LARGE-SCALE FLOW PATTERNS IN THE SOLAR ATMOSPHERE

K.R.Sivaraman
Indian Institute of Astrophysics
Bangalore 560034
INDIA

INTRODUCTION: It is now well established (McIntosh 1979; Makarov and Sivaraman 1983) that the filament and filament channels seen in the H-alpha spectroheliograms (or filtergrams) can be used as reliable tracers for studying the time evolution of large-scale magnetic fields on the Sun. These features represent the neutral lines between the unipolar regions of opposite polarity. Comparison of the synoptic charts compiled from H-alpha pictures with those from full-disc magnetograms for the same period shows very good agreement and hence the former can be used with confidence for time evolution studies of large-scale unipolar regions for those periods when the magnetographs did not even exist. In this paper we shall present one of the results of our study (Makarov and Sivaraman 1983, 1989) on the migration of H-alpha filaments, namely, the existence of the meridional flow on the Sun. We shall extend it further to show the participation of this meridional flow in the solar cycle variation.

DATA AND ANALYSIS: Starting from the H-alpha and K_{232} spectroheliograms of the Kodaikanal and Kislovodsk stations we constructed the H-alpha synoptic charts for the period 1904-1982. For the period 1964-1973 we used McIntosh's (1979) synoptic charts themselves. These charts show clearly the continous boundaries of the large-scale unipolar regions and it is possible to assign a mean latitude to every filament band over each solar rotation. We then plot such mean latitude values for the polemost filament band as well as for other filament bands as a function of time. The filament migration derived thus for the period 1910-1982 (Makarov and Sivaraman, 1989) is shown in Fig.1.

RESULTS: The filament bands start their poleward migration with small speeds ranging from 5 to 20 m sec^{-1} synchronously with the rising phase of the solar cycle (Fig.1) Around the peak of activity, these filament bands, which previously move slowly, experience a sudden acceleration resulting in velocities as high as 40-m sec^{-1} or more and on reaching the pole they cause the reversal of the polar fields.

E. R. Priest and V. Krishan (eds.), Basic Plasma Processes on the Sun, 101–105.

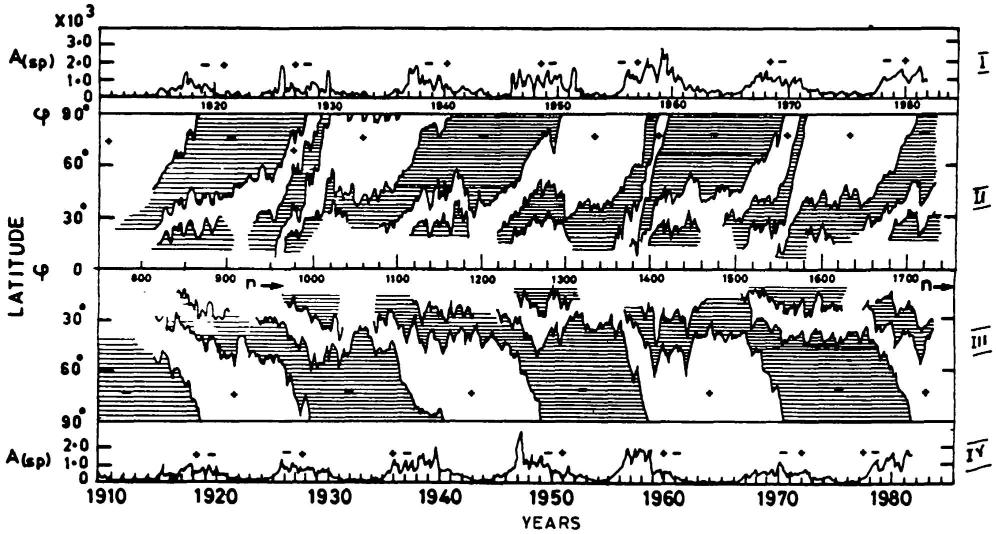

Fig.1. Boxes II and III show the migration trajectories of magnetic neutral lines (filament bands) in the North and South hemispheres for the period 1910-1982. Hatched areas: negative polarities and clear areas: positive polarities. Boxes I and IV: continous curve represents the run of the mean daily areas of sunspots [A(Sp)] in millionths of the visible hemisphere averaged over one rotation with 3 point smoothing.

Topka et al. (1982) have done a similar analysis for the period 1964-80 and there is perfect agreement between their results and ours for this period. We interpret that the motive force that causes the poleward migration of the filaments (which is also the transportation of unipolar magnetic regions) is a meridional flow towards the poles in the solar photosphere that has a mean velocity of 25-40 m s^{-1}. Topka et al. (1982) have shown that the process of diffusion alone is inadequate while a meridional flow can acount for the observed poleward transport. After the polar reversal, the filament bands which are to cause the next reversal are still at low latitudes (20°-30°) meandering with a quasi-oscillatory motion and they start the poleward journey only after the sunspot activity has increased.

DISCUSSIONS: Let us look at the Doppler measurements which show the meridional motion and compare these with the filament migration diagram. With the Doppler Zeeman Analyser, Beckers (1977) detected the meridional flow with velocity of 42 ± 9 ms^{-1}. Based on measurements on 89 days in the period July 1977-March 1978, Duvall (1979) detected in the latitude zone 10°-50° a meridional flow of 20 m s^{-1} from the Stanford magnetograph data. Howard (1979) from the analysis of Mt.Wilson Doppler measures for the period 1974-1977 also detected a poleward meridional flow with velocities of 20 m s^{-1}. Snodgrass reanalysing the Mt.Wilson data derived a latitude dependent polynomial fit to this flow and obtained a mean value of 10 m s^{-1} for the

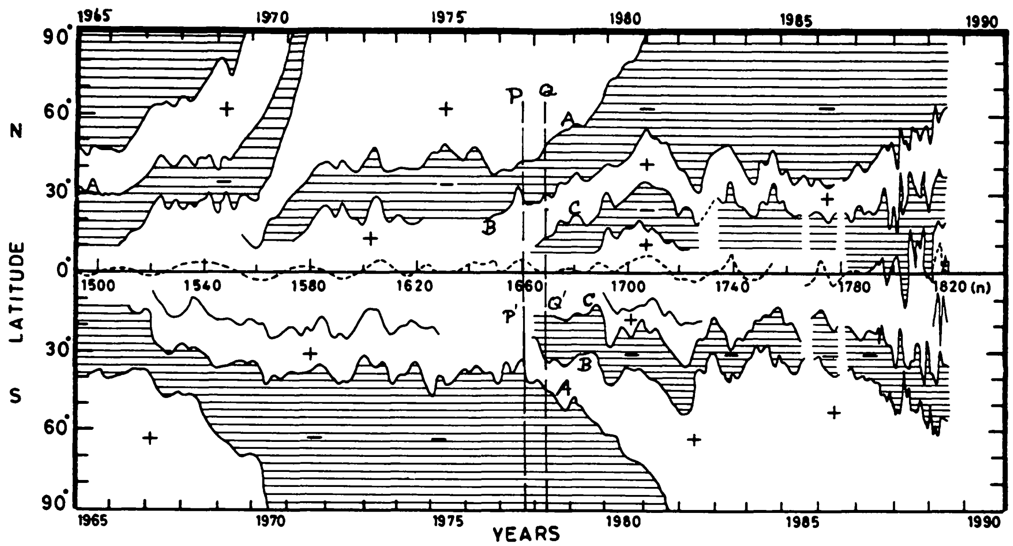

Fig.2. Migration trajectories for the period 1965-1988. The period July 1977 to March 1978 of Beckers' Doppler measurements (1978) is shown by the two vertical broken lines PP' and QQ'. Notice the filament bands, A, B and C in both the hemispheres show poleward migration during this period and are confined to the latitude zone 10°-40° where Beckers also detected the meridional flow.

period May 1982 to March 1984.

In Fig.2 we have reproduced the filament migration for the years 1965-1982 from Fig.1 and extended this to 1988 on a bigger scale to help comparison with the Doppler measurements. For example, Beckers' measures (1978) were obtained during July 1977 to March 1978. We have marked this period on Fig.2 in the north and south hemispheres. The meridional motion measured by him is reflected by the poleward moving filament bands A, B, & C (Fig.2). Similarly, the measurements of Duvall (1979) and of Snodgrass (1984) also fit well with the filament migration. Snodgrass's (1984) determinations show that the maximum of the velocity occurs around 30° latitude and this is what is to be expected from the migration diagram (Fig.2).

Another direction from which there is additional support is the meridional motion derived from line asymmetries of photospheric lines, but their agreement with the results of the filament migration studies have not been generally good. A possible reason could be that the Doppler measurement of meridional flow are in general complicated by a possible confusion with the latitude variation of the limb shift effect. In this respect the meridional motion determined from tracer measurements are superior and reliable. Cavallini et al. (1985, 1986) find a residual in the differences between the meridional and equatorial line shifts in the Fe I lines 6302.5A in July-August 1984 and July-September 1985. Their measurements on 6302.5A show a maximum at 30°-40° latitude and agree with Fig.2 although their velocities of 50 m s^{-1} are higher. Their measurements using 5576A done in July-

September 1985 do not agree with our migration diagram.

Ambroz's (1987) analysis of the evolution of unipolar magnetic regions in different latitude zones using the H-alpha synoptic charts for the short period April-September 1979 show both zonal and meridional flows. To study the effects accompanying the evolution of unipolar reions he employed test vectors at many points on the boundaries of these regions and looked for the changes in their orientation as the regions evolve. Their orientations distinctly show that a purely zonal flow prevails at heliographic latitudes above $\pm 50°$, while at lower latitudes, the meridional component is predominant. We find from Fig.2 that this is what is to be expected. This latter period is the ascending phase of the solar maximum. As the level of solar activity increases so also the velocity of the flow and in addition the flow spreads to higher and higher latitudes. The filament bands below the polemost one also show similar poleward migration. During such an epoch a Doppler measurement would bring out the meridional flow at all latitudes on the sun.

It is thus clear from the migration diagrams (Figs 1 & 2) that during the years of the solar minimum, the filament bands do not show signs of a continous migration towards the poles. They remain at low latitudes with a quasi-oscillatory motion. But with the commencement of the solar activity, they start all of a sudden moving polewards suggesting that the motive force driving them which is absent or very weak during the solar minimum starts operating from this epoch onwards. This behaviour is unmistakably seen cycle after cycle (1910-1982) in both hemispheres of the Sun.

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DISCUSSION

VAN BALLEGOOIJEN: How did you define the latitude of a filament band?

SIVARAMAN: This is done by measuring the latitudes of the filament band in every 20° longitude zone and averaging them over one solar rotation. This mean value forms one data point on the migration trajectory curve.

PRABHAKARAN: The poleward migration of filaments does not have the same velocity throughout the cycle. How well does it agree with other measurements?

SIVARAMAN: The agreement between the Doppler measurements showing the meridional motion and our filament trajectory diagram is quite good. The fact that the poleward migration does not have the same velocity throughout the cycle is exactly the point I am emphasising by saying that the meridional motion participates in the solar cycle variations.