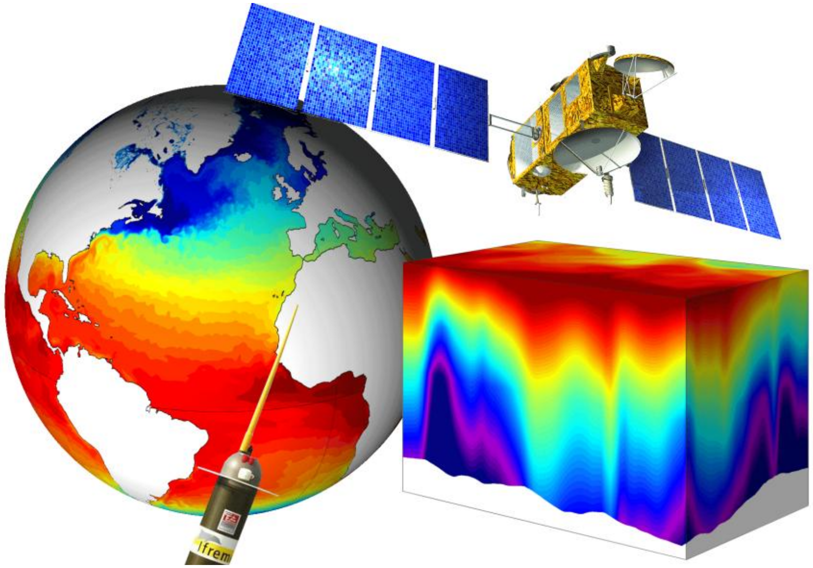
From satellite altimetry to Argo and operational oceanography : three revolutions in oceanography

P.Y. Le Traon

Ifremer and Mercator Ocean



EGU Vienna, Fridtjof Nansen Medal Lecture, April 25, 2012

Outline

- Satellite altimetry
  - ✓ Overview
  - ✓ TOPEX/Poseidon: the breakthrough of high precision altimetry
  - ✓ Development of high resolution merged altimeter products
  - ✓ Applications for mesoscale variability studies

- Argo
  - ✓ The development of Argo
  - ✓ Complementarity with altimetry
  - ✓ Euro-Argo

- GODAE and the development of global operational oceanography
  - ✓ Vision, development and achievements
  - ✓ European contributions (GMES/MyOcean, EuroGOOS)

- Lessons, conclusions and perspectives

GODAE

GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT

The first revolution : satellite alimetry

Satellite altimetry – 20 years of progress

One of the most important satellite technique for oceanography. It provides measurements of sea surface topography (sea level) which is an integral of the ocean interior => Strong constraint for the 4D ocean circulation estimation.

Very mature technique (> 20 years) : GEOS-3 (1975), SEASAT (1978), GEOSAT (1985-1989), ERS-1 (1991-1996), ERS-2 (1995- 2002), GFO (1998 - 2008), TOPEX/POSEIDON (1992-2006), Jason-1 (2001 - ?), ENVISAT (2002 - ?), Jason-2 (2008 - ?), Cryosat-2 (2010-?), HY-2A (2011-?).

but also one of the most challenging in terms of accuracy

Major advances in sensor and processing algorithm performances over the last 20 years. Only possible through a continuous dialogue between engineers and scientists.

As a result, accuracy evolved from several meters to a few cm only

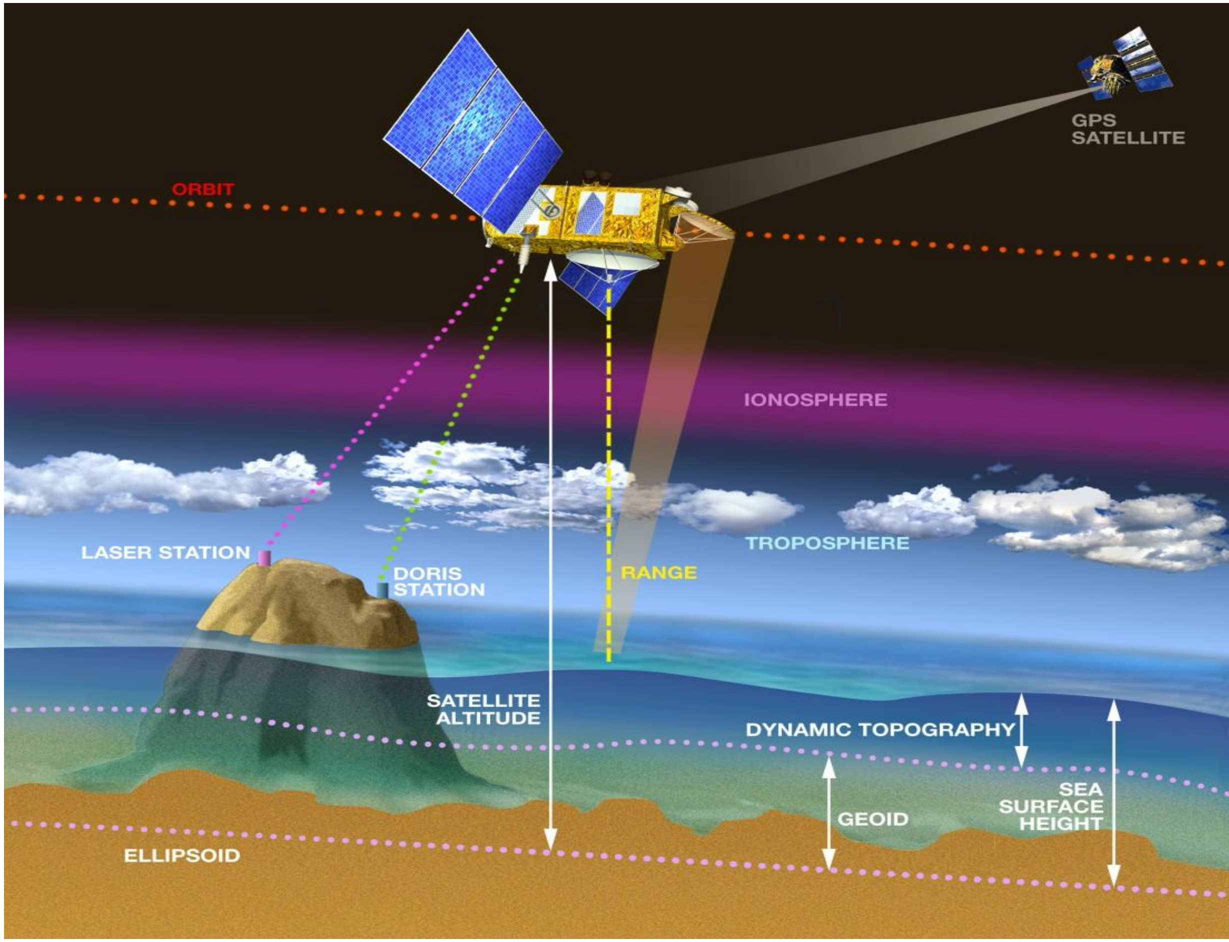
Principle of satellite altimetry

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

SSH = Orbit – Range – Σ Corr

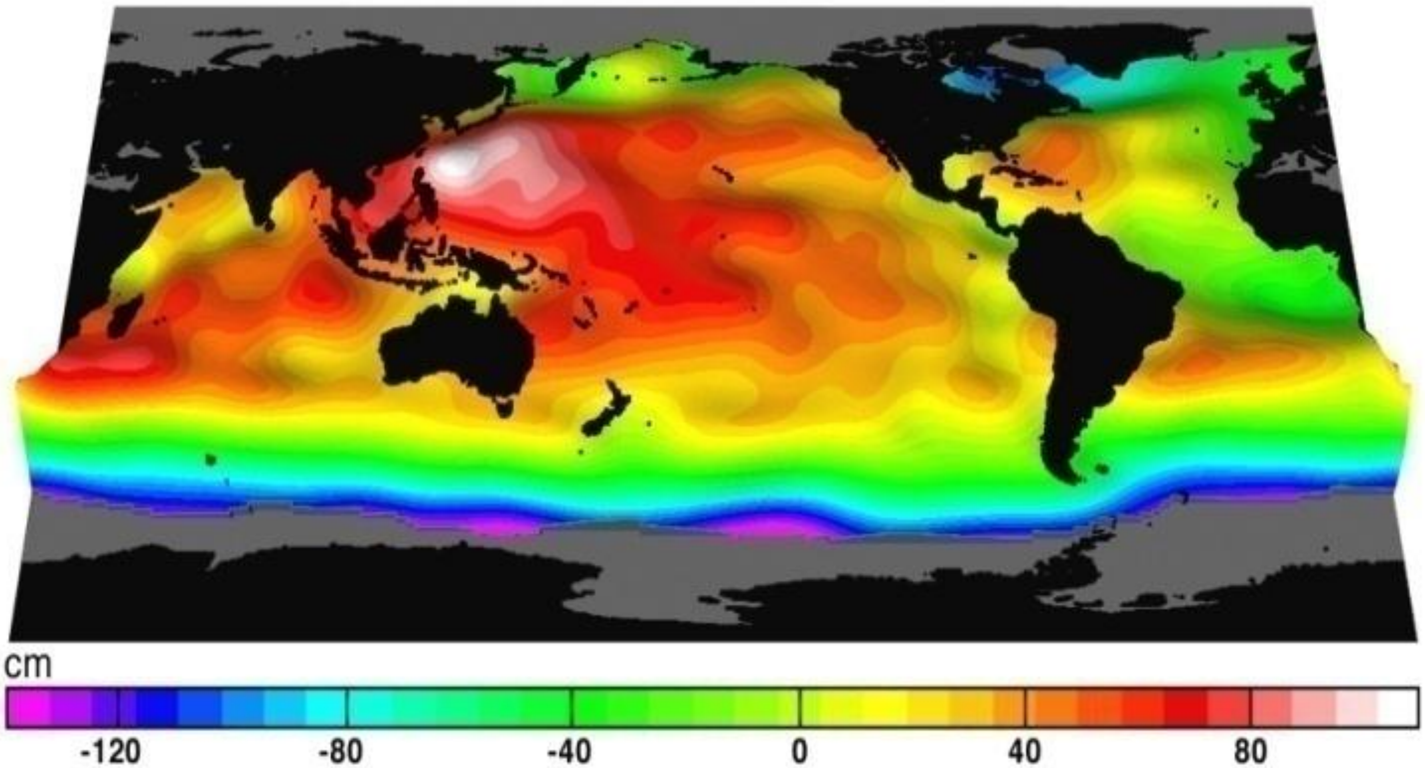
Precision of the SSH

- Orbit error
- Errors on the range
  - Instrumental noise
  - Various instrumental errors,
  - Tropospheric and ionospheric effects
  - Various geophysical errors (e.g., tides, inverse barometer effects, …)



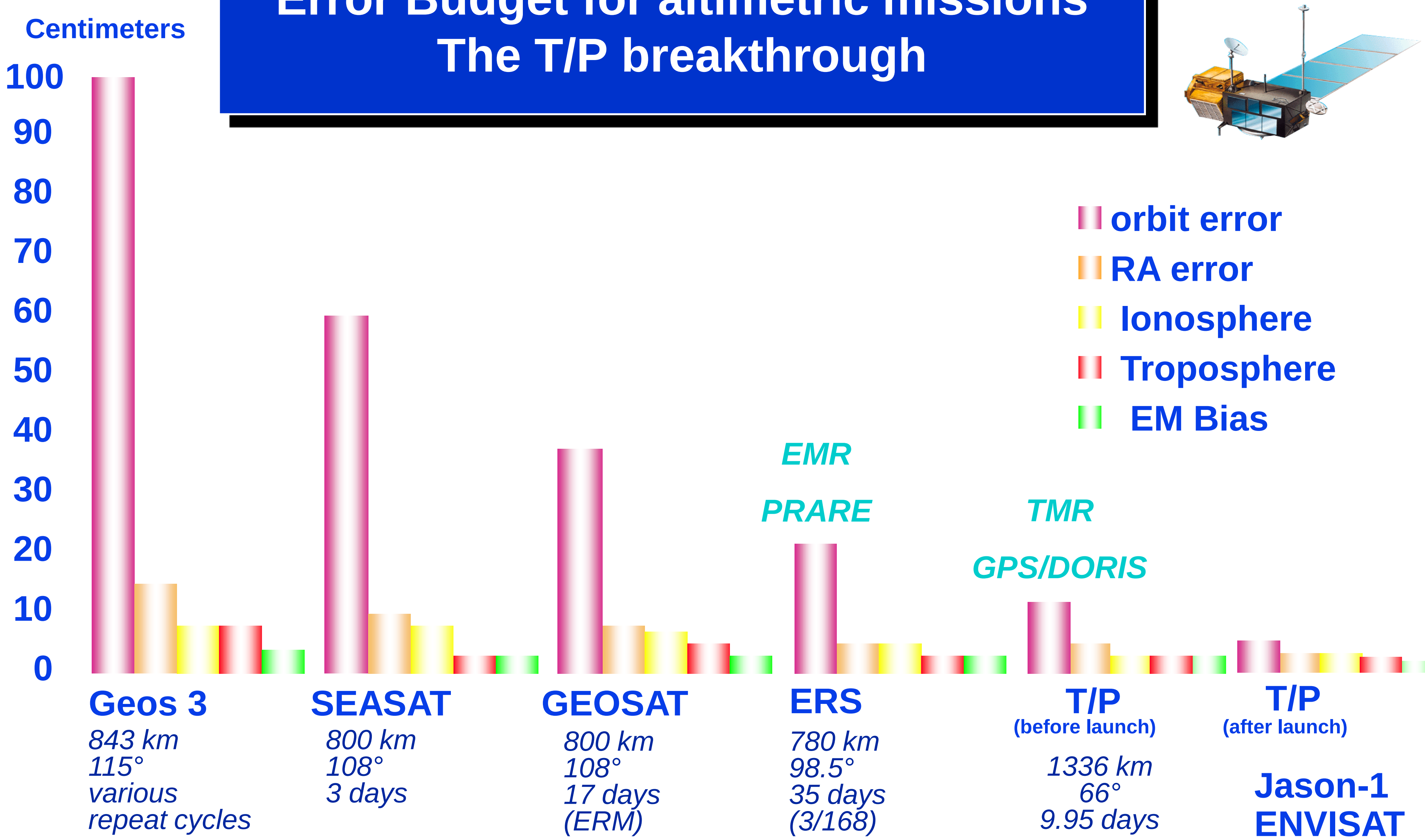
SSH = dynamic topography + geoid

Satellite altimetry provides measurements of the dynamic topography η (i.e. sea level relative to the geoid)



$\eta \Leftrightarrow$ surface geostrophic ocean circulation

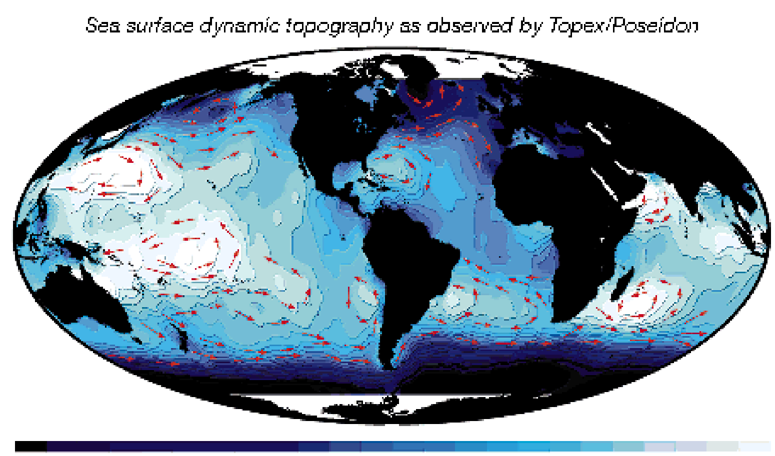
Error Budget for altimetric missions
The T/P breakthrough



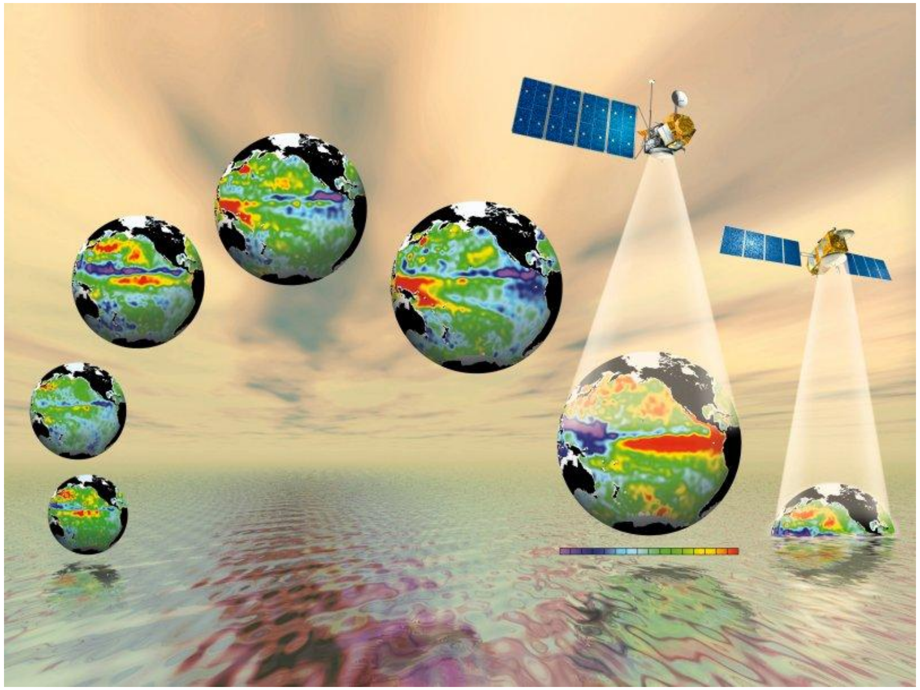
T/P- Jason => Instantaneous sea level error < 4 cm

TOPEX/Poseidon and the Jason series
The revolution of high precision altimetry

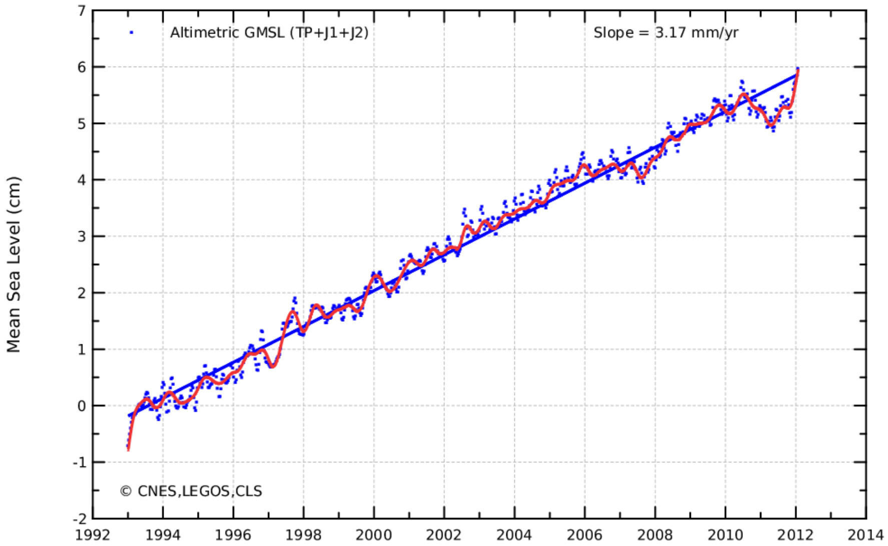
- Topex/Poseidon launch in August, 1992. Jason-1 in 2001, Jason-2 in 2008.
- Payload and satellite orbit optimized for sea level measurements.
- For the first time, observations of the large scale sea level and ocean circulation variations.
- Mean sea level variations with an accuracy < 1 mm/year.

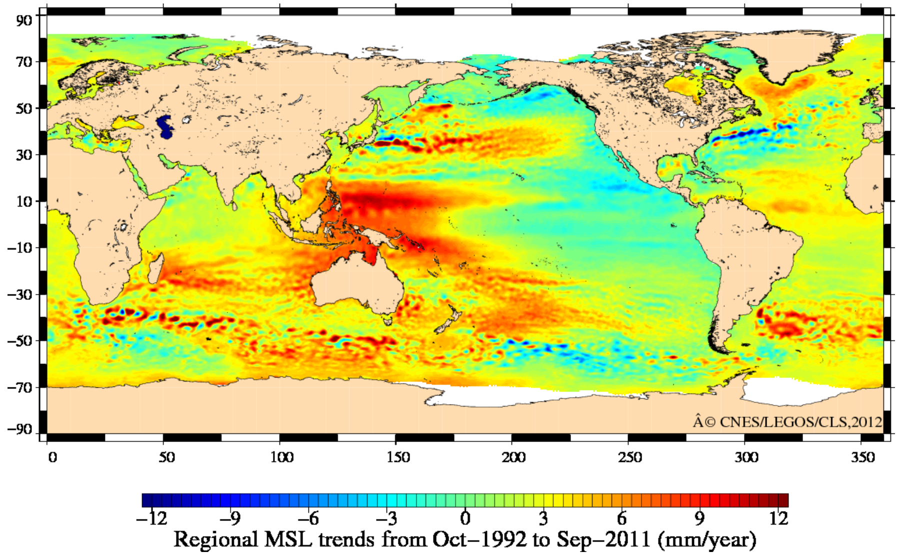


Two illustrations of the TOPEX/Poseidon (and Jason) outstanding achievements for large scale sea level monitoring



El Nino/La Nina/tropical dynamics from T/P and Jason-1





Mean Sea Level Rise from T/P, Jason-1 and Jason-2

The critical role of TOPEX/Poseidon SWT and OSTST

A strong and committed international scientific team dedicated to the improvement of altimeter performance for science investigations

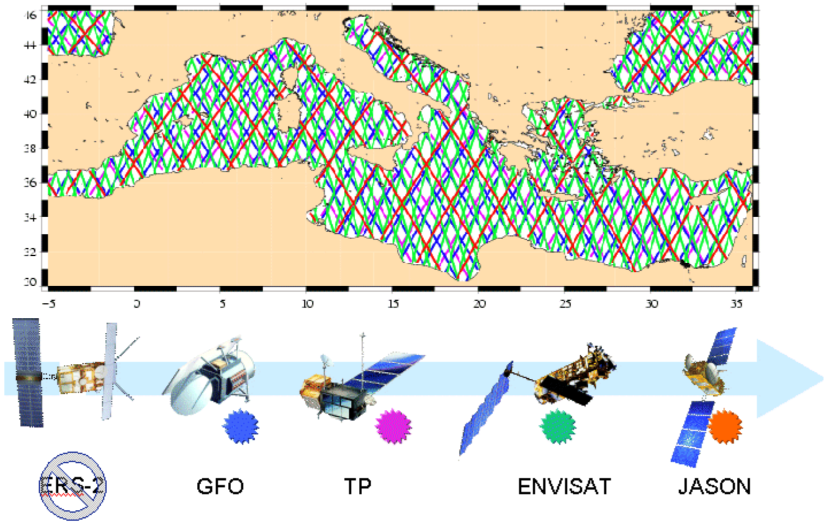
«Swinging» from mesoscale to large scale focuses

The 70s and the mesoscale decade: POLYGON, MODE and POLYMODE

Pre-TOPEX/Poseidon era : mesoscale variability (GEOSAT)

TOPEX/Poseidon: large scale variability (new views) – WOCE

Post TOPEX/Poseidon era: renewed interest in mesoscale variability thanks to the availability of multiple altimeter missions => (much) better recognition and understanding of the role and importance of eddies



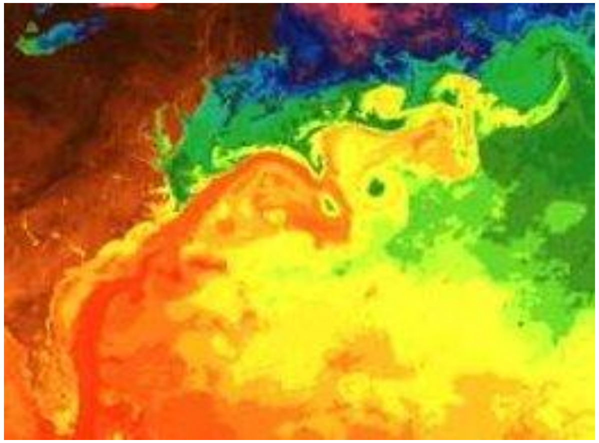
Satellite altimetry and mesoscale variability

The ocean is a turbulent system. Its circulation is dominated by mesoscale variability : eddies, meanders, rings, filaments, waves, fronts…

Energy exceeds the mean flow by an order of magnitude.
Space/time scales of 50 -500 km and 10-100 days.

Main forcing mechanisms : instabilities of the mean flow (direct wind forcing, role of bathymetry).

Feedback on the mean flow (eddy-driven).



A better understanding of ocean circulation (including large scale and its role on climate) requires to observe and model it at high space and time resolution.

A major contribution of satellite altimetry. A "new" vision of the ocean. Requires multiple altimeter missions and merging techniques.

Merging multiple satellite altimeter data
Not an easy task !

Need homogeneous and inter-calibrated data sets

Need to use consistent mean profiles calculated over the same time period to extract Sea Level Anomaly (SLA)

Merge the different data sets via a mapping technique

A brief history of the development of multiple altimeter products (SSALTO/DUACS) (1)

- **In 1992, ERS-1 was flying simultaneously with T/P.** Less precise altimeter mission but orbit well suited for mesoscale studies. Merging multiple altimeter missions first required to reduce ERS-1 orbit error (>30 cm for real time).

- **Use of T/P to improve ERS-1 accuracy**

- **Start working on the problem in 1994 and first demonstration in 1995:**
  - ✓ Le Traon, P.Y., P. Gaspar, F. Bouyssel, and H. Makhmaraa, 1995: Using Topex/Poseidon data to enhance ERS-1 data. Journal of Atmospheric and Oceanic Technology, 12, 161-170.
  - ✓ Le Traon, P.Y., P. Gaspar, F. Ogor, and J. Dorandeu, 1995. Satellites work in tandem to improve accuracy of data EOS, Trans. AGU, 76, 385-389

A brief history of the development of multiple altimeter products (SSALTO/DUACS) (2)

- Demonstration done in 1994/1995. Our group was ready to reprocess ERS-1 data and prepare improved ERS-1 data sets adjusted onto T/P.

- Next step was to convince funding agencies. The most difficult part. Not clear who should fund such an activity. **User requirements and user surveys (CEO programme – EC Environment and Climate Programme)** (pathfinder and proof of concept studies in 1995/1996).

- 1995-1998: support from CNES, Midi Pyrenees Regional Council and several European projects (AGORA, MATER, CANIGO). **Develop and improve the multiple altimeter mapping technique. Global and regional applications.**

- 1998-2001: DUACS (Developing Use of Altimetry for Climate Studies) European project (CLS, ECMWF, UKMO, MPI, Cerfacs) => develop the near real time processing system. **A major step forward.**

- 2002- now: Part of the CNES multi-satellite ground segment (SSALTO/DUACS). System continuous improvements through EC projects (ENACT, MERSEA, GMES/MyOcean).

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 103, NO. C4, PAGES 8045–8057, APRIL 15, 1998

ERS-1/2 orbit improvement using TOPEX/POSEIDON: The 2 cm challenge

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Collecte, Localisation, Satellites Space Oceanography Division, Ramonville Saint-Agne, France

JOURNAL OF ATMOSPHERIC AND OCEANIC TECHNOLOGY

An Improved Mapping Method of Multisatellite Altimeter Data

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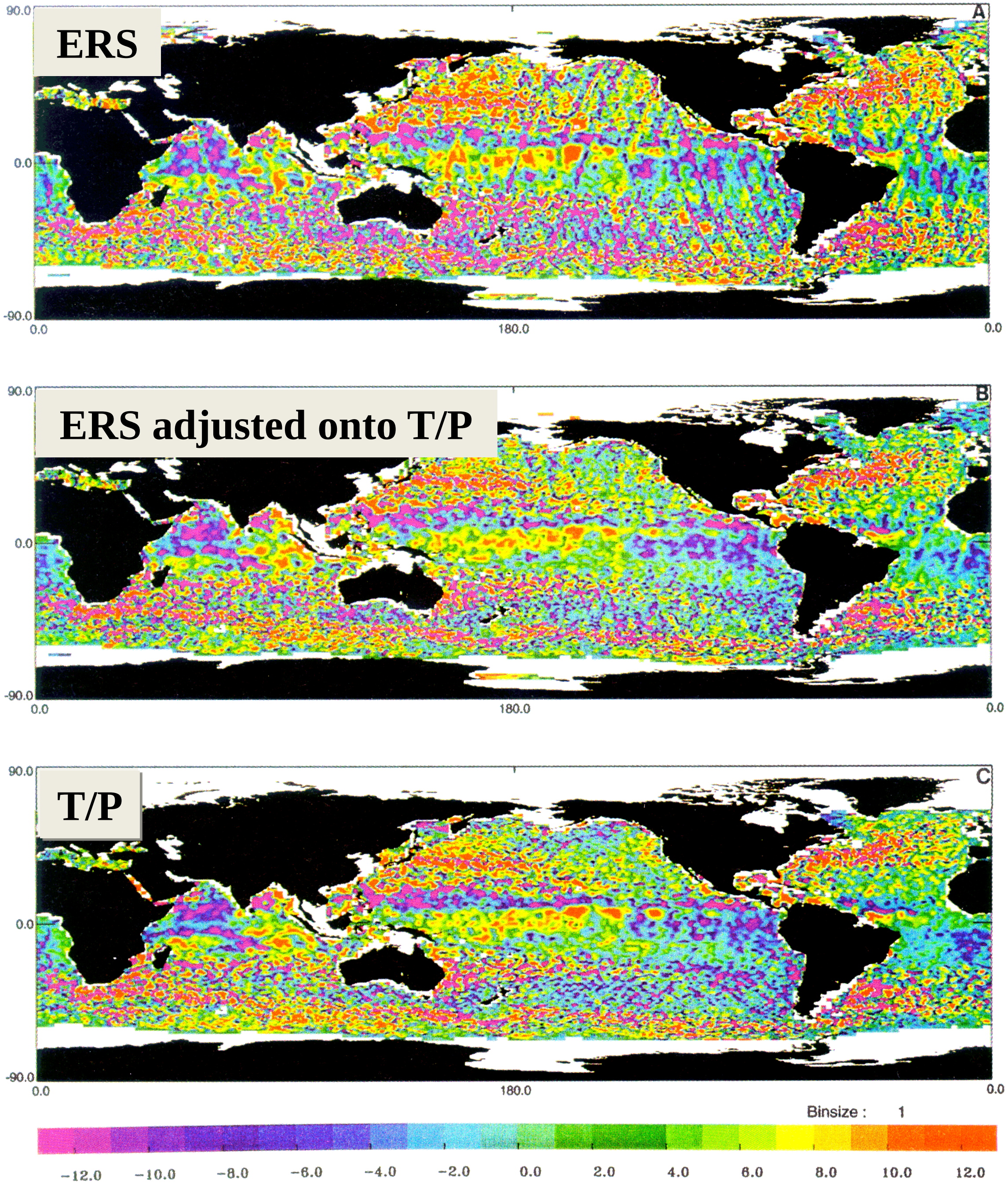
CLS—Space Oceanography Division, Toulouse, France

(Manuscript received 16 October 1996, in final form 14 April 1997)



Use of TOPEX/POSEIDON as a reference for the ERS-1/2 missions

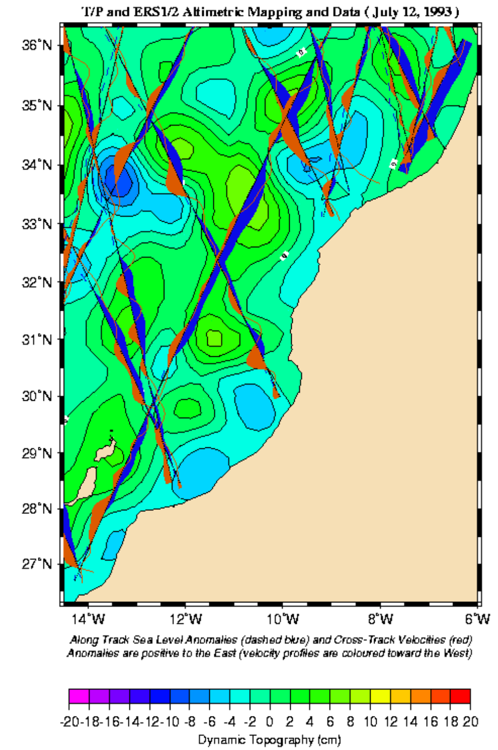
Global minimization of dual (TP-ERS) and (ERS-ERS) crossover differences

Reduces ERS-1/2 biases and orbit errors

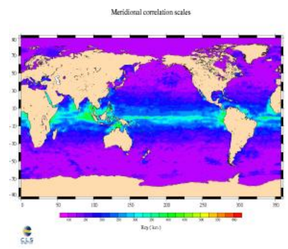
Le Traon and Ogor, JGR, 1998

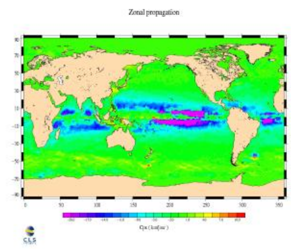
Objective analysis for mapping altimetry data

Weighting scheme (optimal interpolation) to map irregular altimeter data onto a regular grid (Bretherton et al., 1976)



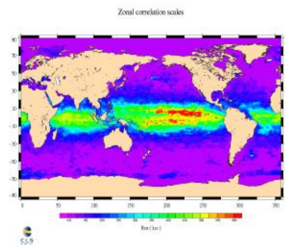
Use **an a priori knowledge of space and time scales of signal (covariance)** (derived from altimeter observations). Includes propagation velocities.

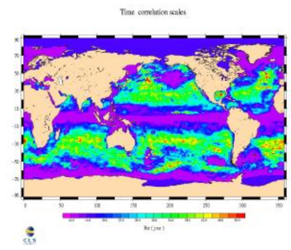


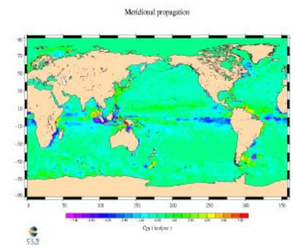


Space and time scales, propagation velocities derived from TP+ERS maps

Noise characterization is essential: white noise, unresolved scales, correlated noise (e.g. tides, high frequency effects – pressure and wind).





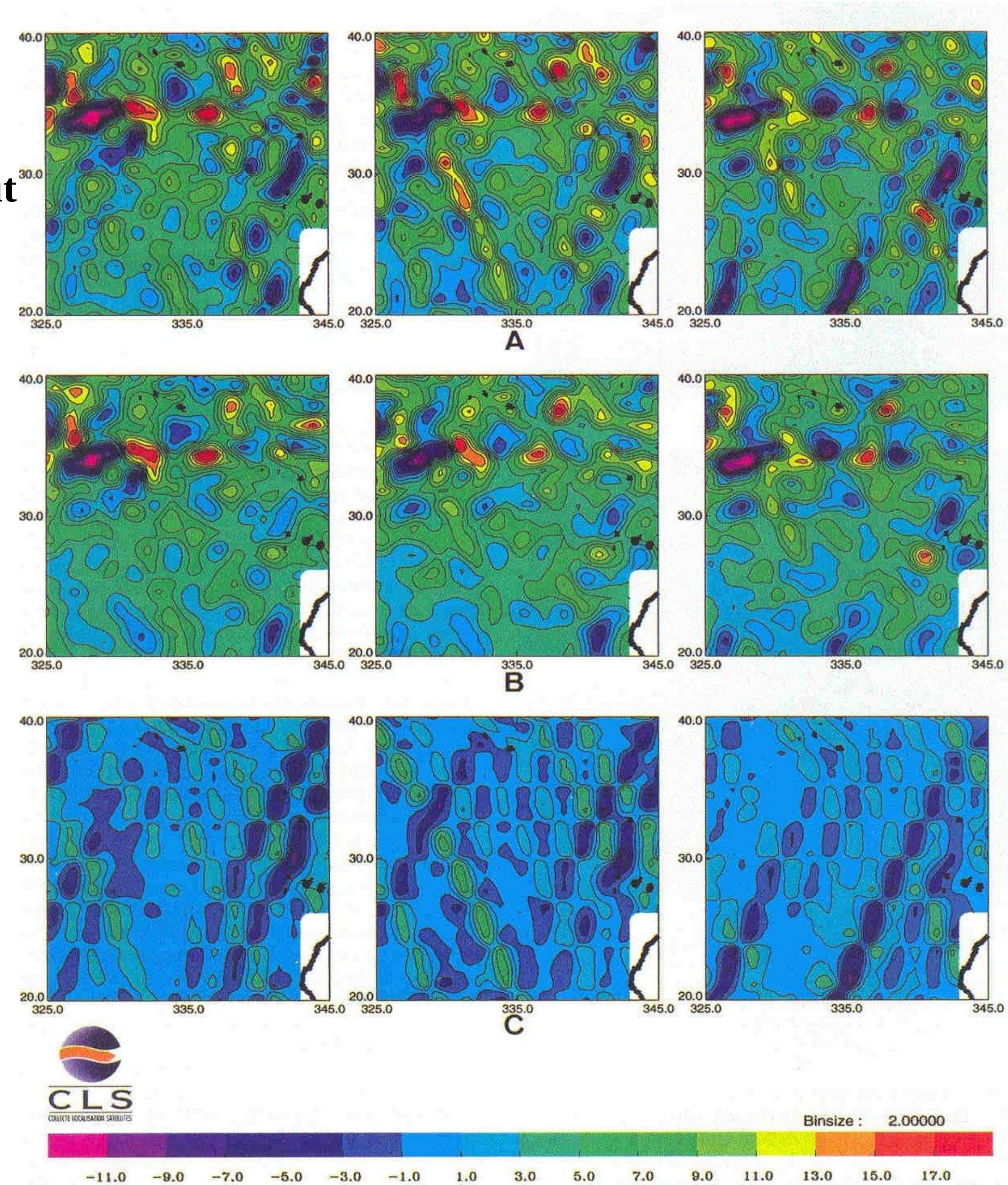


Taking into account long wavelength errors (LWE) in the optimal interpolation technique (Le Traon et al., 1998)

Without LWE

With LWE

Diff.



The noise covariance <εi εj> is usually diagonal. Here is takes the following form:

- **$\langle \varepsilon_i \varepsilon_j \rangle = \delta_{i,j}\, b^2$ for points i, j not on different tracks/cycles**
- **$\langle \varepsilon_i \varepsilon_j \rangle = \delta_{i,j}\, b^2 + E_{LW}$ for points i, j on the same track/cycle**
- **b^2 = measurement noise variance**
- **E_{LW} = variance of long wavelength errors and high frequency signals**

Conventional analysis (COA) versus the new method (LWA)

T/P + *ERS-1*	COA	LWA	(COA–LWA)
$\langle h^2 \rangle$	23	17	5
$\langle u^2 \rangle$	50	39	10
$\langle v^2 \rangle$	100	52	41

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 105, NO. C8, PAGES 19,477–19,498, AUGUST 15, 2000

Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and -2

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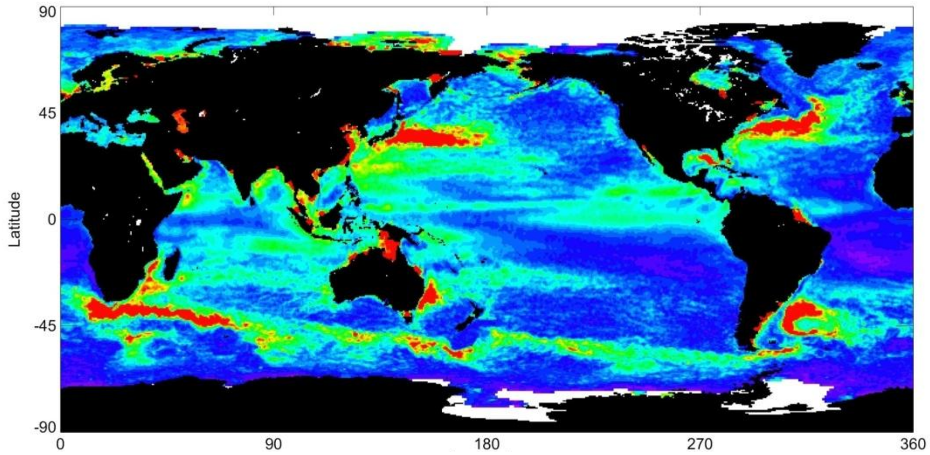
First global detailed description of mesoscale variability from T/P and ERS-1/2. Global maps from T/P and ERS-1/2

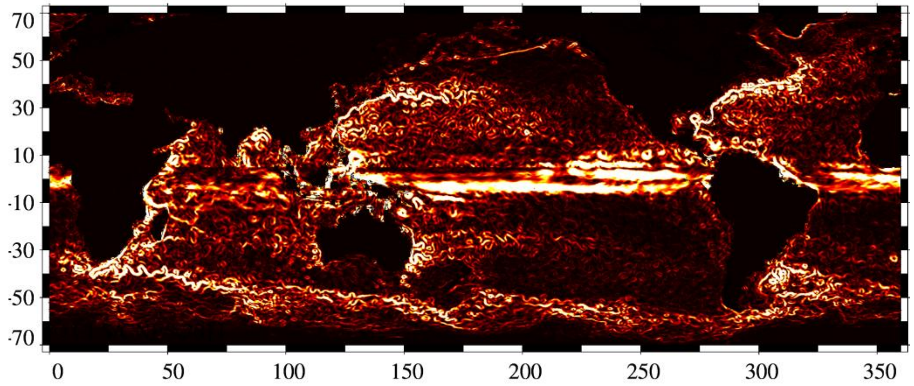
The task of merging satellite data is formidable and requires considerable statistical skill…The best picture yet of the ocean and its vigorous eddy component (Stammer, News and Views, Nature, 2000)

The merged T/P-ERS altimeter products: a new view of the ocean

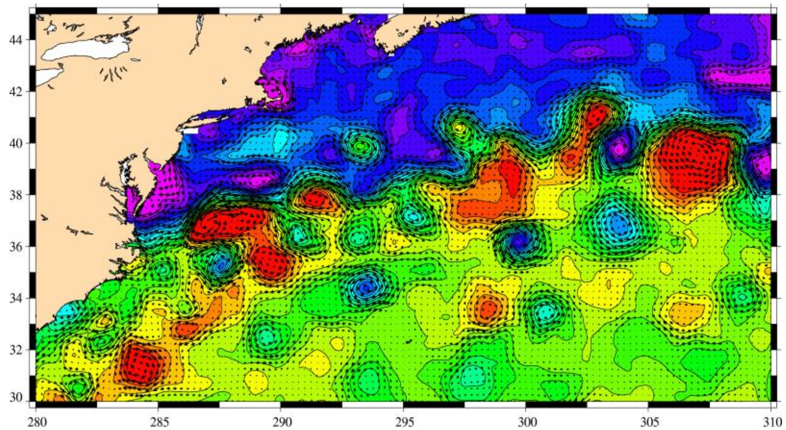


Rms Sea Level Variability from T/P and ERS maps

Mesoscale variability ubiquitous in all oceans and latitudes



Kinetic Energy from a SSALTO/DUACS altimeter map



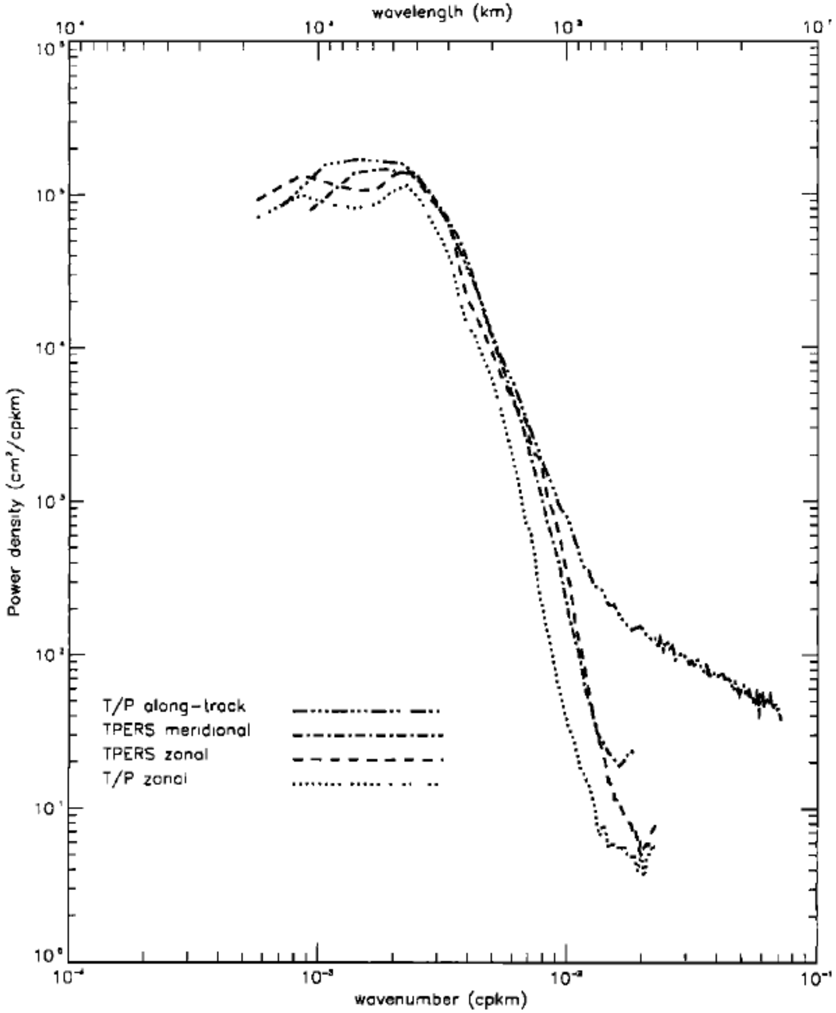
The Gulf Stream and its meanders/eddies from T/P and ERS

A stimulating debate in the 90's

What do multiple altimeters resolve ? Can we map eddies ?

- Greenslade, Diana J. M., Dudley B. Chelton, Michael G. Schlax, 1997: The Midlatitude Resolution Capability of Sea Level Fields Constructed from Single and Multiple Satellite Altimeter Datasets. *J. Atmos. Oceanic Technol.*, 14, 849–870.
- Tai, C-K., 1998: On the spectral ranges that are resolved by a single satellite in exact-repeat sampling mode. *J. Atmos. Oceanic Technol*, 15, 1459–1470.
- Le Traon, P-Y., and G. Dibarboure, 1999: Mesoscale mapping capabilities of multiple-satellite altimeter missions. *J. Atmos. Oceanic Technol.*, 16, 1208–1223.
- Le Traon, P. Y., G. Dibarboure, N. Ducet, 2001: Use of a High-Resolution Model to Analyze the Mapping Capabilities of Multiple-Altimeter Missions. *J. Atmos. Oceanic Technol.*, 18, 1277–1288.
- Le Traon, P. Y. and G. Dibarboure, 2002: Velocity Mapping Capabilities of Present and Future Altimeter Missions: The Role of High-Frequency Signals. *J. Atmos. Oceanic Technol.*, 19, 2077–2087.
- Tai, C-K., 2004: The resolving power of a single exact-repeat altimetric satellite or a coordinated constellation of satellites. *J. Atmos. Oceanic Technol*, 21, 810–818.
- Chelton, Dudley B., Michael G. Schlax, 2003: The Accuracies of Smoothed Sea Surface Height Fields Constructed from Tandem Satellite Altimeter Datasets. *J. Atmos. Oceanic Technol.*, 20, 1276–1302.

Wavelengths resolved by T/P+ERS altimeter maps (Ducet et al., 2000)

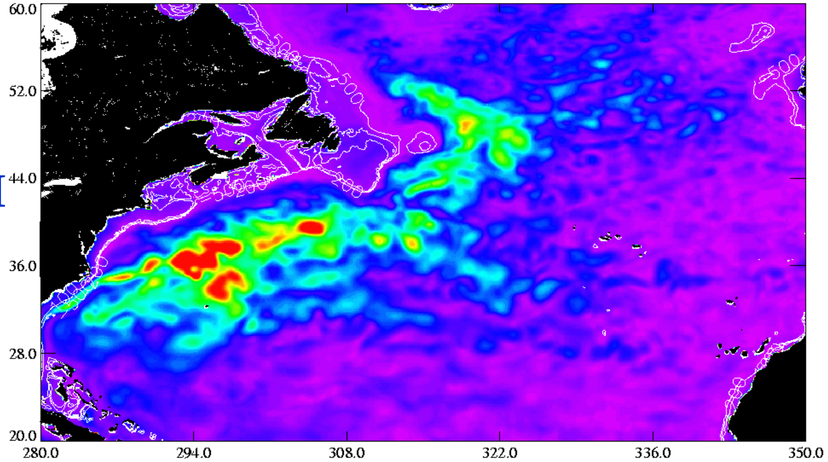


Sea level spectra from along-track and mapped data

Only wavelengths larger than 200 km are reproduced on mapped data

Sea level mapping error from Jason-1+ENVISAT simulated from the Los Alamos Model (Le Traon et al., 2001; Le Traon and Dibarboure, 2002)

LAM rms SLA

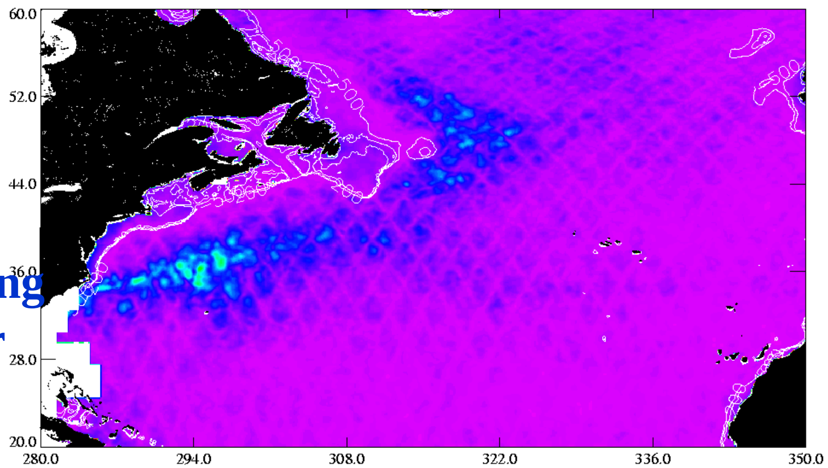


Sea level can be mapped with an accuracy of 5 to 10% of the signal variance

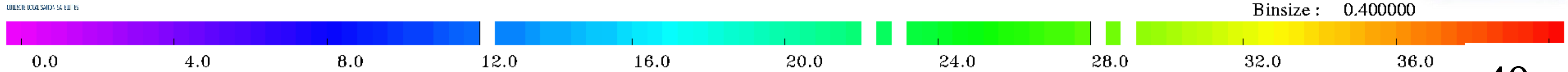
Velocity mapping error from 20 to 40% of the signal variance

A large part of mapping errors is due to high frequency (< 20 days) and high wavenumbers signals.

Rms Mapping error

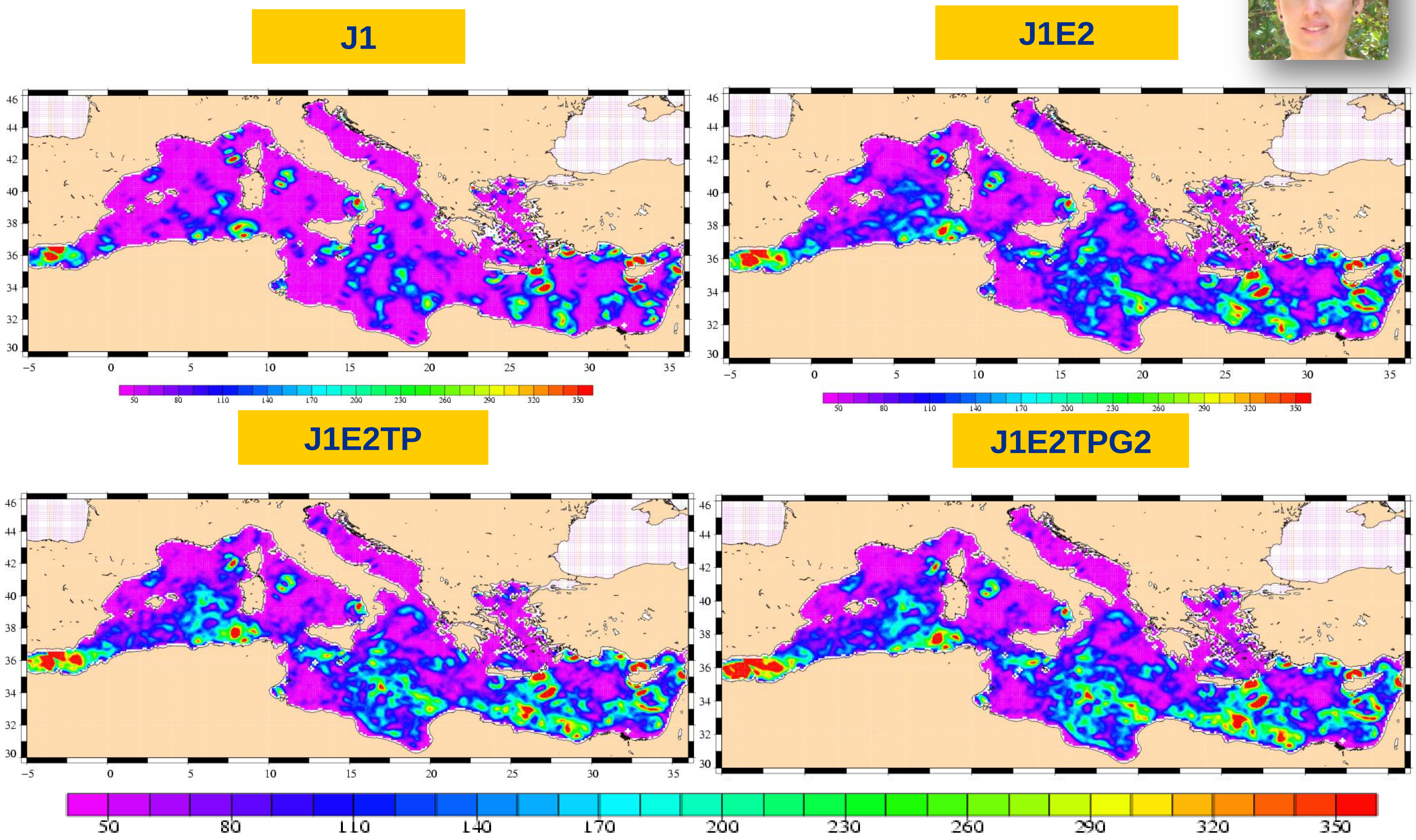


CLS



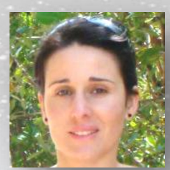
40 cm

Eddy Kinetic Energy in the Mediterranean Sea (Pascual et al., 2004) from multiple altimeter missions => need multiple altimeter missions for surface velocity monitoring



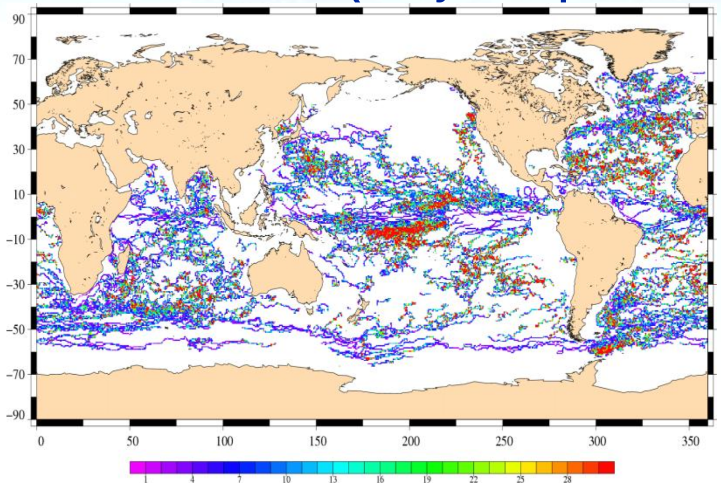
Surface current mapping using 4 altimeters

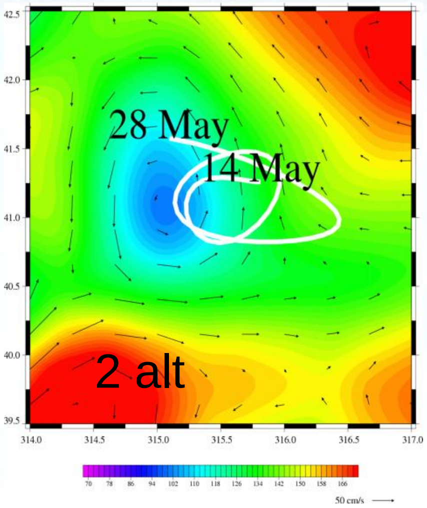
Altimetry (+geoid+winds) vs drifters

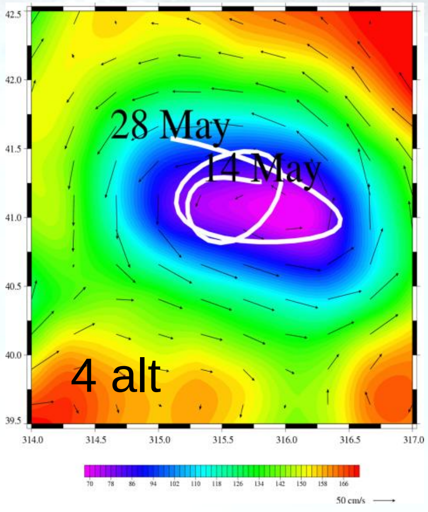


(Pascual et al., GRL, 2006)

673000 measures (3 days low pass filter)







	Geostrophic Velocity Anomalies	Absolute Geostrophic Velocity	Absolute Velocity (+Ekman component)	Improvement using 4 sat missions
U	59.6%	34.2%	24.3%	9%
V	39.2%	32.1%	28.4%	15%

Need > 2 altimeters and precise mean dynamic topography (geoid)

Contribution of multiple altimeters

Mesoscale variability and global characterization of eddies

Monitoring fronts in the ACC

Multiple migrating quasi zonal jets

Eddies and Rossby waves

Model validation

Testing turbulence theories

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

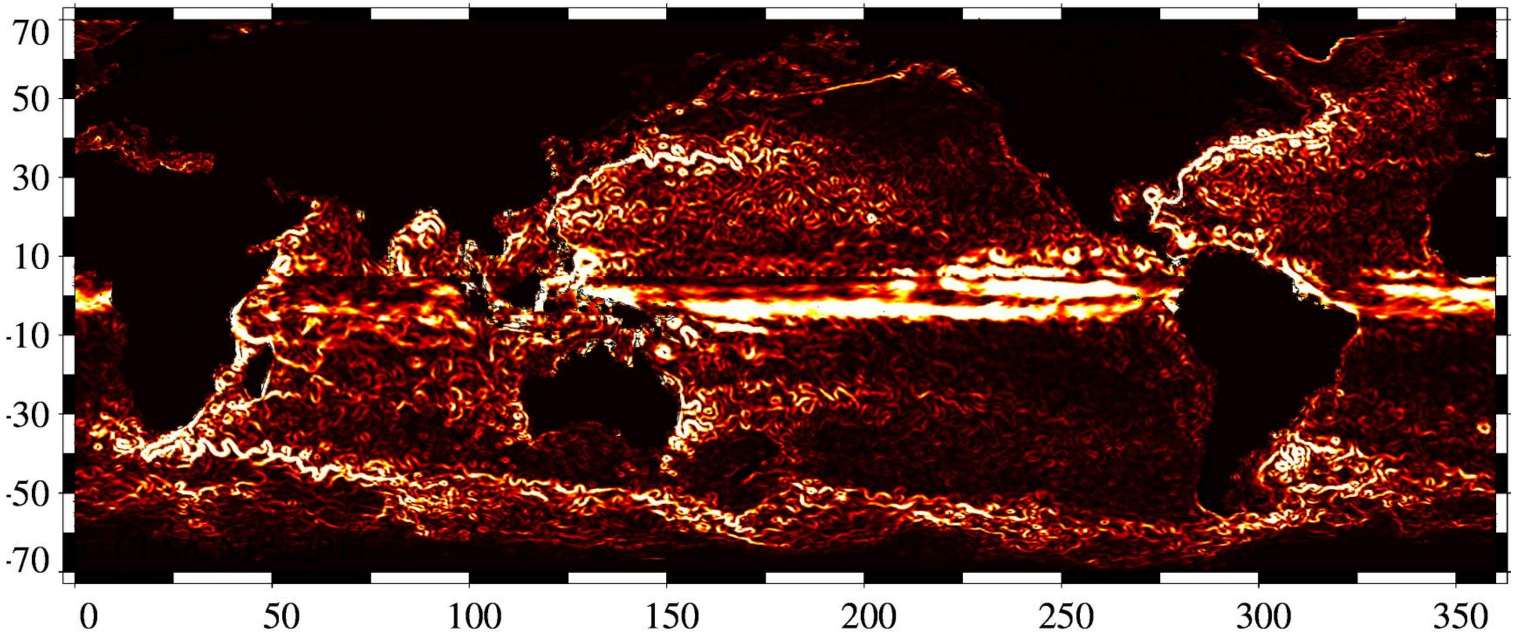
Coastal dynamics

Argo and altimetry

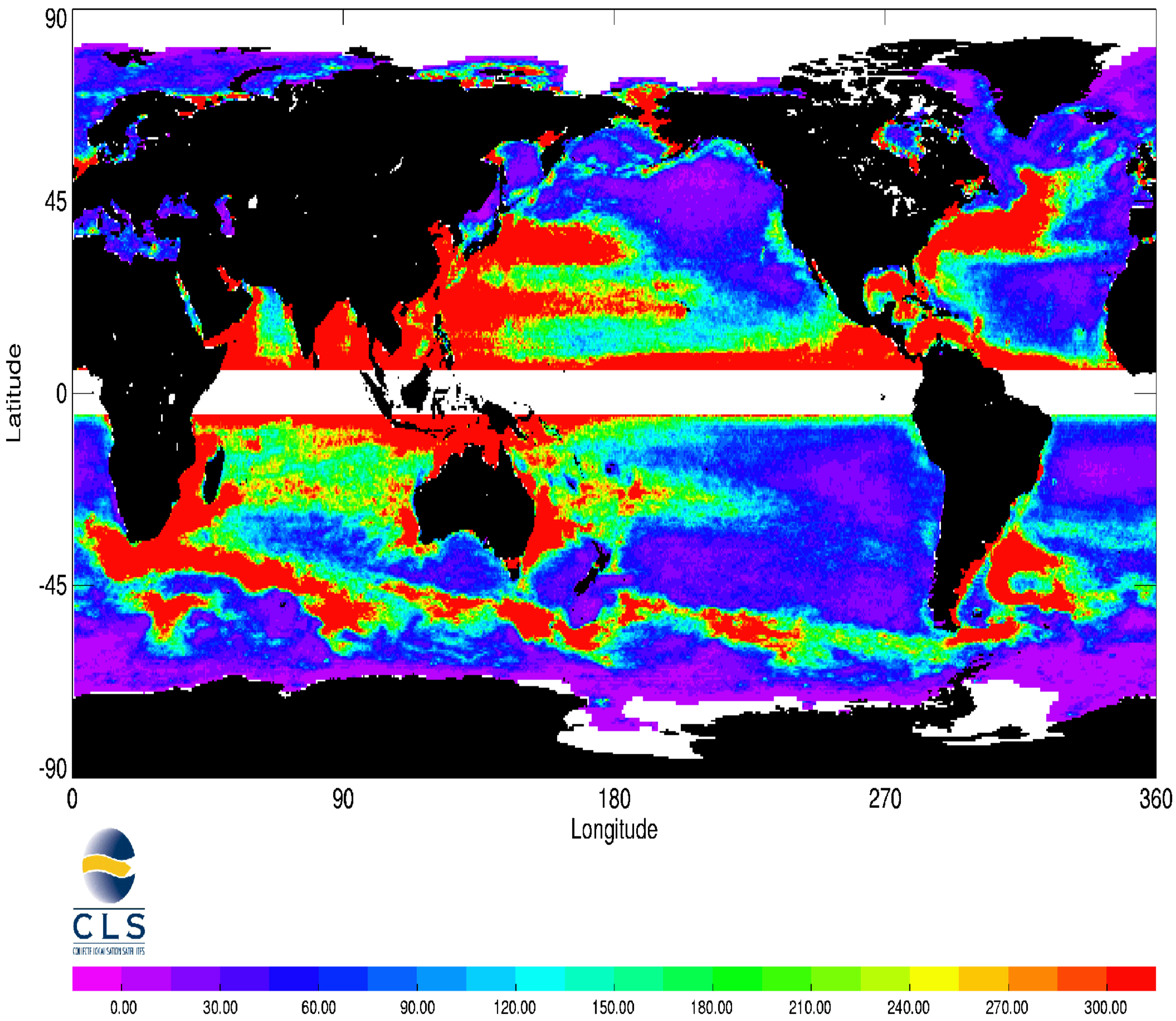
Data assimilation

Applications and operational oceanography

A few illustrations of the contribution of altimetry to mesoscale variability studies



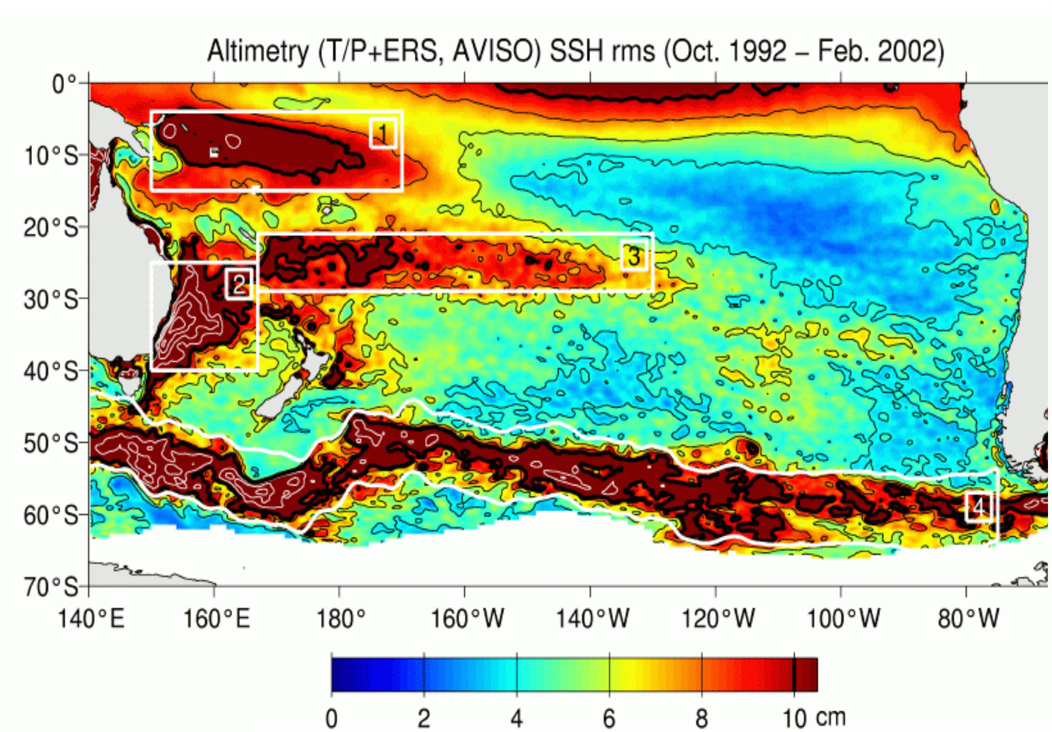
Eddy Kinetic Energy from T/P+ERS

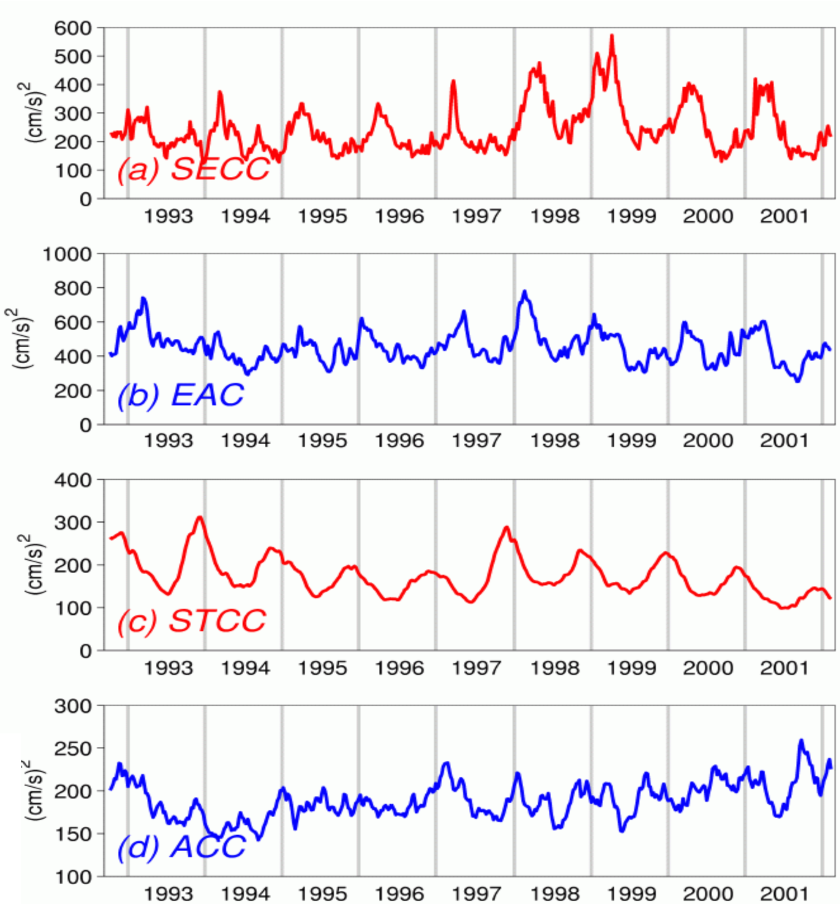


The improved resolution from T/P and ERS has provided a characterization of the EKE with a level of detail never before achieved at a global scale (Ducet et al., 2000).

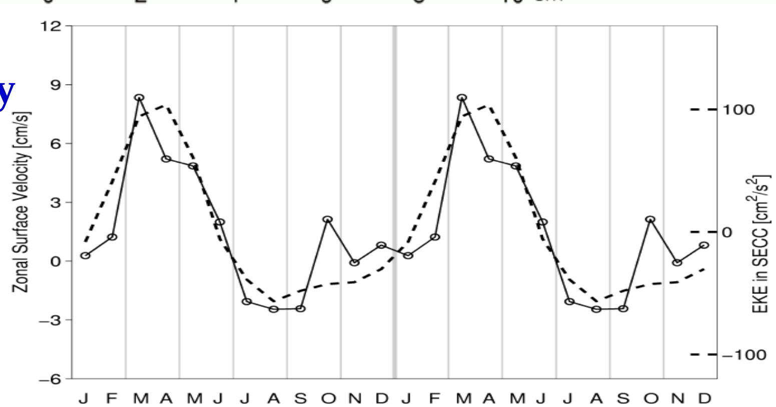
It has also allowed the characterization of anisotropy and a better description of eddy/mean flow interactions (e.g. Ducet et al., 2000; Ducet and Le Traon, 2001).

Seasonal Modulation in the EKE Field of the South Pacific Ocean (Qiu and Chen, JPO, 2004)



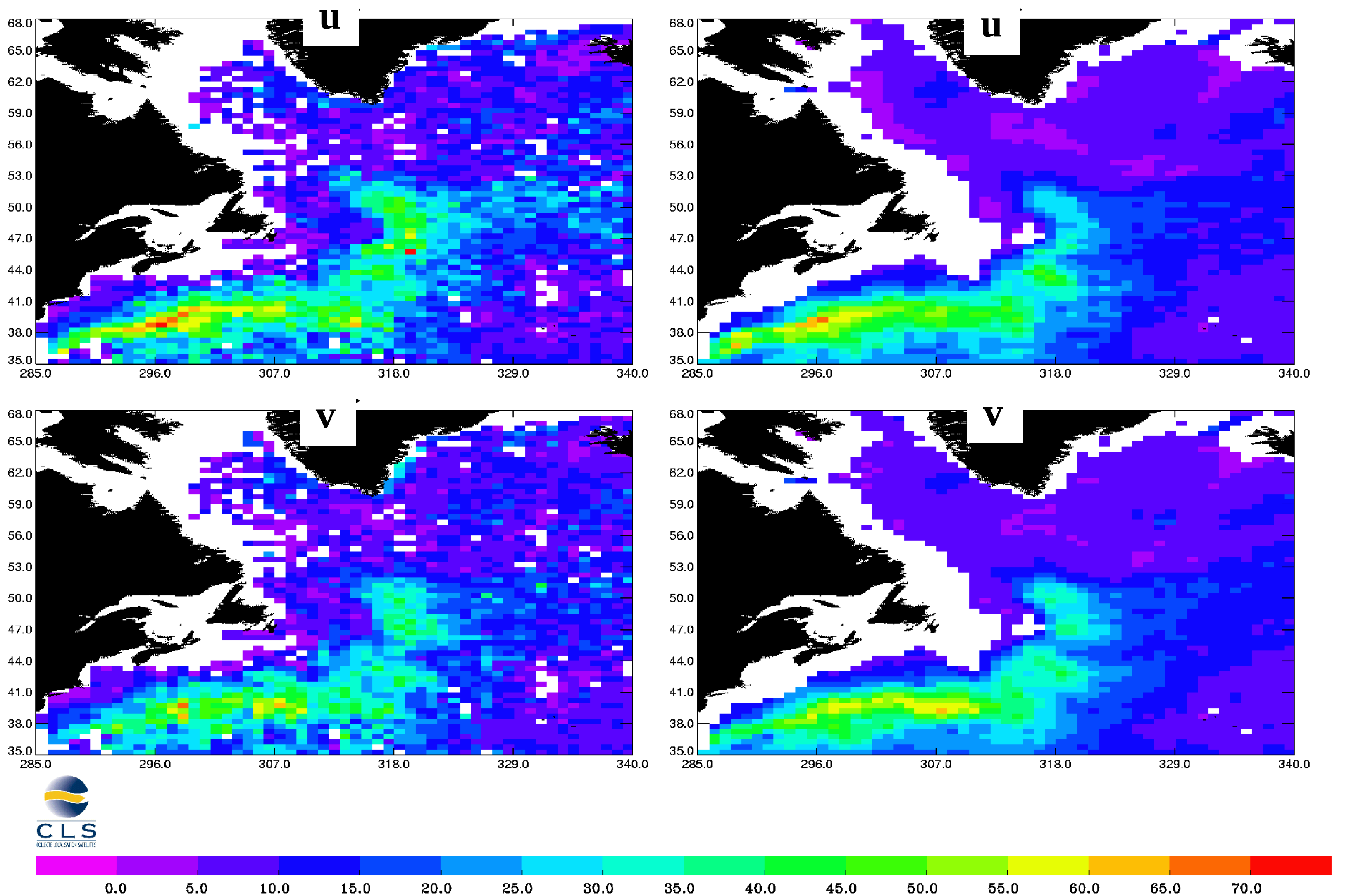


SECC intensity vs. EKE level in SECC-SEC

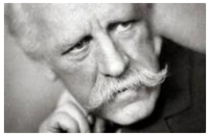


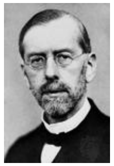
EKE seasonal modulation results from baroclinic (STCC) and barotopric (SECC) instabilities

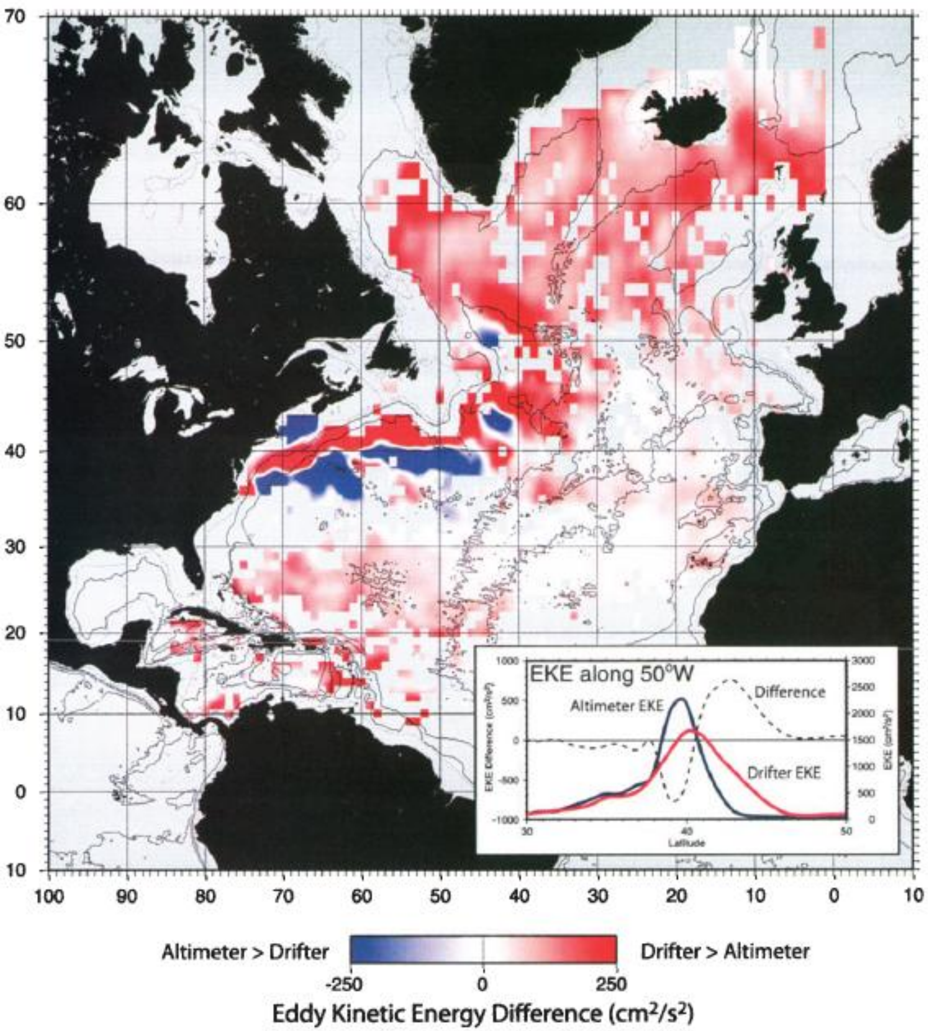
Rms of Velocity from drifters (left) and T/P+ERS (right) (Ducet et al., 2000)



Drifter velocities also include Ekman currents
which are corrected here (small effect)







Differences in EKE between altimetry and drifters (Fratantoni, 2001)

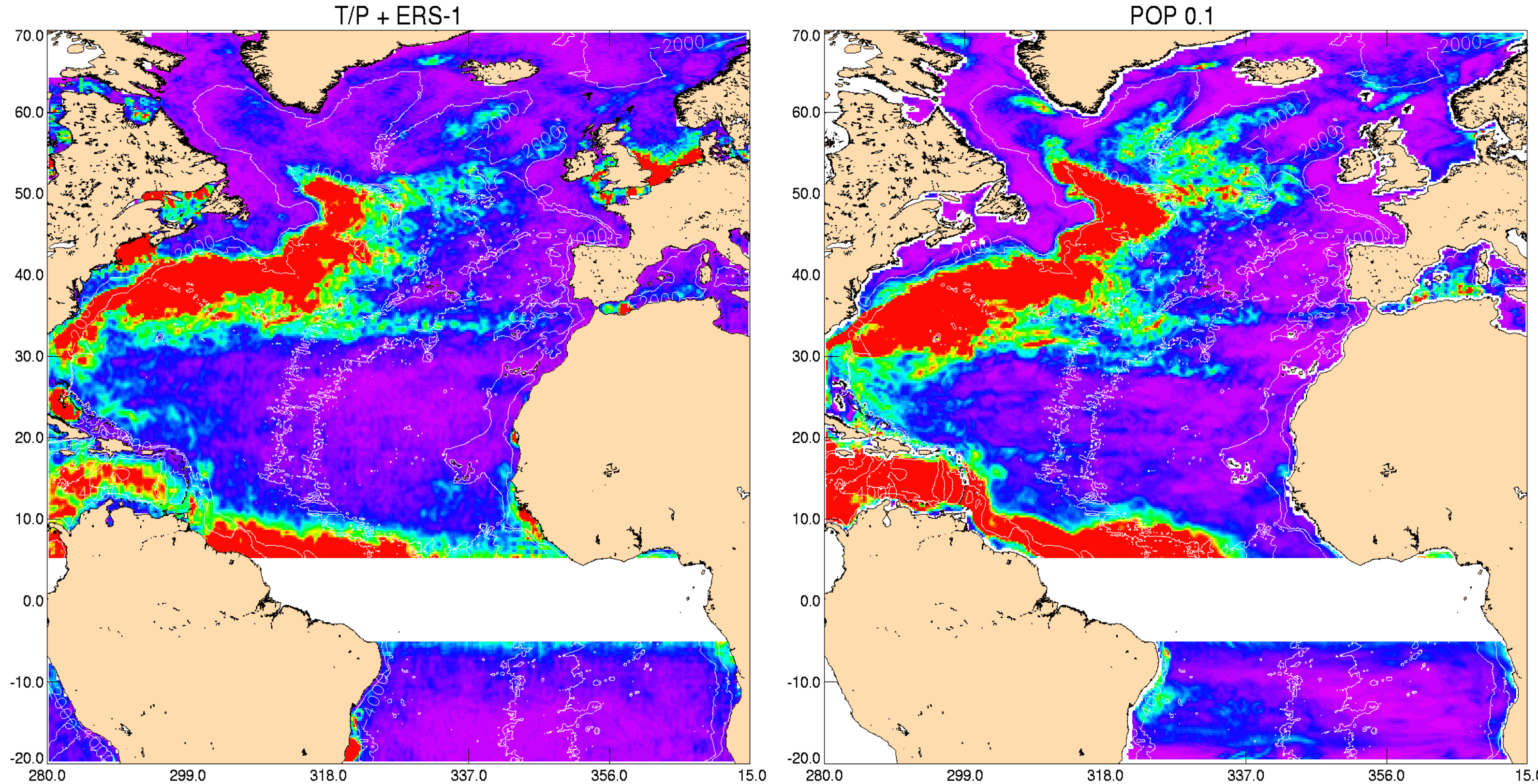
⇒ mainly sampling issues both for drifters and altimetry

⇒ Le Traon and Dibarboure (1999, 2002). Two satellite maps underestimate velocity variance by 20 to 40%.

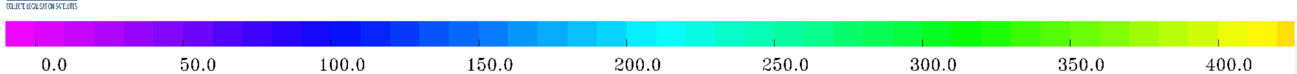
⇒ Maximenko and Niiler (2006) **=> real physics due to cyclostrophic effects.** Geostrophic velocity (slightly) underestimates (overestimates) velocity in anticyclonic (cyclonic) eddies

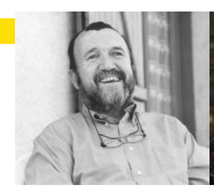
⇒ Differences highly correlated with sea level variability skewness (Thompson and Demirov, 2006)

Note that altimeter data have recently been used to diagnose errors in global drifter array velocities due to drogue loss (Rio et al., 2011; Grodsky et al., 2011)



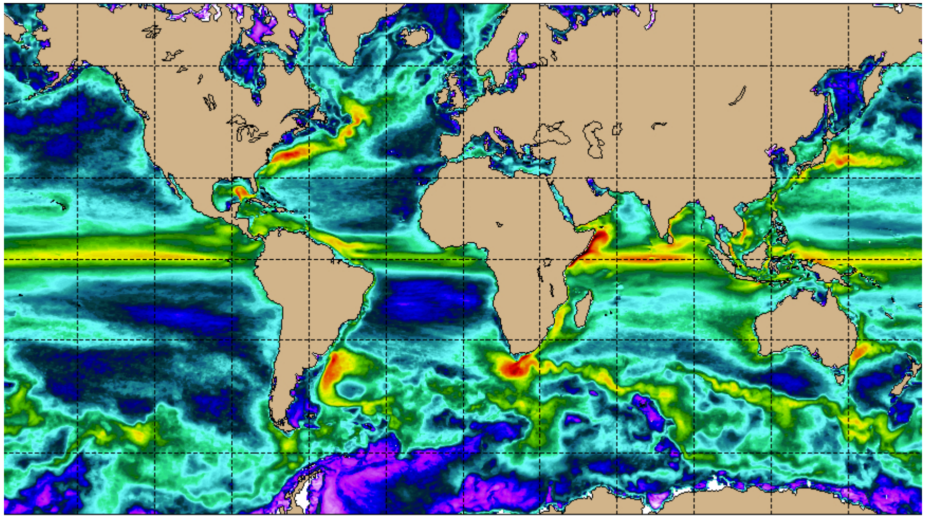
Brachet et al., 2004



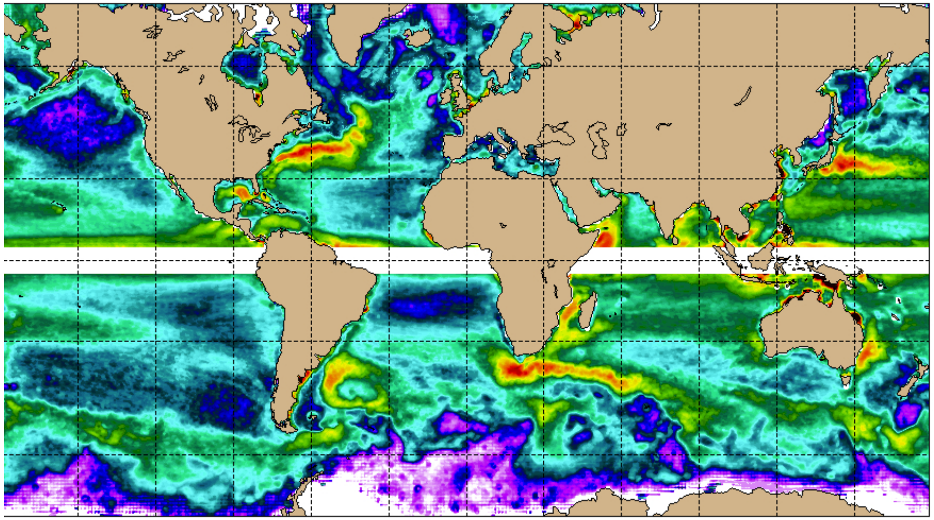


EKE TOPEX/POSEIDON+ERS-1/2 and Los Alamos Model 1/10° resolution model

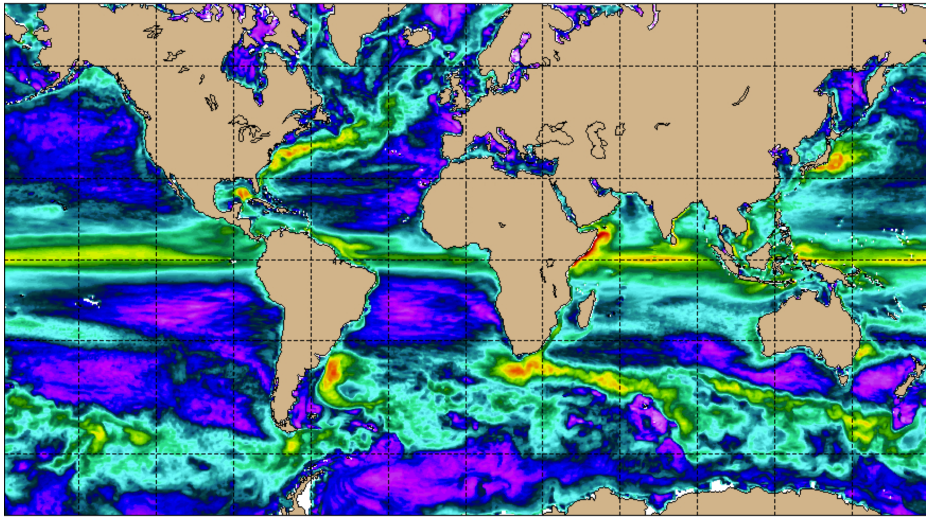
Unique contribution of satellite altimetry for eddy resolving model validation



ORCA 1/12°



T/P-ERS



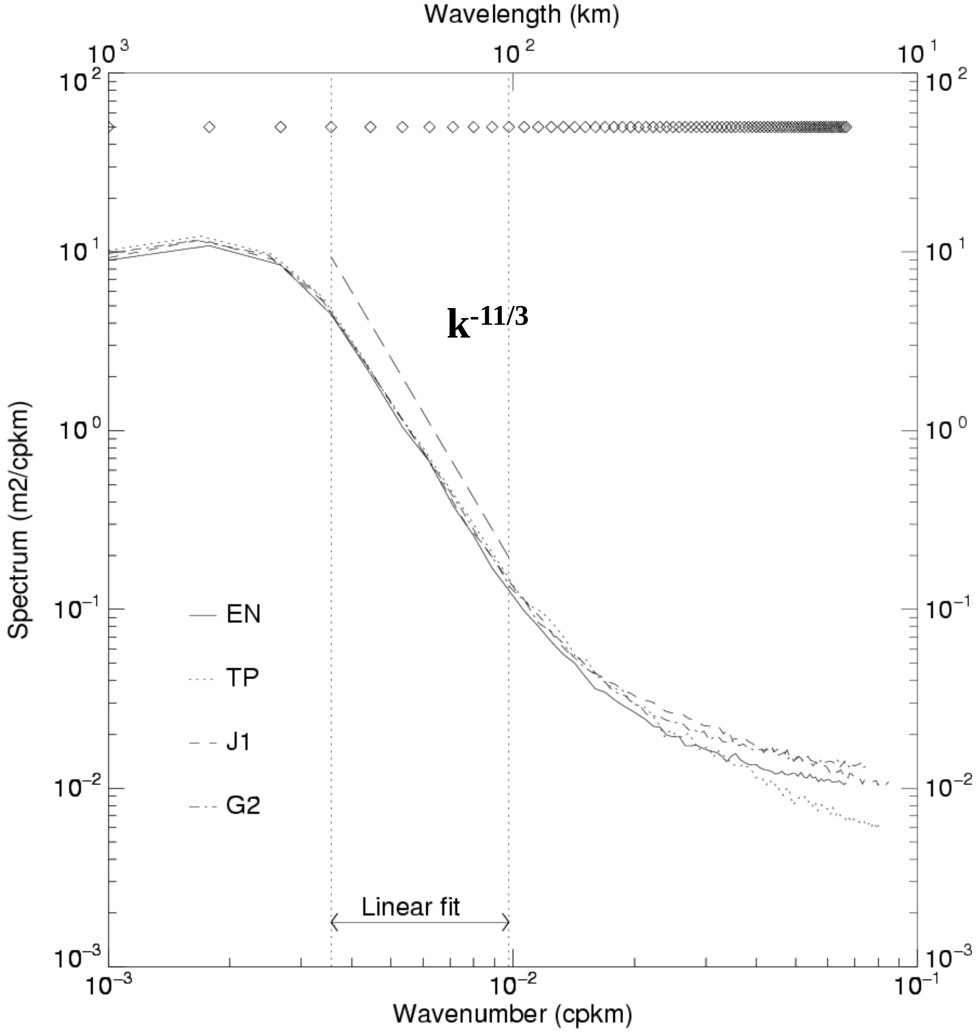
ORCA 1/4°

Eddy Kinetic Energy (EKE) from T/P and ERS-1/2 and a global 1/4° and 1/12° ocean model (NEMO/ORCA)

Courtesy B. Barnier, J.M. Molines

Turbulence theories : QG versus SQG ?

Gulf Stream

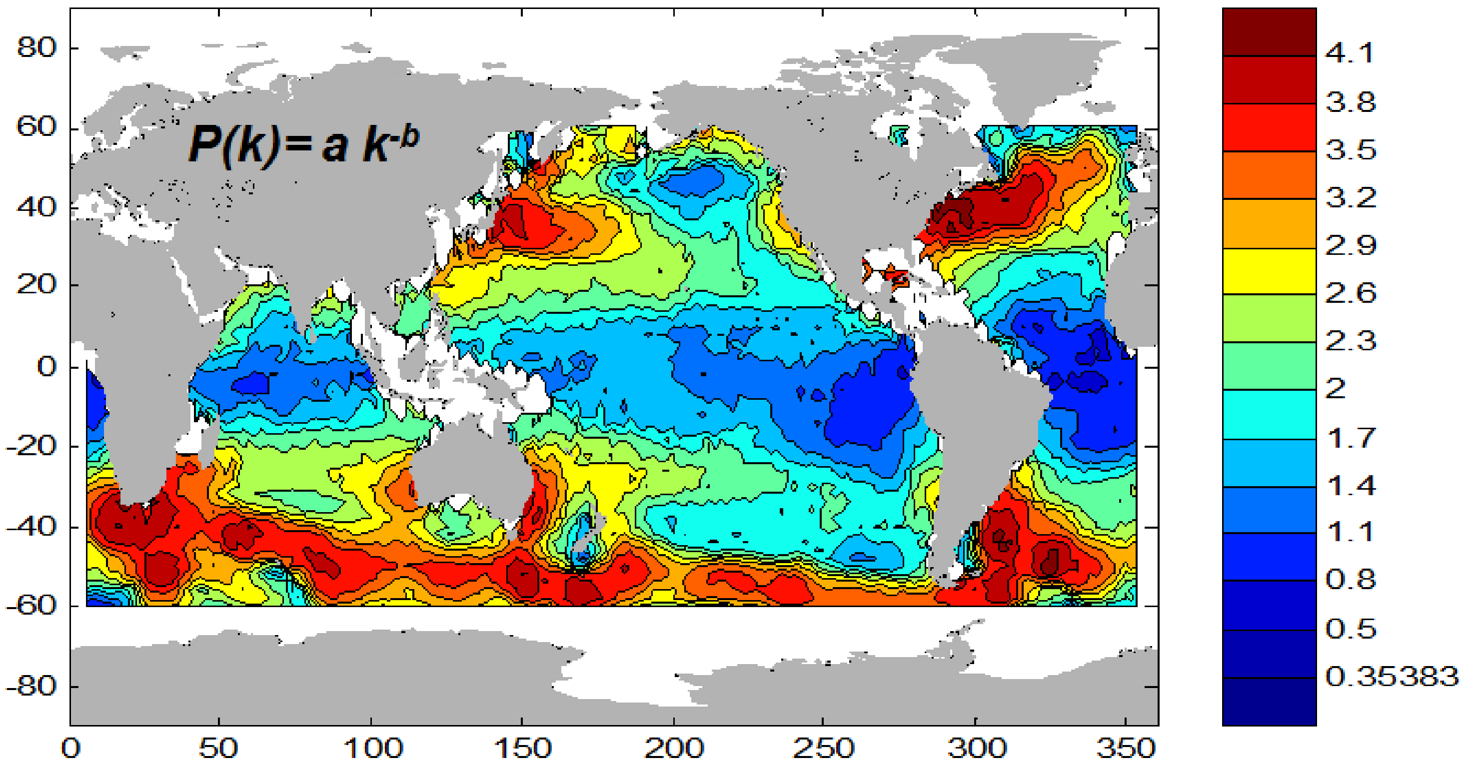


Le Traon, Klein, Hua and Dibarboure, JPO, 2008

Long and on-going debate on altimeter wavenumber spectral shapes from Fu (1983), Le Traon et al. (1990), Stammer (1997), Le Traon et al. (2008) to Xu and Fu (2011)

In high EKE regions, altimeter wavenumber spectral slopes in the mesoscale band closely follow a $k^{-11/3}$ slope as predicted by surface quasi-geostrophic theory (SQG) (Lapeyre and Klein, 2006; Klein et al., 2007)

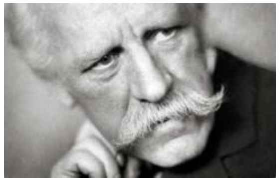
SQG could be a better dynamical framework than the QG turbulence theory to describe the ocean surface dynamics



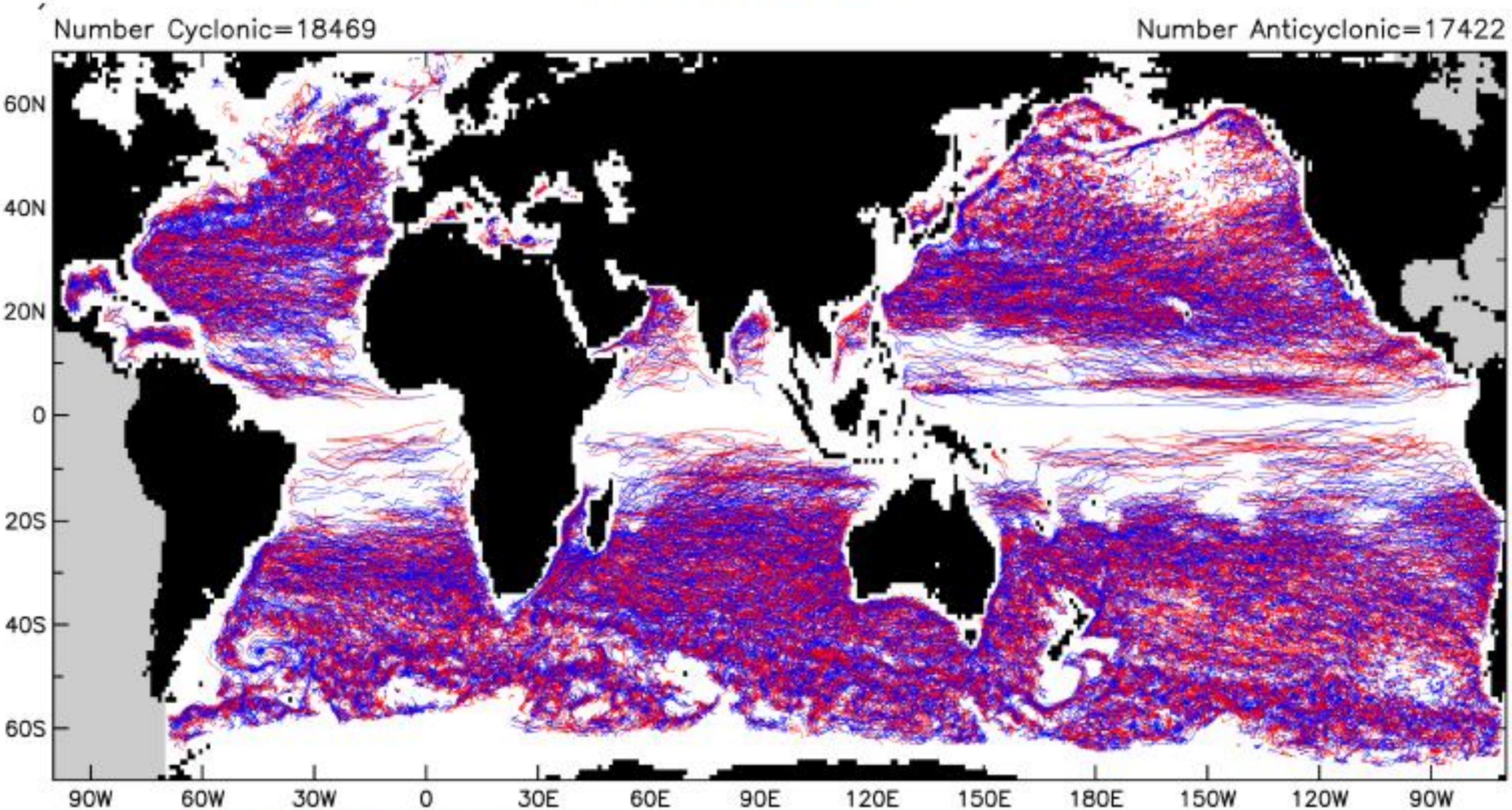
Xu and Fu (2011)

Slopes from 70 km to 200 km wavelength closer to k^{-4} in high EKE regions. In low EKE regions, slopes are closer to k^{-2} / k^{-3} : lower signal/smaller scales => stronger impact of noise, other dynamical effects (e.g. internal waves*)

***first observed by Nansen, 1902 on the Fram**
T/P observations (e.g. Ray and Mitchum, 1996)



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



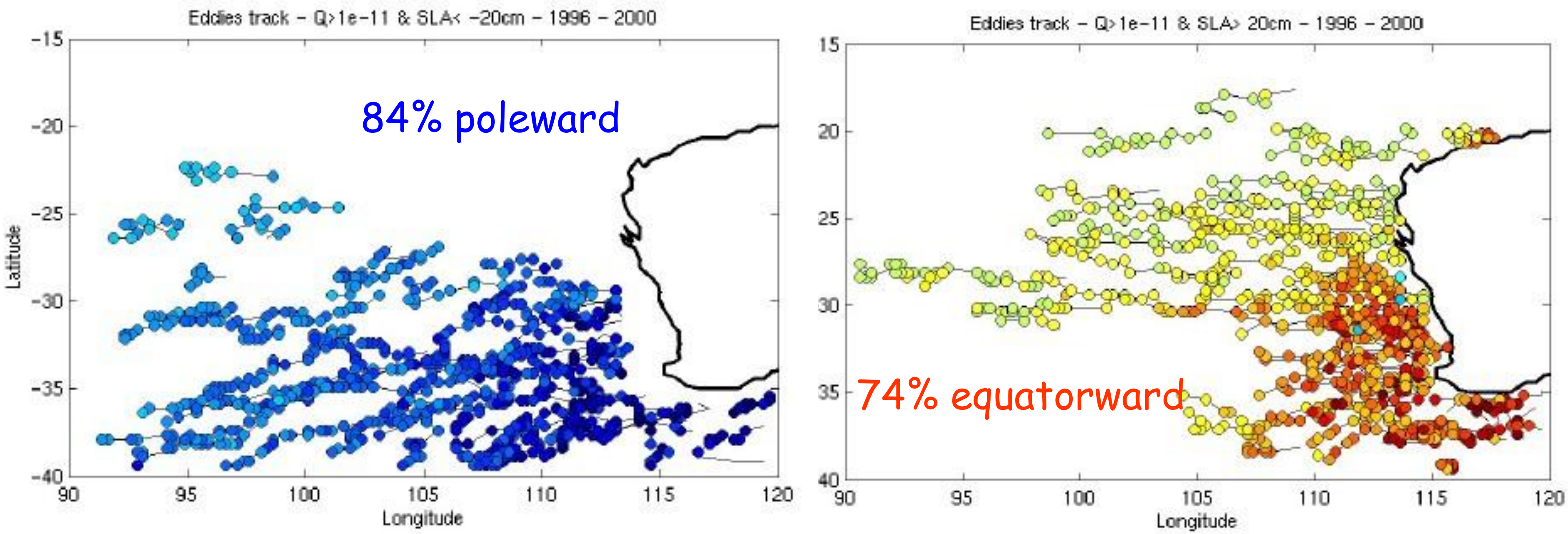
Average lifetime: 32 weeks
Average propagation distance: 550 km
Average amplitude: 8 cm
Average horizontal radius scale: 90 km

Total number of observations: ~1.15 million

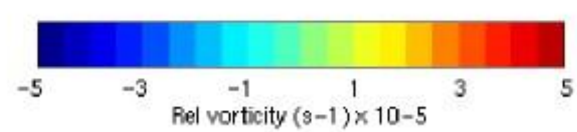
Chelton et al., 2011

Cyclones and Anti-cyclones diverge!

Meridional propagation : Cyclones (cold-core eddies) tend poleward. Anti-cyclones (warm-core eddies) tend to propagate equatorward;

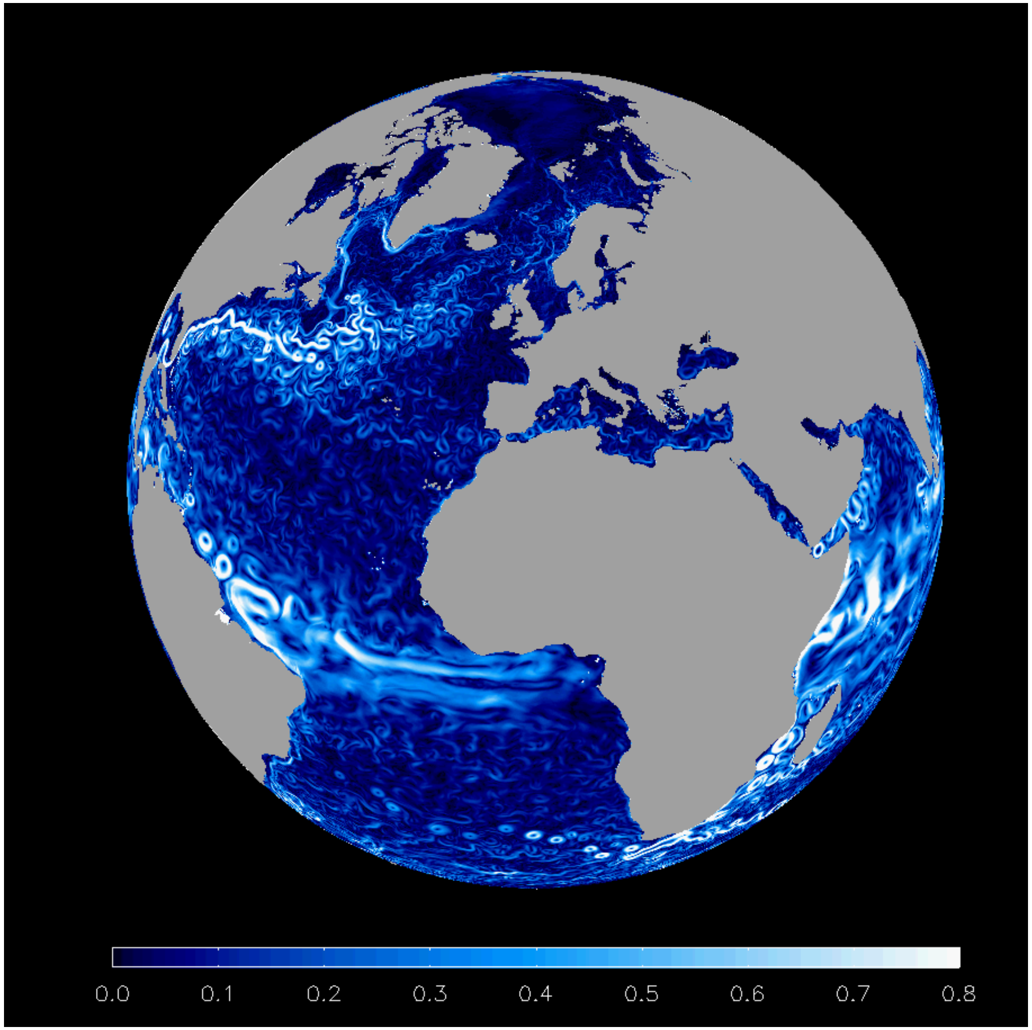


Divergent propagation occurs away from strong jets and bathymetric features. (Morrow et al., GRL, 2004; Chelton et al., 2011)



Eddy propagation advected by mean circulation : Pacific NW : Isoguchi and Kawamura, GRL, 2003; ACC : Hughes et al., JGR, 1998.

Data assimilation and modelling capabilities



Operational oceanography now uses high resolution models with data assimilation: 1/12 (global), 1/36 (regional) (MyOcean)

This poses much stronger requirements for an altimeter constellation (observation capabilities lag behind).

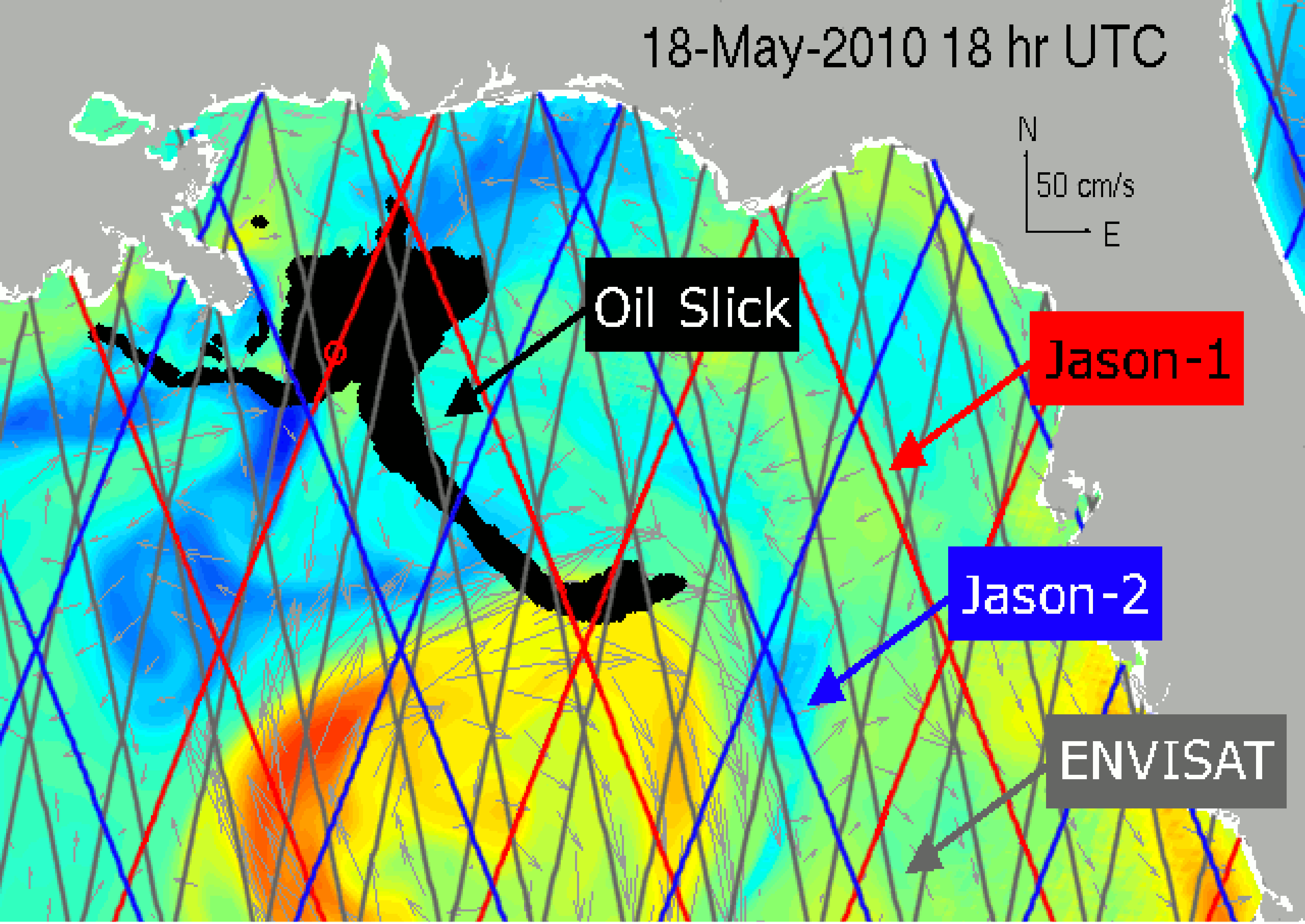
Availability of multiple altimeters (4 needed) is essential

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

myOcean

Mercator Ocean

Ocean Forecasters



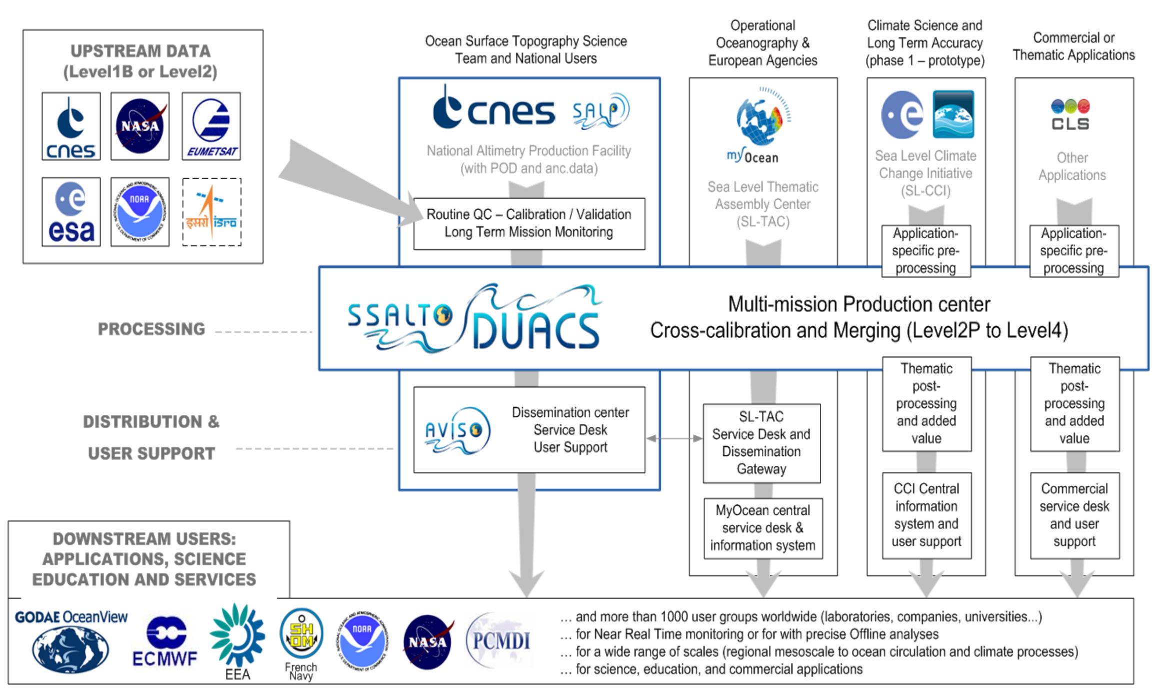
High resolution altimetry and Deep Horizon oil spill (J. Lillibridge, NOAA)

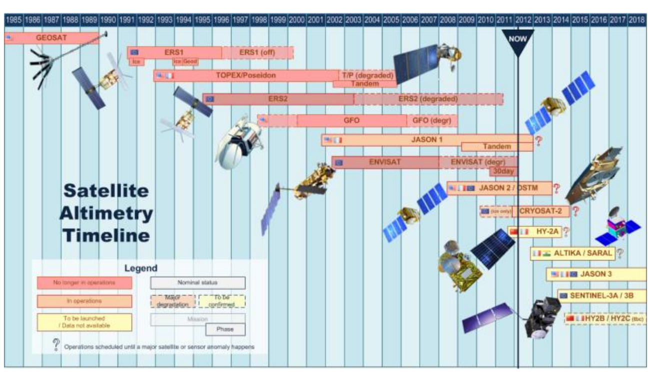
Many colleagues and friends at CLS, Phd students and post docs contributed to the development and scientific use of SSALTO/DUACS products. Different and complementary skills. Essential for transforming a scientific demonstration into a widely use and operational product. Long term support from CNES was essential.

SSALTO/DUACS in 2012

Homogeneous, inter-calibrated and directly usable high quality altimeter data from all altimeter missions

- ✓ Along-track & gridded products in near real time and delayed mode.
- ✓ Global/Regional products
- ✓ New and improved products (e.g. MSLAs, MDTs).
- ✓ Daily products
- ✓ Timeliness improved
- ✓ 60 years of data - 9 satellites



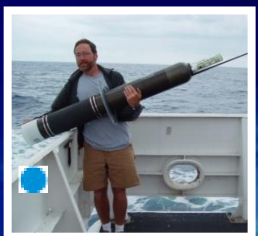


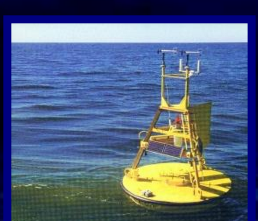
- ➢ *2000 registered users in 2012*
- ➢ *80 publications in 2011 (multiple altimeter maps)*

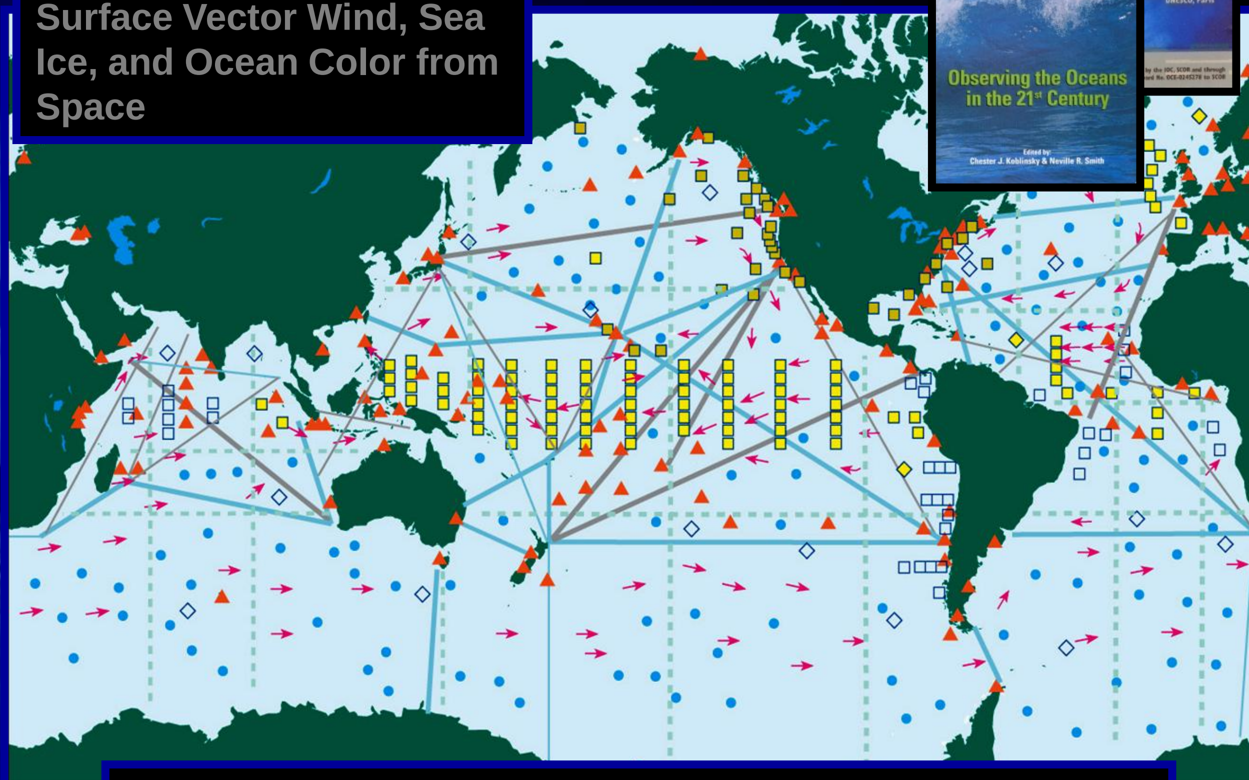
http://www.aviso.oceanobs.com/duacs (AVISO WWW site)

Global Ocean Observing System
About 60% complete

Sea Surface Temperature, Sea Surface Height, Surface Vector Wind, Sea Ice, and Ocean Color from Space

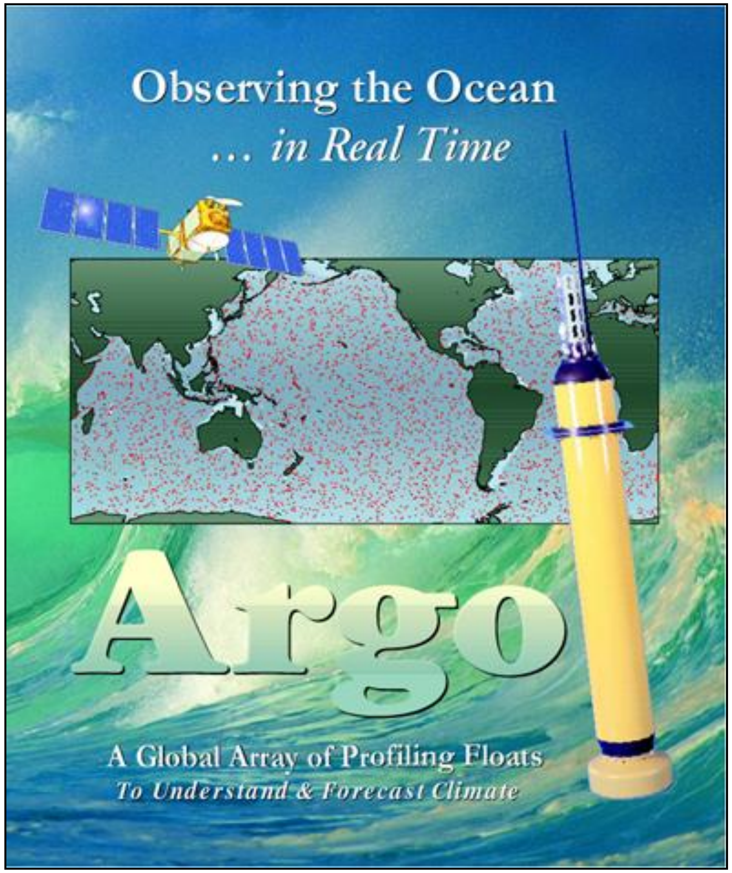


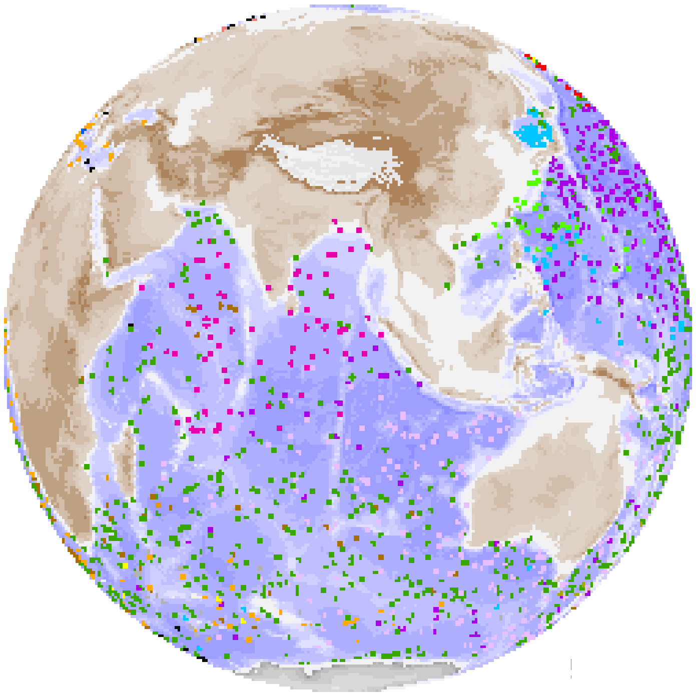


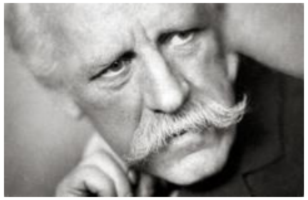


Tide Gauge Network	58 % complete	
3˚x3˚ Argo Profiling Float Array	52% complete	
5˚x5˚ Surface Drifting Buoy Array	79 % complete	
Moored Buoy	Existing	Planned
Ocean Reference Station	Existing	Planned
High Resolution XBT and Flux Line	Existing	Planned
Frequently Repeated XBT Line	Existing	Planned
Carbon Inventory & Deep Ocean Line	Global Survey @ 10 years	

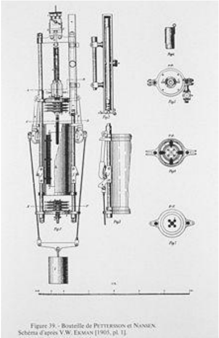
The second revolution : Argo







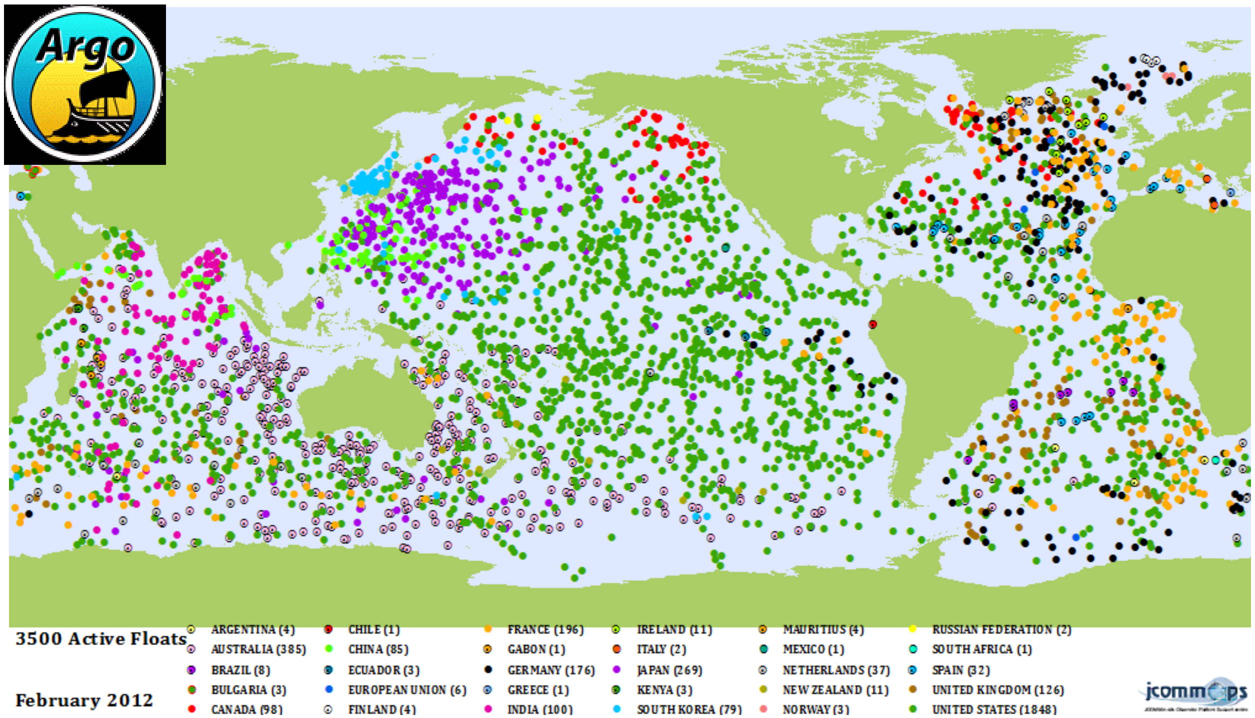
A modern and autonomous version of the Nansen bottle designed in 1910 by Nansen

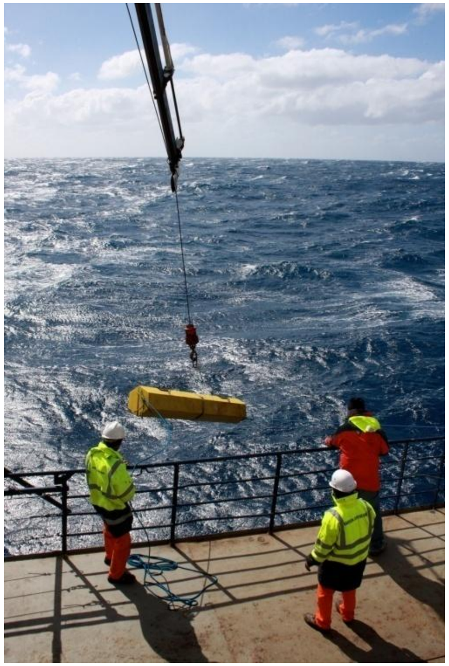


Argo : a revolution in oceanography

the first global real time in-situ ocean observing system

3000 profiling floats worldwide measuring the temperature and salinity to a depth of 2000 m

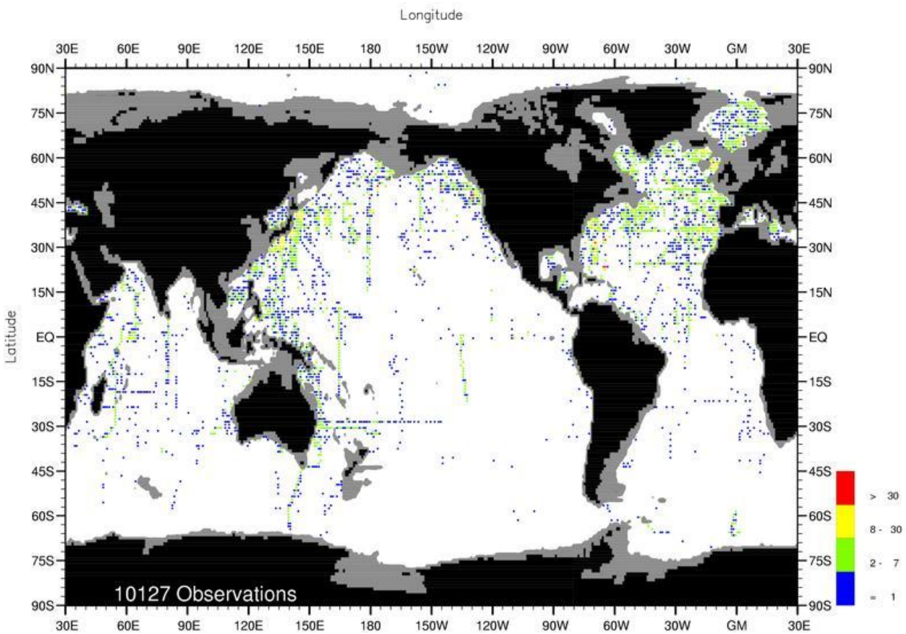




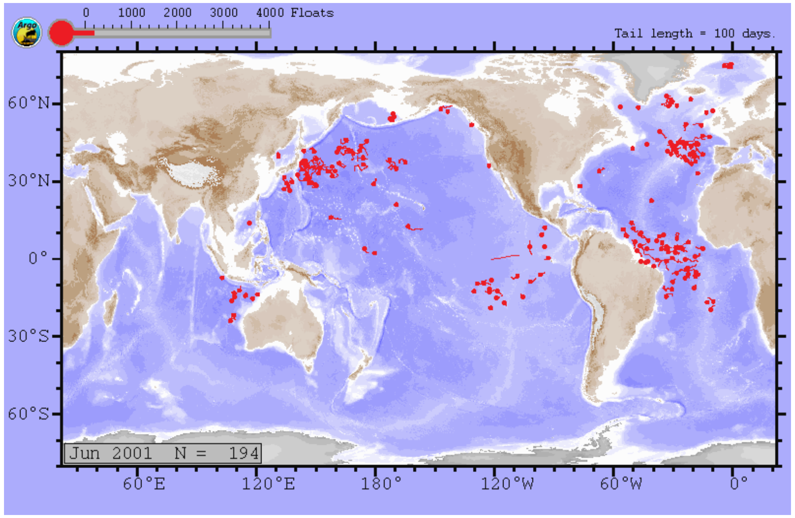
A major contribution to the global ocean and climate observing system. Strong complementarity with altimetry (Jason / Argo).

Argo development: an outstanding achievement

2000: start of the array - End of 2007: 3000 floats. > 30 countries



Historical observations of temperature at 1500 m depth in July



Argo float deployments (2001-2012)

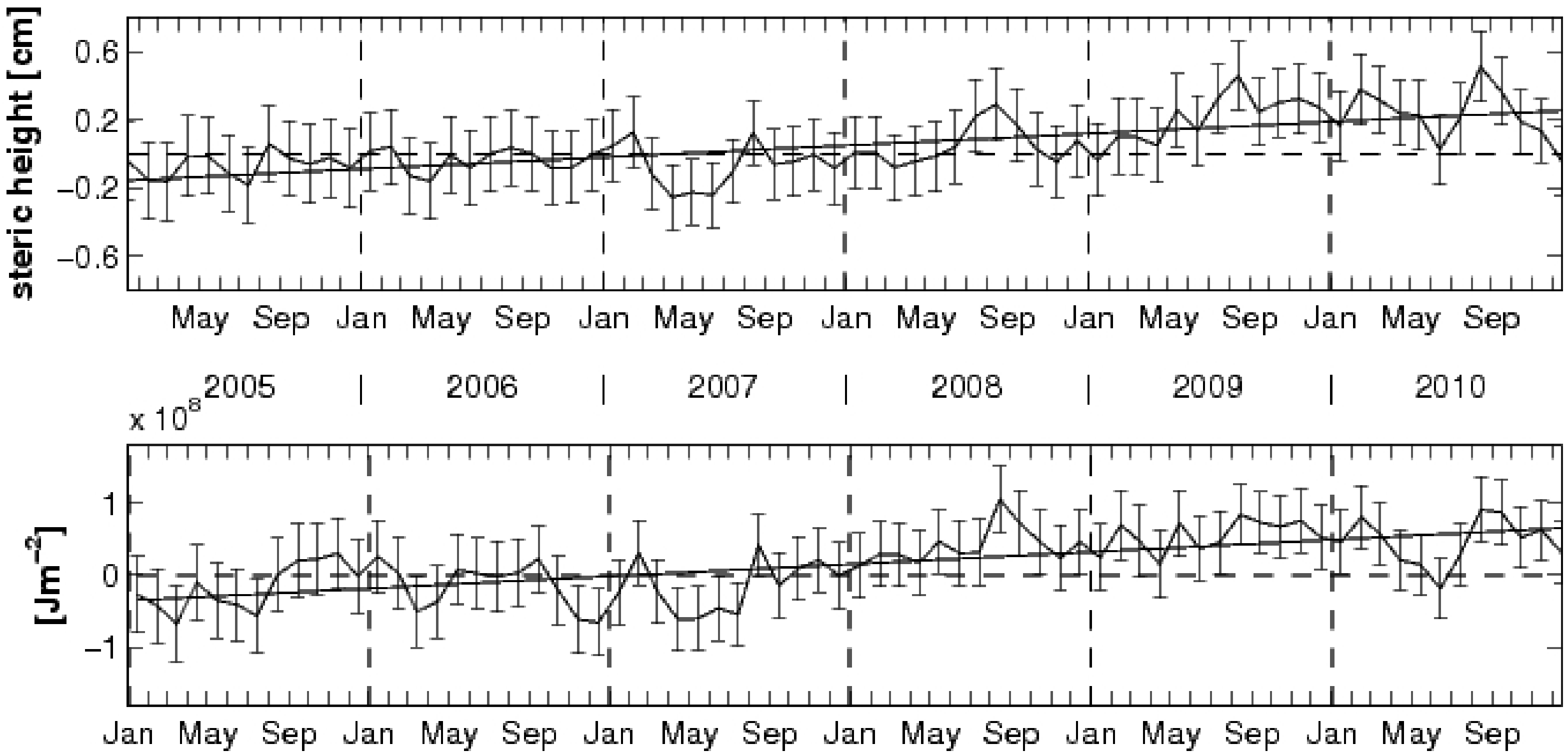
About 200 publications/year
Research papers often jointly use Argo and altimetry

Argo data are now systematically used together with altimeter data for ocean analysis and forecasting

The role of the Argo Science/Steering team

One of the Argo's most important contributions is a major improvement in estimations of heat stored by the oceans

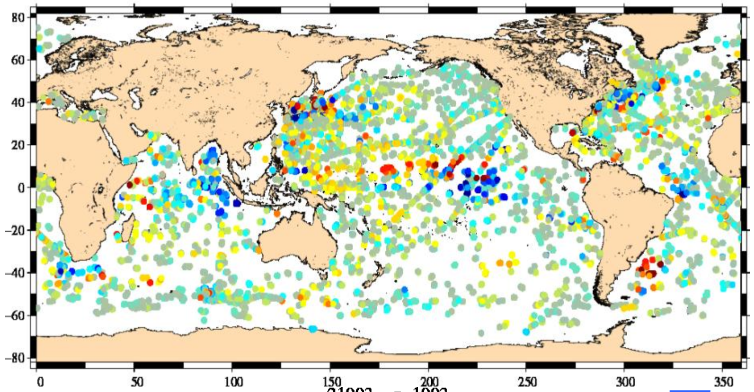
=> A better understanding of the mechanisms behind rising mean sea level => complementarity with altimetry and GRACE



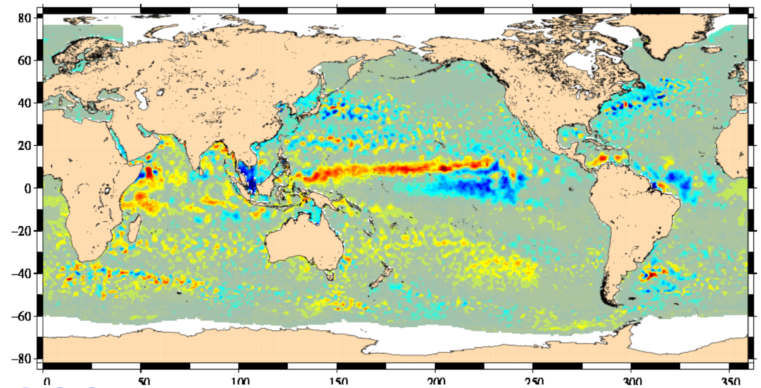
Global ocean heat content and mean steric sea level variations derived from Argo data (2005-2010) (Von Schuckmann and Le Traon, 2011)

Use of Altimetry, SST and Argo observations to reconstruct 3D mesoscale temperature fields

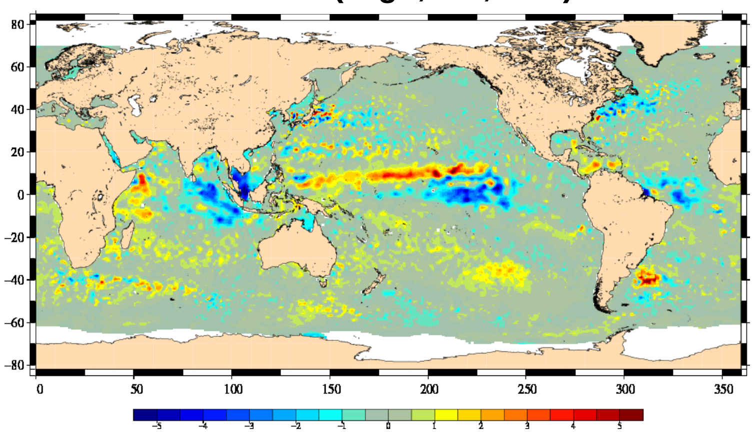
Argo observations



Synthetic T : from alti and SST

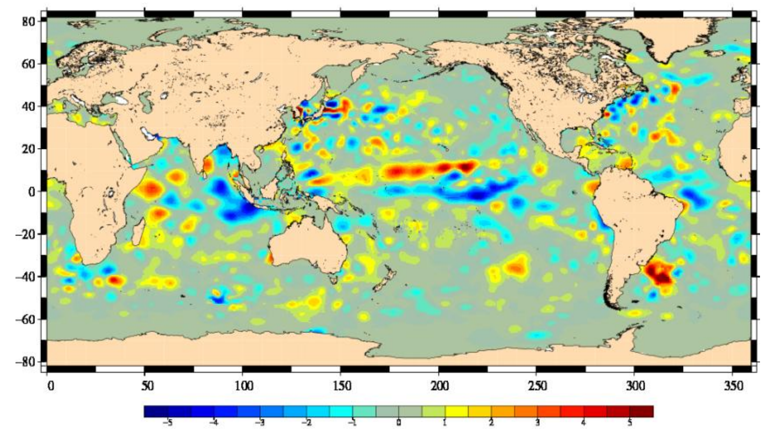


Combined T (Argo, alti, SST)



T at 200 m

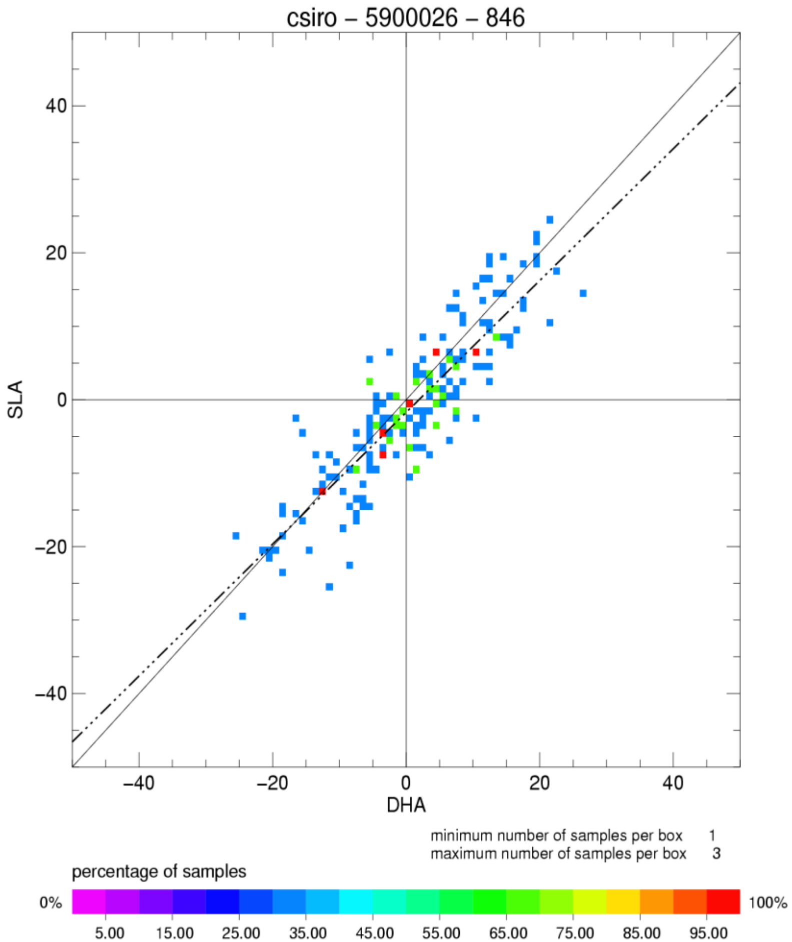
Argo alone



Temperature anomalies from Levitus monthly climatology (°C)

Improvements Argo+Alt+SST vs Alt+SST = 20 to 30% of the signal variance (Guinehut et al., 2004, 2012)

Use of altimeter data in Argo quality control (Guinehut et al., 2009)



Statistics Y–X

mean = –1.86108
rms = 5.27513
rms (%rms(X)) = 27.29221
rms (%rms(Y)) = 26.79463
std = 4.93413

Statistics Y,X

samples = 197
covar = 89.66322
r = 0.88094

Linear regression

type: least squares y=f(x)

y = ax + b
a = 0.89717734
b = –1.71680028

Statistics X

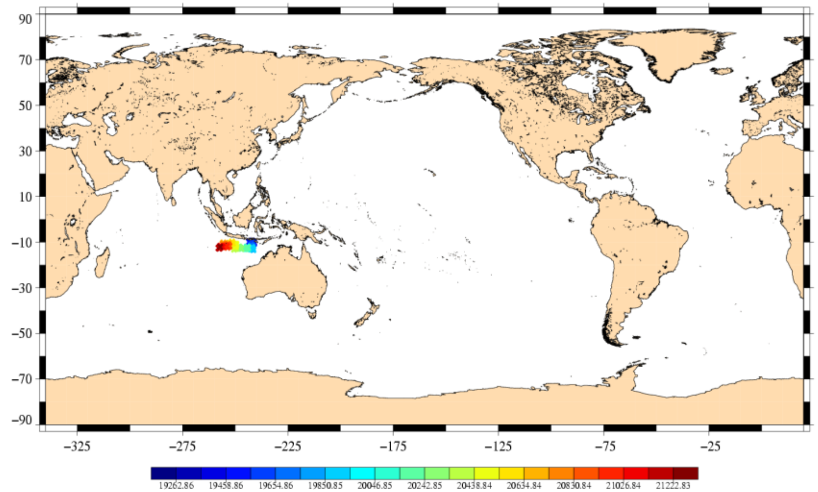
mean = 1.42132
rms = 10.09749
std = 9.99696

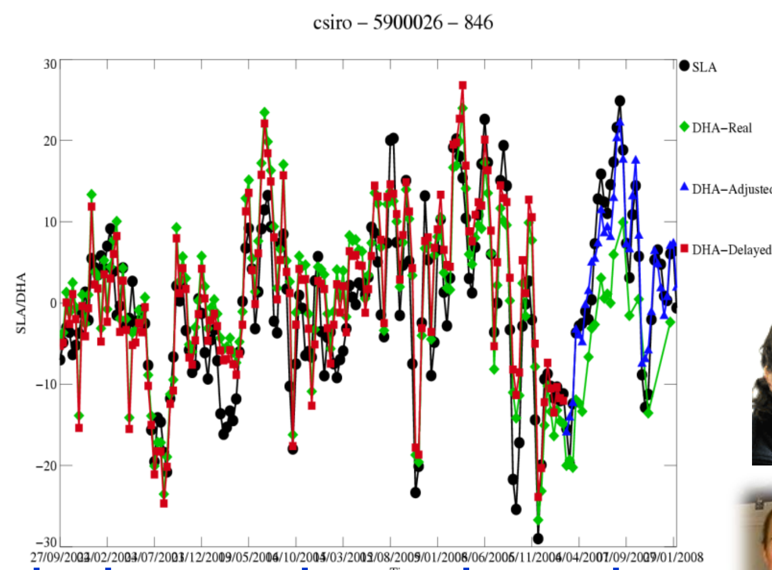
Statistics Y

mean = –0.44162
rms = 10.19082
std = 10.18125

Legend

–. Linear regression
— y=x





➔ **Very good consistencies between the two time series**
➔ **Impact of the delayed-mode and real-time adjustment**

Euro-Argo : A new European Research Infrastructure

- **Objective: ensure a long term European contribution to Argo.**

- **Proposal : Europe establishes an infrastructure for ¼ of the global array**
  - Requirement : 250 floats per year including regional enhancements (Nordic seas, Mediterranean&Black seas)
  - Dual use : research/climate and operational oceanography (GMES)

- **Euro-Argo Preparatory phase : 2008- 2011**

- **2012 => Euro-Argo ERIC :** A new European legal structure that will allow European countries to improve their contribution to Argo. Agreements are at ministerial level and this will help to ensure long term sustainability.

The third revolution

Global Operational Oceanography

Operational oceanography

The GODAE vision

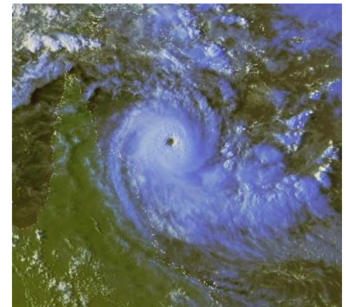
"A global system of observations, communications, modelling and assimilation, that will deliver regular, comprehensive information on the state of the oceans, in a way that will promote and engender wide utility and availability of this resource for maximum benefit to the community"
(GODAE Strategic Plan, 2001)

A major breakthrough for oceanography

Smith, N. and M. Lefebvre (1997): The Global Ocean Data Assimilation Experiment (GODAE). In "Monitoring the oceans in the 2000s : an integrated approach". International Symposium, Biarritz, October 15-17, 1997.

Operational Oceanography applications





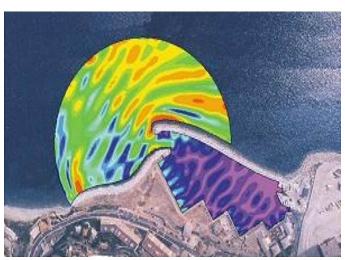
Global warming, climate and seasonal forecasting, weather

Fisheries and fishery management


Offshore Industry
Ship routing

Maritime security
Marine Safety

Navies



Coastal applications and environmental monitoring

Ocean and ecosystem research

others…

GODAE

Global Ocean Data Assimilation Experiment

A practical demonstration of the feasibility & utility of high-resolution, global analyses & short-range forecasts of 3D temperatures, salinities and currents

Global operational oceanography

The GODAE main demonstration phase (2002-2008) was phased from the start with the launch of Jason-1 and ENVISAT

The French contribution to GODAE

Developed at the early stage of GODAE: Mercator Ocean, Coriolis, Jason. Strong links with research community.

The starting event

(La Chapelle Aubareil, 1995)

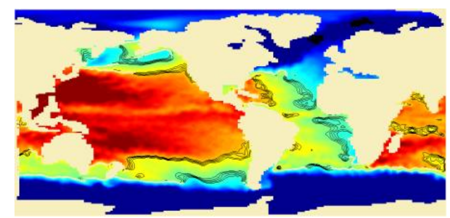
OBSERVATION
SATELLITE

JASON

OBSERVATION
IN SITU

Coriolis
OPERATIONAL OCEANOGRAPHY

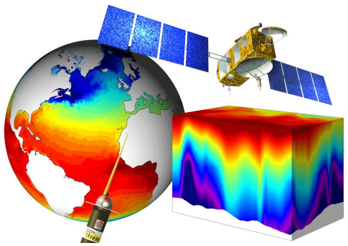
MODELISATION
ASSIMILATION



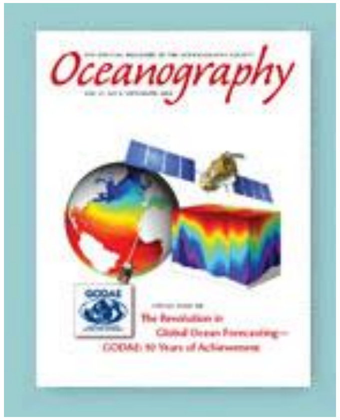
Mercator
Ocean
Ocean Forecasters

Altimetry, Argo and the development of operational oceanography

- **Strong links** from the start of GODAE (1997-2000)
- **Argo a joint venture between CLIVAR and GODAE:** In 2000, the in-situ observing system was clearty inadequate for the global scope of GODAE
- **Satellite altimetry community was keen to develop/contribute to an integrated approach**. Need and willingness to develop the links with applications.
- **Ocean analysis and forecasting models are strongly dependent on the availability of multiple altimeter data and Argo observations :**
  - ➢ Sea level is a strong constraint to infer the 4D ocean circulation
  - ➢ Only can high resolution altimetry constrain the mesoscale circulation
  - ➢ Argo needed to constrain large scale T&S fields



GODAE Achievements and Successes



Implementation of observing and data processing systems

- Argo and GHRSST-PP (pilot projects), altimetry, in-situ

Implementation of global modelling and data assimilation capabilities

- high resolution and climate

Implementation of data/product serving capabilities - standardization

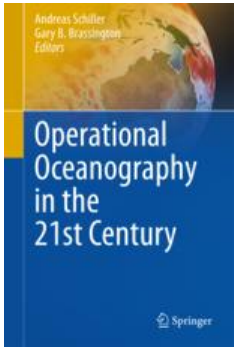
Intercomparison / validation, metrics and standardization

Demonstrations of feasibility and utility

- Mesoscale nowcasting and forecasting, ocean climate and research, marine pollution and safety, weather forecasting, marine resources, etc

Scientific advances

- Modelling, data assimilation, scientific validation

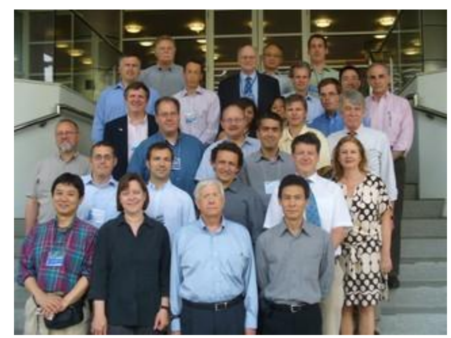


The International GODAE Steering Team

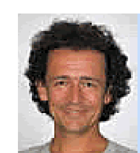


- The IGST was formed in 1997 => responsibility for the development of GODAE.
- Many scientists have served as members and contributed greatly to the success of GODAE. Excellent "spirit" and willingness to share data&products, expertise and experience (GODAE common)
- Supported by the GODAE Patrons   and a project office 






- Symposia and Summer Schools
- New long term program : GODAE OceanView and its Science Team


Eric Dombrowsky
Mercator-Ocean
France


Andreas Schiller
CSIRO
Australia

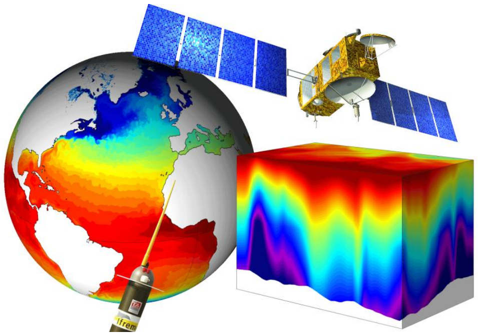
MyOcean

GMES Ocean Monitoring and Forecasting Service

European Operational Oceanography

Conclusions

- **1992-2012 : 20 years of major achievements in oceanography**
  - Satellite altimetry
  - Argo and the global in-situ observing system
  - Global operational oceanography : GODAE



- **Birth of a new community**

- **These three major successes did not happen by chance (although I was lucky to be involved in the three of them!).** They result from a well thought (vision) and planned integrated approach : in-situ, satellite and modelling.

Venice, Septembre 24-29, 2012
Celebration of achievements and future prospects (altimetry, Argo)

Some lessons learnt…

- **Long term and forward vision for ocean science (integrated oceanography, the role of observations)**

- **Ability of a community to work together for a common cause with a shared sense of purpose and achievement**

- **Importance of International collaboration. Role of strong and committed T/P – OST, Argo and GODAE science teams**

- **Synergies advanced research, technology and applications**

- **Continuity of observations and continuity of qualified teams is essential.**

Perspectives/Challenges

- Consolidating/sustaining the long term ocean observing system
  - Optimizing/improving the altimeter constellation
  - Sustaining Argo and the in-situ ocean observing system
  - Modelling/assimilation
  - Science and technology infusion
  - A major role for Europe (GMES Marine Service)

- New challenges
  - The very high resolution – altimetry (SWOT), modeling
  - The new phase for Argo (biogeochemistry, deep Argo)
  - Moving from physics to ecosystems and to large scale to coastal scale: observations&modelling

Thanks

- To many international colleagues and friends
- T/P SWT– OSTST, Argo and GODAE Science Teams
- Space agencies and engineer teams
- CLS Space Oceanography, Mercator Ocean and Ifremer teams
- Phd students and post-docs

A <u>truly</u> collective work

ALTIMETER MISSIONS (adapted from Wilson et al, 2001)