Lecture 6:
Solar wind powers magnetosphere

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Goals for the lecture 6

- Goal 1: Understand where does substorm energy originate from and how does it circulate in the magnetosphere.
- Goal 2: Learn to compute substorm energy input from solar wind into the magnetosphere.

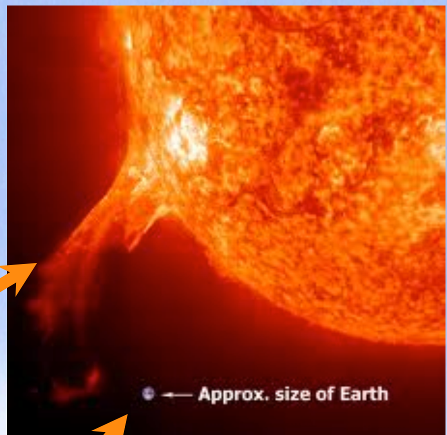
(Goal 3: Shift the solar wind data to the magnetopause.)

Additional reference: Weiss, L.A, P.H. Reiff, J.J. Moses et al., Energy dissipation in substorms, Proceedings of the (ICS-1), May 1992.

Goal 1:

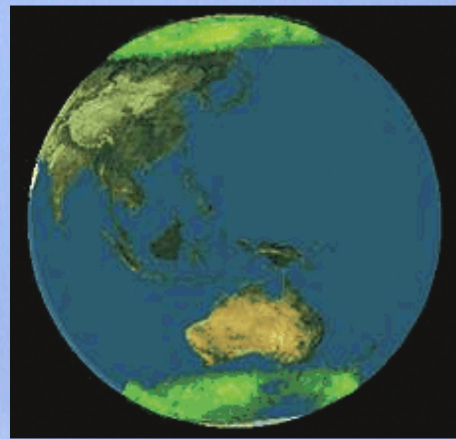
Understand where does substorm energy originate from
and how does it circulate in the magnetosphere.

Solar sources of substorm energy



Solar disturbance

The Earth



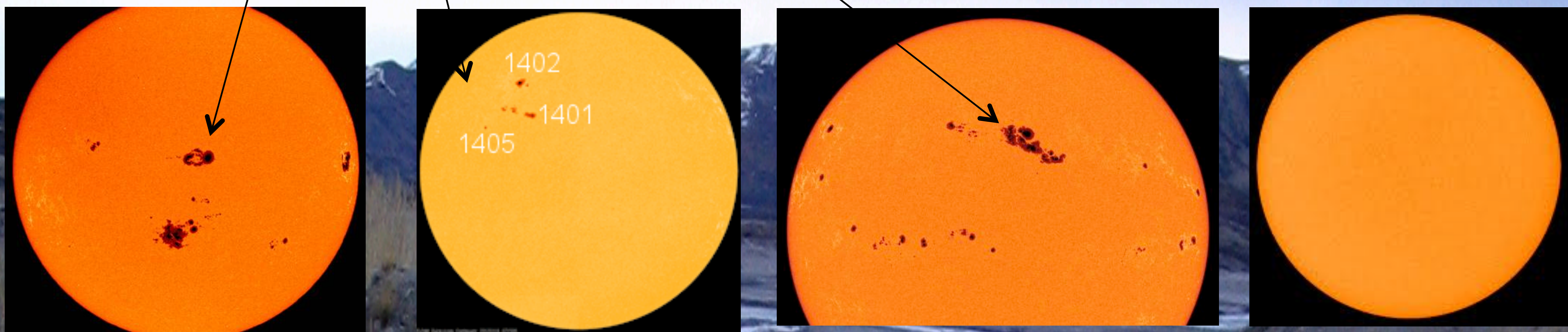
Auroral ovals

Sun is powering substorms

Solar magnetic field becomes most easily visible by sunspots, which have been observed by naked eye since thousands of years.

Sunspots are areas of intense magnetic field where the solar surface temperature is lower than on an average.

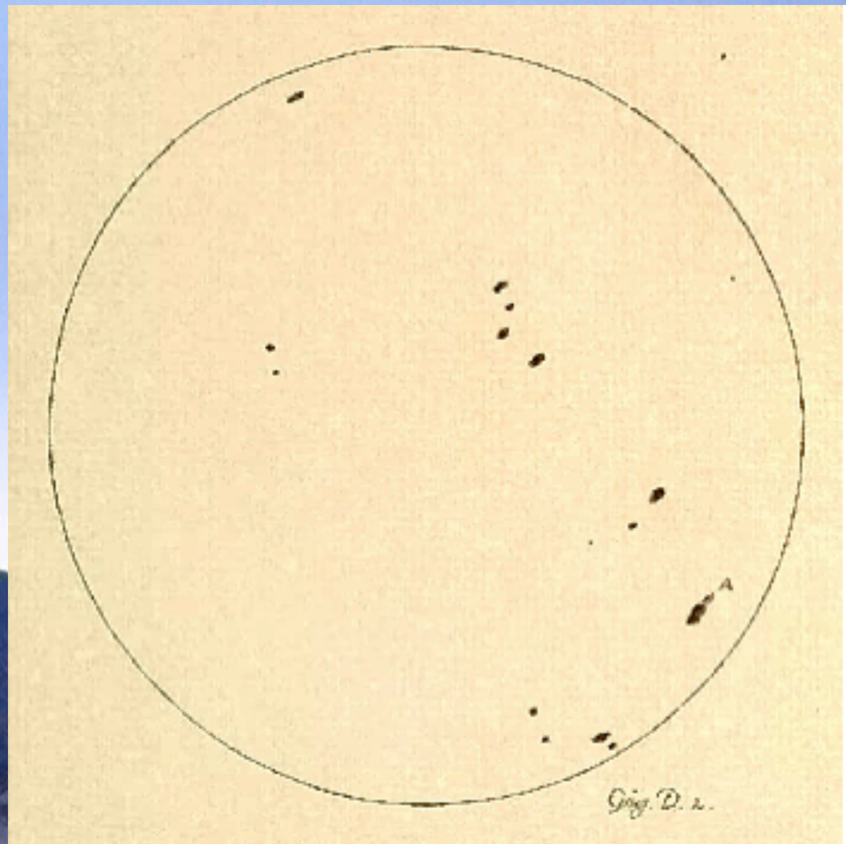
The temporal variation of magnetic fields is called solar activity.



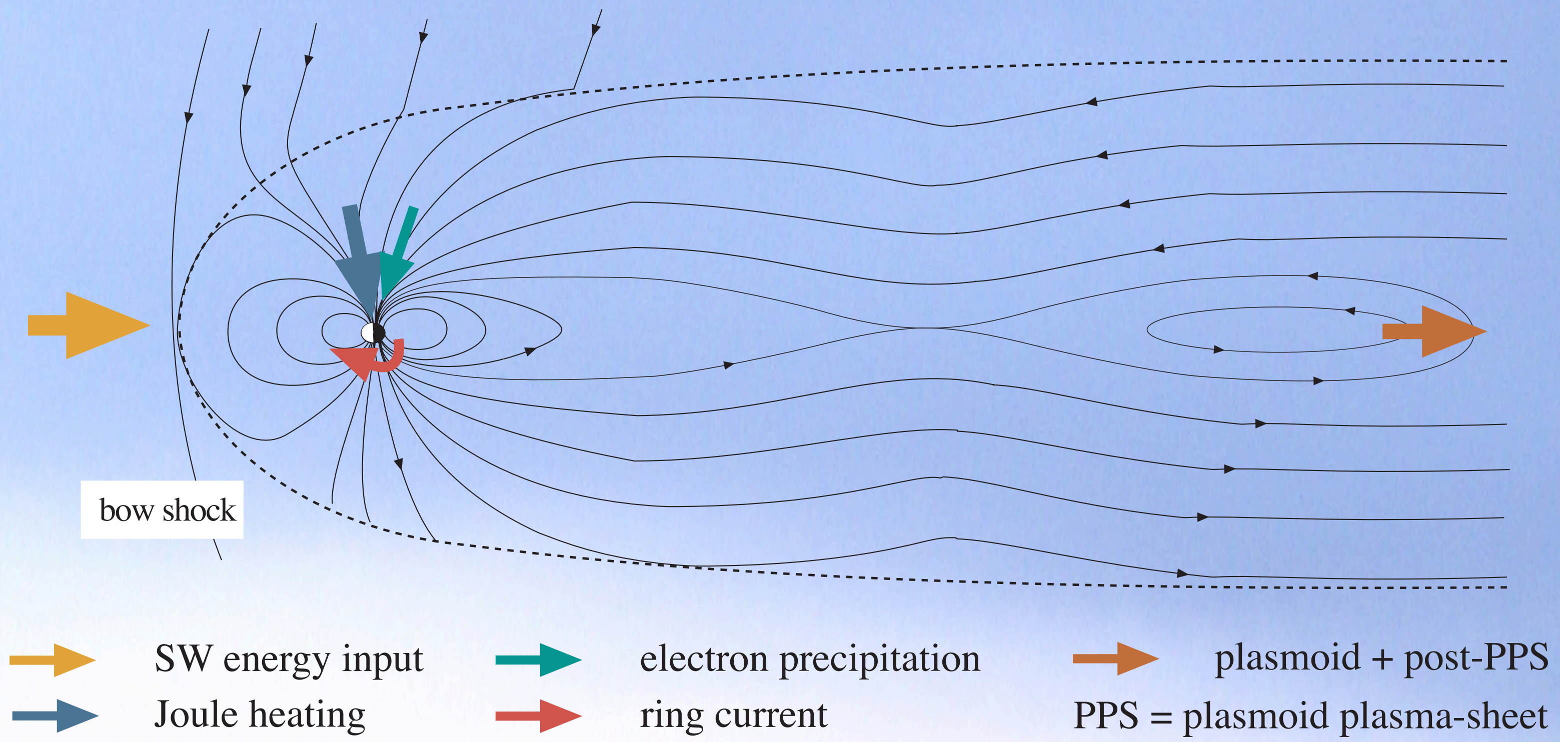
Historical sunspot observations

Earliest known sunspot drawing
AD 8.12.1128, England.

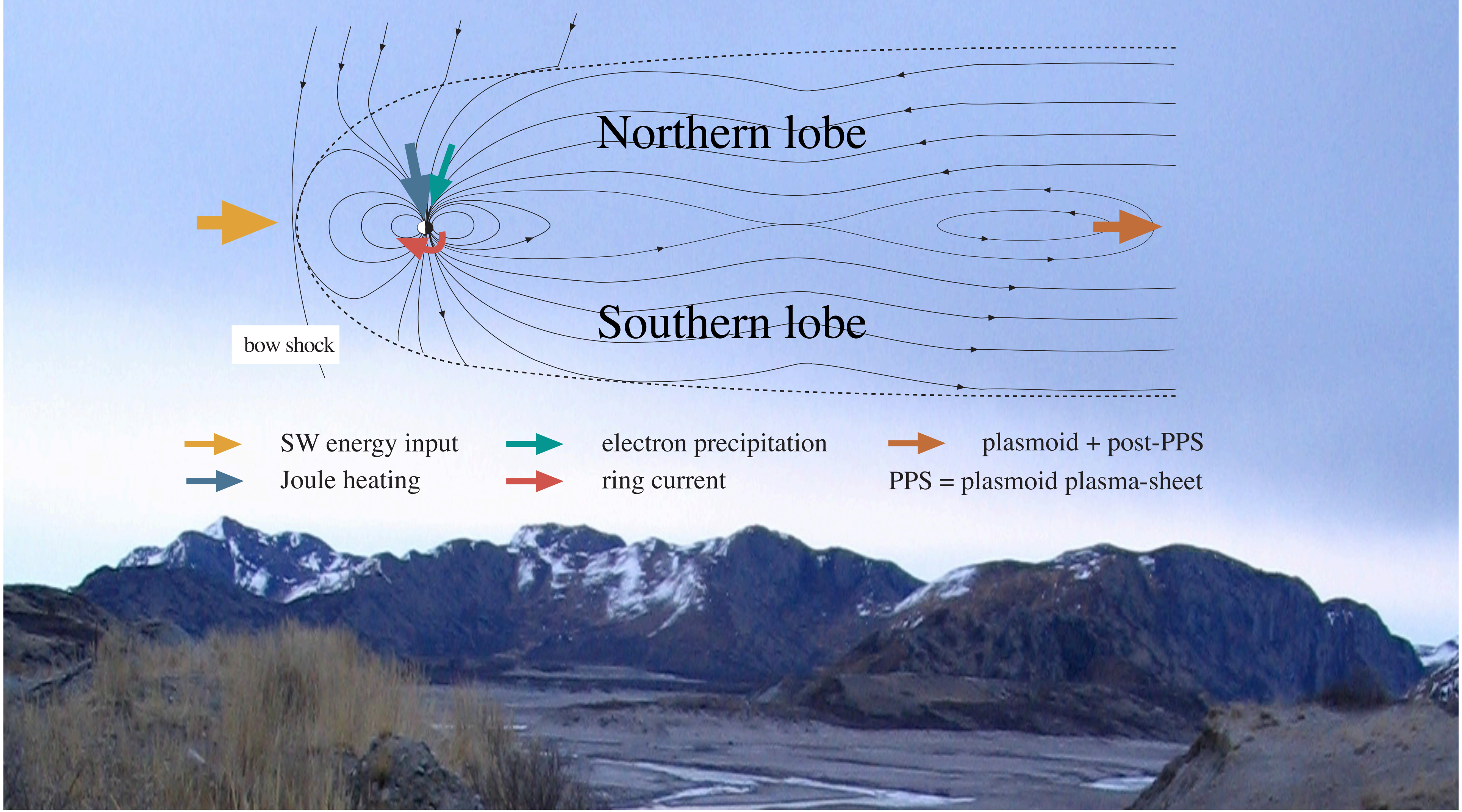
Drawing of sunspots by G. Galilei
showed that the Sun rotates.



Substorm energetics: input and sinks

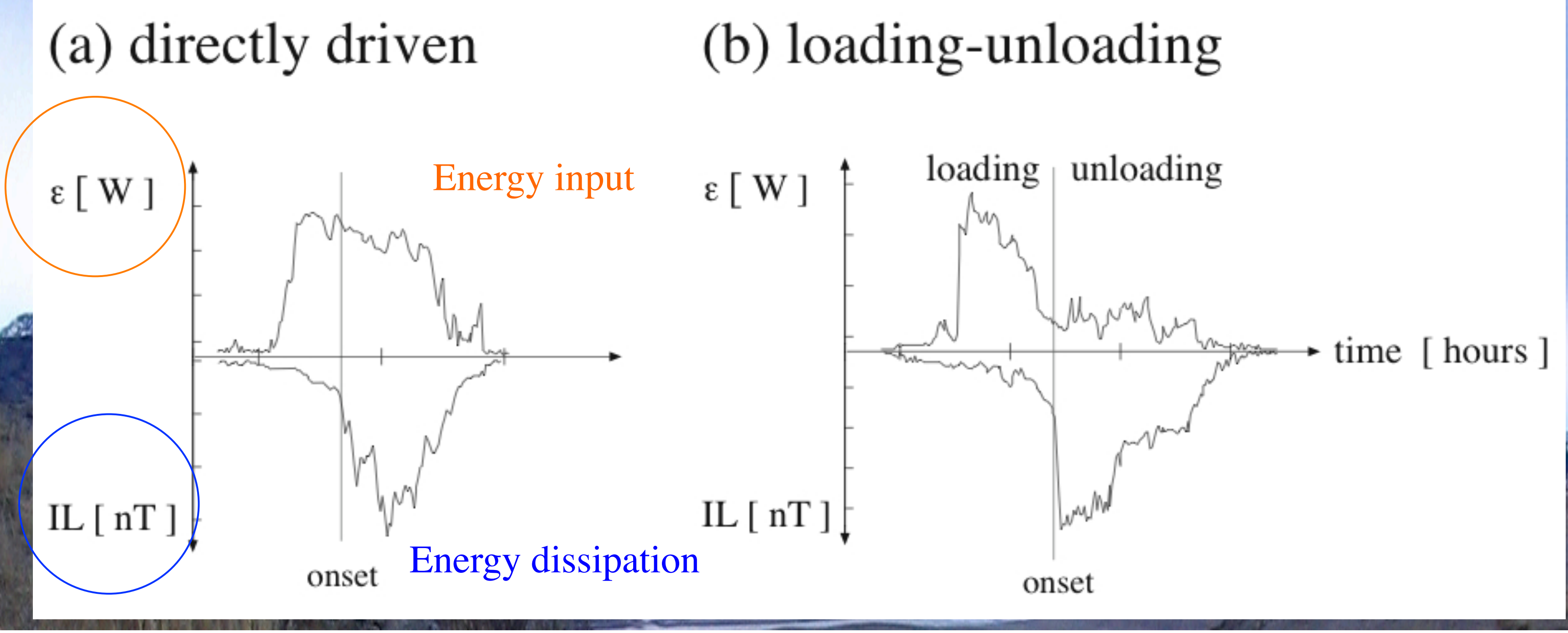


Magnetotail lobes store magnetic energy



Loading-unloading processes

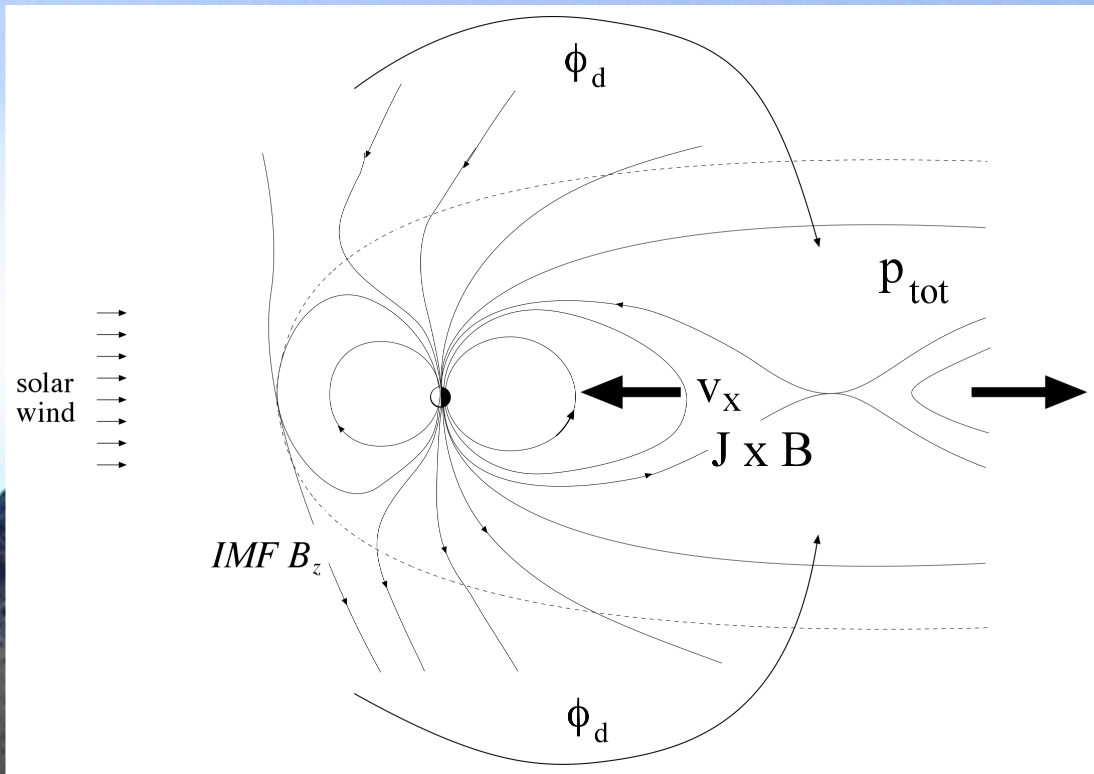
- Over 80% of substorms are directly powered by solar wind (i.e. type a).
- Substorm growth phase is necessary for preconditioning the magnetotail to allow a global instability to grow.
- Size of substorm depends on mostly of the energy dissipated in substorm expansion phase.



Magnetotail convection modes

Four magnetospheric convection modes:

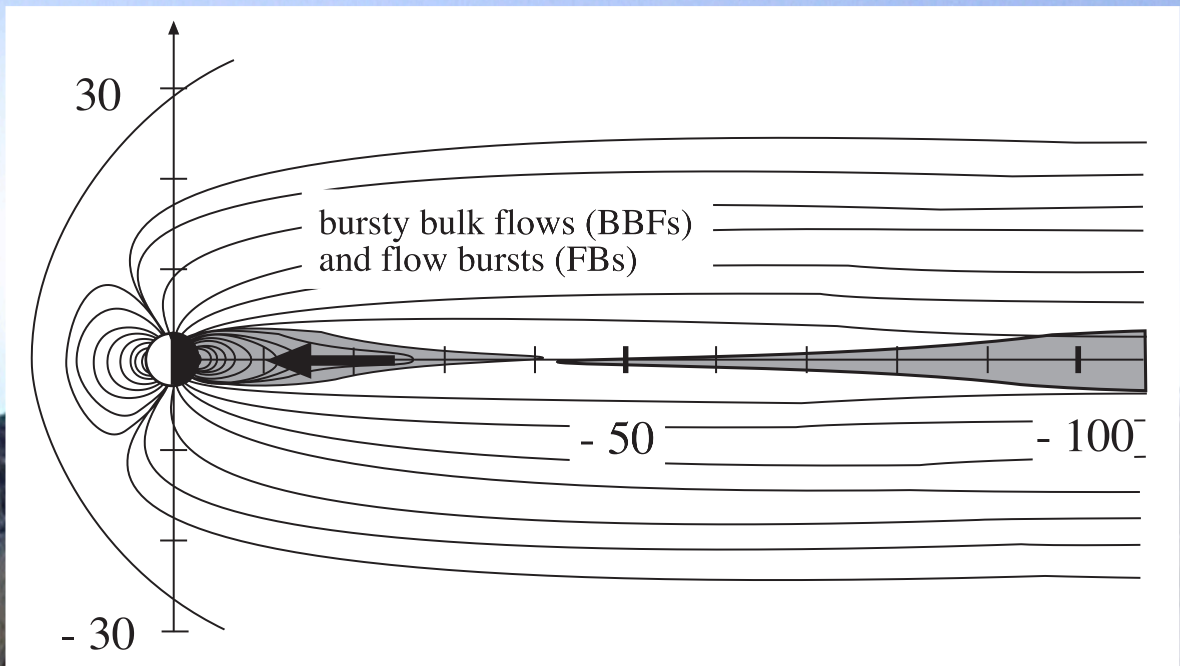
(1) Loading: magnetic flux ϕ_d into magnetosphere
(2) Unloading: magnetic flux and flows towards the Earth
(3) Continuous magnetospheric dissipation CMD: continuous flux flow from sw to Earth
(4) Steady magnetospheric convection SMC: continuous and steady flux flow



CMDs are as common as substorms (loading-unloading cycles).

Magnetotail plasma sheet flows

- Earth's plasma sheet is highly disturbed and bursty. Regular plasma flows i.e. flow bursts FBs and bursty bulk flows BBFs towards the Earth.
- Flow frequency distinguish loading-unloading (minimum 30 min storage time) and continuous dissipation modes from each other.

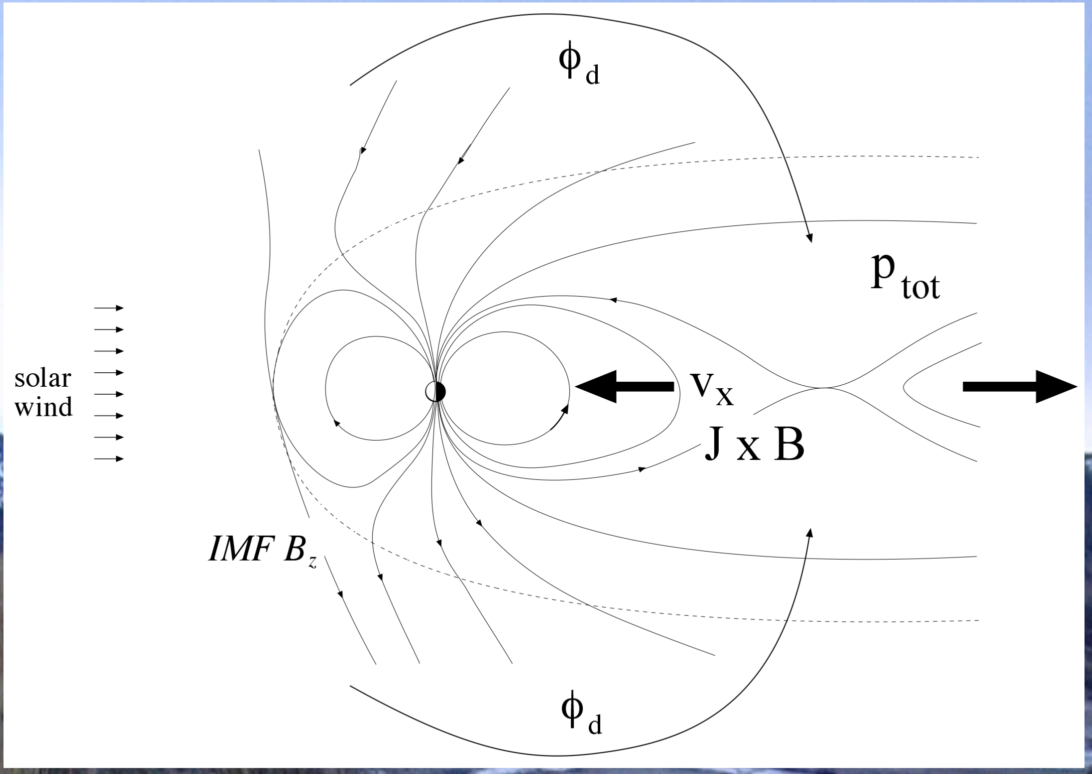


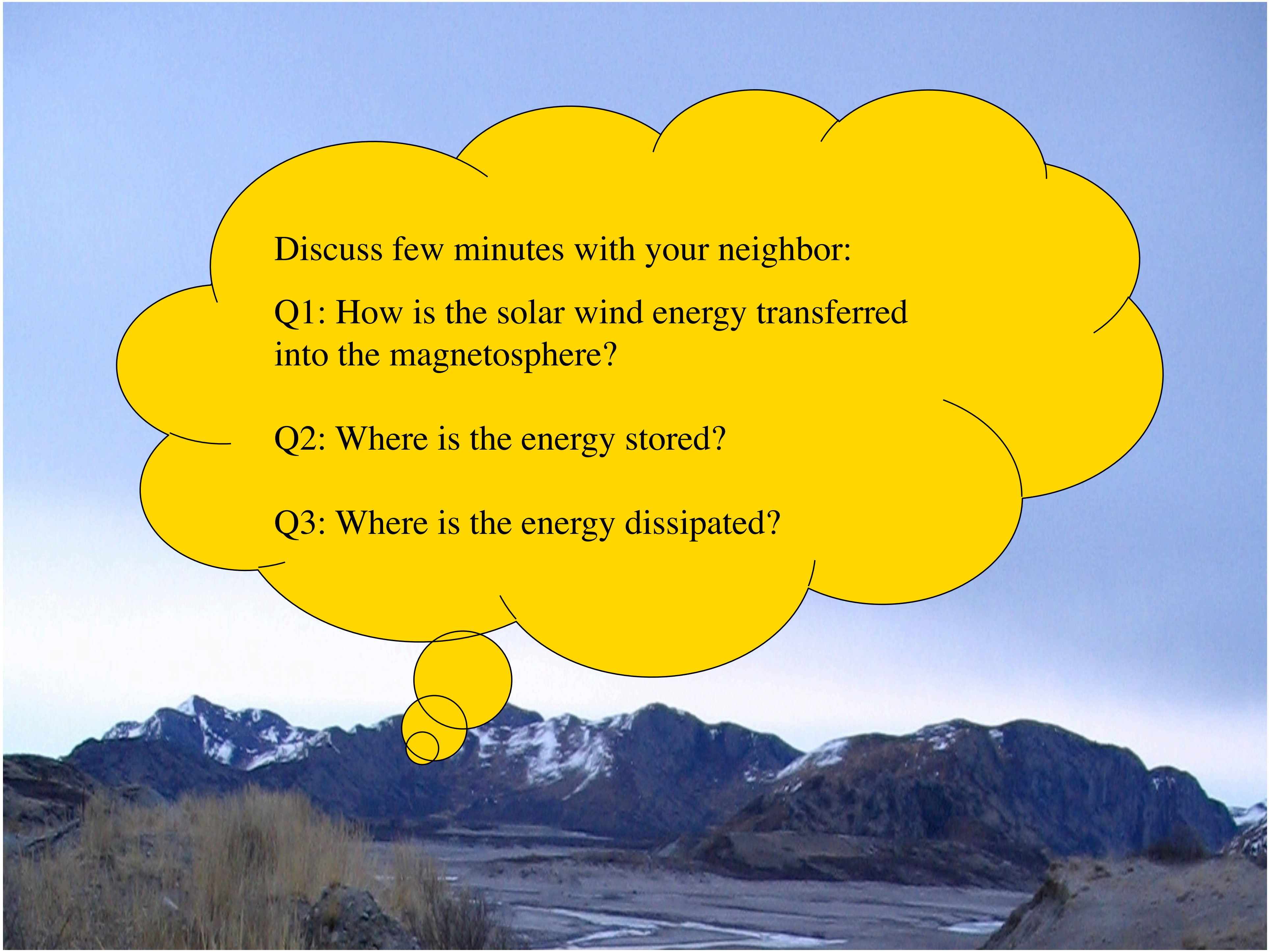
FBs are shorter (few minutes) & slower (< 400 km/s) than BBFs.

State of the magnetotail

State of the magnetotail is described by using three measures:

- Plasma sheet flow speed v_x,
- Magnetotail total pressure p_{tot} (thermal, dynamic and magnetic pressure)
- Magnetotail stress & stretch $(JxB)_x$.





Discuss few minutes with your neighbor:
Q1: How is the solar wind energy transferred into the magnetosphere?
Q2: Where is the energy stored?
Q3: Where is the energy dissipated?

Goal 2:

Learn to estimate energy input
from the solar wind during substorms.

Reference: Weiss, L.A, P.H. Reiff, J.J. Moses et al., Energy dissipation in substorms, Proceedings of the International Conference on Substorms (ICS-1), Kiruna, May 1992.

Epsilon parameter

- Akasofu's epsilon parameter is the most commonly used parameter to estimate the energy input from the solar wind into the magnetosphere.

$$\varepsilon = \left({4\pi}/{\mu_0} \right) v B^2 l_0{}^2 \sin^4\left(\tfrac{\theta}{2}\right), \quad l_0 = 7R_E$$

- Average solar wind energy input during a single substorm is 1.7 x 10^{15} J.

Energy input , W_ε

Shifting data will be studied few slides later.

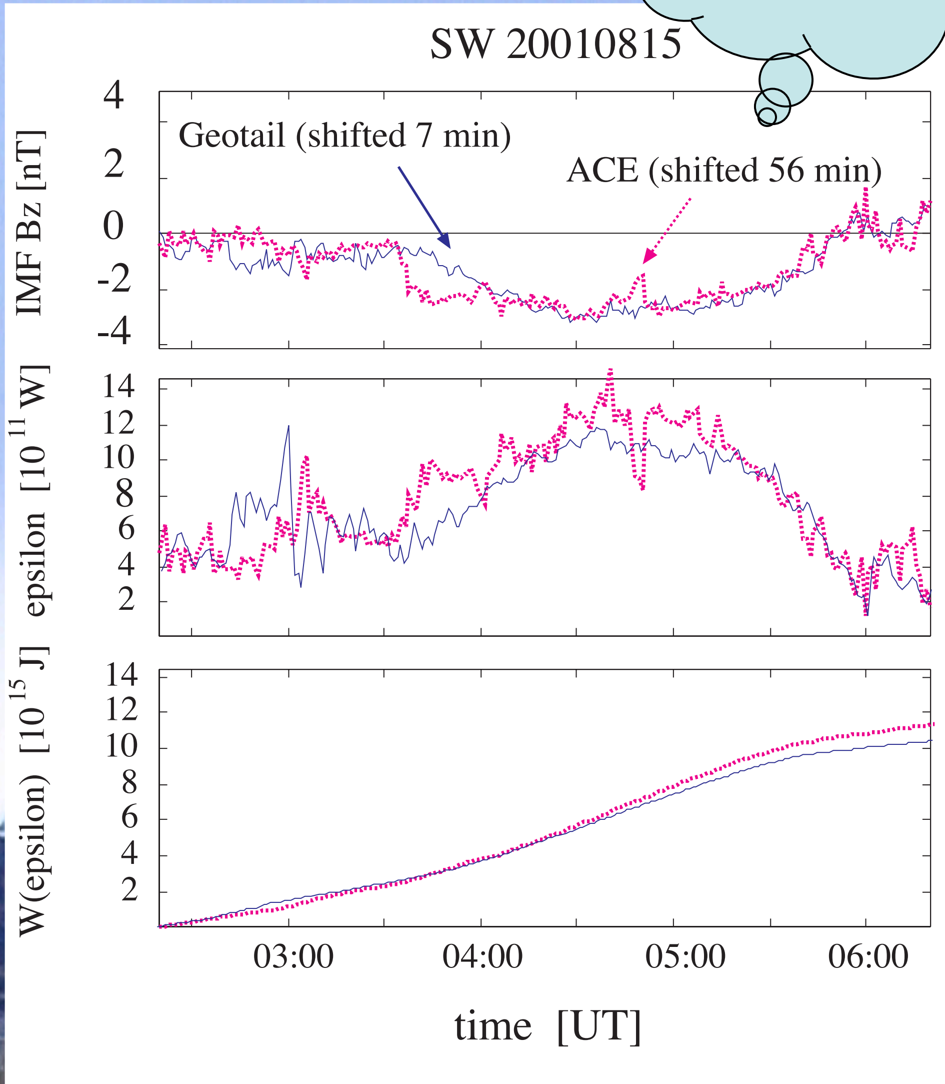
Interplanetary magnetic field north-south component from ACE and Geotail spacecraft.

$$\varepsilon = 10^7 vB^2 \sin^4(\theta/2)\cdot l_0^2$$

$$where \quad l_0 = 7R_E$$

Total energy input:

$$W_\varepsilon = \int \varepsilon \, dt$$



1.1*10^15 J

1.0*10^15 J

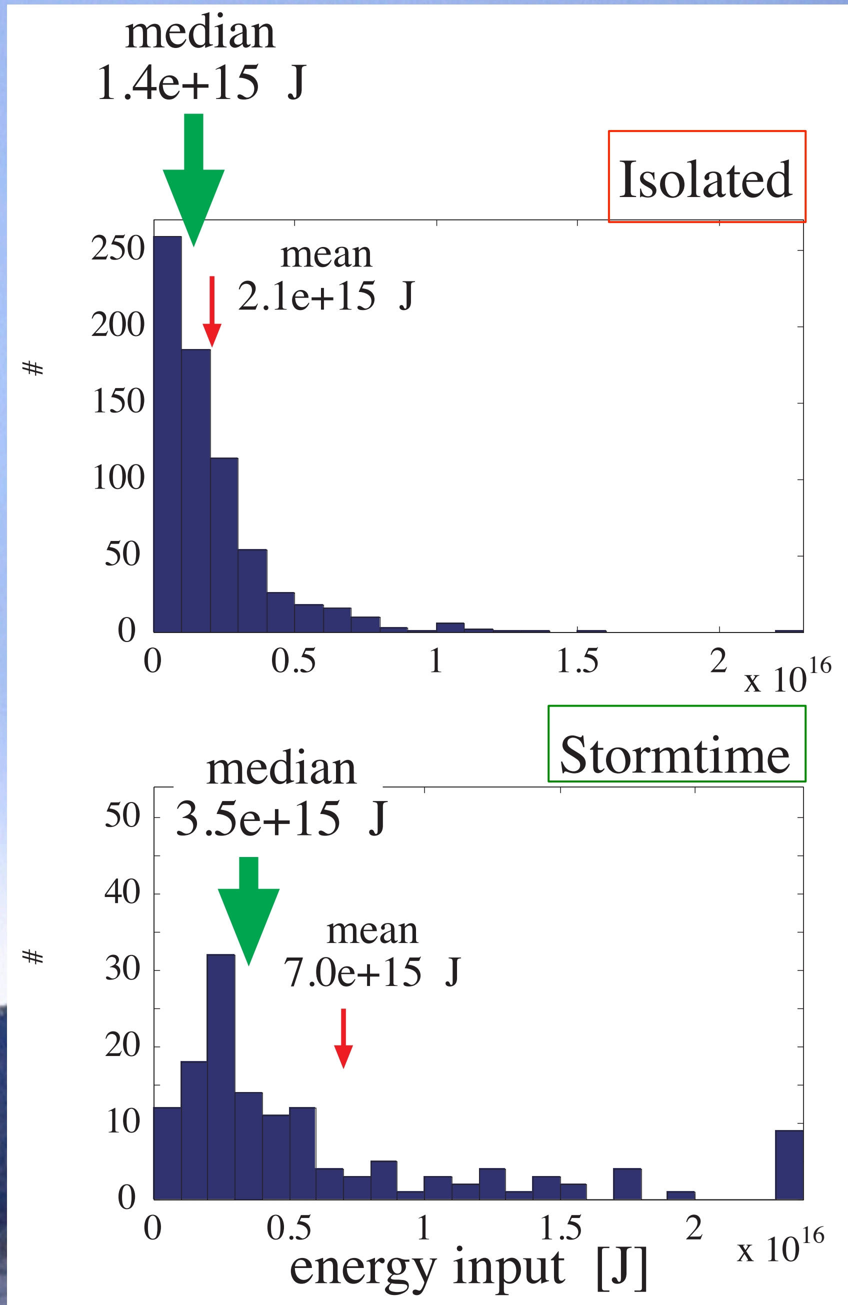
Typical energy input

Isolated substorm =
Substorm that occur when
storm-index Dst > -50 nT
i.e no simultaneous storms.

Typical: 1.4 x 10^15 J

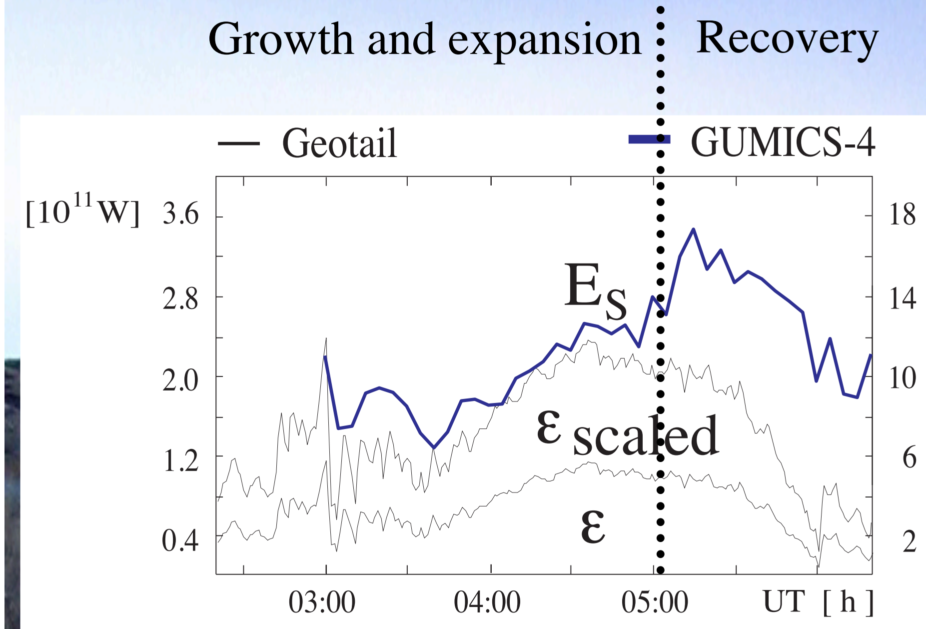
Storm-time substorm =
Substorm that occur when
storm-index Dst < -50 nT.

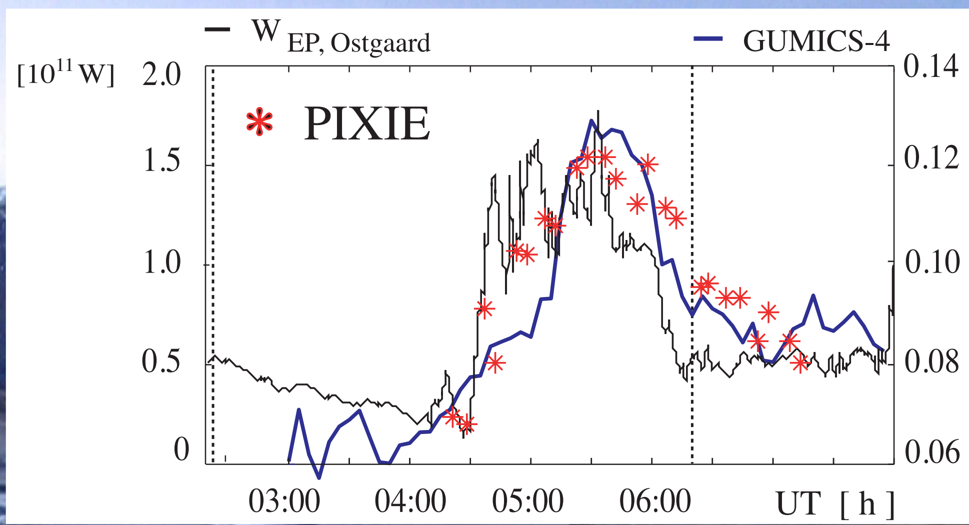
Typical: 3.5 x 10^15 J

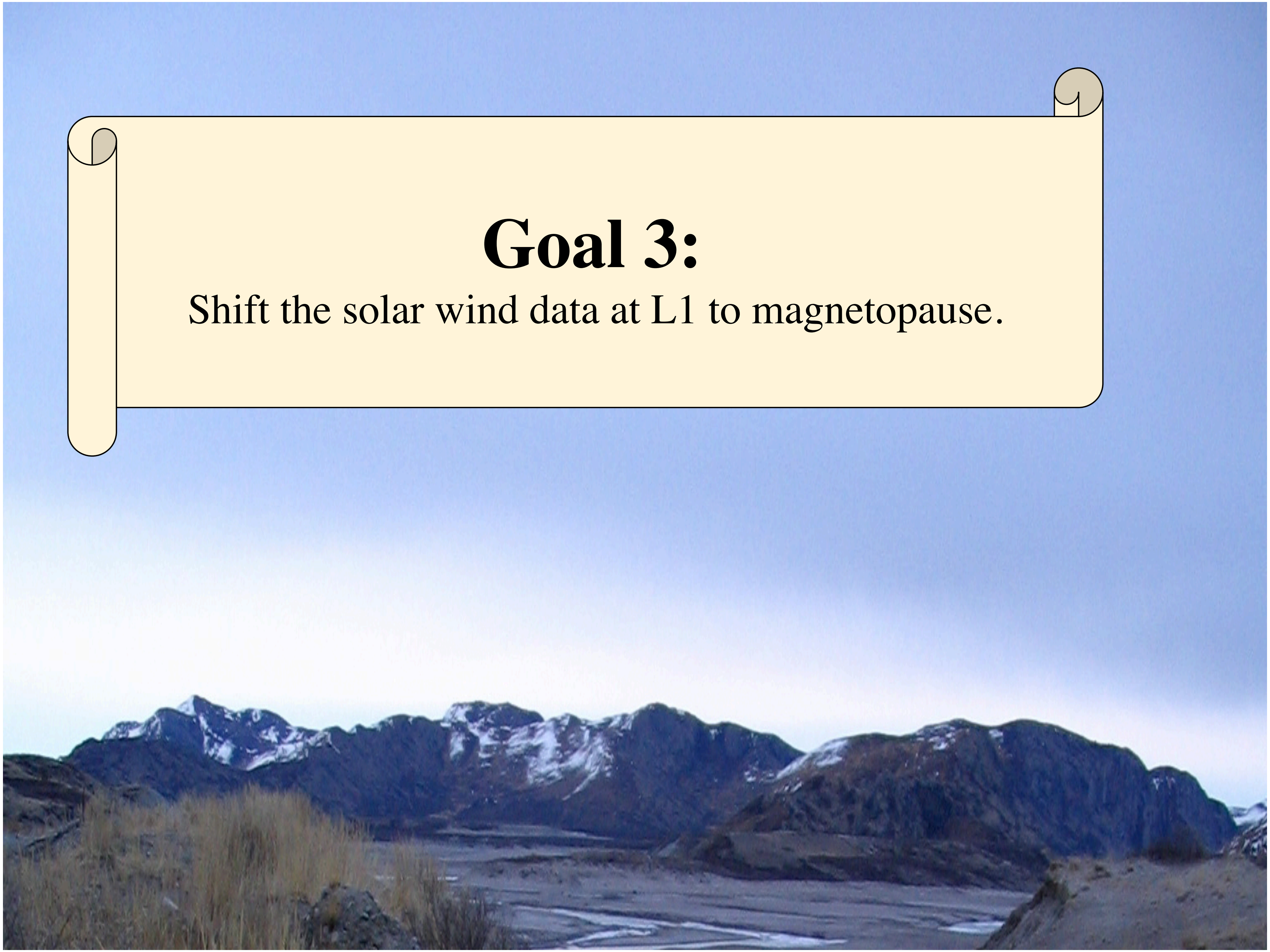


Subtorm energy budget observations and MHD simulation results

- Simulation and empirical input proxy gives similar temporal variations during growth and expansion phases, but show differences during recovery phase.
- Simulation and empirical dissipation proxy for electron precipitation gives similar temporal variations, but the simulation gives almost ten times smaller values.







Goal 3:

Shift the solar wind data at L1 to magnetopause.

Solar wind data shift methods

Solar wind data needs to be shifted to the magnetopause before comparing with the magnetospheric measurements.

Most typical methods are:

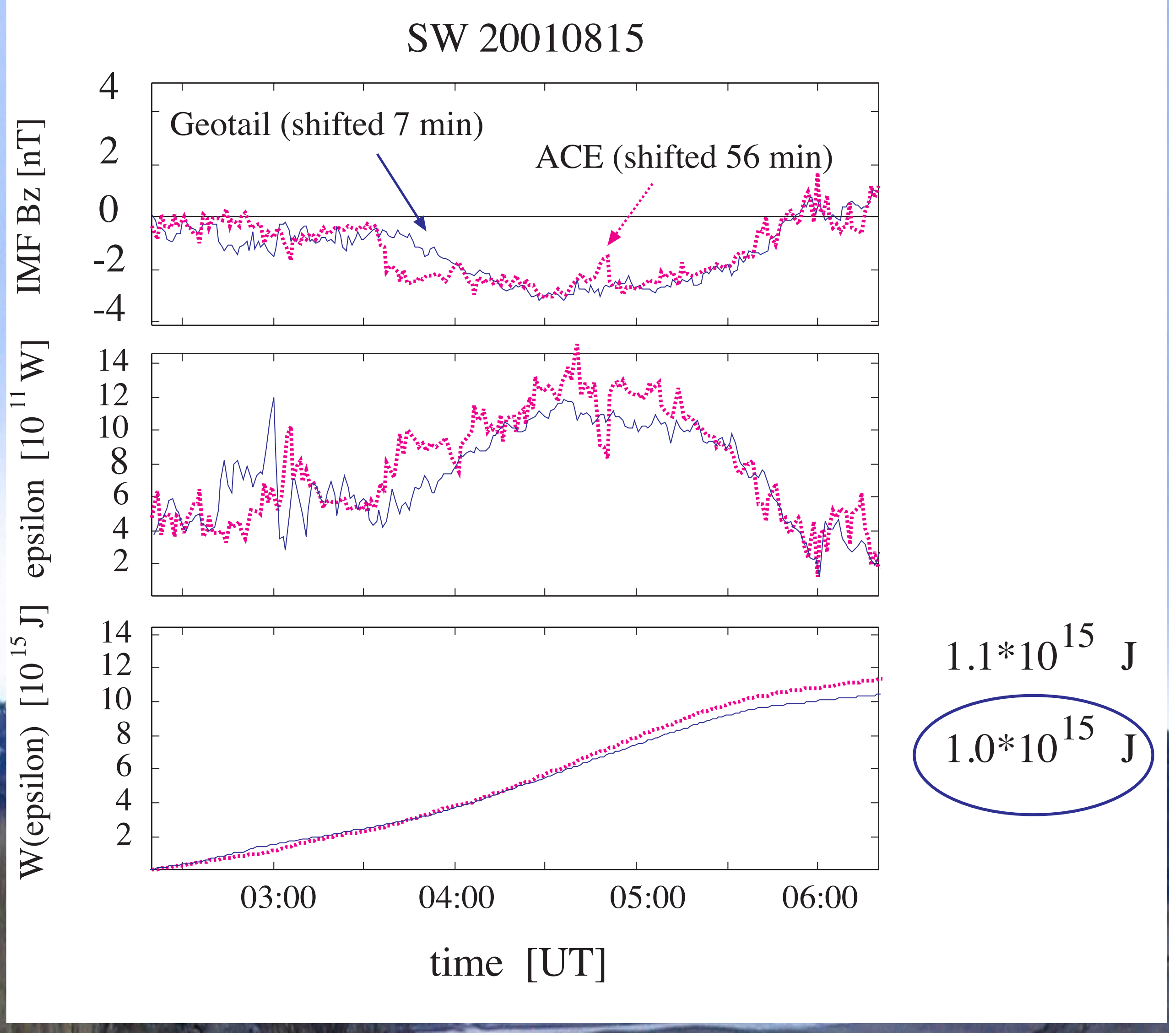
(1) Convection shift by an average velocity during the event of interest. MOSTLY USED

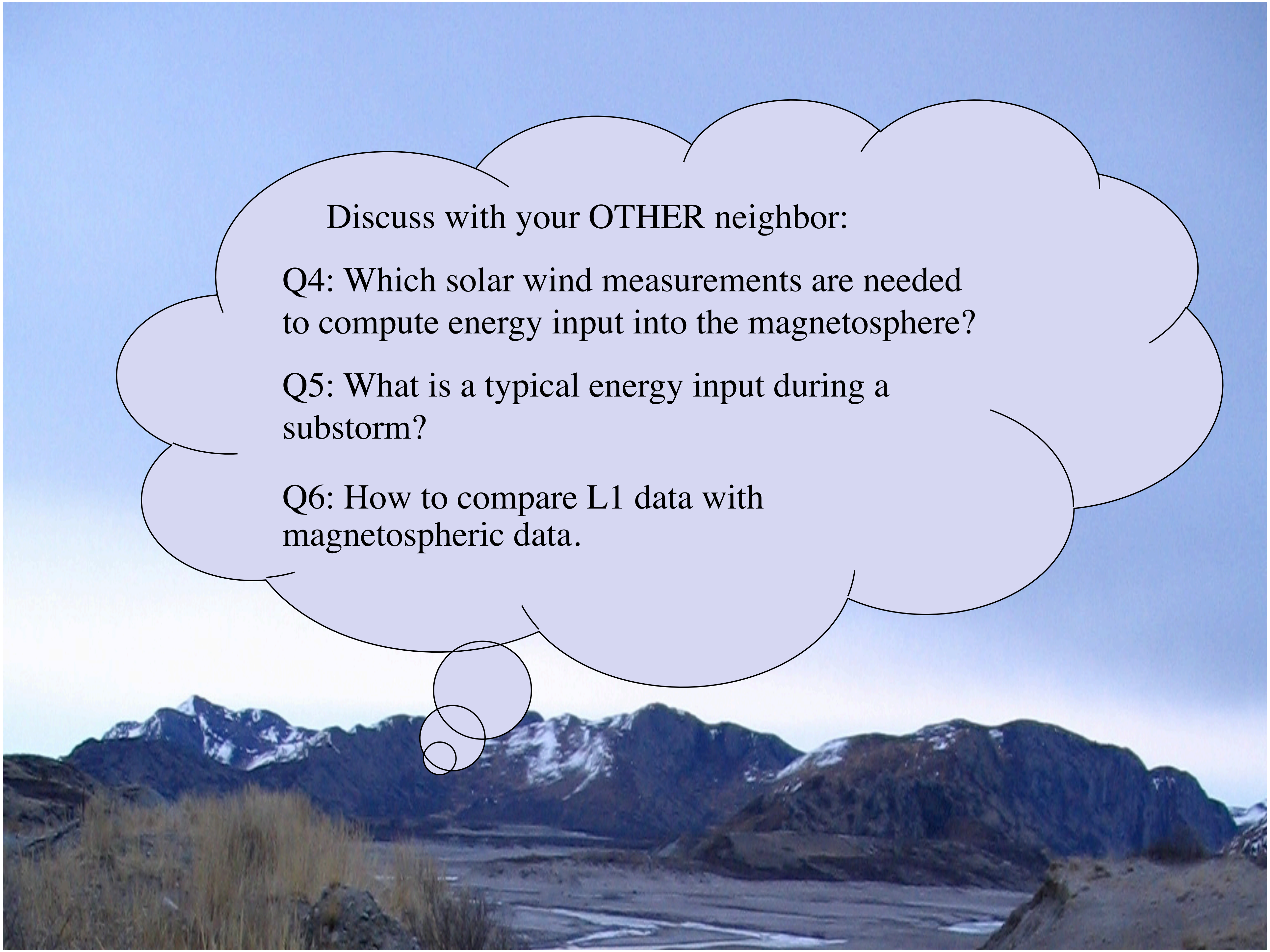
(2) Convection shift + disturbance orientation correction. Needs data from multiple s/c or modeling efforts. NEEDS MULTIPLE S/C

(3) Shifting each data point separately → causes non-continuous data. NOT GOOD.

(4) Finding signatures on same structures in other measurements and Estimating the time shift based on the structures seen. WORKS FOR SINGLE EVENTS

Convection shifted data




Discuss with your OTHER neighbor:
Q4: Which solar wind measurements are needed to compute energy input into the magnetosphere?
Q5: What is a typical energy input during a substorm?
Q6: How to compare L1 data with magnetospheric data.