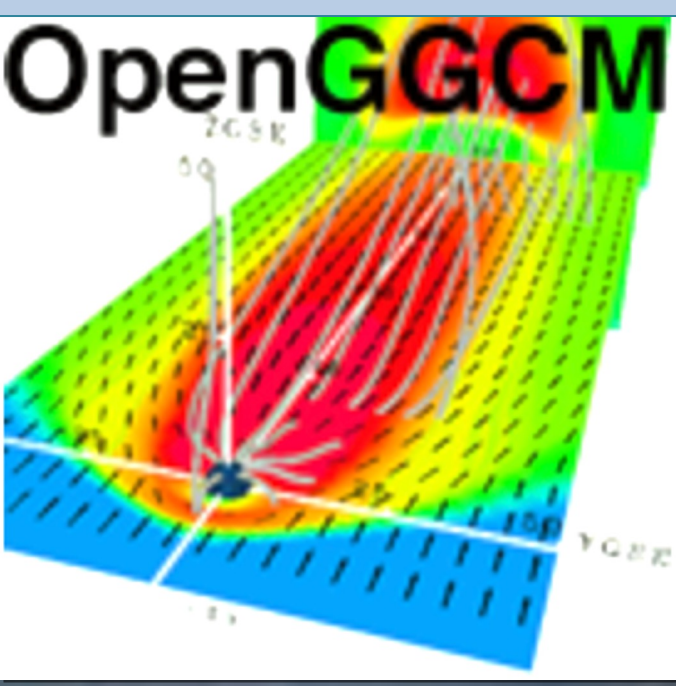




Global MHD Simulations of Solar Wind Tangential Discontinuities Interacting with Earth's Bow Shock using OpenGGCM



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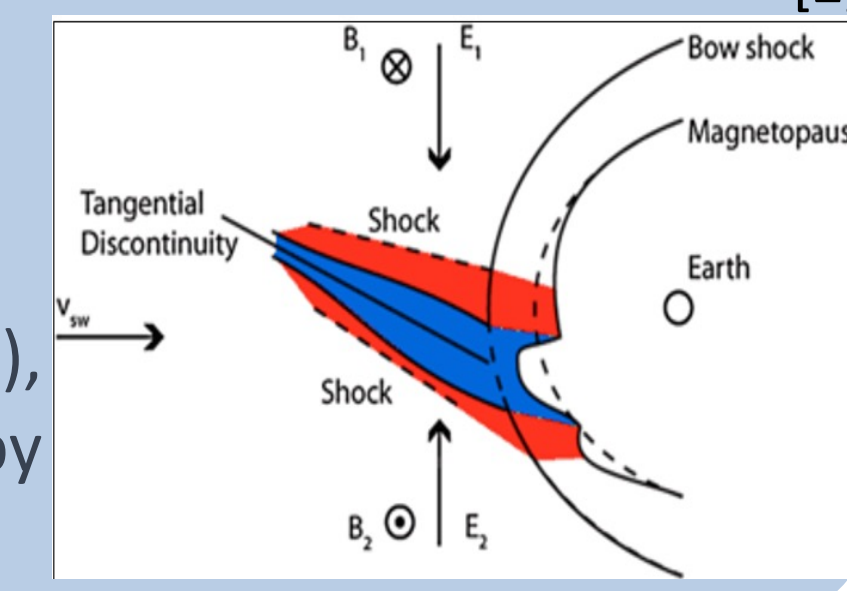
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Background & Motivation

Tangential discontinuities (TDs) in solar wind are the most commonly observed type of interplanetary or directional discontinuity. These discontinuities exhibit an abrupt alteration in the direction of the solar wind's magnetic field, accompanied by simultaneous changes in the plasma parameters. Importantly, there is no mass flow or magnetic flux crossing the surfaces of these discontinuities. However, tangential field component can vary in both direction and magnitude across the discontinuity. They are highly abundant in solar wind and can occur with a frequency ranging from several minutes to several hours. It is important to note that any tangential discontinuity must interact with **Earth's Bow Shock (BS)** before reaching the magnetosphere, giving rise to intriguing consequences and effects.^[1]

One of that phenomenon is **Hot Flow Anomalies (HFAs)** [3], which are characterized by disturbances in solar wind, showing distinctive features such as : [2]

- Hot central region accompanied by enhanced magnetic field
- Bulk flow velocities that are slower than ambient solar wind
- Formation of a bulge on the bow shock surface (BS), potentially resulting in the deformation of magnetopause by a few Earth radii (R_E).

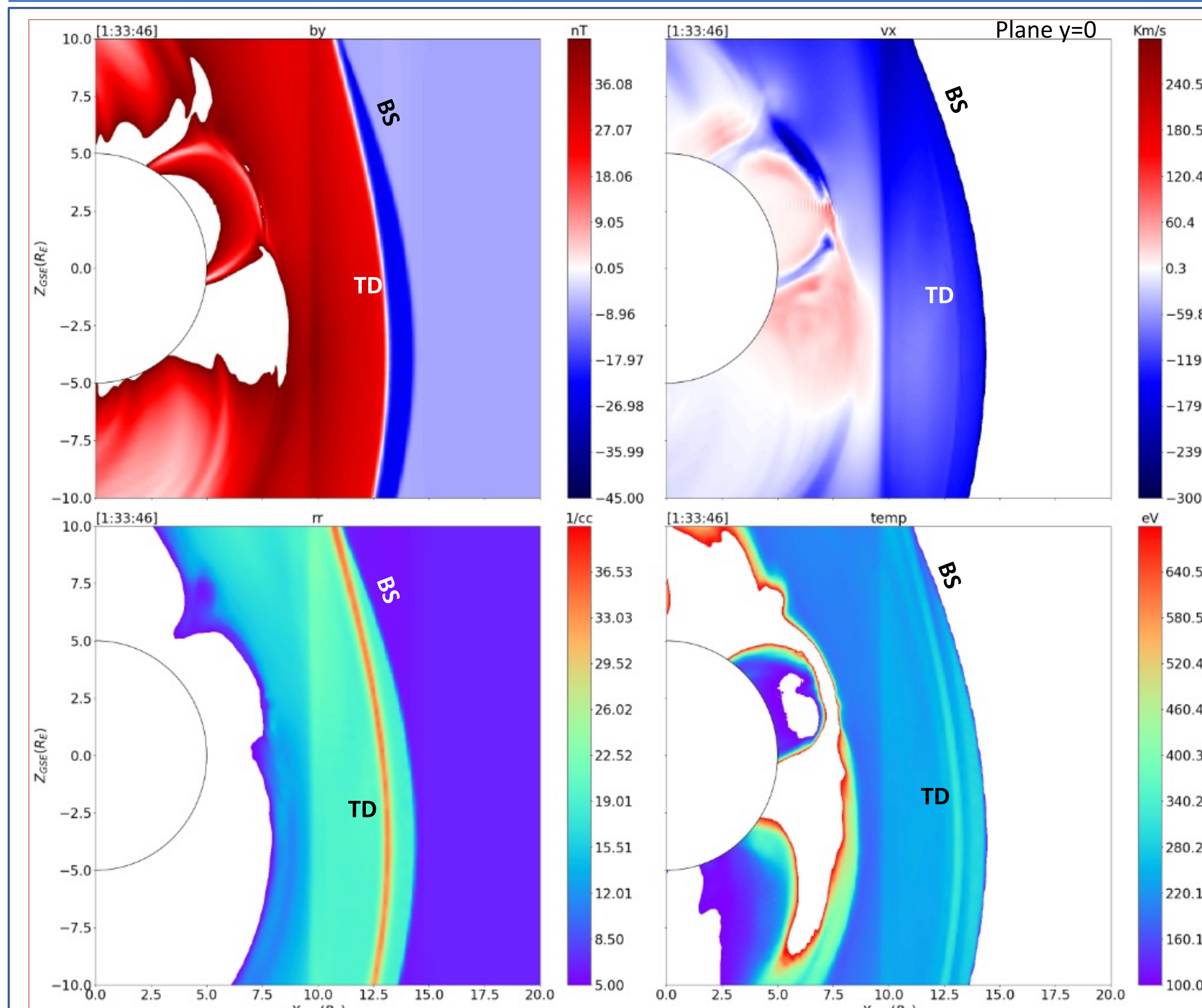


Numerical Model

In this study, our objective is to simulate interaction between two synthetically generated tangential discontinuity (not a real recorded solar wind data) and Earth's Bow Shock using a global magnetohydrodynamics (MHD) simulation model known as **Open Geospace Circulation Model (OpenGGCM)**. **OpenGGCM** is comprehensive global model of Earth's geospace environment, encompassing the solar wind, interplanetary magnetic field, upper atmosphere, and ionosphere. It employs semi-conservative formulation of MHD equations to simulate motion of single-fluid plasma within a 3-D, stretched cartesian grid, allowing us to use very high resolution in area of interest.

OpenGGCM Simulation Results

Case Study I



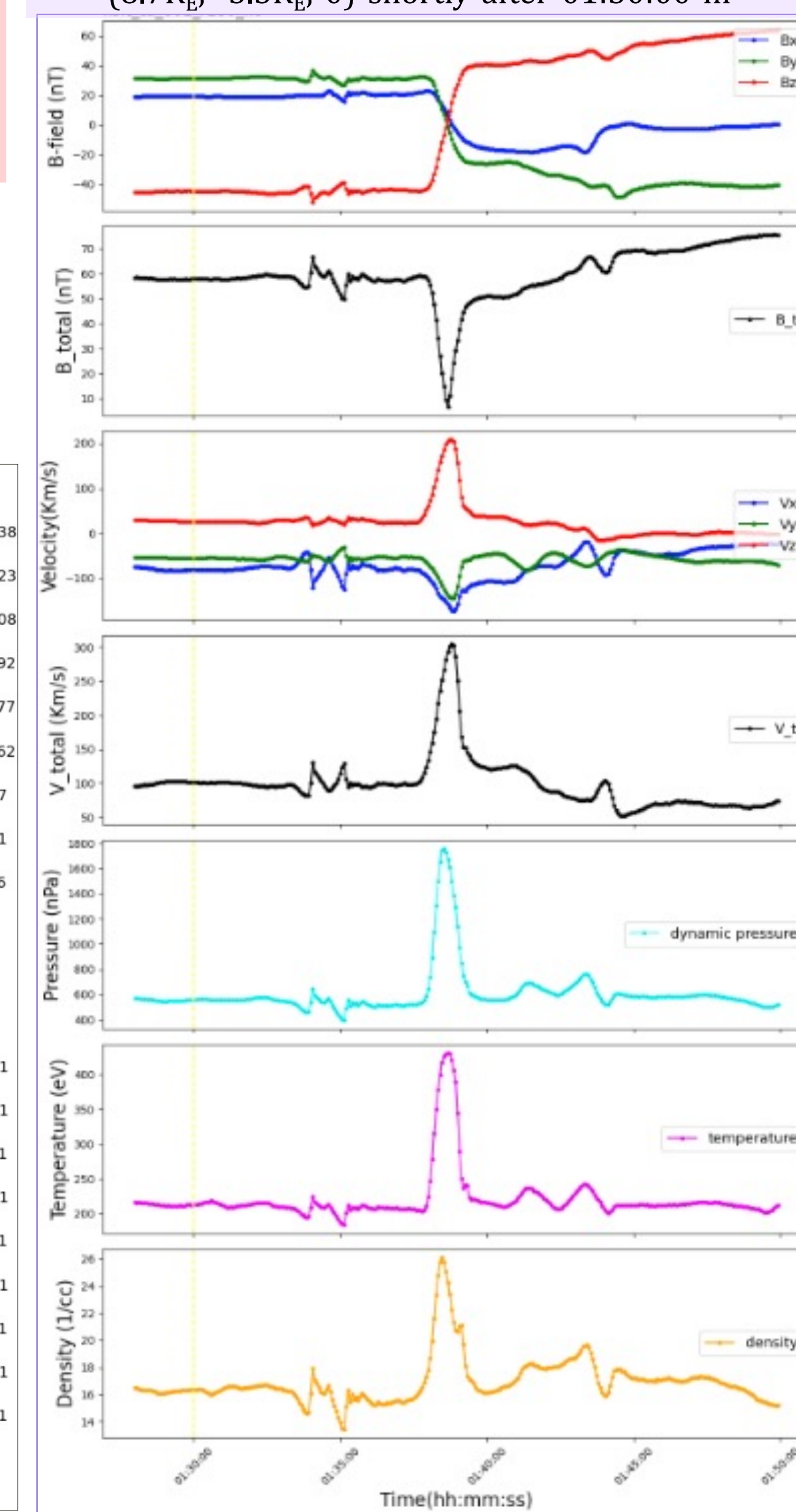
Input Magnetic field orientation for this TD in Solar Wind
 $B_d = (0, 8, -12)$ nT $\rightarrow B_u = (0, -8, 12)$
 Normal $(n) = (1, 0, 0)$

Input Solar Wind Parameters :
 Velocity (V_{sw}) = -450 Km/s (anti-sunward)
 Temperature (**temp**) = 8.6 eV
 Density (**rr**) = 6 /cc
 $M_A = 8$

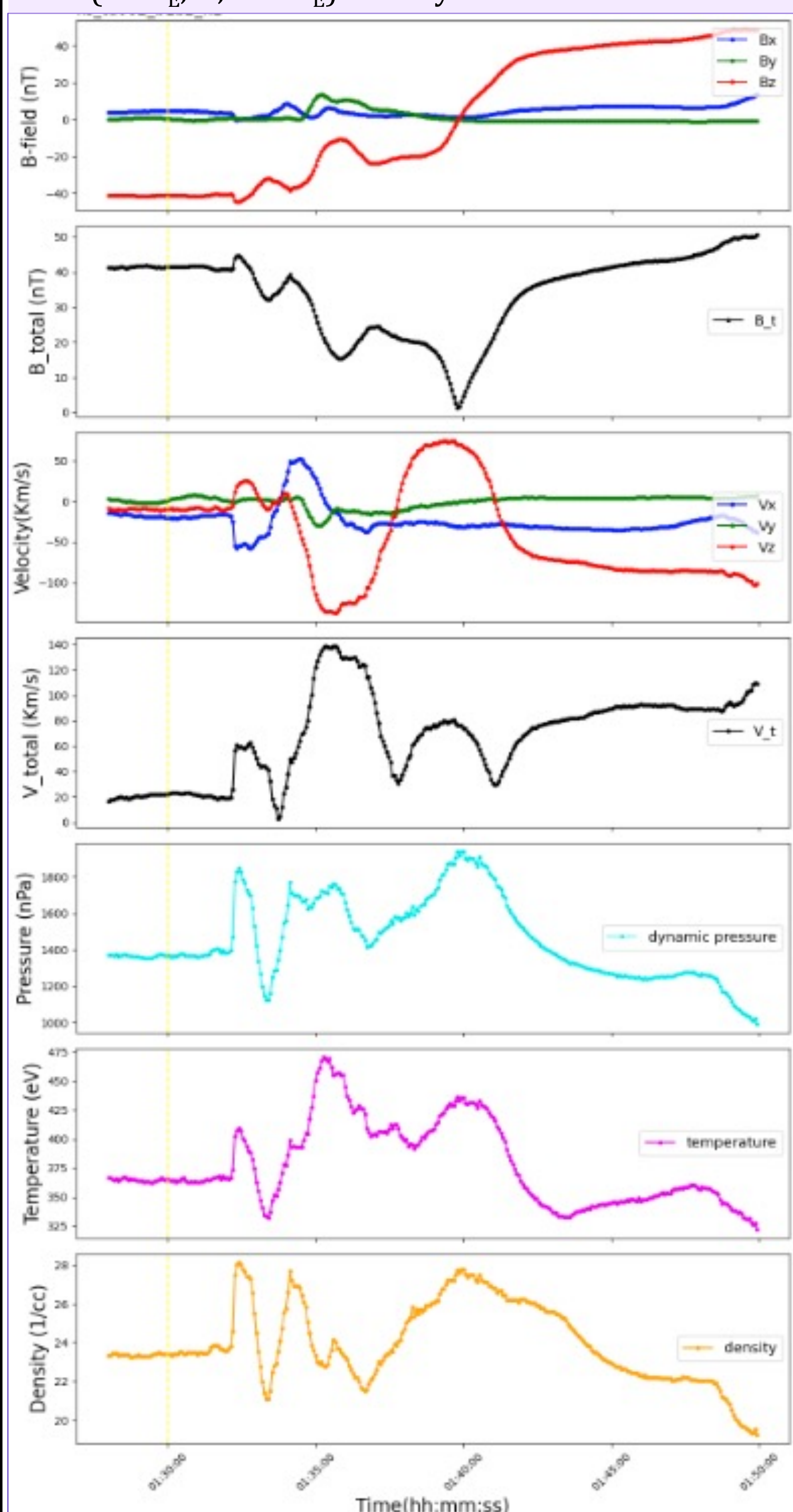
- A strong fast-mode wave is transmitted to inner magnetosphere within seconds of TD hitting the BS and directed towards inner magnetosphere
- Simultaneously, a reflected wave propagates away from magnetopause towards BS, undergoing reflection back towards the magnetosheath
- Formation of a high-density and pressure ridge, accompanied by an increase in temperature profile
- Strong plasma flows near magnetopause are induced by reconnection events happening at the cusp

Contour plots for Case II : Tangential discontinuity interacting with BS. TD enters the simulation box from the right-bottom corner, with normal vector $(n) = (1, 0, 0)$

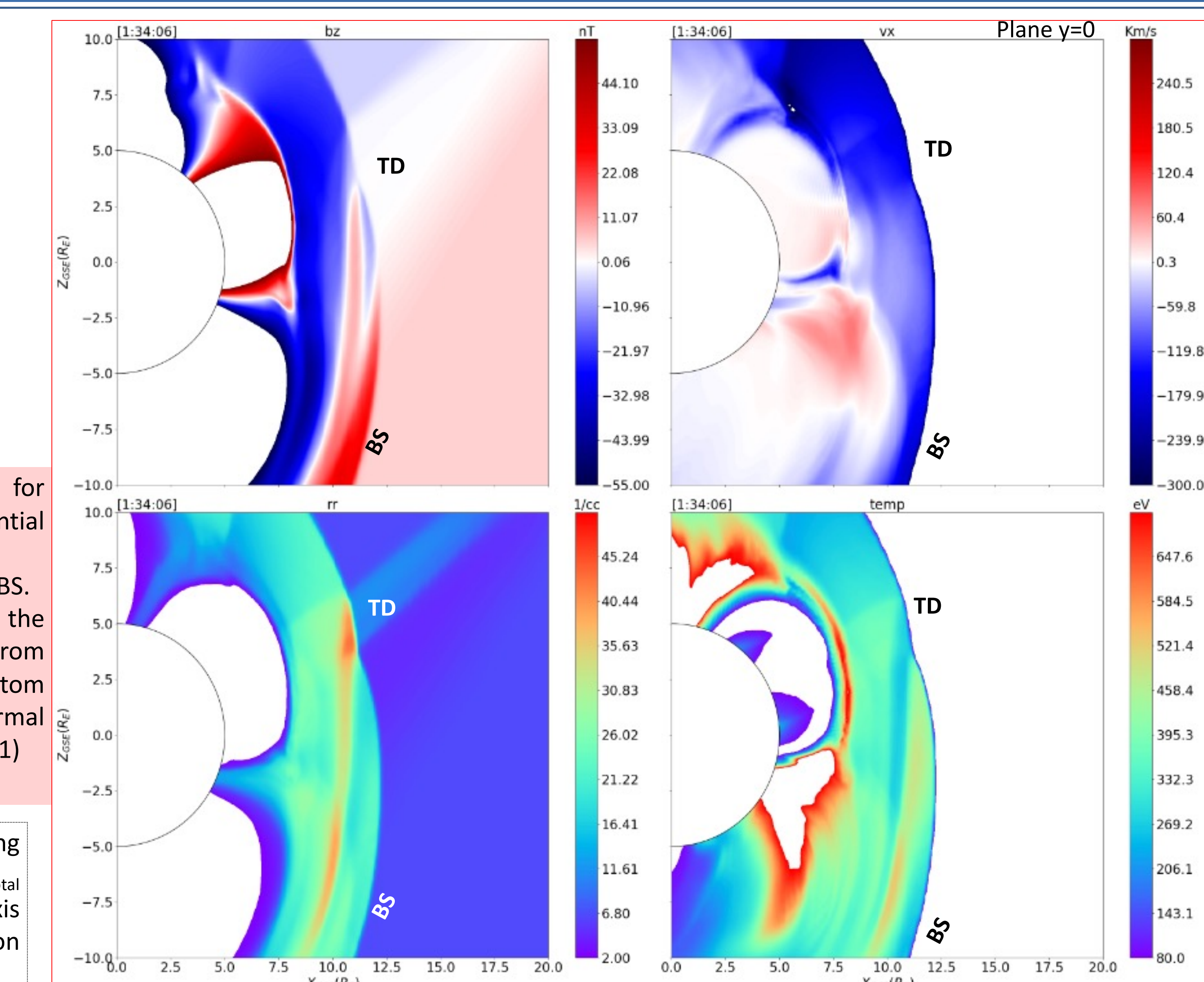
Temporal evolution of magnetic field-components, total magnetic field, velocity, pressure, temperature and density profiles with respect to time, investigated at hypothetical spacecraft location $(8.7R_E, -3.3R_E, 0)$ shortly after 01:30:00 hr



Temporal evolution of magnetic field-components, total magnetic field, velocity, pressure, temperature and density profiles with respect to time, investigated at hypothetical spacecraft location $(8.9R_E, 0, -3.3R_E)$ shortly after 01:30:00 hr



Case Study II

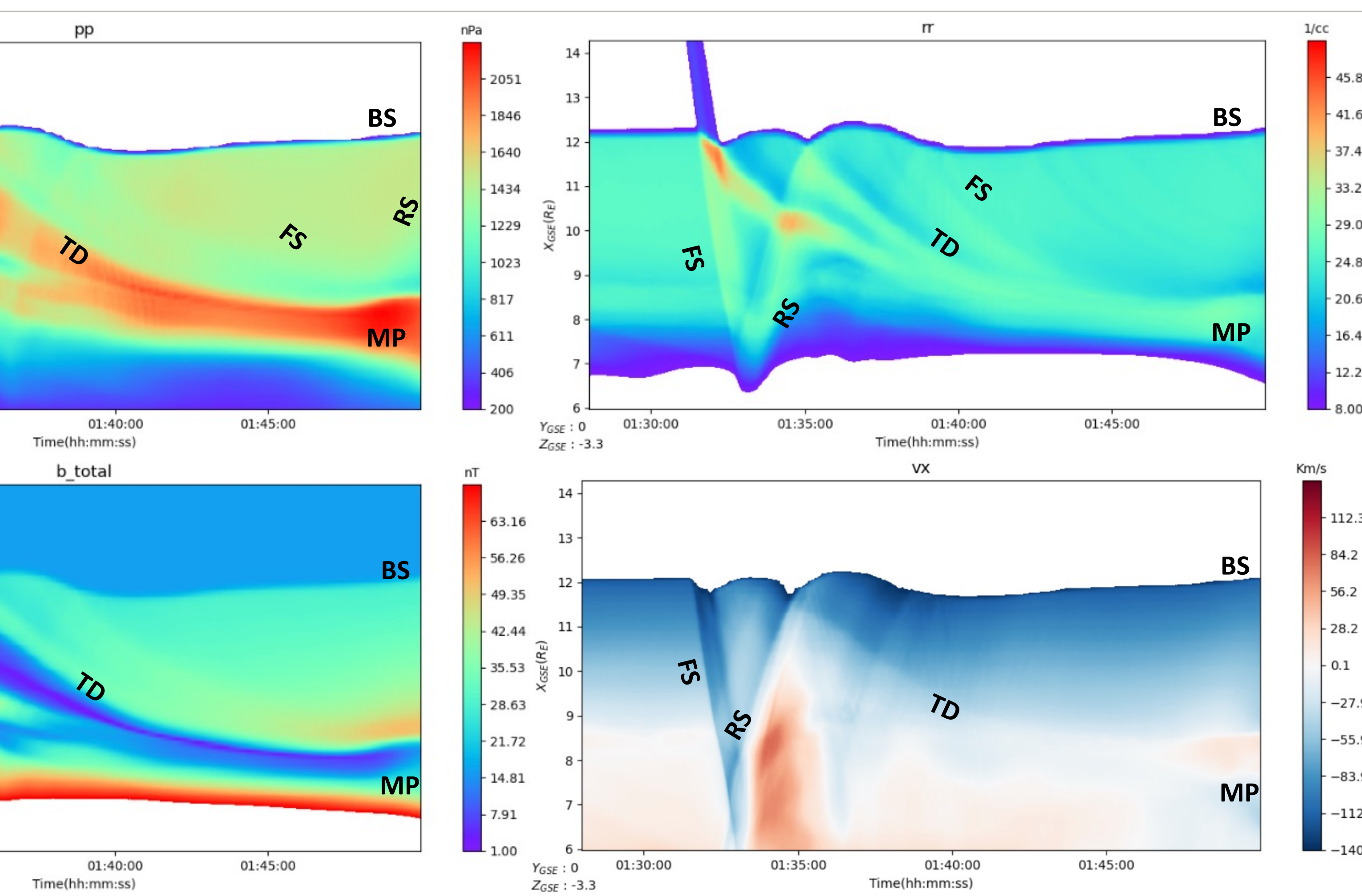
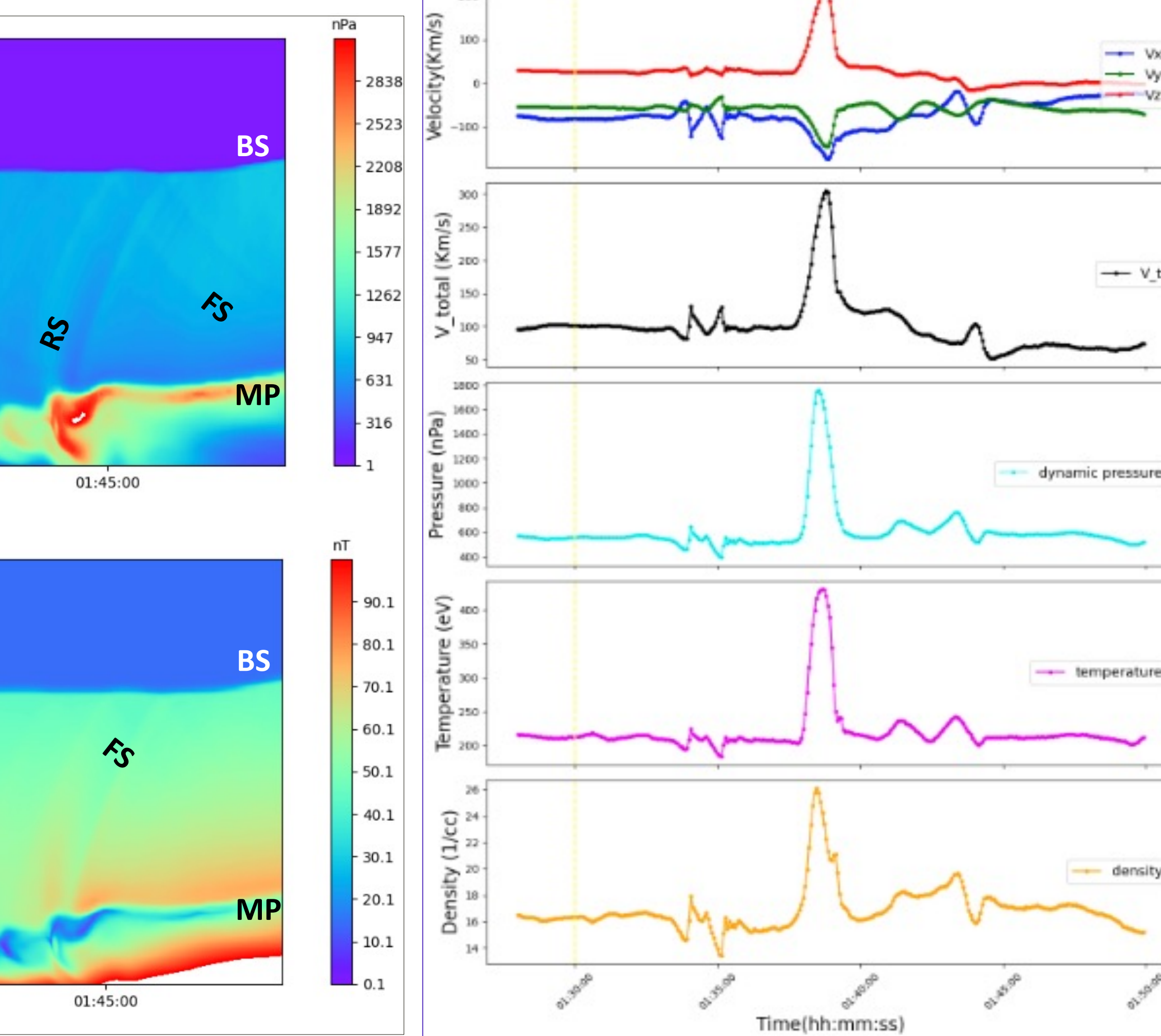
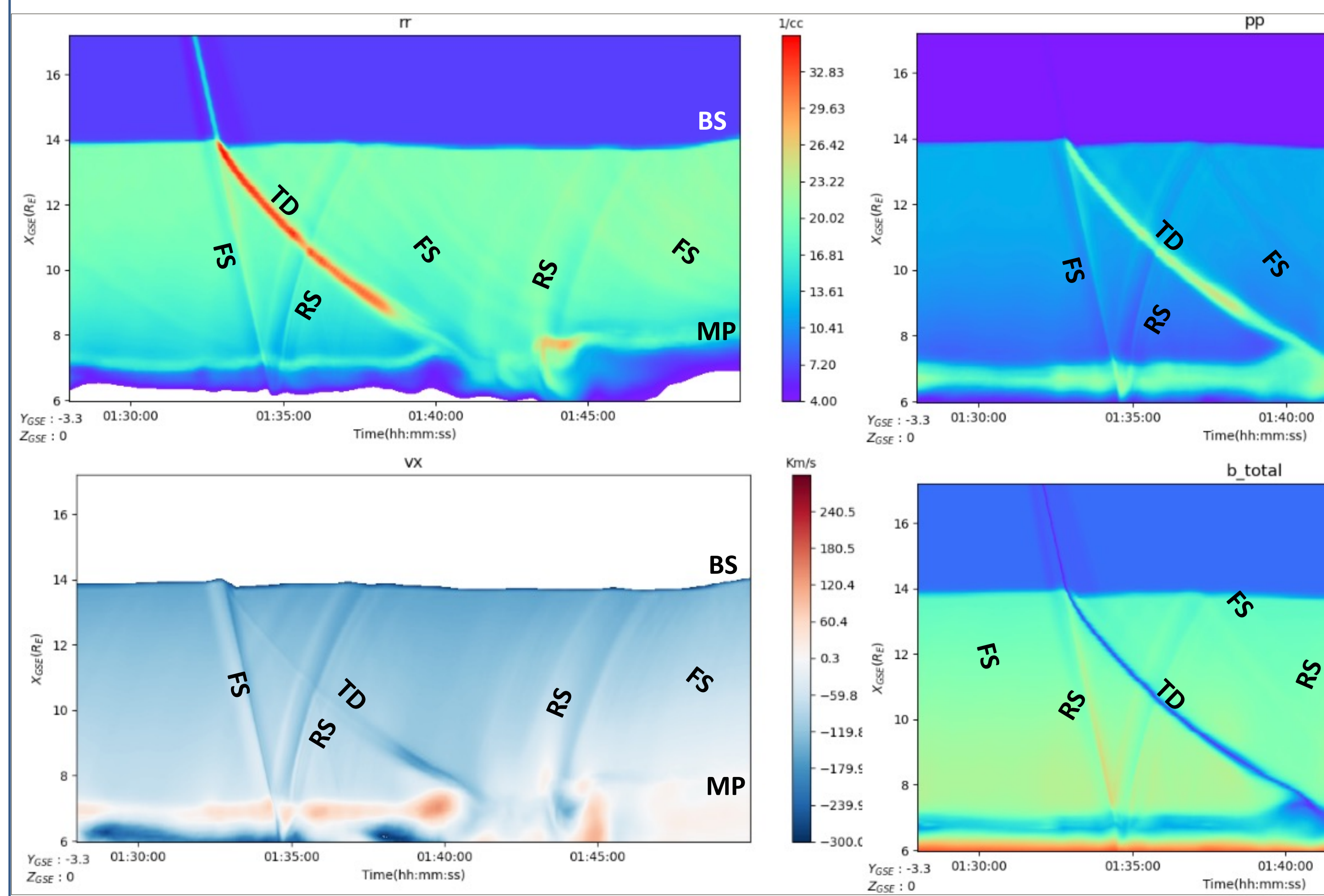


Input Magnetic field orientation for this TD in Solar Wind
 $B_d = (5, 0, -5)$ nT $\rightarrow B_u = (5, 0, 5)$
 Normal $(n) = (1, 0, 1)$

- Similar to Case I, rapid transmission of fast mode wave occurs in magnetosheath
- When TD encounters BS, it is displaced inward and subsequently rebounds, forming a protusion-like structure along BS boundary
- From velocity profile, a robust sunward flow is observed, which influences the magnetopause and as a consequence MP undergoes displacement by approximately $1R_E$

Contour plots for Case II : Tangential discontinuity interacting with BS. TD enters the simulation box from the right-bottom corner, with normal vector $(n) = (1, 0, 1)$

Keograms depicting Pressure, Density, Btotal and Vx along x-axis spatial cut as function of time



Conclusion

The interaction of any tangential discontinuity (TD) with the bow shock (BS) results in the rapid propagation of both forward (FS) and reverse (RS) fast-mode waves within the magnetosheath and inner magnetosphere.

- Several features characteristic of Hot Flow Anomalies (HFAs) are observable in Case Study II.
- Notably, there is a prominent displacement of the magnetopause.
 - Sunward plasma flow is also observed in conjunction with HFAs.
 - The presence of protusion-like structures is evident in the bow shock.
 - A distinctive feature includes the existence of a high-temperature trailing edge along the TD
 - Another observed phenomenon is the thinning of the magnetosheath.

Future Work

To investigate and gain a deeper understanding of these interactions by examining various cases of TDs, as well as other directional discontinuities. Ultimately, we intend to utilize observed solar wind data from spacecraft located either upstream or downstream of the bow shock as an input for the model. That will enable us to conduct comprehensive study and analysis.

References

[1] Burlaga, L. F., N. F. Ness, Tangential discontinuities in the solar wind, *Sol. Phys.*, 9, 467–477, 1969.
 [2] Schwartz et al. (1985). *An active current sheet in the solar wind.*, 318(6043), 269–271.
 [3] Eastwood et al. (2008). THEMIS observations of a hot flow anomaly: Solar wind, Magnetosheath, and ground-based measurements.

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