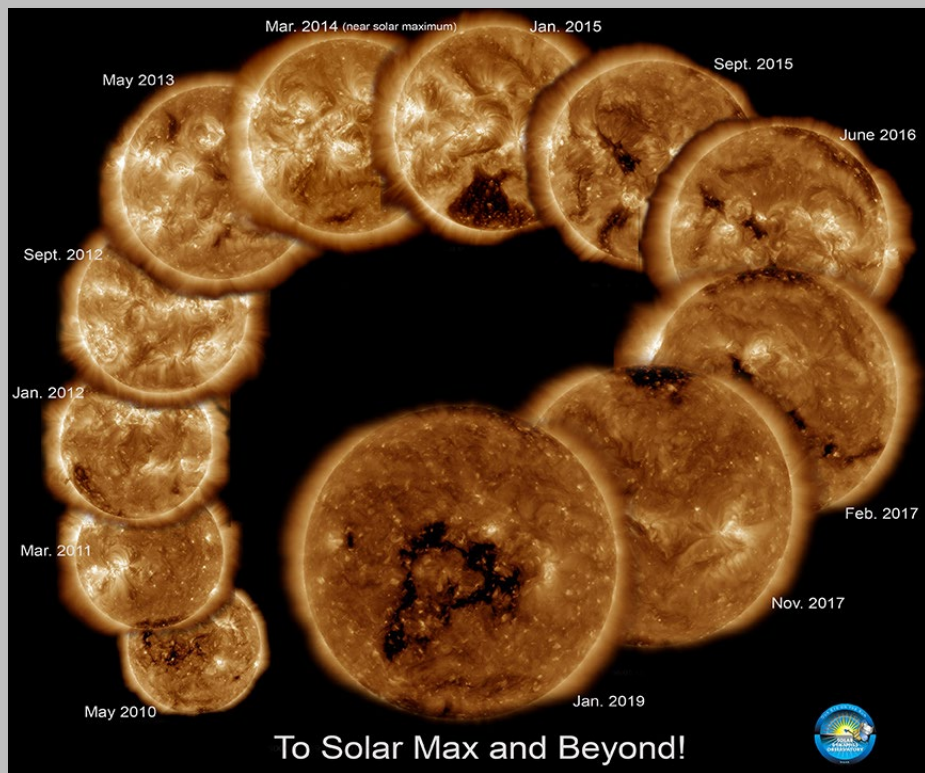


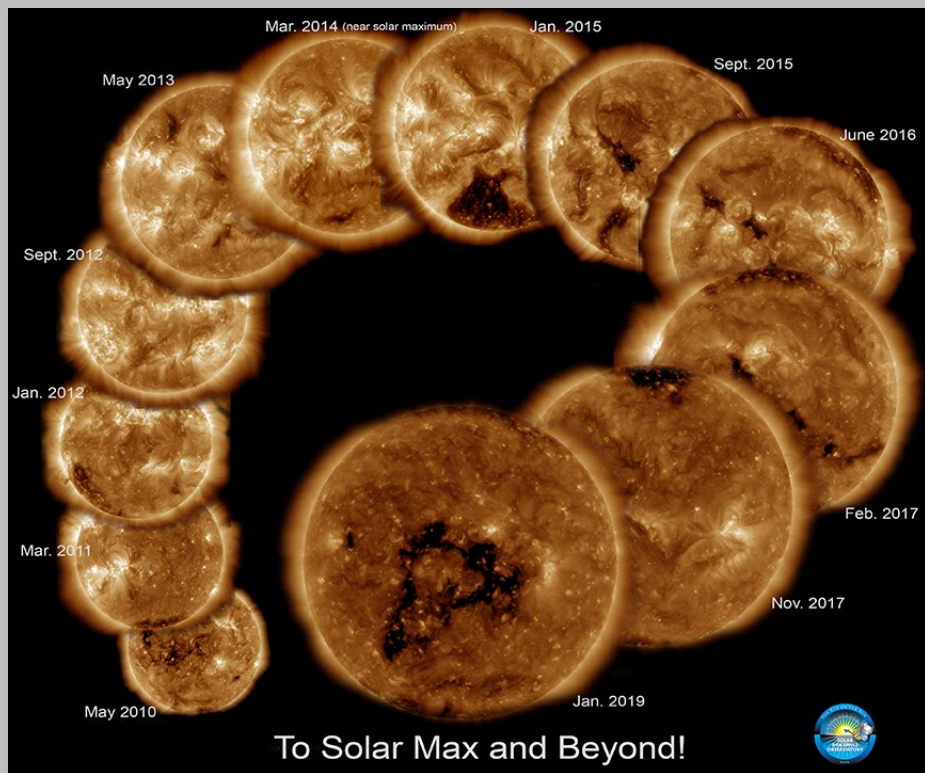
# *How Well Can We Predict Solar Cycle 35?*



W. Dean Pesnell

NASA, Goddard Space Flight Center

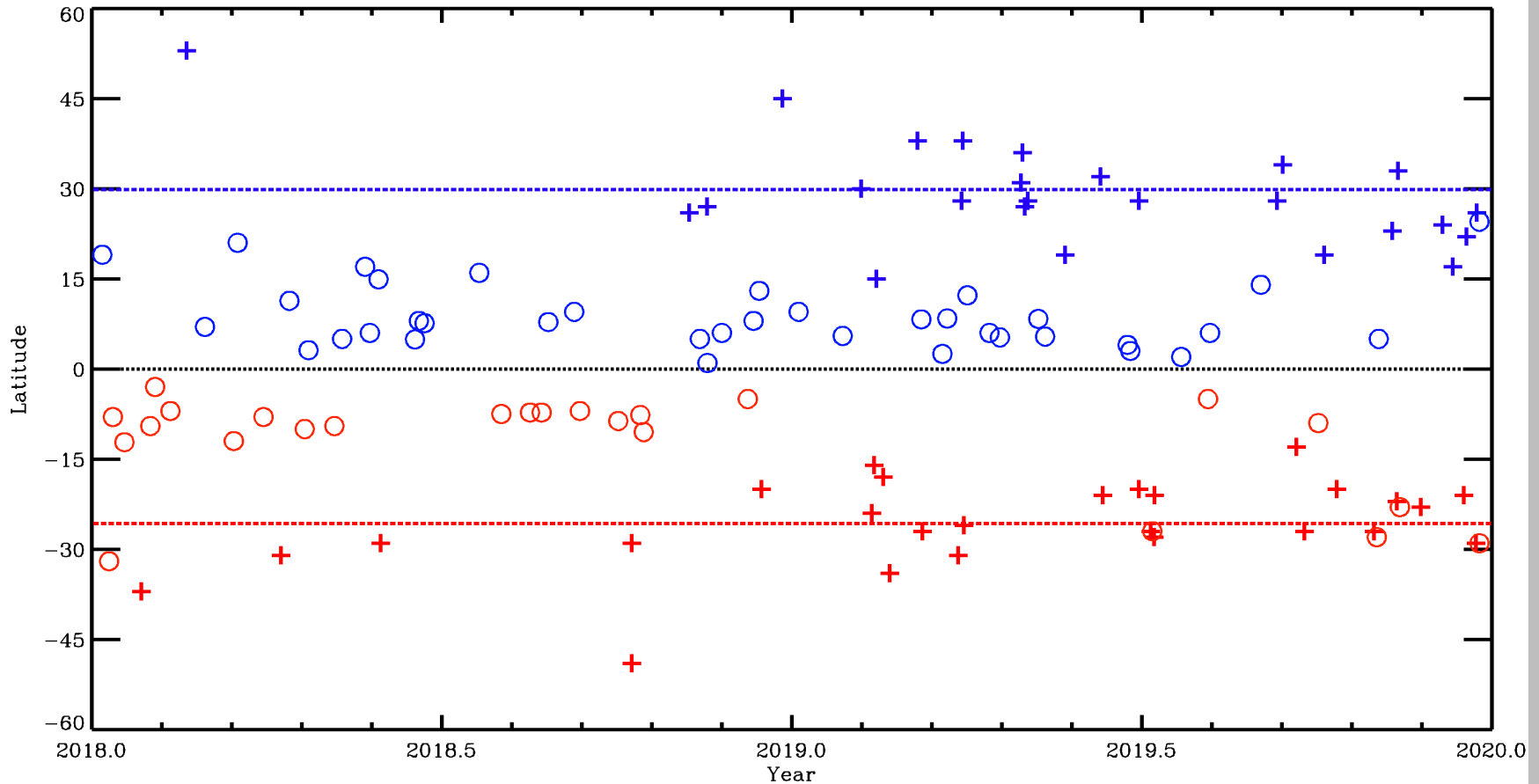
# *Solar Cycle 25: Era of the Error?*



W. Dean Pesnell

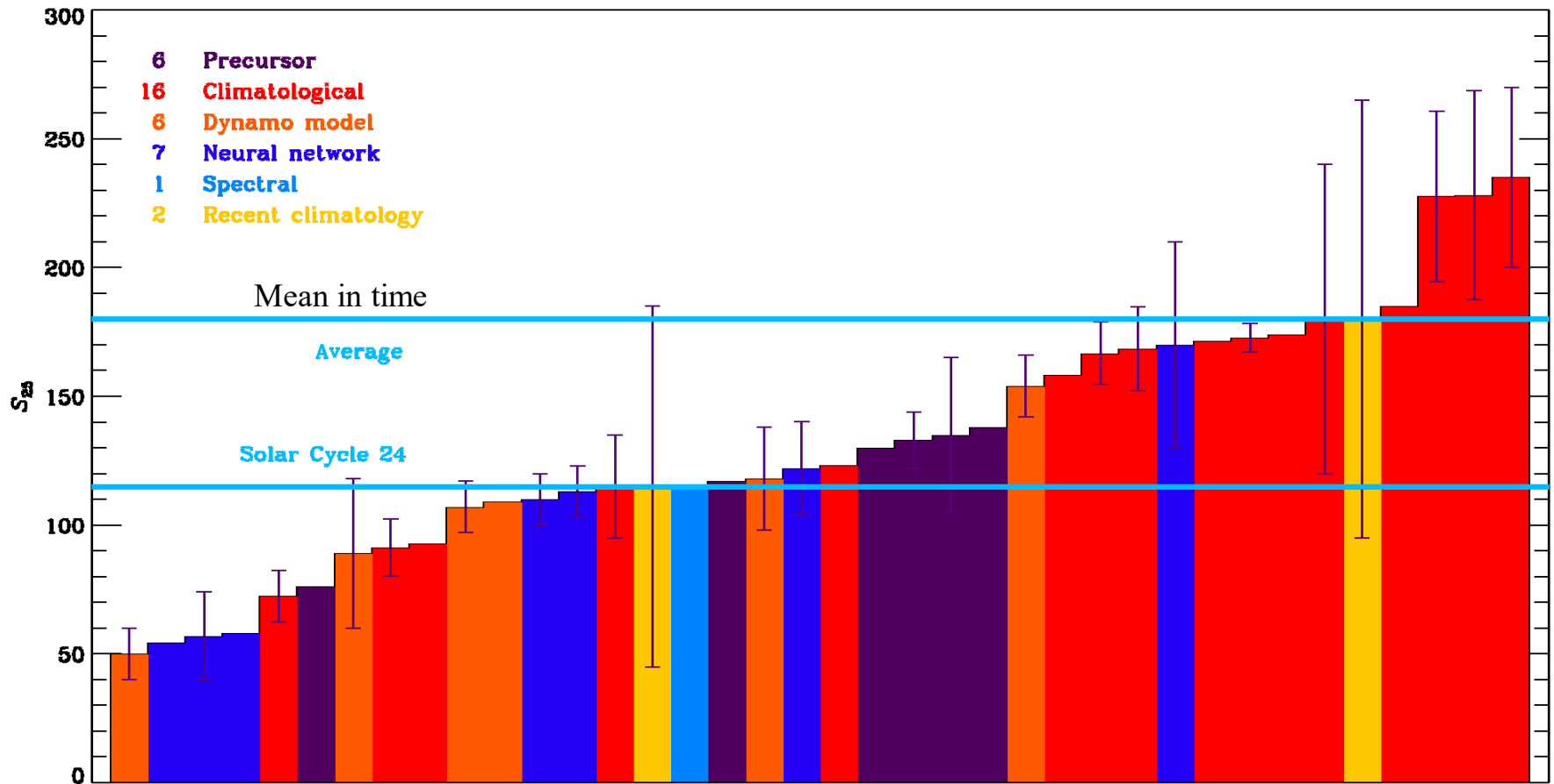
NASA, Goddard Space Flight Center



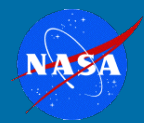


A butterfly diagram of ARs (circles, from SolarCycleScience.org and NOAA) and SC 25 ephemeral regions and ARs (plus signs, from [solen.info/solar/cycle25\\_spots.html](http://solen.info/solar/cycle25_spots.html) and courtesy of Jan Alvestad)

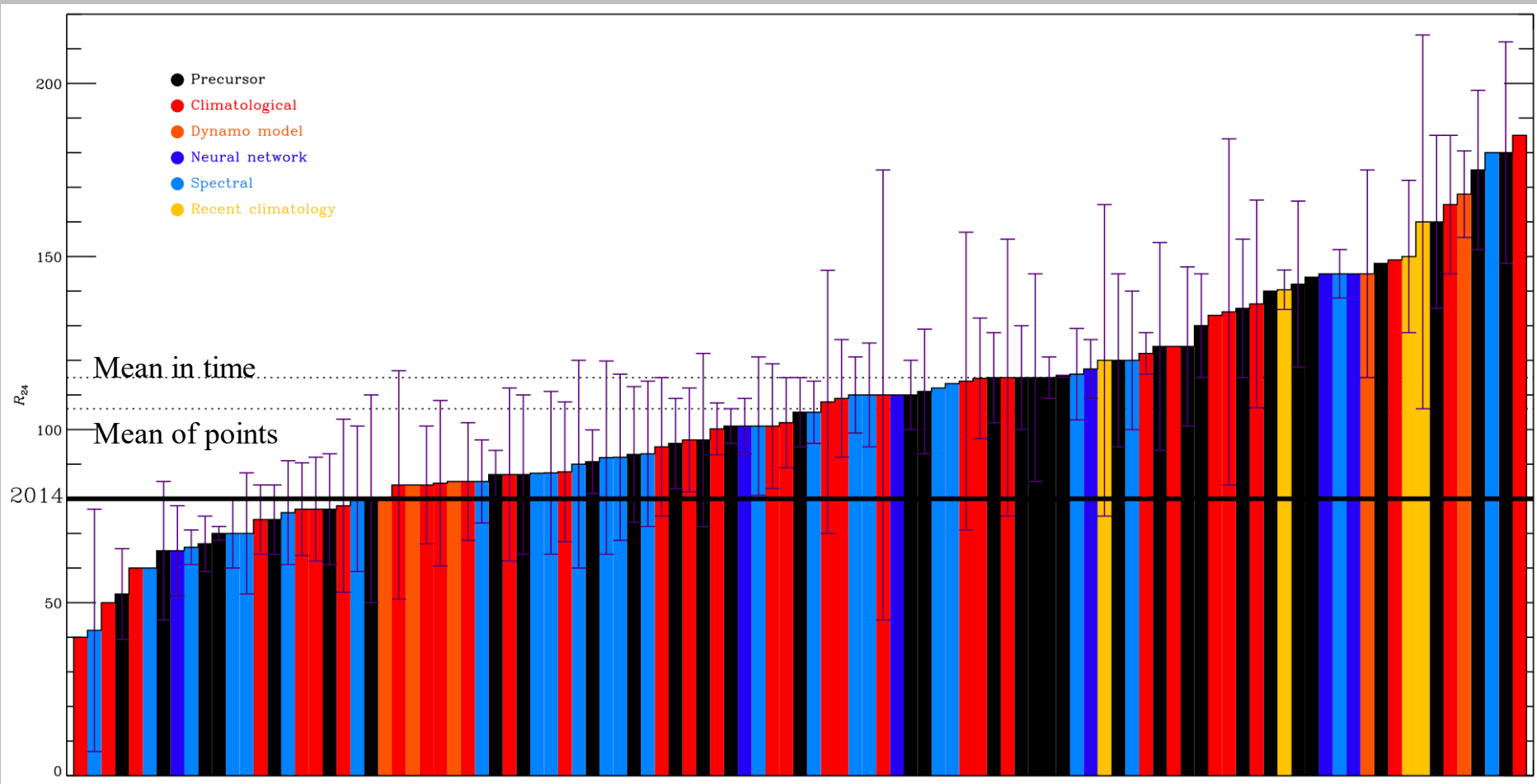
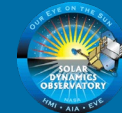
# 38 Predictions of Solar Cycle 25



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



# 105 Predictions of Solar Cycle 24



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

# 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



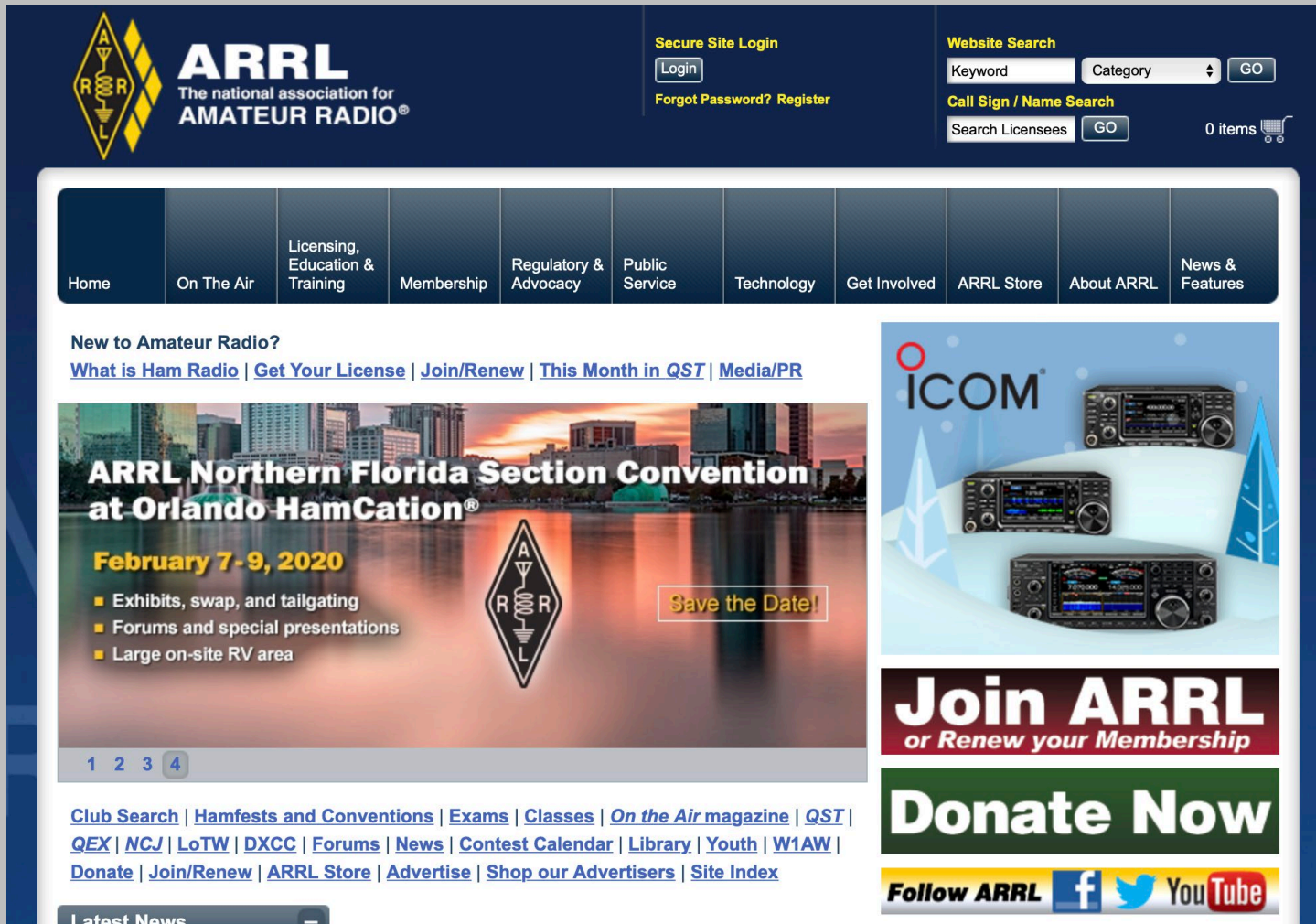
Mission designers and operators want solar cycle predictions today. The predictions must be believable even they aren't physically correct. They like F10.7 but want a standard variable. That standard is now  $S$ .

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



The screenshot shows the ARRL (American Radio Relay League) website. At the top, there is a navigation bar with the ARRL logo and tagline "The national association for AMATEUR RADIO®". To the right of the logo are links for "Secure Site Login" (with a "Login" button and "Forgot Password? Register" link) and "Website Search" (with a "Keyword" input field, a "Category" dropdown, and a "GO" button). Below the search bar is a "Call Sign / Name Search" section with a "Search Licensees" input field and a "GO" button, and a shopping cart icon showing "0 items".

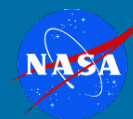
The main content area features a horizontal menu with the following items: Home, On The Air, Licensing, Education & Training, Membership, Regulatory & Advocacy, Public Service, Technology, Get Involved, ARRL Store, About ARRL, and News & Features. Below this menu is a section titled "New to Amateur Radio?" with links for "What is Ham Radio", "Get Your License", "Join/Renew", "This Month in QST", and "Media/PR".

The central banner advertises the "ARRL Northern Florida Section Convention at Orlando HamCation®" for "February 7-9, 2020". The banner includes a list of activities: "Exhibits, swap, and tailgating", "Forums and special presentations", and "Large on-site RV area". A "Save the Date!" button is also present. The banner is decorated with a cityscape background and the ARRL logo.

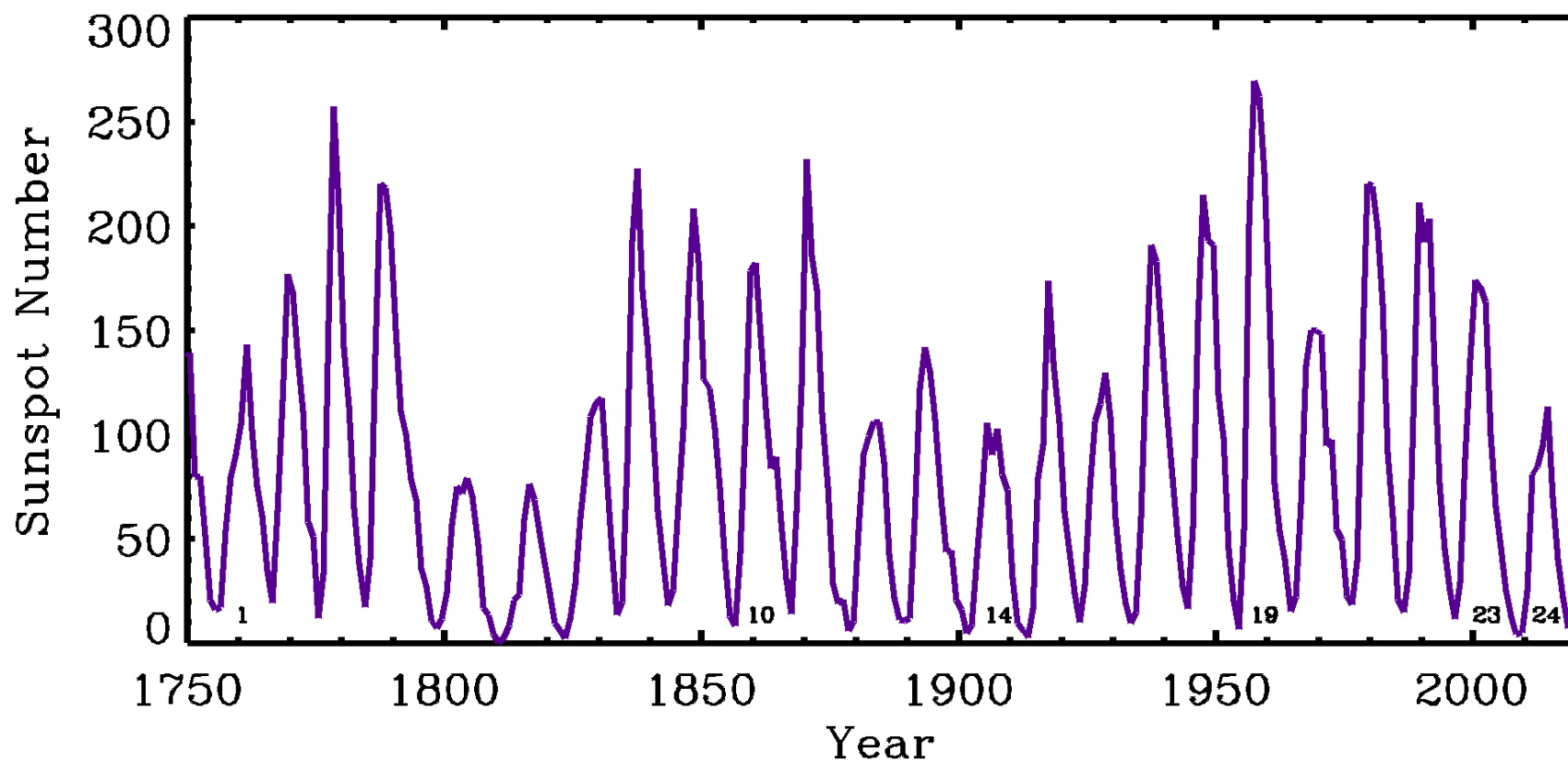
Below the banner is a section titled "Join ARRL or Renew your Membership" and "Donate Now". At the bottom of the page, there is a "Follow ARRL" section with social media icons for Facebook, Twitter, and YouTube.

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

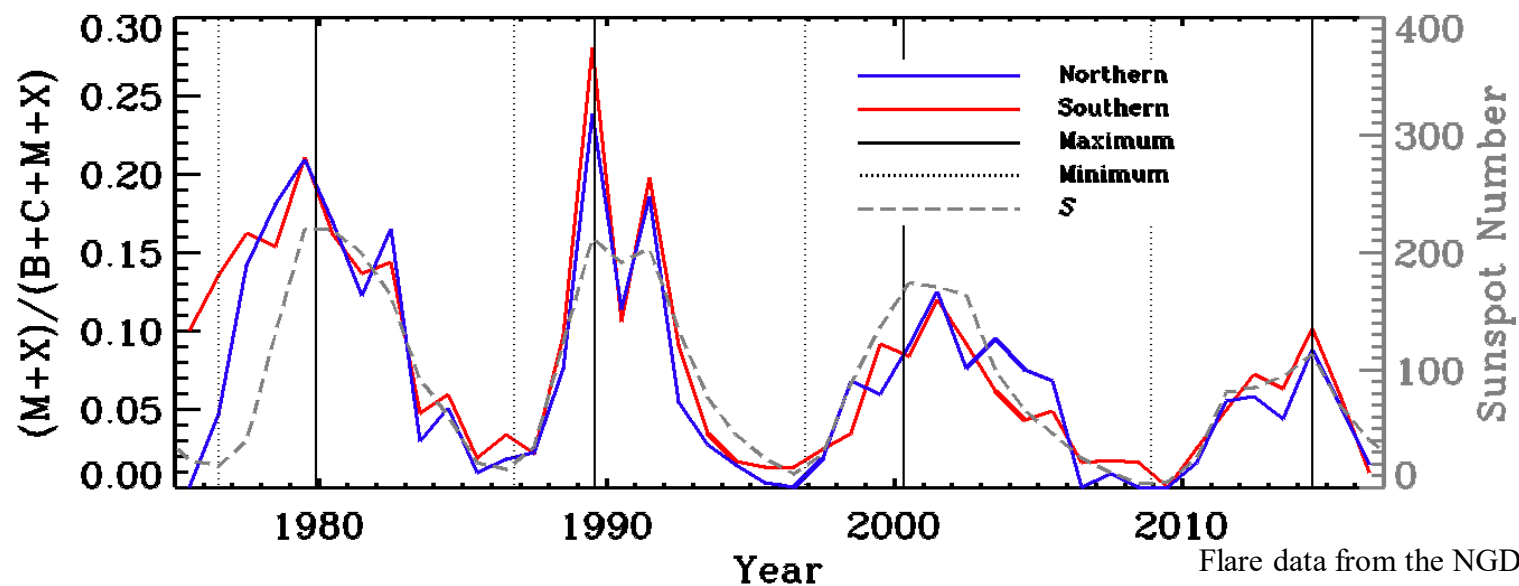
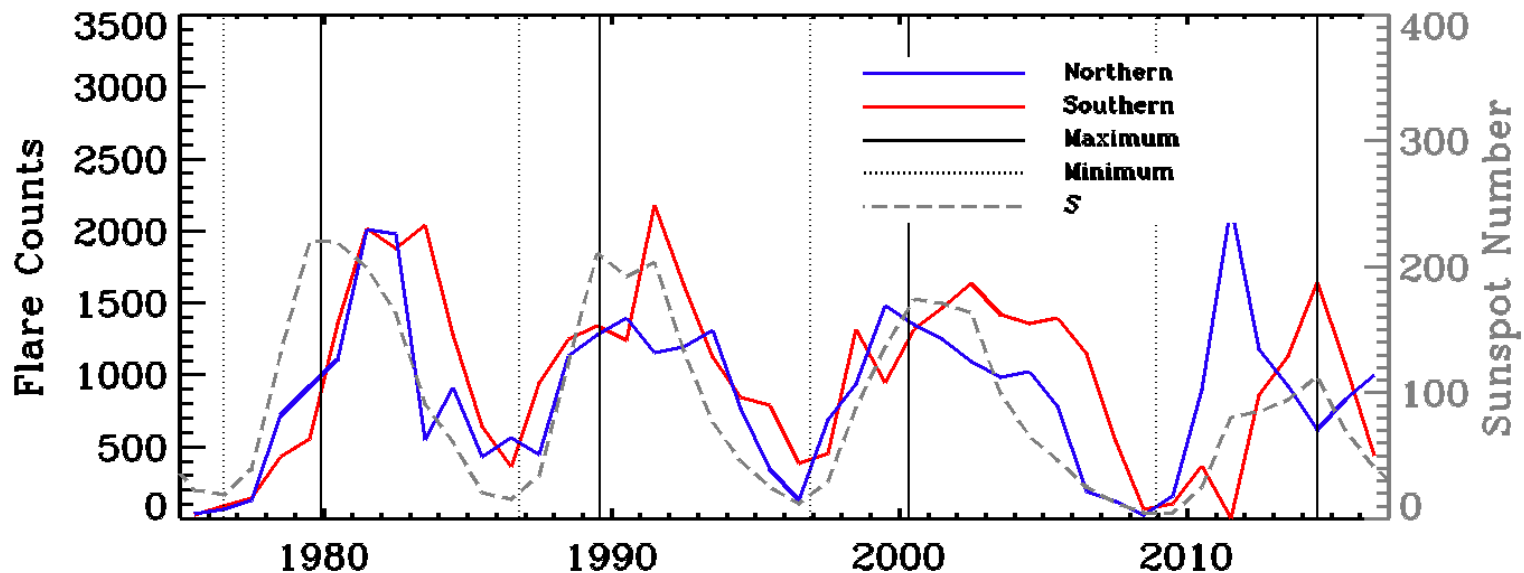
Solar Cycle 14: Similar to Solar Cycle 24

Solar Cycle 19: Largest cycle in record

Solar Cycle 23: My first predicted cycle

Sun Climate, Tucson, Jan 2020

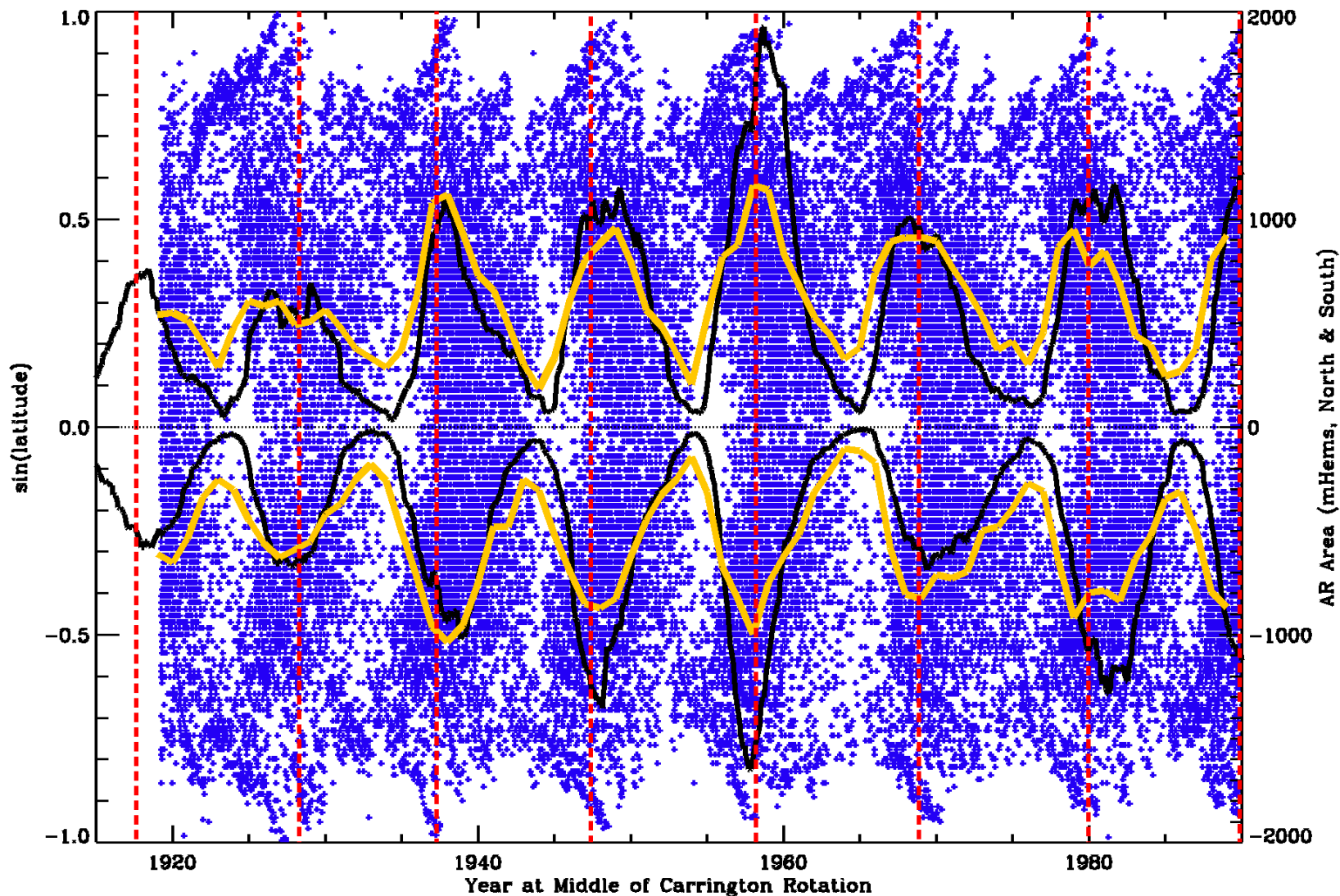
# NASA What to Predict? Flares?



Flare data from the NGDC



# What to Predict? Filaments?

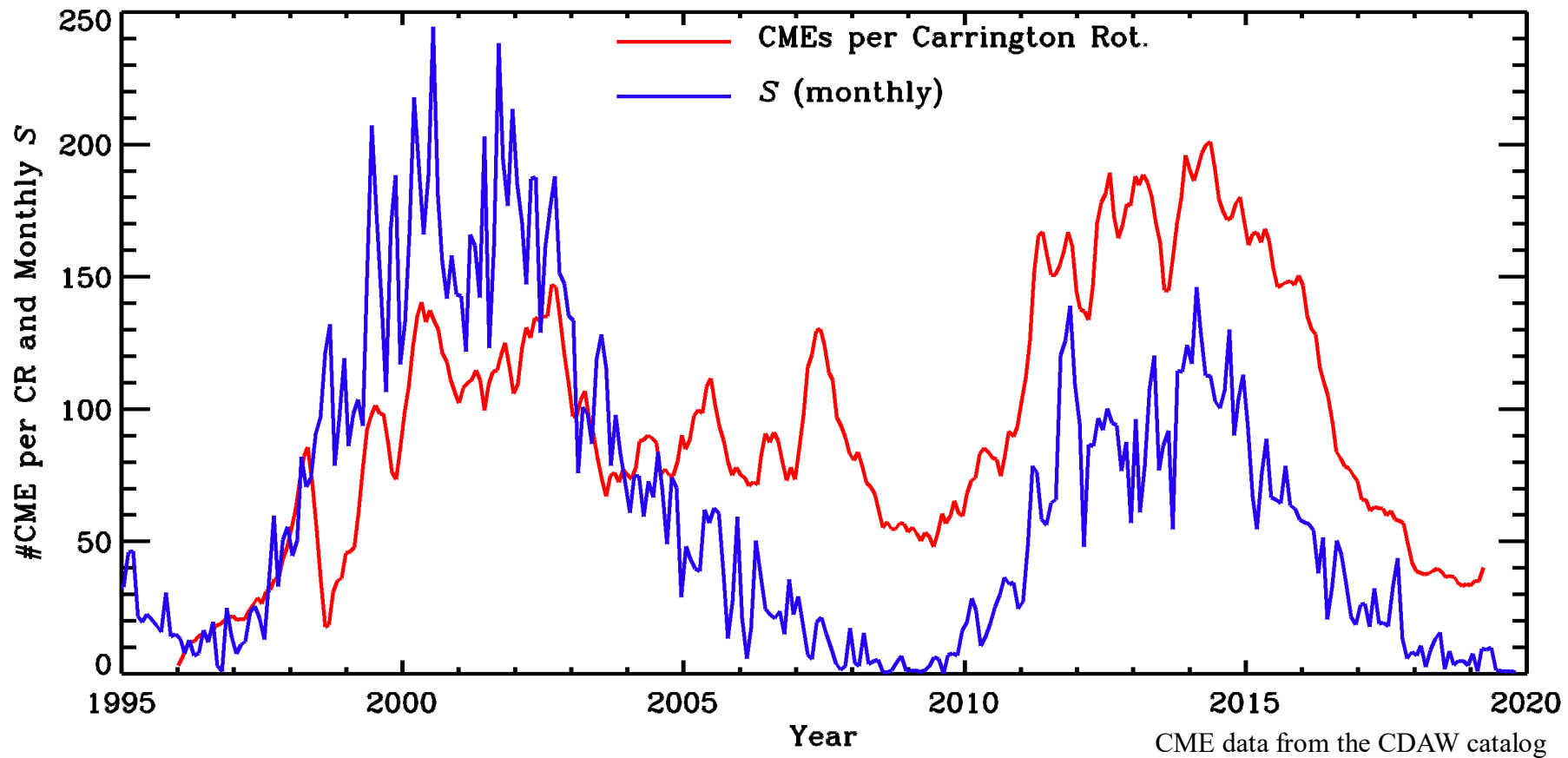
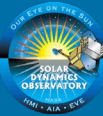


Filament data courtesy of the Carte Synoptiques, Area data courtesy of Hathaway

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

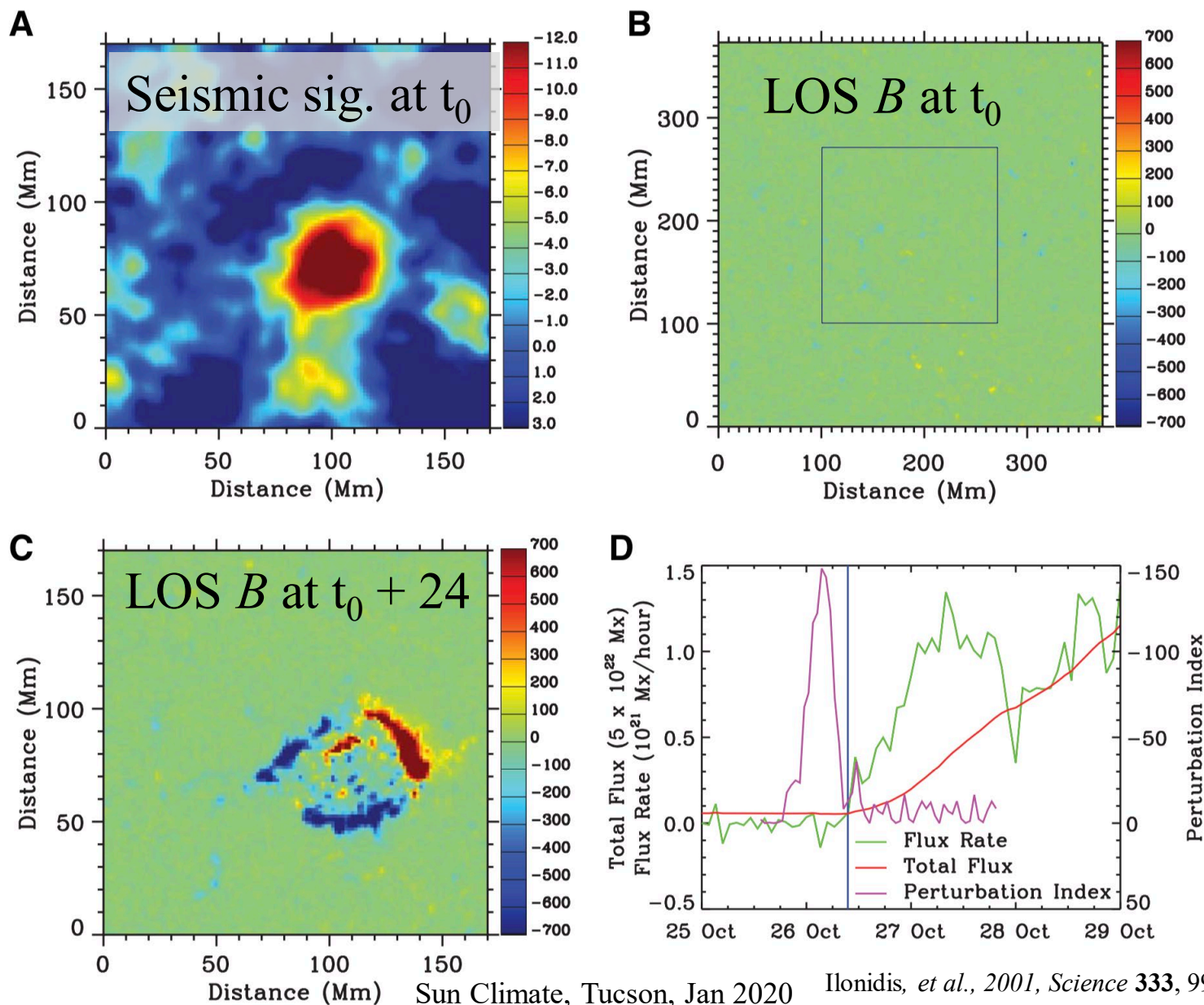
Sun Climate, Tucson, Jan 2020

# NASA What to Predict? CMEs?

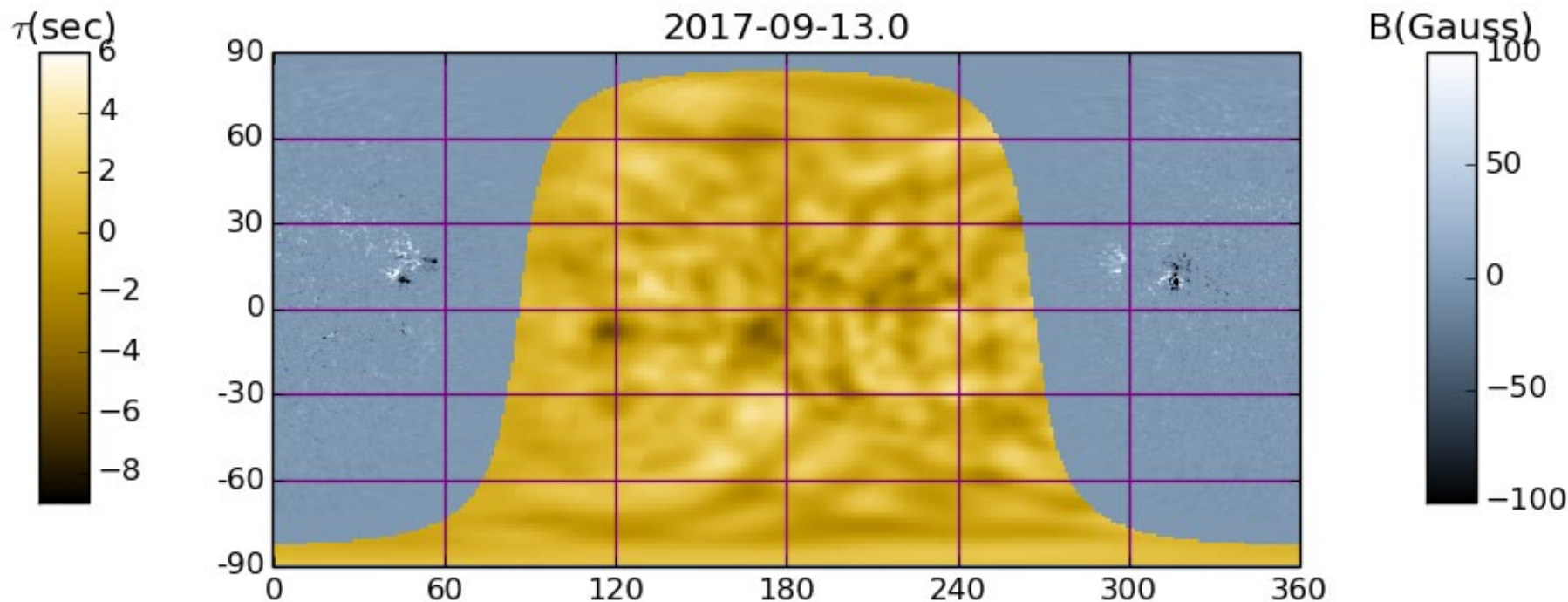


Uncorrected CME rate is well-correlated with fine structure. Systematic corrections show the rate follows  $S$  (Wang and Colaninno, 2014, *ApJ*, **784**, L27). Poor time coverage.

# What Timescale to Predict? Days?

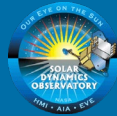
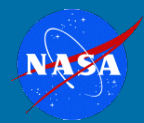


# What Timescale to Predict? Days?

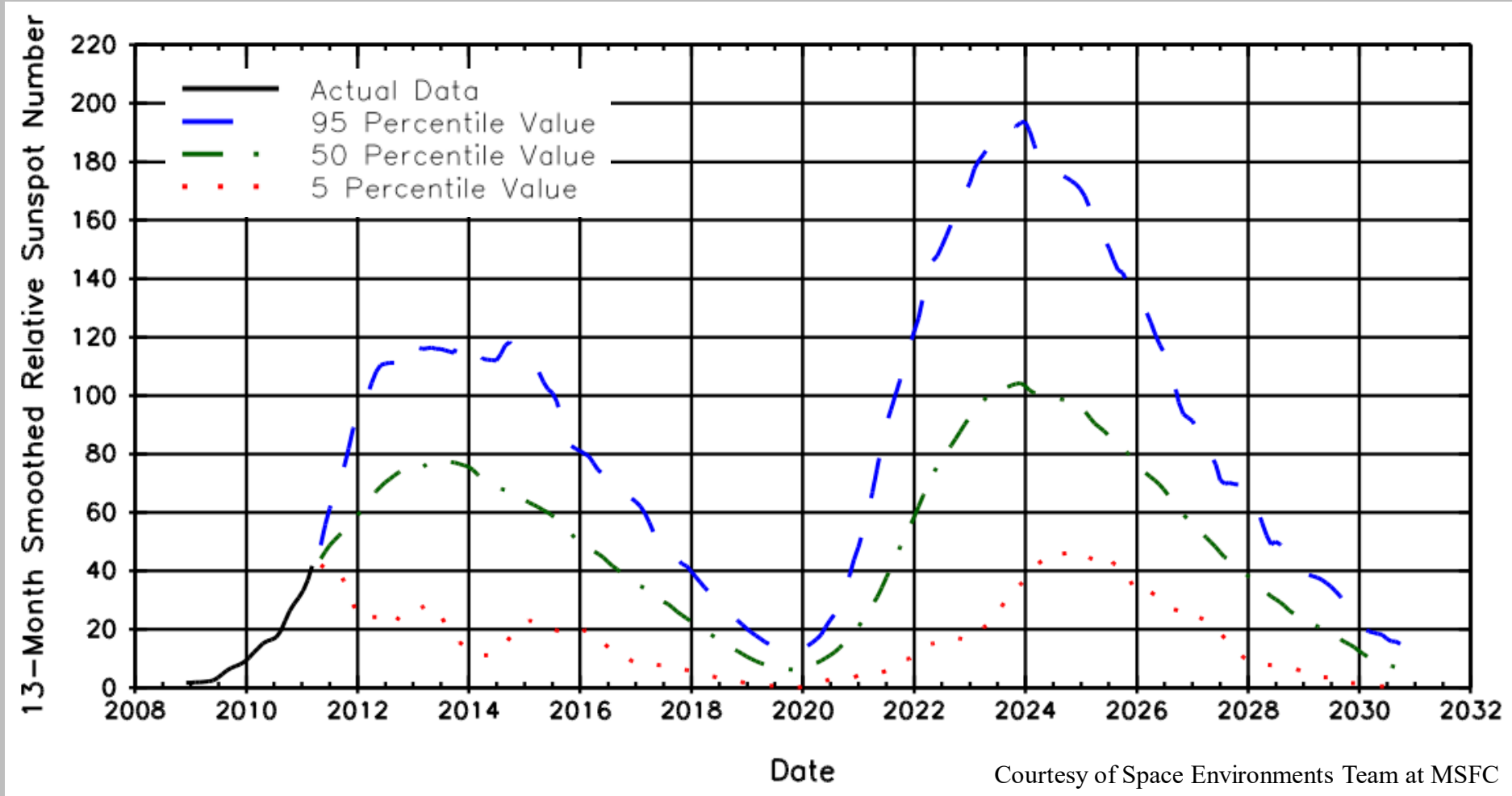


Courtesy of the HMI Science team



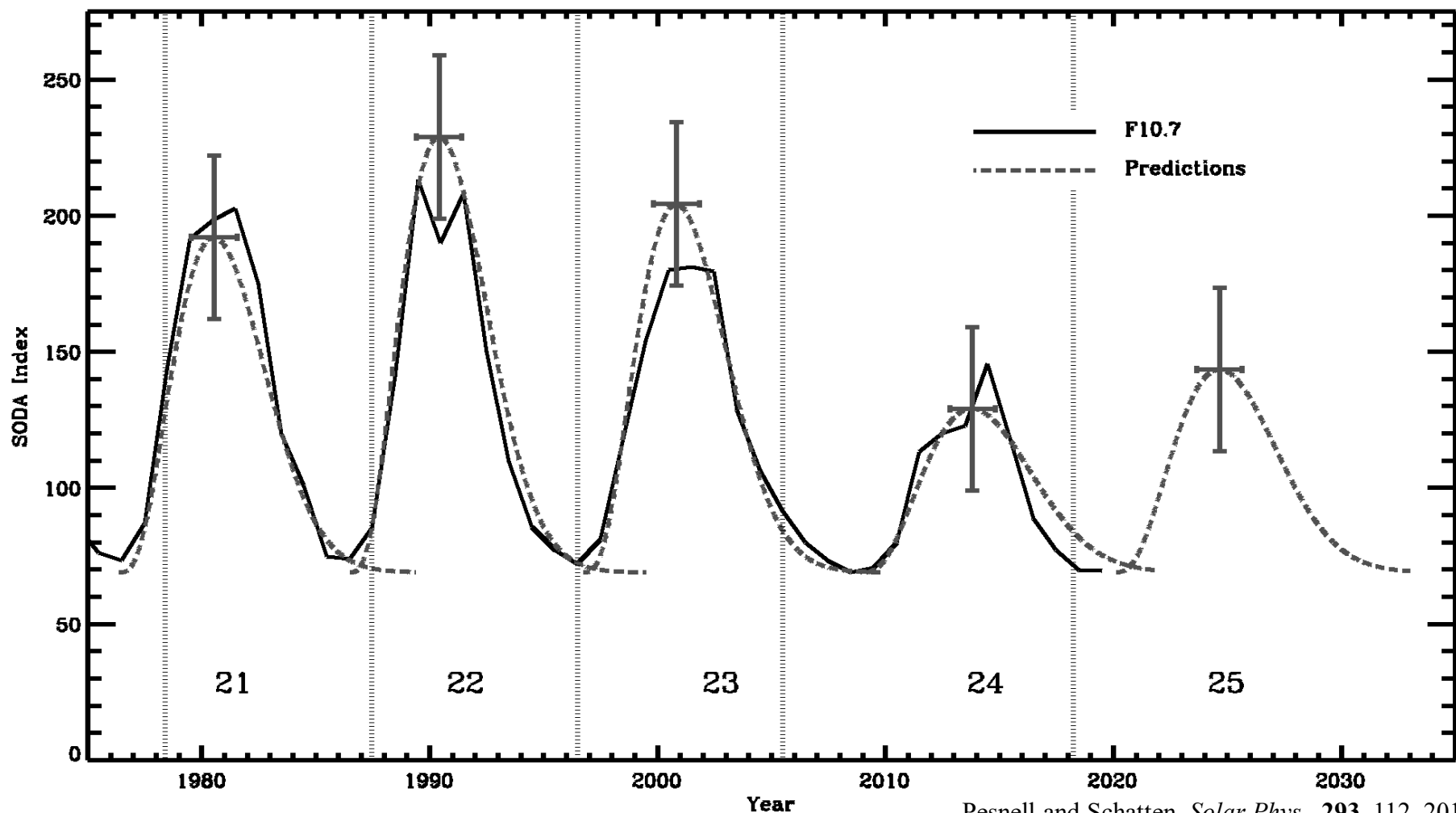


# What Timescale to Predict? Months?



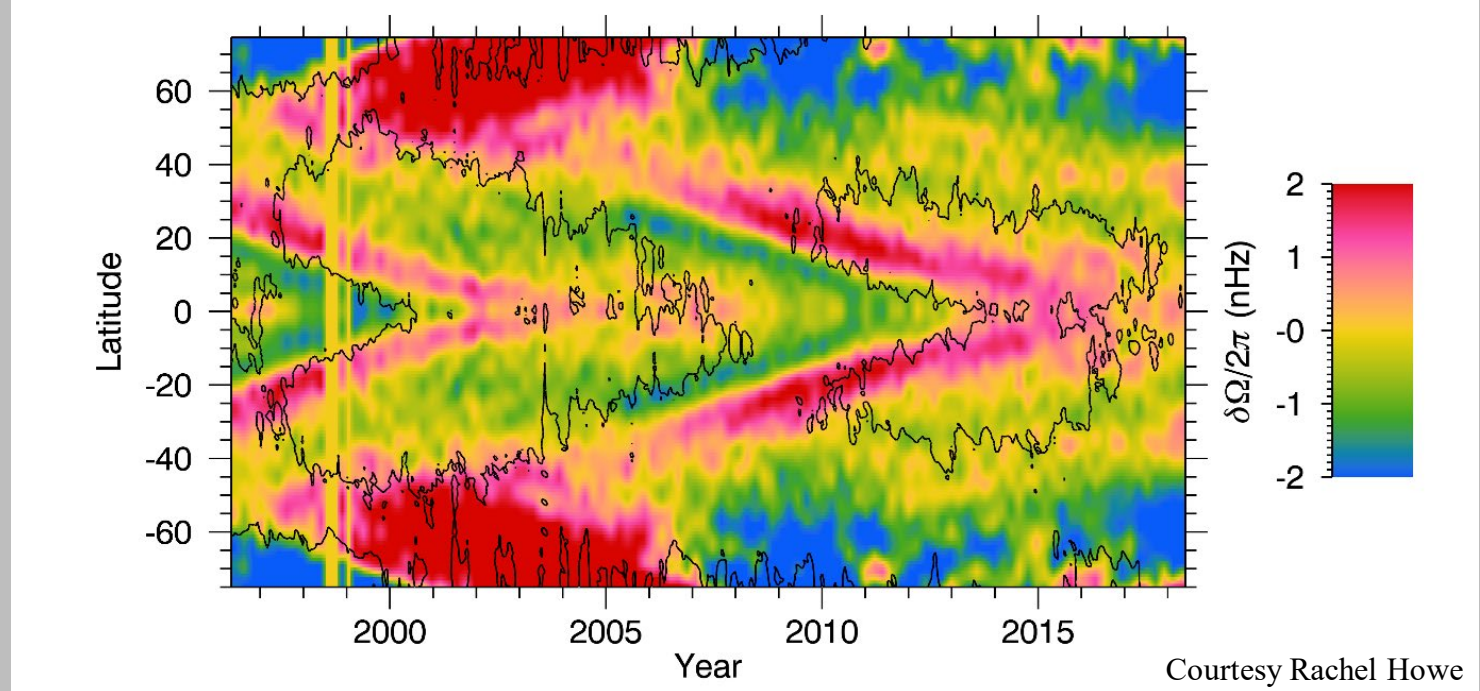
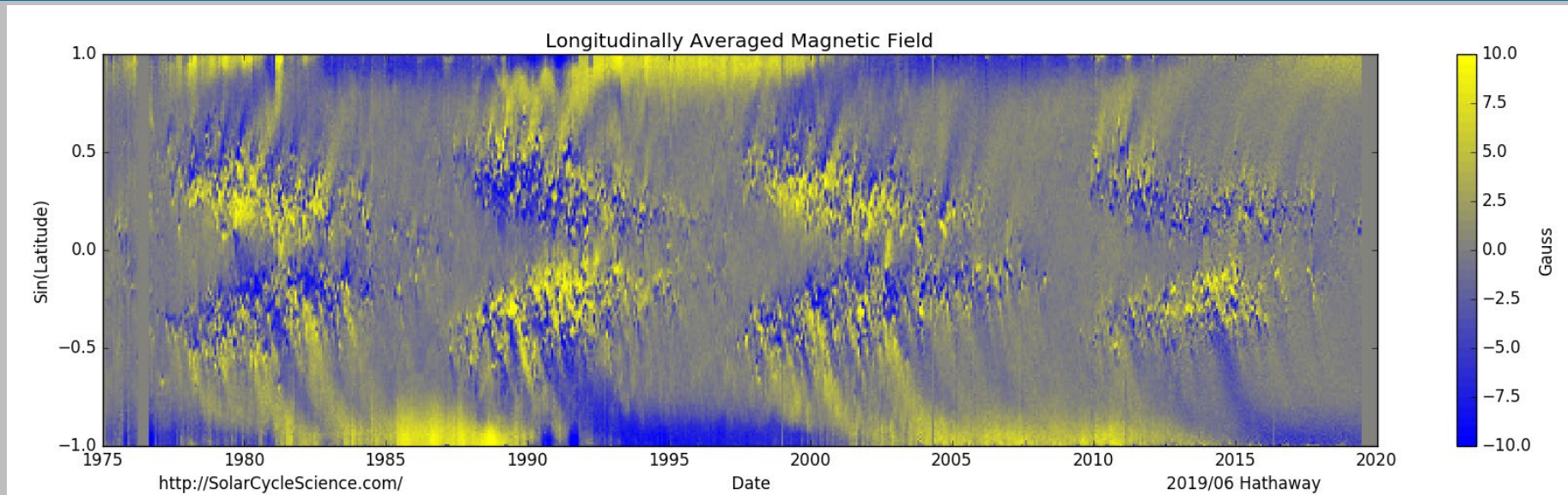
The Lincoln-McNish method provides fairly-accurate extrapolations of solar activity out to several years (Suggs, *et al.*, 2011)

# What Timescale to Predict? Years?

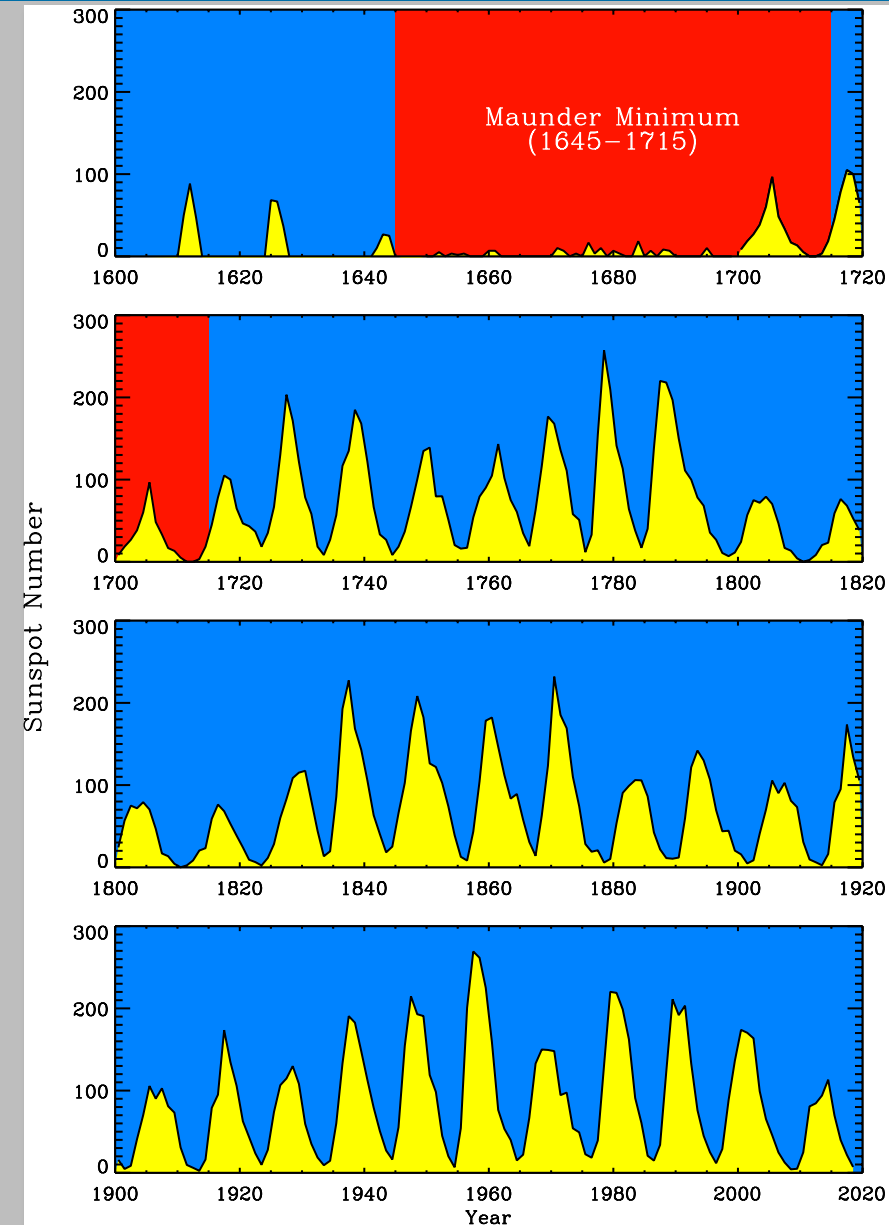
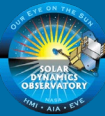


Polar field precursors (like SODA) have done a reasonable job of predicting the peak of four cycles, often before minimum.

# What Timescale to Predict? Decades?



# NASA What Timescale to Predict? Longer?

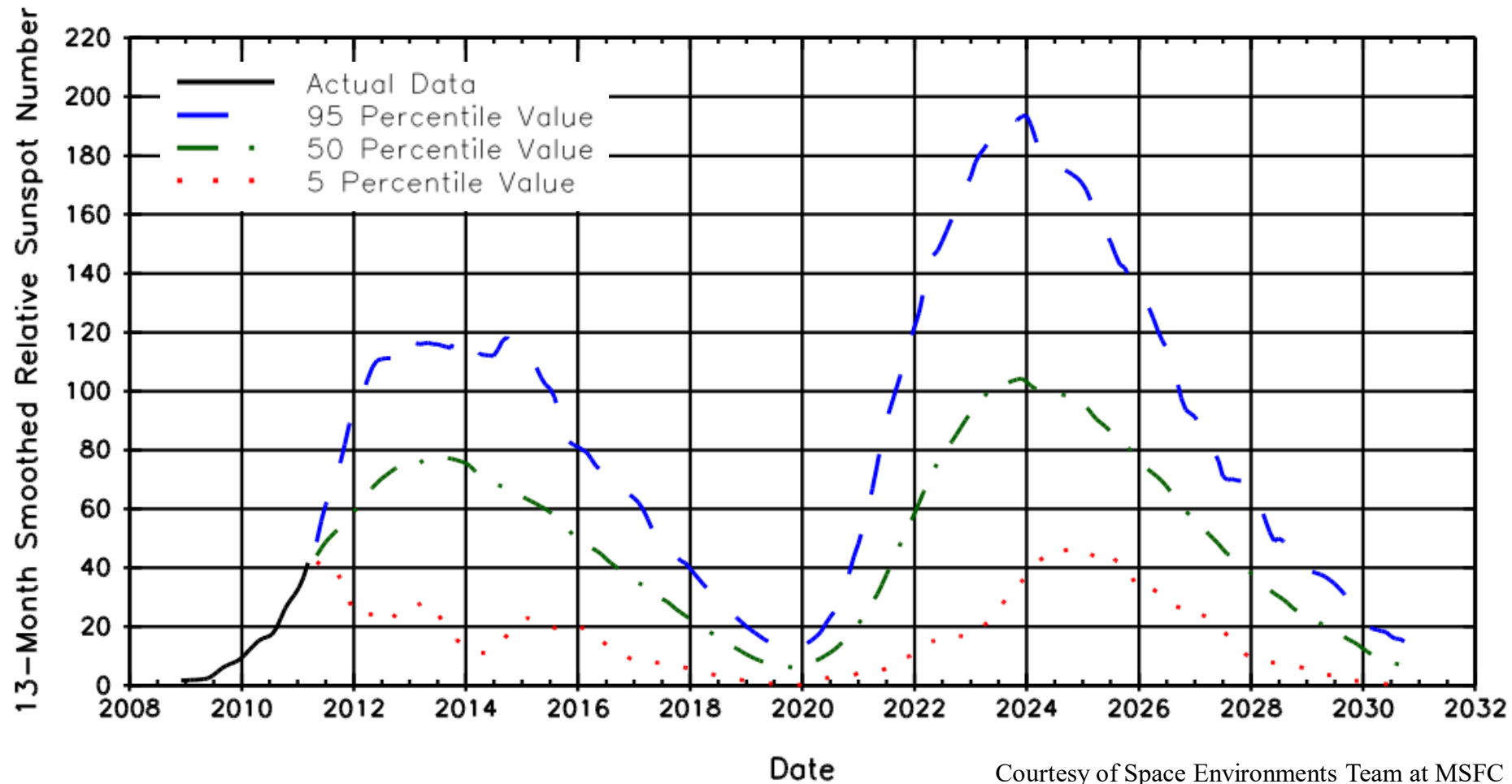


At even longer timescales we rely on timeseries analysis of sunspot number, cosmic ray radioisotopes, and other proxies.

The biggest problem becomes controlling the error of the prediction.

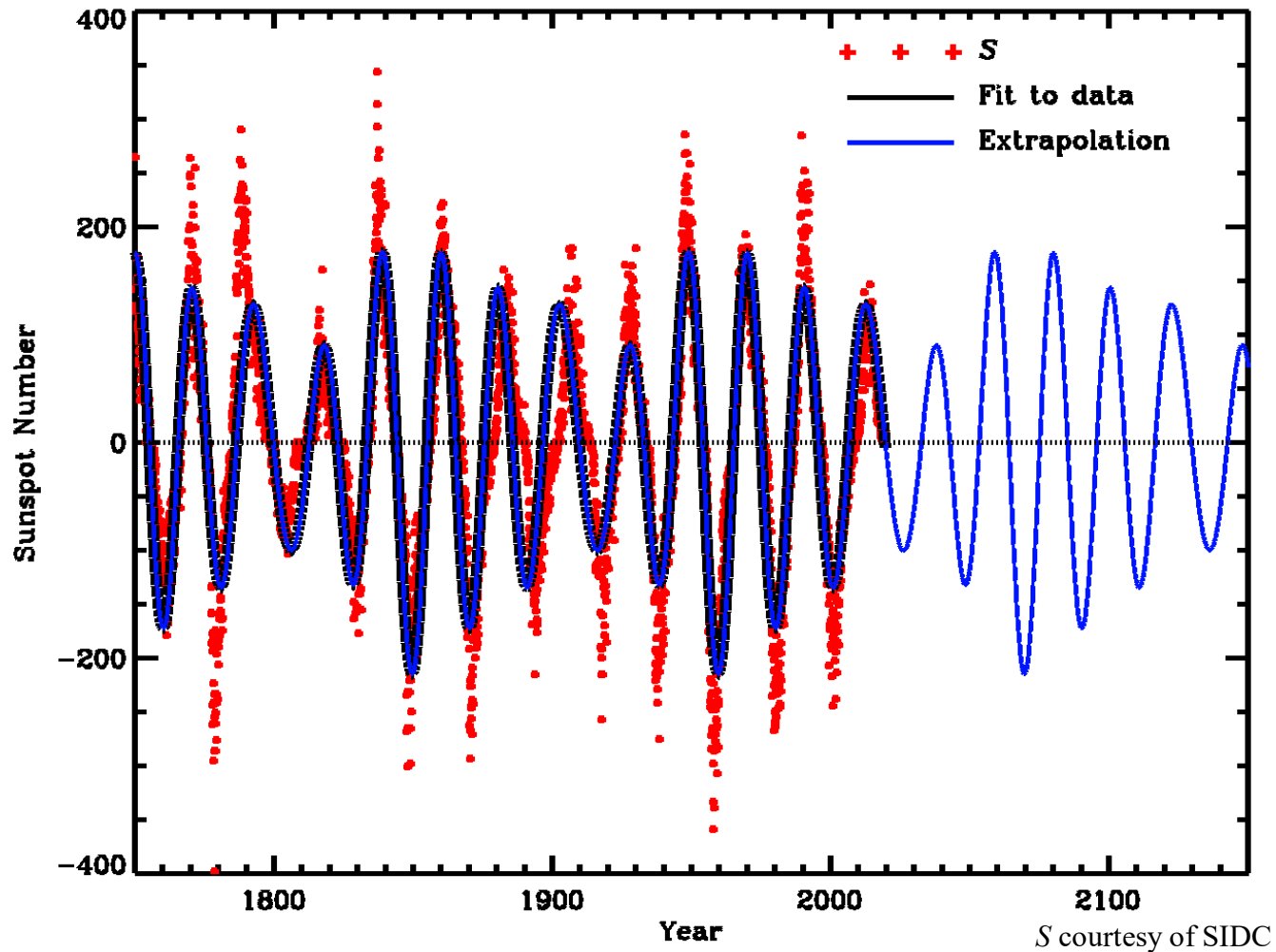
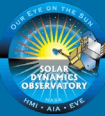


# NASA Estimated Error Grows in Time



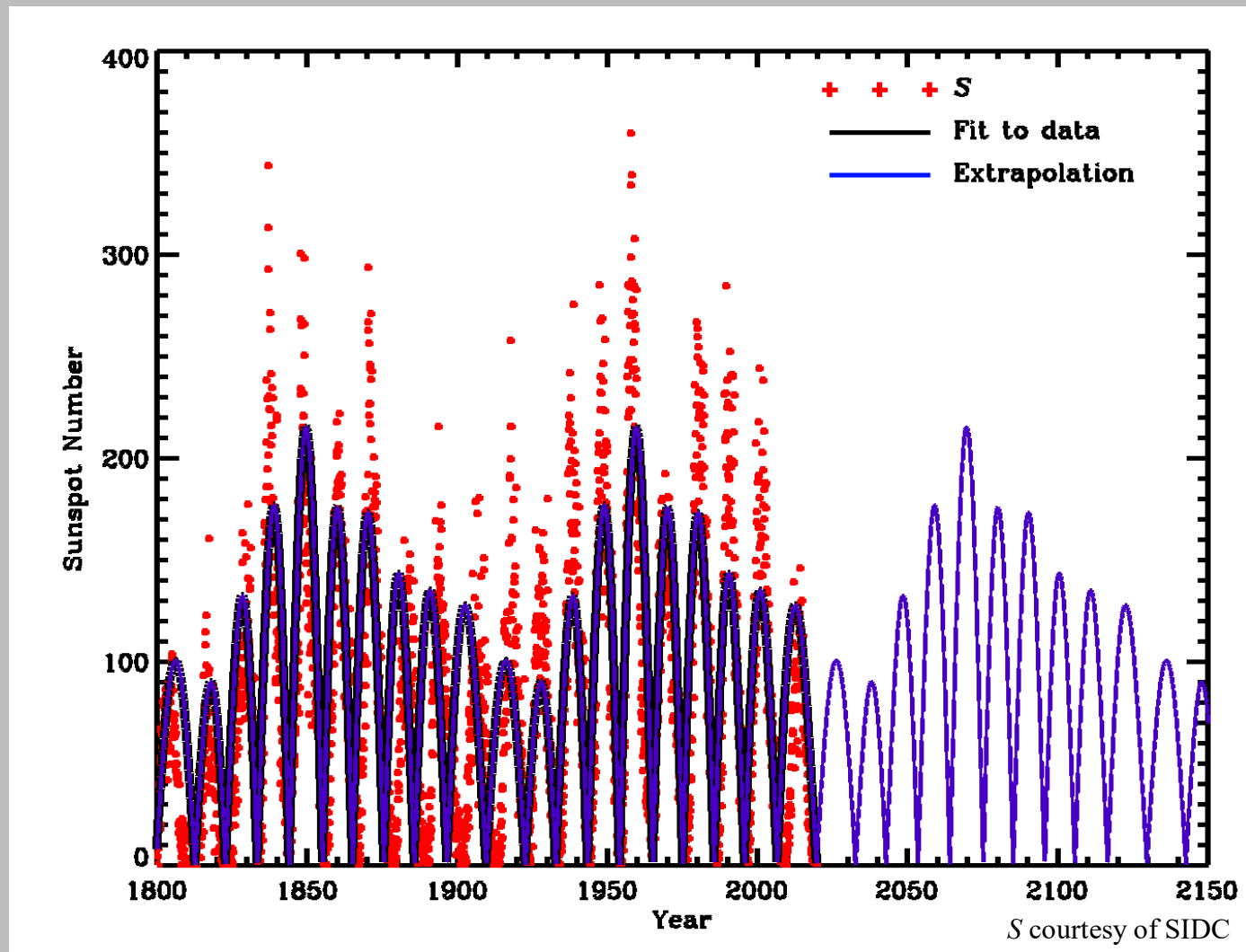
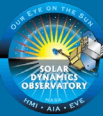
Distance from 50% to 95% (i.e.,  $2\sigma$ ) grows from 40 at the peak of SC 24 to 90 at the peak of SC 25.

# Error in Fourier Fit is Difficult



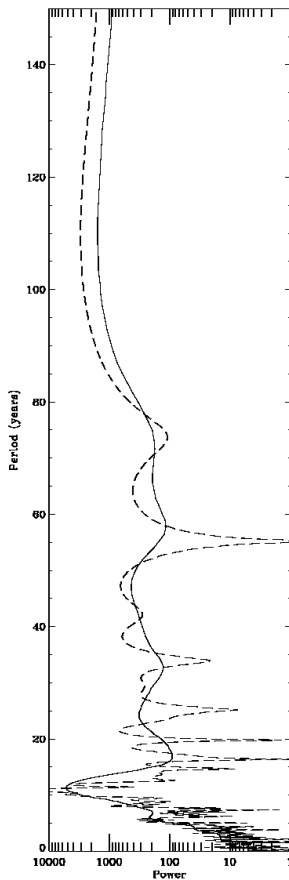
Fourier fit to  $S$  with a base period of 110 years, 5 partials, signed sunspots cycles to make a 22-year solar cycle.

# NASA Error in Fourier Fit is Difficult

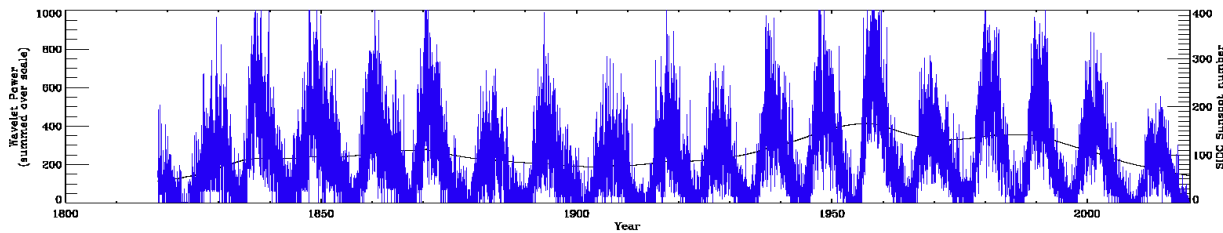
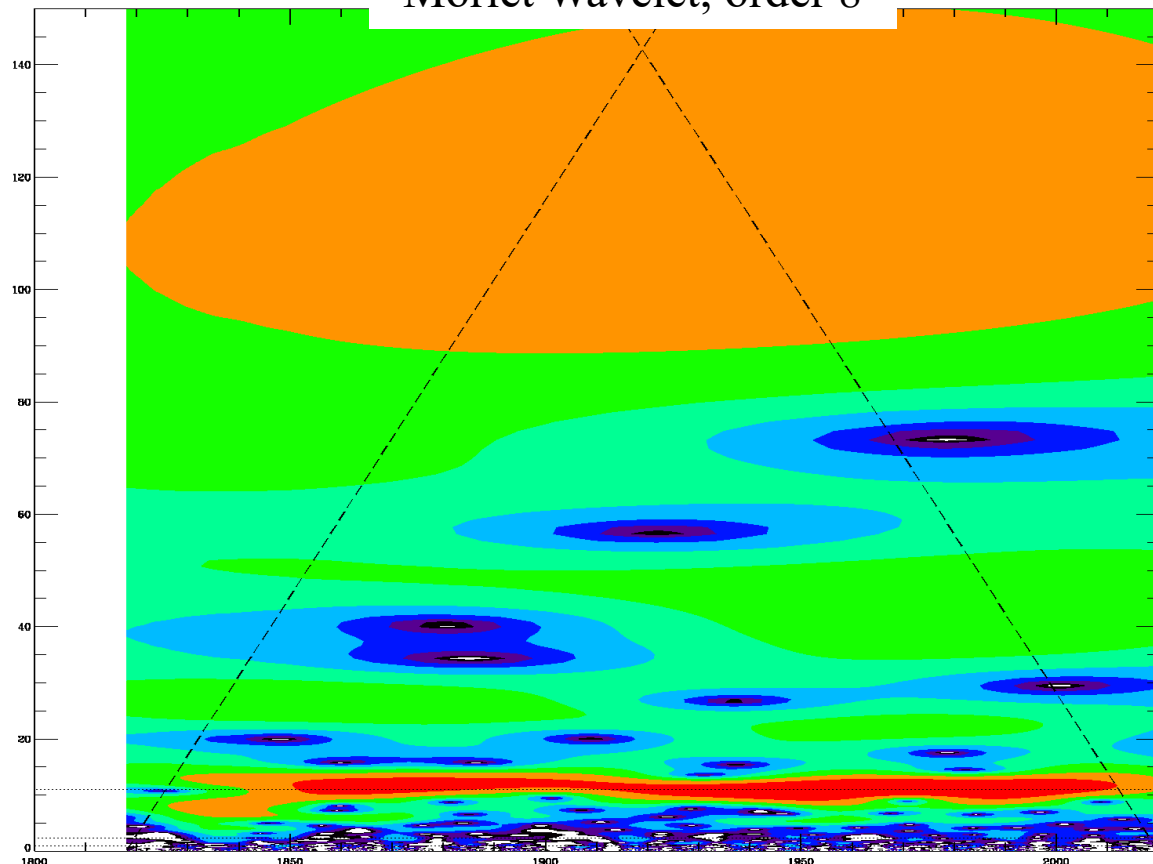


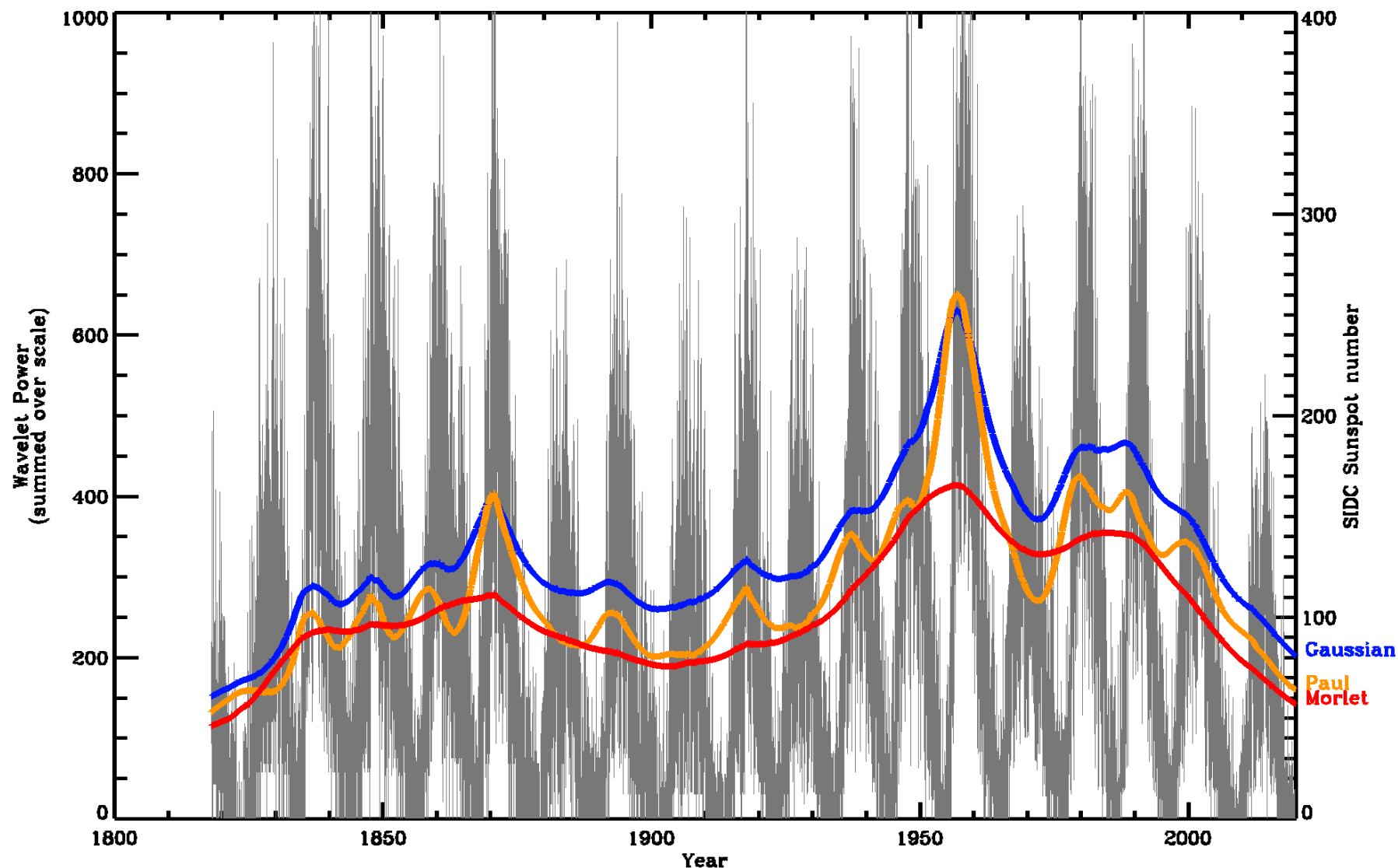
Fourier fit to  $S$  with a base period of 110 years, 5 partials, signed sunspots cycles to make a 22-year solar cycle. Frequencies and amplitude vary with time.

Fourier transform and summed over time

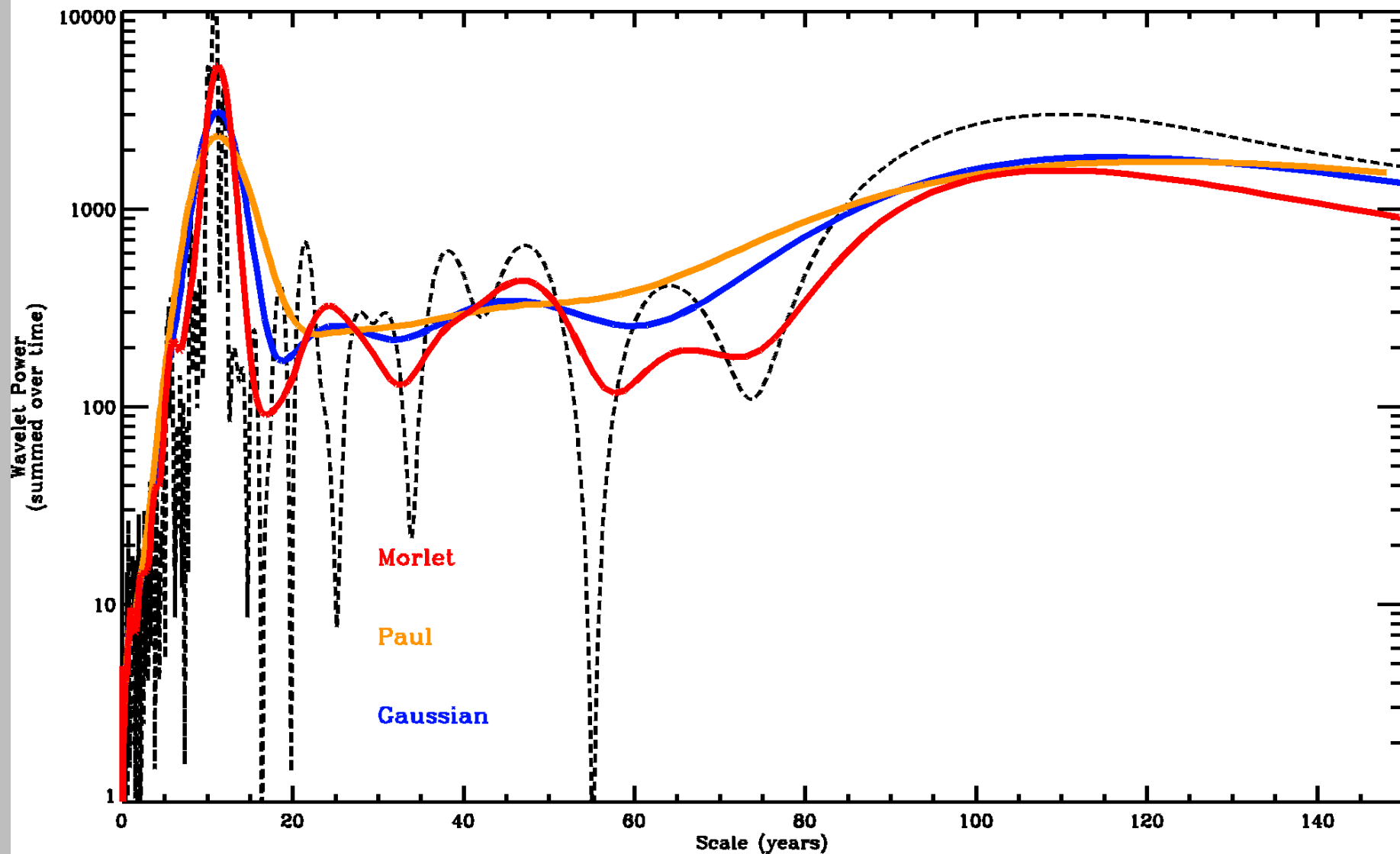


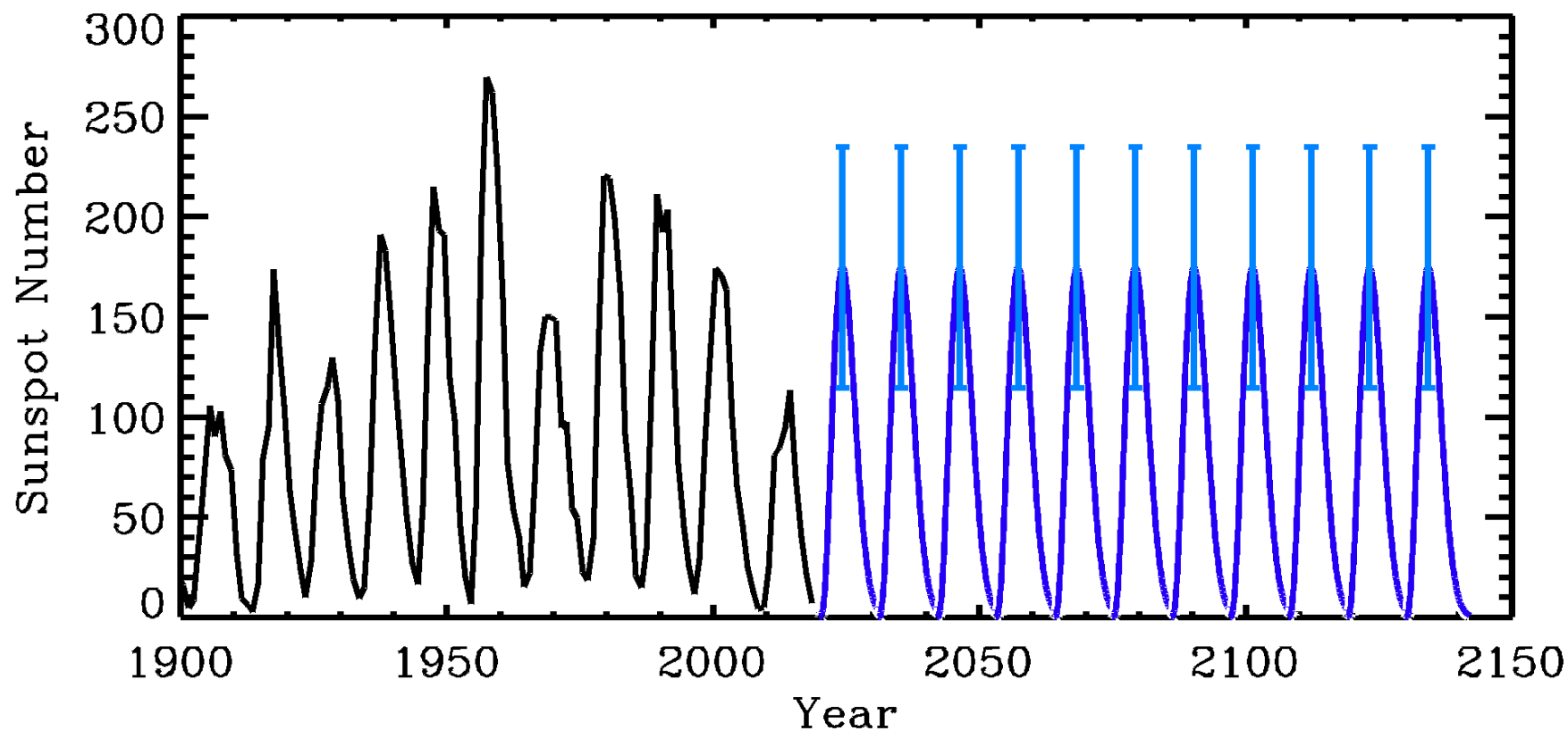
Morlet Wavelet, order 8



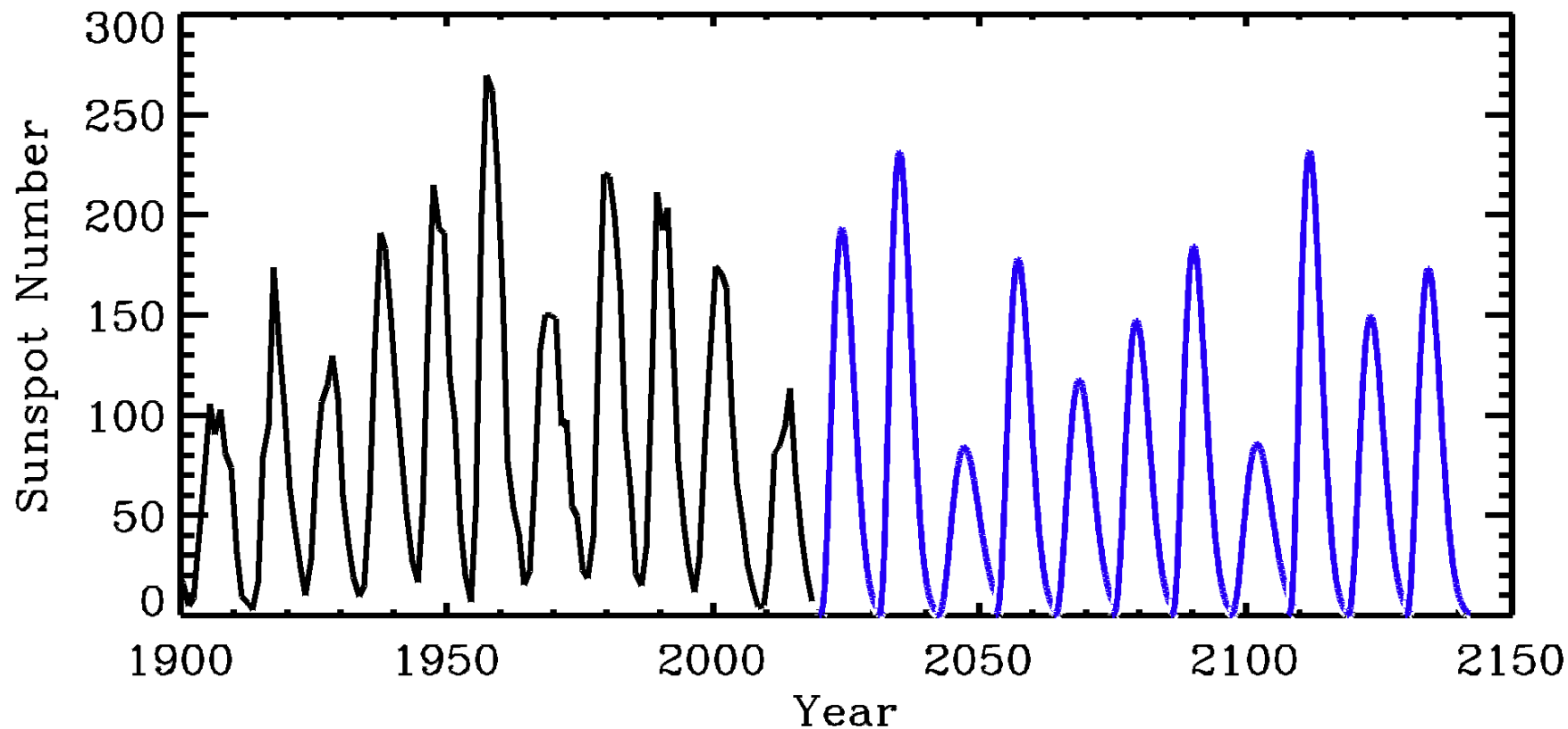




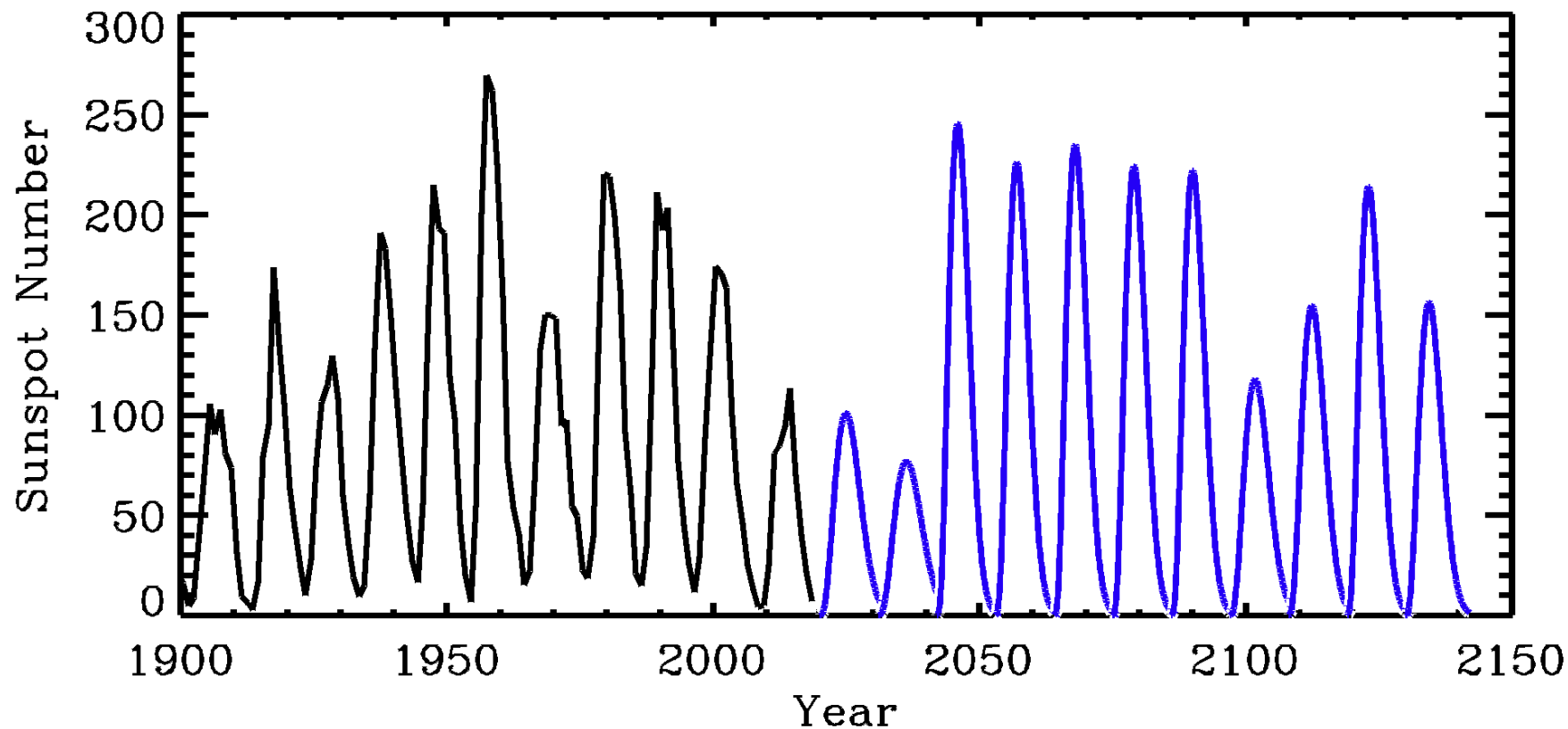




One long-term prediction is to assume the climatological average.

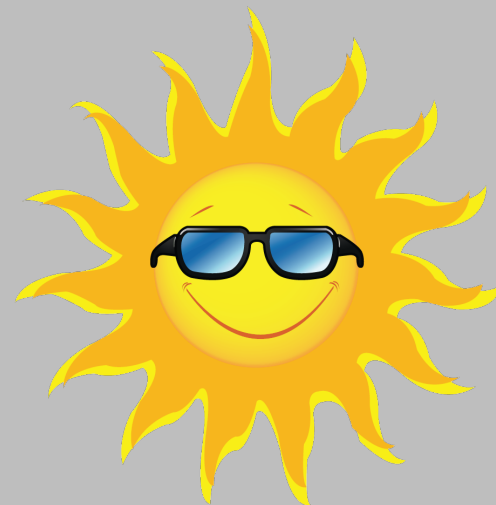


Better is to assume a normal distribution of variations  $\pm\sigma$  about the climatological average.

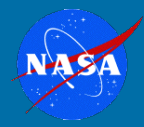


Even better is to assume an ensemble of variations with a normal distribution  $\pm\sigma$  about the climatological average.

- 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!***

