New way of processing near-surface magnetic data: The utility of the Comprehensive Model of the Magnetic Field

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In assembling near-surface magnetic surveys (e.g., airborne or marine data) for regional geologic studies, one often has a problem in properly merging different surveys without applying ad-hoc leveling methods or warping the long-wavelengths of individual data sets. A new comprehensive long wavelength and long time span magnetic field model based on satellite and observatory data may, at last, resolve this problem. The model, the Comprehensive Model (CM), is developed by Terry Sabaka of Raytheon ITSS/NASA and Nils Olsen of the Danish Space Research Institute. The present version of the model, CM3, incorporates data from magnetic field satellites POGO (1965-1970), Magsat (1979-1980), Ørsted (2000 to present), and CHAMP (2001 to present) and magnetic observatory data from the early 1960s to 2002.

To isolate magnetic effects of geologic sources, CM3 defines in a continuous manner (space and time) many long-wavelength magnetic fields that users of crustal magnetic anomaly data sets aim to remove from their magnetic observations: the main field and quiet time external magnetic fields from magnetospheric and ionospheric sources (for example, the effect of magnetospheric Ring Current and solar quiet, or Sq, ionospheric activity which primarily add base-level variations in aeromagnetic and marine magnetic observations).

While preliminary results of CM in representing the external fields in aeromagnetic surveys are promising, the external fields component of the model is applicable presently only for quiet magnetic conditions (planetary index Kp < 1+). In this article we will therefore focus only on the utility of CM for minimizing base-level shifts from surveys carried out over a large time span. Base-level shifts from one magnetic survey to another can lead to significant long-wavelength anomaly corruption and, consequently, in errors in interpretation of regional magnetic sources. In magnetic data processing, it is customary to remove from observations a model of the main or the core-generated magnetic field for the epoch of the magnetic survey—a model such as the International or Definitive Geomagnetic Reference Field (IGRF or DGRF) updated every five years. These models are generally adequate for removing the main magnetic field effects from surveys carried out in short time span. However, because the IGRF/DGRF models are not continuous from one epoch to another, any imprecision in correctly modeling temporal variations of the Earth's main field can be aliased on the first-order as a small bias. When a number of surveys (flown at disparate times) and their associated inaccuracies are adjacent to one another, the error surface can be complex. On the other hand, CM incorporates detail to the level of magnetic observatory hourly means and, hence, it is able to precisely separate and model the secular variation of the Earth's main field and the external fields. The improvement of CM over IGRF is evident in the NURE (National Uranium Reconnaissance Evaluation) surveys in the United States carried out in the 1970s. Figures 1a and 1b show, respectively, IGRF and CM3 main-field-removed NURE anomalies from about 25 NURE quadrangles (each NURE quad being 2° of longitude and 1° of latitude). The anomalies processed with CM3 smoothly merge from one NURE quad to the next (Figure 1b), whereas those processed with IGRF (Figure 1a) show discontinuities at the edges of many of the quadrangles. An index of the years of the surveys (Figure 2) superimposed on Figure 1a shows that discontinuities are especially prominent from 1976 to other years, but normally they tend to accumulate over a few years' period.

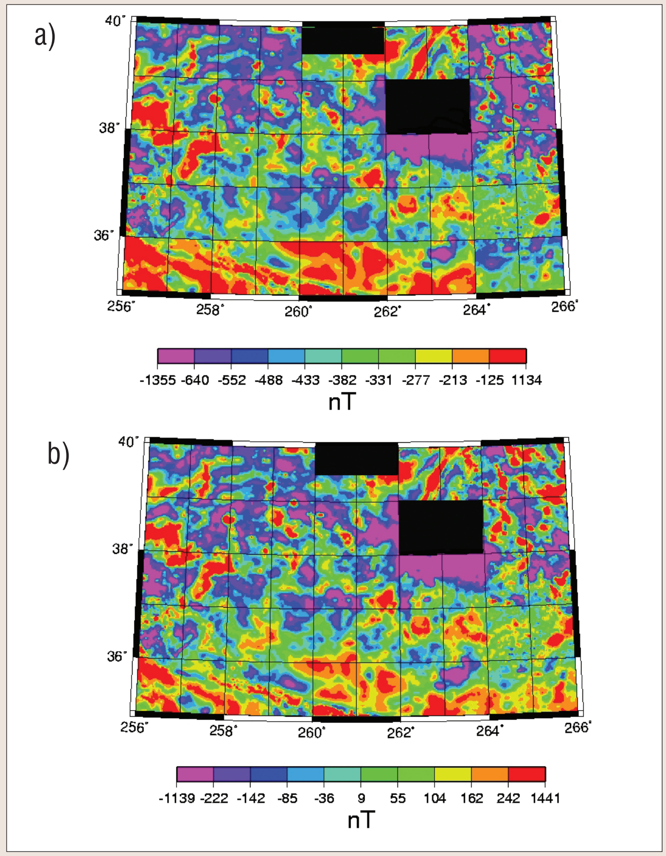

Figure 1. (a) Residual magnetic field derived from adjacent NURE quads (2° of longitude and 1° of latitude) in Kansas and processed with IGRF to remove the main field and with base-station magnetometer data to remove external fields. The processing results in anomaly base-level discontinuities at the edges of many of the quads. (b) Residual magnetic field processed using the CM3 model for the main field and the external fields. This data compilation shows no discontinuities at the edges of the quads.

Similar results are also obtained using the regional long wavelength Canadian aeromagnetic surveys in the 1960s and 1970s flown by the Earth Physics Branch of the Geological Survey of Canada. Figure 3a shows the difference between the magnetic fields processed with the DGRF models and CM3, and Figure 3b shows the locations and dates of these surveys. Discontinuities of about 10-40 nT are apparent between adjacent surveys carried out during different years. In addition to base-levels offsets, the difference surfaces are of high-order nature due to the different spherical harmonic degrees used in CM (degree and order 13) and IGRF/DGRF (degree and order 10). As shown by Bob Langel and his coworkers, in the power spectrum of the global magnetic field, the change from primarily main field to crustal field occurs at degree 13. How the actual observations fit with main field models of degree 10 and 13 can be seen in Figure 4. The

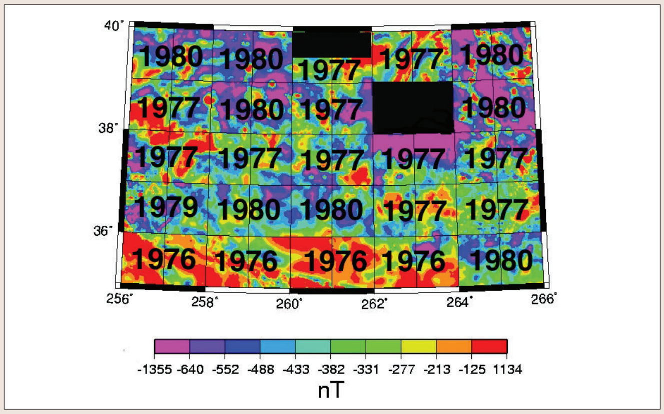

Figure 2. Year of the survey superimposed on each NURE quad in Figure 1a.

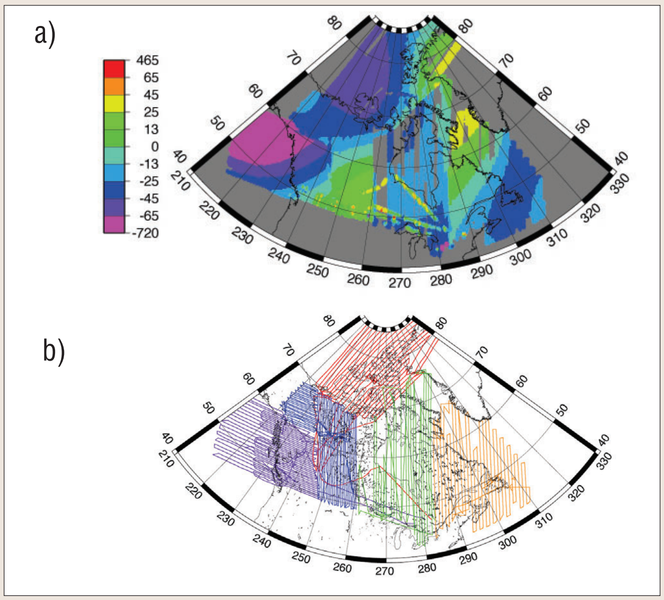

Figure 3. *(a) The difference between magnetic anomalies over Canada processed with the main field computed by CM3 and DGRFs. The magnetic data were derived from the long-profile regional aeromagnetic surveys carried out by the Earth Physics Branch of the Geological Survey of Canada. (b) Location of individual profiles from the above surveys color-coded according to the year of data collection (1969 = magenta, 1970 = red, 1972 = blue, 1974 = green, 1976 = orange).*

figure shows some NURE data plotted with respect to observation time and indicates that CM with spherical harmonic degree 13 nearly passes through the observations (as it should, unless one happens to be on a large anomalous region), whereas the degree 10 IGRF produces about 600 nT bias in the anomaly field. This bias would need to be artificially removed, especially if different surveys were merged. Recognizing the need for a better approximation of the main field models, the International Association of Geomagnetism and Aeronomy (IAGA) Main Field working group in a 2001 Hanoi meeting decided to calculate IGRFs to degree 13 for the epochs when satellite magnetic data are available.

The examples we have shown here clearly show the utility of the CM approach in the processing of near-surface magnetic anomalies. Effectiveness of CM depends on the spatial and temporal matching of the main and external field variations that it attempts to approximate. Thus, data distribution as well as continuity is particularly important. While many landmasses are adequately covered with magnetic observatories, there are large gaps in the oceanic regions. These gaps are filled with discontinuously collected satellite magnetic data, interpolated through the intervening time periods. The

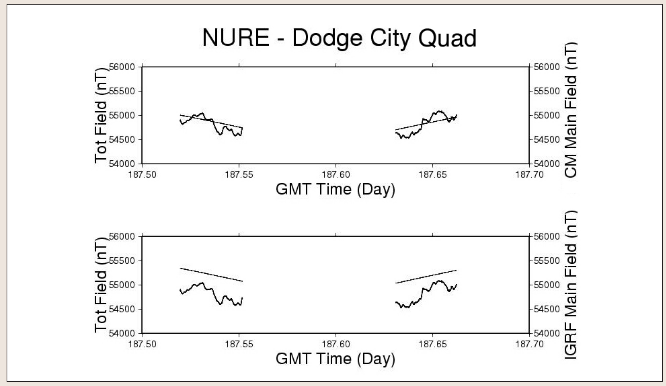

Figure 4. *An example of the fit between raw magnetic observations and the CM model (the top panel) and the IGRF (the bottom panel). Degree 10 of the IGRF is not sufficient to model the observations whereas the CM with degree 13 does an excellent job of fitting the observations in this region.*

main field features change only gradually and, hence, we feel that the temporal coverage of the satellite data since 1965 is adequate to describe the main field over regions with large spatial gaps (except perhaps the Earth's poles). At this point in time, we feel that it would be extremely advantageous for magnetic data processors to incorporate CM and examine its clear effectiveness in removing the main field and external fields from both their scalar and vector data. The details of CM can be obtained from its originators, Terry Sabaka (*sabaka@geomag.gsfc.nasa.gov*) or Nils Olsen (*nio@dsri.dk*).

Suggested reading. "A comprehensive model of the quiet-time, near-Earth magnetic field: Phase 3" by Sabaka et al. (*Geophysical Journal International*, 2002). TLE

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