Empirical ocean tide analysis of cross-calibrated multi-mission altimeter data

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Abstract: The capability to empirically estimate ocean tides from satellite altimetry data suffers from the large ground track spacing and the satellites repeat cycles leading to severe alias effects. The spatial sampling can be improved by combining data from altimeter satellites with different ground track pattern. Different orbit imply however different capability to de-alias and separate dominant tidal constituents. This turns into an advantage if the tidal analysis combines multi-mission altimeter data carefully cross-calibrated in advance by a global adjustment of nearly simultaneous crossover events. We consider the tidal analysis on a dense system of grid points and investigate to what extend it is possible to de-correlate major tidal constituents.

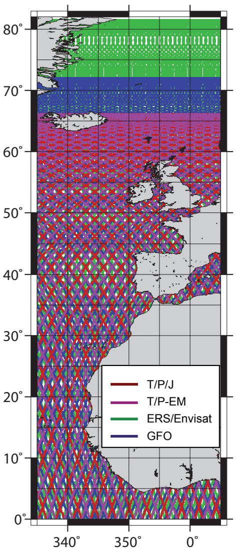

Fig. 1: The area of investigation with the subsatellite tracks of TOPEX/Poseidon and Jason1 (T/P/J in red), the shifted ground tracks of TOPEX/Poseidon extended mission (T/P-EM in purple), of ERS-1/2 and ENVISAT (ERS/ENVISAT in green) and of GFO in blue.

Table 1: Altimeter mission data used for the present 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 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.

Data Analysis: As the altimeter data is already corrected by the FES2004 ocean tide model a residual ocean tide 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 1.125°. A Gauss function with half weight width of 0.375° is applied for weighting inverse proportional to the distance.

Results of residual tidal analysis

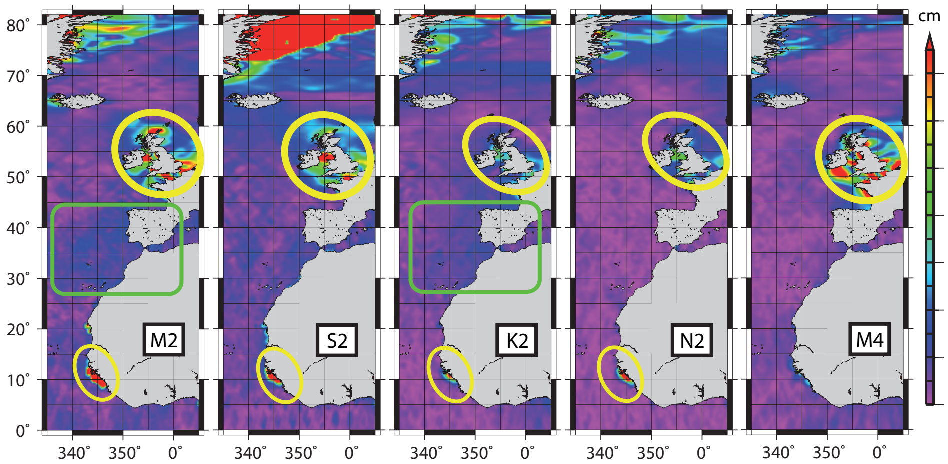

Fig. 2: Residual amplitudes (cm) of major semidiurnal constituents (M2, S2, K2, N2) and the shallow water constituent M4. The yellow ellipses indicate areas with significant residuals (up to or even above dm level). The green rectangles point to areas with large scale pattern of residuals with 1-2 cm amplitude.

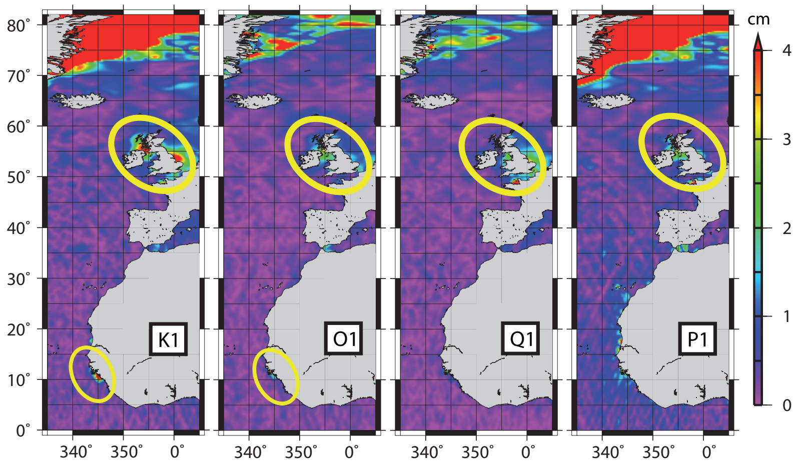

Fig. 3: Residual amplitudes (cm) of major diurnal constituents (Q1, P1, K1, O1). The yellow ellipses indicate areas with residuals up to five centimetres. Note, the colour scale for amplitudes differs from the color scale of Fig.2

Validation: To validate the analysis results bottom pressure records for shallow water sites were used as kindly 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.

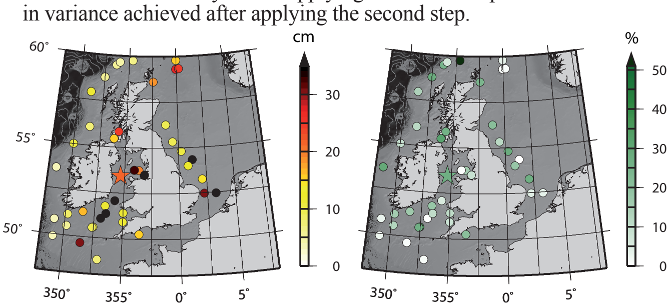

Fig. 4 Left: Standard deviation (cm) of sea level variability for the BODC bottom pressure gauges after subtracting the FES2004 tidal elevations. Right: The reduction in variance (in percent) achieved by applying the residual tide corrections. The gain in variance is up to 30 %.

Correlation analysis

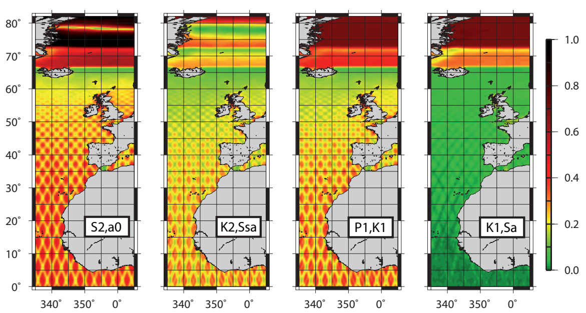

Fig. 5: Geographical distribution of the correlations between the most problematic tidal constituents S2 , K2, P1, and K1 and mean sea surface (a0), annual (Sa) and semiannual (Ssa) variations of sea surface.

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.

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