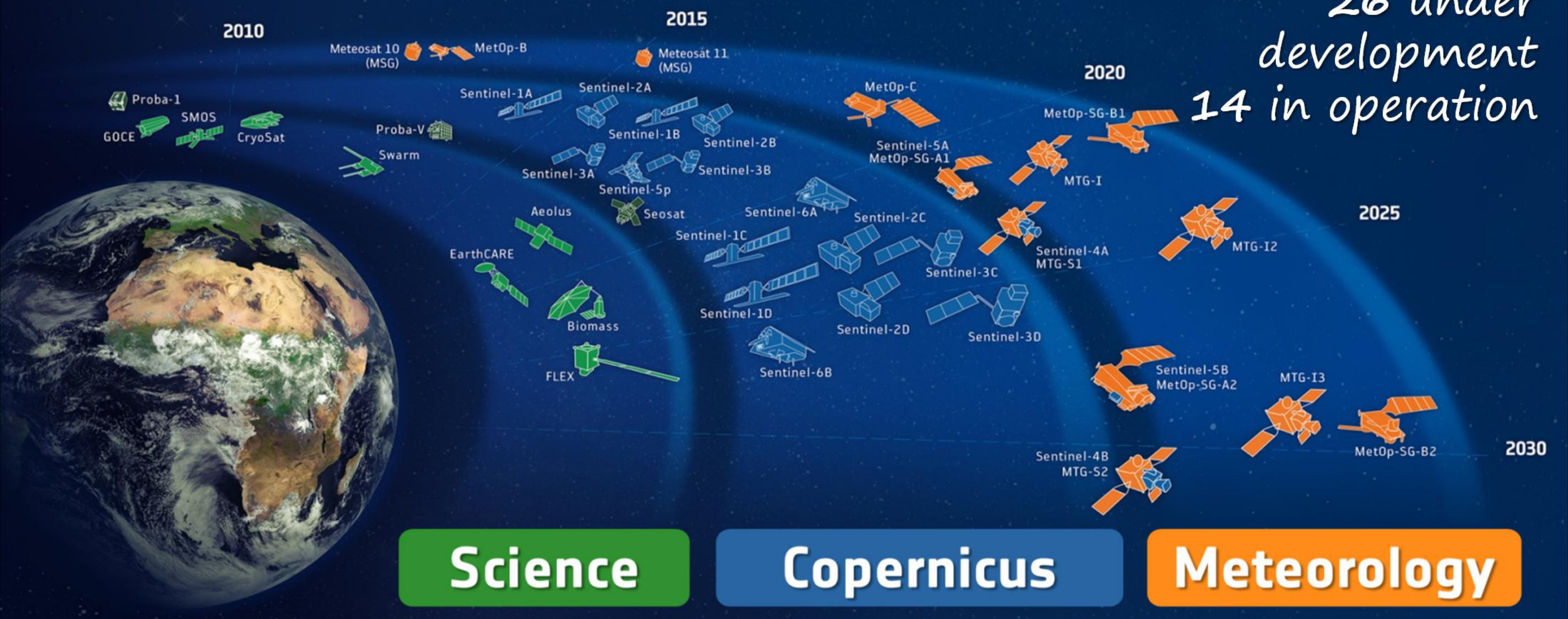
ESA & Copernicus EO missions for Ocean Remote Sensing

Advanced Training Course in Ocean and Coastal Remote Sensing
Shenzhen University, P.R. China, 12 November 2018

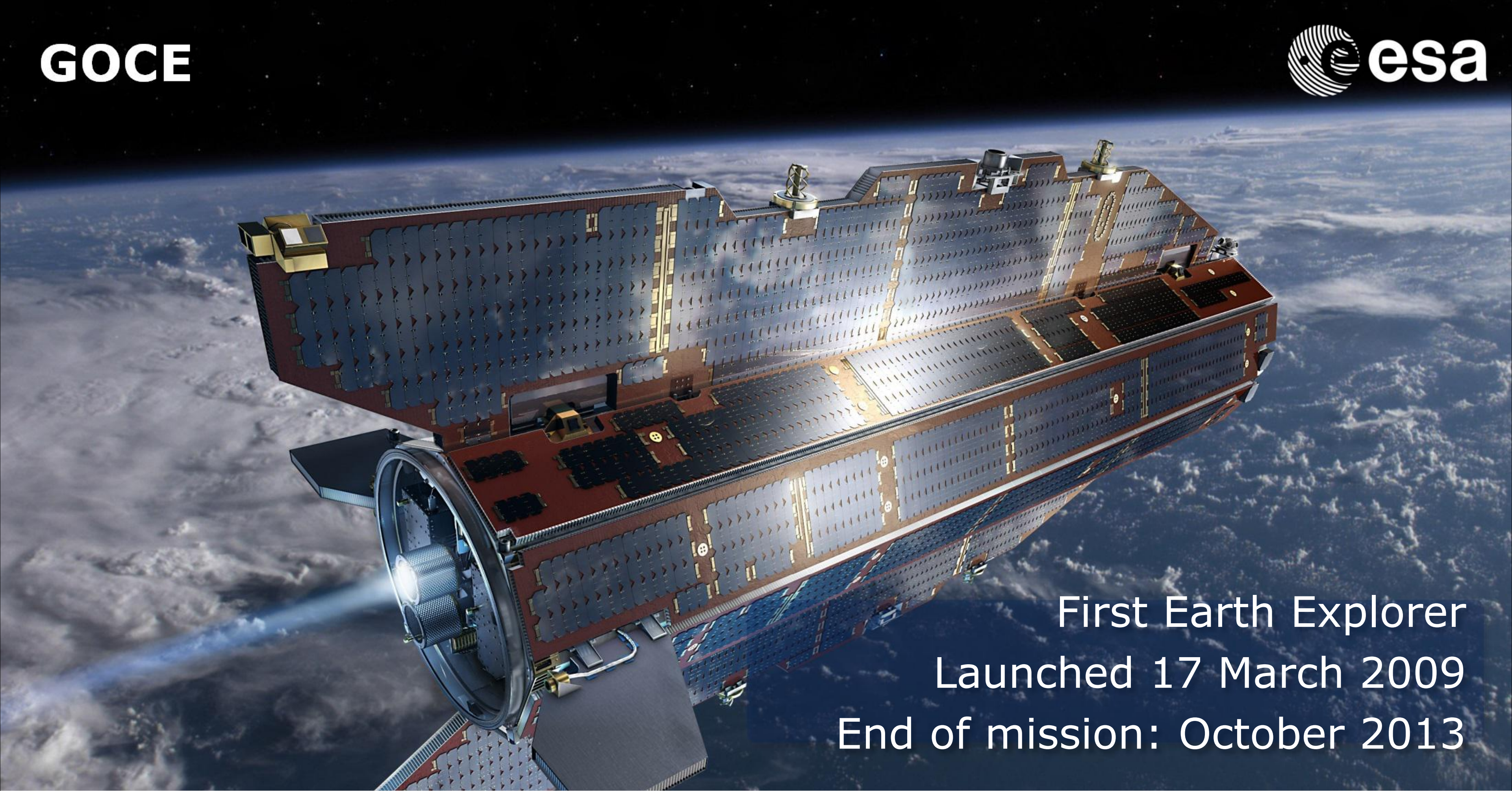
Marie-Helene RIO, ESA

ESA-DEVELOPED
EARTH OBSERVATION MISSIONS

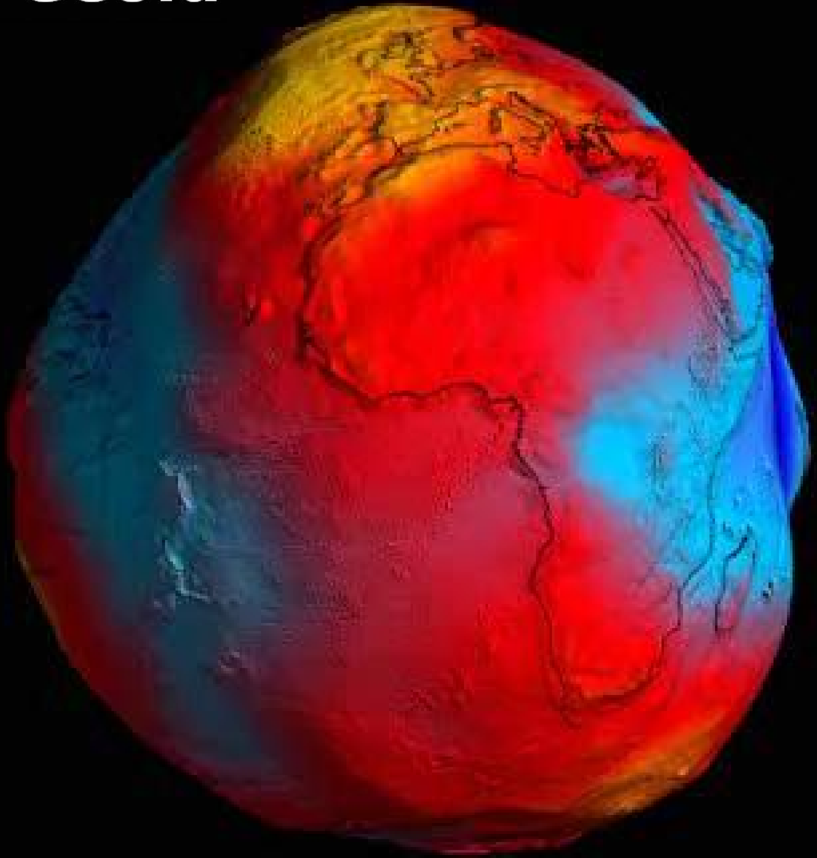
Satellites
26 under
development
14 in operation



The Earth Explorers


GOCE
esa
First Earth Explorer
Launched 17 March 2009
End of mission: October 2013

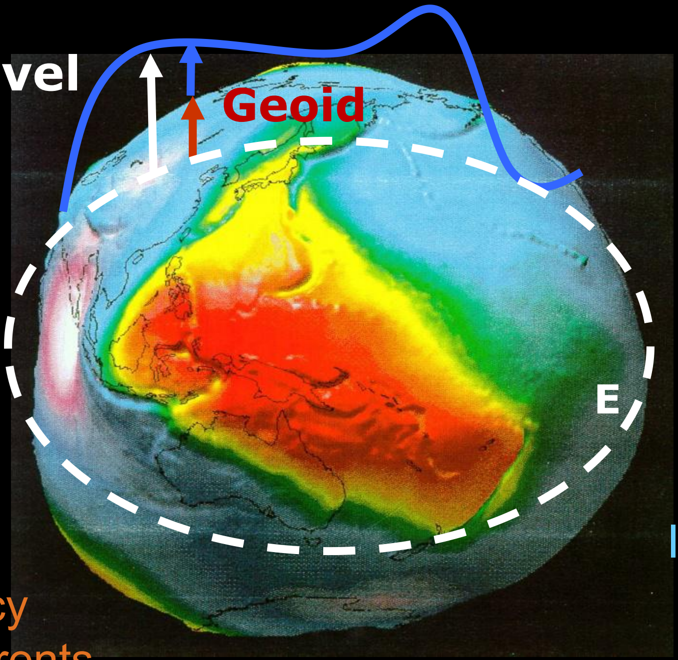
GOCE: Earth's Geoid



Most precise geoid ever produced

Ocean dynamic topography

Altimeter sea level



Geostrophic currents

Ekman currents

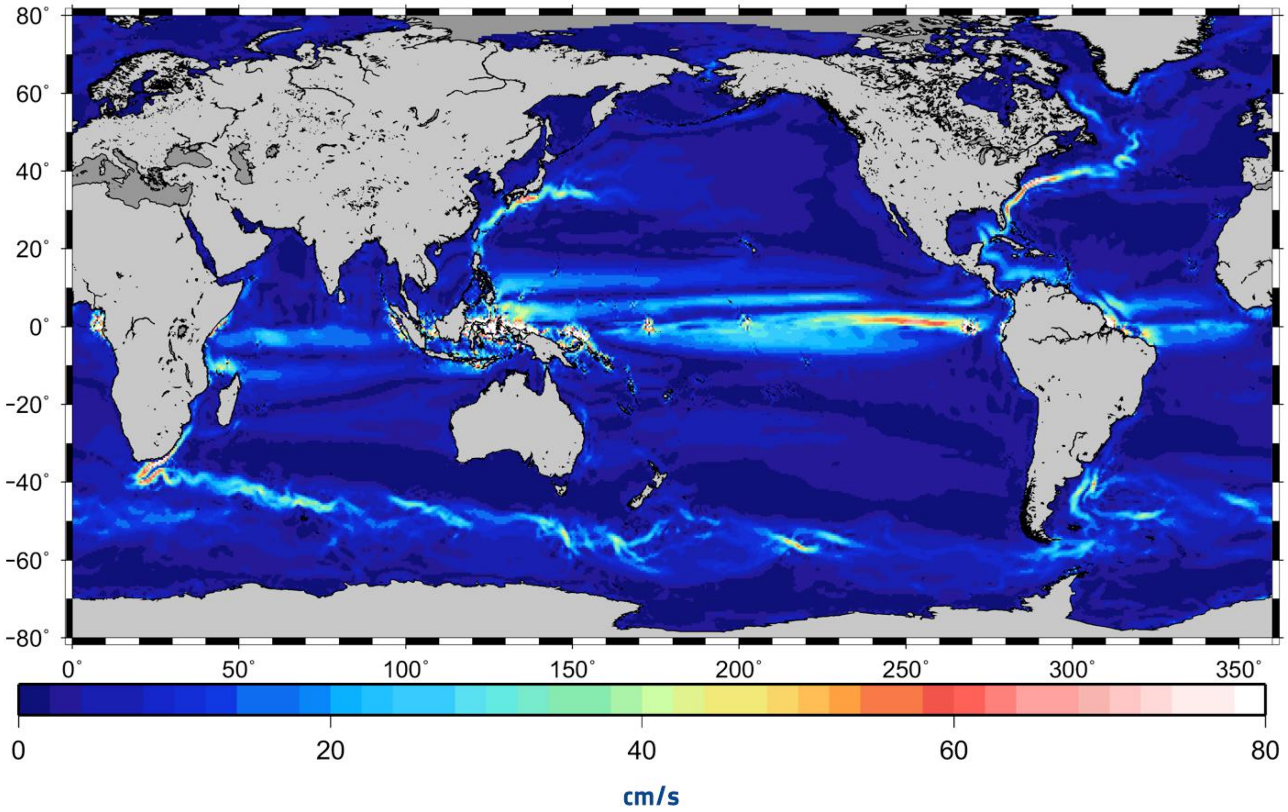
Stokes drift

Inertial oscillations

High frequency ageostrophic currents

Tidal currents

Global Ocean Currents



Mean ocean circulations derived from GOCE geoid & sea altimetry data

Height unification

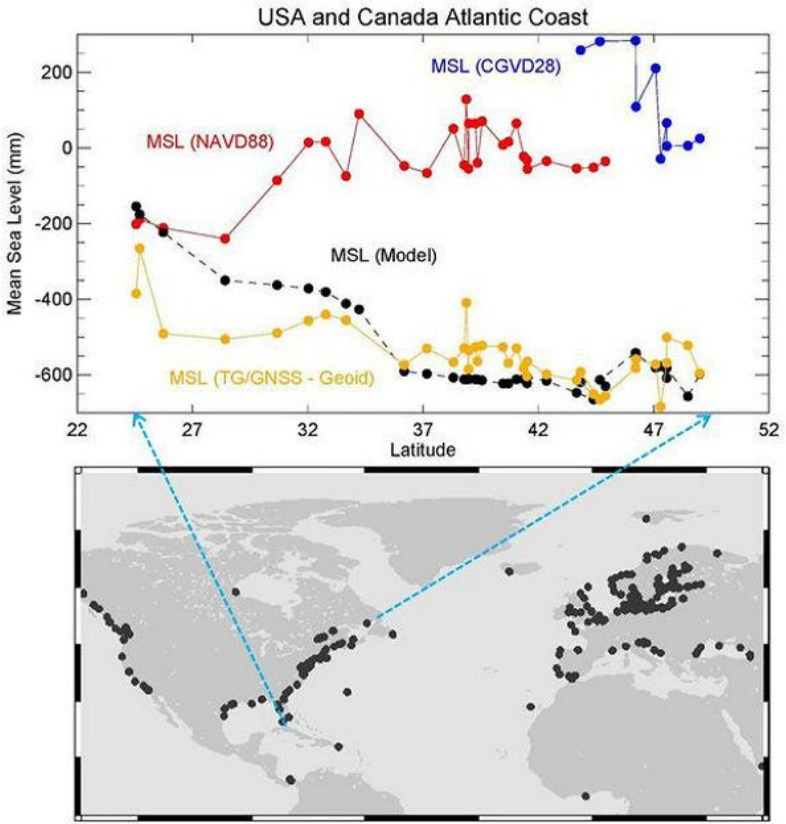
GOCE data has allowed to resolve a long-debated mystery

For decades, scientists have disagreed about whether the sea is higher or lower heading north along the east coast of North America.

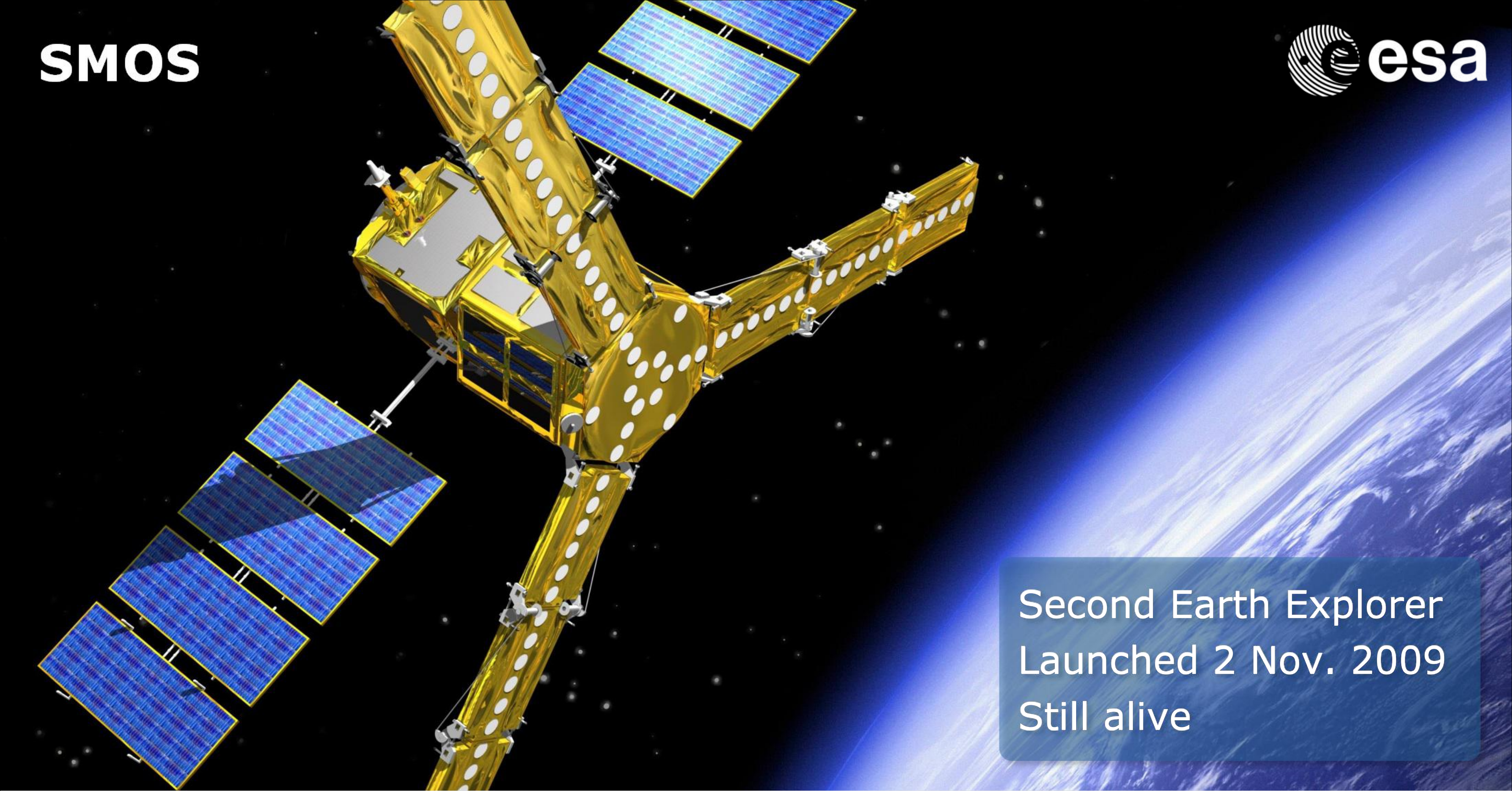
Red: From conventional levelling: National surveying datum assumed to be level reference surfaces

Black: Ocean numerical models

Yellow: Using GOCE as reference surface

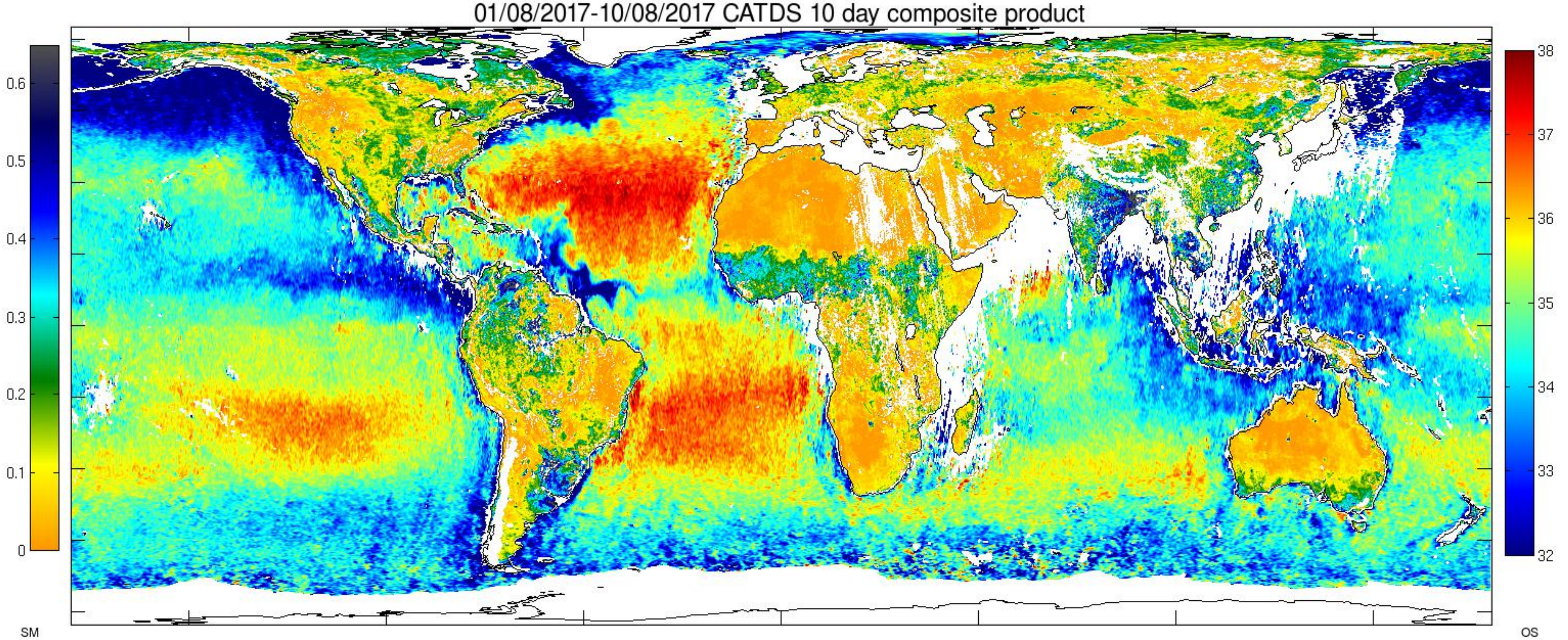


SMOS



Second Earth Explorer
Launched 2 Nov. 2009
Still alive

SMOS: L-band radiometer for Soil moisture and ocean salinity measurements



SMOS Applications over ocean

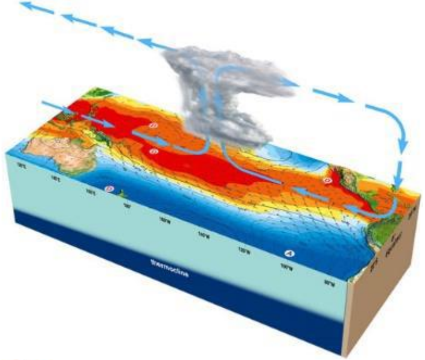
- ✓ **Large Scale Climate indexes**
  - ➢ Detection and monitoring of Large scale SSS anomalies related to climate fluctuations ENSO and IOD
- ✓ **Ocean circulation and modelling**
  - ➢ Characterizing mesoscale variability of SSS (and density) in frontal structures, eddies
  - ➢ Monitoring key oceanic thermohaline circulation processes: Gulf Stream
  - ➢ T/S Diagrams and water masses formation
  - ➢ Detecting Tropical Instability Waves -TIW
  - ➢ Monitoring of planetary waves –Rossby
  - ➢ Assimilating SMOS in OGCM
- ✓ **Air-Sea (or Land-Sea) interactions**
  - ➢ Monitoring freshwater river plumes
  - ➢ Detecting Upwelling and barrier layers
  - ➢ Monitoring precipitation-induced signals
  - ➢ Characterizing SSS variability in high evaporation/precipitation zones
- ✓ **Marine Biology / Biogeochemistry**
  - ➢ Ocean Acidification
- ✓ **Numerical Weather Prediction**
  - ➢ Hurricane/storm tracking and intensity forecasting

Large scale climate variability:

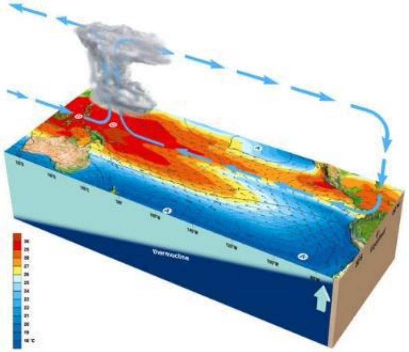
SSS & ENSO in the Equatorial Western Pacific (Warm & Fresh Pool)

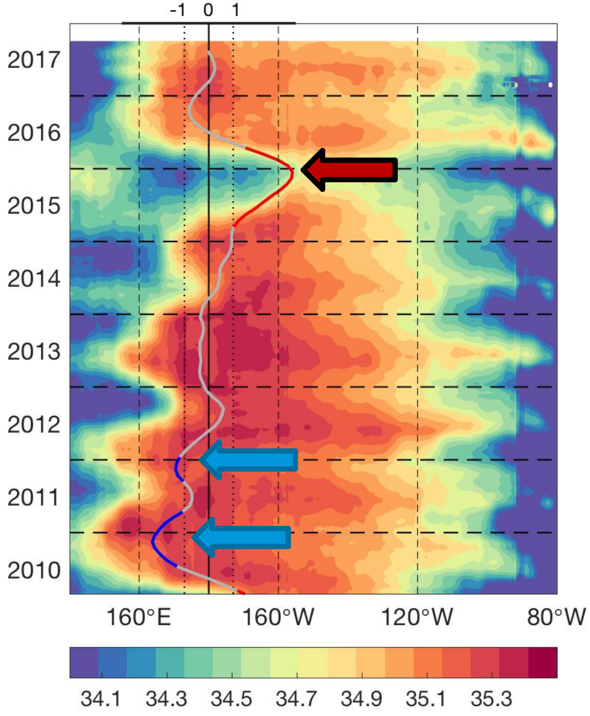
Signatures of ENSO in SMOS SSS at the Equator(2°S-2°N)

El Nino



La Nina





Salinity from SMOS data

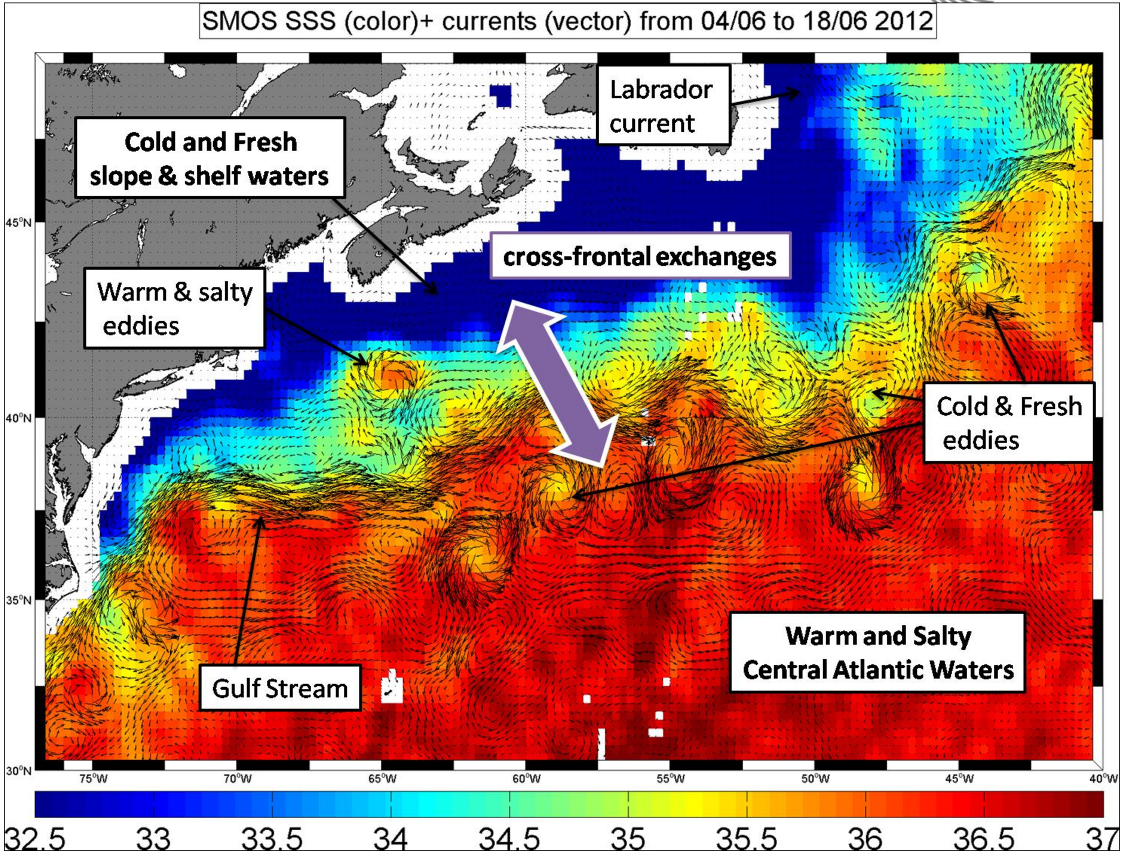
Hasson et al, 2017

Ocean Circulation

- SMOS reveals SSS structure of the Gulf Stream with high space and time resolution

- Cold/fresh Core rings are much better captured by SSS than by SST during summer.

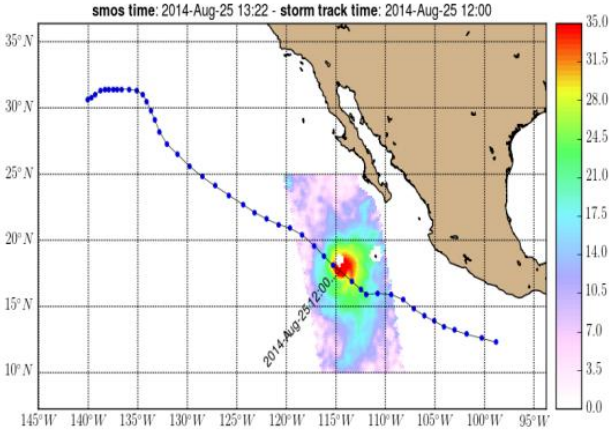
Reul et al, 2014

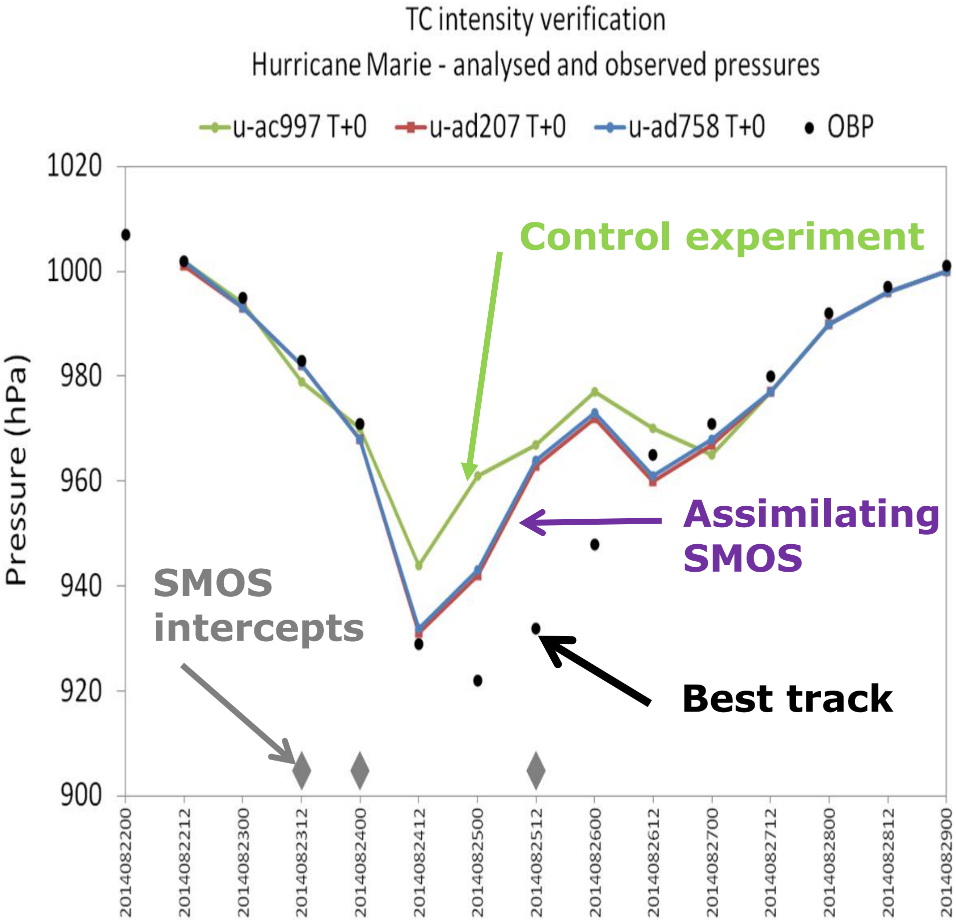


SMOS and winds

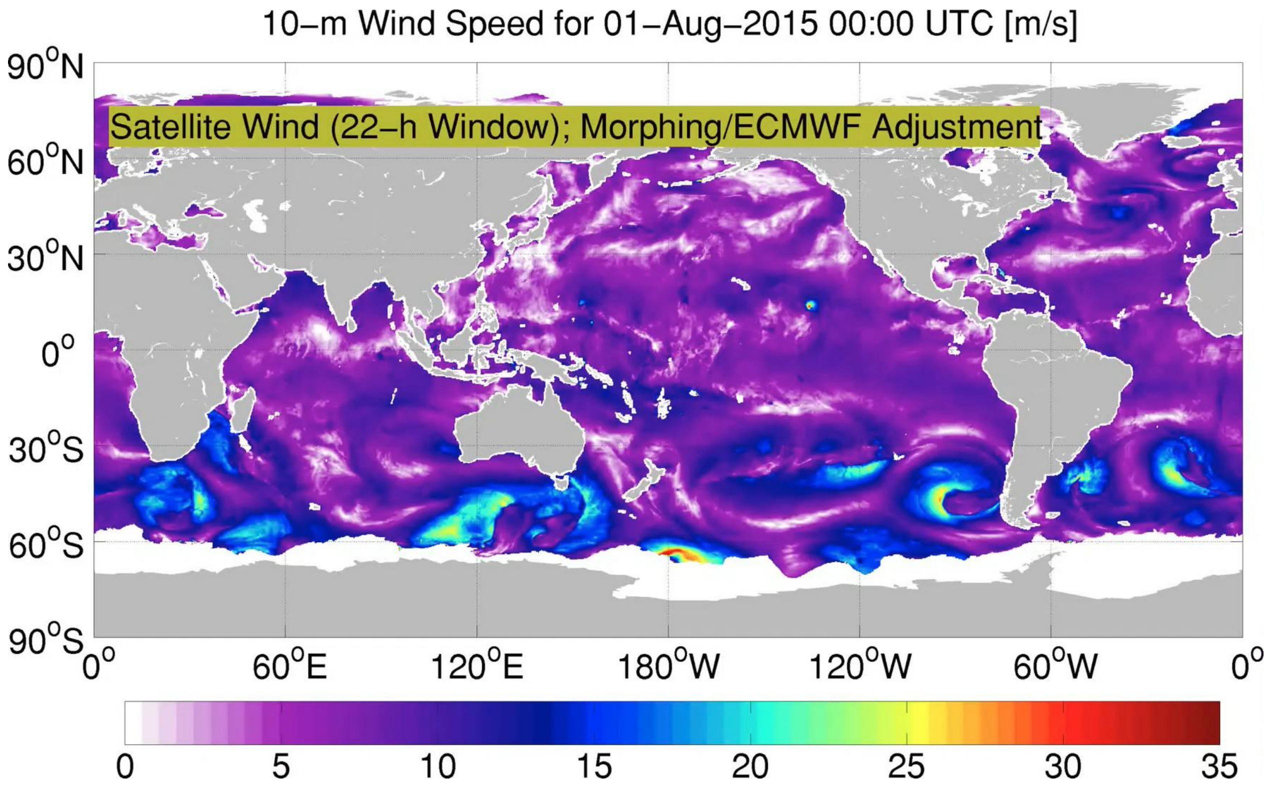
- At L-band the measured brightness temperature exhibit good sensitivity to ocean surface wind speed even in very high winds
- SMOS data has been proved to be a valid input to provide strong ocean wind speeds without saturation even over 35 m/s.

Track and intensity of Hurricane Marie, Aug 2014 retrieved from SMOS data





SMOS and winds:
New multi-satellite blended product

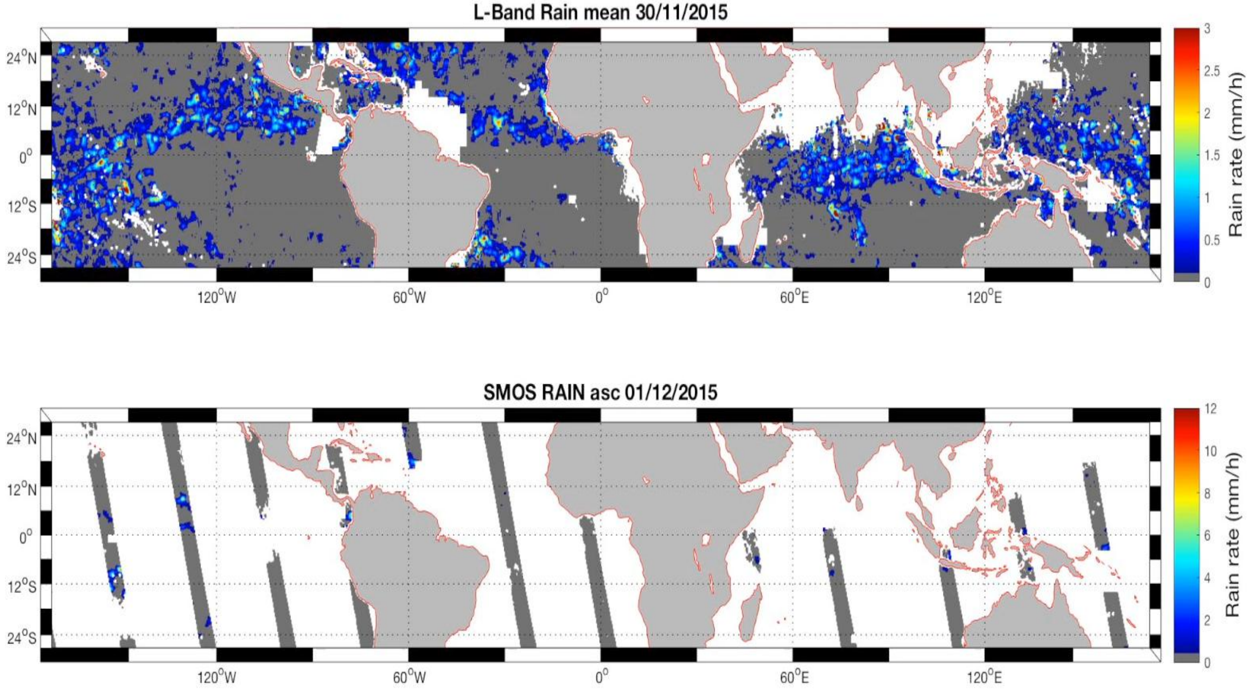


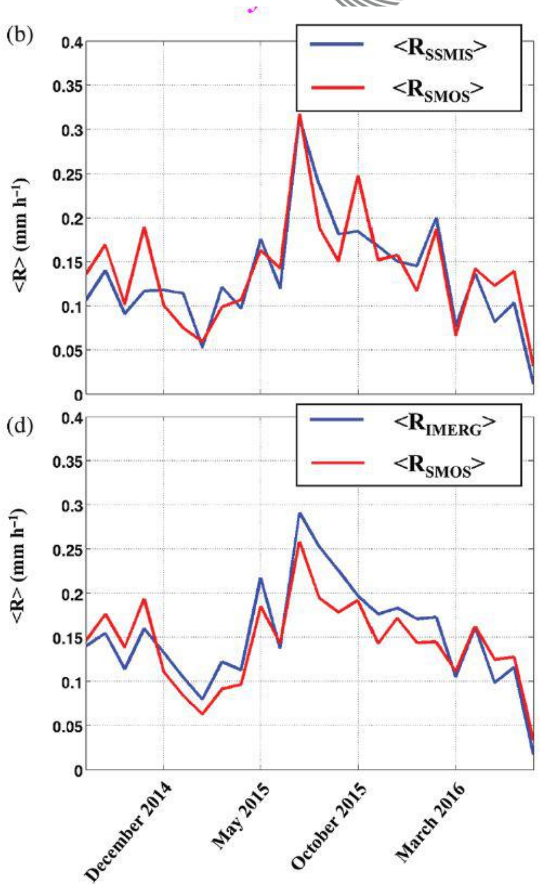
SMOS data has been proved to be a valid imput to provide strong ocean wind speeds without saturation even over 35 m/s.

A new approach for combining non-synoptic satellite wind speeds (SMOS, SMAP and AMSR-2) to create synoptic wind maps is showed here that use variational data assimilation together with an atmospheric model (such as ECMWF).

Source: IFREMER, OceanDataLab (FR)

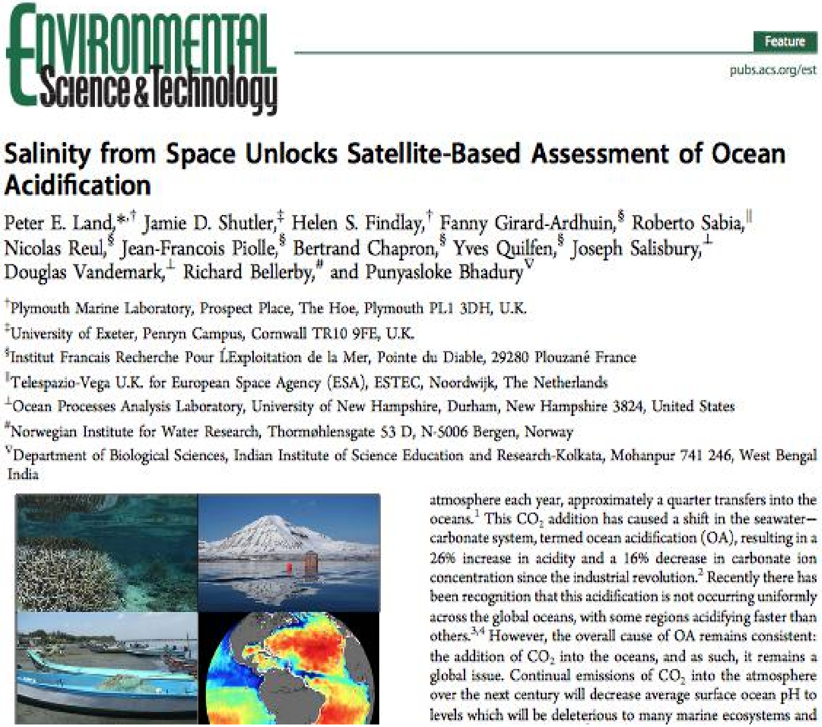
SMOS and rain rates over the ocean





Boutin et al, 2017

SMOS and Acidity:
First satellite based ocean acidity observations

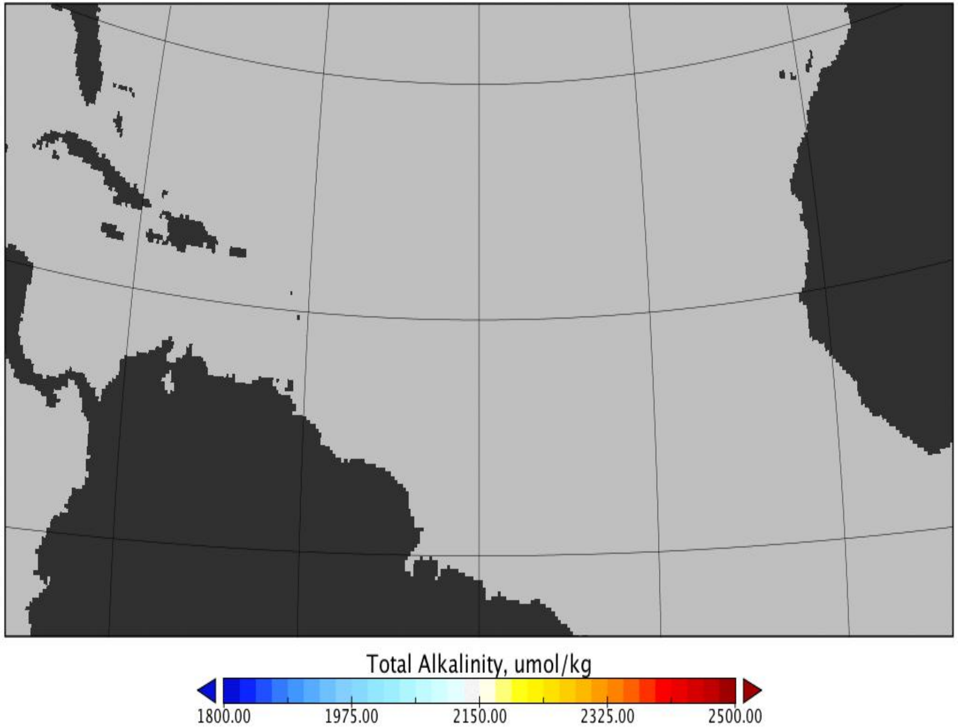

Environmental Science & Technology
Feature
pubs.acs.org/est

Salinity from Space Unlocks Satellite-Based Assessment of Ocean Acidification

Peter E. Land,[*,†] Jamie D. Shutler,[‡] Helen S. Findlay,[†] Fanny Girard-Ardhuin,[§] Roberto Sabia,[∥] Nicolas Reul,[§] Jean-Francois Piolle,[§] Bertrand Chapron,[§] Yves Quilfen,[§] Joseph Salisbury,[⊥] Douglas Vandemark,[⊥] Richard Bellerby,[#] and Punyasloke Bhadury[∇]

[†]Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, U.K.
[‡]University of Exeter, Penryn Campus, Cornwall TR10 9FE, U.K.
[§]Institut Francais Recherche Pour ĹExploitation de la Mer, Pointe du Diable, 29280 Plouzané France
[∥]Telespazio-Vega U.K. for European Space Agency (ESA), ESTEC, Noordwijk, The Netherlands
[⊥]Ocean Processes Analysis Laboratory, University of New Hampshire, Durham, New Hampshire 3824, United States
[#]Norwegian Institute for Water Research, Thormøhlensgate 53 D, N-5006 Bergen, Norway
[∇]Department of Biological Sciences, Indian Institute of Science Education and Research-Kolkata, Mohanpur 741 246, West Bengal India

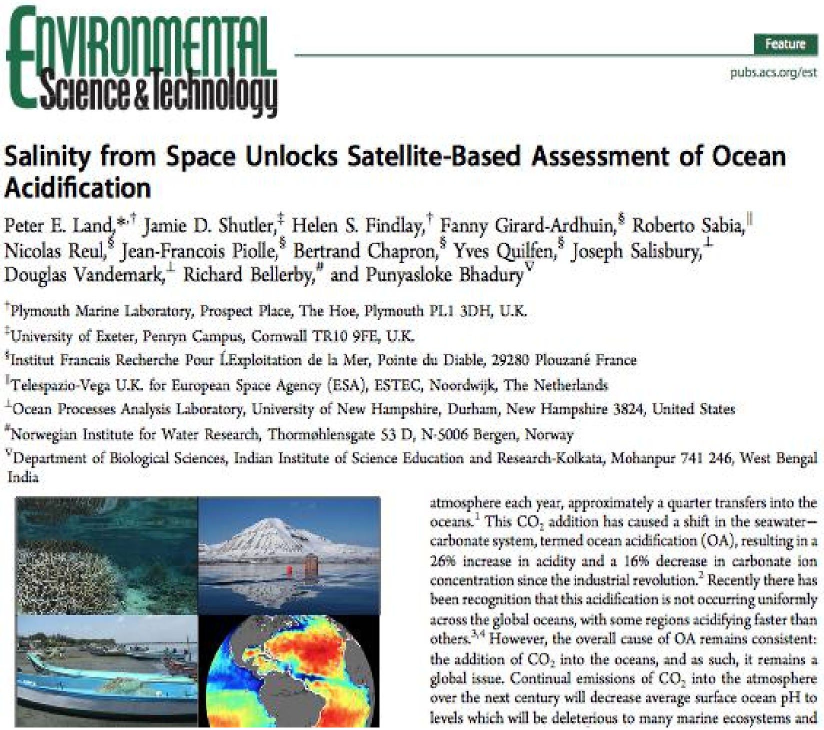
atmosphere each year, approximately a quarter transfers into the oceans.[1] This CO_2 addition has caused a shift in the seawater–carbonate system, termed ocean acidification (OA), resulting in a 26% increase in acidity and a 16% decrease in carbonate ion concentration since the industrial revolution.[2] Recently there has been recognition that this acidification is not occurring uniformly across the global oceans, with some regions acidifying faster than others.[3,4] However, the overall cause of OA remains consistent: the addition of CO_2 into the oceans, and as such, it remains a global issue. Continual emissions of CO_2 into the atmosphere over the next century will decrease average surface ocean pH to levels which will be deleterious to many marine ecosystems and



Total alkalinity from SMOS (waters ability to resist a change in pH). The pulses of very low values are due to the large river outflow from the Amazon during the wet season. **This is a new** EO-based synoptic view of Total alkalinity anywhere on Earth and it illustrates how the Amazon impacts much of the Central Atlantic. **Source: PML (UK) Pathfinder-OA**

SMOS and Acidity:

First satellite based ocean acidity observations



ENVIRONMENTAL Science & Technology

Feature

pubs.acs.org/est

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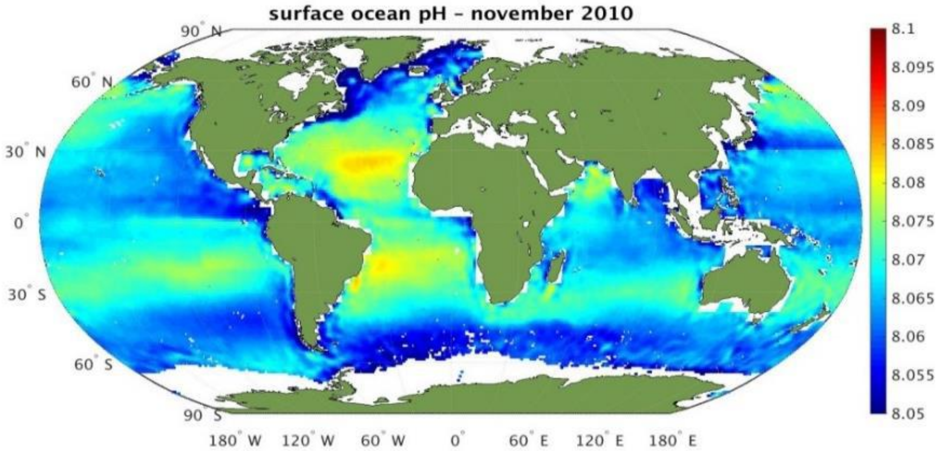
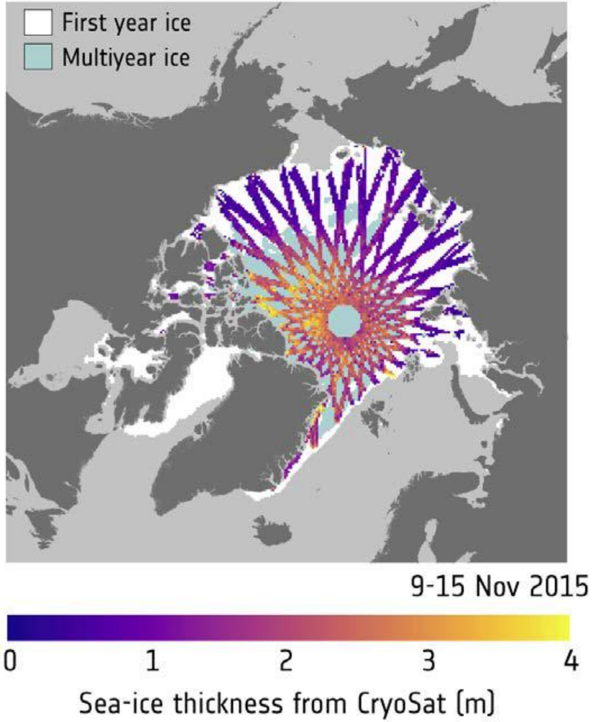


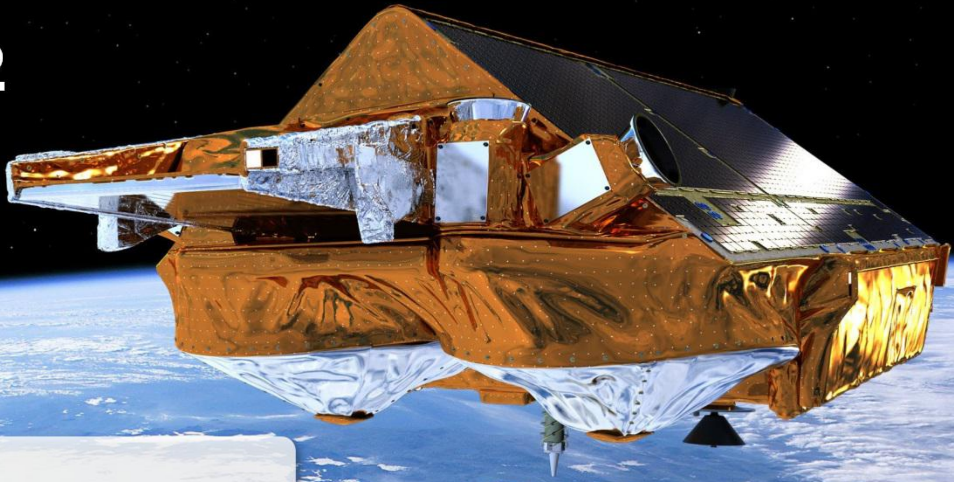
First-ever estimates of EO-based global surface ocean pH **using SMOS SSS, satellite SST & ocean color** .
(credits: ESA/R. Sabia)

SMOS and Ice



- Thickness of thin sea ice can be retrieved from SMOS Brightness Temperature
- Spatial distribution of thin first year (seasonal) ice thickness detected by SMOS
- Perennial (multiyear) and first-year ice thickness distribution measured by CryoSat
- Optimal combination of CryoSat and SMOS Arctic data with different sensitivities to sea-ice thickness

Cryosat-2



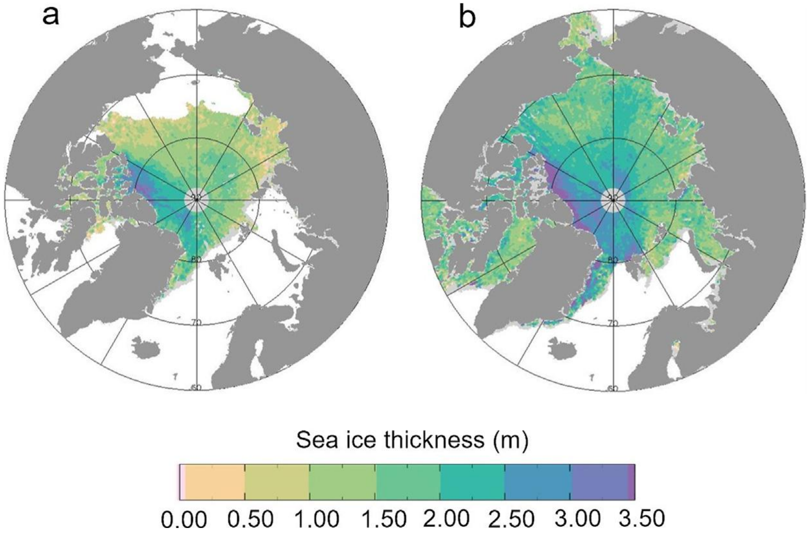
Third Earth Explorer
Launched 8 Nov. 2010

Mission Objectives:
To determine the regional and basin-scale trends in Arctic sea-ice thickness and mass
To determine the regional and total contributions to global sea level of the Antarctic and Greenland ice sheets.

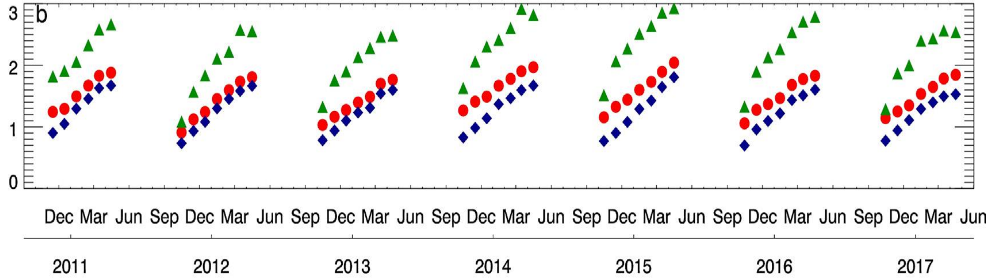
CryoSat and Sea Ice Thickness monitoring

Sea Ice Thickness

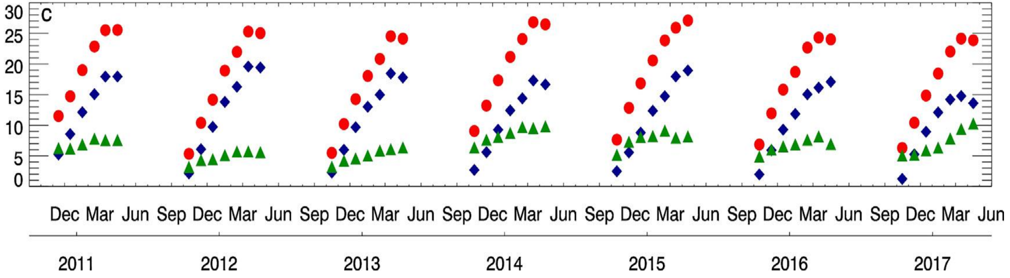
Autumn 2016 Spring 2017



Sea Ice Thickness



Sea Ice Volume



Blue: first year ice; green: multi-year ice; red=total

Tilling et al, 2017

Cryosat and Global Mean Sea Level Trend budget

Insight onto the Land Ice (glaciers+ice sheets) melting contribution to sea level change

Sea Level Budget: Observed Global Mean Sea Level = Ocean Thermal Expansion + Ocean Mass

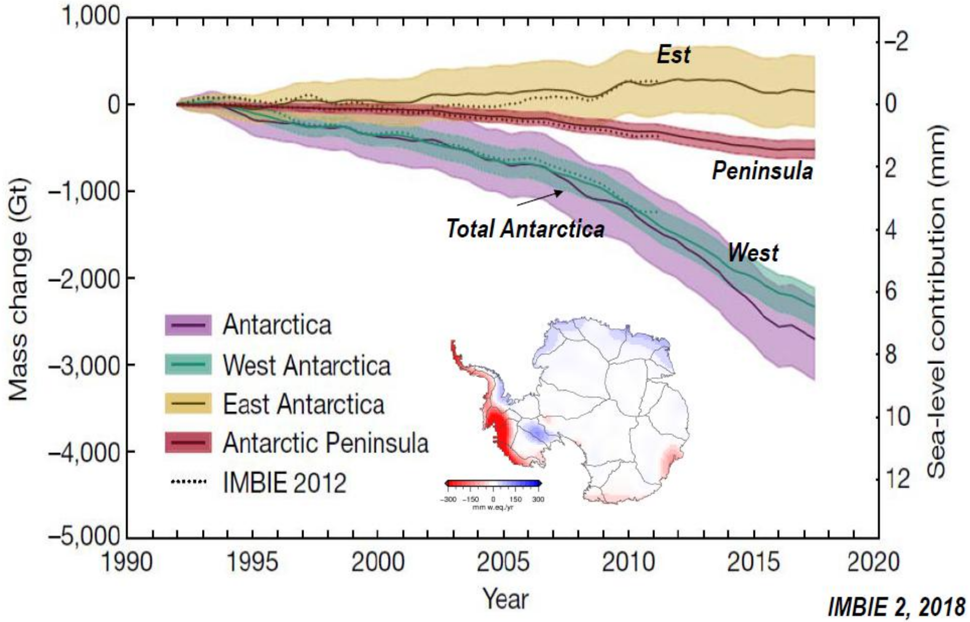
$$\Delta M_{ocean} = -\Delta M_{LI} - \Delta M_{LW} - \Delta M_{WV} - \Delta M_{Snow} - \ldots\ldots$$

Ocean mass; Land ice; Land waters; Atmospheric water vapor; Snow

Mass Budget

Δ = Time variation
M = Mass components
LI = Land Ice (glaciers + ice sheets)
LW = Land Waters
WV = Water Vapour

Ice mass loss from the Antarctica ice sheet (1993-present)



IMBIE 2, 2018

Cryosat and Global Mean Sea Level Trend budget

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Sea Level Budget

Observed Global Mean Sea Level
=
Ocean Thermal Expansion + Ocean Mass

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Ocean mass; Land ice; Land waters; Atmospheric water vapor; Snow

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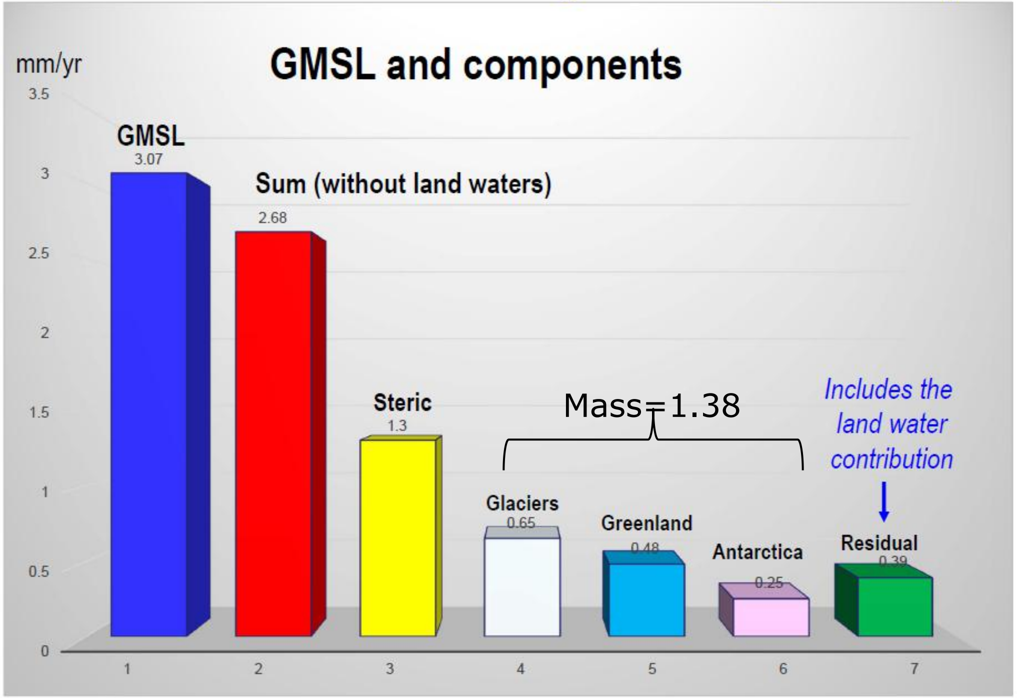
Mass Budget

Global Mean Sea Level Budget: trends (1993-2015)

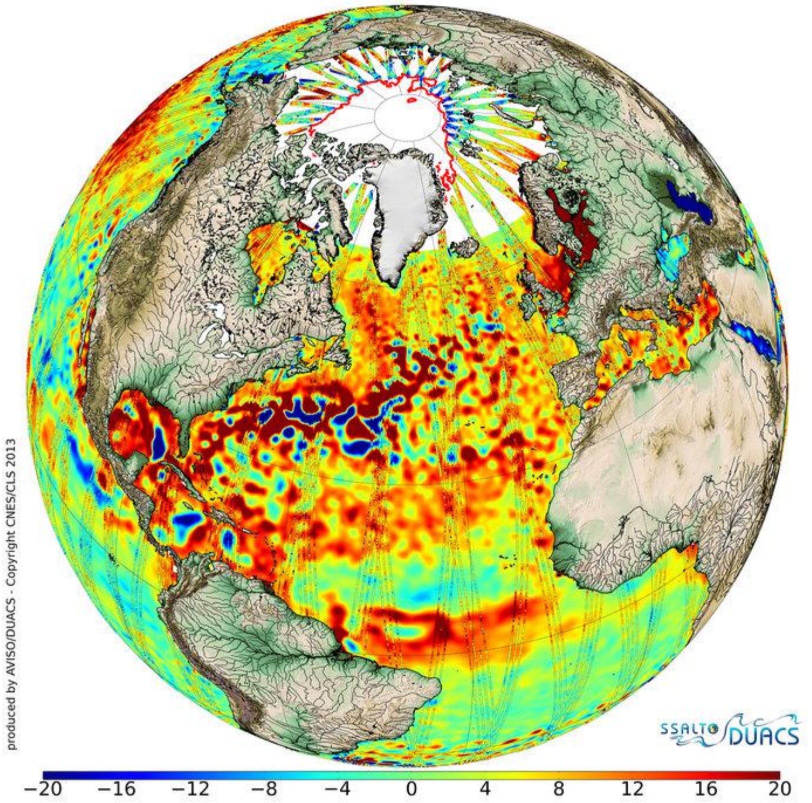


WCRP Global Sea Level Budget Group, ESSD, 2018 & ESA Sea Level Budget Project

CryoSat is not only for Ice

- CrySat-2 altimeter data over oceans as an additional altimeter constellation member (for SSH, wave height and wind speed retrieval)

- CryoSat-2 offered the first ever possibility to perform coastal altimetric studies using SAR/SARIn altimetry. With this technological leap forward it is now possible to observe sea level in very small water bodies and also to provide coastal sea level very close to the shore.



Future Earth Explorers

Status Future Earth Explorers

9

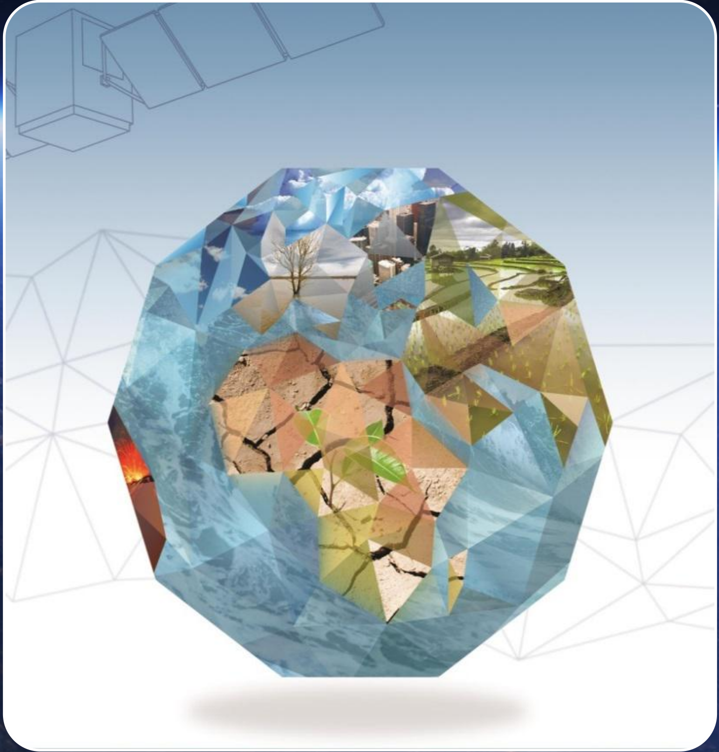
2 Candidates

- FORUM or SKIM
- Mission selection in Sept. 2019
- Launch around 2025

10

3 Candidates

- STEREOID or Daedalus or G-CLASS:H_2O
- Launch around 2027/2028



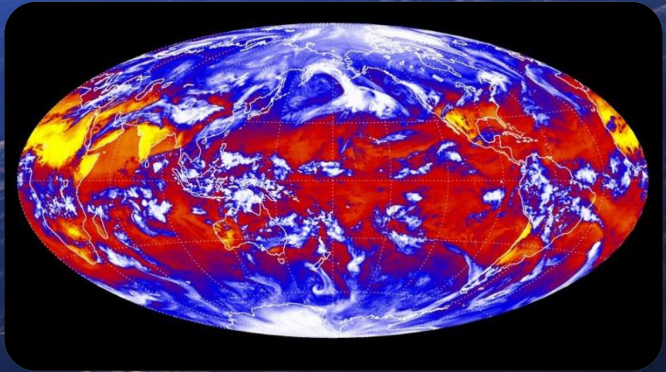
Earth Explorer 9

Launch around 2025

FORUM

Far Infrared Spectrometer

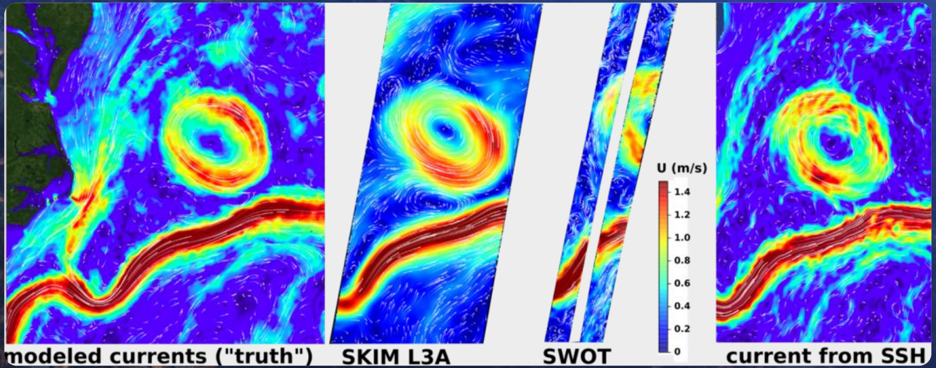
Greenhouse Effect / Climate Change



SKIM

Doppler-enabled wave-scatterometer

Ocean Surface Currents and waves

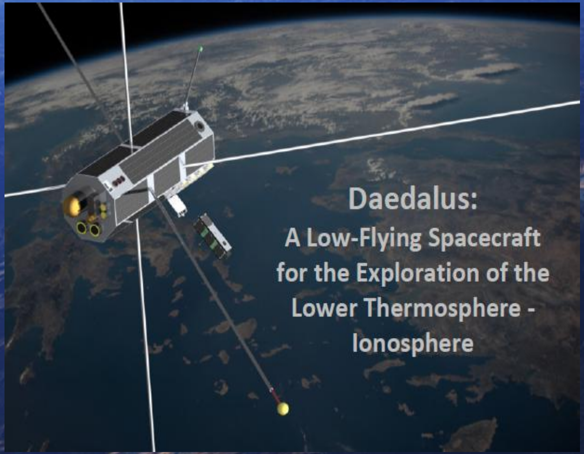


Earth Explorer 10

Launch around 2027-2028

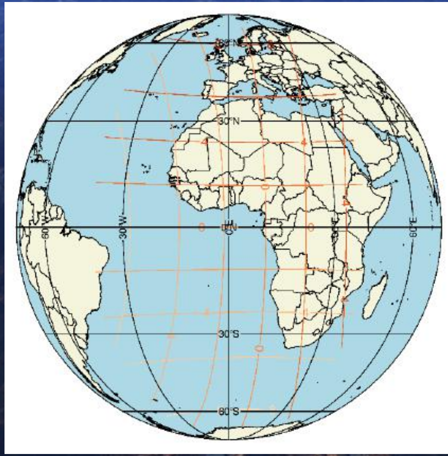
Daedalus

Lower Thermosphere-Ionosphere



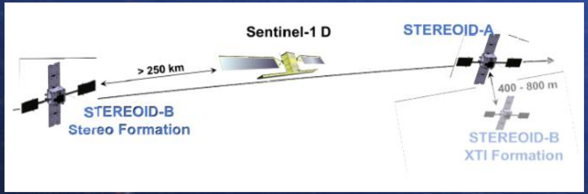
G-Class:H_2O

Intense rainfalls



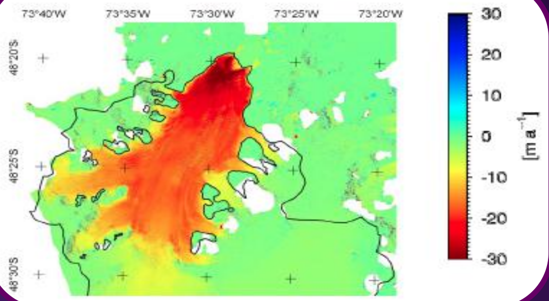
STEROID

Cryosphere/Oceanography/Geosphere



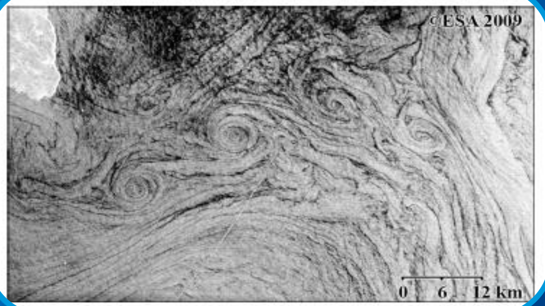
STEREOID - Scientific Goals

Cryosphere



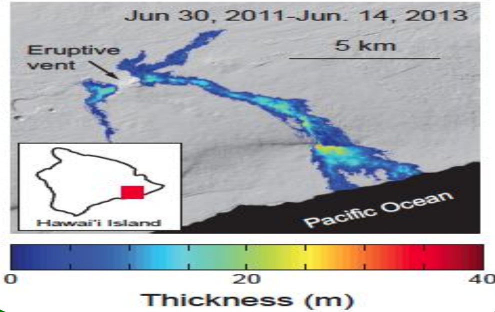
Glacier mass balance, dynamics of sea ice and marginal ice zone

Oceanography



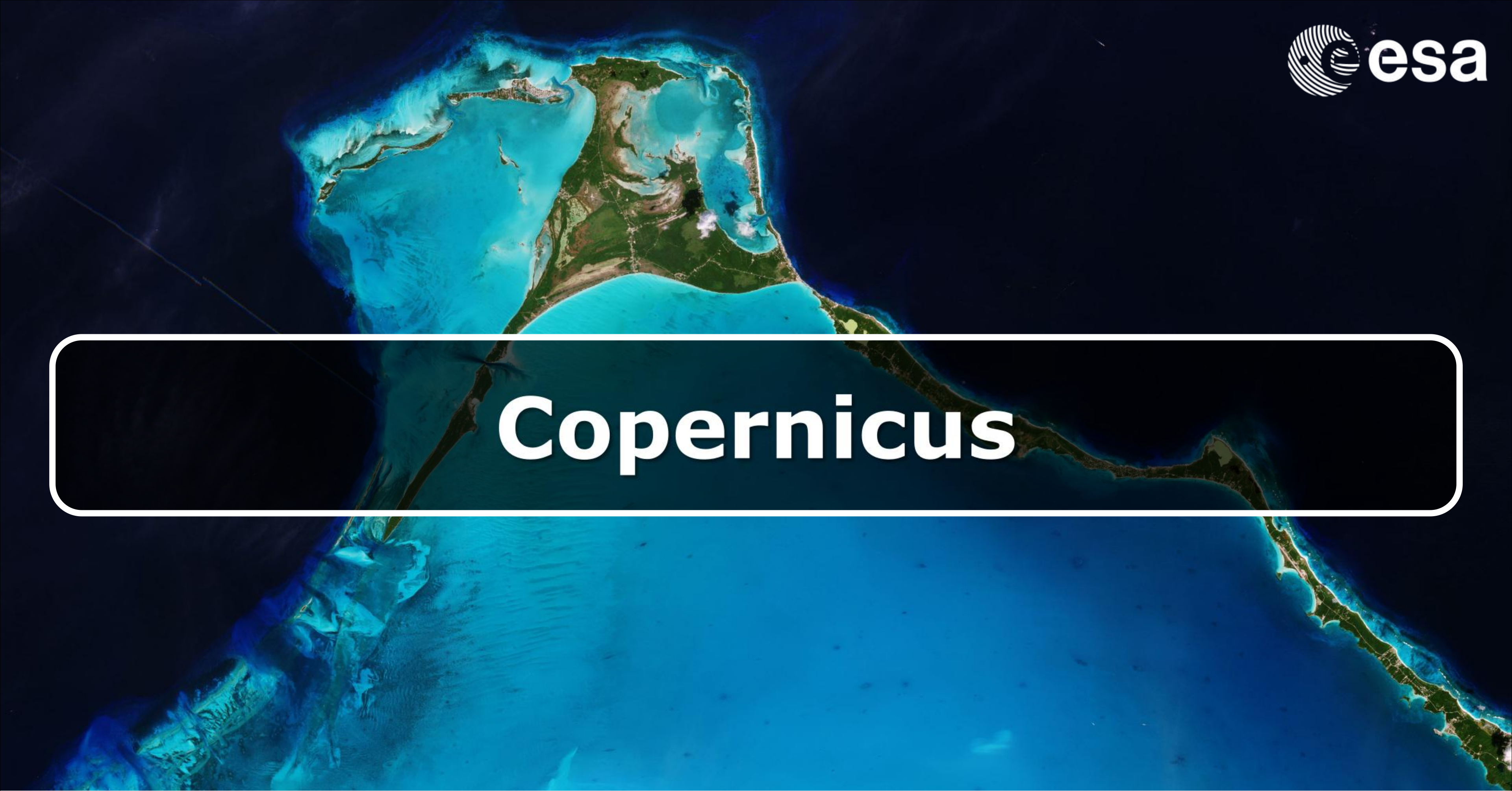
High resolution surface currents and wave data modelling, ocean small scale dynamics, extreme weather events

Geosphere



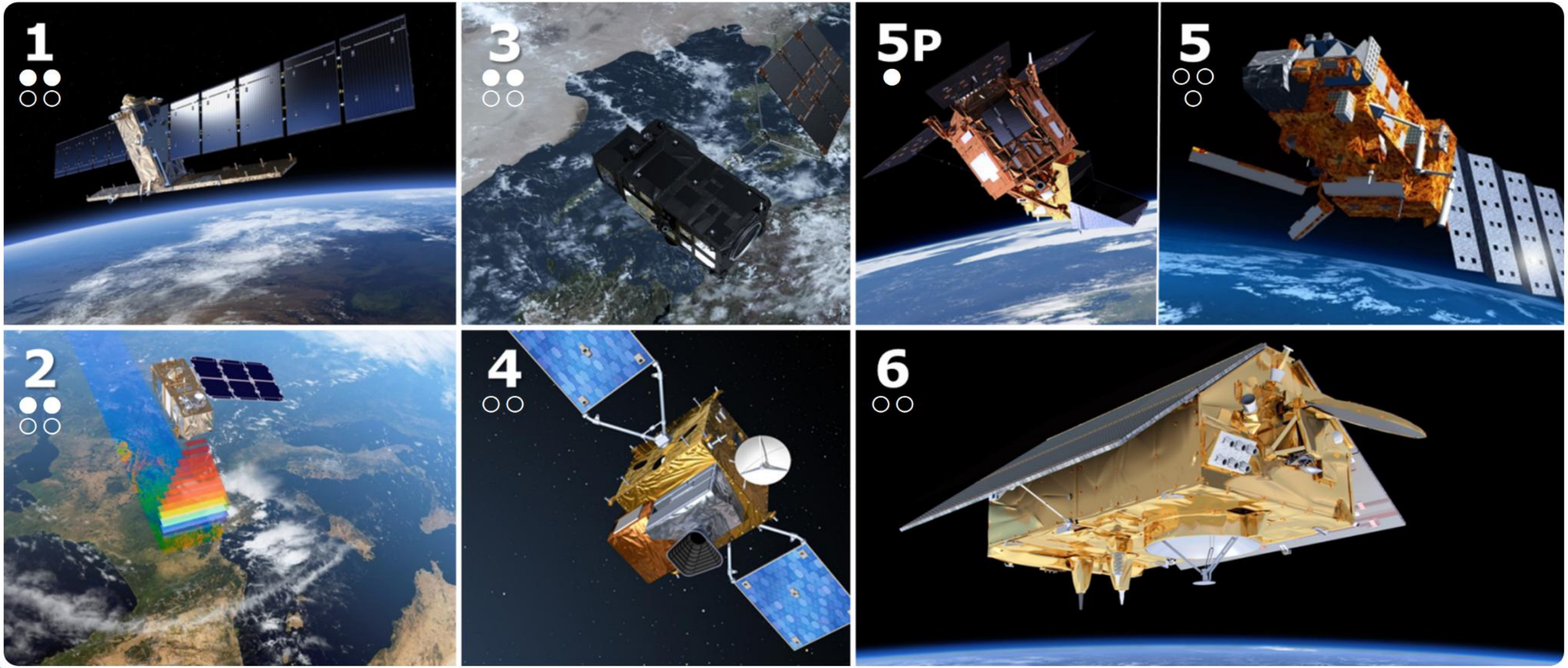
3-D deformation fields and topography changes relating to landslides, post-seismic deformation, volcanism

Copernicus



The Big Data Revolution

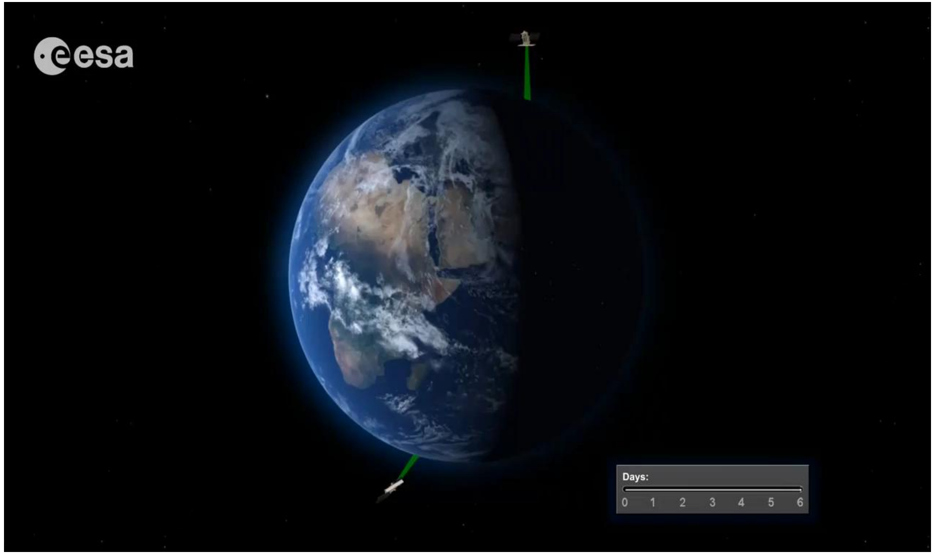
Copernicus is the largest producer of EO data in the world



S1 & S2 temporal revisit

S1 A & B operating 180 degrees apart, global coverage every 6 days

S2 A & B operating 180 degrees apart global coverage every 5 days



S-3 temporal revisit instrument dependent

S3 A & B SLSTR operating 180 degrees apart, global coverage **every 1 day**, swath 1400km of the nadir instrument (1km data)

S3 A & B OLCI operating 180 degrees apart, global coverage **every 2 days**, swath 1270km of the nadir instrument (300m data)

Sentinel-1

Sentinel-1 is a C-band Synthetic Aperture Radar (SAR)

The power of the backscattered signal depends on the surface roughness.
It provides an all-weather, day-and-night supply of imagery of Earth’s surface for numerous Ocean and Ice applications:

- Wind and wave monitoring

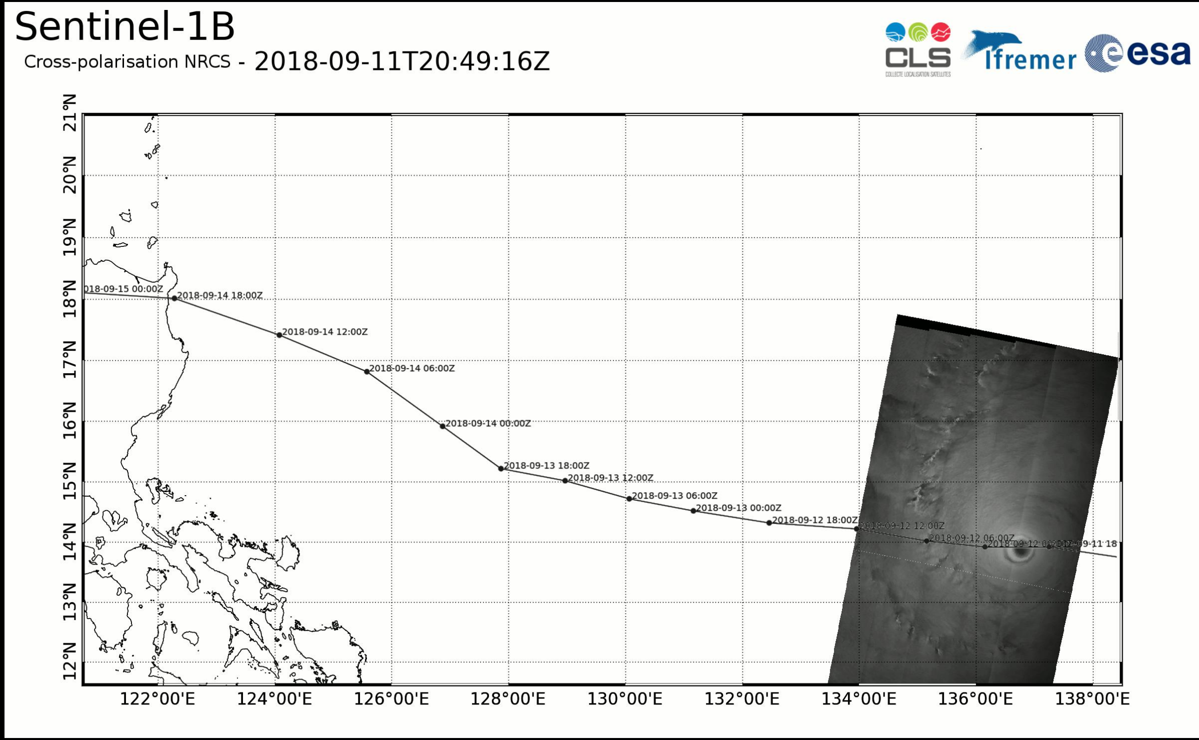
- Sea-ice mapping (distinguishing between first
- year and multi-year sea ice)

- Oil-spill monitoring
- Ship detection for maritime security

Sentinel-1 A and B acquisition during the Mangkhut Typhoon

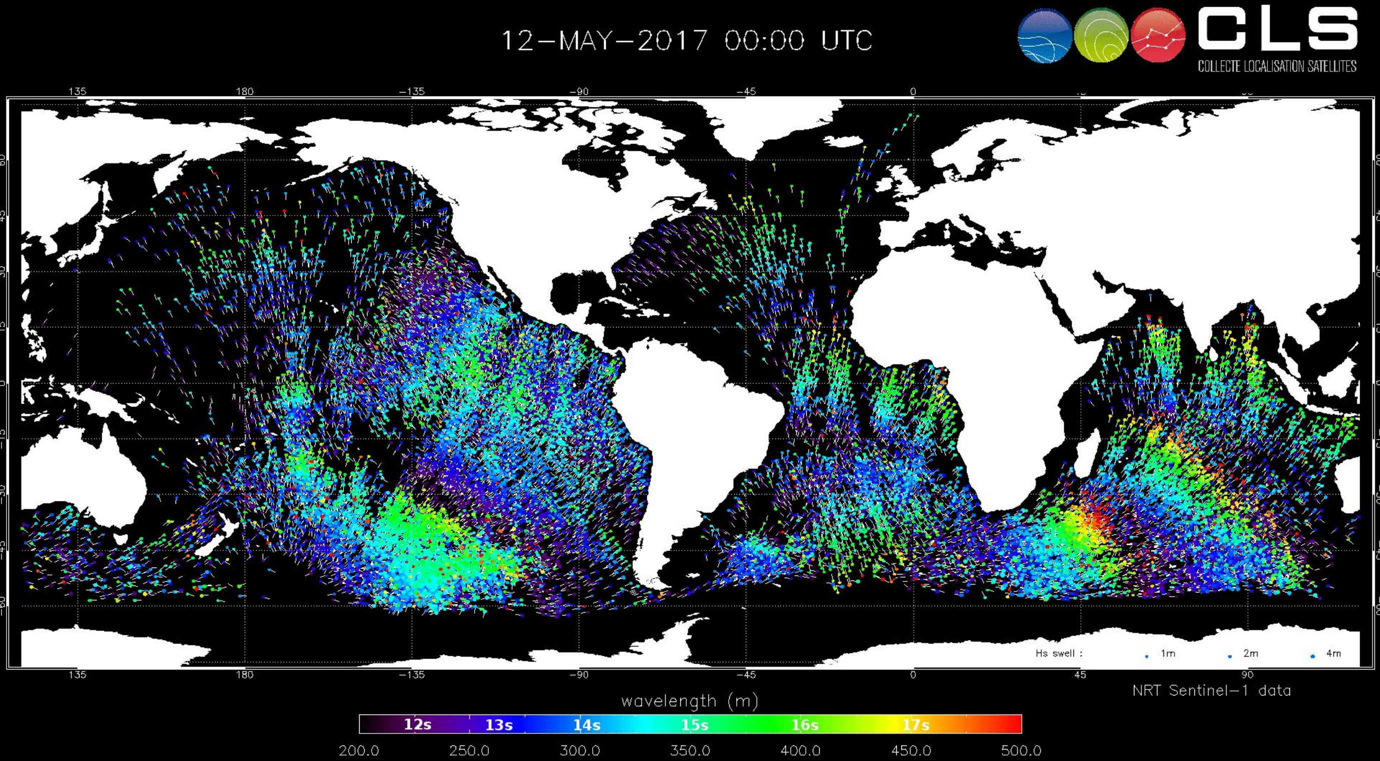
The dark areas of low backscattering values: "quiet" areas, such as the eye of the cyclone.

On the contrary, light areas with high backscattering values: rough surfaces (strong waves or rain).



Sentinel-1 is THE swell instrument

S1A and S1B Global NRT Swell tracking (Wave Mode over 10 days)



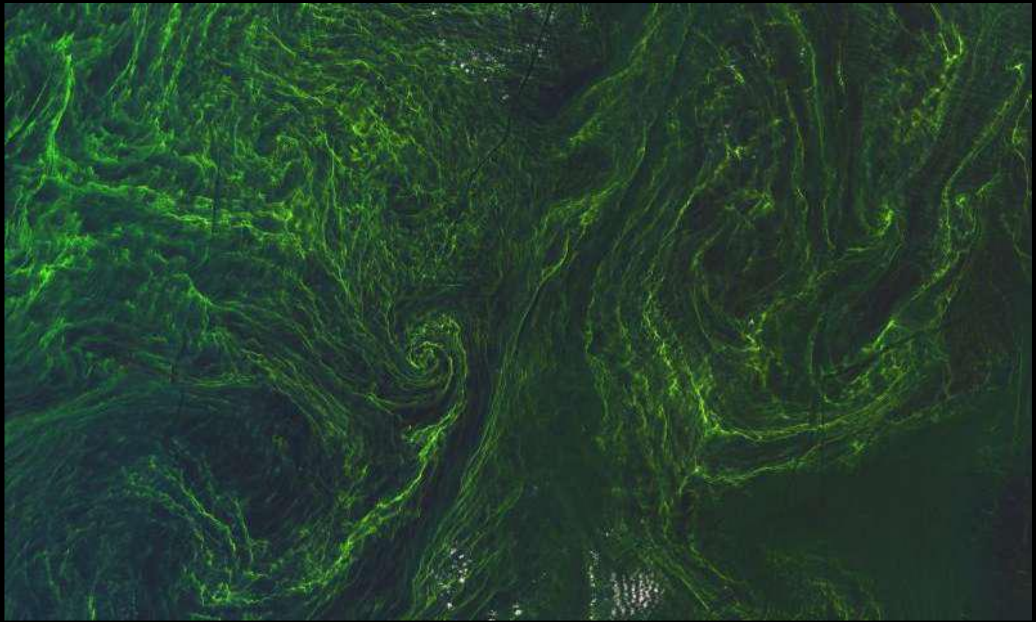
Sentinel-2

SENTINEL-2 is a wide-swath, high-resolution, multi-spectral (13 bands) imaging mission, supporting Copernicus Land Monitoring studies, including the monitoring of vegetation, soil and water cover, as well as observation of inland waterways and coastal areas.

Algal bloom in the Baltic Sea

This red–blue–green composite image from Sentinel-2A taken on 7 August 2015 has a spatial resolution of 10 m.

Useful for biological studies and physical studies: the algae concentration is drawn out by the water circulation.

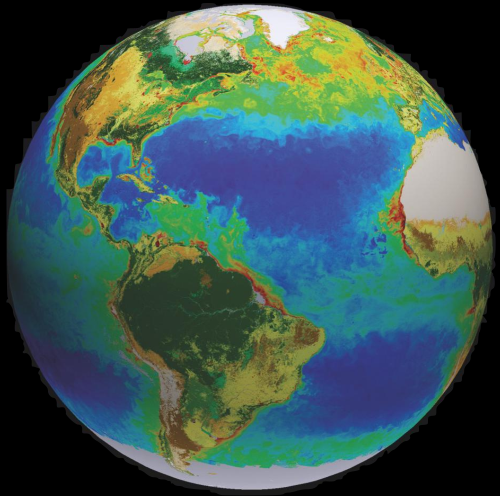


Credit: Copernicus Sentinel data/ESA

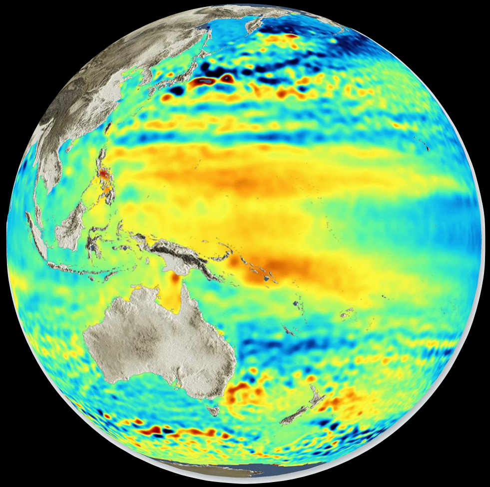
Sentinel-3

Sentinel-3 is primarily an **ocean mission.**

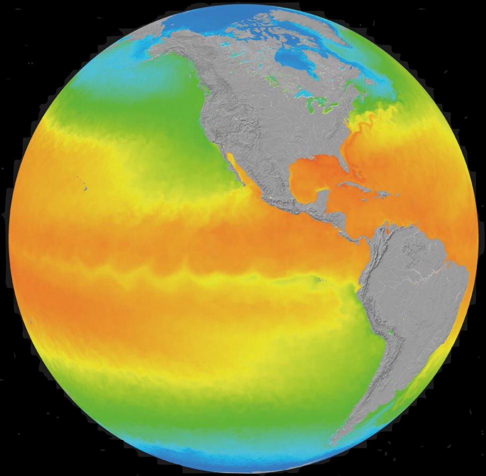
Ocean and Land Colour Instrument (OLCI)



SAR altimeter (SRAL)



Sea and Land Surface Temperature Radiometer (SLSTR)



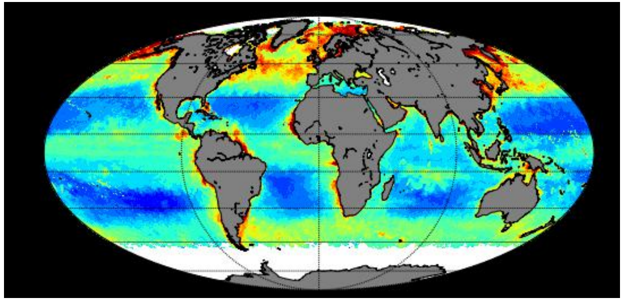
Sentinel-3 OLCI: Ocean Colour

A high number of parameters can be retrieved from ocean colour sensor

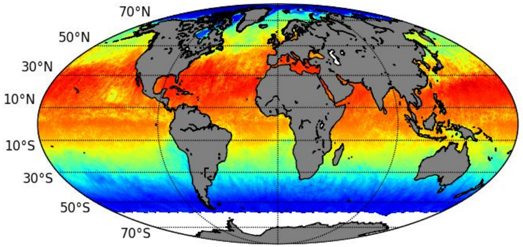
Among others:

- The phytoplankton biomass (as indexed by Chl-a)
- The photosynthetically active radiation (PAR)

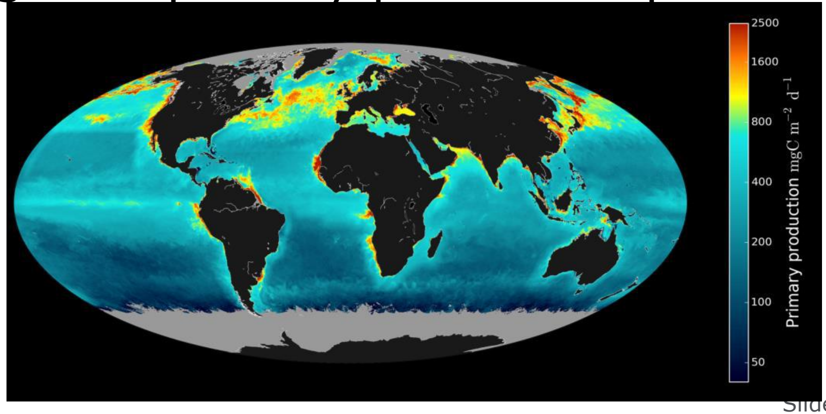
ESA OC-CCI Chl-a



New ESA PAR product



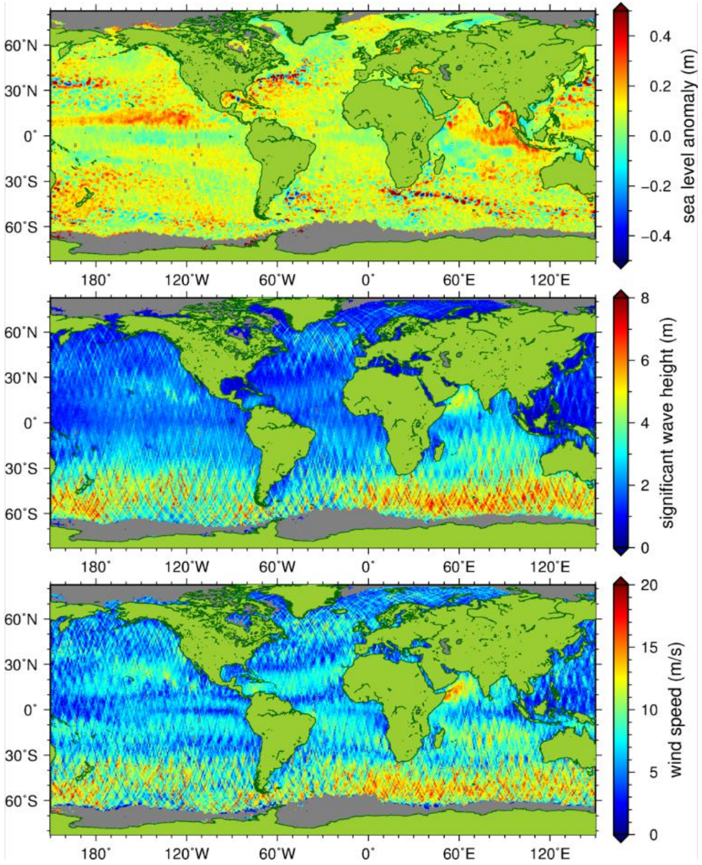
ESA integrated primary production product



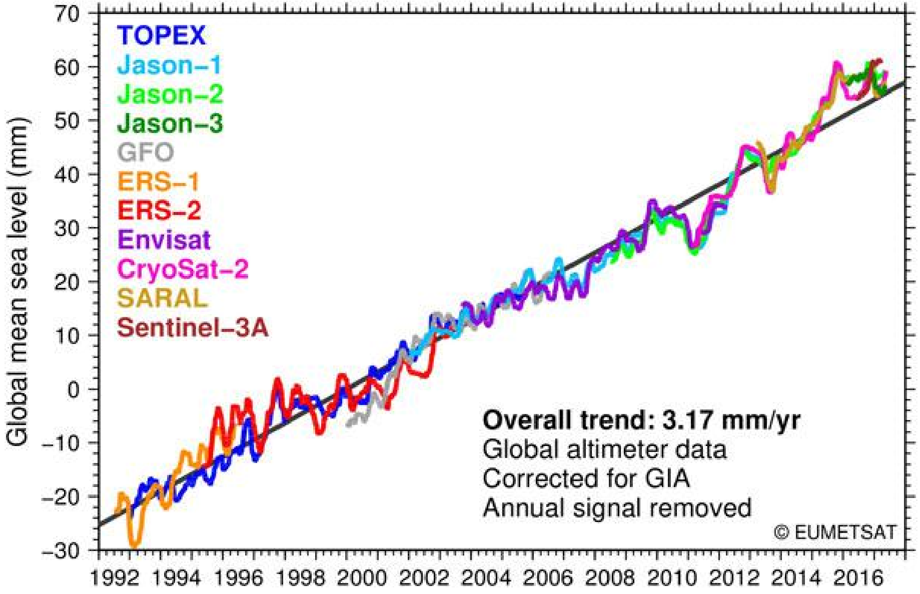
PAR is essential for the carbon-cycle modellers to convert the measured chlorophyll concentration into an estimate of ocean productivity, and hence of carbon sequestration.

Bouman et al (2018) ESSD

Sentinel-3 SRAL

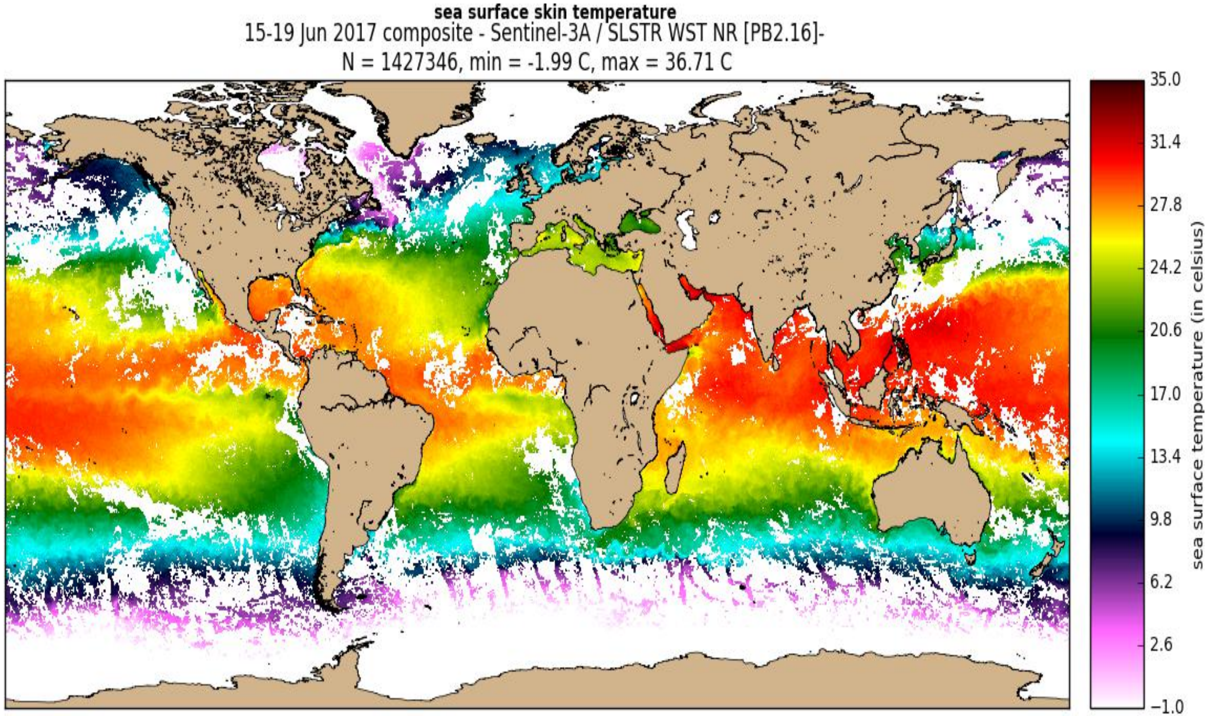


S-3 contributes to the monitoring of Sea Level Change



Sentinel-3 SLSTR: Sea Surface Temperature

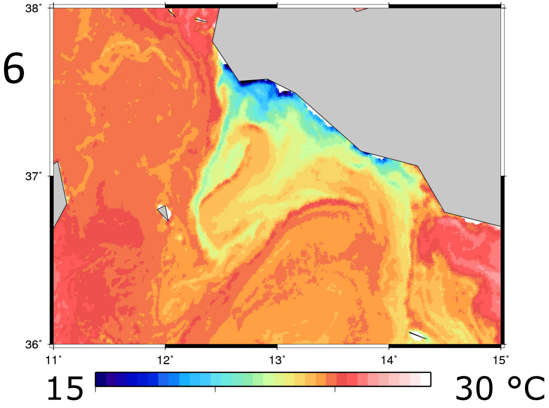
- Major indicator of climate change
- Monitor the onset and evolution of future El Niño events
- The surface temperature of the oceans also affects the intensity of hurricanes and tropical cyclones
- Retrieval of sea ice parameters



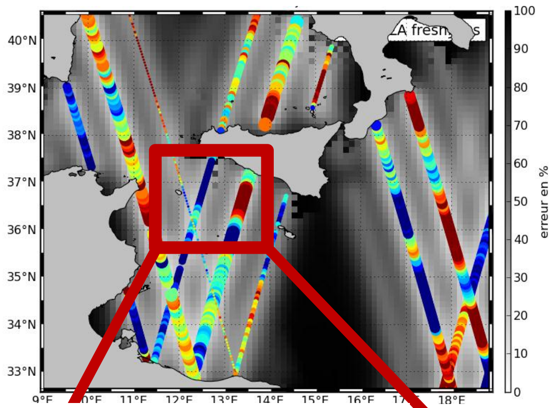
Sentinel-3 data merging for ocean currents retrieval

July, 28th 2016

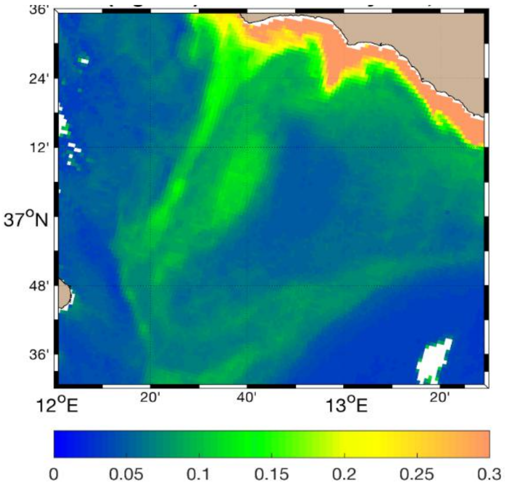
S-3 Sea Surface Temperature



S-3 along-track Sea Level Anomalies (+- 5 days)

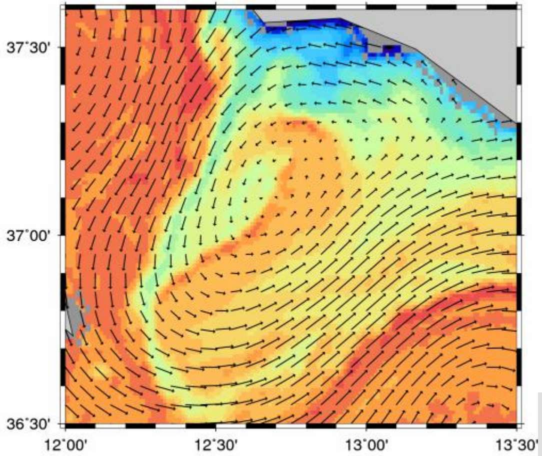


S-3 Chl-a concentration



mg.m^{-3}

S-3 SSH currents

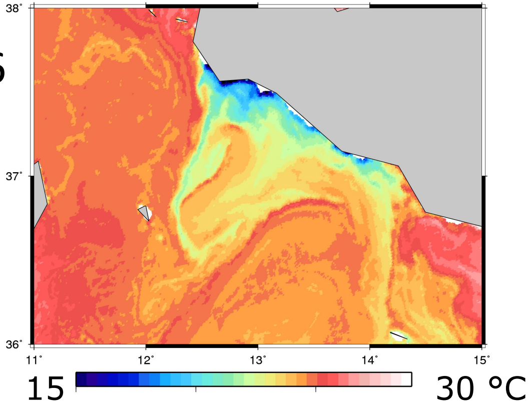


Rio et al, 2018

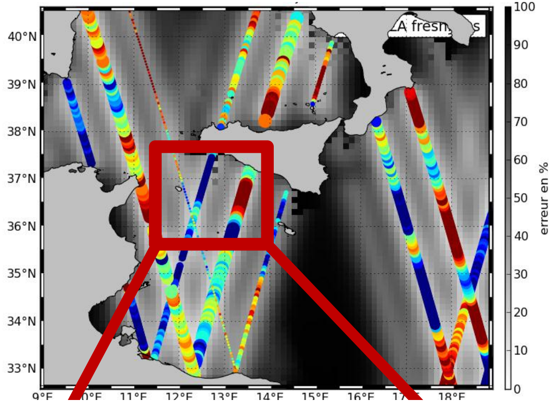
Sentinel-3 data merging for ocean currents retrieval

July, 28th 2016

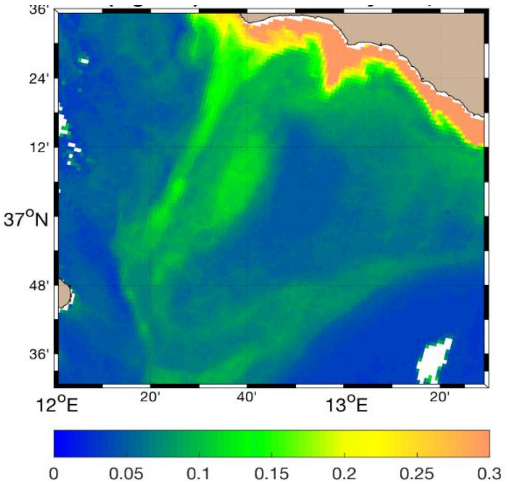
S-3 Sea Surface Temperature



S-3 along-track Sea Level Anomalies (+- 5 days)

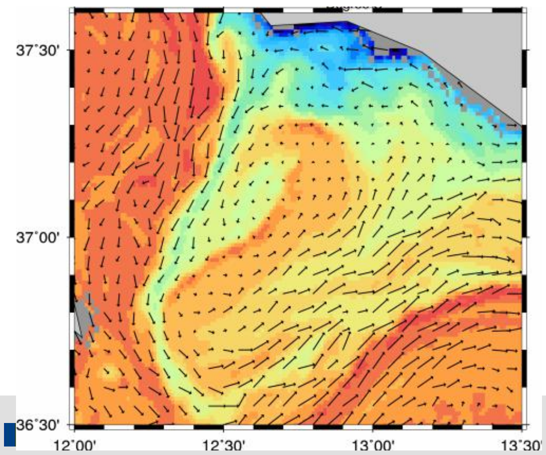


S-3 Chl-a concentration



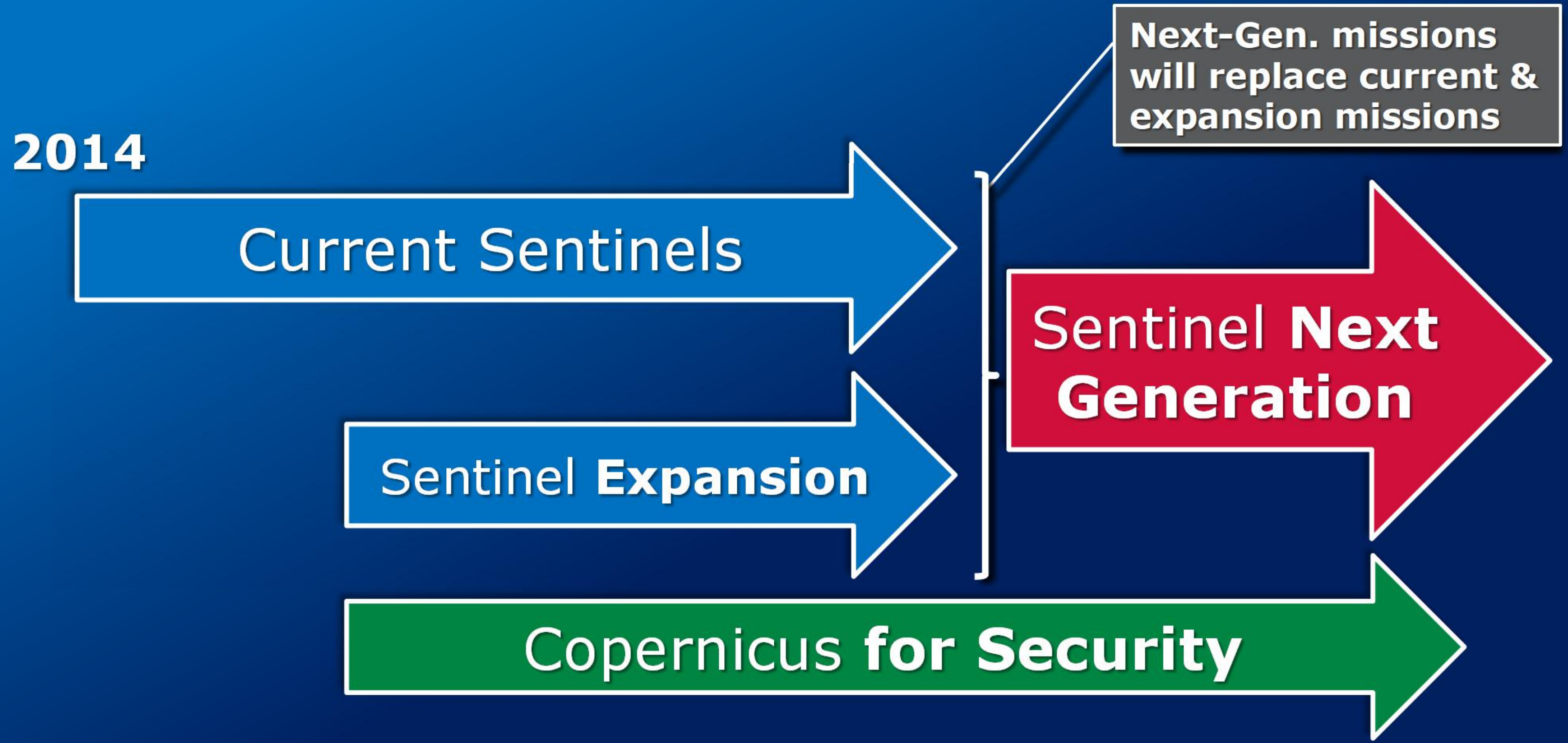
mg.m^{-3}

S-3 SSH+SST currents



Rio et al, 2018

Copernicus Space Component Evolution



Initial CSC Evolution

Current & New Sentinels

S1 — C-band SAR

S2
S8
S10

MSI (VNIR/SWIR Imaging)
TIR Imaging
Hyper-Spectral

S3 Altim. + opt. in SSO — OPT TOPO

S6 Reference Altim.

S9 Altimetry ice snow

S4
S5P, S5
S7

GEO
LEO
CO2

Next Generation

C-band SAR NG
L-band SAR
Low-frequ. (eg L/C-band) radiometers

S1 NG

MSI+TIRI NG
Hyper-spectral NG
OLCI+SLSTR NG

S2+S3 NG

GEO

ALT in SSO NG
ALT reference NG
ALT ice snow NG

TOPO

LEO / CO2 + …

ATM

Candidates to be verified through requirements process (+ observations optimisation through architecture studies)

Capability

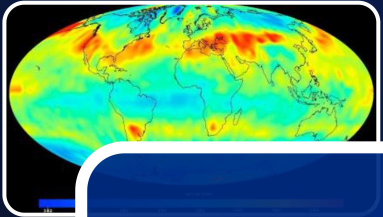
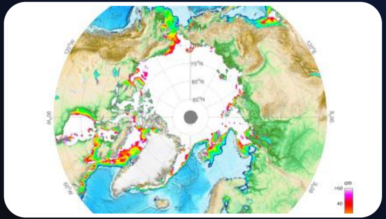
Earth Microwave (4D) Imaging

Earth Optical Imaging

Earth Topography by Altimetry

Earth Atmosphere by Spectroscopy

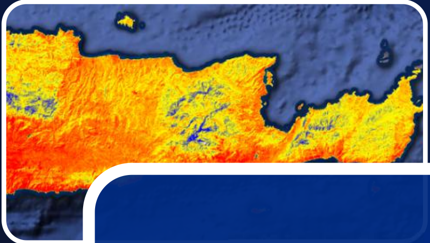
Sentinel Expansion (7 to 12)

High Priority Candidate Missions		Applications
	Anthropogenic CO_2	Climate Change (Causes)
	Polar Ice & Snow	Climate Change
	Passive Microwave Imaging	Sea Surface Temperature & Sea Ice Concentration

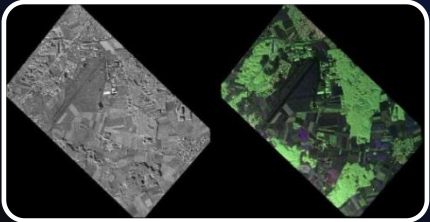
Status: Phase A/B1 system studies

Sentinel Expansion (7 to 12)

High Priority Candidate Missions



High Resolution
Land Surface



L-band
SAR

Applications

Agriculture & Urban
Management Services

Soil, Vegetation, Food
Security & Ground Motion

Status: Phase A/B1 system studies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