Effects of Hysteresis Between Maximum CME Speed Index and Typical Solar and Geomagnetic Activity Indicators During Cycle 23

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Introduction

Studies of the relationship between different coronal activity indices during the solar cycle may provide evidence about the storage of energy in the corona. It has been shown that some of these activity indicators such as 10.7 cm microwave flux, Ca II K index and Lα irradiance at 1216 Å follow different paths for the ascending and descending phases of the solar cycle displaying a 'hysteresis' like phenomena. In some cases, these observed hysteresis patterns start to repeat over more than one solar cycle, giving evidence that this is a normal feature of solar activity.

DATA

Data covering period 1 January 1996 - 31 December 2006 (solar cycle 23).

The solar activity indicators used in this study are briefly described as follows:

i) The MCMESI data are derived from the Large Angle and Spectrometric Coronagraph (LASCO) on the SOHO mission, as compiled in the CME catalog. The determination of the MCMESI is based on the measurements of highest daily linear CME speed averaged over one month.

ii) Flare Index (FI) is evaluated as a measure of the short-lived activity on the Sun and is roughly proportional to the total energy emitted by a flare.

iii) Coronal Index (CI) is derived from measurements of the total energy emitted by the corona in the emission line of Fe XVI at a wavelength of 5303 Å. Lomnicky Stit in the Slovak Republic served as the reference station for calculating this index.

iv) Solar Radio Flux (F10.7) is derived from the daily measurements of the integrated radio emission originating from the high chromosphere and low corona at 2800 MHz , which has been reported by the National Research Council (NRC) of Canada since 1947.

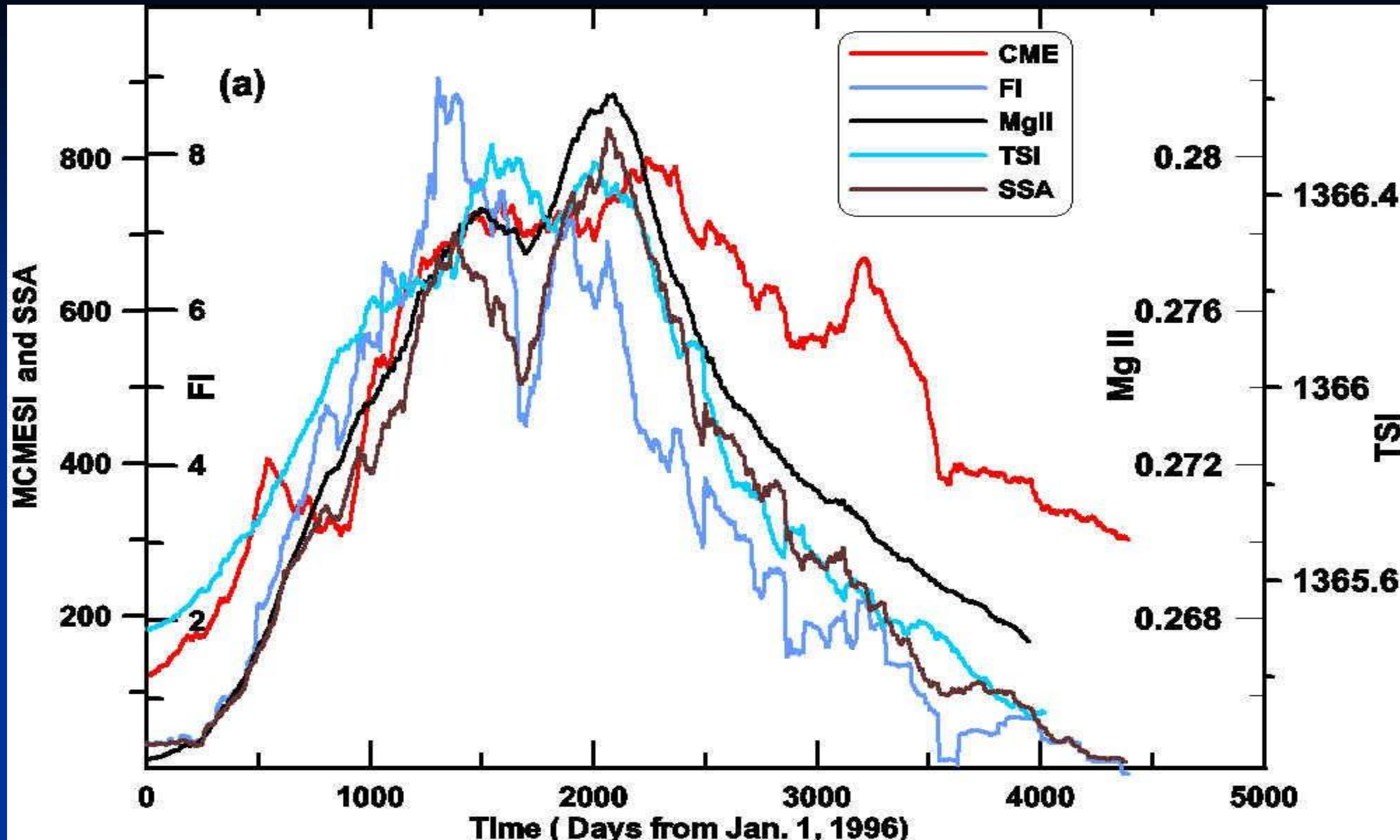
v) Sunspot Area (SSA) is observed, measured, and compiled by the Royal Greenwich Observatory and USAF/NOAA. It is taken from the web page of the Marshall Space Flight Center. The FI, CI, and F10.7 data are taken from NGDC.

vi) Mg II index is defined as the ratio between the core emission and the solar continuum intensity in the wings. We used the NOAA Mg II daily index version 9.1 prepared by NOAA, Space Environment Center.

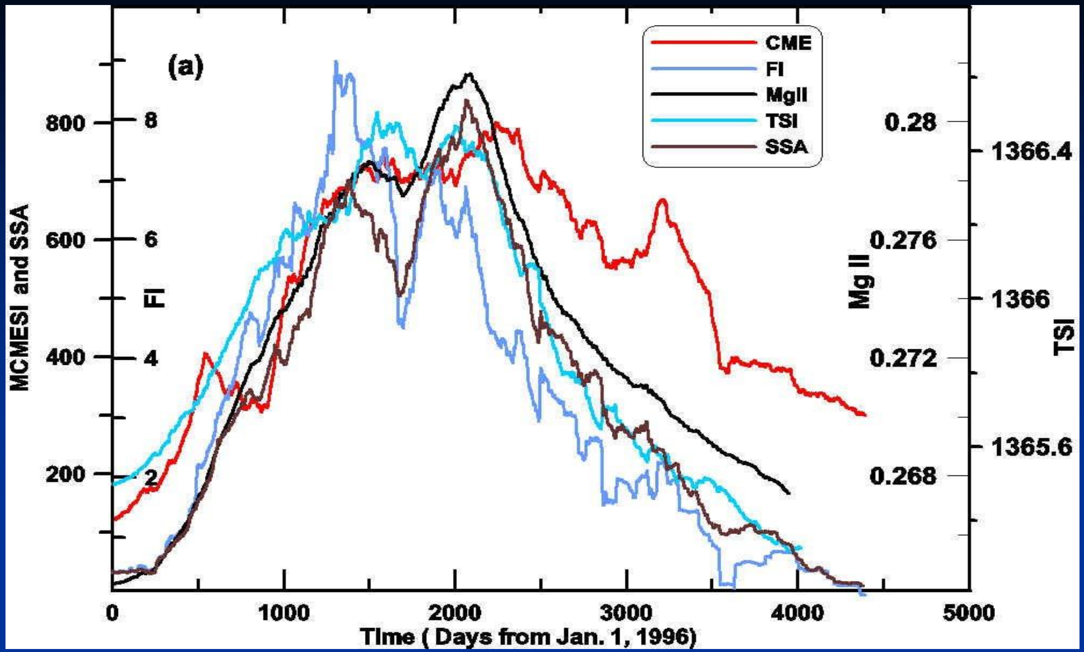
vii) Total Solar Irradience (TSI) a composite record of the Sun's total irradiance, is compiled from measurements made by five independent space-based radiometers since 1978. We used version 41 of that data set, which can be found at the webpage of PMODWRC.

viii) Geomagnetic activity index, aa, which represents an average disturbation over 24-hour, is taken from SPIDR NGDC.

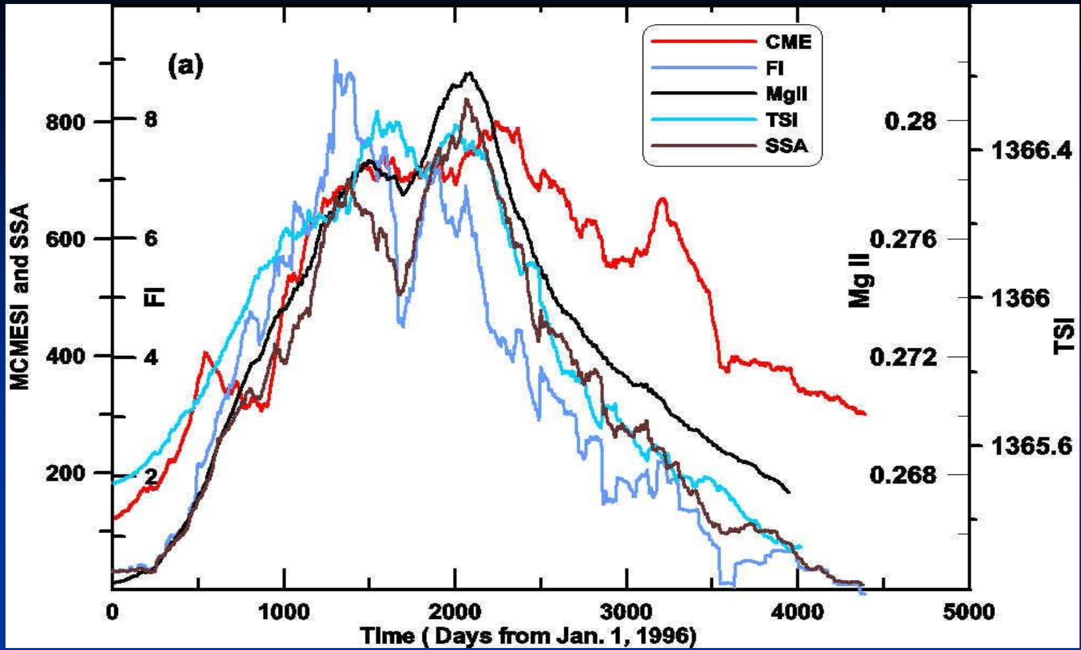
vix) Disturbance storm time, Dst, data is calculated every hour and is obtained from the World Data Center for Geomagnetism, Kyoto (http://wdc.kugi.kyoto-u.ac.jp/).



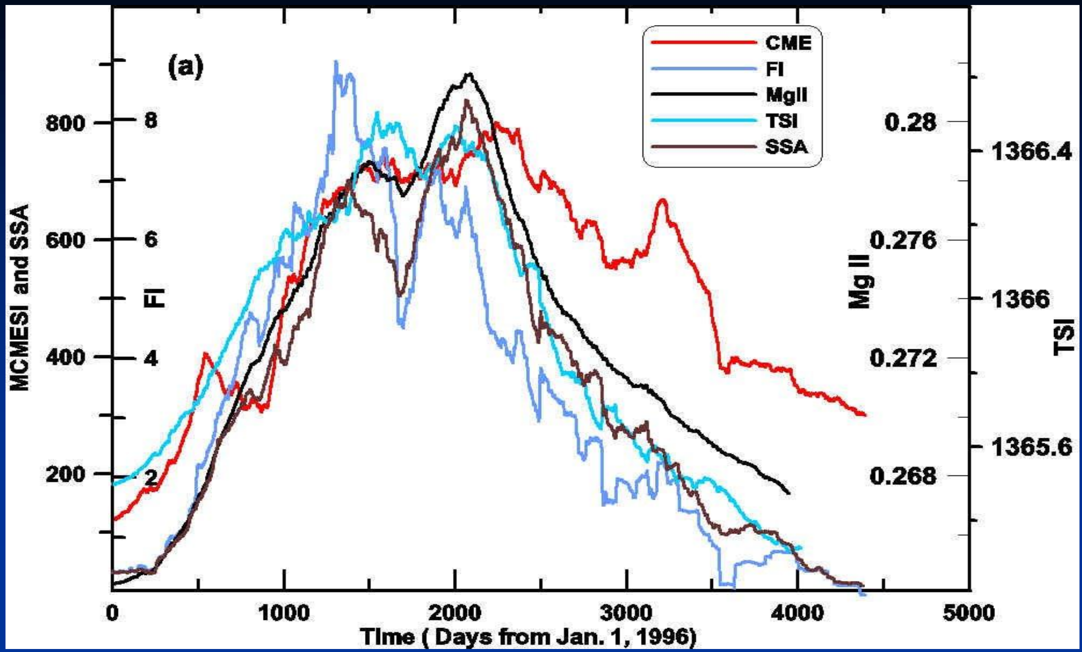
Time evolution of smoothed chromospheric and global indices. Each plot is drawn with 365-day running means. The SSA values are divided by 2.5 to adjust to the MCMESI axis.



i) Figure shows a clear example of hysteresis between MCMESI and four indices, FI, Mg II, SSA, and TSI during cycle 23. An obvious delay in MCMESI is visible with respect to these four indices during the declining phase; clearly, MCMESI attains its peak later than the other indices.

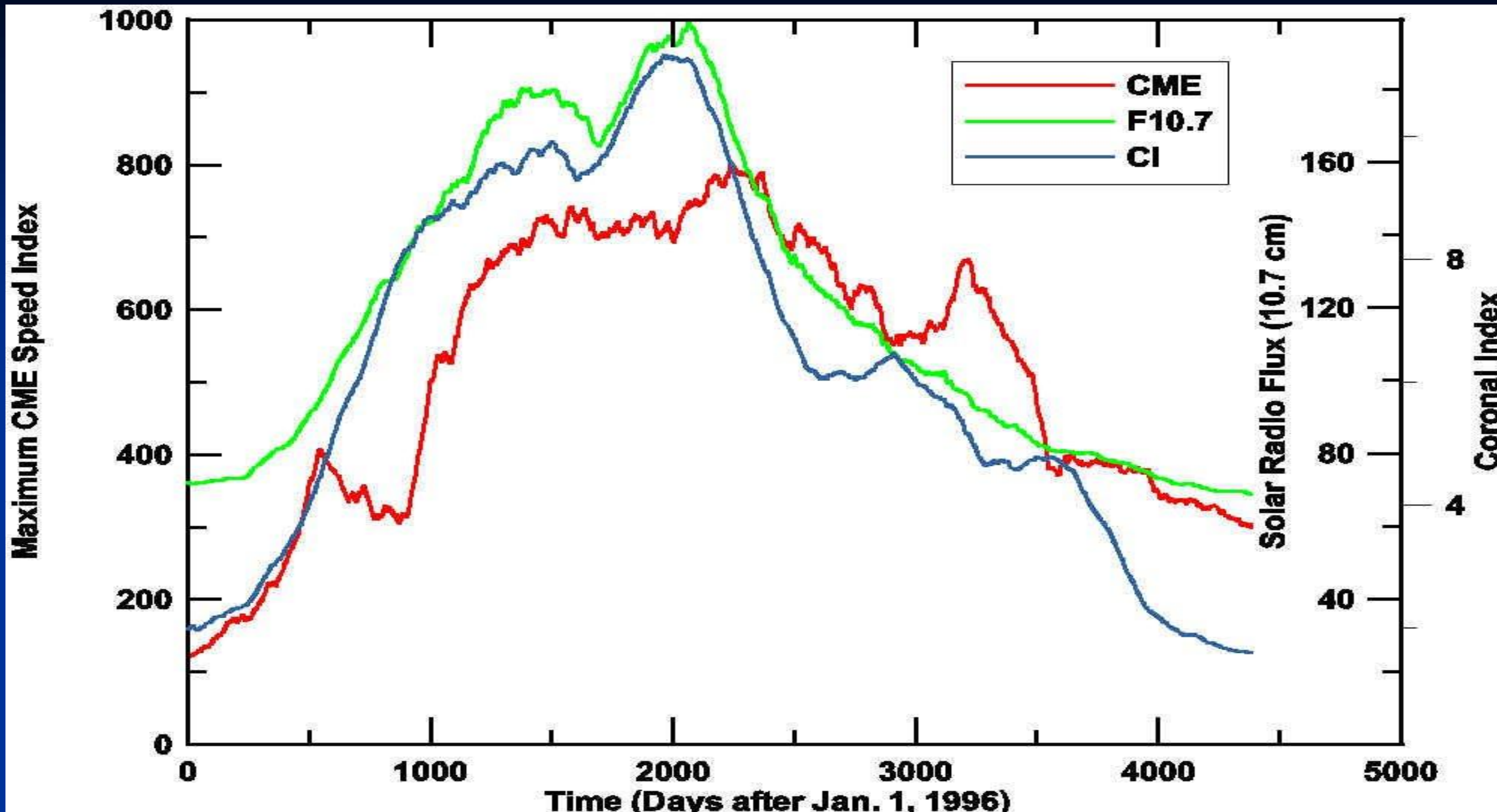


ii) As the ascending phase proceeds, these four indices increase almost simultaneously; likewise, during the descending phase they decline almost in parallel, except for MCMESI.



iii) These four indices show very sharp double-peak maxima while MCMESI shows broad, double-humped structures.

iv) The relative strengths of the two humps are different for different activity indices.



Time evolution of smoothed coronal indices (CI, F10.7, and MCMESI). Each plot is drawn with 365-day running means.

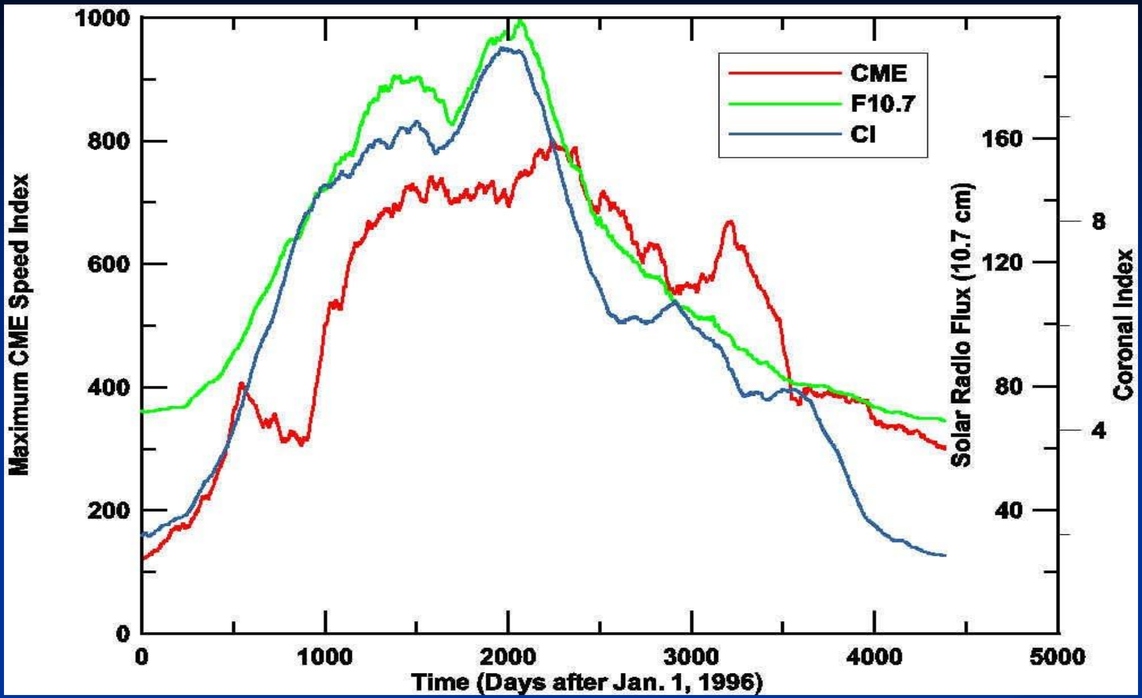
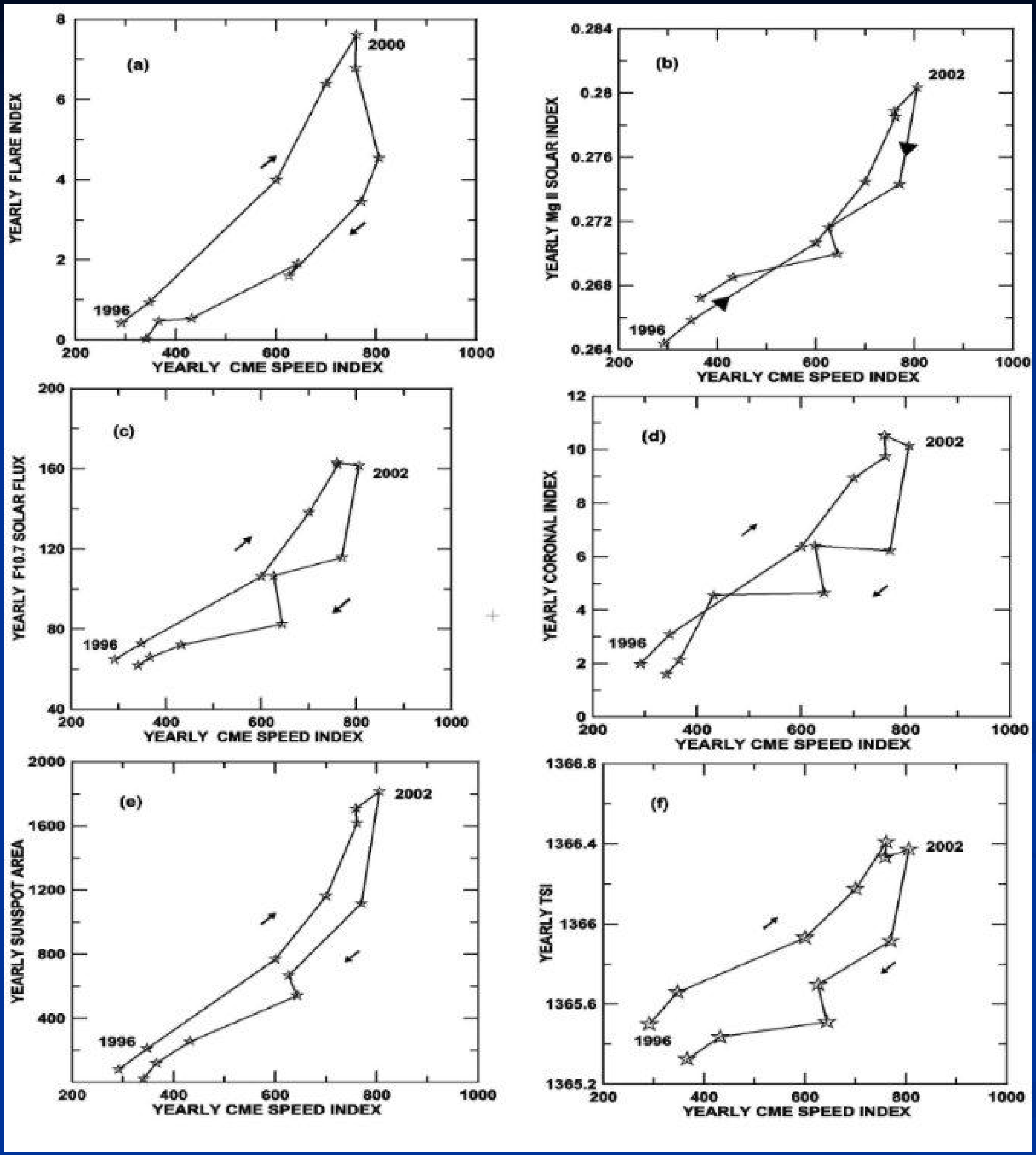
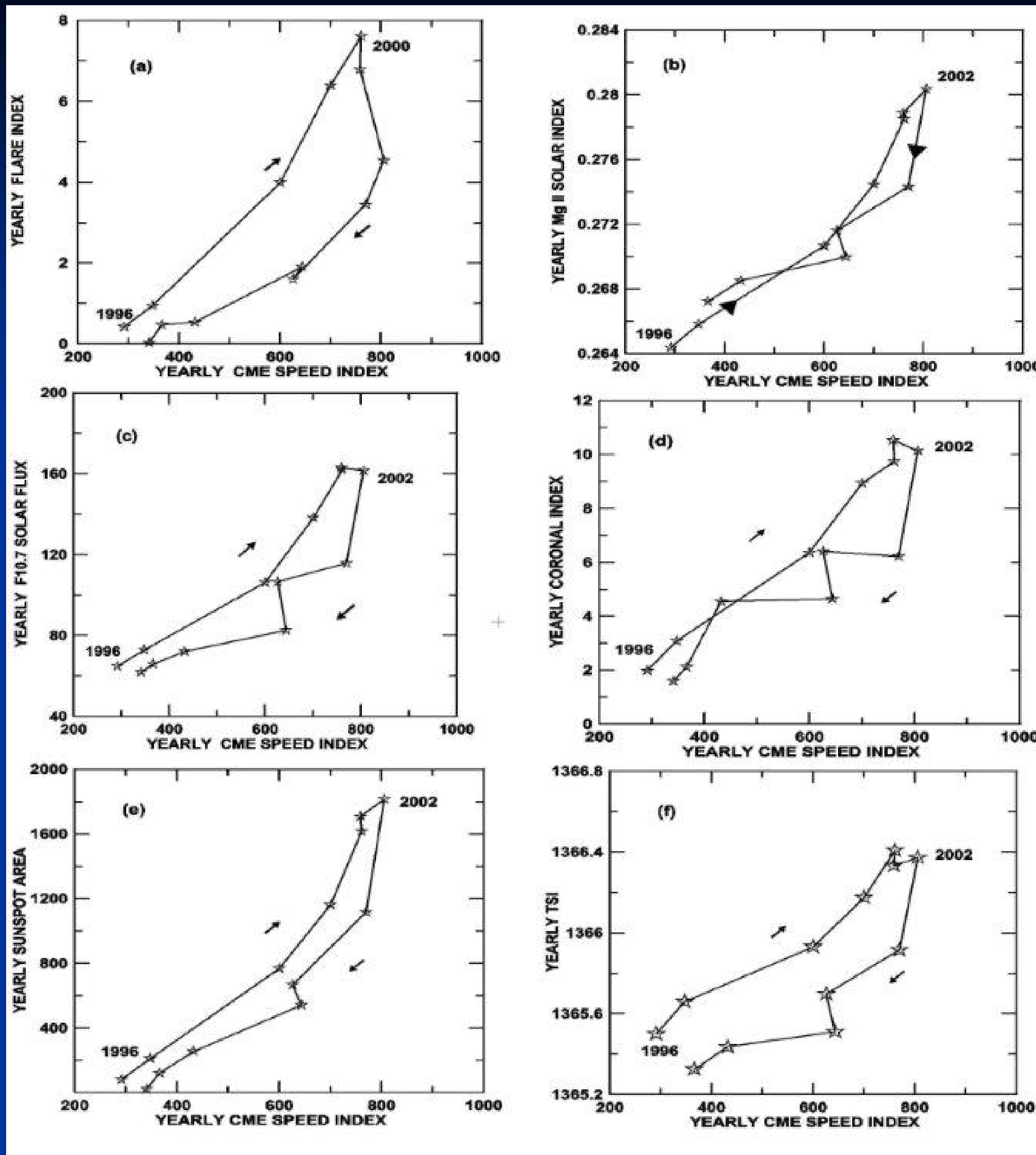


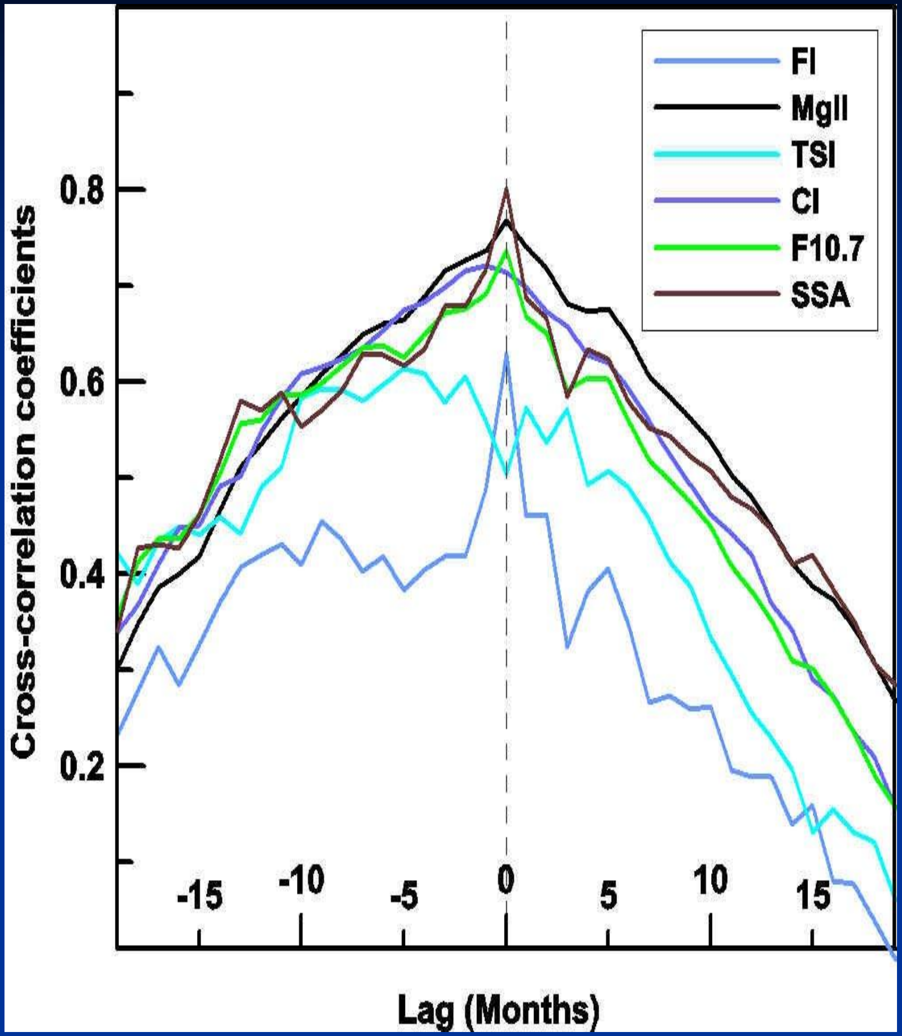
Figure shows also a clear example of hysteresis between MCMESI and two other indices, F10.7 and CI. Contrary to the other four indices, these two indices show hysteresis during the ascending phase of the cycle as well as during the descending one.



We choose CME speed index to be the abscissa of the plots with the equal scale in the this figure to display the effects of hysteresis most clearly.



The hysteresis cycles exhibit clockwise circulation, e.g., the descending path follows a lower track than for the ascending one, which is not a normal characteristic of hysteresis in magnetic materials.

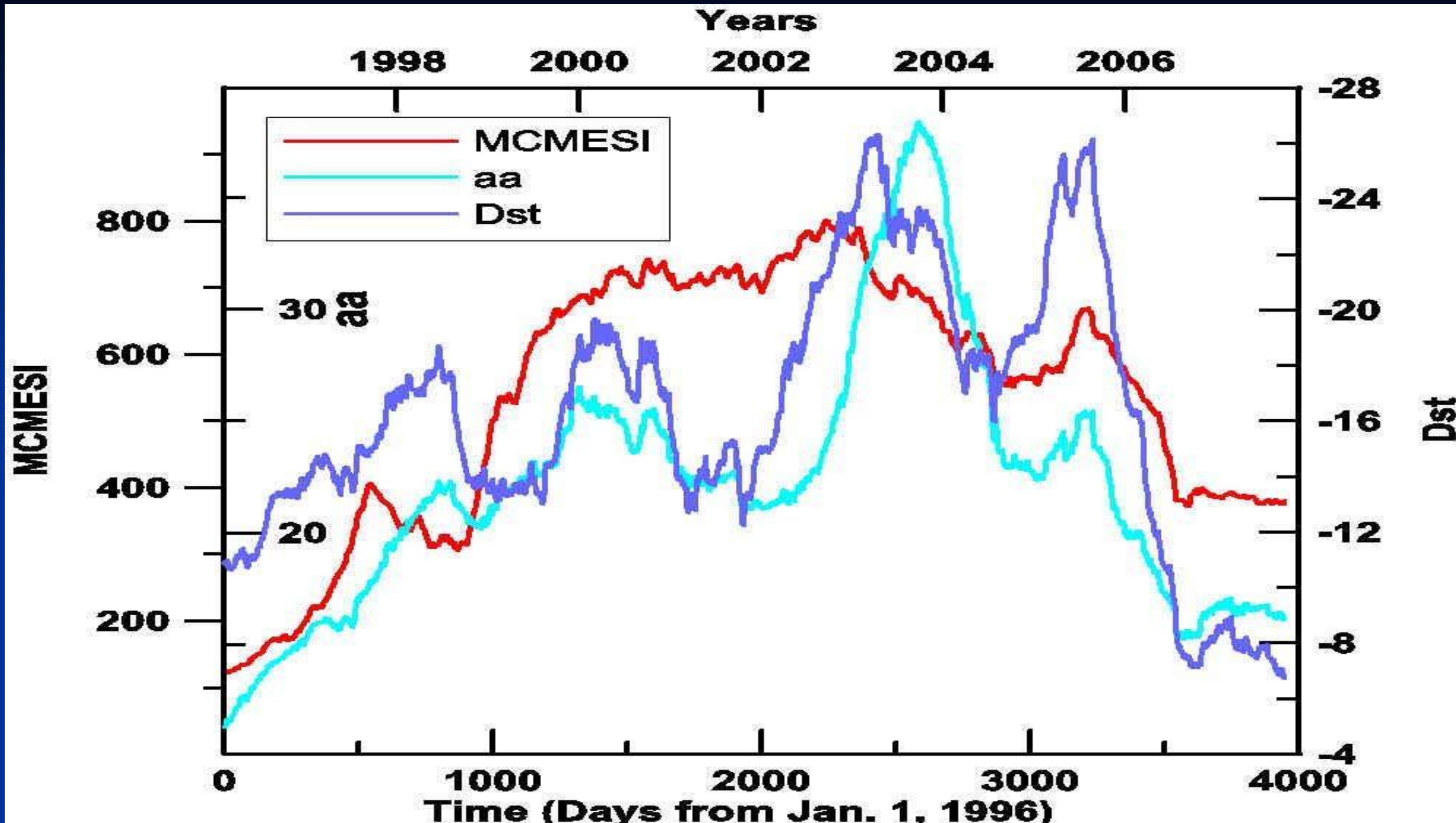


We find that the hysteresis effects are regarded approximately as simple phase shifts, and we quantify these phase shifts in terms of lag times behind the leading index, MCMESI.

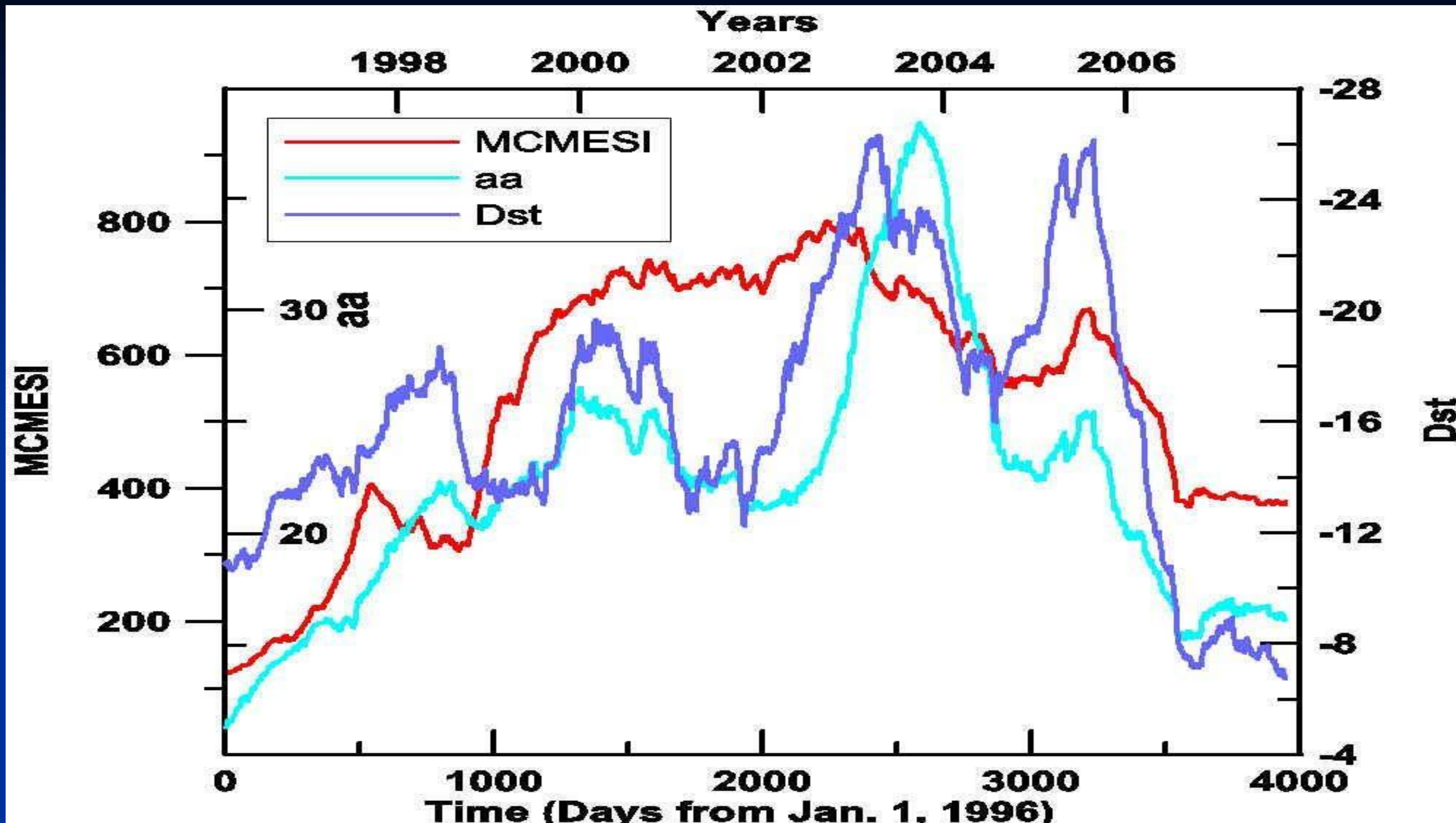
A cross-correlation analysis has been applied to the studied parameters in order to find the delay times.

Time lag (months) and correlation coefficient between MCMESI and six activity indices for solar cycle 23.

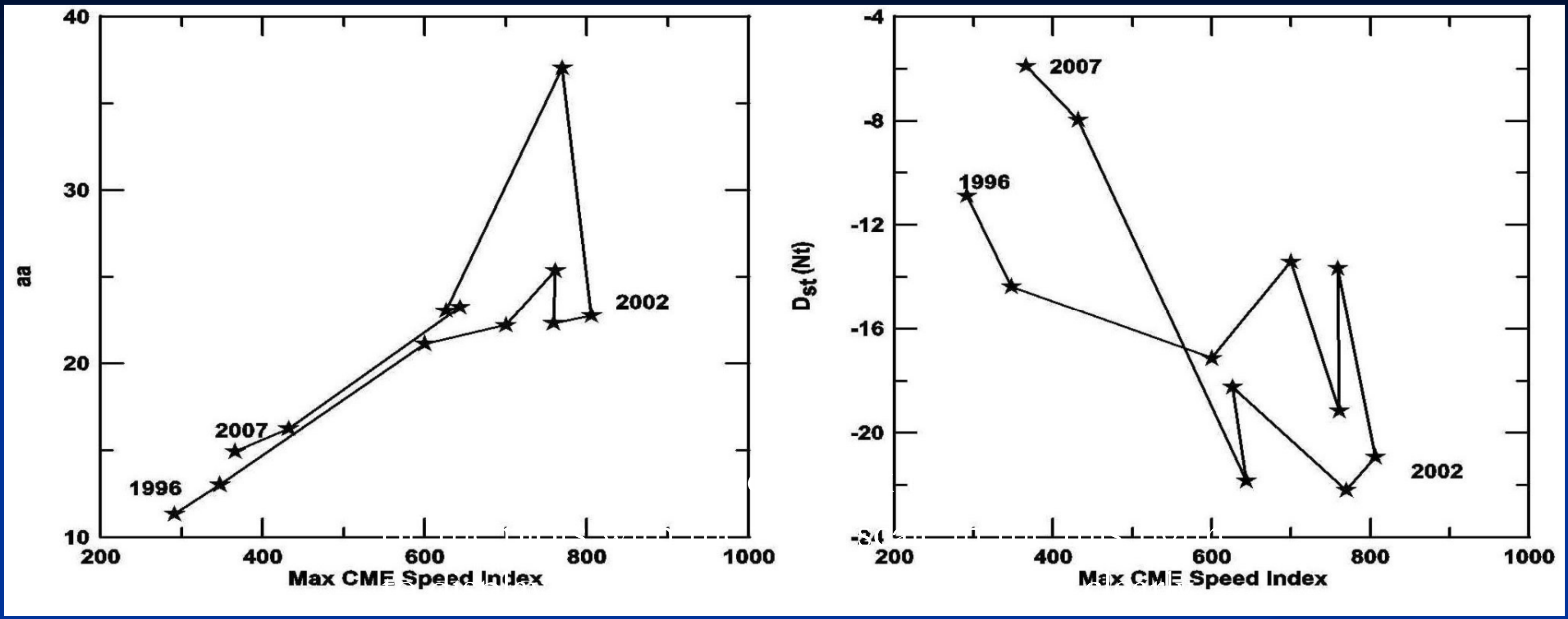
Activity index	Lag time (month)	Corr. Coef.
Flare index	0	0.63 ± 0.11
Sunspot area	0	0.80 ± 0.08
Solar radio flux	0	0.74 ± 0.09
Coronal index	2	0.72 ± 0.09
Total solar irradiance	6	0.61 ± 0.12
Mg II	0	0.77 ± 0.08



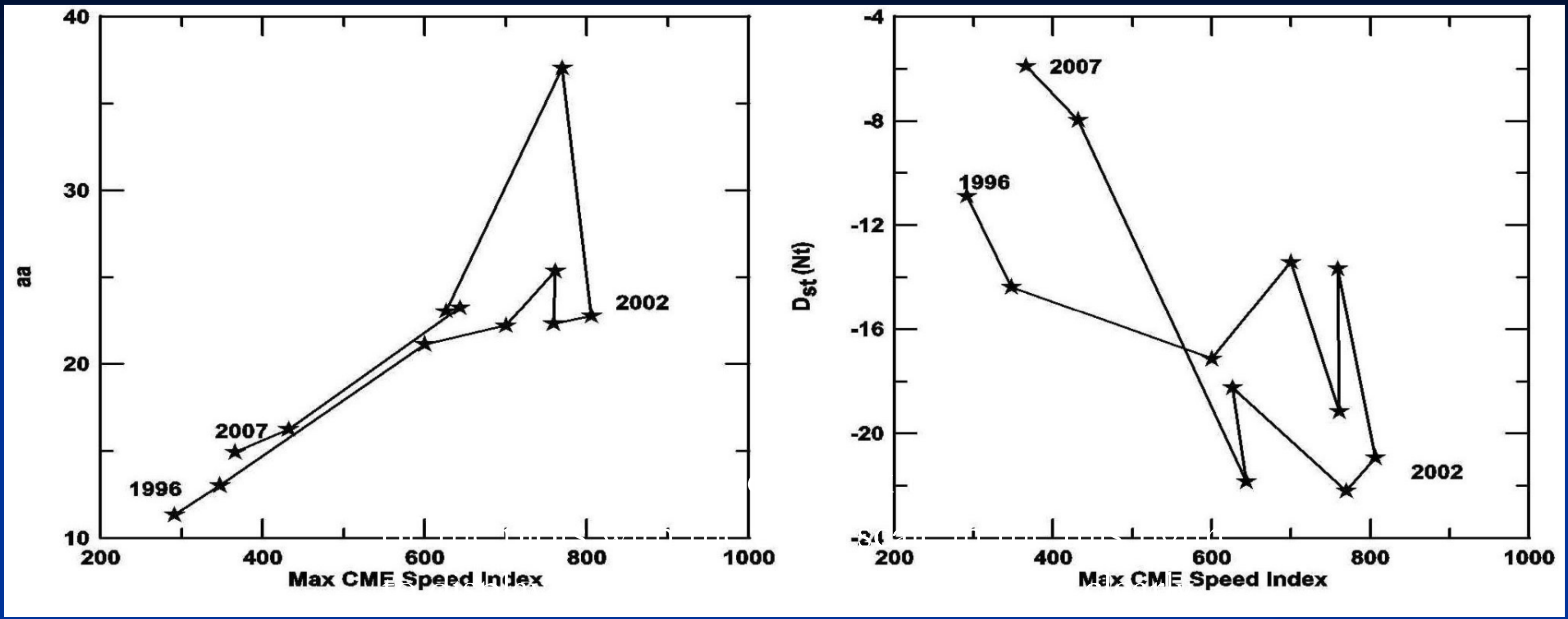
Time evolution of smoothed geomagnetic indices (aa, Dst, and MCMESI). Each plot is drawn with 365-day running means.



The phase shift between MCMESI and the two indices is quite visible.



We choose CME speed index to be the abscissa of the plots with the equal scale in the this figure to display the effects of hysteresis of the geomagnetic indices most clearly.



Contrary to the other indices aa index shows hysteresis only during the maximum phase. The hysteresis cycle exhibites counterclockwise circulation.

Conclution

Hysteresis is due to the fact that the magnetic fields at different scales make different contributions to the total magnetic flux in diverse phases of the cycle.

In the ascending branch, the curve of MCMESI and FI, Mg II, and TSI are similar.

In the declining phase, MCMESI decreases much more slowly than FI, Mg II, and TSI and hence results in a hysteresis.

Conclution

Since the solar cycles represent complicated nonlinear dynamical phenomena, predicting the shape and the importance of the hysteresis effect is still elusive despite the large amount of observational manifestations.

MCMESI may be a good indicator of relevant solar-terrestrial phenomena. If this hypothesis is true, MCMESI time series could be regarded as a proxy data set to account for peculiar solar-induced effects in the heliosphere.

Conclution

Our results show that the hysteresis warrants serious considerations as a possible long-term feature of solar activity.

Finally, we argue that this phenomenon represents a real delay both in the onset phase and in the decline phase of the solar activity; thus it could be an important clue in the search for physical processes responsible for changing solar emission at various wavelengths.

THANK YOU