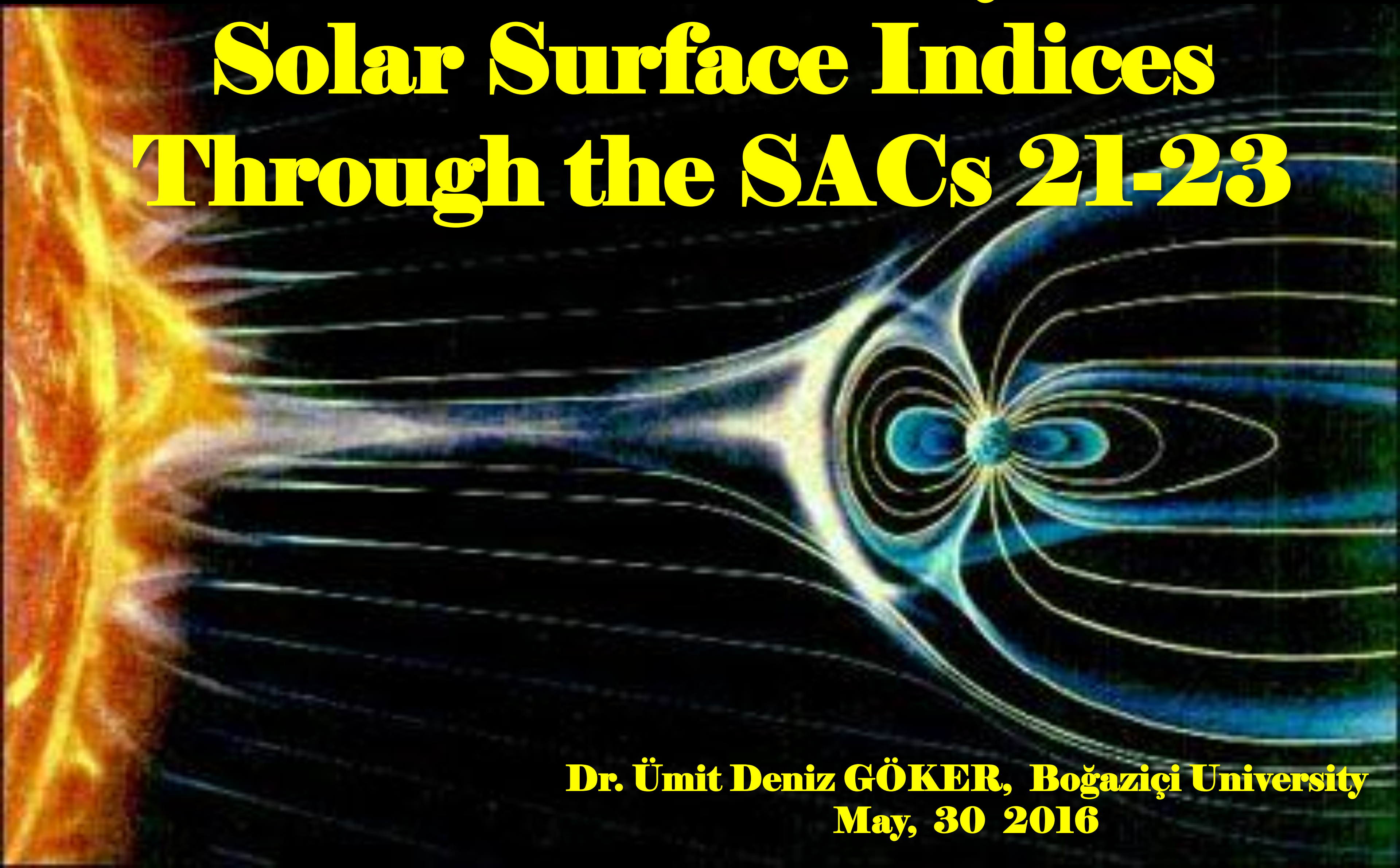
A Statistical Analysis of Solar Surface Indices Through the SACs 21-23



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A Statistical Analysis of Solar Surface Indices Through the Solar Activity Cycles 21-23

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* The magnetic flux emerging in sunspots, faculae or plage and network is investigated by analyzing the effects of dark and bright regions on the solar disc. Time series analysis of solar surface indices according to group type and sunspot size.

* Large SGs (D, E, F and G) : contain penumbrae both in the main leading and following spots

Small SGs : (A and B : no penumbra) ; (C, H and J : at least one main sunspot with penumbra)

* TSI (changes in the areas of dark sunspots and bright faculae)

* SAC 23 (distinctive decrease in the area of bright faculae and chromospheric plages, along with the decrease of the ratio of dark faculae and plage)

* Ca II K-flux observations are important because plage regions account for roughly one-half of total magnetic flux from the Sun

* We analyzed (data, plotted line, scatter and bar plots) with the use of Python libraries (Pandas, NumPy & SciPy and Matplotlib)

Analyzing Procedure with Python

(1) The monthly averaged sunspot counts, magnetic field, TSI, FA, Ca II K-flux, PA and the ratio of FA to Ca II K-flux data were grouped for each month by applying the aggregate function of arithmetic mean

(2) After grouping, sunspot counts and solar surface indices data were joined over the same month and year (merging operation)

(3) Cross-correlation analysis between SGs and solar surface indices are applied to unsmoothed merged monthly mean values

(4) Moving average of time series (rolling_mean function of Pandas) ⟶ selecting the window size of the simple moving average at 7 days

(5) Bar plots were generated by grouping the time series data into years and averaging the data of each year by its arithmetic mean

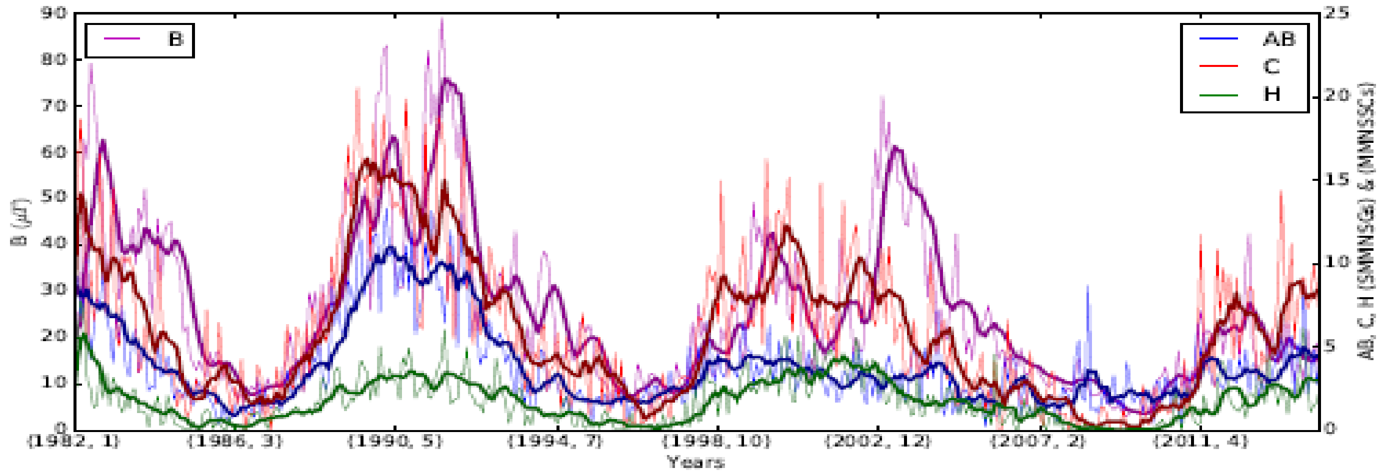
(6) Each type of sunspot counts was normalized by dividing it with the sum of all types of sunspot counts

(7) After normalization, sunspot counts were grouped by year and averaged for each year

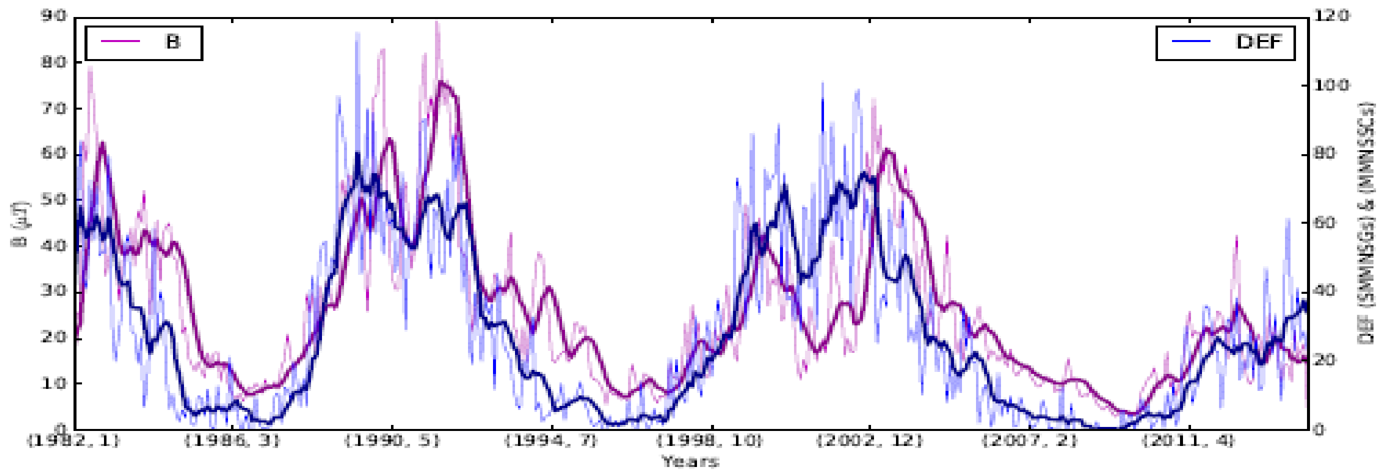
(8) The normalization of averaged sunspot counts for each year : $\frac{AB}{TSSN} + \frac{C}{TSSN} + \frac{DEF}{TSSN} + \frac{H}{TSSN} = 1$

(9) Yearly grouped and average data for plotting bar plots (no scattering) : relative change of the sunpot counts by type of each year.

(10) Pearson product-moment correlation coeff. (Pandas corr_function for dataframes)

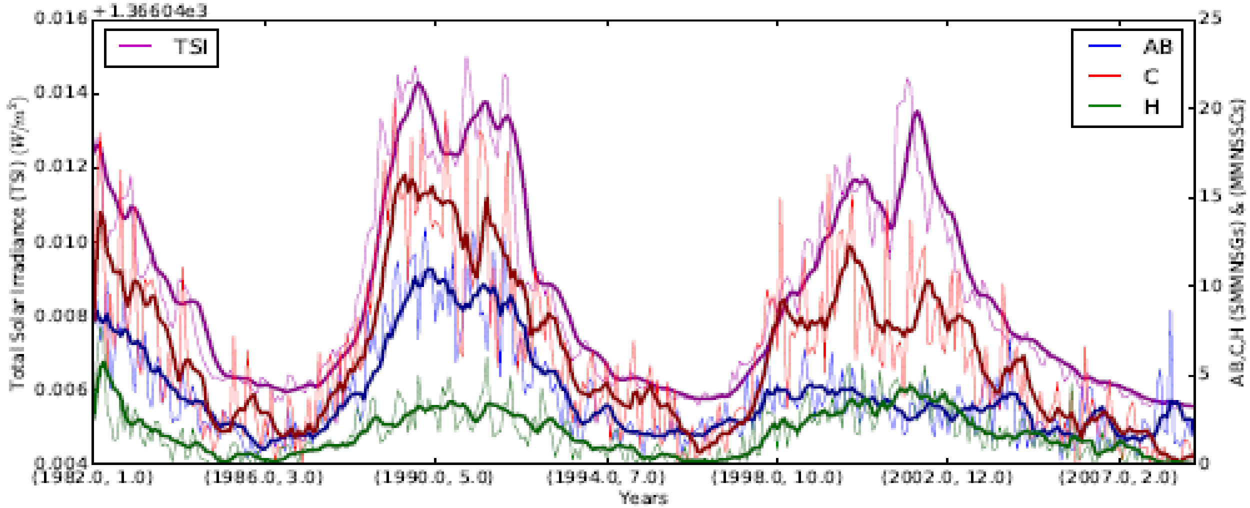


(a) Time series of AB, C and H type SGs and SSCs are compared with absolute value of the monthly grouped and averaged magnetic field. Thick lines are 15 day simple moving averages.

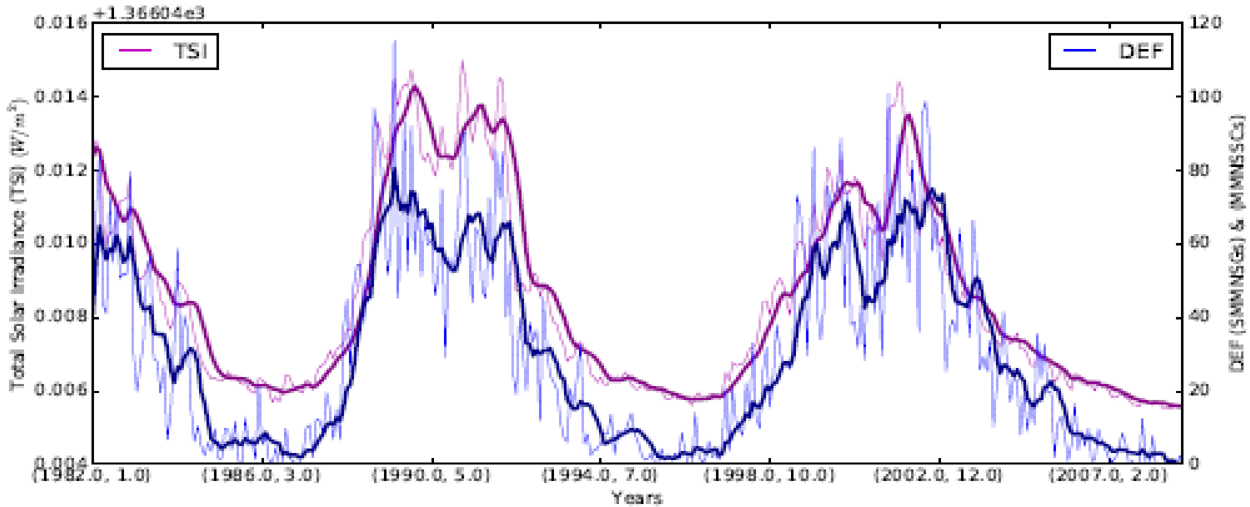


(b) Time series of DEF type SGs and SSCs are compared with absolute value of the monthly grouped and averaged magnetic field. Thick lines are 15 day simple moving averages.

Figure 1. The x-direction denotes the years and the y-direction denotes the monthly mean SGs and SSC numbers (right) and monthly mean magnetic field (left). The magnetic data start from January, 16 1982 and complete May, 1 2014 while SGs and SSC numbers start from January, 16 1982 to May, 1 2014. The SG and SSC numbers of AB, C and H in Fig. (a) and DEF in Fig. (b) are shown with blue, red, green and violet, respectively while magnetic field is shown with purple color in both figures.



(a) Time series of monthly grouped and averaged TSI are compared with AB, C and H type SGs and SSCs. Thick lines are 15 day simple moving averages.



(b) Time series of monthly grouped and averaged TSI are compared with DEF type SGs and SSCs. Thick lines are 15 day simple moving averages.

Figure 2. The x-direction denotes the years and the y-direction denotes the monthly mean SGs and SSC numbers (right) and monthly mean TSI (left). The TSI start from January, 16 1982 and complete December, 16 2008 while SGs and SSC numbers start from January, 16 1982 to December, 16 2008. The SGs and SSC numbers of AB, C and H in Fig. (a) and DEF in Fig. (b) are shown with blue, red, green and violet, respectively while TSI value is shown with purple color in both figures.

Compared two equivalent three-year time intervals centered on the maxima of cycles 22 [1989-1991] and 23 [2000-2002]

* **Magnetic field:** (1) AB SGs (SAC 22 > SAC 23 max. p.) & (SAC 22 > SAC 21 > SAC 23 min. p.)

(2) C SGs (SAC 22 > SAC 23 max. p.) & it decreased to zero values for SAC 23

(3) DEF SGs (No important difference between all cycles) & (The number of these groups in the first and second max. are SAC 22 ≳ SAC 23 and SAC 22 ≲ SAC 23) & (SAC 21 and SAC 22 had similar decreasing)

(4) The effect of large SGs was more dominant in the last SAC.

(5) H SGs (SAC 22 ≳ SAC 23 max. p.) & No distinct data in the min. p.

* **TSI:** (1) SAC 23 (has a distinct double peak) & (second peak began in the middle of 2001, finished at the end of 2002) & (coinciding with the peak of large SGs)

(2) SAC 22 (comparable increasing for double peak).

(3) Large SGs reached their max. about two years later than the small SGs (time difference is less effective in TSI than in magnetic field)

(4) Large SGs present on the disk during the second half of cycle 23.

(5) Small SGs (efficient in TSI after the max. in SAC 22 (beginning 1990) & max. of SAC 23 (the year 2000) and Large SGs (show double peak both in SAC 22 and SAC 23 & dominant after the year 2002 & influenced in the FA and sunspot area)

(6) Why was the TSI value comparable with the SAC 22 while the large SGs were higher?

* **Magnetic field:** (6) The magnetic field distinctively lower in SAC 23

(7) Small and large SGs appear (before the magnetic field increasing in SAC 23) & (magnetic field and SGs change in a synchronized way in SAC 22).

(8) SAC 22 max. (end of 1991) & C SGs correlated with the first peak of the magnetic field in SAC 22.

(9) SAC 23 max. (middle of 2003) & huge difference with the second peak of the magnetic field in SAC 23.

(10) First (end of 1989) and second (end of 1991) peaks are correlated with large SGs but magnetic field is still lower in SAC 23 while large SGs comparable with SAC 22

(11) Why did the magnetic field decrease in that situation?

Compared two equivalent three-year time intervals centered on the maxima of cycles 22 [1990-1992] and 23 [2001-2003]

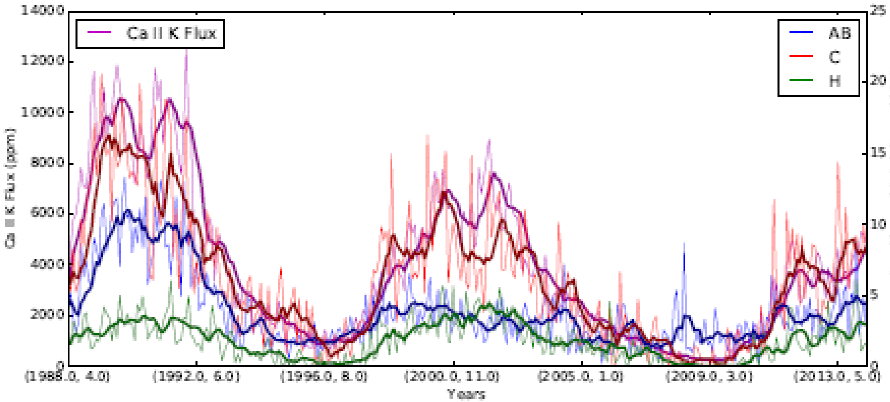
* **Facular Area and Ca II K-flux:** (1) Ca II K-flux (lower in SAC 23 both for small and large SGs).

(2) Ca II K-flux variations are comparable with **C** and DEF type SGs. However, small SGs and Ca II K-flux variations change synchronized in SAC 22 and SAC 23.

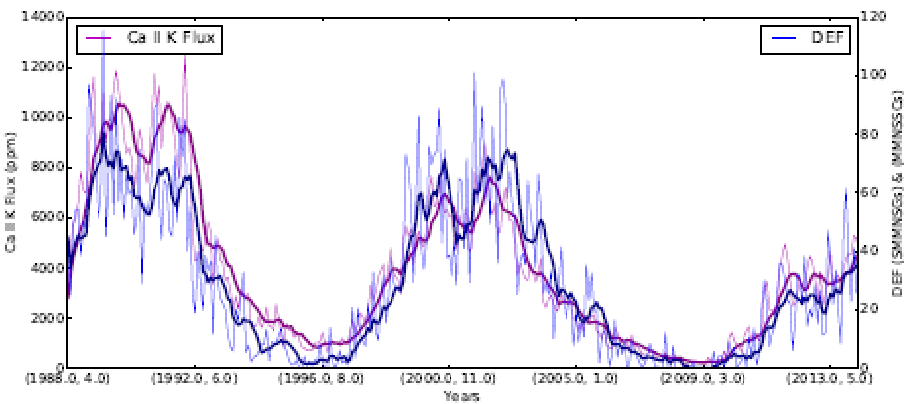
(3) Ca II K-flux variation is 30% lower in SAC 23 than SAC 22.

(4) Ca II K-flux: Small SGs (correlated with SAC 22) & (anti-correlation in SAC 23 – year 1999).

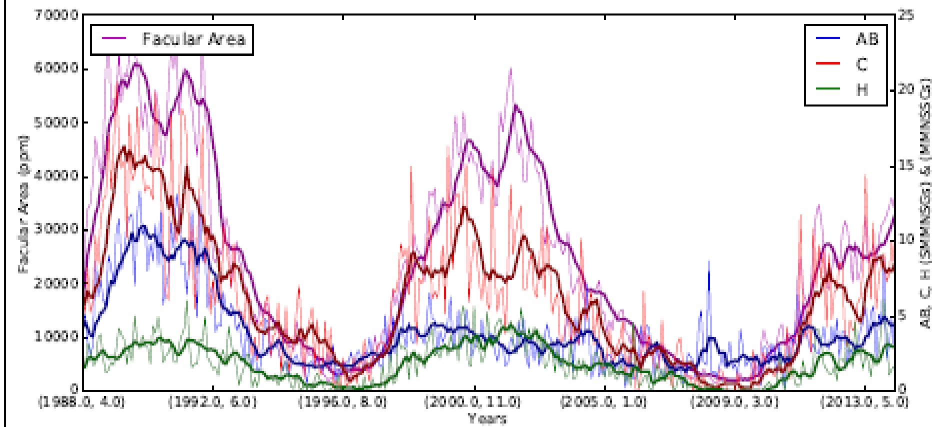
(5) Not clear first peak (year 2000) & second peak starts (beginning of 2003)



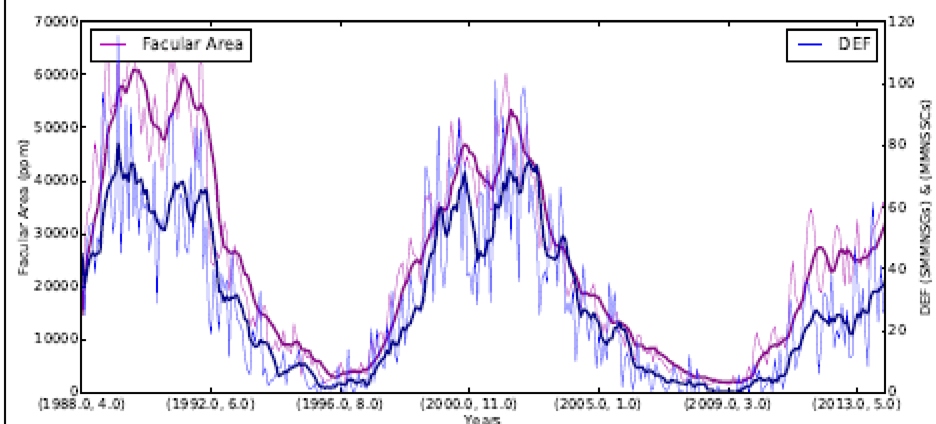
(a) Time series of monthly grouped and averaged Ca II K-flux are compared with time series of AB, C and H type SGs and SSCs. Thick lines are 15 day simple moving averages.



(b) Time series of monthly grouped and averaged Ca II K-flux are compared with time series of DEF type SGs and SSCs. Thick lines are 15 day simple moving averages.



(c) Time series of monthly grouped and averaged FA are compared with time series of AB, C and H type SGs and SSCs. Thick lines are 15 day simple moving averages.



(d) Time series of monthly grouped and averaged FA are compared with time series of DEF type SGs and SSCs. Thick lines are 15 day simple moving averages.

Figure 3. The x-direction denotes the years and the y-direction denotes the monthly mean SGs and SSC numbers (right) and Ca II K-flux (a, b) and FA (c, d) (left). The Ca II K-flux and FA data start from April, 25 1988 and complete April, 3 2014 while SGs and SSC numbers start from April, 25 1988 to April, 3 2014. The SGs and SSC numbers of AB, C, H and DEF in Figs. (a-d) are shown with blue, red, green and violet, respectively while Ca II K-flux and FA are shown with purple color in both figures.

* **Facular Area and Ca II K-flux:** (6) FA and Ca II K-flux were seperated from synchronization in the beginning of 1999. FA (increase, 1999 – 2009) & (increase, after 2010).

(7) FA: The double peak is clear and the level of the peak is higher (SAC 23).

(8) The number and the coverage of C SGs on the solar surface were smaller while the total area of faculae covered more surface on the Sun.

(9) Ca II K-flux was lower in SAC 23 while FA were comparable both for SACs 22 and 23.

(10) Coverage of FA and Ca II K-flux: higher (year 1990 in SAC 22) & lower (year 2001 in SAC 23)

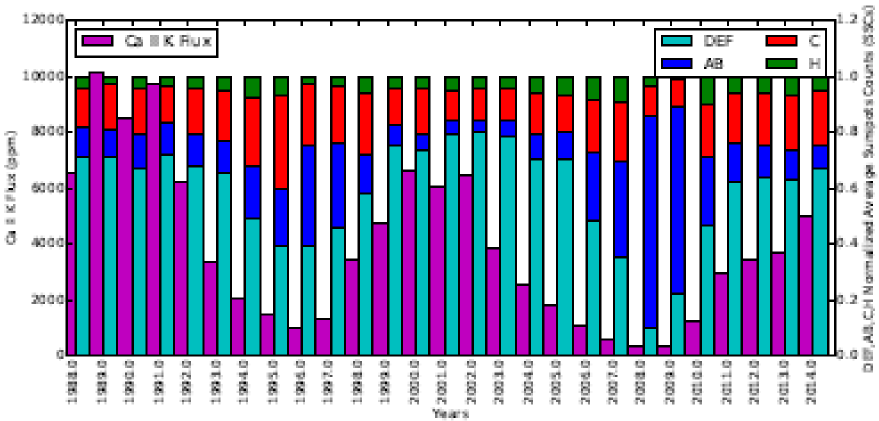
(11) FA highly correlate with the large SGs for both SACs. Max. peaks also correlate with large SGs.

(12) The area ratio of faculae to Ca II K-flux was 60% (SAC 22) & 69% (SAC 23) – because of the decrease of Ca II K-flux.

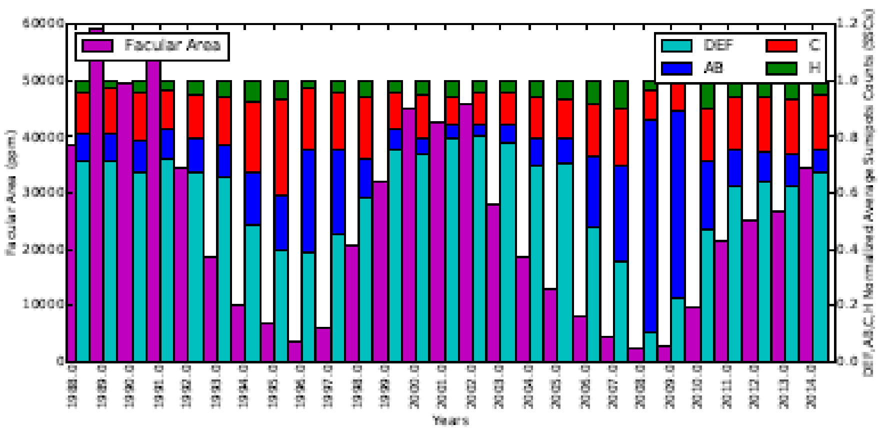
(13) The coverage of FA on the solar surface decreased only 20% (SAC 22-SAC 23) & Ca II K-flux decreased 30%.

* **BAR PLOTS:** (1) Yearly variations & their percentage variations in one column & boxes give the percentage share of the parameters.

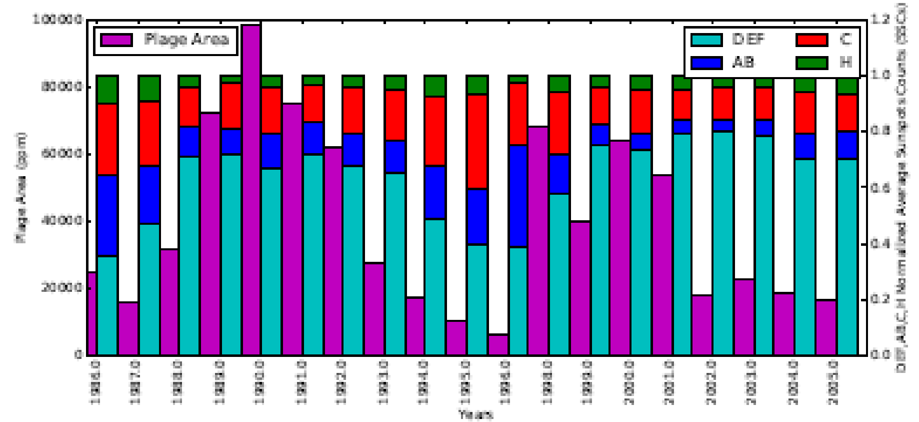
(2) The peak of large SGs count delay relative to the solar cycle minimum. FA are declining with time and the decrease in peak cycle amplitude is also seen in the normalized average of sunspot counts.



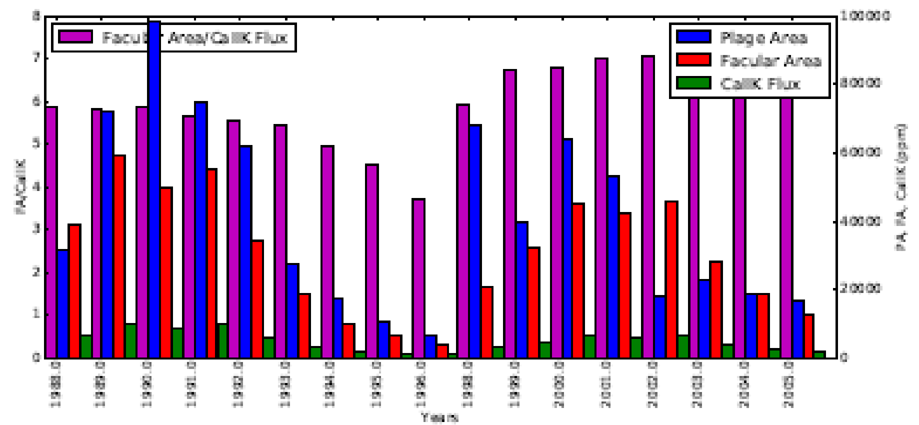
(a) Comparison of Ca II K-flux with normalized average sunspots counts in a time scale of a year is shown. The time intervals correspond to the Ca II K-flux are June, 15 1988-March, 1 2014.



(b) Comparison of FA with normalized average sunspots counts in a time scale of a year is shown. The time intervals correspond to the FA are June, 15 1988-March, 1 2014.



(c) Comparison of PA with normalized average sunspots counts in a time scale of a year is shown. The time intervals correspond to the PA are June, 15 1986-June, 15 2005.



(d) Comparison of grouped ratio of FA to Ca II K-flux with PA and FA, and Ca II K-flux in a time scale of a year is shown. The horizontal axis corresponds to the period August, 3 1988-June, 27 2005.

Figure 4. Variations of monthly mean Ca II K-flux, FA and PA data and sunspot numbers versus years are given. The horizontal axis corresponds to the period June, 15 1988-March, 1 2014 for the Figs. 4(a) and 4(b) while it corresponds to the period June, 15 1986-June, 15 2005 and August, 3 1988-June, 27 2005 for the Figs 4(c) and 4(d), respectively. The y-axis on the left-hand sides show the Ca II K-flux, FA and PA with the purple color while the averaged SSC numbers for AB, C, H and DEF classes are indicated on the right-hand sides of the y-axis with blue, red, green and light-green colors for the Figs. (a), (b) and (c), respectively. In addition to this, the y-axis on the left-hand side shows the grouped ratio of FA to Ca II K-flux with the purple color while the PA and FA, and Ca II K-flux are the blue, red and green colors are indicated on the right-hand side of the y-axis in Fig. (d).

* **BAR PLOTS:** (3) 2002-2008: DEF ratio is decreasing with decreasing FA & AB, C and H ratio is increasing. FA ratio decreases with increasing activity levels. PA correlates with the C SGs.

(4) **Fig. 4(a):** Decreasing of Ca II K-flux (SAC 23) & SAC 24 has a lower values than SAC 23 & highest Ca II K-flux (SAC 22)

Min. p. SAC 22 (Ca II K-flux decreases with decreasing percentage of SGs as C > DEF > AB from 1991 to 1995) & (the total number of large SGs are still higher)

Max. p. SAC 23 (increase with DEF SGs from 1996-2000)

Min. p. SAC 23 (the yearly percentage of the SGs – DEF > AB > C) & Ca II K-flux highly decreased & From the year 2001 to 2005 – DEF > C > AB & From 2006 to 2009 – AB SGs started to increase.

Fig. 4(b): Max. p. SAC 22- From the year 1988 to 1990 – Fa and Ca II K-flux show similar variations.

Min. P. SAC 22- FA is higher or comparable & the average area of Ca II K-flux (and faculae) 37% (63%)

Max. p. SAC 23 – FA started to increase from 1996 to 2000. FA correlates with large SGs & the total area of faculae was higher even in the decreasing phase of SAC 23 (beginning 2001) & the average area of Ca II K-flux (and faculae) 45% (56%)

Min. p. SAC 23 - the average area of Ca II K-flux (and faculae) 13% (87%)

Max. P. SAC 24 - the average area of Ca II K-flux (and faculae) 13% (87%)

Fig. 4(d): Plot the grouped ratio of FA to Ca II K-flux:

The percentages for the total area ratio of faculae to Ca II K-flux; the total area of plages; facula and Ca II K-flux are given as (Min. p. SAC 22- 31%; 47.44 %; 42% and 34.43%) & (Min. p. SAC 23-46%; 31.3%; 43.87%; 53.28%). Only total area of plages (decreased – SAC 23)

The average values of the area ratio of faculae to Ca II K-flux; the total area of plages; facula and Ca II K-flux are given as (Min. p. SAC 22- 31.8%; 47.40 %; 43.66% and 36.78%) & (Min. p. SAC 23 -39%; 26%; 38%; 47.46%). Only average area of faculae (decreased – SAC 23)

The covered area of faculae and Ca II K-flux on the solar surface was small & PA was still influence in the ascending phase fo SAC 23.

Fig. 4(c): For PA:

Min. p. SAC 23 – SAC 22 (38%) >> SAC 23 (25.3%)

Max. p. SAC 23 – SAC 22 (19.6%) ≈ SAC 23 (17%)

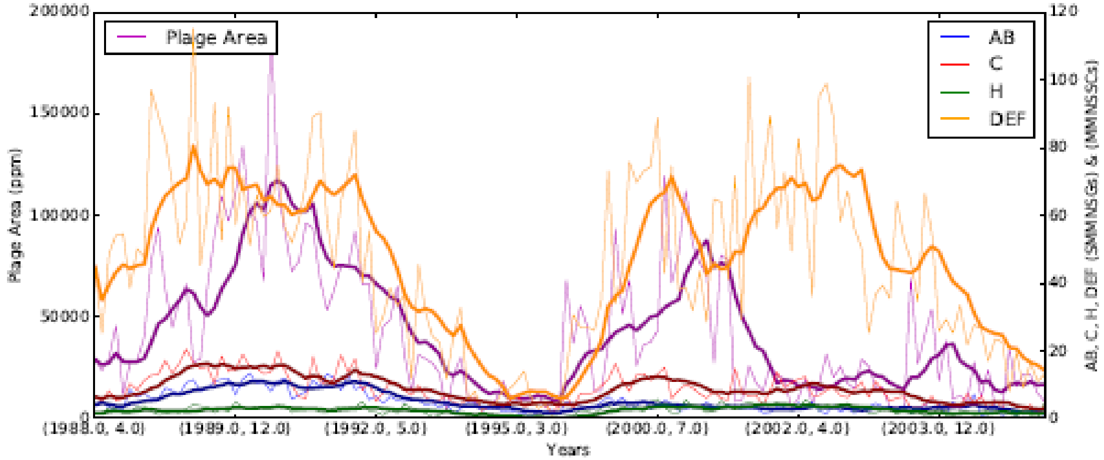
Average PA: Min p. SAC 23 - SAC 22 (36%) >> SAC 23 (20%)
Max. p. SAC 23 – SAC 22 (23.4%) ≈ SAC 23 (20.4%)

PA are mostly related with DEF and C SGs rather than AB and H SGs.

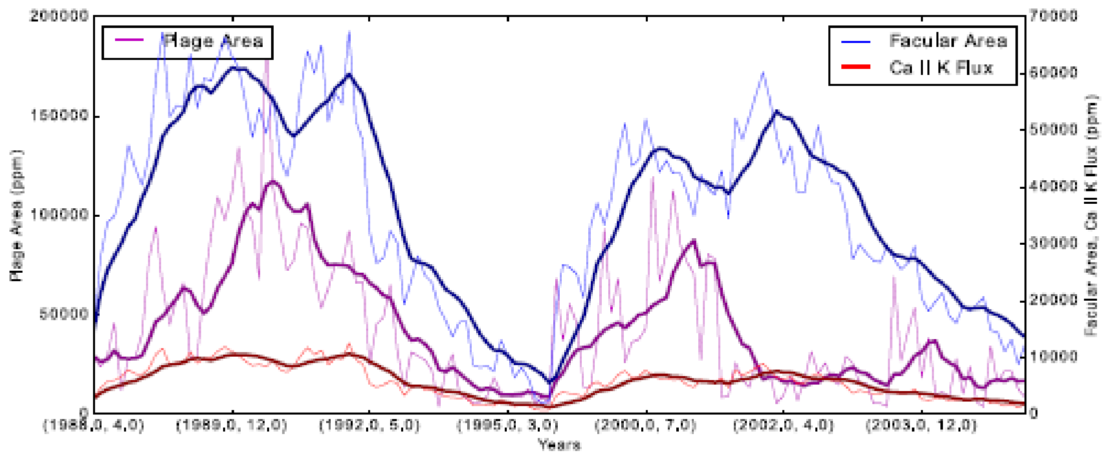
Why do the PA in a low numbers while Def SGs are higher numbers in all SACs? What did cause this decreasing in the PA?

Table 1. Pearson Correlation Coefficients between Solar Indices (SI) and AB, C, H and DEF type SGs.

SI	AB	C	H	DEF
$\lvert B \rvert$	0.626	0.632	0.455	0.630
TSI	0.736	0.840	0.754	0.896
FA	0.708	0.859	0.752	0.890
Ca II K-Flux	0.760	0.864	0.704	0.869
PA	0.612	0.595	0.266	0.411



(a) Time series of monthly grouped and averaged PA compared with time series of AB, C, H and DEF type sunspot counts are given. Thick lines are 15 day simple moving averages.



(b) Time series of monthly grouped and averaged PA compared with monthly grouped and averaged FA and Ca II K-flux are given. Thick lines are 15 day simple moving averages.

Figure 5. The x-direction denotes the years and the y-direction denotes the monthly mean SGs and SSC numbers (right) and the monthly grouped and averaged PA (left) in Fig. (a). Besides, the y-direction denotes the monthly grouped and averaged FA and Ca II K-flux (right) and the monthly grouped and averaged PA (left)in Fig. (b). The SSCs data start from April, 17 1988 and finish in December, 20 2005 while PA and FA, and Ca II K-flux data start from April, 17 1988 till to December, 20 2005. In Fig. 5 (a), the PA is shown with purple color while AB, C, H and DEF are shown with blue, red, green and yellow colors, respectively. In Fig. 5 (b), the PA is indicated with purple color while FA and Ca II K-flux are shown with blue and red color, respectively.

* **Plage Regions:** (1) DEF SGs start their rising before the PA evaluate & other SGs follow the evolution steps of PA.

(2) The covered area of plages decrease (after the middle of 2002) & the connection between PA and DEF SGs is in a lower percent.

(3) Large SGs have peaks in the max. p. SACs 22 (beginning of 1990 and 1992) and 23 (end of 2000 and middle of 2002) & small SGs have regular variation & peaks for PA are closer and start in the beginning of 2001 (SAC 23)

(4) FA reach the first and second peaks in the middle of 1990 and 1992 & PA show only one peak in 1991 (SAC 22) and FA reach the first and second peaks in the beginning of 2001 and middle of 2002 & PA show only one peak in 2001 (SAC 23)

(5) FA evaluated before the evolution of plage regions & reach max. before than the PA.

(6) Small SGs (AB and C) : lower in SAC 23

Large SGs (DEF): higher (or comparabele with SAC 22) in SAC 23

Large SGs: effective in the second max. (after the year 2002) & FA were higher from the beginning of 2001 opposite to Ca II K-flux

The covered area of plages decreased after the middle of the year 2002.

In SAC 23, large SGs reached their max. number about two years later than the small SGs & this difference is more efficient for magnetic field than TSI

MAGNETIC FIELD İS RELATED WITH SMALL SGs WHILE TSI VALUES ARE RELATED WITH LARGE SGs && LARGE SGs FOLLOW SACS WELL-ORDERED THAN SMALL SGs.

We investigated for the first time,

(1) Compared the solar surface indices with the types of SGs for different Solar Activity Cycles (21-23).

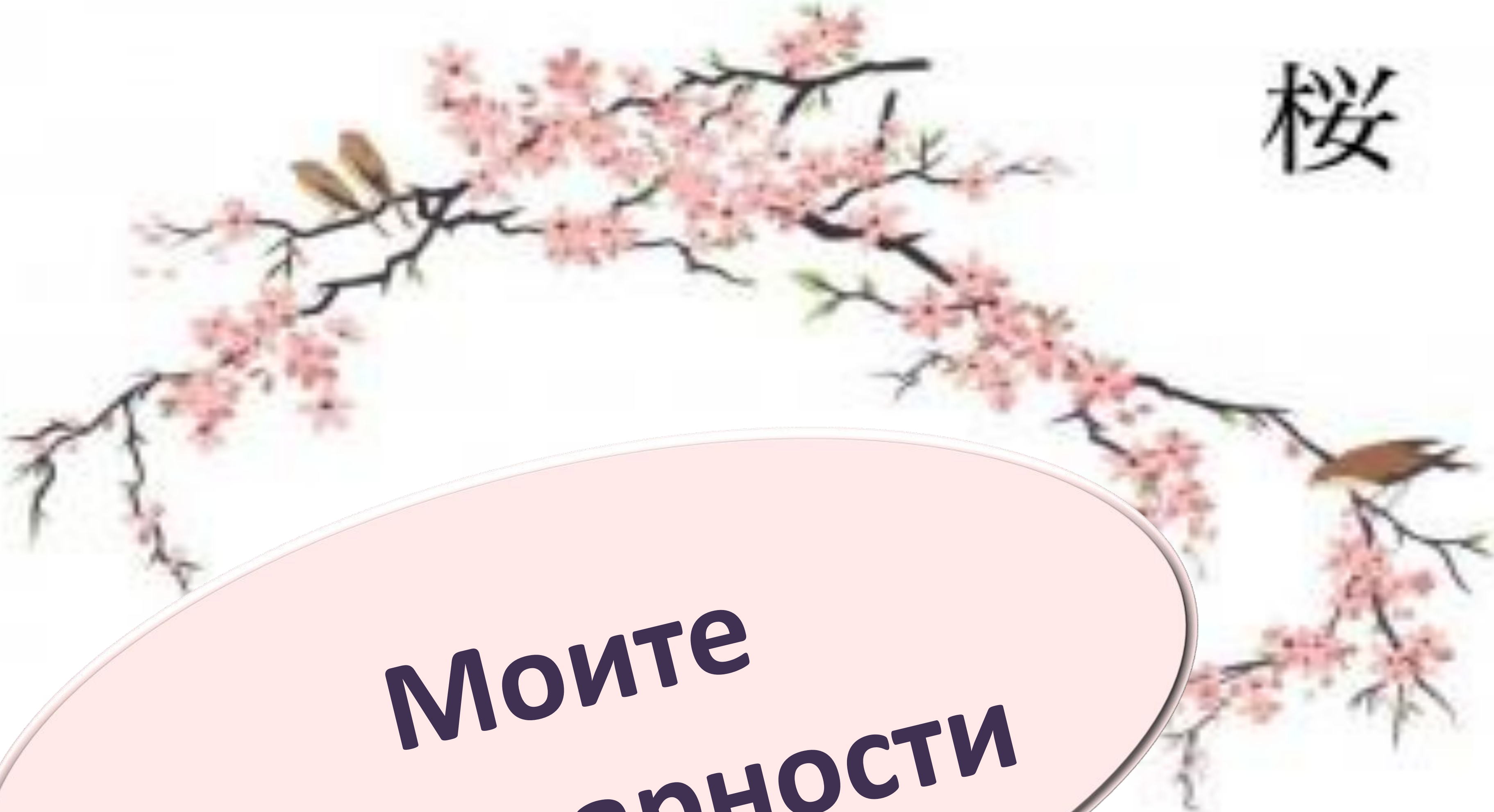
(2) FA have a strong influence on the TSI & Local magnetic field is strongly related with plage regions.

(3) Ca II K-flux and PA ⟶ small SGs (especially C SGs) & FA ⟶ large SGs & FA and Ca II K-flux were seperated from sychronization in the beginning of 1999 (FA increase, Ca II K-flux decrease) & This structure explains the variations in the intensity profiles and especially for UV region of the spectrum.

(4) Our results show the importance of solar surface indices to the length of 11yr solar cycle and their relation between the time distribution of SGs depending on their types (size and complexity of different type of SGs) for the first time in the literature.

(5) The dynamo problem and/or helio-seismic oscillations inside the Sun will be proved our findings.

(6) The inner parts of the Sun remarkably changed in SAC 23 and our first definitions changed the general definitions about the SACs.



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