THE RELATION BETWEEN THE LARGE-SCALE SOLAR MAGNETIC FIELD DISTRIBUTION AND THE GLOBAL HORIZONTAL CIRCULATION IN THE PHOTOSPHERE

P. Ambrož
Astronomical Institute of the Czechoslovak Academy
of Sciences, Ondřejov Observatory, Czechoslovakia

ABSTRACT. Using H-alpha Synoptic Charts (SGD), the character of the development of the structure and distribution of the regions of both magnetic polarities and their boundaries are derived. A procedure was found of describing qualitatively the direction of the horizontal streaming of solar photospheric plasma under the assumption of divergence-free flow. Time-variable large-scale vorticity flow was found in the region of the active zone, as well as zonal flow at higher latitudes where the polar vortex is formed. Active regions are formed exclusively in places where global circulation displays maximum vorticity. Filaments occur in regions where the value of the velocity gradient is high perpendicular to the filament axis. The condition for these two manifestations of solar activity to form is the presence of the boundary between the two magnetic polarities.

СВЯЗЬ МЕЖДУ РАСПРЕДЕЛЕНИЕМ КРУПНОМАСШТАБНЫХ СОЛНЕЧНЫХ МАГНИТНЫХ ПОЛЕЙ И ГЛОБАЛЬНОЙ ГОРИЗОНТАЛЬНОЙ ЦИРКУЛЯЦИЕЙ В ФОТОСФЕРЕ. По $H\alpha$ -синоптическим картам(SGD) , установлены характер развития структуры и распределение областей обеих магнитных полярностей и их границ. Примененная процедура заключается в качественном описании горизонтальных направления потоков солнечной фотосферной плазмы в предположении о бездивергентном гидродинамическом движении. Был обнаружен меняющийся со временем крупномасштабный вихревой поток в зоне активных областей, а также зональный поток в высоких широтах, образующий полярный вихрь. Активные области возникают преимущественно в тех местах, где глобальная циркуляция показывает максимальную завихренность. Волокна встречаются в областях, где высоки значения градиента скорости перпендикулярно осям волокон. Условием для возникновения этих двух проявлений солнечной активности является наличие границы между двумя магнитными полярностями.

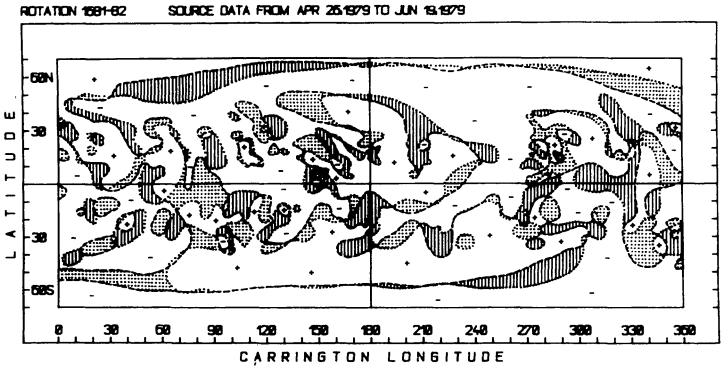
VZTAH MEZI ROZLOŽENÍM SLUNEČNÍCH VELKOROZMĚROVÝCH MAGNETICKÝCH POLÍ A GLOBÁLNÍ HORIZONTÁLNÍ CIRKULACÍ VE FOTOSFÉŘE. V práci je na základě H-alfa Synoptic Charts (SGD) odvozen charakter vývoje struktury a rozložení oblastí obou magnetických polarit a jejich rozhraní. Byl nalezen postup, jímž lze kvalitativně popsat směr horizontálního proudění sluneční fotosferické plazmy za předpokladu bezvířídlového proudění. Bylo nalezeno časově proměnlivé velkorozměrové vorticitní proudění v oblasti aktivní zony a zonální proudění ve vyšších šířkách, kde se formuje polární vortex. Aktivní oblasti se formují výhradně tam, kde globální cirkulace vykazuje maximální vorticitu. Filamenty se vyskytují v oblastech, kde kolmo k ose filamentu existuje vysoká hodnota gradientu rychlosti. Podmínkou formování obou těchto projevů sluneční činnosti je přítomnost rozhraní obou magnetických polarit.

The purpose of this study is to show the character of global horizontal circulation in the solar photosphere in qualitative form within a particular short interval of time, as derived from the analysis of H-alpha Synoptic Charts (SGD - Boulder) for the period of Carrington rotations Nos 1681 - 1684, which covers observations from April 26 to August 13, 1979. This period was chosen quite randomly.

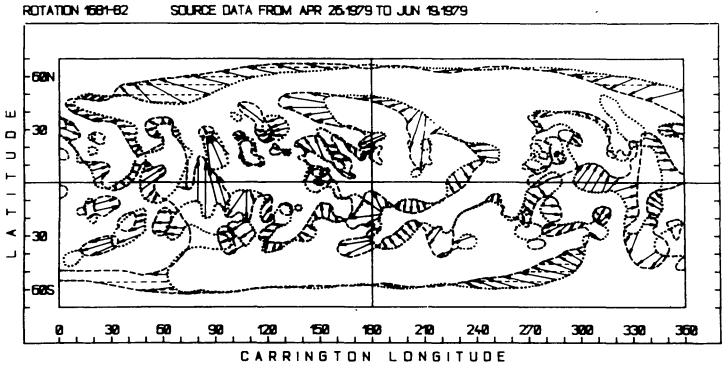
The distribution of the boundaries of the two polarities was compared in each case on two consecutive maps; in places where a displacement of the boundary had occurred, the polarity was determined which was replaced by the opposite polarity. Under the assumption that the magnetic field is frozen in the plasma and, therefore, the displacement of the polarity boundary and of the magnetic regions themselves represents a transfer of photospheric plasma as a whole, the basic trends in development were established. In this sense, the above assumption is consistent with the commonly used method of tracers. Conservation of the magnetic flux and vertically divergence-free horizontal flow are assumed. The separate stages of processing the data are illustrated in Figs 1a - 1d.

Fig. 1. The horizontal large-scale velocity field derived from the charts of distribution of regions of opposite polarity of the background magnetic field for Carrington rotations Nos 1861 and 1682. a) The dotted line represents the polarity boundary for rotation 1681, the dashed line for rotation 1682. The vertical hatching marks regions of negative polarity expansion, the dotted areas regions of positive polarity expansion. b) The full arrows mark the vectors which describe the tendencies of development of some of the regions on the solar surface due to the large-scale velocity field. The dashed vectors at higher latitudes represent the variant in which the meridional velocity component is neglected. c) Schematic representation of the structure of the large-scale horizontal velocity field. d) The structure of the velocity field illustrated by means of unit vectors.

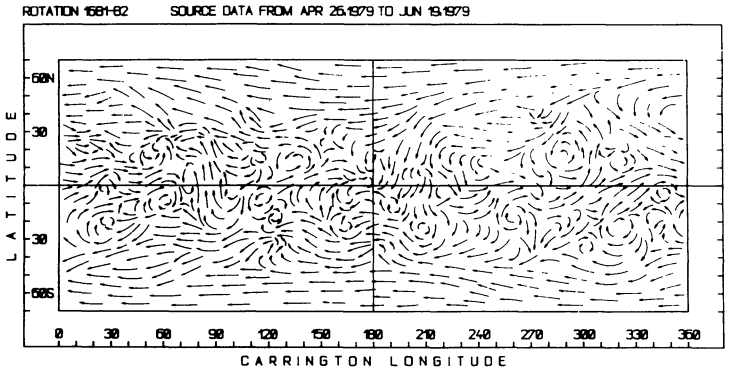
1a)



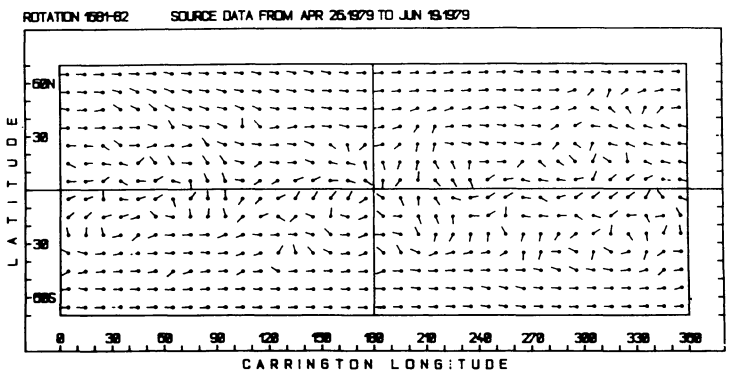
b)



c)



d)



The presented result is only a preliminary communication, because quantitative data are not available at the present stage of development of the method. However, the following results, and the consequences they imply, can already be drawn at this stage:

The global horizontal circulation in the solar photosphere has a distinctly vortical character which is reflected mainly in the extent of the active zone;

The flow in the active zone is, therefore, neither purely nor predominantly zonal, since a meridional component of the horizontal velocity, comparable in magnitude with the zonal component, is present there. The character of the global flow is mainly zonal at higher heliographic latitudes, poleward of the active zone;

In both hemispheres, a number of formations with distinctly cyclonal flow is generated in the active zone. Intensive flows across the solar equator in the meridonal direction were observed from the northern as well as southern hemisphere;

Evolutional changes in the character of the flow in the individual parts of the active zone were found for the short interval of time being studied. By this we understand the local changes in the direction of flow, and the genesis and decay of circulation patterns. The centres of some of the vorticity patterns gradually change their positions relative to Carrington's grid;

All the conclusions drawn above were derived from data characteristic of the year 1979. There are good reasons for assuming that the character of global circulation changes in the course of the solar activity cycle.

In relation to some of the manifestations of solar activity, the global horizontal circulation in the photosphere displays the following features:

Sunspot groups form in the active zone in regions of maximum vorticity. As a rule, these regions are close to the centres of vorticity patterns, or in places where the direction of flow changes abruptly. As yet, the initial observational material used to construct the velocity field does not enable the causal dependence between the formations of the patterns with a high degree of vorticity and the generation of sunspots to be determined due to the small time resolution;

The dark solar H-alpha filaments are formed in regions of quasilaminar flow where a relative high horizontal velocity gradient can be assumed perpendicular to the longitudinal axis of the future filament. These regions are, as a rule, located at the margins of circulation patterns, in regions where two circulation patterns make contact, and at the boundary between the active zone of circulation and the polar zone, in which the polar vortex is formed;

No well-defined structural relation was found between the distribution of the photospheric magnetic field and the structure of the global horizontal velocity field, excepting that the boundary between the two polarities was always observed in the centre of patterns with a high degree of vorticity. Also local maxima of the intensities of background magnetic fields can be, in general, identified in these regions;

The characteristic diameter of the vorticity patterns in the active zone is about 30 - 40° heliographic. As regards their lifetime, the interval being analysed is too short to be able to draw definite conclusions, however, in view of their very close relation to the existence of sunspots, one may assume that the lifetime of the circulation patterns and sunspot groups will be compatible;

No relation has so far been found between the large-scale velocity vorticity patterns, on the one hand, and the giant cells and super giant regular magnetic structures, discovered earlier. However, these structure are by no means located in the same positions as the vorticity patterns.

The above conclusions lead to the following consequences:

In view of the above results, the differential nature of solar rotation, described in terms of dependence on heliographic latitude Φ as

$$\omega = A + B \sin^2\Phi + C \sin^4\Phi ,$$

appears to be a rough, average first approximation of the much more realistic state of global solar atmospheric circulation. Since sunspots and filaments are formed in various characteristic regions of global flow, this explains, to some extent, why parameters A, B and C are given different values by various authors using different methods of processing and dealing with different manifestations of solar activity. This will probably also be the reason why the data on differential rotation, determined for sunspots and filaments by the method of tracers, differ distinctly from the values derived from measurements of the radial plasma velocities;

To understand correctly the large-scale velocity field in the solar photosphere, it is necessary to stop neglecting the meridional component of the velocity vector in advance. This means discarding the deeply-rooted concept that differential rotation is the result of just the latitude-dependent zonal flow, and replacing it with a more general model of global atmospheric circulation;

With a view to the results reported above, also the time-integration factor is important in describing solar rotation. The statistical results obtained by averaging over long periods of time provide only minimum information about the actual structure of horizontal flow in the solar photosphere. They, therefore, only document the average state, or serve only to determine average long-term variations;

The relation found between the positions of sunspot groups and the centres of the large-scale circulation patterns prompts the question of the mechanism of sunspot generation and the relatively strong magnetic fields within them. We still do not know whether the centre of the vorticity pattern is formed here, e.g., because a new intensive magnetic flux emerges there as a result of a bouyancy force. Another possibility is the reverse process in which the large-scale velocity field, within the scope of global relations, forms a high-vorticity pattern and, in its centre, the magnetic field intensifies and sunspots or sunspot groups are formed due to high local turbulence, or

another effect. To be able to verify the structure of global horizontal atmospheric circulation in the solar photosphere, as presented above, by direct measurements of radial velocities, it is necessary to employ methods of measurement and interpretation which would yield reliable data on the zonal, meridional and radial components of the velocity vector at any point of the solar surface. The derived structure of motion indicates that the direction of horizontal flow varies on a characteristic scale of about 1 minute of arc. The method of measurement and interpretation must be able to separate the granular and supergranular velocity field from the large-scale field;

The positions of the observed filaments proves that the horizontal velocity gradient plays an important part in forming them. Consequently, one may infer that the basic condition of their existence is the presence of horizontal flow whose velocity gradient is perpendicular to the large-scale flow of photospheric plasma. Another necessary condition is the presence of a sufficiently large gradient of the normal component of the magnetic field intensity at the polarity boundary. All these three conditions must be satisfied simultaneously in the immediate neighbourhood of the filament in the solar photosphere.

The suggested concept of global atmospheric circulation provides scope for interpreting the existing controversies in determining the parameters of solar rotation, and indicates new variants of explaining the origin of a number of active phenomena on the Sun.

ДИСКУССИЯ

А.М. Могилевский

Можно ли установить что первично: перестройка (завихрения) в крупномасштабном поле или такая структура крупномасштабного поля вызвана активными областями ?

П. Амброж

Здесь наверно трудно дать ответ. Мое личное мнение такое, что крупномасшабное вихры формуют условия для локальной турбулентности, которая принимает участие на усилениях фоновых полей и формировке локальных полей.