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AN EQUIVALENT LAYER MAGNETIZATION MODEL FOR THE UNITED STATES DERIVED FROM MAGSAT DATA

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Abstract. Long wavelength anomalies in the total magnetic field measured by Magsat over the United States and adjacent areas are inverted to an equivalent layer crustal magnetization distribution. The model is based on an equal area dipole grid at the Earth's surface. Model resolution, defined as the closest dipole spacing giving a solution having physical significance, is about 220 km for Magsat data in the elevation range 300-500 km. The magnetization contours correlate well with large-scale tectonic provinces.

Introduction

Techniques developed for interpretation of Pogo satellite magnetic anomaly data (Mayhew et al, 1980; Mayhew, in press) were aimed at 1) modeling the anomaly field itself and separating it from core and external fields, and 2) deriving models of large-scale crustal magnetization which have geologic significance. These techniques have now been applied to data taken over the U.S. by Magsat, which was considerably lower than Pogo, and initial results are given in this paper. The approach has been to apply the well-known equivalent source technique (e.g. Dampney, 1969), adapted for spherical-earth geometry. The equivalent source technique is a simple method of generating a synthetic magnetic anomaly field which fits the data over its full elevation range. Magnetic dipoles are arrayed in an equal area grid at the Earth's surface and mathematically oriented in a fixed direction. In previous applications, the direction has been taken to be the same as that of the core field. A set of dipole moments is determined by a generalized least squares method such that the dipoles collectively give rise to a magnetic anomaly field best fitting that observed. Although previous applications have used only the anomaly in the total field as input data, in principle vector component measurements can be used directly just as readily. For the work reported here we have used total field anomaly data as computed from the measured vector components. The set of dipole moments is divided by a surrounding volume given by the dipole spacing and an arbitrary vertical thickness, so that the resulting solution is expressed as apparent magnetization variation in a constant-thickness layer (thus, an equivalent layer model). This is in contrast to a magnetic model for the crust which would have constant magnetization but variable thickness; a realistic geological model would in general include variations in both parameters. Magnetization parameter solutions and the associated fit of synthetic and measured fields display a characteristic behavior as a function of dipole spacing. As the spacing decreases (number of dipole sources increases) the fit of the field improves rapidly but with diminishing returns beyond a critical spacing. At about this spacing the stability of the solution, as measured simply by the parameter standard deviation, begins to deteriorate rapidly. Decreasing the spacing further causes the magnetization values to take on increasingly larger positive and negative values. The critical spacing can be defined rather closely. For spacings close to, but not less than, this limit, magnetization variations appear to be physically meaningful, in as much as they are systematic and correspond closely to large-scale geologic provinces (Mayhew et al, 1980; Mayhew, in press). For smaller spacings, solutions are not physically meaningful, although they do give a slightly better fit to the data. Examples of such "trade-off" graphs for Pogo data are given in the above references. A trade-off graph for Magsat data over the western United States and adjacent areas is given in Figure 1. The stability limit for Pogo data (above 450 km altitude) corresponds to a source spacing of about 300 km; for Magsat data (mostly above 300 km) we infer a limit of about 220 km. The lower data leads to better resolution models, as expected. Mayhew (in press) describes a method of determining a magnetization distribution for a dipole array with spacing half that of the critical spacing (for the present data, 110 km), and this method has been applied in producing the magnetization distribution described below. Equivalent layer magnetization models can be readily transformed to more realistic models of magnetization variation in a magnetic crust of variable thickness, provided some independent information is available for calibration.

Results

A virtue of the equivalent source technique is that the anomaly field can be represented over a surface of constant altitude and displayed in map form. Figure 2 shows the equivalent source total field anomaly at 320 km altitude computed from a 136 km - spacing equivalent source array. Data and sources within about 32° of the magnetic pole were not used in order to avoid external field effects in the auroral zone.

Figure 3 is a magnetization model derived from Magsat total field anomaly data. Contours are in tenths of A/m, and represent an apparent magnetization contrast distribution within an equivalent layer 40 km thick. The prinipal features are the same as in a model derived from Pogo data (Mayhew, in press), but the present model shows considerably more detail. Many of the magnetization anomalies correlate with large-scale tectonic features. In the western United States, the pattern corresponds to large-scale heat flow provinces (e.g. Lachenbruch and Sass, 1977), and may reflect Curie isotherm undulations. In particular, the Basin and Range and Rio Grande Rift are regions of high heat flow, and are delineated by magnetization lows (possibly indicating a shallow Curie isotherm), while the relatively lower heat flow provinces of the Sierra Nevada and Colorado Plateau correspond to magnetization highs. The boundary between the Appalachian-Ouachita belt and the Precambrian craton is marked by a strong gradient along its length. The Wichita Uplift, flanked on the north by the Anadarko Basin, is marked by a magnetization gradient. It is interesting that in the western midcontinent the boundary between Mesozoic/Cenozoic cover and older rocks marks a distinct change in orientation of the magnetization anomalies. The Keweenawan rocks of the Lake Superior Syncline appear to be associated with a local magnetization positive. Attention is called to the similarity between the contour pattern of Figure 3 and the magnetic map of the United States based on filtered aeromagnetic data given by Sexton et al (this issue).

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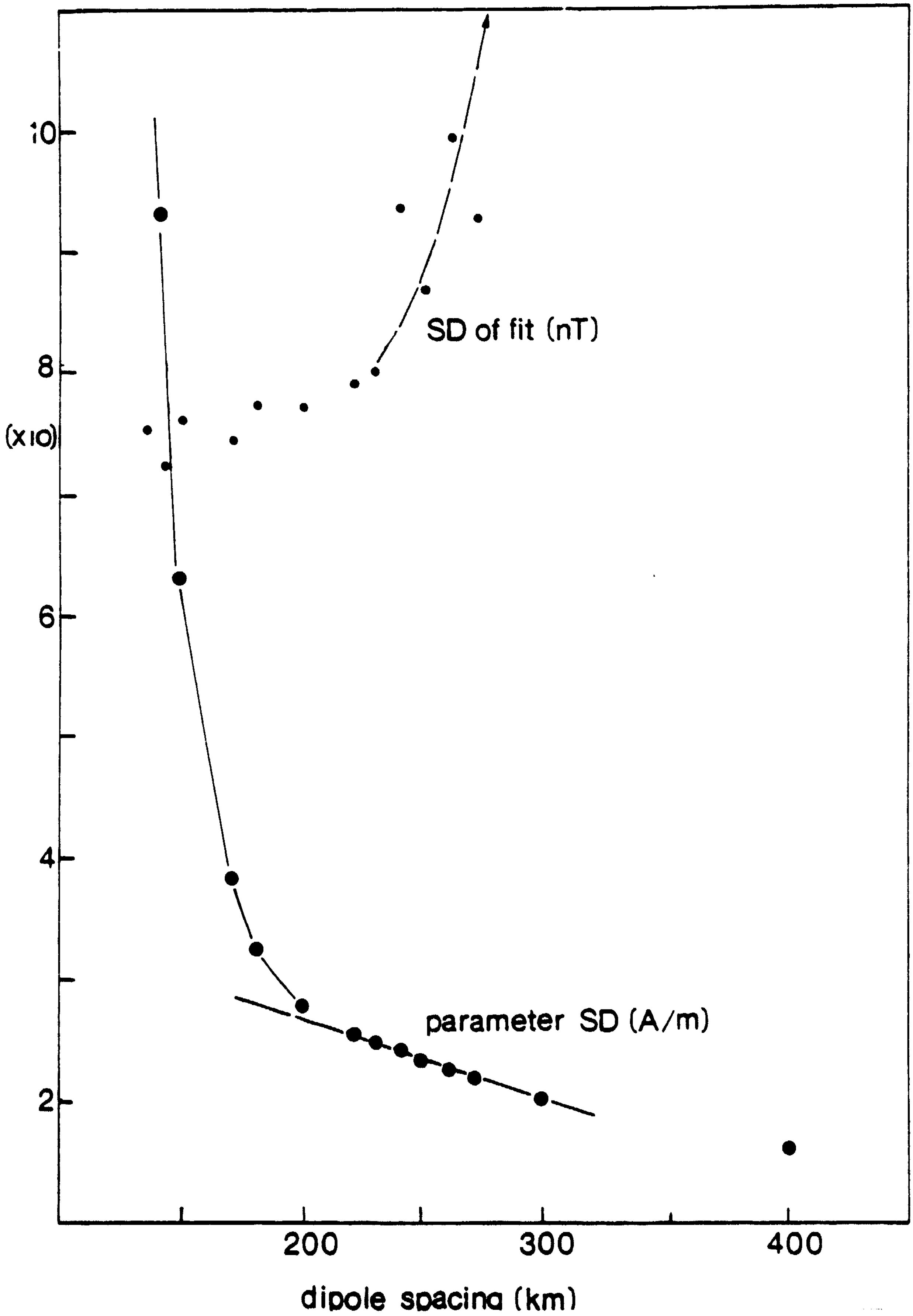
Figure Captions

Fig. 1. Trade-off as a function of dipole spacing (kilometers) between 1) the fit of the equivalent source magnetic anomaly field to the field observed at satellite elevations (tenths of nT) and 2) "stability" of inversion as indicated by standard deviation of solution parameters (tenths of A/m). Optimal solution inferred to be at source spacing of about 220 km. SD means standard deviation.

Fig. 2. Equivalent source representation of magnetic anomaly field at a height of 320 km. Source spacing is 136 km. Contour interval 1nT. Albers equal area projection.

Fig. 3. Apparent magnetization contrast in a 40 km thick layer. Distribution is obtained by inversion of Magsat total field anomaly data. Model is series of staggered 222 km - spacing dipole grids computed separately, but machine contoured together without smoothing on 111 km grid. Contour interval is 0.1 A/m. Dashed lines indicate generalized tectonic province boundaries which are geographically related to the magnetization distribution. Letters represent the following; S: Sierra Nevada block, BR: Basin and Range province, CP: Colorado Plateau, R: Rio Grande Rift, SR: Snake River Plain, P: western boundary of Great Plains, A: Appalachian Ouachita front, W: Wichita uplift, K: Kentucky anomaly, LS: Lake Superior Syncline. Boundary between Mesozoic/Cenozoic cover and older rocks is indicated by short dashed line. Albers equal area projection.



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(x10)
6
4
2
SD of fit (nT)
parameter SD (A/m)
200
300
400
dipole spacing (km)

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