CIRs/Corotating Streams and Geomagnetic Activity

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- Increased rate of energy deposition into the Earth's magnetosphere may lead to geomagnetic activity

- Rate determined principally by
  - strength of southward magnetic field component => increased reconnection between solar wind and magnetospheric fields (Dungey, 1961)
  - solar wind speed, ($V_x B_s$ => E_y)
  - density

e.g., epsilon parameter (*Perreault and Akasofu*, 1978)

$\varepsilon = l_o^2 V B^2 \sin^4(\theta/2)$, where

l_o^2 is the area of the magnetopause through which the energy enters,

θ is the "clock angle" of the IMF relative to the Sun-Earth line

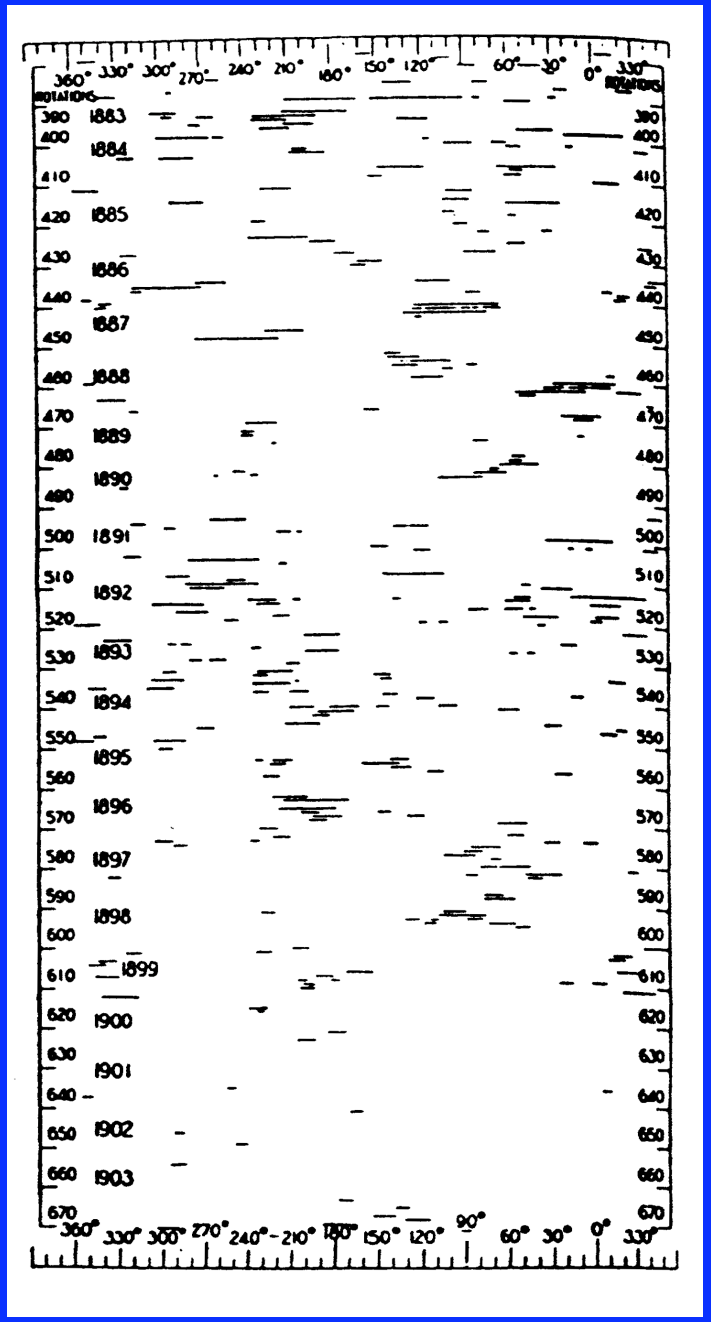
- Magnetic field variations (magnitude and direction) dominate changes in ε.

Geomagnetic Activity Associated With CIRs/High-Speed Streams

- Generally recurs at the solar rotation period
- Relatively weak compared with the activity associated with some transients.
- Enhanced activity can last many days; transient storms are generally much shorter
- New realization (e.g., Manaus, Ambleside workshops) that the weaker, but extended, activity associated with CIRs/streams can be an important energy input into the magnetosphere/ionosphere

Recurrent geomagnetic activity established by *E. W. Maunder* (1905)

- Observations in 1882 – 1903
- Horizontal lines indicate periods of enhanced activity vs. solar longitude

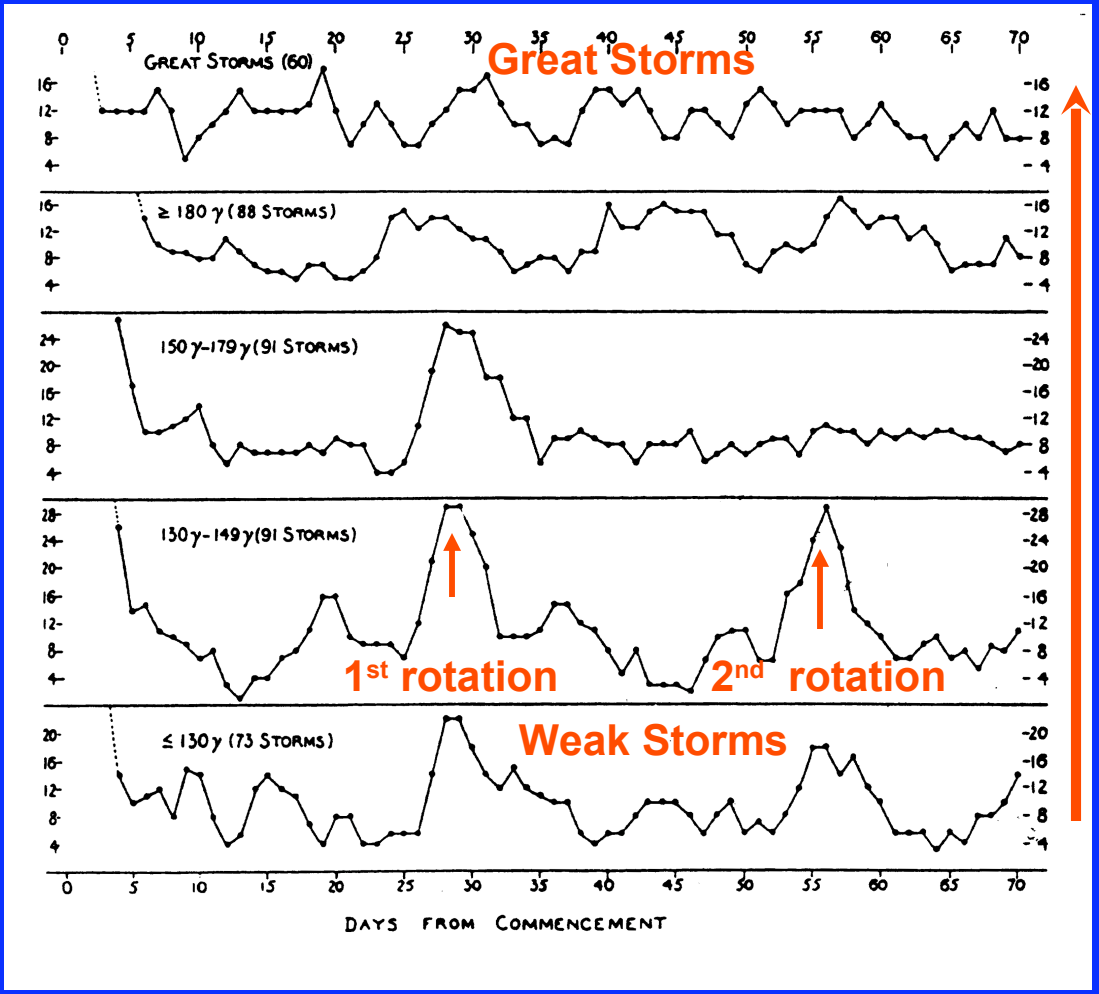


Maunder (1905)

- “Definite and restricted areas" on the Sun give rise to geomagnetic disturbances
- No association with sunspots, faculae, or prominences
- Recurrence explained “by supposing that the Earth has encountered, time after time, a definite stream ... which, continually supplied from one and the same area of the Sun's surface, appears to us, at our distance, to be rotating with the same speed as the area from which it arises”
- Duration of activity implied stream diameter of ~20^{o} of solar longitude
- Removed Lord Kelvin’s objection to the high energy required to produce geomagnetic activity by a spherical “wave” from the Sun

Greaves and Newton (1929)

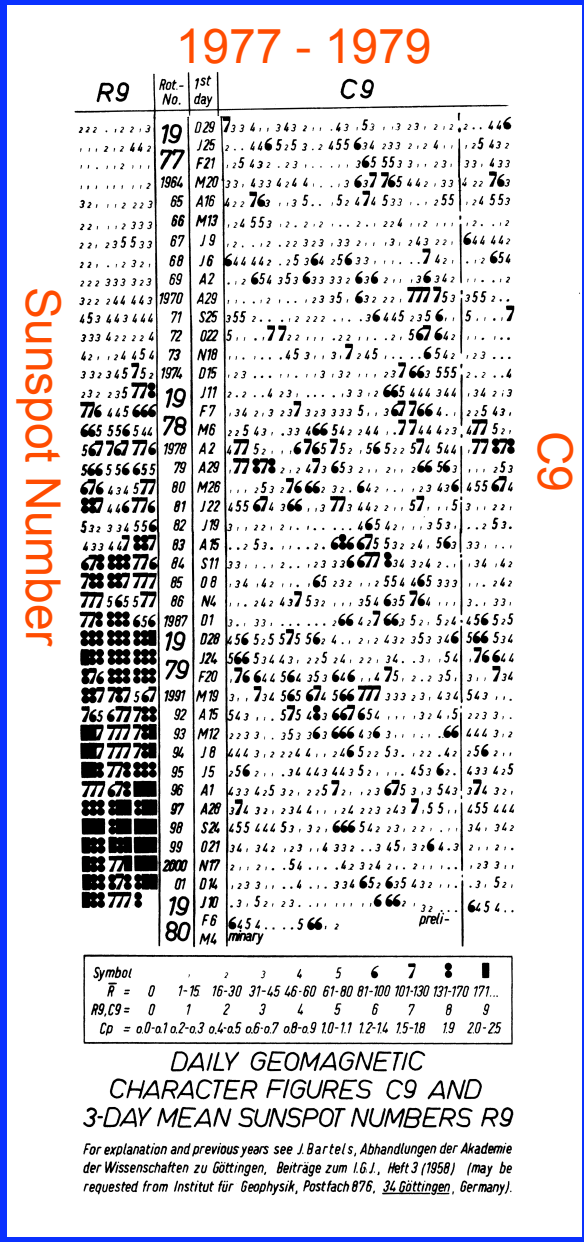
- Superposed epoch analysis - % of cases when storm activity was observed on a given day following activity of a particular size



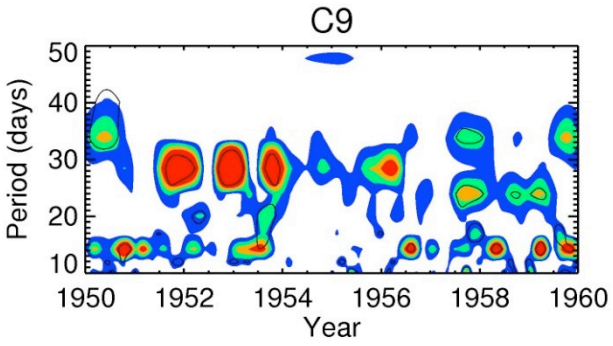
70 days

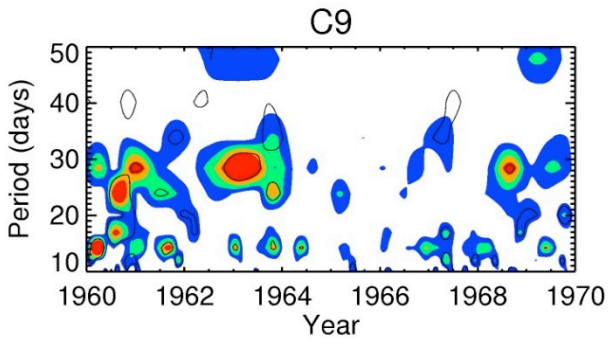
Bartels (1932, 1940)

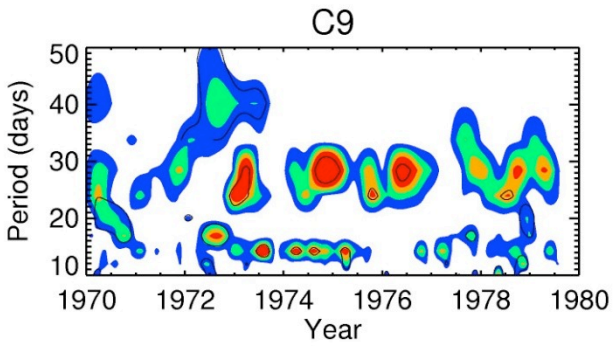
- 27-day (solar rotation period) stackplots of the geomagnetic C9 index (for 1906 – 1931)
- Sunspots independent of sources of recurrent activity ("M (mystery) – regions")
- Two types of magnetic storms:
  - Sporadic (Sunspot associated; solar maximum)
  - Recurrent (M-regions; solar minimum; often strong during declining phase)

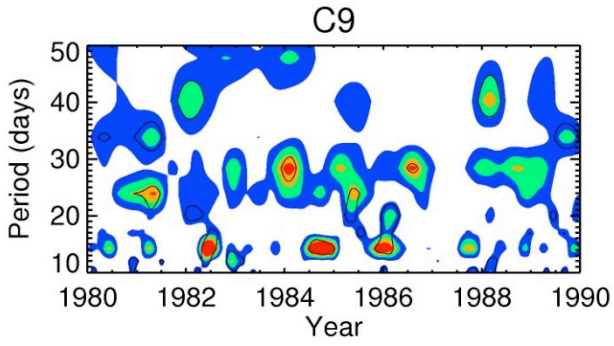


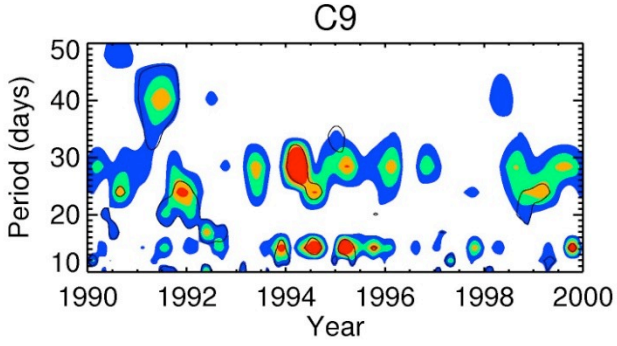
Wavelet Analysis of Geomagnetic C9 Index for 1950 – 2004 (Time vs. Period vs. Power)

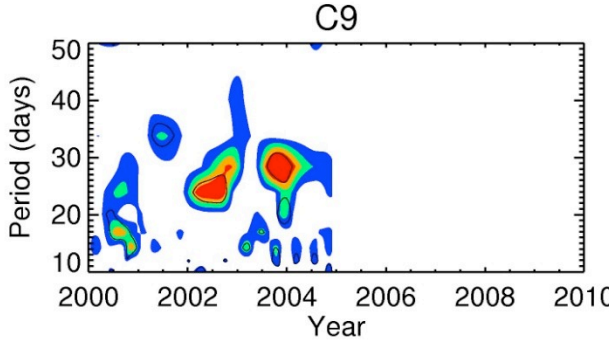






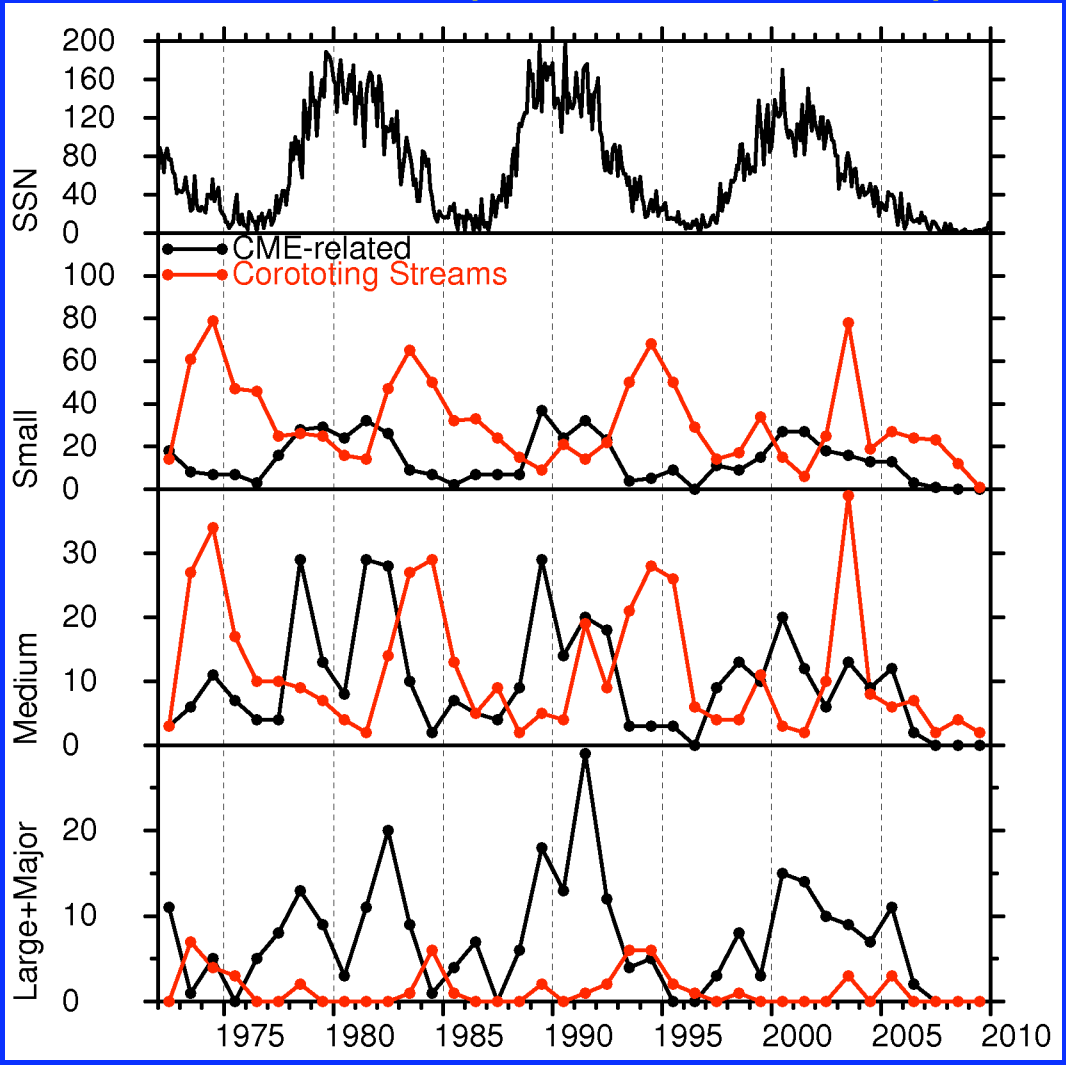






Richardson, AGU Monograph 167, 2006

Occurrence rates of CME and stream related "small", "medium" and "large"+"major" storm days (based on Kp*) in 1972 - 2009



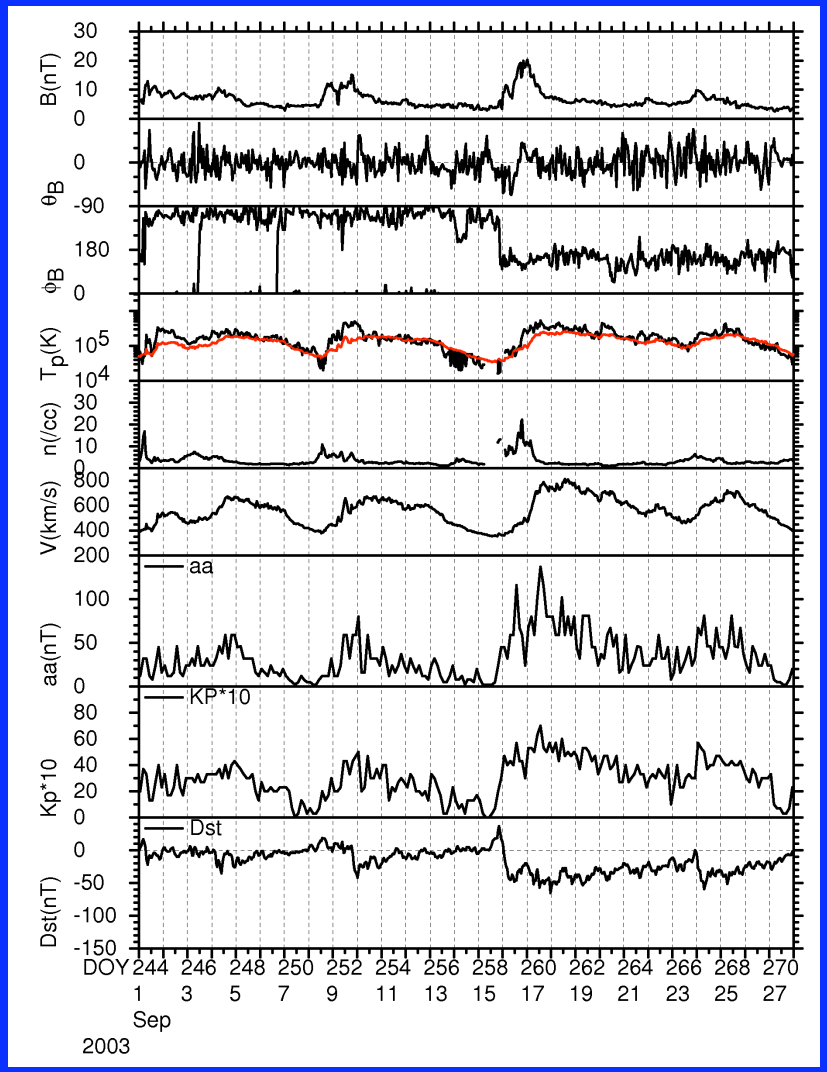
Stream-related storms are:

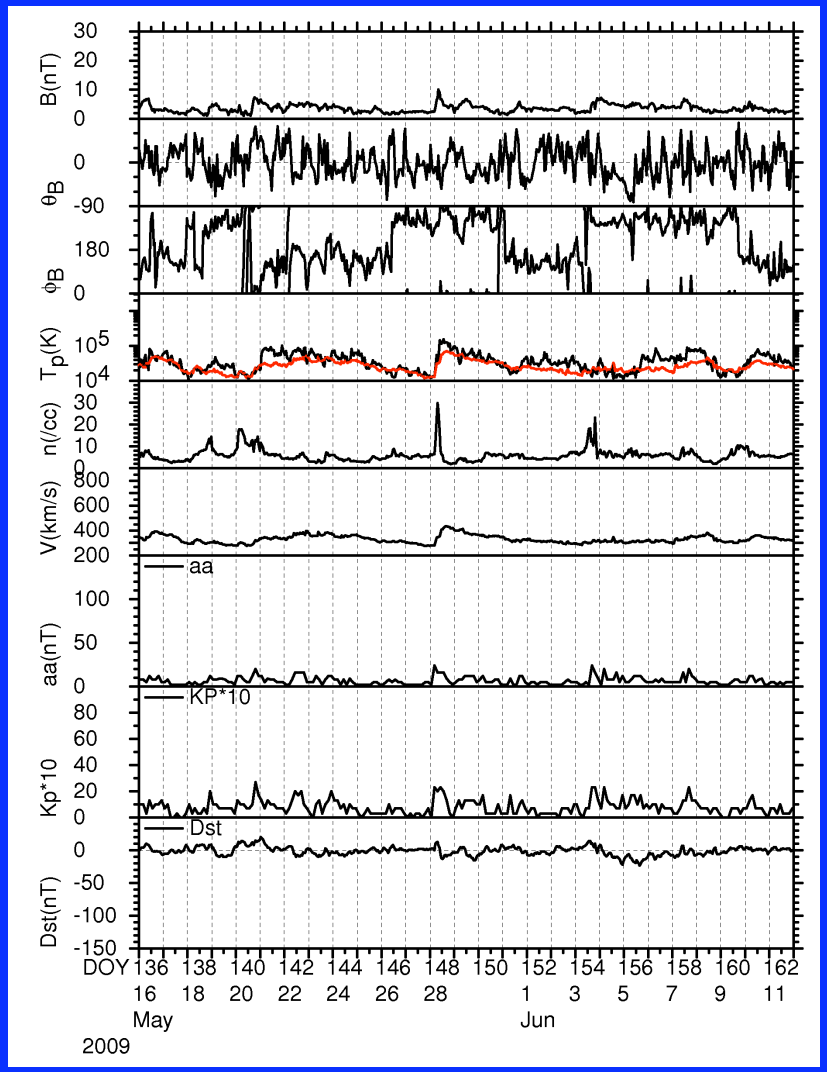
- Predominantly small or medium (rarely large)
- Most prominent during the declining phase of the cycle.
- Comparatively few stream-related storms during the declining phase of cycle 23 (peak in 2003)

* As defined by *Gosling et al.* 1991

Updated from Richardson et al., 2001; Richardson, 2006

Comparison of Streams and Geomagnetic Activity in 2003 and 2009

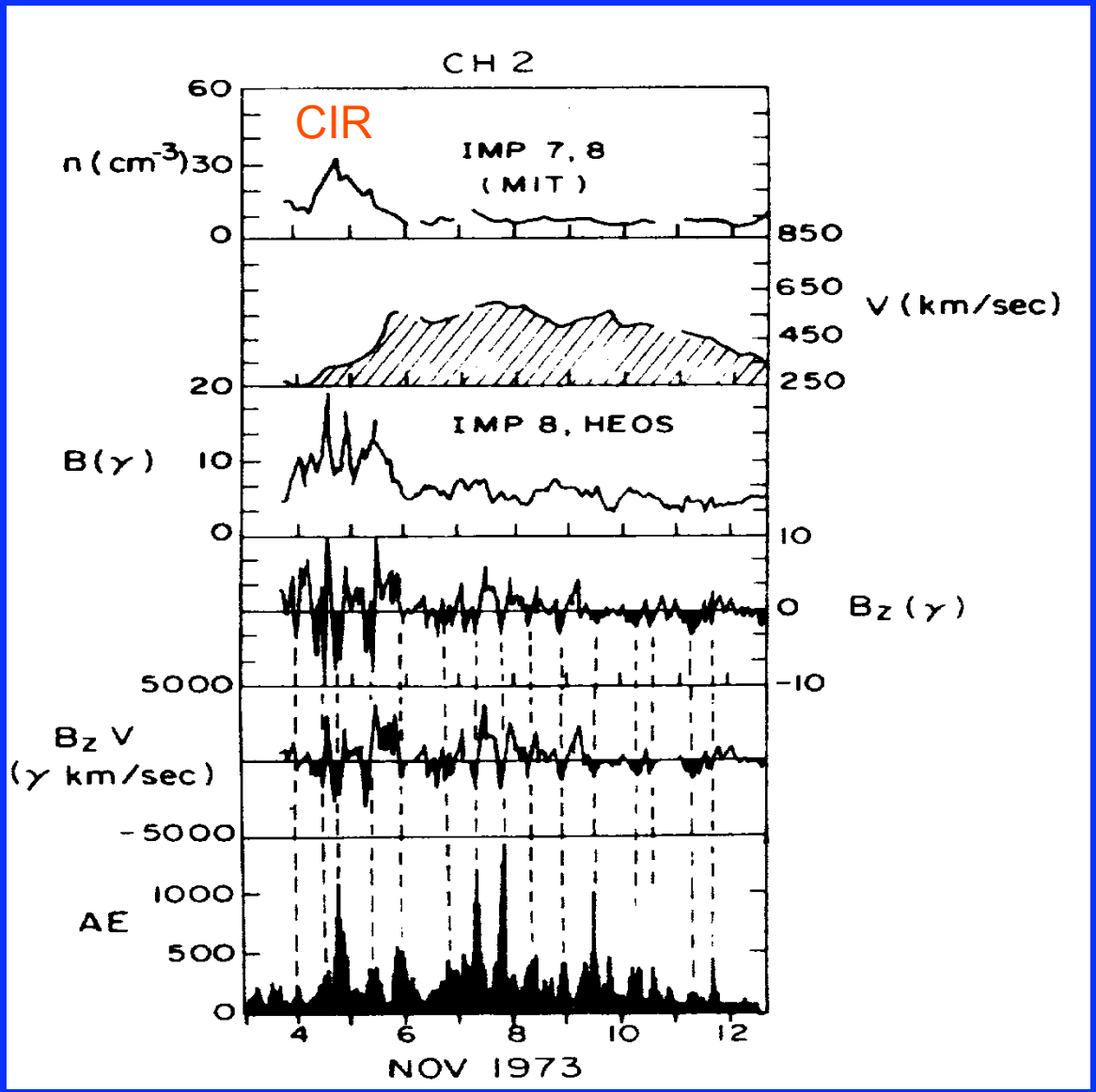




Origin of CIR/Stream-Associated Geomagnetic Activity

Crooker (2000):

"A common misunderstanding about high-speed streams is that the high-speed flow itself causes geomagnetic storms"



Burlaga and Lepping, 1977, "The Causes of Recurrent Geomagnetic Storms"

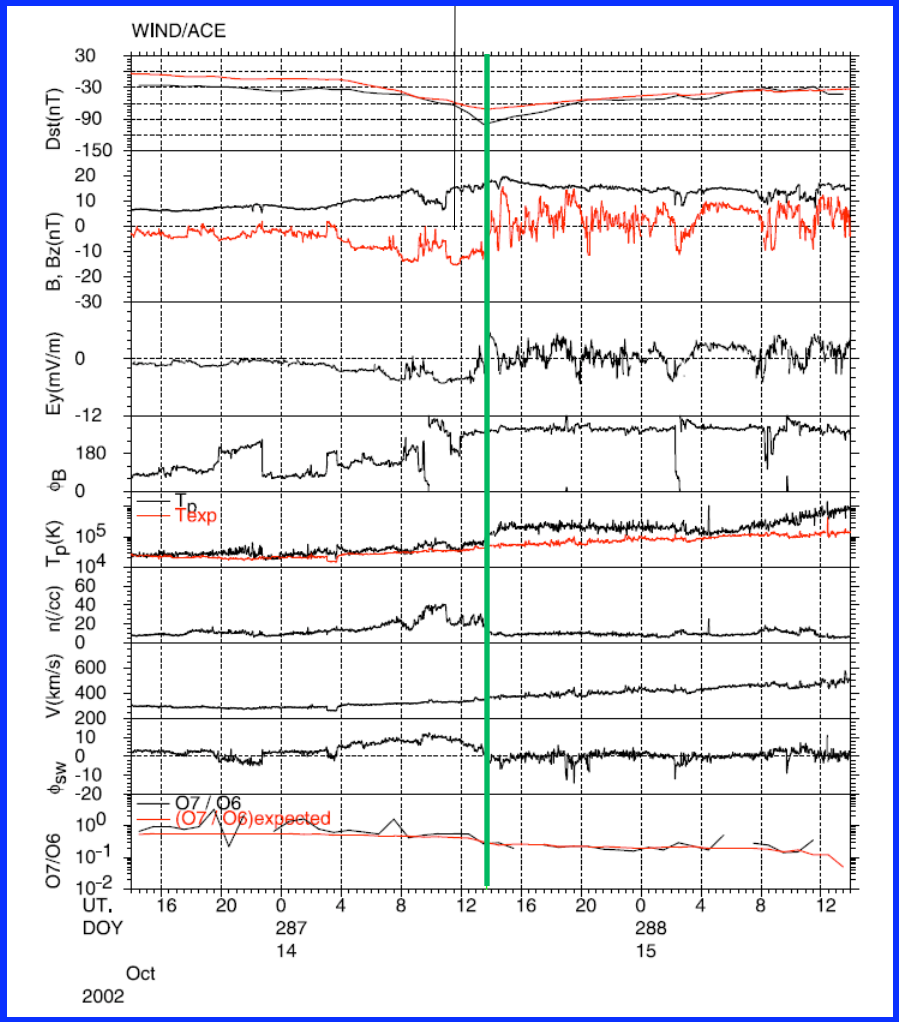
- "Striking correlation" between bursts in AE and large southward (negative) values of B_z
- "B_z is an essential factor in causing the geomagnetic activity"
- Particularly large fluctuations in B_z within CIR; Compression of ambient fluctuations (Alfvén waves) by stream steepening?

- ~10% of the 80 geomagnetic storms with Dst < -100 nT in cycle 23 were caused by CIRs/streams (Richardson et al., 2006; Zhang et al., 2007, 2008)

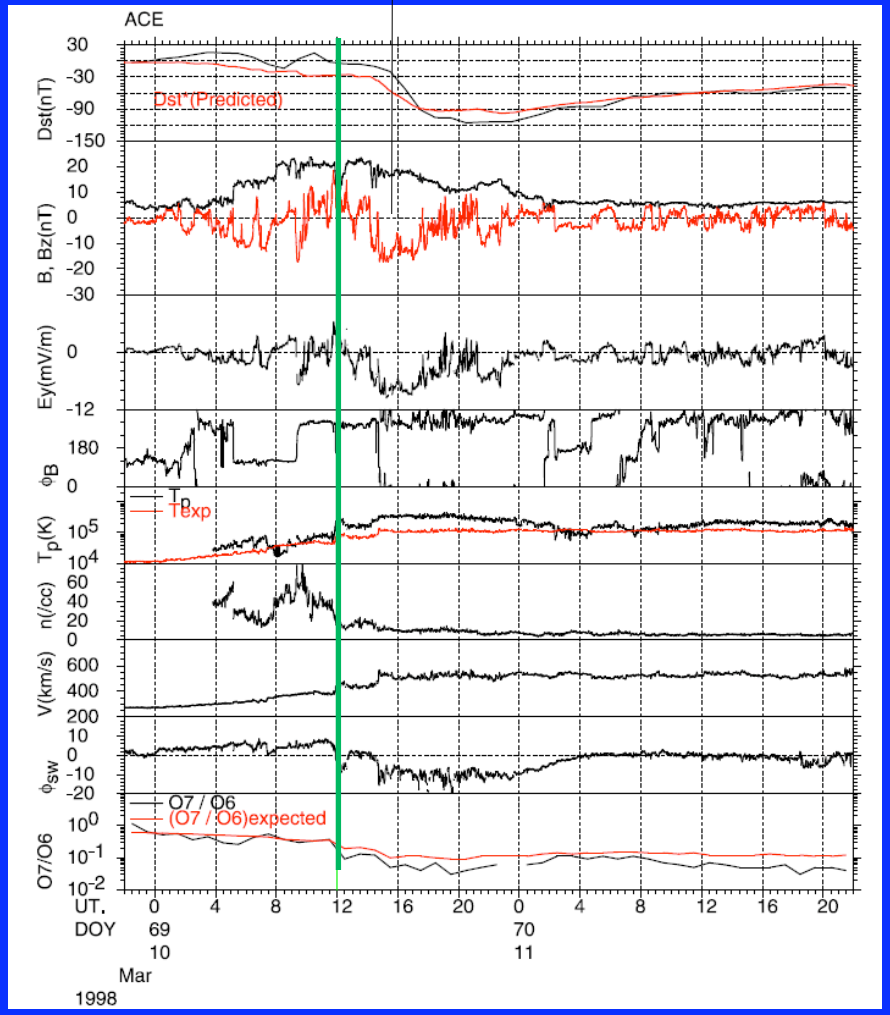
- Extended intervals of B_s present in the CIR, either before or after the stream interface.

Examples of CIRs Associated With Dst < -100 nT Storms

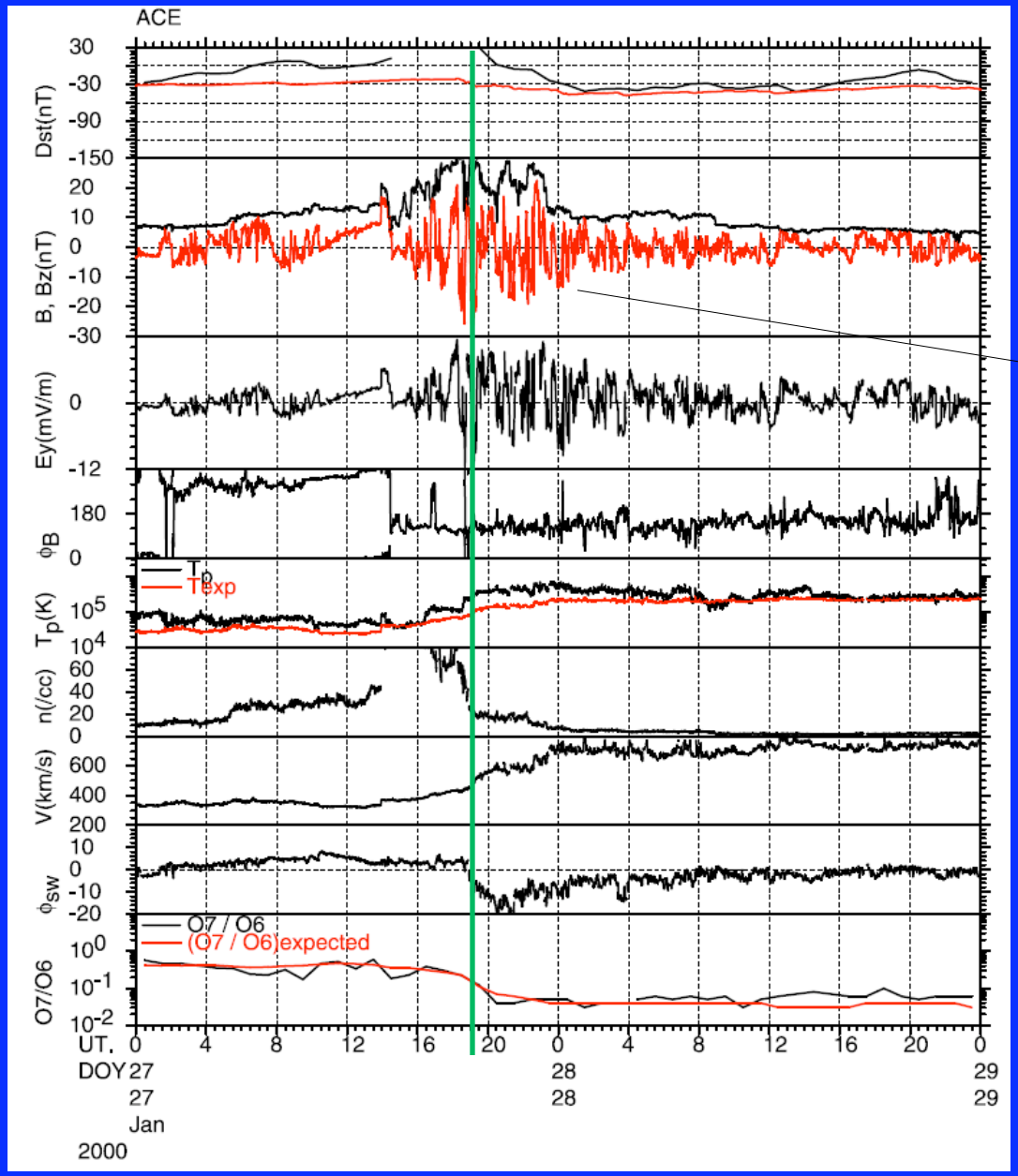
B_s before stream interface



B_s after stream interface



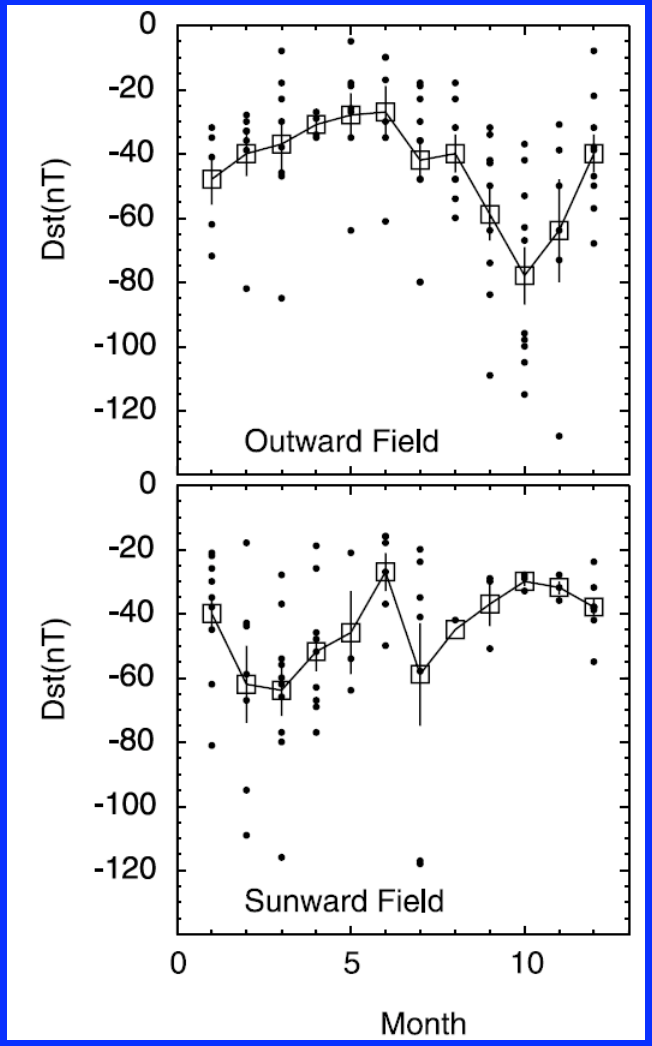
Richardson et al., 2006

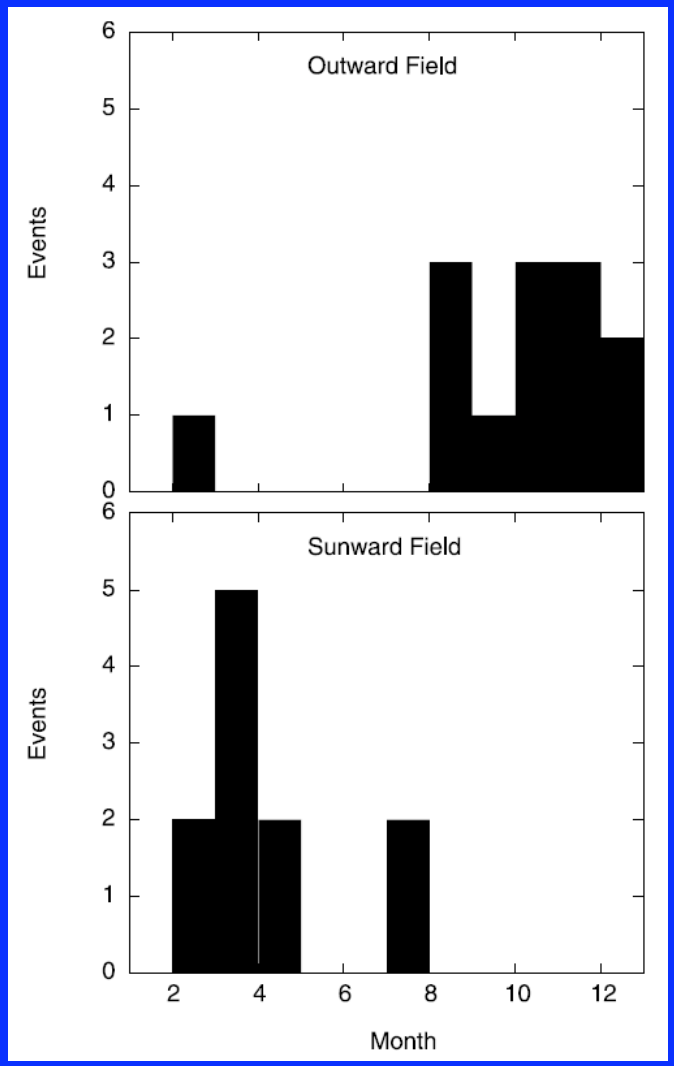


A well-developed CIR that gives only a weak storm, due to rapidly fluctuating B_z in the vicinity of the stream interface

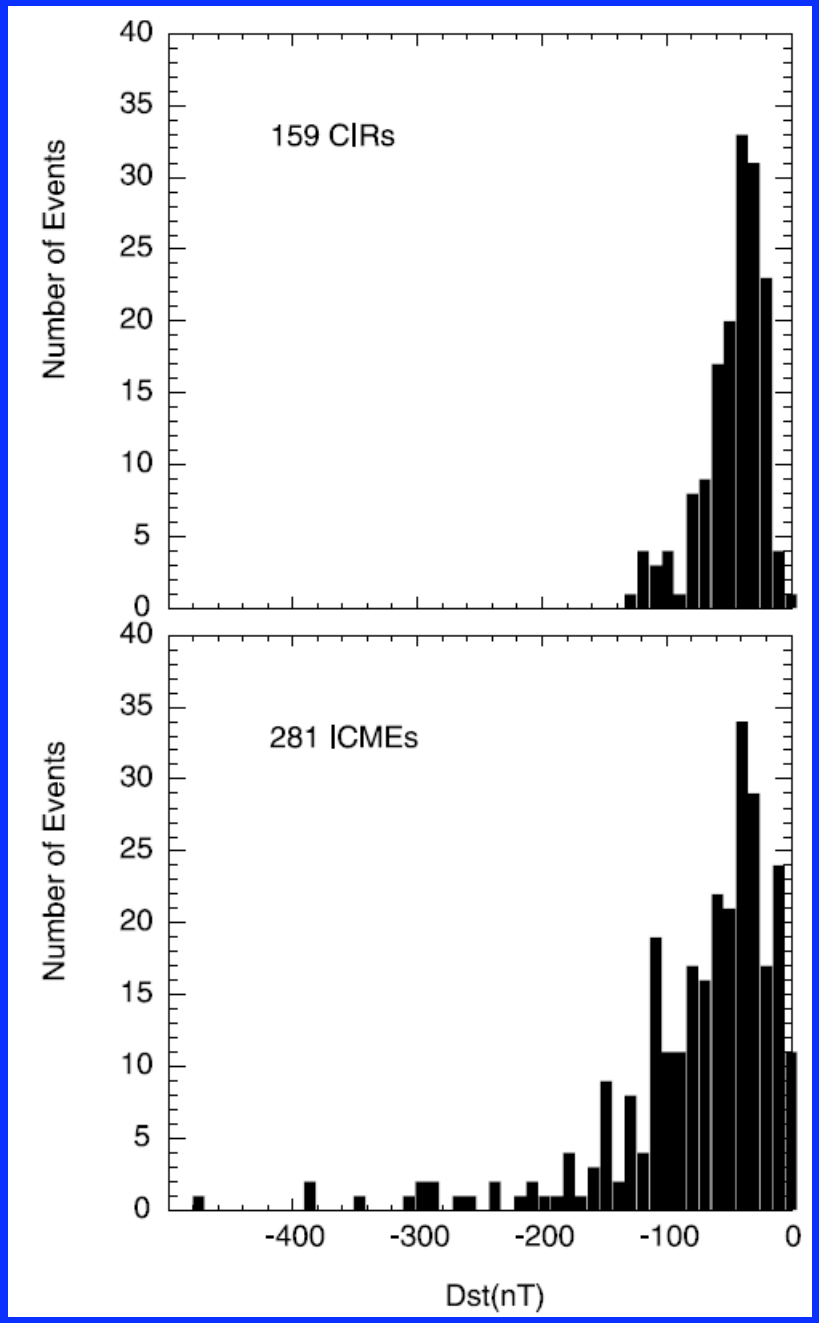
Richardson et al., 2006

Significant Seasonal ("Russell-McPherron") Effect on CIR Storm Size (Left) and Monthly Occurrence of Dst < -100 nT Storms in 1972-2005 (Right) Caused by Outward and Sunward Magnetic Fields





Richardson et al., 2006



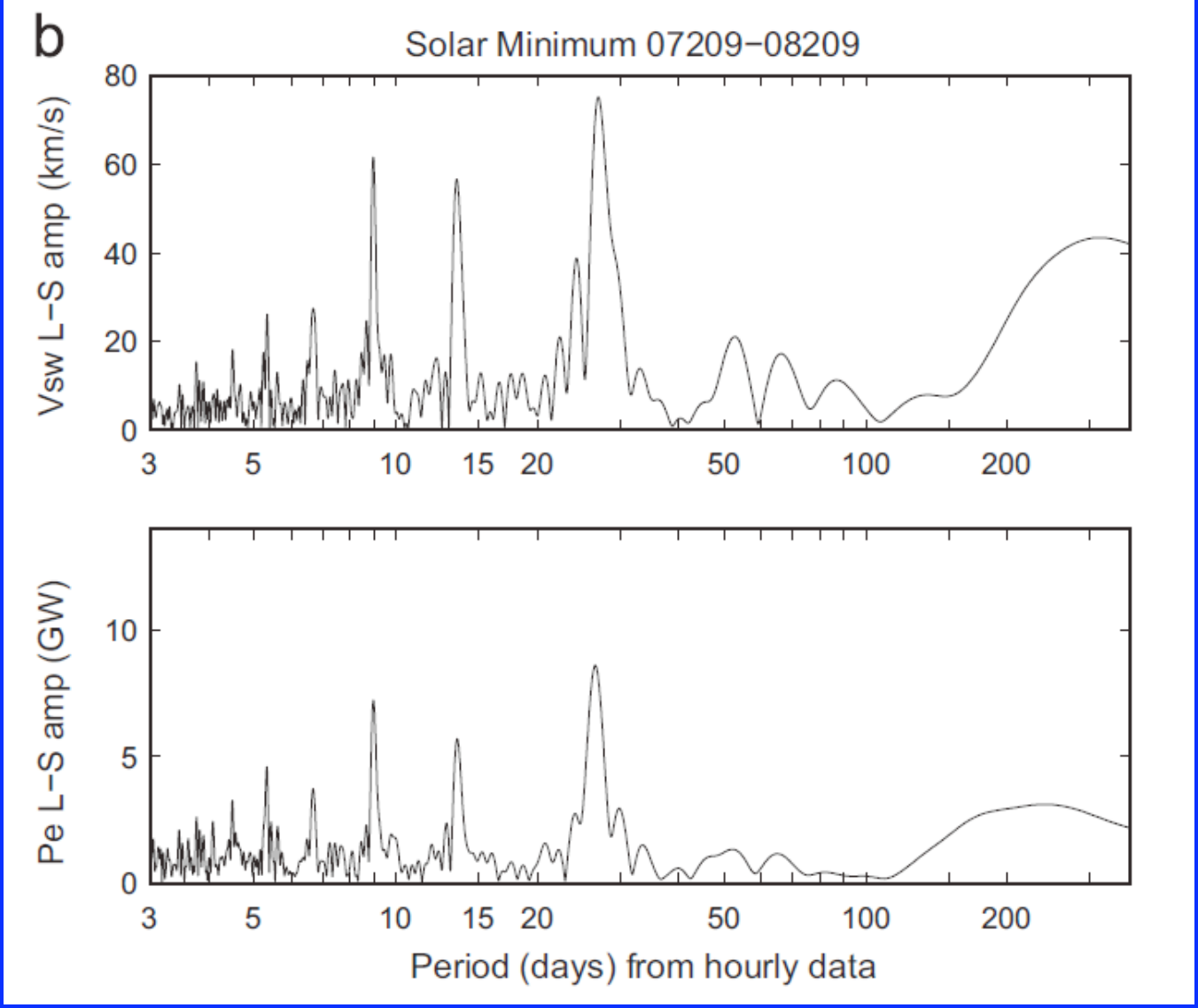
Richardson et al., 2006

Distributions of minimum Dst for 159 CIRs and 281 ICMEs in 1996-2005

Note the absence of an intense storm tail for CIRs; maximum storm size ~ -130 nT.

Limited by field intensity resulting from stream interaction (typically ~20 nT), and solar wind speed (~400 km/s) => Ey ~8 mV/m. O'Brien-McPherron formulae suggest CIR storms will rarely exceed Dst ~ -180 nT

Similar Periodicities in Solar Wind Speed and Electron Power Deposition into the Auroral Zones



Emery, Richardson, Evans and Rich, JASTP, 2009

Summary

Geomagnetic activity related to CIRs/streams is:

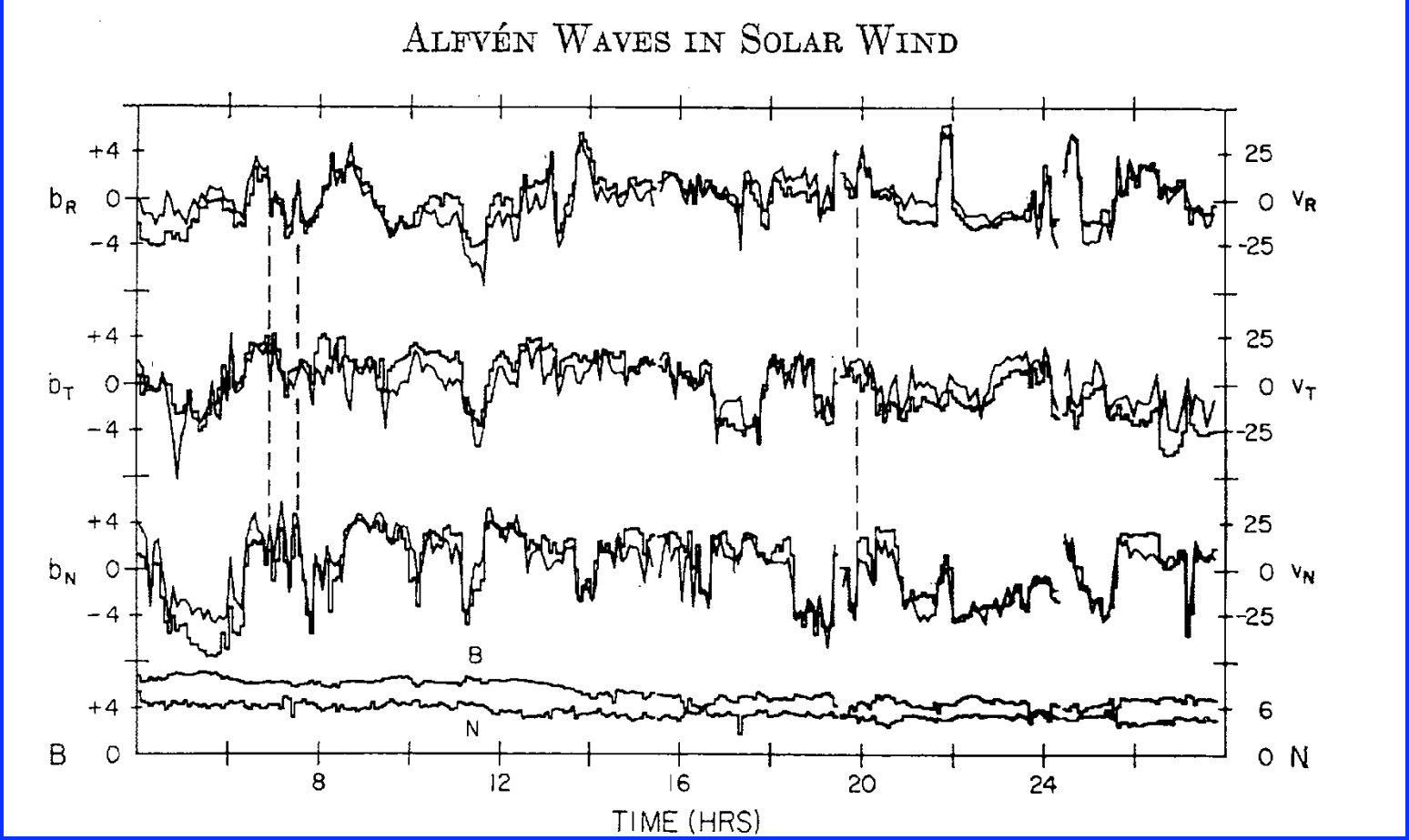
- Recurrent;
- Associated with intermittent southward B turnings related to Alfvén waves (also maybe transient structures??)
- Weaker than ICME-associated activity but more extended;
- Provides an important energy input into the magnetosphere/ionosphere, especially at high latitudes.

Greaves and Newton (1929)

- Recurrence is a property of smaller geomagnetic storms

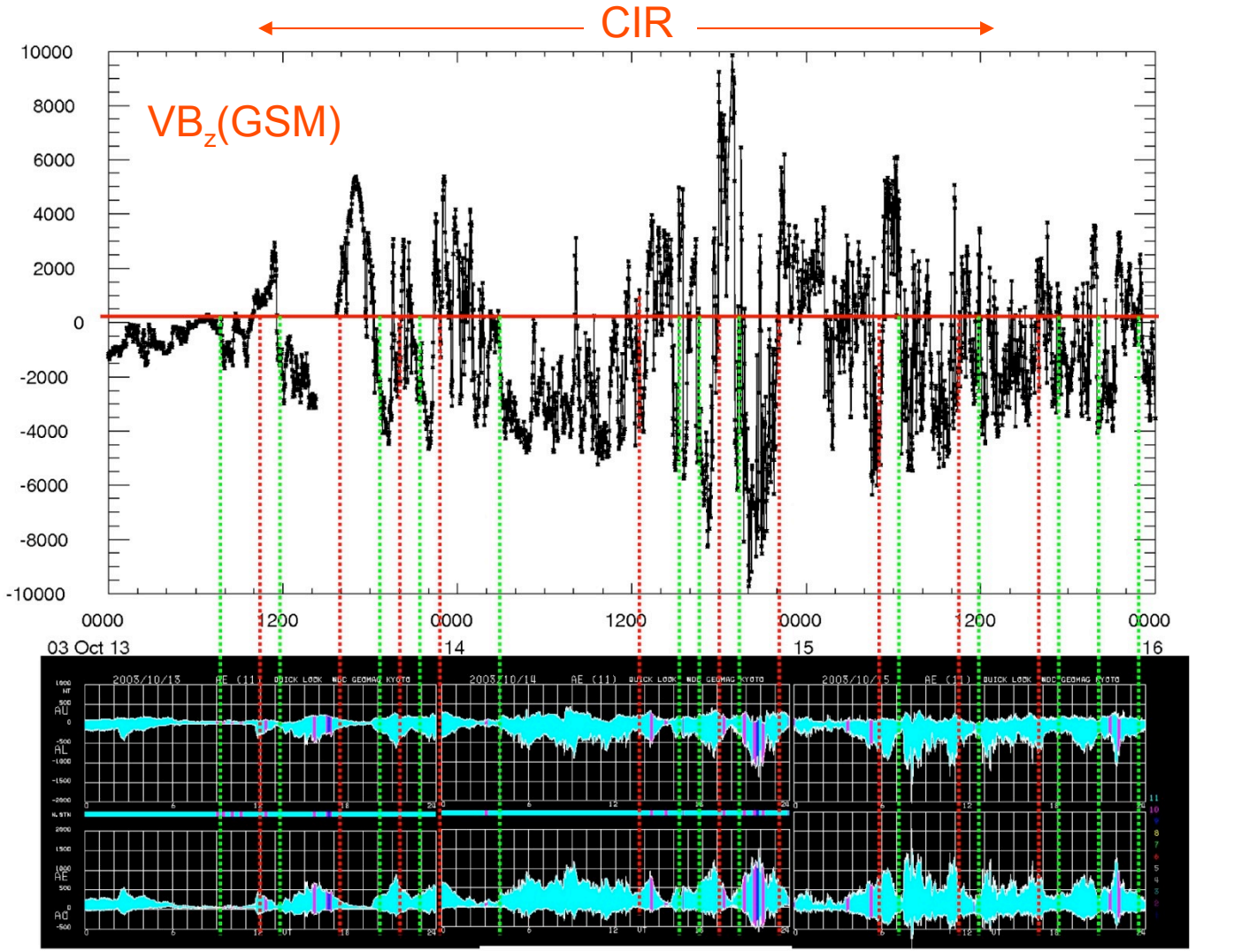
- Not exhibited by major storms even though these are associated with large sunspots which often persist for more than one solar rotation

Alfvén waves $\mathbf{B}=\pm(\mu_o\rho)^{1/2}\,\mathbf{V}$

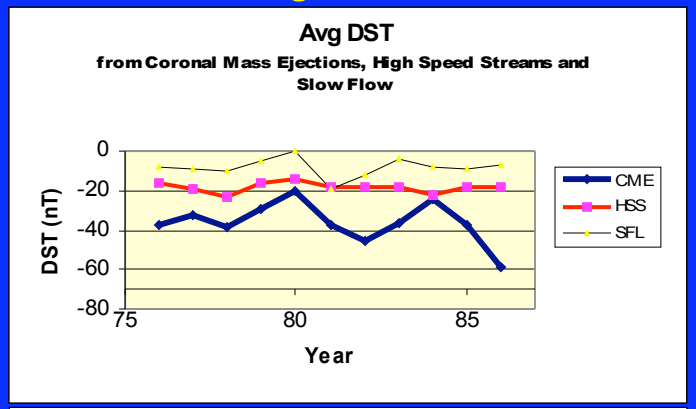


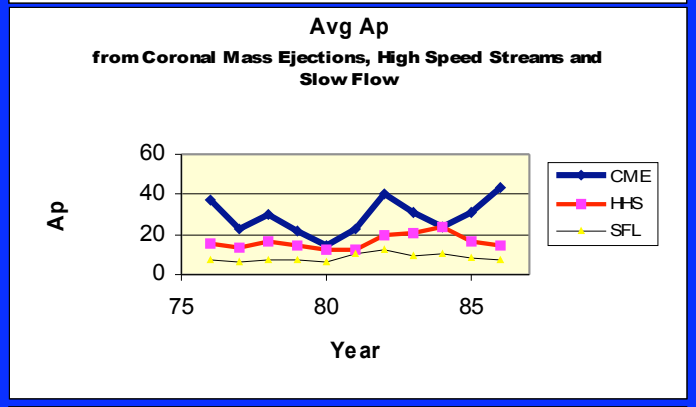
Belcher and Davis, 1971

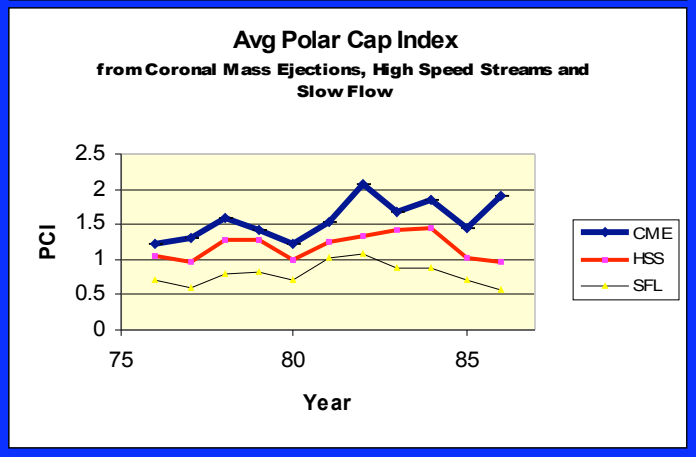
VB_z(ACE) and AU, AL, AE (WDC-Kyoto), October 13 – 15, 2003



Average Value

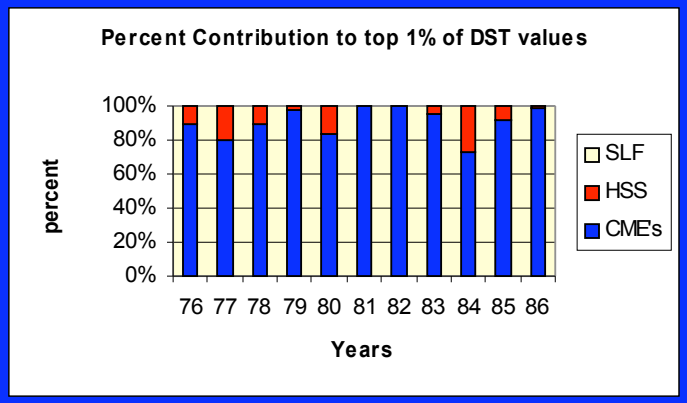




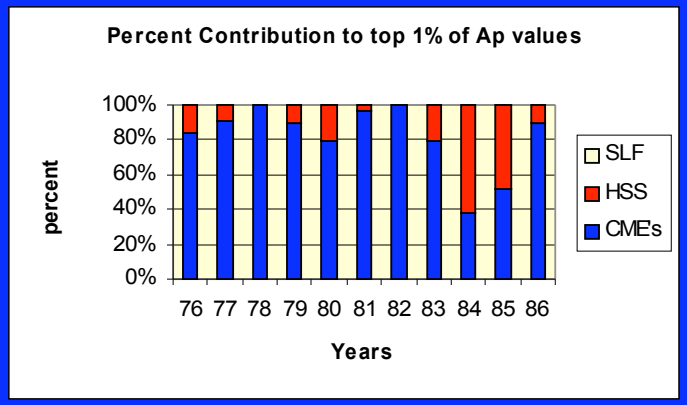


% contribution to top 1% of values

Knipp, 2000



DsT



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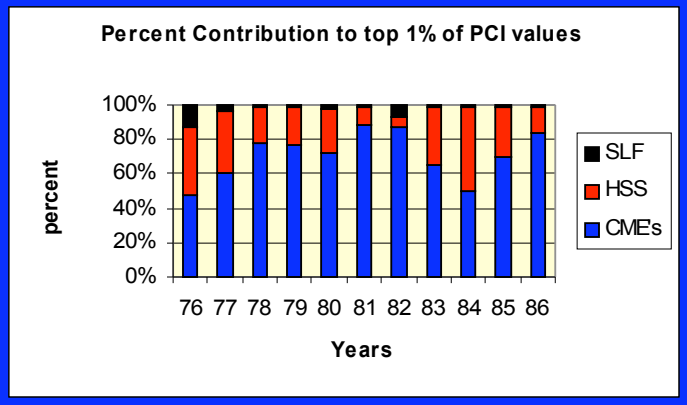

Polar Cap Index