UNIVERSITY OF NEWCASTLE UPON TYNE

# Ocean Tide Loading in the British Isles


**Craig Allinson, Peter Clarke, Stuart Edwards, Matt King** School of Civil Engineering and Geosciences, University of Newcastle upon Tyne, UK • email c.r.allinson@ncl.ac.uk

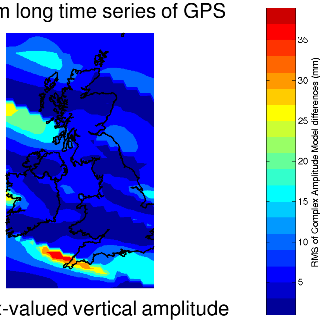
**Paul Cruddace** Ordnance Survey, Southampton, UK

**Trevor Baker** **Proudman** Oceanographic Laboratory, Liverpool, UK


## Introduction

Model predictions show that the range of deformation due to ocean tide loading (OTL) can be as large as 10cm's in the British Isles. The effects of an intricate coastline and interaction of tides between the open ocean and the more restricted nearby seas also make OTL large in uncertainty. We therefore seek direct observations of OTL displacements in the British Isles from long time series of GPS measurements.

Our estimates of OTL will be compared to predictions calculated from a range of various ocean tide models[1]. Our OTL estimates will then be used to help to validate, or refine these models, and to provide direct calibration for future short-term GPS measurements.




The figure above, shows the complex-valued vertical amplitude difference of the $M_2$ constituent from the FES99, FES95.2, CSR3.0, TPXO.2 and GOT.002 models. Discrepancies are shown to be as large as 35mm in SW England.

## Methods

The aim is to estimate the principal semi-diurnal and diurnal OTL components at each GPS station in the British Isles network (~60 GPS stations), estimating both the phase and amplitude for the vertical, north and east components, using the following method:

- Precise Point Positioning method used with the GIPSY/OASIS II software[2], using a 1000-day span of GPS data we processed each location and each RINEX file (24-hours) independently.
- To attain high accuracy, we minimise/model inaccuracies in the GPS measurement.
  - Model tropospheric ZWD as a random walk parameter.
  - Model Earth and pole tides[3].
  - Use JPL precise orbits, 10˚ elevation mask.

We then combined the multiple-day solutions using an iterative least-squares Kalman filter approach to produce the 'final' 1000-day estimates

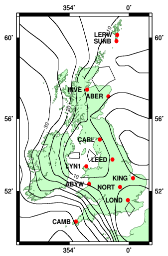
- Use covariance information to improve parameter estimates.
- Apply correct weight to covariance matrices, by calculating the variance factors in an iterative solution.
- Apply astronomical arguments and nodal corrections[4].

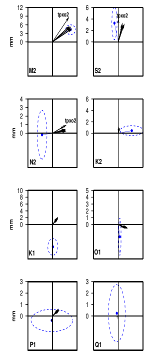
Current progress – data from 12 GPS sites has been processed so far (see location map, opposite).

## Results

The 1000-day estimates (shown in phasor plot format, below) have provided us with the following:

- Good agreement with model results for the larger magnitude constituents.
  - $M_2$ amplitude misfit of ~0.7mm (7% of the total signal) from the FES99 OTL model.
- Larger misfit values among the smaller magnitude constituents, especially in the phase component.
  - Phase misfits in excess of 100˚ for $P_1$ and $Q_1$, and remain 10-40˚ for $K_1$, $K_2$ and $O_1$.
  - $N_2$ shows a very large, unexpected phase misfit (~180˚), which has so far not been explained.
  - Estimates agree best with the FES99 OTL model, and worst with the TPXO.2 model.




**Location Map**. The location of 12 continuously operating GPS receivers used to directly measure OTL in the British Isles. The contours show the vertical $M_2$ OTL amplitude (mm), predicted by the FES99 OTL model.

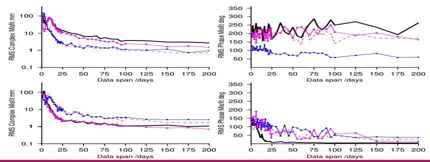
**Phasor Plots**. Phasor plots produced for the LEED station, showing our 1000-day GPS estimates for the vertical OTL semi-diurnal and diurnal components. Estimate results are shown in blue circles, with associated 95% confidence error ellipses. Predicted results for each component (arrows) are from the FES99, FES95.2, CSR3.0, GOT00.2, TPXO.2, TPXO.6 and NAO.99b models.

**Convergence Graphs** (opposite). Results from the LEED site, showing N-day RMS misfit relative to the 'true' 1000-day GPS estimates. Graphs read (from bottom left, clockwise): semi-diurnal complex-valued amplitude misfit, diurnal complex-valued amplitude misfit, diurnal phase misfit and semi-diurnal phase misfit.

## Data Span Study

OTL estimates were produced using the same GPS processing strategy, but with N-days of data in the solution (where N = 1,2,3...25,-30,35..100,125,150…200). The aim of this was to establish how much data is required to sufficiently estimate the OTL parameters from GPS observations.

- For the larger magnitude components the complex-valued amplitude converge with ~90-days GPS observation ($M_2$, $S_2$, $N_2$ and $O_1$).
- Smaller magnitude components, mostly diurnal components ( $K_1$, $Q_1$, $P_1$ and $K_2$), do not converge during the 200-day period.
  - The phase component is the most difficult to estimate accurately, with the diurnal constituents showing no signs of convergence.
  - Tests have shown that in excess of 2000-days are required for a sufficient level of resolution for these constituents.




The lower, semi-diurnal, graph symbols are: black line = $M_2$, red line = $S_2$, blue line = $N_2$, and pink line = $K_2$. The upper, diurnal, graph symbols are: black line = $K_1$, red line = $O_1$, blue line = $P_1$, and pink line = $Q_1$.

## Conclusion

- Kalman filter estimation method requires a minimum of ~90-days for sufficient resolution of the larger magnitude semi-diurnal and diurnal constituents.
  - Test results show that the accuracy associated with these estimates should be ~10% of the long-term value.
- The 1000-day results have shown good resolution for $M_2$, $S_2$ and $O_1$
- For a similar resolution, at least 2000-days of GPS observation are required for the $K_2$, $K_1$, $P_1$ and $Q_1$ constituents
- $N_2$ constituent has unexpected large misfit – not yet explained.

## References


1. Agnew, D.C., NLOADF: A program for computing ocean-tide loading, J. Geophys. Res., 102, 5109-5110, 1997.
2. Zumberge et al., 1997
3. Melchior, P., The Earth Tides, 114 pp., Pergamon Press, New York, New york,1996.
4. McCarthy, 1996;
5. Godin, G., The Analysis of tides, 264 pp., University of Toronto Press, Toronto, 1972.