THE MAGNETIC HEARTBEAT OF THE SUN

Diagnosing Pulses in the Solar MgII Index Using Wavelet Analysis

Lindsay Rand
Carleton College
Northfield, MN

Odele Coddington and Martin Snow
Laboratory of Atmospheric Space Physics
Boulder, CO
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
Wavelet Analysis

- We can use Wavelet Analysis to find frequency and temporal position of a pulse.

**Mysterious Pulse**

- Pulse 1: Poor temporal and frequency correlation
- Pulse 2: Good temporal, poor frequency correlation
- Pulse 3: Good temporal, good frequency correlation

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

- Now we know the frequency and temporal location of the pulse in the data set.
Initial Results – Global Power Spectra

![Global Power Spectra Graph]

- **Solar Rotation**
- **Active Region Lifetime**
Active Region Lifetime (4-7 month)
Initial Results – Global Power Spectra

Solar Rotation
Active Region Lifetime
Year long cycle?
Likely 11 year cycle
Initial Results - Wavelet Power Spectra

NOAA

Period

Index

Time (year)


Solstice

Period

Time (years)


Bremen

Period

Time (years)

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
• 1-2 year signal is common to space-based and ground-based instruments
Compare with Temporal Difference in Hemispheric Sunspot Number

Sun Spot Difference by Hemisphere

- Sunspot Difference
- 1-2 year cycle
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**

\[ x = \sum_{i,t} A^i s^i_{i,t} \]

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., 2004]

\[ p(s, A) = p(x - As)p(s)p(A) \]

Posterior PDF  Measuremnt Error PDF  A priori PDF (abundance s)

**A priori PDF (wavelet signal)**

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
- Marty Snow
- Odele Coddington
- Erin Wood
- Magnesium Mafia (Boulder Branch)
- Magnesium Mafia (Wider Community)
- Christopher Torrence and Gilbert P. Compo