NRIAG Journal of Astronomy and Geophysics 7 (2018) 15–19

Contents lists available at ScienceDirect

NRIAG Journal of Astronomy and Geophysics

journal homepage: www.elsevier.com/locate/nrjag

Full length article

Forecasting the peak of the present solar activity cycle 24

R.H. Hamid*, B.A. Marzouk

National Research Institute of Astronomy and Geophysics (NRIAG), 11421, Helwan, Cairo, Egypt

ARTICLE INFO

Keywords:
Solar activity cycle
Spotless events
Solar flux F10.7
Geomagnetic index aa_{min}

ABSTRACT

Solar forecasting of the level of sun Activity is very important subject for all space programs. Most predictions are based on the physical conditions prevailing at or before the solar cycle minimum preceding the maximum in question. Our aim is to predict the maximum peak of cycle 24 using precursor techniques in particular those using spotless event, geomagnetic $aa_{min.}$ index and solar flux F10.7. Also prediction of exact date of the maximum (T_r) is taken in consideration. A study of variation over previous spotless event for cycles 7–23 and that for even cycles (8–22) are carried out for the prediction. Linear correlation between maximum of solar cycles (R_M) and spotless event around the preceding minimum gives $R_{24t} = 88.4$ with rise time $T_r = 4.6$ years. For the even cycles $R_{24E} = 77.9$ with rise time $T_r = 4.5$ y's. Based on the average $aa_{min.}$ index for cycles (12–23), we estimate the expected amplitude for cycle 24 to be $R_{aamin} = 99.4$ and 98.1 with time rise of $T_{raamin} = 4.04$ & 4.3 years for both the total and even cycles in consecutive. The application of the data of solar flux F10.7 which cover only cycles (19–23) was taken in consideration and gives predicted maximum amplitude $R_{24\ 10.7} = 126$ with rise time $T_{r107} = 3.7$ years, which are over estimation. Our result indicating to somewhat weaker of cycle 24 as compared to cycles 21–23.

1. Introduction

It is well known that solar activity variations control the disturbance in space weather, variation in the climatic parameters as well as the most activity on the Earth. Long term recorded aspect of the solar activity in all the astrophysical ones are that of sunspots which have been observed since 1610. It's cyclic behavior was noticed by Schwabe (1844). The sunspot number Rz (Wolf number) is widely used in solar terrestrial physics as a proxy for general state of solar activity when daily averaged are frequently available (Hoyt and Schatten, 1998a,b). Their number in time interval may in one way or another represent an index of general solar magnetic activity (Eddy, 1976, 1977, Hoyt and Schatten, 1997, 1998a,b).

The maximum phase of activity cause higher emission of the ultraviolet UV and UV flux, which can modulate the middle and upper terrestrial atmosphere and total solar irradiance which have effect on terrestrial climate (Hoyt and Schatten, 1997). Also the occurrence of large solar flare during the maximum phase of activity associated with energetic particles cause communication disturbance and failures in electronic solid state components etc. (Siscoe, 2000).

All these facts justify the scientific and practical importance of predicting the strength of the upcoming solar cycles. During the past decade numerous techniques have been arduously developed and proposed by many scientific researchers to predict the amplitude, the phase of activity and the maximum strength of the fourth coming cycles.

Different approaches were used to achieve a good forecasting of the level of the next cycle in which features of the preceding cycle are used for this purpose (Kane, 2011, Ajabashirizadeh et al., 2011, Du, 2012). Among these are methods depend on odd/even behavior (Kopecky, 1991, Wilson, 1992, Letfus, 1993, Kane, 1999), the mixed methods (Wilson et al., 1998, Hanslmeier et al., 1999, Hathaway et al., 1999, Lantos, 2000) and spectral technique (Badalyn et al., 2001, AShrafi and Roszman, 1992, Volobuev and Makarenko, 2008). Precursor technique characterized by both solar and geomagnetic as their physical basis, and geomagnetic precursor based on the records of the geomagnetic storms i.e. the indices of aa, Ap or both of them (Boinar et al., 1997, Rajmal, 1997, Joselyn et al., 1997, Kane, 2007, Thompson, 2008) have been used. Another category of the precursors are solar polar magnetic field (Tlatov, 2006) and precursor based on the records of spotless days along two years around the preceding minimum of cycle under test (Hamid and Galal, 1994, Hamid, 2000).

A promising method depends on the time analysis, as neural network, fuzzy neural network and genetic algorithms derived from nonlinear statistical algorithms that determine and model a complex relationship between inputs and outputs. It can be combined with other

Peer review under responsibility of National Research Institute of Astronomy and Geophysics.
* Corresponding author.
E-mail addresses: rabab_helal@yahoo.co.uk (R.H. Hamid), bmarzoke@yahoo.com (B.A. Marzouk).

https://doi.org/10.1016/j.nrjag.2018.02.002
Received 16 November 2017; Received in revised form 31 January 2018; Accepted 7 February 2018
Available online 06 March 2018

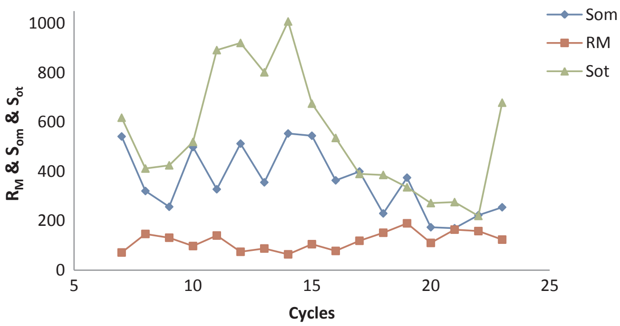

Fig. 2.1. The maximum number of solar cycles R_M, the total spotless event S_{ot} and precursor spotless events S_{om} against solar cycle (7–23).

technique including spectral methods to increase the accuracy (Calvo et al., 1995, Lantos, 2000, Attia et al., 2005).

According to Janssens (2006) and Pesnell (2008) another suggested categories have been approved which are climatology, recent climatology and dynamo methods.

2. Data sets

2.1. Spotless Events

Since we depend in our precursor method on the count of spotless event in interval of two years around the minimum of each cycles starting from solar cycle 7 up to minimum of cycle 24, it was found that total number of this count is 6567 days out of the total observing data of 70795 days. The data set was taken from http://NGDC.noaa.gov/stp/solar/sunspot_numbers/internation.

We noticed that as the number of spotless events around the preceding minimum increase, the solar cycle achieve a low level of strength and vice versa. Fig. 2.1 illustrates solar cycles (7–23) versus the total spotless events S_{ot} along each cycle, the precursor spotless events S_{omn} (around the preceding minimum), and the maximum sunspots number of each cycle R_M.

2.2. Geomagnetic index aa

The aa-index is a simple global geomagnetic activity index. It is derived from the K indices from two approximately antipodal observatories and has units of 1nT. The main advantage of using aa index is that the time series spans further back to (1868) than any of the other planetary index time series; and also up to data values are produced and made available on weekly basis. Definitive aa are published by International Series for Geomagnetic Indices (ISGI).

2.3. Flux F10.7

Another indicator of the level of solar activity is the flux of radio emission from the sun at wavelength 10.7 cm (2.8 GHz frequency). It is one of the popular substitution of R_z. The advantage of F10.7 is its immediate availability. The values of F10.7 always measured within hours while the definitive of R_z is always delayed by month. It is an important indicator of solar activity level because it tends to follow the change in solar ultraviolet (UV) that influence the earth's upper atmosphere. It has been measured since 1947 and it follows sunspot number. Current values of F10.7 can be found at ftp://ftp.ngdc.noaa.gov/stp/solar_data/solar/flux/pentiction.

Fig. 2.2 illustrates the comparison between number of sunspots, geomagnetic index aa and solar flux F10.7. it is clear that the three variables have the same trend of variations.

3. Analysis

The statistical approaches are important process to detect our calculation of the strength of solar cycle number 24.

3.1. Forecasting the peak of the solar cycle 24 using Spotless events

To carry out the predicted count of spotless events at the minimum of the upcoming cycle in advance, we first use the following logarithmic empirical formula (Eq. (1)), so it is easy to estimate the maximum phase of the next cycle (Hamid and Galal, 2006).

$$\ln\left(\frac{R_M}{R_m}\right) = a + b\left(\frac{S_{om}}{S_{omn}}\right) \quad (1)$$

Where R_M and R_m are the maximum and the minimum of solar cycles, S_{om} is the count of spotless events (days) along an interval of two years around the preceding minimum and S_{omn} is the count around the minimum of the incoming solar cycle under test.

Fig. 3 illustrates the above relation (Eq. (1)).

Since cycle 24 is already started, the observed time series of the spotless event at minimum of cycle 24 were used to forecast the amplitude and the time of rise.

The evaluation of the peak of cycle 24 can be given by Eq. (2). Note that our calculation starting from cycle 7 up to cycle 23 (cycles 7–9 and 10–23 are classified as good cycles and modern era).

$$R_{24Somnt} = 183.82\text{–}0.1814\ S_{omn} = 88.4 \quad (2)$$

The corresponding time of rise is represented by:

$$T_{24Somnt} = 2.722 + 0.0036\ S_{omn} = 4.6\ years \quad (3)$$

Fig. 3.1 illustrates the relation between the count of spotless days (S_{om}) and maximum sunspots number (R_M), while Fig. 3.2 illustrates the relation between the count of spotless days (S_{om}) and time of rise (T_r).

We also used the data sets of the even cycle (8–22) to calculate R_{24E} and T_{r24E} as follows:

$$R_{24E} = 180.634\text{–}0.1954\ S_{omn} = 77.9 \quad (4)$$

And

$$T_{24E} = 2.8335 + 0.0031\ S_{omn} = 4.5\ years \quad (5)$$

3.2. Forecasting the peak of the solar cycle 24 using aa index

The observed data of geomagnetic index aa, are available only from 1868 onward i.e. from cycle 12 (inclusive). Our predictions are dedicated for estimation of the strength and the timing of the minimum (aa_{min}) for both total and even cycles. The regression equations can be written as:

$$R_{24aamint} = 18.0359 + 8.1359\ aa_{min} = 99.4 \quad (6)$$

$$T_{24aamint} = 4.7627\text{–}0.073\ aa_{min} = 4.0\ years \quad (7)$$

Fig. 3.3 illustrates the relation between the geomagnetic index (aa_{min}) and maximum sunspots number (R_M), while Fig. 3.4 illustrates the relation between the geomagnetic index (aa_{min}) and time of rise (T_r).

3.3. Forecasting the peak of the solar cycle 24 using solar flux F10.7

The solar radio flux emission at wavelength 10.7 cm (F10.7) tends to follow the sunspots number quite closely. Its observation started in 1947, but the current observation were in 1954 which come to coincide with started time of cycle 19, the most strongest cycle in all records of solar activity. The calculation of the maximum phase and the time of rise using the solar flux at the minimum can be illustrated by the following formula:

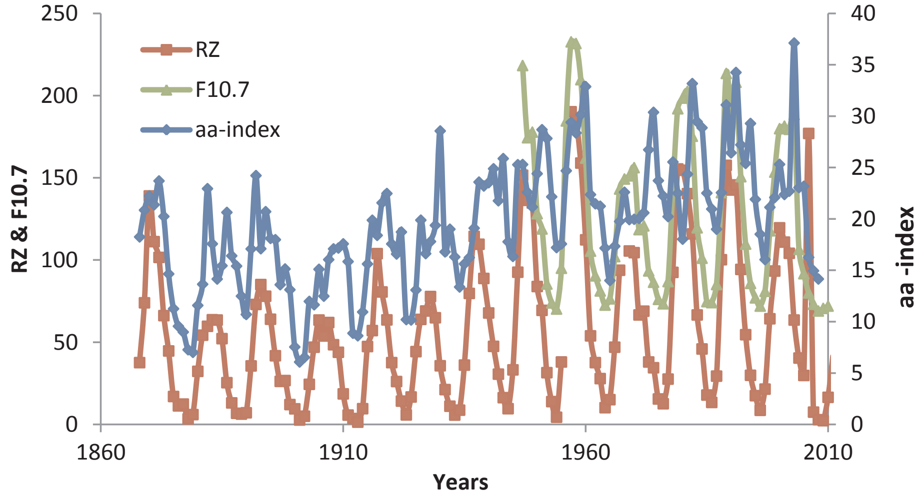

Fig. 2.2. Comparison between number of sunspots, geomagnetic index, and solar flux F10.7.

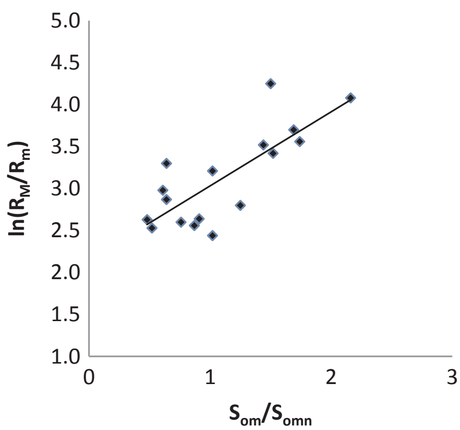

Fig. 3. The relation between ln (RM/Rm) and the ratio of spotless events (Som/Somn).

$$R_{24F10.7} = 1974.5 - 25.966\ (F_{10.7})_{min} = 126 \tag{8}$$

$$T_{24F10.7} = 8.3122 - 0.1707\ (F_{10.7})_{min} = 3.7\ years \tag{9}$$

Fig. 3.5 illustrates the relation between the solar radio flux at wavelength 10.7 cm (F10.7) and maximum sunspots number (R_M).

Fig. 3.6 illustrates the relation between the solar radio flux at wavelength 10.7 cm (F10.7) and time of rise (T_r).

4. Results and discussion

Reconstruction of the sets of data and the predictions of the strength of solar cycle 24 have been done, using three solar and geophysical activity variables (spotless event "days", geomagnetic index aa and solar flux F10.7 cm) at minimum phase. In general, our results significantly show that the maximum phase of cycle 24 varies according to the different data sets.

The analysis of available data conspicuously indicate that the distribution of the spotless event across successive solar cycles are responsible for the variety of their strengths. The more frequent and longer are the spotless events at a given cycle the smaller the value of the maximum wolf number reached.

Also our analysis indicated that the three variables have the same trend of variations.

On the other hand, our results obviously show that: by using the data of spotless events for calculation of the strength of cycle 24 we get R_{M24} = 88.4 & 77.9 and T_{r24} = 4.6 y's & 4.5 y's for total and even solar cycles in consecutive order. While it achieves values of $R_{24\ aamin}$ = 99.4 and 98.1 with time of rise $T_{r\ aamin}$ = 4.04 y's & 4.3 y's for total and even cycles.

Finally we get $R_{24\ F10.7}$ = 126 with $T_{\ F10.7}$ = 3.7 y's.

According to Pesnell (2012), a wide range predictions (more than 75) have been carried out for forecasting the strength of cycle 24 and placed into categories. Out of them about 28 predictions used precursor techniques with ranges (70–180). Nine depends on geomagnetic aa index with ranges (97–160), and the others with ranges from (70–175).

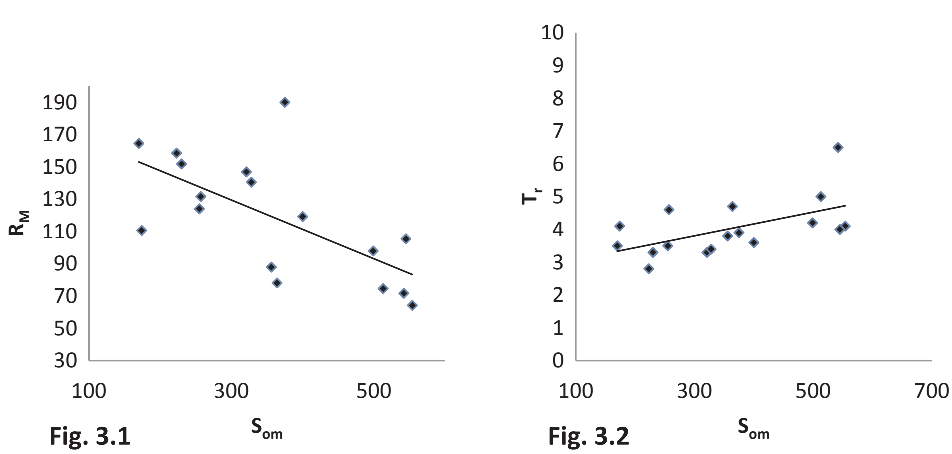

Fig. 3.1 and 3.2. Relation between maximum sunspots numbers (RM) and spotless events (left), and the time of rise (Tr) and spotless events (right).

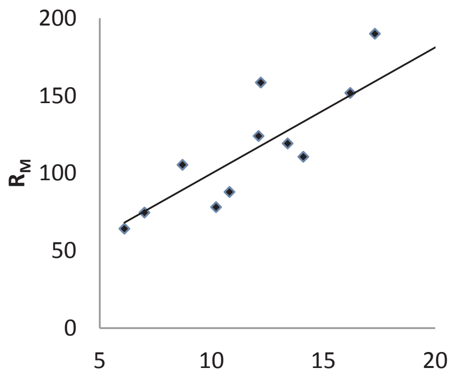

Fig. 3.3

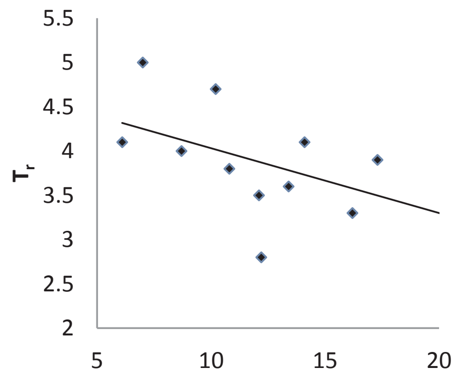

Fig. 3.4

Fig. 3.3 and 3.4. Relation between maximum sunspots numbers (RM) with geomagnetic index aa_{min} (left), and the time of rise (Tr) with geomagnetic index aa_{min} (right).

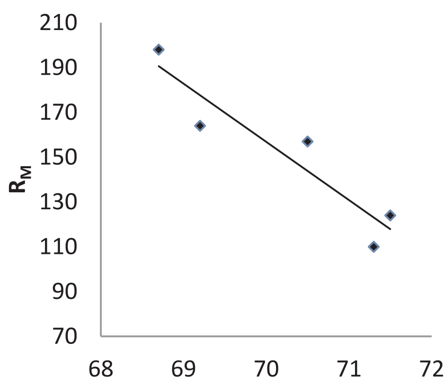

Fig. 3.5

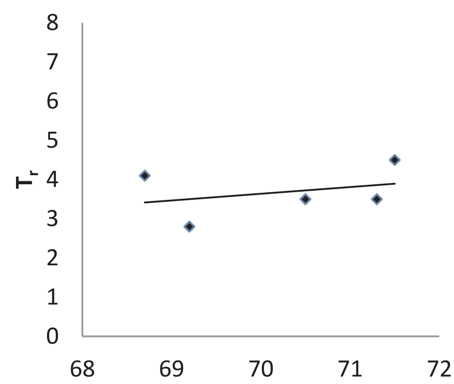

Fig. 3.6

Fig. 3.5 and 3.6. Relation between maximum sunspots numbers (RM) and solar flux (F10.7) (left), and the time of rise (Tr) and solar flux (F10.7) (right).

Table 1
Predictions of solar cycle 24 using precursor techniques.

R_{24}	Timing	Methods of Analysis	Author	Date
180 ± 32	–	Disturbed days Analysis	Panel*	2007
152–197	–	Integral of sunspot number	Podladchikov et al.	2006
160 ± 25	–	Analysis of aa-index	Hathaway and Wilson	2006
148	–	aa at minimum	Panel*	2007
144	–	aa during decline of 23	Jain	2006
142 ± 24	–	aa at solar minimum	Kane	2007
140	2012.5	Disturbed days Analysis	Chopra and Dabas	2006
135 ± 20		aa/R_z Precursor	Panel*	2007
130 ± 15		Complexity of H synoptic charts	Tlatov	2006
124 ± 30		Value of aa at solar minimum	Nevanlinna	2007
121 ± 23		Number of disturbed days in Ap	Dabas et al.	2008
120 ± 25		Behavior of aa	Panel*	2007
115 ± 30		Number of disturbed days	Robin	2007
115 ± 28	2010.5	Precursor + nonlinear dynamics	Sello	2006
115 ± 15		Area of high latitude unipolar regions	Tlatov	2006
115 ± 13		Large-scale magnetic field	Tlatov	2006
115 ± 6		Geomagnetic Precursor (aa)	Ahluwalia	2008
111 ± 18		Minimum value of Ap	Thompson	2008
110 ± 10		Dipole. Octuplet magnetic moments	Tlatov	2006
105 ± 10		Average four precursor predictions	Obridko (2008)	2008
97 ± 25		Geomagnetic precursor (aa/solar wind speed)	Wang and Sheeley	2009
96 ± 13		Geomagnetic precursor (Ap)	Kryachko and Nusinov	2008
90.7 ± 9.2		Number of spotless days at Mini.	Hamid and Galal	2006
87 ± 7		Statistics of low-latitude sunspot	Javaraiah	2008
74 ± 10		Statistics of low-latitude sunspot	Javaraiah	2007
70 ± 2		Polar M. F. strength at solar min.	Svalgaard et al.	
65 ± 20	2015	Geomagnetic precursor contributing Ap, F10.7 and a recurrence index	Pesnell	2009

* Is predictions that were created during the panel deliberations for cycle 24 (2007).

Table 2
Our predictions using variables of Spotless events, geomagnetic index, and solar radio flux.

R_{24}	Timing	Methods of Analysis	Author	Date
99.4	2013	Present work (cycle 7–23) aa index	Hamid & Marzouk	2018
98.1	2013.2	Present work (cycle 8–22) even aa index	Hamid & Marzouk	2018
88.4	2013.5	Spotless event cycle (7–23)	Hamid & Marzouk	2018
77.9	2013.5	Spotless event cycle (8–22)	Hamid & Marzouk	2018
125	2012	Solar flux f10.7 (19–23)	Hamid & Marzouk	2018

Table 1 illustrates those that used the precursor techniques. Our results are summarized in table (2). Comparing our results with those of table (1), we found that our predictions agree with some (Wang and Sheeley, 2009, Kryachko and Nusinov, 2008, Javaraiah, 2008, Hamid and Galal, 2006, Shatten, 2005, Javaraiah, 2007, Tlatov, 2006, Nevanlinna, 2007; Dabas et al., 2008) and contradict the others (see Table 2).

5. Conclusions

We can conclude that:

- In fact, the large scale discrepancy in the results are attributed to the large scale of the forecasting methods and data sets.
- Our work illustrate that cycle 24 will achieve a very low amplitude, so, we can say that it is weaker than solar cycles 21–23, which confirm our expectations that this cycle covers a minimum stage of the century – long scale.
- Precursor techniques are a major contributor to consensus prediction of solar cycle strength i.e. it is the most successful method for prediction.
- The high value of $R_{M10.7}$ may be attributed to the limitation of the data set of solar flux F10.7 (about 5 cycles) starting with cycle 19 (1947), the strongest cycle in all records of the solar cycles.
- The simultaneous results carried out in this work show the effectiveness of the proposed method of analysis and confirm our early prediction (Hamid and Galal, 2006).

References

Ajabshirizadeh, A., Jouzdani, N.H., Abbassi, S., 2011. Res. Astron. Astrophys. 11,491.
Attia, A.F., Abdel Hamid, R., Quassim, M., 2005. Solar Phys. 227, 177.
AShrafi, S., Roszman, L., 1992. NASA STI/Recon Technical Report N92-2887192, 1.
Badalyn, O.G., Obridko, V.N., Sykora, J., 2001. Solar Phys. 199, 421.
Boinar, K.H., Cliver, E.W., Boriaka, J., 1997. Solar Phys. 176, 211.
Calvo, R., Ceccatto, H., Piacentine, R., 1995. NNPOSA. Astron. J. 444, 916.
Chopra, P., Dabas, R.S., 2006, In the Cospar Proceeding, Beijing.
Dabas, R.S., Sharma, K., Das, R.M., Pillai, K.G.M., Chopra, P., Sethi, N.K., 2008. Sol. Phys. 250, 171.
Du, Z.L., 2012. Astrophys. Space Sci. 338, 9.
Eddy, J.A., 1976. Maunder Minimum Sci. 192, 1189.
Eddy, J.A., 1977. The solar output and its variations. O.R. White Colorado Associated University Press, Boulder.
Hamid, R.H., Galal, A.A., 1994. Bull. NRIAG.
Hamid, R.H., 2000. Bull. NRIAG J.
Hamid, R.H., Galal, A.A., 2006. Proc. IAU Sympos. 233, 413.
Hanslmier, A., Denkmayr, K., Wass, P., 1999. Sol. Phys. 184, 213.
Hathaway, D.H., Wilson, R.M., Reichmann, E.J., 1999. Geophys. Res. 104, 22375.
Hathaway, D.H., Wilson, R.M., 2006. Geophys. Lett. 33, L18101.
Hoyt, D.V., Schatten, K.H., 1997. Oxford Uni. Press, New York.
Hoyt, D.V., Schatten, K.H., 1998a. Solar Phys. 179 (189), 1998.
Hoyt, D.V., Schatten, K.H., 1998b. Solar Phys. 181, 491.
Jain, R., 2006. 36th COSPAR Scientific Assembly. Held 16 - 23 July 2006, in Beijing, China. Meeting abstract from the CDROM, 642.
Janssens, S., 2006. numbers, Chellobe/j.janssens/Sc.24.html.
Javaraiah, J., 2007. Not. R. Astron, Soc. 377, L34.
Javaraiah, J., 2008. Sol. Phys. 252, 419.
Joselyn, J.A., Anderson, J.B., Coffy, H.K., Hathaway, D., Heckman, G., Hilner, E., Mende, W., Schatten, K., Thompson, R., Thomson, A.W.P., White, O.R., 1997. EOS Trans. AAGU 78, 205.
Kane, R.P., 1999. Sol. Phys. 149, 405.
Kane, R.P., 2007. Sol. Phys. 246, 487.
Kane, R.P., 2011. Indian J. Radio Space Phys. 40, 72.
Kopecky, M., 1991. Bull. Astron. CZeh. 42, 157.
Kryachko, A.V., Nusinov, A.A., 2008. Geomag. Astron. 48, 145 10, 1007/s 11478008-2002-7.
Lantos, P., 2000. La Recherche 332, 16.
Letfus, V., 1993. Sol. Phys. 149, 405.
Nevanlinna, H., 2007. Geomag. Precursor based on aa prediction submitted to panel Jan. 3.
Obridko, V.N., 2008. Predictions submitted Dec. 8, 2008, prediction is average of four separate prediction, all in the precursor category.
Pesnell, W.D., 2008. Sol. Phys. 252, 209.
Pesnell, W.D., 2009. Division Meeting #40, AAS/ Solar Phys. Division Meeting 40 #1105. Sol. Phys.
Pesnell, W.D., 2012. Sol. Phys. 281, 507.
Podladchikov, T., Lefebvre, B., Van der Linder, R., 2006, Peak sunspot number for solar cycle 24 prediction submitted Sep. 12.
Rajmal, J., 1997. Sol. Phys. 176, 431.
Sello, S., 2006. Up dated of Prediction email dated 4- October.
Schwabe, H., 1844. Sonnenbachtungen in Jahre 1843 Von Hem Hofrath Schwabe in Dessau Astromische Nachrichten, 21, 233.
Shatten, K., 2005. Fair space weather for solar cycle 24.
Siscoe, G., 2000. J. Atmos. Solar-Terr. Phys. 62, 1223.
Svalgaard, L., Cliver, E.W., Kamide, Y., 2006. Cycle 24: the smallest sunspot cycle in 100 years? Geophy. Res. Lett. 32. http://dx.doi.org/10.1029/2004GL 021664.
Thompson, R.J., 2008. Prediction for cycle 24 using minimum value of AP (12 month average) prediction submitted March.
Tlatov, A.G., 2006. Indices of solar activity minimum of sunspot cycle and prediction of solar cycle 24. Prediction submitted 26 September.
Volobuev, D.M., Makarenko, N.G., 2008. Solar Phys. 249, 121.
Wang, Y.M., Sheeley, N.R., 2009. AP. J. Letter 694, 11.
Wilson, R.M., 1992. Sol. Phys. 140, 181.
Wilson, R.M., Hathaway, D.H., Reihmann, E.J., 1998. J. Geophys., Res 103, 6595.