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A Dynamic Model of Mercury's Magnetospheric Magnetic Field

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1. Introduction

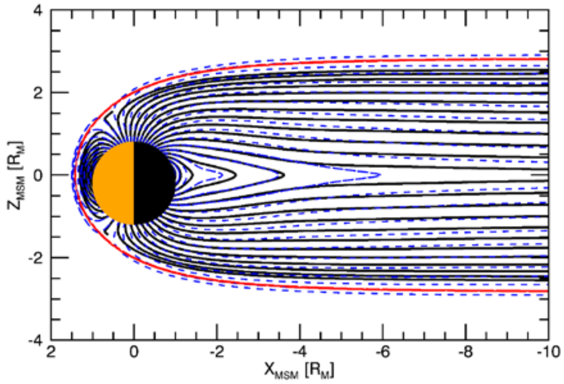
Mercury's solar wind and interplanetary magnetic field environment is highly dynamic, and variations in these external conditions directly control the current systems and magnetic fields inside the planetary magnetosphere. We update our static KT14 model of Mercury's magnetic field [1] by incorporating variations in the magnetospheric current systems, parameterized as functions of Mercury's heliocentric distance and magnetic activity [2] to yield the first dynamic model of Mercury's magnetospheric magnetic field. The new model, termed KT17, uses the same structure and mathematical framework as the KT14 model, but includes variable parameterizations for the magnetopause standoff distance and for the magnetotail current intensity.

2. Dependence of Parameters on Magnetic Activity

The solar wind dynamic pressure balances the magnetic pressure of the planetary field at the magnetopause so that temporal variations in ram pressure affect the location of the sub-solar magnetopause, R_{SS}. To determine the dependence of R_{SS} on magnetic activity, we followed the approach in [3]. First, we fit a model magnetopause to the magnetopause crossing locations observed during the period from Mercury orbit insertion on 24 March 2011 to the end of the MESSENGER mission on 30 April 2015. Then, the R_{SS} values were then sorted into 20%-wide bins of the magnetic disturbance index, and the average R_{SS} and Mercury's average heliocentric distance of the observations, r_h, were computed for each magnetic disturbance bin. The linear fit to the r_h-normalized R_{SS} values as function of the magnetic disturbance index shows that the magnetopause standoff distance decreases with increasing magnetic activity as is expected if the increased magnetic activity is associated with higher solar wind dynamic pressure.

An increase in magnetic activity also leads to an enhancement of the electric current that flows in the central magnetotail from dawn to dusk to form the cross-tail current sheet. The cross-tail current generates an external magnetic field, which was modeled as a superposition of a disk and a sheet current [1]. To determine variations in the cross-tail current intensity with magnetic activity, 1-min averages of magnetic field observations acquired within the magnetosphere were sorted into bins of the magnetic disturbance index each again 20% wide. The data in each bin were then fit by minimizing the root-mean-square (rms) residual of the model field with respect to the MESSENGER observations to yield the current intensity parameters for each range of magnetic activity. The minimization procedure accounts for dependence of R_{SS} on r_h determined above. Linear fits to these parameters as a function of magnetic disturbance index were calculated. Higher cross-tail current intensities were obtained for higher magnetic activity. This result is consistent with the hypothesis that elevated magnetic activity leads to higher reconnection rates, stronger circulation of magnetic flux, and, ultimately, an increase in the strength of the cross-tail current.

A magnetic activity-dependent model of Mercury's magnetic field was developed by replacing the static values of the sub-solar magnetopause standoff distance and the cross-tail current intensity parameters in the KT14 model with the linear dependencies on the magnetic disturbance index identified above. The figure below shows the magnetic field configurations of the revised model, termed KT17, for magnetic disturbance indices of 95% (black line) and 5% (blue dashed line) together with the average magnetopause (red line) for the 50% activity level. The tracing of magnetic fields lines shows a modest change in the size of the magnetosphere in response to variations in magnetic activity.



3. Summarized Discussion

The new, dynamic model reproduces the location of the magnetopause current system as a function of systematic pressure variations encountered during Mercury's eccentric orbit, as well as the increase in the cross-tail current intensity with increasing magnetic activity.

To test improvements in the model afforded by dynamic specification of parameters, we computed the residuals between the observed magnetic field and that modeled using the associated magnetic disturbance index and heliocentric distance. The rms value of these residuals is a measure for the goodness of the model, and a reduction thereof is an indicator for the improvement of the model. The rms residual of the KT17 model computed from data acquired between Mercury orbit insertion and the end of the mission is 25.3 nT and is slightly higher than the 24.8 nT reported for the KT14 model, which was fit to data acquired from orbit insertion to 28 November 2012. The increase in the magnitude of the residual field may result from higher solar activity during the later orbital mission phase as indicated by a secondary maximum in the sun spot number in 2014 that was higher than that during the first peak in 2011. Consistent with this conjecture, the rms residual of the KT14 model fit to the entire orbital dataset is 26.5 nT, which is slightly higher than the value obtained for the KT17 model. Comparison of the misfit shows that the KT17 model yields only a minor reduction of the rms residual. Thus, despite the enhancements in the external field parameterization, the residuals between the observed and modeled magnetic field inside the magnetosphere indicate that the dynamic model achieves only a modest overall improvement over the previous static model.

The spatial distribution of the residuals in the magnetic field components shows substantial improvement of the model accuracy near the dayside magnetopause. Elsewhere, the large-scale distribution of the residuals is similar to those of the static model. This result implies either that magnetic activity varies much faster than can be determined from the spacecraft's passage through the magnetosphere or that the residual fields are due to additional external current systems not represented in the model or both. Birkeland currents flowing along magnetic field lines between the magnetosphere and planetary high latitude regions have been identified as one such contribution. The remaining dependence of the magnitude of the residuals on magnetic activity is consistent with this conjecture.

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