Satellite Altimetry – and recent advances towards the coast

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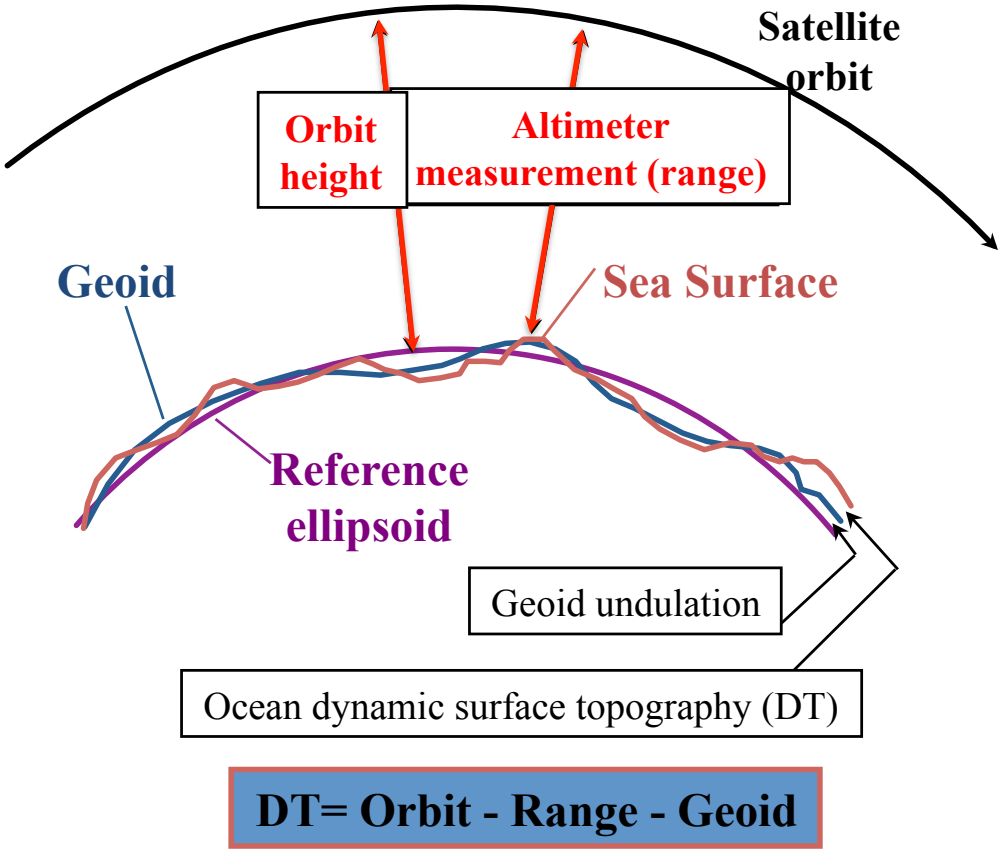
Basic Principles of Altimetry

- The altimeter is a radar at vertical incidence
- The signal returning to the satellite is from quasi-specular reflection
- Measure distance between satellite and sea (**range**)
- Determine position of satellite (precise **orbit**)
- Hence determine **height** of sea surface (absolute if **geoid** is known, otherwise relative)
- also measures **waves** and **wind**



“Retracking” of the radar waveforms

= fitting the radar echoes (waveforms) with a waveform model,
→ we estimate the three fundamental parameters

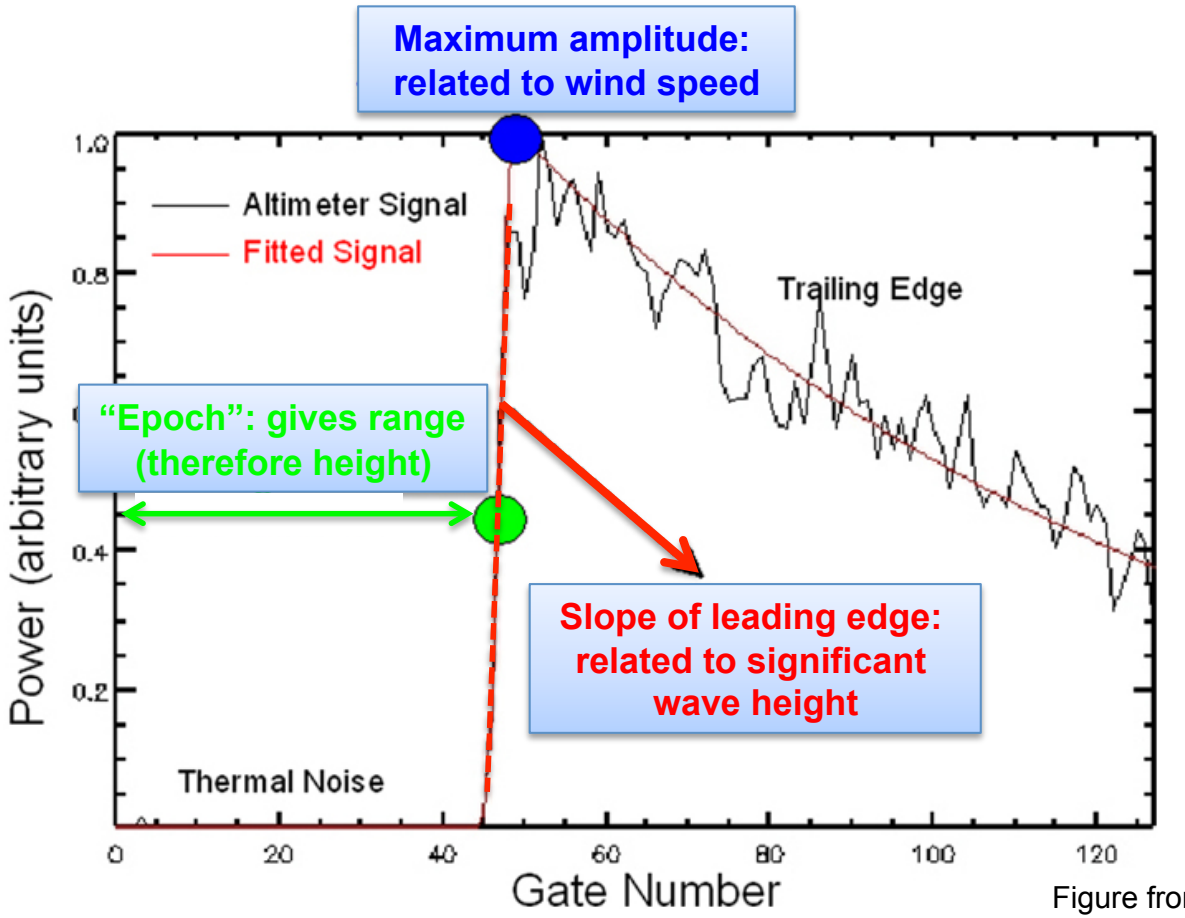
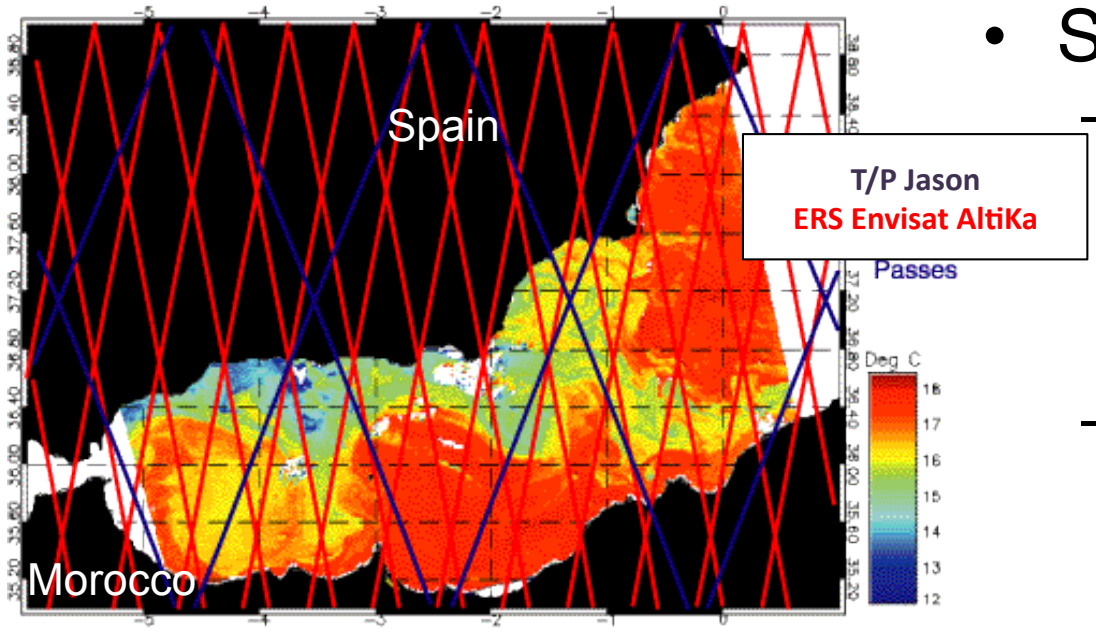


Figure from J Gomez-Enri et al. (2009)

Satellite Altimetry: a mature technique

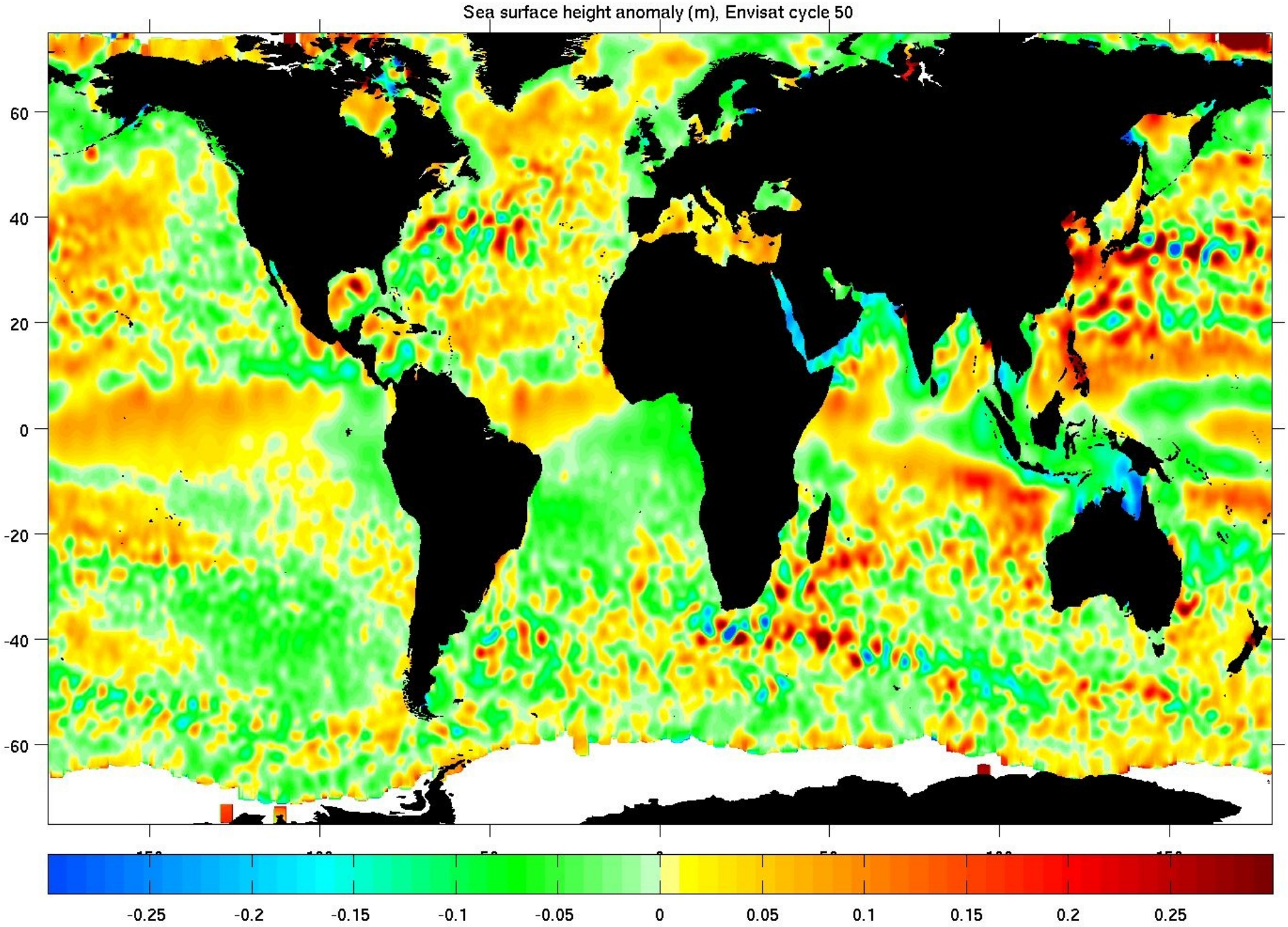
- workhorse of operational forecasting systems – extensively used
  - (but there are still research issues to be resolved for the assimilation)
- 23 years of good quality data
- use for climate studies (long-term **sea level rise**): ESA Climate Change Initiative
- precise (i.e. repeatable) and accurate (i.e. small biases)
- even more impetus from technological advances:
  - **SAR altimetry from CryoSat-2 (2010–), Sentinel-3 A/B/C/D (forthcoming), Sentinel-6 (2018)**
  - **Ka-band altimetry from AltiKa (2013–)**

Sea Surface Height

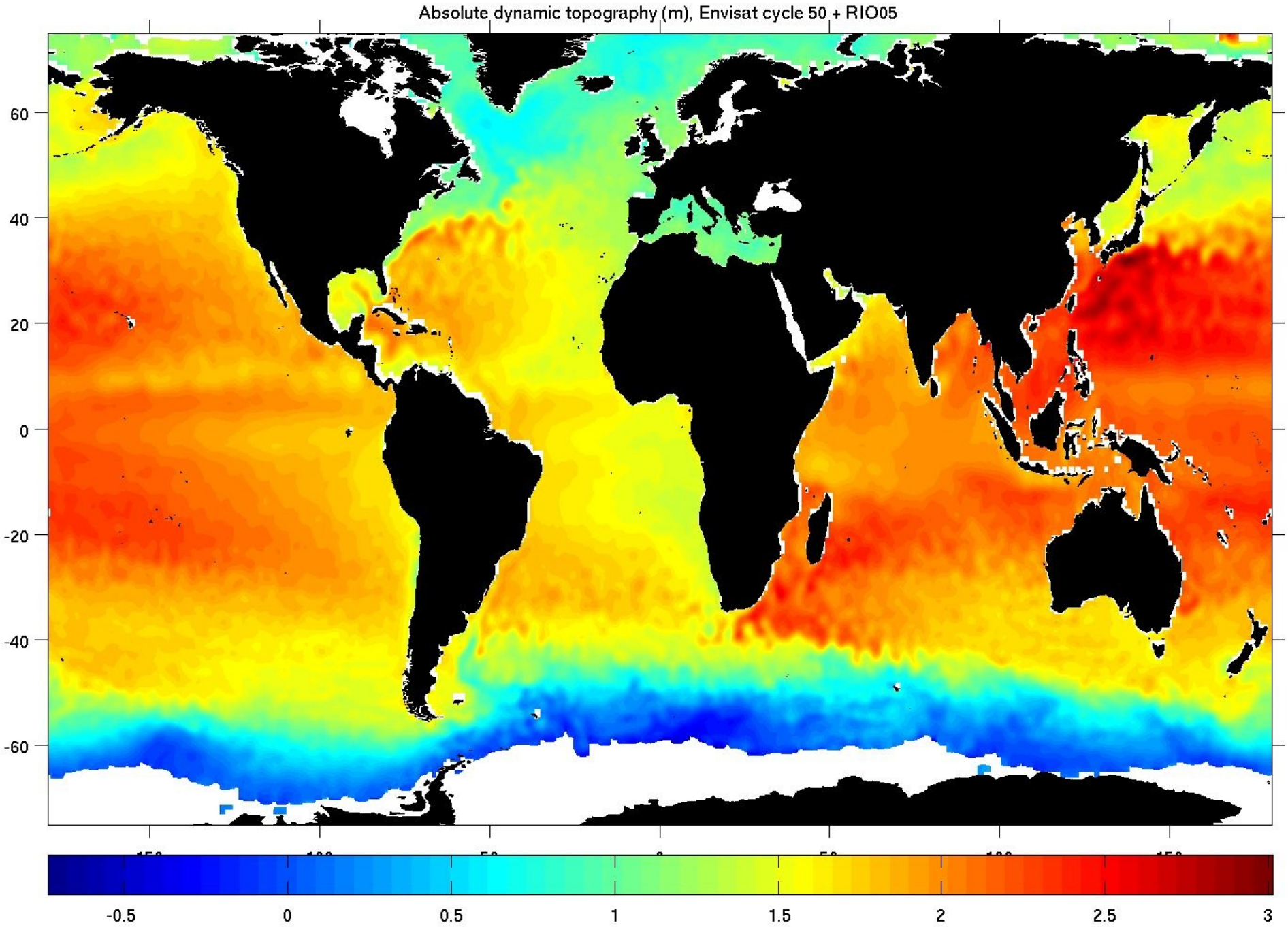


- SSH for ocean currents
  - SSH anomaly assimilated along-track in most operational ocean systems
    - FOAM/NEMO, ECMWF, Mercator
  - Fast delivery & dense time/ space sampling essential
    - Mesoscale eddies & fronts

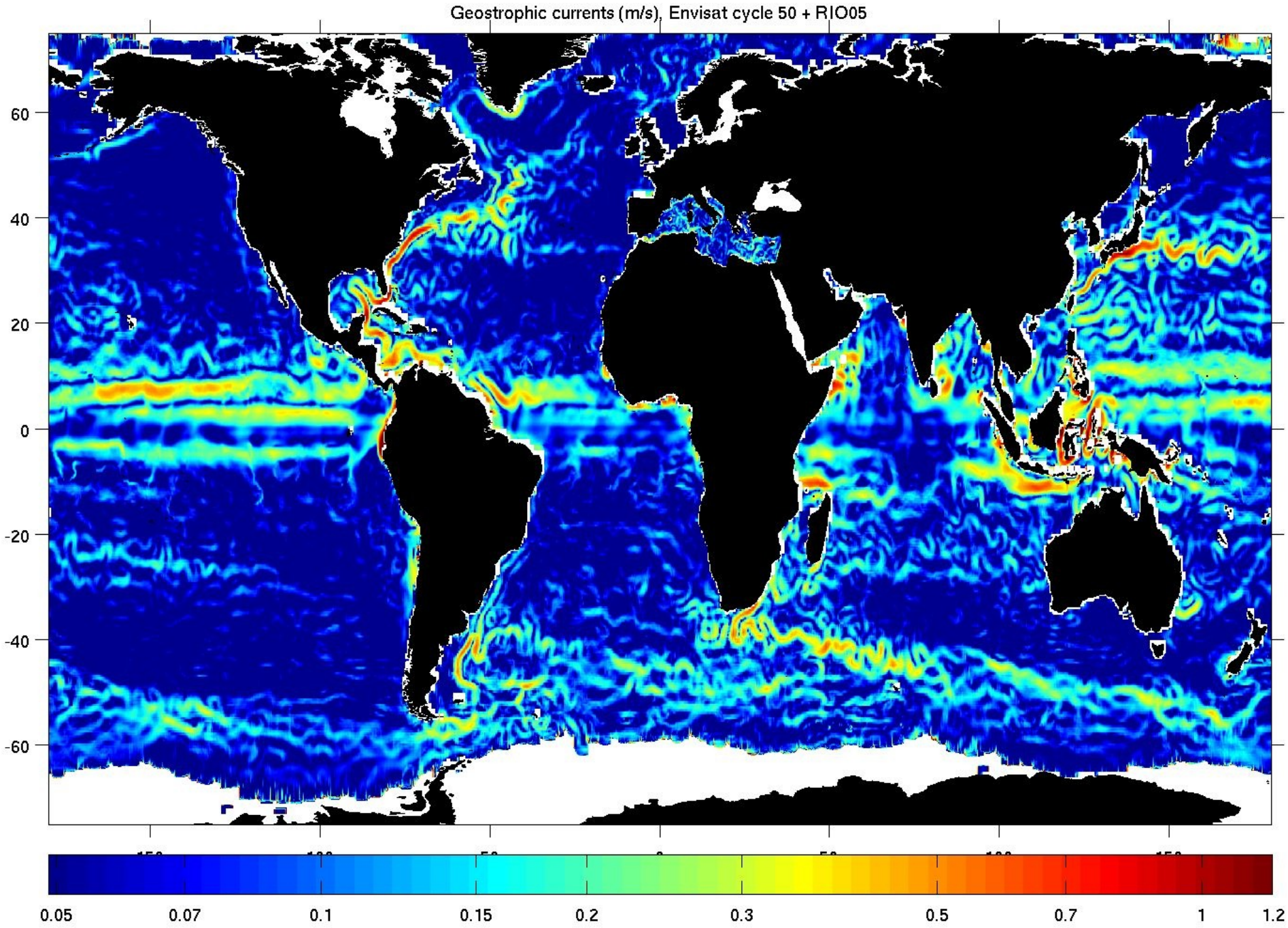
SEA LEVEL ANOMALY



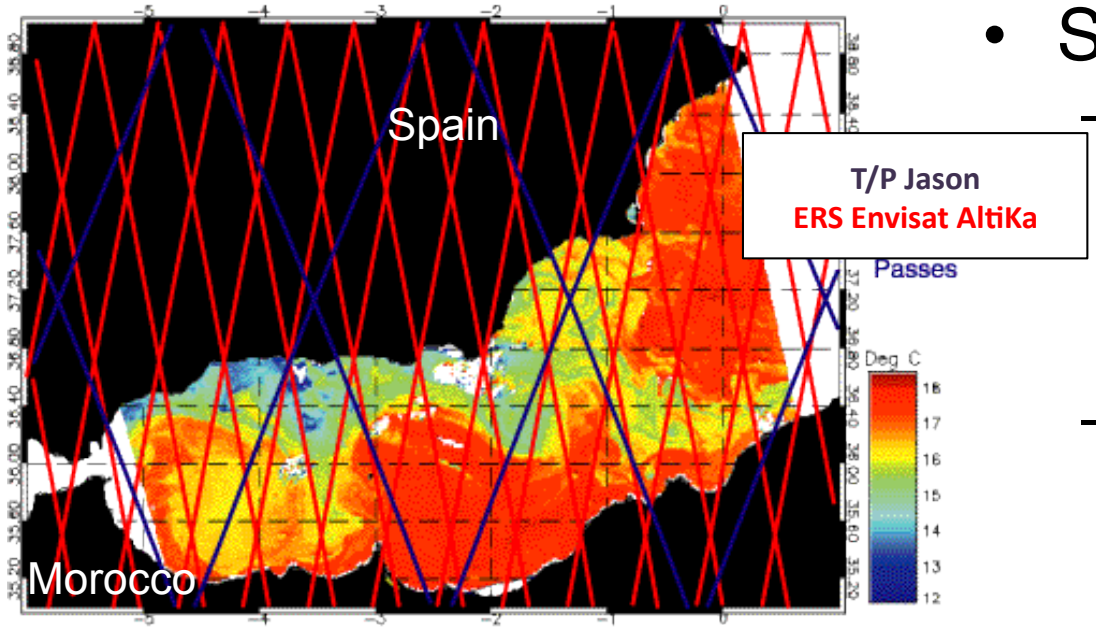
ABSOLUTE DYN TOPO



SURFACE CURRENTS



Sea Surface Height



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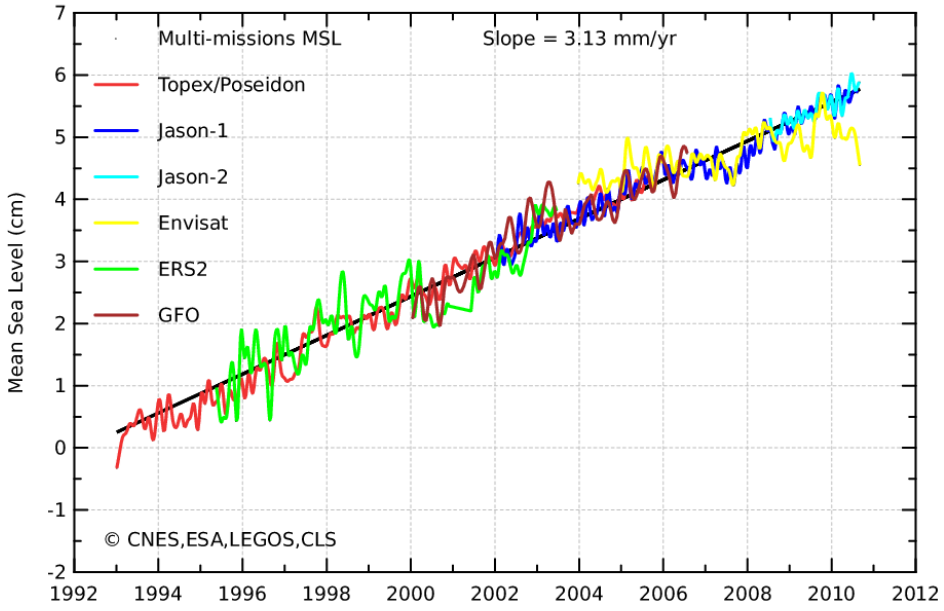
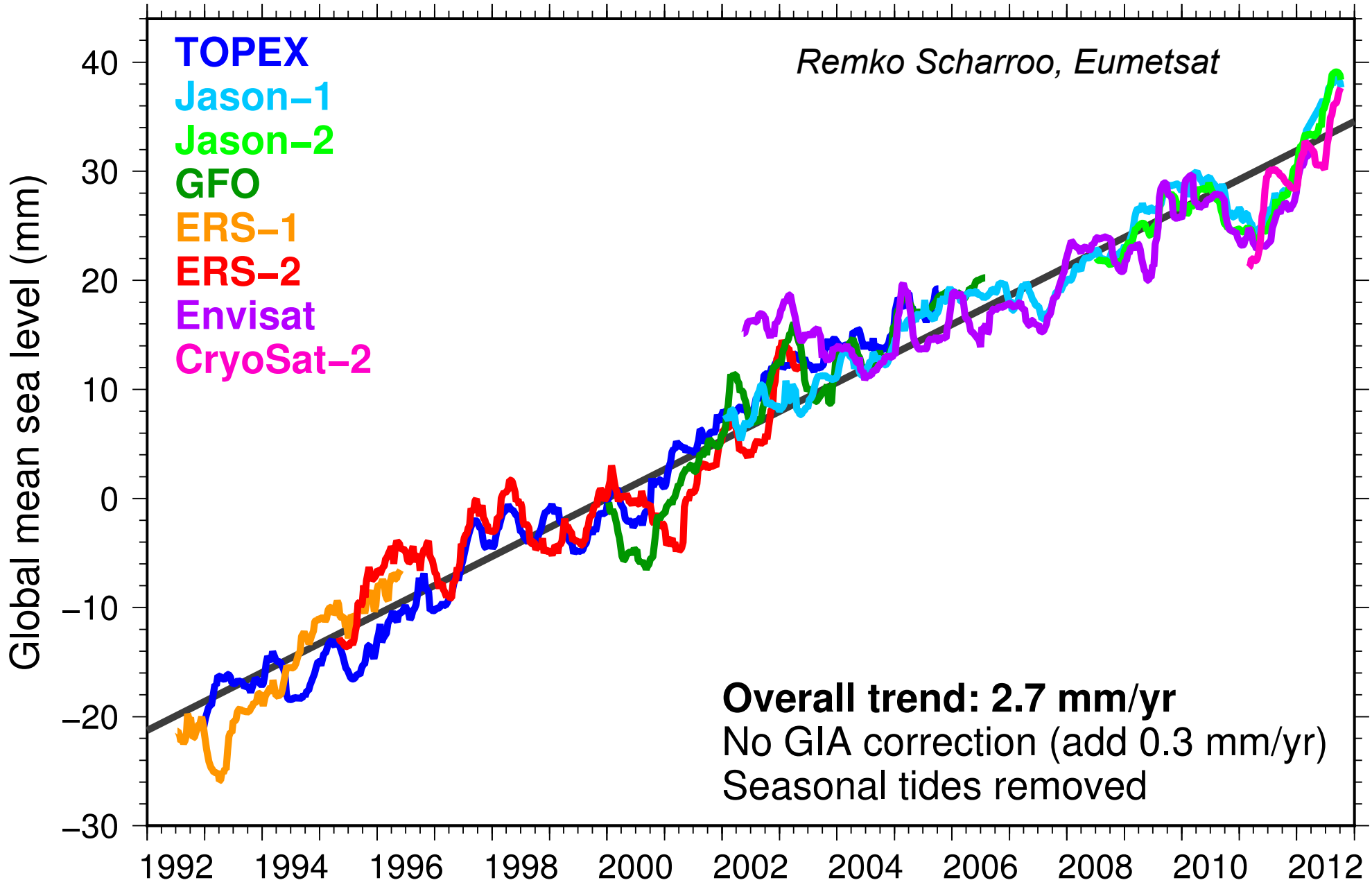
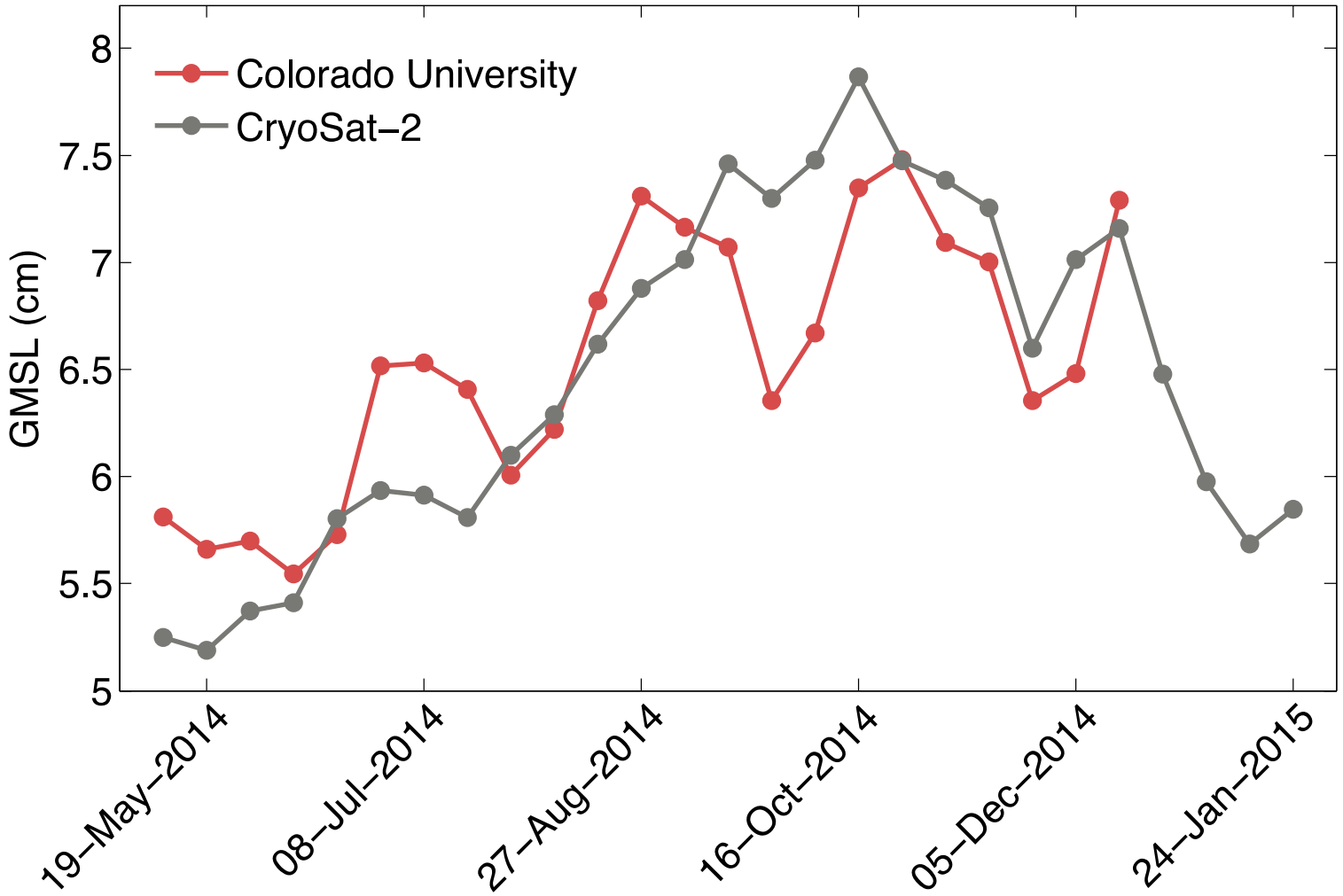
- SSH for sea level
  - Long-term trends
    - globally and regionally
  - Multi-mission
    - Continuity, redundancy and stability



SEA LEVEL RISE - global

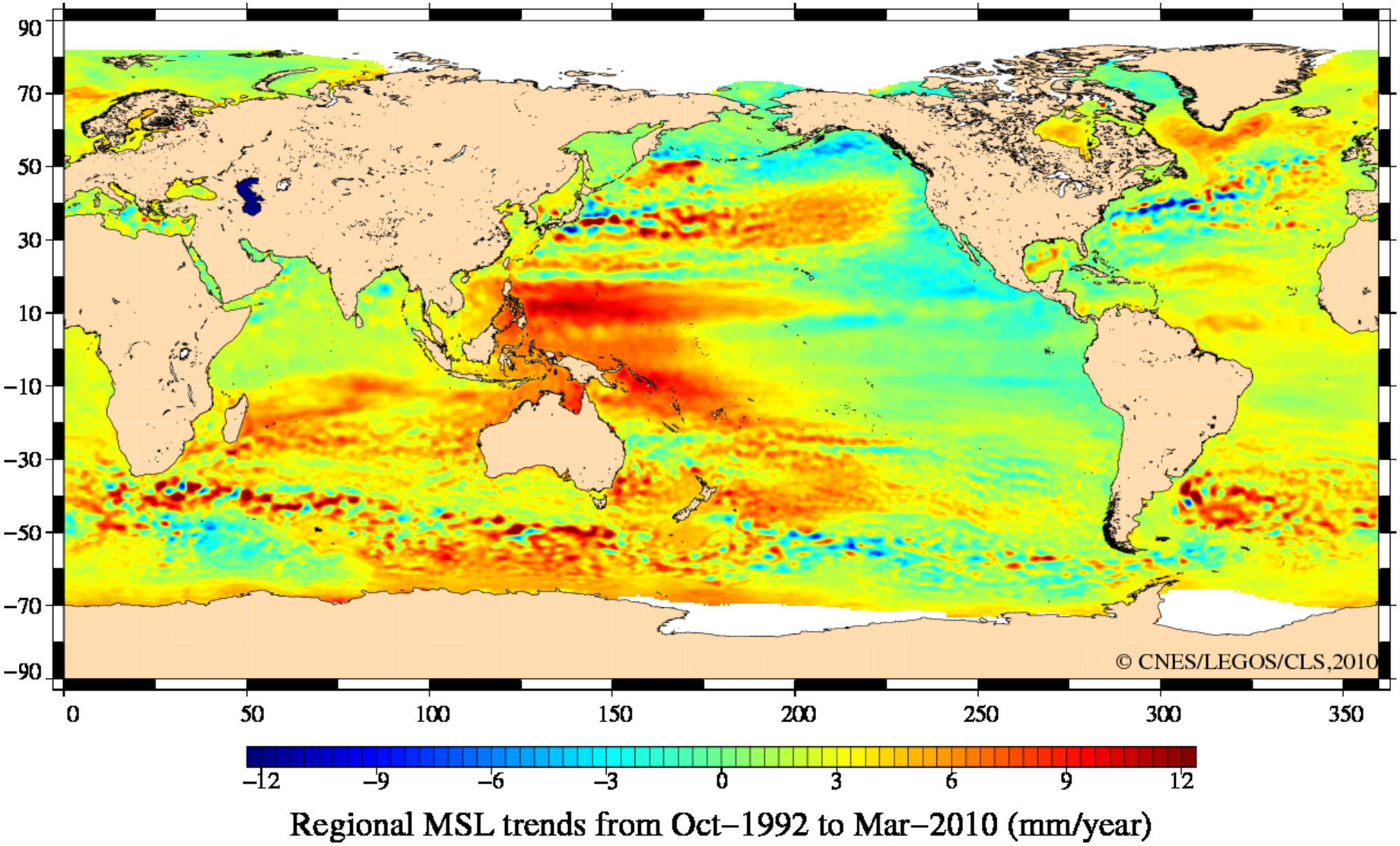


Recent global mean sea level

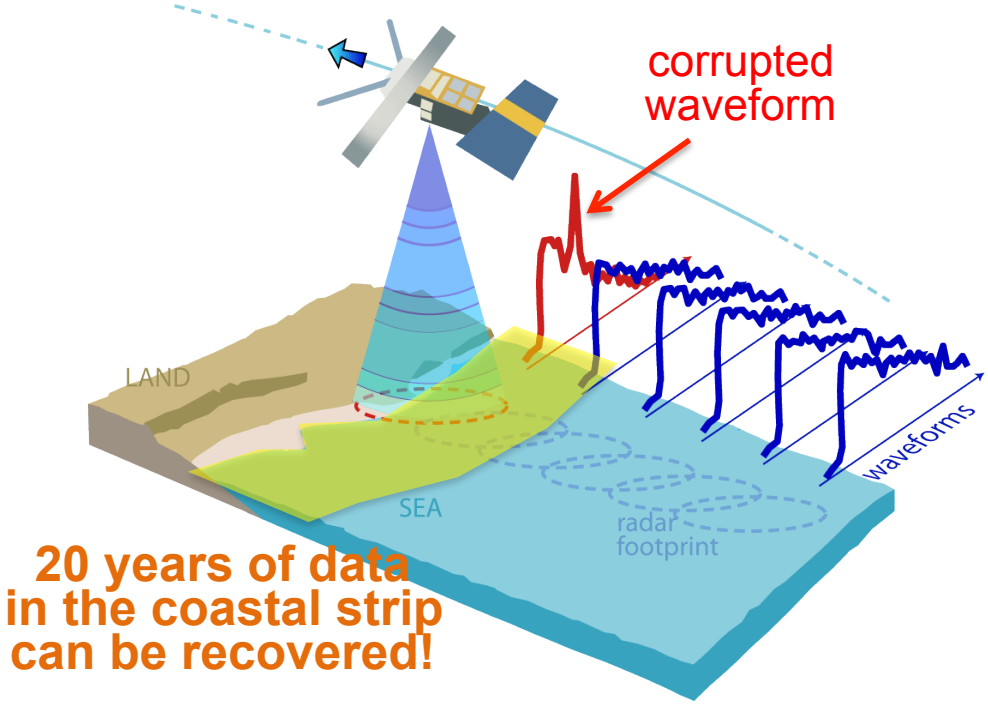


SEA LEVEL TRENDS - map

→ Sea Level component on dedicated ESA programme, the “Climate Change Initiative”



The new frontier - coastal altimetry



20 years of data in the coastal strip can be recovered!

Traditionally, data in the **coastal zone** are flagged as bad and left unused

(coastal zone: as a rule of thumb 0-50 km from coastline, but in practice, **any place where standard altimetry gets into trouble** as waveforms are non-Brown and/or corrections become inaccurate)

In recent years a vibrant community of researchers has started to believe that most of those coastal data can be recovered

http://www.coastalt.eu/community

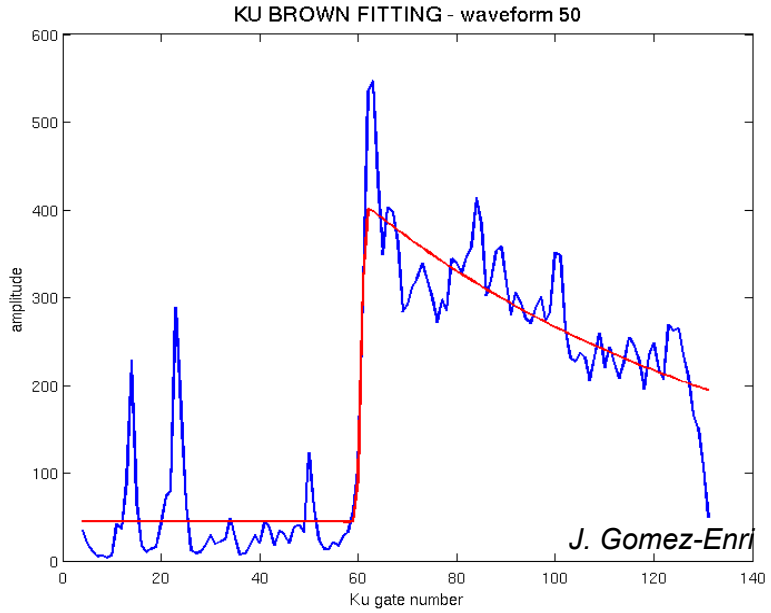
Also important for **SAR & Ka-band altimetry, having good coastal performance - and for coastal wave field**

How we recover more data

0-10 km

A. Specialized **retracking**

- Use better waveform models, accounting for change of shape in coastal environment
- Use specialized (2-D or sequential) retracking



0-50 km

B. Improved **Corrections**

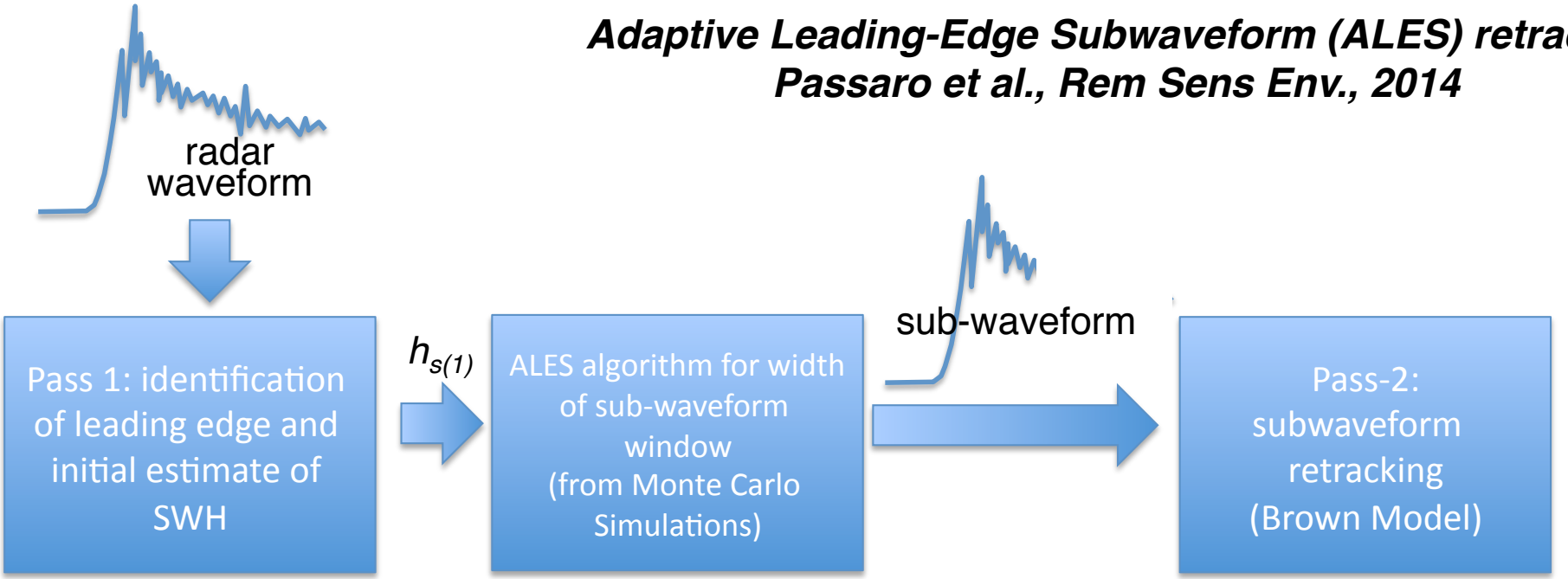
- Most crucial is the correction of path delay due to **water vapour** (“wet tropospheric” correction)
- Some applications require correction of **tidal** and **high-frequency** signals, which are also difficult to model in the coastal zone

COASTALT

www.coastalt.eu

NOC's ALES retracker

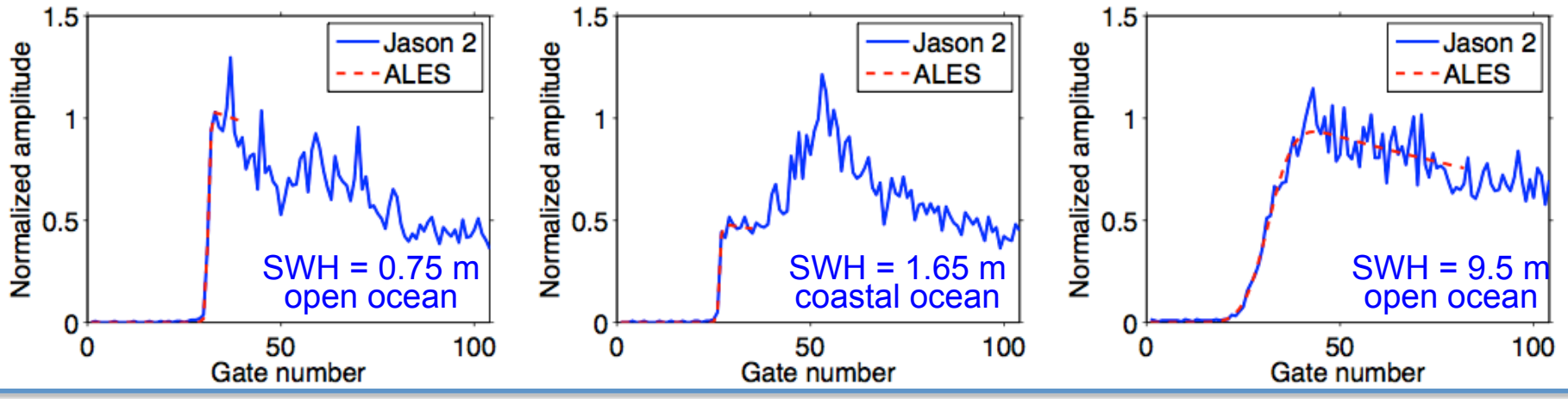
Adaptive Leading-Edge Subwaveform (ALES) retracker
Passaro et al., Rem Sens Env., 2014

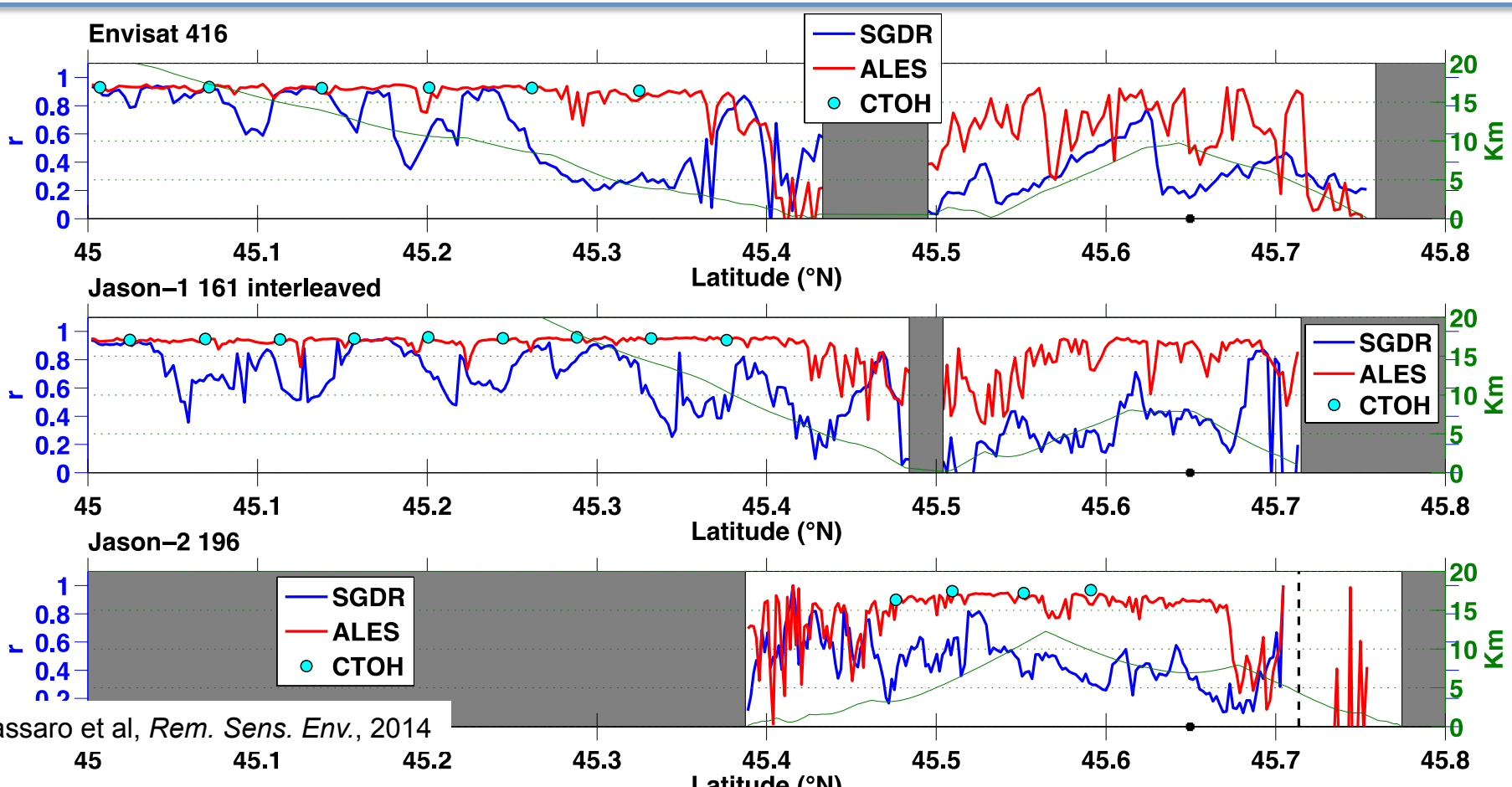


The sub-waveform approach keeps the measurement focused on the pulse-limited footprint of the instrument → prevents any non-homogeneities in the far-view field from degrading its accuracy.

→ very good for **coastal zone and fine scales**

New ALES retracker: examples with Jason-2

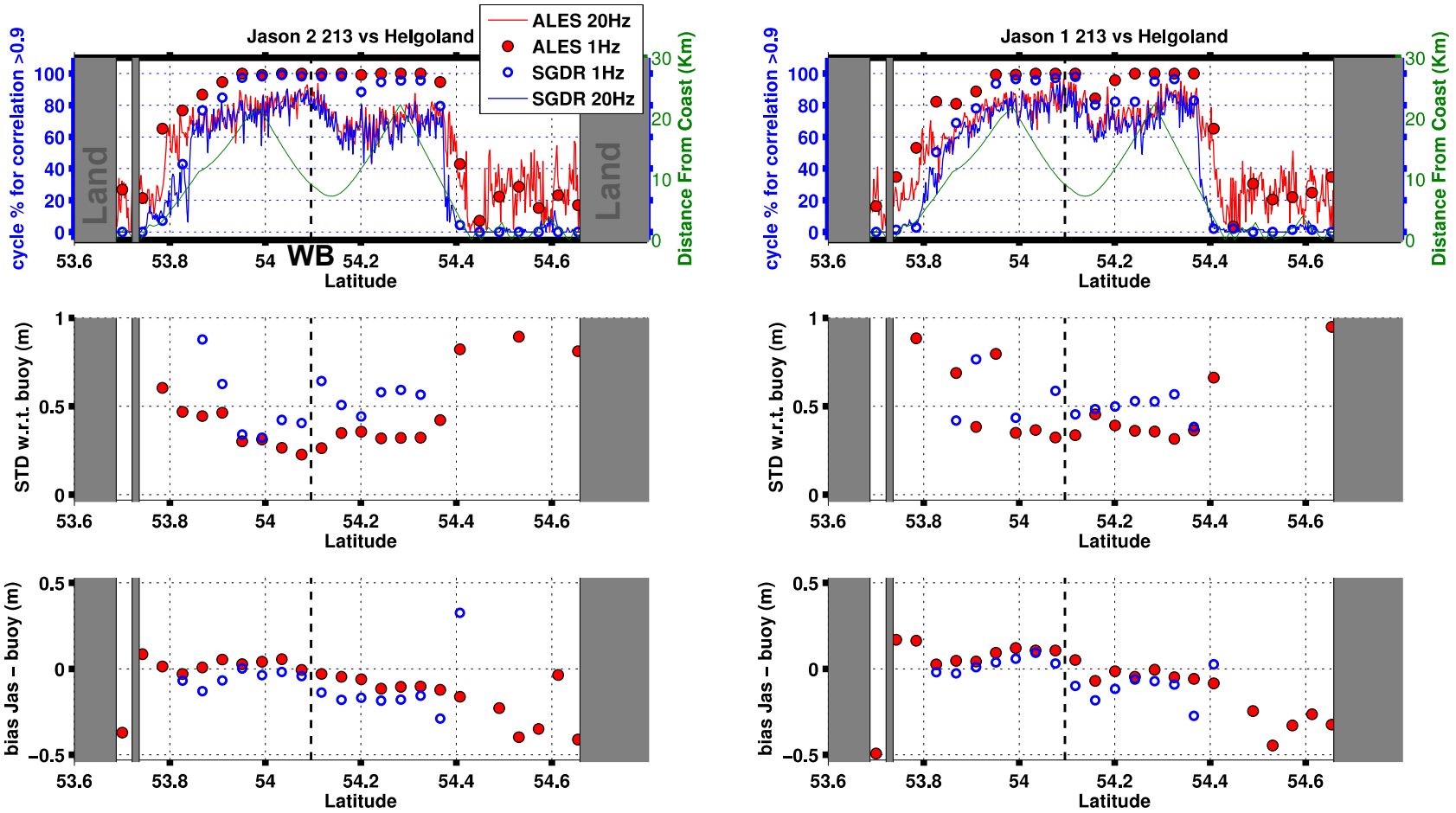




Passaro et al, *Rem. Sens. Env.*, 2014

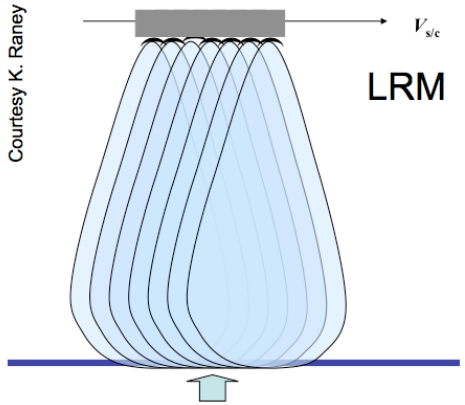
Validation now extended to SWH

using SWH from wave buoys in the German Bight (Passaro, Fenoglio & Cipollini, *IEEE Trans. Geoscience and Rem. Sens.*, 2015)

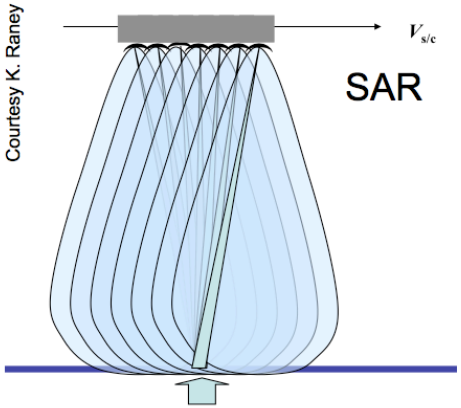


→ ALES represents a significant step forward in retracking altimetry in the coastal region (and works well also offshore!)

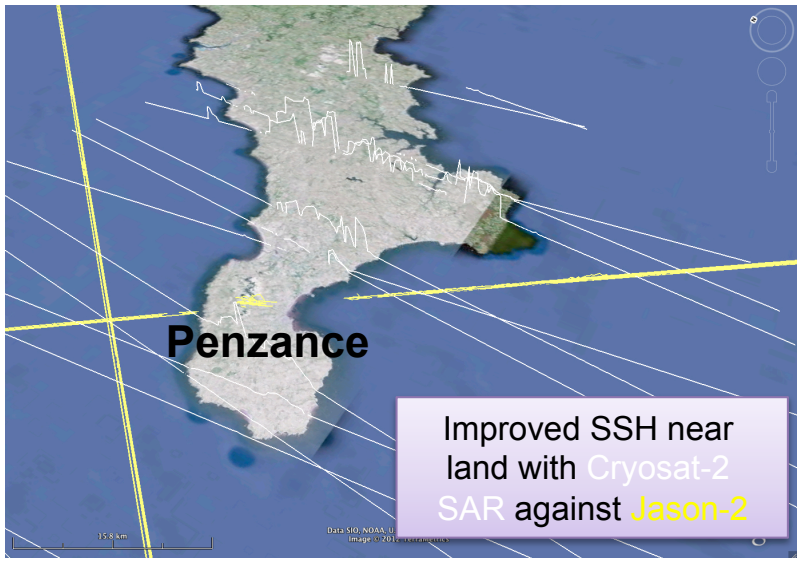
The SAR altimetry revolution

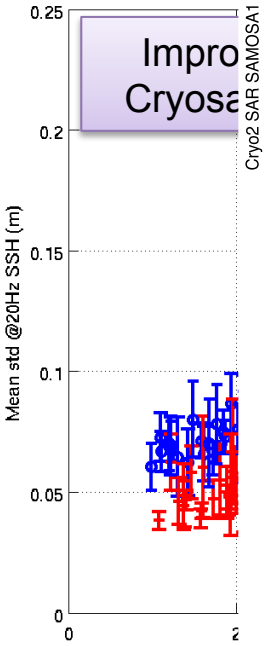


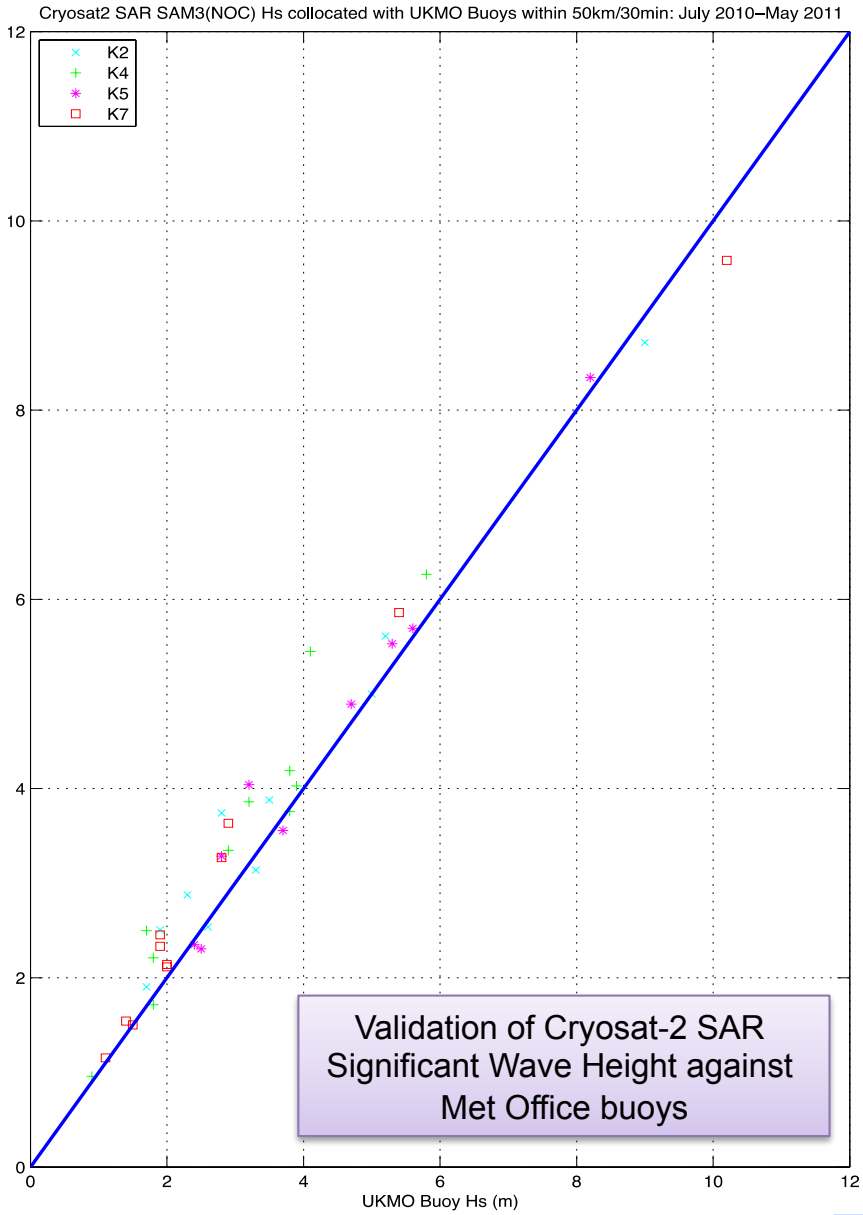
- Conventional pulse-limited aka Low-Rate Mode (PRF ~ 2kHz)

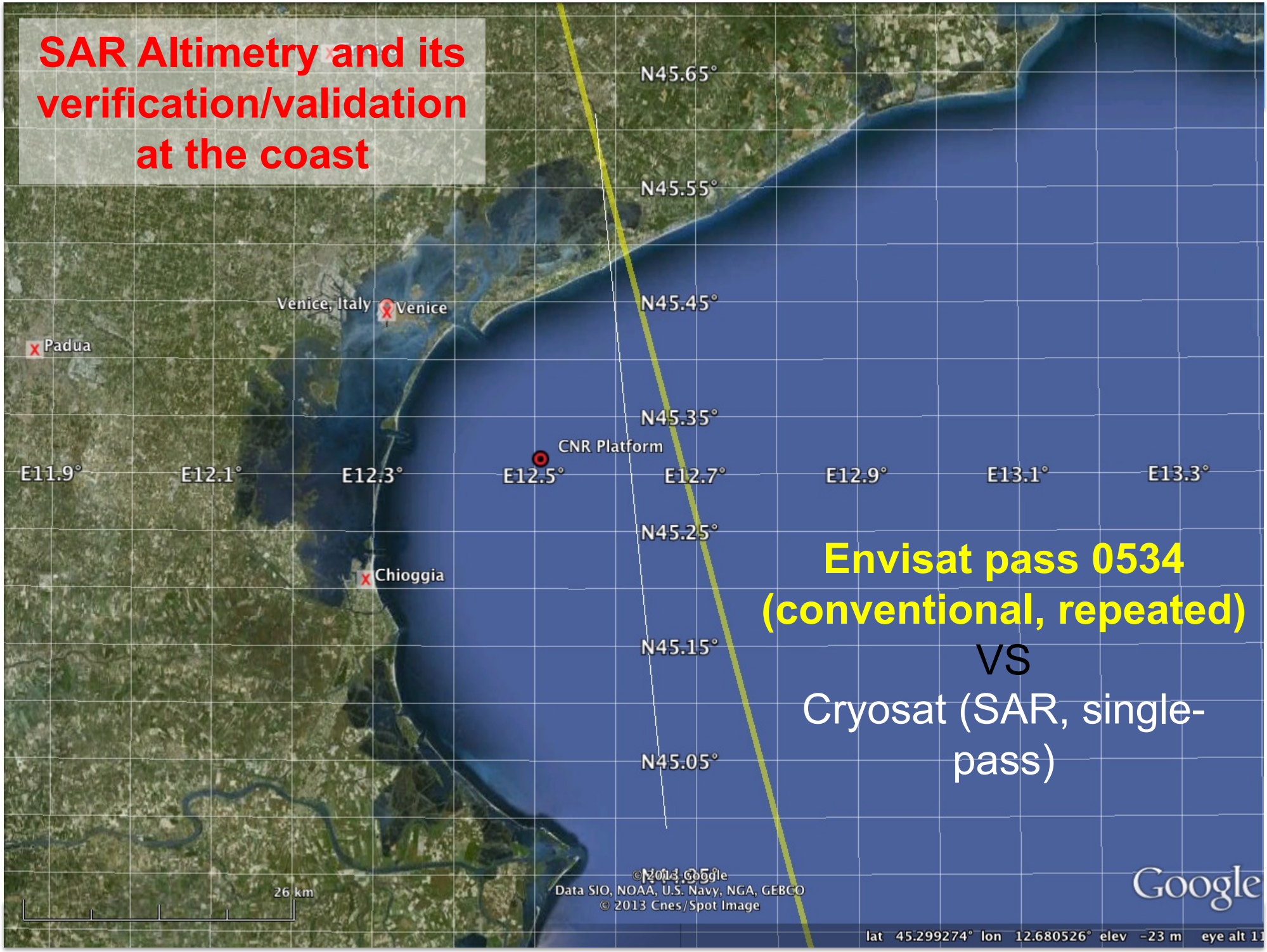


- Delay Doppler aka SAR (Bursts & PRF ~ 20kHz)



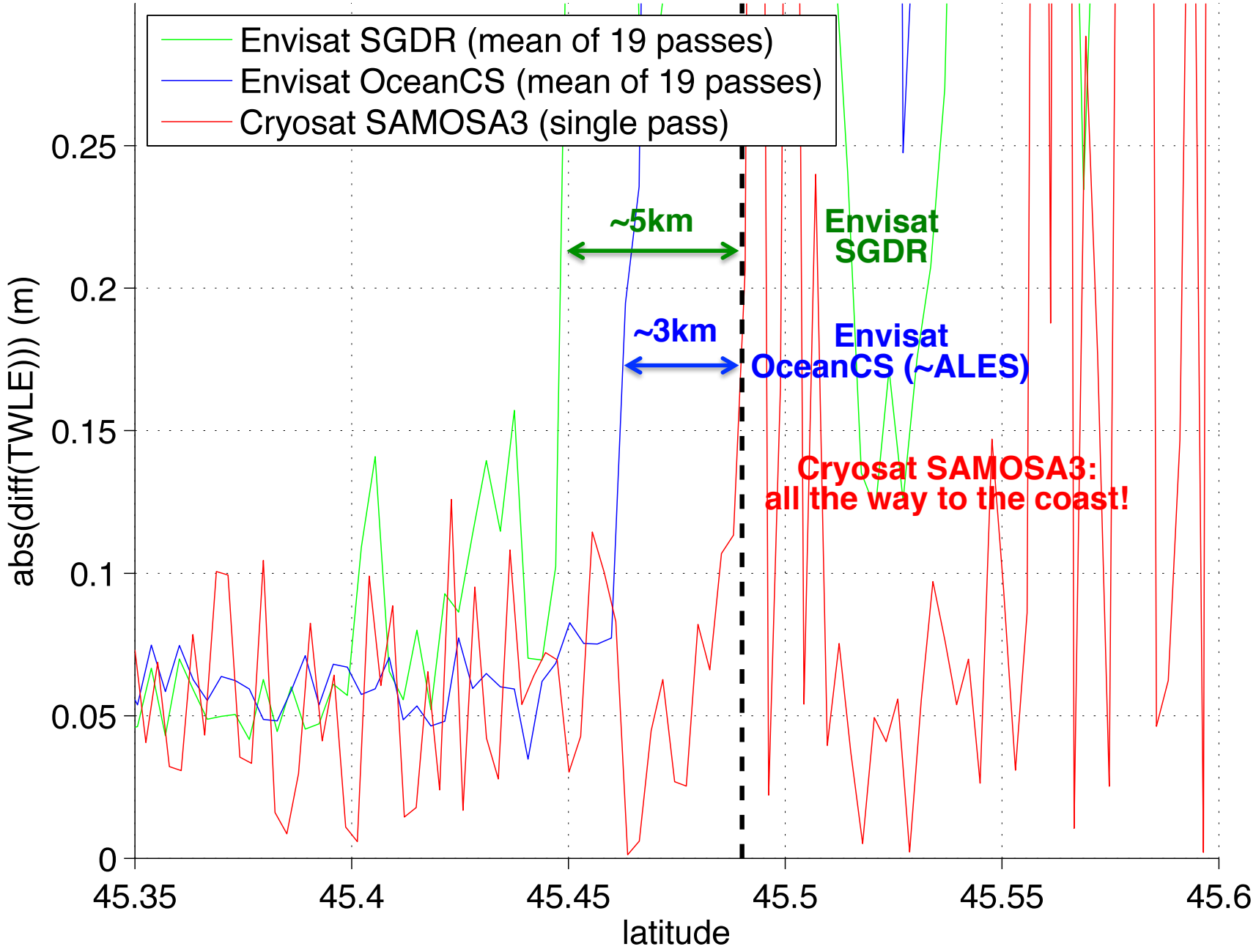




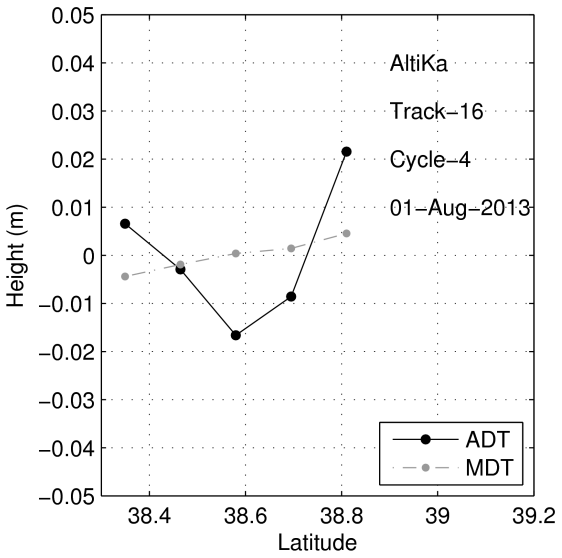

SAR Altimetry and its verification/validation at the coast
N45.65°
N45.55°
N45.45°
N45.35°
N45.25°
N45.15°
N45.05°
Venice, Italy
Venice
Padua
CNR Platform
Chioggia
E11.9°
E12.1°
E12.3°
E12.5°
E12.7°
E12.9°
E13.1°
E13.3°
Envisat pass 0534 (conventional, repeated)
VS
Cryosat (SAR, single-pass)
26 km
© 2013 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2013 Cnes/Spot Image
Google
lat 45.299274° lon 12.680526° elev -23 m eye alt 11

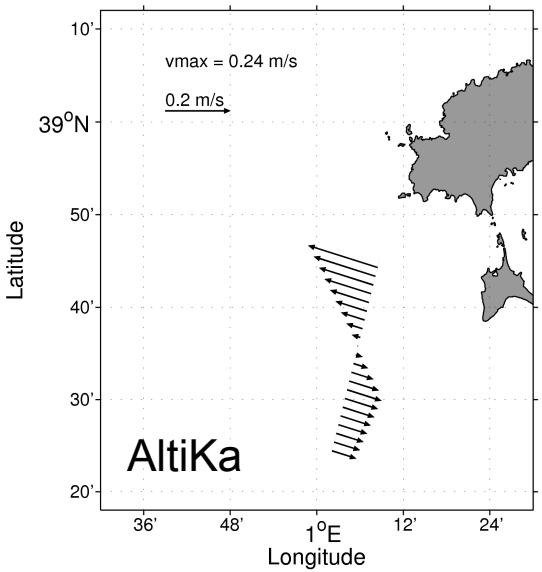
Total Water Level Envelope – sea level inclusive of tides and pressure/wind effects

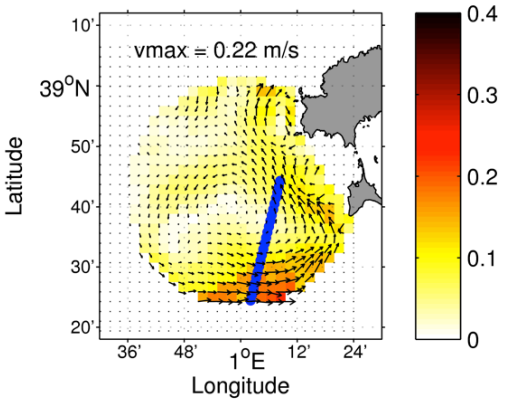
abs() of TWLE difference amongst consecutive 18–Hz samples

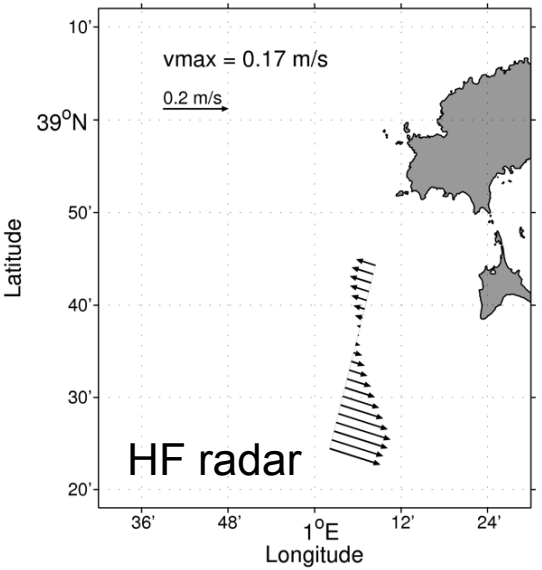


Application example 1 : coastal dynamics







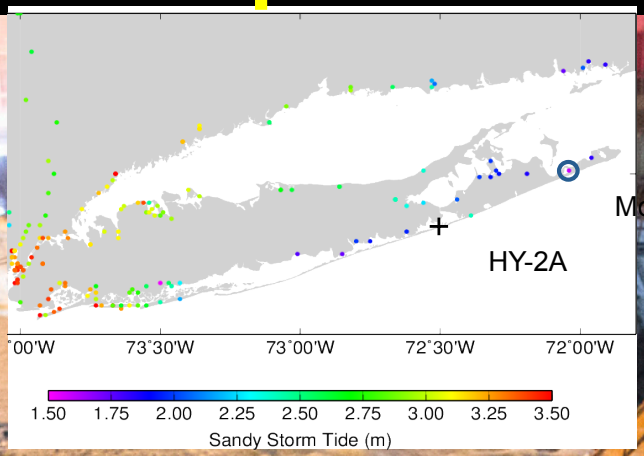


Example at Ibiza, W Med: SARAL/AltiKa derived velocities reveal coherent mesoscale features with general good agreement with HF radar fields

A. Pascual et al

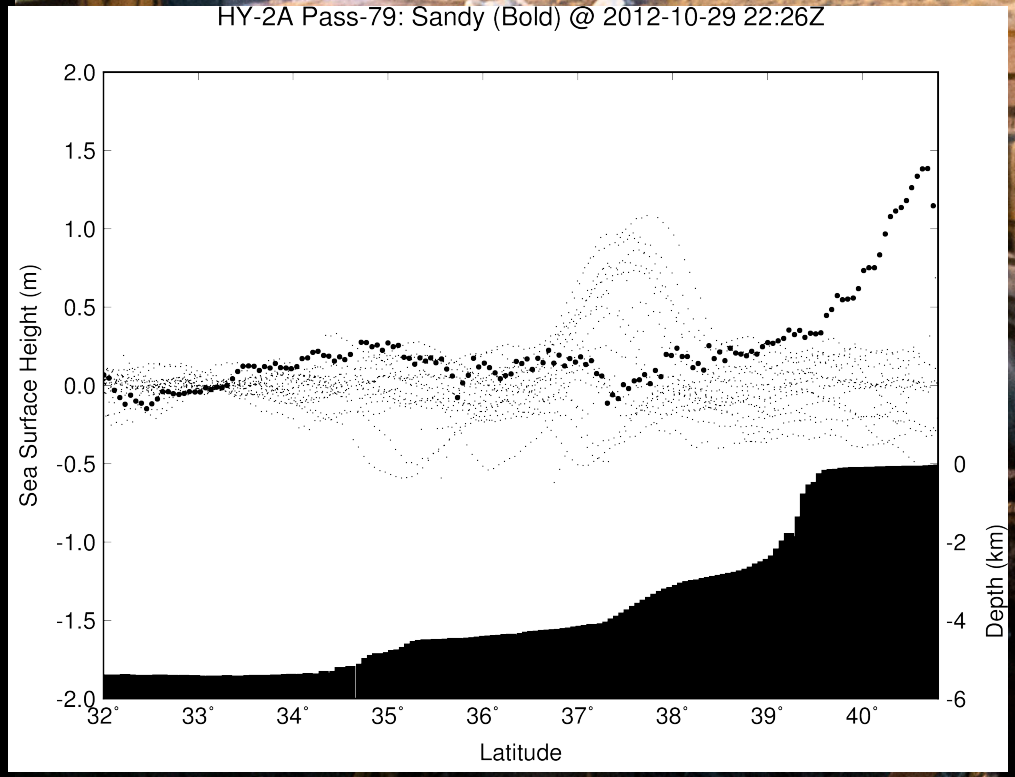
Application example 2 : storm surges

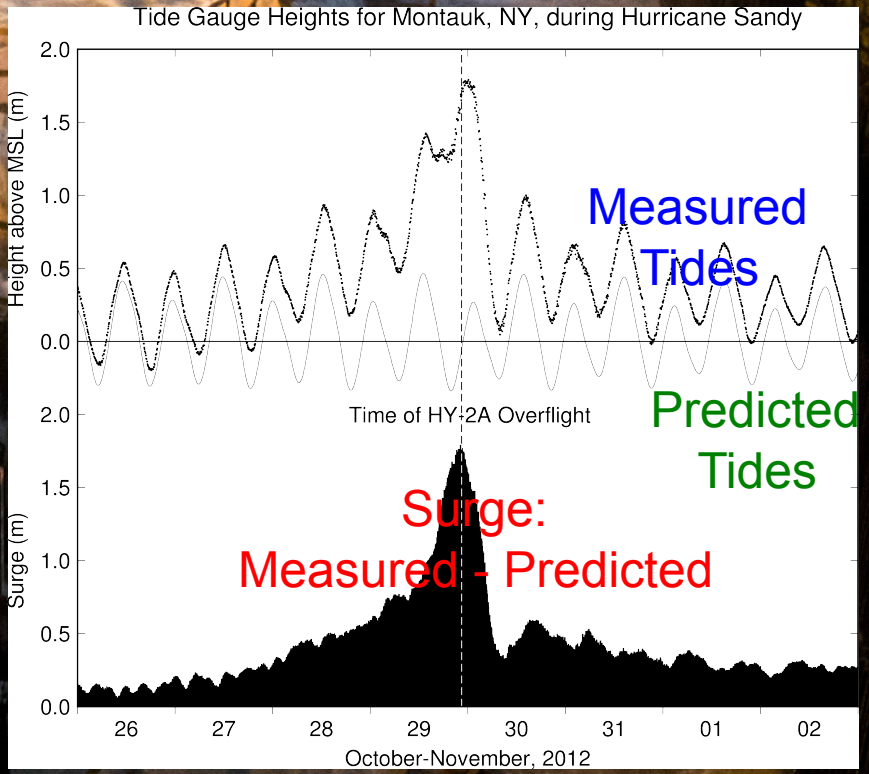
Storm Surges



Lillibridge et al - Hurricane Sandy storm surge

HY-2A only altimeter to capture surge < 12 hr duration





Hurricane Sandy storm surge flooding the World Trade Center construction site

Summary and conclusions

- Altimetry is a mature technique of proven value over the open ocean, and whose future is secured by a string of missions
- Recent improvements in processing techniques and corrections have opened up a number of applications in the coastal zone
  - today we are mainly concerned with regional and coastal sea level
- Support to R&D by Space Agencies has been instrumental for this advance, and remains crucial for the future