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Anomalous tidal loading signals in South-West England and Brittany

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The tidal deformation of the Earth, including ocean tide loading (OTL), sheds light on the Earth's internal structure. Uncertainties in the knowledge of this deformation may be a source of both direct and propagated periodic errors in GPS geodesy. The increasing number of global GPS stations with long histories of observations, as well as recent developments in precise GPS geodesy such as the availability of reprocessed satellite orbits, enables further study of these geophysical and geodetic phenomena.

There are more than 10 worldwide regions where OTL displacement amplitudes exceed 25mm. In our work we considered one such region covering South-West England and stretching southward along the coasts of France, Spain and Portugal. Estimates of three-dimensional harmonic site motion at each of the principal diurnal (K1, O1, P1, Q1) and semi-diurnal (K2, M2, N2, S2) frequencies were obtained for 40 European stations with at least 2 year observation span, using the GIPSY-OASIS II software package with reprocessed precise satellite orbits from JPL. All GPS data available from 2002.0 to 2010.0 were considered. 34 stations were situated close to the Atlantic coast; a further 6 inland stations at similar latitudes were processed as a check on solid Earth tide models. Inter-model OTL displacement differences are small, especially for the inland sites; the problematic Bristol Channel area of South-West England was excluded.

We validated the quality of our GPS estimates by using and comparing three different analysis strategies:

(1) Harmonic estimation of total tidal displacement in 24-hour Precise Point Positioning (PPP) batch solutions: harmonic displacements are estimated per coordinate component for each of the eight principal tidal constituents. OTL is not modelled a priori, and nodal corrections are applied in post-processing after combination of the daily results;

(2) Harmonic estimation of residual tidal displacement in 24-hour PPP batch solutions: OTL is modelled a priori using the FES2004 model in the reference frame of the whole Earth system (CM); the residual harmonic displacements are estimated per component per principal tidal constituent. Minor tidal harmonics are removed a priori using the routine "hardisp" by D. Agnew. Because of this, post-processing nodal corrections are not applied;

(3) Amplitude and phase from kinematic PPP processing: kinematic GPS processing with a priori OTL modelling using FES2004 and hardisp as in (2); amplitude spectra are later estimated from the entire coordinate time series using the Lomb-Scargle periodogram method.

We typically obtain excellent (0.3-0.7mm except for the K1 and K2 constituents) phasor agreement between all three strategies, comparable to the inter-model agreement between computed OTL displacements and suggesting that the GPS analysis strategy robustly detects actual tidal displacements. For sites in inland Europe where computed OTL displacements are less than 10mm with inter-model differences of less than 0.2mm, residual harmonic amplitudes are also at the 0.3-0.7mm level, confirming that solid Earth tides are modelled to at least this accuracy.

For GPS stations located in South-West England and Brittany, onshore of the continental shelf, anomalous residual tidal signals were detected of about 2-3mm magnitude for the vertical M2 OTL constituent (10% of the expected signal). In contrast, sites in the Iberian Peninsula, with similar expected OTL magnitudes, have residuals at the expected 0.3-0.7mm level. Sites near to the Bay of Biscay show transitional behaviour between these regimes. Therefore at these locations, the different modern ocean tide models that agree very well must all either be systematically in error, or the difference in behaviour may be caused by errors in the displacement Green's functions applicable to loads on the nearby continental shelf.