The Magnetic and Velocity Fields of Solar Active Regions
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EVOLUTIONARY CHARACTERISTICS OF LARGE-SCALE MAGNETIC AND VELOCITY FIELDS

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ABSTRACT Long-term evolution of solar large-scale magnetic fields in relation to the local active phenomena is studied. The changes of the magnetic flux distribution are influenced by the horizontal transport of magnetized plasma. The whole system of magnetic field changes is interpreted as a global process which is controlled by the large-scale convective patterns. The large-scale horizontal velocity field of transporting motions is determined in various approaches with similar results. Regions with positive divergence in the field of horizontal flow field are found to be closely connected with the occurrence of solar active regions. The process of the horizontal flow was analysed by the "cork" method. The corks reveal a pattern of giant cells which are persistent for several solar rotations. These large cells are interpreted as giant convective elements. Occurrence of new strong magnetic flux in regions of positive divergence is then interpreted as a result of emergence of flux in the upflowing parts of that pattern.

Large-scale photospheric magnetic fields indicate patterns in the global magnetic flux distribution. Temporal changes in the magnetic flux distribution (Ambrož 1992) demonstrate large-scale horizontal transport in the convection zone, in addition to vertical transport. The observed magnetic flux distribution results from magnetic flux emergence, followed by flux redistribution caused by convective motions of different characteristic length and time scales.

The evolution of the large-scale magnetic field is characterized by displacement and deformation of individual magnetic regions. A map of displacements can be interpreted as a chart of horizontal velocities. The horizontal velocity vectors can be computed from the numerical comparison of subsequent magnetic synoptic charts. Algorithms for calculation of these transverse velocities have been developed by November (1986) and Darvann (1991) on the basis of local cross correlation techniques.

The arrows in Figure 1 indicate the local horizontal velocities that can account for the displacement of magnetic field[1] structures. These velocities probably represent a mixture of the horizontal large-scale plasma motion and effects of turbulent diffusion.

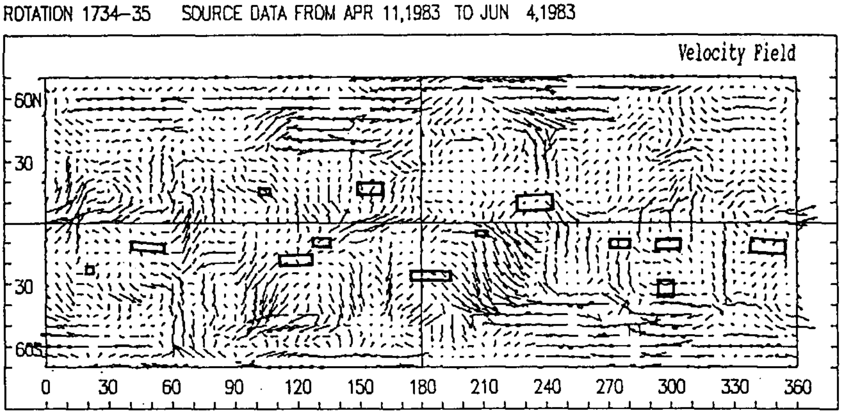

Fig. 1. The horizontal velocity field inferred from magnetic flux displacements averaged over period of two consecutive rotations. An arrow length corresponding to 10 heliographic degrees equals the velocity of 100 m/s. Active regions visible during the period of Carrington rotation No. 1735 are displayed by rectangles.

Large-scale flow structures in the photosphere inferred from the magnetic field evolution are conveniently characterized by the divergence in that horizontal velocity field. In Figure 2 the regions of positive divergence (the sources) are hatched.

Note the strong tendency for sunspot groups to occur in locations characterized by a very low horizontal velocity, in regions of positive divergence. The individual vectors are usually oriented radially outward from the spot group center.

Not only active regions show a strong preference for areas of positive divergence—also polarity inversion lines in the large-scale magnetic field are found there. The regions of negative divergence (the sinks) usually are located inside large magnetically unipolar regions.

The above discussion is based on large-scale horizontal flows calculated from a magnetic flux displacement between two consecutive solar rotations. The discussion can be based on other aspects of the horizontal flow field as well. One procedure is to determine the system of streamlines by numerical integration of the 2-D streamline equation. The streamline map can be

[1] The synoptic maps of the large-scale magnetic field, from which the displacements are computed, were generated from the spherical harmonic functions up to principal index $n = 19$ according to still unpublished Stanford data, kindly provided by Dr. T. Hoeksema (1992).

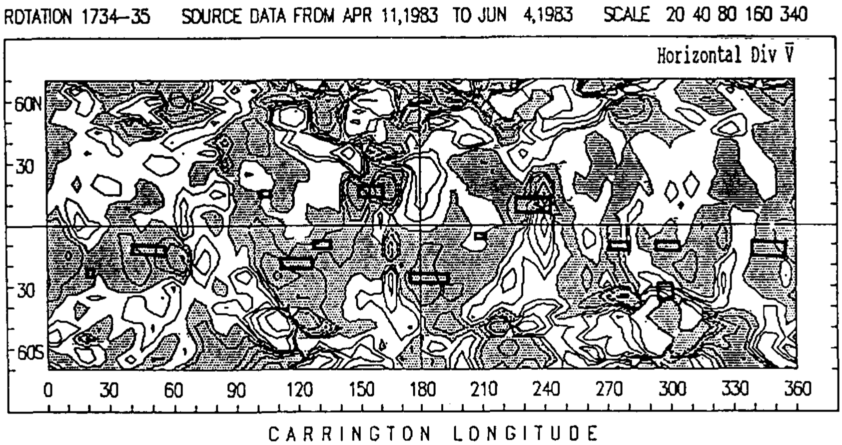

Fig. 2. Isoline chart of the divergence of the horizontal flow field which is plotted in Figure 1. Grey indicates regions of positive divergence (sources).

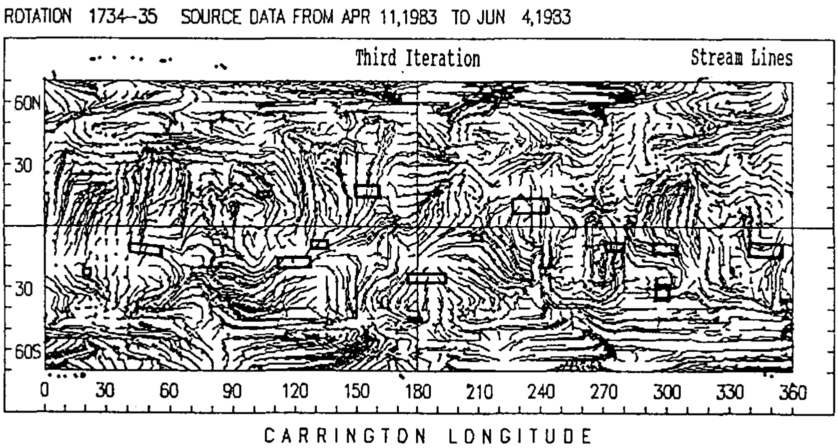

Fig. 3. Streamline map calculated from the velocity field. The flow structure is enhanced by repeated iterration of the stationary velocity distribution. The end points of streamlines are concentrated in regions of negative horizontal divergence, indeed the sinks.

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enhanced by multiple iteration of the stationary velocity field—one such result is shown in Figure 3.

Another procedure is to visualize the time-dependent large-scale horizontal flow by asking where that flow field would carry free particles ("corks") that are originally distributed uniformly in the photosphere. The cork paths represent the streamlines of the flow. Regions of diverging or converging flow appear as regions of low or high cork density, respectively (see Figure 4). Again it is found that the positions of sunspot groups correlate positively with regions of diverging flow. Following the time dependent velocity field introduces noise into the shape of the streamlines but the character of the large-scale flow is conserved.

Figure 4 shows that the initially uniformly distributed "corks" carried by the flow field to apparent "cell boundaries", clearing a fairly well developed system of nearly empty "cells". In the flow divergence maps these cells have typical diameters of about 60 to 70 heliographic degrees. Clearly, the cell "boundaries" are locally absent or quite fluffy, but there are just enough markers to suggest a cellular pattern. Several of the empty cells are particularly well developed.

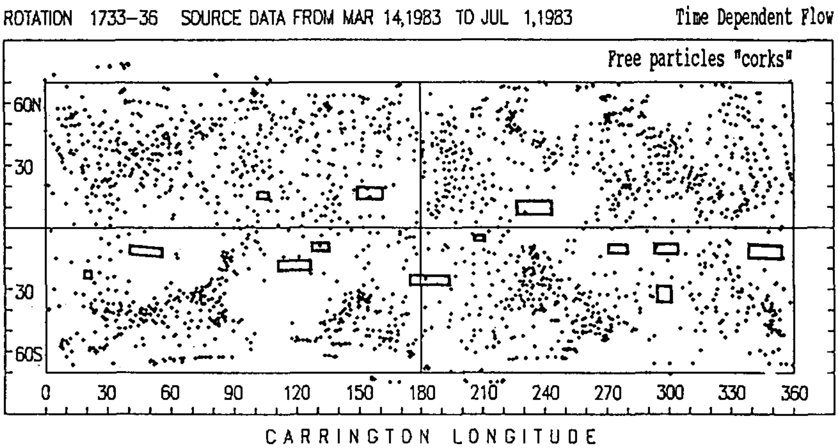

Fig. 4. Originally uniformly distributed cork particles are carried by flows to the apparent cell boundaries. In this case the real time-dependent velocity field acting over 4 solar rotations was used.

These cells are suggested to be large-scale convective elements located in deep layers of the convection zone. In this picture the preferred occurrence of active regions in areas of positive divergence can be explained as the result of flux loops brought up in upward flows of giant convection cells. In persistent upflow regions, repeted emergences of magnetic flux can create complexes of activity clustered in the compact activity nests (see van Driel *et al.* 1992).

Comparison between maps of the flow field based on the momentary horizontal velocities (Figures 1, 2, and 3) and the cork distribution after four months of action of the real time-dependent flow field (Figure 4) suggests that the giant cells have long lifetimes. This has been investigated by an analysis of the temporal evolution of the divergence maps over a period of two years

(Carrington rotations Nos. 1715-16 to 1743-44). Stackplots of the divergence charts were used, displaying 20 degrees zones of the latitude, stepped from 60N to the equator. Some new characteristics of the divergence patterns emerged from this study.

The divergence cells appear to form relatively longlived and structured patterns. In each investigated latitude zone about five sectors of positive and also five sectors of negative divergence were found. The patterns for different solar latitudes display different periods of recurrence: the synodic mean period of recurrence for equator is about 26.5 days and for the northern latitude circles 20, 40 and 60 degrees the periods are 27.0, 27.8 and 28.7 days respectively. The scatter of individual values represents about 0.5 day for each latitude. The lifetime of the divergence patterns is usually not longer than 10 to 12 Carrington rotations, typical lifetimes are about 8 to 9 rotations, but also lifetimes shorter than 3 to 4 rotations were found.

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