Do Statistical models capture magnetopause dynamics during sudden magnetospheric compressions?

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Key Findings:

- The Shue et al. [1998] magnetopause model is an reasonable estimate of standoff distance to within an uncertainty of 1 R_E during 'average' steady-state solar wind driving.
- The Shue et al. [1998] becomes inaccurate when the magnetopause is strongly compressed or out of equilibrium:
  - When **compressed below 10 R_E**, magnetopause standoff distance is **significantly overestimated** by the Shue et al. [1998] model.
  - During **storm sudden commencement** the MP is **6% closer to Earth.**

1. Introduction

During interplanetary shocks which drive geomagnetic storms, the magnetopause becomes significantly compressed, playing a role in the depletion of radiation belt plasma via magnetopause shadowing. During compressed times, empirical models cannot capture the time-dependent nature of the magnetopause.

The Shue et al. (1998) magnetopause model is a statistical model which calculates magnetopause standoff distance for given upstream solar wind dynamic pressure and IMF B_Z. In order to test the accuracy of Shue model during magnetopause compressions, we compiled a database of 20,000 spacecraft crossings of the dayside magnetopause.

2. Magnetopause Crossing Database

We compiled a database of ~25,000 magnetopause crossings from Geotail (Raymer 2018), Cluster (Case and Wild 2013), and THMIS (Plaschke et al., 2009; Staples et al., 2020). For the following analysis we used the 20,000 crossing which occurred on the dayside magnetopause.

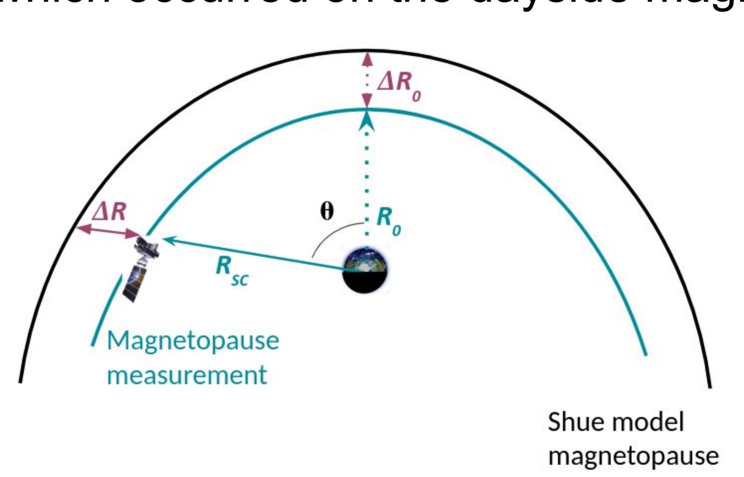


Figure 1: Schematic to illustrate how ΔR and ΔR_0 correspond the spacecraft crossing and the model.

$$\Delta R = R_{Mod} - R_{SC}$$

R_{SC} - spacecraft standoff distance

R_{Mod} - model standoff distance

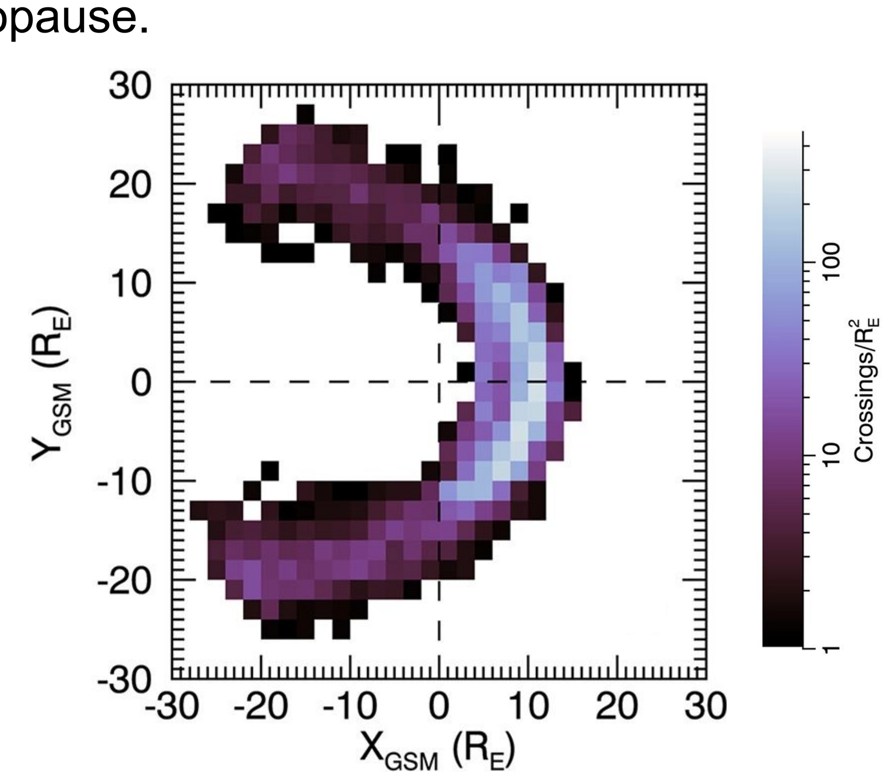
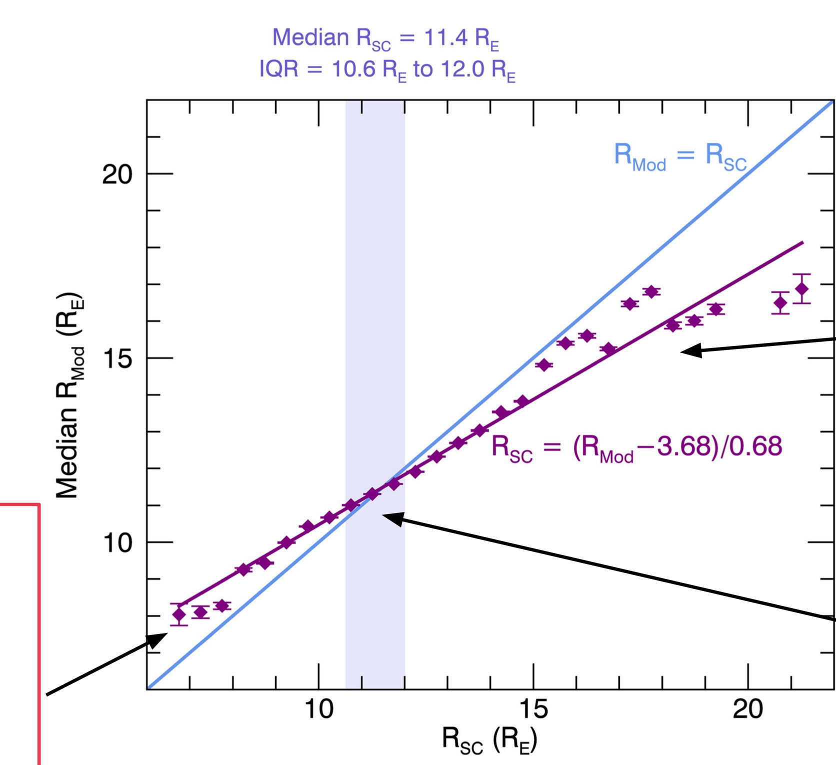


Figure 2: Distribution of magnetopause crossings in the X-Y GSM plane (Staples et al. 2020).

3. Statistical Offset between R_{SC} and R_{Mod}

The model accurately calculated magnetopause standoff distance within ~ 1 R_E for 74 % of crossings, though ΔR was greater than model uncertainty (~ 0.4 R_E) for 60 % of crossings.

Figure 3: Average R_{Mod} as a function of corresponding measurement of R_{SC}. Blue line- where ΔR = 0, shaded area- interquartile range of R_{SC}, purple line- linear regression to data (Staples et al. 2020).



Model underestimated standoff distance for crossings further than 13 R_E.

Model overestimated standoff distance for crossings closer than 10 R_E.

Average $R_{Mod} \approx R_{SC}$ for crossings between 10 and 13 R_E.

4. Storm-Time Magnetopause Offset

The response of magnetopause to magnetic field perturbations resulting from ring current enhancement is not accounted for in the Shue et al. (1998) model. Figure 5 tests ΔR for varying geomagnetic conditions, quantified by SYM-H index at the time of the magnetopause crossing.

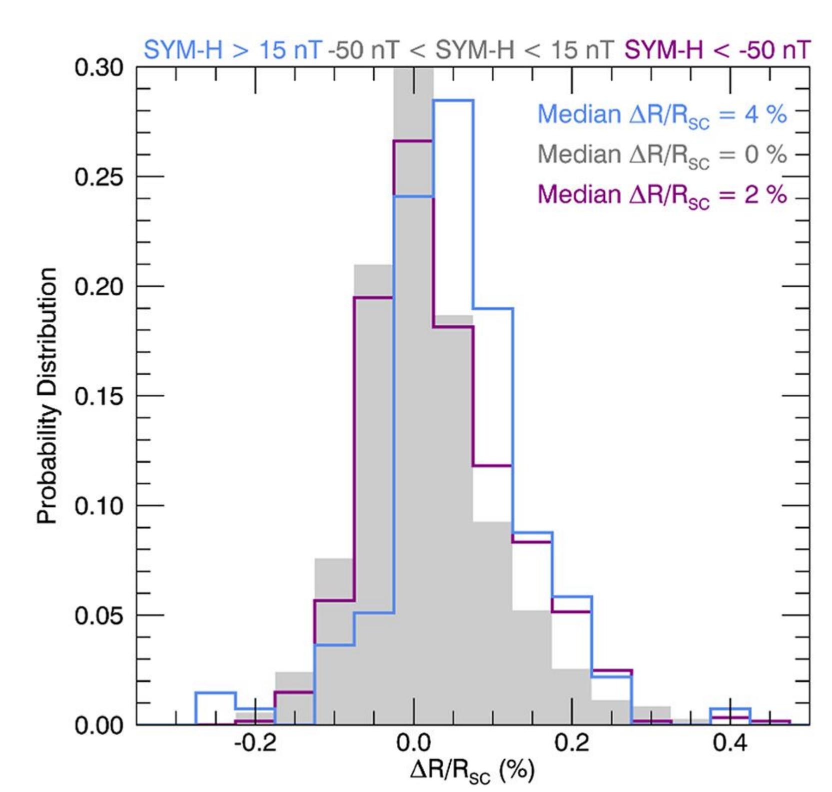
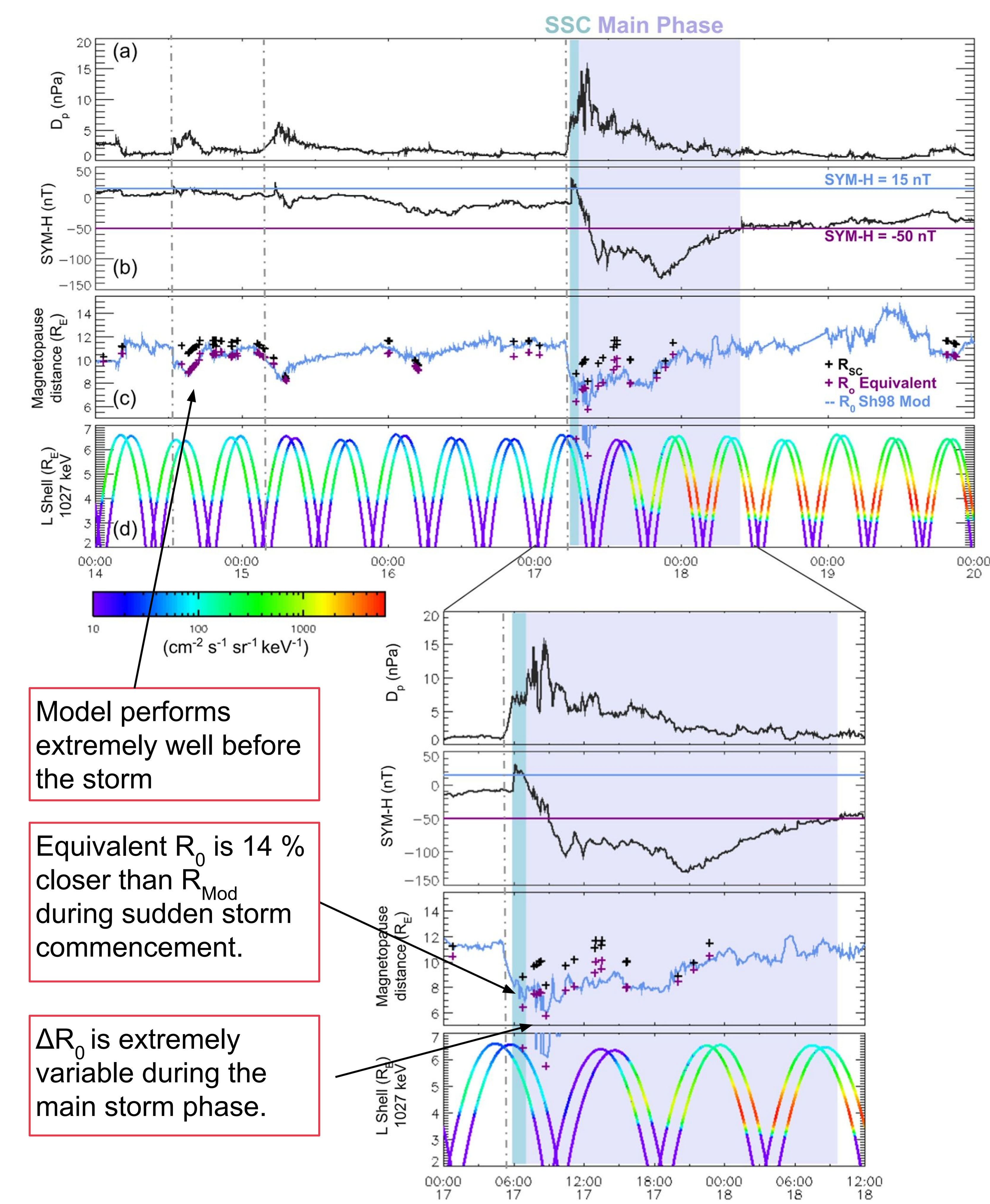


Figure 4: Probability distribution of $\Delta R/R_{SC}$ separated by geomagnetic activity (Staples et al., 2020)

- ➔ $\Delta R/R_{SC}$ during storm sudden commencement (SSC) and geomagnetic storms are significantly different from the quiet time distribution (Mann-Whitney U test significance > 0.95).
- ➔ For SYM-H > 15 nT, $\Delta R/R_{SC}$ increases with positive SYM-H.

Superposed epoch analysis of crossings where SYM-H > 15 nT shows solar wind conditions characteristic of interplanetary shocks.

4. St Patrick's Day Storm 2013



Model performs extremely well before the storm

Equivalent R_0 is 14 % closer than R_{Mod} during sudden storm commencement.

ΔR_0 is extremely variable during the main storm phase.

Figure 5: Case study of the St. Patrick's day storm 2013. (a) solar wind dynamic pressure; (b) SYM-H index; (c) blue line - subsolar magnetopause standoff distance calculated by Shue et al. [1998], black cross - measured magnetopause standoff, purple cross - projection of R_{SC} to subsolar point; (c) RBSP ~1 MeV electron Flux. (Staples et al. 2020)

For more information on this poster, please comment and ask questions in the chat, read the full paper here, or email **frances.staples@ucl.ac.uk**

References:

Case and Wild (2013) *J. Geophys. Res* 118.10, DOI: 6127-6135, Plaschke, et al. (2009) *Geophys. Res. Lett.* 36.2, Raymer (2018) , http://hdl.handle.net/2381/43064, Shue, et al. (1998) *J. Geophys. Res.* 103.A8, DOI: 17691-17700, Staples et al. (2020), *J. Geophys. Res* 125, DOI: 10.1029/2019JA027289

Acknowledgements:

Data used in this study obtained via rbspgway.jhuapl.edu/psd and cdaweb.gsfc.nasa.gov.

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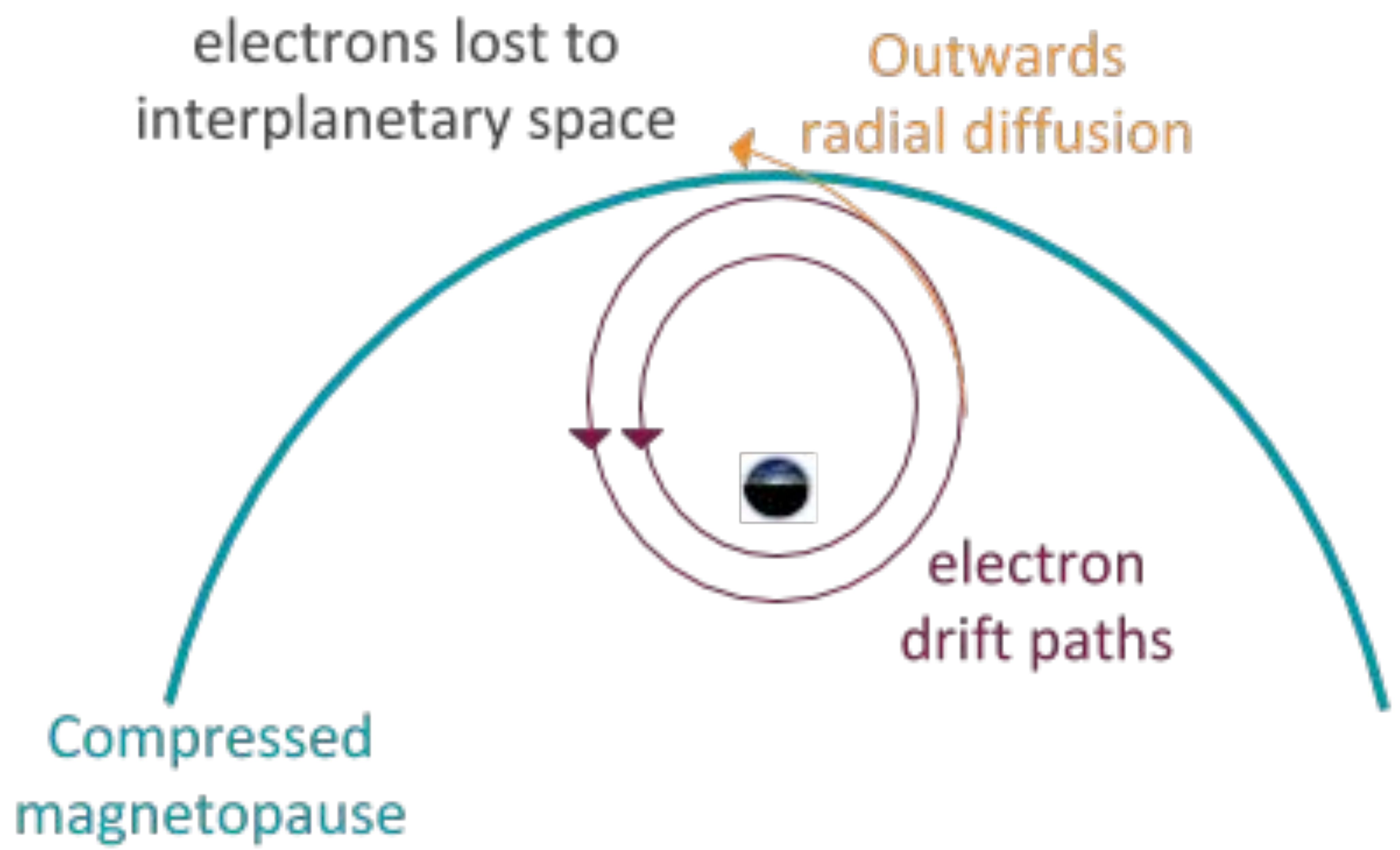
Magnetopause Shadowing:

If the magnetopause is compressed within the radiation belts, electron drift paths are intersected and trapped particles are lost into interplanetary space.

Electrons may also radially diffuse to higher drift shells, where they cross the magnetopause and are lost to interplanetary space.



Magnetopause Shadowing

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The Shue et al. (1998) magnetopause model:

The Shue et al. (1998) model describes the magnetopause by the function

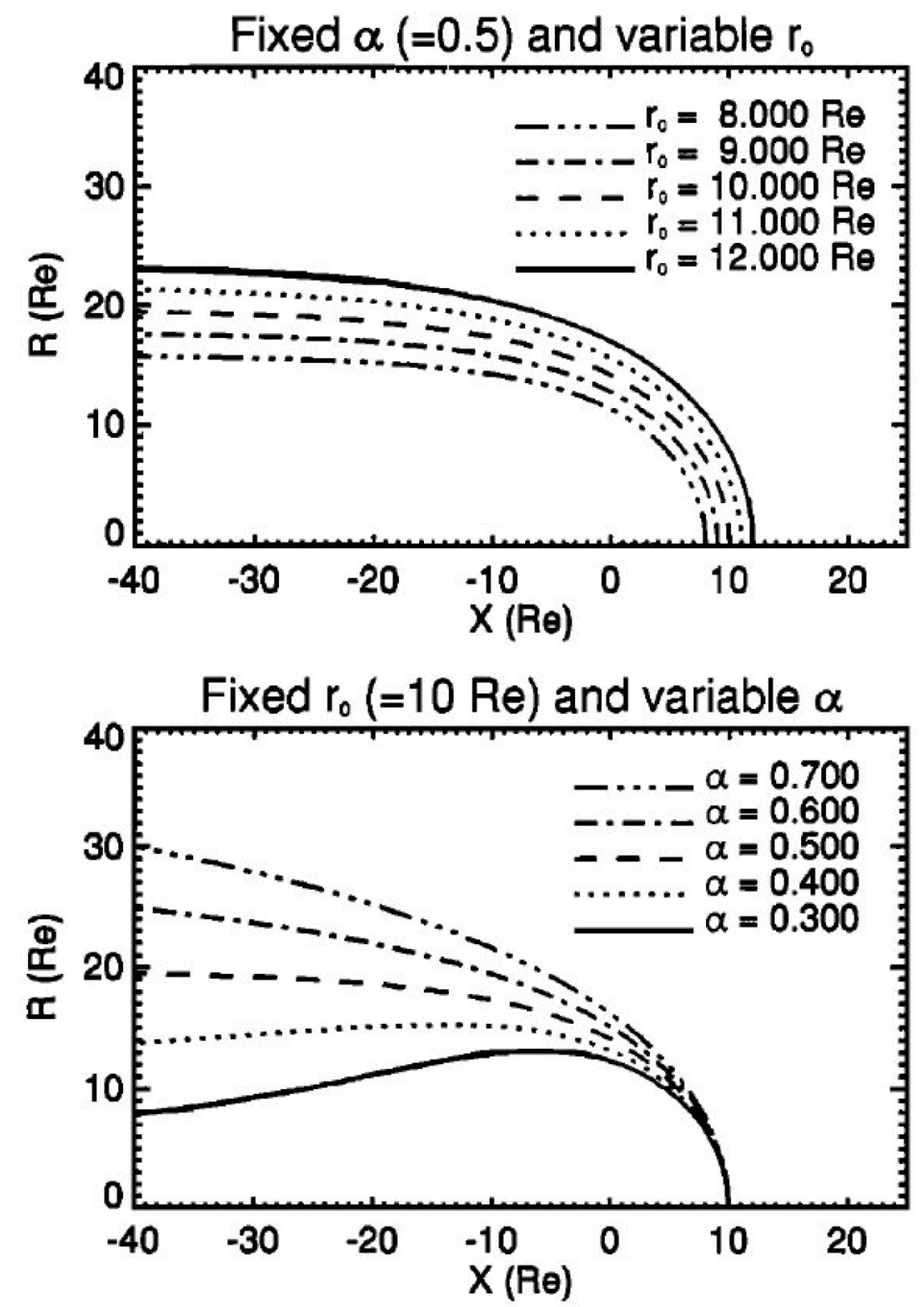
$$r = r_0 \left(\frac{2}{1 + \cos\theta} \right)^{\alpha}$$

Where r - standoff distance at solar-zenith angle, θ

r_0 - subsolar standoff distance

α - level of tail flaring

r_0 and α dependence on B_Z and D_P empirically determined by fitting functional form of magnetopause to 553 spacecraft crossings.



This figure from Shue et al. (1997) shows how the functional form varies for different values of r_0 and α.

Ref: Shue, et al. (1998) *J. Geophys. Res.* 103.A8

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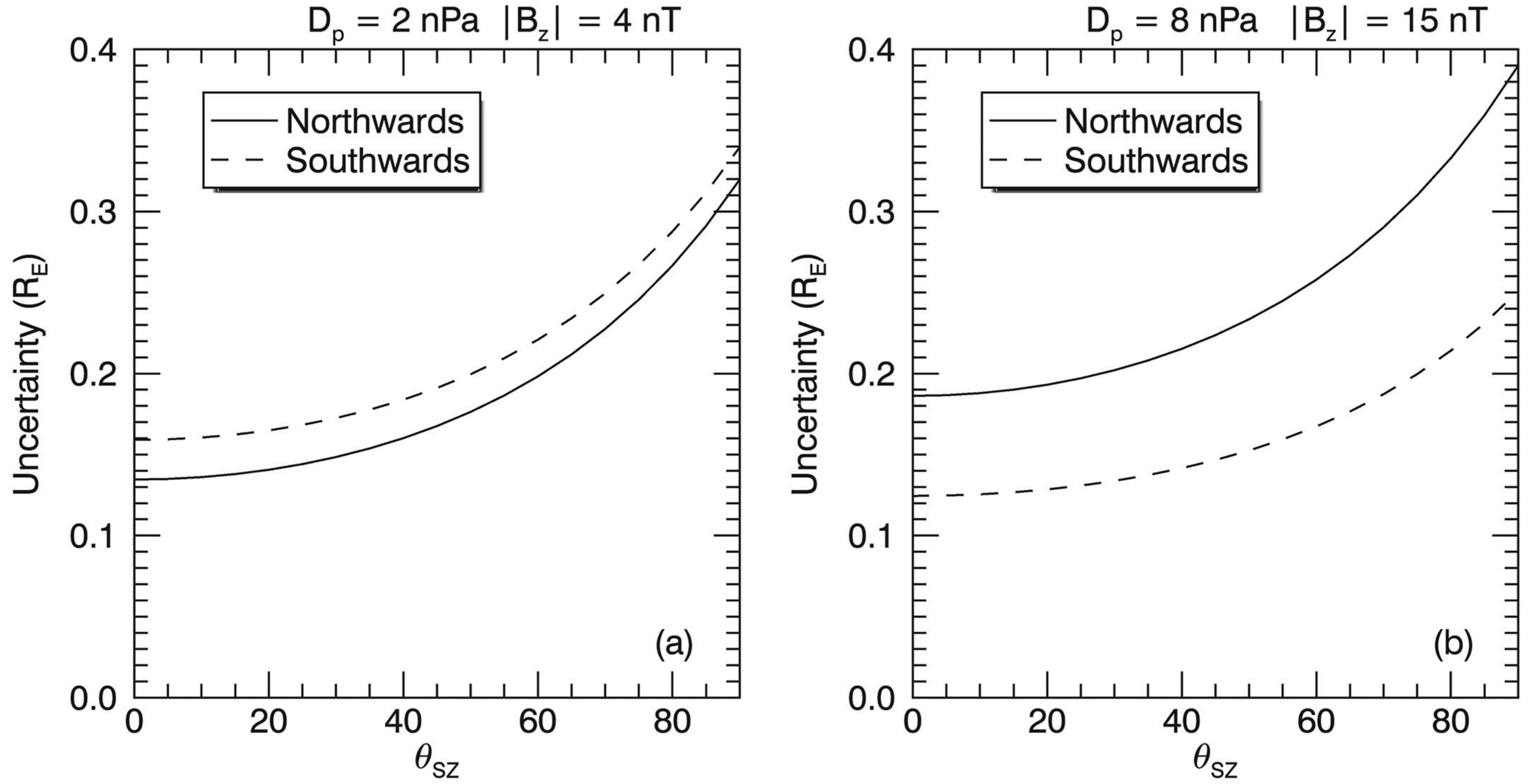
The Shue et al. (1998) magnetopause model uncertainty:

Shue et al. (1998) calculated uncertainty as a function of IMF B_z, D_p, and solar zenith angle. The figure below shows how the model uncertainties vary with solar zenith angle and IMF B_z orientation, given (a) moderate, and (b) strong, solar wind driving (Staples et al., 2020).



In our analysis, we take the uncertainty of the Shue et al. (1998) model to be approximately 0.4 R_E on the dayside magnetopause, and 0.2 R_E at the subsolar point.

Ref: Shue, et al. (1998) *J. Geophys. Res.* 103.A8;
Staples, et al. (2020) J. Geophys. Res. 125, DOI: 10.1029/2019JA027289

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Magnetopause Crossing Database:

We create a new THEMIS crossing database by using a semi-automated classification method. We identify magnetopause crossing candidates from magnetic field and plasma density measurements. When THEMIS is crossing from the magnetosphere to the magnetosheath,

1. the change in the B_z component of the magnetic field, in GSM coordinates, must be less than -0.6 nT s^{-1}, and the change in ion density must be greater than 0.08 cm^{-3} s^{-1};
2. within the magnetosphere, the average B_z component of the magnetic field must be greater than 5 nT and the average ion density must be less than 7 cm^{-3} for a 48 s interval;
3. the first two crossing criteria must be met within a 60 s interval.

If THEMIS is crossing from the magnetosheath to the magnetosphere, we reverse the first criteria. We then manually verify all crossings on a daily basis.

Multiple crossings of the magnetopause were discarded and we cross referenced our crossings with the Plaschke et al. (2009) database to ensure we didn't double count crossings.

Spacecraft	Number of crossings used	Interval of classification	Classified by
Geotail	8,549	1996-2015	Raymer et al. (2018)
Cluster	2,688	2002-2010	Case and Wild (2013)
THEMIS	1,910	2007	Plaschke et al. (2009)
THEMIS	11,821	2007-2016	Staples et al. (2020)

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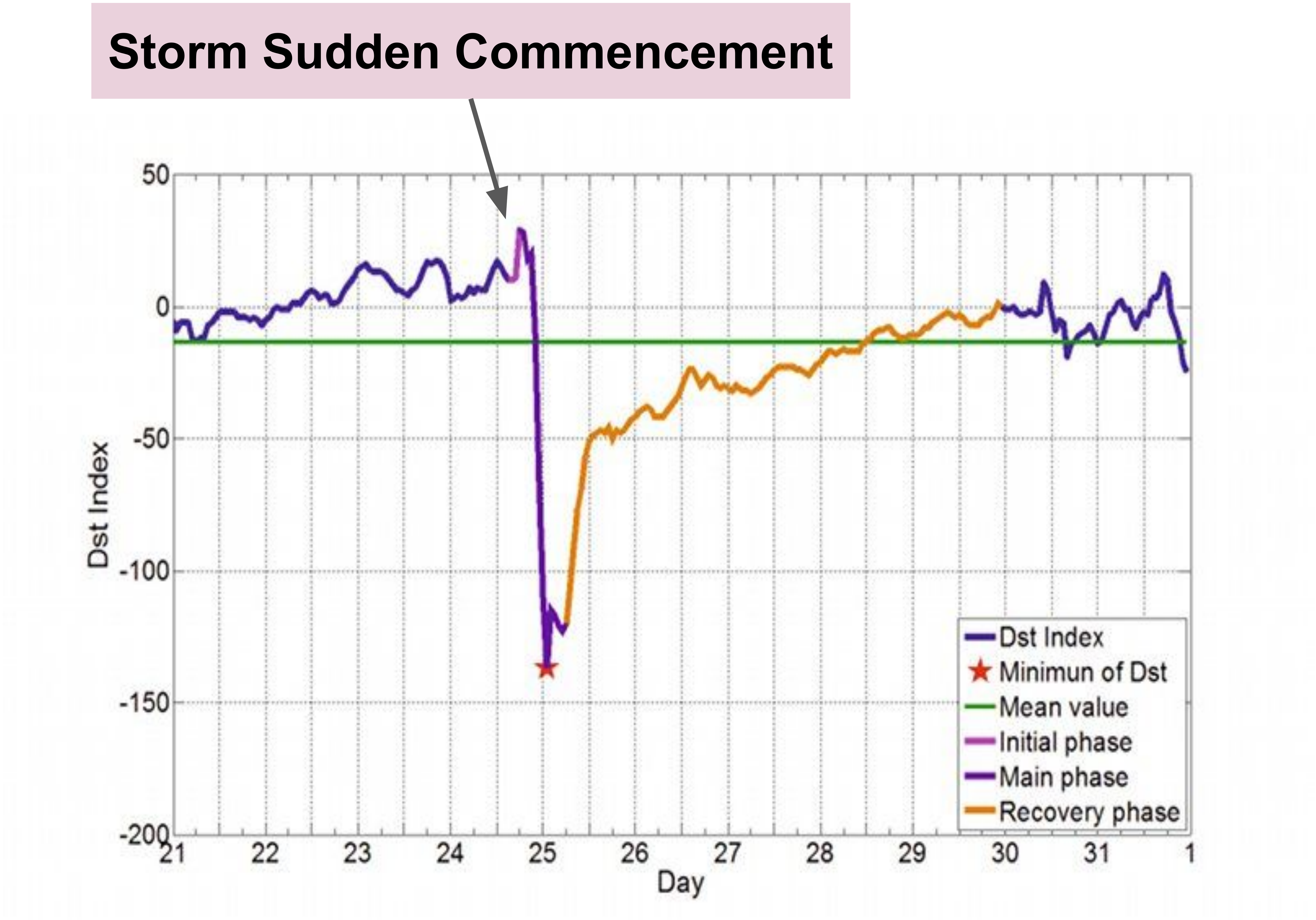
Ref: Staples, et al. (2020) *J. Geophys. Res.* 125, DOI: 10.1029/2019JA027289

Storm Sudden Commencement:

Storm sudden commencement is a phase which usually precedes a geomagnetic storm. SYM-H index can increase by 10s of nT on minute timescales (Dessler et al., 1960) in response to the arrival of an interplanetary shock front rapidly compressing the dayside magnetosphere, in increasing magnetopause currents.

Large sudden positive increases in SYM-H typically correspond to the storm sudden commencement phase of a geomagnetic storm.

In our analysis we assume that SYM-H values exceeding 15 nT are associated with a storm sudden commencement.



Sarachaga et al. (2014)

Ref: Dessler et al. (1960) *J. Geophys. Res.* 65(9), 2715–2719.
DOI: 10.1029/JZ065i009p02715

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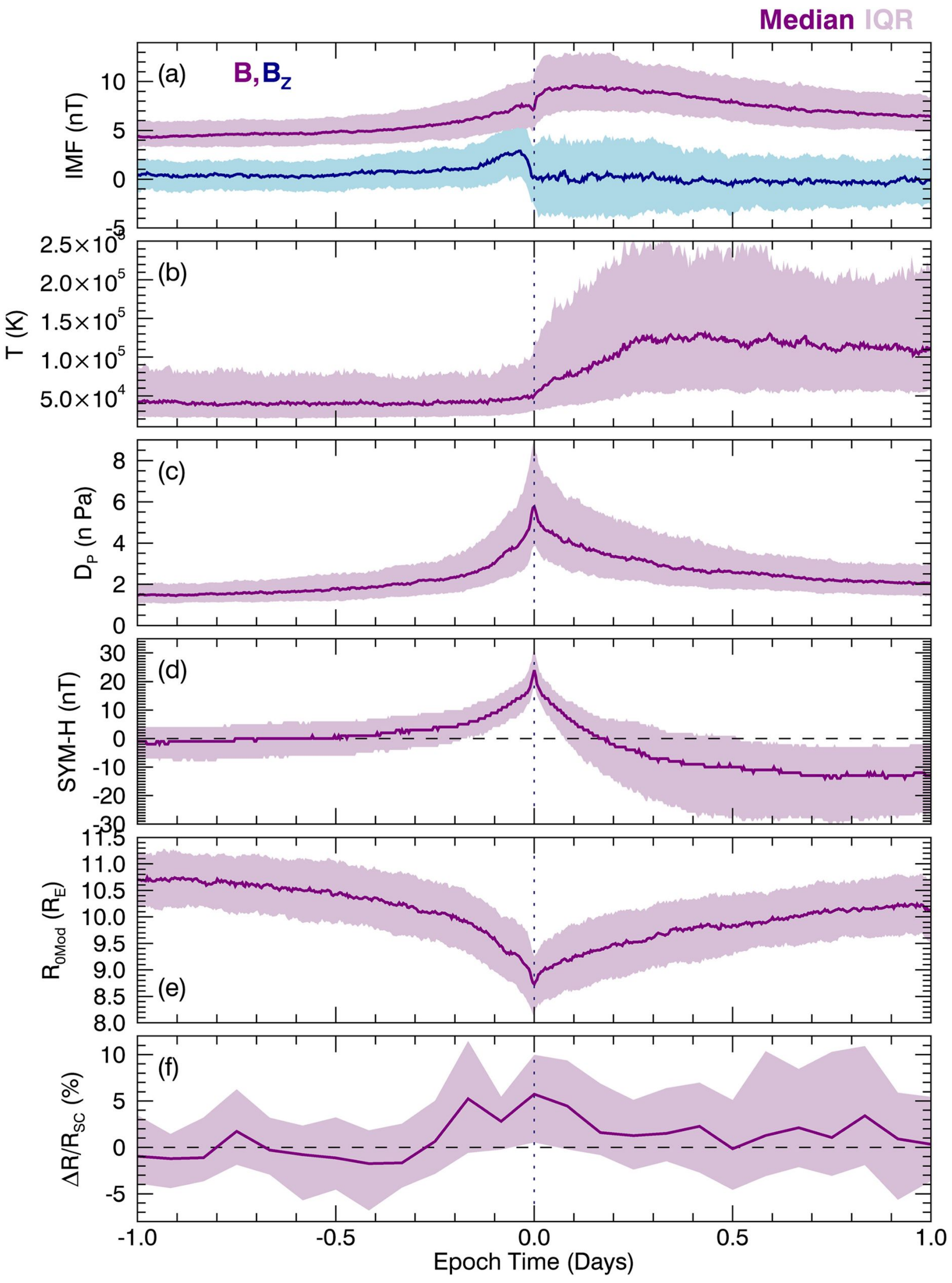
The figure presented shows a superposed epoch analysis of solar wind drivers during strongly positive SYM-H conditions. We selected events for this analysis where there is a peak in SYM-H which exceeds 15 nT, and where there is a spacecraft measurement of the magnetopause within a day of the peak SYM-H. Epoch time zero is chosen as the peak value of SYM-H. In total there were 392 individual events used in the analysis, and 3,629 spacecraft crossings of the magnetopause across all of the epochs used.

The presented figure shows strong evidence of solar wind discontinuities characteristic of forward interplanetary shocks; a sudden increase in temperature and an increase in magnetic field strength following t_0, and a sharp peak in Dp.

Ref: Staples, et al. (2020) *J. Geophys. Res.* 125, DOI: 10.1029/2019JA027289



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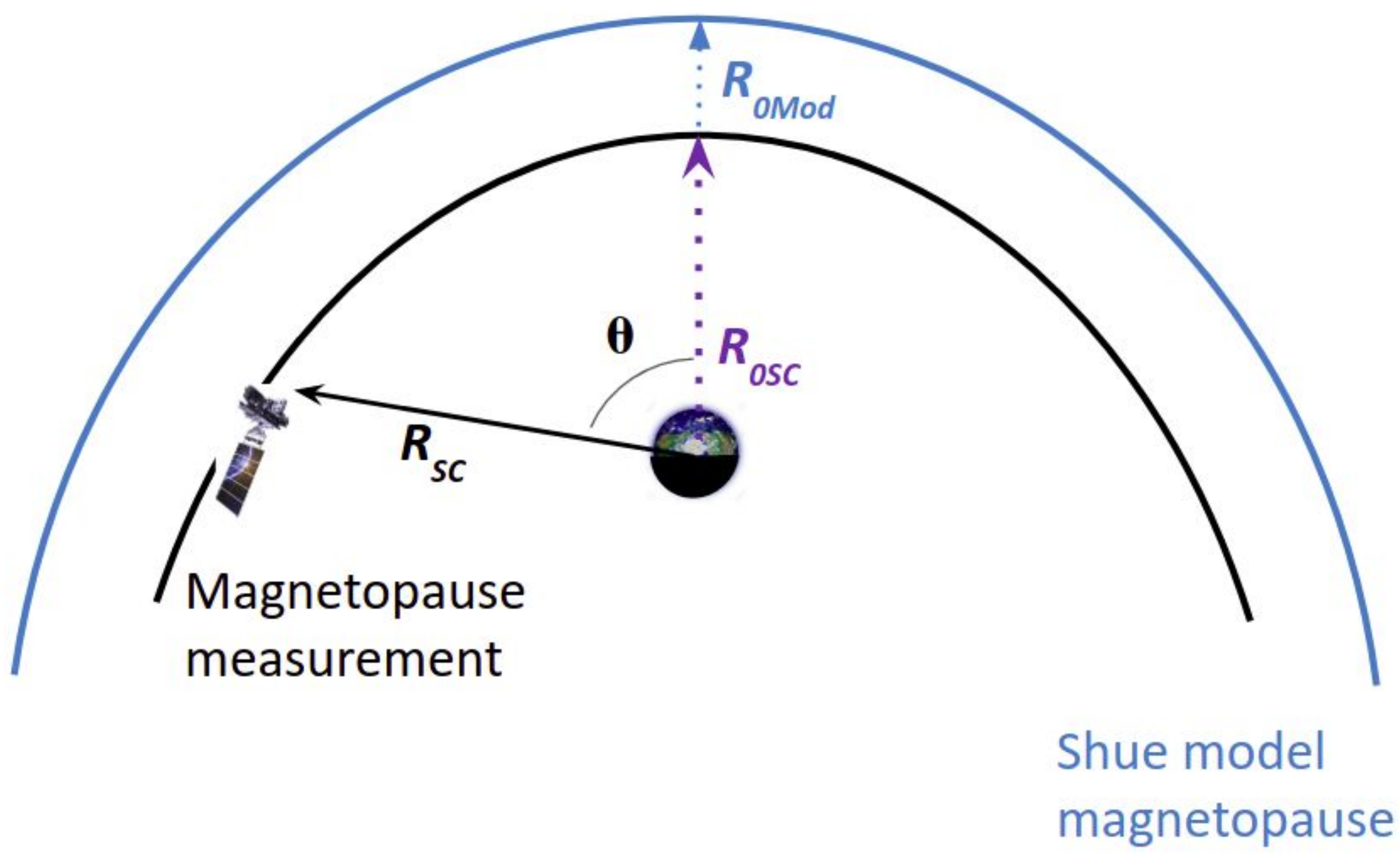
‘Equivalent’ subsolar standoff distance:

By assuming that the shape of the Shue et al. (1998) model (i.e. the tail flaring angle, α) we can rearrange the functional form of the Shue et al. (1998) model to estimate the ‘equivalent’ subsolar standoff distance, R_{0SC}, from the spacecraft measurement of the magnetopause. I.e.

$$R_{0_{\mathrm{SC}}} = R_{\mathrm{SC}}\left(\frac{2}{1+\cos\theta}\right)^{-\alpha}$$



Ref: Staples, et al. (2020) *J. Geophys. Res.* 125, DOI: 10.1029/2019JA027289

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Hi, because I am an early career researcher, many people in our community may not know me. We sadly cannot meet at EGU in person, so I thought I would introduce myself (and my poster) here!

I am Frances Staples, a third year PhD candidate at the Mullard Space Science Laboratory, University College London.

My PhD research investigates how electrons are lost from the Earth's outer radiation belt via magnetopause shadowing. In this paper I investigated how well the location of the magnetopause is captured by the Shue et al. (1998) model during magnetopause compressions as it is commonly used by radiation belt physicists.

I am pleased to be co-convening the EGU session ST2.2 'Dayside Magnetosphere Interactions'. Please get involved in this session's chat on Friday, 8 May 2020, 14:00–15:45.

I can be contacted via email at frances.staples@ucl.ac.uk

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