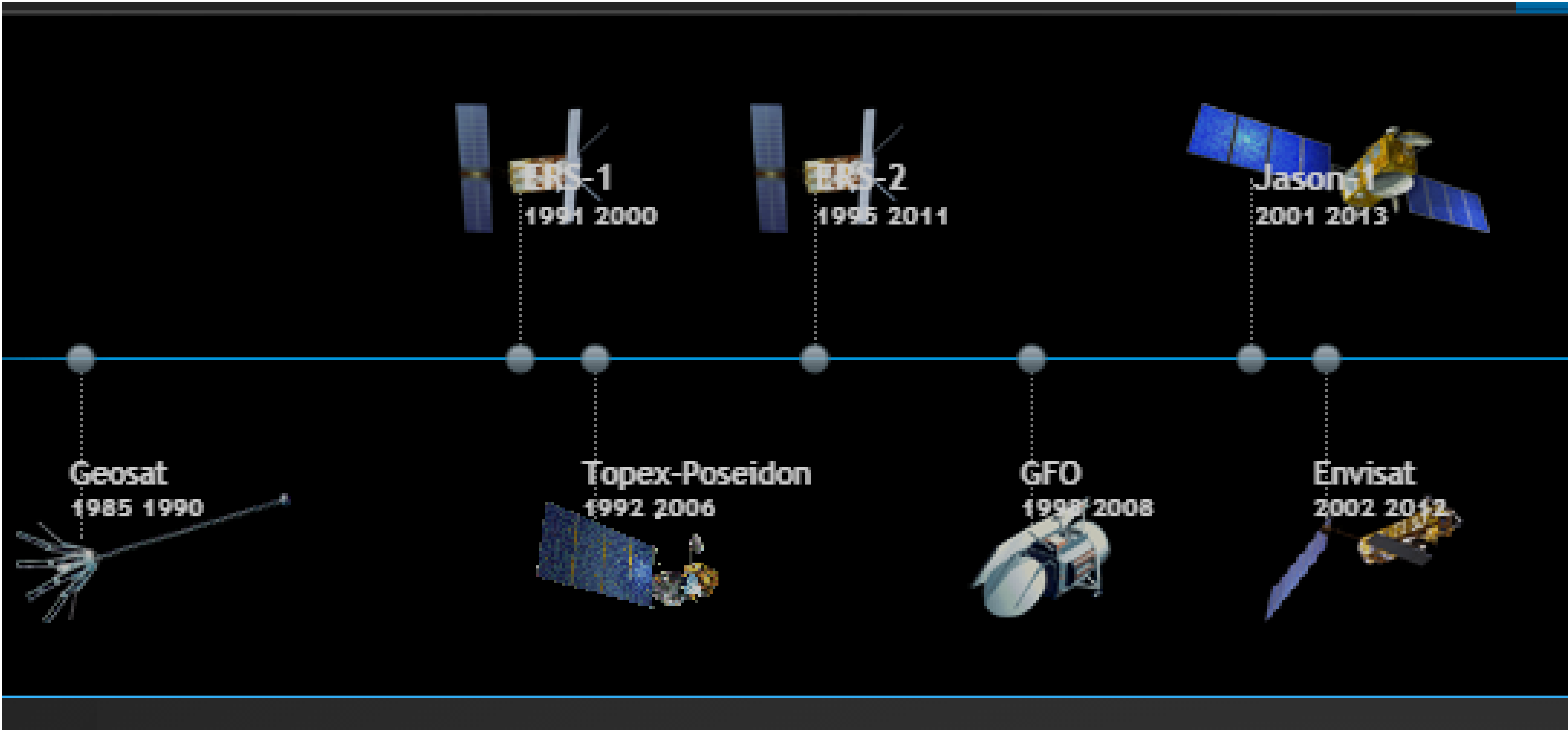
# OMARSAT 2017

IEAPM – ARRAIAL DO CABO (RJ)

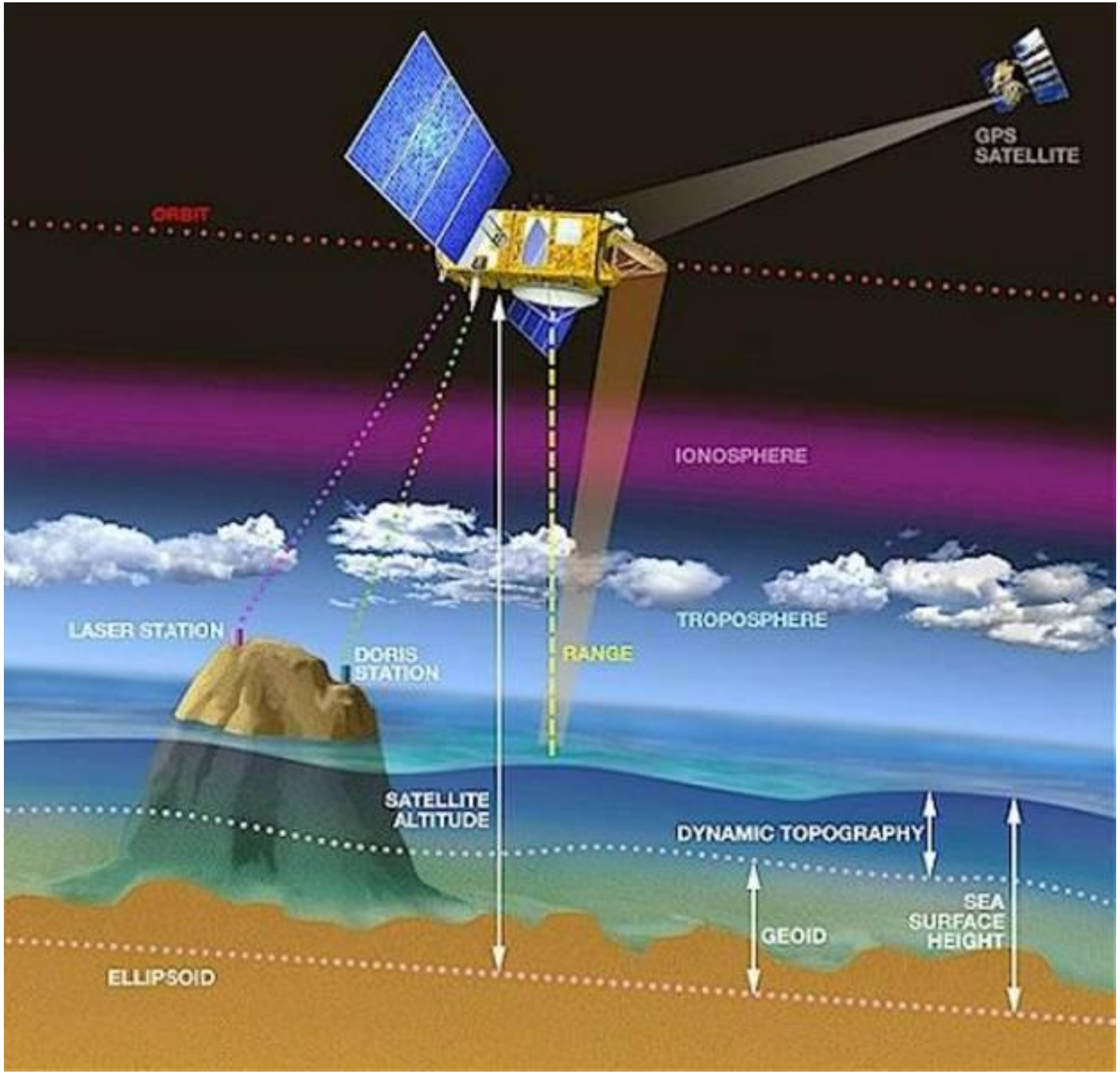
# “25 ANOS DE ALTIMETRIA DE SATÉLITE: AVANÇOS E PERSPECTIVAS (ANÁLISE DE DADOS DE ALTIMETRIA NO ATLÂNTICO SUDOESTE)”

JOSEPH HARARI – IOUSP

03 de outubro de 2017


ERS-1
1991 2000
ERS-2
1995 2011
Jason-1
2001 2013
Geosat
1985 1990
Topex-Poseidon
1992 2006
GFO
1998 2008
Envisat
2002 2012


Jason-2
2008
HY-2
2011
Sentinel-3a
2016
CFOSAT
2018
Swot
2021
Cryosat
2010
Saral
2013
Jason-3
2016
Jason-CS / Sentinel-6
2020
Past missions
Current missions
Future missions

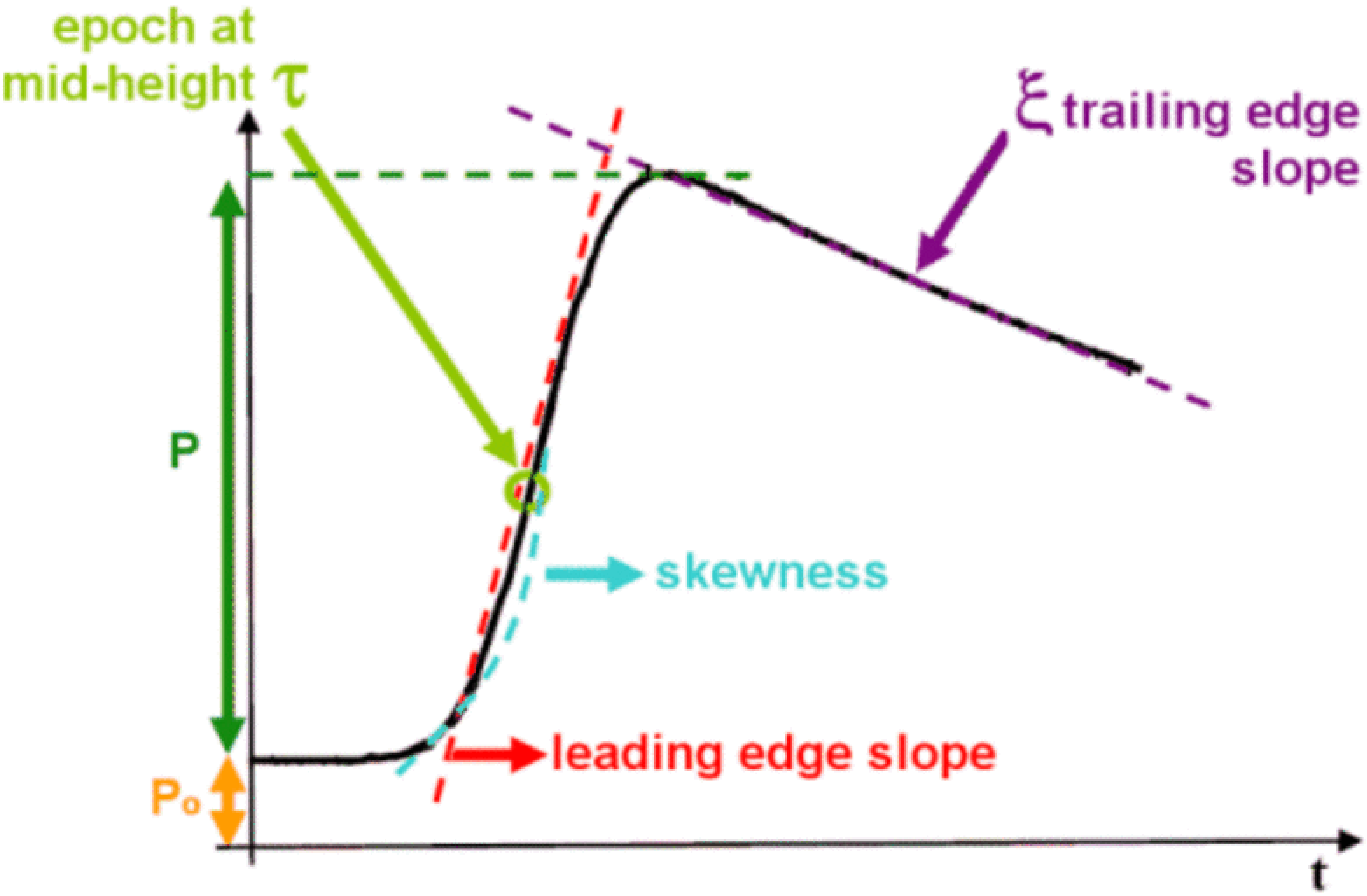


# ALTIMETRY PRINCIPLES

SEA SURFACE HEIGHT SSH =
SATELLITE ALTITUDE S – RANGE R

SEA SURFACE HEIGHT SSH =
GEOID G +
DYNAMIC TOPOGRAPHY DT

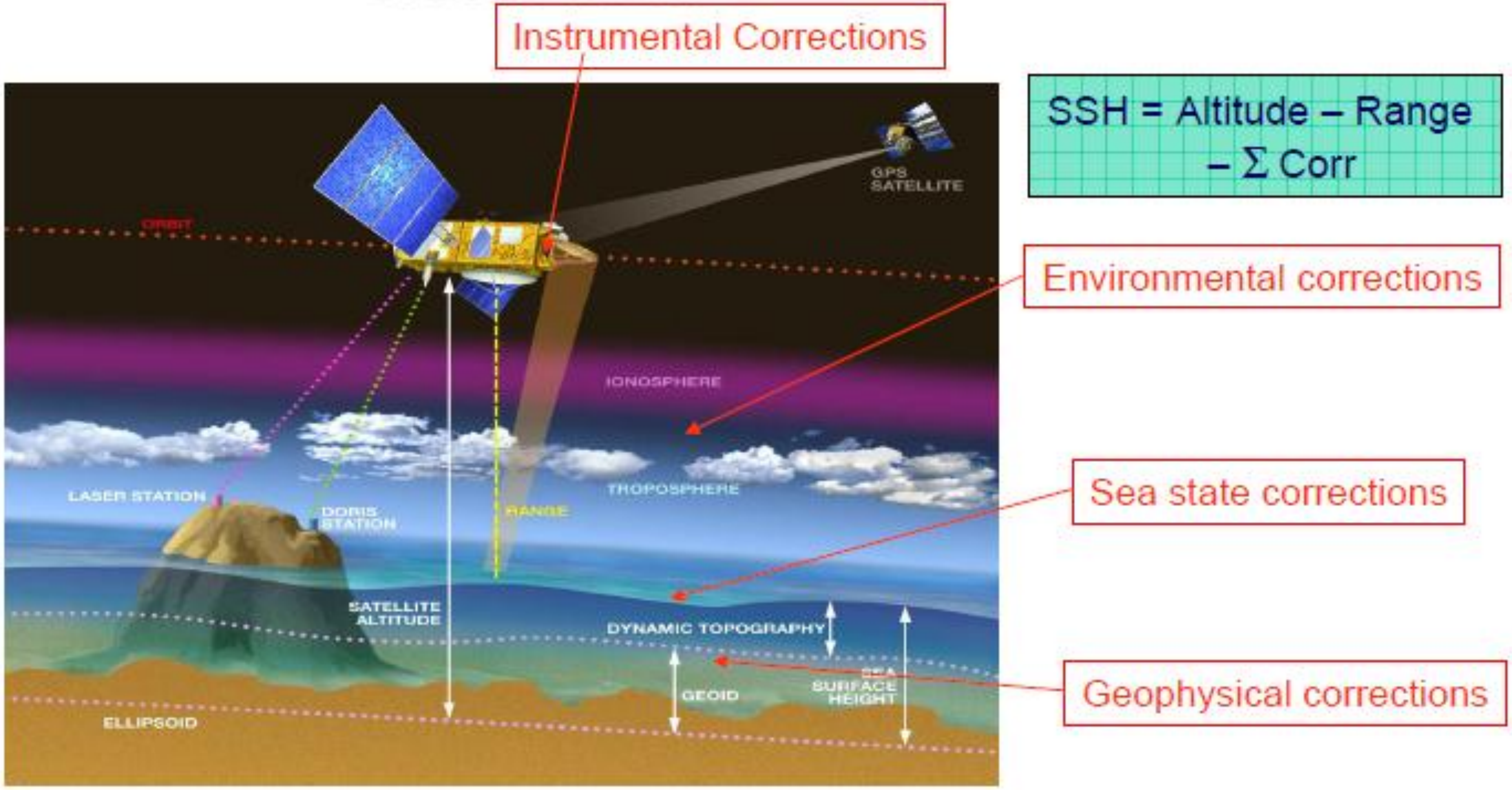
# Waveforms characteristics:



**epoch at mid-height**: this gives the time delay of the expected return of the radar pulse → RANGE R

P: the amplitude of the useful signal. This amplitude with respect to the emission amplitude gives the **backscatter coefficient**, sigma0. → WIND SPEED

**leading edge slope**: this can be related to the significant wave height →SWH



Instrumental Corrections

SSH = Altitude – Range – Σ Corr

Environmental corrections

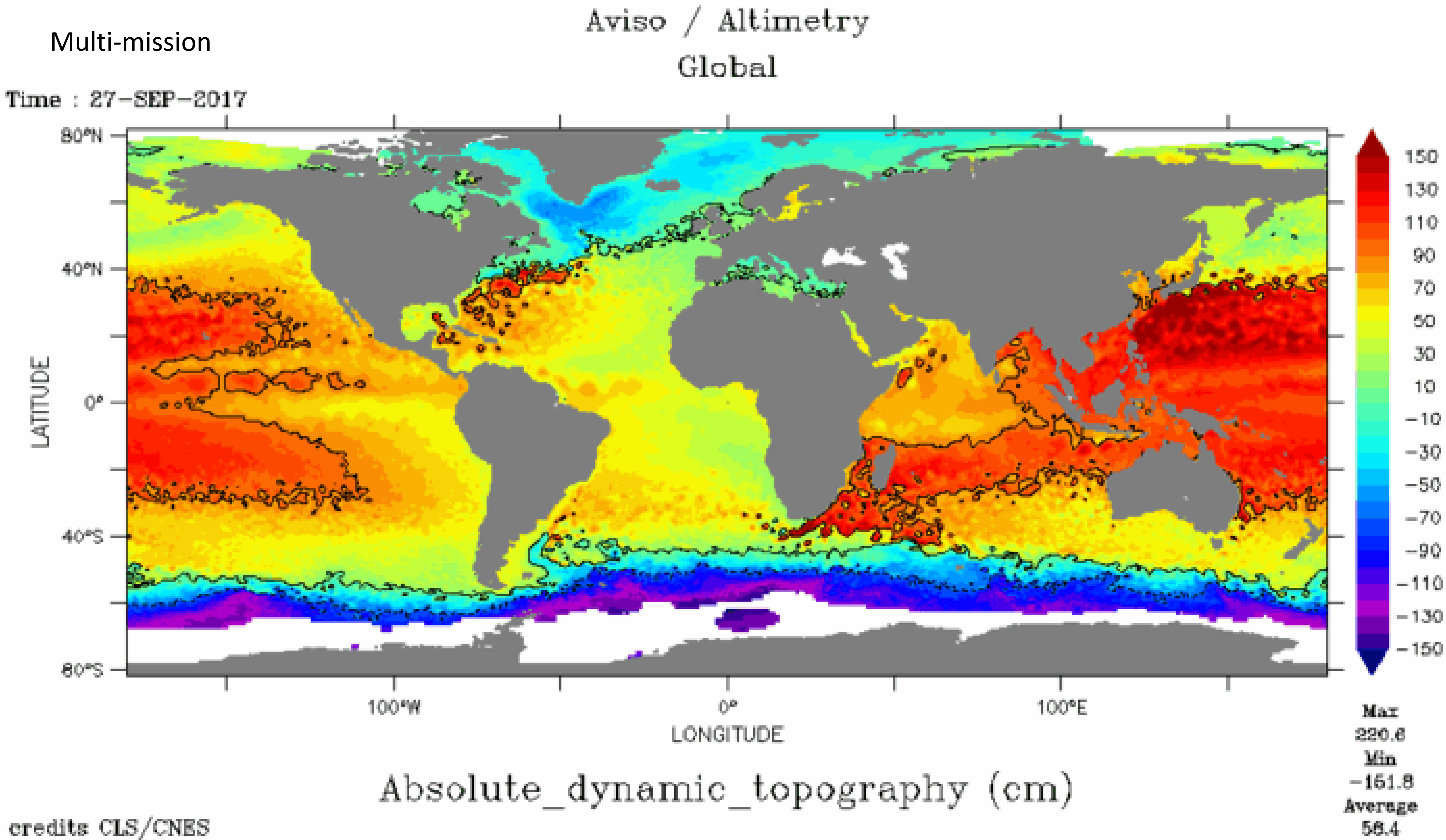
Sea state corrections

Geophysical corrections

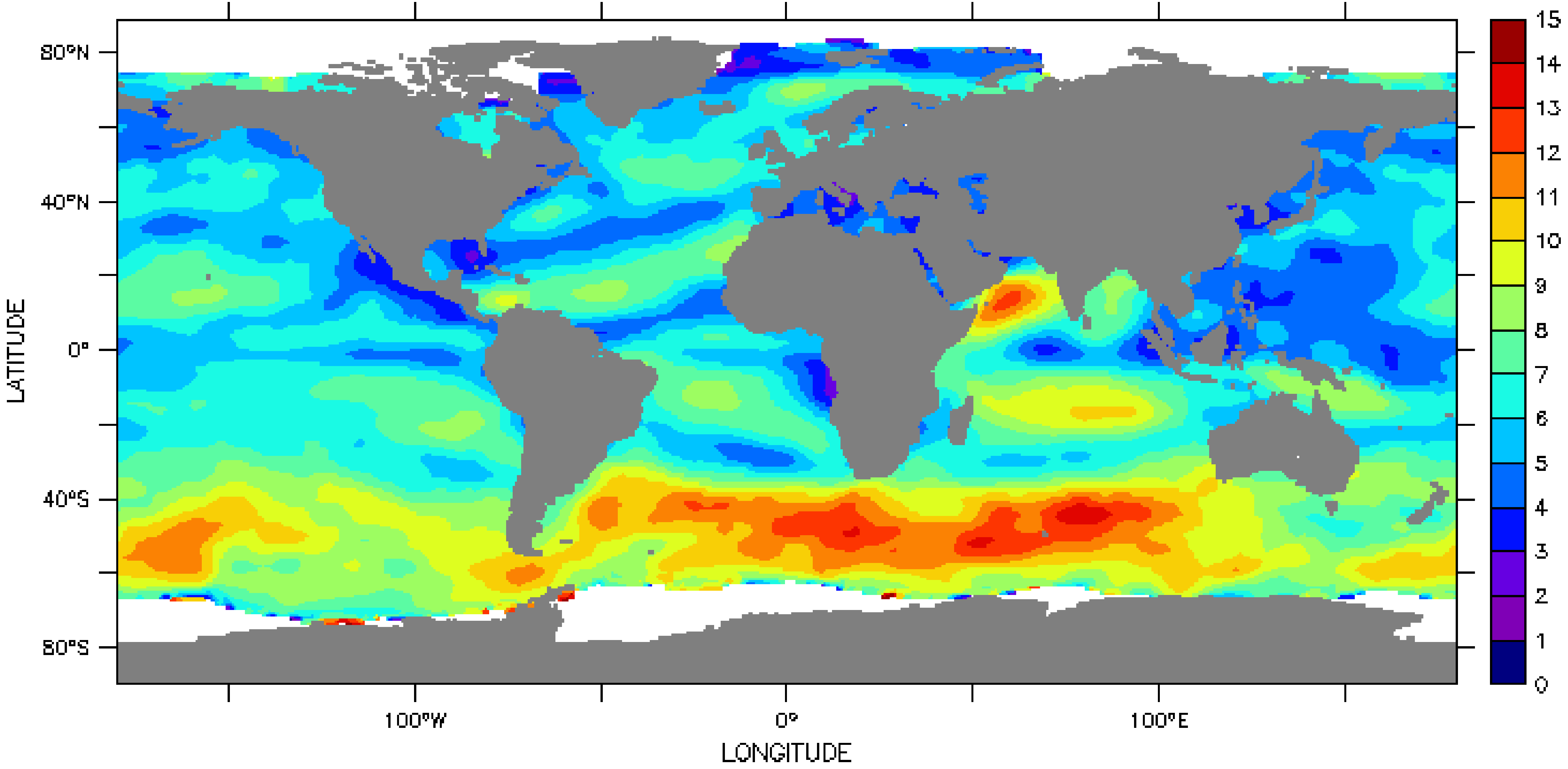
Environmental corrections:

Ionosphere
Dry toposphere
Wet troposphere

Multi-mission

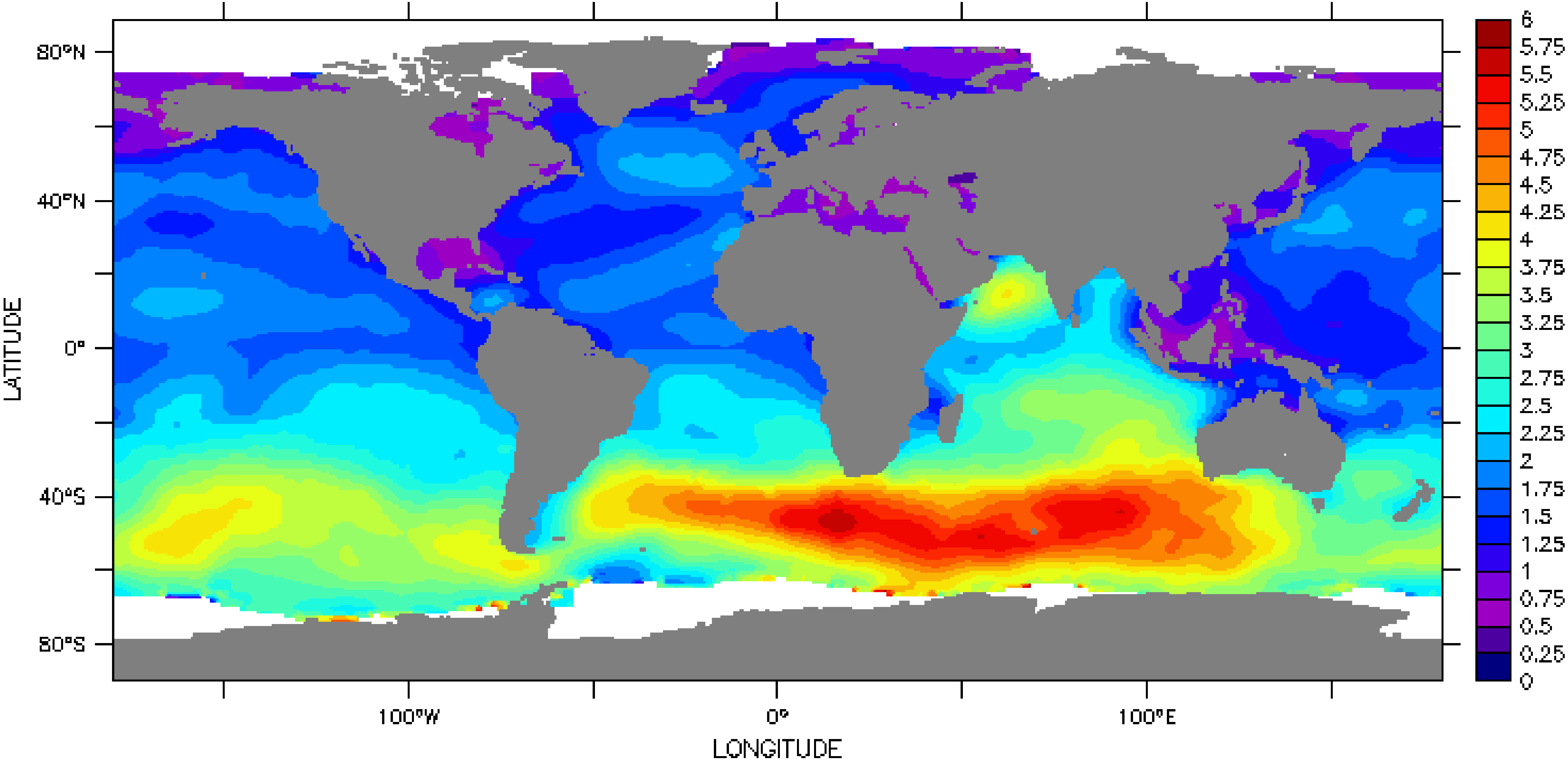


# WIND SPEED

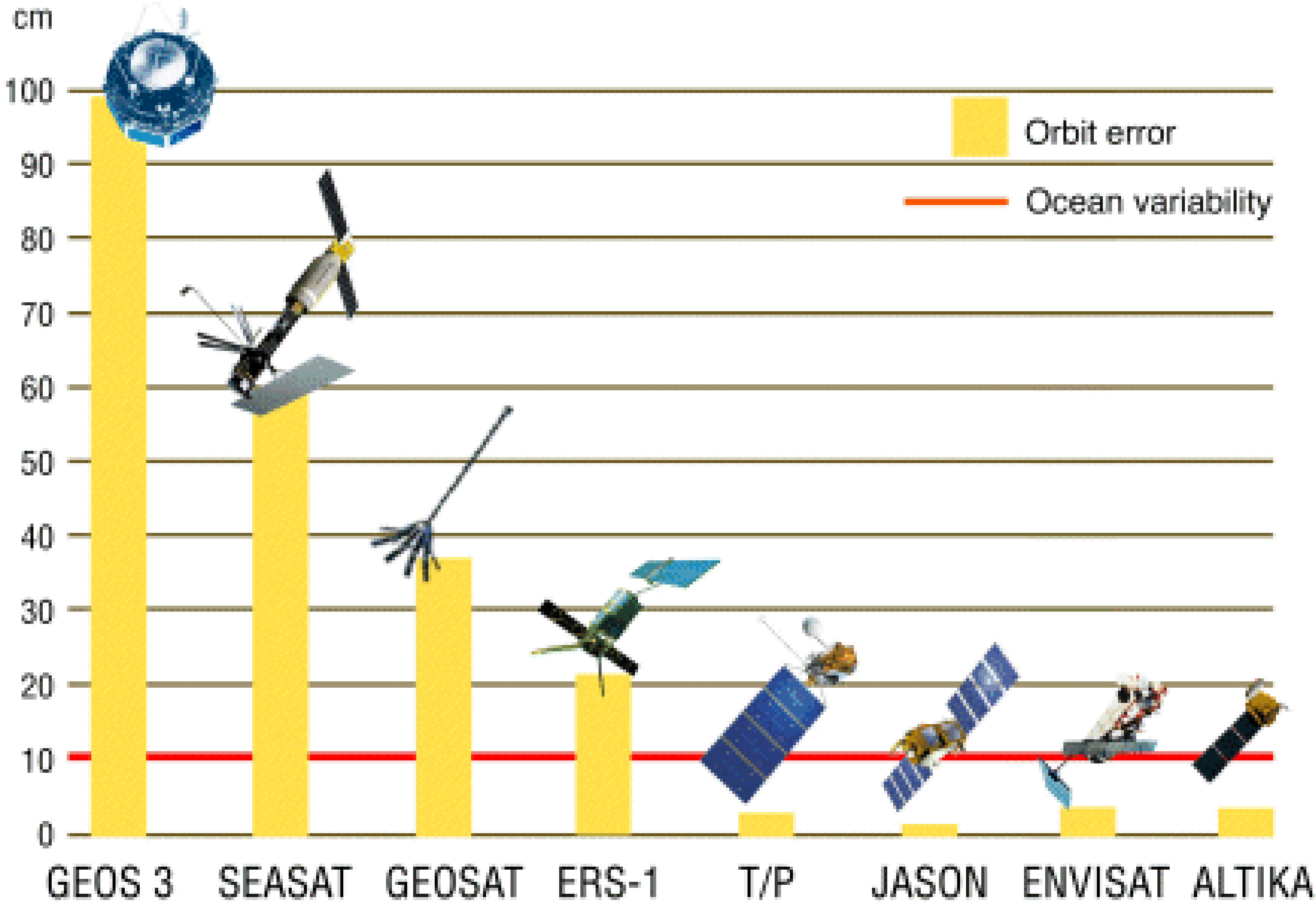


Wind speed modulus merged_1 [ t= 01-Jul-2007 00:00:00 : 31-Jul-2007 00:00:00 @ave] (m/s)

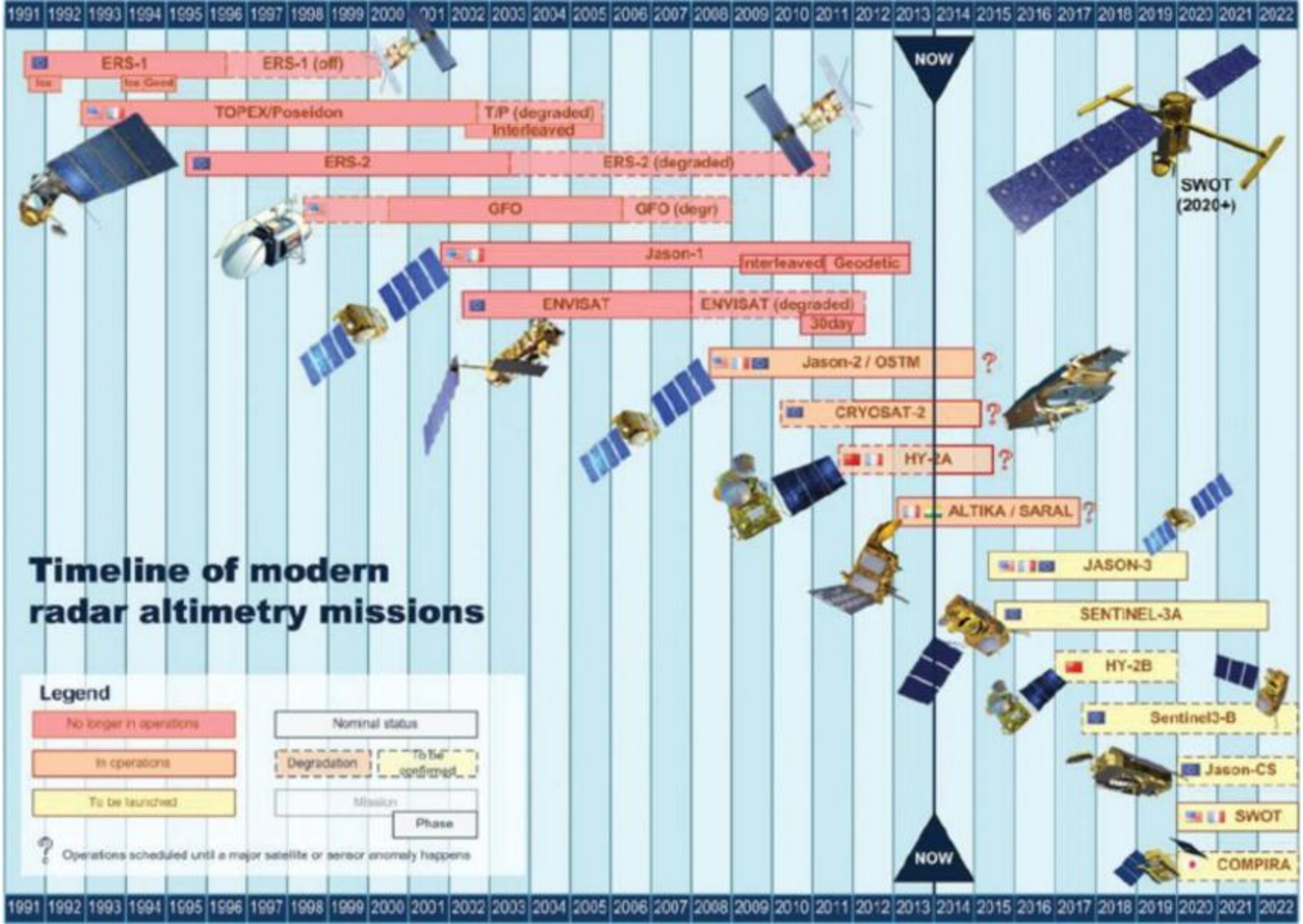
# SWH



Significant wave height merged_1 [ t= 01-Jul-2007 00:00:00 : 31-Jul-2007 00:00:00 @ave] (m)


cm
100
90
80
70
60
50
40
30
20
10
0
Orbit error
Ocean variability
GEOS 3
SEASAT
GEOSAT
ERS-1
T/P
JASON
ENVISAT
ALTIKA

# Timeline of modern radar altimetry missions



| | |
|---|---|
| Satellite | Topex/Poseidon |
| Launch on | 10/08/1992 |
| End Date | 18/01/2006 |
| Altitude | 1336 km |
| Inclination | 66 ° |
| Repetitivity | 9.9156 days |
| Agency | Nasa/Cnes |
| Goals | Measure sea surface height |
| Link | http://www.cnes.fr |

**There are six altimetry satellites currently in service (2017 September)**:

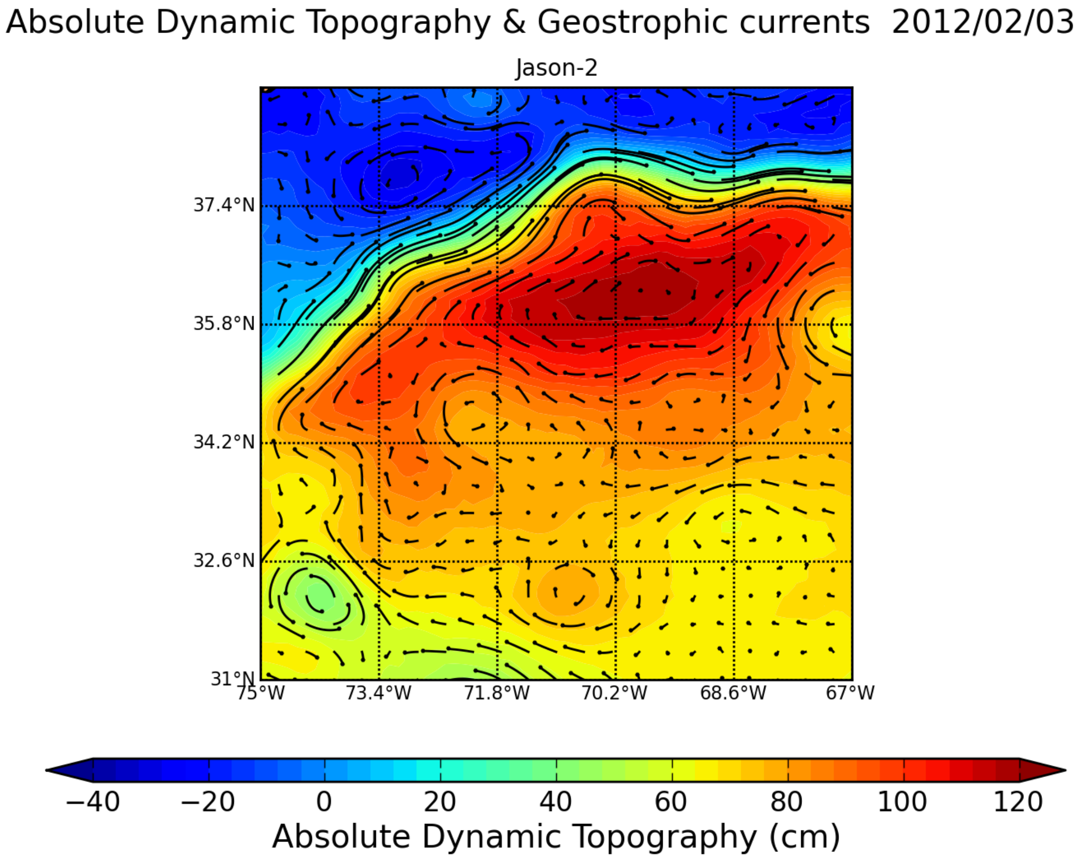
**Two satellites Jason-2 and Jason-3** with a relatively short repeat cycle (10 days), able to observe the same spot on the ocean frequently but with relatively widely-spaced ground tracks (315 kilometres at the equator). Jason-3 is located on the former orbit of Topex/Poseidon (before 2002), Jason-1 (before February 2009), and Jason-2 (before July 2017). From July 2017, Jason-2 is operating on a lower orbit (named LRO for Long Repeat Orbit) at 1309.5 km.

**One satellite, Saral**, on a 35-day repeat cycle, on the same ground-track as ERS-1&2 and Envisat (during its repetitive orbit, before 2010/10); it is complentary to Jason-2 ground tracks. From July 2016, SARAL is on a drifting orbit for a new phase of the mission named “SARAL-DP” for SARAL-Drifting Phase". The repetitive ground track is no more maintained and with the natural decay of the orbit, the ground track is drifting.

**One satellite - Cryosat-2** - with an altimeter (Siral) ables to work with an interferometric mode, with a high orbit inclination of 92° to satisfy the scientific requirements for observing the poles and the ice sheets, and with an orbit non-sun-synchronous (commonly used for remote-sensing satellites).

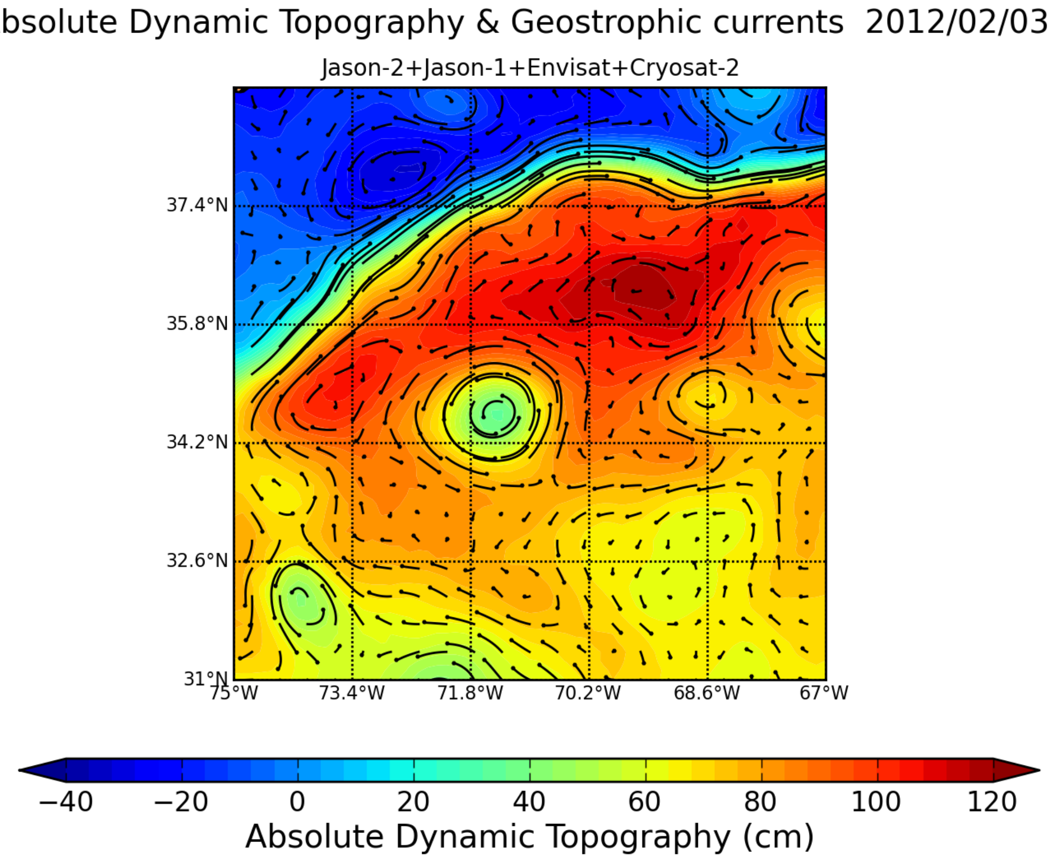
**HY-2A**, with a 14-day orbit at 963 km, until March 2016, then on a geodetic orbit (2 km higher, 168-day cycle with 2315 orbits in the full cycle)

**Sentinel-3** with ground tracks similar to those of ERS-1&2, ENvisat and Saral but with a 27-day repetitive cycle.


Absolute Dynamic Topography & Geostrophic currents 2012/02/03

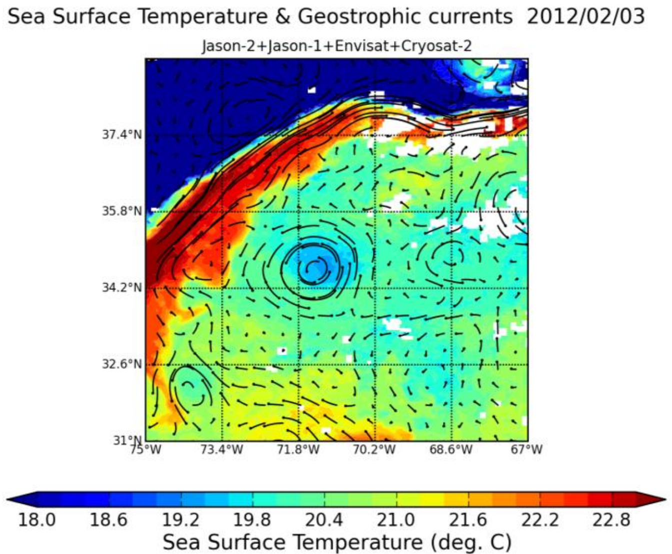
Jason-2

**JASON-2**


Absolute Dynamic Topography & Geostrophic currents 2012/02/03

Jason-2+Jason-1+Envisat+Cryosat-2

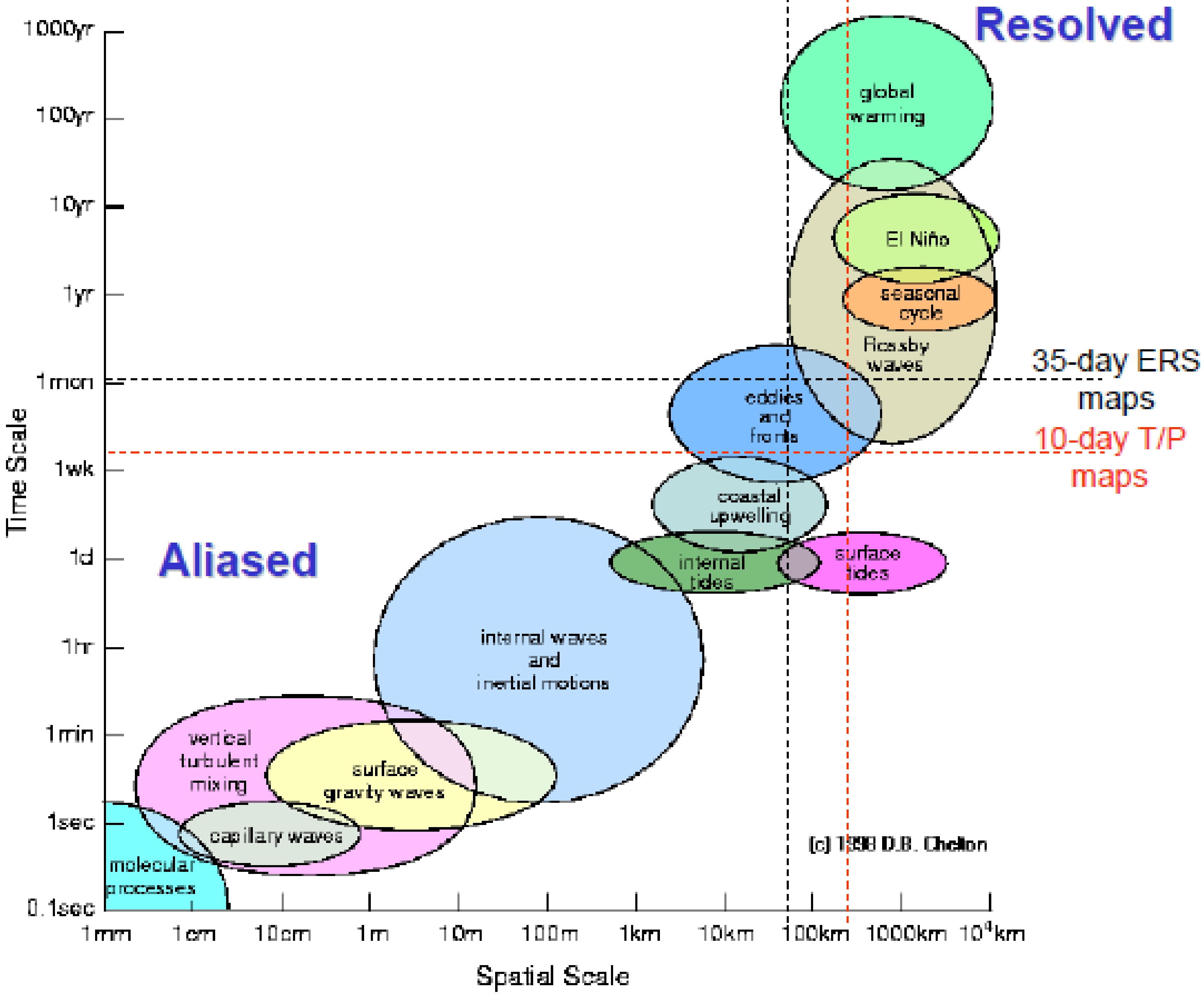
**JASON-2+JASON-1+**
**ENVISAT+CRYOSAT-2**


Sea Surface Temperature & Geostrophic currents 2012/02/03

Jason-2+Jason-1+Envisat+Cryosat-2

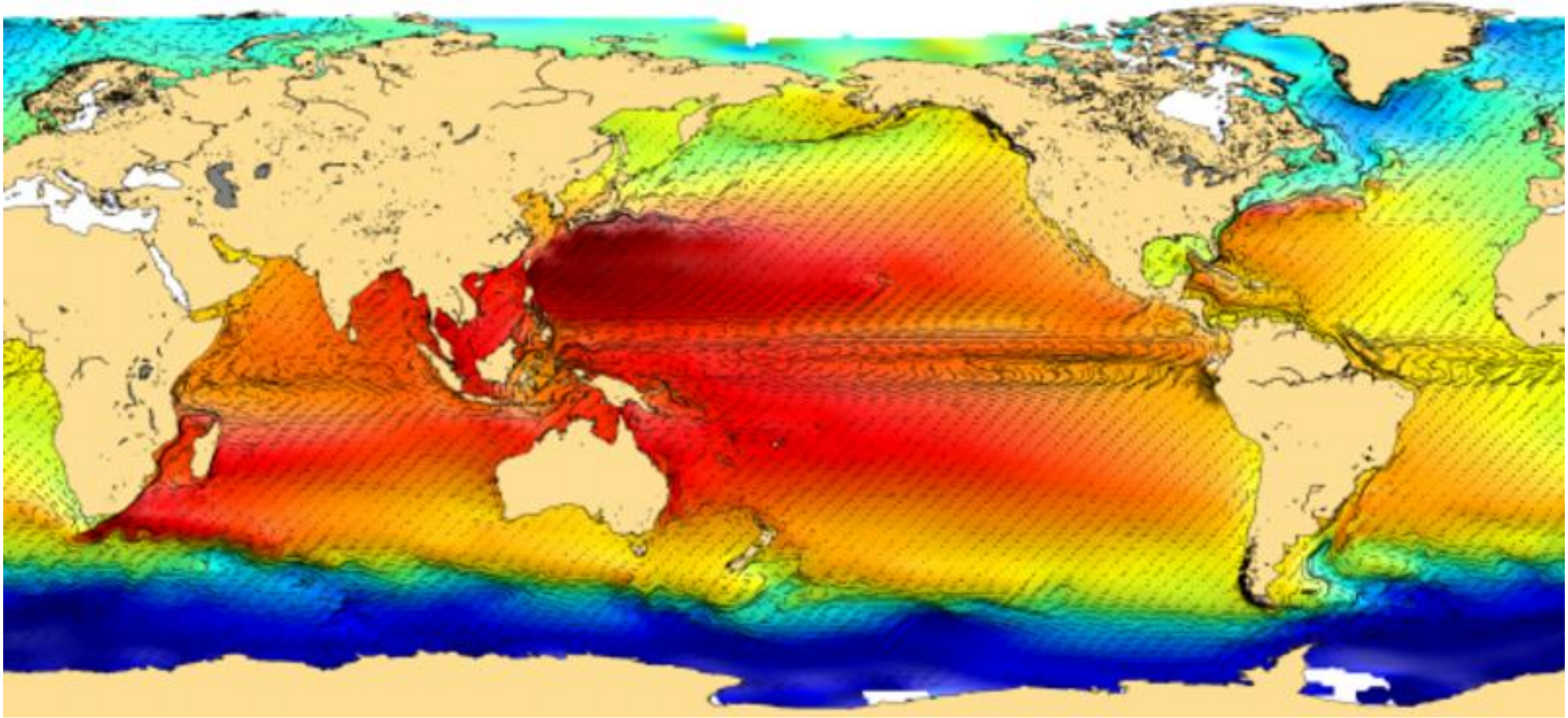
**SST**

# SPACE AND TIME RESOLVED BY ALTIMETRY

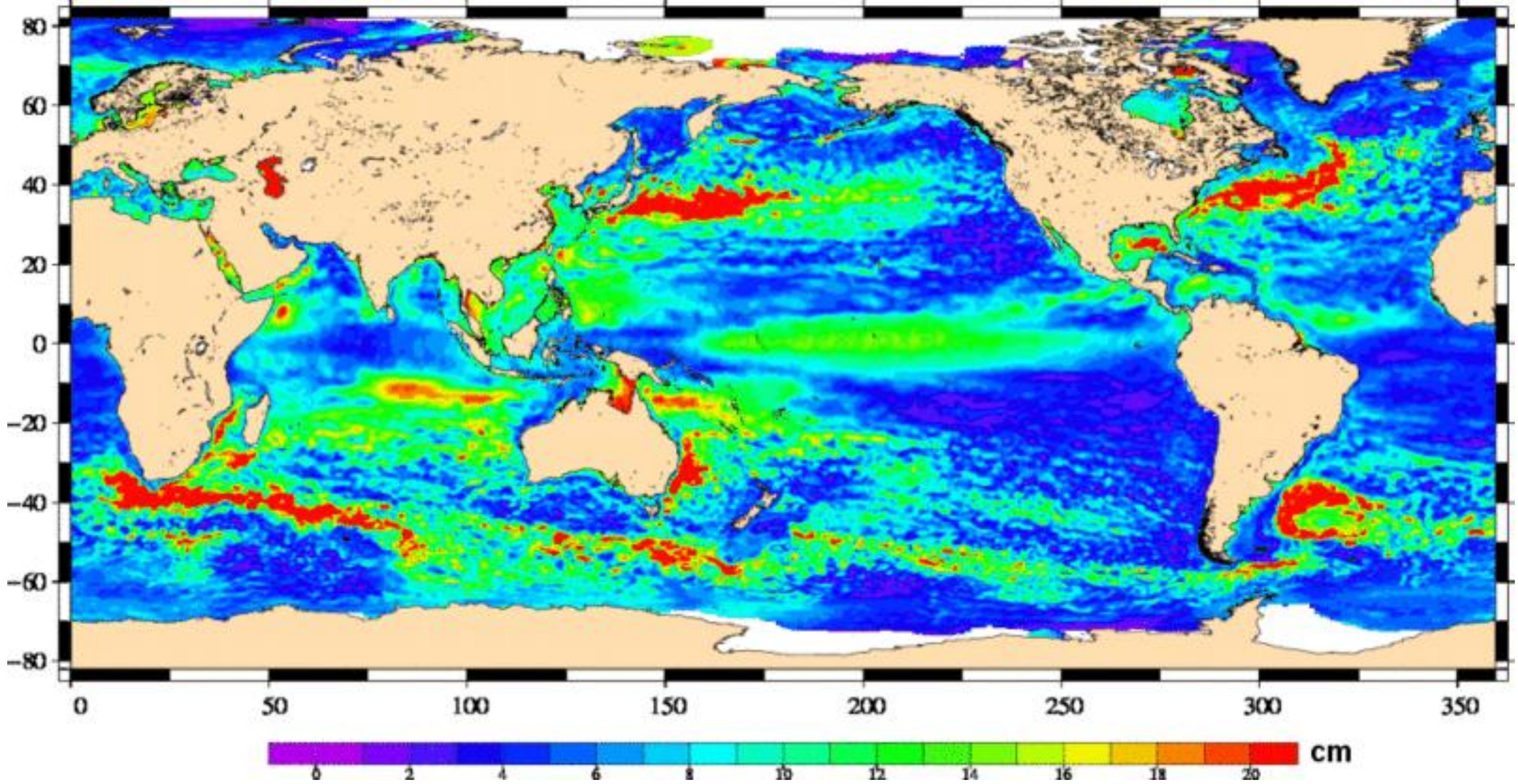


# 25 YEARS OF SATELLITE ALTIMETRY

# SCIENTIFIC RESULTS



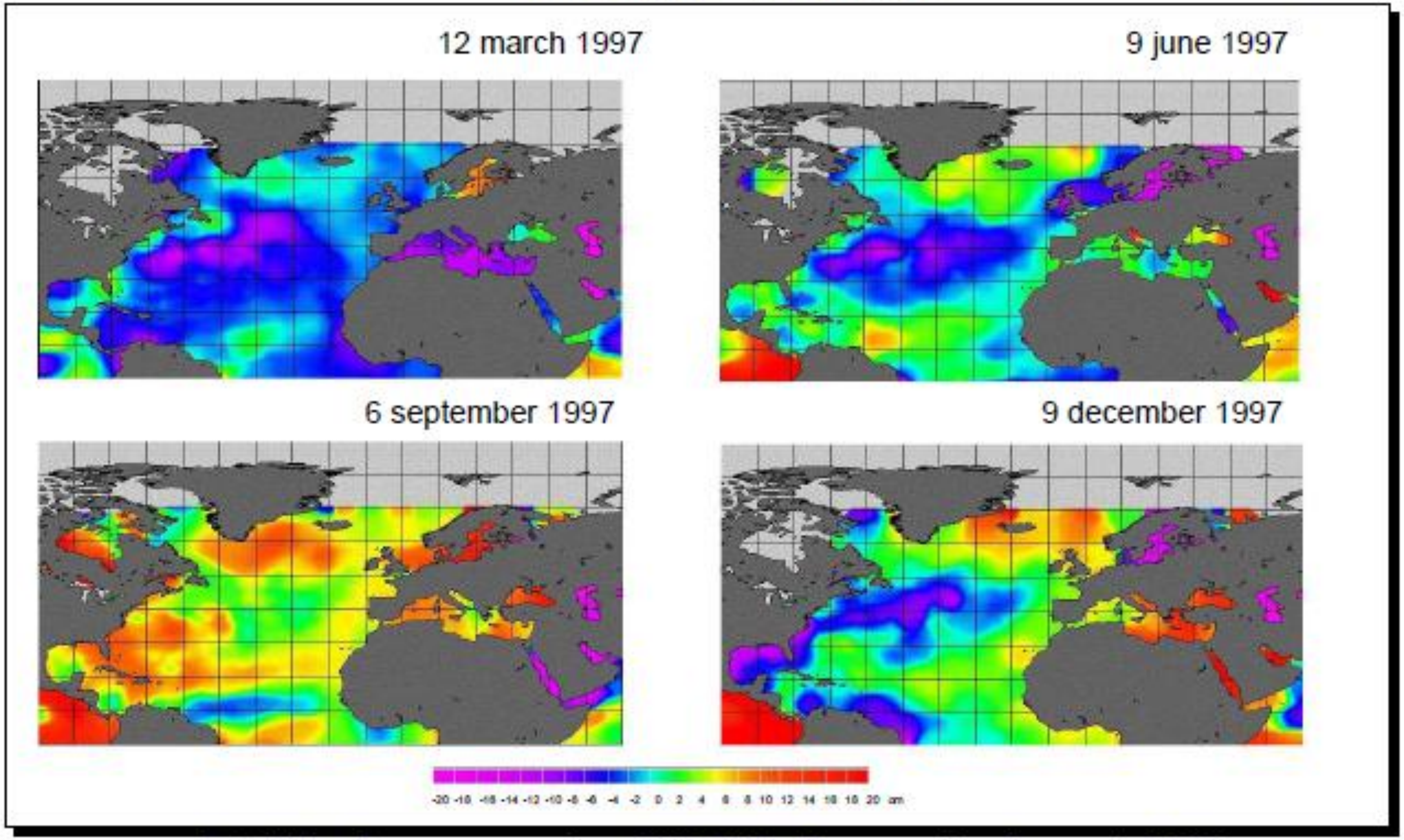
Mean dynamic topography, i.e. oceanic relief corresponding to permanent ocean circulation. Arrows are proportional to current speed. (Credits CNES/CLS, 2012).

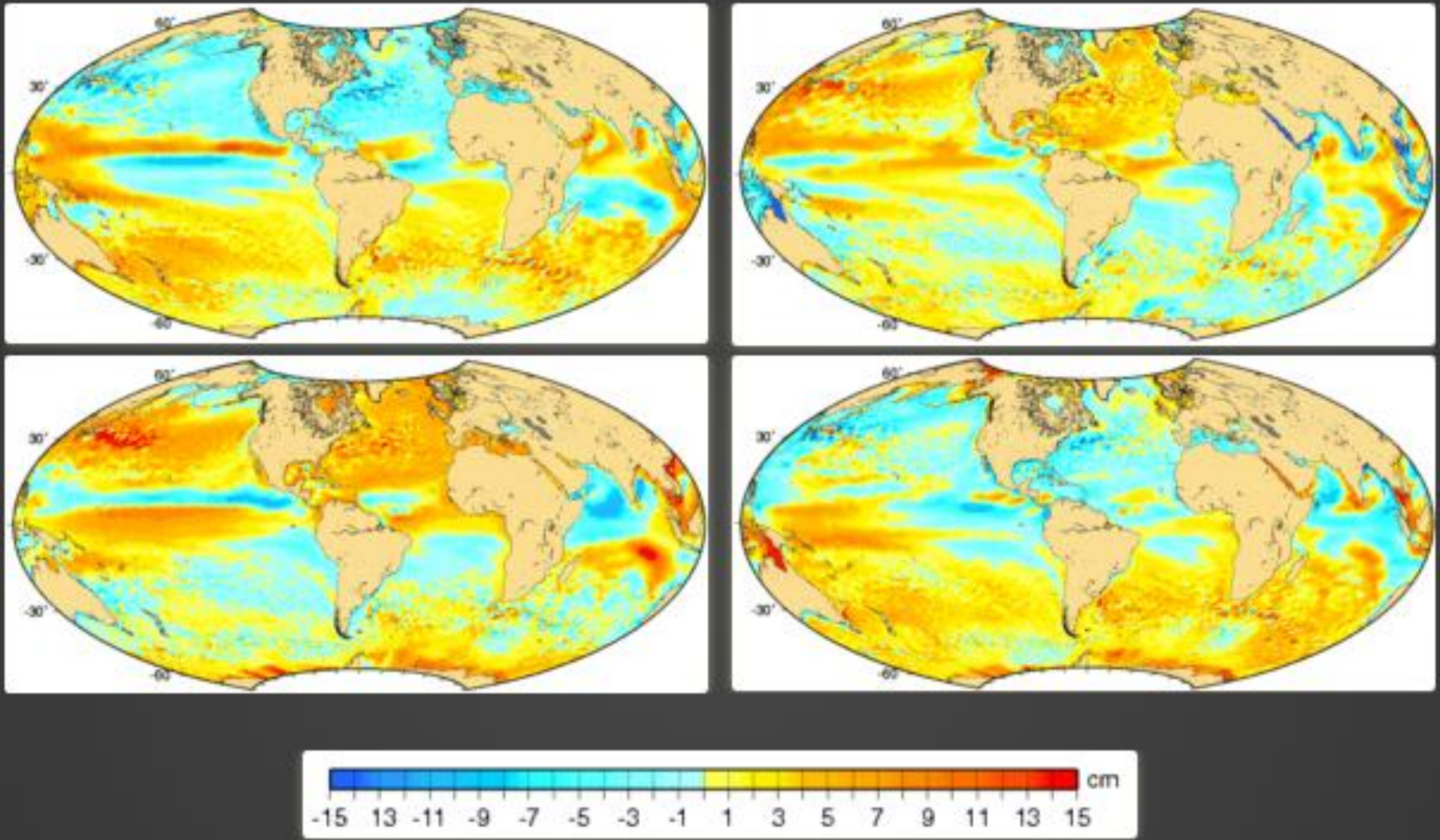


RMS of the Sea level anomalies over the whole Jan 1993-March 2010 period. Red areas are the one where the sea surface heights change the most (Credits Cnes/CLS)

# TOPEX-POSEIDON

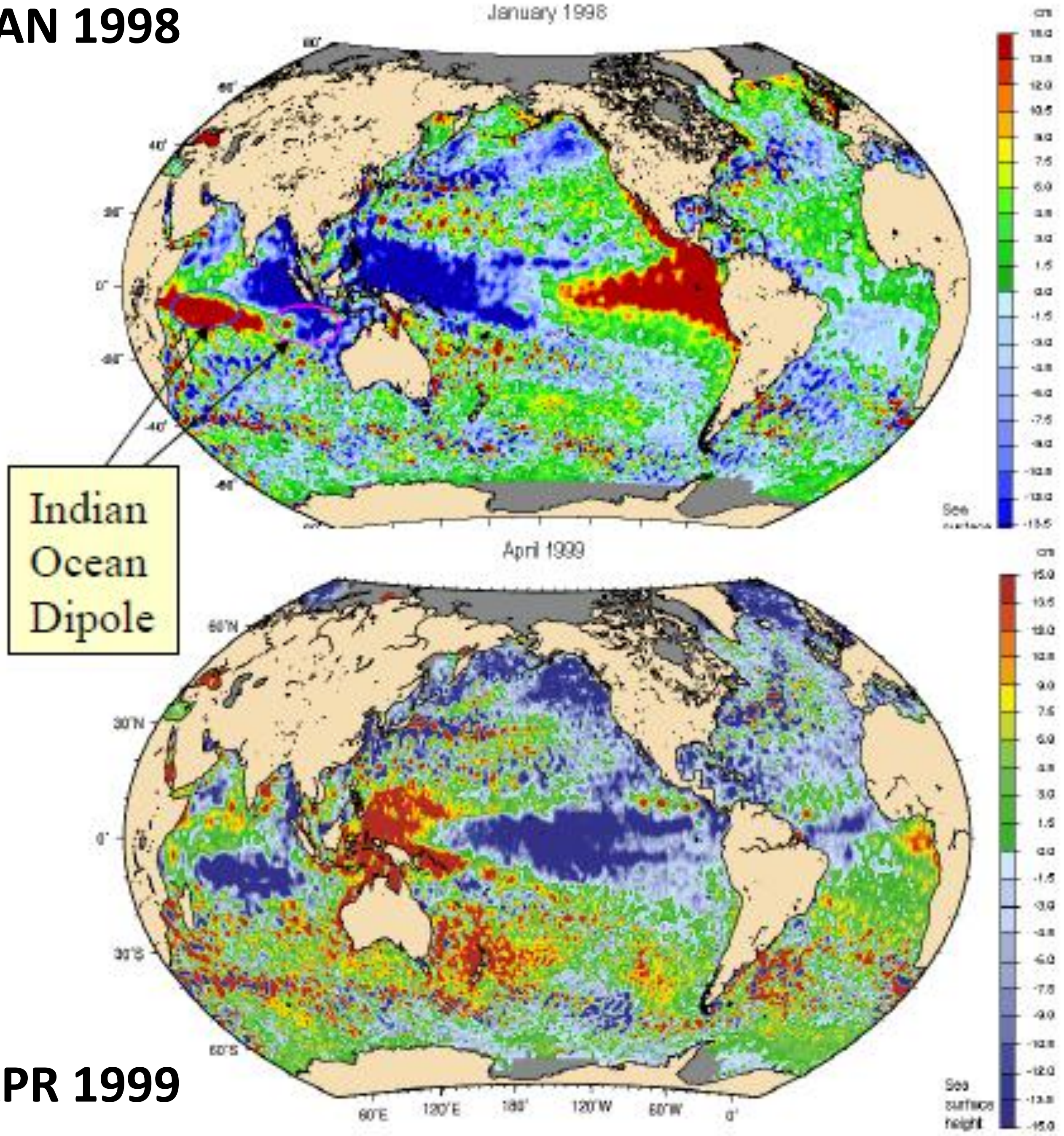
## Oceanic Seasons





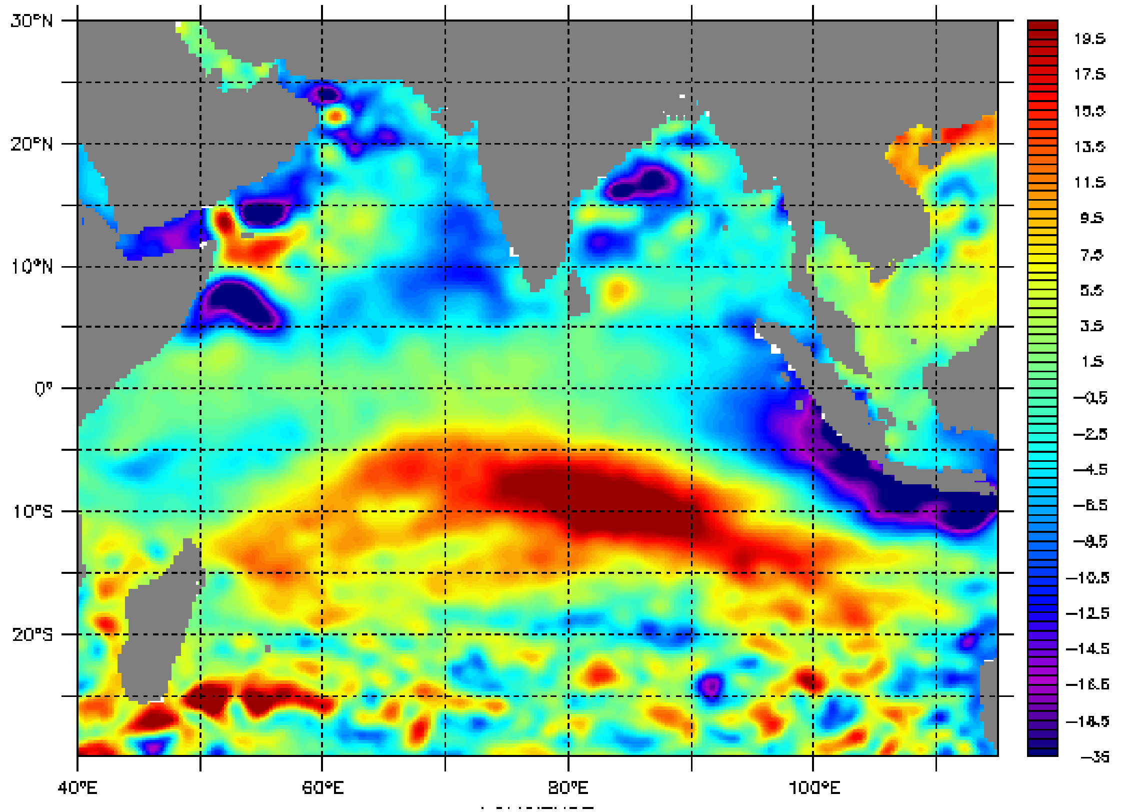
*Averaged over 15 years of sea level variations over Northern Hemisphere Spring, Fall, Summer and Winter (from left to right and top to bottom). The water warms in Summer, and cools in Winter, thus explaining a difference of about + or - 10 cm in the sea level between the seasons, with the seasons being inversed in the Northern and Southern Hemisphere.*

**JAN 1998**



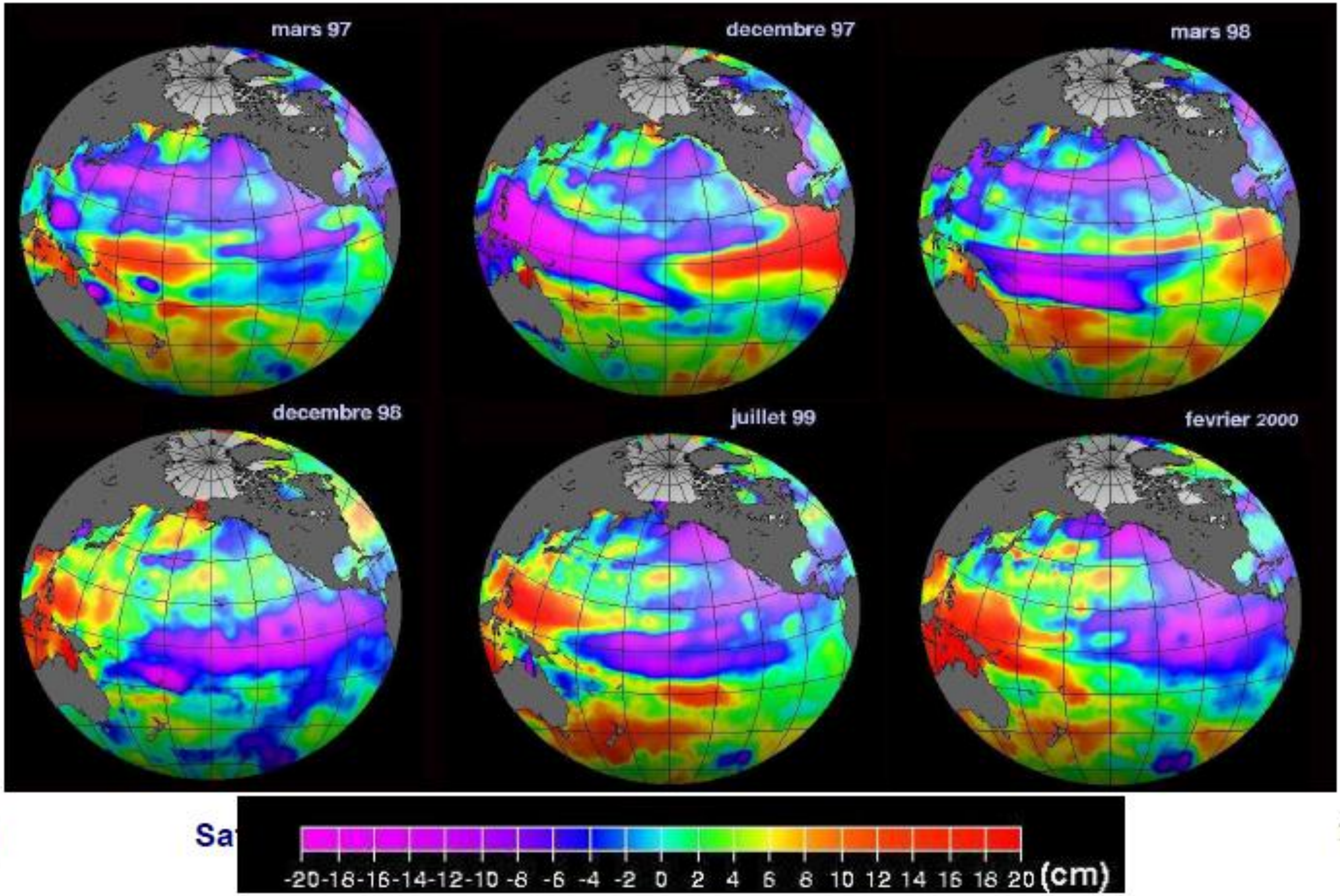
**APR 1999**

# INTER-ANNUAL VARIATIONS



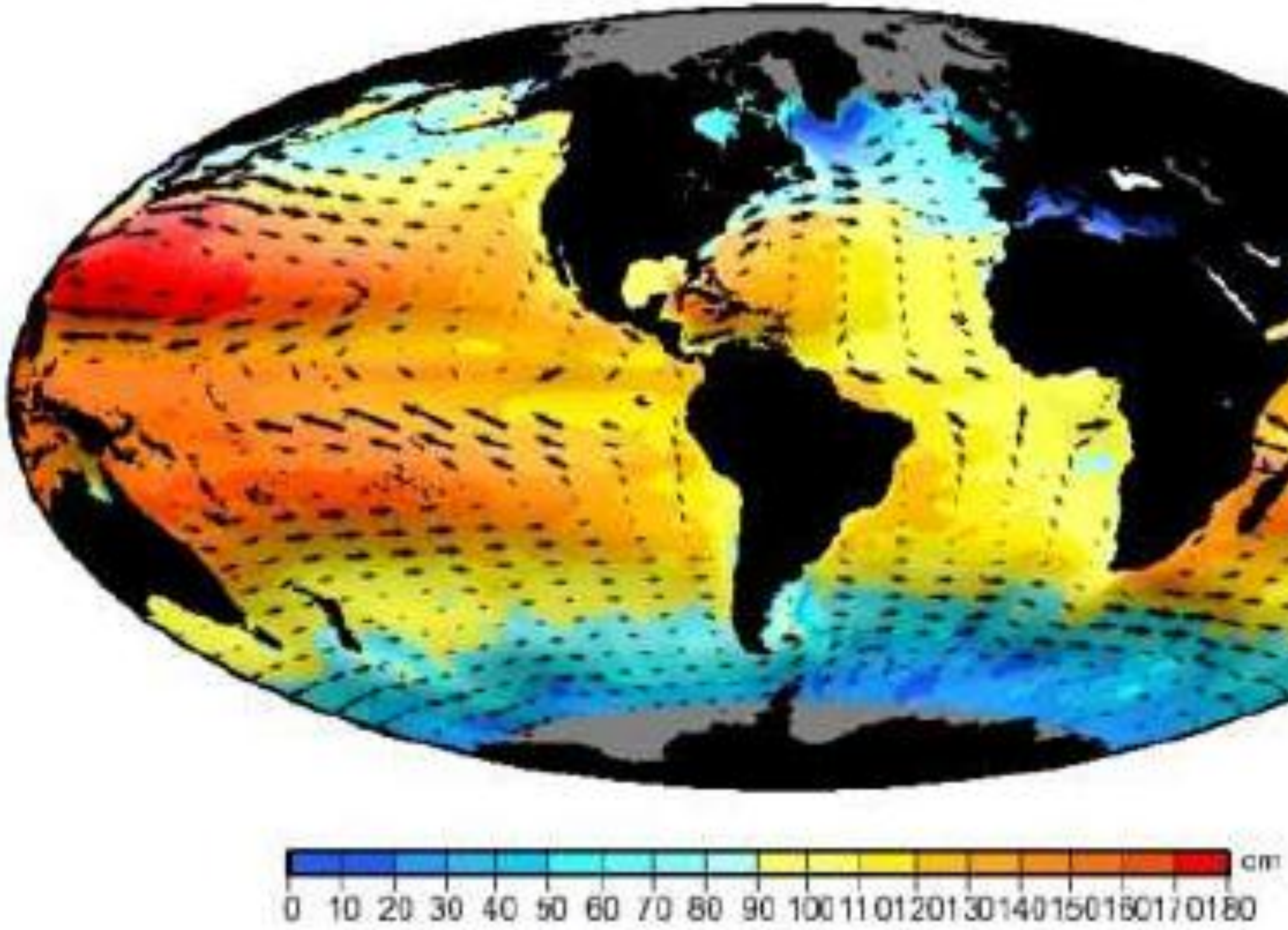
Map of Merged Sea Level Anomalies (SLA) in cm and averaged over fall months (September-November) for year 2006. Maps made with the LAS.

# TOPEX/POSEIDON El Niño/La Niña 97-99

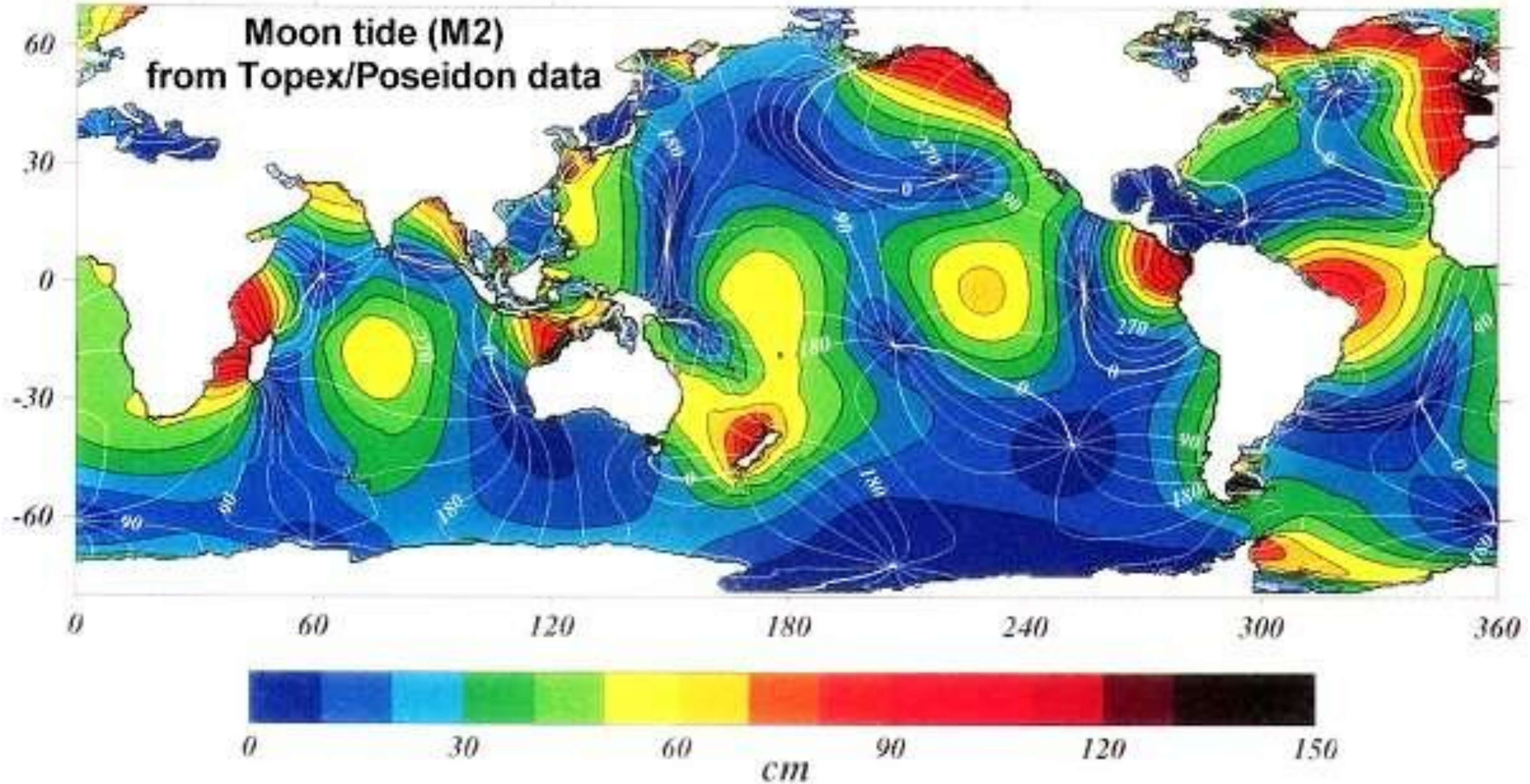


**Sa**

# Surface Mean Dynamic height, with mean geostrophic currents



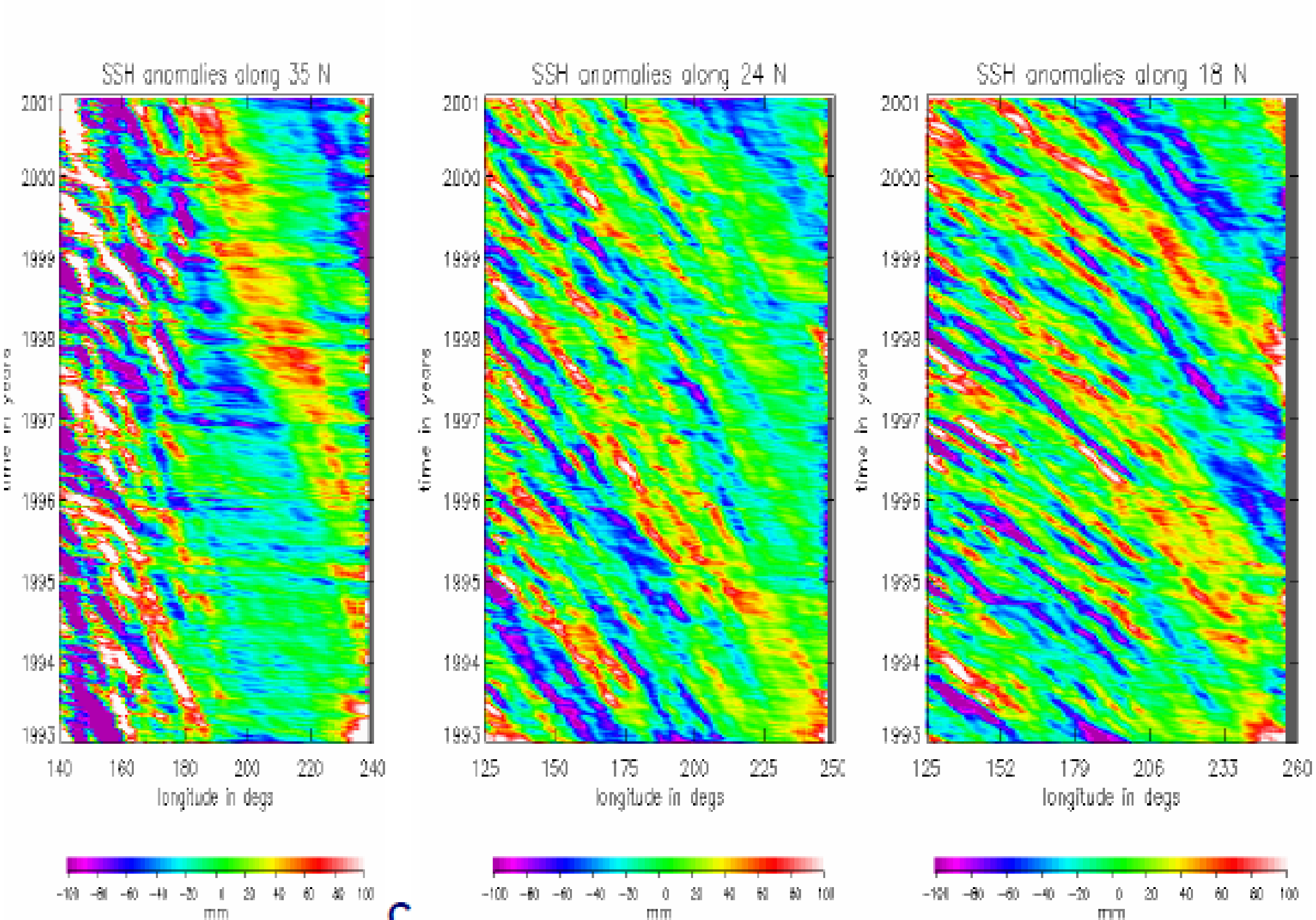
# TIDAL ANALYSIS

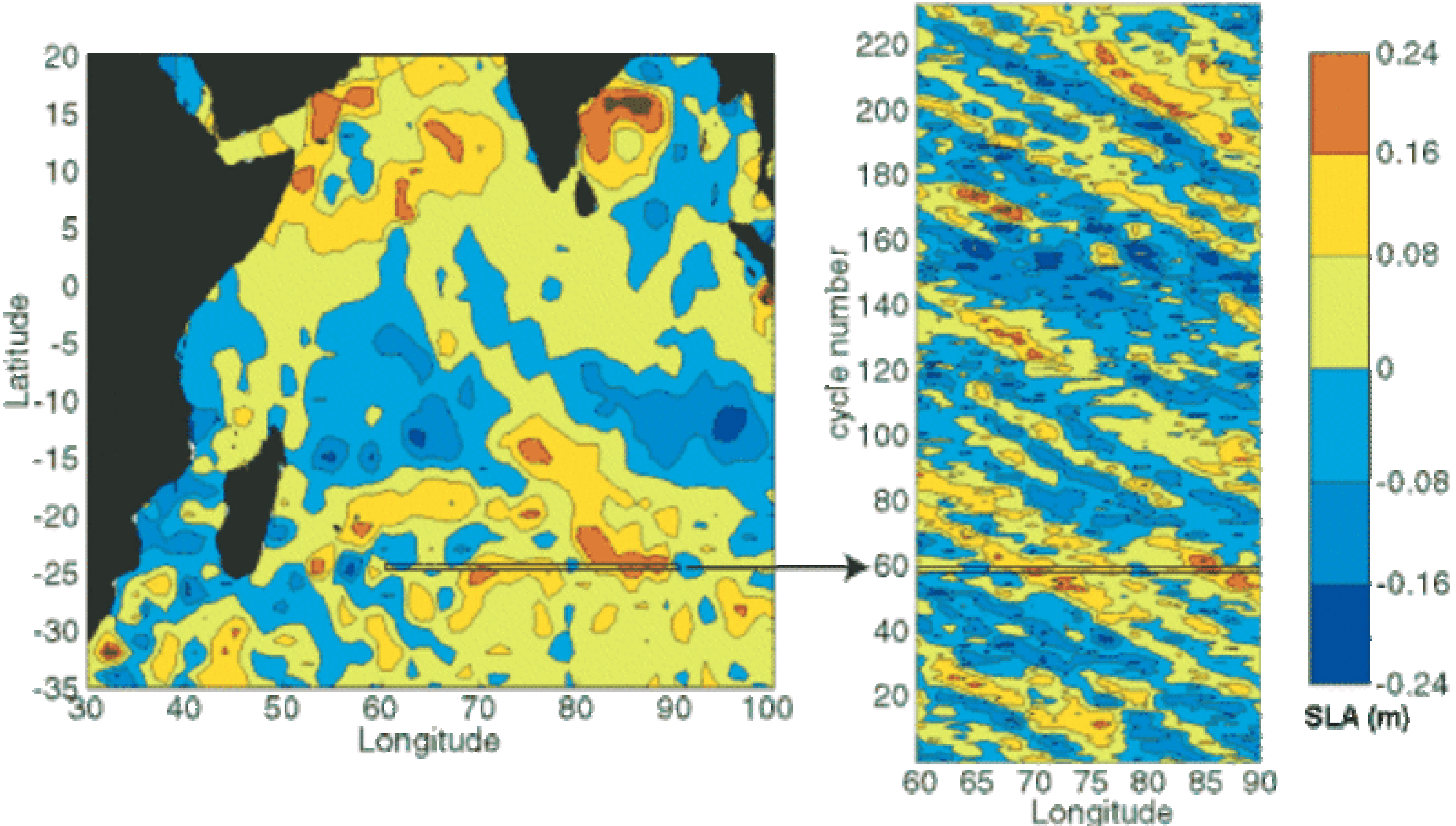


# *Rossby Waves in the North Pacific*

## Low-frequency adjustment to wind forcing change

35° N 24° N 18° N



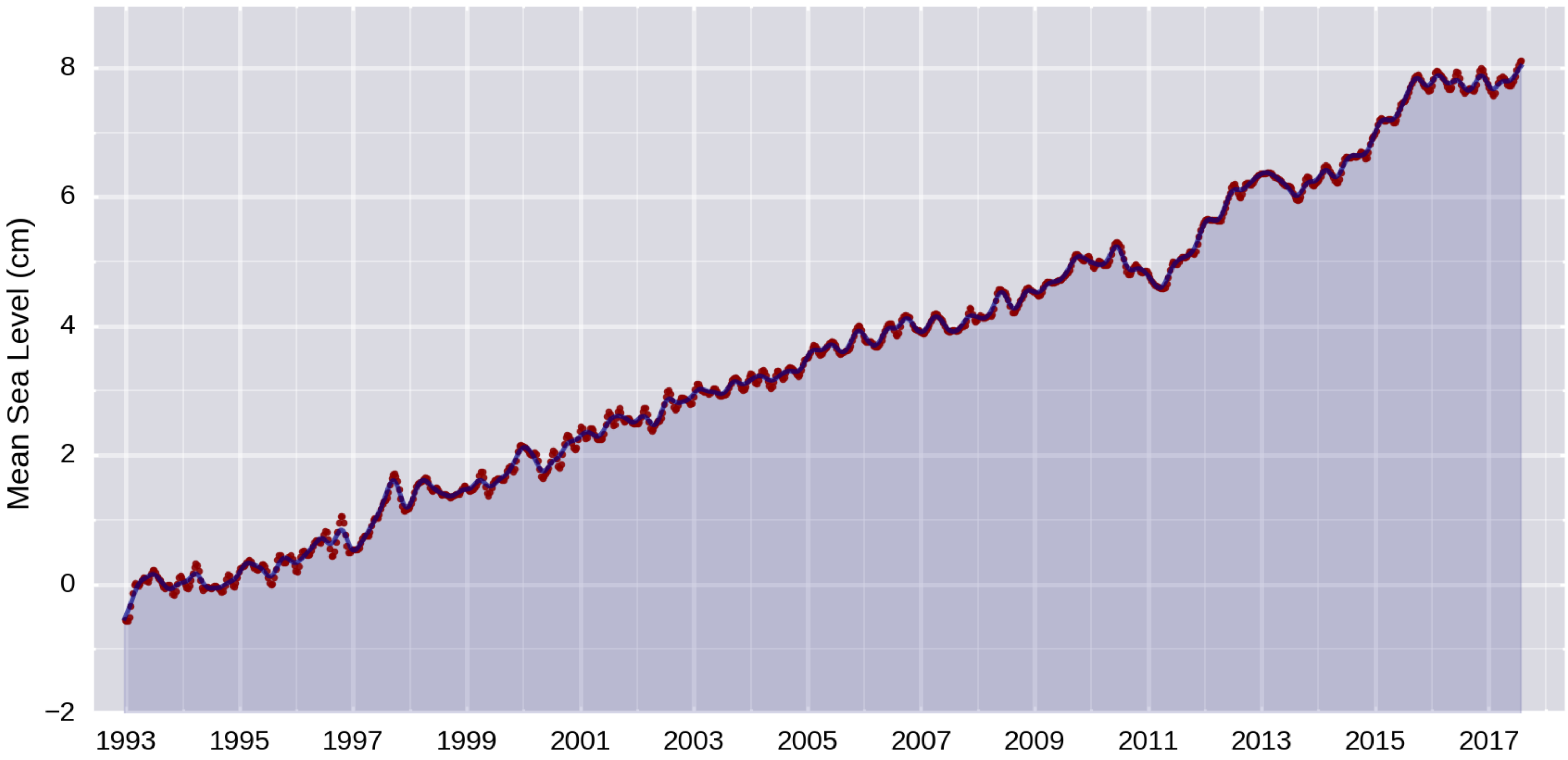


20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
Latitude
30
40
50
60
70
80
90
100
Longitude
220
200
180
160
140
120
100
80
60
40
20
cycle number
60
65
70
75
80
85
90
Longitude
0.24
0.16
0.08
0
-0.08
-0.16
-0.24
SLA (m)

Latest MSL Measurement
10 August. 2017

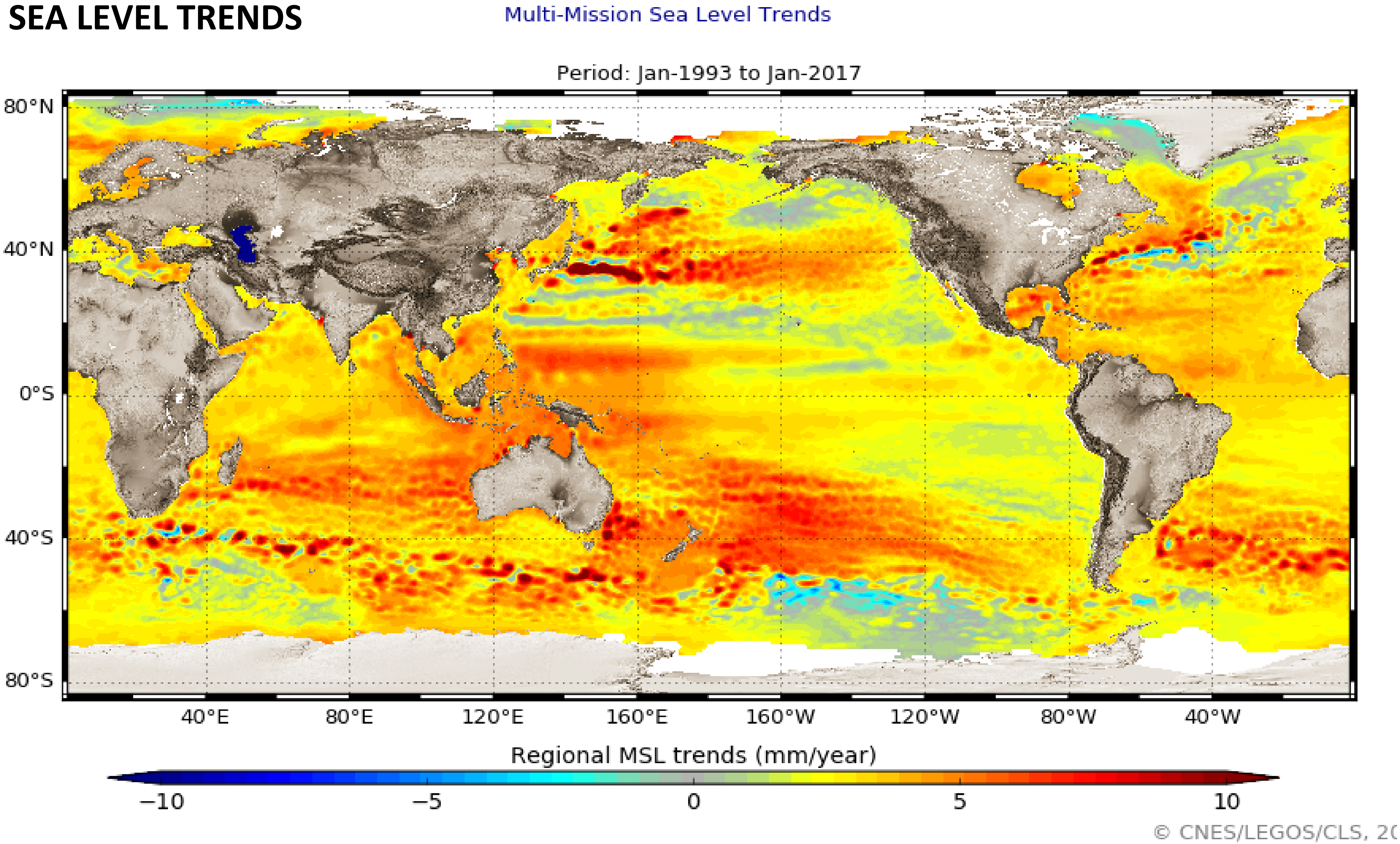
# MSL - MEAN GLOBAL TREND +3.29 mm/yr

Reference GMSL - corrected for GIA

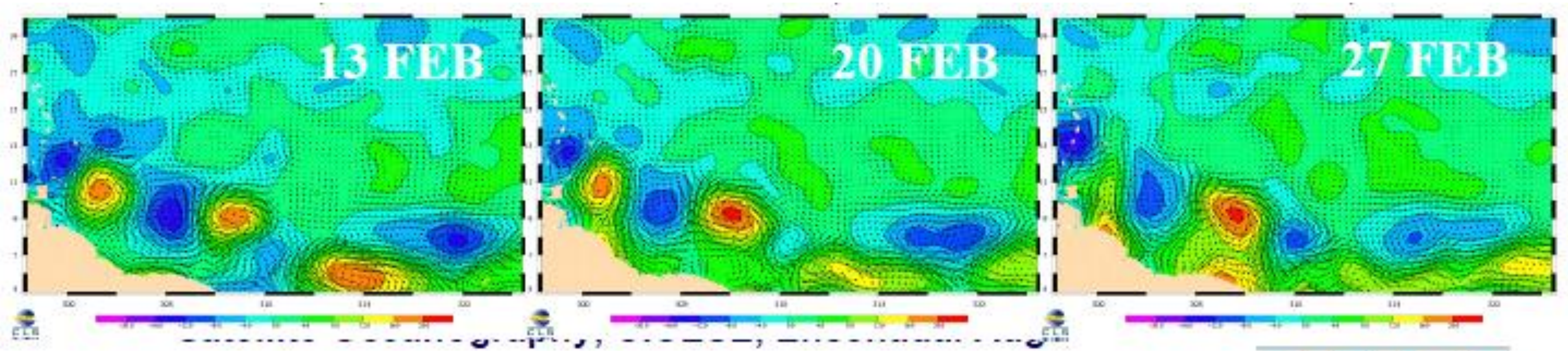


© CNES,LEGOS,CLS

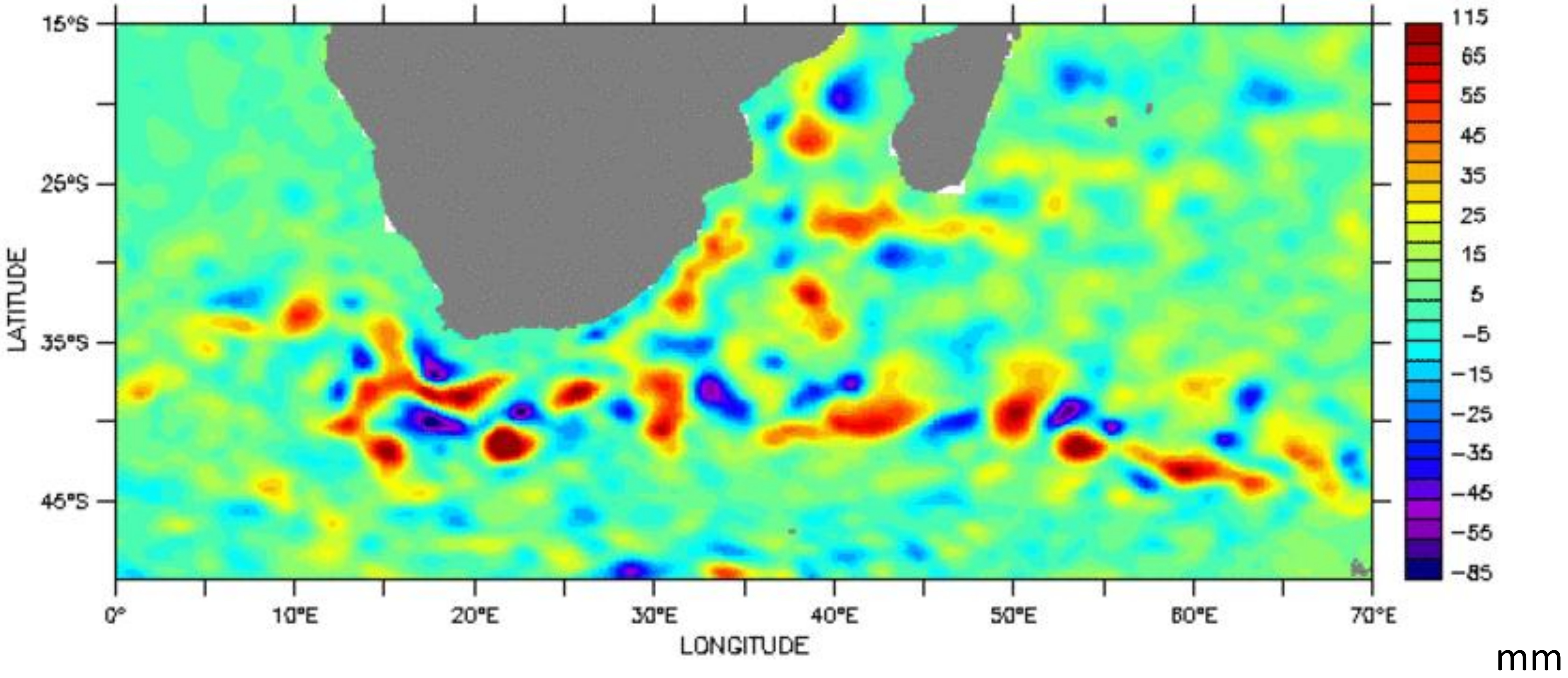
# SEA LEVEL TRENDS



# Real-time monitoring of North Brazil Current Rings



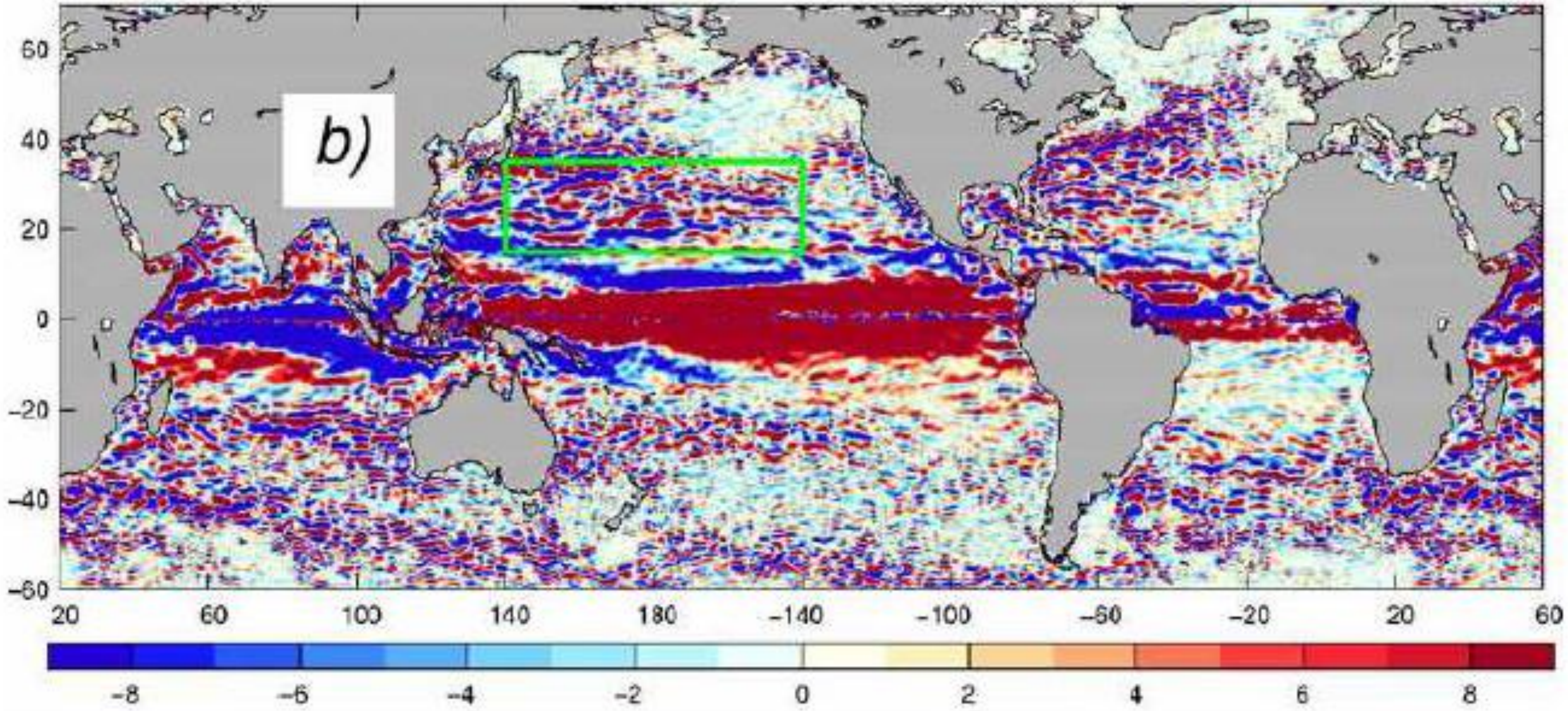
# AGULHAS RINGS



Map of Sea Level Anomalies (SLA) the 28th of February 2007, drawing with the LAS from merged altimetric data.

# Fronts and Jets

## Time-varying zonal jets populate all the oceans



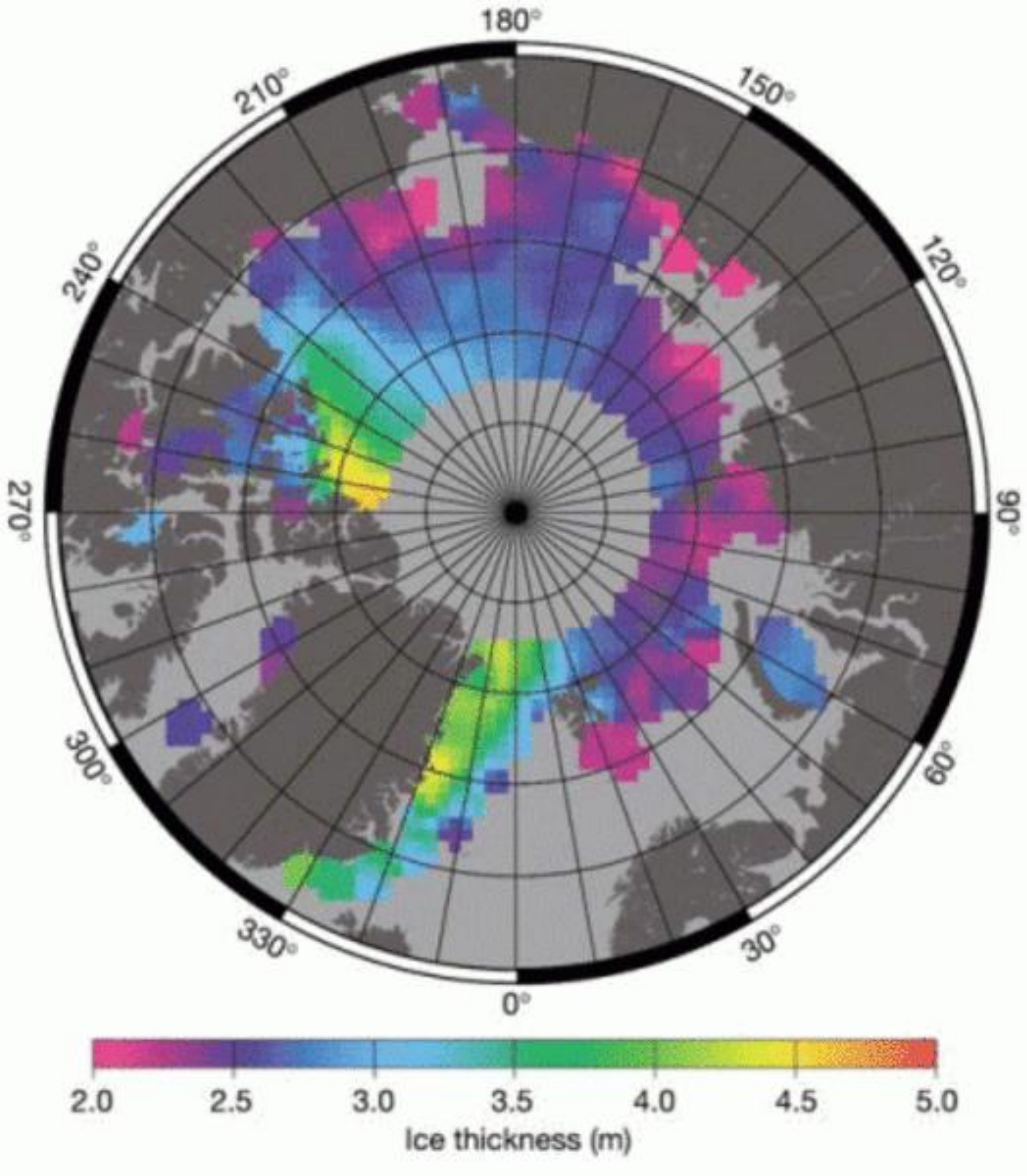
b) : 18-week averages of geostrophic velocity U'.

Fronts and jets revealed from the velocity or vorticity field : ∇SLA

Maximenko et al., GRL 2005.

Also Hughes and Ash, JGR, 2001

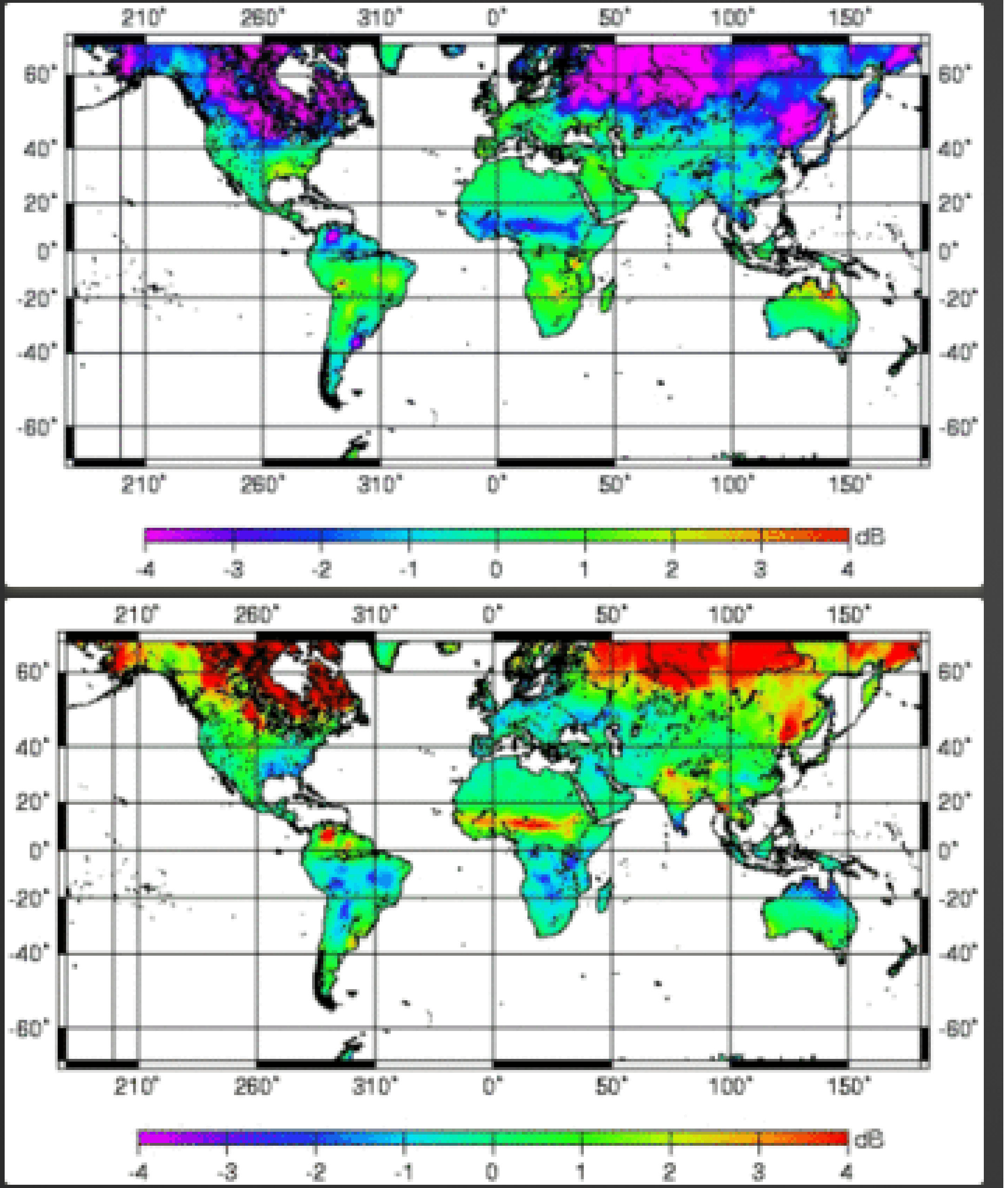
Models show they have high vertical coherence



SEA ICE

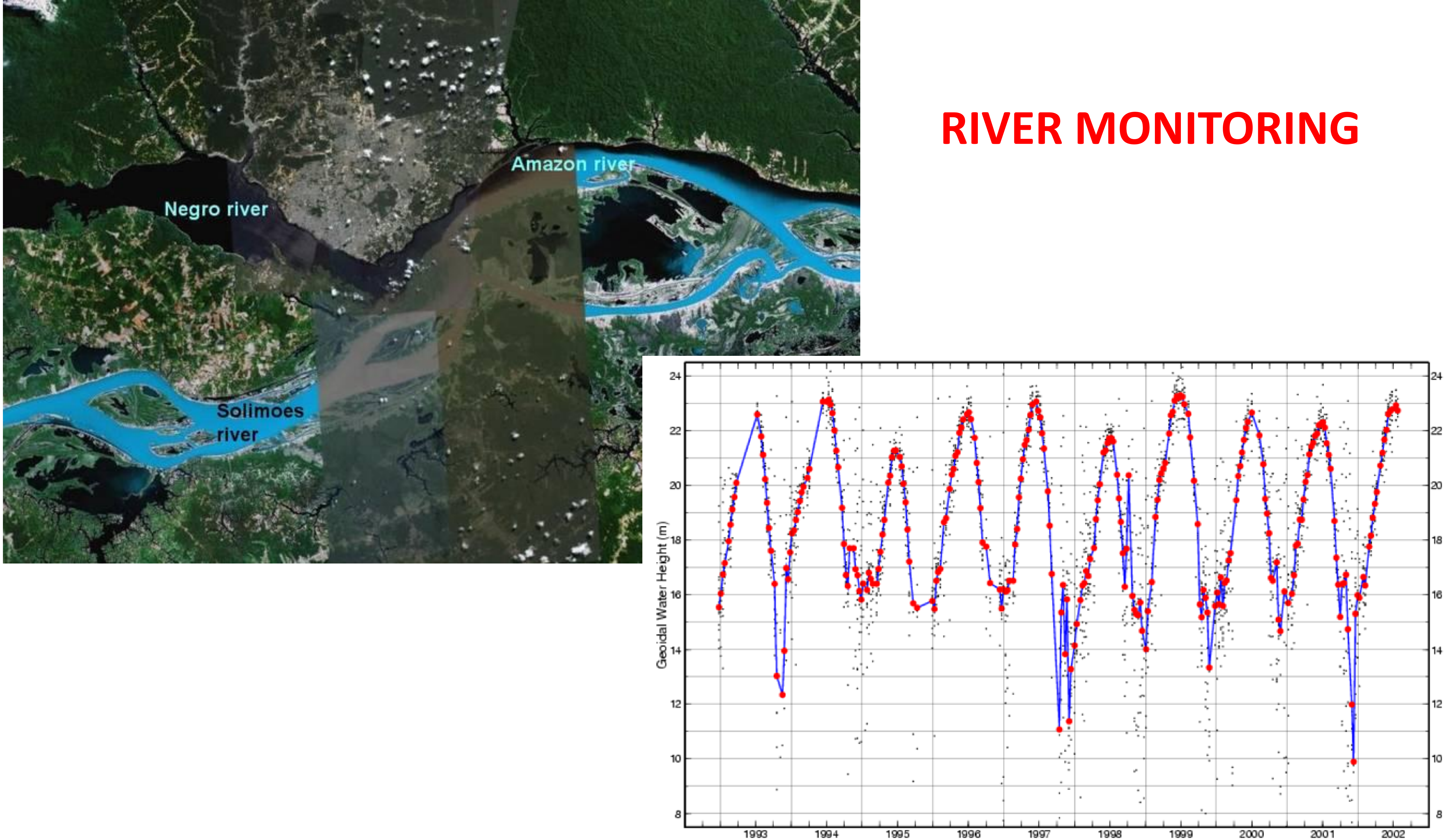
Average winter (October to March) Arctic sea ice thicknesses from October 1993 to March 2001 from satellite altimeter measurements of ice freeboard. Data are not available for the marginal ice zone, or above the ERS latitudinal limit of 81.58°N. Ice freeboard data are converted to thickness using fixed ice, snow and water densities and regional monthly snow depth. The mean thickness excludes thin ice (less than 0.5-1 m) and open water. (Credits University College London UCL).

# ALTIMETRY OVER LAND

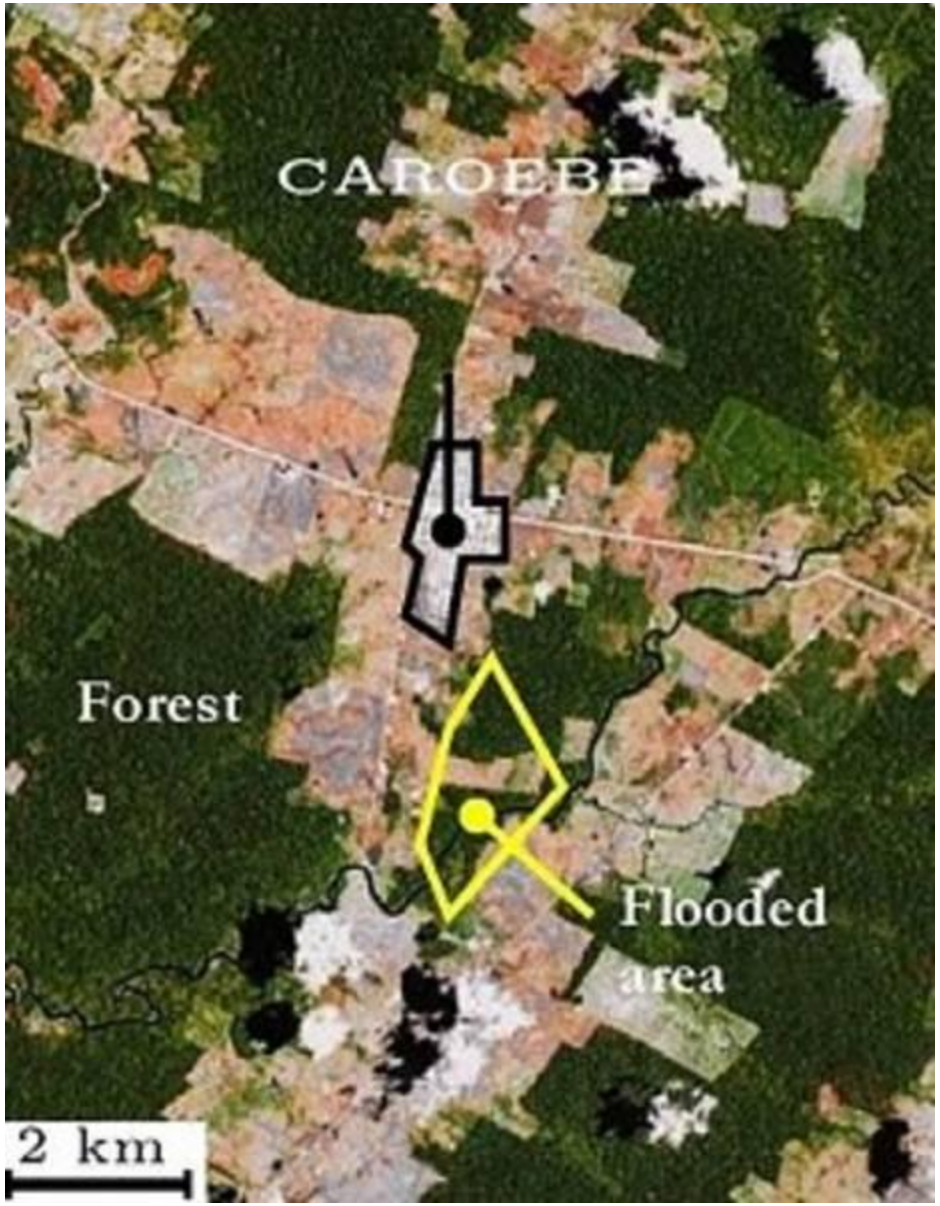


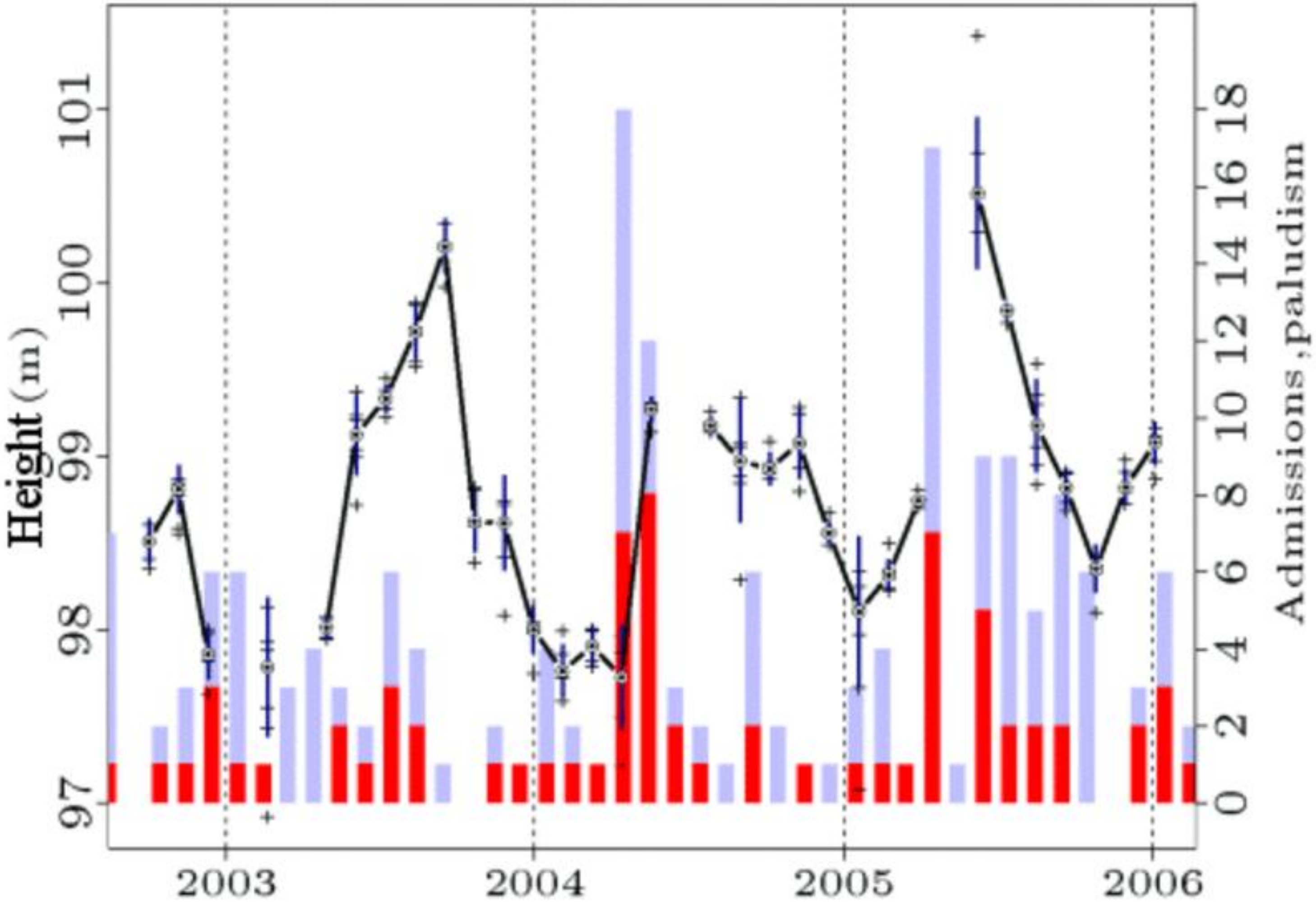
Seasonal anomalies of the backscatter coefficient for Topex in Ku band, in winter (top) and summer (bottom) for the first ten years of measurements. Strong variations can be seen, especially for regions which are covered by snow in winter (higher than 55°N), or which have a marked rainy season (equator, India). (Credits Legos).

# RIVER MONITORING



# MALARIA AND ALTIMETRY IN THE AMAZON

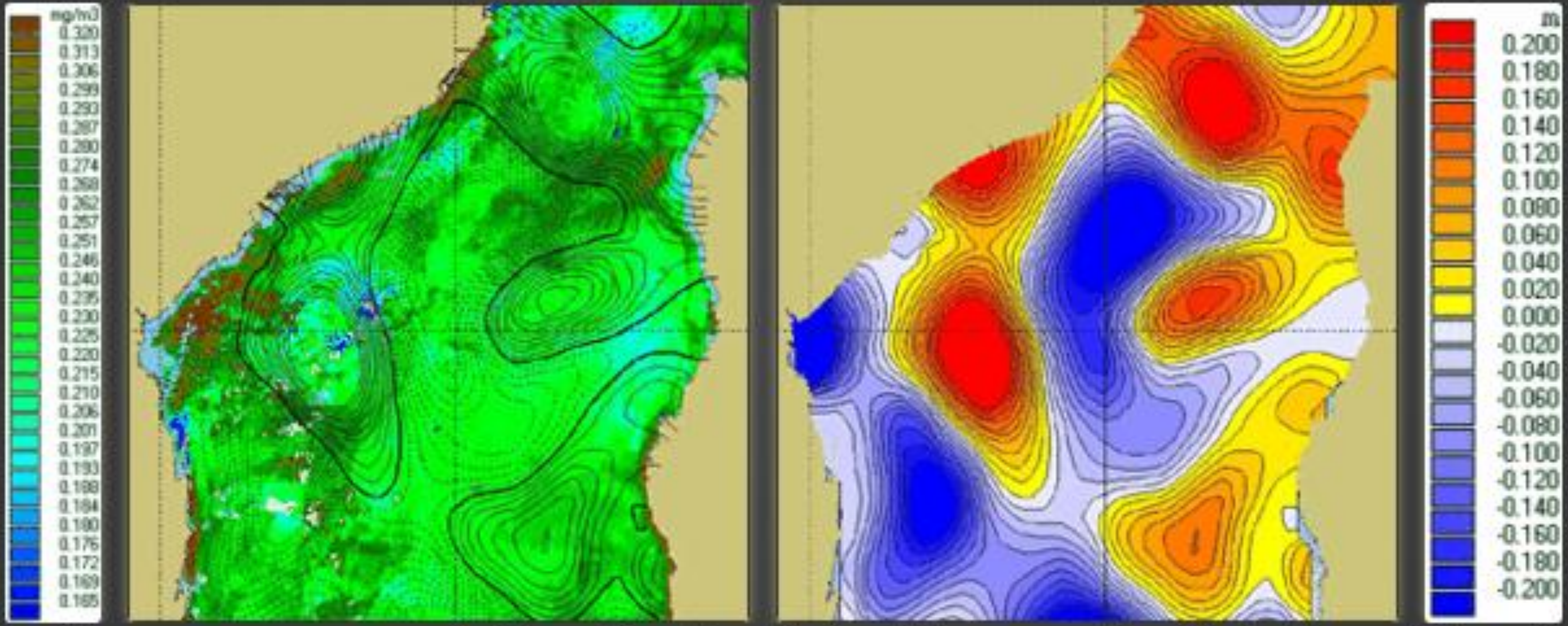




Water level variations measured by the Envisat satellite (black curve, left-hand scale) across a small area of flooding adjoining deforested areas, and hospital admission numbers (bar chart, right-hand scale) for infectious parasitic diseases including malaria (shown in red) for the nearest town, Caroebe (Brazil). A clear correlation can be seen between the water level and the incidence of infectious parasitic diseases: both follow an annual cycle and appear to be increasing over the longer term. (Credits IRD).

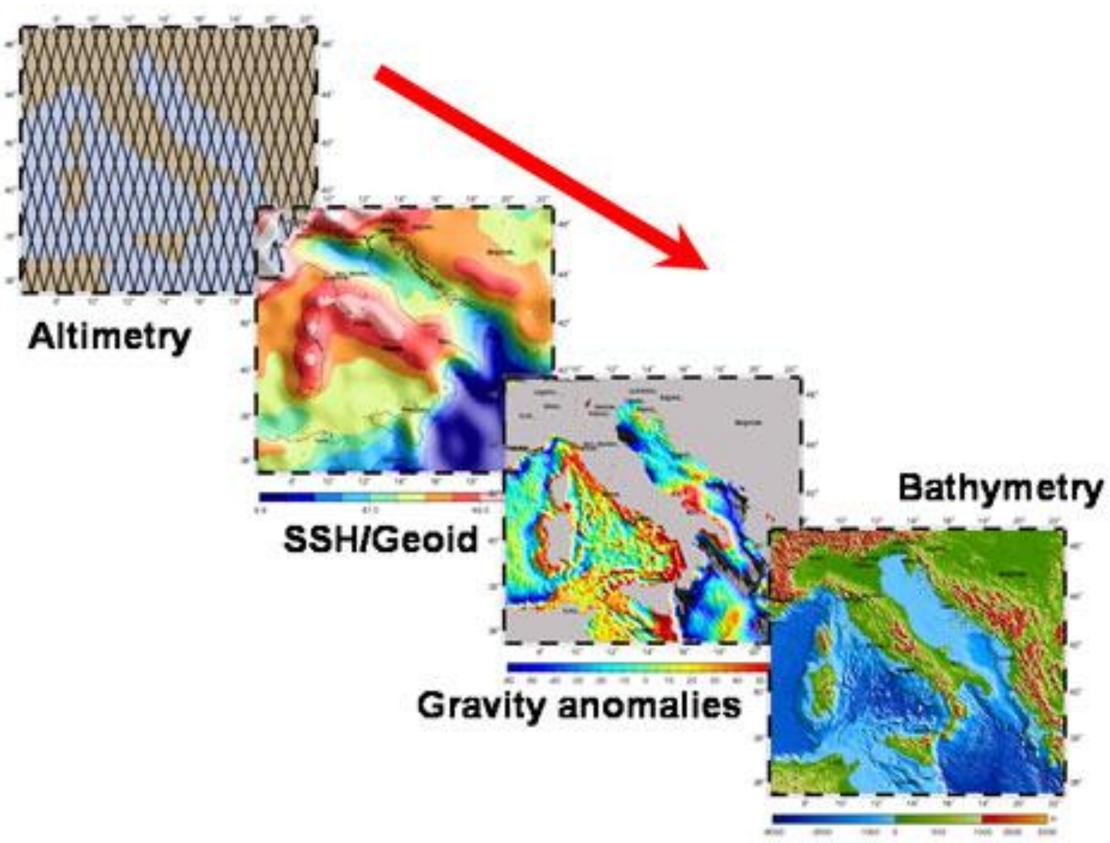
# ALTIMETRY AND PHYTOPLANKTON

More than forests this phytoplankton is producing the oxygen and recycling carbon. It is also the first element of the ocean food chain. Joint observations from infrared (ocean color) and altimetry satellites are very interesting for their understanding.



*Sudden phytoplankton blooms are seem on ocean color images (here from the Vegetation sensor onboard Spot, between Africa and Madagascar). Those blooms can be correlated to the eddies and currents seen by altimetry. (Credits CLS).*

# GEODESY AND GEOPHYSICS

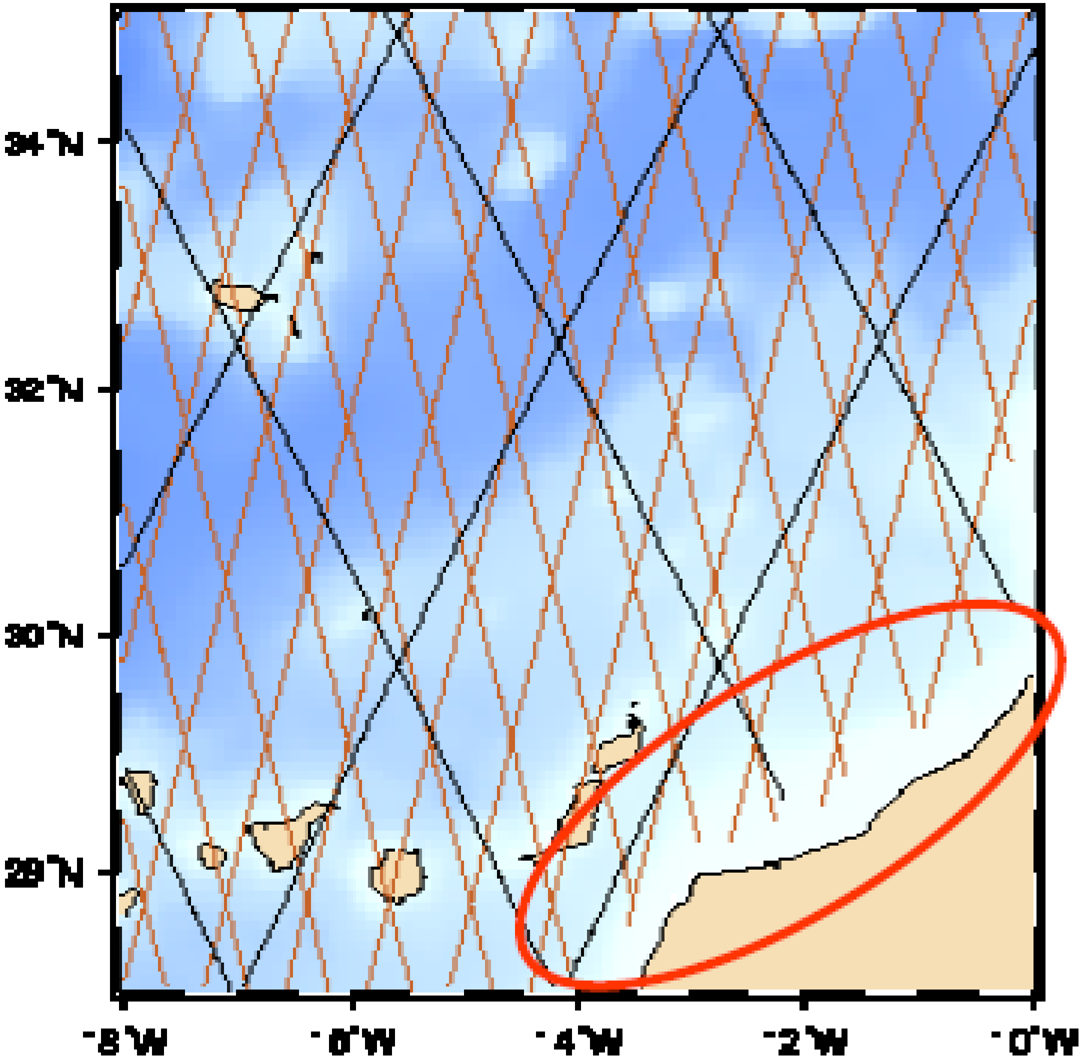


Example of geophysical information extracted from altimetry (around Italy). (Credits University of Calgary).

# 1. Coastal Sea Level

Satellite altimetry sea level observations are not well-adapted to the coastal domain :

- 30-50 km from the coasts, the radiometer and altimetric footprint is « blinded » by the presence of the coast,
- certain corrections (tides, inverse barometer effect) adapted for the open ocean, are underestimated in the coastal zone.



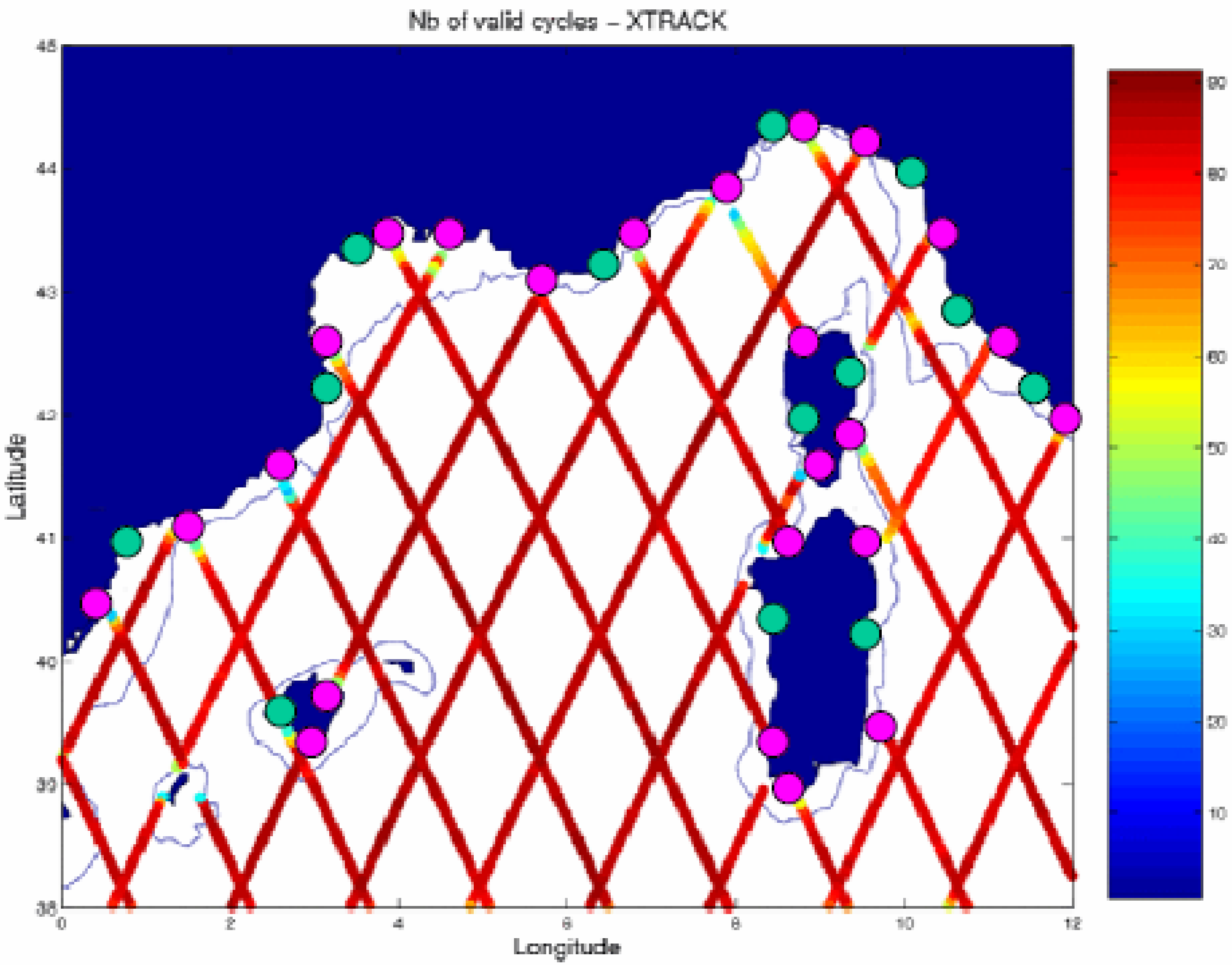
# Solution 1) Combining altimetry and tide gauges

Reconstruct coastal sea level : then calculate coastal currents

- ● Observed tide gauge SL time series
- ● Interpolated « pseudo » SL time series

*Strub et al., California Current*

*Griffin et al., Australian coast.*



**Solution 2) Combining satellite SST and altimetry : High resolution coastal currents**

**Solution 3) Combining altimetry and HF radar**

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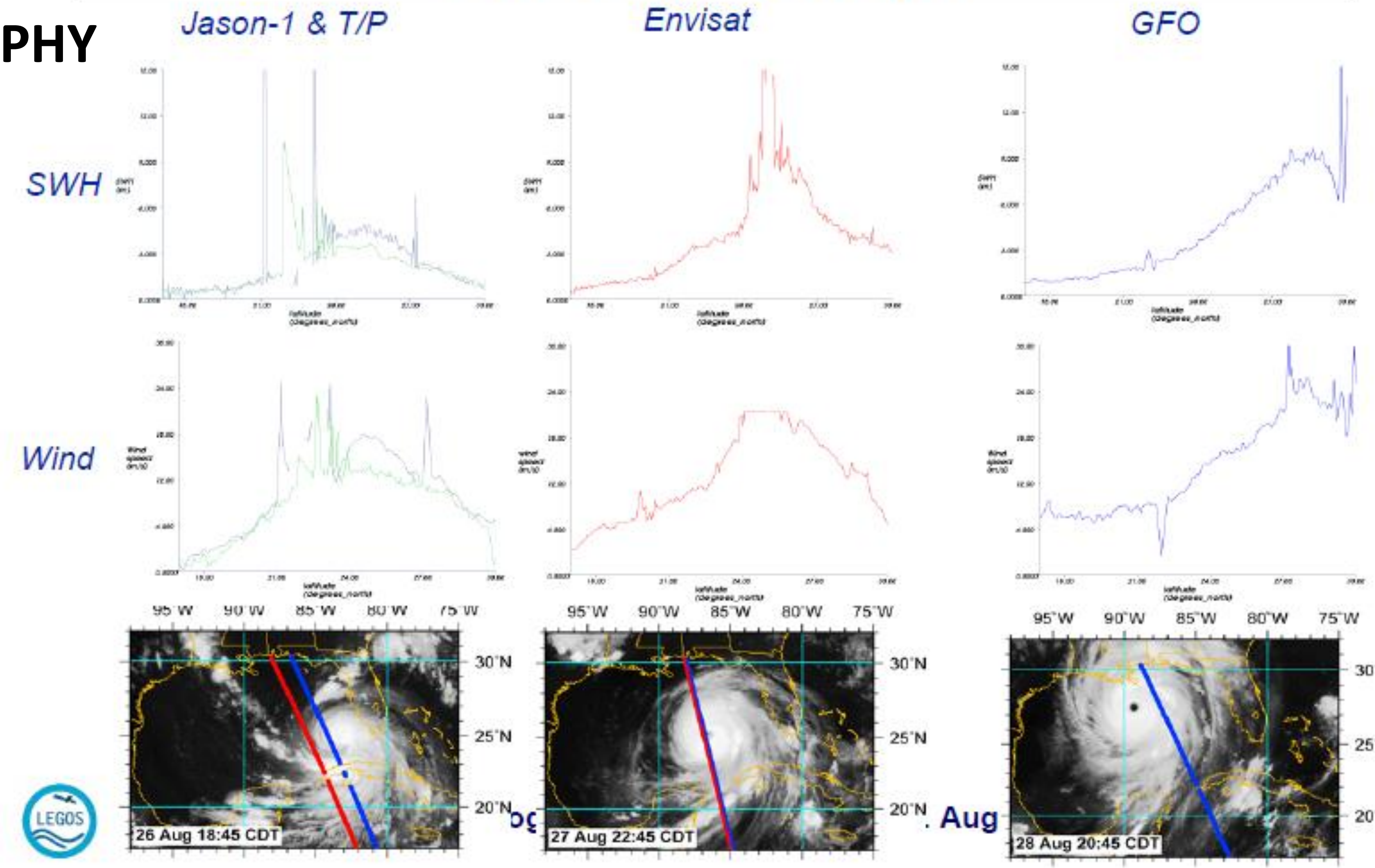
**Solution 4) Calculating filament positions from mesoscale altimetry : FSLE**

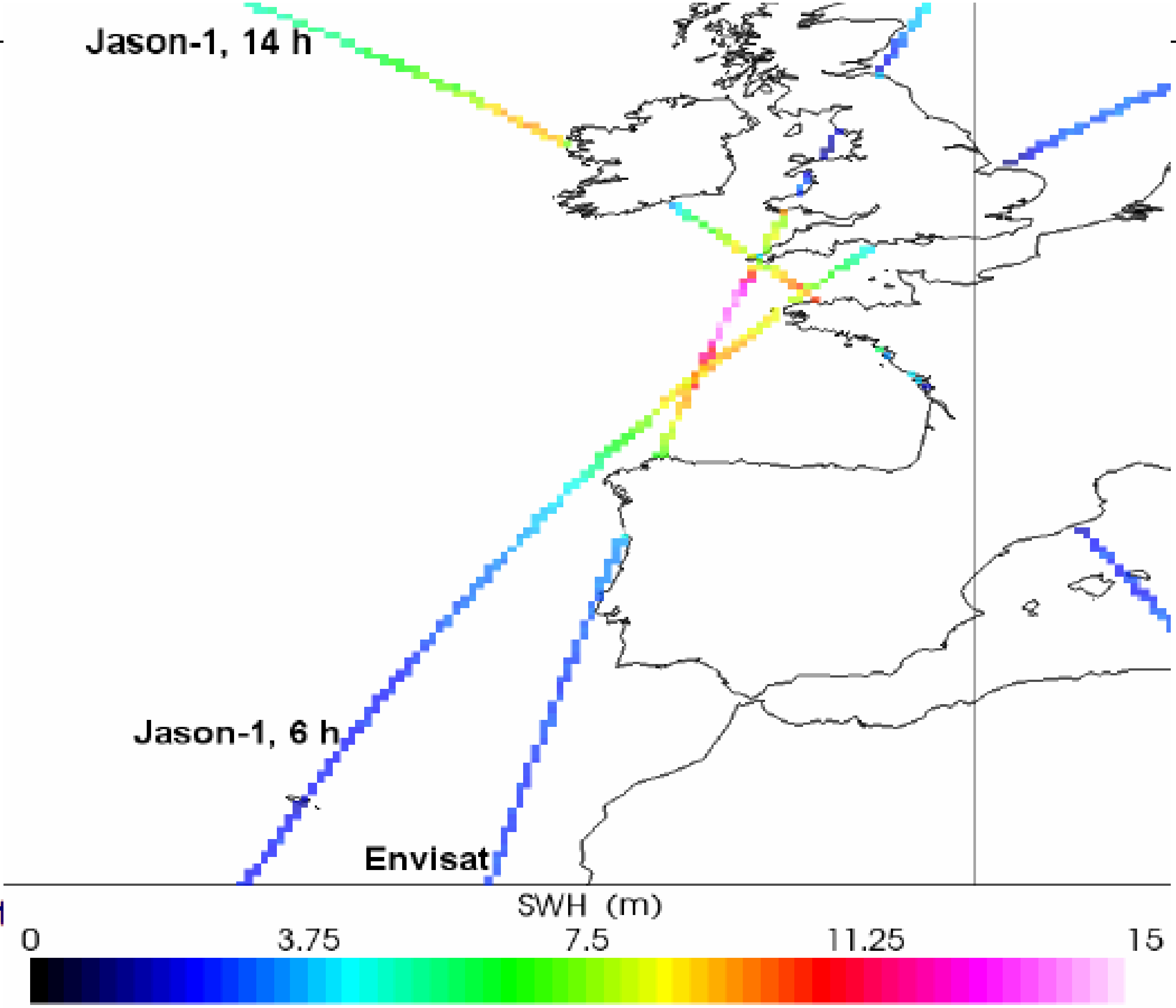
# OPERATIONAL OCEANOGRAPHY

# Hurricane Katrina



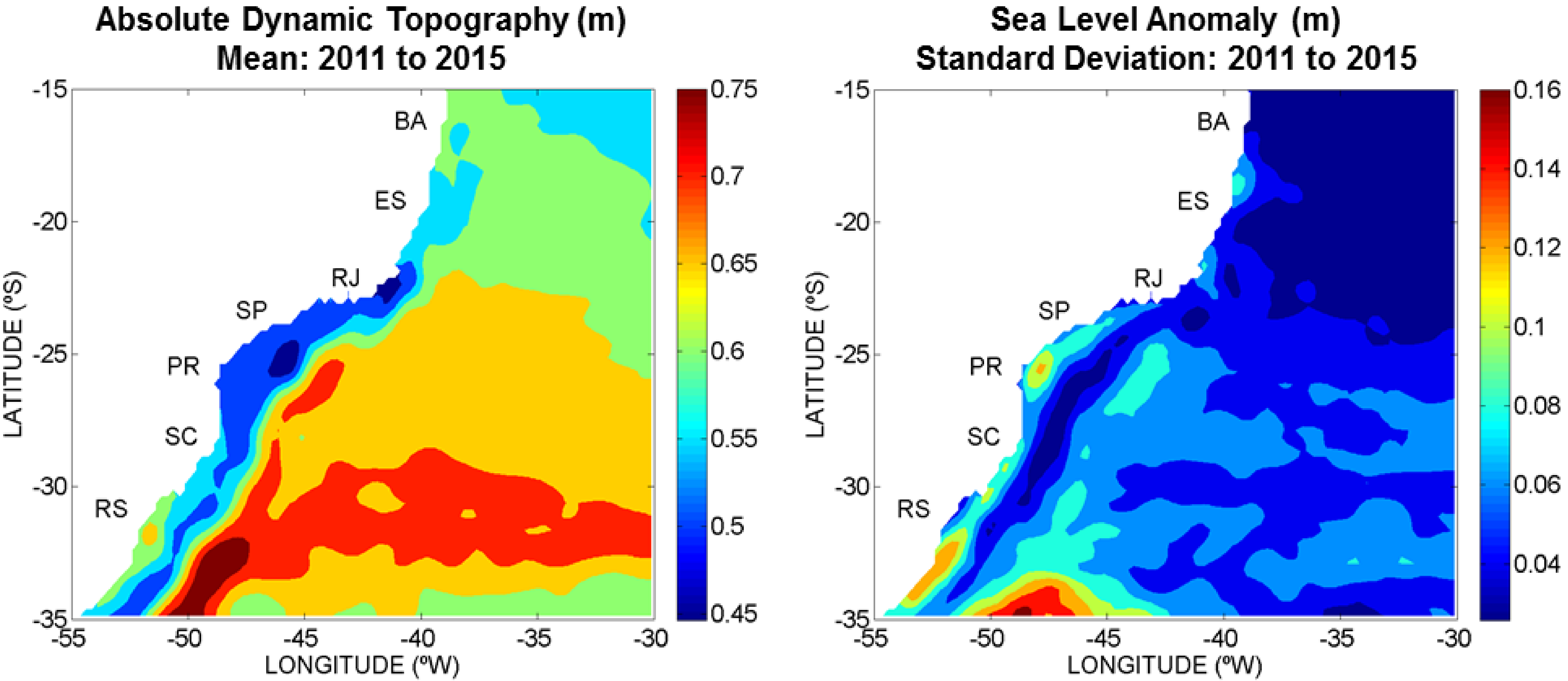
# North Atlantic Storm (9 Dec. 2007)

Significant wave heights along the tracks of Jason-1 and Envisat on December 9, 2007, during an especially strong storm (buoys measured SWH as high as 18 m near Ireland). (Credits CLS)

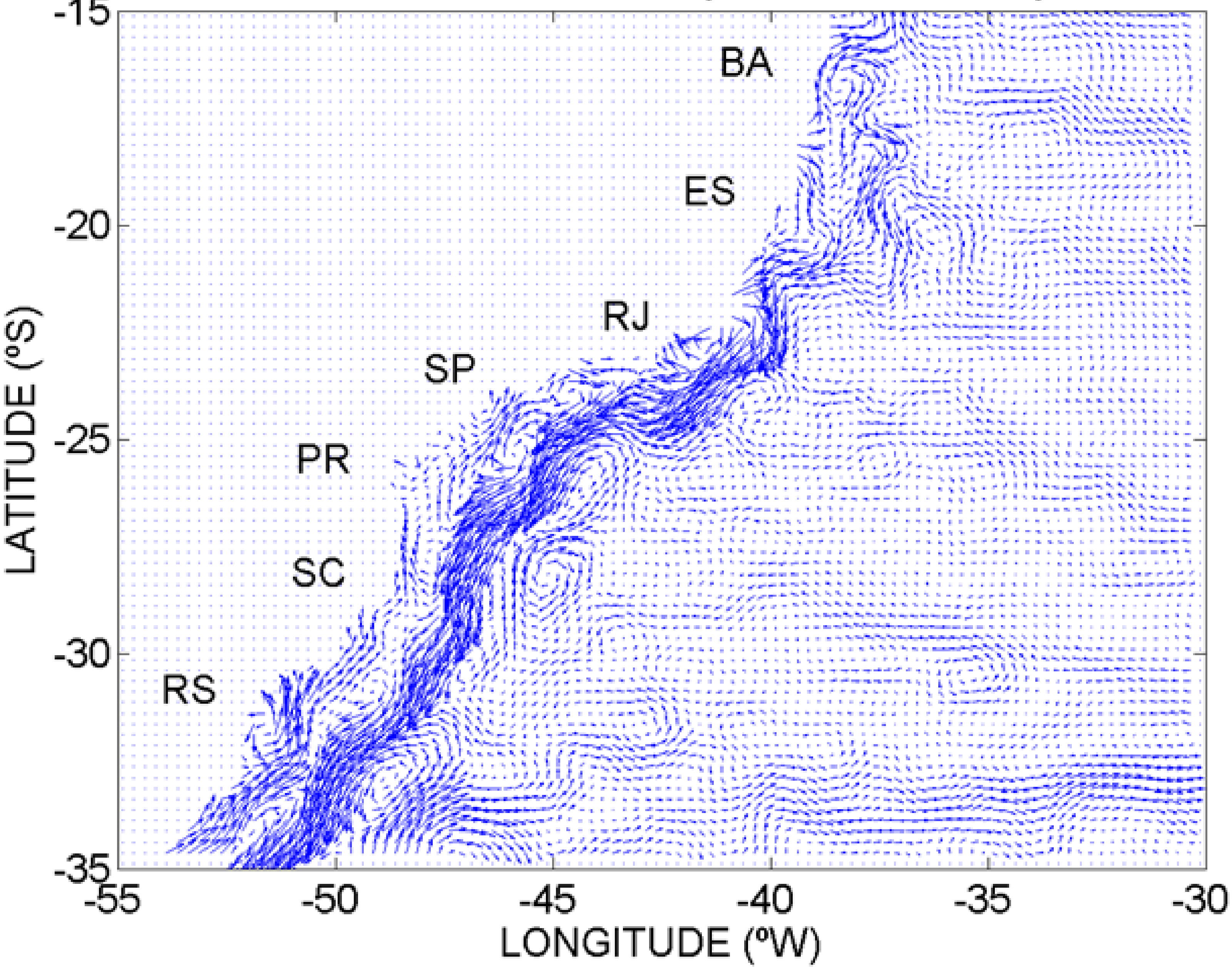


**Satellit**

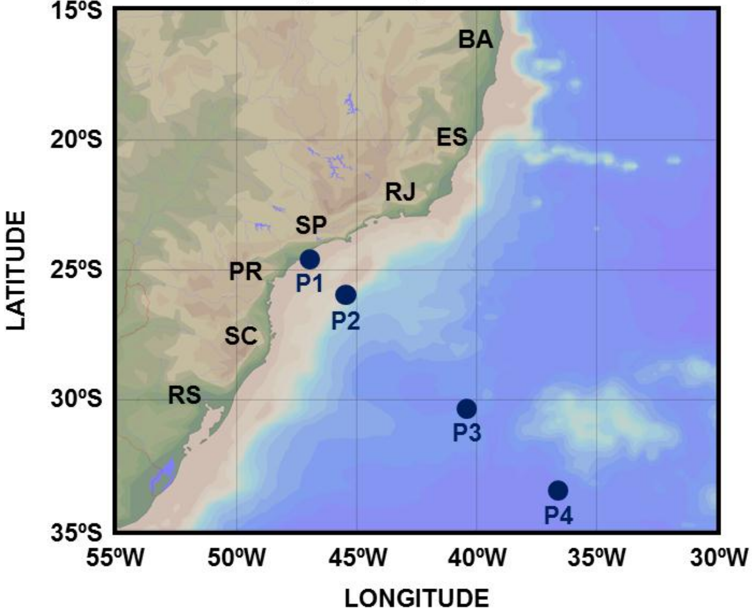
# ALTIMETRIC DATA PROCESSING – SOUTHWEST ATLANTIC



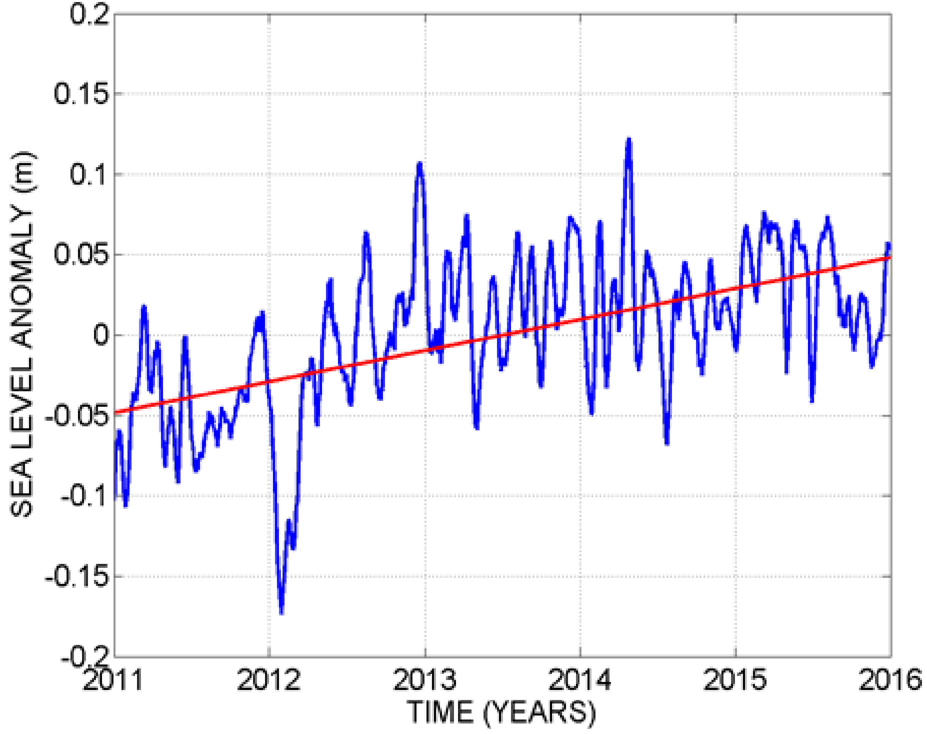
# Geostrophic Currents at Surface
# Mean: 2011 to 2015 (Max = 0.38 m/s)



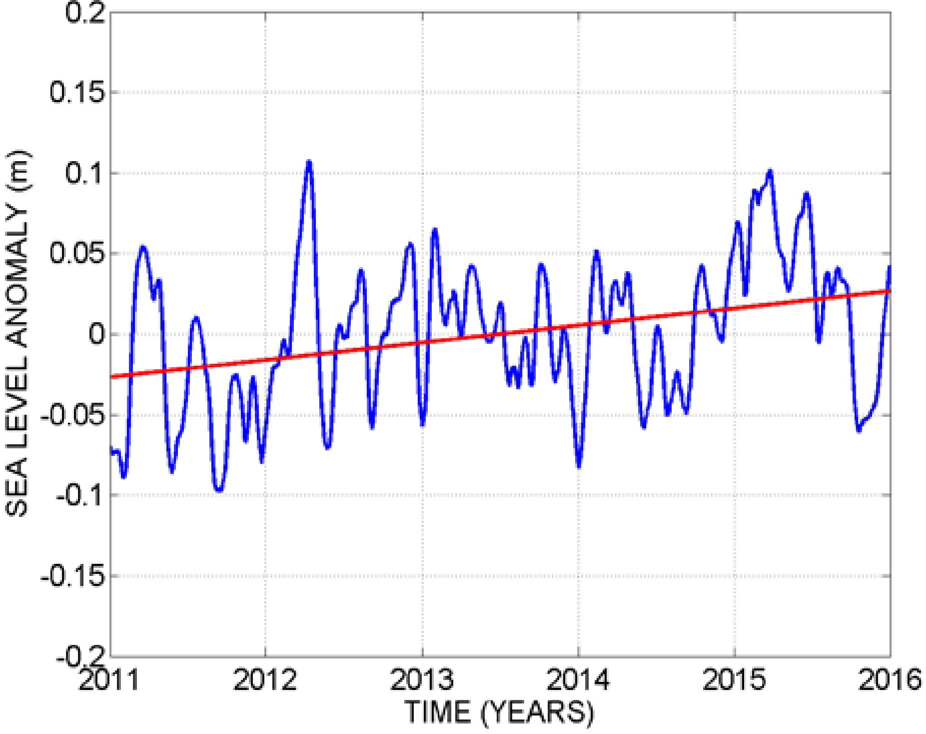
Study Area Map and Stations



Sea Level Anomaly (m) – Station P2
Linear Trend (in red): 0,0193 m / year



Sea Level Anomaly (m) – Station P4
Linear Trend (in red): 0,0107 m / year



# PERSPECTIVES

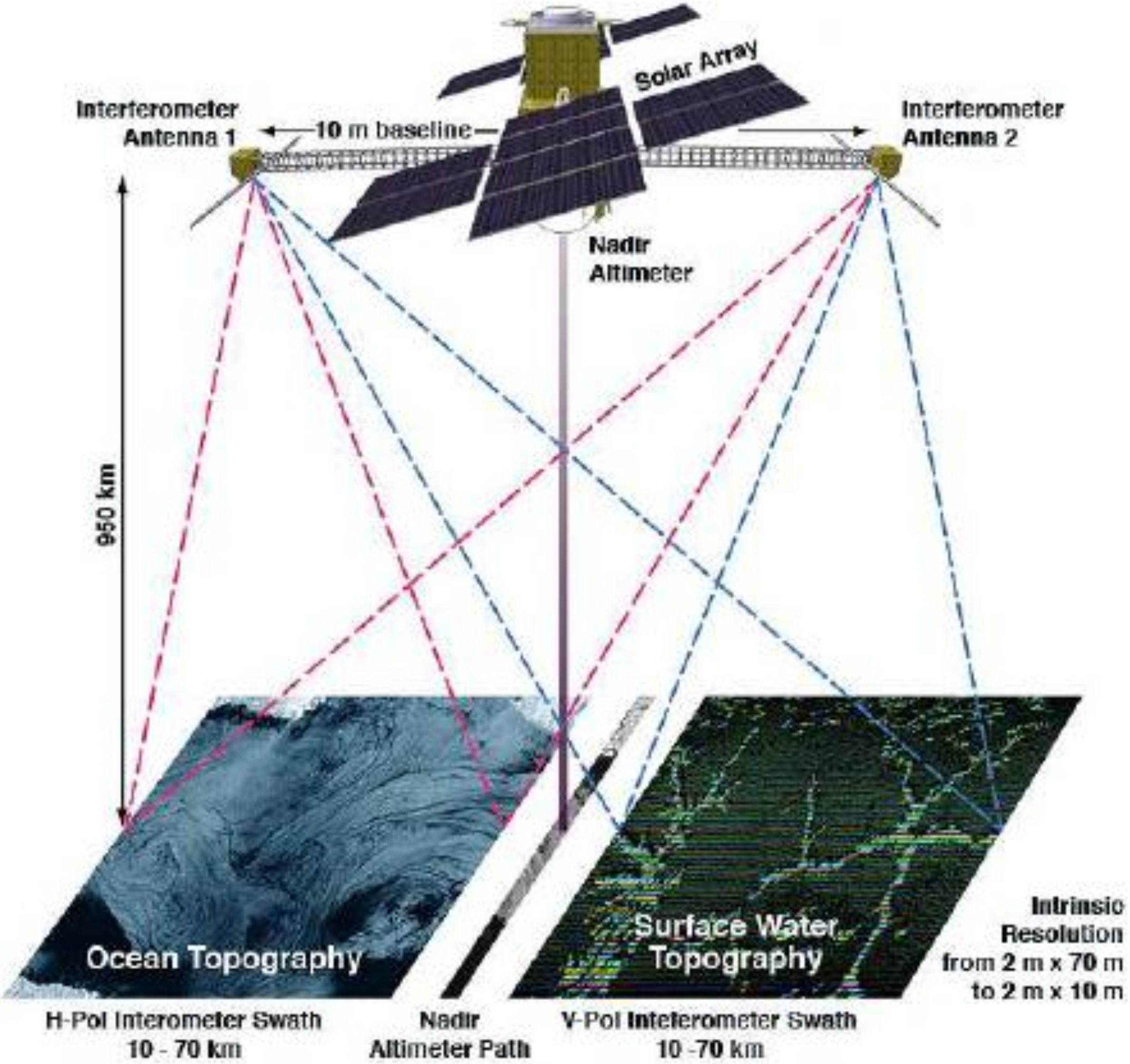
## *SWOT*

**Future technology :**
**Wide Swath Altimetry**

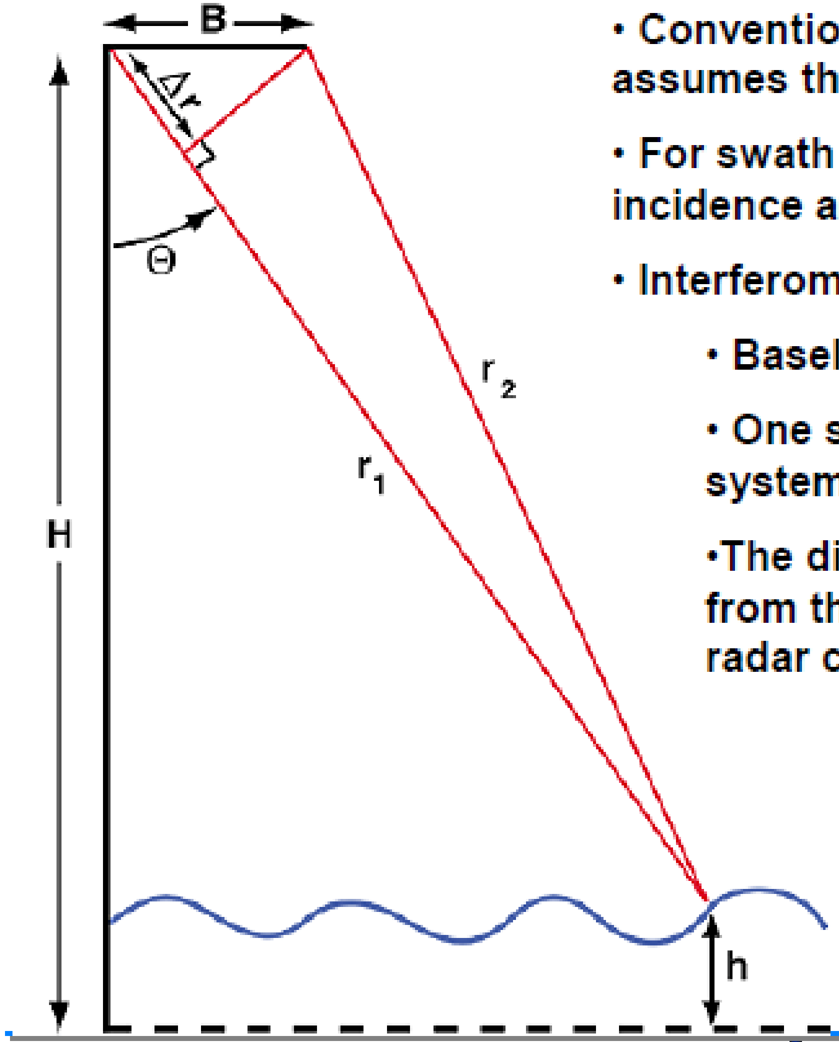
**SWOT**
**(Surface Water Ocean Topography)**

# SWOT

## Schematic of the SWOT measurement system



# SWOT Interferometric Measurement Concept

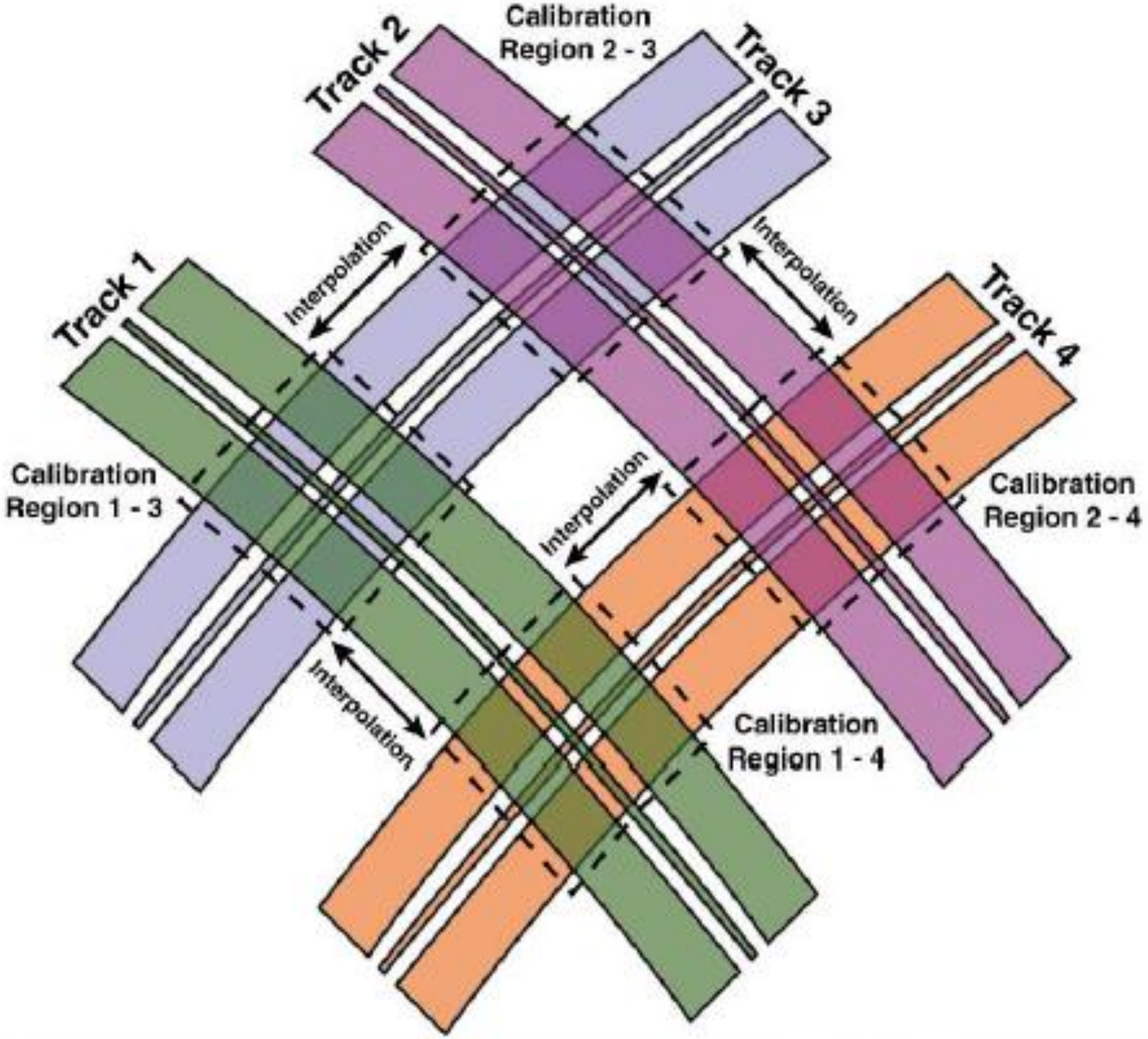


- Conventional altimetry measures a single range and assumes the return is from the nadir point
- For swath coverage, additional information about the incidence angle is required to geolocate
- Interferometry is basically triangulation
  - Baseline B forms base (mechanically stable)
  - One side, the range r1, is determined by the system timing accuracy
  - The difference between two sides ($\Delta r$) is obtained from the phase difference ($\Phi$) between the two radar channels.

$$\Phi = 2\pi\,\Delta r/\lambda = 2\pi B \sin\Theta/\lambda$$

$$h = H - r1 \sin\Theta$$

# Cross-Over Calibration Concept



- Roll errors must be removed by calibration
- Assume the ocean does not change significantly between crossover visits (< 10 days)
- For each cross-over, estimate the baseline roll and roll rate for each of the passes using altimeter-interferometer and interferometer-interferometer cross-over differences, which define an over-constrained linear system.
- Interpolate along-track baseline parameters between calibration regions by using smooth interpolating function (e.g, cubic spline.)

# SWOT

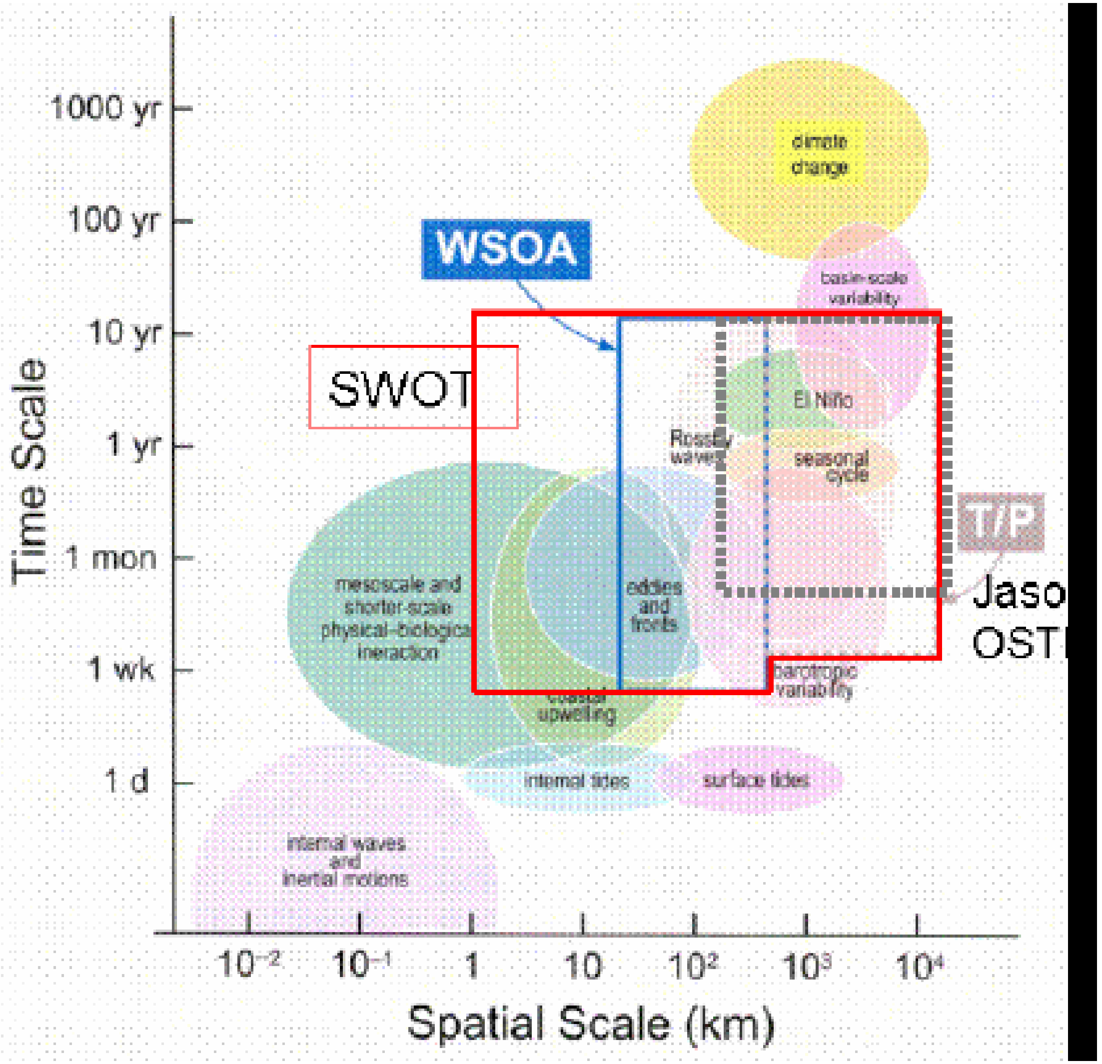
## Space-time scales resolved by SWOT

Original WSOA technology could resolve to 15-20 km resolution.

SWOT resolves to 1 km resolution

Good for sub-mesoscale ocean dynamics

Excellent for monitoring small lakes and river levels

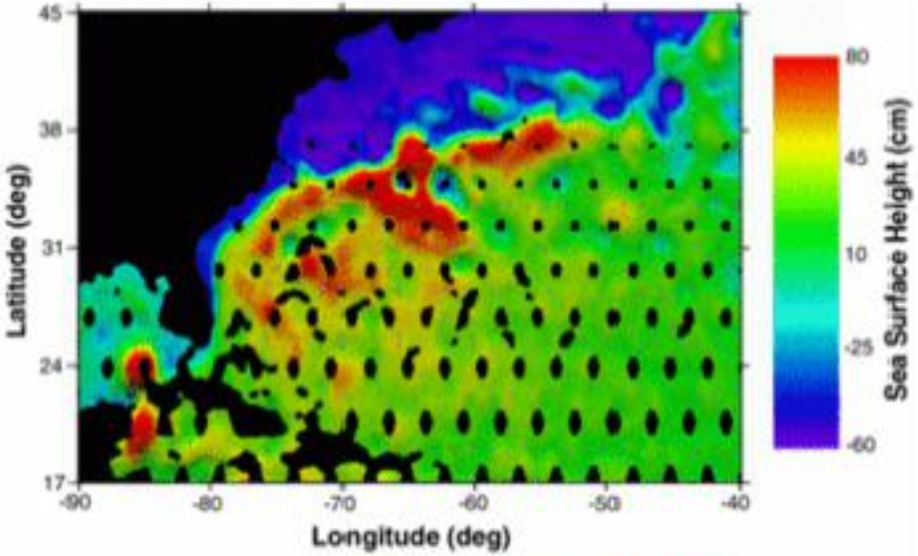


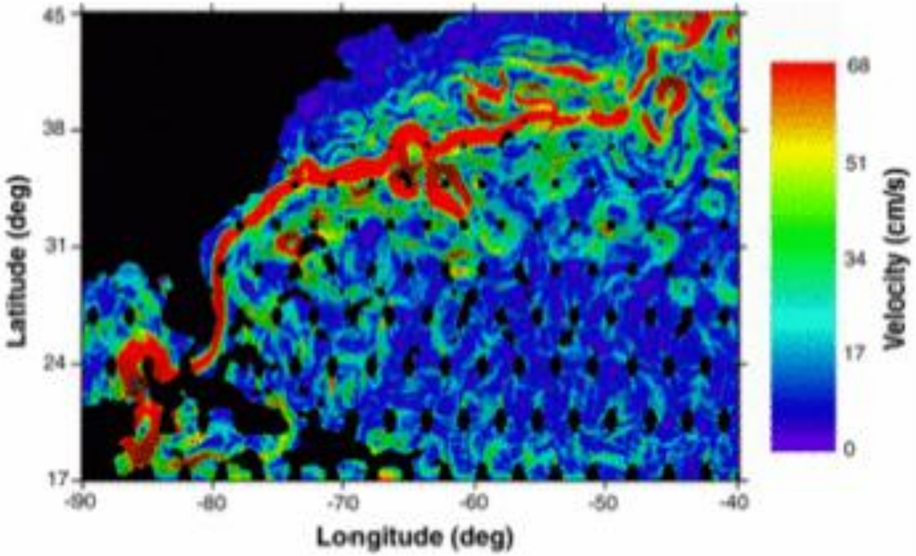
# SWOT

## Height and velocity from SWOT

Typical spatial coverage from a 10-day Jason-1 orbit

Mid-to-high latitude, « crossover » points covered many times in 10 days.





# PERSPECTIVES

**HIGH PRECISION SATELLITE TRACKING**
**MULTI-SATELLITE MISSIONS**
**ALTIMETRY IN GNSS SATELLITES (GPS)**
**SWOT**

**... What else ???**