Solar Predictions Using Nobeyama Data

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SPRO2012, Nagoya University, 22 November 2012
Outline

- The hard-to-measure solar polar fields
- Polar brightness seen in Nobeyama 17 GHz
- Correlation with polar magnetic fields
- Importance of polar fields for solar wind
- Polar field and activity asymmetry
- Full-disk radiometry
- Too few sunspots forming
- A Grand Minimum looming?
Observing the Polar Magnetic Flux

LOS Solar Polar Field Strength vs. Time

Strong annual Bo variation [by factor of two]
Can we predict Solar Activity?

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!
So, the polar field precursor method seems to work
A different view of polar fields (?): Nobeyama Image of 17GHz Emission

\[ \nu_{17 \text{ GHz}} = \lambda_{1.76 \text{ cm}} \]

\[ \nu_e = B (\text{Tesla}) \cdot 28 \text{ GHz} \]

17 GHz is 3\text{rd} harmonic \( \nu_e \) for 2000 G

Beam width 10”

1. General Limb brightening
2. Active regions bright

A. Gyro-resonance is thought (?) to result as 3\text{rd} harmonic of 2000 G

B. Also Bremsstralung from hot atmosphere [10,000 – 13,000 K]
Bright Patches in Polar Regions

“A year ago…

Polar regions at brightness temperature 10,000 and 13,000 K. (333 K between contour lines).

Bright Patches Mark Strong Magnetic Fields (?)

“One still unresolved puzzle about the chromosphere is why at some frequencies (at least 10-100 GHz) the polar coronal holes appear brighter than the rest of the quiet Sun. There is some evidence that all coronal holes, even those not at the poles, are brighter”

http://web.njit.edu/~gary/728/

Lectures 10 & 11

“still-mysterious polar brightenings” Bastian et al. (1998, FASR)
Magnetic Flux in the Polar Caps

A year ago…

No Flux

Old Cycle Flux

Yesterday…

New Cycle Flux

No Flux

Answer: There is no flux judging from the 17GHz images

WSO Polar Fields

WSO

Average flux above 55°: First North reversing, now the South…

Question: At solar maximum, are the polar caps, when reversing field, covered with equal amounts of opposite polarity magnetic fluxes or isn’t there any flux?
Few or Weak Bright Patches at Solar Maximum, 2000

Only a few scattered, weak patches. So no magnetic flux of the kind that makes patches [~2000 G], thus the polar fields are not an equal mixture of opposite polarities. There aren’t any.

What does WSO measure? Not the ‘pepper and salt’
But at Solar Minimum, Oh Boy!

Rotate and long-lived
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

Suggesting that the ‘patches’ are the integrated effect of several individual sources along the line of sight.

Matching the polar patches to other features has not been successful.
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
This shows that the brightening is not just general limb brightening, but is concentrated at the pole just as the polar magnetic field (is thus due to the field?)
Excess $T_b$ over 10,800K, signed according to WSO polar field sign
Strong Rotational Modulation

Daily Means

Strong Rotational Signal = Longitudinal Structure
Rotational Period and 14-day Signal
Structure of the Polar Fields
Scattered strong elements concentrating at pole


The Polar Fields are Crucial for correct Modeling of the Source Surface Neutral Line

This is true both for the Potential Field Models and even more so for MHD models.

Current practice interpolates or ‘fills in’ polar fields from one measurement point per year [at large B₀].

Instead, Real Time Data from Nobeyama could be helpful.

Svalgaard & Wilcox, 1978 Review
"Corrected and Fitted Polar Fields"

If you don’t get the polar fields right you may miss a coronal hole and its high-speed stream.
Asymmetric Solar Activity

Hemispheric Asymmetry Sunspot Numbers

Hemispheric Asymmetry of Solar Activity
Comparing Cycles 14 and 24

Solar Cycle 14

Sunspot Number

Not corrected for Waldmeier Effect

Solar Cycle 24

Sunspot Number

(calculated from F10.7)

Sunspot Group Numbers for Cycle 14

Sunspot Group Numbers for Cycle 24

N  S

14

N  S

24
Observed Polar Field Reversals

Supersynoptic charts MWO

MWO: Roger Ulrich, 2012
Reversals due to Migration of Fields are no News


The main direction of motion of the migrating fields is eastward and poleward. The following polarity in each hemisphere usually predominates in the poleward drift of fields. The polar magnetic field measurements record this quantized migration of fields (Undoubtedly, as has already been pointed out, this drift of following polarities was responsible for the reversal in polarity observed in the polar fields during the last maximum.)
“This just in:”
Large (-) Flux Injection Heading for the South Pole

Todd Hoeksema, 2012: “It wouldn't surprise me if this is the region that eventually moves poleward to reverse the stalled southern pole”
Full-disk Microwave Flux

Nobeyama 1.0, 2.0, 3.75, 9.4 GHz
Toyokawa 1950s – 1994.5

Penticton 2.8 GHz
Ottawa 1947.2 – 1991.5
Nobeyama Measurements

On both sides of ‘F10.7’
All observations are highly correlated, especially the ones [2000, 3750] flanking 2800 MHz.
This allows us to scale all observations to 2800 MHz

The scaled values match each other very well, except 9400 MHz where the solar activity component is rather noisy.
If the calibrations of the data have not changed over time, the ratios between the scaled fluxes and the 2800 MHz flux should be constant = 1

Within the scatter, the ratios appear to be lower than 1 before 1991 and higher thereafter. We interpret that as a 2% downward jump in Pentiction compared to Ottawa. We therefore reduce the Ottawa 2800 MHz flux by 2%.
After the correction, we rescale 2000 and 3750 MHz again to 2800 MHz, and construct a composite

\[
F_{2800} = 4.56239 \times 10^{-6}x^3 - 7.93355 \times 10^{-4}x^2 + 1.13869 \times 10^0x + 1.10179 \times 10^1
\]

\[R^2 = 0.9939\]

Note how the minimum values do not vary with time (within green box)
There is a well-known, strong [slightly non-linear] relationship between the solar flux and the sunspot number (black diamonds). This relationship seems to have changed in solar cycle 23 (red circles).

same conclusion reached by others, e.g. Tapping (2010)

Because of the agreement between the Japanese and Canadian measurements we must conclude that the change is in the Sun
Plotting the reconstructed Sunspot Number (pink) from the composite 2800 MHz flux using the 1947-1990 relation shows the increasing discrepancy with the SIDC ‘official’ sunspot number (blue) the past ~15 years:

As the Japanese and Canadian microwave data support each other so well, we must ask: how sure are we of the calibration and stability of the sunspot number?
Sunspot Number Observed and Reconstructed from Composite Flux Series

SSN Observed
SSN From 2800 Flux
Is the SSN Always a Good Measure of Solar Activity?

Since ~1990 we record progressively fewer sunspots than expected from observations of F10.7 microwave flux.
We see fewer sunspots for given MPSI

MPSI is the sum the absolute values of the magnetic field strengths for all pixels where that value is between 10 and 100 gauss. The sum is then divided by the total of number of pixels in the magnetogram.

Same result if Ca II or Mg II index is used
Confirmation Using MDI Magnetograms

The STARA Algorithm does not perform well for very small spots [box, under ~1500 G]
From 1998 to 2012 Livingston and Penn have measured field strength and brightness at the darkest position in umbrae of 3148 spots using the large Zeeman splitting of the infrared Fe 1564.8 nm line.
Spot Umbral Intensity [Temperature] and Magnetic Field Changing
Evolution of Distribution of Magnetic Field Strengths

Sunspots form by assembly of smaller patches of magnetic flux. As more and more magnetic patches fall below 1500 G because of the shift of the distribution, fewer and fewer visible spots will form, as observed.
Conclusion

Recent work has argued that either a full blown grand minimum or much weaker cycles are likely in upcoming decades. If the Sun indeed is near a transition from a state of relatively vigorous to relatively low activity, a comprehensive observational record of Cycle 24 (both resolved and disk-integrated) is paramount. In any event, current observations (e.g., of the polar fields, solar wind and cosmic ray fluxes) suggest that Cycle 24 will be unlike any of the four prior cycles of the space era.

The Nobeyama observations form a homogenous and extensive archive and must be continued in order to cover this transition into potentially uncharted territory.
Abstract

The size of a solar cycle seems to be controlled by the strength of the polar fields at the preceding minimum, which therefore provides a good precursor for the prediction of the next cycle. Measurements of the magnetic fields at the poles are difficult because of severe projection effects. It appears that the magnetic field elements with strong vertical fields have a signature in the radioheliographic maps in 17 GHz produced at Nobeyama. These observations thus provide an alternative method of determining the polar fields, without the projection problems of the direct measurements of the magnetic field. Now that minimum is past, we focus on the upcoming polar field reversals which we already know will be highly asymmetric, with the reversal of the South Pole seemingly much delayed with respect to the North Pole. Such asymmetry is important for the question in dynamo theory of to what degree the two hemispheres are coupled (or as it appears - de-coupled). We’ll discuss the asymmetry in this and several previous solar cycles relating it to hemispheric asymmetry in sunspot production and decay.