GPS estimation of anomalous tidal loading displacements

Maxim Keshin[1], Nigel Penna[1], Peter Clarke[1], Machiel Bos[2], Trevor Baker[3]

[1] School of Civil Engineering and Geosciences, Newcastle University, UK • [2] CIMAR/CIIMAR, University of Porto, Portugal • [3] National Oceanography Centre, Liverpool, UK

1. Introduction

Uncertainties in the knowledge of tidal deformation of the Earth may be a source of both direct and propagated periodic errors in GPS geodesy. Deformation at tidal periods consists of two parts: that due to direct gravitational attraction of the Sun and Moon (the solid Earth tides), and that due to surface mass loading by the ocean tides (ocean tide loading [displacement], or OTL[D]). Our aim is to investigate systematic regional and global differences between actual and predicted tidal displacements which may indicate errors in ocean tide or Earth models. As a first step, we validate GPS 3D harmonic site motion estimates for stations in Europe.

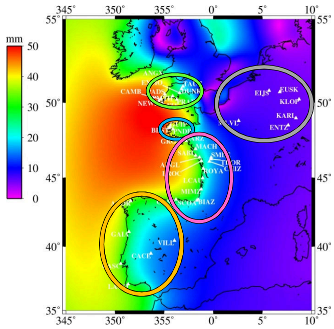

Figure 1. M2 OTLD height amplitudes across the area of interest together with the 40 GPS sites (grouped by ellipses, see text) used in this work.

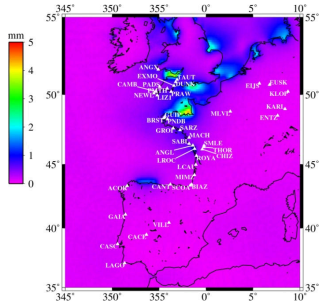

Figure 2. RMS error of M2 OTLD height vector differences across the area of interest computed using five modern ocean tide models: GOT00.2, CSR4.0, NAO.99b, FES2004, TPXO7.1.

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 we discovered anomalous tidal signals; [3] Iberia (large OTL, near deep oceans, straight coastline, excellent inter ocean tide model agreement); [4] Biscay to assess the extent of any transitional zone between Brittany and Iberia. In addition, stations in [5] Inland Europe were added at similar latitude to SW England to check for possible Earth body tide model errors. Groups are indicated by ellipses of different colours in Fig. 1.

2. 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;
- All available GPS data from 2002.0 to 2010.0 were used;
- GIPSY-OASIS II 5.0 software in PPP mode using reprocessed JPL orbits and clocks;
- Earth body tides modelled according to the IERS 2003 Conventions
- 7 degree elevation cut-off with the VMF1 mapping function;

	Total harmonic	Residual harmonic	Kinematic
Estimated quantity	Total OTL site displacement	Residual OTL site displacement	Residual amplitude spectrum (Lomb-Scargle periodogram)
Processing	24-h PPP batch	24-h PPP batch	Kinematic PPP
A priori OTL model	none	FES2004	FES2004
Minor tides	Nodal corrections are applied to combined yearly OTLD solutions	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 (Table 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.

3. Comparison of the estimation strategies

The results obtained with the GPS strategies are shown in Table 2. In general, we obtained excellent agreement between all three strategies (about 0.1 mm RMS, except for K1 and K2 which are aligned with the GPS satellite orbital period), and for Iberia and Inland Europe, these agree with the FES2004 model displacement to about 0.7 mm. The harmonic strategy results are systematically slightly larger than the kinematic results at some stations (by up to 0.2-0.3 mm), 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. An example demonstrating this phenomenon for station NEWL in Newlyn, South-West England is shown in Figures 4-6.

	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.

4. Anomalous tidal signals

The results of OTL displacement harmonic estimation for the 40 GPS stations grouped in five regions are shown in Table 2 and Fig. 3. 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 two regions.

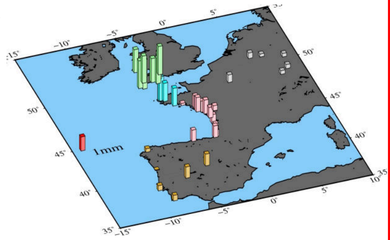

Figure 3. GPS-FES2004 M2 OTL height displacement vector differences, in mm, for the 40 GPS stations considered. The residual harmonic strategy GPS results have been used.

5. Harmonic and kinematic GPS results for station NEWL

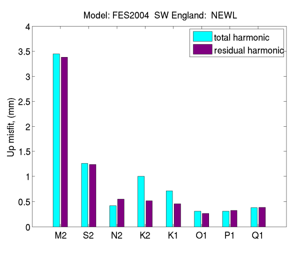

Figure 4. GPS (total and residual harmonic estimation) minus FES2004 misfits for station NEWL (Newlyn, SW England). GPS formal errors are typically 0.4-0.5mm (except for K2 and S2).

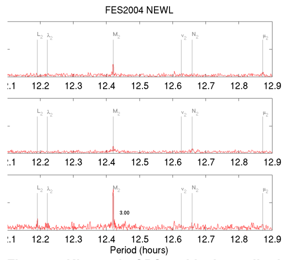

Figure 5. Kinematic GPS residual amplitude spectrum for station NEWL (Newlyn, SW England) after applying the FES2004 model.

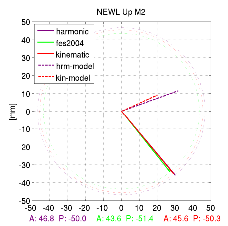

Figure 6. Phasor GPS vs FES2004 plot for station NEWL (Newlyn, SW England). Phasors of the vector differences are plotted with a magnification factor of 10.

Harmonic and kinematic GPS results for station NEWL in Newlyn, South-West England are shown in Fig. 4, 5 and 6. As seen from the plots, the harmonic results for the M2 constituent show marginal excess over the kinematic results obtained using the Lomb-Scargle periodogram method. Nonetheless, the three estimation strategies consistently show the presence of anomalous M2 tidal signals.

6. Summary

When performing validation of GPS harmonic site motion estimates for European stations, we found anomalous tidal signals of about 3 mm for GPS stations in South-West England and Brittany. We investigated them by using three different strategies of GPS OTL displacement estimation. Excellent (about 0.1 mm RMS, except for K1 and K2) agreement between all three strategies was obtained. It suggests that our GPS analysis robustly detects actual tidal displacements. Comparisons with tide gauges were made to assess the ocean tide model errors in the region considered to check whether the errors in the ocean tide models can explain the discrepancies observed in the GPS data. The results of these comparisons as well as some geophysical implications of our findings are discussed elsewhere in this workshop (Bos *et al*., oral presentation).

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. This work was funded by NERC grant NE/C003438/1.