CORRESPONDENCE

Reply to "Comments on 'Preconditioning Deep Convection with Cumulus Congestus'"

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ABSTRACT

In his comment, D. M. Schultz asked for clarification concerning (i) the validity of the results of C. Hohenegger and B. Stevens for the development of convection over the midlatitudes and (ii) the exact meaning and computation of the term "moisture convergence." This reply aims at clarifying these two aspects.

Using satellite observations and large-eddy simulations of the development of deep moist convection over the tropics, Hohenegger and Stevens (2013) argued that the moistening of the atmosphere by congestus clouds is too slow to explain the observed fast transition times, from congestus to cumulonimbus. Schultz (2013) wondered whether this result remains valid for the midlatitudes. Although a full analysis as performed in Hohenegger and Stevens (2013) has not been conducted for the midlatitudes, some insight can be gained based on the results of Zhang and Klein (2010). They studied the transition from shallow to deep convection over the Atmospheric Radiation Measurement (ARM) Climate Research Facility Southern Great Plains (SGP) site during summer. Their analysis can be employed here to estimate τ_*, the transition time between congestus and cumulonimbus, as well as τ_c, the time needed by congestus clouds to moisten the atmosphere. Figure 3d in Zhang and Klein (2010) indicates a τ_* of O(1–2 h). Recalling Eqs. (1a)–(1c) of Hohenegger and Stevens (2013), τ_c can be expressed as

$$\tau_c = \frac{\Delta q_v}{(dq_v/dt)_c}, \quad (1a)$$

$$\Delta q_v = \frac{1}{z_2 - z_1}\int_{z_1}^{z_2} q_v(t_2, z)\,dz - \frac{1}{z_2 - z_1}\int_{z_1}^{z_2} q_v(t_1, z)\,dz, \quad (1b)$$

and

$$\left(\frac{dq_v}{dt}\right)_c = \frac{\overline{w'q'}_{\text{cb}}}{z_2 - z_1} = \frac{\text{LH}}{L_v \rho (z_2 - z_1)}, \quad (1c)$$

with q_v specific humidity, z height, t time, $\overline{w'q'}_{\text{cb}}$ moisture flux at cloud base, LH latent heat flux, L_v enthalpy of vaporization ($2.5 \times 10^6\,\text{J kg}^{-1}$), and ρ air density at cloud base (assumed as $1\,\text{kg m}^{-3}$).

Based on a visual inspection of Figs. 4 and 6 in Zhang and Klein (2010), LH is set to $300\,\text{W m}^{-2}$ and Δq_v to $1.5\,\text{g kg}^{-1}$. Note that a value of $300\,\text{W m}^{-2}$ is on the upper range of the measured values and strictly speaking only valid between 1200 and 1400 local standard time (LST). We estimate Δq_v as the difference in mixing ratio at 1130 LST between days with shallow and deep convection, whereby the difference is assumed to remain constant above 4 km. With $z_1 = 500\,\text{m}$ and $z_2 = 5000\,\text{m}$, Eqs. (1a)–(1c) yield $\tau_c = 16\,\text{h}$. This is much longer than the observed τ_*. Even if it may be argued that $1.5\,\text{g kg}^{-1}$ is too large for the requested amount of moistening as only the moistening by congestus clouds should be considered, a τ_c of 2 h, on the order of τ_*, would imply $\Delta q_v = 0.2\,\text{g kg}^{-1}$. This seems very small. Hence, this analysis suggests that the results of Hohenegger and Stevens (2013) remain valid for the midlatitudes. Zhang and Klein (2010) also noted that moistening of the free troposphere, albeit by shallow convection, is likely too weak to promote deep convection.

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Schultz (2013) also asked for clarification concerning the exact meaning of the term ‘‘moisture convergence.’’ In a strict sense only the vertical component of the moisture convergence, $w(dq_v/dz)$ [see Eq. (3c) in Hohenegger and Stevens (2013)], was considered in Hohenegger and Stevens (2013). This means that both the advection and the mass convergence term (w is assumed constant in the vertical) in the expression for the horizontal moisture flux convergence, as detailed by Schultz (2013), are zero. In a more practical sense it would be sufficient for any of these terms to be on the order of the estimated vertical moisture convergence to be able to promote a fast-enough transition to deep convection. In particular, a change in moisture advection would affect the tendency of q_v at a point (e.g., Arakawa 2004), whereas the sole presence of a height-varying w would generate a nonzero mass convergence term. This further highlights the importance of the mass convergence term for an ingredients-based forecasting of convective initiation, as emphasized in Banacos and Schultz (2005). We thank Schultz (2013) for bringing this point to our attention.

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