MEAN OCEAN DYNAMIC TOPOGRAPHY FROM GOCE AND ALTIMETRY

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INTRODUCTION

One of the main objectives of GOCE is to provide a sufficiently accurate geoid model to allow a precise estimation of absolute dynamic topography from altimetry. In practice the best procedure to get an estimation of the absolute dynamic topography (and its error) ($\eta = <\eta> + \eta'$) from altimetry will be :

1. Estimate a mean dynamic topography ($<\eta>$) from GOCE and altimetry. The mean should correspond to a mean over a precise time period determined by the sea level anomaly calculation (typically several years or the duration of an altimetric mission). The longer is the time period, the better as the scales of the mean signal will be larger.
2. Add this mean dynamic topography to sea level anomaly (η') derived from repeat-track analysis.

The product that oceanographers will ultimately need from GOCE will thus be a mean dynamic topography (and its error). Such a computation will require to estimate a precise mean geoid for wavelengths larger than 100 to 200 km. This will be best achieved through the combination of GOCE with GRACE and CHAMP data. This geoid should then be subtracted from a very precise altimeter mean sea surface. It will be then necessary to filter the resulting mean dynamic topography taking into account the geoid and mean sea surface errors. This mean dynamic topography could be in a next step improved using in-situ measurements (e.g. Argo).

We report on efforts underway at CLS and GRGS to derive a mean dynamic topography from existing and future geoid models and to derive an independent estimate from in-situ data using a synthetic geoid approach. In the perspective of GOCE, our goal is to define a strategy for estimating (and validating) a global mean dynamic topography and ultimately develop a precise mean dynamic topography product combining altimetry, gravimetry and in-situ data. This product will be of major interest for scientific and operational applications (e.g. GODAE, MERCATOR) of satellite altimetry.

ESTIMATION OF A MEAN DYNAMIC TOPOGRAPHY FROM A GEOID

The estimation of a mean dynamic topography from a geoid requires to subtract it from a mean sea surface (referenced to an ellipsoid). As a result, one gets a mean dynamic topography over the time period corresponding to the altimeter mean sea surface. Note that geoid models which use altimeter data generally directly solve for a mean dynamic topography.

The geoid models which are now available for the oceanographic community are not sufficiently accurate to provide a useful estimation of the mean dynamic topography. Typical accuracy is of 10 to 20 cm rms for a spherical harmonic development of the order of 20 (i.e. wavelengths larger than 2000 km). This is of the order of or larger than the accuracy of existing mean dynamic topographies derived from ocean models or in-situ data. In addition these geoids are not independent from altimetric data and they certainly have absorbed part of the oceanic signal. In particular, they directly contain the oceanic signal above the cut-off dynamic topography expansion degree used in the geoid model representation.

As an illustration, we have used here the EGM96 [1] geoid model together with the a very precise and high resolution Mean Sea Surface (MSS) recently calculated by CLS [2]. The MSS corresponds to a 7-year mean (1992-1999) and uses the most recently processed TOPEX/POSEIDON, ERS-1/2 and GEOSAT data. A T/P mean profile over 7 years is first calculated. T/P data are then used to correct ERS-1/2 data (geodetic mission and 35-day repeat cycle) for orbit error and ocean variability. ERS-1/2 (35-day repeat cycle mission) and GEOSAT mean profiles are referenced to T/P mean profile through a global crossover adjustment. An inverse technique is then applied to estimate the MSS and its formal error from these data on a 1/30° grid. This technique takes into account the long wavelength biases on altimeter arcs and also the oceanic variability noise. The MSS formal error is about 2-3 cm rms in most ocean regions and increases to about 5 cm close to the coasts. The error is consistent with errors derived from the differences with independent altimeter mean profiles (e.g. ERS-1 3-day repeat cycle).

The EGM96 geoid was subtracted to the MSS and differences were then filtered to remove wavelengths shorter than 1500 km using a 2D Loess filter (similar results are obtained using spherical harmonics filtering). The corresponding mean dynamic topography is shown on figure 1. Given the errors in the MSS, the mean dynamic topography errors are dominated by geoid errors. At these resolved scales, they are of about 10 to 15 cm rms.

In the future, we expect a dramatic improvement on these estimations with the use of CHAMP, GRACE and mainly GOCE. This should allow, in particular, to estimate a geoid independent from altimetry (which is not the case, for example, for EGM96). We think that the preparation and validation of a mean dynamic topography product (and its associated error) should be part of the GOCE project activities. This is mandatory first to validate the GOCE geoids (see below) and this is the product which is needed by the oceanographers.

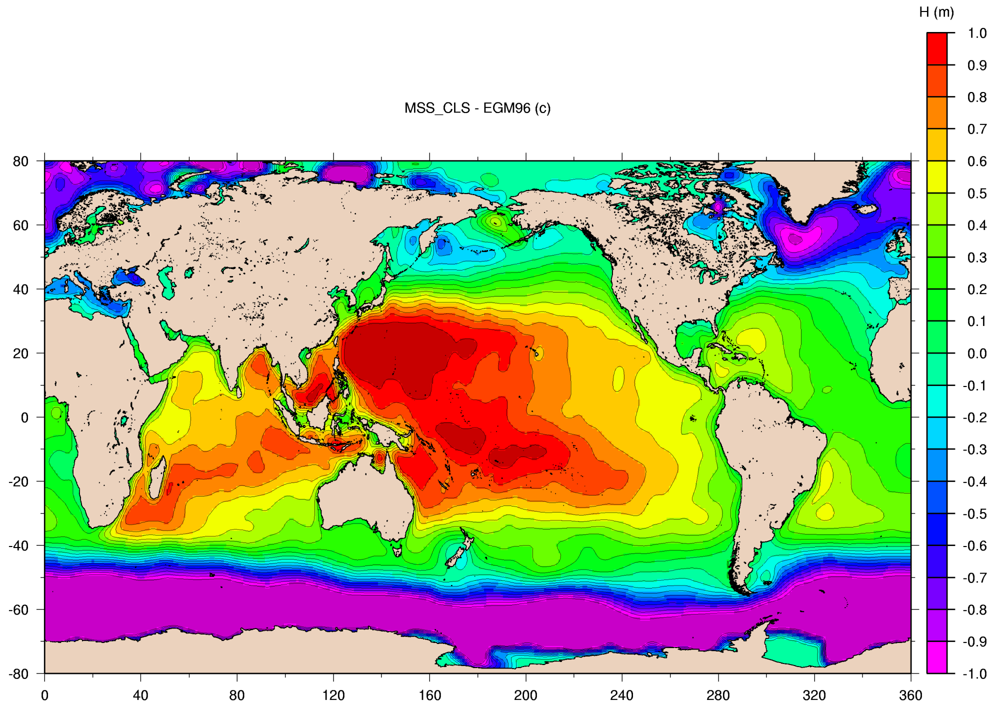

Fig. 1 : Mean dynamic topography derived from the EGM96 geoid and the CLS Mean Sea Surface.

MEAN DYNAMIC TOPOGRAPHY FROM IN-SITU DATA

Mean dynamic topographies have been derived in the past from climatological in-situ data. The most widely used mean dynamic topography is the one derived from the Levitus climatology [3]. These estimations require to assume a reference level or level of no motion and are thus missing part of the surface dynamic topography, in particular, at high latitudes where the barotropic component of the flow can be large (e.g. Antarctic Circumpolar Current). Deep floats could be used, however, to provide an estimation of the missing signal at the reference level [4]. This can be done directly or using also dynamical constraints through an inverse method [5].

One of the disadvantages of such estimations, however, is that to reduce the ocean variability noise, they have to use in-situ data over several decades. The corresponding mean dynamic topographies (in addition to estimation error) thus do not correspond to mean dynamic topography compatible with the altimeter sea level anomaly data.

Another approach is to combine the altimeter sea level anomalies with simultaneous in-situ data to estimate a synthetic «geoid» or more exactly mean dynamic topography. The technique proceeds as follows. In-situ data can provide estimates of the absolute dynamic topography η (although the barotropic part maybe more difficult to estimate) and satellite altimetry can give η' at the position and time of in-situ data; the combination of the two estimates thus yields the mean dynamic topography $<\eta>$ over the needed time period. This may be a very powerful methodology but it requires a large number of simultaneous data. This technique has been applied in the Gulf Stream [6], the Kuroshio [7] and the Azores Current [8].

This technique has been applied for the first time to the global ocean using in-situ temperature and salinity profile data (XBT, CTD) and T/P and ERS-1/2 altimeter data. This has allowed us to correct the Levitus mean dynamic topography so that it corresponds to a mean dynamic topography over the needed time period. Results are shown on figure 2a and 2b. One can see the improvement in the mean dynamic topography model in particular in western boundary currents where the fronts are much better defined. In the tropical Pacific ocean because of large interannual variability, the Levitus climatology cannot be taken as a good proxy for a mean dynamic topography over a time period of several years.

This new mean dynamic topography provides an improved comparison when altimeter data are compared with in-situ data. The rms difference between a global sets of XBT data and T/P-ERS altimeter data is, for example, reduced from 9.5 cm rms if Levitus is used to reference the altimeter data to only 7.5 cm rms with the new mean dynamic topography.

A similar calculation has been done with surface drifters. Velocities were corrected first from wind effects using an empirical Ekman model. They were then corrected for ocean variability using T/P and ERS-1/2 and a mean dynamic topography was computed. This mean dynamic topography also provides improved comparison with in-situ data. This calculation will soon be extended to the global ocean and will be combined with the calculation performed on temperature and salinity profiles.

With the development of new observing techniques (in particular, the Argo – array of profiling floats), these techniques should allow, in the future, the estimation of mean global dynamic topography with an accuracy of a few cm rms for scales larger than a few hundreds of km.

As these estimations will be totally independent from the ones derived from GOCE (and CHAMP/GRACE) geoids, they will be extremely useful first to validate them and in a next step to improve them. The in-situ and GOCE/GRACE/CHAMP topographies will have very different error characteristics and will thus be very complementary. It is likely, in particular, that the in-situ data estimations will be very accurate in well sampled regions and low variability regions. In other regions and also at high latitudes and in coastal regions (where the barotropic component will not be well estimated) they will be less useful.

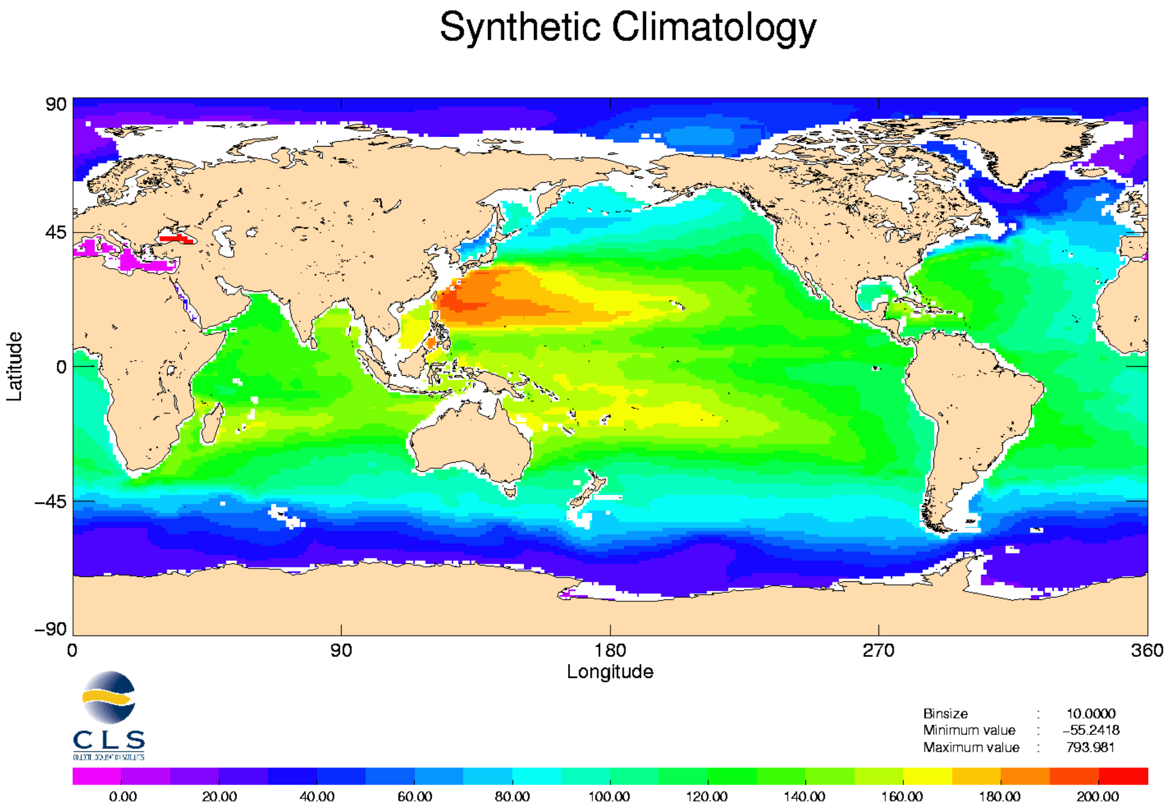

Fig 2a : Mean dynamic topography (referenced to 700 m) derived from the synthetic geoid methodology. Units are cm.

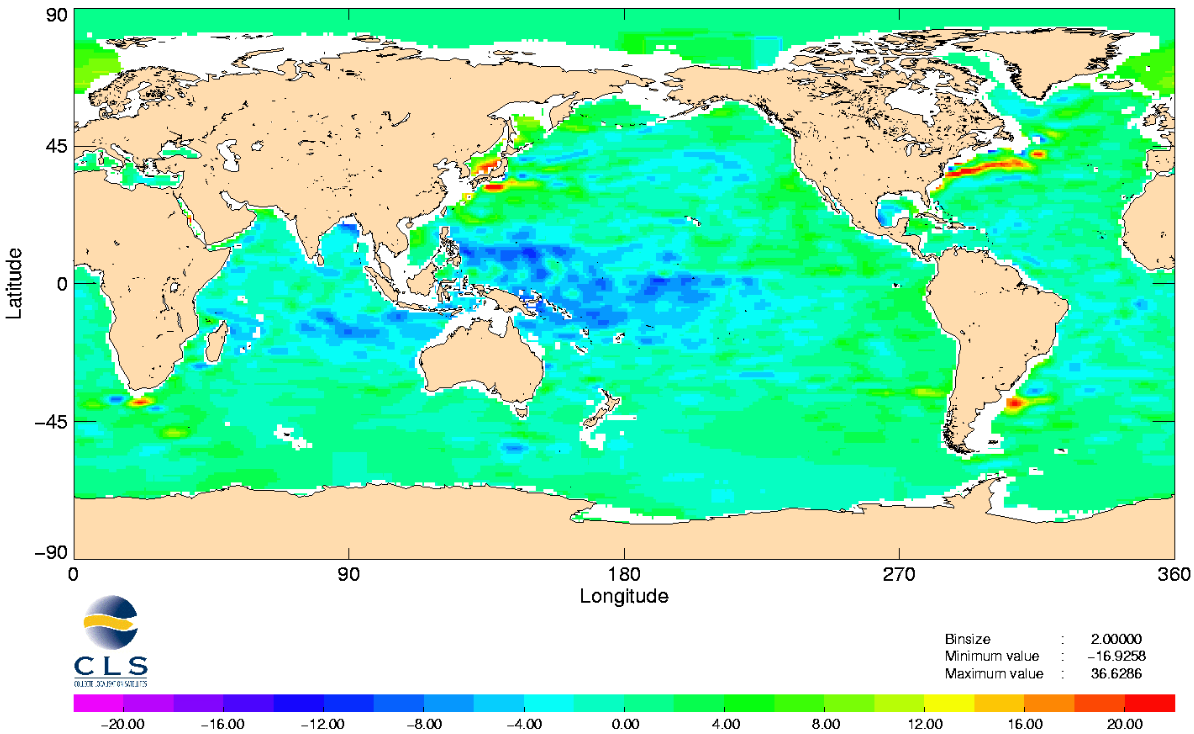

Fig 2b : Difference between the mean dynamic topography derived from the synthetic geoid methodology and the Levitus climatology. Units are cm.

CONCLUSIONS – PERSPECTIVES FOR GOCE

Our goal is to combine gravimetric and in-situ data to get the best possible mean dynamic topographies (thus absolute dynamic topographies) for altimeter data. This will have a major impact on the use of altimetry alone or in data assimilation systems (see [5], [9] and [10]).

In the perspective of GOCE, we believe that mean dynamic topography products should be prepared (at least combining the GOCE/GRACE/CHAMP geoids with an altimetric MSS) as part of the project activities. This will facilitate and develop the use of GOCE products by the ocean community. This is also needed to validate these geoids (and their associated errors) via the comparison with improved mean dynamic topographies (and the corresponding geostrophic circulation) that could be derived from in-situ data (e.g. using synthetic geoid or data assimilation techniques). The next step will be to combine these different estimations to provide the most adequate product for the ocean community.

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