Predictions for the Next Solar Maximum

Frank Eparvier

eparvier@colorado.edu

LASP
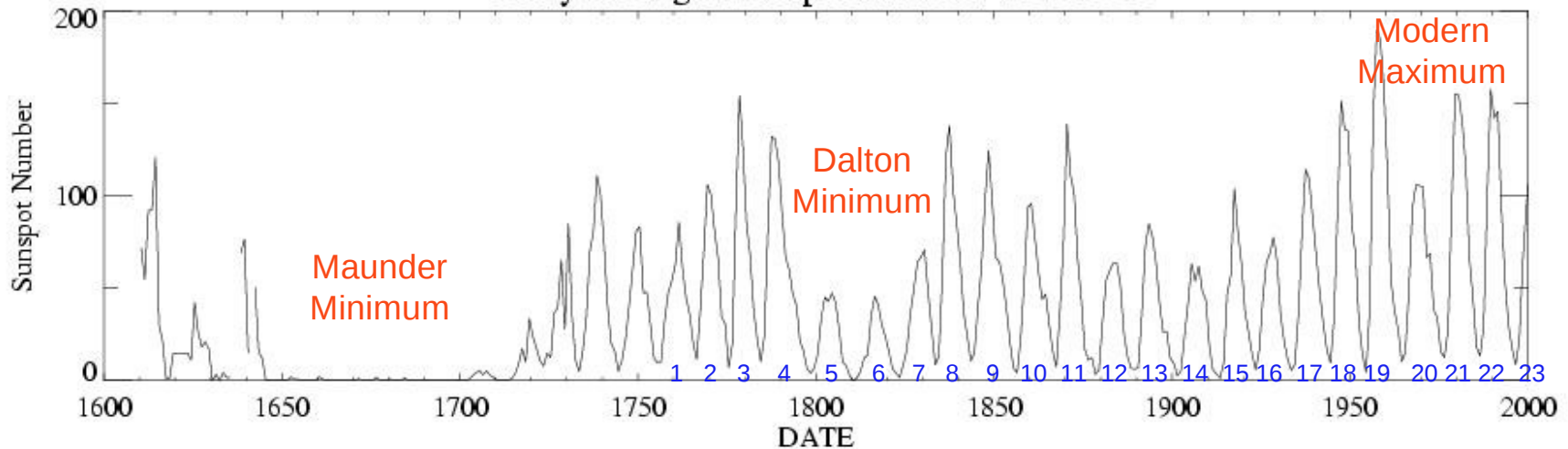LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS
UNIVERSITY OF COLORADO AT BOULDER

"If you're not confused, you're not learning."

D. Bell, circa 1981
Neil Armstrong High School
Neenah, Wisconsin

The Solar Sunspot Cycle Record

Yearly Averaged Sunspot Numbers 1610-2000

Sunspot image from NASA MSFC, with additional labels added.

- There is a longer record of SSN than any other directly measured solar property (because they're relatively easy to see & count)
  - Sunspots counted since 1610
  - Solar Sunspot Cycles numbered with first starting in 1755

- SSN is well correlated with other space weather phenomena:
  - Solar irradiances in general
  - Rate and energy of solar flares
  - Rate of CMEs
  - Cosmic Rays (anti-correlation)
  - Geomagnetic Activity (shifted forward by ~3 yrs to declining phase of cycle)

Other Solar Cycle Indices

- Solar 10.7 cm radio irradiance (F10.7 index)
  - Measured from ground since 1947
  - Good correlations with ultraviolet irradiances
- Space-based Indices:
  - Better correlations with irradiances that drive space weather
  - Only measured in recent decades (mostly since the late 1970s)
  - eg. HI Ly-a (121.6 nm), Mg II C/W ratio, TSI
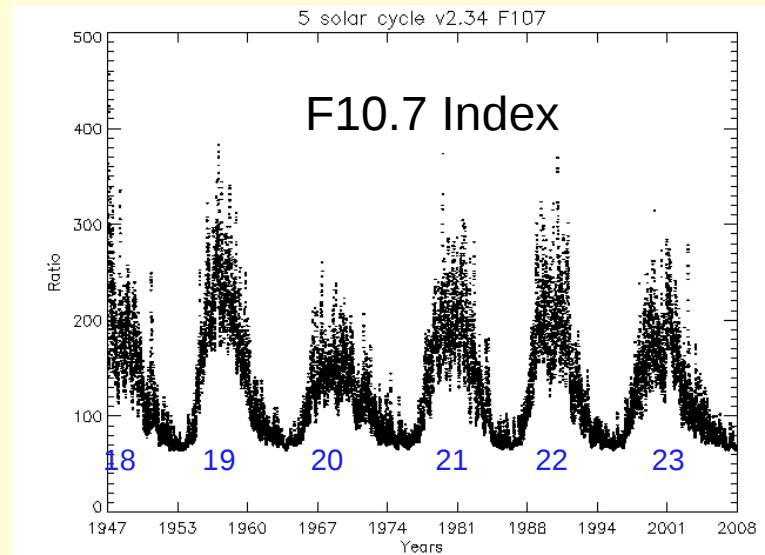
F10.7 plot from Space Env. Tech., with additional labels added.
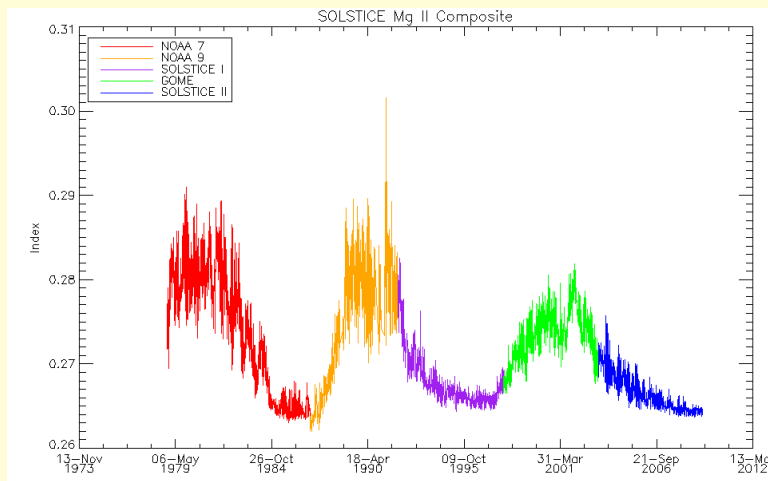

MgII C/W Ratio composite plot from M. Snow, 2009.
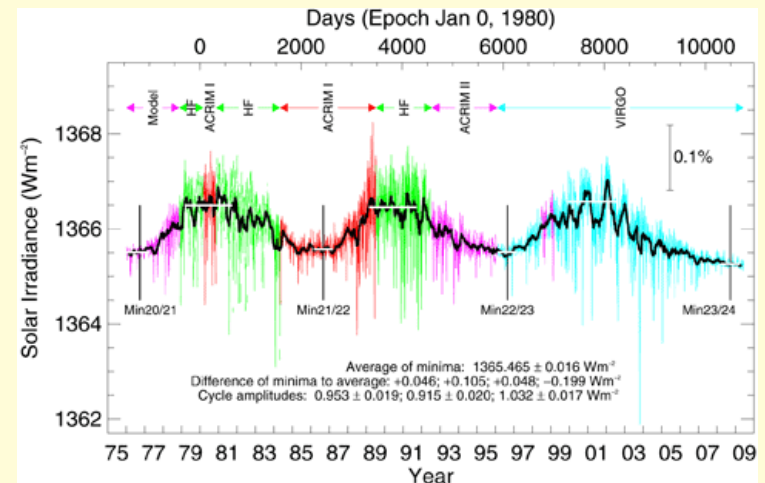
TSI composite plot from C. Frölich, 2009.

Solar Cycle 24 Predictions Panel

- International group formed to generate the **"official"** prediction for NOAA, NASA, and the International Space Environment Services (ISES)
  - This is only the 3rd solar cycle with such a prediction panel formed
  - SC24 Panel has 12 voting members (with additional consultants)
  - Charged with predicting for SC24:
    - Timing of maximum and minimum
    - Strength of cycle in 10.7 cm radio flux ($F_{10.7}$) and Sunspot Number (SSN)
- SC24 Panel Timeline
  - October 2006: First Meeting
  - March 2007: Consensus Statement
  - June 2008: Prediction (non)Update
  - May 2009: Prediction Update

Panel Member	Affiliation
D. Biesecker (chair)	NOAA SWPC
M. Dikpati	NCAR HAO
K. Dowdy	USAF
D. Hathaway	NASA MSFC
T. Hoeksema	Stanford Univ.
E. Kihn	NOAA NGDC
H. Lundstedt	Swedish Inst. Space Sci.
D. Pesnell	NASA GSFC
M. Rast	Univ. Colorado
L. Svalgaard	ETK Inc.
R. Thompson	IPS Australia
R. Van Der Linden	Royal Obs. Belgium
J. Kunches (ex officio)	NOAA SWPC
O.C. St. Cyr (ex officio)	NASA GSFC

Ask 12 Scientists: Get 54 Answers
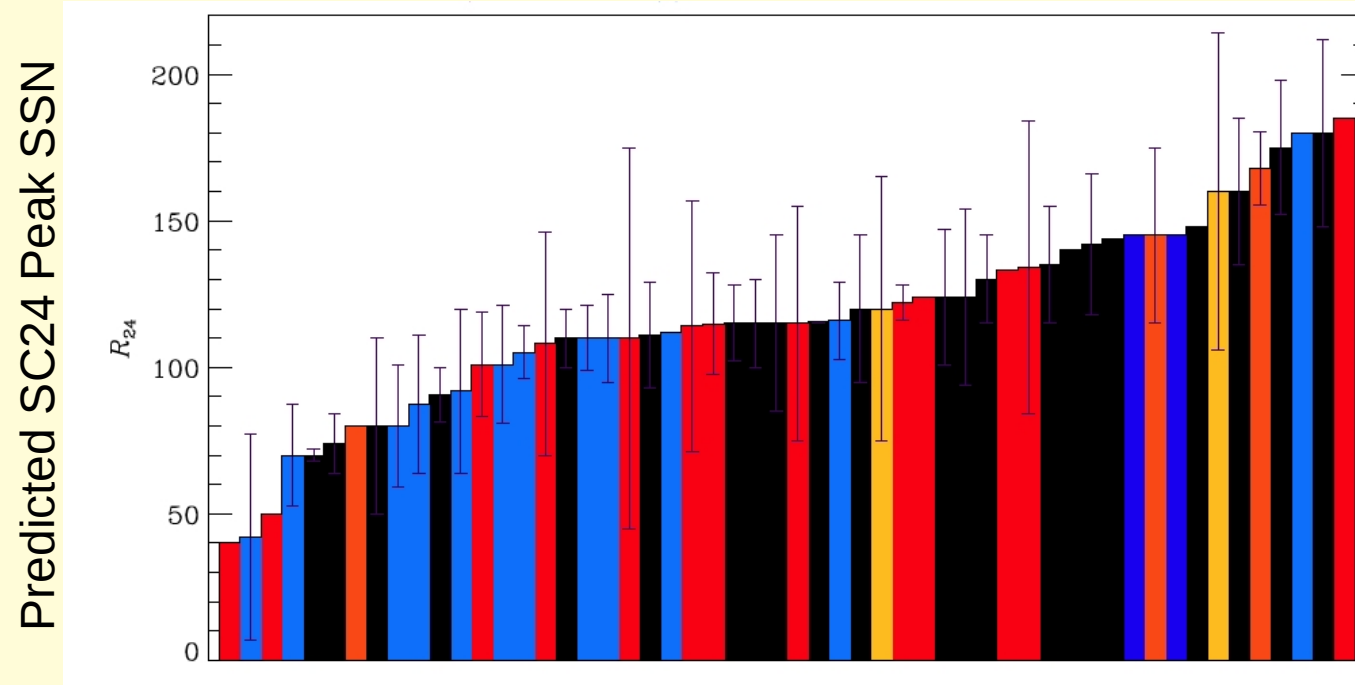
Empirical Methods
◆ **Precursor (22)**
◆ **Climatology (13)**
◆ **Recent Climatology (2)**
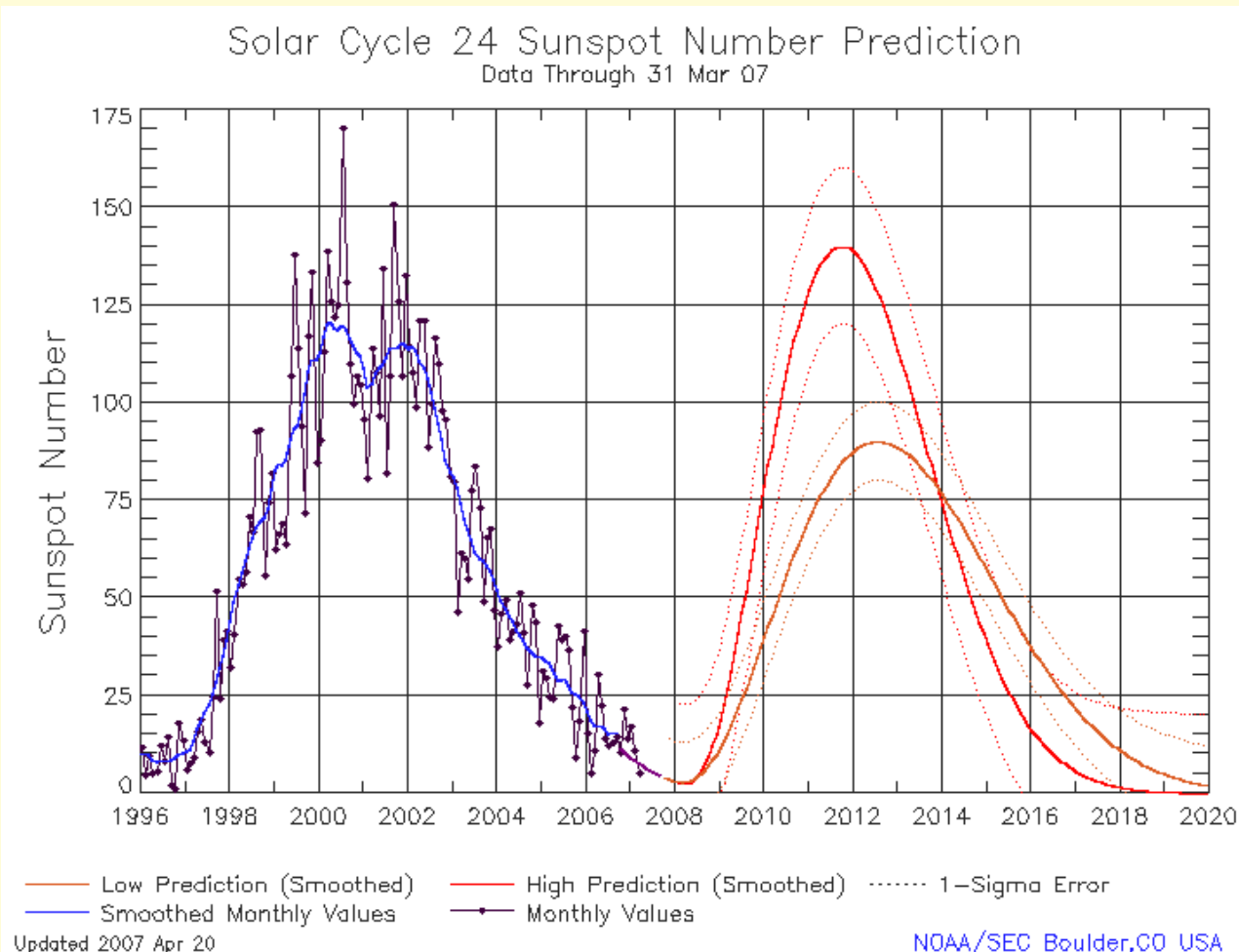◆ **Neural Network (2)**
◆ **Spectral (12)**

Physics-Based Methods*
◆ **Dynamo Model (3)**

* SC24 was the first panel to have solar dynamo models available for making predictions.

2007 Panel Prediction: A Split Decision

Unable to reach a single consensus, the panel released two predictions.

Solar Cycle 24 Sunspot Number Prediction
Data Through 31 Mar 07

Legend:
- Low Prediction (Smoothed)
- High Prediction (Smoothed)
- ······ 1−Sigma Error
- Smoothed Monthly Values
- Monthly Values

Updated 2007 Apr 20

NOAA/SEC Boulder, CO USA

- <u>Solar Min:</u>
  - Mar 2008 (±6 mo)
- <u>Low SC24 Peak:</u>
  - SSN = 90 (±10)
  - Aug 2012
- <u>High SC24 Peak:</u>
  - SSN = 140 (±20)
  - Oct 2011

Note: The mean of cycles 1-23 predicts SSN = 115±40 on Apr 2011.

SC24 as Prediction Discriminator

- Methods of prediction:
  - Cycle averages (recent or long term)
  - Trends or periodicities in cycle sizes (even-odd)
  - Statistical analysis (regression techniques)
  - Precursors using information from other cycle indicators besides sunspots or irradiances
  - Dynamo models constrained by data

- The actual behavior of SC24 should help determine the validity of the many empirical prediction techniques and may discriminate between dynamo models.
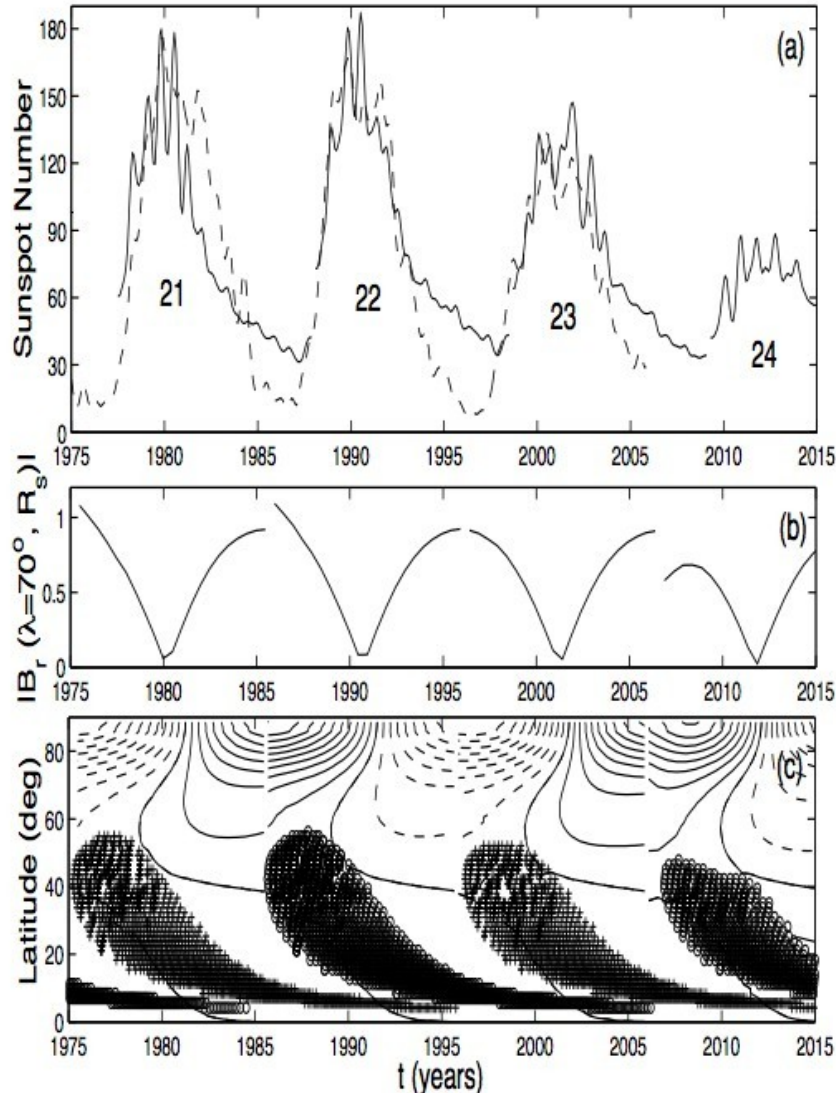
Dynamo Model Predictions (1)
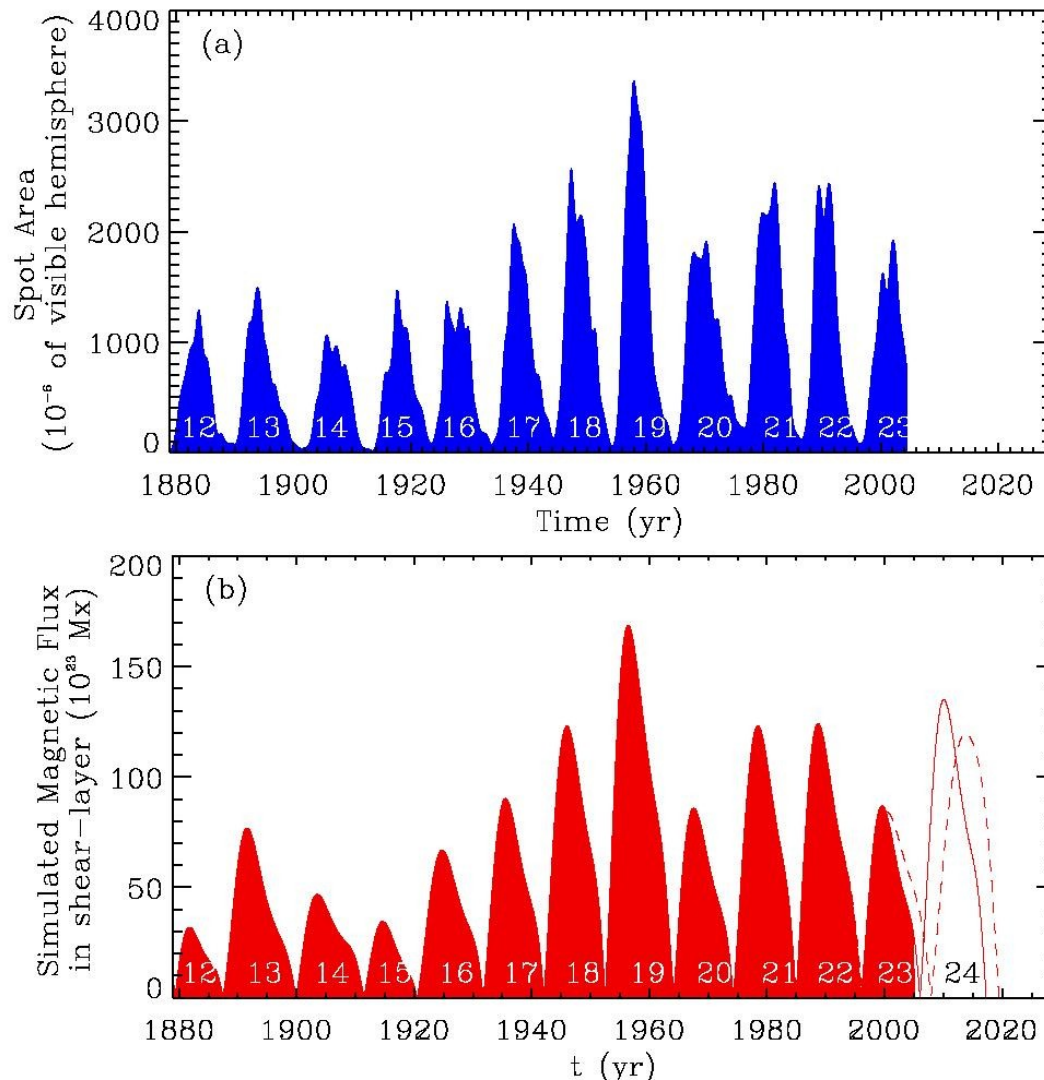
- **Dikpati, deToma, and Gilman (*GRL, 33*, 2006)**
- Flux transport dynamo models magnetic flux "conveyor belt" equator to pole at surface then pole to equator inside Sun
- Uses sunspot area and position data as constraints
- Previous cycles' "information" is remembered inside Sun and influences current cycle
- **2006 Prediction for SC24:**
  - **Larger than average**
  - **SSN = 180 ± 15**
- **2009 Update: stand by prediction of large cycle**

Dikpati, et al., 2006.

Dynamo Model Predictions (2)

Choudhuri, et al., 2007

- **Choudhuri, Chatterjee, and Jiang, (*Phys. Rev. Lett, 98, 2007*)**
- Another flux transport dynamo model
- Uses solar polar magnetic field measurements as constraints
- Treats diffusion differently than Dikpati, et al.
- **2007 Prediction for SC24:**
 - **Smaller than average**
  - **SSN = 75**

Precursor Predictions

- Precursor methods can be more than just "numerology" as they use indicators that are related to the physical processes that dynamo models try to capture.
  - Geomagnetic Indices
    - Influenced by solar activity so an indirect measure of solar magnetic activity
  - Solar Polar Magnetic Fields
    - Direct measure of magnetic flux transport
  - Combined techniques
- Precursor predictions initially spanned the board
- Predictions made after solar minimum arrived became consistent:
  - **SC24 will be small and late**

How is SC24 Unfolding?

- By 2009 it was clear that minimum hadn't been reached in March 2008.
- It was also uncertain whether the rising phase of SC24 had even started.

ISES Solar Cycle Sunspot Number Progression
Data Through Sep 09
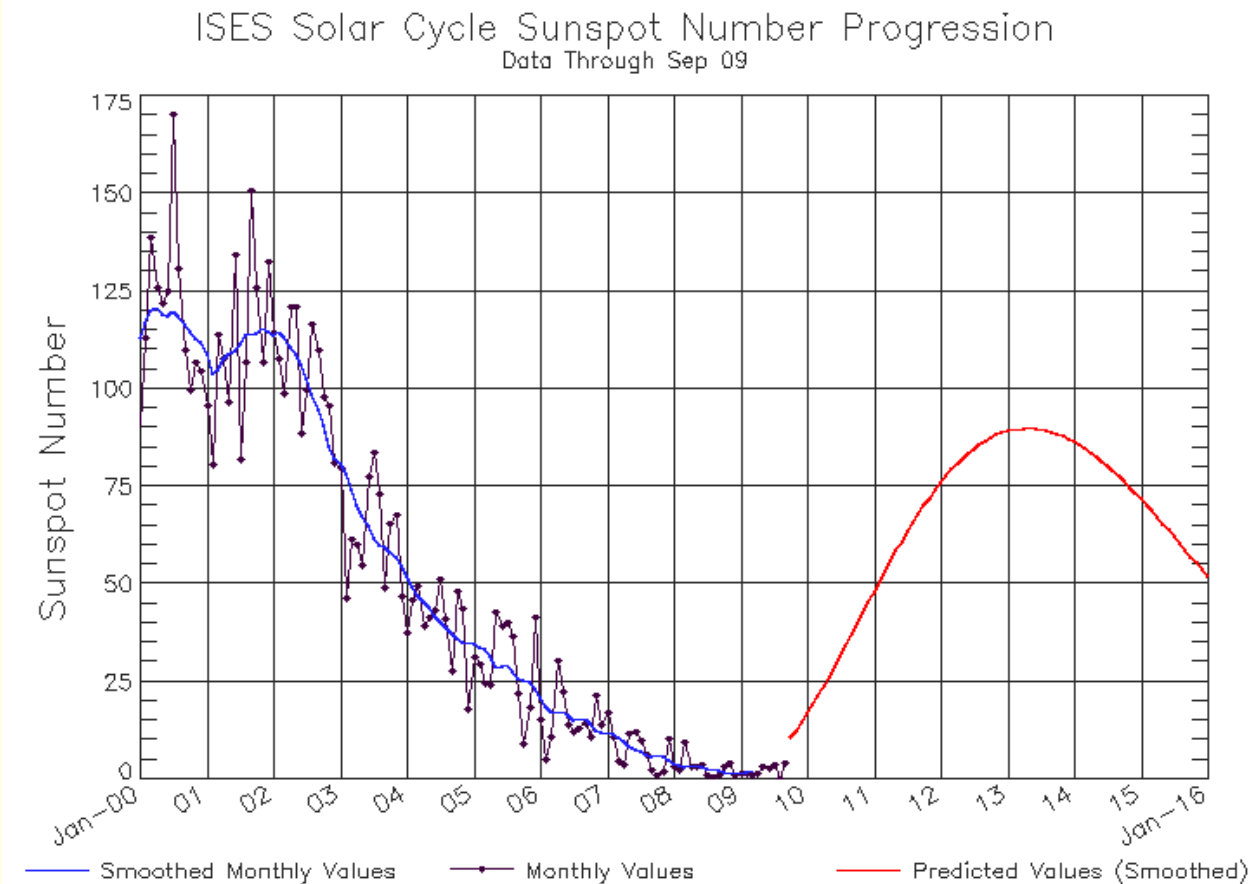
Updated 2009 Oct 6

NOAA/SWPC Boulder,CO USA

Updated consensus Apr 09: SC24 would be **late and low** High prediction abandoned

No official update since, but sticking with **late and low**

What have we learned?

- The current minimum has been long, so expect the **next maximum to be later** than initially predicted.

- Precursor techniques using polar fields and geomagnetic indices seem to be reliable, but only if you wait until true solar minimum. **They predict a small SC24.**

- Flux Transport Dynamo Models give us hope we may someday understand the Sun well enough to predict it using physics, but we're probably not quite there yet.

Bottom line:
The Sun will do what the Sun will do.