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Large-scale patterns, complexes of solar activity and 'active longitudes'

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Abstract. Typical latitude zones and longitude sectors with a dominant occurrence of newly emerging magnetic flux were systematically detected during three last activity cycles. Two long time persistent longitude sectors with the preferred occurrence of a new strong magnetic flux are characteristic for magnetic flux distribution and their rotation rate is latitude dependent in the relationship with differential rotation rate. Recent new information about the large-scale flows in convection zone relates to a concept of the expected giant cells and jets and show a new relationship with different scales of the large-scale circulation. Non-axially symmetric horizontal flow in upper part of convection zone gives a good motivation for an extension of the existing axially symmetric 2D models into new 3D concept.

Keywords. Sun, Sun: magnetic field, solar activity

The motivation for the present contribution is: which kind of symmetry in large-scale solar activity occurrence is observed on the Sun? Well known latitude dependence of solar activity occurrence is considered as a substantial criterion for the solar cycle temporal evolution with distinct symmetry according to equatorial plane. However, during the last half century some studies showed the non random distribution of the active phenomena were also present in the heliographic longitude. It was shown, that the distribution of the activity on the Sun is generally non-axially symmetric.

Large-scale processes on the Sun are generally connected with characteristic dimension, which is greater than 100 Mm. In this case the physical quantities are generally parameterized and lose their original physical meaning. Usual objects studied in this connection are the active regions and their complexes (Gauzaiskas *et al.* 1983), large-scale magnetic fields (Bumba & Howard 1969) and corresponding magnetic flux, large-scale coronal structures, their evolution and relationship with interplanetary magnetic field.

In the second half of the last century many studies describing '*Sonnefleckenherd*' (Becker 1955), active nests (Castenmiller *et al.* 1986), complexes of activity (Gaizauskas *et al.* 1983; Bumba & Howard 1965), active longitudes (Berdyugina & Usoskin 2003) and 'hot spots' (Bai 1988) were prepared. Many authors used different methods and specific terminology, however, a very similar phenomenon is considered. A recent study of the strong magnetic field confirmed the existence of preferred longitudes for the emergence of big sunspot groups. These longitudes occur in pairs, rotate at the same rates and are separated by 180° in longitude. The northern and southern hemispheres behave differently regarding the occurrence of activity in longitude. Hot spots with different rotation periods coexist in the same hemisphere during the same solar cycle. Active longitudes are affected by the differential rotation and migrate in Carrington longitude according to the mean latitude of sunspot manifestation. Usually one or two active longitudes are dominant and dominance switches in time, known as the 'flip-flop' effect (Berdyugina & Usoskin 2003). The mean time between two consecutive switches is of the order of

20 Carrington rotation periods. In fact, the rotation period is mixed with the period of switches, and creates two period side lobes, below and above of the period of rotation. Formation of preferred longitudes is closely connected with another phenomenon in which a position of newly emerging strong magnetic flux is nearly identical with previous in the place of just decaying magnetic flux. The scatter in position is usually only a few heliographic degrees. Terms of activity nests or hot spot were introduced. This mechanism supports creation of the persistent in time regions with dominant occurrence of the solar active phenomena. Lifetime of such processes vary from one to several activity cycles, therefore this process is not always continuously active throughout its lifetime. The differential rotation responsible for the migration of active longitudes is different from that obtained from individual spots.

The newly emerging magnetic flux is expected to be transported in the upper part of the solar convection zone due to turbulent diffusion and large-scale motions. In both directions, in addition to global differential rotation and meridional circulation also the large-scale departure from axially symmetric motions were observed. Large-scale horizontal motions with a characteristic dimension of about 40° in both zonal and meridional directions and with characteristic velocity about $10\,\mathrm{m\,s^{-1}}$ were detected in the photosphere by Ambrož (2001) and also below it up to depth 12 Mm by Zhao & Kosovichev (2004).

Departure of zonal velocity from axial symmetry near the bottom of the convection zone can, according to theoretical considerations, initiate specific instabilities in tachocline leading to the tipping of the basic toroidal fields in both solar hemispheres. Study of this process with determination of a tip angle and a position angle of the tilted toroid still confirm Norton & Gilman (2005) the possibility of this mechanism . A tipped toroid is characterized by its position angle in longitude and can be a way to a 3D non-axially symmetric model of the solar dynamo. Excellent representation of stable evolving active longitudes was obtained by analysis of the total dipole component of the photospheric magnetic field. Position of the north pole, evolving in latitude and longitude during activity cycle confirm that all previous conclusions about active longitudes, the 'flip-flop' effect also in the upper corona and interplanetary magnetic field. All arguments show that the above mentioned large-scale processes are typical symptoms of the function of the solar dynamo and solar cycle mechanism and can be typical of the activity processes also other Sun-like type stars.

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