Solar system plasma intermittency: methods and observations over the solar cycle

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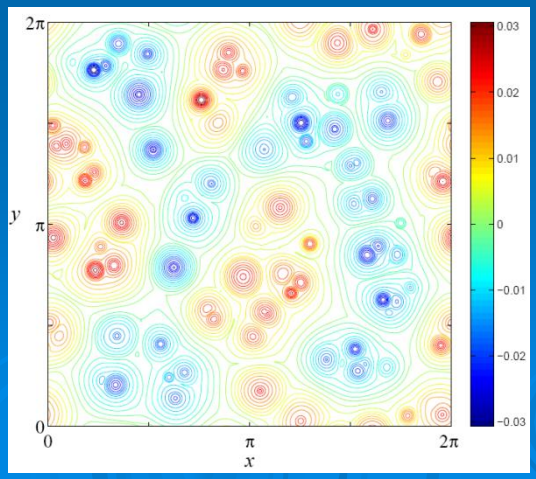

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STORM

Solar system plasma Turbulence: Observations, inteRmittency and Multifractals

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OUTLINE

- Intermittency and criticality: the importance of power laws and statistics
- Power laws in solar and geomagnetic activity: a coarse grained survey of the last two solar cycles
- Methods to quantify intermittency from times series
  - Probability distribution functions (PDFs), Moments of PDFs, Wavelets and Local Intermittency Measure, Structure Functions, Fractals, Multifractals
- Intermittency at the interface with the solar wind : CIR and magnetospheric response from Cluster observations
- Intermittency in geomagnetic activity at temporal scales ([1 hour, 1 year]) – the last two solar cycles
- Summary

Terminology

- **Criticality**: physical equivalence of all temporal and spatial scales (*Consolini and Chang, 2001*)
- **Intermittency**: dynamical emergence of burstiness followed/preceede by quiteness (e.g. coherent structures interation in turbulence: convective forms, nonlinear solitary structures, pseudo-equilibrium configurations, etc.), sporadic and localized interactions (*Chang, 2004*)
- **Self Organized Criticality**: ``spontaneous emergence of criticality in complex dissipative systems'' (*Bak et al., 1987*); F/SOC magnetosphere driven by the solar wind (*Chang, 1992*).

T. Chang, Space Plasmas, Dynamical Complexity in, ***Encyclopedia of Complexity and Systems Science***, Springer-Verlag, 2009

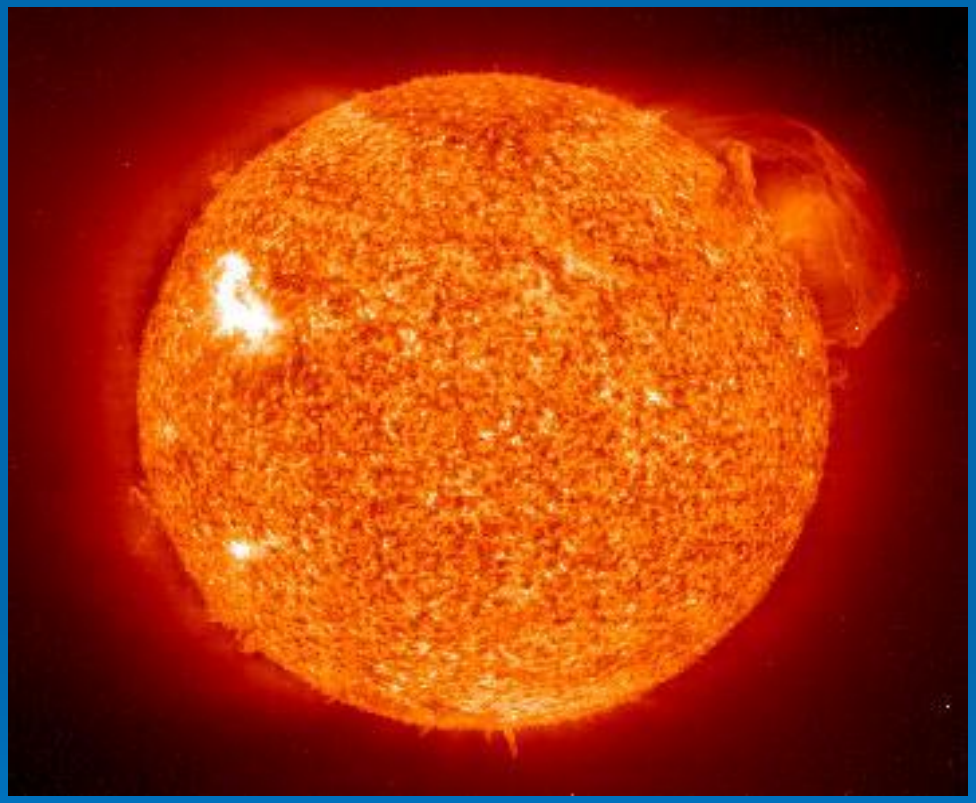
Dynamical Criticality and Intermittency

No correlations: the system reacts to the external forces with small, similar sized events

The intermediate case:
The (critical) sand pile where events (avalanches) span many decades of sizes
(Bak et al., 1987)

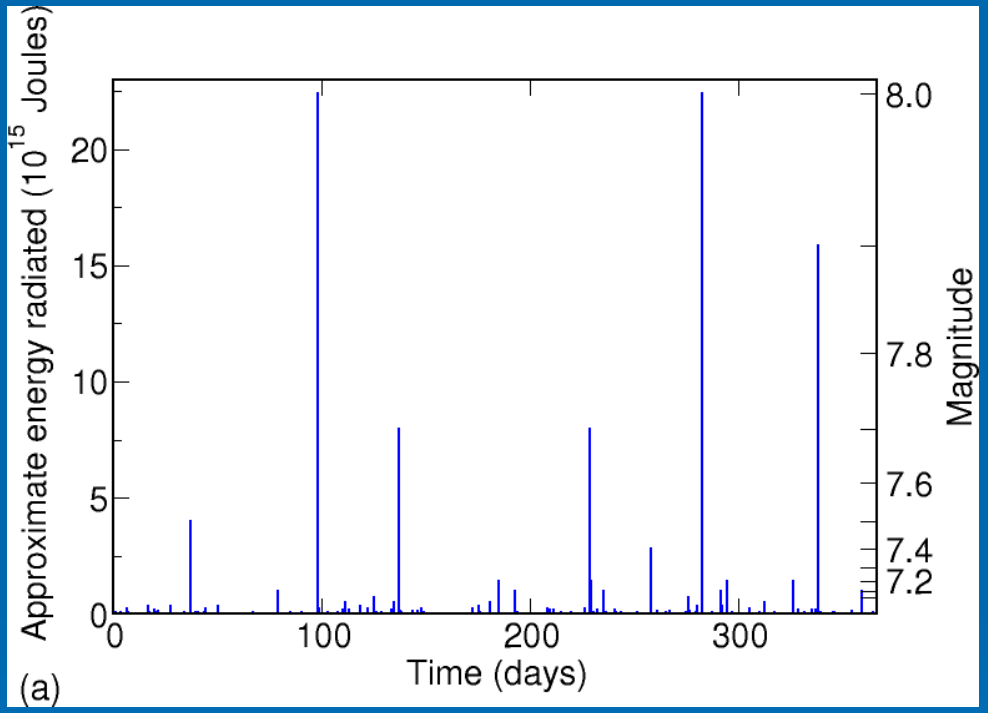
Very strong binding forces: the system react to the external driver by a single (big) event.

Dynamical Criticality and Intermittency



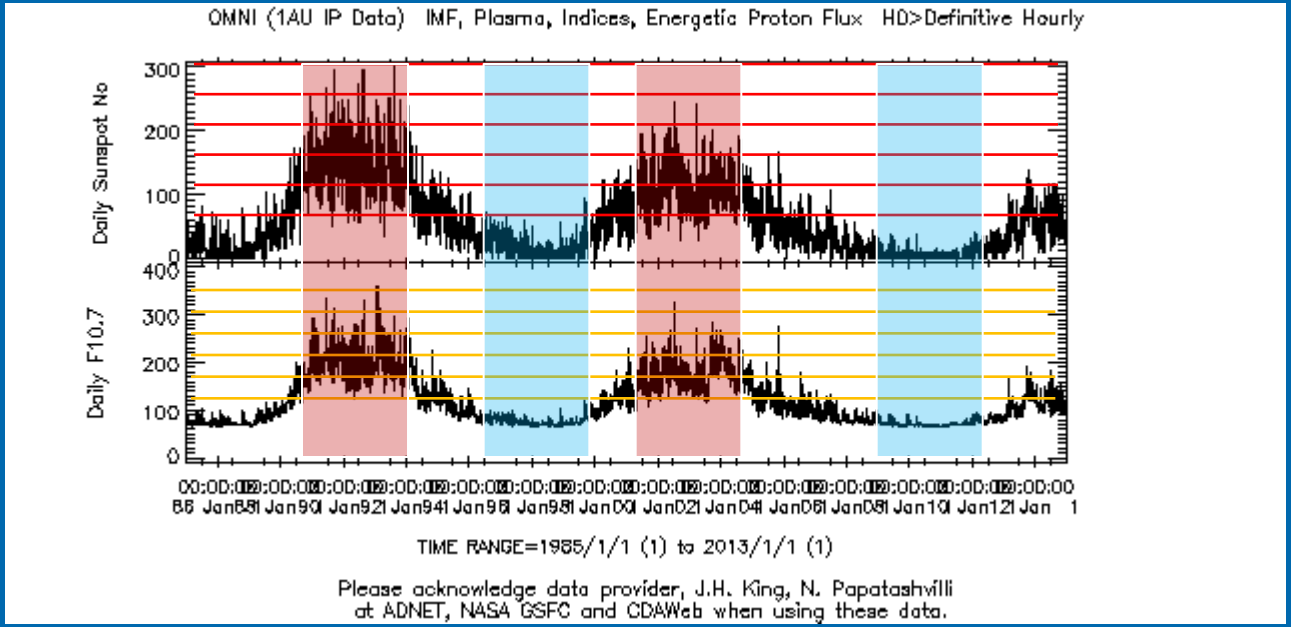
The Sun and Self Organised Criticality of solar flares (Lu et al., 1993, Charbonneau et al., 2001)

Dynamical Criticality and Intermittency



Crackling noise (Sethna et al., Nature, 2001): the Earth crackles in response to the slow plate drift (Earthquakes in 1995); intermittent violent events over a broad range of scales (intensities)

(coarse grained) Power laws from Sun activity proxies



Sunspot binning: 45 levels (from 0 to 450)

F10.7 binning: 50 levels (from 0 to 550)

Compute histograms and look at power law behavior in log-log:

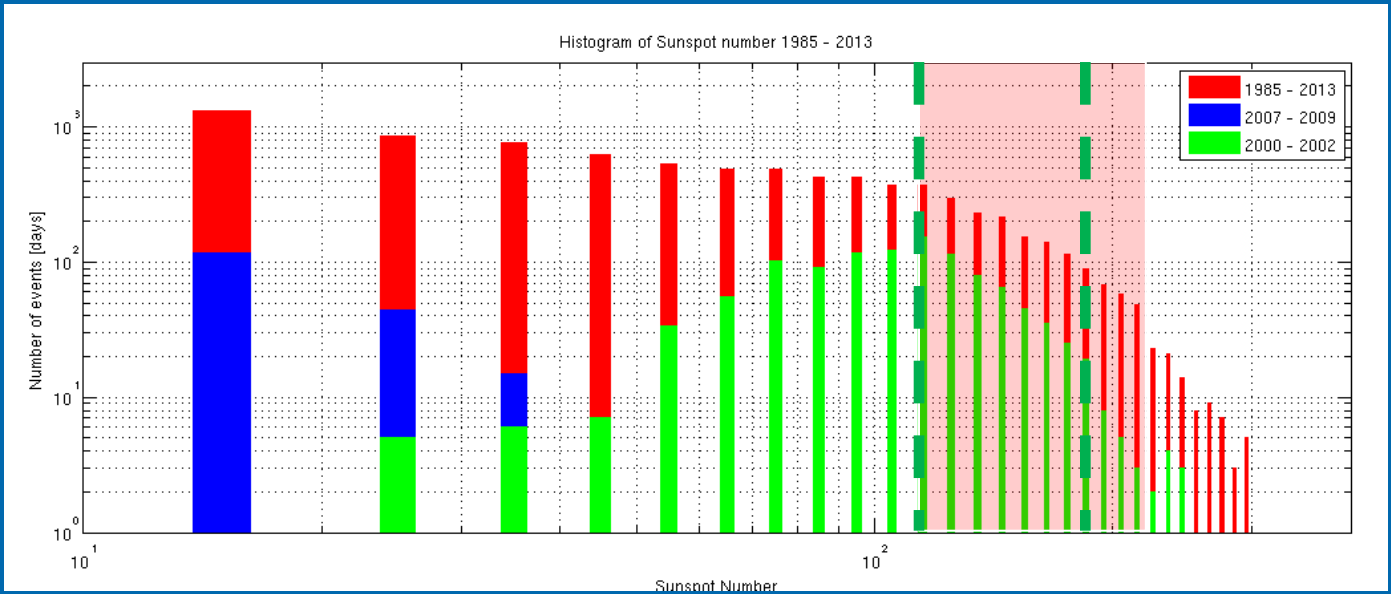
entire time period: 1985 -2013

maximum: 1990-1992, 2000-2002

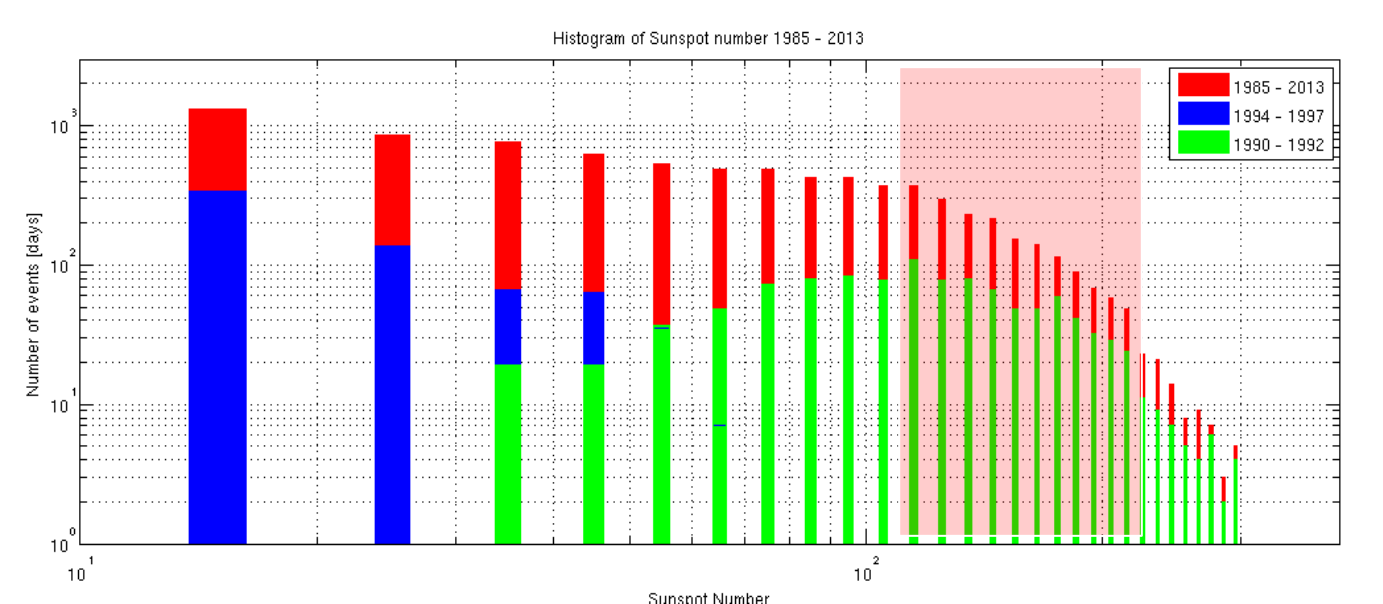
minimum: 1995-1997, 2007-2009

Histograms of Sunspot Number log-log

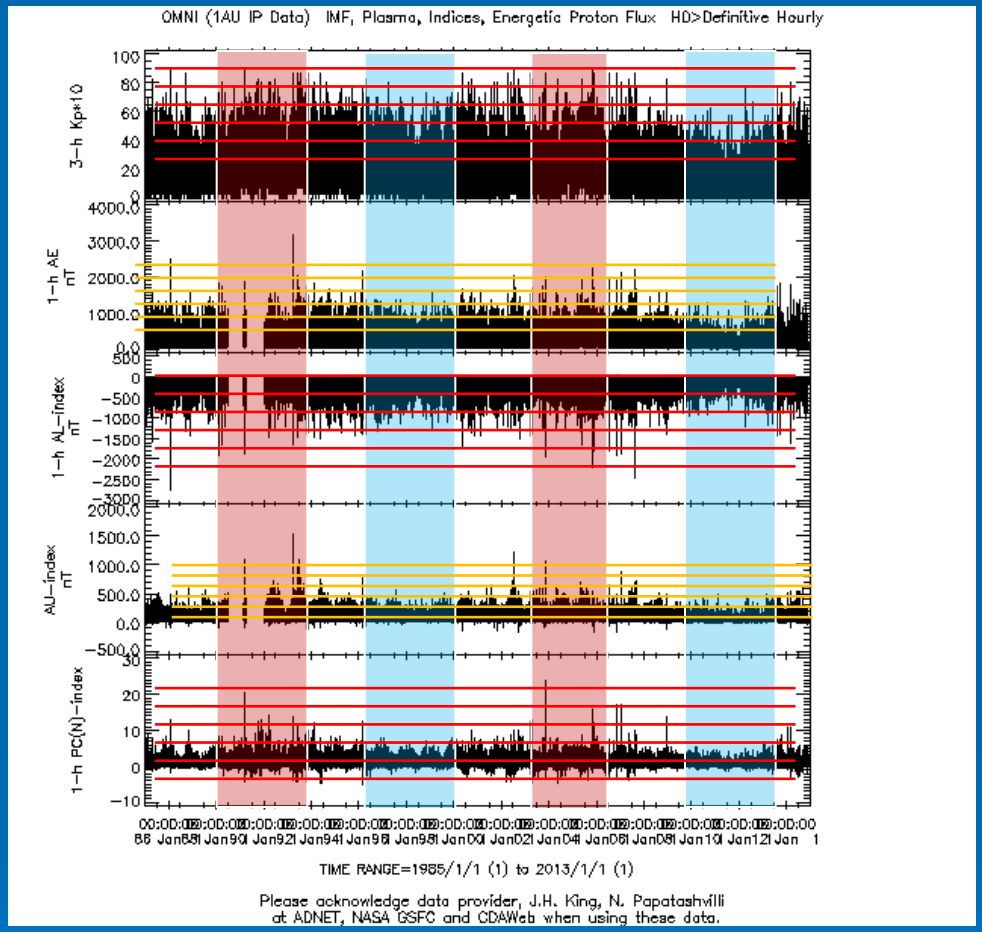
Cycle 23



Cycle 22



Power laws geomagnetic indices



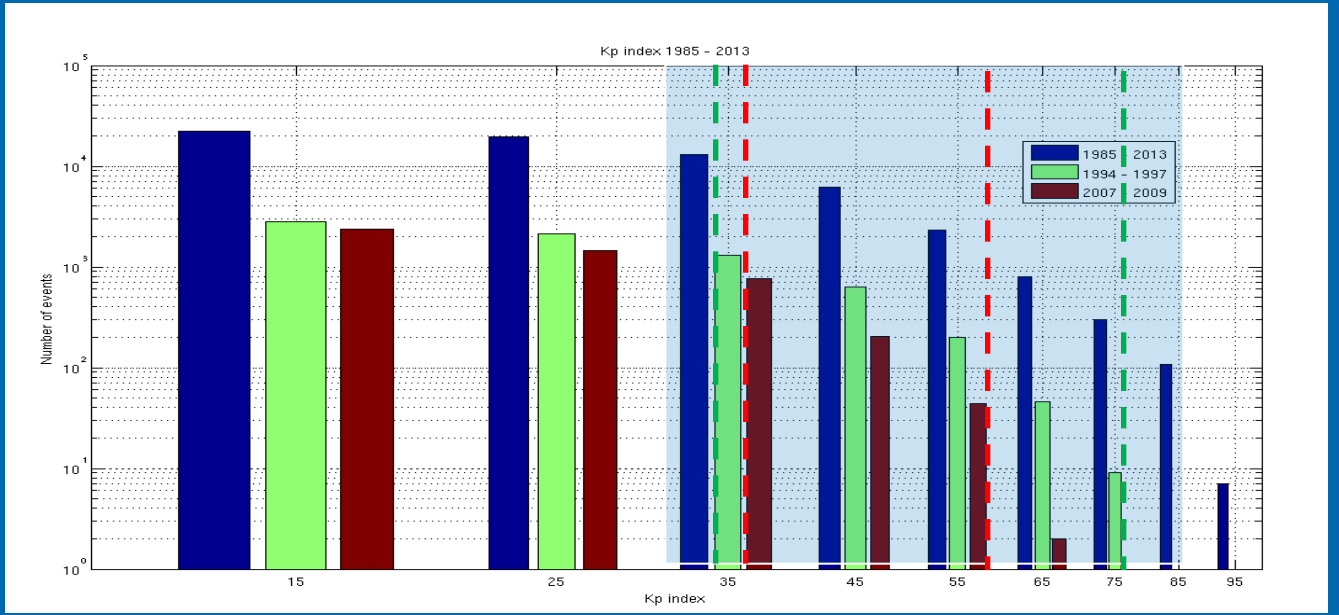
Kp binning: 10 levels (from 0 to 100)
Dst binning: 40 levels (from -300 to 100)
AE binning : 10 levels (from 0 to 4000)
AL binning : 7 levels (from -3000 to 0)
AU binning : 15 levels (from 0 to 1500)
PC index : 08 levels (-10 to 30)

Compute histograms and look at power law behavior in log-log:

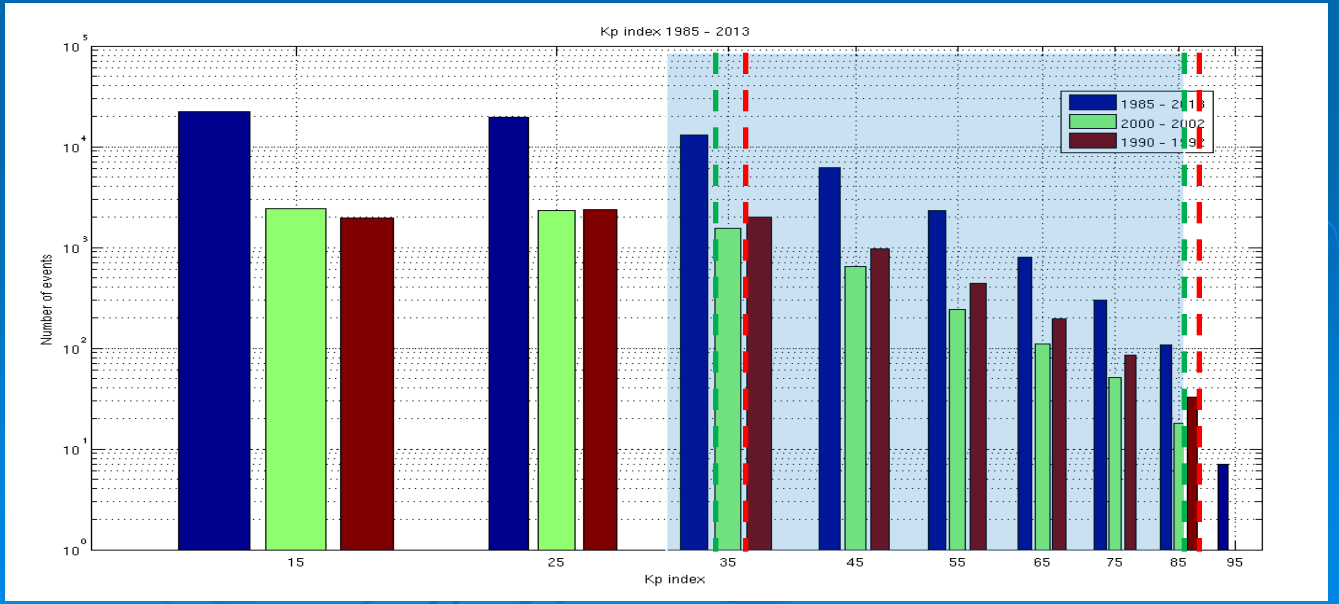
entire time period: 1985 -2013
maximum: 1990-1992, 2000-2002
minimum: 1995-1997, 2007-2009

Histograms of Kp (3 h) log-log

Last two minima
(2 yrs)

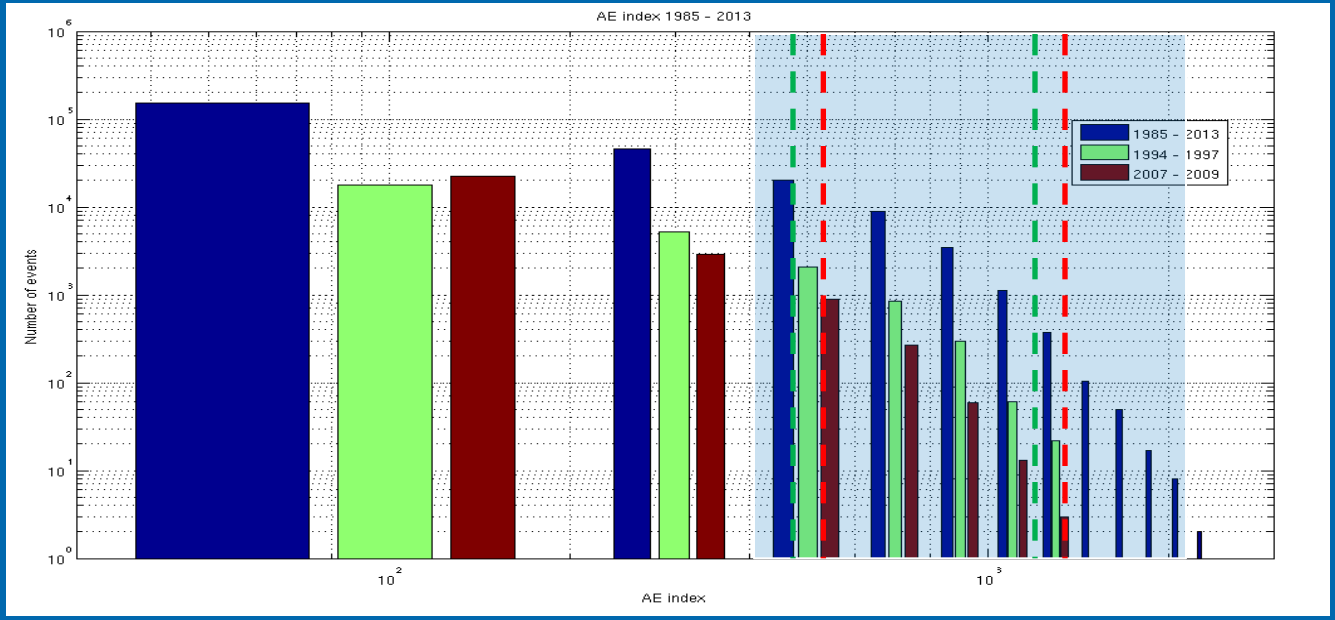


Last two maxima
(2 yrs)

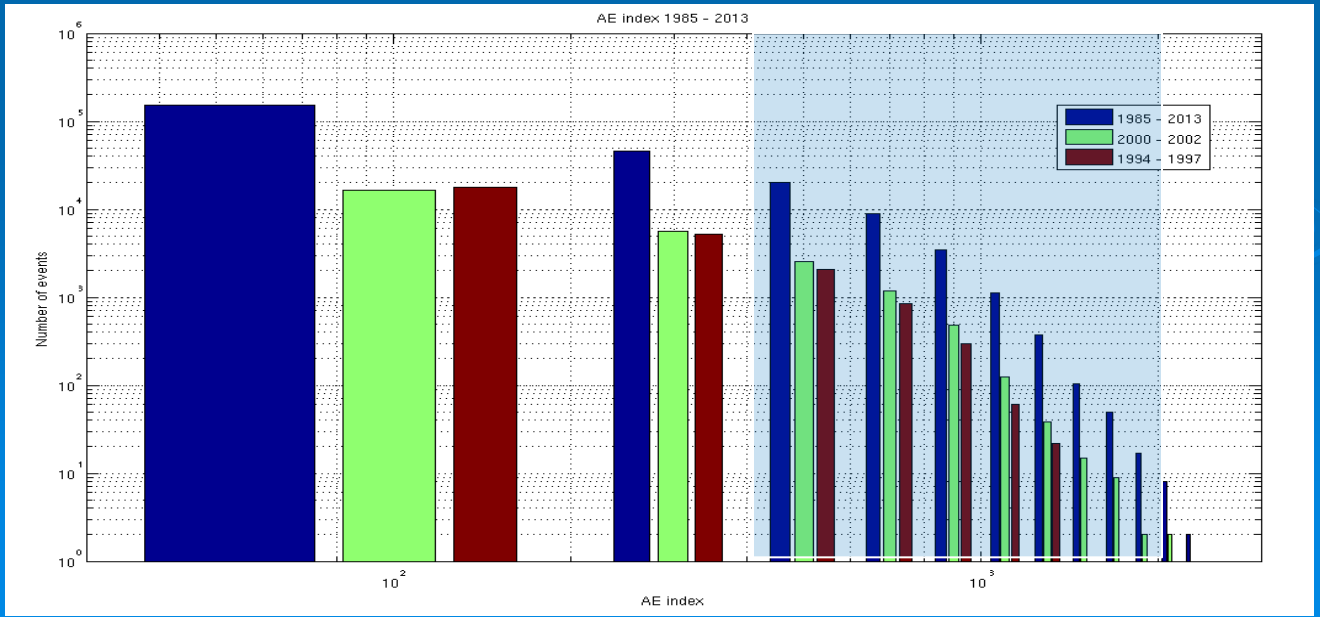


Histograms of AE (1 h) log-log

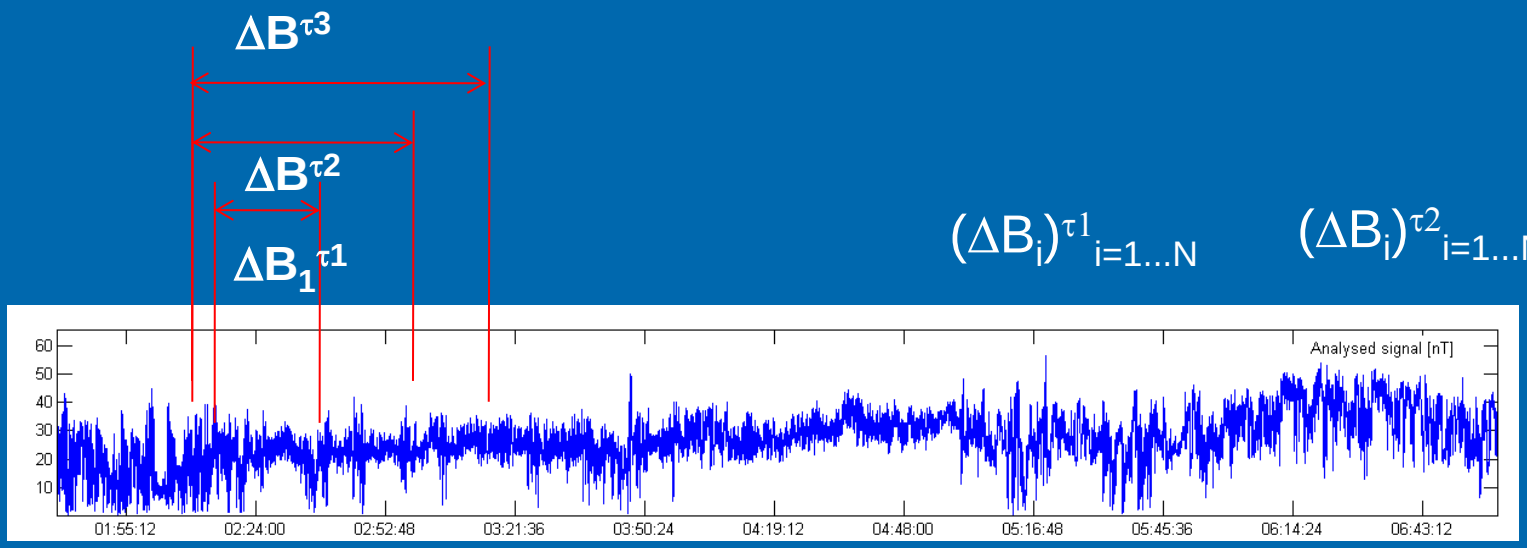
Last two minima
(2 yrs)

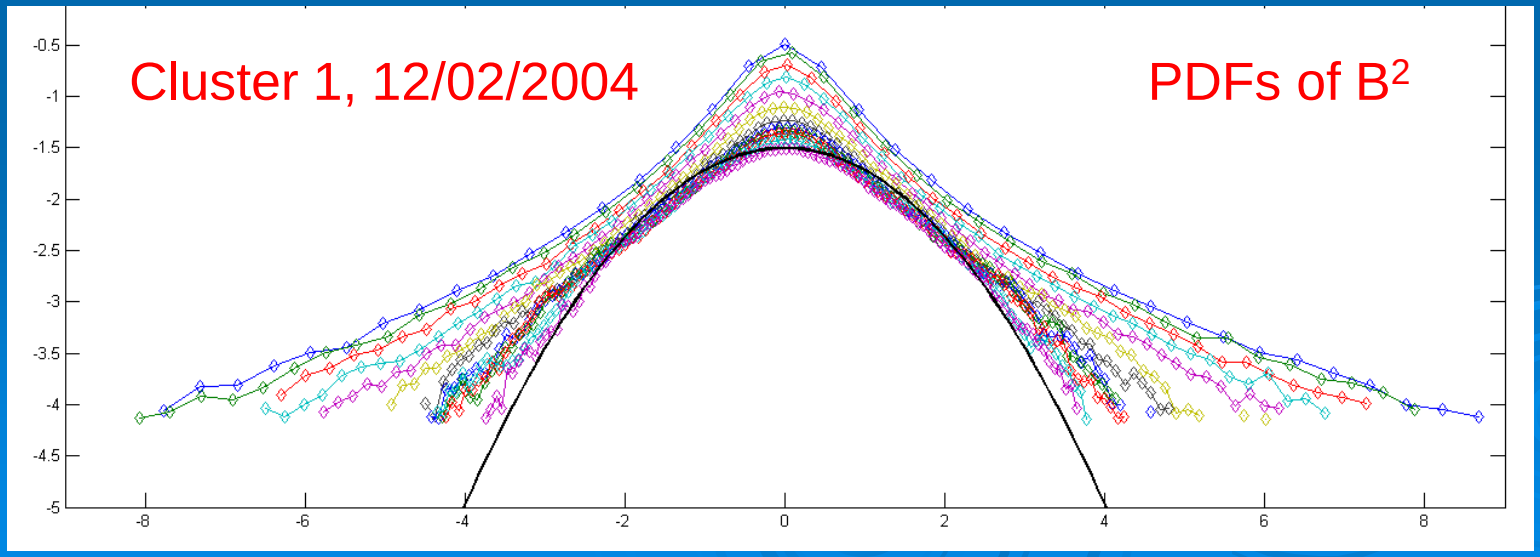


Last two maxima
(2 yrs)



Probability Distribution Functions (PDFs)

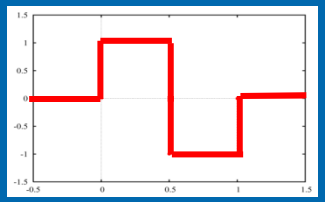




Local Intermittency Measure (LIM)

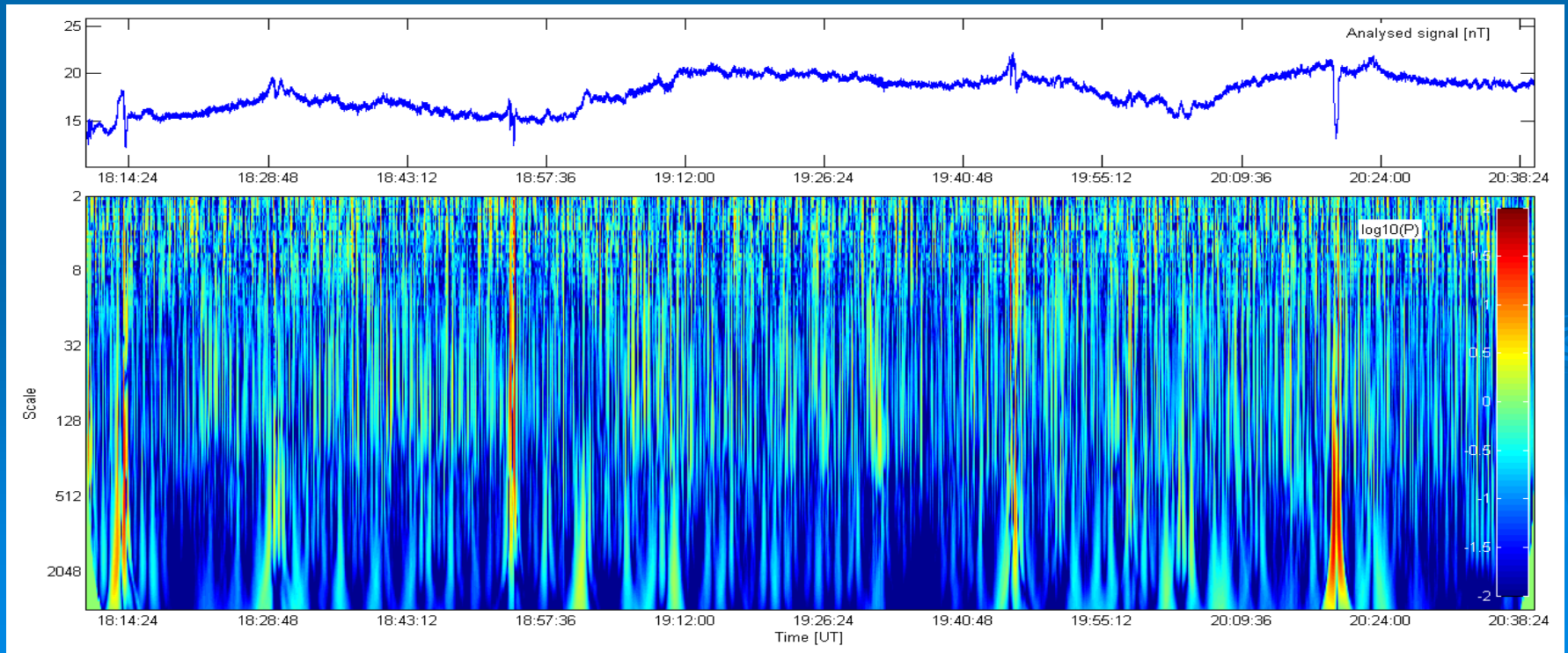
The Local Intermittency Measure (LIM) is defined as a normalized average of wavelet coefficients (Farge, 1991)

$$LIM(\tau, t) = \frac{|C(\tau, t)|^2}{< |C(\tau, t)|^2 >}$$

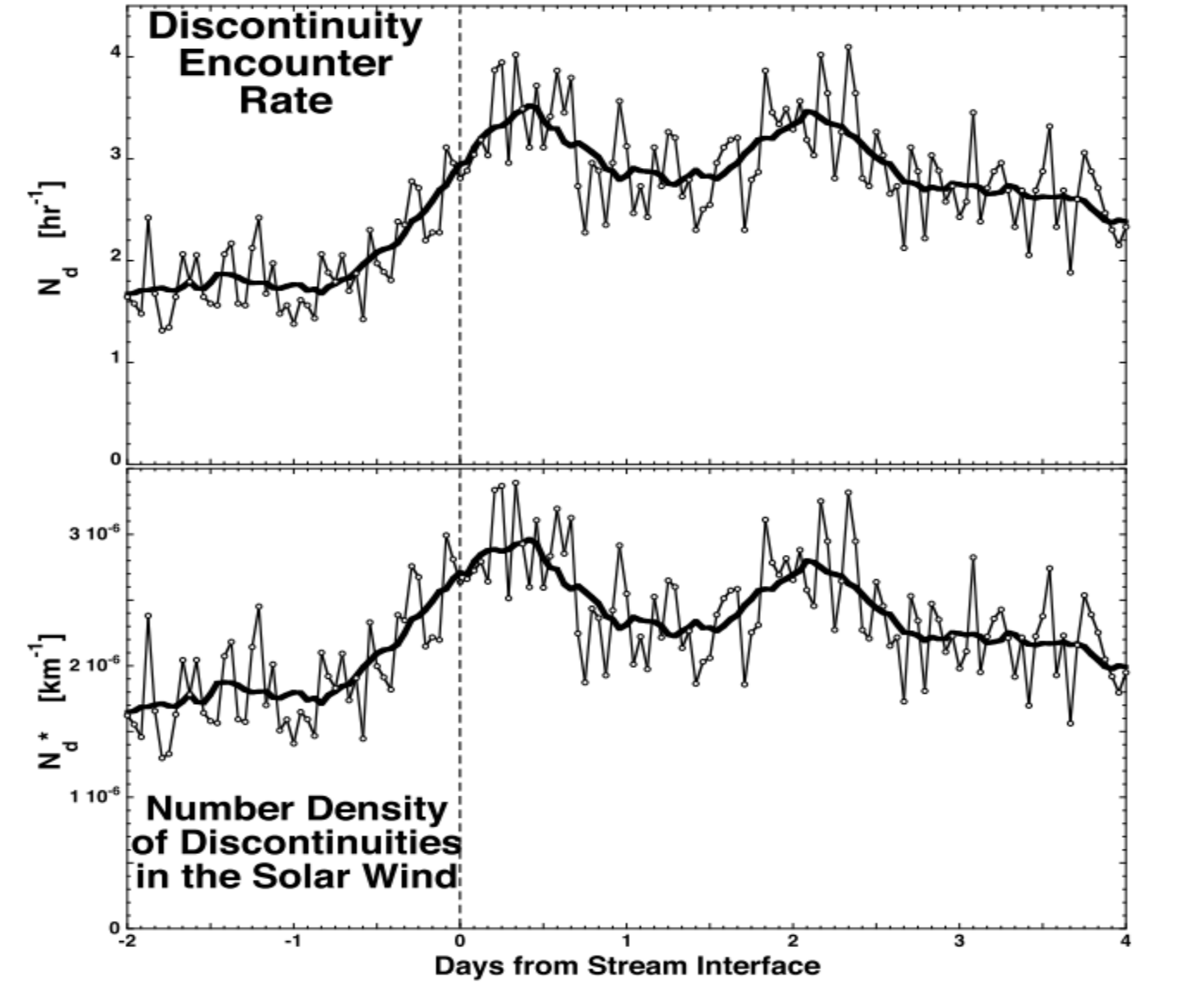


Haar wavelets

LIM of magnetic field fluctuations in the trailing edge of a high speed stream from Cluster; Haar wavelet base



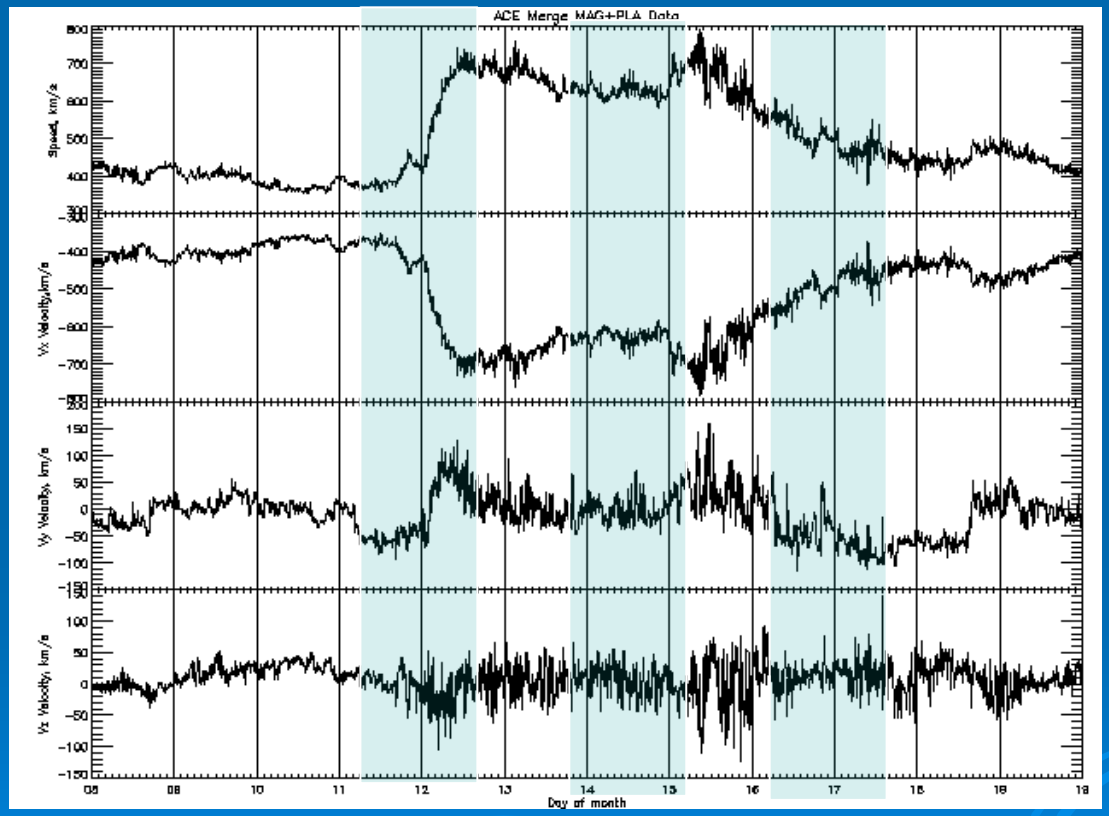
Intermittency and CIR at 1 AU



Borovsky and Denton (2010)

Intermittency and CIR at 1 AU

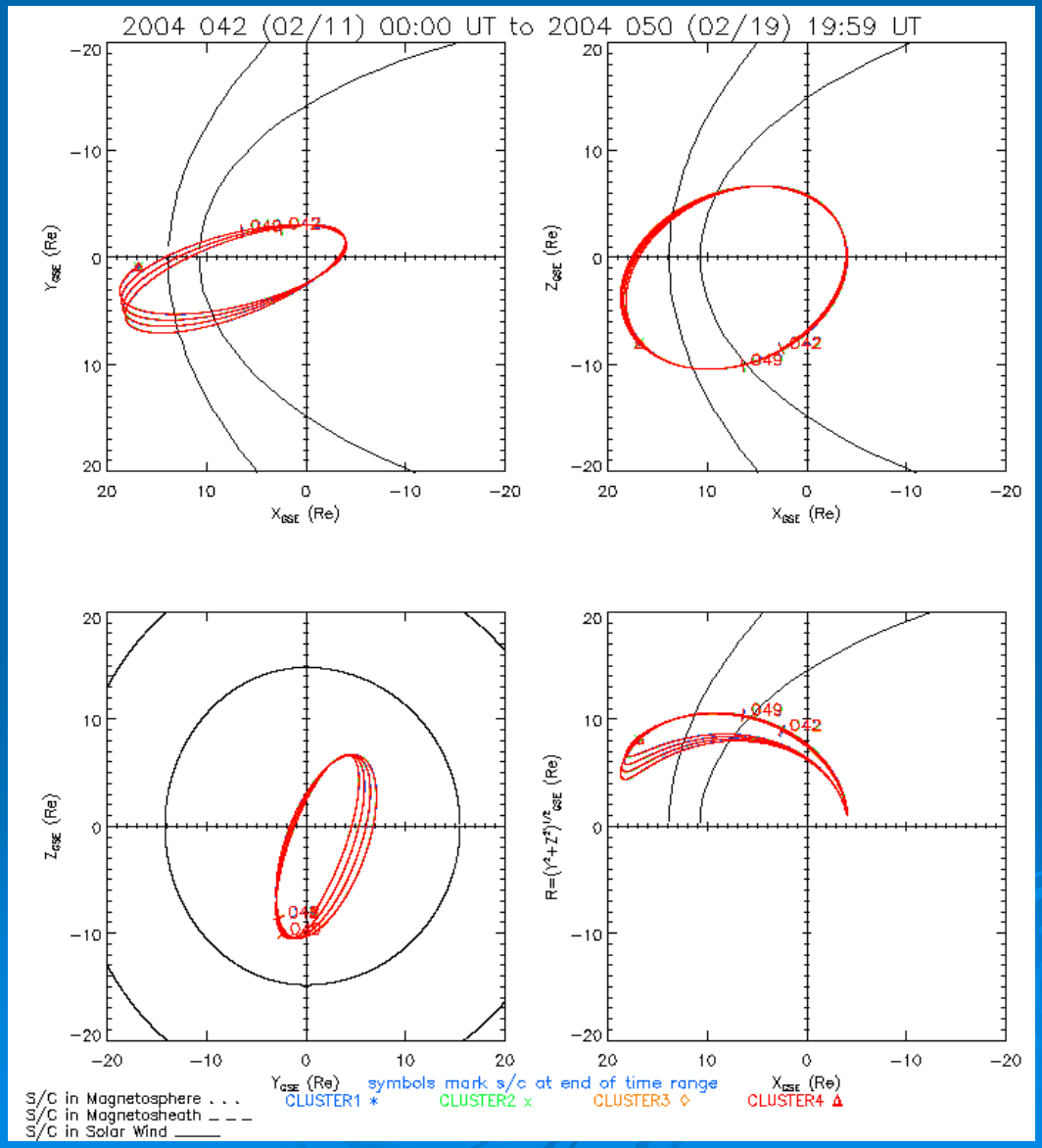
- events selected from the list of Borovsky and Denton (2010)

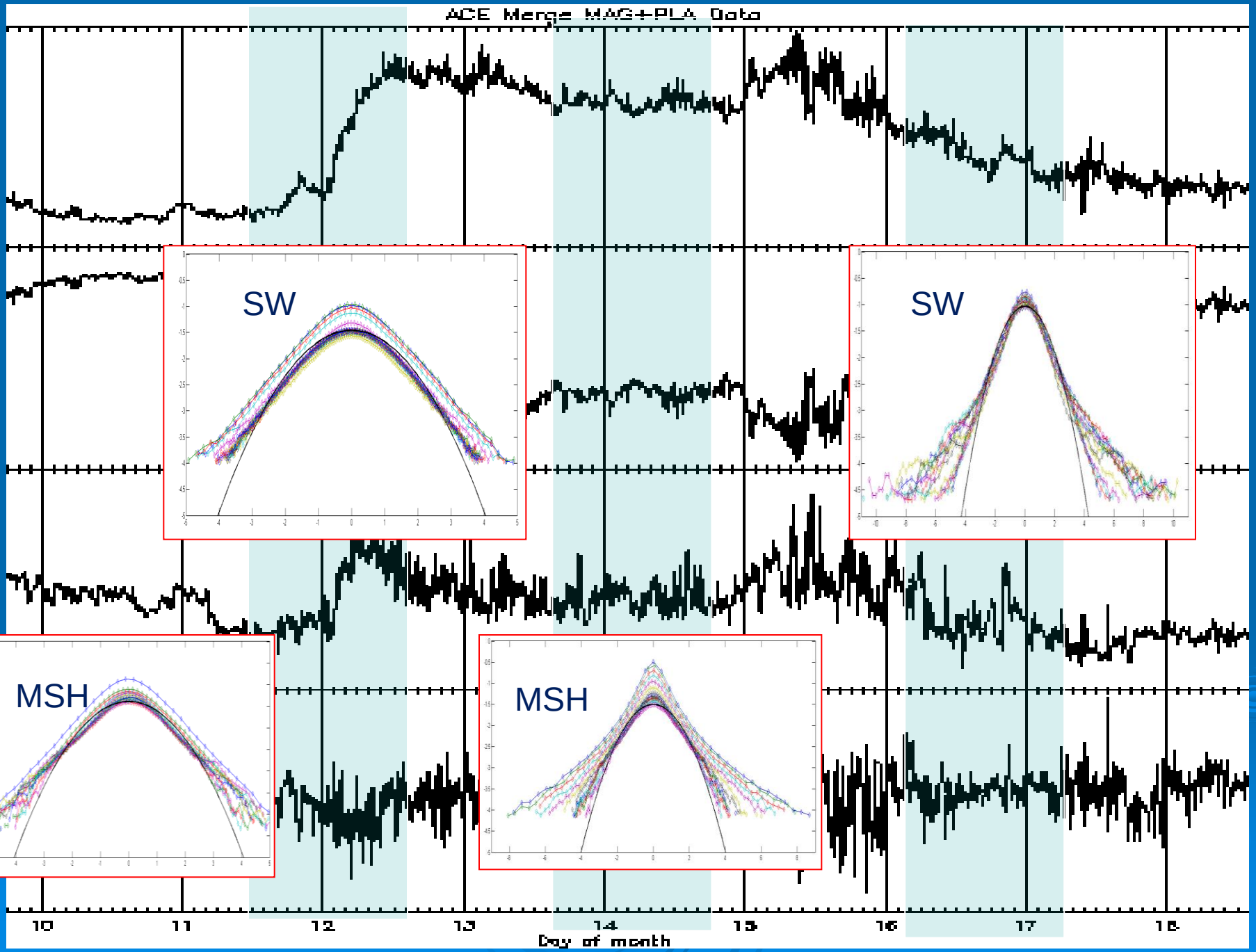


ACE: 12/02/2004

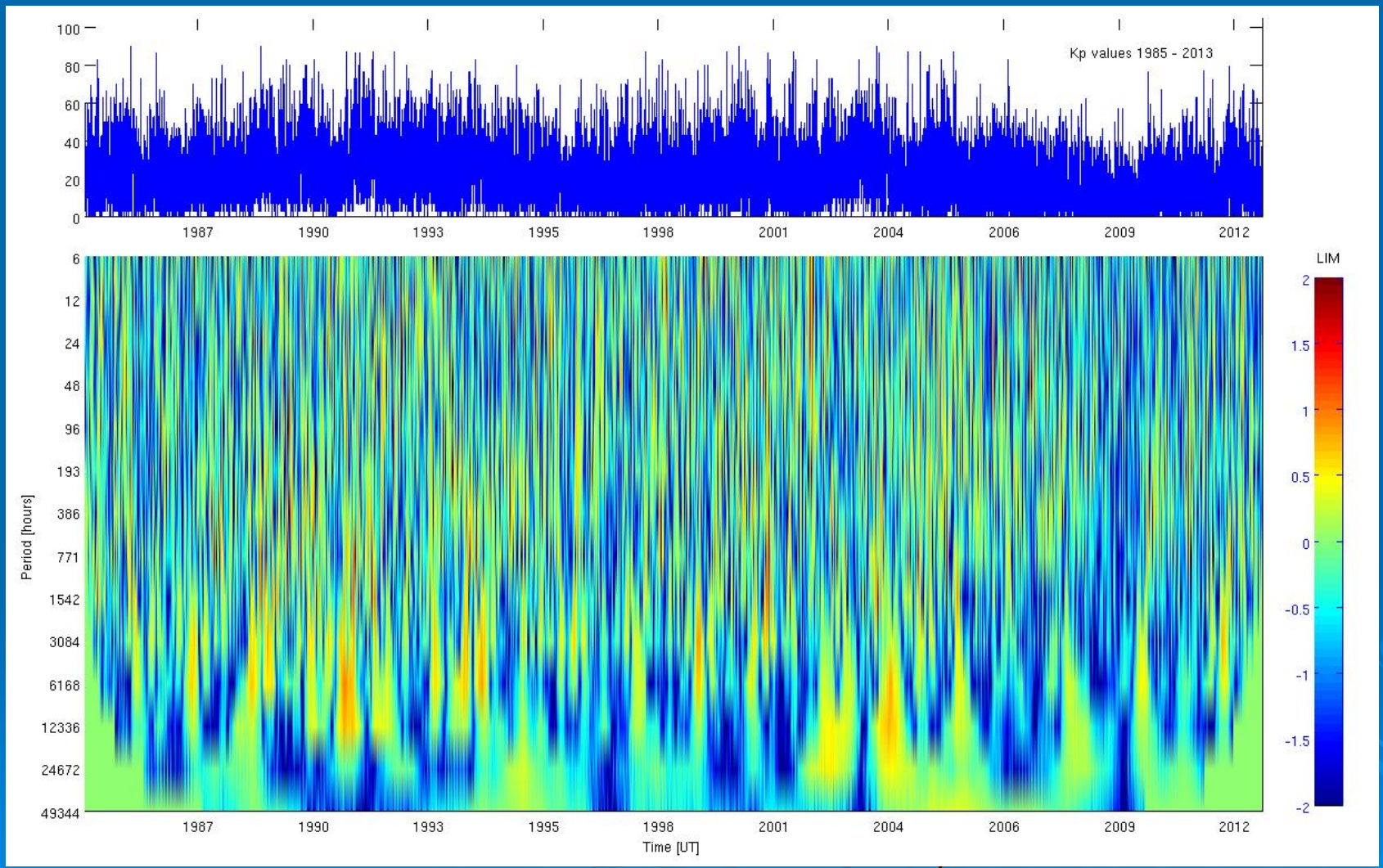
Intermittency and CIR at 1 AU

- Cluster data from the solar wind and the magnetosheath



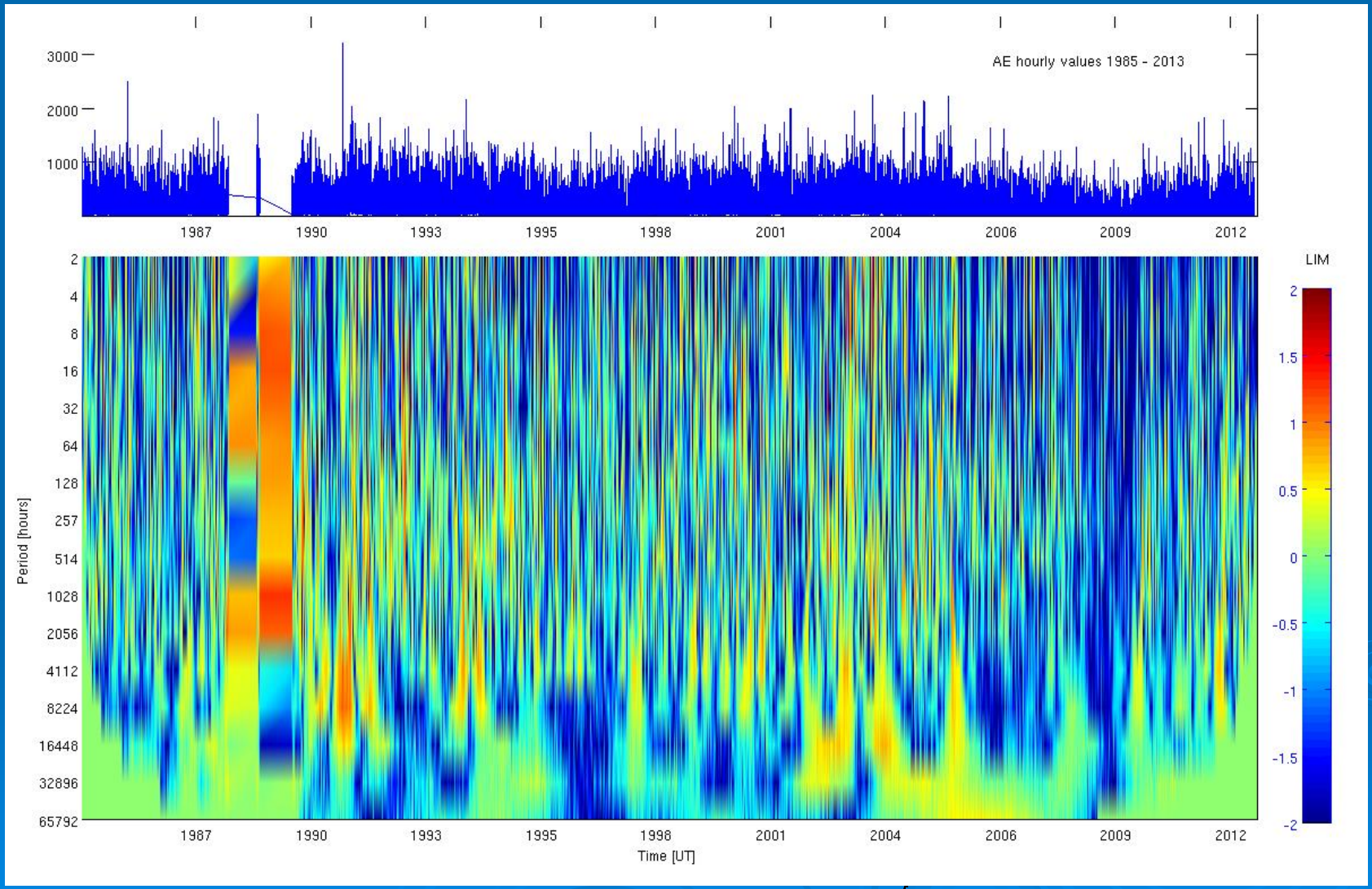

ACE Merge MAG+PLA Data
SW
SW
MSH
MSH
10
11
12
13
14
15
16
17
18
Day of month

Intermittency of geomagnetic indices 1985-2013 - Kp



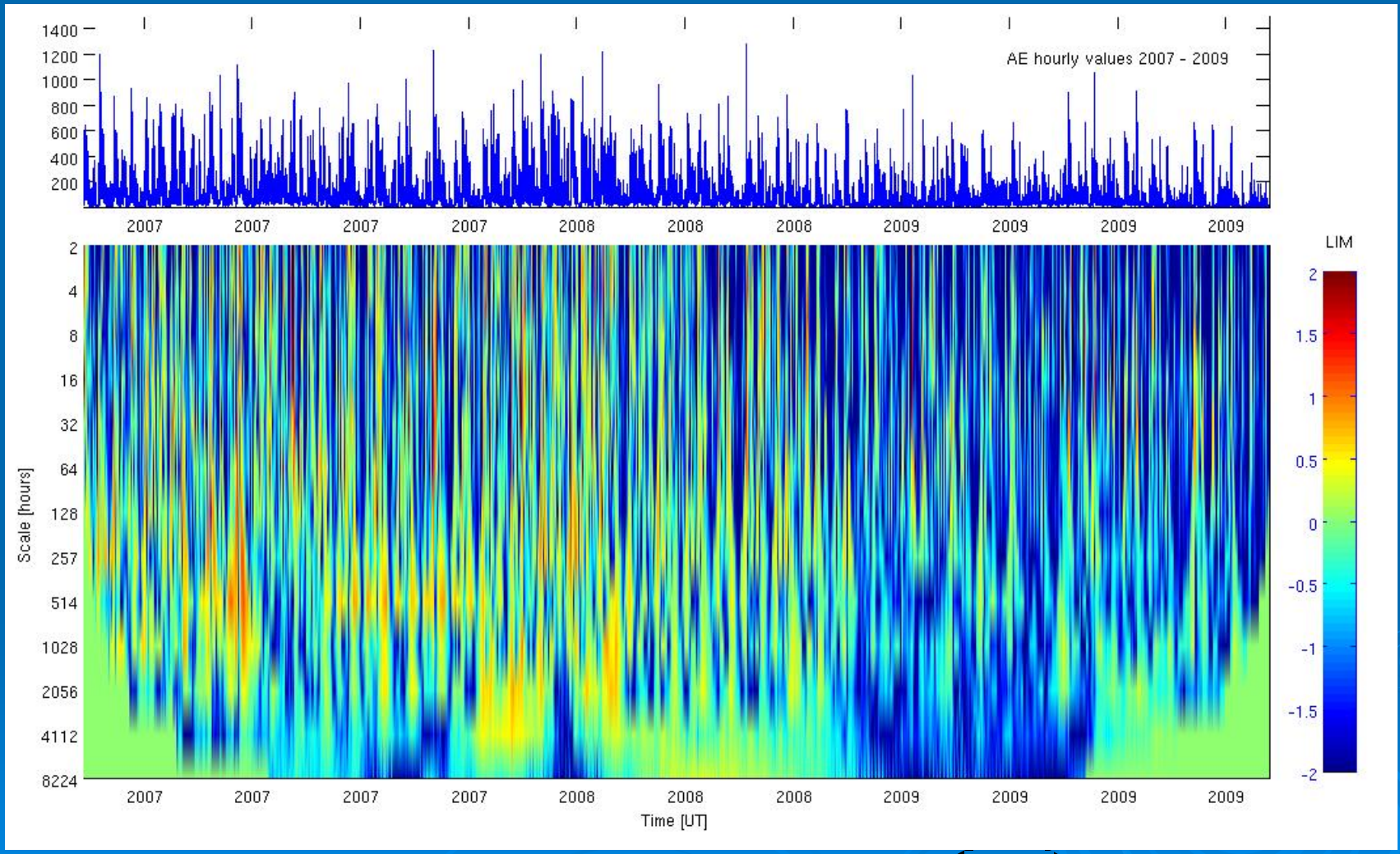
LIM Kp, 1985-2013

Intermittency of geomagnetic indices 1985-2013 - AE



LIM based on Haar wavelets for AE, 1985-2013

Intermittency of geomagnetic indices 2007-2009 - AE



LIM based on Haar wavelets for AE, 2007-2009

Summary

- Statistics of geomagnetic indices suggest existence of power laws whose scaling seems to be the same during the solar cycle; supports the cracling noise type of magnetospheric response to the driving
- sunspot number is too coarse to provide information about possible criticality of the Sun dynamics
- PDFs, LIM characterize qualitatively and quantitatively the solar system intermittency
- Intermittency of the solar wind changes over time periods of days, from weak to strong (sometimes associated to the different sources of the wind), there is a corresponding response of the magnetospheric sheath at the interface with the wind
- Intermittency of the geomagnetic response changes significantly over the last two cycles; the low occurrence rate of extreme events and the reducing of the scale sizes suggest that the magnetosphere approached a noncritical state during the last minimum