MODELING GRAVITY AND MAGNETIC FIELDS FOR CRUSTAL AND UPPER MANTLE STRUCTURES

John M. DeNoyer
U.S. Geological Survey
Reston, Virginia 22090

The purpose of this paper is to: (1) make a direct comparison between the gravity and magnetic fields near the ellipsoid and at the height expected for the Geopotential Research Mission (GRM) for the same geologic model, (2) obtain realistic estimates of the gradients that can be expected at the orbit height of the GRM, and (3) demonstrate the value of data that the GRM could provide for investigating upper mantle and deep crustal anomalies.

The fields that have been computed are the vector components of the gravity and magnetic fields, the components of the gradient tensors, and the components of the "second derivative" tensors of rank 3. The forward calculations were carried out for the same geologic model at heights of 2 and 160 km above the ellipsoid. A grid spacing of 50 km was used for the low-gradient portions of the 2-km-height field, and spacings of 25 and 5 km were used for the higher gradient portions of this field. A constant grid spacing of 100 km was used for the 160-km-height field. All components of the fields are given with respect to the north, east, and vertical directions.

The model is of a hypothetical rift valley. There is an elongate (approximately 1,300 by 240 km) region in the upper mantle where the density is lower than normal. This low-density region is 25 km thick at the axis and decreases in thickness linearly toward the edges. In the upper crust, the model includes a graben-type structure (about 450 by 80 km), with sides sloping at 45 degrees, that is filled with low-density material to depths reaching 5 km below the ellipsoid. The rocks along the sides of the graben are assumed to have magnetic properties, and the direction of the Earth's magnetic field is assumed to differ over various parts of the model. A crude topography has been included along the edges of the graben to represent mountain ranges. The susceptibility of the mountains varies from 0 to 8 A/m. The 8 A/m portion of the model represents a thick (up to 1.5 km) volcanic field on the northwest side of the graben. Additional sedimentary material has been included between the mountains so that the part of the graben above the ellipsoid is half full of low-density material.

The method of forward calculations is to construct the model from a set of bodies. Each body is completely bounded by plane polygons that can be in any orientation and can have an arbitrary number of vertices. Each body can have a density value, a susceptibility, or both. Each field is then computed using surface integrals over these bodies.

The long-wavelength gravity anomaly at 160 km orbit height would be clearly defined by the GRM. The vertical component would suggest an extensive low-density structure with added mass near its center. The gravity gradients place constraints on the length of the added mass of the topography, but do not resolve the width. Use of the combined GRM and near-surface gravity fields would place constraints on interpretive models that could improve the reliability of the solutions.

Gravity gradients with an accuracy of ± 0.01 Eötvös units appear to be adequate to define the gradient fields for this model at the GRM orbit height. The shorter wavelength content of the gradient components could be an important aid for delineating the trend and some dimensions of the structures that cause the gravity anomaly.

The magnetic field produced by the structures in this model is a combination of the lack of magnetic materials in the graben and induced magnetization in the flanking mountain ranges. The cumulative effect is a low-amplitude (- 3 nT), generally featureless anomaly that would be on the borderline of detectability by magnetometers of the type used on Magsat. This anomaly would be difficult to interpret without the gravity field over the same region. Correlation with the gravity field would indicate that the magnetically disturbed rocks are in a broad region of mass deficiency and correspond in location to the position of added mass in the low-density region. This would be an important guide for selecting the type of model to represent the anomalous features. An additional use of the combined fields would be to compute the pseudo-gravity field to obtain an estimate of the relative amounts of material that are disturbed due to density variations and due to susceptibility variations.

The magnetic gradients at this orbit height are small. A sensitivity of ± 0.001 nT/km would be needed to define the gradients with any degree of confidence. A lower measurement height, between 130 and 140 km, would significantly improve the quality of both the magnetic field and magnetic gradient measurements.

The example discussed in this paper is only one model. It would be desirable to carry out similar calculations for a variety of geologically realistic models to document the types of structures that the GRM may delineate.