Reconstruction of solar magnetic field during Cycles 15-19 based on proxies from Kodaikanal Solar Observatory

Alexander V. Mordvinov[1], **Bidya Binay Karak[2]**, Dipankar Banerjee[3,4,5], Subhamoy Chatterjee[5], Elena M. Golubeva[1], Anna I. Khlystova[1]

[1]Institute of Solar-Terrestrial Physics, Irkutsk, 664033, Russia

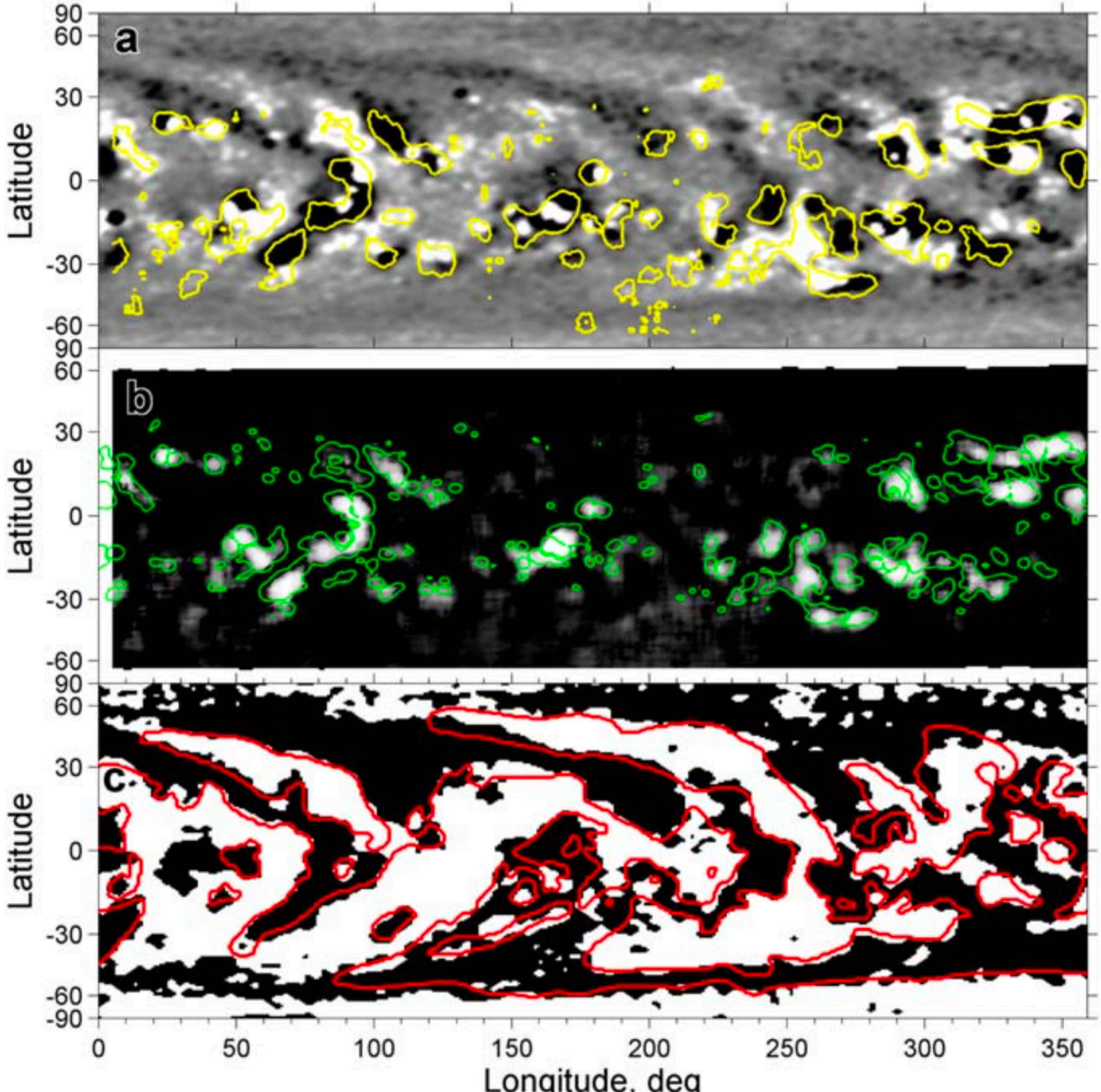
[2]Department of Physics, Indian Institute of Technology (Banaras Hindu University), Varanasi, India

Reference: Mordvinov, Karak, Banerjee, Chatterjee, Golubeva & Khlystova ApJL (2020)

Introduction

- Chromospheric filaments outline large-scale magnetic patterns. McIntosh (1979) compiled synoptic maps of magnetic fields using long-term observations.
- **Makarov, Fatianov, and Sivaraman (1983)** analysed similar synoptic maps from Kodaikanal Solar Observatory (KoSO). They studied global evolution of magnetic fields and found a poleward migration of chromospheric filaments.
- Their approach, however, did not provide any information on magnetic field strength.
- **Pevtsov et al. (2016)** reconstructed solar magnetic fields using the CaK observations from Mount Wilson Observatory data and on sunspot polarities **(Virtanen et al. 2019).**
- We developed new reconstruction method by using synoptic maps of the CaK and Hα emission from KoSO.
- To reconstruct magnetic fields, we estimated empirical regression relations between the CaK intensity and unsigned magnetic flux (NSO/KPVT).
- Signs of the magnetic flux were accepted according to the corresponding maps of dominant polarities (Makarov & Sivaraman KoSO archives 1986-2007).

Magnetic flux, the CaK plages, dominant polarities CR 1717



Magnetic flux (KPVT).

The yellow contours: locations of Ca II K plages that exceed a threshold of 170.

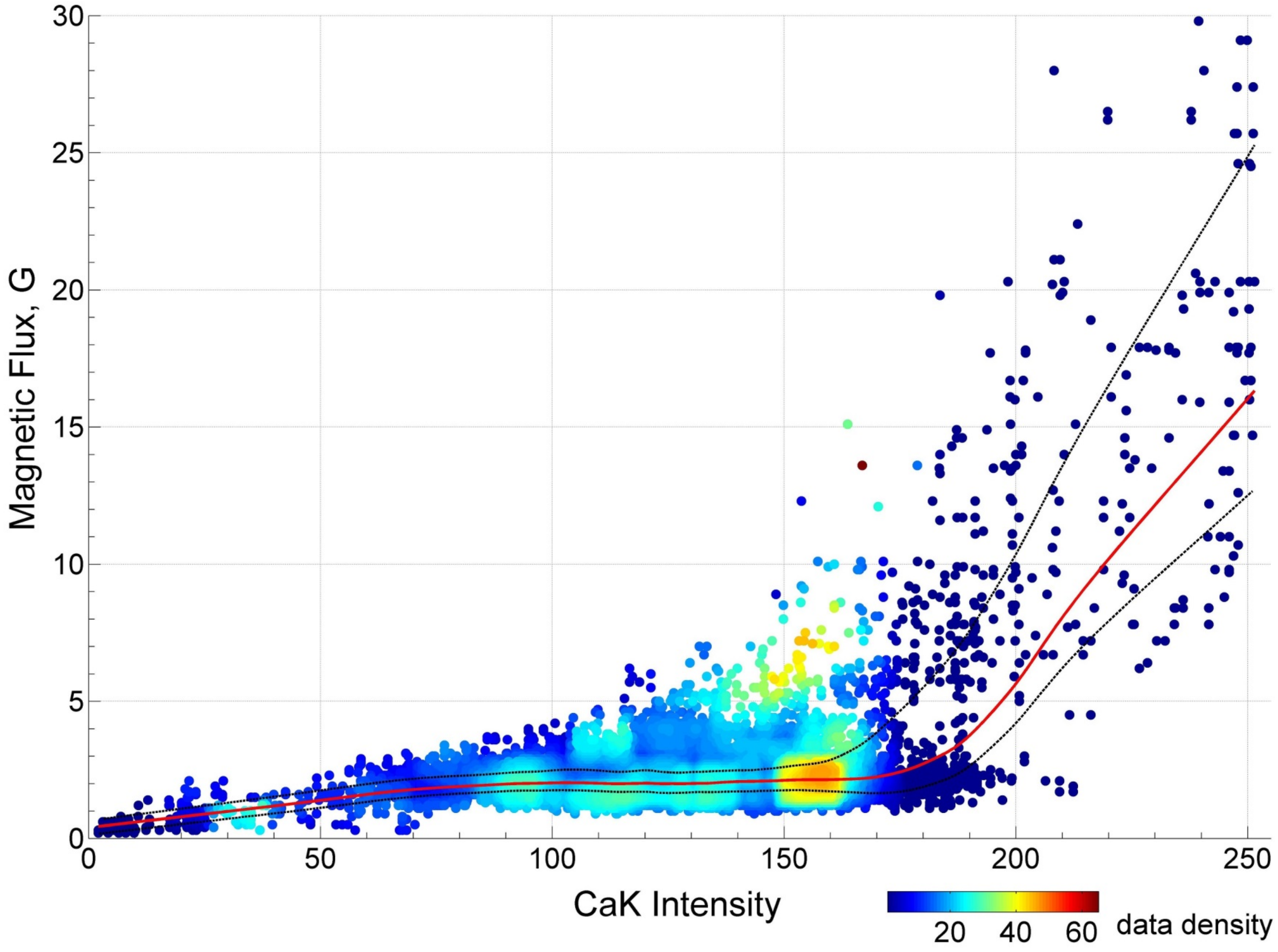
The Ca II K intensity map; Green contours: abs(flux) ≥ 20 G.

sign(flux) and

Polarity Inversion Lines (PIL); McIntosh (1979)

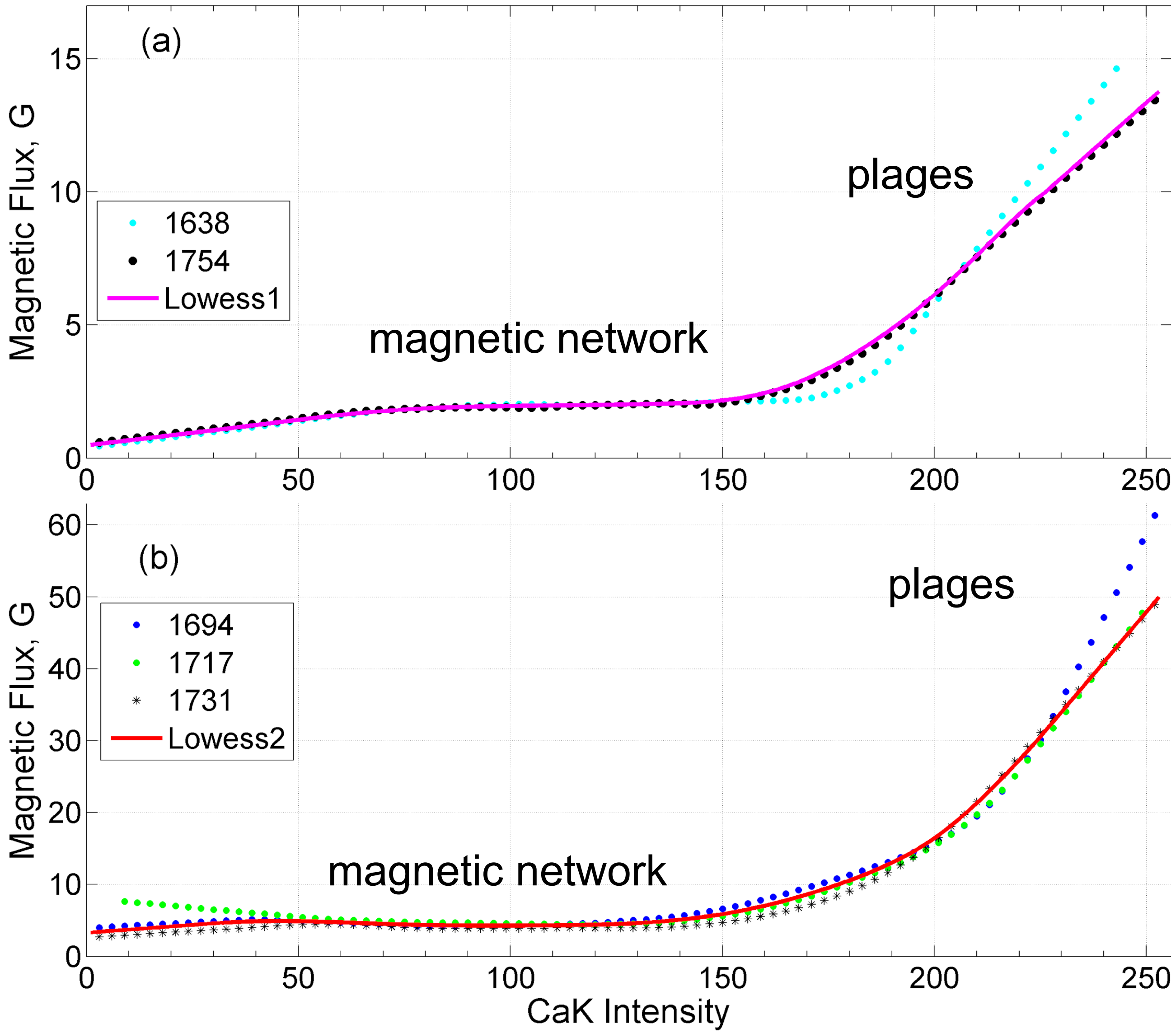
2-29 Jan 1982

Regression relation the CaK intensity-magnetic flux, CR 1638



The CaK intensity (8-bit KoSO native scale) vs magnetic flux density (KPVT).
Locally Weighted Scatterplot Smoothing (Lowess) algorithm (Cleveland, 1979)

The intensity-flux regression at low- and high-activity levels

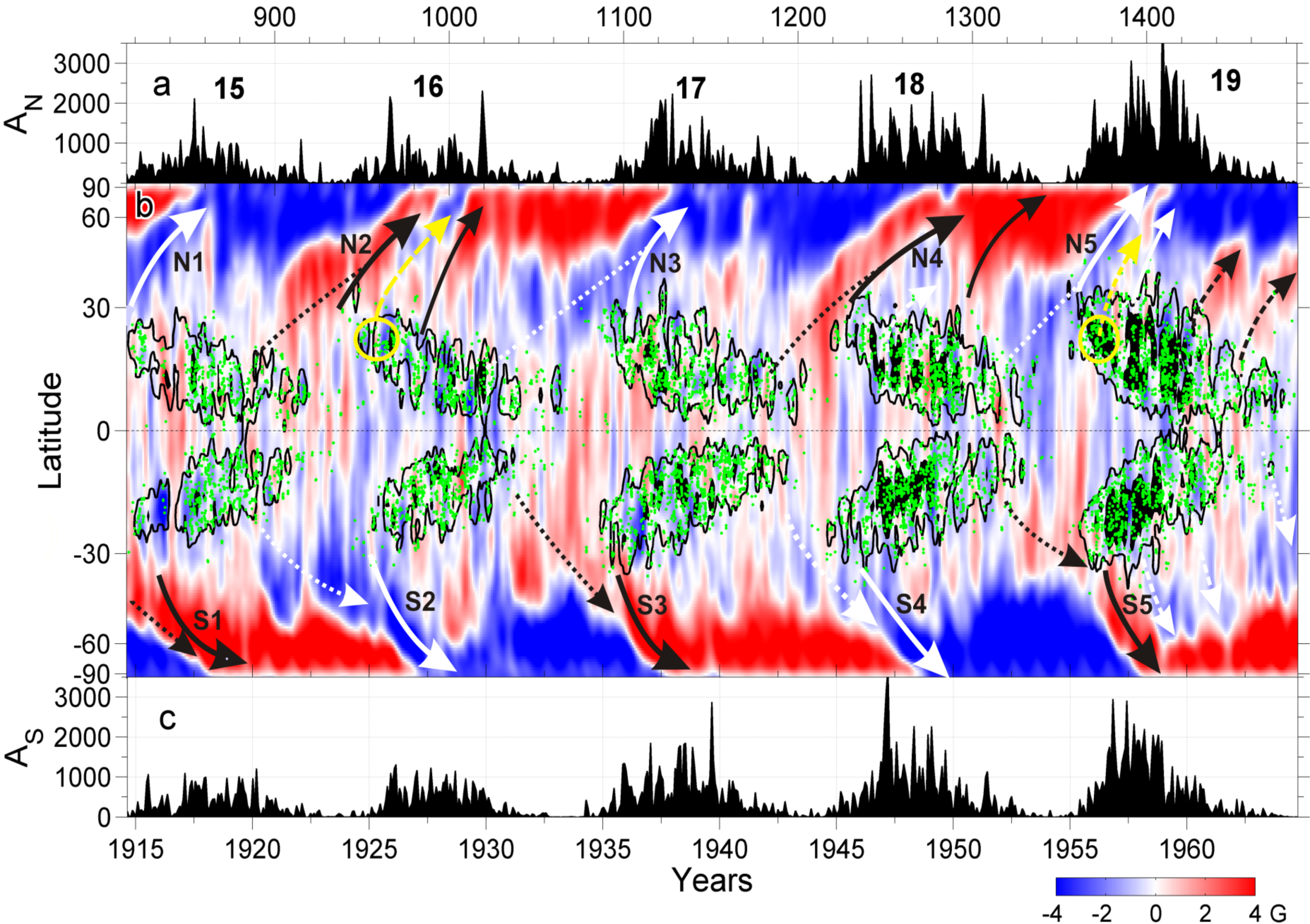


mean CaK intensity
(at activity minima)

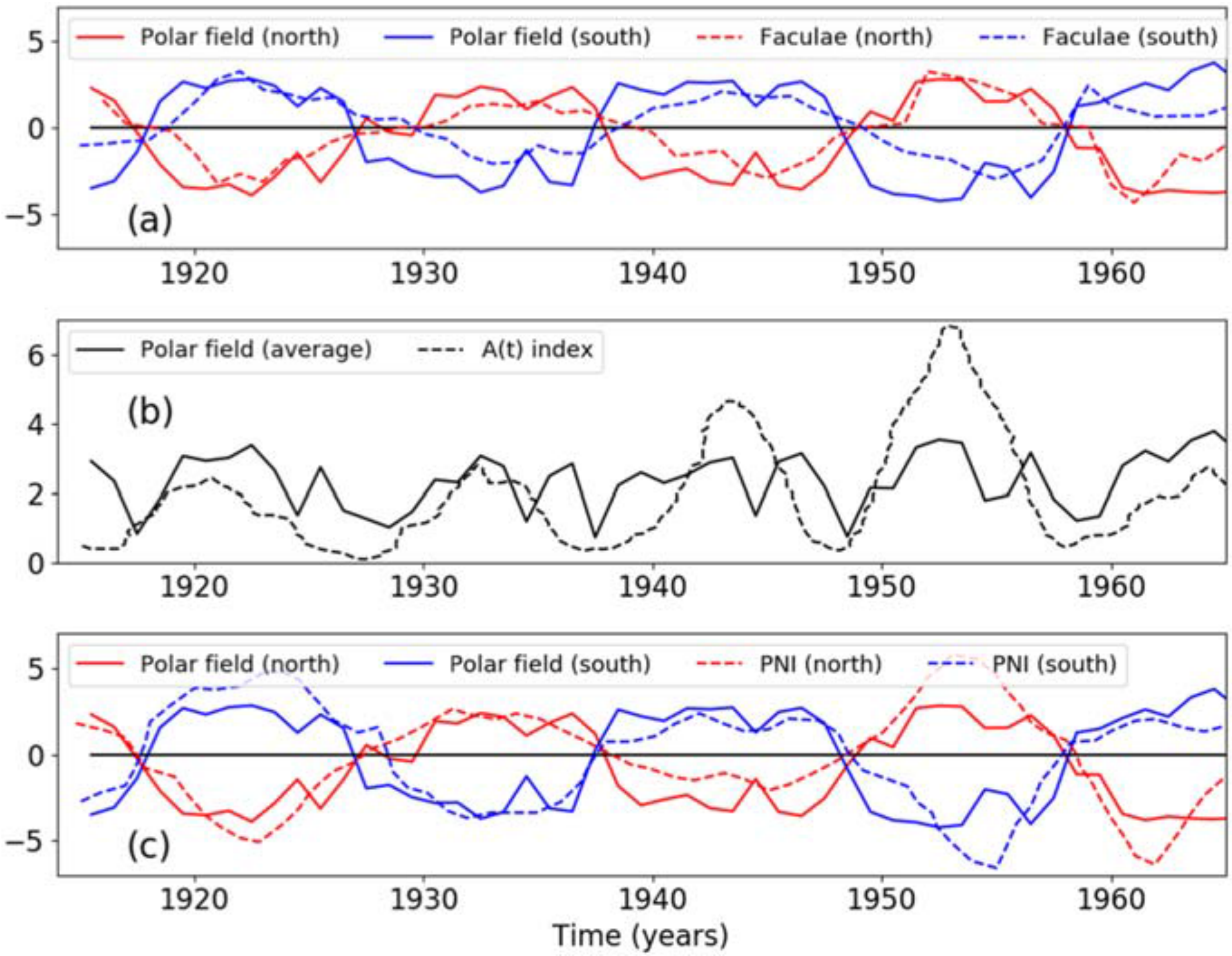
mean CaK intensity
(at high magnetic activity)

The CaK intensity vs unsigned magnetic flux (KPVT)

Butterfly diagram of reconstructed magnetic field on the solar surface in cycles 15-19



Comparison of our reconstructed polar magnetic field with other proxies



(a) Comparison with polar faculae count (Muñoz-Jaramillo et al. 2012).

(b) Makarov's A(t) index.

(c) Polar Network Index (PNI; Priyal et al. 2014 ApJ).

Comparison of our polar field computed by averaging the reconstructed magnetic field from 55° to pole (solid lines) with other proxies.

Conclusions

- We develop a new method of magnetic flux reconstruction using synoptic observations of the Sun's emission in Ca II K and Hα lines from KoSO.
- A spatiotemporal behavior of the reconstructed magnetic flux was studied in Cycles 15-19.
- The decay of non-Joy and anti-Hale ARs results in leading-polarity surges that disturb the usual order in magnetic flux transport and sometimes lead to multiple polar field reversals.

Thank you!

The poleward filament migration and polar-field reversals

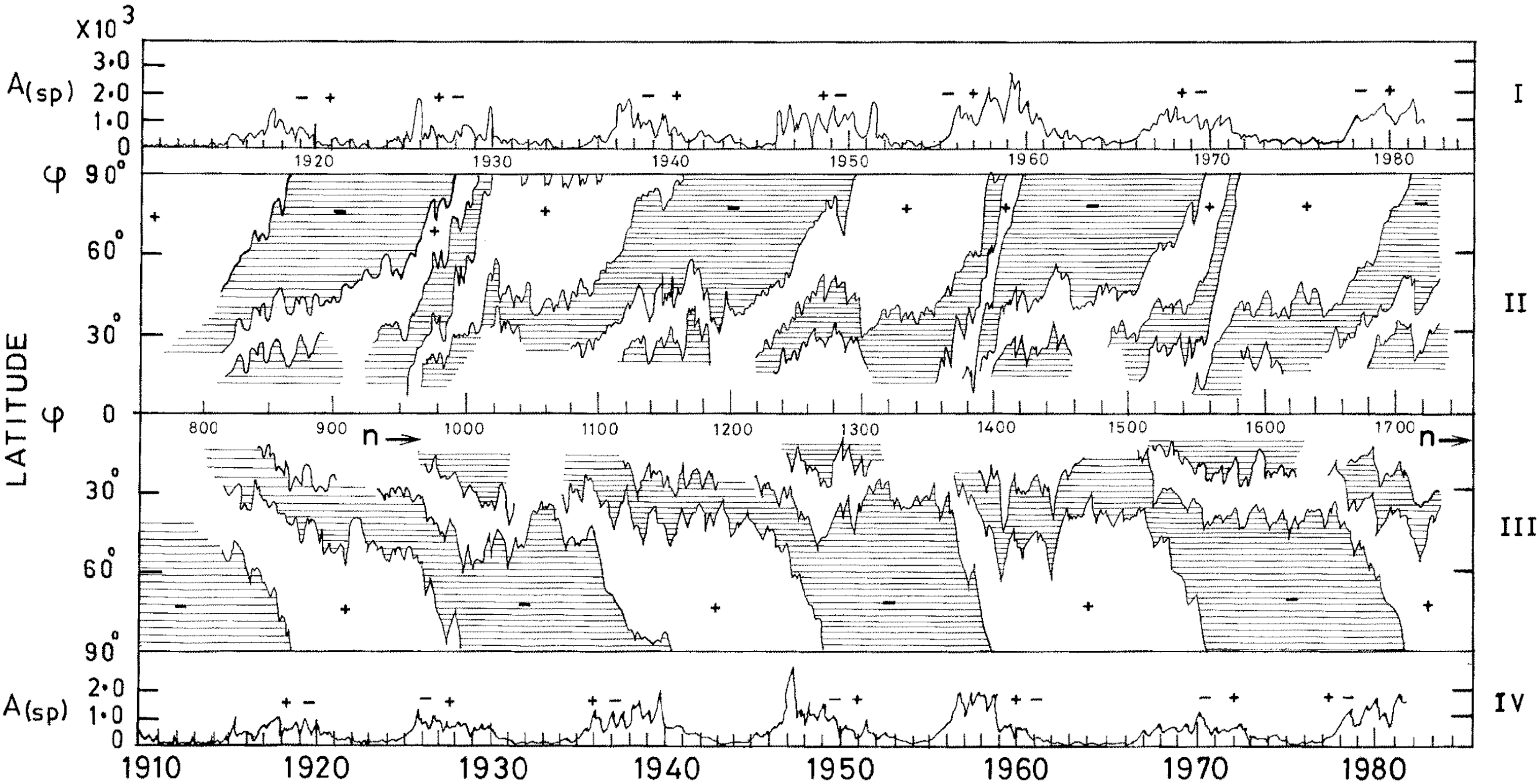
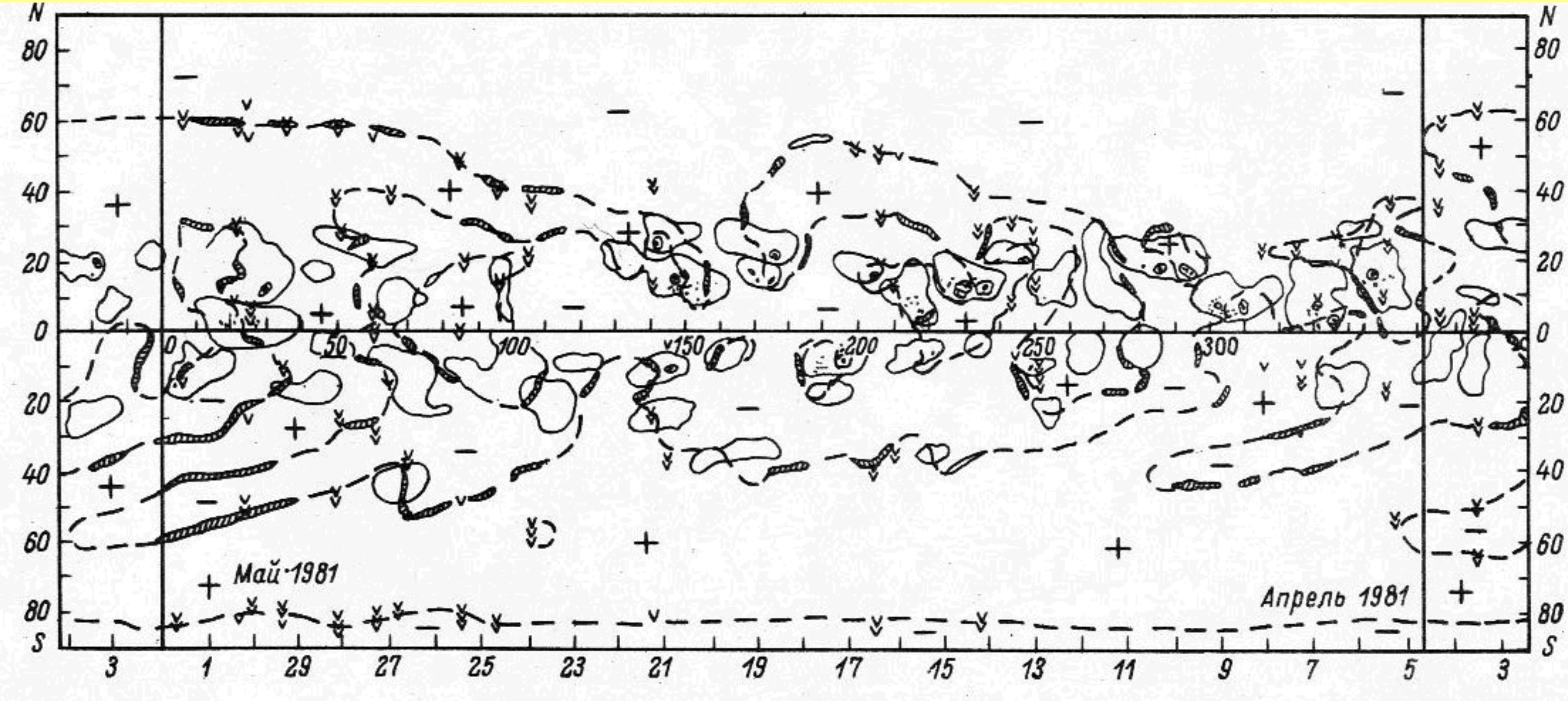


Fig. 1. Boxes II and III show the migration trajectories of magnetic neutral lines (filament bands) derived from H-alpha synoptic charts in the northern and southern hemispheres for the period 1010–1982. Dashed areas correspond to negative polarities and clear areas to positive polarities. Boxes I and IV: The continuous curve represents the run of mean daily areas of sunspots average over one rotation with 3-point smoothing. *A* (Sp) are the areas of sunspots in millionths of the visible hemisphere.

- Makarov and Sivaraman (1983) found triple reversals of the Sun’s polar fields in Cycles 16,19, 20.
- So far, there is no convincing physical explanation of these phenomena.

The Hα synoptic map outline large-scale magnetic patterns CR=1707



- Makarov and Sivaraman compiled Hα synoptic maps using long-term observations from KoSO.
- We digitized these maps in 180x360 pixel format. These maps quantify large-scale magnetic fields with ±1 values for cycles 15-19.

Interrelation between adjacent solar cycles

New surges were found. They are marked with dotted arrows**.** These surges demonstrate the interrelation between adjacent cycles. The individual 11-yr cycles are linked in pairs.

Leading-polarities UMRs were formed near the equator. During the epochs of activity minima, these UMRs were transported at mid-latitudes.
At the beginning of the next cycle, ARs appear. After their decay new surges are formed. The leading-polarity surges from previous cycle strengthen following-polarity surges in the next cycle. The merger of these surges leads to an increase of the poleward flux transport that results in strengthening of polar magnetic fields in subsequent cycle.

It is believed that magnetic flux reconnects near the equator by the end of every cycle.
This interrelation between 11-yr cycles suggests a possible long-term memory in solar activity that varies on a secular timescale.