Photospheric Manifestations of Supergranules During the Last Two Solar Minima

Peter E. Williams and W. Dean Pesnell

*Code 671, NASA Goddard Space Flight Center, Greenbelt, MD, USA*

**Abstract.** Solar supergranulation plays an important role in generating and structuring the solar magnetic field and as a mechanism responsible for the 11-year solar cycle. It is clearly detected within SOHO/MDI Dopplergrams, from which a variety of properties may be derived. Techniques that extract spatial, temporal and kinematic characteristics and provide comparisons for the two most recent solar minima are described. Although supergranule lifetimes are comparable between these minima, their sizes may be slightly smaller during the recent minimum.

1. **Introduction**

Supergranules are the largest scale component of solar convection readily seen with present observing techniques. They are typically \(\sim 30\) Mm across and have been observed to live from anywhere between 1–2 days (Duvall 1980). Their relationship with local magnetic fields have been seen via diffusion studies and spatial observations of both magnetograms and CaIIK chromospheric data.

Since its inception, SOHO/MDI (Scherrer et al. 1995) Dynamics Runs have provided yearly 60-day sets of 1-minute Dopplergrams. Analysis of the 1996 data has quantified a wide variety of supergranule characteristics (for example, Hathaway et al. 2000; Beck & Schou 2000).

The most recent solar minimum has sparked much interest due to its lengthy minimum. Many studies are currently underway to understand the causes and consequences of this recent minimum.

This paper extends the analysis of supergranule characteristics to 2008 data and the results are compared to similar studies performed on 1996 data.

2. **Methods**

A series of data reduction processes were applied to the Dopplergrams to isolate the Doppler velocity signals of supergranules. The analysis was then split into studies of supergranule velocities, cell sizes and their 1/e lifetimes.

2.1. **Data Reduction**

The p-mode oscillations were removed by performing a weighted average over 31 1-minute de-rotated Dopplergrams (Hathaway 1988). The resulting time-series was sampled every 15 minutes, producing 96 images per day. Next, the global flow fields were removed (Hathaway 1987, 1992). The remaining Doppler
signals are due to the photospheric convective velocity field. These convective Dopplergrams were remapped to heliographic coordinates followed by a projection onto the spherical harmonics to produce their respective power spectra (Hathaway et al. 2000). Instrumental calibration artifacts were also removed.

2.2. Supergranule Velocities

Hathaway et al. (2002) performed a study of supergranule velocity flows using the 1996 data and compared the relative strength of the radial and horizontal components. That study was extended to investigate both the 1996 and 2008 data, detailed by Williams & Pesnell (2010, in preparation).

2.3. Supergranule Lifetimes

Correlation techniques have been used to follow supergranule patterns in the Dopplergrams as they traverse across the solar disk and measure the change in the pattern over the period of a day. A data strip, extracted near the equator, was selected from an image. A similar strip window in a subsequent image, at a given time-lag from the original, was moved longitudinally prograde across the image and the correlation noted for each pixel shift. This process was performed for all images within a single day, resulting in a two-dimensional array (pixel-shift vs. time-lag) of correlation coefficients. The region of decaying positive correlation pertaining to the evolving supergranule pattern was isolated using a Radon transform, from which the maximum correlation coefficient, \( C(\tau) \), at a given time lag, \( \tau \), was found. A plot of \( \ln C(\tau) \) vs. \( \tau \) was linearly fitted, the slope of which provided the decay coefficient of the correlation (Figure 1). The inverse of this decay coefficient gave the \( 1/e \) decay-time of the supergranule pattern.

Performing this process for the 1996 & 2008 data resulted in a series of decay-times for each day. Treating each decay-time as an independent result, a harmonic mean provided the average decay-time for each data-set.

2.4. Supergranule Sizes

Using the method described by Hathaway et al. (2000), power spectra were produced for each Dopplergram contained in the 1996 and 2008 datasets. Mean spectra were produced for both years by averaging over all the individual spectra. A best-fit to the supergranule feature (\( 1 \leq \ell \leq 250 \)) was deduced, using a modified Lorentzian function (Figure 2). Although the fit deviates from the data at higher wavenumbers, this is of no consequence to the study as only the behavior near the peak is of interest. The location of the peak in the fitting determines \( \ell_{\text{max}} \) and the FWHM of the supergranule distribution. From the peak and FWHM, the typical diameter and size range of supergranules was determined.

3. Results

The supergranule velocity analysis was performed out to an angular distance of \( \rho \sim 30 \) degrees. The 2008 data produced radial and horizontal RMS velocity components of \( v_r = 40 \) m/s and \( v_h = 303 \) m/s, with \( v_r/v_h = 0.13 \). The 1996
Supergraules During the Last Two Minima

Figure 1. A log-linear plot (crosses) of correlation coefficient vs. time-lag represents the change of a supergranule pattern during a single day. A linear fit to the plot (solid line) extracts the decay coefficient for the convection pattern and, subsequently, its $1/e$ decay-time. The squares signify the points between which the fit was performed. For this particular day (in this case May 4, 2008), the decay coefficient is 0.0643, giving a decay-time of 16 hours.

Figure 2. A 60-day average of MDI convection spectra from 2008 (points) is fit with a modified Lorentzian. The fit (dashed line) is produced within a given range ($1 \leq \ell \leq 250$). The function is extended throughout the full data range for illustration purposes (dotted line). The FWHM (solid line) is shown within the supergranule feature.

data produced $v_r = 24$ and $v_h = 278$ m/s, with $v_r/v_h = 0.09$. These values have an error of $\pm 1$ m/s.

For 2008, the correlation analysis gave a mean decay coefficient of $0.056 \pm 0.001$ correlation coefficient units per hour. Calculating decay-times from each
coefficient, the harmonic mean calculation gave a $1/e$ decay time of 18 hours. This value was also derived using the same process for the 1996 data.

For the supergranule size analysis, the 2008 dataset gave a peak wavenumber of $\ell = 124 \pm 1$ and an FWHM of $\Delta \ell = 168 \pm 5$. These results respectively correspond to an average supergranule diameter of 35.2 Mm and a diameter range of 18.7-67.2 Mm. For 1996, the peak wavenumber was found to be $\ell = 121 \pm 1$ and an FWHM of $\Delta \ell = 160 \pm 3$, corresponding to an average diameter of 36.1 Mm with a diameter range of 19.5-68.3 Mm.

4. Analysis, Discussion and Conclusion

While the $1/e$ lifetimes are found to be the same for both years, the supergranule cell sizes tend to be slightly smaller during 2008. A significant discrepancy, however, is found within the velocity analysis.

Although the 1996 results are in line with those found by Hathaway et al. (2002), the 2008 velocity values are considerably greater. Image defocusing during 1996 (Korzennik et al. 2004) may influence the velocity values contained within the Dopplergrams by altering the resolution of the instrument. Active regions present on the disk may contribute to spurious velocity values within the calculation (Liu & Norton 2001). Any images displaying significant activity are currently removed from the analysis, whereas future analyses will use magnetograms to mask out these regions so the images may be included.

Comparing the past two solar minima, the decay rate and decay-times of the supergranule pattern have not changed. Missing images within a day’s data currently means removing that day from the analysis, which reduces the sampling for the averaging. Future work will update the analysis process so that loss of data within a day will not mean that the whole day needs to be skipped.

The size analysis is much less problematic although it can be improved using a statistical analysis of the extracted parameters for each Dopplergram-derived spectrum. This is planned for the future along with producing similar statistics for the lifetimes and velocity analyses.

Acknowledgments. Peter Williams is supported by the Solar Dynamics Observatory via the NASA Postdoctoral Program, managed by Oak Ridge Associated Universities of Oak Ridge, Tennessee. SOHO is a project of international cooperation between ESA and NASA.

References

Beck, J.G., & Schou, J. 2000, Solar Physics, 193, 333
Duvall, T.L., Jr. 1980, Solar Physics, 66, 213
Hathaway, D.H. 1987, Solar Physics, 108, 1
Hathaway, D.H. 1988, Solar Physics, 117, 1
Hathaway, D.H. 1992, Solar Physics, 137, 15
Hathaway, D.H., Beck, J.G., Bogart, R.S., Bachmann, K.T., Khatari, G., Petitto, J.M., Han, S., & Raymond, J. 2000, Solar Physics, 193, 299
Hathaway, D.H., Beck, J.G., Han, S., & Raymond, J. 2002, Solar Physics, 205, 28
Korzennik, S.G., Rabello-Soares, M.C., & Schou, J. 2004, Solar Physics, 602, 481
Liu, Y., & Norton, A.A. 2001, SOI Technical Note 01-144
Scherrer, H. et al. 1995, Solar Physics, 162, 129