MESSENGER OBSERVATIONS OF MERCURY'S MAGNETIC FIELD STRUCTURE. Catherine L. Johnson[1,2], Michael E. Purucker[3], Brian J. Anderson[4], Reka M. Winslow[1], Manar Al Asad[1], Haje Korth[4], James A. Slavin[5], Igor I. Alexeev[6], J. Andreas Ritzer[1], Roger J. Phillips[7], Maria T. Zuber[8], Sean C. Solomon[9]. [1]Department of Earth and Ocean Sciences, University of British Columbia, BC, V6T 1Z4, Canada, cjohnson@eos.ubc.ca. [2]Planetary Science Institute, Tucson, AZ 85719, USA, cjohnson@psi.edu. [3]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA. [4]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA. [5]Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan, Ann Arbor, MI 48109, USA. [6]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, 119991, Russia. [7]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302, USA. [8]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA. [9]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC 20015, USA.

Introduction and Overview: Orbital data from the Magnetometer (MAG) on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft allow modeling of Mercury's magnetic fields. Observations inside the magnetosphere extend from ~60°S to 86°N; those below 1000 km altitude are confined to the northern hemisphere, with global coverage in body-fixed longitude and in local time. The orbital observation geometry together with Mercury's weak internal field [1] mean that external fields generated by currents on the magnetopause and in the magnetotail contribute substantially to the measured field strength and orientation. We use a paraboloid magnetospheric model [2,3,4] with a cross-tail current sheet to quantify the time-averaged internal dipolar field and external fields. The best-fit model for observations taken during the first 264 days in orbit provides an excellent first-order fit to the data, with residuals in field magnitude typically less than ±10% of the observations. The dipole field is southward-directed, offset northward along the rotation axis from the planetary center by 484 km, with a negligible tilt, and a dipole moment of 195 ± 10 nT-R_M^3 [5]. Residuals contain multiple signatures of different origins, such as plasma within the magnetosphere [6] including the high latitude northern cusp [7], and possible signatures of remanent crustal magnetization [8]. In this, and a companion paper [8], we investigate how to minimize the contributions of signals that are dominantly controlled by magnetic local time, to then analyze non-dipolar contributions to the internal field of either crust or core origin.

Magnetospheric Model: The paraboloid magnetospheric model includes 11 parameters that collectively describe the internal and external fields. The orbital observations allow us to estimate these parameters directly from the magnetic field observations as described below. We do not model penetration of the interplanetary magnetic field into the magnetosphere, since this varies on an orbit-by-orbit basis and our interest here is in establishing the long-wavelength, time-averaged contributions to the field. We include an aberration correction in the model, calculated for each MESSENGER orbit using Mercury's instantaneous orbital speed and a mean solar wind speed of 405 km/s.

Magnetopause Fields. Fields due to currents on the magnetopause (MP) depend on the internal dipole field (below) and the MP shape. The MP shape is specified by two parameters: the subsolar stand-off distance (R_{SS}) and the flaring of the magnetopause (γ) [2]. Inbound and outbound MP crossings are identified on each magnetosphere pass. The crossings are fit well on the dayside and on the nightside close to the planet by a paraboloid of revolution with R_{SS} = 1.4 R_M (where R_M is Mercury's radius). Although the MP crossings are consistent with a value for γ greater than 1, such values yield unrealistic MP shapes in which the minimum distance to the MP boundary is not at the subsolar point. We thus set γ equal to 1. We also fit a Shue model [9] to the magnetopause crossings; this model provides a better overall fit to the MP crossings, and in particular provides a good fit to the crossings at large down-tail distances.

Tail Fields. Fields due to the tail current sheet are specified by three parameters: the current sheet half-width (D_D), the closest approach of the current sheet to the planet (R_2), and the flux in one tail lobe (F), or an equivalent tail field parameter (B_T) [2]. The current sheet is identified in the MAG data via a rotation in the field direction and a depression in the field magnitude, B. We find a median half width of 0.31 R_M close to the planet and 0.13 R_M at greater downtail distances. The tail flux is calculated using the Shue MP boundary model and observations of B in the southern lobe, away from the influence of the planetary field and the MP boundary. This procedure gives an average tail flux of 2.6 MWb. In the magnetospheric model we use average values for D_D, R_2, and B_T (where B_T is calculated from F, D_D and R_2) of 0.25 R_M, 1.3 R_M and 140 nT, respectively.

Internal Dipole Field. The internal dipole field is specified by six parameters: the dipole offset along three orthogonal axes (*DX*, *DY*, *DZ*), the colatitude and longitude of the pole, and the dipole moment (*m*). We use the MAG data to constrain the dipole tilt and offset. Observations of Mercury's magnetic equator indicate that it is offset northward from the planetary center: i.e., *DX*=*DY*=0, and *DZ*=0.198 R_M. To first order, the field is axisymmetric about the rotation axis. The last remaining model parameter, *m*, is constrained by the goodness-of-fit of the model to the MAG data, and we find $m = 195 \pm 10$ nT-R_M^3 [5].

Results: The paraboloid model successfully matches the first-order global signature of the field, with residual amplitudes typically less than 50 nT. An example for the second Mercury year of data is shown in Figure 1. In aberrated Mercury solar orbital (MSO) coordinates, the cusp signature is seen clearly in the residuals as the magnetic field depression north of ~60°N, approximately centered on local noon. Other signatures in the residuals governed by local time are plasma signatures in the tail current sheet and orbit-to-orbit and within-orbit signatures due to temporal variability in magnetospheric currents and/or currents not captured in the paraboloid model.

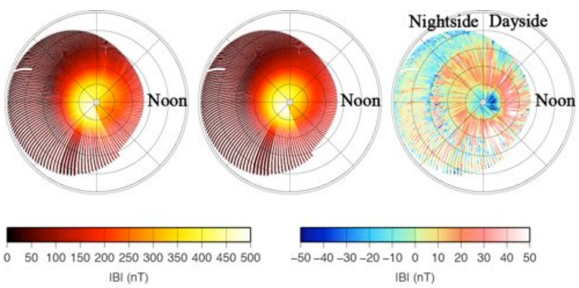

Figure 1. Stereographic maps of magnetic field magnitude, *B,* in aberrated MSO coordinates for the second Mercury year of observations. Left-to-right: data, model predictions at observation locations, residuals (B_{data} - B_{model}). Grid lines in local time are every 3 h. Maps are plotted from 60°S to the north pole; latitude grid lines are every 30°.

To further investigate possible signatures of internal origin in the residuals, we show the residuals from four sidereal days in Mercury body-fixed (MBF) coordinates (Figure 2). North of 30°N spacecraft altitudes are below 700 km, so this region is best suited to investigations of internal fields. Criteria for contributions due to steady core fields or remanent crustal magnetization include repeatability from one MBF transit to another, and signals in the radial, colatitudinal, and azimuthal components that are consistent with a common field geometry. The latter two components are not consistent from one transit to another, and, in fact, these signatures are better organized in the MSO frame. The radial field component exhibits signatures of the cusp region, but also a positive anomaly north of 60°N, elongated in the longitude region around 45°E and consistent among all four transits. In a companion paper [8] we specifically investigate a crustal origin for this signature.

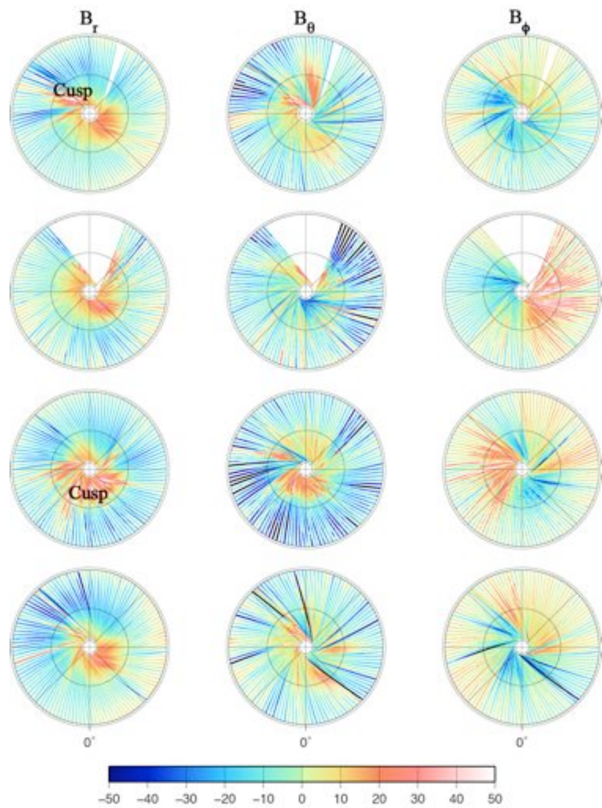

Figure 2. *R*esiduals for descending tracks in MBF coordinates. Rows (top to bottom) show residuals for the first through fourth sidereal day of MESSENGER observations. Columns are the radial, colatitudinal, and azimuthal components of the residuals. Data are plotted north of 30°N, latitude lines are every 30°, and 0° longitude is labeled in the bottom row.

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