Detection and analysis of small scale convective patterns observed with Hinode compared to RHD simulations

B. Lemmerer[1], D. Utz[1], A. Hanslmeier[1], A. Veronig[1], H. Grimm-Strele[3], S. Thonhofer[1,2], I. Piantschitsch[1]

[1]IGAM/Institute of Physics, University of Graz, Austria
[2]Instituto de Astrofísica de Andalucía IAA-CSIC, Granada, Spain
[3]Institute of Mathematics, University of Vienna, Austria

Abstract: Recent results from high resolution solar granulation observations indicate the existence of a population of small granular cells on scales below 600 km in diameter. They strongly contribute to the total area of granules and are located in the intergranular lanes. Hinode SOT data and high resolution RHD simulations were studied in order to detect small granular cells and analyze their physical properties. An automated image segmentation algorithm specifically adapted to high resolution simulations for the identification of granules was developed. The algorithm was also applied to observations from Hinode and was used to analyze and compare physical quantities provided by the simulation and the observations. We found that small granules make a distinct contribution to the total area of granules. Both in observations and simulations, small granular cells exhibit on average lower intensities and vertical velocities.

Introduction

The granulation is a distinct feature of the solar photosphere generated by convection, which can be studied in detail by automated segmentation algorithms. The recent discovery of a distinct subpopulation of granular cells with scales smaller than the dominant scale of 1000 km, has again drawn attention to the topic of the solar granulation, as their formation and dissipation is unclear (Abramenko et al. 2012).

In this study, we investigate high resolution solar observations and Radiation Hydrodynamics (RHD) simulations in order to detect and analyze small convective patterns. For this purpose, a new segmentation algorithm was developed, which also takes physical properties of convection into account.

Data from Simulations and Observations

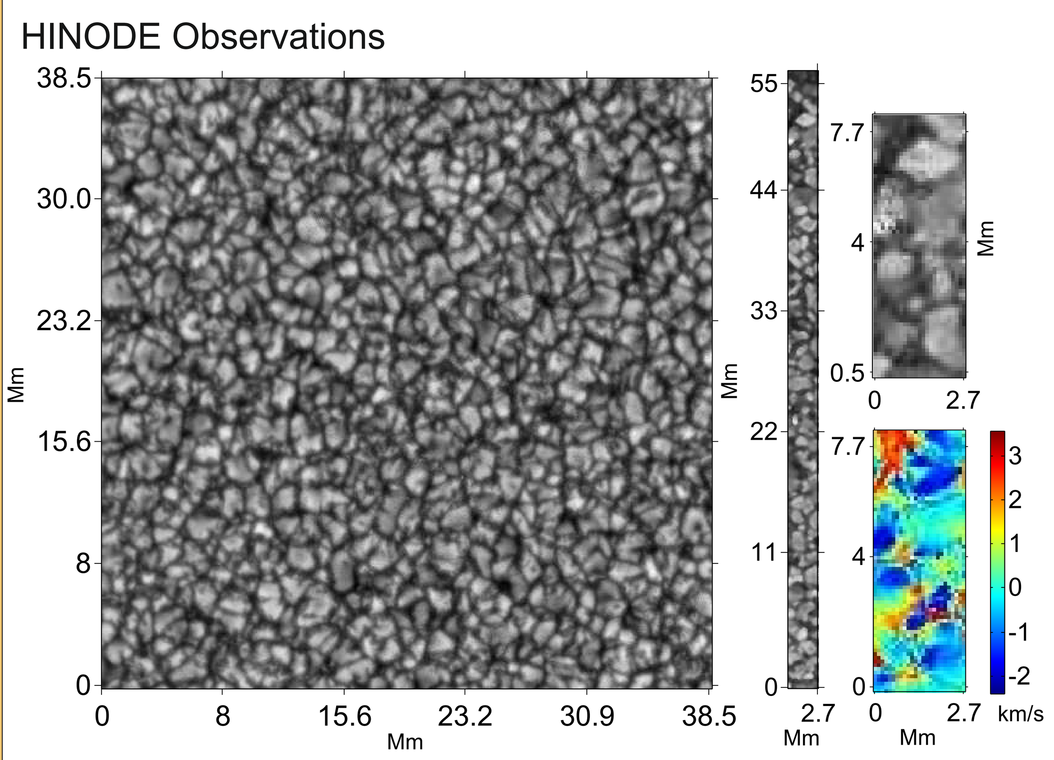


Fig.1: (left) shows a white light exposure taken by the SOT/BFI (geometric resolution: ~77 km per pixel). (right panel) : A slit exposure taken by the SOT/SP and the inverted LOS velocity profile with a resolution of ~110 km per pixel.

For this study, white light images observed by the Japanese Hinode Solar Optical Telescope (SOT; Tsuneta et al. 2008) were analyzed. The segmentation algorithm was applied to a selected data set of 108 white light images taken by the SOT/BFI from 2010-05-01 to 2010-07-31, as well as white light exposures taken from the SOT/SP.

In order to study the vertical velocities of the segmented granules, the line of sight velocities resulting from the application of the inversion code MERLIN to spectropolarimetric data, were analyzed (Lites, 2010). For this purpose the algorithm was applied to an inverted dataset from 2007-01-20 consisting of 29 images.

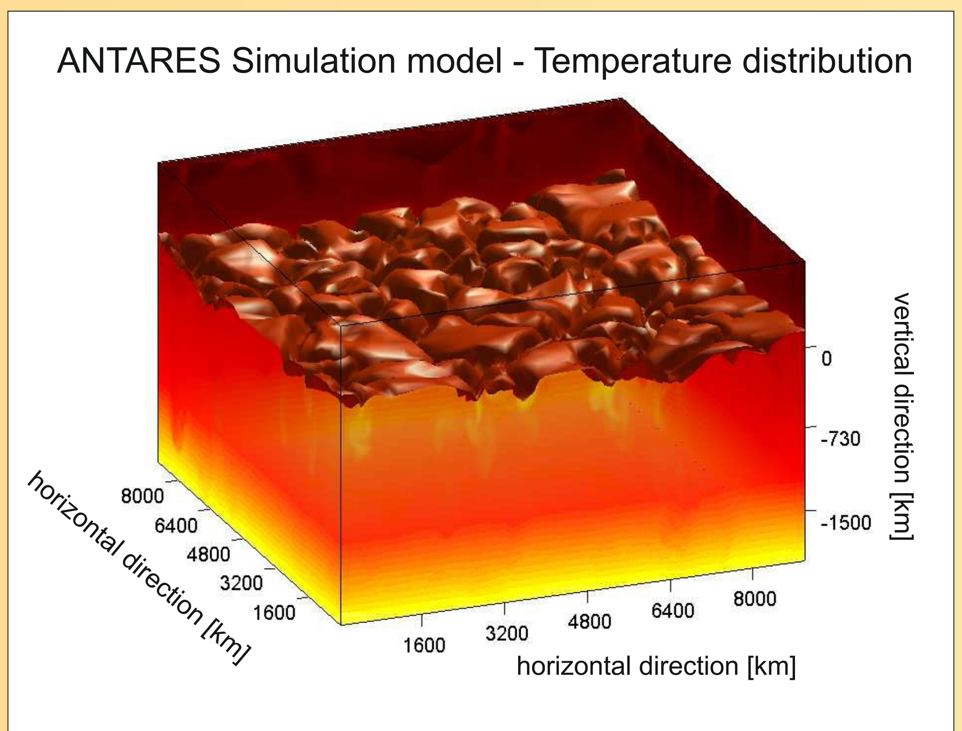


Fig.2: Simulation box of the ANTARES model. Granular pattern visible at a iso-surface of tau=1. The box comprises 9 Mm in the horizontal directions and over 5 Mm in the vertical direction, whereof about 700 km are situated above the optical surface.

ANTARES (**A** **N**umerical **T**ool for **A**strophysical **RES**earch) is a RHD code to numerically simulate the solar near-surface convection (box-in-a-star approach), developed by Muthsam et al. (2010).

The code solves the set of RHD equations using a 5th-order accurate weighted essentially non-oscillatory (WENO) numerical scheme.

Open boundary conditions in the vertical direction allow free in- and outflow. All quantities are assumed to be periodic in horizontal directions. In the upper ~30% of the simulation box the radiative transfer equation is solved with the short characteristics method using the grey approximation for the frequency dependence. In the deeper layers, the diffusion approximation is valid.

Segmentation Algorithm

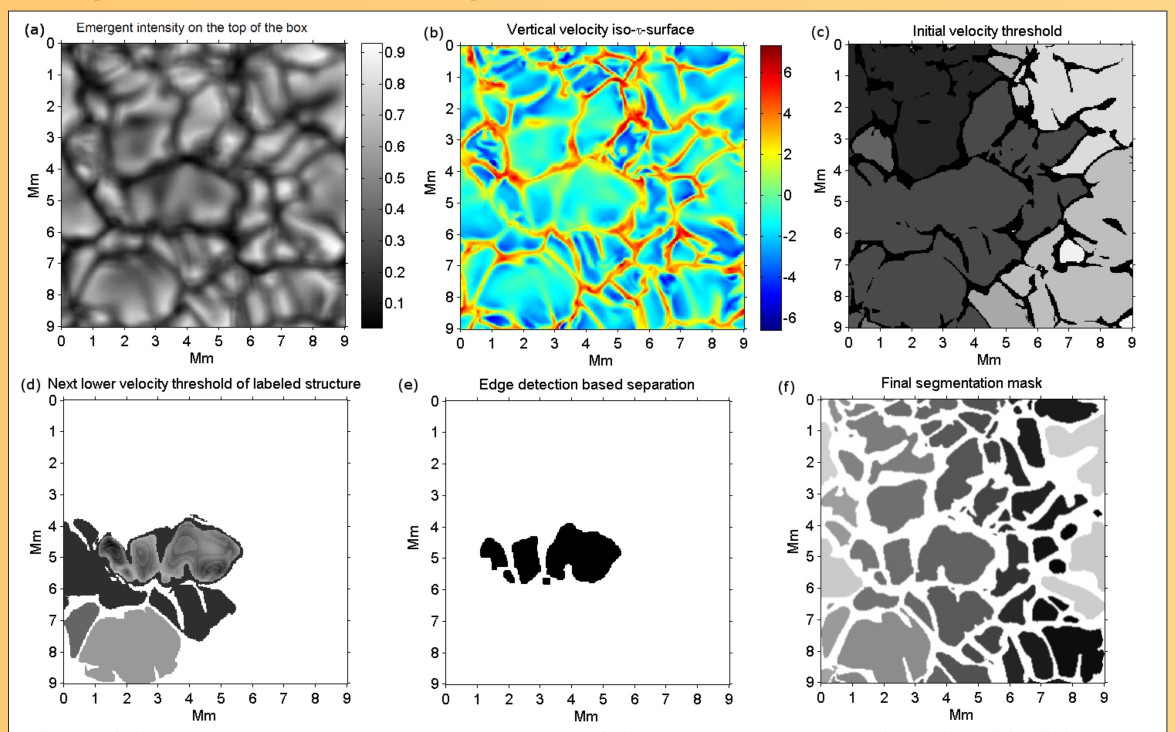


Fig.3: (a) Normalized emergent intensity and (b) vertical velocity profiles (RHD) , (c) initial vertical velocity threshold, (d) subsequent lower threshold applied to the structure, (f) edge detection applied to the emergent intensity of the object, (i) final segmentation mask.

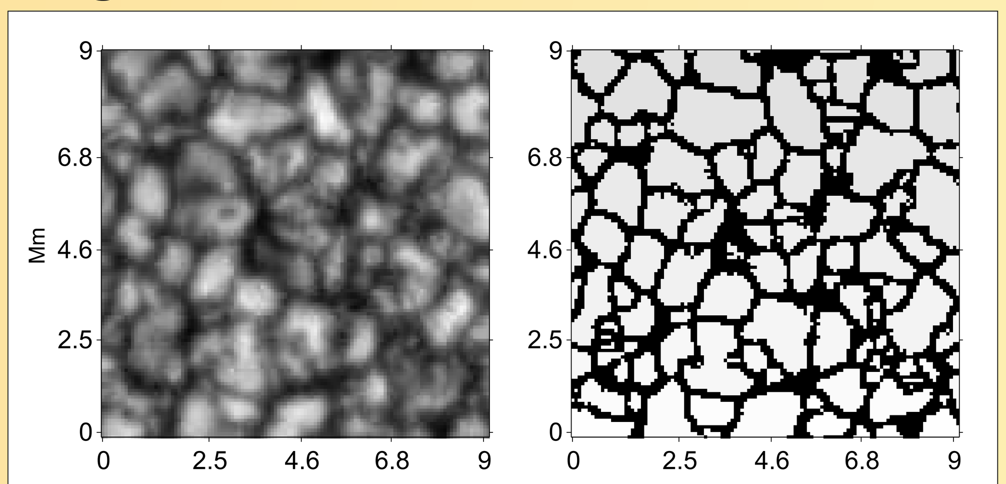
The newly developed 2D segmentation algorithm is based on the idea of using multiple thresholds and incorporating methods of pattern recognition, like edge detection routines and morphological operations. The whole scheme is a 'bottom-up' approach.

- Large fragments are sequentially broken down into smaller structures by changing threshold levels.
- The segmentation itself is done by a recursive thresholding routine, requiring an initial upper threshold as well as a minimum lower threshold as input parameters.

The algorithm can be applied to intensity as well as to vertical velocity profiles. For processing RHD and Hinode SOT/SP data we used the vertical velocity and the line of sight velocity from the inverted SP data. In the case of the white light images from the SOT/BFI instrument, intensity images can be processed instead.

The applied image processing steps, plus a labeling of all objects, result in the final segmentation mask, which is then applied to various profiles of physical quantities in order to extract statistical information of the identified granules.

Segmentation Results



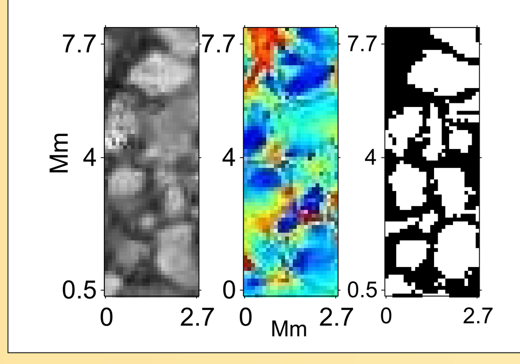


Fig.4: (upper panels) Hinode SOT/BFI white light image and the segmentation result.

(lower left panel): Application of the segmentation algorithm to Hinode SOT/SP white light and line of sight velocity profiles and the segmentation result.

Analysis

For our analysis of the RHD data we used a two-hour long data set with a temporal resolution of 30 seconds. In Fig.5, 6 and 7, we compared the analysis of the intensity and vertical velocity distributions as well as the structural information of granules derived from RHD data to Hinode BFI and SP data via scatter plots.

Figure 5 shows the mean granular intensity of the simulation, the white light images from the SOT/BFI, and the SOT/SP instrument versus its equivalent diameter. In case of the RHD and the SP data, the intensity increases up to a diameter of 1000 km, indicated by the slope of the 3rd polynomial and linear fits (dashed pink and solid black lines). For RHD data, the linear fit indicates a weakly decreasing trend for granules larger than 900 km in diameter. In the intensity distribution derived from the BFI images a linear trend towards higher intensities is visible.

The distribution of the mean vertical velocity of identified small granules (see Fig.7) exhibit a large scatter, which may also refer to different stages of their evolution, as they are predominantly found in deeper layers (see Lemmerer et al. 2013). The polynomial and linear fits demonstrate a decrease of vertical velocity (upwards moving plasma) with decreasing granular diameters and are thus strengthening the concept of the existence of two distinct populations.

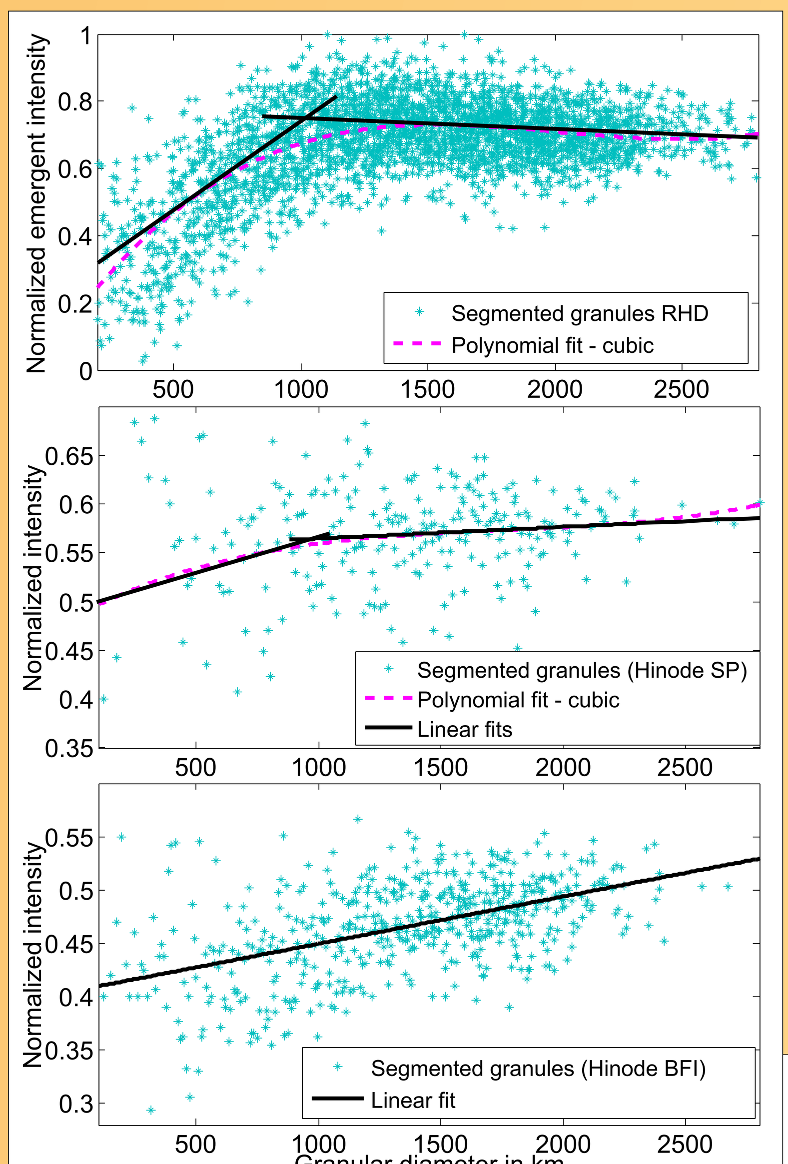


Fig.5: Granular diameter vs. normalized emergent intensity of granules for RHD data (upper panel), Hinode SP data (middle) and Hinode BFI data (lower panel).

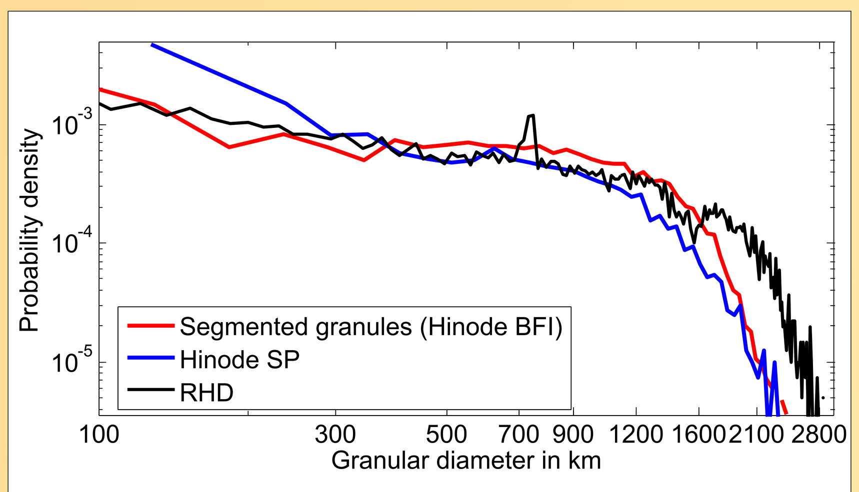


Fig.6: The probability density functions for ANTARES data, Hinode SOT/BFI and SOT/SP data. The probability density functions of the equivalent diameters show an increase in the number of detected objects towards smaller scales.

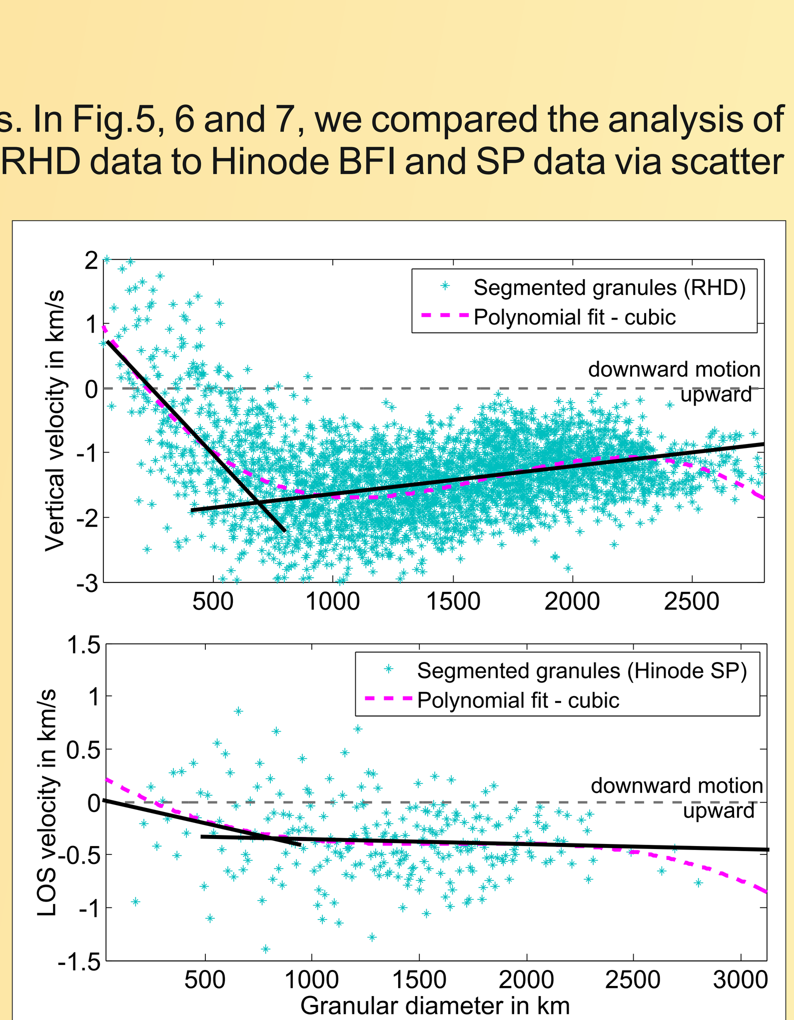


Fig.7: Scatter plot of granular diameter vs. mean vertical velocity of segmented granules for RHD data (upper panel) and Hinode SOT/SP data (lower panel).

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Muthsam, H.,J. et al. 2010, New A, 15, 460
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Outlook:

In the future, a more complete understanding of the behavior of small granules will be gained by studying the 3D evolution of the upstreaming hot plasma plumes in the convection zone. For this purpose, we plan to develop a generalization of the segmentation algorithm applicable to three dimensions.

Acknowledgements:

The research work was funded by the Austrian Science Fund (FWF): P23818 and P20762. D.U. wants to emphasize the special support given by project J3176 (Spectroscopical and Statistical Investigations on MBPs). The model calculations have been carried out at VSC (P70068, H. Muthsam).