Insights into the solar cycle from global helioseismology

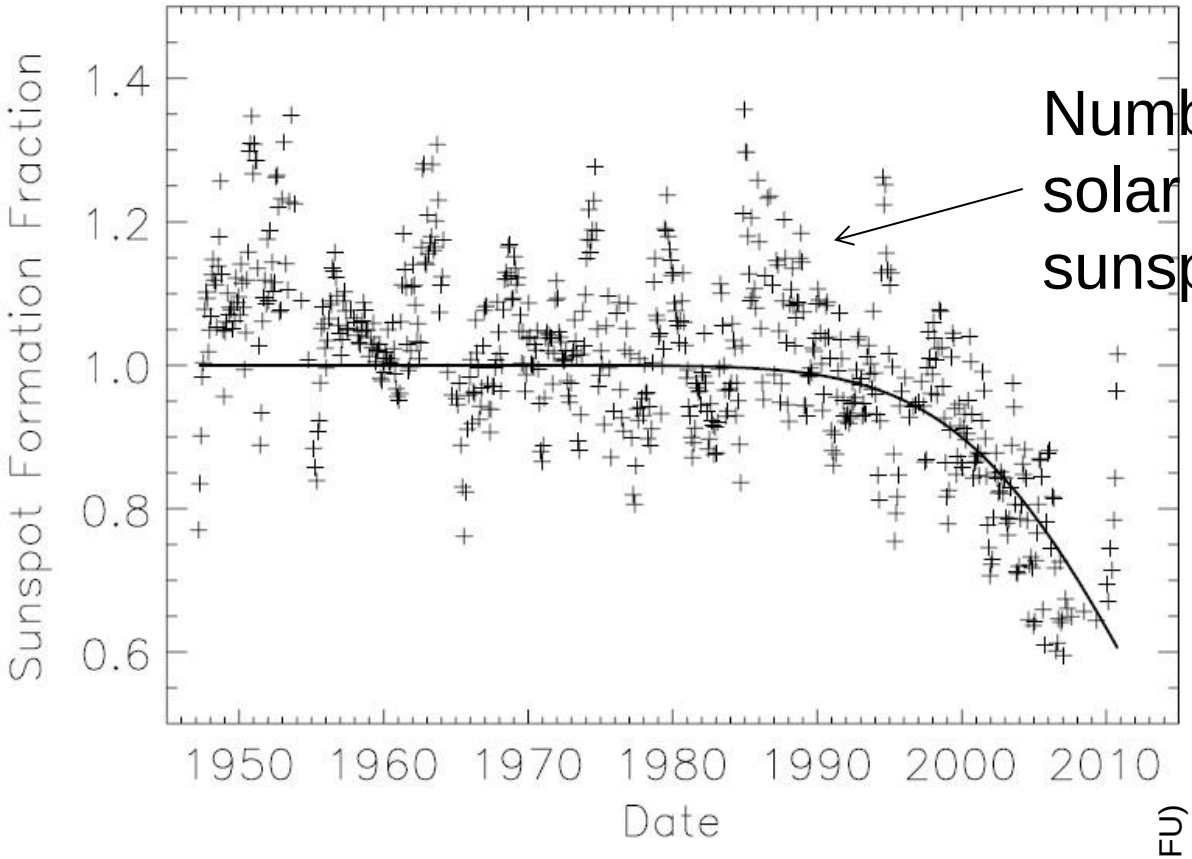
Anne-Marie Broomhall

Global Research Fellow
Institute of Advanced Study, University of Warwick
Centre for Fusion, Space, and Astrophysics, University of Warwick

Outline

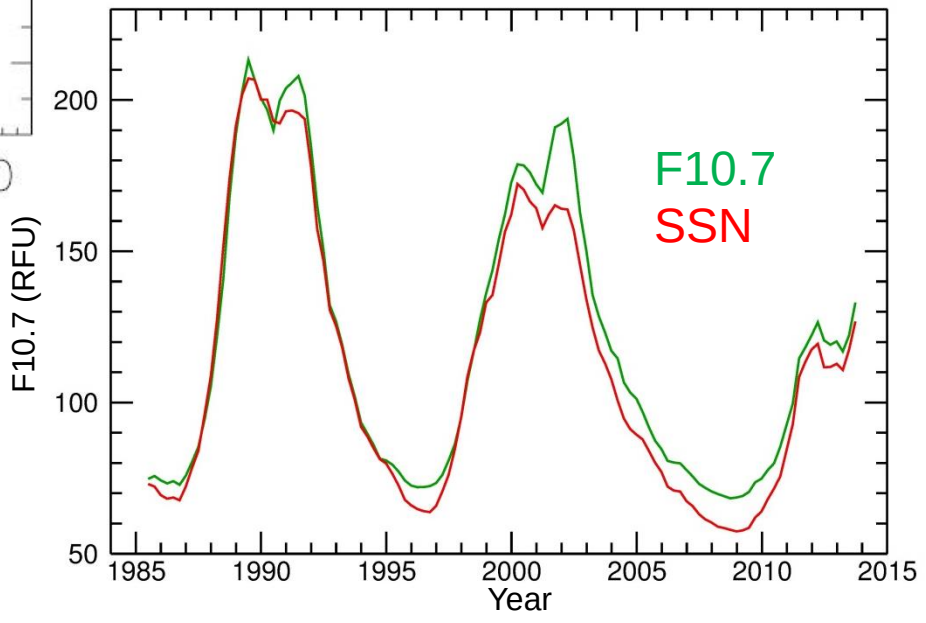
- The work of Livingston and Penn has led to comparisons of global proxies of solar activity.
  - Magnetic fields in sunspots have weakened.
  - 10.7cm radio flux and SSN are diverging.
- Properties of the p modes are proxies of the solar activity.
  - Frequencies
  - Lifetimes
  - Powers.
- Energy supply rate.

Comparison of F10.7 and SSN



Number of sunspots seen on the solar surface divided by number of sunspots predicted by 10.7cm flux.

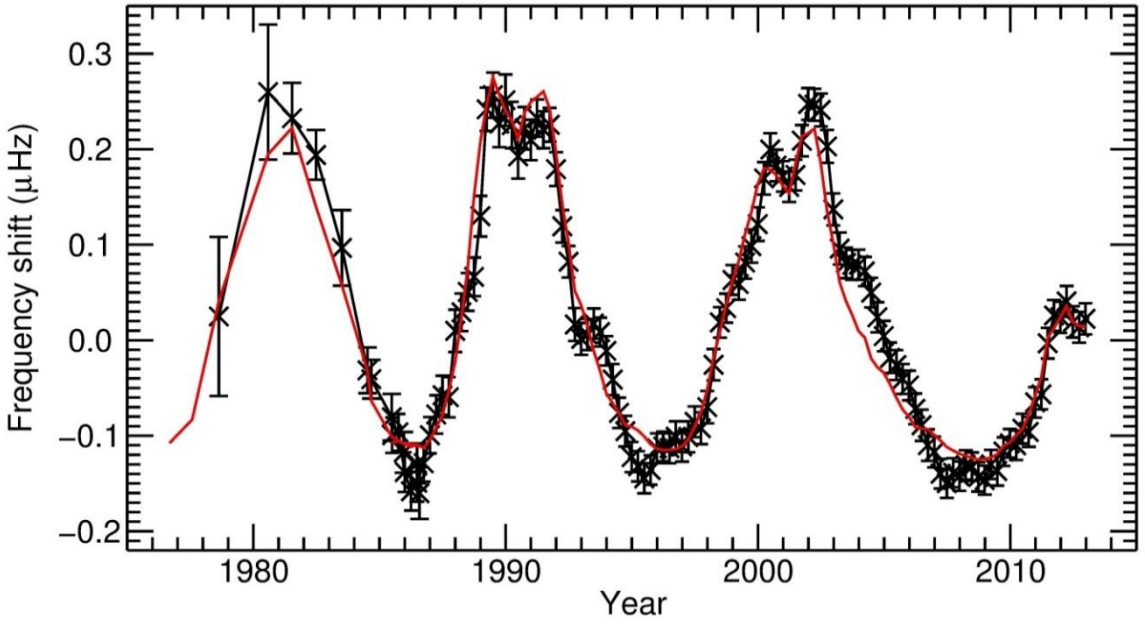
Livingston, Penn, & Svalgaard, 2012



Seismic frequencies and the solar cycle

- Seismic frequencies respond to changes in the surface activity (Woodard & Noyes ,1985).
- Using Birmingham Solar Oscillations Network data.
  - 365d data, overlapping by 91.25d, include l=0,1,2, $2400 \leq \nu \leq 3400 \mu Hz$.

Scaled 10.7cm flux = predicted frequency shift

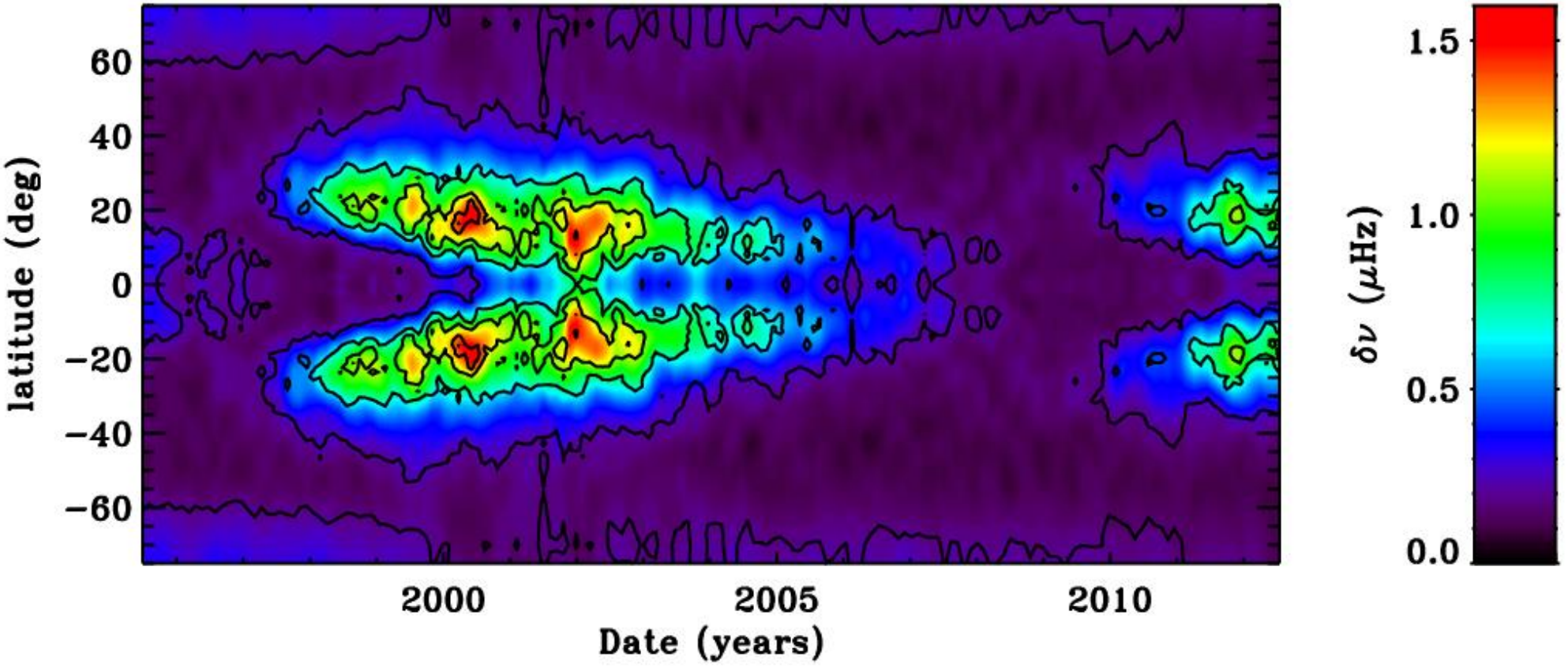


shift ≈ 0.01% of mode frequency

Shift of ≈ 0.03μHz G^{-1}

Frequency shift inversions

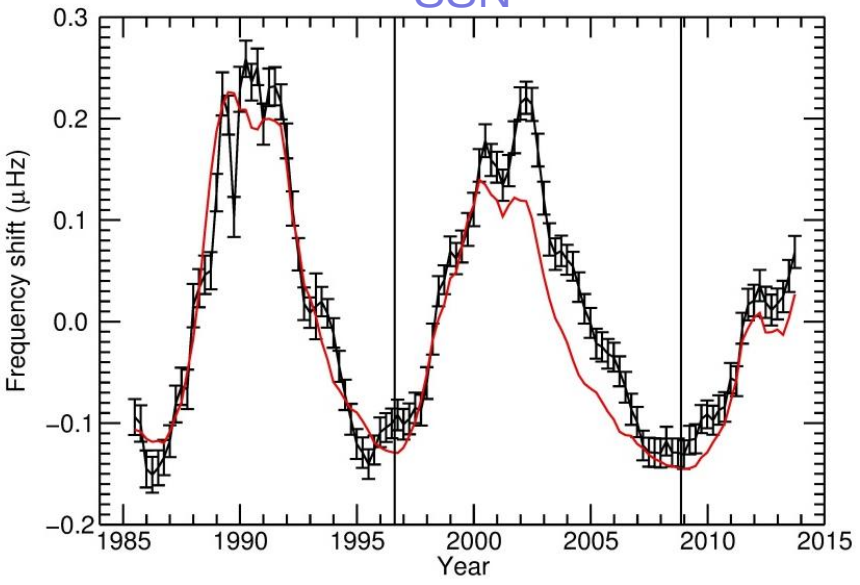
- Howe et al. (2002) localized the frequency shifts in latitude.



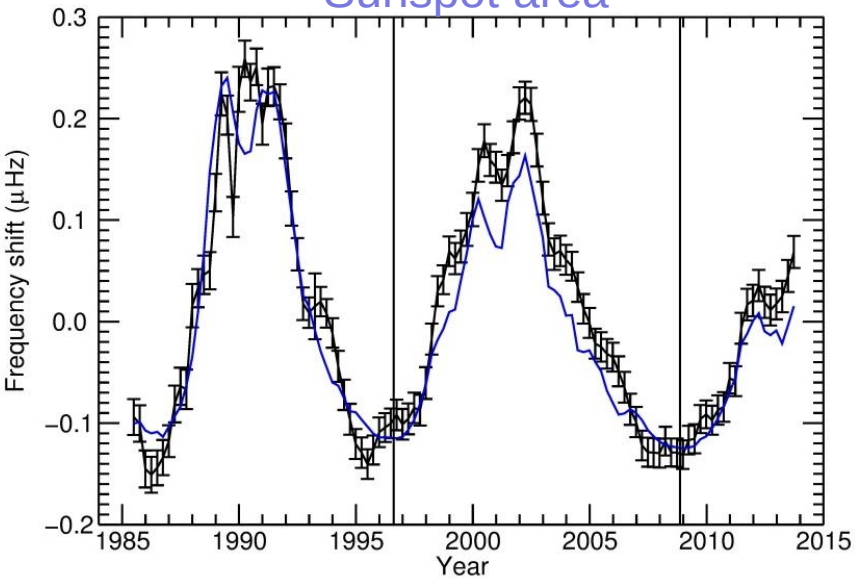
Courtesy of Rachel Howe

Comparisons with global proxies

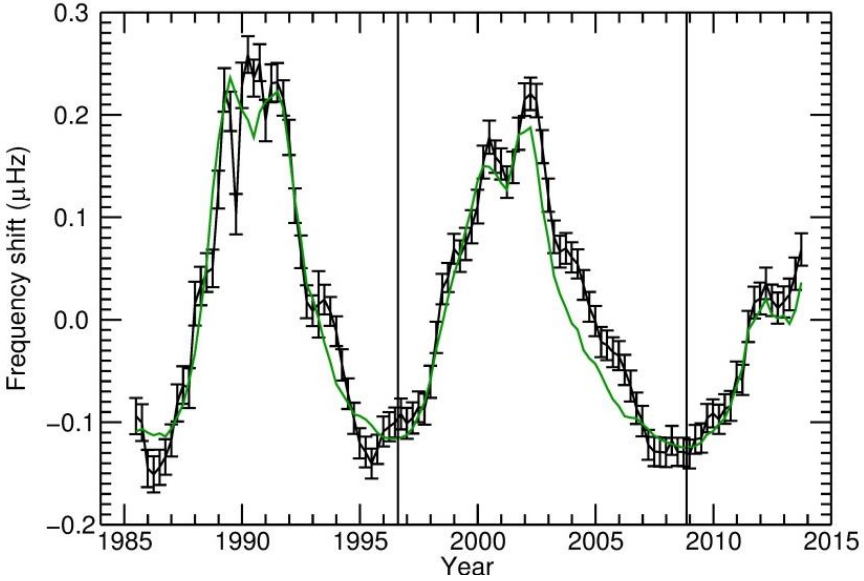
SSN



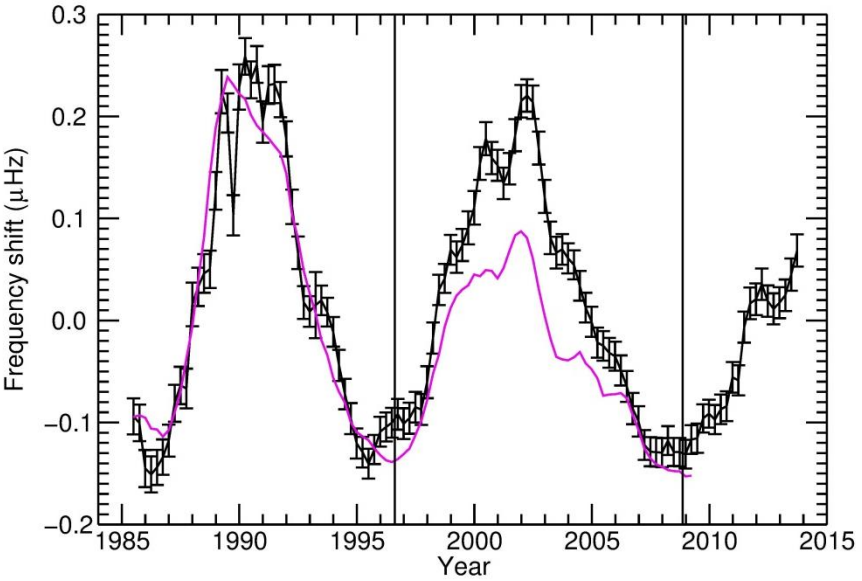
Sunspot area



F10.7

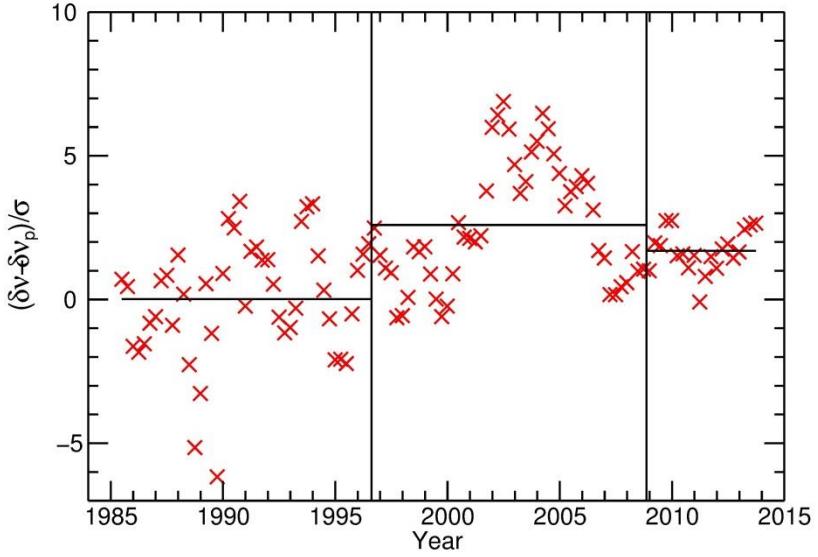


Coronal index

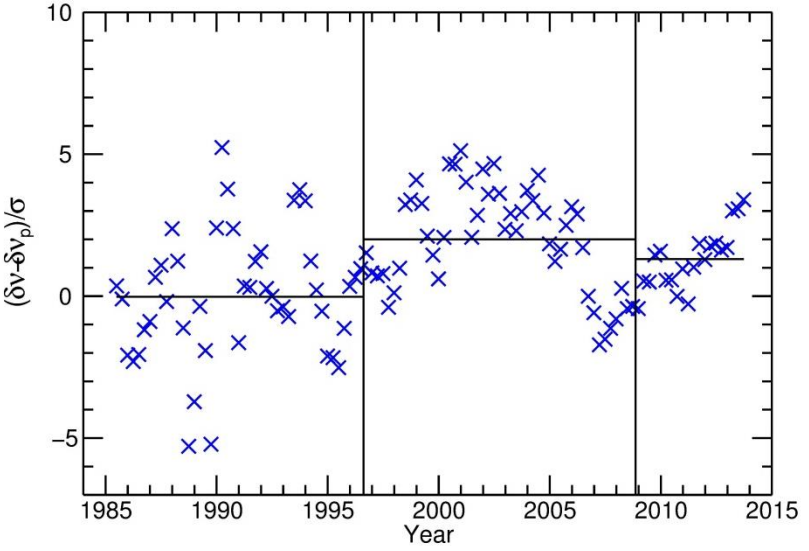


Difference with seismic frequencies

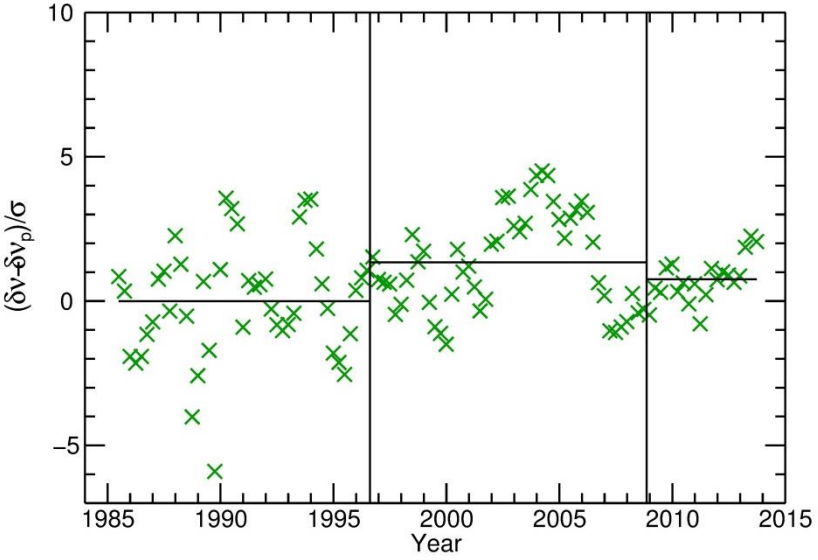
SSN



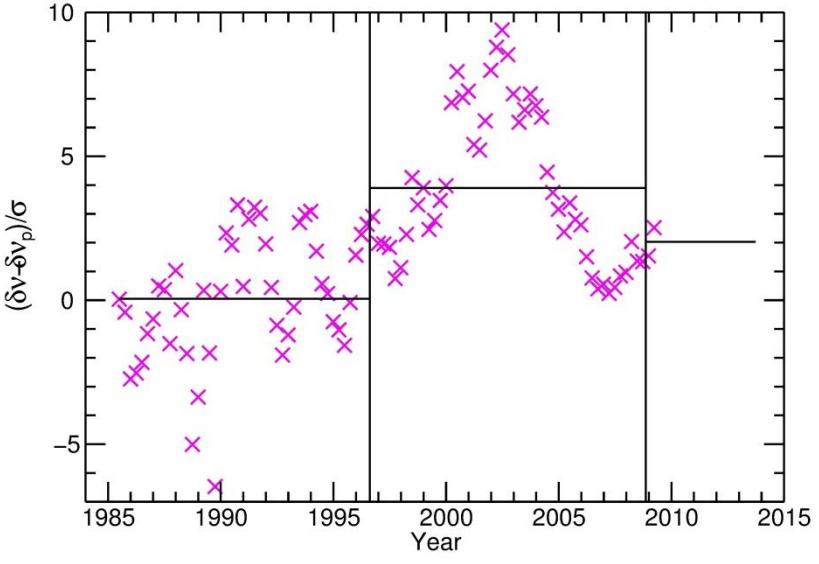
Sunspot area



F10.7

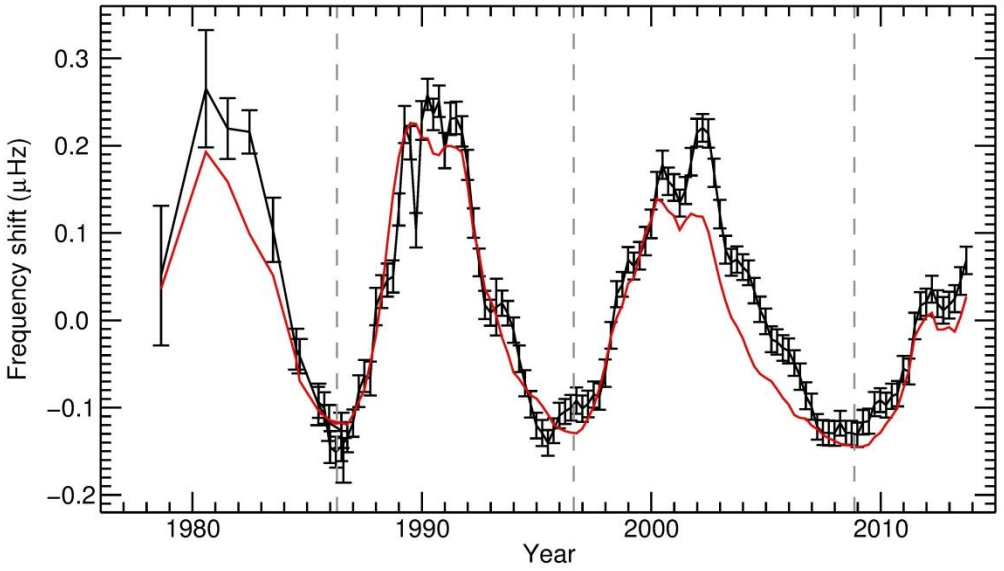


Coronal index

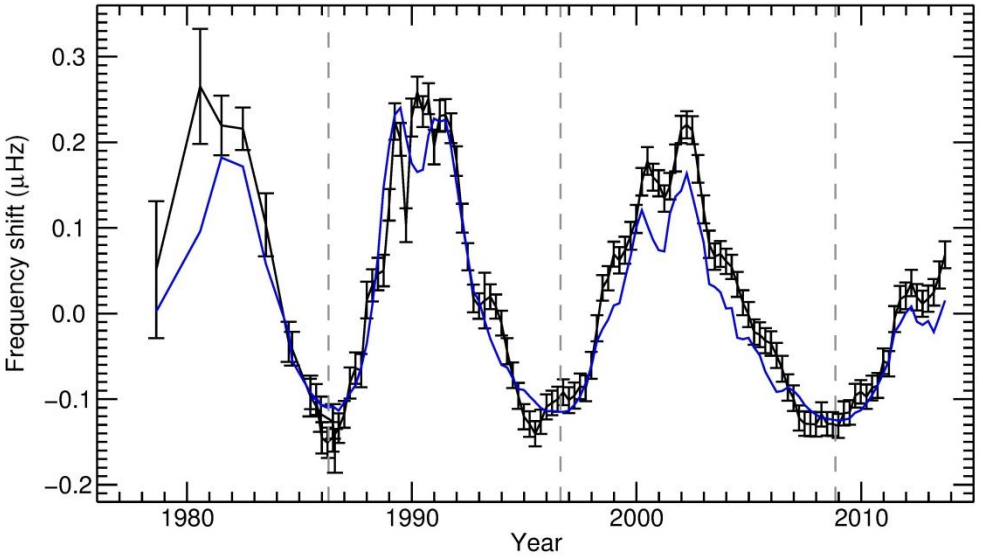


What about cycle 21?

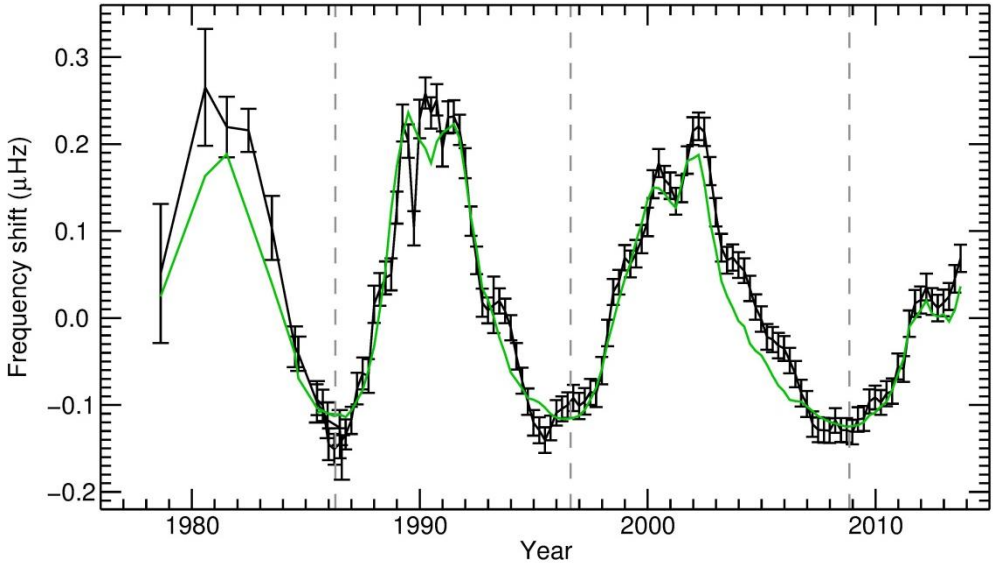
SSN



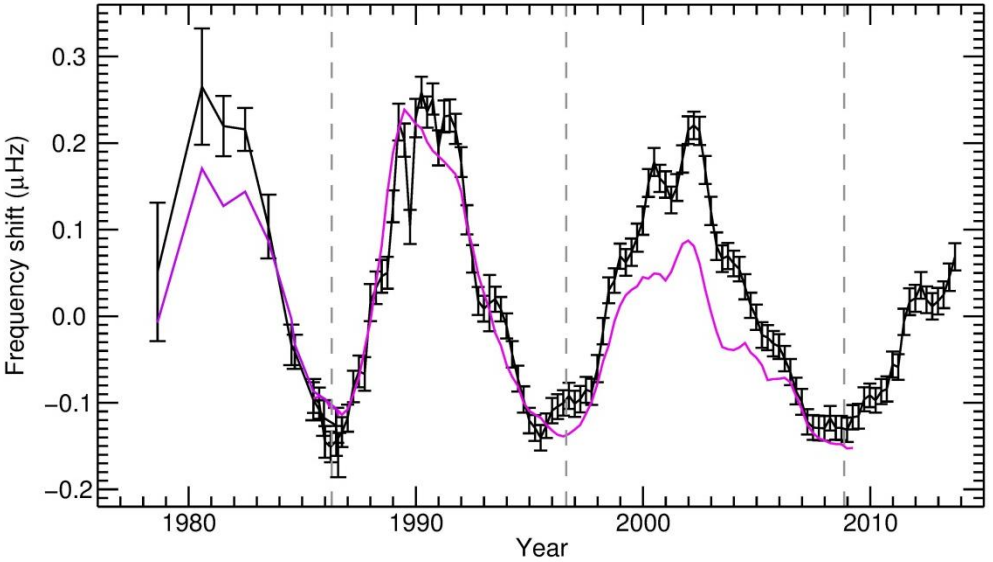
Sunspot area



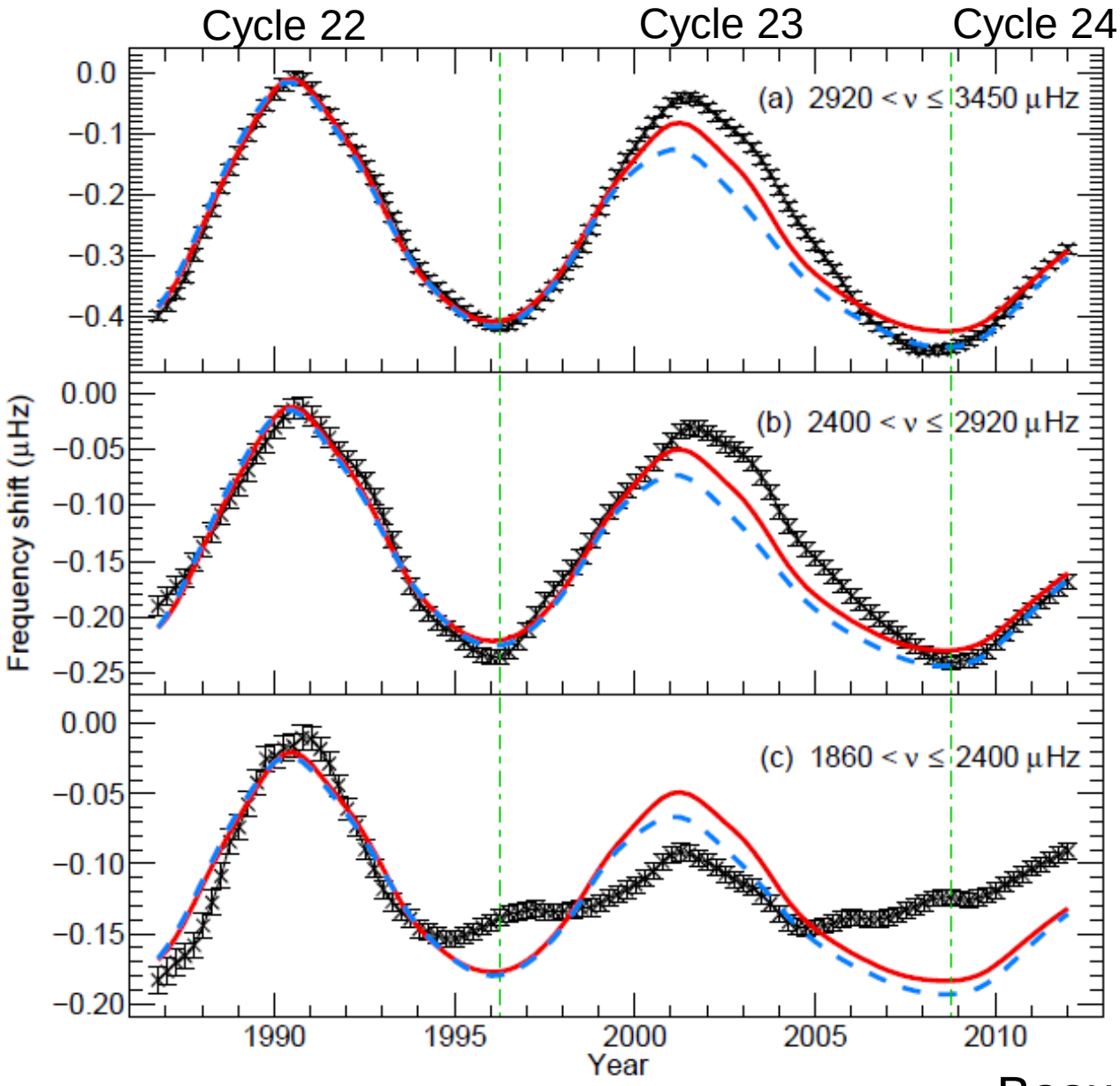
F10.7



Coronal index



The unusual solar cycle – smoothed



Black=average frequency shift

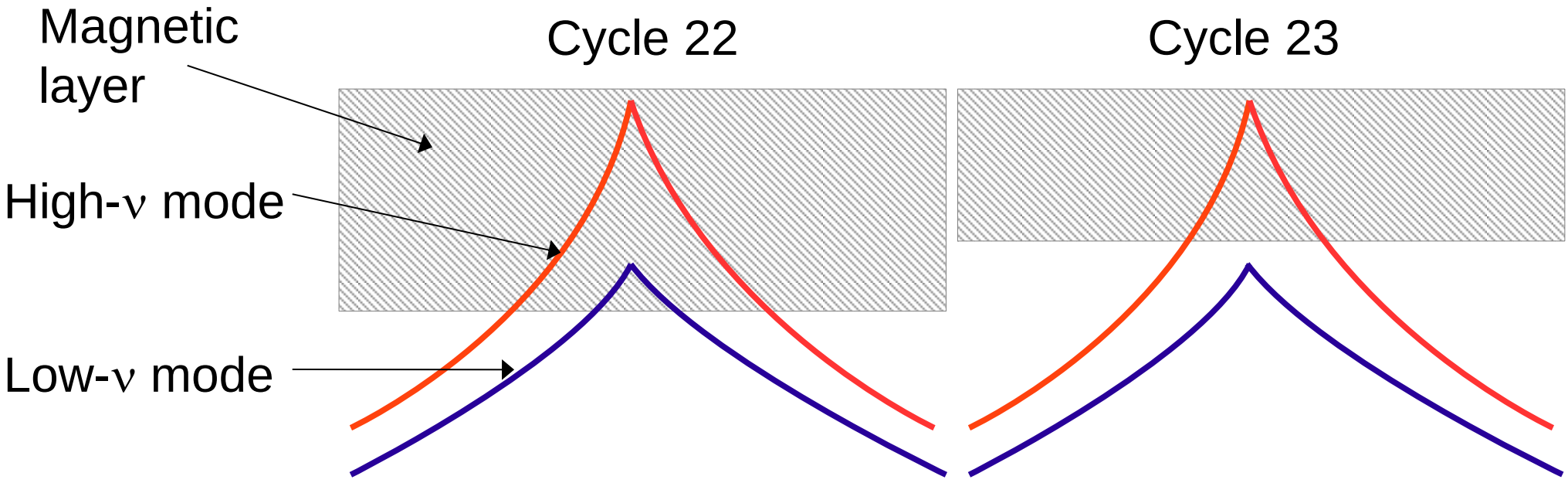
Red=10.7cm flux

Blue=ISN

Basu et al. (2012)

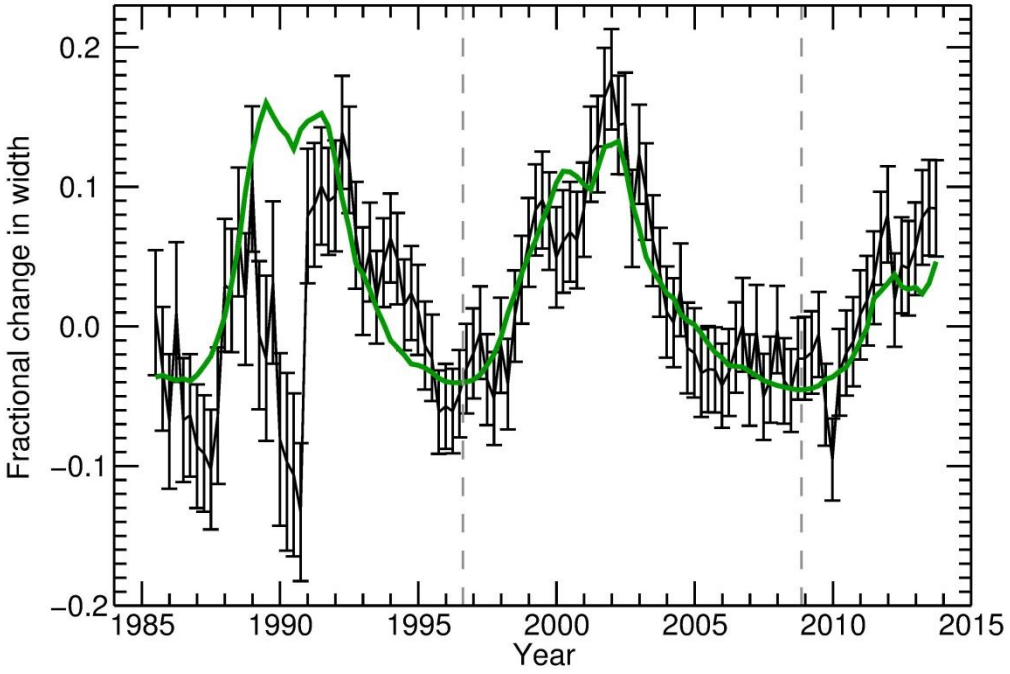
Changes in the magnetic layer

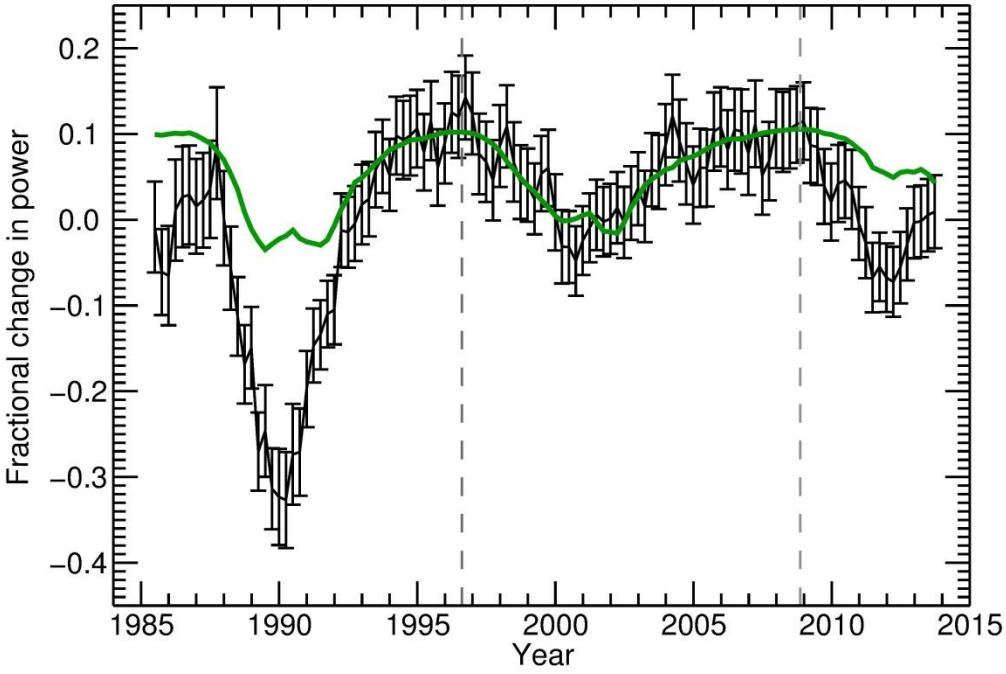
- The upper turning point of the low-ν modes are beneath the magnetic layer in cycle 23
- The changes must occur above $0.9965R_{\odot}$.



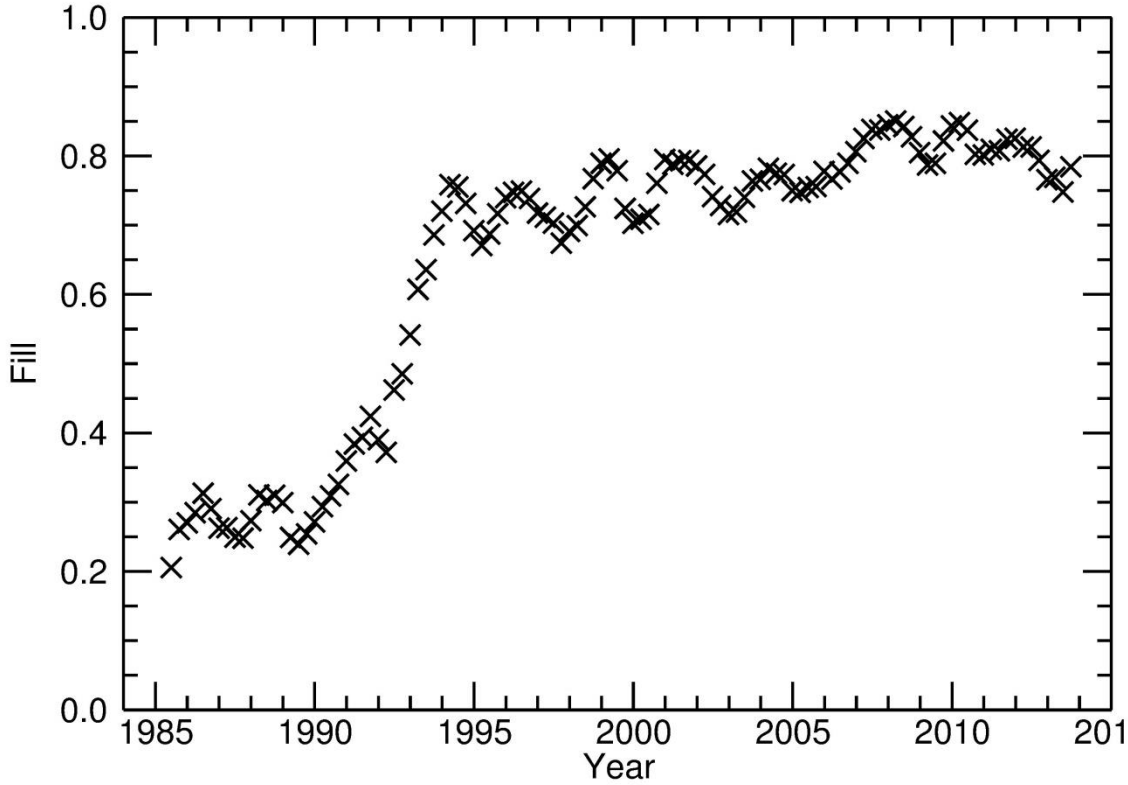
Mode damping rates and powers

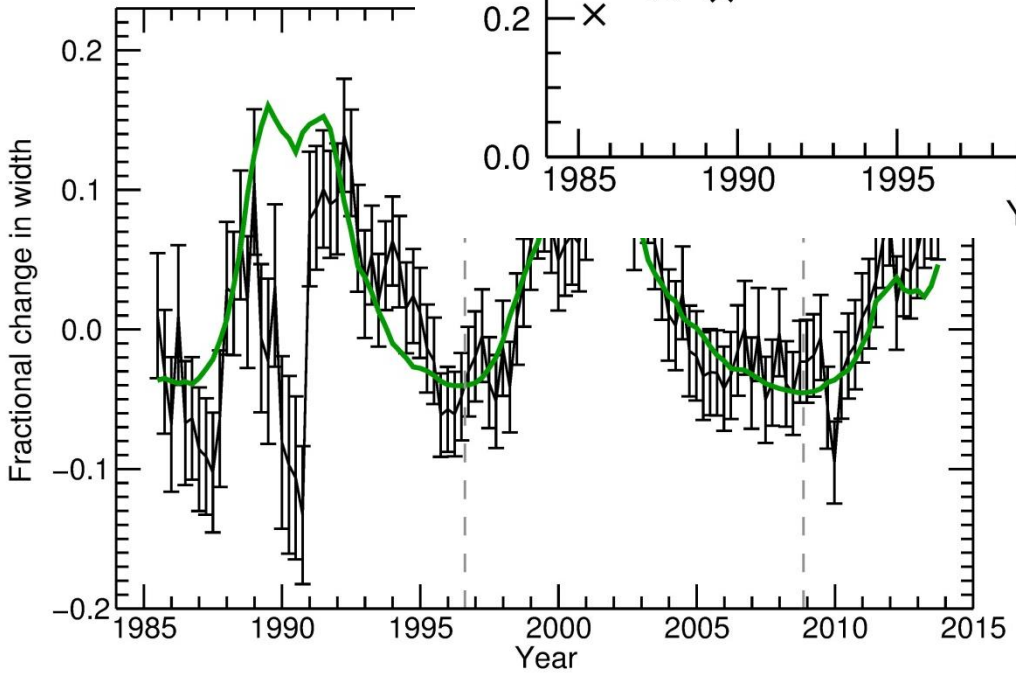
- From cycle minimum to maximum
  - Damping rates increase.
  - Mode powers decrease.

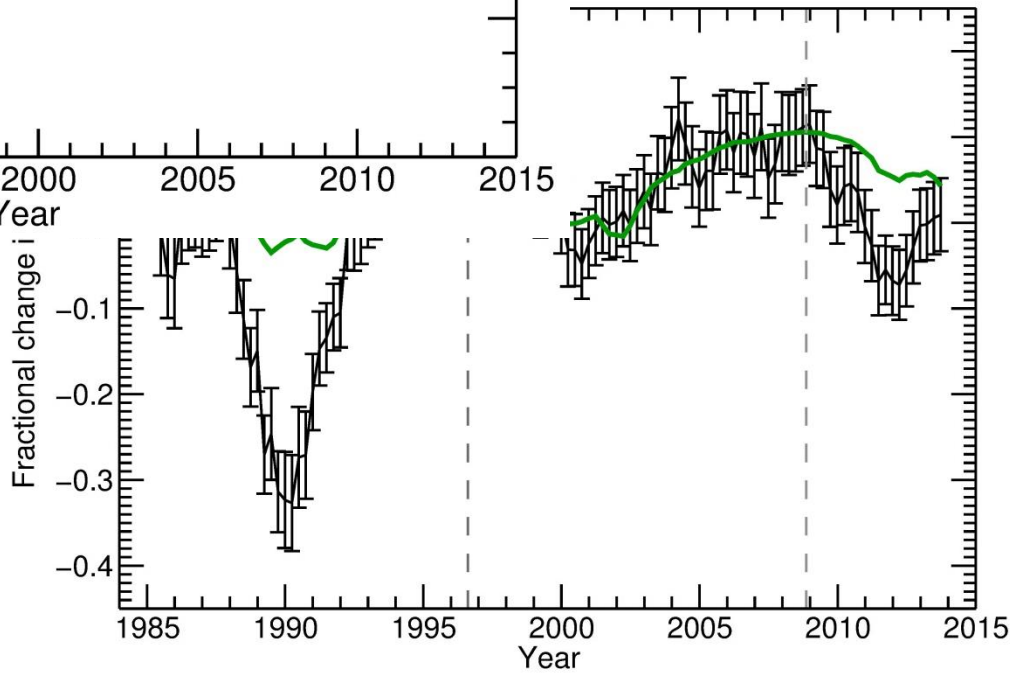




Fill?

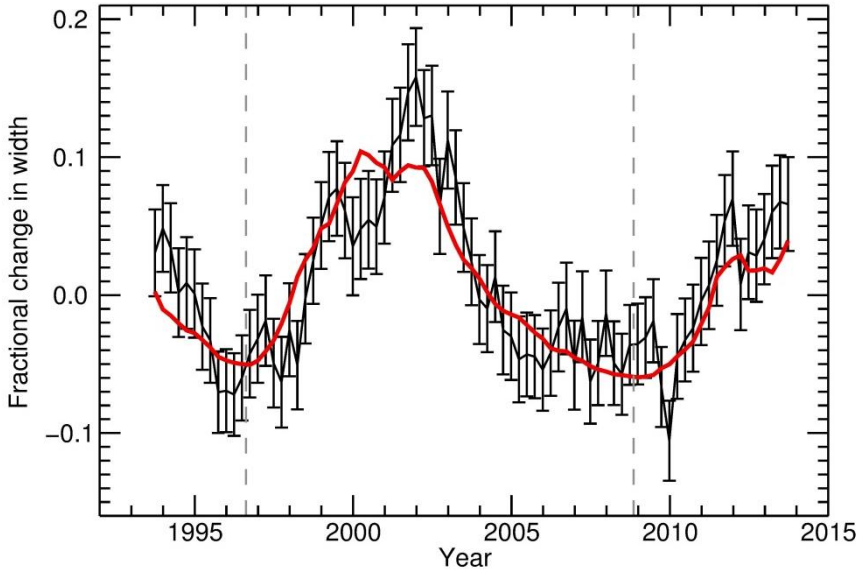

Fill
Year
1.0
0.8
0.6
0.4
0.2
0.0
1985
1990
1995
2000
2005
2010
2015


Fractional change in width
Year
0.2
0.1
0.0
−0.1
−0.2
1985
1990
1995
2000
2005
2010
2015

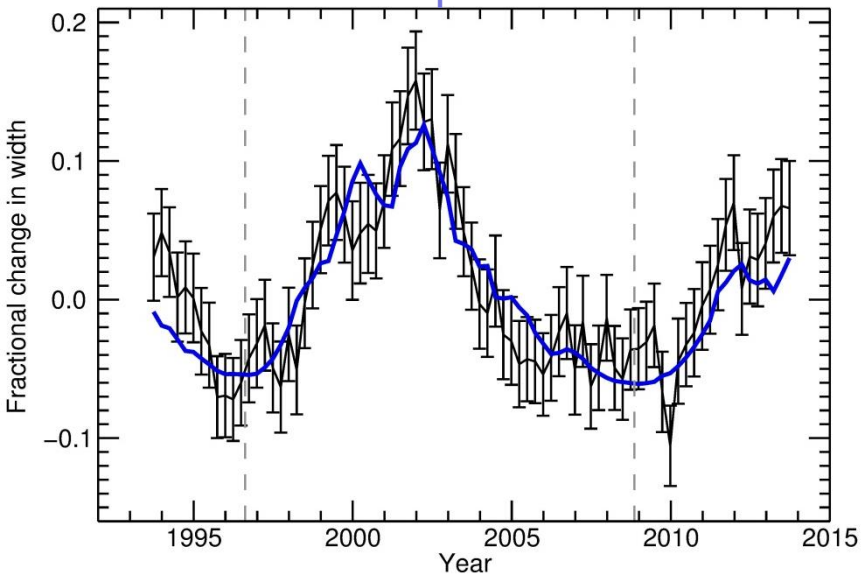

Fractional change i
Year
−0.1
−0.2
−0.3
−0.4
1985
1990
1995
2000
2005
2010
2015

Variations in damping rates

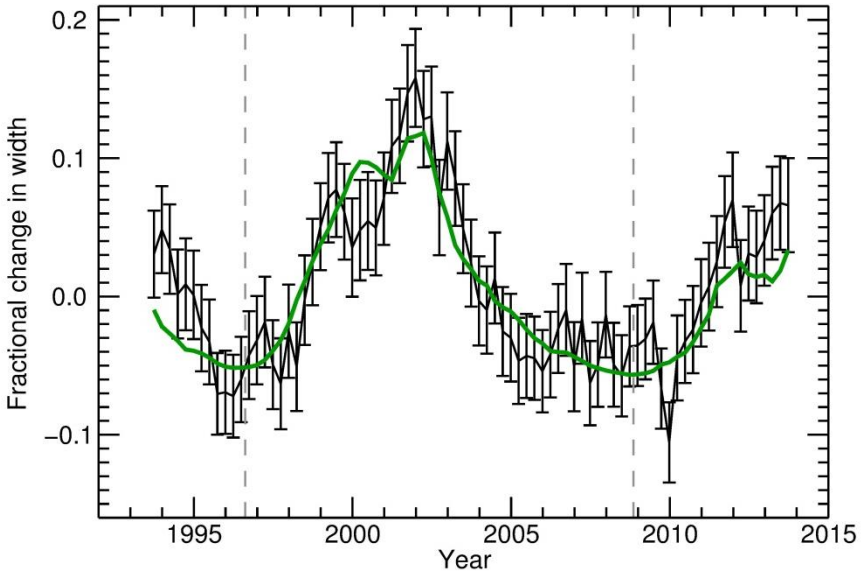
SSN



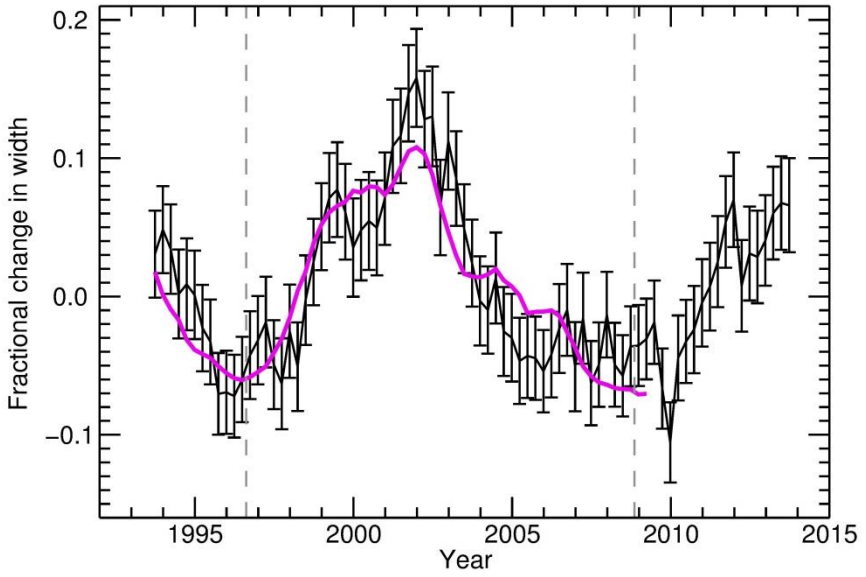
Sunspot area



F10.7

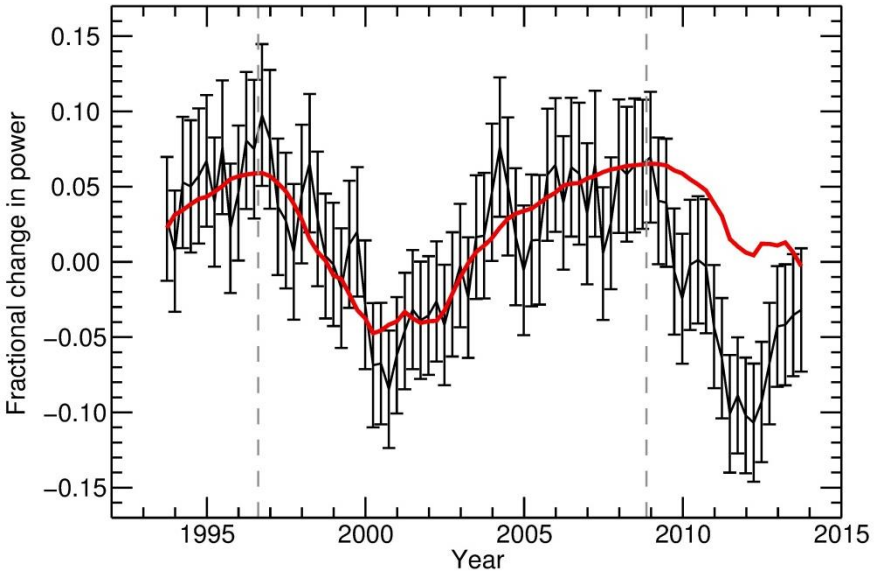


Coronal index

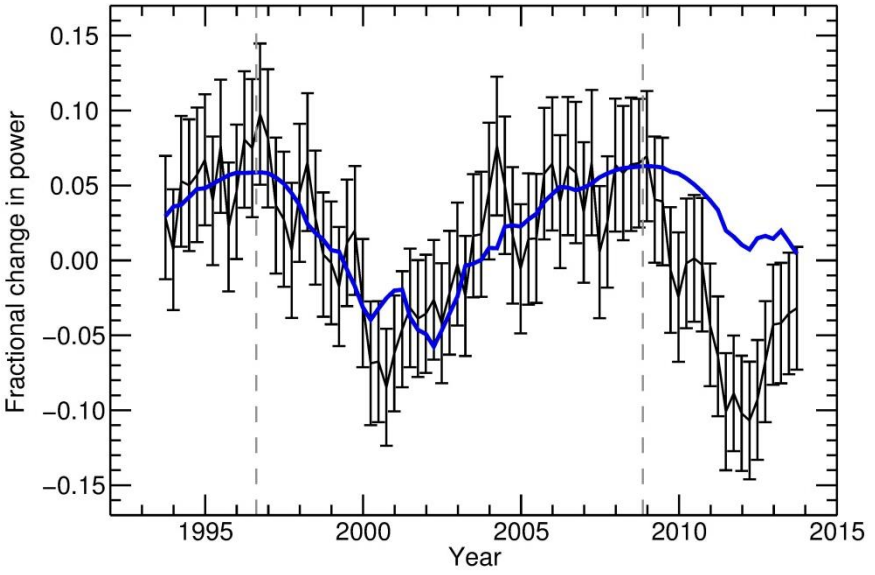


Variations in powers

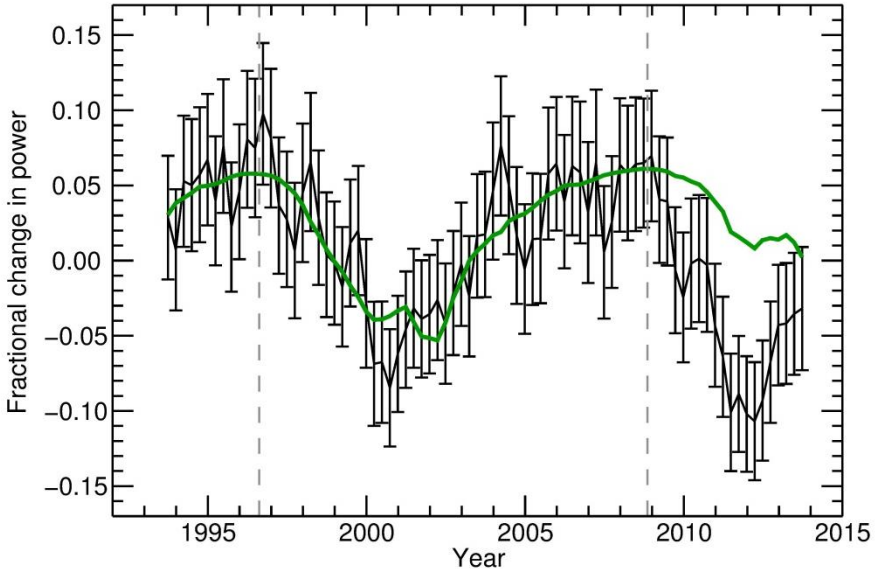
SSN



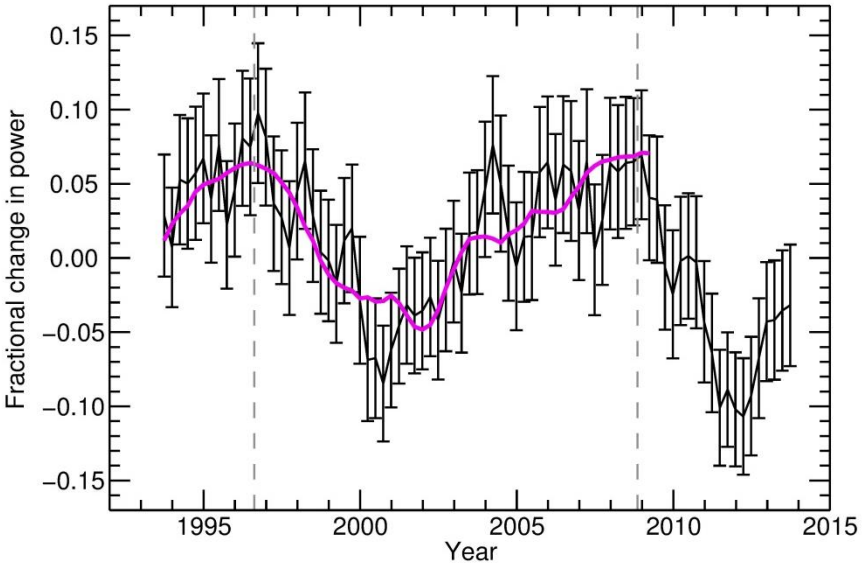
Sunspot area



F10.7

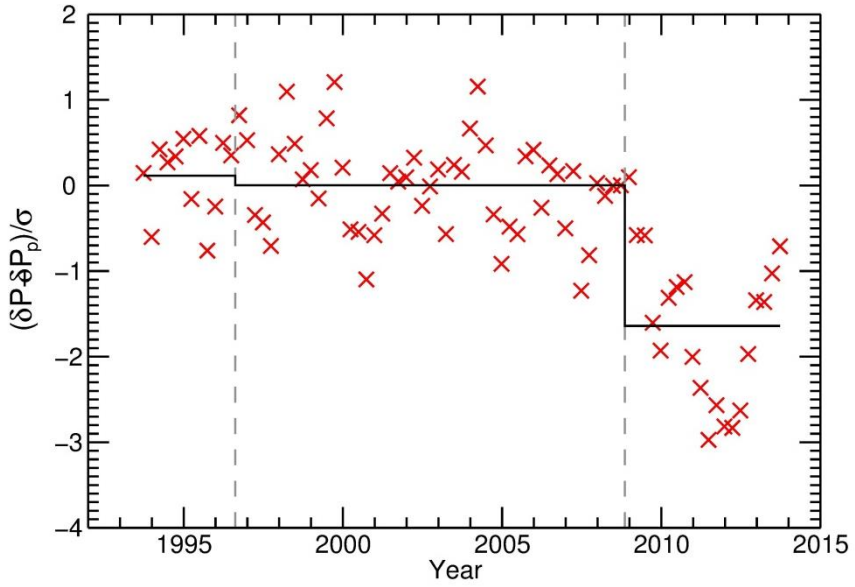


Coronal index

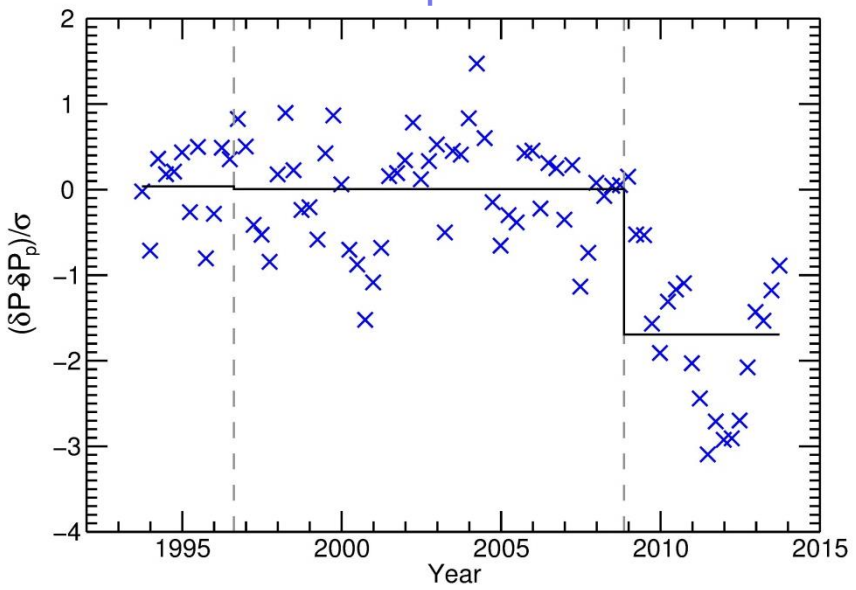


Significant departures?

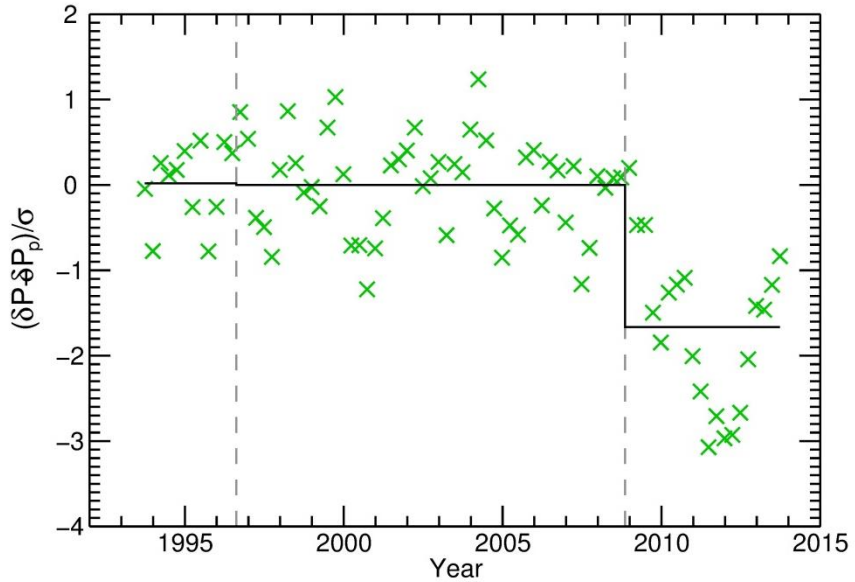
SSN



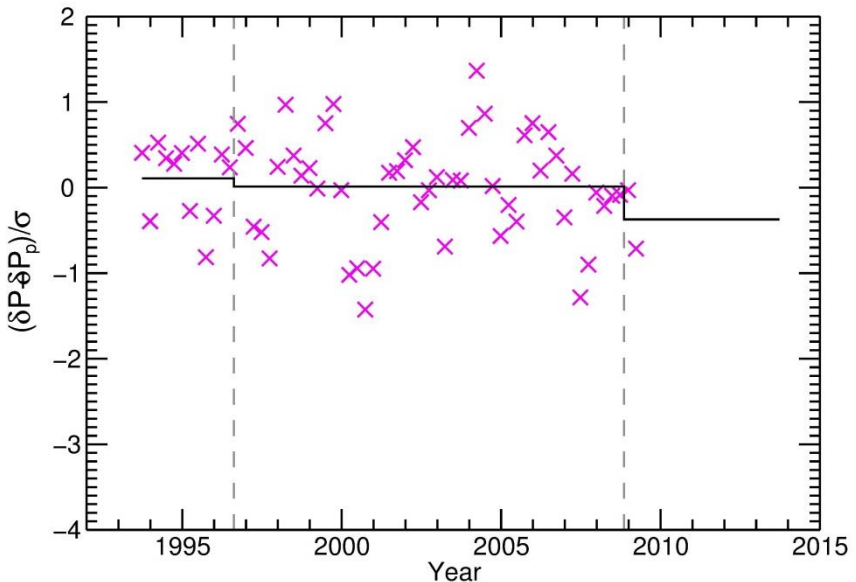
Sunspot area



F10.7

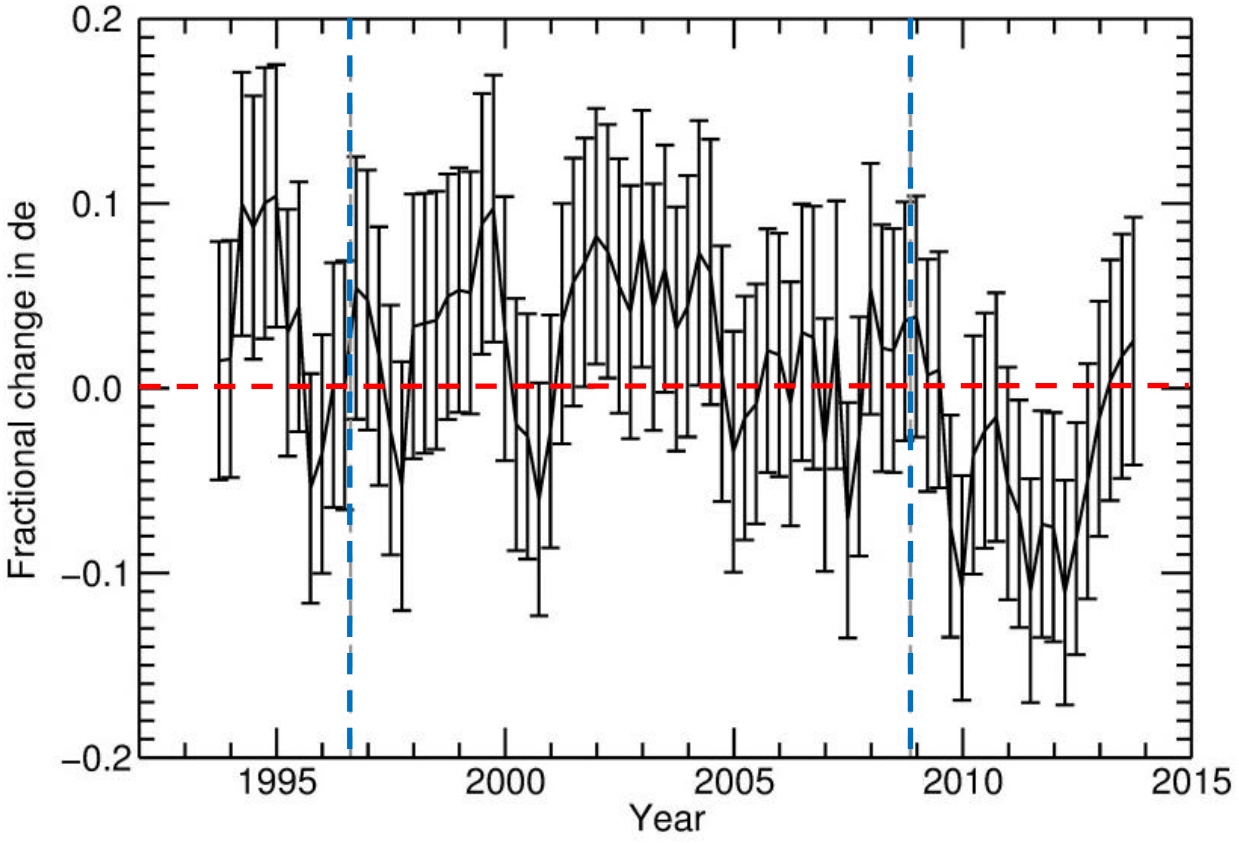


Coronal index



Energy supply rate

- Mode energy=power $\times$ mode mass.
- Energy supply rate $\propto$ energy $\times$ width.



Differences in proxies

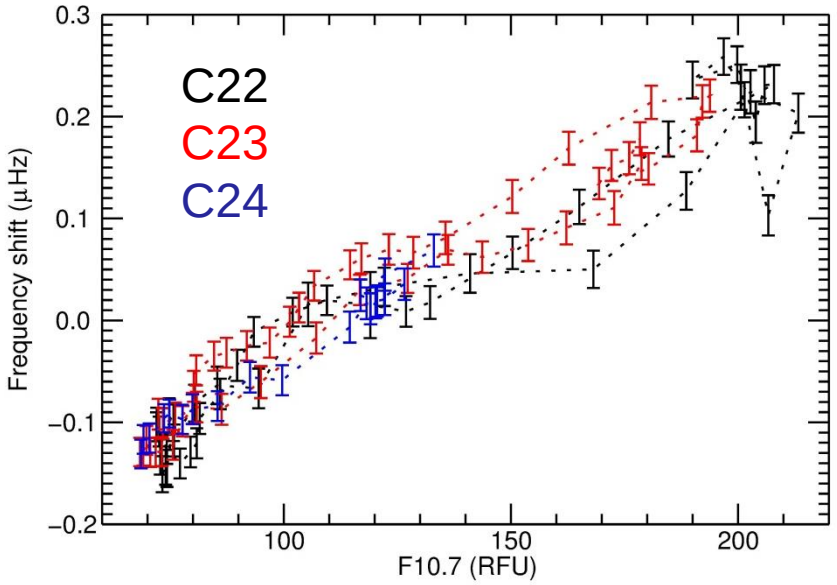
- Livingston, Penn, Svalgaard (2012): average magnetic field of sunspots has decreased.
  - Sunspots can only form if magnetic field strength exceeds 1500G $\rightarrow$ magnetic field that reaches surface but cannot form spots.
- Clette & Lefevre (2012): small spot deficit.
  - Could be explained by decrease in average magnetic field of sunspots.
  - SSN gives equal weighting to all sunspots.
  - Sunspot area: dominated by largest active regions.
  - 10.7cm flux: dominated by largest active regions and chromospheric excess from additional plages and faculae.
  - CI: additional effect from low latitude coronal holes.

Conclusions

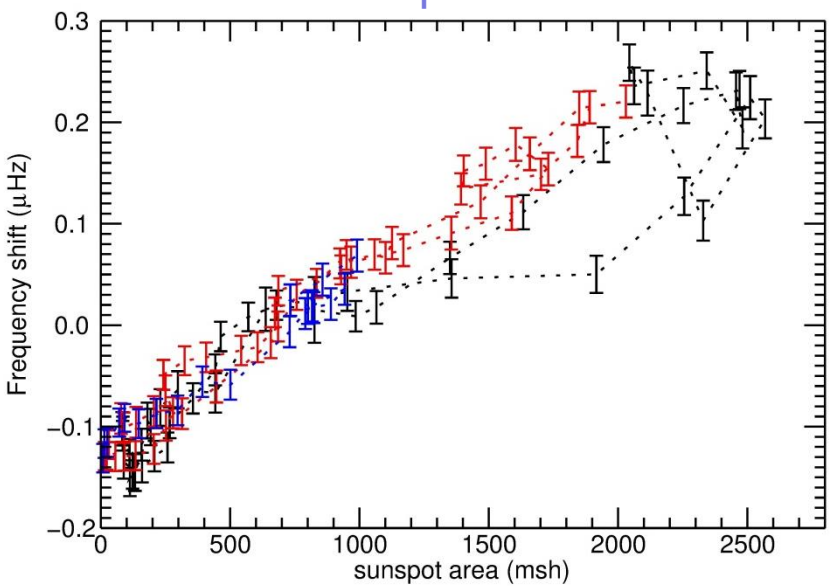
- Discrepancy observed between frequencies and proxies: SSN and CI
  - Consistent with explanations of discrepancy between SSN and 10.7cm flux.
- Change in frequency dependence of shift in frequencies implies thinning of magnetic layer.
- Discrepancy between powers and proxies in rising phase of C24.
  - Leads to small drop in energy supply rate.

Comparisons with global proxies

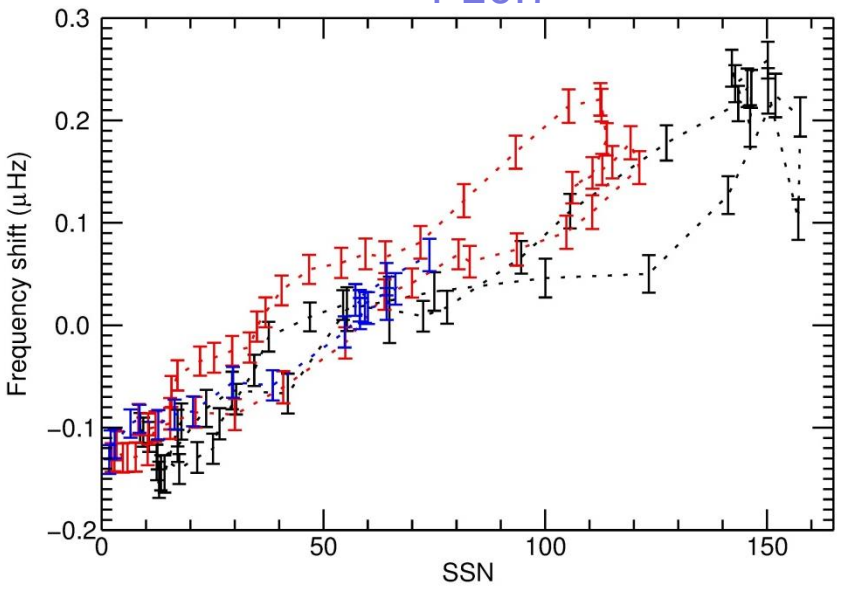
SSN



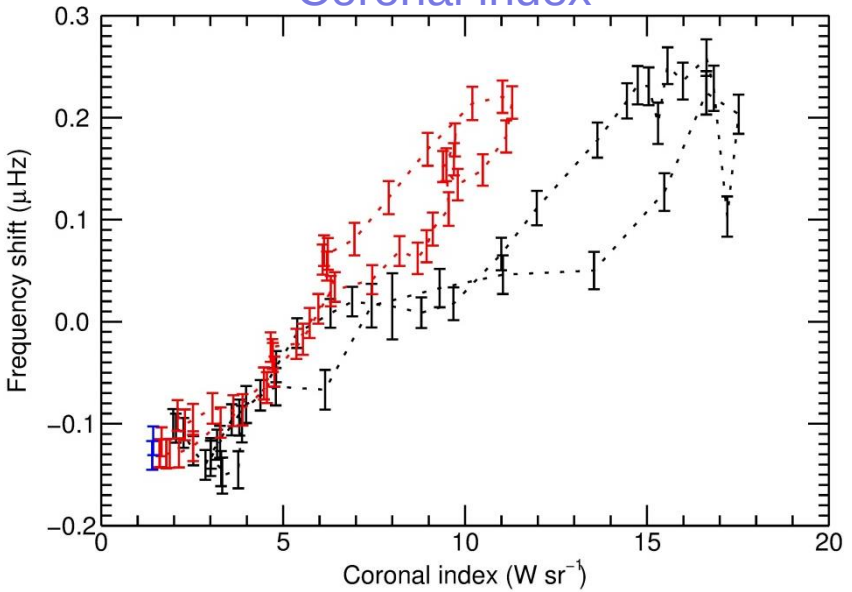
Sunspot area



F10.7

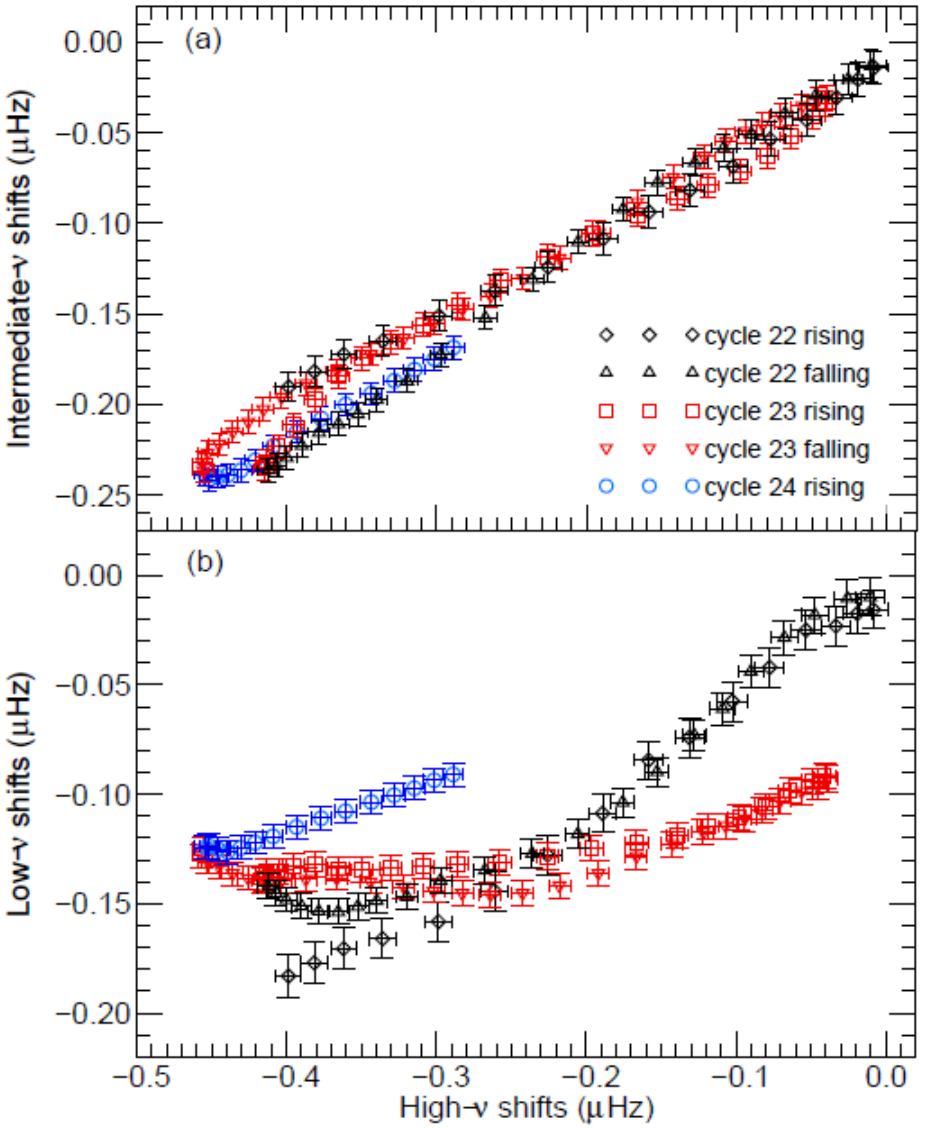


Coronal index



Comparing frequency ranges

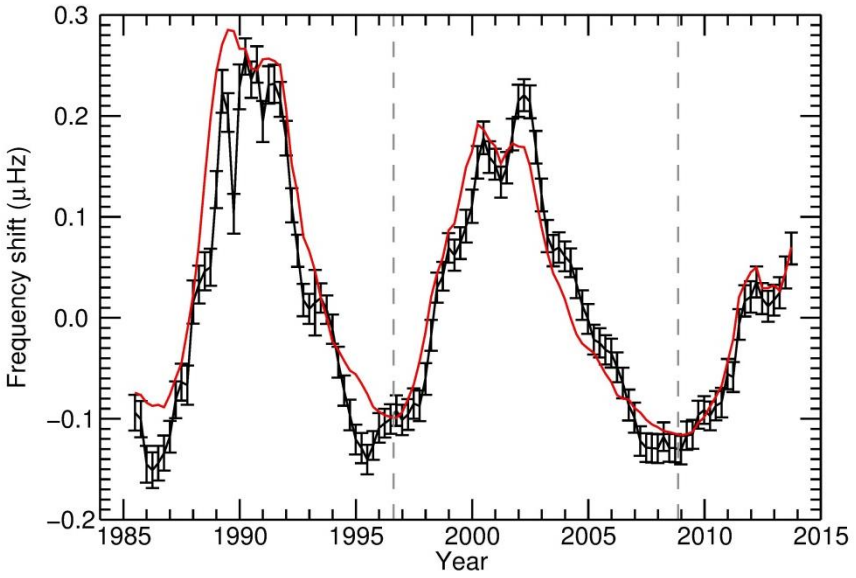
- High-ν and intermediate-ν behave in a similar manner in all cycles.
- Low-ν behaves differently in cycle 23.



Basu et al. (2012)

Frequency shifts compared to C23

SSN



F10.7