Operational applications from altimetry

P.Y. Le Traon CLS Space Oceanography Division

with contributions from F. Bonjean, B. Cheney, D. Griffin, B. Leben, A. Vidard and GODAE IGST

SWT, Arles, November 2003

Outline

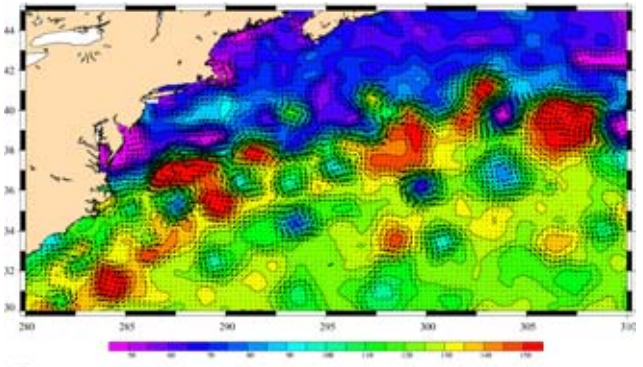
- **Near real time altimeter data processing (SSALTO/DUACS)**
- **Operational applications of altimetry**
- **Operational oceanography and GODAE**
- **Future requirements and expected improvements**

SSALTO/DUACS (CLS/CNES) : Real time processing of TOPEX/POSEIDON, ERS-1/2, GFO, Jason-1 and ENVISAT

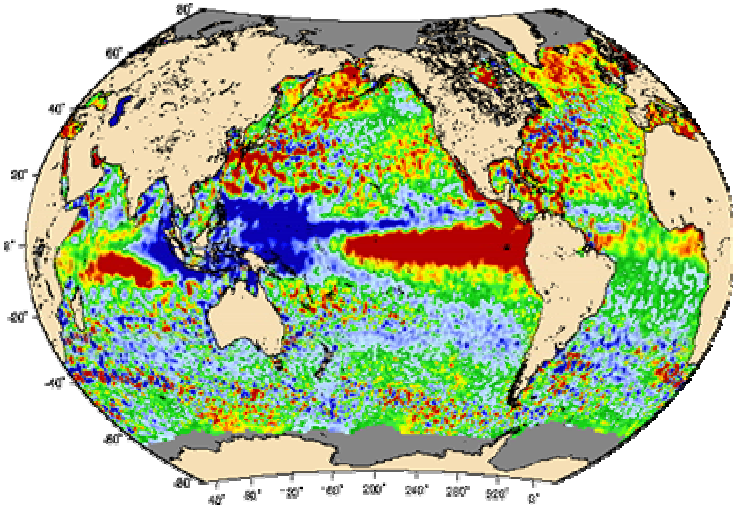
Serving operational oceanography (GODAE : MERCATOR, FOAM, TOPAZ, MFS, etc), climate forecasting centers (ECMWF, etc) and applications (fisheries, offshore industry)

Global crossover minimizations, inverse techniques to remove long wavelength errors => high accuracy SSH (Sea Surface Height) data.

Consistent mean profiles to reference multiple altimeter data => consistent SLA (Sea Level Anomaly) data



High resolution sea level and currents from Jason-1, ERS-2 and GFO



Real time processing of T/P and ERS-2 data during the 1998 El Nino

Products directly useable for scientific and operational applications (climate and mesoscale)

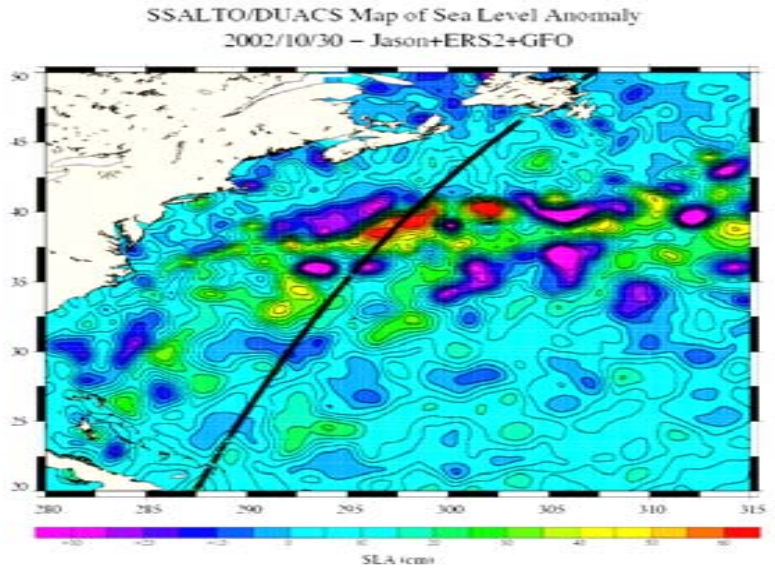
http://www.aviso.oceanobs.com/duacs (AVISO WWW site)

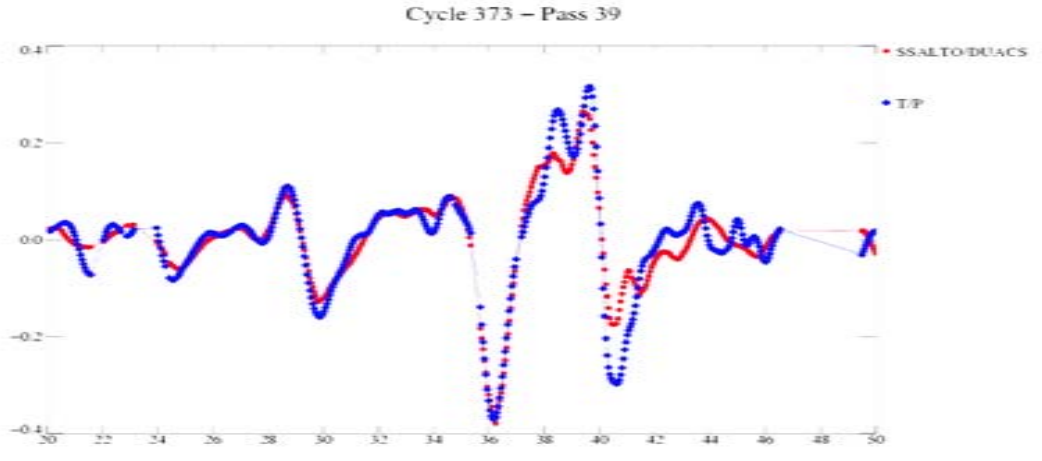
SSALTO/DUACS - UPDATES

First system developed as part of DUACS (Developing the Use of Altimeter data for Climate Studies) (CLS, ECMWF, UKMO,MPI, Cerfacs) (operational since 1998)

New system (SSALTO/DUACS) (CLS/CNES) operational in early 2002 to serve GODAE and climate forecasting centers :

- ***Includes GEOSAT Follow On***
- ***SLA relative to a new 7-year mean***
- ***New covariance for ocean signal (propagation velocities)***
- ***Improved algorithms for orbit and long wavelength error correction and noise***
- ***Maps on MERCATOR grid (1/3°) - NetCdf format***
- ***Jason-1 operational since July 2002***
- **Twice weekly processing (Tuesday and Friday) (March 2003)**
- **ERS-2 off since June 22, 2003 - NRT ERS-2 off early July 2003**
- **ENVISAT replaces ERS-2 September 5, 2003**
- **TOPEX in SSALTO/DUACS by the end of 2003 (4 satellites).**

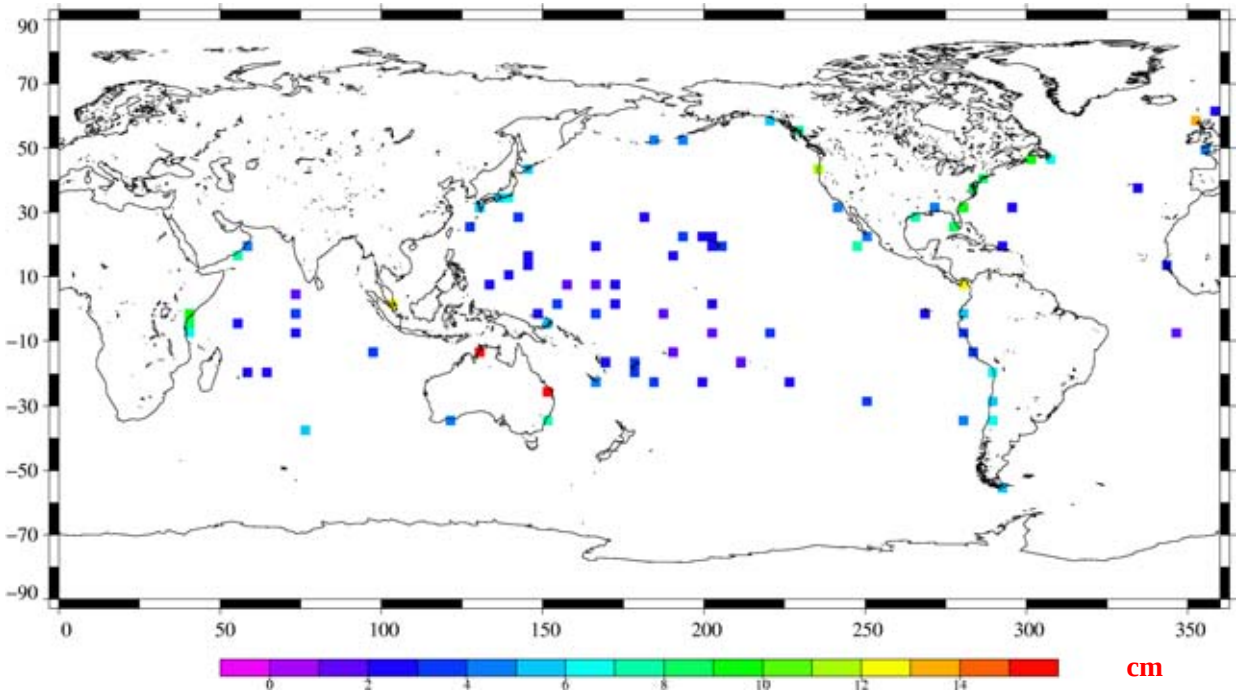




Validation of SSALTO/DUACS Sea Level Anomaly along an independent T/P track

Comparison with tide gauges from the University of Hawai Sea Level Center (104 tides gauges) (S. Guinehut, F. Lefèvre)

Excellent agreement (2-3 cm rms) except for coastal tide gauges



Summary of T/P+ERS (Jason-1+ENVISAT) mesoscale variability mapping capabilities

(from Le Traon and Dibarboure, 1999; Ducet et al., JGR, 2000; Le Traon et al., JAOT, 2001; Le Traon and Dibarboure, JAOT, 2002)

- **Sea level can be mapped with an accuracy of about 10% of the signal variance (i.e. 3 cm rms for a 10 cm rms signal). Large improvement compared to T/P only (factor 4).**

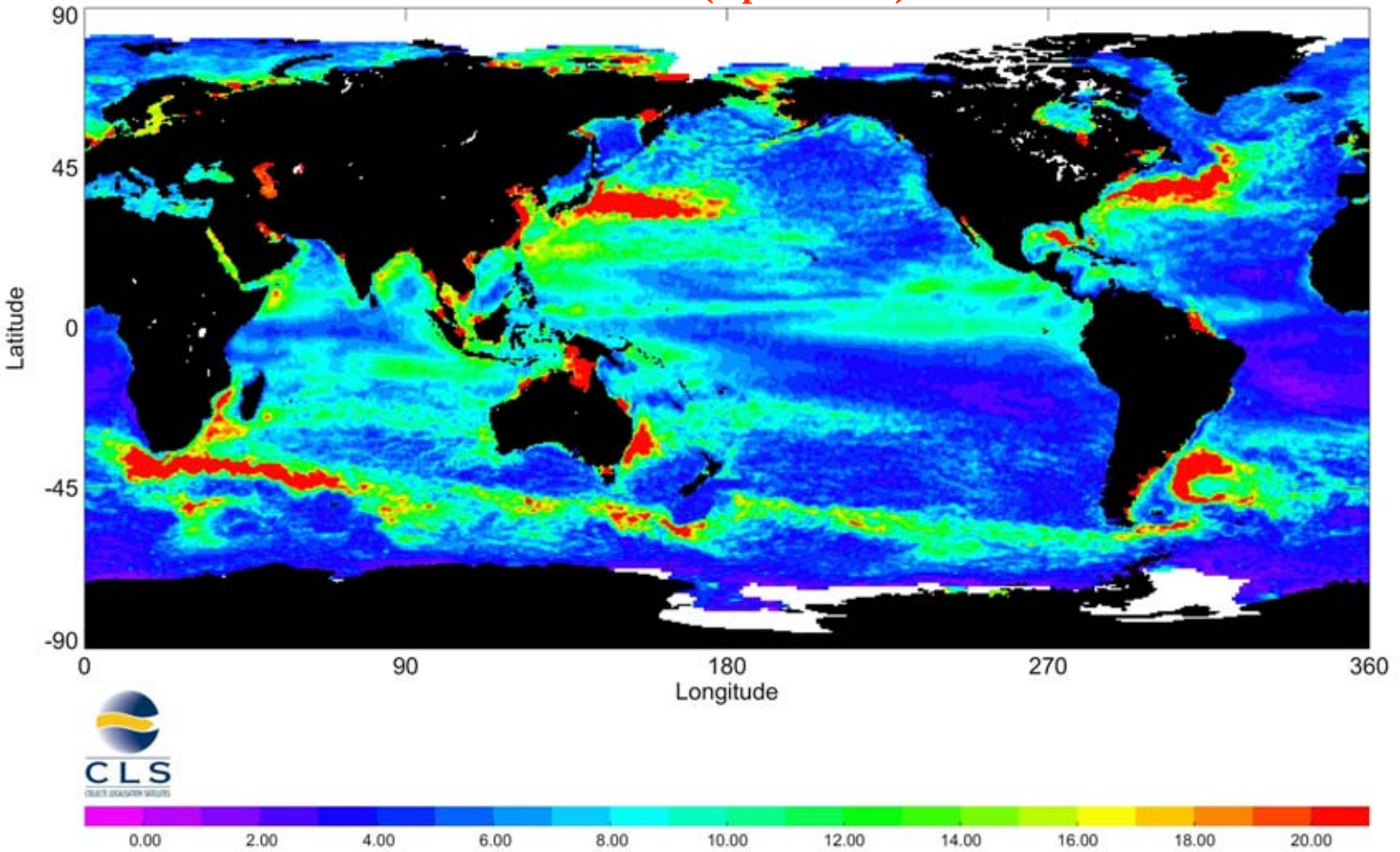
- **The two components of velocity between 20 and 40% of the signal variance (depending on the latitude)**

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

⇔ ***"Good" observation of the mesoscale variability. This is crucial for most of the operational applications (velocity)***

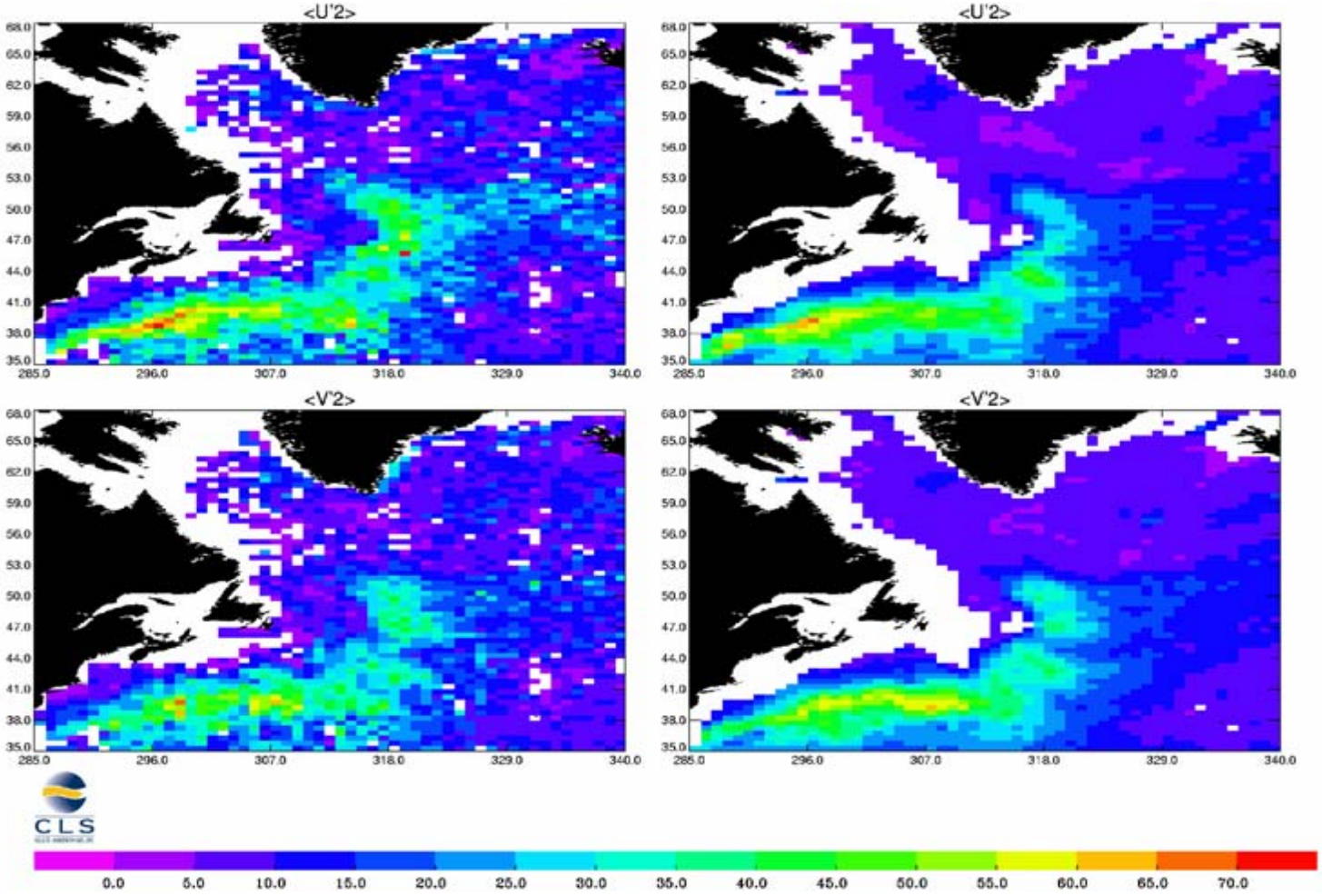
⇔ ***This is improved with the use of GFO and tandem mission***

Satellite altimetry = a unique capability for global NRT description of mesoscale variability for operational and scientific applications. Need at least 2 altimeters (3 preferred)



Rms Sea Level Variability from T/P and ERS data (Ducet et al., 2000)

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



Applications and users

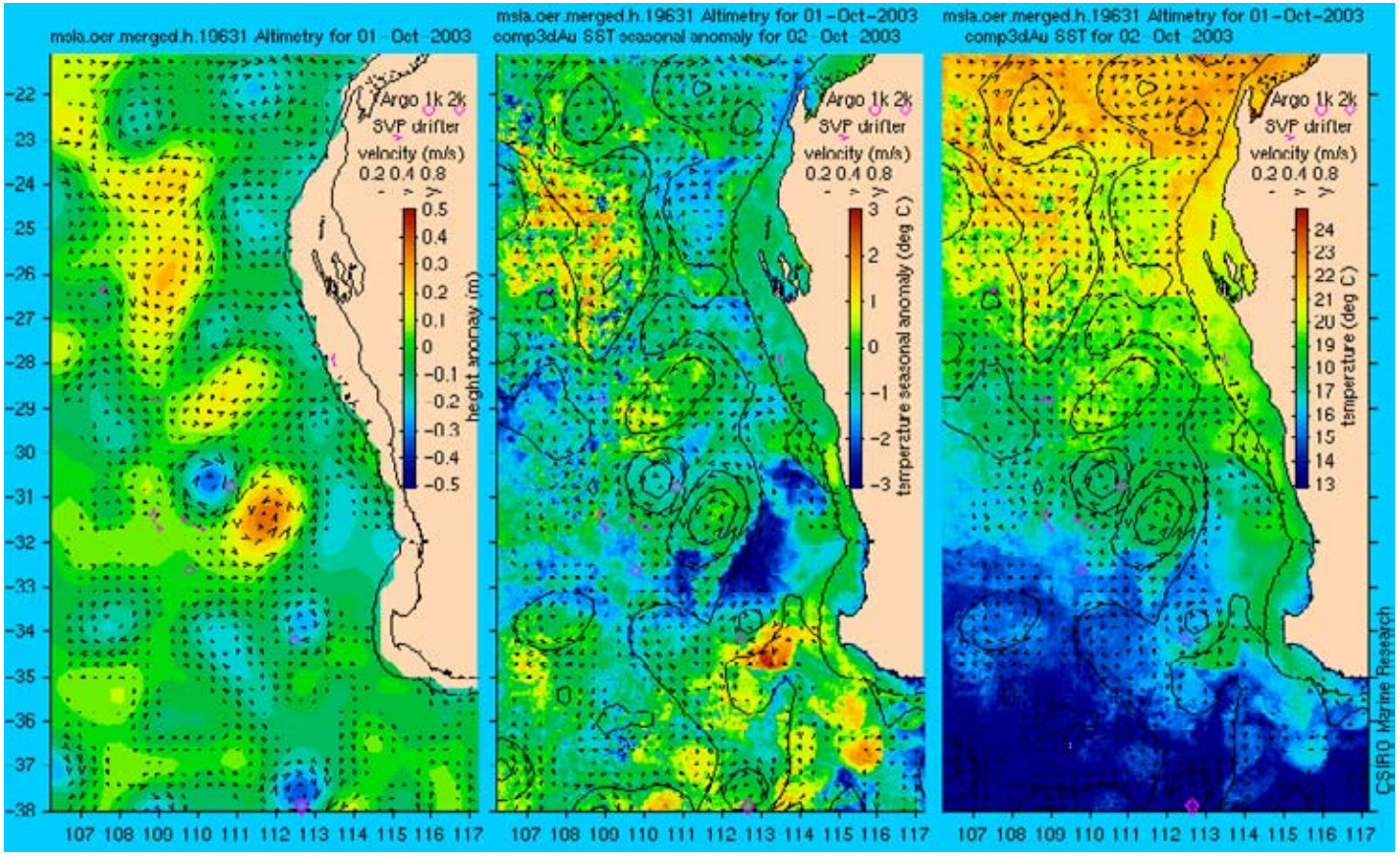
Thanks to the NRT availability of high quality products AND the sampling by two or more altimeter missions, operational altimetry has shown a strong development over the past five years.

It now covers an increasing range of applications and users :

- **Scientific applications (cruise optimization, ecosystem studies, study of fish/marine mammals behavior)**
- **Seasonal prediction and climate applications**
- **Hurricane prediction**
- **Fishery and Offshore industries**
- **Marine safety**
- **Operational oceanography centers (MERCATOR, GODAE), Met. Offices, Navies and their related applications**

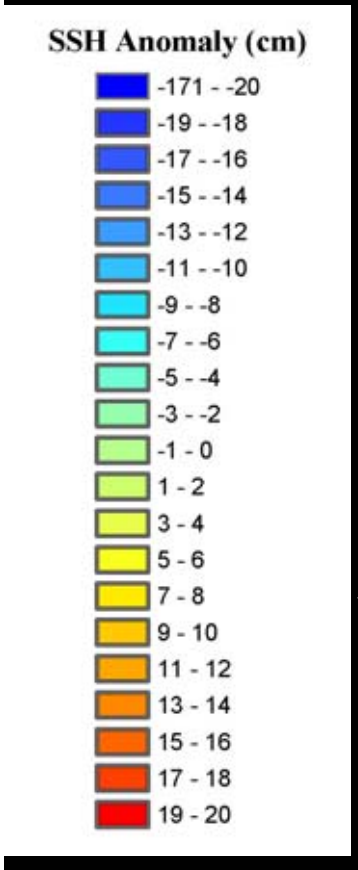
Requirements depend on applications : timeliness/accuracy trade-offs

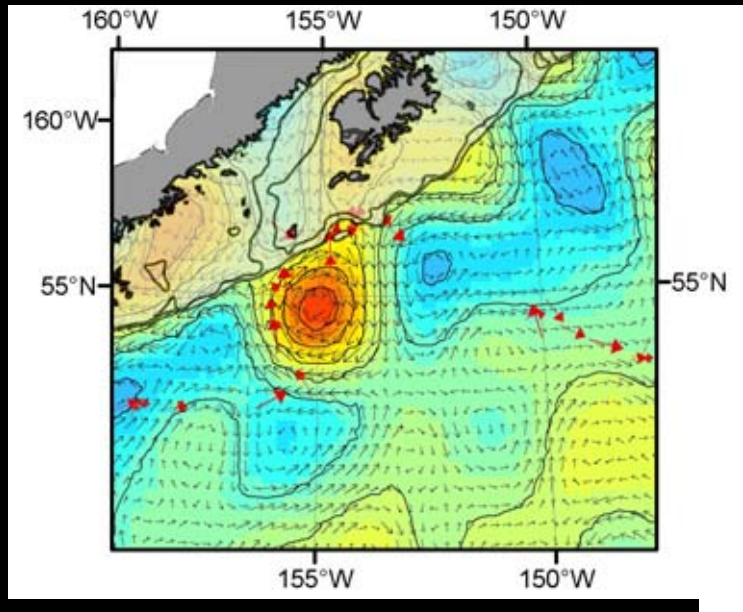
Use of operational altimetry for cruise planning (D. Griffin)

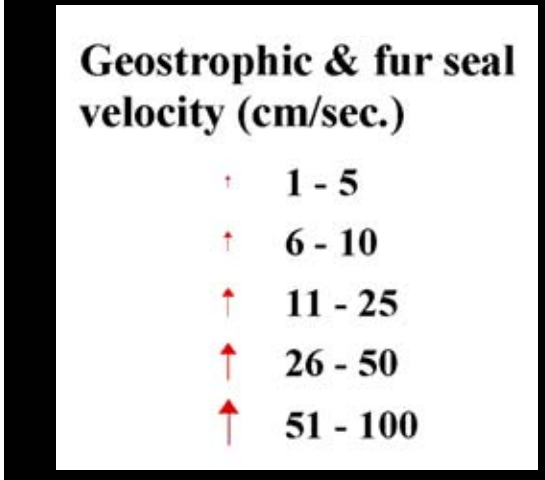


Large-scale situation at the beginning of the cruise. Used to decide which eddies to study, and where they were at the moment.

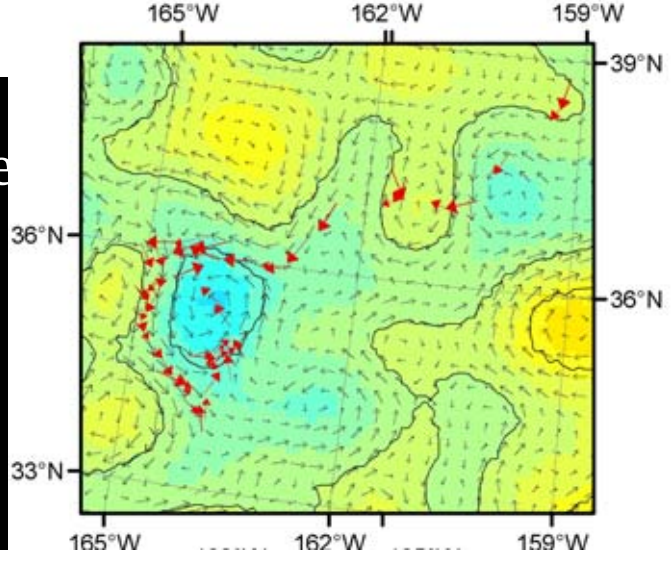
Satellite tracked northern fur seals (B. Leben)







Fur seals linger near mesoscale eddy features in North Pacific during wintertime migration.

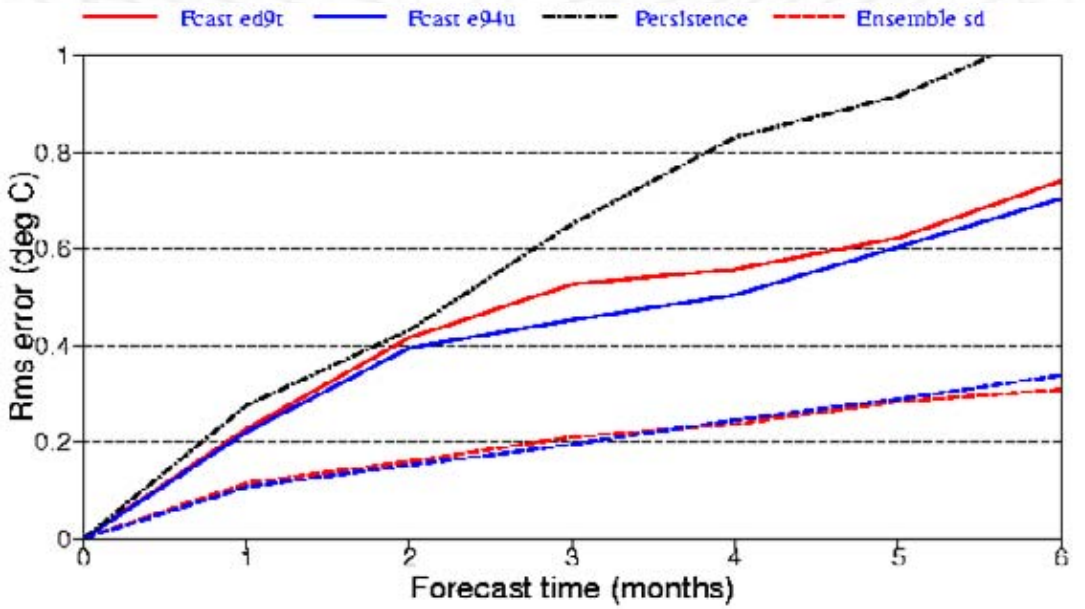


Altimeter data assimilation at ECMWF
Impact on forecast

OI(in situ)

OI(in situ+Alt)

Central Pacific SST rms error

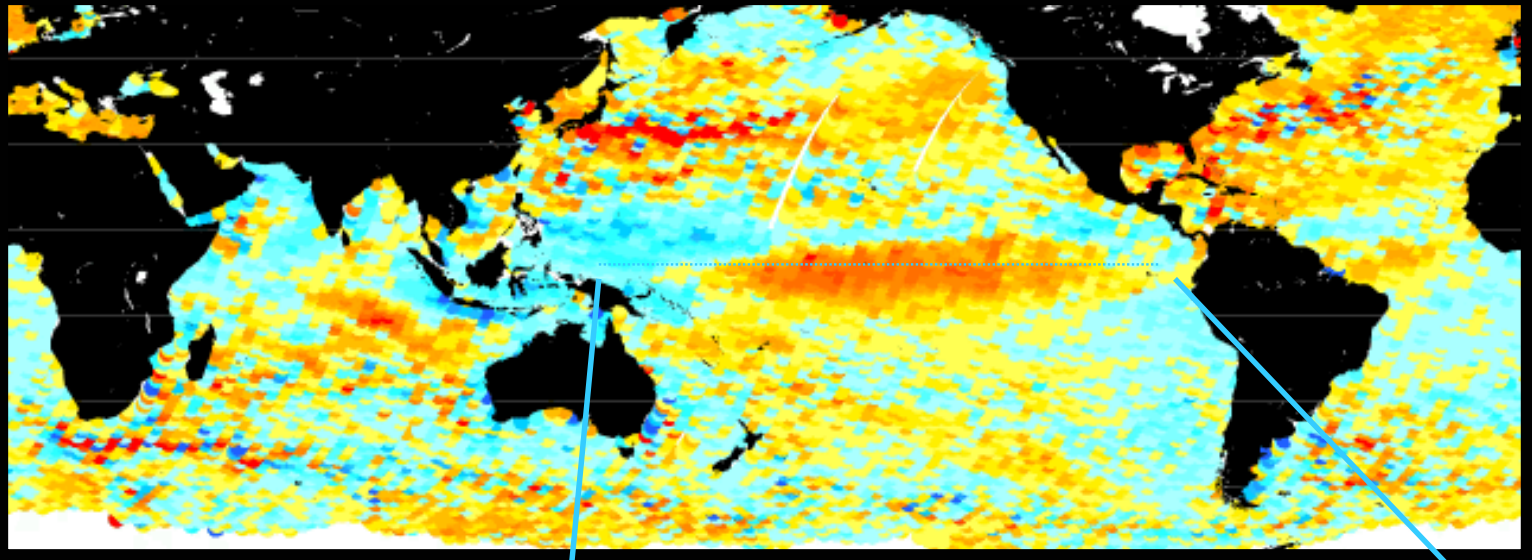


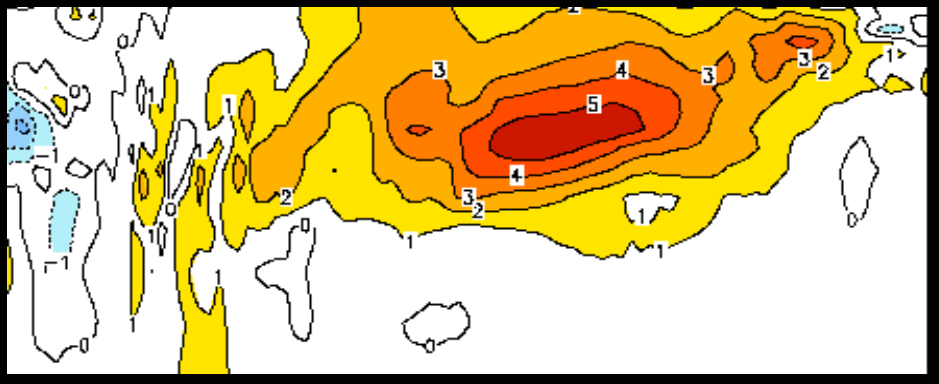
Courtesy A. Vidard

El Nino Monitoring/Forecasting

Jason-1

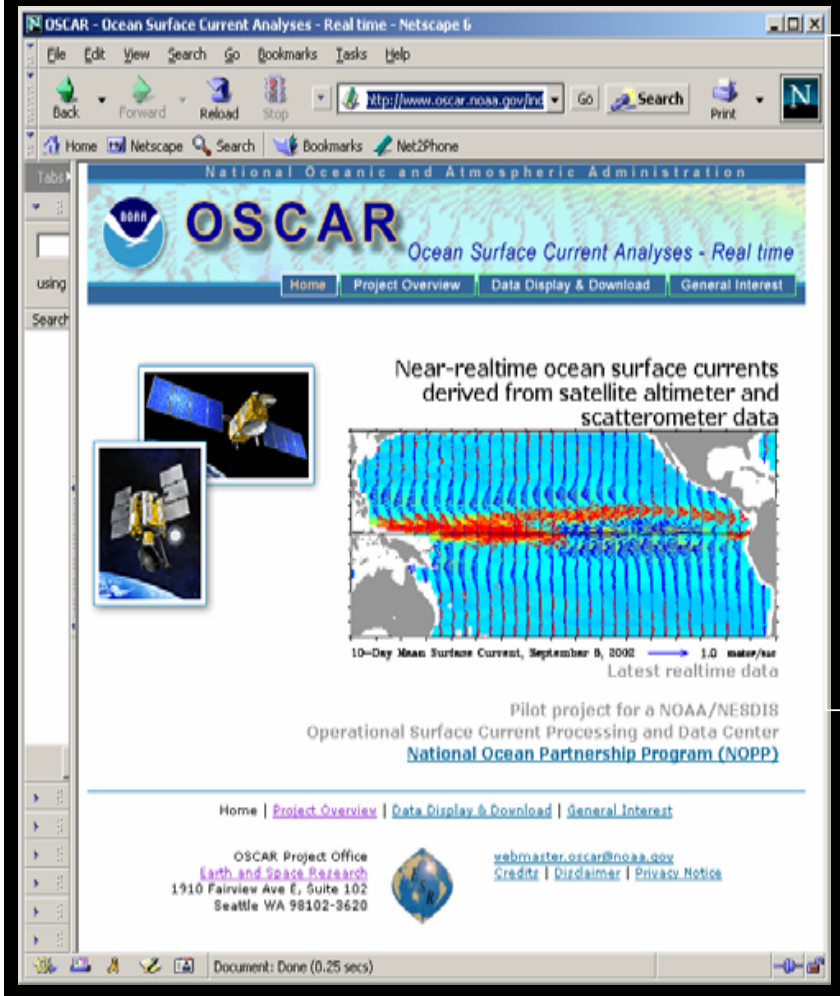
Sep 24-Oct 4, 2002





NOAA ocean model: anomaly of sub- surface temperature (C) for Oct 2, 2002

Courtesy B. Cheney

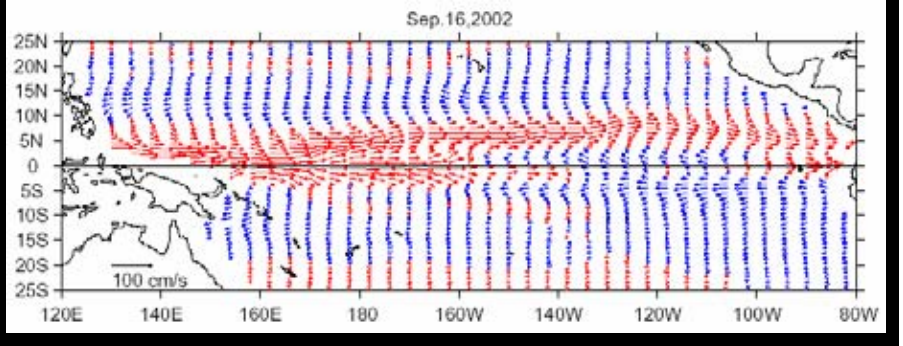


Real-Time Ocean Surface Currents

JASON-1 height data for geostrophic currents

Quikscat winds for surface Ekman currents

Website operational Oct 2002: www.oscar.noaa.gov

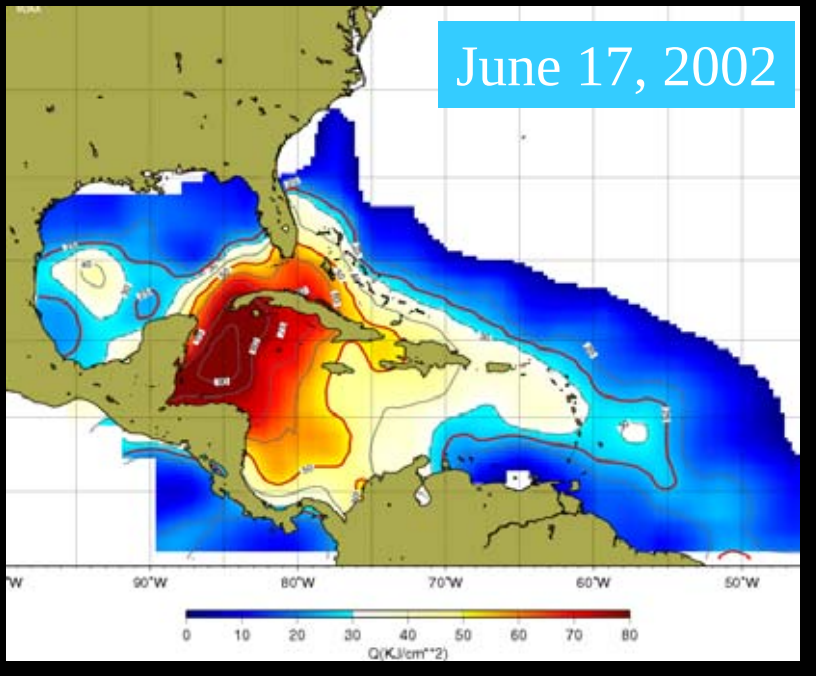


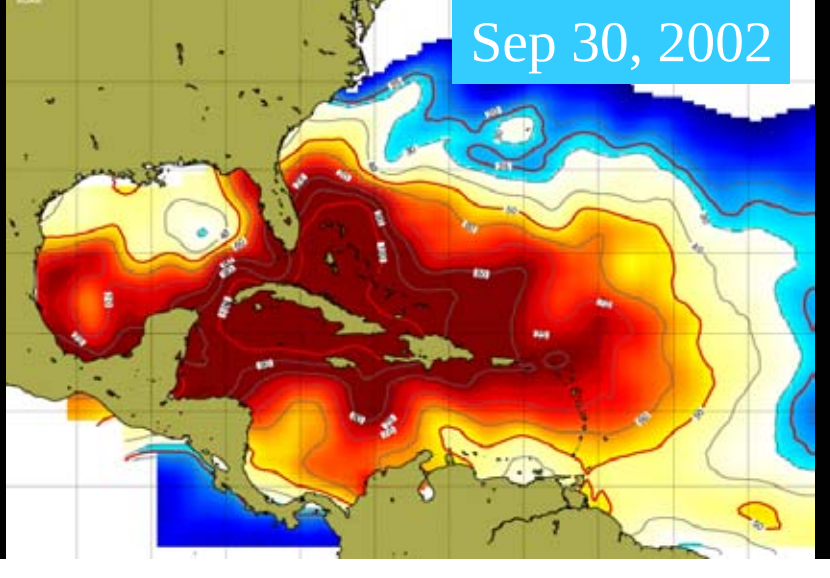
Courtesy B. Cheney, F. Bonjean

Improving Forecasts of Hurricane Intensity

Maps show Hurricane Heat Potential: integrated temperature from the sea surface to the 26C isotherm.

Derived from:
- SST
- altimeter sea level deviations
- two layer model





Courtesy B. Cheney

Offshore Operational Support: Gulf of Mexico (B. Leben)

Data User: Capt. Karl Greig, captain of a large anchor handling tug boat owned by Edison Chouest Offshore.

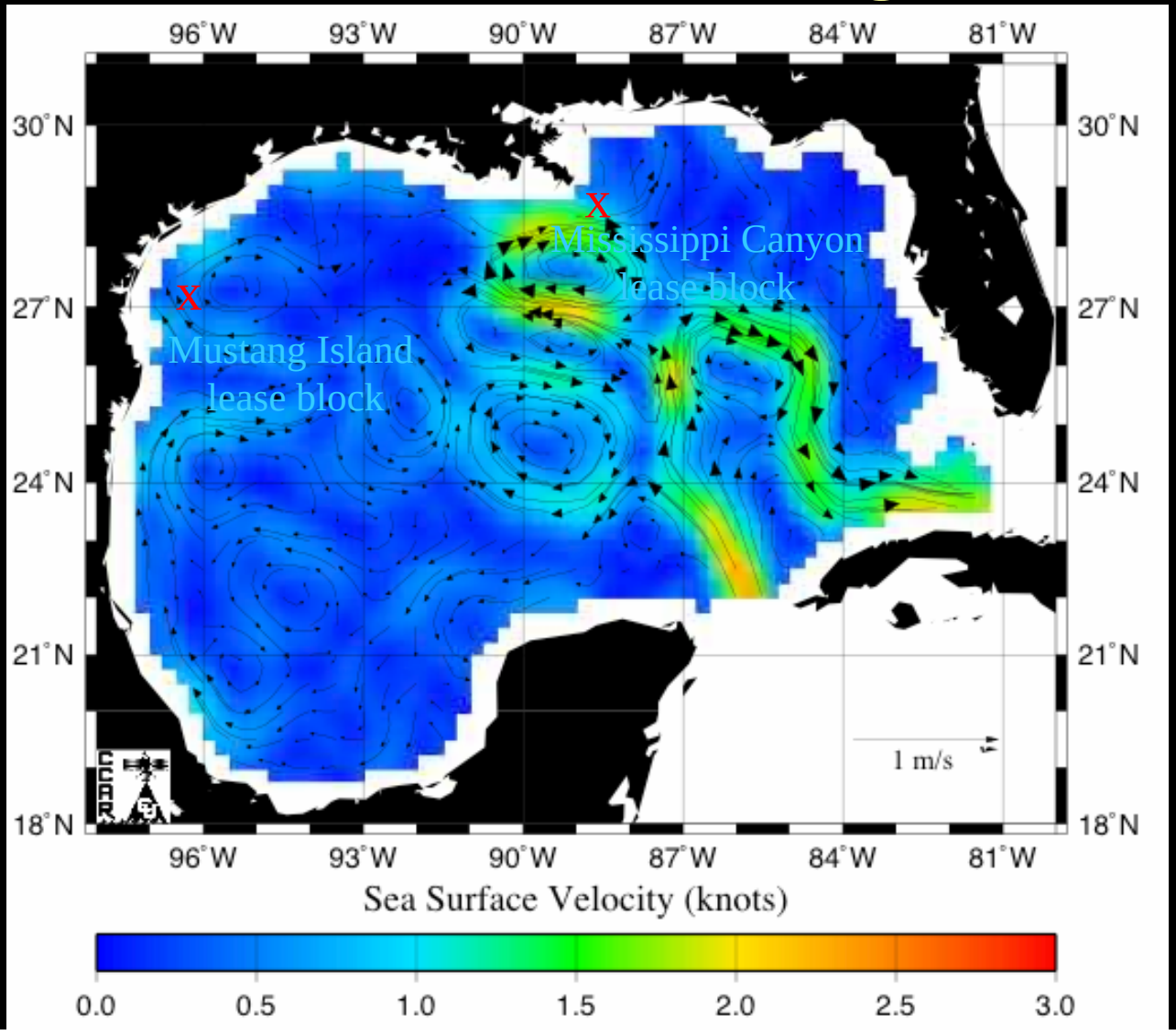
Application: Route finding for towing semi-submersible drilling rigs used in deepwater oil and gas exploration.

Operation: Moving a rig from Mississippi Canyon block 68 to Mustang Island block 68, a total of 425 nautical miles. Typical towing speeds are 3 to 4 knots so avoiding and/or using eddy currents significantly reduces transit times, in this case by over 50 hours.

Altimeter Product Used: Overlays of geostrophic velocity vectors on colored magnitudes values accessed on CCAR website by satellite phone.

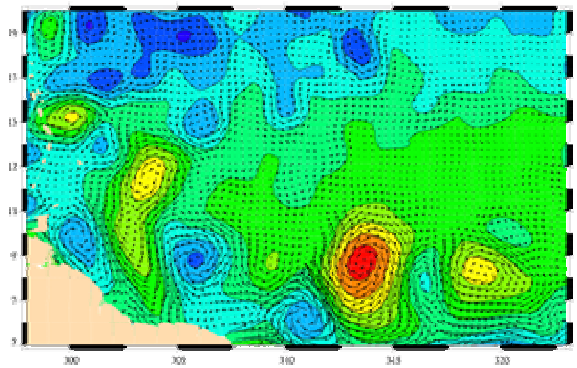
Estimated Savings: $650,000 in rig downtime and towing costs.

Near real-time currents: August 15, 2003

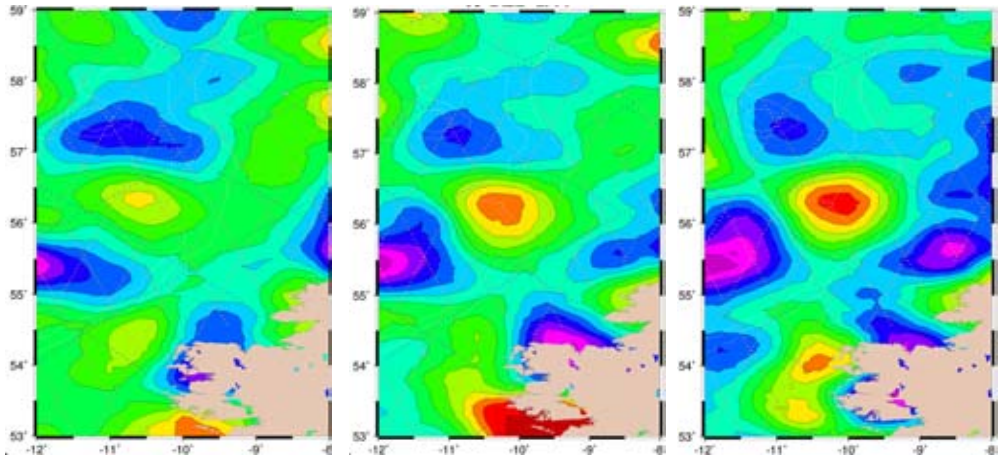


Offshore applications

SSALTO/DUACS products are tested to plan and monitor operations on offshore drilling sites as part of the EMOFOR project (CLS, Nansen Center and Fugro GEOS)



Real-time monitoring of North Brazil Current Rings



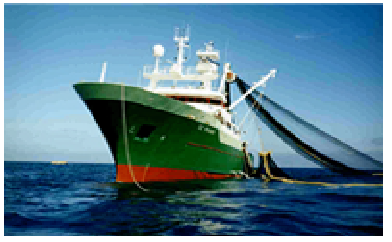
29 January 1999

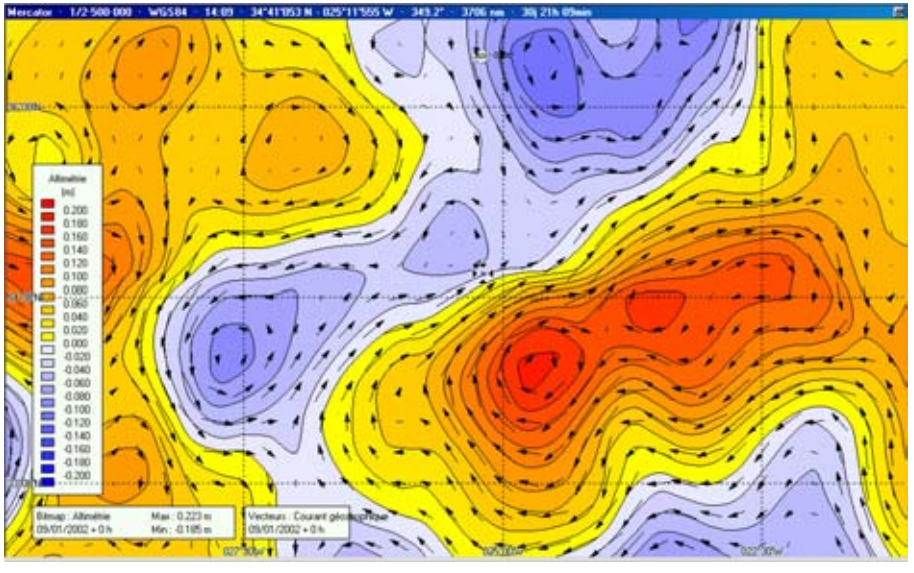
3 February 1999

8 February 1999

Eddy monitoring West of Ireland for offshore operations

Fisheries





SSALTO/DUACS products have been successfully tested by fishing fleets to help locate favorable fishing grounds (CATSAT system).

CATSAT altimeter product

The same information can be used by agencies in charge of managing fish stocks

Altimetry and operational oceanography

Use of synergy with other remote sensing data (e.g. SST, Ocean Colour, winds) and in-situ

Most of the applications will be best served in the future with global/regional/coastal ocean forecasting systems

They provide an integration of in-situ (Argo, TAO, XBT) and remote sensing data (altimetry, SST, etc) => improved ocean description

+ Forecast capabilities

The Global Oceanic Data Assimilation Experiment

Objective: **To provide a practical demonstration of real-time operational global oceanography**

Includes the main operational and research institutions from Australia, Japan, the United States, the United Kingdom, France, Norway, Europe

Main demonstration phase : 2003 to 2005 - Consolidation phase 2006 - 2007

Research, Climate and seasonal forecasting, marine safety, fisheries, the offshore industry, Navy applications and management of shelf/coastal areas are among the expected beneficiaries of GODAE

Satellite altimetry (2 satellites at least) is a strong requirement for GODAE => global, near-real time and high space/time resolution

GODAE Development

Organisation : Patrons group : representatives of agencies, International GODAE Steering Team (IGST) (8 meetings), Project office, Melbourne

Strategic Plan (2001) and Implementation Plan (2002, under revision)

Rationale, required inputs and outputs, evaluation
Implementation: GODAE components, work plan

Main activities (2002/2003)

Pilot projects (Argo, GHRSST)

=> develop a specific component (with a broad perspective) (global in-situ observing system for Argo, global high resolution SST fields for GHRSST)

Prototype systems (N Atlantic, N Pacific, equatorial Pacific, Global)

- **Test the whole chain from observing system to applications and users**

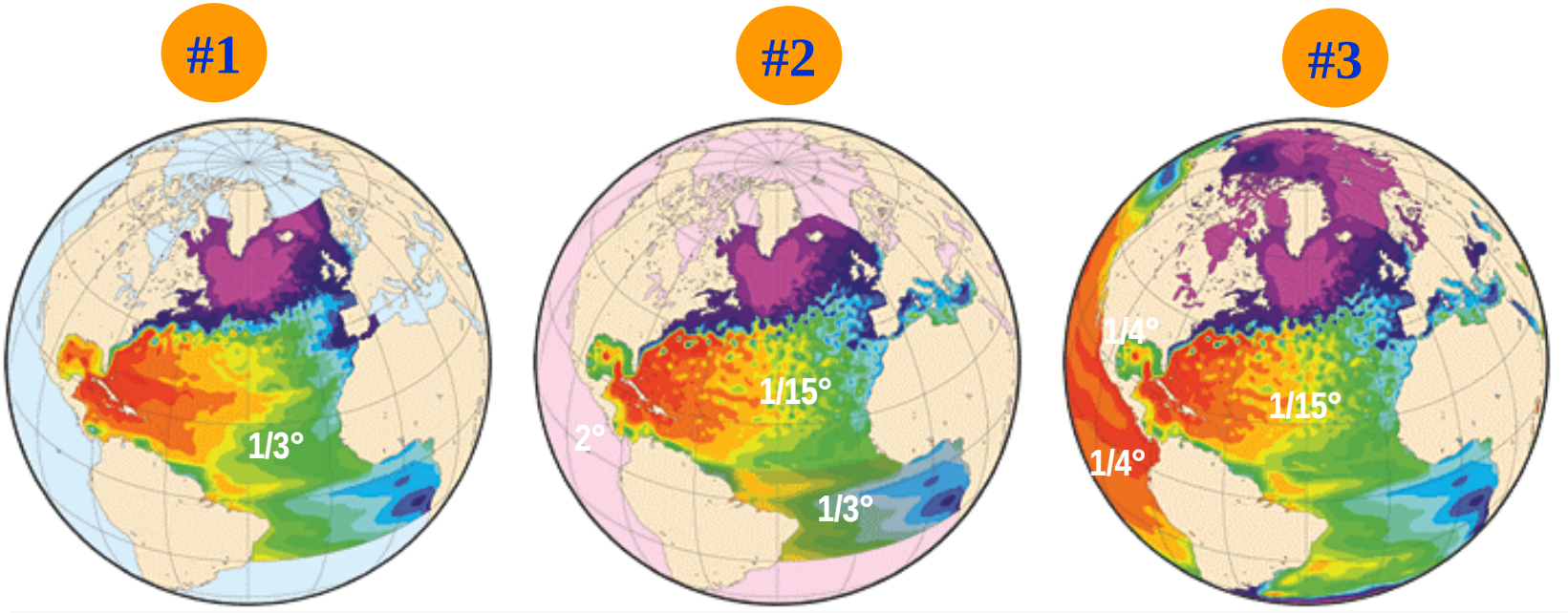
Continue development of ocean state estimation methodologies

Development of data/product serving capability and product assessment and intercomparison

Planned GODAE system

Modeling and Assimilation

From prototype systems to GODAE Target

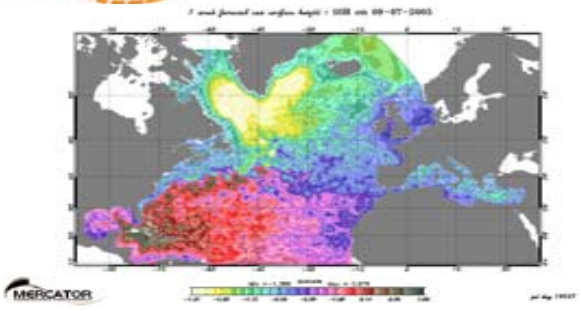


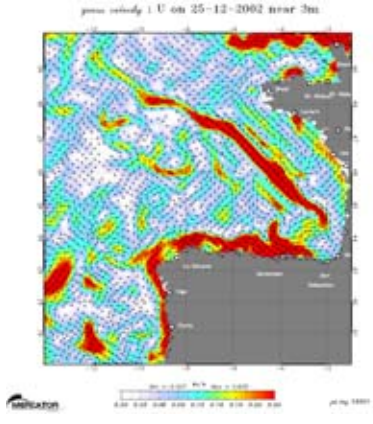
1st prototype (1/3°): operational since January 2001. One bulletin per week since the beginning. Successful demonstration. Multivariate in Fall 2003.

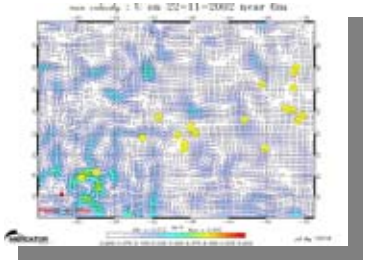
2nd prototype : North Atlantic/Med Sea 1/15° prototype routinely operated since January 2003. A 2° global ocean component added in Spring.

3rd prototype = GODAE target. ¼° global ocean configuration. Summer 2004.

Applications

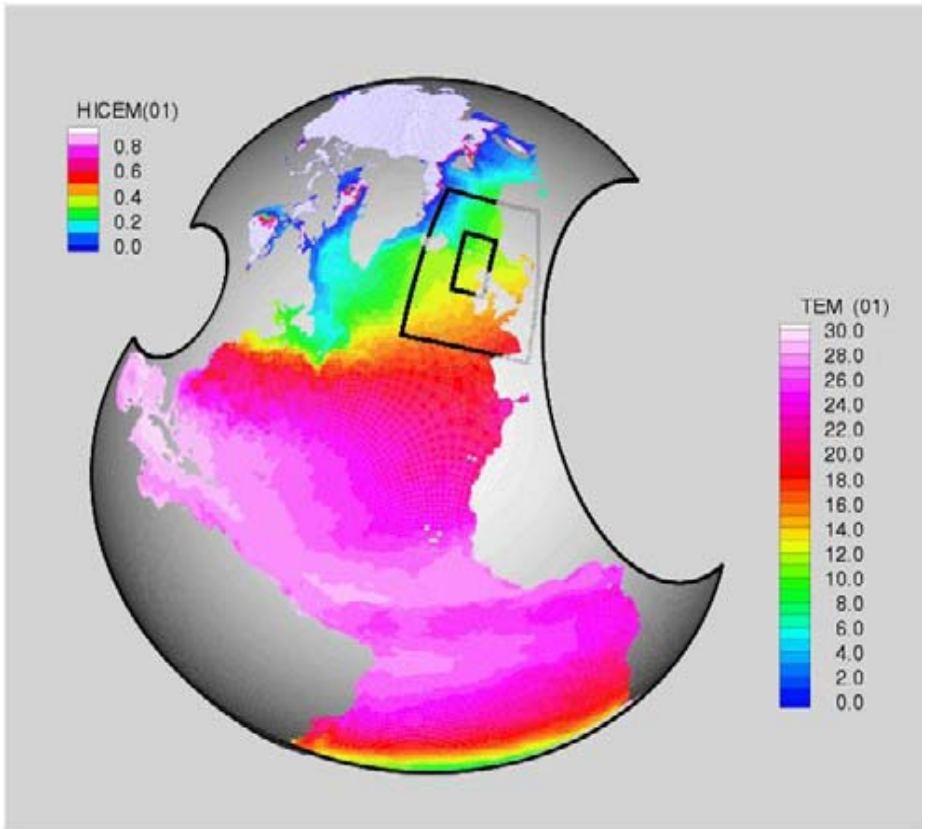




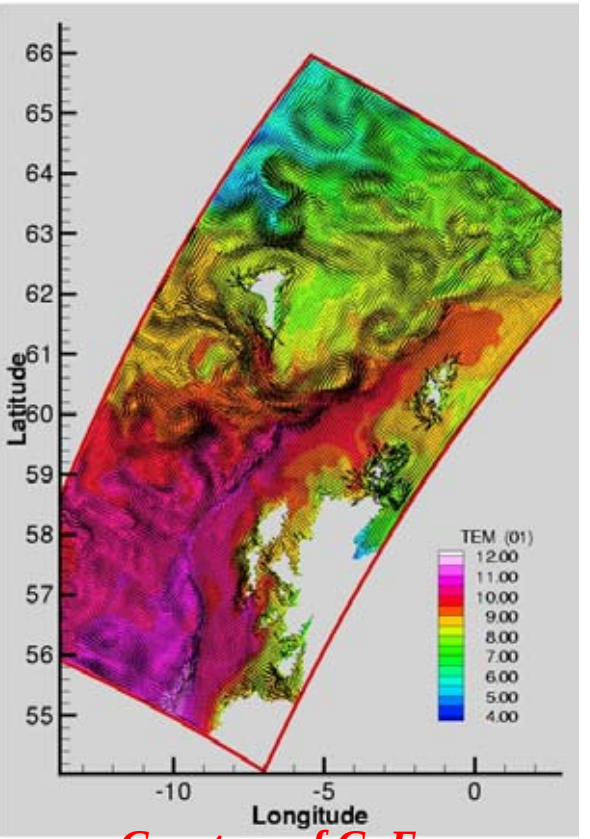


Increasing use of MERCATOR products by ocean service providers

- **Public Service** : strong involvement in oil spill forecasting after the Prestige tanker disaster
  - Ocean bulletins by Mercator forecasters
  - System outputs available for coupling with oil spill dissemination models (Météo-France and Met.No)
- **Nautical Events** : Ocean races such as Route du Rhum or (now) Transat race Jacques Vabre ; etc
- **Research** (cruise planning)
- **Commercial** : fisheries (Catsat service)



DIADEM/TOPAZ and regional high resolution modelling for offshore applications



Courtesy of G. Evenssen

Global => Regional => Coastal

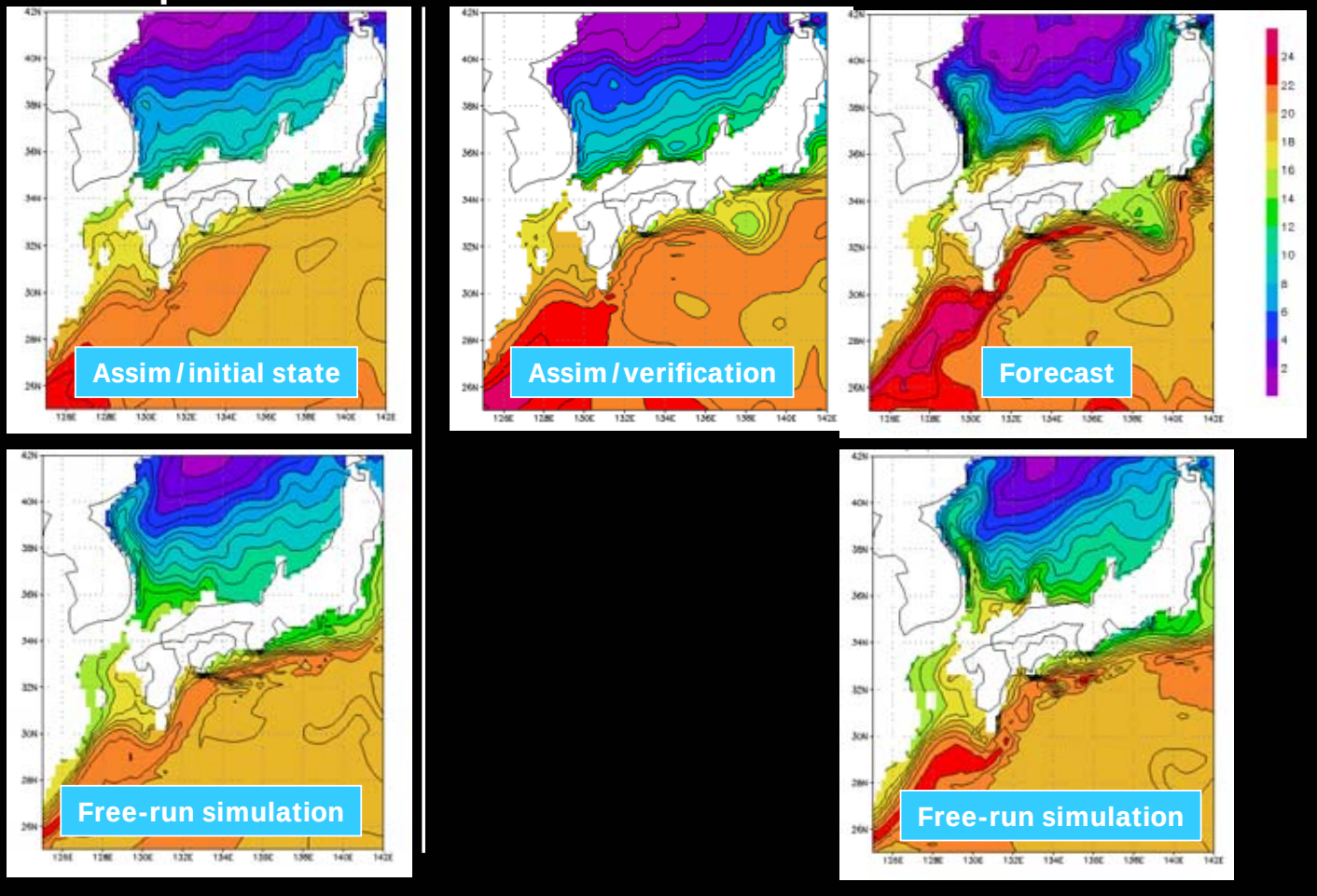
(physics and ecosystems)

A new COOP/GODAE pilot project ?

An Example of Forecast Skill (1)
60-day Prediction of a Kuroshio Meander
Temperature (°C) at 115m

30 April 1998

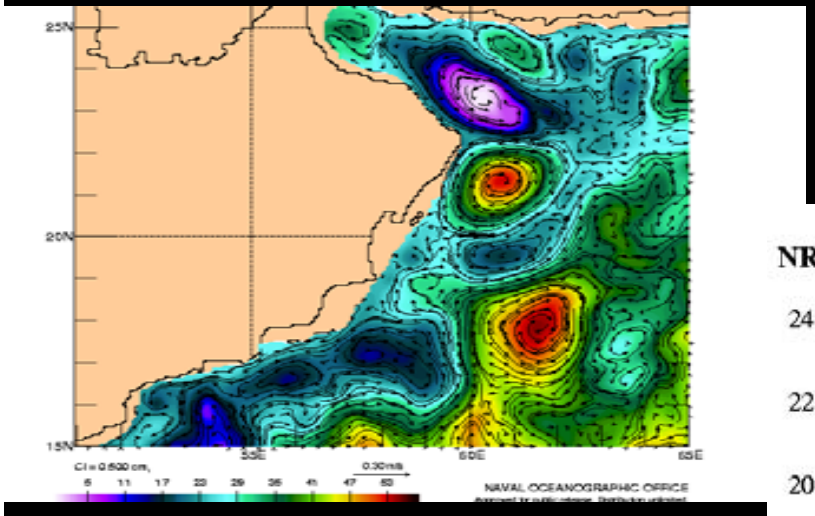
29 June 1998



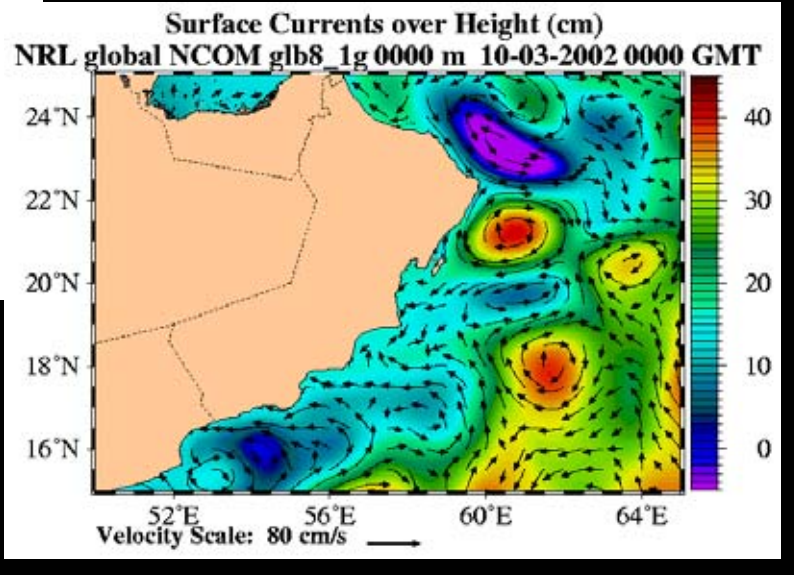
Japan Meteorological Agency COMPASS-K Ocean Prediction System (Kuragano & Kamachi, 2002)

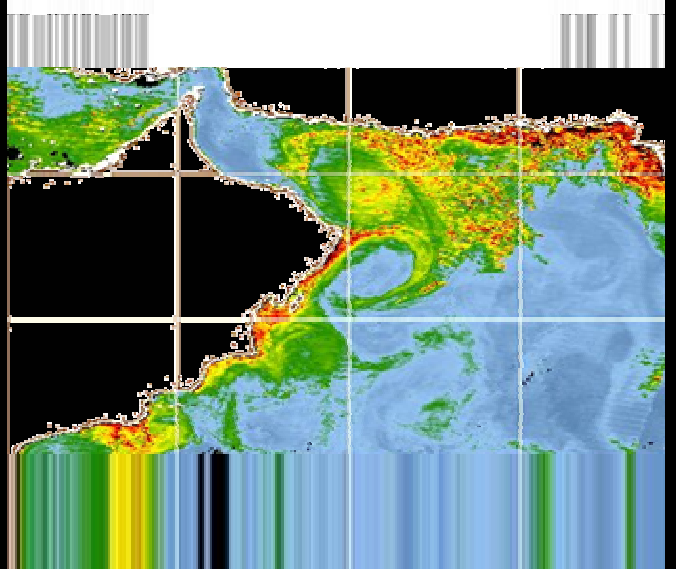
Comparison of NCOM, NLOM and SeaWIFS near the Arabian Peninsula

Global NLOM : Oct 3 2002



Global NCOM: Oct 3 2002

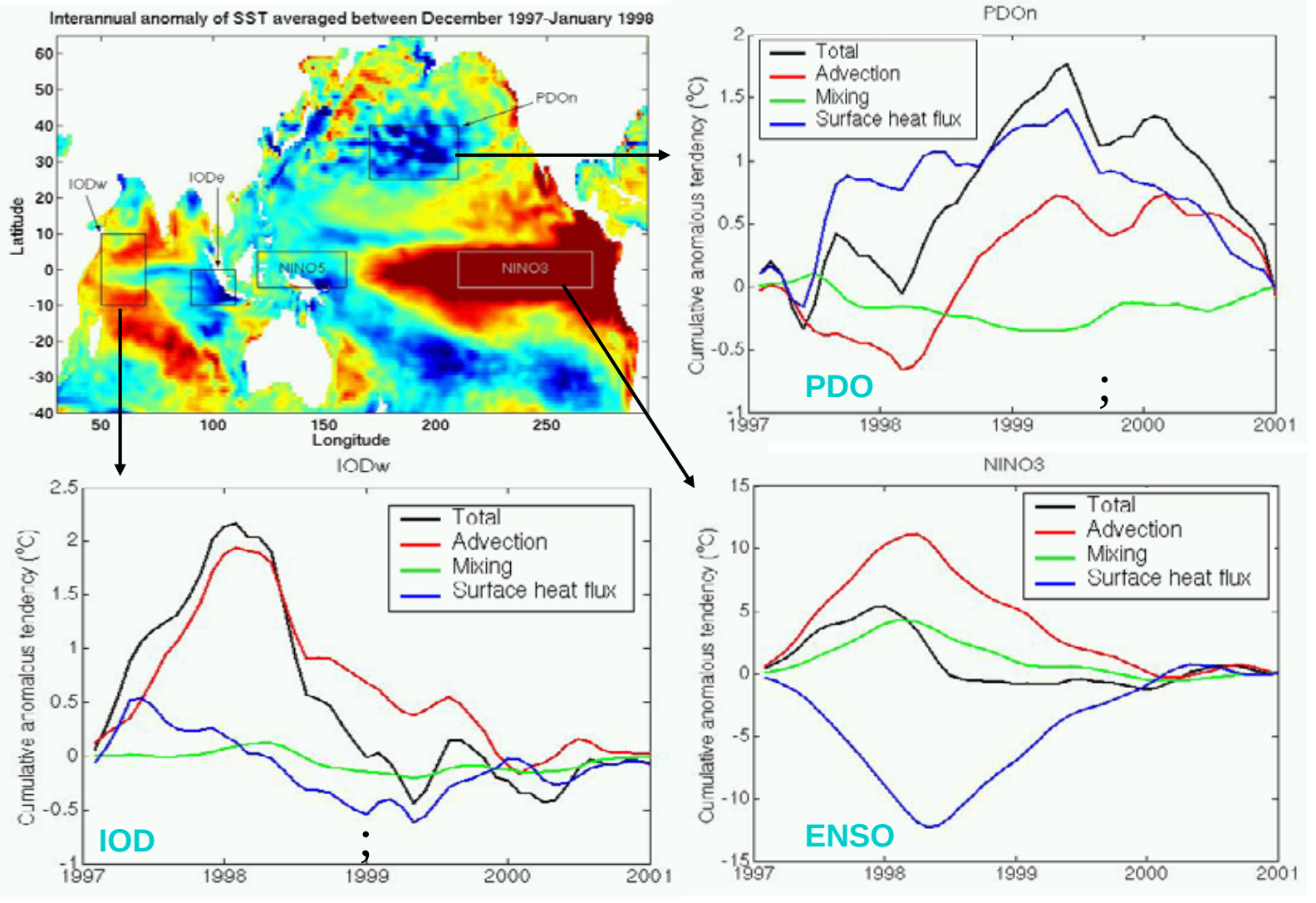




SeaWIFS composite

Sep 30-Oct 7 2002

Mixed-layer heat budget: contrasting various climate events



Courtesy T. Lee

Data and Product Servers

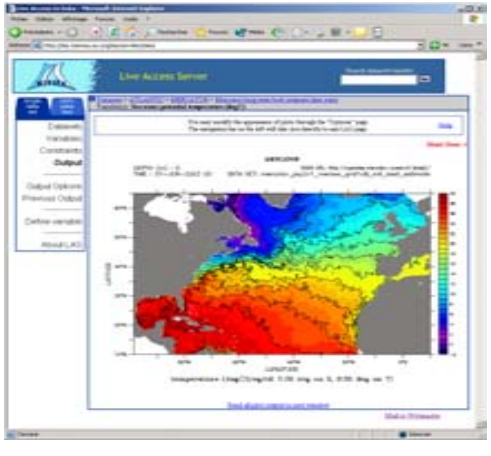
Specialized servers : SSALTO/DUACS – NAVOCEAN (altimetry), Coriolis (in-situ), etc

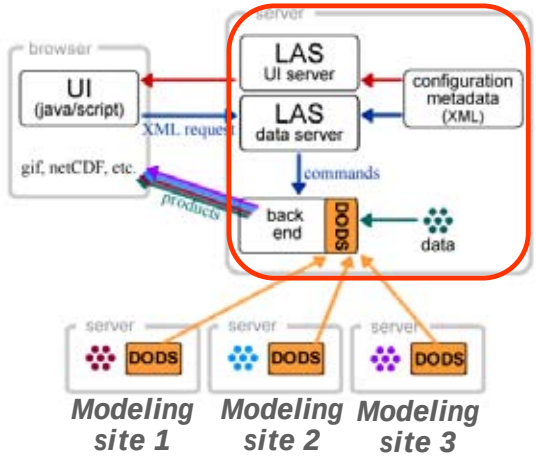
GODAE Monterey server established to provide real-time in situ observations, atmospheric forcing, assimilation products

ECMWF analyses/forecasts available through ESSC (Reading University)

Product servers for the different GODAE centers

=> use of OpenDaP (DODS) and Live Access Server (LAS)
=> intercomparison, standardization of model outputs (grids, format)





Future improvements for applications

+use of GRACE (then GOCE) geoids + in-situ data to get precise absolute dynamic topography => a large impact on applications and forecasting models

+improve the product quality (e.g. correction of high frequency effects with a barotropic model)

+develop specific products for coastal/shelf regions

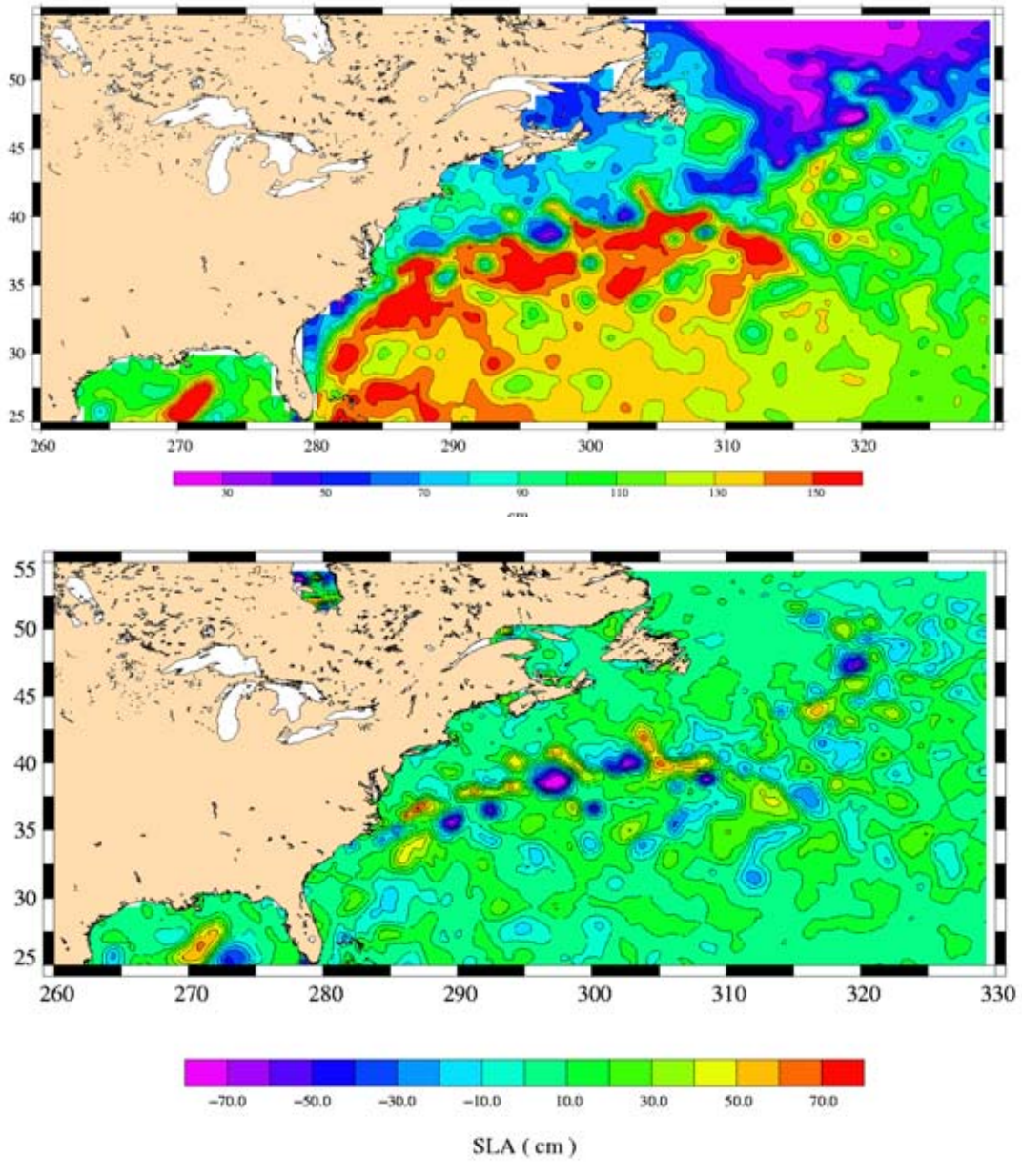
+reduce time delay (1 day) for specific applications

+ Use the tandem mission with ENVISAT and GFO

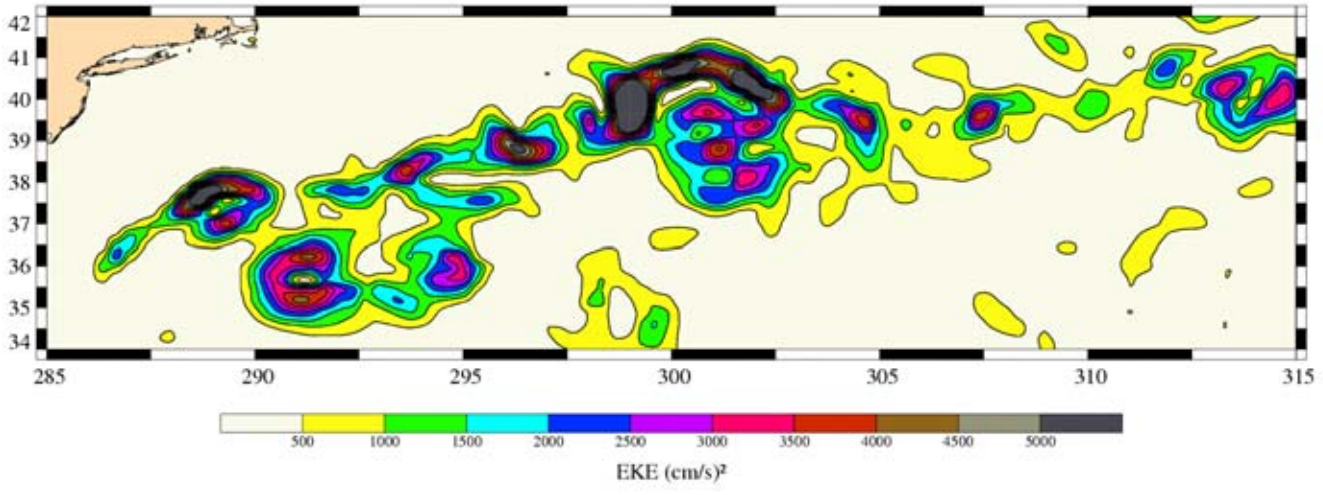
+Improvements of the ocean forecasting systems

Absolute dynamic topography (using Rio et al., 2003 MDT) versus sea level anomaly in the Gulf Stream area.

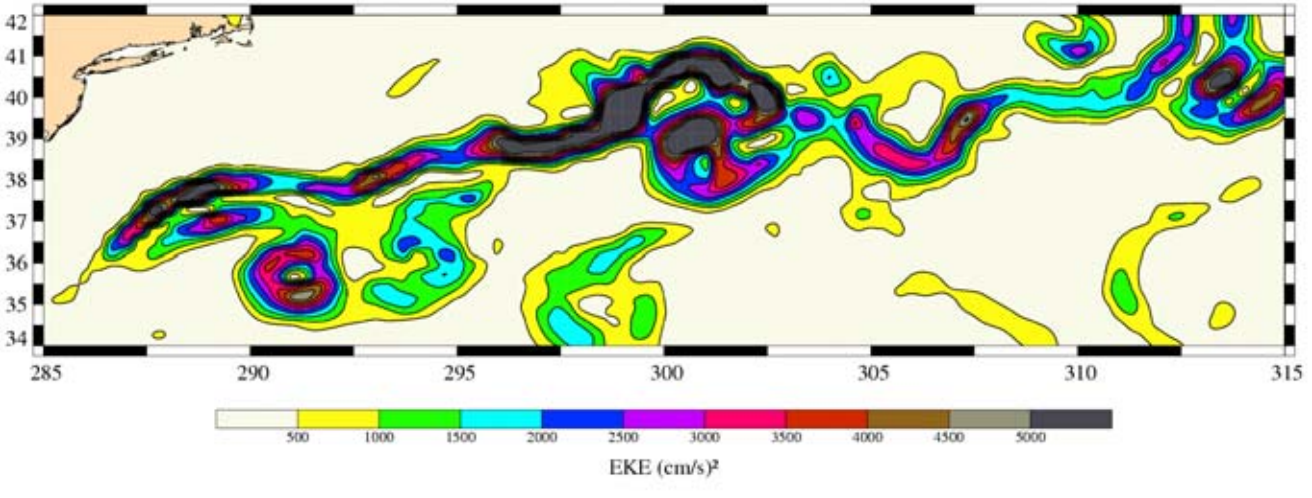
Large impact for ocean forecasting models and data interpretation (Le Traon et al., 2003)



December 2002, Eddy Kinetic Energy in the Gulf Stream area



Jason-1



Tandem mission (Jason-1/TP)

Conclusions

Altimetry is now serving a wide range of users for both mesoscale and climate applications => This demonstrates the unique contribution of satellite altimetry to global operational oceanography.

Altimetry often used in synergy with other data (e.g. SST, ocean colour, in-situ). Integration through data assimilation is the way to go forward (GODAE) (analyses and forecasts)

Need to ensure a long-term high resolution satellite altimetry observing system for operational oceanography – A critical issue !

Minimum requirement is to continue flying a two satellite configuration (after Jason-1 and ENVISAT) :

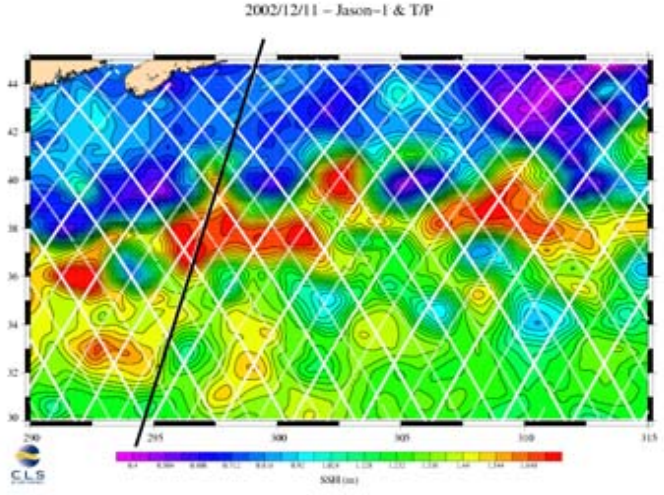
- **Continue the Jason series for long-term, precise altimeter system (Jason-2) (overlap Jason-1 and Jason-2 needed !)**
- **Fly a "mesoscale" mission after ENVISAT**

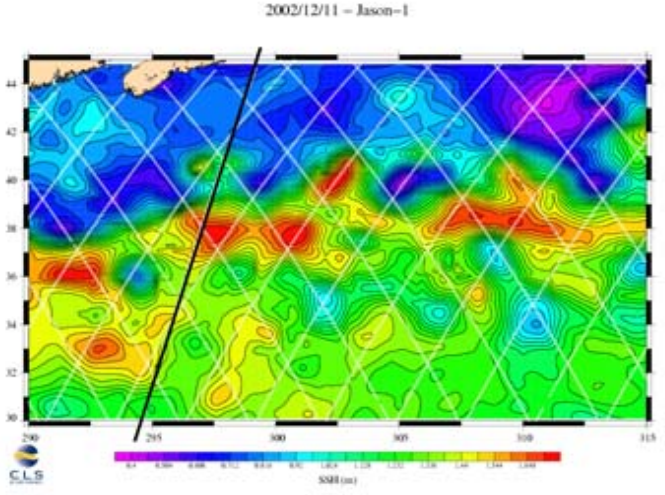
A denser space and time sampling will allow us to much better address scientific and operational applications => Swath techniques and/or constellation of « small » altimeters.

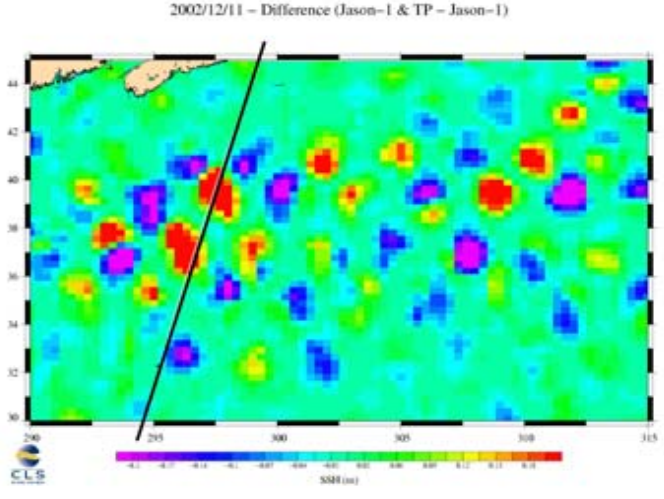
CLS

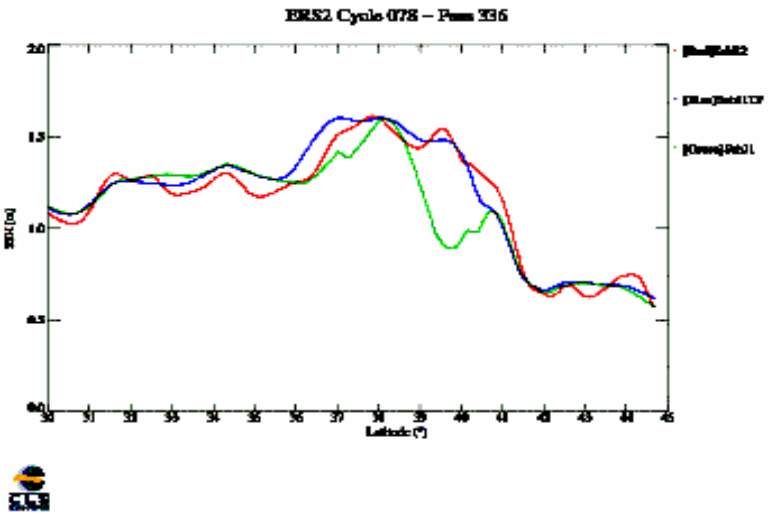
The Jason-1 – TOPEX/POSEIDON tandem mission

A unique opportunity for mesoscale variability studies









ERS track (in black) used as a reference to compare Jason-1 and Jason-1+T/P