Vertical Velocity in the Gray Zone

Nadir Jeevanjee

NOAA Geophysical Fluid Dynamics Laboratory, Princeton NJ
Program in Atmosphere and Ocean Sciences, Princeton University, Princeton NJ

Abstract

Though it is now commonplace to run non-hydrostatic atmospheric models in the 'gray zone', wherein the horizontal resolution is too high for the hydrostatic approximation to hold but too low to fully resolve convection, it is not always clear at what resolution vertical velocities should converge, or how this convergence might differ for a hydrostatic model. In this talk we present analytical formulae for vertical accelerations as a function of resolution which map the gray zone, giving a sense of where and how vertical velocities should converge, and which also quantify how hydrostatic models over-estimate vertical velocities and fail to converge at high resolution. We validate our results with numerical simulations, and give intuition for them in terms of Davies-Jones's 'effective buoyancy' and the closely related 'buoyancy pressure' of Jeevanjee and Romps.

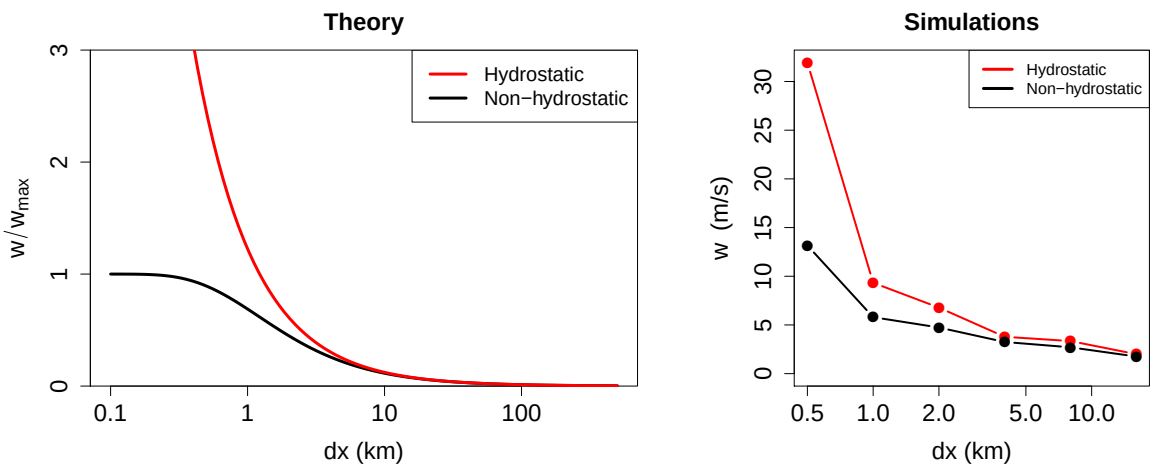

Figure 1: **(Left)** Analytical expressions for the scaling of vertical velocity w of an idealized parcel as a function of its width dx, for both hydrostatic and non-hydrostatic systems. Parcel height is assume to be 1 km, and w is normalized by $w_{\max} \equiv \lim_{dx\to 0} w$. **(Right)** Plot of average in-cloud w at 500 hPa from cloud-resolving radiative-convective equilibrium simulations, using both hydrostatic and non-hydrostatic solvers. Note that in both panels, the hydrostatic approximation overestimates w and yields a divergent w as $dx \to 0$. For the non-hydrostatic system, w converges but only at sub-kilometer resolutions.