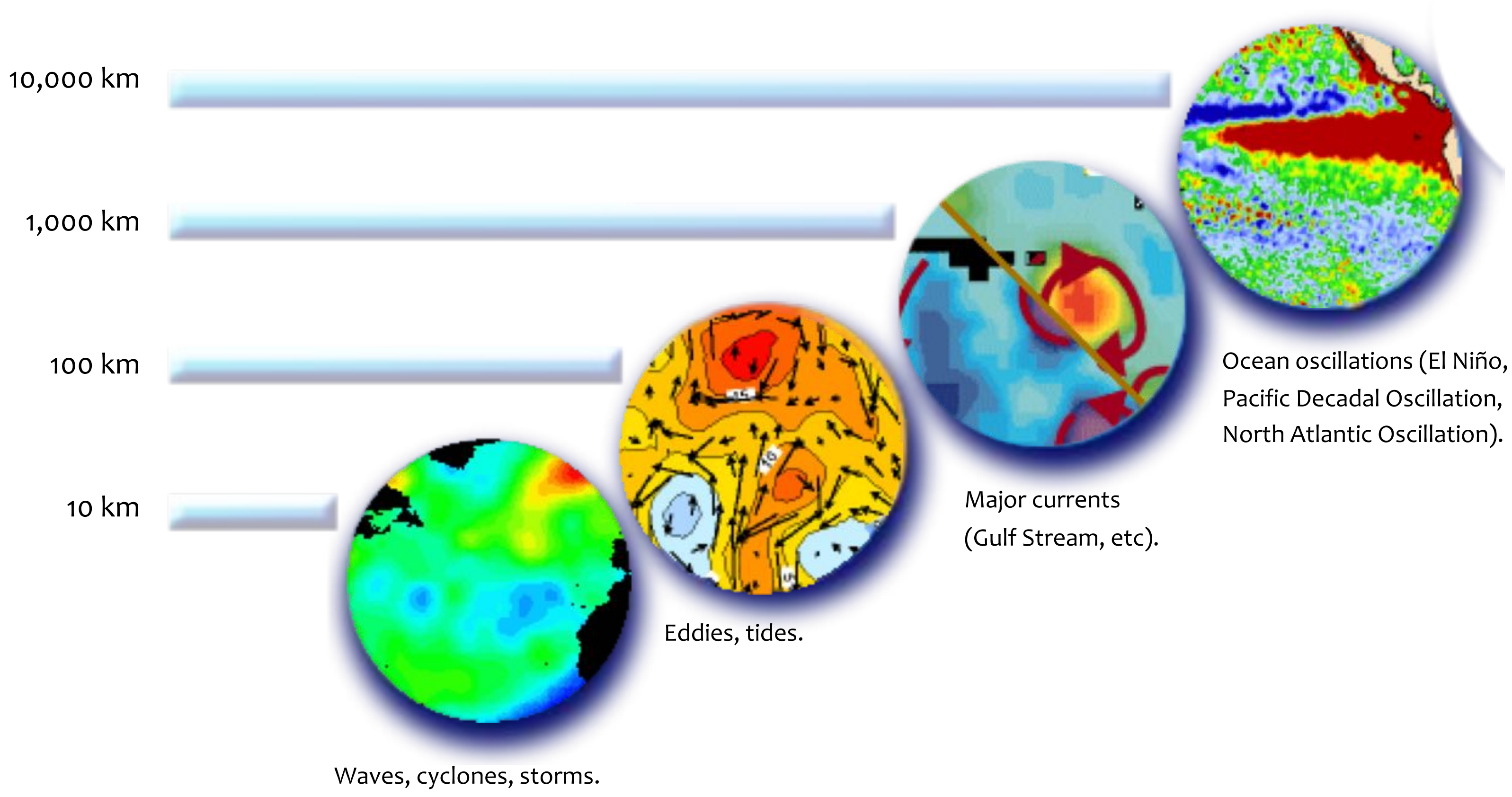
Altimetry / Sea Level

Sea Level Copernicus Marine Service Thematic Assembly Center

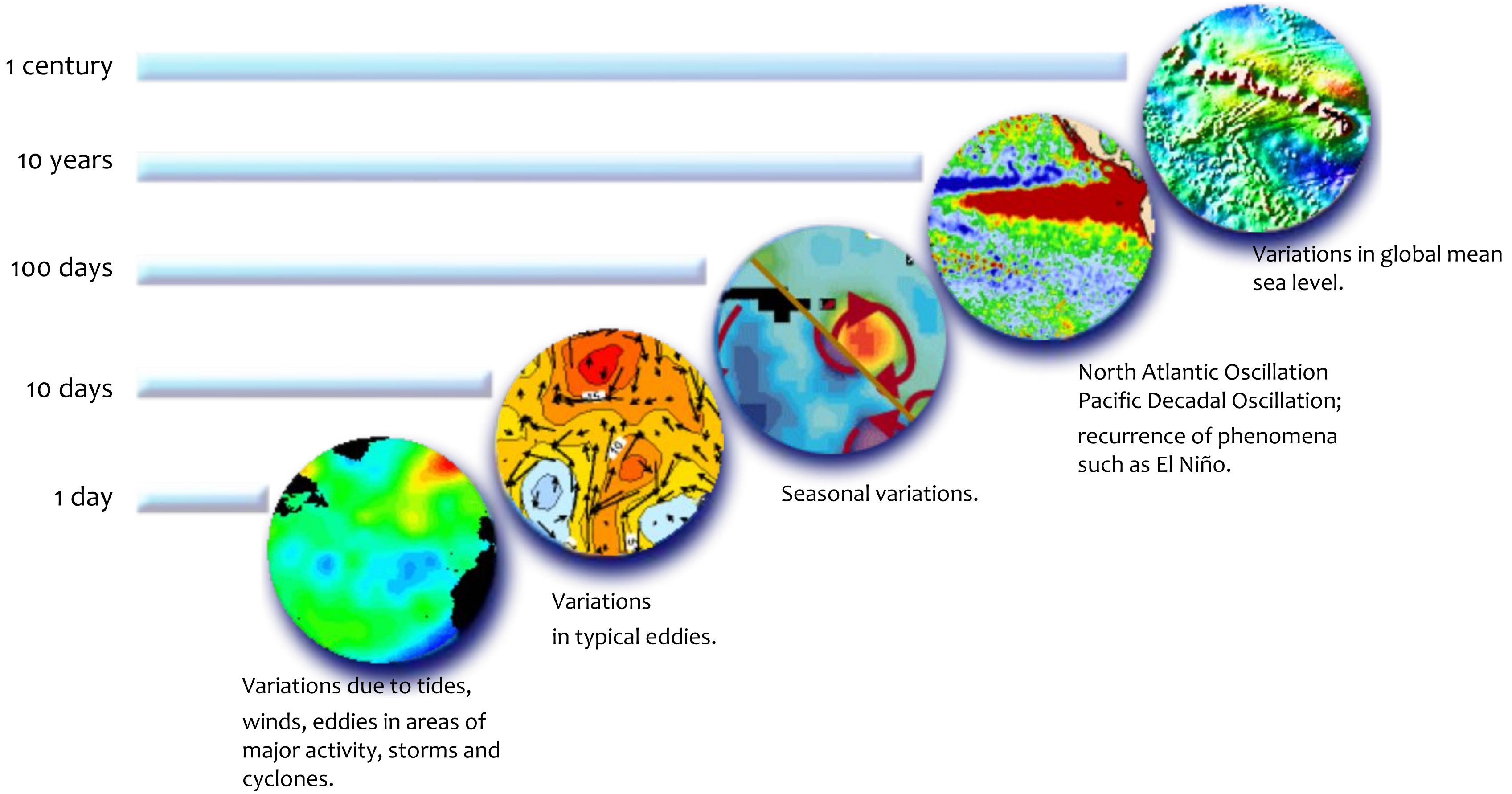
Vinca Rosmorduc, CLS / CMEMS Sea Level TAC

What are we observing?

Spatial scales



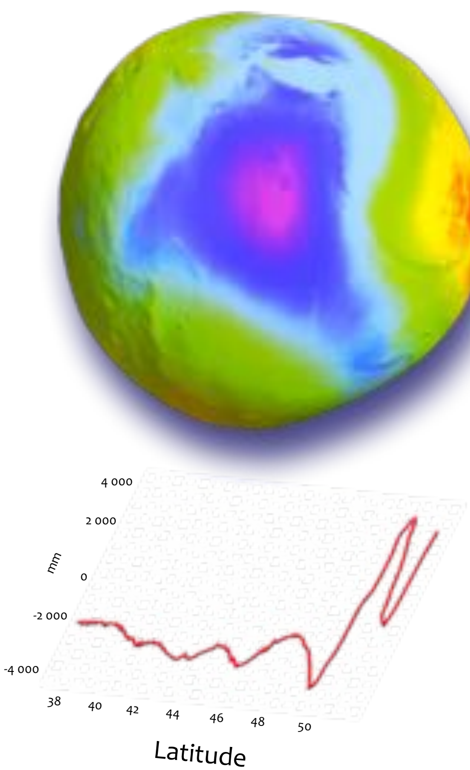
Time scales


1 century
10 years
100 days
10 days
1 day
Variations in global mean sea level.
North Atlantic Oscillation Pacific Decadal Oscillation; recurrence of phenomena such as El Niño.
Seasonal variations.
Variations in typical eddies.
Variations due to tides, winds, eddies in areas of major activity, storms and cyclones.

Varying amplitude

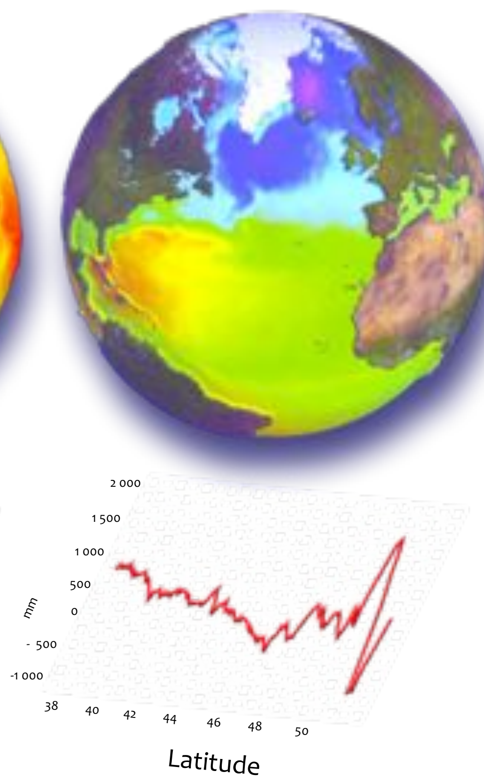
Geoid undulations:

Amplitude of a several tens of metres.



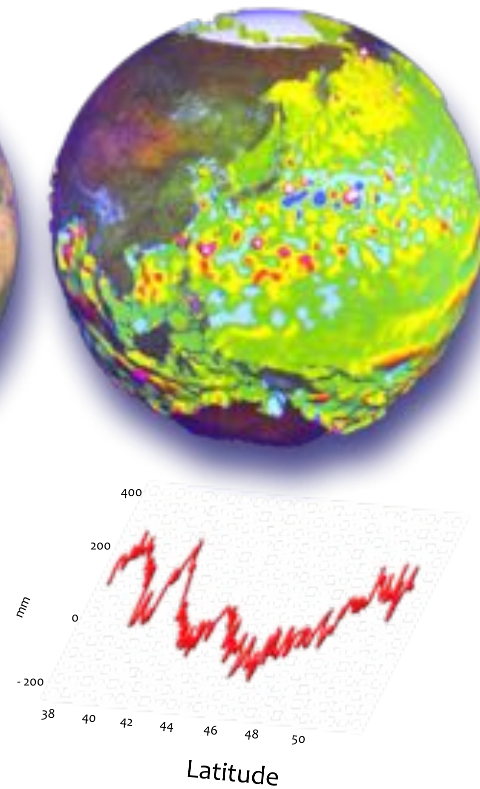
Major western boundary currents:

Amplitude of about 1 metre.



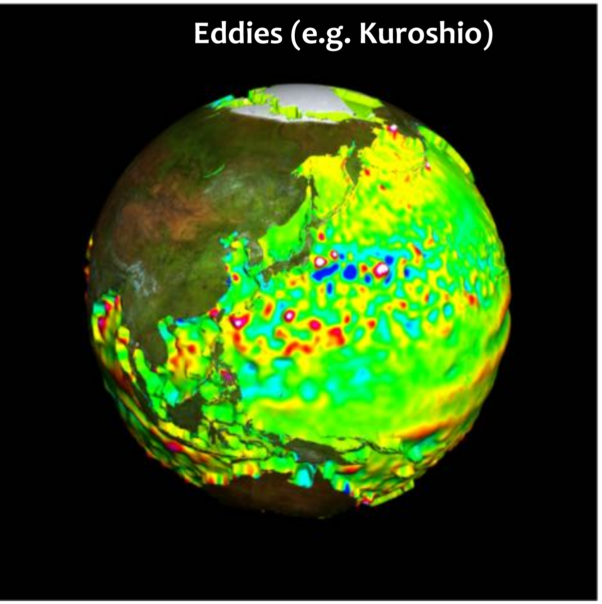
Mesoscale circulation:

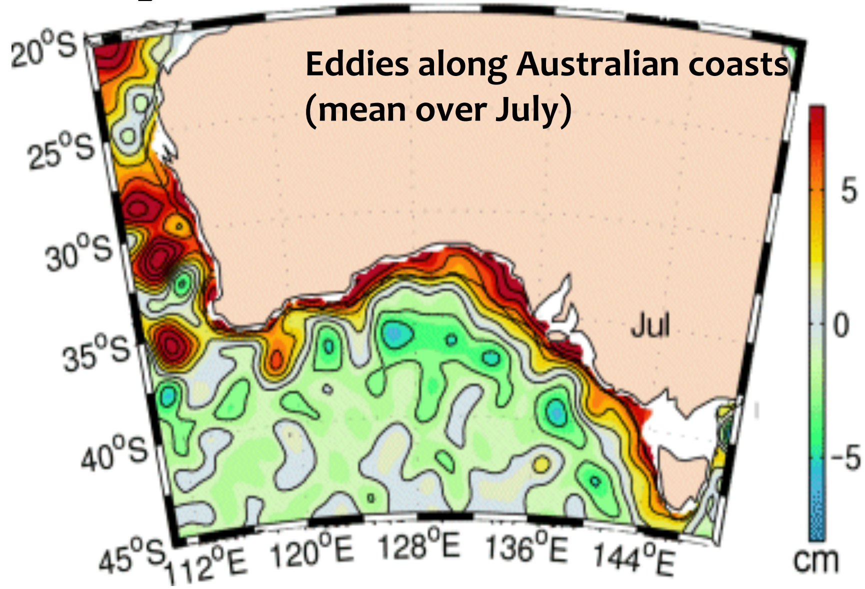
Amplitude of about 1 decimetre.

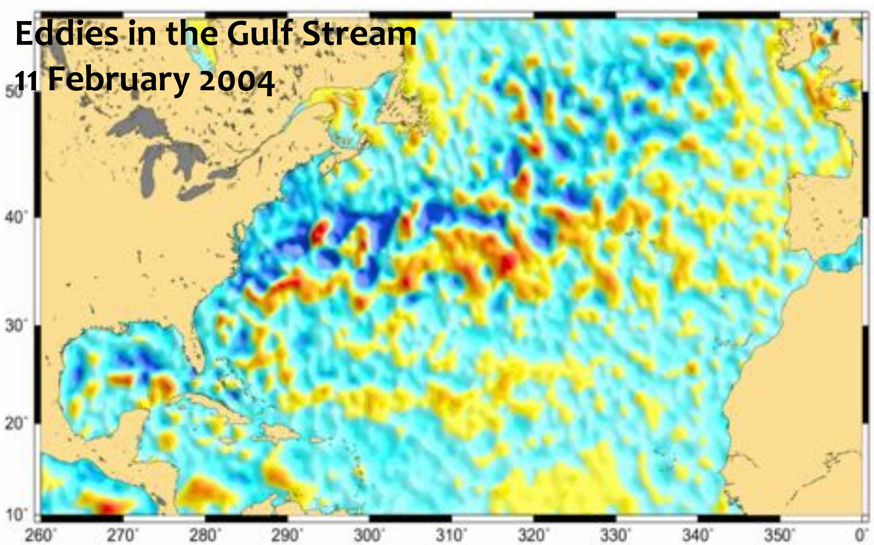


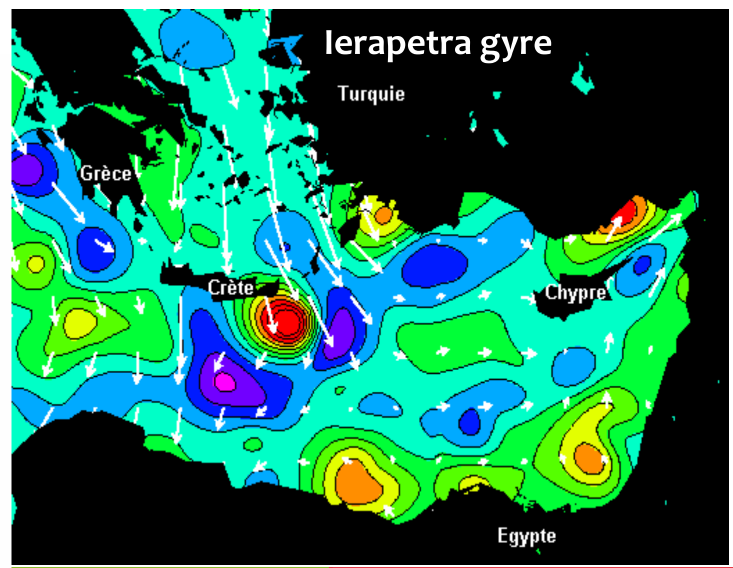
The amplitude of the phenomena observed ranges from a few tens of metres to several millimetres for the mean sea surface height signal.

What can altimetry show?



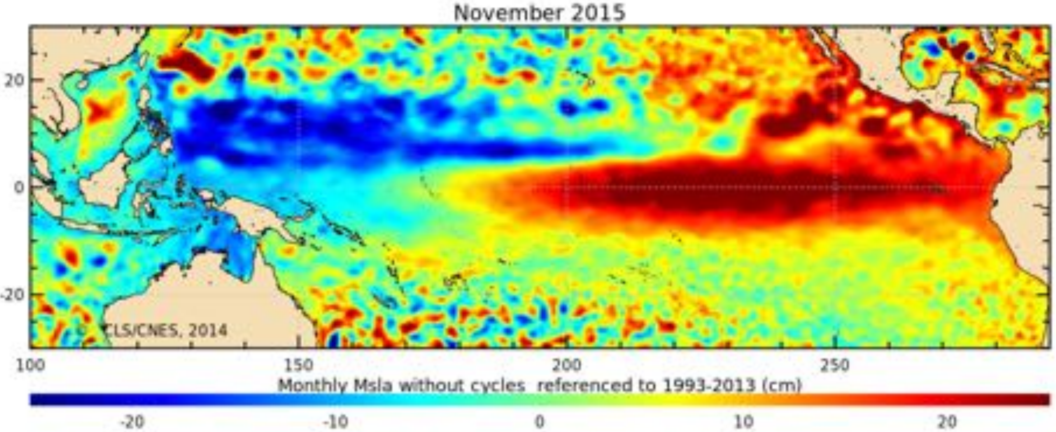


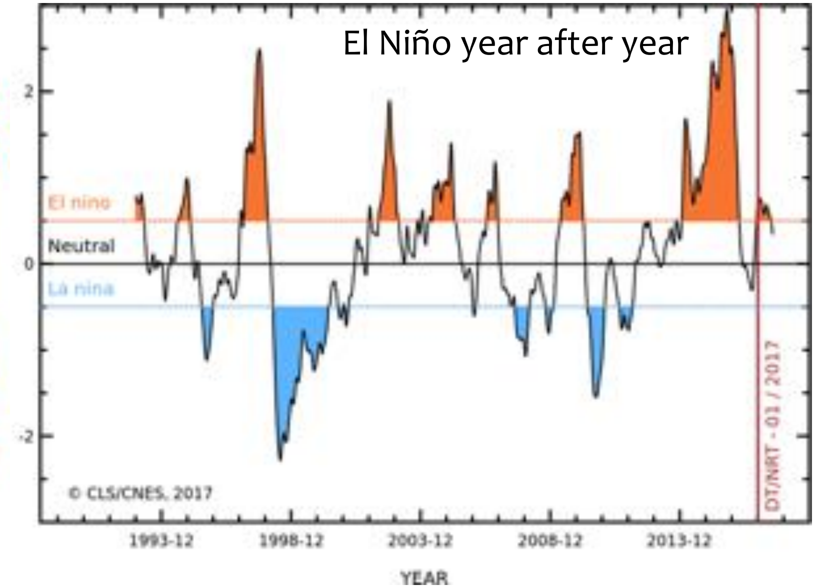




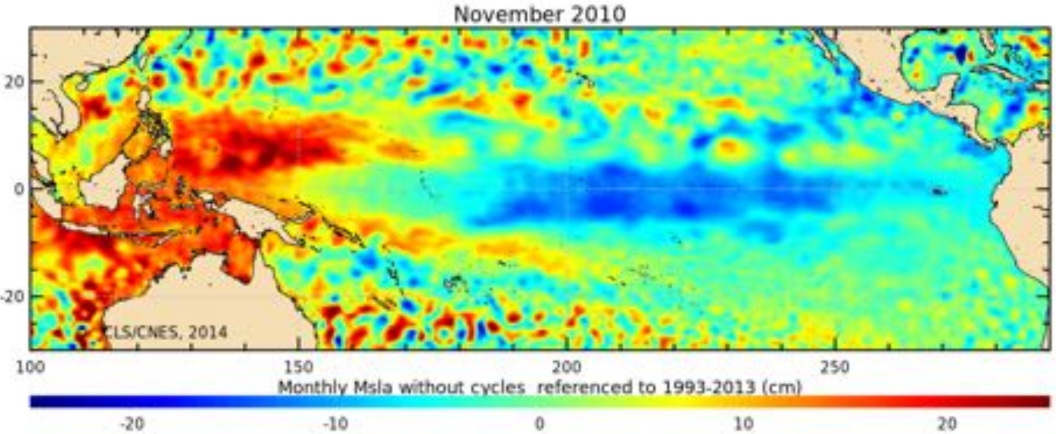
What can altimetry show?

El Niño

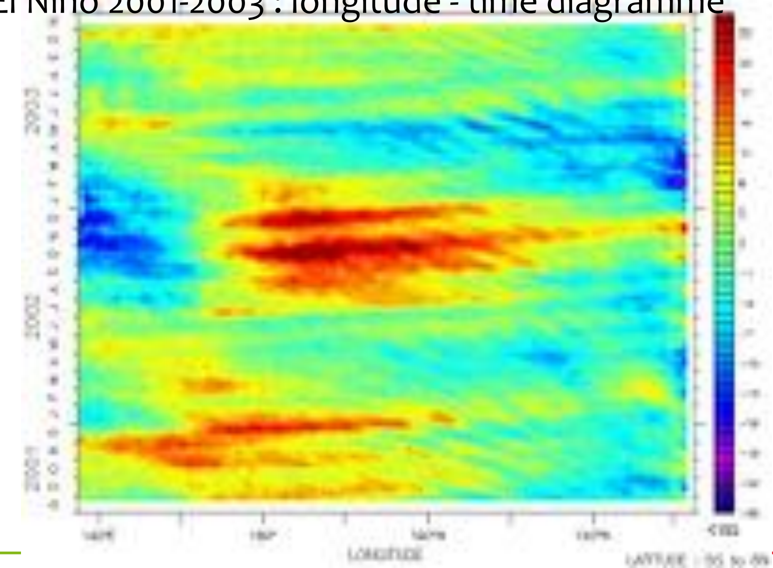




La Niña

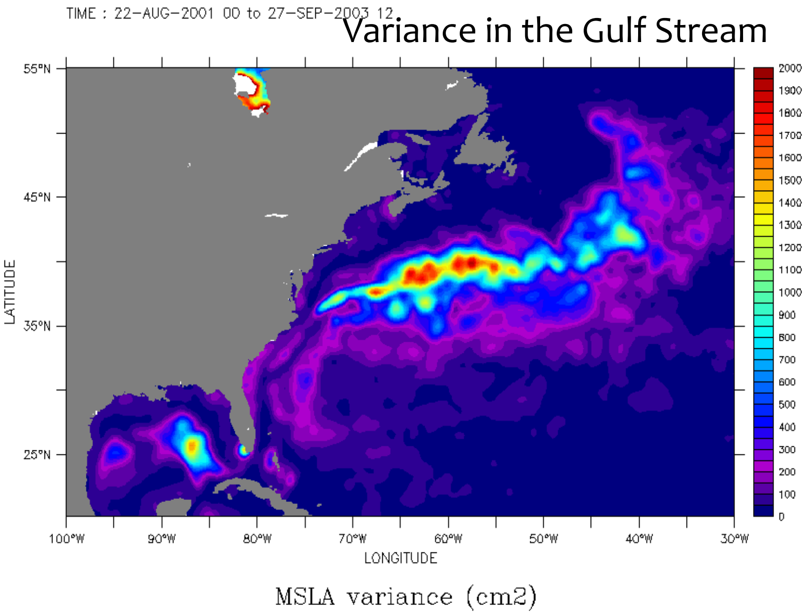


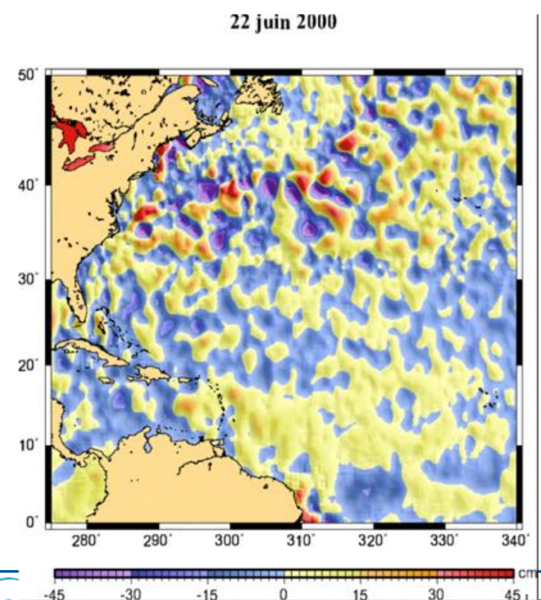
El Niño 2001-2003 : longitude - time diagramme



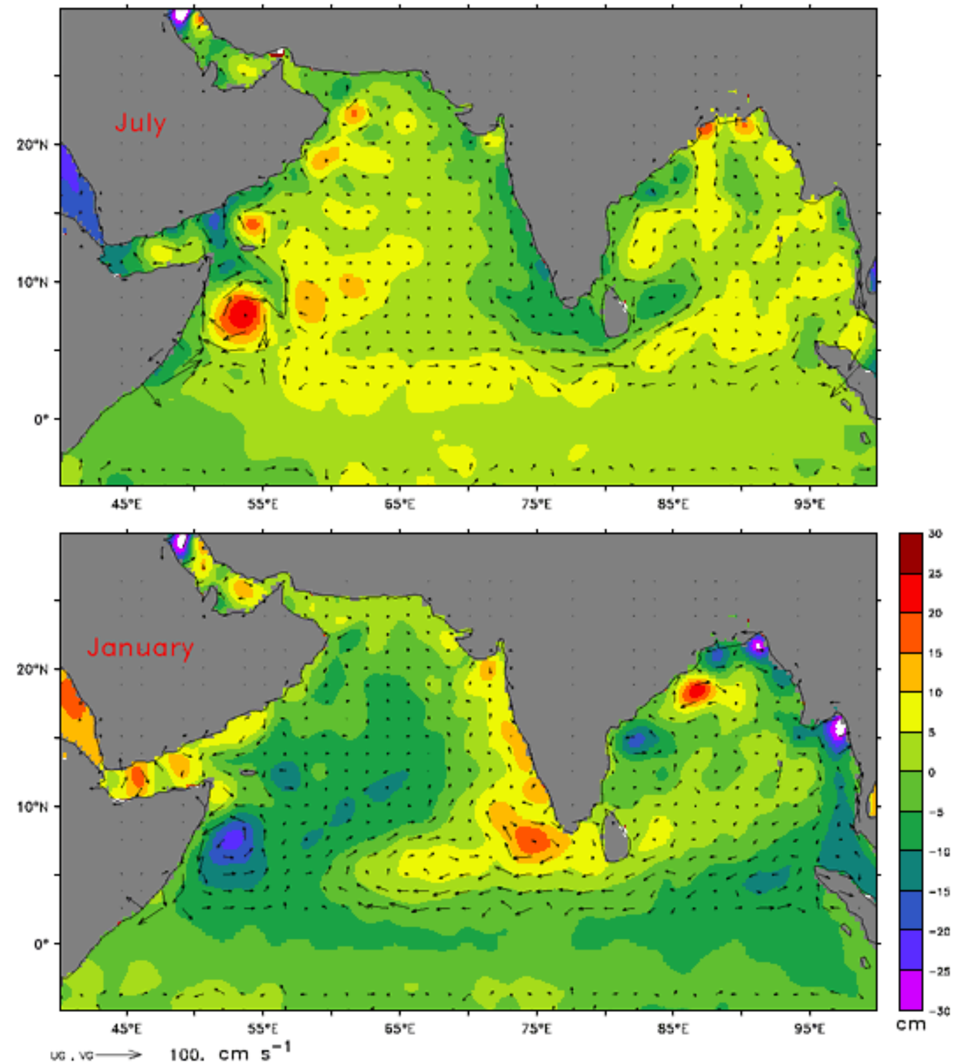
What can altimetry show?

Variance in the Gulf Stream



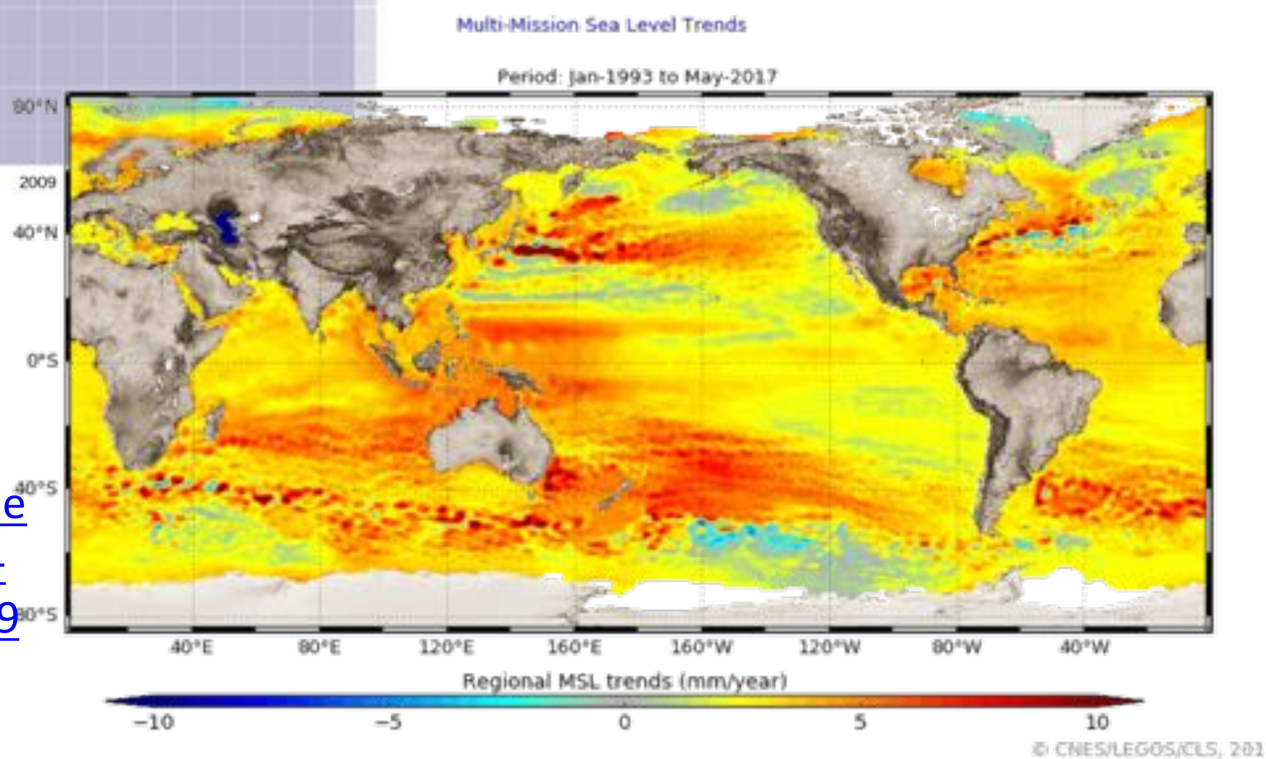


The Gulf Stream (with a turtle)



What can altimetry show?

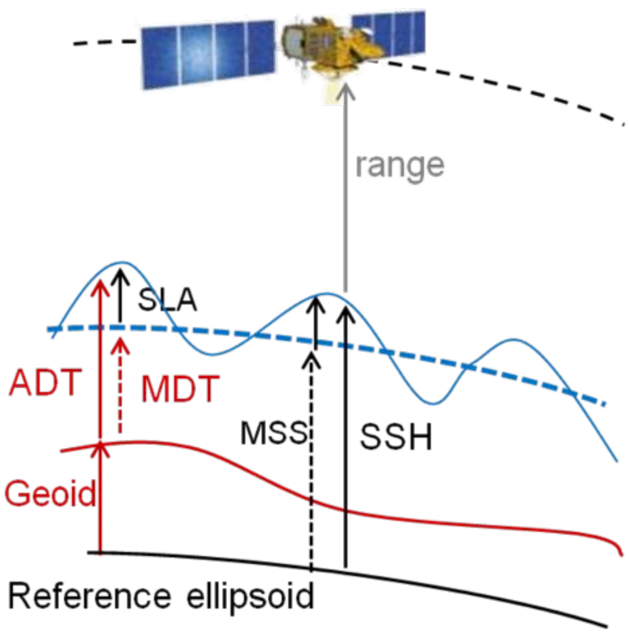
Mean Sea Level variations



Ocean Monitoring Indicators – Sea Level

http://marine.copernicus.eu/science-learning/ocean-monitoring-indicators/catalogue/?product=97285

Some definitions&acronyms…



Reference ellipsoid: mathematical surface approximating the ocean surface .

SSH: Sea Surface Height
in altimetry, tacitly, SSH with respect to the *reference ellipsoid*.

SLA: Sea Level Anomalies (also **SSHA**)
(aka sea surface height with respect to a mean sea surface; seasonal variation not removed)

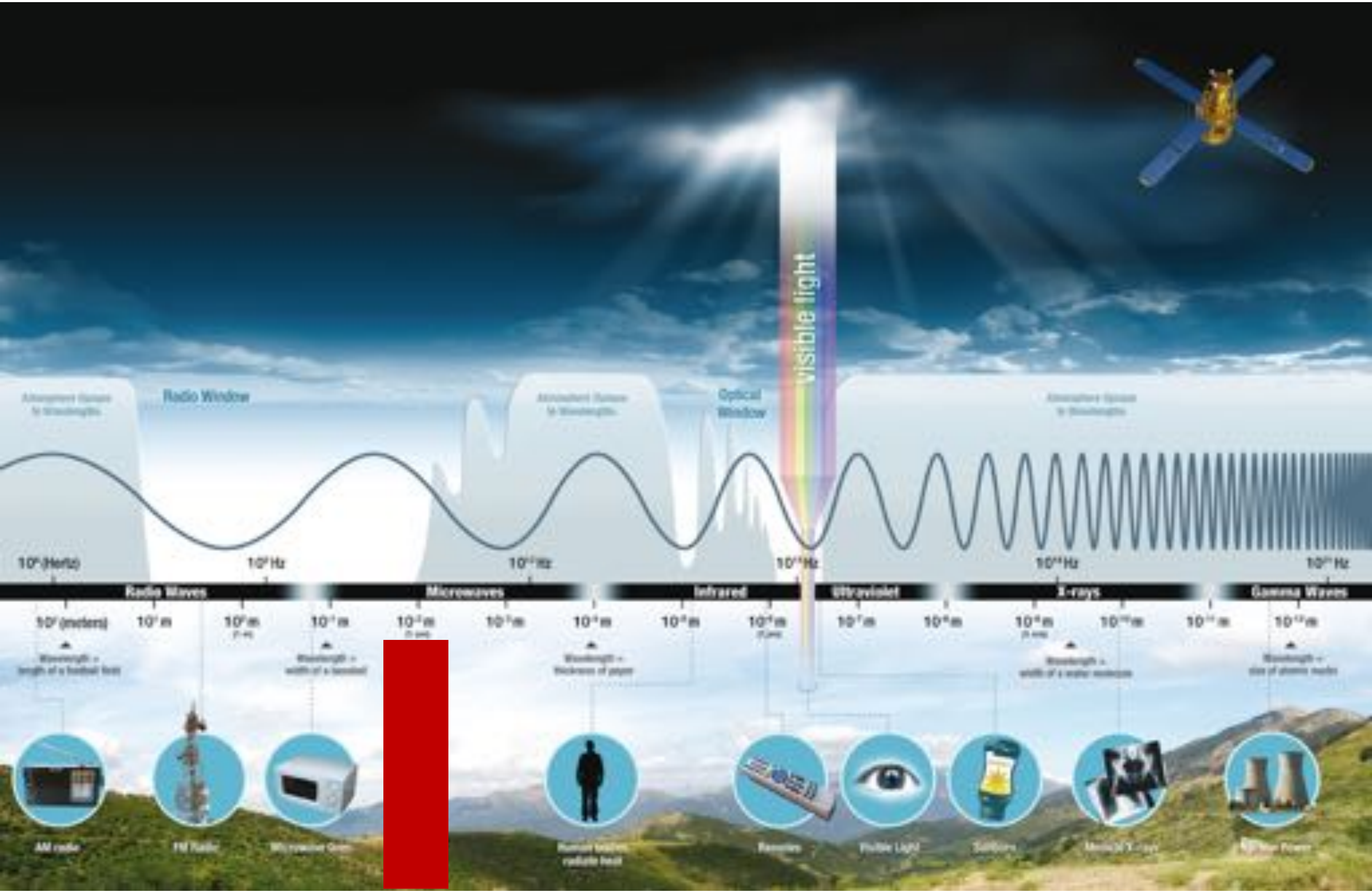
MSS: Mean Sea Surface (multi-year mean of SSH) [reference surface]

ADT: Absolute Dynamic topography
(sea surface height with respect to the geoid); often called SSH

MDT: Mean Dynamic Topography [reference surface]

MSL: mean sea level (global geographical mean of the sea level, monitored cycle by cycle)

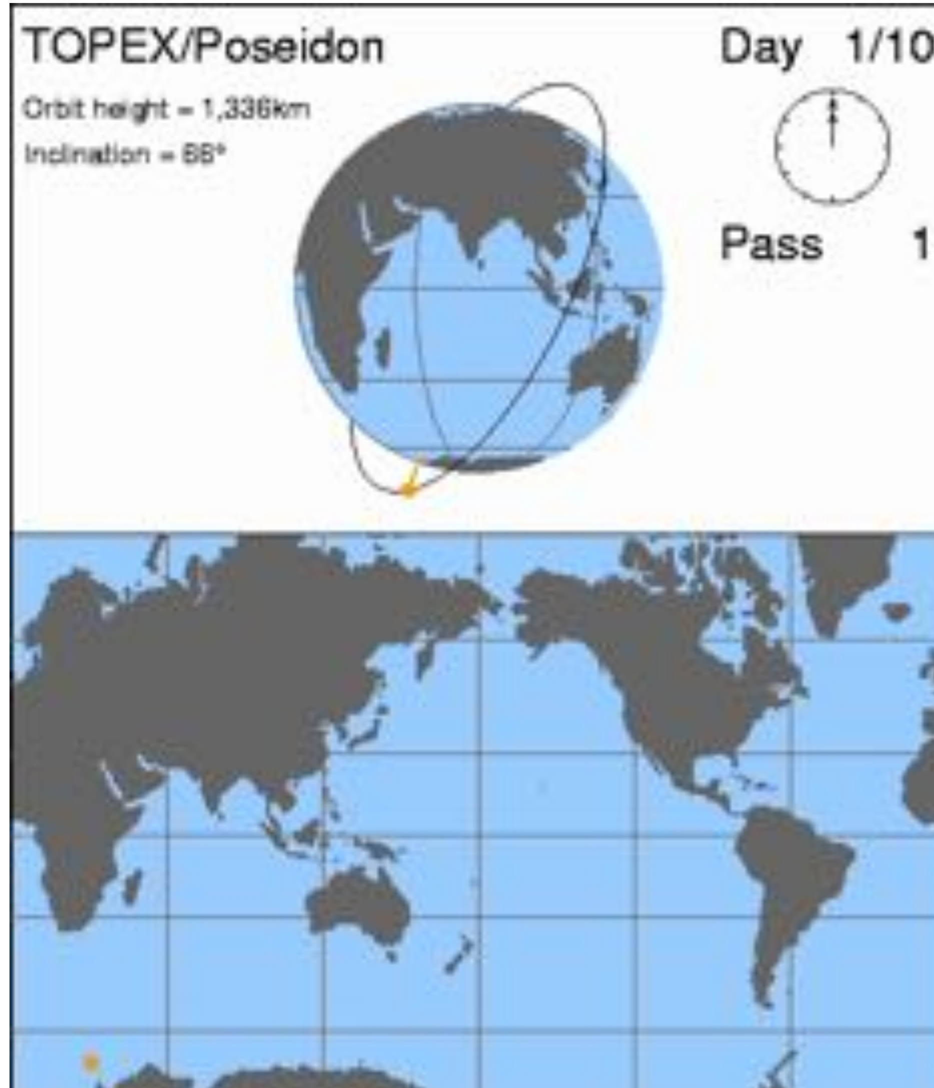
<u>How it works?</u>



13 GHz to 35 GHz

Altimetry is **not** imagery… (for now)

NB. basically altimetry data are "along-track", i.e. a narrow thread of measurements just beneath the satellite



Courtesy CSIRO

Satellite coverage

Altimetric satellites only measure perpendicularly below their orbital position ➔ ‘linear’ measurement.

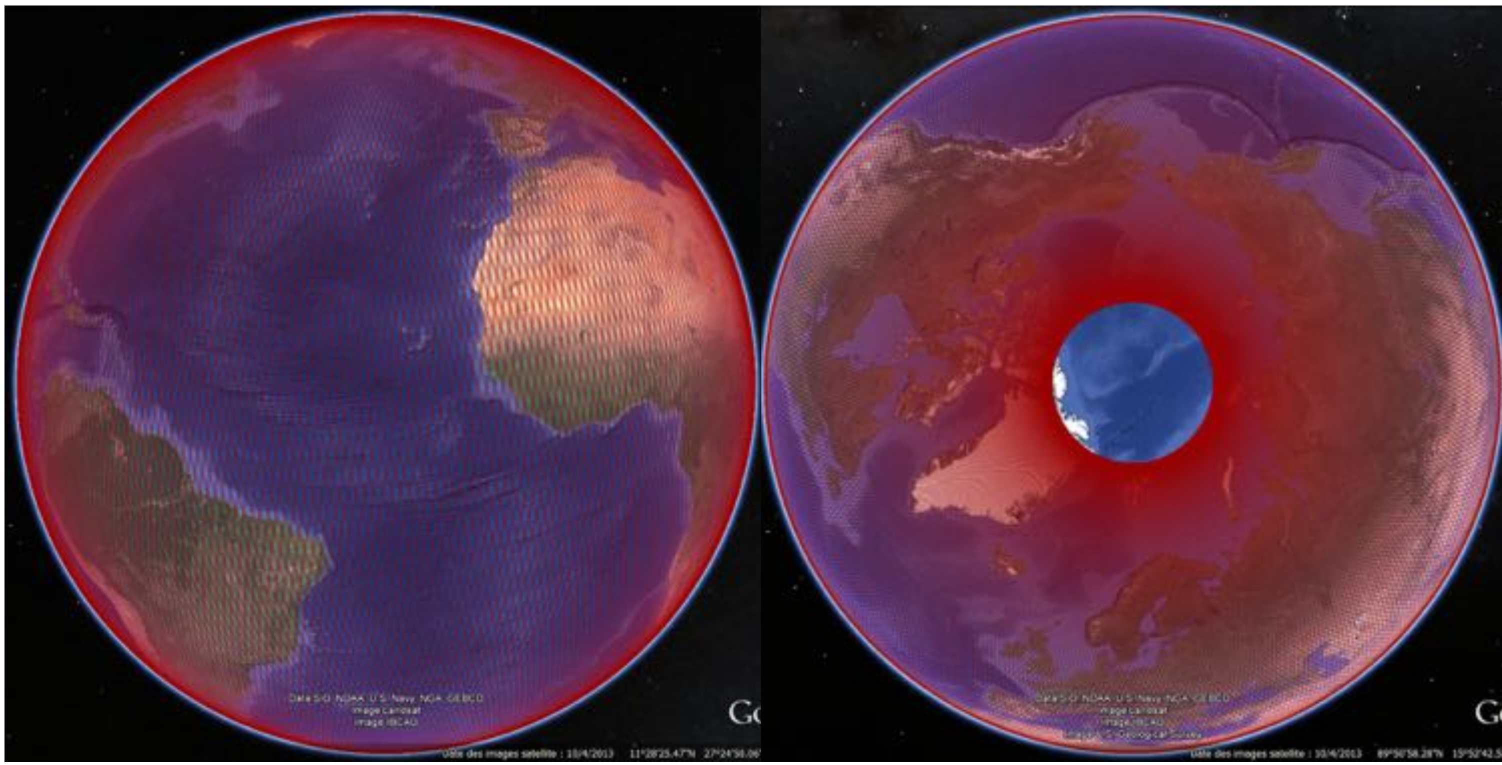
- With a single satellite the orbit parameters can be selected to improve either spatial or temporal revisit frequency:
  - Narrow spatial coverage implies that the satellite passes infrequently over the same point.
  - Frequent revisit coverage implies a broad spatial coverage.
- Several satellites making simultaneous measurements are essential for obtaining a global view of ocean dynamics.

T-P and Jason orbits:

- Priority for temporal coverage.
- 10-day revisit capability.
- Observe large-scale signals.

ERS/Envisat/Saral/ Sentinel-3 orbits:

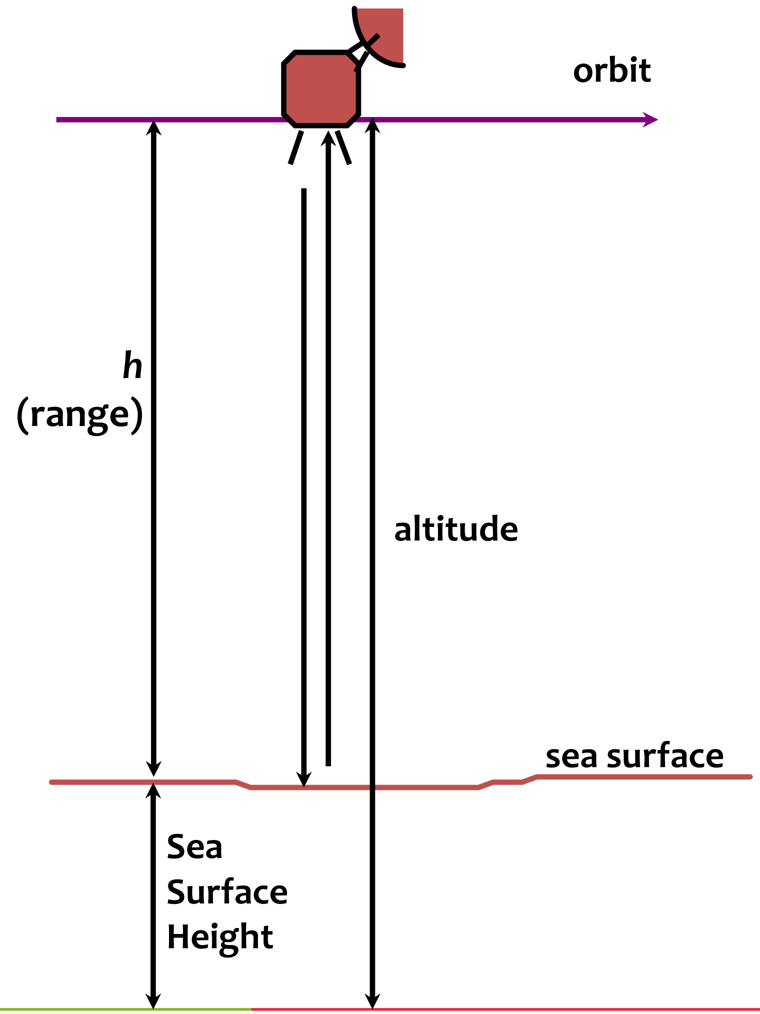
- Priority for spatial coverage.
- 35-day revisit capability (27 days for S3)
- Observe small-scale signals: eddies.



Sentinel-3 coverage

How it works? (simplified)

- Measure travel time, 2T, from emit to return
- h = T×c ($c \approx 3x10^8$ m/s)
- Sea Surface Height is the difference between h ("range") and the altitude. SSH = altitude - range



Altimetry: not "only" sea surface height

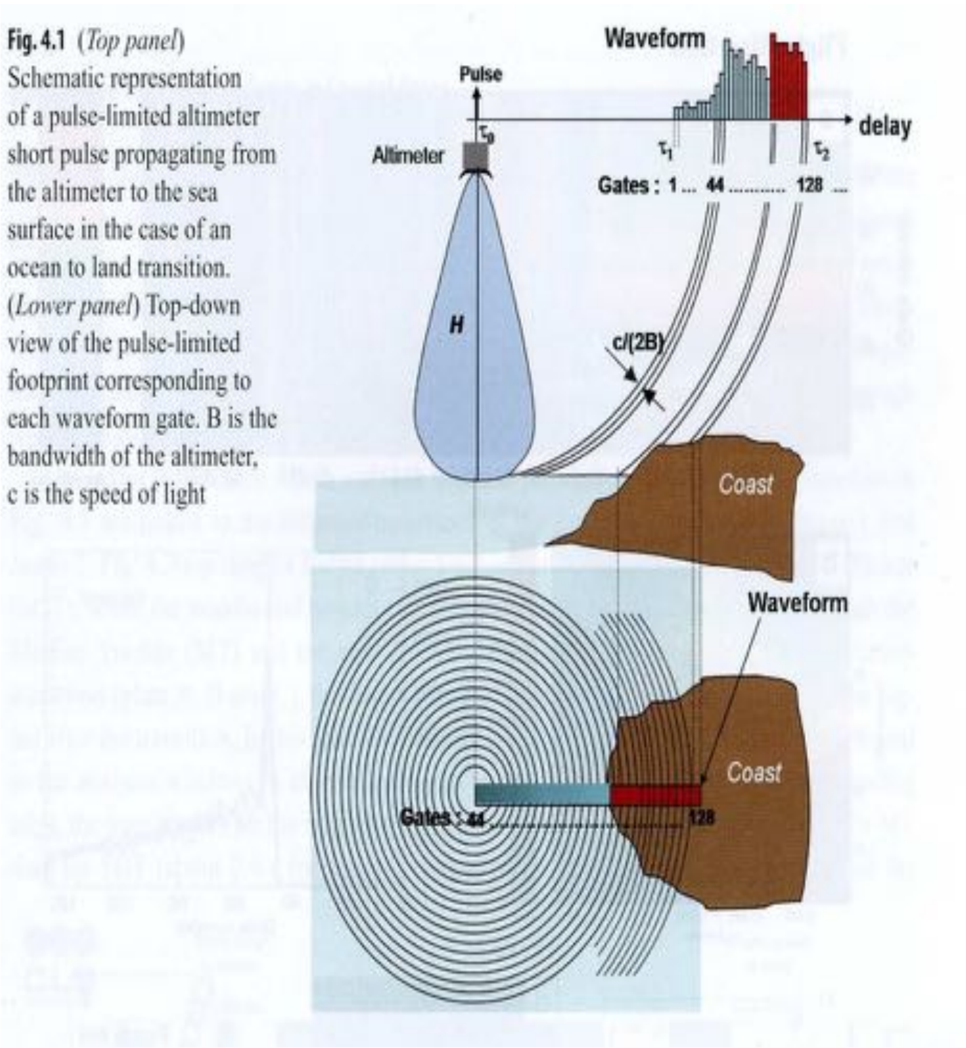
- The main output expected from altimetry is the "sea surface height" (and its variations)
  However, it is not the only one:
  - Significant **wave height** is deduced from the fact the radar wave bounces on the wave crests before the wave troughs
  - **Wind speed** is deduced from the dispersion of the radar wave
  - Other water bodies level can be measured (**lakes, rivers**… provided the satellite flies over them)
  - As well as ice (**sea ice** or **ice sheets**, provided the satellite flies over them)
  - And even some "solid land" can provide with interesting results (deserts, and snow-covered areas)

Limitations / Advantages

- Limitations
  - Resolution: measures only along the precise orbit repeat track
    ➔Merging satellite data
  - Detects only the variable signal
    ➔ An independent measure of gravity and/or mean currents is needed
  - Not fully reliable in coastal areas (improvement ongoing)
- Advantages:
  - non sensitive to clouds
  - High precision, unremitting work on product accuracy
  - Integrated measurement (the whole water column)
  - Database since 1978 (Seasat); continuous intercalibrated series since 1991 (ERS-1) / Oct. 1992 (Topex/Poseidon)
  - Almost always at least 2 simultaneous satellites since 1992

Coastal altimetry

- What is observed might be unclear (water/land mixed)
- Corrections not optimized over lands (radiometer)
- SAR altimetry much better than classical
- Processing to improve



Credits P. Thibaut, in Gommenginger et al., 2011

How it works (less simplified)

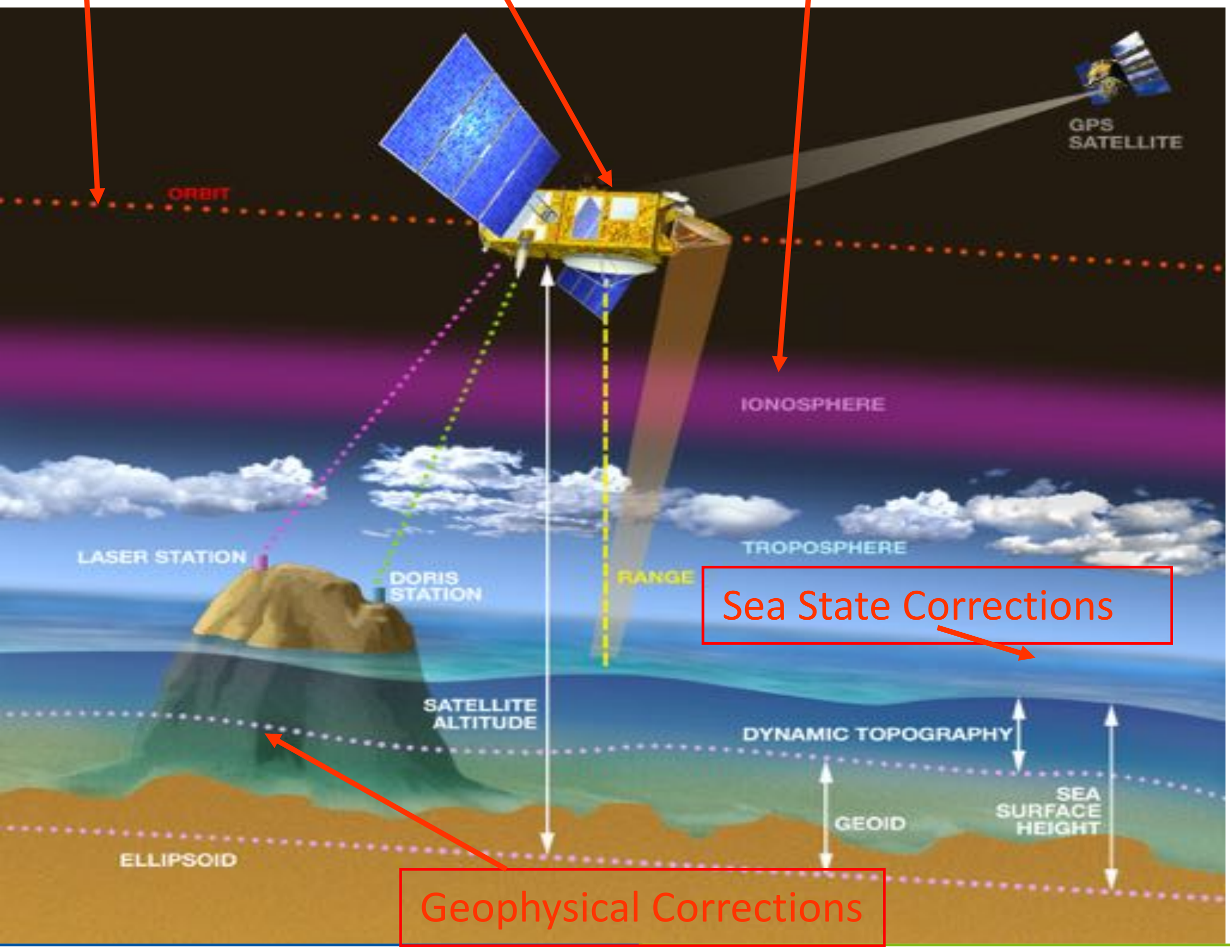
Sea Surface Height (SSH) (relative to an earth ellipsoid)= Orbit height – Range

Orbit

Instrument and Instrumental Corrections

Environnemental Corrections

SSH = Orbit – Range – Σ Corr



Corrections applied:

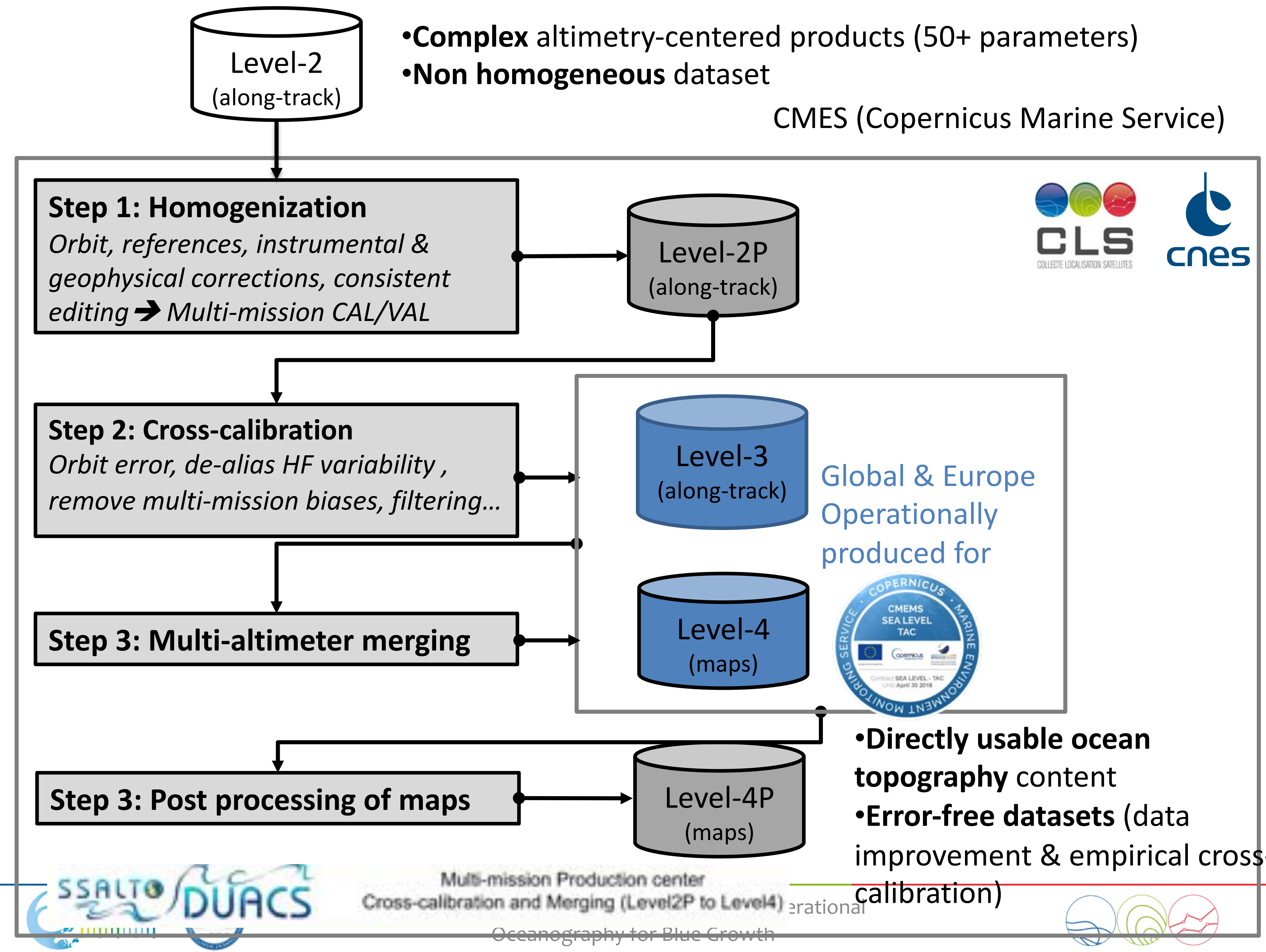
- instrumental
- water in the troposphere
- electrons in the ionosphere
- atmosphere
- atmopheric pressure (inverse barometer)
- sea state bias (wave crests and troughs)
- tides (ocean, solid Earth, pole)

- Now, you may think I've missed something, since you may have seen maps from altimetry.

  Yes. They exist.
  But they're not made directly from the measurement of one single satellite

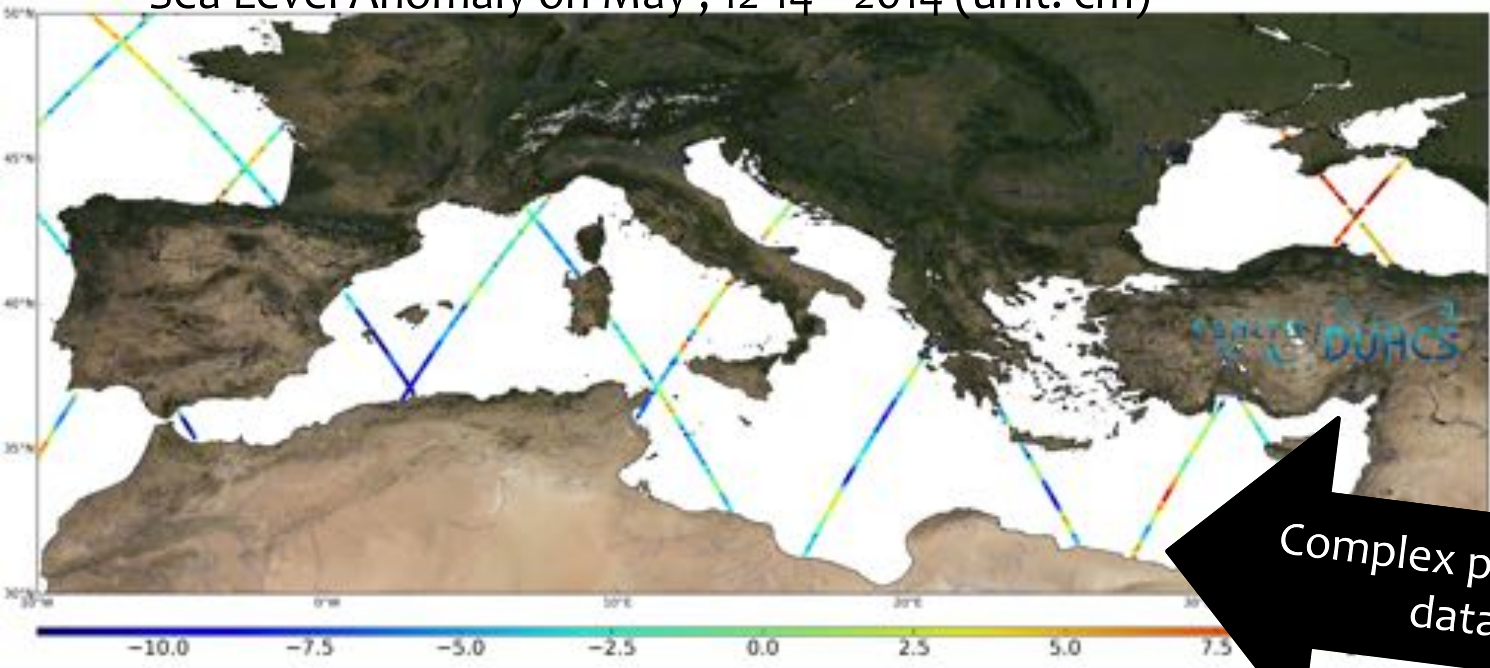
Since 1998, the Duacs processing

- In 1998 a European Commission project: Developping Use of Altimetry for Climate Studies.
  Became in 2003 part of the CNES SSALTO ground segment: Data Unification Altimeter Combination System
- An operational production system
- Two components:
  - Near Real Time: provides operational applications
  - Delayed Time: maintains a consistent record for climate applications
- Since 2008, the backbone for the Sea Level production center for the Copernicus Marine Service (CMEMS) & now also Climate Change Service (C3S)


•Complex altimetry-centered products (50+ parameters)
•Non homogeneous dataset
CMES (Copernicus Marine Service)
Level-2 (along-track)
Step 1: Homogenization
Orbit, references, instrumental & geophysical corrections, consistent editing → Multi-mission CAL/VAL
Level-2P (along-track)
CLS
COLLECTE LOCALISATION SATELLITES
cnes
Step 2: Cross-calibration
Orbit error, de-alias HF variability , remove multi-mission biases, filtering…
Level-3 (along-track)
Global & Europe Operationally produced for
Level-4 (maps)
COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE
CMEMS SEA LEVEL TAC
Step 3: Multi-altimeter merging
Step 3: Post processing of maps
Level-4P (maps)
•Directly usable ocean topography content
•Error-free datasets (data improvement & empirical cross-calibration)
SSALTO DUACS
Multi-mission Production center
Cross-calibration and Merging (Level2P to Level4)
Oceanography for Blue Growth

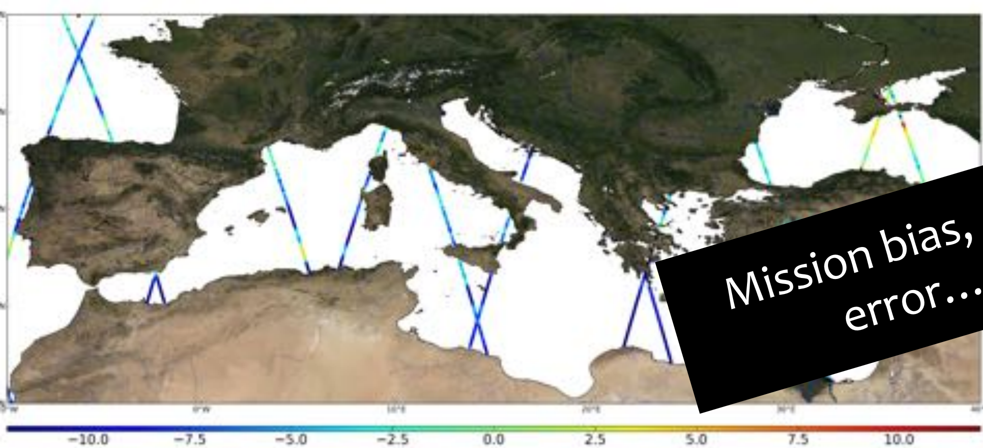
Homogeneization and Cross-calibration

Sea Level Anomaly on May , 12-14th 2014 (unit: cm)

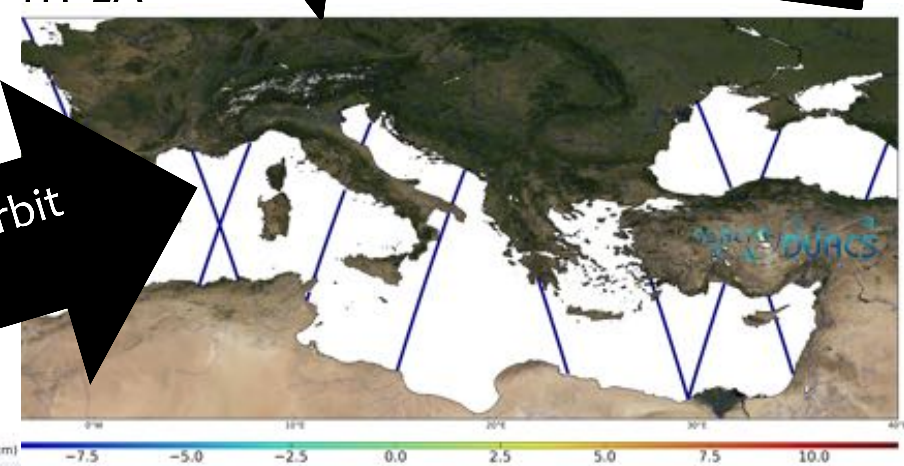


Jason-2

Saral



HY-2A

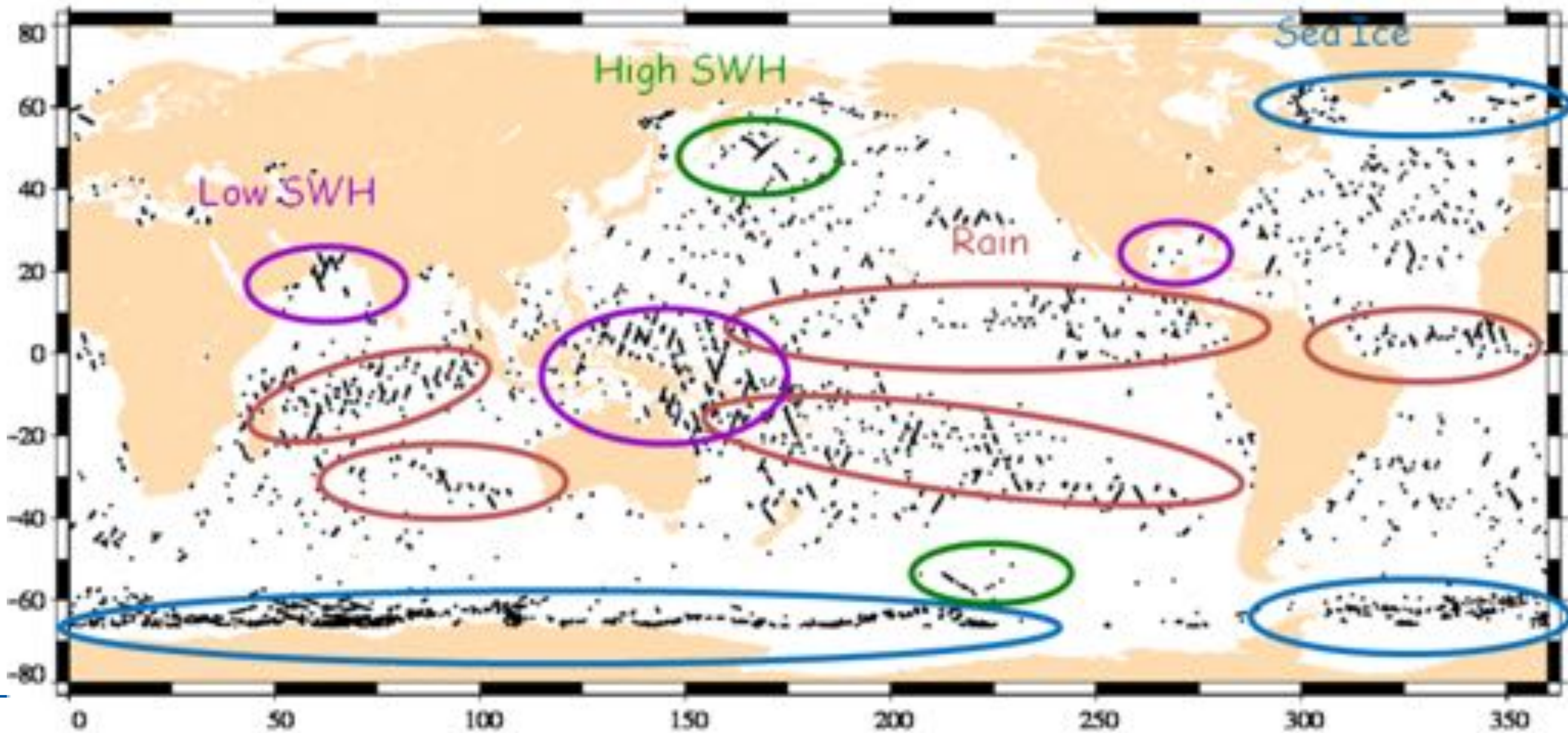


- exercise:
  00_dataDownload.ipynb
  04_L3 along-track.ipynb
  04_SWH L3 along-track.ipynb

  Retrieve data on CMEMS servers
  Look at intercalibrated along-track data;
  Select an area and save it in a file
  Look at SWH from altimetry data

Step 1: Homogenization

Editing: detect and remove the erroneous measurements. This a **critical process**!
•Various algorithm applied
•Automated editing tuned for open ocean application => reject a small % of the dataset

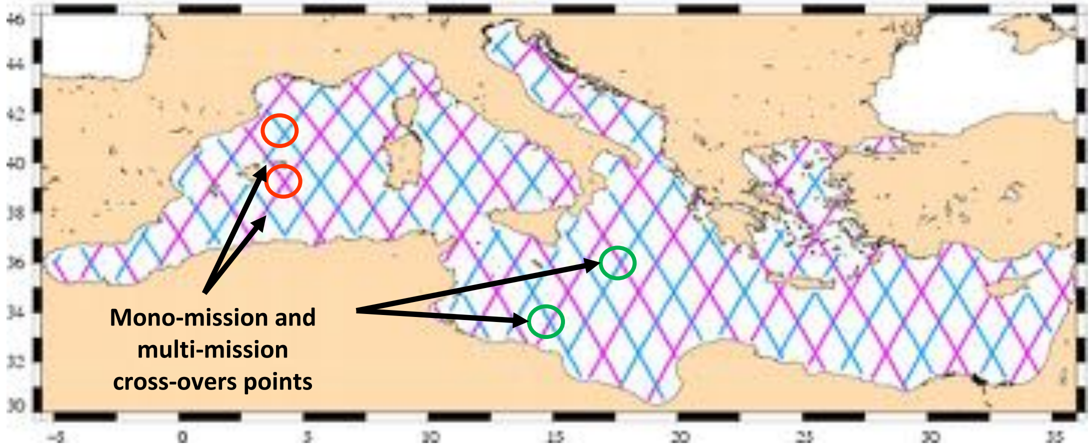


Step 2: Cross-calibration

Step 2a : Reduction of the crossover differences

•**Purpose** : Reduce orbit error and ensure coherence between different altimetric missions by using the most accurate mission as a reference to correct the others.

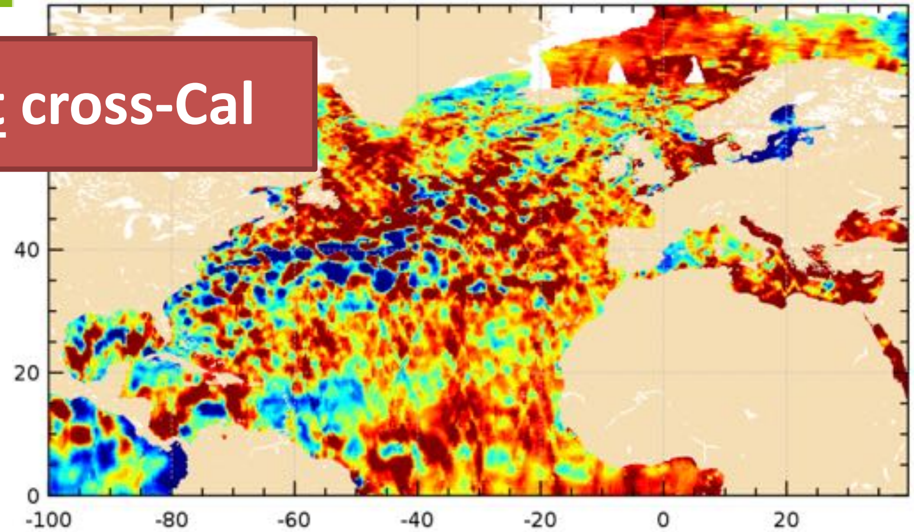
•**Method** : Estimation of errors with a cubit-spline estimator *(Le Traon and al., 1995, JAOT 12)*



At a same point (crossover) and within less than 5 days, the difference in measured SLA is considered as a mono-mission or multi-mission orbit error. Smooth cubic-spline functions provide a continuous estimation of the orbit error over time.

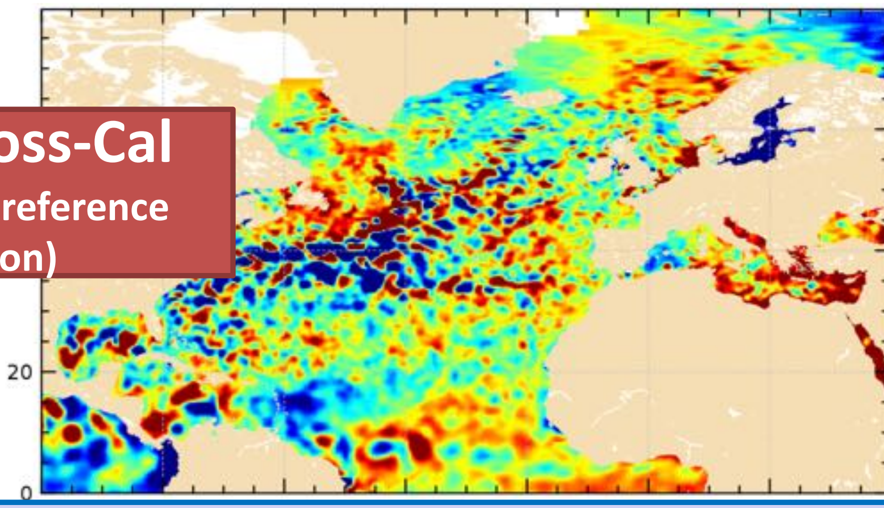
Step 2: Cross-calibration

Without cross-Cal



Maps of sea level anomalies from altimetry satellites on February 2013 Using Jason-2 and Cryosat (CPP)

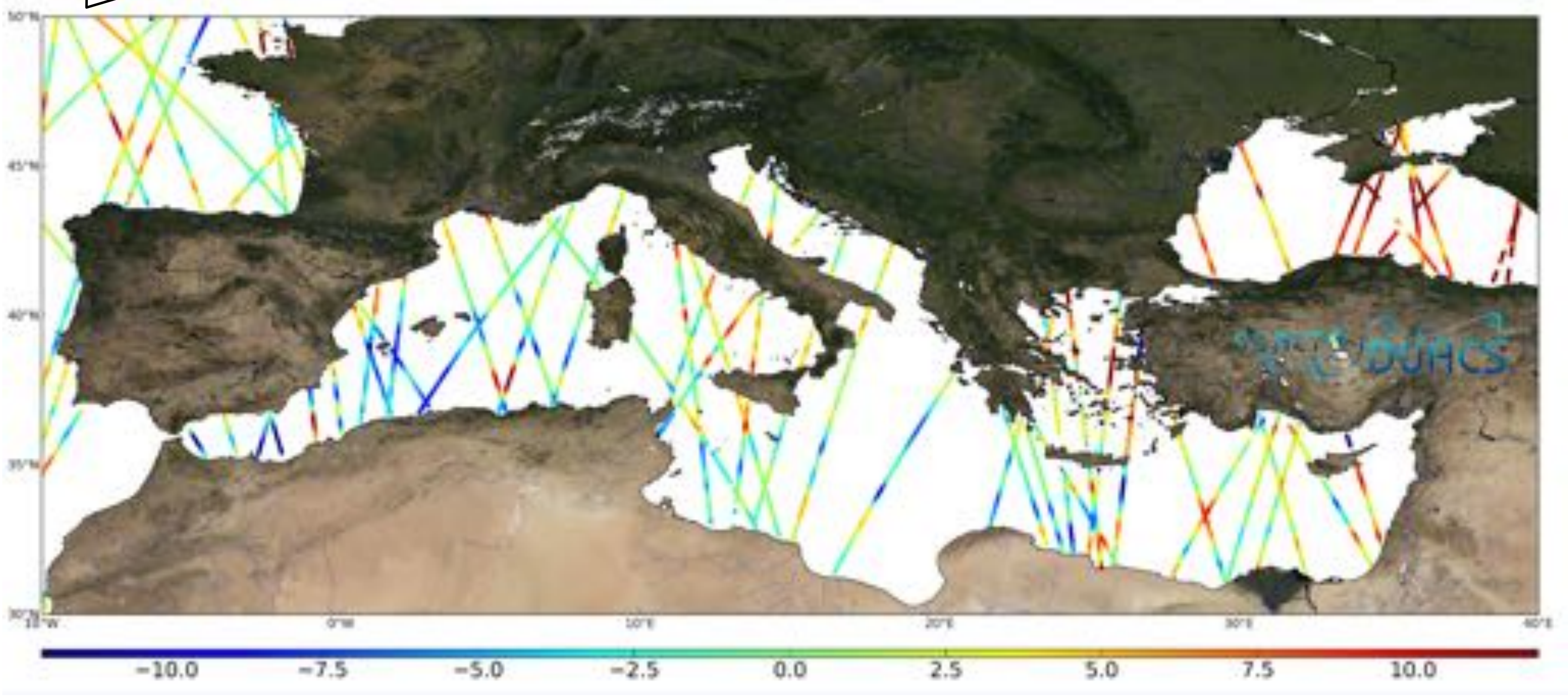
With cross-Cal
(Jason-2 as reference mission)



Detection and monitoring of centimeter-level uncertainty at basin scale and monthly scale needed to be **minimized optimally** in DUACS

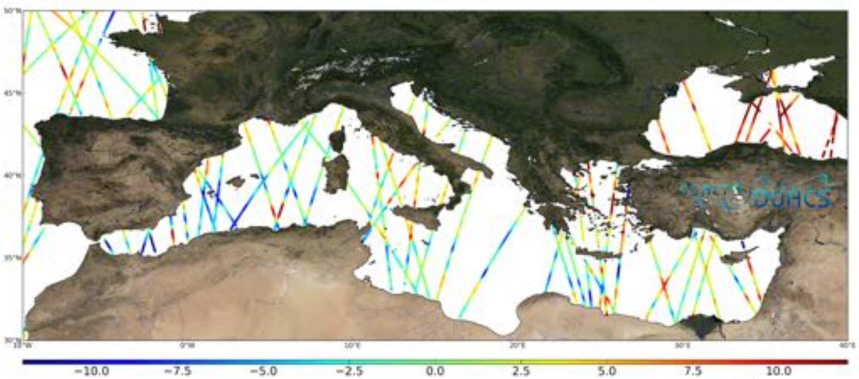
Homogeneization and Cross-calibration

Assimilating L3 in ocean models is straightforward (content directly usable)



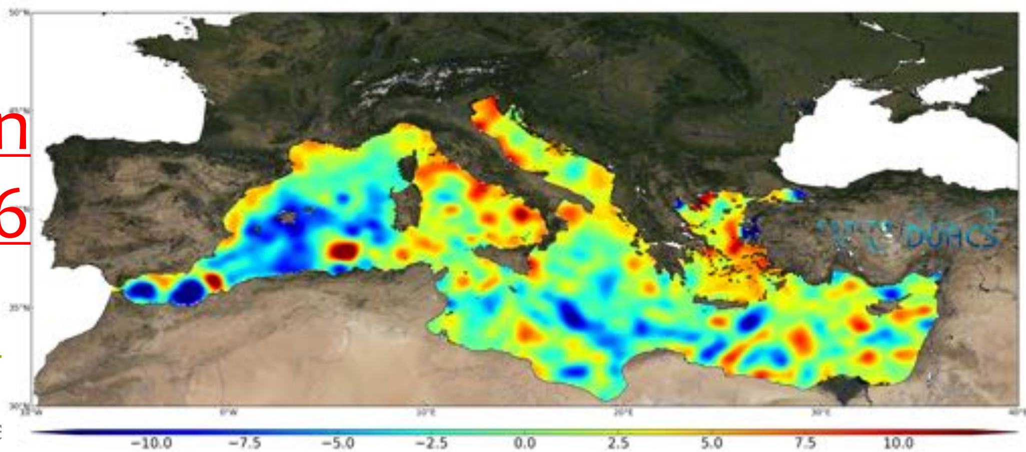
Multi-altimeter merging

- Goal of the mapping procedure:
  Construct a **regular-gridded** data set merging along-track SLA data from different altimetry missions, taking into account the errors due to the measurement imperfections
- Multimission merging is based on an **optimal interpolation** using an a priori knowledge of the covariance of the sea level and the measurement errors



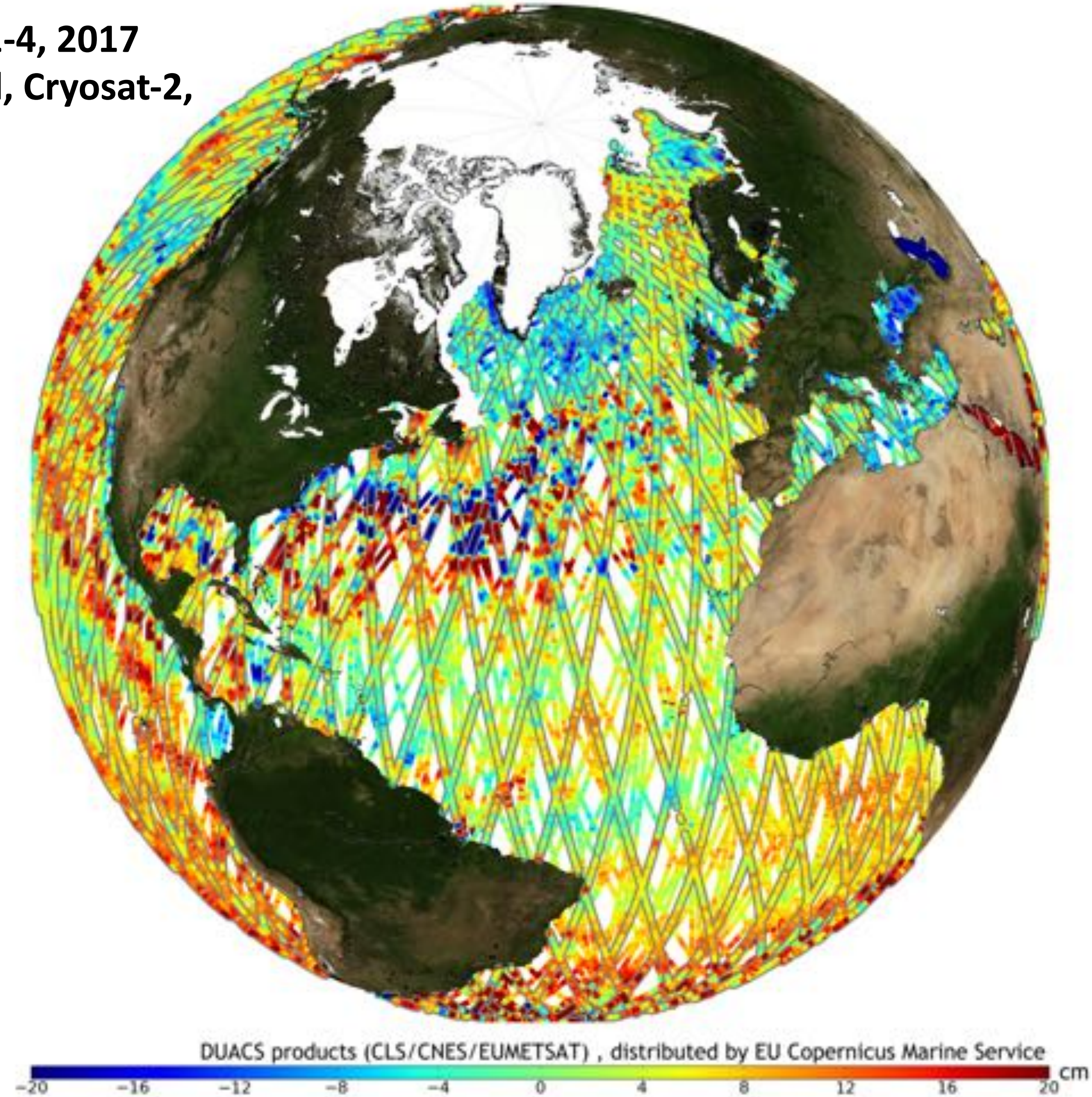
Optimal interpolation method

Le Traon et al., 1998; Le Traon&Dibarboure, 1999; Ducet et al. 2000;

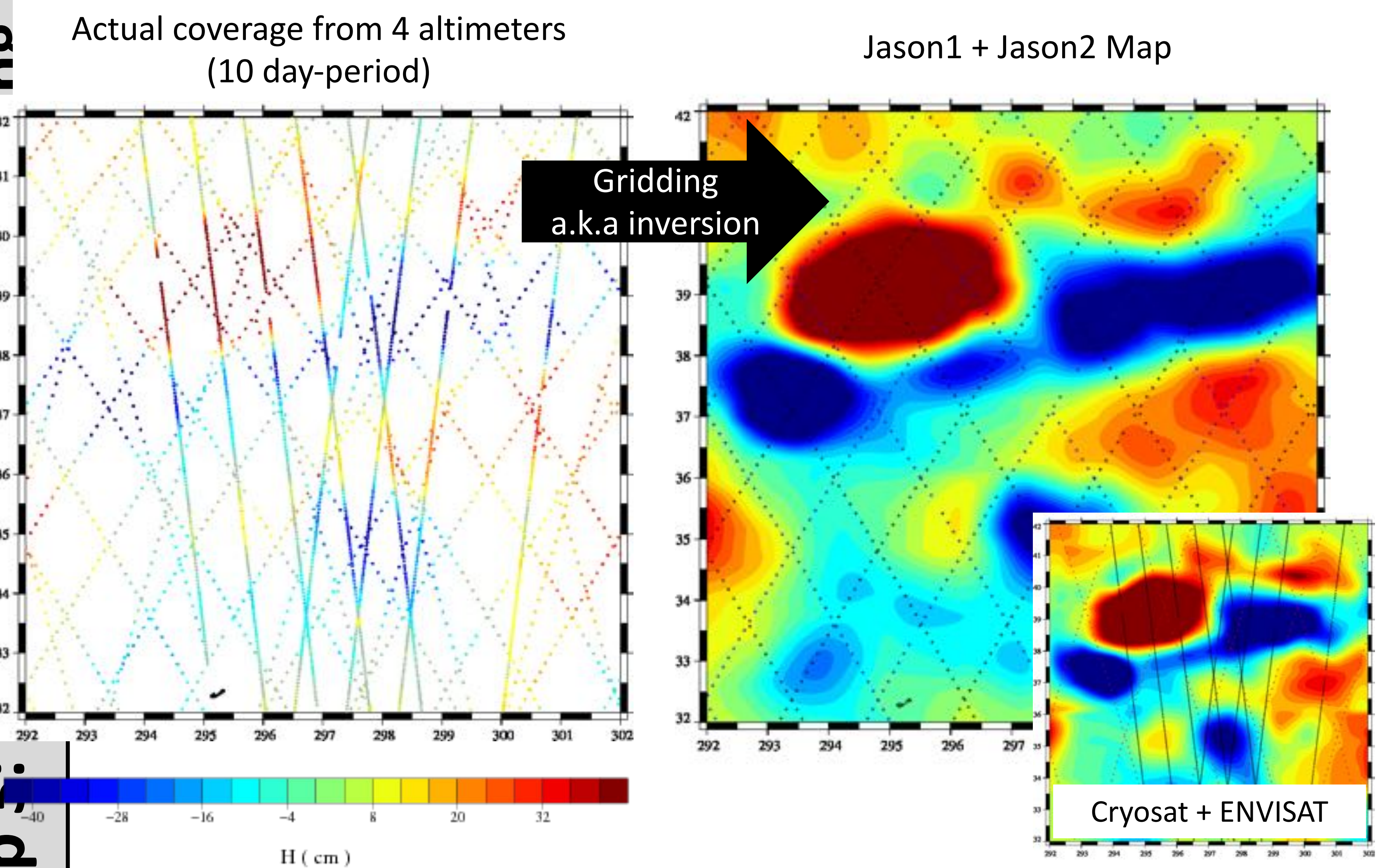


NB. gridded data available in CMEMS by mid-January 2016

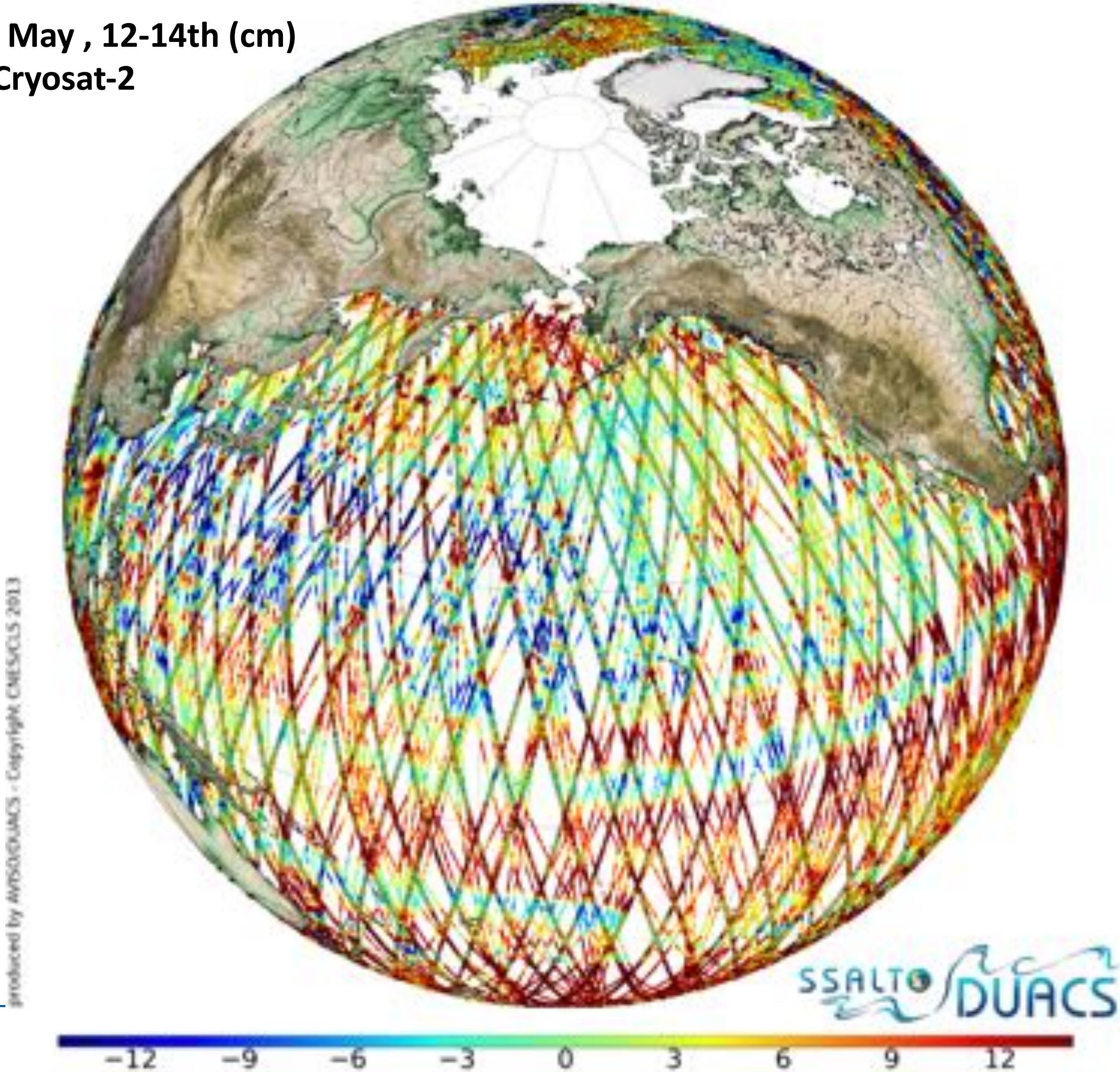
Sea Level Anomaly on March 1-4, 2017 From Sentinel-3, Jason-3, Saral, Cryosat-2, Jason-2



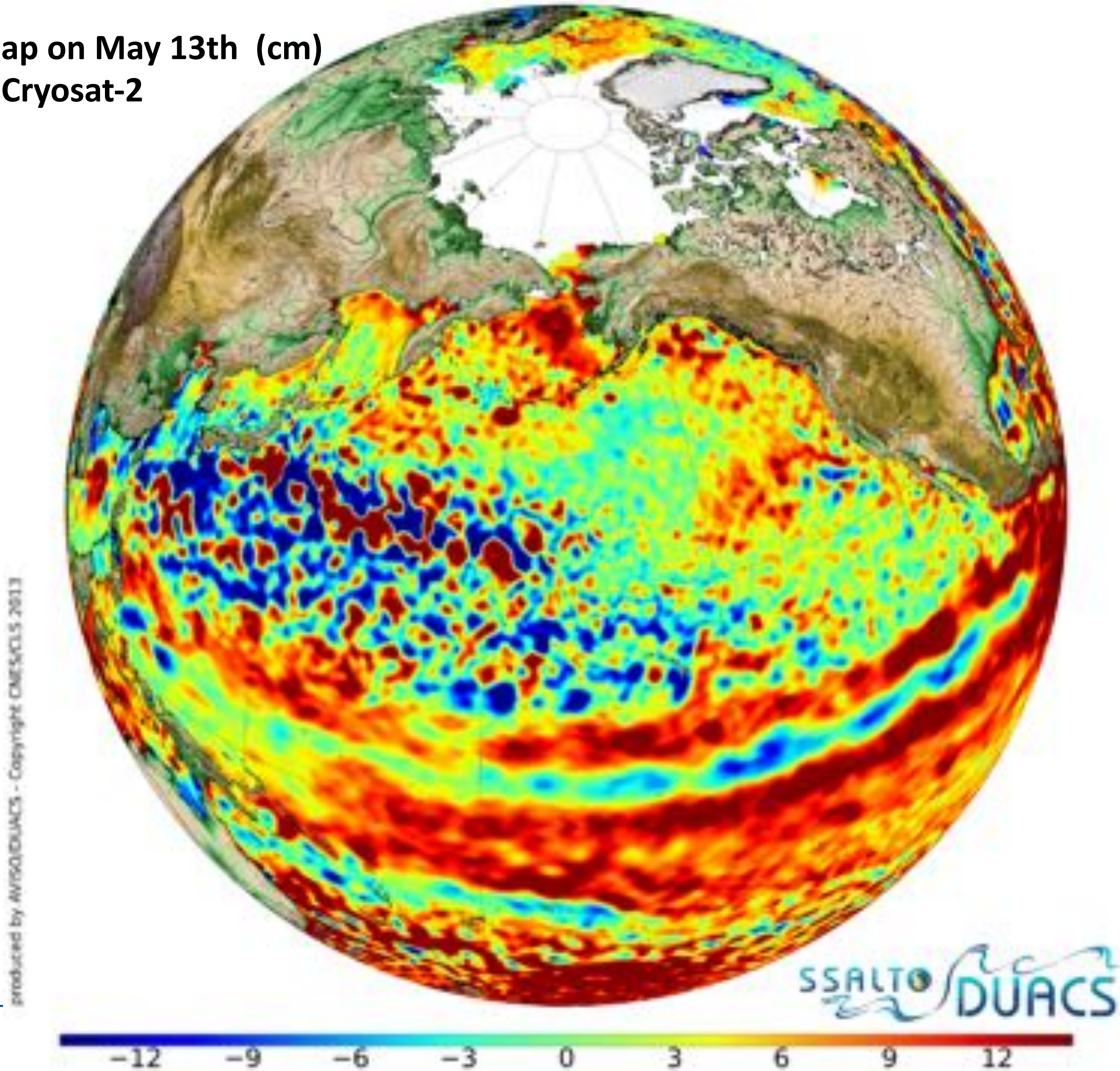
Step 3: Multi-altimeter merging



Sea Level Anomaly on May , 12-14th (cm)
From Jason-2, Altika, Cryosat-2
and HY2A

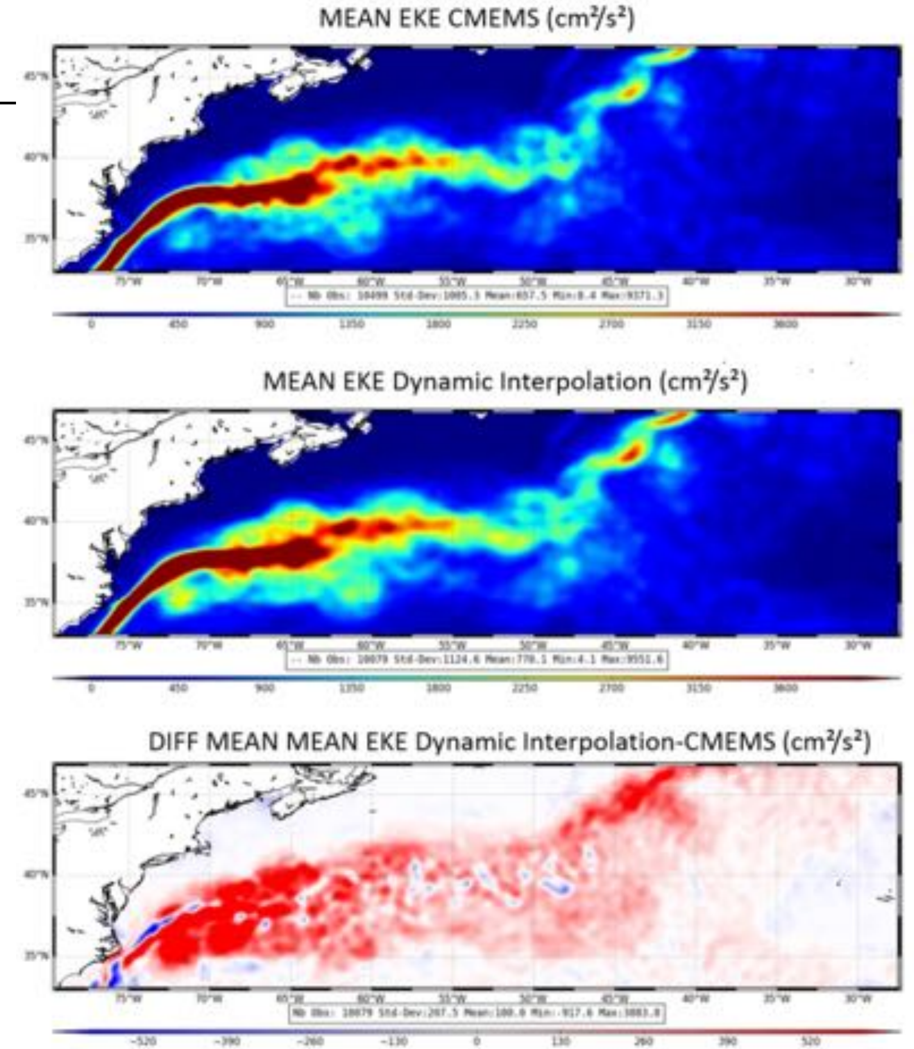


Sea Level Anomaly Map on May 13th (cm)
From Jason-2, Altika, Cryosat-2
and HY2A



Perspectives

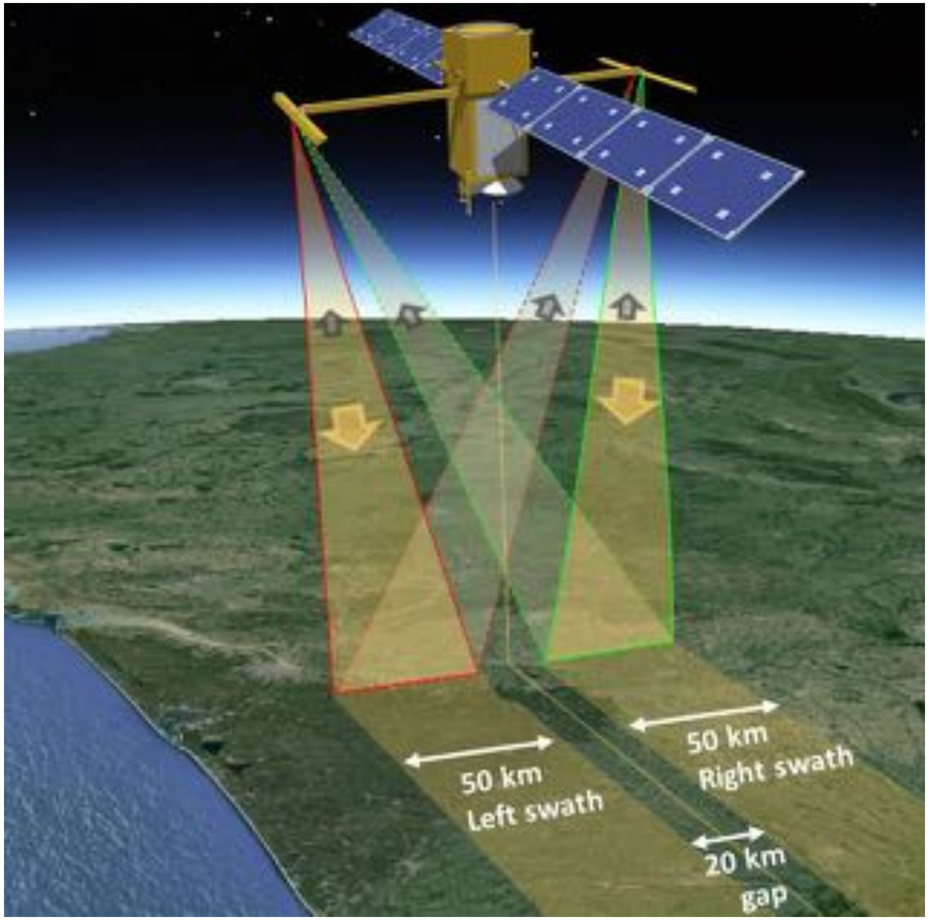
- new experimental Duacs products on Aviso (Cnes) center, making the most of Sentinel-3 capabilities
- Derived products & experimental ones
- Next challenge: Swot satellite (2021)



mean Eddy Kinetic Energy (EKE) [12/04/2014-31/12/2015] : operational (top), new experimental computed with Dynamic Interpolation (middle) and the difference between the two (bottom) where red color indicates areas of higher energy. Credits CNES/CLS. (www.aviso.altimetry.fr)

SWOT: altimetry will be imagery in 2021

- Surface Water and Ocean Topography
- Nasa/Cnes/UKSA/CSA
- Swath interferometer, with a nadir (classical) altimetry in the middle
- Coastal abilities
- Launch planned in April 2021



- exercise:
  05_L4 grids.ipynb
  use and plot some gridded files

- exercise:
  06_using grids.ipynb
  06_using grids-geostr_vel.ipynb
  compute some things with those grids