ANALYSIS OF MAGNETIC FIELD DATA FROM THE THIRD MARINER 10 FLYBY OF MERCURY: COMPARISON WITH MESSENGER DATA AND CONSTRAINTS ON SECULAR VARIATION. Lydia C. Philpott[1], Catherine L. Johnson[1,2], Reka M. Winslow[1], Brian J. Anderson[3], Haje Korth[3], Michael E. Purucker[4], Sean C. Solomon[5], [1]Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, BC, V6T 1Z4, Canada, lphilpott@eos.ubc.ca. [2]Planetary Science Institute, Tucson, AZ 85719, USA. [3]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA. [4]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA. [5]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.

Introduction. Mariner 10's third Mercury flyby on 16 March 1975 (hereinafter M10-III) confirmed the existence of an intrinsic magnetic field suggested by the first flyby in 1974 and provided an initial estimate of 330 nT-R_M^3 for the dipole moment [1], where R_M is Mercury's radius. Subsequent analyses of the M10-III data yielded a dipole moment of 136-350 nT-R_M^3, the large range of estimates reflecting the uncertainties in the magnetopause and non-dipole fields [2]. Orbital data from the Magnetometer (MAG) on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft have enabled the development of a baseline time-averaged magnetic field model for Mercury's magnetic field. The model includes an average dipole moment of 190 nT-R_M^3, offset 0.2 R_M north of the planetary equator [3,4].

The Mariner 10 and MESSENGER observations are separated by nearly 40 years. We revisit the M10-III data using techniques developed in the analysis of MESSENGER data and look for evidence of secular variation in the planetary field. We examine the M10-III data for changes in the location of the magnetic equator and in the dipole moment. Taken together, these two mission data sets constrain estimates of secular variation in the axial dipole and axial quadrupole components of Mercury's dynamo field.

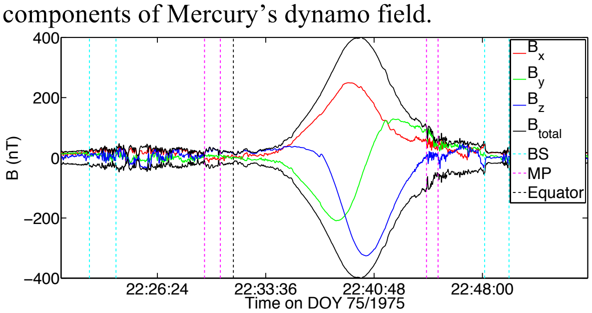

Figure 1. Magnetic field data from the M10-III flyby. The positions of the bowshock (BS) and magnetopause (MP) crossings and the magnetic equator are identified (vertical dashed lines, see legend).

Analysis of M10-III magnetic field data.

Magnetopause Boundary Positions. Following the method used for MESSENGER orbital data [5], we identified inner and outer limits for the inbound and outbound M10-III magnetopause crossings (Figure 1) after transforming the data to Mercury Solar Orbital (MSO) coordinates [5]. These magnetopause positions agree with those previously identified [6].

Magnetic Equator Identification. For a spacecraft trajectory crossing the magnetic equator, the equator position can be identified by $B_\rho = 0$, where B_ρ is the radial component of the magnetic field in a cylindrical coordinate system in which the z-axis is aligned with the planetary spin axis. Analysis of MESSENGER equator crossings between 24 March 2011 and 2 March 2012 yielded an average equator offset of 479 ± 6 km for descending (low-altitude) crossings and 486 ± 74 km for ascending (high-altitude) crossings [7]. We used this approach to identify the equator crossing for the Mariner 10 third flyby. The M10-III data yielded an equator offset of 882 ± 35 km (Figure 2).

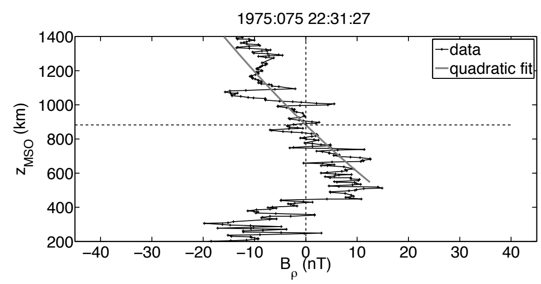

Figure 2. z_{MSO} vs. B_ρ for the M10-III flyby in the region near the equator crossing. A quadratic fit is shown by the solid gray line; the dashed lines indicate the magnetic equator crossing obtained from the fit.

The M10-III equator crossing occurs at an altitude of 3415 km and an MSO longitude of 113°E, a comparable altitude and MSO longitude to some of the ascending (high-altitude) MESSENGER equator crossings. We analyzed ascending MESSENGER equator crossings between 24 March 2011 and 27 September 2012 and identified 39 equator crossings in the longitude interval 80°E to 125°E (Figure 3). Although the identified M10-III equator offset of 882 ± 35 km is significantly different from the average equator offset determined from the MESSENGER orbital data, it is not atypical when compared with ascending MESSENGER crossings at similar MSO longitudes.

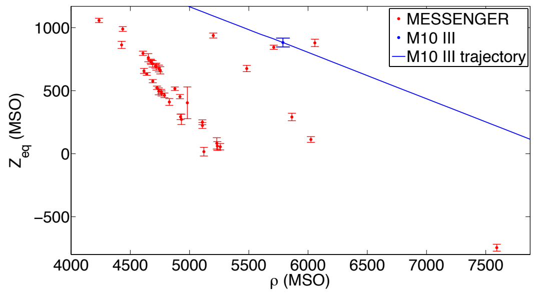

Figure 3. Magnetic equator crossing z_{MSO} position, Z_{eq} vs. $\rho = (x^2_{MSO} + y^2_{MSO})^{1/2}$, for ascending MESSENGER equator crossings with MSO longitudes between 80°E and 125°E. The M10-III flyby equator crossing is shown, together with the spacecraft trajectory in this region. Error bars indicate three standard errors.

Dipole moment estimation. In the time-averaged baseline model [4] derived from the MESSENGER orbital data, all but one of the model parameters were directly estimated from the data. The final parameter, the dipole moment *m*, was obtained via a grid search. To compare the M10-III data with the MESSENGER-derived baseline model, we considered the variation of three parameters: the dipole offset Z_d, the sub-solar magnetopause distance R_{SS}, and the dipole moment *m*. We estimated the best-fit dipole moment to the M10-III profile by considering two values of Z_d: the average equator offset of 479 km from the MESSENGER orbital data [7], and the instantaneous equator offset of 882 km observed in the M10-III data.

The sub-solar standoff distance was estimated from the M10-III magnetopause crossing positions using a model magnetopause [5,8], the two values for the equator offset described above, and a correction for the solar wind aberration [4]. We found an average R_{SS} from the inner and outer inbound magnetopause crossing positions of 1.40 R_M for both values of Z_d, and average outbound values of 1.21 R_M and 1.12 R_M for Z_d = 479 km and 882 km respectively. We also considered an R_{SS} value derived from the average relationship between Mercury's heliocentric distance, r_{helio}, and the magnetopause standoff, as determined from the MESSENGER data: $R_{SS} = 1.9855\ (r_{helio})^{1/3} = 1.54\ R_M$.

The dipole moment was obtained by a grid search to minimize the misfit between the magnetospheric model and the M10-III data. This grid search was carried out for each of the six combinations of the two Z_d values and three R_{SS} values. The results are summarized in Table 1. A comparison of the fits shows that a dipole offset of Z_d = 479 km results in a better fit to the data than an offset of Z_d = 882 km, and that the results are relatively insensitive to the choice of R_{SS}.

MESSENGER flybys. We also revisited the first and second MESSENGER flybys of Mercury (hereafter M1 and M2, respectively) that occurred in 2008. As these flybys were almost equatorial we could not obtain an estimate of the instantaneous magnetic equator position, so we used the average offset of Z_d = 479 km. The R_{SS} values for M1 and M2 using the heliocentric distance scaling are 1.41 R_M and 1.39 R_M, respectively. The dipole moments obtained for M1 and M2 (Table 1) are consistent with the average dipole moment obtained from the MESSENGER orbital data [4].

Table 1. Best-fit dipole moment, *m*, for the M10-III, M1 and M2 flybys. See text for details.

	Z_d (km)	R_{SS} (R_M)	m (nT-R_M^3)	RMS misfit (nT)
M10-III	479	1.21	187	9.53
	882	1.12	123	30.39
M1	479	1.41	190	15.34
M2	479	1.39	186	11.34

Discussion and summary. Data from the third Mariner 10 flyby and the first two MESSENGER flybys yield no evidence for secular variation in Mercury's dipole moment. Although the position of the magnetic equator at the time of the M10-III flyby was found to be considerably higher than the average value obtained from the MESSENGER orbital data, it nonetheless lies within the range of values seen in MESSENGER crossings with similar trajectories. A paraboloid model with a dipole offset of 479 km was found to provide a significantly better fit to the M10-III data than a model with an offset determined from the magnetic equator crossing position for M10-III. Furthermore, with Z_d = 479 km the best-fit dipole moment m = 187 nT-R_M^3 agrees well with the average value from the MESSENGER orbital data. Our results, together with error estimates on the best-fit dipole moment, suggest that any variation in Mercury's axial dipole and axial quadrupole terms over the past four decades are smaller than ~10 nT and ~4 nT (40% of the axial dipole term [7]), respectively.

References. [1] Ness N. F. et al. (1975) *Nature 255,* 204-205. [2] Connerney J. E. P. and Ness N. F. (1988) *Mercury*, pp. 494-513. [3] Anderson B. J. et al. (2011) *Science 333*, 1859-1862. [4] Johnson C. L. et al. (2012) *JGR 117*, 10.1029/2012JE004217. [5] Winslow R. M. et al. (2013) *JGR Space Physics 118,* 10.1002/jgra.50237. [6] Ness N. F. et al. (1976) *Icarus 28*, 479–488. [7] Anderson B. J. et al. (2012) *JGR 117,* 10.1029/2012JE004159. [8] Shue J.-H. et al (1997) *JGR 102,* 10.1029/97JA00196.