Global Ocean Tide Models – Assessment of Errors and their Impact on GRACE gravity fields

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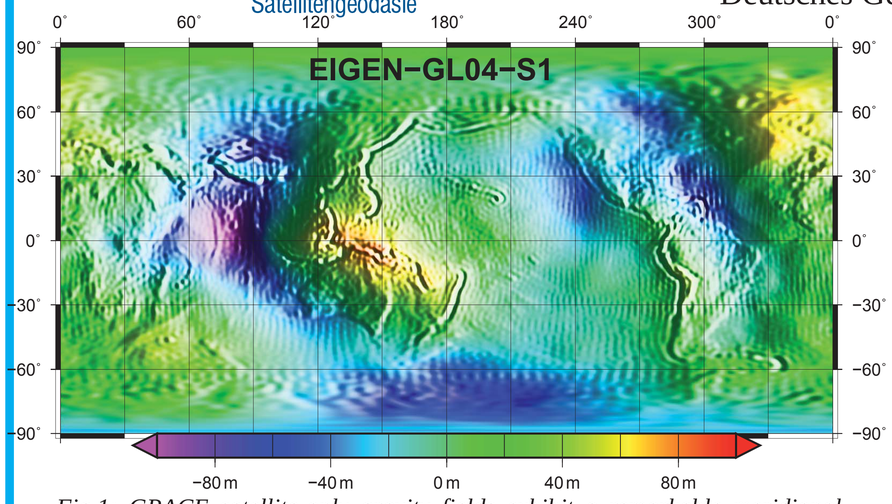

Fig.1: GRACE satellite-only gravity fields exhibit a remarkable meridional striping visible by illuminating the geoid from West. Errors of global ocean tide models are a possible cause for these artefacts

Objectives

The FES2004 ocean tide model performs rather well in open ocean but tides in shallow water area are significant less well known. Empirical analysis of cross-calibrated multi-mission satellite altimeter data can assess errors of global ocean tide models. A combined analysis with sufficient long time series from altimeters with different sampling characteristic has been performed on a nearly global 15' grid leading results for the constituents such as M2,S2,N2,K2,K1,O1,Q1,P1 and M4.
In shallow water areas the semidiurnal constituents exhibit significant regional error pattern with amplitudes of up to 15 cm. Diurnal constituents and the non linear effects like M4 can take amplitudes up to 5cm. The impact of these errors on the GRACE gravity fields is analyzed.

Data Pre-processing

The altimeter data listed in table 1 has been upgraded and harmonised by replacement of new orbits and correction models. The inverted barometer correction was replaced by the dynamic atmospheric corrections (DAC) produced by CLS Space Oceanography Division using the MOG2D model from LEGOS. To ensure consistency between all missions the radial error components estimated for a global multi-mission crossover analysis (Bosch 2007) have been corrected.

Table 1: Altimeter mission data used for the pesent analysis

Mission (Phase)	Cycles	Period	Source	Replacements
TOPEX/Poseidon	001-481	1992/09/23-2005/10/08	MGDR-B NASA	DAC, FES2004, SSB(Chambers), TMR repl. product
Jason1	001-135	2002/01/15-2005/09/14	GDR-B NASA/CNES	DAC, FES2004
ERS-1 (C & G)	083-101 144-155	1992/04/14-1993/12/20 1995/03/24-1996/04/28	OPR-V6 CERSAT	DAC, FES2004, DEOS orbits, pole tide, 1.5ms time bias
ERS-1 (D, E & F)	102-143	1993/12/25-1995/03/21	OPR-V3 CERSAT	DAC, FES2004, DEOS orbits, pole tide, 1.5ms time bias
ERS-2	000-085	1995/04/29-2003/07/02	OPR-V6 CERSAT	DAC, FES2004, DEOS orbits, pole tide, 1.3ms time bias
ENVISAT	009-040	2002/09/24-2005/09/19	GDR ESA/CNES	DAC, FES2004, DEOS GRACE based orbits
GFO	037-159	2000/01/07-2005/10/04	GDR NOAA	DAC, FES2004

Data Analysis

As the altimeter data is already corrected by the FES2004 ocean tide model a residual analysis is performed by estimating simultaneously mean value, trend, seasonal variations (annual and semi-annual periods), corrections to eight major tidal constituents (M2, S2, K2, N2, Q1, P1, K1, O1) and to the shallow water constituent M4. To mitigate the correlation problems the analysis is performed on a regular geographical 15'x15' grid. For every grid node normal equations are accumulated using all measurements inside a spherical radius of 1.5°. A Gauss function with half weight width of 0.5° is applied for weighting inverse proportional to the distance.

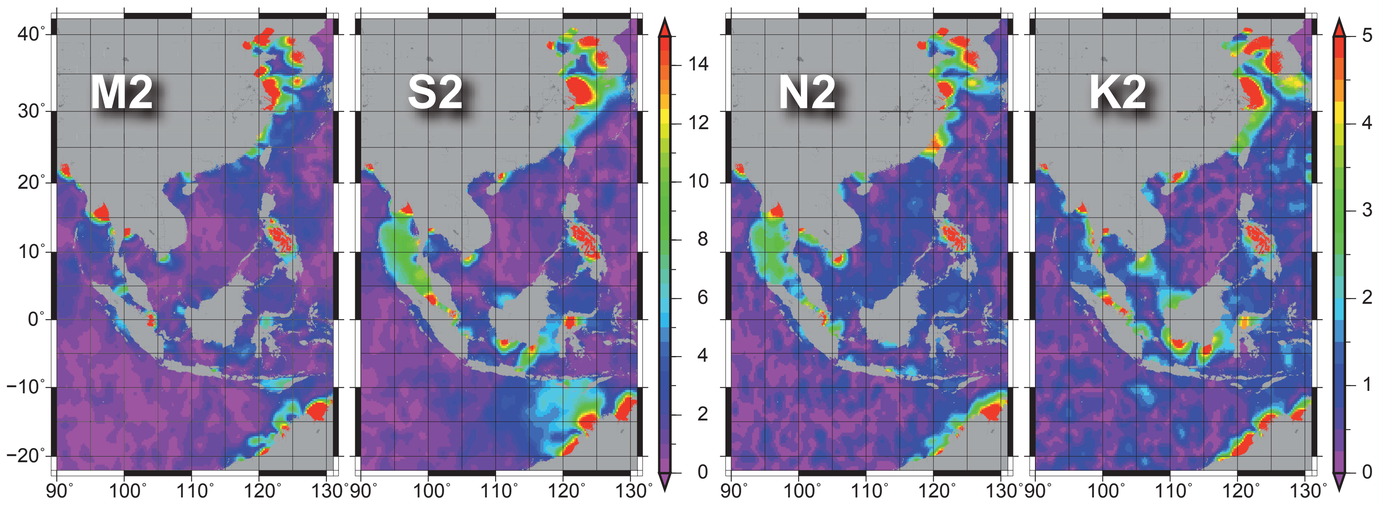

Fig. 2: Residual amplitudes (cm) of the semidiurnal constituents M2, S2, N2, K2. The amplitudes are residuals with respect to the FES2004 model used to correct the altimetry data. For M2 and S2 there are areas with residuals up to or even above 15 cm. For N2 and K2 the residual amplitudes go up to 5 cm (Note the different colour scale for M2,S2 and for N2,K2).

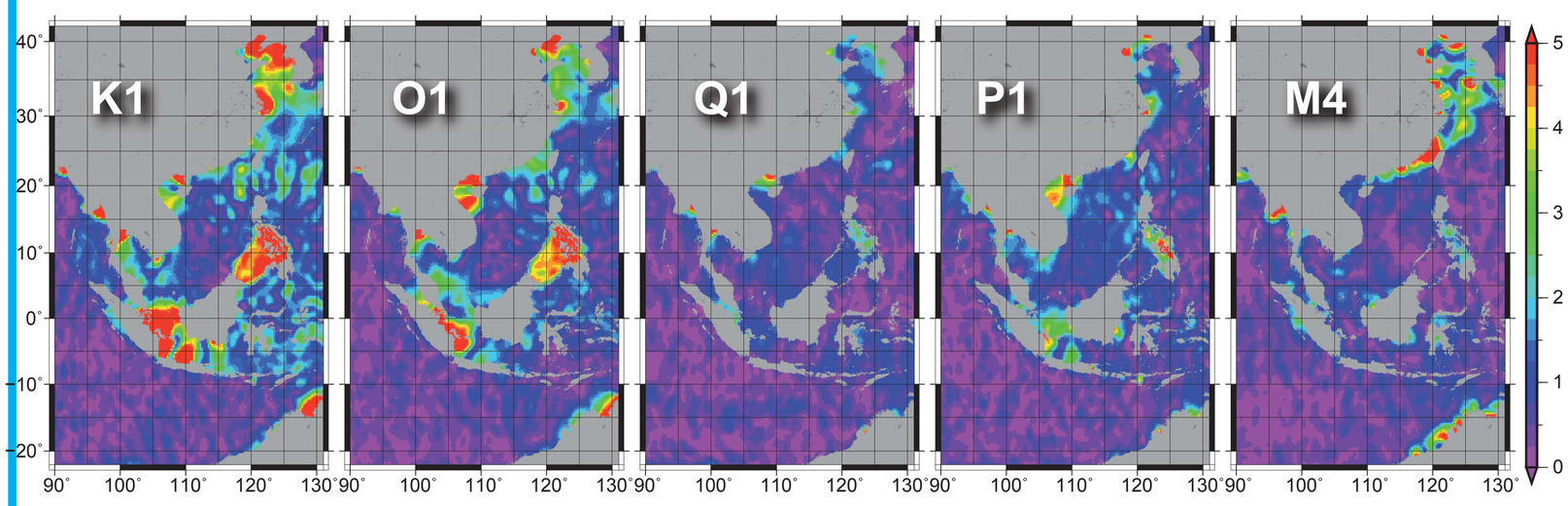

Fig. 3: Residual amplitudes (cm) of major diurnal constituents K1, O1, Q1, P1 and the shallow water constituent M4.

Validation

To validate the analysis results bottom pressure records for shallow water sites were used as provided by the British Oceanographic Data Centre BODC. In order to measure the improvements over the FES2004 model, the time series of the bottom pressure records were first reduced by tidal constituents of FES2004. In a second step the residual tide corrections of this analysis were subtracted. Figure 4 opposes the sea level variability before applying the second step with the reduction in variance achieved after applying the second step.

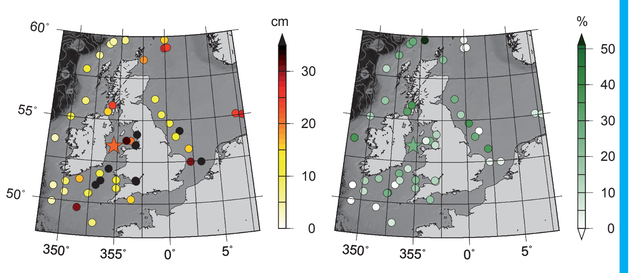

Fig. 4 Left: Standard deviation (cm) of sea level variability for the BODC bottom pressure gauges after subtracting the FES2004 tidal elevations. Right: The reduction in variance (in percent) achieved by applying the residual tide corrections. The gain in variance is up to 30 %.

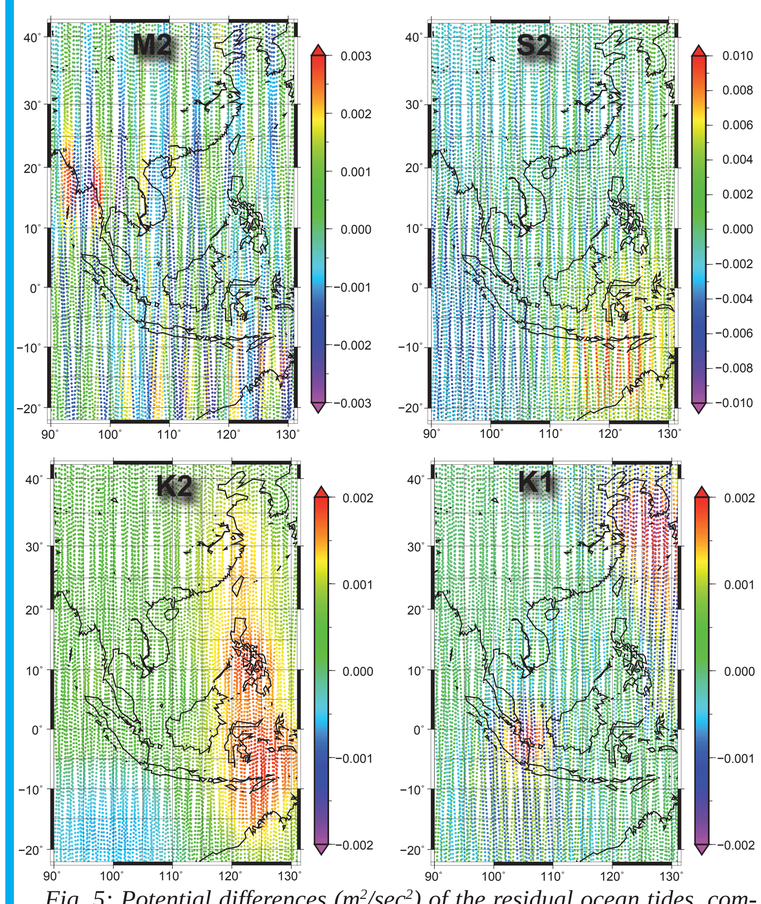

Fig. 5: Potential differences (m^2/sec^2) of the residual ocean tides, computed for the GRACE ephemeris in August 2003. For M2 (top left panel) the potential differences show a considerable track dependency similar to the meridional stripes of EIGEN-GL04S. The K2 errors (bottom left) and – to a lesser extent – also S2 and K1 map to a large scale pattern.

Impact on GRACE gravity fields

The impact of ocean tide errors on GRACE gravity field models depends on the sampling rate of GRACE and the periods of the individual constituents. Some constituents have severe alias effects with outstanding long alias periods (see Table 2). Errors of such constituents do not average out and are one by one mapped into the Earth gravity field.

Table 2 (courtesy of T. Mayer-Gürr): GRACE alias periods (days) for the most important tidal constituents.

	Sa	Ssa	Mm	Mf	Mtm	Msq	Q1	O1	P1	K1	2N2	N2	M2	S2	K2	M4
Sa	365	365	30	14	9	7	9	14	322	422	7	9	14	288	499	7
Ssa		183	32	15	10	7	10	15	2726	196	7	10	15	1363	211	7
Mm			28	27	14	10	14	27	33	28	9	14	27	33	28	9
Mf				14	28	15	27	2726	15	14	14	27	1363	15	14	13
Mtm					9	32	2726	28	10	9	27	1363	28	10	9	26
Msq						7	32	15	7	7	179	33	15	7	7	144
Q1							9	28	10	9	27	2726	28	10	9	26
O1								14	15	14	14	27	2726	15	14	13
P1									171	183	7	10	15	2726	196	7
K1										2726	7	9	14	171	2726	7
2N2											7	28	14	7	7	739
N2												9	28	10	9	27
M2													14	15	14	14
S2														161	183	7
K2															1363	7
M4																7

Conclusions

- The time series of TOPEX/Poseidon and Jason-1 altimetry are long enough for a reliable and accurate estimation of all major diurnal and semidiurnal tidal constituents.
- Although the data of ENVISAT, ERS and GFO missions are suboptimal for the tide analysis they essentially improve the spatial resolution.
- In the high latitudes areas (above 66°) the empirical tidal analysis is very difficult due to absence of TOPEX/Poseidon and Jason-1 data. The combination of ERS and GFO data alone doesn't lead to the essential decorrelation of the most problematical tidal constituents such as S2 and K1.
- The comparison with independent bottom pressure records at the North-West European shelf proves that the presently available time series of multi-mission altimetry data can significantly improve state-of-the-art global ocean tide models in shallow water areas.

References

Lyard, F., F. Lefèvre, T. Letellier and O. Francis, 2006, Modelling the global ocean tides: a modern insight from FES2004. *Ocean Dynamics*, 56, 394-415.

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