ON THE ACCURACY OF CURRENT MEAN SEA SURFACE MODELS FOR THE USE WITH GOCE DATA

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ABSTRACT

The mean sea surface (MSS) is a fundamental parameter in geodesy and physical oceanography and knowledge about the error on the MSS is fundamental for the interpretation of GOCE geoid model for the study of large scale ocean circulation.

The MSS is the sum of the geoid height G and the temporal mean of the ocean mean dynamic topography (MDT) like MSS = G + MDT, where the MDT is the quantity bridging the geoid and the MSS and the quantity constraining large scale ocean circulation.

In order to evaluate the accurate of satellite derived ocean currents from the difference between the MSS and the new and future GOCE geoids it is of fundamental importance to know the error on the MSS.

In this presentation, preliminary results investigating the various contributions to MSS model differences as well as quantifying the various contributions to the total MSS error are characterized and the error sources are analyzed with respect to magnitude and scale.

1. INTRODUCTION

The challenge in MSS mapping is to derive the optimal combination/averaging of multi-mission satellite altimetry to achieve the most accurate filtering of the temporal sea surface variability with a limited time span and simultaneously obtaining the highest spatial resolution.

In this presentation the various error sources in the determination of altimetric MSS are presented.
The errors are grouped into three categories:

- Interpolation errors
- Errors due to the applied range and geophysical corrections.
- Correlated errors and errors due to map smoothing.

Various MSS models will be different and their mutual differences are a consequence of these errors and how they are mapped into the MSS derivation, consequently accurate error estimation is different. One example is that errors in the applied range and geophysical corrections might/will be absorbed in the interpolation process. It is also important to notice that the list of errors shown above is not exhaustive and there will be more errors contributing to the full set of errors, but these will be treated in a later publication

In this presentation we will not attempt at determination of which MSS are the more accurate but focusing on the fact that causes recent MSS (CLS01, CNES-CLS10, DNSC08 and DTU10) to be different. Here the preliminary investigation will demonstrate that different mapping of long term sea level variability will cause errors of the same magnitude as the estimated MSS errors. Consequently it is important to be aware of the averaging period averaging period and long term sea level variability when using MSS for studying MDT using GOCE geoid model.

2. INTER-ANNUAL AND LONG TERM SEA LEVEL CHANGE

Before investigating the various errors in MSS determination, it is important to notice that the MSS is derived in the presence of inter-annual to long term sea level variability like decadal variability and sea level change. Consequently MSS cannot be compared using simple differencing to investigate the error. MSS models will be different due to the averaging period applied in their derivation, and one should always be aware of which period has been used for the averaging [see, i.e.Andersen, 2008].

To illustrate the importance of accounting for different averaging period, an inspection of the difference between two of the most widely used global MSS models is shown in Figure 1. These are the CLS01 MSS model [*Hernandez and Schaeffer*, 2002] and the DNSC08MSS [Andersen and Knudsen, 2008]. CLS01 is based on seven years of satellite altimetry covering the period 1993-1999, whereas the DNSC08MSS is based on 12 years of averaging (1993-2004).

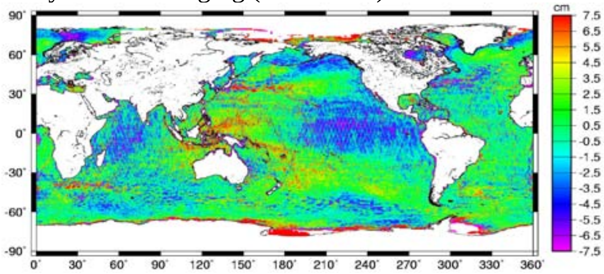

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__Figure 1.__ The difference between DNSC08MSS (1993-2004) and CLS01MSS (1993-1999). A two cm offset due to different IB correction have been removed. Figure courtesy of S. Holmes and N. Pavlis

Figure 1 gives an indication of the magnitude of the difference between recent MSS models which should be kept in mind when evaluating the error of the MSS models.

Large scale differences of the order of +/- 5 cm from east to west in the Pacific Ocean. These differences reflect inter-annual ocean variability that is averaged differently. The east-west dipole in the Pacific Ocean is largely caused by the different influence of the large 1997-1998 El Nino on the 7 years CLS01 mean period (1993-1999) and on the 12 year DNSC08MSS mean period (1993-2004).

Upon updating the DNSC08MSS to DTU10MSS, more years of data were added and the method was improved. Consequently a different averaging period was used (1993-2009). The difference between these two DTU models is seen in Figure 2 and is roughly 3 cm on average. The two centimeters are due to the use of the improved MOG2D Dynamic Atmosphere correction compared to the old inverse barometer correction. The different mean pressures in the two models (1013 versus 1011 mbar) raises the MSS by roughly 2 cm. The last cm is contributed to the fact that 6 years of additional data enters the DTU10MSS (2004-2009) shifting the center by 3 years. Sea level change of around 3 mm/year which raises the MSS by another 1 cm over 3 years.

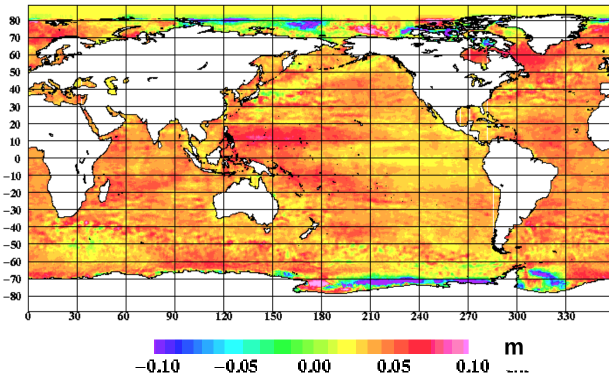

Figure 2. Differences between the DNSC08MSS and the DTU10MSS with scale in meters.

3. INTERPOLATION ERRORS

The interpolation error is generally delivered along with the MSS models and can be used as a proxy for the vertical accuracy of MSS. The interpolation error are the apriori errors from the interpolation of highly accurate mean sea tracks where oceanographic signal have efficiently been averaged out (like along the T/P-Jason and ENVISAT mean profiles) with low accurate observations from Geodetic mission profiles which are high density but non-repeating profiles containing the full oceanographic signal at the time of observations.

Figure 3 and 4 shows the interpolation error for the CLS and DNSC08 models. The global map shows the spatial variation of the error estimate with zones of higher and lower error correlated with the sea state. The interpolation error is on average around 4-6 cm globally for both models. The error shows latitudinal variation with lowest values around the 65°parallel, where the density of the T/P+Jason-1 observations are highest.

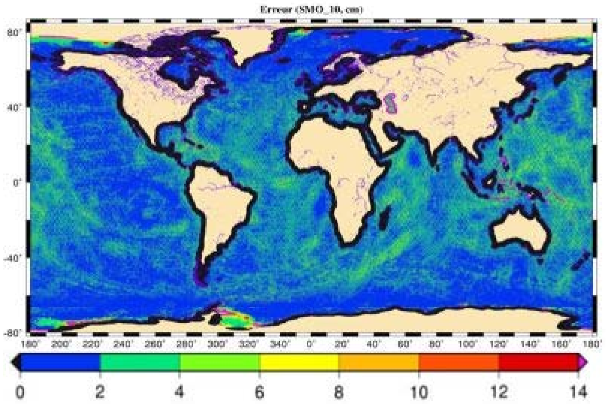

Figure 3. The formal interpolation error from the optimum interpolation applied by CLS in their derivation of MSS models (in centimetres)

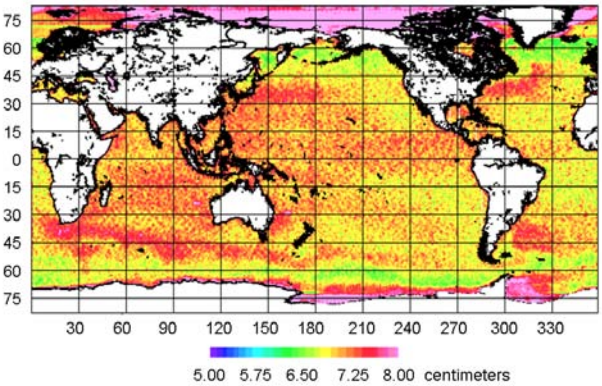

Figure 4. Global interpolation error fields for the DTU10MSS/DNSC08MSS. The color scale is given in centimeters.

4. ALTIMETRY ERRORS DUE TO RANGE AND GEOPHYSICAL CORRECTIONS.

The height, h, of the sea surface above the reference ellipsoid is given like

$$h = H - R_{\text{corrected}}$$
$$= H - (R_{\text{obs}} - \Delta R_{\text{dry}} - \Delta R_{\text{wet}} - \Delta R_{\text{iono}} - \Delta R_{\text{ssb}})$$

where *H* is the height of the spacecraft determined through orbit determination and R is the range by the spacecraft.
The following state of the art range corrections shown in Table 1 was invested to test the accuracy of the range by computing the effect of using different range corrections on the computation on a MSS based on 6 years of data. The six years of data were chosen as longer periods did not change the conclusions significant and as six simultaneous years of observations are available for both Jason-1 and ENVISAT satellite without having to merge different satellite missions.

	Corrections
Dry Troposphere	ECMWF (Model) NCEP (Model)
Wet Troposphere	Radiometer (onboard) ECMWF (Model)
Ionosphere	Smoothed Dual Frequency Radiometer IRI 2007 (model)
Dynamic Atmosphere Correction	IB (Model. Local pressure) MOG 2D_IB Model
Tides	FES 2004 (Model) GOT 4.7 (Model)
Sea State Bias	BM4 (model) CLS NPARAM-GDRC (model)

Table 1 The set of range and geophysical corrections tested in a derivation of a 6 year MSS.

Figure 5 and Figure 6 shown the difference in centimetres computed using 6 years of Jason-1 and ENVISAT data respectively. The figures shows the dry troposphere (first row), wet troposphere (second row), ionosphere (third row), dynamic atmosphere correction (fourth row), ocean tide (fifth row) and sea state bias correction (sixth row).The Root sum square (RSS) difference for all 6 corrections is shown in the seventh row and has been computed as the square-root of the sum of the RMS for all six corrections.
In both the Jason-1 and the ENVISAT case the sea state bias is dominating with amplitudes above one cm in many regions. This is a natural cause of the fact that this correction is a "bias" correction unlike most other corrections which are averaged out. Also the wet troposphere correction stands out as a significant contributor with amplitudes up above on cm.
If the value was computed using six years of Envisat data a more complicated and different results are seen. This is because Envisat is sun-synchronous. Consequently, sun-synchronous contributions to the range and geophysical corrections will be observed at the same phase and averaging the satellite altimeter observations over time will not average them out. As such these sun-synchronous contributions might end up in the sea level anomalies.

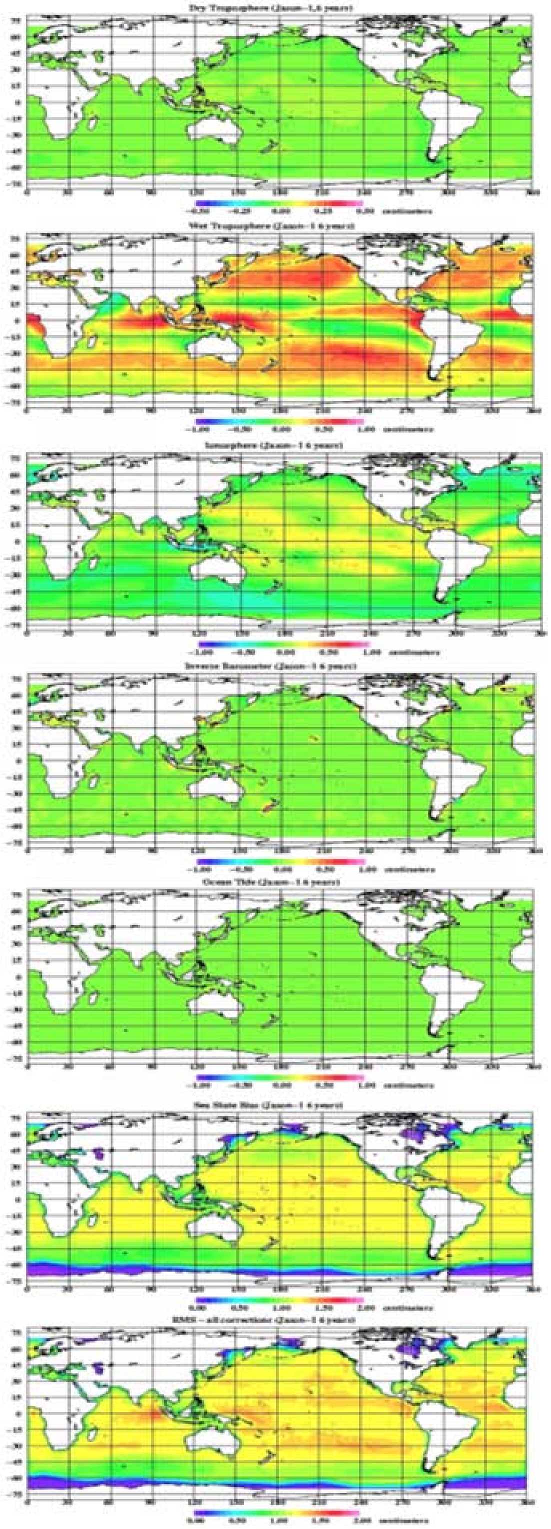

Figure 5. The difference (cm) for the dry troposphere (first row), wet troposphere (second row), ionosphere (third row), dynamic atmosphere correction (fourth row), ocean tide (fifth row) and sea state bias correction (sixth row) and the RSS of all 6 corrections (seventh row) based on 6 years of Jason-1 altimetry.

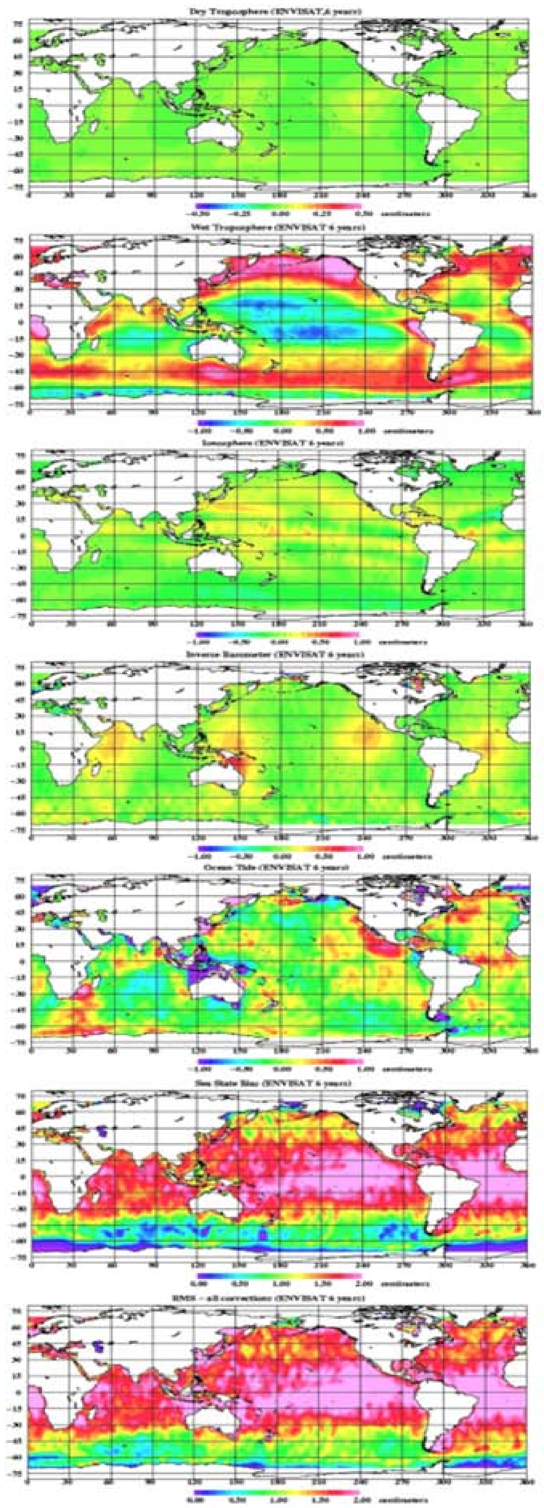

Figure 6. The difference (cm) for the dry troposphere (first row), wet troposphere (second row), ionosphere (third row), dynamic atmosphere correction (fourth row), ocean tide (fifth row) and sea state bias correction (sixth row) and the RSS of all 6 corrections 8seventh row) based on 6 years of ENVISAT altimetry.

Global pattern of highs and lows are seen in both the difference between the applied tide models and difference in the applied dynamic atmosphere correction. Both correspond to aliasing of the S_2 constituent. For the ocean tide the effect is most likely due to the difference in the amplitude of the S_2 tide between the FES2004 and GOT4.7 ocean tide models.

For the dynamic atmosphere correction in the lower panel of Figure 29, the cause is the fact that the S_2 atmospheric tide is included in the MOG2D_IB correction, but not in the inverse barometer correction. Interested readers are referred to Rio and Andersen (2009) for a more detailed investigation of the subject.

5. CORRELATED ERRORS AND MAP SMOOTHING ERRORS.

The following two contributions to the total MSS error in Table 2 are investigated in this section. Notice that this list is NOT exhaustive and at least for additional errors appears on the full list of errors, but due to space limitations these will not be included in this presentation.

A	Correlated error averaging (discrepency between missions -> mix of errors)
B	Map smoothing (scales which cannot be resolved away from known tracks, degrading along-track content)

Table 1 Two contributor to the MSS error.

The correlated error averaging arised from the MSS "average and mix" og data from sensor which all have specific errors due to the length of the averaging period and the inherent error of the observations. To estimate how the gridded MSS absorbs correlated errors from individual missions (even on charted tracks), Figure 7 shows the residuals between the MSS and the mean profile used by the gridding process along the ERS/ENVISAT track. The difference often exceeds 2 to 3 cm with correlated patterns larger than 100km. These errors that gets eliminated are frequently the errors related to the geophysical corrections being averaged differently due to the sampling interval shown in Figure 5 and 6.

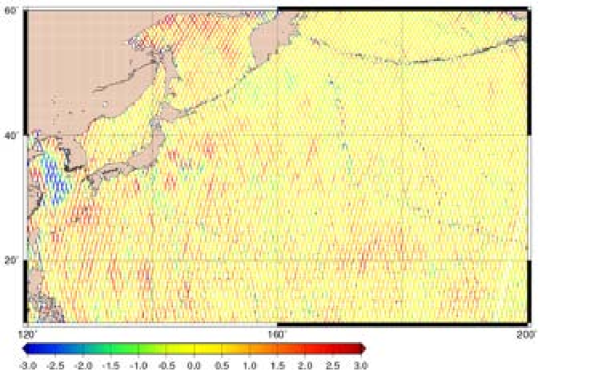

Figure 7 The difference between the mean profile from ERS/ENVISAT and the gridded MSS surface created from the interpolation process.

To quantify smoothing error and noise level as it is possible to look at the difference between MSS and the EGM08 geoid. Since only altimetry is able to resolve the shortest scales of the geoid at global scale, the difference to EGM08 highlights either actual geodetic features or artifacts (smoothing, background noise, outliers). The figure shows a comparison of this difference over the Caribbean Sea. Although most features are similar for both MSS, in some areas (highlighted in red) the content is different. For short scales, the differences are far from trivial as they can locally exceed 5 to 7 cm.

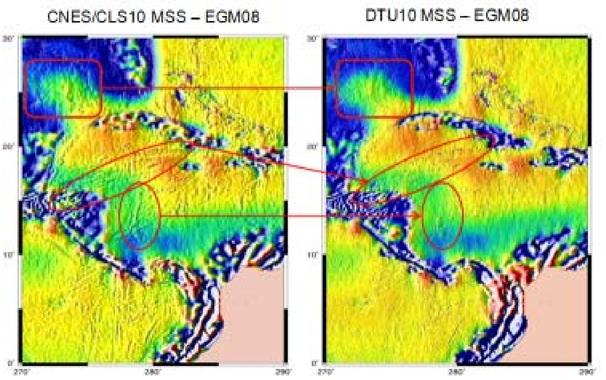

Figure 8 Differences (m) between CNES/CLS2010 (left) or DTU10 (right) and EGM08.

6. CONCLUSION

In this presentation, preliminary results investigating the various contributions to MSS model differences as well as quantifying the various contributions to the total MSS error are characterized and the error sources are analyzed with respect to magnitude and scale.
The investigation indicates various errors clearly on the sub-decimeter level like the errors from using different range and geophysical corrections. Also errors due to the interpolation process and the smoothing errors have been shown to contribute significantly in local regions.
The largest errors are however still found in coastal and polar regions.
However the conclusions are still preliminary as the work is currently in progress and more

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