GRANULAR EVOLUTION FROM 2D(X,T)-SLICES AND FROM TRACKING GRANULES

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ABSTRACT

The evolution of granules can be investigated in various ways, two of them have been selected for this paper. The first method makes use of 2 dimensional slices of the data set containing granulation images with one spatial and one time dimension. In these slices the evolution can be seen very clearly. The second method tracks individual granules from one image to the next. With these methods we want to find automatically different types of granules, like exploding granules, merging granules, or granules that fade away. In combination with velocity fields (divergence patterns) we also want to show the relation between exploding granules and mesogranules.

Key words: sun;granulation;mesogranulation.

1. INTRODUCTION

The Russian astronomer Alexis Hansky (1870 – 1908) used a conventional astrograph and an enlarging camera for high-resolution photography of the solar disk. He tried to get sequences of granulation photographs separated by short time intervals in order to study the changes in the granules with time. Although his attempts were only partially successful, he derived an estimate of about 5 minutes for the mean lifetime of the granules. With better instruments and better data acquisition these measurements have been improved and a lot of questions arose. The evolution of the individual granules did not behave in a simple manner. The lifetime measurements (e.g. Bray & Loughhead (1984), Deubner et al. (1978), Mehltritter (1978), Alassandrakis et al. (1987)) have been done with some restrictions, the birth and death of granules had to be defined. Mehltritter (1978) found that merging granules have shorter lifetimes and granules that dissolve live longer. Kawaguchi (1980) found a relation between the size of the granules and their birth. Hirzberger et al. (1999) investigated the evolution of granules and defined several different types of granules; he obtained 30.2% fragmenting, 15.9% dissolving, and 52.9% merging granules - the selection of the types was done manually.

2. OUR DATA

The data were obtained by G. W. Simon, P. N. Brandt, and R. A. Shane (Simon et al. (1994)) on 5th of June 1993 at the Swedish Solar Observatory on La Palma. A total of more than 3700 images (2 images per 21 sec) at a wavelength of 468±5 nm with very high quality have been obtained in 11 hours. The corrected and reduced images had a size of 64 x 64 arcsec (8 pixels/arcsec) including apodised borders (5%) and the length of the series was about 8.75 hours (1500 images, the better one of each image pair was taken). 76% of the images have a contrast better than 8%.

3. METHODS

3.1. Space-Time Slices

Space time slices are 2 dimensional sections through a 3 dimensional data set in the time direction, i.e. the resulting data set has one time and one spatial dimension. The simplest way is just to use one row or column of each image and put them together in ascending time. In our case we used a row in the center of our images. The resulting image has then the dimensions 64° x 8.75 hours (512 x 1500 pixel).

Such an image (as Fig. 1) shows very clearly the evolution of the granules that are intersected, it even seems to be the case that there are granules that can be followed through the whole time series. The next step is to distinguish between granular and intergranular regions, this is done by a simple unsharp masking procedure. The unsharp masking is applied line by line so that only a spatial smoothing is performed. In order to find the granular type the geometrical granular centers in each line are marked.

By this procedure granules are defined as structures with \((x,t)\) coordinates, they are temporal cross-sections at a fixed location. Events such as fragmenting, merging, or fading away can happen more than once per granule. In Fig 2 one can see that a granule can have branches upwards and downwards, the upward branches are fragmenting events, the downward branches are merging events, and each dead end is a fading away event.


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The type of the granule events is then detected by counting the number of centers and interpreting the change of this number. A merging happens when the number of centers decreases and the pixel after the last centers is not intergranular. A fragmenting event occurs when the number of centers increases. If the number of centers decreases it has also be checked if the following pixel is intergranular, which will lead to a fading away event. A hole, which is an intergranular region inside a granulum, consists of a fragmenting and a merging event, this can also be wrong if the granulum is only ring-like or u-shaped. In Fig. 2 we show how the types are selected in principle. Exploding granules are only detected in the fragmenting type of granules – a cross section through an exploding granule shows in most cases more than one center (e.g. if it is ring-like a cross section will show 2 granules, except the section is tangential). Not all exploding granules are detected in this way, but they are larger in size than other granules and therefore they are more likely to be detected. The detection of exploding granules is done by calculating the mean velocity of the expanding branches in our granule. If a threshold velocity of 2 km/s is set 4.2% of all events are exploding events, with 3.0 km/s only 2.0% are remaining.

3.2. Tracking Granules

In this method granules are tracked forward in time from one image to the next. At first granules have to be separated from the intergranular regions, this is done with a Fourier filter described in Roudier & Muller (1986).
The granule tracking method

<table>
<thead>
<tr>
<th>Rel. Num. (%)</th>
<th>fr</th>
<th>fa</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Dia.</td>
<td>52.9</td>
<td>19.7</td>
<td>27.4</td>
</tr>
<tr>
<td>Mean diverg.</td>
<td>1.94&quot;</td>
<td>0.35&quot;</td>
<td>1.84&quot;</td>
</tr>
</tbody>
</table>

The space-time-slice method

| Rel. Num.     | 35.7 (4.2) | 46.5 | 17.8 |
| Mean diverg.  | -0.023 (-0.006) | 0.004 | -0.025 |
| Hirzberger et al. | 30.2 | 15.9 | 52.9 |
| Mehlitrette | 50 | 20 | 30 |

| Granule types and divergence: The relative numbers for the different types: (fr) fragmenting, (fa) fading, (m) merging, exploding are put into brackets. The mean diameter depends on the type, but the mean divergence is nearly the same for all types. |

Table 1. Granule types and divergence: The relative numbers for the different types: (fr) fragmenting, (fa) fading, (m) merging, exploding are put into brackets. The mean diameter depends on the type, but the mean divergence is nearly the same for all types.

Figure 4. Space-time slice of divergence: The divergence was integrated over 20 minutes (= 57 images), then a column of each divergence image was taken and plotted. The bright ridges are the upflow regions (mesogranules?), from this image their size seems to be about 3", their lifetime somewhere between 50 and 150 minutes and they show horizontal motions from the mesogranule in the white rectangle one can derive a velocity of about 0.5 km/s.

3.3. Mesogranules

In order to make the mesogranulation visible, November et al. (1981) averaged velocity images in Fe I, Mg I, and Ca II lines over about 1 hour. They averaged them at different resolutions (1", 3", and 9"), the best images of the mesogranular pattern were obtained by subtracting the 9" averaged supergranular pattern from the 1" averaged velocity images. As a result they got a cellular pattern of 5 to 10 Mm in size.

Our mesogranulation images were produced by the following method: The displacement vectors between each pair of images in our time series were calculated with the Local Correlation Technique method using a Gaussian window of 1.5 and of 6°. Then the difference between the 6° and the 1.5 velocities have been taken in order to remove the supergranular background. In the temporal direction a moving average over 20 minutes (57 images) is applied. If from each of these divergence images only one column is taken (always at the same spatial position) and combined to a space-time slice, an image as shown in Fig. 4 is obtained. The plot shows dark and bright ridges corresponding to downflow and upflow regions, respectively. The bright upflow regions can be interpreted as mesogranules.

4. RESULTS

When detecting the granular types, also the position of each granule has to be stored, the position is defined by all granule pixels and the time, when the event happens. Table 1 shows the number obtained with the two different methods and a comparison with two other authors. The two methods produce more or less completely different results, especially the number of granules that fade away is enormous for the space-time-slice method. The values of the tracking method are in relatively good agreement with Hirzberger et al. (1999), who obtained their results manually, but they investigated only 481 granules whereas we had 49819. The mean divergence of the granule positions are nearly 0 (the maximum possible divergence values are \( \pm 5 \times 10^{-5} \) s

The exceed plots in Fig. 5 show the following: In the upper left panel one can see that the mean divergence is negative, and additionally the whole histogram is not symmetric. There are more small negative divergence values than small positive ones, but more large positive divergence values than large negative ones. The fragmenting and the merging types show nearly the same underlying velocity field, they are lying on positive divergence regions. The fading away granules show the opposite behavior, they have a strong depression in positive divergence values (down to -30%).
not far away from the result of Hirzberger et al. who had obtained their values manually.
Using space-time slices is affected with the problem of velocities perpendicular to the slices, i.e. in an \( x \times t \) slice the \( y \) velocities are not taken into account. Due to this perpendicular velocity field a lot of granules seem to fade away because they leave the slice and move into the neighbor slice. The \( x \times t \) slice show at a first glance very clearly the granular evolution, but in this form they cannot really be used for investigating the temporal behavior of the granulation.

These results are not in coincidence with Straus et al. (1992), who could not find a dividing line between granulation and mesogranulation. An additional test with different averaging times of the mesogranular field lead to the same results which is contradictory to Rieutord et al. (2000), who showed that it is possible to generate different mesogranule properties by various averaging techniques and scales.

In the future we also want to separate exploding granules with the tracking method, and see if their behavior is more linked to the mesogranular field than that of the fragmenting granules.

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5. DISCUSSION

Table 1 and Fig. 5 show a completely different result. This is mainly due to the mean divergence of the total field, which is negative. But the field is not only negative it is also asymmetrical, which tells us something about the upflows and downflows. The excess is positive for large divergence values, which means that upflows are faster, and the downflows seem to be slower, because there excess is positive for small divergence values. Fragmenting granules are expected to be at locations where the matter expands and the granules split up therefore, this implies a positive underlying divergence field, which is the case. But also merging granules show the same behavior, that means that granules mainly merge when they are expanding and not when they are pushed together. Granules that fade away should show that they are located at downflow regions, which can be seen clearly in Fig. 5, because the excess is much higher for negative divergence values than for positive.

The difference in the relative numbers in table 1 between the different authors has a relatively simple reason: The relative number depends strongly on the way how these events are counted, Hirzberger et al. followed a granule as long until an event happened, we only looked into the next or the preceding image, in our routine most of the granules did not show any event. We found merging granules by a backward search, i.e. we looked for fragmenting granules in a negative time direction, in this case granules that merge do only count for one granule, otherwise one would get much more than twice as much merging granules, since there are always 2 or more granules that are necessary for a merging event. If we take this into account we get following relative numbers: fragmenting \(< 41\%\), fading \(< 15\%\), and merging \(> 44\%\), which is

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