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LARGE-SCALE DISTRIBUTION OF MAGNETIC FIELDS, GREEN CORONA AND PROMINENCES DURING AN EXTENDED ACTIVITY CYCLE

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Abstract. The interrelations of the latitudinal distribution of the coronal green emission maxima, maximal numbers and areas of prominences, magnetic fields, sunspots, and polar faculae in the 20th and 21st sunspot cycles have been investigated. It is again demonstrated how the behaviour of all studied data depends on their heliographic latitude. In the polar zone, well separated from the equatorial we observe following polarity magnetic fields transported only polewards, while the equatorial zone is occupied mostly by leading polarity fields, developed there, moving equatorwards, and crossing the equator to the other hemisphere with the new cycle during the minimum of sunspot activity.

This magnetic field distribution is well emphasized by the places of maximal occurrence of prominences and by the distribution of coronal green emission maxima which also differ in dependence on latitude.

The question of identifying the first and last evolutionary stages of an extended cycle of activity is discussed and the existence of a magnetic activity cycle lasting 15–17 years is suggested.

1. Introduction

In this note we discuss the observations of the coronal green emission obtained during the 20th and 21st cycle from many sites and compiled by Rybanský (1975) from the point of view of an extended cycle of solar activity (Wilson *et al.*, 1988; Wilson, 1987; Makarov *et al.*, 1987; Howard and LaBonte, 1981; Snodgrass, 1987); above all, we have concentrated on the latitudinal distribution of its maxima. For the same purpose we used the graphs of the latitudinal distribution of numbers and areas of solar prominences observed during practically the same period of time at the Lomnický Peak Observatory of the Astronomical Institute of the Slovak Academy of Sciences (Rušin *et al.*, 1988). We relate both distributions to those of other solar activity phenomena, and particularly of magnetic fields.

2. Green Corona Maxima, Activity and Magnetic Field Latitudinal Distribution during the Years 1965–1986

Monthly latitudinal means of the green corona intensities display two local maxima above the N- and S-hemispheres. The principal one has its occurrence in low-latitude zones of each hemisphere and of each cycle. Subsidiary maxima are observed at higher heliographic latitudes ($> \pm 45°$). These polar maxima are scattered in latitude, and may be well defined three to five years before and one to two years after the minimum of

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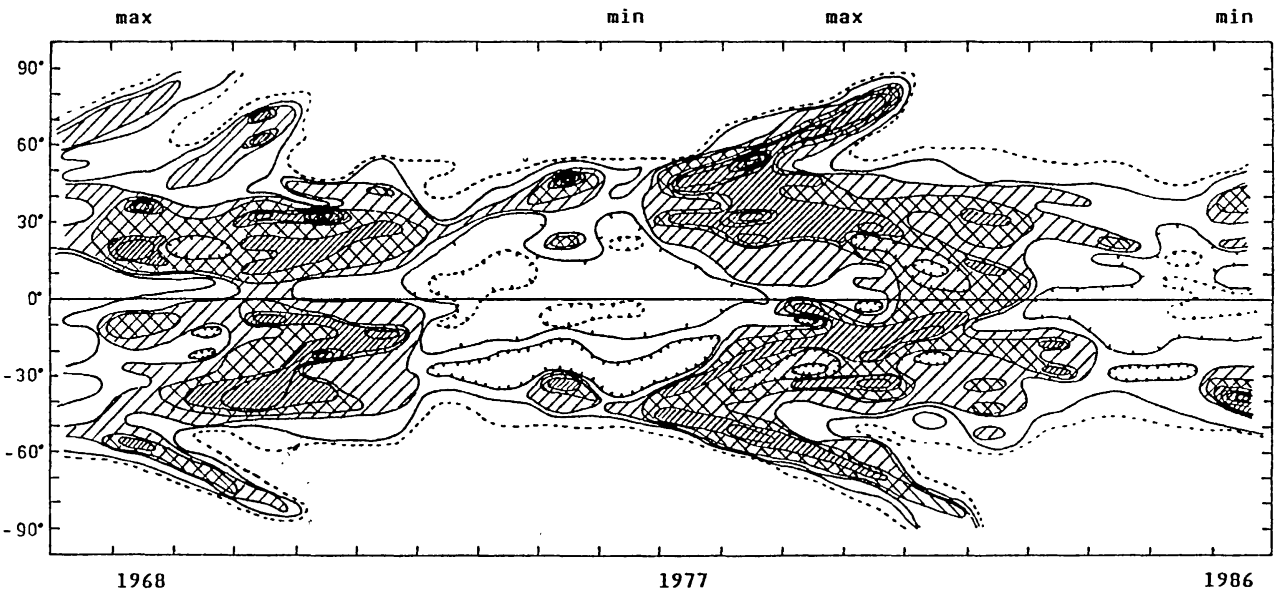

Fig. 1a. Latitudinal distribution of solar prominence areas over years 1967–1986 at the Lomnický Peak Observatory.

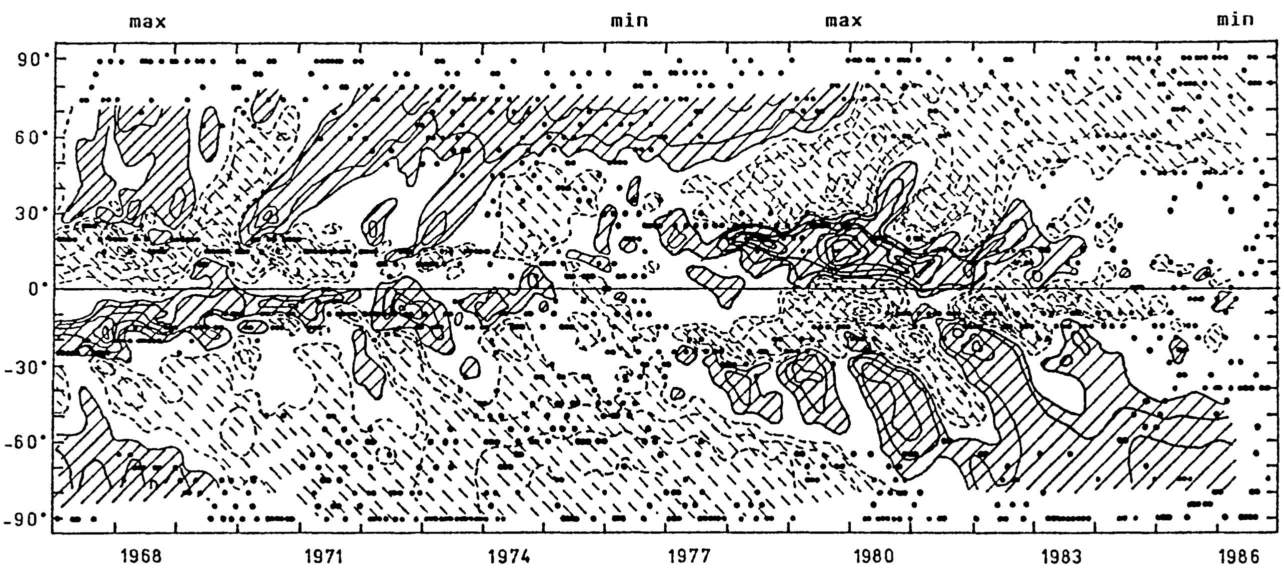

Fig. 1b. Relation between the synoptic chart of zonally averaged longitudinal magnetic field (Snodgrass, 1987) and the latitudinal distribution (monthly means as obtained from a homogeneous data set) of green coronal emission maxima (dots). Regions of positive magnetic polarity are shown with solid contours and lines, and region of negative magnetic polarity are shown with dashed contours and lines. Contour intervals are $\pm 5.5, 1.0, \ldots, 3.0 \times 10\ \mathrm{m\ s^{-1}\ km^{-1}}$.

sunspot activity. The main narrow low-latitude branches are observable until the next minimum, when they almost reach the equator.

In the polar regions the only better determined feature running from high-latitudes continuously equatorwards seems to be the leading edge of the field of dispersed polar secondary emission maxima, while its trailing edge shifts from latitudes of about $\pm 45°$

polewards (Bumba, Rušin, and Rybanský, 1989, 1990). In our observational material we do not clearly see the polar coronal branches shifting polewards, as indicated by Waldmeier (1955) and Leroy and Noens (1983). If they existed, the trailing edge would be their demarcation.

If we compare our coronal distribution with the sunspot and polar faculae butterfly diagram (for example, Makarov *et al.*, 1987) (Figure 2), we see that the coronal green emission maxima run, in both hemispheres, slightly polewards from the centres of

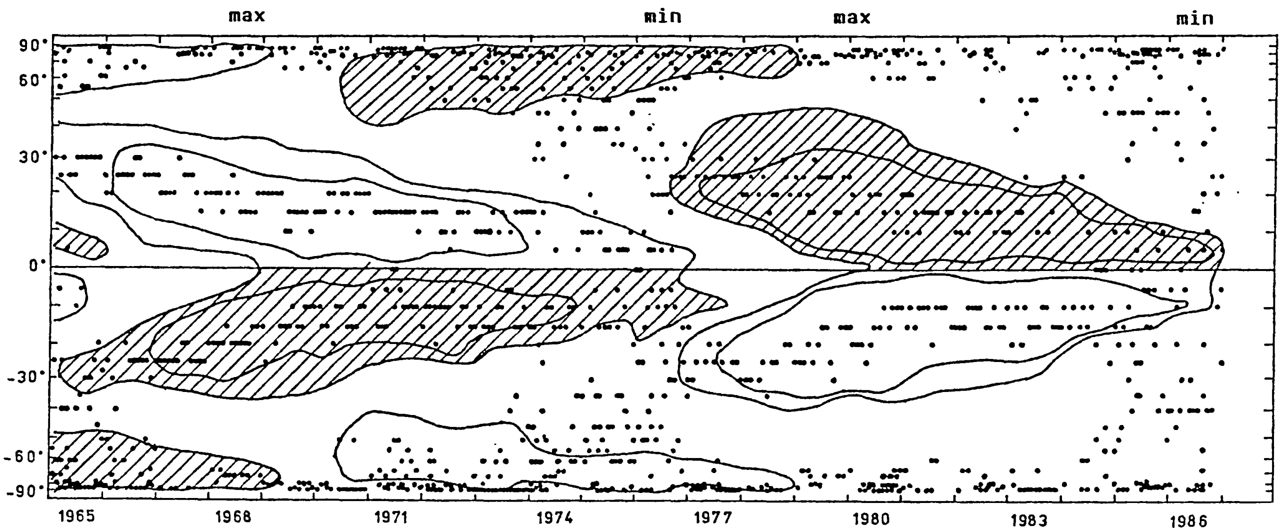

Fig. 2. Relation between the latitudinal distribution of the coronal green emission maxima (dots have the same meaning as in Figure 1(b)) and the butterfly diagram of sunspots and polar faculae (Makarov *et al.*, 1987). Heliographic latitudes are drawn on a nonlinear scale.

gravity of the butterfly wings of the sunspot distribution, starting about one year prior to the spot minimum at latitudes $\pm 45°$. The polar secondary coronal emission maxima partially cross the main concentrations of polar faculae, but both distributions have different forms and cover different regions.

The comparison of the latitudinal distribution of the coronal green emission maxima with that of the solar magnetic fields (Howard and La Bonte, 1981; Snodgrass, 1987) (Figure 1(b)) shows that all main coronal branches border the leading polarity equatorial zones on their poleward side. In polar regions we did not find an unambiguous relation between the positions of the subsidiary coronal emission maxima and polar magnetic fields.

3. The Relation of Latitudinal Prominence and Magnetic Field Distributions

Our graphs of the distribution of prominence numbers and areas (Figure 1(a)) in 1967–1986 do not differ from those presented by De Jager (1962) and Ananthakrishnan (1952, 1954). The well-defined polar branches are narrow, while the main lower-latitude zones have a rich internal structure.

The polar zones are formed as prolongations of one of the secondary equatorial branches oriented slightly poleward. They arch over several years in the period of low as well as of maximal sunspot activity. At the same time they connect the main low-latitude with the polar branches. They last for nine (without) or fifteen (with the main zones) years. They clearly demonstrate their relation to the cycle ending its equatorial region prominence activity, eight or nine years earlier. The equatorial prominence zones of the new cycle of sunspot activity seem to be detached from this long polar prominence zone of the old cycle again at latitudes $\pm 45°$.

The described latitudinal distribution of maximal prominence occurrences, which is identical to the distribution of the maximal occurrence of magnetic field polarity boundaries (Figures 1(a) and 1(b)), creates the two main latitudinal belts without prominences, i.e., also without substantial magnetic activity: the polar belts extend to latitudes of $\pm 50° - \pm 60°$ and are filled in by following polarity field of the old cycle and by their polar faculae (Bumba, 1990). They last nine to ten years. The equatorial belts, lasting for five to six years, reach latitudes $20°-30°$ on both sides of the equator. In the equatorial belts without prominences the leading polarities of magnetic fields, formed by the active regions shifting equatorwards, seem to cross the equator during the times of sunspot minima to start their activity again as leading polarities of the new cycle in the opposite hemisphere (Figure 1(a)).

In comparing the main equatorial zones of prominence areas and green coronal emission maxima (Figures 1(a) and 1(b)) we see that both run parallel, the prominences a few degrees closer to the pole (cf. Waldmeier, 1955). The polar belts without prominences are just filled in to their boundaries by the polar subsidiary maxima of the green coronal emission. In these regions we see nothing noticeable in the magnetic field distribution.

4. Latitudinal Coronal, Prominence, and Torsional Oscillation Patterns

The main equatorial zones of green coronal emission maxima coincide well with the poleward dividing lines between the positive and negative velocity patterns of the torsional oscillations (LaBonte and Howard, 1982) in both hemispheres. But this is so only for the narrow, well-defined, low-latitude parts of these branches. At higher latitudes the coincidence deteriorates and the centers of gravity of the body of the dispersed polar green coronal emission maxima shift toward the regions of negative velocity patterns of the oscillations.

The coronal maxima distribution agrees with the distribution of areas of positive values of the shear oscillation patterns published by Snodgrass (1987, cf. Figure 2), but there is a lack of shear data for high heliographic latitudes. In Figure 3 we show that the green coronal maxima avoid the regions of decreased shear.

We see no remarkable coincidence in the comparison of prominence frequency distribution with the torsional oscillation patterns.

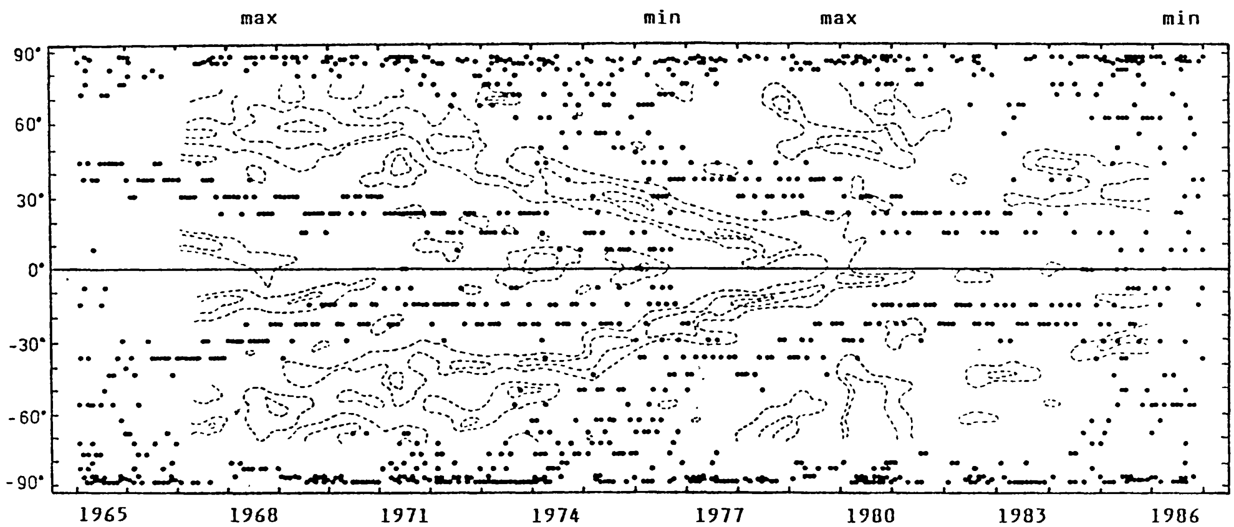

Fig. 3. Relation between the green coronal emission maxima (dots) latitudinal distributions and the torsional shear oscillations (shear decrease pattern is shown with dashed contours, Snodgrass, 1987). Heliographic latitudes are drawn on a nonlinear scale.

5. Discussion of Results

5.1. Existence of two main latitudinal belts

The dynamics of all the latitudinal distributions in the 20th and 21st cycles of activity, discussed above, display two different latitudinal types of behaviour of all the studied phenomena. The dividing lines between the polar and equatorial belts coincide with the $\pm 45°$ parallels.

The polar belts are the zones of following polarity magnetic fields pushed there from the main activity equatorial belt (Bumba and Růžičková-Topolová, 1969; Howard and LaBonte, 1981; Topka *et al.*, 1982). The leading polarity fields may reach the polar regions very quickly only during a threefold polar field reversal. These polar following polarity magnetic fields alternate regularly. For only less than one half of a sunspot cycle they are in contact with the low-latitude fields. For a greater part of the magnetic field cycle, they are well separated through the extended regions of weak or balanced mixed polarity fields (Giovanelli, 1982), or during their last evolutionary stages, through the following fields of opposite polarity of the new cycle. Due to this last polar-most phase the magnetic activity cycle, which starts with the formation of the first active region around latitudes $\pm 40°$, lasts about 15–17 years.

The equatorial belts are the zones of the leading polarity magnetic fields which develop in these belts. These fields first grow in intensity and then slowly decay, shifting equatorwards at the same time. They seem to cross the equator during the time of the sunspot minimum to function again as leading polarities in opposite hemispheres with the new activity cycle.

From a global point of view, we then observe the polar belts with magnetic fields transported there and redistributed by convection. The problem of new emerging magnetic flux in these belts remains to be solved. And in the equatorial belts, on the contrary, the leading polarity fields develop *in situ*. During this process the convection evidently plays an important role (Bumba and Howard, 1965; Bumba, 1981).

The prominence distribution underlines the sharp separation of the polar and equatorial belts as well as of the old and new cycles, although their equatorial zones of the new cycle are separated from their polar zones of the old cycle.

Also the distribution of the green coronal emission maxima shows two different latitudinal qualities.

5.2. Our observational data and the concept of an extended activity cycle

We have to emphasize that our conclusions have a preliminary character due to the use of only highly integrated latitudinal data.

If we observe the magnetic fields produced by a sunspot cycle of activity, we see that 15–17 years lapse from the first simultaneous appearance of both leading and following polarities of this sunspot phase before the polar field reversal occurs. This also means that the following polarity fields of the polar regions represent the last stage of this cycle of magnetic activity. Our prominence data confirm this fact.

As concerns the extended activity cycle, our coronal as well as prominence data do not demonstrate a clearly defined high-latitudinal phase shifting equatorwards and we did not find any counterpart of our coronal data in the photosphere or in its magnetic fields.

If the extended cycle does actually begin at high latitudes after the polar field reversal, then its first and last phases of development should be identical. But in such a case we must explain why the unipolar fields would first play the role of following and then of leading polarity fields and to answer many other questions. For this we would need many more observations as well as investigations.

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