Looking for Changes in Photospheric Temperature Gradients over Solar Cycle 24 Using Hinode/SP

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Introduction

Throughout the 11-year Solar Cycle, changes can be observed in the magnetic field of the Sun. However, it's less known how the structure of the quiet solar photosphere changes throughout this cycle. In this project, using a simple Milne-Eddington inversion, we attempt to see if differences in the structure of the Solar Photosphere are detectable. For this project, Hinode/SP spectropolarimetric data was used, primarily for two reasons: (1) data is available from throughout the solar cycle, and (2) the data has high spectral resolution over two magnetically sensitive lines of neutral iron that are commonly used to diagnose photospheric conditions. **We focus on the search for the changes in the source function (temperature) gradient.**

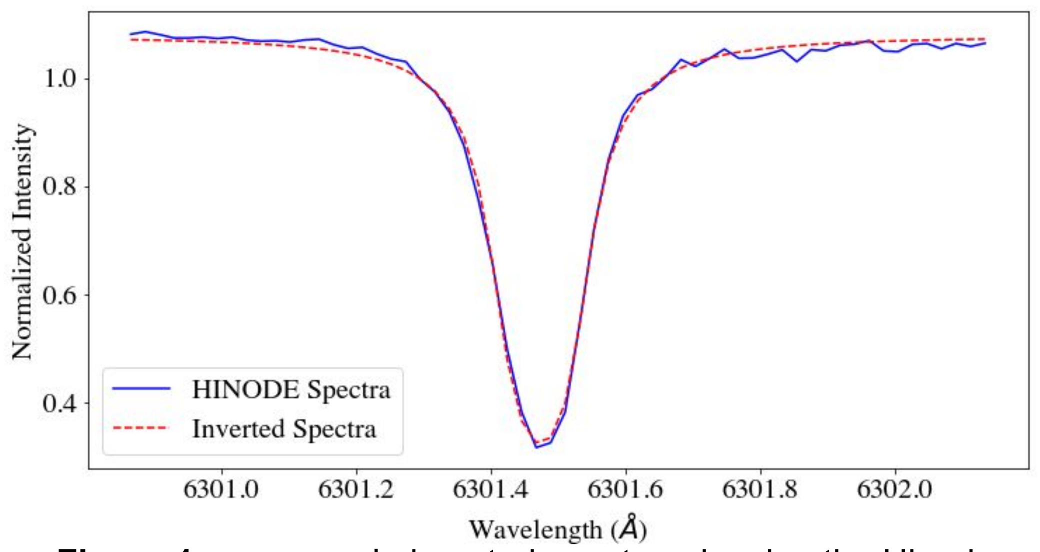

Figure 1: an example inverted spectra, showing the Hinode spectra data (blue), and the model inversion (red)

Milne-Eddington Inversions

The **Milne-Eddington model** is an approximation of the solar photosphere that allows absorption lines to be modeled with 6 parameters. Using scipy.optimize, a package in Python, an inversion scheme was developed.

Inversions find a model atmosphere that closest resembles the spectra (Figure 1). By inverting many spectra (Figure 2), we can learn about the distributions of parameters, and hope to compare these distributions between years, in both granules and intergranules.

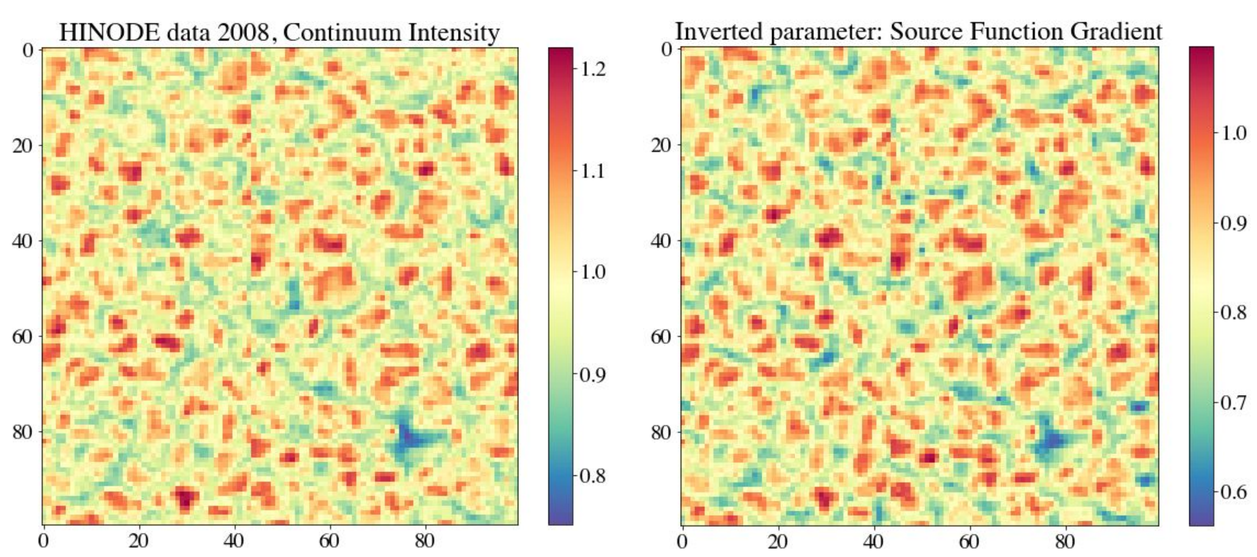

Figure 2: a map of Hinode continuum data (left), and a corresponding map of the inverted source function gradient (right). Both maps show granulation commonly observable in the Solar Photosphere

Datasets Selected

Four datasets from the Hinode archive were selected from throughout Solar Cycle 24: one in 2008, 2010, 2012, and 2014. These datasets were chosen to be near the Solar Center and absent of magnetic signatures.

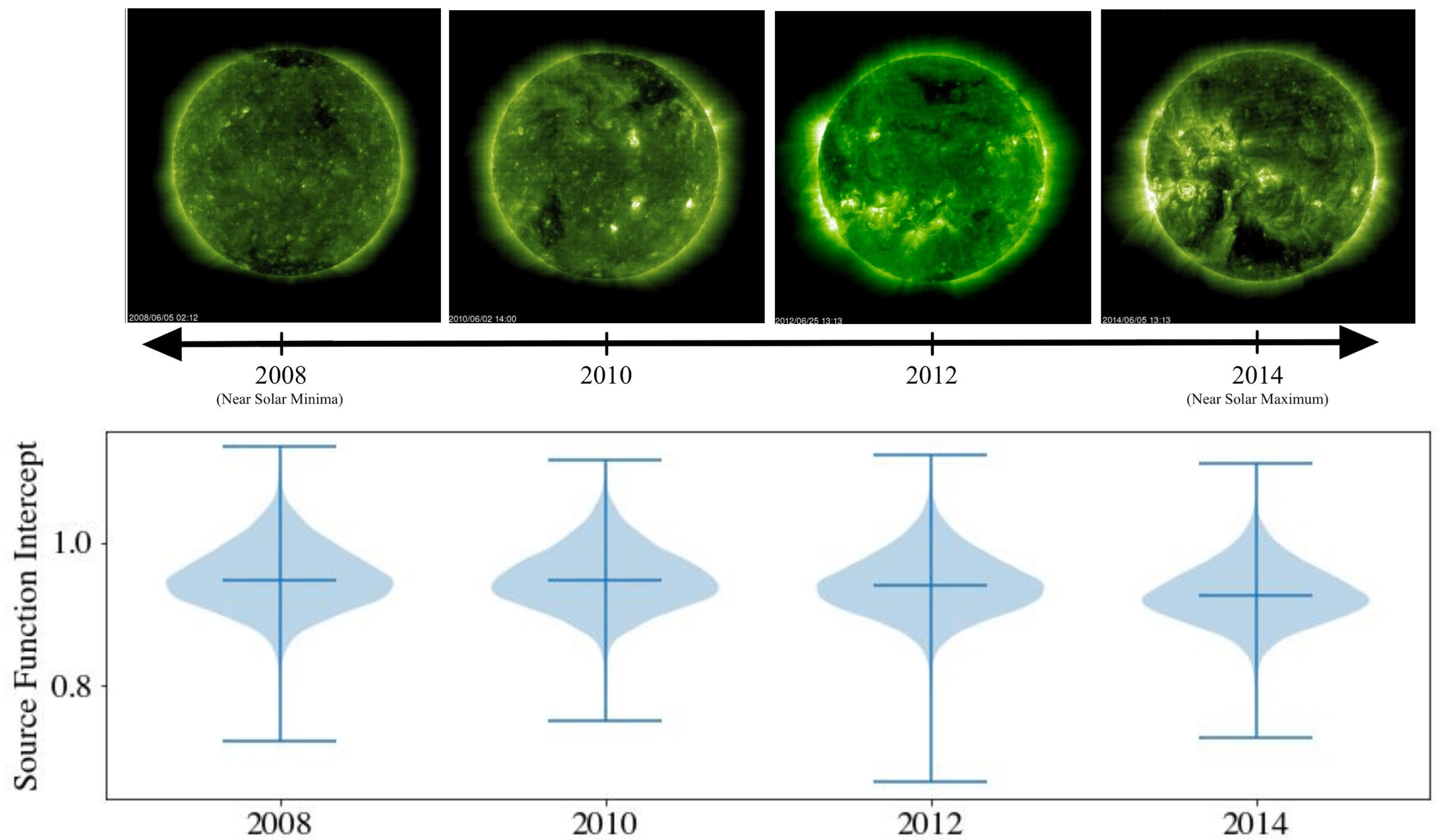

Figure 3: Top: Images of the sun (courtesy of SOHO, NASA), Bottom: distributions of the inverted source function gradient

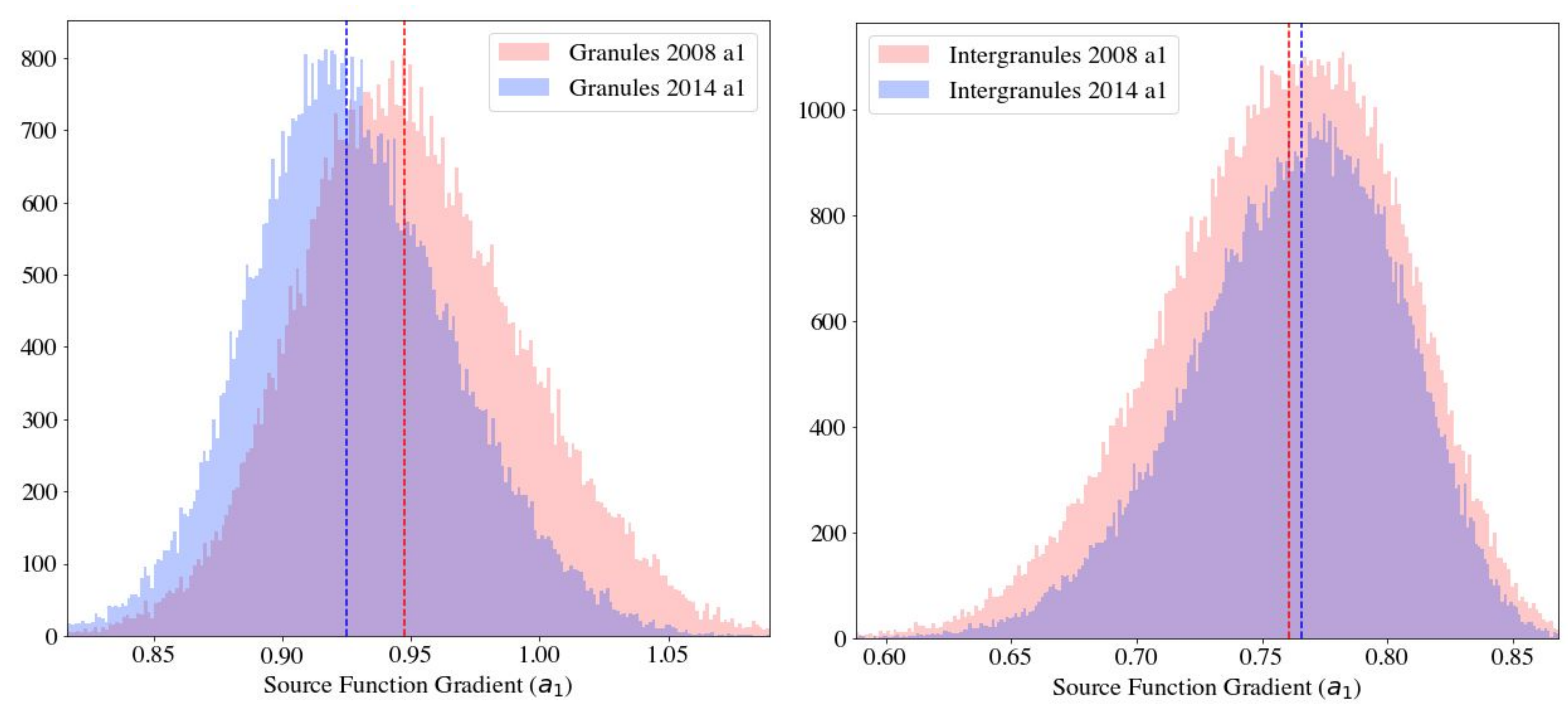

Figure 4: Results of inversions, showing the Source Function gradient distribution in the quiet Sun granules and intergranules, at a solar minimum (2008) and a solar maximum.

Inversion Results

The results of inverting data from throughout the solar cycle did not show significant systematic differences of the source function slope corresponding to changes across years. Although differences were present, and these differences were larger in granules of the Sun, these didn't change in a predictable way over the cycle.

Conclusions and Future Work

Using the methods described, we did not find significant systematic differences in the model parameters, and therefore in the temperature gradient of the Sun. This could be for a few reasons: first, there might not be detectable differences in the model parameters, and a more sophisticated model could be needed, or other factors, like subtle instrumental effects (e.g. scattered light) might obscure the variations.

We hope that more complicated models or inversion codes will be able to find systematic differences in photospheric parameters between years. Features of more sophisticated code could include velocity gradients or a more complicated source function (i.e. temperature) structure. Additionally, the effects of the magnetic field can be taken into account. We plan to continue this research using the SIR code (Ruiz Cobo & del Toro Iniesta 1992).

References

Ruiz Cobo, B.; del Toro Iniesta, J. C., 1992, Astrophysical Journal v.398, p.375