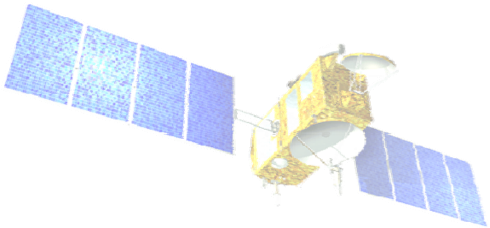
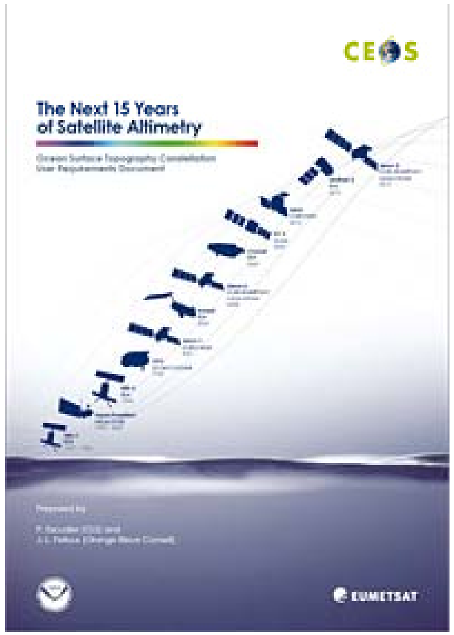
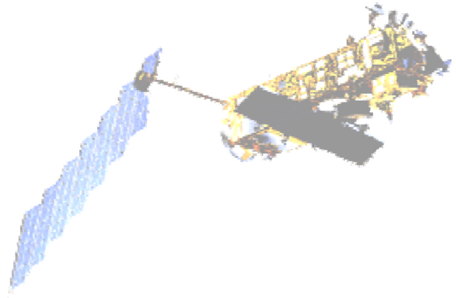
Science and operational applications from the altimeter constellation

P.Y. Le Traon

Thanks to inputs from G. Dibarboure, D. Chelton, R. Morrow, P. Bahurel,Y. Faugère, M.H. Rio, N. Maximemko, J. Lillibridge, H. Bonekampf, G. Goni, G. Jacobs







Outline

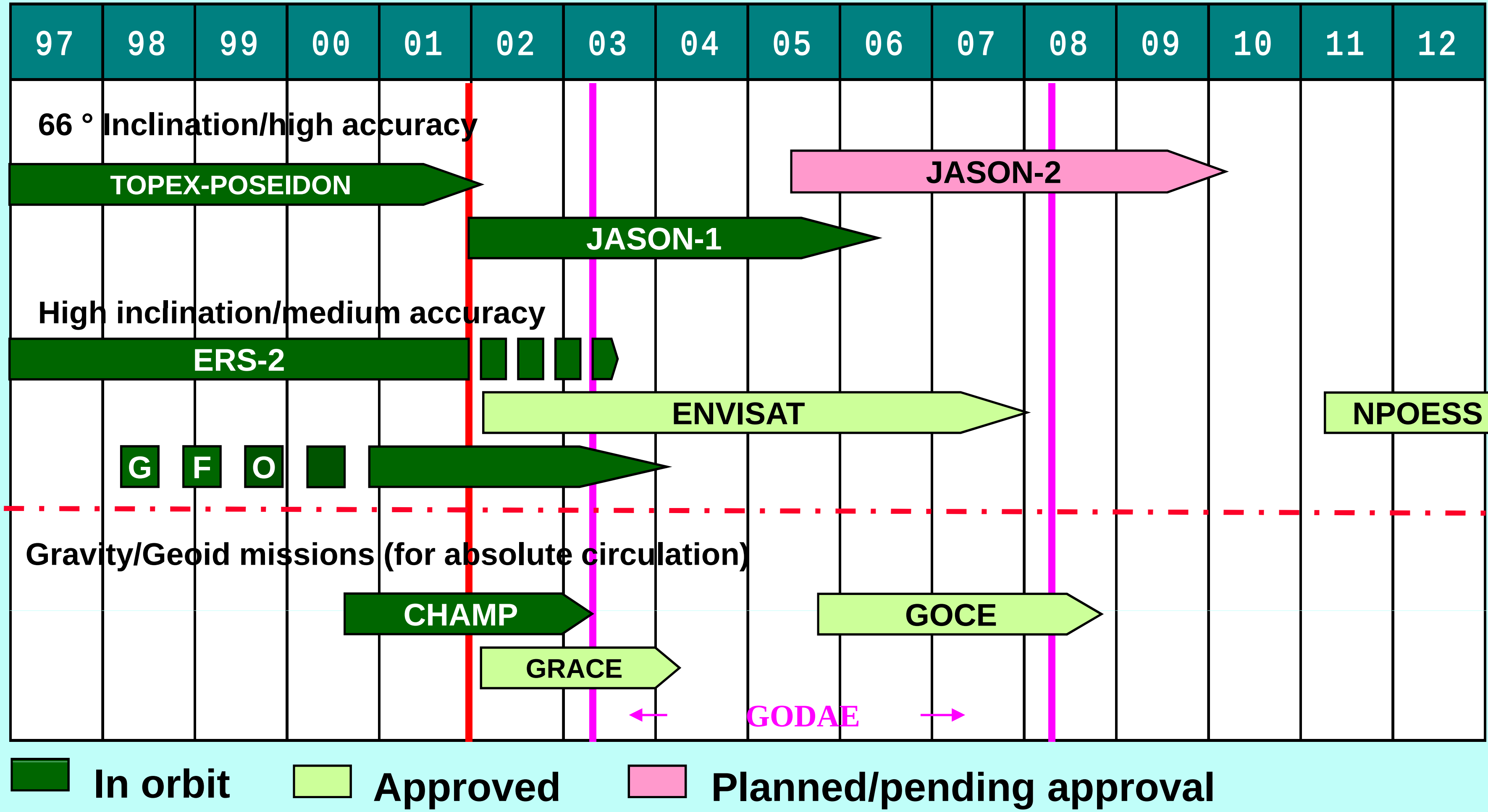
- The altimeter constellation 10 years ago and today: status and requirements
- Overview of results obtained from the merging of multiple altimeter data.
- The altimeter constellation: short term issues
- Summary and recommendations

Altimeter constellation

10 years ago

Vision and issues

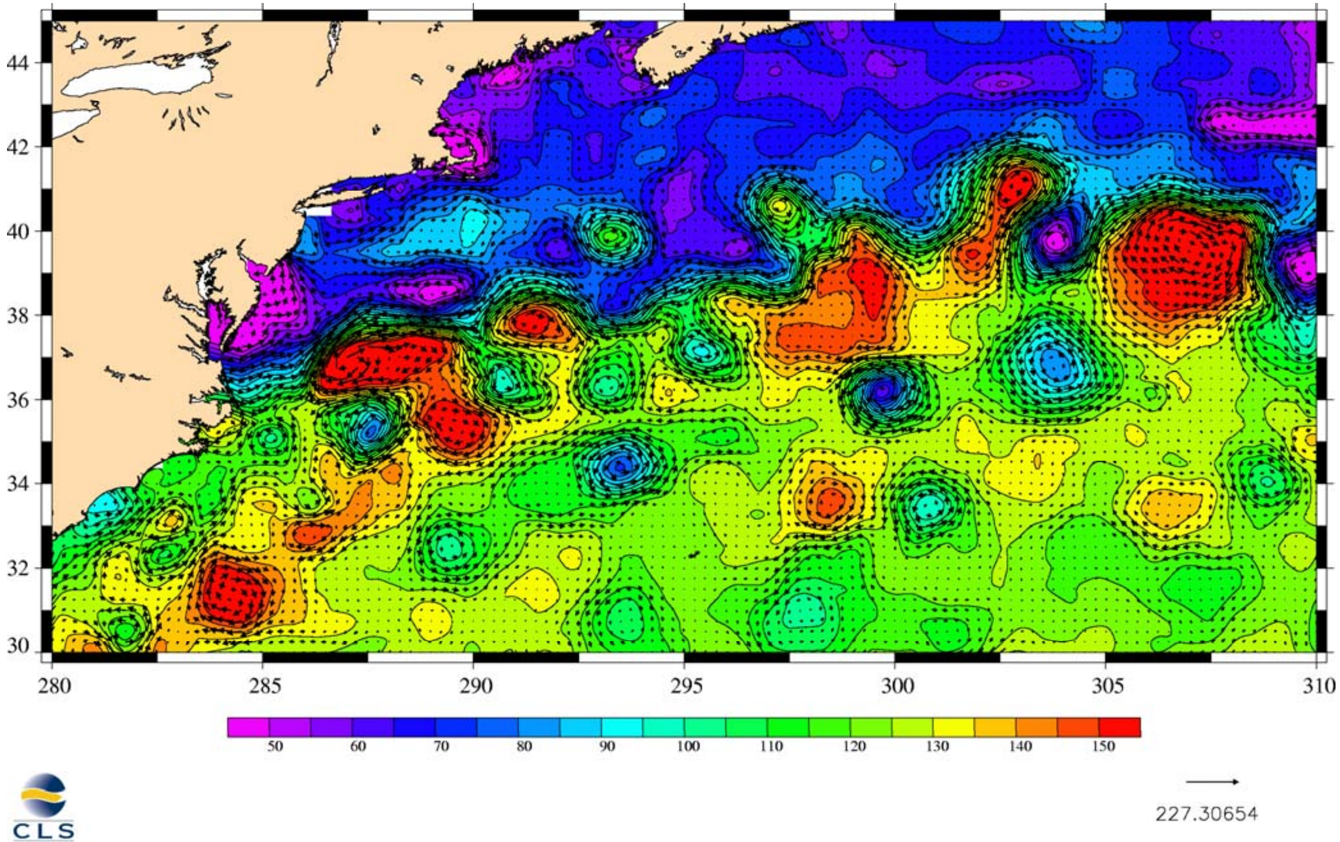
Status of Altimeter «constellation » (Ratier, 2001) (Oceanobs99, St Raphael)



- Real time capabilities on ERS (wind/wave), JASON and ENVISAT(wind/wave, topography)
- GEOSAT-FO (GFO), launched in 1998, has started providing useful data end of 2000.
- ERS-2 operations approved only until end of 2002. ERS-2 has gyro problems (zero-gyro mode tested)
- An ocean circulation observing system requires at least two altimeter missions simultaneously coverage of all significant time-space scales, with at least a TOPEX/JASON class mission.
- Gravity missions necessary for altimetry to access absolute circulation at all climate-significant scales

01/2002

**In 2001, we had almost 10 years of T/P-ERS observations =>
Merged products were available for mesoscale investigations**



CLS

**High resolution description from the real time merging of
Jason-1, ERS-2 and GFO**

Our requirements : 10 years ago

1. At least two and preferably three altimeters

2. Need homogeneous (consistent processing between missions) and inter-calibrated data sets. DUACS methodology = use the most precise mission (T/P) as a reference for the other satellites. Use consistent mean profiles for SLA estimation.

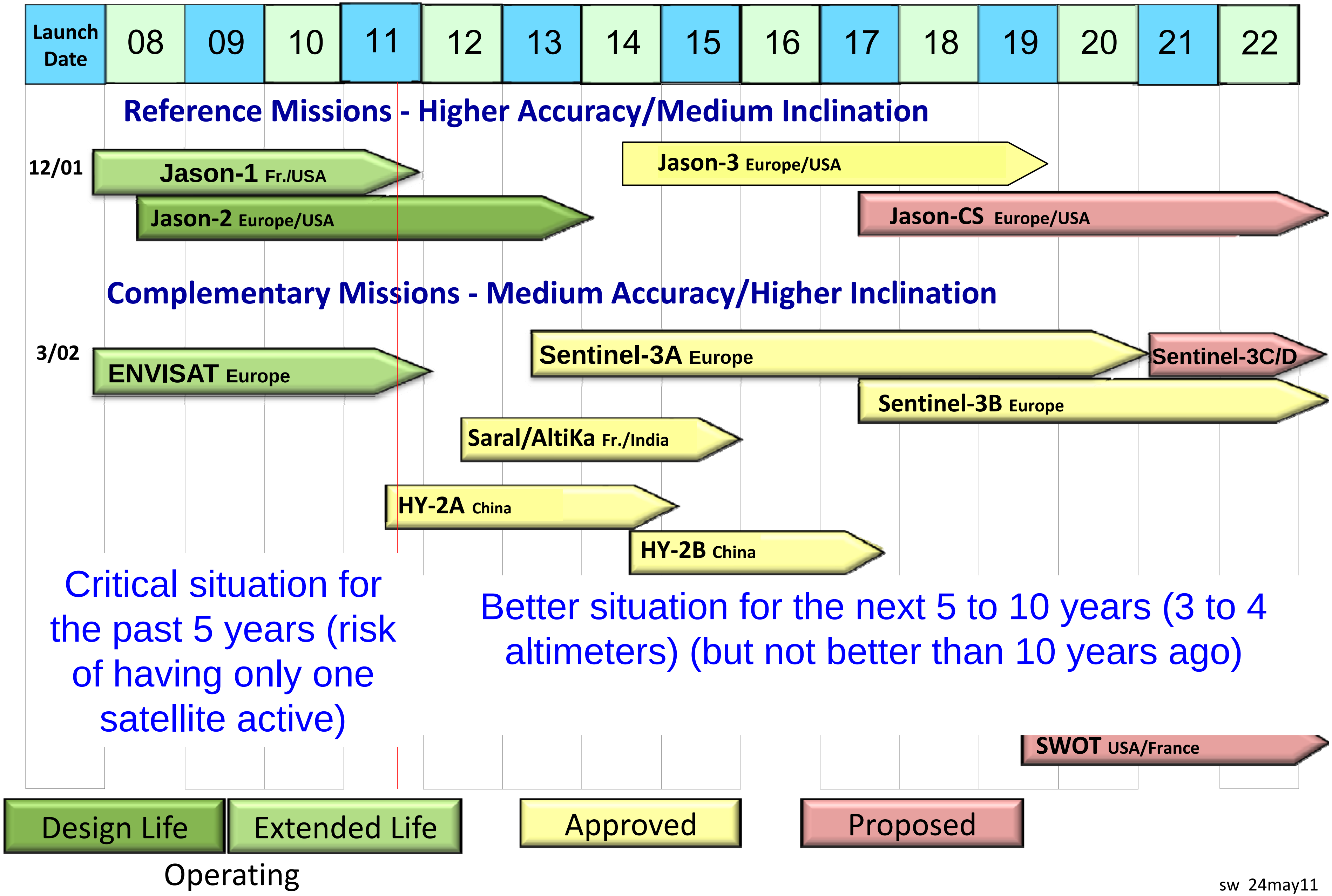
3. Main drivers : mesoscale circulation, modelling and data assimilation, operational oceanography (GODAE) and waves

Altimeter constellation

The present situation

OSTST, San Diego, October 21-23, 2011

ALTIMETER MISSIONS (adapted from Wilson et al, 2001)



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OST Virtual Constellation : Status & Issues

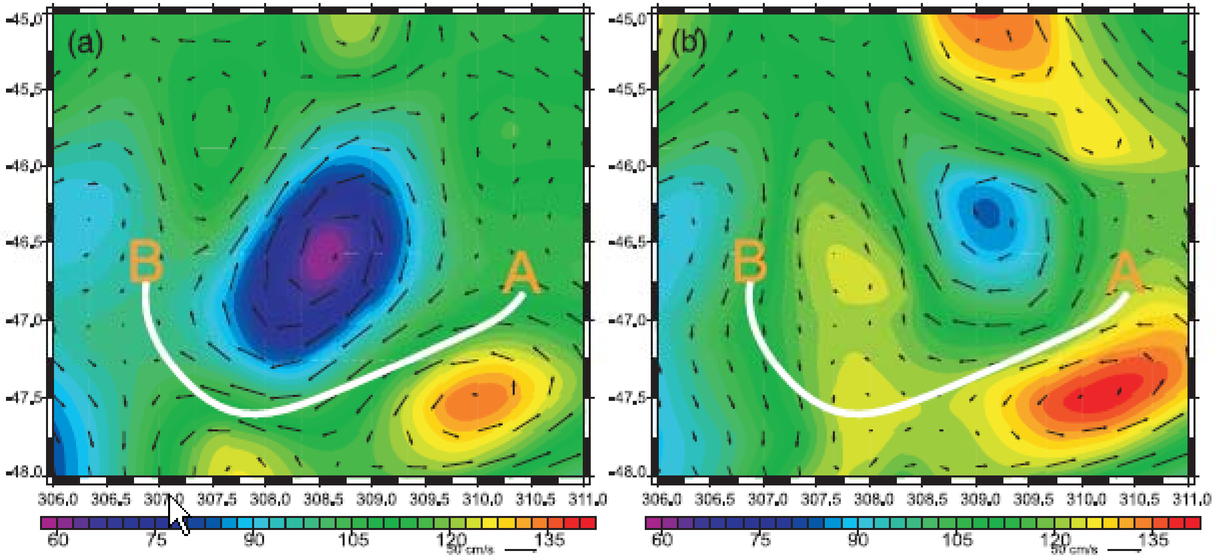
(adapted from Wilson et al., 2011)

- **Continuity of Climate Record for Sea Level**
  - **Jason-1 & -2** – Operating in interleaved orbits
  - **Jason-3** – Development underway
  - **Jason-CS** – ESA – with EUMETSAT, NOAA, CNES & NASA – has initiated Phase B study; funding issues
- **Continuity of Complementary Coverage**
  - **Cryosat-2** – Launched 8 Apr 10; awaiting availability of operational products for ice-free ocean
  - **ENVISAT** – Starting 22 Oct 10 orbit became non-repeating
  - **HY2-A** Successfully launched in August, 2011
  - **SARAL/AltiKa** – Launch planned for April 2012; if Jason-1 is still OK at end of SARAL's commissioning phase, it will move to a geodetic orbit
  - **Sentinel-3A & B** – Development proceeding with 1st launch in 2013 but phasing issues
- **New altimeters tested (SIRAL, SRAL, Ka) (science infusion)**
- **New concept : SWOT (NASA/CNES) (December 2019)**

The altimeter constellation : the today vision

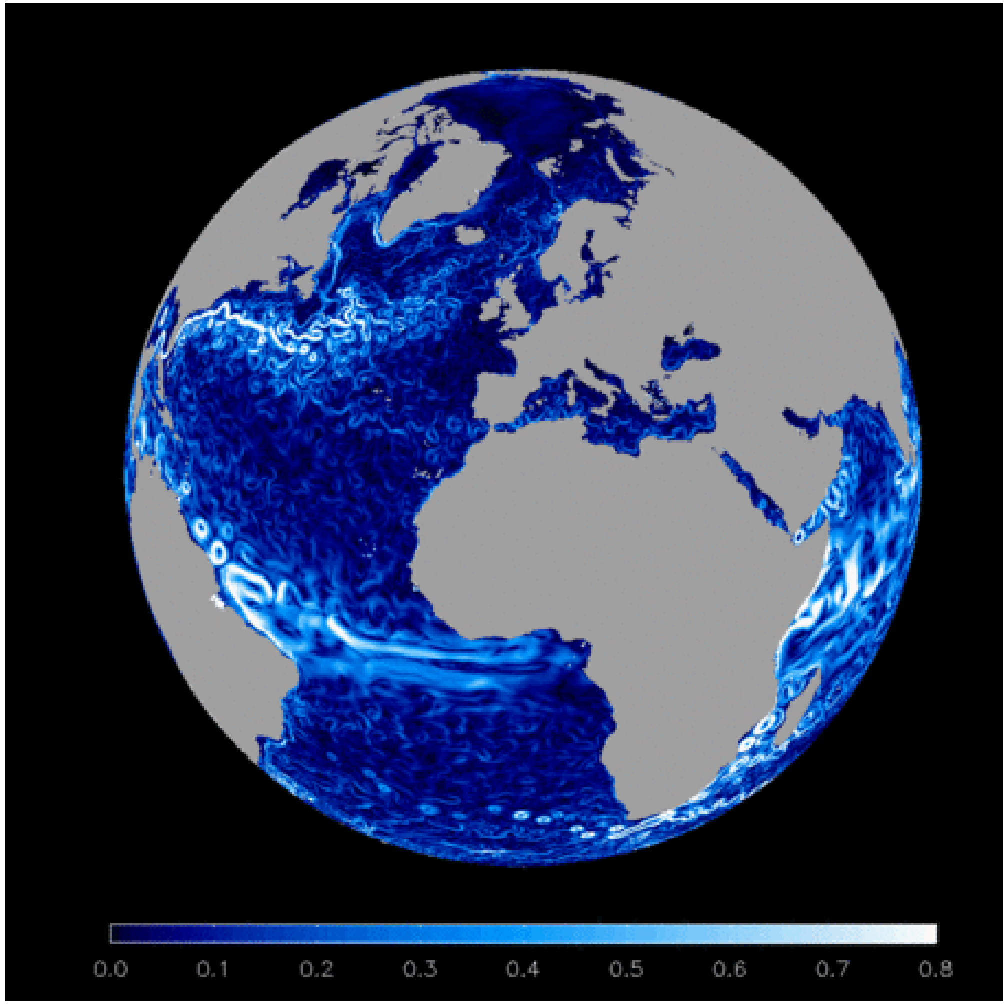
- Better understanding of the value of multiple altimeters. Unique contribution of T/P-Jason-1 and Jason-1/2 tandem missions.
- Better understanding of errors through extensive validation and intercalibration exercices.
- Stronger requirements from real time applications (e.g. surface currents). Need to rely on multiple altimeters (reduce the risk of a single failure). Real time applications require 4 altimeters.
- New challenges (mesoscale/submesoscale, coastal, coupling physics/biology), operational oceanography and applications require higher space/time resolution.
- Major evolution of models => very high space/time resolution « views » of the ocean. Observation capabilities lag behind.

2 altimeters in delayed mode (left) and in real time (right)



Comparison with tide gauges and drifters data shows that 4 altimeters in real time are needed to achieve a similar accuracy as 2 altimeters in delayed mode (hindcasting) (Pascual et al., 2009)

Data assimilation and modelling capabilities



MyOcean/Mercator-Ocean global 1/12° model with multiple altimeter data assimilation

Operational oceanography now uses high resolution models with data assimilation : 1/12° (global), 1/36° (regional), 1 km or less for coastal regions (e.g. GODAE Ocean View, MyOcean)

This poses (much) stronger requirements for an altimeter constellation.

Degradation of results when an altimeter fails !

Contribution of multiple altimeters
See splinter sessions

Mesoscale variability and global characterization of eddies

Monitoring fronts in the ACC

Multiple migrating quasi zonal jets

Model validation and testing theories (e.g. QG and SQG)

Coupling physics and biology (e.g. altimetry and ocean colour)

Coastal dynamics

Argo and altimetry

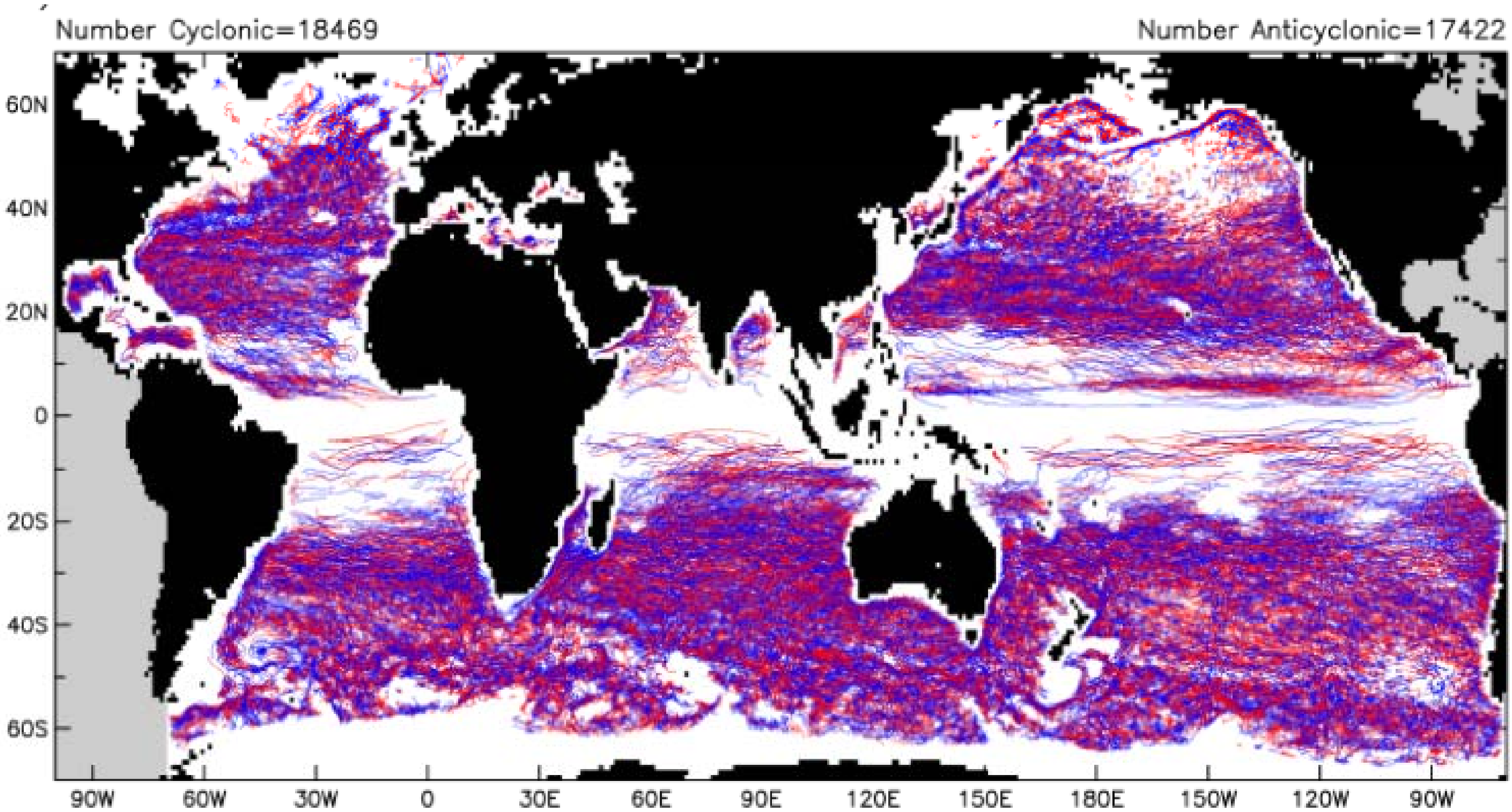
Data assimilation

Wind/waves

Applications and operational oceanography

…

Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 16 Weeks
(35,891 total)

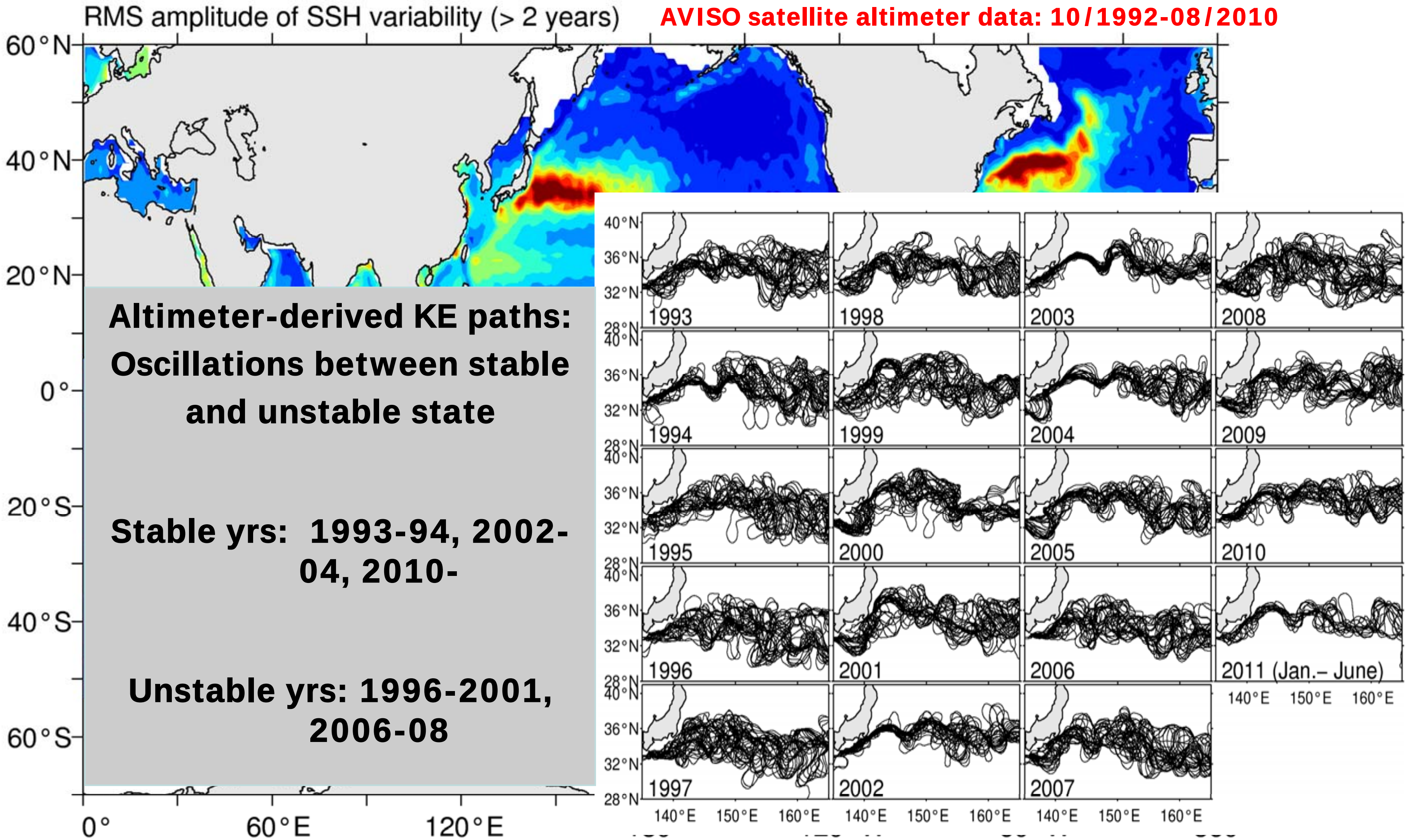


Average lifetime: 32 weeks
Average propagation distance: 550 km
Average amplitude: 8 cm
Average horizontal radius scale: 90 km

Total number of observations: ~1.15 million

Chelton et al., 2011

Decadal Predictions of the Kuroshio Extension Dynamic State based on Multiple Satellite Altimeter Missions (B. Qiu)



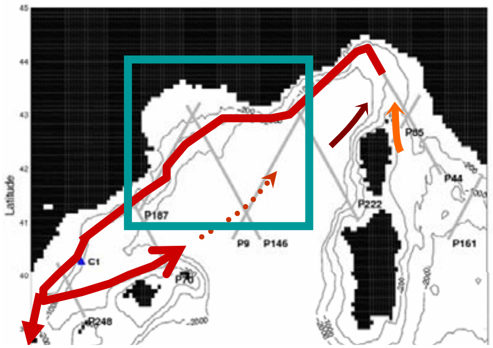
Altimeter-derived KE paths: Oscillations between stable and unstable state

Stable yrs: 1993-94, 2002-04, 2010-

Unstable yrs: 1996-2001, 2006-08

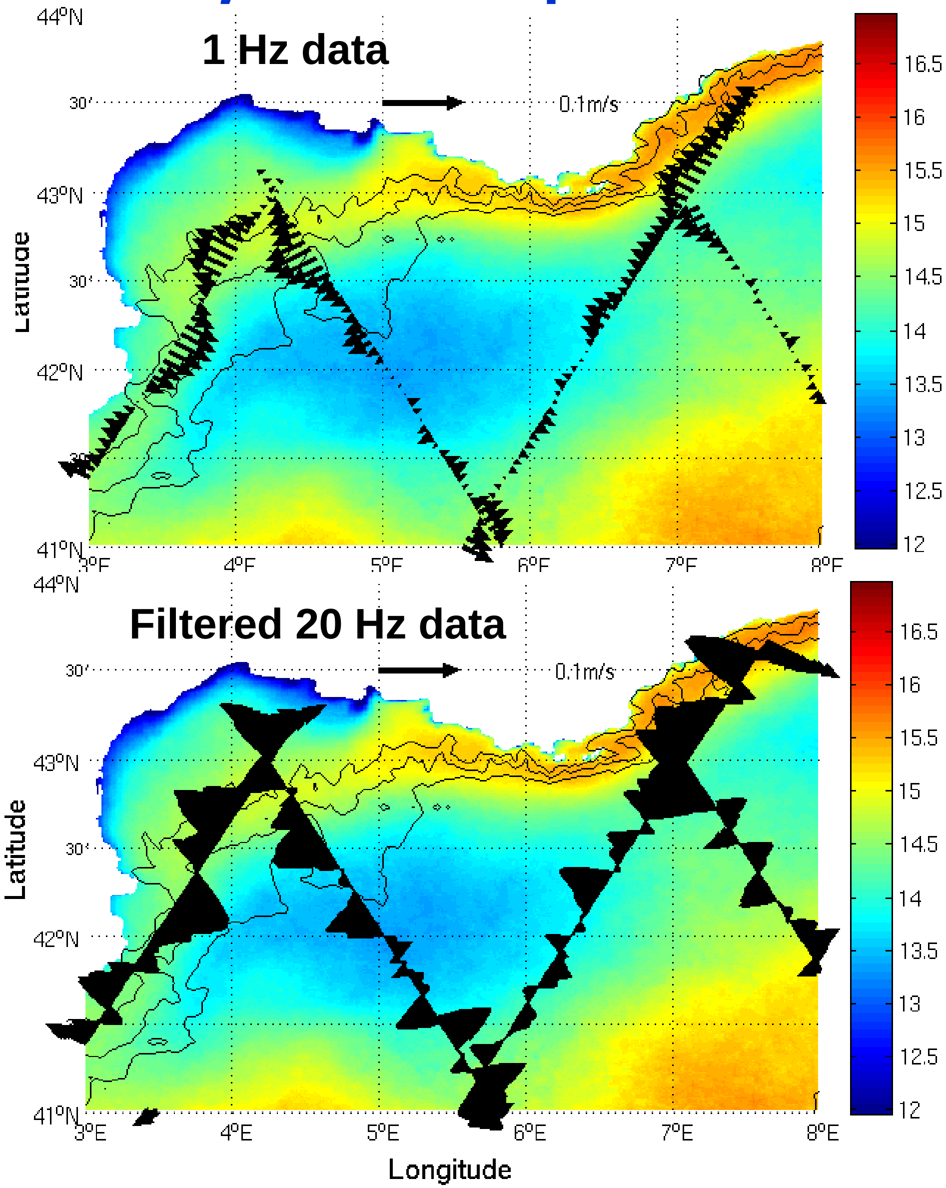
Extending altimetry into the coastal zone
see Coastal Altimetry Workshop

LPC Current circulation

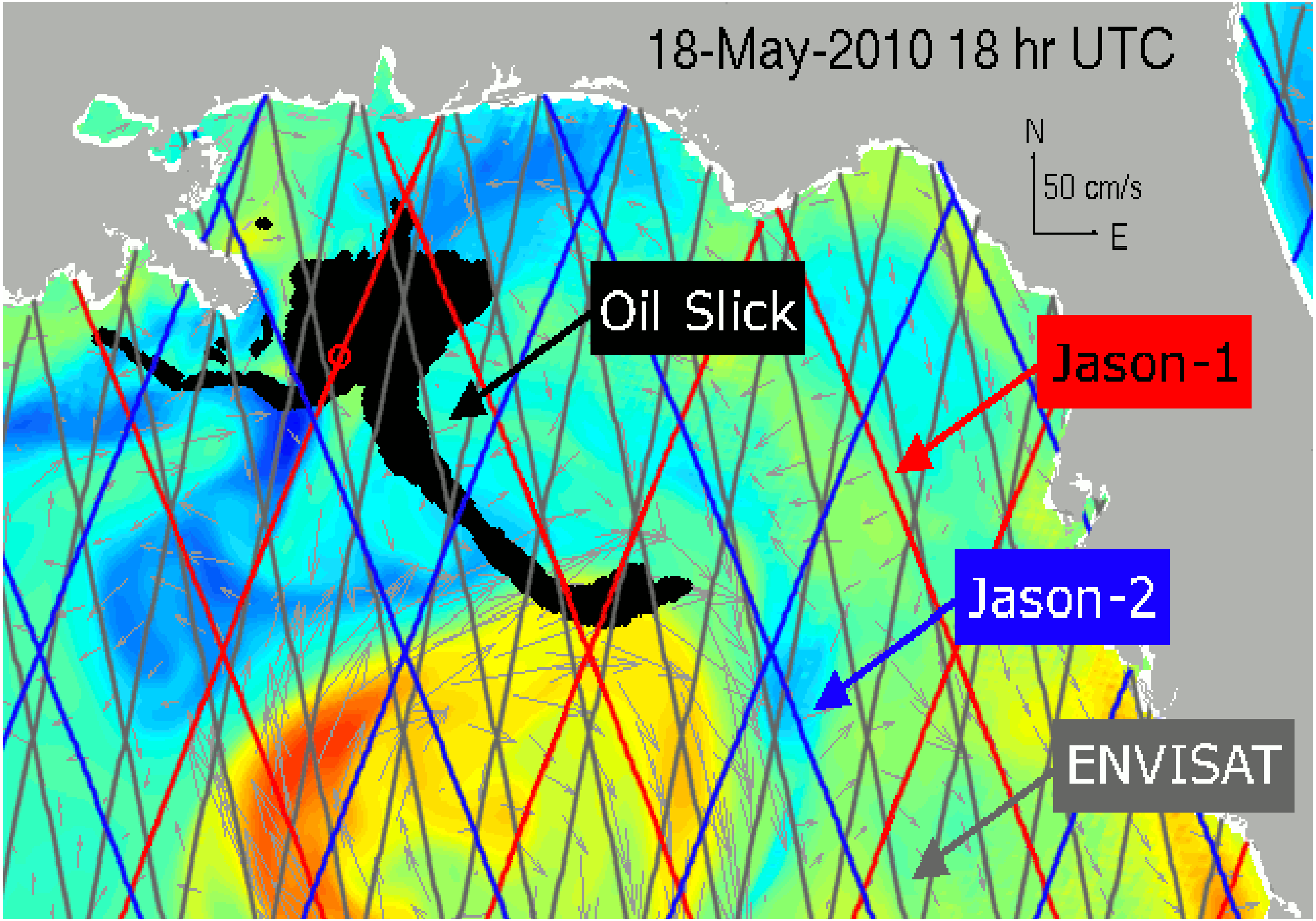


Monthly climatology of:

- SST (AVHRR over the period 1998-2007)
- Cross-track geostrophic current anomalies (altimetry – T/P & Jason-1 over the period 1993-2007)

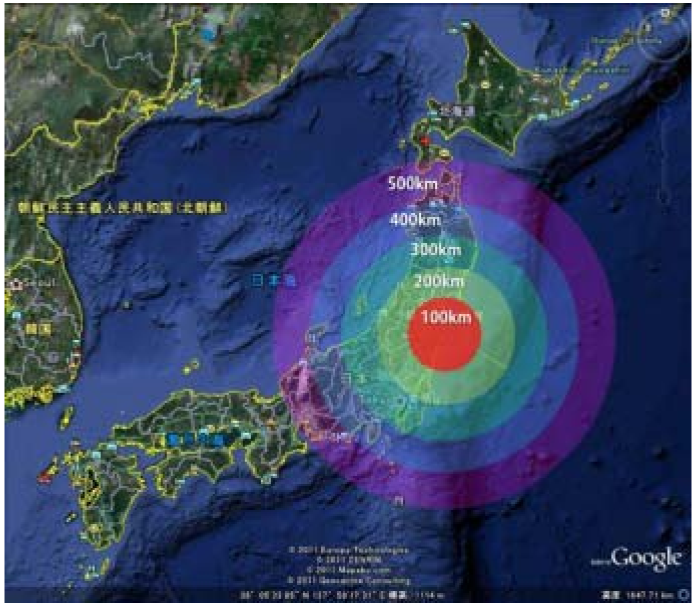


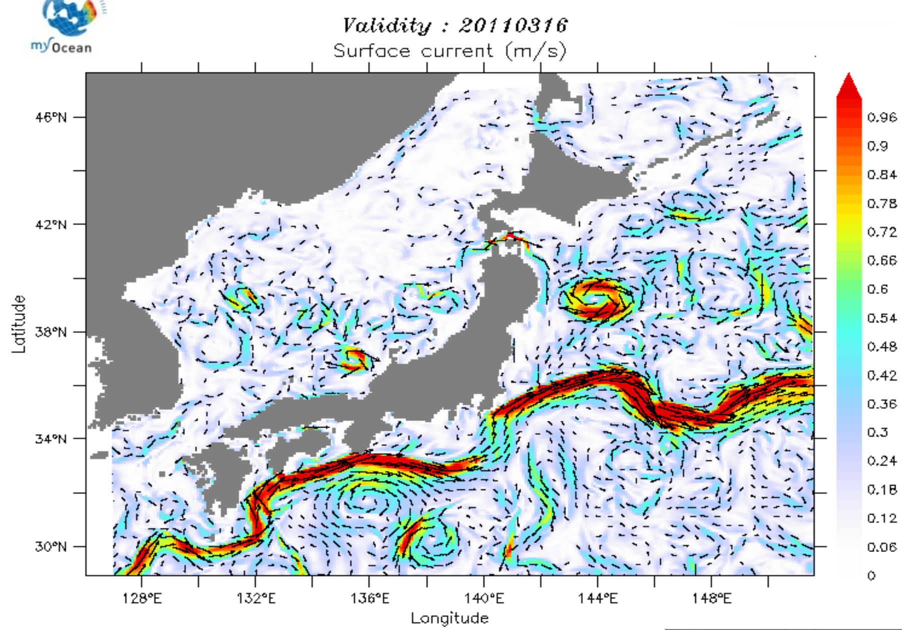
http://ctoh.legos.obs-mip.fr/products/coastal-products

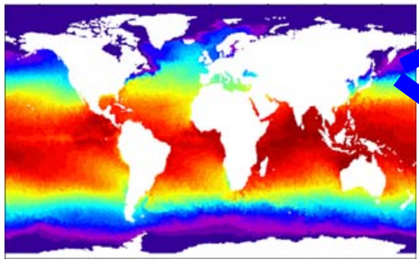


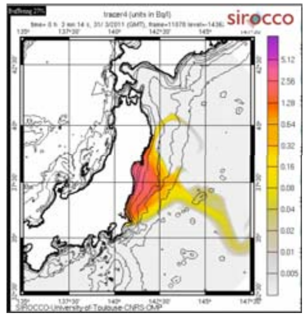
The altimeter constellation and DH oil spill (J. Lillibridge, NOAA)

Fukushima
MyOcean *Global Ocean* capacity

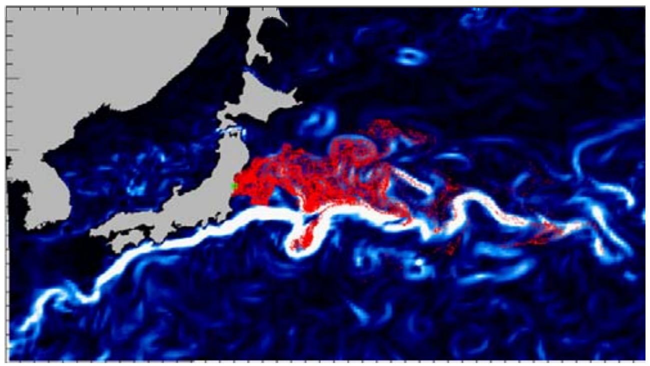








MyOcean Global Ocean Service



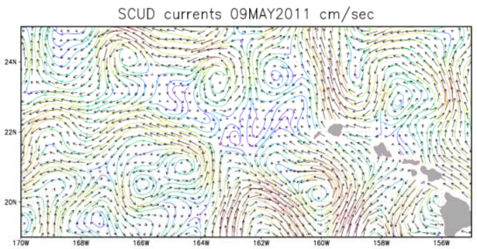
P. Bahurel
Mercator Ocean

Talk at the NRT Splinter Session, Thu, 9:30

Modeling distribution of marine debris before and after tsunami of March 11, 2011

Nikolai Maximenko[1], Jan Hafner[1], and Rick Lumpkin[2]
[1] IPRC/SOEST, University of Hawaii
[2] NOAA AOML

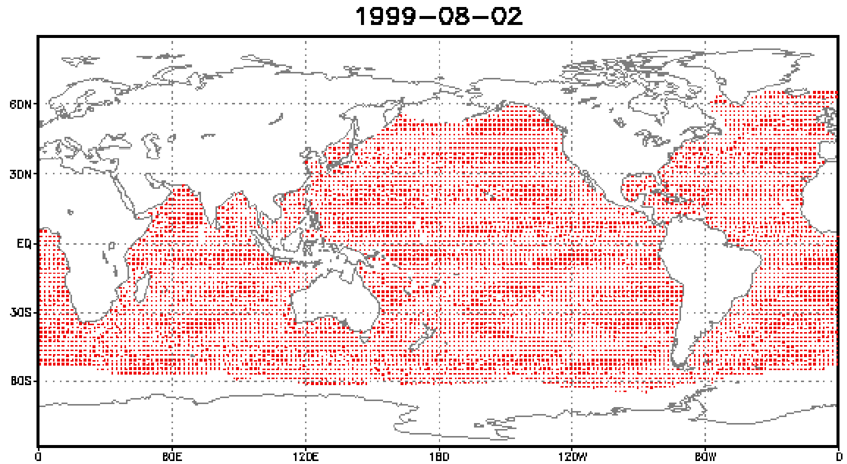
SCUD = Surface CUrrents from Diagnostic model
Input: mean dynamic topography, AVISO sea level anomaly, QuikSCAT/ASCAT wind.
Output: surface velocities, consistent with trajectories of SVP/GDP drifting buoys.

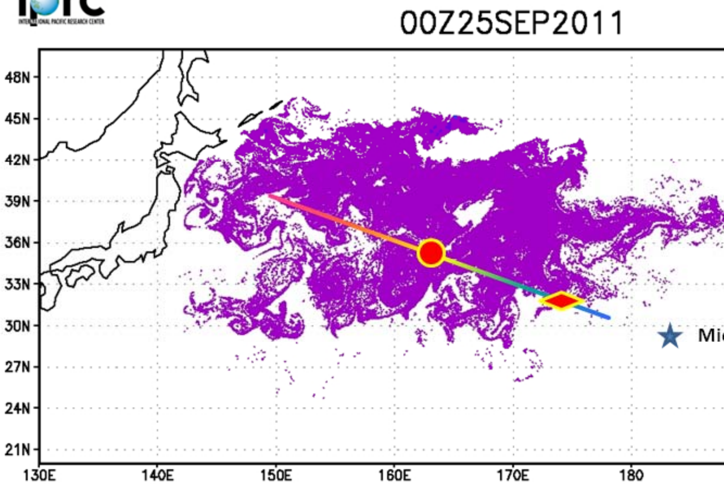


Snapshot of SCUD velocities near Hawaii

After six months of “blind” integration, location of March 11, 2011 tsunami debris from Japan is confirmed by STS “Pallada”

Global modeling of floating marine debris





Altimeter constellation

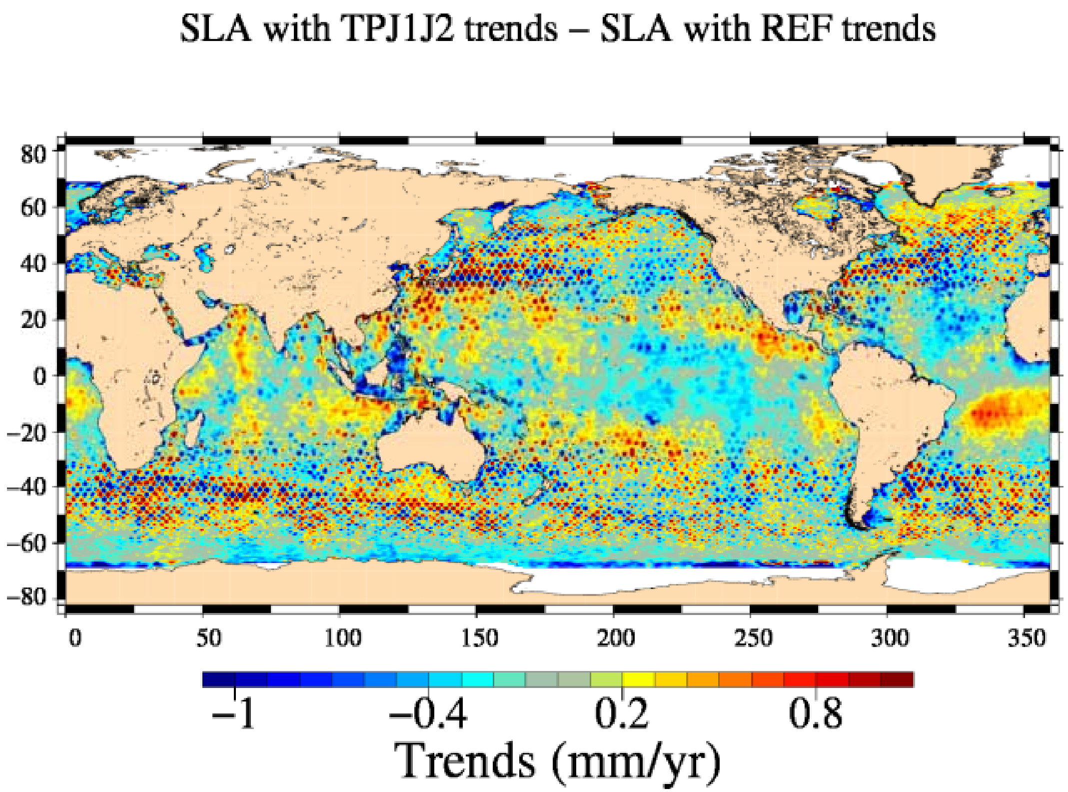
and climate applications

Altimeter constellation needed for climate studies ? (CNES/SALP project and ESA Sea Level CCI)

Differences in MSL trends over 17 years (1993-2010)

Altimeter maps with 1 or 2 altimeters

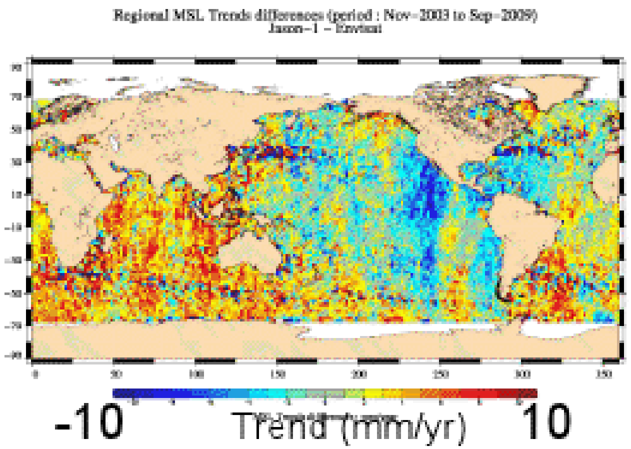
Faugère et al., 2011



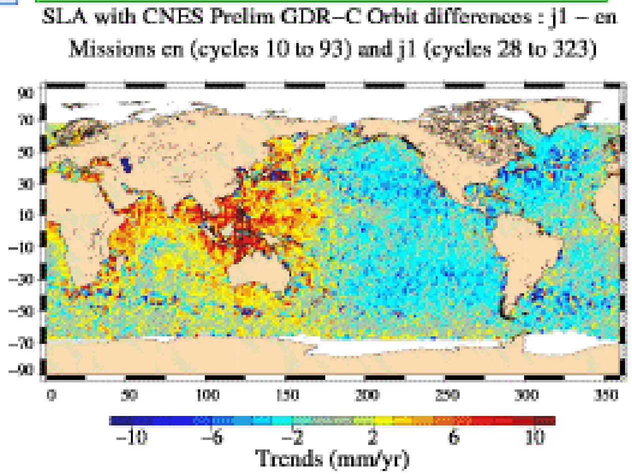
Main message and cautionary note : multi-mission merging is useful/needed for climate investigations (e.g. reduce aliasing and errors) but adding missions **does not automatically improve the quality for climate studies**

Regional Mean Sea Level trend differences Jason-1-Envisat and orbit standard impact

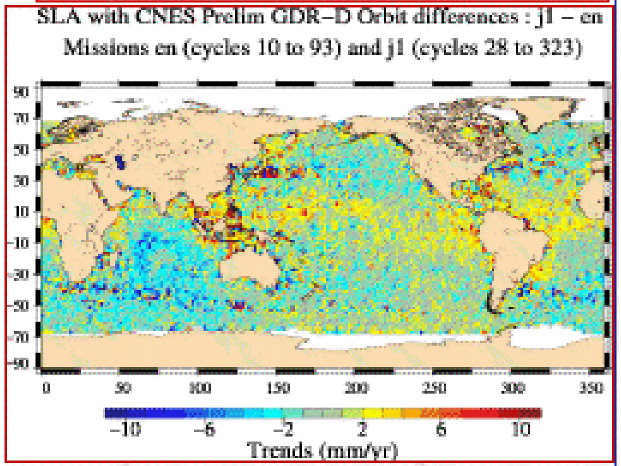
SLA using GDR-A-B Orbits



SLA using GDR-C Orbits



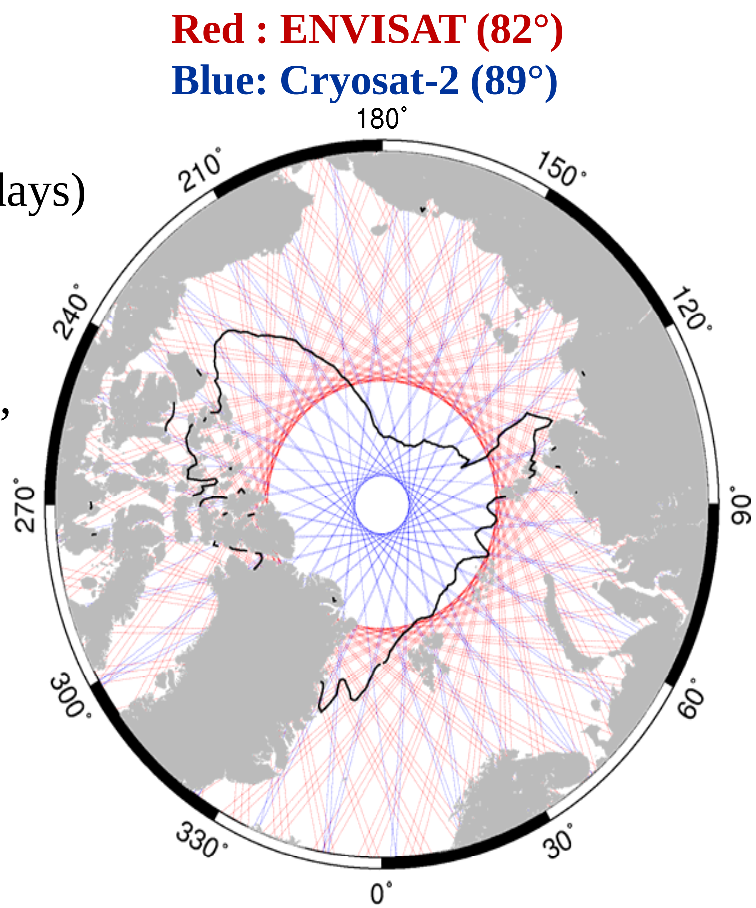
SLA using GDR-D Orbits



- Thanks to multimision analysis, Geographically correlated biais were observed on Envisat and Jasons missions.
- Notably, the gravity field used in the orbit solution was shown to have a great impact on the long term drift for all missions. With the latest standard (futur GDR-D), regional consistency between mission is largely improved.

Short term issues to improve the altimeter constellation

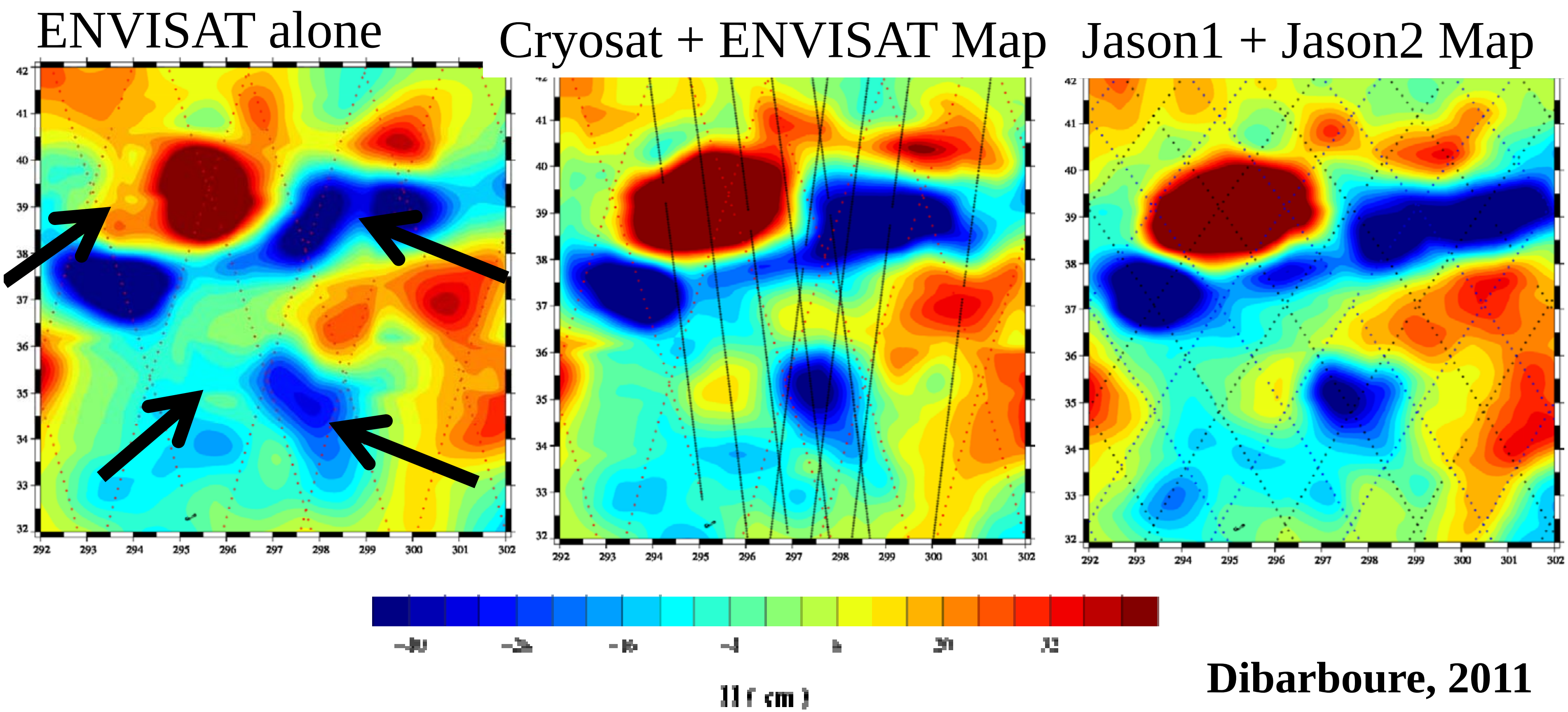
Contribution of Cryosat-2 to the constellation



- Cryosphere oriented altimetry mission
  - Non-repeat (cycle: 369 days, sub-cycles: 30 days)
  - Quasi polar orbit (89°)
  - High-quality altimeter (but no radiometer)
  - Experimental Earth Explorer (not operational, oceanography is a secondary objective)
- Three instrument modes
  - LRM (traditional): ocean and continental ice
  - SARin (interferometry): freeboard and on PI request (mask)
  - SAR (along-track doppler): sea ice and latitudes higher than 60 – 70°
- Prototypes for ocean have demonstrated that Cryosat can be exploited in NRT for operational applications. Cryosat can complement existing missions and mitigate the effect of the loss of a satelllite (we are in a critical time period for the altimeter constellation).

Contribution of Cryosat in a constellation

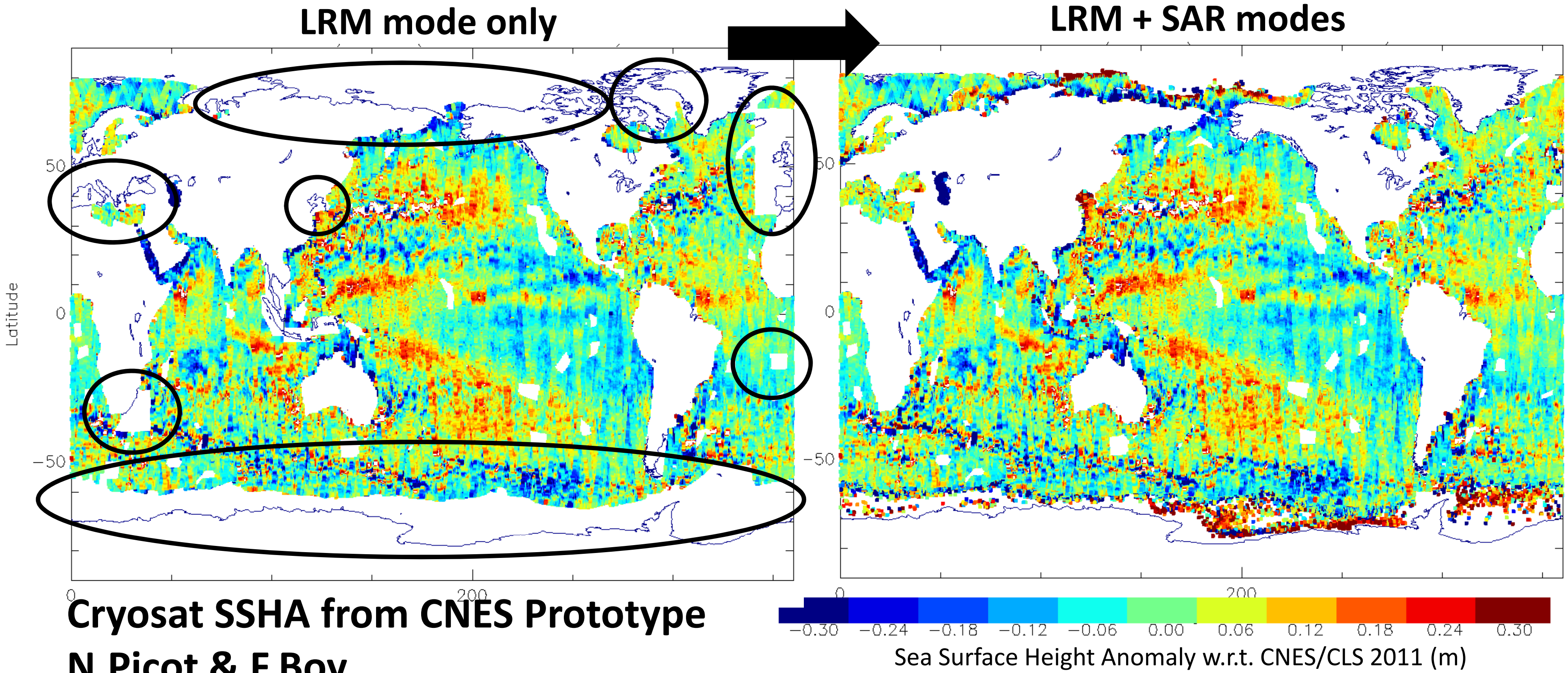
- When Cryosat is added to ENVISAT, eddies are better resolved and more coherent with the Jason1+Jason2 map



Dibarboure, 2011

Benefits of Cryosat-2's SAR coverage

- Cryosat's SAR/doppler mode is activated in various zones of interest: European seas, Algulhas, high latitudes…
- Exploiting the SAR coverage is valuable → Seamless SAR/LRM product needed
- Seamless transitions between true LRM and « pseudo-LRM » is already possible



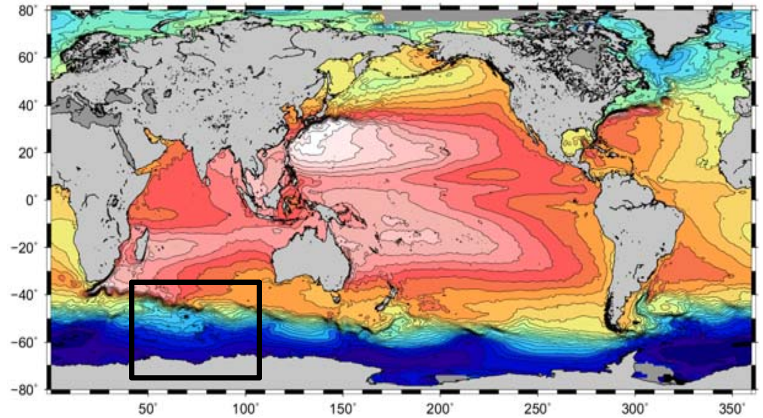
Cryosat SSHA from CNES Prototype
N.Picot & F.Boy

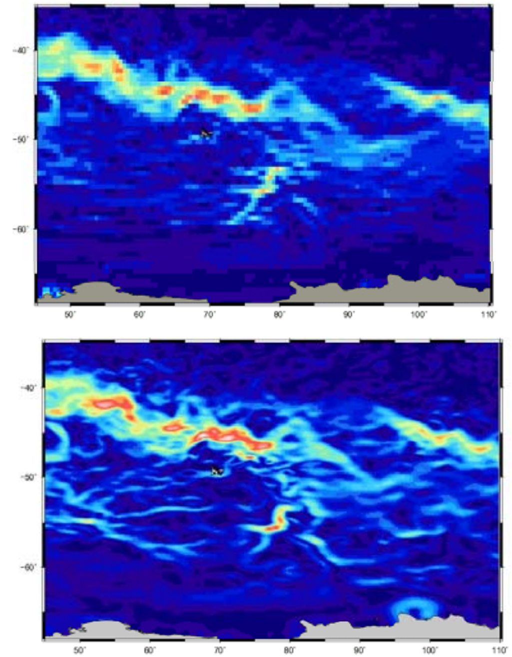
Mean Dynamic Topography (MDT)

- Past altimeter studies have been focused on the analyis of sea level and velocity anomalies because of geoid errors

- With GRACE and GOCE, one can now compute precise MDTs => absolute dynamic topography and currents. A major impact in the use of multiple altimeter data

- Need high resolution MDTs with errors of a few cm. Not there yet but progress expected (see Rio et al., 2011).





Mean currents from existing and refined (GOCE, in-situ) MDT

Summary

- Use of multiple altimeter missions is now common practice for most altimeter investigations. This is mandatory for operational oceanography applications.

- Many new results are based on the use of multiple altimeter data. Science and operational oceanography (see splinter sessions)

- Use of multiple altimeter missions (incl. significant overlap between successive missions) helps a lot to understand errors in a given altimeter system (and improve it).

- Impact at climate scales but some caution is needed when analyzing climate signals from merged products.

- Minimum requirement is 3 to 4 altimeters. Much better space/time sampling needed for mesoscale/submesocale and coastal investigations and applications.

- **Strong need to optimize/improve the operational altimeter constellation for the next 10 years.**

Recommendations

- CRYOSAT over the ice free ocean. Feasibility and utility fully demonstrated. Need to implement as soon as possible a real time processing system for Cryosat (LRM and pseudo LRM for SAR).

- S3A and S3B. Proposed orbit phasing between S3A and S3B is far from being optimal for altimetry. Need to be revisited.

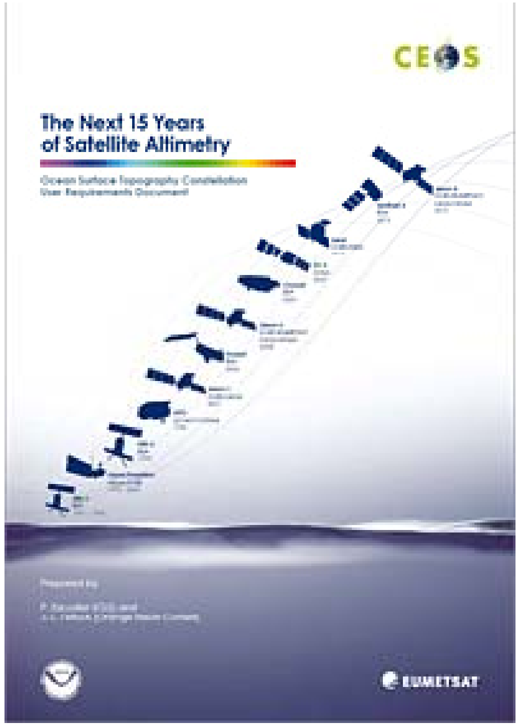
- Use of HY-2 in the merged altimeter products.

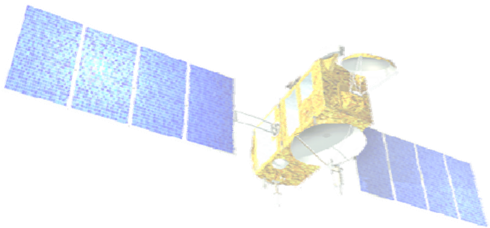
- New missions allow testing evolution of instrumentation (Ka Band for AltiKa => SWOT, SAR mode for Cryosat => S3A-B, Jason-CS) (science infusion). SAR processing looks very promising (see splinter). Need to be carefully assessed by the scientific community.

- Better use of altimeter constellation when geoid is precisely known at smaller scales. A new global MDT at high resolution is needed.

On the virtual constellation concept

- Very much needed
- The main challenge for the CEOS virtual constellation approach is to:
  - ensure a sufficient space/time coverage
  - optimize the design and planning of different missions
  - prepare the integration of new altimeter technologies while maintaining a "good" operational constellation
  - ensure homogenous and consistent processing and reprocessing between agencies.
- Significant progress over the past years but this remains a challenging task !





NEED A STRONG(ER) OSTST !!!