Solar wind energy dissipation into the magnetosphere

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Space Climate 9.5.2019

Goals for lecture 6b

- Goal 1 Learn basics of Joule heating and study empirical methods to estimate the JH dissipation during substorms.
- Goal 2: Compute electron precipitation for substorms.
- Goal 3: Study substorm energy budget and balance.

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

Goal 1:

Learn basics of Joule heating and study empirical methods to estimate the JH dissipation during substorms.

Joule heating, W_{JH}

- Ahn et al. 1983, 1989; Richmond et al. 1990

$$P_{JH} = 2 \cdot c \cdot 10^{8} AL(nT), \quad c = 2, 3, 4$$

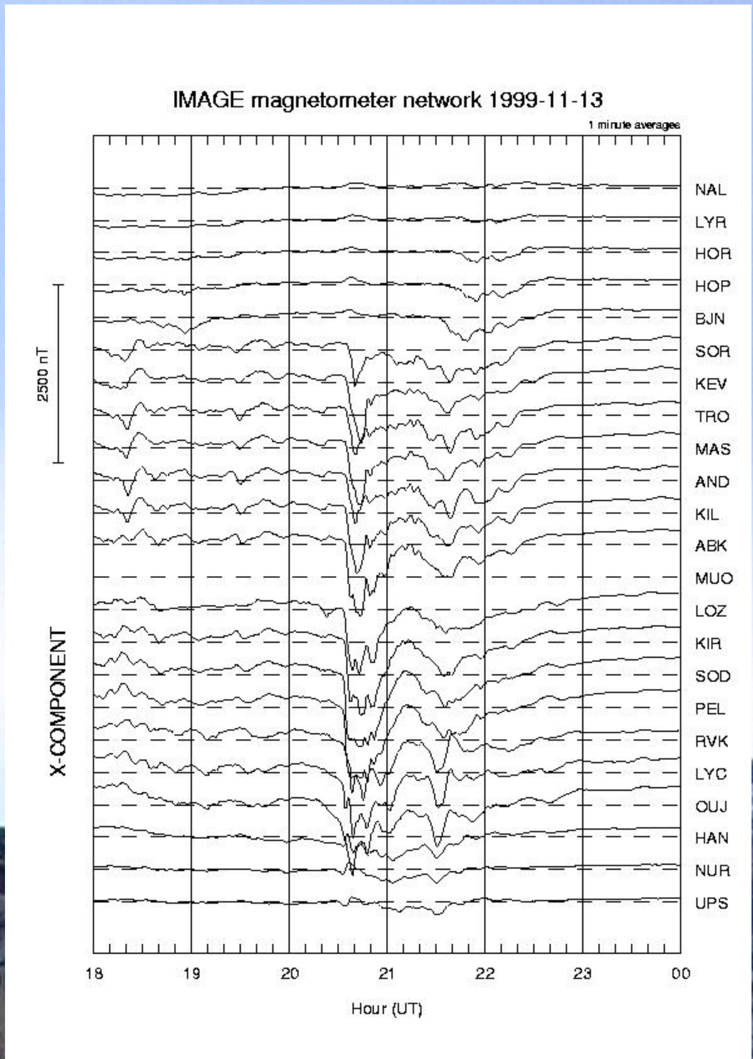
- Ostgaard et al. 2002

Summer hemisphere   Winter hemisphere

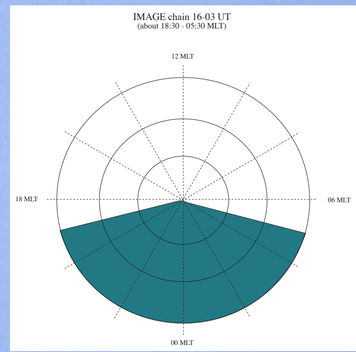
$$P_{JH} = 0.33 \cdot AE \cdot 10^{9} + (0.21 \cdot AE + 1.8) \cdot 10^{9}$$
$$= (0.54 \cdot AE + 1.8) \cdot 10^{9}$$

$$W_{JH} = \int P_{JH}\, dt$$

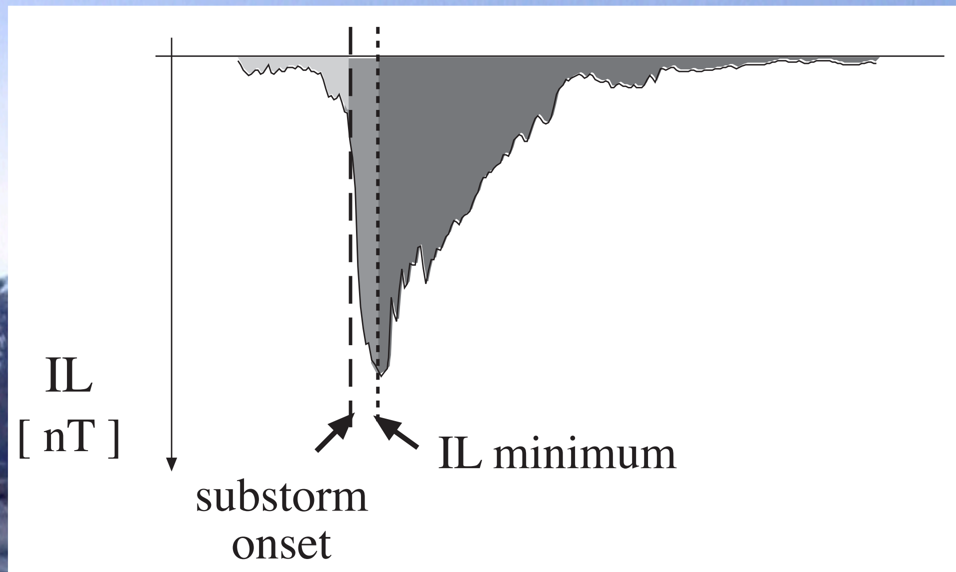
Westward electrojet index formation



Following AL description IL index is formed based on IMAGE ground-based magnetic measurements in UT-sector 16-03 UT.



UT-sector 16-03 UT

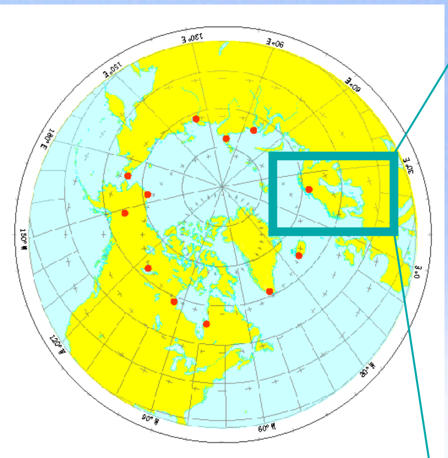


Data to westward electrojet index

AL index

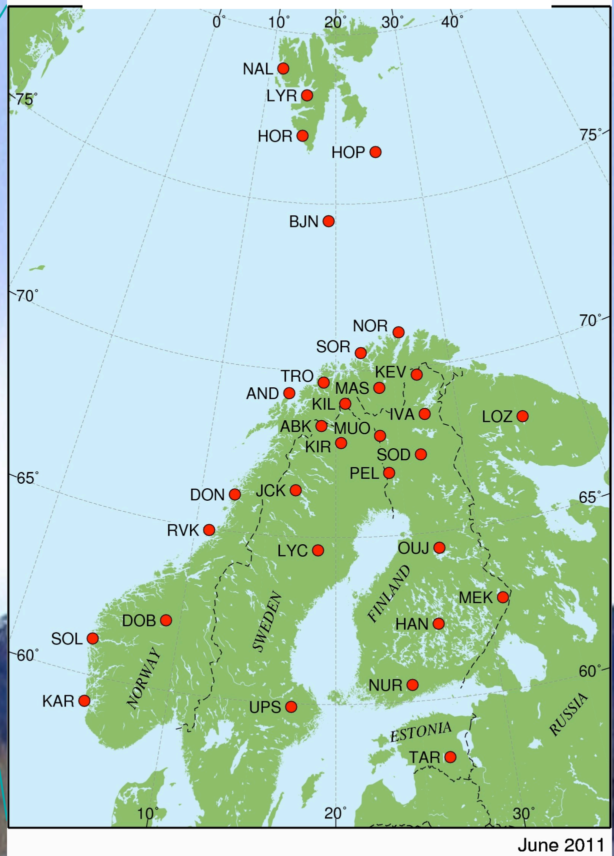
IL index

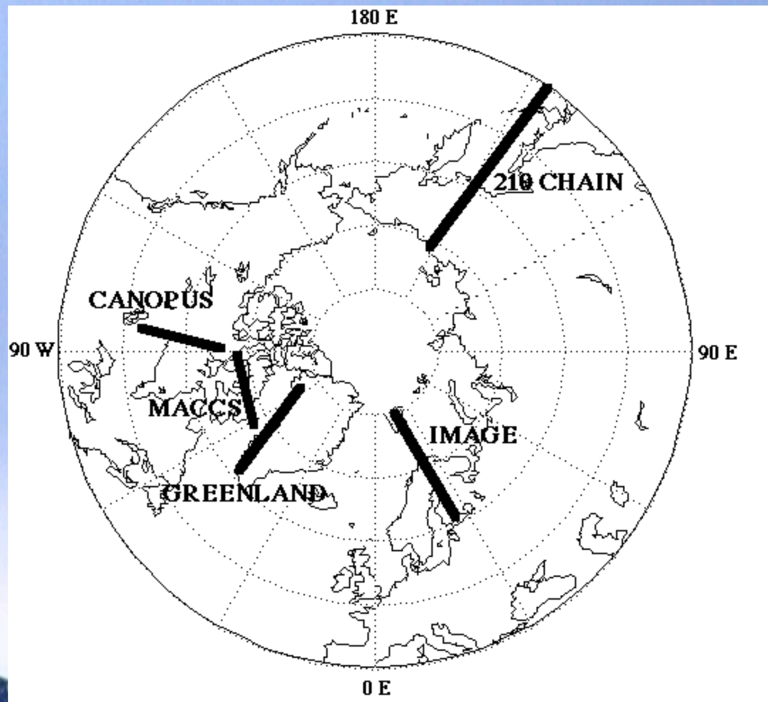
GL, CL etc. indices



12 Kyoto observatories

31 IMAGE observatories

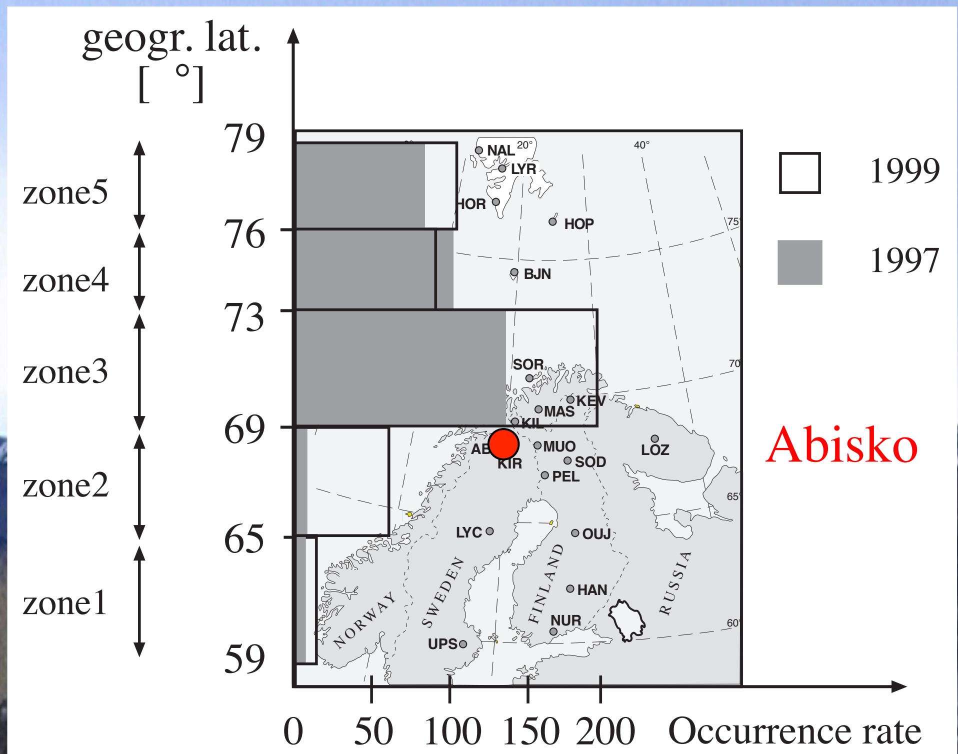




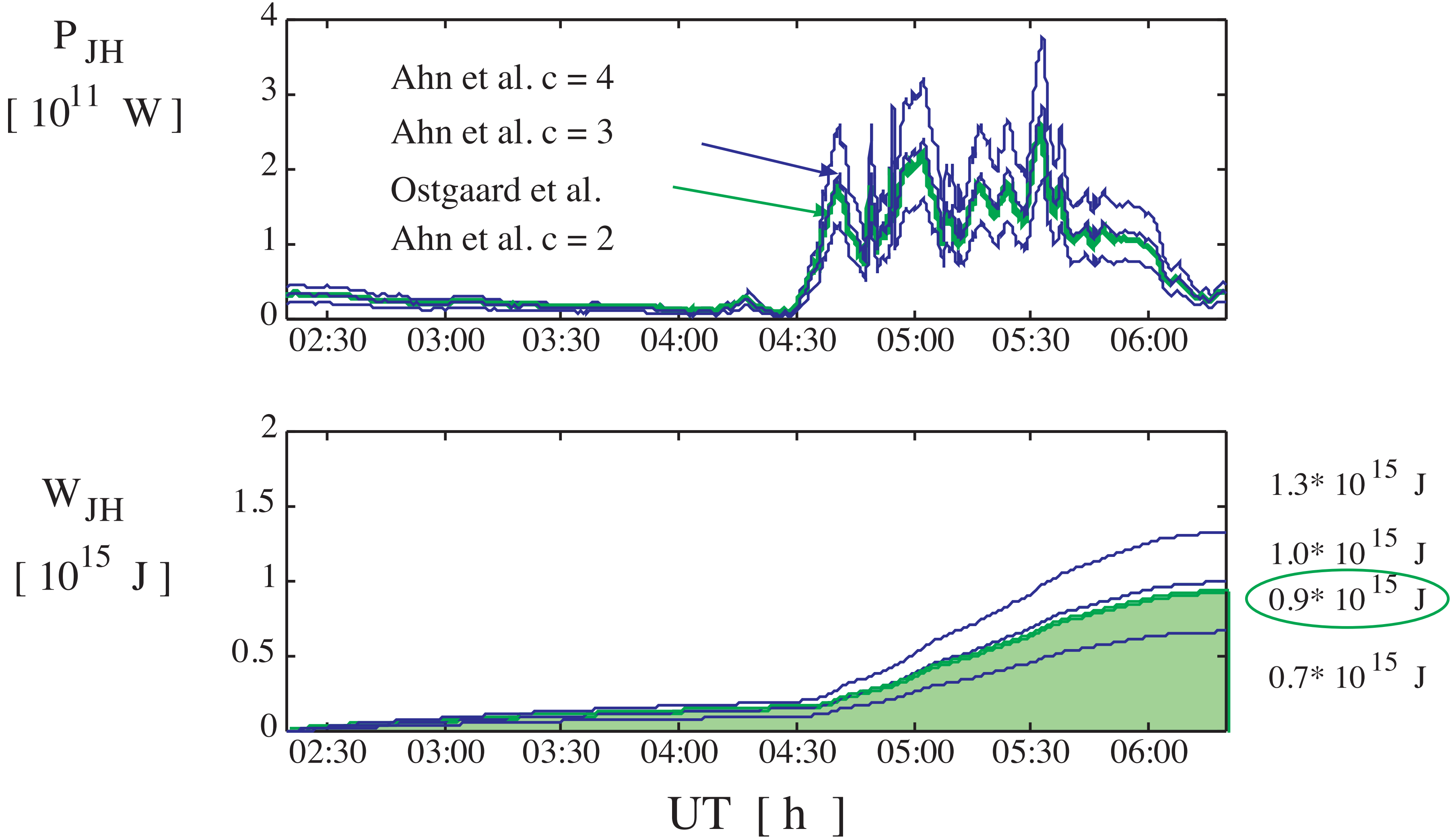
Why meridional chains?

About 90% of the substorms observed north from Abisko (ABK), which is the standard AL station in IMAGE time sector (Tanskanen et al., JGR 2002)

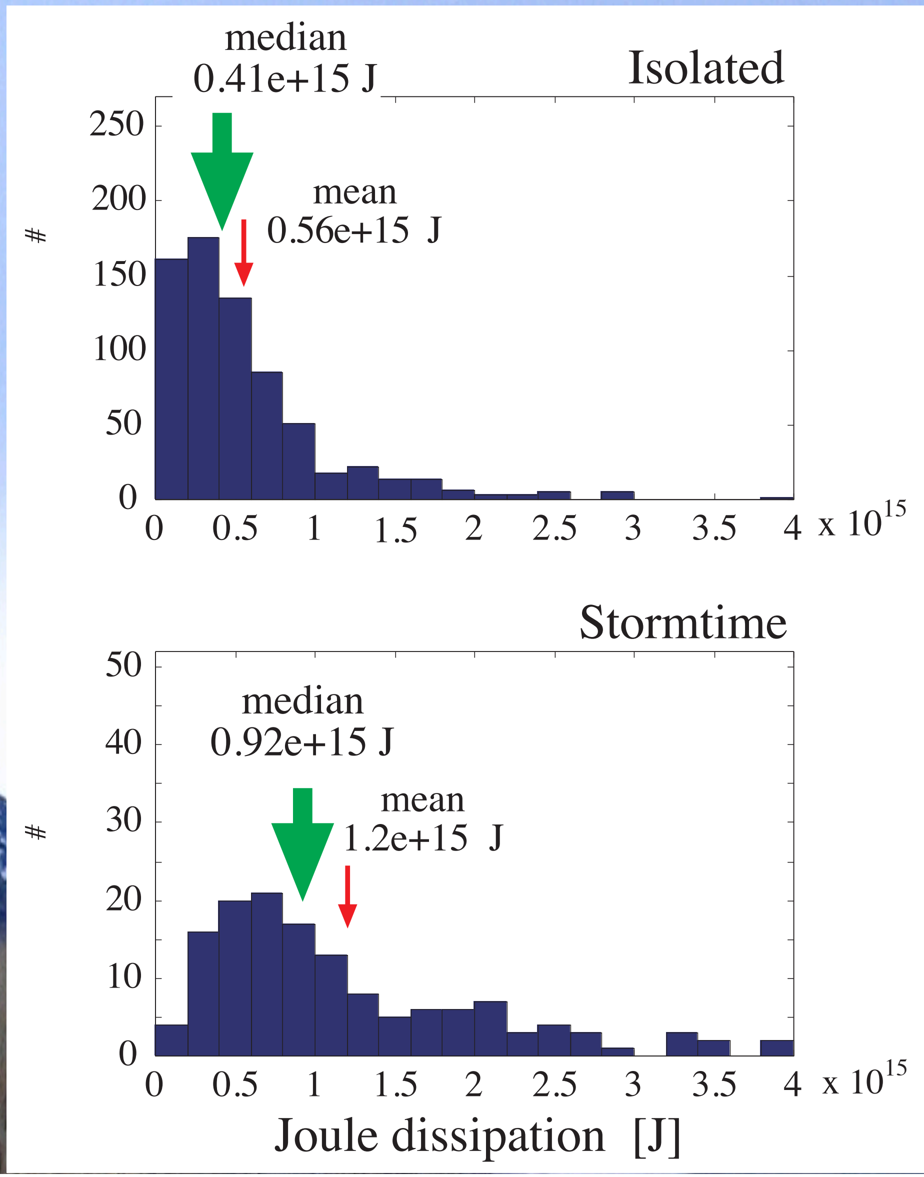
→ Kyoto AL underestimates and misses large portion of geomagnetic activity.



Comparing different JH estimates



Joule heating for 1997 and 1999 substorms



Note: For one hemisphere only.

Goal 2:

Compute electron precipitation for substorms.

Electron precipitation , W_{EP}

Both hemispheres included.

Ahn et al. 1983 $P_{EP}(W) = 2 \cdot 0.8 \cdot 10^{8} \cdot AL(nT)$

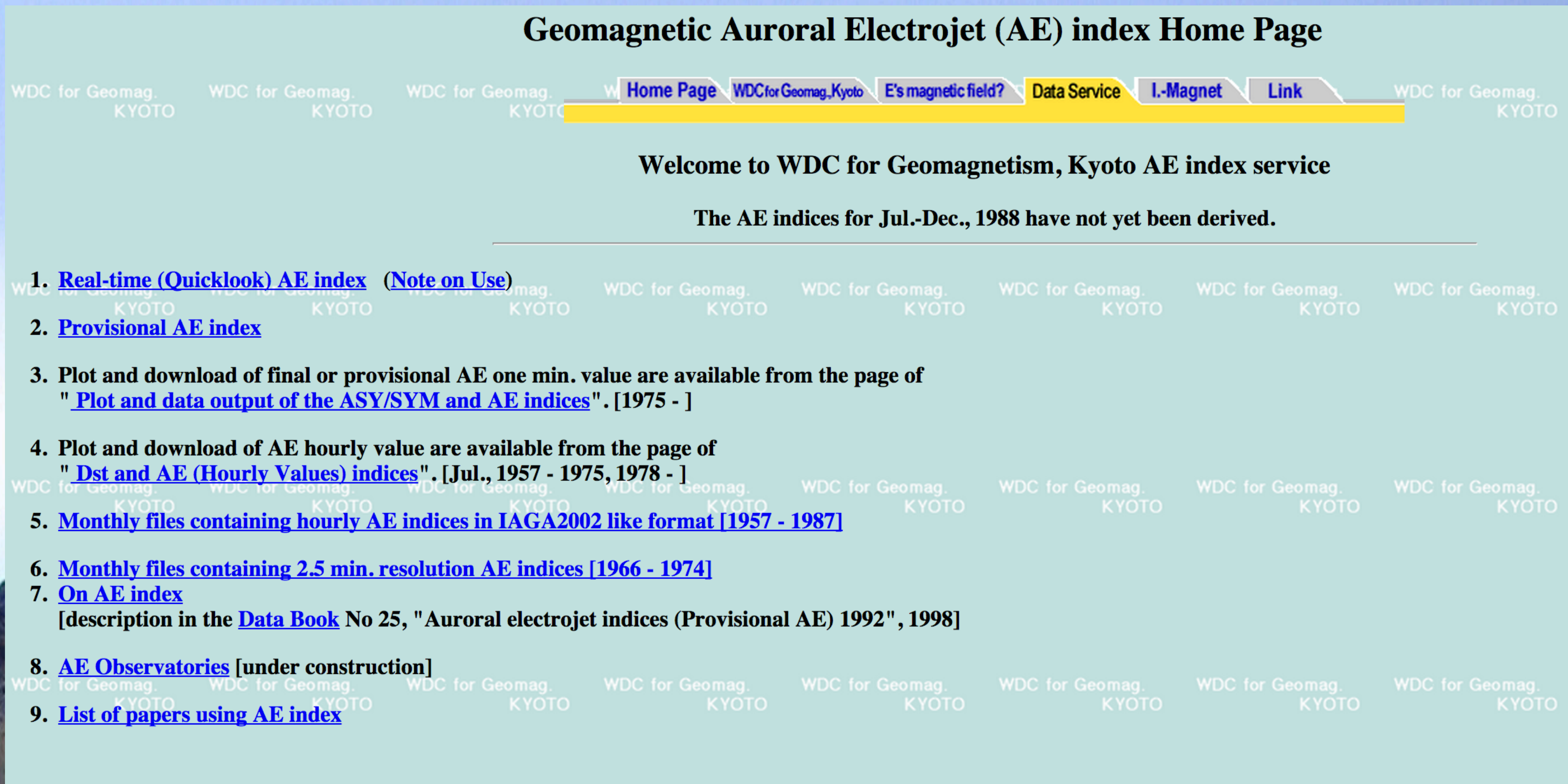
Spiro et al. 1982 $P_{EP}(W) = \left(1.75 \cdot \frac{AE}{100nT} + 1.6\right) \cdot 10^{10}$

Ostgaard et al. 2002 $P_{EP}(W) = 2 \cdot \left(4.4 \cdot AL^{1/2} - 7.6\right) \cdot 10^{9}$

$$W_{EP} = \int P_{EP}\, dt$$

Where to get AE/AL/AU index?

http://wdc.kugi.kyoto-u.ac.jp/aedir/



Geomagnetic Auroral Electrojet (AE) index Home Page

Home Page | WDC for Geomag. Kyoto | E's magnetic field? | Data Service | I.-Magnet | Link

Welcome to WDC for Geomagnetism, Kyoto AE index service

The AE indices for Jul.-Dec., 1988 have not yet been derived.

1. Real-time (Quicklook) AE index (Note on Use)
2. Provisional AE index
3. Plot and download of final or provisional AE one min. value are available from the page of " Plot and data output of the ASY/SYM and AE indices". [1975 -]
4. Plot and download of AE hourly value are available from the page of " Dst and AE (Hourly Values) indices". [Jul., 1957 - 1975, 1978 -]
5. Monthly files containing hourly AE indices in IAGA2002 like format [1957 - 1987]
6. Monthly files containing 2.5 min. resolution AE indices [1966 - 1974]
7. On AE index
   [description in the Data Book No 25, "Auroral electrojet indices (Provisional AE) 1992", 1998]
8. AE Observatories [under construction]
9. List of papers using AE index

Where to get IE/IL/IU index?

http://space.fmi.fi/image/il_index/

IMAGE electrojet indicators IL, IU and IE

Select the date for analysis:

Year	Month	Day
1982	10	1

Start analysis !

IMAGE electrojet indicators are simple estimates of the total eastward and westward currents crossing the magnetometer network. Their definition is quite similar to that of the standard AL, AU and AE indices. For each timestep, IL(t) = min({X(t)}), where {X(t)} stands for the (geographic) north components of the magnetic field measured at the selected stations. In the same way, IU(t) = max({X(t)}), and IE = IU - IL.

Select the day using the menu above. It takes some seconds to create the plots, which will appear in another window. There you can modify the time axis, select a new set of stations, or select a new day. You can also look at the magnetograms or the contributions of individual sites to the indicators. As default, all available stations are used. The quiet time baseline is determined automatically by considering 3-hour intervals 00-03, 01-04, ..., 21-24 UT. The X range (max(X)-min(X)) at all sites is calculated for these intervals. The interval with the smallest average range is used as the baseline period.

The plots are only for quick-look purposes. For a detailed scientific analysis, we ask you to contact Ari Viljanen (*ari.viljanen (at) fmi.fi*).

Comments can also be sent to Lasse Häkkinen (*lasse.hakkinen (at) fmi.fi*).

IMAGE home page
Updated: 10.2.2010

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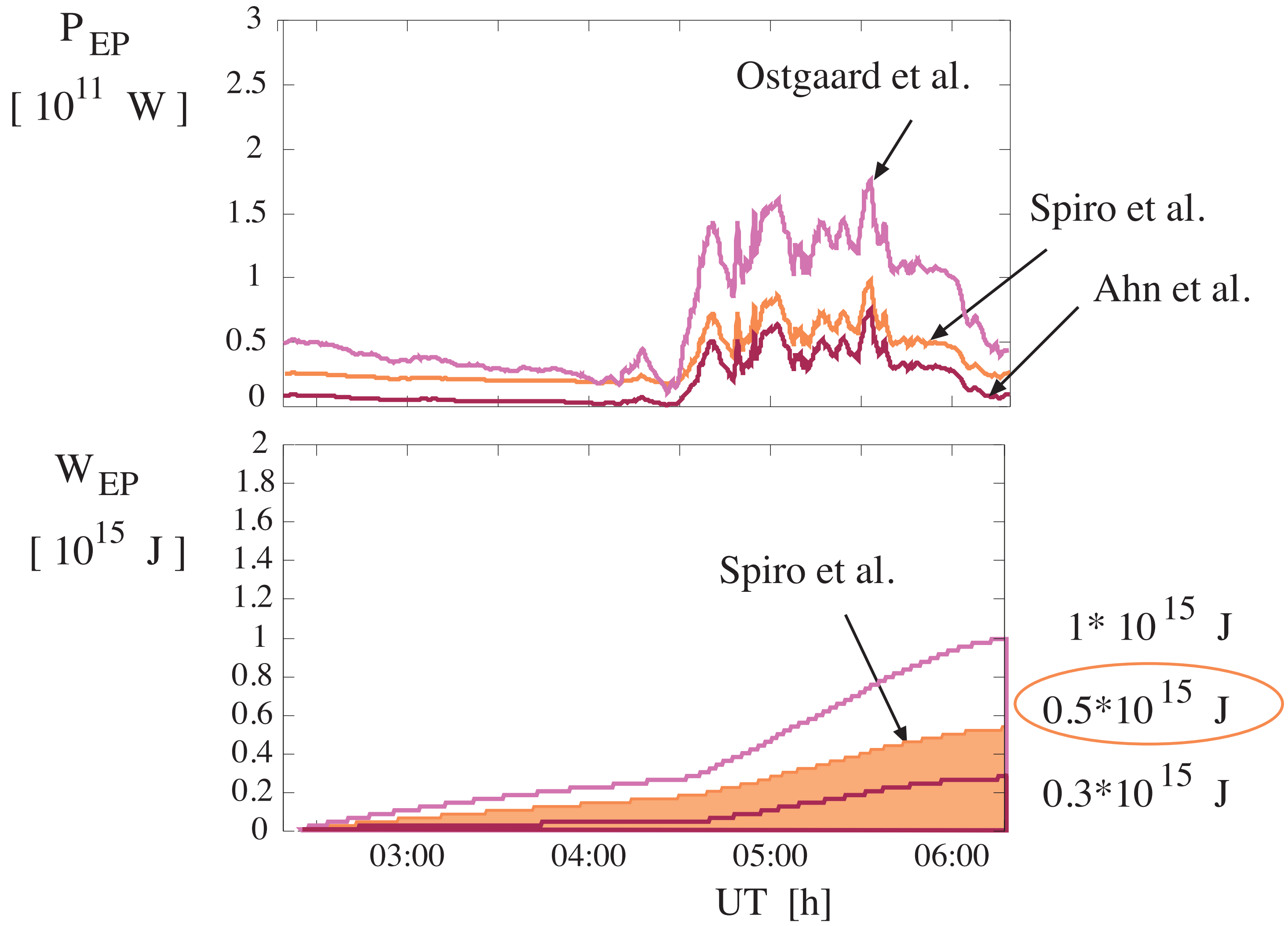
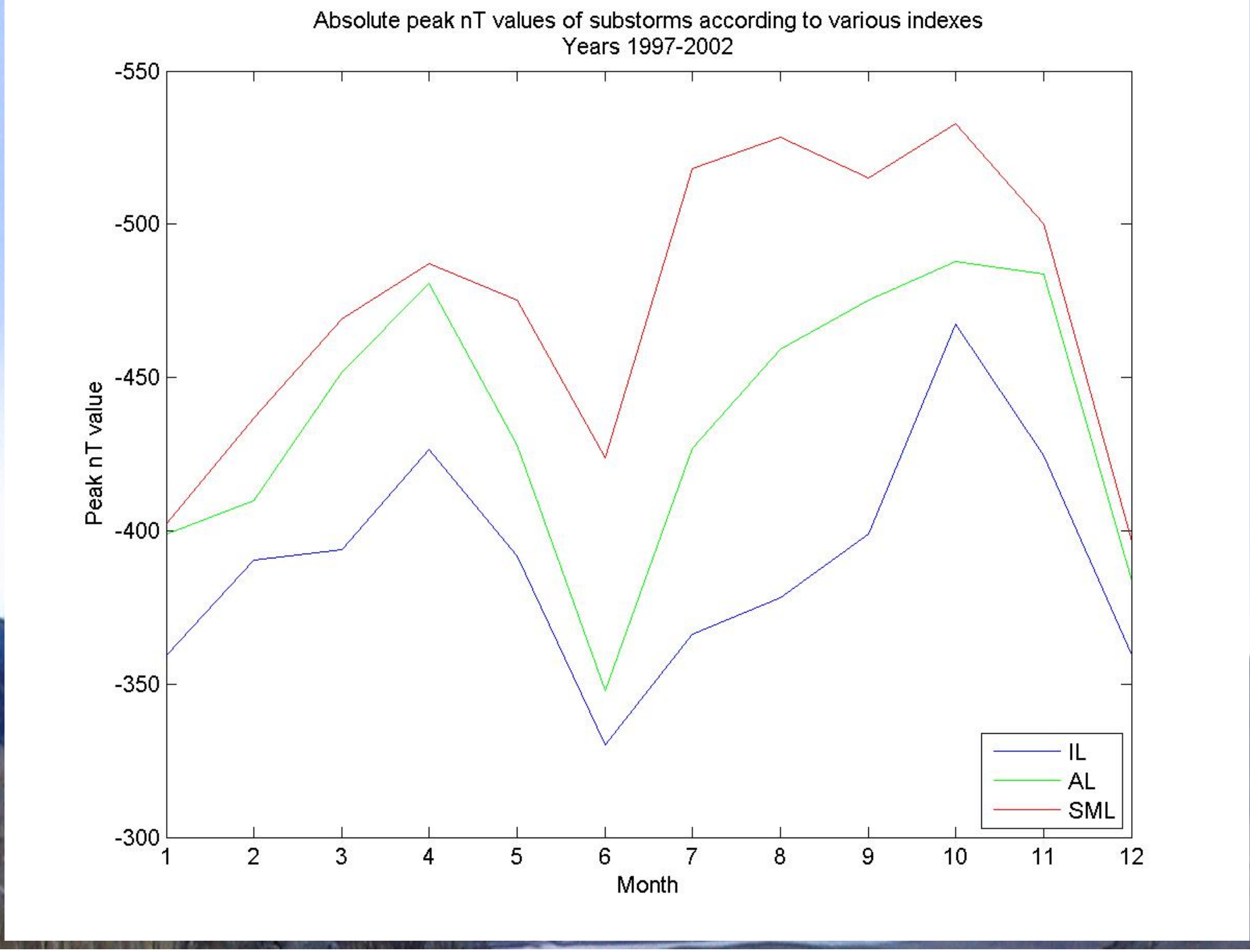
Comparing different EP estimates



Peak amplitude AL/IL/SML

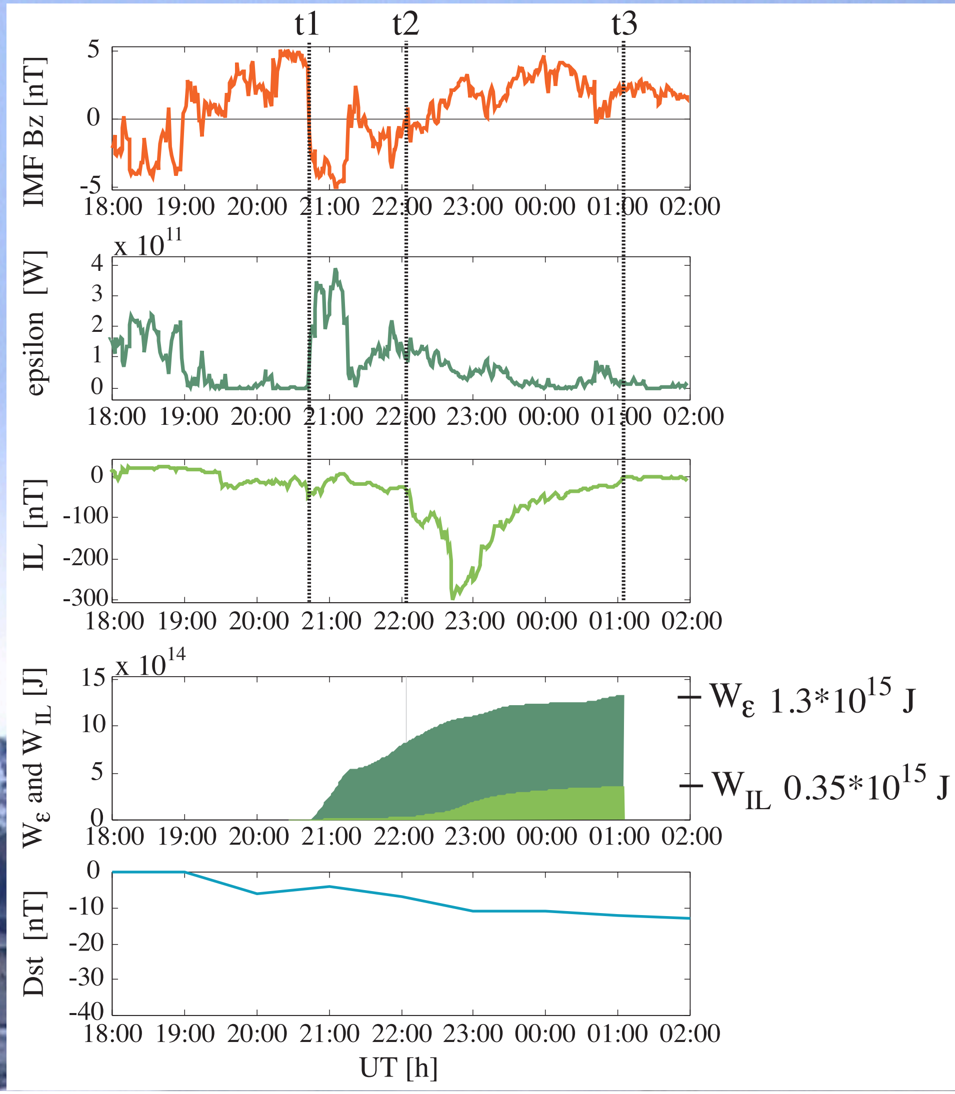


Goal 3:

Examine substorm energy budget and balance

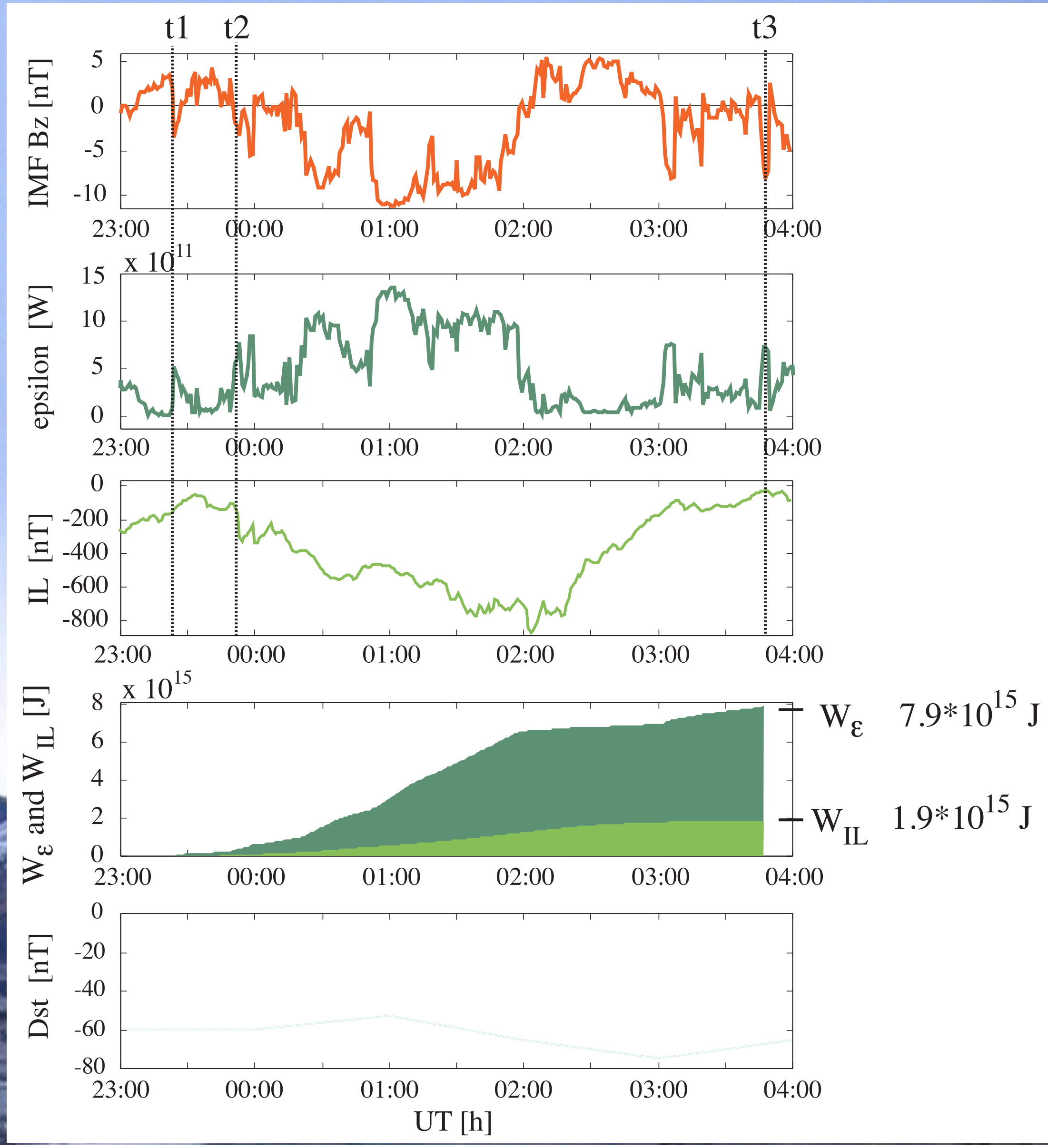
An example substorm: June 23, 1997

Medium-sized isolated substorm during year of low solar activity.



Second example: March 1, 1999

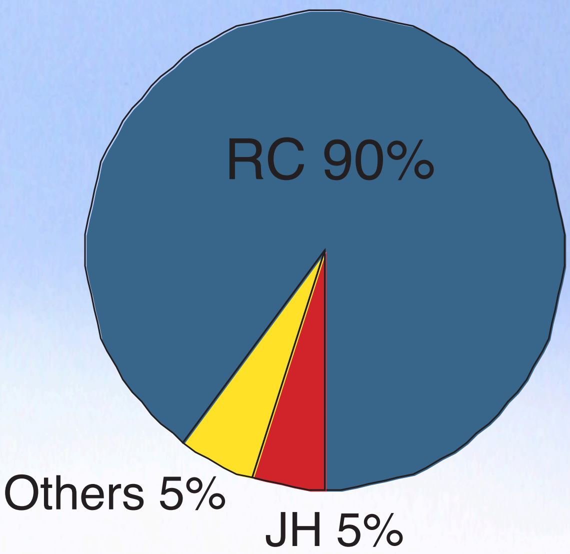
An intense stormtime substorm occurring during storm recovery phase at 1999.



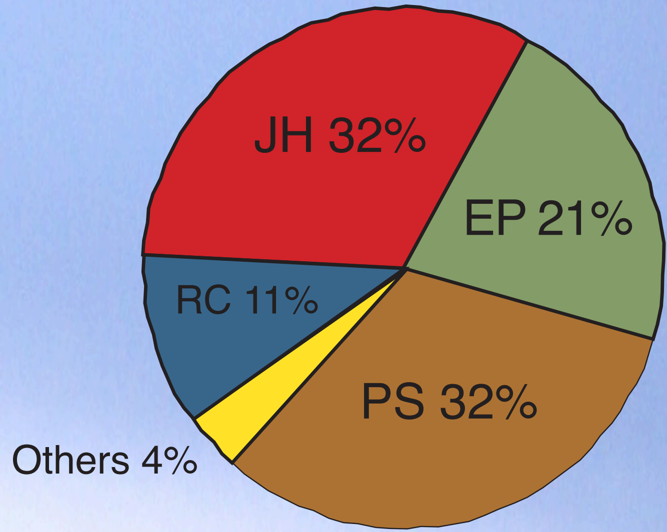
Substorm energy budget

Tanskanen et al. 2002; Østgaard and Tanskanen, AGU Monograph 2004

Average energy budget:



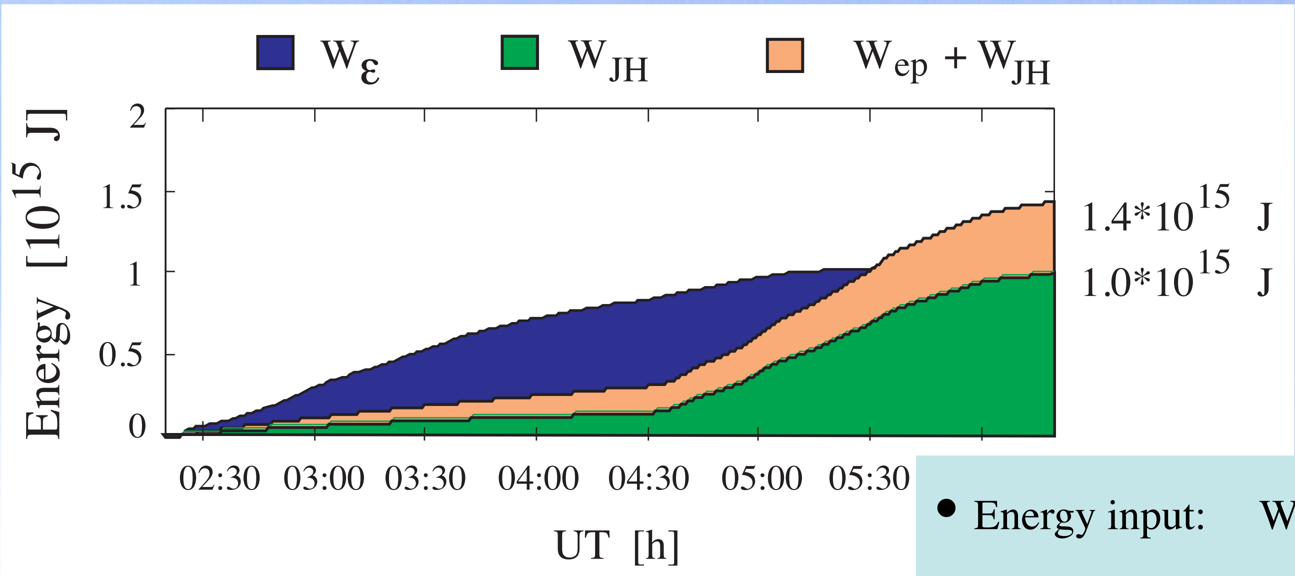
NEW view:



- The ionosphere (joule heating and electron precipitation) receives the major part of the energy during storms and substorms, dissipating at least 50% during storms and even over 70 % during substorms.
- Joule heating, JH; Electron precipitation, EP; Ring current, RC; Plasmoid and plasma sheet heating, PS

Input output non-balanced
→ Need to re-scale epsilon

Non-storm substorm on 15 August 2001 at 2:20 - 6:20 UT



- Energy input: $W_\varepsilon = 1.0*10^{15}$ J

- Energy output: $W_{JH} + W_{EP} = 1.4*10^{15}$ J

- Other dissipation channels:

- Ring current	dissipation small
- Plasmoid	no data
- Plasma sheet heating	no data

--> W_ε clearly underestimates the input

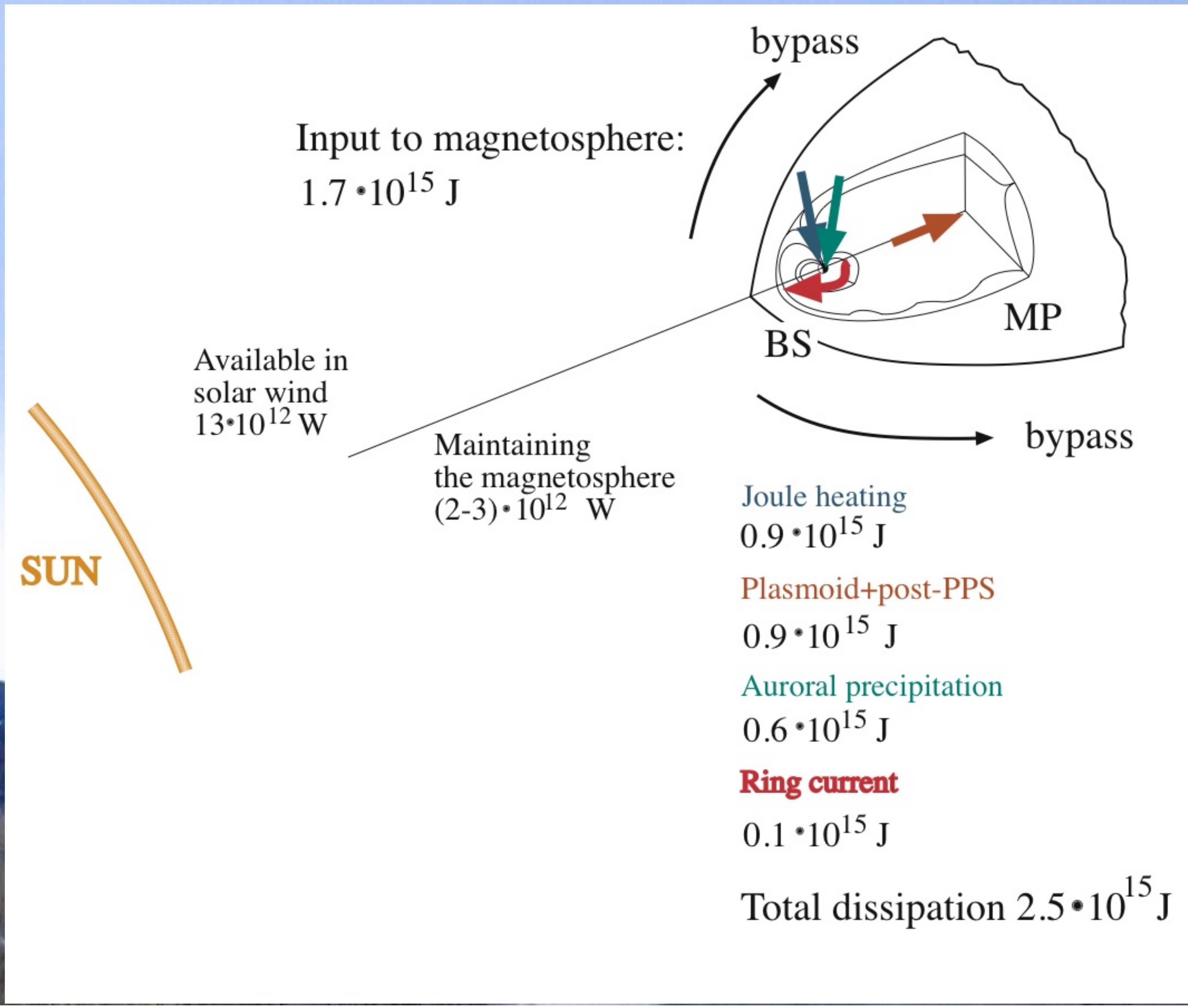
Rescaled epsilon parameter

- Theoretical and empirical input-output analysis suggest that the epsilon parameter needs to be scaled by a factor of 1.5 to agree with current energy sink estimates.

$$\varepsilon_{scaled} = \left(4\pi \big/ \mu_0 \right) v B^2 l_0^{\,2} \sin^4\left(\tfrac{\theta}{2}\right), \quad l_0 = 9 - 10 R_E$$

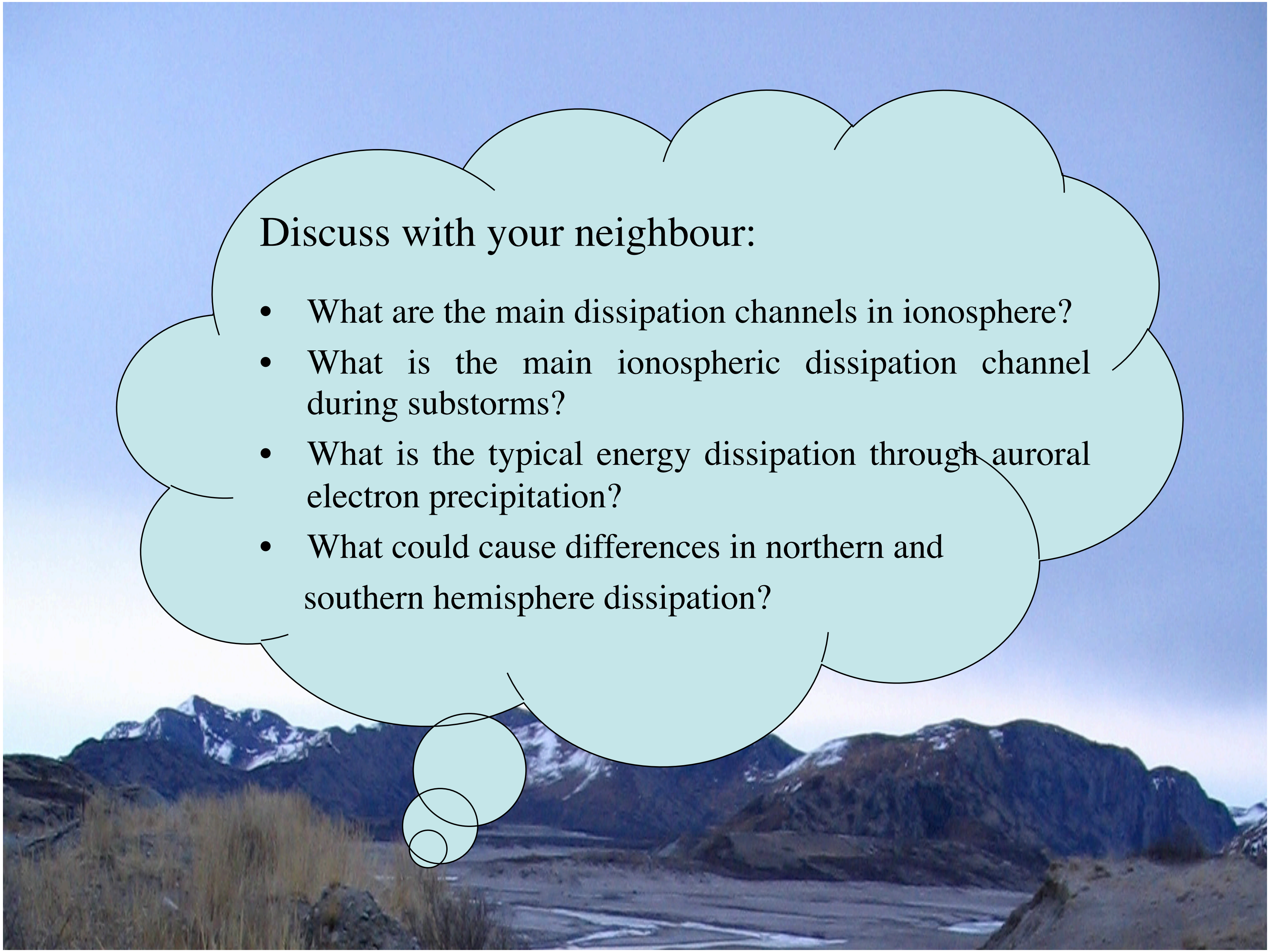
$$\varepsilon_{original} = \left(4\pi \big/ \mu_0 \right) v B^2 l_0^{\,2} \sin^4\left(\tfrac{\theta}{2}\right), \quad l_0 = 7 R_E$$

Heliospheric energy budget



Discuss with your neighbour:

- What are the main dissipation channels in ionosphere?
- What is the main ionospheric dissipation channel during substorms?
- What is the typical energy dissipation through auroral electron precipitation?
- What could cause differences in northern and southern hemisphere dissipation?



Ground induced currents, GICs – source of errors in dissipation estimates

- Magnetospheric variations observed at the Earth's surface are primarily caused by magnetospheric and ionospheric currents, and secondarily affected by currents induced within the Earth.

- However, inductive part can be up to 40% of the IL during substorm onset, while during other substorm phases it is about 20%.

- For magnetic storms the inductive part is about 30% during the storm main phase and 20% during other storm phases.