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ACOUSTIC FLUX AND TURBULENCE IN THE SOLAR PHOTOSPHERE

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Conference paper

Abstract. Using slit scans of solar photospheric spectral lines originating in the middle photosphere a 2-D field on the Sun was obtained and the occurrence of acoustic flux is investigated. As proxies for acoustic flux generation enhanced turbulence (measured by $fwhm$ variations) as well as large continuum intensity values are used. The results show that acoustic flux is not limited to the intergranular space and is also produced by horizontal motions that may become supersonic leading to turbulence. These motions lead to brightenings as it was predicted by theoretical models.

Key words: solar photosphere - acoustic flux - turbulence

1. Introduction

Acoustic flux is assumed to be an important heating source for at least the lower chromosphere. The observation of the onset of acoustic flux requires spatially highly resolved observations under excellent seeing conditions.

Several authors discussed different aspects of flux generation. Nesis *et al.* (1992) argued that regions of supersonic horizontal flow form intermittently in the vicinity of the downflow lanes. The origin of solar oscillations was described e.g. in the paper of Goode *et al.*, 1998. Seismic events, mainly observed in the intergranular lanes may be the origin of p-modes and not the deceleration of upgoing matter in the granulum.

In this paper we give some examples of line parameter variations that are regarded as proxies for enhanced turbulence and shock formation.

2. Theoretical Considerations

The solar surface convection manifests itself by bright rising granular and dark sinking intergranular elements. The upflow occurs more gentle, nearly laminar, however the downflow is restricted to smaller areas and hence larger velocities occur. The motions in the intergranulum are not laminar at all. For the discussion of acoustic flux occurrence, one has also to consider horizontal expansions. During the expansion of the gas brightenings near the granuluar/intergranular borders may occur indicating the occurrence of shocks due to supersonic motions.

In hydrodynamics, the Reynolds number Re determines the behaviour of the flow:

$$\mathrm{Re} = \frac{\rho u L}{\eta} \tag{1}$$

L denotes a typical length scale, u a typical velocity, ρ the density and η the viscosity of the matter. For the two cases

- Granulum: we denote the values by subscript g.
- Intergranulum: values are denoted by subscript ig.

In relation to the granulum the values for the intergranulum are:

$L_{ig} < L_g$, $\rho_{ig} > \rho_g$, $u_{ig} > u_g$. The viscosity depends mainly on temperature and $\eta_{ig} < \eta_g$. This leads to $\mathrm{Re}_{ig} > \mathrm{Re}_g$. We thus see that it is to be expected that higher Re occur predominantly in the intergranulum thus explaining turbulent behaviour there. On the other hand, large horizontal velocities in connection with decreasing temperatures because of radiative cooling could also yield large Re numbers at granular/intergranular transitions (shocks) and thus to turbulence related with acoustic flux generation.

3. Observations and Data

In order to test the occurrence of acoustic flux, we used eight 2-D scans performed with the VTT at the Observatorio del Teide. The data were taken on June, 22, 1999 and a magnetically non active region near the Sun's disc centre was selected. The spatial sampling interval was 0.4 arcsec and the total scanned area was 12.8×20 arcsec. Since each exposure lasted for about 2.5 s, a total scan could have been constructed within 125 s. The two lines selected were: Fe I, at a wavelength of 630.1508 nm, equivalent

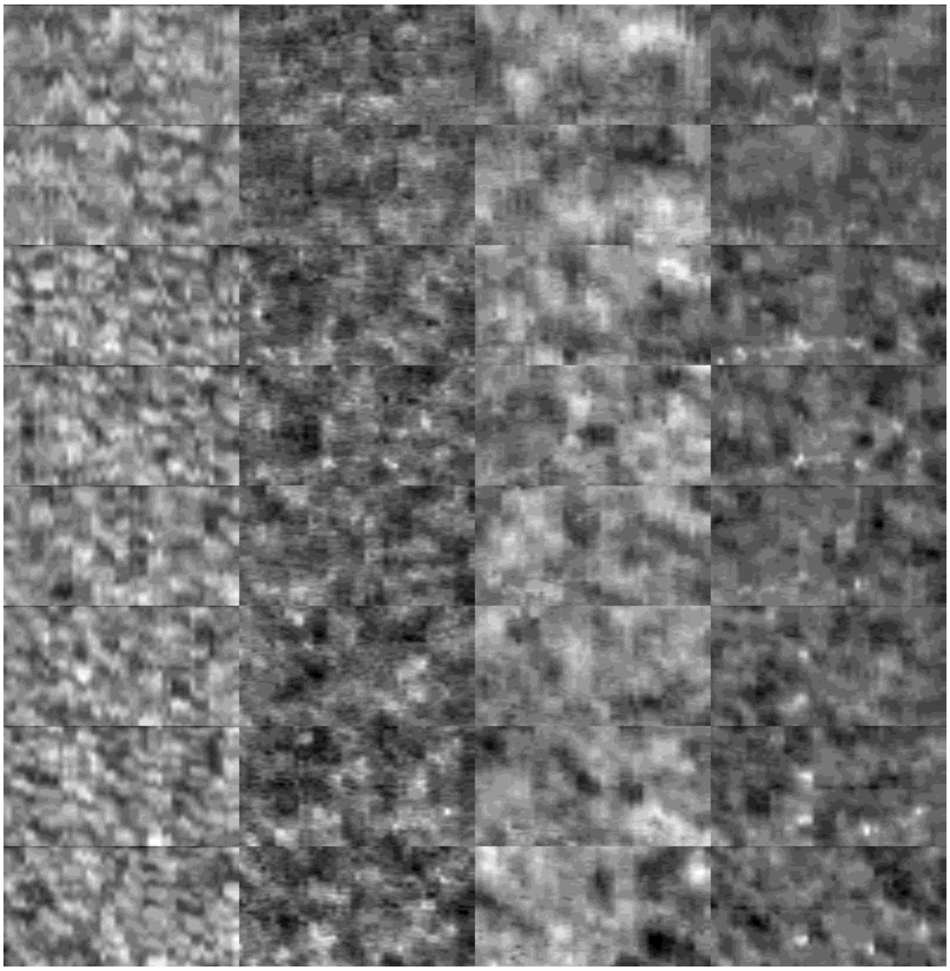

Figure 1: Higher line: Evolution of line parameters. Column 1 denotes I_c, column 2 fw, column 3 v_c and column 4 I_r.

width of 127 mÅ and formation of line core at a height of 378 km (higher line), Fe I at a wavelength of 630.2499 nm, 83 mÅ, height of line core formation 270 km (deeper line). The observations yield the line profiles and from these continuum intensity, I_c, line centre intensity I_r, full width at half maximum, fw and line centre velocity v_c were obtained.

A detailed description of the observations and data reduction was given by Hanslmeier *et al.*, 2004.

4. Results

In order to isolate regions of enhanced acoustic flux we tried to enhance the contours of the line parameter plots by applying a Sobel filter. Acoustic flux

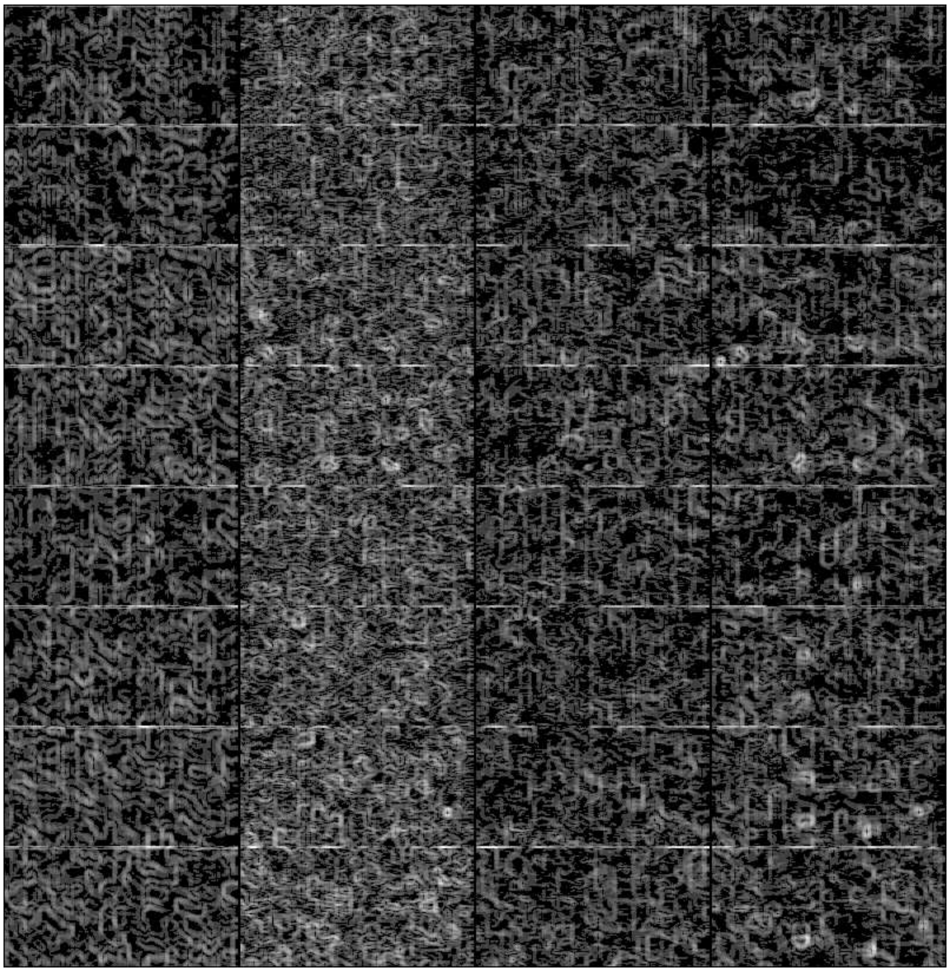

Figure 2: Higher line: Evolution of line parameters but now after applying the Sobel filter. Column 1 denotes $I_c(120)$, column 2 $fw(25)$, column 3 $v_c(25)$ and column 4 $I_r(80)$. The range of the variation is given in ().

is expected to occur near sharp transitions of line parameters and therefore such a filtering seemed to be adequate.

The general form of a Sobel filter is obtained as follows. Let F_{jk} denote the pixels in an image F. Then the Sobel filter G_{jk} is defined by

$$G_{jk} = |G_x| + |G_y| \tag{2}$$

where G_x and G_y are given by:

$$G_x = F_{j+1,k+1} + 2F_{j+1,k} + F_{j+1,k-1} - (F_{j-1,k+1} + 2F_{j-1,k} + F_{j-1,k-1}) \tag{3}$$

$$G_y = F_{j-1,k-1} + 2F_{j,k-1} + F_{j+1,k-1} - (F_{j-1,k+1} + 2F_{j,k+1} + F_{j+1,k+1}) \tag{4}$$

In Figure 1 the line parameters for the higher line are shown as function of time. The image at the bottom is the first in the time series. The columns are a) I_c, b) fw, c) v_c and d) I_r. Figure 2 shows the same parameters after applying the Sobel filtering. We clearly see that here edges are enhanced. Some granular like pattern can be recognized in the first columns (showing the Sobel filter applied to the continuum images). The patterns become completely stochastic when applied to the fw values (second column). The results given here are for the higher originating line. For the deeper line a similar behaviour was found.

In order to quantify the relations with and without Sobel filtering, the behaviour of correlation between the different line parameters was studied. The correlations were calculated over each of the 8 images from 2-D scans in the time series. Thus 8 values were obtained. In this paper we only consider correlations that may be important for acoustic flux.

In the following Figures the correlations are plotted by:
full line: corr(I_c, fw),
dotted: corr(I_c, v_c),
dashed: corr(I_c, I_r),
dashed dotted: corr(v_c, fw),
dashed-dotted dotted: corr(v_c, I_r).

Figure 3 gives the results for the lower originating line and Figure 4 for the higher originating line.

For the deeper originating line (Figure 3), the values for the original data are similar with the exception of corr(I_c, v_c) (dotted line) which is higher with an average of negative values of about 0.4. The negative correlation between these two parameters of course indicates that upward motion

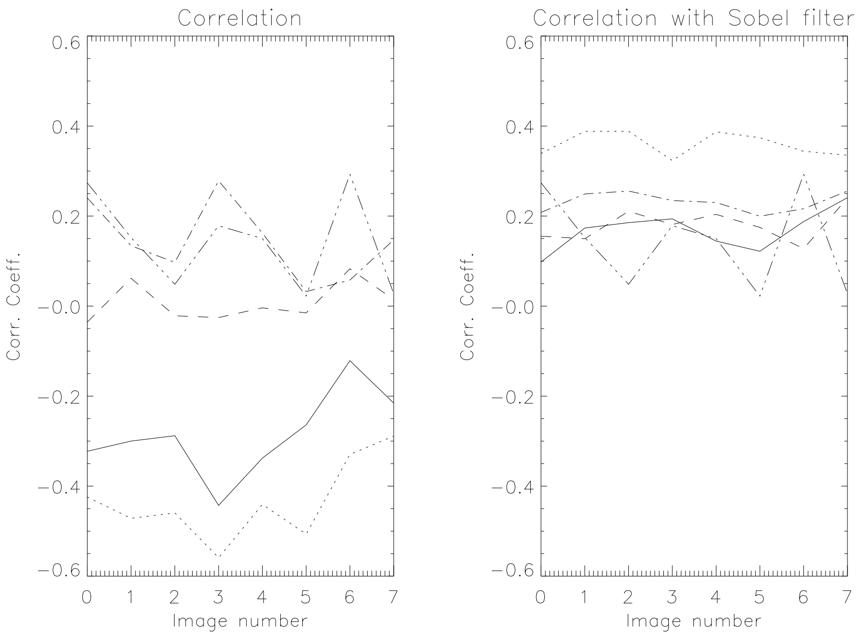

Figure 3: Deeper line: Evolution of correlation coefficients a) original line parameters, b) filtered parameters.

(bright elements) is correlated with negative velocities. After applying the Sobel filter the correlation values again become positive whereas the fluctuations seem to be larger than for the higher line. The correlation I_c, v_c becomes positive at values of about 0.35.

For the higher originating line (Figure 4) the correlations

$(I_c, fw), (I_c, v_c), (I_c, I_r)$

are negative and when applying the Sobel filter they turn to positive values too. As it is expected for higher originating lines, the correlation between continuum intensity I_c and line centre velocity v_c is low (dotted line). After applying the Sobel filter, it is seen that all correlation become positive and are around 0.2.

Summarizing we can state that the continuum evolution and other line parameter evolution can be clearly followed in the time series. Enhanced fw regions occur both in bright granular areas as well as in dark intergranular areas. The Sobel filter enables to detect edges and to enhance them.

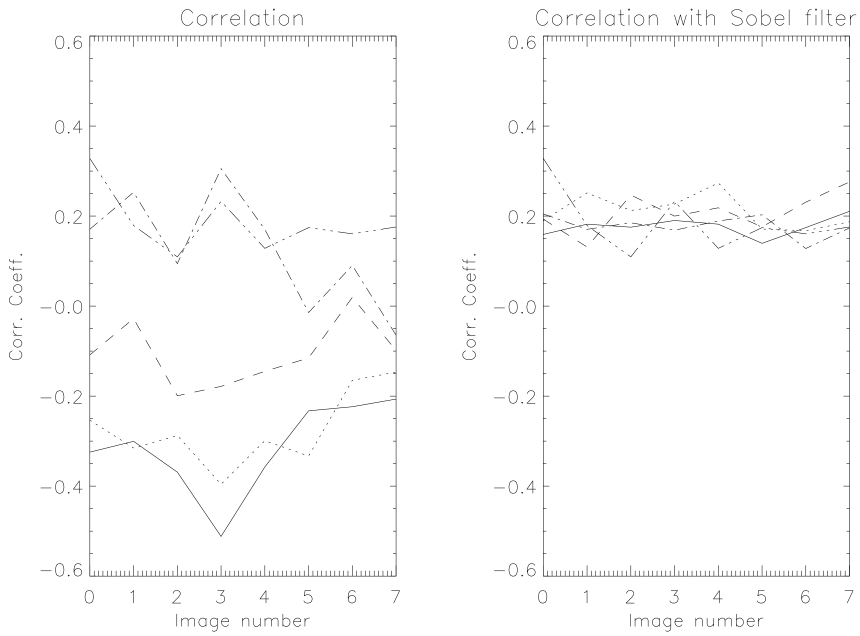

Figure 4: Higher line: Evolution of correlation coefficients a) original line parameters, b) filtered parameters.

The Sobel filtered fw values show quite a stochastic pattern that does not seem to be related to the granular field. The fields evolve rapidly and corresponding patterns are hardly recognized after a time step of 2 min.

5. Discussion

First we have to mention that the data were not filtered for the 5 min oscillations because a true filtering in a $k-\omega$ domain was not possible. The variation of the correlations found thus may be related to the 5 minutes oscillation. However, it has also to be stressed that these variations were found to be larger in the case for the Sobel filter applied to the deeper forming line where the influence of oscillation should be smaller because they increase in amplitude with height.

The variations of the functions thus can be partly explained by oscillations and by the evolution of the convective field itself. Let us consider in particular the corr(I_c, fw). As it is predicted by different authors (see e.g. Hoekzema, Rimmele and Rutten, 2002), enhanced turbulence and rapid variations of continuum intensity due to rapid granular decay should indicate acoustic flux. In our original data, enhanced I_c is correlated with lower fw values, indicating turbulence predominantly in darker intergranular areas. The fact that after applying the Sobel filter the sign of the correlation changes means, that here we observe enhanced line broadening features with enhanced continuum values that are produced by shocks.

The values of the fluctuations are low but the time evolution shows some consistency and thus the results at least are a strong hint for horizontal shocks that are connected with turbulence and enhanced brightenings. Using numerical simulations, in that context Rast (1999) and Skartlien and Rast (2000) speak of convective collapse.

Comparing the Figures 3 and 4 one sees, that in case for Sobel filtered data, the fluctuations for the deeper line are significantly higher than for the higher originating line. This may by also a hint for the greater influence of granular/intergranular evolution in the deeper photosphere.

The stochastic nature of the occurrence of turbulence is demonstrated by the chaotic pattern that is obtained after applying a Sobel filtering to the fw data (see Figure 2). The images obtained are only weakly correlated to the granular field as it also shown by the low but positive correlation between I_c, fw.

Decay of convective cells resulting in intergranular areas and resembling the scenario given by Rast (1999) and Skartlien and Rast (2000) may be associated with the regions enhanced fw and small I_c. There seems to be no significant difference between the two lines. However, to observe in more detail the relation with convective motions, deeper forming spectral scans are needed.

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AKUSTIČKI TOK I TURBULENCIJA U SUNČEVOJ FOTOSFERI

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Izlaganje sa znanstvenog skupa

Sažetak. Skeniranjem pukotinom spektralnih linija fotosfere dobiveno je 2-D polje i istražena je pojava akustičkog toka. Pojačana turbulencija izmjerena promjenama poluširina spektralnih linija kao i velike vrijednosti intenziteta kontinuuma uzete su kao približne vrijednosti u stvaranju akustičkog toka. Rezultati pokazuju da akustički tok nije ograničen samo na međugranularni prostor već se stvara i horizontalnim gibanjima koja mogu postati nadzvučna i dovesti do turbulencije. Ta gibanja dovode do teoretski previđenih povećanja sjaja.

Ključne riječi: Sunčeva fotosfera - akustički tok - turbulencija