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Geophysical analysis of zonal tidal signals in length of day

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SUMMARY

The Earth's zonal response coefficient κ is estimated from the tidal signals in the observed length-of-day (LOD) data. Its magnitude and phase are functionals of the Earth's internal structure and dynamics. In this paper, an analysis of 13 years of precise LOD data (1980–1992) reveals strong signals for nine zonal tidal groups ranging from 5 to 35 days in period. Numerical estimates of κ for 27 major tides are thus obtained, 11 among which are considered sufficiently high in signal-to-noise ratio to provide meaningful geophysical constraints on the Earth's rotational dynamics. The results favour a κ magnitude close to, but somewhat smaller than, 0.315, which is the theoretical value for an elastic mantle completely decoupled from the fluid core plus equilibrium oceans. A small amount of dispersion is also detectable, where shorter periods tend to have lower κ magnitude and larger phase lag. Our κ magnitude estimates are consistent with two recently published non-equilibrium ocean-tide models and an anelastic response in the mantle, although an equilibrium response in the ocean and a purely elastic response in the mantle is not disallowed. Phase lags of a few degrees are required by both ocean-tide models, and by our data.

Key words: Earth's rotation, length of day, ocean tides, solid tides.

1 INTRODUCTION

The rotational speed of the solid earth varies slightly with time, causing variations in the length of day (LOD). Precise measurements of LOD in the last three decades have revealed variations on time-scales ranging from decadal, interannual, seasonal, intraseasonal, down to days and (recently) sub-daily. Apart from a secular 'braking' (e.g. Lambeck 1980) and small semidiurnal librations (Chao *et al.* 1991) due to external luni-solar tidal torques, LOD varies as a consequence of internal geophysical mass movements under the conservation of angular momentum. These mass movements occur in all components of the Earth: atmosphere, hydrosphere, solid mantle and fluid core.

In particular, as first pointed out by Jeffreys in 1928, LOD will change as a result of changes in the Earth's axial moment of inertia caused by zonal tidal deformations in the Earth. The amount of tidal deformation, under given forcing, depends on the Earth's physical structure and dynamical behaviour. The response of an elastic, spherically symmetric earth to external forcings is described by a set of transfer functions, namely Love numbers, which are dimensionless gross-Earth functionals. Among them only the second-degree zonal potential raised by the luni-solar tides is of concern here. Such a tidal potential induces a second-degree zonal response in a spherically symmetric earth; and only such response can affect LOD via conservation of angular momentum, as all other harmonics are 'orthogonal' to ΔLOD. The induced ΔLOD in an elastic, spherically symmetric earth is thus proportional to the second-degree zonal transfer function, or the Love number k_2.

The concept of the transfer function can be extended naturally to include other dynamic behaviour of the Earth in the geophysical excitation of ΔLOD. Called the zonal response coefficient κ (as a function of frequency ω) by Agnew & Farrell (1978), it is defined as the ratio of the fractional change in LOD to the prescribed second-degree zonal tidal potential normalized with respect to the Earth's surface gravitational potential:

$$\frac{\Delta\mathrm{LOD}(\omega)}{\mathrm{LOD}} = -\kappa(\omega)\frac{\sqrt{5}}{3\sqrt{\pi}}\frac{a^3}{GC}V_2(\omega), \tag{1}$$

where G is the gravitational constant, a is the Earth's mean radius and C its axial moment of inertia, and the prescribed tidal potential equals the tidal potential amplitude V_2 multiplied by the fully normalized surface spherical harmonic Y_{20}.

If the Earth were entirely elastic, then its κ would be identical to the (static) k_2. This can be seen from the