Predicting Solar Cycles with a Dynamo Model

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Plan of the talk

- Methodologies of prediction.
- The Dynamo model *Surya*.
- Initializing using relevant information from past cycles.
- Comparison of model output with observations of cycles 21, 22 and 23 and forecasting the amplitude of cycle 24.

Methods of forecasting

- Polar field precursor method

  The precursor methods invoke a solar dynamo concept, where the polar field in the declining phase of a cycle n is the seed of future sunspot fields (toroidal fields) within the sun in cycle $n+1$ that will cause solar activity (e.g., Schatten and Myers, 1996; Schatten, 2005; Svalgaard et al, 2005).

Methods of forecasting

- Polar field precursor method
- Geomagnetic activity

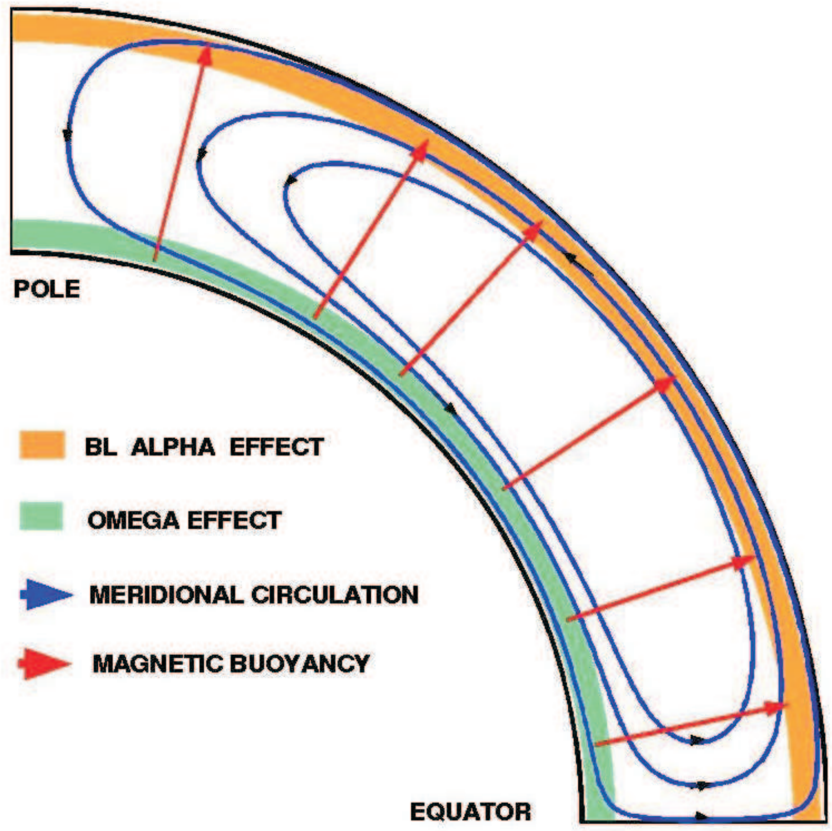
  High speed solar wind streaming from low-latitude coronal holes give rise to recurrent geomagnetic disturbances that are used as the predictor of the strength of the next cycle (e.g., Thompson, 1993). Geomagnetic precursors serve as proxies for predicting the solar cycle as physical connection exists between the polar field, coronal holes, the interplanetary field, and geomagnetic activity.

Methods of forecasting

- Polar field precursor method
- Geomagnetic activity
- Dynamo models

  Feed observational polar field data into State-of-the-Art Solar Dynamo Models to calculate sunspot activity (Dikpati et al, 2006; Choudhuri et al, 2007, Jiang et al, 2007).

Basic Dynamo Theory



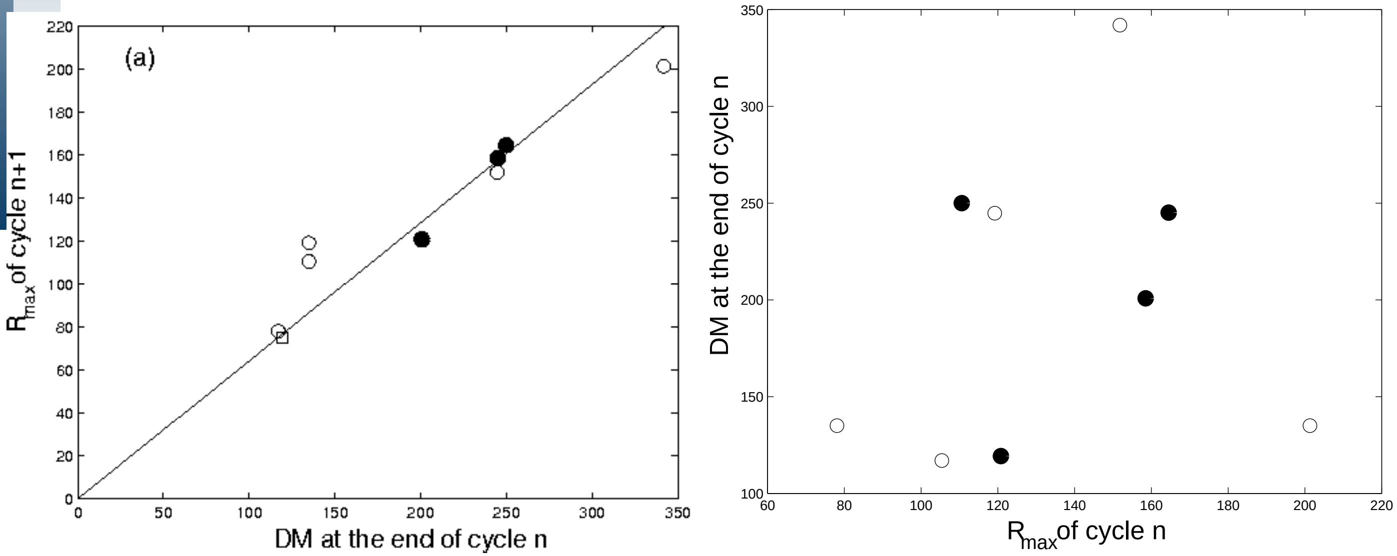
Details provided in Chatterjee et al, 2004

Modern Solar Dynamo Models incorporate THREE basic processes.

1. *The poloidal field gets converted to the strong toroidal field by stretching due to the differential rotation.*
2. *The toroidal field generated in the tachocline rises to the surface due to magnetic buoyancy and forms active regions. The tilted bipolar active regions decay to produce poloidal field by Babcock-Leighton mechanism*
3. *The meridional circulation carries the poloidal field first to the poles and then to the tachocline situated at $0.7R_{\odot}$.*

Observational support for precursor methods.

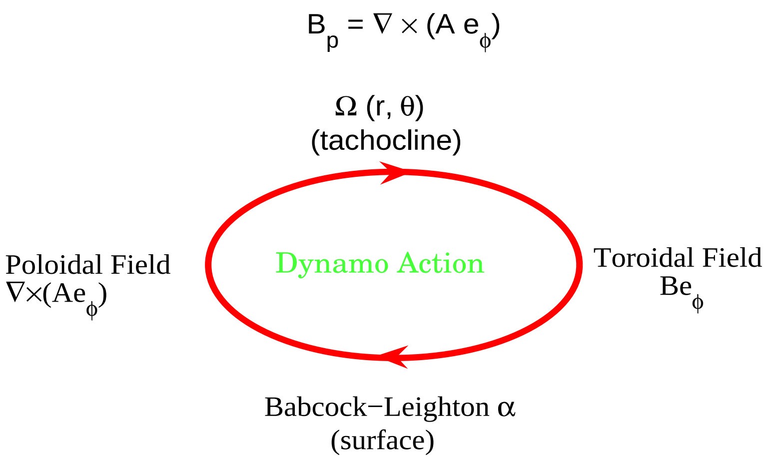
Observational data provide good support to the hypothesis that the polar field at the preceding minimum is a reliable precursor for the strength of the next maximum. DM or the solar magnetic dipole moment is the difference between N-S polar field at a given minima.

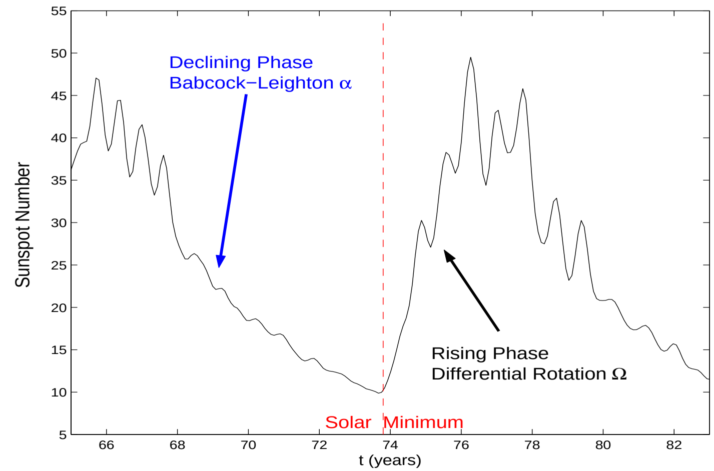


Left panel: Strengths of solar cycles plotted against DM values of the preceeding minima. The solid circles are based on actual polar field data whereas the open circles are based on polar field inferred from position of Hα filaments (Makarov et al 2001).

Right panel: DM values of polar fields plotted against the strengths of previous solar cycles

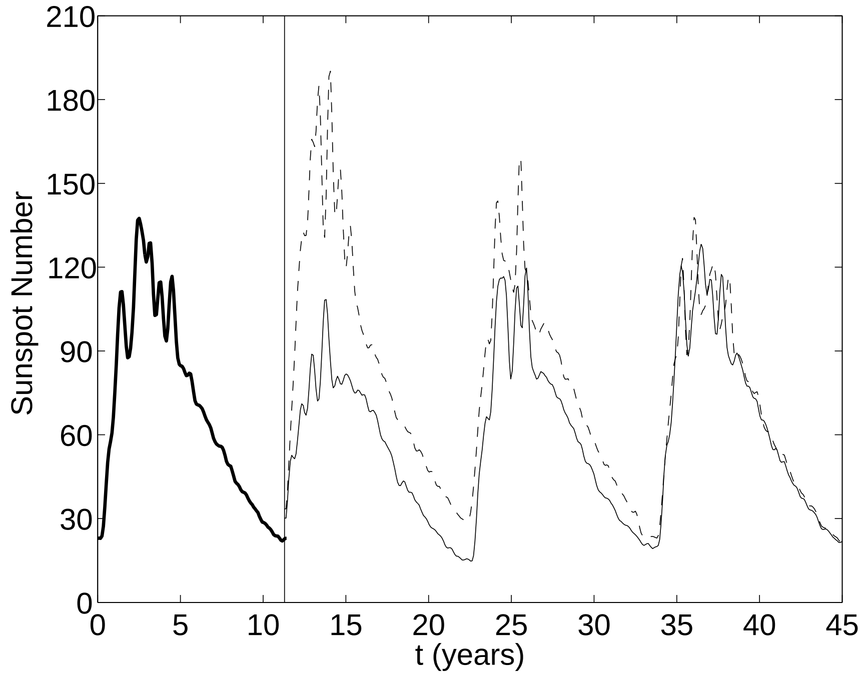
Predicting Solar Cycle 24



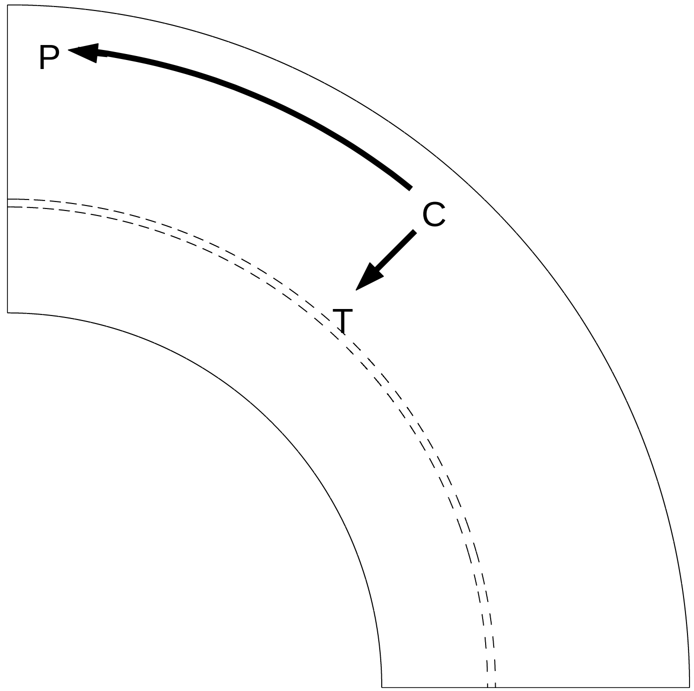


- *Poloidal field generated from an active region by the Babcock–Leighton process depends on the tilt, the scatter in the tilts introduces a randomness in the poloidal field generation process.*
- *The polar field at the solar minimum produced in a mean field dynamo model is some kind of 'average' polar field during a typical solar minimum. The polar field during a particular solar minimum may be stronger or weaker than this average field.*
- *We propose the following methodology for modelling the solar cycles with a mean field dynamo model. We run the dynamo code in the usual way from one solar minimum to the next. Then, at the time of the minimum, we change the amplitude of the polar field suitably to make it agree with the observed value of the polar field and run the code again to the next minimum.*

Persistence in our model



Monthly smoothed sunspot number plots by increasing (dashed line) and decreasing (solid line) the poloidal field by 30% above $0.8R_\odot$ at a solar minimum (indicated by the vertical line), based on our model.



A sketch indicating how the poloidal field produced at *C* during a maximum gives rise to the polar field at *P* during the following minimum and the toroidal field at *T* during the next maximum.

Observational inputs into Surya

Cycle	Dipole Moment μTesla ABS(North - South)	Observed Rmax	Predicted Rmax	Prediction Error
22	245.1 ± 2.7	158.5	154.1	2.9%
23	200.8 ± 3.6	120.8	126.2	4.3%
24	119.3 ± 3.2	?	**75.0**	3.6% (Assumed)

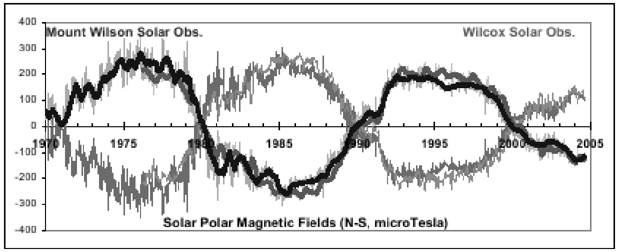


Table 1 from Svalgaard et al., 2005 giving the magnitude of Sun's Dipole magnetic Moment (DM) as the average unsigned difference between two polar fields for three epochs – 1983.7-1986.7, 1993.6-1996.6 and 2003.8-2004.8. Compare observed and predicted monthly smoothed sunspot number R_{max}

Figure 3 from Svalgaard et al., 2005 showing time variation of solar magnetic axial dipole moment (DM). The relative strengths of the polar fields at the end of cycles 20, 21, 22 & 23 are measured by ratios of the DM at the end of that cycle with DM at end of cycle 22. We call this ratio γ.

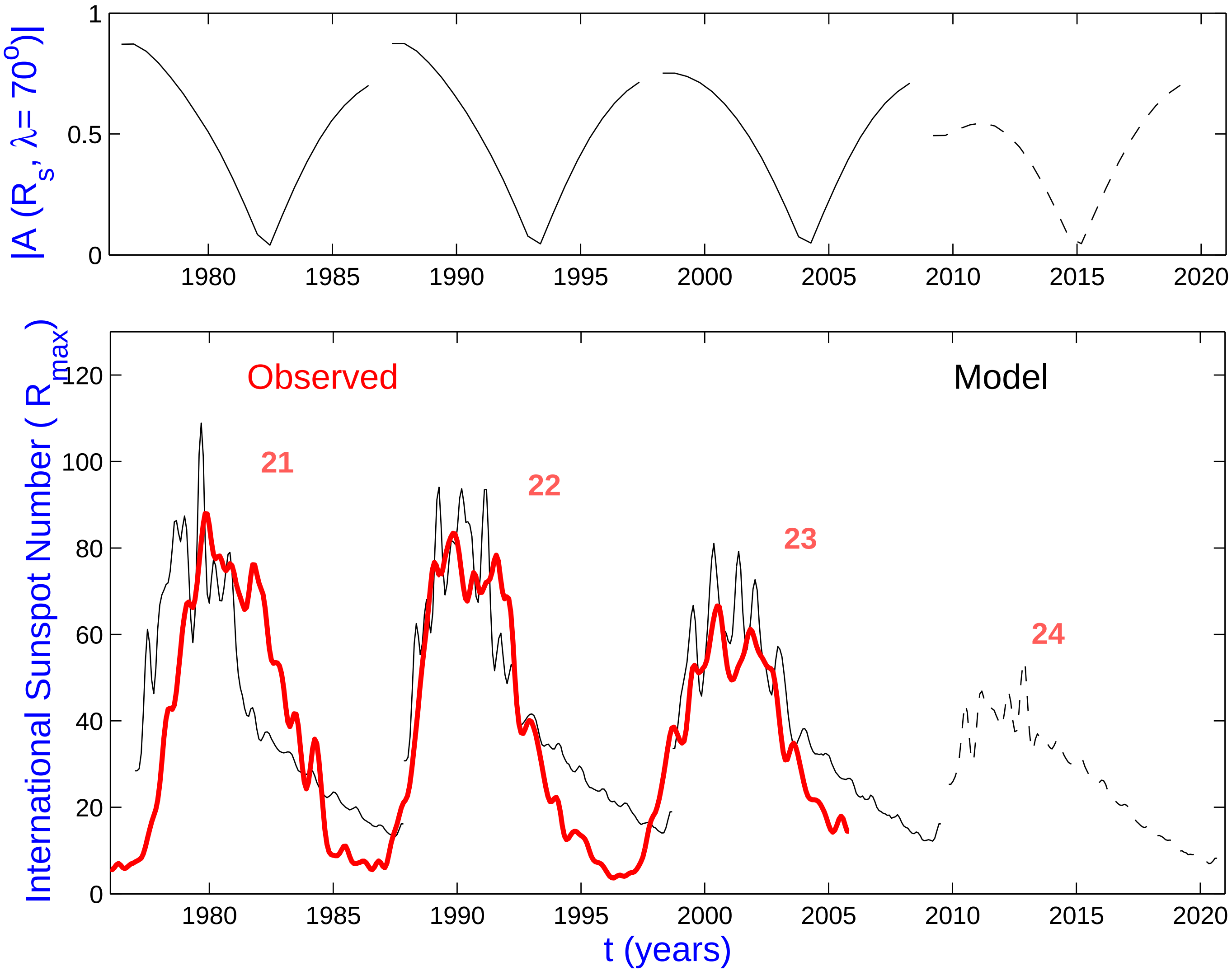
Methodology

1. Using the DM values we calculate γ at the ends of cycles 20–23, our procedure for generating a forecast for cycle 24 is now straightforward.

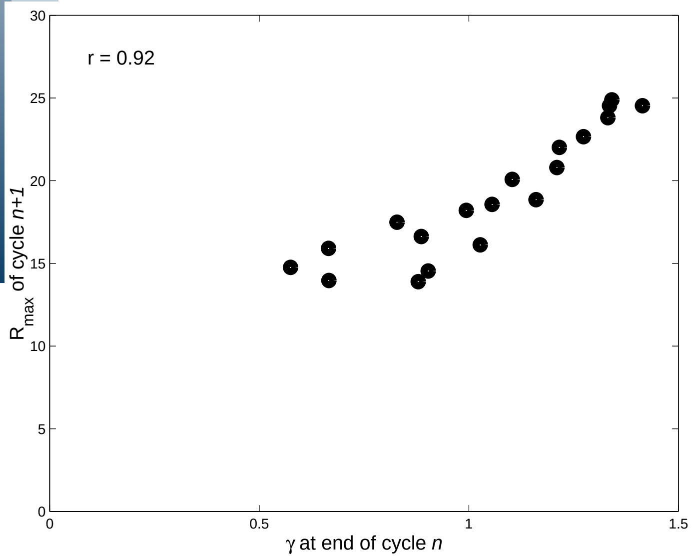
2. We take a relaxed solution of our dynamo code which has been stopped at a solar minimum. We identify this minimum as the minimum at the end of cycle of 20 and change the the values of A above $0.8R_\odot$ in accordance with the value of γ (which is 1.25).

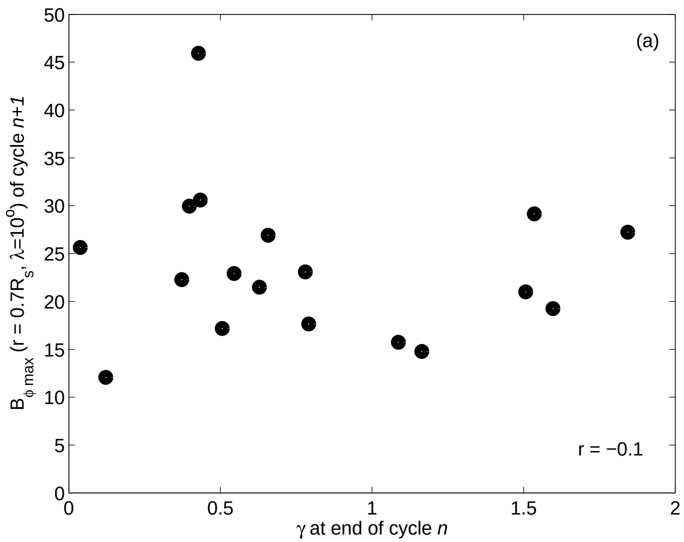
3. Then we run the code till the next minimum and again change the values of A above $0.8R_\odot$. Doing this thrice, we come to the minimum at the end of the cycle 23. The next run after this generates the forecast for cycle 24.

Cycle–24: Weak or Strong?



Validation of precursor method from our model





The strength of the maximum of cycle *n+1* plotted against the randomly chosen value γ at the end of cycle *n*. γ is the factor by which the average poloidal field produced at the end of a cycle by the regular model is corrected.

Keypoints

- Our model predicts that cycle 24 will be 35% **weaker** than cycle 23 in contrast to Dikpati et al, 2006, who predict that cycle 24 will be 50% **stronger** than the present cycle .
- Our model shows a strong correlation between the polar field strength at the end of the cycle and the sunspot number in the following maxima in accordance with observations. Thus our model lends support to the precursor method of predicting solar cycles.
- If our identification of the polar field generation mechanism as the only random process in the dynamo cycle is correct then that limits the predictive capability of solar cycles to 7–8 years.

References

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Thank You!