



# Physics-Based Approach to Predict the Solar Activity Cycles

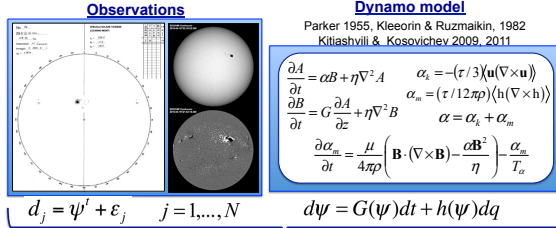


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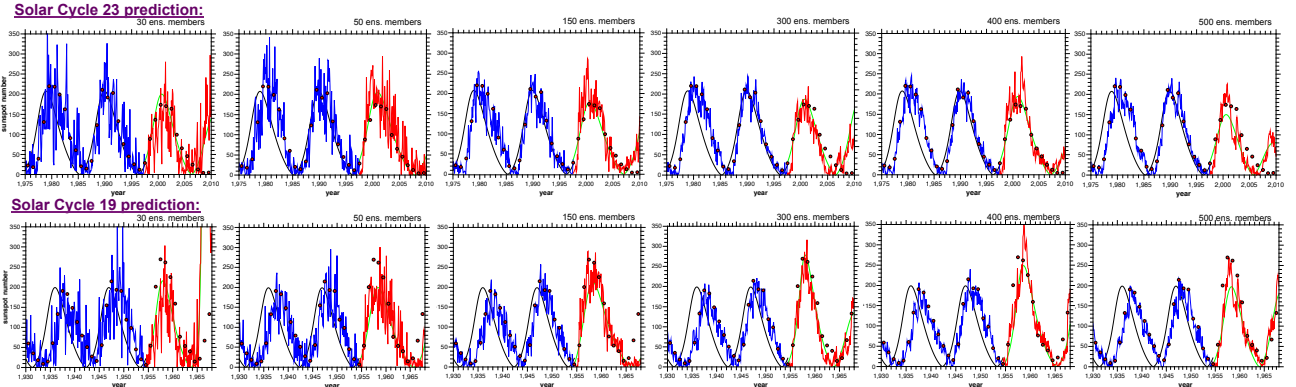
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Observations of the complex highly non-linear dynamics of global turbulent flows and magnetic fields are currently available only from Earth-side observations. Recent progress in helioseismology has provided us some additional information about the subsurface dynamics, but its relation to the magnetic field evolution is not yet understood. These limitations cause uncertainties that are difficult to take into account, and perform proper calibration of dynamo models. The current dynamo models have also uncertainties due to the complicated turbulent physics of magnetic field generation, transport and dissipation. Because of the uncertainties in both observations and theory, the data assimilation approach is a natural way for the solar cycle prediction and estimating uncertainties of this prediction. I will discuss the prediction results for the upcoming Solar Cycle 25 and their uncertainties and affect of Ensemble Kalman Filter parameters to resulting predictions.

## Data Assimilation Methodology



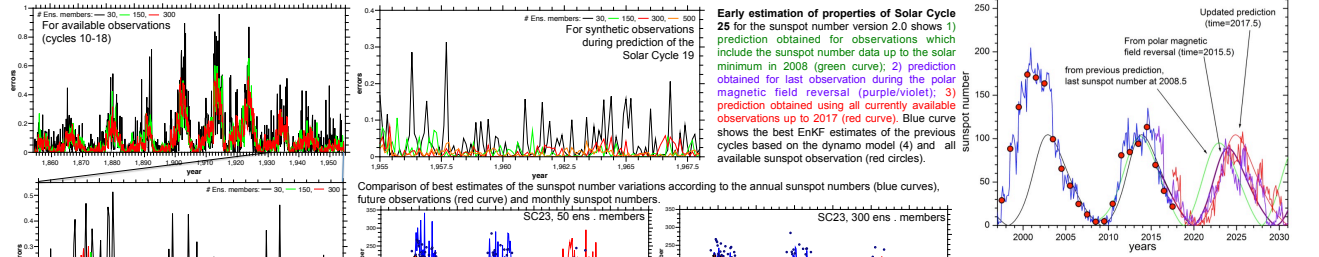
## Effect of the Ensemble Kalman Filter Parameters on predictive capabilities of Solar Cycles



Test predictions of Solar Cycles 23 (top row) and 19 (bottom) reveal influence of the number of ensemble members on ability of the dynamo model to predict future activity cycles.

Discrepancies between the model solutions and observational data for Solar Cycles 10 - 18, and synthetic data generated for different number of ensemble members in test cases of the prediction for Solar Cycle 19.

## Uncertainties in Prediction of the Solar Cycle 25

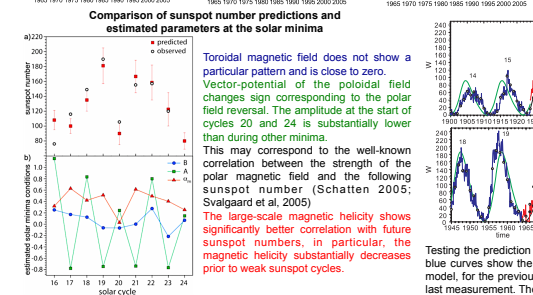
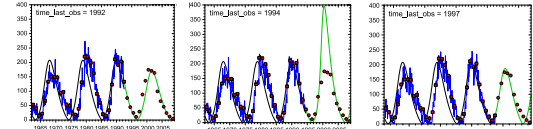
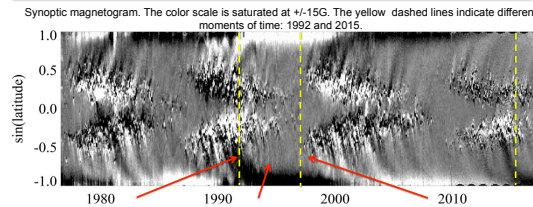


Previous experience and tests have shown that the EnKF procedure based on the dynamo model and sunspot number measurements has good predictive capabilities in estimating future solar activity in the time range from 7 - 8 years to a whole solar cycle. However, our attempts to make predictions for a period longer than one cycle often fail due to accumulation of errors.

## Conclusions

Prediction of solar cycles is one of most interesting problems closely linked to dynamo processes inside the Sun. The difficulty is due to our incomplete understanding of the physical mechanisms of the solar dynamo and also due to observational limitations that result in significant uncertainties in the initial conditions and model parameters. We have developed a relatively simple non-linear mean-field dynamo model, which nevertheless can describe essential general properties of the cycles and the observed sunspot number series (such as Waldmeier's rule). Combined with the data assimilation approach, this model provides reasonable estimates for the following solar cycles. In particular, the prediction of Cycle 24 calculated and published in 2008 is holding quite well so far. It was found that the best periods for predicting the future solar cycles are during the preceding solar minimum or solar maximum. This effect is explained by the fact these periods correspond to the solar dynamo state when the primary magnetic field components: toroidal or poloidal change their polarity. During these periods the uncertainty of predictions is decrease because the model ensemble primarily depends only on one of the field components. However, the accuracy of the prediction is reduced when the polarity reversals are not simultaneous and occurs in the Northern and Southern hemispheres with some time delay. The reason is that the current dynamo theories are not able to model the hemispheric asymmetries. This finding was unexpected, and will require further investigation. Using the current observational data, prediction and prediction uncertainties have been calculated for Solar Cycle 25: The updated prediction of Cycle 25 shows that this cycle will start in about 2021 reach the maximum in 2024 - 2025, and the mean sunspot number at the maximum will be about 90 (for the v2.0 sunspot number series) with the error estimate ~15%. The model result shows that deep extended solar activity minimum (about 2019-2021) is expected. Solar maximum will likely have double peak or extended maximum activity (up to 2 - 2.5-years long).

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## Testing the Prediction Capabilities

