A consistent assimilation of altimetric and temperature data in a model of the tropical Pacific ocean

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1.Introduction

The altimetric measured signal, i.e. the Sea Surface Height (SSH) can only be used in oceanography in its "residual" component, i.e. the Sea Level Anomaly (SLA) because of geoid uncertainties. The recent advances of our knowledge of the geoid brought by the CHAMP and GRACE satellite gravity missions provide the possibility to exploit the absolute Dynamic Topography (DT), deduced from altimetry, on physical oceanography studies and especially on altimetric data assimilation. In this study, we investigate the combined assimilation of the satellite DT signal and of the TAO temperature data in a numerical model for the tropical Pacific ocean.

The DT observations consist of along-track SLA from the TOPEX/Poseidon and ERS satellite altimeters (Aviso Center) which are referenced to the satellite Mean DT deduced from the difference between the Mean SSH based on a 7-year mean (1993-1999) of altimetric data, and the EIGEN-GRACE02S Earth gravity field model from GFZ, Germany , developed to degree 60 and based on 110 days of GRACE satellite data.

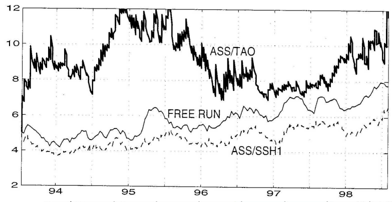
The assimilation experiments are performed with the global version of the OPA model (Madec et al., 1998). The model solves standard ocean primitive equations and uses a free surface formulation. The extratropical 2°x2° Mercator mesh has a meridional grid spacing refinement down to 0.5° in the tropics to improve the equatorial dynamics. Along the vertical, there are 31 z-levels.

The assimilation scheme is based on the Singular Evolutive Extended Kalman (SEEK) filter (Pham et al., 1998). Data assimilation is only applied in the region of interest, i.e. the tropical Pacific ocean, even if the model is global. The dominant modes of error covariances used in this study are representative of mean and variability errors. More details on the model and on the assimilation scheme can be found in Castruccio et al. (2006).

2.Effects of a non realistic Mean Dynamic Topography

The model, especially in the tropics, suffers from bias in its mean structure (see **Fig. 2 Top**). SLA data are not relevant to correct for errors in the mean model state, and classically, SLA are referenced to the mean model state when they are assimilated. If such assimilation is able to reduce RMS error in term of sea level, some inconsistencies exist when 3D in situ temperature data are assimilated (See **Fig. 1**). It illustrates that errors in the mean structure of the model renders the combined assimilation of satellite SLA and of in situ temperature data hazardous.

Fig. 1 *: Evolution of RMSD in term of Dynamic Topography cm) between the altimetric data, and respectively the free simulat (FREE RUN), the SLA assimilation experiment (ASS/SSH1), and TAO temperature data assimilation (ASS/TAO). (From Parent et 2003)*



3. A realistic Mean Dynamic Topogaphy from satellite

The quality of the satellite Mean DT is tested with regard to the modeled Mean DT, and compared with in situ measurements. The tropical Pacific ocean is continuously observed through the 70 TAO/TRITON moorings located in the 8°N-8°S equatorial band where the ocean exhibits a dominant baroclinic signature, and they provide 0/500 dbar TAO dynamic heights.

The difference of mean state between the DT based on a) the mean model state, and b) the satellite MDT and the *in situ* 0/500 dbar TAO dynamic height for the 1993-2001 period is shown on **Fig. 2**. Differences in the mean structure give a 4 cm RMSD when using the modeled MDT against 1.9 cm RMSD when using the satellite MDT. It illustrates errors on the mean model state, and the accuracy of the satellite solution. The satellite MDT provides a better comparison with the TAO dynamic heights than the MDT from the Levitus climatology (2,4 cm RMSD, not shown).

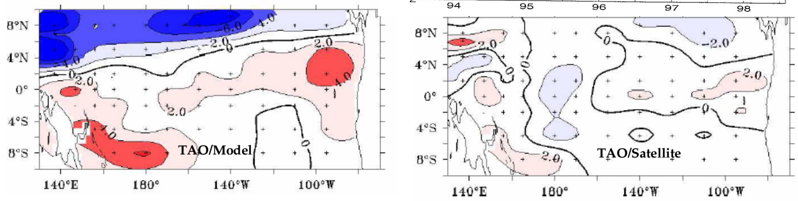


Fig. 2*:Difference for the 1993-2001 period between the mean 0/500 dbar TAO dynamic height and left) the modeled MDT and right) the satellite MDT. Contour interval is 2 cm. TAO moorings are located at crosses.*

4. An interannual assimilation of altimetry and in situ data

An assimilation experiment was performed over the 1993-1998 period. The model was initialised with a free simulation relaxed to the Levitus climatology. Absolute DT data from the altimetric and gravimetric satellite missions; and in situ TAO temperature profiles were assimilated every 5 days. A free simulation was performed to evaluate the impact of the assimilation.

a. Statistical Validation

For the different simulations, the temporal series are analysed with regard to the observations assimilated (**Fig. 3**). For the free run, the RMS Differences are of 8.1 cm in DT, and of 1.54°C in temperature over the six years. For the Assimilation run, the RMS Differences decrease to 6.3 cm in DT, and to 0.9°C in temperature, and they are relatively constant in time. It shows that globally the combined assimilation of satellite and in situ data has been successful.

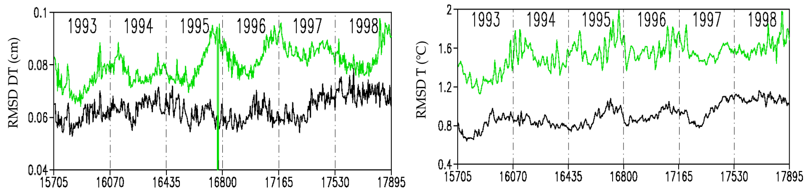
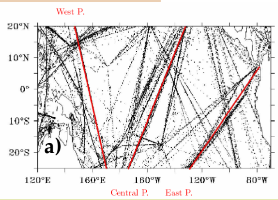


Fig. 3*: RMS Difference in term of Dynamic Topography (Left,units : cm), and of temperature (Right,units :°C). between the assimilated data, and the free (green curve) and assimilation (black curve) runs.*

b. Independant in situ validation

XBT data from the VOS program are used as in situ independent data to validate the simulations. Three ship lines, frequently observed, characteristics of the Western, Central, and Eastern Pacific are selected. **Fig. 4** exhibits the mean structure difference between the observations and the simulations without (top), and with (bottom) assimilation. Most of the errors are initially concentrated in the thermocline and the equatorial wave guide with magnitude up to 5°C. These errors are drastically reduced in the assimilation run, even off the TAO array area. Nevertheless, high errors exist below the thermocline, at 10°N on the Central line. The resolution of the GRACE geoid is too low for the DT to correctly simulate the fine latitudinal structure relative to the North Equatorial Counter Current. Some inadequacies may appear between the altimetic and TAO data in the 8°N-10 N latitude range when both data types are assimilated.



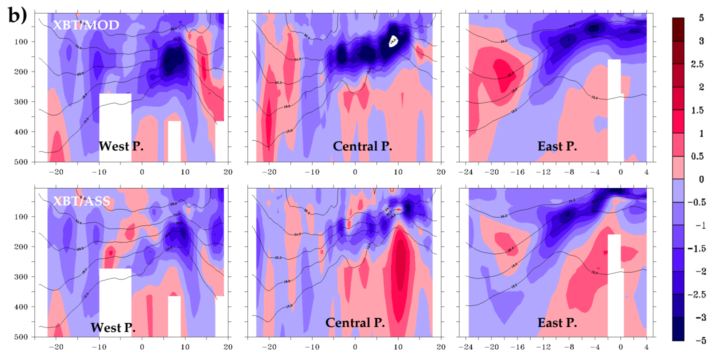


Fig. 4*: a) Selection of the Western, Central, and Eastern Pacific ship lines. b) Mean temperature difference between the XBT data and the simulations without (top)/with (bottom) assimilation for the Western (left), Central (middle) and Eastern (right) Pacific ocean.*

C. Currents and Warm Water Volume

The improvement of the simulated thermical structure brought by the assimilation has a direct influence on the simulated currents from the surface down to the thermocline. The transports of the different currents, estimated as in Johnson et al. (2000), show a 25% (35%) increase for the South Equatorial Current (the North Equatorial Counter Current). The transport changes associated with the ENSO cycle give a westward transport in the SEC as high as 42 Sv during La Nina and as low as 17 Sv during El Nino. Eastward tranport in both the NECC and the Equatorial UnderCurrent has a smaller variability than observed,ranging from 24 Sv during La Nina to 35 Sv during El Nino.

These transports are related to the Warm Water Volume (WWV) in the equatorial band which is at the basis of the recharge/discharge theory of ENSO introduced by Wyrtki (1985). The time evolution of the WWV in the equatorial region was reduced by about 23% coincident with the 1997-98 ENSO (**Fig.5**). The WWV varies out of phase between the eastern and western parts of the Equatorial Pacific. In the West Pacific, the build-up prior to the 1997 El Nino takes place slowly, followed in late 1997 by a large accumulation of WWV in the East Pacific as described by Meinen and McPhaden (2001)

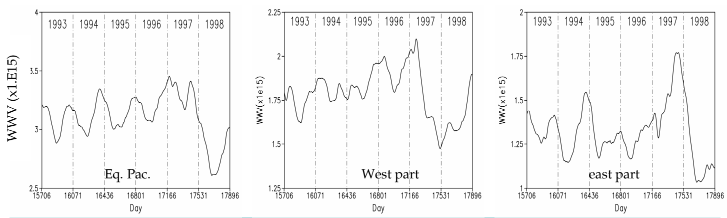


Fig. 5*: Time series of the Warm (T>20°C) Water Volume (m³) within the tropical Pacific [156E- 95°W; 10°N-10°S] region (left), and split into parts west (middle) and east (right) of 155°W.*

5. Conclusion

Geoid from the GRACE satellite gravimetric mission has been used to reference altimetric data. The deduced absolute Dynamis Topography was assimilated jointly with in situ TAO temperature to model the equatorial Pacific. The benefit of the GRACE data is the compatibility between the satellite and in situ data which renders their assimilation efficient. Results seem robust in a physical point of view,even if more investigations are needed. Some limitations always exist,most of them are relative to the resolution of the geoid used. The next estimations of the geoid might push back the actual limits.

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