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Granule and Supergranule properties derived from solar timeseries

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Abstract. In this paper we mainly aim at the understanding of temporal evolution and spatial characterization of solar granular and supergranular features. For this purpose we apply an automatic feature-tracking algorithm to three different solar granulation timeseries and to a supergranular timeseries of near-surface divergence fields. The single lifetimes are calculated measuring the time elapsing between the birth and death of each target. In addition, we investigate spatial order of surface flows studying the $g_2(r)$ function of time-averaged supergranular fields.

Key words. Granulation – Supergranulation – Numerical Techniques

1. Observations and image pre-processing

In this paper we present results based on the analysis of three different granulation timeseries and a supergranular sequence derived from MDI Dopplergrams.

The first granulation image sequence (hereafter THEMIS99) we used has been acquired at the THEMIS telescope (Observatorio del Teide, Tenerife, Spain) in IPM observing mode on July 1, 1999.It is made up of 30 " × 30 " 608 broad-band images with 0.04 s exposure time. A detailed description of observations and the data reduction procedures can be found in Berrilli et al. (2002). A second image sequence (hereafter NSO96) has been acquired at the NSO Vacuum Tower Telescope (Sacramento Peak, Sunspot, New Mexico) on October 16, 1996.This broadband sequence is made of 512 images with field of view of 31.5 " × 31.5 ", each taken with an exposure time of 0.008 s. Refer to Cauzzi et al. (1998) for a detailed description of these data. The third granulation timeseries (hereafter SVST95) has been acquired at the Svedish Vacuum Solar Telescope (Roque de los Muchachos, La Palma, Spain) on June 30, 1995. The

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series is made up of 220 broadband images with field of view of 18 " $\times$ 18 ", each taken with an exposure time of 0.011 s. The 5-minutes oscillation pattern has been removed from the three timeseries via $k_h - \omega$ filter.

The Supergranulation sequence (hereafter DG2K) derives from the application to a timeseries of SOHO-MDI full-disk Dopplergrams and magnetograms of a time-distance helioseismological technique. This technique was developed by Duvall and others (Duvall et al. (1993)) and uses acoustic wave travel times to infer the structure and dynamics of the solar interior. The details of the data pre-analysis procedure are described in the paragraph 2 of Duvall and Gizon (2000).

2. TST: Two-level Structure Tracking procedure

We developed and applied to the image series an automatic procedure of recognition and tracking, in order to objectively describe morphological and dynamical properties of solar features. The Two-level Structure Tracking (TST henceforth) procedure recognizes structures in single images, to derive morphological end topological information on such structures, or, using image timeseries, to trace structures in time, in order to investigate their time properties and reconstruct horizontal velocity fields. For the description of the TST procedure we post to other publications (Berrilli et al. (2003)).

3. Discussion

In this section we discuss the results obtained from the application of our procedure on 4173 tracked granules found in the THEMIS99 timeseries, on 6940 tracked granules found in the NSO96 timeseries, on 1952 tracked granules found in the SVST95 timeseries, and on 360 tracked supergranules found in the DG2K timeseries.

3.1. Horizontal velocity fields and velocity histograms for granulation timeseries

Horizontal velocity fields can be derived using the intensity barycenter motion of identified structures. The atmospheric seeing introduces spurious motions producing a horizontal velocity field, which superpose on the actual granular movement. In order to remove this false field we compute the average barycentres position each 40 seconds for granulation images. The relative displacements, between these averaged barycentres, are used to derive a sparse array of velocities, which could be interpolated to improve the density of sampling. Horizontal velocity histograms have been calculated from TST derived horizontal velocity fields for both time series. NSO96 and SVST95 series show a clear peak around 1.5 $km\ s^{-1}$ and a typical Maxwellian distribution, as expected, while THEMIS99 series histogram has a missing peak around 1.5$-$2.0 $km\ s^{-1}$ and a long tail towards high velocities. Such a tail should be due to image motion introduced by a not efficient tip/tilt correction.

3.2. Granular lifetime distributions

The temporal behaviour of recognized features, both granular and SG, can be investigated using TST procedure. Their lifetimes can be obtained measuring the time elapsing between their birth and death, deriving the distribution functions reported in Figure 1. A double exponential fit (gray line) is superimposed on each histogram to estimate mean lifetime. The double exponential seems to be a sign of the presence of at least two different granular populations: one with a very short mean lifetime ($\tau \sim$ 1 minute) and a second with a longer mean lifetime ($\tau \sim$ 4 minutes).

3.3. Supergranular lifetime distributions

In Figure 1 we report the number of supergranule vs their lifetime. A single

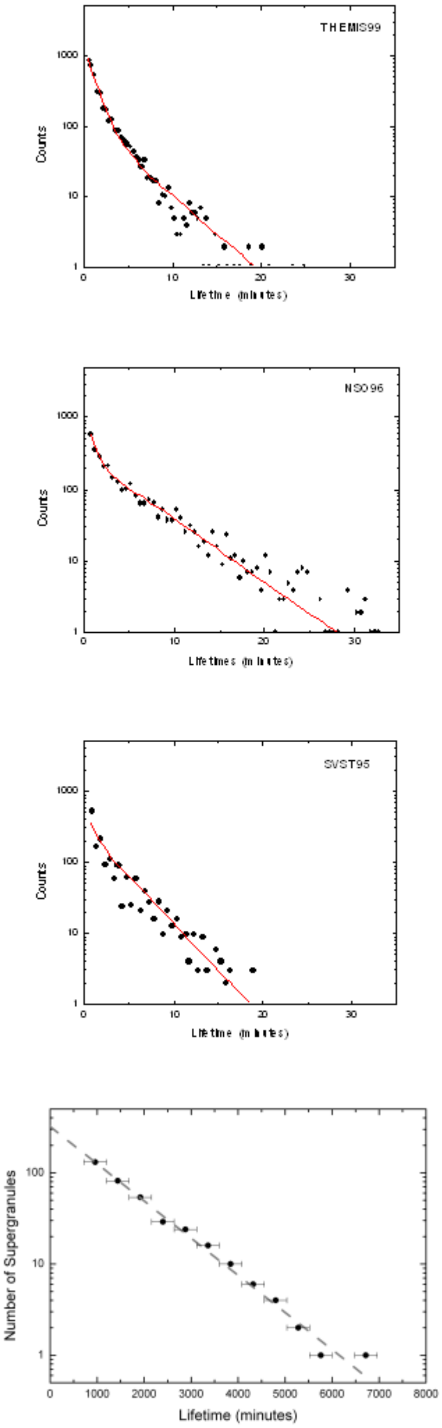

Fig. 1. Histogram of structures lifetime for THEMIS99, NSO96, SVST95 and DG2K series with exponential fit to the data superposed.

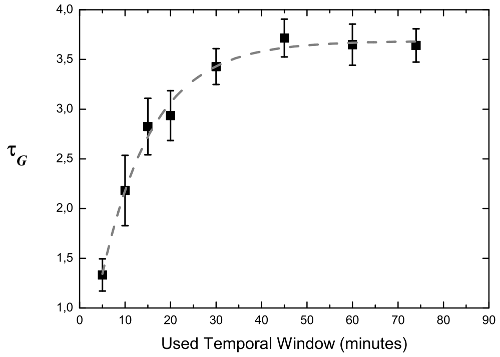

Fig. 2. τ_G values (black squares with error bars) vs timeseries length for SVST95 and an exponential growth fit (gray dashed).

exponential decay law seems to fit very well the data and we derive τ_{SG}= 1065 minutes ($\sim$ 18 hours) as the estimated mean lifetime.

Such value for τ_{SG} is comparable to the dataset length ($\sim$ 6 days), so we decided to investigate the effect of the dataset length on the evaluated value τ_{SG}. In order to perform this check we used the quiet granulation timeseries investigated via the TST procedure. In this case we already know that $\tau_G \ll$ whole dataset duration, so we were able to derive the τ_G as a function of the used temporal window length. The result of such analysis for the SVST95 series is reported in Figure 2. More in detail we can be confident about the lifetime value only when the observation period is much greater ($\geq$ 10 times) than the τ_G. Using the plot of Figure 2 to estimate the correction, we obtain a adjustment of about 20%, corresponding to an actual value of $\tau_{SG} \sim$ 22 hours.

4. Pair correlation function $g_2(r)$ of supergranular fields

In this section we plan to investigate the presence of a structure underlying the supergranular pattern. In order to reveal and describe a possible near neighbour organization we used the *Pair Correlation*

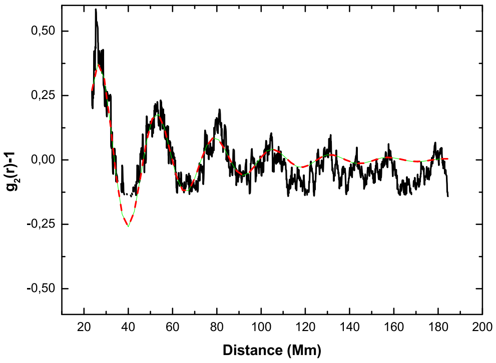

Fig. 3. $g_2(r)$ of the time-averaged image of DG2K timeseries (black continuous) and a damped sine fit (gray dashed).

Function $g_2(r)$. For the description of the implementation of $g_2(r)$ algorithm we post to other publications (Berrilli et al. (2003)).

In order to probe the existence of a structural organization in the supergranular pattern we have time averaged the DG2K series over the full observing period to retrieve the mean supergranulation pattern. In Figure 3 we show the $g_2(r)$ extracted from this time-averaged image with superimposed a damped-sine fit. From this fit we obtain an ordering pace of $\sim$ 26 Mm and a decorrelation length of $\sim$ 40 Mm. In order to check this evaluation, we have also performed a Fourier analysis, which revealed a major peak at $\sim$ 26 Mm. This ordering pace can be related to the mean size of supergranular cells. The short (less than 2·pace) decorrelation length suggests no interaction but the first-neighbourhood one. Should this be the case, as observed for example in amorphous material, the $g_2(r)$ would present few bumps placed in positions corresponding to local ordered structures, while at long distance its behaviour would be similar to completely disordered systems (i.e. $g_2(r) \longrightarrow 1$ as $r \longrightarrow \infty$).

5. Conclusions

The TST procedure we developed extracts histories of single structures, from image timeseries, that can be used to derive horizontal velocity fields and granulation/supergranulation temporal properties. Applying the TST procedure to the THEMIS99, NSO96 and SVST95 image series, it led to comparable results. The lifetime's distributions of granules show two-population behaviour, one with short ($\sim$ 1 minute), the other with longer ($\sim$ 4 minutes) lifetimes. The TST procedure has been successfully applied also to the DG2K timeseries, leading to an estimation of supergranular lifetime ($\sim$ 22 hours). We investigated the possible organization in SG field via the application of the $g_2(r)$ function on the mean SG pattern derived from the DG2k series. Such analysis suggests only local (first-neighbourhood) interactions of supergranules, however, this interpretation has to be corroborated with other $g_2(r)$ analysis of SG fields, in order to acquire a more conclusive statistic.

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