Choice of Basis Functions for the Representation of Seasonal Surface Loading Signals in Geodetic Time Series

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1. Introduction

Forward modelling of geodetic site displacements is frequently performed using gridded surface mass datasets and a Green's function approach, but because these Green's functions are reference frame dependent, it may be difficult to account properly for the effects of geocenter motion (Blewitt, 2003).

Spherical harmonic representation allows the transparent use of the correct reference frame independent Love numbers and so does not suffer from this drawback, but fine-scale (higher-degree) resolution becomes unattainable due to the compact-ocean distribution of geodetic displacements (Wu et al., 2003, 2004; 2006). A further problem, which affects both these methods but is readily correctable using the spherical harmonic approach, is the appropriate treatment of mass conservation and of the ocean-ecliptic relative to the gravitational attraction of the Earth's core.

The aim of this poster is to show how a modified set of basis functions derived from mass-conserving, tidally-equilibrated, land-based spherical harmonics can be used to overcome some of these limitations, and to discuss other possible representations of the data.

2. Forming the basis functions

It is apparent from Figure 1 that the variability in the total continental load is far greater than that over the oceans. If standard spherical harmonics are used as basis functions, much of the information content is “wasted” in maintaining a smooth oceanic load. When inverting GPS displacement data for Earth's (true) load, little of this information content is available, so the solution becomes unstable, even at low degrees, unless a priori oceanic constraints are applied (e.g. Wu et al., 2003). Moreover, the variability in oceanic load is predominantly due to the equilibrium tidal response to the land load, not that due to other changes in the ocean.

We form basis functions \( B'(\Omega) \) by masking standard spherical harmonics \( Y_{nm} \) (with oceanic constraints \( C'(\Omega) \)) as shown in Figure 2. We then correct the raw (land-only) \( B'(\Omega) \) by adding an oceanic term \( C''(\Omega) \) to enforce global mass conservation and to allow the ocean to respond to the land load only.

3. Testing goodness of fit

(a) Gridded surface mass data

We test the efficiency of our basis functions by fitting them to a synthetic dataset formed from ECCO ocean bottom pressure data (http://www.ecco-group.org), continental atmospheric pressure data from the NCEP reanalysis (Kalnay et al., submitted, 2004) and land hydrology from either the LaD (Milly & Shmakin, 2002) or CPC (Fan & van den Dool, 2004) models, summed and corrected to enforce global conservation of mass and self-consistency (Clarke et al., submitted, 2004).

As seen in Figure 7, goodness of fit at the sample locations does not necessarily imply global fidelity to the “true” signal. Because we are using a synthetic dataset, we can test the fidelity of our fit by comparing the actual (synthetic) gridded displacements with those generated from our fitted basis functions. This allows us to compare the network base that occurs when using our basis functions with the basis that occurs when using spherical harmonics. We generally see poor variance reduction at the sample locations due to the bias in sampling the higher degree coefficients are worse, on the other hand, we are under-representing the data. Conversely, at high degrees the variance reduction is poor or even negative, because of oscillatory behaviour in unconstrained regions. Our basis functions lead to a far better global fit to the “true” signal, because they incorporate a plausible physical model of oceanic behaviour whilst allowing the land load to vary in a model-independent manner.

4. Testing global fidelity of fit

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5. Discussion and conclusions

We have demonstrated that a physically reasonable set of basis functions, derived from spherical harmonics, can be used to represent the seasonal variation in surface mass and associated displacements of the solid Earth. Our representation achieves better fit to realistic synthetic data than does a spherical harmonic fit with the same degree of freedom, is more robust to the biasing effect of network geometry, and is less prone to oscillation in unconstrained regions. The basis functions directly incorporate the physics of reference frame definition, conservation of mass, and equilibrium ocean response to the land load, whilst parameterising the land load in a model-independent way. A spherical wavelet or spherical cap harmonic representation might achieve a more detailed regional fit where data are available, but would lack most of these advantages.

References


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