EMAG3: A 3-arc-minute resolution global magnetic anomaly grid compiled from satellite, airborne and marine magnetic data

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Summary

NOAA's National Geophysical Data Center (NGDC) has extensive holdings of airborne and marine magnetic data. Such data have been collected for more than half a century, providing global coverage of the Earth. Due to the changing main field from the Earth's core, and due to differences in quality and coverage, combining these data to a consistent global magnetic anomaly grid is challenging. A key ingredient is the long wavelength magnetic field observed by the low-orbiting CHAMP satellite. To produce a homogeneous grid, the marine and aeromagnetic trackline data are first line-leveled and then merged with the existing grids of continental-scale compilations by Least Squares Collocation. In the final processing step the short-to-intermediate wavelengths of the near-surface grid are merged with a CHAMP satellite magnetic anomaly model. In analogy to NGDC's 2-arc-minute resolution ETOPO2 grid, we call our initial 3-arc-minute magnetic anomaly grid EMAG3. The grid will be updated regularly. It is available in digital form and as plug-ins for *NASA World Wind* and *Google Earth.*

Introduction

Magnetic anomaly maps derived from ship and airborne surveys have played a key role in developing the theory of plate tectonics (Wegener 1912; Vine and Mathews, 1963), and unraveling the structure of the Earth's lithosphere (Phillips, 1991). Stitching together large numbers of surveys, magnetic anomaly maps have been produced for all of the continents (Fairhead, 1997; Minty, 2003). A large marine magnetic track-line data-base is being maintained at the National Geophysical Data Center (http://www.ngdc.noaa.gov/mgg/geodas/trackline.html). These marine track-line data provide a reasonably dense coverage of ocean areas, although sparse data in parts of the southern oceans remain a serious limitation for global mapping.

A key issue in producing a global magnetic anomaly grid is the control of the longest wavelengths (Ravat et al., 2002). Magnetic anomalies with wavelengths of more than a few hundred kilometers are not reliably determined by stitching together near-surface airborne and marine data. Only satellites can provide the global perspective. The POGO (1967-1971) and Magsat (1979-1980) missions showed that the long-wavelength crustal magnetic field is visible at satellite altitude. The key breakthrough in this technology was achieved with the launch in July 2000 of the CHAMP satellite, equipped with a new generation of highly accurate space magnetometers.

Following a scientific review of candidate submissions, the first version of our magnetic anomaly grid (Maus et al., 2007a) was selected by the International Association of Geomagnetism and Aeronomy (IAGA) as the base-grid for the World Digital Magnetic Anomaly Map (Reeves, 2008).

Here, we provide a brief overview of the data sources and processing methodology for EMAG3. Snapshots are presented of the satellite-derived MF6 magnetic field model and of EMAG3 plug-ins for *NASA World Wind* and for *Google Earth.* We end this paper with an optimistic outlook for future updates of the grid, which will benefit from new CHAMP and upcoming *Swarm* satellite data, and increasing contributions to our archives of airborne and marine magnetic surveys.

The satellite perspective

Satellites in low-Earth orbit (LEO) provide the most effective means of mapping the long wavelengths of the crustal magnetic field. A comprehensive overview of satellite-base crustal field mapping was given by Langel and Hinze (1998). Initial satellite magnetic anomaly maps were produced from POGO data by Regan et al (1975). However, it was soon recognized that vector magnetic field measurements are required in order to accurately map the magnetic field in the equatorial region. In 1979/1980, Magsat was the first satellite to carry an accurate vector magnetometer with attitude determination using a star imager (Mobley et al., 1980). Following a period of 20 years without accurate satellite magnetic coverage from space, the CHAMP satellite was launched in July 2000 (Reigber et al., 2002). Apart from an order of magnitude improvement in magnetometer accuracy, CHAMP has remained in a particularly low-altitude orbit for a full decade, leading to excellent spatial and temporal data coverage.

EMAG3: A global magnetic anomaly grid

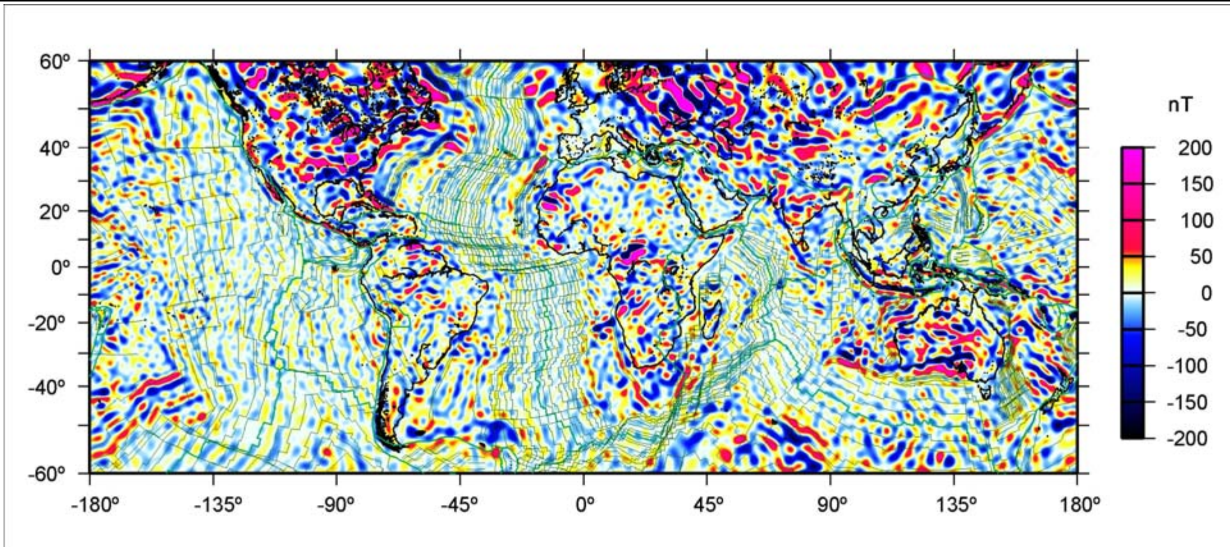

Figure 1: Vertical component of the CHAMP-satellite-derived MF6 crustal magnetic field at the Earth surface, overlain with the isochrons of an ocean-age model inferred from independent marine and aeromagnetic data by Muller et al. (2008).

The latest CHAMP crustal magnetic field model MF6 (http://geomag.org/models/MF6.html) resolves the crustal magnetic field to spherical harmonic degree and order 120, corresponding to length scales down to 333 km. The MF6 model is the first satellite-based magnetic model to resolve the direction of oceanic magnetic lineations, revealing the age structure of oceanic crust (Fig. 1). This model will provide the long-wavelength portion of the 2nd version of our EMAG global magnetic anomaly grid. The first version of the grid used its predecessor MF5 (Maus et al., 2007b, http://geomag.org/models/MF5.html). The shorter wavelengths are provided by compilations of airborne and marine magnetic surveys, discussed in the following.

Airborne and marine magnetic data

NGDC maintains a secure long-term archive for aeromagnetic and marine magnetic data. The data providers are acknowledged in a dedicated web page at: http://geomag.org/models/EMAG/acknowledge.html. The challenge in combining these surveys to a common map is that the data sets, which can be in grid or profile format, vary greatly in survey dimensions, altitude and data quality.

The guiding principles of our processing methodology for the EMAG global magnetic anomaly grid are (1) to provide the most accurate estimate of the magnetic anomaly field on the final grid, and (2) to produce a homogeneous grid whose horizontal derivatives were dominated by geological features rather than by data artifacts. In implementing the second goal, we accept that the resulting product is somewhat smoother than the true magnetic anomalies. Two methods are used to achieve these goals: Using a global line-leveling technique, we correct for random offsets between single marine and aeromagnetic track-lines, primarily over the oceans. The line-leveling also adjusts the track-lines to the gridded data sets in the overlapping regions. Finally, to deal with the immense inhomogeneity of the input data and their varying altitudes, we use a Least Squares Collocation method (Langel and Hinze, 1998, Chapter 5.3.3) to join all airborne and marine input data to a common grid. For a given grid cell, Least Squares Collocation, also called Kriging, provides the best estimate of the magnetic field from all surrounding measurements, taking their distance and co-variance into account.

Merging long and short wavelengths

There are several possible ways to replace the long wavelengths of the combined airborne and marine survey grid with a satellite crustal field model in the spectral domain. For the first version of EMAG3, we chose a processing route via the magnetic potential. A complication arises from the fact that total-intensity magnetic anomaly data coverage on the sphere does not completely constrain the magnetic potential. The ambiguity is further increased by the incomplete data coverage of the combined airborne and marine survey grid. By using a least squares method and rejecting the Eigenvectors with the lowest Eigenvalues, one can select the smoothest magnetic potential that represents the observed anomaly. We find an excellent

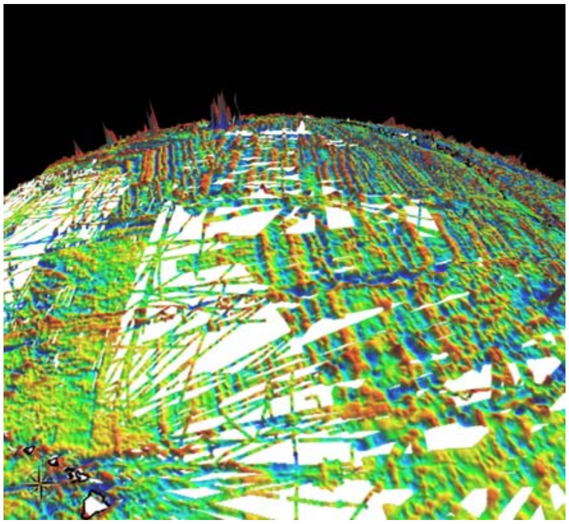

Figure 2: Our global magnetic anomaly grid in the 3D display software *NASA World Wind*. Shown here is a view northward from Hawaii. The *World Wind* plug-in can be downloaded from:

http://www.getech.com/downloads/WDMAM.htm

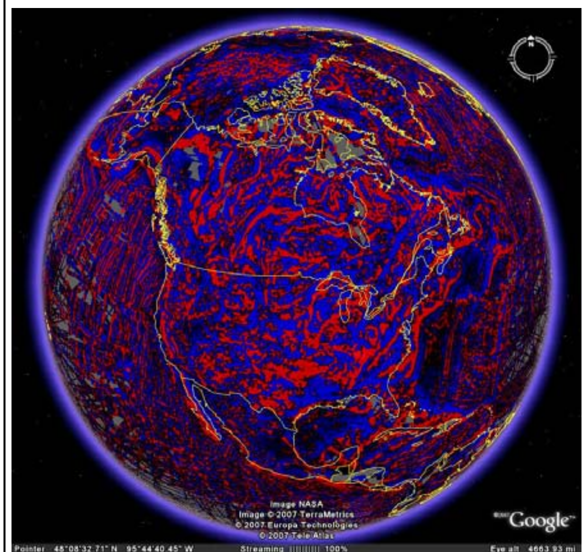

Figure 3: The first version of our global magnetic anomaly grid in *Google Earth*. The KMZ file can be downloaded from:

http://geomag.org/models/wdmam.html

agreement between the power level of the satellite-based and near-surface data grid at 400 km wavelength. We therefore used a sharp cut-off to substitute the long wavelengths of the near-surface data with the satellite model. This substitution was carried out by subtracting the near-surface model to the cut-off degree from each grid cell and then adding on the prediction from the satellite model. For the first version of EMAG (Maus et al., 2007a) we used a cut-off at degree 100 and substituted with the MF5 model (Maus et al., 2007b), while the MF6 model with a cut-off at degree 120 will be used for the 2nd generation of the grid.

Results

The first version of our EMAG3 global magnetic anomaly grid provides the anomaly of the total magnetic intensity at an altitude of 5 km above mean sea level at 3 arc minute resolution. The digital grid, images, processing information and supporting materials are available for download at http://geomag.org/models/EMAG.html. Follow-on versions will be posted at the same location. A snapshot of the visualization in *NASA World Wind* is displayed in Figure 2. The necessary plug-in files can be downloaded from the GETECH website cited in the figure caption. A corresponding plug-in, but without 3D capability, is also available for *Google Earth*. A snapshot is displayed in Figure 3, with the download address for the plug-in again given in the caption.

Outlook

The EMAG global magnetic anomaly grid will be updated regularly, approximately in 2-year intervals, as new satellite, airborne and magnetic data become available.

The CHAMP satellite is expected to continue to provide excellent data in magnetically quiet solar-minimum conditions into mid-2009. In particular, the decreasing orbital altitude will lead to substantial further improvements in anomaly precision and map resolution. Following CHAMP, the European Space Agency will launch a triple-satellite constellation mission around 2010.

A difficulty with a single, polar-orbiting satellite, like CHAMP, is that all satellite tracks are strictly oriented North/South with no “tie-orbits” which could be used for line-leveling. To address this problem, the European Space Agency’s upcoming Swarm constellation mission (http://www.esa.int/esaLP/LPswarm.html) will have a pair of low-orbiting satellites flying side-by-side that will act as a magnetic gradiometer system, helping to resolve North/South trending magnetic anomalies. These anomalies are particularly relevant to studies of sea floor spreading at low latitudes.

Further improvements in the resolution and accuracy of EMAG can be expected from the future availability of further airborne and marine magnetic surveys, such as for Algeria (Bournas et al., 2007). We actively encourage private and public institutions to contribute data to the NGDC public archives and/or the EMAG mapping effort.

Acknowledgements

The German CHAMP satellite is operated by GeoForschungsZentrum Potsdam. Airborne and marine magnetic data used for the EMAG global magnetic anomaly grid are acknowledged on a dedicated web page at: http://geomag.org/models/EMAG/acknowledge.html