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Predicting minima and maxima of solar cycles based on prominences and emission corona

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Abstract. Predicting maxima and minima of solar activity cycles, including their magnitude, is important not only for a better understanding of the underlying physical processes on the Sun, but also from the point of view of solar-terrestrial relations. Such predictions employ a variety of well-know relations like those between even and odd cycles, or between the AA index and the Wolf number. Our prediction is based on the properties of large-scale meridional motions of prominences and the areas of enhanced intensities of the green line corona. We predict two maxima of cycle 24; first at the end of 2011, the other at the end of 2012. Although our method is unable to predict the magnitude of cycles, a relatively stable structural pattern of the above-mentioned meridional motions makes this method suitable for long-term predictions of the maxima/minima timings up to 2025.

Key words: Sun: solar cycle – Sun: prominences and emission corona – Sun: predicting minima/maxima

1. Introduction

The Sun is a magnetically variable star. Its variability manifests itself through a plethora of both temporally and spatially framed phenomena observed on its surface (*e.g.*, occurrence of sunspots), in its atmosphere (*e.g.*, prominences), as well as in its electromagnetic radiation, like the change of the intensity of the green coronal line Fe XIV 530.3 nm. The basic period of Sun's variability is the so-called Hale cycle of about 22 years, although better known is a shorter, 11 year period inferred from observations of sunspots going back to 1610. It is also well known that peaks of cycle maxima are characterized by a number of flares, eruptive prominences and CMEs with a huge release of energy, influencing considerably also the Earth's atmosphere (auroras, magnetic storms, changes in the density and temperature of the ionosphere, *etc.*). Even the total irradiance of the Sun is sensitive to the phase of a solar cycle, the difference between maxima and minima being of about 0.1–0.2%. It is therefore important to attempt to offer reliable predictions of solar variability. And this not only as per its period(s), but also its magnitude(s); a brief inspection of Fig. 1 reveals that the latter is quite different for different cycles.

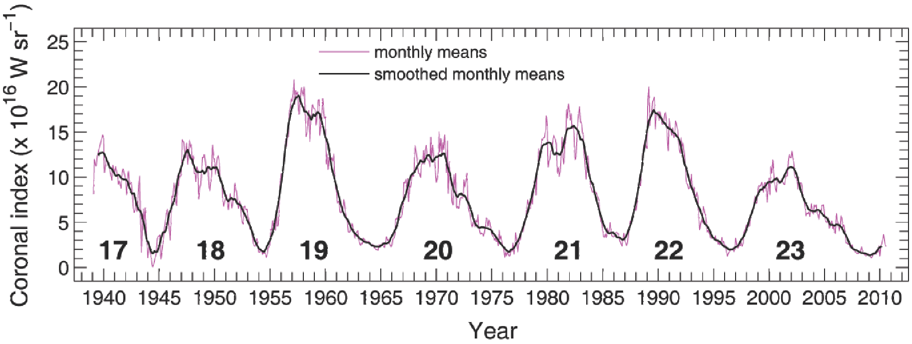

Figure 1. Cycles of solar activity in terms of the variation of the coronal index, as computed from a homogeneous data sequence of the enhanced intensities of the green corona. (Source of data: NOAA NGDC website `http://www.ngdc.noaa.gov/stp`)

A plethora of methods have been suggested and/or developed to predict variations of solar activity, starting with that which employs an intricate link between even and odd cycles and ending with that based on the magnitude of magnetic flux in the regions close to the poles. Some of these methods give quite contradictory predictions (for a detailed, up-to-date survey of the methods, as well as their shortcomings, see Hathaway (2010)). Almost all methods employing solar indices rest on observations of solar phenomena at low and/or middle latitudes, *i.e.*, in regions up to ± 40 degrees from the solar equator. Recently, starting essentially with the SOHO era, also large-scale meridional circulations/motions have gradually been taken into account. Our method is based on observations of prominences in the Hα line of 656.3 nm and the green line corona. Both the phenomena are observed throughout a whole solar cycle and, more importantly, around the whole solar limb; our focus will be on those observations from higher latitudes and/or the regions close to the poles.

2. Prominences

Prominences are basically aggregates of a relatively cool hydrogen-dominated plasma embedded in a rather hot corona that, unlike sunspots, can be observed at any phase of the solar cycle and across the whole solar globe; however, not everywhere but only in the vicinity of so-called neutral lines of magnetic fields. It is a firmly established observational fact that, in general, at the beginning of a solar cycle prominences are mostly seen in the middle heliographic latitudes and with the course of the cycle they gradually migrate towards the poles where they disappear at the end of the cycle. Prominences have been observed since the 19th century and one can distinguish the following three cases:

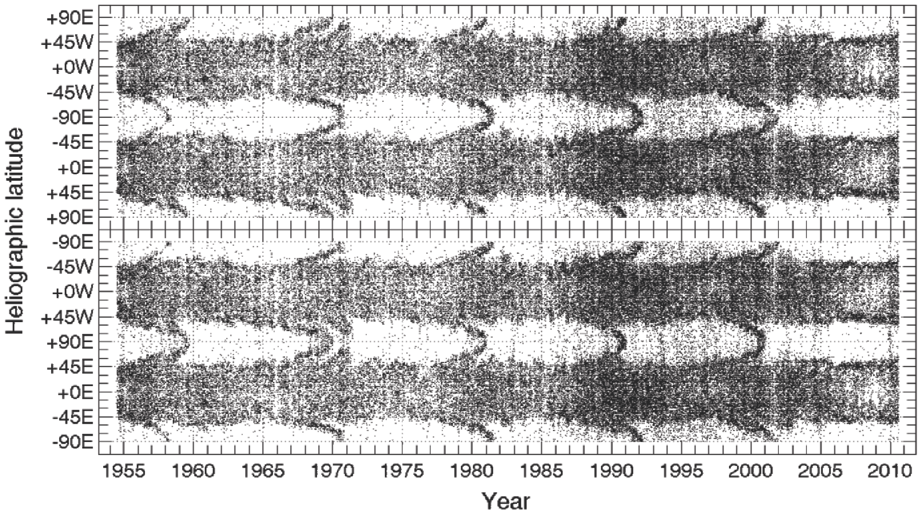

Figure 2. A latitude-time distribution of prominences in the interval from 1954 to 2010, shown separately as viewed from the south (top) and north (bottom) pole. (Source of data: Lomnický Štít coronal station and *Solnechnye Dannye*.)

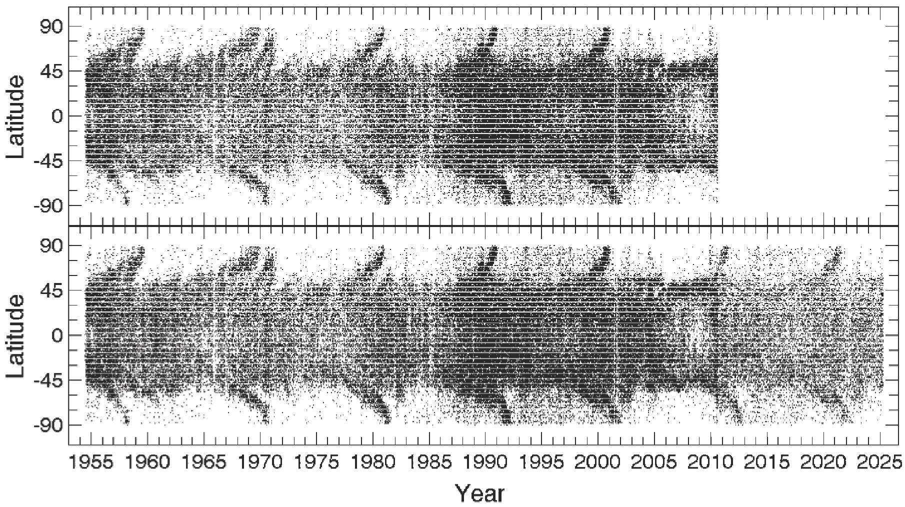

Figure 3. A latitude-time distribution of prominences in the period from 1954 to 2010 as in the preceding figure, with its predicted behavior up to 2025. (Source of data: Lomnický Štít coronal station and *Solnechnye Dannye*.)

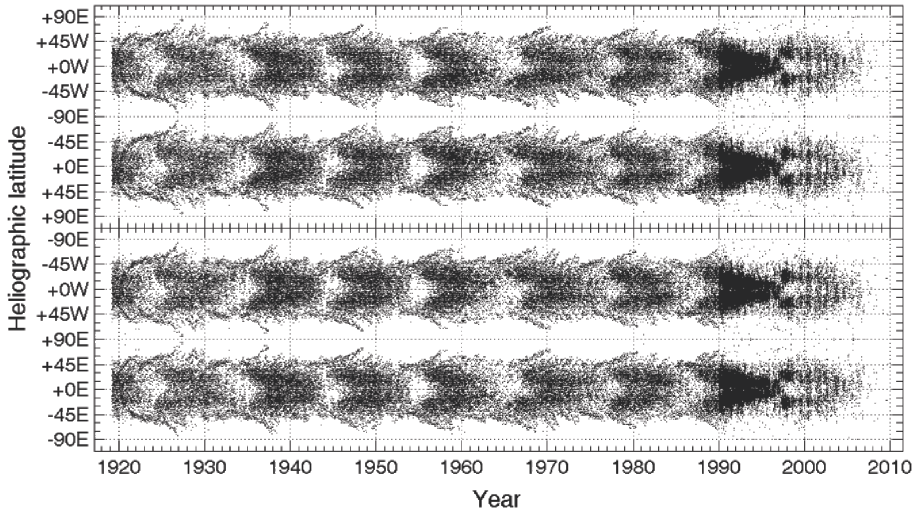

Figure 4. A latitude-time distribution of filaments for the period from 1919 to 2010. (Source of data: `ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_FILAMENTS/CARTE_SYNOPTIQUES/1919_1957.DATA/`, `ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_FILAMENTS/`)

a) a class of prominences that are tied to sunspots and which move from the middle latitudes towards the equator where they disappear, like sunspots, shortly before the next *minimum* of a cycle;
b) a similar class of prominences originally located in the regions whose latitudes differ from those of sunspots' zone by ± 10 degrees, and whose temporal evolution is the same as in the previous class;
c) a family of prominences which move from middle latitudes towards the poles where they disappear around the *maximum* of a cycle.

As first shown by Waldmeier (1957), such motion lasts about 3 or 4 years and is almost independent of the amplitude of a cycle when expressed by the Wolf number. In particular, he showed that if the "strength" of the cycle (defined in terms of Wolf's number) is low (less than 100), then polar branches[1] reach the poles at about half a year before the maximum of the cycle. On the other hand, if the amplitude of the cycle is above 100, then these polar branches get to the poles as late as one and a half year after the maximum.

Using mostly our own data, we have created latitude-time distributions of prominences, as depicted in Figs. 2 and 3. From careful inspection of these figures we infer that in current cycle 24, the polar branches of prominences should reach

[1]A polar branch of prominences is an aggregate of prominences moving to the poles.

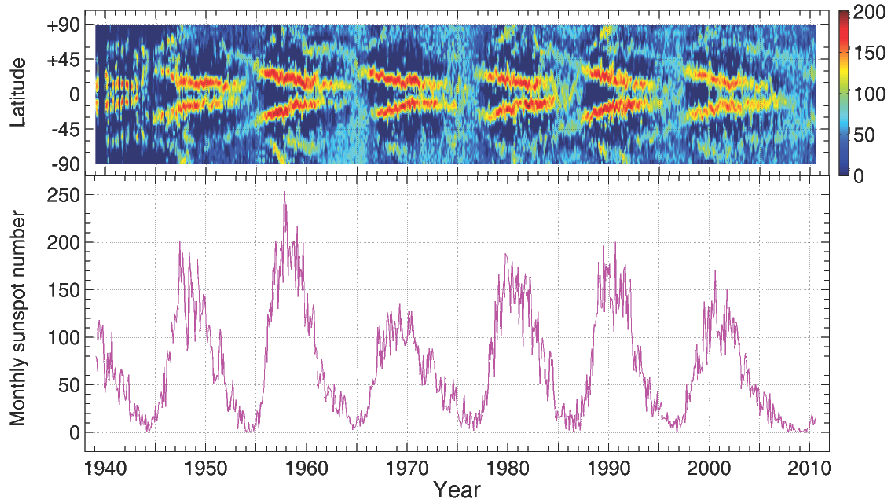

Figure 5. A comparison of the latitude-time distribution of the local maxima of the intensity of the green coronal line (top) and time-variation of the monthly sunspot numbers (bottom). (Source of data: NOAA NGDC website `http://www.ngdc.noaa.gov/stp` (top) and `http://www.spaceweather.com/java/archive.html` (bottom).)

the north pole at the end of 2011 and the south pole one year later. If we focus on a latitude-time distribution of filaments (*i.e.*, projections of prominences on the solar disk), we have at our disposal data going back to 1919 (cycle 16) and the corresponding plot is shown in Fig. 4. Although filaments above 80 degrees of latitude are not observable, the times of arrival of polar branches up to 70-80 degrees are well discernible. The fact that the structural pattern and periodicity of meridional motions of prominences and filaments are rather stable in the period under study makes this method suitable for long-term predictions of the maxima/minima timings up to 2025 (Fig. 3).

Our estimate of the time of maximum of cycle 24 is based on a series of consecutive shifting and overlapping of a distribution-chart of prominences for a given solar cycle with respect to other ones so that any two charts are adjusted in such a way to best correlate the regions near poles where polar branches disappear. By averaging a number of such comparisons one gets a "representative" distribution with a certain characteristic value of the cycle length that can be used for prediction. This value amounts to 10.4 ± 0.7 (N) and 10.9 ± 1.7 (S) years for prominences, and to 10.83 years for filaments. In cycle 23, the northern/southern polar branch of prominences disappeared at 2001.0/2002.0, which gives the corresponding estimate for the maxima of cycle 24 at 2011.4 ± 0.7 and 2012.9 ± 1.7.

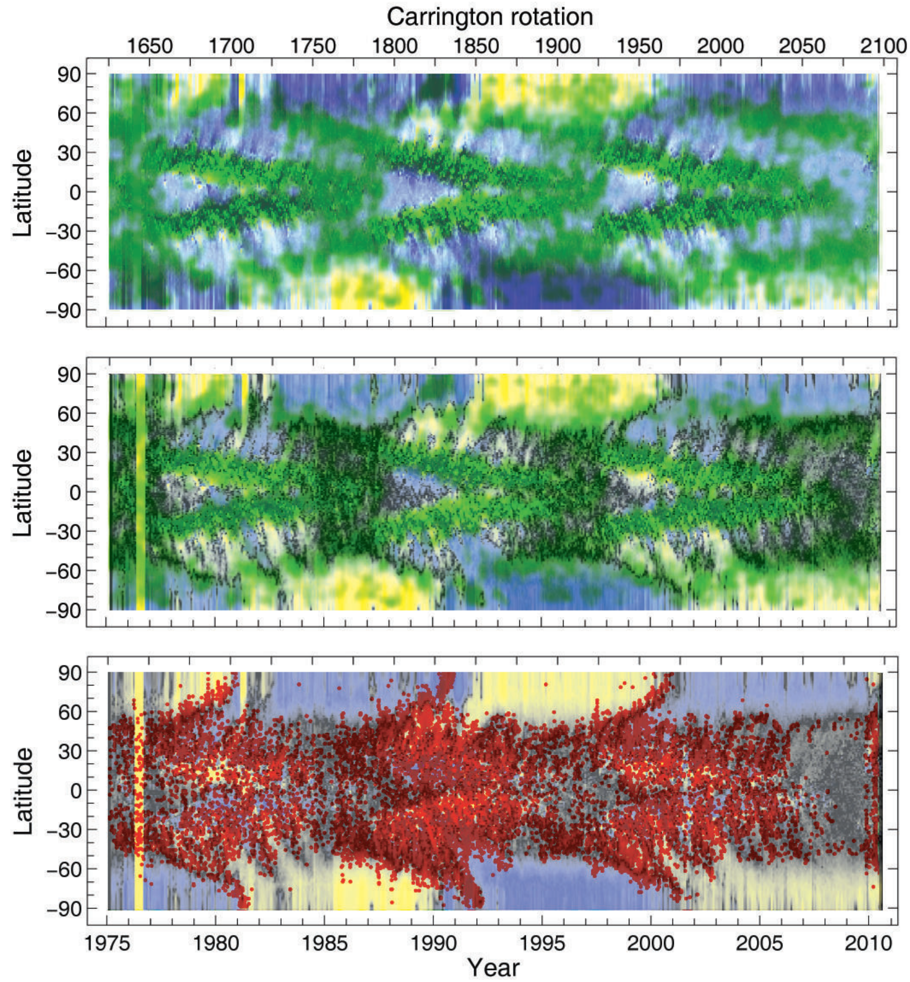

Figure 6. A latitude-time distribution of the local intensities of the green coronal line (green color), overlaid on that of the average magnetic fields at the Sun's surface. *Middle:* The same as above, but with the magnetic field strength shown in absolute values. *Bottom:* The same as in the middle panel for a latitude-time distribution of prominences (red color). (Sources of data: NOAA NGDC website `http://www.ngdc.noaa.gov/stp` (green corona).)

3. Green corona

Almost identical results have been obtained when studying the motion of polar branches of the enhanced intensities of the green corona, as illustrated in Fig. 5. It is worth reminding the reader here of the fact that the local maxima of the green line corona are very latitude-dependent given the sensitivity of this line on magnetic field strength in observed areas (see Fig. 6). From Fig. 5, even an extended cycle of the green corona, lasting on average about 17–18 years, can be ascertained. This kind of cycle starts at high latitudes of about 70 degrees, from where the areas of enhanced intensities of the green line move towards the equator, where they disappear around the next maximum. During the first minimum these areas reach middle latitudes, which are the site of separation of polar branches, the latter decaying close to the poles during the maximum. Roughly one year later, the onset of the new areas of the same extended cycle is observed at latitudes of 70 degrees. Some of extended cycles (*e.g.*, cycle 18 and 19) are "peculiar" in the sense of exhibiting two distinct polar branches.

Fig. 6 illustrates a very intimate connection between the distributions of the averaged photospheric magnetic fields (locations of the "neutral line"), green line corona and prominences. From this figure one also sees that

a) the local maxima of both the intensities of the green line and prominences are located close to the boundaries of different magnetic polarity;
b) these boundaries reach the poles at more-or-less the same time as polar branches of both green line enhanced intensities and prominences;
c) within a relatively short period, about one year, both poles can exhibit the same polarity;
d) there are some tiny, small-scale variations in all the three quantities moving towards the poles, however, without a need of reaching them.

The reader interested in more details about our method and associated techniques of data reduction is referred to Rušin *et al.* (2009) and Minarovjech *et al.* (2011).

4. Conclusion

We have briefly described our method of the prediction of the timing of minima/maxima of solar cycles, which is based on the time of arrival to the poles of polar branches of both prominences and areas of enhanced intensities of the green corona. We predict that cycle 24 will feature two maxima, one at the end of 2011 and the other one year later, and that the minimum between cycles 24 and 25 will be in 2018/2019. Cycle 24 should thus be a bit shorter than the preceding one.

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