Refined requirements for satellite altimetry

Climate and operational oceanography applications

GAMBLE final meeting

Arles, November 17, 2003

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Outline

- **Climate and operational oceanography applications (SSALTO/DUACS)**
- **General requirements for satellite altimetry**
- **Summary of recent studies on sampling requirements**
- **Refined requirements**

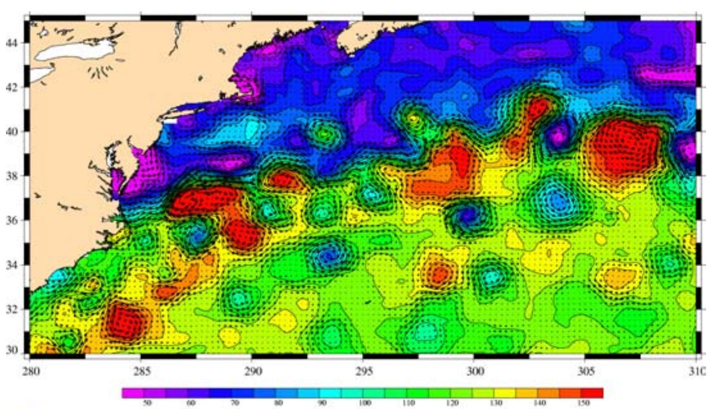
CLS
COLLECTE LOCALISATION SATELLITES

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

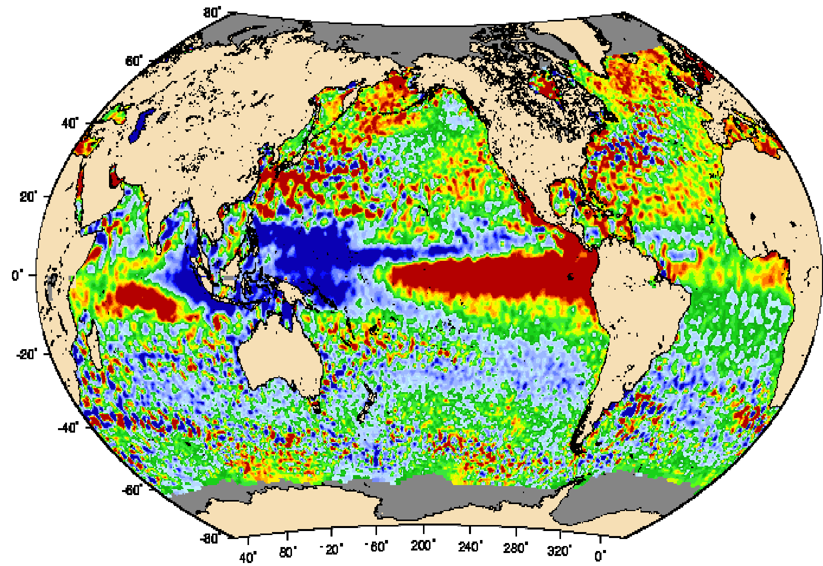
Serving operational oceanography (GODAE : MERCATOR, FOAM, TOPAZ, MFS, etc), climate forecasting centers (ECMWF, etc) and applications (fisheries, offshore industry)

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)

Applications and users

SSALTO/DUACS is serving a large range of applications and users :

Real-time Scientific applications (cruise optimization)

Seasonal prediction and climate applications (e.g. ECMWF)

Operational oceanography centers (MERCATOR, GODAE), Met. Offices, French Navy system (SOAP)

Fisheries, offshore industry

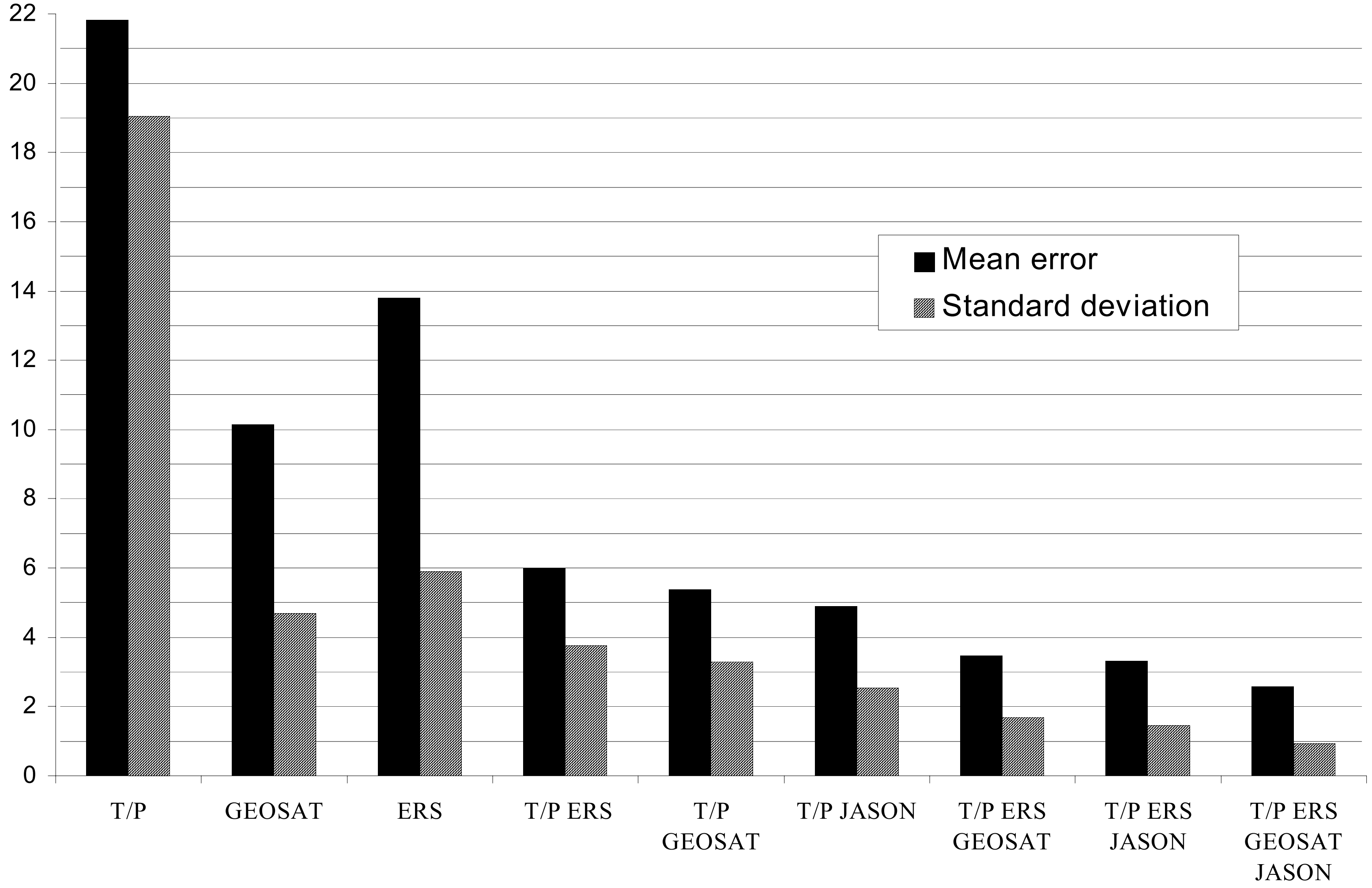
Requirements for sea level measurements

***Main requirements for climate and mesoscale applications* : *at least two altimeter missions with one very precise long-term altimeter system are needed (e.g. Koblinsky et al., 1992)*.**

The long-term altimeter system is supposed to provide the low frequency and large scale climatic signals and to provide a reference for the other altimeter missions. **It requires a series of very precise and inter-calibrated missions** (e.g. T/P, Jason).

The role of the other missions is to provide the higher wavenumbers and frequencies and, in particular, the mesoscale signal, which cannot be well observed with a single altimeter mission. This does not require precise altimeter systems as most of the altimetric errors are at long wavelengths and they do not impact significantly the mesoscale signal.

Le Traon and Dibarboure (1999), Le Traon et al. (2001) and Le Traon and Dibarboure (2002) quantified the contribution of single/multiple altimeter missions for the mapping of mesoscale variability. **Results from these studies are used to provide refined requirements for climate and (mainly) mesoscale applications.**



Mean and standard deviation of Sea Level Anomaly (SLA) mapping error for single and multiple altimeter missions (Le Traon and Dibarboure, 1999). Units are in % of signal variance. The calculation assumes a space scale of 150 km and a time scale of 15 days and a noise/signal ratio of 2%.

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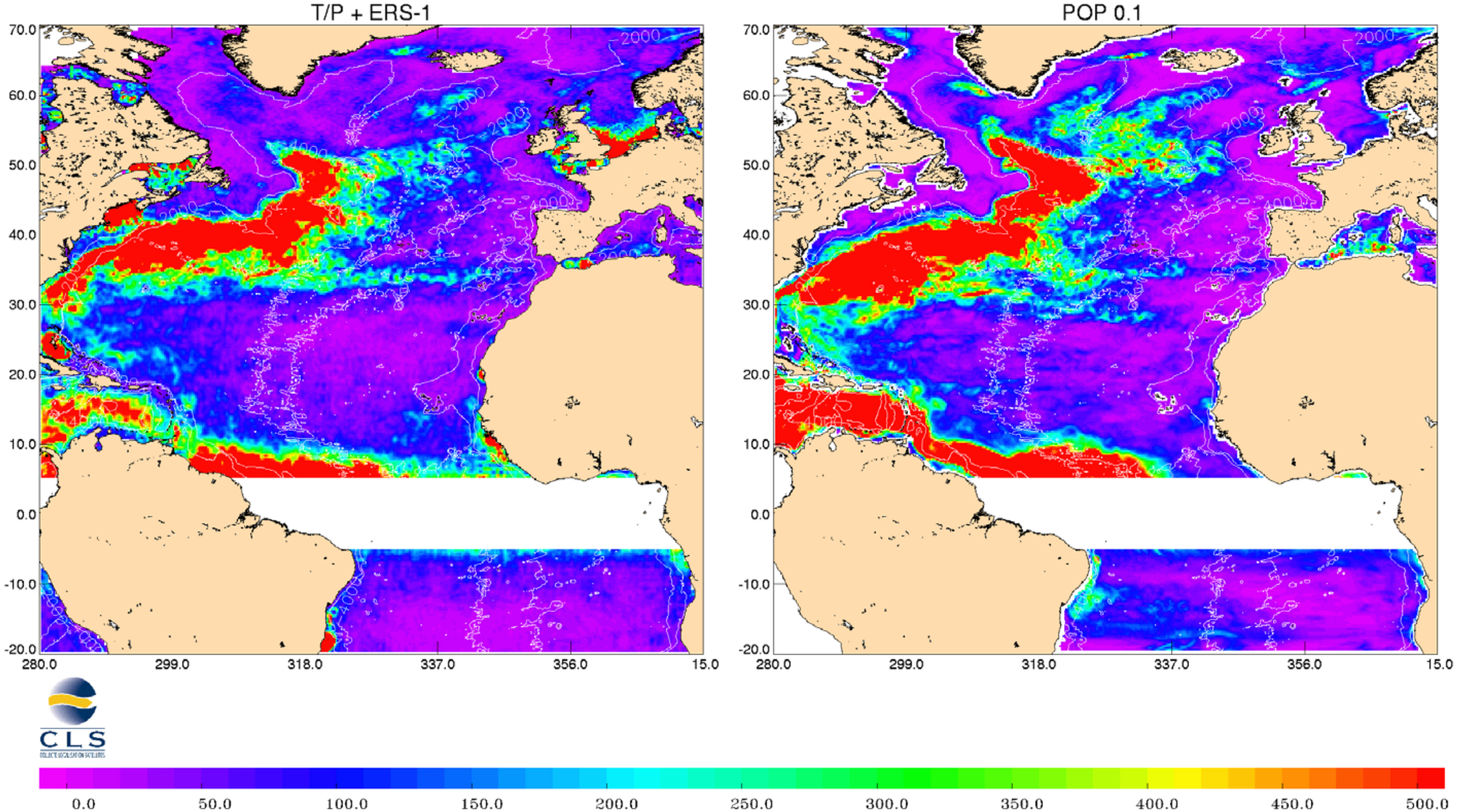


CLS

EKE TOPEX/POSEIDON+ERS-1/2 and Los Alamos Model

Use of Los Alamos model to analyze the sampling characteristics of multiple altimeter missions and improve the T/P+ERS processing (Le Traon et al., 2001; Le Traon and Dibarboure, 2002)

Simulations with the Los Alamos Model - Methods

Subsample model fields (sea level anomaly) along altimeter tracks

Add a random noise of 3 cm rms to the simulated along-track data (WSOA - errors from E. Rodriguez)

Use of a sub-optimal space/time mapping method to reconstruct the 2D sea level anomaly signal from simulated along-track data on a 1/10° grid. Take into account noise (uncorrelated).

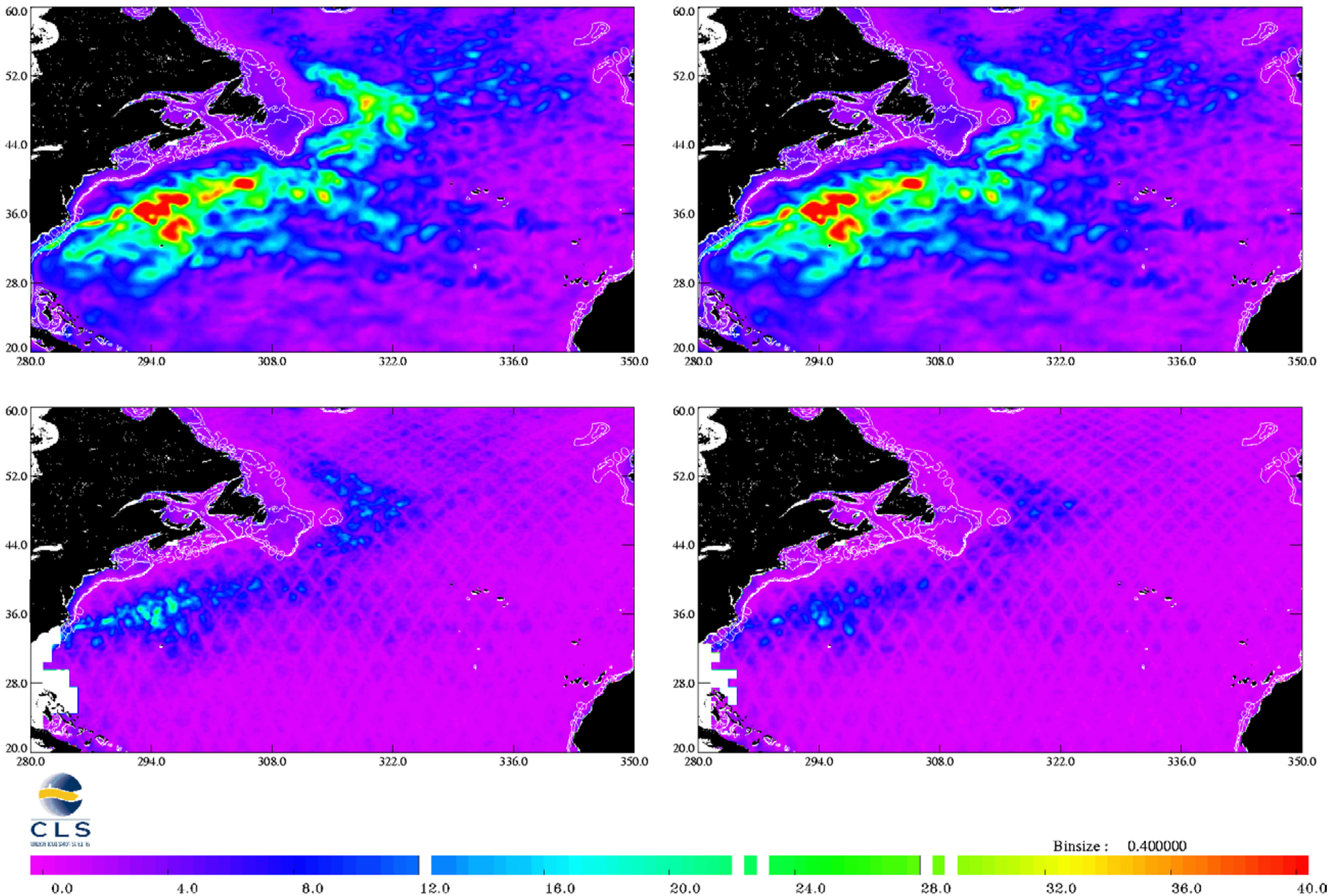
Compare the reconstructed fields with the reference (model) fields (sea level, zonal and meridional velocity) => allows an estimation of the sea level, zonal and meridional velocity mapping error

Add 10% noise and compare the reconstructed fields with the 10-day average fields => allows an estimation of the mapping errors on 10-day average fields

Sea level mapping error from T/P+ERS simulated from the Los Alamos Model (instantaneous and 10-day average fields)

LAM rms SLA

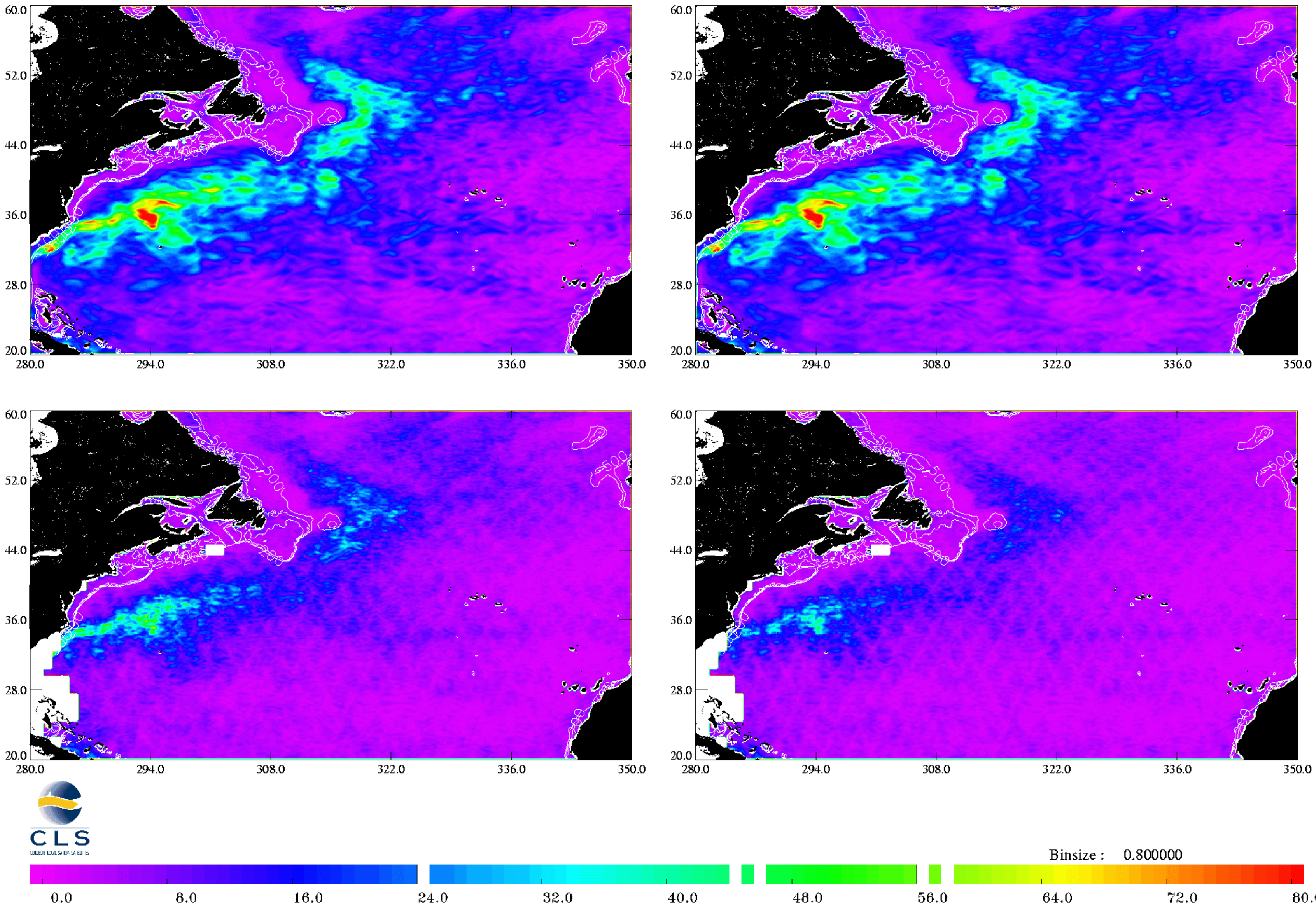
Rms Mapping error



Zonal velocity mapping error from T/P+ERS (instantaneous and 10-day average fields) simulated from the Los Alamos Model

LAM rms U

U Rms Mapping error



Summary of T/P+ERS mapping capabilities

- **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)**

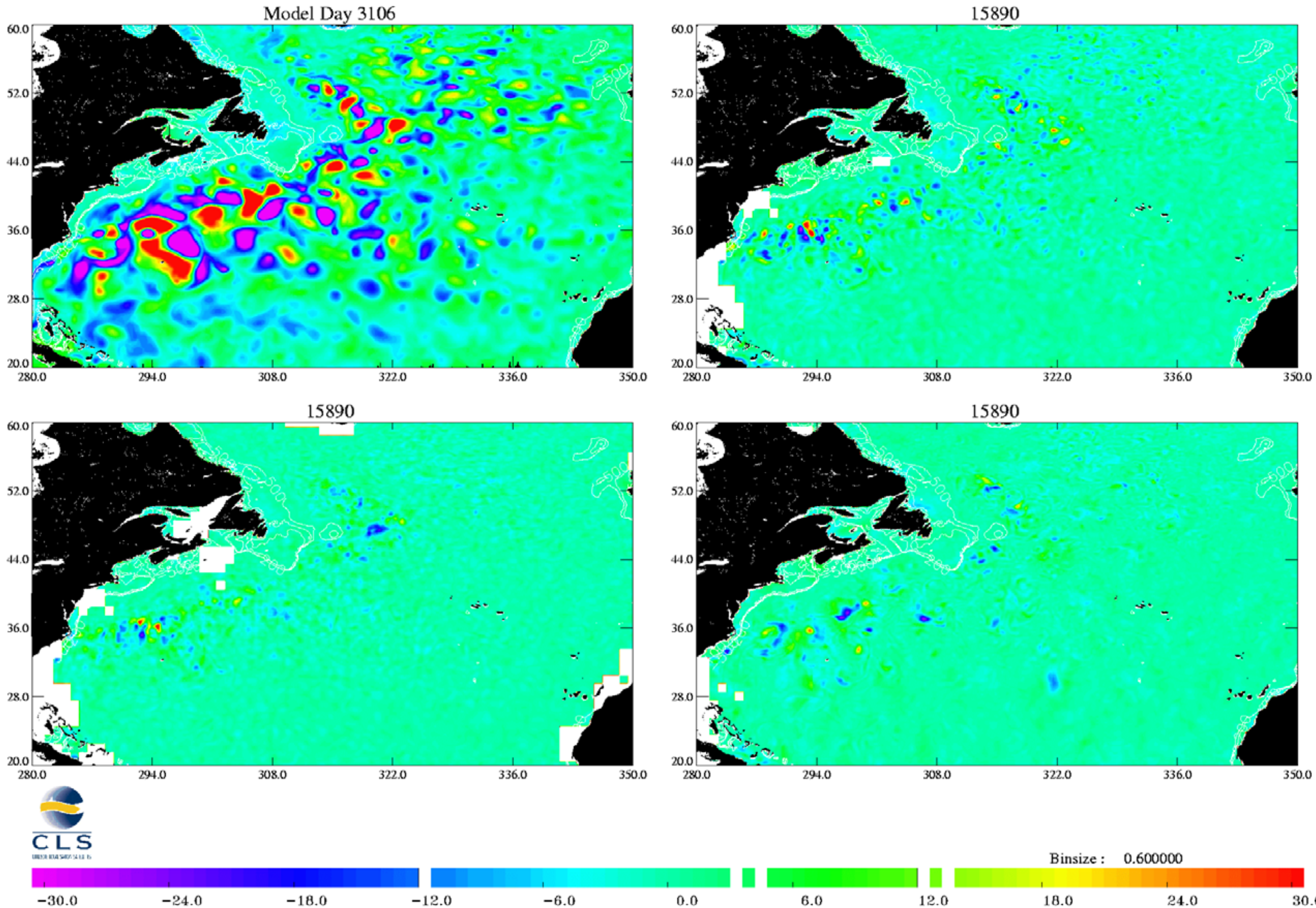
- **A large part of the mapping errors is due to high frequency (< 20 days) and high wavenumbers signals.**

Mapping capabilities of future missions

Simulations with the Los Alamos Model

- **T/P+Jason-1, T/P+ERS+Jason-1, T/P+ERS+Jason-1+GFO**
- **Three interleaved Jason-1 (no time separation)**
- **Three interleaved Alti-Ka (ERS/ENVISAT orbits)**
- **Four interleaved Jason-1 (no time separation)**
- **WSOA* (assumes uncorrelated errors - data preprocessing)**

Example of sea level mapping error from T/P+ERS, T/P+ERS+Jason-1 and WSOA* - instantaneous fields

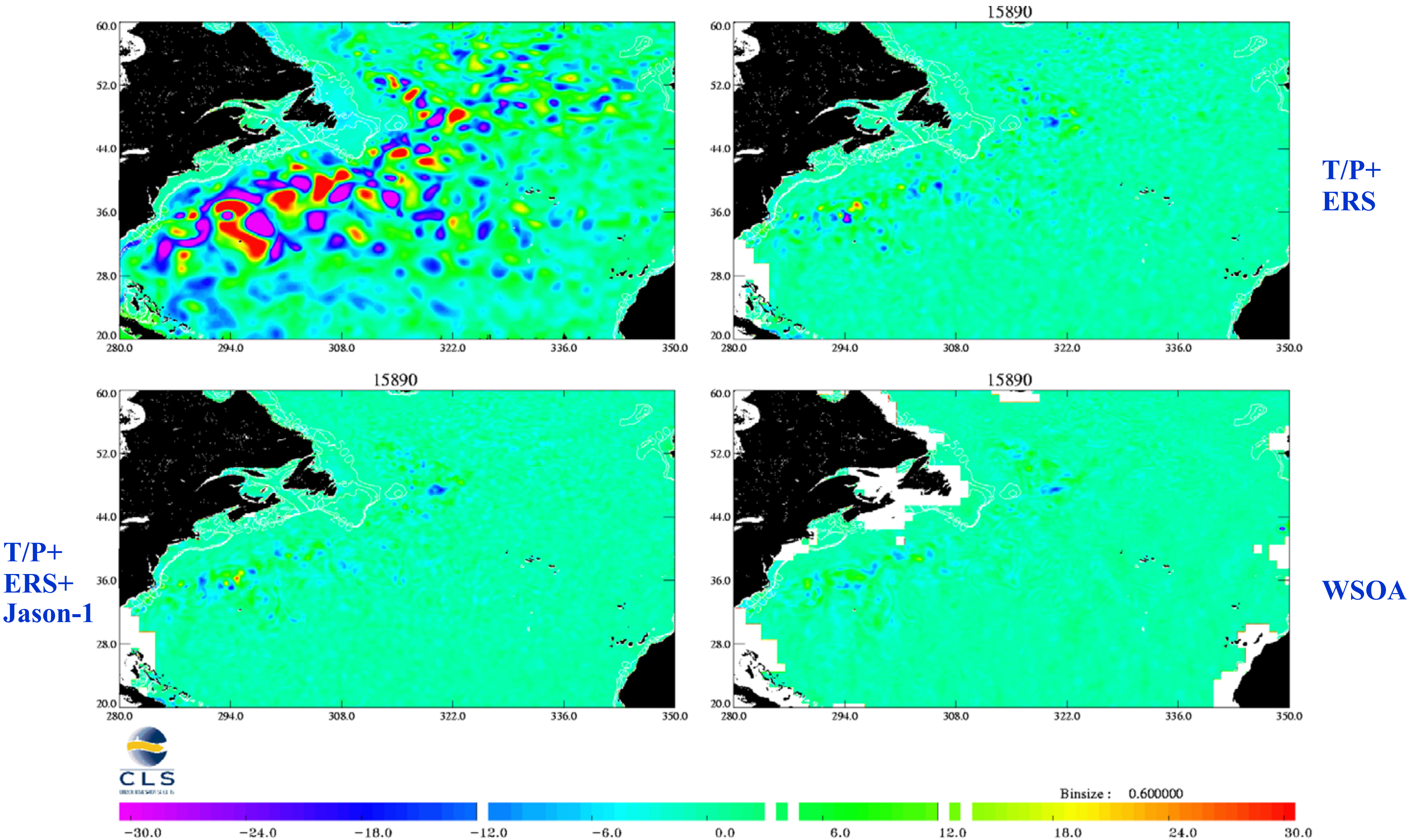


T/P+ ERS

T/P+ ERS+ Jason-1

WSOA

Example of sea level mapping error from T/P+ERS, T/P+ERS+Jason-1 and WSOA* - 10-day mean fields



Sea Level and velocity mapping errors
(Le Traon and Dibarboure, 2002)

	H	U	V
T/P + ERS	**7.2 / 3.2**	**26.3 / 9.9**	**35.0 / 13.5**
T/P + Jason-1	**5.0 / 2.0**	**21.6 / 7.4**	**24.2 / 8.9**
T/P+Jason-1+ENVISAT	**4.2 / 1.8**	**19.6 / 6.9**	**22.3 / 8.3**
Three interleaved Jason-1	**3.7 / 1.5**	**17.9 / 5.3**	**20.6 / 6.3**
Four interleaved Jason-1	**3.4 / 1.0**	**16.9 / 3.9**	**20.1 / 4.5**

Table 1: Sea Level (H), zonal (U) and meridional (V) velocity mean mapping errors for regions with rms sea level variability larger than 15 cm. Errors expressed in percentage of the mean sea level and velocity variance. They are given both for "instantaneous" and 10-day averaged signal mapping.

TANDEM MISSION ANALYSIS (GAMBLE STUDY)

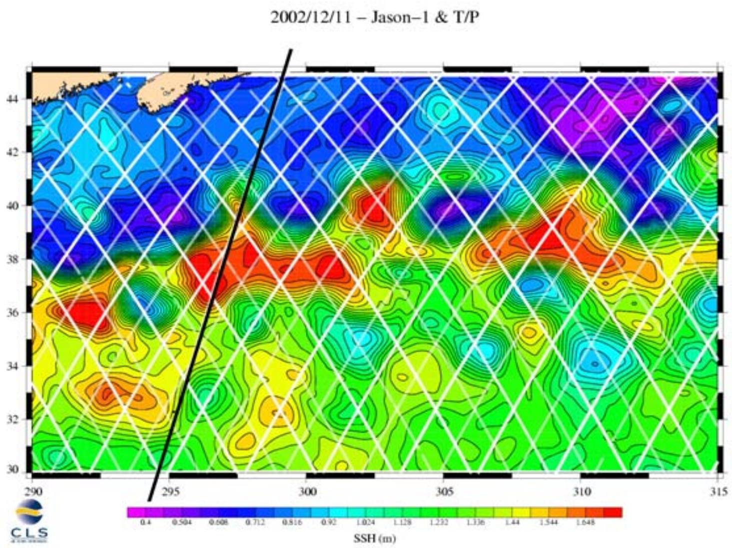
Several months of the TOPEX/Poseidon – Jason-1 tandem mission were analysed. Results from the tandem mission were compared with those derived from Jason-1 alone and an external verification was performed with ERS-2 data.

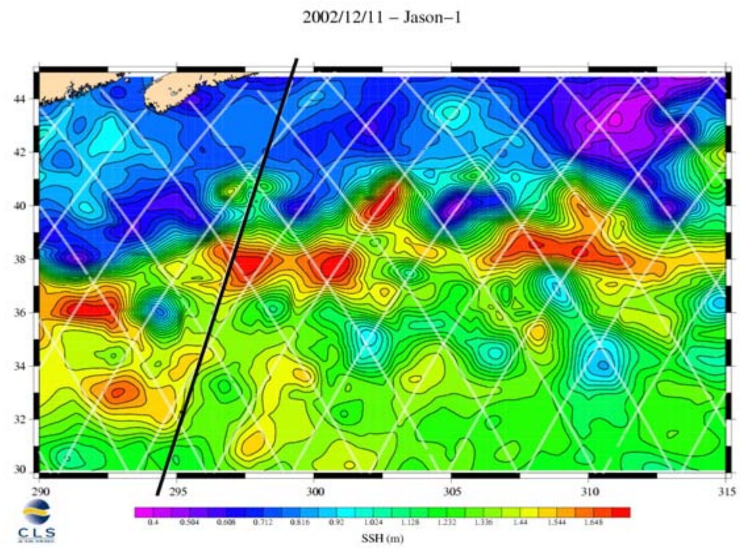
Results demonstrate the potential of an optimised two-satellite constellation for the mesoscale circulation monitoring. They also confirm Le Traon et al. (2001) and Le Traon and Dibarboure (2002) theoretical analyses that were used as an input for GAMBLE WP2.

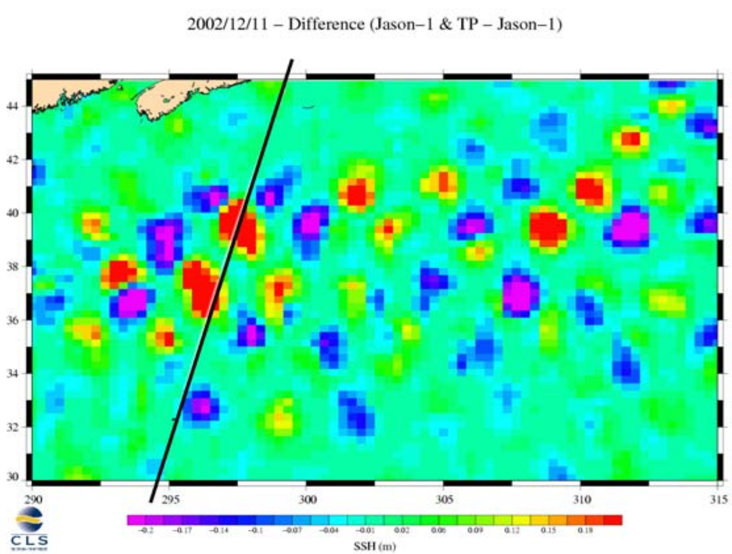
The recommendations for future missions given in Work Package 2 final report can thus now be used with more confidence as an input for Work Package 8.

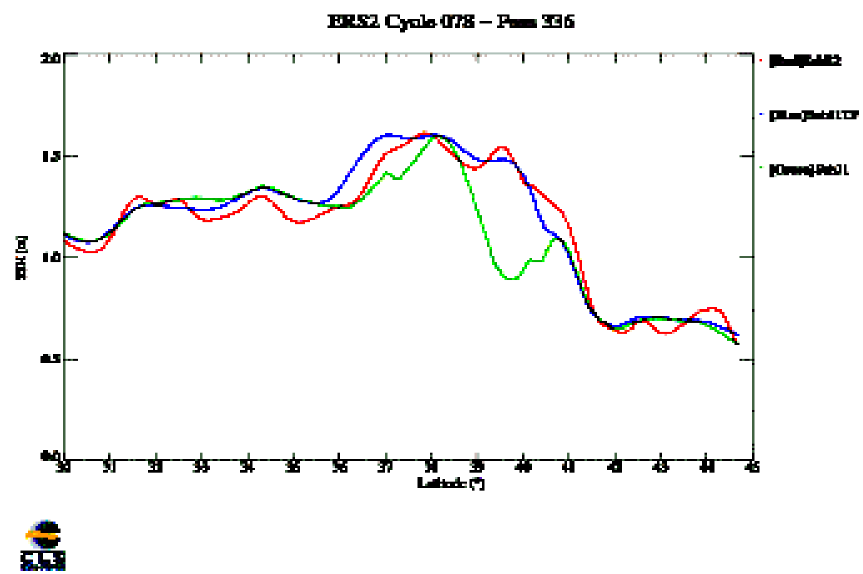
The Jason-1 – TOPEX/POSEIDON tandem mission

A unique opportunity for mesoscale variability studies



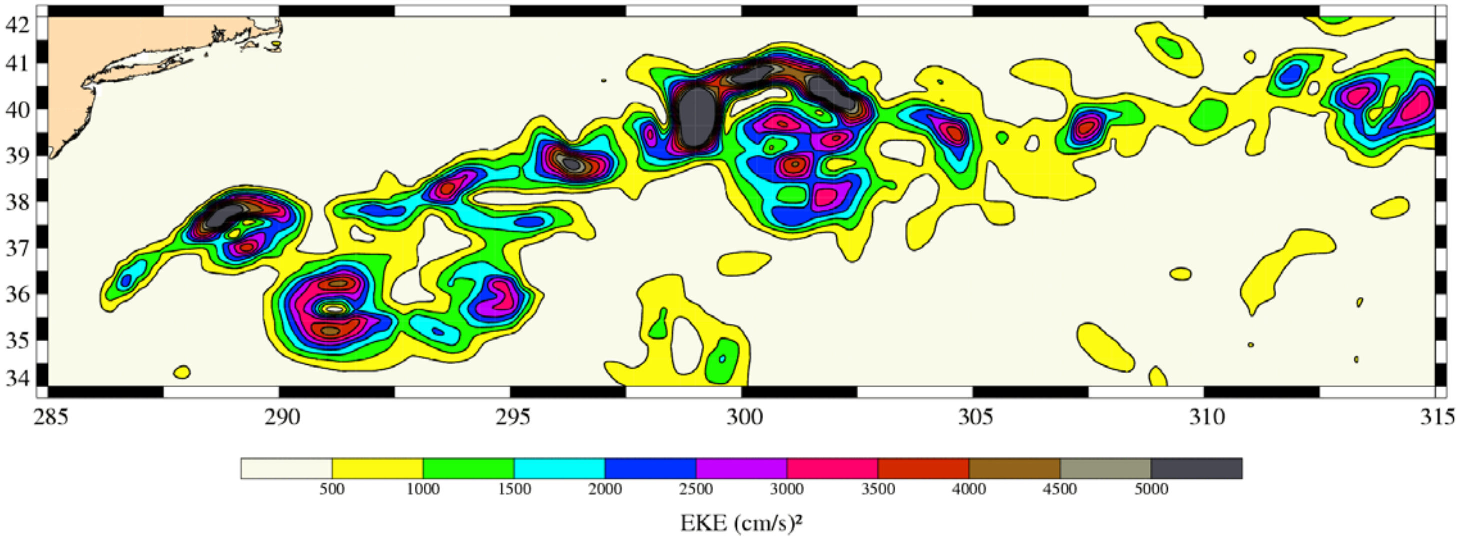




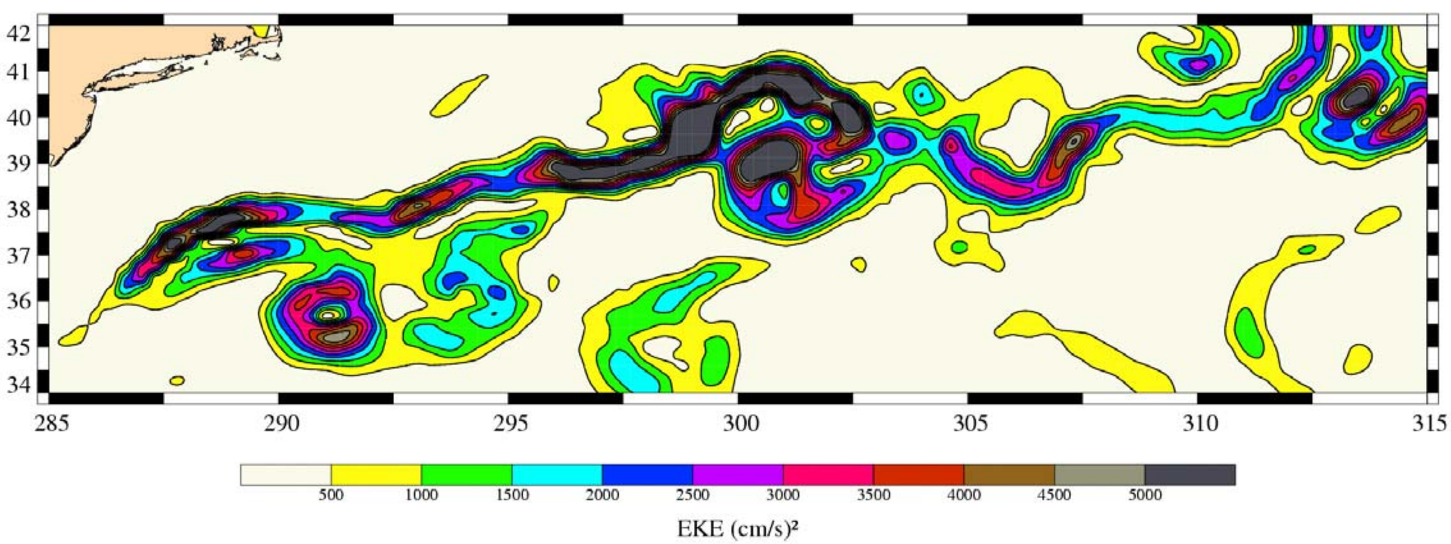


ERS track (in black) used as a reference to compare Jason-1 and Jason-1+T/P

December 2002, Eddy Kinetic Energy in the Gulf Stream area

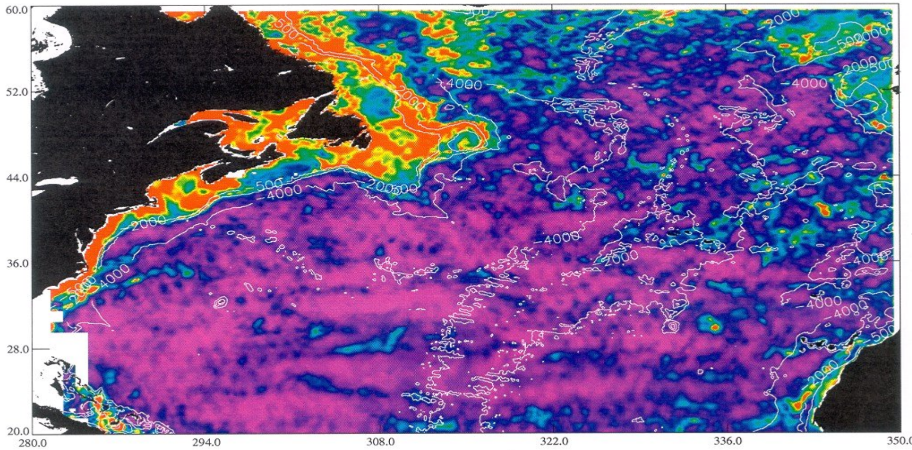


Jason-1

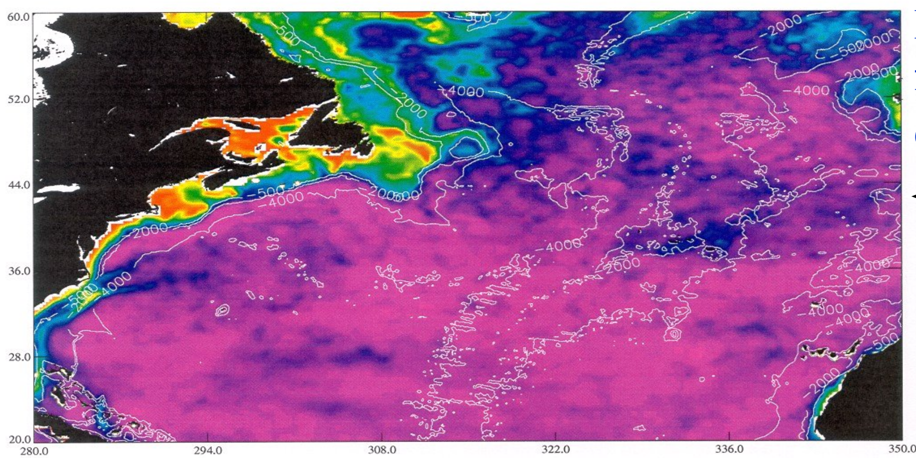


Tandem mission (Jason-1/TP)

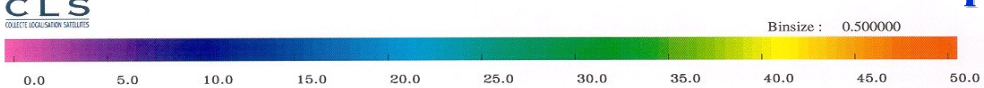
Simulation with the Los Alamos Model - Role of the high frequency in the sea level mapping errors



Sea level mapping error from T/P+ERS+GFO+Jason-1 (in percentage of signal variance)



Percentage of variance of high frequency signals (periods <20 days)

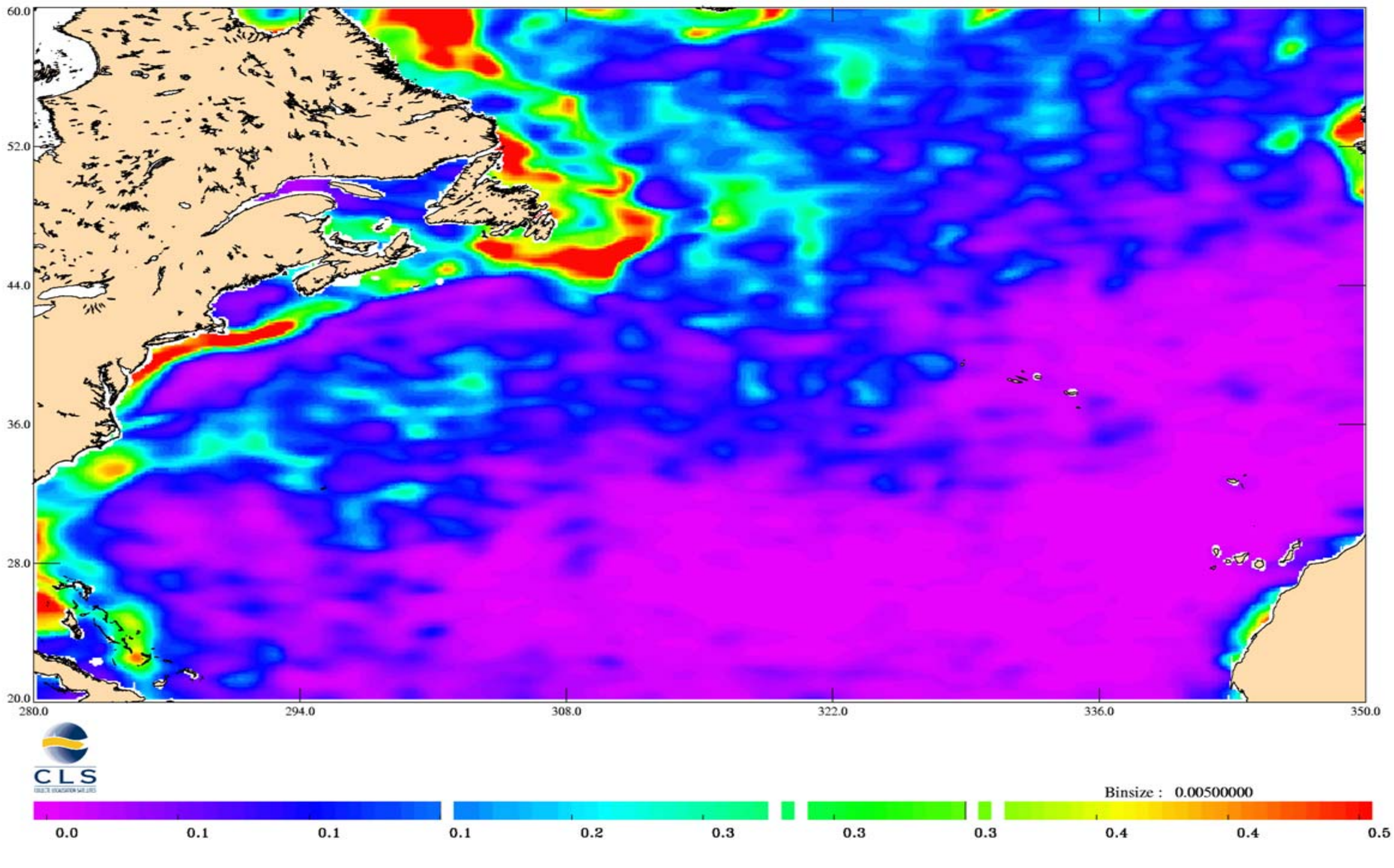


Most of mapping error is due to high frequency signals (general result for configurations with 3 and 4 satellites)

To reduce the mapping error (and/or to reduce the aliasing problems), one needs a time sampling better than 10 days

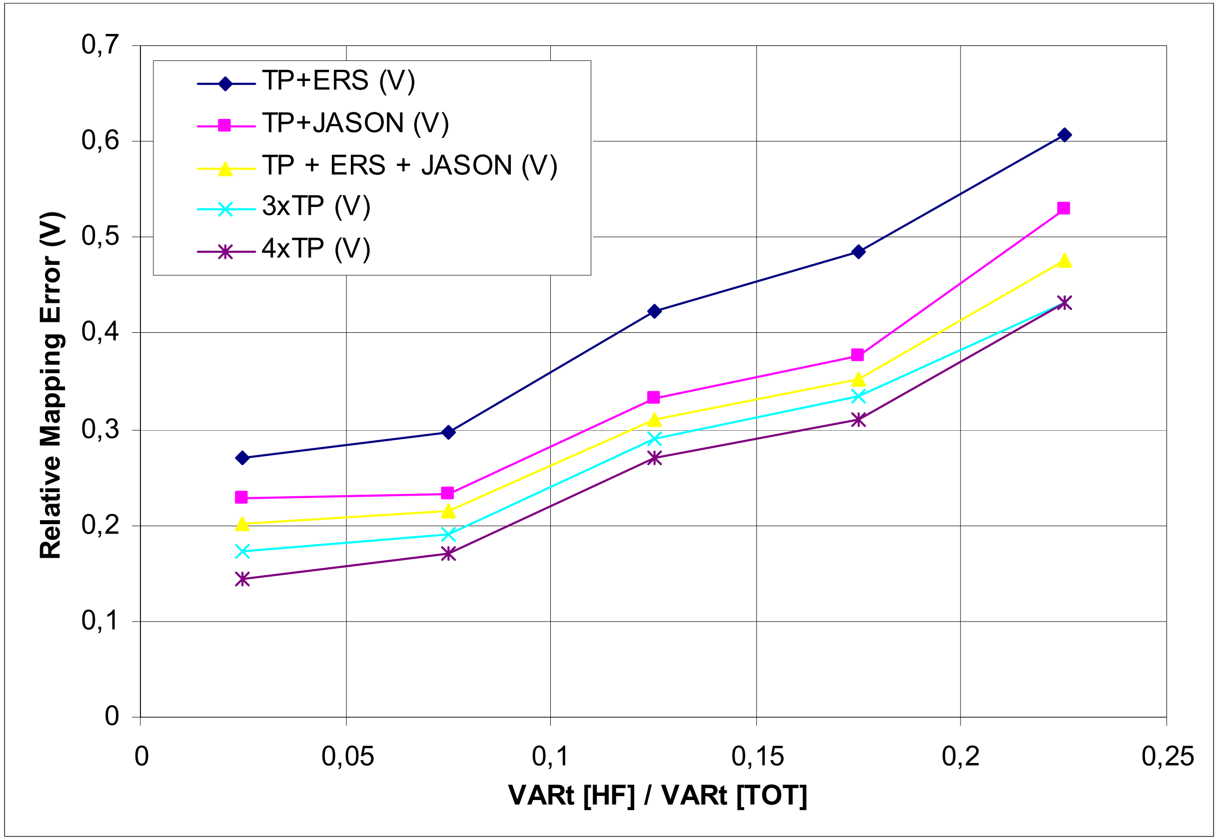
Percentage of zonal velocity variance of high frequency signals (periods < 20 days) in the Los Alamos simulation

A time sampling below 10 days is required to map the velocity signals with an accuracy better than 20% (Le Traon and Dibarboure, JTECH, 2002)



50%

Velocity mapping errors according to the relative energy of high frequency signals



Le Traon and Dibarboure, JTECH, 2002

Summary of contribution of future systems
Refined requirements

- **The T/P+ERS (Jason-1+ENVISAT) configuration is already a « good » configuration for mesoscale studies. For the post Jason-1 period, this is a <u>minimum</u> requirement.**

- **Three/four interleaved Jason-1 (or three ERS/ENVISAT) will allow a very good mapping of sea level and velocity. Compared to T/P+ERS, improvement by a factor of 3 (more than 10 compared to T/P) (+ high frequency barotropic signals).**

- **Velocity mapping errors will remain, however, of about 20% of the signal variance because of high frequency and high wavenumber signals. To map these signals (and/or to reduce aliasing problems), one needs a much higher time (and space) sampling (e.g. <100 km and 10 days) (constellations > 6) and/or wide swath techniques***

**** Need a demonstration (WSOA on board Jason-2). Note that a "best case" WSOA will not perform better than a 3 or 4 satellite constellation (see HOT SWT report)***

Requirements for measurement errors

1. Assuming the Jason series provide a long term reference, **the other systems do not have to provide very precise measurements** (very long wavelength errors are not important) but **it is crucial to get precise (1 - 2 cm) real time orbits for the Jason series**. Spectrum of orbit error is needed.

2. Amplitude of the mesoscale signal is 4 to 8 cm rms in the open ocean and 20 to 40 cm rms in energetic regions. **A 2 or 3 cm (1 second) measurement noise is thus satisfactory**.

3. Wet troposphere and ionospheric corrections are associated to medium and large scale signals. **They should be corrected for with a dedicated instrumentation (radiometer, dual frequency).** The subject deserves, however, to be revisited since most of the studies date from the GEOSAT period (1985-1990). Studies could be undertaken, in particular, to quantify the degradation of results for an altimeter mission without a radiometer on board (given continuous improvements of ECMWF wet tropospheric corrections).

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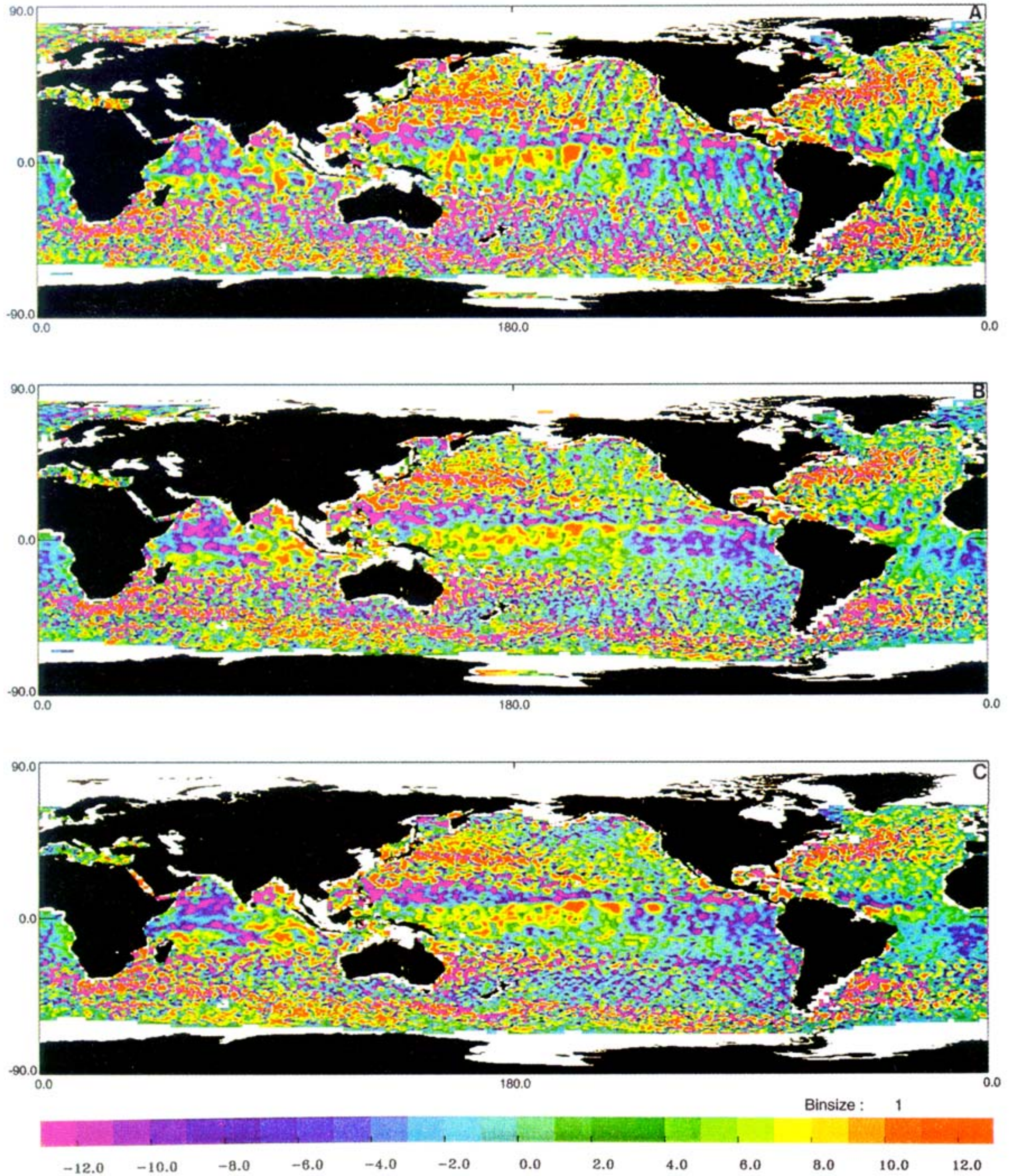
ERS

ERS adjusted onto T/P

T/P

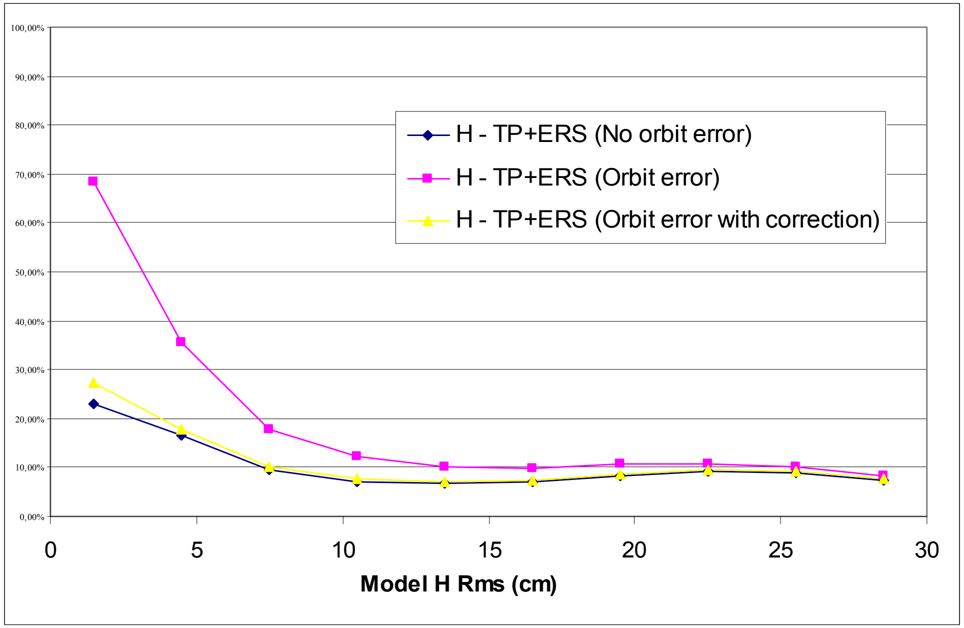


<u>Use of TOPEX/POSEIDON (Jason-1) data to improve ERS (ENVISAT) and GFO data quality</u>

ERS/GFO data are adjusted onto TP or Jason-1 data

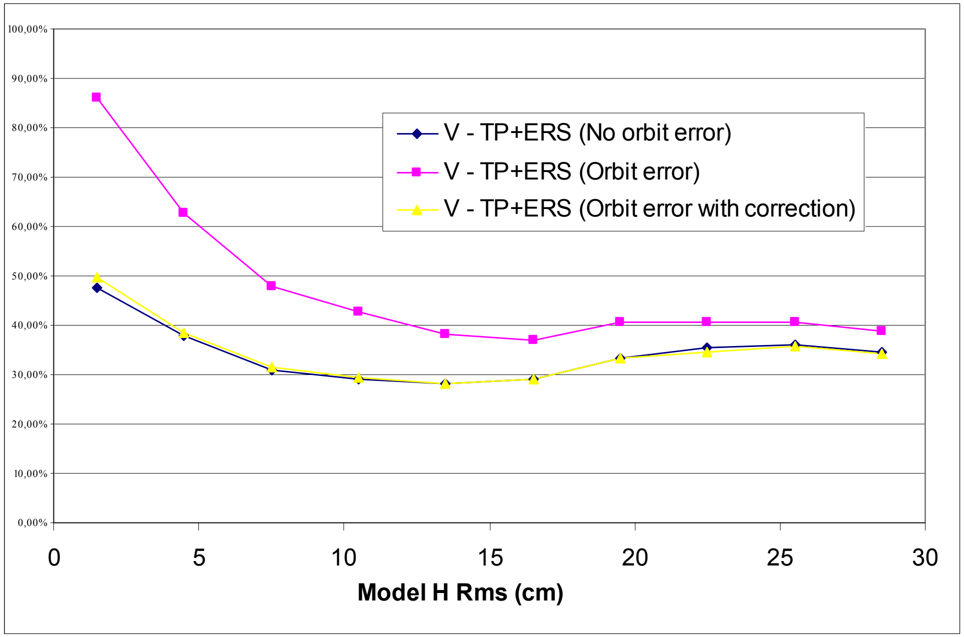
=> « near real-time » intercalibration and reduction of ERS, GFO orbit errors

Le Traon and Ogor, 1998



Impact of orbit error on sea level and velocity estimations (Le Traon and Dibarboure, 2002)

Simulated orbit error is one cycle/rev and 1 cm rms for T/P and 3 cm rms for ERS



Large impact but if orbit errors are taken into account in the mapping/assimilation, the effect is (almost) negligible

(same holds for large scale high frequency effects)

(a priori knowledge is required)

Summary : Altimetry requirements (SSH)

- **Minimum requirement :**
  - Continue the Jason series for long-term, precise altimeter system
  - Fly a post-ENVISAT mission to continue the T/P+ERS (Jason-1+ENVISAT) configuration after 2006 => Alti-Ka is a good candidate and demonstrator for a future constellation system (GANDER).
- **"more ambitious" requirement**
  - Fly a three satellite constellation (interleaved Jason tracks or ENVISAT with a 35/3 repeat period) (in addition to the Jason series) that will provide a very significant improvement for SSH operational applications and will "pave the way" for GANDER.
- **Need a demonstration of WSOA on board Jason-2 before considering swath techniques for future operational systems (post 2010)**

SSH Errors

Radiometer and ionospheric corrections (Ka or dual) are needed. Should be revisited if this becomes a critical issue.

Orbit error should be below 2 cm rms in real time for the Jason series (goal). This can be relaxed for the other missions (if tracking system is an issue).

Orbit should be maintained in a +/-1 km band. Can be relaxed if along ERS or T/P tracks.