PROMINENCES AND THE GREEN CORONA OVER THE SOLAR ACTIVITY CYCLE*

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Abstract. Prominences, in contrast to other solar activity features, may appear at all heliographic latitudes. The position of zones where prominences are mainly concentrated depends on the cycle phase of solar activity. It is shown, for prominence observations made at Lomnický Štít over the period 1967–1996, how the position of prominence zones changes over a solar cycle, and how these zones could be connected with other solar activity features. Our results obtained could be an additional source to do a better prediction of solar activity. Time-latitudinal distribution is also shown for the green corona (Fe XIV, 530.3 nm). Distribution of the green coronal maxima shows that there are equator-migrating zones in the solar corona that migrate from latitudes of 45° (starting approximately 2–3 years after the cycle start) to higher latitudes 70°, and then turn (around the cycle maximum) towards the equator, reaching the equator in the next minimum (this duration lasts 18–19 years). Polar branches separate from these zones at the cycle minimum (2–3 years before above-mentioned zones) at latitudes of 50°, reaching the poles at the maximum of the present cycle. The picture becomes dim when more polar prominence zones are observed. Prominences show both the poleward and equatorward migration. Comparison between both solar activity features is also discussed.

1. Introduction

At present, the origin of solar activity is still unknown, even when it is generally supposed that magnetic fields of the Sun (global and local) are responsible for its existence. The 'term' solar activity was based on observations of variable features in the solar atmosphere, e.g., sunspots, prominences, flares, etc. In recent years there were found variations in irradiance of the Sun, observed practically in all parts of the electromagnetic spectrum. All these changes in solar activity are interrelated.

It is generally known that solar activity has an influence on the heliosphere, including the Earth. This is one of the reasons to study features of solar activity in detail.

Solar prominences are seen in Hα on the limb as bright phenomena of various shapes, lifetime, structure, reaching heights of up to 10^{4-5} km. Their property to appear in all heliographic latitudes and to outline the border between magnetic fields with different polarities makes them suitable tracers both for the large-scale pattern of the weak background magnetic field and recently for studying the extended solar cycle. McIntosh (1972) developed guidelines for inferring magnetic polarities on the Sun from observations of filaments (filaments are prominences observed against

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the solar surface) and filament channels. Results obtained with direct measurement of magnetic fields on the solar surface are very good, even when the final charts do not provide any information on magnetic field strengths. Nevertheless, the distribution of prominences and filaments can provide the possibility for investigation of global properties of large-scale magnetic fields, especially when magnetographic observations were (are) not available.

Since Secchi (1872) discovered the zone of polar prominences and its poleward migration, this phenomenon has been observed in every cycle. Later, both poleward and equatorward migrations were deduced by, e.g., Abetti (1957). Waldmeier (1973) has established 3 narrow zones, which show different latitudes and different behaviour in the l1-year cycle:

(1) The so-called sunspot-type prominences (post-flare loops), flares, surges and sprays. They are bound with the sunspots and appear only in the zone of spots, and they shift together with them to the equator over the cycle.

(2) The long-lived, stable prominences. They develop from centers of activity, thus out of the spot zone. They are shifted 15° towards the poles (from zone 1) and migrate together with the spot zone to the equator.

(3) The well-known polar zone of prominences. This forms at latitudes around 45°, at minimum, and then migrates to the poles with a velocity from 10 to 25 m s^{-1}, reaching the poles, around the cycle maximum. Then the polar zone prominences disappear. It is very important to stress that this zone follows the same law in every cycle, independent of the magnitude of the cycle. This conclusion is not valid for sunspots.

Waldmeier (1973) showed, for the first time, that over cycle 20, two polar zones of prominences appeared above the northern hemisphere. The second zone moved with a faster velocity towards the pole, and it appeared 2.5 years after the first one. Similar behaviour for two polar prominence zones was found in cycle 22 (Dermendjiev *et al.*, 1993), however above the southern hemispere. The time shift between them was in this case only 1.7 year.

While the existence of a polar zone (zones – two branches in one cycle) is clearly observable, the zones moving to the equator were not confirmed by Makarov and Sivaraman (1989). On the other hand, Bumba, Rušin, and Rybanský (1990), using observations made at Lomnický Štít over the period 1967 to 1986, confirmed the existence of the equatorward zones, both in number and area of prominences. They stressed that the main lower-latitude zones have a more intricate internal structure. Moreover, they established that polar zone maxima are formed as prolongations of some parts of main zones. Already Howard and LaBonte (1981) and Topka *et al.* (1982) demonstrated that the polar magnetic fields are remnants of the following polarity expelled from the main activity equatorial zone. It seems that the leading polarities of magnetic fields, moving and weakening, cross the equator during the minimum to act again as leading polarities in the opposite hemispheres with the new sunspot activity. Therefore, the polar zone of prominences traces the last evolutionary stage of a magnetic cycle.

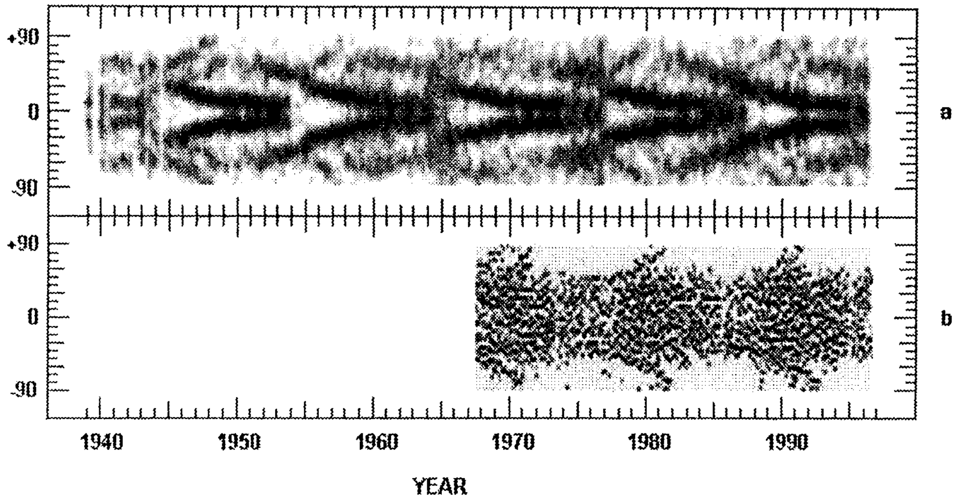

Figure 1. Time–latitude distribution of local maximum intensities of the green corona (a) as derived from HDS. The lower part (b) displays the 'prominence index' (for details see text).

In our paper, we will deal with the time–latitude distribution of prominences as observed at Lomnický Štít over the period 1967 (May)–1996 (May). We will also compare prominence data with the distribution of the emission in the green corona. The green coronal intensities are observed at all times and everywhere around the Sun, and they very well reflect solar surface activity, e.g., Rušin and Rybanský (1992).

2. Observational Data and Method of Analysis

We have used the data of regular limb observations of solar prominences (height, relative brightness, and area) carried out at Lomnický Štít in the years 1967 (May)-1996 (May). The green coronal data over the period 1939 to 1996 were taken from homogeneous coronal data set (HDS), e.g., Rybanský *et al.* (1994, and references therein). The data in the years 1995-1996 were made from the Kislovodsk, Norikura, and Lomnický Štít coronal stations.

3. Results and Discussion

The time–latitude distribution of the 'prominence index' in the period 1967 (May)–1996 (May), defined as *brightness* $\times$ *area*, is shown in Figure 1(b) (for a comparison in Figure 1(a) is shown the distribution of local maximum intensities of the green corona). One may see from Figure 1(b) that there are polar zones (crowns) of prominences. The distribution of prominences in mid and low latitudes is very complicated. There may be found 'small chains' (with a distinct local maximum) which mostly have a tendency to move to the higher latitudes, where they usually vanish around latitude 60°, except in the polar zones. It should be quite possible that these 'small chains' are subsidiary polar branches, observed for the first time in cycle 20 by Waldmeier (1970) that reach the poles very rarely or never. However, since the first Waldmeier observation, the existence of similar branches has already been observed again, e.g., Dermendjiev *et al.* (1994). These 'small chains' have a wide range scale of lifetimes, ranging from several months to 11 years or more. The polar crown of prominences in cycle 21 has been clearly observed between two polar branches of the green corona (see Figures 1(a) and 1(b)). It seems that a similar pattern of prominence–corona distribution happens also in other cycles. It could be supposed that the latitudinal distributions of the green coronal maxima and prominences are not uniform. Prominences appear after (behind) the green coronal maxima, in general.

There are, however, in the mid and low equatorial zones, 'small chains' which have a tendency to move towards the equator. Between individual 'chains' exists relatively empty space with a width of 10–15°. The existence of several polar crowns, even when they have not fully reached the poles, is in good agreement with the global large-scale pattern of weak magnetic fields as deduced by Makarov and Sivaraman (1989), McIntosh (1992), Makarov and Mikhailutsa (1992) from observations of filaments on the solar surface. A similar pattern of the distribution was found by Guhathakurta and Fisher (1994) in coronal temperature and density (white-light corona from the Mauna Kea K-coronameter). The main polar crowns do not reach the poles at the same time, rather the northern one reaches the pole a year before the southern one. Our results confirm the earliest Waldmeier (1973) conclusion that the time interval between poleward branches is clearly 11 years, independent of the length of the solar cycle. At this time, 'thin chains' are observed in the mid-latitudes, and one could suppose that they will continue to develop into new polar crowns, and the poles will be reached in the year 2002.5 (the northern one) and/or 2003.5 (the southern one).

The time–latitude distribution of intensities of the green corona is shown in Figures 2(a–c). They differ only in the computation method of local maxima of the green corona. Figure 2(a) displays maximum intensities derived from 13-day-smoothed values from observed data (the homogeneous data set has also interpolated data, details see, e.g., Rybanský *et al.*, 1994). In Figures 2(b) and 2(c) are shown similar maxima for both the 27- and 81-day-smoothed averages.

While in Figure 2 we have presented only data without any average in the position angle, Figures 3(a–c) display the same data, however with a smoothed average over three position angles (in latitudes), and common for both the E and W limbs and N and S hemispheres. From Figure 2 we can recognize that the maximum intensities of the green corona in each hemisphere appear in two polar branches. The first polar branch (crown) appears at latitude 50° in cycle minimum (this happens approximately one year later, when the main branches reach the

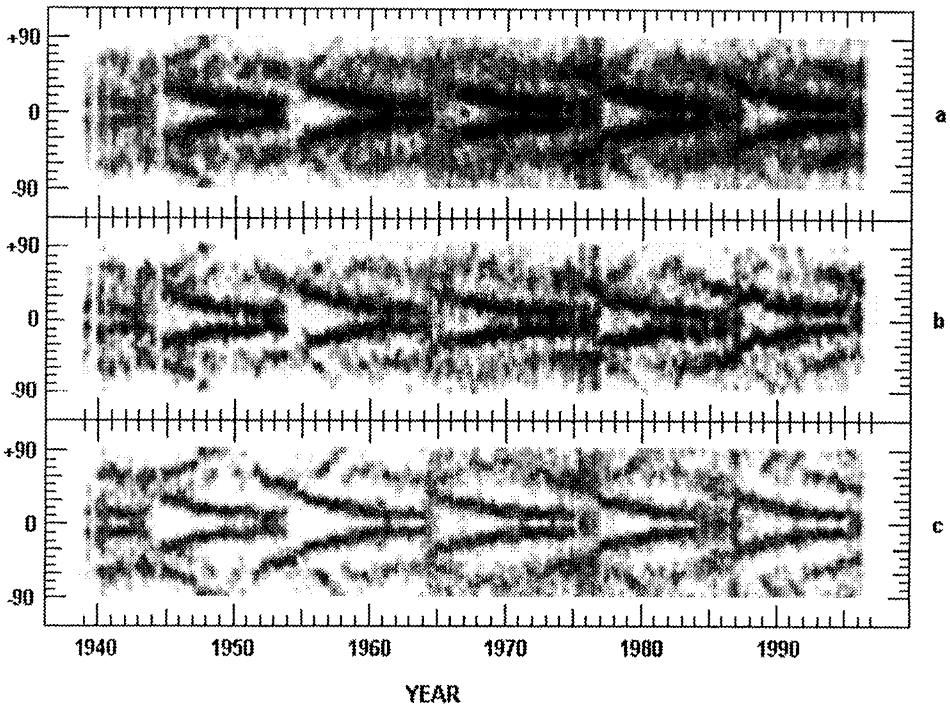

Figure 2. Time–latitude distribution of the green corona local maxima intensities for smoothed-averaged of (a) 13 days, (b) 27 days, and (c) 81 days as derived from HDS.

equator, starting 17–19 years in the previous cycle). This poleward-migrating zone ends at the polar region, and its duration is 5 years. The second one (the 'main activity zone') appears at a latitude of 45°, approximately 2 years after the first one. At the beginning, this zone migrates to latitudes of 70–80°, and reverses (at the moment when the first zone reached the poles or a year later) to equatorward migration, reaching the equator at the end of the next solar cycle. It ends very abruptly at latitudes around 5–10°. A similar distribution of maximum intensities of the green corona was observed by Altrock (1988) and Harvey (1992), even when their interpretation differs slightly from ours. They suppose that this 'main activity zone' starts only at high latitudes (70–80°). The same conclusion was made by Rušin and Rybanský (1990).

We have found that a remarkable regularity appears in the polar branches in the green coronal maximum brightness. From a separation of the first polar branch (it reaches the poles approximately in 3–5 years) to the reaching of maximum latitude of the second branch (it happens in every one of the 5 observed cycles) takes 5–6 years, and 17 years is required to reach the equator. This together represents the 22-year cycle in the green emission corona. We suppose that a new polar branch will start toward the poles in the next few months. We would like to stress that

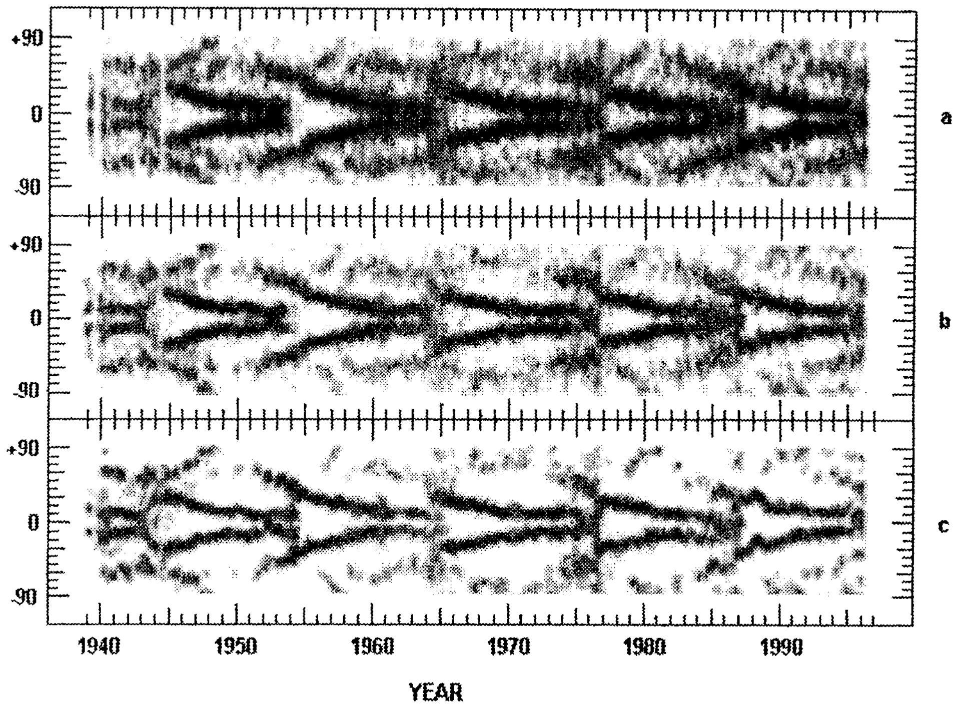

Figure 3. Time – latitude distribution of local maximum intensities of the green corona for smoothed averages over (a) 13 days, (b) 27 days, and (c) 81 days and averaged over 15° in positional angle as derived from HDS.

such a picture is rather more complicated if we take data only from one solar limb. The reason is that polar intensities are usually low, and occasionally mistakes in observations can alter their true distribution.

4. Conclusion

The following conclusions were drawn:

(1) Polar crowns of prominences reach the poles every 11 years, with a time difference between both poles (the northern one precedes the southern one).

(2) Very thin and fine subsidiary polar branches can appear, following the first one, reaching the poles only occasionally. In that case, with a higher speed than the first one.

(3) There exist zones of prominences migrating towards the equator from mid-latitudes.

(4) The occurrence of polar crown prominences is located between polar branches as observed in the green coronal maxima (or they lie behind the zone). This pattern is faint and non-continuous when more polar prominence branches

appear in the same cycle or when the polar prominence strip is wide (in the sense of heliographic distribution).

(5) A new cycle of enhancement in local intensities of the green coronal maxima, (the first or main polar zone) as defined from their latitudinal distribution, begins at mid-latitudes (at the minimum as defined by Wolf number or other indices) from the zone of increased intensities that appeared in the previous cycle. This polar branch migrates to the poles, reaching them around cycle maximum. The second mid-latitude branch, or the beginning of a new 'main activity zone', appears 2 years after the first one, also from the 'main activity zone' of the previous cycle. At the beginning, it migrates to higher latitudes (70–80°), reaching these latitudes 2–3 years later as the first polar zone reaches the poles. Then, it turns and continues in its migration to the solar equator, where it vanishes at the cycle minimum. The duration of the 'main activity zone' from its maximum latitudes to the equatorial region (the end of the cycle) lasts 16–17 years. Taking into an account that the time interval between the beginning of the first polar zone and the maximum latitudes of the 'main activity zone' is 5–6 years, then the full period takes 22 years. It seems that the time–latitude distribution of maximum intensities of the green corona is a continual process in which the same events (separations) appear every 11 years, however, the length of one complete period is 22 years.

5. Future Work

In order to have a better pattern of the prominence-coronal development and relationship during solar cycles, we propose to gather all earlier observations of prominences and the red corona, and continue this work. We should be able to do this, having asked for the data. New satellite data, e.g., from *Yohkoh* or SOHO missions should be also available.

We plan to do a forecast of the latitudinal occurrence of the emission corona and prominences and to check these distributions with observations.

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