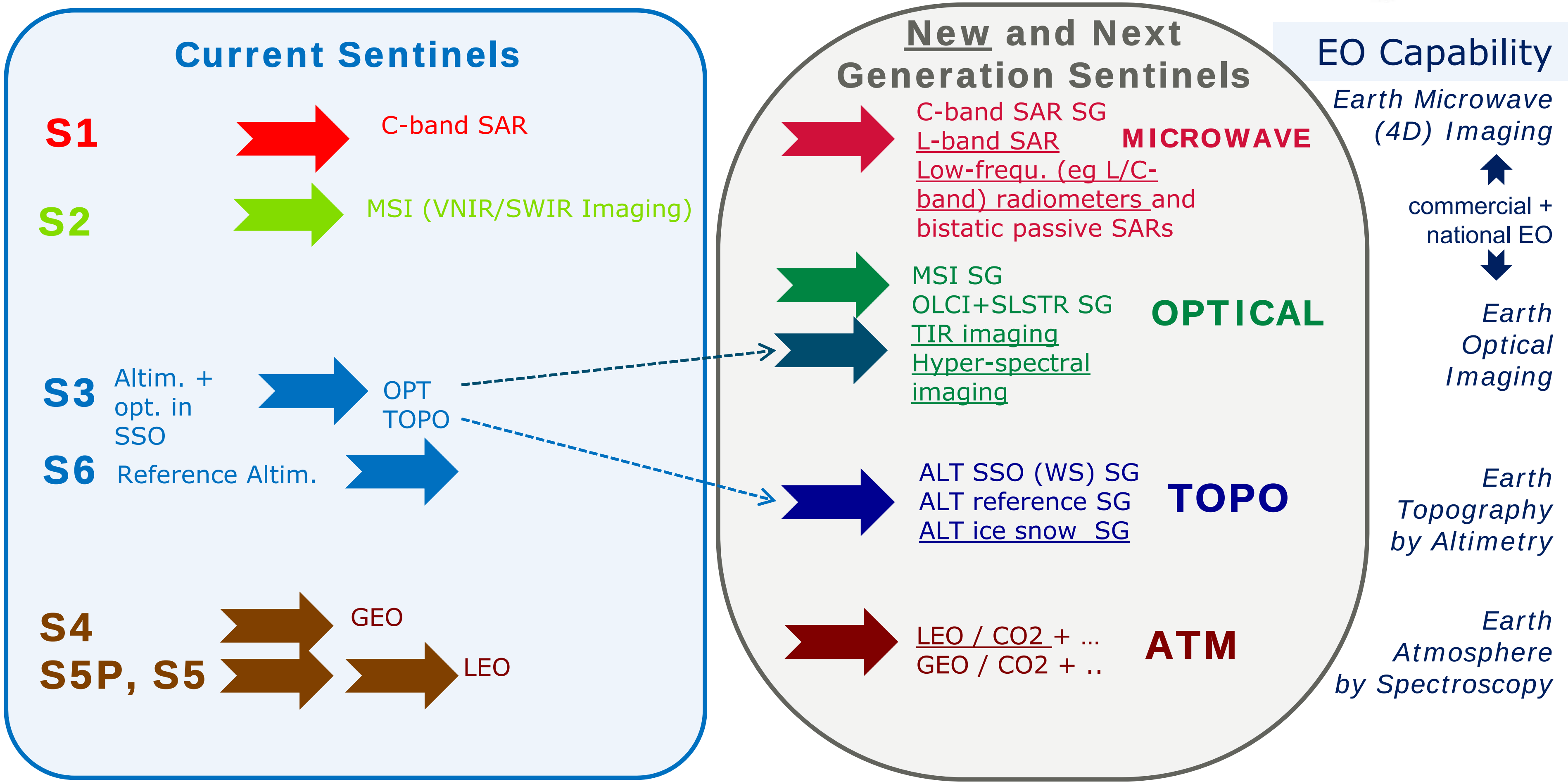
Combined Snow Extent and Snow Melt Maps

Advanced product providing Fractional Snow Extent and Snow Conditions (dry/wet)



http://cryoportal.enveo.at/

Copernicus Space Component Evolution



CSC Evolution

High Priority Candidate Missions	**Applications** (*incl. Water relevant)
Anthropogenic CO_2	Monitoring Anthropogenic Emissions – Paris Agreement
High Spatial/Temporal Res. Land Surface Temperature	Agricultural productivity and Water Resource Management
Polar Ice & Snow Topography	Land & Sea Ice Thickness Change (others incl. sea, river and lake water level)
Passive Microwave Imaging	Sea Ice Concentration and Sea Surf Temp. (others incl. soil moisture and SWE)
Hyperspectral Imaging	Agriculture/food security, forestry, raw materials, soil properties and biodiversity (others incl. water quality)
L-band SAR	Forestry, Natural Hazards, Crop type & Precision Farming, Sea ice type (others incl. soil moisture and InSAR water extraction)

Copernicus Candidate Mission: High spatio-temporal resolution LST Monitoring (LSTM)

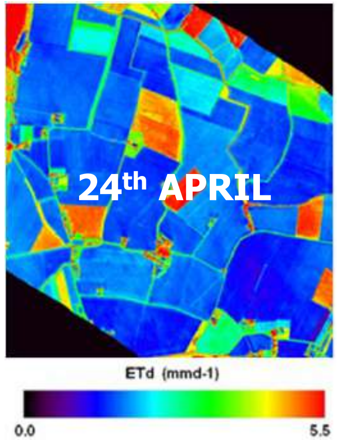
Mission Objective:

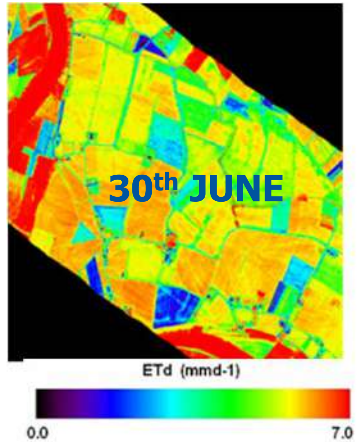
- To complement Sentinel observation capabilities with high spatio-temporal resolution Thermal Infra-Red observations over land and coastal regions ***in support of agriculture management services***, and possibly a range of additional applications and services
- Addressing policies related to water and food security – EU Water Framework EU Directive, Common Agriculture Policy, UN SDGs, UNFCCC, UNCCD
- User requirements: timely management information at field scale for irrigation, water abstraction, water pollution, land degradation

Primary mission requirements:

- Land surface temperature and emissivity at 30-50 m, daily (goal), 3-5 TIR bands & minimum VNIR/SWIR

Synergies: Potential cross calibration/validation activities with Landsat, Sentinel-3, Trishna, preparation studies as part of Ecostress





Copernicus Expansion Candidate: Imaging Microwave Radiometer

Mission Objective

Responds directly to the ***Integrated EU Arctic Policy***

- Climate Change and Safeguarding the Arctic
- Environment Sustainable Development in and around the Arctic
- International Cooperation on Arctic Issues

Characteristics

- Single satellite with conical-scan Multi-frequency Microwave radiometer
- Loose convoy flight with MetOp-SG(B) to exploit synergy with MWI etc.
- 99% global coverage every day

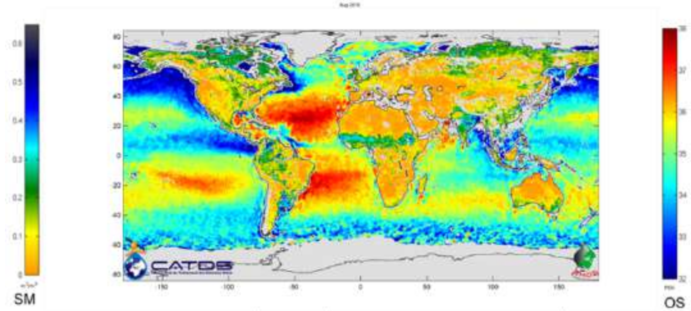
Channels (GHz):	1.4,	6.9,	10.65,	18.7	36.5
Resolution (km):	50	10	≤10	≤5	≤5

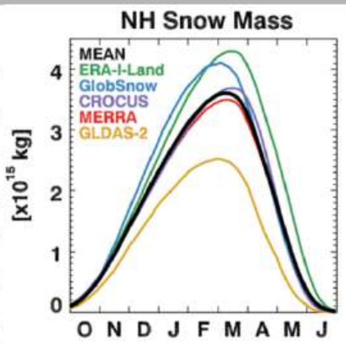
In addition:

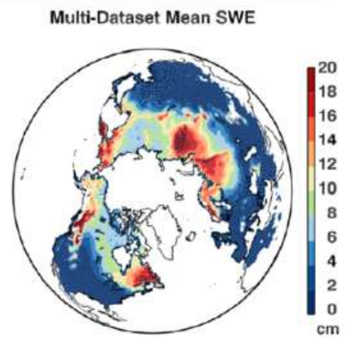
- Sustains AMSR-2 & SMOS/SMAP type capability
- Prevents gap in MW capability @~7GHz
- Integrate and enhance value of Sentinel-1, -2, -3, and MetOp-SG by providing downscaling and enhanced retrievals of:
  - o surface/ root zone soil moisture
  - o Snow Water Equivalent (continental scale)
  - o Soil freeze/thaw

Primary Products

Sea Ice Concentration Sea Surface
Temperature Thin Sea Ice
Thickness Sea Ice Drift
Ice Type
Sea Surface Salinity
Extreme Wind



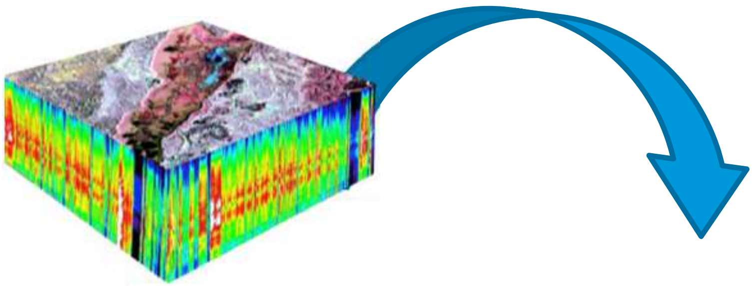


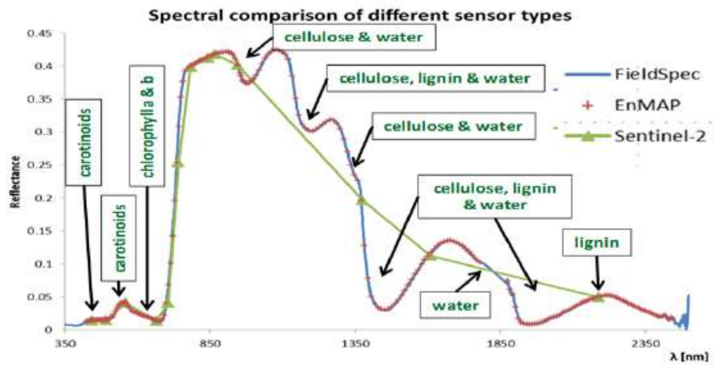


Copernicus Expansion Candidate: Hyperspectral Imaging Mission

Objective: products in support of EU and related policies for the management of natural resources, assets and benefits. This visible-to-shortwave infrared spectroscopy observational capability will support new and enhanced services for **food security**, **agriculture** and **raw materials.** This includes sustainable agricultural and biodiversity management, soil properties characterization, sustainable mining practices and environment preservation

- **Spectral coverage**: Contiguous spectral coverage between 400 and 2500 nm
- **Spectral sampling**: ≤ 10 nm at FWHM
- **Spatial resolution**: 20 m – 30 m
- **Temporal resolution**: Geometric Repeat observations needed every 10 days max





Copernicus Expansion Candidate: L-band SAR

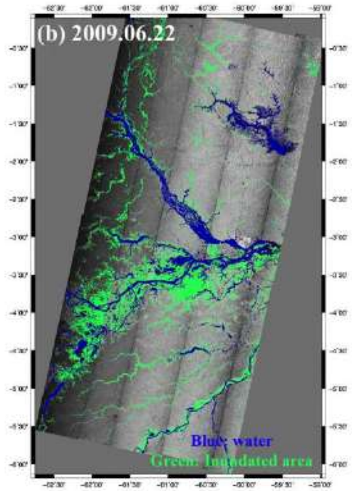
Responds to EC policies and Copernicus service needs:

Fill measurement gaps from existing Sentinels, leveraging unique all-weather information provided at L-band:

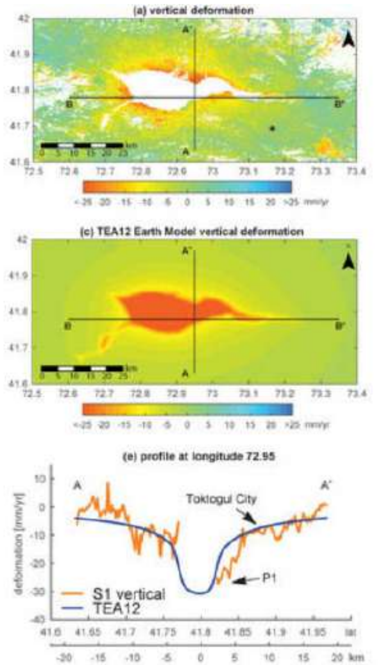
- High resolution soil moisture information
- Improved InSAR coherence beneath vegetation canopies
- Improved classification and change detection in tropical regions
- Inundation/flooding
- Sub-surface moisture in arid zones

Enhanced continuity of current Copernicus SAR observations e.g improved accuracy, product quality, resolution

- Greatly enhanced information of different parameters (in combination with other frequency radar missions e.g. Sentinel-1, Cosmo-Skymed)



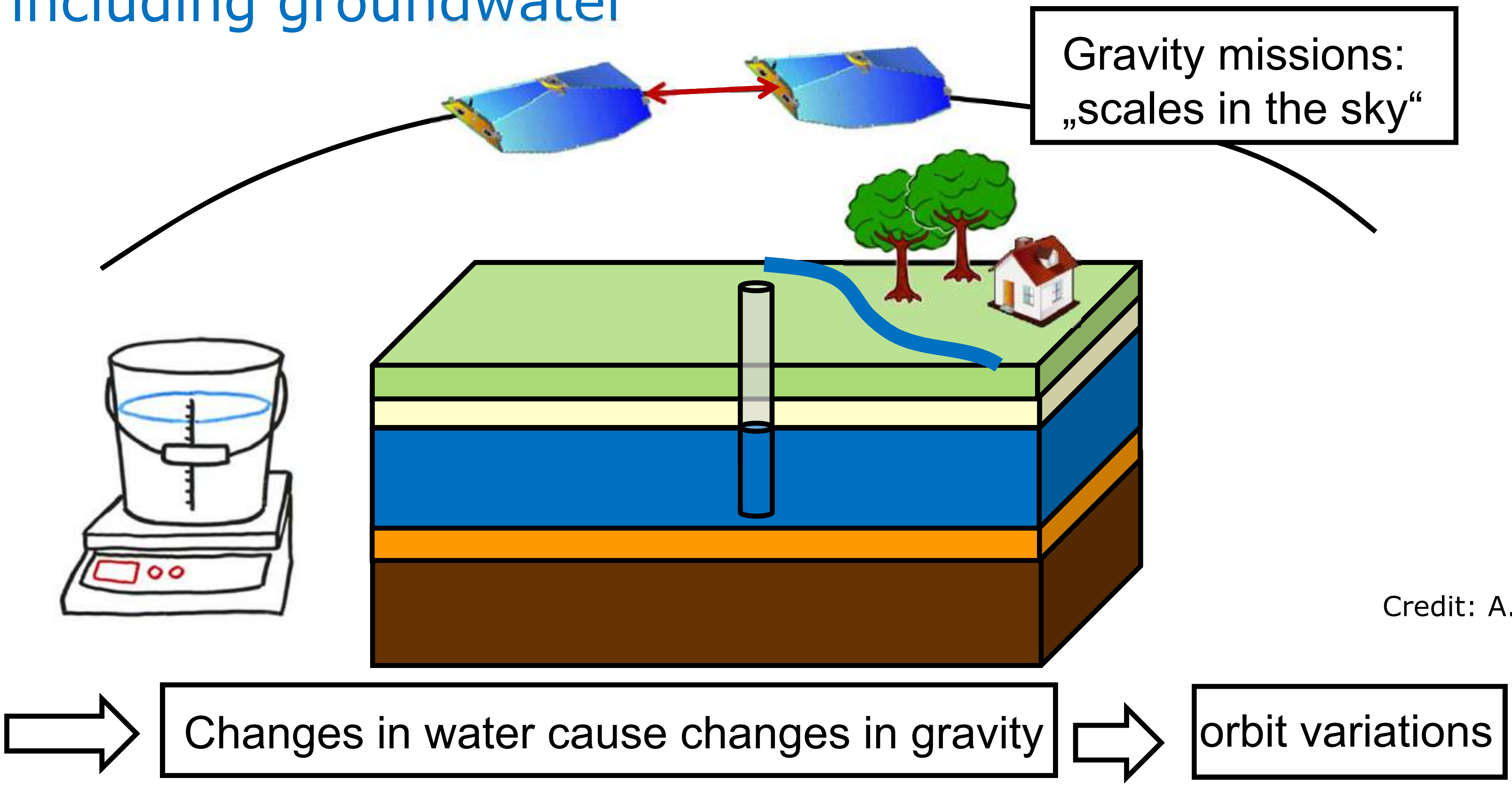
Inundation in dense Vegetation using PALSAR



InSAR Ground deformation From aquifer pumping

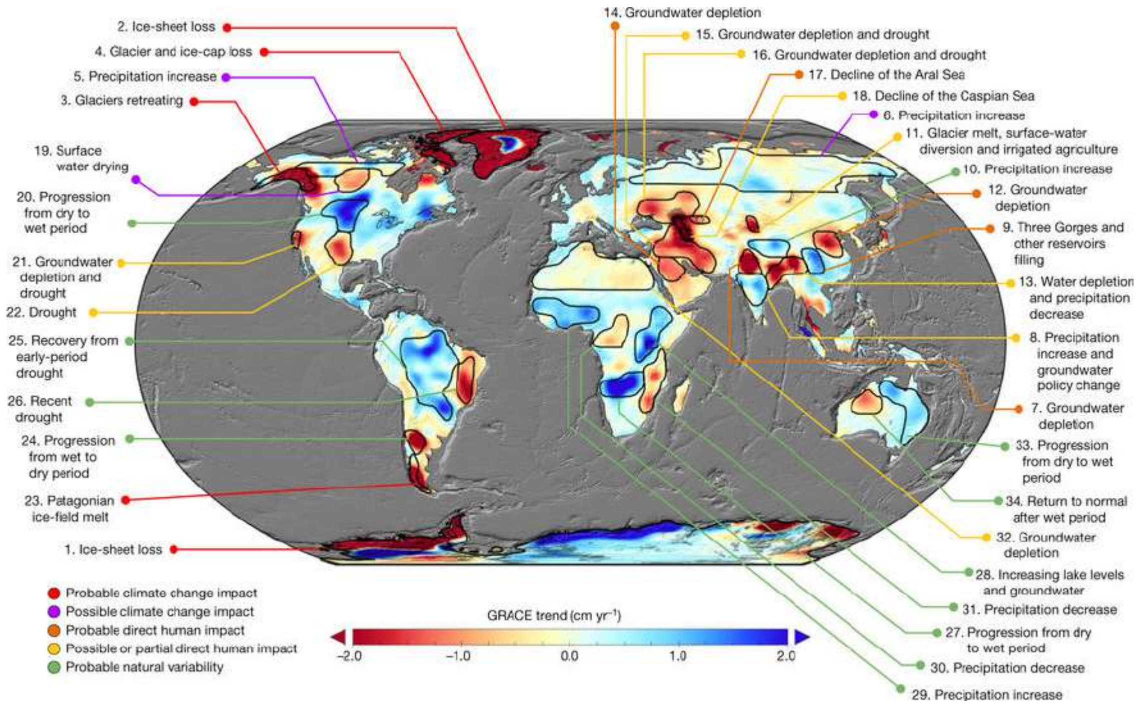
Temporal variations in Soil moisture & Crop type

Future Gravity: Water cycle observations including groundwater



Credit: A. Eicker

GRACE: weighing up trends in global freshwater availability



GRACE derived trends in terrestrial water storage (after Rodell et al, 2018)

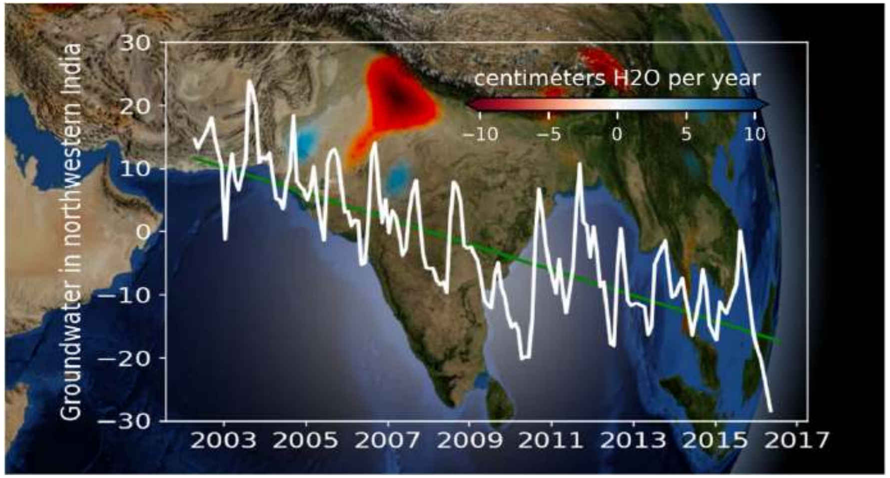
- World's water landscape is responding to human impacts and climate variations
- Gravity Recovery and Climate Experiment (GRACE) collected gravimetric data from 2002–2016 to accurately detect time-varying mass anomalies
- Data enable monitoring of seasonal to inter-annual variability and trends in changes in freshwater availability
- Highlights locations of unsustainable groundwater consumption, climate change or combinations of both
- Continued GRACE-FO data fundamental to evaluating and predicting emerging threats to water availability

Gravity: Groundwater observation for water use and drought

Irrigation

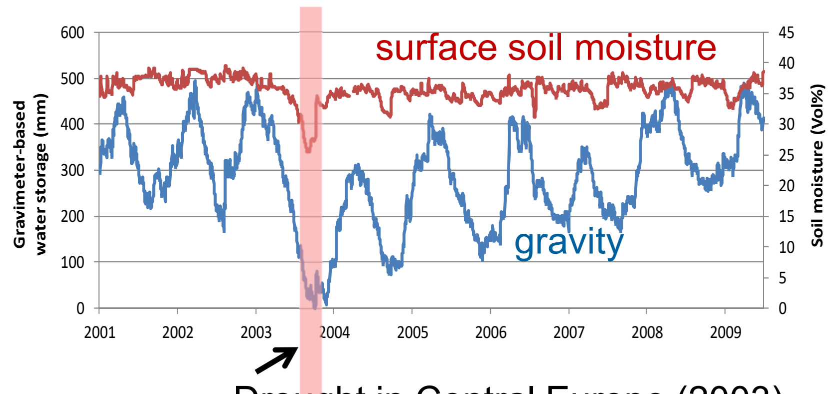
+

Groundwater extraction



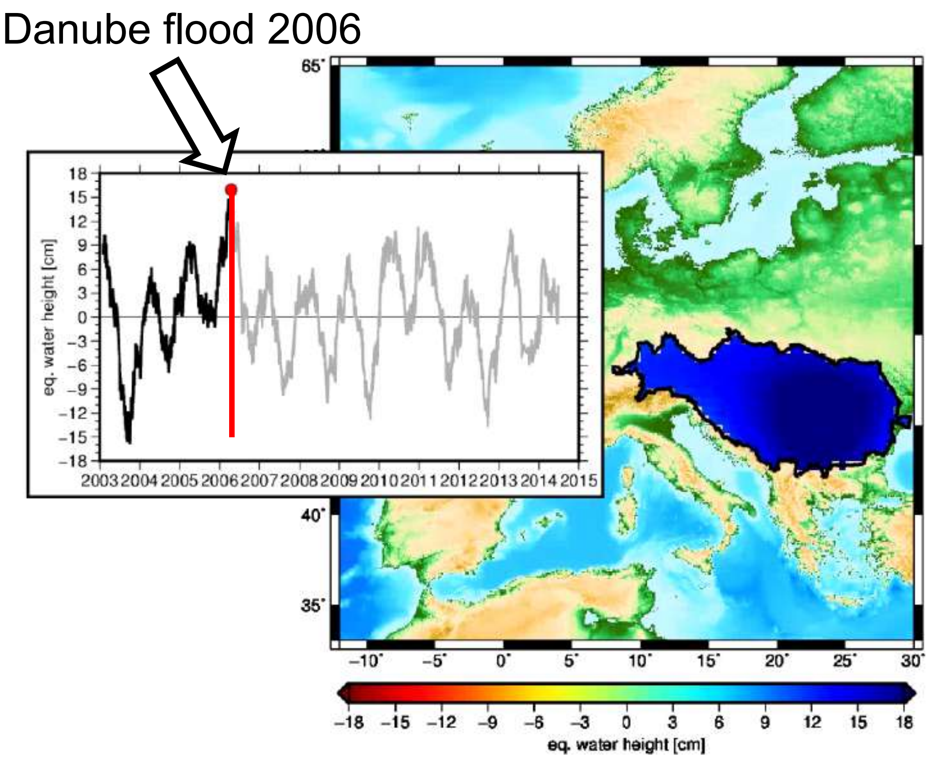
Over exploitation of groundwater resources

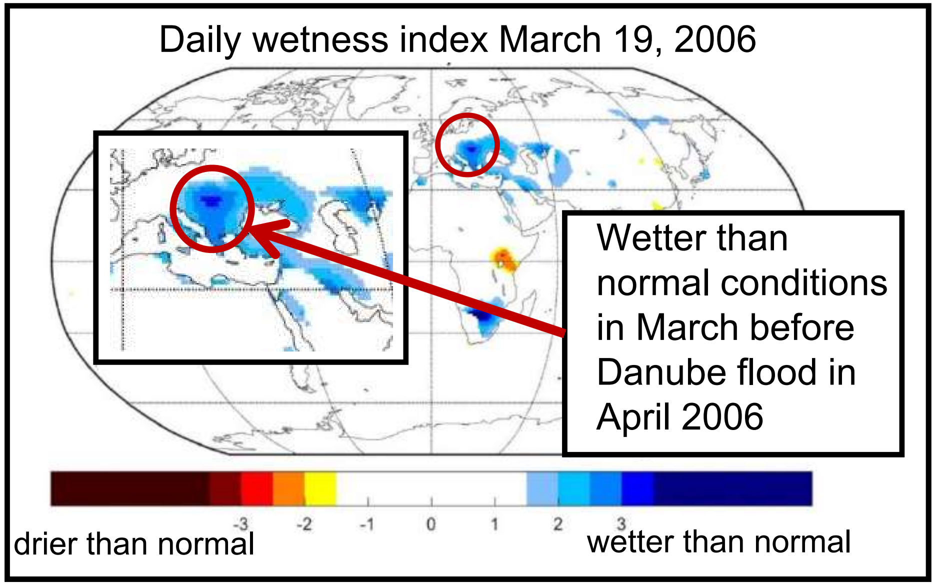
Water storage in Wettzell (Germany)



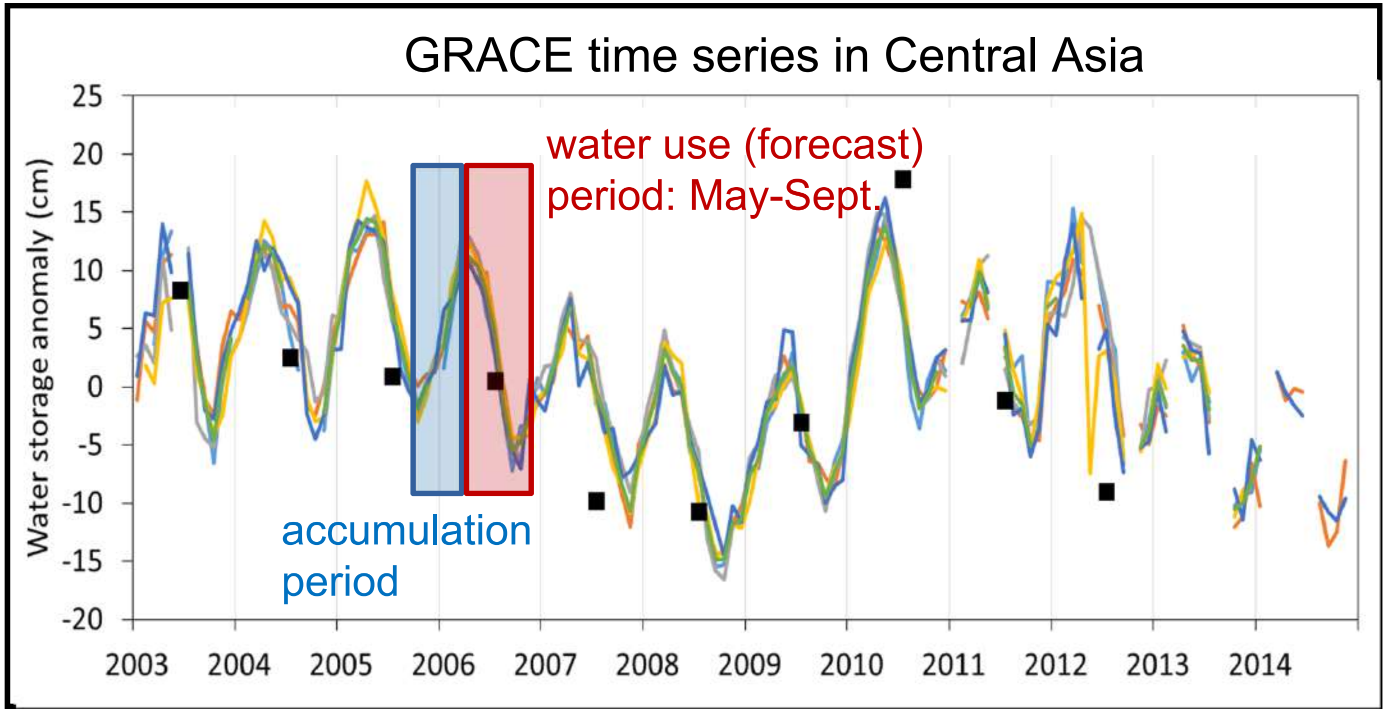
Slow recovery of water storage after 2003

Gravity: for early warning of flood risk?



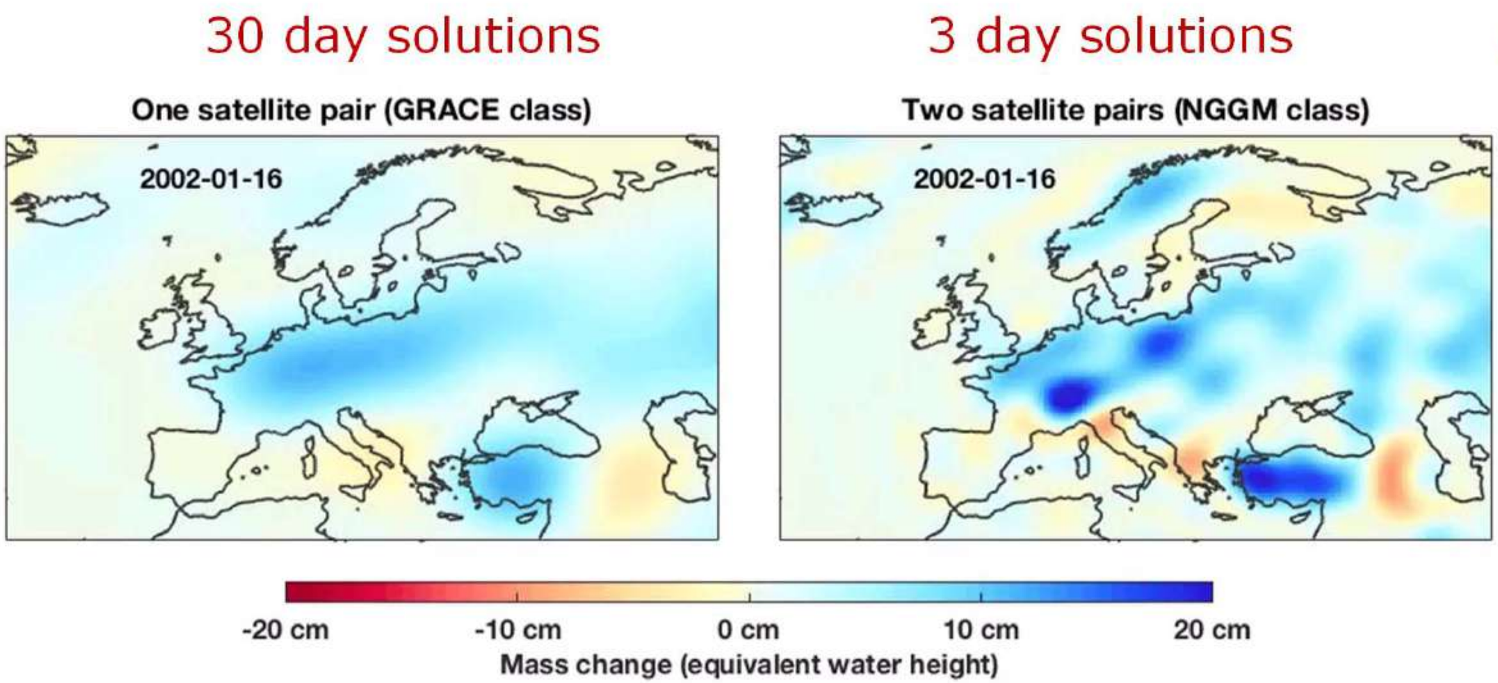


Gravity: State of the art seasonal streamflow forecasts



Management / allocation of water resources
=> Irrigation (food security) and hydropower generation

Future Gravity Mission: Example of simulation results



- Two satellite pairs (in NGGM configuration) resolves 3 day variability at catchment scale

Opportunity to reach operational-class monitoring

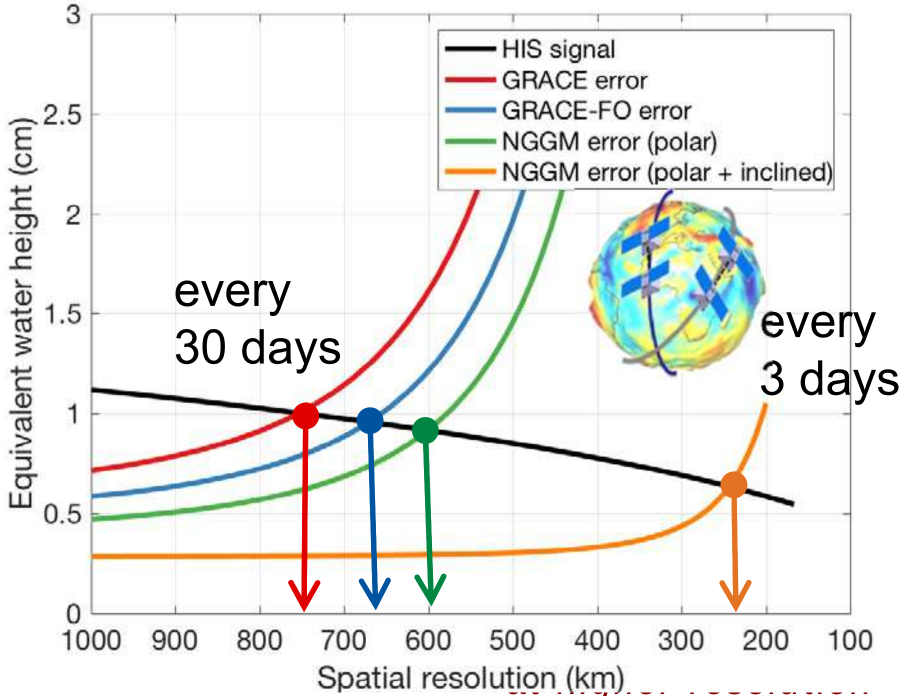
Increase of time resolution
1 month → 3 days (10 x better)

Increase of spatial resolution
600 km → 200 km (3 x better)

Solves problem of undersampling
Fast mass changes in ocean and atmosphere

30+ years time series for climatology
Disentangle natural and anthropogenic phenomena

US GRACE II and European NGGM joint return >> sum of the two missions

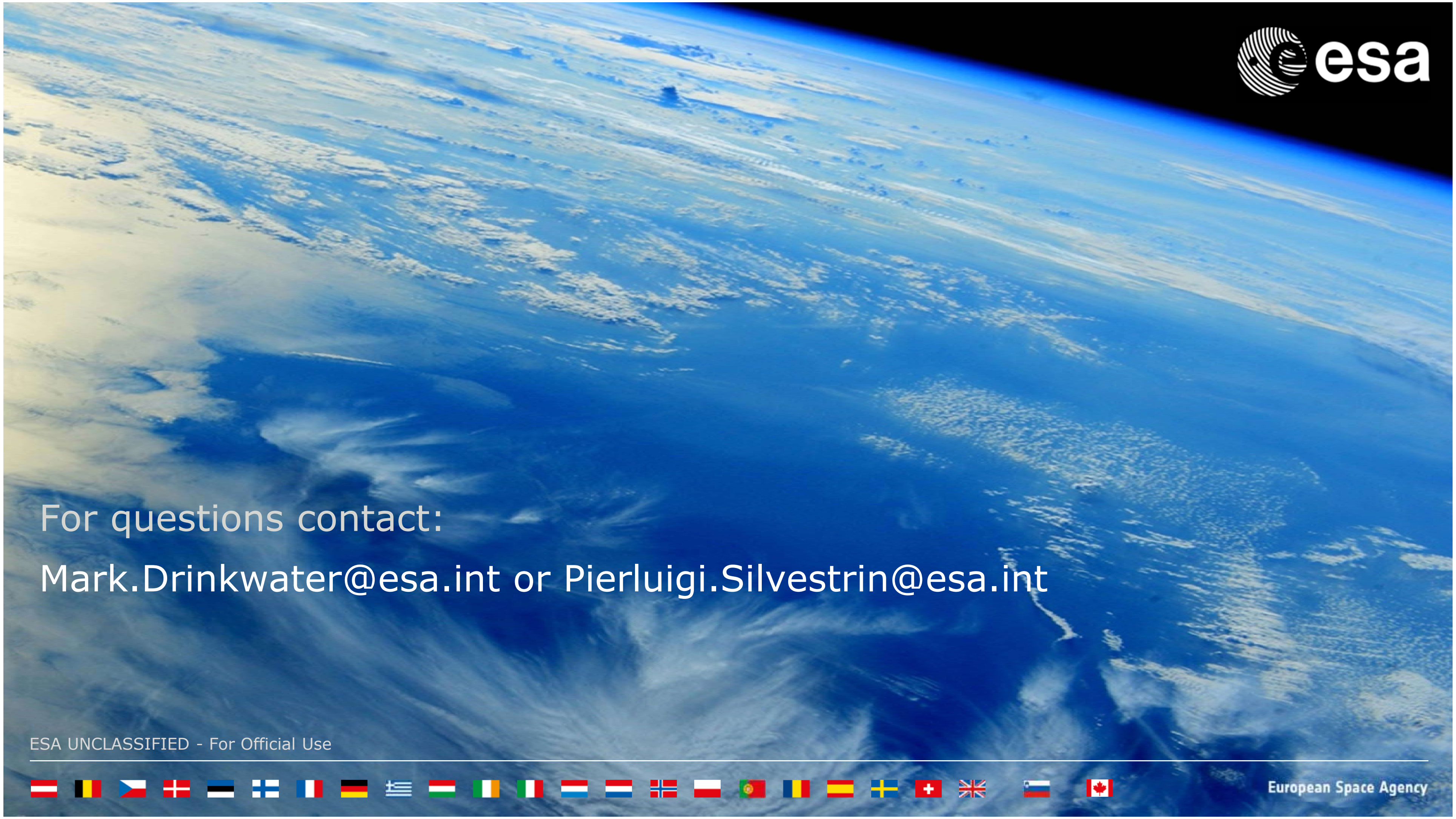


Summary (1 of 2)

- Significant progress in development of water management applications/services using both optical & microwave (active and passive) data. Progress includes:
  - improved understanding of the remote sensing signal and application at all wavelengths
  - user maturity (users know what they can expect and what they want)
  - processing environment including moves to cloud processing, expert systems, deep learning, etc.
- Development of user-driven, on-demand services based on existing capabilities in response to EU Policy, UN and International Conventions, Agenda 2030 and the its SDGs, UNFCCC/CBD/UNCCD, and flooding, wetland rehabilitation and Add points about Expansion in relation to gaps
- Strong potential for augmentation of existing capabilities with candidate Expansion Sentinels – and other future concepts (e.g. TIR, gravimetry)

Summary (2 of 2)

- Some Remaining challenges:
    - Time/space sampling requirements
    - Access to total drainable water/water storage (per catchment)
    - Mitigating cloud limitations of optical data
    - Improved detection beneath vegetation canopy (longer wavelengths)
    - Improved DEM required for self-consistent image orthorectification, classification, downscaling and hydrological basin definition
    - Automation of processing to develop time series/statistics (incl. use of mixed asc/desc data)
    - Integrated use of different sensor technologies (radar/optical/gravity)
    - Further development of modelling tools/frameworks to bridge time-space sampling, and to synthesise multi-sensor data


esa
For questions contact:
Mark.Drinkwater@esa.int or Pierluigi.Silvestrin@esa.int
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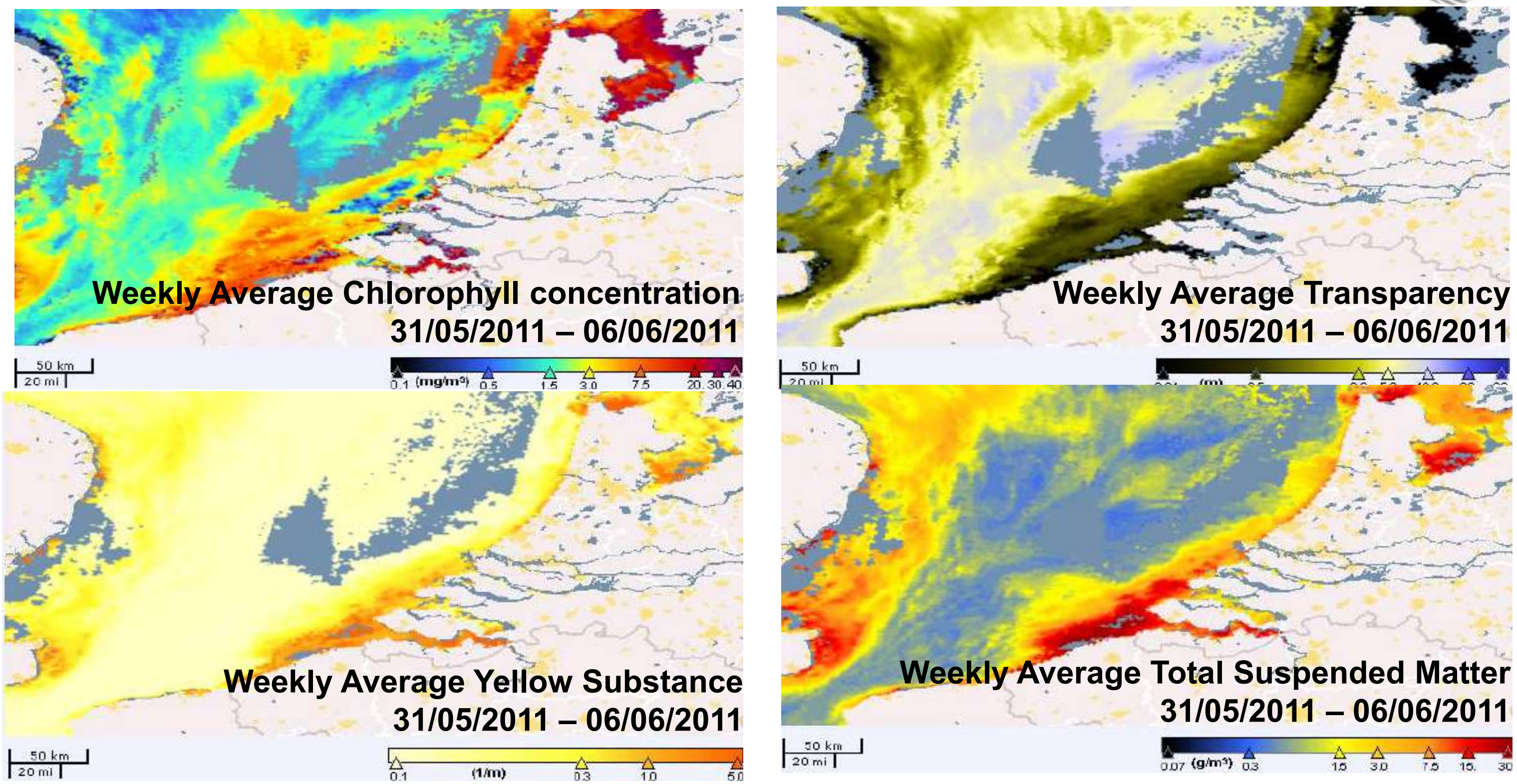
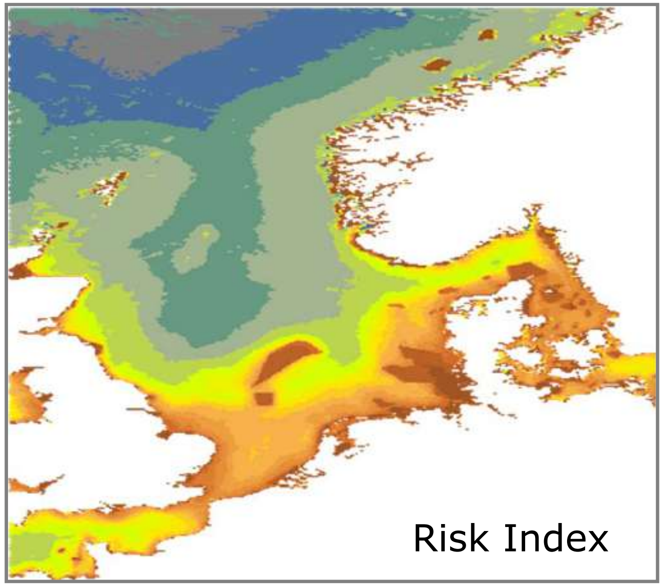
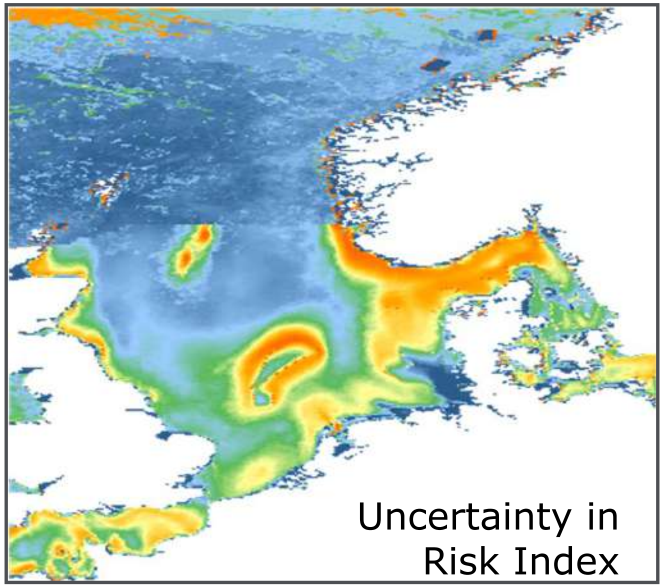
Coastal Water Quality



Satellite Ocean Colour from S-2 and S-3 – provides water quality parameters such as chlorophyll concentration, turbidity and algal bloom detection are required to support Water Framework Directive and Marine Strategy Framework Directive requirements.

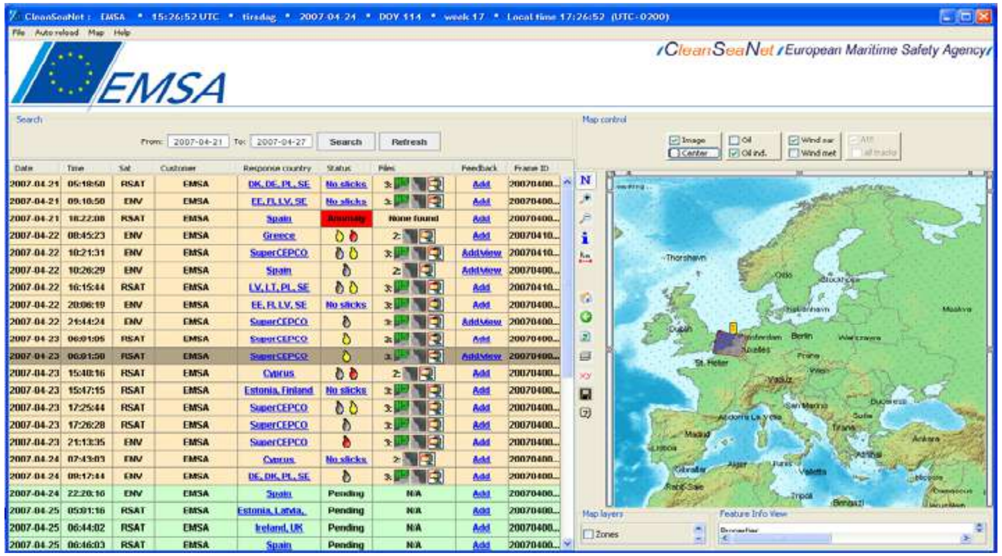
Invasive Species: Ship Ballast Water

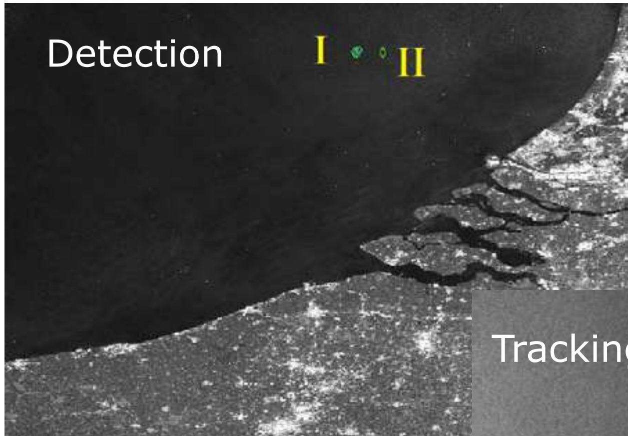


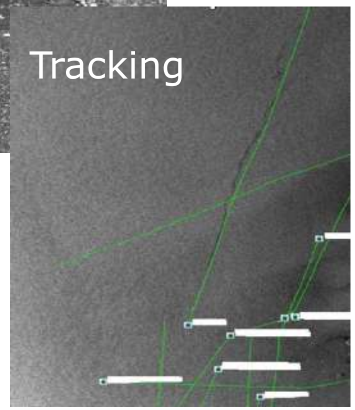


Satellite data can provide rapid information on ocean conditions over a wide area. This includes temperature, transparency, chlorophyll concentration and surface salinity. In addition satellites can provide up to date maps of the extent of different key habitats.

Vessel and Oil Pollution tracking

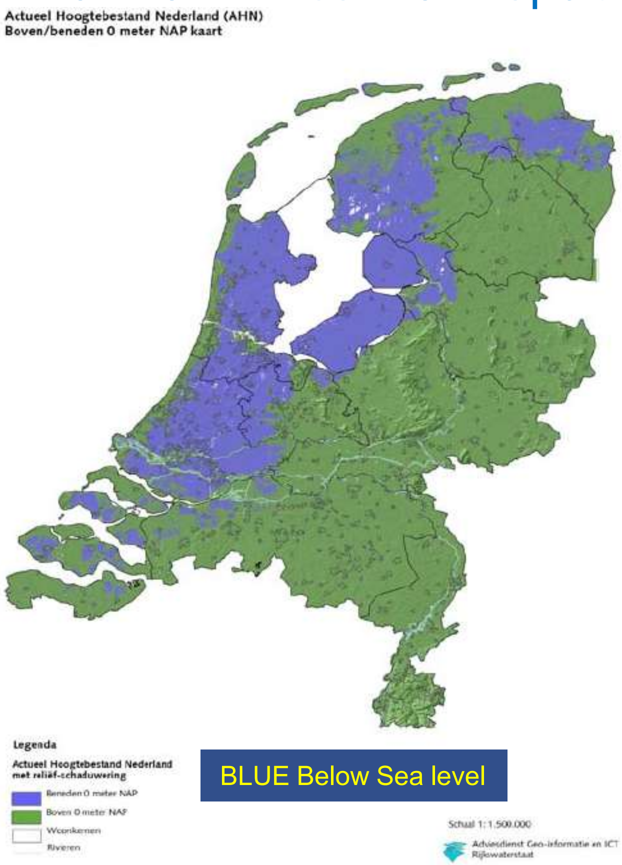






Satellite derived oil pollution information can optimise the patrol schedule of aircraft and cue them directly to priority areas of interest. In addition, satellite imagery can be used to extend the geographic coverage of current surveillance systems in a cost effective manner.

Can we monitor Dikes from space for flood defence?



Courtesy R. Hansen Delft Institute of Earth Observation and Space Systems

InSAR monitoring of Dike Stability for flood defence

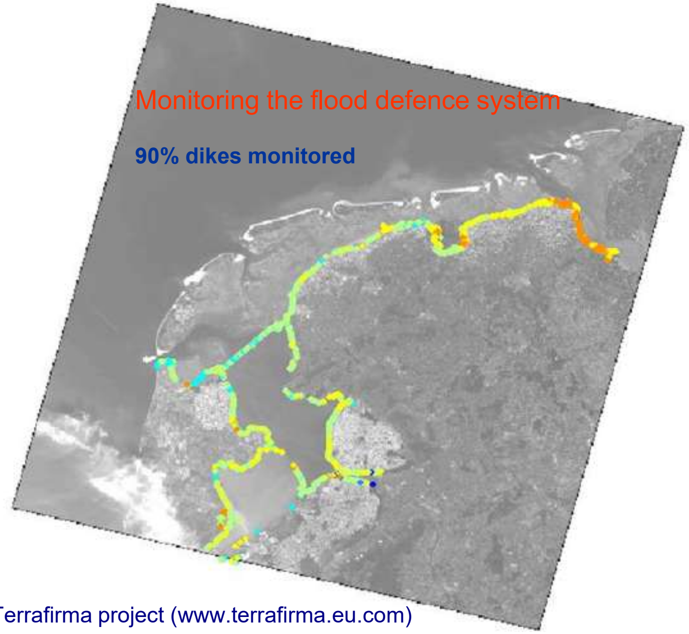
Blue, below sea level

BLUE Below Sea level

Legenda
Actueel Hoogtebestand Nederland met reliëf-schaduwering

17000 km of water barriers: 3565 km primary water barriers (big rivers, sea, IJsselmeer, Markermeer), 14000 km regional water barriers

Deformation mm/year
- -10.0 – -6.5
- -6.5 – -4.0
- -4.0 – -1.3
- -1.3 – 1.3
- 1.3 – 4.0
- 4.0 – 7.0
- 7.0 – 10.0



Credits: Hansje Brincker, Terrafirma project (www.terrafirma.eu.com)

Courtesy R. Hansen Delft Institute of Earth Observation and Space Systems