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EARTH ROTATION AND CORE TOPOGRAPHY

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The NASA Geodynamics program has as one of its missions highly accurate monitoring of polar motion, including changes in length of day (LOD). These observations place fundamental constraints on processes occurring in the atmosphere, in the mantle, and in the core of our planet. Short-timescale ($t \lesssim 1$ yr) variations in LOD are mainly the result of interaction between the atmosphere and the solid earth, while variations in LOD on decade timescales result from exchange of angular momentum between the mantle and fluid core. One mechanism for this exchange of angular momentum is through topographic coupling between pressure variations associated with flow in the core interacting with topography at the core-mantle boundary (CMB). Work done under another NASA grant addressing the origin oflong-wavelength geoid anomalies as well as evidence from seismology, resulted in several models of CMB topography. The purpose of work supported by NASA5-819 was to study further the problem of CMB topography, using geodesy, fluid mechanics, geomagnetics, and seismology. The grant under which this work was done has now expired. This is the final report describing the work done under this grant.

Density contrasts in a convecting mantle result both in flow and in dynamically supported topography at the surface, the CMB, and at any other interior boundaries in composition that might exist (e.g., the 670 km seismic discontinuity or the top of the D" layer just above the CMB). The mass anomalies associated with this dynamic topography are comparable in magnitude and opposite in sign to those associated with the interior density contrasts driving the flow. As a result, the geoid anomalies associated with mantle convection are relatively small differences of larger quantities.

As we showed in work supported by other NASA grants, the distribution of dynamic topography among the boundaries of a convecting system, and the resulting geoid anomalies, depend strongly upon the distribution of viscosity with depth and the presence or absence of chemical stratification. If the density differences driving flow in the mantle can be estimated, e.g., through seismic tomography, comparison of the observed geoid with model geoids predicted by forward modeling using a variety of assumed mantle structures places useful constraints on the dynamic structure of the mantle. Using this approach, we have been able to explain $\approx$ 90% of the variance in the observed geoid at wavelengths longer than 4,000 km.

The flow models also predict the pattern and amplitude of the dynamic topography at the surface and at the CMB. CMB topography is particularly interesting because the coupling between the solid mantle and fluid core is strongly affected by this topography. Because of its high temperature, the CMB is unlikely to support static topography like that due to crustal thickness variations at the surface: it is likely that any topography at the CMB is dynamically maintained. Thus if the topography of the CMB can be constrained, it would provide powerful tests of our dynamic models. Several approaches to modeling CMB topography have been attempted in the past few years, although, as yet, the results are not straightforward to reconcile.

Probably the most accurate estimate of CMB topography is that provided by models of coupling of core and mantle nutation. The shift in resonance period of the free core nutation from that predicted using hydrostatic theory, observed using VLBI geodesy, has been interpreted as due to an excess ellipticity of the CMB of $\approx$ 500 m (Gwinn et al, 1986). At this time, this VLBI technique has been used only to look at CMB ellipticity, not at any higher order component of CMB topography.

Seismological estimates of the long-wavelength components of CMB topography have had large amplitudes (~ 10 km) (e.g. Morelli and Dziewonski, 1987), but the models proposed by the three groups most active in modelling the CMB region (Harvard, MIT, Caltech) show little similarity to each other.

A third way to constrain CMB topography is to calculate the mechanical interaction between flow in the mantle and bumps on the CMB (e.g. Hide, 1986). If the temporal variation in the dynamic pressure at the top of the core can be obtained, the change in torque exerted by the flow in the core on the overlying mantle can be computed and compared to the observed changes in length of day. Unfortunately, there are many uncertainties involved in estimating the pressure field in the core. Nevertheless, we have spent substantial effort in calculating models of core-mantle coupling in the belief that, while the details of the models are probably incorrect, they can place useful bounds on CMB topography.

In order to estimate the pressure field at the top of the core, we have followed Hide (1986) in assuming that the flow there is, to a first approximation, geostrophic. The main assumption, somewhat controversial (e.g., Bloxham, 1988), is that near the boundary with the (assumed insulating) mantle, the magnetic field is small.

At the time this work was initiated, there was only one model available that was believed to be geostrophic (Le Mouel et al, 1985). This model has since been shown to be only approximately geostrophic (Bloxham, 1988). Testing it against our initial models of CMB topography gave decade length changes in LOD an order of magnitude larger than observed (Spieth et al, 1986; Hager, 1987).

The seismological estimates of CMB topography (Morelli and Dziewonski, 1987) gave even larger predicted variations. We are in the process of obtaining truly geostrophic flow models from C. V. Voorhies and J. Bloxham to test the robustness of our results.

Our tentative conclusion (Hager, 1987), was that the bumps at the CMB predicted by our initial mantle flow models are an order of magnitude too large to be consistent with the observed changes in LOD. The even larger bumps inferred from tomography present an even more serious problem. Resolution of this paradox will be discussed below, and in papers in preparation or submitted after the expiration of this work. Our seemingly too large estimates of CMB topography, as well as the *a priori* expectation that the CMB is a thermal boundary layer and might also be chemically distinct from the overlying mantle, led us to include these parameterizations in a third generation of flow models. These models include an additional one to two layers above the CMB, for a total of up to 6 layers. The layer above the CMB can be low-viscosity, chemically distinct, or both. Including D" in the parameterization allows nearly as good a fit to the geoid with (small) CMB topography that satisfies the constraints from nutation and LOD.

While it satisfies the geodetic constraints, this small CMB topography seems inconsistent with the estimates from seismic tomography. One resolution (Hager, 1987) is to speculate that there is a layer of molten silicate floating on the metallic core just below the solid mantle. Since dynamic topography is inversely proportional to the density contrast across an interface, the small density contrast between molten silicate and solid mantle would result in large dynamic topography, consistent with the seismological models. These "anti-oceans" of molten silicate would shield the CMB topography from flow in the metallic core, removing the problem of excessive predicted changes in LOD.

Implications of high inferred core temperature and bounds on heat flux from the core were discussed by Ahrens and Hager (1987). The indication is that D" is stably stratified against convection, otherwise the heat flux from the core would exceed the surface heat flux. If this is the case, use of fluid dynamical models to calculate core topography is suspect unless lateral heterogeneities in the D" layer can be included.

Seismological estimates of the structure of D" and the CMB were carried out by Gudmundsson et al (1986; 1987a; 1987b). Their initial models had large topography (Gudmundsson et al, 1986), comparable to that deduced by the Harvard group, discussed above. Their later models (1987a, 1987b) showed that including structure in D" or anisotropy in the outer core could satisfy the seismological observations with substantially less topography.

During the single year funded by this grant, we opened more issues than we resolved. This has stimulated us to continue to address these problems, supported by other sources. We expect to learn much about processes at the CMB by completing the research initiated here.

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