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Using simulations of solar surface convection as boundary conditions on global simulations

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Abstract. Direct numerical simulations of convective stellar envelopes, are divided between two different physical regimes, that are rather difficult to reconcile — at least with the computational power of present-day computers. This paper outlines an attempt at bridging the gap between surface and interior simulations of convection.

Keywords. convection, hydrodynamics, radiative transfer, Sun: interior

1. The Dichotomy

Global scale simulations Have spherical geometry, include rotation, and have no lateral boundaries. They do have top and bottom boundaries, which for lack of better alternatives, are hard impenetrable and heating at the bottom and cooling at the top. This realm is optically deep and radiative transfer is well into the diffusion limit. The bulk of the solar convection zone can be well approximated by not only an ideal gas but even a perfect gas. The simplified physics is key to making such simulations feasible.

If the relevant features are resolved in the simulations, they can realistically describe the large scale convection, meridional flows, overshoot at the bottom of convective envelopes, dynamo action and probably also magnetic cycles.

Surface simulations, on the other hand, are small boxes straddling the photosphere. Here, the radiative transfer needs to be solved explicitly, for several directions, and the effect of millions of spectral lines has to be accounted for. This region also covers the major ionization zones so that at least the ionization and dissociation balances of H and He has to be included in a realistic simulation of stellar convection.

The resolution has to be large enough to resolve the granules and the steep photospheric temperature gradient. A realistic simulation of stellar convection also has an open bottom boundary, so as not to recycle the entropy deficiency, turbulence and vorticity of the downdrafts (which have been cooled at the photosphere) into the upflows, weakening the contrast between the two flows. Such simulations can be directly compared to all imaginable observations of the Sun and stars (**?**),and can greatly improve our interpretations of these observations.

The scale of convection increases rapidly, when going inward from the photosphere, giving rise to a fundamental scale-separation between interior and surface.

2. Giant Cells

Apart from the scale, the surface of the global scale simulations looks exactly like the photosphere of the surface simulations, as shown in the middle and right-hand-side panels, respectively, of Fig. 1. This granulation pattern is caused by the very rapid cooling in the photosphere or from the artificial solid cooling slab put on top of the global simulations.

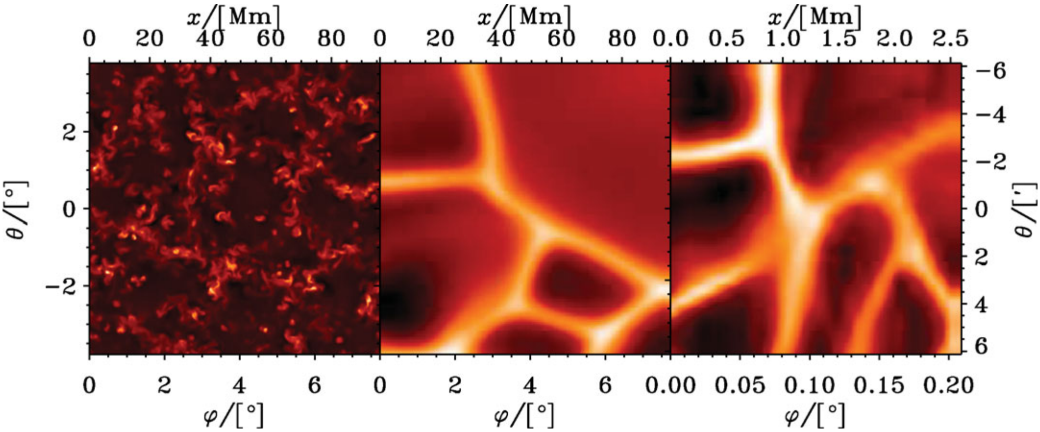

Figure 1. Comparing the morphology of vertical velocities at the top of a global ASH simulation of the solar convective envelope by **?** (middle), with a surface simulation (left) at the same depth of $0.979\,R_{\odot} = 14.6\,\mathrm{Mm}$ below the photosphere. The right panel shows the photospheric velocities of the surface simulation, enlarged by a factor of 37 to match the top of the ASH simulation.

This, however, looks nothing like the location in the large surface simulation by **?**, that corresponds to the top of the global simulations, as shown in the left panel of Fig. 1.

A lot of the difference between the middle and left panels of Fig. 1, is due to the factor of 22 in physical resolution between the two simulations, but even resampling the surface simulation to 45×45-points, would not result in the middle panel. The loosely connected network of downflows with many isolated downflows in between, cannot be reproduced with the closed boundary, cooling layer of the global simulations.

Below about a Mm from the photosphere, the flux is carried out by a number of discrete, entropy deficient, over-dense downdrafts — not a homogeneous cooling layer. We therefore propose to open the top boundary of the global simulations for such downdrafts, stochastically reproducing, e.g., the correlation of entropy and velocity of the downdrafts of the surface simulations. This procedure would be subject to conservation of mass at the top boundary and the approximate constancy of convective flux.

The curved spherical segment (CSS) code for simulations of wedges of convection zones **?** is going to be used as a testbed for these new boundary conditions. This code can be seen as an intermediate step between the surface and the deep interior, as it is fully compressible, only covers a fraction of the radial and horizontal extent, but does employ spherical geometry, only includes radiation in the diffusion approximation, and has a resolution and covers time-scales in-between the two other cases. This fast and highly parallelizable code is ideal for these kind of experiments and in itself can be used for analyzing the effect of the boundary conditions on, e.g., the near surface shear-layer.

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