Dear Bob,

I'm sending you a progress report on preliminary tests I've been running on the high-cadence simulations of compressible convection you sent me. Most of these so far have been for the purpose of chasing bugs in software I've devised to handle the data. However, I've recently computed some temporal power spectral statistics on the vertical velocity, which I will call v_z. Directly below, I've plotted what I roughly consider to be the power in vertical motion for horizontal wavelengths longer than 9.6 Mm, which would be equivalent to spherical-harmonic degrees up to about 450.* These are shown at depths of 0 (blue locus), 2(green) and 4 Mm (red).

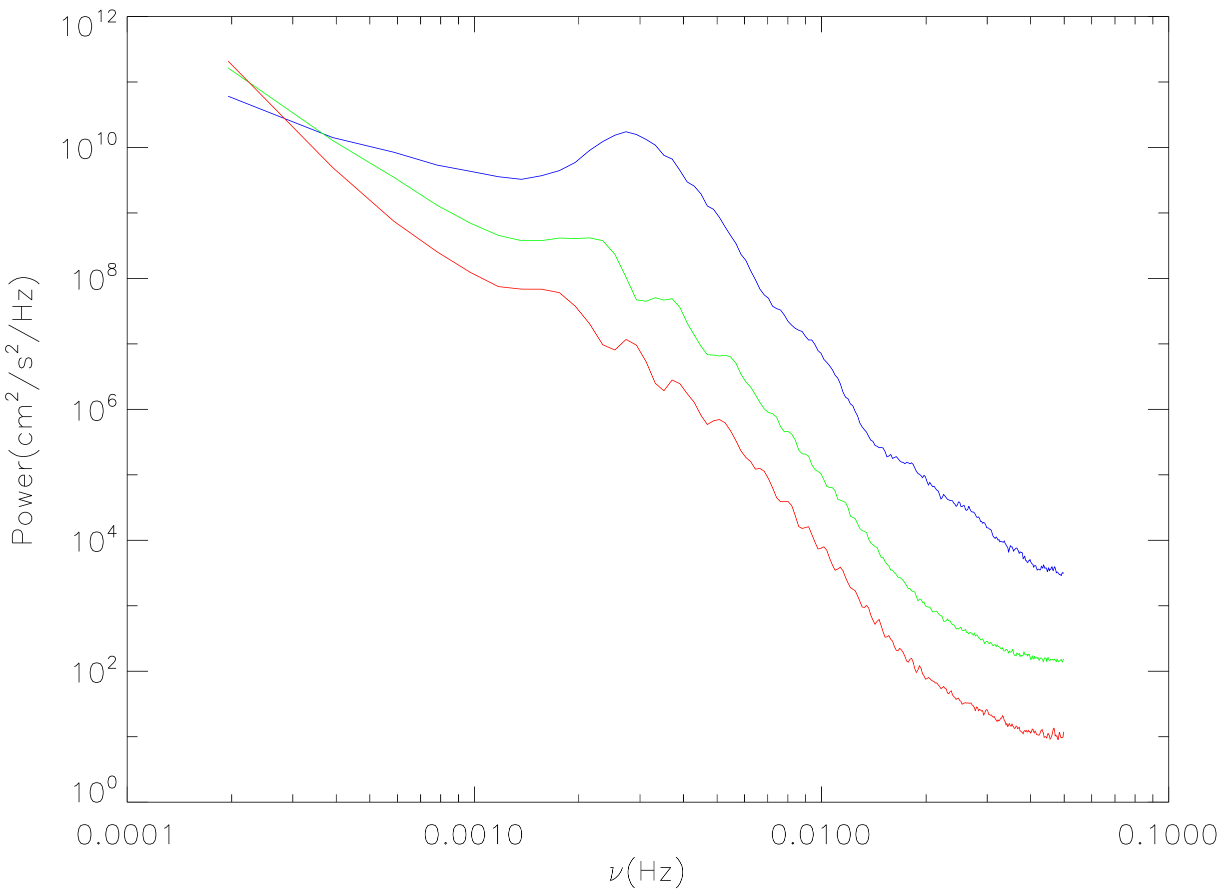

Figure 1: Plots of low-degree acoustic power at depths of 0(blue), 2(green) and 4 Mm (red).

The rates at which the power decreases with frequency are significantly greater than I expected. In the range 5 to 20 mHz, the power at the surface, which I suppose to be nearly all acoustic at low degree, drops at a rate of approximately 7.2 decades in power

* To be more precise, I collapsed the original 1000×1000-pixel frames to 20×20-pixel frames, each pixel containing the mean vertical velocity over a 50×50 pixel region in the original vertical-velocity map. I then computed the power-spectra of these 400 pixels and plotted the average.

per decade in frequency. As I understand it, this suggests that acoustic waves in this part of the spectrum would have a relatively minor role in heating a non-magnetic chromosphere even if the distribution in power were isotropic.†

A couple of questions:

(1) Could the steep decrease in power with frequency be a result of numerical viscosity or some other computational artifact?

(2) How important could radiative damping be, in place of viscosity, in limiting the efficiency of acoustic wave generation at relatively high frequencies? I asked Joe Werne this question. He responded that the Prandtl number in the upper convection zone is approximately 10^{-9}, which I understand to mean that radiative diffusion is generally a far stronger damper than atomic viscosity. Is there an effective Prandtl number for your computation, supposing that you would replace the atomic viscosity of the solar medium with an appropriate numerical viscosity?

Evindently, as the depth increases, the loci of the power spectra in Figure 1 look more and more like the dorsal profile of a stegosaurus, while otherwise maintaining the rapid decrease with frequency. I began to examine this with the tentative assumption that this is a character of relatively localized convective plumes penetrating to these depths. This is mainly because I understand that low-degree power between about 2 and 20 mHz at depth zero is primarily due to acoustic waves, and I do not see why these should take on such a character simply by having propagated downward to 2 or 4 Mm beneath the surface.

To get an assessment of the relative locality of the high-frequency contribution by downflowing plumes, I applied a 10–20 mHz temporal filter to the original vertical velocity timeseries.‡ Figure 2, below, shows a sample snapshot taken from the resulting timeseries. Fig 2a shows a snapshot of the vertical velocity (v_z) over the full spectrum. Fig 2b shows v_z in the 10–20 mH spectrum. Fig 2c renders the image shown in Fig 2b at approximately 50 times the contrast of Fig 2c. In this rendition the 10–20 mHz vertical velocities in the regions co-local with downflowing plumes tend to be thoroughly saturated. This image can be separated into two, regions, both somewhat disjoint. The first shows large amplitudes that vary stochastically from one pixel to the next, roughly co-local with supercell boundaries. The other, roughly co-local with supercell interiors,

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† The reasoning here, perhaps somewhat oversimplified, is that the low-degree power spectrum shows us a fraction of the power that is inversely proportional to k_{max}^2, where

$$k_{max} = \frac{2\pi\nu}{c}.$$

Hence, the isotropic power is proportional to ν^2 times the power plotted and therefore decreases with a power-law exponent of $-7.2+2 = -5.2$, which itself leans heavily towards relatively low frequencies.

‡ This analysis is applied to the original, uncollapsed vertical velocity, and is therefore no longer limited to low-degree vertical motion.

shows relatively smooth variations whose characteristic wavelengths are approximately the sound speed at 4 Mm ($\sim$20 km/sec) divided by 10–20 mHz, i.e. about 1–2 Mm. Thus, I'm inclined to identify the relatively smooth variations as the signature of local motion of the medium due to acoustic noise passing through it and the stochastic variations as non-acoustic transients resulting from downflowing plumes encroaching into the pixels that show these. (You probably recognize that the characteristic horizontal wavenumbers, k_{plume}, of the stochastic variations in the supercell boundaries are far greater than $2\pi\nu/c$, so these disturbances would have to be highly evanescent on the whole and going nowhere.) Fig 2d shows the result of a masking exercise designed to discriminate between these two regions, admitting only those regions in which what I judge to be the acoustic motion dominates.

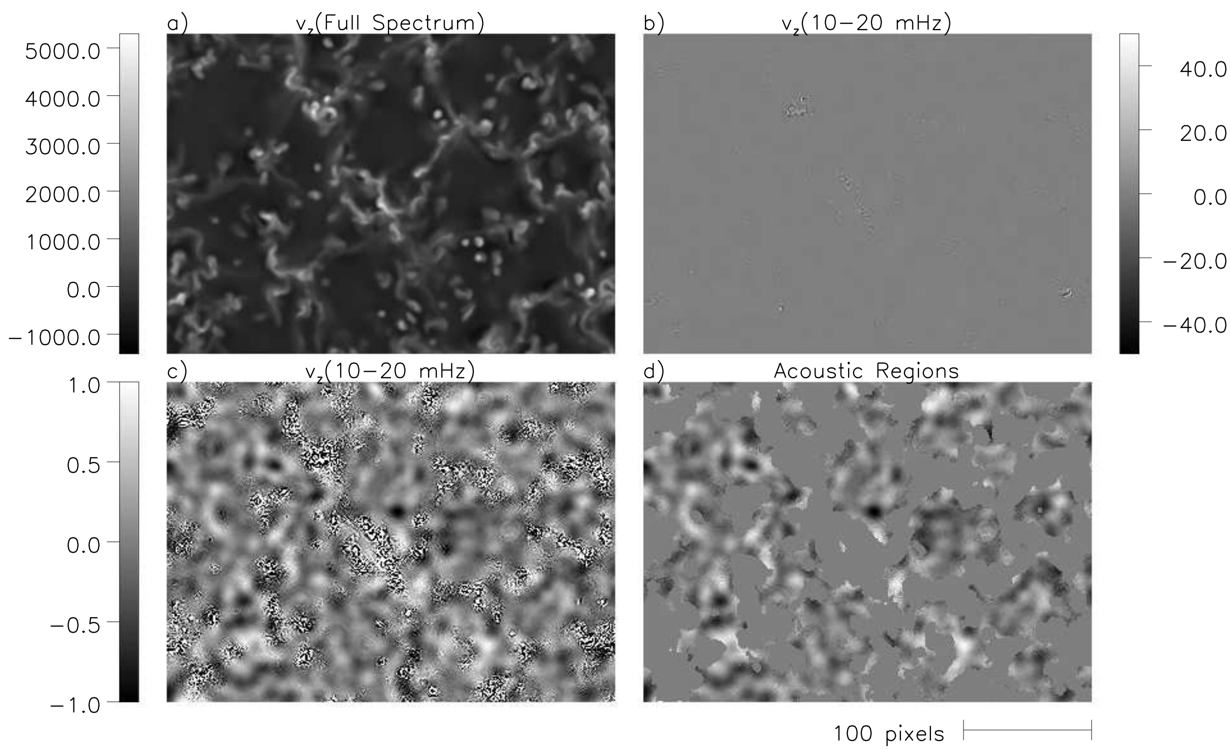

Figure 2: Snapshots of (a) vertical velocity (v_z) over the full spectrum, (b) v_z in the 10–20 mH spectrum, (c) the map in frame (b) rendered at 50 times the contrast, and (d) the map in frame (c) showing only regions in which I judge v_z to be predominantly the result of background acoustic noise passing through the local medium. All velocities are in units of m/sec

Returning to Figure 1, I am curious about the inflection from about 10 mHz to the Nyquist frequency (50 mHz) in which the slopes of the loci tend to level out at 2 and 4 Mm. My rough, and very tentative, assessment, based on a masking experiment from 40–50 mHz similar to that done from 10–20 mHz is that the inflection characterizes the spectrum of the acoustic noise as well as that of the down-flowing-plumes. Do you think this is a computational artifact?

In closing, I want to say that I'm enjoying your simulations very much. I've taken the liberty to show Joe Werne what I'm sending you. Consultations with him have been very educational for me.

Charlie