AN OCEANOGRAPHIC ASSESSMENT OF THE PRELIMINARY GOCE GEOID MODELS ACCURACY

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ABSTRACT

In the framework of the ESA HPF (High Processing Facility), a number of gravity models have been computed from the GOCE data since the beginning of the mission in 2009. In addition to the classical method (the so-called direct approach) that combines orbit and gravity modelling using the orbit perturbation theory, two alternative methods have been newly developed dedicated to the GOCE mission, i.e. the time-wise and the space-wise approaches. Also, after preliminary models based on 71 days of GOCE data were delivered in June 2010, new models have been made available recently, based on more than six months of data.

In the framework of the ESA GUT (GOCE User Toolbox) project, the accuracy of these different models for oceanographic application has been assessed. Both the impact of the different methodolgies used to compute the gravity field as well as the contribution of the four months of supplementary data have been checked.

For that purpose, the different GOCE geoids were used to determine the ocean MDT (Mean Dynamic Topography) which was subsequently compared with other MDT estimates derived using other geoid models or in-situ oceanographic data. The MDT comparisons were carried out by analysing MDT residuals as well as their associated geostrophic surface currents at different maximum harmonic. Finally, both global and regional assessments have been performed.

1. INTRODUCTION

The objective of this study is to carry out an independent validation of the geoid models provided by the ESA High Processing Facility (HPF) and computed from the GOCE (Gravity field and steady-state Ocean Circulation Explorer) mission in order to quantify their performances for oceanographic applications. To achieve this goal, we have computed Mean Dynamic Topographies (MDT) from the different geoid models and compared them with independent observations.

The HPF has used three different approaches to compute the geoid models [1]. The time-wise [2] and the space-wise [3] approaches have been especially developed for the GOCE mission while the direct approach [4] is more classical. Two releases computed from respectively 2 months and 6 months of GOCE data are available for each geoid models based on the time-wise and the direct approaches. Only one release based on the space-wise approach is available and uses 2 months of GOCE data.

The two releases based on the direct approach (EGM_DIR_R1 and EGM_DIR_R2) are developed to order and degree 240 of spherical harmonics (83 km resolution). EGM_DIR_R1 results from 2 months of GOCE data constrained toward Eigen_51C that combines surface and GRACE data [4] while EGM_DIR_R2 results from 6 months of GOCE data constrained toward ITG_Grace2010s that is a GRACE (Gravity Recovery And Climate Experiment) only solution [5]. The first release based on the time-wise approach (EGM_TIM_R1) is developed to order and degree 224 of spherical harmonics (89 km resolution) while the second release (EGM_TIM_R2) is developed to order and degree 250 (80 km resolution). EGM_SPW is based on the space-wise approach and is developed to order and degree 210 of spherical harmonics (95 km resolution).

2. METHOD

In order to investigate the quality of the new GOCE geoid models we have first compute MDTs from EGM_DIR, EGM_SPW and EGM_TIM. To quantify the improvement of GOCE relative to GRACE mission we have also computed MDT from ITG-Grace2010s developed to order and degree 180 and using seven years of GRACE data [5].

The MDTs are computed by subtracting the different geoid models from an altimetric Mean Sea Surface. The Mean Sea Surface used in this study is the

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MSS_CNES_CLS10 estimated for the 1993-1999 period [6]. The MSS resolves spatial scales as short as 10-20 km while the geoid models are developed up to degree and order 210-250 (i.e. 95-80 km resolution) for the GOCE solutions and up to degree and order 180 (i.e. 111 km resolution) for the GRACE solution. Further filtering is hence needed. We applied a gaussian filter using for the resolution scales six different values (100, 125, 150, 200, 250 and 350 km).

In this study, we have mainly focused on the geostrophic currents deduced from the MDTs that are an estimation of the MDT gradients and thus are more sensible to noise than the MDT itself. Moreover it is more convenient to have a reliable estimate of geostrophic currents from in-situ data than an estimate of height above geoid. The estimate of the mean geostrophic currents (called 'synthetic' currents in the following) is deduced from all the 15 meter drogued drifting buoy data collected from 1993 to 2008 in the framework of the international WOCE and TOGA Surface Velocity Program. These data are distributed by AOML where they first have been quality controlled and krigged [7] in order to provide 6-hourly velocity measurements. In order to extract from the drifting buoy velocities only the geostrophic component, the Ekman current was first modelled [8] and substracted. Then, a 3 day low pass filter was applied to the velocities to remove inertial and tidal currents as well as residual high frequency ageostrophic currents. Finally the geostrophic velocity anomalies deduced from the Sea Level Anomalies relative to the 1993-1999 period are interpolated along the drifter's trajectories and substracted from the associated instantaneous geostrophic currents to have an estimate of the mean geostrophic currents relative to the same 7 year period. The altimetric SLAs used in this study are computed by the SSALTO/DUACS center and distributed by AVISO [9]. The synthetic currents obtained as described above are then filtered at the same resolution scales and using the same gaussian filter than the MDTs computed from geoid models.

Standard deviations of the differences between the geostrophic currents associated with MDTs computed from geoid models and synthetic geostrophic currents deduced from independent observations are computed at different resolution scales. The results will be discussed in the following sections.

3. IMPROVEMENT OF GOCE OVER GRACE

Figure 1 shows, at different resolution scales, the standard deviation of the difference between synthetic geostrophic current and geostrophic velocities estimated from GRACE and GOCE MDTs. In this part, only the first releases of the GOCE geoid models computed with 2 months of data are used.

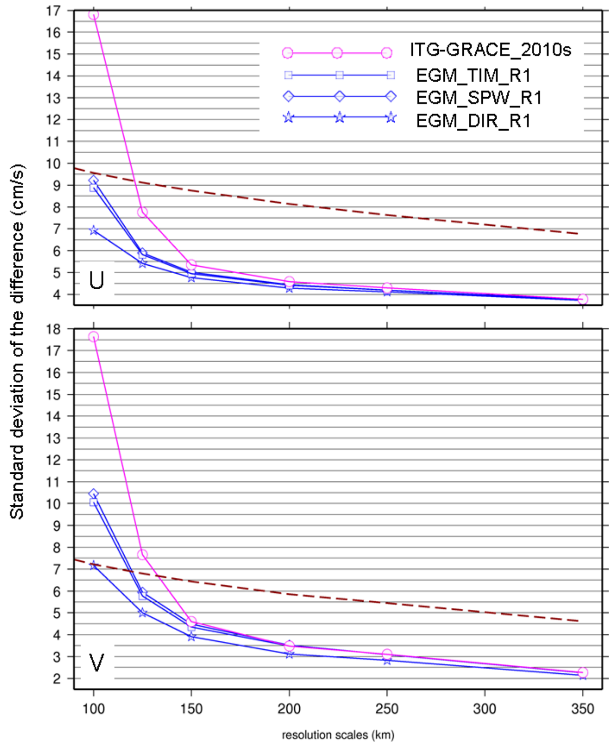

Figure 1: Standard deviation over the global ocean of the difference between the synthetic geostrophic currents and geostrophic currents associated with MDTs computed from (pink circles) ITG_GRACE2010s, (blue squares) EGM_TIM_R1, (blue diamonds) EGM_SPW_R1 and (blue stars) EGM_DIR_R1 .The top plot (resp. bottom) shows results for the zonal (resp. meridional) component. The red dash line shows the standard deviation of the synthetic estimate of the mean geostrophic velocities.

At scales smaller than 200 km, the standard deviations of the difference are much smaller with MDTs computed with GOCE geoid models (blue lines) than with GRACE geoid model (pink lines). At 100km, GOCE improves a lot the comparisons to independent observations; the gain of EGM_TIM_R1 compared with ITG_Grace2010s $\left(\frac{\sigma^2_{ITG-Grace2010s} - \sigma^2_{EGM\_TIM}}{\sigma^2_{ITG-Grace2010s}}\right)$ is 72% for the zonal velocities and 68% for the meridional velocities. In the Gulf Stream area (Figure 2) the circulation is well described by MDTs computed with GOCE data while MDT computed with ITG_Grace2010s is very noisy. At 150 km GOCE geoid models give standard deviations of the difference (Figure 1) smaller by more than 1.5cm/s than ITG_Grace2010s and smaller than the synthetic variability itself (red dash lines) for both components. At these scales, only 2 months of GOCE data improve a lot the mean oceanic circulation compared with 7 years of GRACE data.

At scales larger than 200km, the difference between geoid heights estimated from GRACE data and GOCE data are less than 1.5 cm. Thus, it is difficult to see this difference studying MDTs. At theses scales GOCE and GRACE have similar performances for the computation of Mean Dynamic Topography.

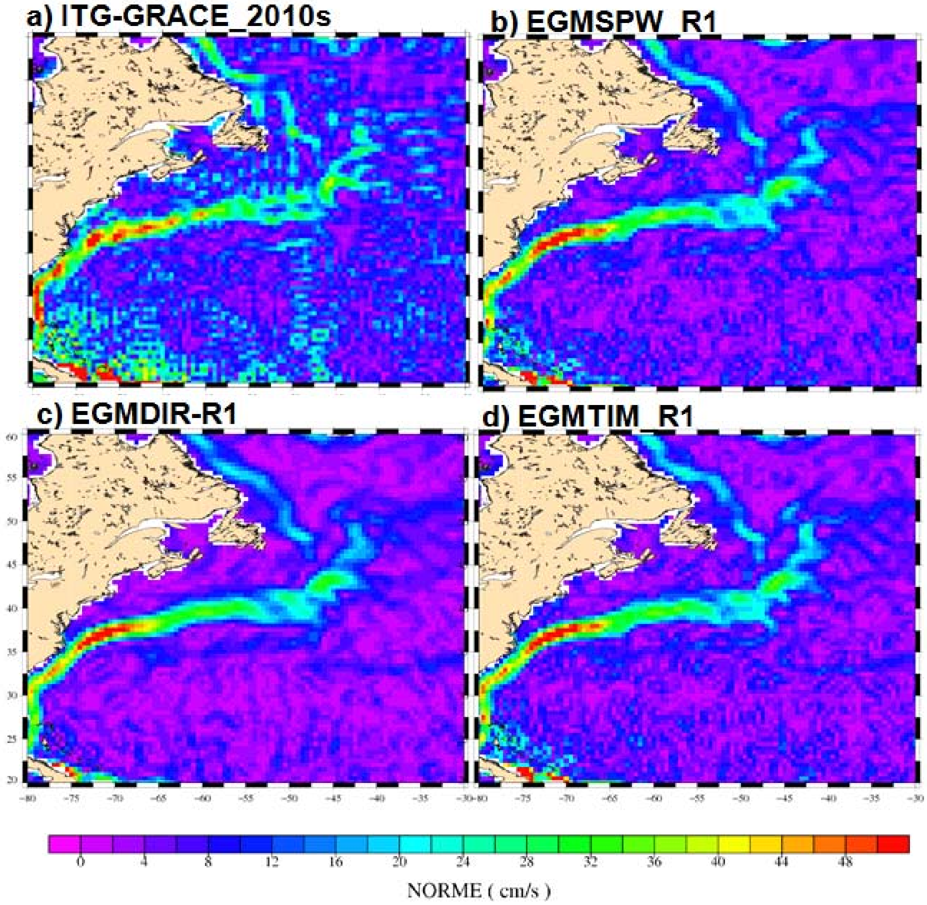

Figure 2: Intensity of the mean geostrophic currents (cm/s) in the Gulf Stream area from the 100km-filtered MDTs computed from (a) ITG-GRACE2010s, (b) EGM_SPW_R1, (c) EGM_DIR_R1 and (c) EGM_TIM_R1

4. COMPARISON BETWEEN THE DIFFERENT APPROACHES

In this section, we investigate the influence of the different approaches (time-wise, space-wise and the direct one) in the computation of the mean oceanic circulation.

The blue lines on Figure 1 show the results of the comparison to independent observations for the different approaches used in the first HPF releases. EGM_DIR_R1 is constrained toward Eigen51C, a geoid model that combines GRACE and surface data. The surface data help to improve small scales compared with the satellite only geoid models. Thus, it is not surprising that the direct approach gives smaller standard deviations of the difference than the other approaches. EGM_SPW_R1 and EGM_TIM_R1 give almost similar results, the space-wise approach give slightly smaller standard deviations. Figure 3 illustrates

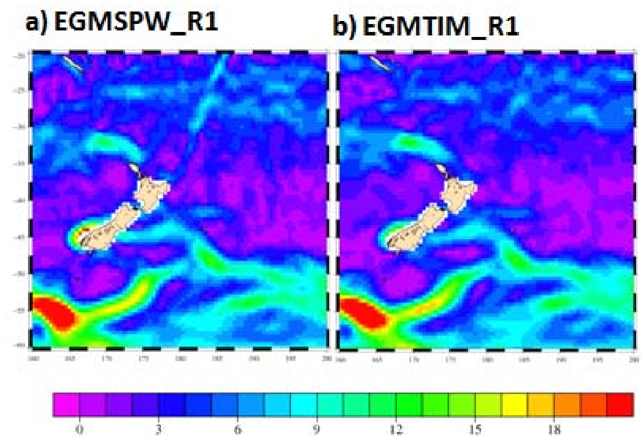

Figure 3: Intensity of the mean geostrophic currents (cm/s) in the New Zealand area from the 150km-filtered MDTs computed from (a) EGM_SPW_R1 and (b) EGM_TIM_R1.

that the space-wise approach is a bit noisier than the time-wise approach in the North-East of New Zealand. In this area, the high gravity gradients on the boundary between the Pacific and the Indo-Australian Plates are hardly resolved in the geoid models. On the contrary the Mean Sea Surface has higher resolution and resolves these kinds of structures. Thus, the high gravity gradients involve artefacts in the MDT computed by subtracting the MSS and the geoid height.

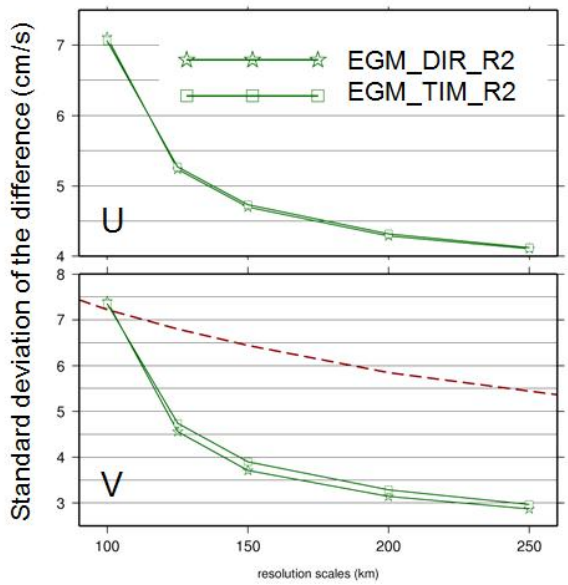

Figure 4: Standard deviation over the global ocean of the difference between the synthetic geostrophic currents and geostrophic currents associated with MDTs computed from (green squares) EGM_TIM_R2 and (green stars) EGM_DIR_R2 .The top plot (resp. bottom) shows results for the zonal (resp. meridional) component. The red dash line shows the standard deviation of the synthetic estimate of the mean geostrophic velocities.

On Figure 4, we compare the geoid models from the second HPF releases. EGM_DIR_R2 and EGM_TIM_R2 give globally similar results. Differences are seen depending on the areas. In the Kuroshio area (Figure 6a and Figure 6c) MDT computed with EGM_DIR_R2 is less noisy than the one computed with EGM_TIM_R2. However, it is the contrary south of Australia (Figure 5) where the computation of the geoid models is difficult because of the influence of the magnetic pole.

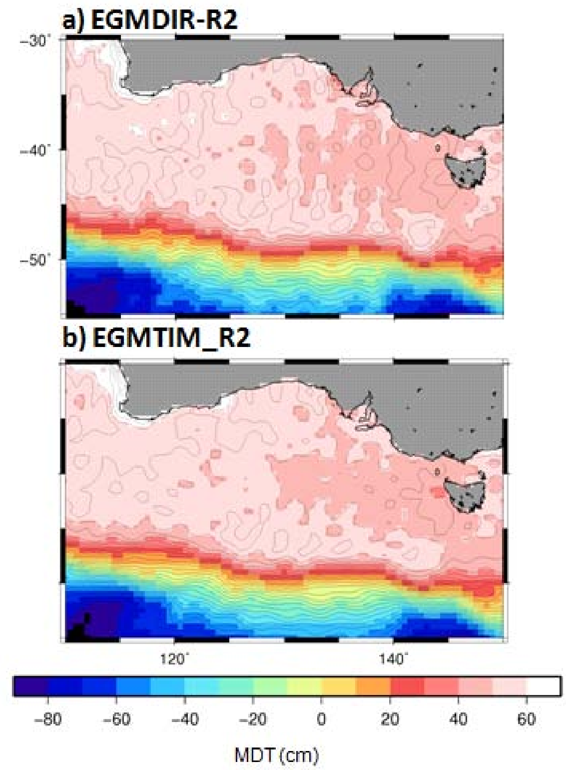

Figure 5: Mean Dynamic Topography (cm) filtered at 100 km south of Australia computed from (a) EGM_DIR_R2 and (b) EGM_TIM_R2.

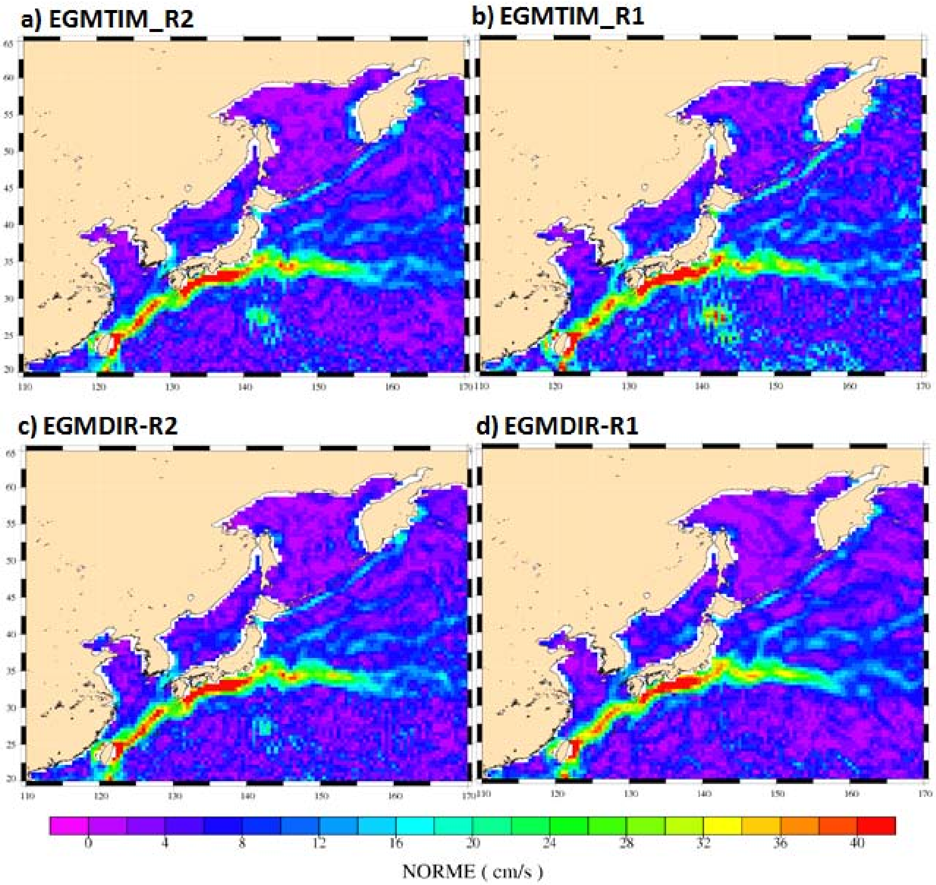

Figure 6: Intensity of the mean geostrophic currents (cm/s) in the Kuroshio area from the 100km-filtered MDTs computed from (a) EGM_TIM_R2, (b) EGM_TIM_R1, (c) EGM_DIR_R2 and (d) EGM_DIR_R1.

5. IMPACT OF MORE GOCE DATA

In this part we will compare the first HPF releases computed with 2 months of GOCE data and the second HPF releases computed with 3 times more GOCE data.

First, the comparison between the first and the second releases of EGM_TIM permit to quantify the impact of using more GOCE data in a GOCE only geoid model. Figure 7 shows that using 3 times more GOCE data improve a lot the comparison to independent observations. At 100km, the standard deviation of the difference for the zonal (resp. meridional) velocities decreases by about 2 cm/s (resp. 2.5 cm/s) with EGM_TIM_R2 compared with EGM_TIM_R1, the gain is 36 % (resp. 46 %). Figures 6 and 8 illustrate the improvement. The MDT computed with the second release of EGM_TIM is globally less noisy than the first release (Figure 8); the improvement is especially visible in the interior and east of the subtropical gyres and south of Australia. Figures 6a and 6c show the improvement in the Kuroshio area.

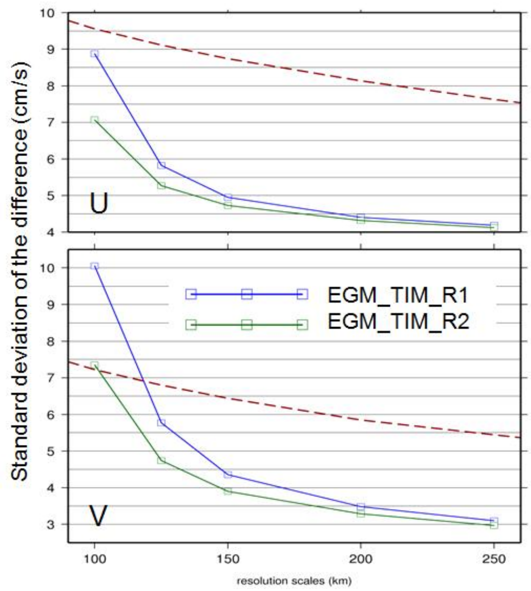

Figure 7: Standard deviation over the global ocean of the difference between the synthetic currents and currents associated with MDTs computed from (blue squares) EGM_TIM_R1 and (green squares) EGM_TIM_R2. The red dash line shows the standard deviation of the synthetic currents.

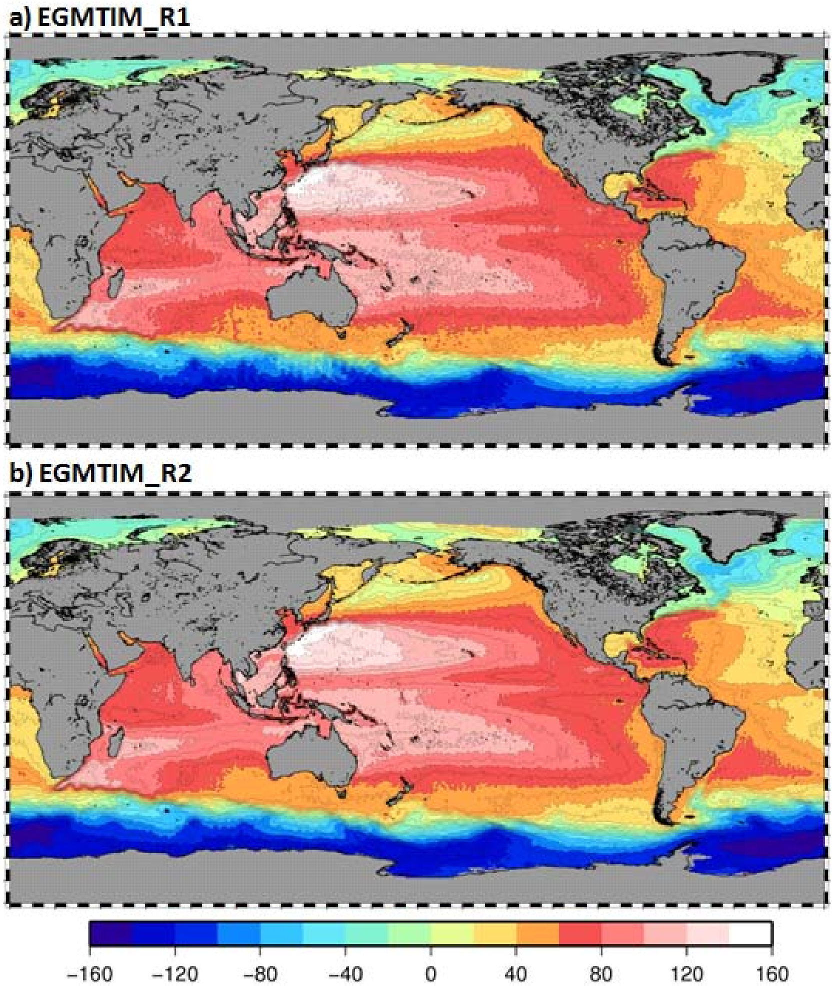

Figure 8: Mean Dynamic Topography (cm) filtered at 100 km and computed from (a) EGM_TIM_R1 and (b) EGM_TIM_R2.

Then, Figure 9 shows results of the comparison to independent observations for the different geoid models using the direct approach. EGM_DIR_R1 and R2 are both constrained toward an apriori geoid model but not the same. EGM_DIR_R1 is constrained toward Eigen_51C that combines surface and GRACE data while EGM_DIR_R2 is constrained toward ITG_Grace2010s (GRACE only solution). To quantify the impact of more GOCE data, we should compare EGM_DIR_R1 (blue stars on Figure 9) and exactly the same model but with more GOCE data (yellow stars on Figure 9). The improvement is less significant than for the time-wise approach (about 1cm at 100 km) because the surface data including in Eigen_51C give already information about small scales. However, the comparison between the two releases of EGM_DIR is very interesting and permits to quantify the impact of GOCE data in a geoid model that include surface data. At 100km, EGM_DIR_R1 gives better results than EGM_DIR_R2 thanks to the surface data. Figures 6c and 6d illustrate that EGM_DIR_R2 is noisier than EGM_DIR_R1 in the Kuroshio area at 100 km resolution scale. But between 120 and 200 km, EGM_DIR_R2 is slightly better (Figure 9). Thus, GOCE improves mostly scales between 120 and 200 km compared with model that combines surface and GRACE data.

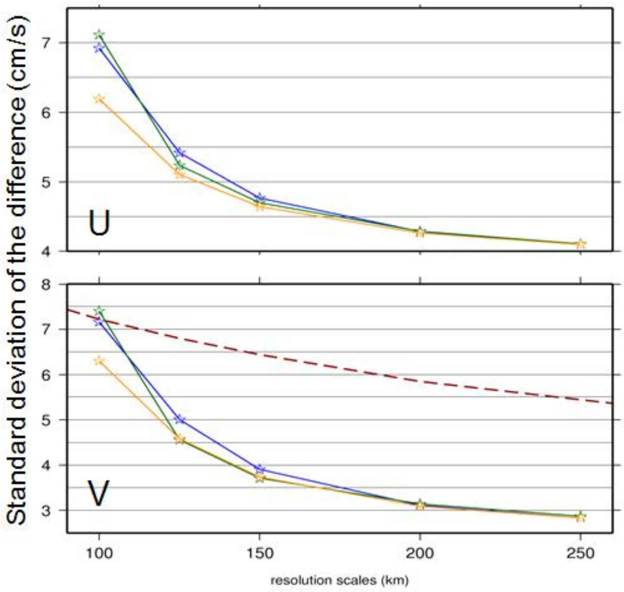

Figure 9: Standard deviation over the global ocean of the difference between the synthetic estimate of mean geostrophic velocities and geostrophic currents associated with MDTs computed from (blue stars) EGM_DIR_R1, (green stars) EGM_DIR_R2 and (yellow stars) a geoid model equivalent to EGM_DIR_R1 but with 6 months of GOCE data. The top plot (resp. bottom) shows results for the zonal (resp. meridional) component. The red dash line shows the standard deviation of the synthetic estimate of the mean geostrophic velocities.

6. CONCLUSIONS

The computation of Mean Dynamic Topographies from different geoid models and the comparisons with independent data from in-situ oceanographic measurements and altimetry permit to carry out an independent validation of the preliminary GOCE Level-2 products at different resolution scales. Only 2 months of GOCE data improve a lot the scales smaller than 200 km (DO 100) compared with ITG-Grace2010s, geoid computed with seven years of GRACE data. Using three times more GOCE data improve a lot the GOCE only geoid models but the improvement is less significant when using a geoid model that combines surface and satellite data. In a combined geoid model, GOCE improves mostly scales between 120 km (DO 166) and 200 km (DO 100).

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