Parameter study of 2D convection and supercomputer performance analysis

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Der Wissenschaftsfonds.

Abstract

We perform hydrodynamic 2D simulations of solar convection. We aim to study the dependence of different physical parameters, the box size, and box aspect ratio on the actual convective motions we observe in the numerical model. Furthermore, we need to evaluate the performance of different Input/Output strategies on supercomputers, in order to plan and run future large-scale magneto-hydrodynamic models of the solar atmosphere. To this end, we use our convection model for a performance analysis of different numerical IO schemes. We use a large simulation domain together with a high grid resolution in order to provide high Reynolds numbers in the numerical model. This allows us to model the solar convection zone down to 20 Mm below the surface and include the solar atmosphere up to 10 Mm. We use 1024x256 grid points with initial conditions matching the gravity, temperature, and density stratification of the Sun. After the bottom of the box is heated sufficiently, the convective motions set in and transports energy towards the surface. At the top of the convection zone, material is ejected into the atmosphere, before falling down again.

We conclude that we require a minimum horizontal extent of the simulation domain and a minimum box aspect ratio, in order to obtain realistic convection cells. Also we find that HDF5 output is required for future large-scale computer models, because the traditional IO strategy of the Pencil Code puts too high demands on nowadays supercomputer file systems, both in storage space requirements and number of file operations.

Context

For simulations the kinematic viscosity ν is often chosen higher than in reality due to stability issues and limited spatial resolution. We study how the value of ν affects the results of the simulation.

We evaluate parallel processing capabilities of the Pencil Code [1].

Methods

We cover a box size of 64 Mm (horizontal) × 20 Mm (convection zone) with 512 x 171 grid points, resulting in a resolution of about 120 km per grid point. We drive the convective heat transport with a constant heat flux through the bottom boundary. The upper atmosphere above the photosphere is also included in the simulation, but acts only as a flexible boundary condition.

Vertical velocity fields

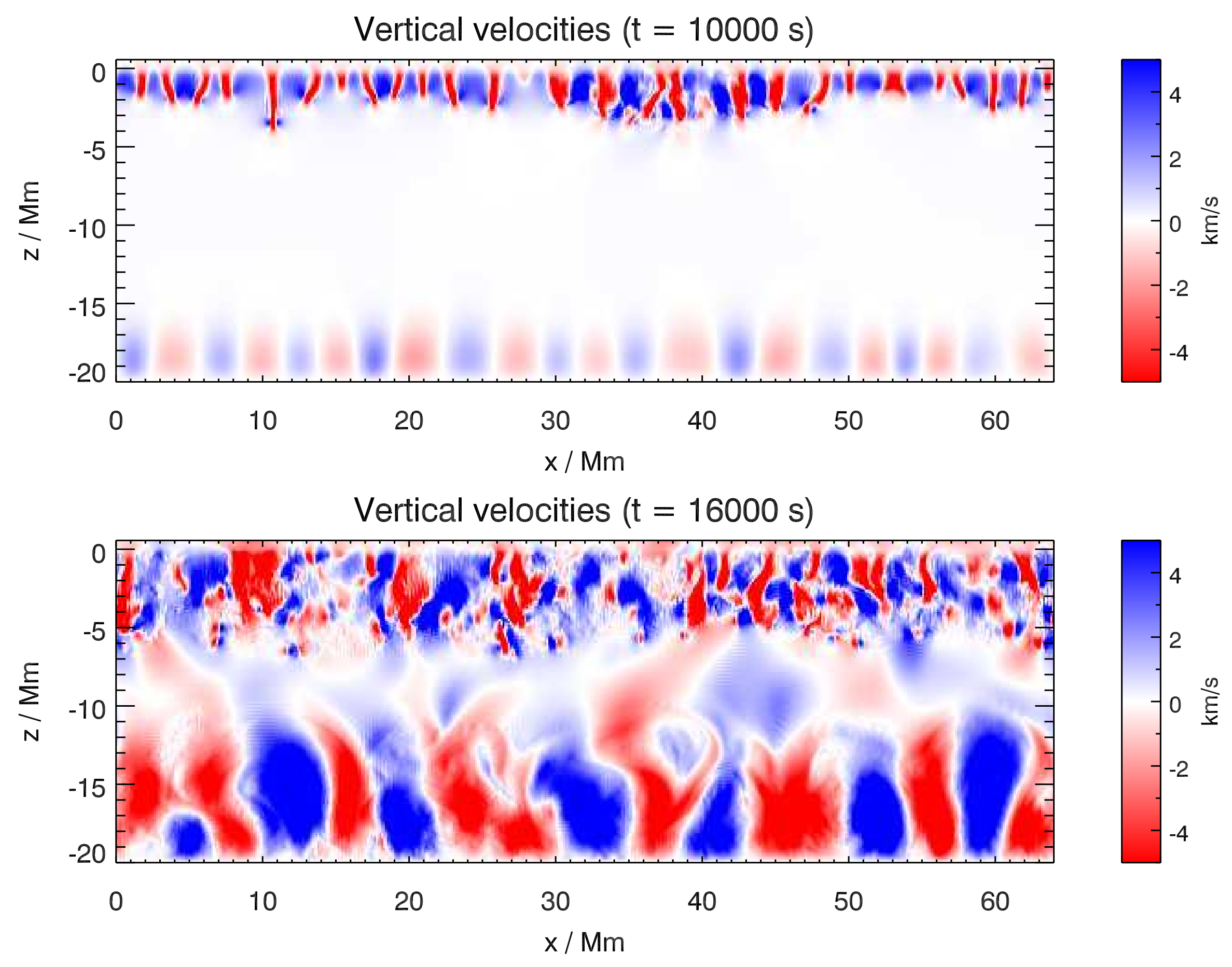

Figure 1: Vertical velocity fields.

Vertical velocities for $\nu = 1.34 \cdot 10^5\ \mathrm{m^2/s}$. Blue areas indicate upflows, red areas downflows. We find different cell sizes at the bottom and at the top, with larger cells at the bottom. We see the cells breaking up into smaller cells towards the surface.

Granulation

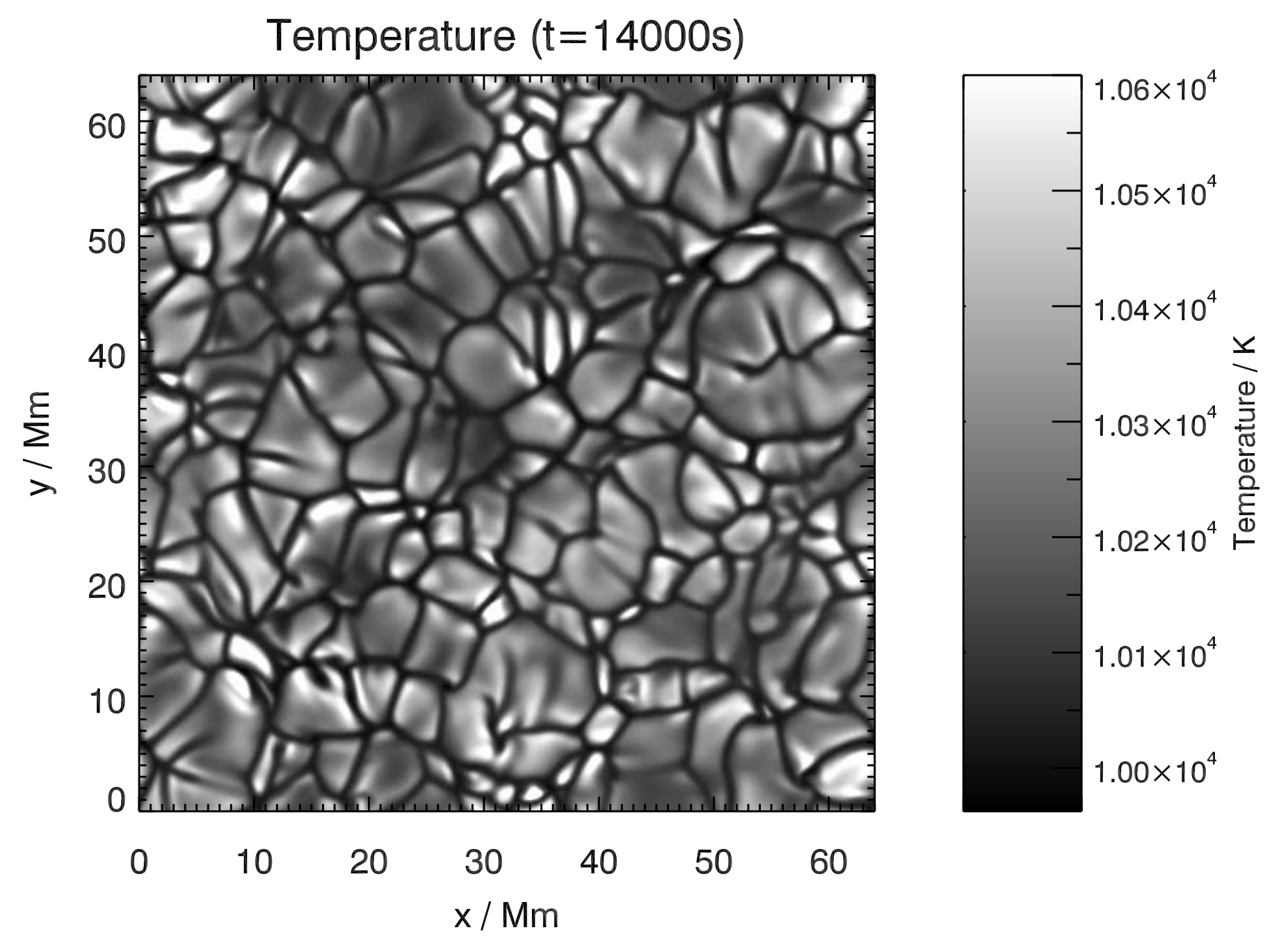

Figure 2: Temperature pattern obtained by a 3D simulation 260 km below the surface.

Our 3D simulation shows a realistic granulation pattern. Temperature fluctuates in the range of a few 100 K, while the vertical velocities are within ±3 km/s. For 2D the minimal aspect ratio to avoid getting spurious shearing motions is dependent on ν. Higher ν requires higher aspect ratios.

Kinematic viscosity ν

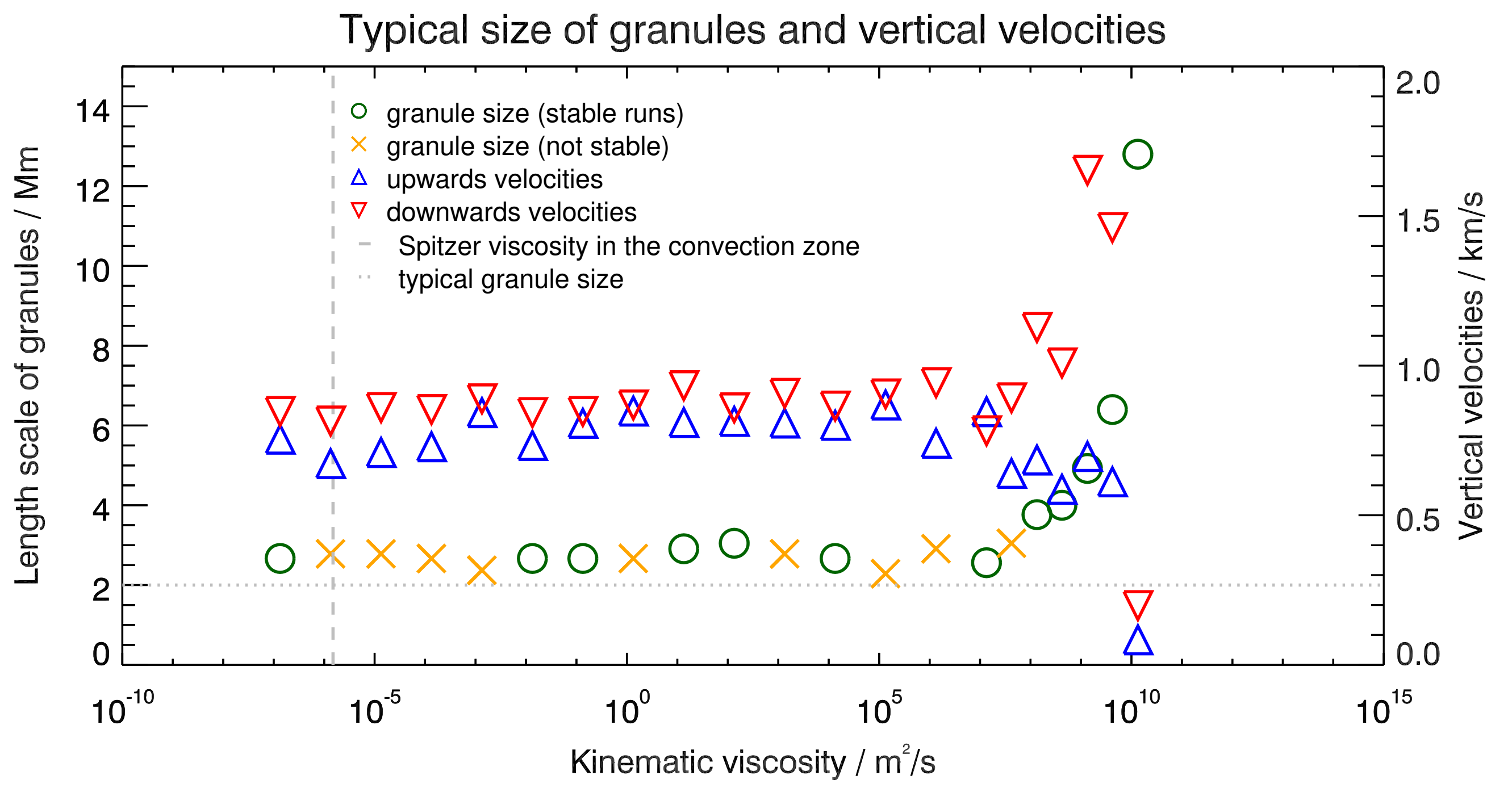

Figure 3: Up- and downward velocities and characteristic granule size vs. ν. Horizontal dotted line is typical granule size [2], vertical dashed line is Spitzer viscosity [3] calculated for the convection zone. Stable runs ran for 24h without crashing.

We see that below a certain value for ν the granule size and vertical velocities show no trend. When ν becomes too small, the simulations are likely to crash. The downflow velocities are slightly higher than the upflows, as the regions with downflows are smaller and the flows have to balance out. At large ν we find large granules, as small scale turbulence is inhibited. Small values for ν on the other hand cause issues with numerical stability and therefore ν has to be chosen according to the grid resolution.

CPU scaling

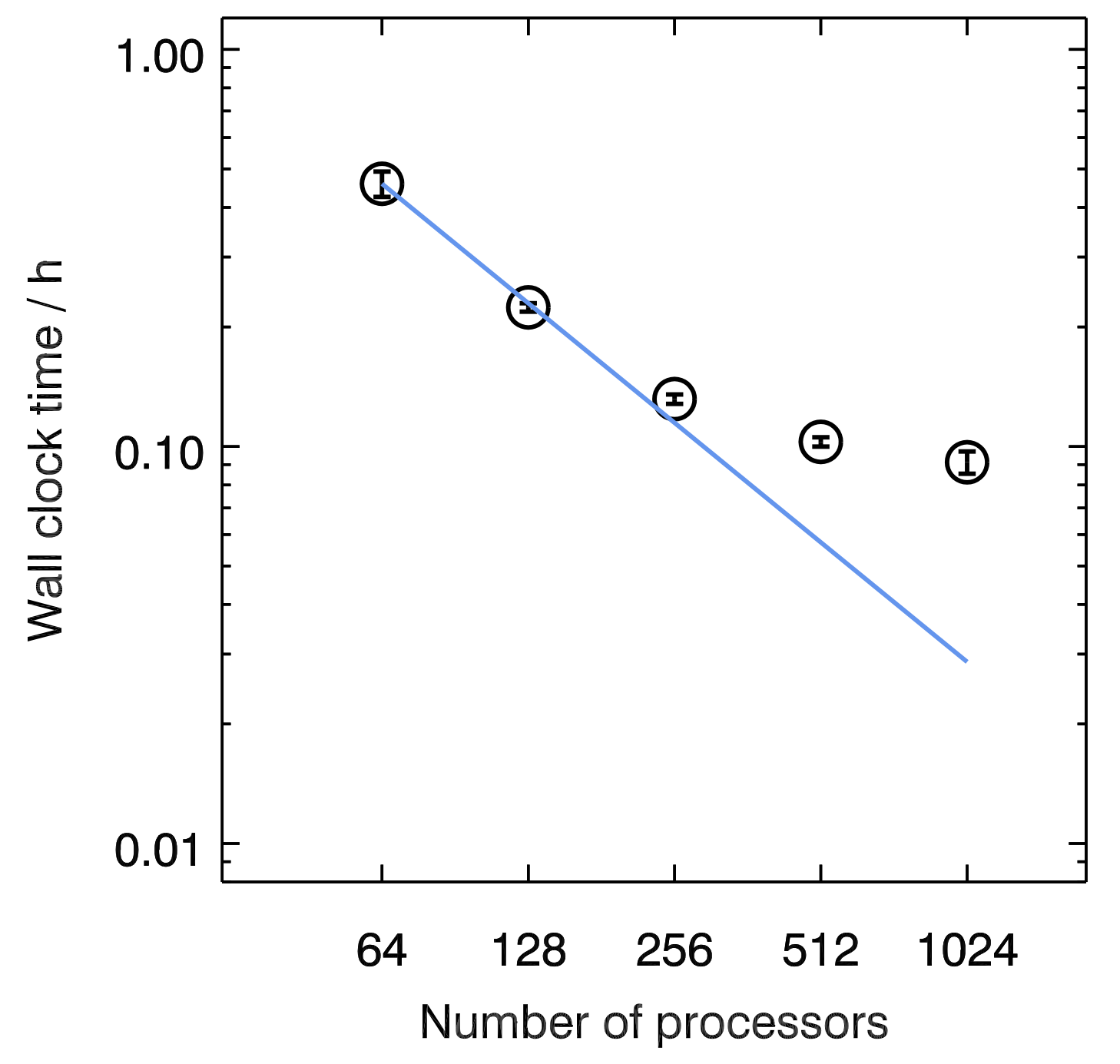

Figure 4: Wall clock time vs. number of processors.

We can efficiently run the setup with 256 processors. More processors provide diminishing returns and we expect the computation time to rise again with more processors due to increased communication between single processors. In terms of writing speed a distributed I/O scheme performs faster than the HDF5 scheme by about a factor of 4, but the file system of a supercomputer may not be able to handle too many file operations.

Conclusions

- Simulations show cells breaking up into smaller cells
- Small values of ν cause issues with numerical stability
- Dependence on ν is only visible above a critical value of $1.34 \cdot 10^7\ \mathrm{m^2/s}$
- Small 2D setups can use a high number of processors effectively

References

1. The Pencil Code Collaboration *et al.*, *Journal of Open Source Software* **6**, 2807, (`https://doi.org/10.21105/joss.02807`) (2021).
2. B. Ruiz Cobo *et al.*, presented at the Cool Stars, Stellar Systems, and the Sun, ed. by R. Pallavicini *et al.*, vol. 109, p. 155.
3. L. Spitzer, *Physics of Fully Ionized Gases*.

Acknowledgements: This research was funded in whole, or in part, by the Austrian Science Fund (FWF) [P 32958-N].