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A Comparison Between the Solar Activity in the 11-Year Sunspot Cycles During the Last Two Centennial Solar Activity Minima. A Comparison of the Geomagnetic Activity During the Same Periods

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Abstract.

When we talk about a change in solar activity, we usually mean a change in the number of sunspots which is known as the 11-year sunspot cycle. The beginning of the cycle is considered to be the time when there is a minimum number of sunspots which may be different for different cycles both in terms of duration and the number of sunspots. It is followed by an increase in the sunspot number until a maximum is reached, and a decrease again to the next minimum. This period lasts approximately 11 years. It has been established that there exists also a quasi-century-old cycle, called Gleissberg cycle. For about 100 years, the number of sunspots in the 11-year cycles changes with a gradual increase followed by a decrease and again an increase. For a long time, only the number of sunspots was a measure of solar activity. In the present work, we compare the number of sunspots in the different phases of penultimate 11-year solar cycles and compare them with the analogous period of the previous century minimum. We also study the development of geomagnetic activity in the indicated period of time.

1. Introduction

In the past, changes in climate were compared with the sunspot number [Sabine, 1852], and later with geomagnetic activity. It is now known that big sporadic (non-recurrent) geomagnetic storms are caused by coronal mass ejections (CMEs). The latter are related to the evolution of the solar toroidal field whose manifestations are sunspots. Thus during sunspot maximum, a maximum in geomagnetic activity is observed. Another source of geomagnetic activity are coronal holes, regions of the open unipolar magnetic field from which the high-speed solar wind emanates [Feynman, 1982]. Disturbances caused by high-speed solar wind are at maximum during the sunspot's declining phase, which leads to two geomagnetic activity maxima in the 11-year sunspot cycle.

2. Observational data

We compared the amplitudes of cycles 12, 13, 14, 23, 24, and 25 with the geomagnetic activity for the same period of time using the following indices:

1.The sunspot number (SSN). calculated by the Sunspot Index Data Center (https://www.sidc.be/silso/datafiles)
2. Geomagnetic index aa https://isgi.unistra.fr/indices_aa.php
3. ap index https://www.ngdc.noaa.gov/stp/geomag/kp_ap.html

3. Analysis and Results

3.1. Evolution of cycles 12 and 13:

Cycles 12 and 13 are the last two 11-year cycles in the preceding Gleissberg cycle. Naturally, their solar activity, measured by the number of sunspots, is lower than that in the middle of the Gleissberg cycle. Although the last cycle is 13, its activity is higher than that of the 12th cycle, but this is natural considering the Gnevishev-Ol rule that "every odd cycle is higher than the previous even cycle".

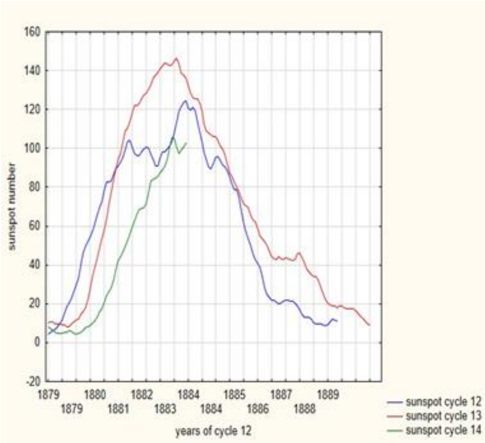

Figure 1. *Evolution of cycles 12, 13 and the beginning of 14.*

The next cycle, the 14th, almost repeats the development of cycle 12th (Fig. 1). after which a significant increase of the 11-year cycles begins. Therefore, we are possibly in one of the most powerful 100-year cycles.

3.2. Evolution of cycles 23 and 24

The period of the great maximum ends with cycle 23, for which the solar activity was the highest for several decades recorded by direct and indirect data in the last 8 thousand years (Solanki et al., 2004). The prolonged and deep minimum of solar activity in 2008-2009 (end of cycle 23 and beginning of 24) is generally considered to end this century-long maximum. Therefore, the question arises as to whether a Maunder-like minimum of solar activity awaits us. The completed 11-year cycle after it, as seen in Fig. 2, was significantly weaker than the previous one. The starting 25th cycle is predicted to be weaker than the previous cycle.

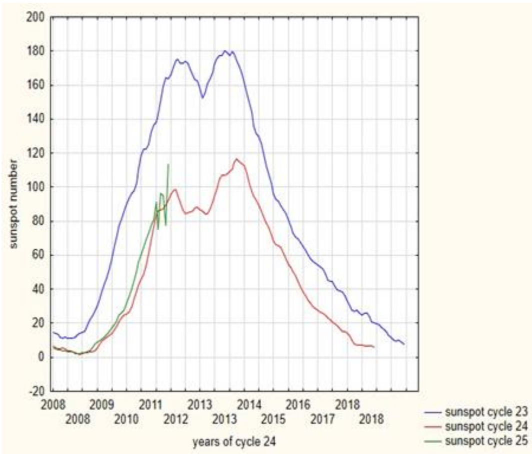

Figure 2. Evolution of cycles 23, 24 and the beginning of 25.

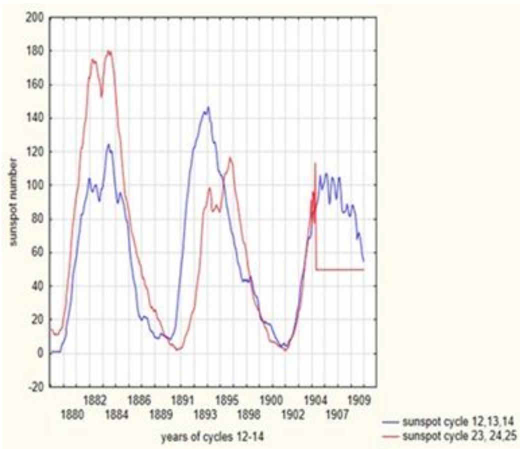

Figure 3. Evolution of cycles 23, 24 and the beginning of 25.

Based on the first data from this cycle, due to the relatively rapid increase in solar activity, it is believed that a significantly high maximum is expected. In fact, the rate of increase in solar activity is not significantly different from that of the 24th cycle, and it seems that these predictions are exaggerated. As it can be seen from Fig. 3, the 23rd cycle is significantly higher than cycle 12. These are the penultimate 11-year cycles in the respective 100-year cycles. However, the 13th cycle, in accordance with the rule of Gnevishev-Oll, is more powerful than the 12th, while the 24th is significantly weaker than the 23rd which is a logical conclusion of the last Gleissberg cycle. While cycles 12 and 13 have single maxima, 23 and 24 have double maxim. As already shown by e.g. Georgieva [2011], the solar dynamo can operate in different regimes determined by the relative importance of diffusion and advection in the upper and bottom parts of the solar convection zone (e.g. Paul Bushby and Joanne Mason, 2004). Based on the estimations for the speed of the surface poleward meridional circulation and diffusion in the upper part of the convection zone, it has been demonstrated that the dynamo operates in a moderately diffusion-dominated regime, in which a part of the flux short-circuits the meridional circulation and diffuses directly to the bottom of the convection zone at mid latitudes. Another part makes a full circle to the poles, down to the base of the convection zone, and equatorward to sunspot latitudes. These two parts of the flux, when transformed by the differential rotation at the base of the convection zone, give rise to two peaks of sunspot activity, which are close but not exactly coinciding. In this way, the double-peaked sunspot cycle and the Gnevyshev gap have their natural explanation in the flux transport dynamo theory. Based on this, we can come to the conclusion that while during the 23rd and 24th cycles, the solar dynamo works in a moderately diffusion-dominated regime, the 12th and 13th are in the advection dominated regime.

The minimum solar activity in 2008-2009 (between the 23rd and 24th cycle) was extremely low and prolonged. This has led many scientists to wonder if the Sun is entering a new grand minimum. The present data the 25th cycle, however, do not show this trend.

3.3. Solar sources of geomagnetic activity

Since the beginning of geomagnetic research, it has been established that there is a relationship between the number of sunspots and the number of geomagnetic disturbances. However, as we know today, sunspots themselves have no effect on Earth, but the presence of more sunspots is associated with more CMEs (e.g. Lindsay G.M., et al. 1995). The latter cause powerful geomagnetic storms. In addition, there is another source of geomagnetic disturbances, namely high-speed solar wind flows, and their source are the so-called "coronal holes".

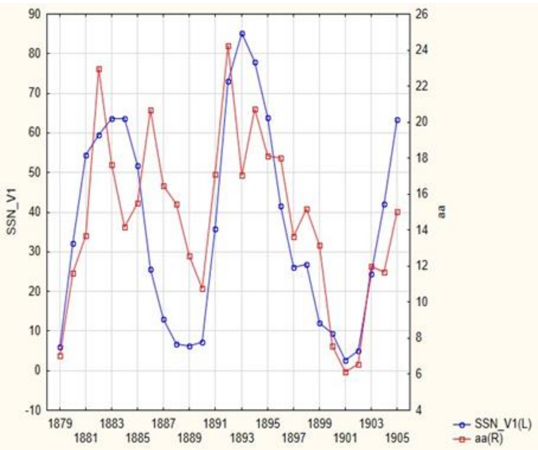

Figure 4. Geomagnetic activity during cycles 12, 13 and the beginning of 14.

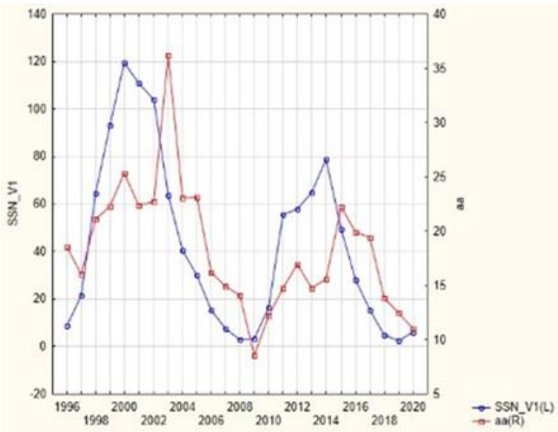

Figure 5. Geomagnetic activity during cycles 23 and 24.

Because most CMEs occur during solar activity maxima, and most geopotential coronal holes occur during the decline of the solar activity, the geomagnetic Fig. 4 Geomagnetic activity during cycles 12, 13 and the beginning of 14 activity has two maxima during the solar cycle. Fig. 4 shows the geomagnetic activity against the sunspot number for cycles 12 and 13.

Looking at the same relationship, but for cycles 23 and 24 (Fig. 5), we see only one maximum of the geomagnetic activity during each of the cycles. This peak is observed to be during the decline of solar activity. This means that either the number of CMEs is not proportional to the number of sunspots or that the corresponding CMEs are not geoefficient.

3.4. How can we evaluate the relative influence of different types of solar activity on the Earth?

To establish the influence of various solar factors on the geomagnetic activity, Feynman examined the dependence of the aa index of geomagnetic activity on the number of sunspots and found that all values of aa lie above a straight line that obeys the equation:

$$aaR = a + b*R,$$

where R is the number of sunspots. According to Feynman, aaR is the geomagnetic activity due to the solar activity associated with sunspots. The values of aa above the line aaR (see Fig. 6) is the geomagnetic activity associated with the high-speed solar wind.

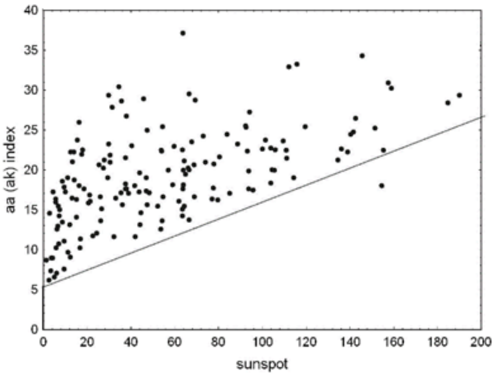

Figure 6. Dependence of the aa index of the sunspot number.

We introduce one additional term aamin, and so the geomagnetic activity at a given time is:

$$aa = aamin + aaT + aaP$$

- aamin - "floor" in geomagnetic activity
- aaT=b*R – geomagnetic activity due to sunspot-related solar activity
- b – sensitivity of geomagnetic activity to sunspot-related solar activity
- aap – geomagnetic activity due to non sunspot-related solar activity

The geomagnetic activity "floor" is the geomagnetic activity in the absence of any sunspots. Practically it is determined by the geomagnetic activity in the sunspot minimum. We can conclude that the geomagnetic activity "floor" is determined by non-sunspot-related solar activity.

We compare the geomagnetic activity with the number of sunspots for cycles 13 and 24 in Fig. 7 and 8, respectively. We see that the floor in cycle 13 is about two times lower than that in cycle 24, but on the other hand, the sensitivity of geomagnetic activity to the number of sunspots is significantly greater for cycle 13 than for cycle 24.

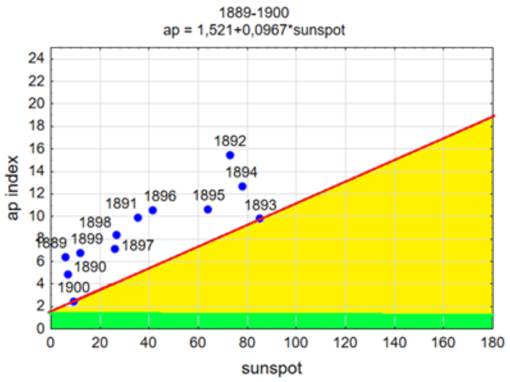

Figure 7. The same as Fig. 6 for cycles 12 and 13.

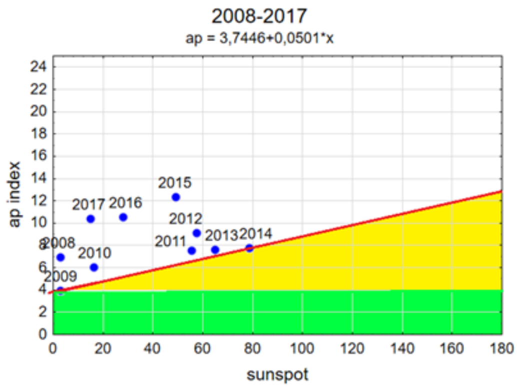

Figure 8. The same as Fig. 6 for cycles 23 and 24.

This once again confirms the conclusion that the solar dynamo operates in two different modes during cycles 12, and 13, and cycles 23 and 24.

Conclusions

The sunspot number at the beginning of cycle 25 follows the behaviour of the sunspot number in cycle 14. This is true for both the number and the rate of increase.

CMEs related to sunspots are less geoeffective during cycle 24. This is the reason for the weaker sensitivity of the geomagnetic activity to the number of sunspots.

During cycles 23 and 24, the solar dynamo works in a moderately diffusion-dominated regime, and during cycles 12 and 13, it is in an advection-dominated regime.

Acknowledgements

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References

Sabine E., "On Periodical Laws Discoverable in the Mean Effects of the Larger Magnetic Disturbances", Phil. Trans. R. Soc. Lond. January 1, 1852 142 103-124; doi:10.1098/rstl.1852.0009.

Feynman J., "Geomagnetic and solar wind cycles, 1900-1975", J. Geophys. Res. 87, 6153-6162 (1982).

Solanki S.K. et al., "Unusual activity of the Sun during recent decades compared to the previous 11,000 years", Nature, 431 (7012), 1084, 2004.

Georgieva K., "Why the Sunspot Cycle Is Double Peaked", International Scholarly Research Notices Volume 2011 | Article ID 437838.

Paul Bushby, Joanne Mason, "Understanding the solar dynamo", Astronomy & Geophysics, Volume 45, Issue 4, August 2004, Pages 4.7–4.13, https://doi.org/10.1046/j.1468-4004.2003.45407.x

Lindsay G.M., Luhmann J.G., Russell C.T., Gazis, P., Solar cycle variation of interplanetary shocks, coronal mass ejections, and stream interactions observed at 0.7 AU. Advances in Space Research 16 (9), 353-353, 1995.