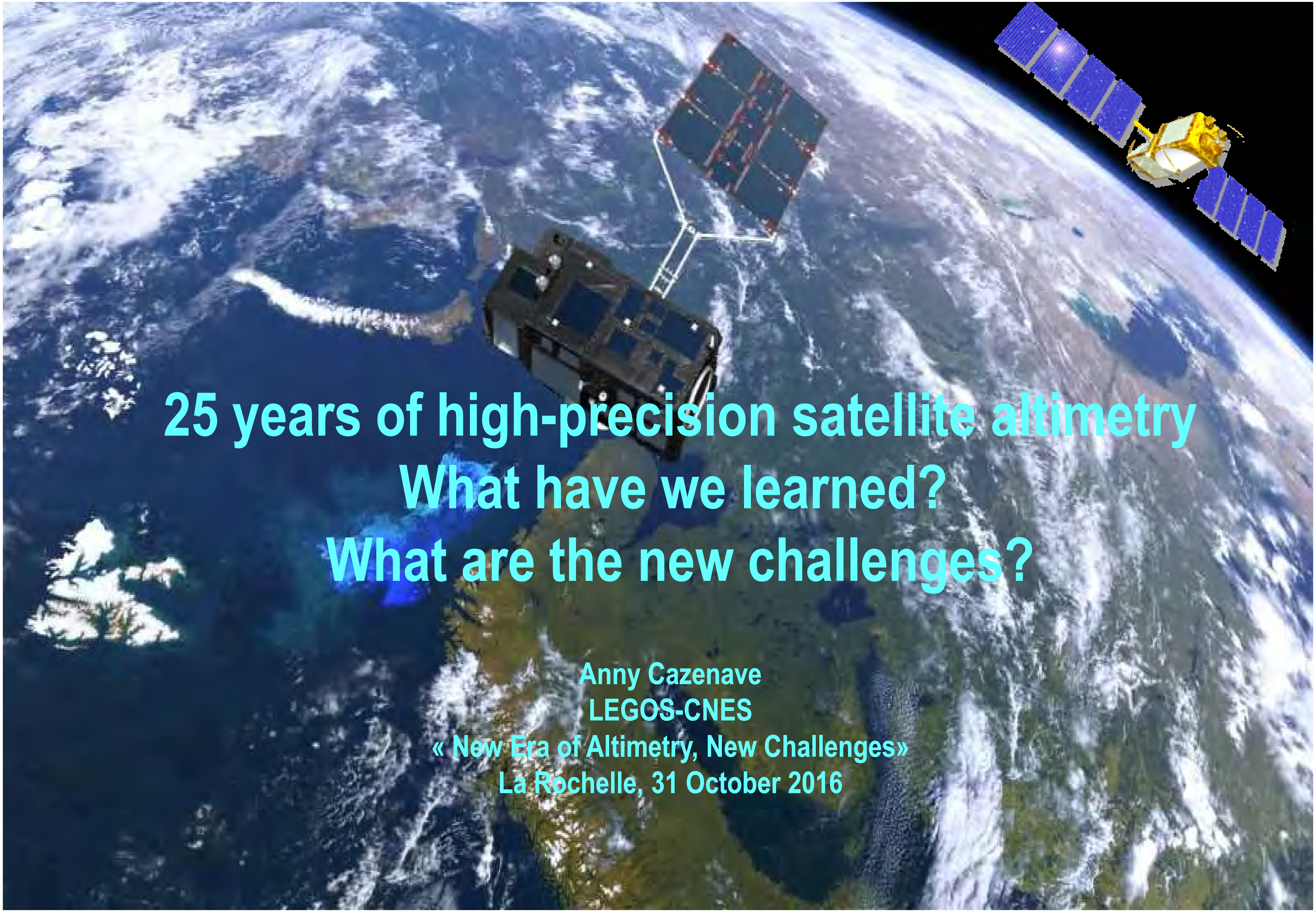
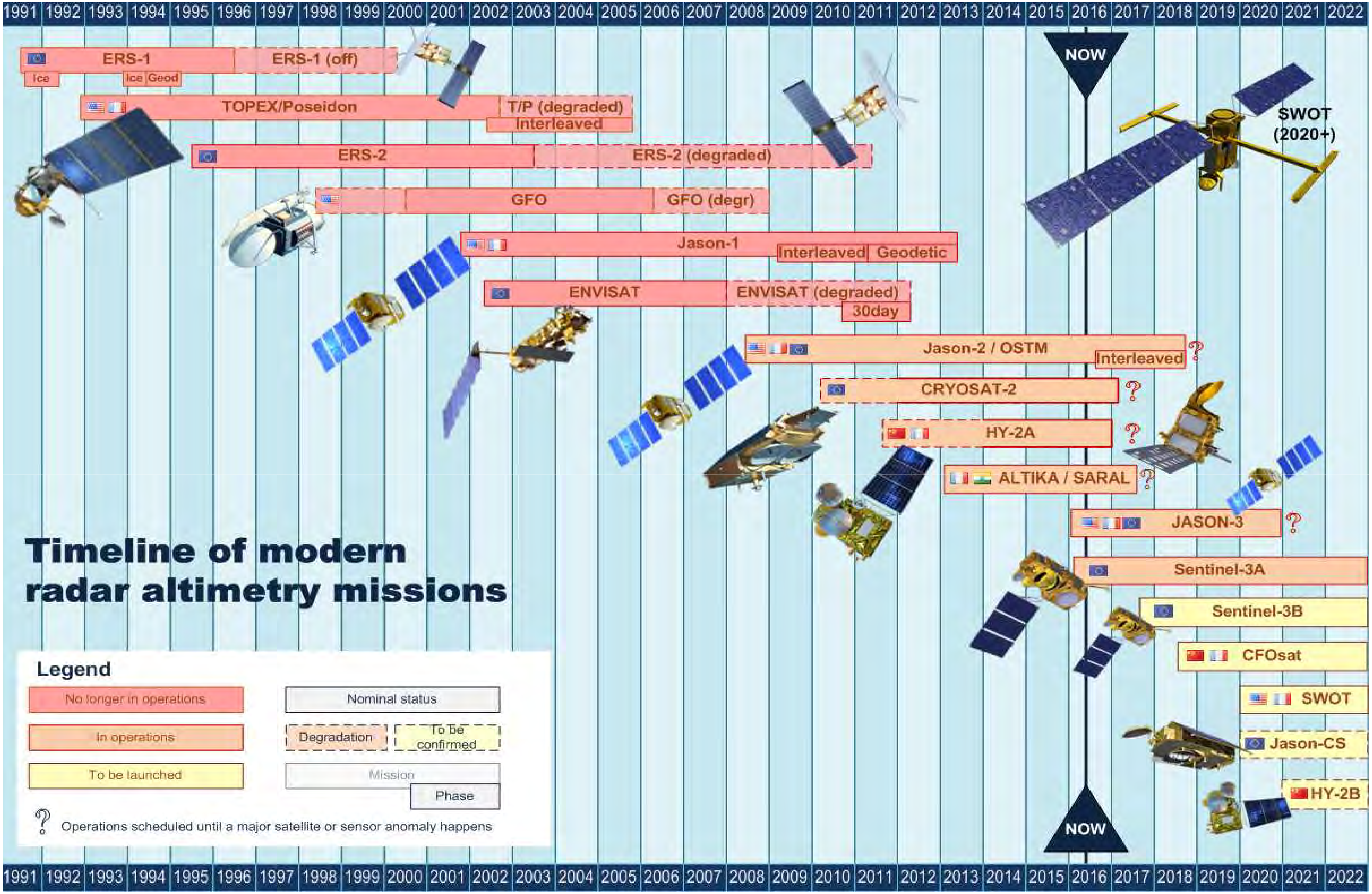


25 years of high-precision satellite altimetry
What have we learned?
What are the new challenges?

Anny Cazenave
LEGOS-CNES

« New Era of Altimetry, New Challenges»
La Rochelle, 31 October 2016



Courtesy : G. Dibarboure

Representatives from operational space agencies –ESA, EUMETSAT, CNES, ISRO, NASA, NOAA- and altimetry products users met under the auspices of CEOS (Committee on Earth Observation Satellites) to discuss altimetry satellite constellations and outline a plan for the following 15 years

Outcome of the Assmannshausen Workshop
→Recommandations for an implementation plan over the following 15 years

- *Maintain continuity of high-acuracy Jason altimetry*
- *Maintain continuity with altimeters on at least 2 complementary, high-inclination satellites*
- *Extend the capability of altimetry to denser observational coverage through swath altimetry*
- *Maintain a continuity partnership with the scientific community*
- *Maintain broad collaboration with engineering & science, research & operations, and international partners*

Outcome of the Assmannshausen Workshop →Recommandations for an implementation plan over the following 15 years

- *Maintain continuity of high-a[illegible] Jason altimetry*

DONE

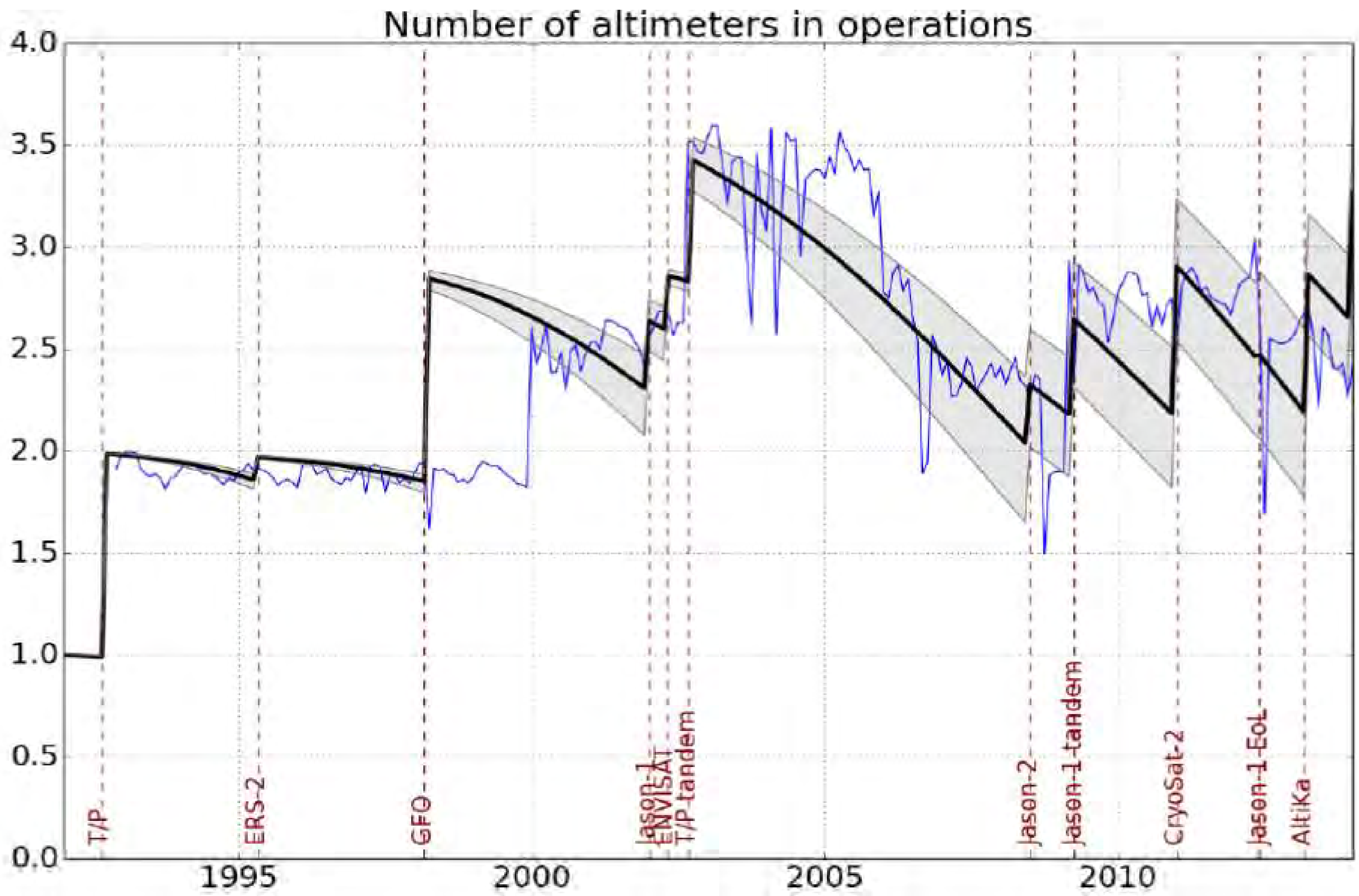
Sentinel 6: Continuity of the Topex-Jason series

Outcome of the Assmannshausen Workshop
→Recommandations for an implementation plan over the following 15 years

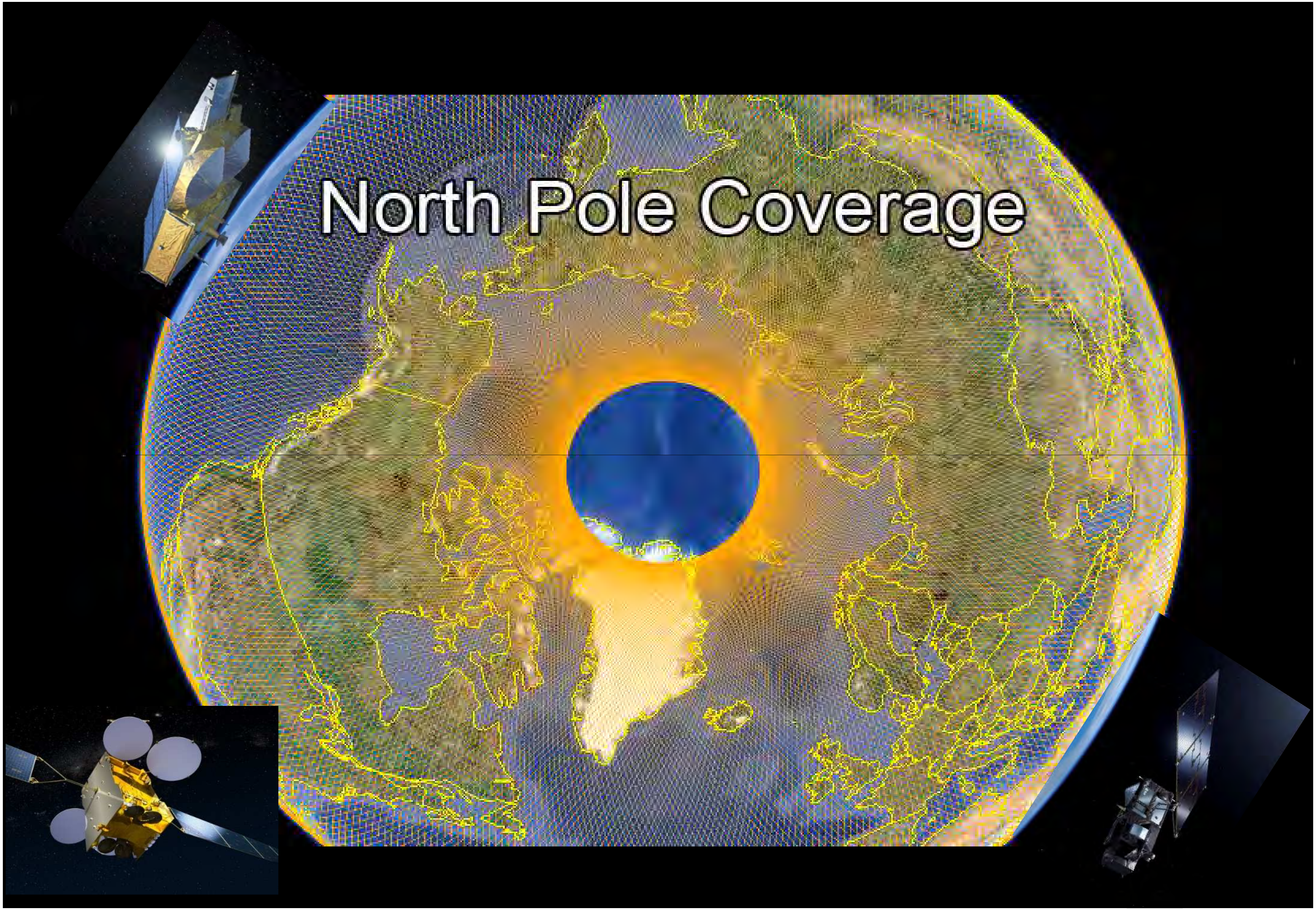
- *Maintain continuity with altimeters on at least 2 complementary, high-inclination satellites*

DONE

Monthly ratio between number of actual measurements divided by the theoretical number of measurements for a given altimeter.



Source : Dibarboure & Lambin, 2016

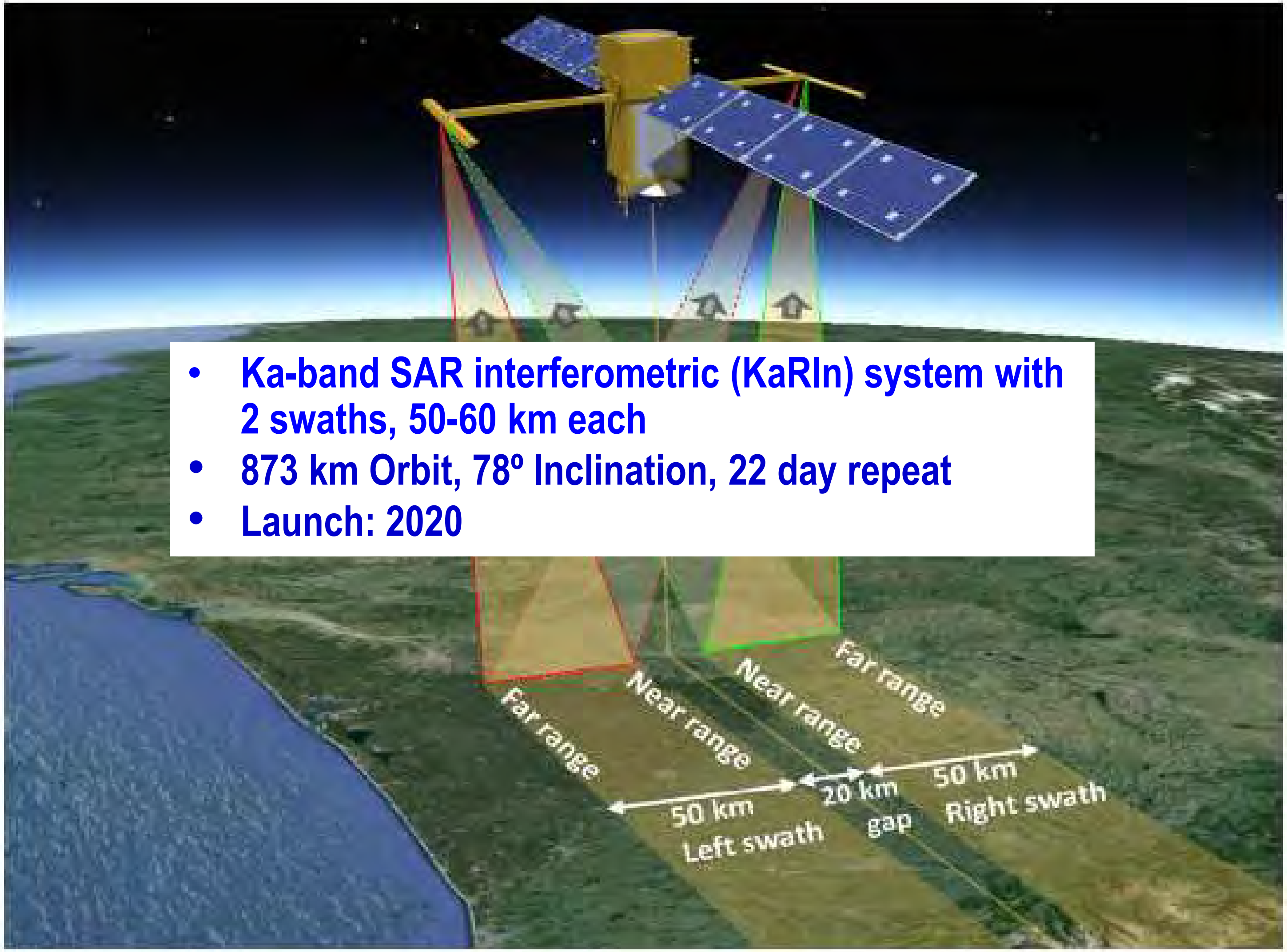

North Pole Coverage

Outcome of the Assmannshausen Workshop
→ Recommandations for an implementation plan over the following 15 years

- *Extend the capability of altim… denser observational coverage through sw…*

DONE

Surface Water and Ocean Topography (SWOT)



- Ka-band SAR interferometric (KaRIn) system with 2 swaths, 50-60 km each
- 873 km Orbit, 78º Inclination, 22 day repeat
- Launch: 2020

Canadian Space Agency, UK Space Agency

Courtesy: Biancamaria et al., 2016

Outcome of the Assmannshausen Workshop →Recommandations for an implementation plan over the following 15 years

- *Maintain a continuity partn[illegible]h the scientific community*
- *Maintain broad collabo[illegible]ith engineering & science, research & operations, [illegible]d international partners*

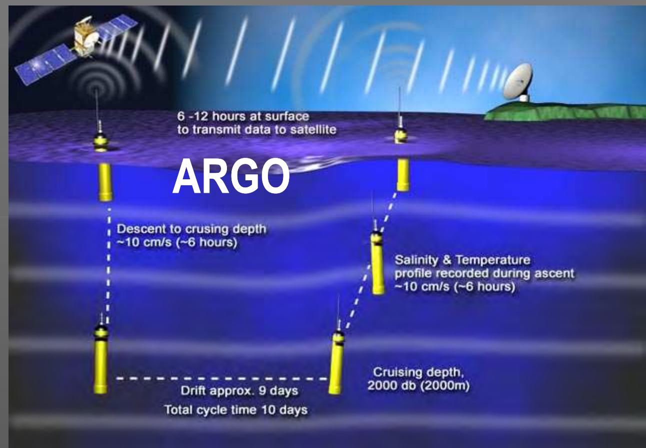
DONE

Annual OSTST meetings, Climate Change Initiative/CCI collocations meetings, EUMETSAT-WCRP Climate Symposium, ESA Living Planet Symposia, etc.

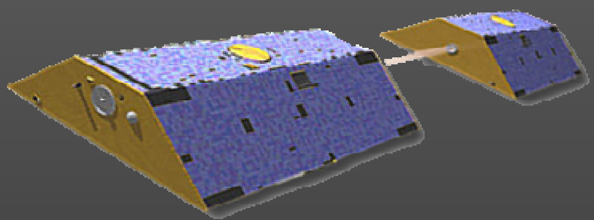
Another important recommendation:
Use different observing systems in synergy

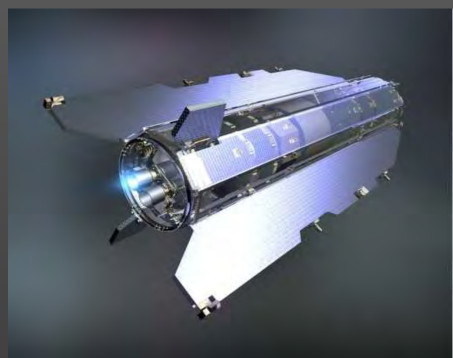
Use of altimetry in synergy with other ‘ocean’ missions and in situ observing systems

→ Argo (steric sea level)
→ GOCE (static geoid)
→ GRACE (time variable sea level)
→ IR radiometry (SST)
→ SMOS/Aquarius/SMAP (sea surface salinity)



→ Ocean modelling → ocean reanalyses



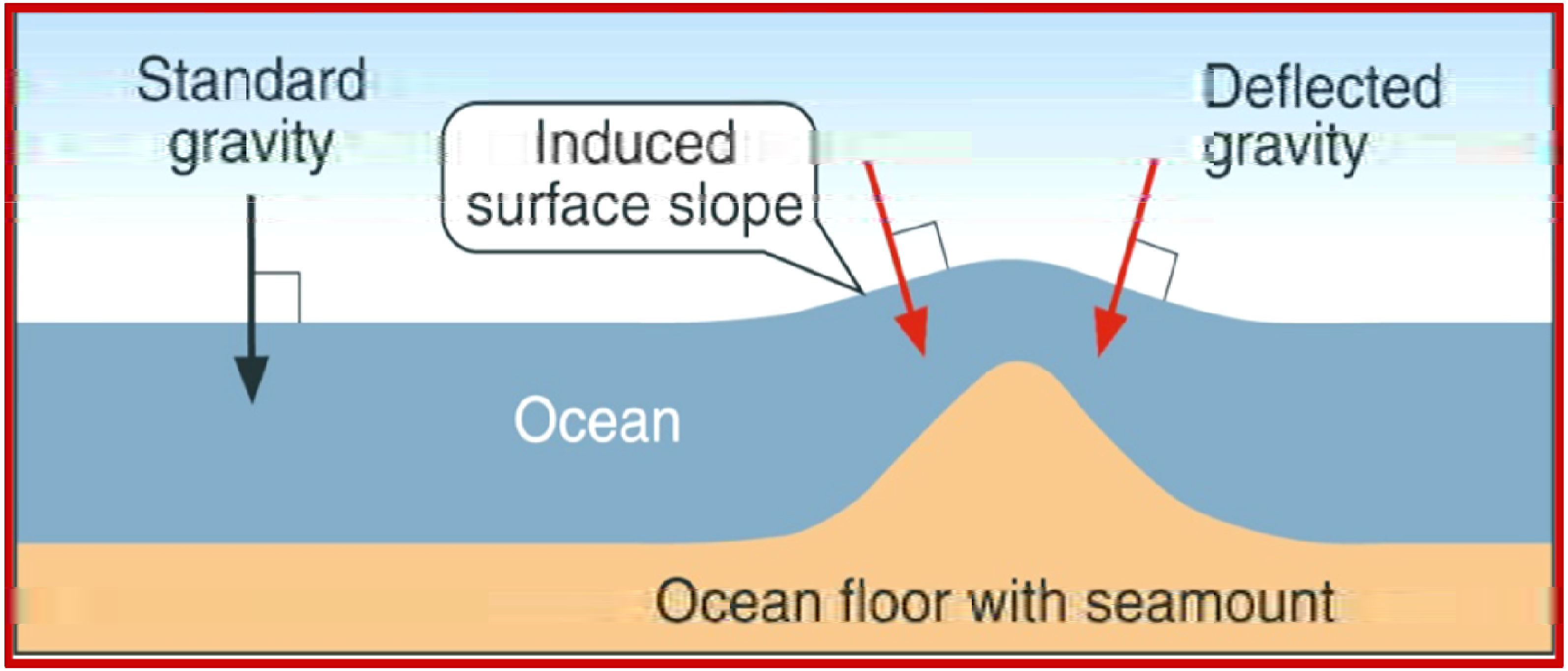


What have we learned from the 25-year long record of high-precision satellite altimetry?

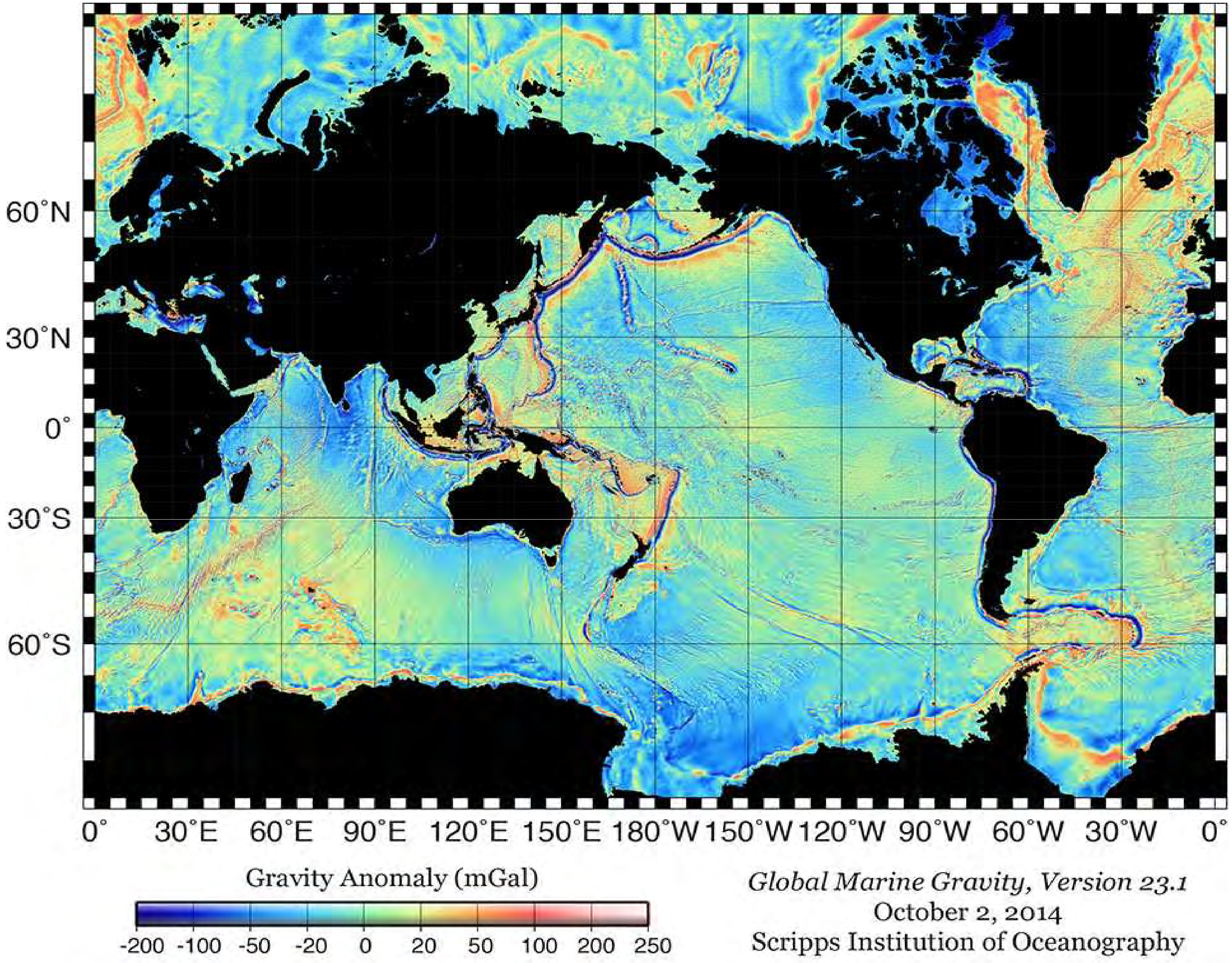
Mean sea surface/marine geoid/ seafloor topography

SEA SURFACE TOPOGRAPHY

- **Static component → geoid/marine gravity field (1m-50+m)**
- **Time-variable component → ocean dynamics, ocean tides, …. (1cm-1m)**



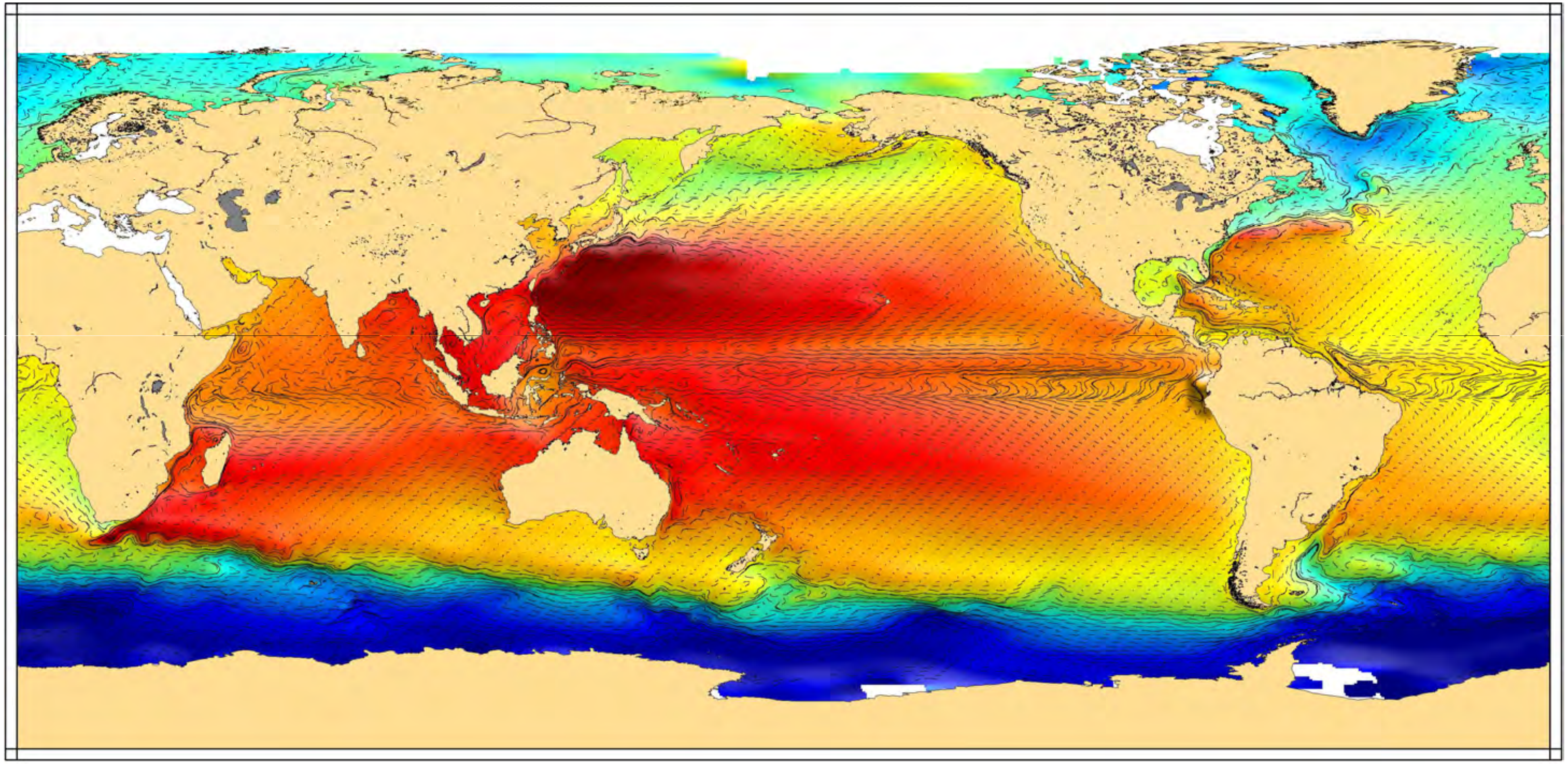
Gravity reveals seafloor topography

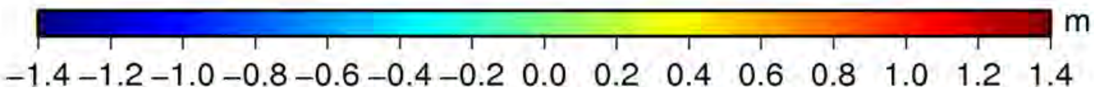


Sandwell, D. T., E. Garcia, K. Soofi, P. Wessel, and W. H. F. Smith, *Towards 1 mGal Global Marine Gravity from CryoSat-2, Envisat, and Jason-1*, 2013
Garcia, E., D. T. Sandwell, and W.H.F. Smith, *Retracking CryoSat-2, Envisat and Jason-1 radar altimetry waveforms for improved gravity field recovery*, 2014

Dynamic topography

Dynamic Topography ('*mean sea surface' above the 'geoid*') → ocean current velocity proportional to the sea surface slope

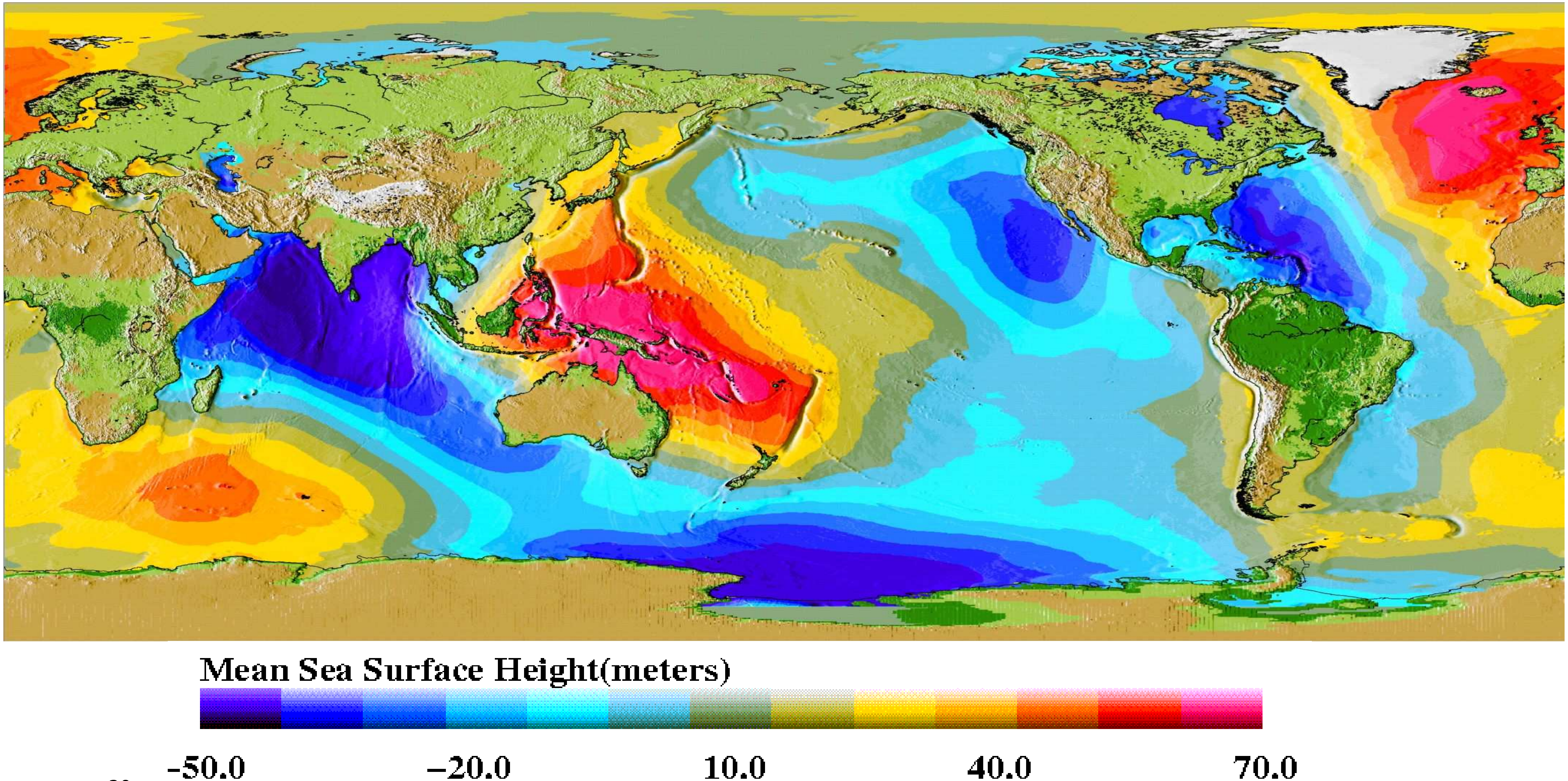




Source: AVISO

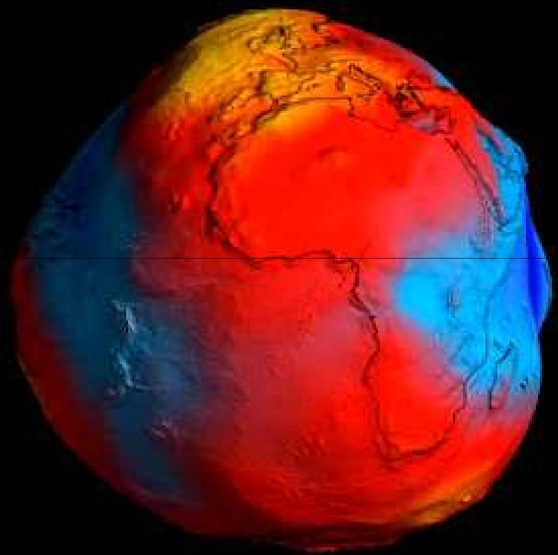
Mean Sea Surface from 20 years of satellite altimetry

DTU15MSS



Courtesy: O. Andersen

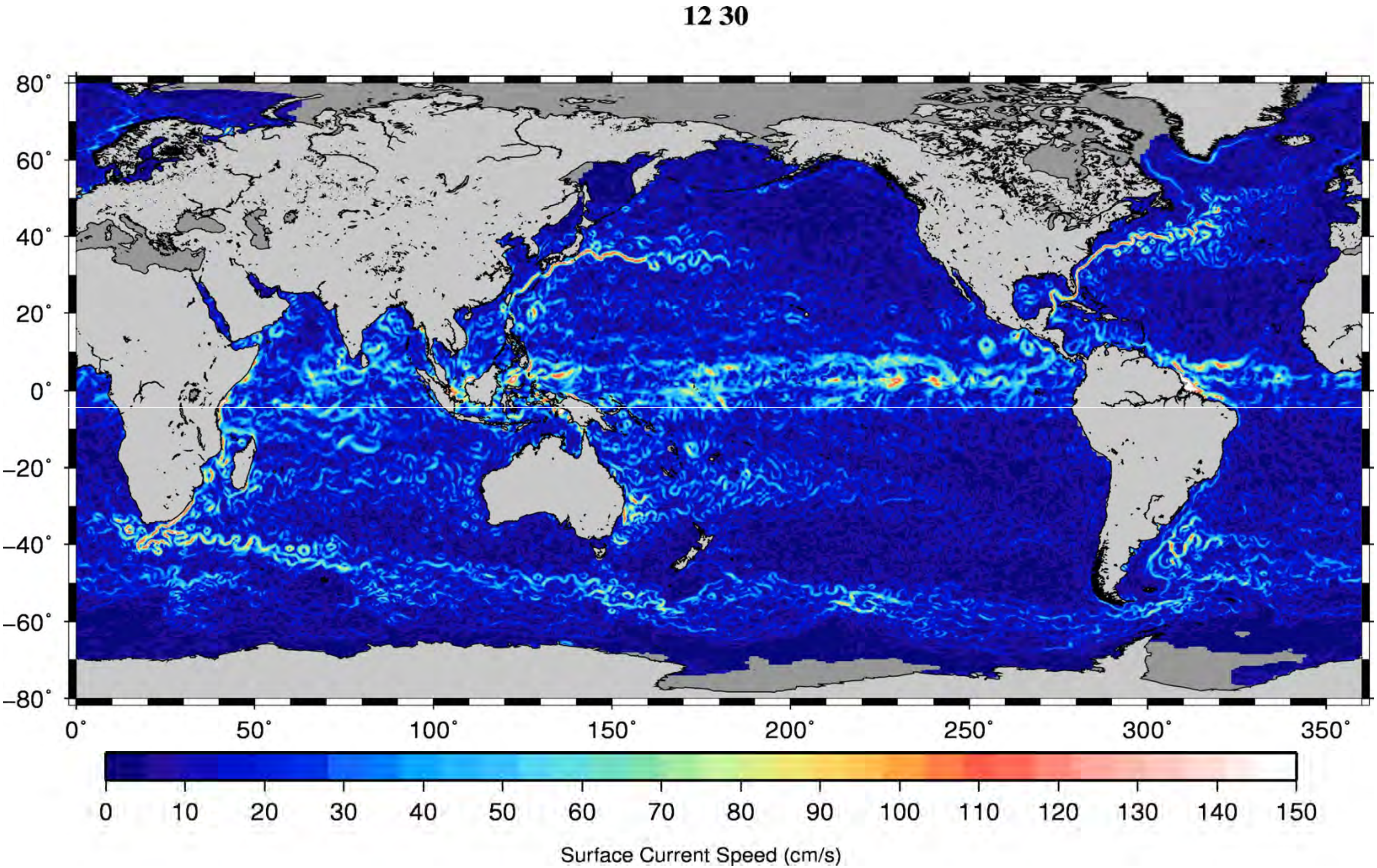
Goce mission
(2009-2013)
ESA

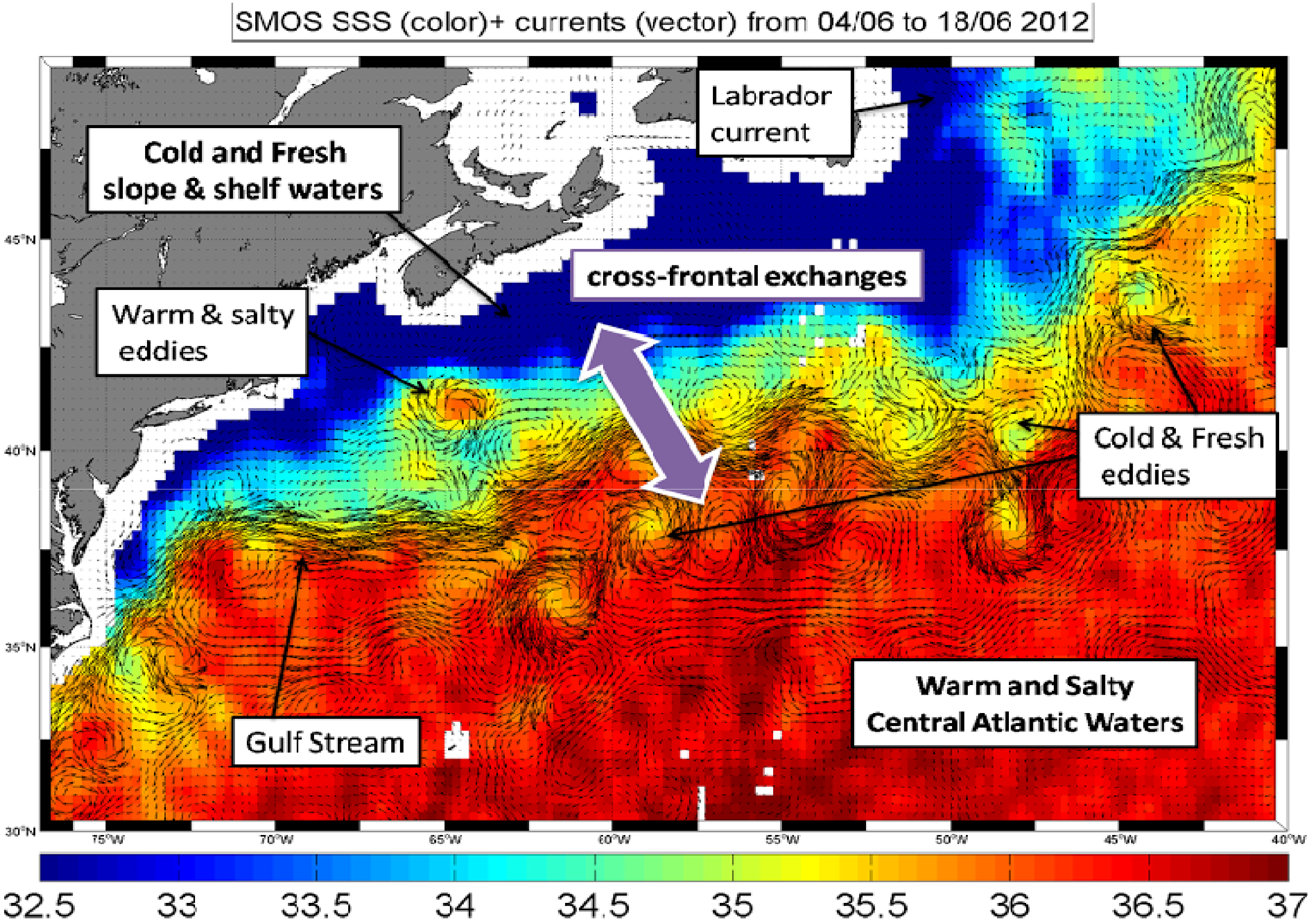


The Earth's gravity feld

Ocean circulation

Courtesy : MH Rio





Source : Le Traon et al., 2015

Operational oceanography

Operational oceanography

Important products derived from operational oceanography are:

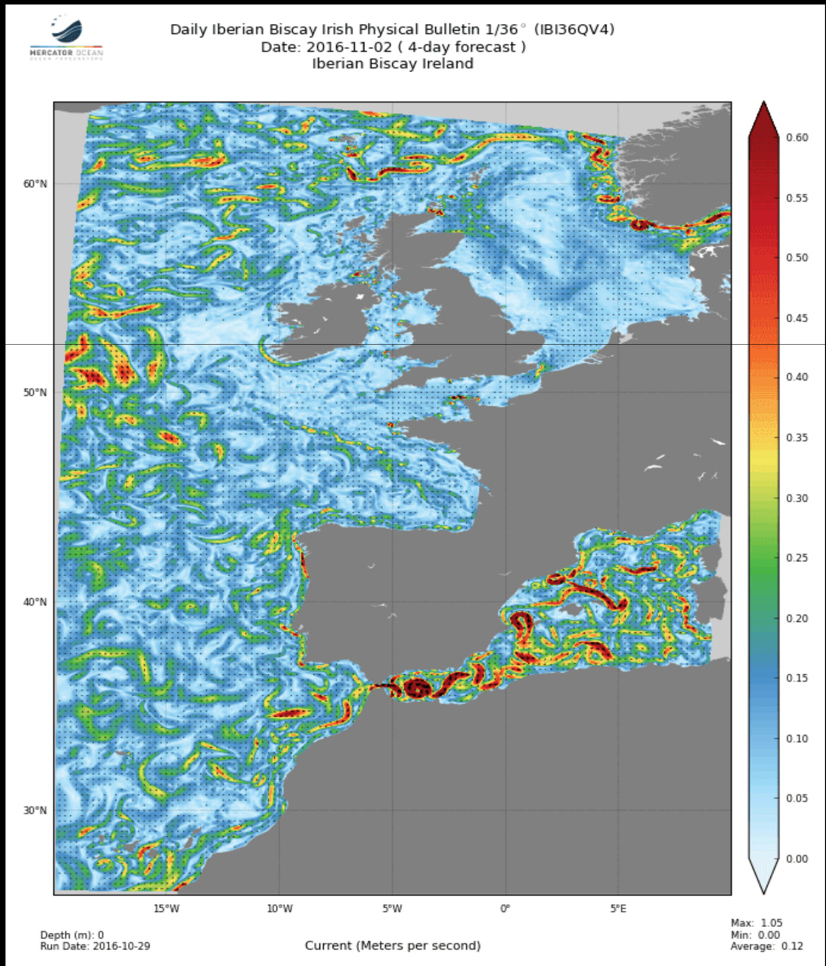
- **nowcasts** providing accurate description of the present state of the ocean
- **forecasts** providing future ocean conditions
- **hindcasts** assembling long term data to describe past states

Satellite altimetry is a key component of operational oceanography

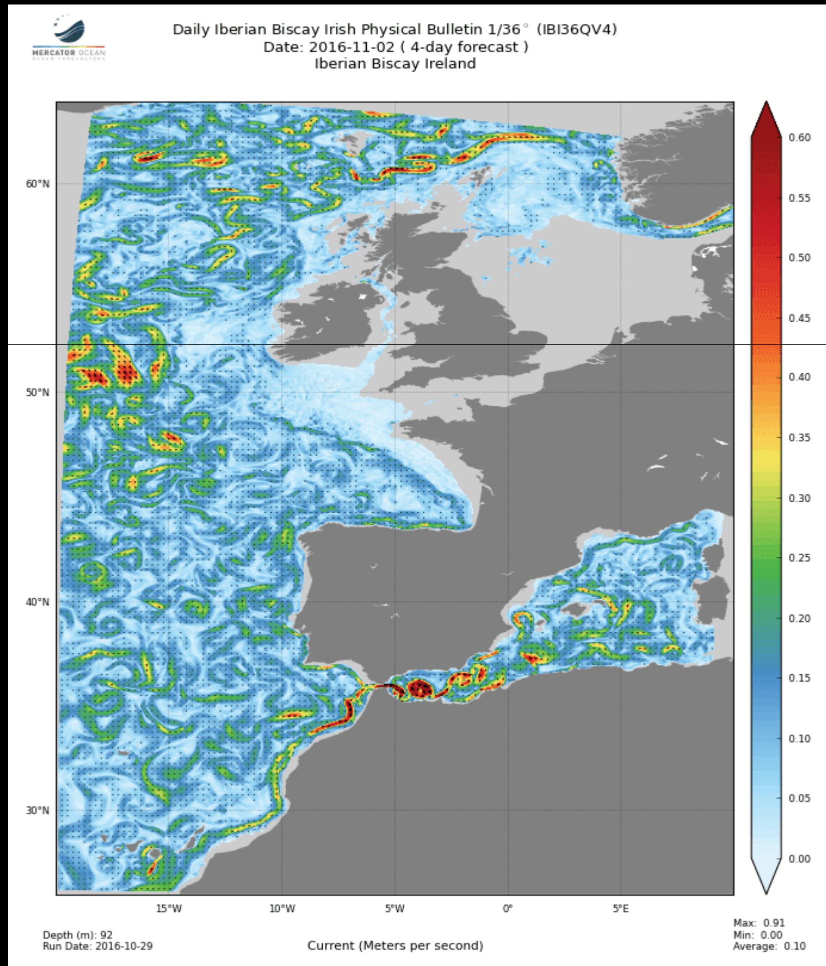
Operational Oceanography

MERCATOR
ocean state forecast → currents (2 Nov. 2016)

surface



100 m depth



Sectors of applications

- Marine transport
- Search and rescue
- Oil spill response

Near surface conditions (currents & T)

- Oil & gas →Currents at small spatial scales
- Naval operations → among others, mesoscale phenomena
- Environmental protection
- Fisheries
- Short-range weather prediction
- Seasonal prediction

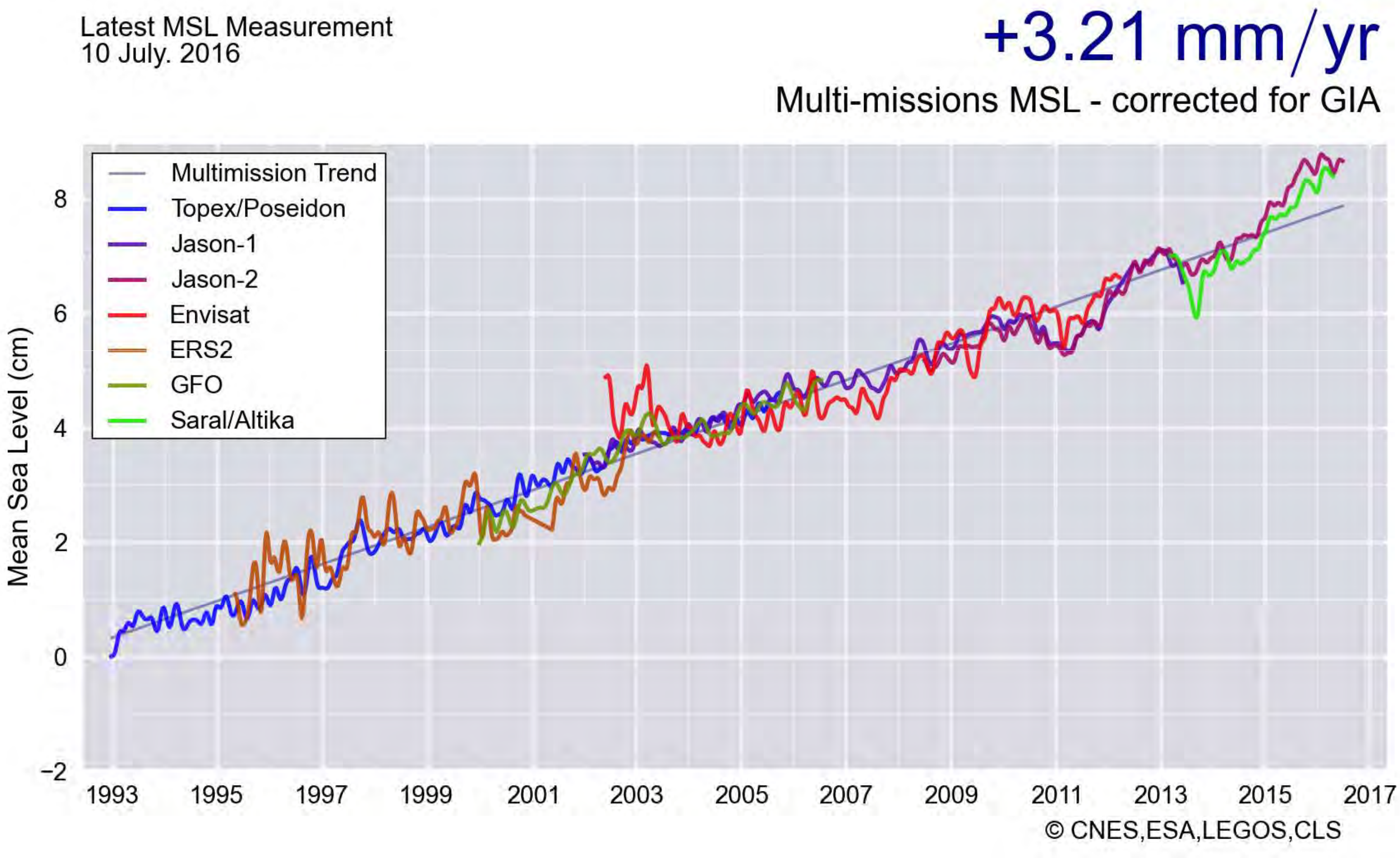
Surface fields

Real time products and hindcasts

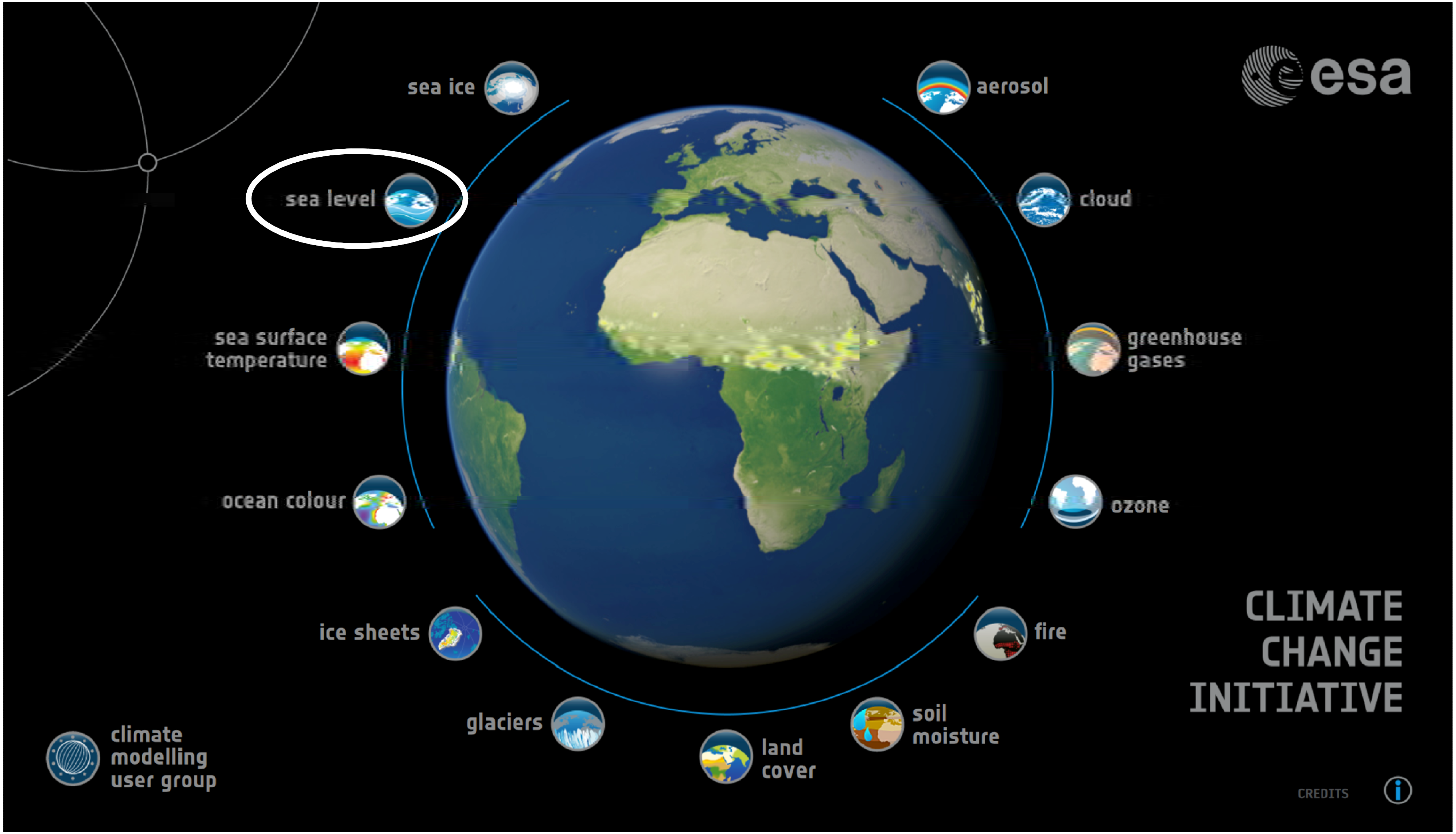
Source: Bell et al 2015

Sea level

Global mean sea level from satellite altimetry multi missions



ESA Climate Change Initiative
13 CCI ECVs, 14 projects



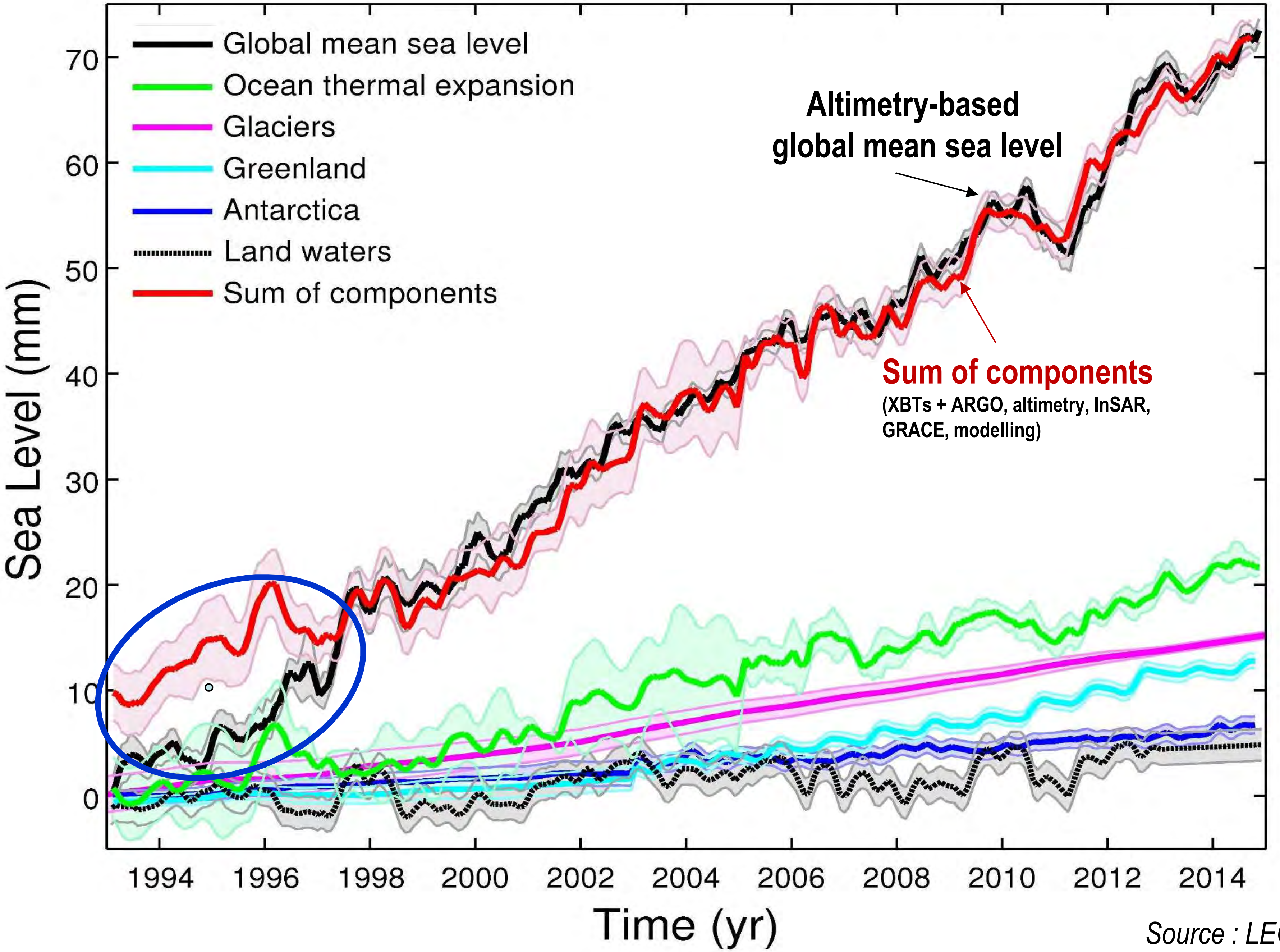
Current Sea Level Uncertainties
«ESA Climate Change Initiative/CCI» products

Spatial Scales	Temporal Scales	GCOS Requirements	Errors of CCI products
Global Mean Sea Level	Long-term trend	<0.3 mm/yr	<0.5 mm/yr
	Interannual signals	0.5 mm over 1 year	< 2 mm over 1 year
Regional Sea Level	Long-term trend	<1 mm/yr	<3 mm/yr

GCOS: Global Climate Observing System

Source: Ablain et al., 2015, 2016

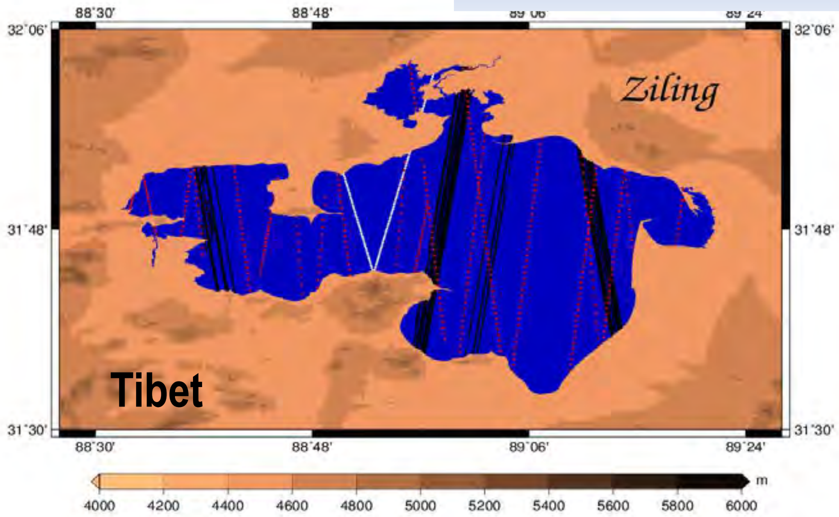
Sea Level Budget (1993-2015)

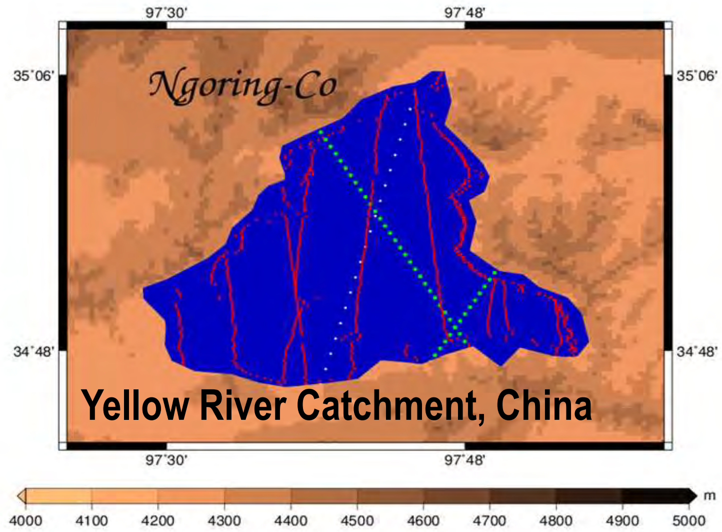


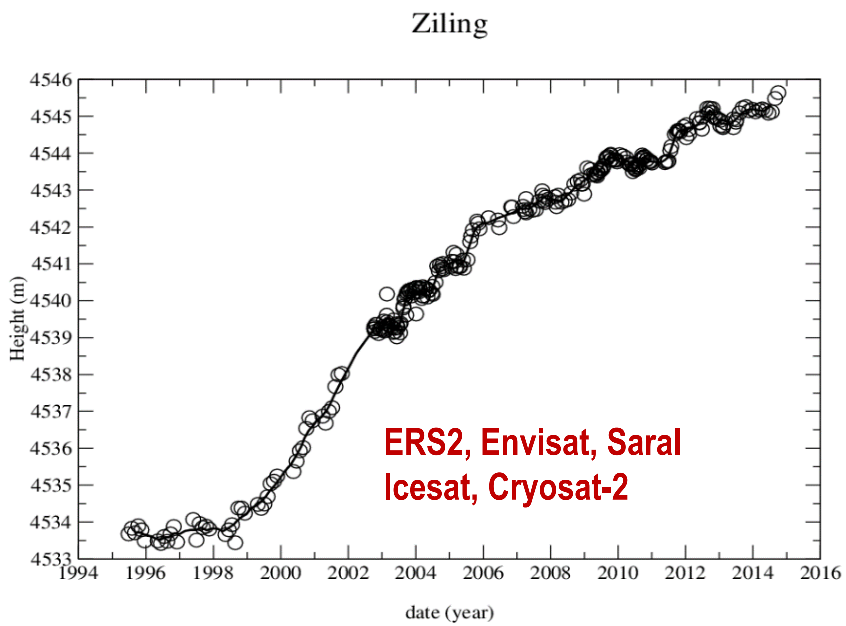
Source : LEGOS

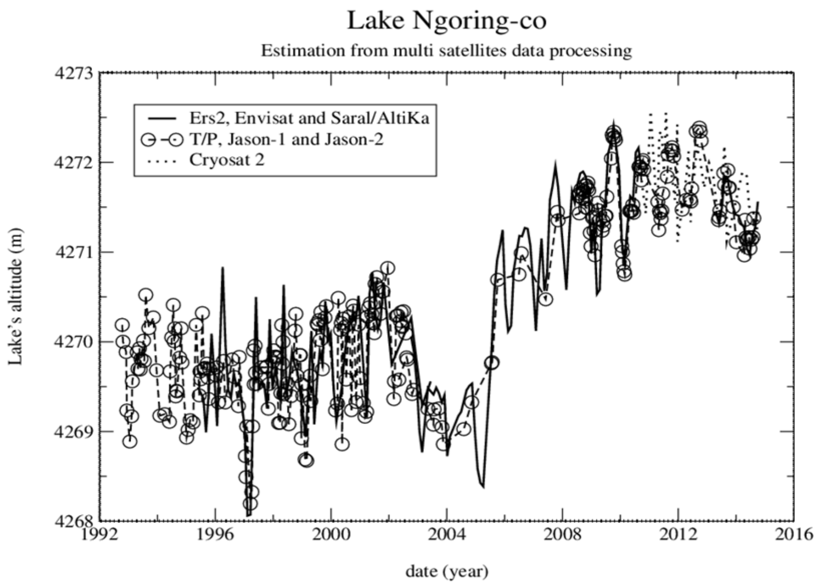
Inland waters

Satellite altimetry over Lakes



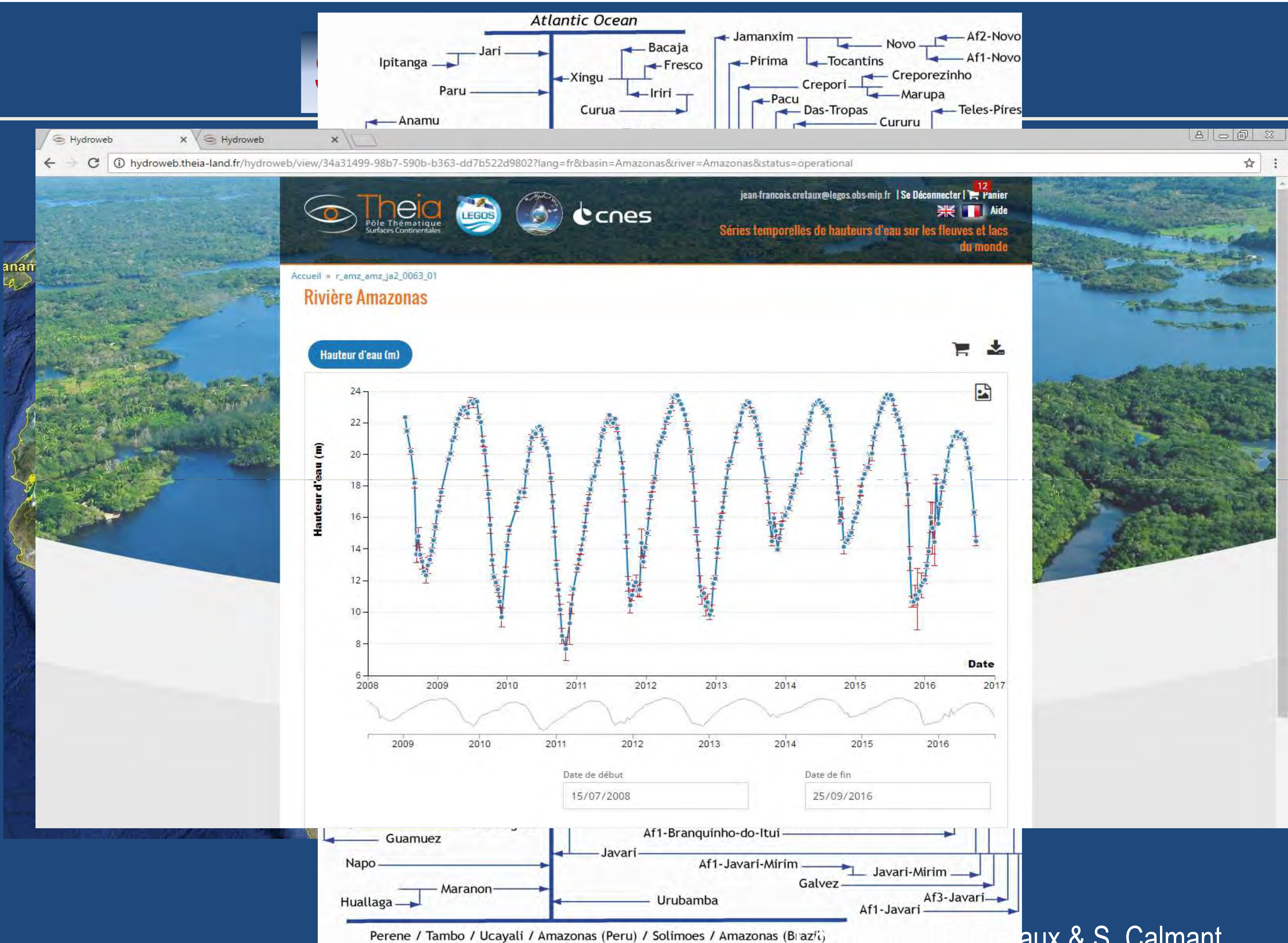






Courtesy: J.F. Cretaux

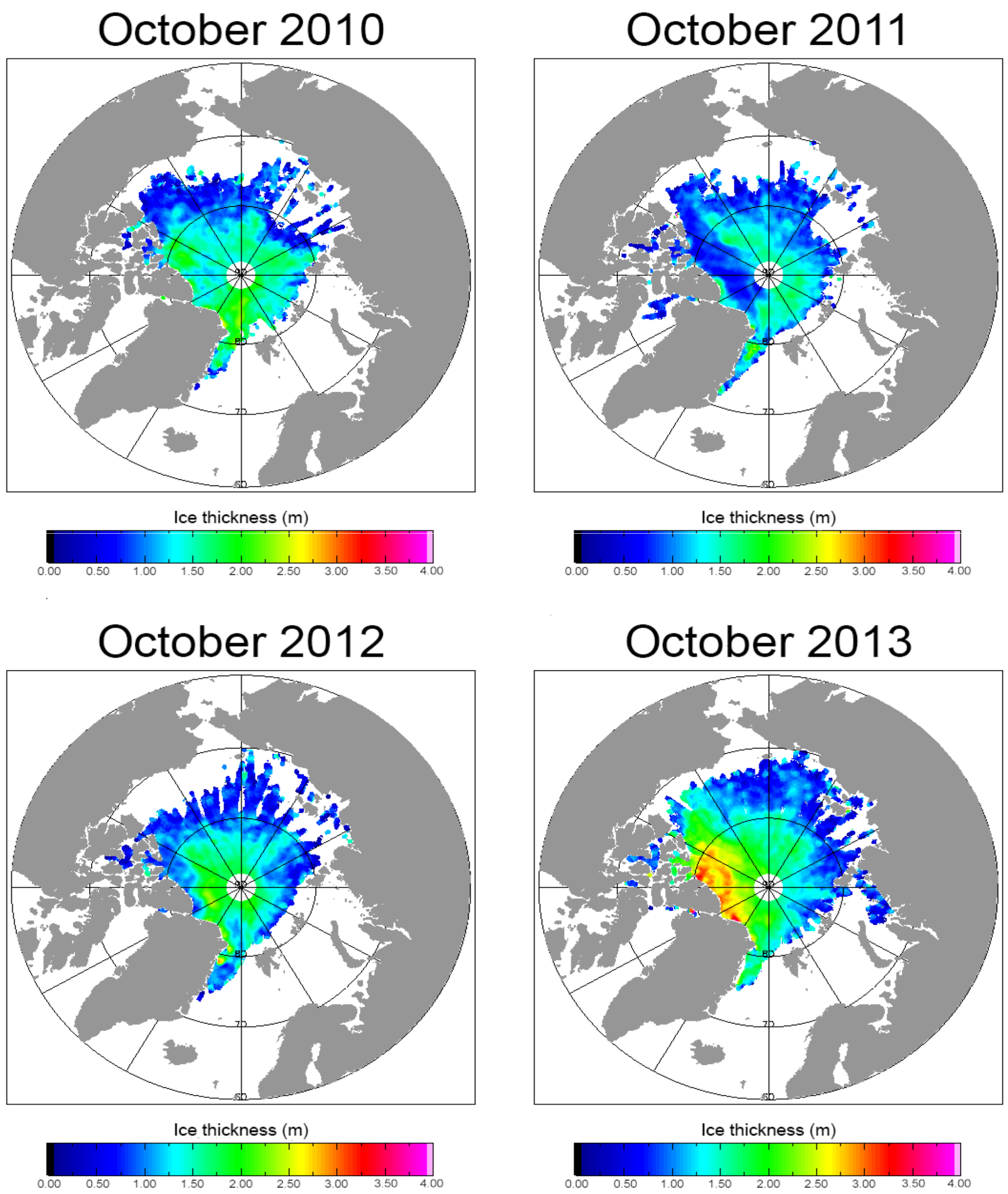
Data available on: http://hydroweb.theia-land.fr/



Courtesy : J.F. Crétaux & S. Calmant

Land and sea ice

Sea ice thickness change from CryoSat



CryoSat/Rachel Tilling, University College London

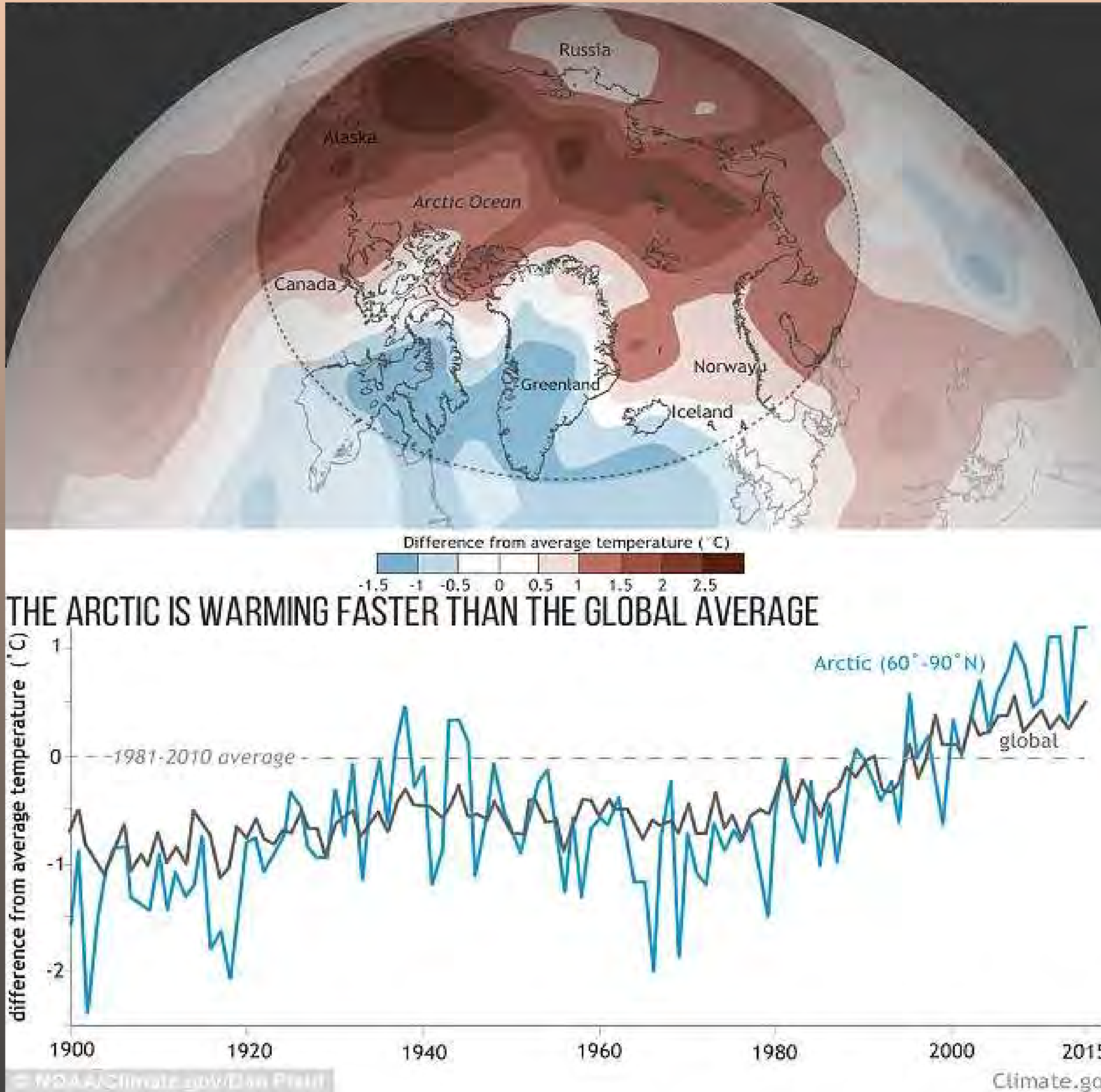
Source: University College, London

What are the new challenges?

A few issues (not exhaustive)

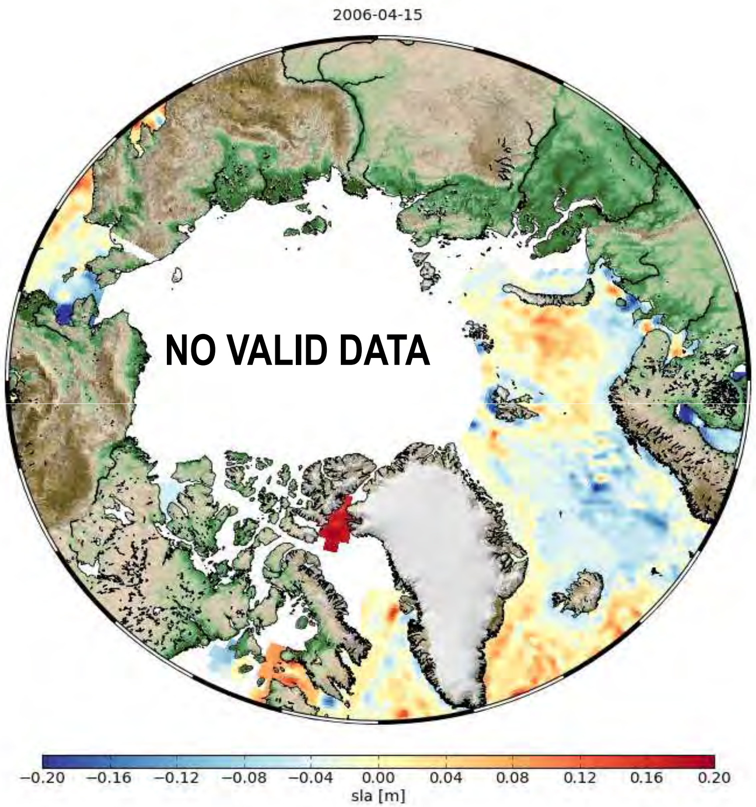
Arctic Region

Year 2015:Arctic land areas showed heat record

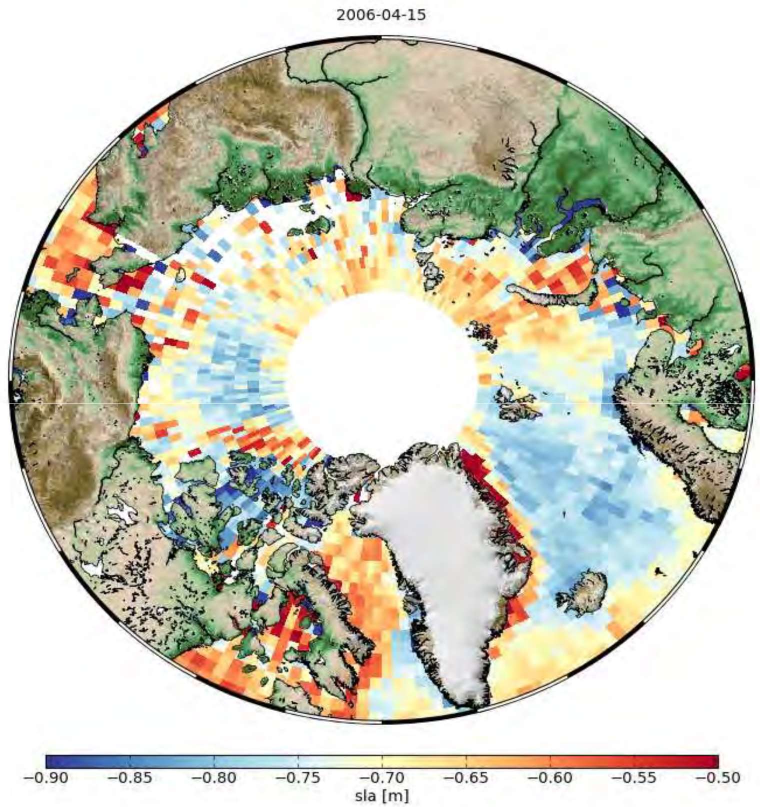


Source: NOAA

Satellite altimetry over the Arctic



Sea Level Anomalies (m)



Sea Level Anomalies (m)

Ablain et al. 2016

Sea Level

Continuity of the « sea level » record….

Copernicus Climate Change Service

Challenges:

- ***Quality assessment***
- ***Account f[...] corrections and new missions***
- ***Reprocessing***
- ***…..***

Who will take care of that?

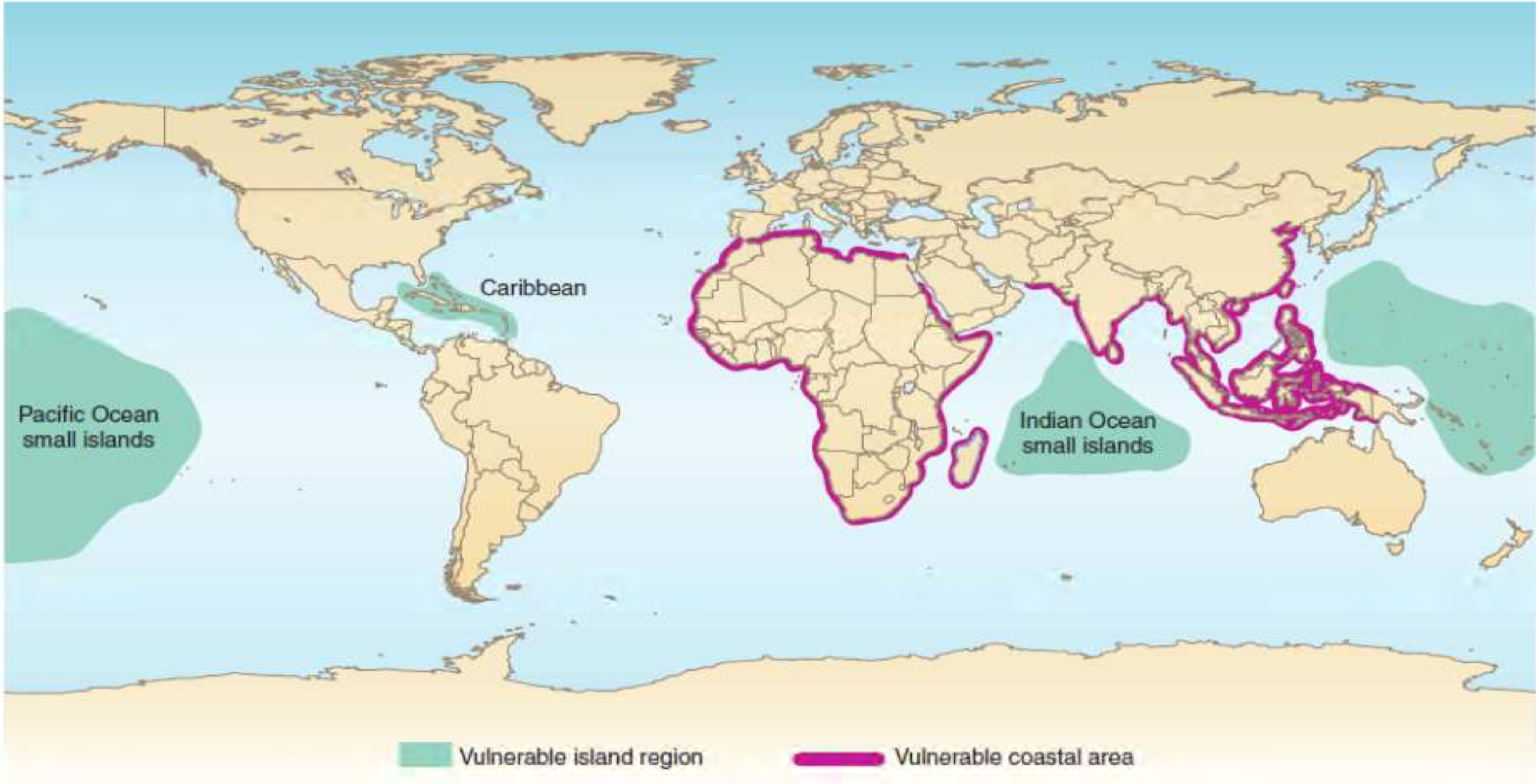
Sea Level

- Coordination required between “space components” and climate services to maintain a balance between R&D and operational production

- Still work to do to fully reach the GCOS requirements in terms of accuracy and stability, include new satellites (CryoSat, Sentinel-3, Jason-3, …), insure continuity of the sea level record for climate research, conduct reprocessing activities, especially for the historical missions (e.g., Topex/Poseidon)….

Coastal Areas

Vulnerable coastal areas under sea level rise



Nicholls and Cazenave, 2010

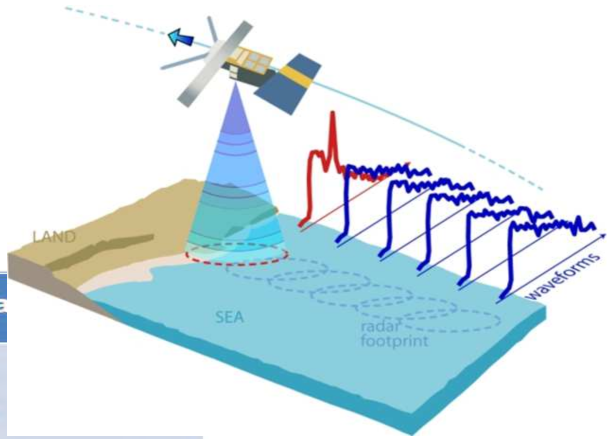

Atlantic coast of France; Courtesy : M. Garcin

- A large fraction of the world shorelines is in erosion (~70% of sandy beaches, Bird, 1985)
- Still unclear what are the respective roles of natural processes, direct human interventions and sea level rise in shoreline retreat and erosion
- We even don't know of the 'climate-related' sea level changes at the coast are similar to open ocean changes
- Finally, what counts at the coast is the **total 'relative' sea level →**

∑ global mean rise + regional trends*+ local oceanic processes + local vertical land motions

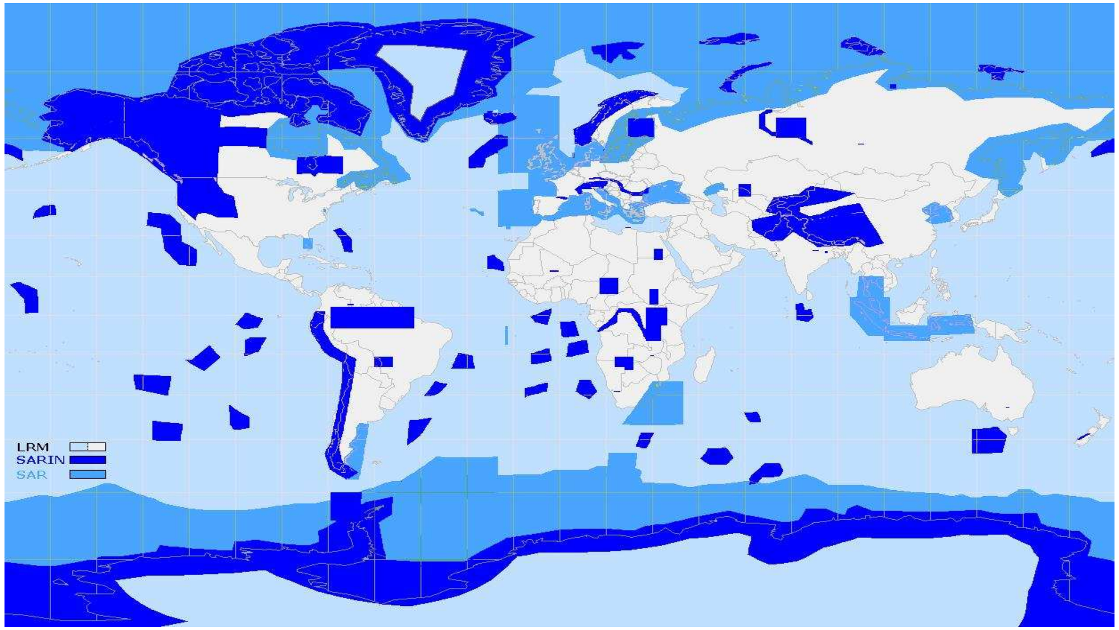
** Including deformations of ocean basins in response to past and on-going land ice melt*

Coastal altimetry



ID	Produced by	Missions	Product level	Posting rate	Coverage	Downloa
AVISO	CLS, CNES CNES	e1,tx,e2, en, j1, j2, c2 (LRM/PRLM), sa	L2, L3, L4 also L4	1 Hz	Global + european regions	AVISO+
CMEMS	CLS CNES	e1,tx,e2, en, j1, j2, c2 (LRM/PRLM), sa	L3 L3 for assim	1 Hz	Global + european regions	marine.copernicus.eu
PISTACH	CLS CNES	j2	L2	20 Hz	Global	AVISO+
PEACHI	CLS CNES	sa	L2	40 Hz	Global	AVISO+
XTRACK	LEGOS-CTOH	tx, j1, j2, gfo, en	L2, L3	1 Hz 20Hz (test)	23 regions	CTOH AVISO+
RADS	EUMETSAT, NOAA, TUDelft	gs, e1, tx, pn, e2, gfo, j1, n1, j2, c2, sa		1 Hz	Global	TUDelft
ALES	NOC	j2, n1 (coming)		20 Hz	Global, <50 km from coast	PODAAC
SARvatore	ESA-ESRIN	c2 (SAR only)		20 Hz	SAR mode regions	ESA GPOD
COP	ESA	c2 (LRM/PLRM)	L2	20 Hz	Global	ESA

http://www.coastalt.eu/community

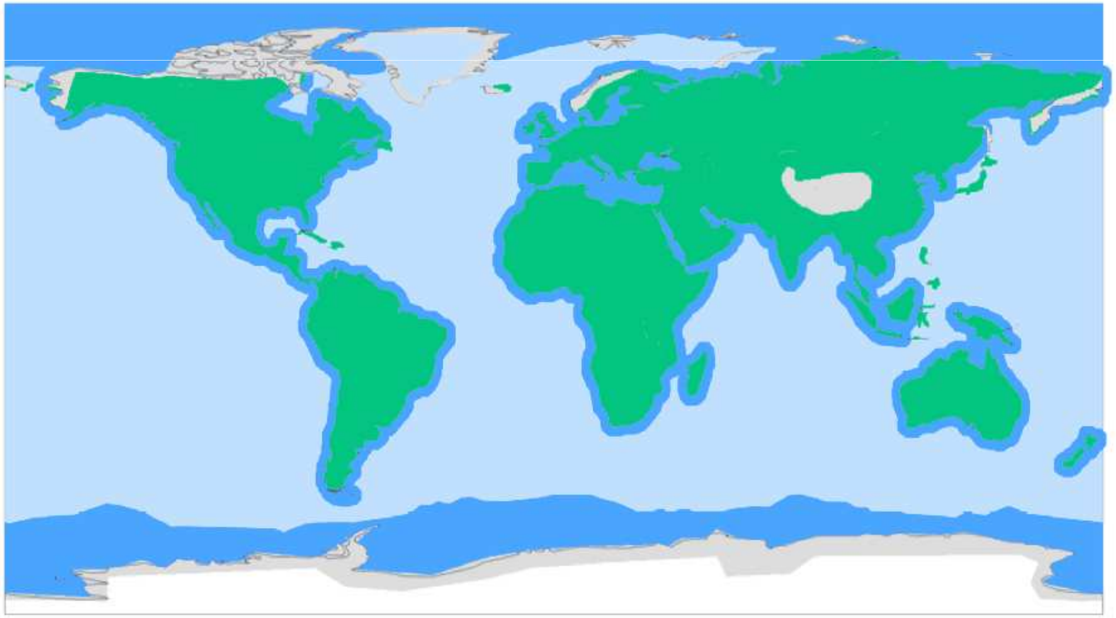


Since 2010: Cryosat-2

- SAR: some oceanic & coastal regions + sea ice

October 2016: Sentinel 3

- SAR: global ocean including coastal + sea ice

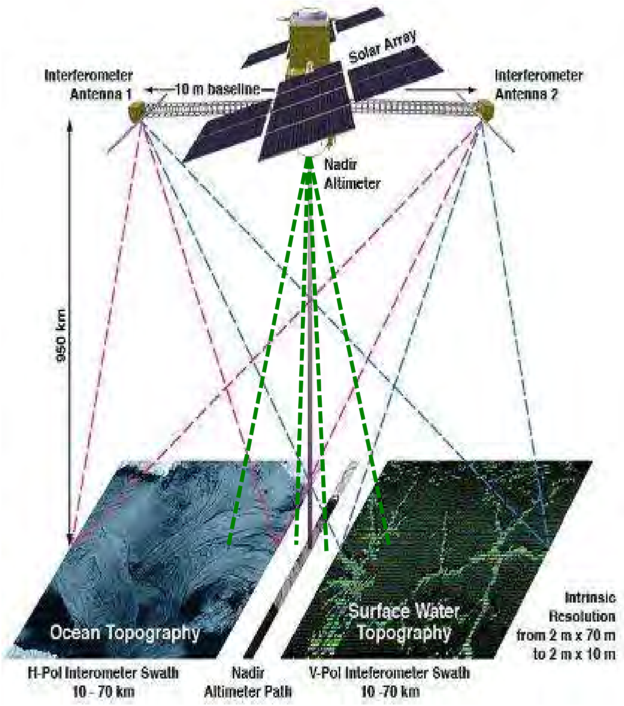


Sub-mesoscale circulation

Targeting the smallest scales of ocean currents with SWOT

•Ocean currents and eddies at scales shorter than 200 km, contain most of the kinetic energy of the ocean, play key roles in the transport of heat, carbon and nutrients. They affect climate via modulation of sea surface temperature and heat flux, as well as the oceanic uptake of carbon from the atmosphere.

•The primary oceanographic objectives of the SWOT mission are to observe the ocean mesoscale and submesoscale circulation at spatial resolutions of 15 km, providing the missing link between 15 km and 200 km for ocean climate studies.



Courtesy: R. Morrow


Thanks for your attention
FRANCIS GIRAUDON