

Solar cycle activity: an early prediction for cycle #25

Stefano Sello *

Mathematical and Physical Models, Enel Research, Pisa - Italy

Abstract

Solar activity forecasting is an important topic for numerous scientific and technological areas, such as space mission operations, electric power transmission lines, power transformation stations and earth geophysical and climatic impact. Nevertheless, the well-known difficulty is how to accurately predict, on the basis of various recorded solar activity indices, the complete evolution of future solar cycles, due to highly complex dynamical and stochastic processes involved, mainly related to interaction of different components of internal magnetic fields. There are two main distinct classes of solar cycle prediction methods: the precursor-like ones and the mathematical-numerical ones. The main characteristic of precursor techniques, both purely solar and geomagnetic, is their physical basis. Conversely, the non-precursor methods use different mathematical and/or numerical properties of the known temporal evolution of solar activity indices to extract useful information for predicting future activity. For current solar cycle #24 we obtained fairly good statistical performances from both precursor and purely numerical methods, such as the so-called solar precursor and nonlinear ones. To further check the performances of these prediction techniques, we compared the early predictions for the next solar cycle #25. Preliminary results support some coherence of the prediction methods considered and confirm the current trend of a relatively low solar activity.

1 Introduction

The current solar cycle #24 has now completed its declining phase reaching the minimum state around September 2018, following a multi-peaked maximum around 2012.20 (lower peak: $R_z = 98$) and 2014.31 (main peak: $R_z = 115.6$), with a prominent Gnevyshev gap, for the monthly smoothed sunspot numbers, as revised by SIDC from 1 July 2015. This new version of R_z is used here. Note that it is 40% - 70% larger than the previous older version (WDC-SILSO [2019]). As reviewed by Pesnell ([2016]), many solar cycle forecasting methods predicted higher values, including statistical, curve fitting, spectral one and some geomagnetic precursor-like ones. It is important to note that except from few examples, most

* stefano.sello@enel.com

of the predictions predict only the amplitude and time of the next solar maximum. Missing is the detailed shape of the curve time behavior, including the timing of cycle extrema, which are usually found by examining not only the sunspot number record but also other measures of solar activity, such as the flare rate or magnetic flux, that may peak at different times of the sunspot cycle. This is a more difficult task than the maximum amplitude prediction as well shown in Sello ([2016]). Those methods using multiple information sources, such as the precursors, have smaller average errors and this led to the general conclusion that precursors were superior, which seems to be valid also for Solar Cycle #24, which was considered to be an atypical sunspot cycle. In fact, some predictions indicated very high levels of activity, others very low even suggesting the tendency to a grand minimum of solar activity. The observations show a below-average amplitude sunspot cycle, with all the usual activity present at quite reduced amplitudes, see for details: Pesnell, ([2016]).

As Solar Cycle #24 fades and reaches its minimum phase, the anticipation of Solar Cycle #25 begins. Several predictions of the amplitude of Solar Cycle #25 have already appeared, along with more difficult longer-term forecasts of solar activity. As few examples we cite here Helal and Galal [2013] which used a correlation between the number of spotless days and the upcoming solar maximum to estimate that Solar Cycle #25 will have: $R_z = 118.2$, peaking 4.0 years after the solar minimum. Yoshida [2014] used correlations between R_z before minimum with the upcoming solar maximum, using the symmetries of the even/odd cycles to derive the prediction: $R_z = 115.4 \pm 11.9$. Cameron, Jiang, and Schssler (2016) using surface flux transport simulations for the descending phase of Cycle #24 with random sources (emerging bipolar magnetic regions) provide a prediction of the axial dipole moment during the incoming activity minimum. The empirical correlation between the dipole moment during solar minimum and the strength of the subsequent cycle suggests that Cycle #25 will be of moderate amplitude, not much higher than that of the current cycle. The authors stress that the intrinsic uncertainty of such predictions resulting from the random scatter of the source properties is considerable and limits the reliability with which such predictions can be made before activity minimum is reached, as we will note below also for our nonlinear method. Among predictors class one of the most efficient and the first physical based precursor is the Solar Polar Field Precursor Method developed by Schatten et al. ([1978]), ([2008]) and it is based on polar fields intensity near the minimum as solar activity precursor.

Longer-term predictions are more qualitative and derive an envelope of activity until 2035 [Shepherd et al., 2014]. Their predictions tend to suggest smaller amplitudes of solar cycles #25 and #26, as the envelope of activity continues the decline of the last four sunspot cycles. Here, we refined our nonlinear prediction method to produce a fairly reliable early prediction for the full shape curve of the next solar cycle #25, see: Sello, ([2001], [2003]). Previous analyses clearly showed that this prediction method is able to give a sufficiently reliable prediction only after the time of the previous cycle minimum, Sello, ([2012]). This is mainly due to the fact that using the maximum amplitudes and the declining phase only of the current cycle, there is not sufficient information about the amplitude and timing of the incoming minimum phase. Thus, a too early prediction tends to underestimate the deep and timing of minimum with a premature increase of the next solar cycle often with an overestimation of the peak amplitude. This behavior is mitigated in our refined prediction method, using a higher value for the embedding dimension. In the following sections we recall briefly the general idea of the method and we show the current prediction for cycle

#25 after a calibration of its parameters based on the best prediction obtained for previous cycle #24.

2 Nonlinear dynamics method

The intrinsic complexity in the temporal behavior of sunspot numbers (irregular and intermittent) and other solar activity indices suggested the possibility of a nonlinear (sometimes chaotic) dynamics governing the related physical processes. In previous works we have shown the results of a numerical method based on nonlinear dynamics techniques, properly designed to predict the medium-time evolution of solar cycles (Sello [2001],[2003],[2012]). In particular, the prediction model is based on the assumption that the underlying dynamics, driven by the evolution of magnetic fields during a solar cycle, is well described by a nonlinear deterministic behavior in a proper embedding space, i.e. a space that mimics the original phase space, (Abarbanel et al. [1990]):

$$f^T(\vec{y}_t) = \vec{y}_{t+T} \tag{1}$$

for a given embedding vector: \vec{y} . The inverse problem to be solved consists of the computation of the smooth map f^T , given a scalar time series (here the sunspot numbers). Following the approach given by Zhang ([1996]), we designed a modified improved version that uses different tools of nonlinear dynamics theory, such as mutual information, linear and nonlinear redundancy, Lyapunov's spectrum etc. For more detailed information about this nonlinear approach to solar cycle prediction the reader can refer to Sello, ([2001]).

3 An early prediction of Cycle #25

A proper refinement of the above nonlinear method, using extended parametric simulations, indicates that describing the dynamic evolution in a 7-dimensional embedding space, with a time lag for the embedding vectors sufficient to produce a little entanglement of the vectors in the phase space, it is able to better predict the behavior of the solar cycle curve for the next solar cycle #25 starting with the information available at or just after the minimum. In particular, we can predict the multi-peaked structure of the cycle, a difficult task for all prediction methods.

The prediction of the next solar cycle #25 is given using an optimal set of nonlinear embedding parameters. As noted by Sarp et al. (2018), other parameters are important, as the starting point, for reliable predictions of the nonlinear method. The known data used are from WDC-SILSO, Royal Observatory of Belgium, Brussels, up to January 2019 where the minimum is well established.

The predicted peak amplitude for the monthly smoothed sunspot numbers in the next solar cycle #25 is near 107 ± 10 , peaking around July 2023 ± 1 (see fig.1). This prediction confirms the current trend towards progressive reduced solar activity cycles.

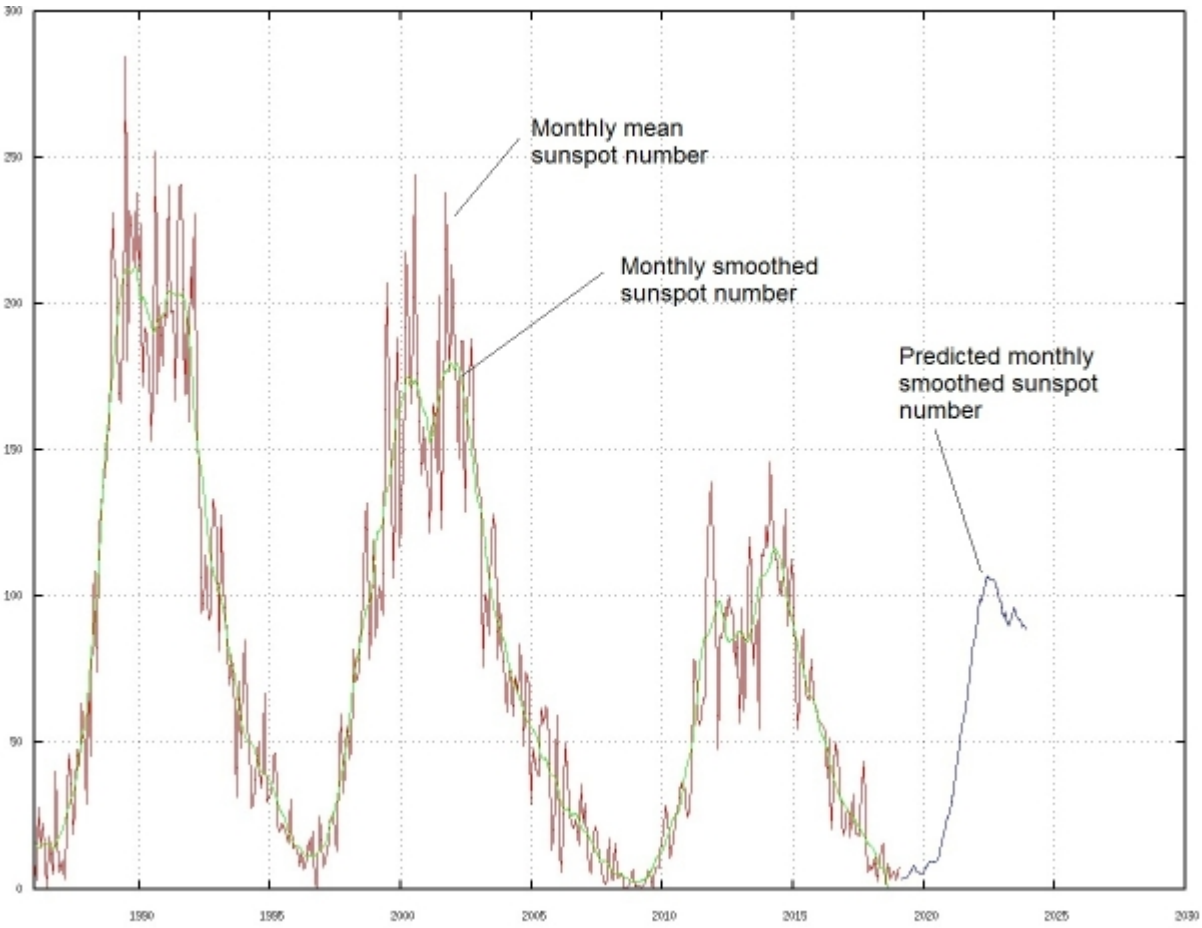


Fig. 1. Predicted evolution for the solar cycle #25 using the information available up to January 2019 and a refined version of the nonlinear method. Red: monthly mean sunspot number (WDC-SILSO), Green: monthly smoothed sunspot number (WDC-SILSO), Blue: Predicted monthly smoothed sunspot number.

Taking into account the uncertainties, our nonlinear prediction method appears quite coherent, both in amplitude and in phase, with other different prediction methods; further, many of these early predictions for the next solar cycle #25, support the tendency towards a reduction in the intensity of solar cycle activity. Here we cite, as few examples, the work by Singh et al. (2019) where, applying different techniques of time series analysis (Hodrick Prescott filtering method, Hurst exponent, etc.) on various solar activity parameters (sunspot numbers, F10.7 cm index and Lyman alpha index), they found a predicted maximum value of sunspot number as 89 ± 9 at February 2024; the work by Gopalswamy, et al. (2018) where, using microwave imaging observations from the Nobeyama Radioheliograph at 17 GHz for long-term studies of solar activity, they found that the smoothed sunspot numbers in the southern and northern hemispheres can be predicted as 89 and 59, respectively, indicating that cycle 25 will not be too different from cycle 24 in its strength; the work by Tan, Baolin (2019), using statistical correlations in the shape of previous solar cycles, found that the Cycle 25 is inferred possibly to be a weak cycle. However, there are also notable exceptions with significant differences in the predicted amplitude and phase of the maximum peak for the next solar cycle: in the cited work by Sarp et al. the authors, using a similar nonlinear dynamics method, predicted that the maximum of Solar Cycle 25 will be at the year 2023.2 ± 1.1 with a peak sunspot number of 154 ± 12 , thus significantly higher

that the previous solar cycle; the work by Li, et al. (2018), using the relations among the feature parameters of solar cycles under the bimodal distribution for the modern era cycles (10-23), they predict the maximum amplitude of solar cycle 25 of 168.5 ± 16.3 in October 2024 thus quite stronger than solar cycle 24; in the recent work by Pesnell and Schatten, (2018), using the well known "Solar Dynamo" (SODA) Index which combines values of the solar polar magnetic field and the solar spectral irradiance at 10.7 cm to create a precursor of future solar activity, the authors predict a peak activity of about 140 ± 30 solar flux units for the 10.7 cm radio flux and a Version 2 sunspot number of 135 ± 25 , suggesting that Solar Cycle 25 will be quite comparable (but higher) to Solar Cycle 24. The estimated peak is expected to occur near 2025.2 ± 1.5 year. Moreover, the authors noted that: "Because the current approach uses data prior to solar minimum, these estimates may improve as the upcoming solar minimum draws closer." Future information with more data will tell us which of these predictions will turn out to be the most correct and reliable.

4 Conclusions

The predictions of atypical solar cycle #24 activity show that in general the complexity of the solar processes related to the evolution of magnetic fields prevents any accurate forecasting of the solar cycle full curve shape and in particular an accurate estimation for both amplitude (multi-peaked) and phase of future cycles. Nevertheless, different methods, both precursor and non-precursor, have obtained fairly good overall performances, suggesting some degree of reliability and usefulness of these prediction approaches. To further check the performances of some prediction techniques, here we computed an early full prediction, for the next solar cycle #25, using a revised nonlinear dynamics method. Our preliminary result, suggests a maximum peak of about 107 ± 10 , peaking around July 2023 ± 1 , supporting the reliability and consistency with other different prediction techniques already proposed: for the next solar cycle our approach confirms the actual trend of a progressive reduced solar activity.

References

- [1990] Abarbanel, H.D.I., Brown, R., Kadtke, J.B., 1990 Prediction in chaotic nonlinear systems: Methods for time series with broadband Fourier spectra *Physical Review A* 41 (4), 1782
- [2016] Cameron, R. H.; Jiang, J.; Schssler, M. Solar Cycle 25: Another Moderate Cycle? *The Astrophysical Journal Letters*, Volume 823, Issue 2, article id. L22
- [2018] Gopalswamy, N.; Mkel, P.; Yashiro, S.; Akiyama, S. Long-term solar activity studies using microwave imaging observations and prediction for cycle 25, *Journal of Atmospheric and Solar-Terrestrial Physics*, Volume 176, p. 26-33.
- [2013] Helal, H. R., and A. Galal (2013) An early prediction of the maximum amplitude of the solar cycle 25, *J. Adv. Res.*, 4(3), 275278,
- [2018] Li, F. Y.; Kong, D. F.; Xie, J. L.; Xiang, N. B.; Xu, J. C., 2018 Solar cycle characteristics and their application in the prediction of cycle 25, *Journal of Atmospheric and Solar-Terrestrial Physics*, Volume 181, p. 110-115.

- [2016] Pesnell, W.D., 2016 Predictions of solar cycle 24: How are we doing?, *Space Weather*, 14, doi:10.1002/2015SW001304.
- [2018] Pesnell, W. Dean; Schatten, Kenneth H. 2018 An Early Prediction of the Amplitude of Solar Cycle 25, *Solar Physics*, Volume 293, Issue 7, article id. 112, 10 pp.
- [2018] Sarp, V., Kilcik, A., Yurchyshyn, V., Rozelot, J. P., Ozguc, A., 2018 Prediction of solar cycle 25: a non-linear approach, *Monthly Notices of the Royal Astronomical Society*, Volume 481, Issue 3, p.2981-2985
- [1978] Schatten, K. H.; Scherrer, P. H.; Svalgaard, L.; Wilcox, J. M., 1978 Using dynamo theory to predict the sunspot number during solar cycle 21 *Geophysical Research Letters*, vol. 5, p. 411-414.
- [2001] Sello, S., 2001 Solar cycle forecasting: A nonlinear dynamics approach *Astronomy & Astrophysics*, 377, 1, 312
- [2003] Sello, S., 2003 Solar cycle activity: A preliminary prediction for cycle #24 *Astronomy and Astrophysics*, v.410, p.691-693
- [2012] Sello, S., 2012 A nonlinear full-shape curve prediction after the onset of the new solar cycle 24 *Journal of Atmospheric and Solar-Terrestrial Physics*, Volume 80, p. 252-257.
- [2016] Sello, S., 2016 Solar cycle full-shape predictions: a global error evaluation for cycle 24 arXiv:1606.01675 [astro-ph.SR]
- [2014] Shepherd, S. J., Zharkov, S. I. and Zharkova, V. V., 2014 Prediction of solar activity from solar background magnetic field variations in cycles 21 - 23, *The Astrophysical Journal*, 795:46.
- [2008] Svalgaard, L.; Schatten, K. H. 2008 Predicting Solar Cycle 24 *American Geophysical Union, Fall Meeting 2008*, abstract SH51A-1593
- [2019] Singh, A. K.; Bhargawa, Asheesh, 2019 Prediction of declining solar activity trends during solar cycles 25 and 26 and indication of other solar minimum, *Astrophysics and Space Science*, Volume 364, Issue 1, article id. 12, 7 pp.
- [2019] Tan, Baolin, 2019 The characteristics of valley phase as predictor of the forthcoming solar cycle, *Advances in Space Research*, Volume 63, Issue 1, p. 617-625.
- [2014] Yoshida, A. 2014 Difference between even- and odd-numbered cycles in the predictability of solar activity and prediction of the amplitude of cycle 25 *Ann. Geophys.*, 32, 10351042, doi:10.5194/angeo-32-1035-2014.
- [2019] WDC-SILSO, Royal Observatory of Belgium, Brussels <http://sidc.oma.be/silso/datafiles>
- [1996] Zhang, Q., 1996 A nonlinear prediction of the smoothed monthly sunspot numbers. *Astronomy & Astrophysics*, v.310, p.646-650 *A&A*, 310, 646