Dynamics of the upper photosphere: coherence and phase analysis

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Abstract.
The dynamics of the upper solar photosphere is investigated by means of a coherence and phase analysis of solar photospheric lines that originated above 300km. Our results confirm that intensity (temperature) fields at these heights are not correlated with lower intensity (temperature) fields. Also the antiphase between velocity and intensity fluctuations is lost.

1. Introduction

The solar photosphere can be divided into two different regimes from the point of view of its dynamics:

- purely convectively driven motions below a certain photospheric height
- above a certain height mainly non convective motions, often called secondary motions and oscillations.

Kneer et al. (1980) did a coherence analysis of granular intensity by comparing the coherence between intensity fluctuations in the continuum and the wings of spectral lines. They found a breakdown of the coherences when approaching a certain distance from the line center.

Komm et al. (1990) made a power and coherence analysis of intensity variations derived from the wings of the Mg b_2 line. For the deep photosphere they found the $-5/3$ scaling law of Kolmogorov but the value of the exponent and the rms -intensity fluctuations decreased with height and reached a minimum at about $170 km$. Smaller structures are coherent up to higher photospheric layers whereas the coherence for larger structures breaks down in the same layers where the rms-intensity fluctuations show a minimum. Large intensity structures are results of convective overshoot and small structures are of turbulent origin.

Nesis and Mattig (1989) showed that granular convective structures disappear up to a height of $160 - 200 km$.

2. Observations

The observations used for this study here were performed with the VTT telescope at the Observatorio del Teide, Tenerife that is run by the Kiepenheuer Institut. For more details about that telescope please refer to Schröter et al (1985). We used simultaneously 4 CCD cameras of $512\times$ 512 pixel size. Due to some problems with the shutter not the whole data set could be used. The three spectral lines we finally analyzed are listed in the table below. For these data we have the following paramters: 1 pixel $= 3.4\, m\AA$ in dispersion and $0.17\, arcsec$ in the spatial direction normal to the dispersion. The integration time was 0.2 s.

Table 1. Line Parameters.

Line	Wavelength	Eq. width	formation height	Camera
Fe I	6301.508	127	340	ATE
Fe I	6302.499	83	250	ATE
Fe I	6494.994	165	500	ATC

After applying standard data reduction (dark current, flat fields) we tried to separate oscillatory motions from convective motions by applying a FFT filter that is described in more detail in Hanslmeier et al. (1999).

3. Results and discussion

In the following Figures we give the power spectra and coherence and phase function for the following parameters: line center intensity fluctuations I_c , line center velocity fluctuations v_c and continuum intensity fluctuations I_o for the two spectral line λ 6302.499 Å and λ 6494.994 Å and in order to demonstrate the different behaviour since the difference in line core formation height is about 250 km. spectral lines.

In Fig. 1 we give the power spectra for the continuum intensity fluctuations and line center velocity fluctuations for the deepest forming line as well as the coherence and phase functions. It is seen that the coherence at granular scale (e.g. for $k > 6 Mm^{-1}$) oscillates around 0.6 and the phase function reaches a value of about 150^0.

In Fig. 2 the plots are given for the line center intensity fluctuation and the line center velocity. It is clearly seen that in this case the coherence oscillates at granular scales only slightly around 0.6 and in that spatial scale the phase

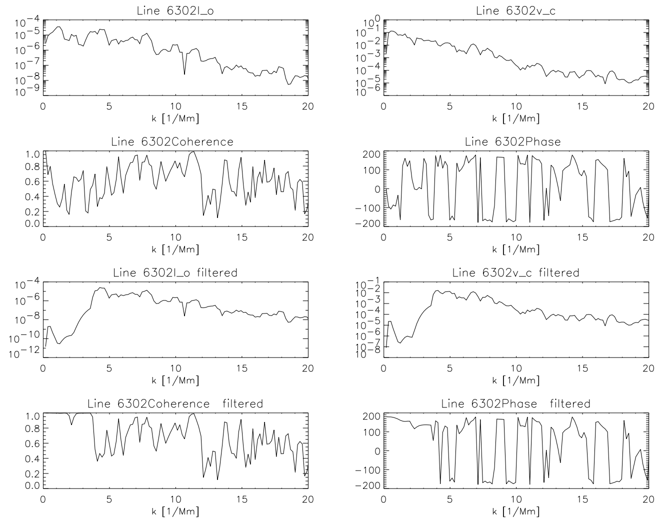

Figure 1. Power spectra of continuum intensity fluctuations and line center velocities, coherence and phase functions, power spectra for the filtered data and coherence and phase functions for the filtered data.

function is near to 0^0. Thus the temperature and velocity fields at that height (around 150km) oscillate in phase.

In Fig. 3 we give similar to Fig. 1 the plots for the highest forming line λ6494Å (500km). It is seen that the coherence values are smaller than in Fig. 1 oscillating around 0.4 and the phase functions is around 100^0. In Fig. 4 which is analogous to Fig. 2 the situation for highest forming line is shown. Here the coherences are larger, oscillating around 0.6 and in the granular range the phases again seem to be around 0^0.

For all Figures, we give also the value for the filtered data. Since no appropriate filtering in the $k - \omega$ domain was possible since we had no time series, only the influence at large scales ($k < 1$) can be seen.

Our results clearly show that intensity and velocity fluctuations in the higher photosphere are only in phase when both fields are considered at the same photospheric levels. Otherwise we get a 150^0 phase shift which is comparable to the values cited in the literature (e.g. Wiehr and Kneer 1988). Such a shift indicates that the bright structures move upwards and the darker downwards. However these authors defined granules at larger sizes ($1 < k < 6$). This trend can be seen in our data also for smaller structures because of the better resolution of the VTT telsecope in comparison with the data used by Wiehr and Kneer from the Gregory telescope. Salucci et al. (1994) used data from the FPI and a UBF at Sac Peak Observatory and found that only the larger granules reach higher levels coherently. Espagnet et al. (1995) analysed a 16 min time series and found that the intensity features in the upper photosphere are not related to the granules whereas the velocity fluctuations are associated to granulation over the whole photosphere.

This is also confirmed by our analysis.

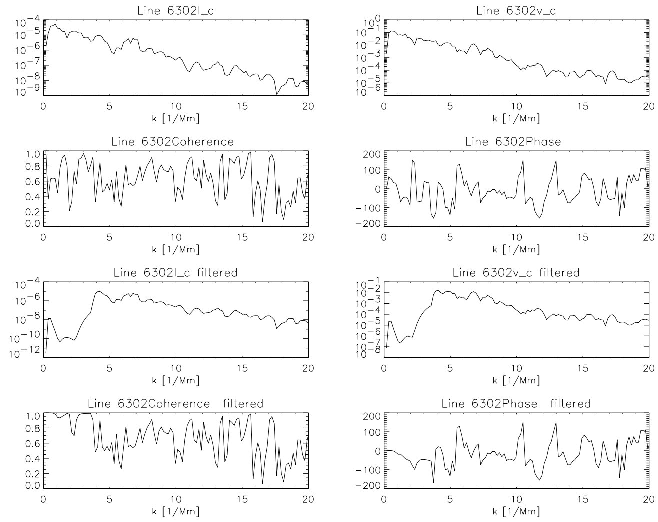

Figure 2. Power spectra of line center intensity fluctuations and line center velocities, coherence and phase functions, power spectra for the filtered data and coherence and phase functions for the filtered data.

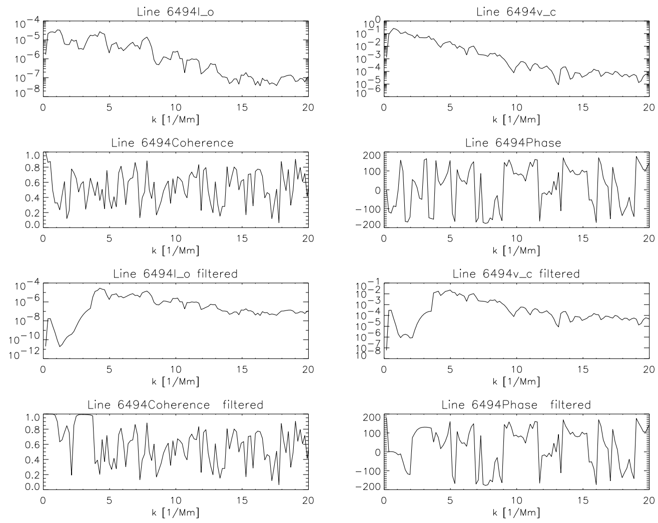

Figure 3. Power spectra of continuum intensity fluctuations and line center velocities, coherence and phase functions, power spectra for the filtered data and coherence and phase functions for the filtered data.

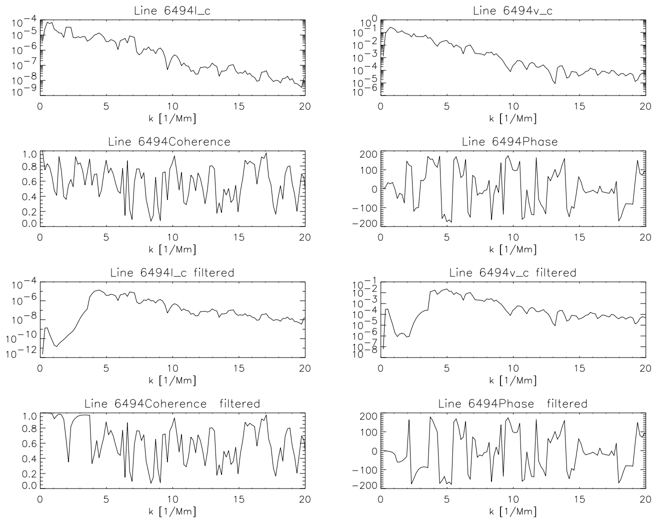

Figure 4. Power spectra of line center intensity fluctuations and line center velocities, coherence and phase functions, power spectra for the filtered data and coherence and phase functions for the filtered data.

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