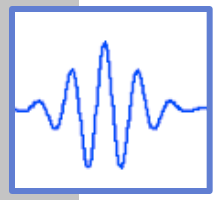
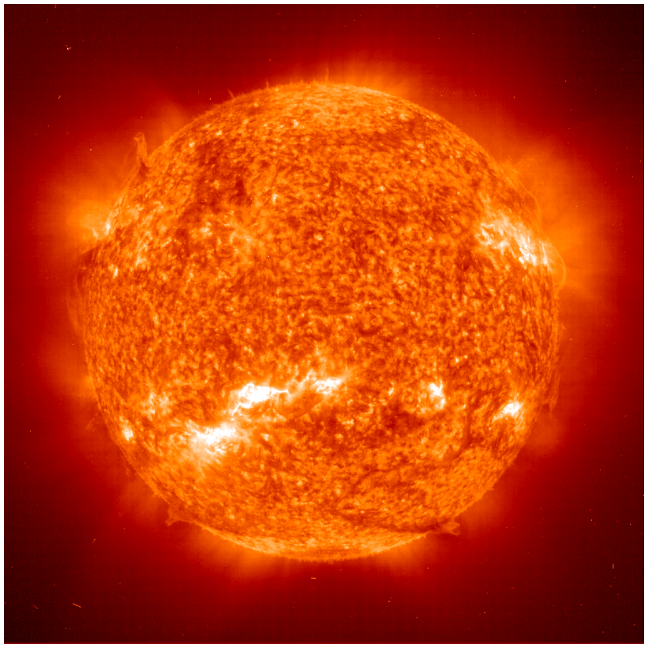
THE MAGNETIC HEARTBEAT OF THE SUN



Diagnosing Pulses in the Solar MgII Index Using Wavelet Analysis



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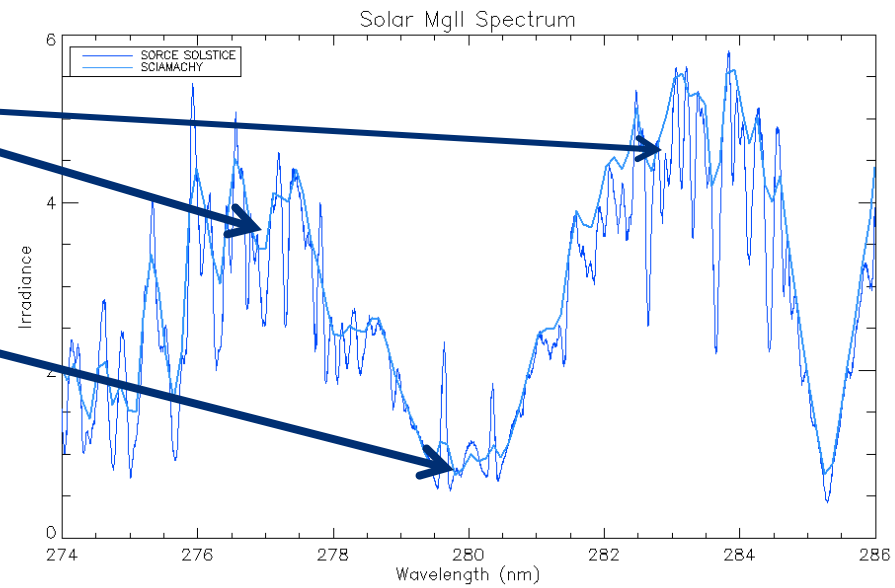
Solar Magnesium II Index

- What is it?
  - Measures core-to-wing ratio in solar UV irradiance Spectrum around 280 nm

Stable Absorption wings (upper photosphere)

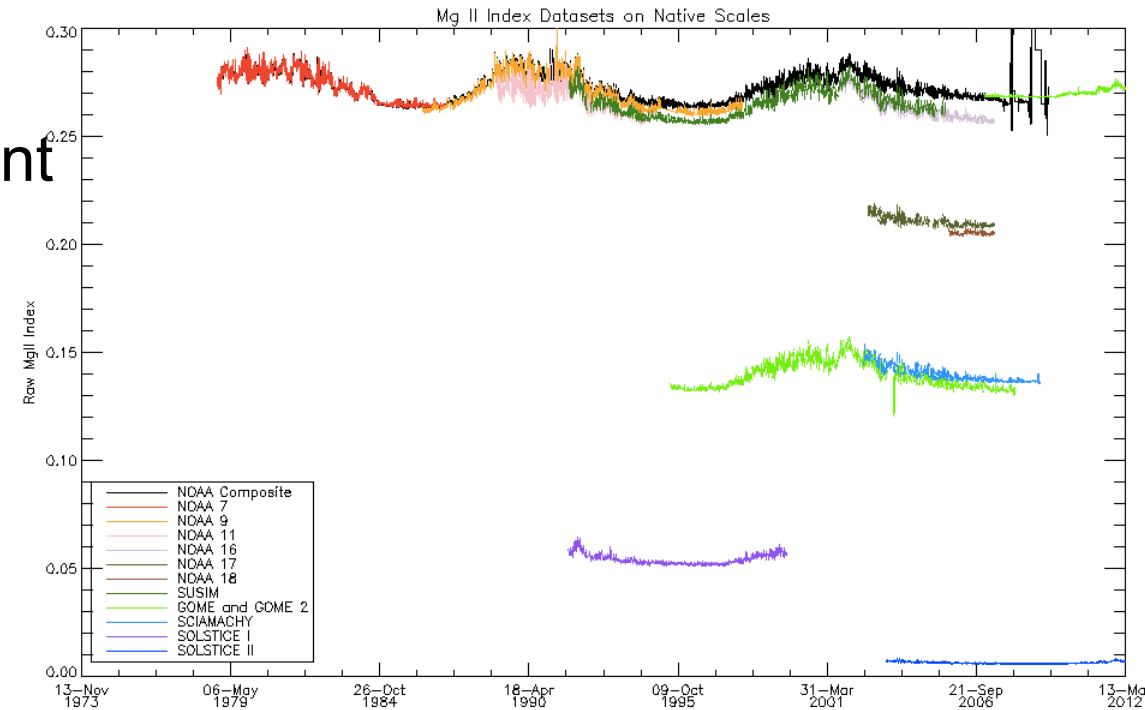
Variable Emission Core (upper chromosphere)



- What is it used for?
  - Solar chromosphere variability proxy
    - Space weather prediction
    - Climate variation

Problem

- Currently there are many different instruments taking data measurements

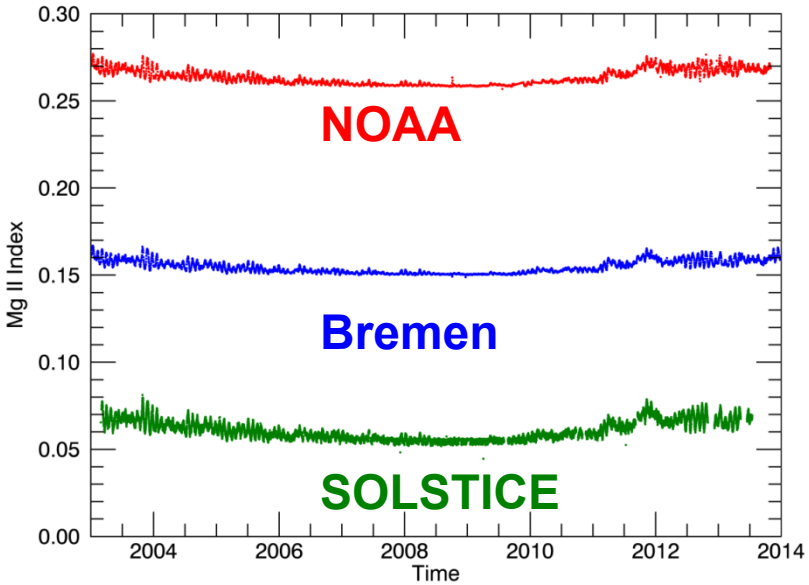


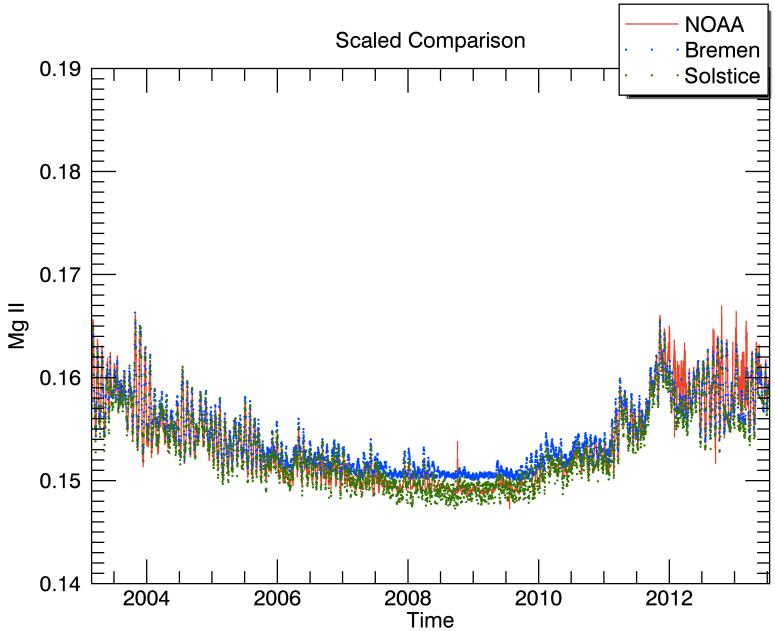
- Instruments have different
  - Time periods
  - Platforms
  - Spectral resolutions
  - Uncertainty

- Different data sets follow diverging trends
  - Leads to different models and predictions

Approach

- Take three data sets with overlapping time periods
  - Bremen Composite, NOAA 16, SORCE Solstice

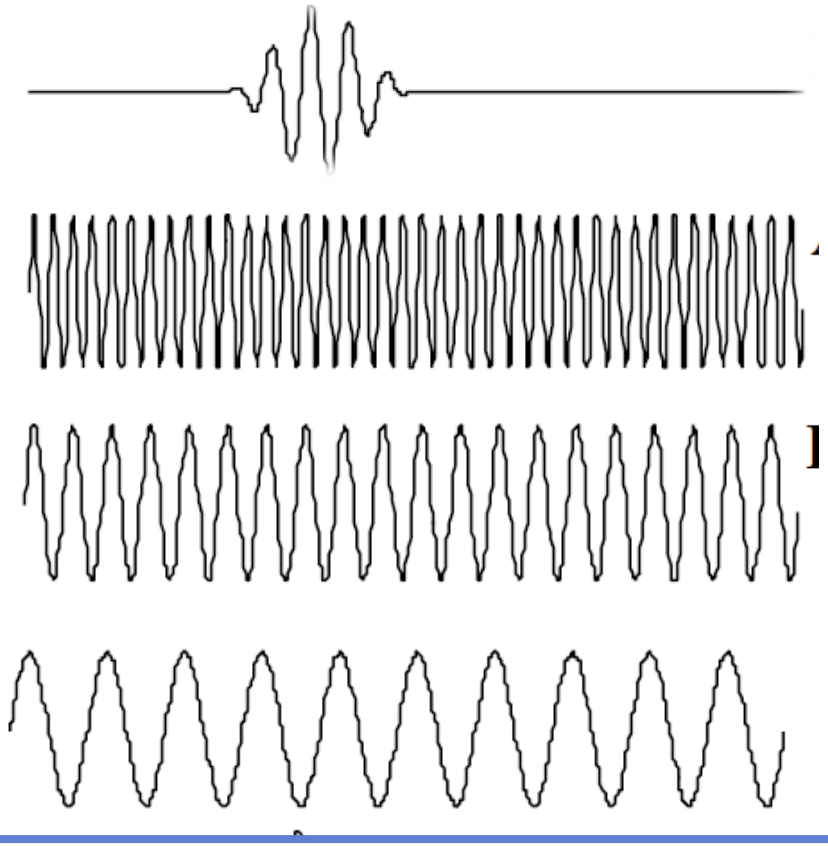




- Apply wavelet analysis to extract known solar time scales
- Investigate remaining trends
- Apply Bayesian Method to construct composite MgII Index

Wavelet Analysis

- First, think of Fast Fourier Transform (FFT):



Mysterious pulse

Try frequency 1:
poor correlation

Try frequency 2:
good correlation

Try frequency 3:
poor correlation

- From FFT we now know pulse frequency… but don't know location

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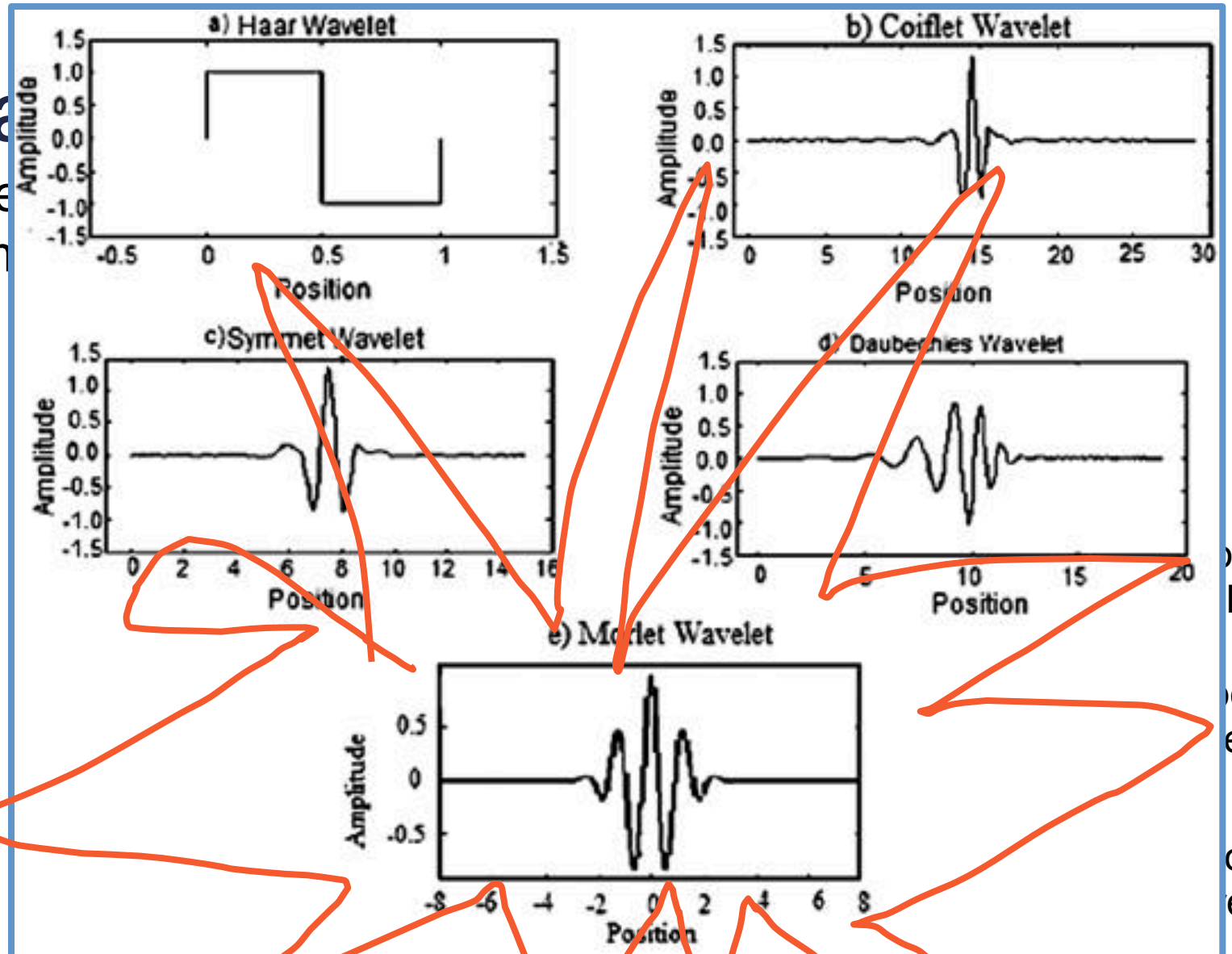

Fig. 1.- Wavelets types: a) Haar, b) Coiflet, c) Symmet, d) Daubechies and e) Morlet.

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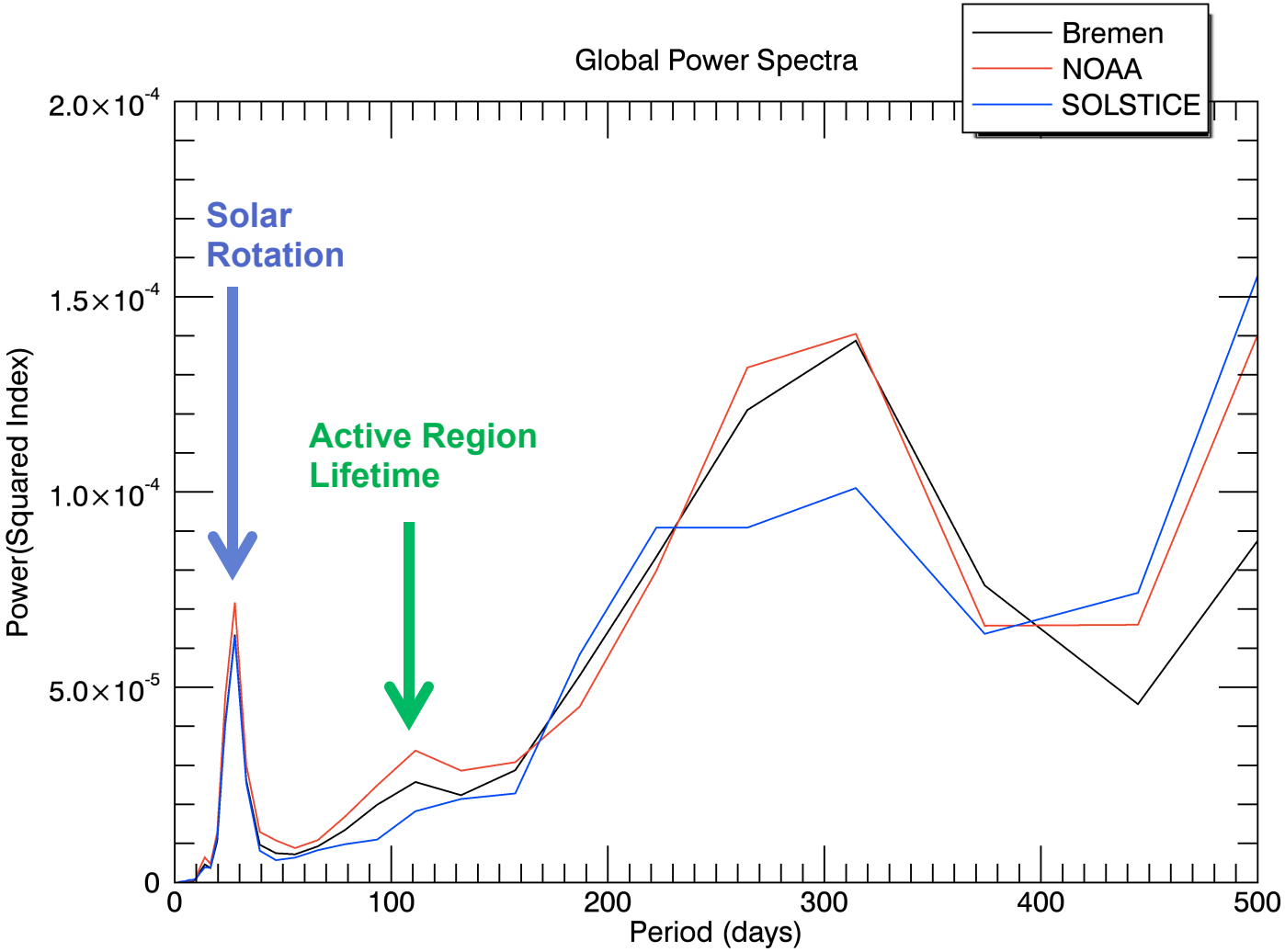
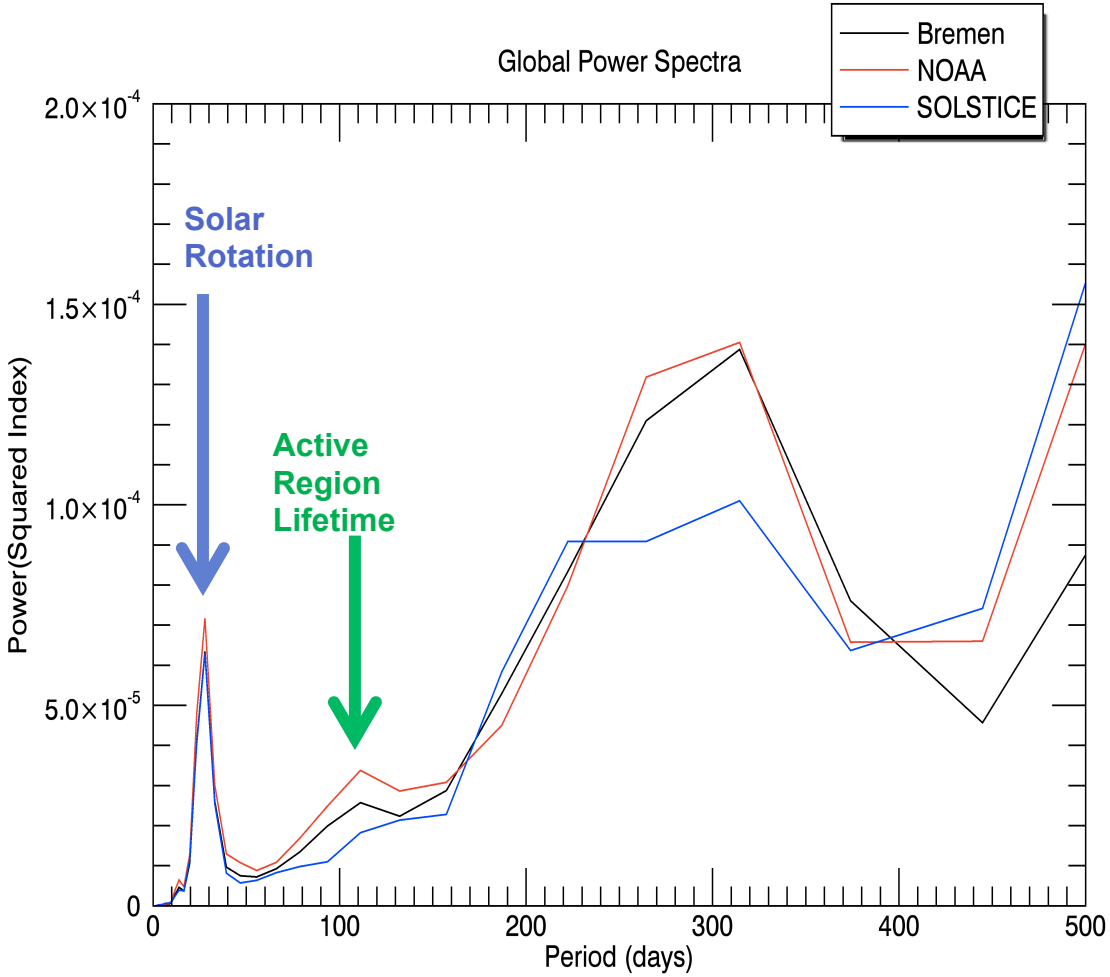
- Now we know the frequency and temporal location of the pulse in the data set

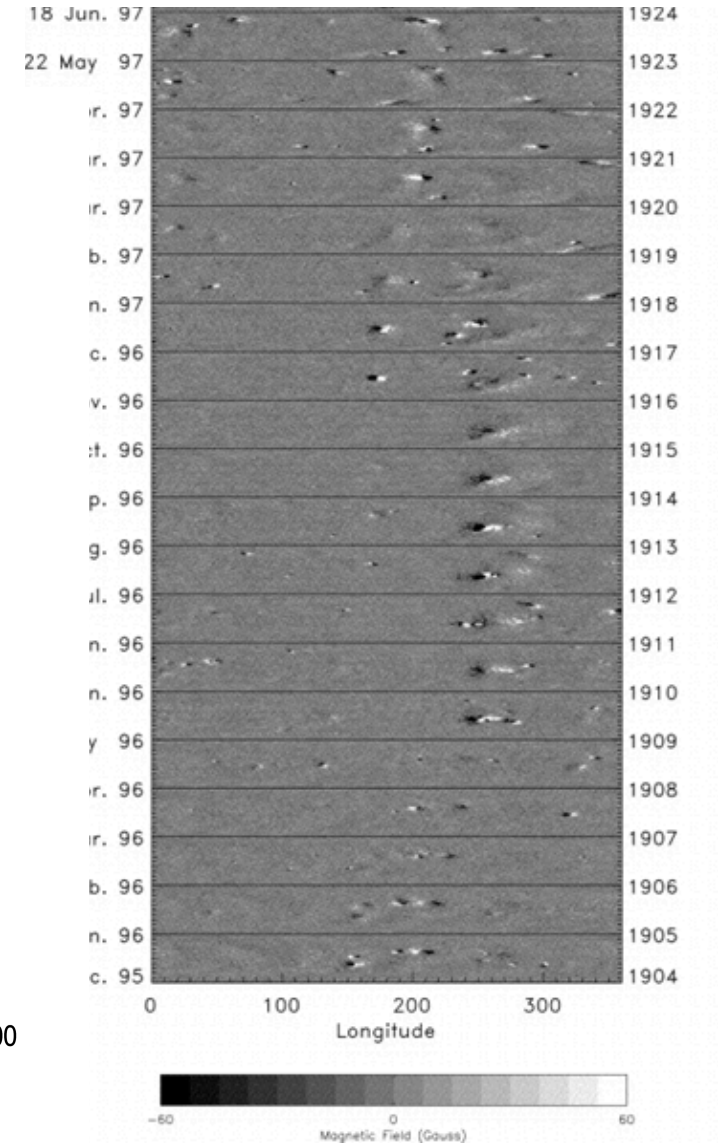
Initial Results –Global Power Spectra



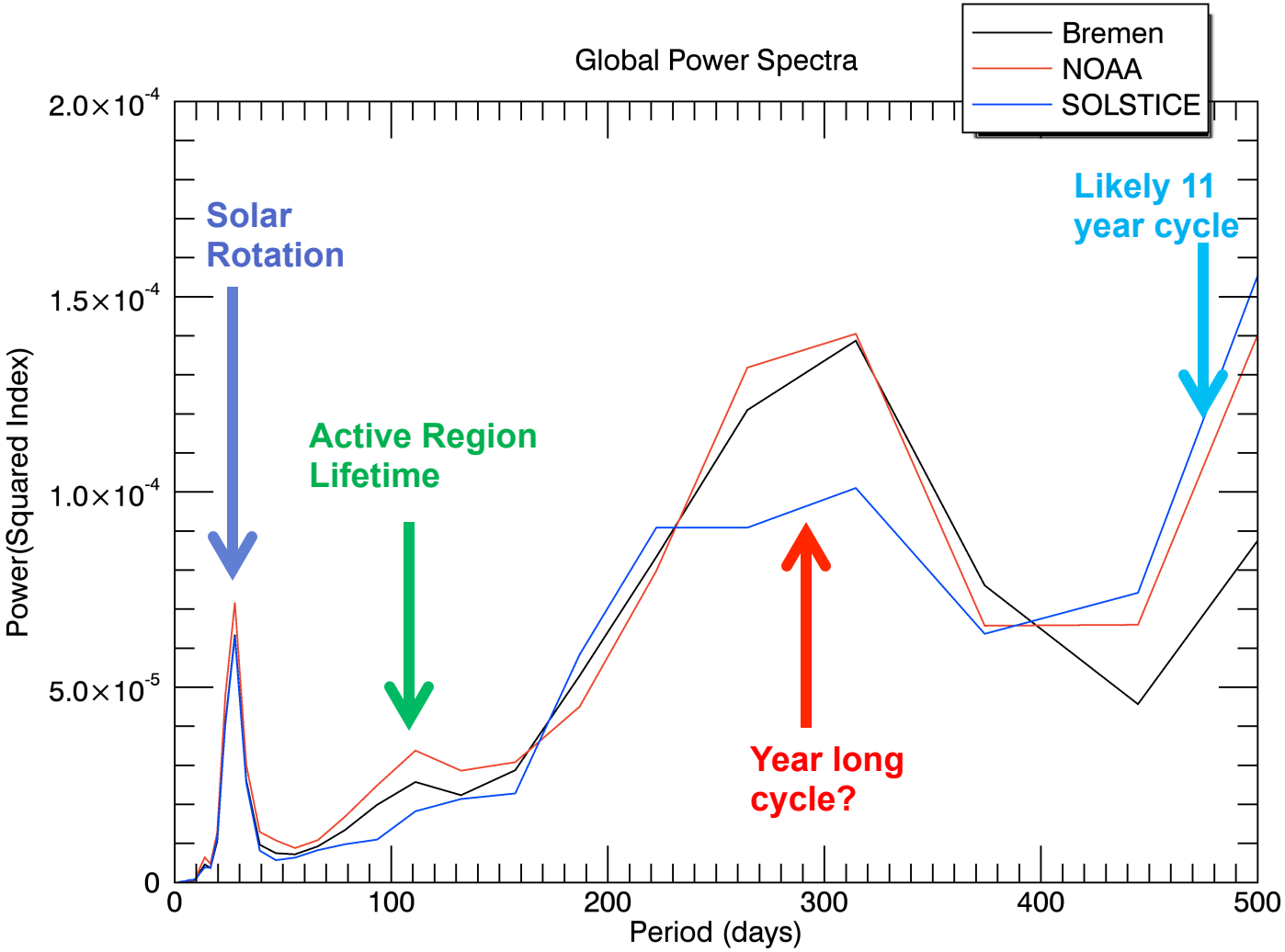
Active Region Lifetime (4-7 month)



NSO/Kitt Peak Magnetic Field Synoptic Map

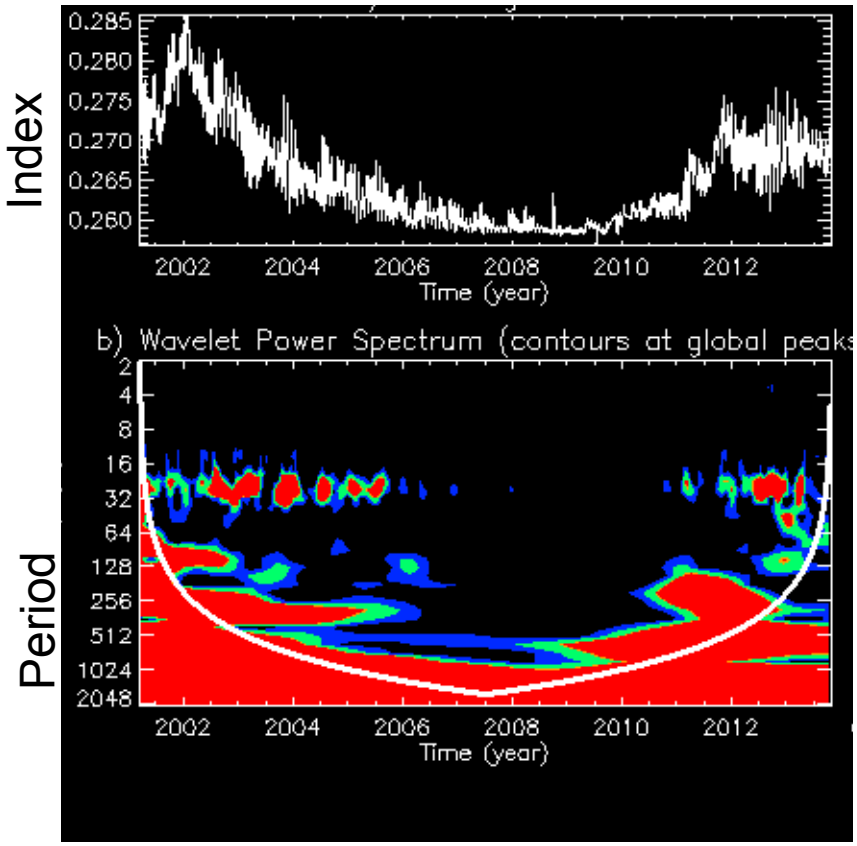


Initial Results –Global Power Spectra

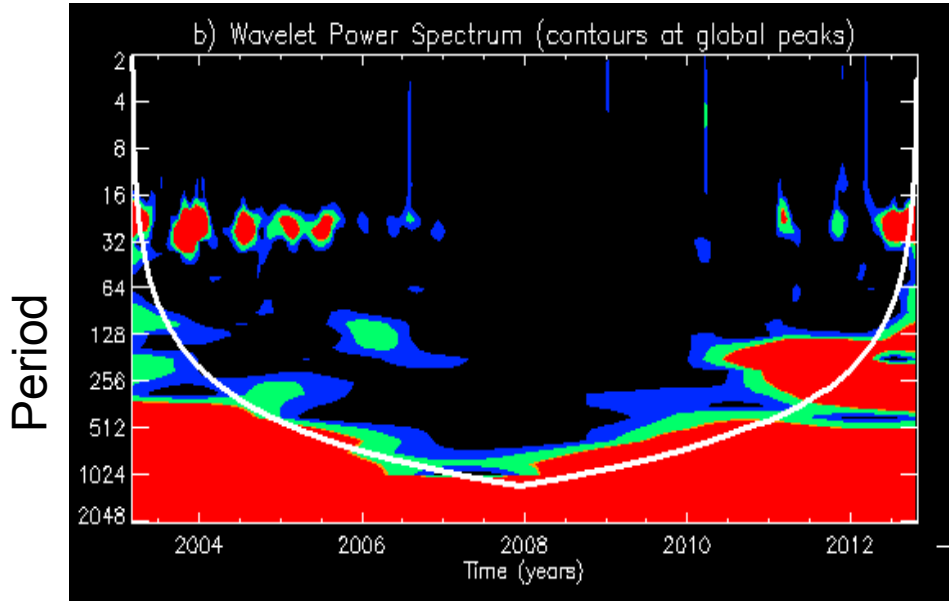


Initial Results- Wavelet Power Spectra

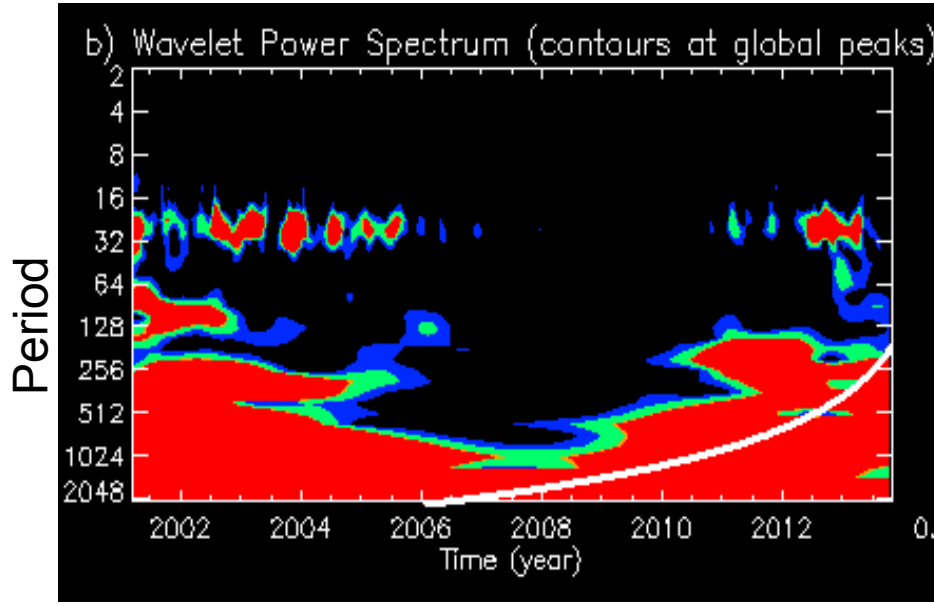
NOAA



Solstice



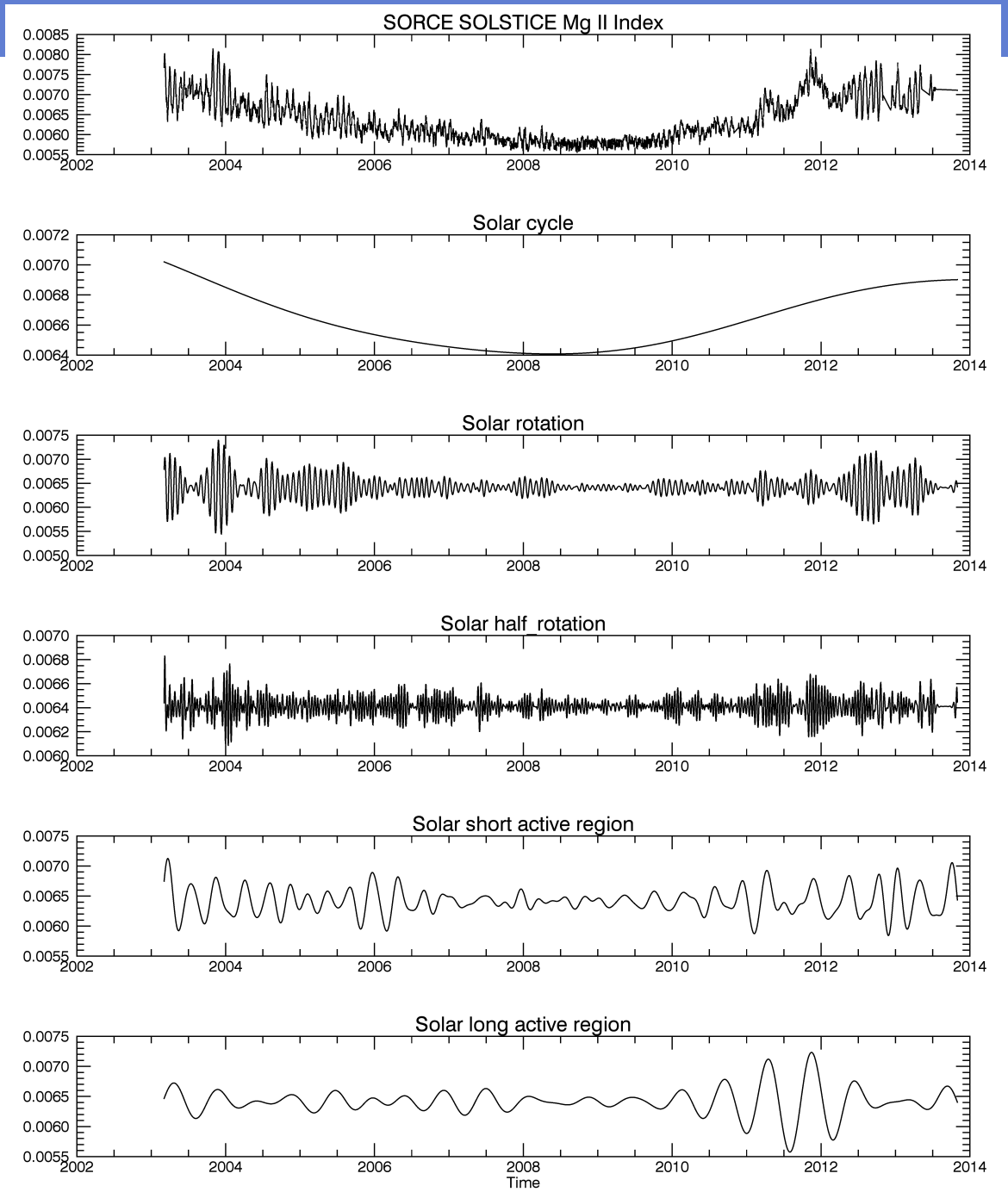
Bremen



SOLSTICE Mg II Record and Signal Elements

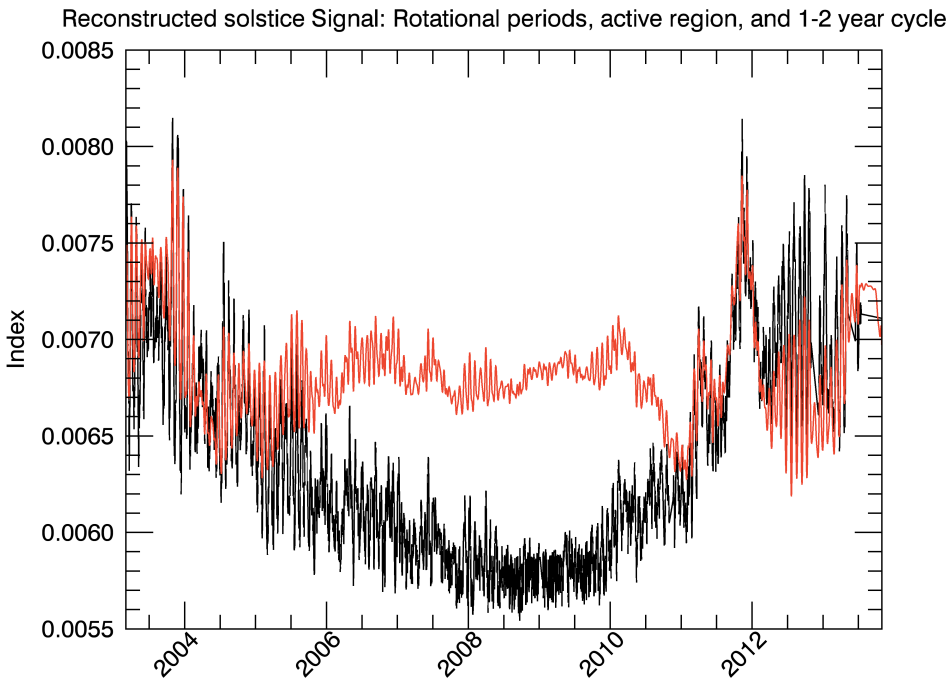
-isolated signals

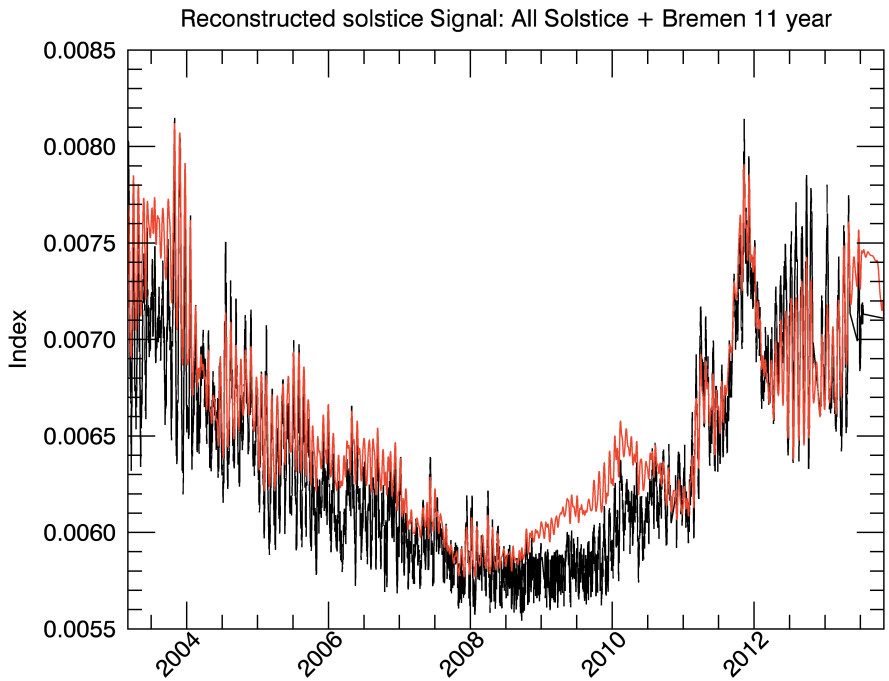
-wavelet allows us to visually see where they occur



Deconstruction Process (misnomer slide)

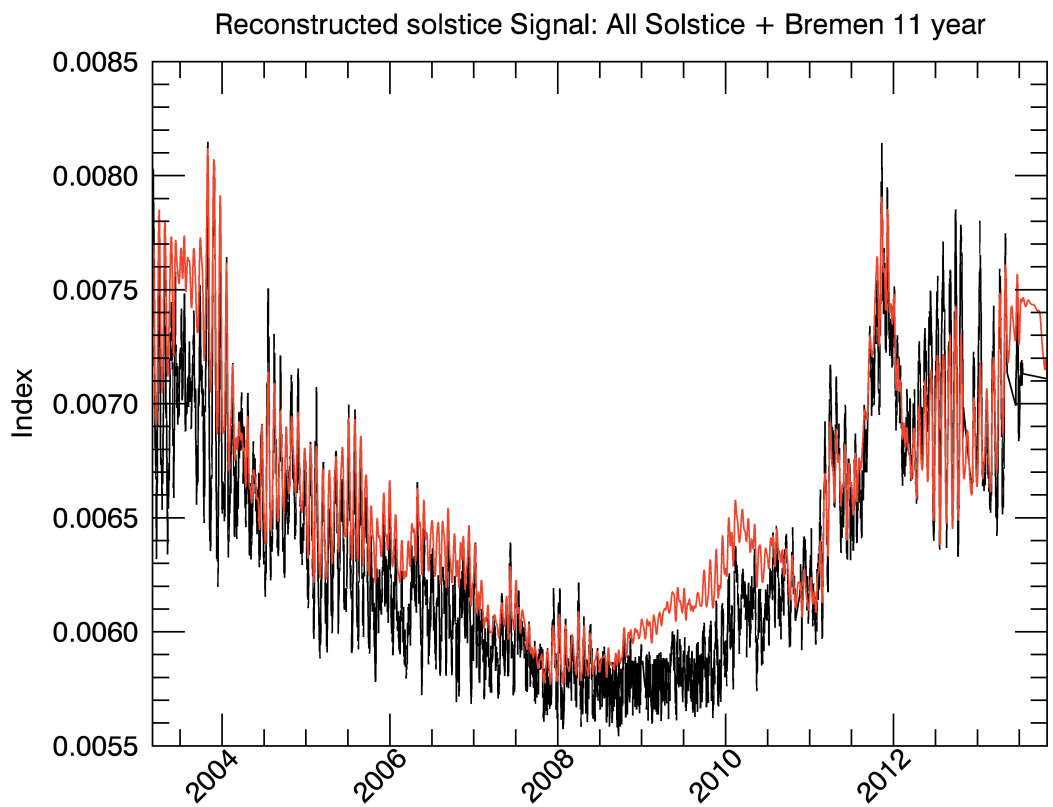
- First want to fully reconstruct (all wavelet periods) signal to match index
- Problem: time period not long enough to reconstruct 11 year
  - Need to extrapolate Bremen-11 year for full reconstruct



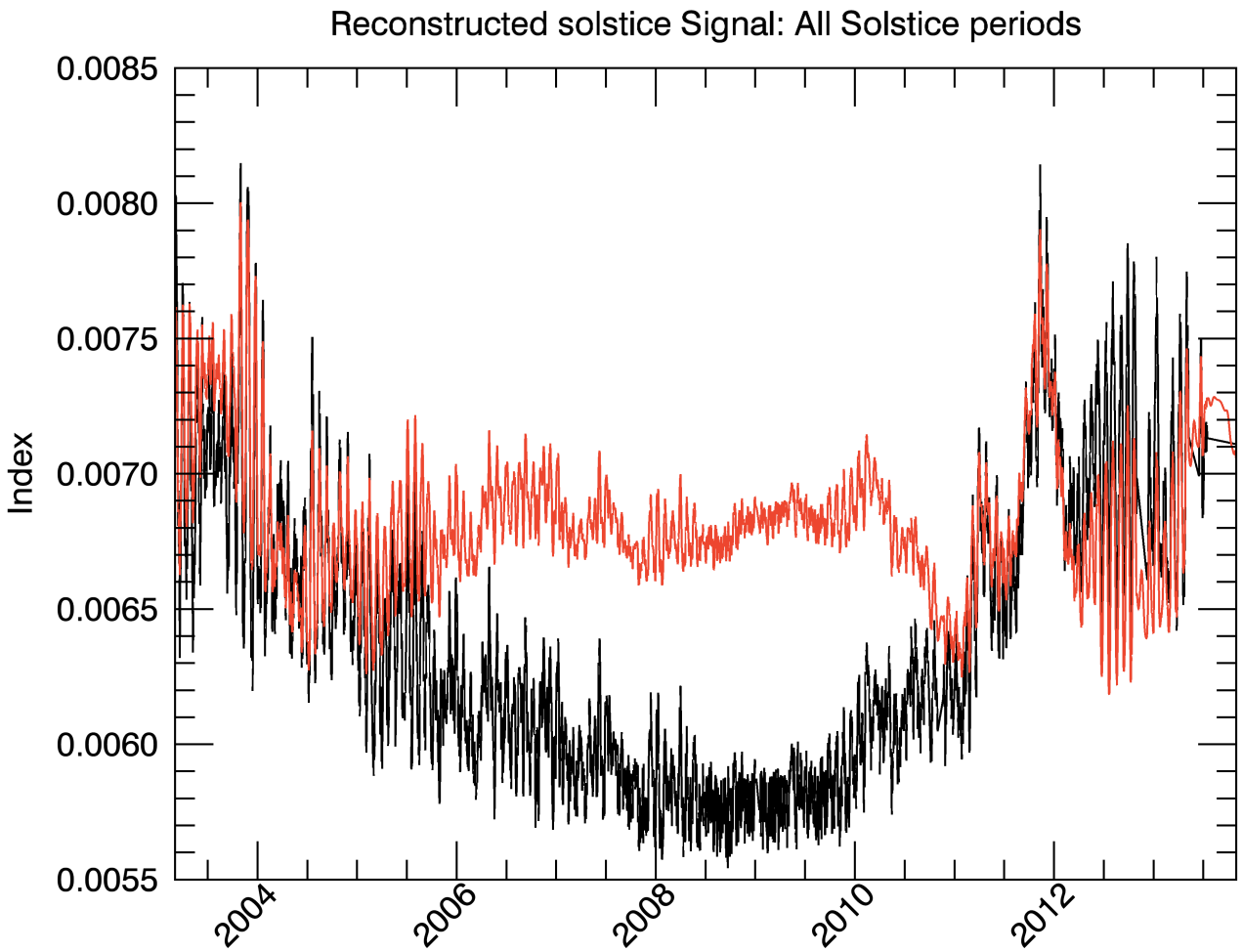


Now we can deconstruct!

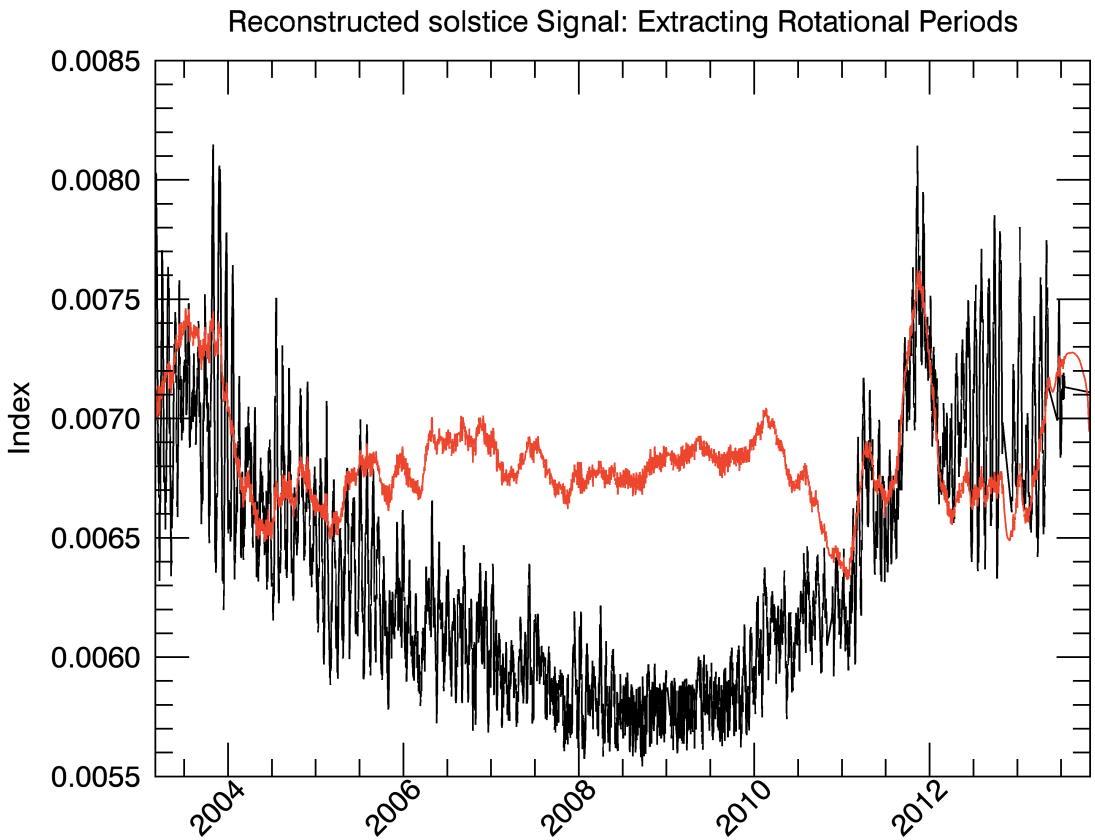
- First take out all known solar cycles



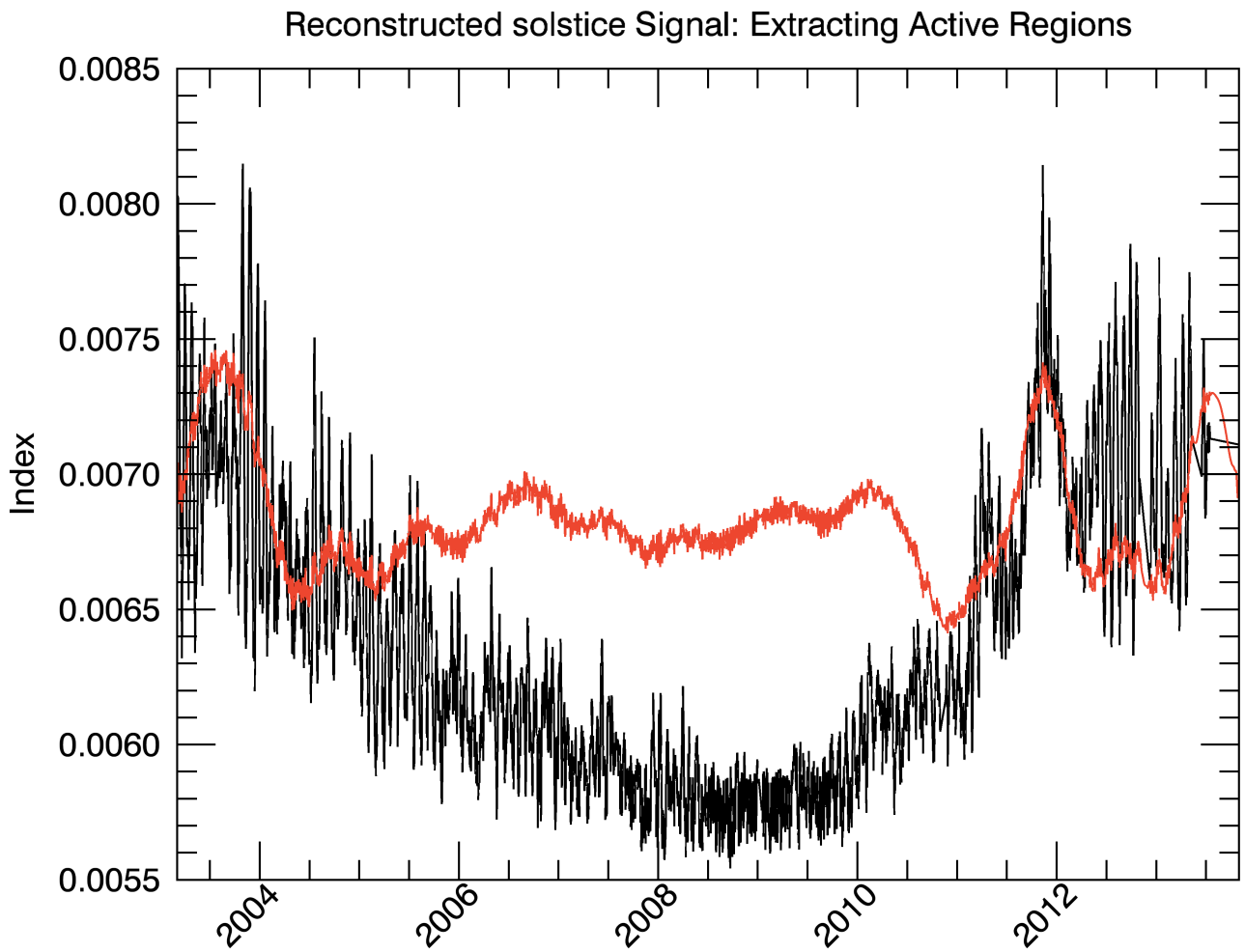
Taking out the 11- year solar cycle



Extracting Solar Rotational Periods and Half Solar Rotational Period

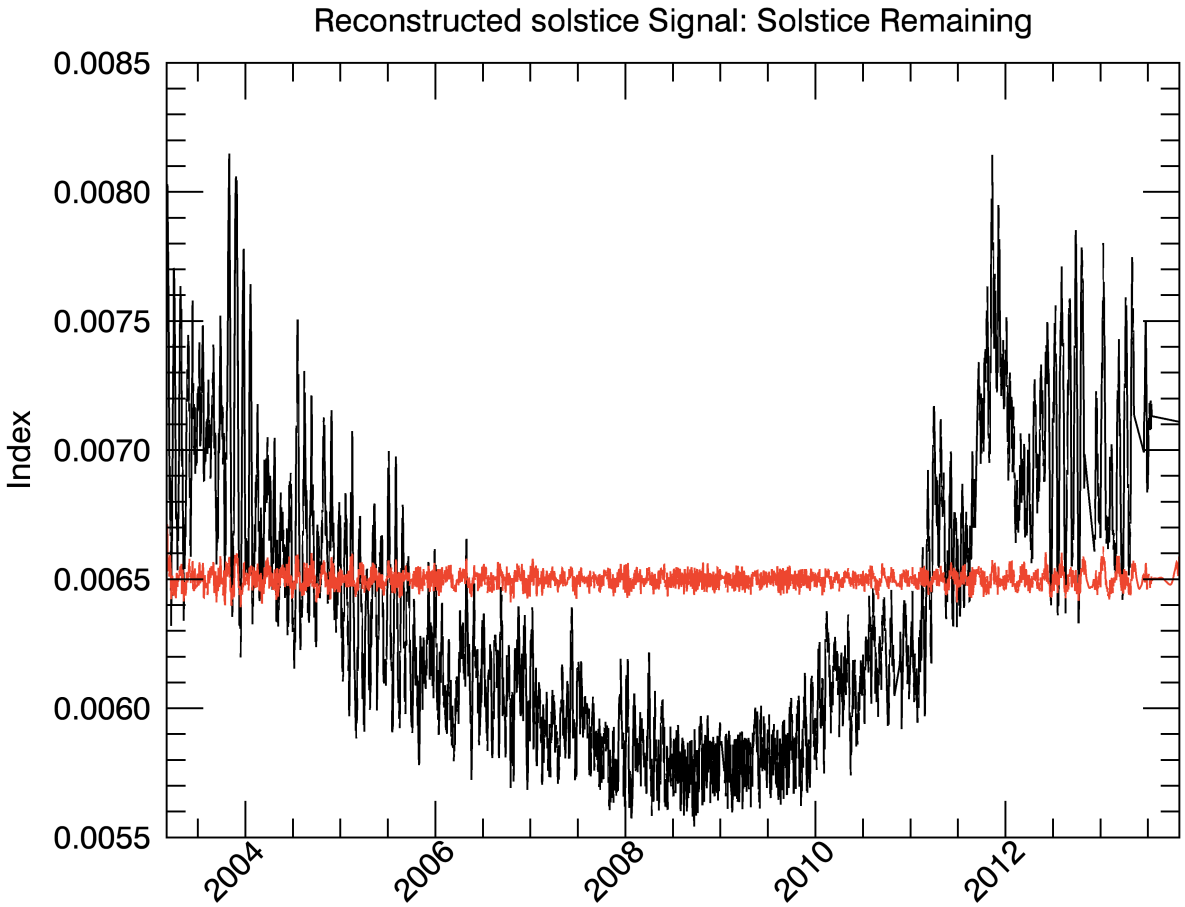


Extracting Active Region Period



With all known solar periods taken out we still have a 1-2 year period!!!

Taking out 1-2 year period (any other mystery signals?)



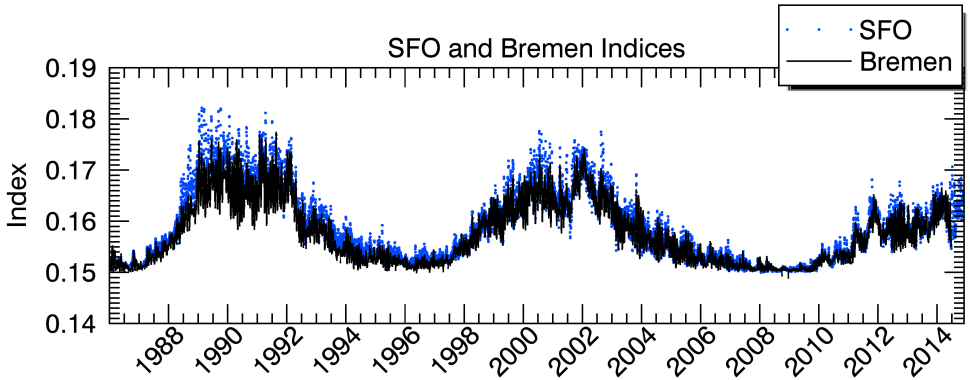
1-2 year signal investigation

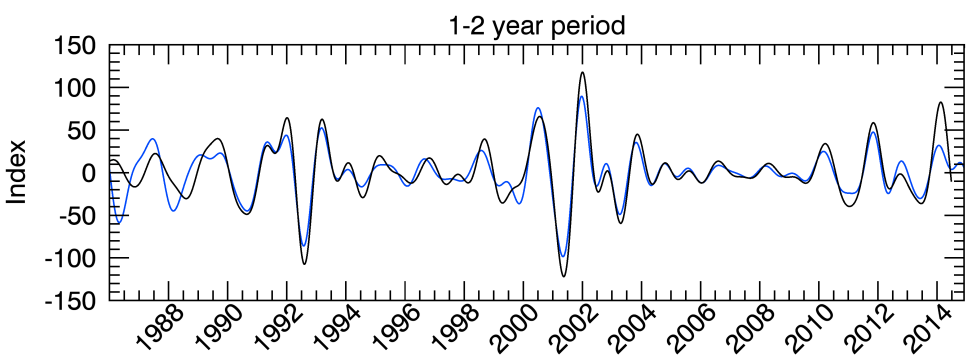
- Common to all three data sets (NOAA, SOLSTICE, Bremen)
- What about ground-based solar chromosphere variability data?

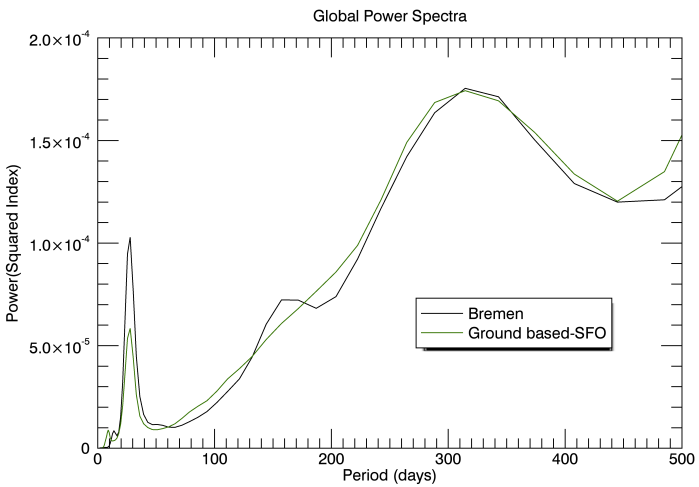
- Use San Fernando Observatory (SFO) Ca II data

SFO Data Comparison

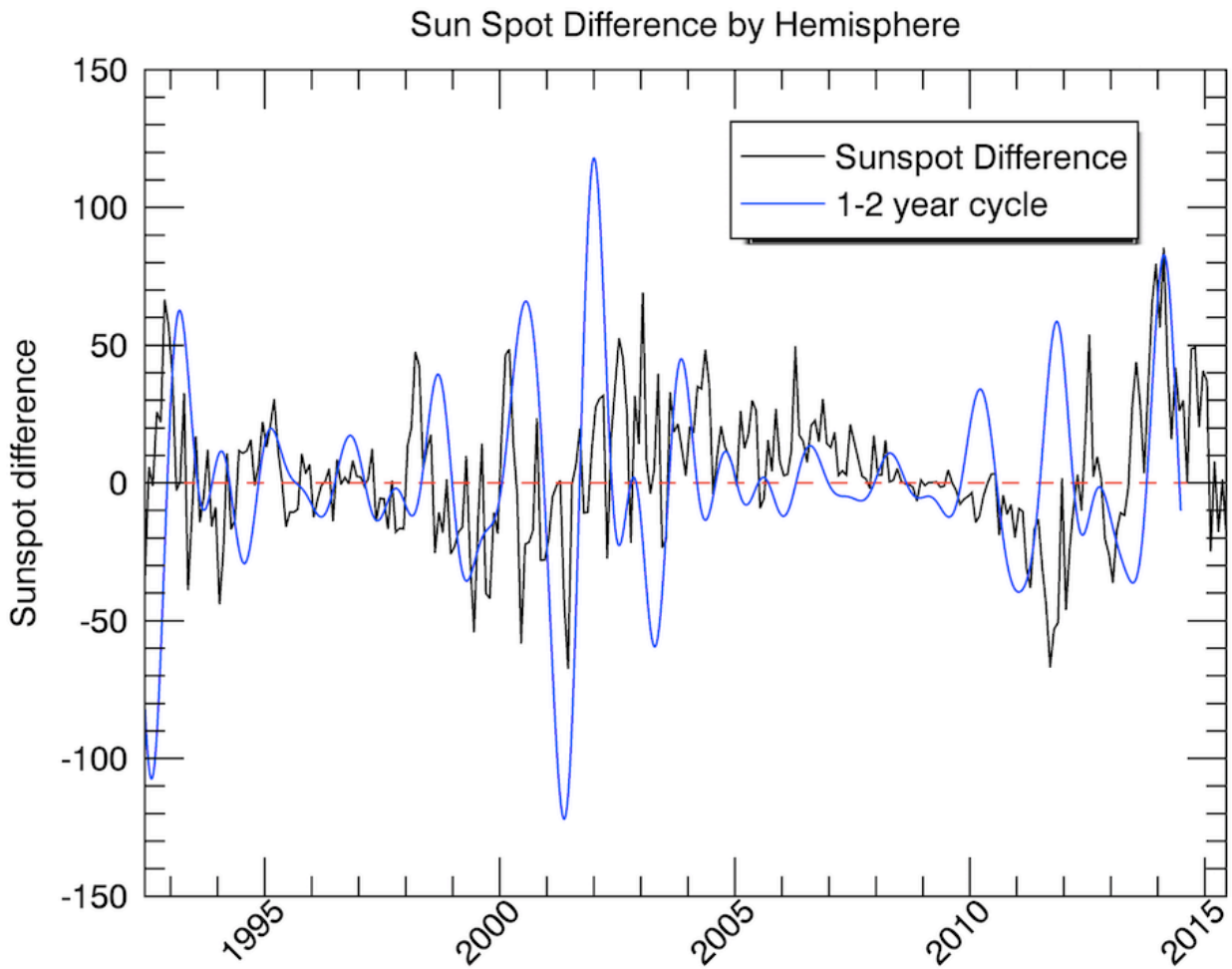
- 1-2 year signal is common to space-based and ground-based instruments





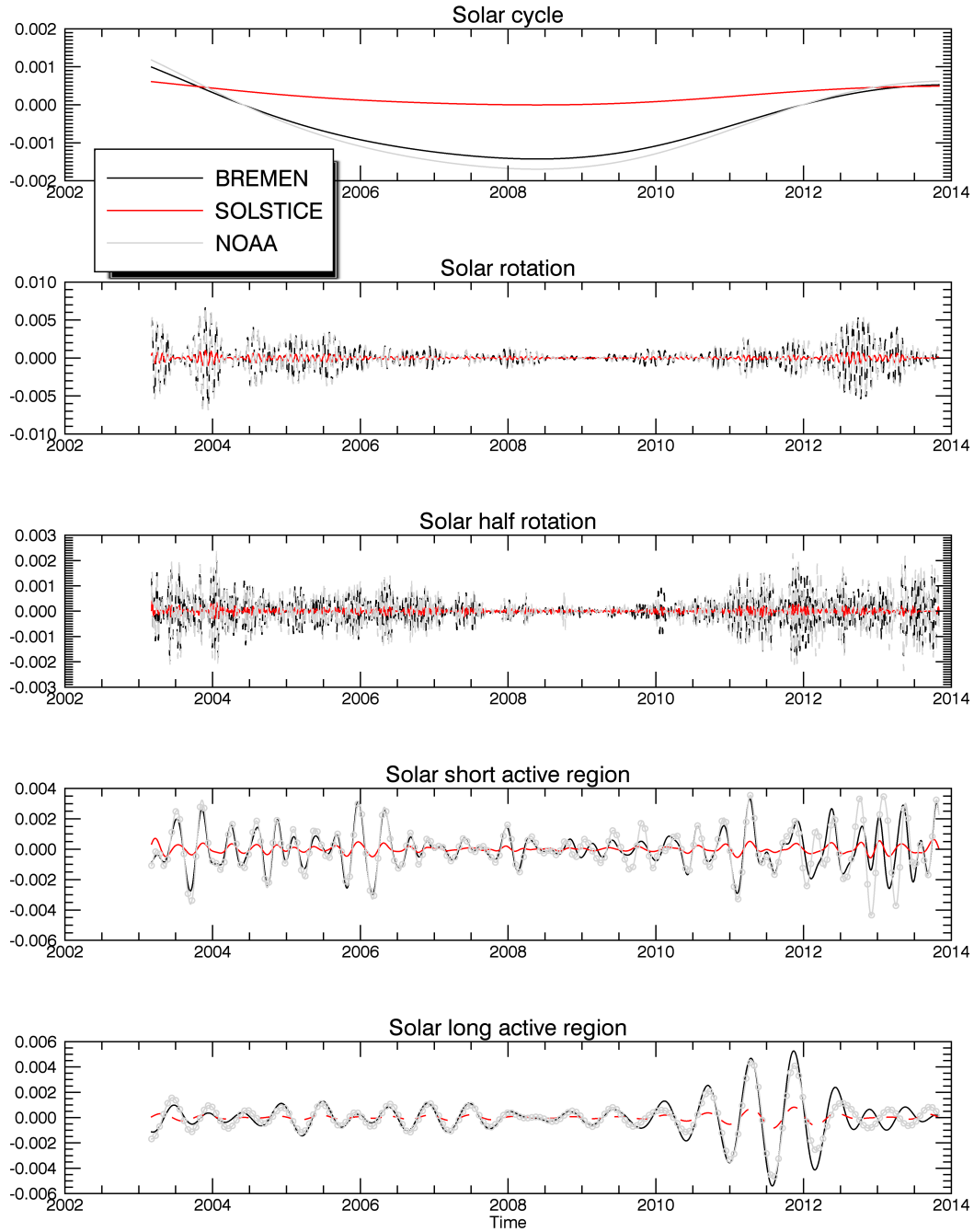


Compare with Temporal Difference in Hemispheric Sunspot Number



Cross-data set comparison problems

-scaling
-phase



This is where we can benefit from Bayesian Approach

Quantifying uncertainties through Informed Source Separation

The wavelet analysis/reconstruction is a linear transformation and does not account for uncertainties.

Linear Mixing Model

$$x = \sum_i A_i s_{i,t}$$

x=data
A_i=Abundance of ith element
$s_{i,t}$=i^{th} signal element (time-dependent)

We consider performing the linear transformation within a Bayesian model, which allows for quantifying the uncertainties in the reconstruction.

Informed Source Separation:

Bayesian Positive Source Separation **[Moussaoui et al.**

$$\underbrace{p(s,\boldsymbol{A})}_{\text{Posterior PDF}} = \underbrace{p(x-\boldsymbol{A}s)}_{\text{Measurement Error PDF}}\underbrace{p(s)}_{\text{A priori PDF (wavelet signal)}}\underbrace{p(\boldsymbol{A})}_{\text{A priori PDF (abundances)}}$$

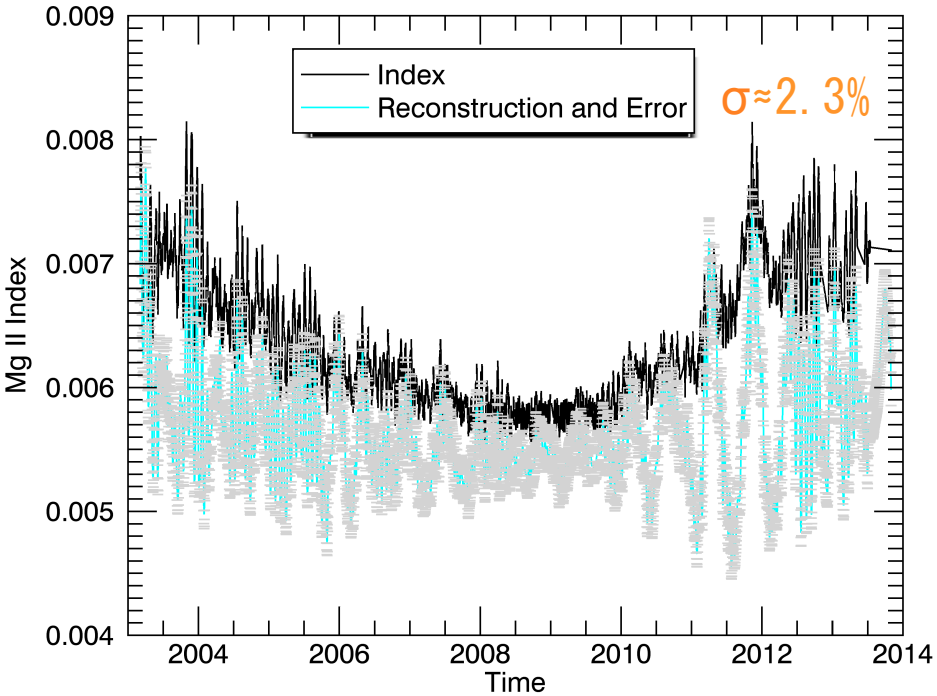
Most probable solution is obtained through iteratively solving a hierarchical ("Layered") Bayesian Model.

These are the steps:

1. Define first guess sources & abundances.
2. Estimate gamma distribution abundance parameters.
3. Optimize New Abundance estimate
4. Estimate source hyperparameters.
5. Optimize new Sources estimate.
6. Estimate noise parameters that minimize x-As.

If convergence reached, evaluate posterior PDF for final estimates of sources and abundance. ***Else***, iterate and re-evaluate.

Initial Bayesian Results: SOLSTICE Mg II

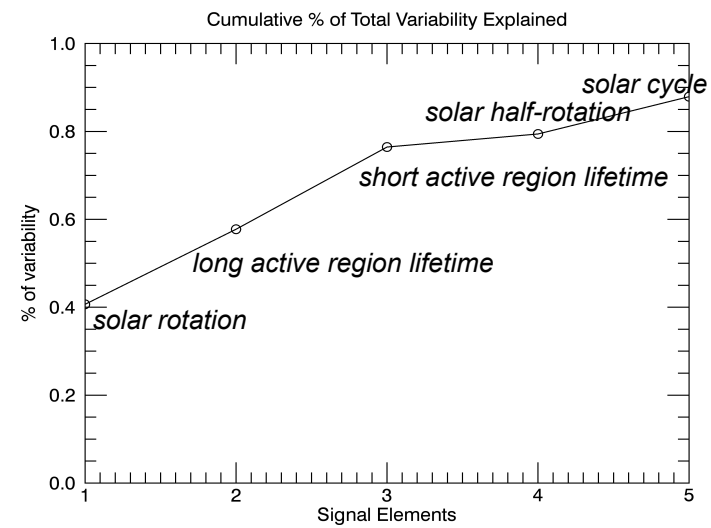


Initial Results highlight remaining challenges.

- Known and expected sensitivity to initial conditions, emphasize the importance of "first guess" assumptions for the applied minimization approach.
- Future Work: A Monte Carlo Markov Chain minimization method (i.e., over a broad range of "first guesses") may prove to be a more robust approach.

The investigated solar signatures (solar cycle, solar rotation, active region lifetime) account for ~80% of the variability in the native data.

- Note: Reported values would change with improved implementation of the method.



Conclusion/Further Work

- Wavelet analysis is a useful method for comparison among data sets deriving from similar sources
- Wavelet analysis results can be strengthened with Bayesian Method

- Further investigation is needed to confidently determine 1-2 year cycle
- More fully applying Bayesian method could help with better quantification of uncertainty in composite record

Acknowledgements

- Sorce/LASP
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- Odele Coddington
- Erin Wood
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- Magnesium Mafia (Wider Community)
- Christopher Torrence and Gilbert P. Compo