MERCURY'S MAGNETIC FIELD: ASSESSING THE EFFECTS OF EXTERNAL FIELDS ON INTERNAL FIELD MODELS. Catherine L. Johnson[1,2], Hideharu Uno[1], Michael E. Purucker[3], Brian J. Anderson[4], Haje Korth[4], James A. Slavin[3], and Sean C. Solomon[5], [1]Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Road, Vancouver, BC, V6T 1Z4, Canada, cjohnson@eos.ubc.ca; [2]Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, CA 92093-0225; [3]Raytheon at Planetary Geodynamics Lab, Code 698, NASA Goddard Space Flight Center, Greenbelt, MD 20771; [4]The Johns Hopkins University Applied Physics Laboratory, 11100 John Hopkins Road, Laurel, MD 20723-6009; [5]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington, DC 20015-1305.

Introduction: Vector magnetic field data returned from the first two flybys of Mercury by the MESSENGER spacecraft confirm the presence of an intrinsic magnetic field [1]. Analyses of the combined data set provided by the MESSENGER and Mariner 10 flybys yield the following constraints on Mercury's internal field: (1) The field structure is primarily dipolar, aligned close to the planet's spin axis [1, 2], and with a strength ~1% of Earth's dipole field [1], (2) residual signal can be modeled by long-wavelength latitudinal and longitudinal structure in the internal field, likely due to core rather than crustal fields [2, 3], (3) the absence of small-scale features in the field near MESSENGER's closest approaches suggests that crustal magnetization is weak [3] or coherent over spatial scales much smaller than the spacecraft altitude.

Assessment of hypotheses for the origin of Mercury's internal field requires characterization of large-scale structure in the field. Inferences to date are limited by the restricted number and geometry of observations, and by difficulties in assessing the contributions of external fields to the observations. Observations taken while MESSENGER is in orbit about Mercury will greatly improve geographical coverage, but Mercury's magnetic field environment will present challenges to the removal of external fields not previously encountered in planetary magnetic field modeling.

We discuss several approaches to modeling external fields, differences among the resulting external field estimates, and their implications for assessing internal field structure and its origin.

Mercury's Magnetic Field Environment: The interaction of Mercury's internal magnetic field with the solar wind and interplanetary magnetic field (IMF) at Mercury might be expected to be similar to that at Earth because of the mainly dipolar nature of the internal fields of the two planets. However, significant differences between the two magnetic field environments result from Mercury's relative proximity to the Sun and the planet's weak dipole moment. At Mercury's orbit, the solar wind pressure is typically a factor of four to ten times greater than at Earth while the IMF is roughly a factor of two to five greater in intensity and more strongly aligned with the planet-Sun line than at Earth. At Earth, external fields (those generated above the planetary surface) include contributions from magnetopause currents, tail currents, the ring current, and field-aligned currents. At Mercury a terrestrial-like closed ring current is unlikely [4], but numerical simulations suggest the presence of a ring of plasma close to the planetary surface [5], in which case this picture may be complicated by diamagnetic effects. Field-aligned currents may not exist at Mercury in a manner analogous to Earth is because of the absence of a conducting ionosphere [4]. In addition, the two flybys of Mercury by MESSENGER illustrate the dynamic nature of Mercury's magnetosphere [6].

Field Modeling Approaches: The magnetic fields measured by MESSENGER and Mariner 10 inside the magnetosphere include contributions from external and internal fields that can be modeled as follows:

Internal Fields. Contributions from Mercury's core and/or crustal fields measured above the planetary surface can be described via a spherical harmonic expansion. The model vector is expressed as Schmidt partially normalized spherical harmonic coefficients, g_l^m and h_l^m, where l and m are the spherical harmonic degree and order, respectively. The internal field is best described in the planetocentric Mercury-Body-Fixed (MBF) coordinate system. The geometry of the observations (coverage and spacecraft altitude) governs the choice of the maximum spherical harmonic degree. Two approaches in planetary field modeling are common. In the first, a truncated least squares or singular value decomposition is performed; typically for Mercury internal field structure is then investigated as far as degree and order 2 [1, 3]. In the second, model structure is restricted by imposing a constraint on the spherical harmonic power spectrum, rather than by restricting the number of model coefficients [2].

External Fields. Recent models for Mercury's external fields have been constructed in one of two ways:

(1) Co-estimation of internal and external fields from the vector magnetic field data: The external field is also described in terms of spherical harmonics; implicit in this assumption is that the observations are made in a region free of current sources. In contrast to internal fields, external fields are best described in the

Mercury-Solar-Orbital (MSO) coordinate system (+x sunward, +z northward perpendicular to the orbit plane, + y-axis completes the right-handed system). The advantage of this approach is that internal and external fields are estimated simultaneously from the inversions; a disadvantage is that the sparse coverage provided by the flyby data severely restricts the complexity of models that can be investigated. Even for models to degree and order two for both the internal and external fields, correlations among model coefficients are high. The latter problem is compounded by the time-varying nature of the magnetosphere, which suggests that a separate external field model may need to be estimated for each flyby. A major limitation of this technique is the requirement that the observations be made in a source-free region. Such observations will likely comprise only a small fraction of data, even during the orbital phase of the mission.

(2) Parameterized models for the magnetospheric current systems: The fields due to magnetospheric current systems are modeled and removed from the data, and the residuals inverted for internal field structure [1-3]. The advantage of this approach is that the locations of magnetopause crossings, solar wind, and IMF data as well as vector magnetic data are used to estimate external fields [5]. At present this approach suffers from the disadvantage is that the models are based on the *TS04* model derived for Earth [7] and may not adequately describe Mercury's environment [5, 8].

Results: External fields are calculated using both approaches. As in [1-3] we use the *TS04* model. The *TS04* model predictions are based on the assumption that the internal field is a centered dipole. We apply the co-estimation approach in two ways, estimating external fields up to $l, m = 2$, and including all spherical harmonic terms: (1) We estimate a single external field model by combining data from all four flybys (i.e., assuming a time-invariant long-wavelength external field geometry). (2) We estimate a separate external field for each flyby. For the co-estimation solutions we model the internal field either to $l, m = 2$ with no regularization or to $l, m = 8$ with a regularized inversion.

Significant differences among the predicted external fields are seen (Figure 1). The results of the co-estimation approach depend on whether different external fields are permitted for each flyby, and on how the internal field is modeled. For example, a single external field model for all four flybys predicts structure in the B_ϕ component along the trajectory for the second MESSENGER flyby of Mercury that is not seen in the data. Much of the variability is currently due to limited data coverage.

We investigate how these differences among external field models affect the resulting internal field structure. The largest effect is on the g_1^0 term, which shows a 20-25% variation for different external fields [1].

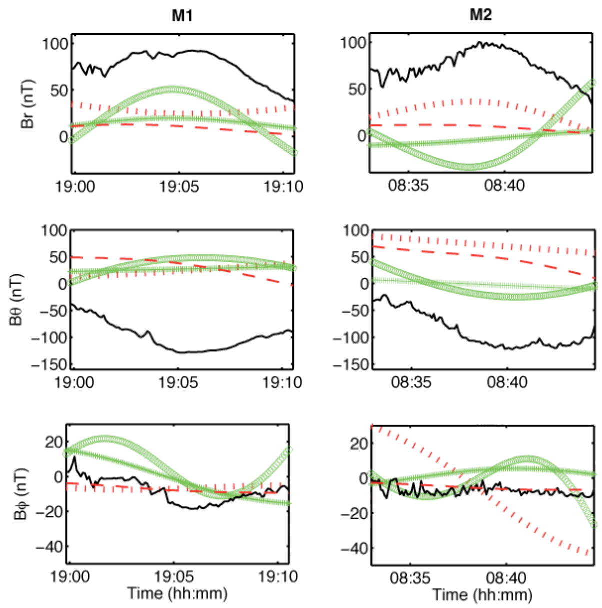

Figure 1: Predictions of external field models for the three orthogonal field components B_r, B_θ, B_ϕ for MESSENGER's first (M1) and second (M2) flybys. External field models: TS04 model (red dashed line), single external spherical harmonic model (red dotted line), different external spherical harmonic models for each flyby for an $l, m = 2$ internal field (green circles), and an $l, m = 8$ regularized internal field (green plus symbols). For reference the magnetic field data are shown (black solid).

We quantify differences in structure in the non-dipolar contributions ($l, m > 1$) to the internal field and assess which of the external field approaches yields the best solution. We investigate whether the spectral techniques [9] designed originally for constant-altitude data can be applied to flyby data to assess wavelength bands uncontaminated by external fields.

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