

# Long-term Solar Synoptic Measurements with Implications for the Solar Cycle

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# Dimensions of Synoptic Observations

- Time Dimension (long-term data sets)
- Spatial Dimension (distribution over the disk of activity, synoptic maps)

Most efficient are visualizations

*combining* the two dimensions, e.g.

- Movies, Butterfly diagram, Rotation sequences, ...

# Classes of Synoptic Observations

- Single Point (e.g. Center Disk spectra)
- Full-Disk (e.g. Sunspot Number, F10.7 flux, Mean Field, Total Solar Irradiance)
- Image-based (e.g. Sunspot Area, Ca K line index, Magnetograms, Synoptic charts)

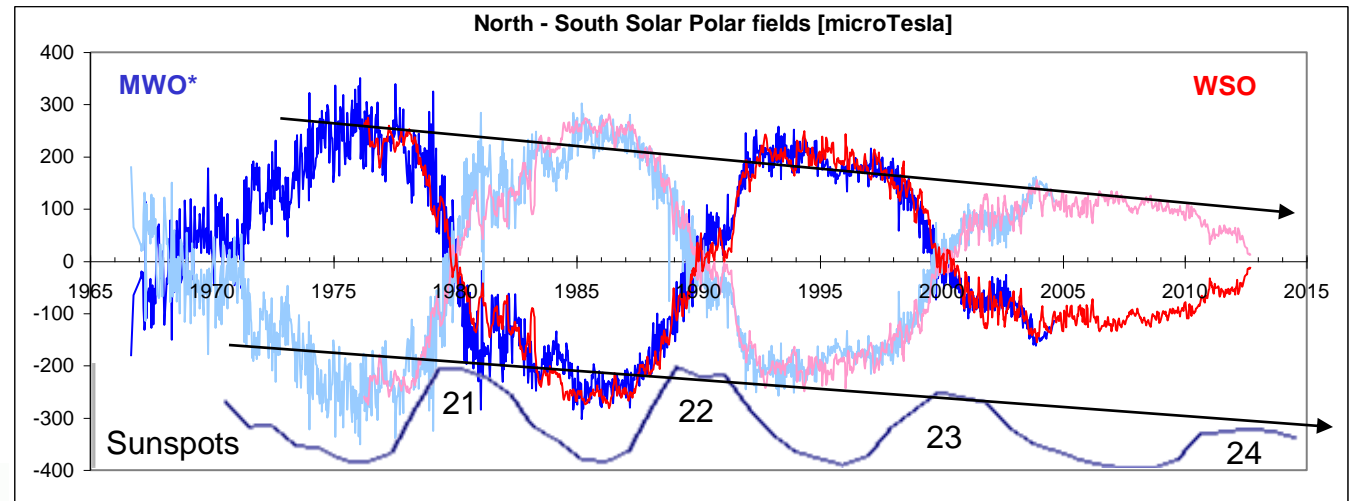
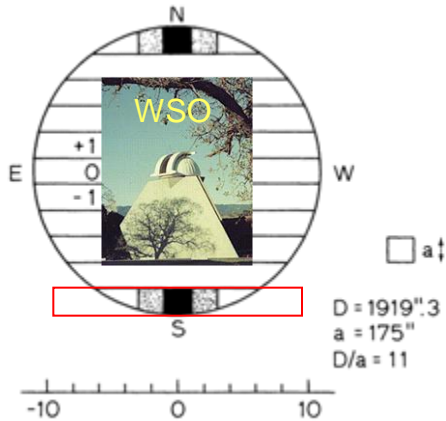
And aggregate views derived from images, e.g.

- Polar Field Evolution
- Hemispheric Asymmetries
- Meridional and 'Torsional' circulations

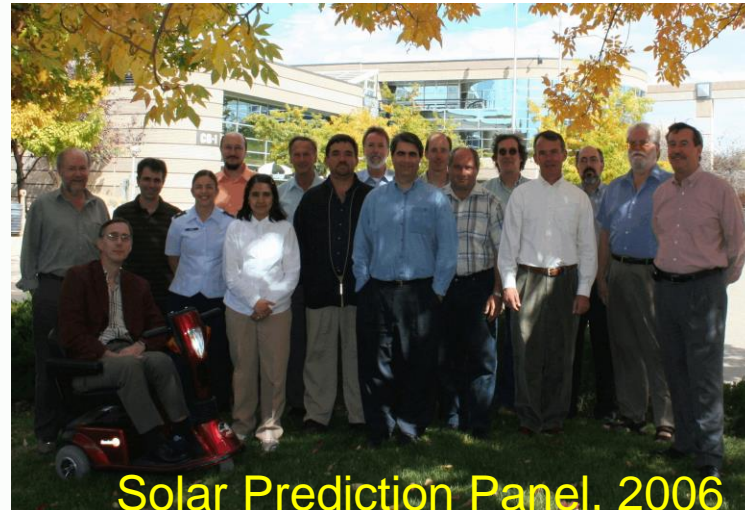
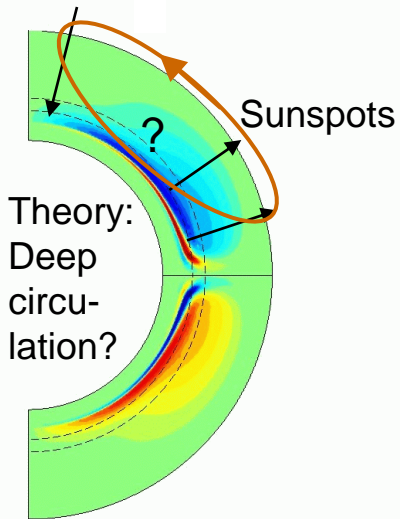
# **Synoptic Observations are important for Understanding and Predicting the Solar Cycle**

- Within my limited time for this presentation I can only touch upon some aspects that have been important for my own research
- It should, however, be clear how those relate to the wider issues, like constraining dynamo theories, forming inner boundary conditions for space weather, affecting the environment of the Earth and our space assets and technological infrastructure.

# Predicting Solar Activity



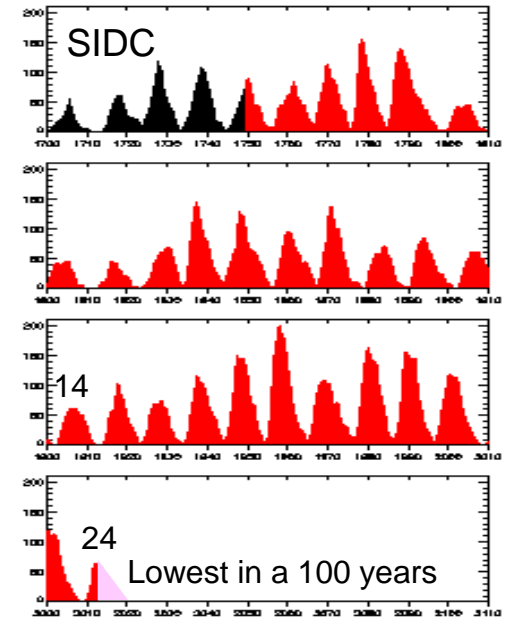
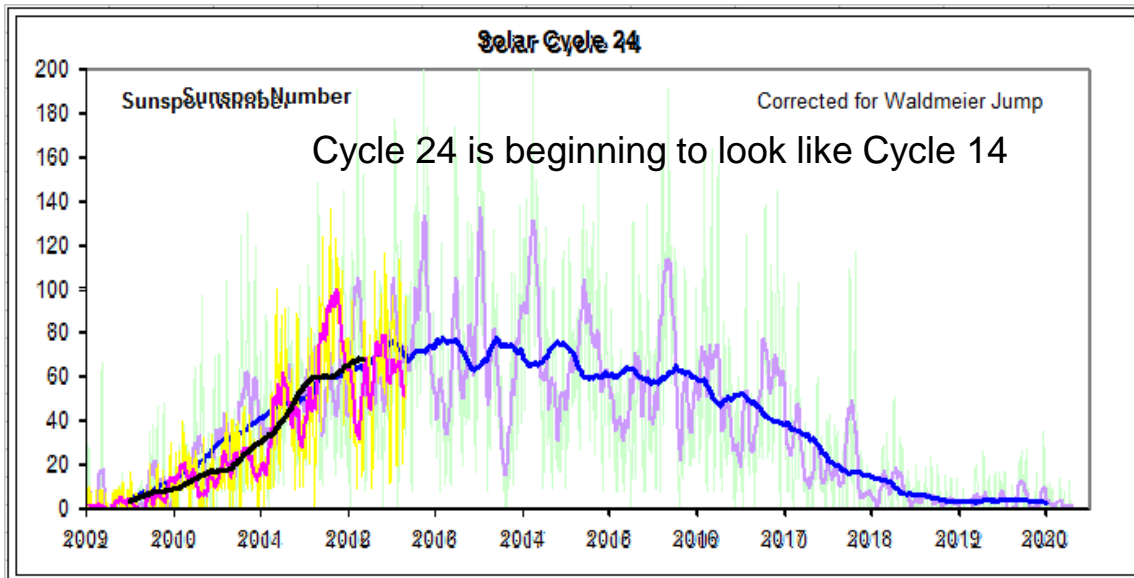
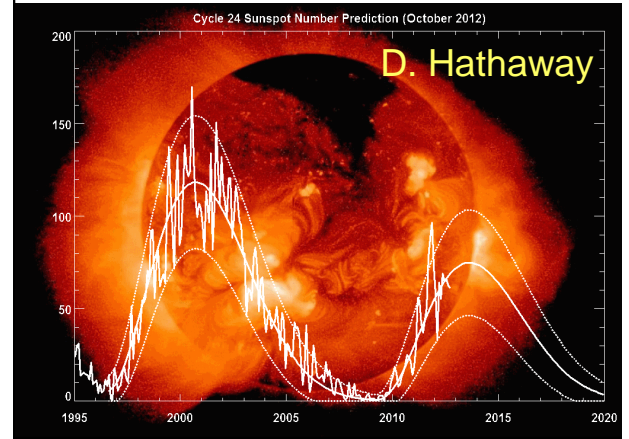
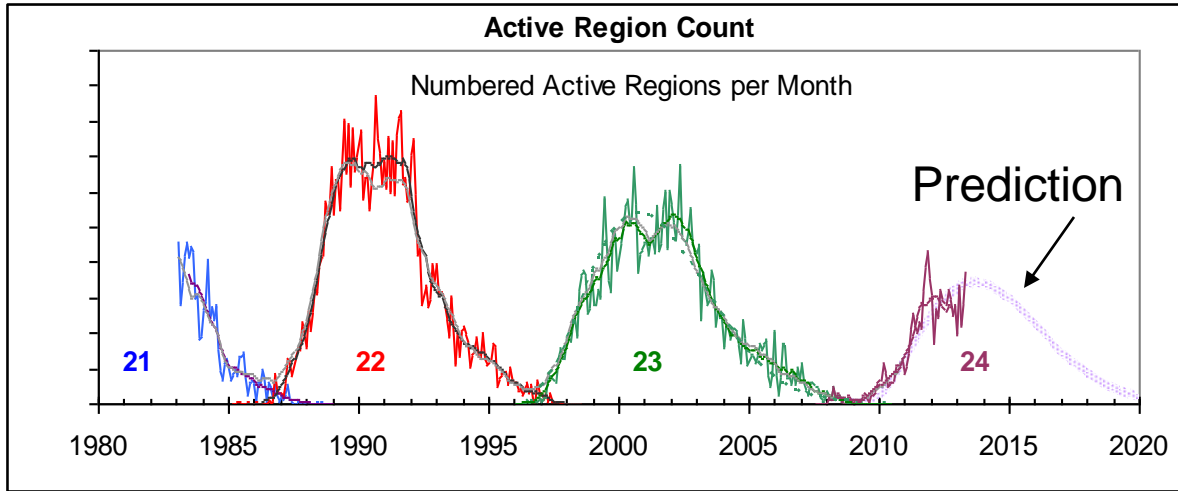
Polar Fields



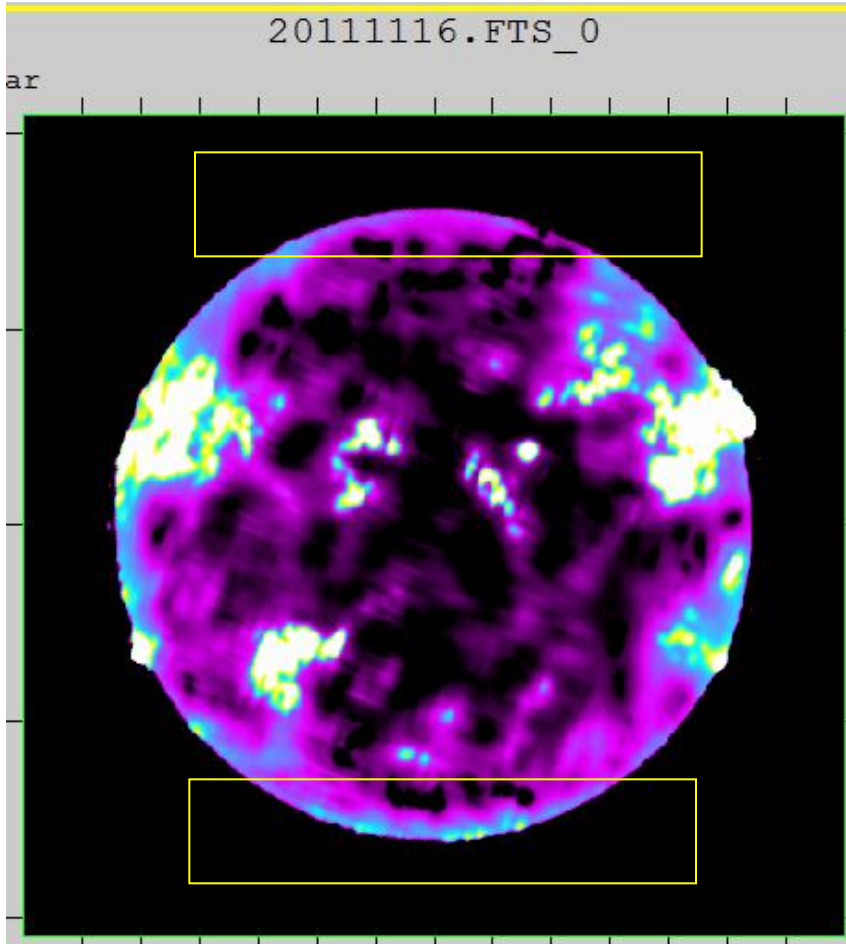
Observations and theory suggest that the magnetic field at the poles of the Sun at solar minimum is a good predictor of the next solar cycle.

The low polar fields at the recent solar minimum predicted a small cycle 24

# How is Cycle 24 Evolving? As predicted 9 years ago using the polar field precursor method



# A different view of polar fields: Nobeyama Image of 17GHz Emission



$\nu_{17} \text{ GHz} = \lambda 1.76 \text{ cm}$

$\nu_e = B \text{ (Tesla)} \times 28 \text{ GHz}$

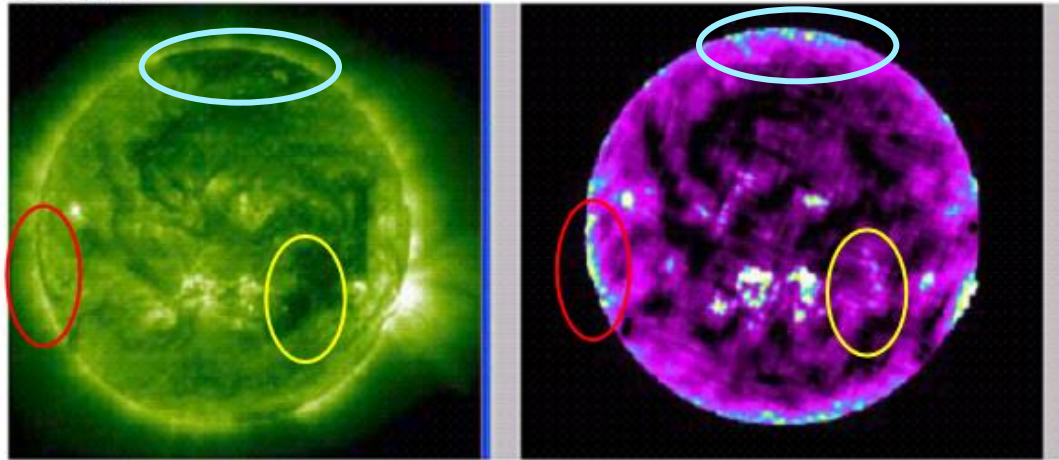
Beam width 10''

1. General Limb brightening:  
Bremsstrahlung (free-free) from hot atmosphere [10,000 – 13,000 K]
2. Active regions bright: Gyro-resonance from strong fields



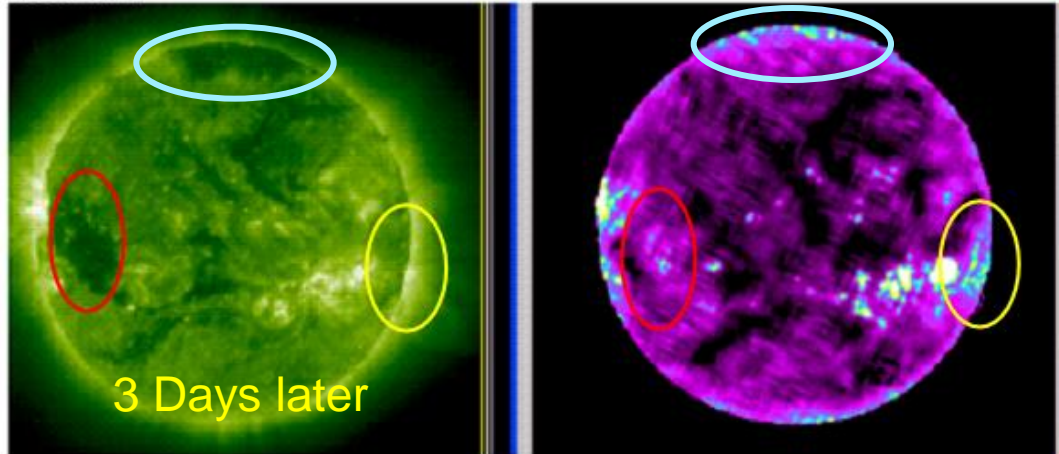
# Coronal Holes everywhere show same behavior as the polar holes

2003/09/10

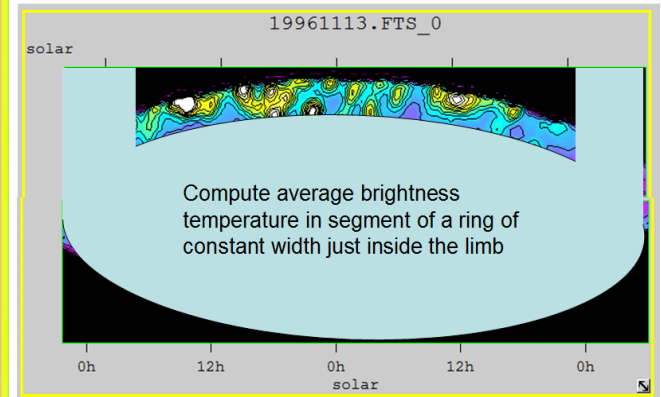


When a coronal hole is at the limb, the bright 17GHz patches appear, otherwise not

2003/09/13

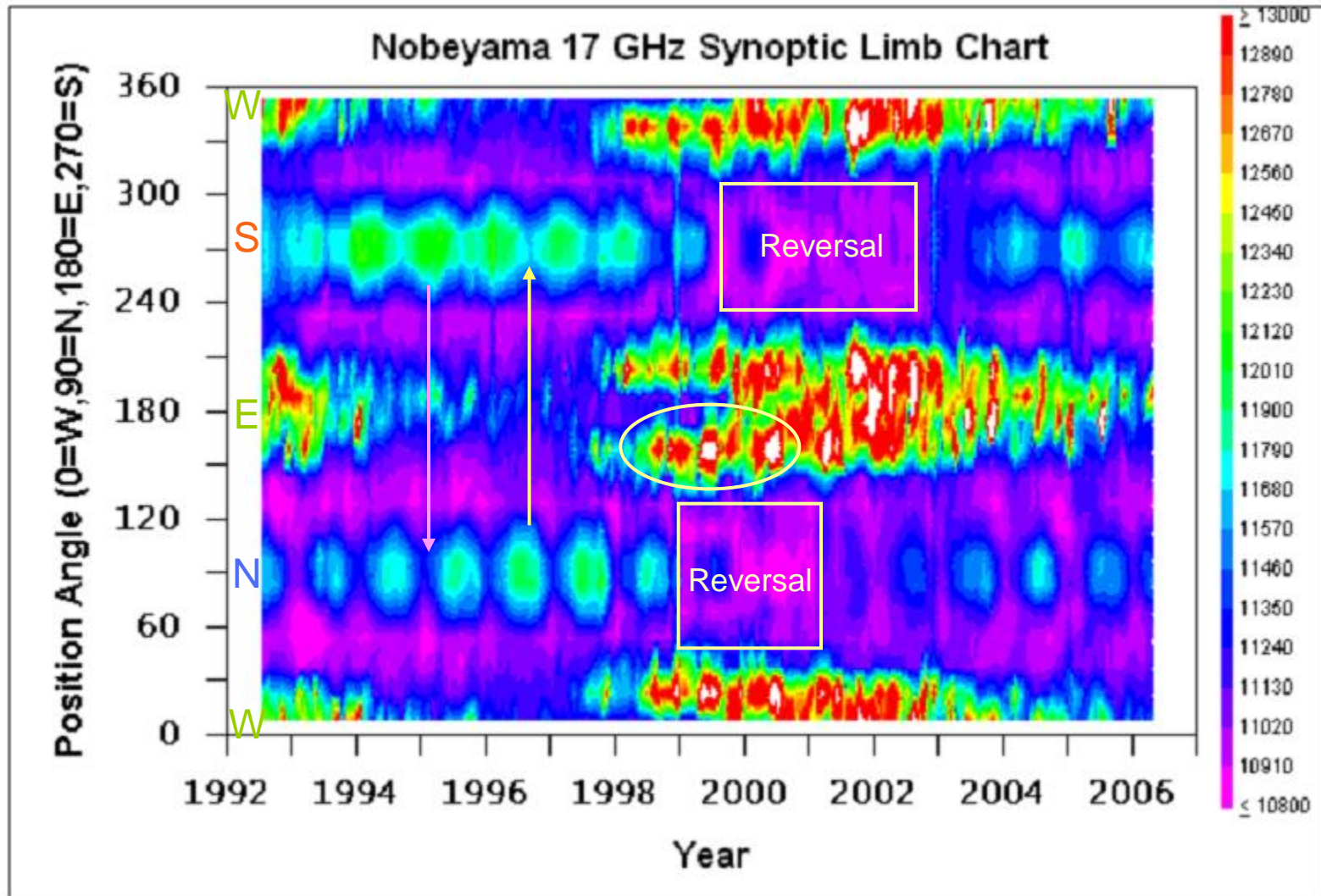


Quantifying the Brightening:

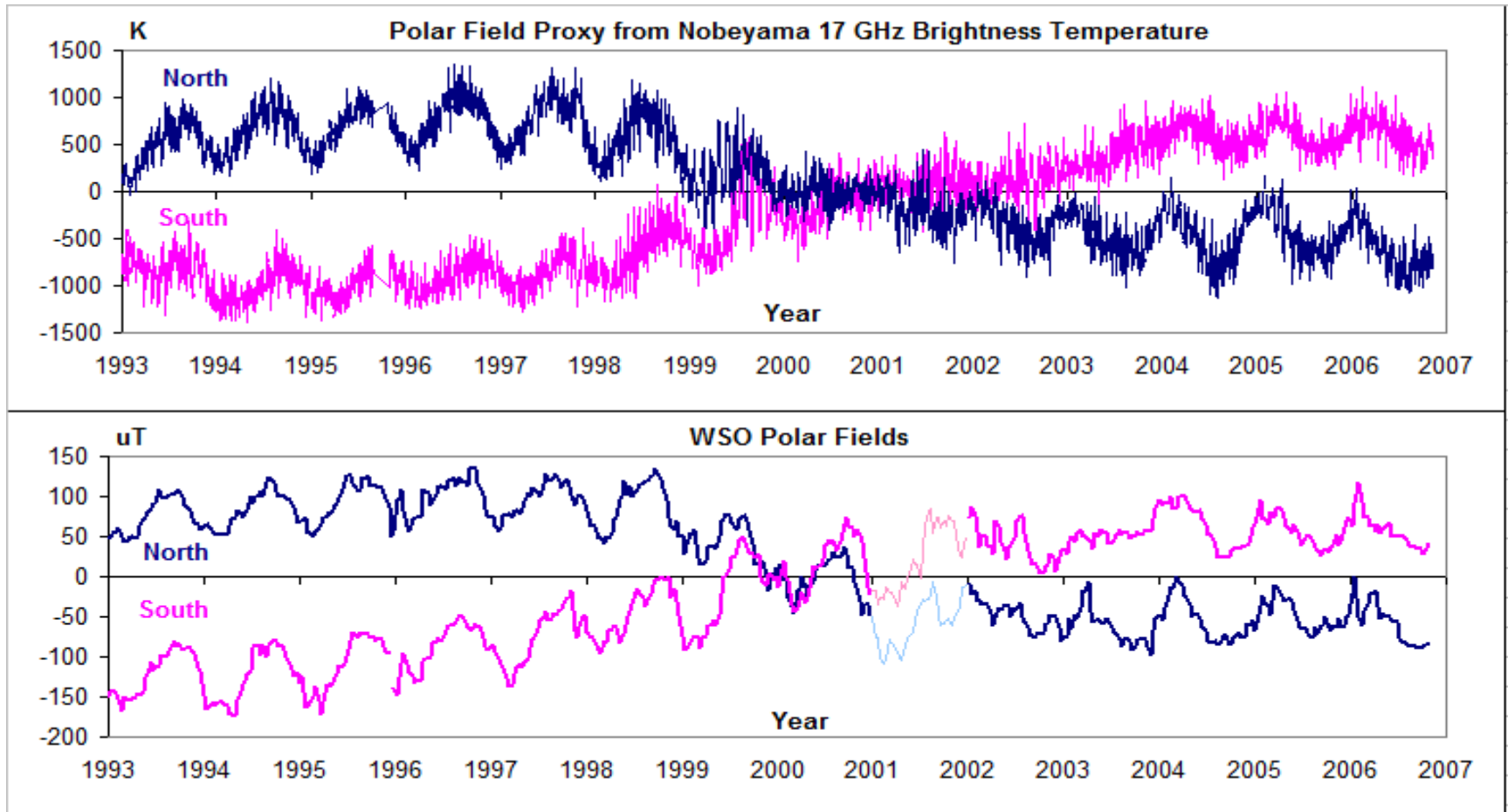




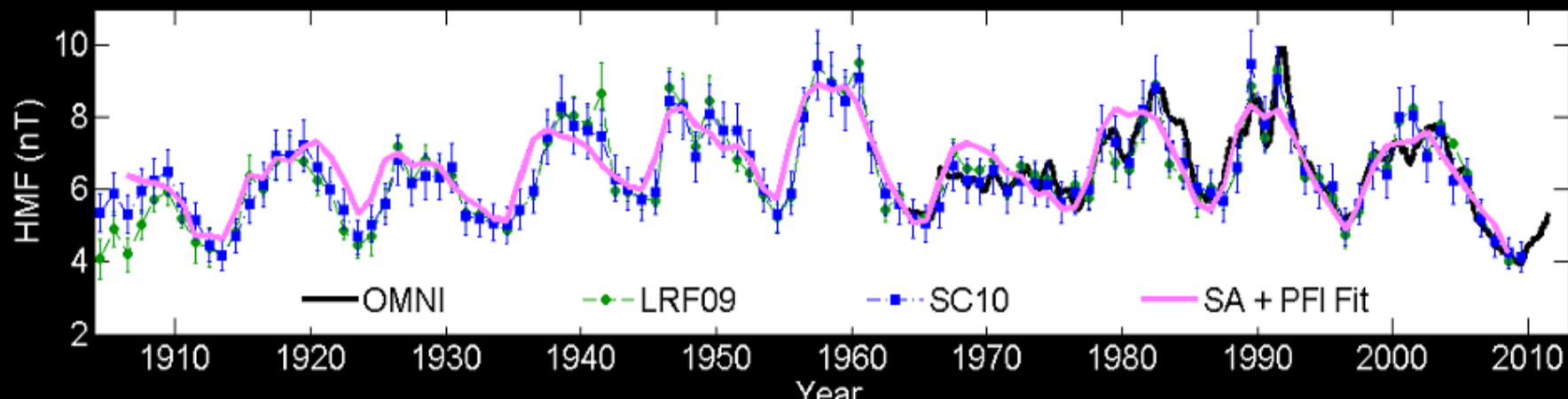
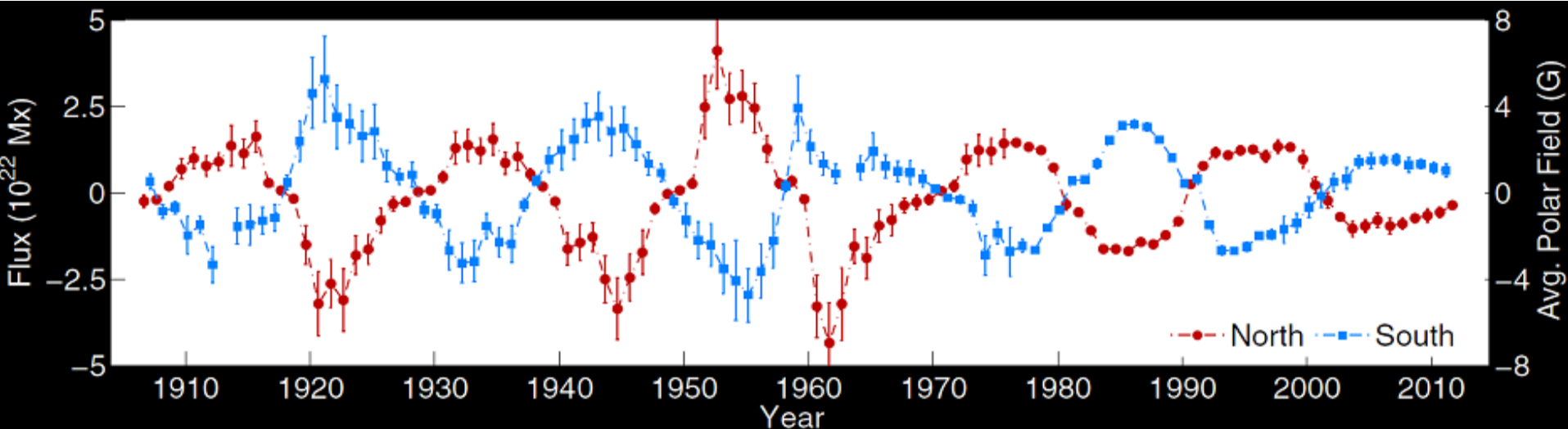
# Evolution of Patches over the Cycle



# Excess $T_b$ over 10,800K, signed according to WSO polar field sign

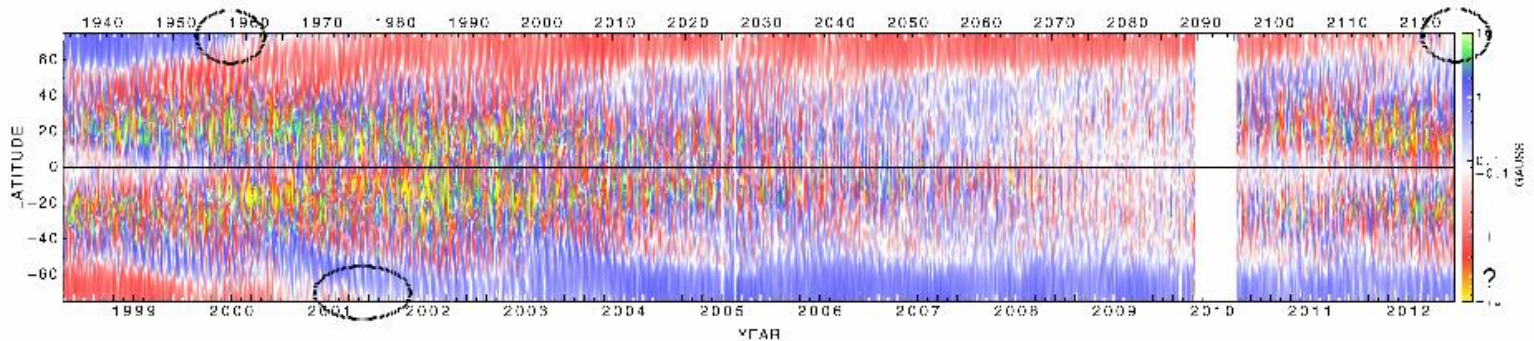
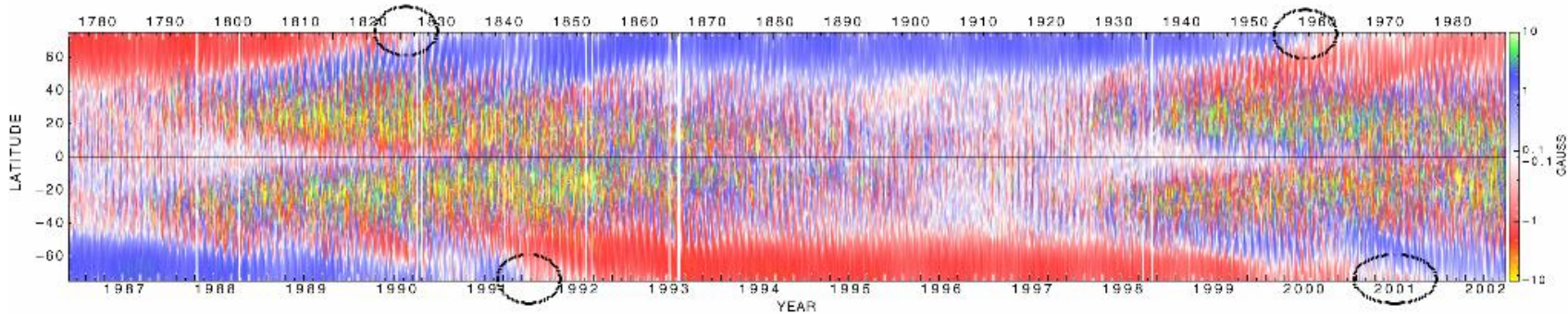
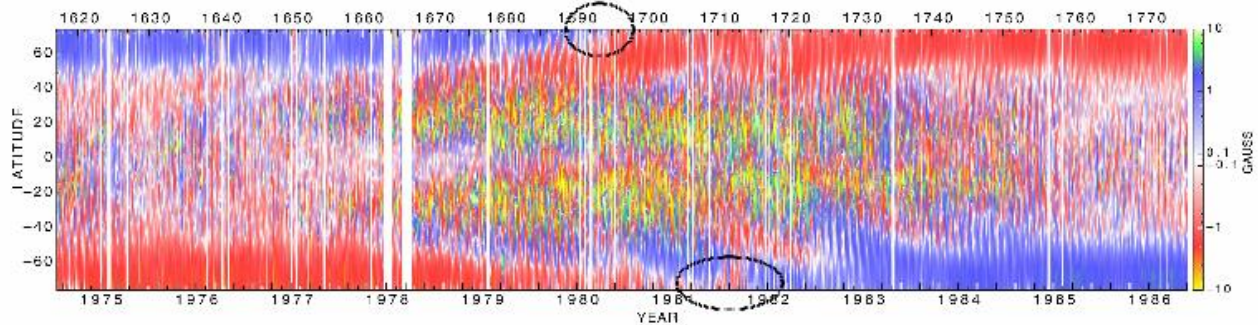


# Using Polar Faculae Count to determine Polar Magnetic Flux and HMF Field Strength



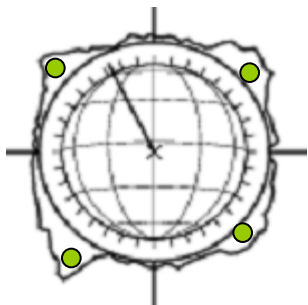
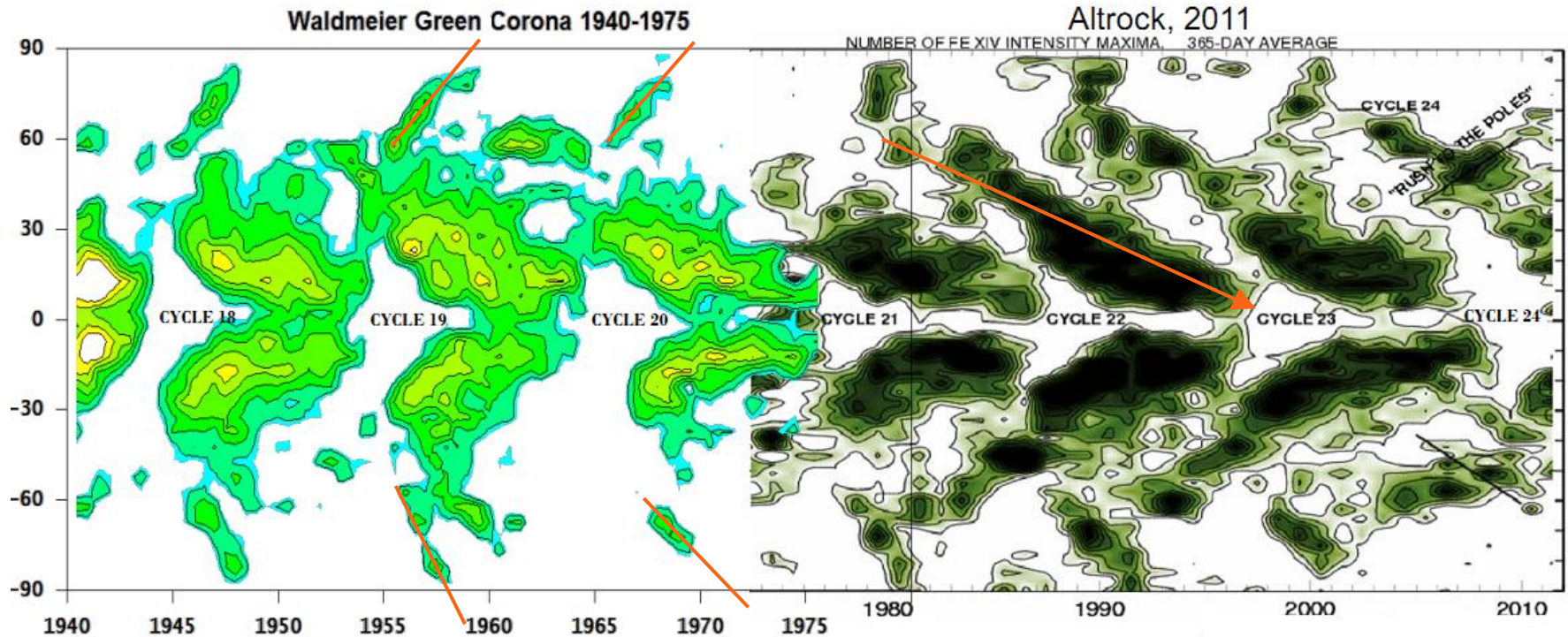
# Observed Polar Field Reversals

Supersynoptic  
charts MWO



MWO: Roger Ulrich, 2012

# And the 'Rush to the Pole' of Coronal Emissions

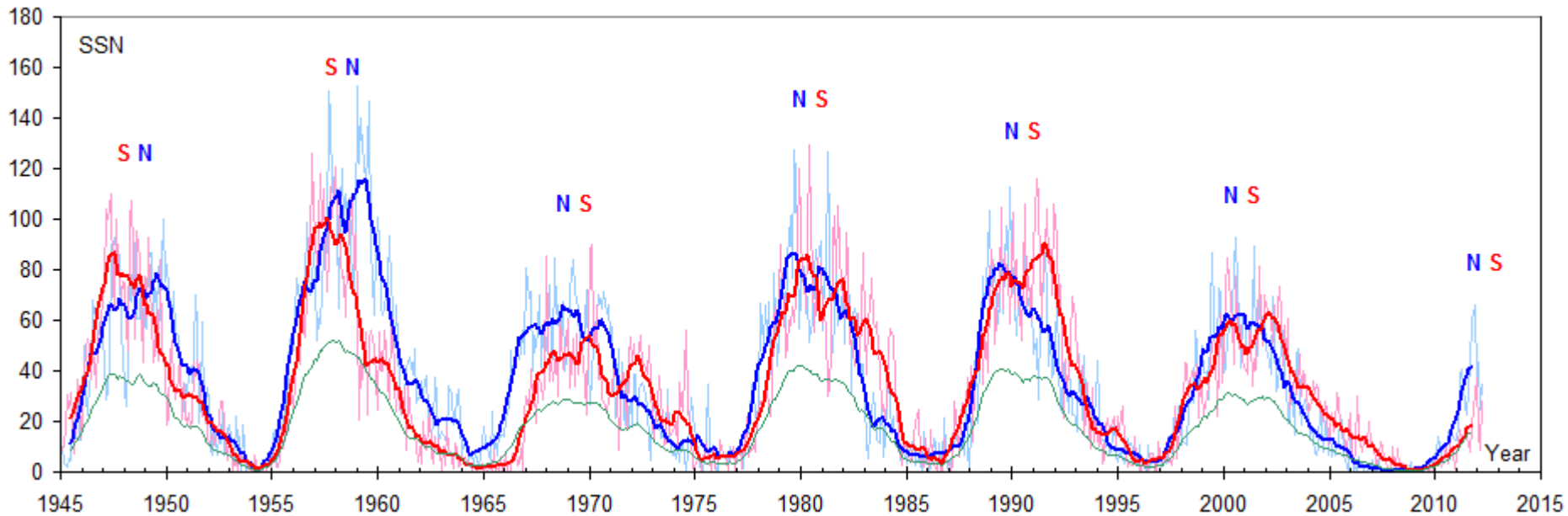


Measurements of the location of 'peaks' of Fe XIV coronal emission at 503 nm (the 'Green Line Corona') over 7 solar cycles. The plots show the probability of observing a 'peak' at a given latitude as a function of time.

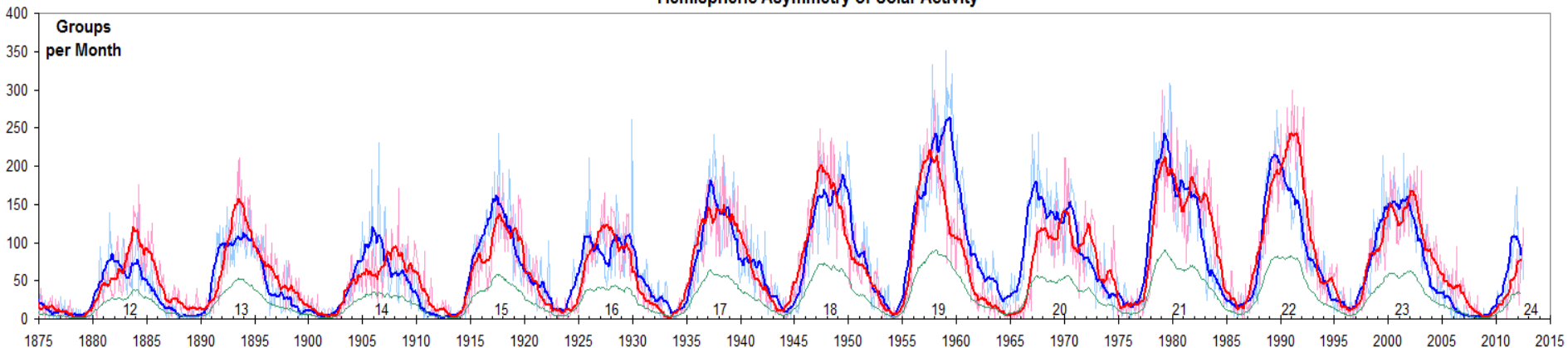
Is there an 'extended' cycle of 17 years?

# Asymmetric Solar Activity

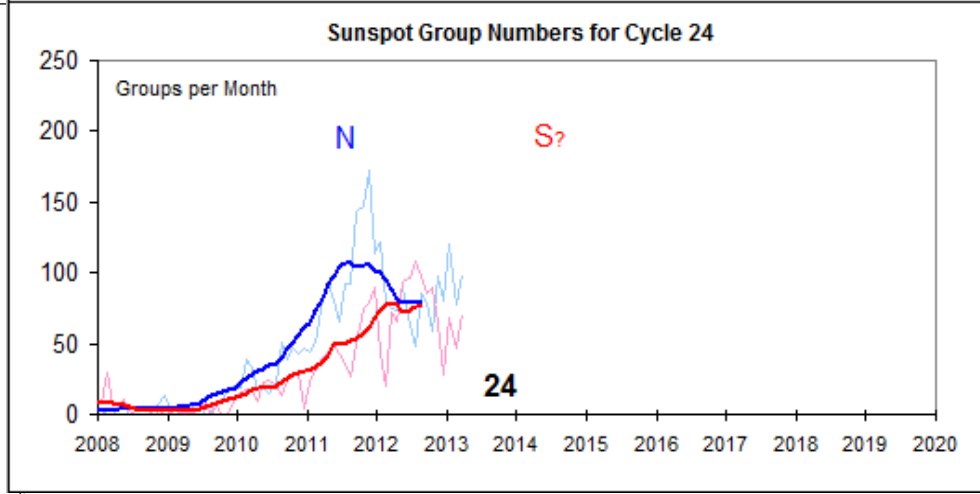
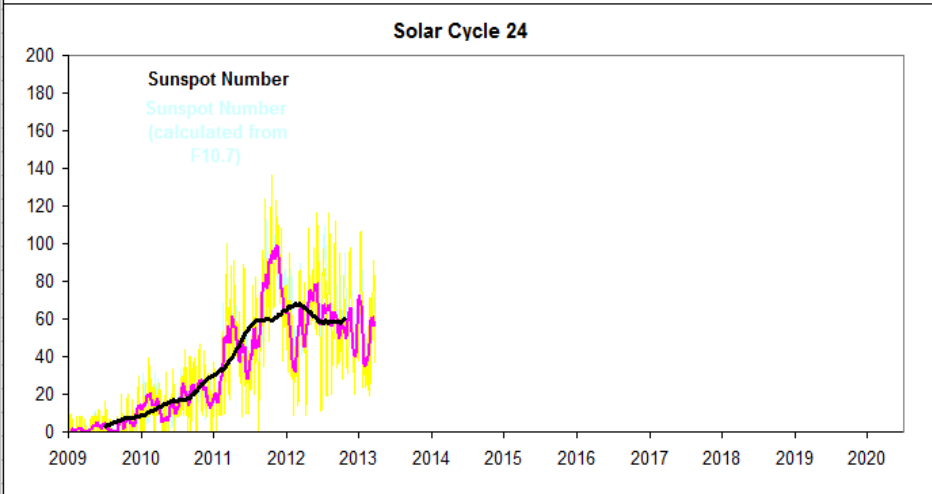
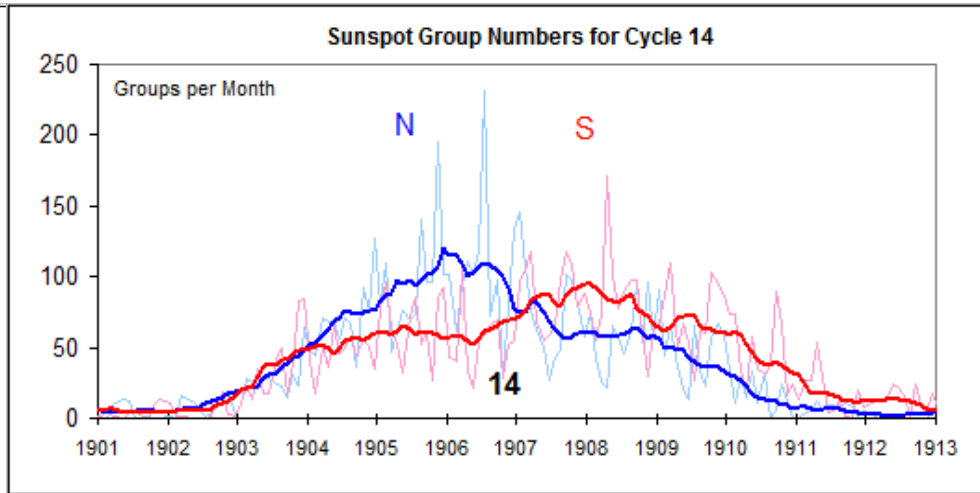
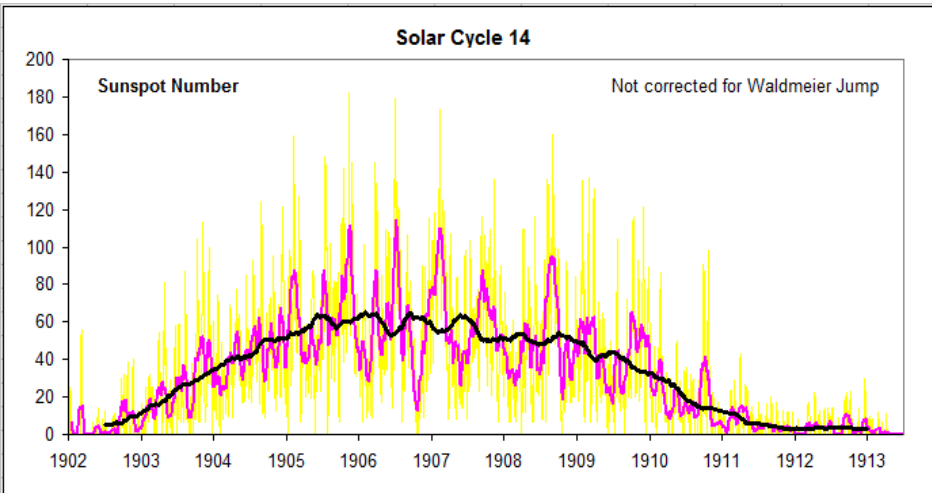
## Hemispheric Asymmetry Sunspot Numbers



## Hemispheric Asymmetry of Solar Activity

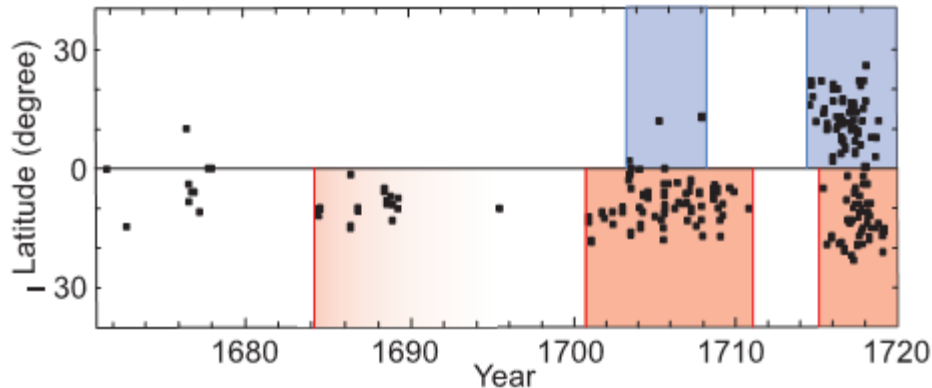


# Comparing Cycles 14 and 24



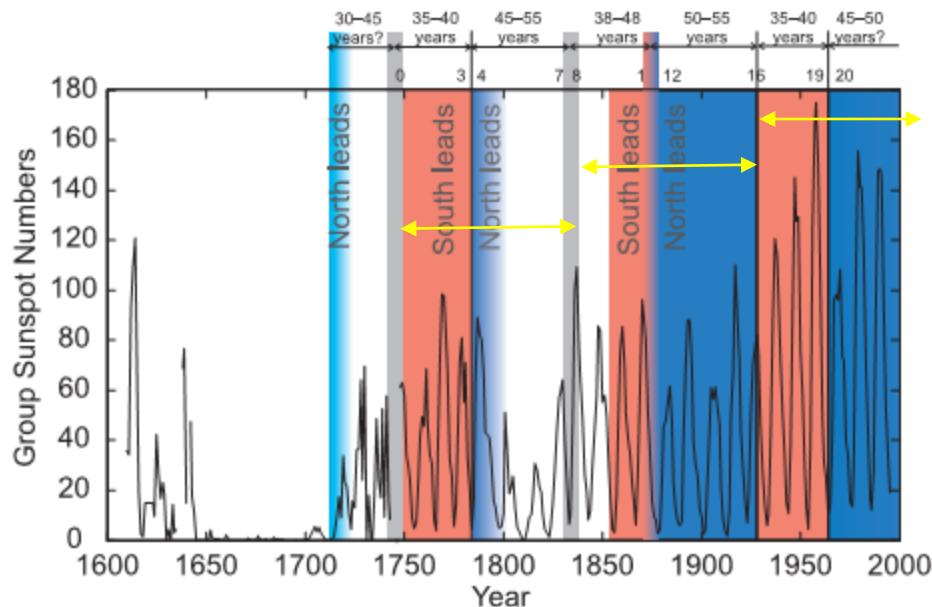
Cycle 14 suggests that the activity in the South might pick up in cycle 24 15

# 70-100 Year 'Gleissberg Cycle' in Solar Activity Asymmetry?



Extreme Asymmetry during the Maunder Minimum...

There are various dynamo theoretical 'explanations' of N-S asymmetry. E.g. Pipin, 1999. I can't judge these...

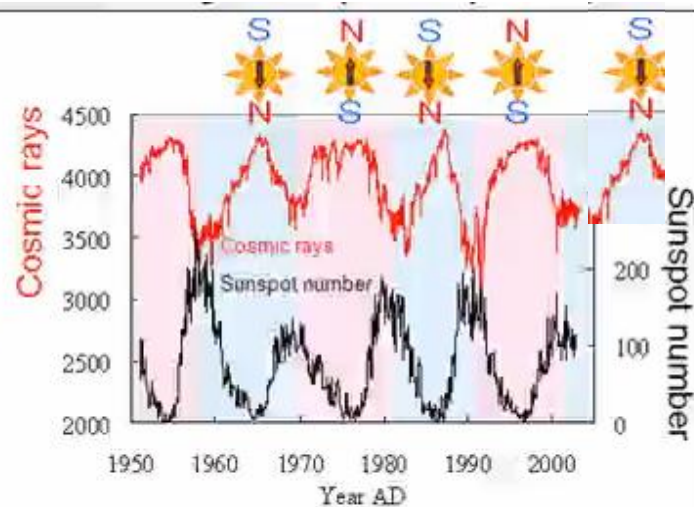
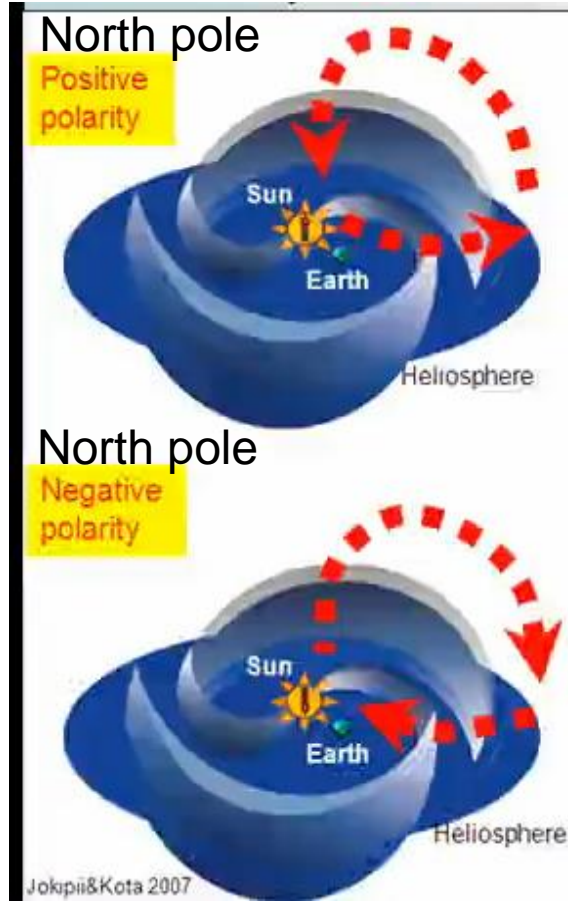


Is this a 'regular' cycle or just over-interpretation of noisy data [like Waldmeier's]?

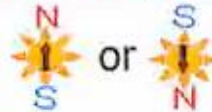
'Prediction' from this: South will lead in cycle 25 or 26 and beyond. We shall see...



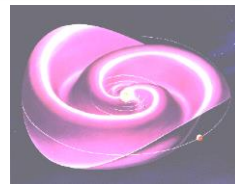
# Cosmic Ray Modulation Depends on the Sign of Solar Pole Polarity



## 1. Magnetic polarity



## 2. Waviness



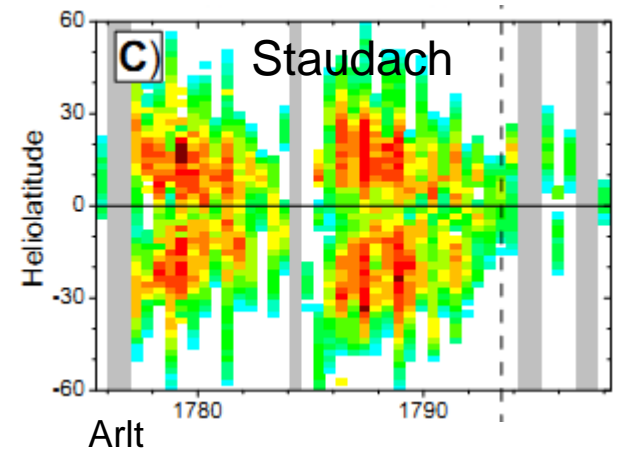
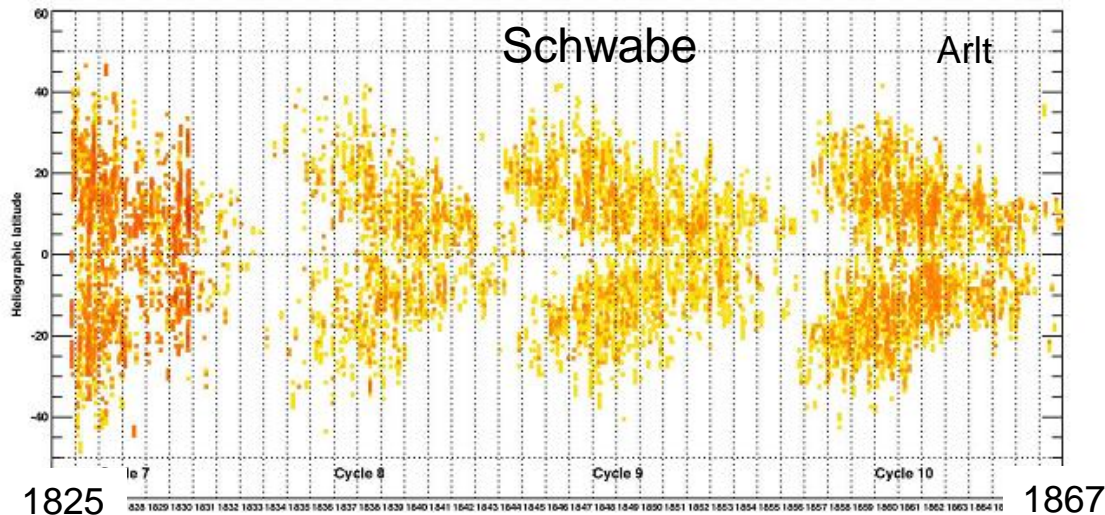
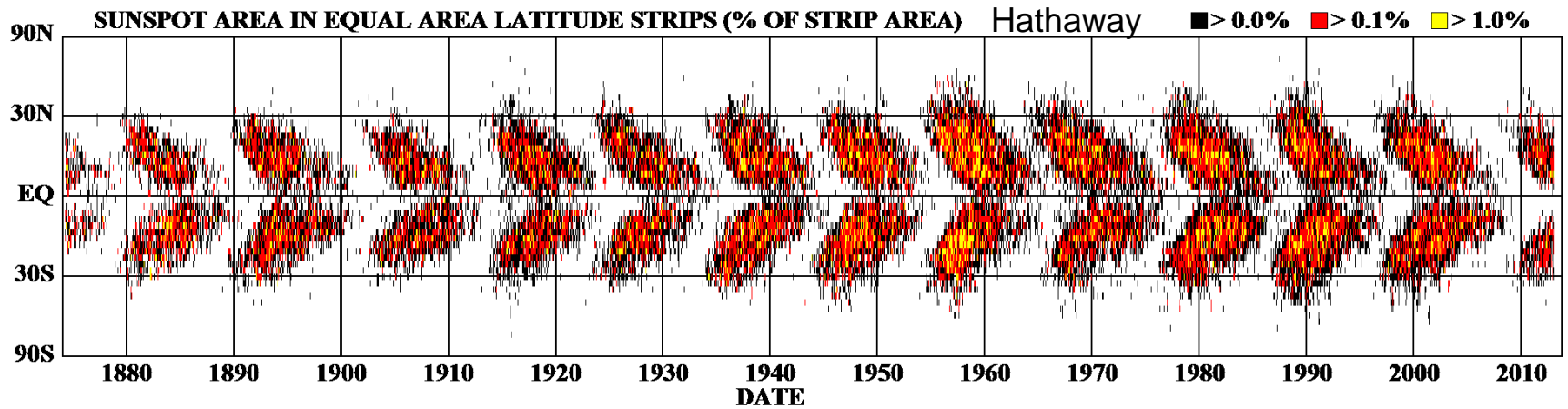
Svalgaard  
& Wilcox,  
1976

The shape of the modulation curve [alternating 'peaks' and 'flat tops'] shows the polar field signs.

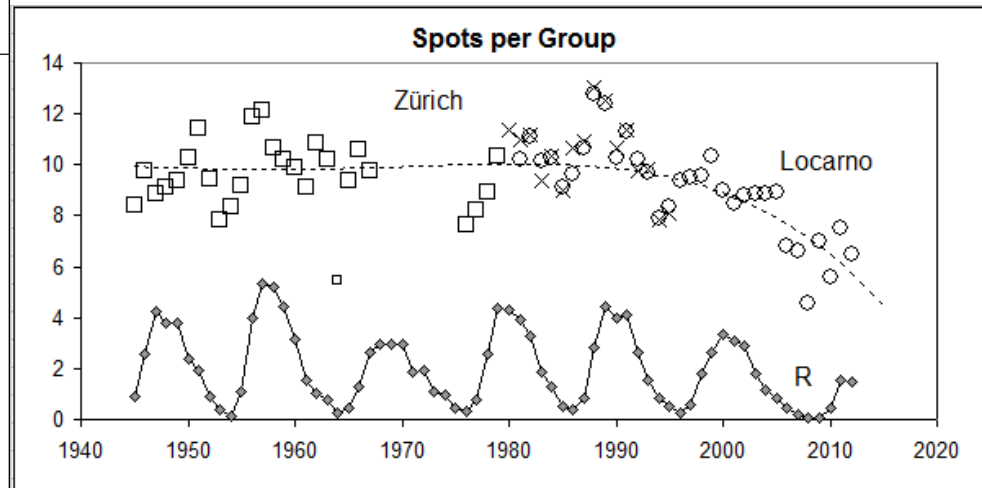
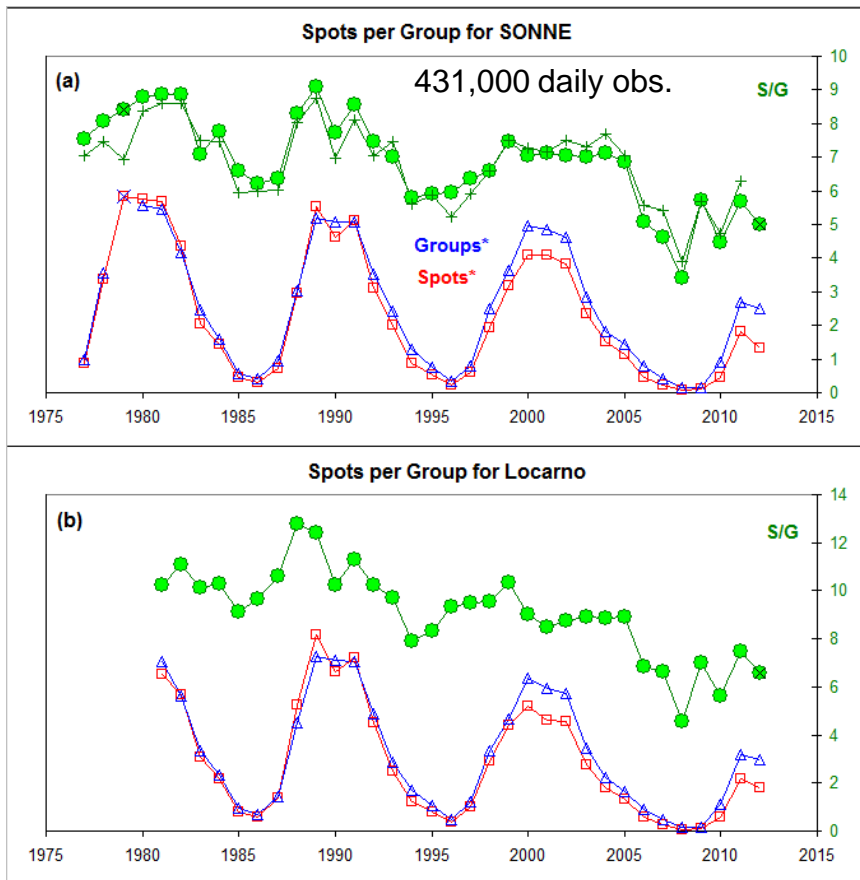
Ice cores contain a long record of  $^{10}\text{Be}$  atoms produced by cosmic rays. The record can be inverted to yield the cosmic ray intensity. The technique is not yet good enough to show peaks and flats, but might with time be refined to allow this.

Miyahara, 2011

# The Butterfly Diagram



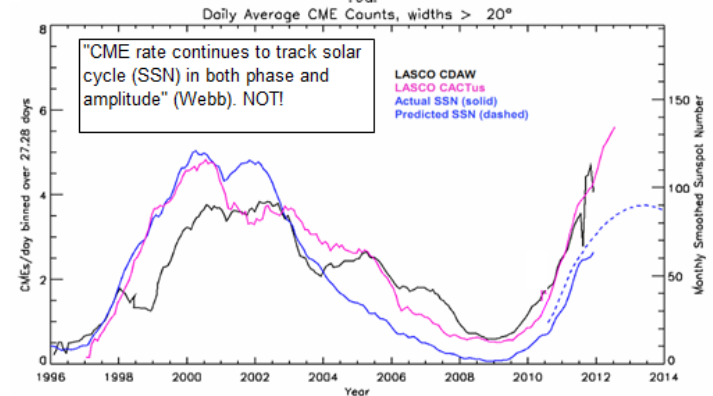
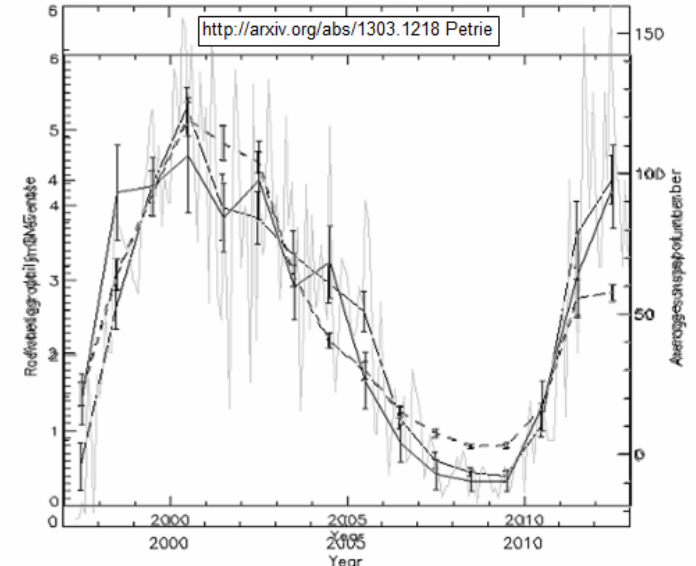
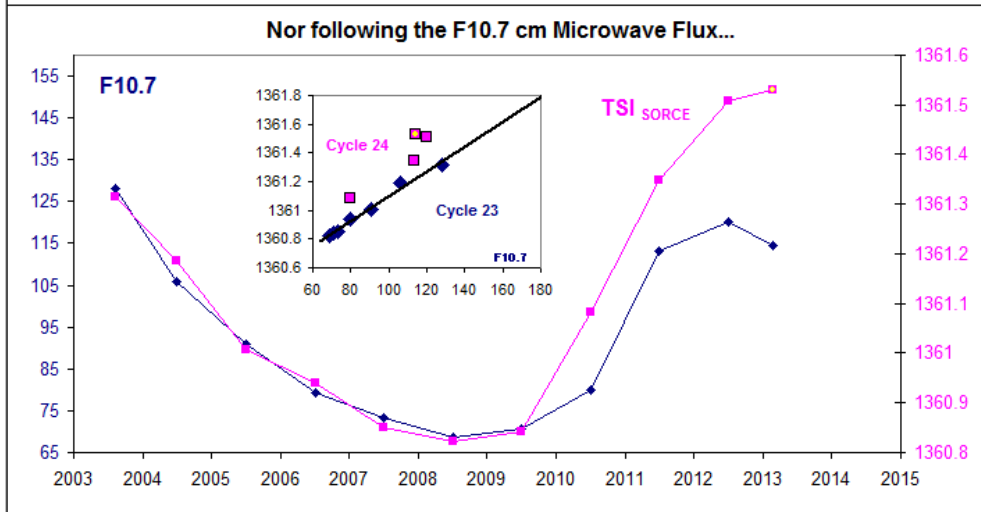
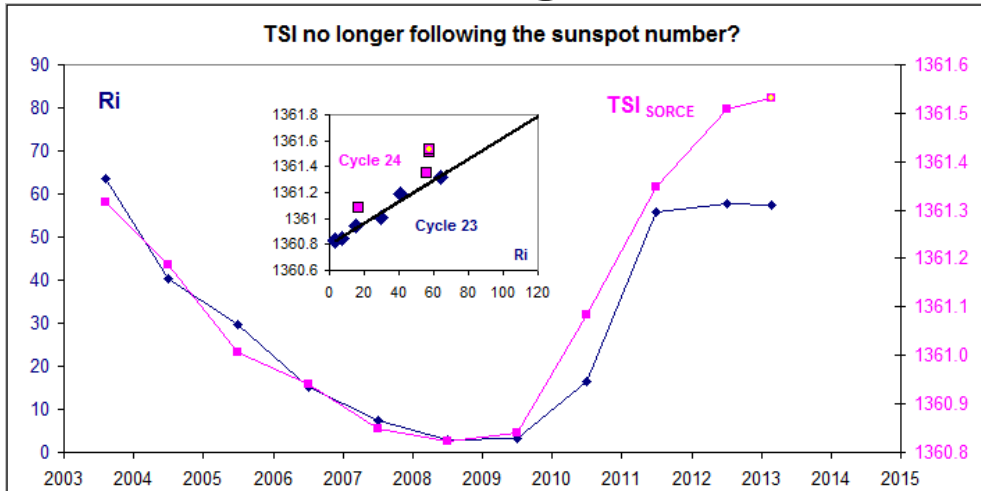
# We Observe Fewer Spots per Sunspot Group



There is a weak solar cycle variation on top of a general downward trend seen by all observers

As the sunspot number is primarily determined by the number of spots, the SSN will be too low as a measure of solar activity

# TSI and CME-rate no longer following the Sunspot Number



DWebb IAU GA12 JD03 22Aug2012

5

# Conclusions

- To enable practical prediction of solar activity synoptic observations in both space and time are indispensable
- The long-term evolution of the solar cycle can only be tracked [and eventually understood] by sustained and calibrated synoptic observations
- I must be preaching to the choir today