Effects of Geometries and Substructures of ICMEs on Geomagnetic Storms

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1. Introduction

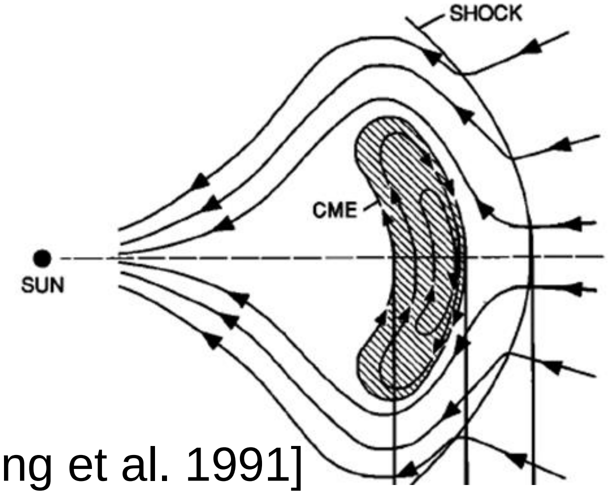
- Interplanetary CME (ICME) and Geomagnetic storm

- ICME-Earth impact geometries

1. Introduction

ICME

- **Interplanetary CMEs (ICMEs)** generally are known as the counterparts of CMEs in the interplanetary space.



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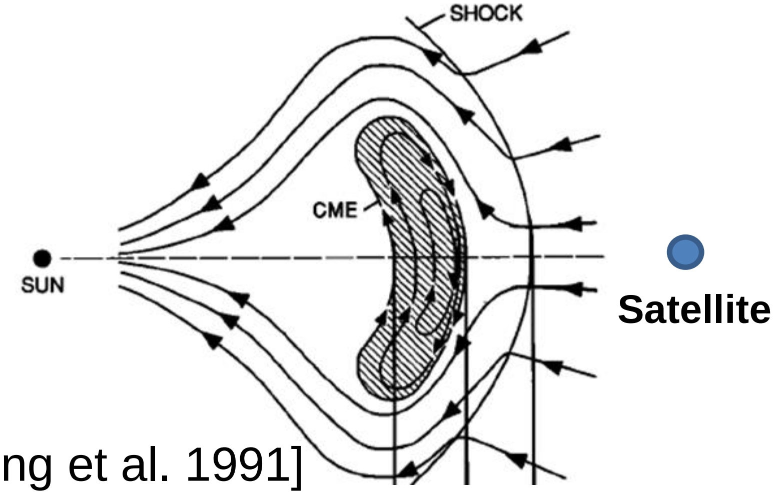

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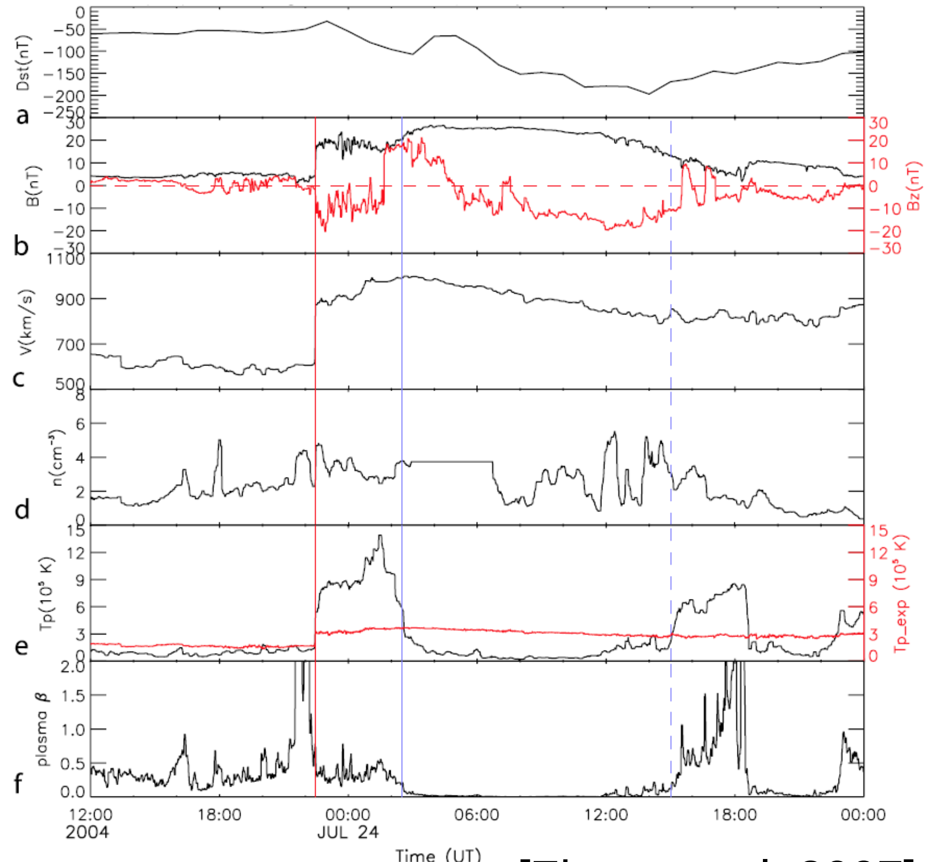

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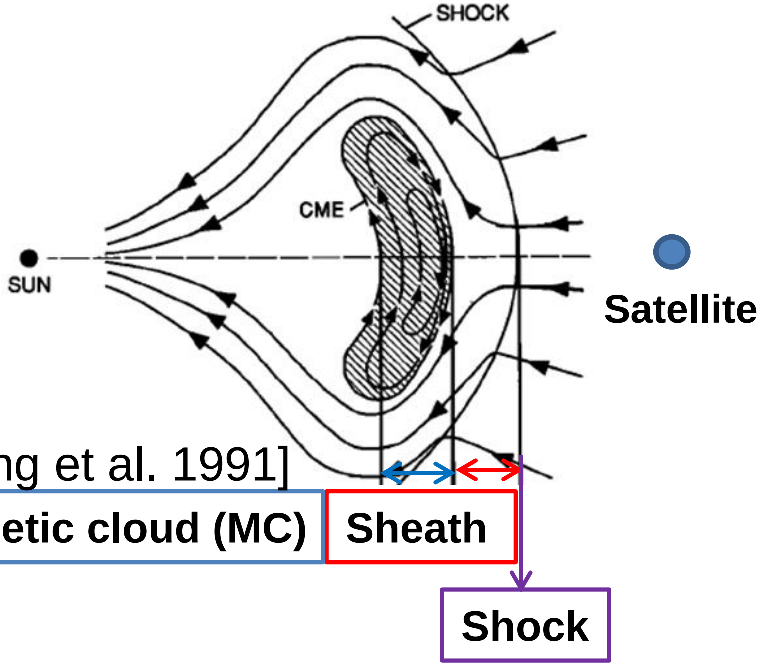

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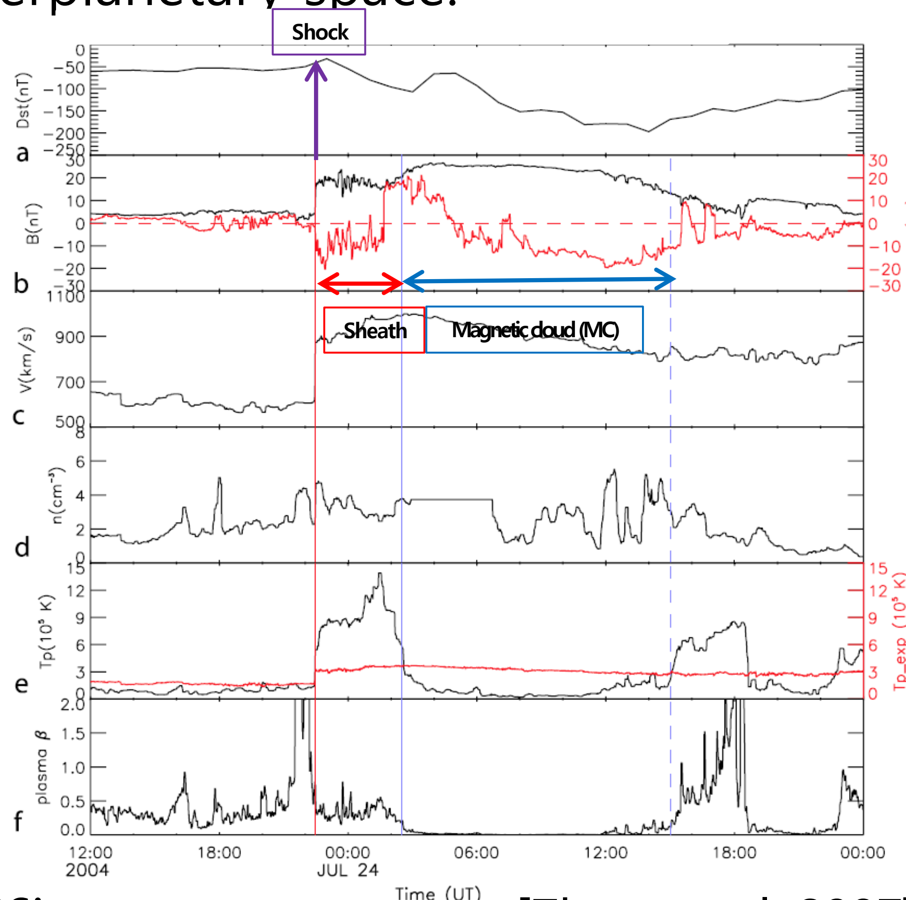

[Zhang et al. 2007]

- ICMEs have three-part structures:

(1) **Shock**-sudden enhancement of solar wind speed or density

(2) **Sheath**-enhanced and fluctuating magnetic field strength

(3) **Magnetic cloud (MC)**-rotating magnetic field signature and low beta plasma

1. Introduction

Storm

- **A geomagnetic storm** is a temporary disturbance of the Earth's magnetosphere and occurs when the southward magnetic field component (B_S) of an interplanetary (IP) structure reconnects with Earth's magnetic field thereby allowing the entry of the solar wind energy into the magnetosphere.

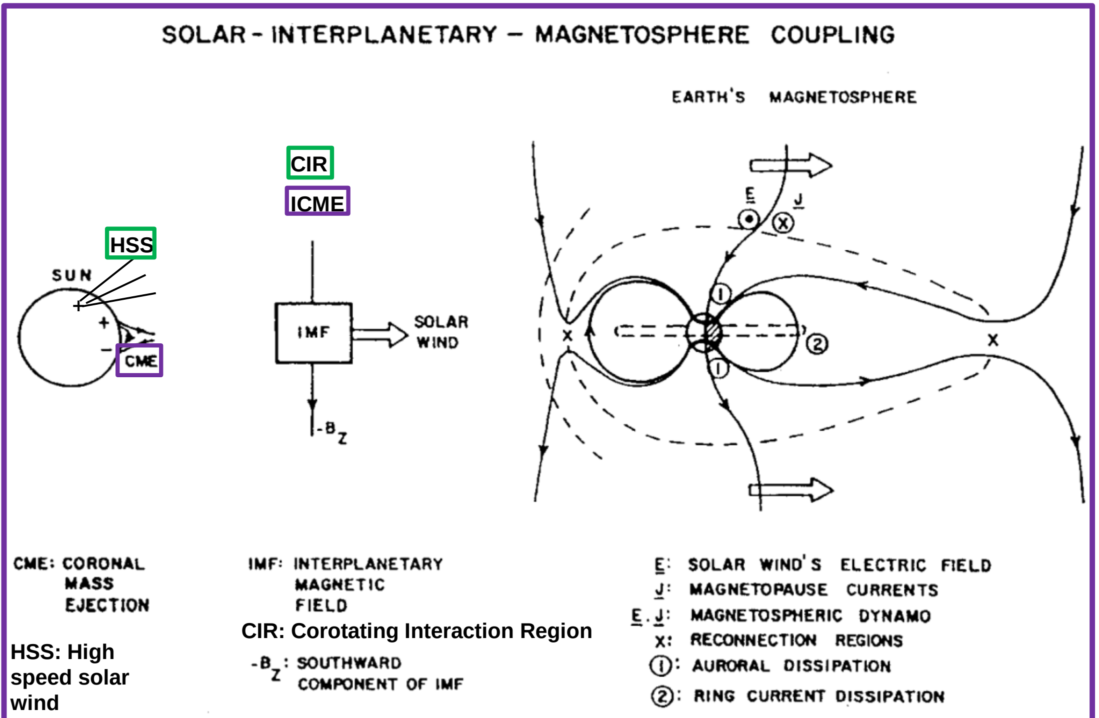

Figure 1. Schematic of interplanetary-magnetosphere coupling, showing the reconnection process and energy injection into the nightside magnetosphere, which lead to the formation of the storm-time ring current (Gonzalez and Tsurutani, 1992). [Gonzalez et al. 1999]

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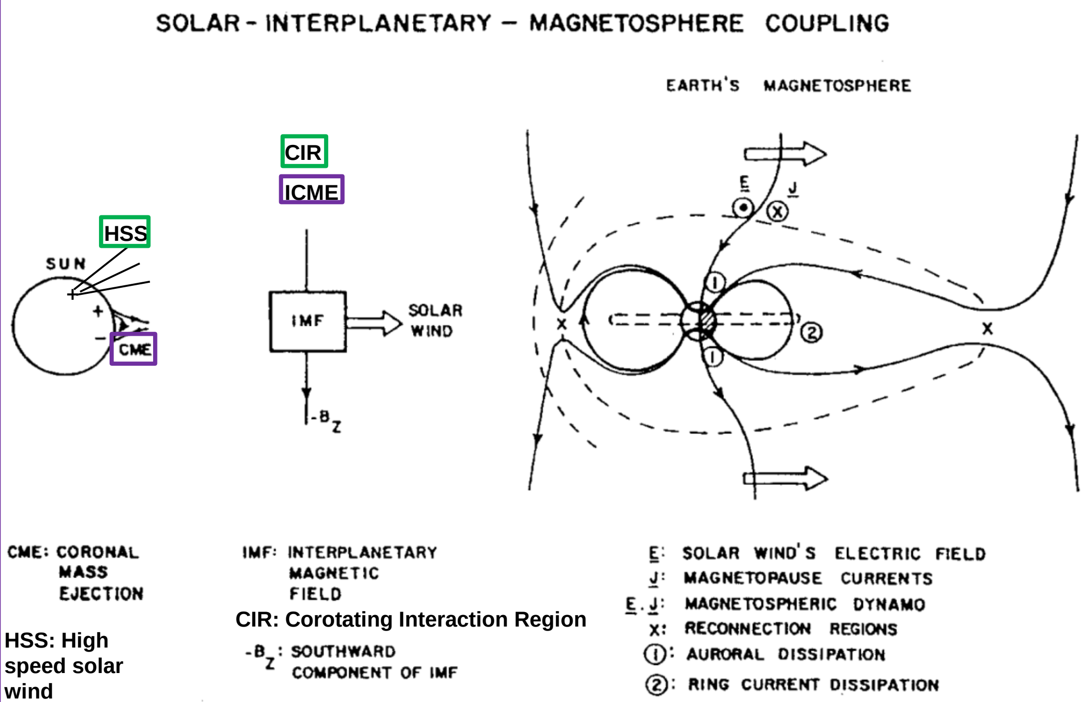
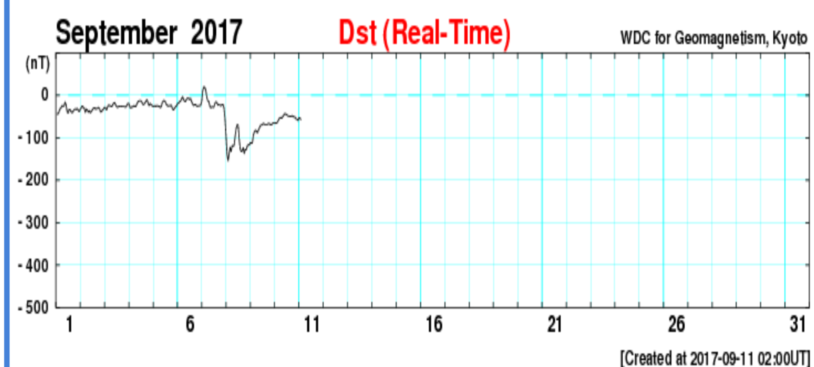


Figure 1. Schematic of interplanetary-magnetosphere coupling, showing the reconnection process and energy injection into the nightside magnetosphere, which lead to the formation of the storm-time ring current (Gonzalez and Tsurutani, 1992). [Gonzalez et al. 1999]

Disturbance Storm Time (Dst) index



Geomagnetic storms can be classified as follows:

Weak (Dst_{min} > -50 nT),

Moderate (- 50 nT ≥ Dst_{min} > -100 nT),

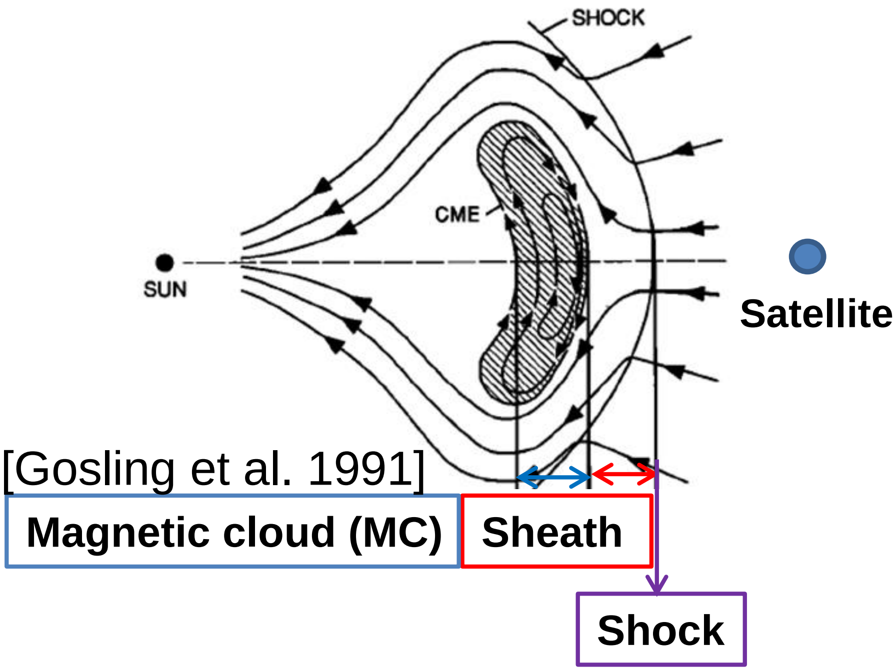
Intense (- 100 nT ≥ Dst_{min} > -200 nT),

Super intense (Dst_{min} ≤ -200 nT)

[Gonzalez *et al.*, 1994; Kim *et al.*, 2010; Lee *et al.*, 2014].

1. Introduction

MC (or sheath)-Storm



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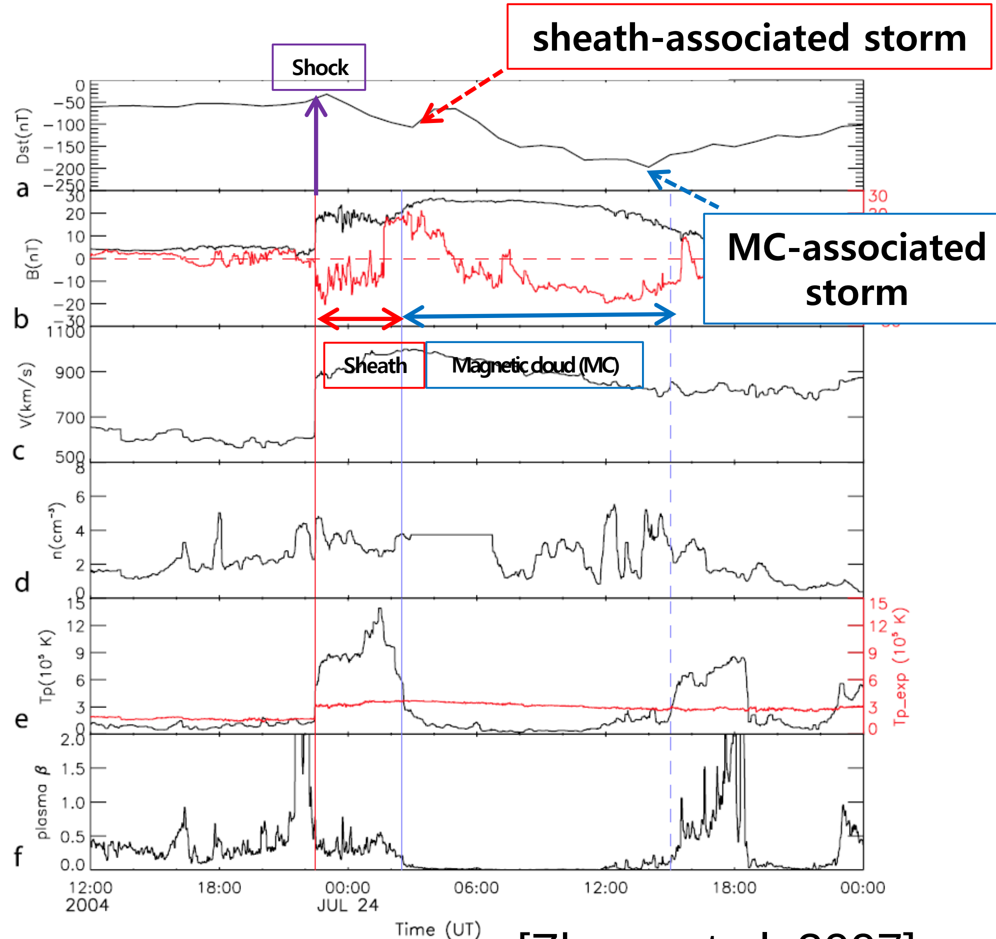


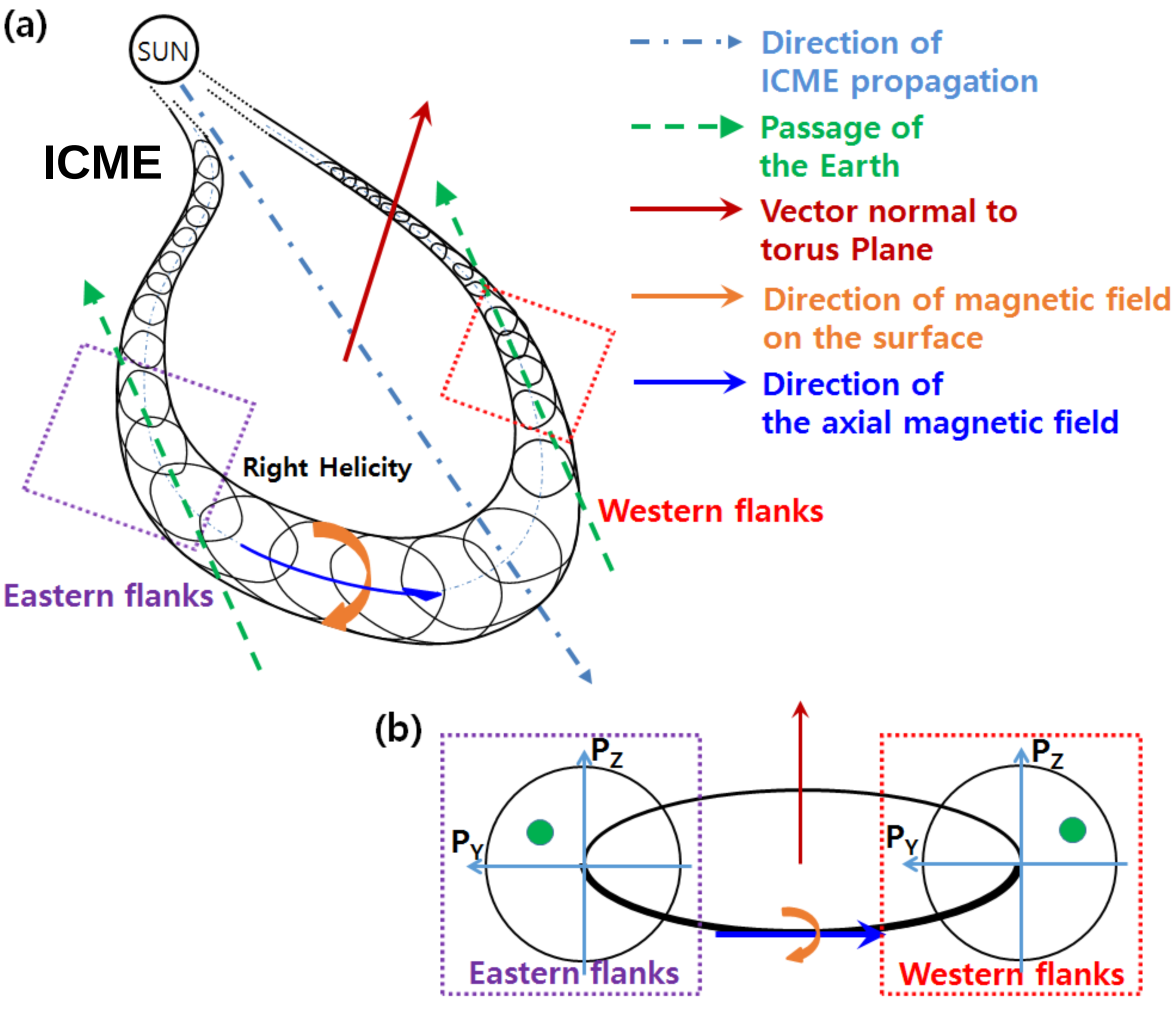
[Zhang et al. 2007]

- If solar wind conditions of sheaths or MCs cause the geomagnetic storms, these kind of events as the **sheath-associated** or **MC-associated storm events**, respectively.

1. Introduction

ICME-Earth geometries

- **3D impact and magnetic field geometries** of ICME can be deduced from the toroidal magnetic flux rope fitting model based on a force-free magnetic field inside a toroidal magnetic cloud [Marubashi & Lepping 2007].



1. Which flank of ICME impact to the Earth (Eastern or Western)

2. Relative position of the Earth trajectory from the ICME axis in the Y-Z plane of GSE coordinate system.

2. Previous studies

- Relationship between solar wind conditions of ICMEs and storms

- Relationship between solar wind conditions of ICME substructures (MC and sheath) and storms

- Relationship between 3D magnetic field structures of ICMEs derived from toroidal magnetic flux rope fitting model and Storms

2. Previous studies

1) Relationship between solar wind conditions of ICMEs and storms

- Several researchers found that the southward magnetic field strength (B_S) and convection electric field ($E_Y = V_{SW} \times B_S$) in ICMEs have higher correlation coefficients (cc) with the Dst index than solar wind speeds (V_{SW}) [Echer et al., 2008; Richardson & Cane 2010]; cc = 0.89 for B_S, cc = 0.90 for E_Y, and cc = -0.54 for V_{SW} [Richardson & Cane 2010].

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2) Relationship between solar wind conditions of ICME substructures (MC and sheath) and storms

- Gopalswamy 2008 found that correlation coefficients of solar wind conditions (V_{SW}, B_S, E_Y) in MC with Dst index are similar to those in sheath; In V_{SW}, cc = -0.65 for MC and cc = -0.67 for sheath and In E_Y, cc = 0.90 for MC and cc = 0.86 for sheath.

- Yermolaev et al. 2010 showed that the efficiency of sheath in the generation of magnetic storms is higher than MC by using the method of superposed epoch analysis.

2. Previous studies

3) Relationship between 3D magnetic field structures of ICMEs derived from toroidal magnetic flux rope fitting model and Storms

- Cho et al. (2017) examined two ICME-storm pairs and suggested that even if an ICME hits the Earth by flank, it can cause a strong storm when its inherent magnetic field keeps southward throughout its passage. The magnetic field conditions change depending on where the Earth located in the ICME.

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★ The main purpose of this study is that to better understand of storm generation by an ICME, we statistically examine the effects of **geometries (impact location of flux rope at the Earth) and substructures (sheath and MC) of ICMEs on geomagnetic storms**. ★

3. Data selection & Analysis

- Data selection

- Analysis

- Solar wind data

3.1 Data selection

- Consider 59 CME-ICME pairs from CDAW list
  "Do all CMEs have flux rope structure?"
  (http://cdaw.gsfc.nasa.gov/meetings/2010_fluxrope/LWS_CDAW2010_ICMEtbl.html)

- Apply the toroidal magnetic flux rope fitting model to the ICME-storm pairs to identify their substructures and geometries, and select 25 MC-associated and 5 sheath-associated storm events.

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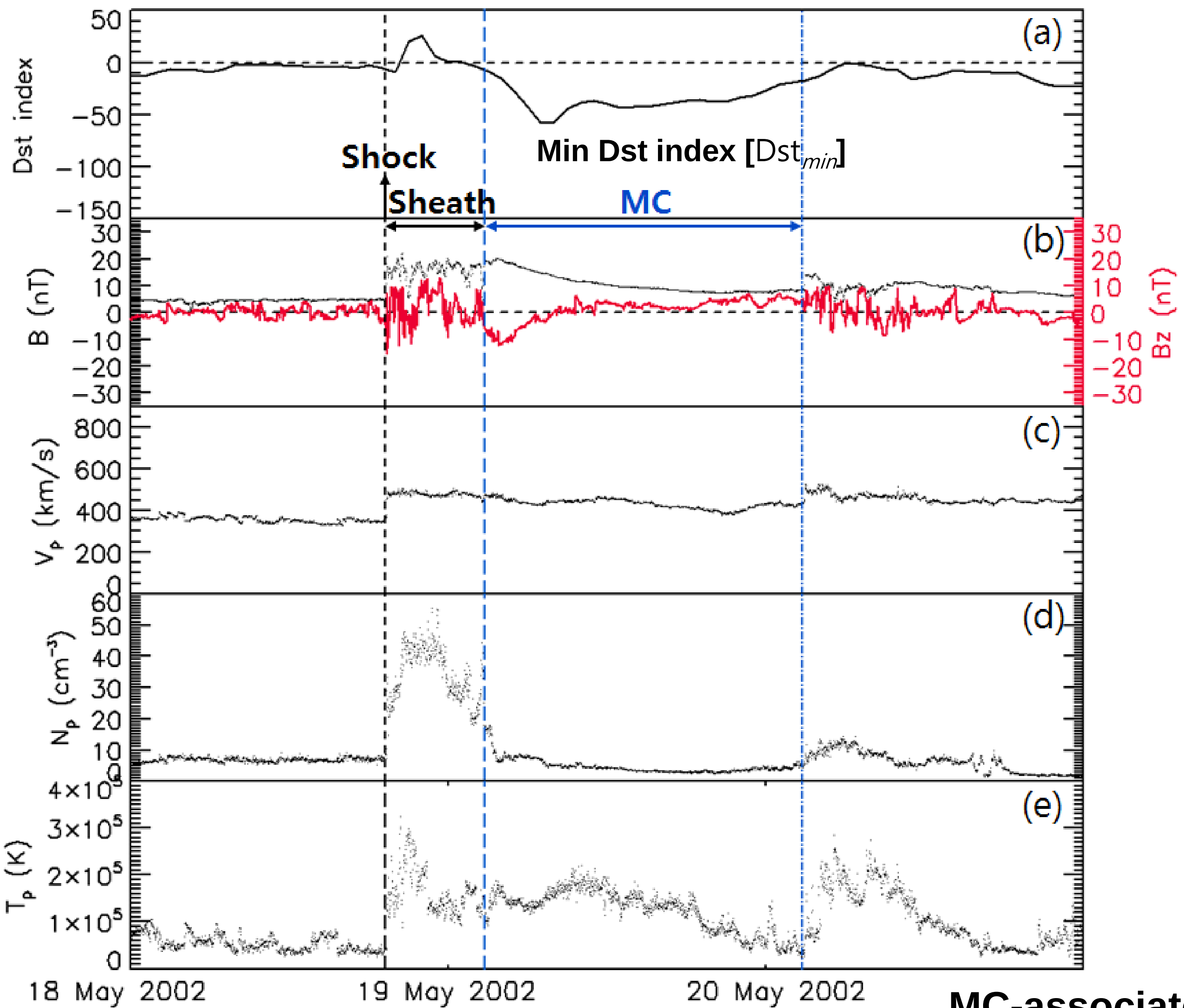
3.2 Analysis

- Make a simple linear-regression analysis to find out the relationship between Dst index and solar wind conditions of ICME substructures (MCs and sheaths).

3.2.1 Solar wind data

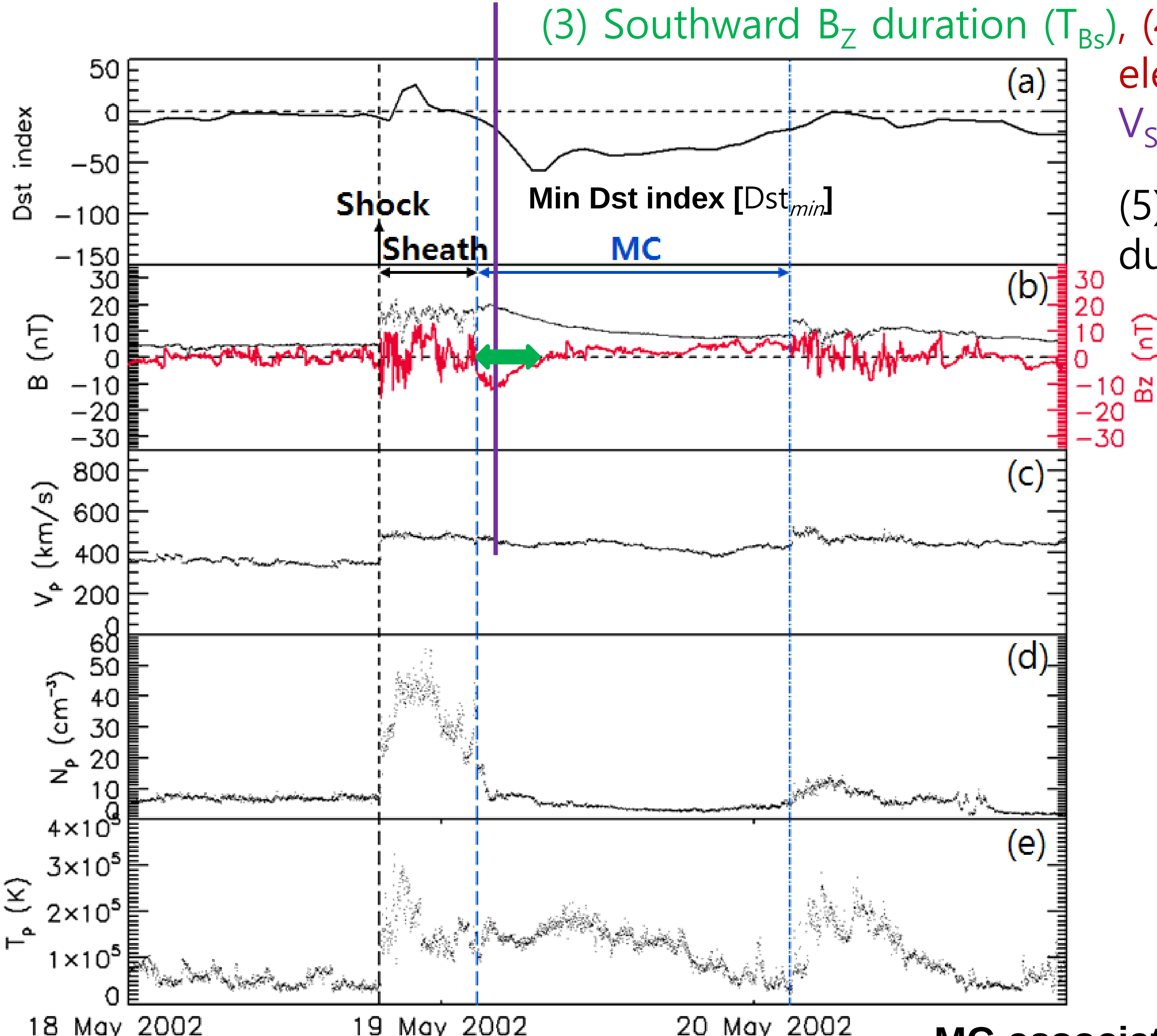


MC-associated storm

3.2.1 Solar wind data

(1) Min southward B_Z [B_S], (2) Solar wind speed [V_{SW}] at B_S

(3) Southward B_Z duration (T_{Bs}), (4) Convection electric field (E_Y) = V_{SW} X B_S



(5) Integraed E_Y during T_{Bs} = E_Y X T_{Bs}

MC-associated storm

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3.2 Analysis

- Make a simple linear-regression analysis to find out the relationship between Dst index and solar wind conditions of ICME substructures (MCs and sheaths).

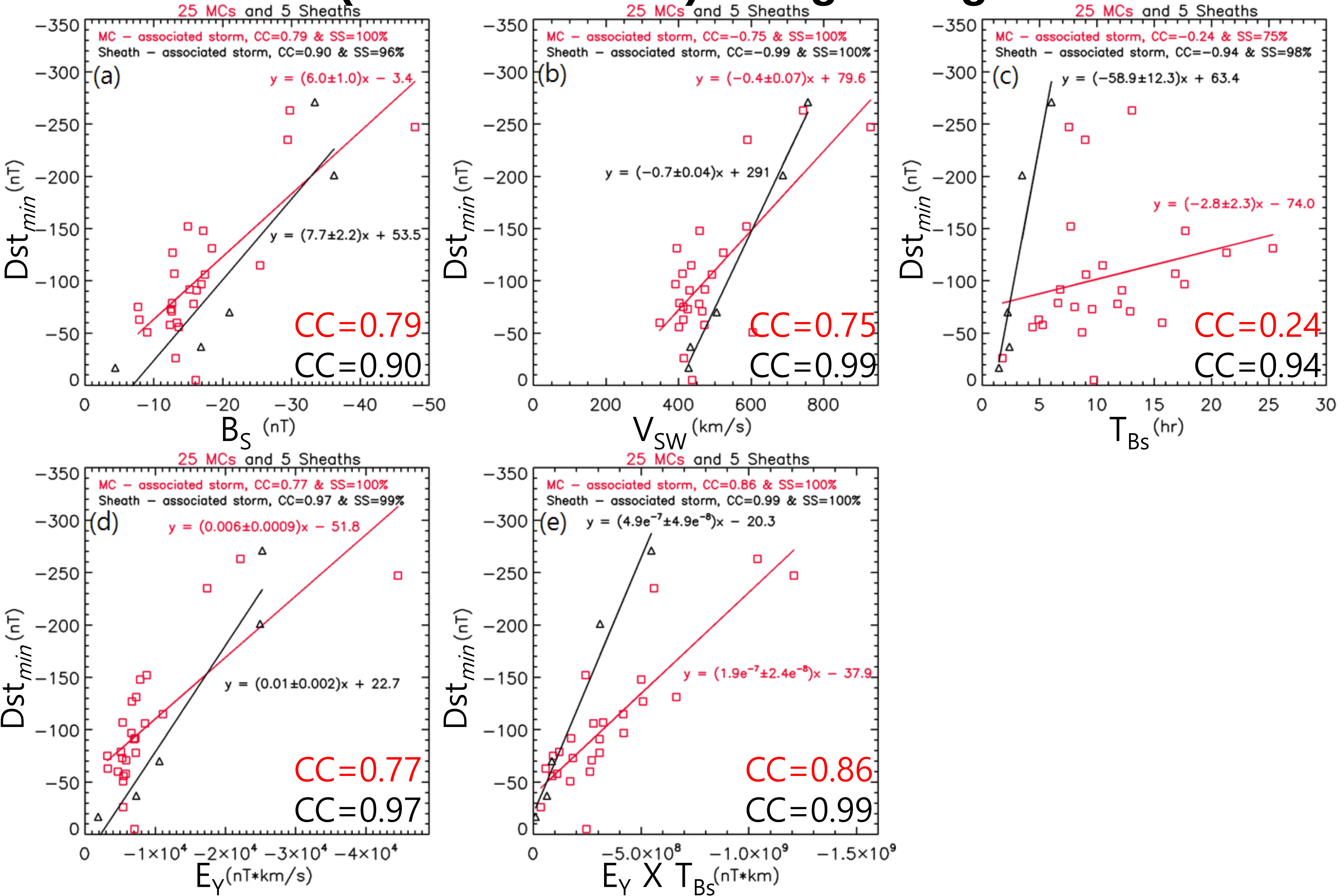
- Examine the dependence of the geomagnetic storms on the combination of ICME-Earth impact geometries such as following: eastern flank and positive value of PY [E+P_{Y+}], eastern flank and negative value of PY [E+P_{Y-}], western flank and positive value of PY [W+P_{Y+}], and western flank and negative value of PY [W+P_{Y-}]. For this, we use the MC-associated storm events.

4. Results

- Relationship between solar wind conditions of ICME substructures (MC and sheath) and geomagnetic storms

- Dependence of the geomagnetic storms on the combination of ICME-Earth impact geometries

4.1 Relationship between solar wind conditions of ICME substructures (MC and sheath) and geomagnetic storms



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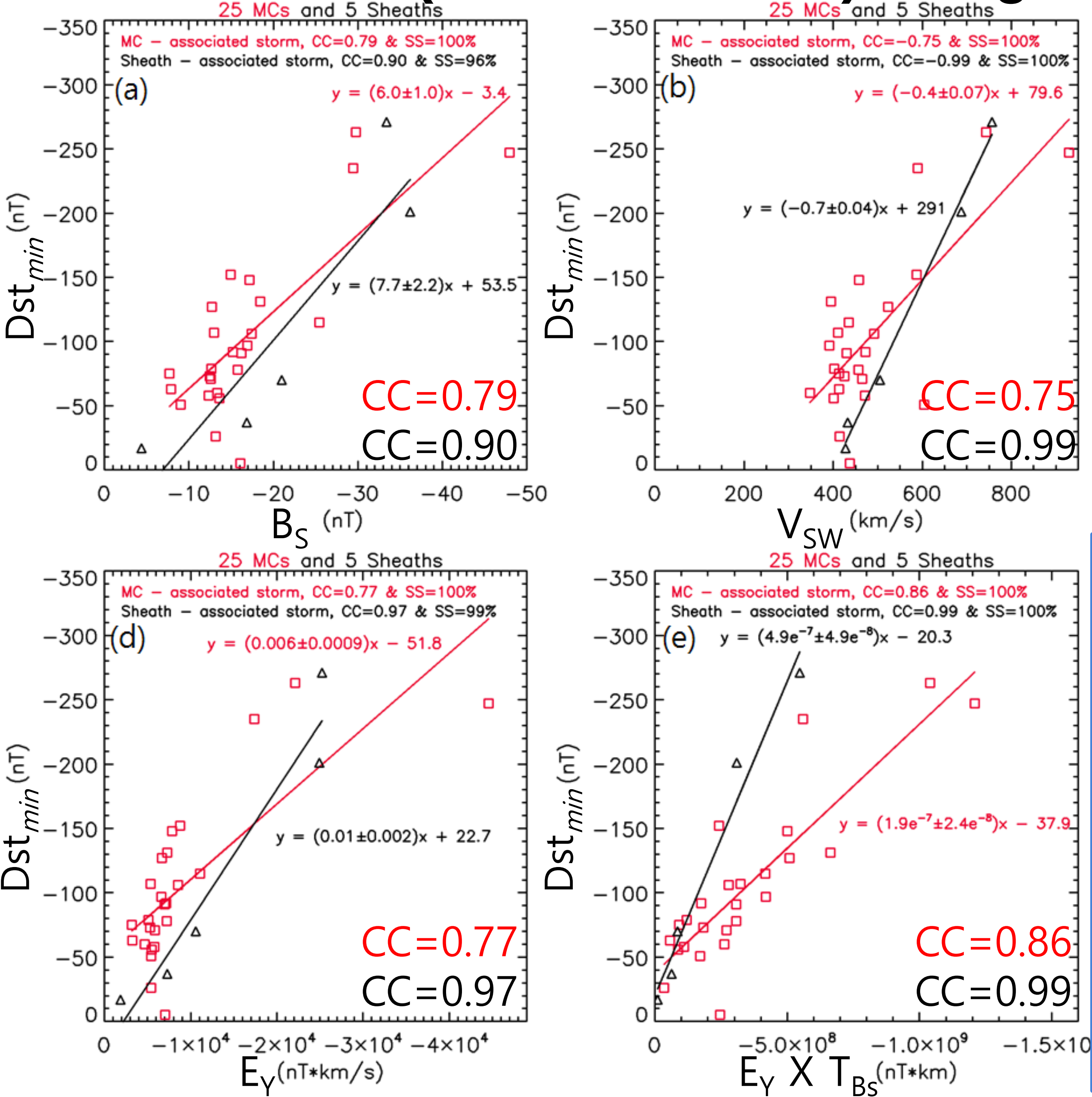

1. The integrated E_Y during T_{Bs} [$E_Y \times T_{Bs}$] has a higher correlation coefficient with Dst index than the other parameters.

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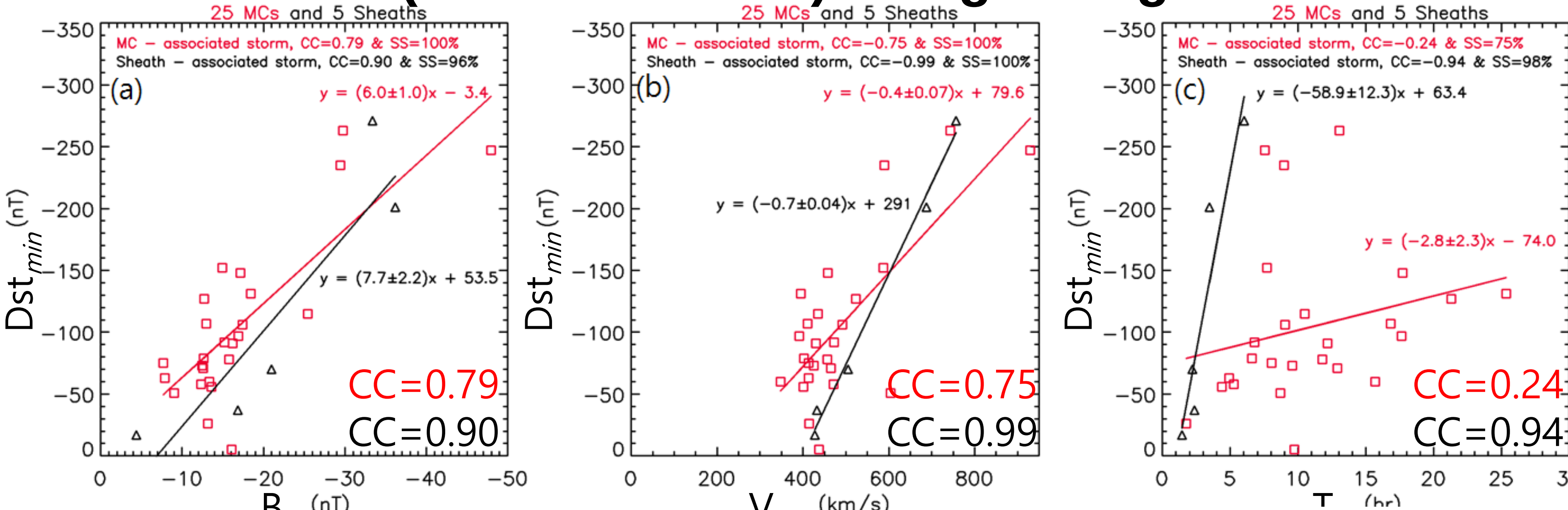

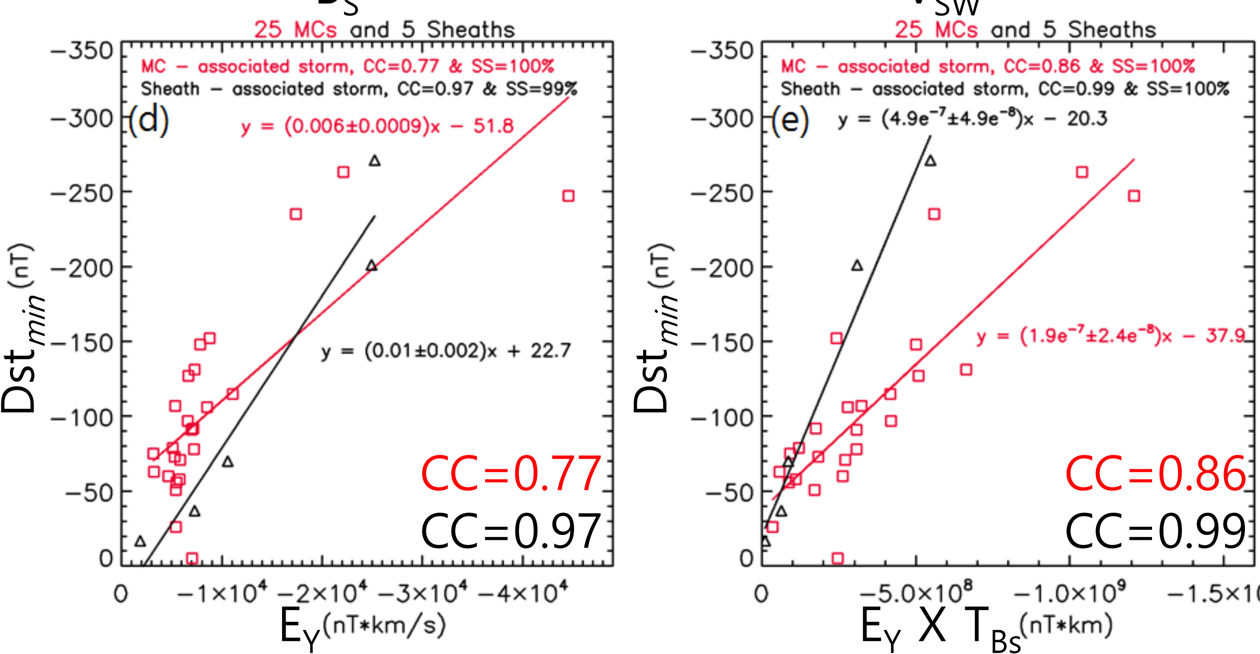

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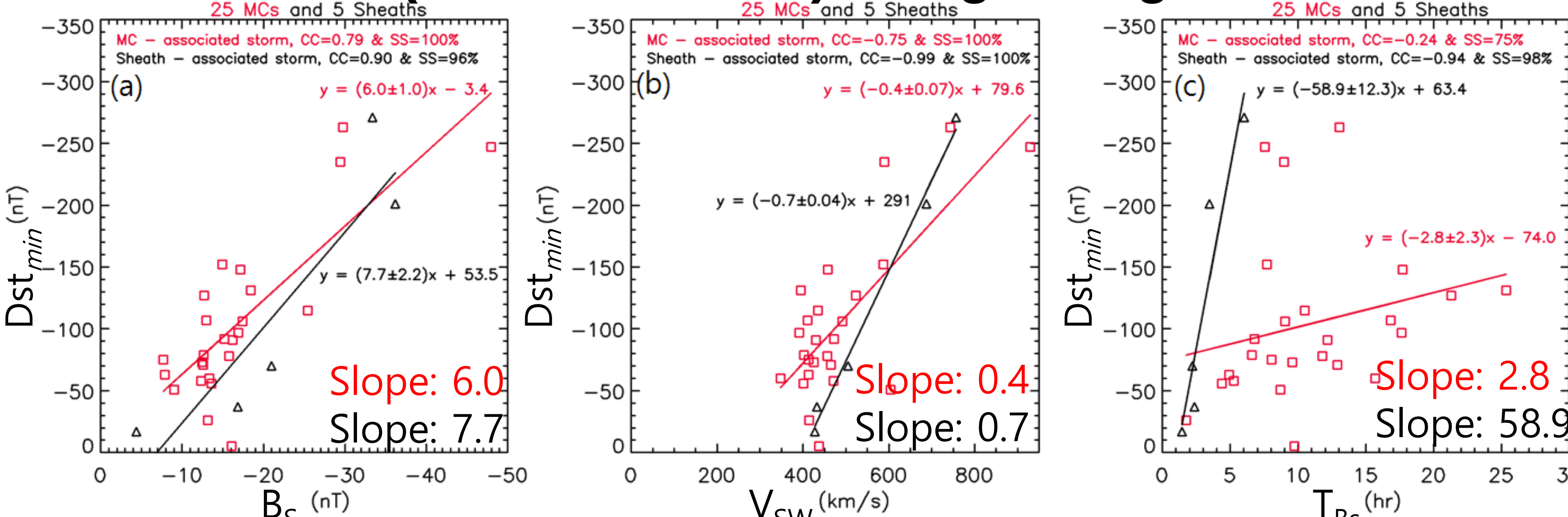
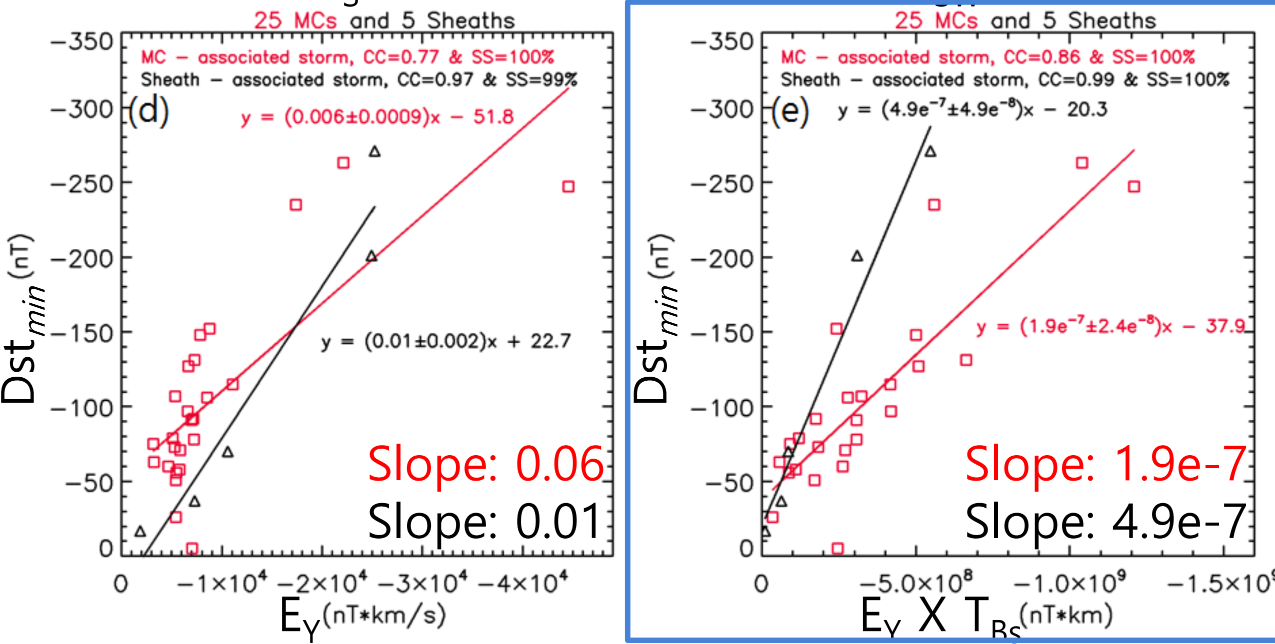
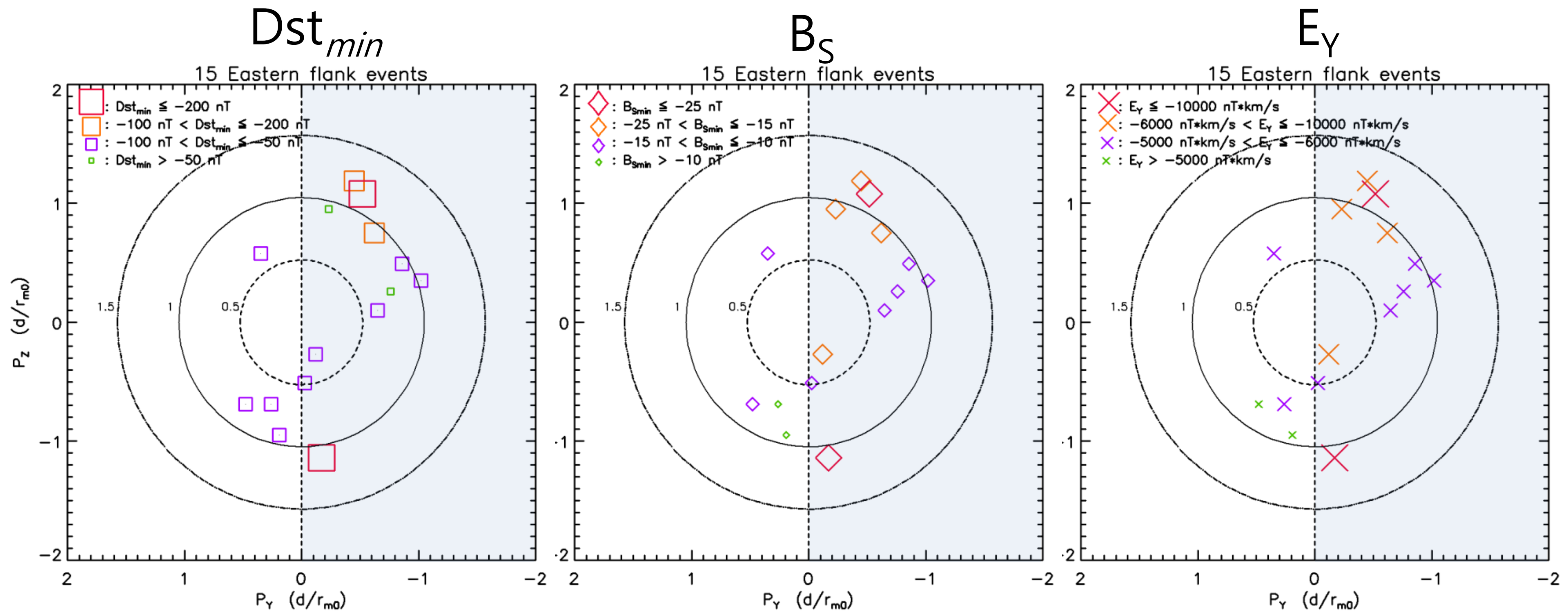
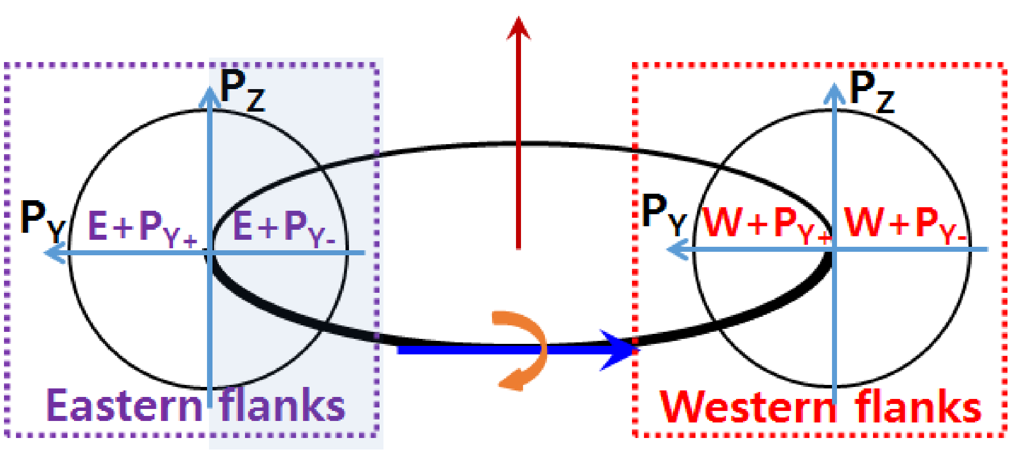




3. The slope of the sheath-associated storm events is about two times larger than that of the MC-associated storm events, implying that sheaths can produce stronger storms than MCs at a given solar wind condition.

4.2 Dependence of the geomagnetic storms on the combination of ICME-Earth impact geometries





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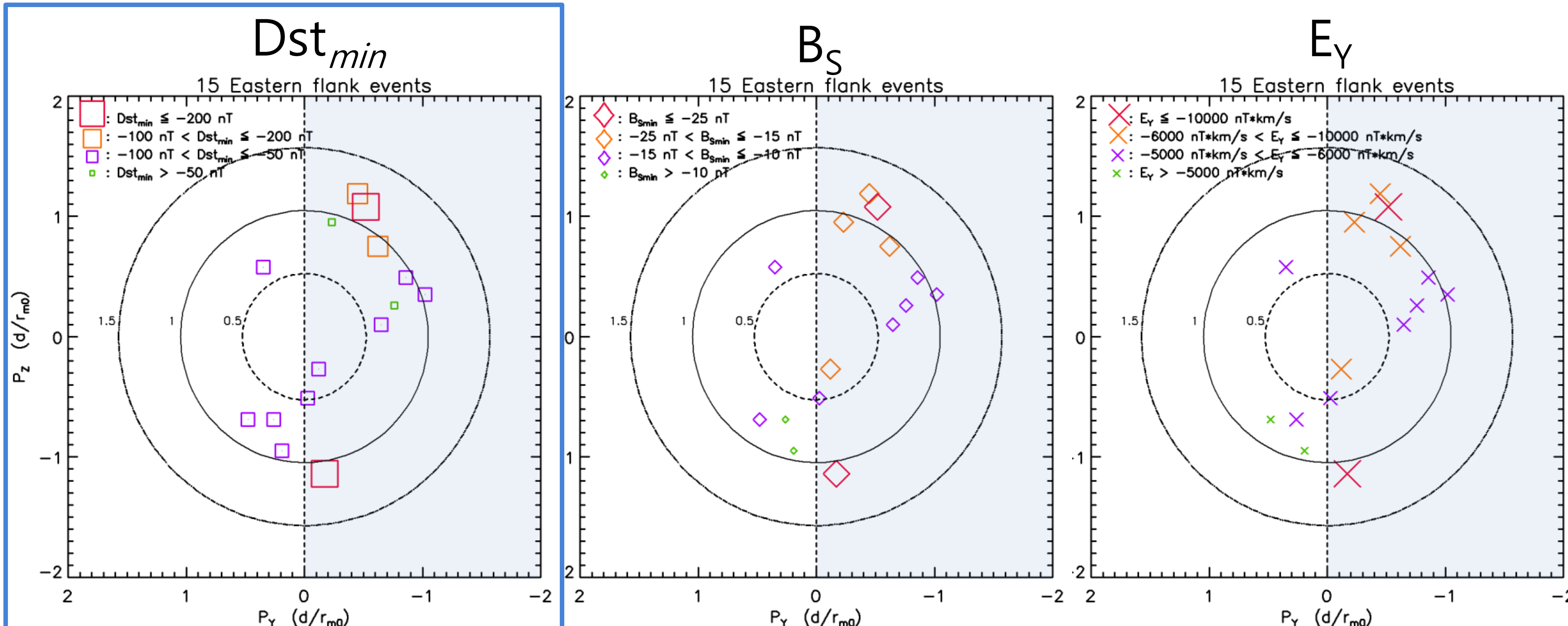
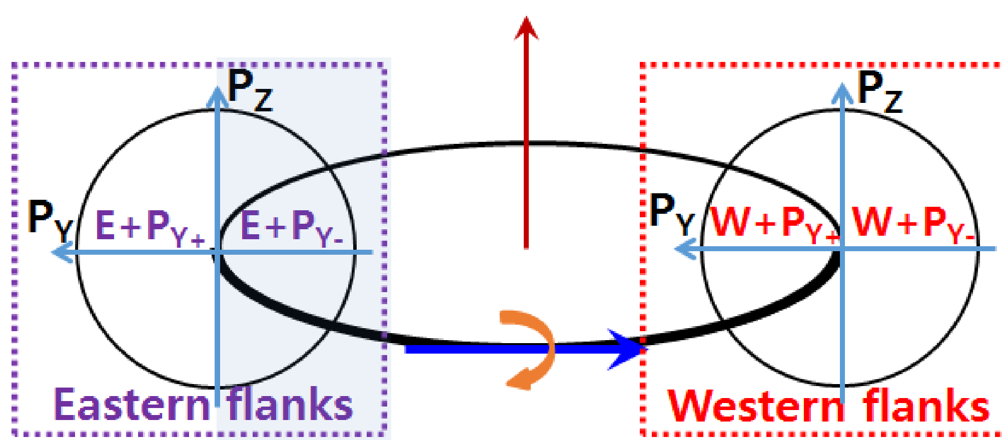


1. 73 % (11/15) of storms and 100 % (4/4) of intense storms ($Dst_{min} \leq -100$ nT) occur in regions at negative P_Y for eastern flank events.



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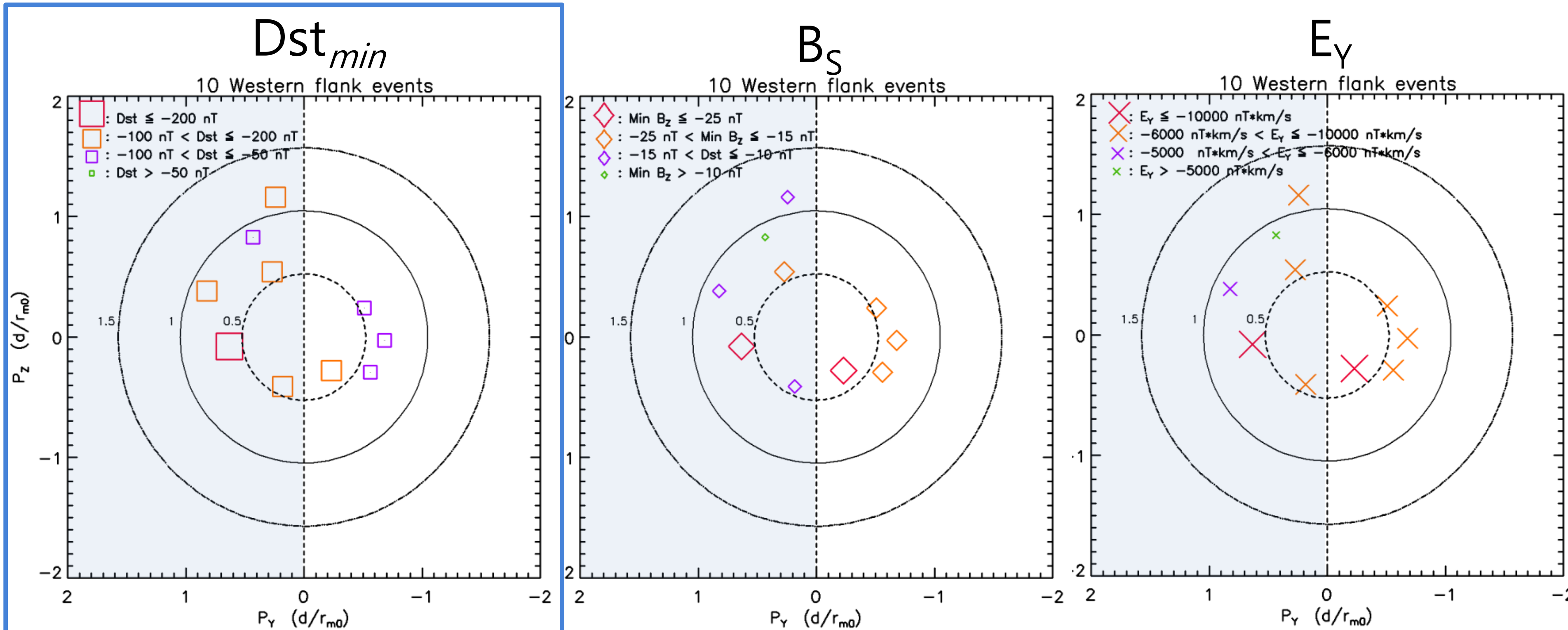
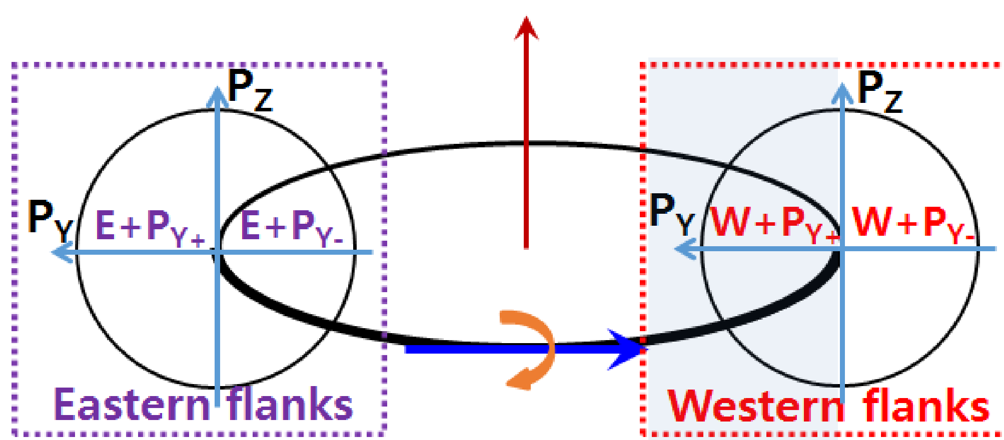


2. 60 % (6/10) of storms and 83 % (5/6) of intense storms (Dst$_{min}$ ≤ – 100 nT) occur in regions at positive P_Y for western flank events.



5. Summary

- Relationship between solar wind conditions of ICME substructures (MC and sheath) and geomagnetic storms

- Dependence of the geomagnetic storms on the combination of ICME-Earth impact geometries

5.Summary

1) Relationship between solar wind conditions of ICME sub-structures (MC and Sheath) and Geomagnetic storms

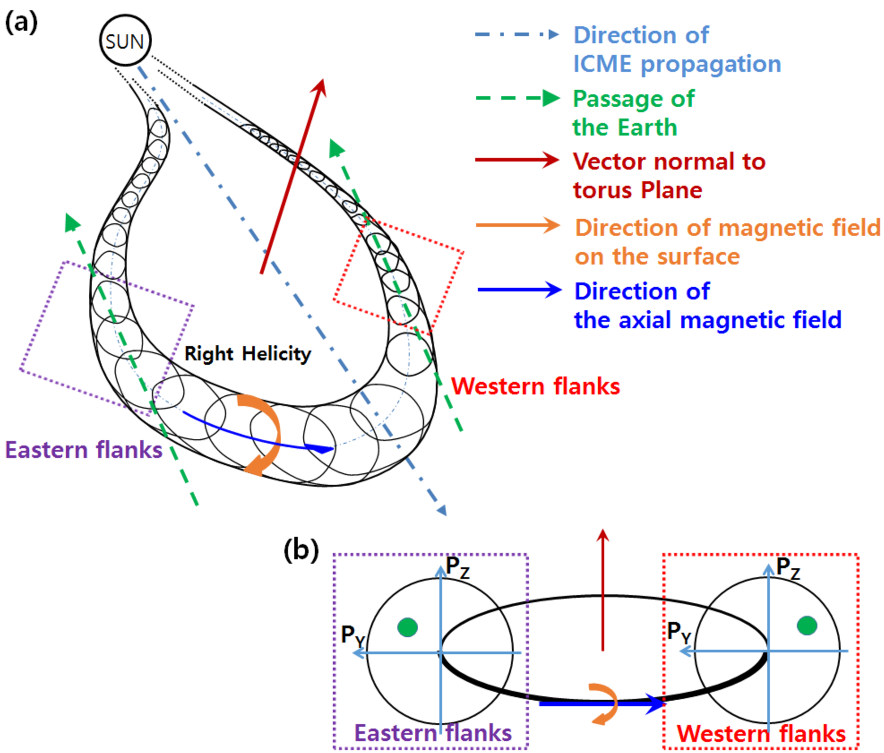
- Correlation coefficients (CCs) of solar wind conditions in sheath with Dst index are higher than those in MC; for EY , CC = 0.97 in sheath and CC = 0.77 in MC.
- The slope of a linear regression line for sheath-storm events is about two times steeper than that of the MC-storm events in the relationship between storm strength (Dst index) and $E_Y \times T_{Bs}$.

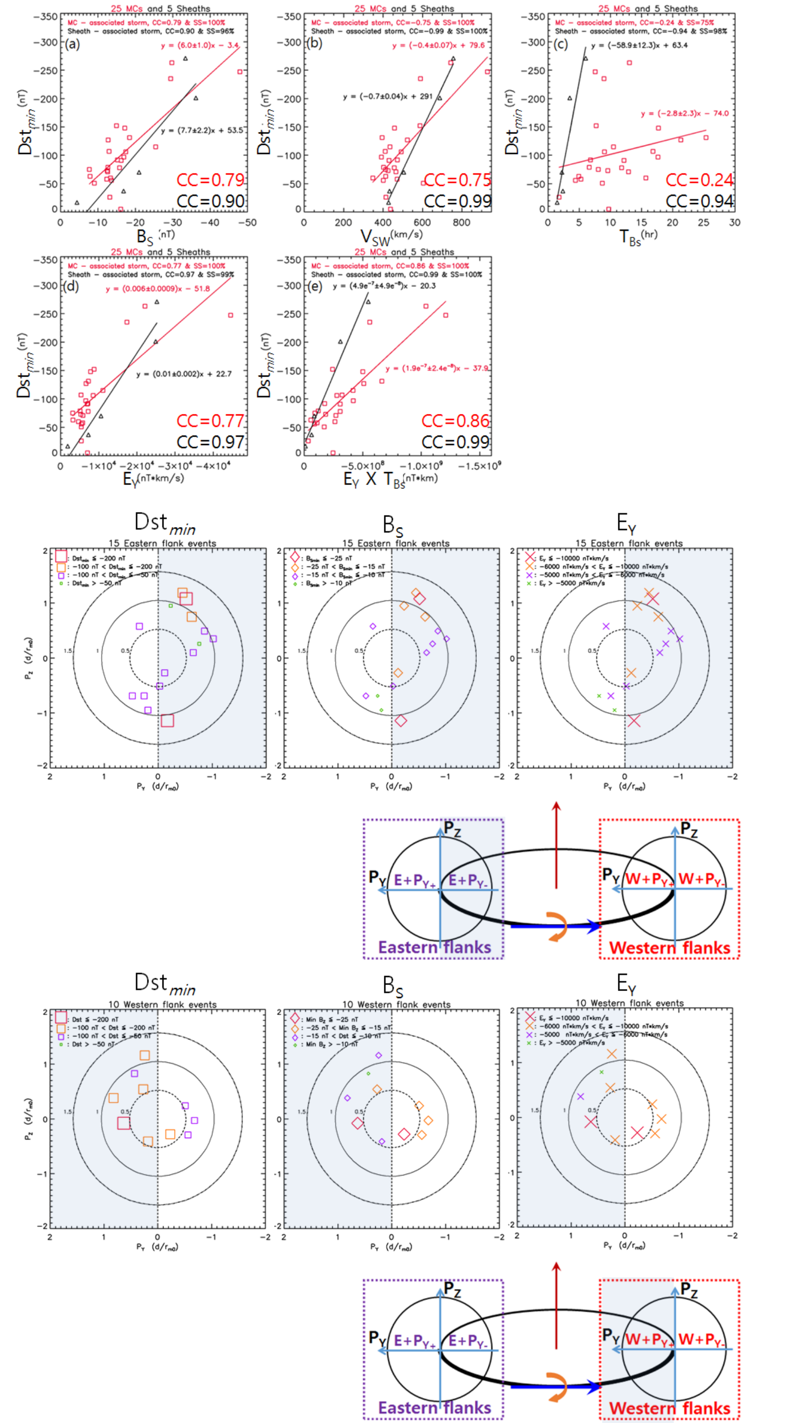
2) Dependence of the geomagnetic storms on the combination of ICME-Earth impact geometries

- 73 % (11/15) of storms and 100 % (4/4) of intense storms ($Dst_{min} \leq$ -100 nT) occur in the regions at negative P_Y for the Eastern flank events while 60 % (6/10) of storms and 83 % (5/6) of intense storms occur in positive P_Y regions for the western flank events.

★ **Our results demonstrate that the strength of a geomagnetic storm is strongly affected by not only ICME substructures (sheaths and MCs) but also ICME-Earth impact geometries (P_Y on ICME-Earth trajectory).** ★

Thank you





We are grateful to Byeongseok Lee who give us the preliminary results.