

140 Years.....

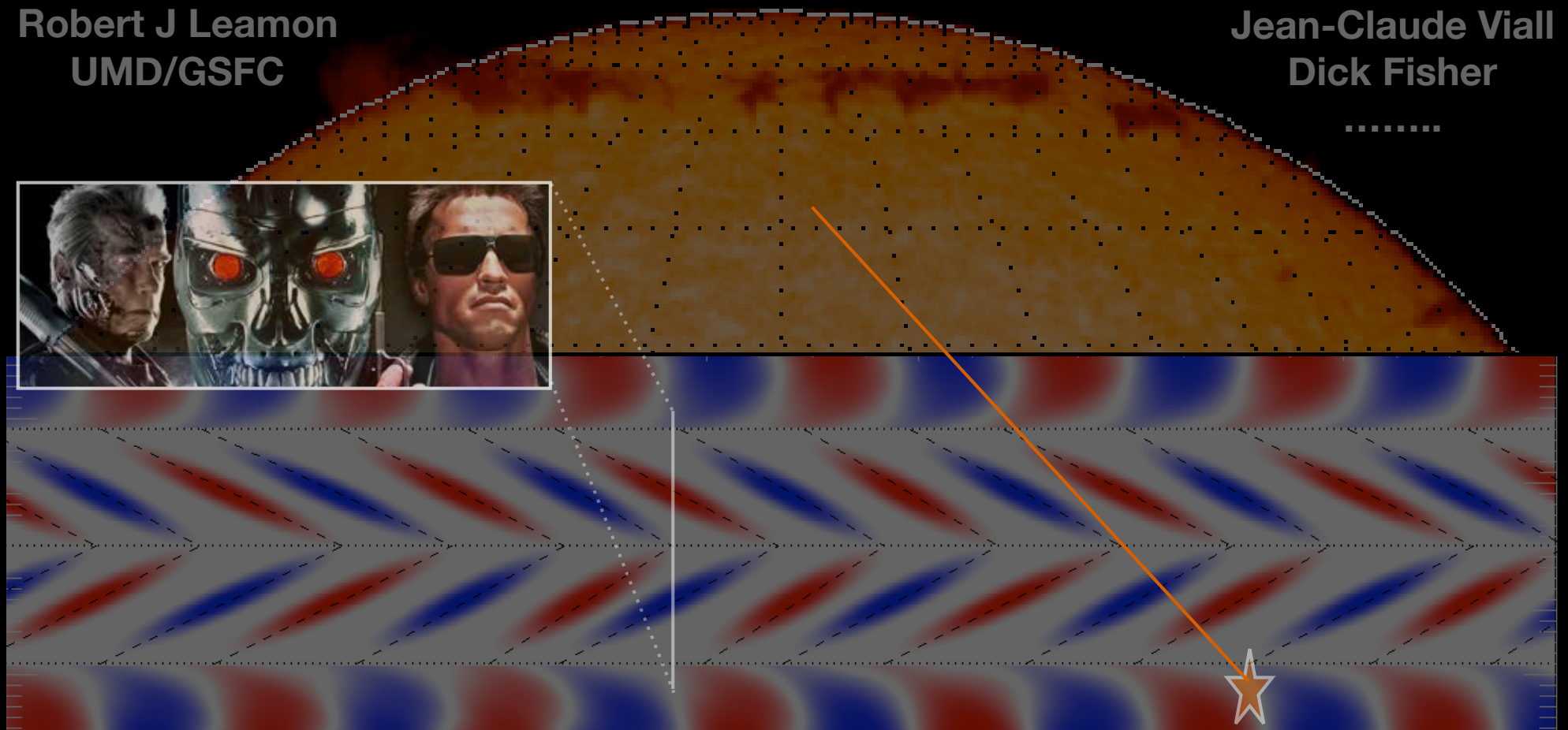
....of the “Extended” Solar Cycle: predictability, expectations for (sunspot) cycle 25 and what may follow...

Scott W McIntosh
NCAR/HAO

Ed Cliver, Dick Altrock
NSO

Charles Chree
Bernard Lyot
Walt Roberts
Karen Harvey
Sara Martin
Jean-Claude Viall
Dick Fisher
.....

Robert J Leamon
UMD/GSFC



140 Years.....

Asking Critical Questions

Part of the scientific method is making critical assessments of the agreement between hypothesis, model and experimental observation

Do we do this for the “dynamo” problem?

Why does the “polar predictor” appear to be most effective in providing information about the upcoming sunspot cycle?



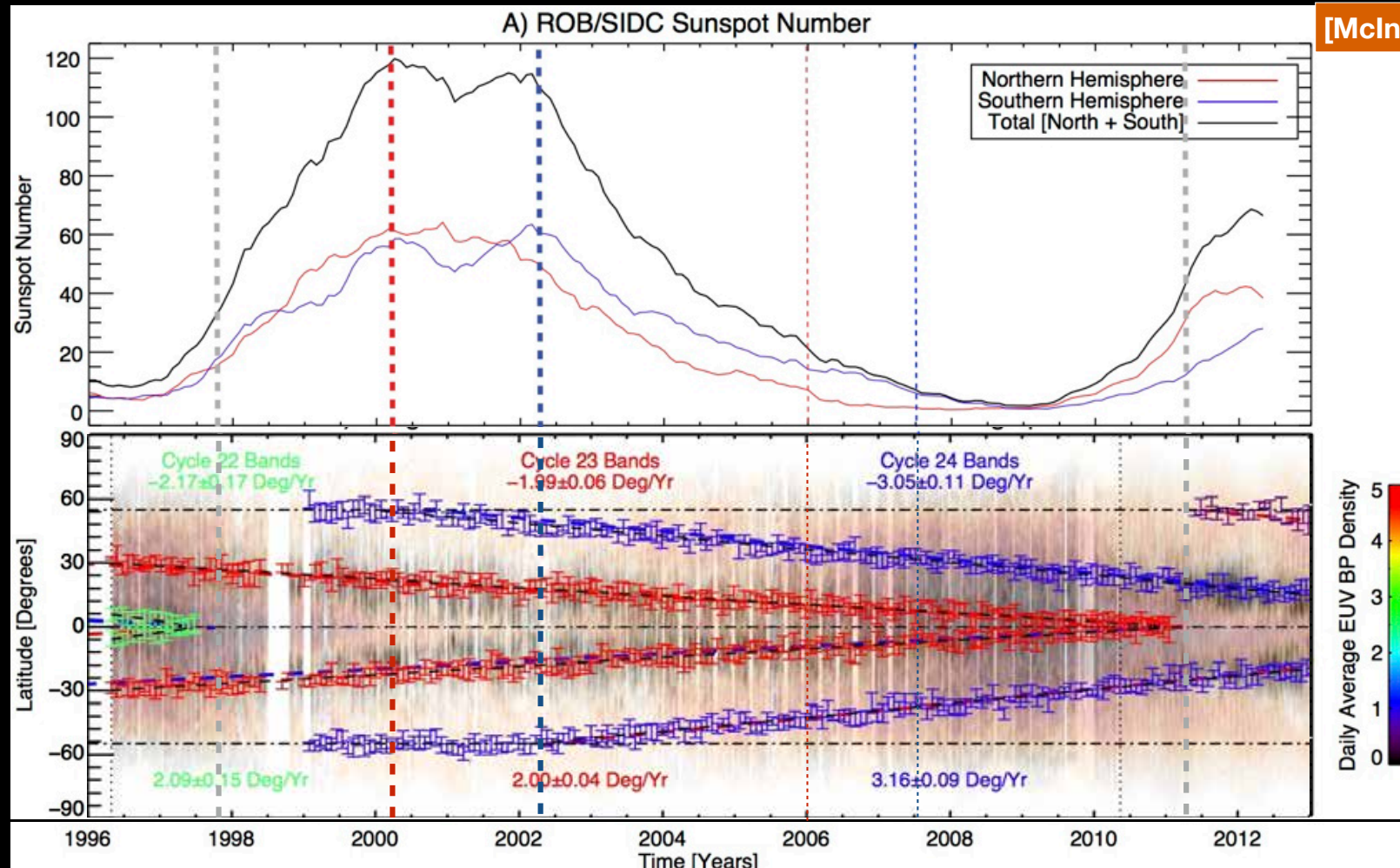
Why is it that when the Sun shows observational clues that indicate that we're looking in the wrong place that they're roundly ignored?

140 Years.....

SORCE 2018

Contemporary Observations 1

Tracking the evolution of small scale - magnetically rooted - features in the Sun's corona leads to a picture of evolution that can be used to explain the landmarks and strength of present, current (and possibly future) sunspot cycles in the context of the 22-year solar magnetic activity cycle.



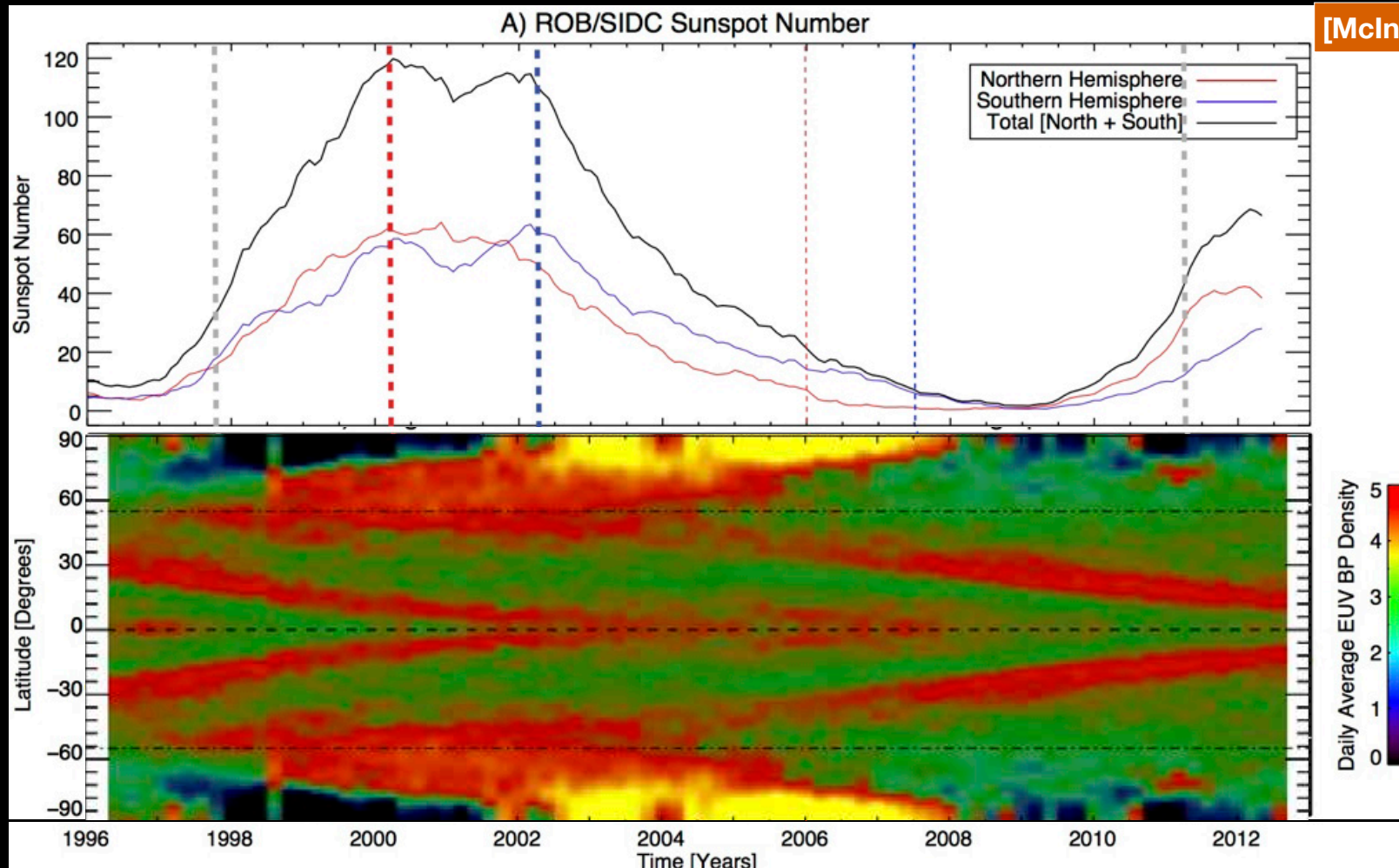
cf. work of Ulrich, LaBonte, Harvey, Wilson, Snodgrass, McIntosh, others in the 1980s

140 Years.....

SORCE 2018

Contemporary Observations 1

Tracking the evolution of small scale - magnetically rooted - features in the Sun's corona leads to a picture of evolution that can be used to explain the landmarks and strength of present, current (and possibly future) sunspot cycles in the context of the 22-year solar magnetic activity cycle.



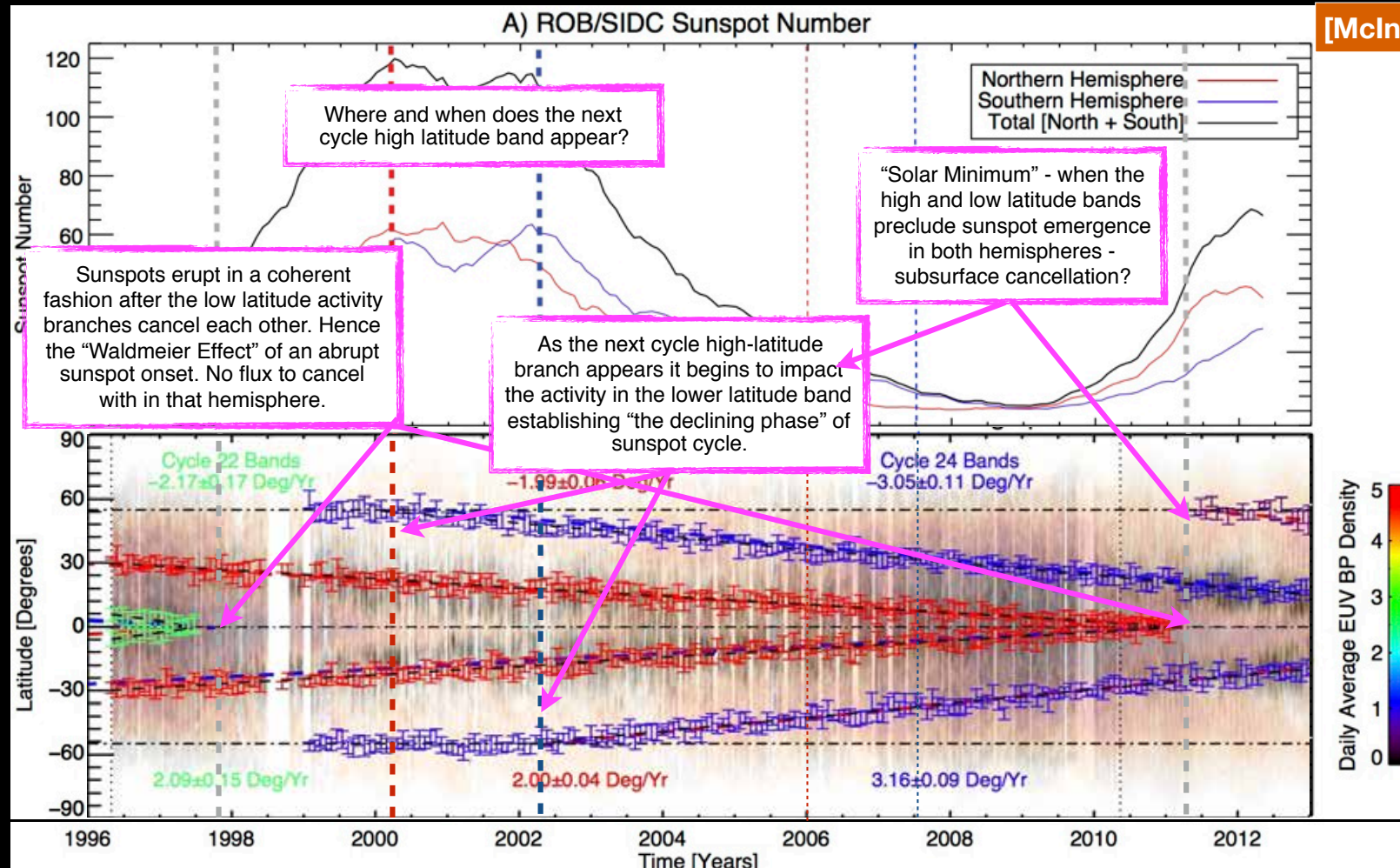
cf. work of Ulrich, LaBonte, Harvey, Wilson, Snodgrass, McIntosh, others in the 1980s

140 Years.....

SORCE 2018

Contemporary Observations 1

Tracking the evolution of small scale - magnetically rooted - features in the Sun's corona leads to a picture of evolution that can be used to explain the landmarks and strength of present, current (and possibly future) sunspot cycles in the context of the 22-year solar magnetic activity cycle.



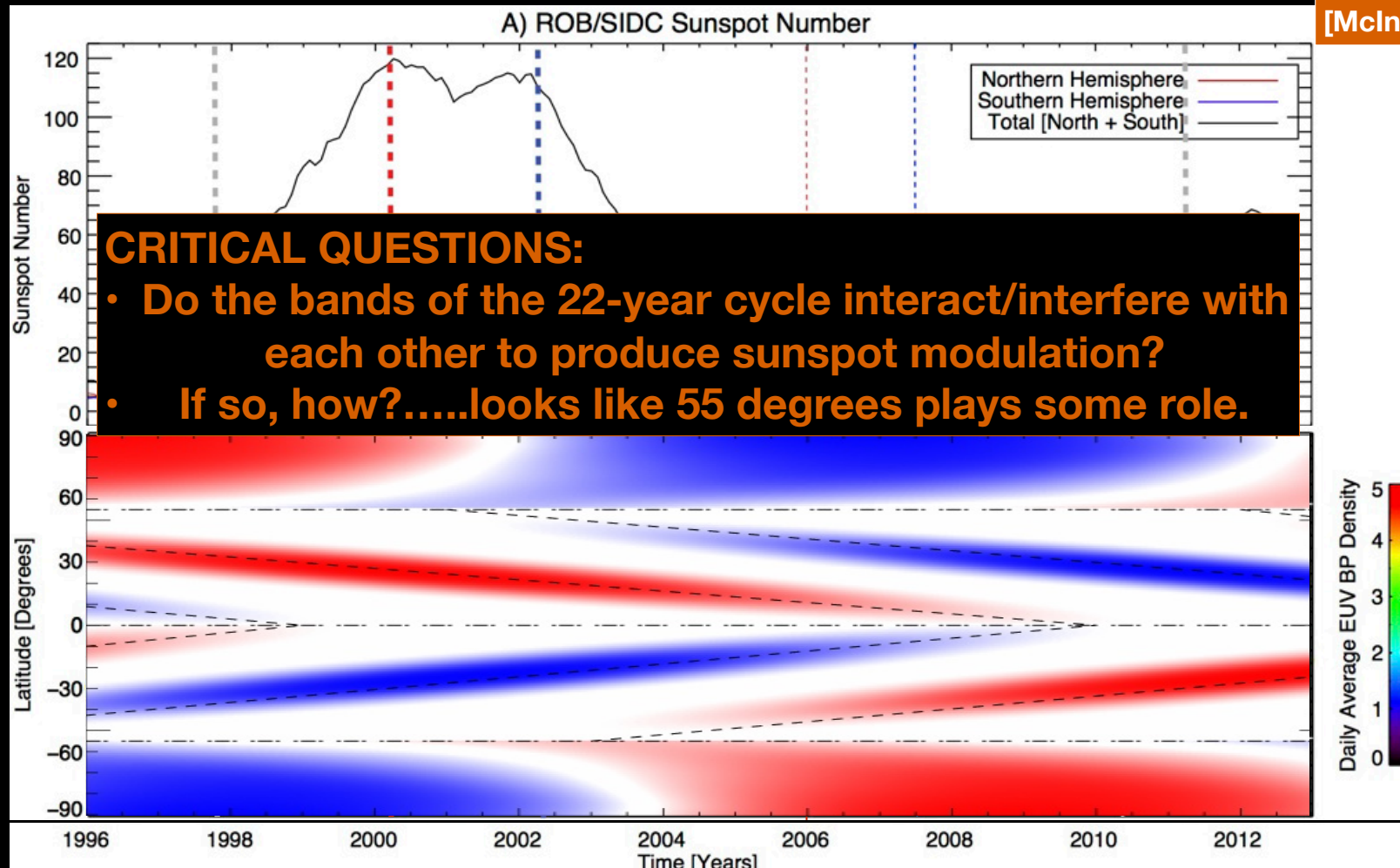
cf. work of Ulrich, LaBonte, Harvey, Wilson, Snodgrass, McIntosh, others in the 1980s

140 Years.....

SORCE 2018

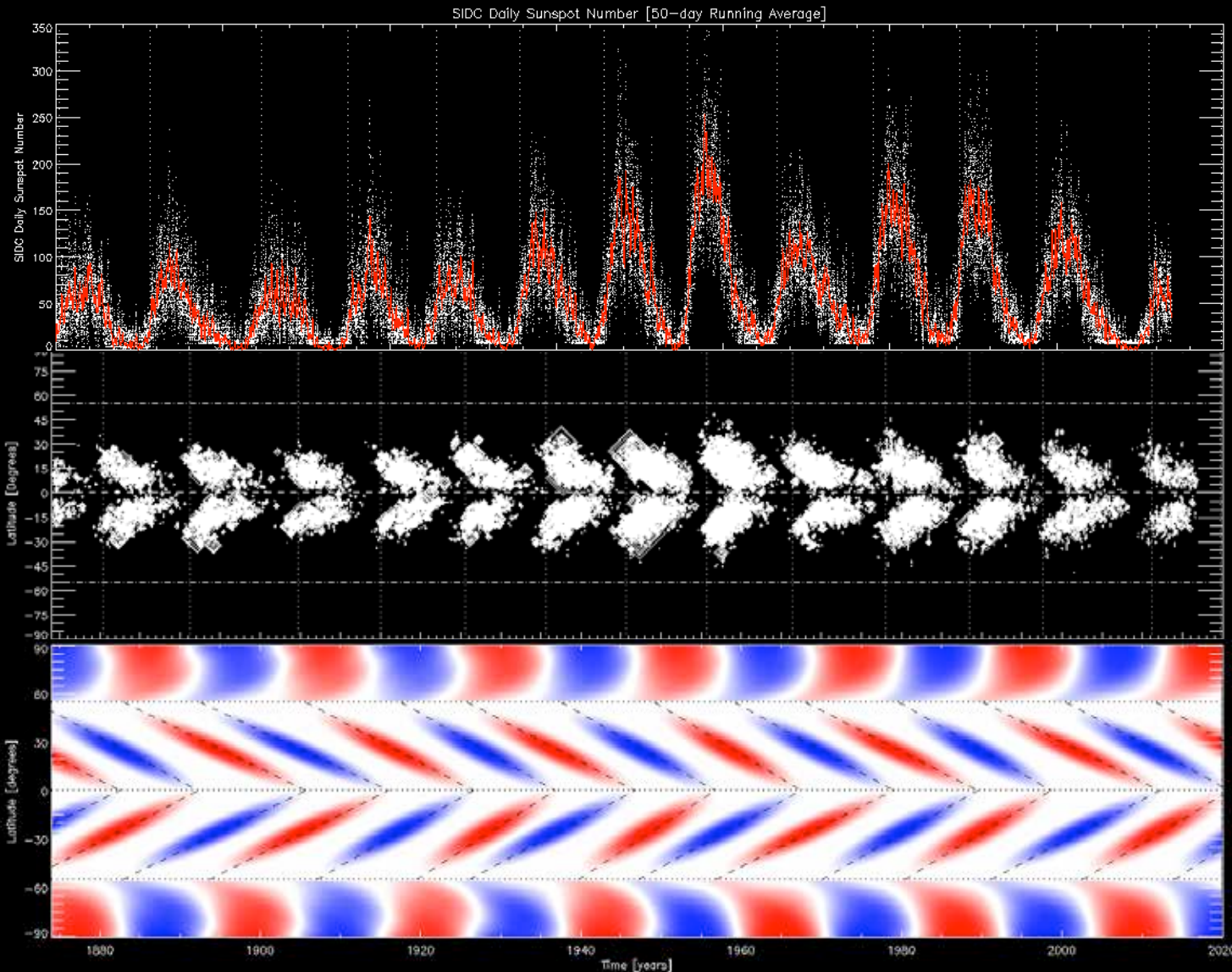
Contemporary Observations 1

Tracking the evolution of small scale - magnetically rooted - features in the Sun's corona leads to a picture of evolution that can be used to explain the landmarks and strength of present, current (and possibly future) sunspot cycles in the context of the 22-year solar magnetic activity cycle.



140 Years.....

Contemporary Observations 1



**Landmarks of
[h]SSN
Butterfly**

**Build a schematic
depiction of evolution:**

- Linear (constant velocities)
- Bands start at 55deg
- Migrate equatorward following hemispheric sunspot maxima.

[McIntosh et al. 2014]

140 Years.....

Contemporary Observations 1

[McIntosh et al. 2014]

[McIntosh et al. 2017]

[McIntosh et al. 2018]

The “prediction” is made possible through the realization that the high latitude behavior of both hemispheres regions is **VERY** regular - like clockwork - even though they are offset from each other.

Crudely: From superposed epoch analysis every **21.8±0.5yrs** the Sun (apparently) produces a new flux system at $\sim 55^\circ$ which begins to travel towards the equator, taking between 17 and 19 years to get there producing the butterfly pattern of sunspots en route, and a **HOST** of other phenomena in between that are **ALL** connected.

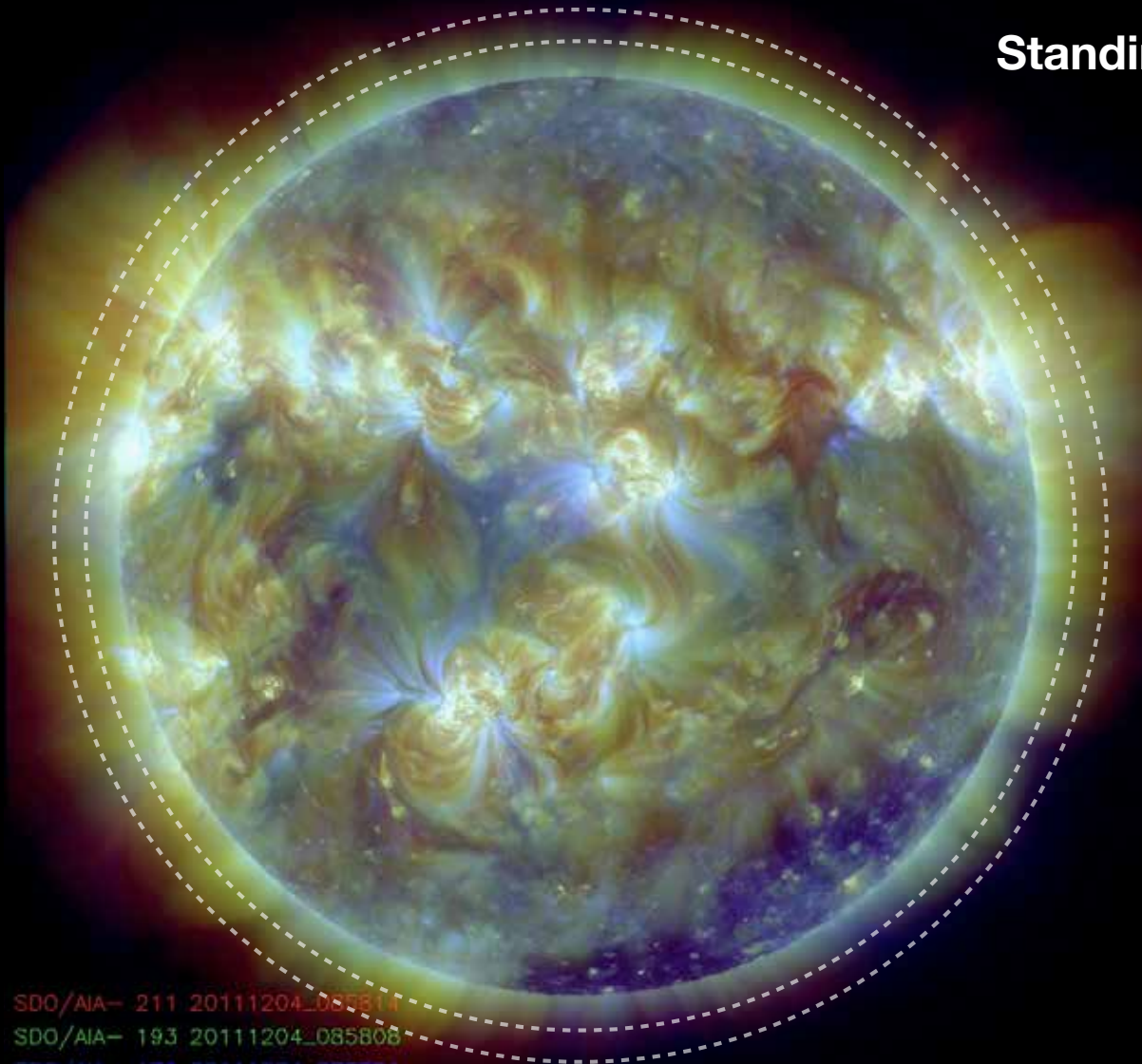
The BIG questions is:

How does that work?

140 Years.....

Contemporary Observations 2

Standing on the shoulders of Dick Altrock



Extract an annulus of emission around the solar corona.....

Identify the local maxima in the coronal annular profile....

Repeat..... what pattern do you see?

SDO/AIA- 211 20111204_085814
 SDO/AIA- 193 20111204_085808
 SDO/AIA- 171 20111204_085801

140 Years.....

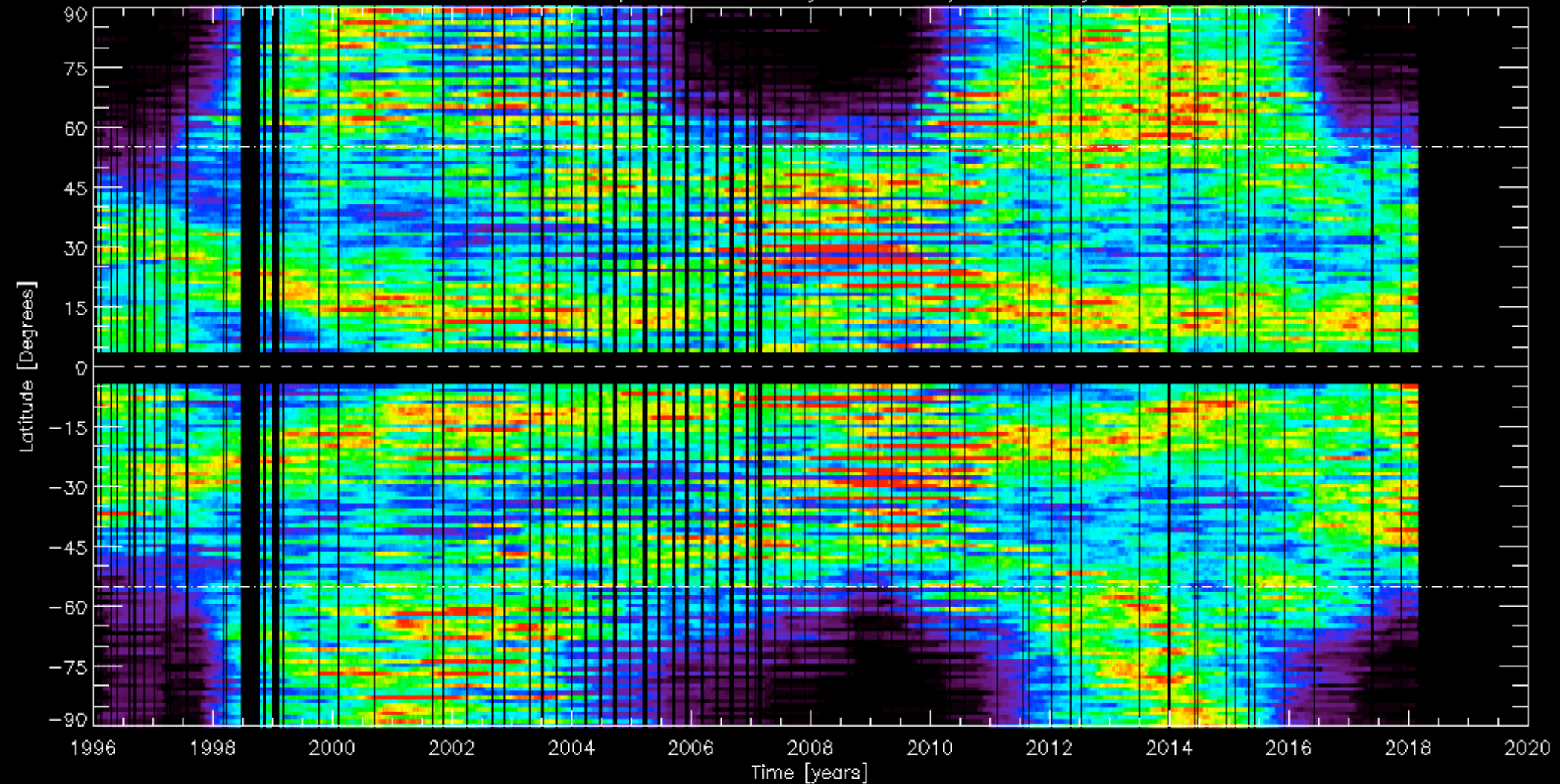
SORCE 2018

Contemporary Observations 2

[McIntosh et al. 2018]

SoHO [1996 - Present]

Southern Hemisphere - Intensity Maxima ± 150 Day Window



140 Years.....

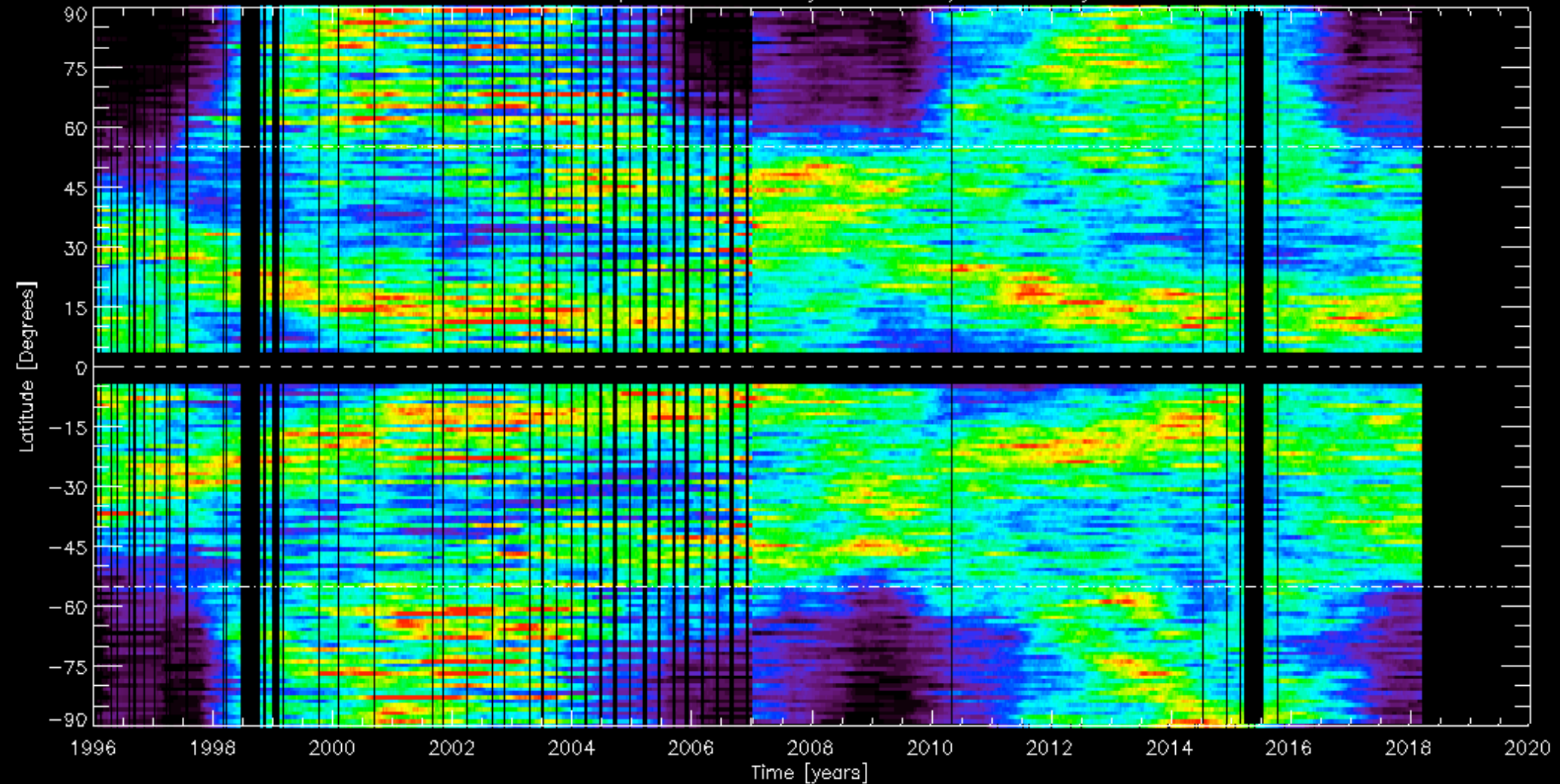
SORCE 2018

Contemporary Observations 2

[McIntosh et al. 2018]

SoHO [1996 - Present] STEREO "A" [2007 - Present]

Southern Hemisphere - Intensity Maxima ± 150 Day Window



140 Years.....

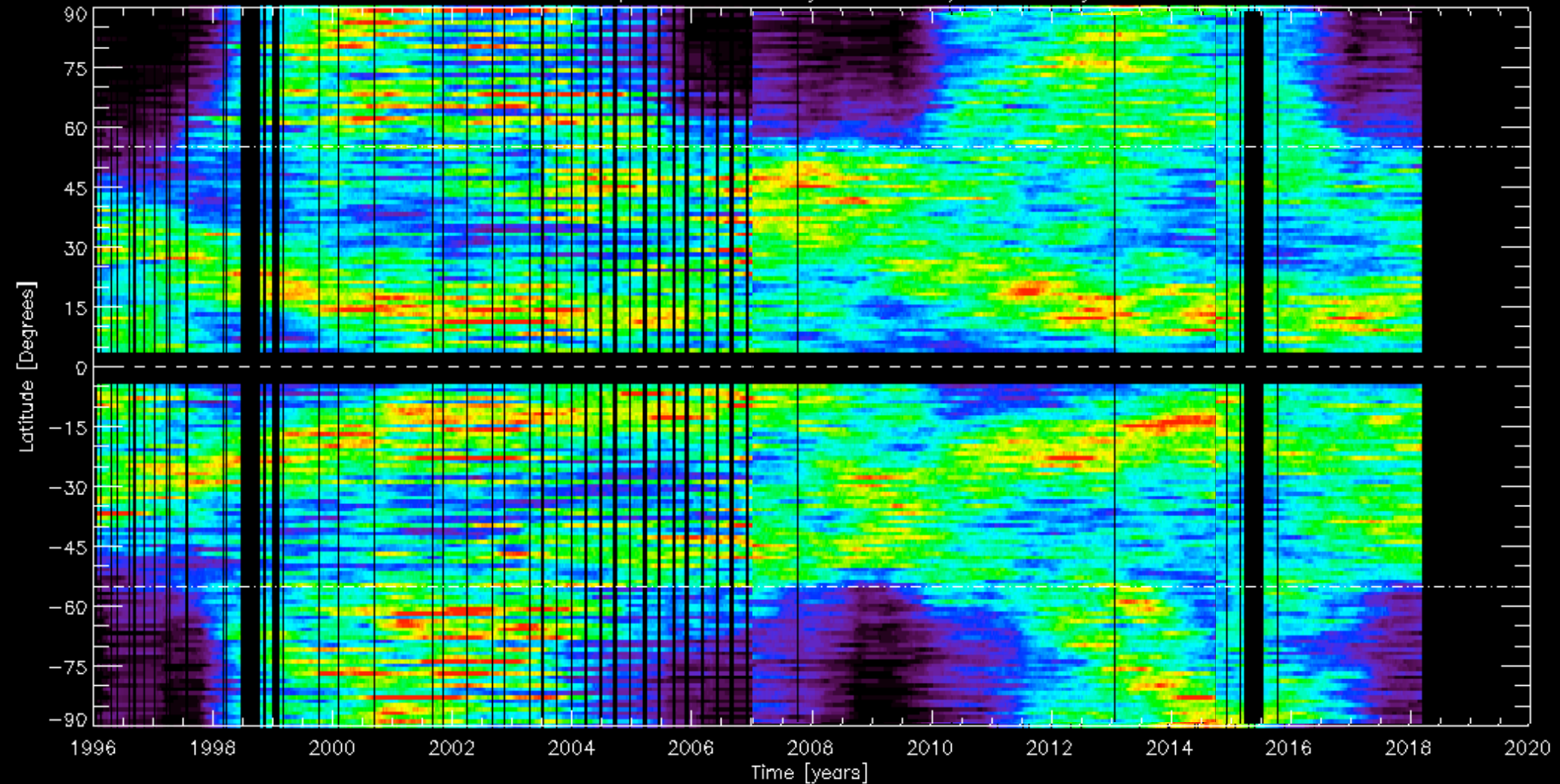
SORCE 2018

Contemporary Observations 2

[McIntosh et al. 2018]

SoHO [1996 - Present] STEREO "A" [2007 - Present] STEREO "B" [2007 - 2014]

Southern Hemisphere – Intensity Maxima ± 150 Day Window



140 Years.....

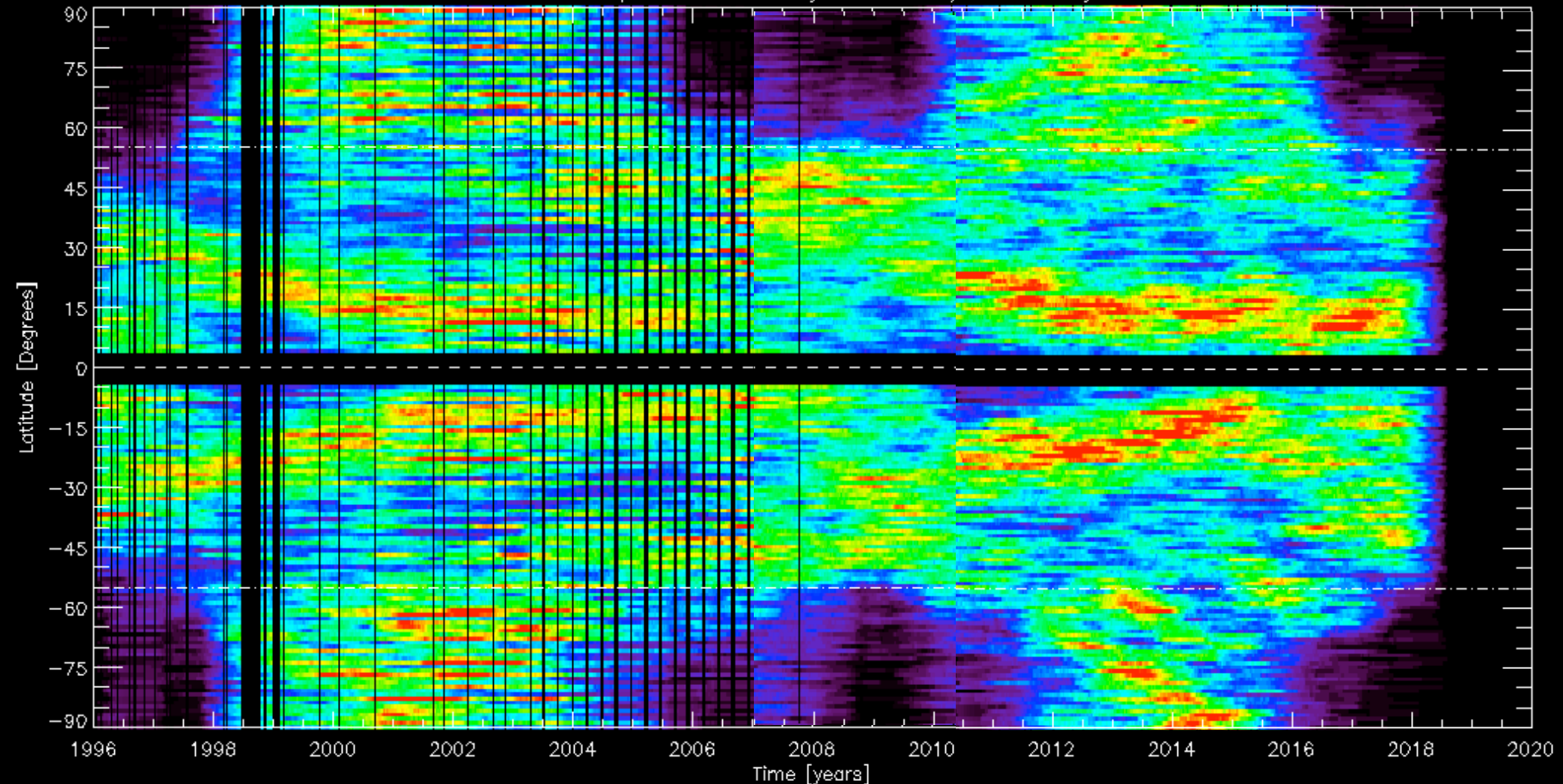
SORCE 2018

[McIntosh et al. 2018]

Contemporary Observations 2

SoHO [1996 - Present] STEREO "A" [2007 - Present] STEREO "B" [2007 - 2014] SDO [2010 - Present]

Southern Hemisphere – Intensity Maxima ± 150 Day Window



Does that pattern look familiar?

Note the Polar Coronal Hole "LIMITS"

140 Years.....

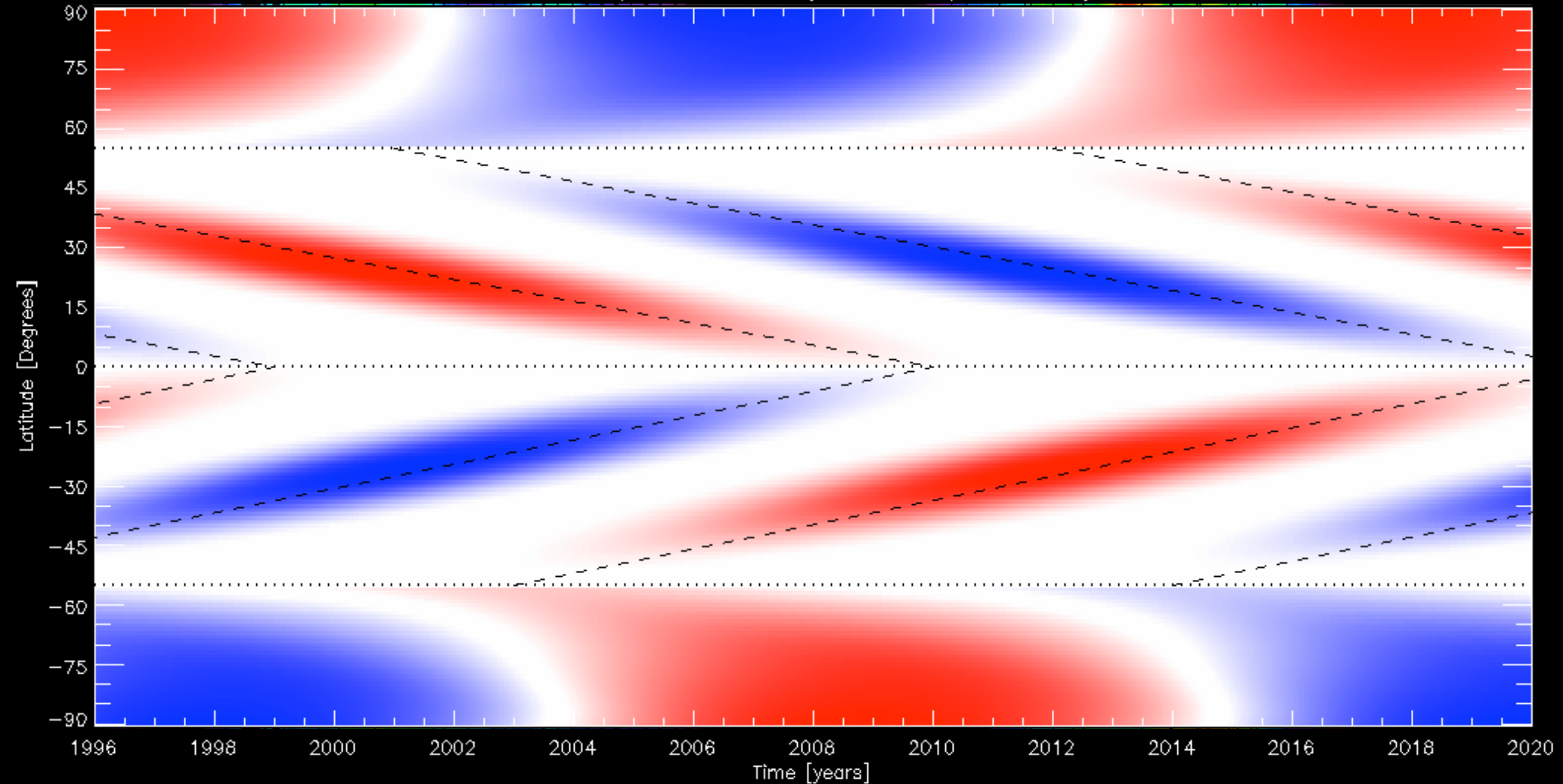
SORCE 2018

Contemporary Observations 2

[McIntosh et al. 2018]

SoHO [1996 - Present] STEREO "A" [2007 - Present] STEREO "B" [2007 - 2014] SDO [2010 - Present]

Southern Hemisphere - Intensity Maxima ± 150 Day Window

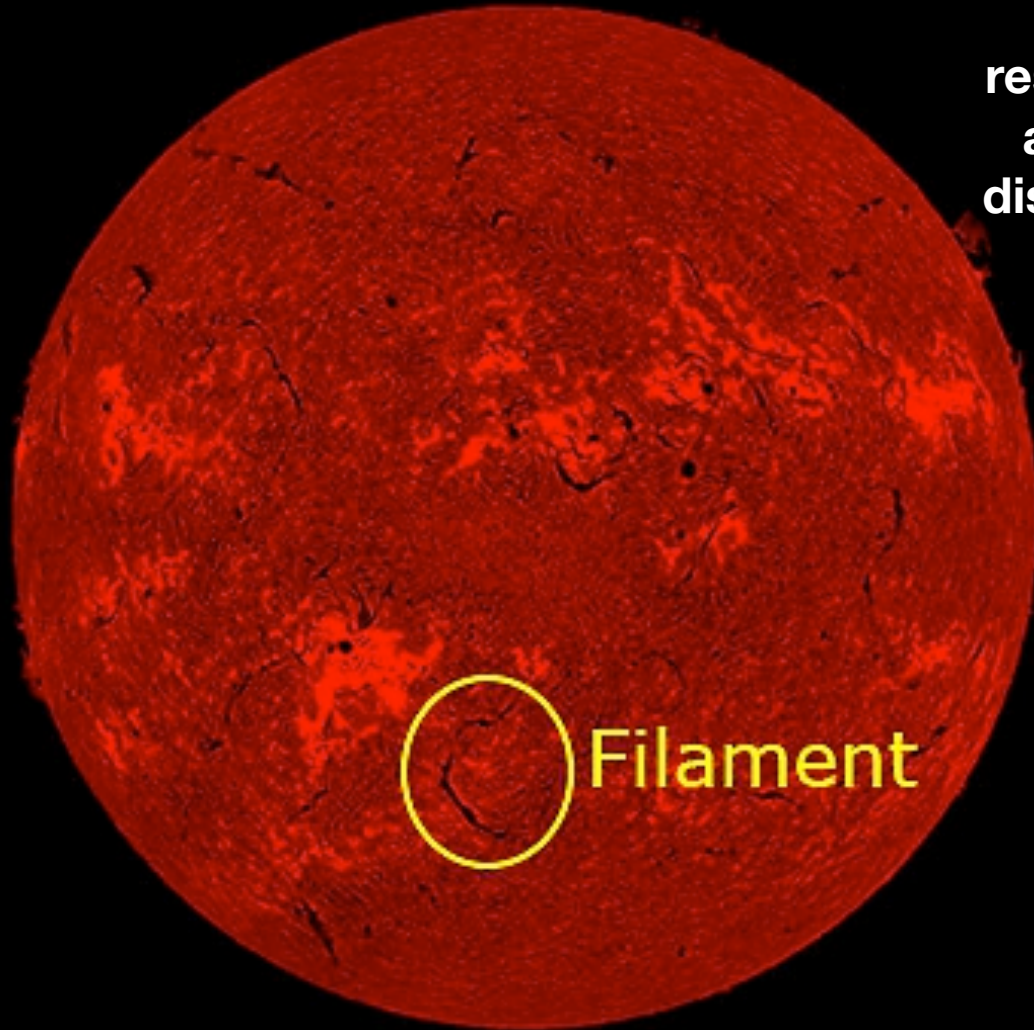


Another pretty good match.....

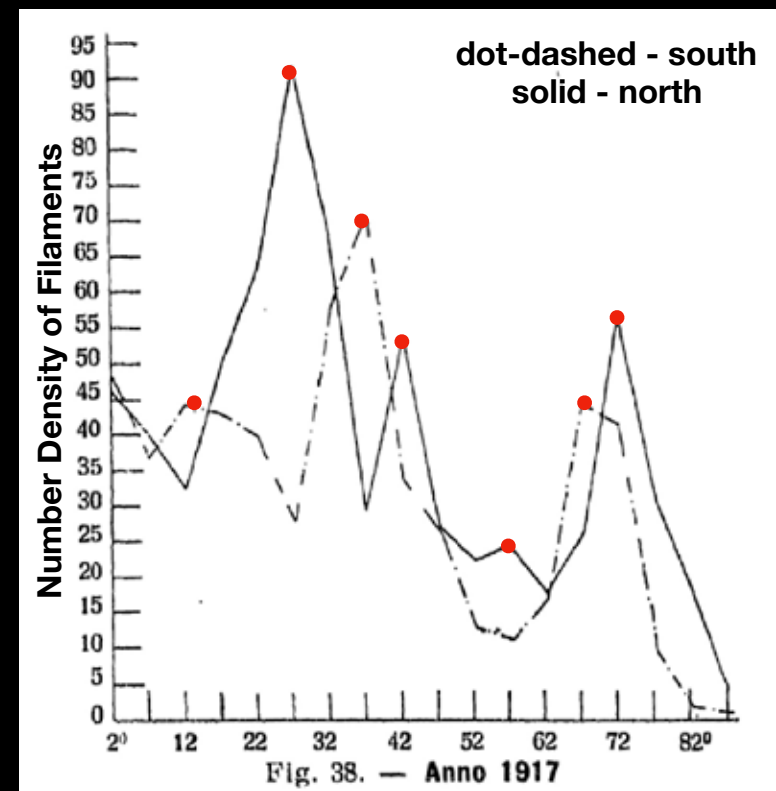
.....but it is only 22 years.....

140 Years.....

Historical Observations 1



From **1880 - 1931** and from **1919 - 1989** the Arcetri and Meudon Observatories respectively cataloged the position, length, and brightness of filaments on the solar disk. Similar efforts continue to the present day.

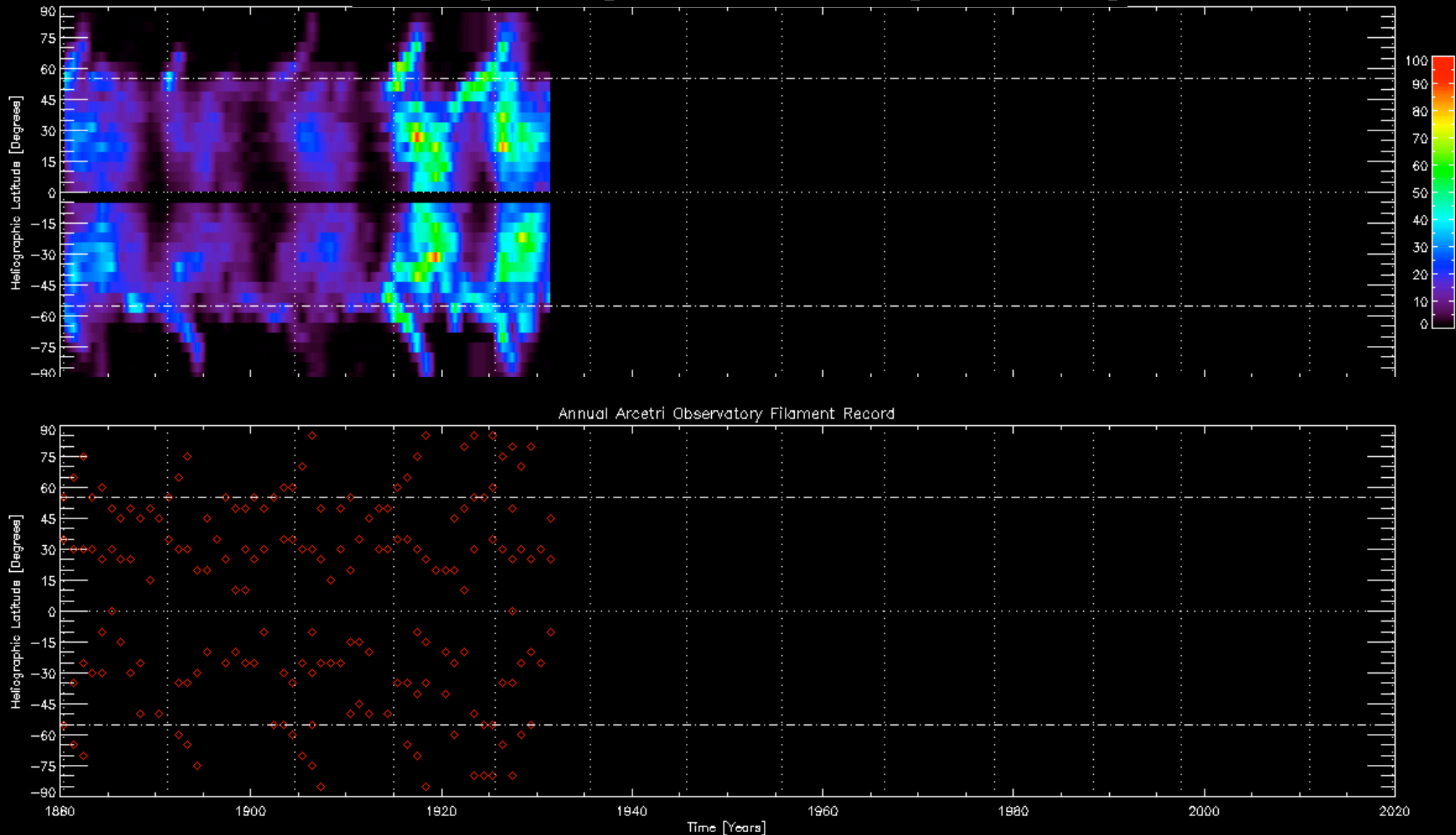


The Arcetri group published their initial results in 1933.

140 Years.....

SORCE 2018

Arcetri [Annual] Filament Record [1880 - 1931]

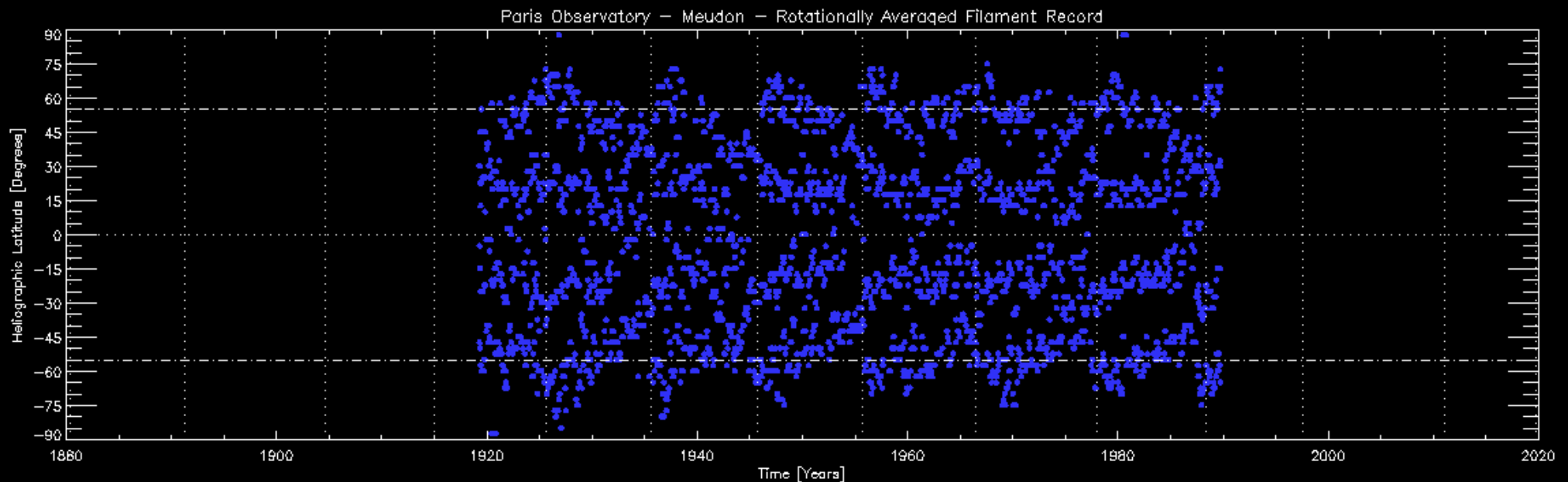
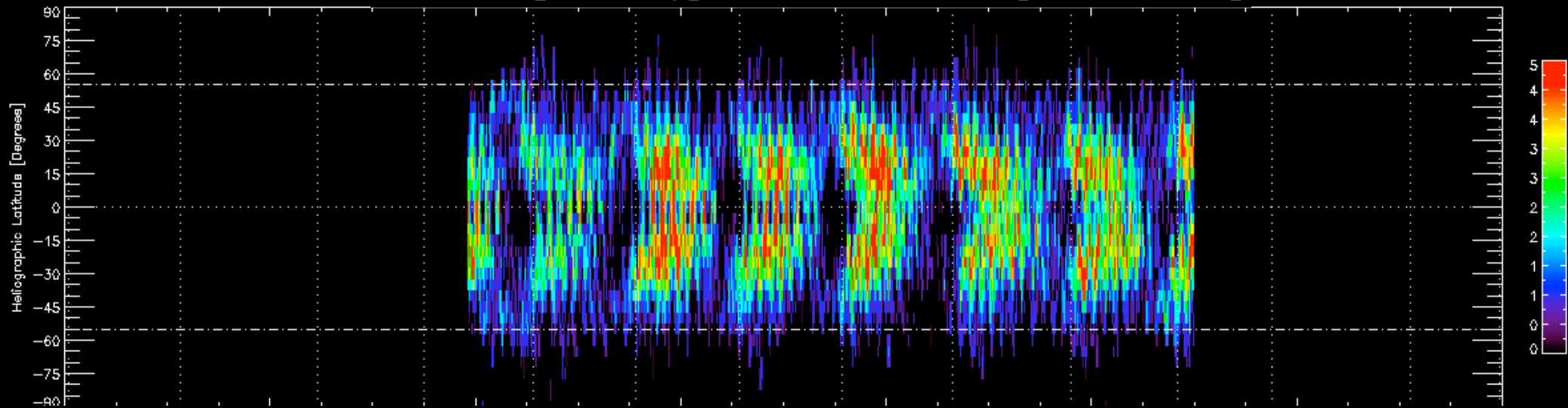


The red dots mark in lower plot show the maxima of latitudinal filament density on each annual slice - the departures from 55 deg every decade or so became known as the “rush to the poles” - the filament maxima locations map out the progression of magnetic neutral lines over many solar rotations.

140 Years.....

SORCE 2018

Meudon [Monthly] Filament Record [1919 - 1989]

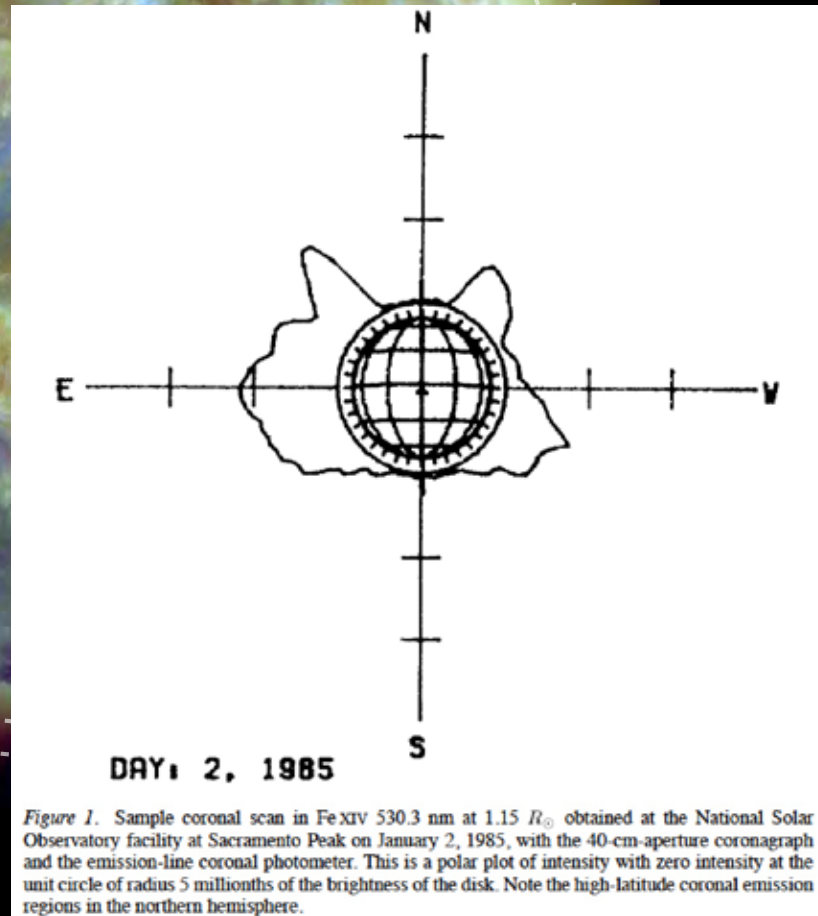


The blue dots mark in lower plot show the maxima of latitudinal filament density on each rotational slice - flick back to see correspondence with Arcetri

140 Years.....

Historical Observations 2

Starting with the advent of the coronagraph in the late 1930s, Lyot and his group made routine measurements of the 5404Å “green line” of the corona - before they knew that it was emission from highly ionized iron.



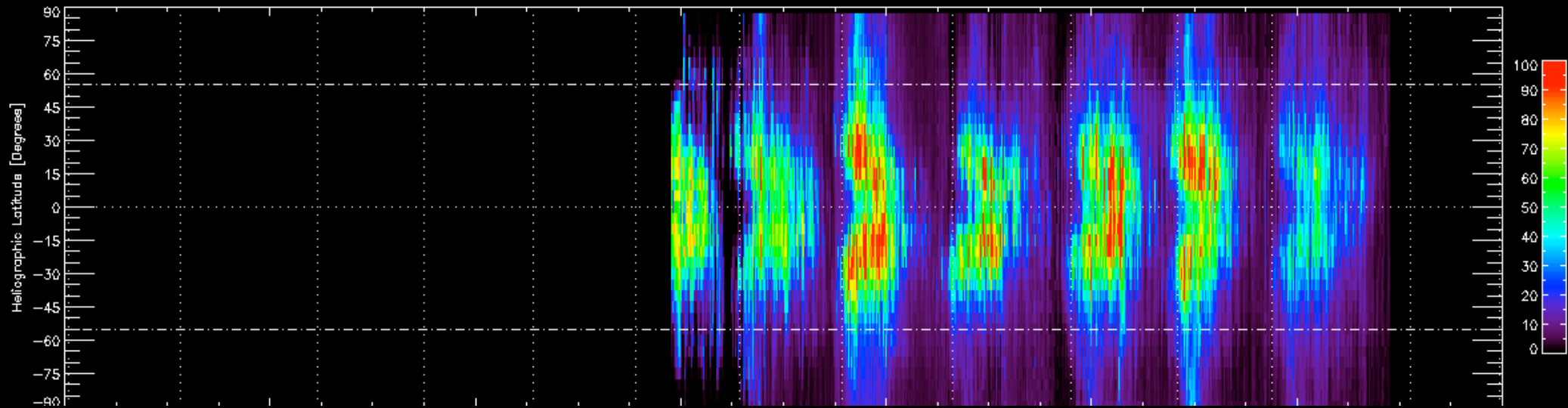
Performed around the globe daily and merged into a continuous record by NGDC.

/AIA- 211 20111204_085811
/AIA- 193 20111204_085808
/AIA- 171 20111204_085801

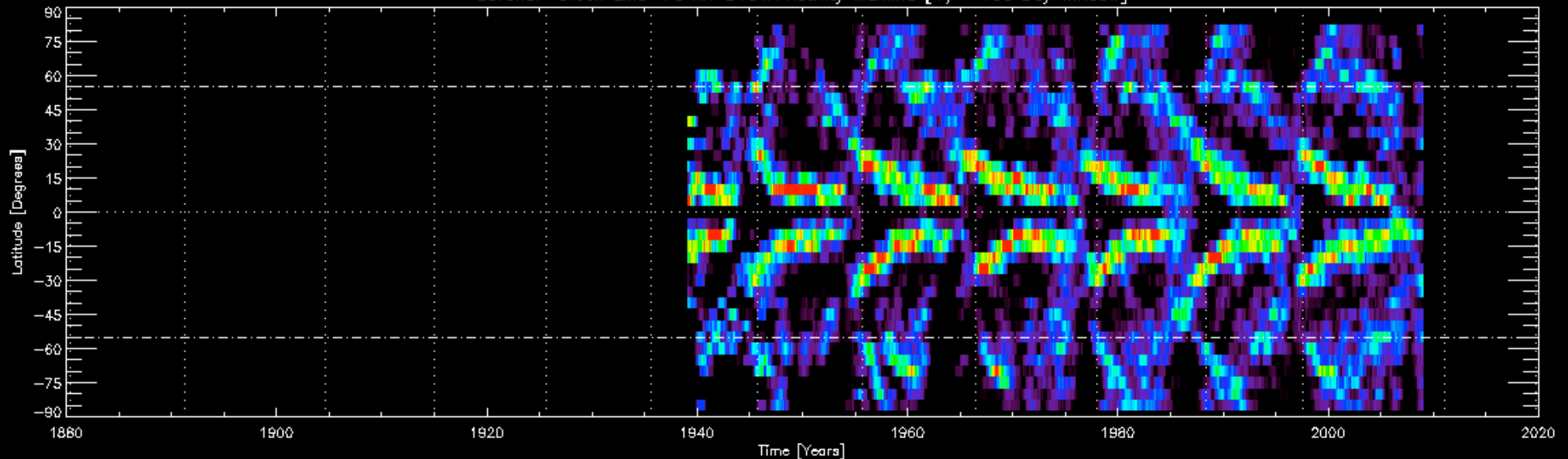
140 Years.....

SORCE 2018

Global [Daily] Coronal Green Line Record [1939 - 2009]



Coronal "Green Line" Fe XIV 5404Å Activity Maxima [± 150 Day Window]

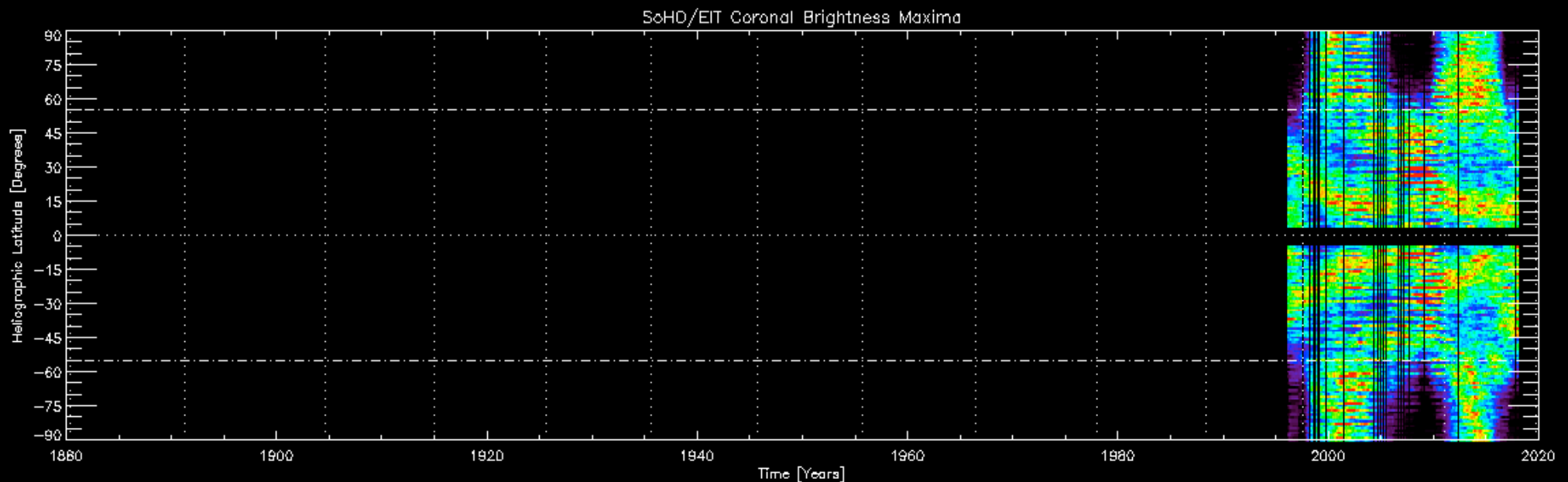
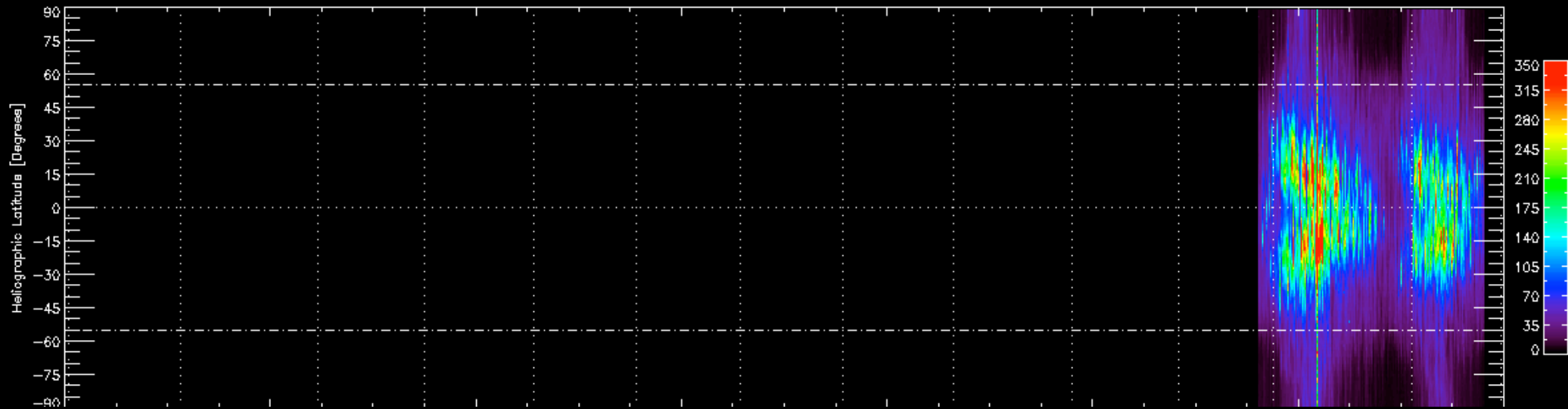


Because the density of data is getting higher the maxima of annular coronal emission slice can be represented in an image.... looking at a running average over 150 days... flick and forth again.

140 Years.....

SORCE 2018

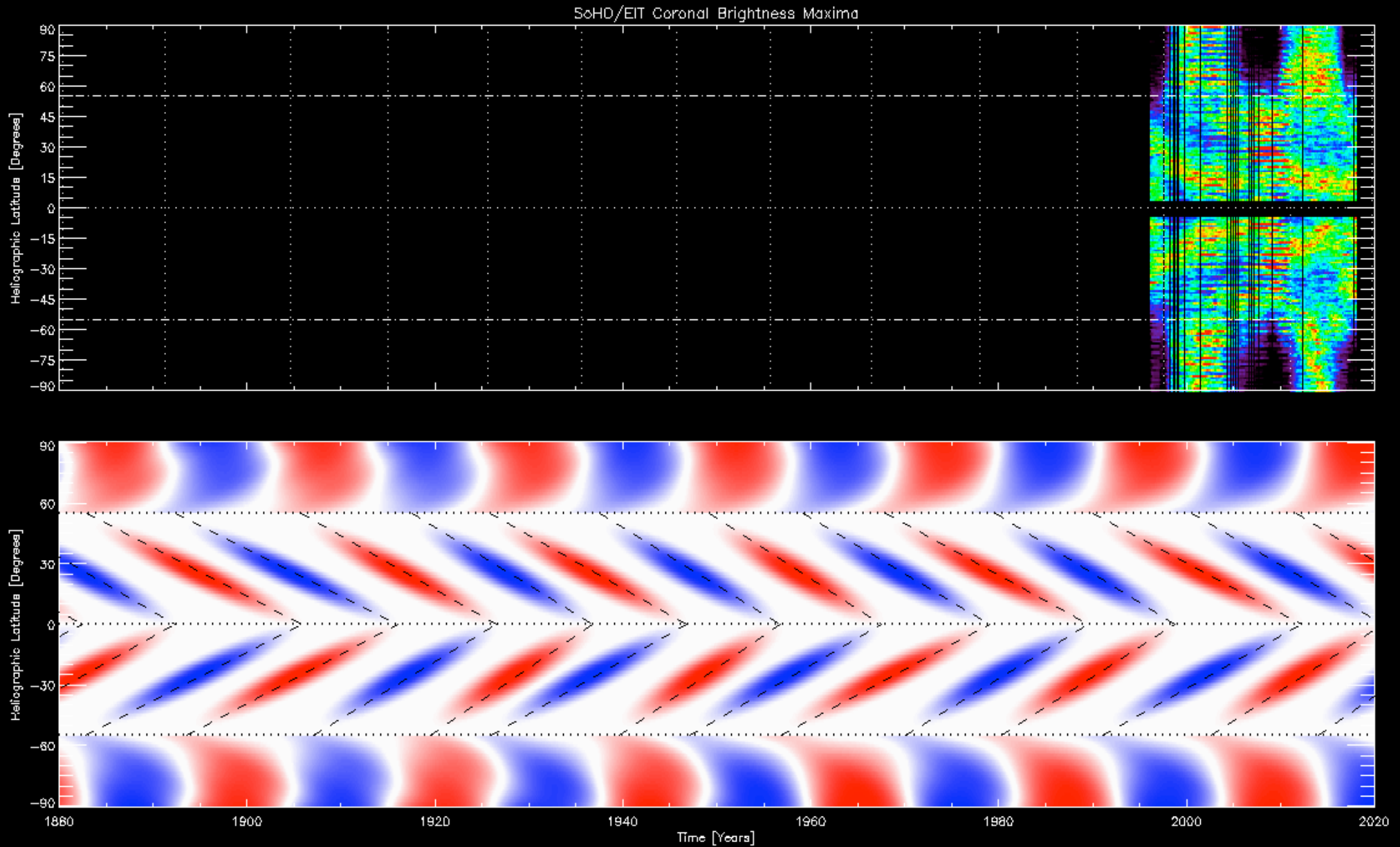
SOHO/EIT Coronal Scan Maxima [1996 - Present]



Same method as before - maximum finding - applied now to 22 years of contemporary data. The same patterns appear. Flick back and forth - number density of points higher still caused by higher resolution.

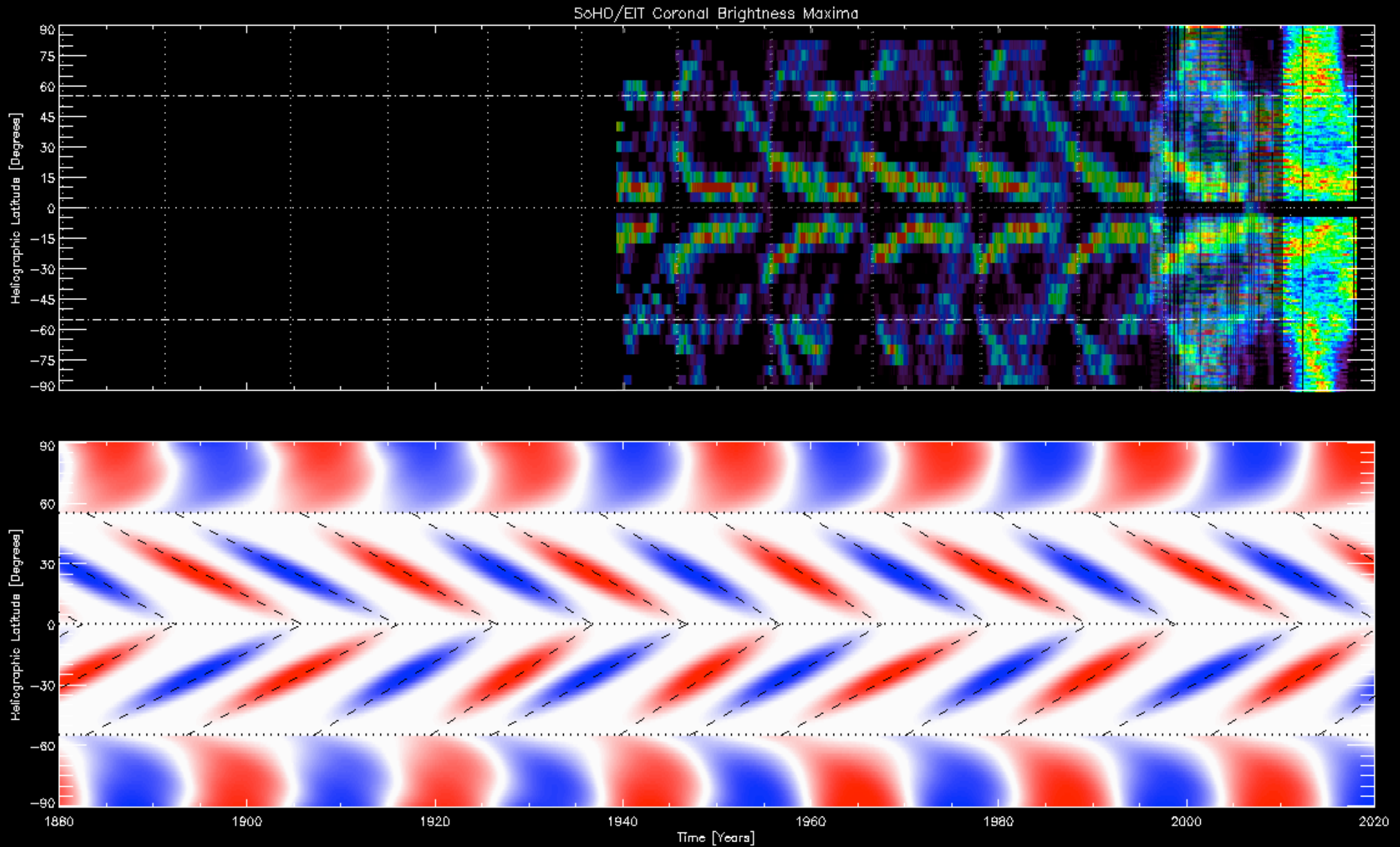
140 Years.....

SORCE 2018



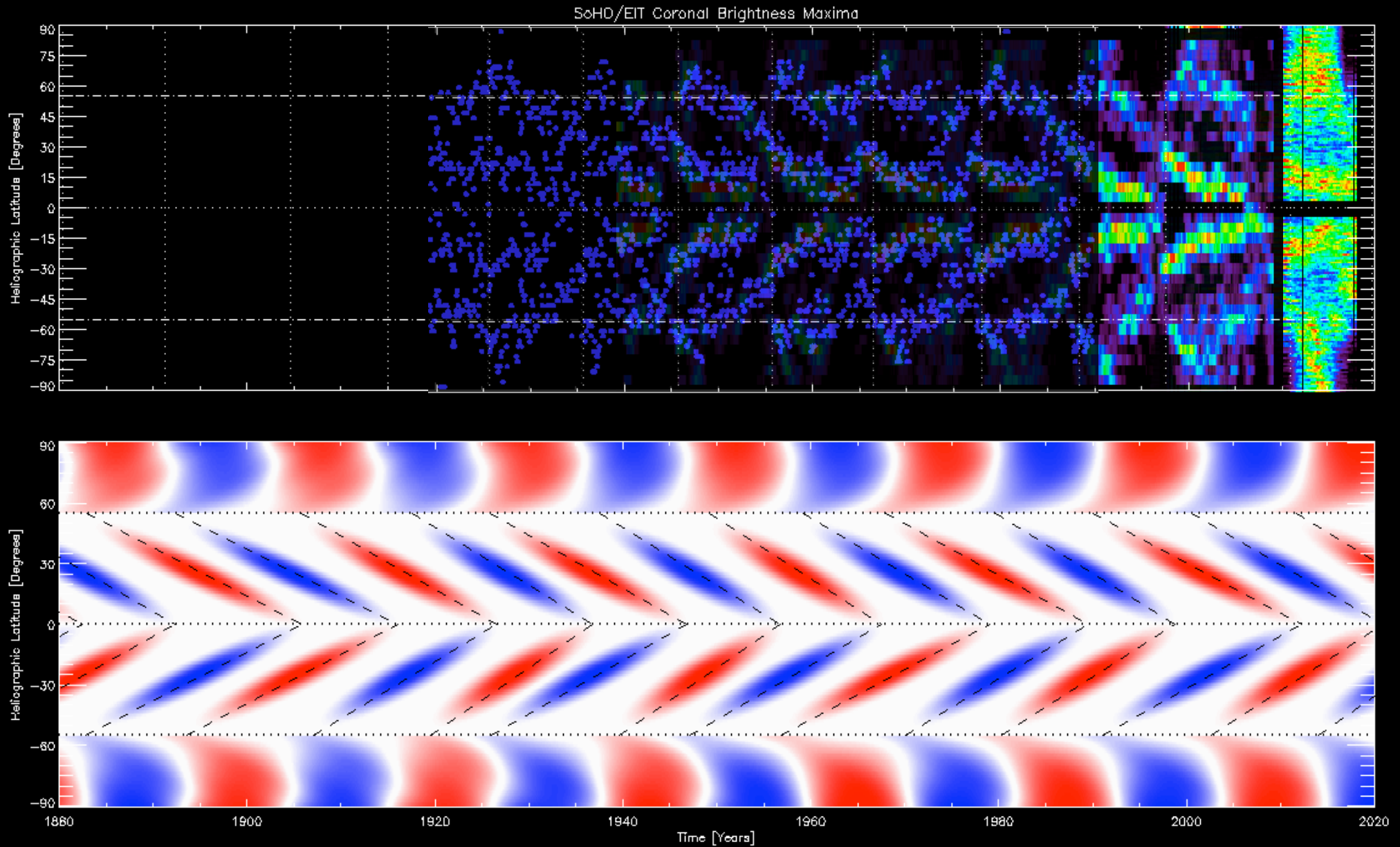
140 Years.....

SORCE 2018



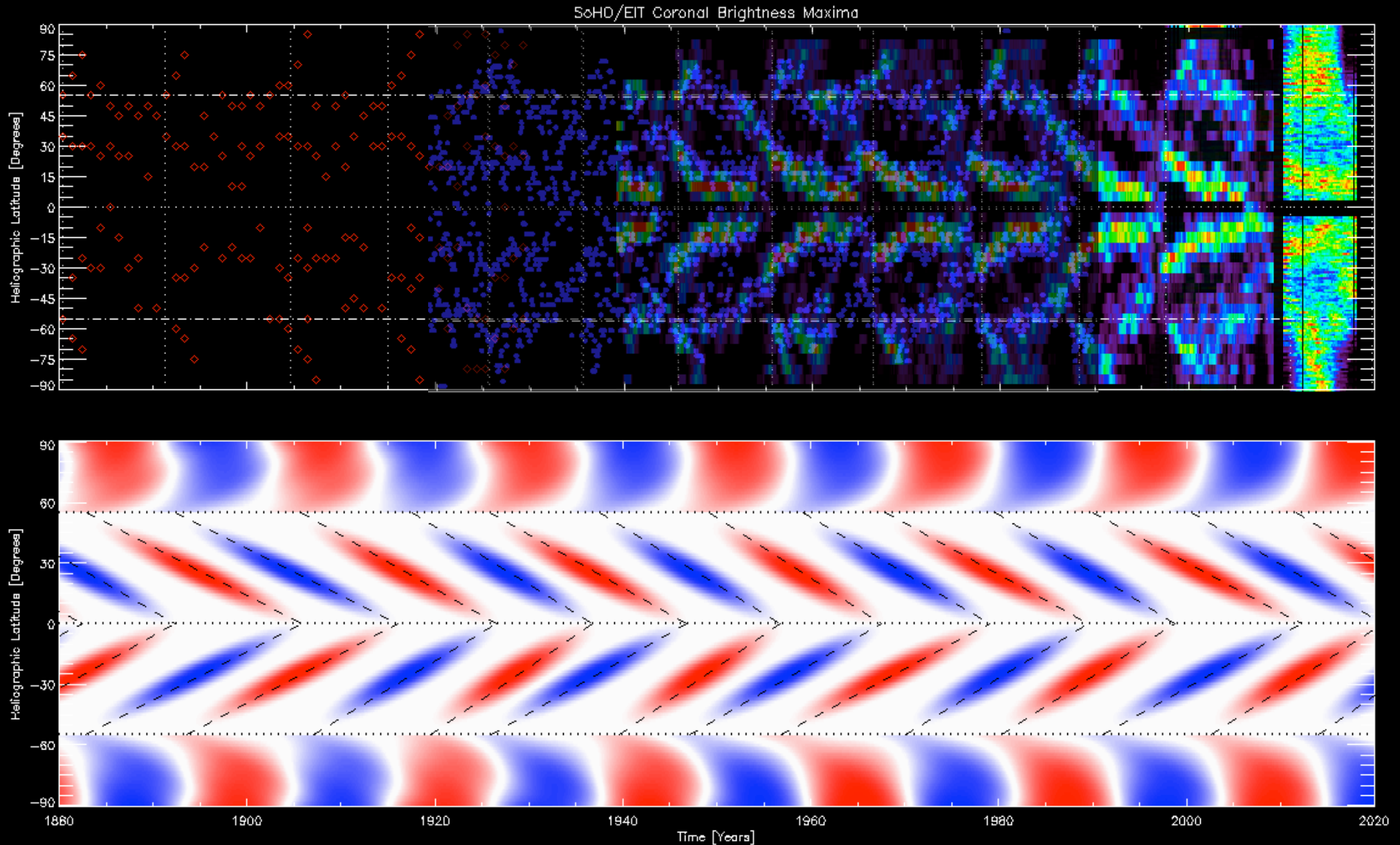
140 Years.....

SORCE 2018



140 Years.....

SORCE 2018



....of the Extended Solar Cycle

140 Years.....

SORCE 2018

Breathe

Quick Recap

**EUV Brightpoints
Global-Scale Coronal Morphology
Torsional Oscillation
Progression of Solar Filaments**



ALL Aligned



**Pattern STARTS at 55°
Take 17-19 years to reach equator
Polar “repetition” time is about 21.8yrs
Pattern is “same” in both hemispheres
for 28 [half-cycles]
Sunspots are a subset of the whole.**

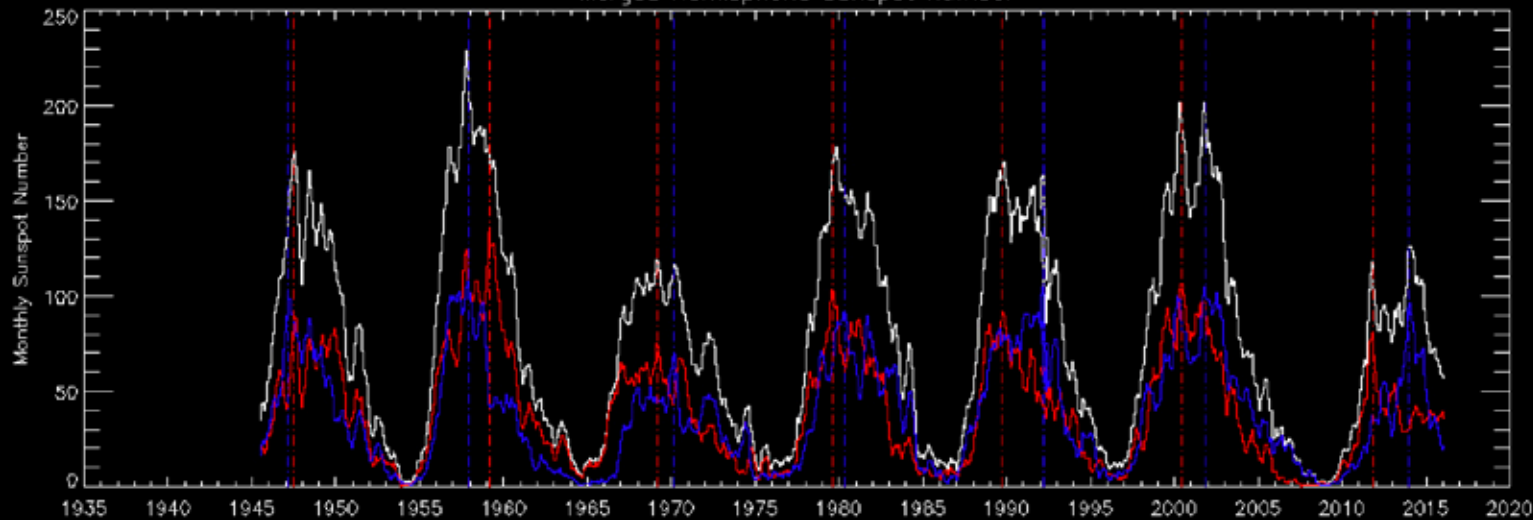
140 Years.....

SORCE 2018

Introducing The “SEA” - Superposed Epoch Analysis

IDL 1

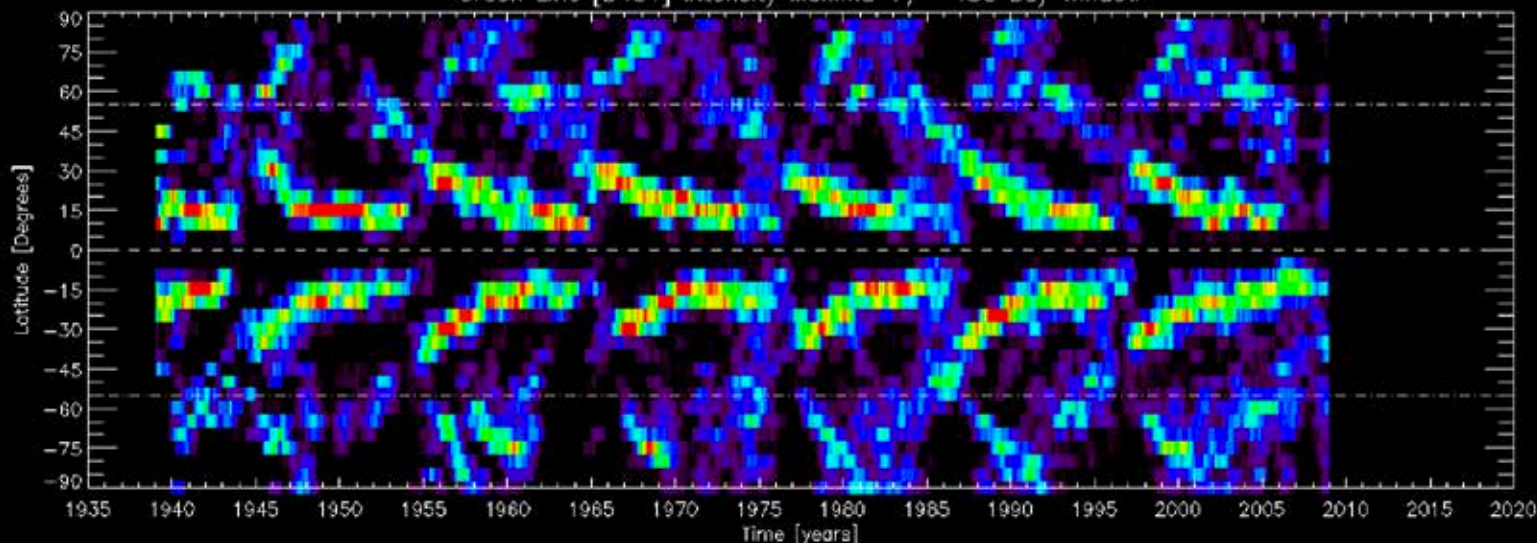
Merged Hemispheric Sunspot Number



1) Use Hemispheric Maxima to delineate the patterns in the two hemispheres

IDL 0

Green Line [5404] Intensity Maxima ± 150 Day Window

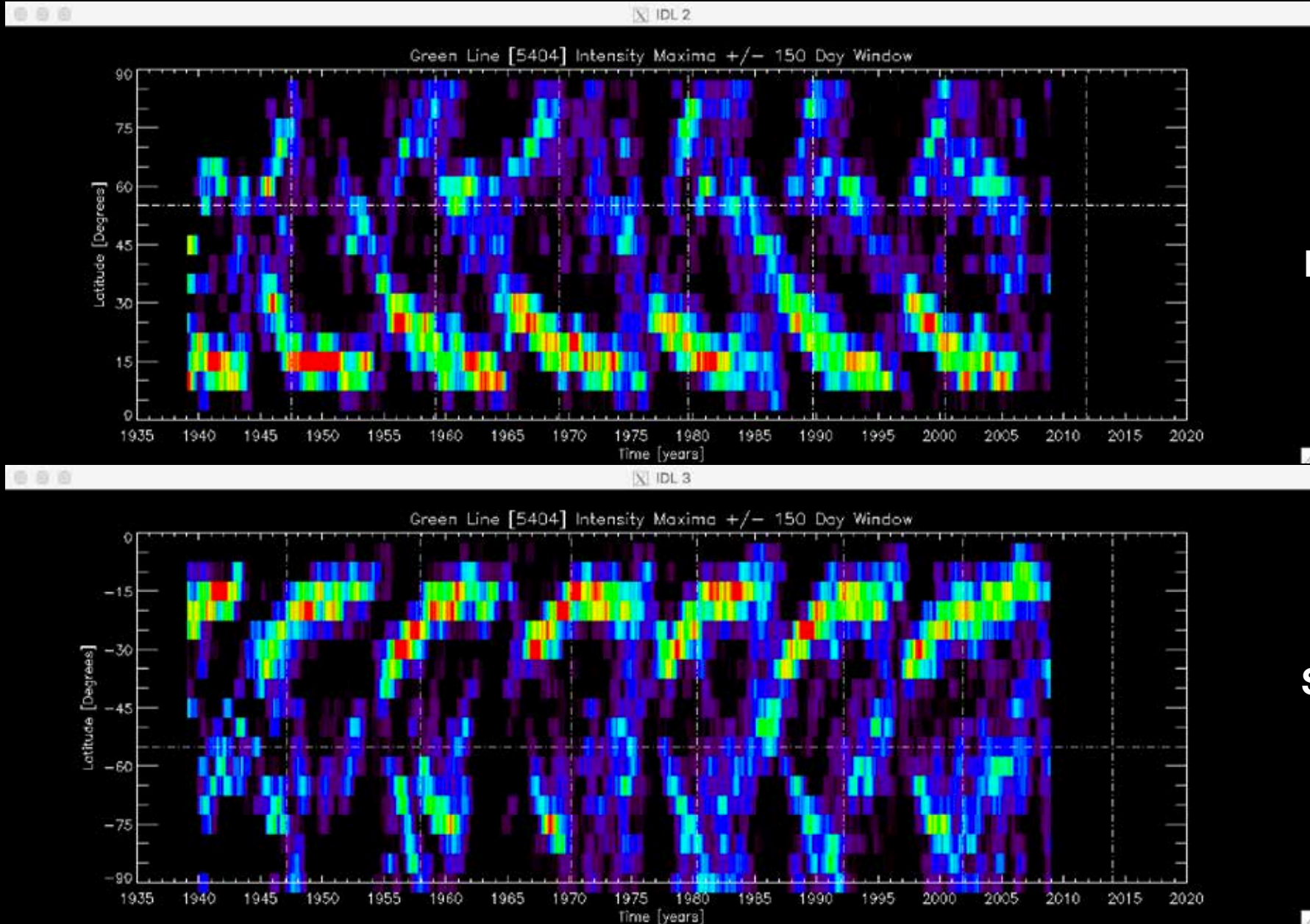


2) “stack” the extracted timeseries ± 11 years about hemispheric max.

140 Years.....

SORCE 2018

Introducing The “SEA” - Superposed Epoch Analysis

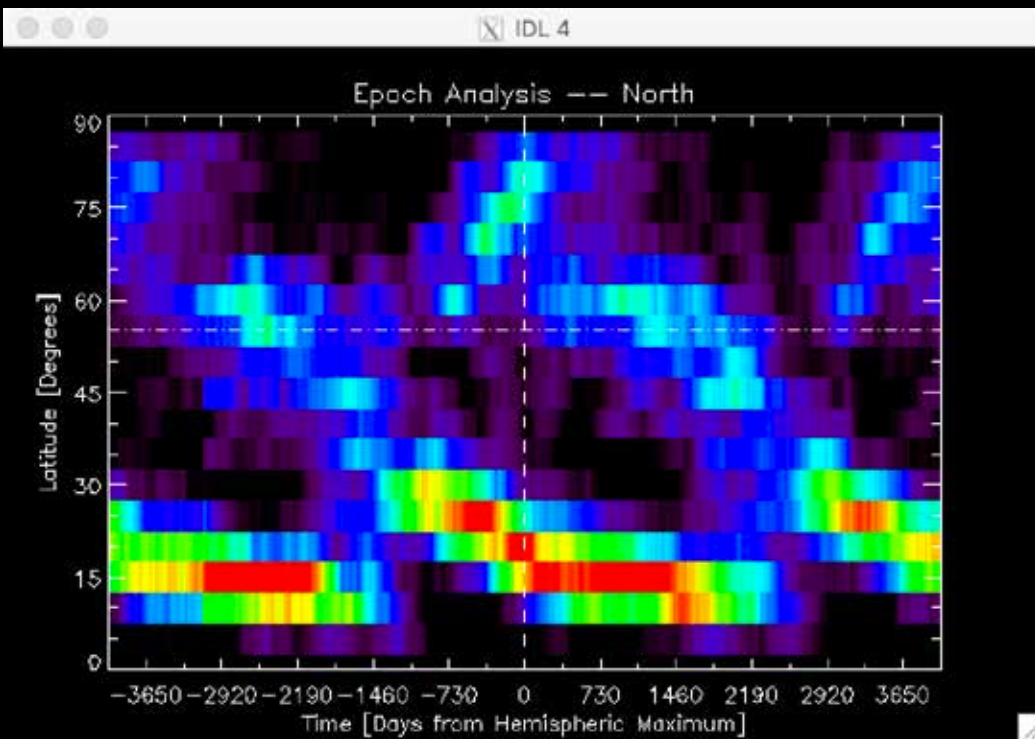


140 Years.....

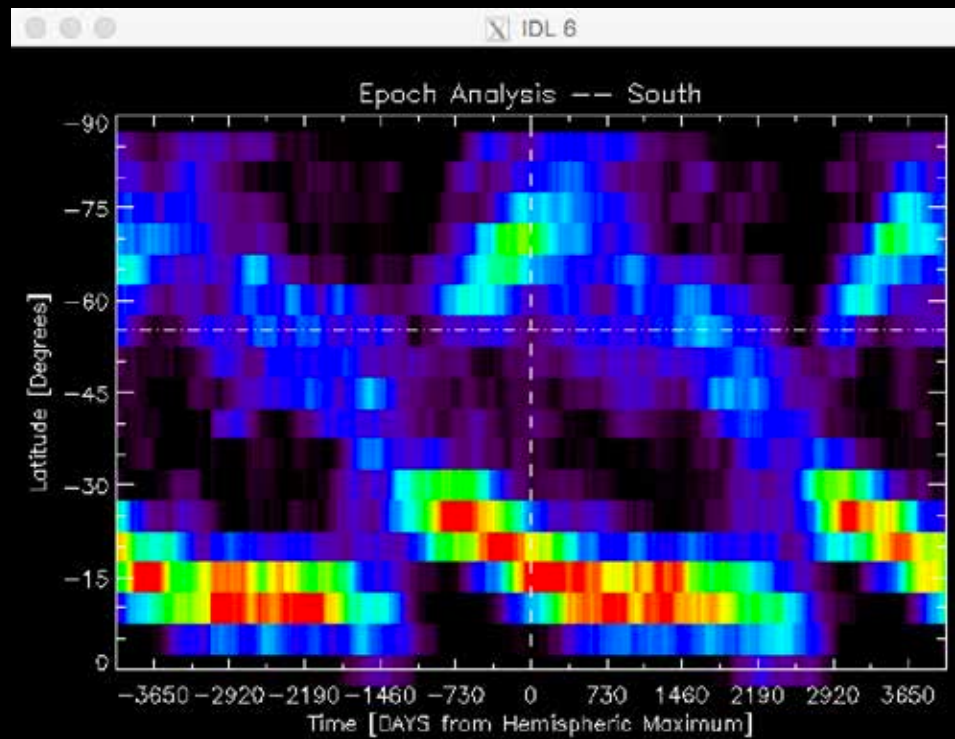
SORCE 2018

Introducing The “SEA” - Superposed Epoch Analysis

The resulting AVERAGE pattern



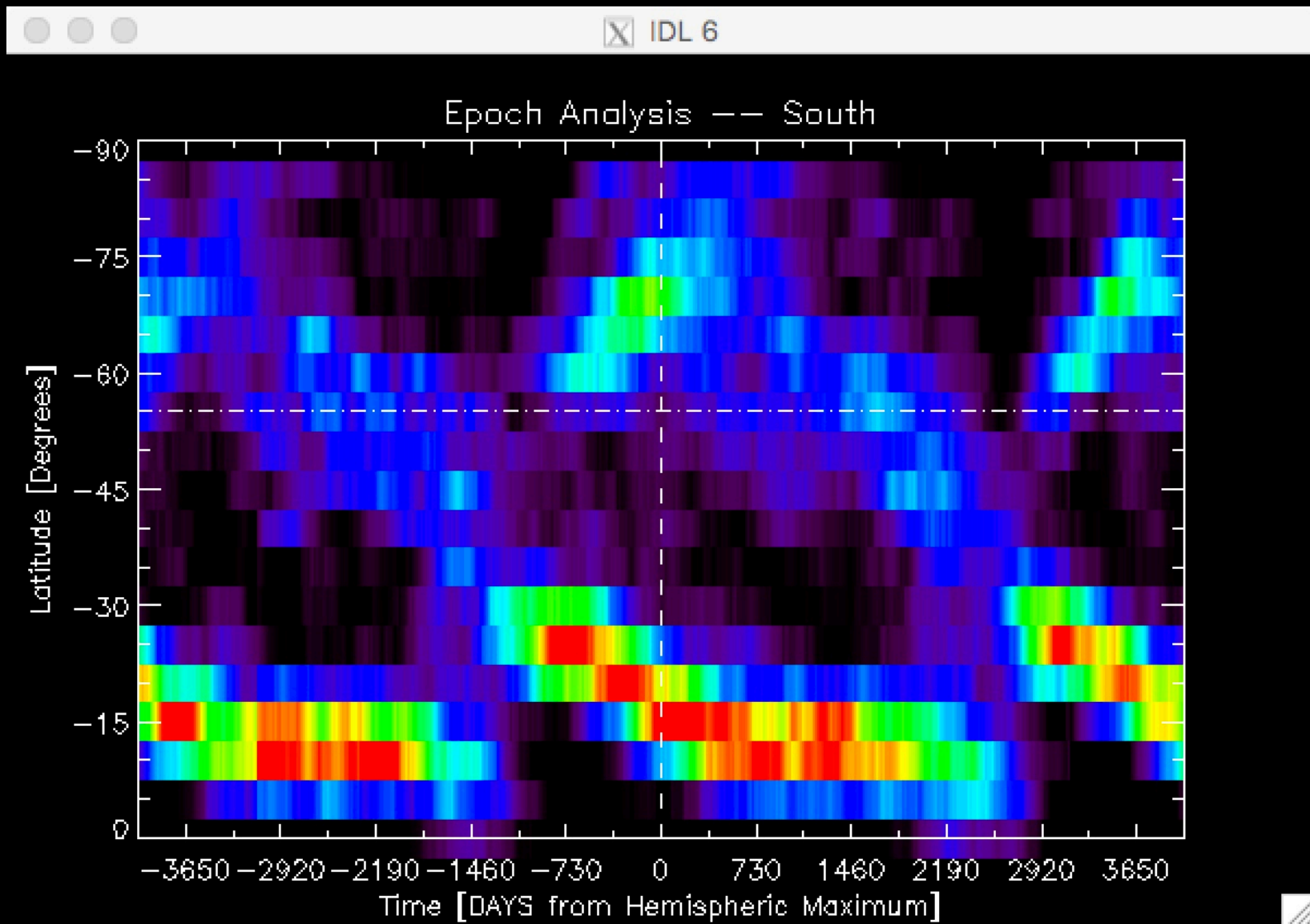
North



South

140 Years.....

SORCE 2018



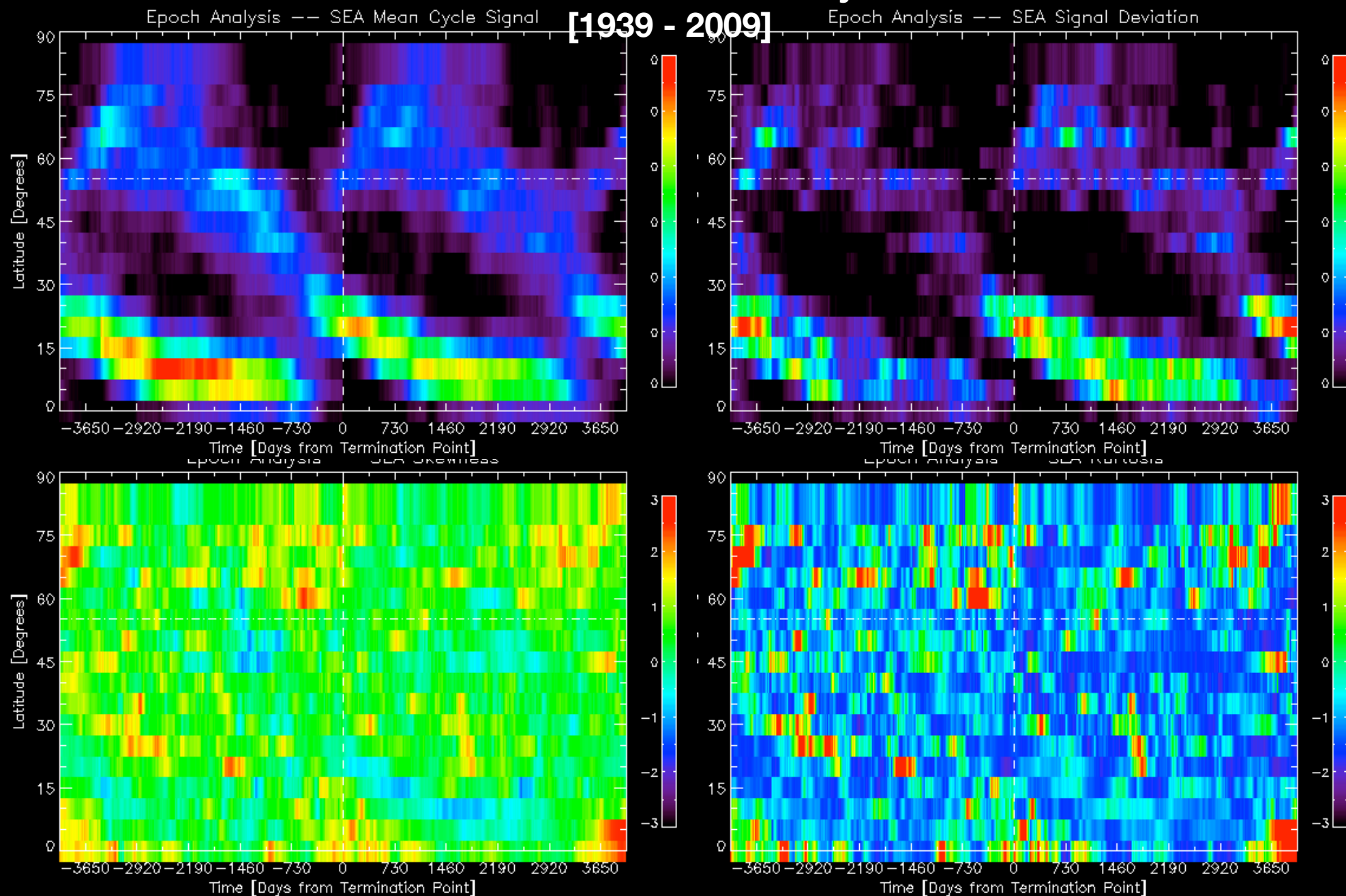
**Average pattern in both hemispheres essentially identical.
Is this then the average repeating unit?**

140 Years.....

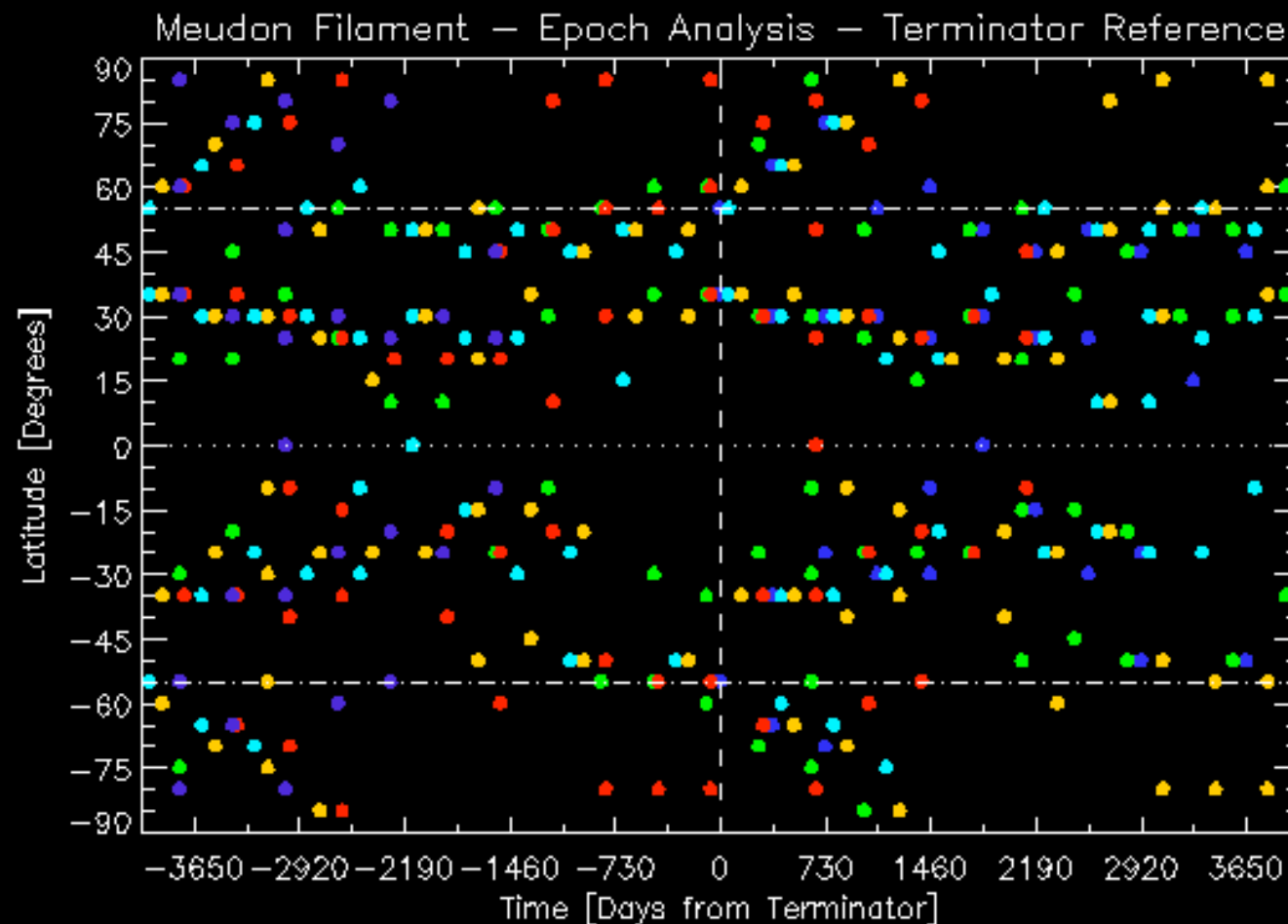
SORCE 2018

Statistical Moments of Coronal Green Line SEA

Termination Point As the “Key Time”



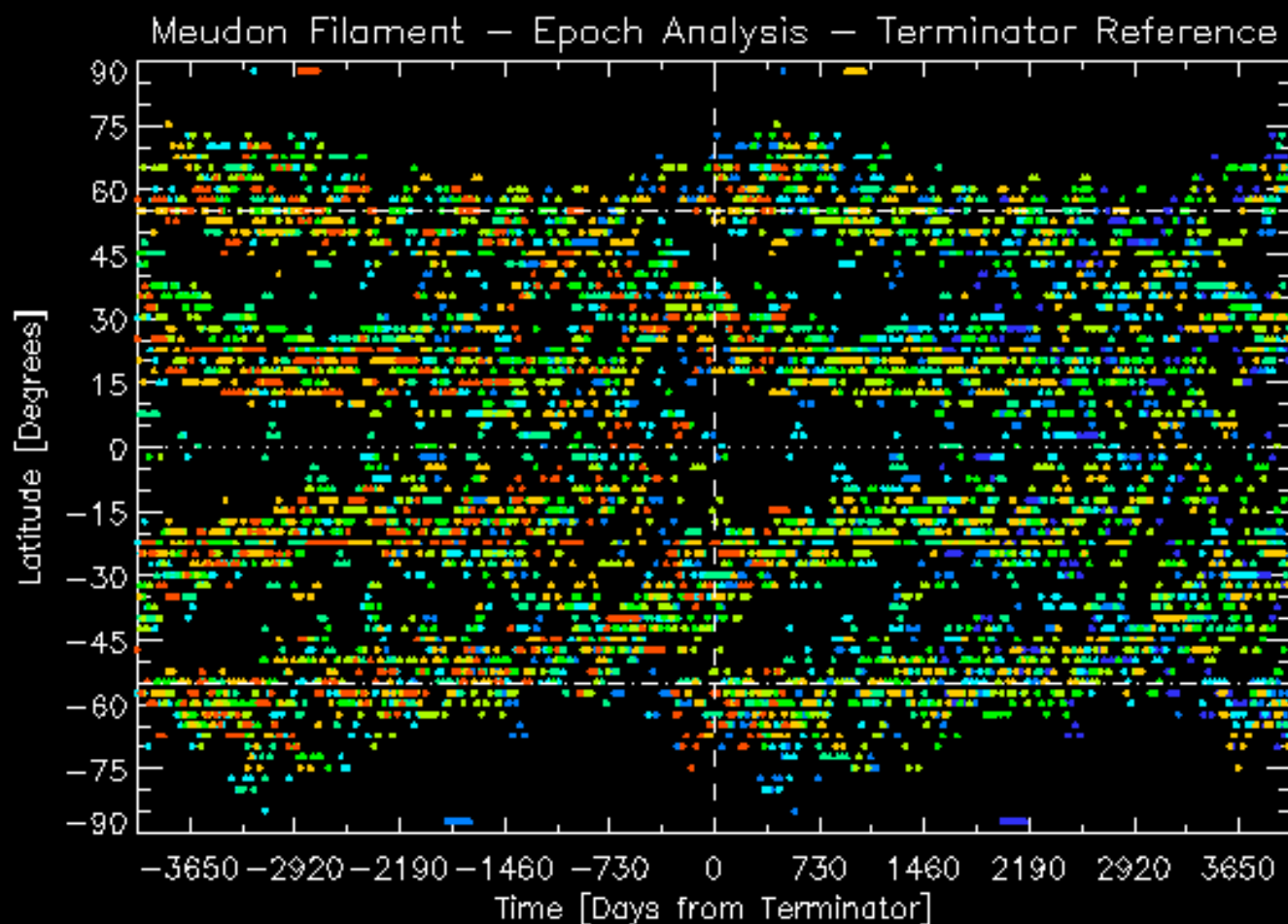
Arcetri Filament SEA Termination Point As the “Key Time” [1880 - 1931]



140 Years.....

SORCE 2018

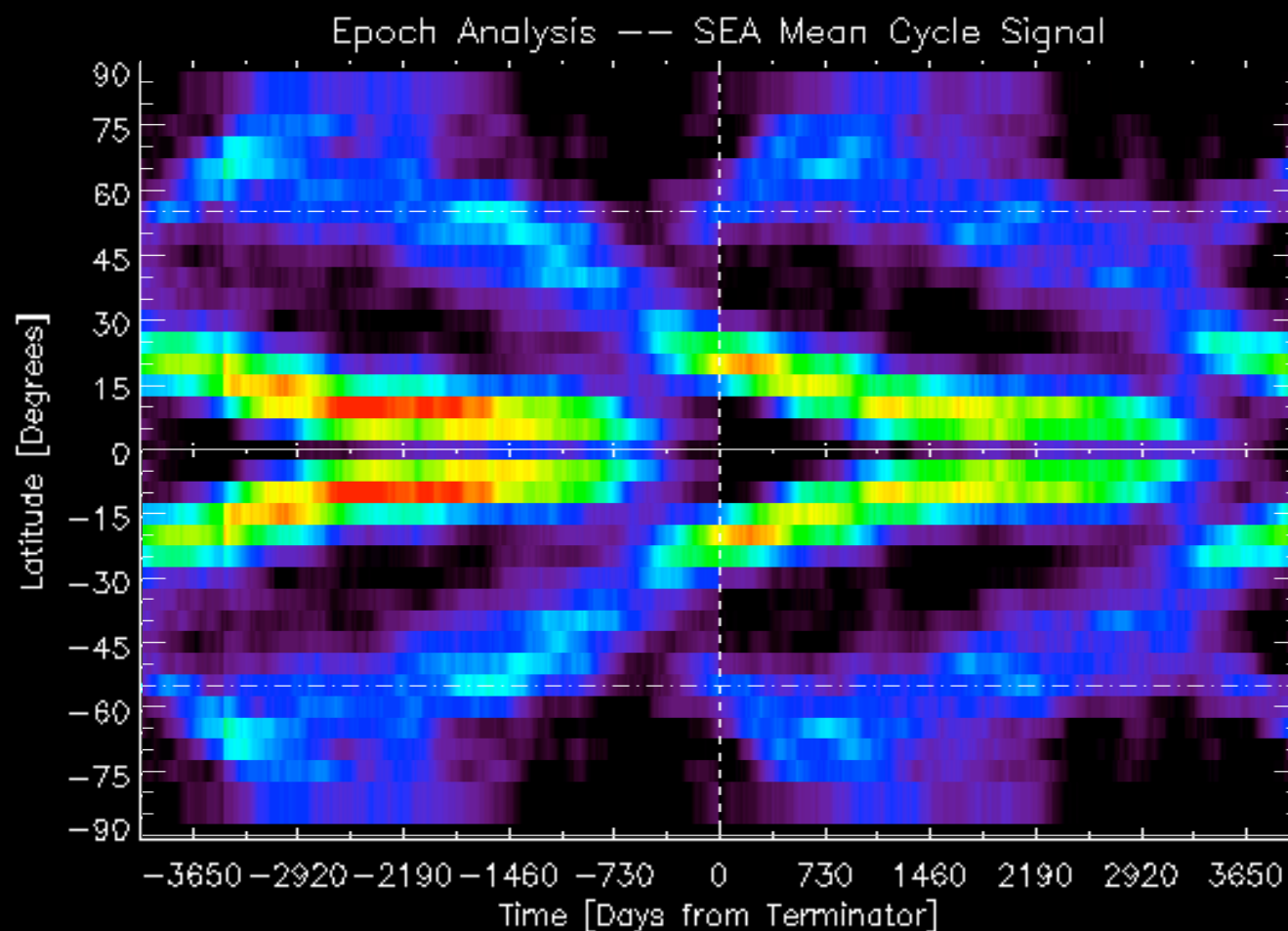
Meudon Filament SEA Termination Point As the “Key Time” [1919 - 1989]



140 Years.....

SORCE 2018

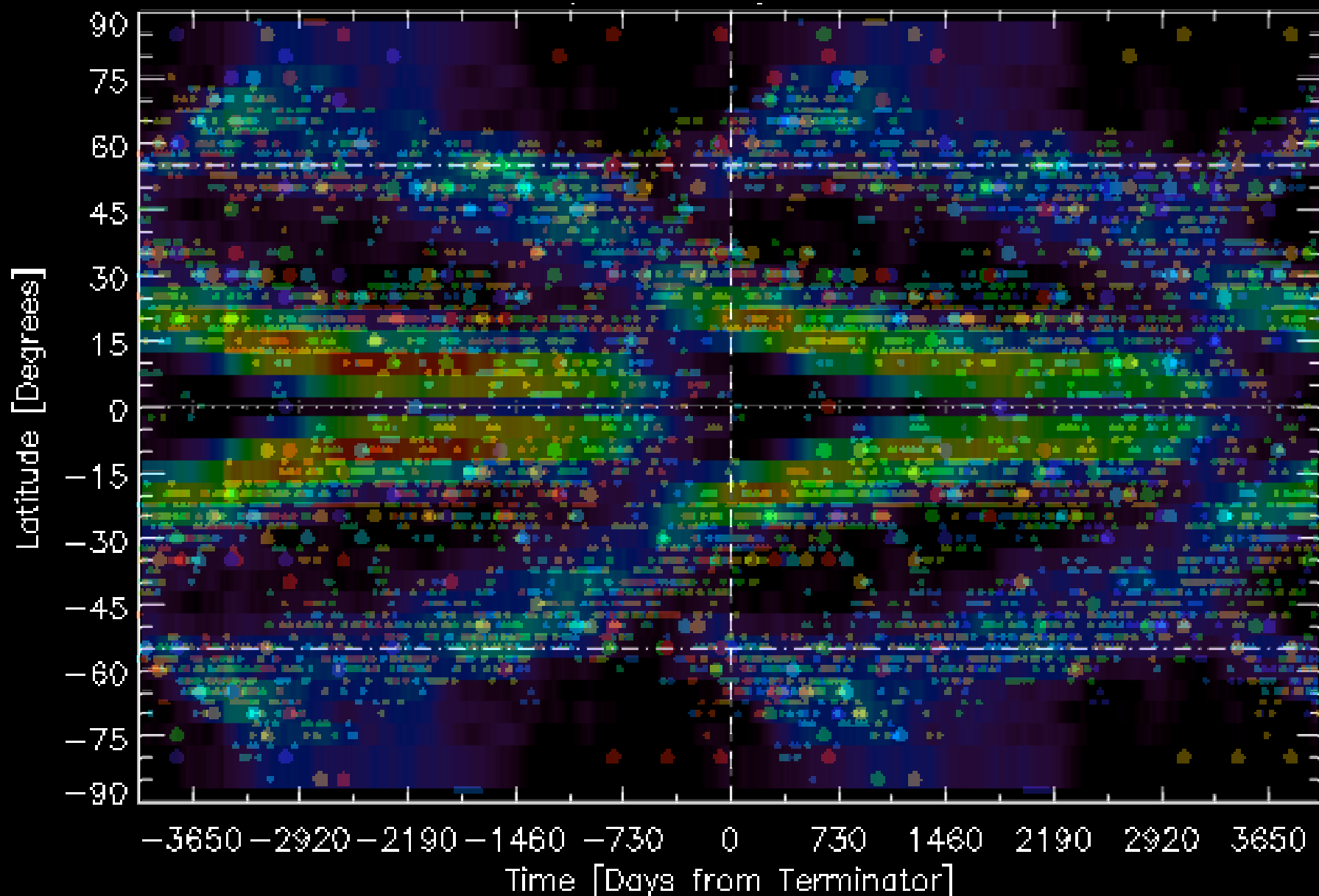
Coronal Green Line SEA Termination Point As the “Key Time” [1939 - 2009]



140 Years.....

SORCE 2018

Comparing SEA Analysis

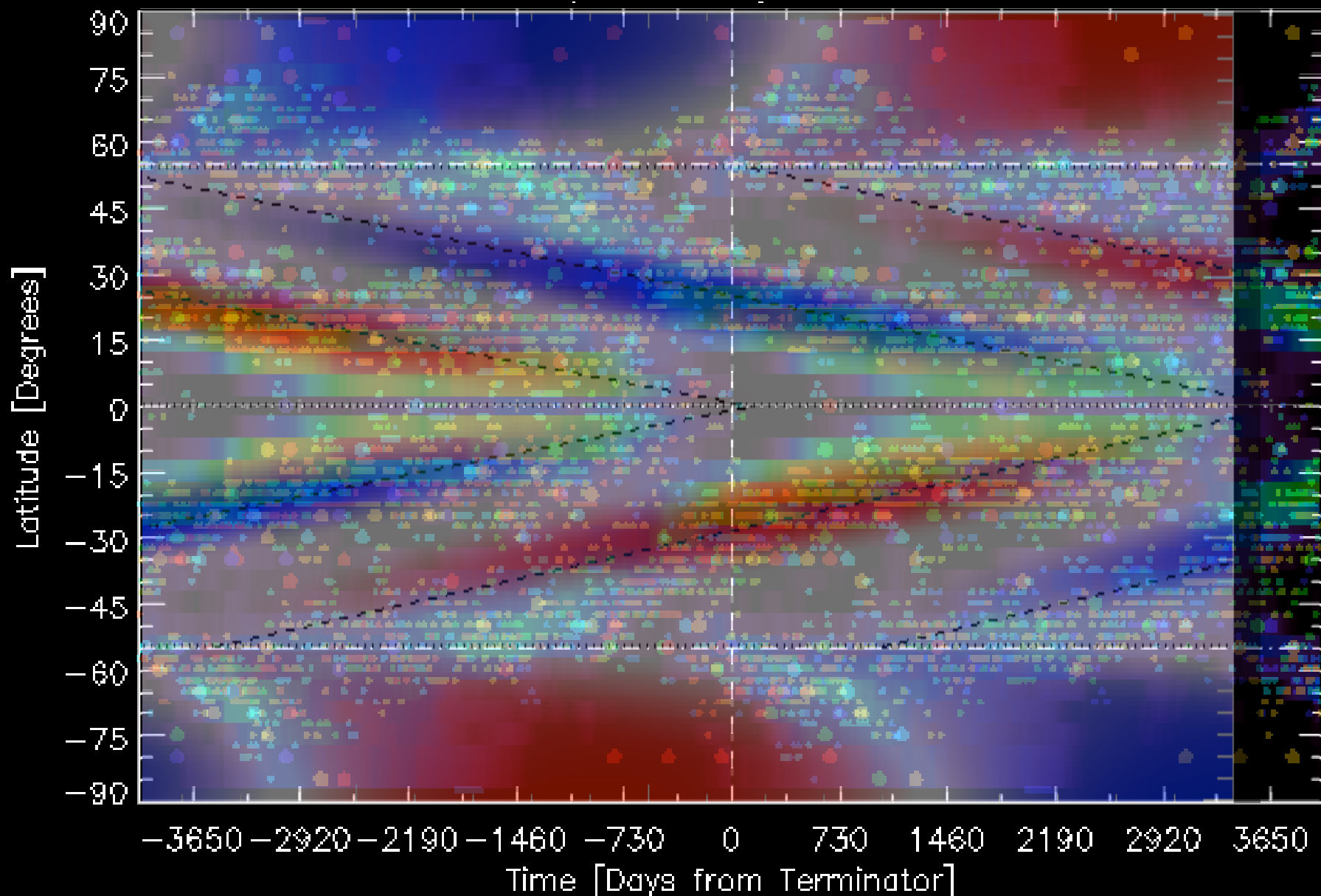


Agreement of 140yrs of data is VERY strong!

140 Years.....

SORCE 2018

Comparing SEA Analysis



Agreement of 140yrs of data is VERY strong!

140 Years.....

Global-Scale [Magnetic] “Telecommunication”

Robust 22-year Periodicity - Traces out Magnetic Activity Cycle

Bands of that Cycle - Overlap & Interact

**Mid-latitude Growth
&
“Rush to the Poles”**



Linked to Termination



**Internal Gravity Wave Coupling
Massive Magnetic Fields**

Sunspots are a bi-product of global overlap/interaction

55° is a CRITICAL latitude!

Predictable?

Resolved Observations REQUIRED.

“Rosetta Stone”

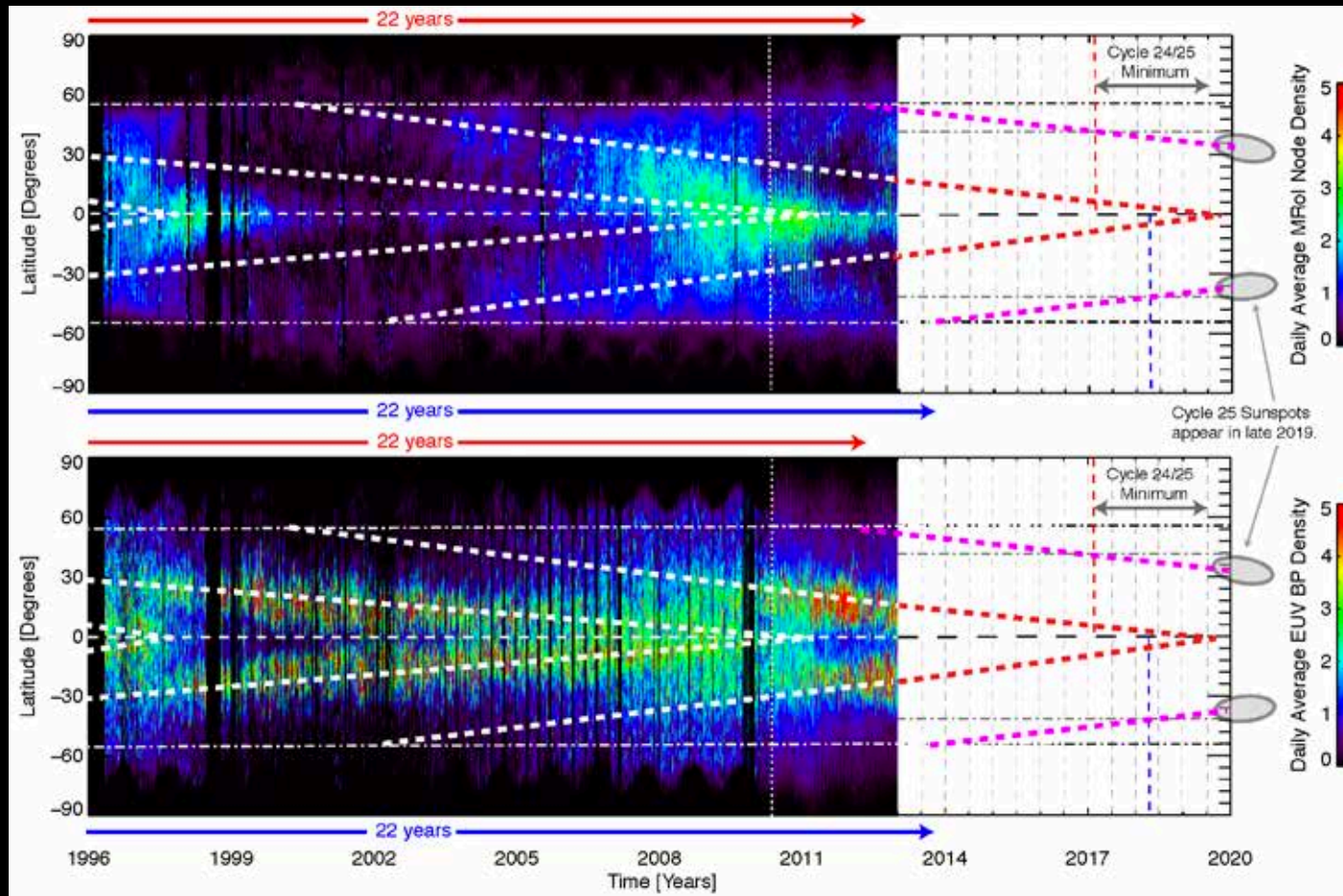
140 Years.....

SORCE 2018

Contemporary Observations N

The closing arguments of McIntosh et al. 2014 indicated that the bands that would produce sunspot cycle 25 may indeed have been visible, and was appearing when/where expected.

[McIntosh et al. 2014]



140 Years.....

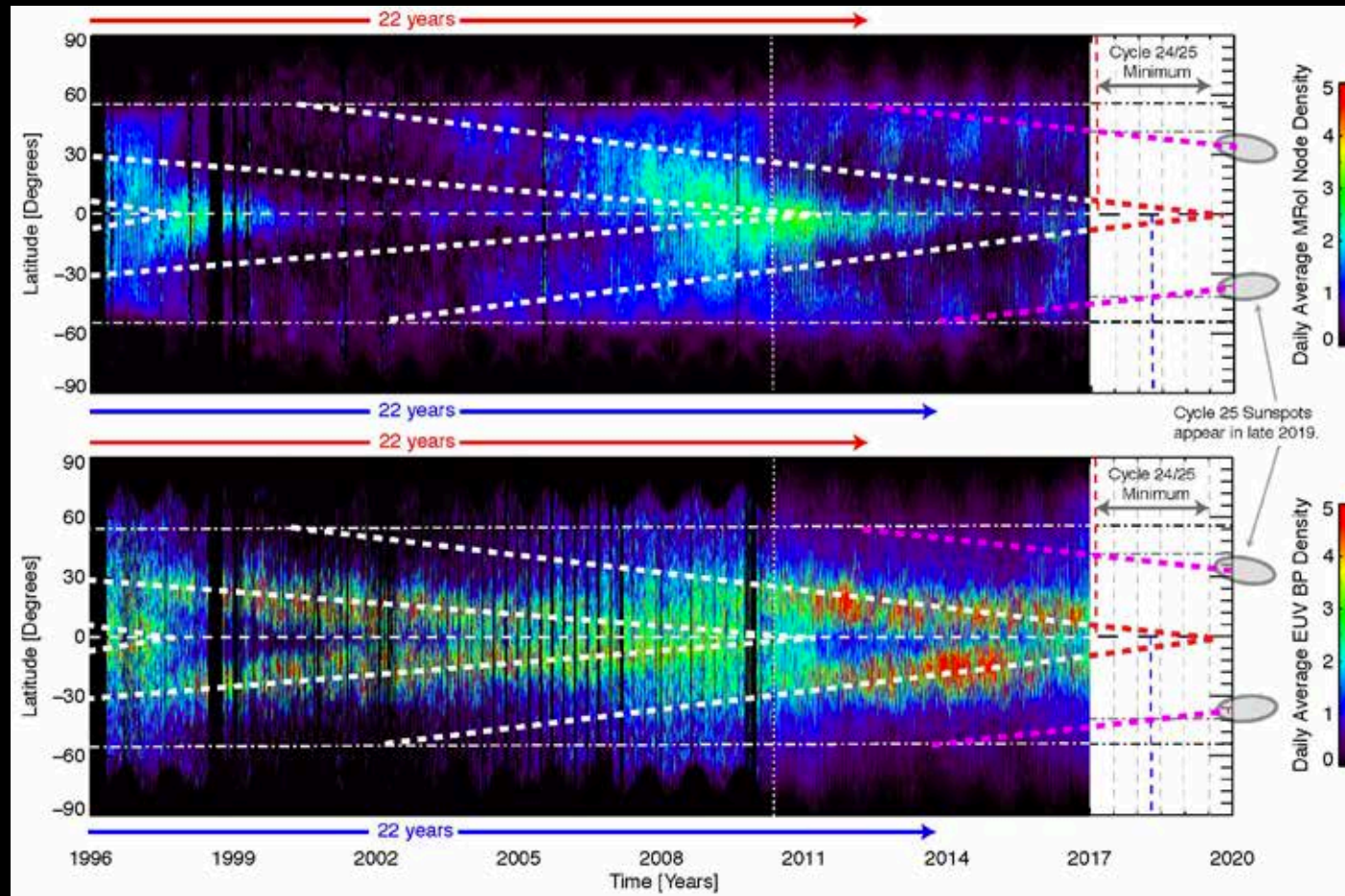
SORCE 2018

Contemporary Observations N

The closing arguments of McIntosh et al. 2014 indicated that the bands that would produce sunspot cycle 25 may indeed have been visible, and was appearing when/where expected.

[McIntosh et al. 2017]

[McIntosh et al. 2014]

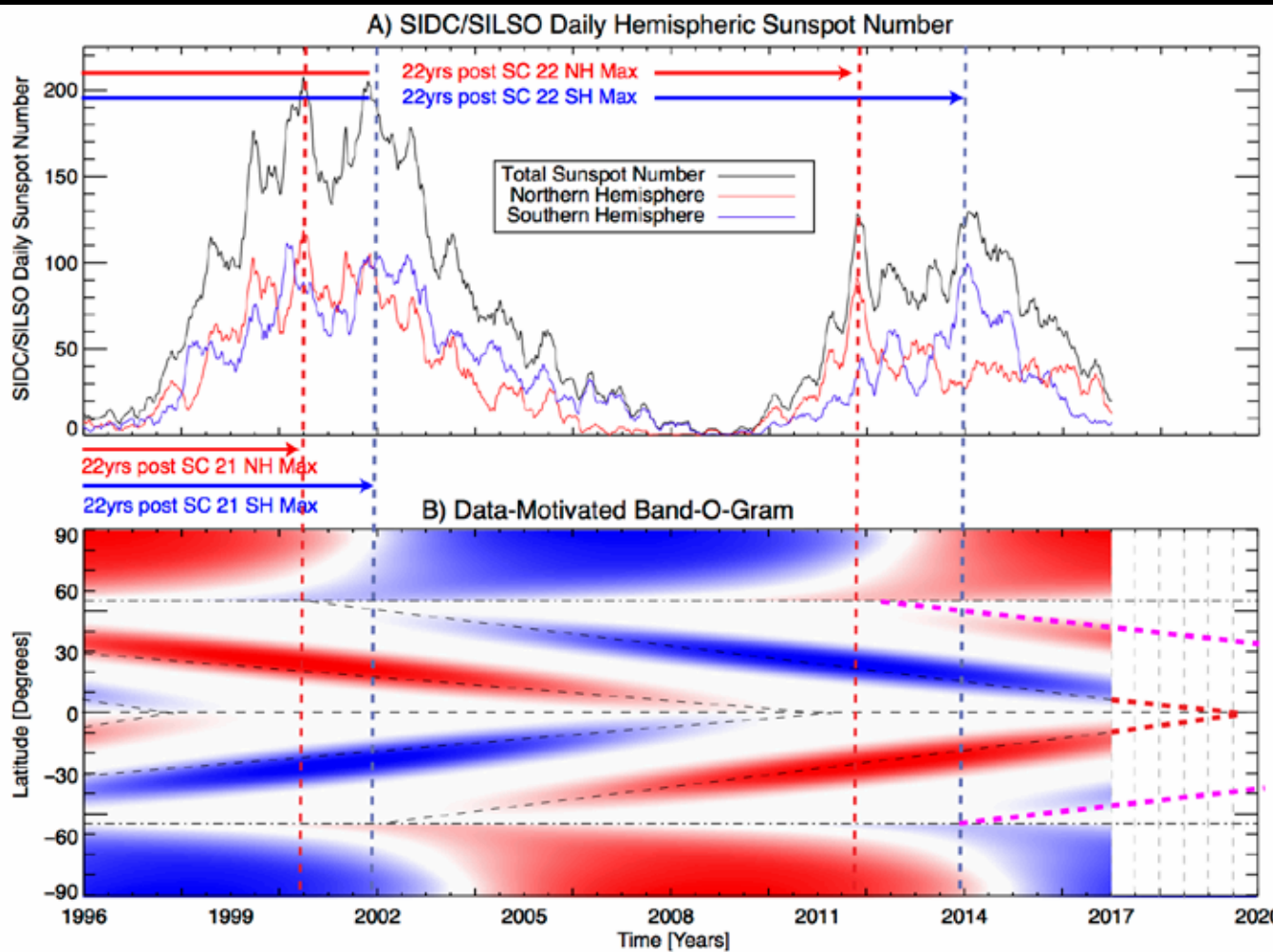


140 Years.....

Schematic “Model” & Forecasting

[McIntosh et al. 2017]

[McIntosh et al. 2014]



Solar Minimum is close!

Solar Cycle 25 is here!

WILL be < cycle 24!

**Spots in
late 2019 - early 2020.**

Terminator in 2020 !

**Are we heading for an extended 24/25 solar minimum?
Maybe en route to a Grand Minimum?**

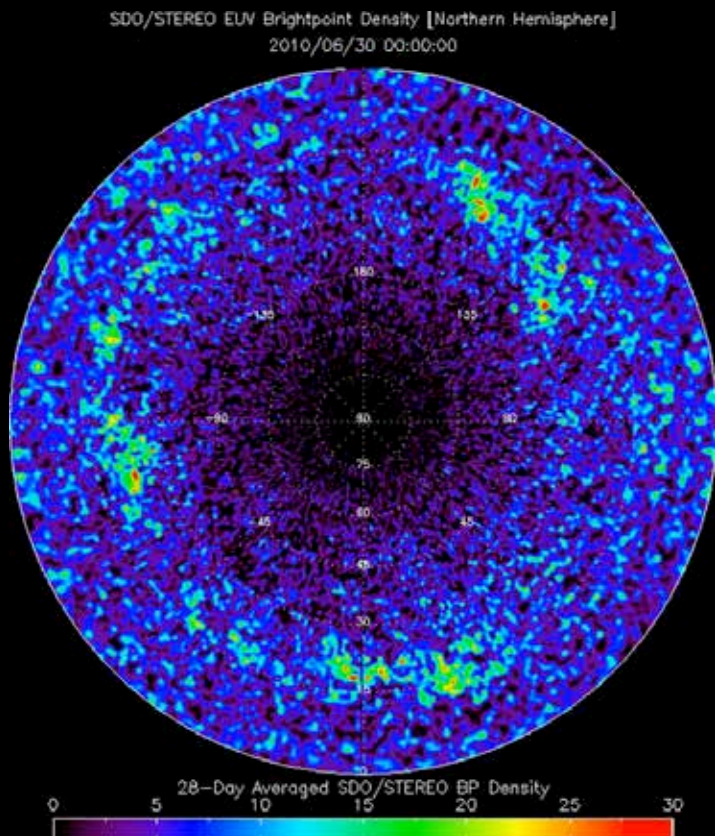
140 Years.....

SORCE 2018

.....of observations illustrate that the “extended solar cycle” really is the progression of the 22-year solar magnetic activity cycle.

Continuous high latitude [polar] observations are critical to identify and monitor the growth of sunspot cycle 26[+] in the early 2020s.

The repeated signature of “Terminators” must be mined for critical information about the conditions of the solar interior.



Questions:

- Is this a “wave-like” solution to the dynamo problem?
- Is the dynamo action taking place at high latitudes?
- Is this consistent with B-L and/or flux-transport models of the dynamo?
- What does this mean for the “Alpha” effect?
- Just how strong is the magnetic field?
- Is it almost always in critical balance?
- What are the controlling parameters?
- Why does 55 appear to be so critical?