IMPROVED HIGH FREQUENCY ELECTROMAGNETIC SOUNDING OF THE LUNAR MANTLE — Floyd Herbert, C. P. Sonett and L. D. Smith, Univ. of Arizona, Tucson AZ 85721.

Introduction

A long-standing method for investigating the lunar interior has been to probe the internal lunar electrical conductivity distribution by intercomparing the power spectra of the magnetic field fluctuations measured by the Explorer 35 spacecraft and the Apollo 12 surface module. The principal method of intercomparison consists of calculating the empirical transfer function associating the solar wind magnetic fluctuation spectrum (the driving signal) and the spectrum measured at the surface (the response). A model transfer function is compared with the empirical one and the conductivity profile characterising the model is varied for maximum agreement of the two transfer functions.

Procedure

The present work consists of new reductions of the Explorer 35/Apollo 12 magnetometer data for high frequencies ($f > 10^{-5}$ Hz) where induction is strongly damped in the lunar mantle, serving as a probe of that region. The magnetic field time series data has been subdivided into about 1000 gap-free 10 minute swaths, for each of which a power spectrum has been computed.

In order to reduce uncertainty owing to solar wind plasma interactions with the local magnetic field, the variation of wave and plasma properties between the vicinities of the two magnetometers, digitization noise, etc., we have selected only those swaths which showed strong correlation between the (time domain) magnetic field components $B$ (Apollo) and $B$ (Explorer). Here $n$ denotes the direction which is normal to the lunar surface at the Apollo 12 site. This selection reduced the number of swaths by about half, but the consistency of the resulting transfer function estimates was improved considerably.

The high frequency transfer function depends strongly upon both the internal lunar conductivity profile and the pseudoscattering angle $\Theta$ between $n$ and the effective incoming wave propagation vector $k$ (e.g., c.f. ref. 1). Thus in calculating the empirical transfer function as a function of $\Theta$ the swaths with similar estimated values of $\Theta$ are segregated into bins. The empirical transfer function is computed at each $\Theta$ bin and value of $f$ by a linear regression (running over the swaths in that bin) of Apollo power vs. Explorer power.

The estimate of the direction of $k$ for each swath is limited in accuracy by the following: contamination power introduced by the original digitization into discrete levels by the magnetometers (which affects the highest frequencies more severely because the signal power diminishes with increasing frequency) and the fact that the algorithm (minimum variance — ref. 2) for estimating $k$ has limited power for finding wave normals. Only in the case of non-colinear (i.e. large-amplitude) Alfvén waves does the result correspond exactly to $k$ (c.f. ref. 3). In addition, the direction found represents an average over the frequencies present, while the fluctuations may consist of multiple waves propagating in different directions. The fluctuations may not even consist principally of waves but might instead be spatial inhomogeneities convected past the moon by solar wind motion, a condition which would invalidate the assumptions of the induction model.
In order to overcome these difficulties, we have selected for binning only those swaths which showed strong anisotropy in magnetic fluctuation (ratio of middle to minimum eigenvalues of the variance matrix > 2). This procedure tends to eliminate cases where the magnetic fluctuations are not wave-like, although purely colinear fluctuations are not eliminated thereby.

Although this work is oriented towards the lunar mantle, as probed by high frequency induction, we have also incorporated some low frequency data (4). This additional data is useful because the separation between the information contained in high and low frequencies about the outer and inner regions of the moon, respectively, is incomplete.

Indeed, it has been frequently observed (5) that the process of modelling the lunar interior conductivity in this manner is beset with potential ambiguities. That is, there are often several profiles that similarly fit the data, and that the data constrains the conductivity better at some depths than at others. In fitting the data we have used a least-squares method (6) that estimates the second derivatives of the sum-of-squares function with respect to the model parameters (log shell conductivities). The eigenvalues of this matrix serve as an estimate of the sensitivity of the fit to each parameter or linear combination (determined by the associated eigenvector) of parameters.

Results

The conductivity profile which, among those tested so far, yields the best-fitting model transfer function is shown in Figure 1. Distinctive characteristics include a rather low conductivity at considerable depth and a (marginally preferred) high-conductivity core. (The exact core conductivity is not derived.)

In varying models to fit the data we have observed the strongest model constraint exerted by the data at radii of about 1200 to 1500 km. The eigenvalue of the estimate of the second derivative matrix corresponding to the 1400 - 1500 km shell conductivity is particularly large, being in the conductivity model shown about 6 or 7 orders of magnitude larger than the next largest one (1300 - 1400 km shell). Thus the "ellipsoids" of constant sum-of-squares function in the (10-dimensional) model parameter space are extremely pancake-shaped (in the model space region investigated so far), indicating great sensitivity to model changes in certain directions.

In many well-fitting models, such as that shown in Figure 1, a moderate conductivity maximum over the range 1000 - 1400 km is favored. Within the constraints of the analysis, the early surmise (1) of a conductivity "spike" can still be accounted for, but further analysis is required to raise the confidence in this anomaly. Layers outside of these levels are constrained to be of low conductivity but the exact values are not well determined.

References

Figure 1 -- Lunar electrical conductivity profile estimated from high frequency electromagnetic sounding data. Conductivities lying between radii of about 1000 to 1500 km are the most well-determined.