GRACE Gravity Field Solutions using different De-aliasing Models

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1. Introduction

Short-term (hourly to monthly) atmospheric and oceanic mass variations have to be taken into account when generating monthly GRACE gravity fields. Till now the GRACE Science Data System (SDS) level-2 processing centers have used the release 1 AOD1B (Atmosphere and Ocean De-aliasing level-1B) product which is routinely generated by GFZ Potsdam [Flechtner, 2003]. This model is using multi-layer 6-hourly ECMWF (European Center for Medium Weather Forecast) meteorological fields, which are integrated vertically to represent the 3D atmospheric mass distribution at each epoch. The ocean's response to wind and pressure and corresponding oceanic mass variation is derived from a barotropic ocean model provided by JPL (PPHA v1.1). This model has some deficiencies which might influence the quality of the GRACE gravity field solutions (such as polar gaps, less variance in bottom pressure than other comparable models (V. Zlotnicki, personal communication 2004) or reduced level of energy compared with in-situ ocean bottom pressure data [Kanzow et al., 2005]).

To investigate the influence of the non-tidal ocean model on GRACE gravity field solutions two experiments have been performed for 3 different de-aliasing products. First, sets of monthly gravity field solutions have been derived which only differ by the applied short-term mass variations. Four months (May 2003, August 2003, November 2003 and February 2004) were selected for processing, to investigate also their seasonal variability. Second, daily gravity field solutions have been calculated for July 2003 until September 2003 without correcting for short-term mass variations and correlated with the candidate de-aliasing products.

2. De-aliasing Products and non-tidal Ocean Models

Three de-aliasing products have been investigated which all are based on same input data and modeling assumptions to guarantee a fair comparison: the same 6-hourly ECMWF meteorological fields were used, the atmospheric and oceanic mass variations were derived by subtracting a 2001+2002 mean field, the atmospheric contribution was calculated by vertical integration (quasi-identical for all products) and the S2 atmospheric tide was filtered from surface pressure data before forcing the non-tidal ocean model. The later is necessary to avoid double book-keeping with the ocean tide model during orbit and gravity field parameter estimation. Thus, the dominating difference between these de-aliasing products is the non-tidal ocean model, used to calculate the oceanic mass variation. Consequently, the de-aliasing products of this study are denoted w.r.t. their applied non-tidal ocean models:

PPHA: This product is identical to the standard AOD1B RL01 product, except that the mean field period has been changed from 2001 to 2001+2002 and the S2 atmospheric tide has been filtered before forcing the non-tidal ocean model PPHA, developed by Pacanowski, Ponte, Hirose and Ali [Hirose et al., 2001]. PPHA computes the component of oceanic mass redistribution ("barotropic sea level") due to wind stress and atmospheric pressure for an area between 65ºN and 75ºS including the Mediterranean Sea, Hudson Bay, North Sea and shallow waters on a 1.125º grid, but lacks baroclinic dynamics and surface buoyancy. Due to the exclusion of the Artic Ocean a pure inverse barometric (IB) response of the sea surface (no mass variation) has to be applied north of 65º and south of 75º latitude, respectively.
MOG2D: This model is provided by GRGS (Groupe de Recherche de Géodésie Spatiale) and is based on the same assumptions as AOD1B RL02, but the non-tidal ocean model is MOG2D, a barotropic, non-linear and time stepping model with global output (including the Arctic Ocean, Hudson Bay, Bering Strait and the Weddell and Ross Seas). The ice cover impact is taken into account through the diminution of the water column height, due to the submerged ice thickness. MOG2D is governed by shallow water continuity and momentum equations. The model can include tides and its main originality is a finite element space discretisation which allows to increase the resolution e.g. from 400 km in the open sea down to 20 km in areas with strong topographic gradients or in shallow waters [Carrère and Lyrad, 2003].
OMCT: The atmospheric contribution is identical to AOD1B RL02 (see "PPHA" above), but the oceanic mass variations were provided by the Technical University of Dresden (TUD). They were derived from the baroclinic Ocean Model for Circulation and Tides (OMCT) which is a further development of the Hamburg Ocean Primitive Equation Model (HOPE) by adjustment to the weather time-scale and coupling with an ephemeral tidal model [Thomas et al., 2001]. In contrast to the HOPE model, OMCT allows to take into account effects arising from loading and self-attraction, atmospheric pressure forcing or the consideration of continental freshwater fluxes. Effects due to sea-ice are accounted for by means of an implemented thermodynamic sea-ice model which allows a prognostic calculation of ice-thickness, -drift and -compactness. As MOG2D, the OMCT output is provided on a global scale.

3. De-aliasing Product Differences

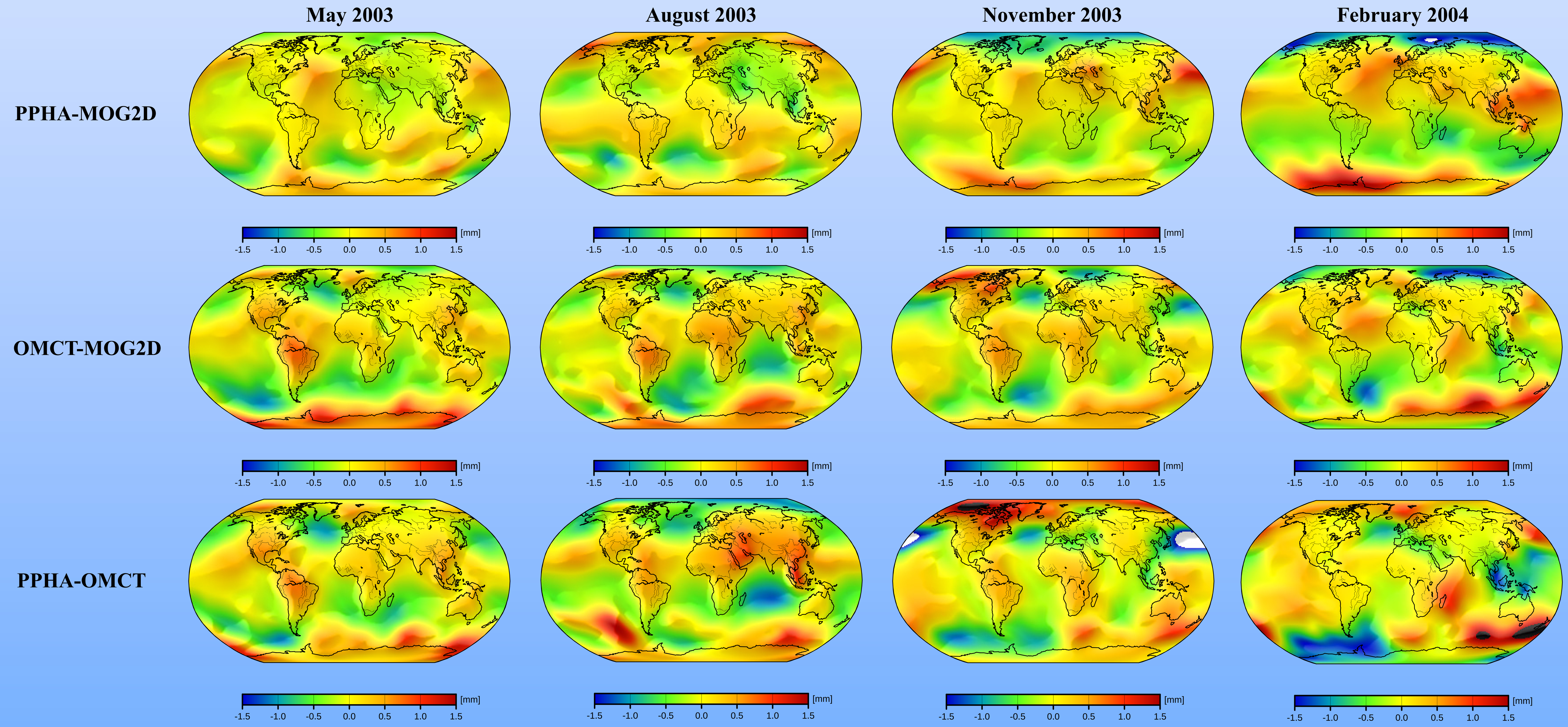

Figure 1: Mean geoid height differences [mm] between PPHA and MOG2D (top), OMCT and MOG2D (middle) and PPHA and OMCT (bottom) derived from de-aliasing products for May 2003, August 2003, November 2003 and February 2004 (from left to right). All figures have been smoothed by a Gaussian filter of 500 km radius, variations in C_{20} have been ignored, n_{max} is 100.

4. Monthly Gravity Field Solutions

Monthly gravity field solutions have been calculated using the standard GFZ level-2 GRACE processing strategy (2-step approach based on GPS code (GPC), GPS phase (GPP) and K-band range-rate (KRR) observations) and background models (initial gravity field, ocean tides, atmospheric tides, Earth tides, etc.) [Reigber et al., 2004]. Only difference was the de-aliasing model. The observation residuals, the degree amplitude and geoid height differences are shown in the following table and figures.

	May 2003	August 2003	November 2003	February 2004
GPC [cm]	53.97 / 53.75 / 53.66	50.33 / 50.11 / 50.38	47.60 / 47.57 / 47.59	47.37 / 47.59 / 47.36
GPP [cm]	1.205 / 1.208 / 1.227	1.157 / 1.183 / 1.181	1.173 / 1.184 / 1.177	1.107 / 1.121 / 1.119
KRR [µm/s]	0.408 / 0.413 / 0.414	0.362 / 0.358 / 0.358	0.362 / 0.366 / 0.366	0.335 / 0.344 / 0.342

Table 1: GPS code (GPC), GPS phase (GPP) and K-band range-rate (KRR) post-fit residual RMS for May 2003, August 2003, November 2003 and February 2004 (from left to right) using MOG2D (left) , OMCT (middle) and PPHA (right) de-aliasing products.

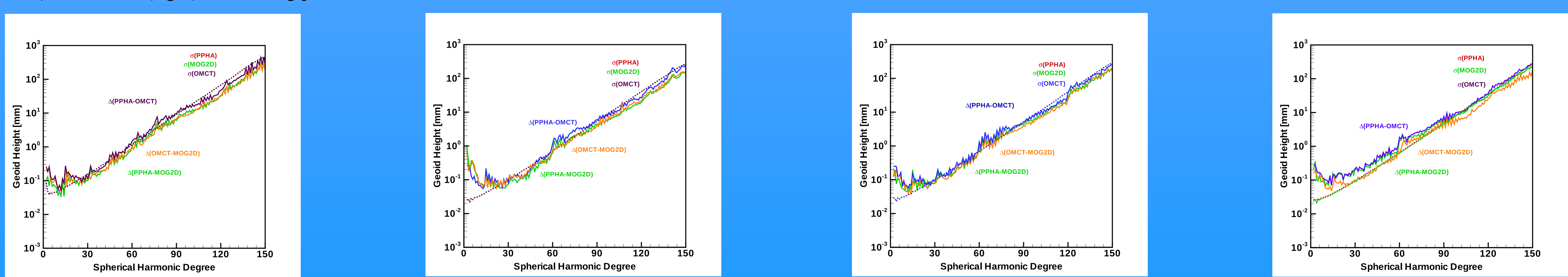

Figure 2: Degree amplitudes of gravity field differences derived with PPHA, MOG2D and OMCT de-aliasing products for May 2003, August 2003, November 2003 and February 2004 (from left to right).

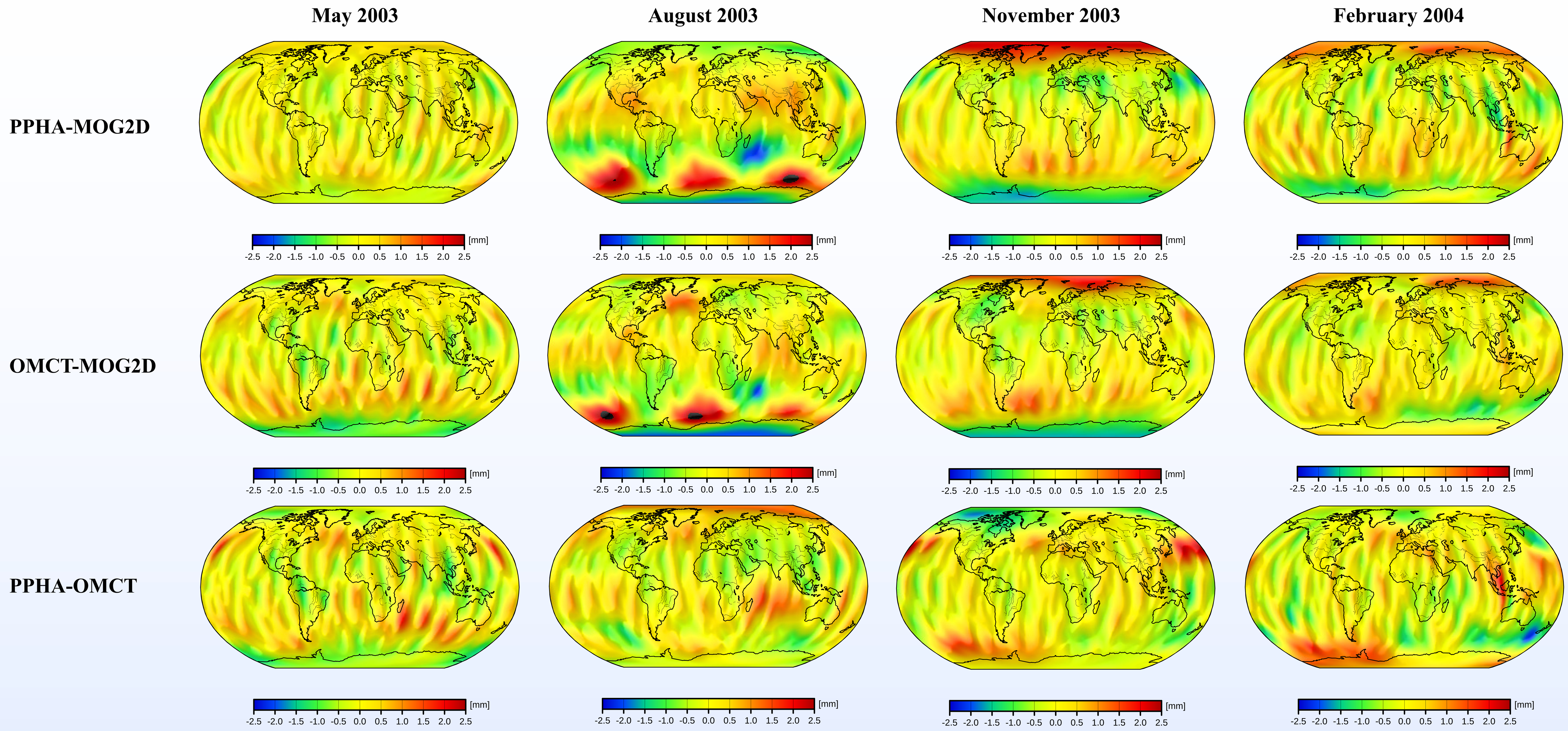

Figure 3: Geoid height differences [mm] between gravity field products derived from PPHA and MOG2D (top), OMCT and MOG2D (middle) and PPHA and OMCT (bottom) for May 2003, August 2003, November 2003 and February 2004 (from left to right). All figures have been smoothed by a Gaussian filter of 500 km radius, C_{20} variations have been ignored, n_{max} is 150.

	May 2003			August 2003			November 2003			February 2004		
	Weighted Root Mean Square of Geoid Height Differences about Mean [m]											
	2.5ºx2.5º	5ºx5º	10ºx10º	2.5ºx2.5º	5ºx5º	10ºx10º	2.5ºx2.5º	5ºx5º	10ºx10º	2.5ºx2.5º	5ºx5º	10ºx10º
MOG2D	1.797	0.406	0.115	1.100	0.272	0.115	1.173	0.283	0.114	0.796	0.219	0.114
OMCT	1.814	0.411	0.115	1.111	0.275	0.114	1.194	0.287	0.114	0.797	0.218	0.114
PPHA	1.947	0.438	0.115	1.147	0.282	0.114	1.219	0.296	0.115	0.865	0.232	0.114
	Weighted Root Mean Square of Gravity Anomaly Differences about Mean [mgal]											
	2.5ºx2.5º	5ºx5º	10ºx10º	2.5ºx2.5º	5ºx5º	10ºx10º	2.5ºx2.5º	5ºx5º	10ºx10º	2.5ºx2.5º	5ºx5º	10ºx10º
MOG2D	38.771	8.235	0.351	23.700	5.210	0.326	25.219	5.442	0.327	17.130	3.911	0.320
OMCT	39.034	8.330	0.352	23.928	5.274	0.326	25.696	5.533	0.327	17.253	3.920	0.320
PPHA	41.980	8.933	0.356	24.664	5.432	0.327	26.135	5.718	0.328	18.648	4.251	0.321

Table 2: Comparison of monthly gravity field products derived from MOG2D, PPHA and OMCT de-aliasing products for May 2003, August 2003, November 2003 and February 2004 with altimeter-derived geoid heights (*N*, CLS01 minus ECCO oceanic geoid) and gravity anomalies (Δg, NIMA marine gravity anomalies) for different grid spacing (10º~n=18; 5º~n=36; 2.5º~n=72).

5. Daily Gravity Field Solutions

Daily time series of gravity field models complete up to degree and order 10 have been produced for the time span July 2 to September 30, 2003 using a modified integrated adjustment method [Zhu et al., 2004]. The standard background models (such as mean gravity field, ocean tides, atmospheric tides, Earth tides etc.) have been accounted for during data processing, while variations in the gravitational potential produced by non-tidal atmosphere and ocean mass transport were omitted. The recovered GRACE gravity changes represented by the daily time series of spherical harmonics were then compared to the corresponding coefficients of the de-aliasing products PPHA, MOG2D and OMCT, respectively. Hydrological mass variations are assumed to change slower than days and can therefore be accounted for by the subtraction of a bias and a trend. It turned out that the recovered gravity field coefficients are highly correlated with the model predictions for low order coefficients, but the agreement degrades when the order is increasing. The highest correlation and smallest residual geoid height differences were derived with MOG2D, followed by OMCT and PPHA, which give quite similar results. A pure IB response of the sea surface assumption produced the worst results (Figure 4). The experiment shows, that GRACE is able to trace geophysical signals at short time scales and GRACE data can be used to validate large-scale mass transport predictions. Detailed results on "High frequency temporal Earth gravity variations detected by GRACE satellites [Hu et al., 2005]" will be presented by S.Y. Zhu on Tuesday, April 26 2005 in Session G3.

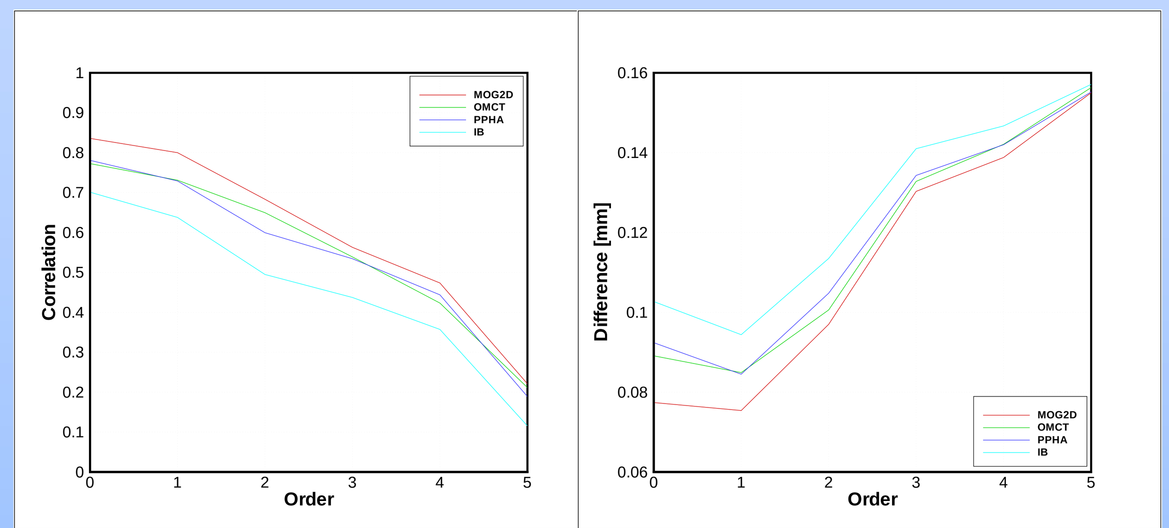

Figure 4: Mean correlation coefficients as a function of order (left) and residual geoid height differences [mm] (right) between the daily GRACE gravity field solutions and different de-aliasing products (degree 1 and 2 ignored).

6. Conclusions

- Three short-term atmosphere and ocean mass variation de-aliasing (AOD) products, which only differ by their non-tidal ocean model (PPHA, MOG2D, OMCT), have been investigated for 4 months covering the seasonal cycle.
- Mean geoid height differences between these products are in the order of ±1.5 mm. Maximum differences are visible in the Artic (no PPHA output), in the Southern ocean and in the North-Pacific.
- Monthly GRACE gravity field solutions show comparable post-fit residuals for all de-aliasing products (with very slightly, but consistently lower GPS phase and K-band range-rate values for MOG2D).
- Monthly degree variance differences are generally smallest for OMCT-MOG2D and slightly higher when comparing to PPHA. The formal errors of the monthly gravity field solutions are below that differences, especially for long wavelengths. More realistic calibrated errors would be much larger (not shown). Thus, the applied de-aliasing product will not change the GRACE gravity model quality drastically.
- The mean geoid height differences between corresponding gravity field solutions reflect nearly 1:1 the mean background AOD differences spatial structure, but scaled by a factor of about 1.5. Additionally, previously observed striping, which is due to other aliasing effects (e.g. insufficient instrument parameterization, ocean tide mid-modeling or GRACE orbit configuration), is still visible.
- Smallest influence of the de-aliasing product on mean geoid height differences is visible for May and February, largest for August and November.
- Comparisons with NIMA gravity anomalies and CLS-ECCO geoid heights show for short-wavelengths (2.5º and 5º resolution) a better mean agreement with MOG2D (~ 3-8 %) and OMCT (~ 2-8 %) than using the "standard" GRACE L1B PPHA model.
- Similar results are obtained when comparing daily times series of 10x10 degrees gravity field models, which have been derived without correcting short-term mass variations, with the candidate de-aliasing products. Again, best correlation and smallest residuals are obtained for MOG2D, followed by OMCT and PPHA.
- The study shows that the PPHA model may be substituted by MOG2D or OMCT. Nevertheless, a significant step to derive the GRACE baseline accuracy will not be made (formal gravity field errors are comparable, striping patterns remain).
- The most realistic assessment of the influence of different de-aliasing products on the GRACE product quality would be a comparison of the different gravity field products derived in this study with ocean currents or in-situ ocean bottom pressure data. This task could best be done by the GRACE Science Team.

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