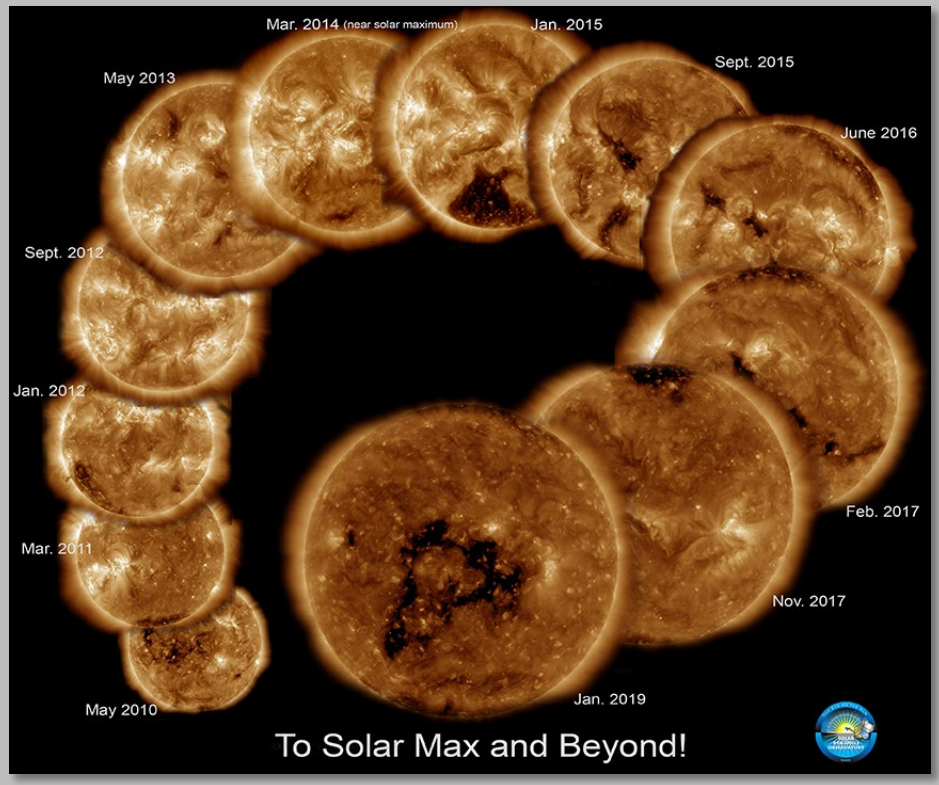
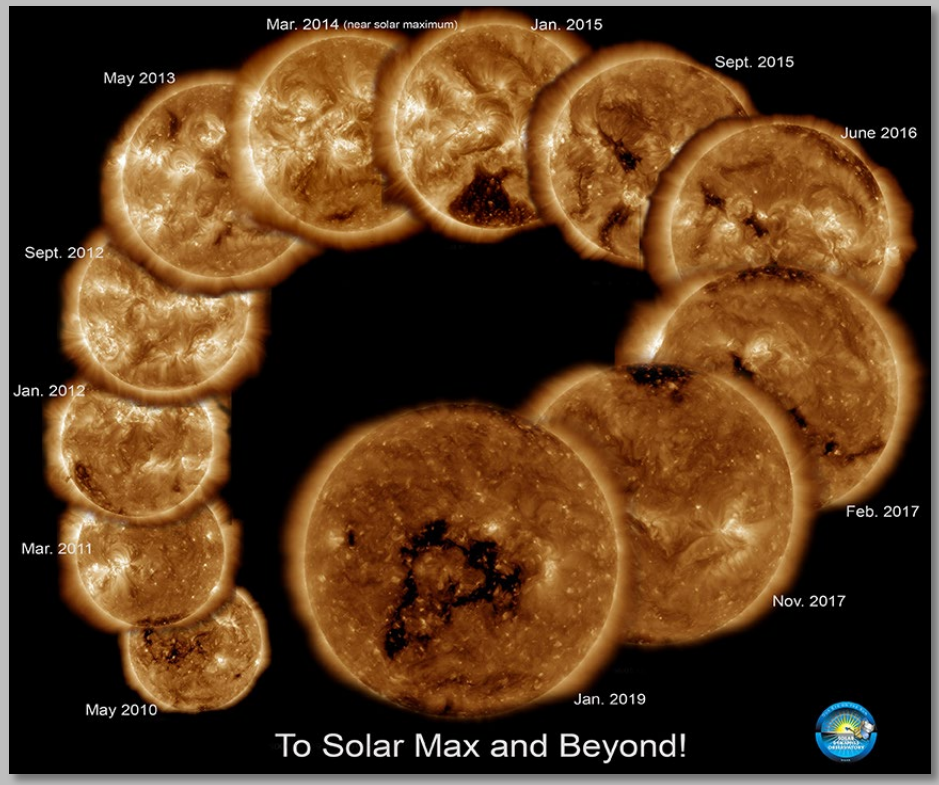
How Well Can We Predict Solar Cycle 35?



W. Dean Pesnell

NASA, Goddard Space Flight Center

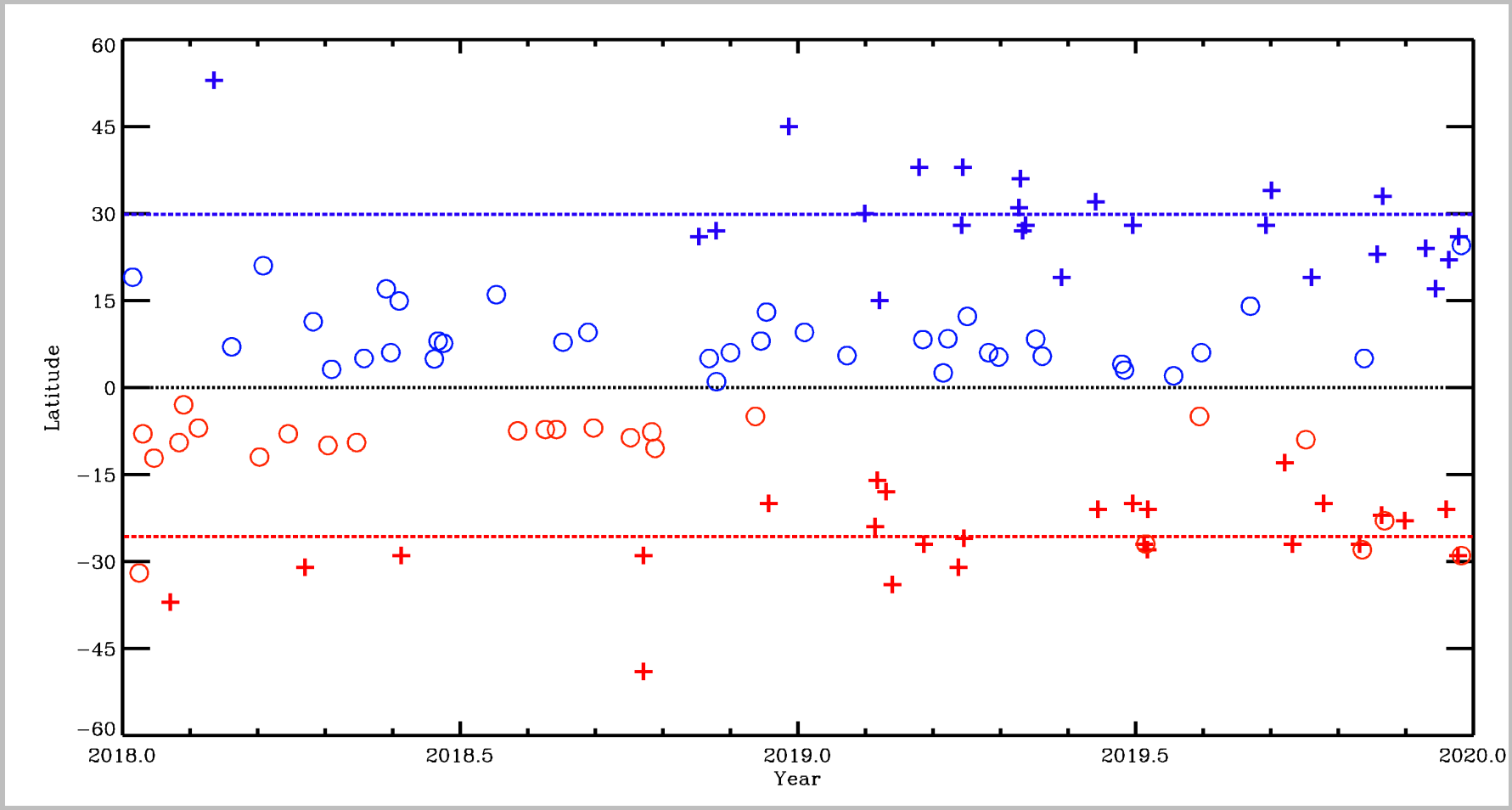
Solar Cycle 25: Era of the Error?



W. Dean Pesnell

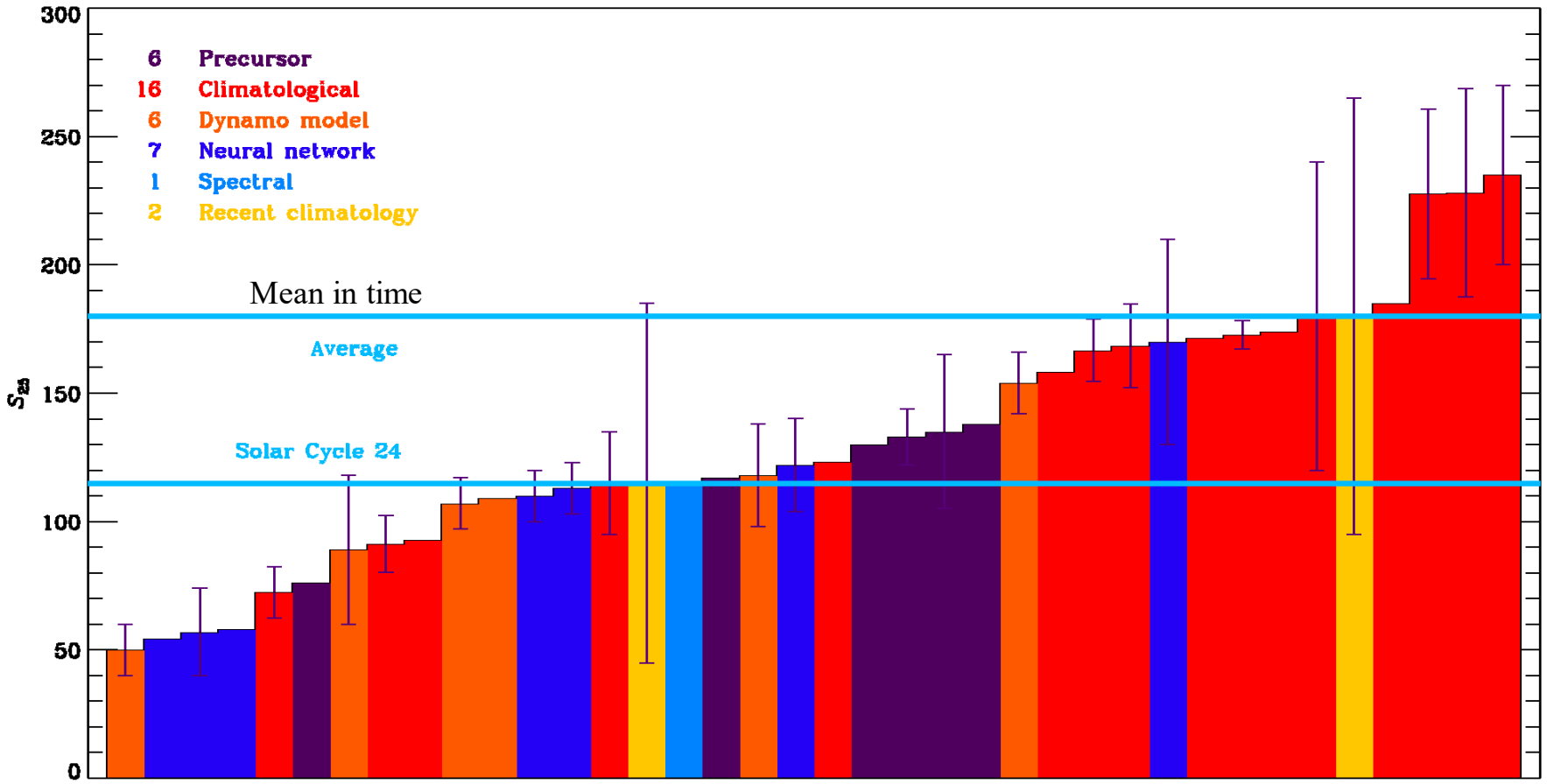
NASA, Goddard Space Flight Center

Solar Cycle 25 is Here!



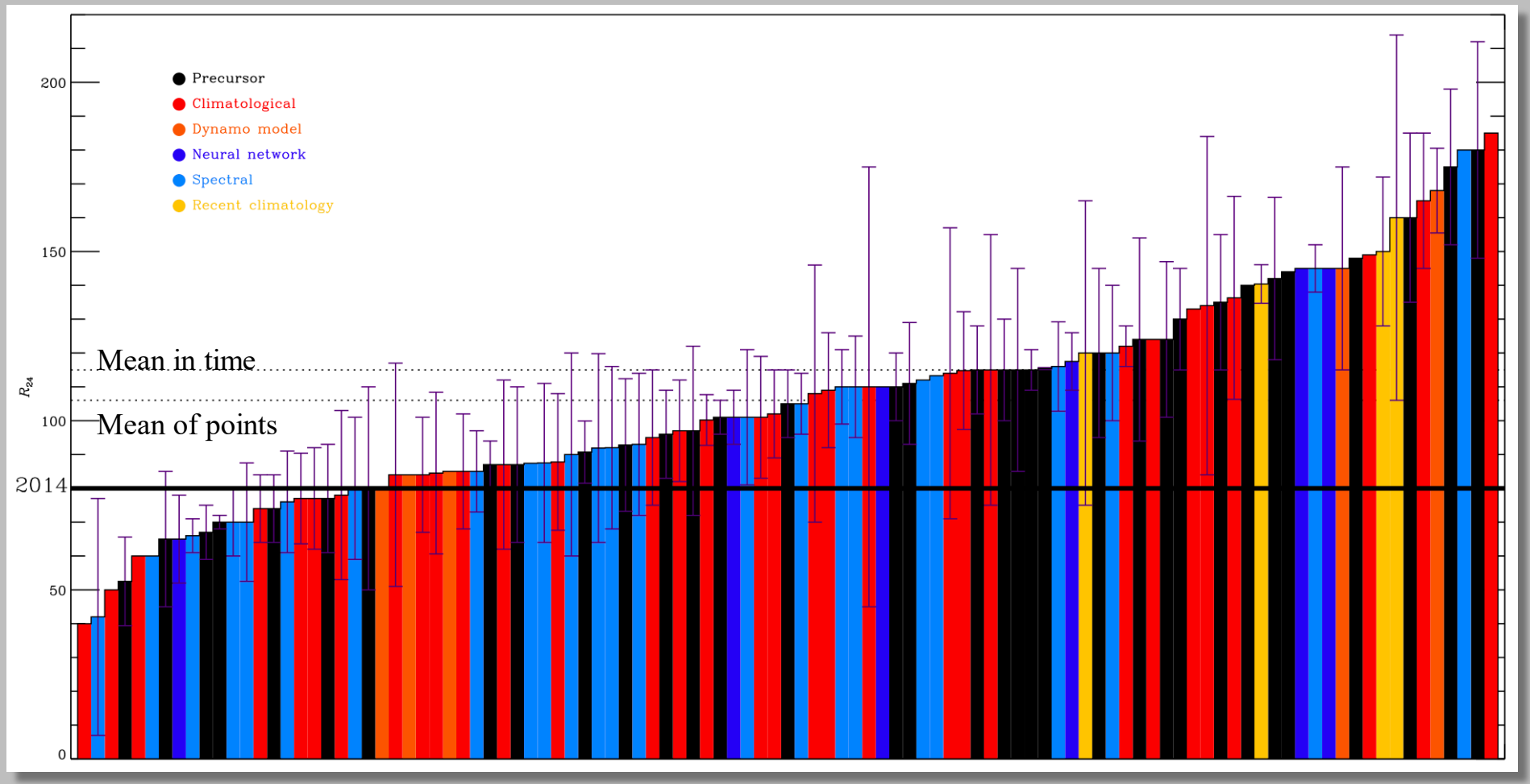
A butterfly diagram of ARs (circles, from SolarCycleScience.org and NOAA) and SC 25 ephemeral regions and ARs (plus signs, from solen.info/solar/cycle25_spots.html and courtesy of Jan Alvestad)

38 Predictions of Solar Cycle 25



38 predictions of the amplitude of Solar Cycle 25 from around the world. Range -2.2 σ – 0.92 σ (excluding vanishing solar activity.)

105 Predictions of Solar Cycle 24



The predictions of the amplitude of Solar Cycle 24. Range -1.9 σ – 1.8 σ (excluding vanishing solar activity).

Sun Climate, Tucson, Jan 2020

Pesnell, *Space Weather*, 2016

NASA & Solar Cycle Predictions

One of NASA's mandates is to build spacecraft that operate in the hostile environment of space. Getting it right means understanding what *can* go wrong and then building and operating payloads so it doesn't.

Two areas of concern:

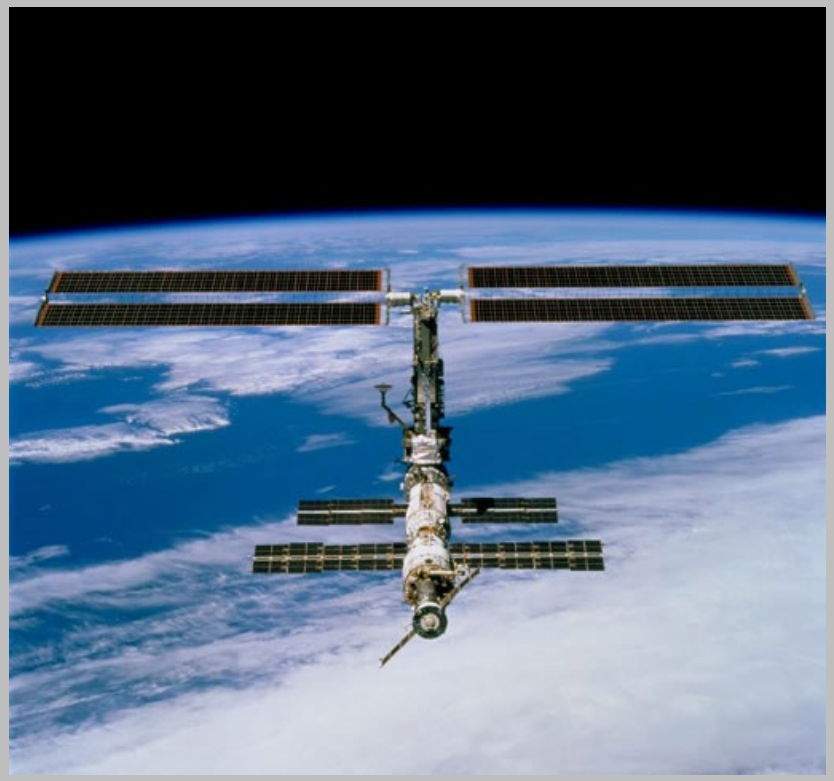
- Orbital decay
- Radiation exposure and damage

The HST orbit decays at 1-2 km/year

NASA & Solar Cycle Predictions

Mission designers and operators want solar cycle predictions today. The predictions must be believeable even they aren't physically correct. They like F10.7 but want a standard variable. That standard is now *S*.

Among the biggest users are people who worry about collision avoidance.



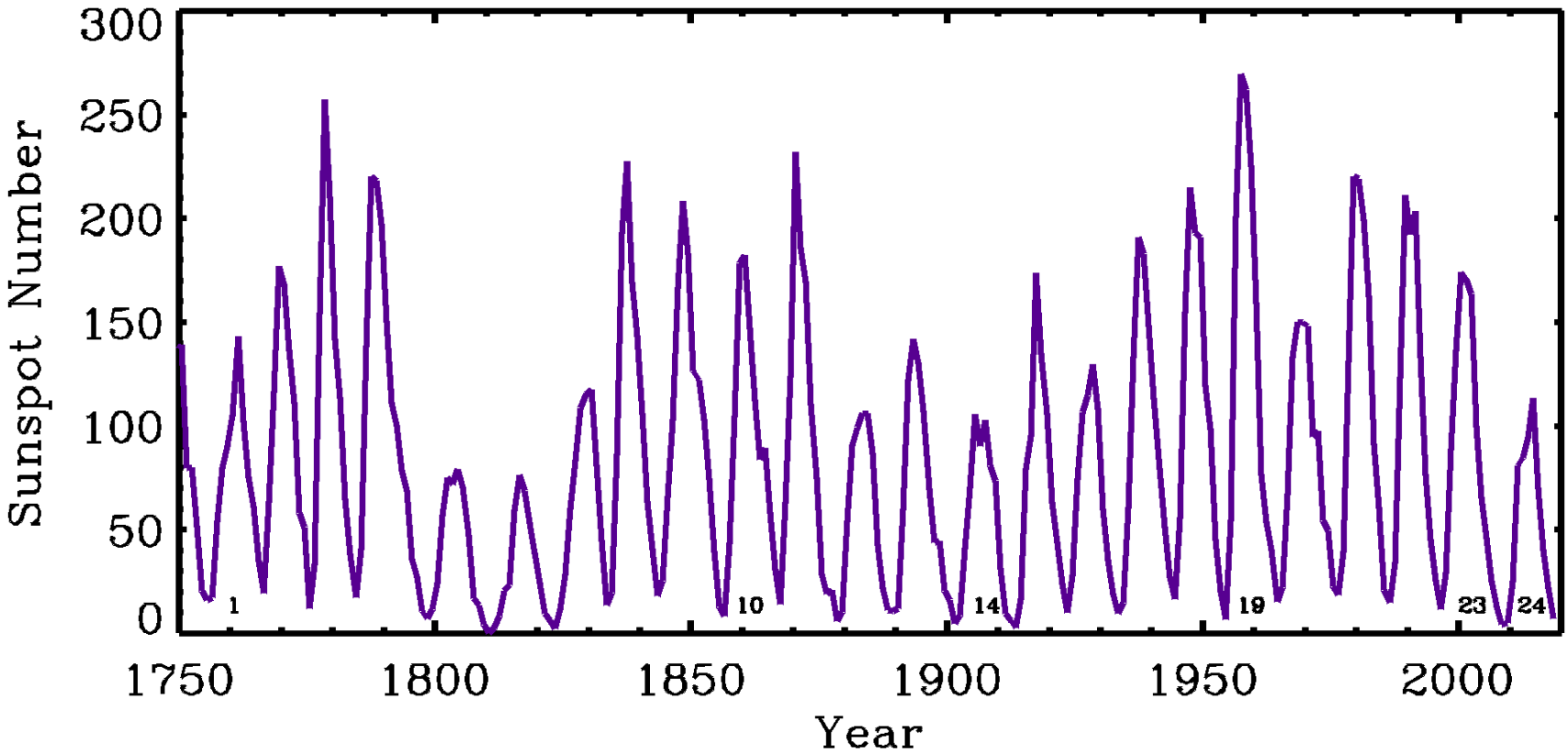
The ISS orbit decays at 0.5-2 km/month

Hams & Solar Cycle Predictions

Several million ham radio operators just lived through the worst sunspot cycle for propagation in the history of HF radio.

Sun Climate, Tucson, Jan 2020

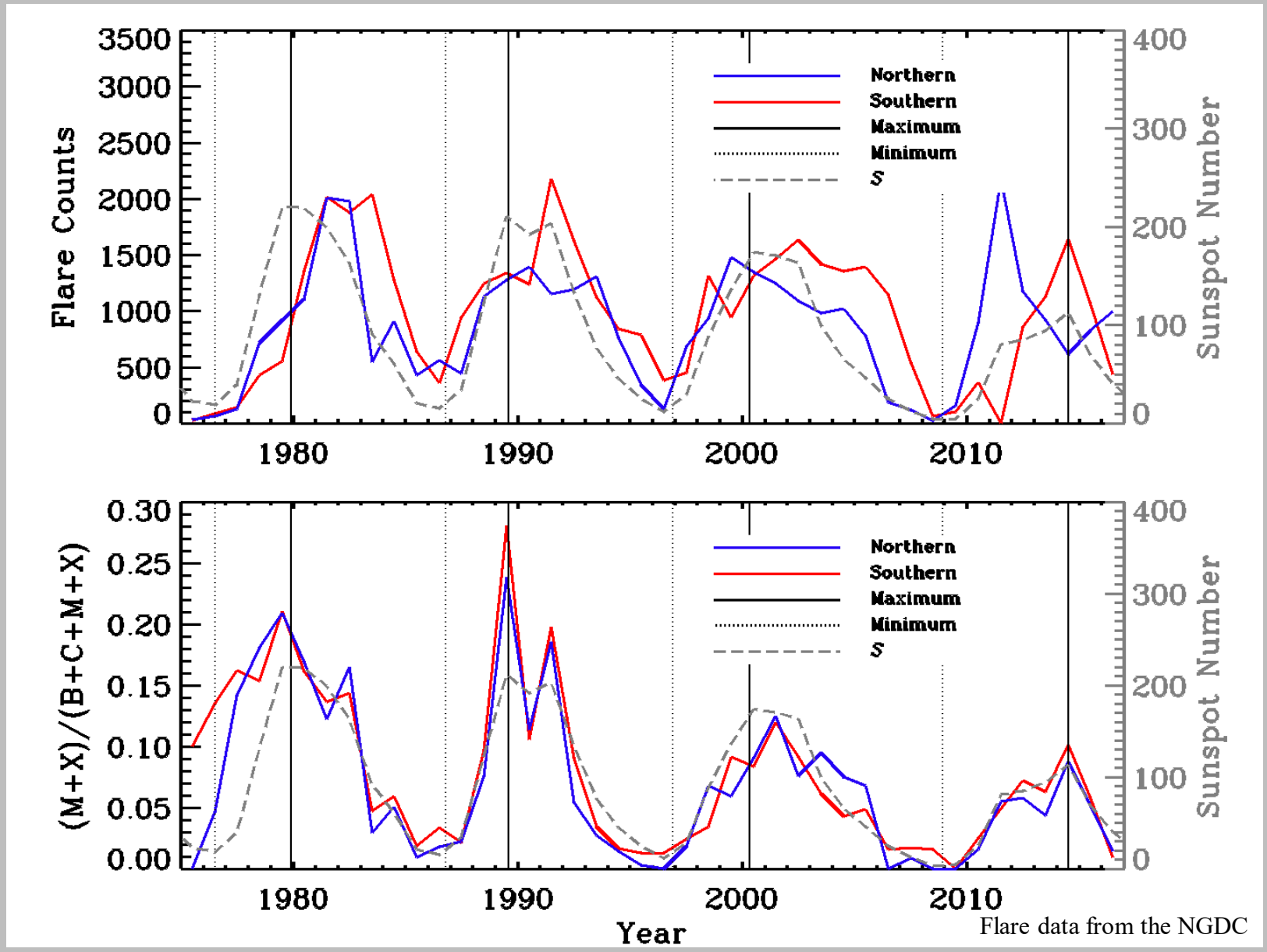
What to Predict? Sunspot Number?



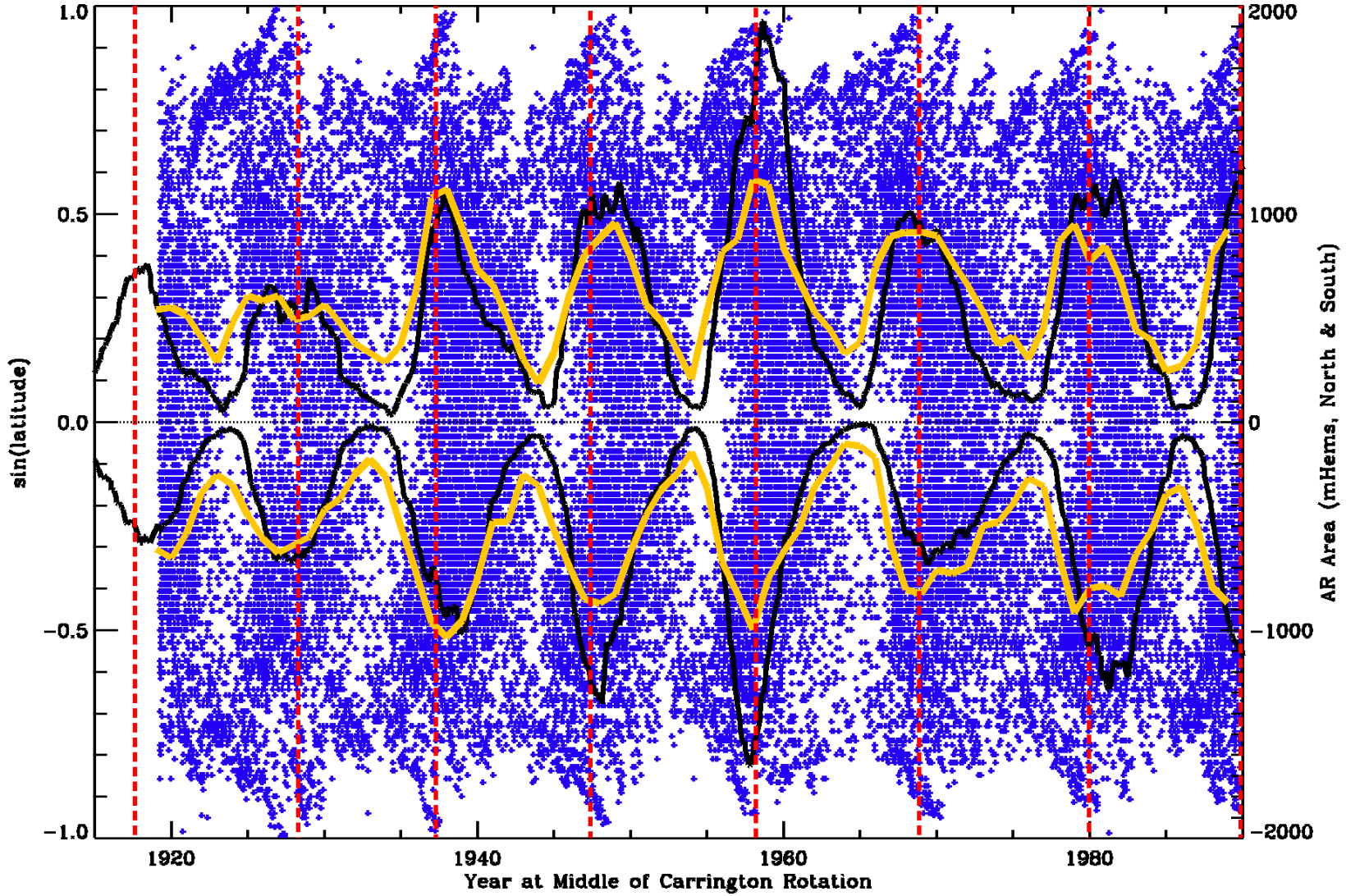
Data courtesy of the SIDC

Solar Cycle 10: Carrington Event
Solar Cycle 14: Similar to Solar Cycle 24
Solar Cycle 19: Largest cycle in record
Solar Cycle 23: My first predicted cycle

What to Predict? Flares?



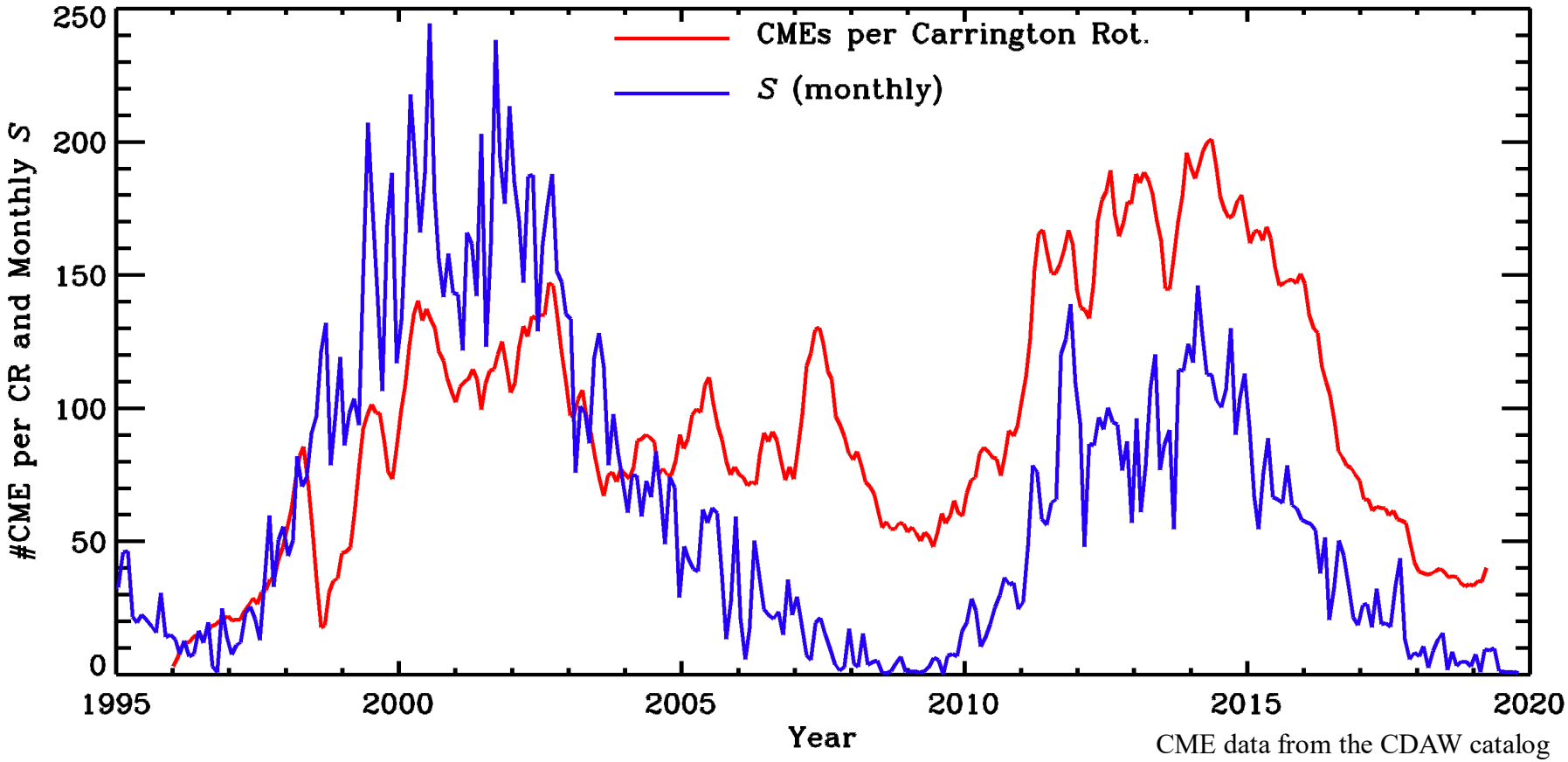
What to Predict? Filaments?



Filament data courtesy of the Carte Synoptiques, Area data courtesy of Hathaway

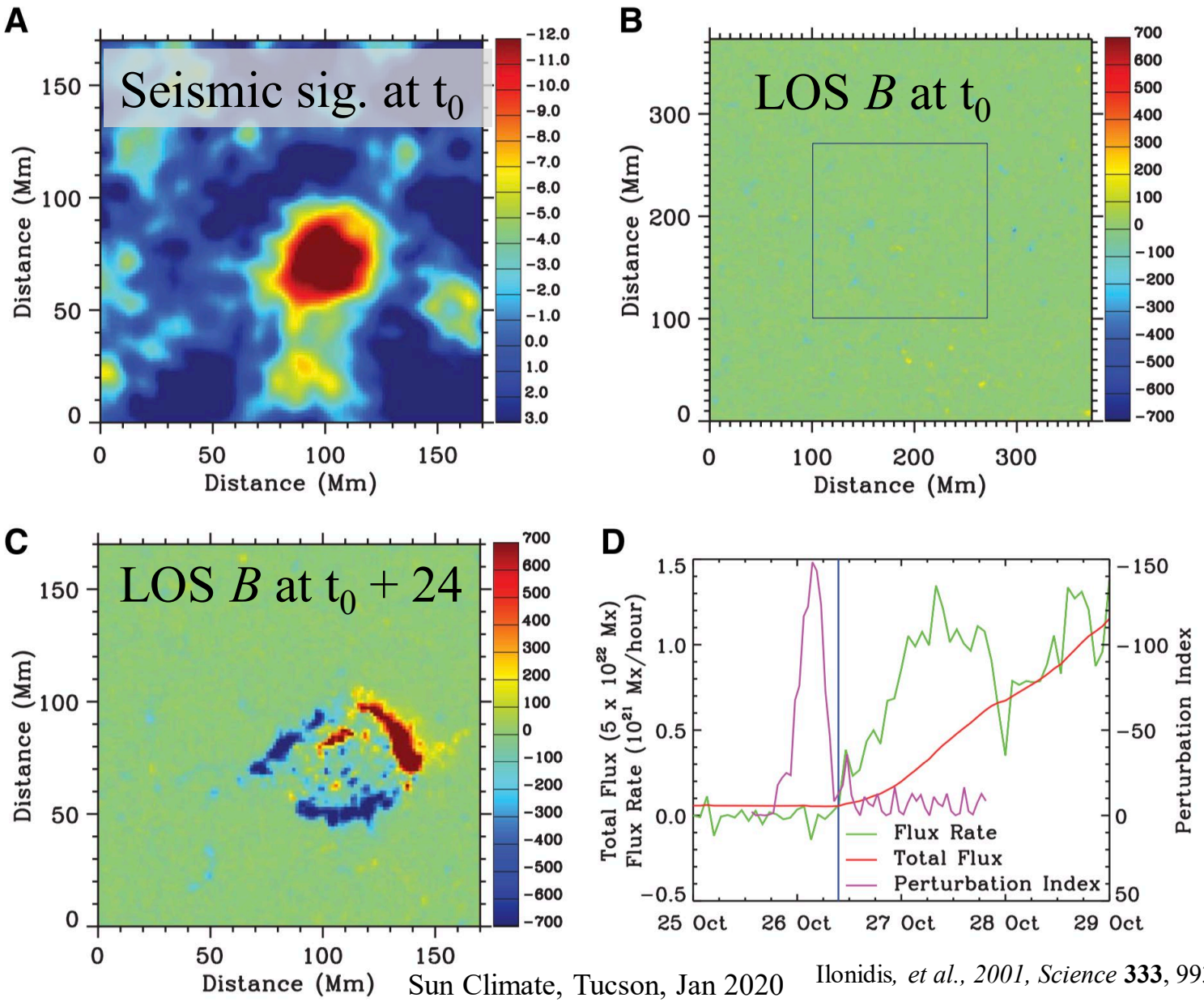
Filaments are phased by AR area but count is not as well-correlated

What to Predict? CMEs?



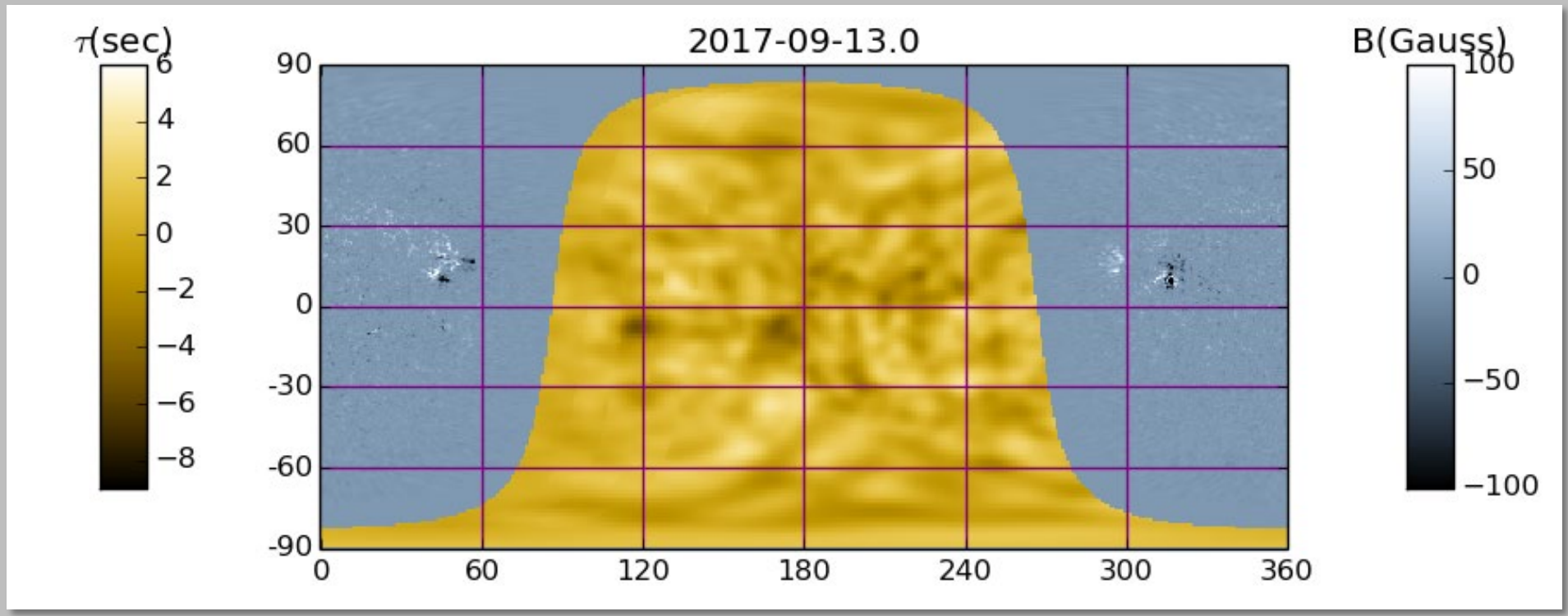
Uncorrected CME rate is well-correlated with fine structure. Systematic corrections show the rate follows *S* (Wang and Colaninno, 2014, *ApJ*, **784**, L27). Poor time coverage.

What Timescale to Predict? Days?



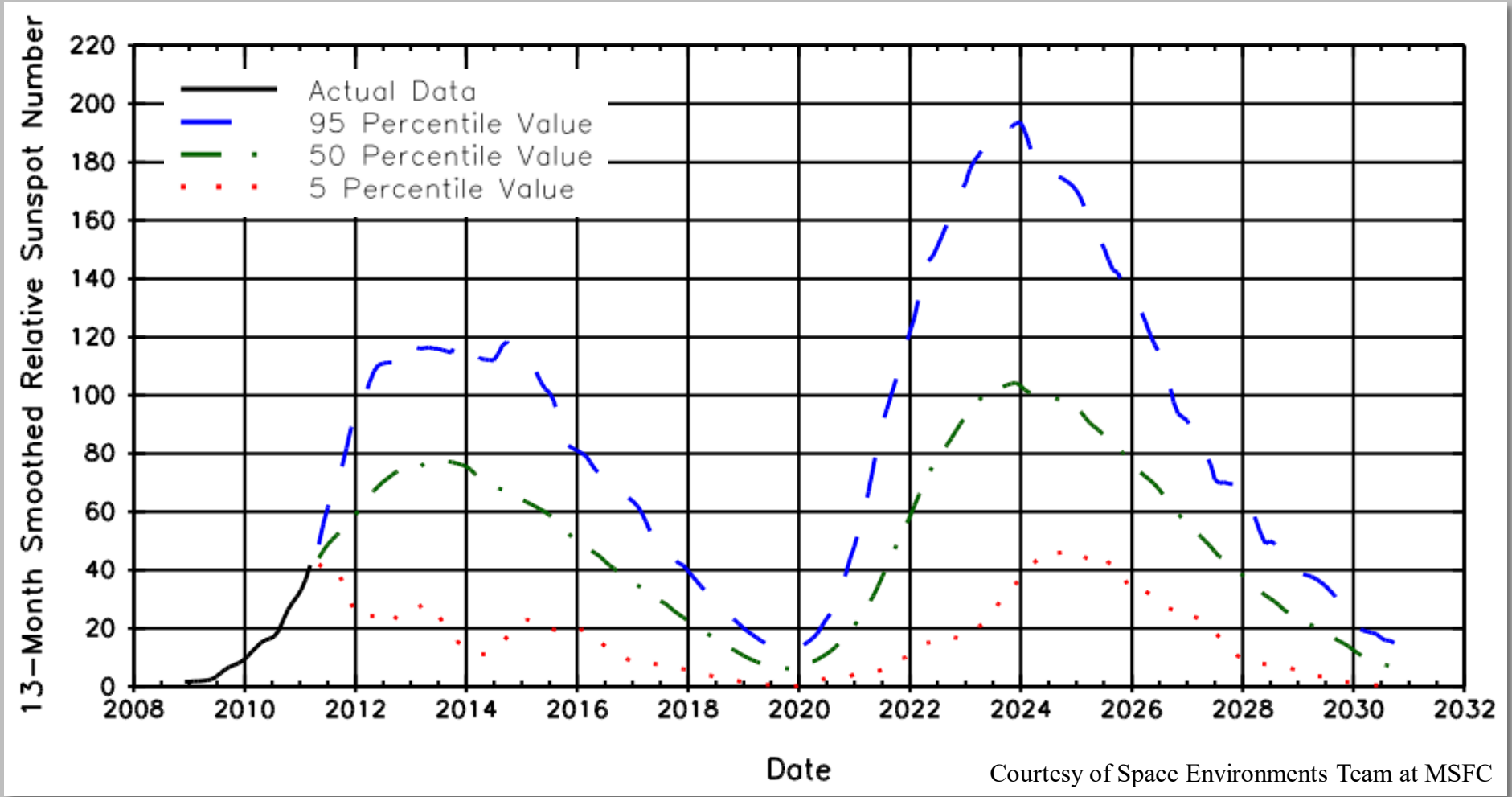
Ilonidis, *et al., 2001, Science* **333**, 993

What Timescale to Predict? Days?



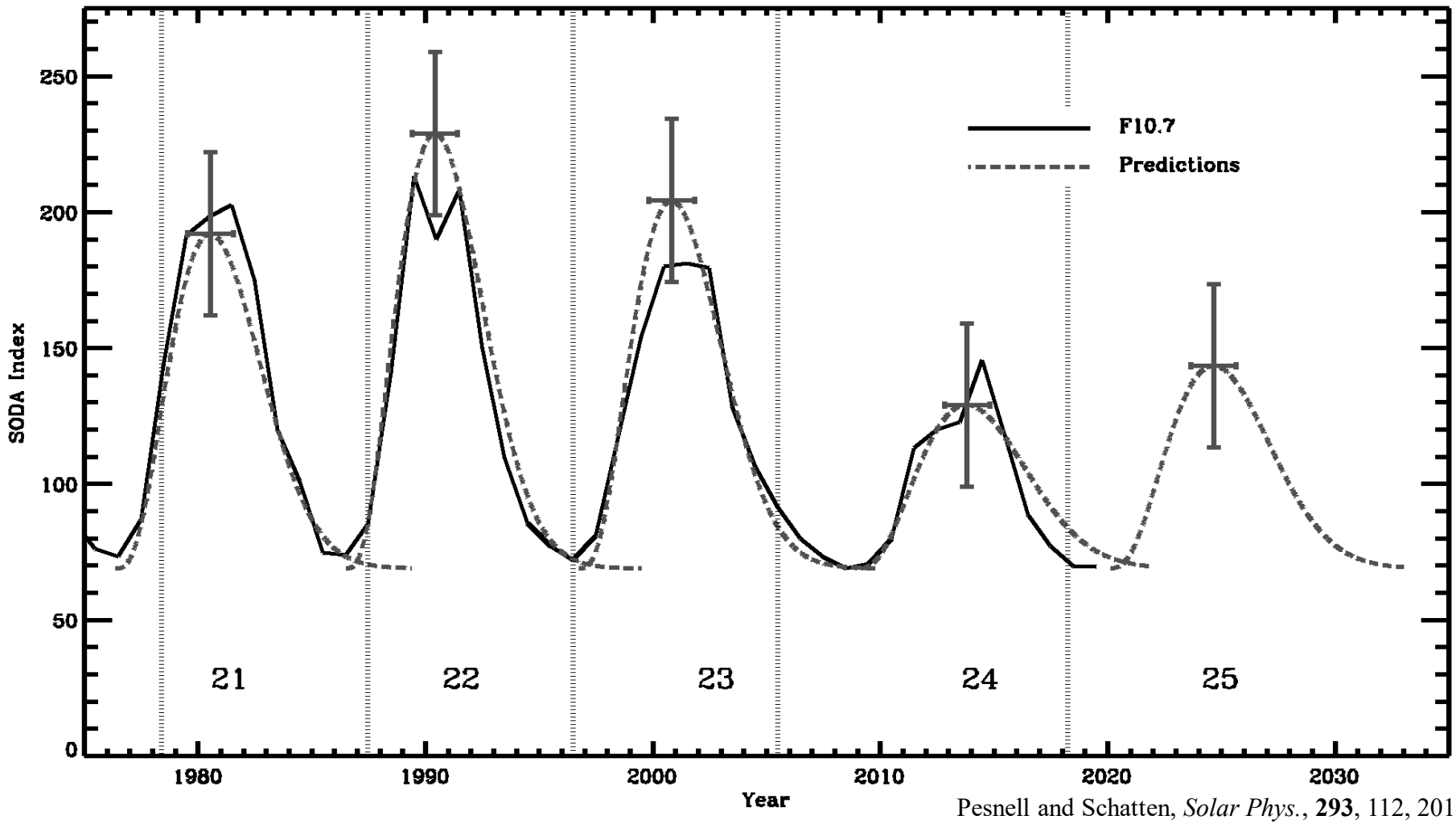
Courtesy of the HMI Science team

What Timescale to Predict? Months?



The Lincoln-McNish method provides fairly-accurate extrapolations of solar activity out to several years (Suggs, *et al.*, 2011)

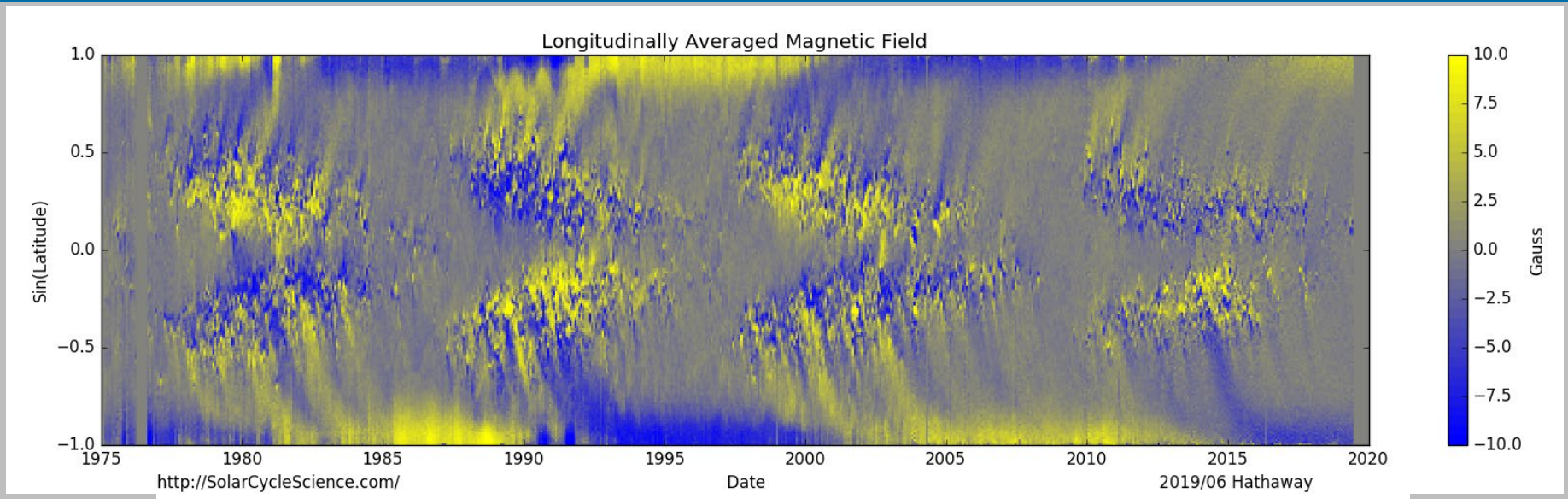
What Timescale to Predict? Years?

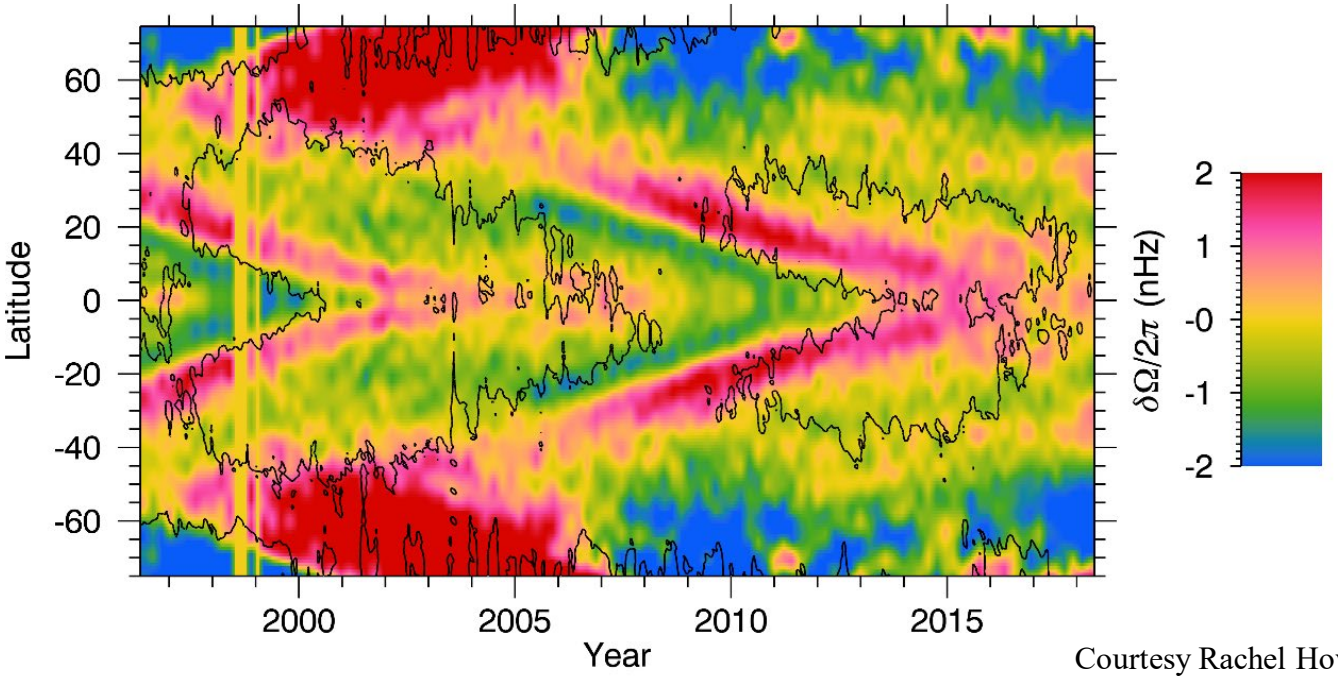


Pesnell and Schatten, *Solar Phys.*, **293**, 112, 2018

Polar field precursors (like SODA) have done a reasonable job of predicting the peak of four cycles, often before minimum.

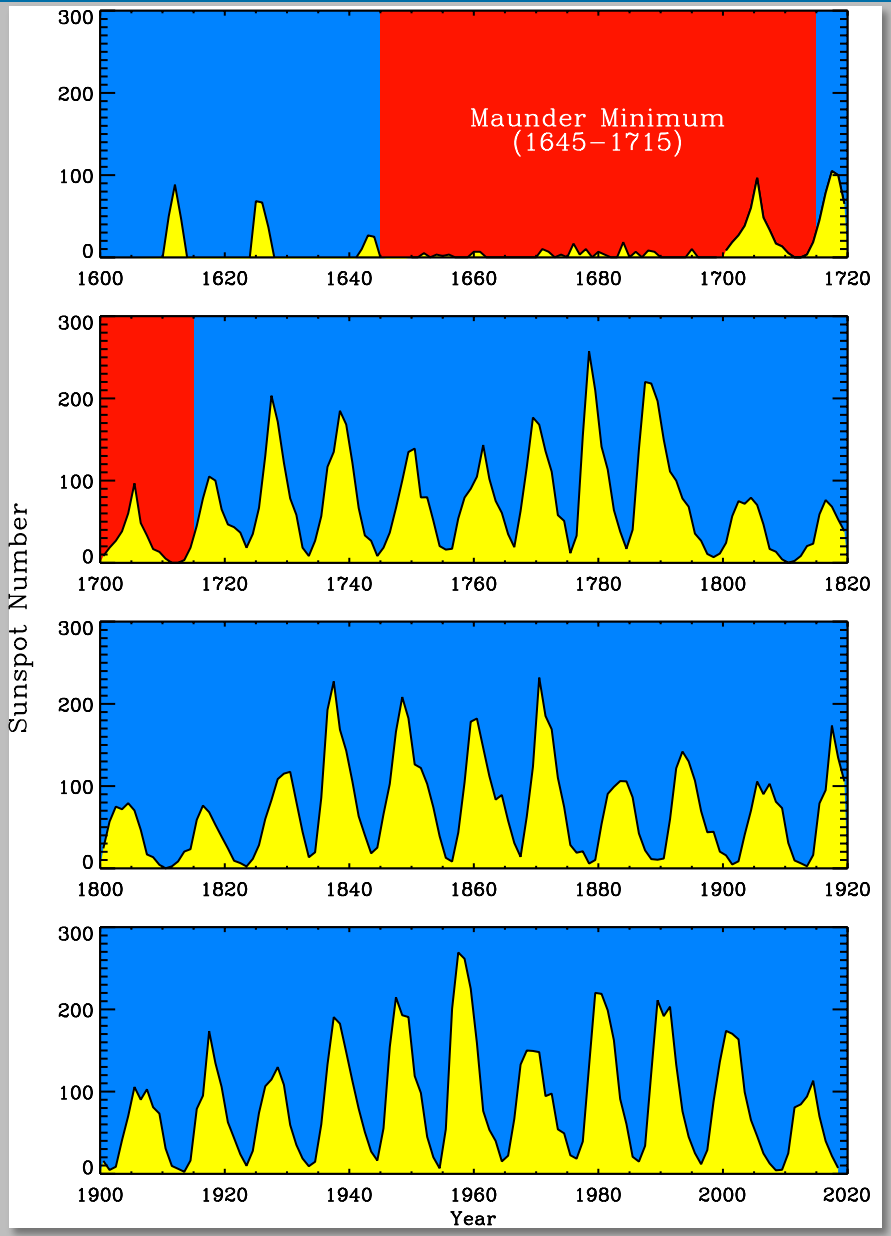
What Timescale to Predict? Decades?





Courtesy Rachel Howe

What Timescale to Predict? Longer?

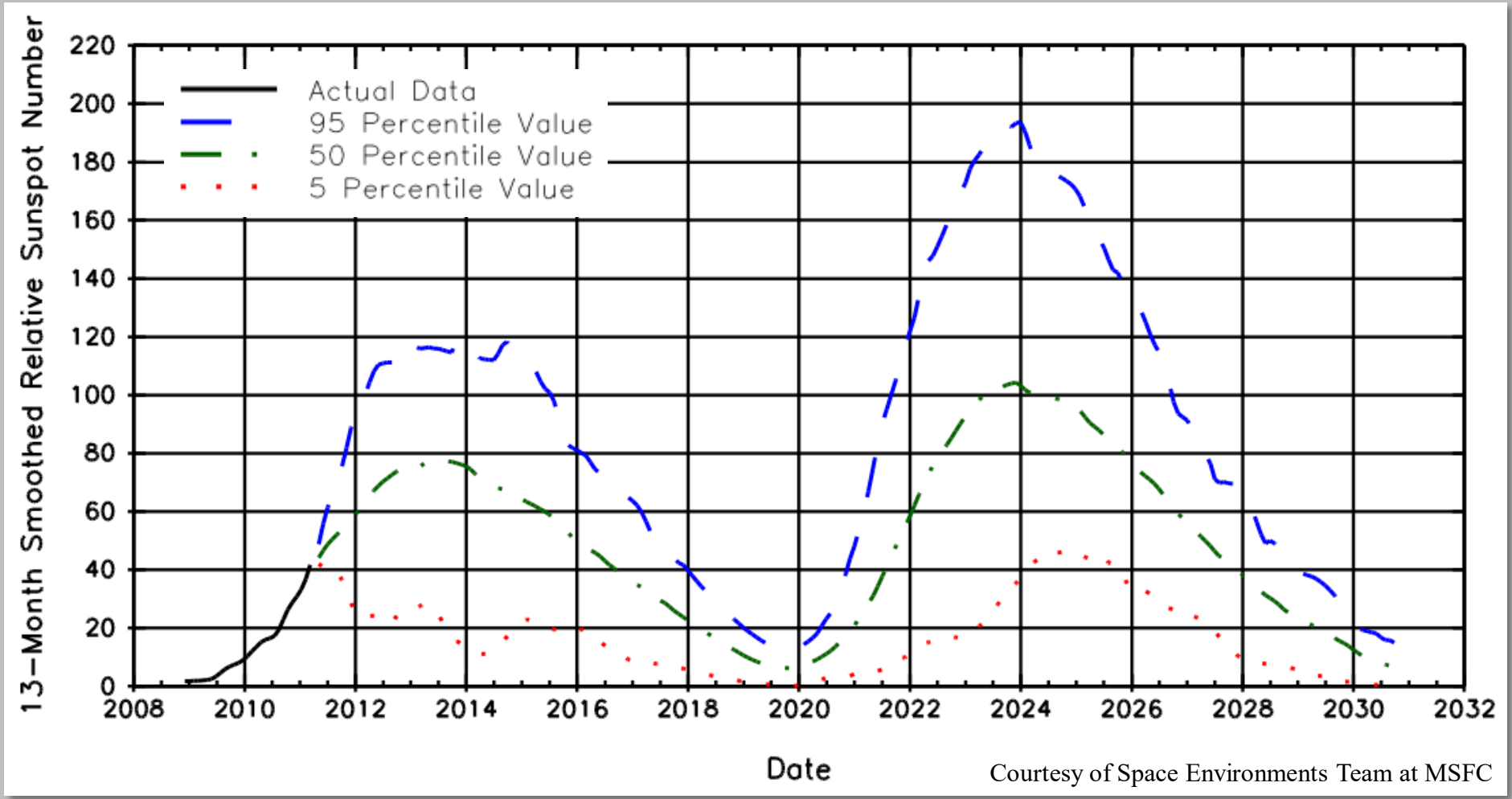


At even longer timescales we rely on timeseries analysis of sunspot number, cosmic ray radioisotopes, and other proxies.

The biggest problem becomes controlling the error of the prediction.

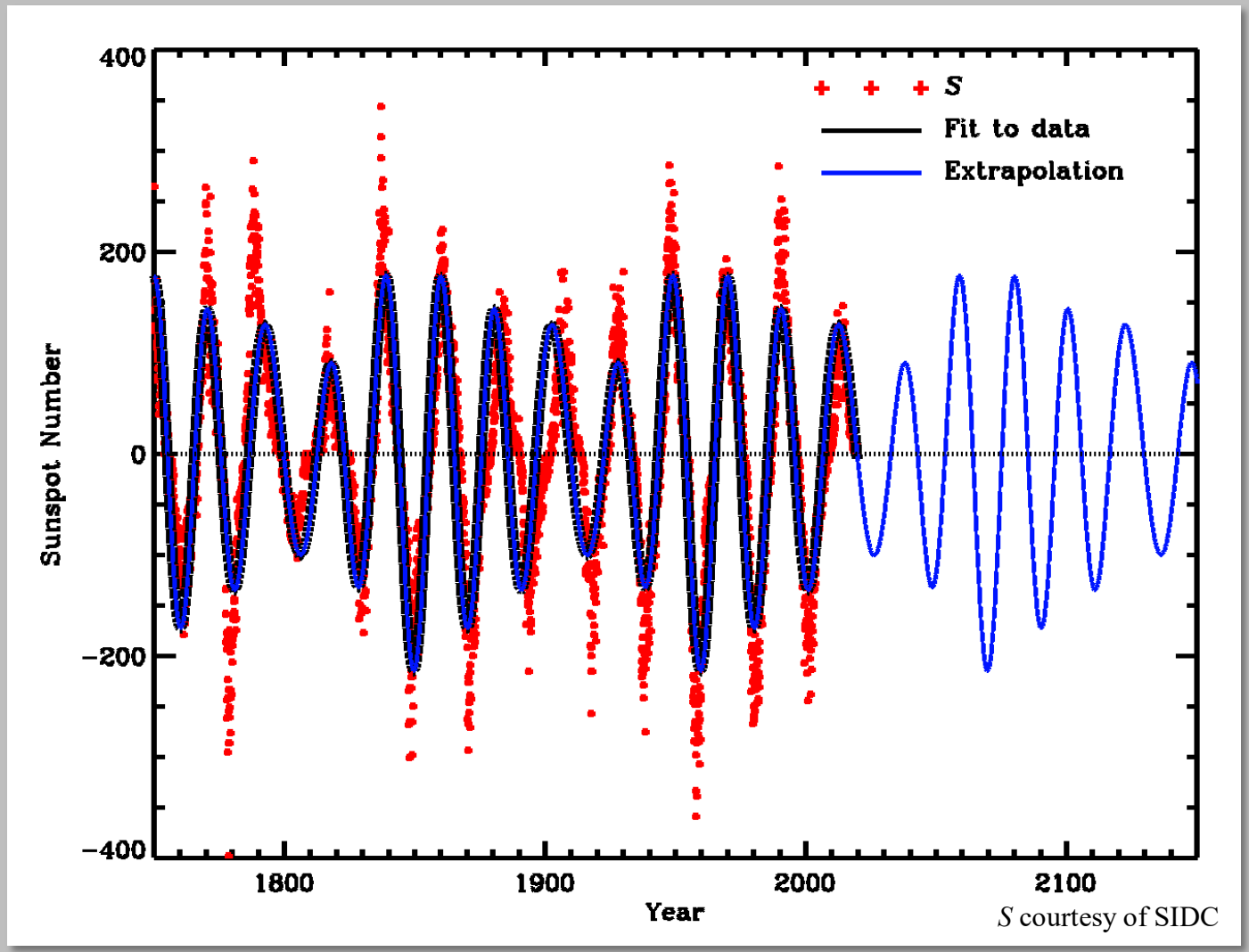
S data from the SIDC

Estimated Error Grows in Time



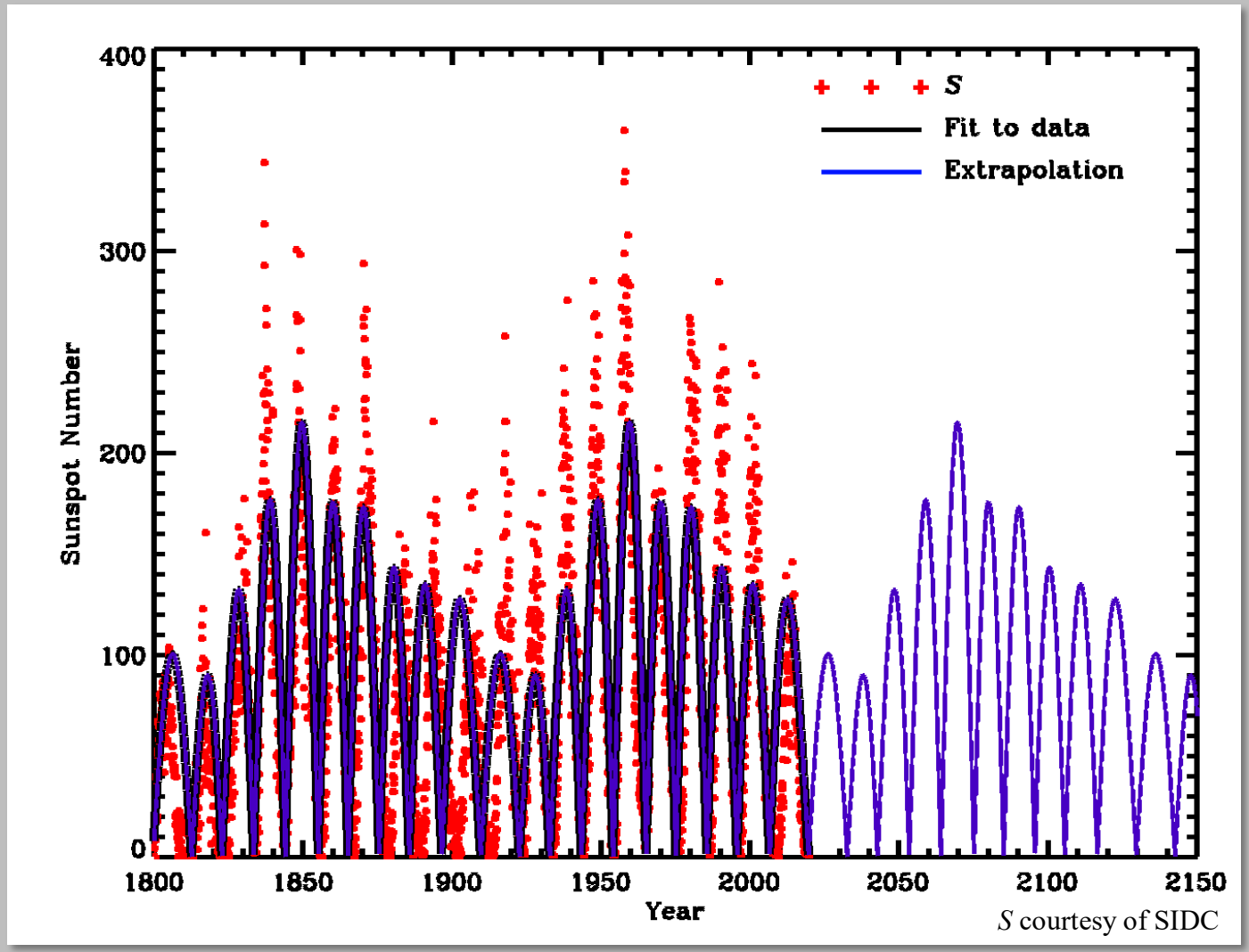
Distance from 50% to 95% (i.e., 2σ) grows from 40 at the peak of SC 24 to 90 at the peak of SC 25.

Error in Fourier Fit is Difficult



Fourier fit to *S* with a base period of 110 years, 5 partials, signed sunspots cycles to make a 22-year solar cycle.

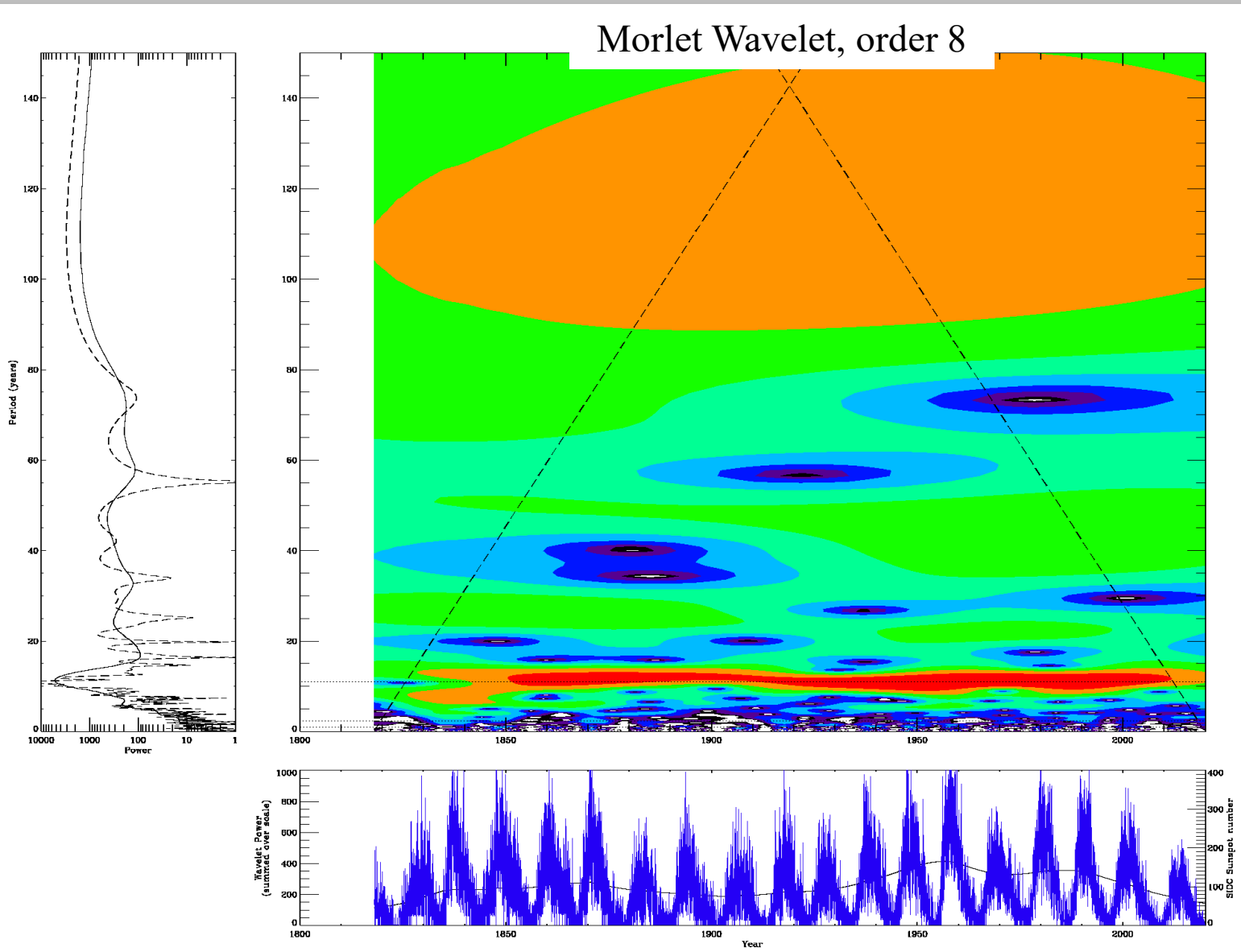
Error in Fourier Fit is Difficult



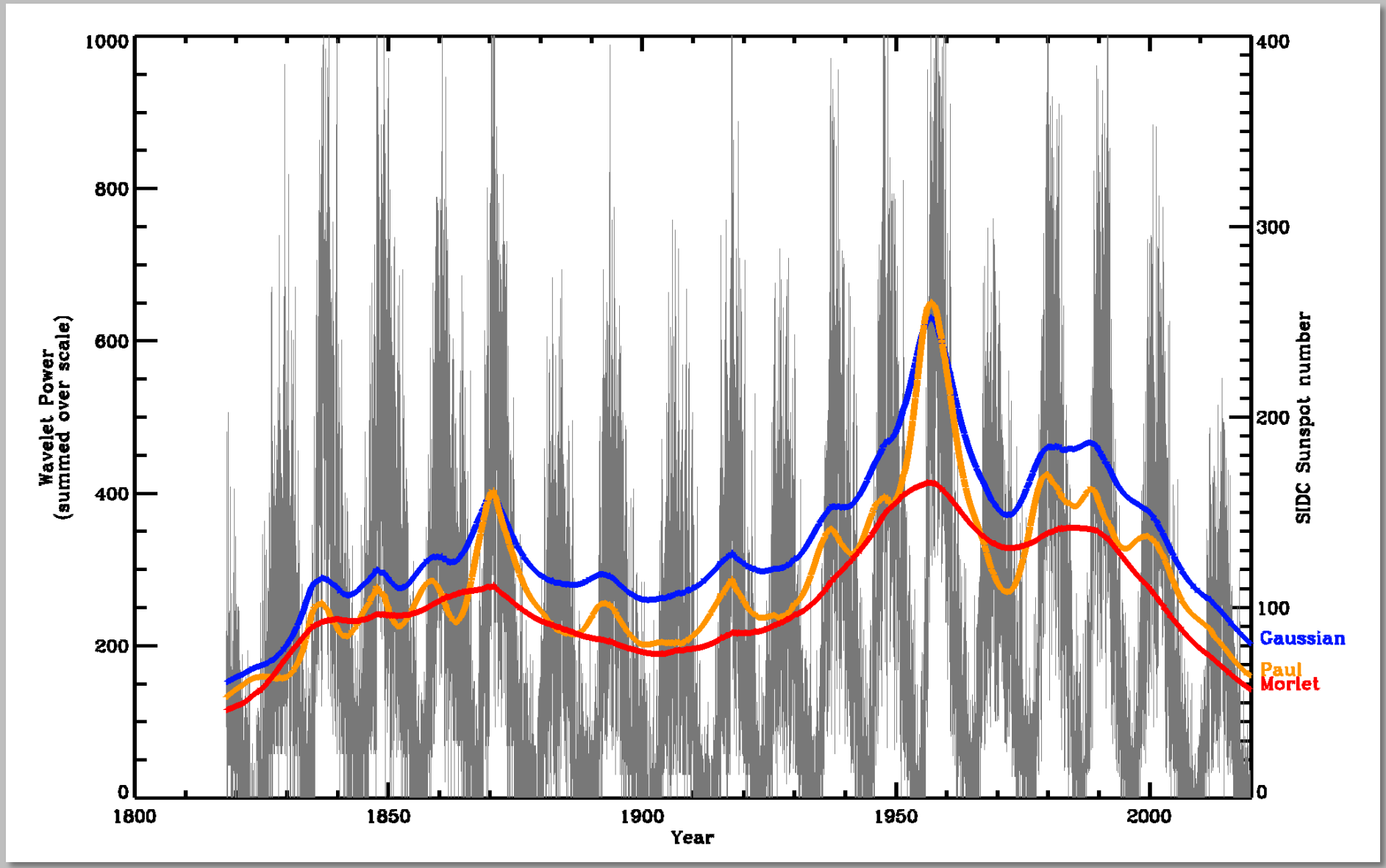
Fourier fit to *S* with a base period of 110 years, 5 partials, signed sunspots cycles to make a 22-year solar cycle. Frequencies and amplitude vary with time.

Long-term Predictions

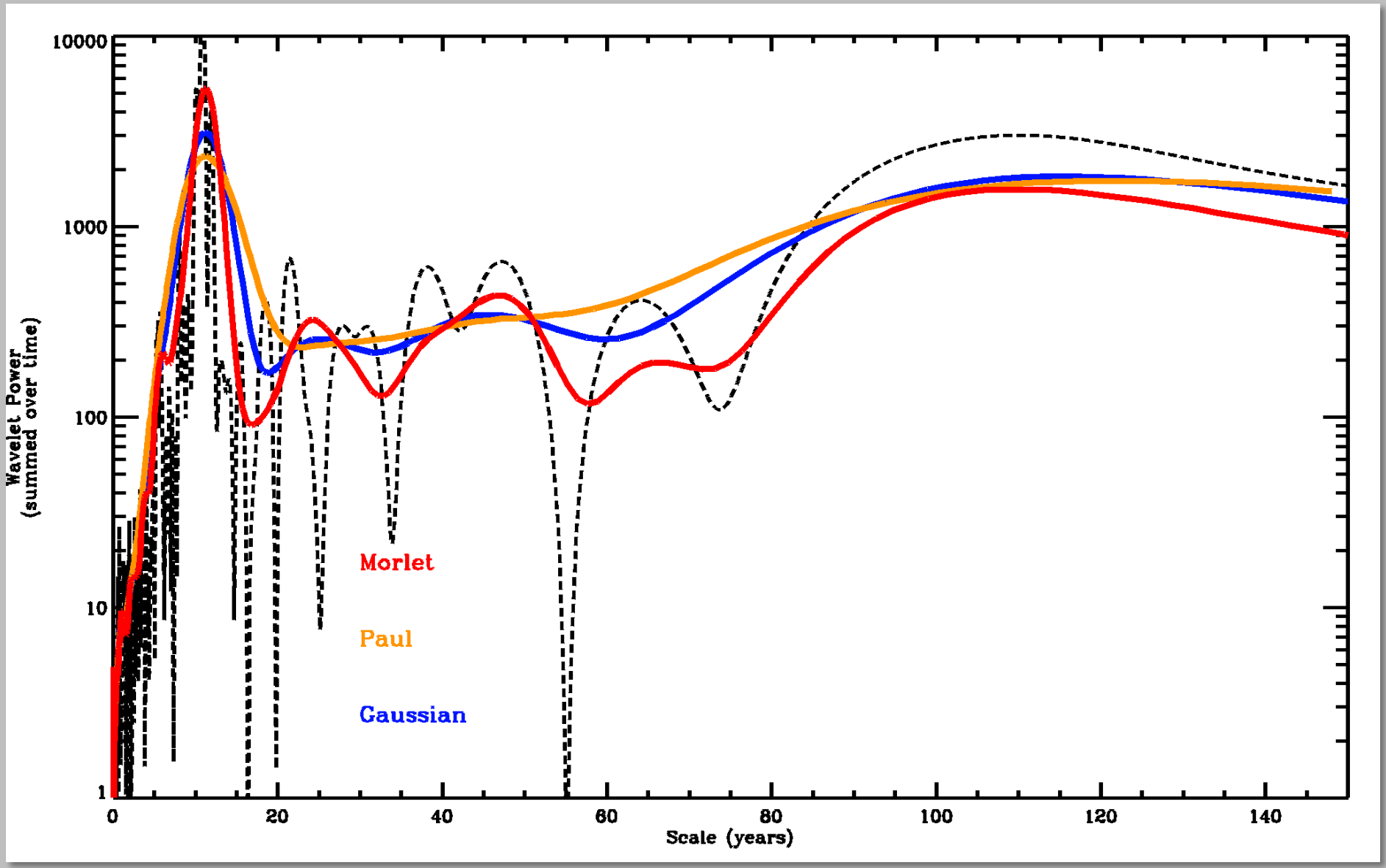
Fourier transform and summed over time



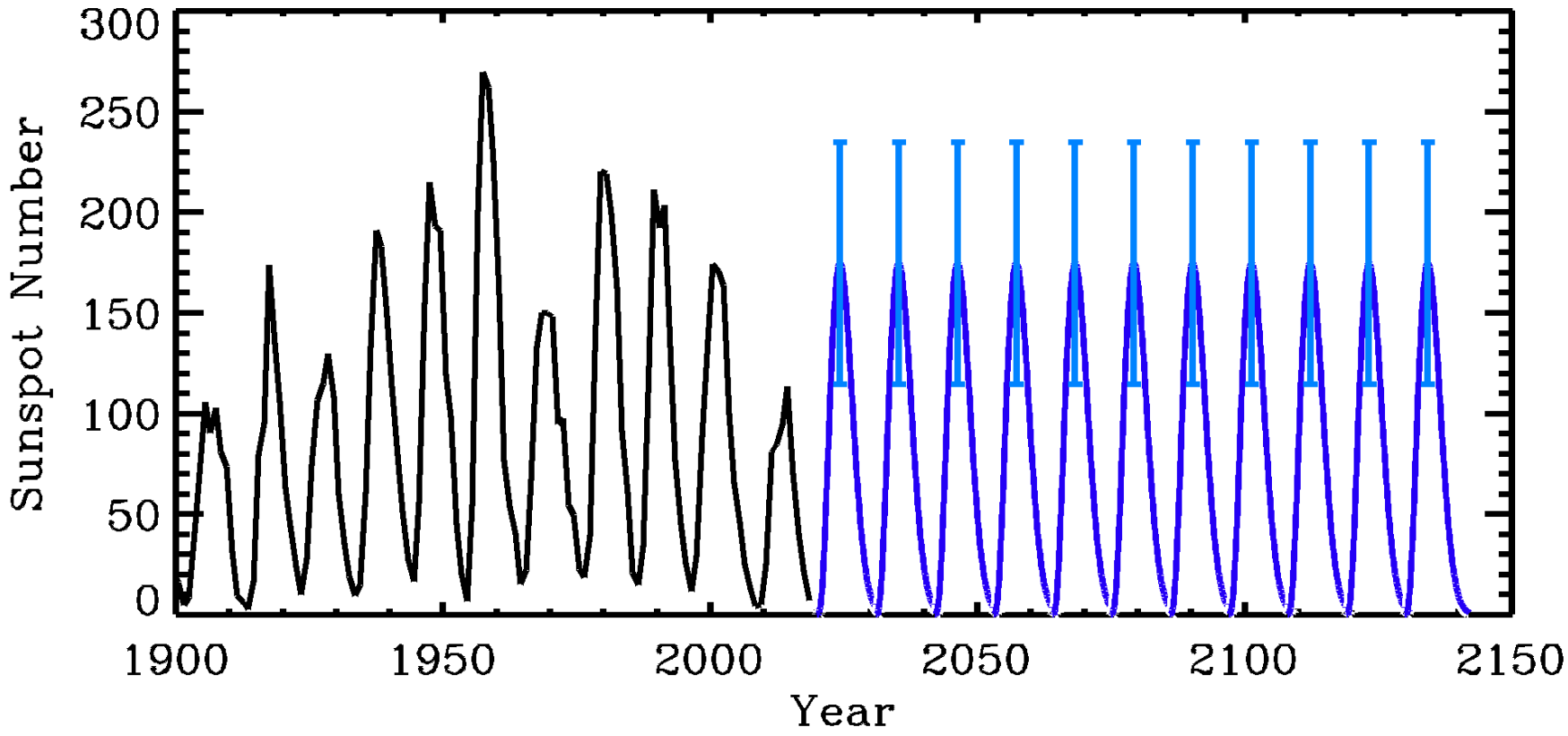
Long-term Predictions



Long-term Predictions

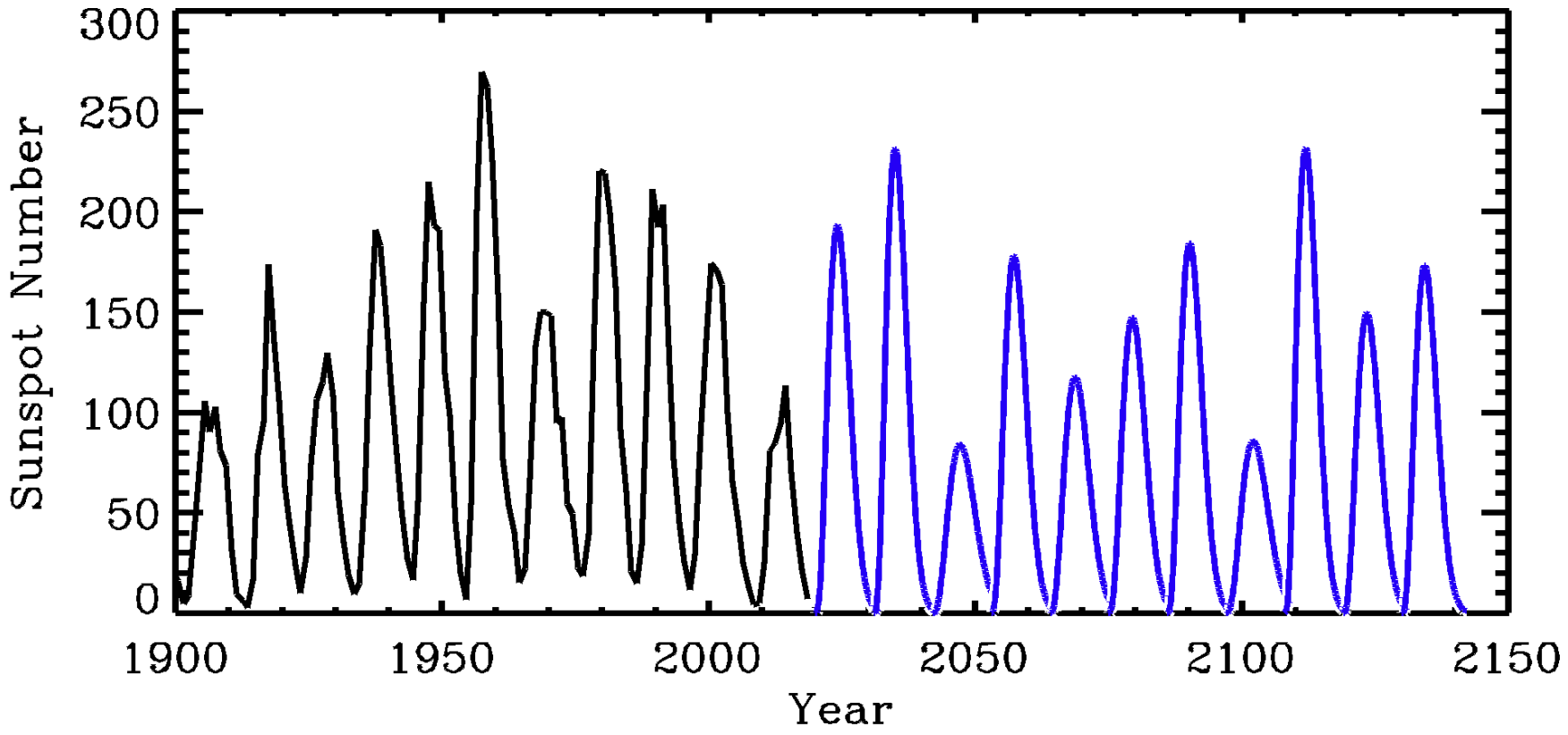


Long-term Predictions



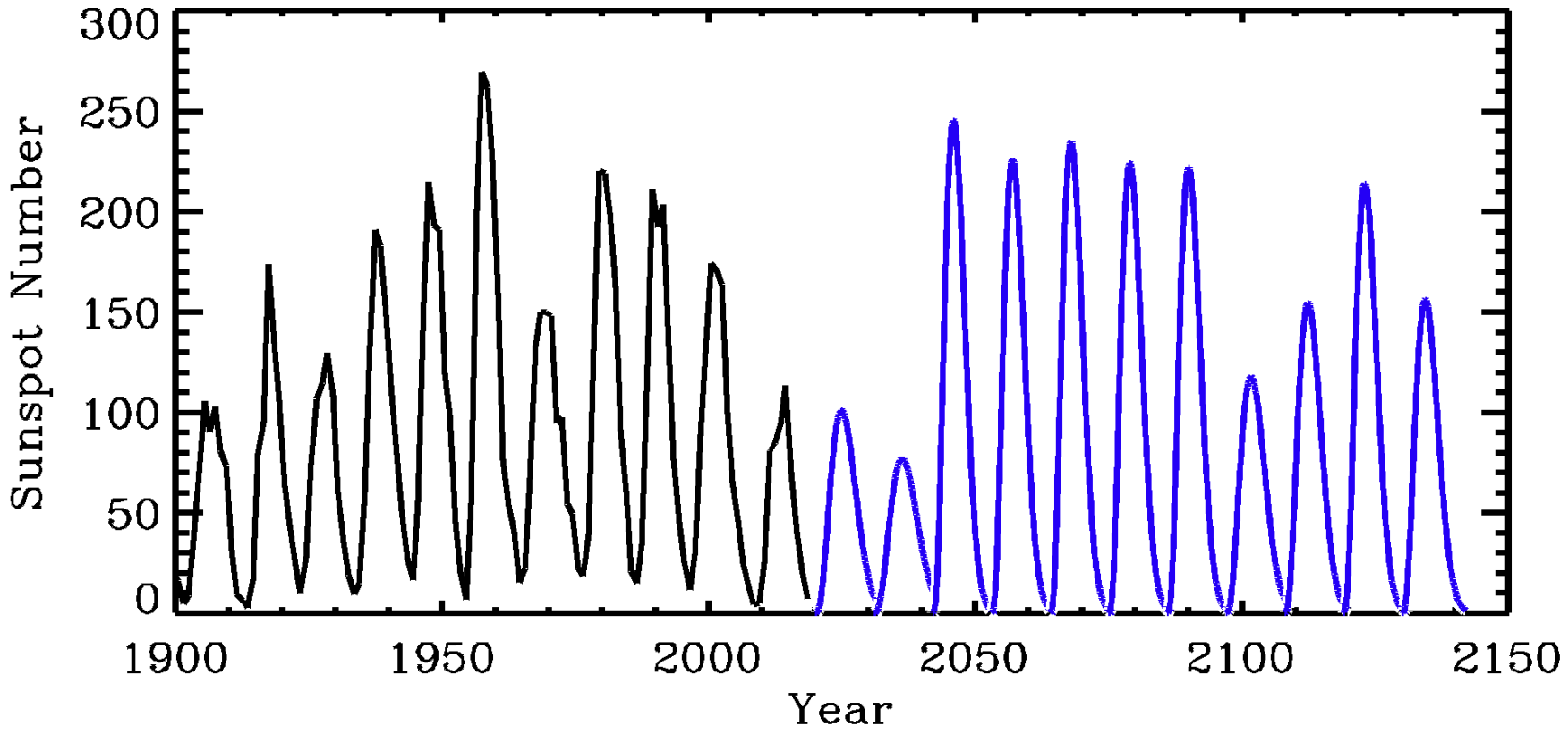
One long-term prediction is to assume the climatological average.

Long-term Predictions



Better is to assume a normal distribution of variations $\pm\sigma$ about the climatological average.

Long-term Predictions



Even better is to assume an emsemble of variations with a normal distribution $\pm\sigma$ about the climatological average.

Last Words

- The climatological average is the only long-term prediction whose error grows slowly
- Accurate long-term forecasting should adopt an ensemble format
- What information are we missing in the poles?
- Solar Cycles 19-24 roughly decreased in amplitude, meaning the Space Age has only seen one cycle that increased in activity. How does that limit our understanding of the dynamo?

Thank You!