RATIONALE FOR A GRAVSAT-MAGSAT MISSION. A PERSPECTIVE ON THE PROBLEM OF EXTERNAL/INTERNAL TRANSIENT FIELD EFFECTS

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The earth's magnetic field at MAGSAT altitudes not only has contributions from the earth's core and static magnetization in the lithosphere, but also from external electric current systems in the ionosphere and magnetosphere, along with induced electric currents flowing in the conducting earth. Hermance (1982) has assessed these last two contributions; the external time-varying fields and their associated internal counter-parts which are electromagnetically induced.

It is readily recognized that during periods of magnetic disturbance, external currents often contribute from 10's to 100's of nanoteslas (gammas) to observations of the earth's field. Since static anomalies from lithospheric magnetization are of this same magnitude or less (Langel et al., 1980), these external source fields must be taken into account when attempting to delineate gross structural features in the crust. Hermance (1982) considered two questions: first, are, in fact, induction effects significant for near-earth satellite observations; second, what are the effects of lateral differences in the gross conductivity structure of the earth at satellite altitudes?

To assess global induction effects one can assume that, to the first-order, the earth is spherically symmetric and is illuminated by the magnetic field of an equivalent ring current system. Therefore, the source field, B_z^o, is assumed to be uniform and polarized perpendicular to the ecliptic plane over the earth's diameter. We adopt the usual spherical coordinate conventions such that in a geocentric coordinate system z is directed from the earth's center through the North Pole, θ is colatitude and r is the radial distance.

For the purpose of our present discussion we will approximate a region of high conductivity (the oceans at short periods, the upper mantle at longer periods) as a super-conductor ($\sigma = \infty$) at a radius of $r = a$.

One can derive the following ratios between the induced field components (B_r^i, B_θ^i) and the external source field B_z^o at the satellite altitude, r:

$$B_r^i/B_z^o = -(a/r)^3 \cos\theta, \qquad (1)$$

$$B^i_\theta / B^o_z = -0.5\ (a/r)^3 \sin\theta. \qquad (2)$$

It is clear that, for a satellite at a nominal altitude of 400 km one has an induced contribution of 34% - 42% (depending on the value of a) of the external field. Since, for example, during the recovery phase of a magnetic storm Dst may have magnitudes of 100 gammas or larger, one may have long-term induced fields which are several tens of gammas in magnitude; larger in fact at satellite altitudes than the static fields from most lithospheric magnetic anomalies (Langel et al., 1980).

There is little doubt therefore that significant induced fields persist at satellite altitudes. Recognizing the problematic aspect of this effect, one must also recognize that such an effect might be turned to one's advantage if a proper strategy can be devised to exploit phenomena associated with external/internal field coupling.

Hermance (1982) showed that, theoretically, such an approach is feasible and in fact argued that under suitable conditions one might be able to delineate the boundary between gross lithosphere structures which have rather subtle differences in electrical properties (an electrical contrast of only a factor of 2). It seems possible therefore that the investigation of the lithosphere in terms of its gross electrical properties might serve as a useful complement to studies of its large-scale magnetization properties.

In my view there have been some very strong arguments advanced in favor of a follow-on mission to MAGSAT. I can only endorse these statements. In addition I would add several arguments of my own in favor of such an experiment.

First, we extend the time base of our primary data set. By flying a second mission in several years we would acquire a better understanding of the long-term contribution from external fields (such as from the ring current) which may have time constants of months to years. In my mind we do not have an adquate time base to separate these external effects from internal secular variations or from long wavelength static anomalies in the lithosphere. Some of our recent work suggests that the MAGSAT reference field model may have as much as a 10 gamma residual due to external/internal field coupling.

Second, by flying this mission during all local times we have a unique opportunity to discriminate between the sources of the external field contribution, i.e., we can study both the effects of ionospheric current systems (during daylight hours, particularly during quiet magnetic conditions) and magnetospheric current systems. I cannot overstate the overwhelming advantages that satellites offer in terms of providing a synoptic view of these current systems. Ground-based observations of certain components of magnetic field variations (particularly the vertical field) are severely contaminated by the presence of induced currents in electrical heterogeneities such as the highly conducting oceans. We have been dramatically unsuccessful in reconstructing global patterns of induced current systems when relying on ground-based observatory data alone. The network is too sparce and one quickly encounters what is best described as aliasing effects in separating out local induction anomalies from larger scale regional anomalies. Satellite coverage provides a global view. And, at an altitude of 160 km, is far enough from truly local anomalies for the data to be unperturbed, while still close enough to the earth to potentially resolve regional anomalies (at the scale of 250 - 1000 km).

References

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