1 Introduction
Error growth in numerical weather prediction models has widely been attributed to amongst the solutions of the (implicit) processes governing the upscale error growth (in recent years) has been found as an important initial component of the chain of error growth in numerical weather simulations. Baumgart et al. (2019) found in a case study that error growth in ICON is initially largely attributable to the convection scheme, more so than to other model schemes. These errors saturate fast (<12 h), ending up importantly affecting the tropopause region, where they spin-up divergent perturbations (subsequent days) which then non-linearly grow and enter Rossby waves dynamics. Bierdel et al. (2017) and Bierdel et al. (2018) show that convective heat sources excite gravity waves and subsequent geostrophic adjustment can be a mechanism for a divergent flow perturbation (errors) to enter the upper tropospheric balanced flow. Bierdel et al. (2017) show that linear superposition applies to such convectively induced perturbations or their errors. We investigate the magnitude and sensitivity of such an upper tropospheric (and lower stratospheric) divergent flow, by perturbing and altering some important processes.

It has been argued that deep convective processes can be accurately simulated at 125 m (Bryan, 2003), as a large majority of the turbulence is then explicitly resolved. Hanley et al. (2014) and Stein et al. (2014) have shown that representation of intermediate to deep convection down to ~3 km likely improves with z < 200 m using the UK MetOffice model, but there are still caveats in the statistical representation compared to radar observations in multidimensional space. We simulate three idealized cases of convection in the cloud resolving model CM3 (Bryan, 2015) in LES mode.

2 Methods

2.1 Configuration

- Grid: rectangular (aspect ratio 2:1) and cubic, Δx - 100-1000 m, vertical depth 20 km.
- Duration 2 hours, Δt = 75 s.

2.2 Wind profiles #1, #2, #3

- Mean flow set such that domain propagates approximately with speed of convective system to increase residence time of flow perturbation inside domain.
- Initiation:
  - Default warm bubble initiation (#1) and #2): max. 0.67 K at ; ≈ 15 km.
  - Coldpool initiation (#3): max ~ -6 K at surface, western half of domain ("equal-time" line).

2.3 Experiments

- Randomly generated perturbations for ensemble (9 members) to depth of the shear layers (~15 T)
- Resolution (RES). Reference run and ensemble have Δx = Δy = Δz = 200 m, Δt = 75 s.
- Latent heat of evaporation adjusted (LV) by -40, -20, -10, +10 and +20% (altered ambient stratification acts similarly).
- Vertical advection of potential and meridional momentum (MSE) adjusted by -50, -25 and 20% (artificially adapted convective momentum transport).
- Vertical advection of water vapor (MSE) by +20 and -20% for the effect of altered energy (re)distribution.

Diagnoses:
- Horizontal divergence (HDIV) has been derived from velocity fields using finite differences on grid points. Mass and energy (MSE) has been computed from potential temperature and water vapor mixing ratio. For this diagnosis of WV we implemented diagnostics in the model code, without (line) divergence contributions.
- Region selection for budget calculations: We average HDIV, mean condensation rate (COND), WV and MSE over an area and selected time t, including most of the region with gravity wave activity excited. These gravity waves leave the model domain during the simulation (convective initiation in the first hour, t = up to about 30 min).

3 Selected results

3.1 Region of budget calculations

In three reference runs (only = 4 min colored). Black rectangles mark the areas selected for budget calculations. Left: #1, center: #2, right: #3, identical areas #1 and #2, and nearly identical total area #3. Evaluation at ; < 50 min (#1 and #2), and ; ≤ 25 min (#3, to limit boundary effects.

3.2 Experiment results

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- Large spread in square line simulation (#1) among ensemble members in HDIV (much larger than in #1 and #2).
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- Decreasing the heat content significantly affects the magnitude (decrease) and distribution (lower altitude) of upper air HDIV, which is amplified by a reduced COND. The effect is even stronger for the other, less strongly forced (warm bubble), cases.
- Effect on HDIV on these simulations (correlates strongly with strength of convection and condense mass).
- Evaporation and sublimation of water and ice (after initial condensation) is slightly higher in squall line simulations
- Squall line simulations are more efficient to redistribute MSE and thereby relax upper tropospheric instability.
- Strong dependence of divergence effects on mode of convection, next to latent heating, is also suggested. The Figure
- Top: dimensionless dependence of the 200-200 m layer divergence on latent heat content. Bottom: scheme for controlled WV.
- Direct feedbacks on the controlled process (momentum/water transport).
- Structure or organization and total area of convection are (often strongly) affected.
- Effect on upper air HDIV not straightforward to attribute to the role of controlled processes.

3.3 Model environmental temperature (green) and dew- point (blue) profile and a parcel forced upward without mixing (red). The wind profiles are shown on the left.

Vertical cross section (y-z plane) of condensation rate (color) and isolines of horizontal divergence in shown (convergence: pink, per = 5 m/s through the cold core after 80 minutes for #3 (ensemble member 3).