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.
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.

Active Region Count

Numbered Active Regions per Month

Prediction

Cycle 24 is beginning to look like Cycle 14

Cycle 24 Sunspot Number Prediction (October 2012)

D. Hathaway

SIDC

Lowest in a 100 years
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: Bremsstralung (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

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

Quantifying the Brightening:

Compute average brightness temperature in segment of a ring of constant width just inside the limb
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

Neil Sheeley, Andrés Muñoz-Jaramillo et al.
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.
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…

Zolotova et al., 2010
Cosmic Ray Modulation Depends on the Sign of Solar Pole Polarity

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

Ice cores contain a long record of 10Be 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

Svalgaard & Wilcox, 1976
The Butterfly Diagram

SUNSPOT AREA IN EQUAL AREA LATITUDE STRIPS (% OF STRIP AREA)

Hathaway
- > 0.0%
- > 0.1%
- > 1.0%

Schwabe

Arlt

Staudach

C) Arlt

1825 1867
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

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.