Predicting the Solar Cycle

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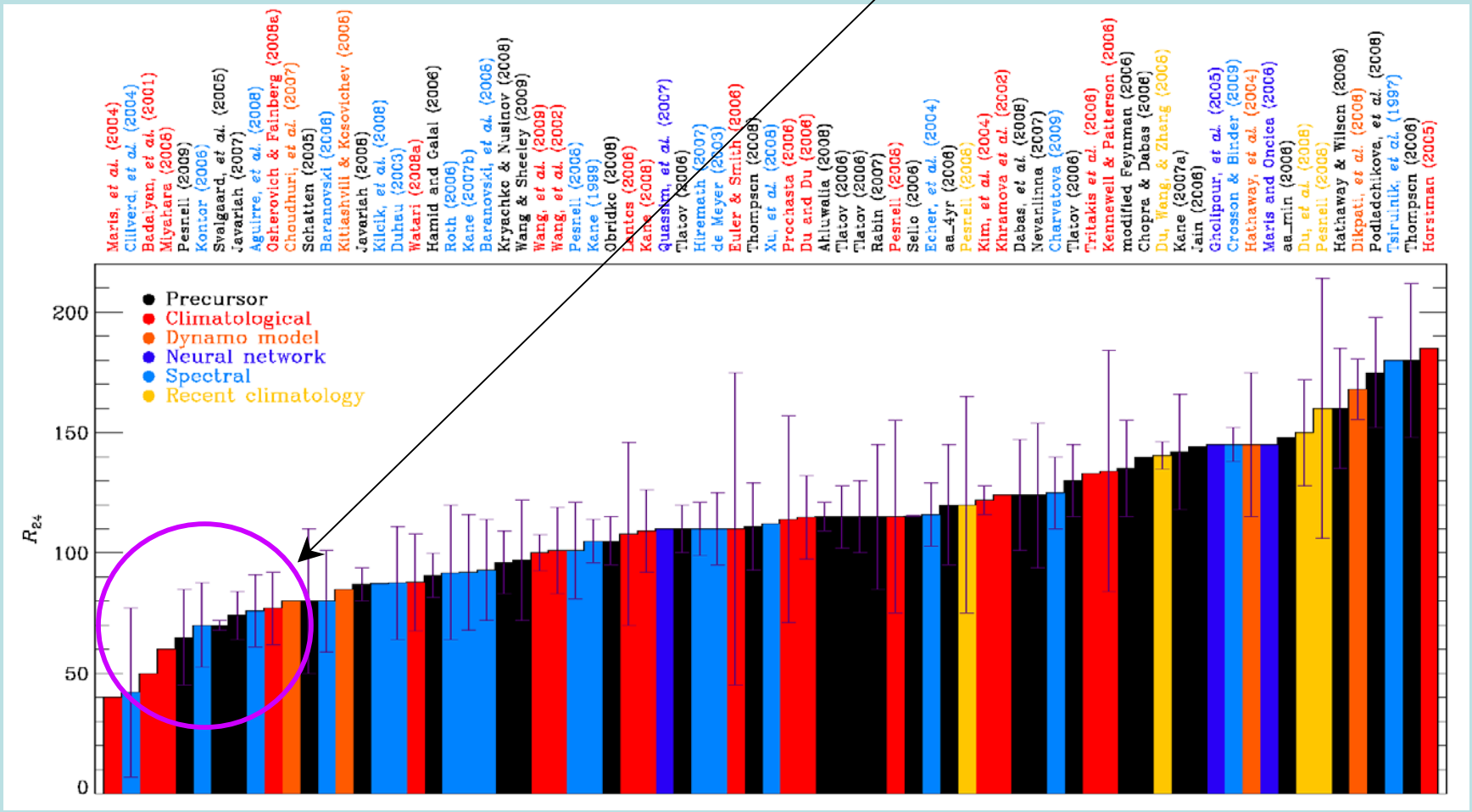
Stanford University

SORCE 2010
Keystone, CO, May 20, 2010

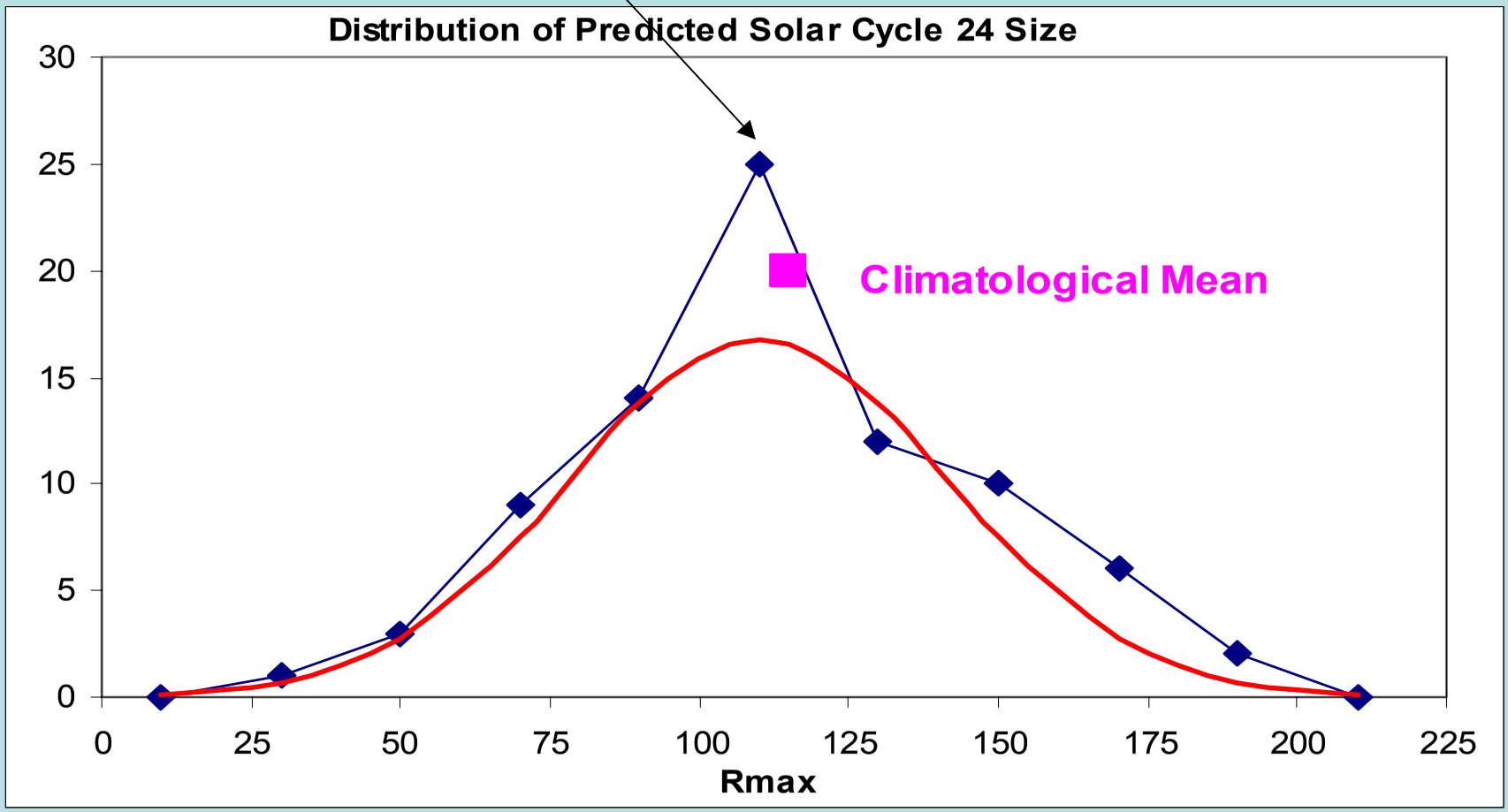
State of the Art: Predicting Cycle 24

What the Sun seems to be doing



Near Normal Distribution = No Skill?

Some preference for Climatological Mean



Flux Transport Dynamo Models

- Dikpati, M., de Toma, G., Gilman, P.A.: Predicting the strength of solar cycle 24 using a flux-transport dynamo-based tool, Geophys. Res. Lett., 33, L05102, 2006.

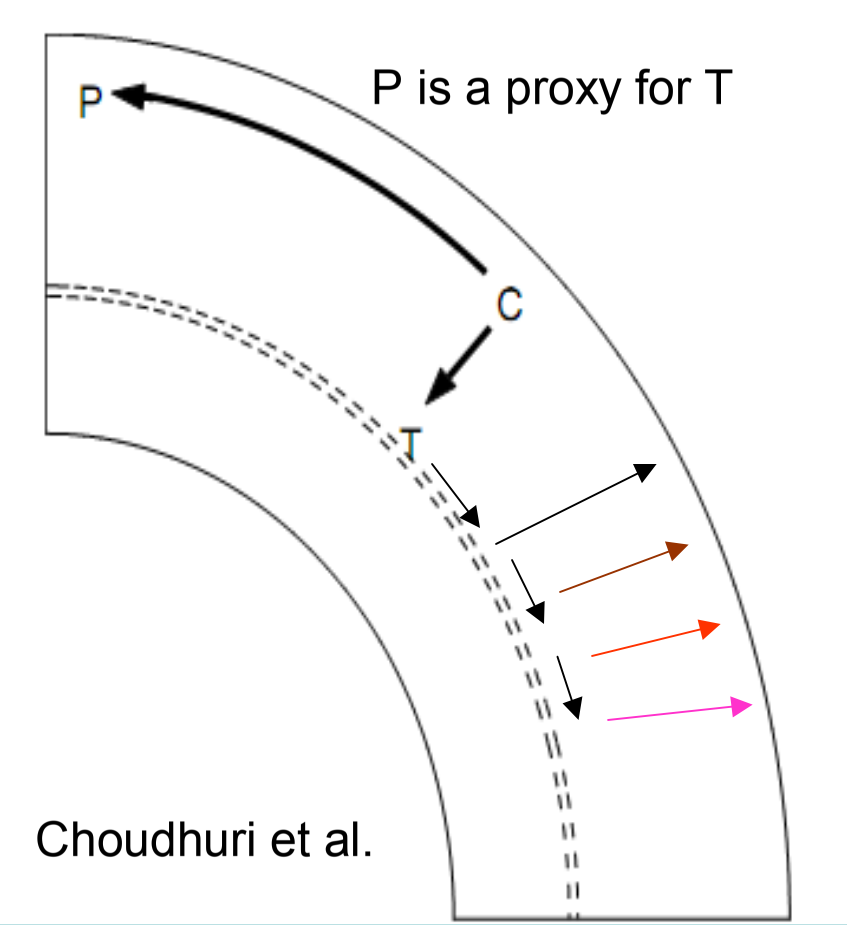
$Rmax_{24}$ = 160-185

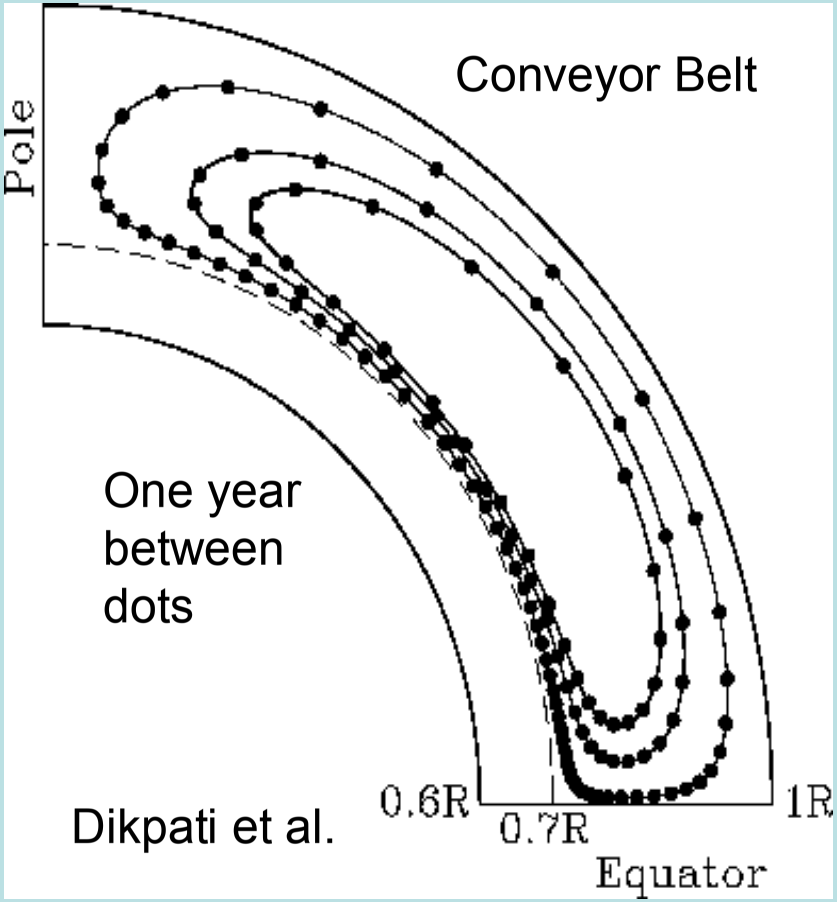
- Choudhuri, A.R., Chatterjee, P., Jiang, J.: Predicting Solar Cycle 24 with a solar dynamo model, Phys. Rev. Lett., 98, 131103, 2007.

$Rmax_{24}$ = 75

- Difference is primarily due to different assumptions about the diffusivity of magnetic flux into the Sun [high = weak cycle]

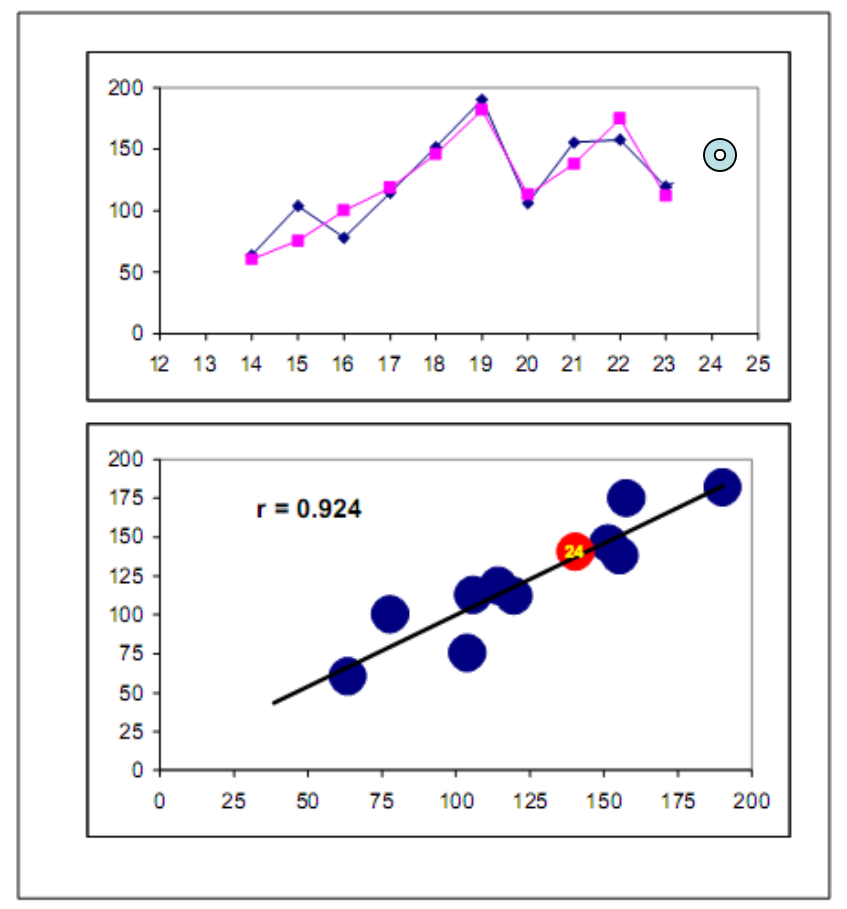
High Diffusivity: Left
Low Diffusivity (Advection): Right



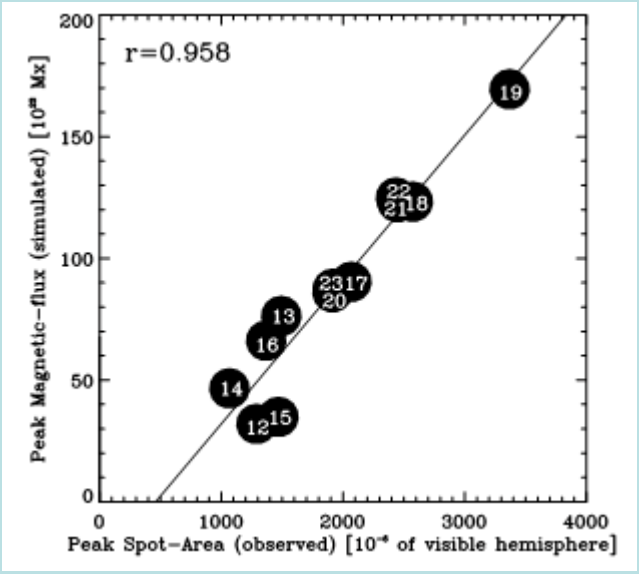


Grow-N-Crash 'Model'

Easy to get a high correlation



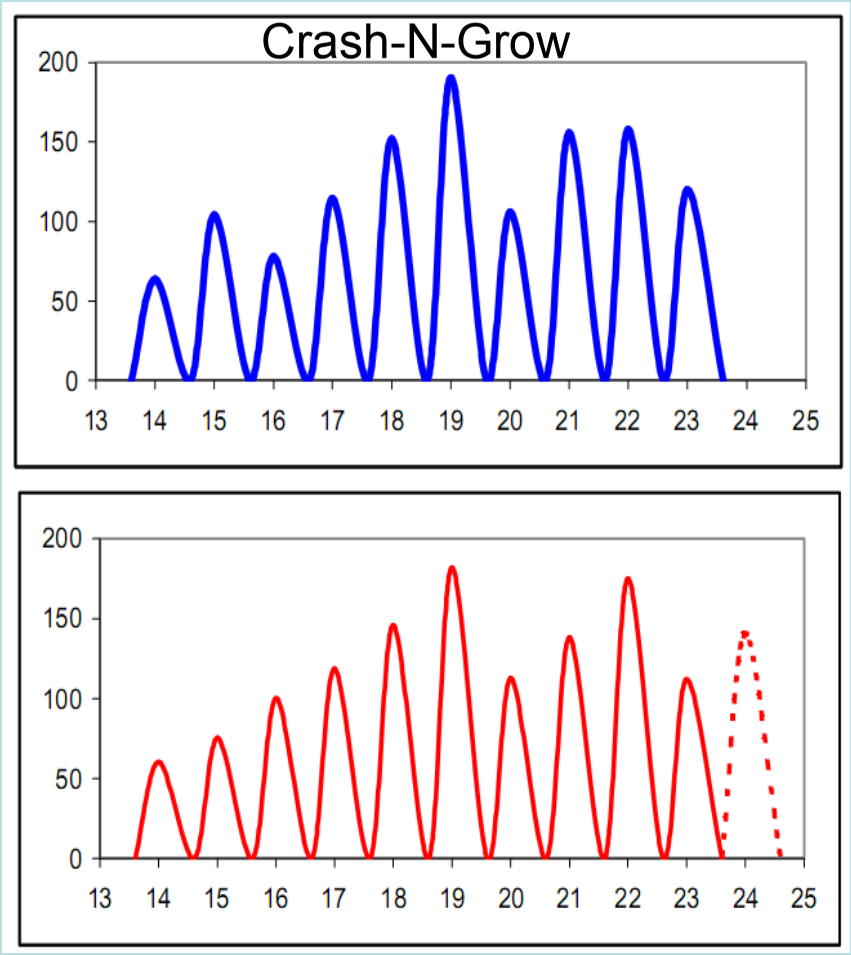
Dikpati et al. 2006

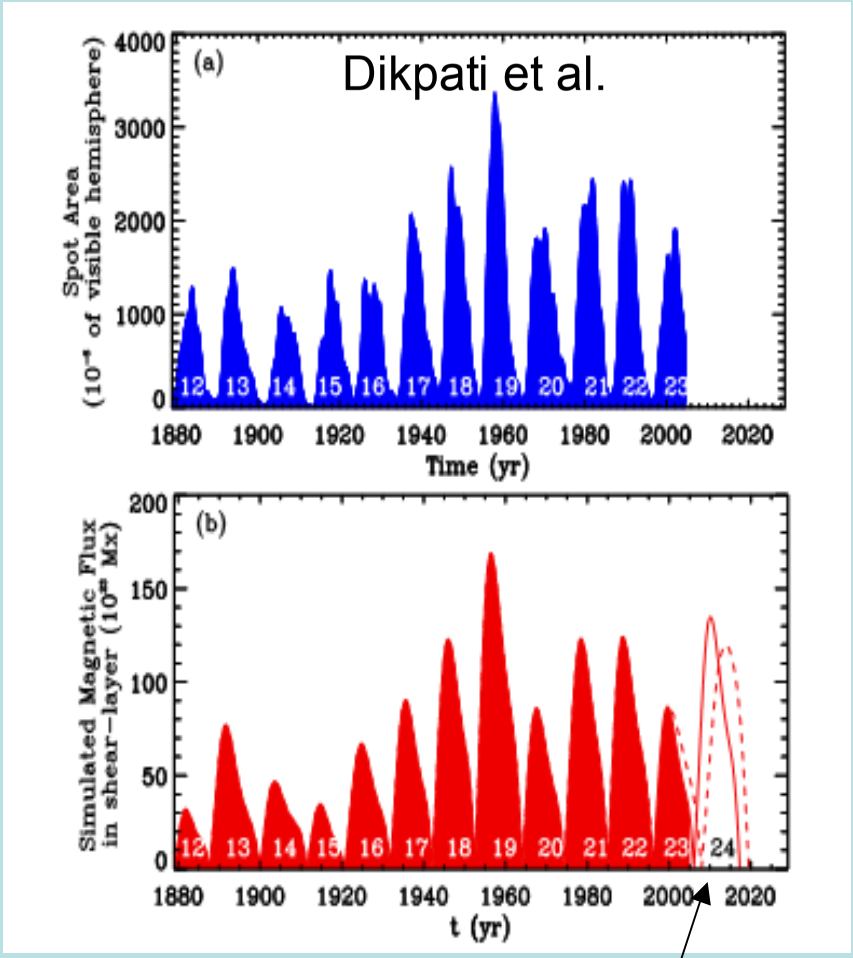



```
    COMPUTE ALPHA = 0.238
    COMPUTE R-TOP = 200

PREDICT-CYCLE.
    COMPUTE P-NBR = C-NBR - 1
    COMPUTE R-ADD         = R-OBS(P-NBR) * ALPHA
    COMPUTE R-PRE(C-NBR) = R-PRE(P-NBR) + R-ADD
    IF R-PRE(C-NBR) > R-TOP
        COMPUTE R-ADJ = (R-OBS(P-NBR) ** 0.5) * 5
        COMPUTE R-PRE(C-NBR) = R-PRE(C-NBR) - R-ADJ - R-ADD
    .
```

Supply a Scaled Standard Cycle Body to get 'Stunning' Correlation





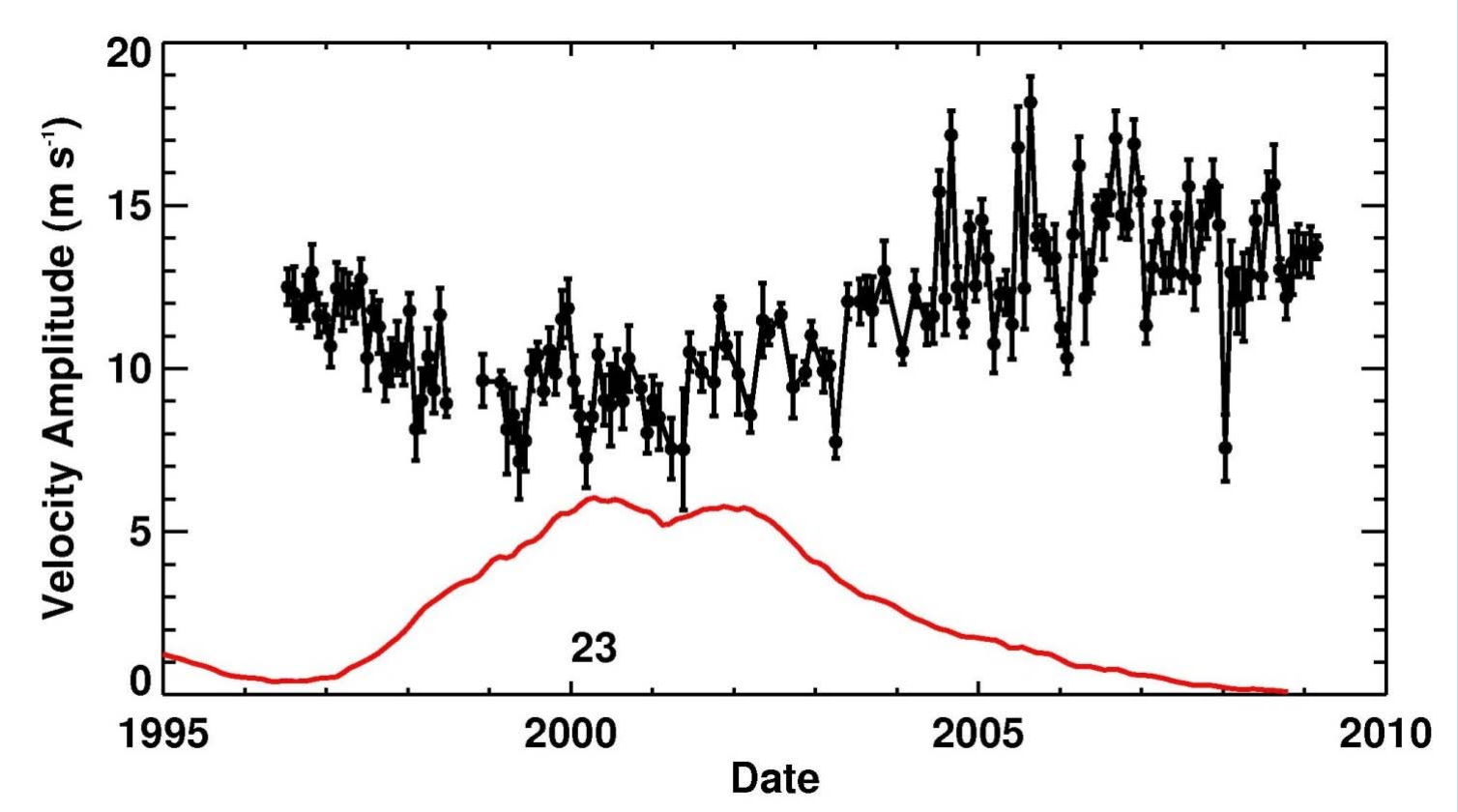
Dikpati et al. assumed constant Meridional Circulation, except for cycle 24

Meridional Circulation

Both (Dikpati, Choudhuri) of these Flux Transport Dynamo Models produce strong polar fields and short cycles when the meridional flow is fast.

However: “Measurements of the meridional flow over Cycle 23 now show that on the approach to Cycle 24 minimum in 2008 to speeds significantly higher than were seen at the previous minimum (David Hathaway, SOHO-23)”

Meridional Circulation



Lisa Rightmire, David Hathaway (2009):
Cross-correlating full-disk magnetograms

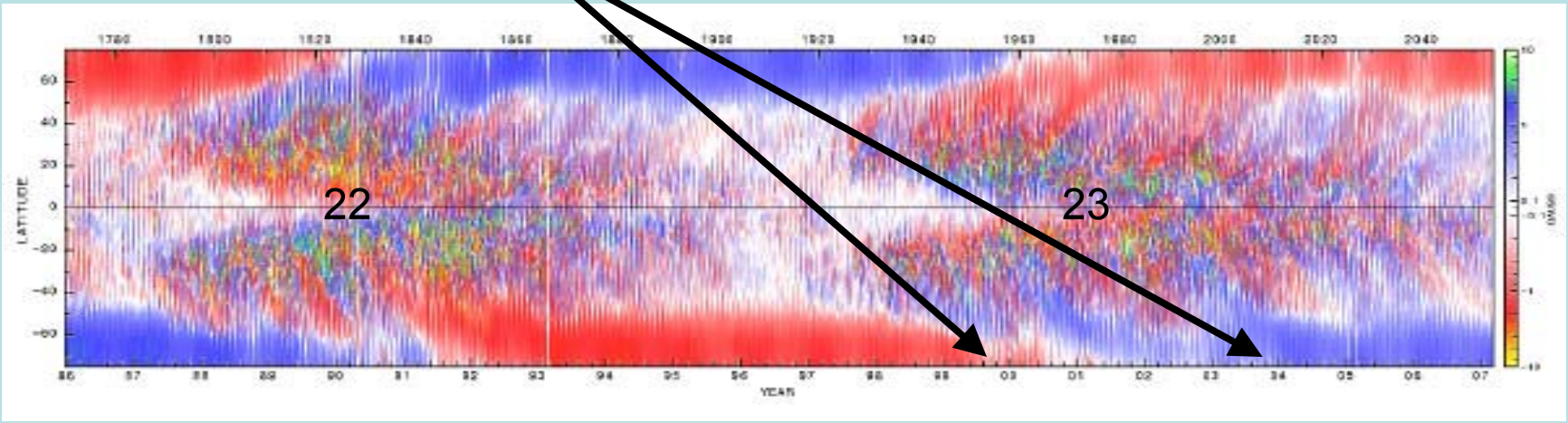
'Flux Transport Models Not Ready Yet'

- "In these models this higher meridional flow speed should produce strong polar fields and a short solar cycle contrary to the observed behavior.
- "These observations, along with others, suggest that Flux Transport Dynamo Models do not properly capture solar cycle behavior and are not yet ready to provide predictions of solar cycle behavior.

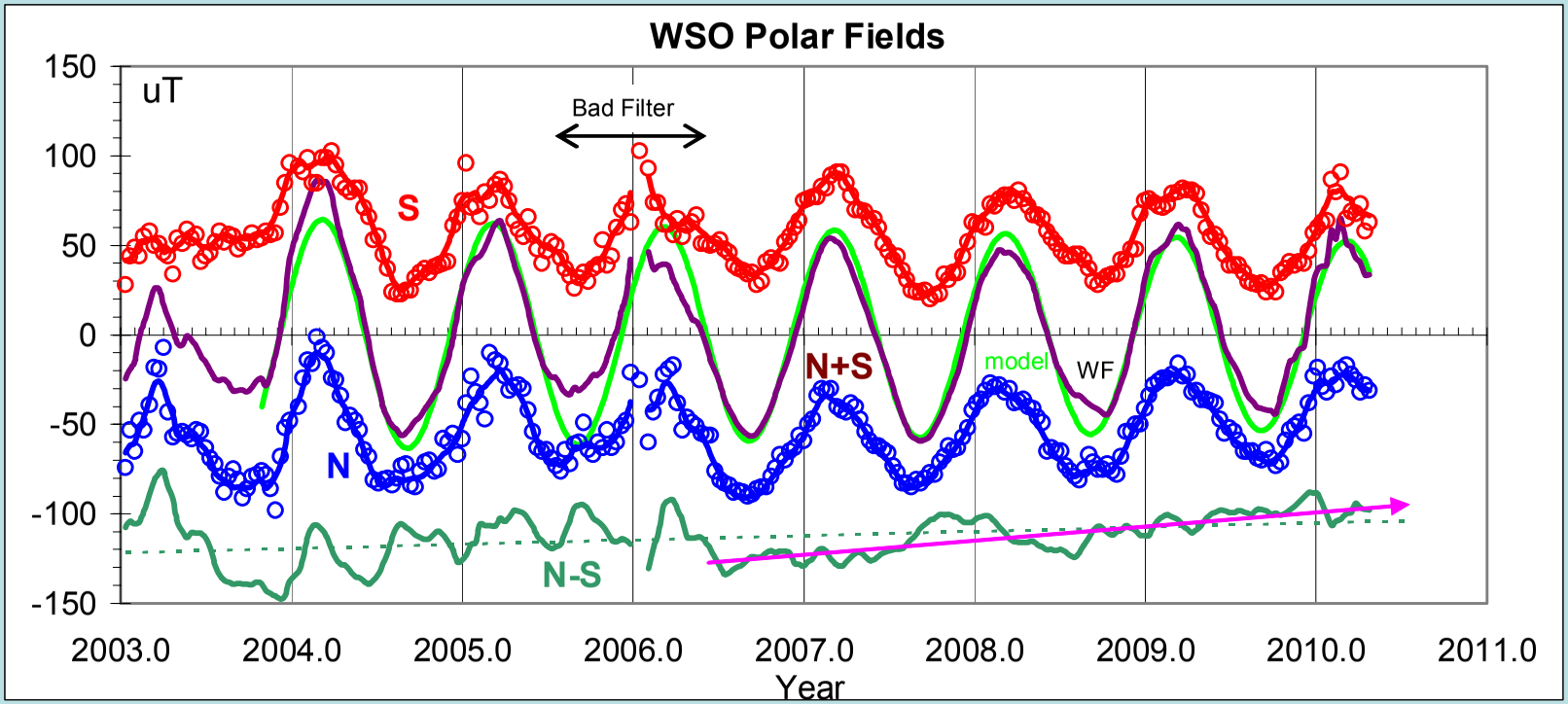
Hathaway, 2009

Is This Too Harsh?

- The polar fields were built several years ago *before* the increase in the Meridional circulation [the polar fields were essentially established by mid-2003]



And Have Not Increased Since Then, rather Beginning to Show the expected Decrease due to New Cycle Activity



Issues with Meridional Circulation

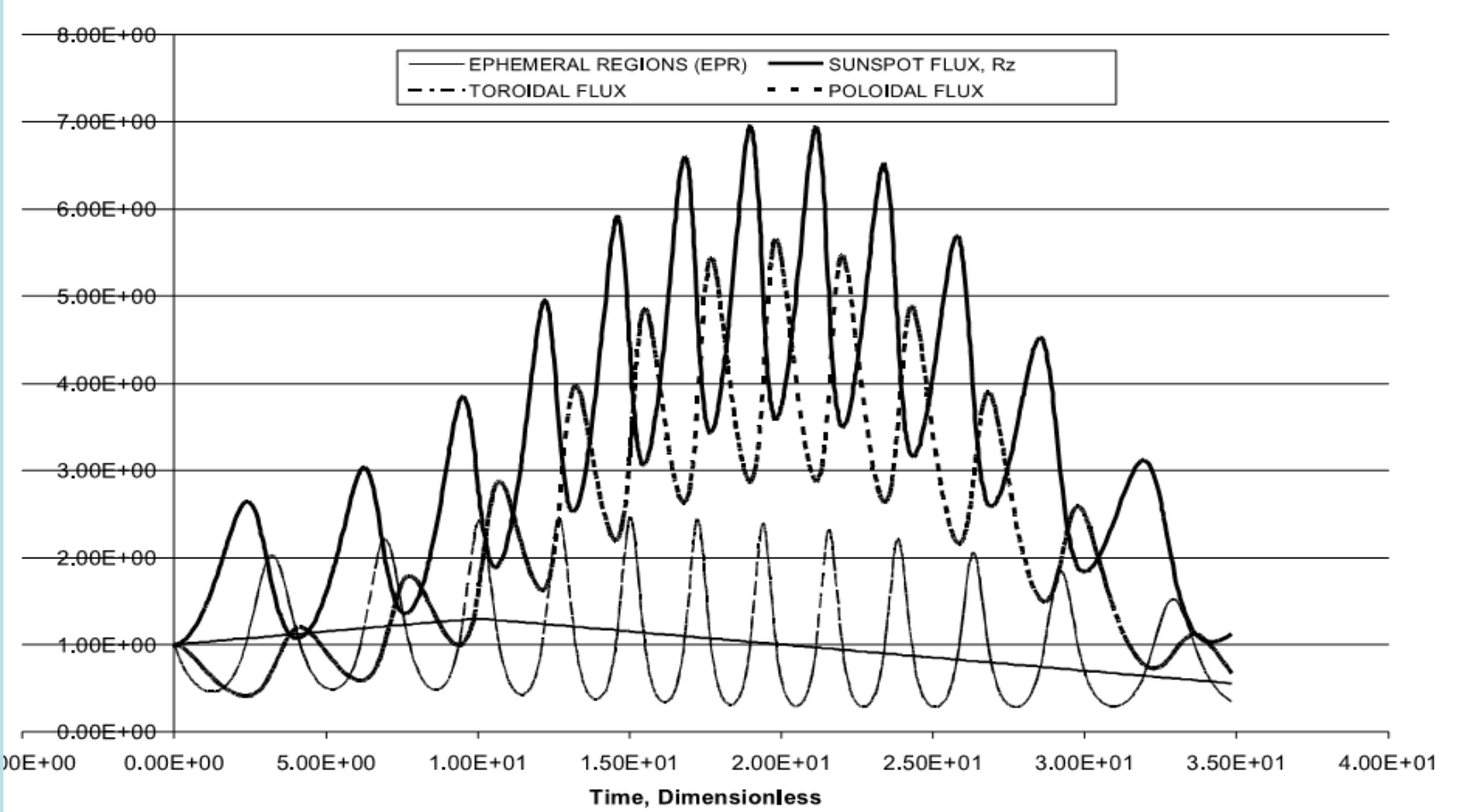
- The question is not whether the M.C. is there or not (multiple cells?), but rather what role it plays in the solar cycle, probably hinging on the value of the turbulent diffusivity.
- An unknown is the degree to which M.C. is affected by back-reaction from the Lorentz force associated with the dynamo-generated magnetic field (chicken and egg).
- The form and speed of the equatorward return flow in the lower convective zone is at present unknown (possibly SDO/HMI will tell us).

Perhaps a Shallow Dynamo?

Ken Schatten [*Solar Physics, **255**, 3-38, 2009*] explores the possibility of sunspots being a *surface* phenomenon [being the coalescence of smaller magnetic features as observations seem to indicate] and that the solar dynamo is shallow rather than operating at the tachocline, based on his Cellular Automata model of solar activity.

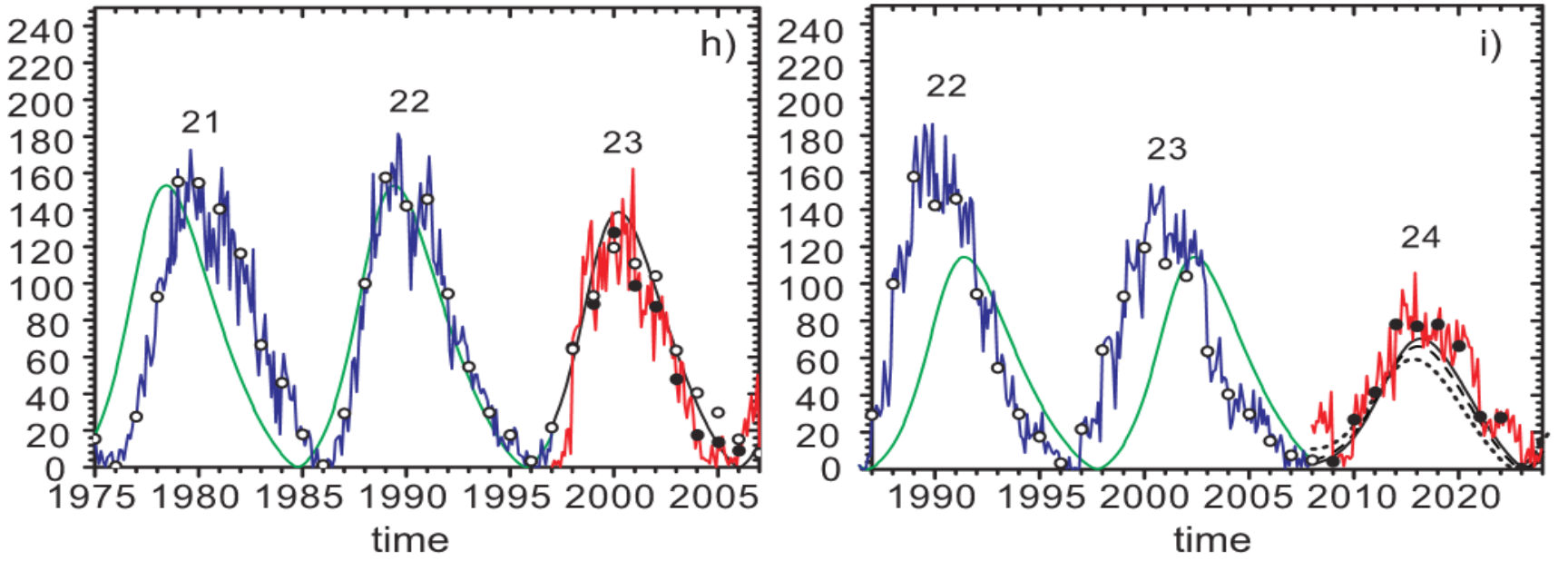
See poster

In his Model, the Polar Flux also Predicts the Sunspot Flux



Other Dynamo Models

The Ensemble Kalman Filter (EnKF) method has been used to assimilate the sunspot number data into a non-linear α-Ω mean-field dynamo model, which takes into account the dynamics of turbulent magnetic helicity.



Kitiashvili, 2009

Back to Empirical Predictions?

With predictions based on Flux Transport Dynamos in doubt or less enthusiastically embraced (and the Shallow Dynamo and the EnKF approach not generally pursued) we may be forced back to Precursor Techniques where some observed features are thought to presage future activity.

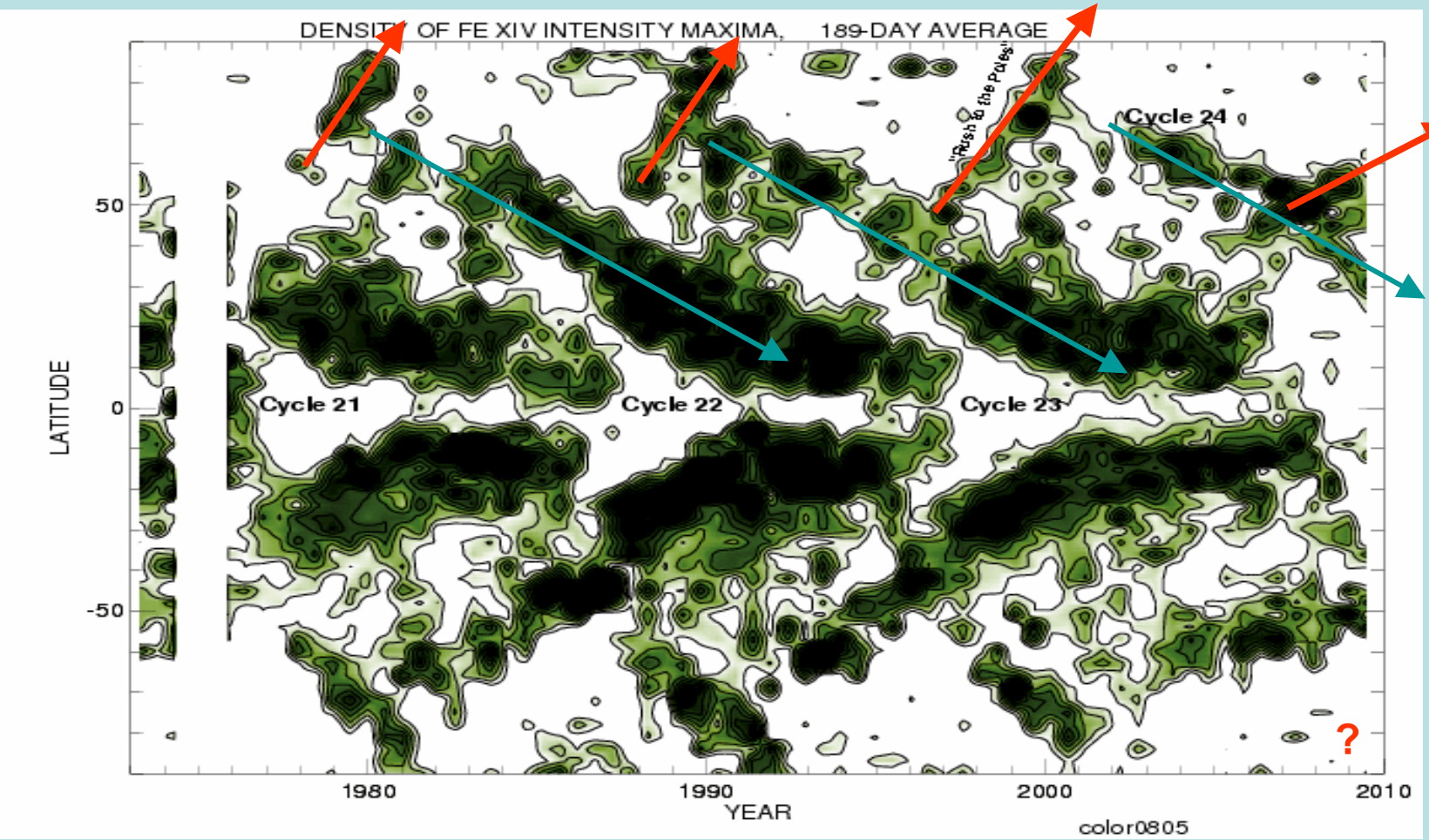
Precursors

- Coronal Structure [Rush to the Poles]
- Torsional Oscillation [At Depth]
- H-alpha Maps [Magnetic Field Proxy]
- Geomagnetic Activity [Solar Wind Proxies]
- Open Flux at Minimum

And that old stand-by:

- Polar Fields

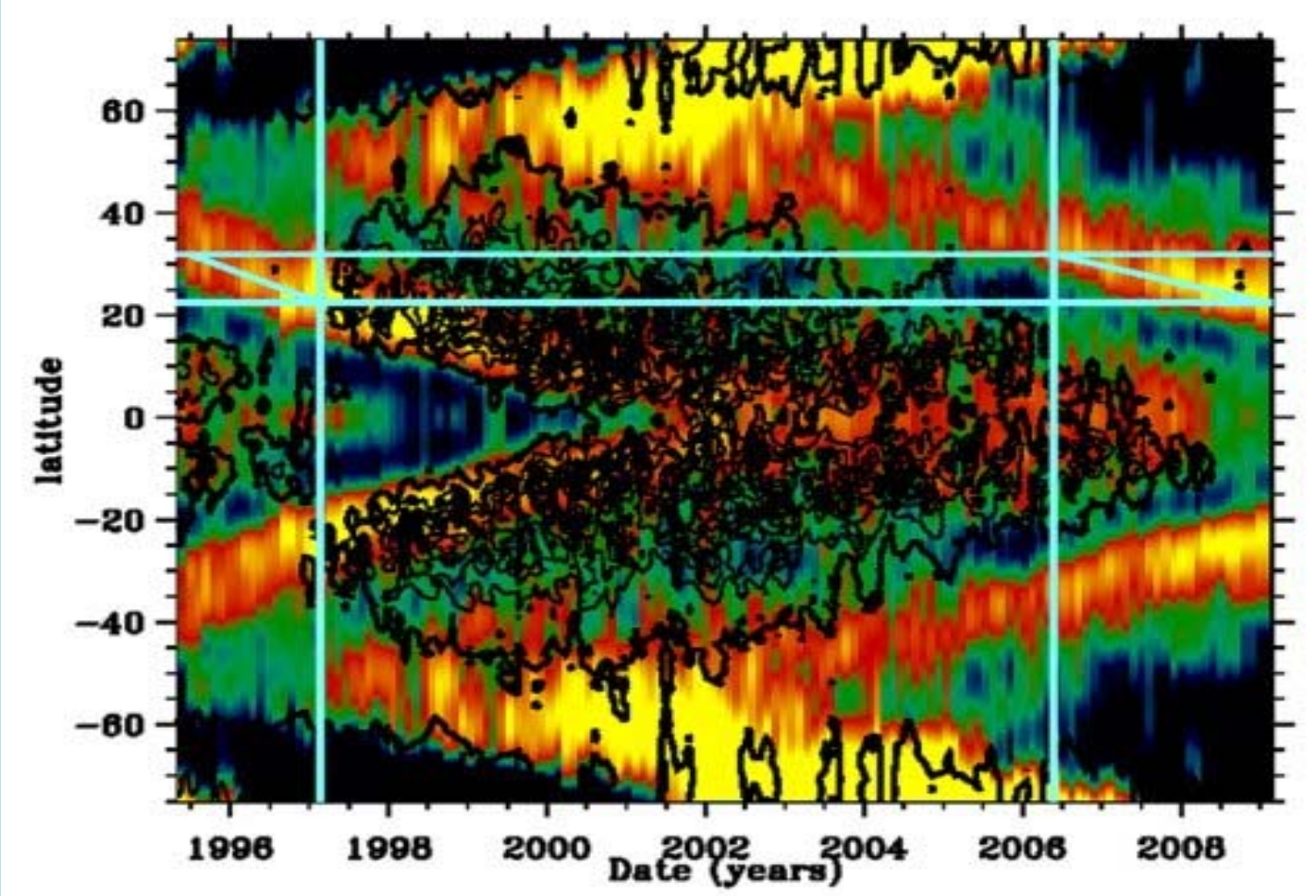
Green Corona Brightness to Determine Time of Maximum



Altrock, 2009

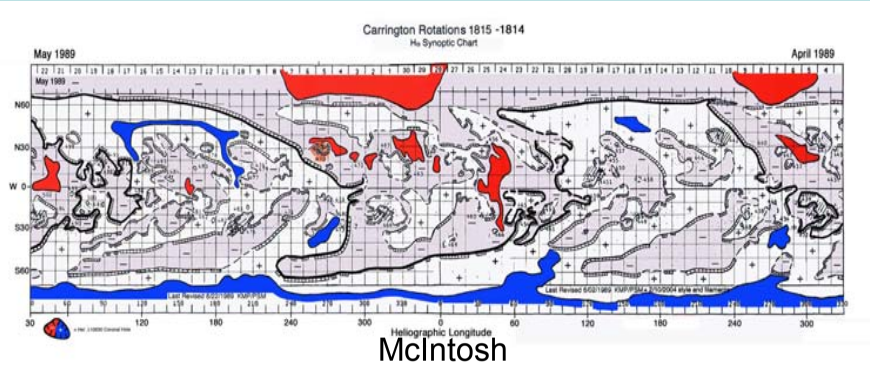
Torsional Oscillation Polar Branch

Where is it? (Chicken & Egg)



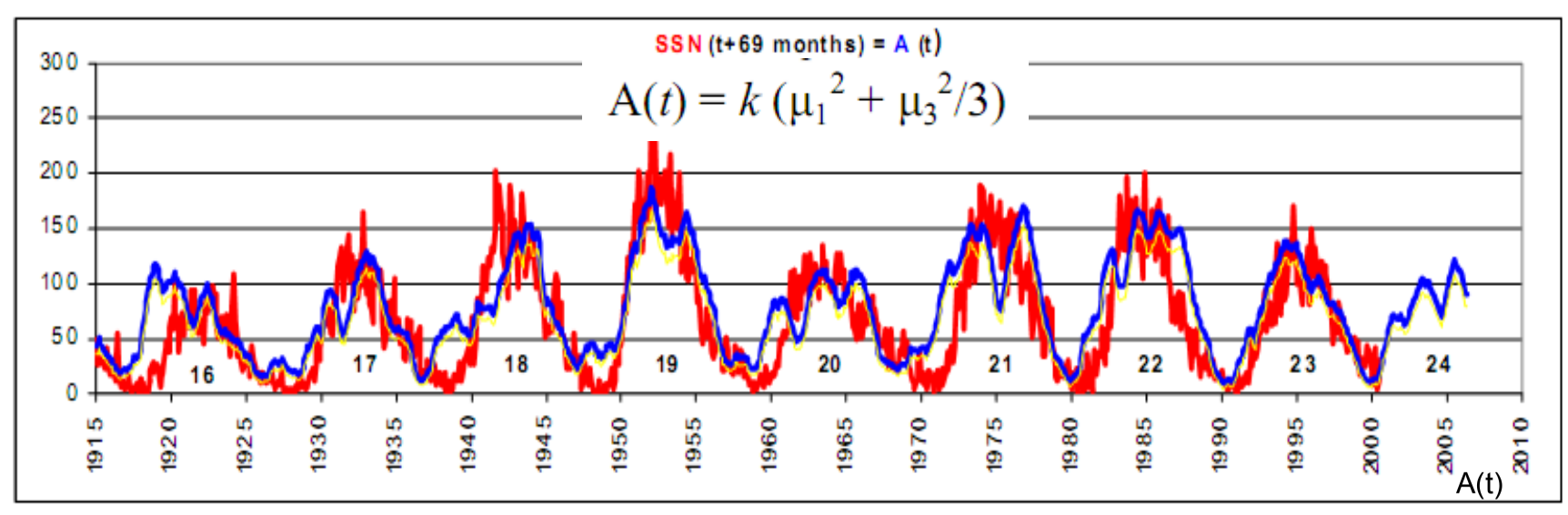
Howe, 2009

Large-Scale ‘Magnetic’ Field from Neutral Lines on Hα Maps



McIntosh

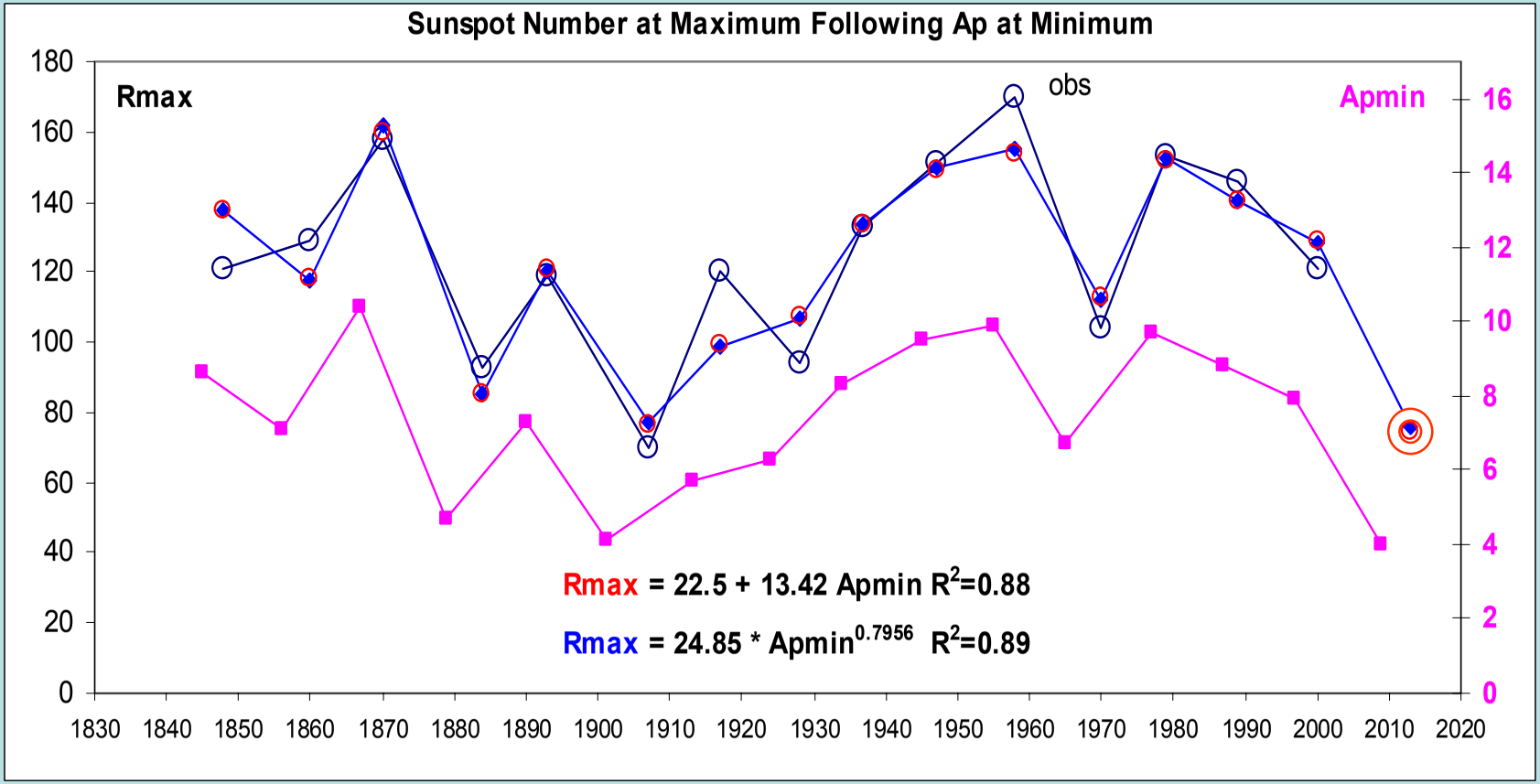
Assigning fields of +1 and -1 to areas between neutral lines, calculate the global dipole μ_1 and octupole μ_3 components. They predict the cycle 69 months ahead



Tlatov et al., 2006

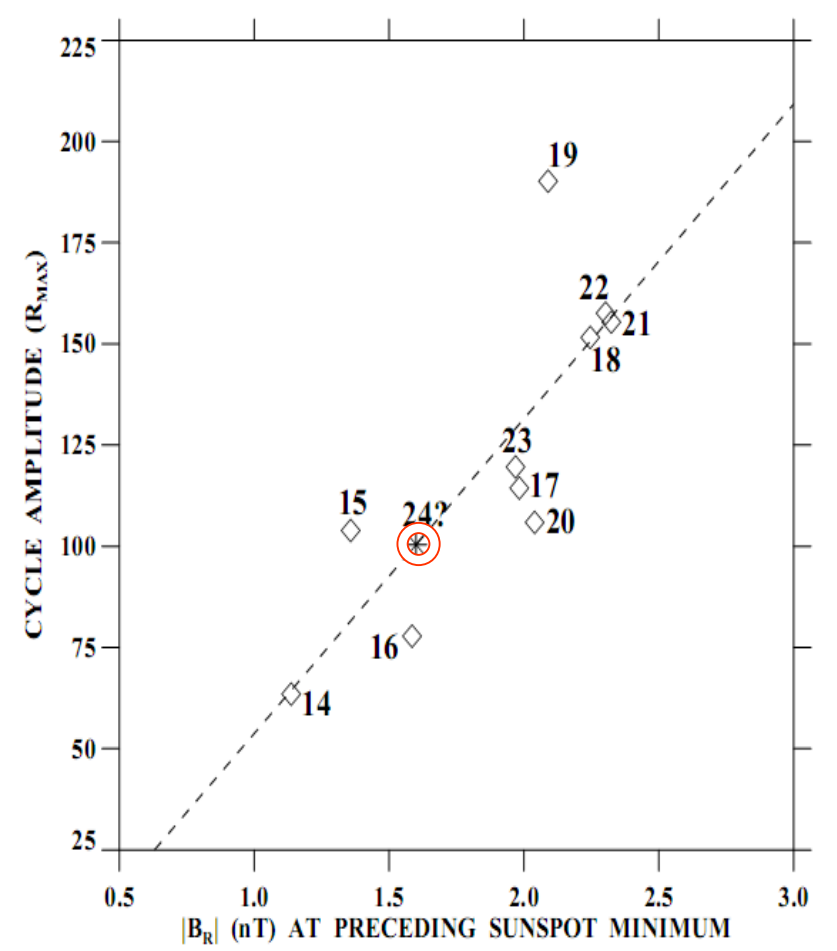
Geomagnetic Activity at Minimum

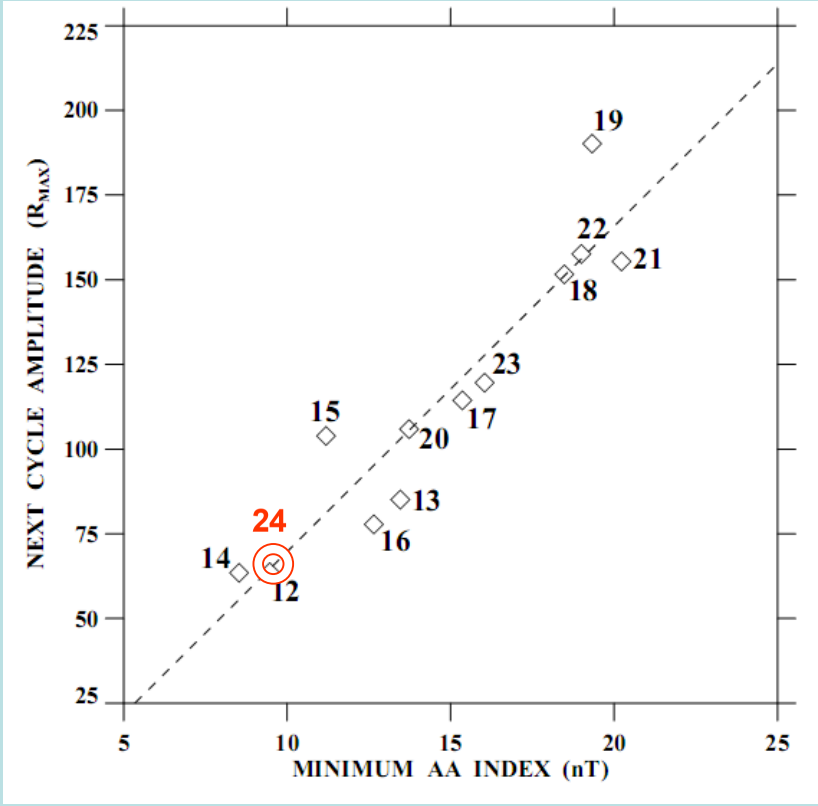
Polar Field Proxy?



Svalgaard, 2009

AA-index as Proxy for Open Heliospheric Magnetic Flux

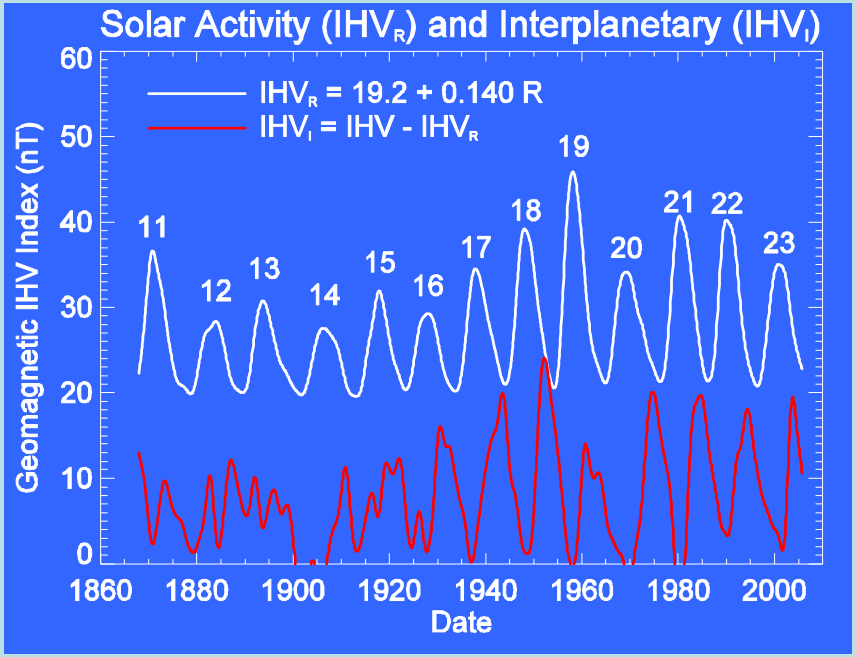


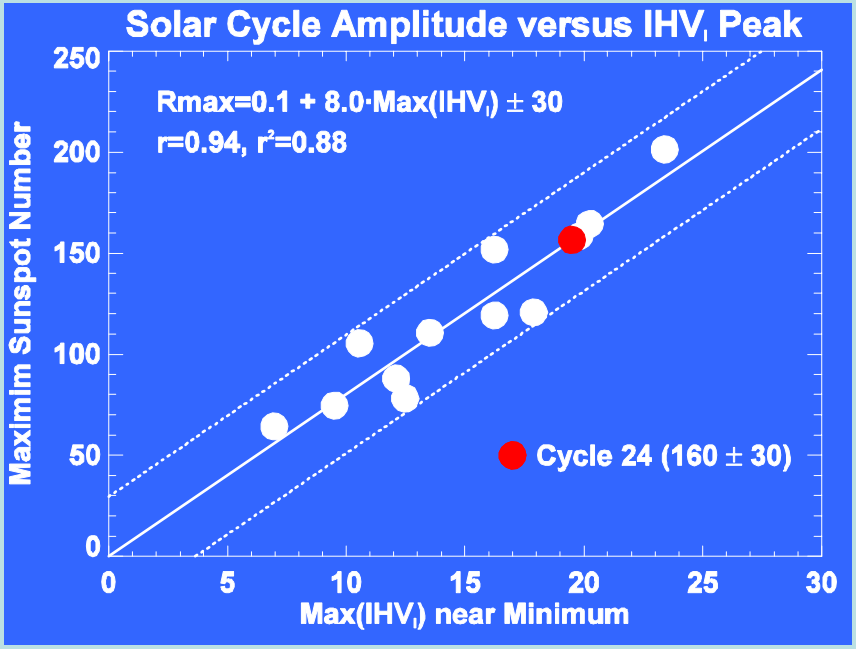


Min AA based on last 12 months

Wang & Sheeley, 2009

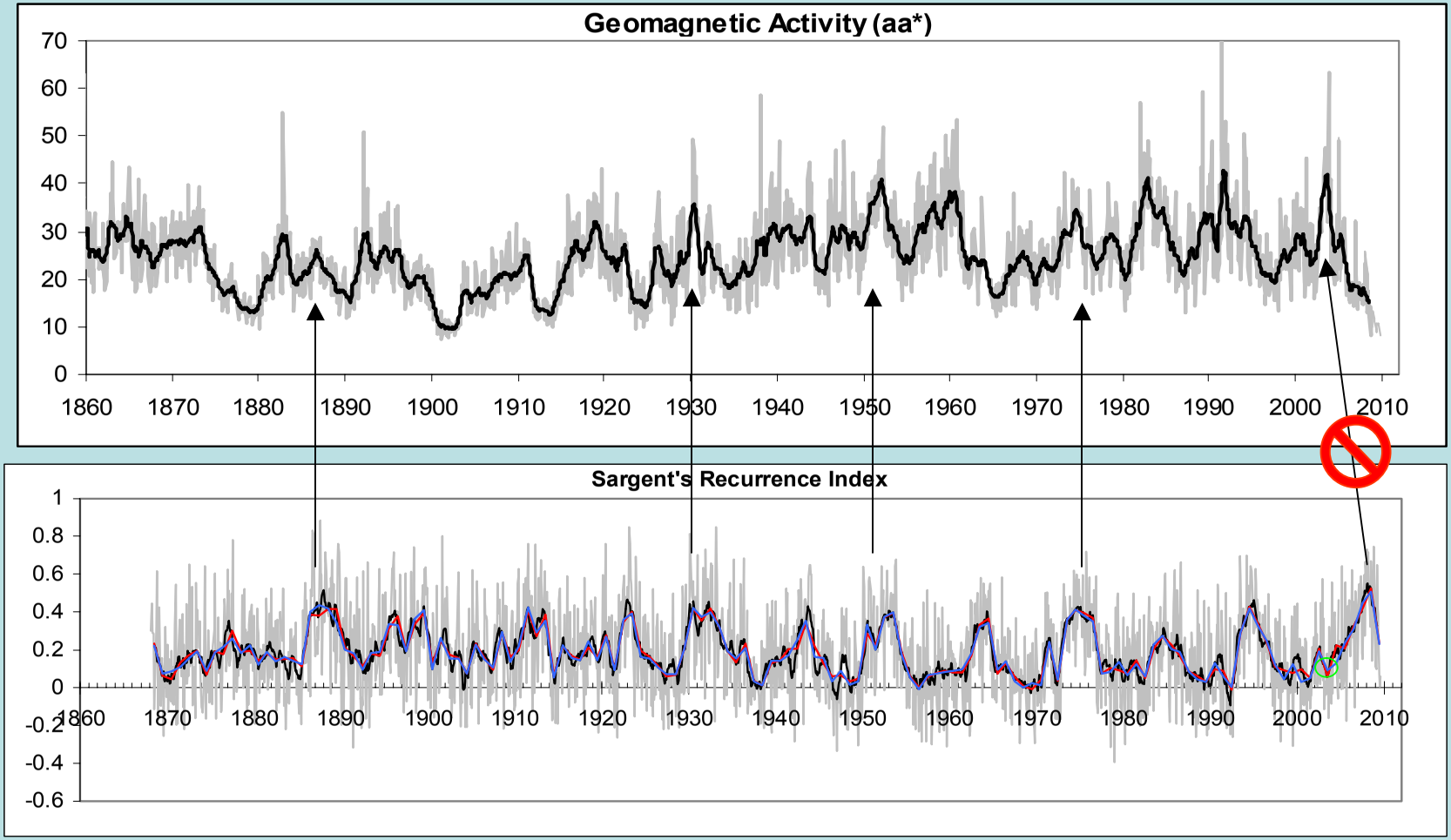
The Size of Recurrent Activity Peaks [Corrected for Sunspot Activity] has been used as a Precursor of the Next Cycle [Physics is Obscure Though]





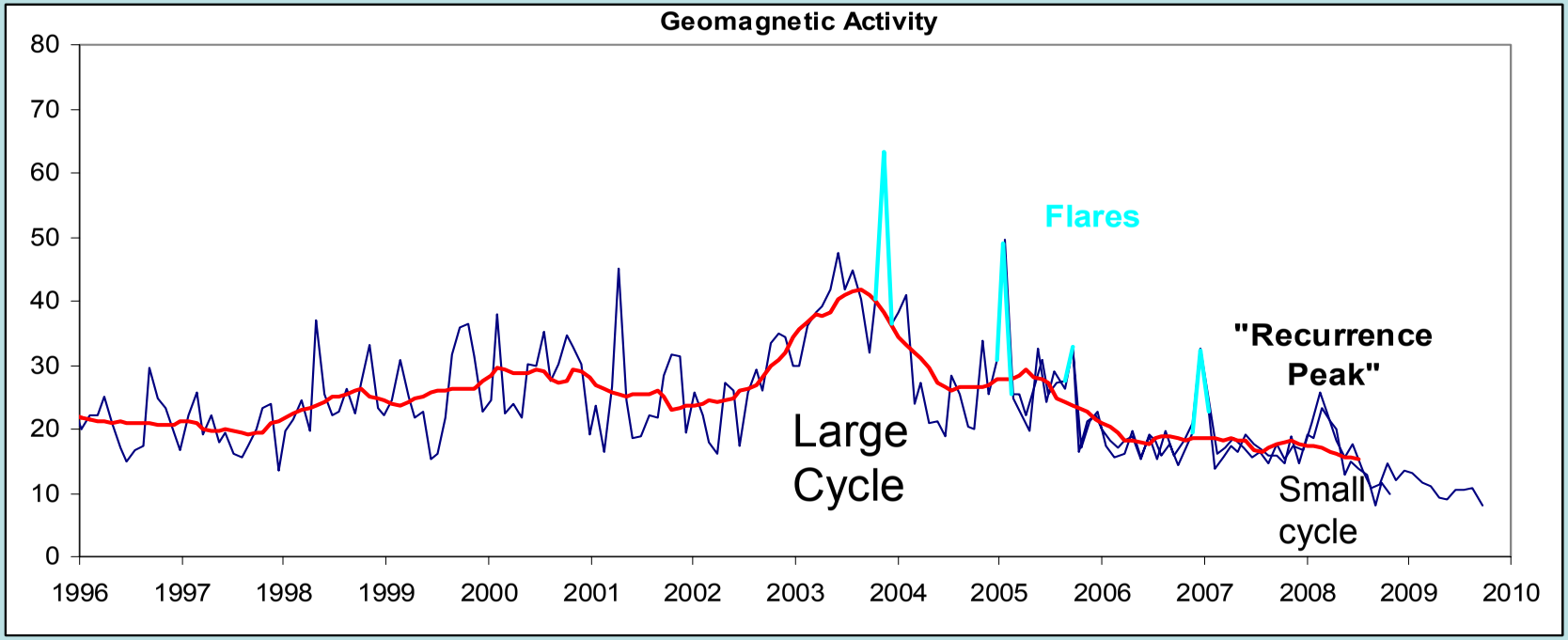
Hathaway et al.

Picking the Wrong Peak [From Filtered Data] Can Lead You Astray

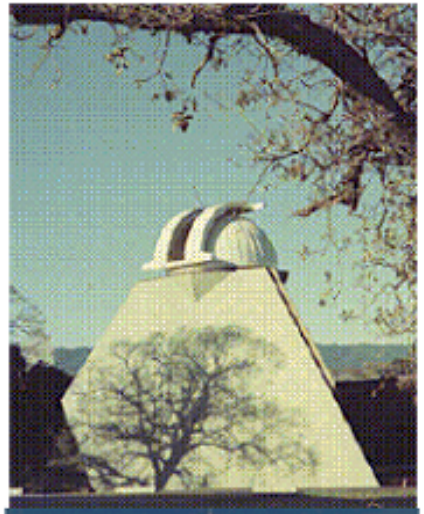


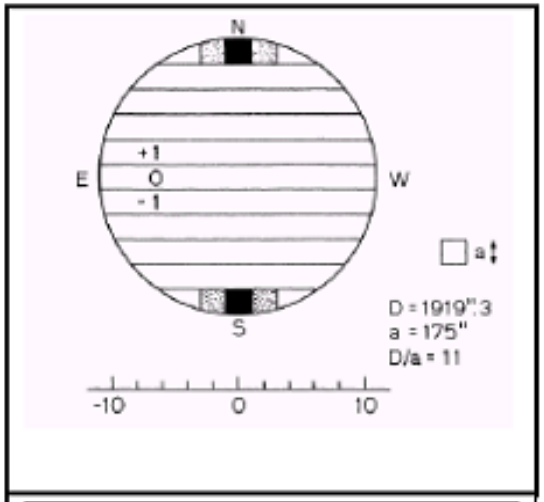
“Picking the Peak”

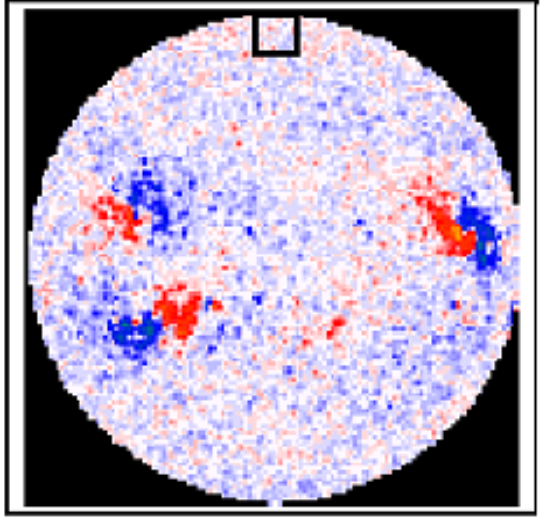
- Using the large peak in 2003 predicted a large cycle [Rmax ~ 160], but perhaps the peak to use [based on the Recurrence Index] is the one in 2008 that predicts a small cycle [Rmax ~ 70]



Definition of Polar Fields







Wilcox Solar Observatory (WSO)

Large aperture: 3'

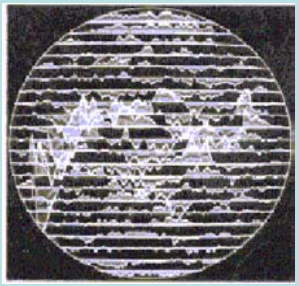
Operational Definition of Polar Fields:
Average field in pole-most apertures (black squares)

Mount Wilson Observatory (MWO)

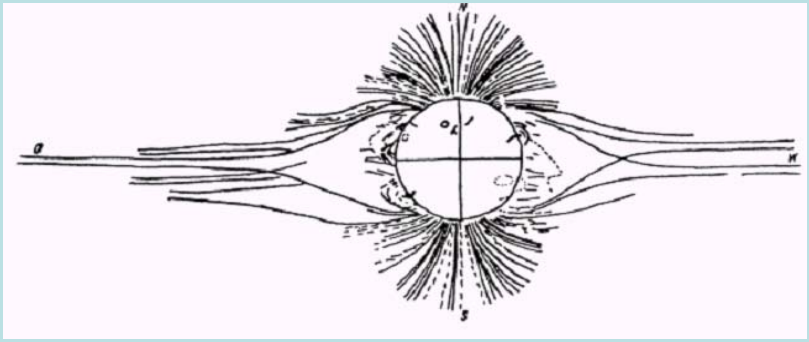
Small aperture: 0.2'

Operational Definition of Polar Fields:
Average field of pixels inside aperture that matches that of WSO

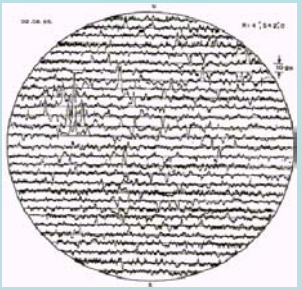
Measurements of Polar Fields

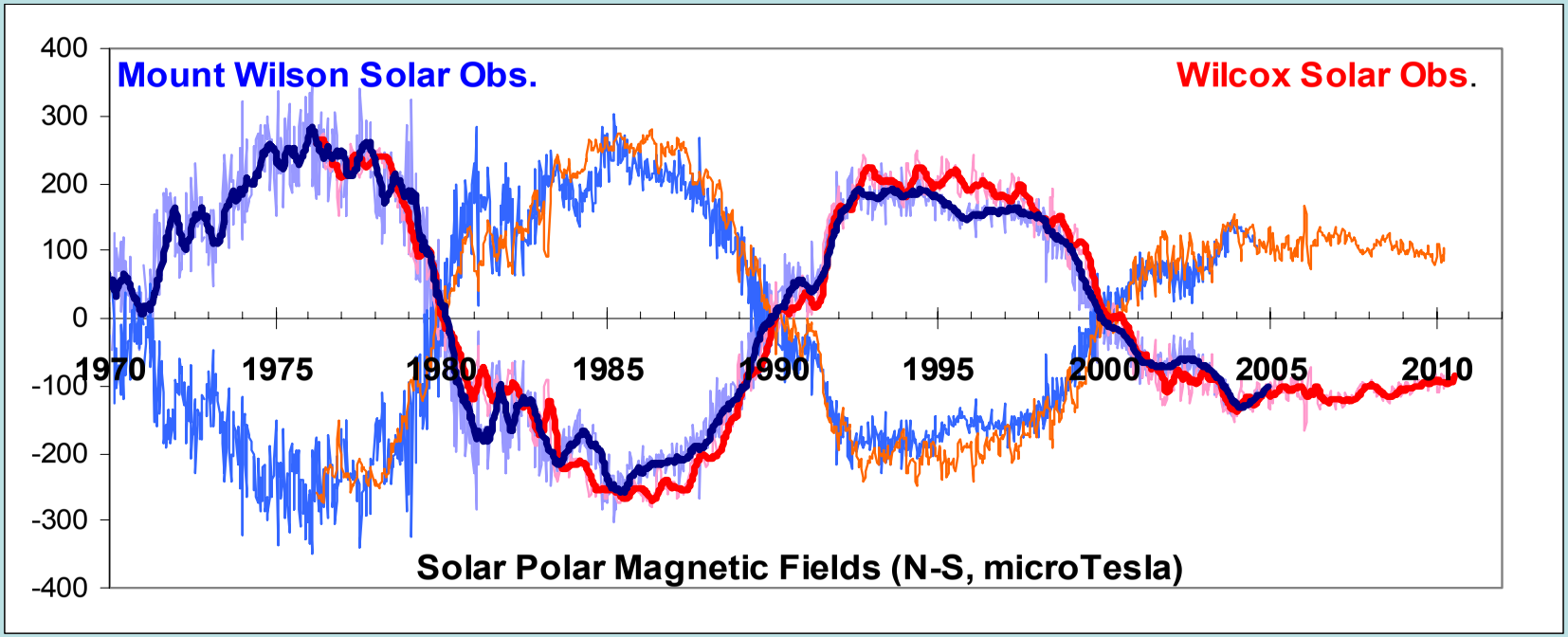


1953



1965

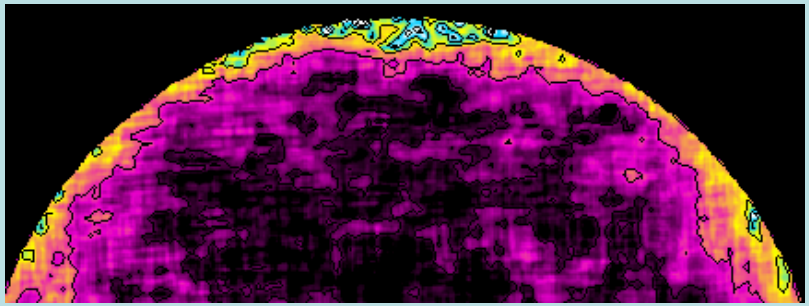


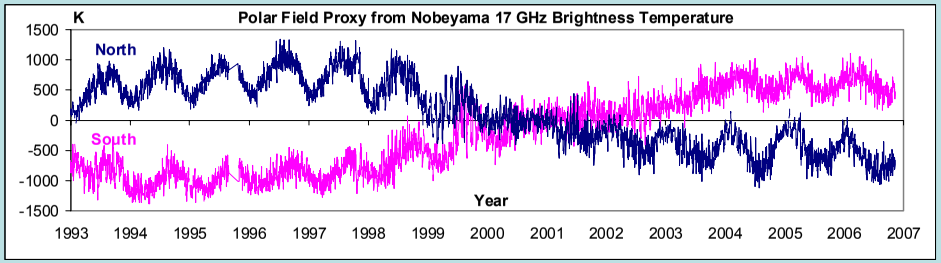


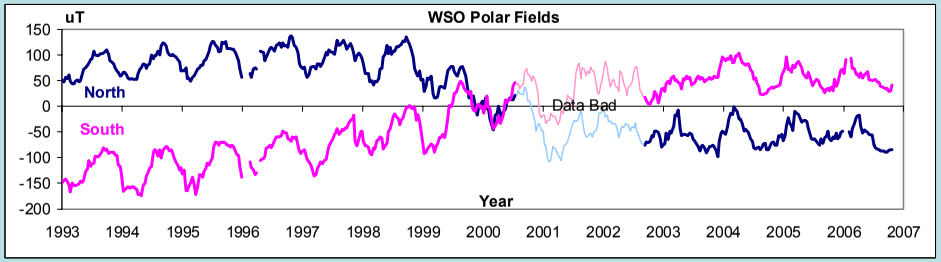
Another Measure of the Polar fields

17 GHz Radio Flux

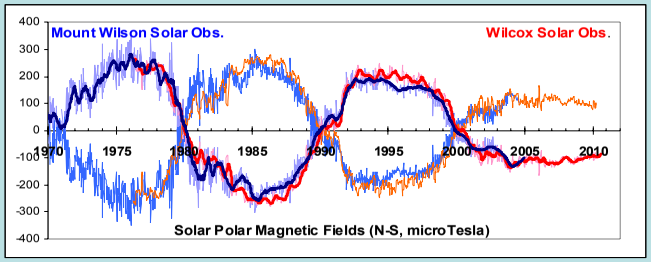
Nobeyama Radioheliograph, Japan





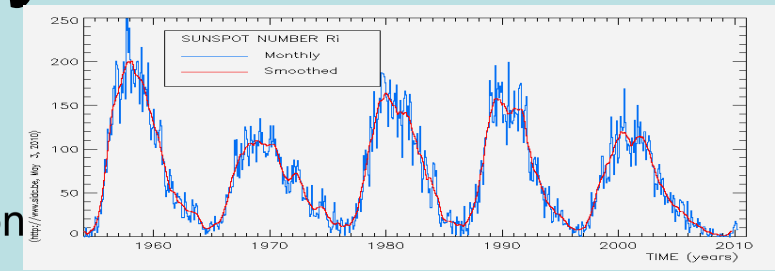


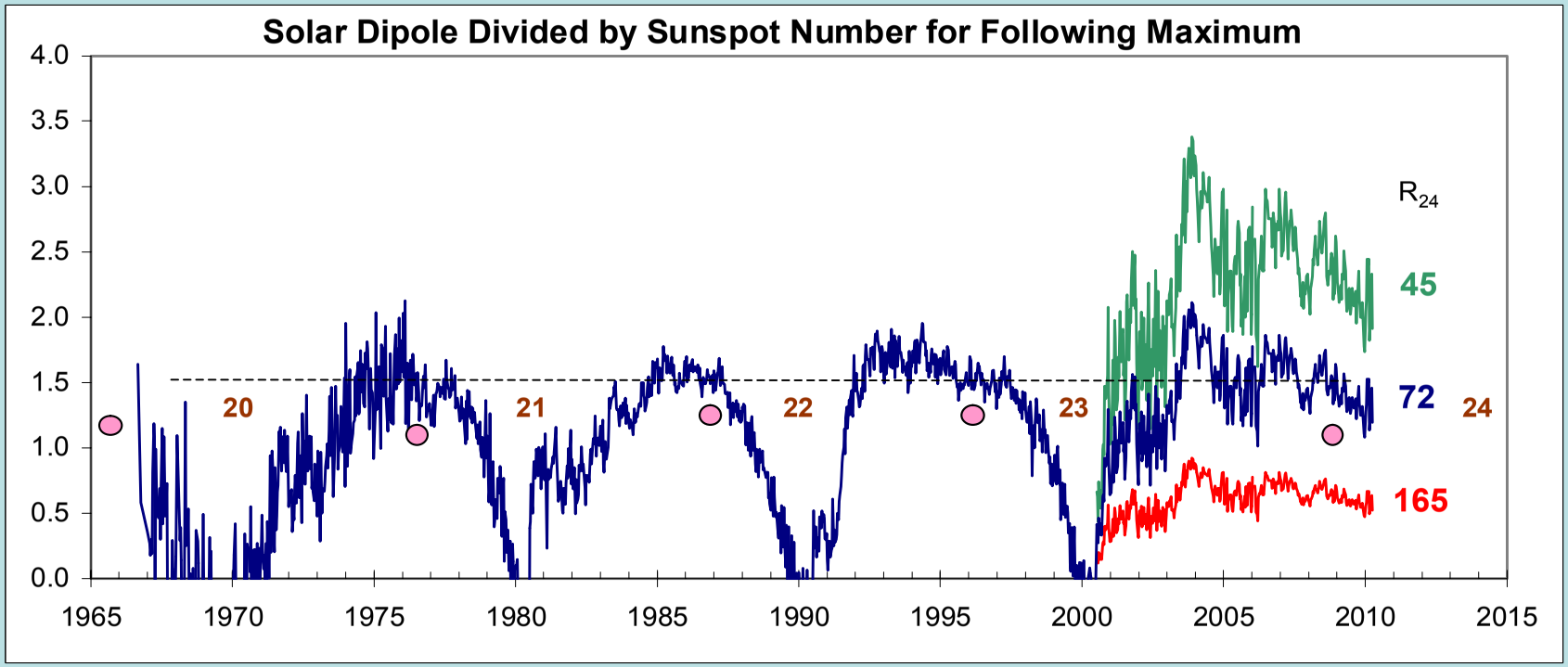
Polar Field Scaled by Size of Next Cycle is Possibly an Invariant

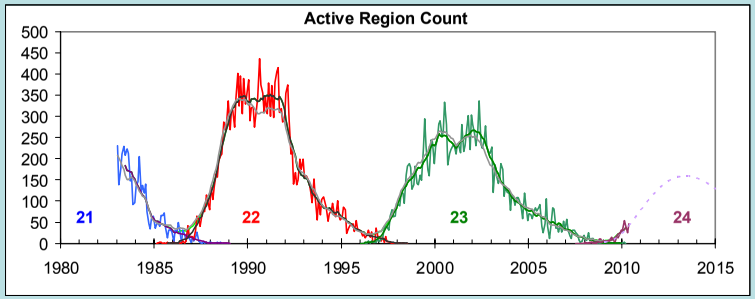


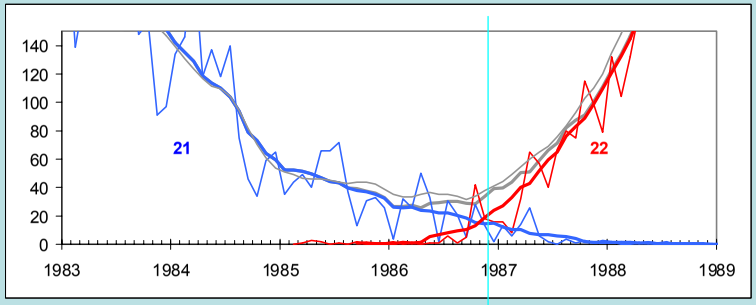
$R_{max24} = 72$

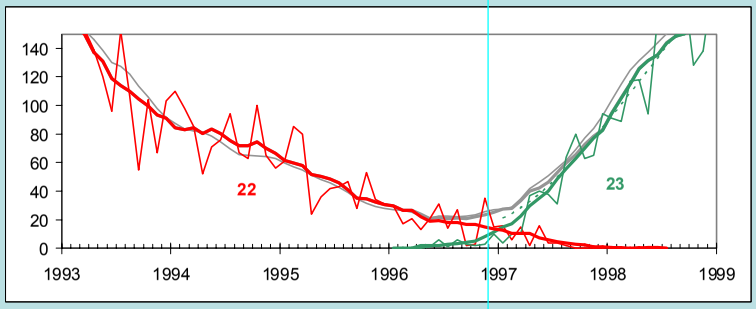
Our Prediction

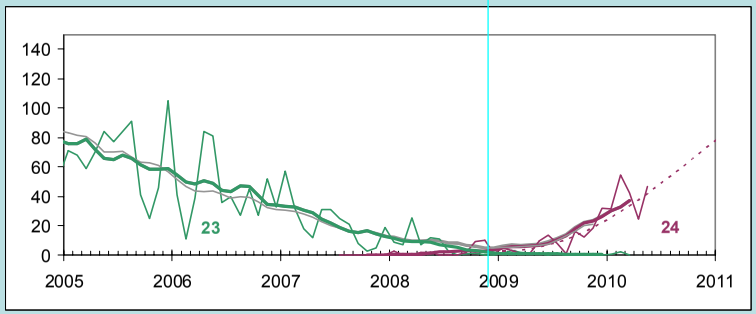








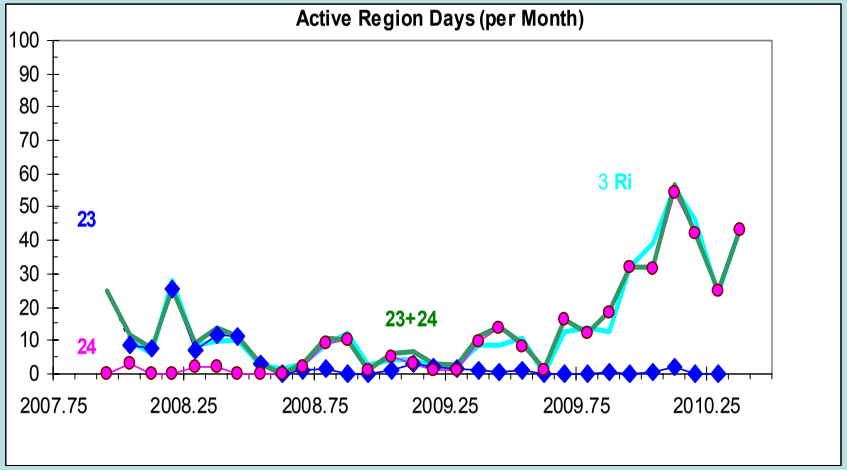




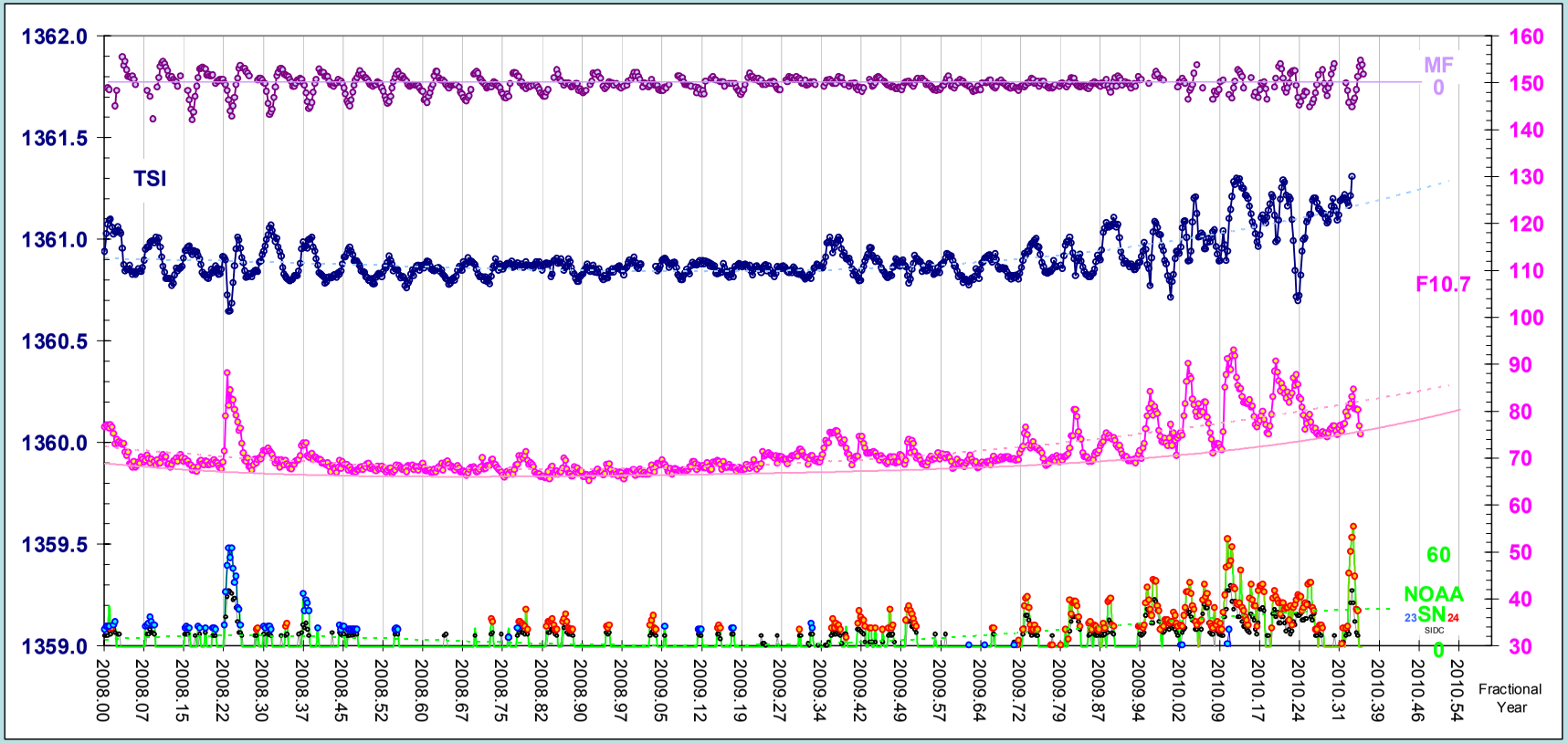
Cycle Transitions

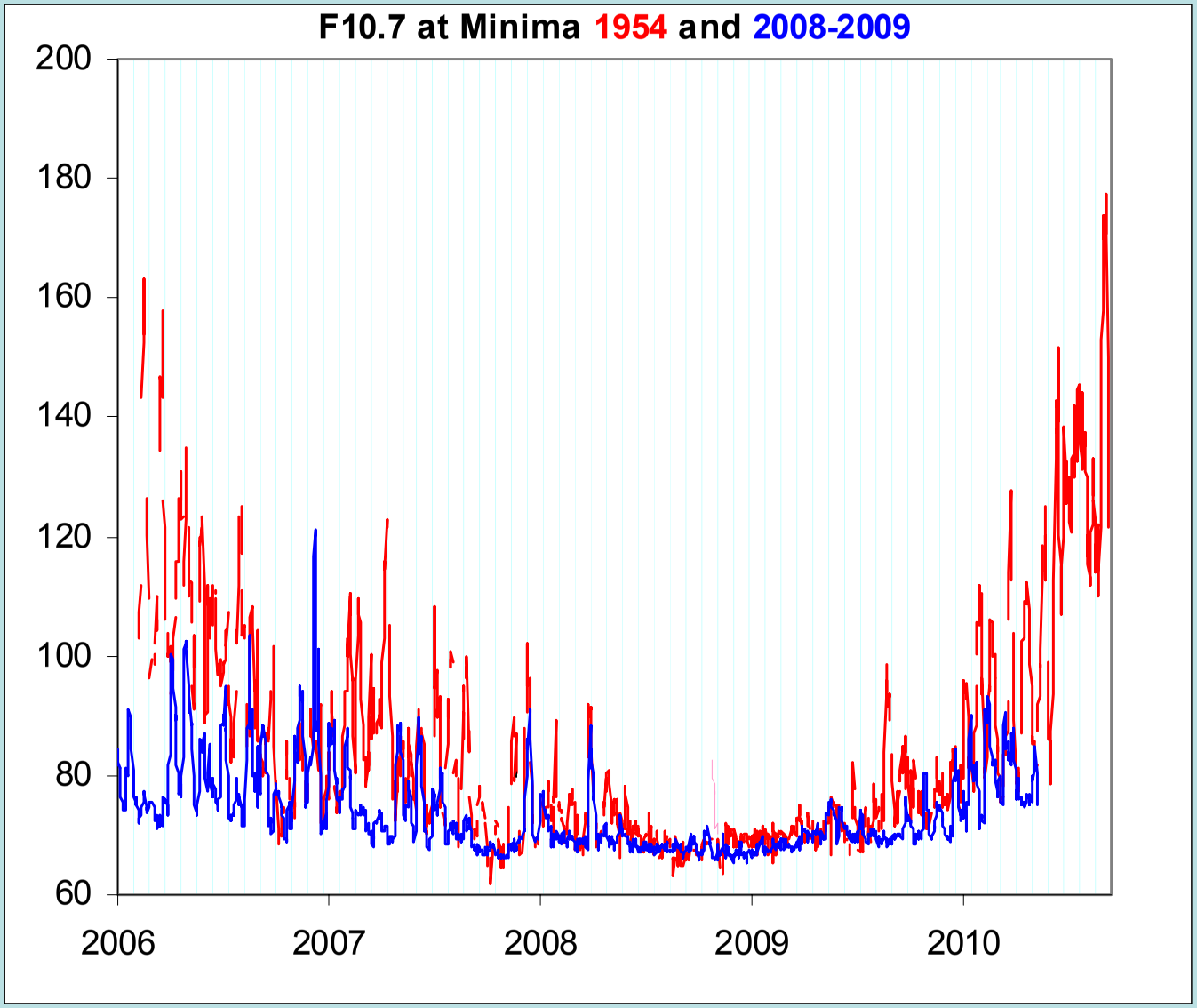
The current minimum is very low [the lowest in a century], and it is clear that Minimum is now behind us.

Dashed line: Hathaway New Prediction



The Diverse 23-24 Minima: Mean Field, TSI, F10.7, SSN(s)

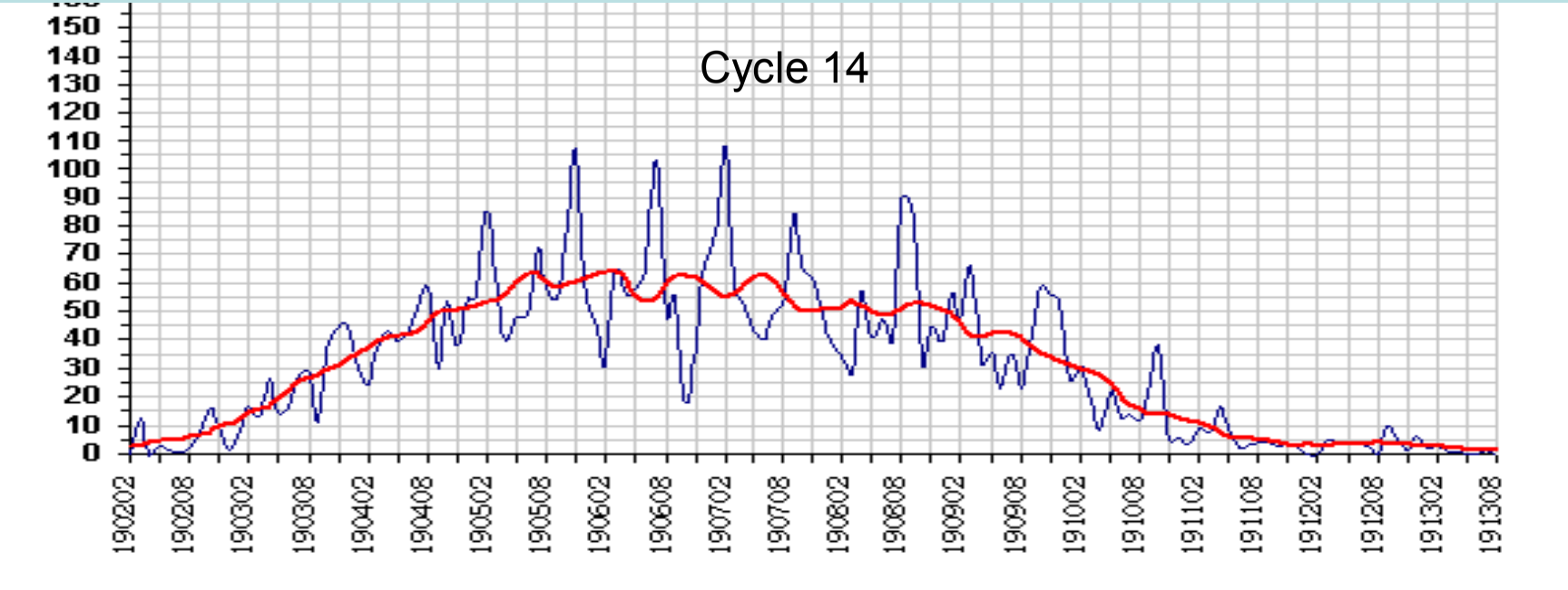




F10.7 at minimum between two large cycles 18 & 19 and two smallish cycles 23 & 24

What Will Cycle 24 Look Like?

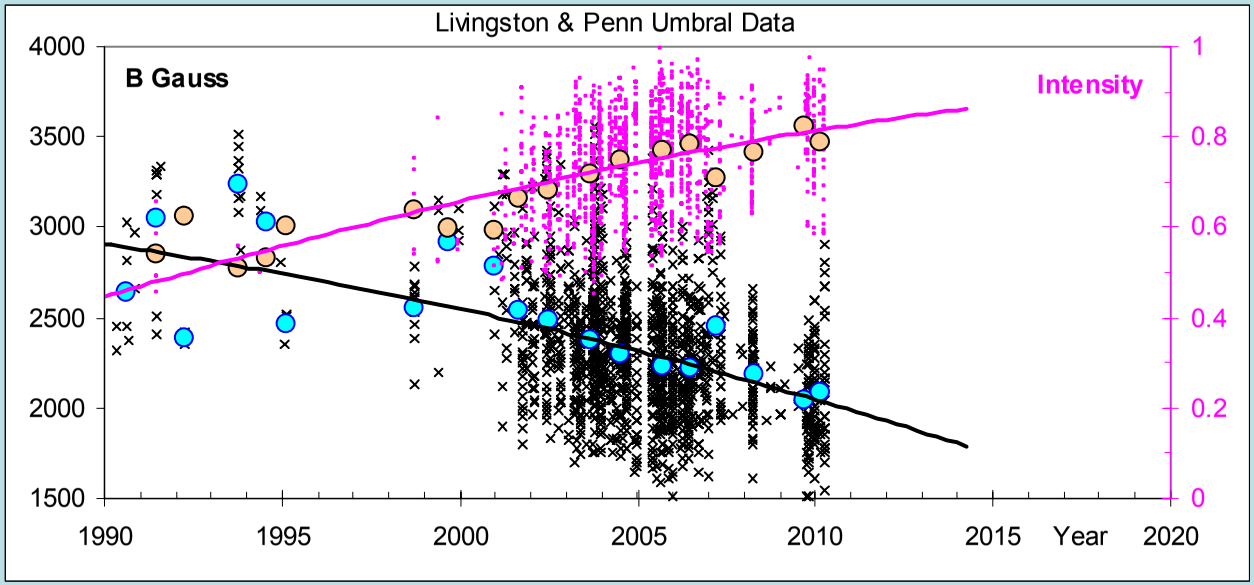
- Perhaps like cycle 14, starting 107 years ago
- Note the curious oscillations, will we see some this time?
- If so, I can just imagine the confusion there will be with ‘verification’ of the prediction



Alvestad, 2009

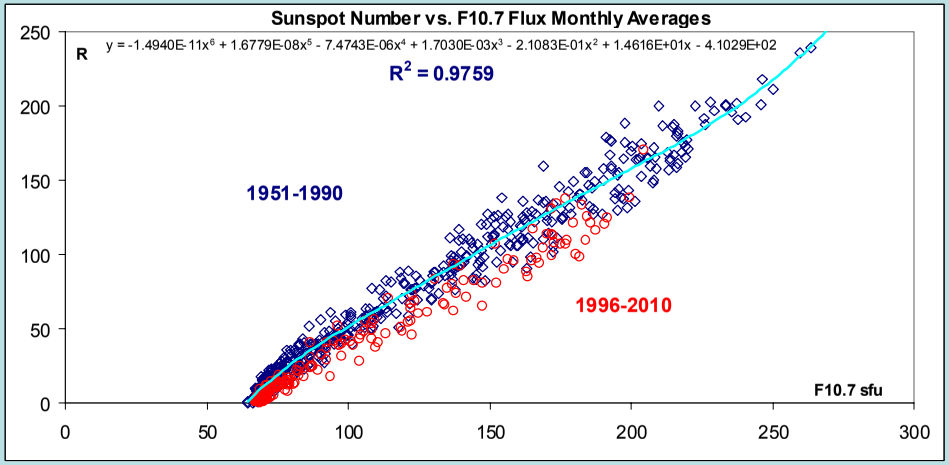
If We Can Just See the Spots…

- Sunspots are getting warmer, thus becoming harder to see. Will they disappear? Or will the Sunspot Number just be biased and too small…



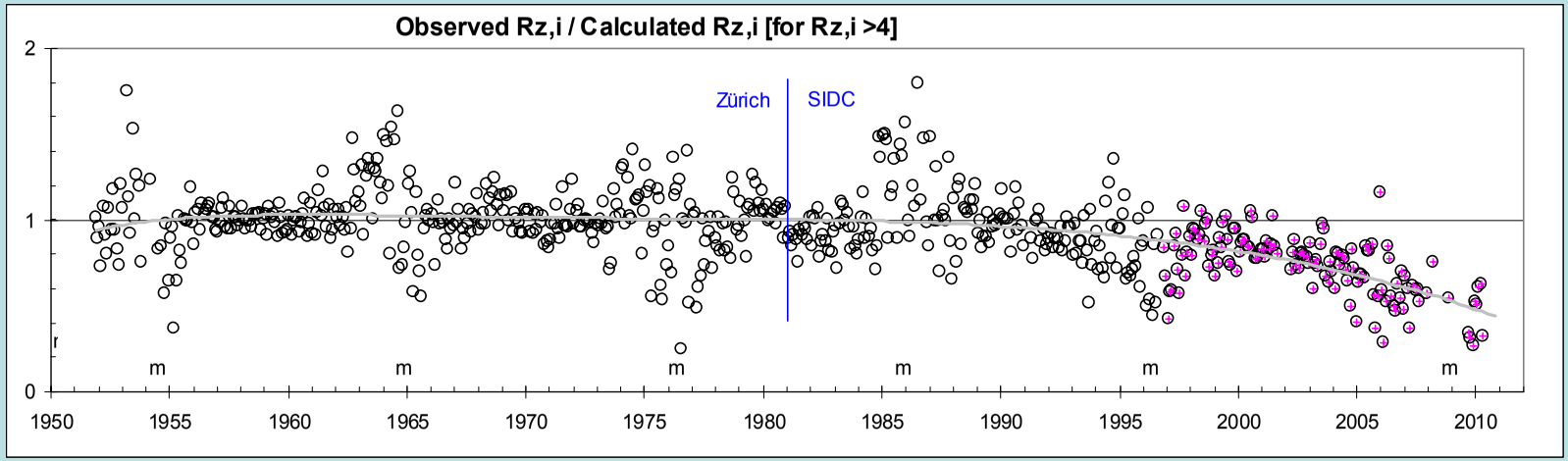
William Livingston, Pers. Comm. 2010

F10.7 Flux Relationship with Sunspot Numbers is Changing



Ratio of observed SSN and SSN computed from F10.7 using formula for 1951-1990

Recent SSN already too low ?



Svalgaard & Hudson, 2009

So What Do We Predict? SSN or F10.7 Flux or Magnetic Regions?

- Since the prediction is based on the magnetic field, we are really predicting a proxy for the field:
- F10.7 120 sfu
- Magnetic Regions 72/12 = 6
- Sunspot Number Who knows?
- Was the Maunder Minimum like this?

Conclusion

"It cannot be said that much progress has been made towards the disclosure of the cause, or causes, of the sun-spot cycle. Most thinkers on this difficult subject provide a quasi-explanation of the periodicity through certain assumed vicissitudes affecting internal processes. In all these theories, however, the course of transition is arbitrarily arranged to suit a period, which imposes itself as a fact peremptorily claiming admittance, while obstinately defying explanation"

Agnes M. Clerke, A Popular History of Astronomy During the Nineteenth Century, page 163, 4th edition, A. & C. Black, London, 1902.

Abstract

We discuss a number of aspects related to our understanding of the solar dynamo. We begin by illustrating the lack of our understanding. Perhaps as exemplified by SWPC's Solar Cycle 24 Prediction Panel. They received and evaluated ~75 prediction papers with predicted sunspot number maxima ranging from 40 to 200 and with a near normal distribution around the climatological mean indicative of the poor State of the Art. Flux Transport Dynamo Models were recently hyped? or hoped? to promise significant progress, but they give widely differing results and thus seem inadequate in their current form. In these models, higher meridional flow speed should produce strong polar fields and a short solar cycle, contrary to the observed behavior of increased meridional flow speed, low polar fields, and long-duration cycle 23. Poorly understood Precursor-methods again seem to work as they have in previous cycles. I review the current status of these methods. Predictions are usually expressed in terms of maximum Sunspot Number or maximum F10.7 radio flux, with the implicit assumption that there is a fixed [and good] relation between these measures of solar activity. If Livingston & Penn's observations of a secular change in sunspot contrast hold up, it becomes an issue which of these two measures of solar activity should be predicted and what this all means. The coming cycle 24 may challenge cherished and long-held beliefs and paradigms. .