Determining Equatorial Magnetospheric Plasma Density Through Solar Wind Pressure Changes

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Overview: Pressure fronts in the solar wind induce a shock in the terrestrial magnetosphere when they impact it. By measuring the differential travel-times of these shocks the density distribution of the plasma can be determined.

This model utilizes a modified form of travel-time magnetoseismology initially developed by Chi and Russell[1]. In the future, we hope to extend our model to 3D as well as explore alternate methods which may improve computation speeds and allow higher resolution profiles to be calculated.

The density structure of plasma in the outer terrestrial magnetosphere is poorly known due to the difficulty of low density measurements and spacecraft charging effects. We have modified a existing method for remotely sensing the magnetospheric plasma density and applied it to the outer dayside magnetosphere.

Dynamic pressure changes in the solar wind interact with the magnetosphere and compress it. Once the front reaches the magnetopause, a wave propagates through the plasma. This wave also enhances the local magnetic field strength.

The shock propagates perpendicular to $\vec{B}$ at the fast mode speed, which is approximately the Alfvén speed.

$$V_A = \frac{B}{\sqrt{\mu_o \rho}}$$

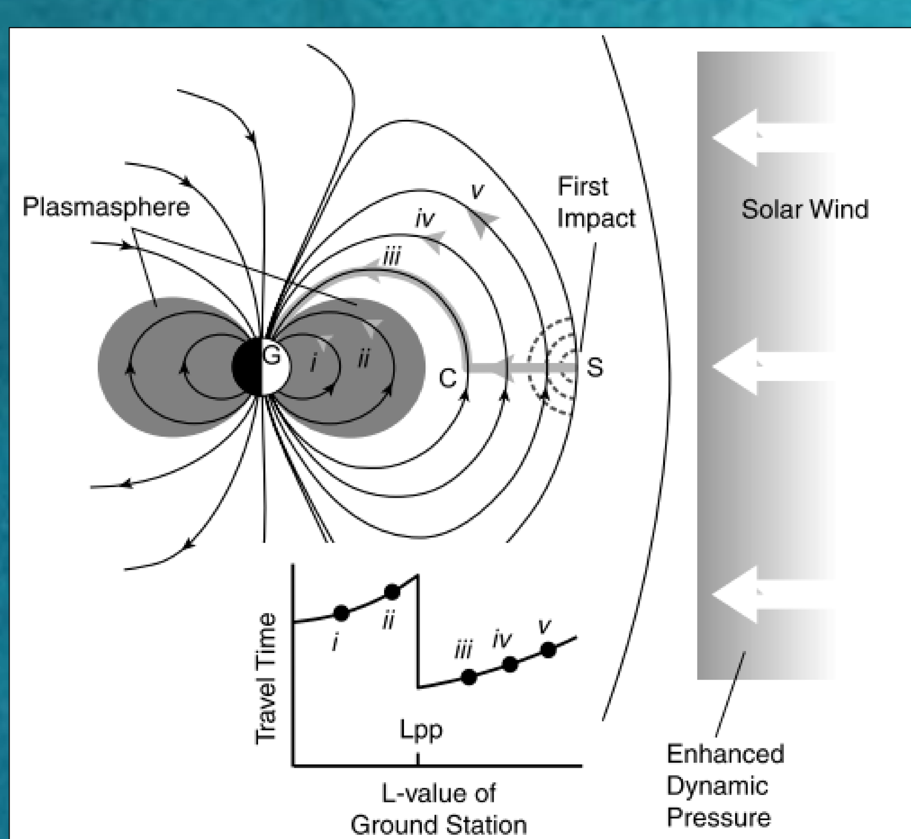

Figure 1: Initially, we are only interested in propagation along the $\overline{SC}$ line. A 3D approach will be a combination of perpendicular and parallel propagation with respect to the field lines.

Image Credit: Chi and Russell[1]

We have adapted travel-time magnetoseismology, originally developed by Chi & Russell[1]. However, we differ in their method as we are solely using satellite data for analysis, whereas their method involved ground based sensors. Initially we are restricting ourselves to the dayside equatorial plane.

We have represented the travel-time integral of the propagation as a linear equation.

$$t = \int_{r_1}^{r_2} \frac{1}{V_A} \cdot d\vec{l} \approx \sum_n \frac{l_n}{V_{A_n}}$$

Which is equivalent to

$$T = A \cdot S$$

Where S is the slowness of each cell, and A is a matrix containing the distance travelled per cell per path. Each cell is assumed to have its own velocity value.

The magnetopause shape assumed was the model determined by Shue et al[2] using magnetopause crossings from ISEE 1 and 2

$$R(\theta) = R_o \left(\frac{2}{1+\cos\theta} \right)^{\alpha}$$

where R_o is the standoff distance and α is the tail flaring parameter. We will be using average values for the standoff distance ($R_o = 10$) and the tail flaring parameter ($\alpha = 0.59$). The magnetopause was initially assumed to be a static object not affected by variations in the solar wind strength or B. The dynamic pressure fronts are also assumed to be planar[3].

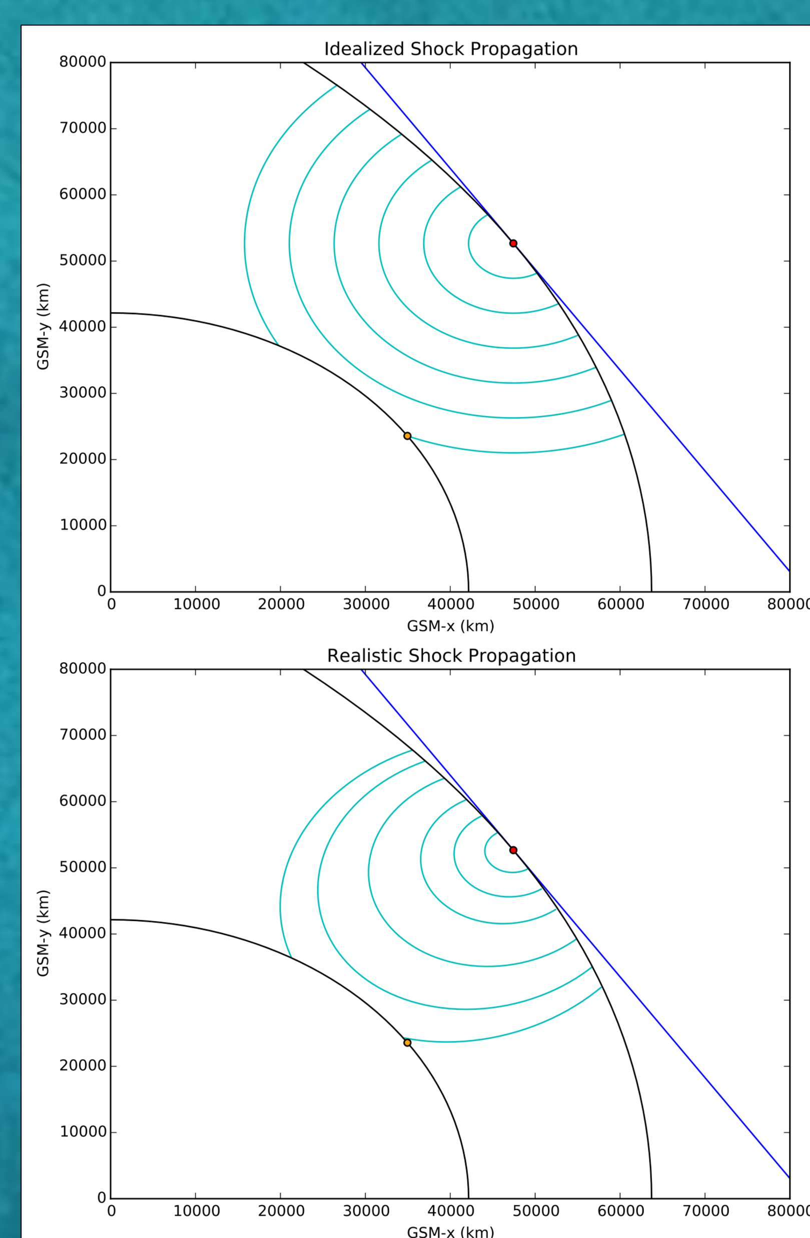

Figure 2: (a) The propagation of the shock assuming uniform Alfvén speed, and (b) assuming a magnetic dipole and the density model suggested by Carpenter et al[4].

The direct travel-times from source to receiver can not be used as we do not know when the shock leaves the magnetopause. We only know when satellites record the event. However, by using the differential travel-time, the difference in recorded time for two satellites recording the same event, there is a suitable time interval for inversion purposes. Instead of the direct path we are using both paths to either satellite to create a differential length. GOES-13 and GOES-15 are well suited for this purpose.

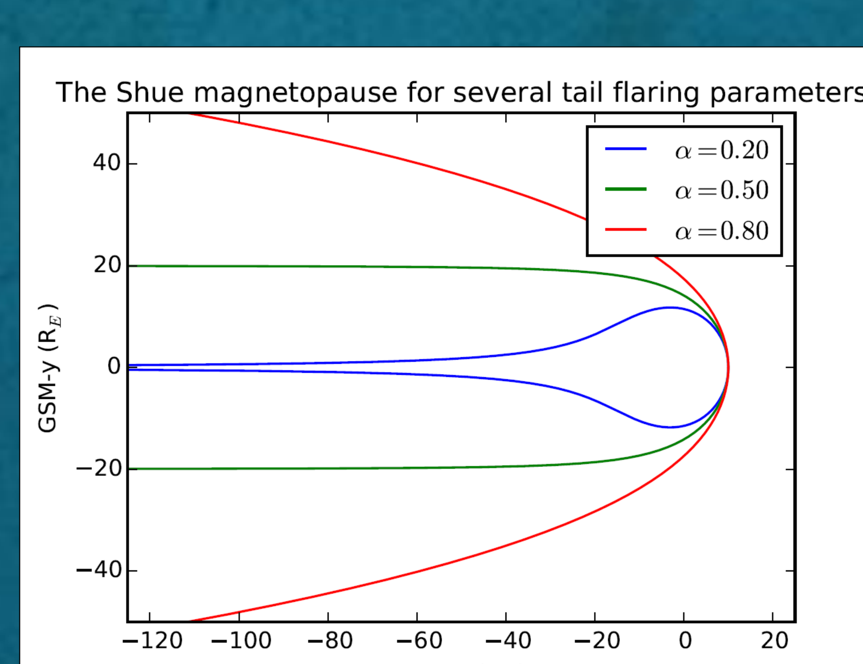

Figure 3: The shape of the Shue magnetopause is closed for $\alpha < 0.5$, opens to a finite thickness for $\alpha = 0.5$ and open for $\alpha > 0.5$. The standoff distance used is $10R_E$.

Acknowledgements:

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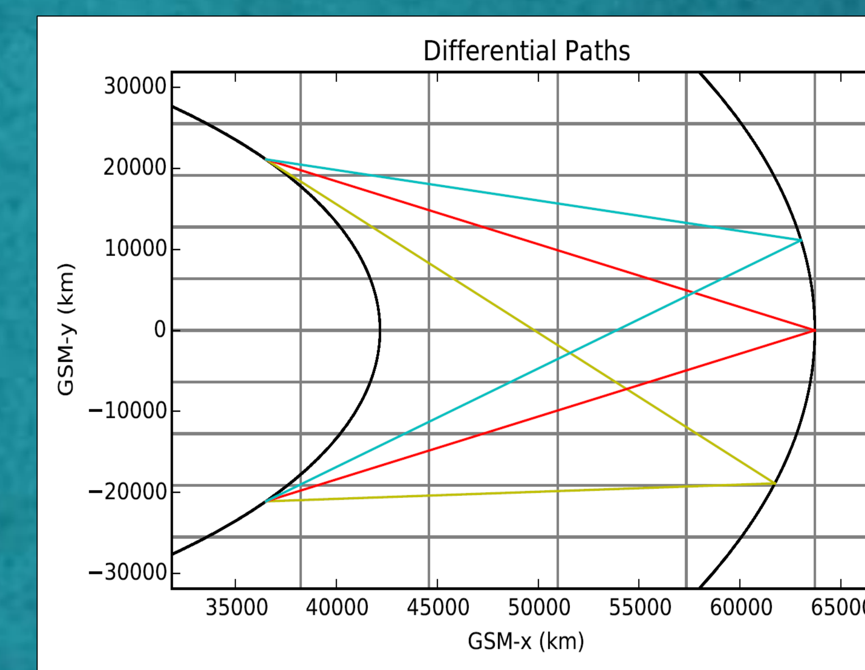

Figure 4: The differential length is simply the difference in path length for each cell in a pair of paths. This can be represented by simply subtracting one row from another.

There is a substantial archive of magnetometer data that we can access. We hope to create density profiles for different solar wind and magnetopause configurations due to changes in $F_{10.7}$ and Interplanetary Magnetic Field B_Z. As well, this data can be correlated with data from the ACE satellite to determine the pressure front orientation. This provides us with all the tools we need to create density profiles.

Future work on this project will include the implementation of a scheme for working in 3D. We can take into account motion both perpendicular and parallel to the field lines.

Uncertainty in the magnetopause geometry will cause errors in the density profile. Exploring how errors in magnetopause structure change the path lengths and thus the velocity profile will demonstrate how accurate our results shall be.

When the technique works in 3D, we can use satellites in any orbit and potentially ground stations as well.

Conclusion: We are developing a new technique for remotely sensing the density of plasma in the outer terrestrial magnetosphere. Existing satellite data can be used to create models which depend on variations in solar wind strength. This allows better knowledge of a region which is not well understood. Future work includes implementation in 3D and examination of changes in the density structure as the solar wind evolves.

References:

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