EPSC Abstracts
Vol. 12, EPSC2018-324, 2018
European Planetary Science Congress 2018

A Proxy for the Upstream IMF Clock Angle at Mars

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Abstract

A method to estimate the upstream direction of the interplanetary magnetic field using downstream magnetic field data is developed. We select MAVEN magnetic fields data in the martian magnetosheath from a single orbit. The magnetic field direction is compared to an empirical model, based on statistical averages of the draped magnetic field direction. Different rotations of the data around the Mars-Sun line are attempted to find which rotation provides the best fit to the data. The method is validated by comparing the proxy clock angle to measured values from orbits when an upstream measurement is made close in time to the downstream measurement. The distribution of proxy clock angles is compared to the observed distribution and are found to be similar.

1. Introduction

An important factor in the interaction of the solar wind with Mars is the direction of the motional electric field in the interaction region, which is set by the direction of the upstream Interplanetary Magnetic Field (IMF) in the plane perpendicular to the solar wind velocity, or the clock angle, ϕ_{IMF}. Although MAVEN often measures ϕ_{IMF}, there are some epochs in which MAVEN does not cross into the solar wind. Furthermore, ϕ_{IMF} is variable on timescales on the same order as the MAVEN orbital period. Thus, a method for estimating ϕ_{IMF} is a useful tool to enable other studies of the solar wind interaction with Mars.

2. Method

We use data from the MAVEN MAG with 30-s time resolution from the magnetosheath on a single orbit and compare those data to an empirical model of the draped magnetic field direction. Magnetosheath data from a single orbit are selected using the fitted location of the bow shock as the upper boundary and the magnetic pileup boundary as the lower boundary [1]. Various limitations of the solar zenith angle of the data included were attempted. The results provided here use data from within solar zenith angles between 45°-135°. Data from 23 Dec 2014 – 14 Aug 2017 were used in this analysis.

The empirical model is a statistical median of the magnetic field direction in the martian magnetosheath in Mars-Solar-Electric field (MSE) coordinates [2]. Three different models are implements based on the upstream magnetic field sign in Mars-Sun direction: $+B_x$, $-B_x$, and $+/-B_x$. The three cases are employed because the B_x component changes polarity as in different IMF sectors. The median approach select values close to zero when data from both sectors are used. This model is binned in Cartesian bins of 0.3 R_M on a side spanning from +/-3 R_M in x, y, and z.

For each MAG magnetosheath data point along the MAVEN trajectory, we compare the direction of the magnetic field with the direction of the model magnetic field in the relevant spatial grid cell. A goodness of fit is computed by

$$\chi^2 = \sum_i \chi_i^2 = (1 - \mathbf{b}_{i\ \mathrm{model}} \bullet \mathbf{b}_{i\ \mathrm{measured}})^2 \qquad (1)$$

The orbital data are then rotated by 1° around the Mars-Sun line and χ^2 for this rotation is calculated. We iterate through 360° in 1° increments to find the rotation with the minimum χ^2 value. This angle is the angle that aligns best with the model of draping in MSE coordinates, so it is the upstream clock angle that produces MSE coordinates for the given orbit, ϕ_{proxy}.

3. Results

The distribution of ϕ_{proxy} is compared with the distribution of ϕ_{IMF} in Figure 1. The distributions are very similar, suggesting that the proxy is able to detect the upstream clock angle fairly well. In Figure

2, a comparison is made between ϕ_{proxy} and ϕ_{IMF} for the orbits when the upstream IMF is measured within 2.5 hours of the proxy value. We examine the distribution of the difference between ϕ_{proxy} and ϕ_{IMF}. Although there are many orbits in which the difference is greater than 10°, the IMF direction is known to change on timescales smaller than 2.5 hours. For example the difference between ϕ_{IMF} from one orbit to the next, or a 5 hour separation is shown in Figure 2 as well. The proxy yield more difference values in the 0-10° bin than the actual variations from orbit to orbit.

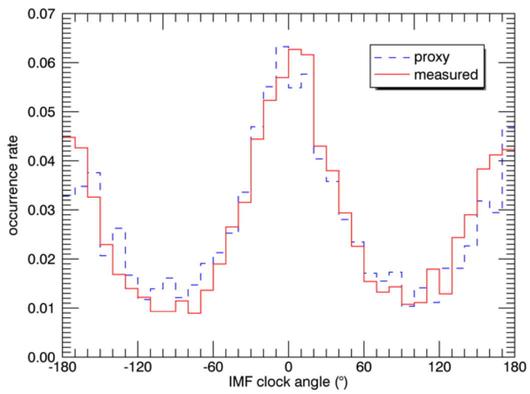

Figure 1: Comparison between the distribution of clock angles measured upstream of Mars by MAVEN and those determined through the proxy method.

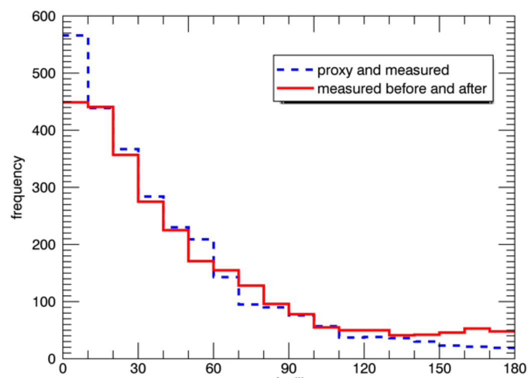

Figure 2. The difference in the proxy value and the measured upstream value is shown in blue. In addition, the natural variation in IMF direction on 5 hour time scales is also shown in red.

4. Conclusions

The proxy developed here is one way to estimate the upstream IMF clock angle using data from within the martian magnetosheath. Other methods also exist [3, 4]. This method may be employed when the spacecraft does not venture into the upstream solar wind, or when the solar wind orientation may have changed from the orientation measured when MAVEN is upstream. Future work may estimate the cone angle of the IMF and the magnitude.

Acknowledgements

Funding for this work was provided by NASA through grant NNX16AL45G. MAVEN MAG data are available at the NASA Planetary Data System.

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