Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
Proceedings IAU Symposium No. 340, 2018
D. Banerjee, J. Jiang, K. Kusano & S. Solanki, eds.

doi:10.1017/S1743921318001059

Nonlinear Prediction of Solar Cycle 25

Volkan Sarp and Ali Kılçık

Faculty of Science, Department of Space Science and Technologies,
Akdeniz University, Antalya, Turkey
email: theneutron@gmail.com; alikilcik@akdeniz.edu.tr

Abstract. Solar activity is a chaotic process and there are various approximations to forecast its long term and short term variations. But there is no prediction method that predicts the solar activity exactly. In this study, a nonlinear prediction approach was applied to international sunspot numbers and performance of predictions was tested for the last 5 solar cycles. These predictions are in good agreement with observed values of the tested solar cycles. According to these results, end of cycle 24 is expected at February, 2020 with 7.7 smoothed monthly mean sunspot number and maximum of cyle 25 is expected at May, 2024 with 119.6 smoothed monthly mean sunspot number.

Keywords. Sun: sunspots, Sun: activity, methods: data analysis

1. Introduction

There are various suggestive evidences of chaos in solar activity. The nonlinearities in dynamo equations or the phenomena like grand minima and maxima can be evaluated as some of these evidences. Therefore applying nonlinear methods to predict the solar cycle is important. Apart from predictive purposes, the insight they yield into the mechanisms of the dynamo may be used to construct more sophisticated dynamo models according to Petrovay (2010).

One popular approach among nonlinear methods is the *simplex projection* described by Sugihara & May (1990). It is a state space prediction algorithm which uses time delayed coordinates of the original time series in an embedding space to search for past patterns in the data. Nearest neighbours are then projected and weighted regarding their proximity to form the forecast. A similar method is applied to predict solar cycle 24 by Kilcik *et al.* (2009) with prospering results.

2. Data and Methods

The data used in this study are taken from SIDC/SILSO as monthly mean total sunspot numbers from 1848 to 2018 and an additional 19 month running average is applied to remove the fluctuations.

The operating principle of the simplex projection is as follows; 1) the time series are transformed into an m-dimensional state space with succesive time delays of t_d. 2) last m points in the data set off the prediction vector. 3) Nearest m+1 neighbours to the prediction vector in the state space are selected. 4) These neighbours are projected along with the desired prediction time. 5) These projections are weighted regarding their distance to the prediction vector to form the prediction.

Time delay (t_d) and embedding dimension (m) should be optimized to get better results from simplex projection. For this purpose, firstly a range of embedding dimensions are selected from 2 to 10. Each embedding dimension is tested by *average displacement function* (Rosenstein *et al.* 1994) and their related time delays are found by this method.

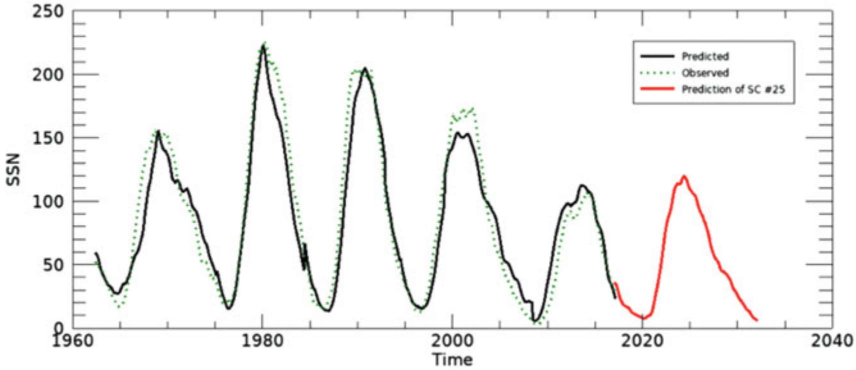

Figure 1. Predictions and observed values of solar cycle 20-24 and prediction of solar cycle 25.

Table 1. Comparison of observed and predicted maximas of solar cycles 20-24

Cycle No	Error Type	Observed	Predicted	Difference
#20	Max. SSN	184,6	170,5	14,1
	Max. Time	02/1969	02/1969	0 months
#21	Max. SSN	226,6	222,2	4,4
	Max. Time	03/1980	01/1980	1 month
#22	Max. SSN	204,2	204,5	0,3
	Max. Time	03/1990	10/1990	7 months
#23	Max. SSN	174,1	153,9	20,2
	Max. Time	12/2001	07/2003	17 months
#24	Max. SSN	107,4	112,4	5,0
	Max. Time	04/2014	07/2013	9 months

3. Results and Prediction

After matching time telays with embedding dimensions, each pair of parameters are tested in the prediction algorithm according to their root mean square error (rms). The smallest rms error is obtained at the embedding dimension 4 with its relevant time delay 26. These parameters were used at out-of sample forecasting for solar cycles 20-25. These predictions can be seen in Figure 1. Observed and predicted maximums of solar cycles 20-24 are compared in Table 1. According to these results, end of cycle 24 is expected at February, 2020 with 7.7 smoothed monthly mean sunspot number and maximum of cyle 25 is expected at May, 2024 with 119.6 smoothed monthly mean sunspot number.

4. Discussion and Conclusion

Except from solar cycle 23 which is called an anomalous cycle (de Toma *et al.* 2004), other four cycles maximum times and sunspot numbers are predicted with small errors. Based on these results, nonlinear methods can be said to work well because of the chaotic dynamics of the solar activity.

References

de Toma, G., White, O. R., Chapman, G. A., Walton, S. R., Preminger, D. G., & Cookson, A. M. 2004, *ApJ*, 609,2

Kilcik, A., Anderson, C. N. K., Rozelot, J. P., Ye, H., Sugihara, G., & Ozguc, A. 2009, *ApJ*, 693,2

Petrovay, K. 2010, *Living. Rev. Solar Phys.*, 7, 6

Rosenstein, M. T., Collins, J. J., & De Luca, C. J. 1994, *Physica D*, 73, 82-98

Sugihara, G. & May, R. M. 1990, *Nature*, 344, 734-741