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Velocity Pattern Evolution Within the Photosphere

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The solar photosphere is the dynamical interface between the convection zone and the chromosphere. It is compressible, convectively stable, and affected by the overshooting granular flow. The photospheric dynamics must thus be investigated as the continuation of the granular dynamics as it spills over into the stable layers.

We investigate empirically the non-oscillatory small-scale velocity field of the photosphere. We are particularly interested in the temporal and height variations of the dynamics and its topological behavior, i.e. in the evolution of velocity patterns in comparison to the granular intensity patterns.

Our analysis is based on time series of 2D spectra taken with the triple etalon spectrograph TESOS at the VTT on Tenerife. Oscillations were filtered out in the Fourier domain. In a 2D time-series analysis, power spectra demonstrate the rapid decay of the vertical overshoot velocities with height by a factor 2 within less than 300 km above the surface, thus implying a decay of the associated kinetic energy flux density by nearly two orders of magnitude over the same height interval. As expected, this decay of the energy flux is accompanied by a change of the scales in the wavenumber domain. 2D coherence maps quantify the drastic change of the pattern of the velocity field with height: While the continuum layers are still governed by the typical granular-like structuring with small-scale isotropy, the higher layers show elongated patterns of upflow and downflow regions with short fragmentation and reorganization time scales. According to a cross-correlation analysis the extension of the granular upflows into the upper photosphere is a strongly local process, suggesting a burst-like nature of the granular velocity.

Over the scale of the field of view, the velocity field loses its horizontal isotropy with height. This suggests the action of a structural instability of the deeper layers. It is an open question which dynamical processes in the overshoot layers cause these effects. The fragmentation and immediate reorganization of the velocity field of the upper photosphere merit further study.

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Introduction

From our previous work it is evident that the overshoot flow looses its dynamics with height in the photosphere. It is an open question whether the intrinsic dynamical time that is found in the granular layers also characterizes the layers above. Therefore it was our intention to investigate the spatial and temporal evolution of the small-scale non-oscillatory vertical velocity patterns at different heights in the photosphere over the observation time. The method applied is the 2D power analysis and 2D coherence analysis. This provides information about the change of the small-scale velocity pattern with height and time. Furthermore, we determined 2D velocity histograms and their correlation in time to investigate the changes of the intrinsic dynamical times in the photospheric layers. For this analysis we used the line core of the line Fe I 557.6 nm and its bisectors at 0.2, 0.5, and 0.75 of its line depth.

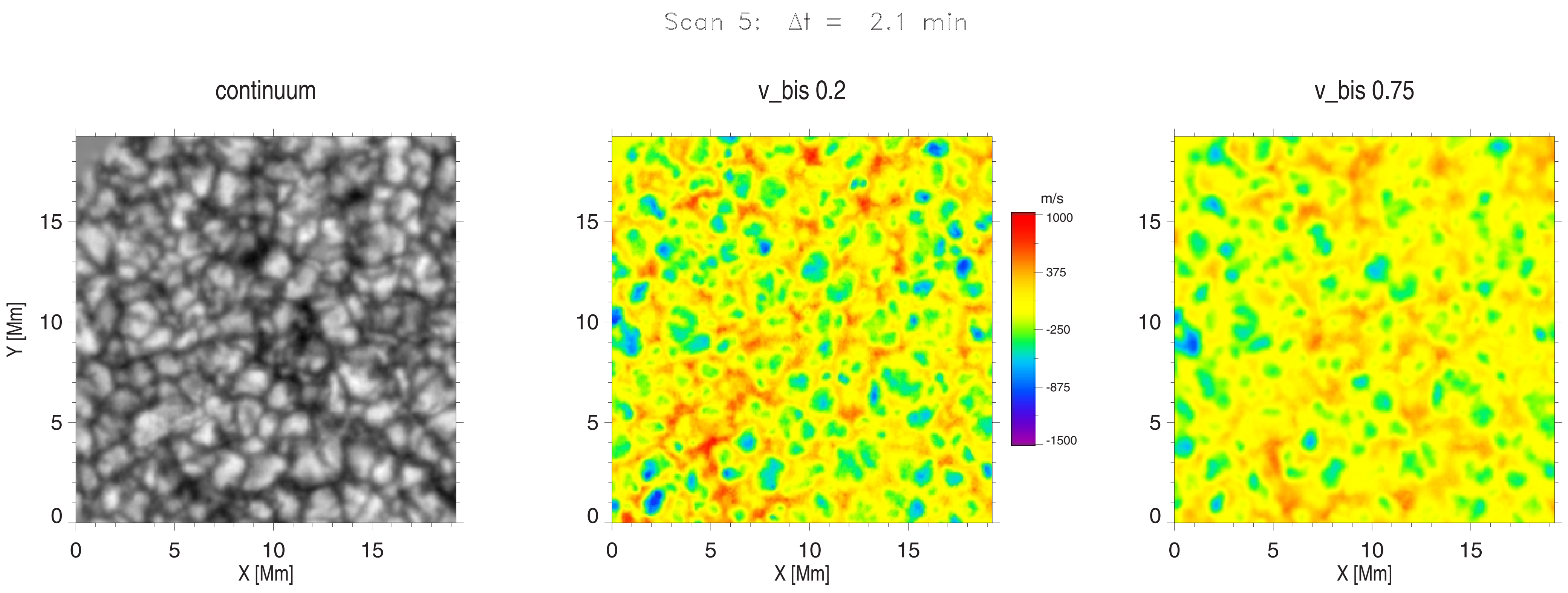

Fig. 1 shows the continuum image together with the maps of radial velocities derived from the Doppler shifts at bisector levels 0.2 and 0.75 (relative line depressions) for the “reference” scan 5. Upflows and downflows are color coded by blue and red, respectively. In the map for bisector 0.2 (deep layers in the photosphere), the green-blue patches closely mark the bright parts of the granulation seen in the continuum image. This correspondence is weaker for the bisector map 0.75 (higher layers), where only the strongest upflows appear as green-blue patches.

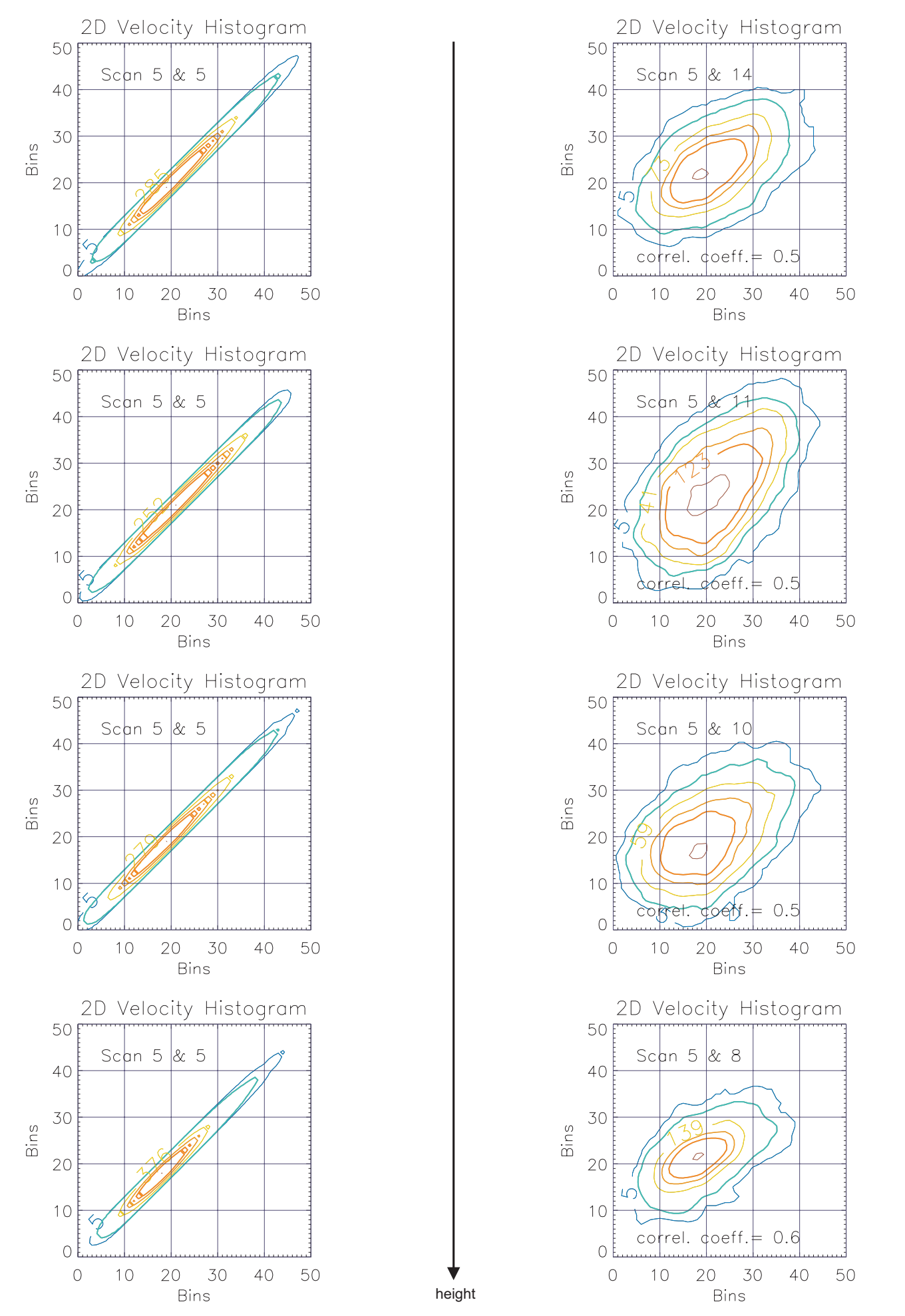

Fig. 2 compares the velocity distribution measured at four different depths within the line profile, and thus at four different heights in the atmosphere: the top row refers to a line depression near the continuum and thus to the deepest photospheric layer, while the bottom row refers to line center and thus to the highest layer, near 300 km in the photosphere. The *right panel* in each row shows contour fits to the 2D velocity histograms combining a reference scan (here scan 5) and a scan taken at a later time. The value at each point measures the number of pixels with a given vertical velocity in reference scan 5, specified as the abscissa value, and a certain velocity value in the comparison scan, specified as ordinate value. Obviously, when the reference scan is combined with itself, all values must lie on the diagonal, as shown for control purposes in the *left panels*. If both scans are taken at different times, the correlation between the velocity fields decays with increasing time difference between the scans, and as a result the distributions broaden. The comparison scans in the four rows were selected such that the decorrelation has reached comparable degrees at all four heights. This is achieved with scans 14, 11, 10, and 8, which were taken at times 3.9, 2.5, 2.2, and 1.3 min after reference scan 5. Therefore the velocity field in the granular overshoot region decays over a *dynamical* time scale Δt_{dyn} that decreases rapidly with height.

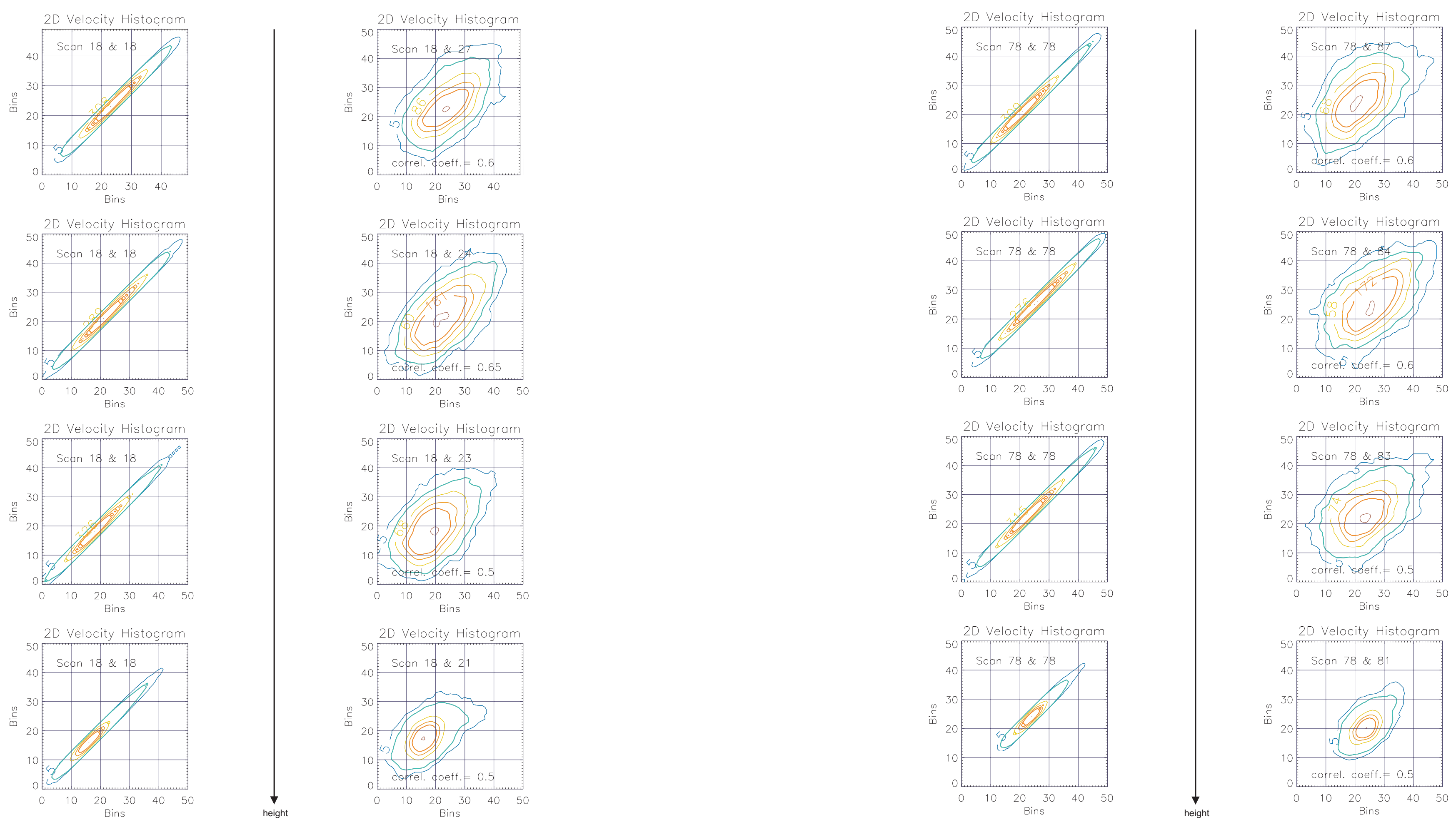

Fig. 3 (*left*) and **Fig. 4** (*right*): Here we followed the same procedure as in Fig. 2, except that we replaced reference scan 5 by scans 18 and 78, respectively. At the corresponding times the seeing quality was lower than at its peak shown in Fig. 2. Nevertheless, the measured dynamical time scales Δt_{dyn} were again found to be the same – i.e., 3.9, 2.5, 2.2, and 1.3 min, respectively, for the four height levels.

In following three figures we show the results of the 2D power analysis and the coherence maps. The 2D power (different colors) demonstrates clearly the attenuation of the velocity power with height (different rows). To show the height variation of the horizontal scale we calculated for each height the azimuthal mean of the 2D power. It is evident that the scale changes with height (*i.e.,* from one row of the figure to the next). The shape of the granular pattern as a function of height can be seen in the coherence maps. It is surprising that the shape is changing from granular into elongated structures with increasing height. This finding is manifested in an increasingly non-isotropic behavior of the coherence (correlation as a function of wave number) from top to bottom.

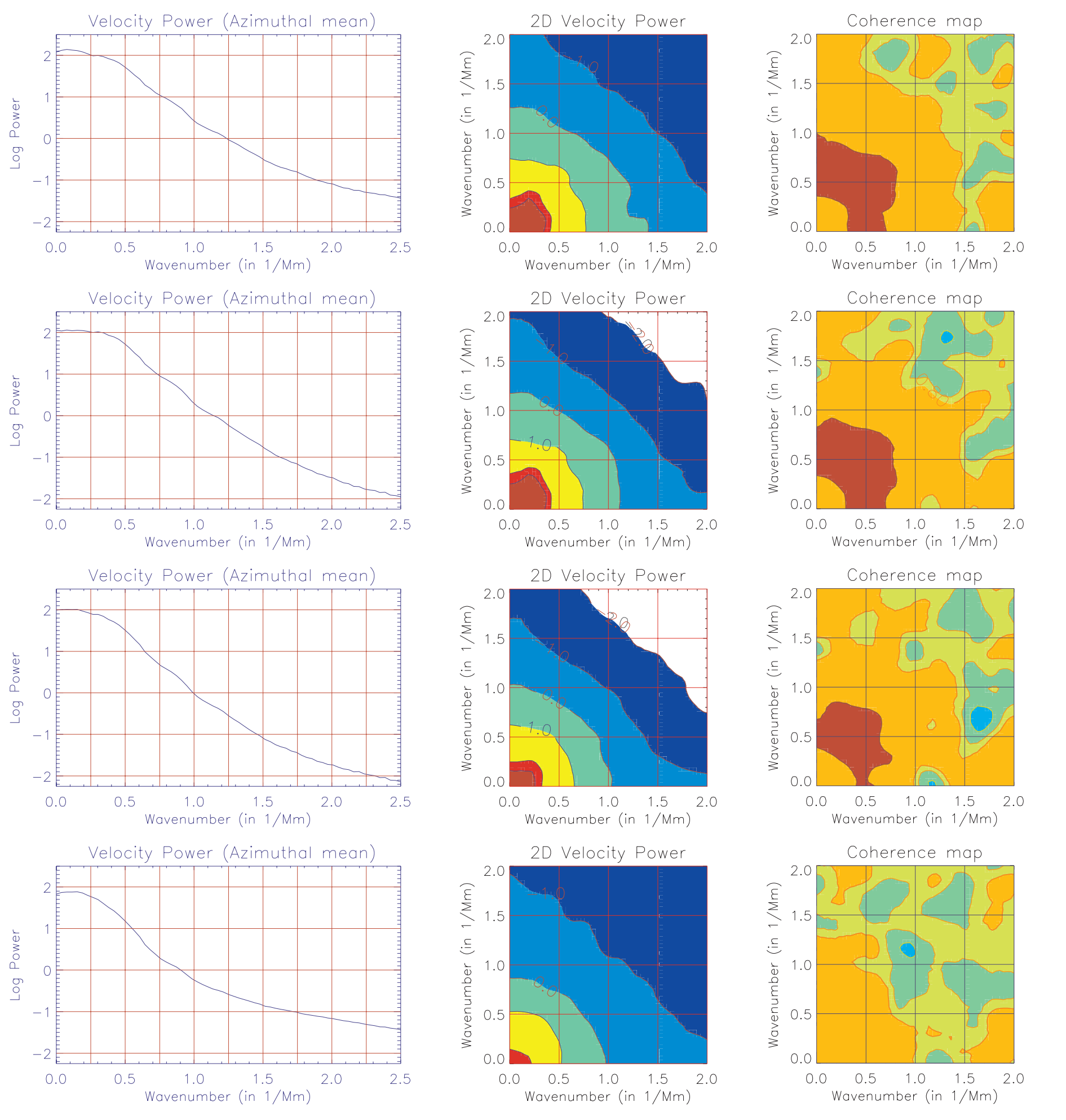

Fig. 5: As in the previous figures, the top row corresponds to the deepest layer and the bottom row the highest layer. The *middle column* shows the 2D velocity power, and the *left column* its corresponding azimuthal mean, plotted as log power vs. wavenumber. The contours in the 2D velocity power (*middle*) are indicated on a color scale from red to blue, with values corresponding to the log-levels of the azimuthal mean power (*left*). The *right column* shows the coherence maps between the velocity structures and the granular intensity structures for all four height levels. Both axes are in wavenumber. The color contours from red to green represent correlation values in steps of 0.1.

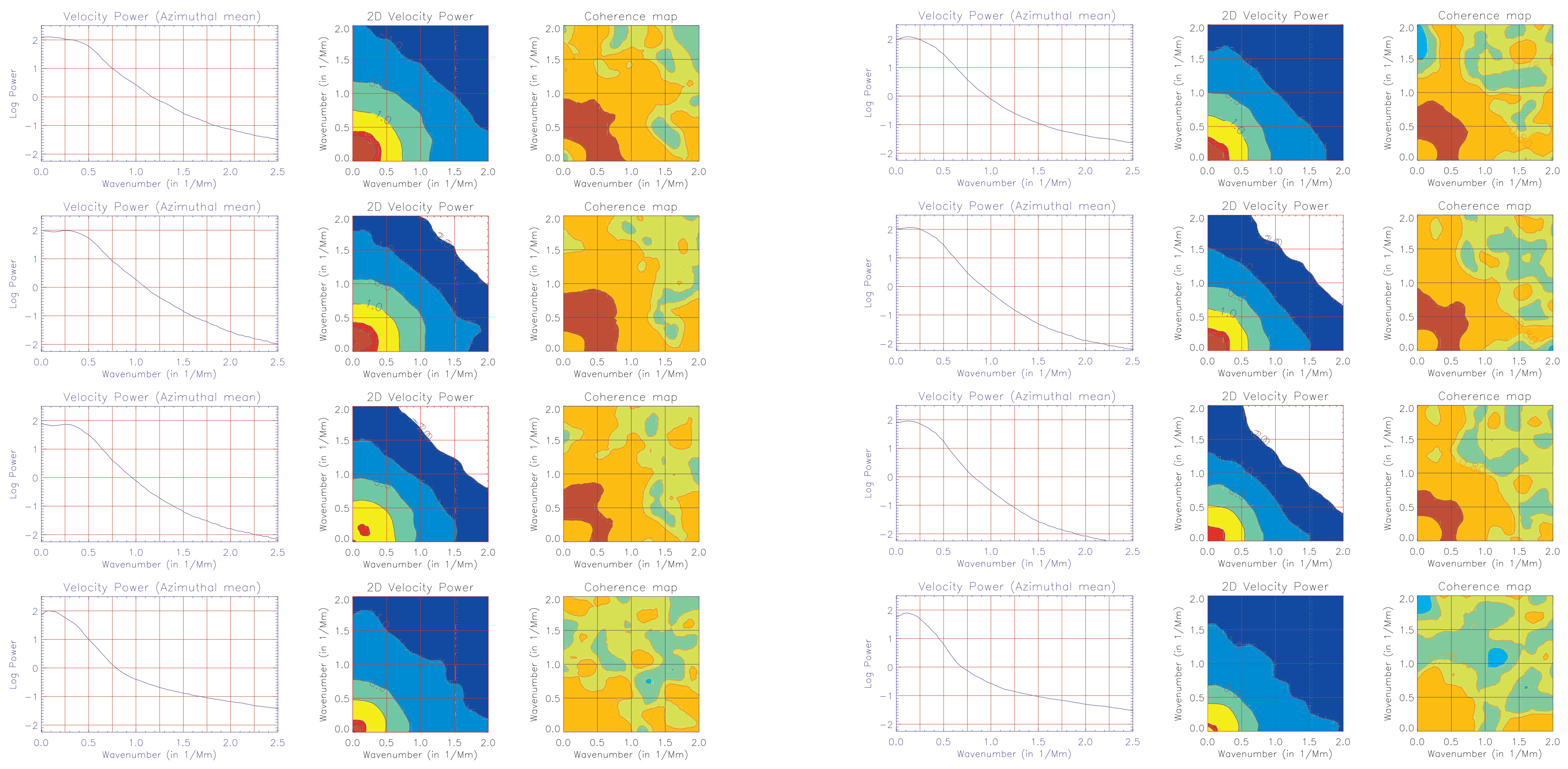

Fig. 6 (*left*) and **Fig. 7** (*right*): show the same results for scans 21 and 71, respectively. Here the seeing quality was lower than for reference scan 5 used in Fig. 5, which marked the moments of best seeing.

Conclusions

- The dynamical time scale of the vertical velocity field decreases rapidly with height.
- The shape of the velocity pattern changes with height from granular-like to elongated.

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