The Magnetic Heartbeat of the Sun

Diagnosing Pulses in the Solar MgII Index Using Wavelet Analysis

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Background

The solar Magnesium (Mg) II index, derived from the ratio of measurements across a solar absorption feature (280nm) in nearby spectral bands, serves as a proxy for solar chromospheric variability. Scientists use the MgII index to create models and predictions for complex dynamics such as climate variability, space weather and other atmospheric phenomena.

Problem:

There are currently various space-based instruments that acquire data for the MgII index and, depending on the instrument used, the data follows different temporal trends. These variations cause variations in model outputs, dependent on the instrument/data set used.

Objective:

We investigate the MgII index data in an effort to reconcile the differences and create one, composite record with elements common to all data sets. For our investigation we focus on the overlapping time segment of the SORCE Solstice, Bremen composite, and NOAA 16 data sets. We use wavelet analysis to analyze the time scales present in the data. We then apply a Bayesian approach to quantify the uncertainties of a record reconstructed with identified solar signals.

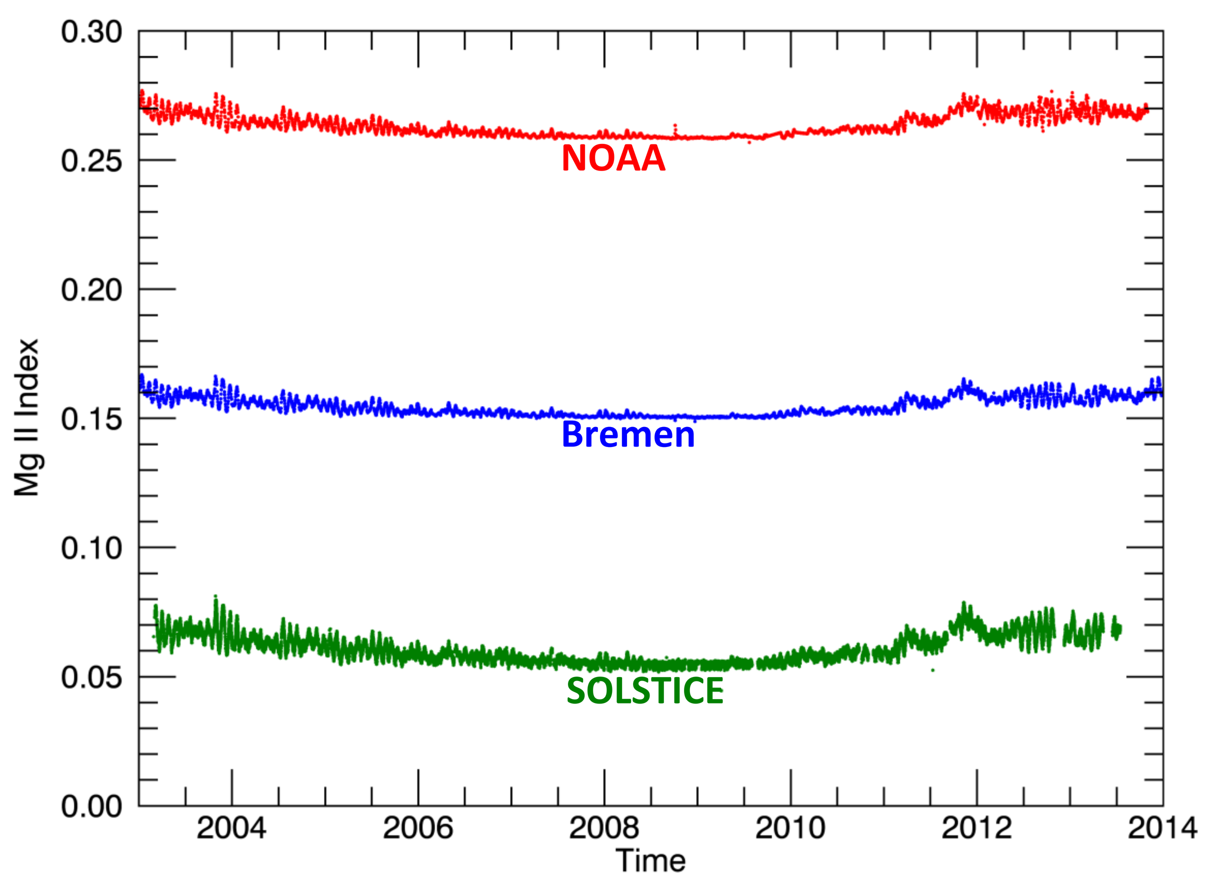

Fig. 1. Native data sets for NOAA, Bremen, and SOLSTICE data during overlapping time period. When offsetting to a common scale variations in trend are qualitatively visible (not shown).

Mathematical Approach

Wavelet Analysis:

In order to best diagnose time scales within the data we use wavelet analysis. Wavelet analysis expands on the mathematical approach of Fast Fourier Transform (FFT). Whereas FFT allows for one to determine the significant periods within a data set, wavelet also allows for one to determine the temporal location of the significant periods within the data. This is important in allowing us to reconstruct our data by knowing where in the time series certain time scales of solar behavior occur. Under this method we apply the Morlet wavelet shape (chosen for its best-fit with the MgII data). One challenge of wavelet analysis is that doesn't account for uncertainties in the data.

Bayesian Method:

To quantify the uncertainties in the linear sum of signals, provided by wavelet analysis, we apply a Bayesian model. This approach requires first defining probability distributions that define the signals (S), their abundances (A), and uncertainty in the reconstruction (σ). For this wrok, we assume the Sources and Abundances are Gamma distributed and the reconstruction uncertainty is Normal distributed, with zero mean and standard deviation, σ.

$$p(S,A\,|\,x) = \frac{p(x\,|\,S,A)\,p(S)\,p(A)}{p(x)}$$

The approach is a hierarchical, iterative, and solutions are obtained through a relative gradient descent.

Deconstruction of Solstice Data

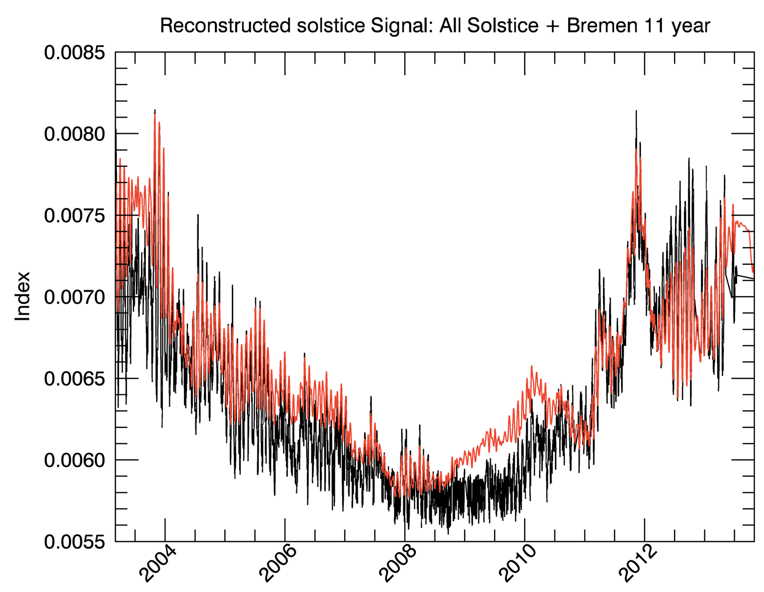

Fig. 2 **Step one:** in order for us to be able to deconstruct the data we must first fully reconstruct it. Here, all solstice periods are reconstructed with an 11-year period (solar cycle) extrapolated from Bremen composite and plotted (in red) over the original Solstice index (black).

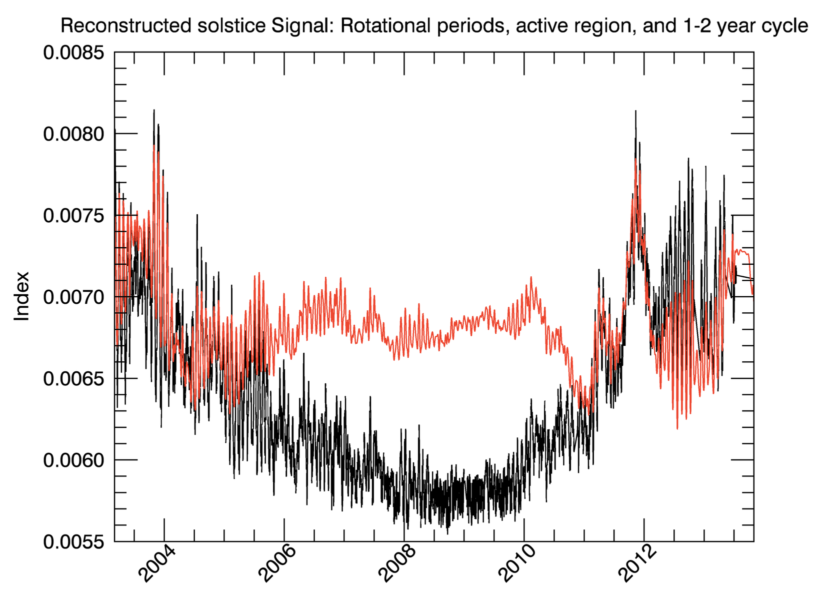

Fig. 3 **Step two:** we begin our deconstruction process by extracting the 11-year period for the solar cycle from our reconstructed data. The range of time scale we use is 9.5 – 13 years.

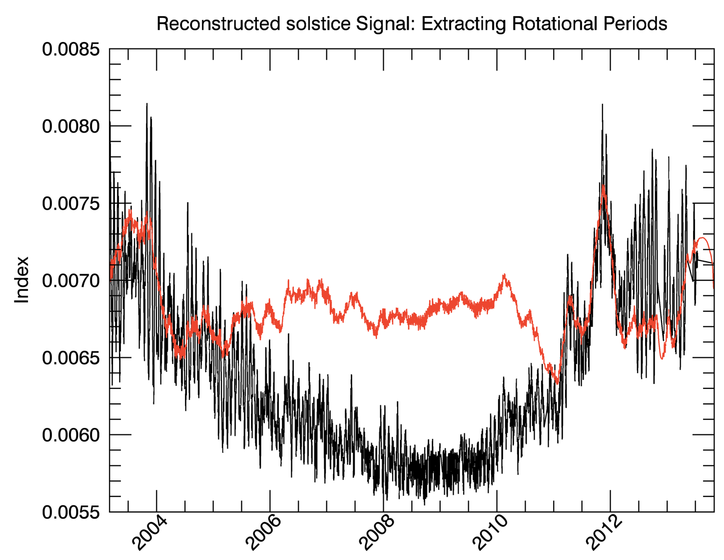

Fig. 4 **Step three:** we then extract the solar rotational and solar half rotational periods for the sun. The range of time scales we use are 24-28 days and 11-15 days, respectively.

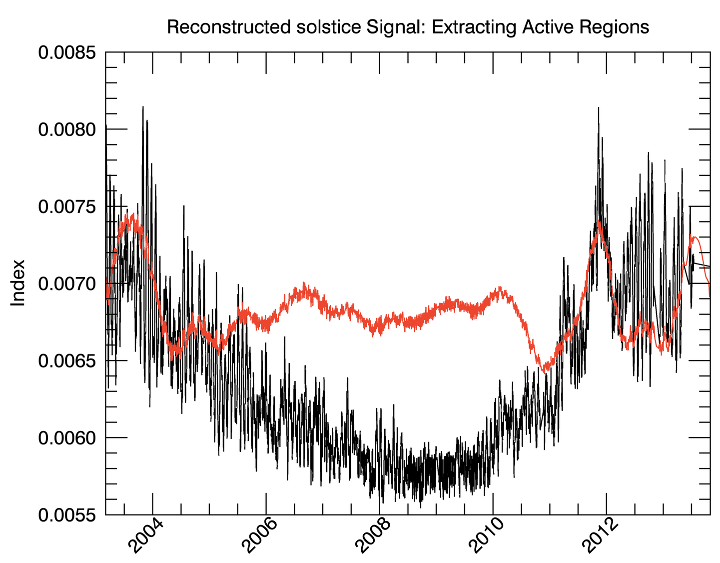

Fig. 5 **Step four:** we finally extract the average lifetime for active periods on the sun from our data. The range of time scale we use is 3-7 months. The remaining data shows that more time scales are present than those of our four original solar signals

Method of Investigation

To investigate our data we apply a wavelet analysis to determine periods of significance. We then specify source signals to extract. We begin by extracting four known solar time scales within an average range: the half rotational period of the sun (14-17 days), the full rotational period of the sun (25-28 days), the lifetime for active regions on the sun (3-7 months), and the 11- year solar cycle (9.5-13 years).

Extracting an average 11 year solar cycle from the data records of similar length is considered dubious due to the constraint in sample size. To overcome this challenge, we extrapolate the cycle signal from the full Bremen record (spanning over 35 years) onto the SOLSTICE and NOAA data sets.

After extraction of known solar trends we found an unexpected 1-2 year period common to all data sets that required further investigation.

Reconstruction Comparison

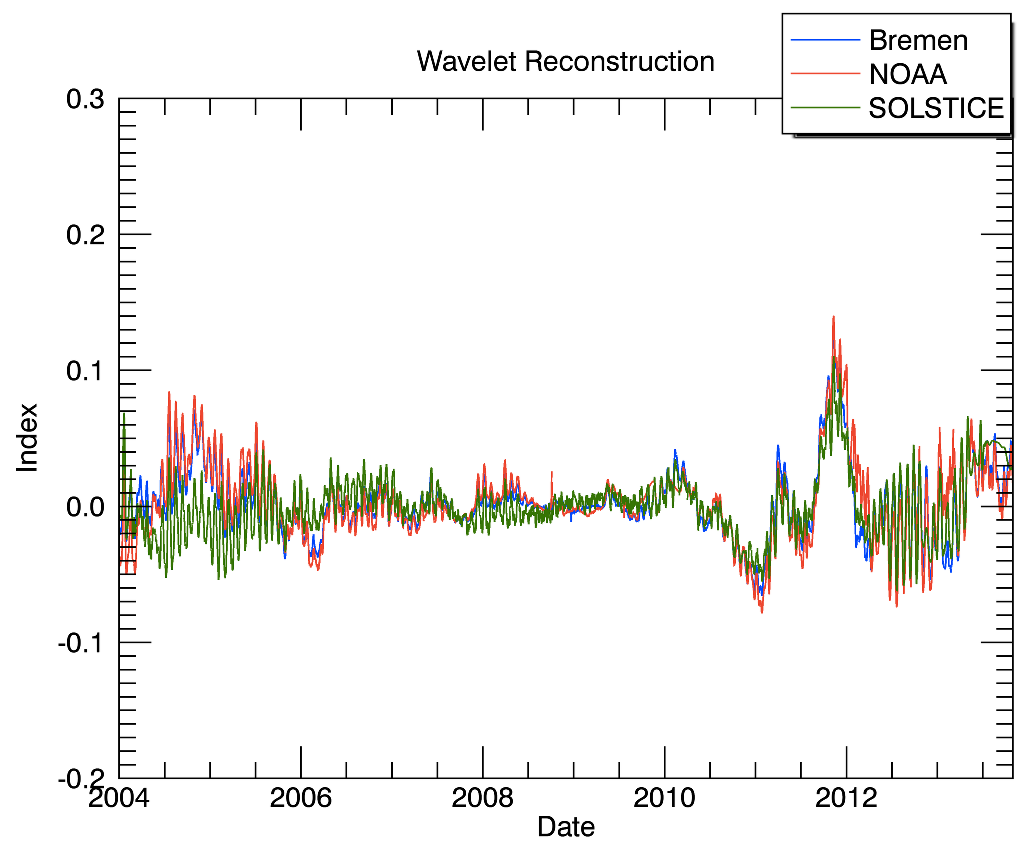

Fig. 6 Bremen, NOAA and SOLSTICE MgII indices reconstructed using the four originally known solar time scales: solar rotational and solar half rotational periods, lifetime for active region, and 11-year solar cycle.

Comparison with Ground-based Data

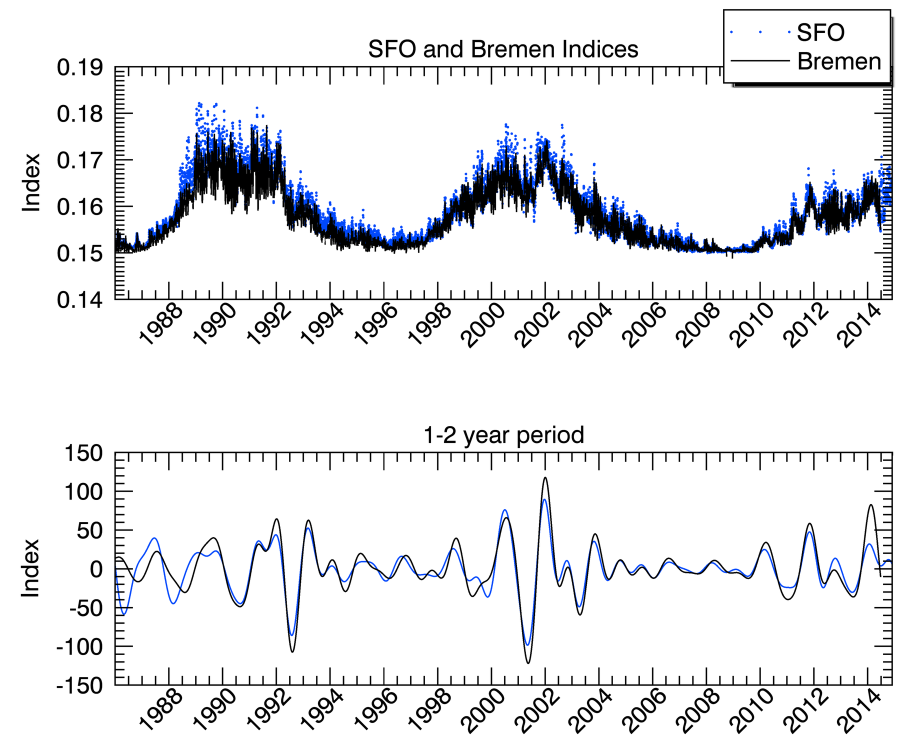

Fig. 7 Chromosphere variability from space-based and ground-based instruments compared (top) and the 1-2 year period is investigated in a comparison (bottom).

Results and Conclusion

Through our investigation we show that wavelet analysis is a viable method of investigation across multiple data sets. Wavelet analysis allows for the specification of periods for defined trends and extraction of these signals and likewise allows for reconstruction of specific signals within the data.

With this process we were able to successfully extract signals we knew to be of solar origin (half rotational, full rotational, active region, and solar cycle periods), in order to investigate the remaining signals in the data. In these remaining signals we found a significant 1-2 year cycle, common to all three sets. Subsequent study of this signal proves that it is common to both ground-based and space-based data collection. This suggests the hemispheric difference in solar activity as a possible source of the signal (see below).

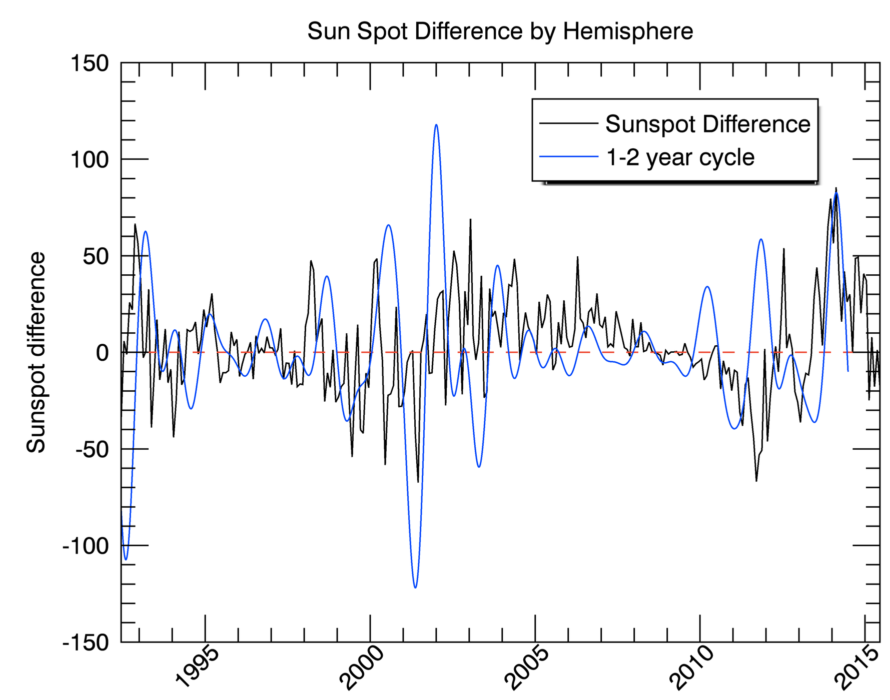

Fig. 8 The1-2 year cycle in MgII data and the temporal difference in hemispheric sunspot number is investigated. The sunspot difference is the difference in sunspot numbers (monthly mean) in each hemisphere (here the Southern sunspot count is subtracted from the Northern sunspot count).

Further Work

Comparison of signals and reconstructions between all three data sets provides information on the discrepancies and their sources between the data sets. Further application of the Bayesian method could lead to a composite MgII index with signal elements common to all records and a quantified uncertainty the resulting record.

References

Christopher Torrence and Gilbert P. Compo. *A Practical Guide to Wavelet Analysis.*

Mark Weber et.al. *The MgII Index: A Proxy for Solar EUV.*

Said Moussaoui et. al. *A Bayesian Method for Positive Source Separation.*