# MAGNETIC FLUX TRANSPORT IN THE PHOTOSPHERE OF THE SUN

**D. G. BARANOV**

*Physical-Technical Institute,*
*St. Petersburg, Russia;*

*d.baranov@bk.ru*

**E.S. VERNOVA, M.I. TYASTO, O.A. DANILOVA**

*IZMIRAN, SPb. Branch,*
*St. Petersburg, Russia;*
*helena@ev13934.spb.edu*

## Data

Synoptic Maps of the Photospheric Magnetic Field produced at the Kitt Peak Observatory (NSO, 1978-2016) were used. Each map contains 180 * 360 pixels - values of magnetic field in Gauss.

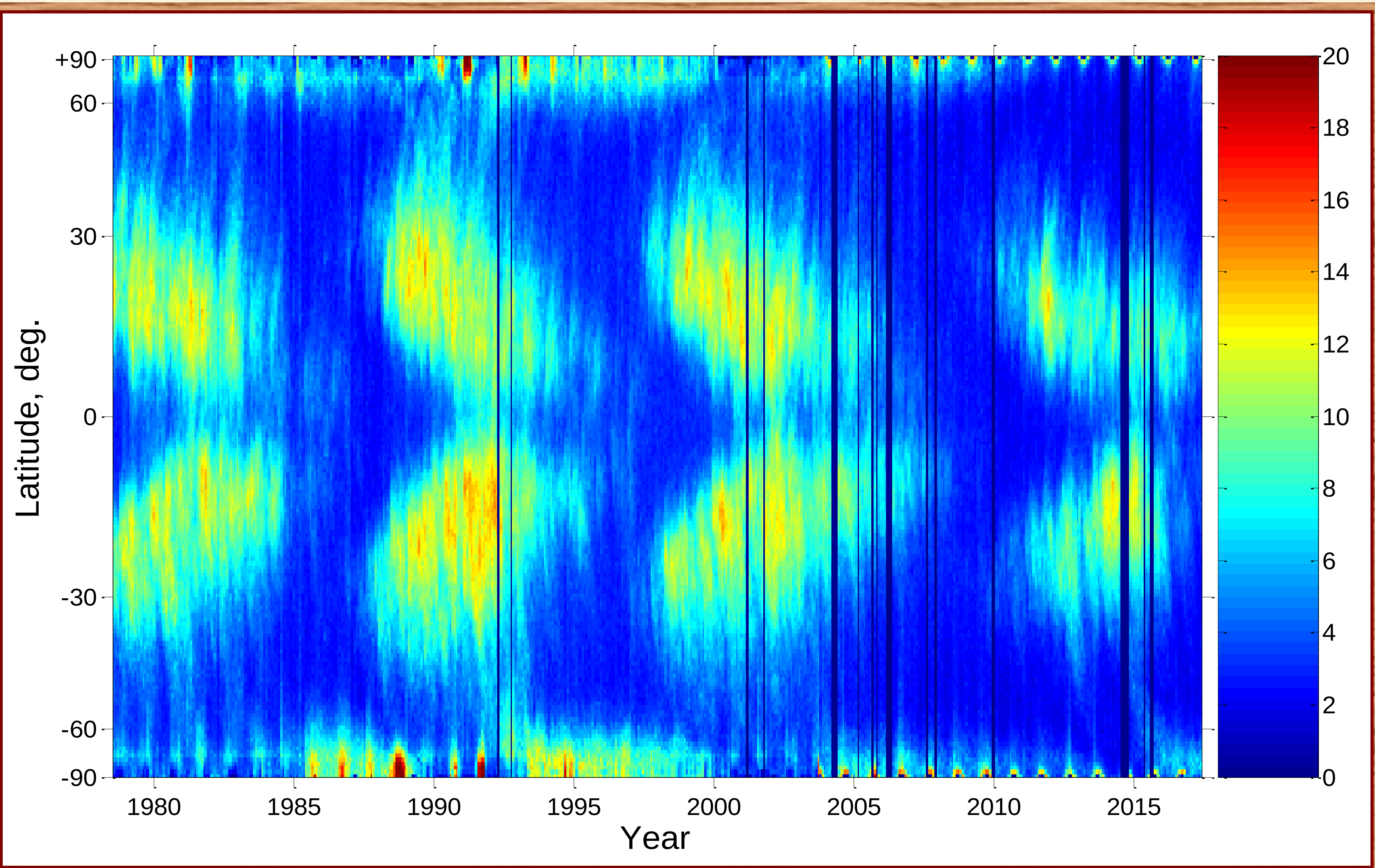
## Method

A time-latitude diagram of the magnetic field was constructed by averaging of synoptic maps over the longitude. When averaging, the sign of the magnetic field was taken into account. Selection of upper limit of intensity **5 G** allowed to consider distribution of weak magnetic fields showing the alternation of different polarity flows drifting towards poles.

## Results

Several different groups of magnetic flows were found. One of the groups can be seen in the diagram as relatively narrow inclined bands of alternating polarity (period **~1-2 yr**) which start near the equator and reach almost the poles of the Sun. The other group includes powerful flows, **3-4 years** wide, extending from the sunspot zone to the poles. The arrival of these streams to the near-polar zone coincides with the inversion of the Sun’s polar field (rush-to-the-poles, RTTP).

# Fig. 1. Time-latitude diagram for the field strength module with the saturation limit **B= 20 G**

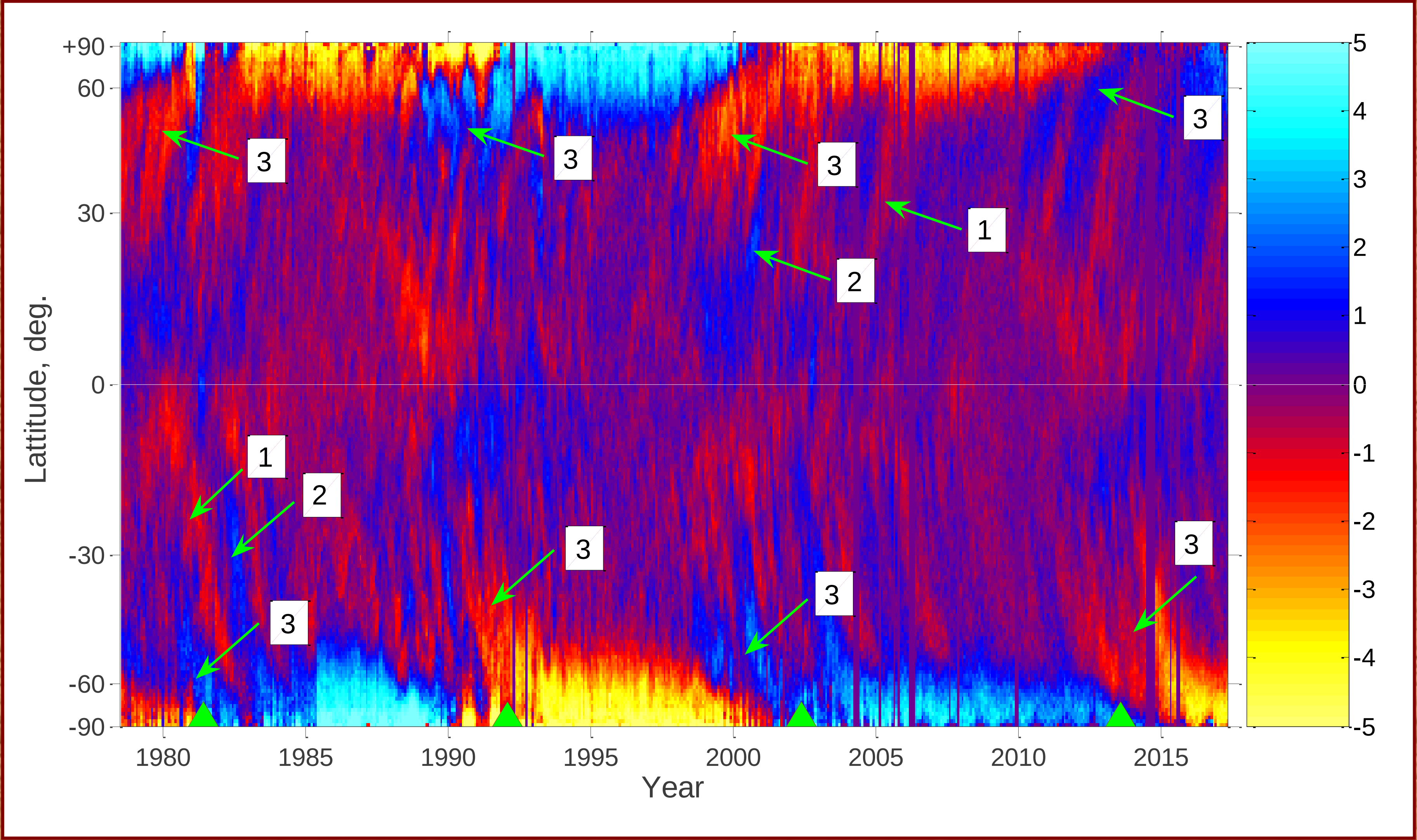


# Two kinds of the time-latitude diagrams

**Fig. 1** shows a conventional time-latitude diagram, which takes into account the absolute values of magnetic field intensity with the upper limit (saturation) at **20 G**. Such a diagram clearly shows Maunder 's "butterflies" and the increase in magnetic field intensity in the polar regions. Sometimes (as in 1993 in the southern hemisphere) it is possible to see the shift of activity from butterflies to the pole.

To study the distribution of weak positive and negative fields, another time-latitude diagram was obtained by averaging magnetic fields over longitude taking into account the field sign. **Fig. 2** shows a diagram with saturation at **5 G and - 5 G**. In this diagram, instead of "butterflies," positive (5 G), negative (- 5 G) magnetic fields are more pronounced in near-polar regions. The diagram shows mainly the distribution of magnetic fields with a strength about 2 G.

# Fig. 2. Time-latitude diagram for the fields B≤5 G



# Comments to the time-latitude diagram

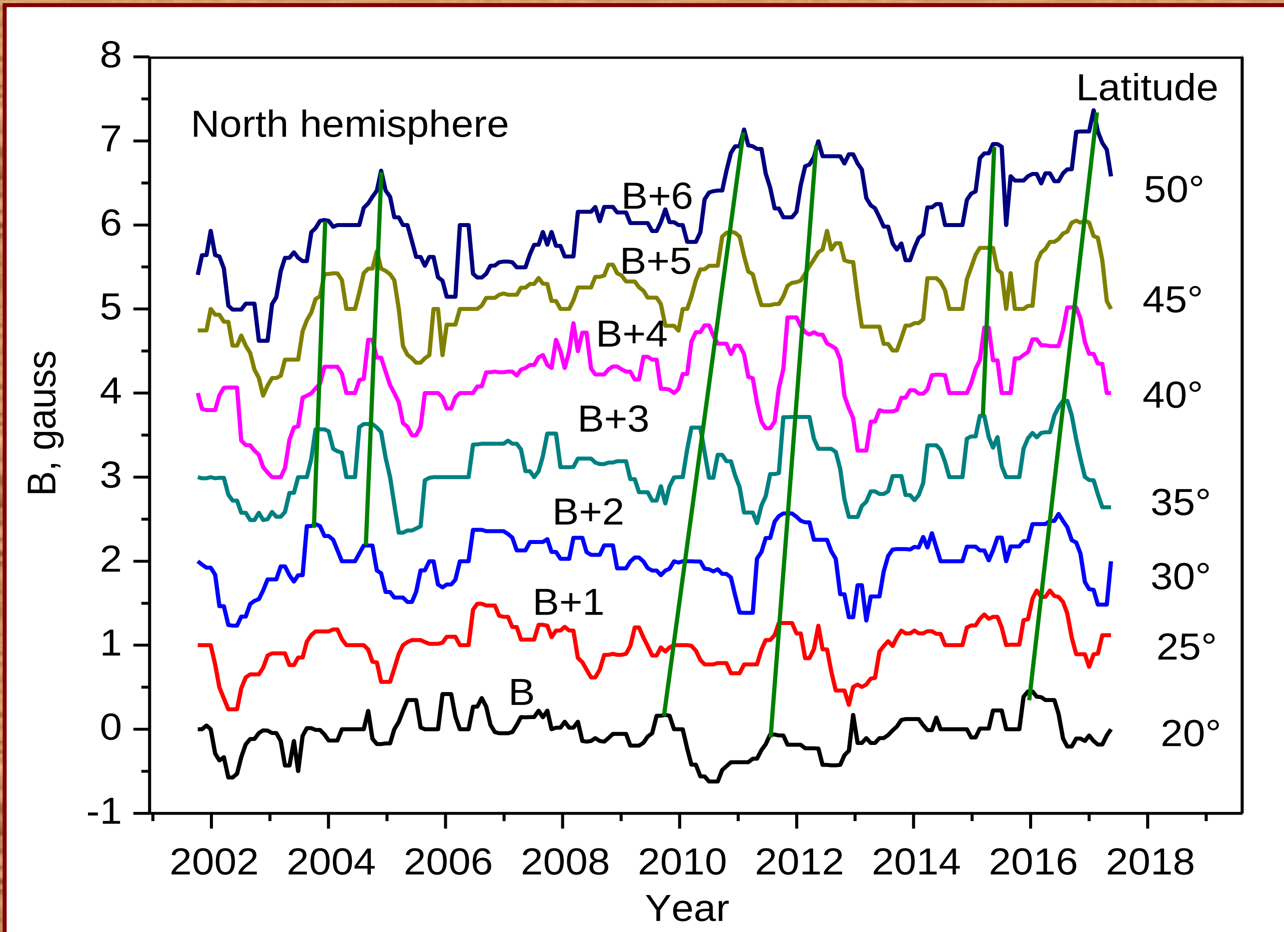
**<u>The numbers in the diagram (Fig. 2) denote:</u>**

1 - negative magnetic field flows (examples)
2 - positive magnetic field flows (examples)
3 - rush-to-the-poles flows (RTTP)

The diagram shows in the form of inclined bands of blue and red colors magnetic field flows of different polarity, drifting from the equator to the poles. Alternating flows of different signs occur at a certain frequency, more or less visible depending on the number of the cycle and the hemisphere of the Sun.

It is possible to distinguish: a) flows that start from the equator and reach almost to the pole (narrow bands); b) flows which start at latitudes ~30° – 40° (broad powerful bands: rush-to-the-poles) that lead to the inversion of the polar field. Inversion periods are marked with green markers.

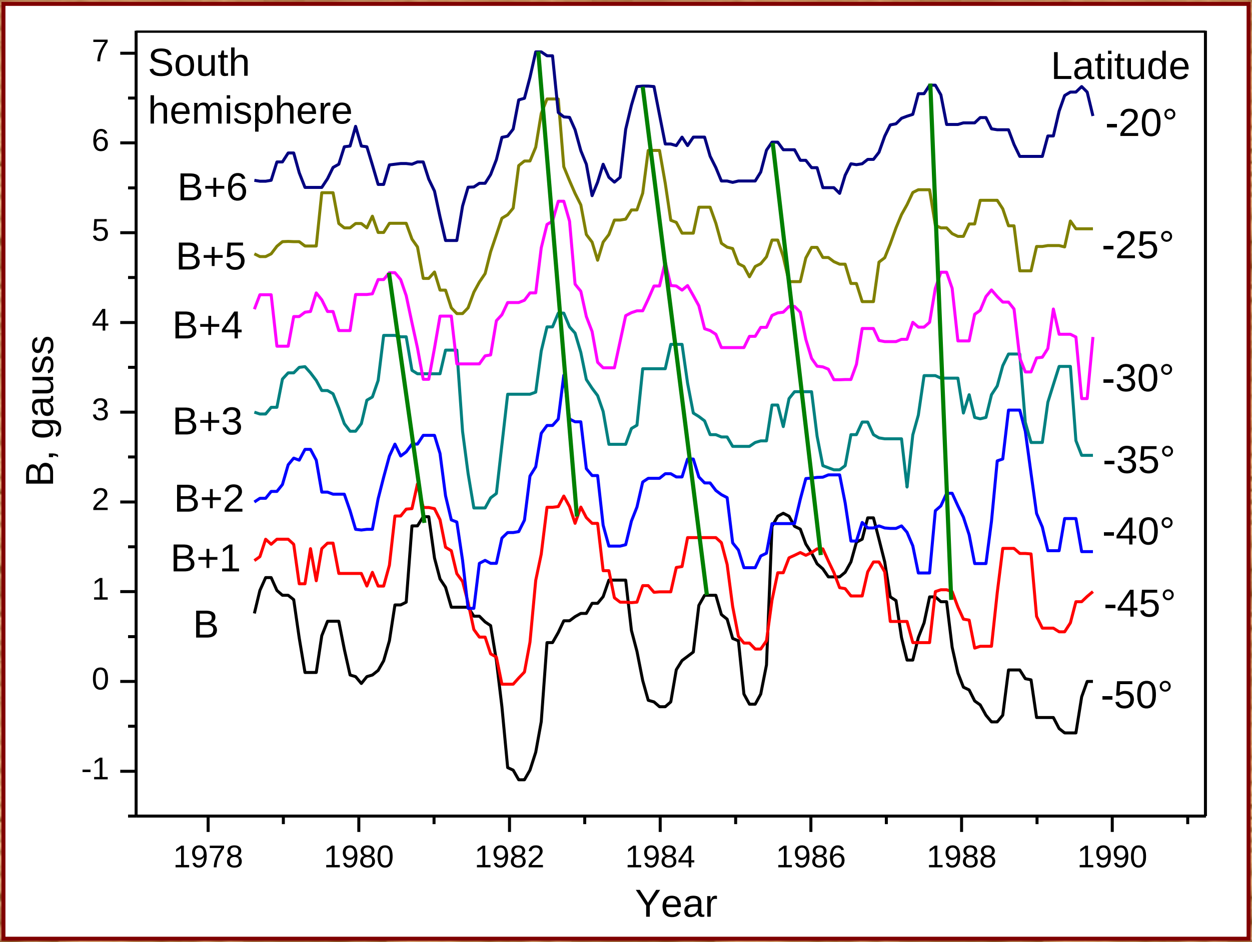
# Fig. 3. Time profiles of the magnetic field **B≤5 G** at latitudes 20°-50° (steps of 5°)




**N-hemisphere**

For convenience of viewing, time profiles for successive latitude intervals are shifted by 1 G relative to each other: B, B + 1,.. B + 6.

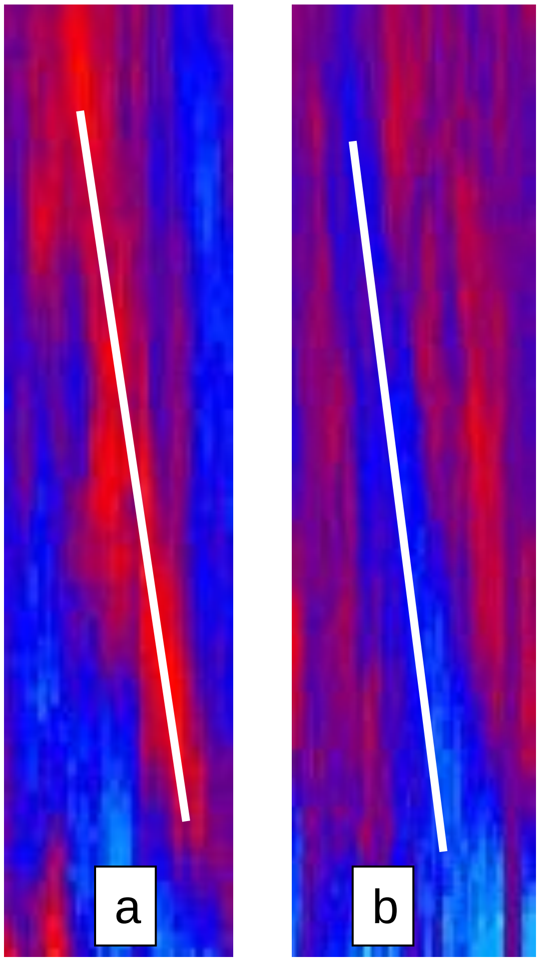
# Fig. 4. The same as in Fig. 3 for the S-hemisphere




The maxima and minima of the profiles correspond to the flows of positive and negative fields drifting towards the poles. Inclined straight lines connecting profile maxima show how positive fields are shifted in latitude over time.

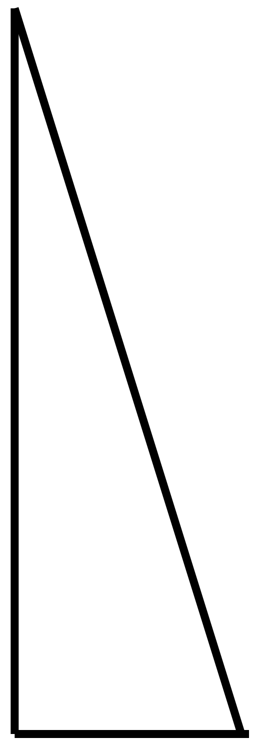
# Transport rate of the magnetic fields

Equator




South pole

$\Delta\theta$



$\Delta T$

The inclination of the magnetic field bands of positive (blue) and negative (red) polarities indicates the drift of the magnetic fields from the equator to the pole.

The drift rate can be estimated by the slope angle of the bands, see diagram and formula:

$$V = R_{sun} \times \Delta\theta/\Delta T,$$

where $\Delta\theta$ – latitude change in the $\Delta T$ time interval.
(a) and (b) – negative and positive fluxes of the magnetic field.

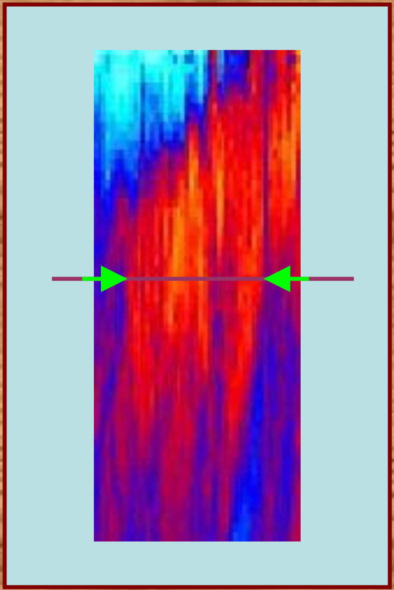
# Estimation of the transport rate for several groups of magnetic flows

Evaluation of the drift rate is possible when the magnetic flux bands appear sufficiently clearly. This occurs from 2002 to 2016 for the northern hemisphere and from 1978 to 1989, and from 2000 to 2012 for the southern hemisphere. Accordingly, the following estimates of the rate of meridian movement of magnetic flows were obtained:

| **North** | **South** |
|---|---|
| **$V=17\pm3$ m/s** | **$V=19\pm2$ m/s** |

# Examples of the rush-to-the-pole flows

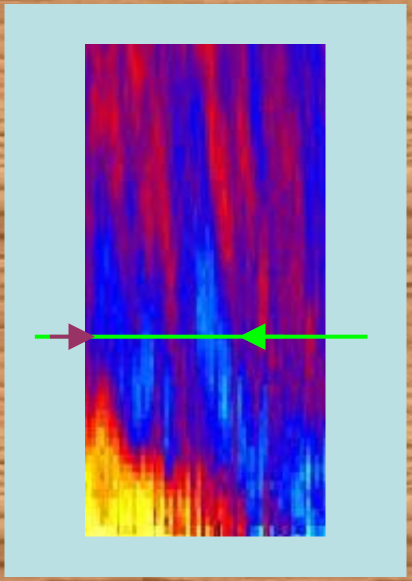
North hemisphere



The figures show examples of the RTTP lifetime estimation at latitudes +50° (N) and -50° (S).

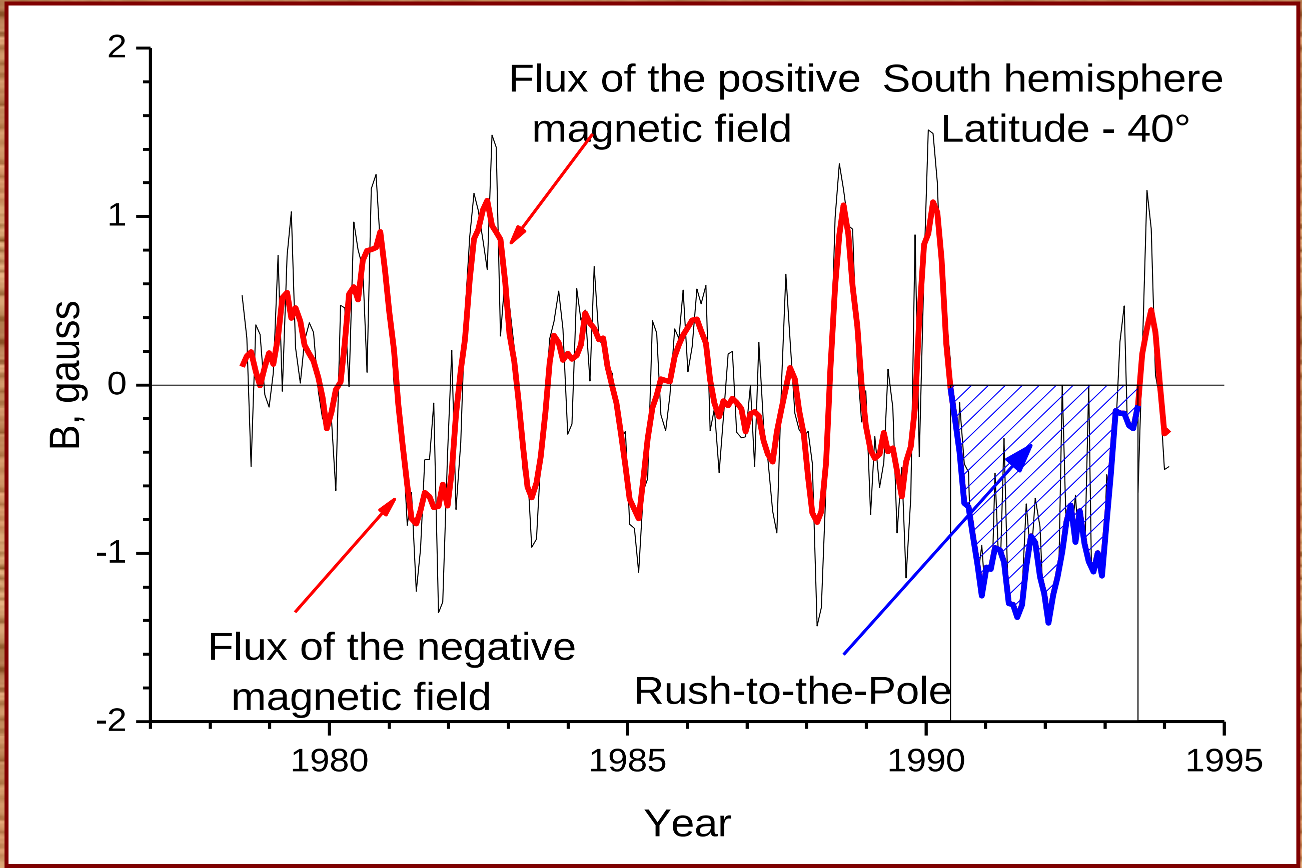
The average time of life of RTTP measured on 8 flows is **3.2 ± 0.3 years**.

South hemisphere



Among the the magnetic field flows drifting to the Sun's poles, there are powerful flows, which are connected with the reversal of the polar field sign. Starting from latitudes ~ 30° - 40°, these flows reach the near-polar regions in a period close to polar field reversal and appear to be its cause. These flows appear to be the so-called **rush-to-the-poles** phenomena.

# Fig. 5. Periodicity of the magnetic flow structure




Variations of the magnetic field strength at a fixed latitude (-40°) show that positive and negative flows alternate, forming a periodic structure. The blue shading points to the period of RTTP.

# Alternation of positive and negative magnetic field flows

| Hemisphere | Period | T, yrs |
|---|---|---|
| N | 1978.54 - 1989.67 | 1.42 |
| N | 1989.97 - 1998.40 | 1.44 |
| S | 1978.54 - 1989.67 | 1.79 |
| S | 2000.94 - 2012.15 | 1.22 |
| | $T_{mean}$=1.47 yr. | |

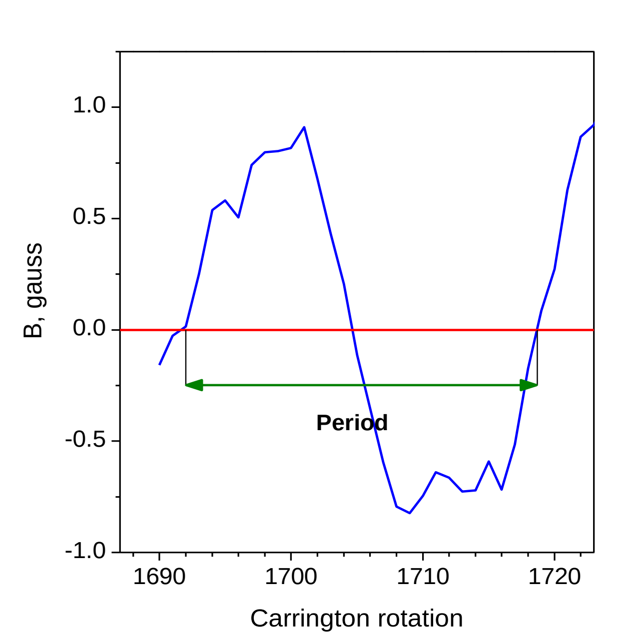



Figure 5 shows the magnetic field profile (latitude -40°) over a time interval in which variations in the polarity of the magnetic fluxes are especially pronounced. There were 4 such intervals during 21–24 cycles (see table). For each of intervals, an average period length was estimated (see diagram). Average period for all data: **Tmean=1.47 yr.**

# Conclusions

On the base of the Kitt Peak Observatory data, the transport of weak magnetic fields of different polarity from the equator towards the poles is considered.
Two groups of magnetic field flows are observed:

a) relatively narrow long bands with alternating polarity (average period of polarity change of **1.5 years**), starting near the equator and reaching almost the poles of the Sun.

b) short powerful flows of positive or negative polarity, **3-4 years** wide, propagating from the sunspot zone and reaching the near-poles region at the polar field reversal. These flows appear to be the so-called **rush-to-the-poles** phenomena.

The inclination of the bands corresponding to magnetic fluxes of different polarity allows to estimate the speed of meridional drift of magnetic fields which for two hemispheres differed a little: **V = (19±2) m/s** for the southern hemisphere and **V = (17±3) m/s** for the northern hemisphere.