A comparative study of reconnection X-line predictions on dayside magnetopause of Earth

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Abstract

Magnetic reconnection is a fundamental plasma process of key importance to several fields. Reconnection at Earth's magnetopause drives magnetospheric convection and provides mass and energy input into the magnetosphere/ionosphere system.
Despite this importance, the factors governing the location of dayside magnetopause reconnection are not well understood. Though a few models can predict X-line locations reasonably well the underlying physics is still unresolved. In this study we present results from analysis of several reconnection regions observed by MMS, to determine what quantities are most strongly associated with the occurrence of dayside magnetopause reconnection. We also attempt to answer under what upstream conditions are global X-line models least reliable.
The eventual goal of the project is to quantify the dependence of each model on different states of plasma, both terrestrial as well as solar wind as well as attempt to answer the question "Under what plasma conditions do each model work best?".

Introduction

As solar wind slams into the earth's magnetic field, the magnetic topology gets rearranged and magnetic energy is converted to kinetic energy, thermal energy, and particle acceleration. This process is called magnetic reconnection.
Though reconnection can occur at any place where two different magnetic fields are present, it is often assumed that the locus of point of reconnection on the dayside magnetopause is a line, which we refer to as X-line.
Though some recent studies assert that reconnection happens in a region, in this study we make the assumption that X-line is a continuous structure. Under this assumption, there are several models in literature (see next section) that predict the location of X-lines on the day-side megnetopause. We compare 4 such models. Each of these models maximizes a specific parameter to find the orientation and location of X-lines.

Models

In this study, we chose the following models for comparative analysis:

1. Maximum magnetic shear [Trattner et al., 2007]

$$\cos(\theta) = (\mathbf{B}_{\rm sh} \cdot \mathbf{B}_{\rm msp}) \,/\, (|\mathbf{B}_{\rm sh}||\mathbf{B}_{\rm msp}|)$$

2. Maximum reconnecting field energy [Hesse et al., 2013]

$$E \propto (B_{\rm sh}^2 \times B_{\rm msp}^2)$$

3. Local field bisection [Moore et al., 2002]

$$B_{\rm rec} = |\mathbf{B}_{\rm msp} \cdot \mathbf{i}_{\rm xn}|$$

4. Maximum exhaust speed [Swisdak and Drake, 2007]

$$V_A = \left[\frac{B_{\rm sh} B_{\rm msp}\,(B_{\rm sh} + B_{\rm msp})}{(n_{\rm p,msp} B_{\rm sh} + n_{\rm p,sh} B_{\rm msp})}\right]^{1/2}$$

DATA

Solar Wind data: OMNI [propagated to magnetopause]
Magnetosheath field: Models [Cooling 2001]
Magnetopause location: Models [Shue 1998]
Magnetospheric field: Models [Tsyganenko 1996 and IGRF]
Observational data: MMS [FPI and FGM]

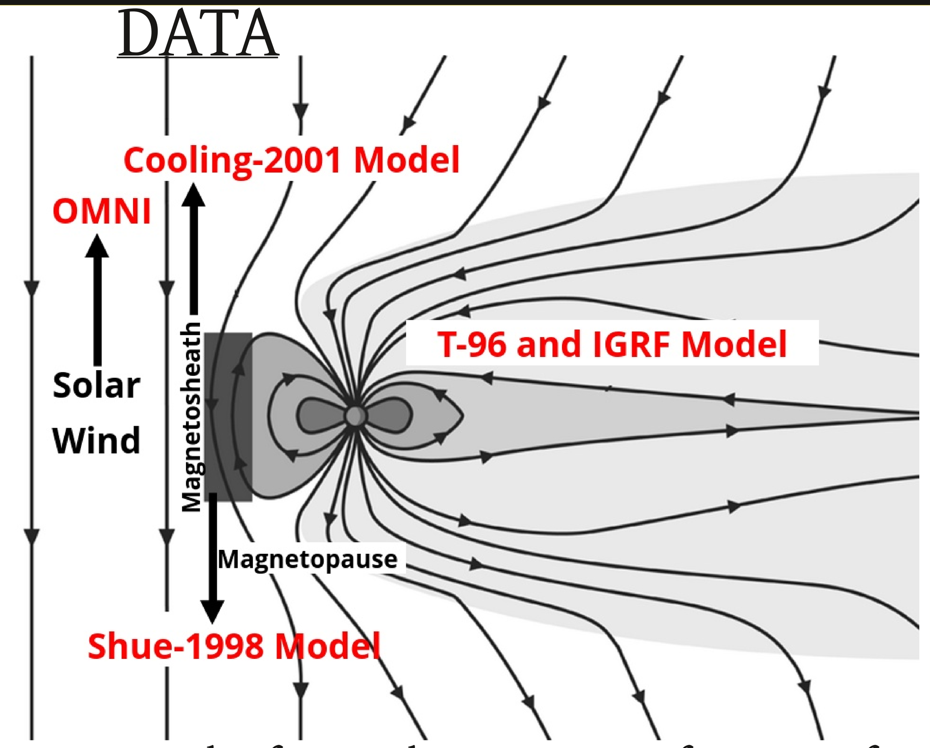


Figure 1: The figure shows region of interest for this study (dark rectangular region), and where we got the data from for different parts.

Methodology

1. Identify magnetopause crossings by MMS. We rely on database maintained by Haaland et al. for this dataset.
2. Check if:
   a) Crossing is close to sub-solar point (within 5 R_E)
   b) If Walen relation is satisfied
3. Determine if ion-jet reversal occurred during MMS crossing of magnetopause.
4. Using data from models and observations, compute the value of each parameter (shear, magnetic field energy, bisection field, and the exhaust speed.
5. Find the location and orientation of X-line as predicted by each model.
6. Measure distance from MMS.

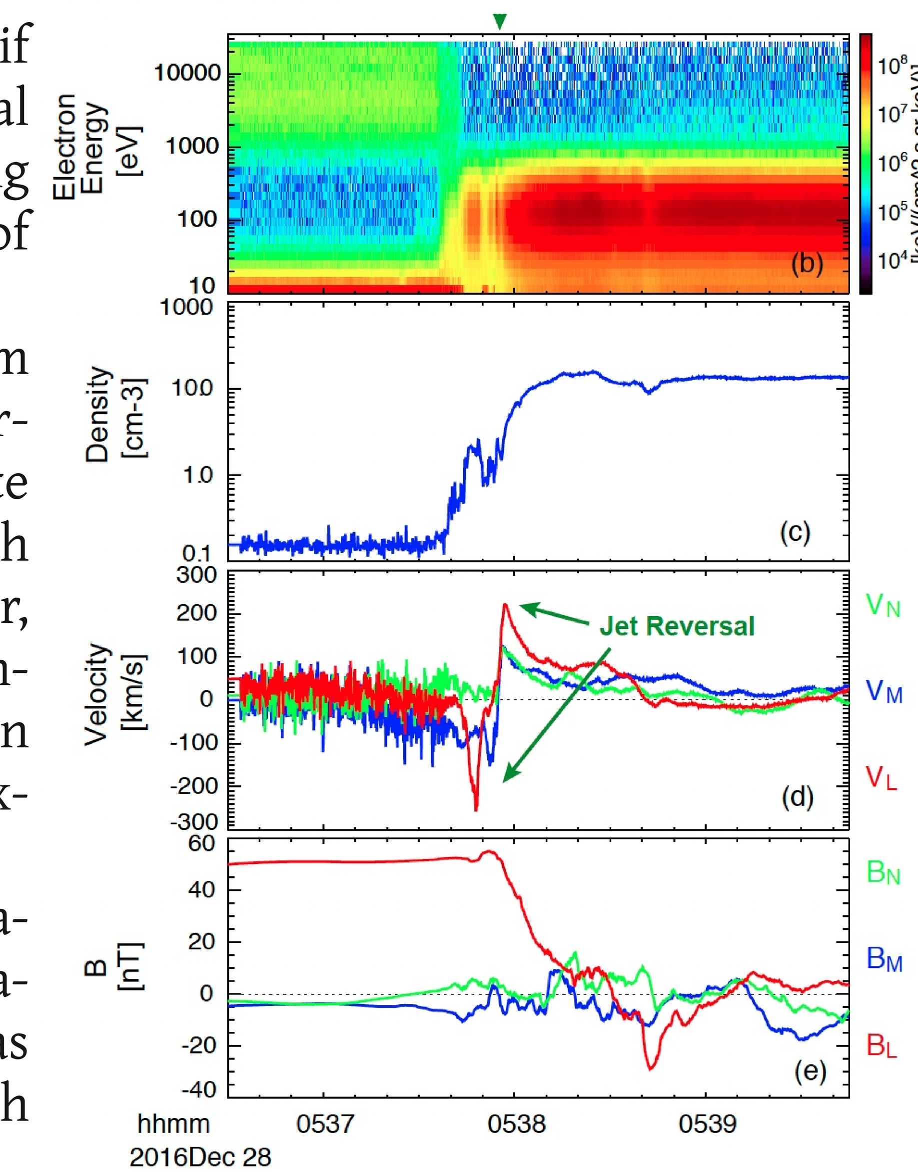


Figure 2: Identification of a reconnection region by Ion-jet reversal, as observed by MMS.

Conclusion

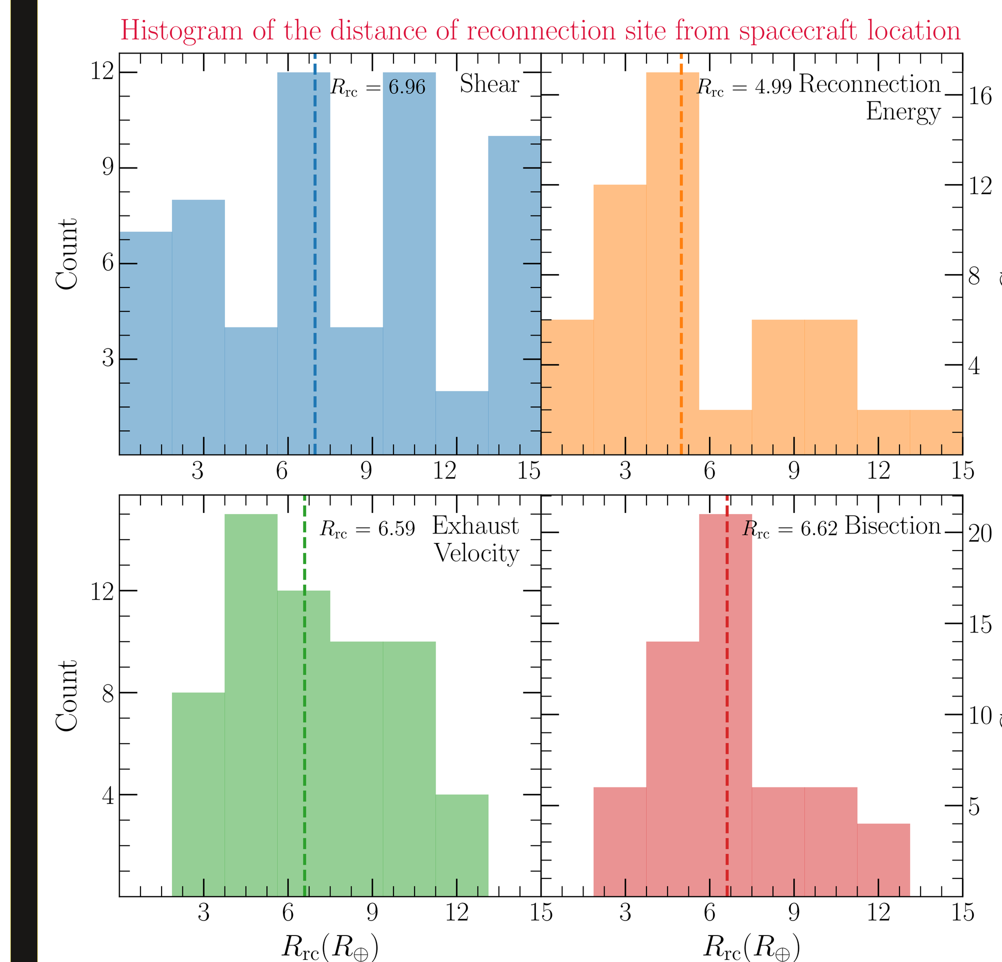


Figure 6. Histogram of measured distance between predicted and actual location of X-line for 4 different models.

Reconnection energy model seems to do the best job of predicting the location of X-line on day-side magnetopause. However, because of limited amount of data used in this study so far (32 reconnection events), at present we remain reluctant in making any such assertion.
We are working towards identifying more ion-jet reversal events which will help us improve our statistics and refine our conclusion.

RESULTS

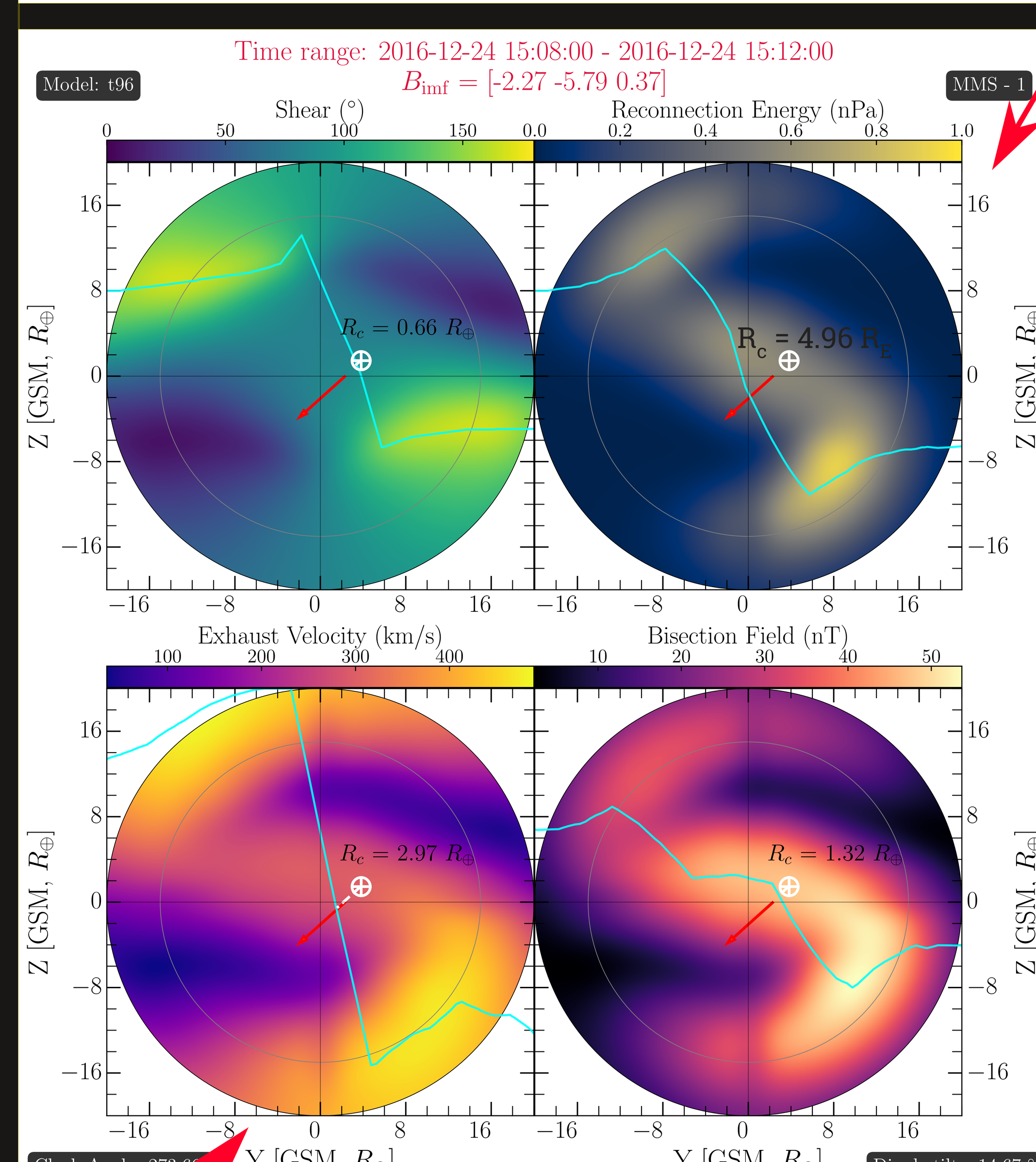
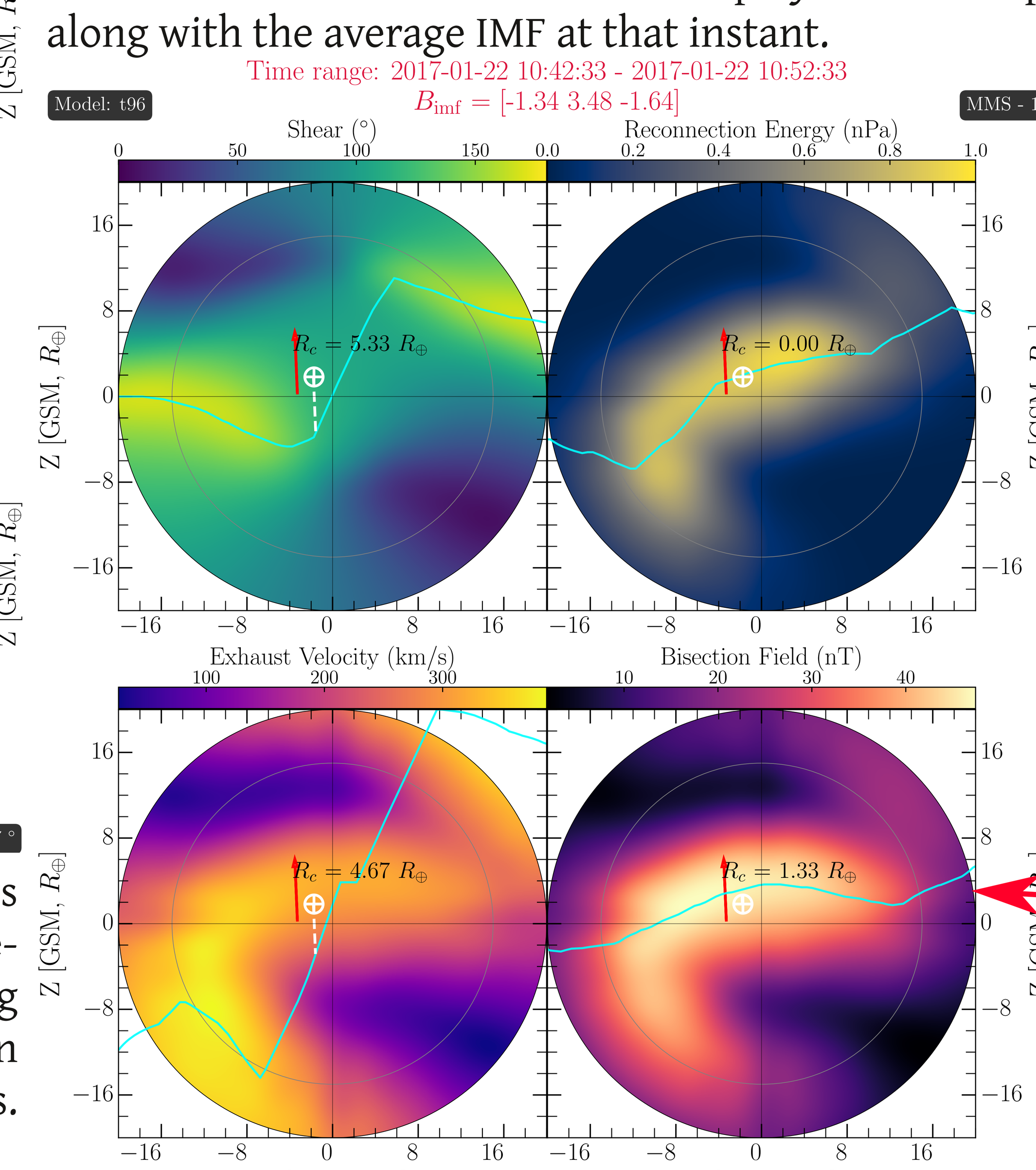


Figure 3. The above figure shows different parameters (shear, normalized reconnection energy, exhaust velocity, and bisection field) plotted on (y,z)-plane along the magnetopause. Cyan line is the predicted location and orientation of the X-line by respective models. Gray circle marks the terminator location.

MMS spacecraft is shows in white circle. The red arrow is the direction of magnetosheath magnetic field as measured by MMS. This is also the direction along which distance to X-line, from MMS, is measured for each model, which is shown in cyan color in earth radii units. Time of observation is displayed at the top, along with the average IMF at that instant.



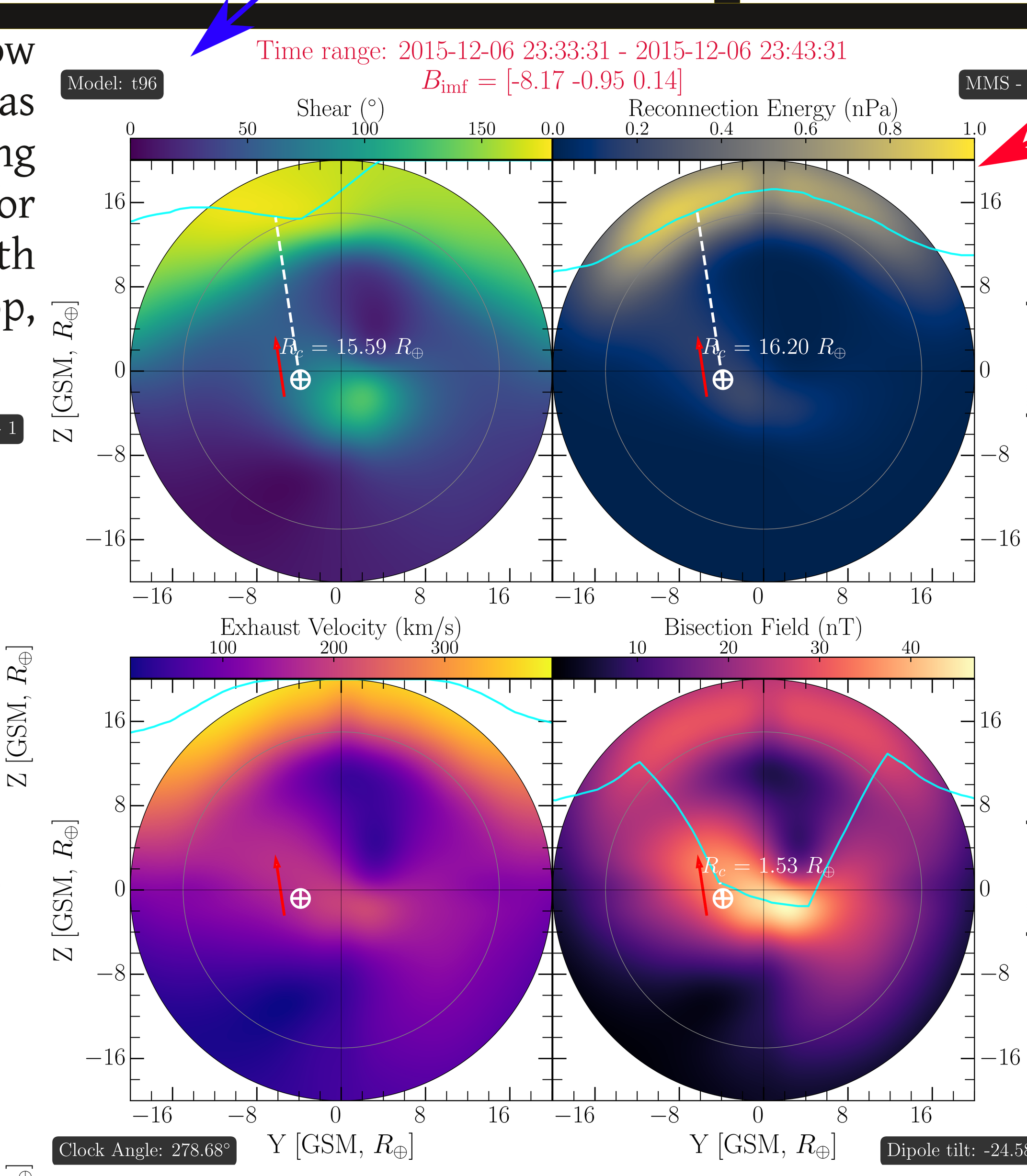


Figure 4. In Figure 3, Shear model seem to have the best agreement with the observed data, whereas in the current figure, for similar location of MMS with respect to sub-solar point but a slightly different IMF conditions, reconnection energy model seem to give the best result, followed by bi-section model.

Figure 5. As shown in this figure., based on preliminary results, most models seem to have comparatively poor predictability when B_z (IMF) is > 0 and B_x is the dominant component.
All models except bisection field, predicted X-line outside the terminator. If reconnection is indeed happening at those locations, MMS is too far to observe ion-jets from those places and most definitely did not cross predicted X-line to observe jet reversal.
We would also like to note that since the interspacecraft distance of MMS is very small compared to Earth's radius, use of different MMS spacecraft (for example, MMS3 instead of MMS1) has no perceivable effect on the computed distance.
We also found little difference when we used T-96 and T-01 models for computing the external magnetic field of Earth's Magnetosphere.