

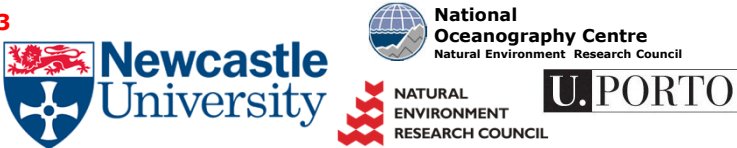
Anomalous tidal loading signals in South-West England and Brittany

Maxim Keshin¹, Nigel Penna¹, Peter Clarke¹, Machiel Bos², Trevor Baker³

¹School of Civil Engineering and Geosciences, Newcastle University, NE1 7RU, UK

²CIIMAR, University of Porto, Ruados Bragas 289, 4050-123 Porto, Portugal

³National Oceanography Centre, 6 Brownlow Street, Liverpool, L3 5DA, UK



Introduction

Uncertainties in the knowledge of tidal deformation of the Earth may affect apparent non-linear motions. In this work we investigate anomalous tidal signals of about 3 mm magnitude detected for GPS stations in South-West England and Brittany. We considered 40 mainly coastal European stations (see Fig. 1) with at least a 2 year observation record, and at which M2 OTL height inter model agreements were sub-mm (Fig. 2). We grouped these stations as follows: 1. **SW England** and 2. **Brittany** where anomalous signals were discovered; 3. **Iberia** (large OTL, near deep oceans, straight coastline, excellent inter-model agreement); 4. **Biscay** to assess the extent of any transitional zone between Brittany and Iberia. In addition, 6. Stations in **Inland Europe** were added due to similar latitude to SW England to check for possible Earth body tide model errors. All 5 groups are encircled by ellipses of different colours in Fig. 1.

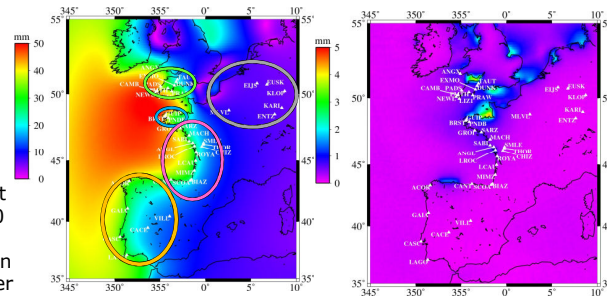


Figure 1. M2 OTL height displacement amplitudes across the area of interest together with the 40 GPS sites (encircled by ellipses, see Introduction) considered in this work.

Figure 2. RMS error of M2 OTL height displacement amplitudes across the area of interest computed using 5 modern ocean tide models: GOT00.2, CSR4.0, NAO.99b, FES2004, TPX07.1.

Results

The results of OTL displacement harmonic estimation for the 40 GPS stations grouped in 5 regions are shown in Tab. 2 and Fig. 4. Anomalous M2 tidal signals of about 3 mm were detected for the stations located in South-West England and Brittany. The Iberia stations with similar OTL magnitudes, have residuals of about 0.7 mm, comparable with the Inland Europe stations at which M2 OTL is small. This also indicates that the anomalies cannot be explained by Earth body tide model errors. The stations near to the Bay of Biscay show transitional behaviour between these 2 regions. The harmonic strategy results are systematically slightly larger than the kinematic results (at some stations by up to 0.2-0.3mm), which may be caused by the fact that several parameters are modelled using the same type of stochastic process (random walk) in the kinematic processing. In this case some energy may leak out of the original amplitude spectrum. The results of the assessment of the OTL contributions of different areas for M2 at Newlyn (South-West England) presented in Fig. 5 show that the areas around Newlyn and the Celtic Sea are dominant for loading in the South-West England and Brittany. Tab. 3 shows M2 vector differences for tide gauges in these 2 areas with FES2004 model. The differences for the 6 Celtic Sea tide gauges represent typical agreement between FES2004 and tide gauges in that area. The tides were modelled on a fine grid of 0.05°x 0.05°. The bathymetry was taken from the ETOPO1 global relief model of Earth's surface. The results reveal 1 to 2% level of agreement for FES2004 with the majority of the tide gauges and provide some evidence that errors in the ocean tide models may not explain the anomalous signals (7-8% of the expected signal) observed in the GPS data.

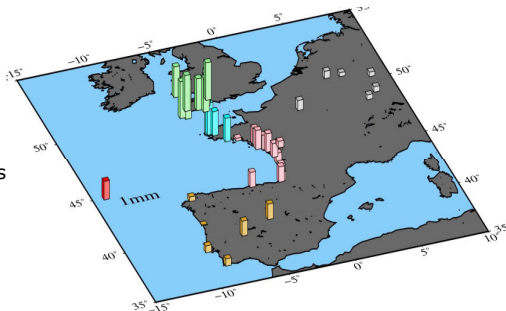


Figure 4. GPS-FES2004 M2 OTL height displacement vector differences, in mm, for the 40 GPS stations considered. The residual harmonic strategy GPS results have been used.

Location	St.Mary's	Newlyn	1.1.5	1.1.6	1.1.12	1.1.55	1.1.57	1.1.85
cm(%)	7(4)	2(1)	2(1)	2(1)	3(3)	4(2)	1(1)	1(1)

Table 3. Vector differences for 2 tide gauges in South-West England (Newlyn and St.Mary's) and 6 tide gauges in Celtic Sea with FES2004 global ocean tide model for harmonic M2. Agreement level in % for the model with tide gauges has been given in brackets.

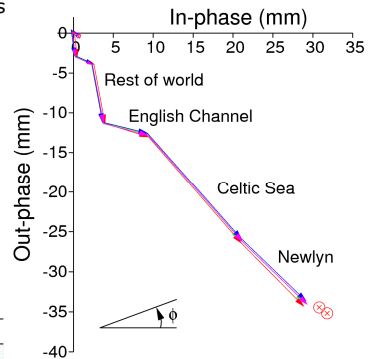


Figure 5. Phasor plot of the OTL contributions of the several surrounding seas for M2 height displacement at Newlyn (SW England) using FES2004, EOT08, TPX07.2 and GOT4.7 models. GPS values are shown by the red crosses.

Conclusions and Future Work

- ◆ We found anomalous tidal signals of about 3 mm for GPS stations in South-West England and Brittany by using three different strategies of GPS OTL displacement estimation. We obtained excellent (about 0.1 mm RMS, except for K1 and K2) agreement between all three strategies. It suggests that our GPS analysis robustly detects actual tidal displacements;
- ◆ We compared tide gauges in South-West England around Newlyn and the Celtic Sea with recent global ocean tide models. The comparison results demonstrated a good agreement (at the 1-2% level) between the models and the majority of tide gauges in these areas. Therefore, the ocean tide model uncertainties are most likely too small to explain the observed anomalous tidal signal;
- ◆ As a next step, we plan to investigate whether the anomalous tidal signals are caused by errors in the displacement loading Green's function due to the nearby continental shelf.

References

Thomas et al (2007), *J Geod.*, 81:359-368

Acknowledgements

We thank JPL for GIPSY 5.0 software and providing reprocessed orbits and clocks. The GPS data were gratefully obtained from the EUREF and NERC BIGF (www.bigf.ac.uk) holdings.

GPS OTL Displacement Estimation

- ◆ 3D harmonic site motion was estimated for 8 principal diurnal (K1, O1, P1, Q1) and semi-diurnal (M2, S2, N2, K2) tidal constituents;
- ◆ GPS data available from 2002.0 to 2010.0 were taken;
- ◆ GIPSY-OASIS II 5.0 software in PPP mode using reprocessed JPL orbits and clocks;
- ◆ 7 degree elevation cut-off with the VMF1 mapping function;

	Total harmonic	Residual harmonic	kinematic
Estimated quantity	Total OTL displacement	Residual OTL displacement	Residual amplitude spectrum (the Lomb-Scargle periodogram method)
Processing	24-h PPP batch	24-h PPP batch	Kinematic PPP
A priori OTL model	none	FES2004	FES2004
Minor tides	Applied to combined yearly OTLD batch solutions (Thomas et al, 2007)	Removed using hardisp.f from IERS Conventions	Removed using hardisp.f from IERS Conventions

Table 1. Summary of the three strategies used for GPS OTL displacement estimation.

We used three GPS OTL estimation strategies to validate the quality of GPS estimates (see Tab. 1). Two strategies represent harmonic displacement estimation using GIPSY's static PPP mode. The kinematic approach is used for validation of the harmonic estimation results and evaluation of the time series noise. The results obtained with the GPS strategies are shown in Tab. 2. An example of kinematic GPS residual amplitude spectrum for station NEWL in Newlyn, South-West England, is shown in Fig. 3. In general, we obtained excellent agreement between all three strategies (about 0.1 mm RMS, except for K1 and K2), and for Iberia and Inland Europe, these agree with the FES2004 model displacement to about 0.7 mm.

	total harmonic	residual harmonic	kinematic
SW England	3.39	3.25	3.27
Brittany	2.34	2.26	2.20
Biscay	1.24	1.18	1.18
Iberia	0.72	0.73	0.64
Inland Europe	0.69	0.63	0.67

Table 2. GPS-FES2004 M2 height RMS misfits (mm) of all stations per geographical group for the three GPS OTL estimation strategies.

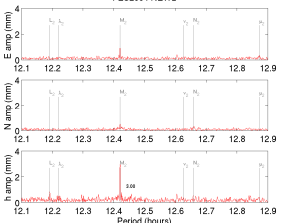


Figure 3. Kinematic GPS residual amplitude spectrum for station NEWL (Newlyn, South-West England) after applying the FES2004 model.