DOI: 10.31401/WS.2021.proc.09

Predictions for SC25, 26 and SC27 Magnitudes in Relation to the Long-Term Solar Activity Changes

Komitov B.P.
Institute of Astronomy and NAO, BAS, Sofia, Bulgaria
komitovboris97@gmail.com

Abstract

In this work the results about the near-maximal amplitudes of present (SC25) as well as the next two Schwabe- Wolf's sunspot cycles SC26 and SC27 are discussed. For this aim two data series has been used: They are the mean monthly sunspot numbers (the new SILSO_version 2) for the epoch Jan. 1818- Jul.2021 and the complemented "historical" Schove's series (214 BC - 2009AD). It has been found on the base of mean monthly data analysis for the first 20 months after the starts (minima) of sunspot cycles that the SC25 near-maximal amplitude should expect to be 149±39, which corresponds to 99±26 as a classical Wolf's number. On the other hand, by using of kinematic model based on time series analysis (T-R periodogram algorithm) the corresponding near maximal Wolf's number of SC25 is in range 75±38. Taken into account that the near-maximal amplitude of SC24 in 2014 AD is ~82 it could to conclude that a violation of the amplitude Gnevishev-Ohl-Kopecky's rule for the even-odd sunspot cycles pair SC24-SC25 is possible. It has been found by using of auto-regression models of sunspot cycles amplitudes in Schove's series that the magnitude of the next SC26 should be expect in range of 90-95 as Wolf's (Ri) number. There is also prediction for a very shallow sunspot minimum between SC26 and SC27 in 2038-2040AD

Introduction

The long term solar activity predictions are significantly more complicate than the related only for the current or next sunspot Schwabe-Wolf's cycle. The reason for this one relates to the circumstance that instrumental space climate data series are relative short, while the forecasts for two or more SC requires information, which includes at least few or more centuries. That's why events like grand solar minima or maxima should be taken into account in such forecasts. On the other hand, the theoretical or mixed solar activity models, based on the modern solar dynamo theory are focused mainly on the quasi 11 (Schwabe-Wolf) a 20-22 yr (Hale) cycles and generally the explanation and forecasting of such events like the grand solar minima is problematic for the most of them. That's why for the aims of long time solar activity and space climate prediction needs to use no only instrumentally indexes data series, but also of indirect historical data series such as the Schove's series [*Schove*, 1955, 1983], "Chinese" giant naked eye visible sunspots [*Witmann and Xu*, 1987], "cosmogenic" radioisotopes (14C, 10Be) [*Stuiver and Quay*, 1980; *Damon and Sonett*, 1991; *Reimer et al*, 2013; Bard et al, 1997, *Usoskin*, 2013]. It has been shown that the using of statistical methods as factor type regressions and autoregressions [*Komitov*, 2007] or kinematic models [*Komitov and Kaftan*, 2003] is very successful. In this study results about the forecasting of the present 25th in Zurich series Schwabe-Wolf's sunspot cycle (SC25) magnitude, as well as for the next two (SC26 and SC27) are shown.

Data and methods

a) Data

The study is based on two types of data series. The first one is the instrumental sunspot Zurich series of the mean monthly sunspot number since January 1750. The both versions of these data has been used – the "classical" Wolf number, presented by the International sunspot number (*Ri* or *SN_v1*) for the epoch January 1750- December 2014 and the new sunspot data series, suggested by Clette and Lefevre few years ago [*Clette and Lefevre,* 2016]. The last one is used for the epoch January 1750- March 2021.

The second data series is by "historical" type. It is the so called "Schove's series", suggested by Derek Schove in 1955 and improved by him in 1983 [*Schove*, 1955, 1983]. It contains the macro- characteristics of the sunspot cycles since 642 BC. These parameters are the calendar years of minima and maxima as well as the cycle magnitude in 9-level scale. The last one is calibrated to the near –maxima annual sunspot *Ri* index data for each cycle between 1750 and 1948 AD in the primary version of this data set [*Schove* 1955] and slightly improved after that in 1980[th] [*Schove*, 1983]. The Schove's series has been constructed on the base of ancient and medieval messages about aurora, giant sunspots, annual tree ring widths data, extreme natural (environmental) events like very cold winters or very dry and warm summers, floods, earthquakes etc. After 1750 AD the Schove's series continues in the instrumental Zurich series.

It is necessary to note that before 219 BC the macro- parameters are established only for separate sunspot cycles. There is also a second calendar interval between 196 and 284 AD where the sunspot cycles data are not complete - the calendar years of sunspot cycles extremes has been established, but the magnitudes are unknown. After 284 AD the Schove's series is complete.

b) Regression models, based on "Waldmeier's rule"

It has been established in an other our previous study [*Komitov et al*., 2011] that the so called "Waldmeier's rule" (the sunspot cycles magnitudes are higher when the corresponding upward sunspot solar cycle phase is faster and shorter) is well expressed even if only the first 1.5-2 years are taken into account. It helps for a relative certain estimation for the mean annual near maximal *Ri* value (magnitude, Ri_{max}) on an earlier stage of the current sunspot cycle. It has been found for the first 18 months after the sunspot minima the following regression relationship between the mean monthly *Ri* change ($\alpha=dRi/dt$) after minimum and Ri_{max} :

$$Ri_{\max} = 2.44\alpha + 69.7 \pm 27 \qquad (1)$$

This relationship is by using of monthly Ri values for the last 17 to this moment sunspot cycles, i.e SC7-SC23 (1818 – 2010 AD). The corresponding correlation coefficient of this relationship is r=+0.69.

It has been found by instrumental data for the first 18 months of SC24 that the corresponding value of α is 0.91. It follows by (1) that Ri_{max} for SC24 should be 72±27. The real Ri_{max} value of SC24 in 2014 AD is 82. Thus it could consider the prediction of SC24 magnitude as successful.

About six months later a new similar analysis has been provided, but this time on base of the first 24 months after minima for the same sunspot cycles (SC7 to SC23) [*Komitov and Kaftan,* 2011] . The regression function was significantly improved. In this case has been found a relationship:

$$Ri_{\max} = 23.63\alpha + 46.9 \pm 17 \qquad (2)$$

with r = +0.91 and Snedecor- Fishers *F*- parameter equal to 5.34, which is around the critical value of last one for 99% confidence ($F_{99} \approx 5.2$) , while for 95% it is 3.24. The corresponding predicted SC24 magnitude in this case is Ri_{max} = 90±17.

It has been also found for the 24-months case that the regression model could even more slightly improved if the monthly *Ri* value for the sunspot minimum (*Rm*) as a second factor is used [*Komitov and Kaftan,* 2011]. In this case

$$Ri_{\max} = 23.63\alpha + 1.94Rm + 41.6 \pm 16 \qquad (3)$$

The corresponding coefficient of multiple correlation in this case is *R*=0.92 with *F*= 5,97. The predicted SC24 magnitude is Ri_{max} =86±16.

Thus all these three regression models, which has been applied to SC24 magnitude prediction indicate their successful fitness to current sunspot cycle forecasting during the earlier stage of its upward phase. To the present moment (~19 months after the sunspot minimum between SC24 and SC25) a one- factor regression model of type (1) or (2) could uses for prediction of SC25 magnitude. In the present study the whole instrumental data series of monthly sunspot numbers *Ri* since January 1750 and up to December 2014 is used. The results are presented and discussed in the section “Results and analysis” of the paper.

c) Autoregression models, based on Schove’s series

In 2007 author found in Schove’s series a regression relationship between the sunspot cycles with even numbered according to Zurich series standard with numbers 2n and 2n+2 [*Komitov*, 2007]. The founded relationship has been extracted on base of whole epoch between 296 and 2000 AD plus the calendar interval 219BC – 196AD, where the sunspot cycles macro-characteristics data are complete. The obtained auto-regression function is

$$\Delta Ri_{max(2n,2n+2)} = 98.5 - 1.06 Ri_{max(2n)} \pm 29 \qquad (4)$$

The quantity $\Delta Ri_{max(2n,2n+2)}$ presents the magnitude difference between even numbered cycles 2n and 2n+2nd . The correlation coefficient is r=-0.71 and F=2.04, while the critical “threshold” for 99% confidence of last one is $F_{99} = 1.59$.

The above mentioned formula (5) for prediction of SC24 magnitude has been used. The magnitude of SC22 ($Ri_{max(SC22)}$ =157) is taken as a predictor. It has been found by this way that $\Delta Ri_{max(SC22,SC24)}$ = -68 and the SC24 magnitude should be 89±29. As the real value $Ri_{max(SC24)}$ = 82 it need to conclude that the prediction, based of regression formula is very succesfull.

The second obtained auto-regression model, based on Schove’s series is of two-factor type [*Komitov*, 2007]:

$$\Delta Ri_{max(2n,2n+2)} = 69 - 1.16 Ri_{max(2n)} + 0.4 Ri_{max(2n+1)} \pm 27 \qquad (5)$$

As a second factor in this model is the odd numbered 2n+1st sunspot cycle magnitude. The characteristics of this model are slightly better as (4): the coefficient of multiple correlation is *R*=0.78 and *F*= 2.45. It has been found by using of formula (5) a predicted SC24 magnitude $Ri_{max(SC24)}$ = 92± 27.

The both above signed SC24 magnitude predicted values indicate for the good applicability of the auto-regression formulas (4) and (5) for prediction of even numbered sunspot cycles magnitudes. In this study it relates to SC26. The passed SC24 magnitude as well as the predicted by SC25 magnitude on base of Waldmeier’s rule regression models are used as predictors.

(d) Kinematic models, based on T-R periodogram algorithm

The T-R periodogram algorithm (TRPA) has been suggested by the author in 1980th as an alternative method on the place of discrete Fourier analysis for detecting and statistical estimation of cycles in time series. The advanced features of this method are generally two: the independence of obtained results from the time series length and the possibility for much better study of low frequency oscillations as the Fourier method, including also such ones which corresponding periods are comparable or even slightly longer as the studied time series (“hyper-cycles”). The T-R periodogram algorithm and its using for time series kinematic models composition have been already in details described in few previous papers [see *Komitov*, 2021 and cites therein].

In the present study two kinematic models have been build – the first one on base of the mean monthly old *Ri* index for the epoch January 1750 to December 2014 and the second one is based on the new sunspot index *SN_v2*. The both models are extrapolated and compared until 2080 AD. The magnitudes of SC25, SC26 and SC27 have been predicted on the base of the extrapolations.

Results and analysis

The predicted SC25, SC26 and SC27 magnitudes, obtained by using of the above mentioned prediction models are shown on Table 1. The first column contains the sunspot cycles numbers in Zurich series, while in the next three ones the corresponding predicted values of the sunspot cycles, calculated by one of the above described statistical models are presented. The used formula (1 to 5) a signed as “Type (1-5)”. The real SC24 magnitude in 2014 is also shown for comparison in column 5.

By comparison of the presented results it could conclude that: 1. the magnitudes of SC25 and SC26 are similar to the SC24 one; 2 Most probably SC25 and SC26 magnitudes should be arround 80-100 as *Ri*-index (the “classical” old sunspot counting system) or 120-150 in *SN_v2* (the new system). It corresponds to sunspot cycles of moderate sunspot cycles unlike SC17-SC23, which magnitudes are in order of 1.5-2 times higher. This prediction supports the thesis for the beginning of a new grand solar minimum in 21st century.

Some authors suggestthat this grand minimum should be of centurial type as the Gleissberg minimum (1898-1924AD), while according to other ones it should be of Dalton-type [*Abdussamatov*, 2004; *Javaraiah*, 2017] or even of Maunder-type [*Zharkova et al*., 2015]. By authors opinion the new grand solar minimum is of Dalton-type due to the circumstance that it is related to the downward and near minimum phase of quasi 200 yr deVries- Suess solar cycle [see *Komitov*, 2021 and cites therein]. An additional indicator for such suggestion is the fact of Gnevishev-Ohl-Kopecky’s rule violation (G-O-K) [*Gnevishev and Ohl*, 1948; *Kopecky*, 1950] for the even-odd pair cycles SC22-SC23. As it has been shown by author and Bonev [*Komitov and Bonev*, 2001] the strong G-O-K violations are precursors namely of Dalton-type grand solar minima.

As it is shown in Fig.1 the new grand Dalton-type minimum should expect to be more continuous as its eponym (the Dalton minimum from 1793/98 to 1833AD) and it will be ended at ~2080 AD (i.e. after SC29 or SC30). The calculated on the base of Waldmeier’s rule regression model (Type 1) indicates that SC25 should be slightly higher as SC24, i.e. G-O-K should be valid for the even-odd pair SC24-SC25. This supports also be the auto-regression models on the base of Schove’s series (see in Table 1, column 3). On the other hand, the kinematic models (Table 1 and Fig.1) predict a well expressed G-O-K for the sunspots cycles pair SC26-SC27. As it is shown on Fig.1 there a local maximum of sunspot cycles magnitudes near to SC27 or SC28 is predicted. It follows by new downward tendency between SC28 and SC30 and new G-O-K violation for the pair SC28-SC29.

SC\Method	Waldmeier’s rule regression for Ri_{max} Type(1); Type(2); Type(3)	Schove’s series auto-regression Type(4); Type(5)	TRPA kinematic model Ri_{max} ; (SN_v2_{max})	Real magnitude Ri_{max}
24	72±27; 90±17; 86±16	89±29; 92±27	78±26; (122±38)	82
25	99±26; - ; -	-; -	58±26; (97±38)	-
26	-;-;-	96±29; 94±27**	79±26; (142±38)	-
27	-;-;-	-;-	113±26; (164±38)	-

Table 1. The predicted and real values of SC24 –SC27 magnitudes

(** - by using of predicted SC25 magnitude on the base of ‘Waldmeier’s rule’)

Very interesting situation is predicted by the both kinematic models for the minimum between SC 26 and SC27 around 2038 AD. This minimum should be very shallow and SC26 seems to be very closely pressed to the more powerful SC27. Such scenario is possible in the case if a significant mixing of the convective zone fluxes of the both sunspot cycles occurs during and even before this minimum. Thus a significant part of observed during the SC26 sunspot activity downward phase could belong to the next SC27 if the magnetic polarity of active regions will be taken into account. That's why the "pure" SC26 sunspot activity could be significantly weaker as the predicted or observed one.

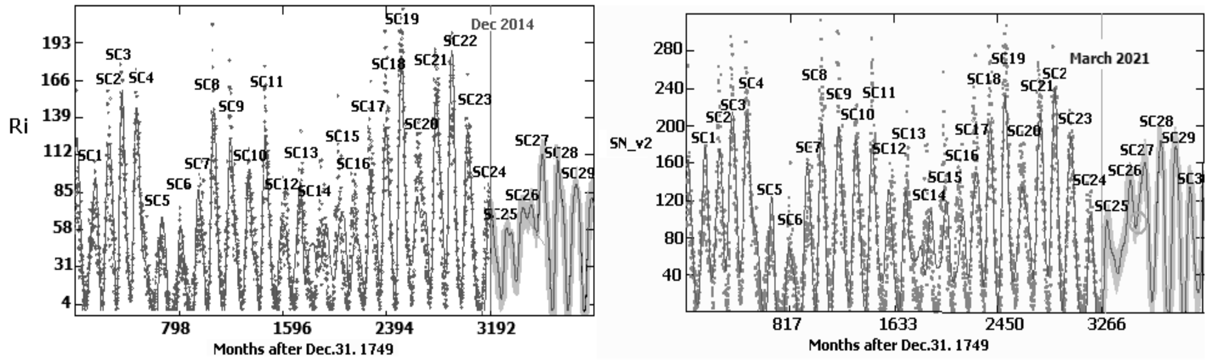

Fig.1 Kinematic model of Zurich sunspot series (old version (left panel): Jan. 1749-Dec.2014) on the base of T-R periodogramm analysis and its extrapolation up to SC30 maximum (~2080 AD); the new version (right panel): Jan. 1750-March.2021

References

Abdussamatov, H.I., 2004, About the long term coordinated variations of the activity, radius, total irradiance of the Sun and the Earth's climate, paper presented at the International Astronomical Union symposium, No.223

Bard E., Raisbeck G., Yiou F. and Jouzel J., 1997, Solar modulation of cosmogenic nuclide production over the last millennium: comparison between 14C and 10Be records, Earth and Planet. Sci. Lett., v150, 453 –462

Clette, F., Lefèvre, L., 2016, The New Sunspot Number: assembling all corrections, Solar Physics, 291, DOI: 10.1007/s11207-016-1014-y.

Damon,P. E. And Sonett,C.P., 1991, in The Sun in Time, ed.Sonett.,C.P.,Giampapa,M.S

Gnevishev. M., Ohl A., 1948, 22yr cycle in solar activity (in Russian), Astron.J,, 38, 18-22

Javaraiah, J., , 2017, " Will Solar Cycles 25 and 26 Be Weaker than Cycle 24?", Solar Physics, Volume 292, Issue 11, article id.172, 13

Komitov B. , 1997, The Schove's series. Centural and Supercentural variations of the solar activity. Relationships between adjacent 11-year cycles, Bulg.Geoph.J,23,74 –82

Komitov B. and Bonev B., 2001 Amplitude Variations of the 11-year Solat Cycle and the Current Maximum 23, Astrophys. J. Lett v.554,L119-L122, 2001 June 10

Komitov B. and Kaftan V., 2003 Solar Activity Variations for the Last Millenia. Will the Next Long-Period Solar Minimum be Formed?, International Journal of Geomagnetism and Aeronomy,v.43,No5,2003, 553-561

Komitov, B., Duchlev, P., Stoychev, K., Dechev, M Koleva, K. , 2011, Determination of the sunspot minimum epoch between the cycles No 23 and 24 and prediction of the cycle No 24 magnitude on the base of the 'Waldmeier's Rule '. Bulg. Astron J., 16, 45-49

Komitov B., 2021, The European Beech Annual Tree Ring Widths Time Series, Solar-Climatic Relationships and Solar Dynamo Regime Changes, Atmosphere 12(7), 829

Kopecky, M., 1950, Cycle de 22 ans de l'activit´e solaire, B. Astron. Institute of Czechoslovakia,, 2, 14–16

Reimer P.J +29 coauthors, 2013, INTCAL13 AND MARINE13 RADIOCARBON AGE CALIBRATION CURVES 0–50,000 YEARS CAL BP, RADIOCARBON, Vol 55, Nr 4,, p 1869–188

Schove, D. J. 1955, The Sunspot Cycle 649 BC to AD 2000, J. Geophys. Res., 60, 127

Schove D.J. ,1983, Sunspot Cycles (Stroudsburg: Hutchinson Ross, Pennsylvania.)

Stuiver M. and Quay P.D., 1980, Changes in Atmospheric Carbon -14 Attributed to a Variable Sun ,Science, v207,No 44, 26

Usoskin I.G., 2013, A History of Solar Activity over Millennia: ArXiv-0810.3972v3

Wittman A. D and Xu Z.D., 1987, A catalogue of sunspot observations from 165 BC to AD 1684, Astron. Astrophys., Supl.Ser.70, 83-94

Zharkova V.V., Sheperd S.J., Popova E., Zharkov S.I., Heartbeat of the Sun from Principal Component Analysis and prediction of solar activity on a millennium timescale, Nature, Sci Reports, open access, 2015, 5:15689; doi: 10.1038/srp15689