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Evolution of solar granulation fields from THEMIS-IPM time series(*)(**)

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Summary. — The temporal evolution of solar granulation has been investigated using a time series of high spatial and spectral resolution images acquired at the THEMIS solar telescope (Observatorio del Teide, Tenerife) using the IPM observing mode. In order to investigate different physical properties of solar granulation (associated horizontal velocity fields, lifetimes, intensity and geometry evolution), we identify and track solar granules automatically. We discuss the obtained results and compare them with results reported in the literature. In order to overcome problems of atmospheric distortions, we also implement a FORTRAN95 code for the application of the Phase Diversity technique that is planned to be used at the THEMIS telescope.

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1. – Introduction

Convective instabilities present in the Sun external layers produce matter flows that are responsible for the appearance of intensity patterns, with different spatial scales, visible on the solar surface. The physical properties of convection, particularly of small-scale convective features (granules), have been investigated using both computer simulations [1-4], and high-resolution spatial and spectral observations. More in detail, the study of horizontal component of granular velocity and of granular lifetimes, has been carried out by several authors (see references in [5]). The observation of surface flows and

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the determination of granule mean lifetime are important since they may be compared with assessments from convective theory and simulations.

In order to trace horizontal flows on the solar photosphere, the small-scale convective features, the granules, may be used. Recently Rieutord *et al.* [6] estimated the spatial and temporal limitations of this approach. With the assumption that trackers motion is mainly driven by plasma flows, it is possible to employ two approaches to infer horizontal velocity fields: local correlation or feature tracking techniques. Recently the feature tracking methods have been used by Hirzberger *et al.* [7] to study the evolution of individual solar granules and by Rieutord *et al.* [8] to investigate the mesogranulation properties.

To study the granulation dynamics, we developed, in IDL language, a procedure that simplifies granules in Two-level Structures and Track them (hereafter TST procedure).

Because atmospheric seeing introduces spurious motions on acquired images there results necessary to implement an experimental set-up to reduce this effect. At the moment an adaptive optics scheme for the THEMIS telescope is under study. The optical scheme also includes a last beamsplitter to apply the Phase Diversity (PD) restoration technique. We wrote and tested a complete numerical procedure in FORTRAN95 language that, using a set of focused-defocused image pairs, produces a set of restored images.

2. – Observations and image pre-processing

The image sequence we used has been acquired at the THEMIS telescope (Observatorio del Teide, Tenerife) in IPM observing mode [9] on July 1, 1999 (from 7:21 UT to 8:24 UT). A detailed description of observations and the data reduction procedures can be found in this issue [10]. The images used in this work have been acquired with the broad-band CCD camera (central wavelength 538.0 nm, band-pass 4 nm). After the standard correction, a sub-field of 30 arcsec × 30 arcsec (222 × 222 pixels) made up the final images. Each image was acquired with an exposure time of 0.04 s. Before our analysis, we removed the acoustic modes pattern from the images by a $k_h - \omega$ filtering, with a cut-off velocity of 6 km s^{-1}, and applied a Wiener filter to restore the image. To further improve the image quality, we are now developing an Optimum Restoration Filter [11], which "measures" the noise and restores images, without any assumption about the SNR (as happens with Wiener filters).

3. – Image segmentation and granule tracking

The numerical procedure which, starting from pre-processed images, produces the life-history of single granules and the horizontal velocity fields, can be divided into three steps:

a) segmentation;

b) labelling;

c) tracking.

The segmentation task (*step a*) breaks up the pre-processed image into regions corresponding to constituent coherent structures (*i.e.* granules). This algorithm, based on a self-adapting procedure using a dynamical threshold [12], produces a two-level, or black and white, version of the granulation image. After an image has been segmented into regions, we label (*step b*) them with a unique index. We retain as granules the regions

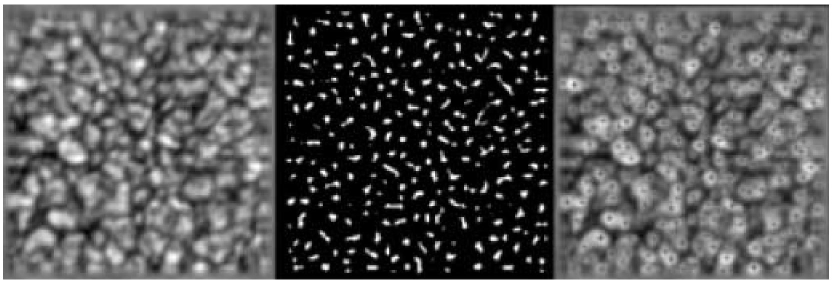

Fig. 1. – Left: pre-processed image. Center: two-level image obtained with adaptive algorithm. Right: the original image with superimposed the location of the barycenters of found granules.

whose areas range from 0.1 and 3 Mm^2 and with a "regular" geometry. The morphological describer Perimeter$^2/4\pi\times$ Area, being 1 for a circle, has proved a good appraiser for the regularity of regions. As we want to discard regions whose deformations can introduce spurious velocity fields, we found reasonable to keep regions whose parameter is less than 4. These bounds represent a good compromise to retain "regular" convective features. After this selection, the procedure extracts and stores geometrical describers of these regions in a database.

The structure tracking (*step c*) is accomplished using both the information collected in the database produced by the *step b* and the two-level granulation images produced by the *step a*. In detail, starting from a chosen image of the temporal series, all stored granules are selected and tracked forward in time. For each granule an area, centered in its barycenter and with a selected radius, is defined. All the granules of the succeeding image, whose barycenters are contained in this area, are compared in shape with the original granule. The granule whose shape closest matches with the original granule's and anyhow is within a maximum allowed deformation value, is retained and considered as the evolution of the original granule, otherwise the process stops. The outputs of *steps a* and *b* are shown in fig. 1. To insure optimal performance on different sets of images, several parameters of the TST procedure have been made self-adapting or easily changeable by the user. TST has been applied on simulated granulation images to test its reliability, finding a velocity field in good agreement with the synthetic one.

4. – Discussion

In this section we discuss the results obtained from the application of our procedure on 4173 tracked granules found in the THEMIS broad-band image timeseries (608 images).

4˙1. *Horizontal velocity fields*. – Horizontal velocity fields can be derived using the intensity barycenter motion of identified granules. 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 average barycenter positions every 10 images (approximately 40 seconds). The relative displacements, between these averaged barycenters, are used to derive a sparse array of velocities, which could be interpolated to improve the density of sampling (fig. 2).

4˙2. *Lifetime of granules*. – The histories of single recognized granules, derived from TST, allow us to study their temporal behavior. For instance it is possible to derive

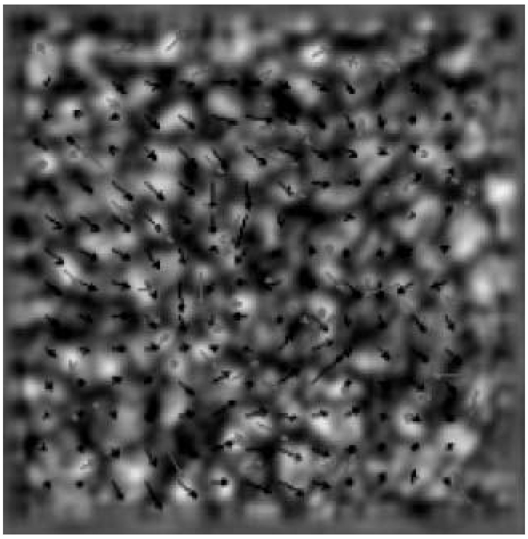

Fig. 2. – Original broad-band image, with averaged horizontal velocity field superposed.

their lifetimes, measuring the time elapsing between their birth and death, deriving the distribution function reported in fig. 3. On the histogram is superimposed a double exponential fit (solid line) to estimate mean lifetime. The double exponential seems to be a sign of the presence of two different granular populations: one with a very short mean lifetime ($\tau \sim 1$ min) and a second with a longer mean lifetime ($\tau \sim 4$ min). Different conditions of birth and death of granules, combined to different sampling intervals, may possibly explain the slight discrepancy between our mean lifetimes and the values reported in the literature (as, for example, in [7] that derives a mean lifetime of ~ 4.5 min).

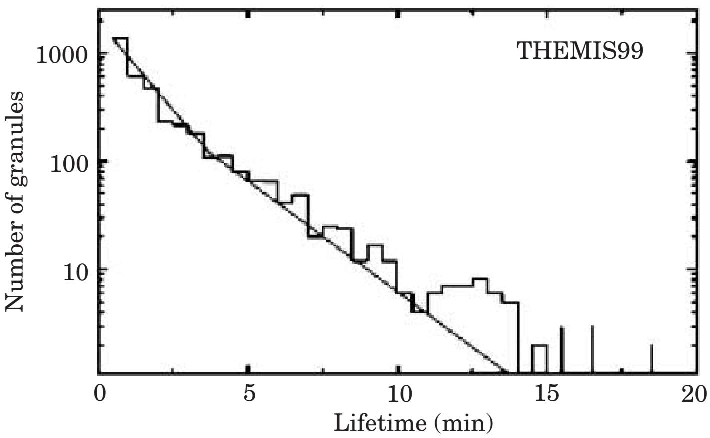

Fig. 3. – Histogram of granule lifetime for observed quiet granulation field. The solid line represents a double exponential fit.

5. – Image restoring

The IPM acquired images are affected by atmospheric seeing degradation. As above discussed, the seeing introduces spurious motions and geometrical distortions that are not proper of the granulation pattern and that should be taken into account. The Phase Diversity technique (PD) can improve the image quality wavefront phase aberrations induced by Earth's atmosphere. The PD determines wavefront aberrations at the entrance pupil of the telescope by means of the information contained in two simultaneously recorded frames, one focused and the other affected by a known amount of defocus [13]. The algorithm, through an iterative procedure, outputs the wavefront, in term of Zernike's expansion coefficients, and the restored isoplanatic-patch frame. The different restored frames are assembled to reconstruct the restored image. We realized the PD software in F95 language in order to save computational time. The required time to restore a single image of 512×1024 pixels is approximately 30 minutes on a Athlon 1.3 GHz PC.

6. – Conclusions

The TST procedure we developed extracts histories of single granules, from image timeseries, that can be used to derive horizontal velocity fields and granulation *d*. As a first result of this procedure, the mean lifetime of granules in THEMIS image series has been estimated. Two populations of granules have been found, one with a shorter mean lifetime (~ 1 min) and one with a longer mean lifetime (~ 4 min).

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