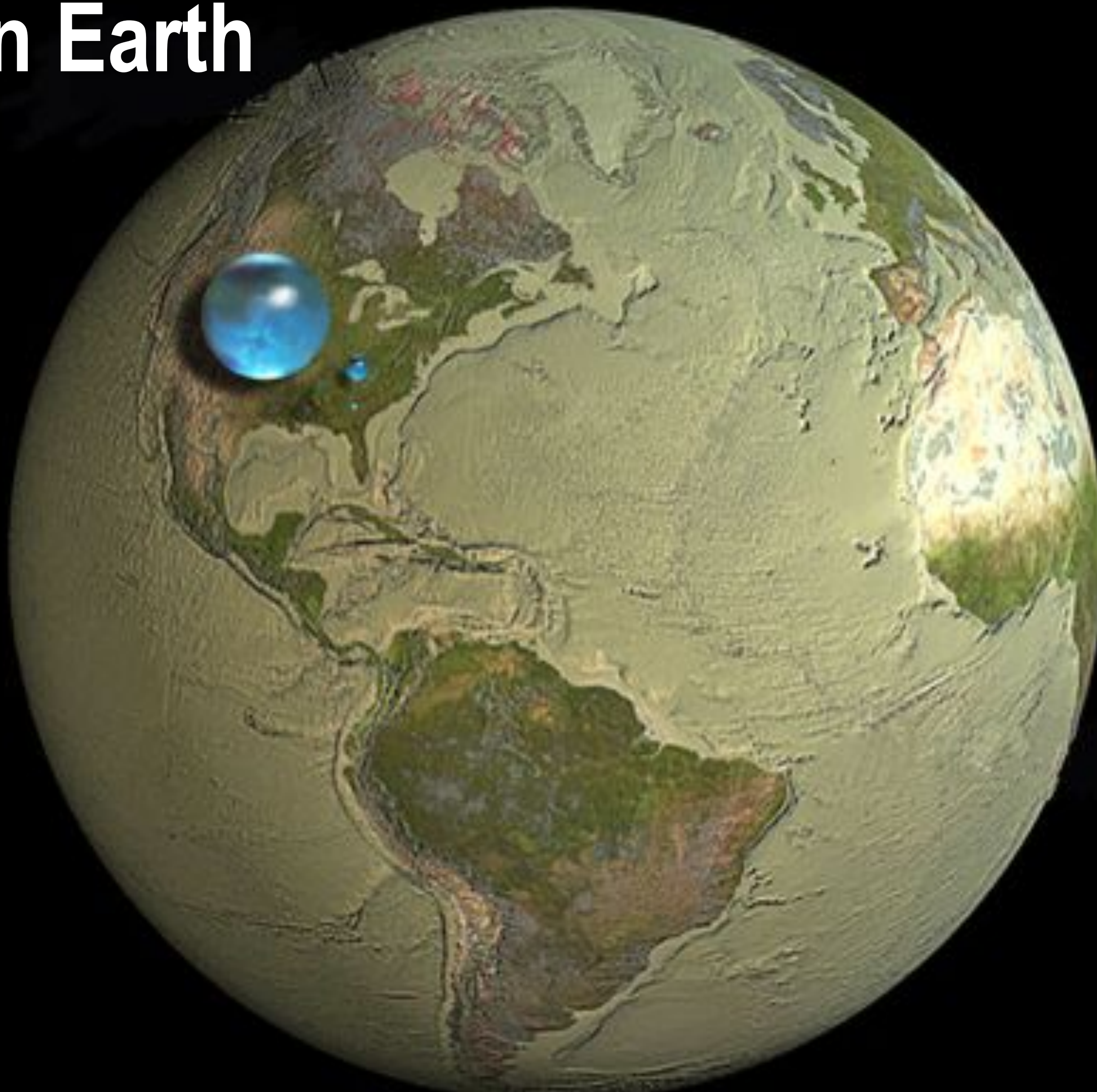
Lesson n°1

« Observing the ocean from space »

Anny Cazenave
LEGOS-CNES, Toulouse, France
Shanghai, July 2014

Ocean : 71%
of the planet’surface

Water on Earth



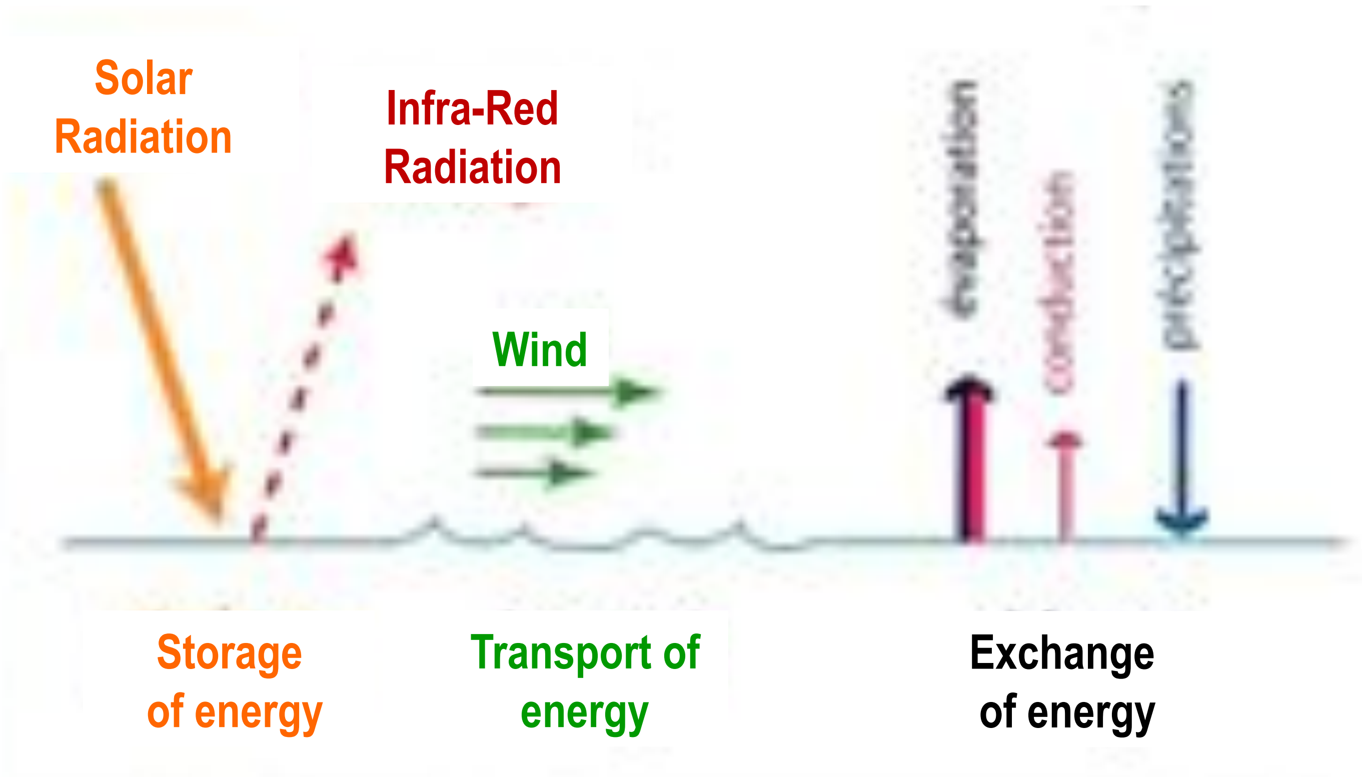
Ocean : 97% of the total volume of water on Earth (1340 billion km^3)

Source : USGS

The ocean:
A complex dynamical system ….

… that stores and redistributes heat
in the climate system

The ocean stores, transports and exchanges energy:



Thermal inertia of the ocean

- Ocean mass = 300 times that of the atmosphere
- Heat capacity of water = 4 times that of air
- Heat storage capability: 1200 times higher than that of atmosphere

Ocean and climate

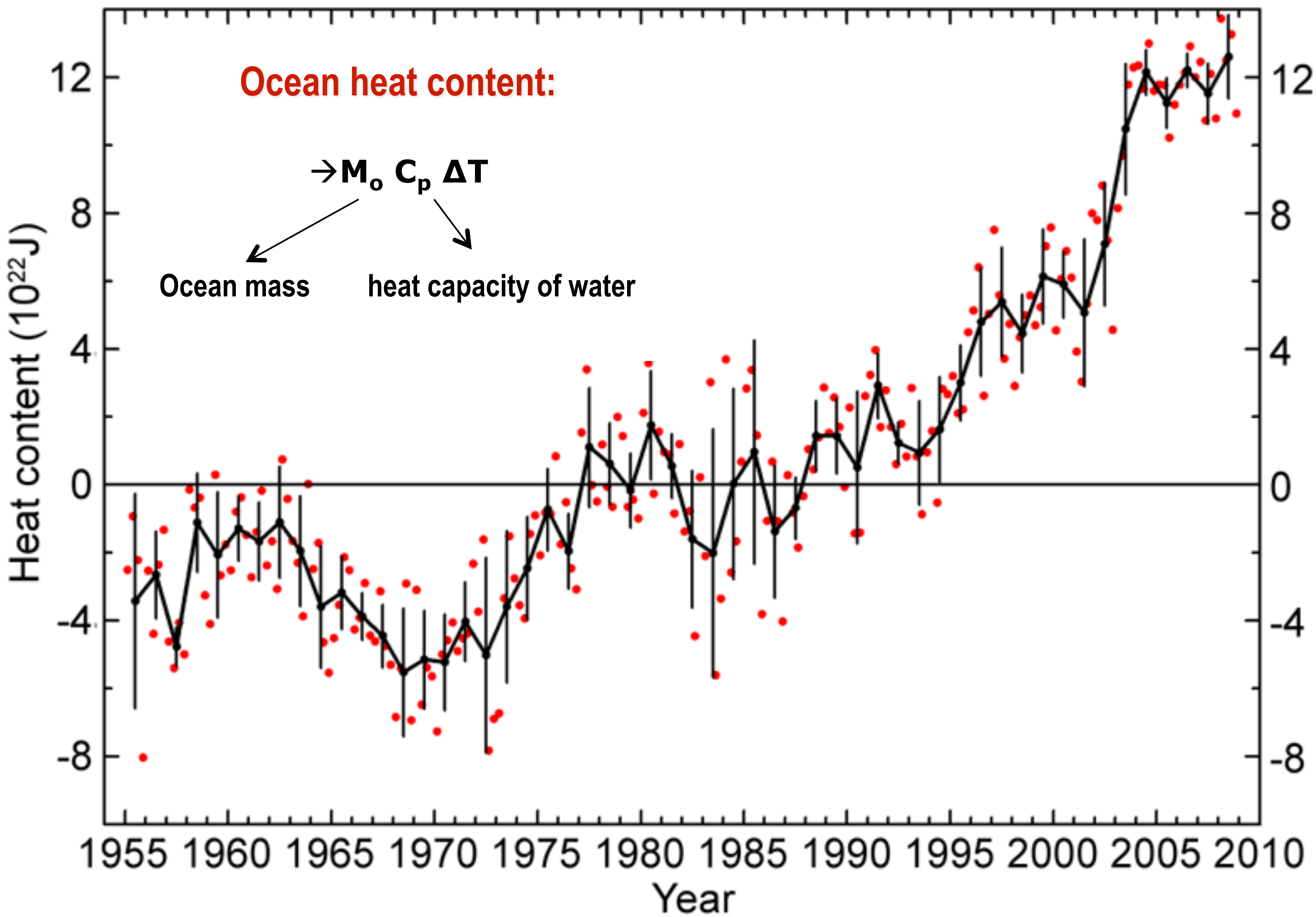
•*Main reservoir of heat in the climate system*

•*Transports and re distributes heat over time scales much longer than the atmosphere*

→ *« long-term memory » of the climate system*

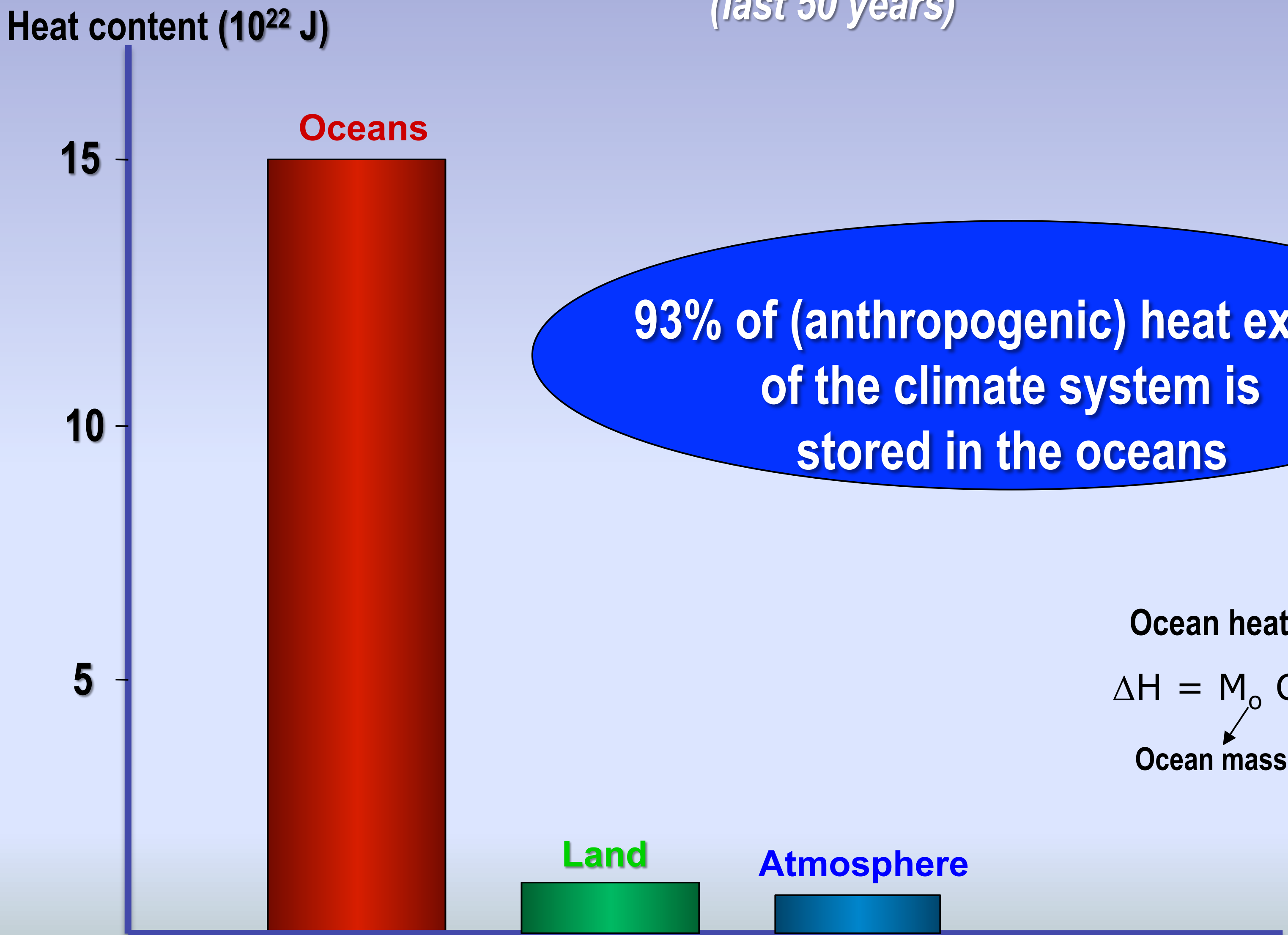
Heat capacity : quantity of heat needed to raise the temperature of 1g water by 1°K

Ocean warming : increase of ocean heat content



Thermal budget of the climate system

(last 50 years)



93% of (anthropogenic) heat excess of the climate system is stored in the oceans

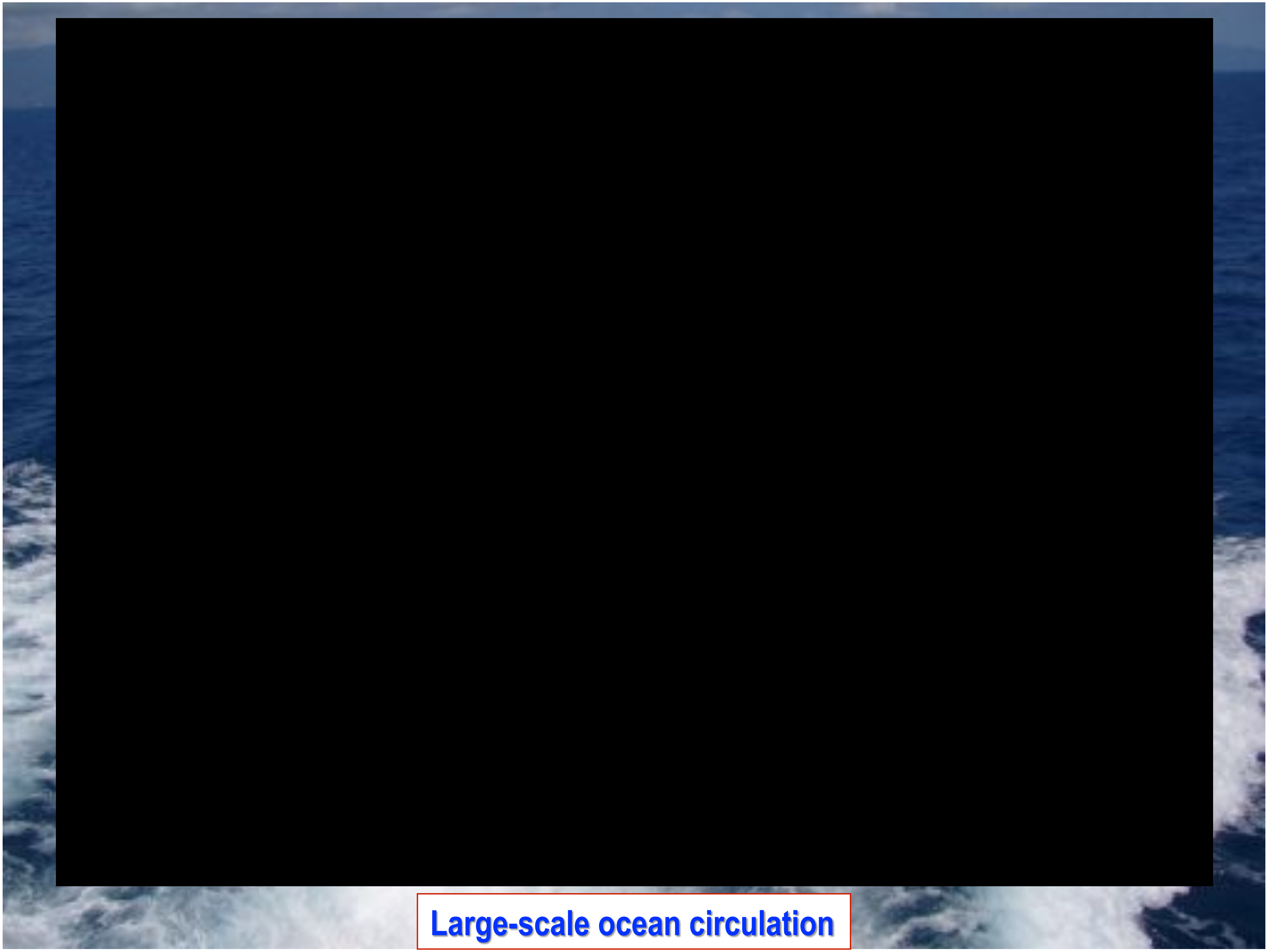
Ocean heat content

$$\Delta H = \underbrace{M_o}_{\text{Ocean mass}} \; \underbrace{C_o}_{\text{Heat capacity of water}} \; \Delta T$$

IPCC AR5

Motions in the ocean:

- *Waves (driven by winds)*
- *Tides (gravitational attraction from Moon and Sun)*
- *Currents (driven by winds, Earth's rotation, temperature and salinity variations)*


Large-scale ocean circulation

Why is it important to observe the ocean ?

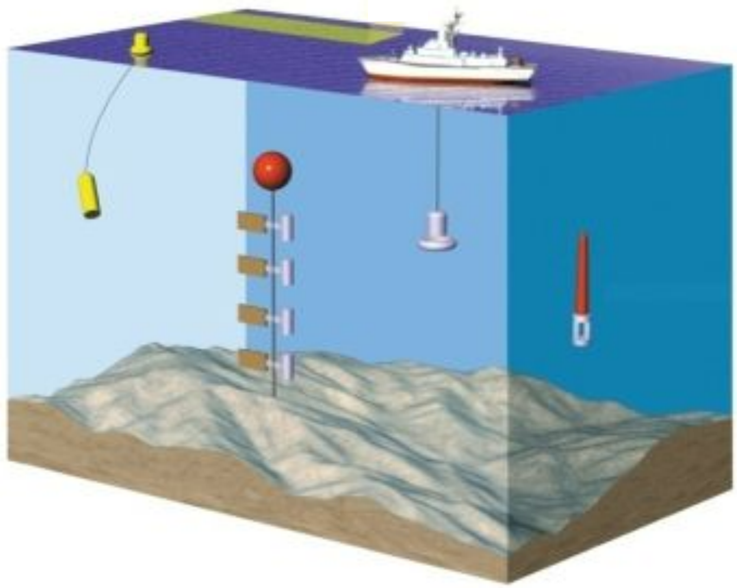
- For better understanding ocean dynamics
- For climate studies
- For operational oceanography

....

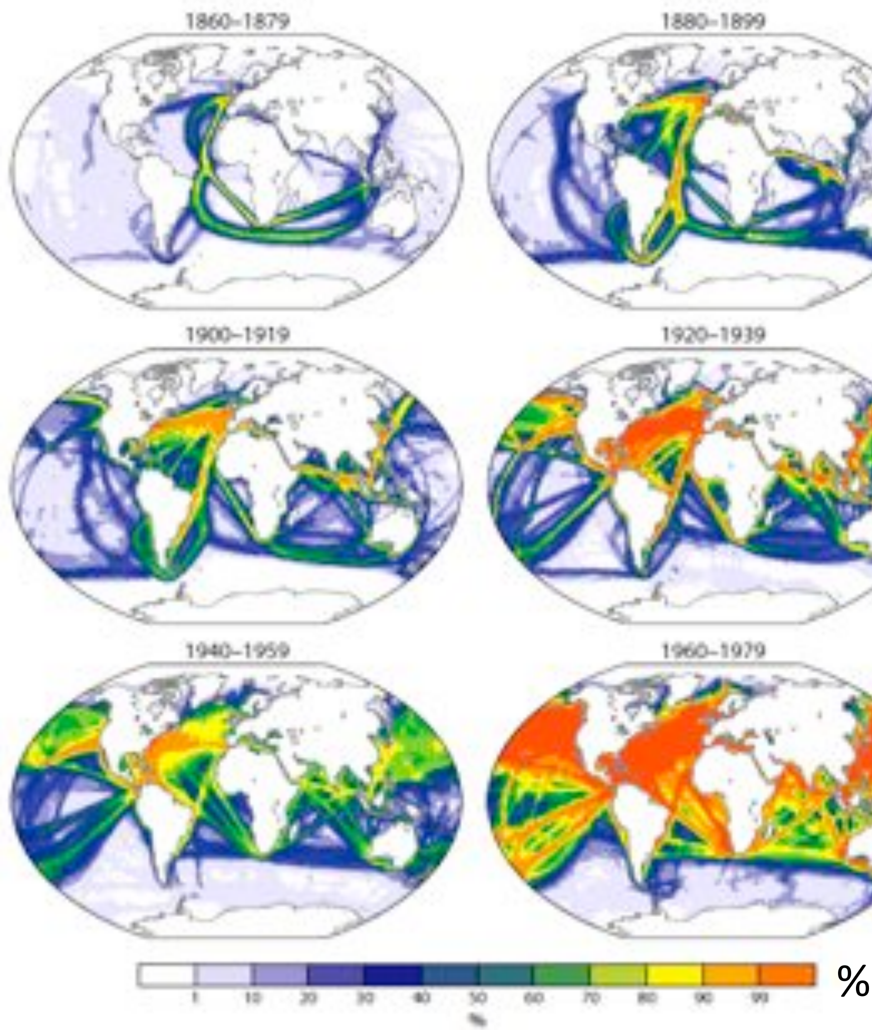
- For navigation
- For exploiting natural resources (fishing, …)

Historical in situ measurements of the ocean properties (temperature, salinity, surface currents, etc.)

Since ~1950 : mostly along main trade roads



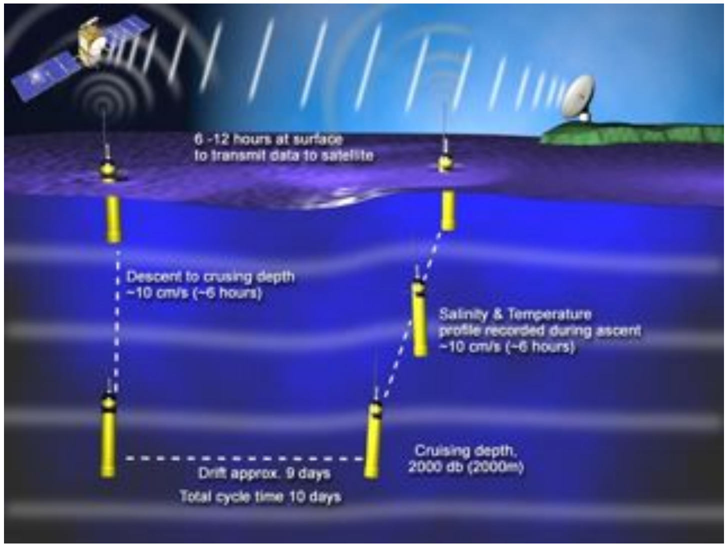
Coverage of in situ sea surface temperature measurements over successive 20-year-long time spans



Percentage de months with at least 1 measurement in a 2°x2° box

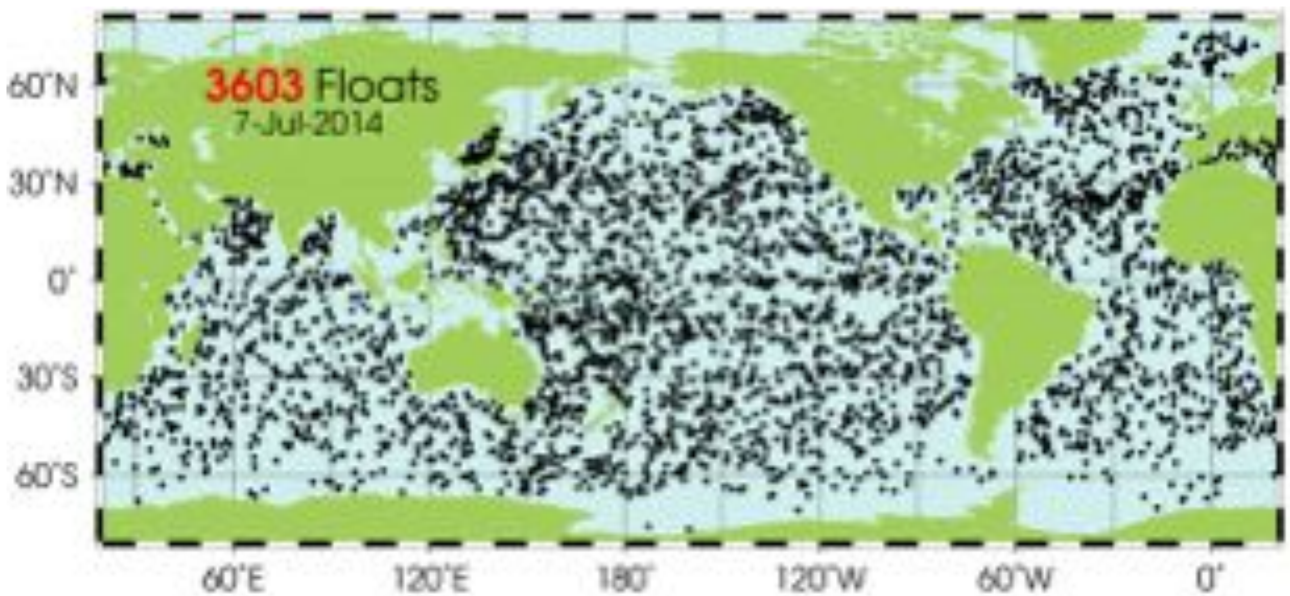
Deser et al. 2010

Last decade: International Argo programme
→temperature and salinity measurements down to 2000 m depth

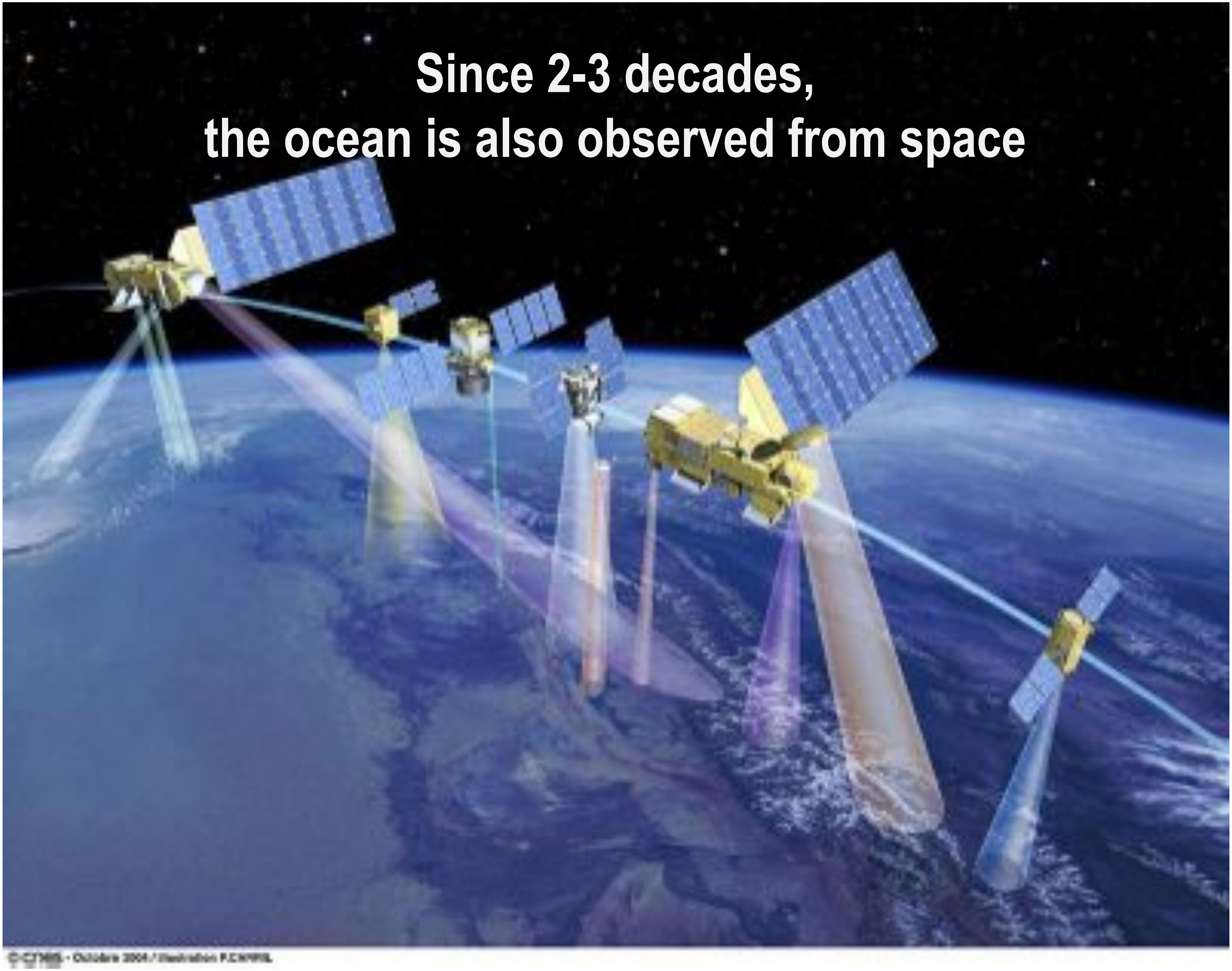


'Argo' profiling floats

coverage



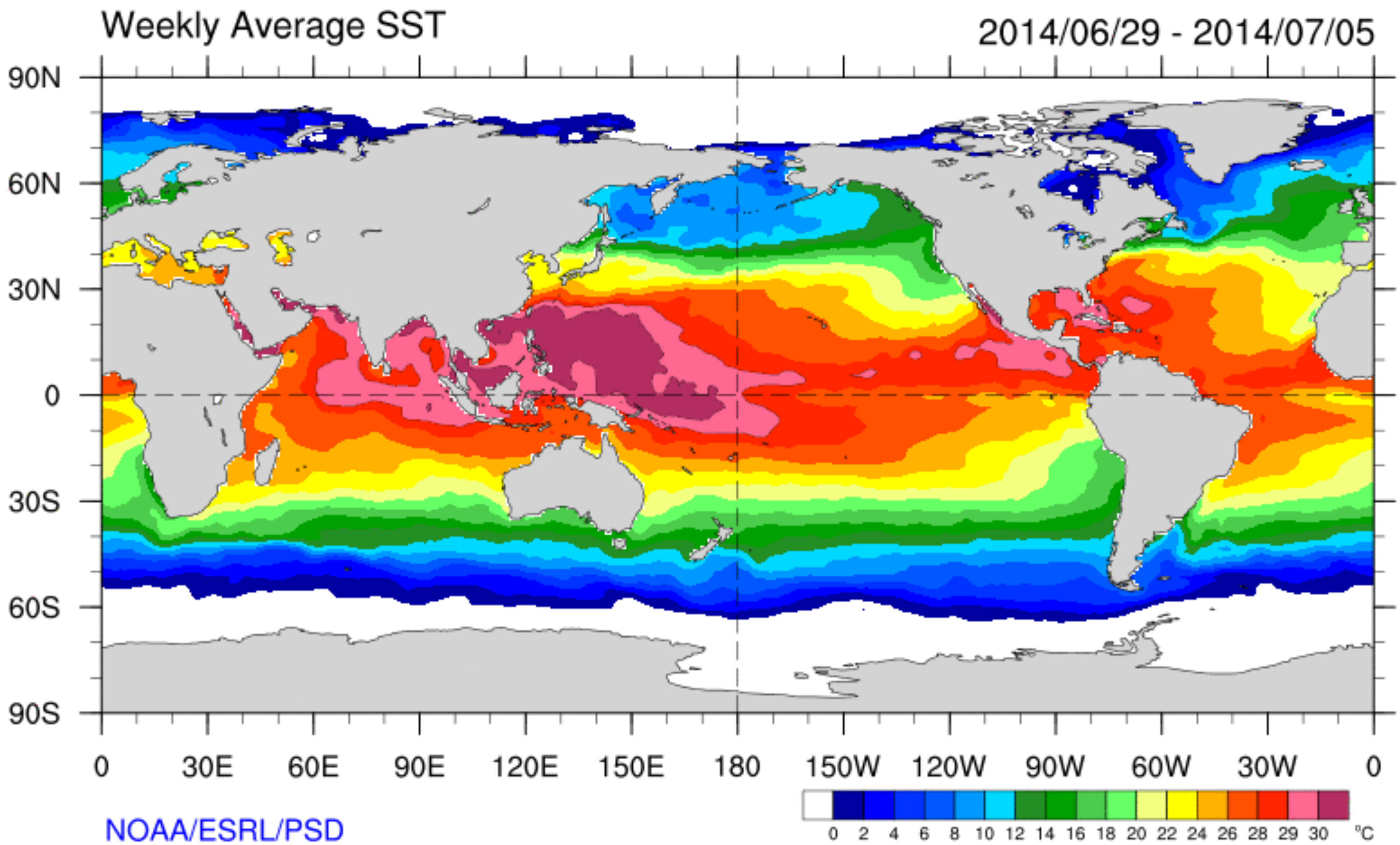
Since 2-3 decades,
the ocean is also observed from space



Main ocean parameters measured from space:

- ***Sea surface temperature :*** Onboard radiometers (passive micro-waves)
- ***Sea surface salinity*** : Radiometry/active micro-waves
- ***Ocean surface topography*** (*currents; tides, sea level) :* Satellite altimetry
- ***Surface winds*** : Active microwaves (radar altimetry/scaterrometry)
- ***Wave height***: Altimetry; Radar imagery
- ***Ocean color*** (phytoplancton→ marine ecosystems): Multispectral imagery
- ***Ocean mass***: Space gravimetry (GRACE)

Sea surface temperature on 1st week of July 2014



Source: NOAA

Why is it important to know sea surface temperature?

-The heat stored in the first few meters of the ocean is as large as that of the whole atmosphere

-Air-sea exchanges of mass (water) and energy essentially depend on sea surface temperature

-<u>SST plays a key role in climate change and variability</u>

-Knowledge of SST is crucial for seasonal climate forecast

SST= Sea Surface Temperature

et interannuelles du clim

- La connaissance de la SST est fondamentale pour les prévisions saisonnières

INTERNAL (natural) VARIABILITY OF THE CLIMATE SYSTEM:
MAIN MODES OF VARIABILITY OF THE OCEAN-ATMOSPHERE SYSTEM

- *El Nino/La Nina (ENSO = El Nino-Southern Oscillation)*
- *Pacific Decadal Oscillation (PDO)*
- *North Atlantic Oscillation (NAO)*
- *.....*

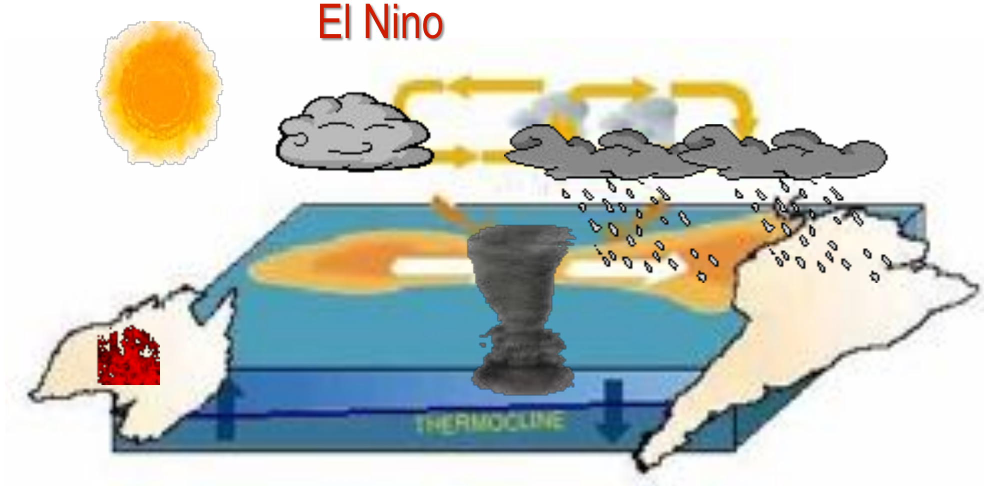
The internal variability results from non linear interactions between the different components of the climate system, with different response times (interannual to multidecadal)

Natural forcings (solar irradiance and volcanic eruptions) superipose to the internal variability and interact with it.

⇒ Climate fluctuations dominated by the internal variability on time scales from season to several decades

EL Nino-Southern Oscillation (ENSO) → a major natural (internal) perturbation of the climate system

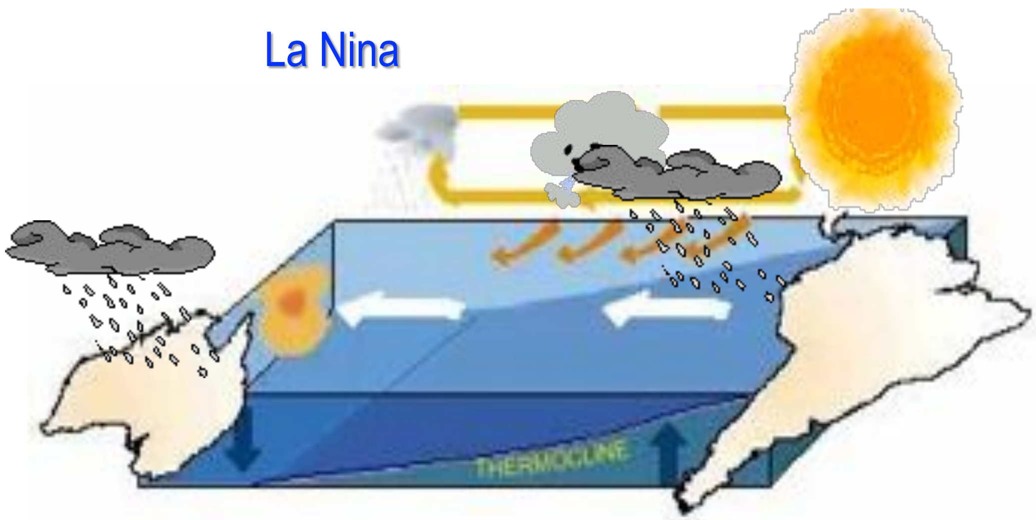
El Nino



El Niño

Warm water and more rain over the central and eastern tropical Pacific

La Nina

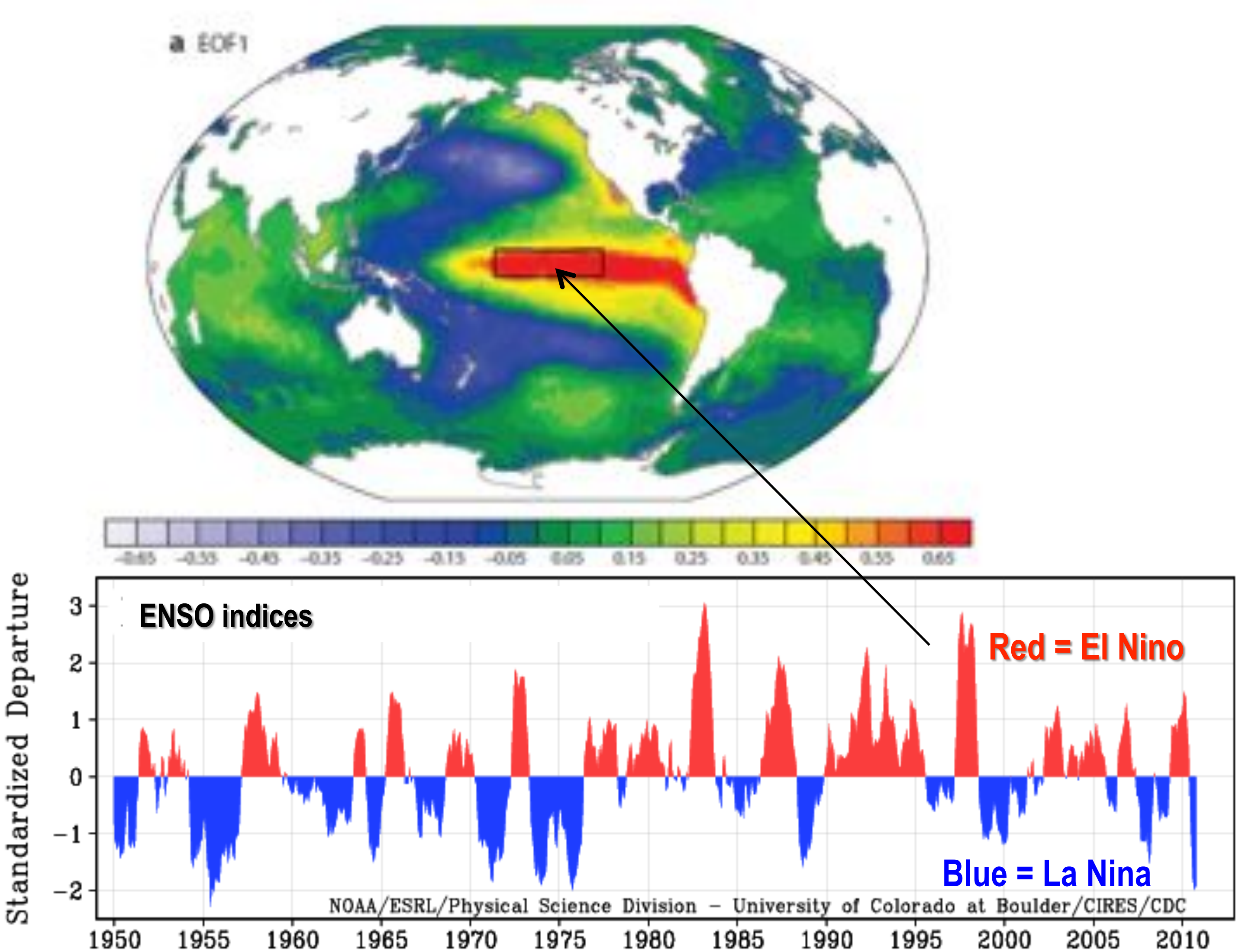


La Niña

Cold phase of ENSO

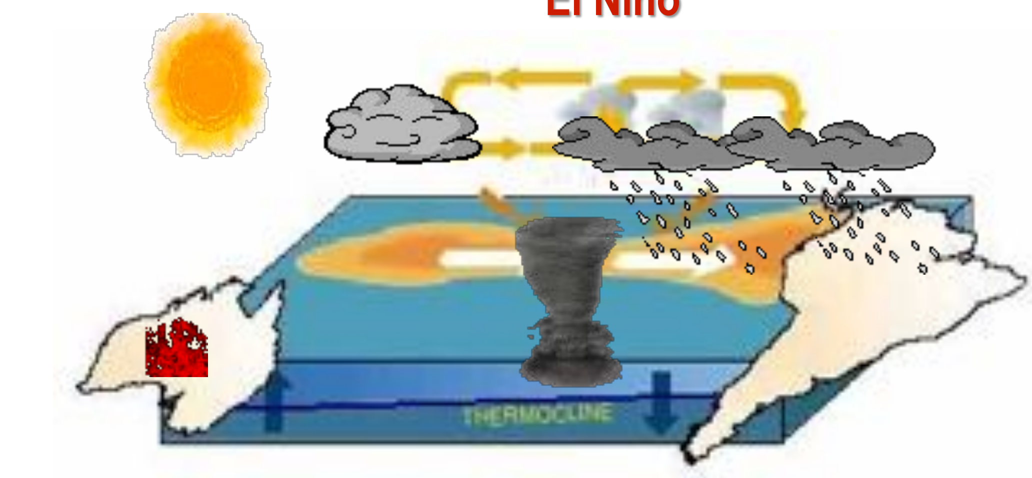
Source: C. Cassou

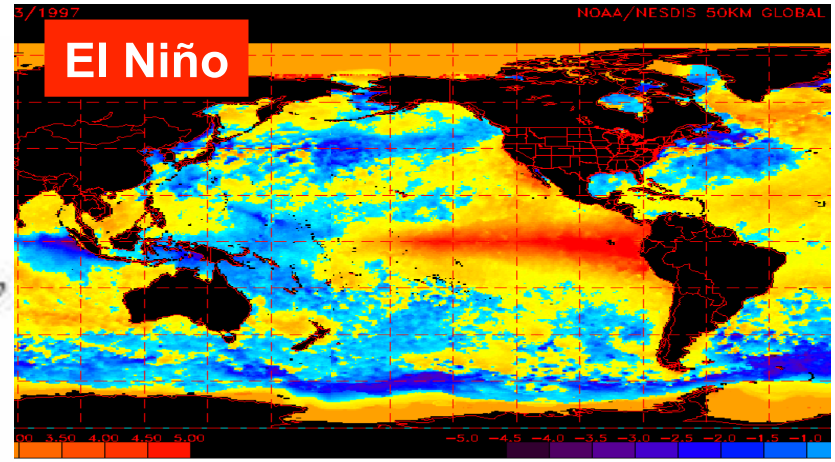
Dominant mode of SST variations in the tropical
→ ENSO (El Nino - Southern Oscillation)



Deser et al., 2010

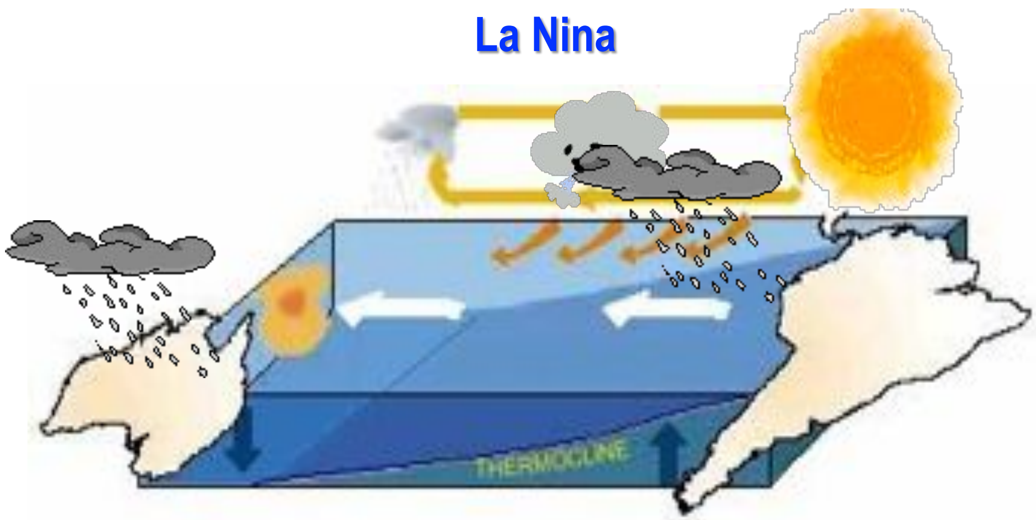
El Nino

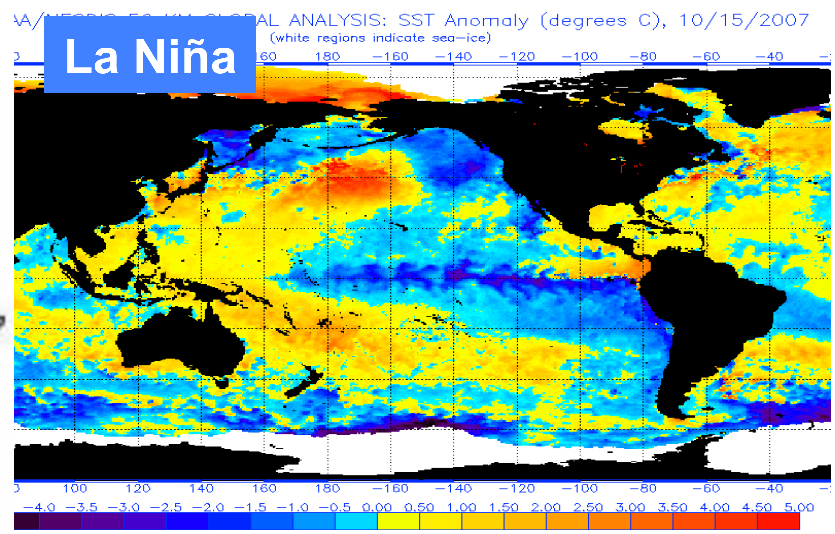




SST anomalies on 13 Nov. 1997

La Nina

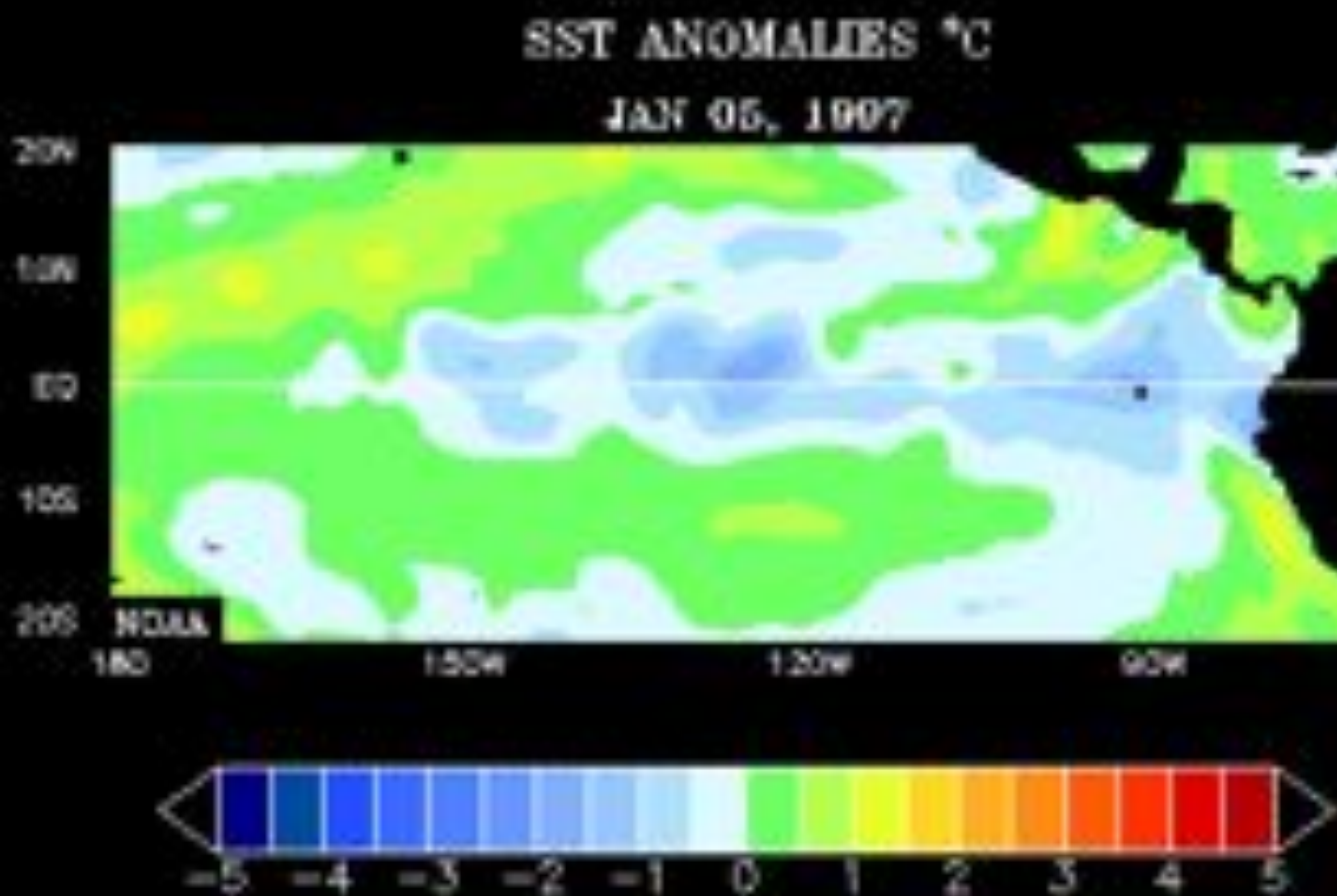




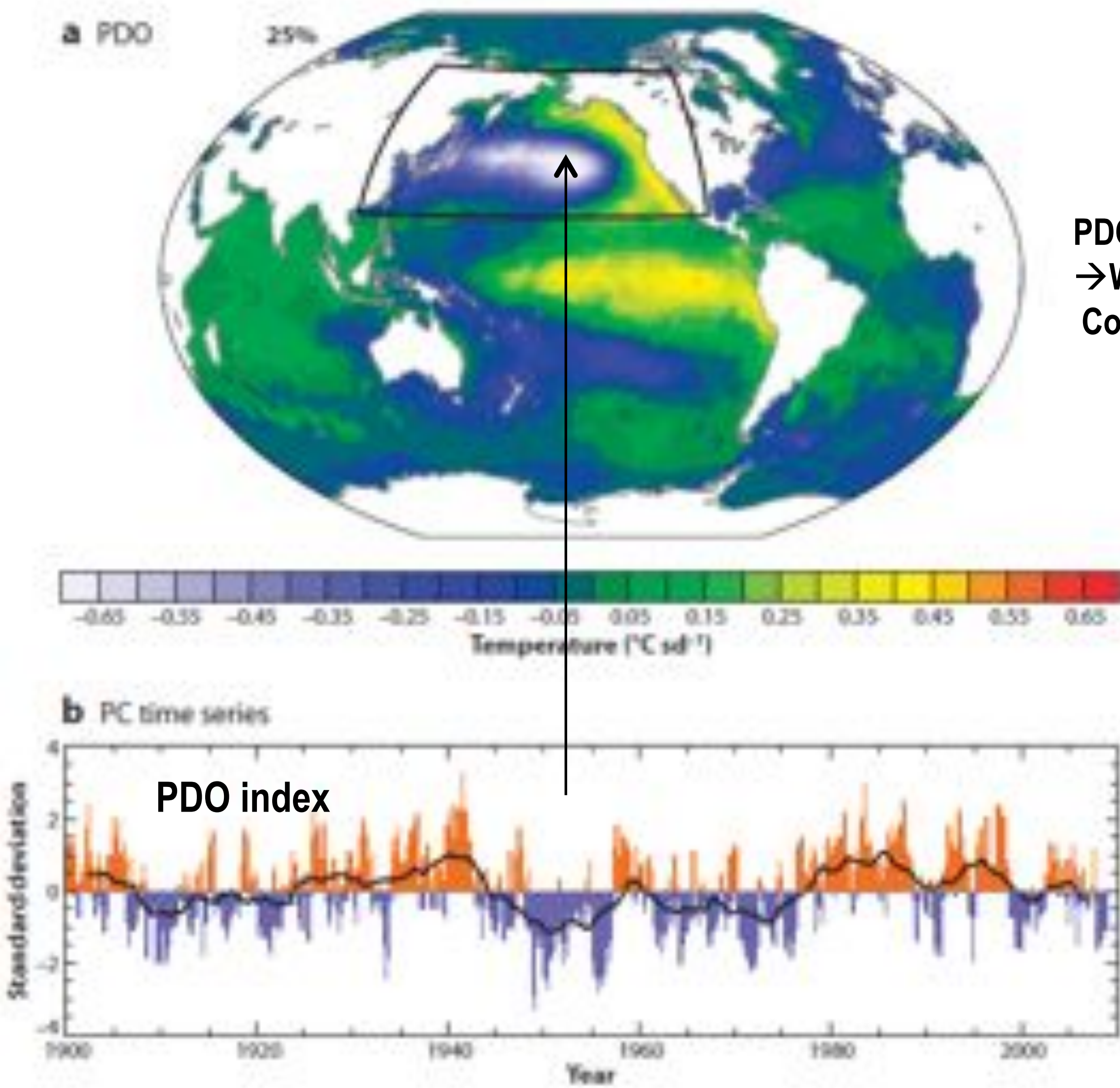
SST anomalies on 15 Oct. 2007

Source: C. Cassou

SST anolalies during the 1997-1998 El Nino



Another longer-term SST oscillation : → Pacific Decadal Oscillation- PDO



Averaged SST oscillation through time

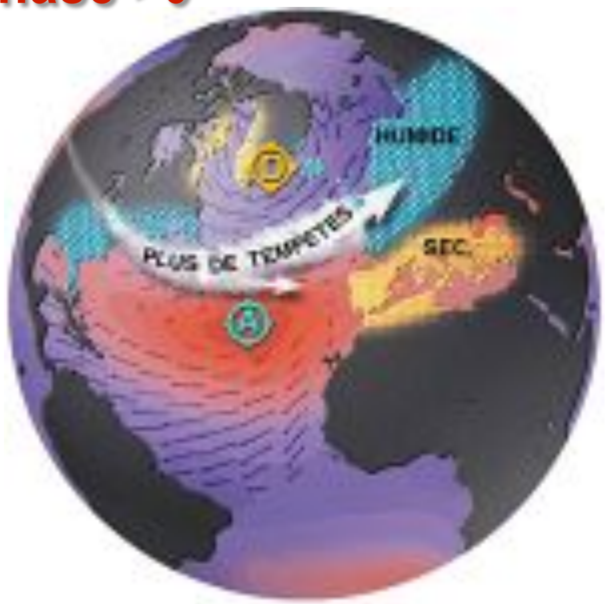
PDO >0
→Warmer tropical Pacific
Cooler northwest Pacific

Deser et al., 2010

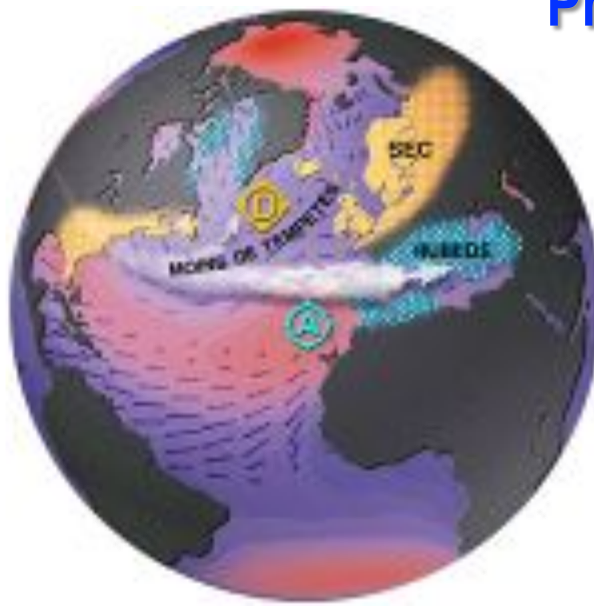
North Atlantic Oscillation (NAO)

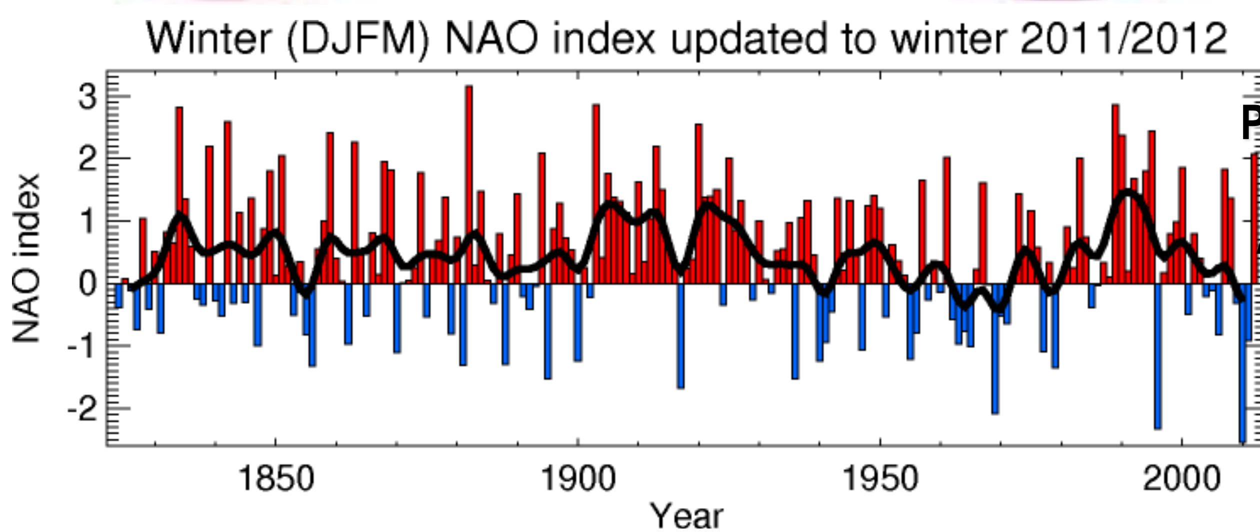
(Combined fluctuation of the Island depression and Azores anticyclon)

Phase >0



Phase <0





Pressure différence between Azores and Island

And also :

AMO = Atlantic Multidecadal Oscillation

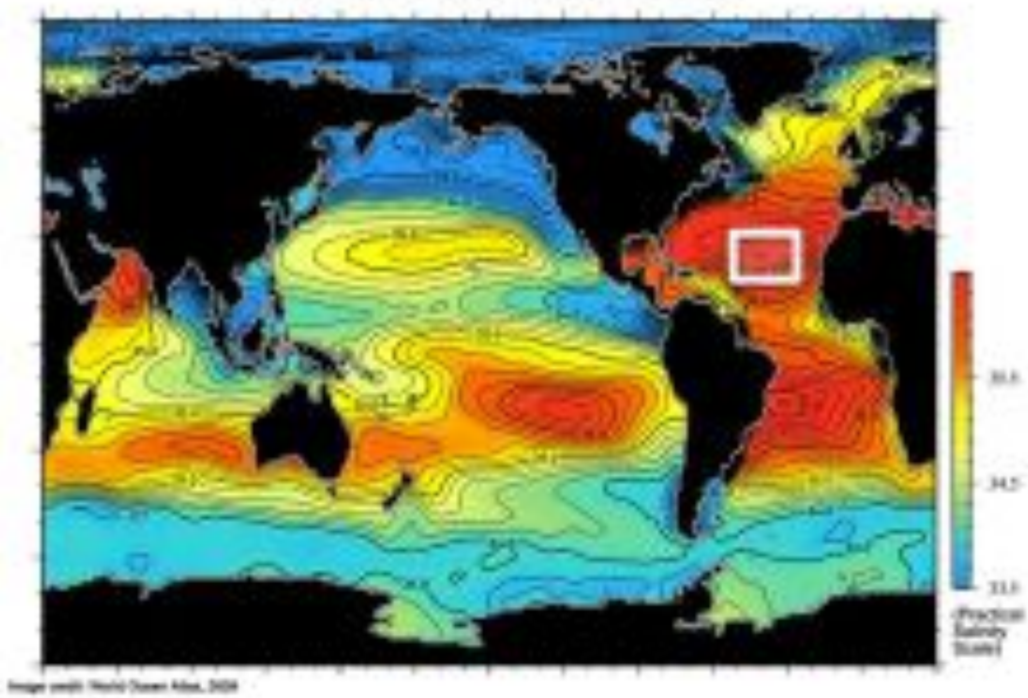
AO = Arctic Oscillation

IOD = Indian Ocean Dipole

……..

Mean sea surface salinity

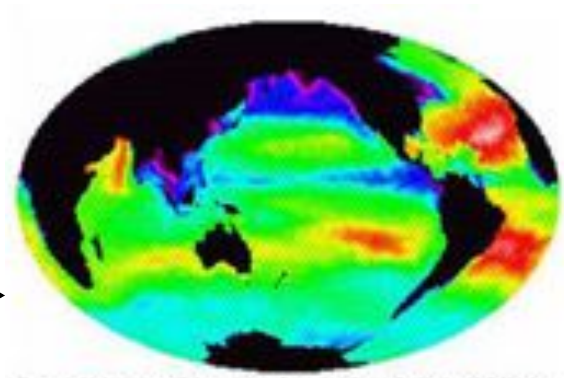
Average salinity from historical ship and buoy data



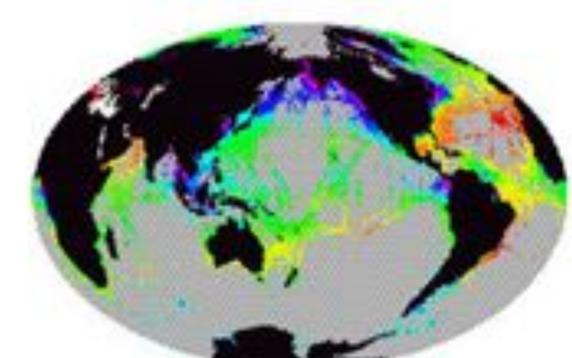
blue
→ Less salty

orange/red
→saltier

8 days
of
satellite
measurements
→



Example 8 days of Aquarius Sea Surface Salinity (SSS) data



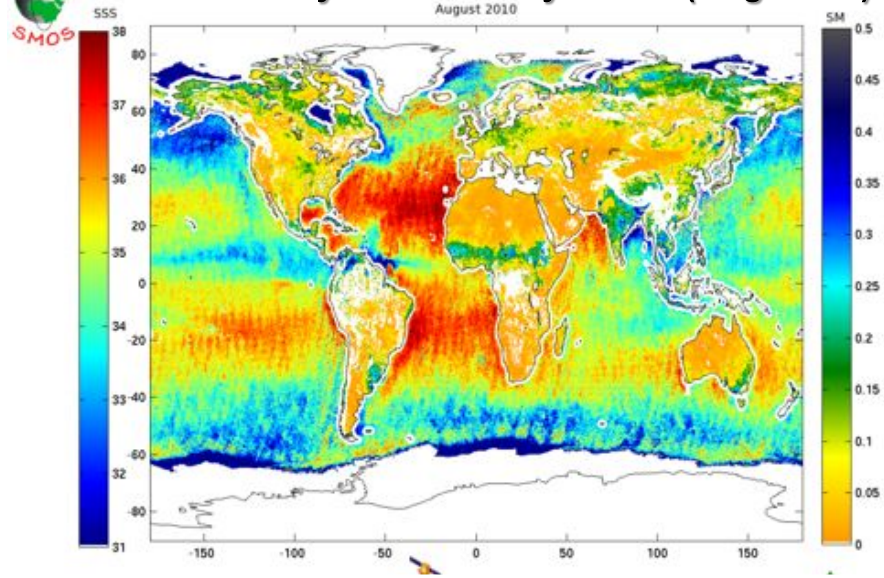
100 years of Sea Surface Salinity (SSS) measurements

100 years
of
measurements
←

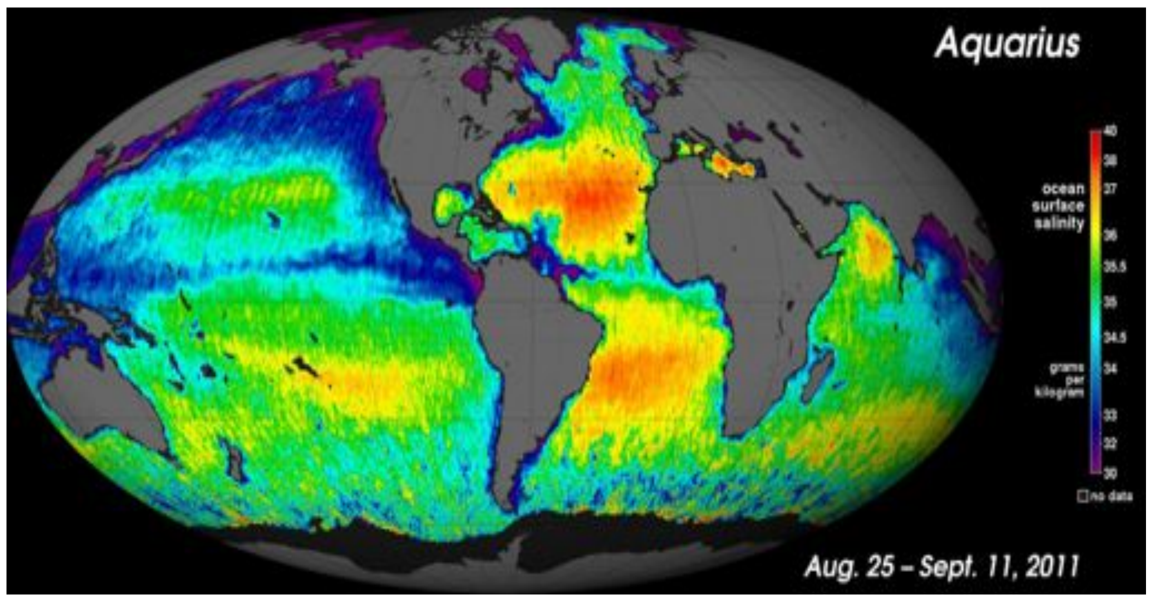
SMOS (Soil Moisture-Ocean Salinity)

ESA mission (2009)

Surface salinity measured by SMOS (Aug. 2010)



Sea surface
Salinity
measured
by
Aquarius
(NASA mission)



Why is it important to know sea surface salinity?

-SSS modifies the density of sea water, hence the ocean circulation and heat transport

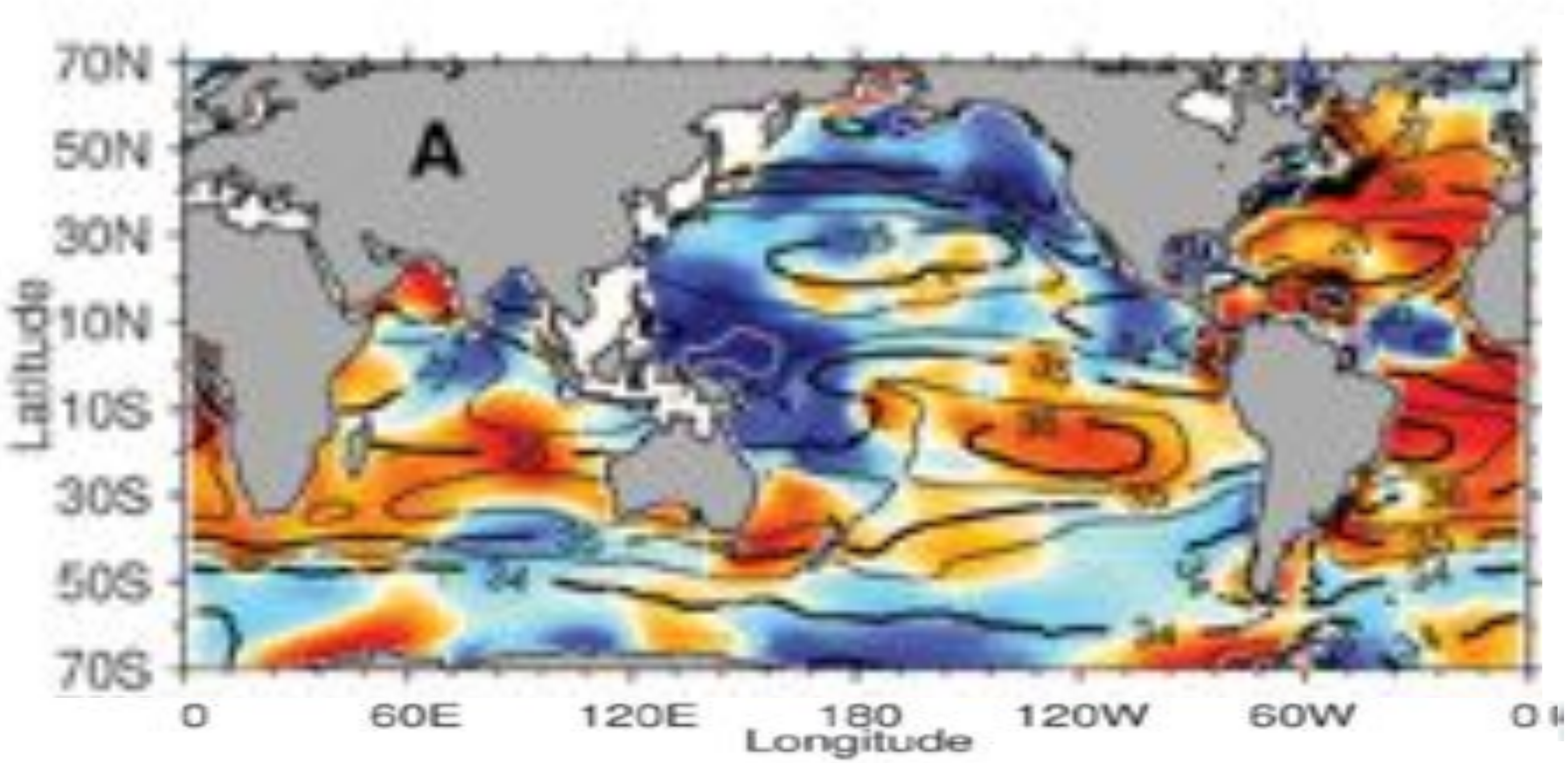
-SSS plays a direct role in ocean/atmosphere water exchanges

→ SSS is highly correlated with P-E
(P= precipitation; E= evaporation)

→ SSS : major indicator of the water cycle intensification

SSS= sea surface salinity

Sea surface salinity: trends over 1950 - 2000
→ Evidence of an intensification of the water cycle



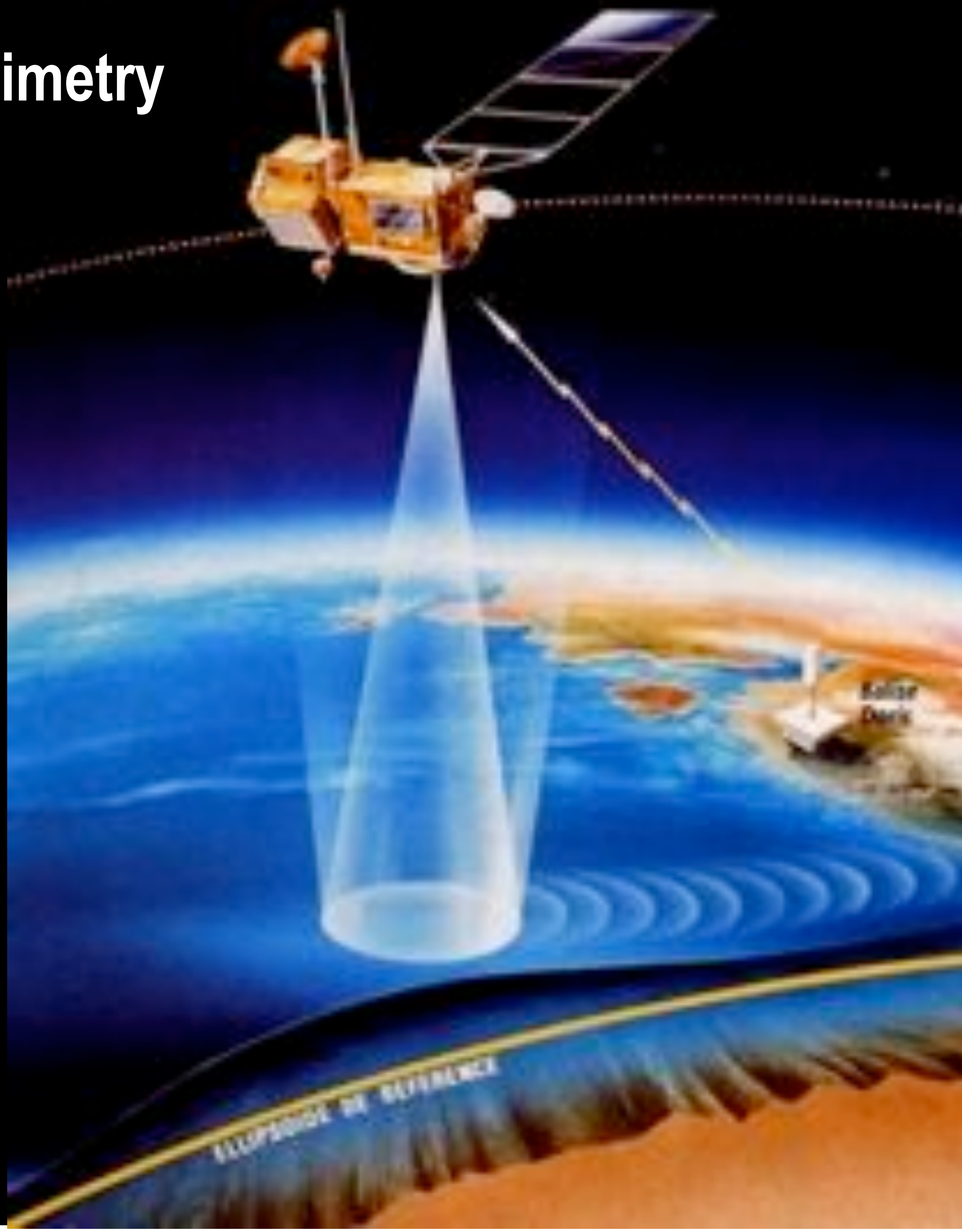
Red= saltier → E-P increases

Blue = less salty → E-P decreases

E= evaporation, P=precipitation

Durack et al., 2012

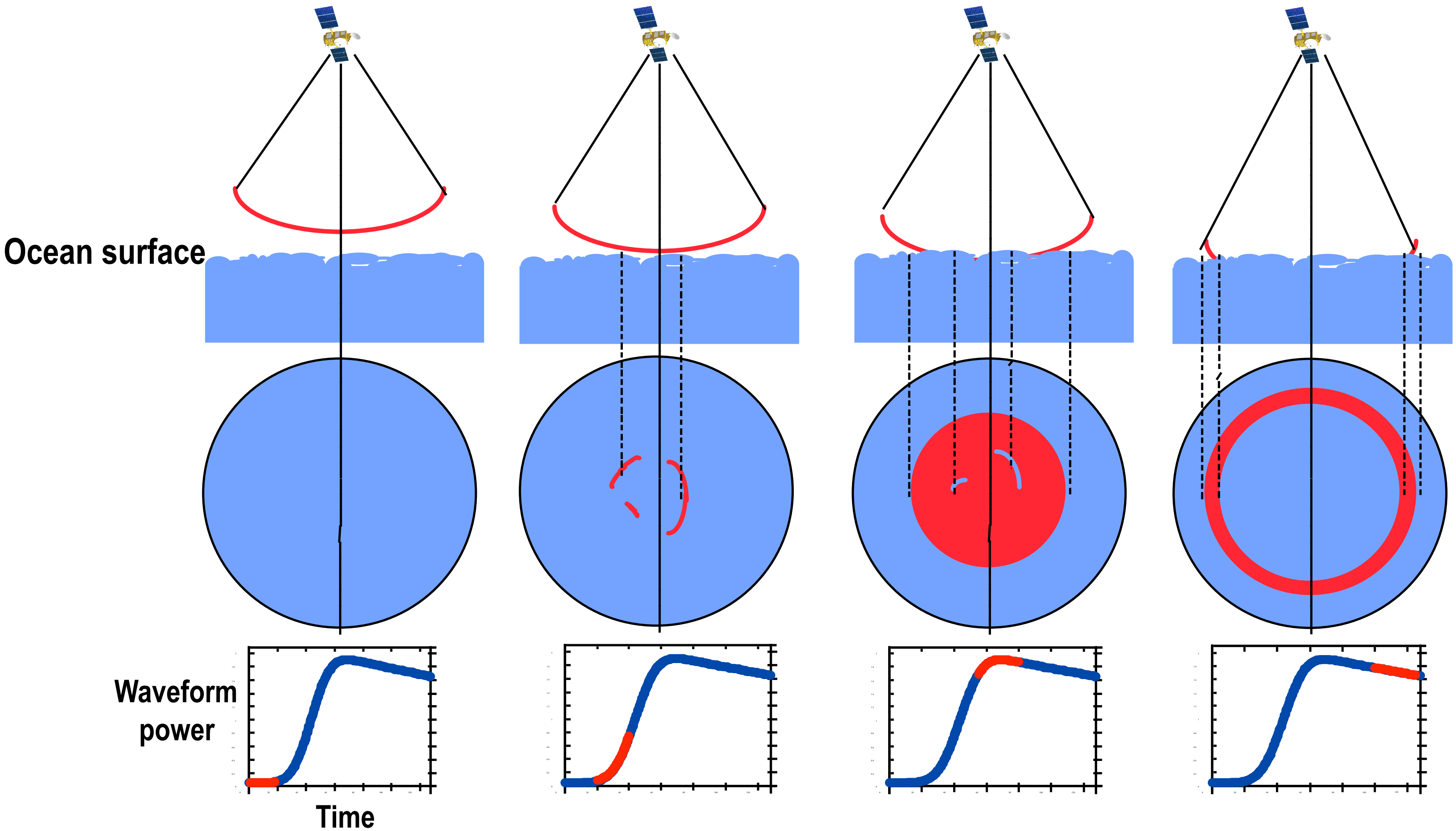
Satellite altimetry



Satellite altimetry : how it works?

Global coverage in a few days (10 days)

Interaction of the radar echoe (waveform) with the sea surface



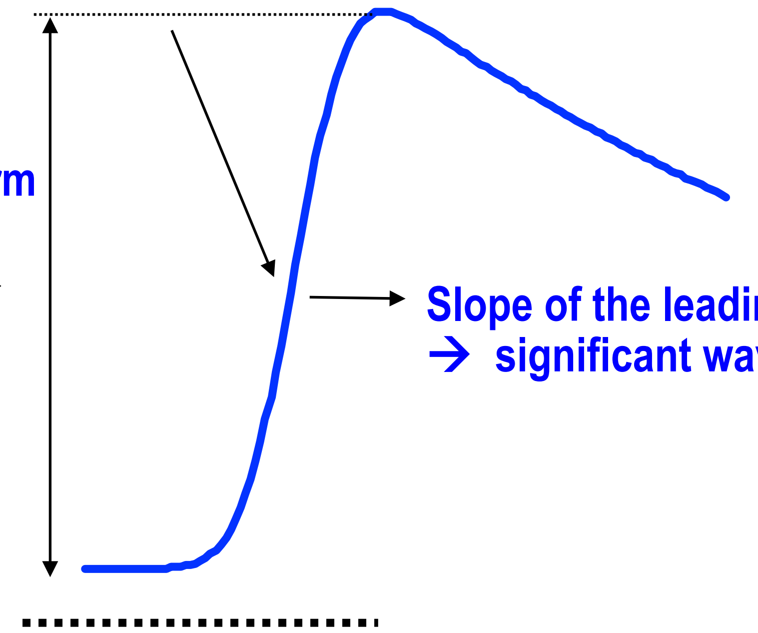
Source: CNES

Evolution of the waveform after reflection on the sea surface (returned waveform)

In addition to the altimeter range h_s, the returned waveform informs on other parameters: waveheight, surface wind speed, type of surface, etc.

➡ altimeter range h_s estimated at the midpoint on the leading edge of the returned waveform

Power of the returned waveform (backscaterring coefficient) ➡



Slope of the leading edge of the waveform
→ significant waveheight

➡ thermal noise

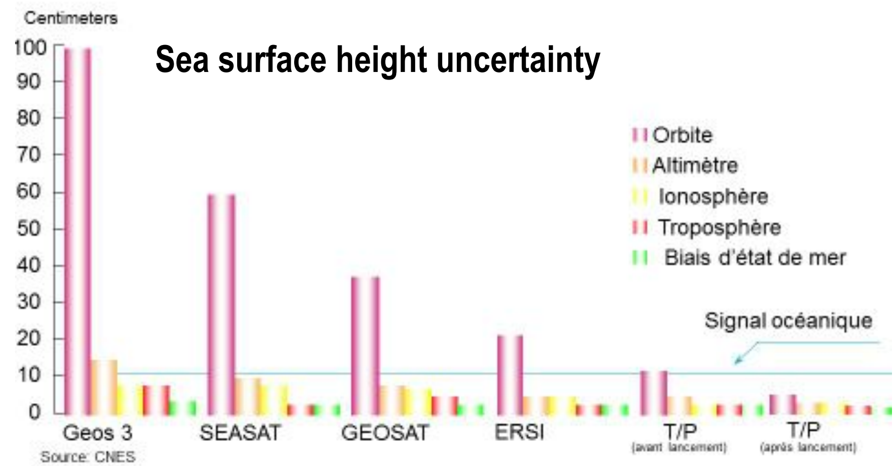
Source : CNES

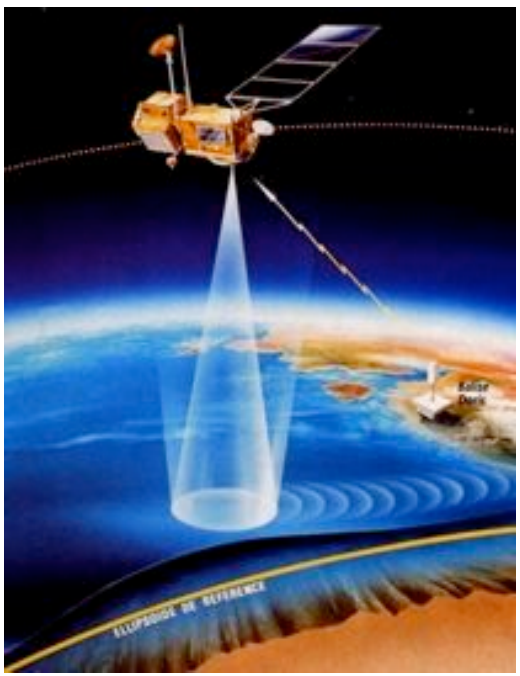
Satellite altimetry missions

1978

1985

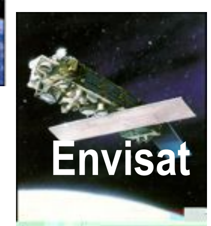
1991; 1995





1992

2001



2002

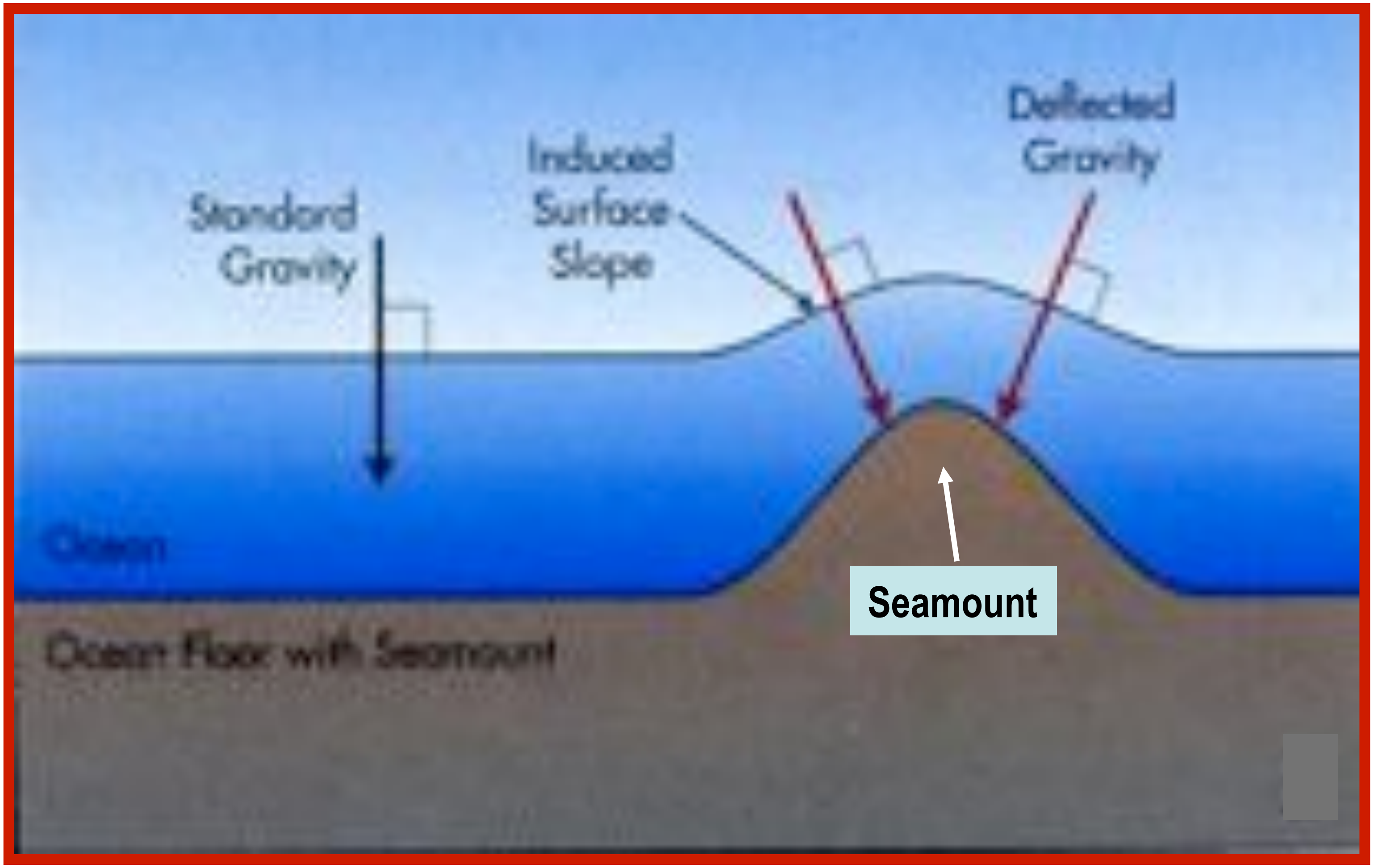
2008

2013

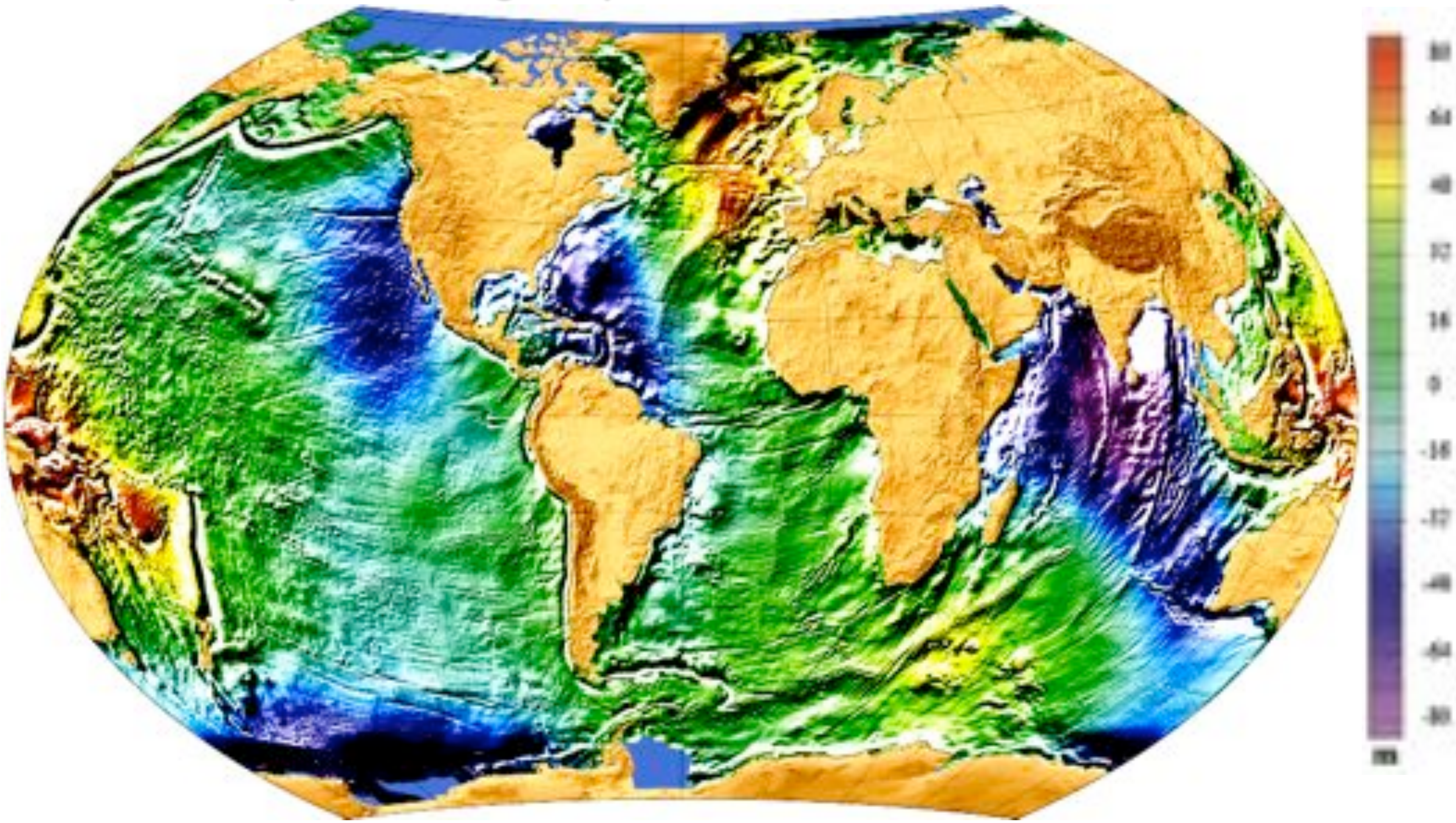
→ 1992: high-precision satellite altimetry

Highs and lows of the sea surface …..

- Time variable component → ocean dynamics, ocean tides, ….
- Permanent component → geoid→ gravity field

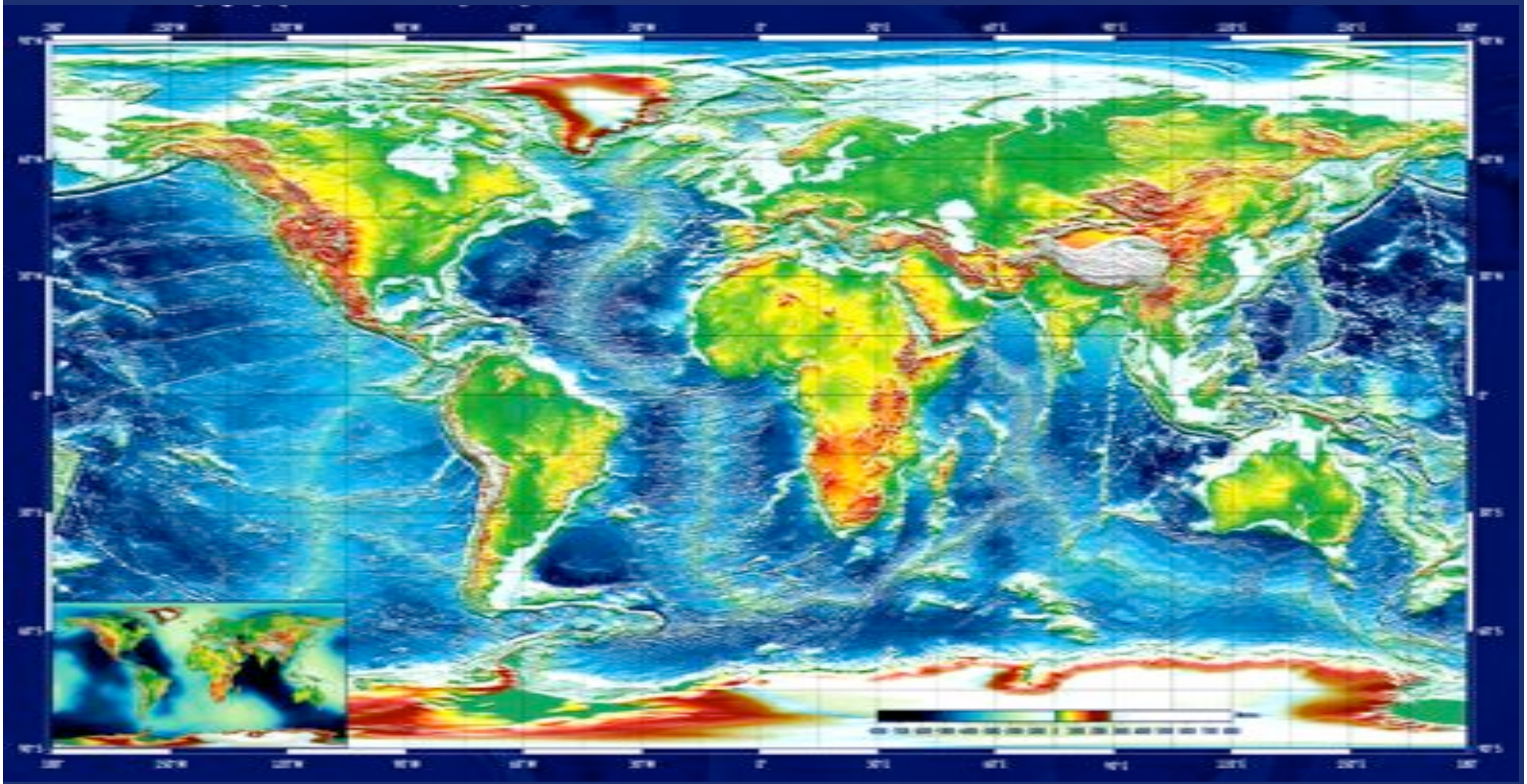


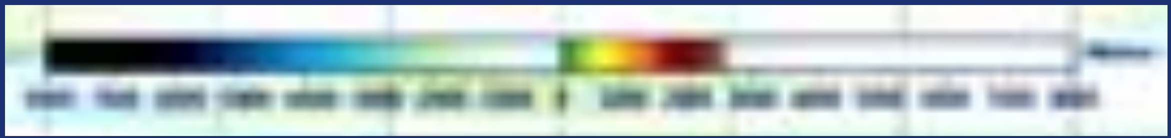
Highs and lows of the mean sea surface (= marine geoid)



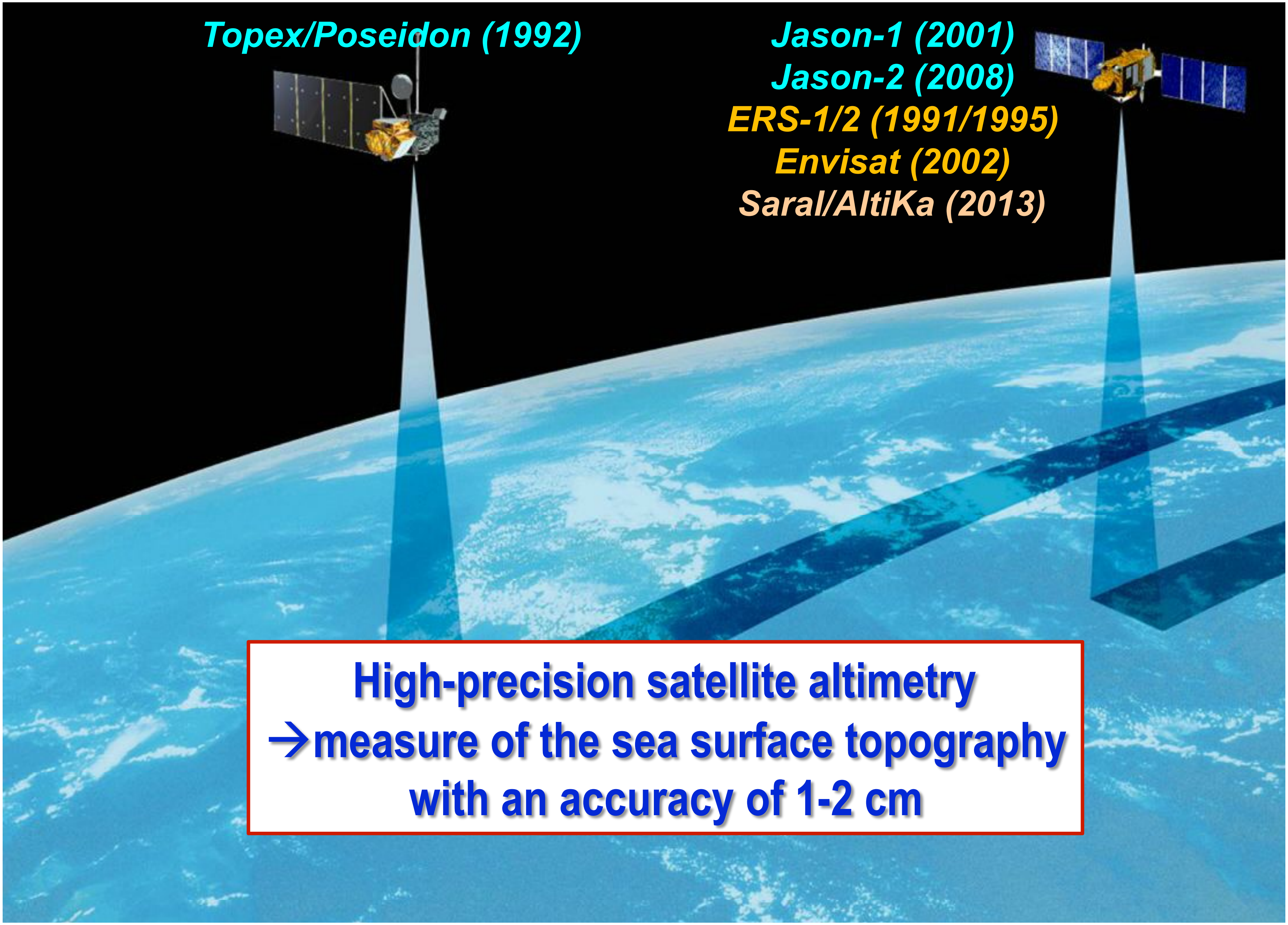
Source : CLS

Seafloor topography mapped by satellite altimetry





Source:: ESA & LEGOS


Topex/Poseidon (1992)
Jason-1 (2001)
Jason-2 (2008)
ERS-1/2 (1991/1995)
Envisat (2002)
Saral/AltiKa (2013)
High-precision satellite altimetry
→measure of the sea surface topography
with an accuracy of 1-2 cm

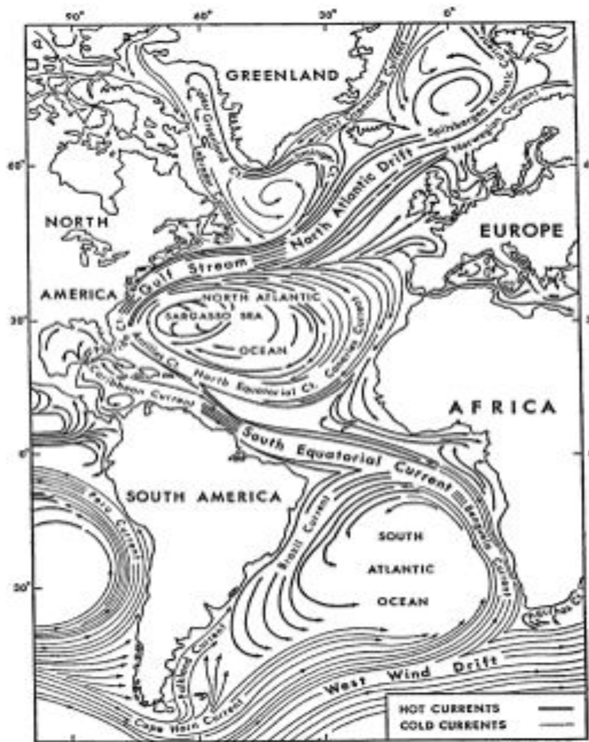
Applications of satellite altimetry

- Currents → ocean circulation
- Tides
- El Nino, La Nina
- Sea level
- Operational oceanograhy
  (sea state forecast ~2 weeks in advance)

Large-scale ocean circulation

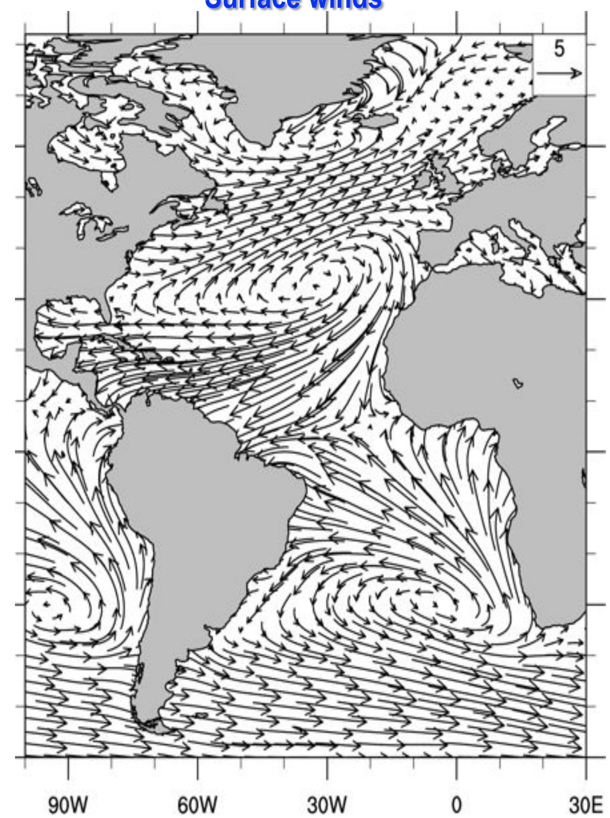
Large-scale ocean circulation highly correlated to large-scale atmospheric circulation

Surface ocean currents



The whole Atlantic circulation

Surface winds



- **The ocean dynamic topography corresponds to atmospheric pressure fields**
- **Like wind currents are derived from atmospheric pressure, ocean currents are derived from the 'ocean dynamic topography'**

Source: B. Voituriez

Ocean circulation

Depends on:

→gravity

→Surface wind stress

→Pressure gradients (temperature & salinity variations + wind-driven water mass accumulation)

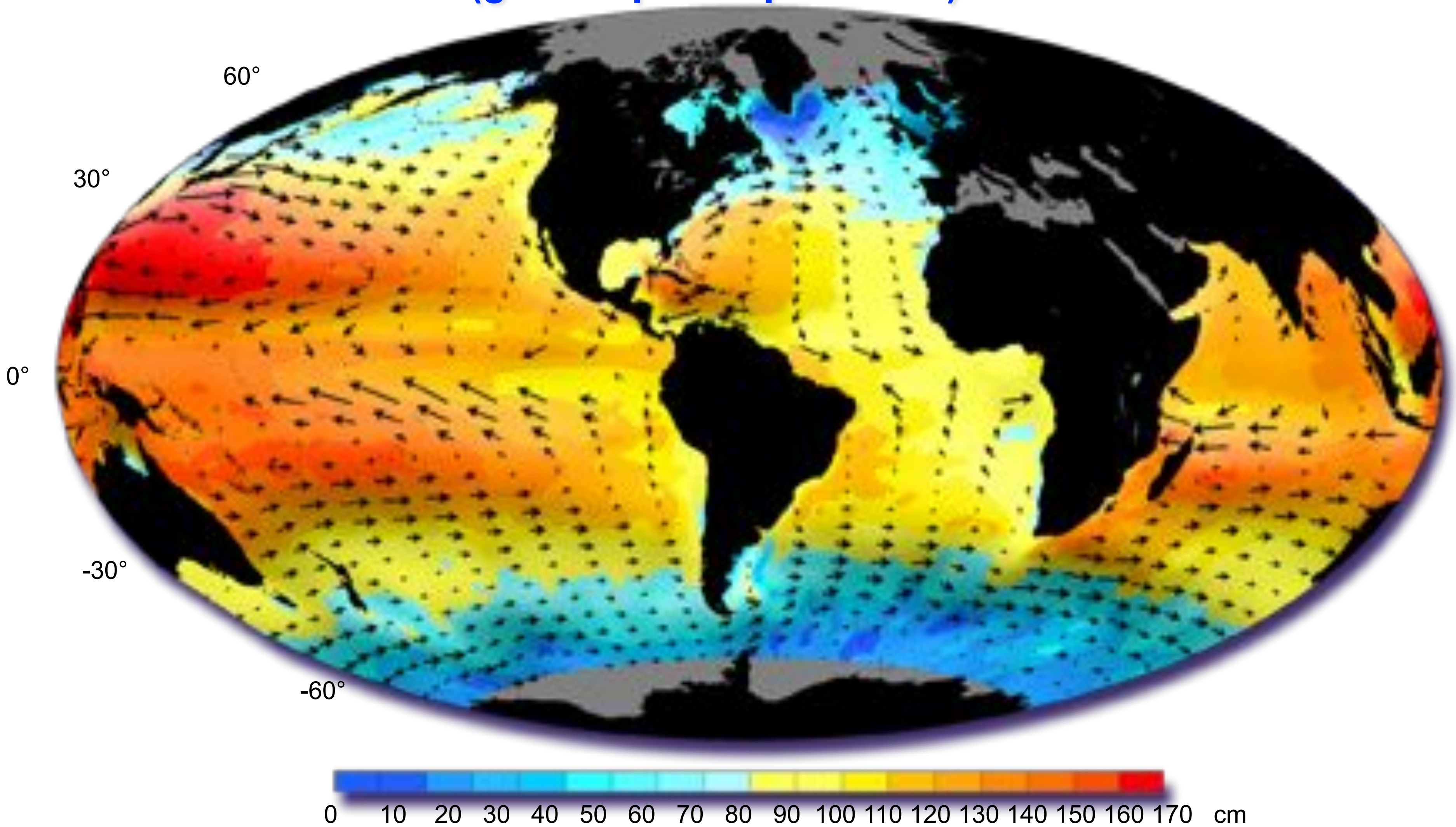
→Coriolis force (Earth's rotation)

→Astronomical forces (tides)

The large scale ocean circulation results from an equilibrium (geostrophic equilibrium) between horizontal pressure gradients and the Coriolis force

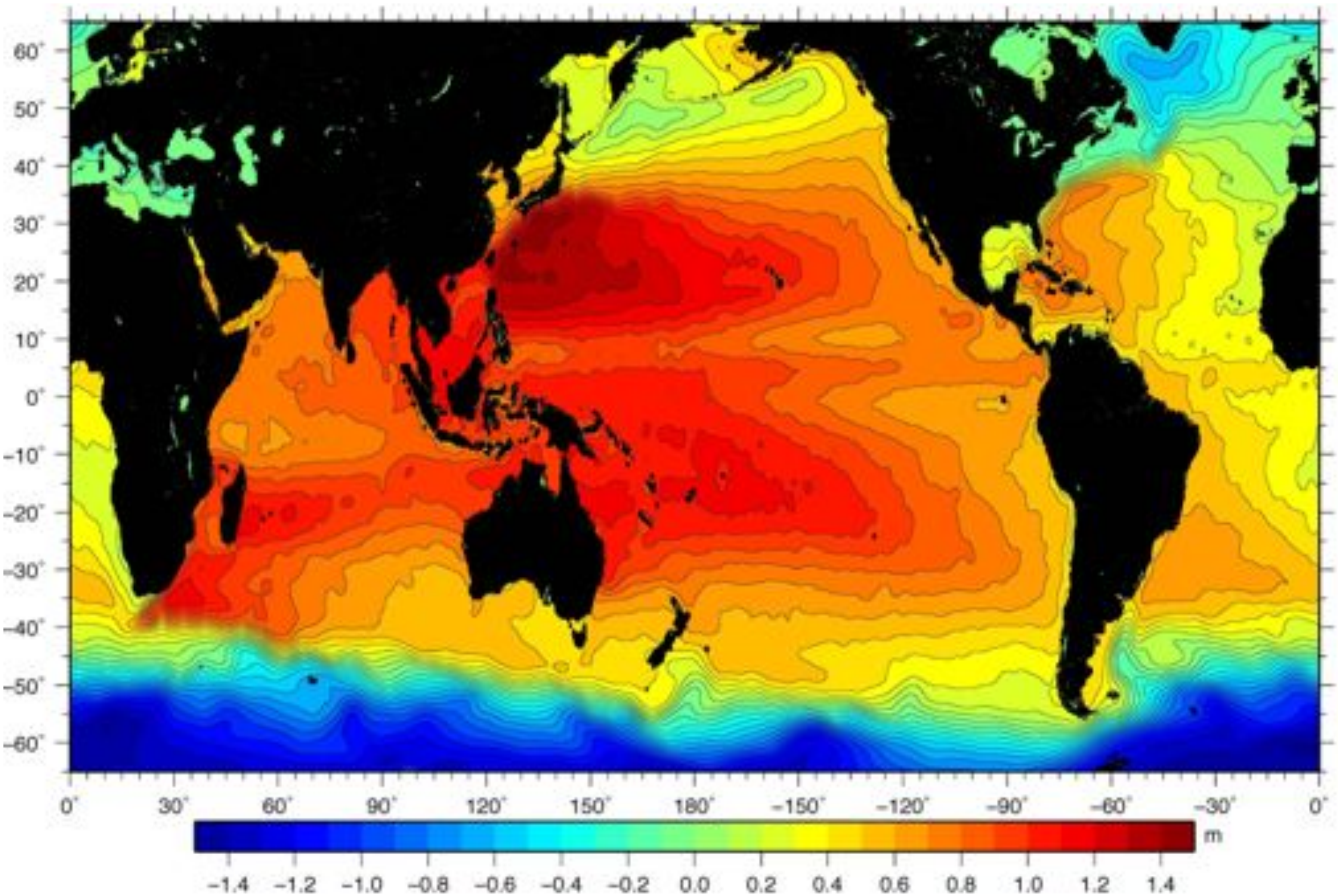
« Dynamic topography » →signature of the geostrophic circulation due to wind-driven water masses and T/S-related water density variations

‘Dynamic’ topography (*above the ‘mean sea surface*’) → ocean current velocity proportional to the sea surface slope (geostrophic equilibrium)

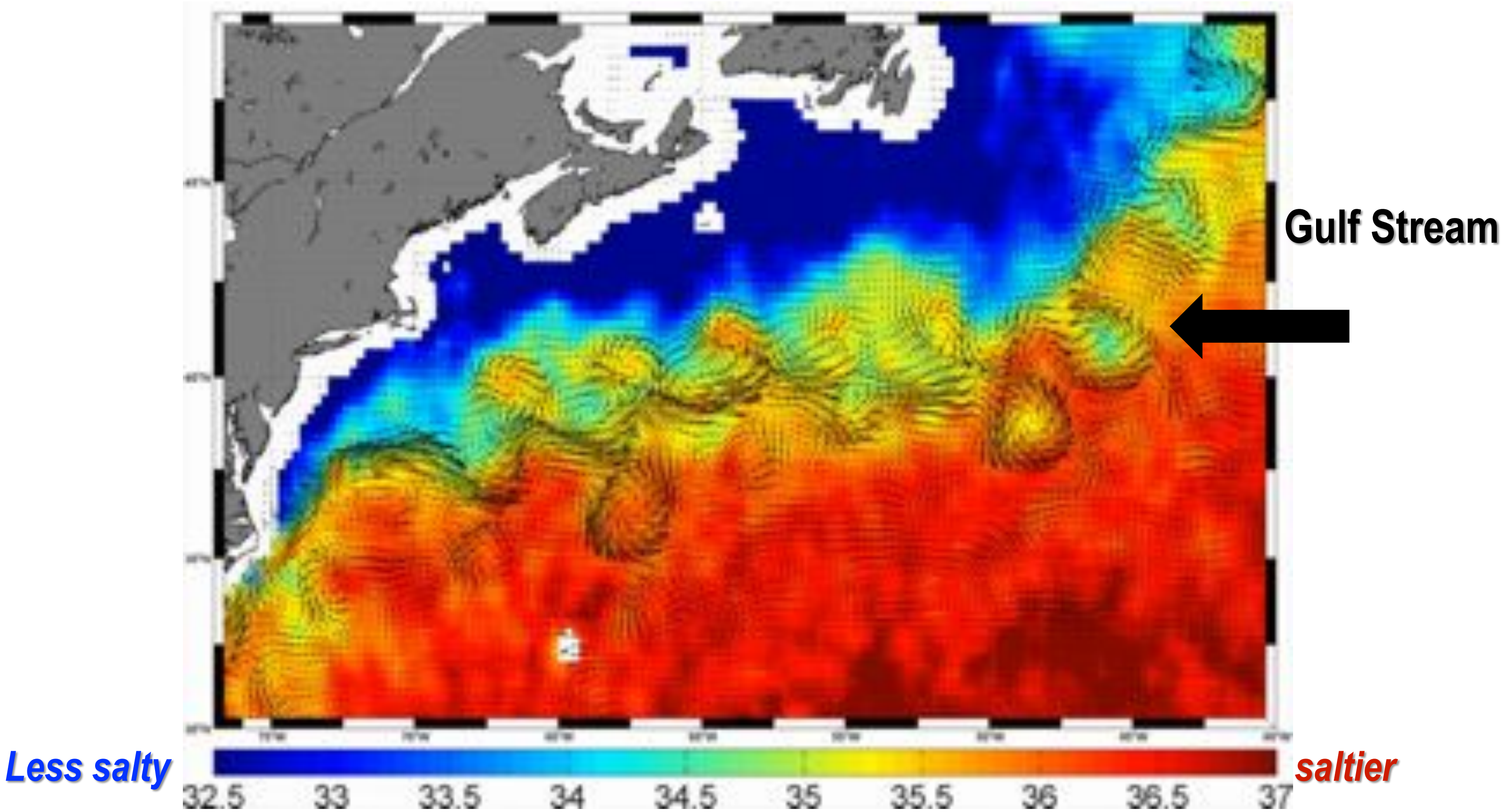


Source: CLS/AVISO

‘Dynamic’ topography (*above the ‘mean sea surface*’) → ocean current velocity proportional to the sea surface slope



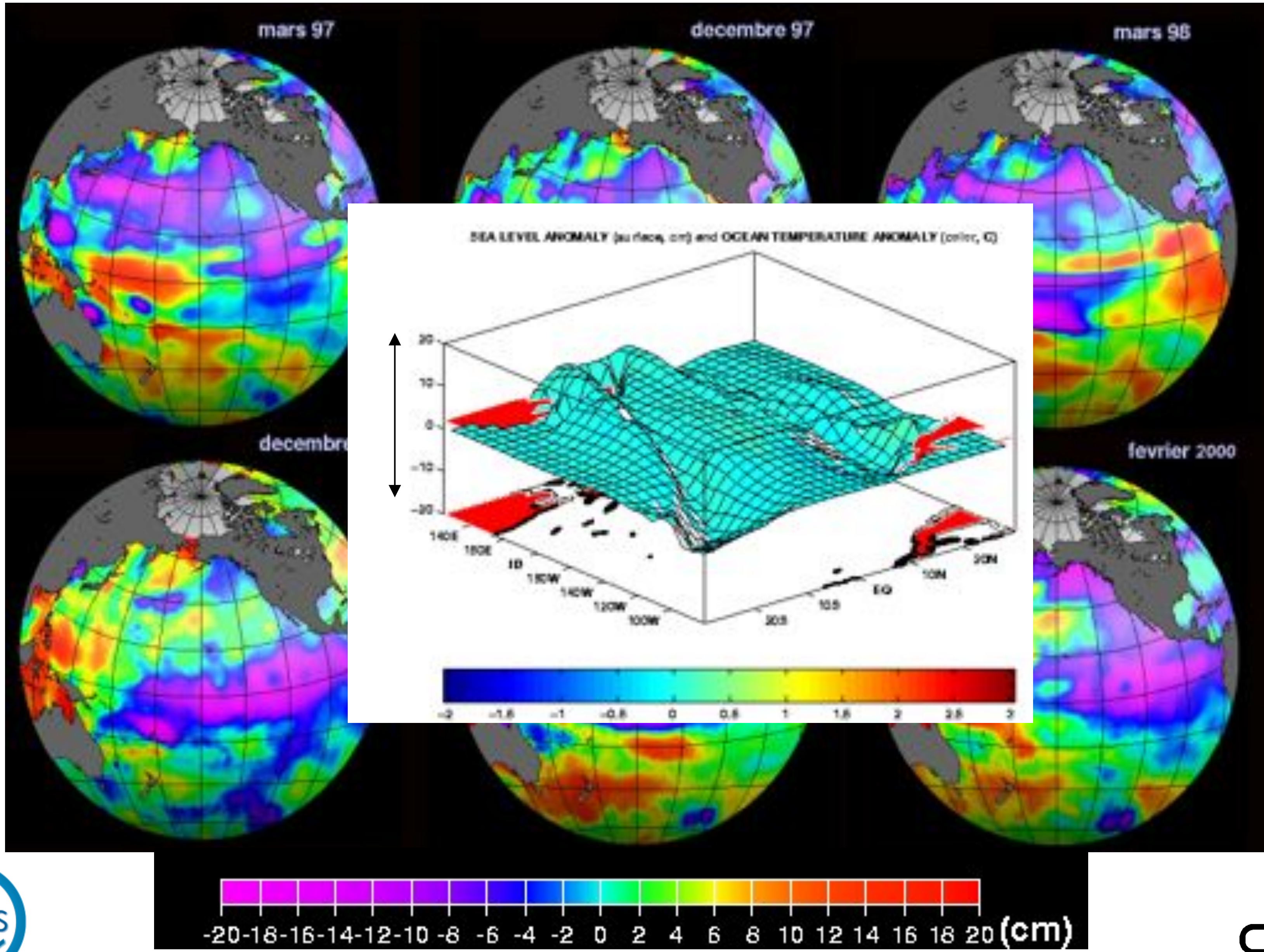
Gulf Stream 'meanders'



Ocean currents from altimetry and salinity from the SMOS satellite mission

Source: AVISO & ESA

1997-1998 El Nino seen by TOPEX/POSEIDON



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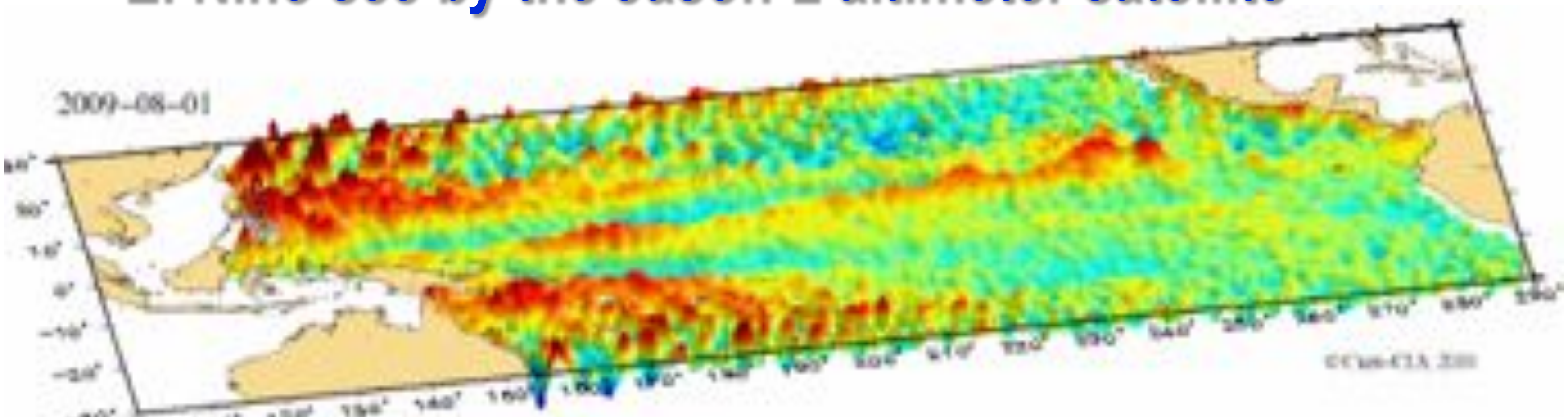
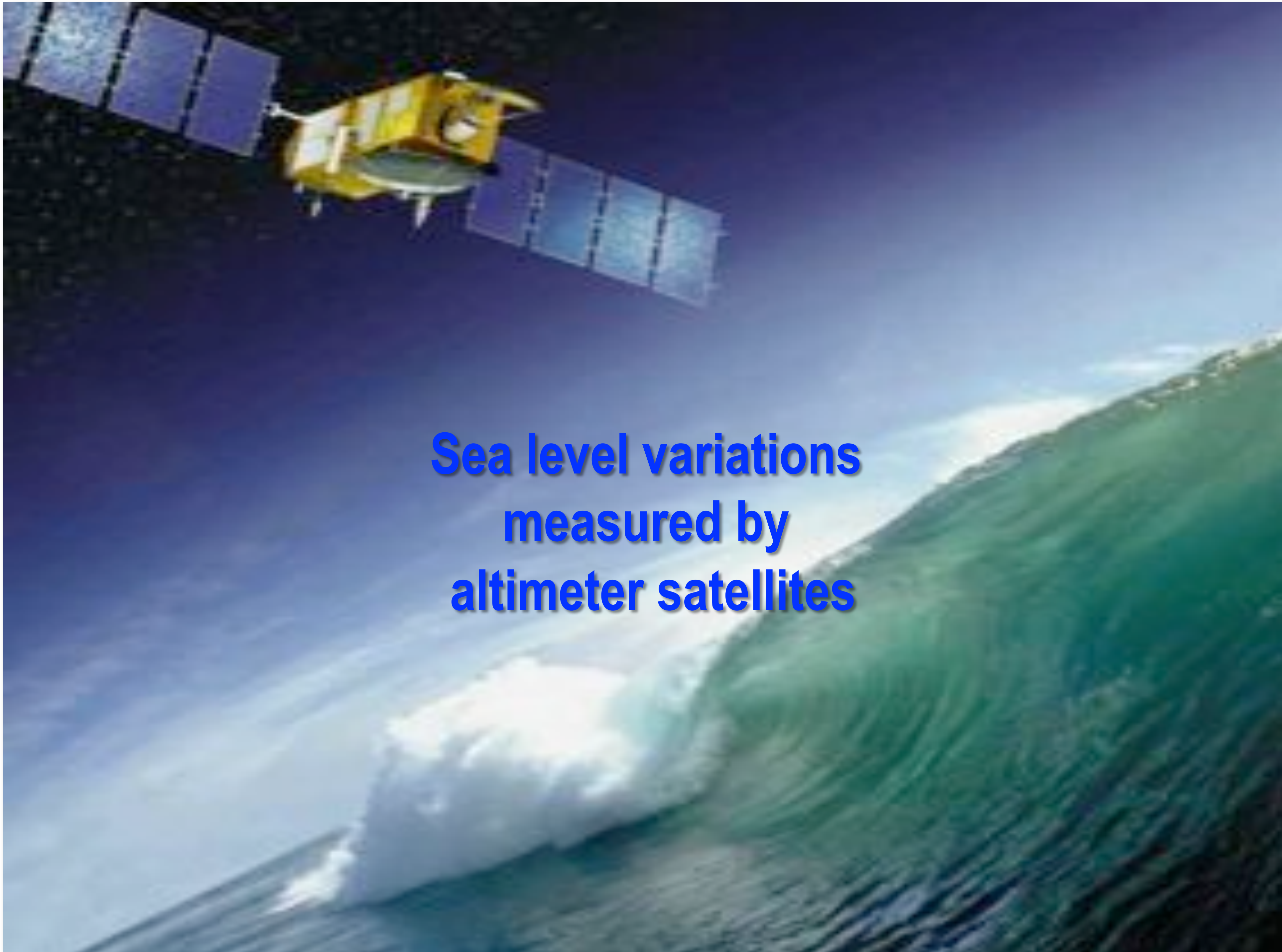
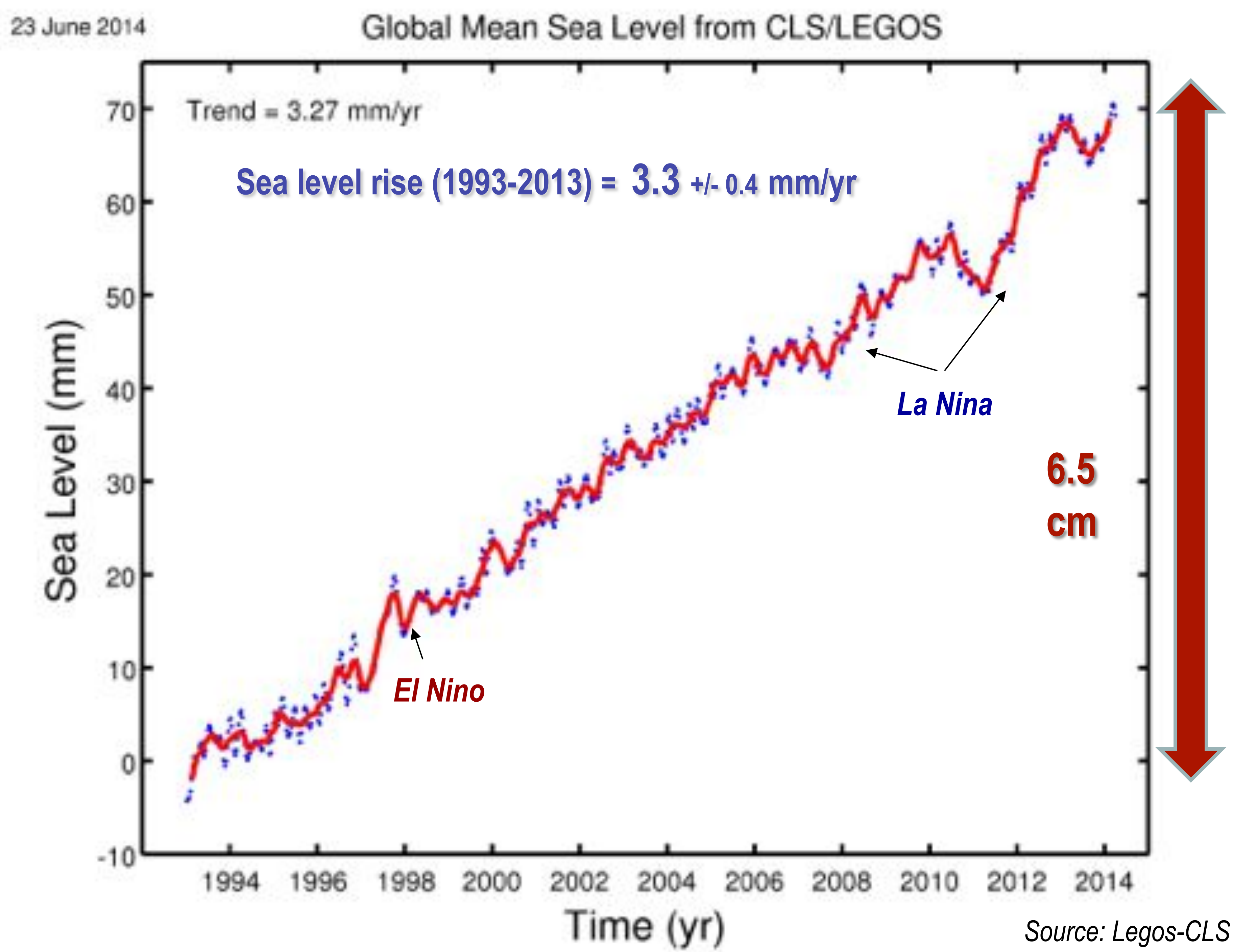
El Nino see by the Jason-2 altimeter satellite



Sea surface height in the tropical Pacific in 2009 - 2010


Sea level variations
measured by
altimeter satellites

Global coverage in a few days



Source: Legos-CLS

Sea surface height above the ellipsoid : H

$$H = h_{sat} - [h_s + h_i + h_{iono} + h_{dry} + h_{wet} + h_{EM} + h_{otide} + h_{stide} + h_{ol} + h_{ptide} + h_{baro}] + \varepsilon$$

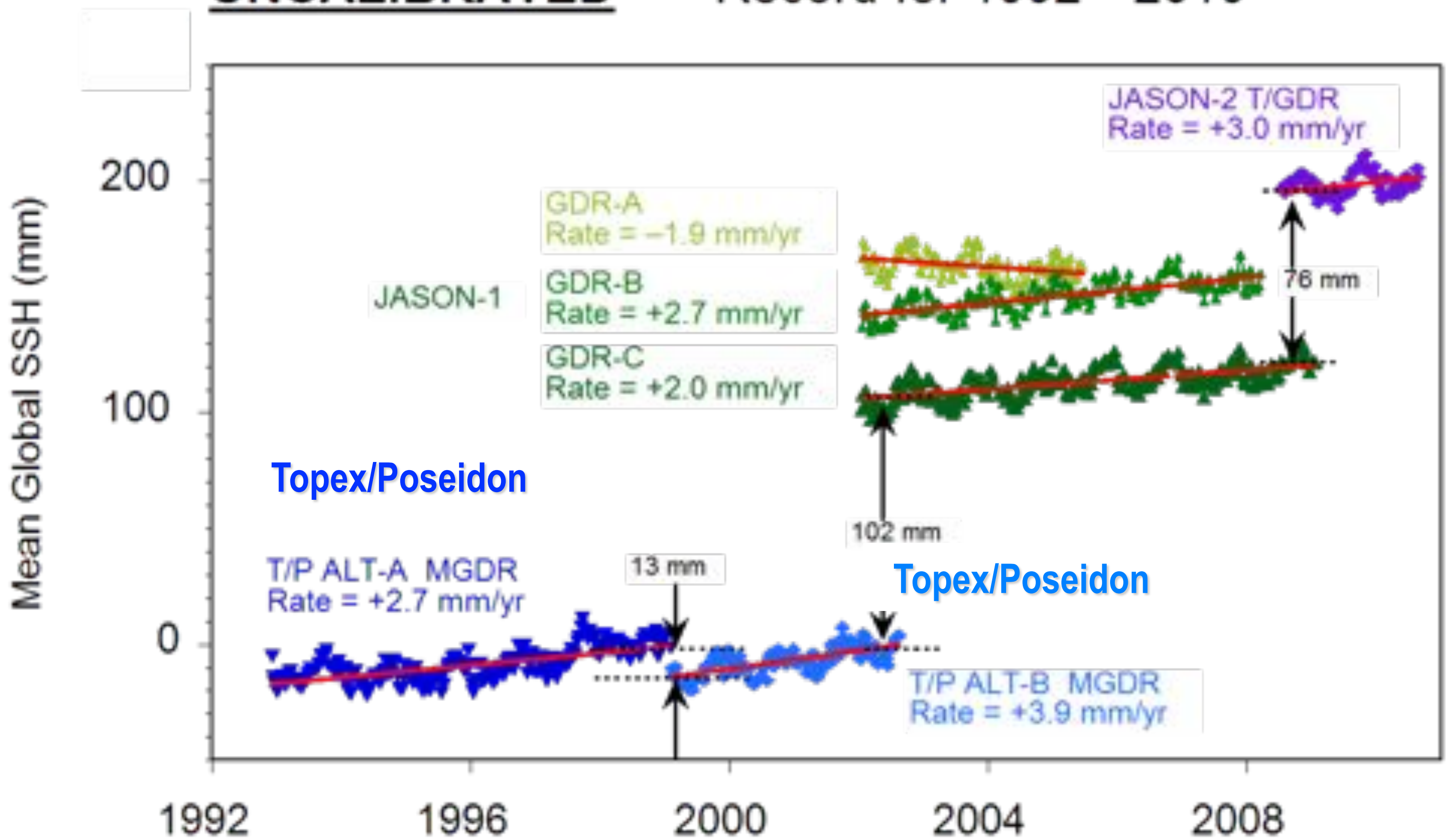
h_{sat} : Satellite altitude above the ellipsoid (radial orbit component)
h_s : instantaneous distance between the altimeter antenna and ocean surface
h_i : *instrumental corrections*
h_{iono} : ionospheric correction
h_{dry} : dry tropospheric correction
h_{wet} : *wet tropospheric correction*
h_{EM} : EM-bias correction
h_{otide} : ocean tide correction
h_{side} : solid Earth tide correction
h_{ol} : ocean loading correction
h_{ptide} : pole tide correction
h_{baro} : inverted barometer correction
ε : random and systematic remaining errors

Sea level : most demanding application of satellite altimetry

Example of sea surface height bias between successive missions (Topex/Poseidon, Jason-1, Jason-2) → calibration very important!

Need for an overlap between successive missions (tandem missions)

Global Sea Level from T/P, Jason-1 and Jason-2:
UNCALIBRATED Record for 1992—2010



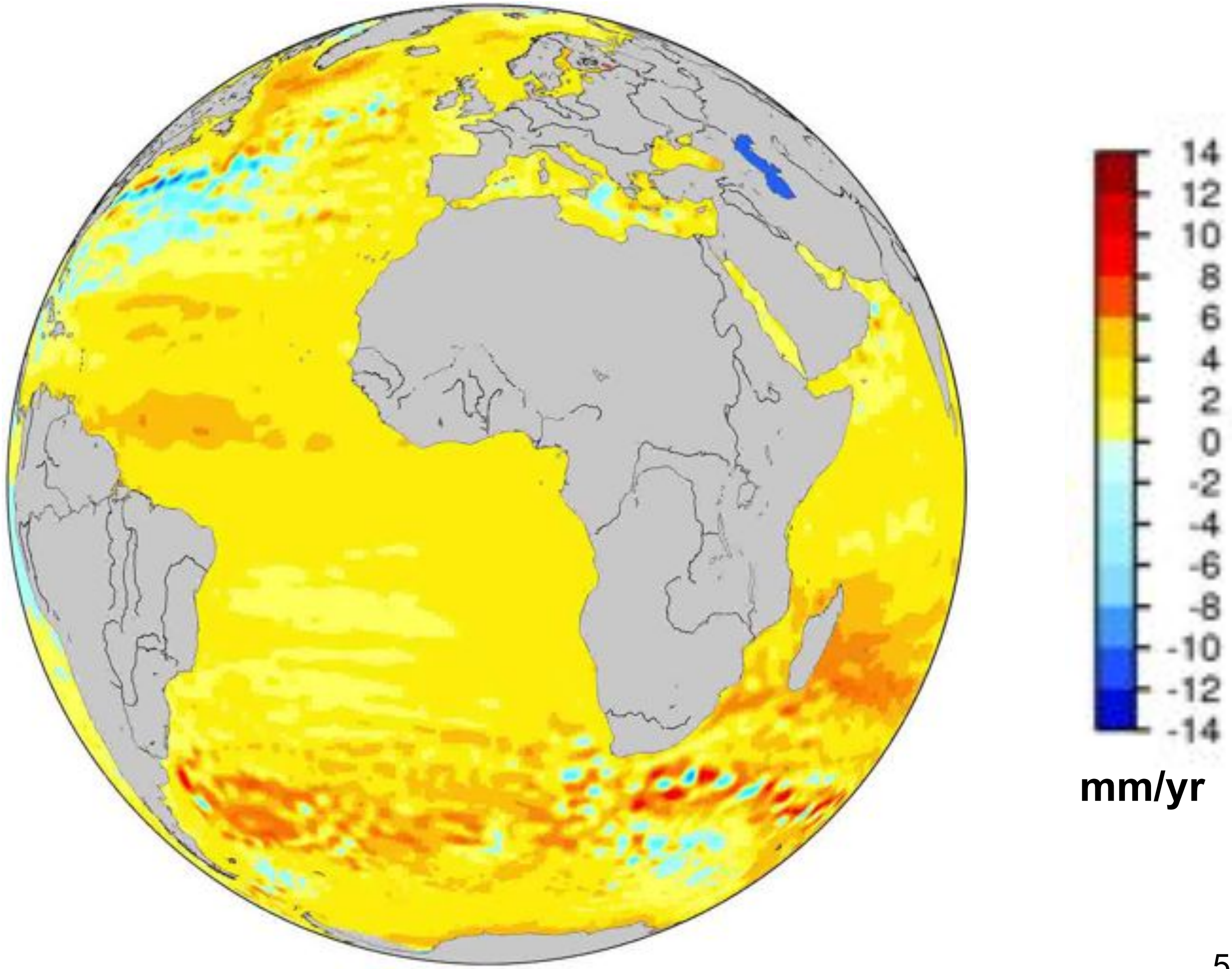
Source: P. Bonnefond

Sources of sea level trend uncertainty

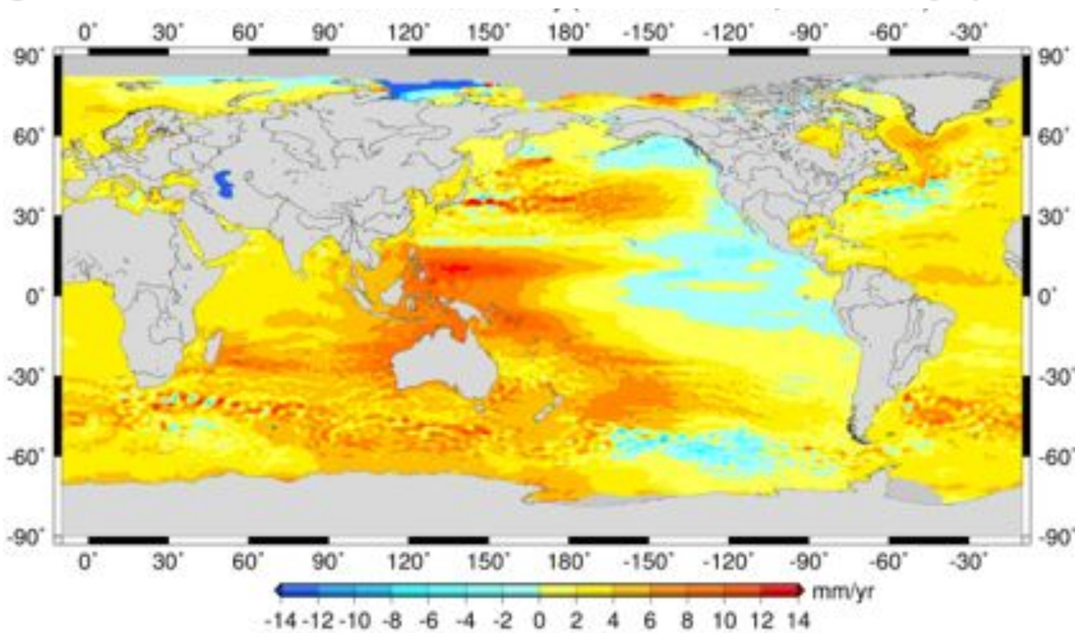
Source	Trend errors (mm/yr)
Orbit error	~0.25
Wet troposphere correction (instrumental drift of onboard radiometers)	~0.3
Intrumental altimeter bias (Topex A-Topex B)	~0.25
Dry troposphere correction (uncertainty of atm. surface pressure data)	~0.1
Sea state bias correction	~0.1
Total error	*~0.4*
Tide gauge calibration (e.g. Mitchum et al., 2010)	~0.4


Sea level is not rising uniformely!

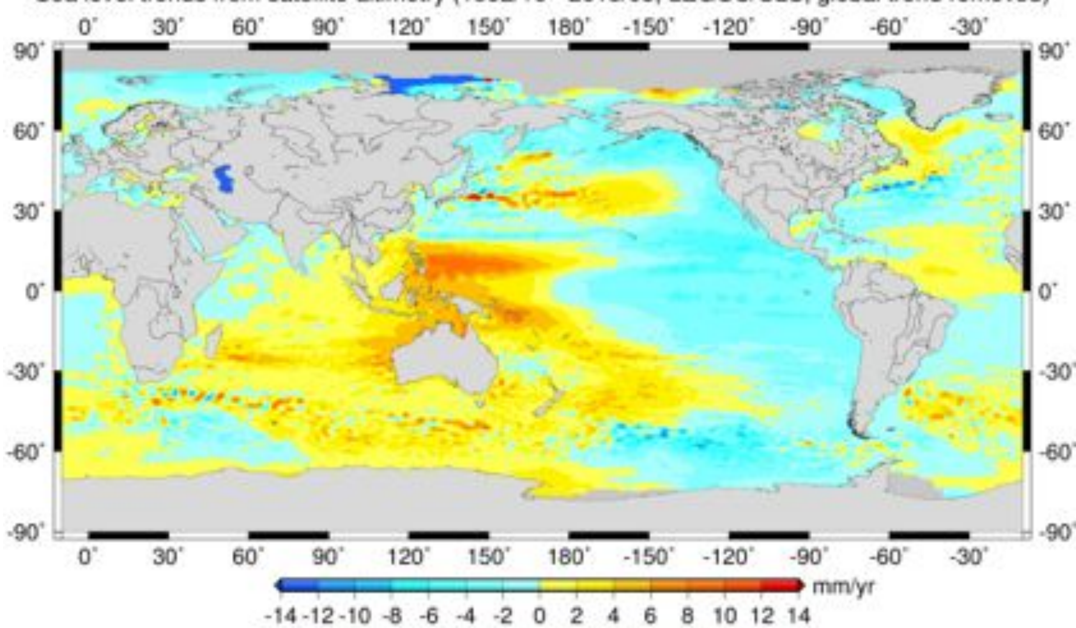
Sea level trend patterns from satellite altimetry (1993-2012)



Regional sea level trends from satellite altimetry (1993-2013)

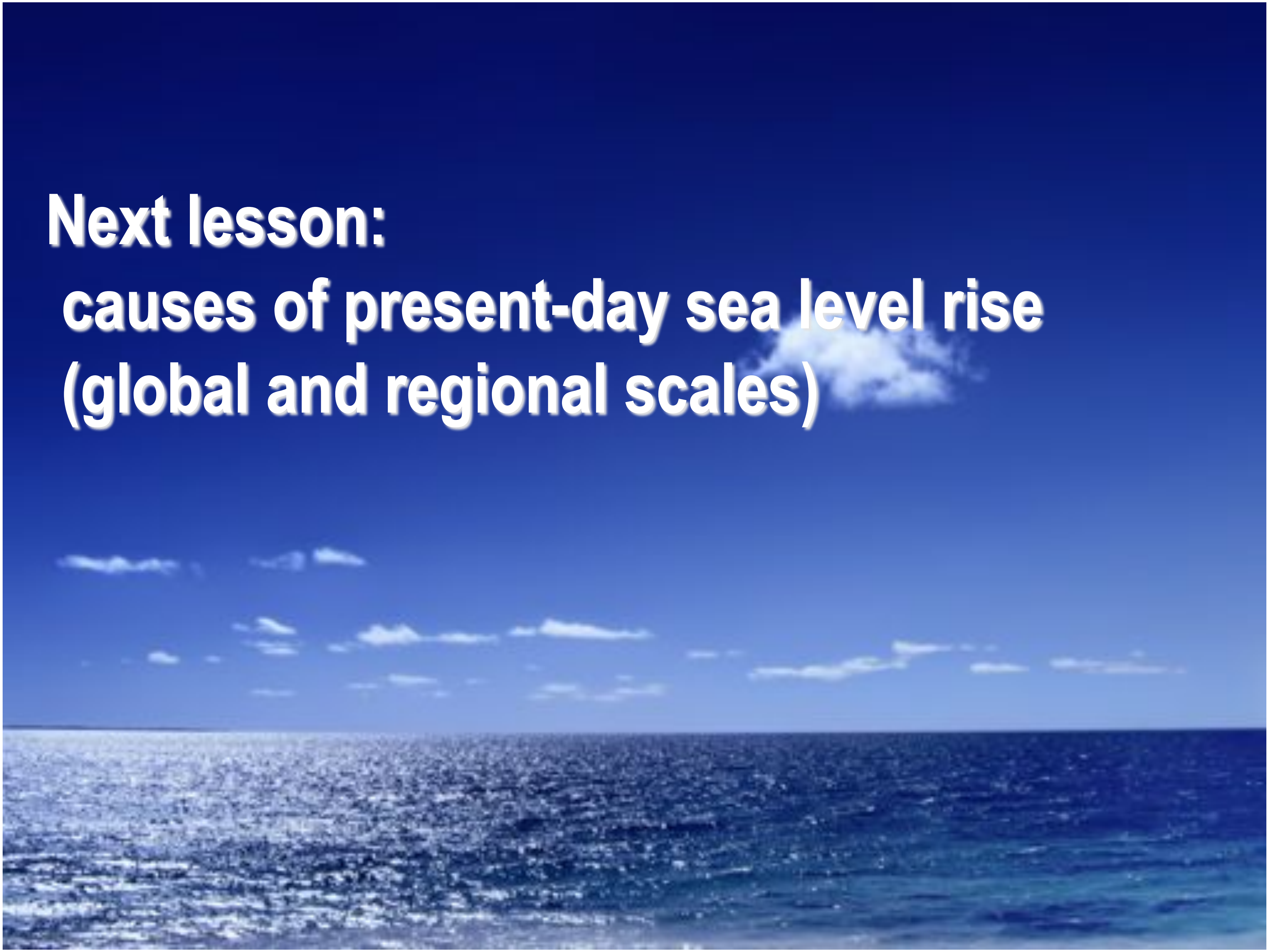


Sea level trends from satellite altimetry (1992/10 - 2013/08, LEGOS/CLS, global trend removed)



Global mean trend removed


Thanks for your attention


Next lesson:
causes of present-day sea level rise
(global and regional scales)