

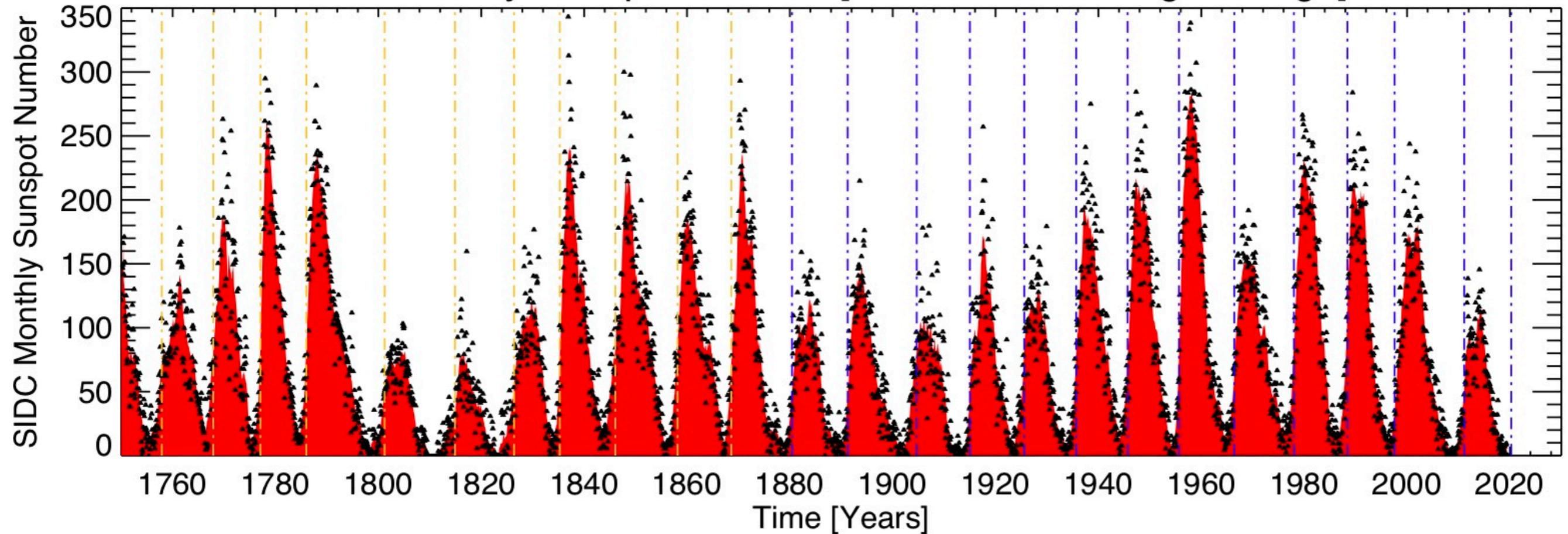
A New “Clock” for the Sun

Sun-Climate Implications & What May Be Looming



McIntosh, Leamon, Chapman, Watkins & Egeland

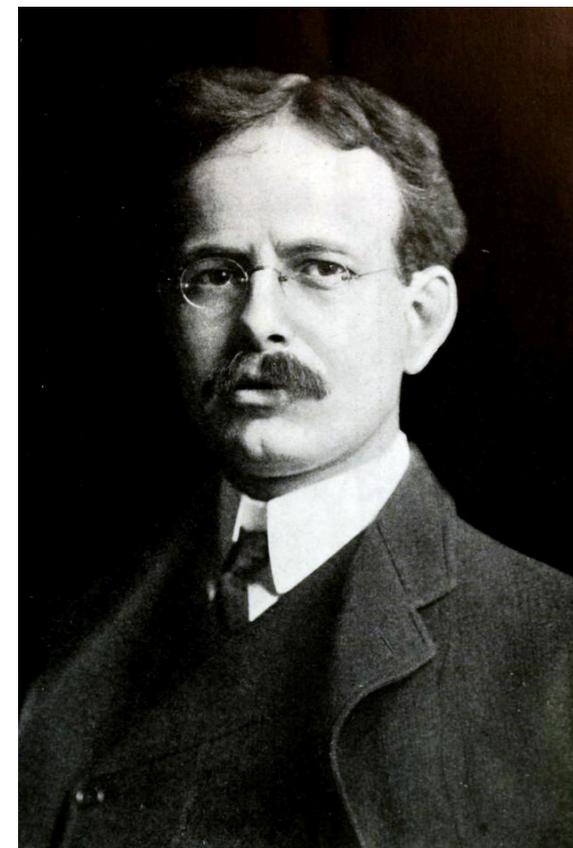
SIDC Daily Sunspot Number [12-month Running Average]



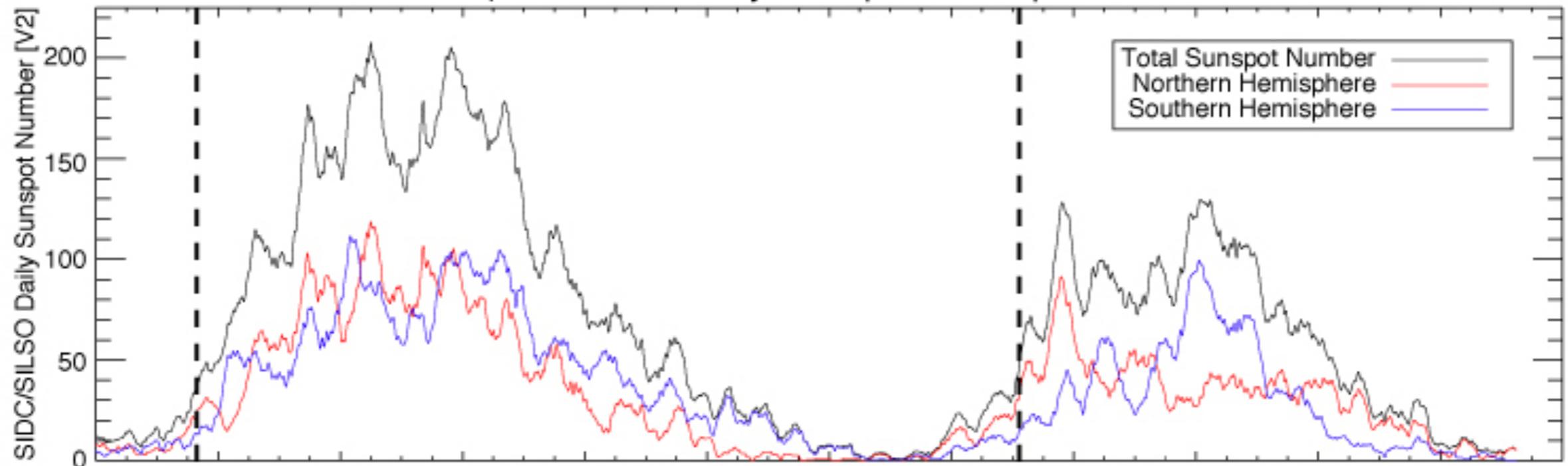
250+ years of the sunspot number?

250+ potential solutions to the puzzle?

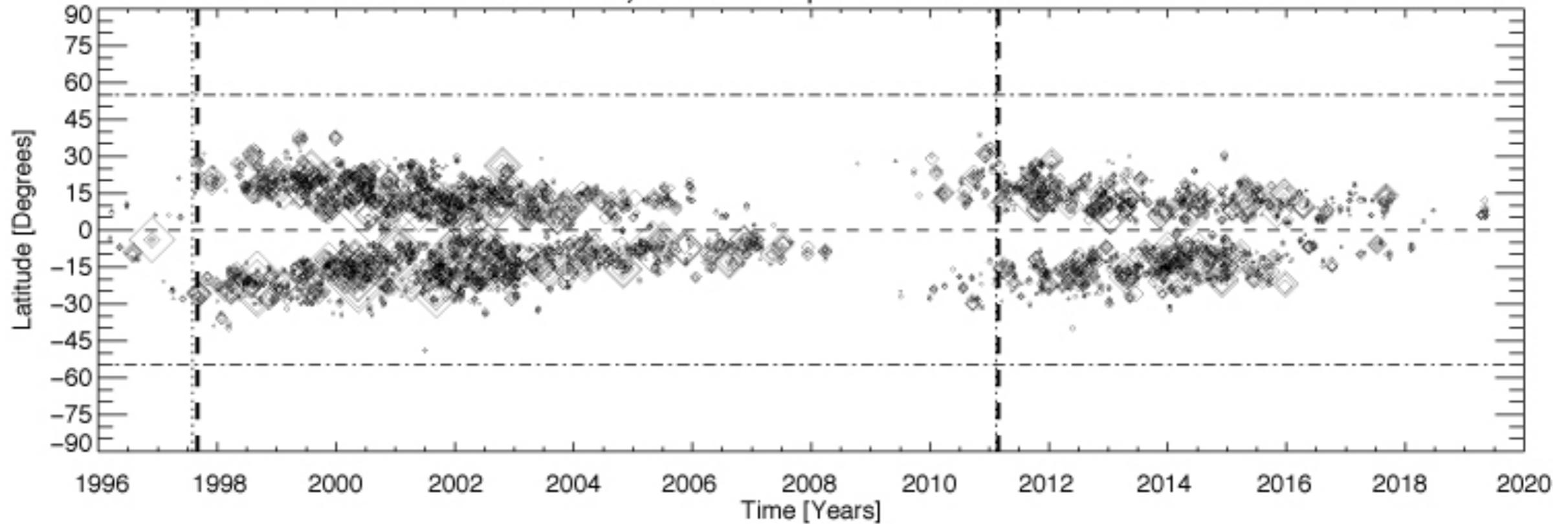
250+ predictions of sunspot cycle 25?



A) SIDC/SILSO Daily Hemispheric Sunspot Number



B) USAF Sunspot Distribution

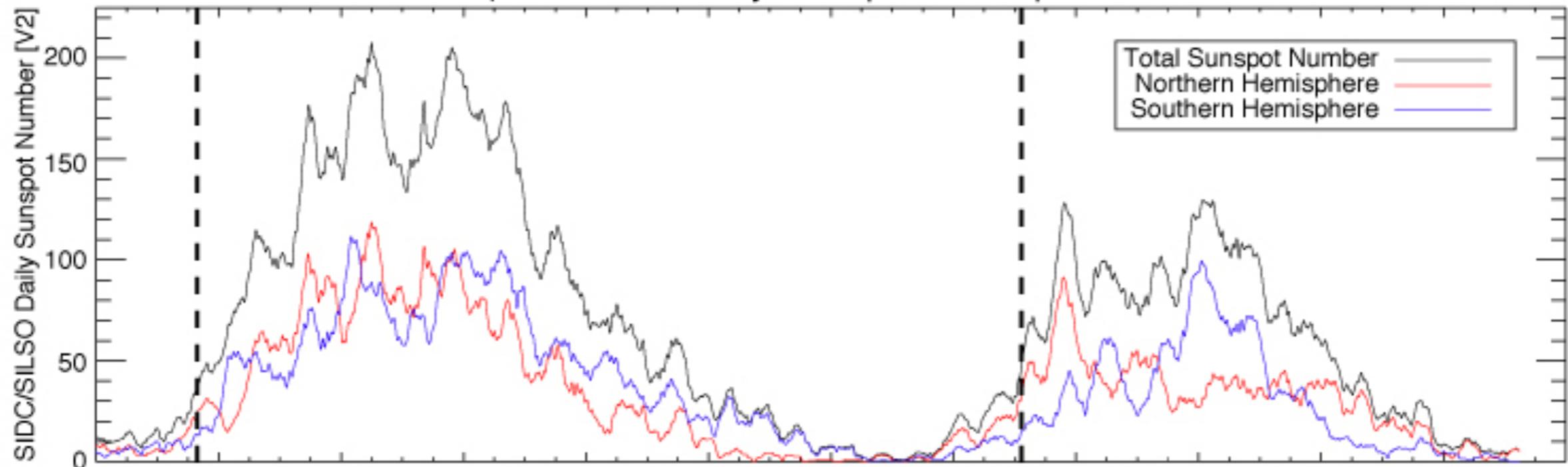


Agree: We are in sunspot/solar minimum?

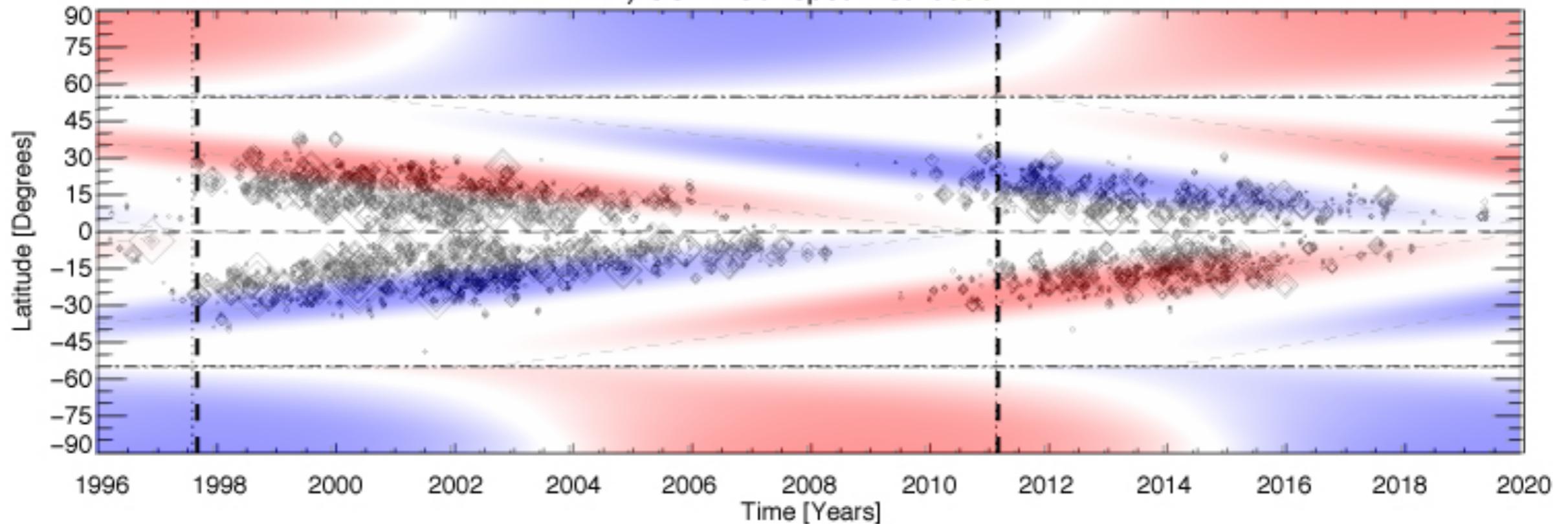
How does minimum end?



A) SIDC/SILSO Daily Hemispheric Sunspot Number



B) USAF Sunspot Distribution

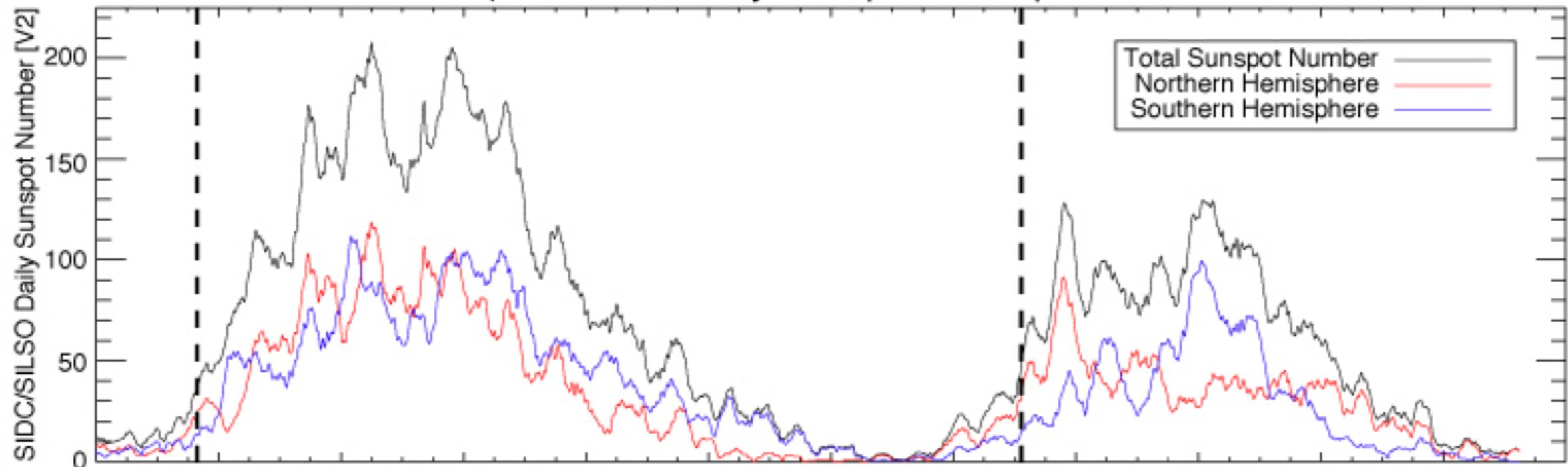


How does minimum end?

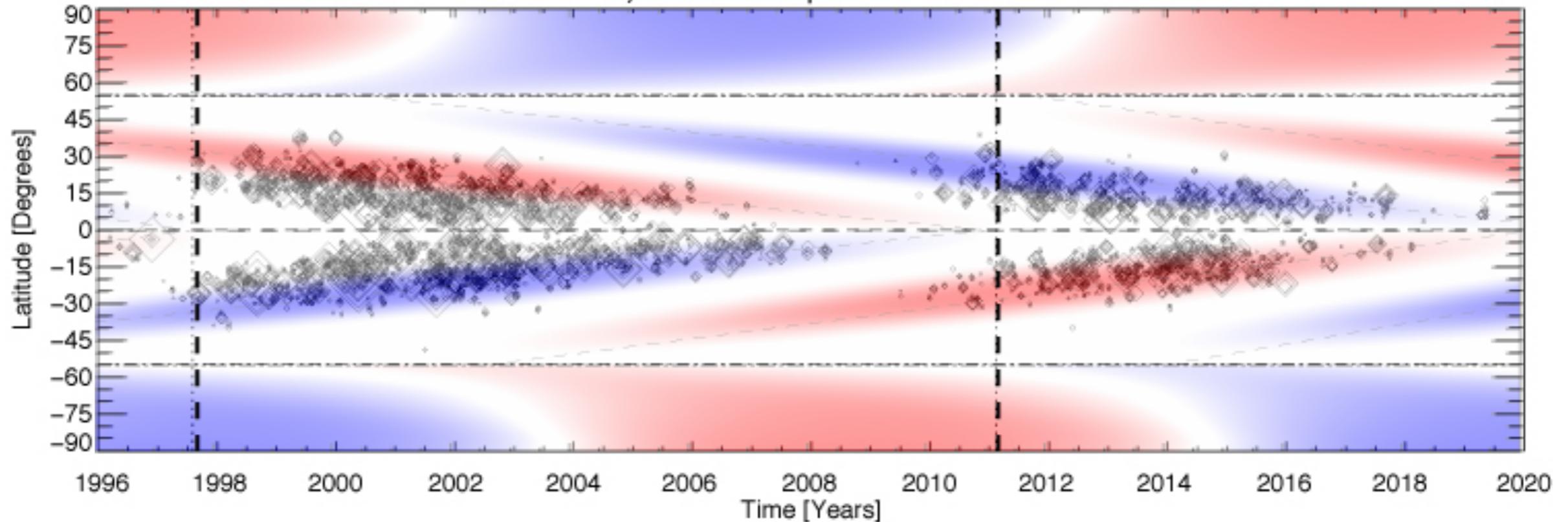
Minimum ends when a Hale magnetic cycle ends!



A) SIDC/SILSO Daily Hemispheric Sunspot Number



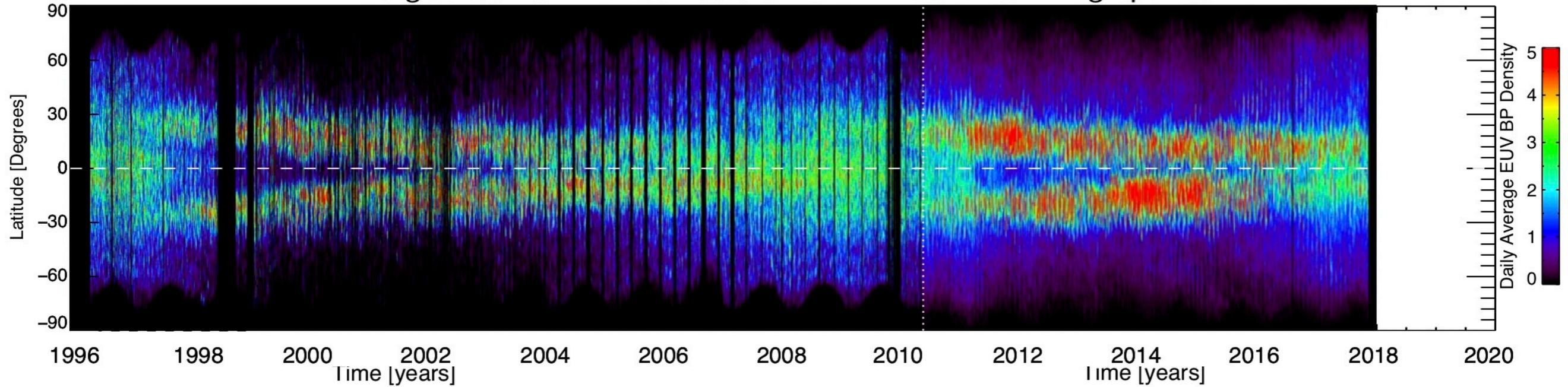
B) USAF Sunspot Distribution



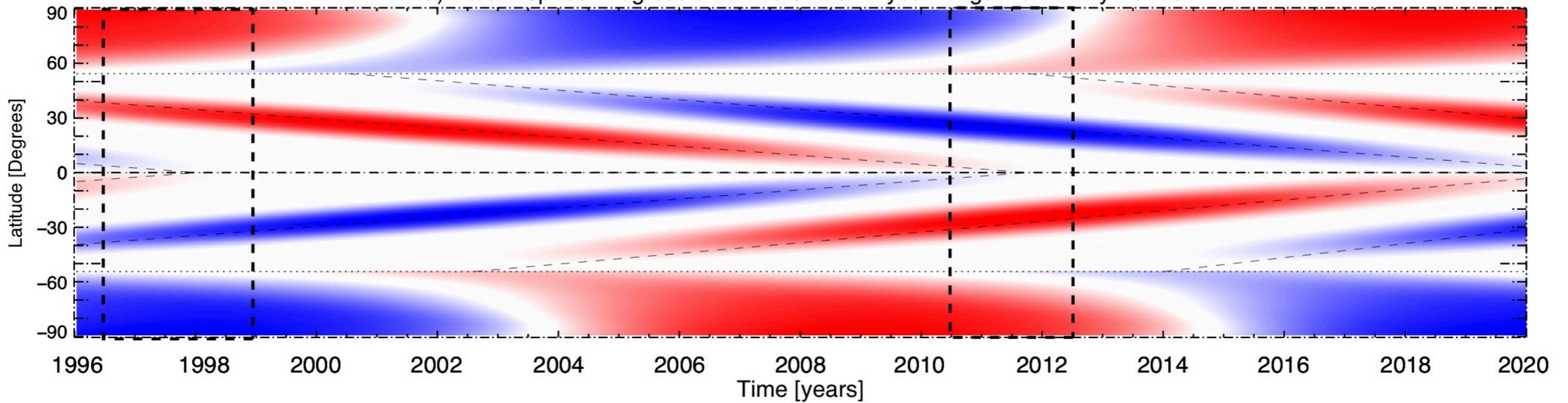
Minimum ends when a Hale magnetic cycle ends!
Interaction of Hale cycles shapes the sunspot cycle.



Merged SOHO/EIT 195Å and SDO/AIA 193Å EUV Brightpoints

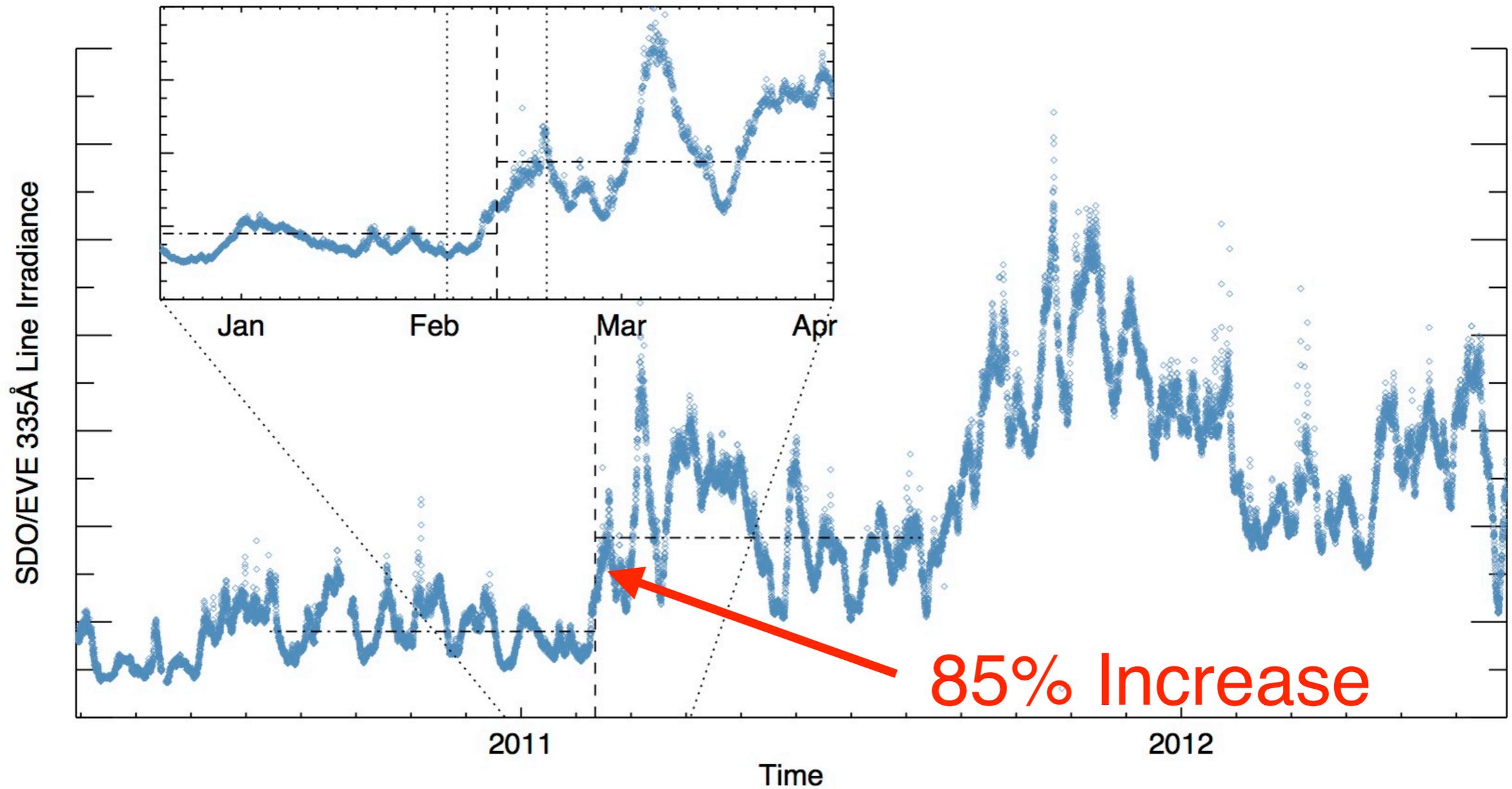


C) Data-Inspired Progression of the Sun's 22-year Magnetic Activity Bands



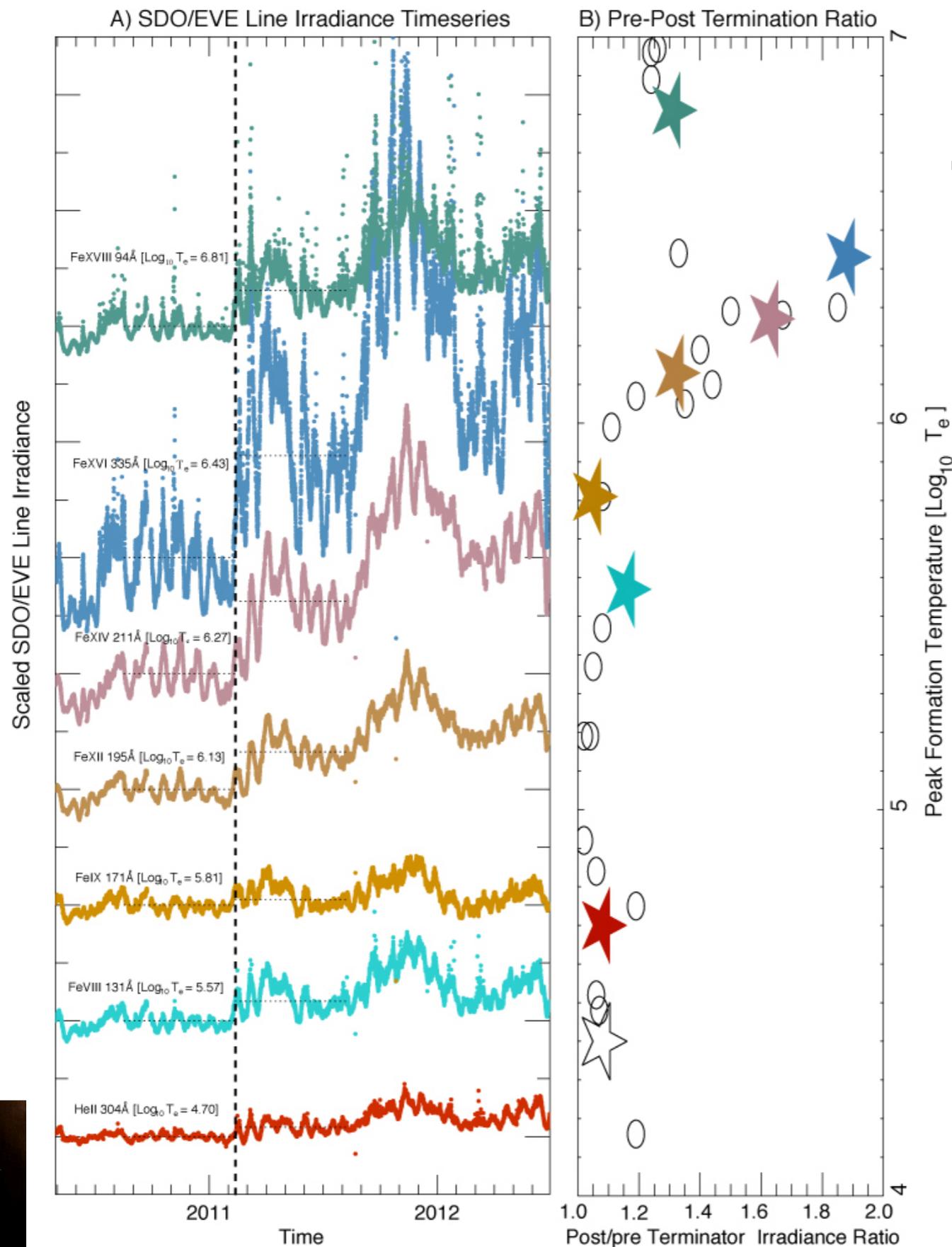
**The magnetic environment of the Sun
changes in a “heartbeat”**





**The radiative environment of the Sun
changes in a “heartbeat”**



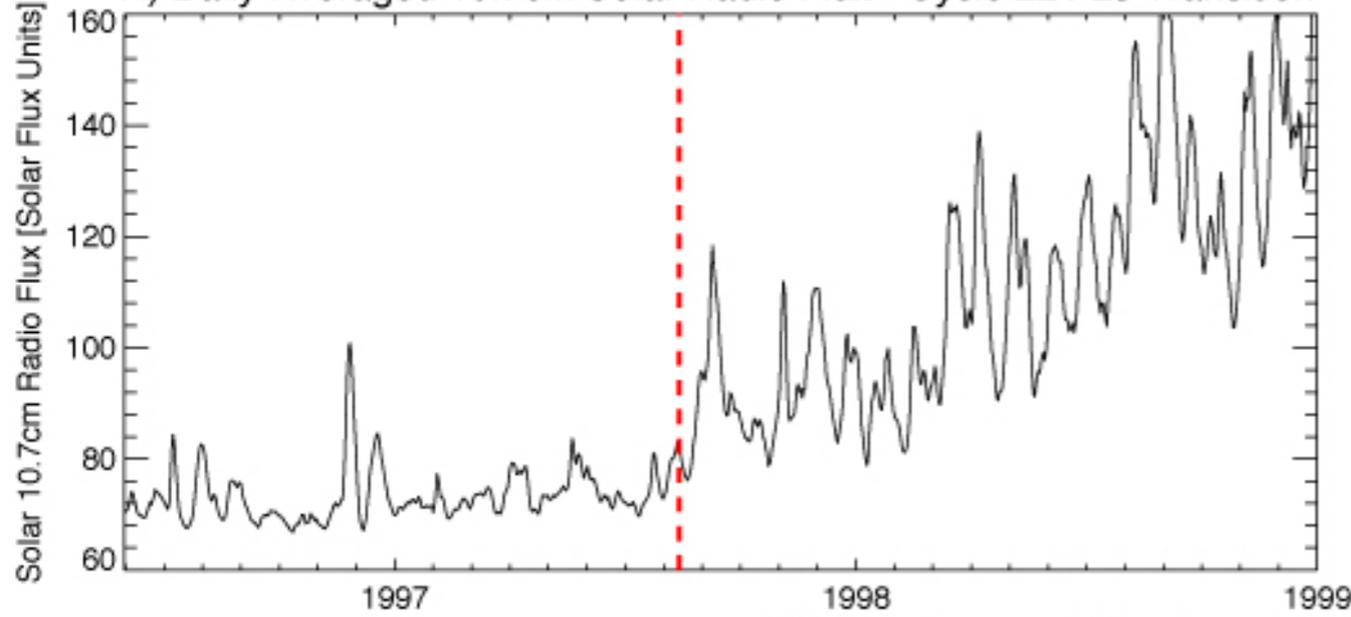


The radiative response to the end of a Hale cycle shows a strong temperature dependence.

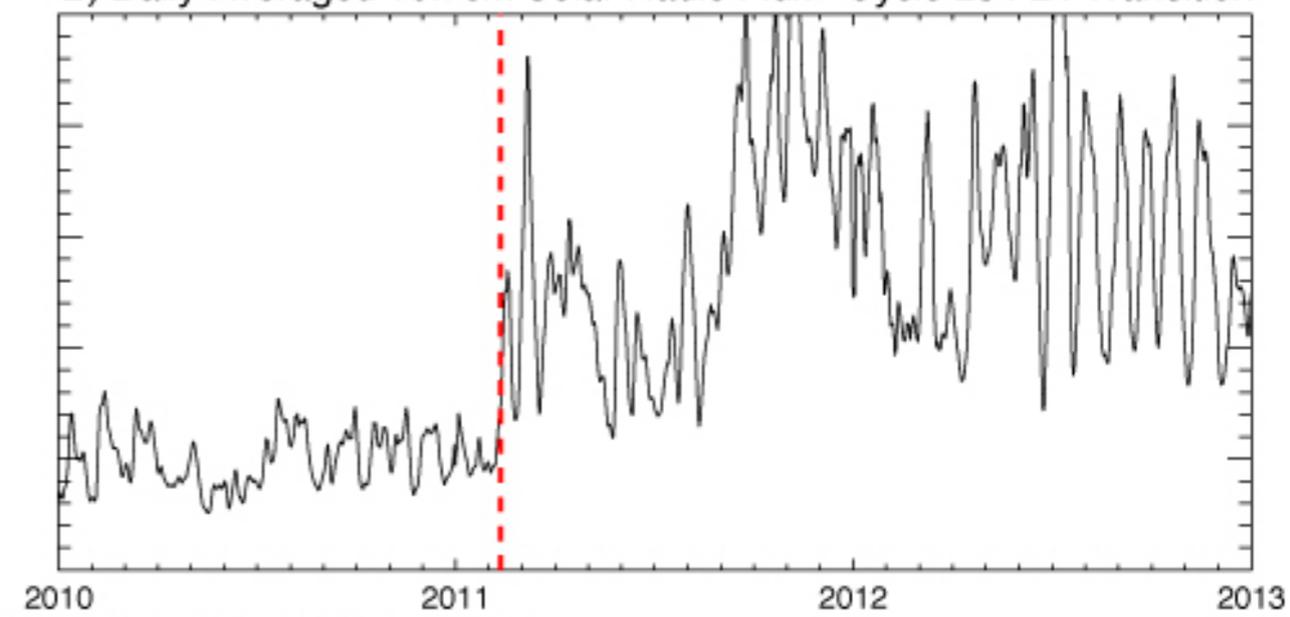
The corona, in response to the magnetic environment beneath, undergoes a rapid metamorphosis.



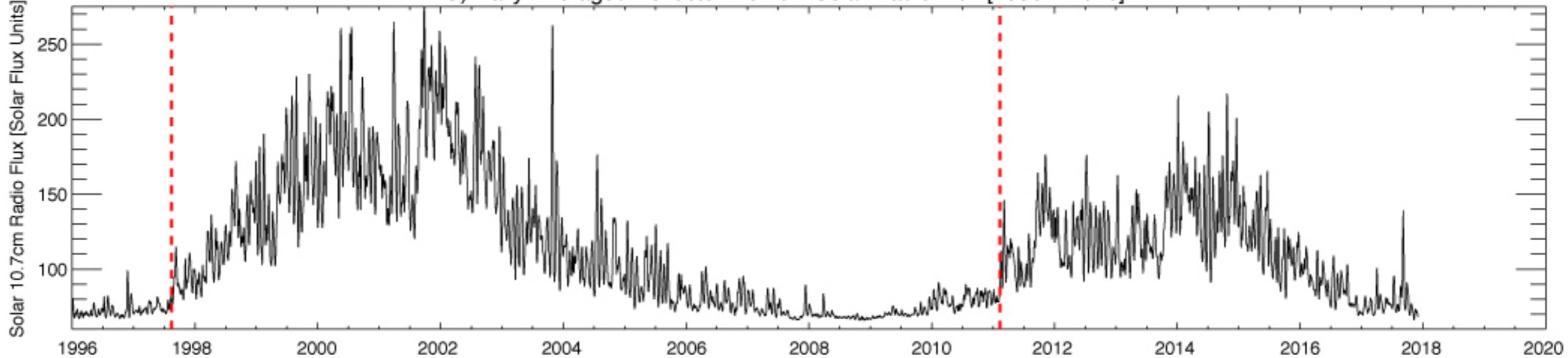
A) Daily-Averaged 10.7cm Solar Radio Flux - Cycle 22 / 23 Transition



B) Daily-Averaged 10.7cm Solar Radio Flux - Cycle 23 / 24 Transition



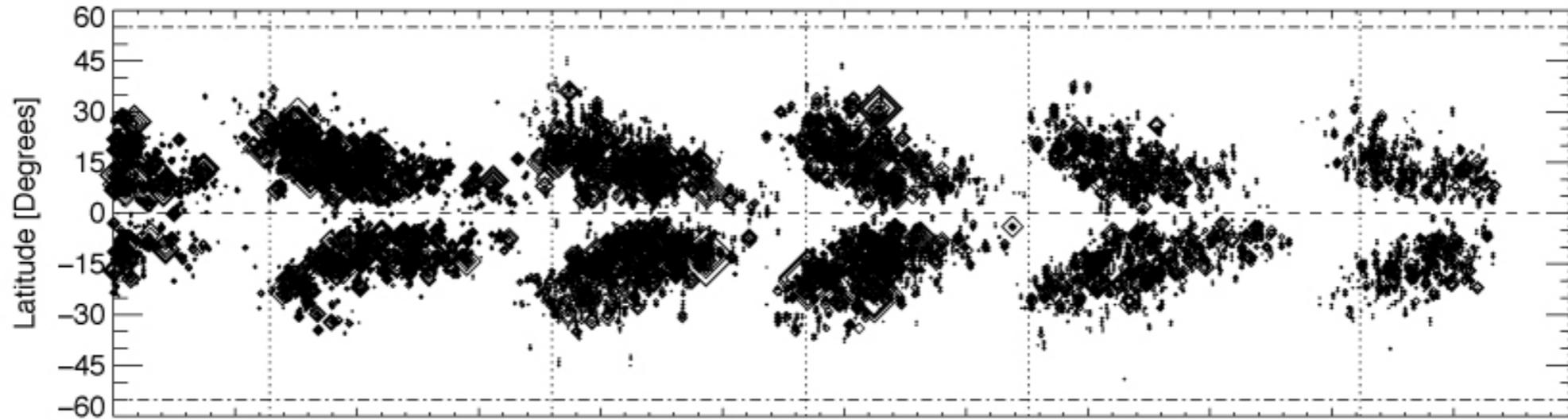
C) Daily-Averaged Penticton 10.7cm Solar Radio Flux [1996 - 2020]



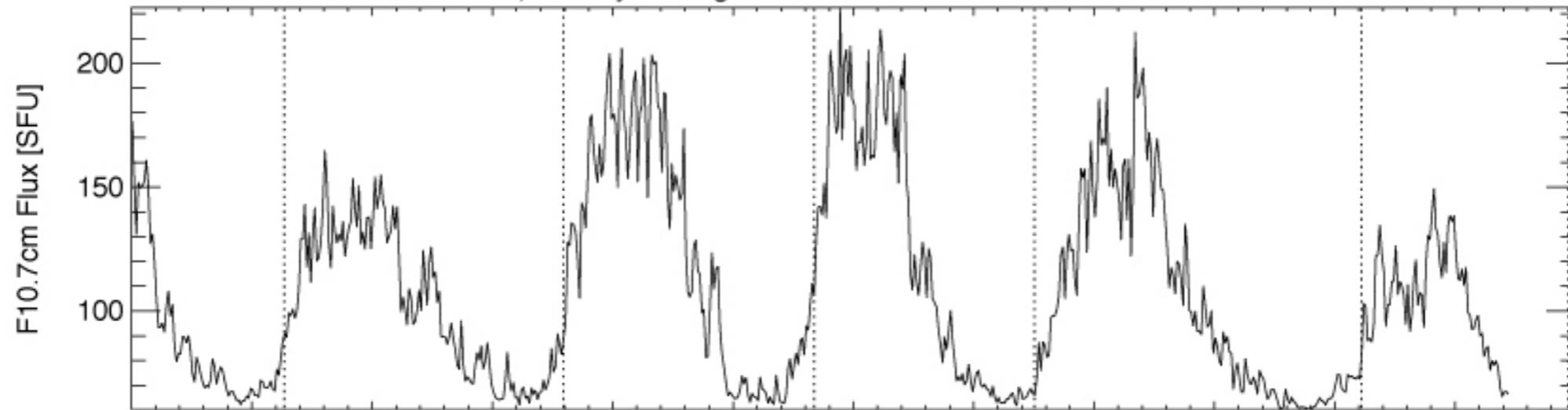
Cycles 23 and 24 are NOT distinct



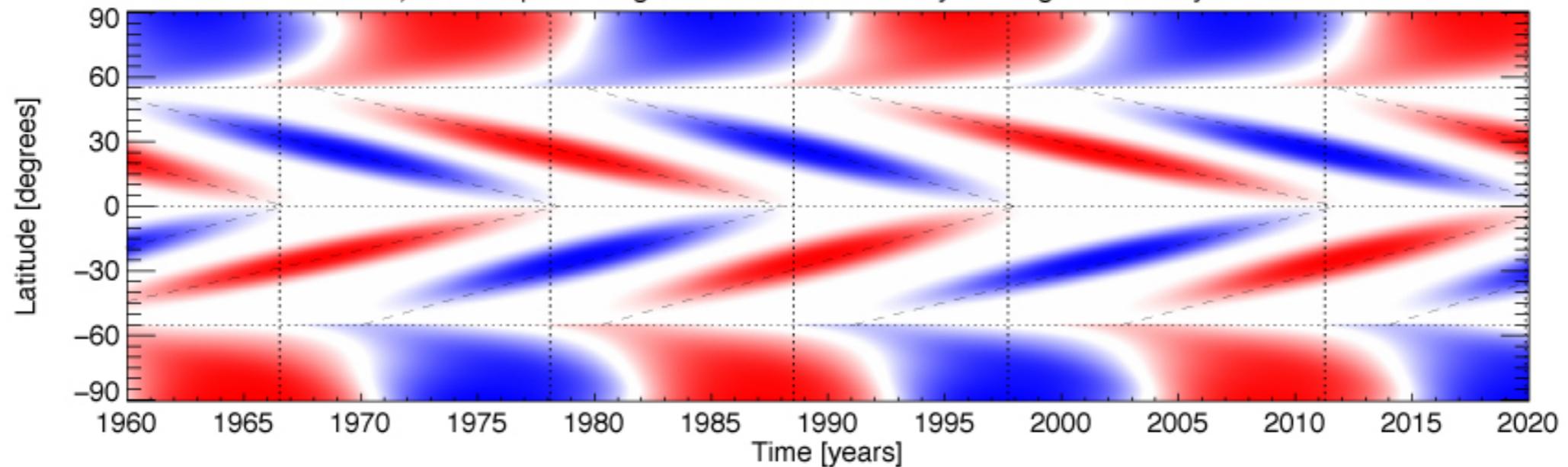
B) USAF Sunspot Distribution



C) Weekly-Averaged Penticton 10.7cm Solar Radio Flux

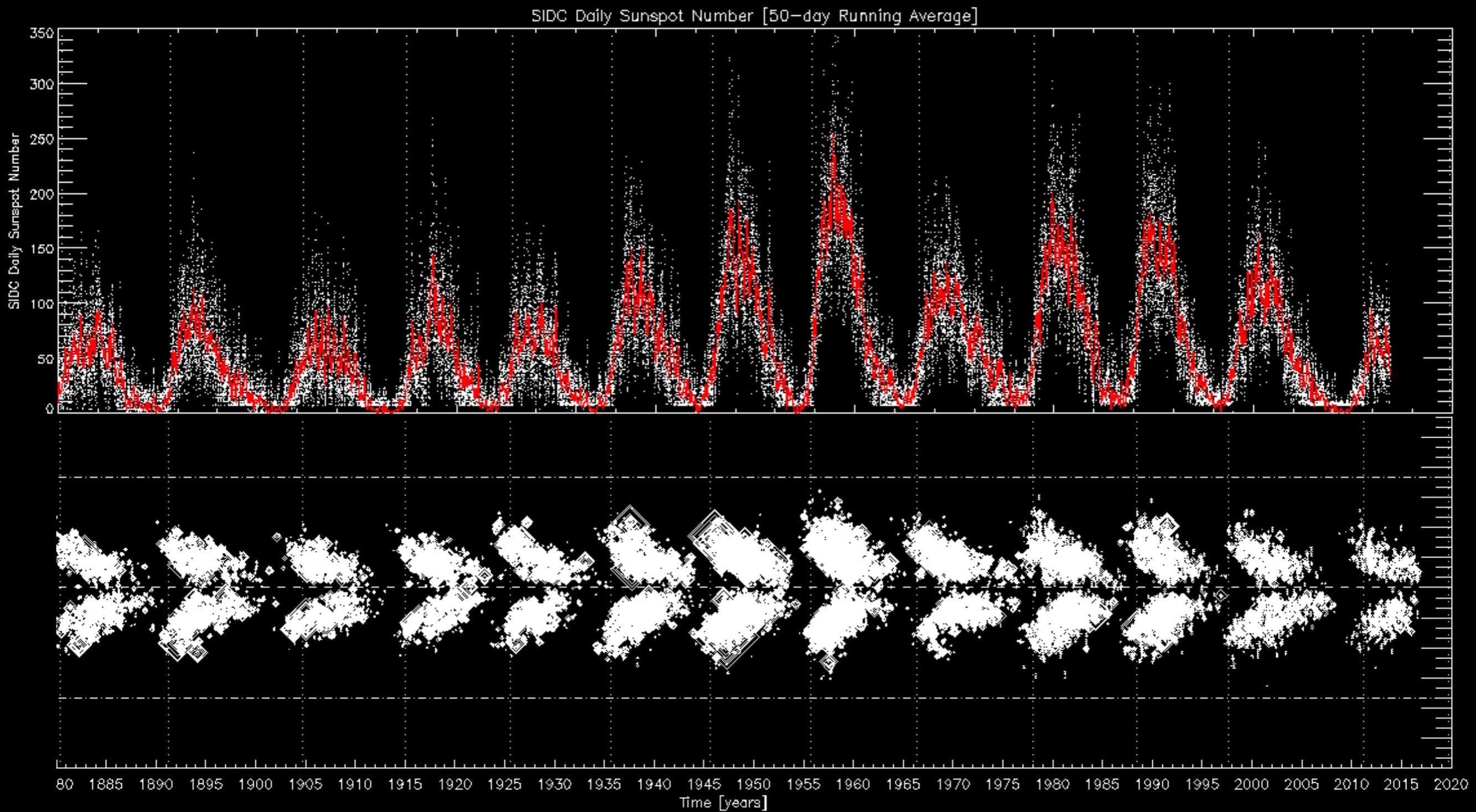


D) Data-Inspired Progression of the Sun's 22-year Magnetic Activity Bands

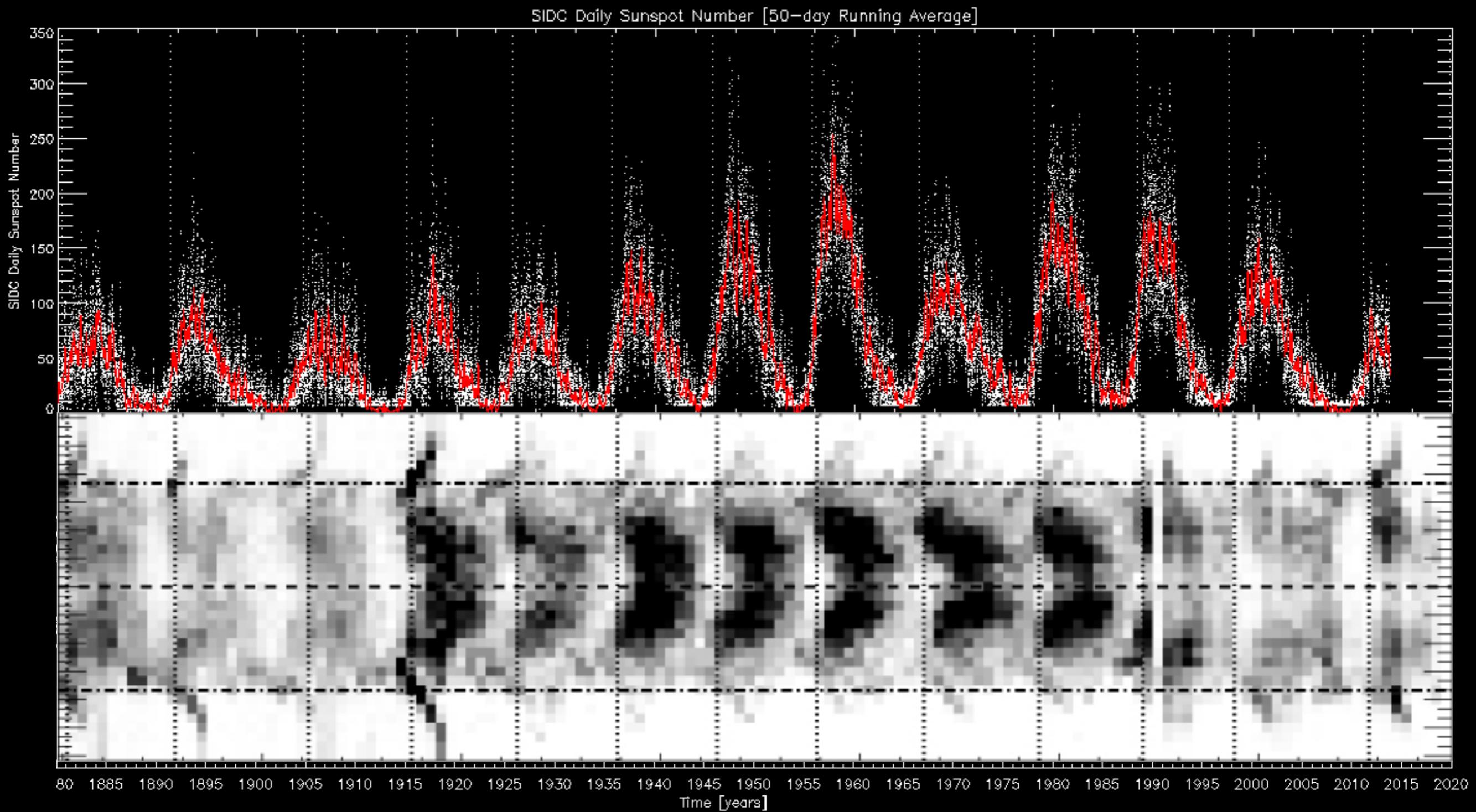


Neither are 22, 21, 20 and 19.....

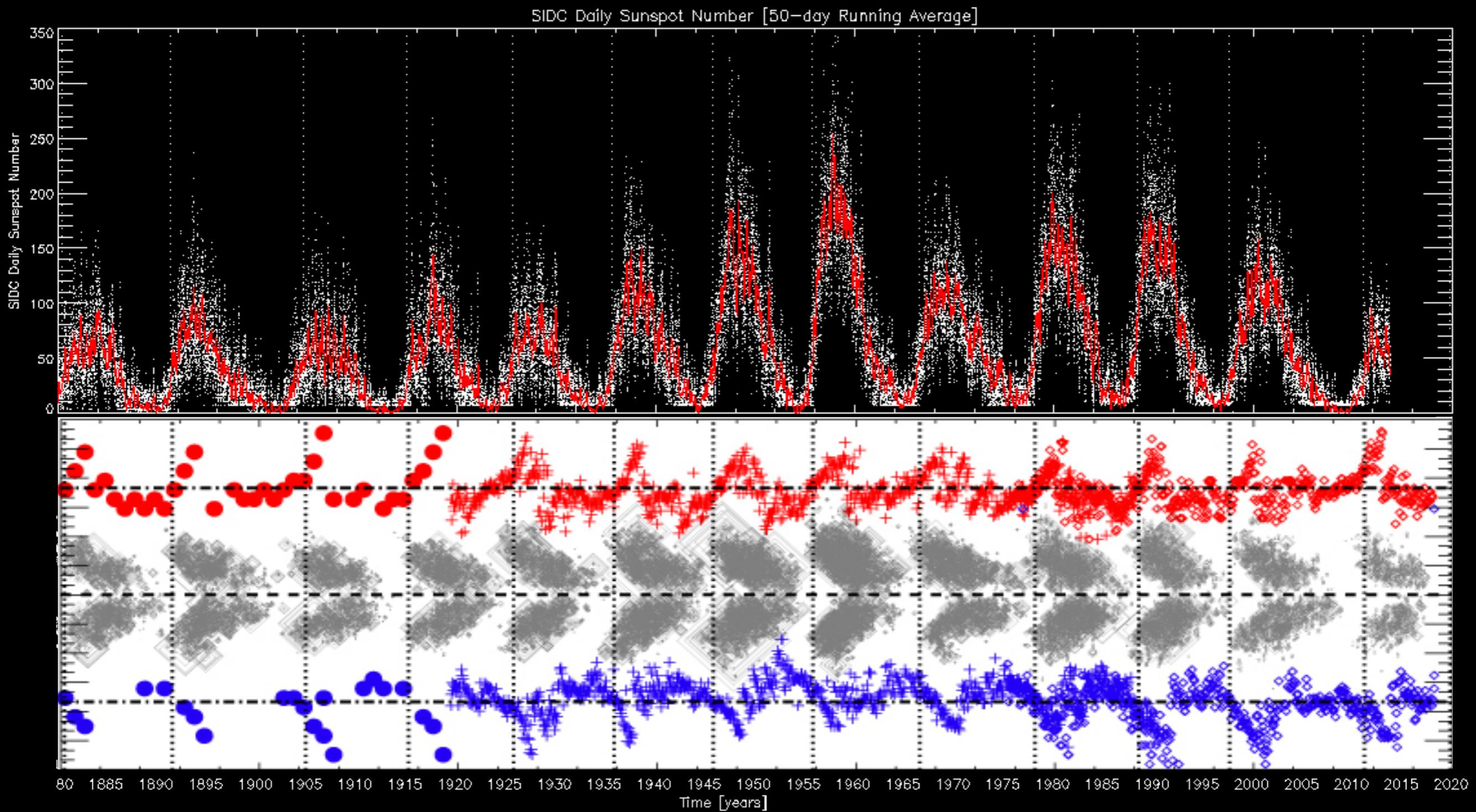
Step-functions in f10.7 coincident with 100 μ H transition



Going back 140 years one notices something odd when you look at filaments.



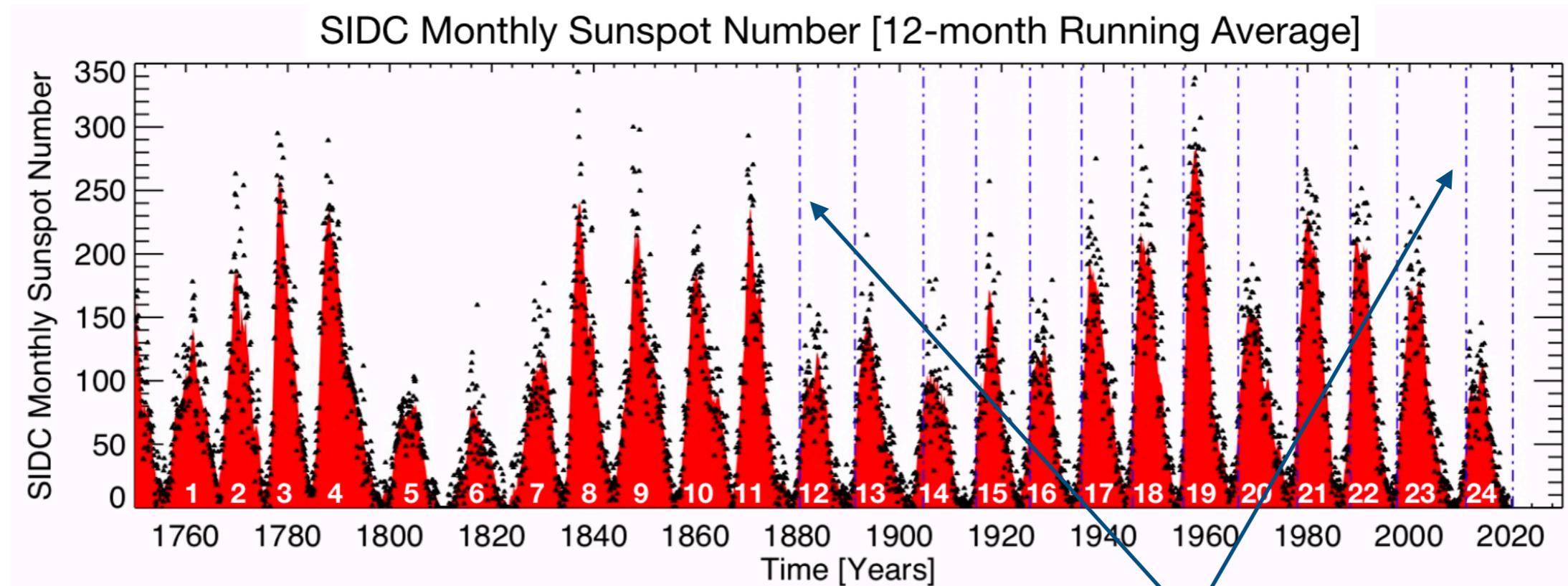
Going back 140 years one notices something odd when you look at filaments.



The end of Hale cycles occurs in (very) close conjunction with the emergence of the sunspot pattern at mid-latitudes AND the start of the polar reversal process ($\sim 55^\circ$).



14 Hale Cycle Terminations - 14 cycles of information - 14 coincidences



Three things to establish:

SUBJECTIVE: Is there an algorithmic approach to terminator detection?

When will the next termination occur?

Does the separation of the termination points give a sense of Hale cycle interaction and predictability of cycle strength?



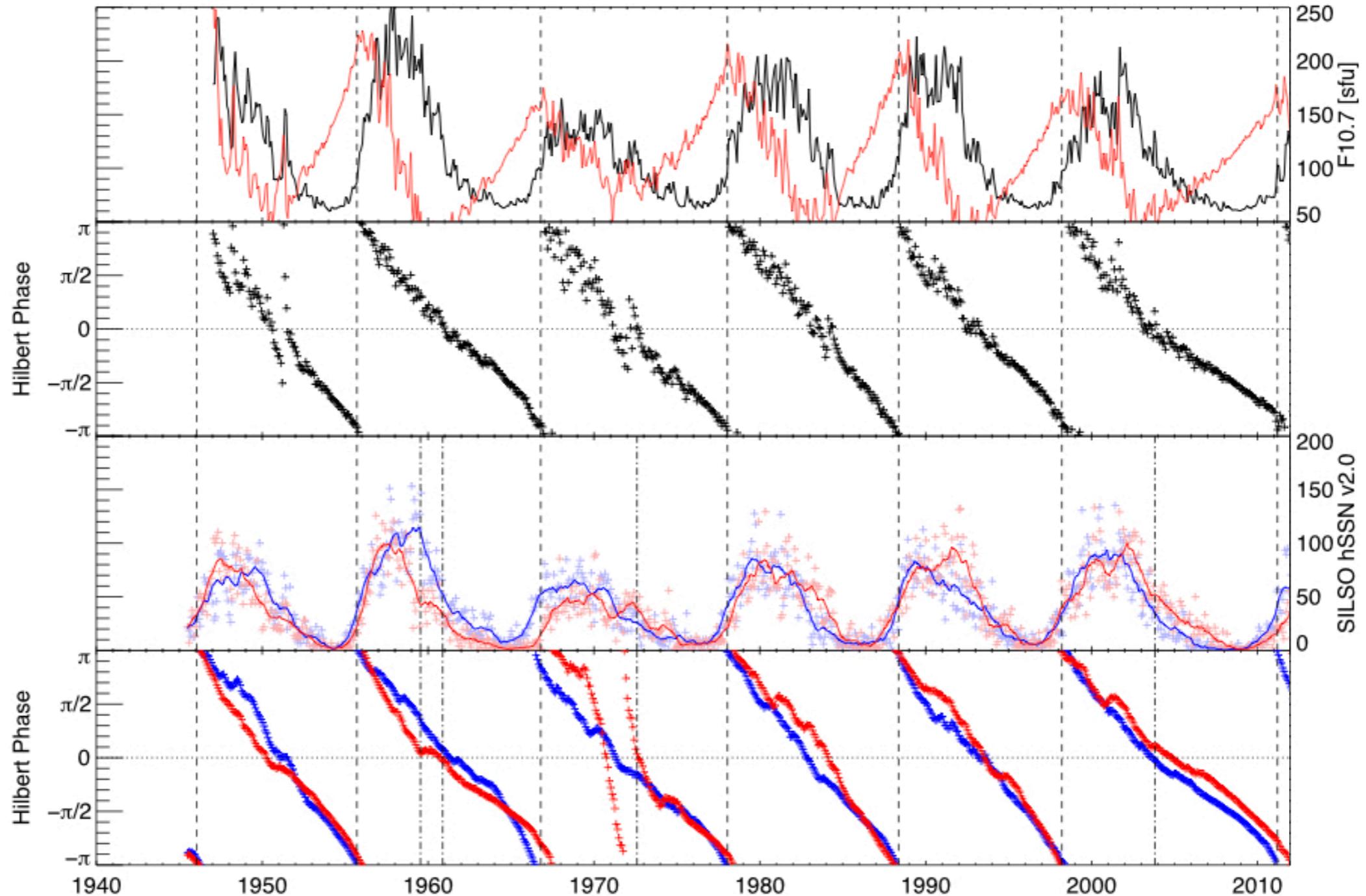
Hilbert Transforms To The Rescue

The Hilbert Transform is an excellent tool for diagnosing phase transitions in timeseries.

Terminators present a unique signature!

H(t) Expresses time series in terms of time dependent amplitude and phase functions

F10.7



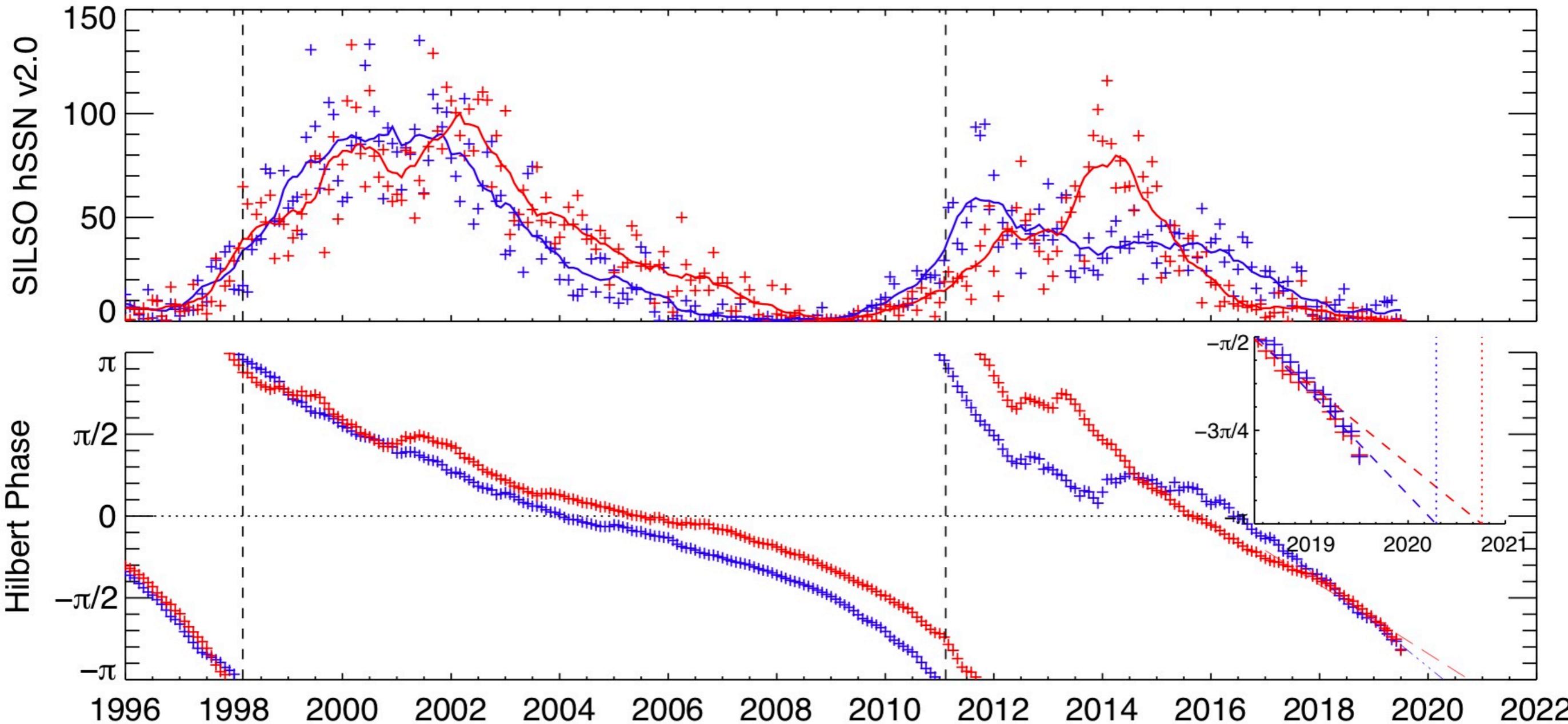
HT-based methodology validates earlier “ad-hoc” determination of terminator times based on sunspot area with accuracy of ~3 months.

<https://arxiv.org/abs/1909.06603>



Hilbert Transforms To The Rescue

Papers in 2014 and then in 2017 anticipated the end of the sunspot cycle 24 producing Hale magnetic bands in early 2020.



Hilbert phase function projected to flip soon

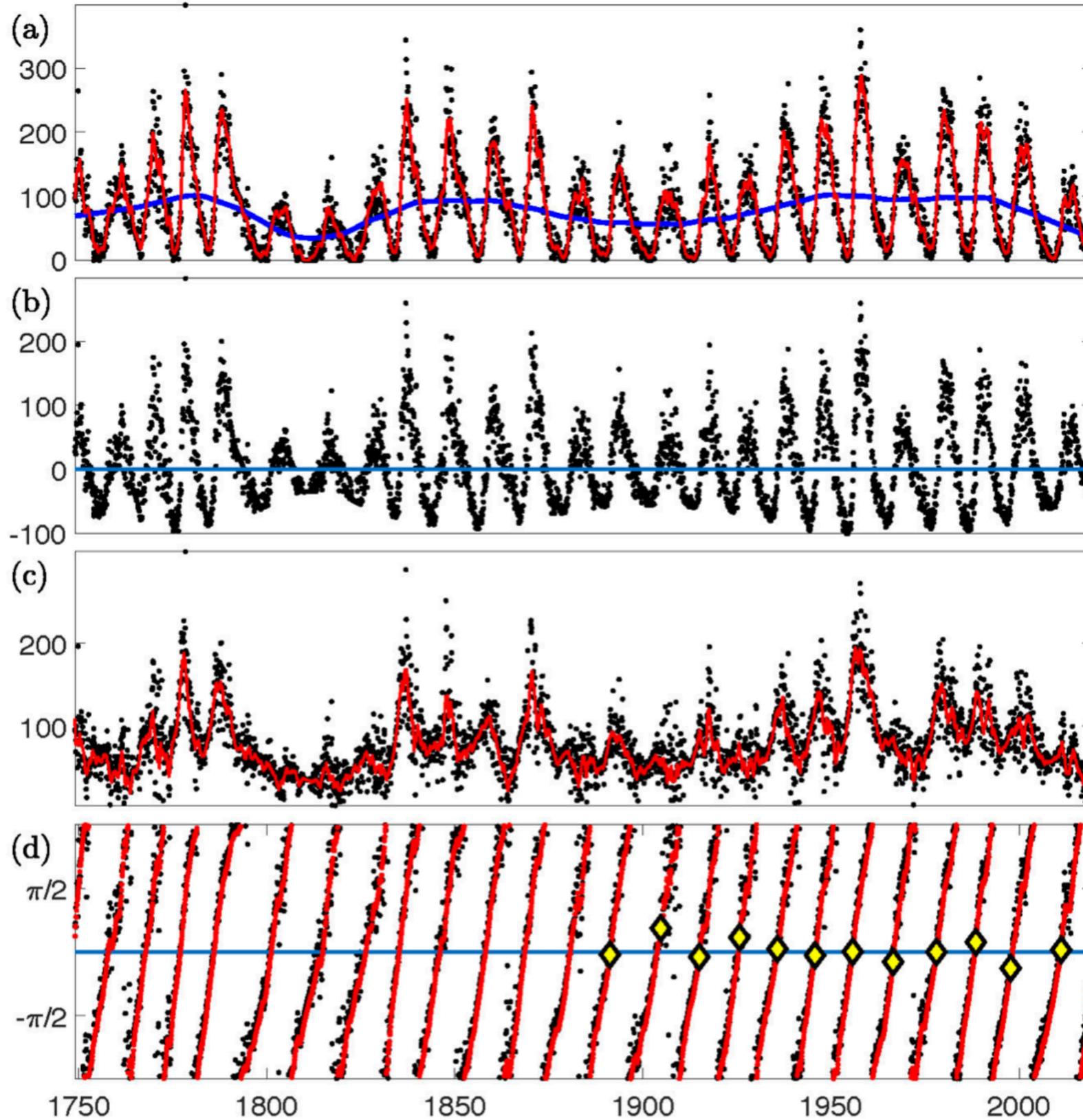
May 2020 +4.0 months
-1.5 months

Only ~9.25 years after cycle 23 band termination.



Statistics - Damn Statistics

Apply $H(t)$ to longest baseline data - **what pattern do you see?**



**MONTHLY
SUNSPOT
NUMBER**

[TREND]

**DETRENDED
MONTHLY
SUNSPOT
NUMBER**

**$H(t)$
Amplitude**

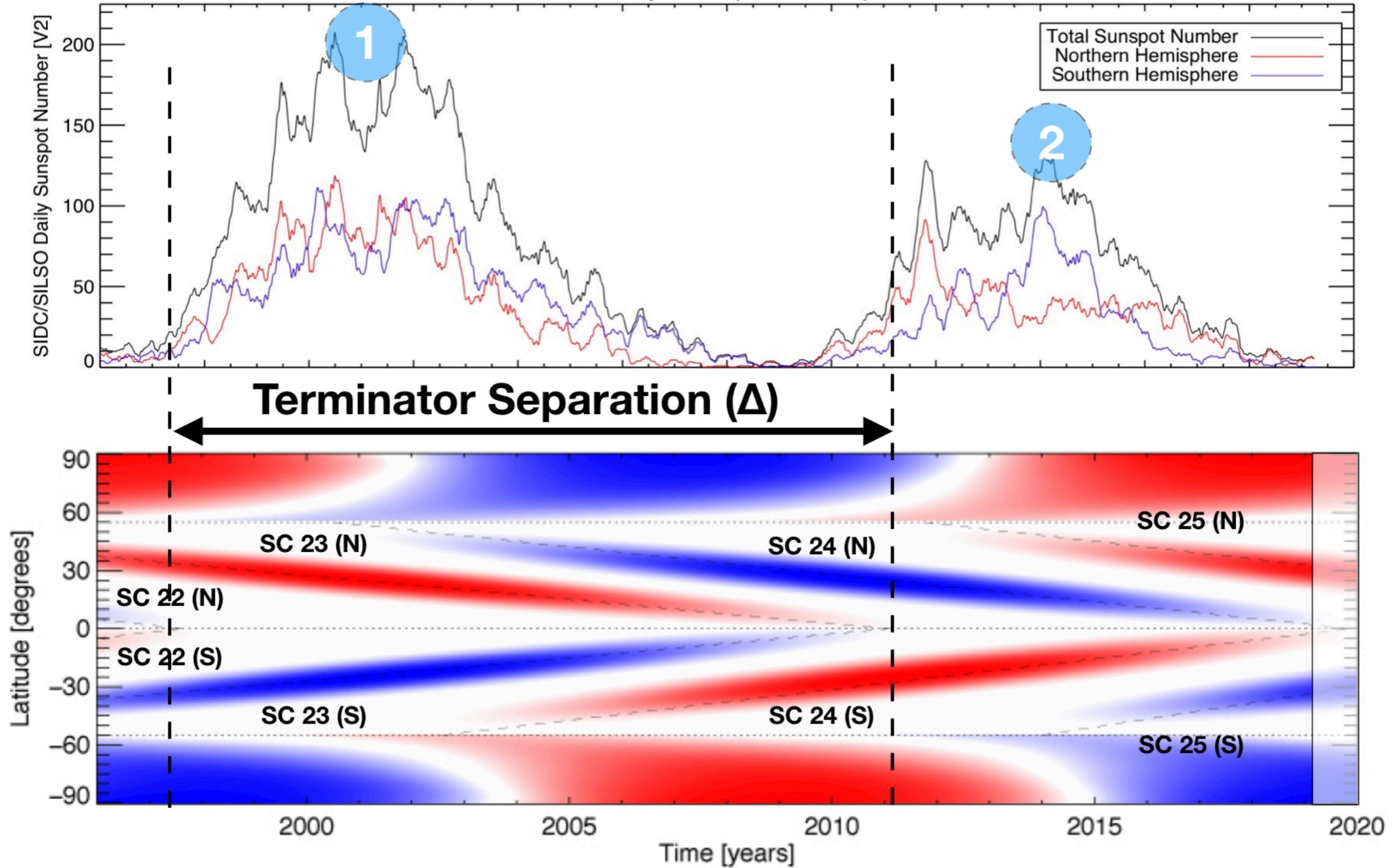
**$H(t)$
Phase**

Terminator

Offsetting phase function by π such that the terminators are now zero-crossings



SIDC/SILSO Daily Hemispheric Sunspot Number

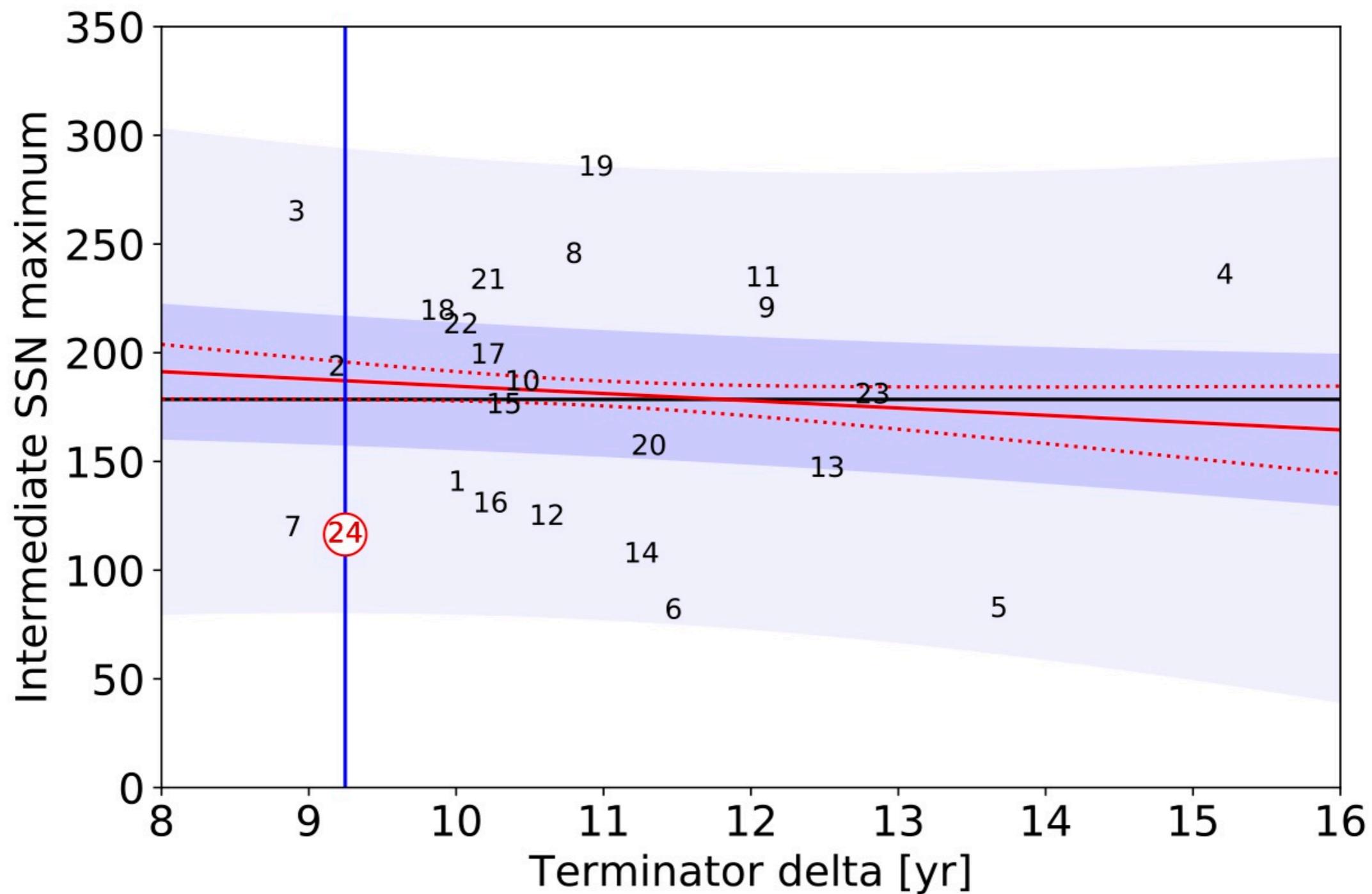


From the 24 sunspot cycles since 1750 look at relationships:

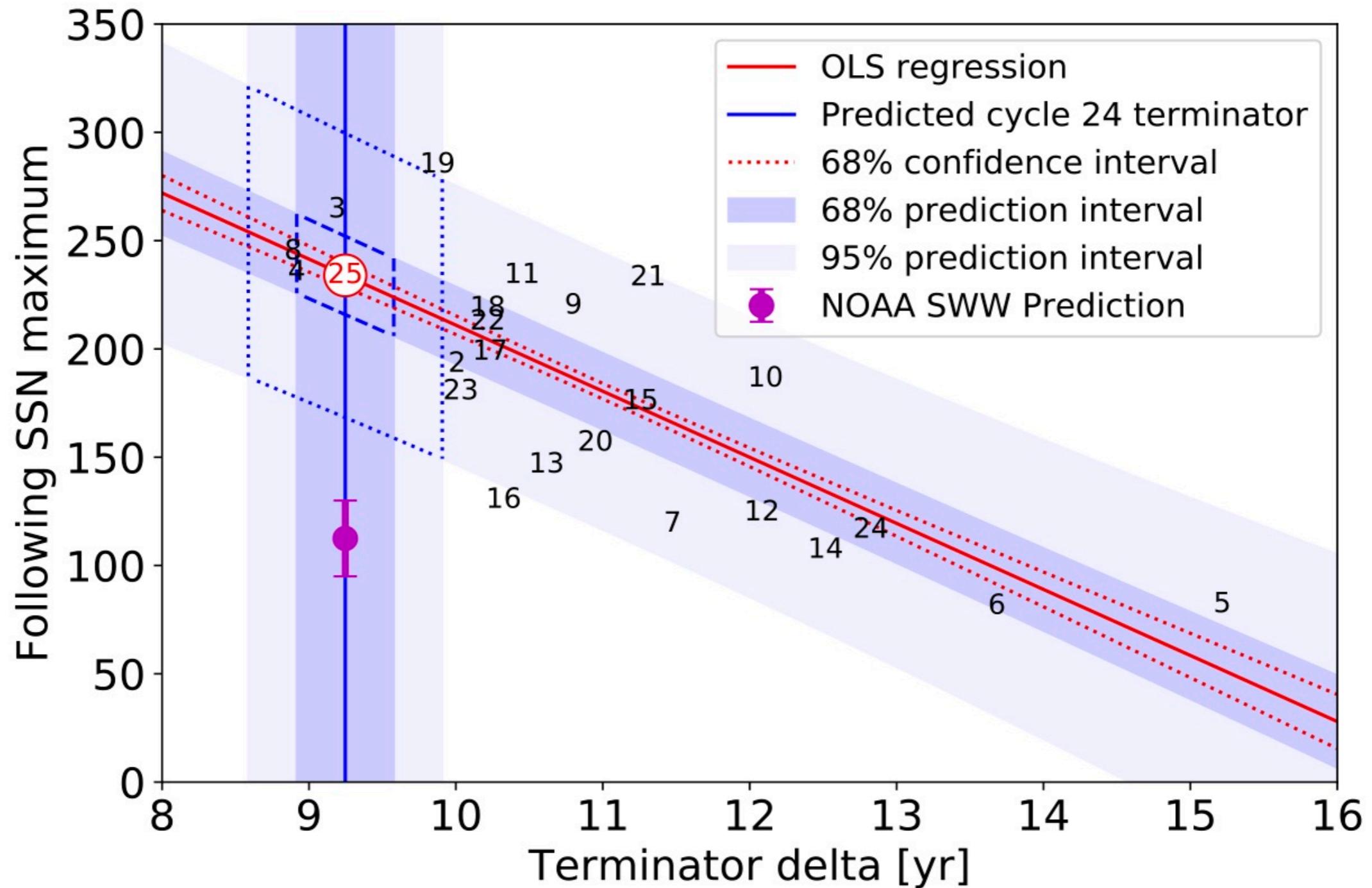
- 1) terminator separation and **INTERMEDIATE** cycle strength
- 2) terminator separation and **UPCOMING** cycle strength



Terminator separation Vs. **INTERMEDIATE** cycle strength



Terminator separation Vs. **UPCOMING** cycle strength



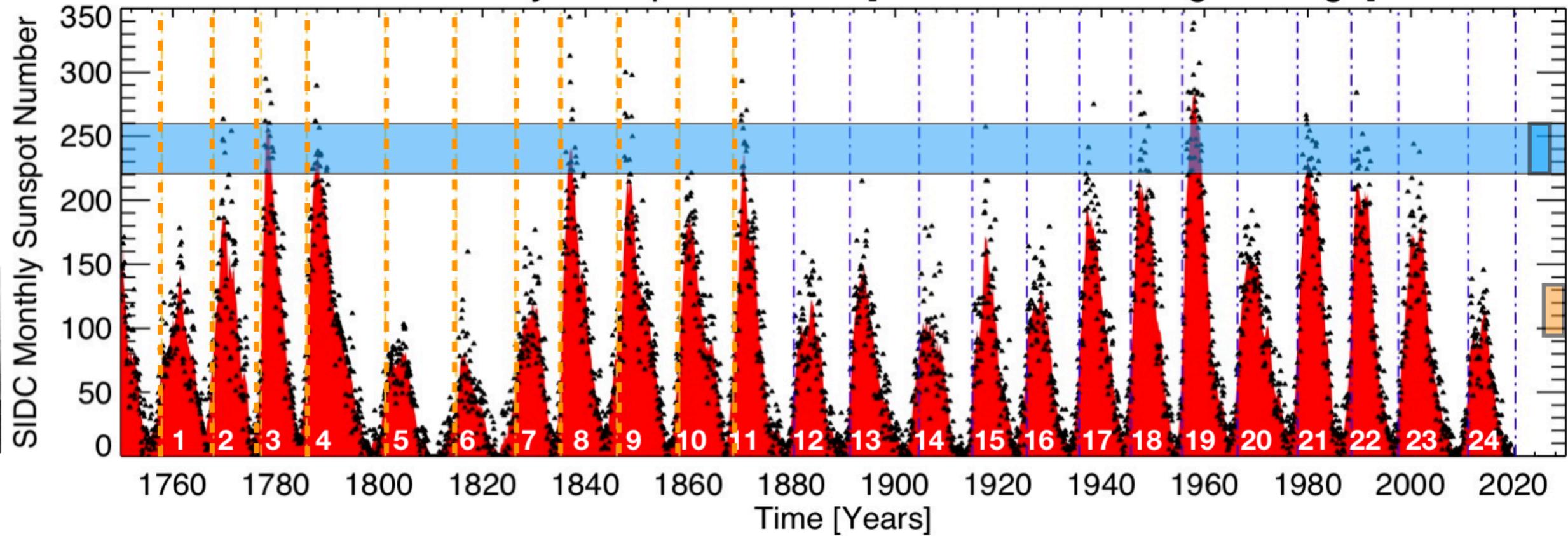
Projected amplitude of sunspot cycle 25

@ 68% confidence: 233 spots (211 - 257)

@ 95% confidence: 233 spots (159 - 310)



SIDC Monthly Sunspot Number [12-month Running Average]



Hale cycles overlap and interfere

Hale cycles end - the end is a “trigger”

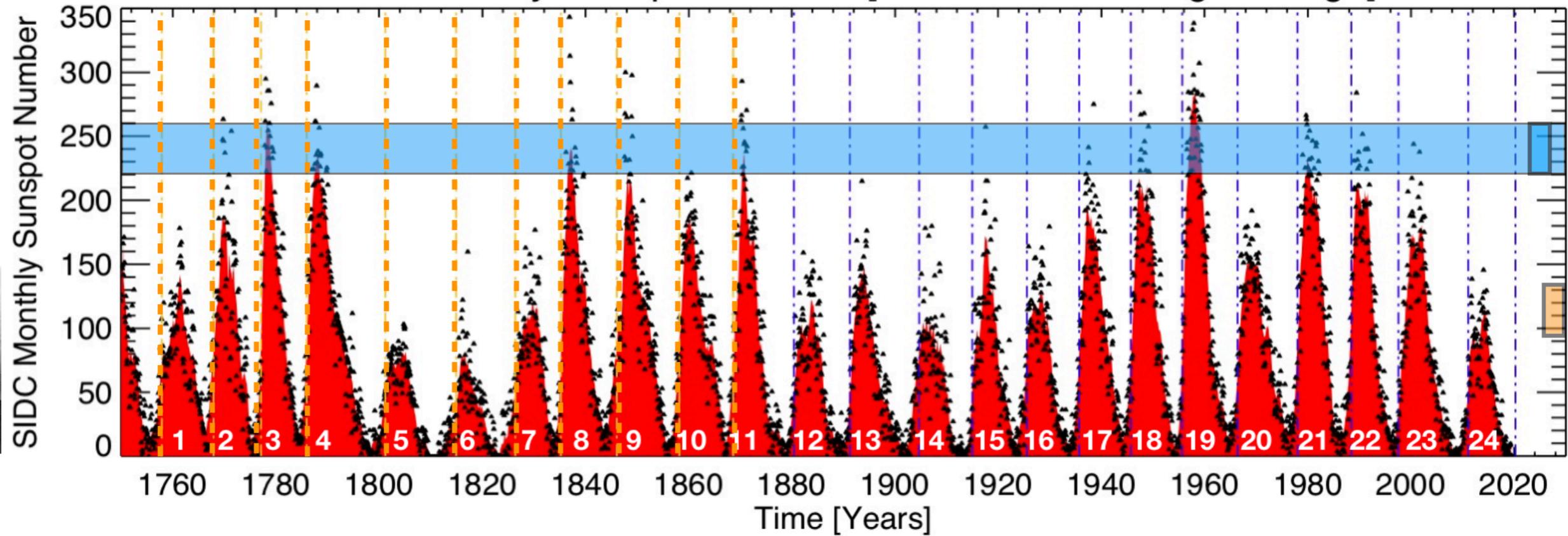
Death of one cycle and VERY rapid growth of activity on the bands of the upcoming cycle

The corona responds almost instantly to the ramp up in global flux emergence

Hilbert Transforms verify observational analysis 1860 - Present

Hale Cycle End is Pending - May 2020
+4.0 months
-1.5 months

SIDC Monthly Sunspot Number [12-month Running Average]



Projected amplitude of sunspot cycle 25

@ 68% confidence: 233 spots (211 - 257)

@ 95% confidence: 233 spots (159 - 310)

Are we ready for a large sunspot cycle?

PSP will fly through the next terminator - if things pan out - at perihelion, what will it see/feel?

As the cycle grows rapidly - the coronal WILL respond as will other things modulated by the Sun's magnetism

How will the Earth's atmosphere respond?