EXPECTED CONTRIBUTION OF THE GEOPOTENTIAL RESEARCH MISSION (GRM) TO STUDIES OF LIQUID CORE FLUID DYNAMICS

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A number of significant questions in geophysics ultimately require magnetic data before progress can be expected: (1) what is the instantaneous configuration and temporal evolution of the magnetic field in the near region external to the Earth? (2) how is permanent and induced magnetization of the crust (above the Curie isotherm) distributed in detail and what is its relationship to surface geology? (3) how large is the electrical conductivity of the deep mantle? (4) is electromagnetic core-mantle coupling strong enough to contribute significantly to observed changes in earth's rotation rate? (5) how does the main magnetic field emanating from the liquid outer core change in time, both in the short run (on time scales of years to decades) and in the longer term (over centuries to millenia and beyond)? (6) what is the source of mechanical energy and the pattern of resulting fluid motion that continually operates as a homogeneous, self-excited dynamo in the outer core? Is the toroidal field in the core weak (~10 gauss) or strong (~100 gauss or more)? (7) what is the heat flux delivered to the core-mantle boundary by fluid motions at depth and does its pattern contribute both to deep mantle plumes and to driving of surface plate tectonics? (8) can the large scale main magnetic field at earth's surface be at all well forecast over a 5 to 10 year period?

GRM can be anticipated to contribute strongly to some items on this list, moderately to others, and hardly at all to the rest. For example, hopefully, one major geomagnetic contribution will be a definitive resultion (at about 100 km) of the crustal magnetic anomaly pattern (item #2) in such a way that it can subsequently be removed from the observations to expose the remaining main magnetic field of deep internal origin. This spatial resolution expected from GRM, enhanced compared to MAGSAT, is obtained primarily from the lower (160 km) orbit height. Yet, that same feature exacerbates the contamination of the observations by ionospheric currents because GRM will fly directly through them. Moreover, the concommitant short lifetime makes it doubtful that GRM can contribute significantly to the direct determination of either continuous geomagnetic secular variation or deep mantle conductivity. On the other hand, there are good prospects for significant contributions to studies of fluid dynamics of the top portions of the liquid outer core.

All fluid dynamic studies to date rest on the frozen flux model for core motions in the low frequency pre-Maxwell theory of electromagnetism. That theory has also survived, very well, a test against seismology. The fluid velocity $\vec{v}$ (relative to the rotating mantle) then interacts with the main magnetic field, $\vec{B}$, to produce secular variation, $\partial\vec{B}/\partial t$:

$$\frac{\partial\vec{B}}{\partial t} = \nabla x(\vec{v}x\vec{B}) \ . \qquad (1)$$

Measurements of $\vec{B}$ and $\partial\vec{B}/\partial t$, taken at and above earth's surface can then, in principle, be downward extrapolated through the mantle which is usually assumed to be an insulator, but which need not be (if only its conductivity structure were known). Then (1) can be inverted for $\vec{v}$ just beneath the core-mantle boundary. Two immediate difficulties are that $\vec{v}$ is a highly nonlinear functional of the observations and moreover, only the component of $\vec{v}$ orthogonal to $\vec{B}$ can be recovered at a single epoch (the details of this ambiguity were originally probed deeply by Backus in 1968).

Recently, Voorhies and Backus have discovered one way to resolve that ambiguity completely (by introducing another physical assumption, namely that the fluid velocity is steady in time). Voorhies' doctoral thesis implements the theory and finds the unique steady motion consistent with magnetic field models based on the interval for 1960 to 1980. Subdividing this period into two decades and then comparing the resulting flows provides a test of the steady motion assumption. The GRM magnetic data, hopefully, not much later than 1990, will increase the total useable data span by 50%, thereby providing a far more satisfactory test for this theory.

Also, equation (1) plus the simplified equations of fluid mechanics imply the existence of a number of physical constraints on both secular variation and core fluid motions. GRM data are needed for thorough testing of these constraints.

Finding satisfactory models of the fluid motions at the top of the core is important for delineating what kind of dynamo is in operation, for estimating the heat flux into the base of the mantle, and for forecasting the magnetic field forward in time. Each of these aspects will be discussed.