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Solar cycle 24 minimum/maximum prediction based on the green corona 530.3 nm data

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Abstract. Predictions of maxima and minima of cycles of solar activity, including their amplitudes, are of importance not only for a deeper understanding of the physical processes responsible for solar activity, but also from societal and economical points of view because peak solar activity has great effects on major geophysical phenomena including space weather, like satellite drag and telecommunications outages, and has even been speculatively correlated with changes in global weather patterns. Such predictions are based on a combination of several different methods, as summarized by the panel of Space Weather Prediction Center (SWPC). Our estimate presented here is based on a long sequence of observations of the intensities of the green coronal line (530.3 nm/Fe XIV), whose local maxima migrate with the course of a solar cycle to the poles as well as to the equator. A careful analysis of the data indicates that the forthcoming solar cycle in the green corona will feature, like the last two ones, a couple of maxima; one at the end of 2010 and the beginning of 2011, the other at the end of 2012.

Key words: Sun – solar cycle prediction – green line data

1. Introduction

As it is well known, prominences and green coronal line are observed across the whole solar disk, i. e. also at high heliographic latitudes, which are completely devoid of sunspots. Although a time-latitudinal distribution of prominences and intensities of the green coronal line shows, in general, a rather complicated pattern, it can nevertheless be used as a fairly reliable indicator of the minima/maxima of solar activity cycles. In particular, around the minimum of a solar cycle there is observed, at middle heliographic attitudes, a splitting of the regions of the local enhanced intensities of the green coronal line into two branches; one which then propagates towards the poles and the other migrating equatorward (Trellis, 1957; Waldmeier, 1981; Leroy and Noens, 1983; Altrock, 1988; Minarovjech, Rybanský and Rušin, 1998, and references therein). A very similar separation and subsequent large-scale migration is also exhibited by prominences (Waldmeier, 1981; Makarov and Sivaraman, 1989; Minarovjech, 2008) and the remnant magnetic fields of opposite polarities, the "settings" of prominences (McIntosh, 2003). There has been found a very intricate connection between the maxima of the intensities of the green corona and the strength of local magnetic fields (Minarovjech, Rušin and Saniga, 2007), which speaks in favour of the hypothesis that magnetic fields are also at high latitudes the primary factor responsible for solar activity. Around the maximum of a solar cycle, the polar branches of both local green line intensities maxima and prominences disappear. Waldmeier (1957), analysing cycles 12 to 18, showed that "the speed of this displacement is the same in different cycles, independent of the intensity of solar cycle." Our prominence analysis of solar cycles 19 to 23 confirmed Waldmeier's findings. As discussed by Altrock, Howe and Ulrich (2007), the time-latitudinal distribution of the local maxima of the green coronal line could reflect the existence and behaviour of torsional oscillation shear and convergence zones, due to solar dynamo effects.

While the minima of solar cycles correlate quite well for all major indexes of solar activity, this is not the case as per the maxima. Thus, for example, the difference between the time when the monthly averages of the green line intensities show their maximum values may differ from that when the smoothed out Wolf number attains its maximal values up to two years (e.g., cycle 21); for some indices, like the total solar irradiance index (Fröhlich, 2008), it is even problematic to uniquely determine the occurrence of maxima. Hence, any prediction of the maximum/minimum of a solar cycle will be sensitive on the index employed; a comprehensive summary of the techniques used can be found in Hathaway (2008) or at `http://users.telenet.be/j.janssens/SC24.html`.

In the present paper, the prediction of the occurrence of the minima/maxima of the forthcoming solar cycle 24 is based on the time-latitudinal distribution of the maximal values of the intensities of the green coronal line, resting on a rich sequence of data acquired since 1939.

2. Observational material and analysis

The first off-eclipse observations of the green emission corona go back as far as to 1939. These were rather sporadic and it was only after the World War II where such observations acquired a systematic status. There are only a few coronal stations across the globe which have been performing this kind of observations up to date. Due to different standards and observing techniques, there exist discrepancies between the data acquired from individual stations. There have been several attempts in the past to bring these data to the unified photometric scale (see, e.g., Sýkora, 1971; and/or Rybanský, 1971), yet without any success (Makarov, Tlatov and Callebaut, 2003). Our homogeneous 1939-2008 sequence of the intensities of the green corona depicted in Figure 1 is based on the data taken from the site `http://www.swpc.noaa.gov/SolarCycle/` and processed by the method whose detailed description is given in Rybanský *et al.* (2005).

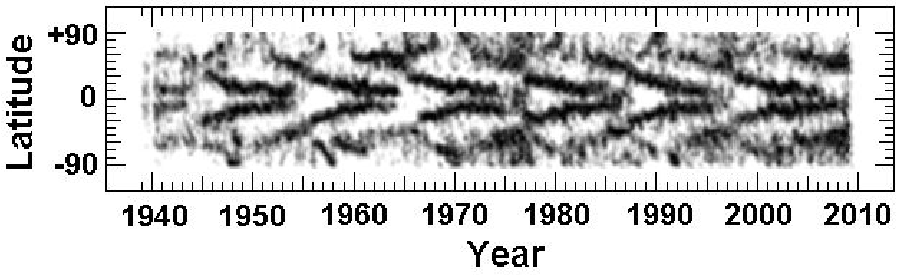

Figure 1. A time-latitudinal distribution of the green coronal intensity maxima in 1939-2008.

As it is obvious from Figure 1, this time-latitudinal distribution of the enhanced green line intensities exhibits a remarkably regular, "pseudo-butterfly" pattern, from which the separation of polar branches around the minima of solar cycles is well visible. In our previous work (Rybanský, Minarovjech and Rušin, 2003), with the data available to date, we estimated the minimum between cycles 23 and 24 to fall around 2007.5. Here, we predict the first maximum of cycle 24 to occur at the end of 2010 and beginning of 2011, and the second one, linked with the occurrence of the second quasipolar branch in the latitudes around 60° (Minarovjech, Rybanský and Rušin, 1998), to be in the second half of 2012 – see Figure 2. Our estimates can be prolonged a bit further to the future, with the minimum between cycles 24 and 25 occurring likely at the end of 2018, followed by the maximum of cycle 25 between 2021 and 2022 and the next minimum in 2029.

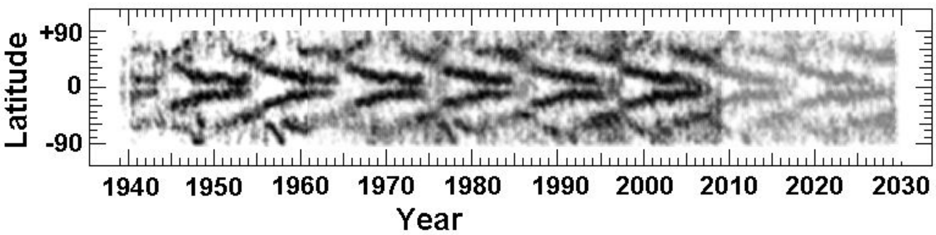

Figure 2. A time-latitudinal distribution of the green coronal line intensities' maxima in 1939-2008 and its predicted behaviour for the period of 2008–2030.

Almost every cycle covered by our data shows in this green coronal index so-called double maxima (see Figure 3), one being, as a rule, more pronounced (primary) than the other (secondary), yet we have no arguments in hands to claim which of the two predicted maxima in current cycle 24 will be the primary and which the secondary one. Some uncertainty in this respect also results from a couple of other factors. The first is the so-called N-S asymmetry (see, e.g., Rušin and Dzifčáková, 1990; and Dzifčáková and Rušin, 1998), that is the fact – which is quite easily discernible from Figures 1 and 2 – that the times of disappearance of both polar and equatorial branches differ for the two solar hemispheres. The second is a rather pulsing character of many phenomena shaping solar activity; this is completely neglected when determining the times of solar activity minima/maxima, as these are usually based on smoothed-out, 13-month averages of the data pertinent to the index under consideration.

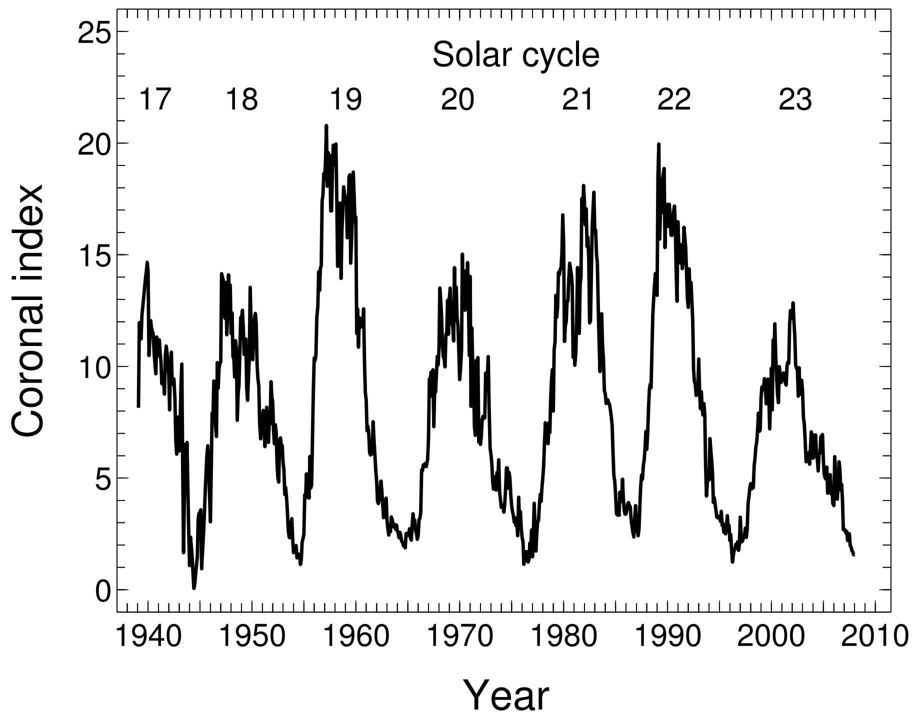

Figure 3. A temporal evolution of the coronal index of solar activity as derived from a homogeneous coronal data set brought to the Lomnický Štít coronal station photometric scale.

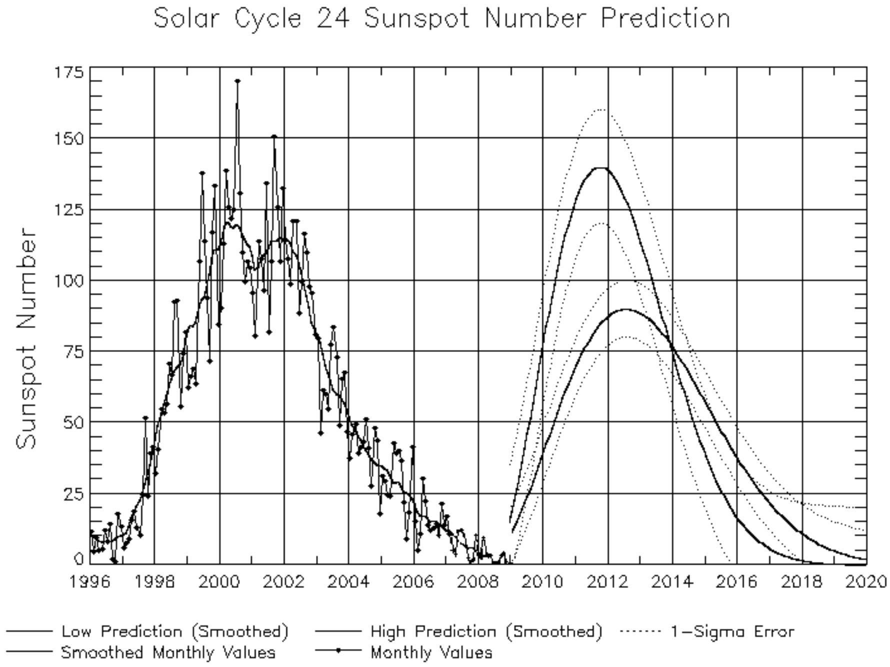

Figure 4. An illustrative summary of several predictions of the behavior of the Wolf number for cycle 24; note a fairly good consensus as per the time of the maximum, yet relatively big disagreement as per the absolute amplitude of the index. (The plot is a composite of the data acquired from `http://www.swpc.noaa.gov/SolarCycle/SC24/index.html`.)

3. Discussion and conclusion

The method employed here for prediction of the minimum and maximum of the forthcoming solar cycle rests on the time-latitudinal distribution of the local maxima of the intensities of the green coronal line for the period from 1939 to 2008, as discussed in detail in Minarovjech *et al.* (2003 and references therein). This distribution is intricately linked with that of global magnetic fields of the Sun (see, e. g., Minarovjech *et al.* 2007), and the maximum of the cycle is in the green coronal line observed around the time when the primary polar branches of enhanced intensities reach the poles.

Our method does not allow yet any prediction of the amplitude of the cycle; anyway, this is obviously a much more delicate issue as several predictions listed at `http://www.swpc.noaa.gov/SolarCycle/SC24/index.html` (and summarized in Figure 4) differ as per the amplitude up to 100% from the mean average,[1] although they do more or less concur as per the time of the cycle maximum (2011–2012), except for Svalgaard and Schatten (2008) who shift it to 2013. There is also a general consensus that the time of the maximum will depend on the amplitude of the cycle; the higher the amplitude, the sooner one can expect the maximum to occur. The cycle already started, although only very few sunspots have been so far observed. The main factor speaking in favour of this claim is the shape and structure of the white-light corona as observed during the last total eclipse (Rušin *et al.*, 2008); there were observed four large-scale helmet streamers above solar prominences at middle heliographic latitudes, which is typical for beginnings of solar cycles. Moreover, the onset of the separation of polar branches in the green corona at latitudes around $\pm 45°$ – and hence the onset of global magnetic fields' polarity reversal – was already witnessed at the end of 2007/beginning of 2008. Given the accuracy of the data available for the work of Rybanský *et al.* (2003), these authors' prediction of the minimum in question to fall on 2007.5 can be regarded as quite good.

Concerning the length of duration of solar cycles, here the green coronal index shows a more or less the same value – 11 years on average, based on available data covering cycles 18 to 22. When compared with the corresponding values inferred from the variation of the Wolf number, there are seen differences $\pm$ 10 months (Minarovjech, Rybanský and Rušin, 2003); the regularly alternating sign of these differences gives a strong support to the "conveyor belt" hypothesis of the inner workings of the Sun as recently proposed by Hathaway *et al.* (2003) or Dikpati, Gilman, and de Toma (2006). The fine structure of our time-latitudinal distribution of the green line intensities seems also to testify that the solar dynamo and its induced meridional flows are indeed the primary mechanisms shaping solar activity. We hope that our green line method of prediction, although simpler and more straightforward than others, will soon be given a firm observational credit.

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[1]Which only demonstrates the fact how far we still are from knowing the true essence of mechanisms responsible for solar activity.

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