Geoid and altimeter data assimilation : oceanographic assessment of CHAMP and GRACE products in the tropical Pacific ocean

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Introduction

Context :

The lack of an adequate knowledge of the MSSH is a recurrent issue on altimetric data assimilation studies which is overcome by using numerical model MSSH (the model MSSH is assumed to be unbiased) or synthetic MSSH (computed from a bench of in-situ and satellite data in general). No solution was found really satisfactory and the bias issue (for example of the vertical thermal structure in the tropic) is a critical today issue for altimetric data assimilation and consequently for operational oceanography.

Scientific objectives :

- explore the impact of gravimetric data and an absolute MSSH on the assimilation of altimetric data.
- analyse results from assimilated run using absolute MSSH deduced from gravimetric missions, in order to get relevant science information, especially on Pacific tropical dynamic.
- help defining the best MSSH products for operational uses

Means :

The assimilation platform is developed around both OPA 8.2 (Madec et al., 1998) in his ORCA configuration, a primitive equations OGCM and the SEEK Filter (Pham et al., 1998), a sequential assimilation method. An Incremental Analysis Update method (IAU) (Bloom et al., 1996) is used in order to reduce reduce analysis-induced initial shocks and avoid data rejection.

Abstract

Altimetry played a catalytic role in the tremendous scientific and technical developments of oceanography in the last decade. It is a major ground of the development of operational oceanography. However, the altimetric measured signal (SSH) is only reliable in its "residual" component (SLA). The mean sea surface (MSSH) reference is indeed contaminated by geoid errors. The opportunity of gravimetric mission such as CHAMP, GRACE and GOCE offers the capability to provide us this reference and therefore the possibility to use the absolute altimetric signal.

The purpose of this thesis work is the exploitation of this absolute altimetric signal in numerical model (OPA, ORCA version) via data assimilation methods (SEEK filter) to reconstruct the oceanic circulations in the tropical Pacific Ocean.

Geoid

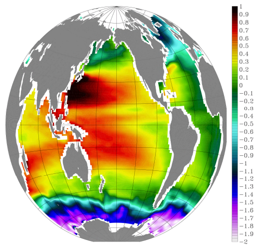


Fig 1 : GRACE MDT

The primary objective of the GRACE mission is to provide with unprecedented accuracy estimates of the global high-resolution models of the Earth's gravity field for a period of up to five years. The temporal sequence of gravity field estimates will yield the mean Earth gravity field. The two GRACE satellites have been launched in march 2002 and a first accurate geoid estimation is now available. It is complete to degree and order 150 and has been calculated from 110 day of GRACE tracking data (Fig 1).

In altimetric data assimilation experiences, the required quantity is the absolute dynamic topography (DT). It is the sea level relative to the geoid :

DT = MDT + SLA

That is the reason why a precise estimation of the Mean Dynamic Topography is needed. The latest gravimetric mission like CHAMP and GRACE, have allowed great improvements of our knowledge of the geoid. Due to this improvements, a good way to evaluate a high resolution, highly accurate MDT, is to estimate the difference between the MSSH (computed from altimeter measurements) and the geoid (fig 2).

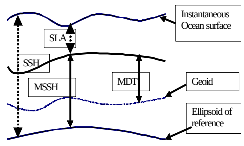


Fig. 2 : decomposition of the Sea Surface Height

DT = SSH - Geoid

We can notice that the gravity field of an OGCM has a spherical symmetry so that the model geoid is a perfect sphere. The MSSH and the MDT are both the same quantity for numerical modelers.

The OPA model

Assimilation experiments will be performed with the OPA 8.2 model, in his ORCA configuration (global 2x2° low resolution with a meridional grid spacing refinement down to half a degree in tropical region to improve the equatorial dynamics). OPA has been developed in the LODyC (Laboratoire d'Océanographie Dynamique et de Climatologie).

OPA is intended to be a flexible tool for studying ocean and its interactions with others components of the earth climate system over a wide range of space and time scale. Prognostic variables are the tree-dimensional velocity field and the thermohaline variables. A specificity of ORCA configuration lies on the horizontal curvilinear mesh used to overcome the North Pole singularity found for geographical meshes. In my configuration, ORCA is interfaced with a sea-ice model.

- A primitive equation model
- Free surface formulation
- Z-coordinate (31 prescribed levels)
- Vertical eddy viscosity and diffusively computed from a 1.5 turbulent closure model based on a prognostic equation of the turbulent kinetic energy
- Tracer diffusion along isopycnal surfaces

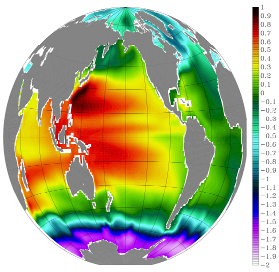


Fig 1 : OPA MSSH over 93-96

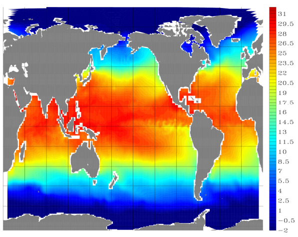


Fig 2 : Snapshot of OPA SST (9/22/1993)

- 2 forcing sets :
  - daily NCEP (Bulk formulation) and ERS/TAO winds
  - daily ECMWF (prescribed flux) and ERS/TAO winds
- Flux correction: feedback term to Reynolds SST (only with prescribed flux) and relaxation on SSS toward Levitus climatology.

The SEEK Filter

The SEEK Filter has been developed in the MEOM group to assimilate satellite observations such as altimetry into high-resolution models of the ocean circulations.

The assimilation method is derived from the sequential estimation theory: A reduced-order Kalman filter, - SEEK (Singuler Evolutive Extended Kalman) -, has been developed in which the error statistics is expressed inside of a three-dimensional, multivariate sub-space.

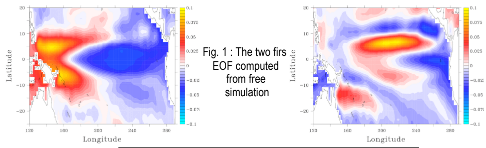


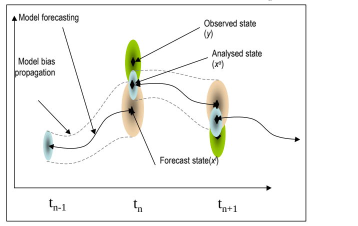
Fig. 1 : The two firs EOF computed from free simulation

The reduced basis of the SEEK filter is evaluated from a three-dimensional multivariate EOF analysis of a reference model simulation (fig. 1).

The dynamical propagation of the error covariance from one analysis step to the next is performed according to the KF equations (schema 1). The increment (x^f – x^a) computed from SEEK analysis is used to force IAU forecast.

The SESAM software allows an easy interface between the SEEK algorithm and the OPA ocean model.

Schema 1 : sequential analysis principle



First results : comparison of OPA simulation with observations

The top panels show the OPA MSSH over the 92-96 period and the MDT computed from GRACE gravimetric data. One can notice a quite strong difference between the model results and the observations.

The bottom panels show the mean depth of the 20°C isotherm for both, OPA and the Levitus climatology.

These four panels clearly illustrate the correlation between the MSSH and the thermocline depth. The assimilation of an absolute sea level (SLA + MDT) using a highly accurate MDT computed from altimetric and gravimetric data should be a powerful way to positively act and constrain the thermal structure of the tropical Pacific ocean.

Absolute altimetric data assimilation should also allow bias correction on surface dynamics. The surface circulation is due at first order to geostrophy. The map of geostrophic current deduced from GRACE MDT (not shown here) is very close to the present knowledge of tropical Pacific

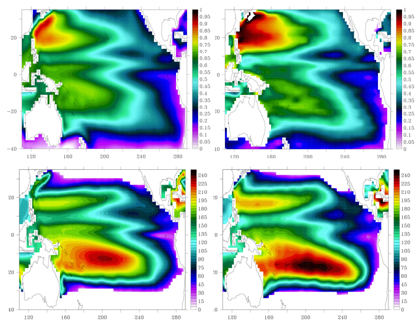


Fig 1 : from left to right and from top to bottom, MSSH OPA over 93-96, MDT GRACE, depth of the 20°C isotherm for OPA and Levitus climatology.

Figure 2 shows the mean temperature along the equator for the OPA free simulation and the Levitus climatology. It illustrates two other bias on the model. Firstly the westward slope of the thermocline is too strong. This bias should be fixed by MDT assimilation as in tropical region, MDT mirrors the thermocline. The same bias can be found on the OPA MSSH slope appearing to be too strong compared to the observations.

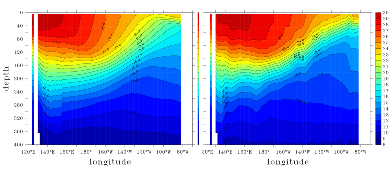


Fig 2 : Mean temperature along the equator for OPA (left) and Levitus climataology (right).

Secondly, the thermocline sharpness in the simulation is not thin enough (the temperature gradient is too weak in the thermocline). This bias should be more difficult to fix than the thermocline slope. If good EOF analysis are computed, correctly representing error between model and the true tropical Pacific ocean, in order to build a smart and efficient SEEK reduced basis, satisfying corrections should also be applied on this bias.

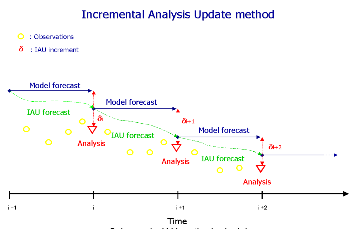
Second results : Implementation of the SEEK with an IAU method

IAU Basics

- Previously designed for intermittent data assimilation systems in meteorology to reduce analysis-induced initial shocks in model forecast. *Bloom et al. (1996)*
- Principle: to incorporate an increment calculated from the SEEK analysis in the model integration as a forcing term

IAU impact

- Acts like a continuous assimilation method
- Suppress gravity waves due to assimilation update (minimise spurious adjustment processes). *Bloom et al. (1996)*
- Impact of the bias on the analysis is reduced as the forecast is continuously corrected.
- Cost of this feature: increase in the integration time of the model (50 to 100% depending on the method)



Schema 1 : IAU method principle

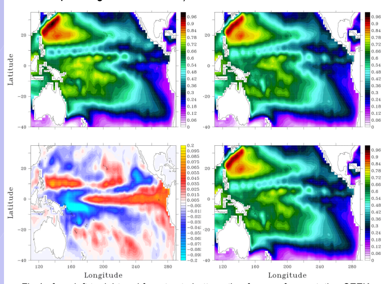


Fig 1 : from left to right and from top to bottom, the free run forecast, the SEEK analysis, the increment (x^a -x^f) and the IAU forced run for the SSH field.

Here are preliminary results on SSH from IAU twin experiments using OPA and the SEEK analysis to compute the IAU forcing increment. Twin experiment principle is the following: observations from a reference simulation (SSH in this case) are assimilated into a perturbed simulation (obtained by perturbing the initial conditions). The IAU increment is only applied on the prognostic variables temperature and salinity as a forcing term.

$$\frac{\partial T}{\partial t} = -\nabla.(TU) + D^T + dT_{iau}$$

$$\frac{\partial S}{\partial t} = -\nabla.(SU) + D^S + dS_{iau}$$

where $dT_{iau} = \gamma(T^a - T^f)$
$dS_{iau} = \gamma(S^a - S^f)$

$\gamma = \gamma(t)$ is a time dependent coefficient such that $\int \gamma(t)dt=1$. In our case, γ = cte = 1/T. The IAU increment is space dependent but similar at each time step for a given grid point.

Figure 1 shows that the IAU forecast is very close to the SEEK analysed state even on a field such as the SSH, which is not directly corrected by IAU scheme.

The RMS misfit to observations are shown in figure 2. The perturbed simulation (green solid curve), the 5-day forecasts (black bullets), the analyses (black circle) and the IAU forced simulation trajectory (red solid curve) are plot on the panels. Figure 2 illustrates the consistency of our assimilation method. The RMS misfit to observations is reduced on all variables (observed or not). One can also notice that the differences between the SEEK analyses and the IAU forced simulation decrease with time.

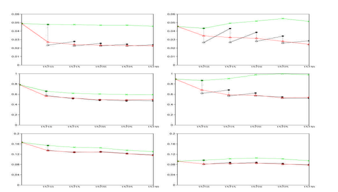


Fig 2 : SSH, temperature and salinity RMS misfit to observations (from top to bottom respectively) for the tropical Pacific (left) and the NINO 3.4 areas (right)

Conclusion and perspectives

The assimilation platform described in this poster is now ready for use. The OPA ORCA configuration has been updated and the assimilation tools (SEEK and IAU) have been implemented in the model. Numerous scripts managing the free runs and the assimilated simulations have been written.

The first comparisons of the OPA free run simulation with the observations show a quite realistic circulation but point out a typical discrepancy on the tropical thermal structure (thermocline depth and pinching) encountered in most OGCM.

The accuracy of the MSSH computed from GRACE gravimetric data and altimetric data appears to be good. The MSSH is in agreement with other observations and the geostrophic currents deduced from this MSSH is consistent with the present knowledge of the tropical circulation. The present product represents a satisfying starting point for my work and it will continue to be improved through dedicated work led in CNES and CLS.

My tasks will now consist in the adaptation of the SEEK filter method to assimilate the absolute dynamic topography for the control of 3D the model state, the thermal structure and the flow dynamics.

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