



GAMBLE

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**An illustration of the unique contribution
of the TOPEX/Poseidon – Jason-1 tandem mission
to mesoscale variability studies**

GAMBLE WP2 –Supplementary Report

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Executive Summary

In September 2002 the TOPEX/Poseidon satellite was moved into an orbit so that the dual orbit configuration of Jason-1 and TOPEX/Poseidon was optimised to measure mesoscale oceanographic features.

In this configuration both TOPEX/Poseidon and Jason-1 are on a 10-day repeat orbit with interleaved ground tracks. This provides twice the spatial resolution achieved by TOPEX/Poseidon alone. The ability of this configuration to map mesoscale ocean features is directly relevant to GAMBLE Work Package 8 (Constellation Optimisation). An important aspect of this Work Package is to assess various potential orbital configurations of combined satellites and identify those which provide sampling regimes best suited to user requirements. It was thus proposed CLS carry out a study for GAMBLE to analyse the ability of the tandem mission versus Jason-1 alone to map sea level and ocean circulation variations.

Several months of the TOPEX/Poseidon Jason-1 tandem mission were analysed. This required first to estimate a mean track for TOPEX/Poseidon that is consistent with a Jason-1 7-year mean. Results from the tandem mission were then compared with those derived from Jason-1 alone and an external verification was performed with ERS-2 data. These preliminary results are summarized in the following report. They are very encouraging and 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 Work Package 2 (Sea surface height error budgets and recommendations for future missions). 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. Future studies should now be performed over a longer time series (at least one year) and should also analyse the contribution of the tandem mission together with ERS-2/ENVISAT and GEOSAT Follow On data. Detailed analysis of velocity mapping error (through the comparison with surface drifters and current-meter moorings) and eddy/mean flow interaction estimations should be carried out. External comparison with very high resolution Sea Surface Temperature or Ocean Color images should also be performed to quantify the capability of multiple altimeter configurations to capture small space and time scales of the mesoscale variability.

1 Introduction

The ocean circulation is dominated by mesoscale variability: eddies, meanders, rings, filaments, waves, fronts are observed almost everywhere in the ocean and their energy exceeds that of the mean flow by an order of magnitude at least. Mesoscale variability can feedback energy on the mean flow and has a significant contribution to the total heat fluxes (e.g. Wunsch, 1999; Roemmich and Gilson, 2001). A better understanding of ocean circulation (including the large scale circulation and its role on climate) thus requires that we observe and model it at high space and time resolution to resolve the mesoscale variability (e.g. Wunsch, 2001). This is also required for ecosystem modeling and for most of the operational oceanography applications (e.g. marine safety, pollution monitoring, offshore industry, fisheries).

Satellite altimetry has made a unique contribution to observing and understanding mesoscale variability (see Le Traon and Morrow, 2001 for a recent review). Altimeter data analyses have provided a global description of the eddy energy and its seasonal/interannual variations. The time and space scales of the mesoscale circulation have been characterized. Satellite altimetry has also allowed a synoptic mapping of large eddies (e.g. Agulhas eddies) which is useful to better understand the role of eddies in transporting mass, heat, salt and nutrient. All these studies provide a good means of testing and validating models and theories.

Two altimeter missions at least are required to monitor the mesoscale variability (Koblinsky et al., 1992). This minimum requirement has been met since 1992 with the NASA/CNES TOPEX/Poseidon (T/P) and ESA ERS-1/2 altimeter missions and their successors Jason-1 and ENVISAT. Le Traon and Dibarboure (2002) (hereafter LD02) provide a recent summary of the mapping capabilities of the T/P+ERS (Jason-1+ENVISAT) configuration. Sea level can be mapped with an accuracy of 5 to 10% of the signal variance while the velocity can be mapped with an accuracy of 20 to 40% of the signal variance (depending on latitude). A large part of these errors are due to high frequency signals (periods < 20 days). As a result, errors on 10-day averaged signals are smaller by a factor of 2 to 3. The contribution of the merging of T/P and ERS is also well illustrated by Ducet et al. (2000) and Ducet and Le Traon (2001). The velocity field was mapped globally; this yielded a characterization of the Eddy Kinetic Energy (EKE), anisotropy and eddy mean flow interactions with a resolution never achieved before.

Although the T/P+ERS merging has provided a much better representation of the mesoscale variability, it is far from fully resolving the mesoscale variability (see discussions in Greenslade et al., 1997 and Tai, 1998). For example, resolving scales larger than 100 km and 10 days would require an optimized constellation of at least three altimeters (Tai, 1998) or the use of swath techniques such as the Wide Swath Ocean Altimeter proposed on board Jason-2 (Rodriguez et al., 2002). While the T/P+ERS relative mapping errors are small enough to analyze large eddies, they thus prevent us to accurately determine the velocity field and eddy-mean flow interaction as well as to analyze the detailed structure of eddies. To improve further our understanding of mesoscale variability, we now need to observe it at higher space and time resolution.

The tandem T/P – Jason-1 mission was proposed with this idea in mind (Fu et al., 2003). Since mid-September 2002, TOPEX/Poseidon has been flying mid-way between two adjacent Jason-1 ground-tracks. This optimized two-satellite configuration is a unique opportunity for mesoscale variability studies. First results from the tandem mission will be presented here to demonstrate its potential for mesoscale variability studies.

2 First results with the T/P–Jason-1 tandem mission

2.1 Data processing

We used 10 cycles of T/P and Jason-1 data spanning the period from mid-September 2002 to mid-February 2003. TP and Jason-1 data are the IGDR distributed by AVISO. The IGDR tidal correction was replaced, however, by the more recent GOT99 tidal correction (Ray, 1999) and we used an inverse barometer correction with a variable mean pressure. To extract the sea level anomalies (SLA) for the different missions, we need to remove a mean profile $\langle \text{SSH} \rangle$ from the individual SSH measurements ($\text{SLA} = \text{SSH} - \langle \text{SSH} \rangle$). The mean profile (MP) contains the geoid signal but also the mean dynamic topography (MDT) over the averaging period. We used for Jason-1, a MP calculated over a 7 year period (1993-1999). Since only a few months of T/P data on its new tracks are available, the T/P mean will not be consistent with the mean used for Jason-1. A specific processing was thus applied to T/P data to get a MP consistent with Jason-1 (see Le Traon et al., 2003). Jason-1, GEOSAT Follow On and ERS-2 data were used to correct T/P data for ocean variability. This provides a T/P mean which is now much more consistent with the Jason-1 mean. The mapping method detailed in Le Traon et al. (2003) was then used to merge the SLA data from the two altimeter missions. We used a white measurement noise of 3 cm for TP and Jason-1 data. In addition, a noise of 10% of the signal variance was used to take into account the small scale variability which cannot be mapped and should be filtered in the analysis. Long wavelength errors (LWE) due to residual orbit errors but also tidal or inverse barometer errors and high frequency ocean signals (e.g. Tierney et al., 2000) were also derived from an analysis of TP data.

2.2 Illustration of the contribution of the tandem mission

Figure 1 provides an illustration of the potential of the tandem mission for a better monitoring of the eddy field. The absolute dynamic topography in the Gulf Stream region on December 11, 2002 derived from the combination of Jason-1 and T/P is shown on the upper left figure. A mean dynamic topography (Rio, 2003) was added to the SLA data to get absolute dynamic topography. Jason-1 and T/P tracks are superimposed in white. The upper right figure is from Jason-1 data only. Lower left figure is the difference between the Jason-1+T/P and Jason-1 map. The Jason-1+T/P map provides a much better description of Gulf Stream eddies and meanders. Gradients are sharper and signals that are missed by the Jason-1 sampling (up to ± 40 cm) are well reproduced with the additional sampling from T/P.

This improvement was quantified through an external comparison with the sea level observed along an ERS-2 track (black track). ERS-2 SLA data were derived from ERS FDP data and using a mean profile computed from past ERS-1 and ERS-2 data (see Le Traon et al., 2003). ERS-2 were then band-pass filtered using a Lanczos filter to retain wavelengths between 60 km and 1000 km. Same processing was applied to Jason-1 and tandem mission SLA data extracted along the ERS-2 track. This allows a reduction of altimeter noise and a removal of long wavelength errors (e.g. orbit error) while preserving most of the mesoscale signal. The Jason-1+T/P map is able to reproduce most the signals observed by ERS (lower right figure) while the Jason-1 map failed to reproduce a Gulf Stream meander.

Sea level anomalies derived from the tandem mission and from Jason-1 alone were compared with all available ERS-2 along-track data over a 4-month time period (October 2002 to January 2003). For regions with a sea level variability larger than 15 cm rms (i.e. regions

with large mesoscale variability), the sea level mapping error from the tandem mission is about 6% of the signal variance which is almost twice as small as the mapping error from Jason-1 data only. Note that these figures provide an upper bound of the mapping errors as they assume that ERS-2 data represent the truth. They are consistent with theoretical estimates given in LD02.

2.3 EKE from Jason-1 and from the tandem mission

Zonal (u') and meridional velocity (v') maps were derived from Jason-1 and Jason-1+T/P sea level maps. From these maps, we then computed Eddy Kinetic Energy (EKE) ($EKE = \frac{1}{2} (\langle u'^2 \rangle + \langle v'^2 \rangle)$). Figure 2a and 2b show respectively a monthly mean of EKE from Jason-1 and from the tandem mission. The picture we get from Jason-1 is, as expected, far from reality. The path of the Gulf Stream is, on the other hand, clearly seen from the tandem mission EKE map as well as the velocity field associated to Gulf Stream rings. This opens up very interesting perspectives for western boundary current monitoring.

3 Perspectives

These first results from the T/P-Jason-1 tandem mission confirm the potential of an optimized two satellite configuration for mesoscale variability studies. With the tandem mission, we now have a much better tool to monitor mesoscale variability. Future investigations that will directly benefit from this improved resolution should focus on velocity estimation, eddy mean flow interaction and eddy heat fluxes. Similar analyses should also be performed to analyze the contribution of the tandem mission together with GEOSAT Follow On and ENVISAT (or ERS-2) data. In addition to an improved understanding of the mesoscale variability, these analyses will provide useful inputs for the definition of future altimeter missions.

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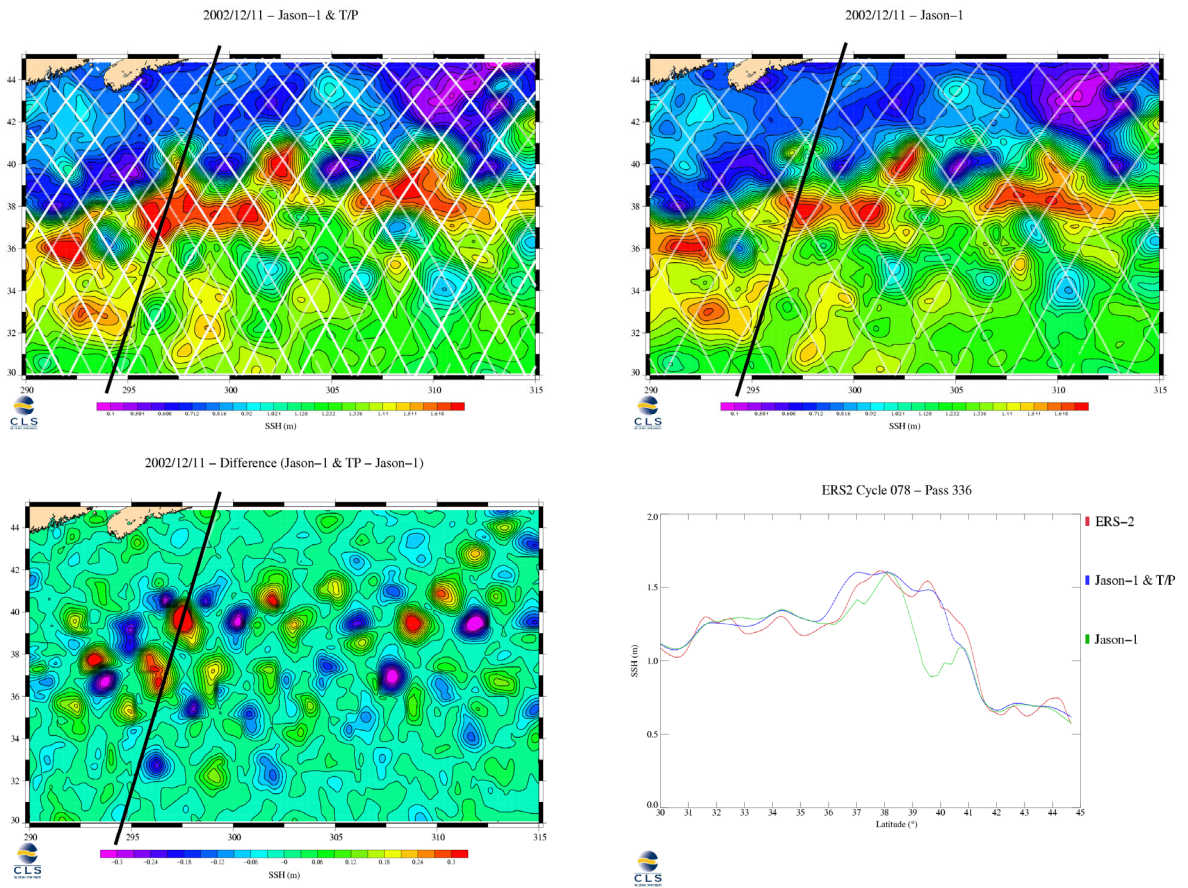


Figure 1: Absolute dynamic topography in the Gulf Stream region on December 11, 2002 derived from the combination of Jason-1 and TOPEX/Poseidon (T/P) (upper left figure). Jason-1 and T/P tracks are superimposed in white. The upper right figure is from Jason-1 data only. Lower left figure is the difference between the Jason-1+T/P and Jason-1 map. Comparison with the sea level observed along an ERS track (black track) (lower right figure).

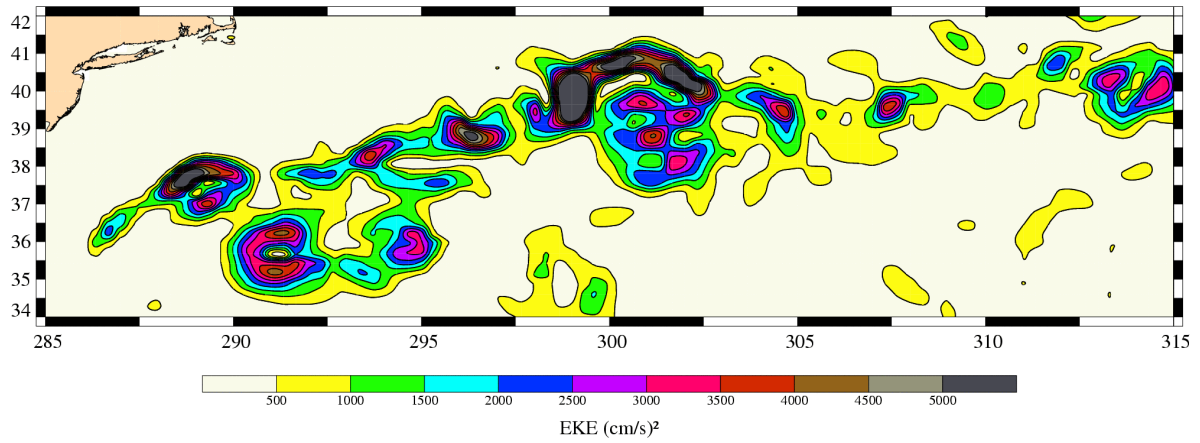


Figure 2a: EKE for December 2002 derived from Jason-1 data. Units are cm^2s^{-2} .

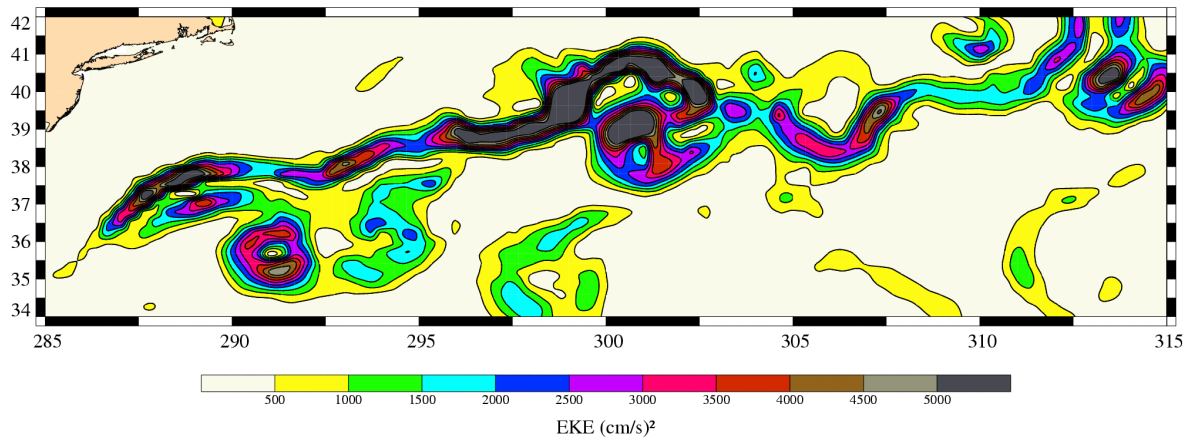


Figure 2b: EKE for December 2002 derived from the tandem mission. Units are cm^2s^{-2} .