

SOLAR DYNAMO MODELS

Mausumi Dikpati
High Altitude Observatory, NCAR



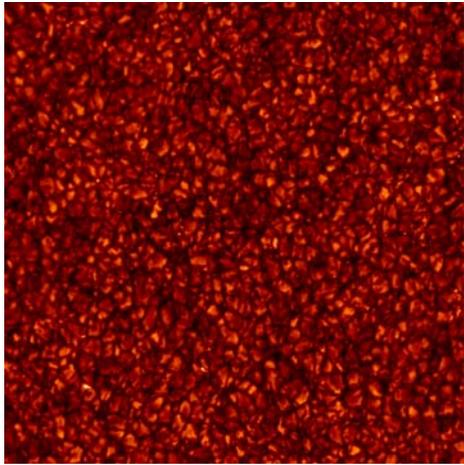
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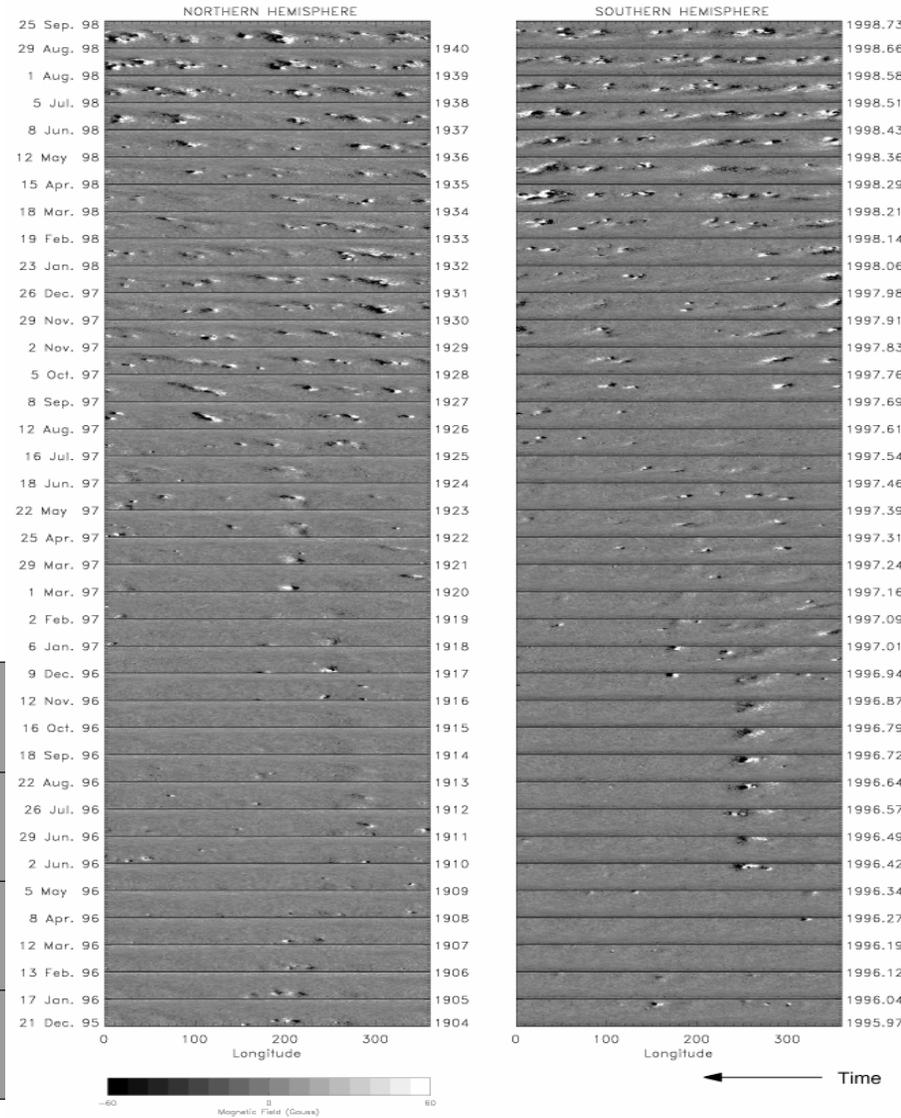
Random vs. persistent, cyclic features

mixed-polarity turbulent fields



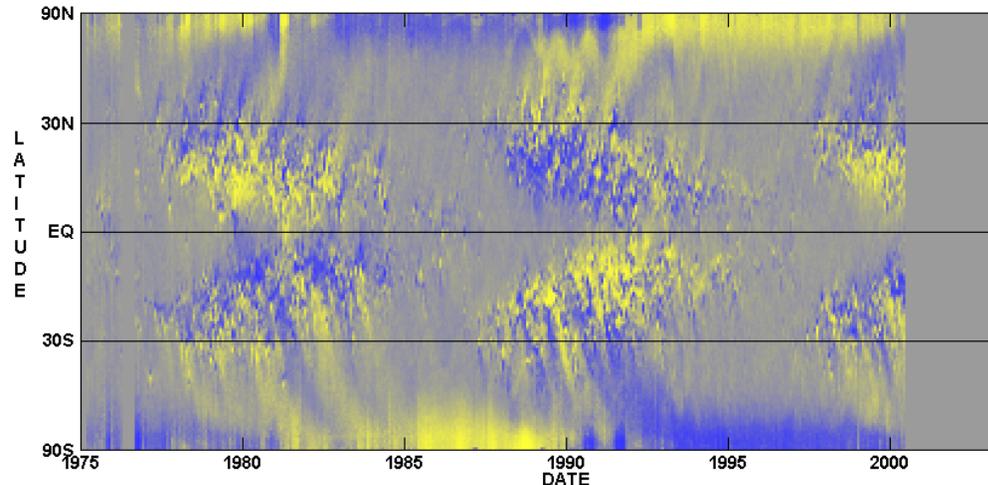
*From
T. Berger*

active longitudes



butterfly diagram, polar reversal

AVERAGE MAGNETIC FIELD

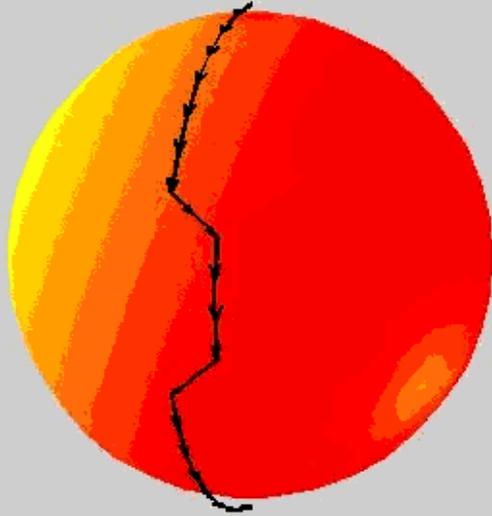


From D.H. Hathaway

From G. de Toma

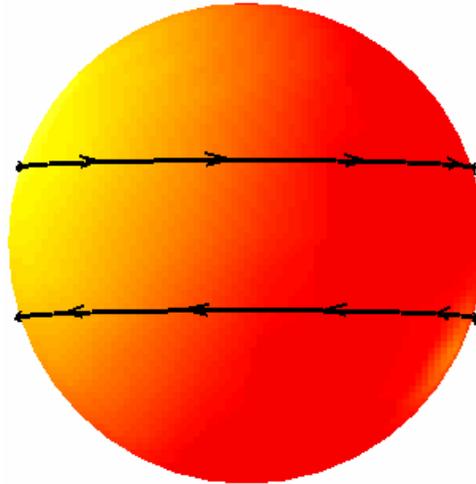


FLUX-TRANSPORT DYNAMO



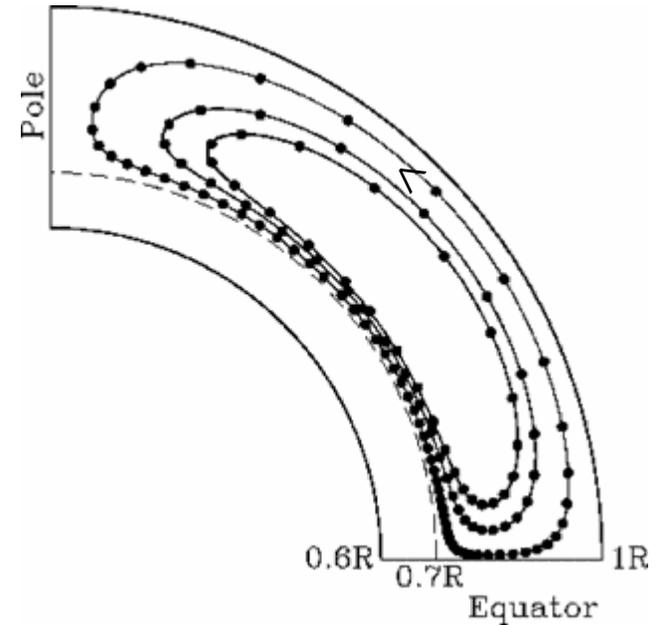
(i) Generation of toroidal field
by shearing a pre-existing
poloidal field by
differential rotation

(Ω -effect)



(ii) Re-generation of
poloidal field by lifting and
twisting a toroidal flux tube
by helical turbulence

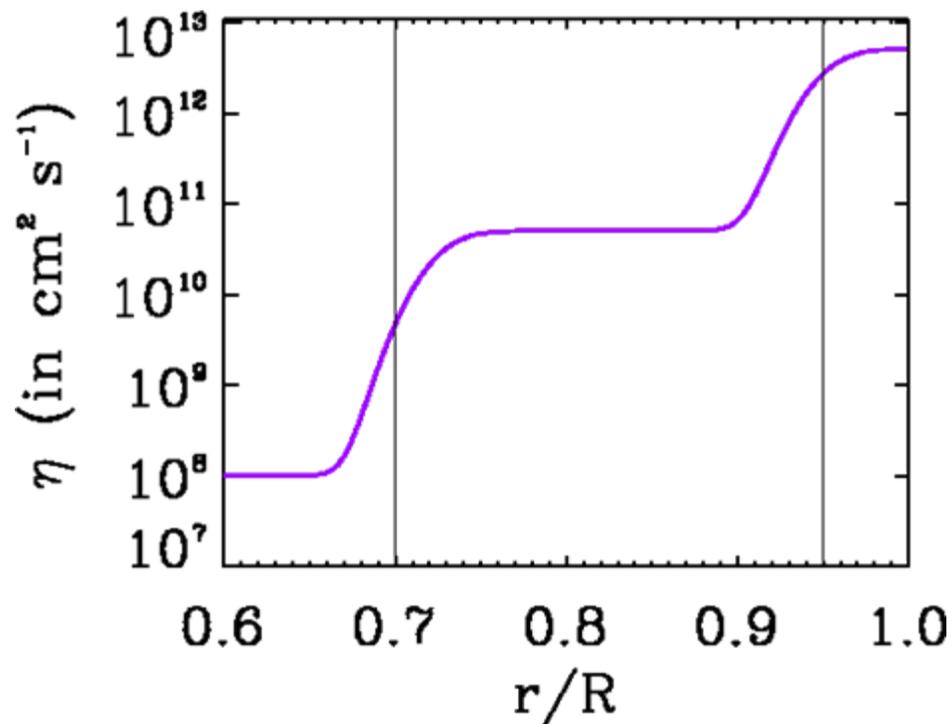
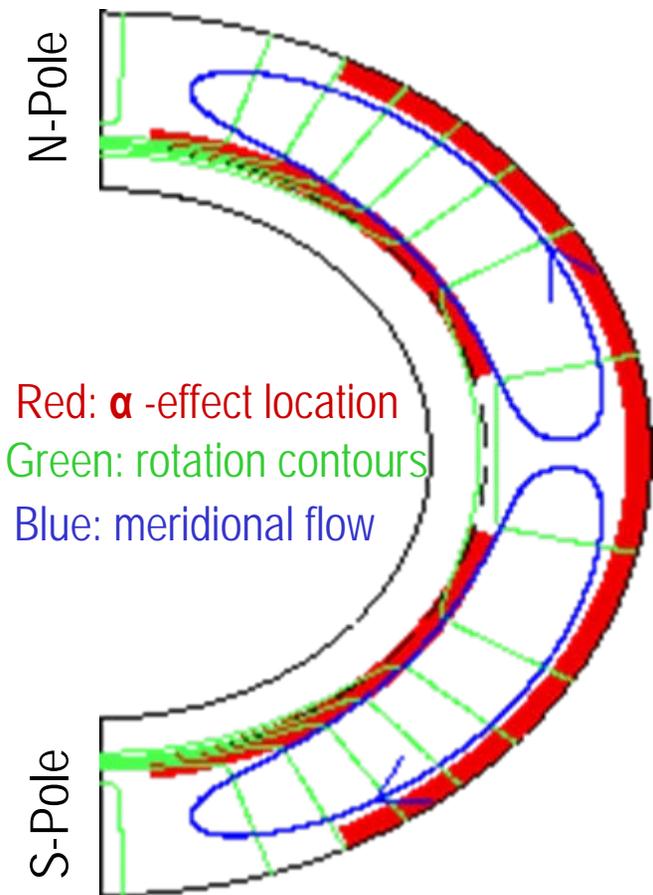
(α -effect)



(iii) Flux transport by
meridional circulation

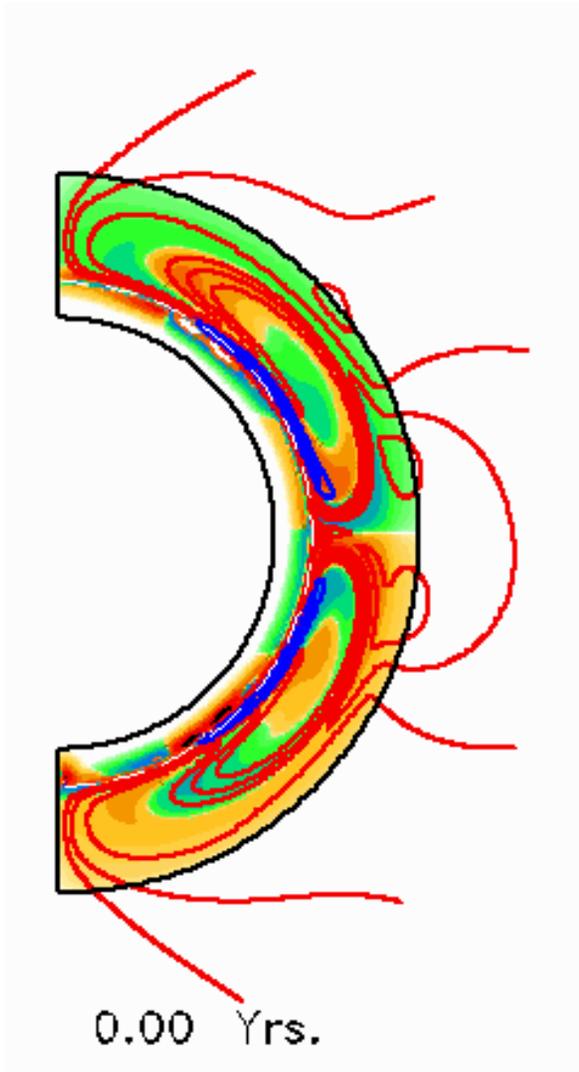
*Wang & Sheeley, 1991
And then many others, including us*

Ingredients of a Calibrated Flux-transport Dynamo Model

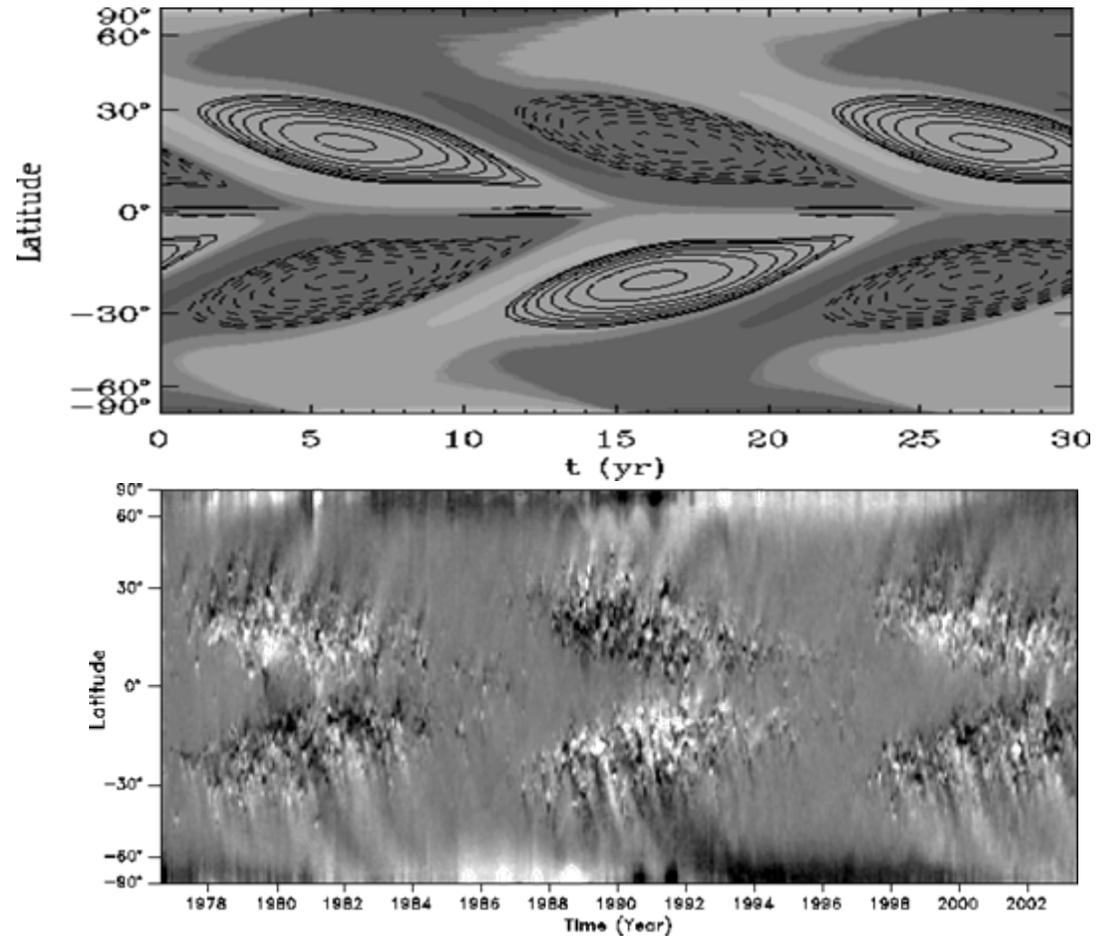


Calibrated flux-transport dynamo model

(Dikpati, de Toma, Gilman, Arge & White, 2004, ApJ, 601, 1136)



Contours: toroidal fields at CZ base
Gray-shades: surface radial fields

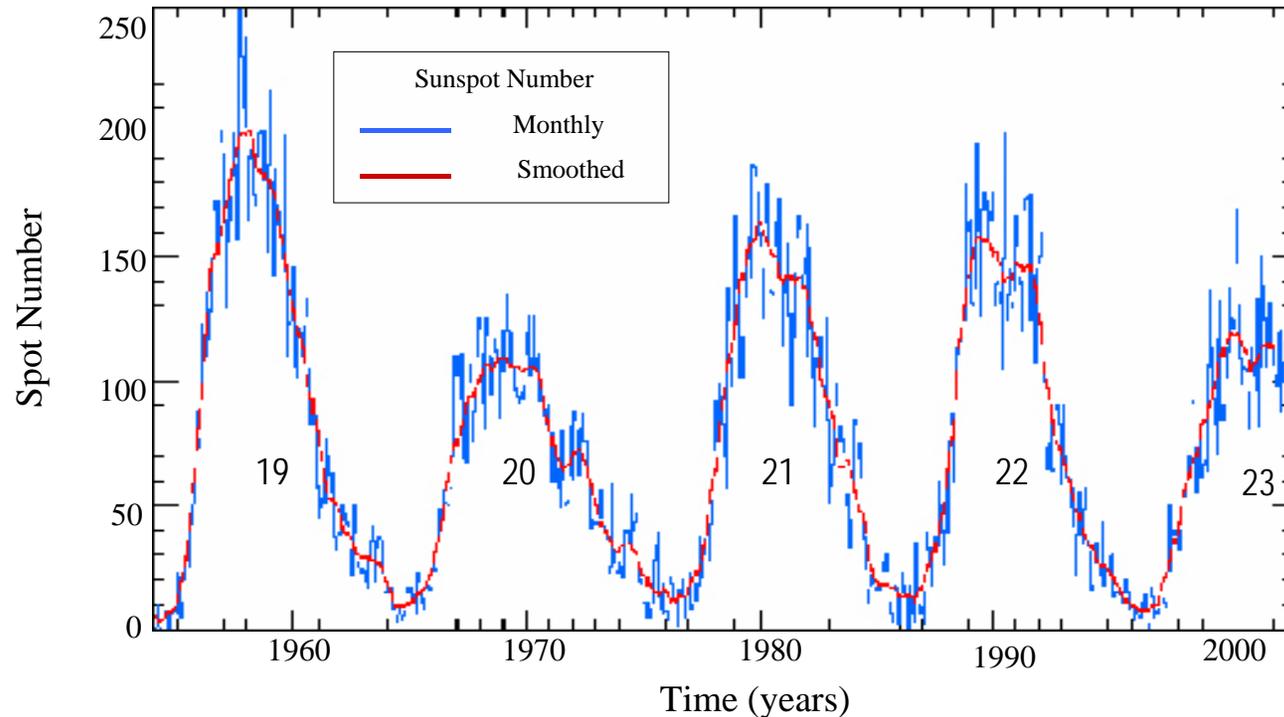


Observed NSO map of longitude-averaged photospheric fields

"Peculiar" Features Of Cycle 23

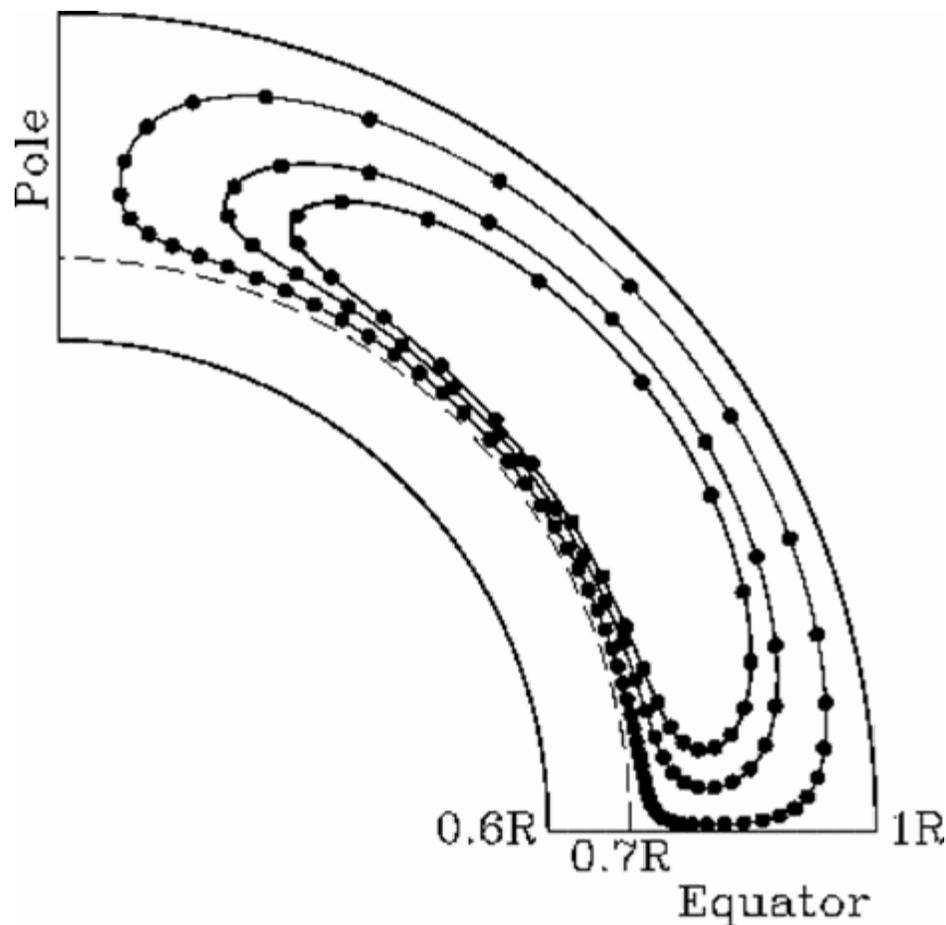
Sunspot index graphics

The monthly (blue) & monthly smoothed (red) sunspot numbers for the latest five cycles



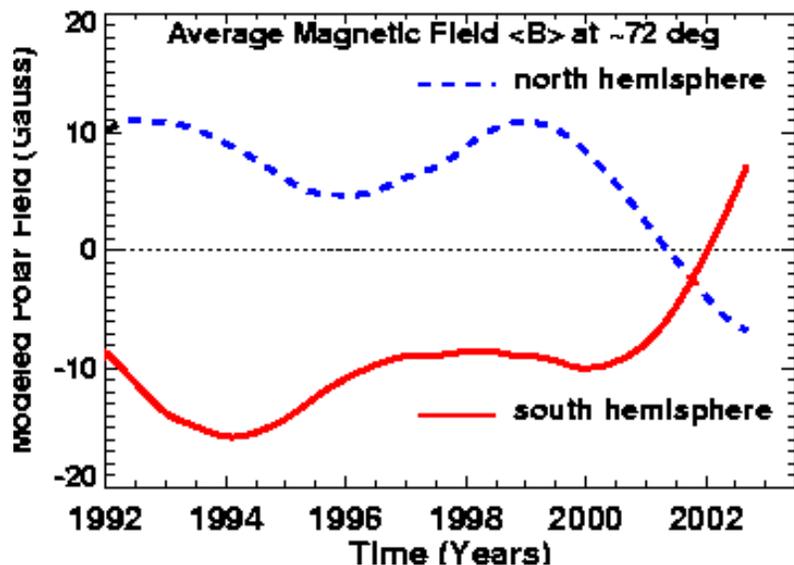
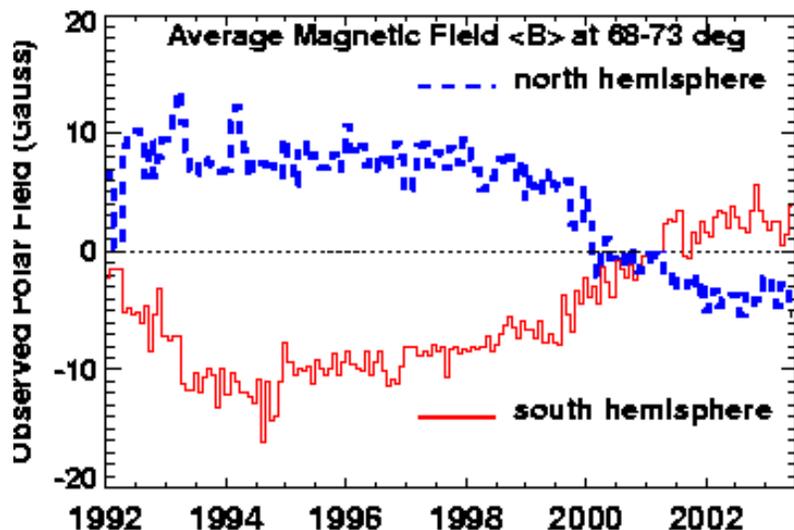
- Rise of this cycle was slow compared to other odd cycles
- It never reached the *expected* strength
- It showed a second peak during its declining phase, unusual for an odd cycle

Flux-transport Dynamo-based Prediction Scheme



We postulate that "magnetic persistence", or the duration of the Sun's "memory" of its own magnetic field, is controlled by meridional circulation.

Polar fields are the continuous solar wind sources that interact with earth's magnetosphere; accurate prediction of the Sun's polar field is important



1. Weak poloidal sources are the causes of major slow-down in cycle 23 polar reversal

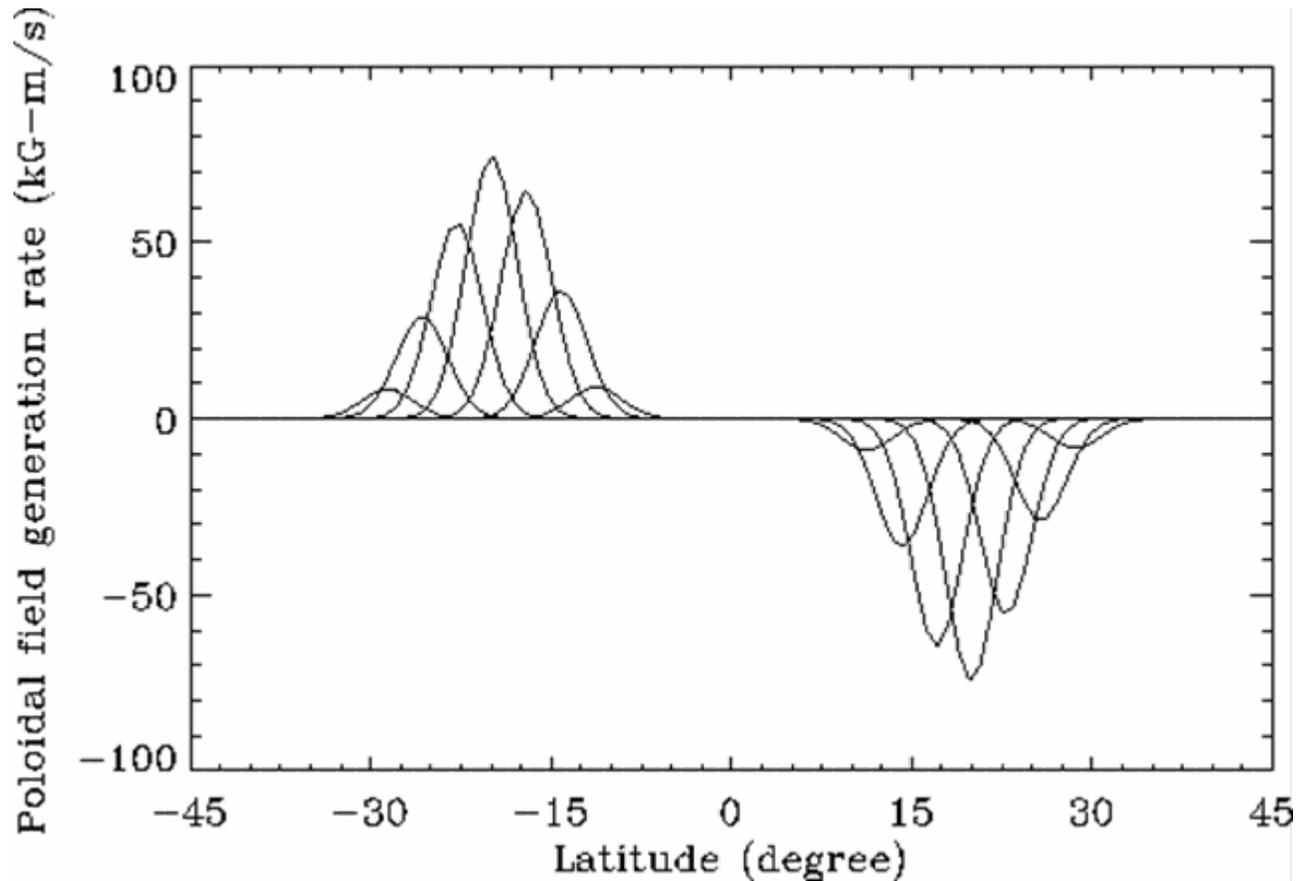
2. High-latitude reversed (equatorward) meridional flow in N-hemisphere is the cause of N-pole reversing ~1yr before S-pole

PREDICTING PEAK AMPLITUDES OF SOLAR CYCLES 12 THROUGH 24 WITH A FLUX-TRANSPORT DYNAMO MODEL

Dikpati, de Toma & Gilman
(to be submitted to ApJ)

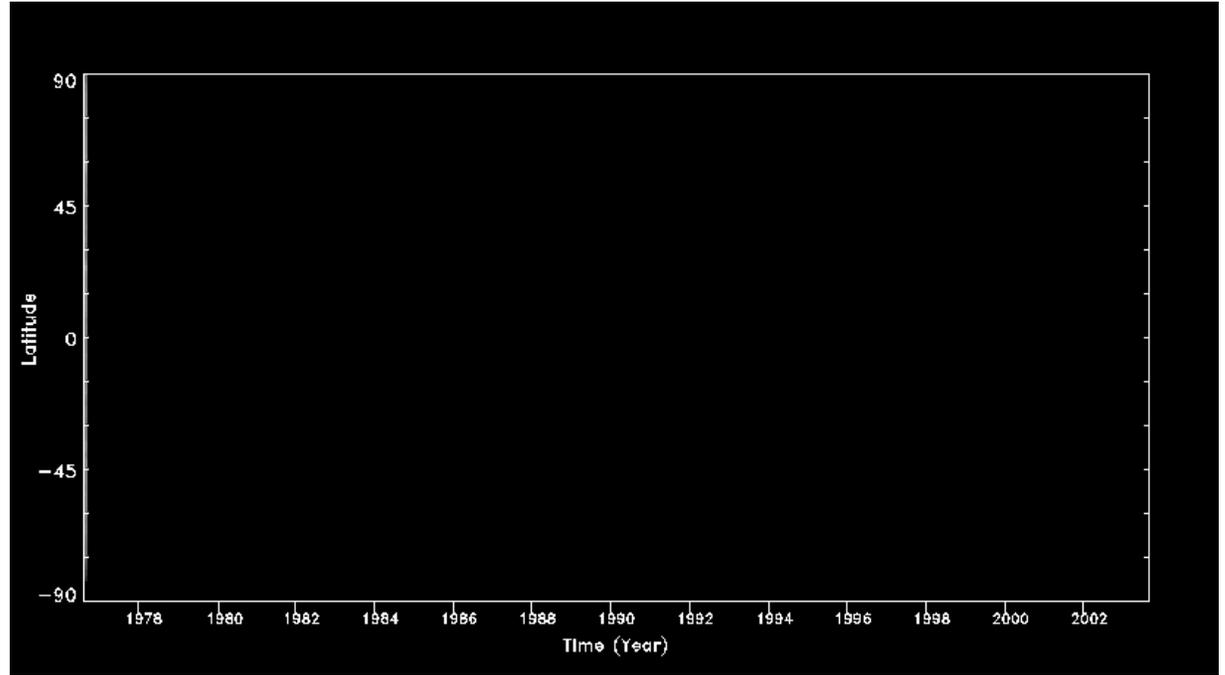
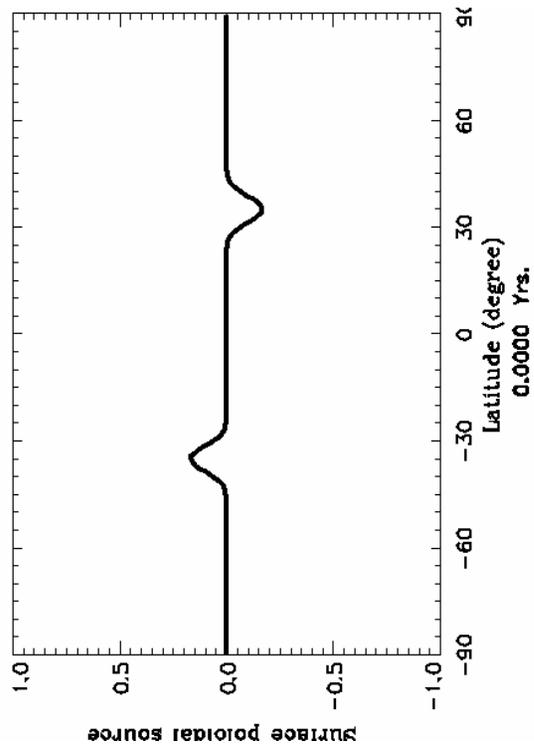


Construction of surface poloidal source

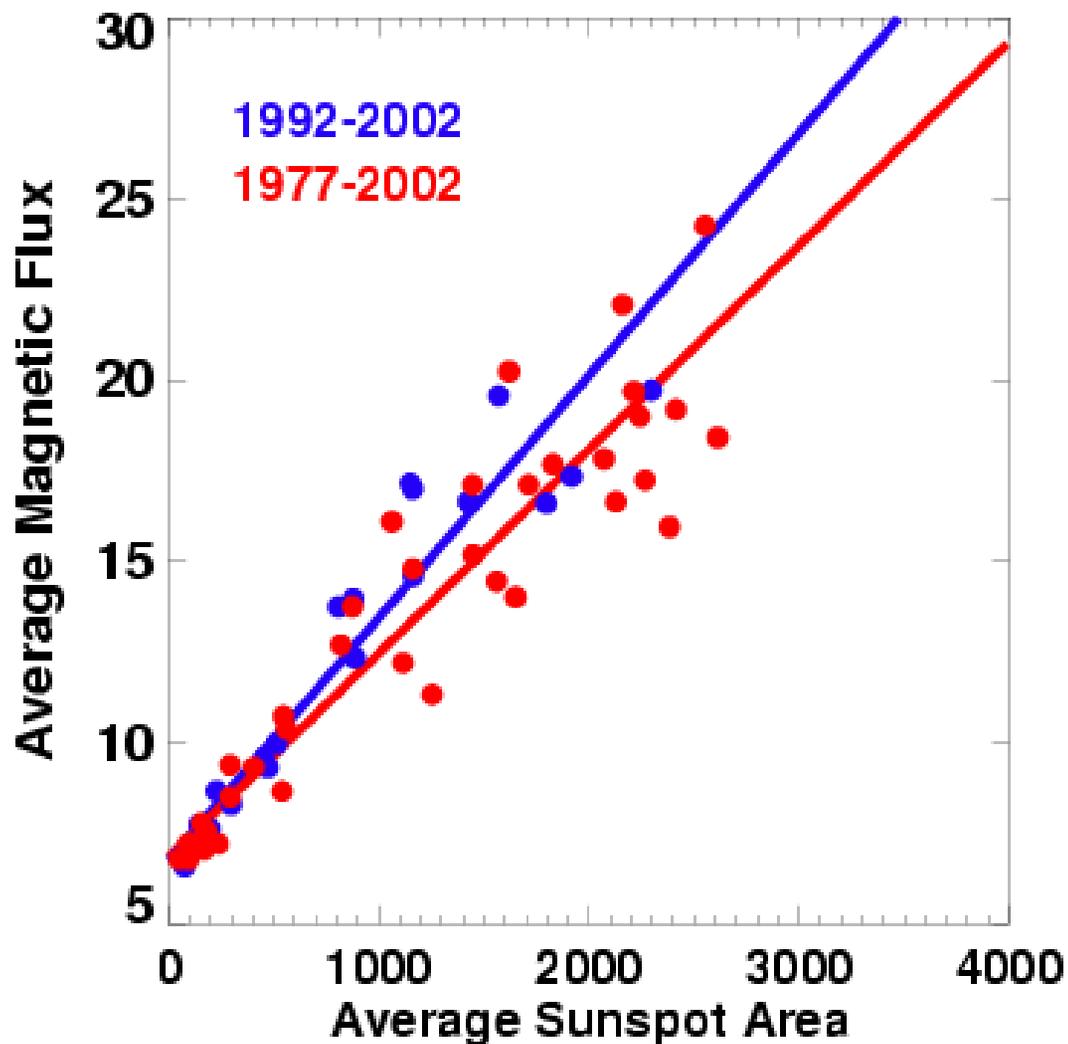


Time-variation of poloidal source function within a single sunspot-cycle
derived from observation

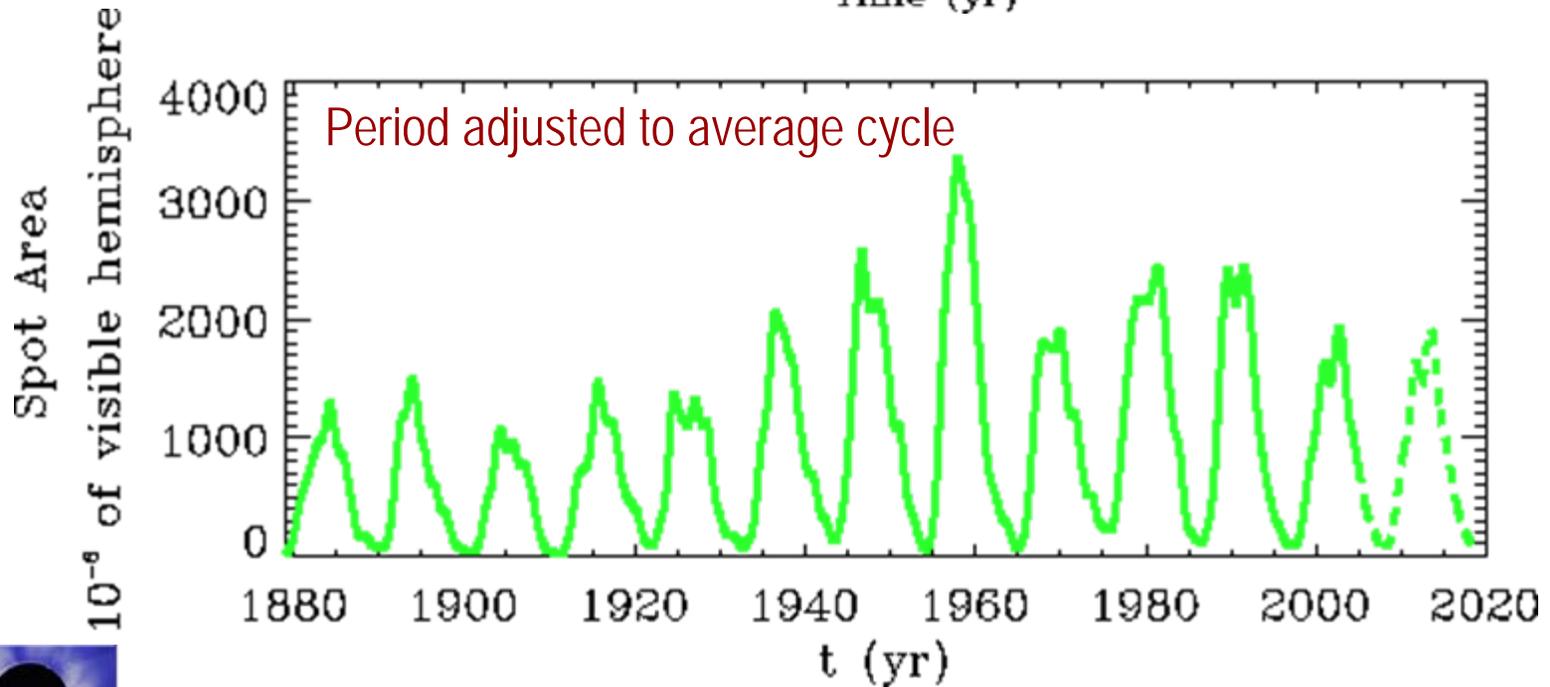
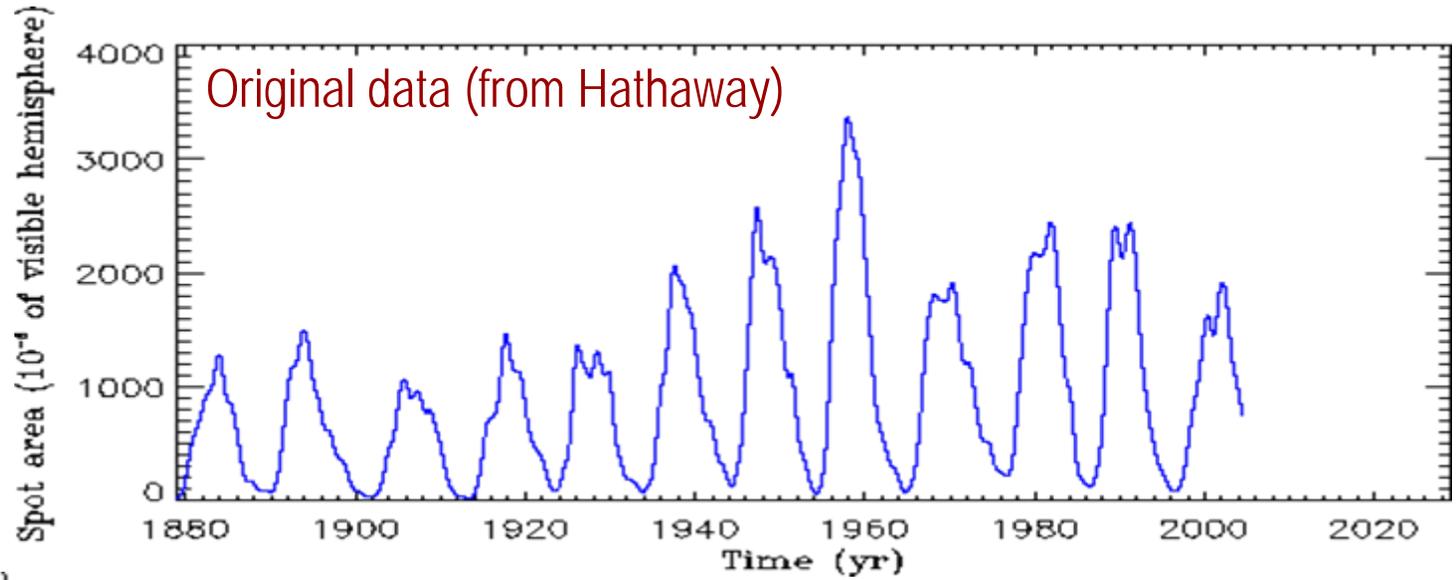
Construction of surface poloidal source



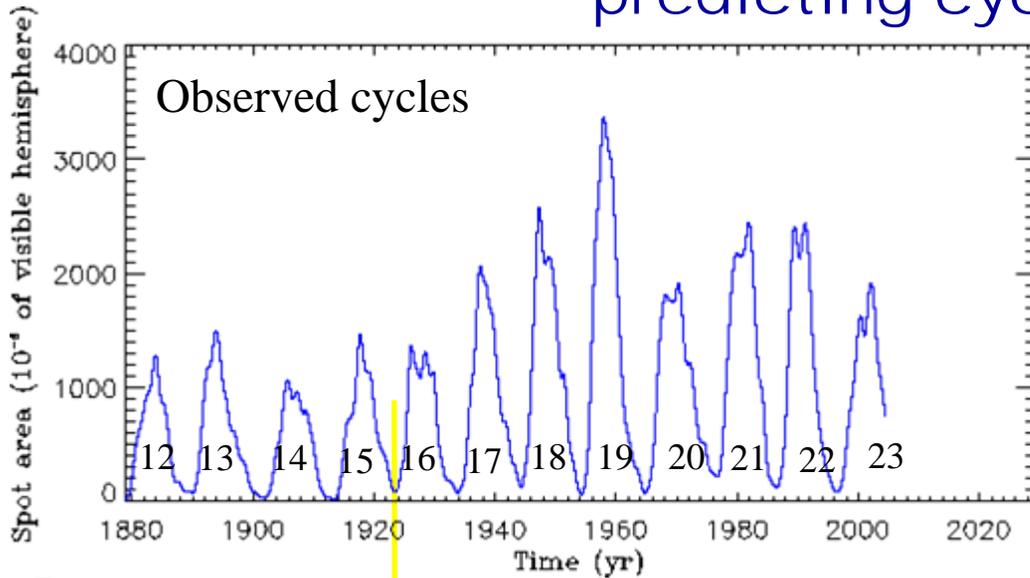
Correlation between photospheric flux and spot area



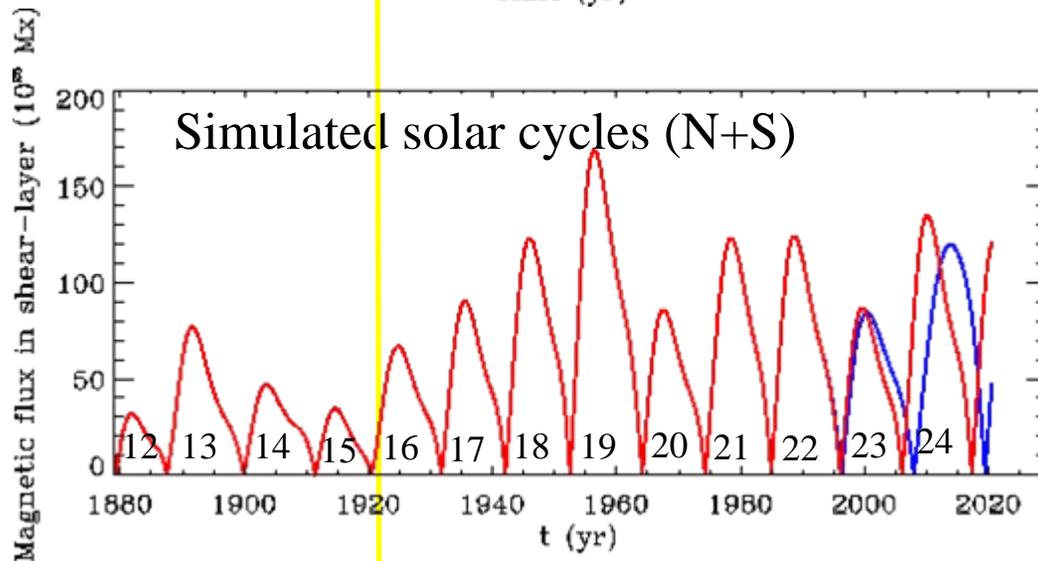
Construction of surface poloidal source (contd.)



Simulating sequence of cycles 12 through 23 and predicting cycle 24

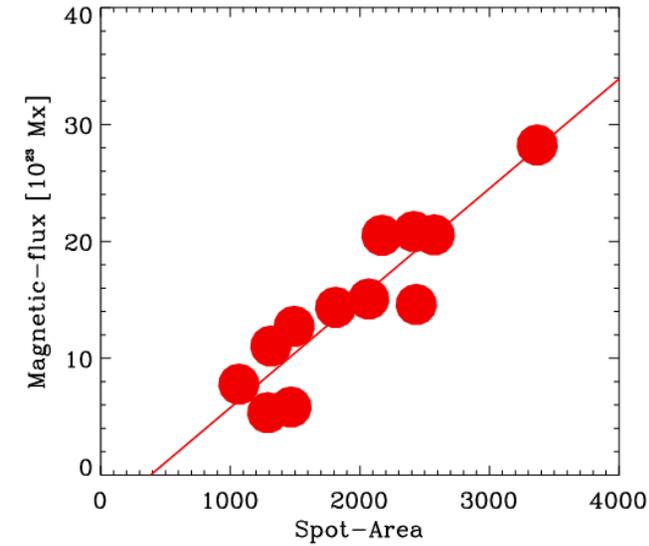


□ Dynamo correctly predicts sequence of relative cycle peaks for cycles 16 through 23; cycles 12-15 are used to build the Sun's memory of its magnetic field

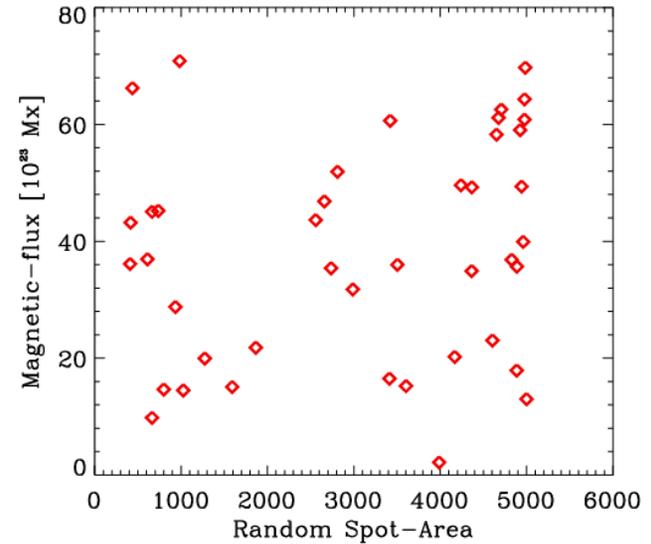


□ Based on successful simulation of past cycle peaks, we predict that the peak amplitude of cycle 24 will be 1.2-1.5 times stronger than cycle 23

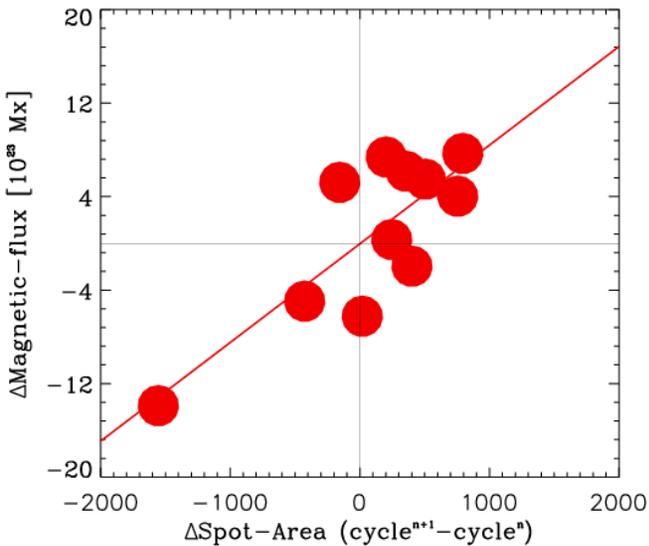
Correlation of observed and predicted cycle peaks



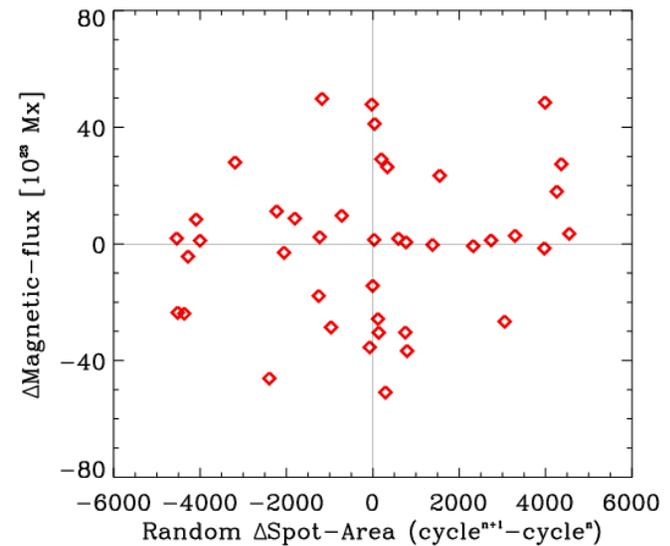
Left column: Observed cycle peaks derived from spot-area statistics; predicted cycle peaks from dynamo-generated toroidal magnetic flux at the base of the convection zone



Right column: cycle peaks predicted from random sunspot area peaks, showing no predictive skill



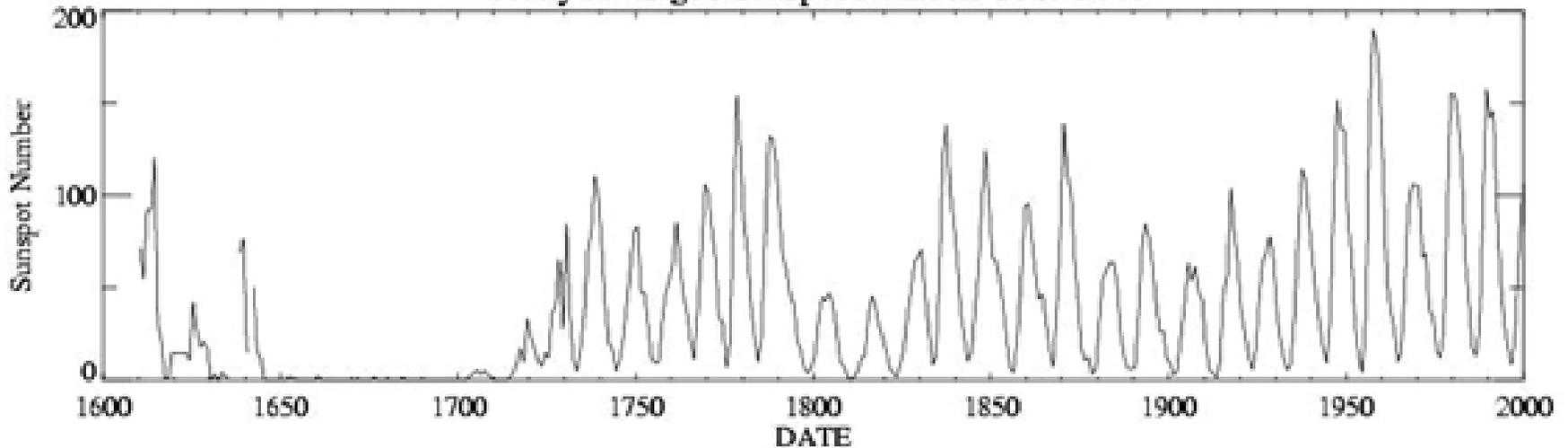
Lower frames show correlation of differences between consecutive cycles



Can we go beyond decadal time-scale?

Can we predict Maunder minima or Medieval maxima?

Yearly Averaged Sunspot Numbers 1610-2000



**Maunder minimum is the absence of sunspots,
but not the absence of cycle**

Summary

- ❑ Flux-transport dynamo driven by observed surface poloidal source shows definite skill in reproducing sequence of cycle peaks from previous cycles
- ❑ Based on that result, we predict that the average amplitude of cycle 24 will be 1.2-1.5 times stronger than cycle 23
- ❑ We also showed that a randomized surface poloidal source leads to no predictive skill
- ❑ The Future: separate predictions for N and S hemispheres; predictions for cycles earlier than 12 from earlier sunspot data; reconstructing the rise and fall pattern of individual cycles; incorporating estimates of variable meridional circulation speed; building deterministic model for simulating Maunder minima

PROSPECTS

- Core part of the code for dynamo simulation is small (~10,000 lines)
- Involves semi-implicit scheme; fast, easy to understand
- It is already being used by Evergreen College, and by Monash University solar physics group
- Can be used for studying the large-scale coronal magnetic structure in conjunction with cyclic interior magnetic fields