

Using Synoptic Magnetograms for Long-Term Solar Activity Forecast

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Building accurate forecasts of solar activity requires knowledge of non-linear multi-scale interactions of turbulent flows and magnetic fields, which can be described by global data-driven MHD models. Long-term synoptic observations provide knowledge about evolution of magnetic fields and sunspots on the solar surface, while very limited information is available about the subsurface dynamics and its long-term evolution. In such state of limited knowledge of the global dynamics, shortage of observational data, and incompleteness of theoretical models, the data assimilation approach provides an efficient way to combine the available data and models while taking into account uncertainties of both the models and observations.

To test capability of the data assimilation approach to predict solar activity we use available synoptic magnetograms for the last four solar cycles (Figure 1), which were obtained for the period from 1976 to 2019 from the Kitt Peak Observatory, the SOLIS instrument, and SOHO/MDI and SDO/HMI. The synoptic magnetograms are decomposed into toroidal and poloidal field components. The resulting annual observations are normalized to match the model periodic solutions for the toroidal and poloidal fields for each hemisphere (Figure 2). Normalization for the poloidal field was chosen for a best agreement in term of the field amplitude. For the toroidal field, the normalization was performed relative to the last observed solar cycle.

In this work, poloidal and toroidal magnetic field components derived from synoptic magnetograms are assimilated, using the Ensemble Kalman Filter method (Evensen, 1997), into a mean-field dynamo model based on the Parker's migratory dynamo theory (Parker, 1955) complemented by magnetic helicity balance equation (Kleeorin et al., 1995). Previously, this approach made it possible to produce a reliable forecast for the whole activity Cycle 24 (Kitiashvili & Kosovichev, 2008).

Three test predictions of SC23 and SC24 using different numbers of the preceding cycles with observed magnetic field have been performed (Kitiashvili 2020). It was found that using two cycles of the synoptic magnetograms can provide a reasonable forecast of the solar activity for the following solar cycle. Taking into account poloidal field observations can noticeably improve the forecast, particularly in the case when the data of three preceding cycles are assimilated in the model. Forecasted hemispheric toroidal field variations are in good agreement with observations, at least up to the following solar maximum, and often make a reasonable prediction for the whole activity cycle (Figure 3a). Predicted poloidal fields are in good agreement with observations for up to two years in the case of assimilation of data for two preceding activity cycles, and for about three years if data for three cycles is assimilated.

According to our analysis, the next Solar Cycle 25 will start after an extended solar minimum during 2019 – 2021, and will be weaker than the current cycle (Figure 3b). The maximum of activity will occur in 2024 - 2025 with sunspot number of about 50 +/- 15 (for the v2.0 sunspot

number series). Solar Cycle 25 will start in the southern hemisphere in 2020 and reach maximum in 2024 with a sunspot number of ~ 28 ($\pm 10\%$). Solar activity in the northern hemisphere will be delayed for about 1 year (with error of ± 0.5 year) and reach maximum in 2025 with a sunspot number of $\sim 23 \pm 5$ ($\pm 21\%$). Detailed description of the analysis procedure, tests and results can be found in Kitiashvili (2020).

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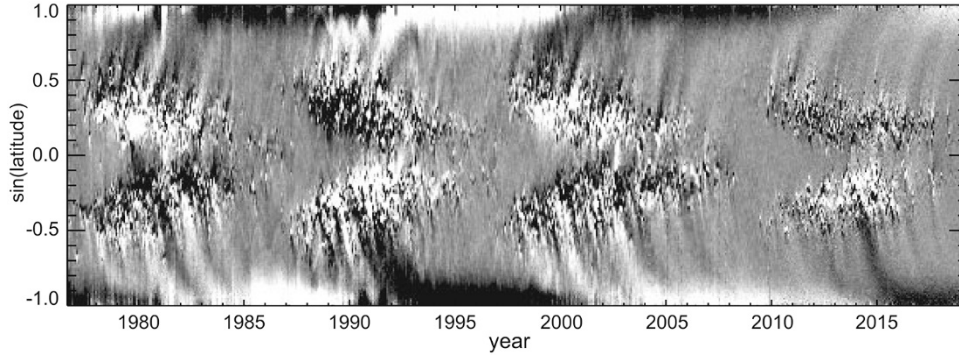


Figure 1. Synoptic magnetogram covering four solar cycles from 1976 to 2019. The gray color-scale is saturated at range ± 10 G.

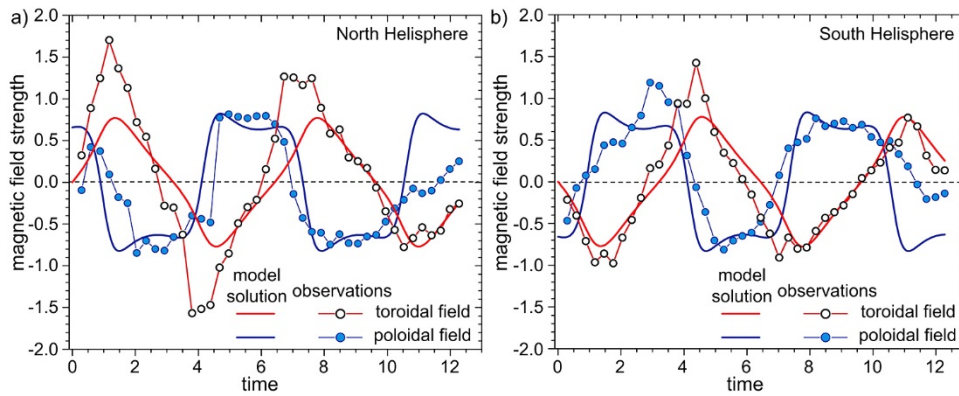


Figure 2. Time series of the annual toroidal (empty dots) and poloidal (blue) field observations calibrated to the corresponding periodic dynamo solutions (thick curves) for the northern (panel a) and southern hemispheres (b). The magnetic fields and time units are non-dimensional.

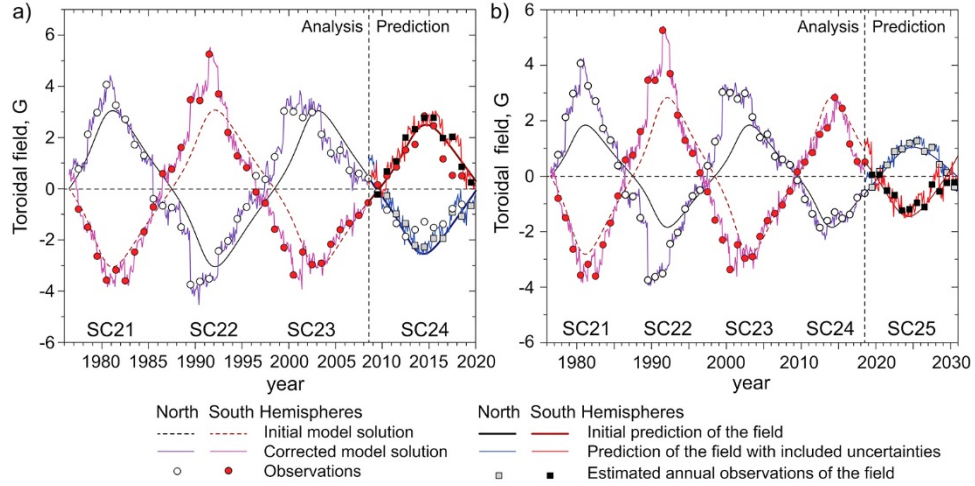


Figure 3. Panel a) Evolution of the mean toroidal fields in the northern and southern hemispheres based on the field observations for three solar cycles, and prediction of the mean toroidal and poloidal field components variation during SC24. Panel b) Prediction for the mean toroidal fields for SC25 in the northern and southern hemispheres based on field observations for three solar cycles. Vertical dashed lines indicate the prediction start time.

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