Development of a statistical dynamic radiation belt model: analysis of storm time particle flux variations

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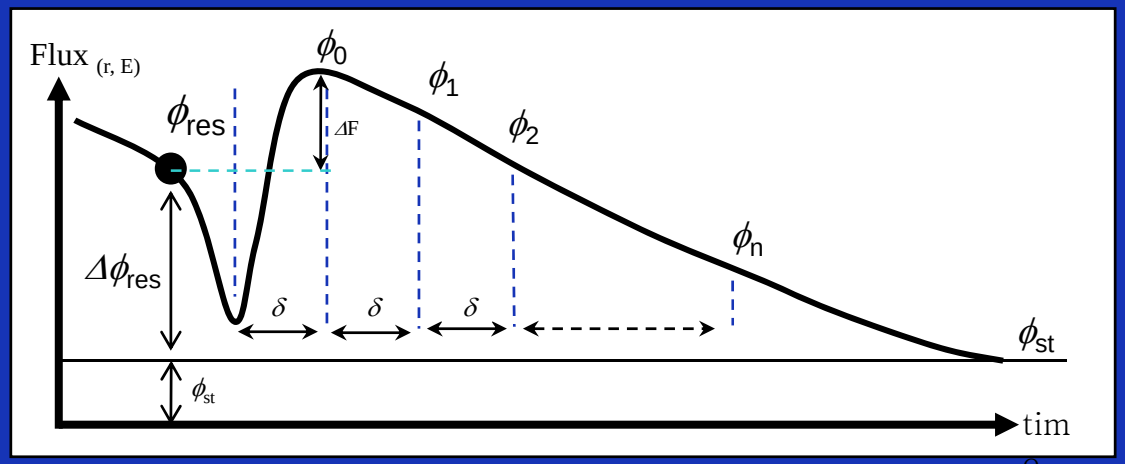
- Introduction
- The Model
- Data and derived parameters
- Preliminary results
- Summary

Quiet time data (2004) may help developing static particle flux models (lower limit) with low variances

- Geomagnetic storm (GS) prediction (Dst<-50 nT) - Occurrence probability
- Flux variation associated to GS
- Flux decay time at any position in space

Model of the dynamics of radiation belt particles



$$\phi_0 = \phi_{st} + \Delta\phi_{res} + \Delta F_{(DST\_prev)}$$

$$\phi_1 = \phi_{st} + (\phi_0 - \phi_{st})e^{-\delta/T} + \Delta\phi_1$$

$$\phi_2 = \phi_{st} + (\phi_1 - \phi_{st})e^{-\delta/T} + \Delta\phi_2$$

$$\vdots$$

$$\phi_n = \phi_{st} + (\phi_{n-1} - \phi_{st})e^{-\delta/T} + \Delta\phi_n$$

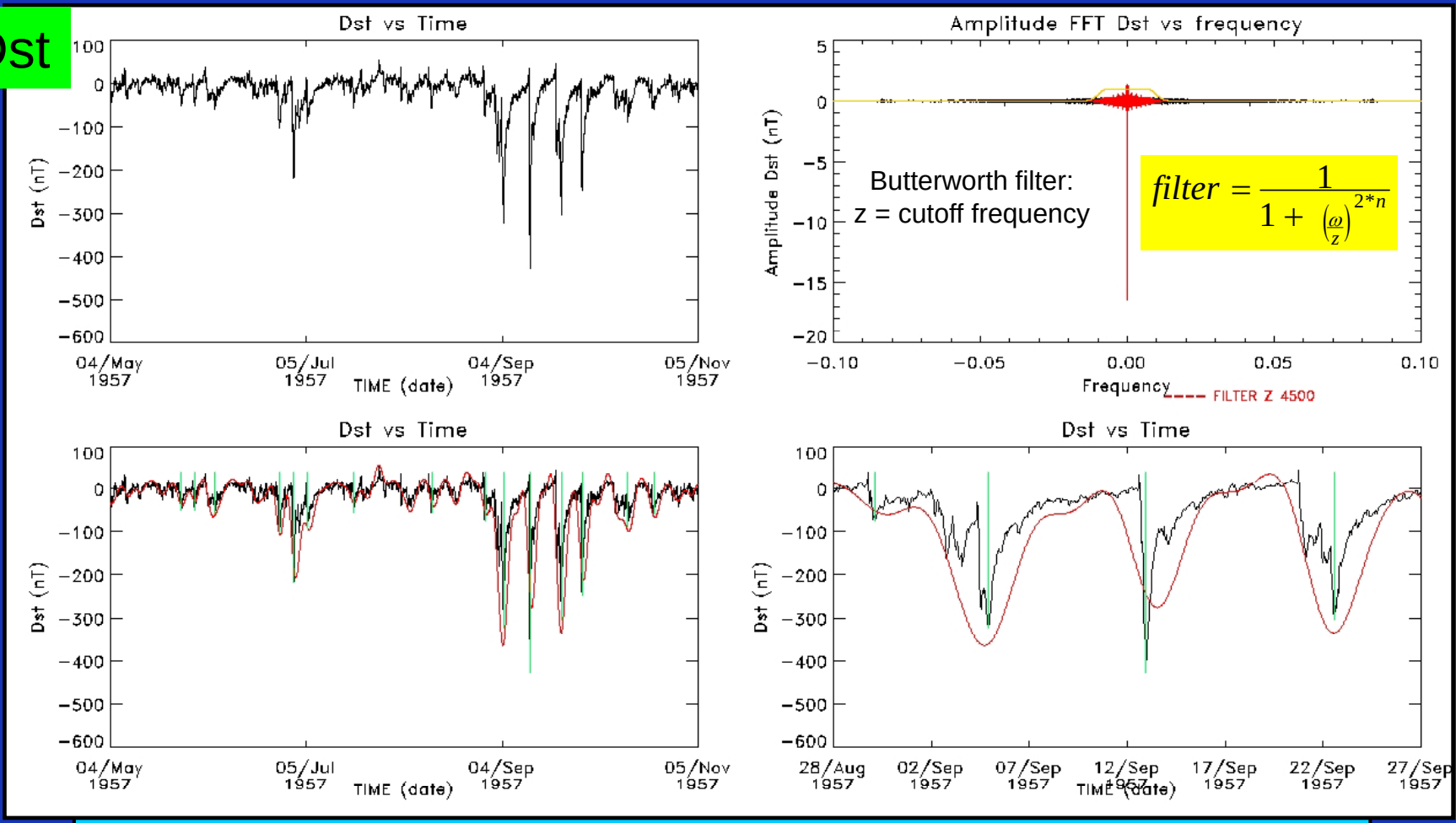
$$\Delta\phi_n = \sum_{k=0}^{N} P_{(Dst_k \mid n\delta, Dst_{prev}, type, s)} \times (\Delta F_{(Dst_k)})$$

$\Delta\phi_n$ = The flux variation following a storm (average)
N = Number of bins in Dst range
Type = Type of storm: CME, CIR, Mix
S = Solar parameter that indicates phase (min, increasing, max, decline) within solar cycle

ϕ_{st} = Steady state flux measured (2004)
$\Delta\phi_{res}$ = Difference between flux before storm and steady state flux
$\Delta F_{(Dst\_prev)}$ = Flux variation induced by previous storm of min Dst_{prev}
Dst_{prev} = The minimum value reached by Dst in the previous storms
T – Decay time of flux at a given space position for a given energy
δ= Time elapsed from the storm min. Dst_prev (or drop-out min) to ϕ_0

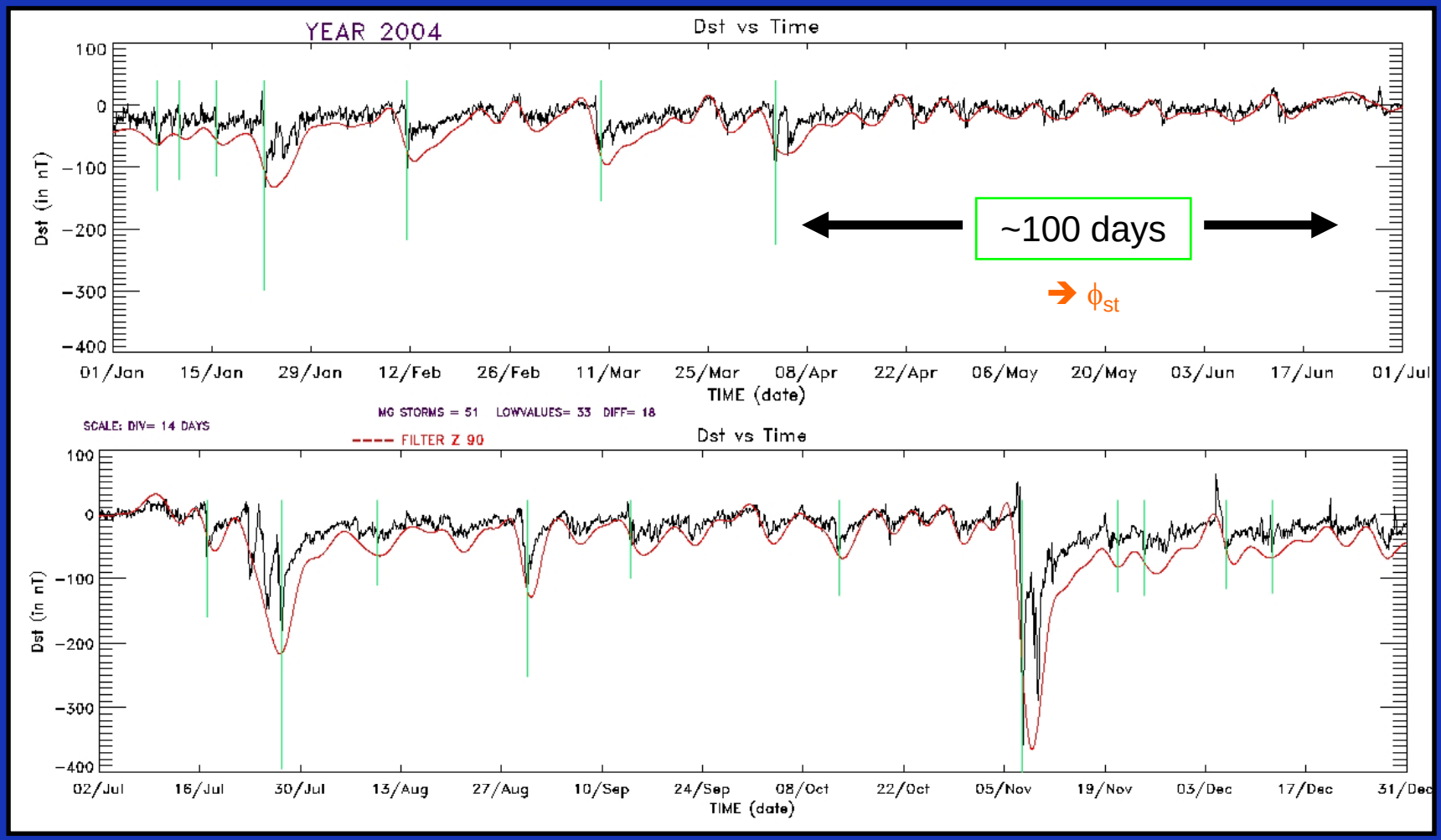
$$\sigma_{(\Delta\phi_n)} = \sqrt{\sum_{k=0}^{N_{act}} P_{(Dst_k \mid n\delta, Dst_{prev}, s, type)} \times (\Delta F_{(Dst_k)} - \overline{\Delta F}_{(Dst)})^2}$$

➢ Dst

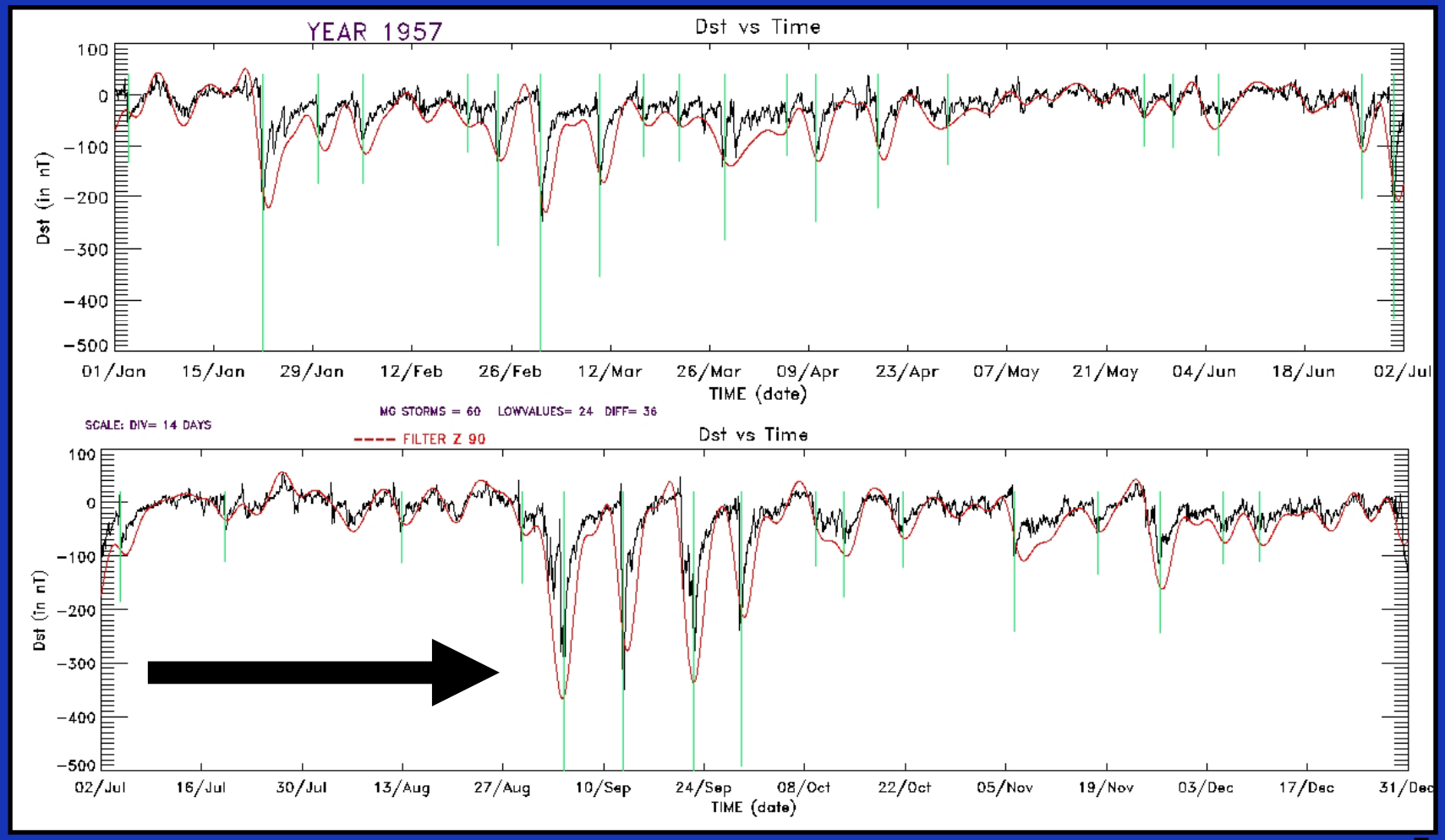


Dst data (black) with filtered data (red): The second graph shows the filter detail, and the fourth shows a closed up of the event, with actual amplitude of the storm in green.

(Dst Data: Courtesy of *World Data Center for Geomagnetism, Kyoto*)



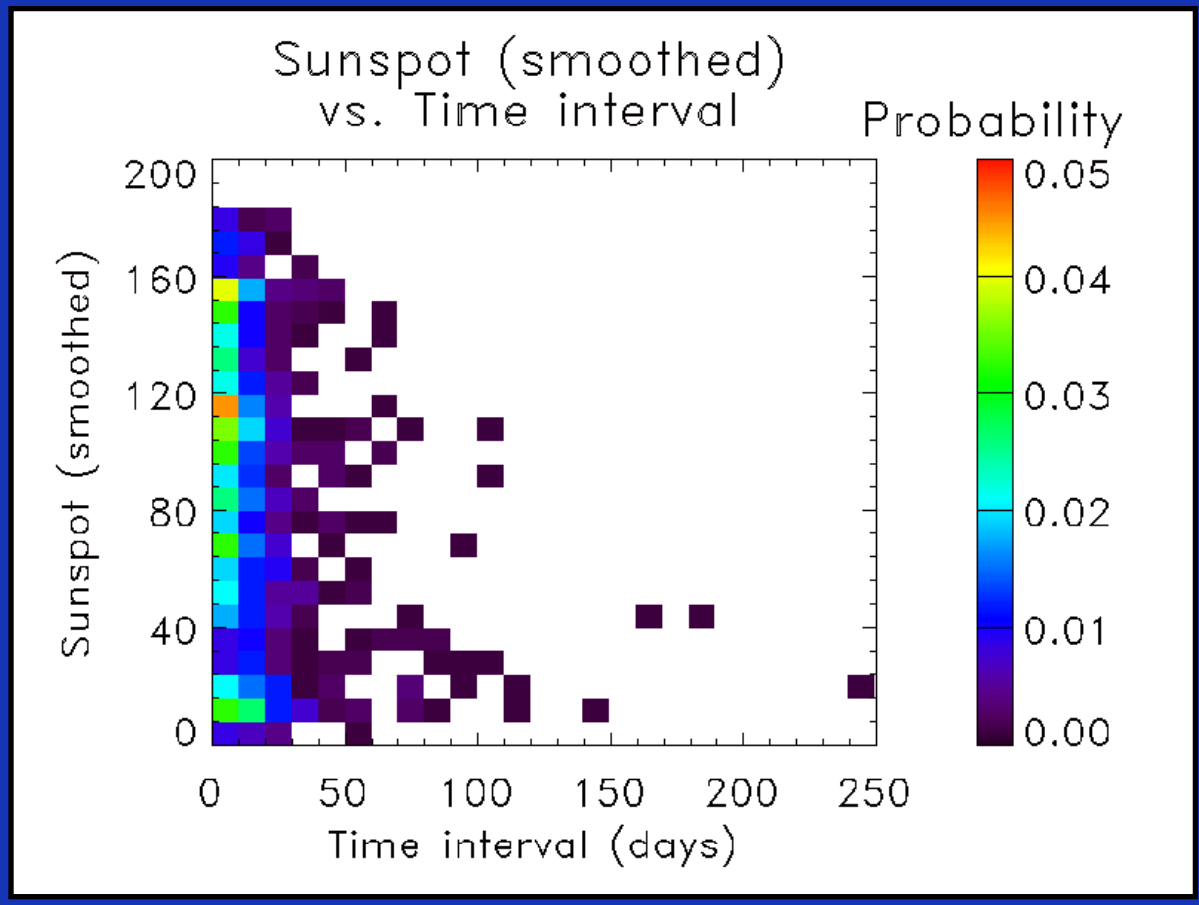
Dst data (black) with filtered data (red) with time of occurrence of the storm in green.



Dst data (black) with filtered data (red) with time of occurrence of the storm in green.

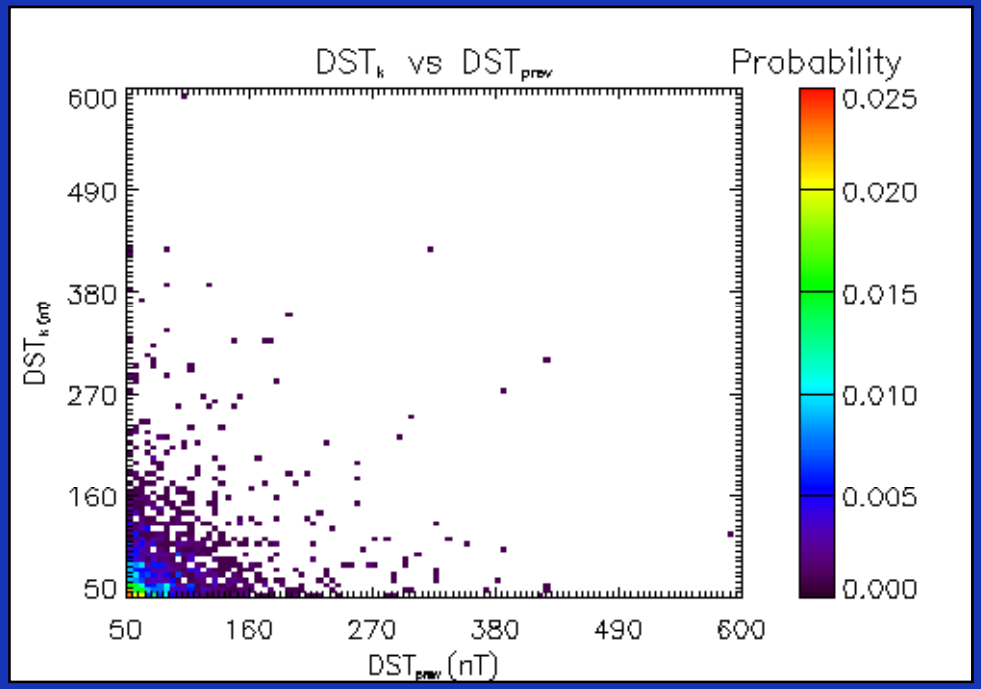
Time interval between storms (τ)

- **Distribution of time interval between storms for <u>all storms in the last 50 years</u> seems to be Poisson-distributed.**



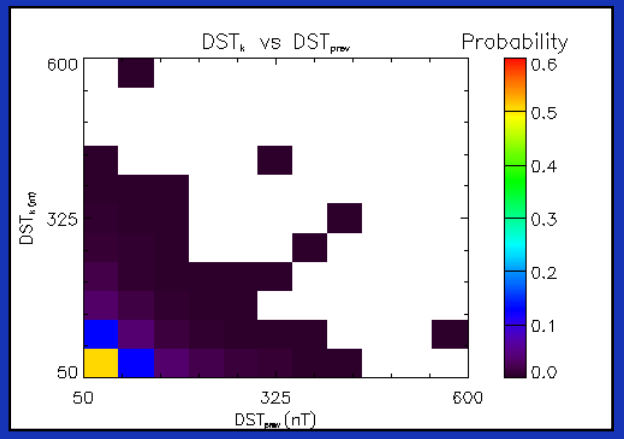
Histogram of smoothed Sunspot number vs. Time interval between storms. (Bin size= 10 days; number of bins = 25)

All Dst_{min} given in absolute value

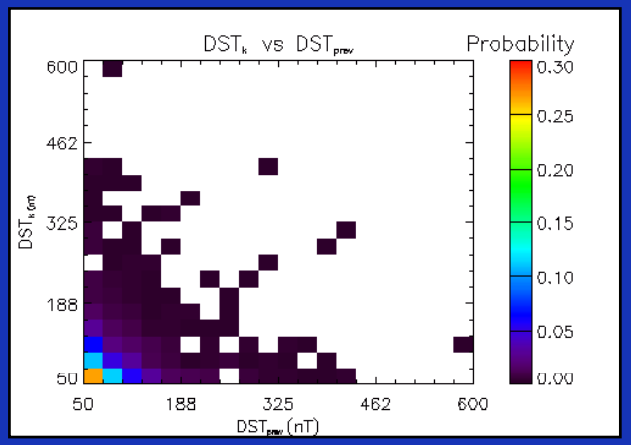


Histogram of Dst_k vs. Dst_{prev}, number of bins = 100

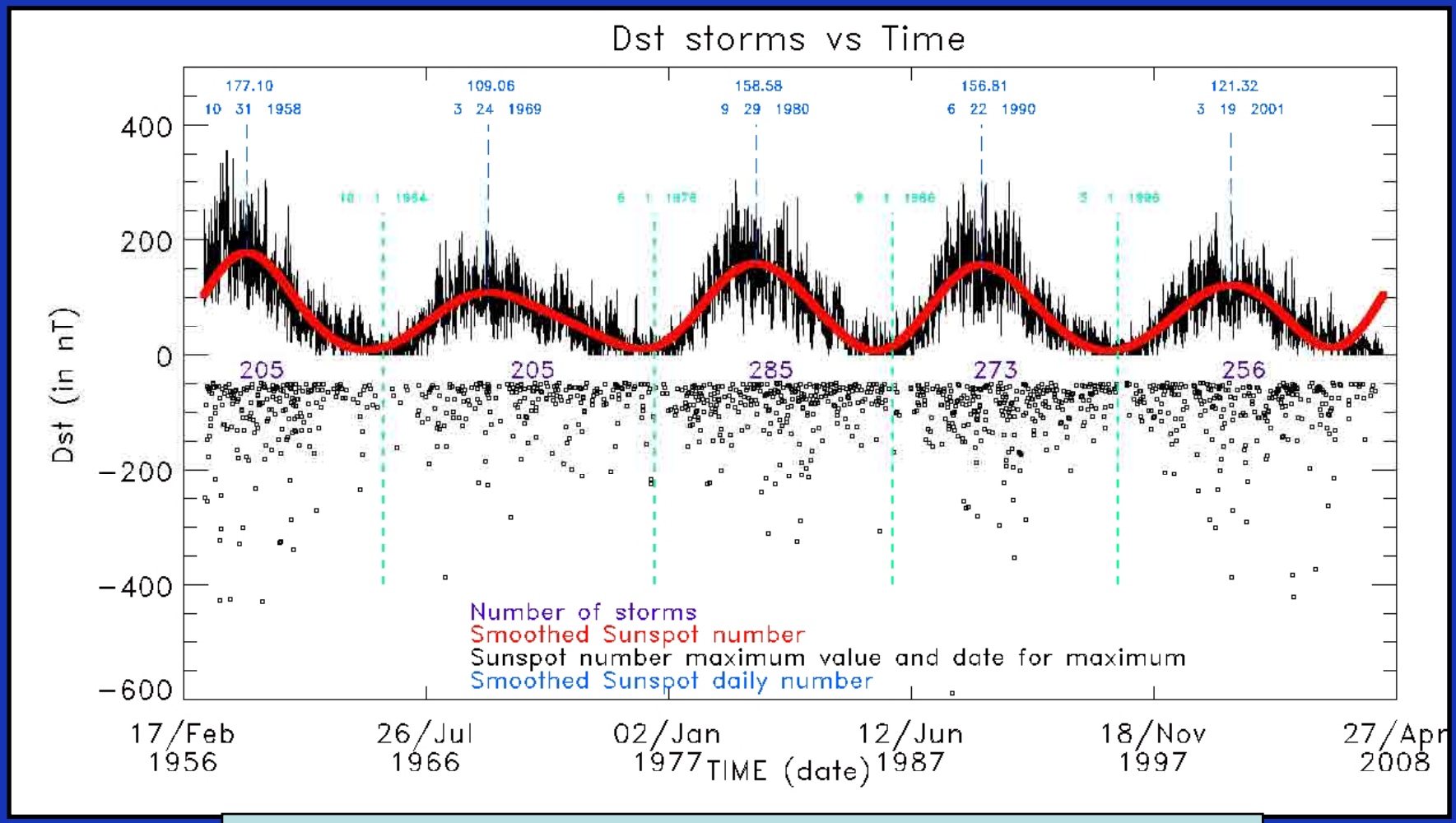
➢**Bin number does not affect distribution.**



Histogram of Dst_k vs. Dst_{prev}, number of bins = 11.

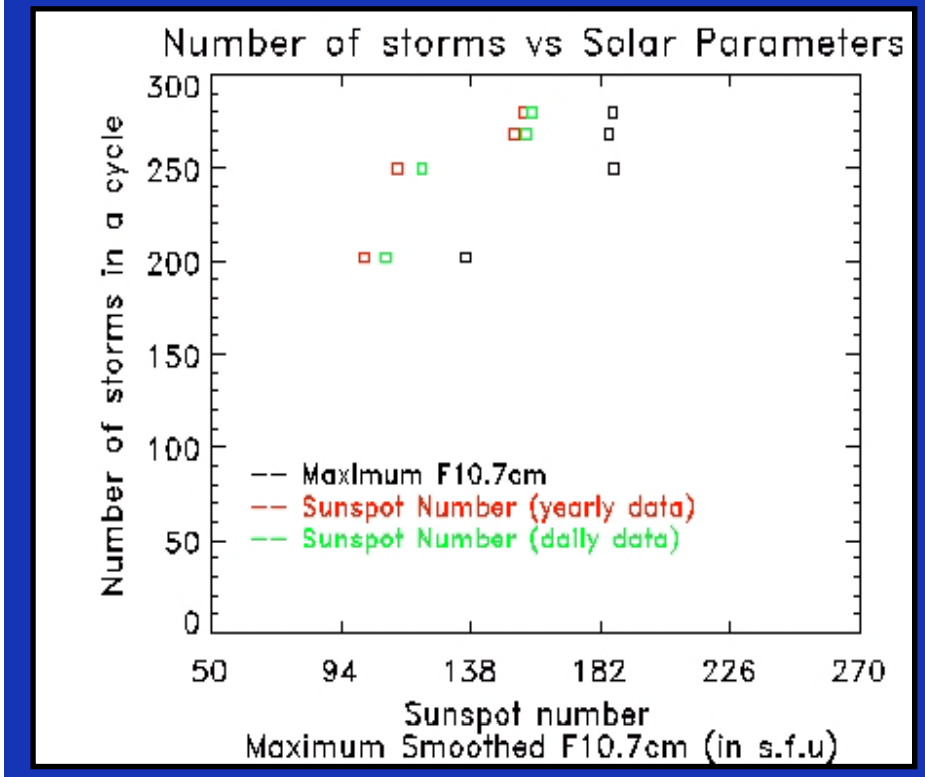


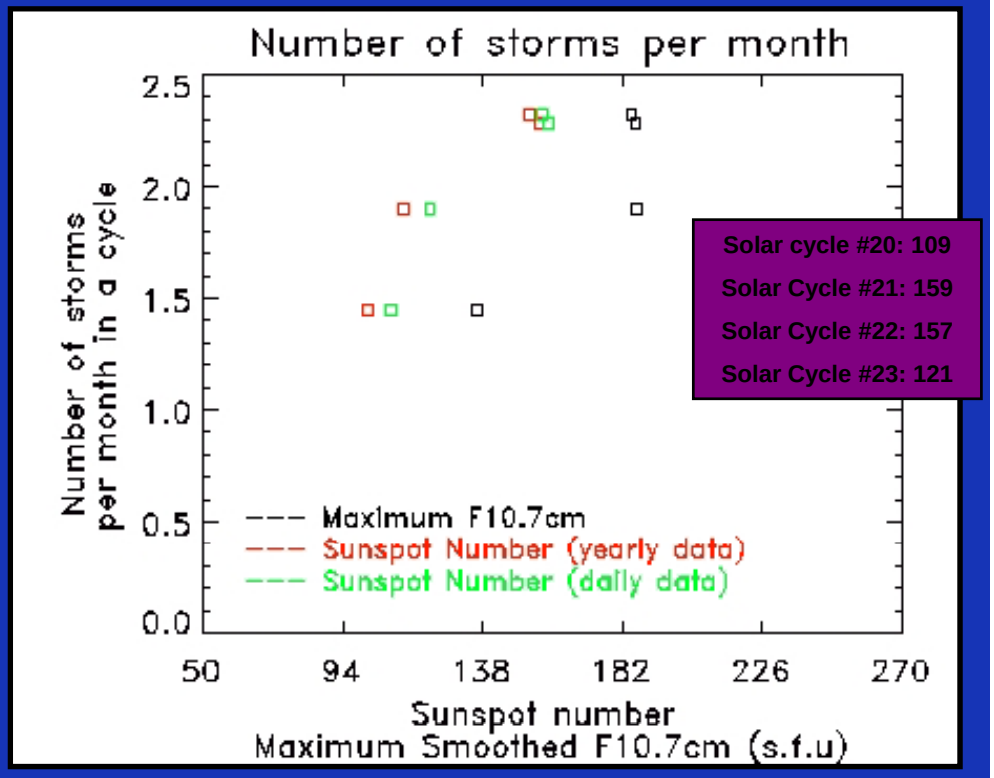
Histogram of Dst_k vs. Dst_{prev}, number of bins = 20



Distribution of Storms vs. Time: Analysis Sunspot number

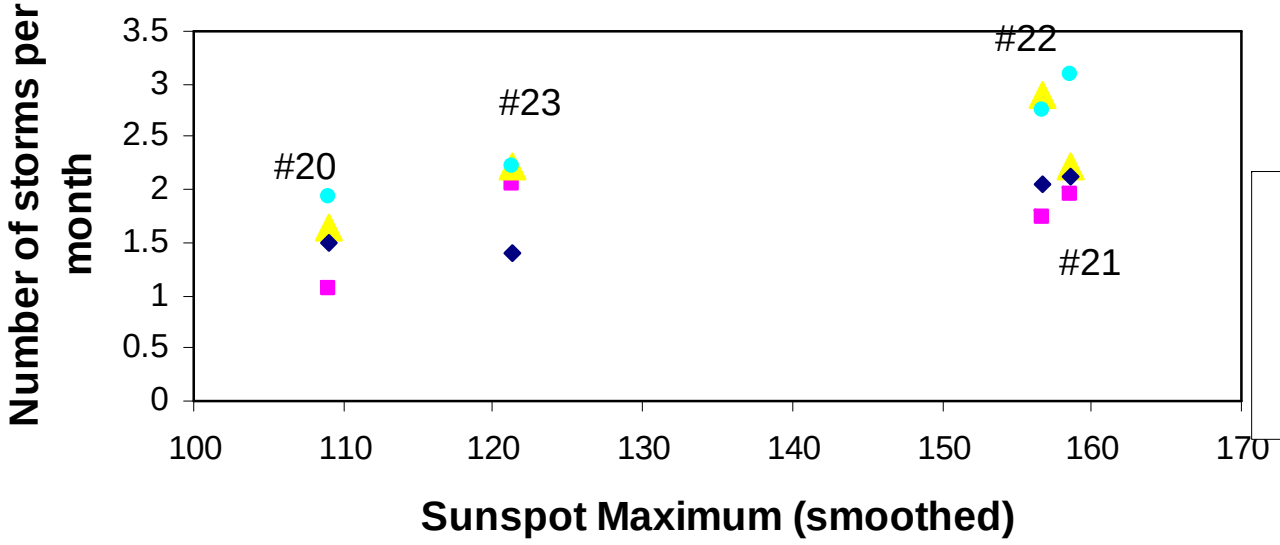
(Sunspot Number Data: Courtesy of *Solar Influences Data Analysis Center – SIDC, Belgium*)

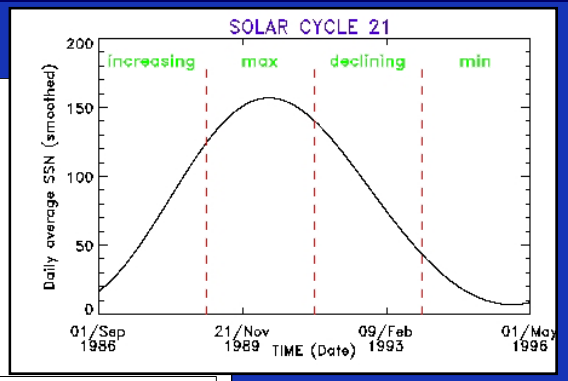




➢**Sunspot number is a good parameter to represent solar cycle activity vs. total number of storms.**

Number of storms (per month) vs Sunspot number Maxima





Sunspot Number Maxima

(smoothed)

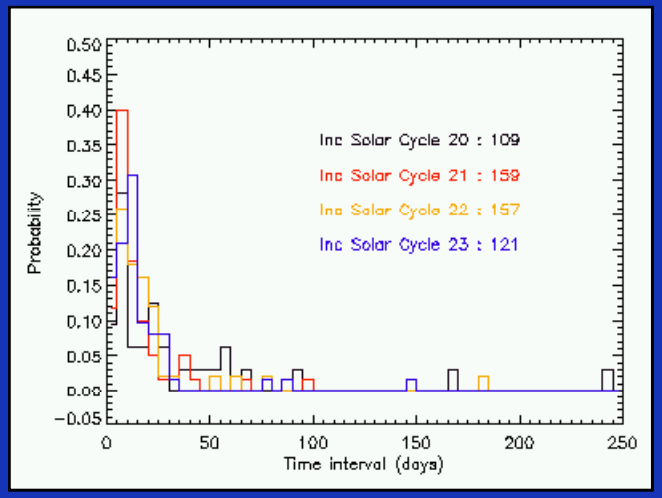
Solar cycle #20: 109

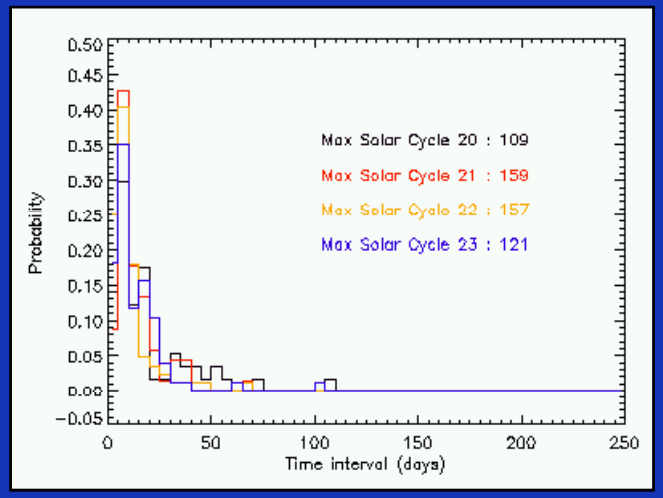
Solar Cycle #21: 159

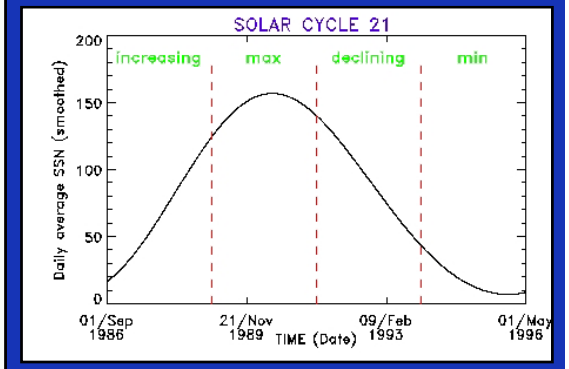
Solar Cycle #22: 157

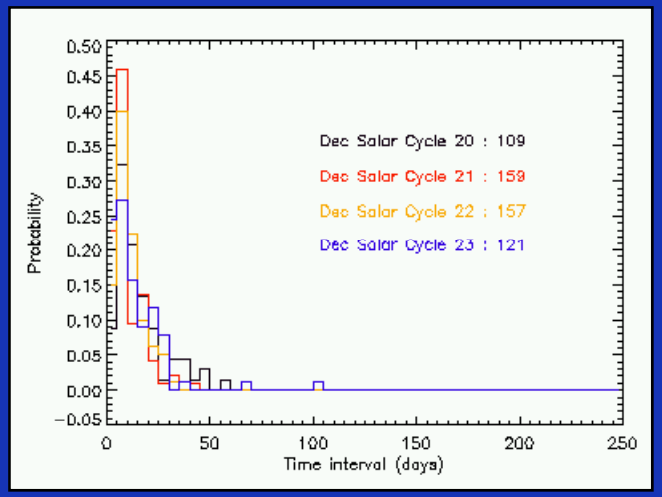
Solar Cycle #23: 121

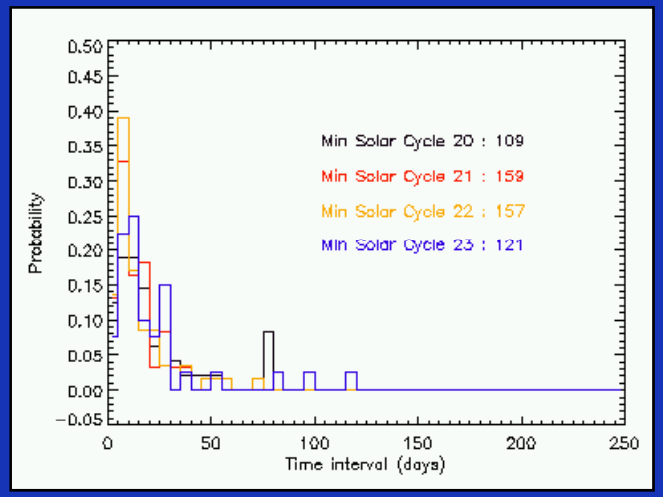
- **Number of storms (normalized per month) for different phases in solar cycle: linear correlation between number of storms per month for different phases in a solar cycle with the Sunspot Maximum corresponding to that cycle.**

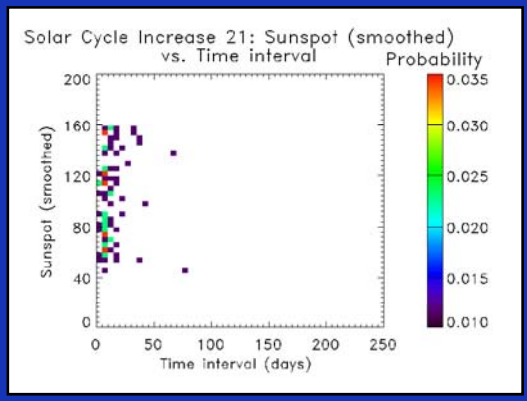












- **Difference of time interval distribution function depending on phase and severity of solar cycle activity**

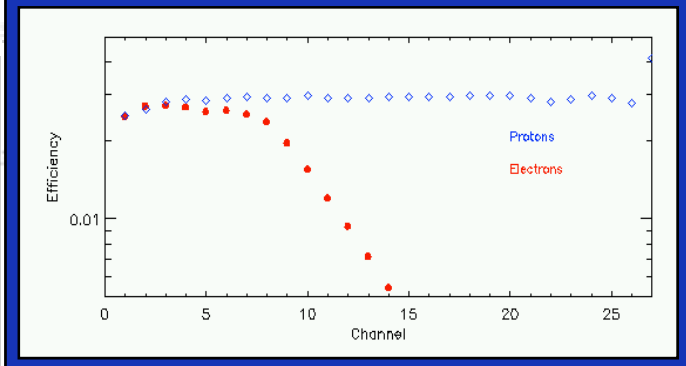
➢ Fluxes

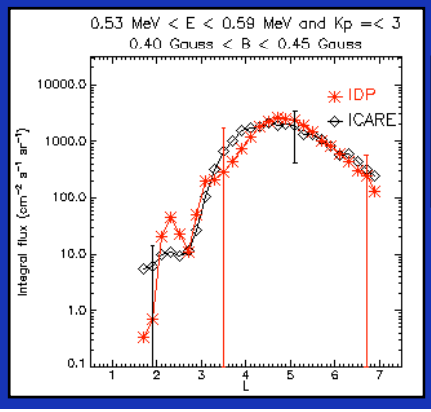
Silicon detector r = 2 cm and d =1mm
Maximum E deposition: 2.4 MeV
ε_{max}~3%
$GF_{max} \sim \pi\varepsilon_{max} A = 1.2$ cm^2 sr
Orbit at 710 km 98.23 deg. Incl.
Efficiency to detect electrons is negligible for channel numbers > 14

DEMETER

ELECTRONS:

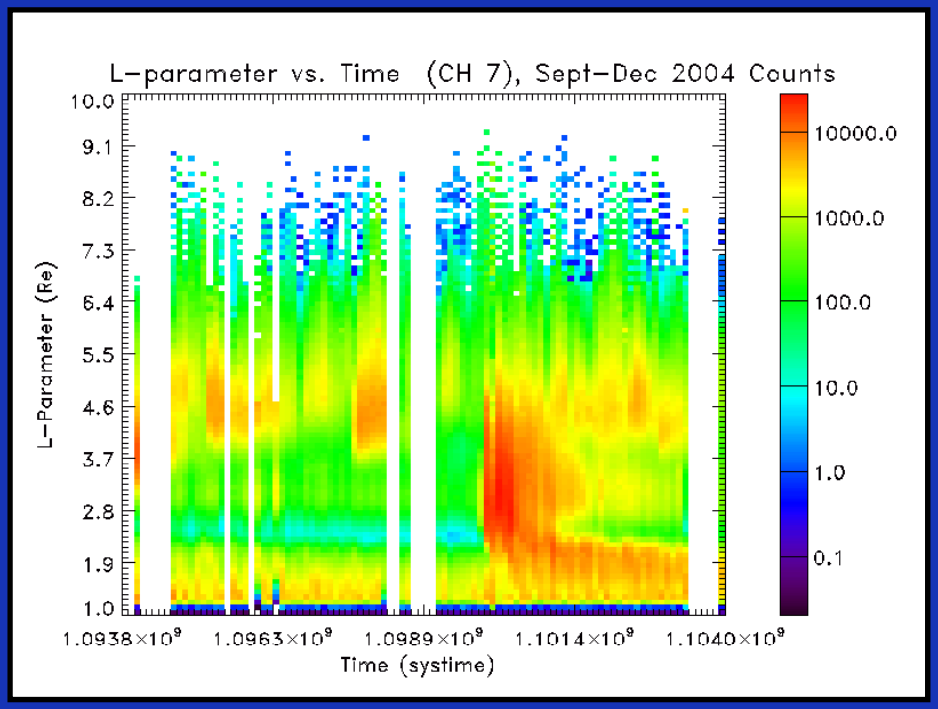
Channel	Lower limit (MeV)	Upper limit (MeV)	Channel width (MeV)	Centroid (MeV)
1	0.0770	0.168	0.091	0.1225
2	0.162	0.256	0.094	0.209
3	0.252	0.344	0.092	0.298
4	0.342	0.434	0.092	0.388
5	0.432	0.524	0.092	0.478
6	0.521	0.614	0.093	0.5675
7	0.607	0.702	0.095	0.6545
8	0.697	0.789	0.092	0.743
9	0.787	0.879	0.092	0.833
10	0.877	0.968	0.091	0.9225
11	0.968	1.057	0.089	1.0125
12	1.056	1.153	0.097	1.1045
13	1.159	1.230	0.071	1.1945
14	1.243	1.299	0.056	1.271

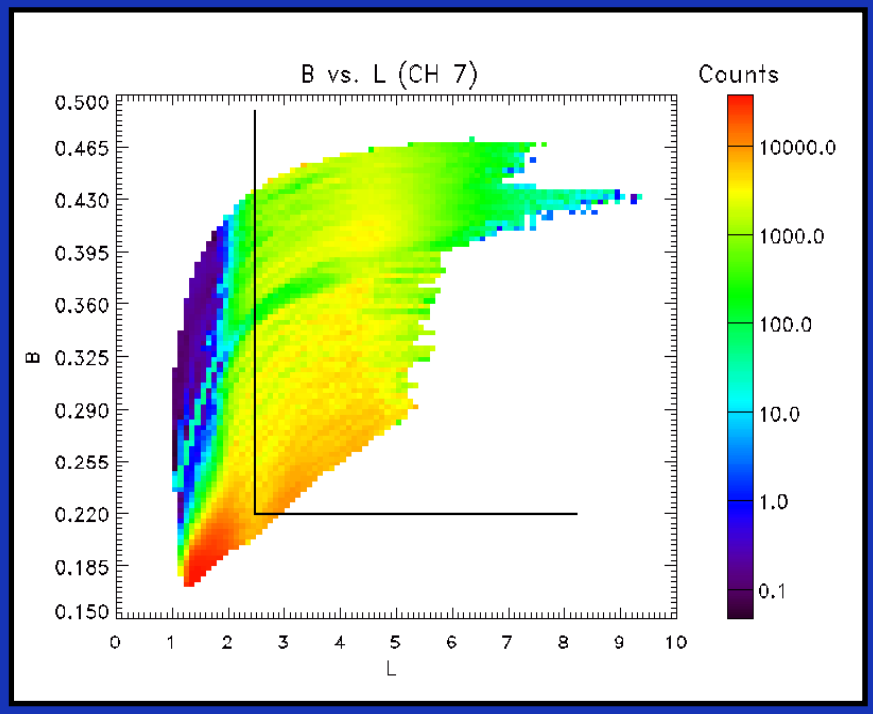




Cross-validation of IDP (DEMETER) with ICARE (SAC-C)

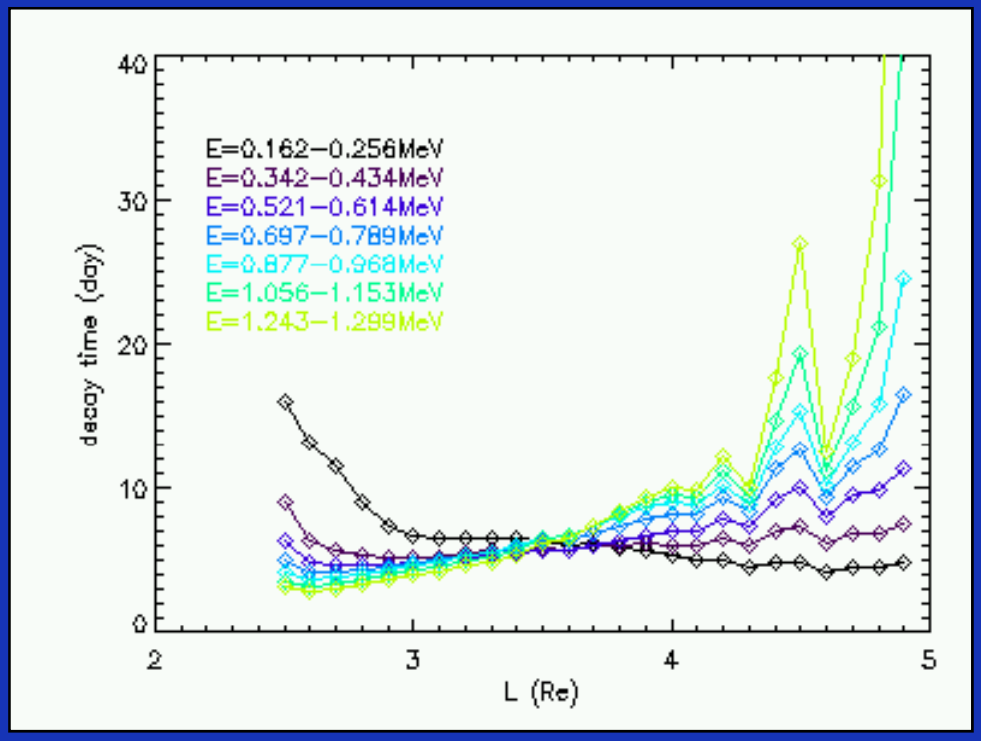
Channel 7: 0.607-0.702 MeV



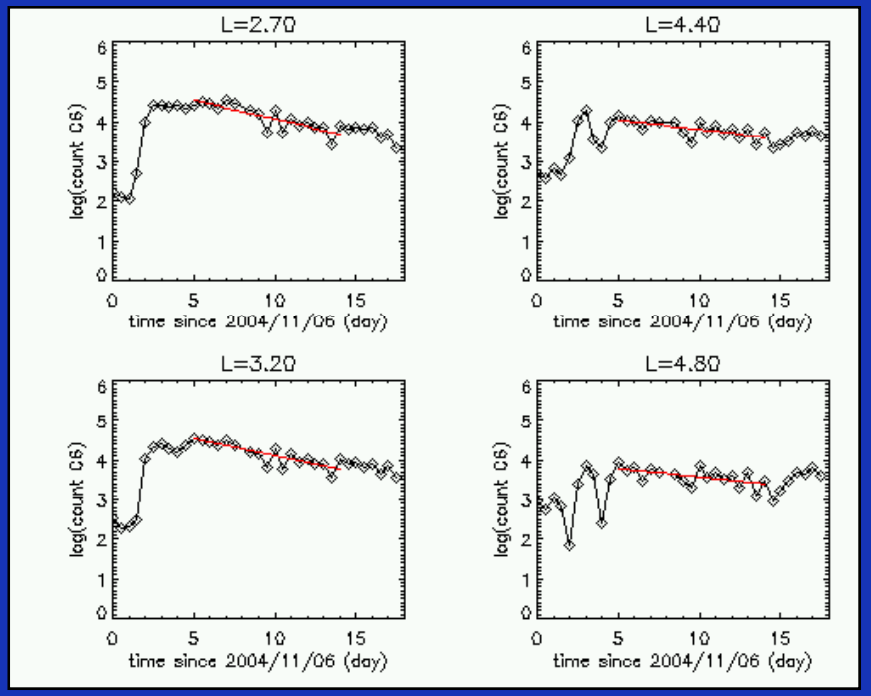


- *L>2.5, B>0.22*

Decay time of electron fluxes (T)



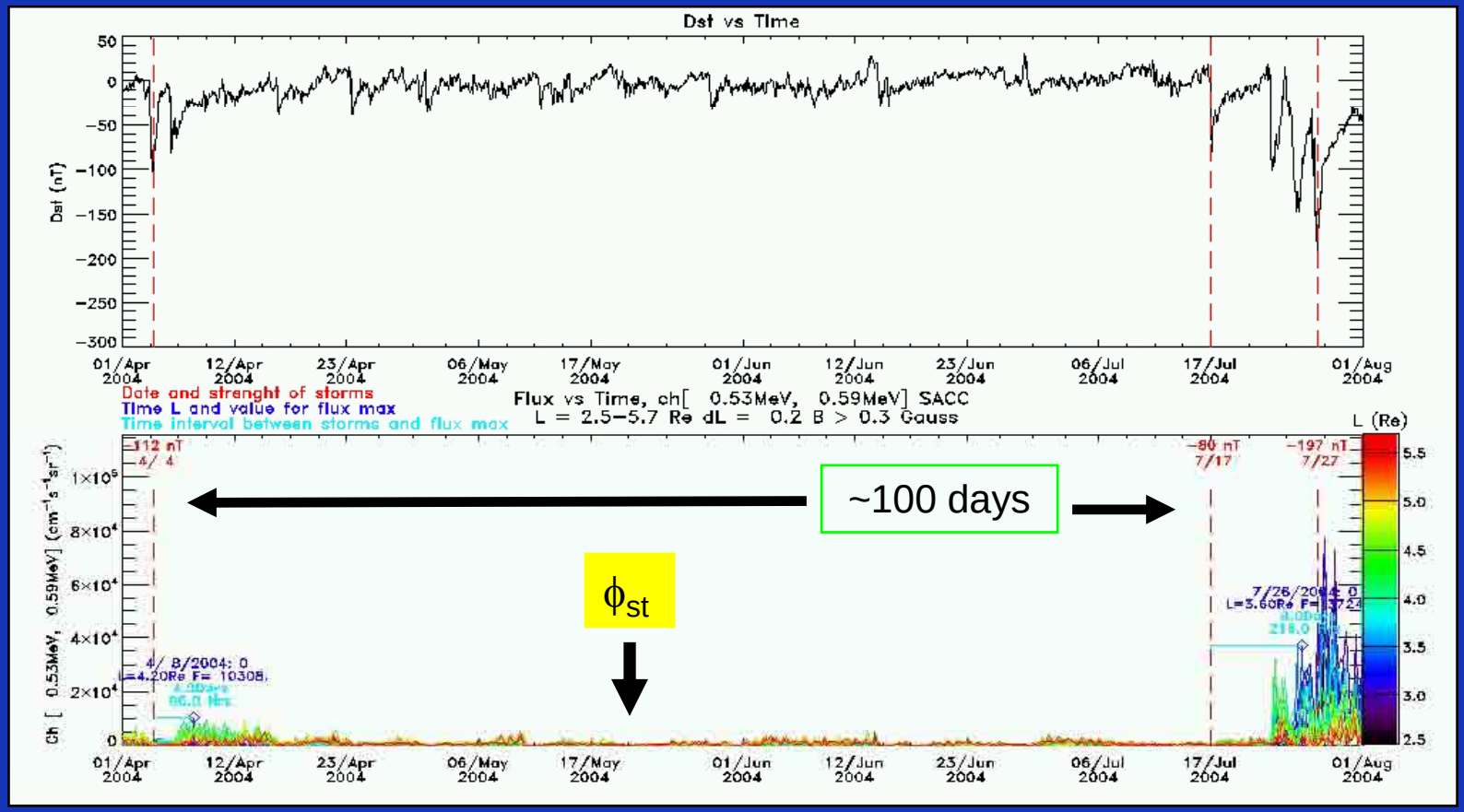
The decay time (after stormtime) of low energy electrons is higher at low L, and is lower for high energy electrons at this L values.



This parameter may be used to validate models of RB electrons dynamics.

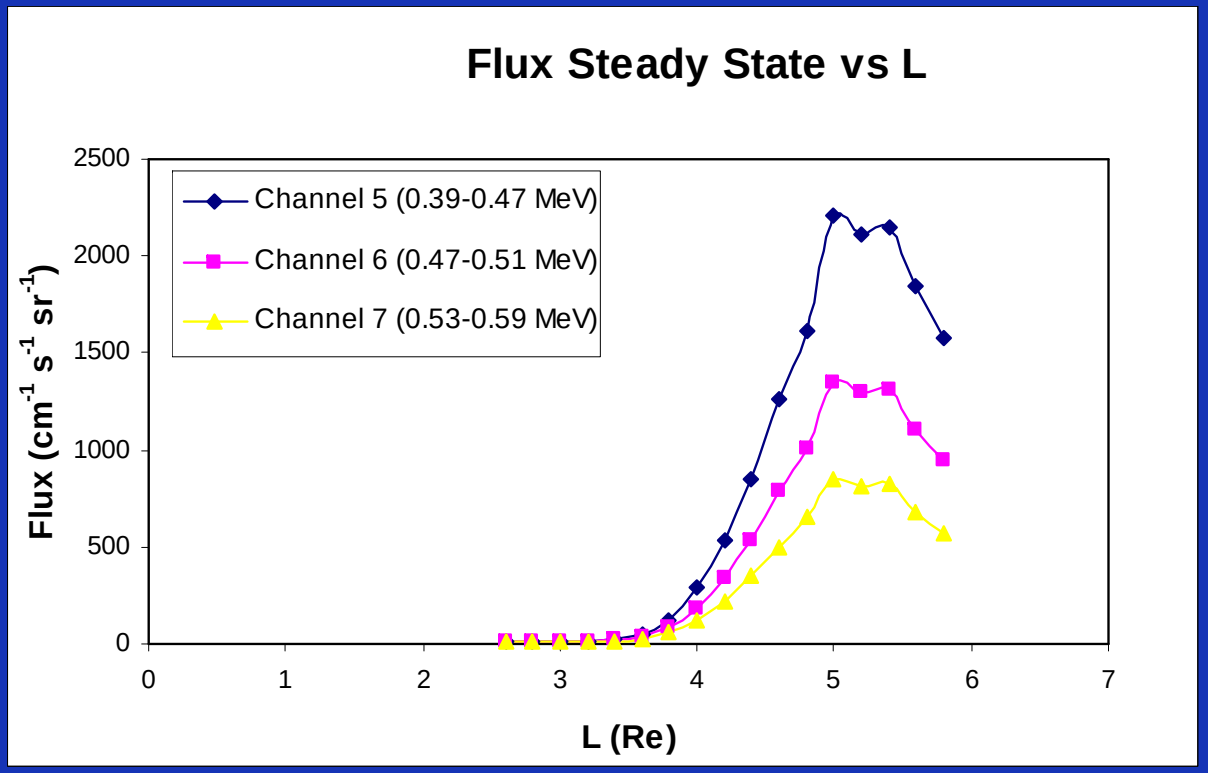
(From Benk et al, to be published)

Φ_{st} measurements



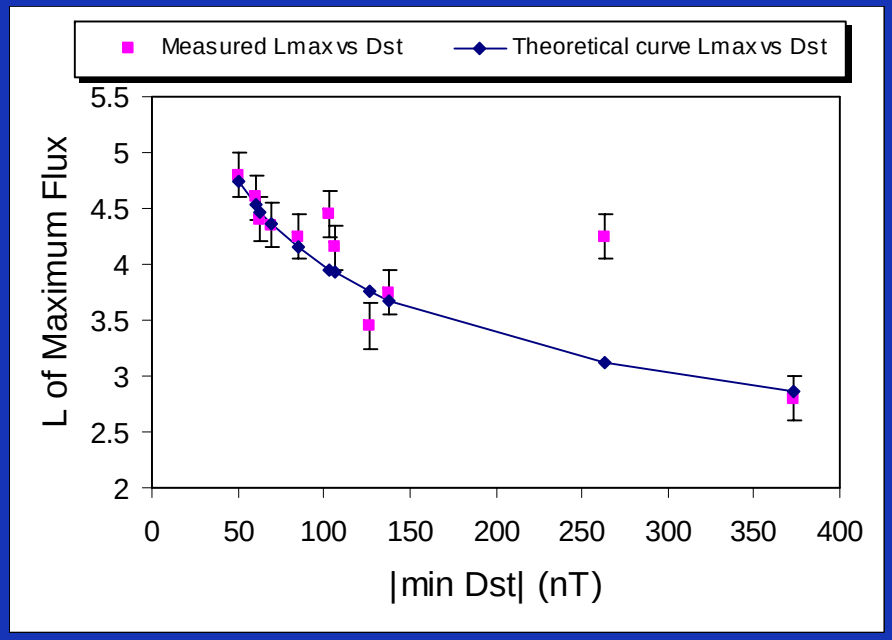
(SAC-C Data: Courtesy of CNES/DCT/AQ/EC Section, ONERA/DESP and CONAE)

Φ_{st} measurements



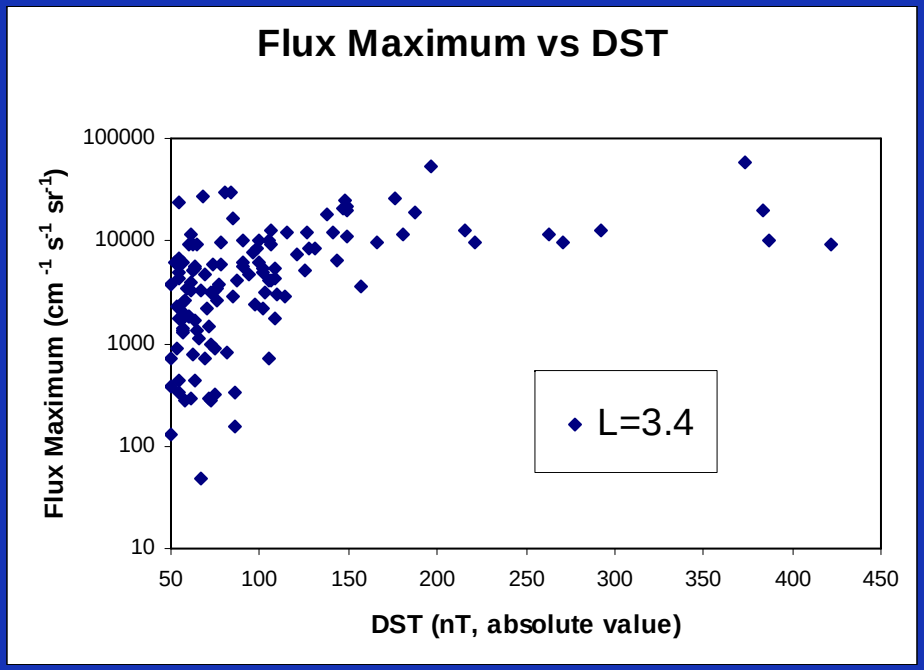
(SAC-C Data: Courtesy of CNES/DCT/AQ/EC Section, ONERA/DESP and CONAE)

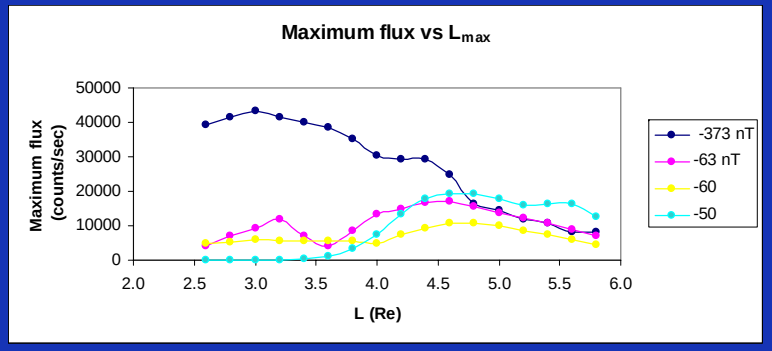
Flux Maximum



$$L_{max} \approx \frac{12.6}{|\min DST|^{\frac{1}{4}}}$$

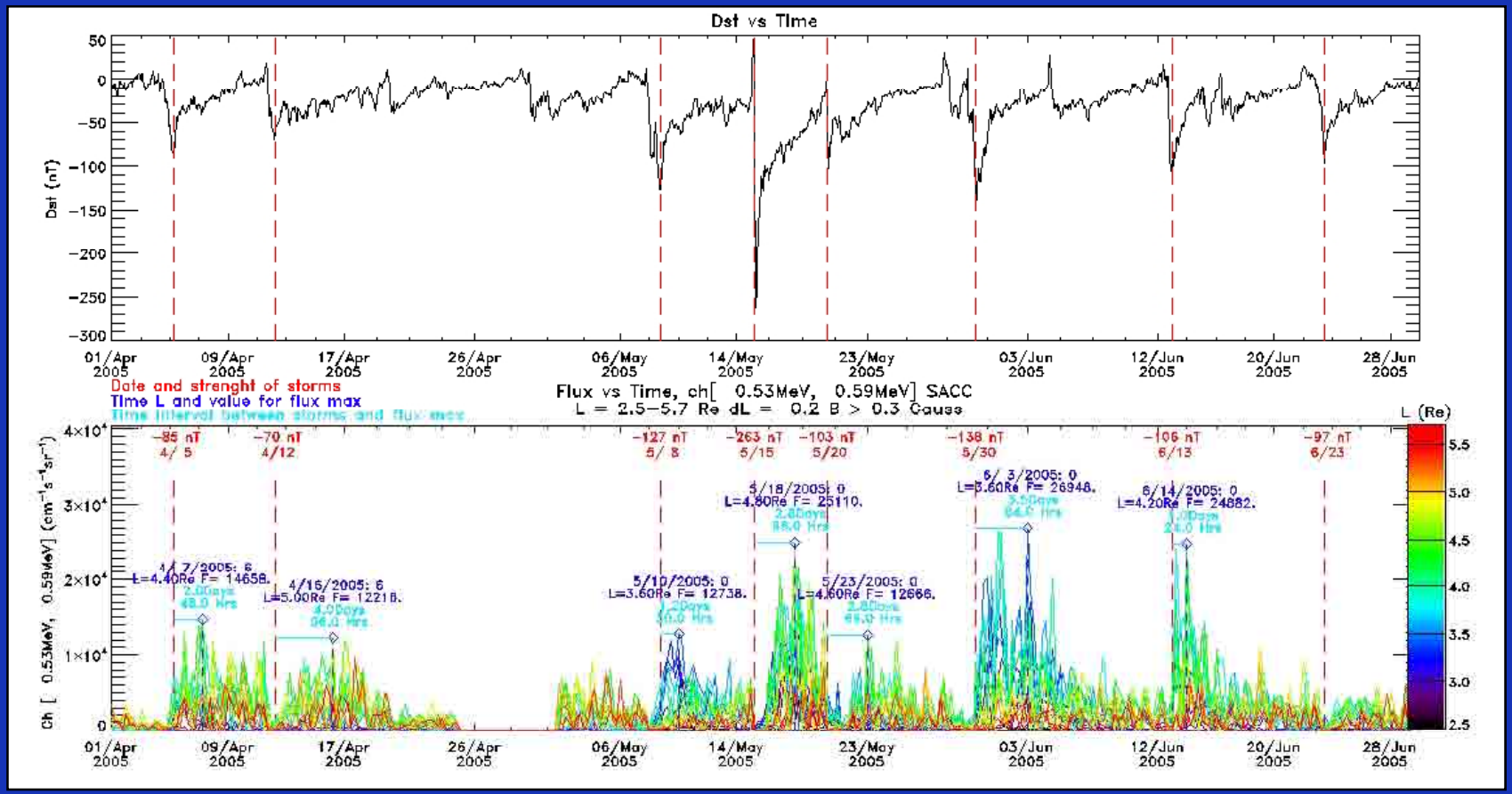
(From Tverskaya et al, 2002)



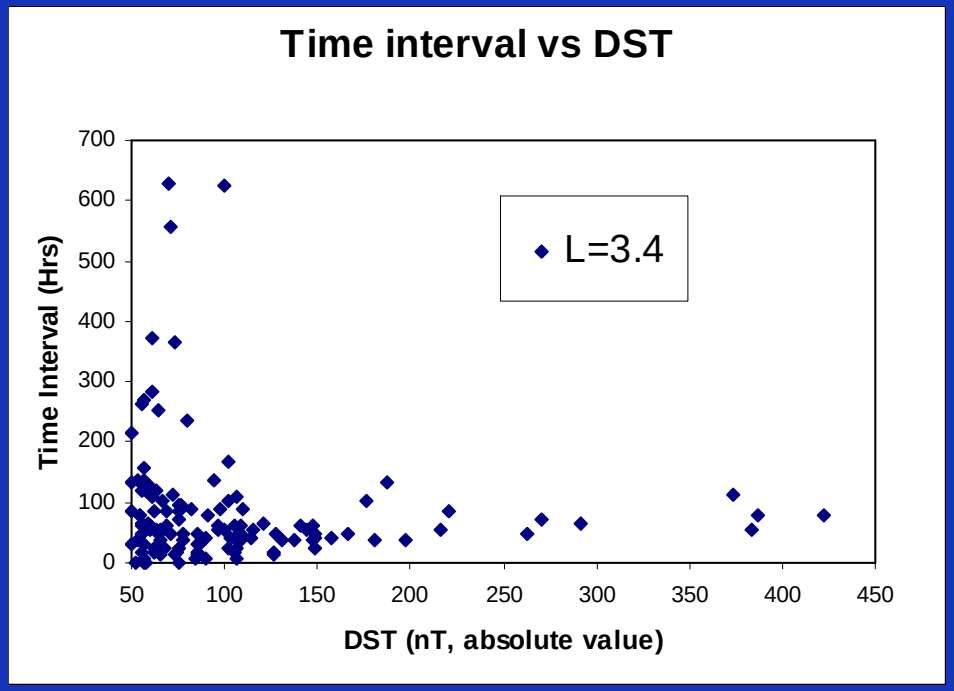


(SAC-C Data: Courtesy of CNES/DCT/AQ/EC Section, ONERA/DESP and CONAE)

Time interval between storm and flux max (δ)

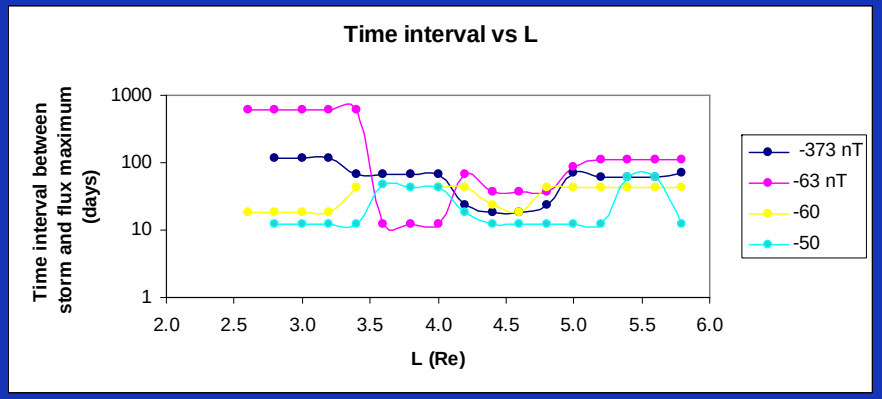


(SAC-C Data: Courtesy of CNES/DCT/AQ/EC Section, ONERA/DESP and CONAE)



(SAC-C Data: Courtesy of CNES/DCT/AQ/EC Section, ONERA/DESP and CONAE)

➢ **The time interval between magnetic storm and flux maximum (δ) seems to be random. It might need other parameters, such as type of storm.**



(DEMETER Data)

❖ *Kataoka and Miyoshi, "Flux enhancement of radiation belt electrons during geomagnetic storms driven by coronal mass ejections and corotating iteraction regions." Space weather, 2006*

Summary

Identified Parameters

- Dst_{prev}, Dst_k (1204 storms!)
- τ (time between two storms)
- Solar Cycle parameter (SSN)
- T (Decay time)
- Maximum Flux

Need further analysis:

- δ (time interval between storm, maximum flux)
- Type of storm?
- Φ_{st}

Model useful to:

- Theoreticians
- Engineers

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