

SH13B-08

Primary and Secondary Solar Polar
Crown Polarity Inversion Lines (PILs)
over Five Solar Cycles

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The Study

We undertake a **five solar-cycle (SC19-23) study of the high latitude polar crown polarity inversion lines (PILs)** or neutral lines that encircle the sun to elucidate deep-seated dynamo processes using the McIntosh Archive. The McIntosh Archive consists of a set of **hand-drawn solar synoptic (Carrington) maps created by Patrick McIntosh** from 1964 to 2009 (SC20-23) **using H-alpha images and magnetograms for PILs**, and He-I 10830A images for coronal holes since 1974. Filaments are the clearest tracer of PILs, along with fibril patterns and active region corridors, and the PILs trace the large-scale pattern of the global magnetic field. Most of these maps have now been **digitized, with some gaps** in SC20 and SC21. We also digitized the Carrington maps created **from Kodaikanal Solar Observatory** data in India by Makarov and Sivaraman (1986) to extend the study back through SC19, or **1959-2009 for this study**.

max are 4 filled squares

McIntosh Archive Synoptic Map

P,S PILs in dashed red/blue

End date (longitude=0):1970-05-10T11:51:19

Start date (longitude=360):1970-04-13T05:57:20

B angle end date -3.16

B angle start date -5.74

CR1560

*Search for primary P

PILs from poles to 37°.

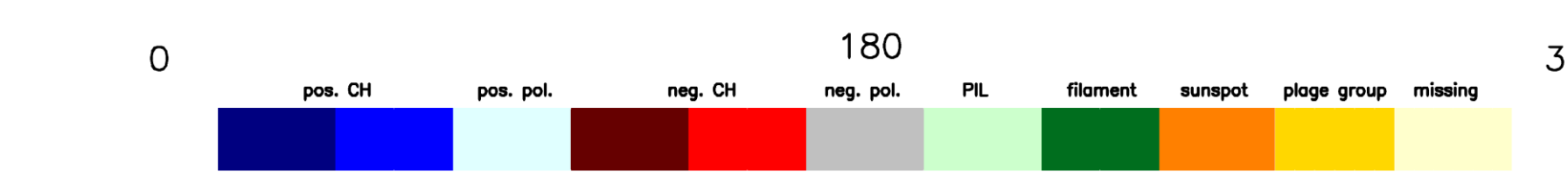
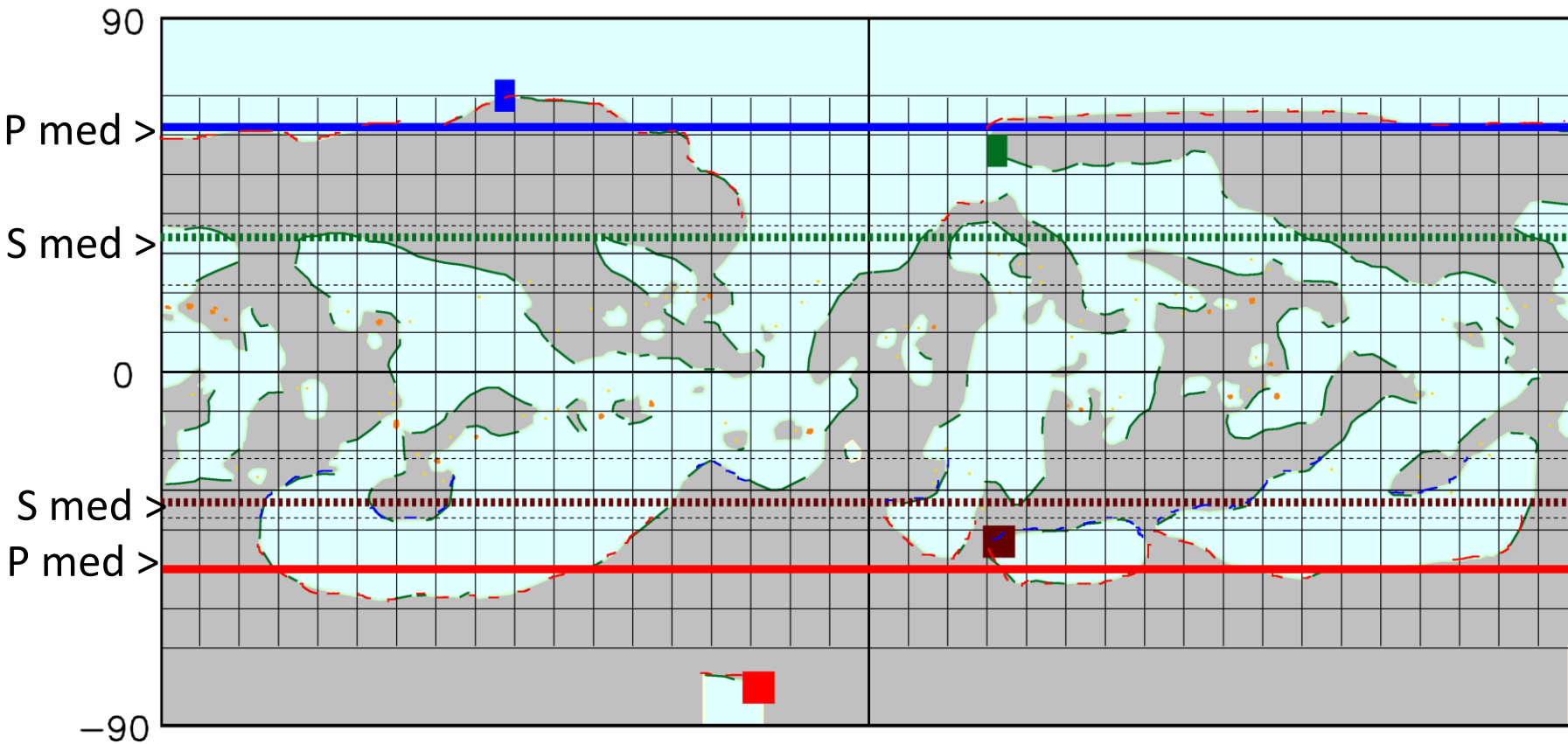
*BLUE pos line at 62NH, max at (70,85).

*RED neg line at 50SH, max at (-80,153).

*Search for secondary S PILs equatorward from primary PILs to 22° with a minimum separation of 4°.

*Dashed pos line at 34NH, max at (56,211).

*Dashed neg line at 33SH, max at (-43,213).



P med >
S med >
0
S med >
P med >

0 180 360

McIntosh Archive Synoptic Map

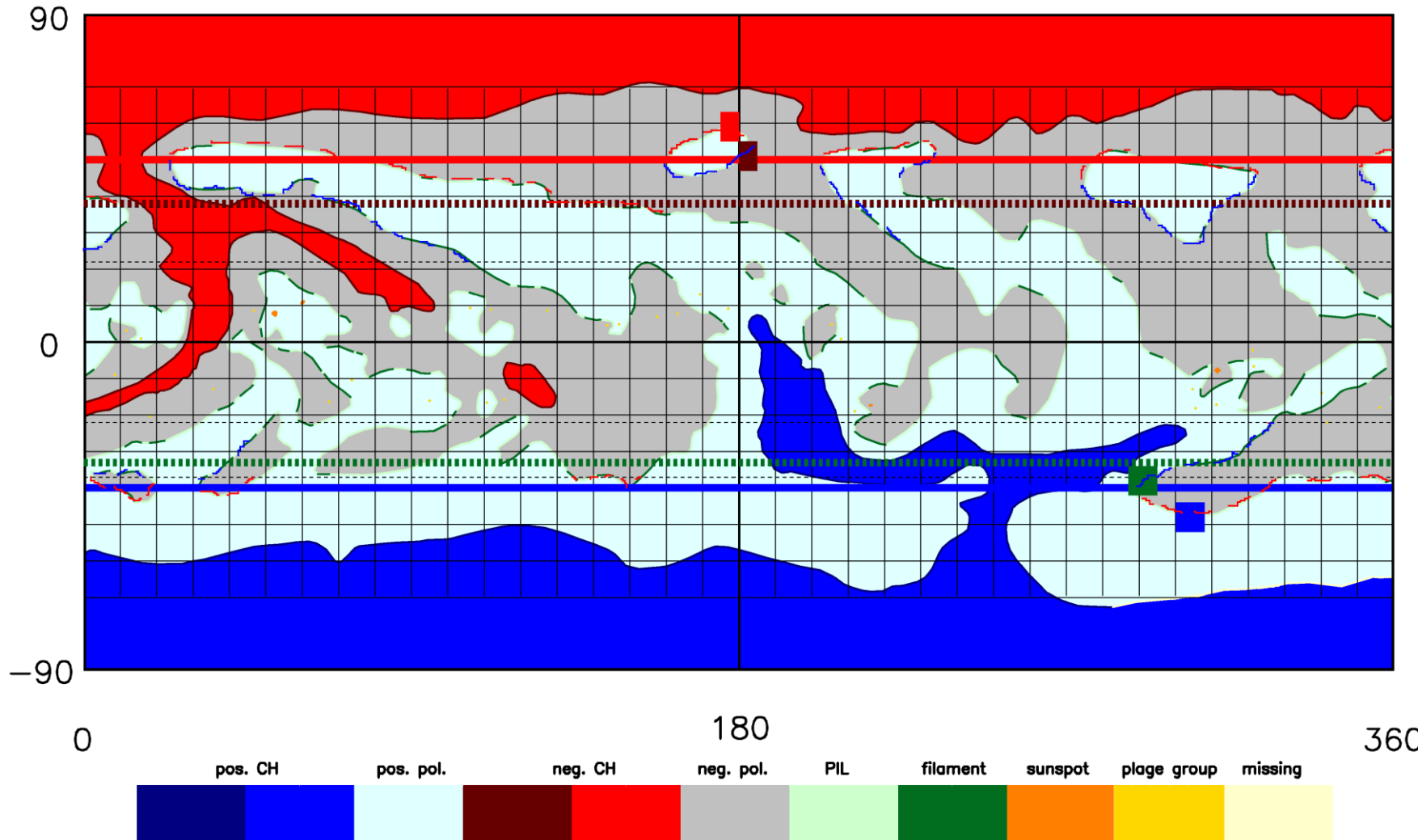
End date (longitude=0):1984-08-13T19:52:39

Start date (longitude=360):1984-07-17T14:36:16

B angle end date 6.600

B angle start date 4.620

CR1751



*RED neg line at 50NH, max at (59,176).

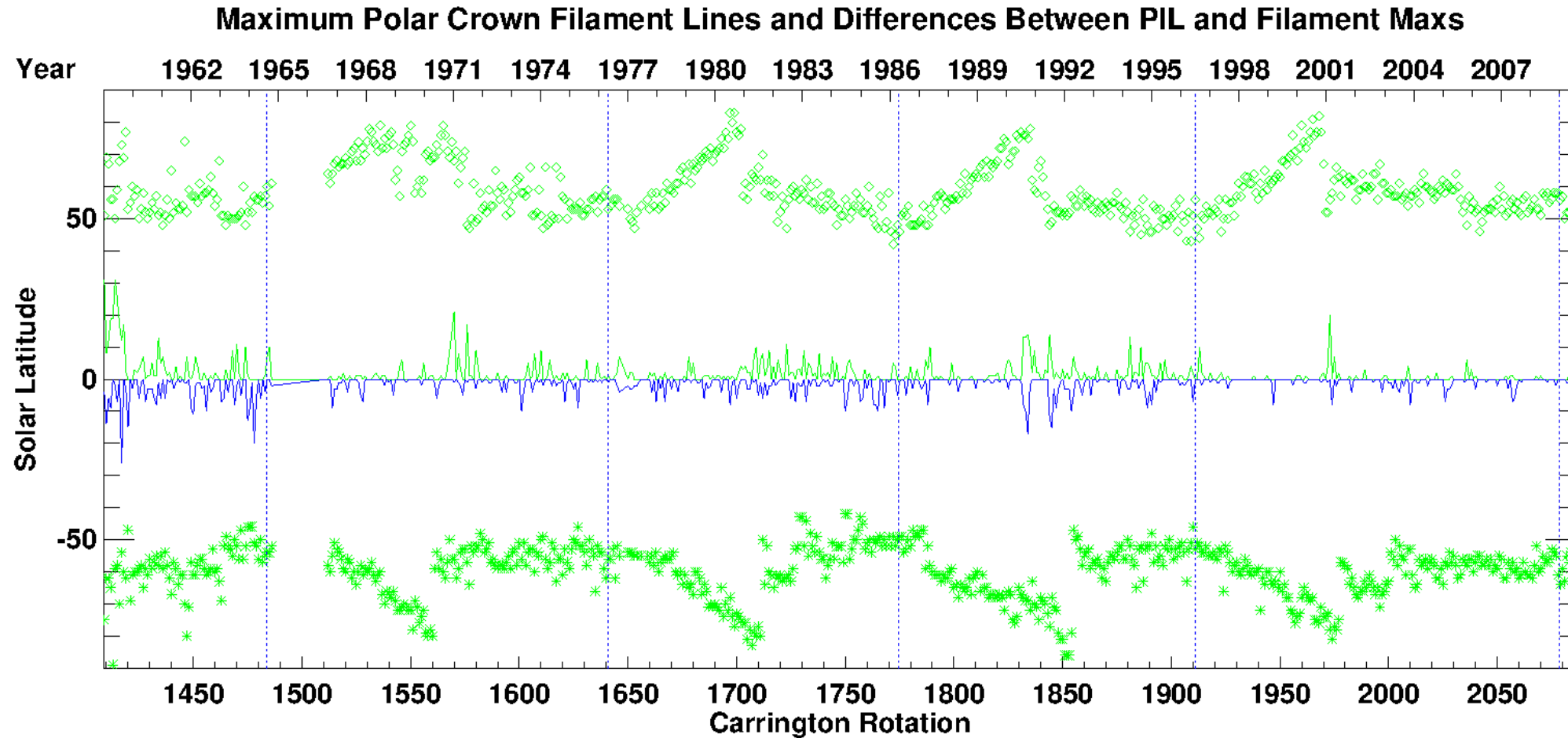
*BLUE pos line at 40SH !MOST EQUATORWARD! with max at (-48,303).

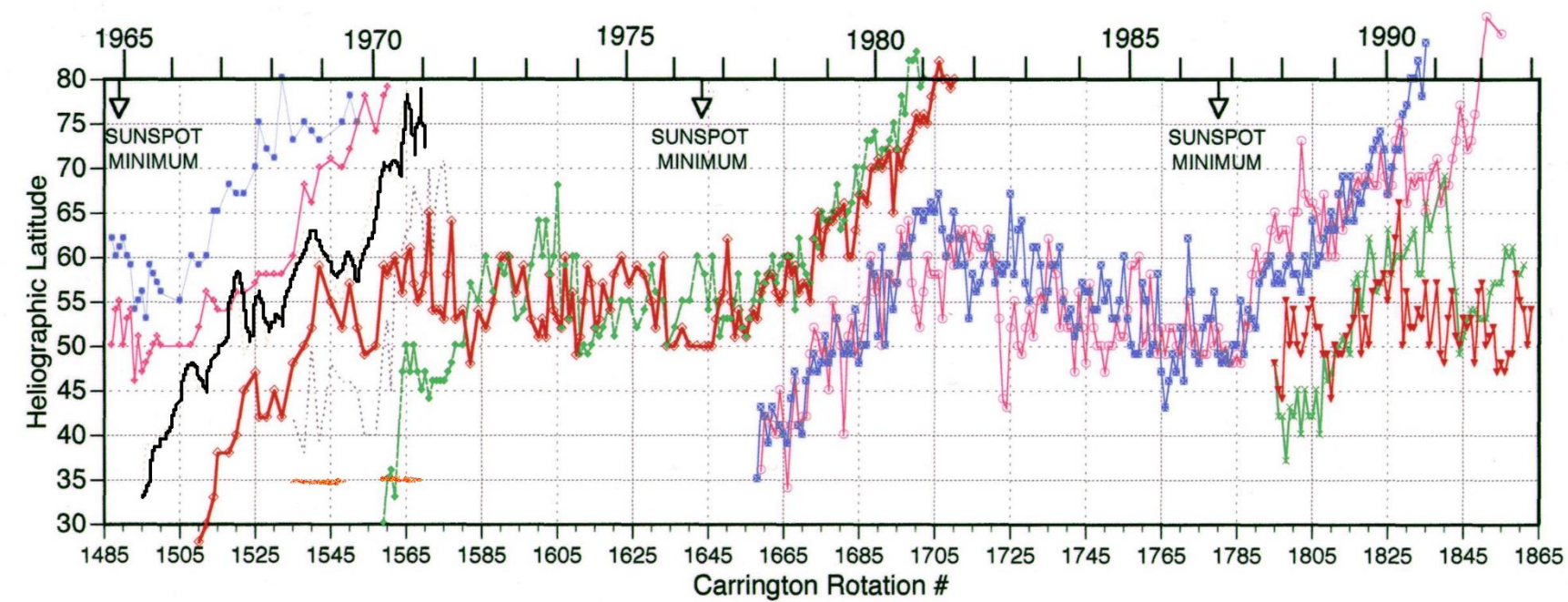
*Search for secondary PILs equatorward from primary PILs to 22° with a minimum separation of 4°.

*Dashed neg line at 38NH, max at (51,181).

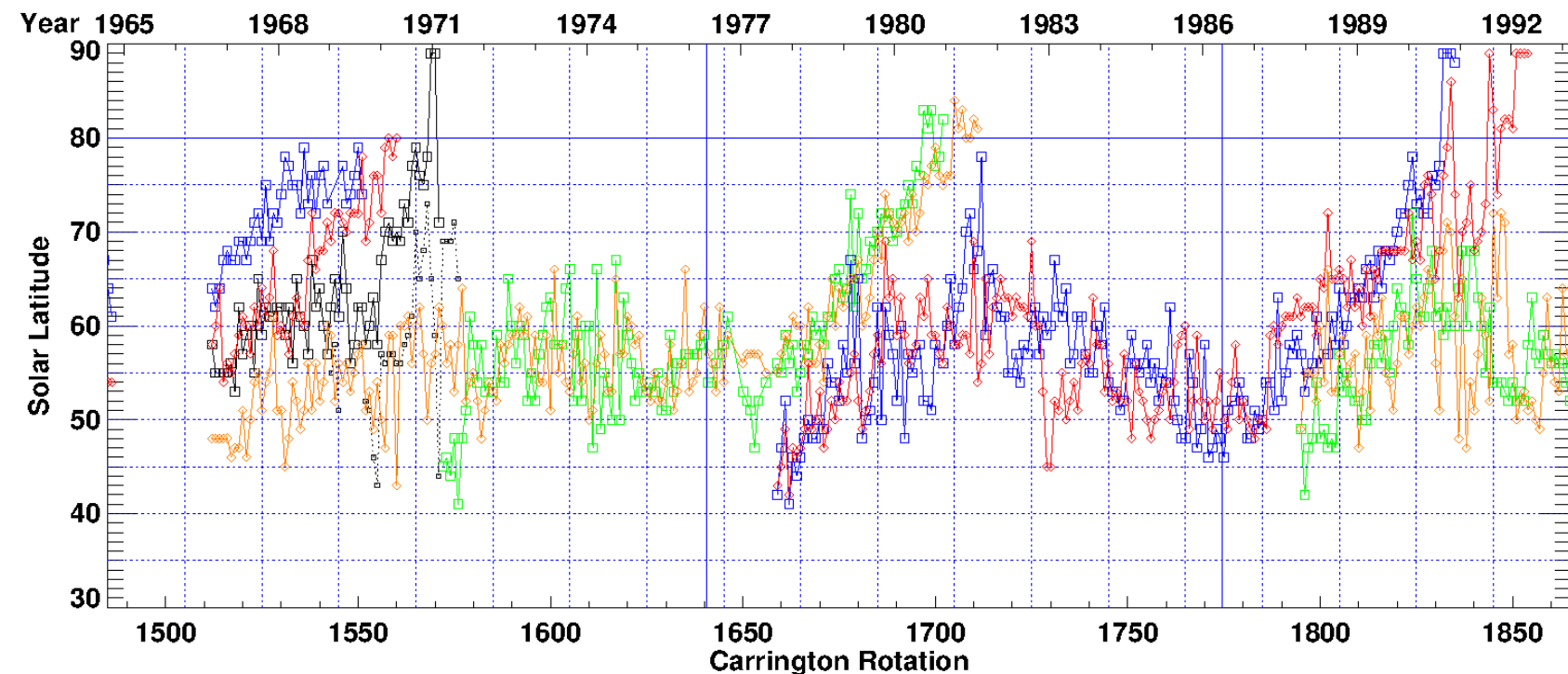
*Dashed pos line at 33SH, max at (-38,291).

- *Max poleward filaments are green diamonds in the NH and green stars in the SH.
- *The max poleward PIL is always the same or more poleward than these max filaments.
- *Max PIL-filament differences are green NH and blue SH lines where median diffs are 0-1° (2° SC19 SH). SC20-23 ave diffs are 1.2-1.3° while SC19 ave diffs are 3.7° SH and 4.4° NH.





The maximal poleward locations of the primary and secondary filaments are from Webb et al. (Front. Astron. Space Sci., 2018) and McIntosh (ESA SP-535, 2003, Fig in b/w).

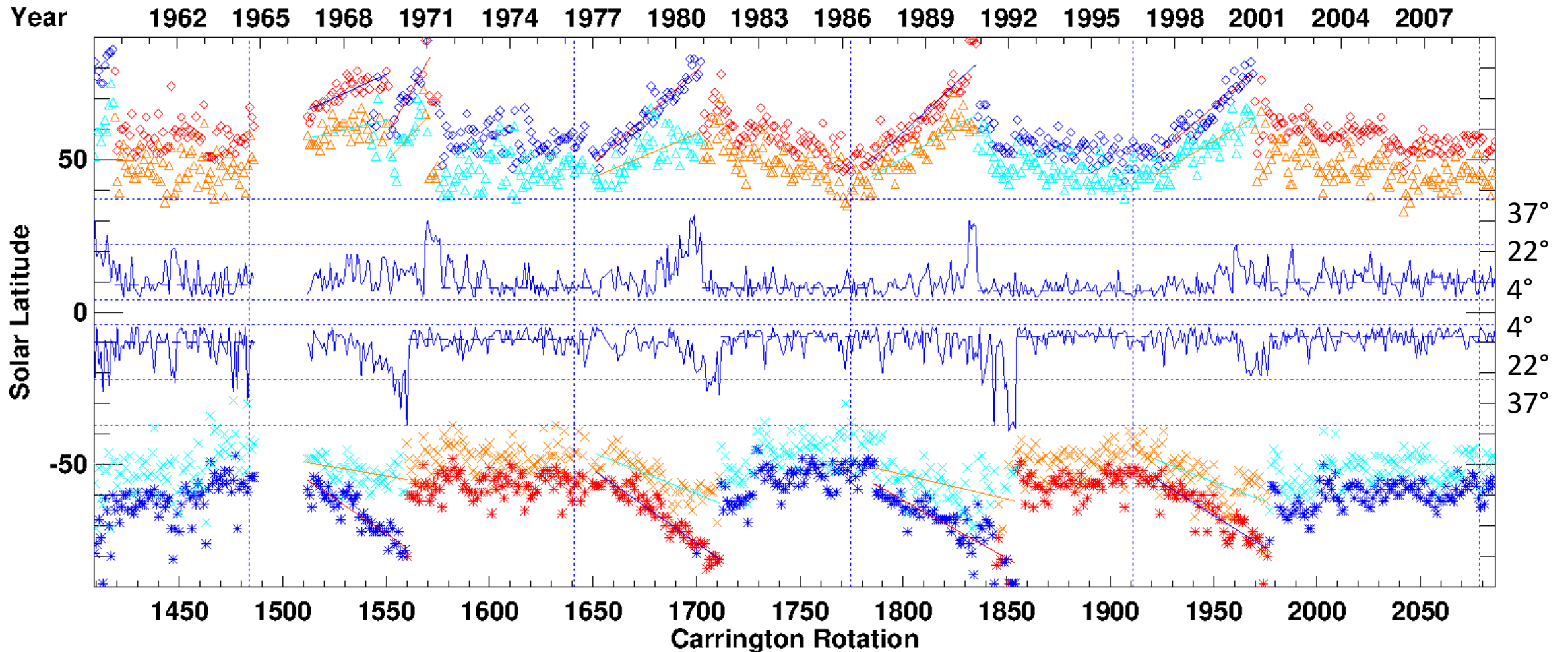


The 3 Rushes to the Poles in the NH of SC20 are shown in blue, black and dotted. Tertiary max are ~CR1544, 64.

*2003 max filaments: P-S ~15° start, ~18-20° end
 *max PILs: P-S ~5° start, ~18° end

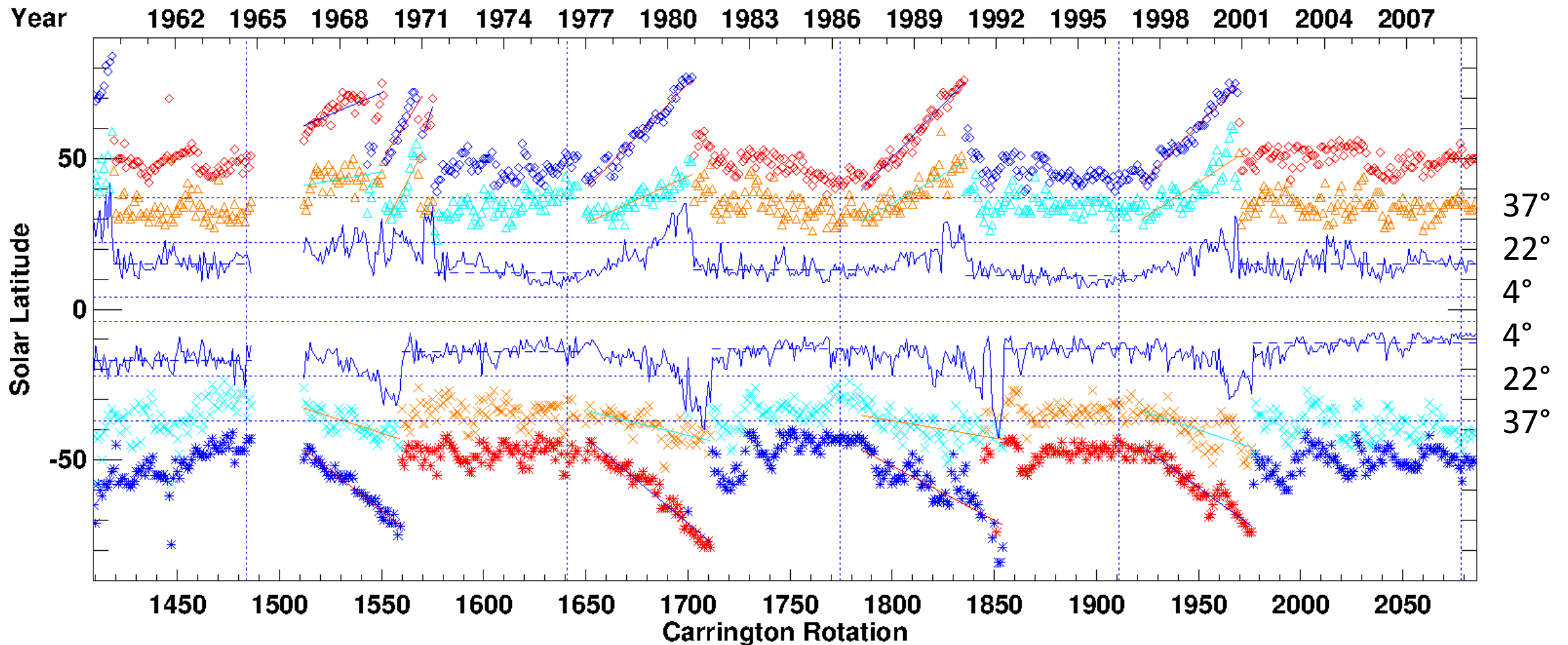
- *Red/orange are for negative polarity at 85NH or 87SH and dark blue/light are for positive.
- *Blue solid lines show P-S differences, which are $\sim 7-10^\circ$ in the descending and smin phases
- *Rush to the Pole (RttP) slopes are steeper for P than S since P-S differences increase from $\sim 5^\circ$ to $\sim 18^\circ$ from the start to the end of the rush. The rush starts 10CR past SILSO smin (vertical).

Maximum Polar Crown PIL Lines and Differences Between Primary and Secondary



- *P and S polar crown PIL median latitudes cleaner than the max PILs.
- *P-S blue line differences are $\sim 11^\circ$ at the start of the RttP, and $\sim 30^\circ$ before polarity reversal.
- *P-S differences in the descending and smin phases are dashed lines $\sim 11-16^\circ$.
- *See oscillations $\sim 20\text{CR}$ apart in the descending/smin portions especially.

Median Polar Crown PIL Lines and Differences Between Primary and Secondary



Averages of Maximum and Median PIL Fitted Slopes and Lats in the Rush to the Poles (RttP) for SC21-23

P=Prime=primary, S=Second=secondary,
max or med PILs

Hemisphere	Prime 1 st lat	Prime last lat	Lat/CR P slope	Second 1 st lat	Second last lat	Lat/CR S slope
Max NH	50	80	0.61	45	62	0.36
Max SH	54	80	0.43	49	62	0.23
Med NH	41	75	0.70	29	48	0.38
Med SH	45	74	0.48	34	44	0.17

(Except for the low med SH S slope)

*P slope ~ 1.8 S slope (~double)

*NH slope ~1.5 SH slope

*Med slopes > Max slopes

*max P-S ~5° at start, ~18° at end

*med P-S ~11-12° at start, ~27-30° at end

*Av start SH P and S lat ~4° poleward of NH

*P ~9°, S ~15° equatorward of max

*P ending lat ~same NH and SH

*med ~5 ° < max

*med SH S ending lat ~4° < NH (slow)

*med S ending lat ~16° < max

Averages of the Median Latitudes of Maximum and Median PILs from the Pole Reversal through Solar Minimum for 5 Solar Cycles (SC19-23)

Hemisphere	Max P	Max S	Max P-S		Med P	Med S	Med P-S
NH	56	47	8		48	34	13
SH	57	48	9		48	35	14

*SH ~ NH

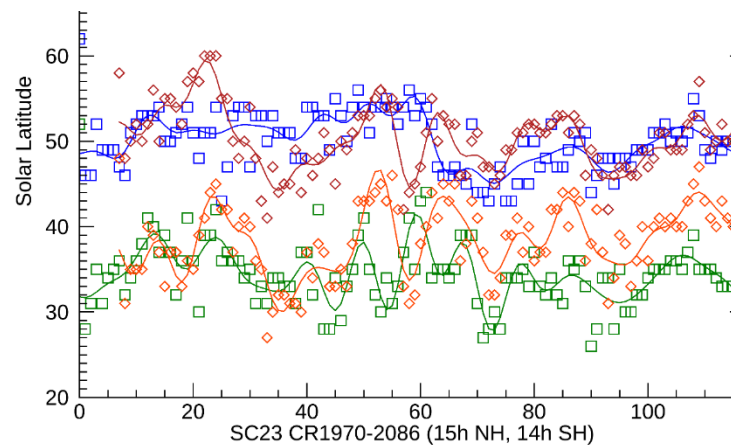
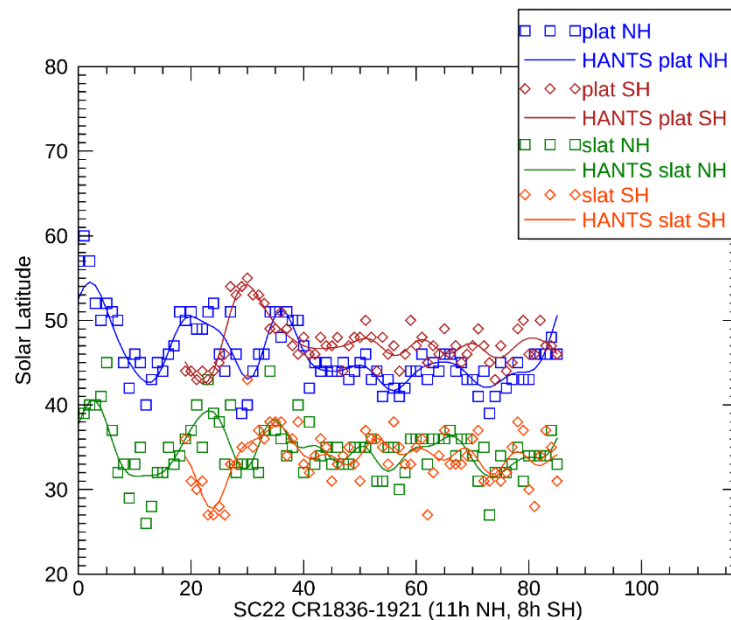
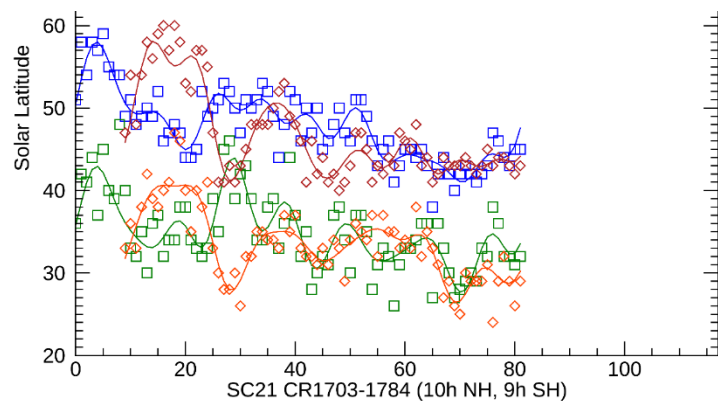
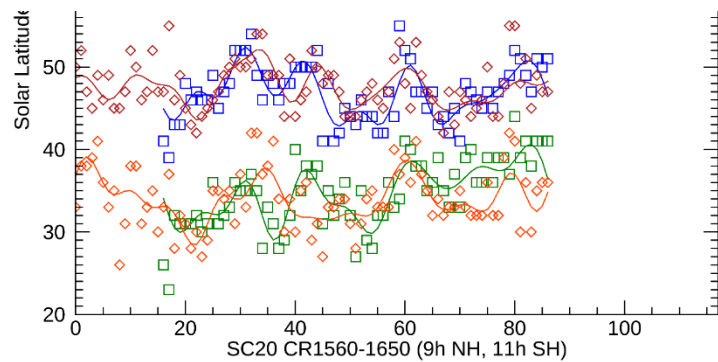
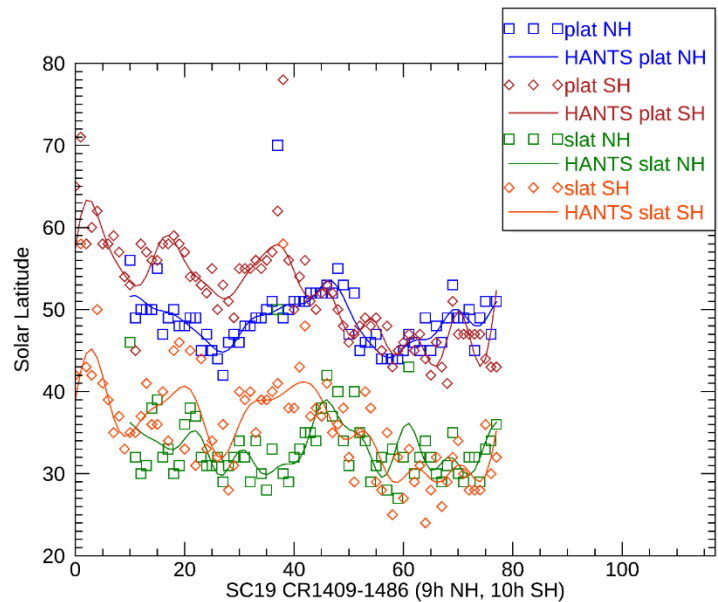
*max P-S ~9°

*med P-S ~13°

*med P ~9° < max

*med S ~13° < max

FFT harmonic analysis (≥ 8 CR) of descending and solar minimum regions.

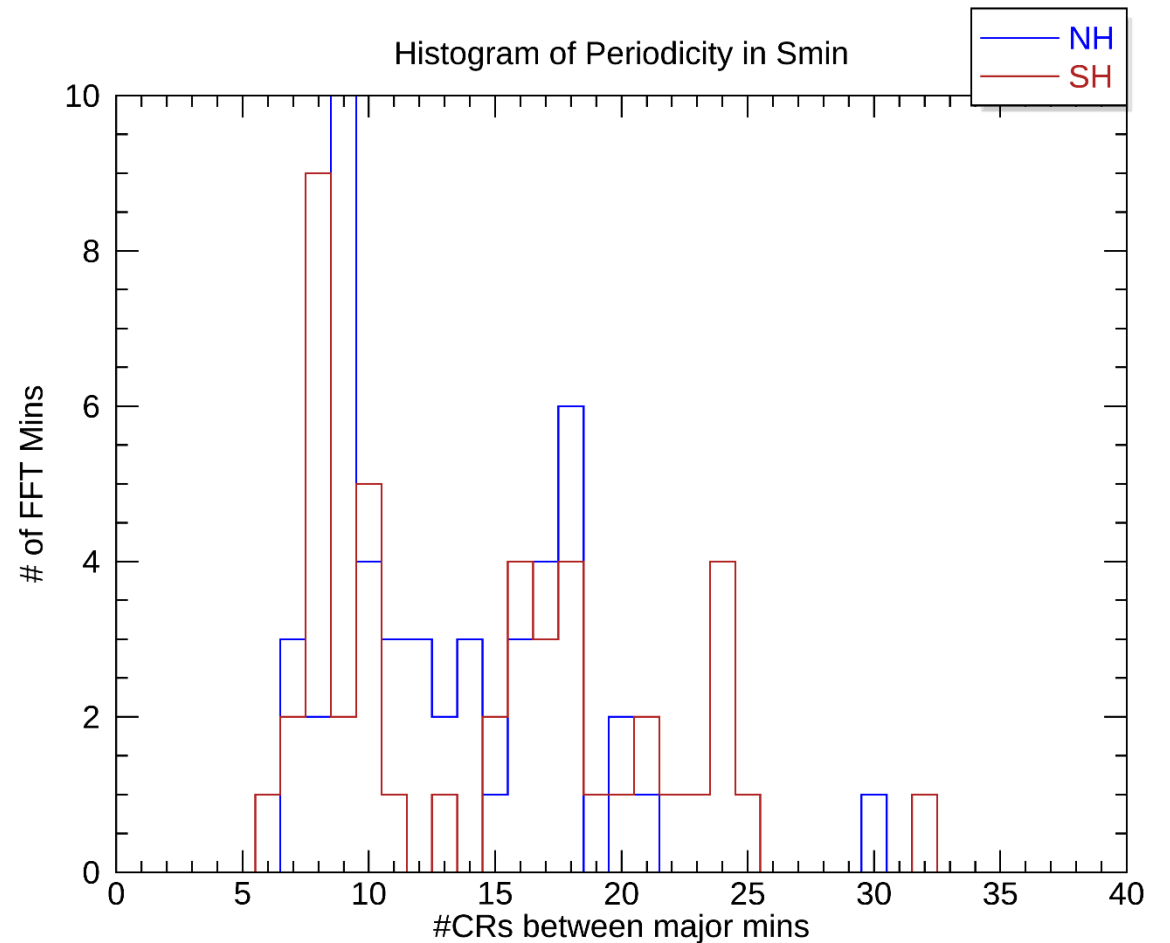
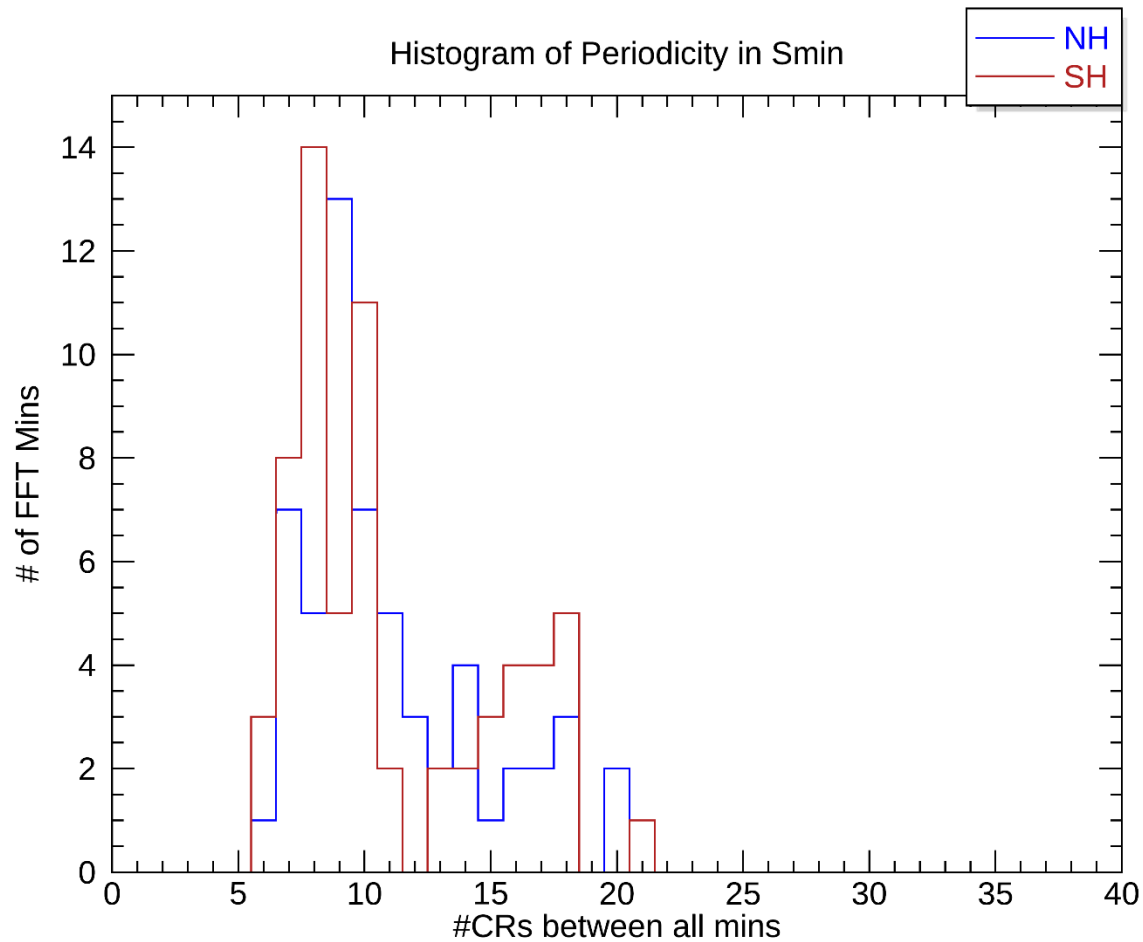


- SH (red/orange) has been moved over NH (blue, green).
- Primary and secondaries are in phase for NH and SH.
- Hemispheres can be in phase (SC20) or out-of phase (start of SC21 and SC22).
- Locations decrease over time for SH SC19, NH and SH SC21.
- Increase over time for secondaries NH SC20 and SH SC23.
- Periods 10-20CR.

Periodicities in Locations of PILs in Smin for All Mins and for Major Mins

Median ~ 10 CR for SH and NH; or bimodal:
 ~ 8 CR SH and ~ 9 CR NH (<13 CR), ~ 16 CR (>12 CR)

2 Populations: ~ 8 CR SH and ~ 9 CR NH;
 ~ 17 CR NH and ~ 18 CR SH



Conclusions

Rush to the Poles (RttP) SC21-23, 3 Solar Cycles:

- 1) The primary PIL line Rushes to the Pole about twice as fast as the secondary for both median PILs (P-S $\sim 11^\circ$ to $\sim 28^\circ$) and maximum location PILs (P-S $\sim 5^\circ$ to $\sim 18^\circ$). The McIntosh (2003) maximum filament locations had P-S $\sim 15^\circ$ to $\sim 18-20^\circ$.
- 2) The NH slope is steeper in a shorter time period, starting $\sim 4^\circ$ more equatorwards than the SH and ending about the same latitude as the SH.

Solar Minimum SC19-23, 5 Solar Cycles:

- 1) The median P-S PIL locations are approximately 13° apart in solar minimum and the P and S lines usually track each other. PIL lines can trend polewards or equatorwards.
- 2) There is a periodicity in the latitude of the primary and secondary median PIL lines, especially in solar minimum periods, which is about every 8-9 or 16-18 CRs, where the NH and SH can be in phase or out of phase.

Summary: Both of these new results, on the evolution of PILs in smin and RttP and their periodicities, are indicative of the deep-seated dynamo process, which modelers need to address.