The LES Mode of the Advanced Research WRF Model

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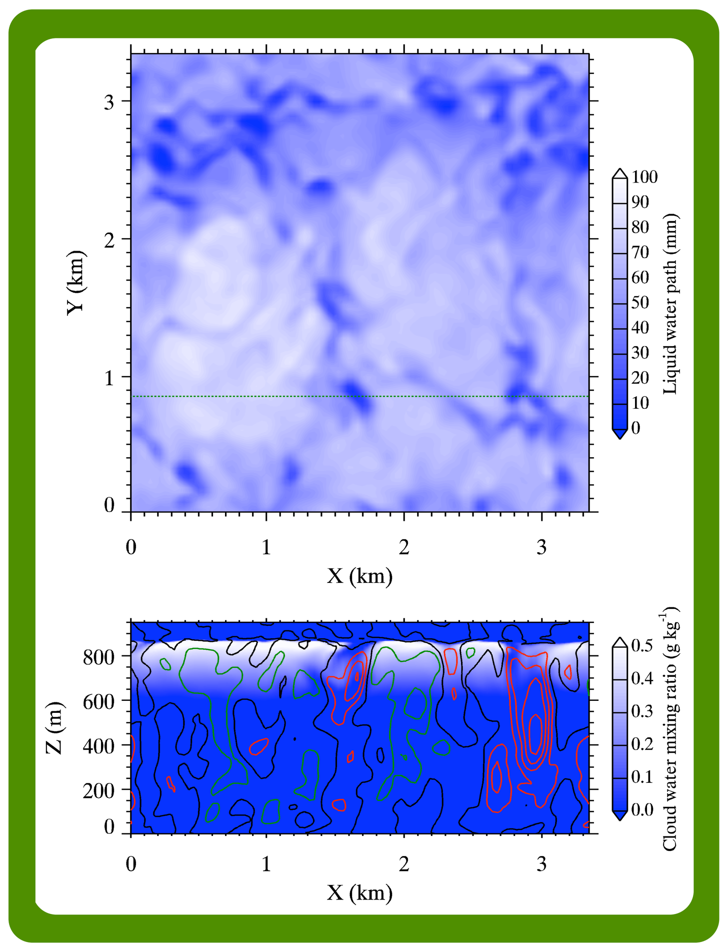
LES with Advanced Research WRF?

The implementation of the LES mode in the Advanced Research WRF model (ARW) is relatively new. A few studies (e.g., Moeng et al. 2007; Wang et al. 2009) have used ARW with an *O*(10 m) grid spacing to perform LES of the atmospheric PBL. However, detailed evaluation of the ARW-LES has not been well documented; Are the simulated cloud and turbulence realistic? How are the results of ARW-LES different from other LES models? What does one should know and care before one's production run? We study ARW-LES from various perspectives with a GCSS (GEWEX Cloud System Study) LES case of DYCOMS-II RF01 (Stevens et al. 2005).

GCSS DYCOMS-II RF01

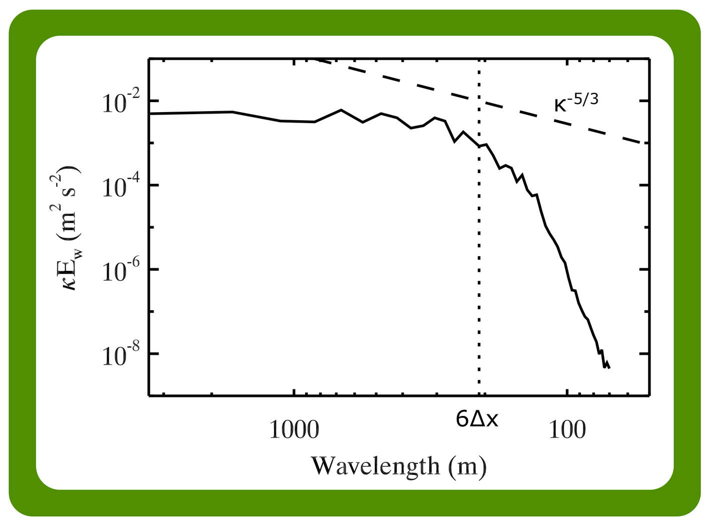
Configurations:

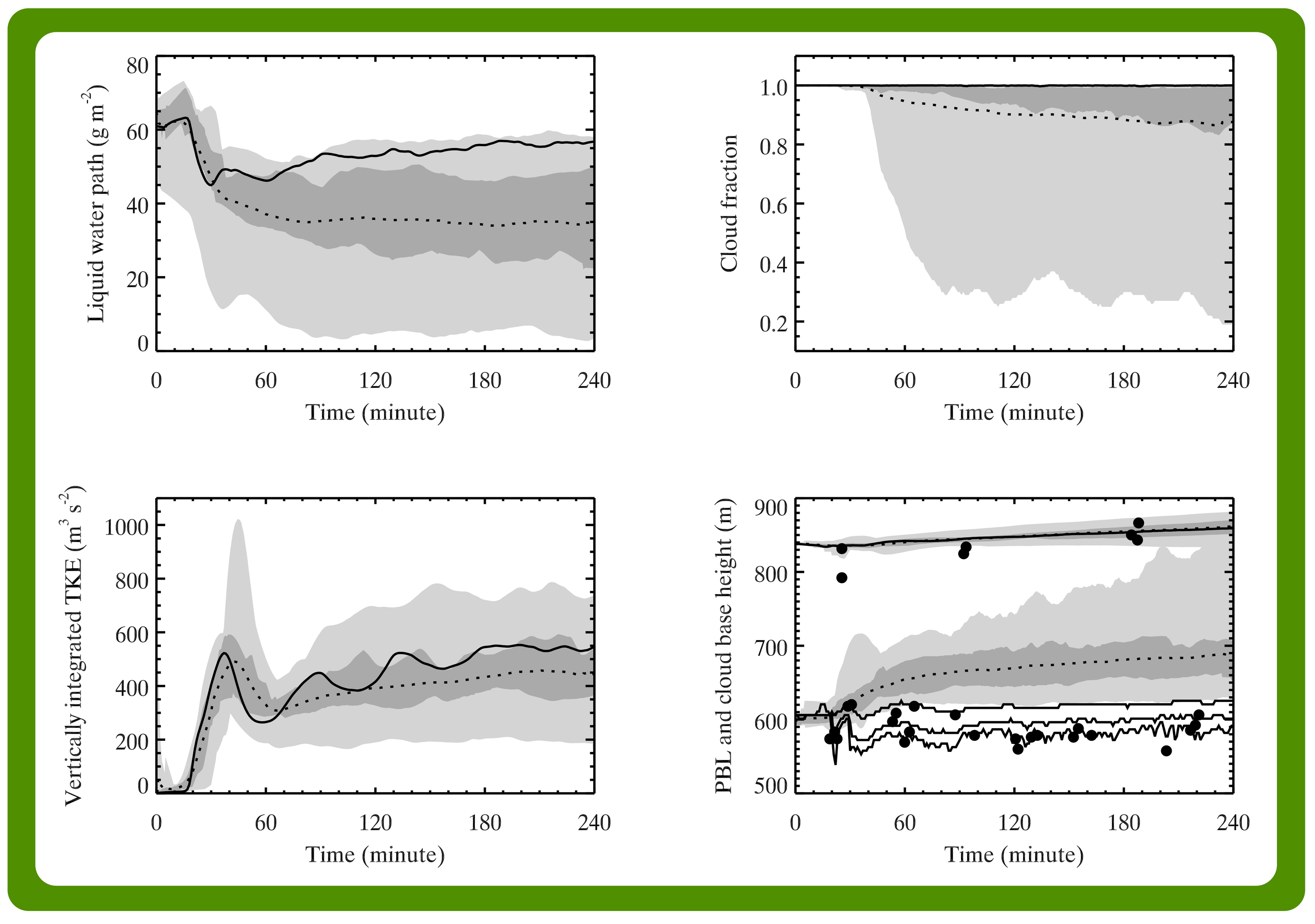
- Resolution: 96x96x300
- Grid spacing: $\Delta x = \Delta y = 35$ m, $\Delta z \sim 5$ m (domain top = 1500 m)
- Time step: 0.1 seconds (physical mode), 0.01 seconds (acoustic / gravity-wave mode)
- duration: 4 hours
- Prognostic 1.5-order SGS TKE closure
- Two-moment microphysics parameterization (Feingold et al. 1998)



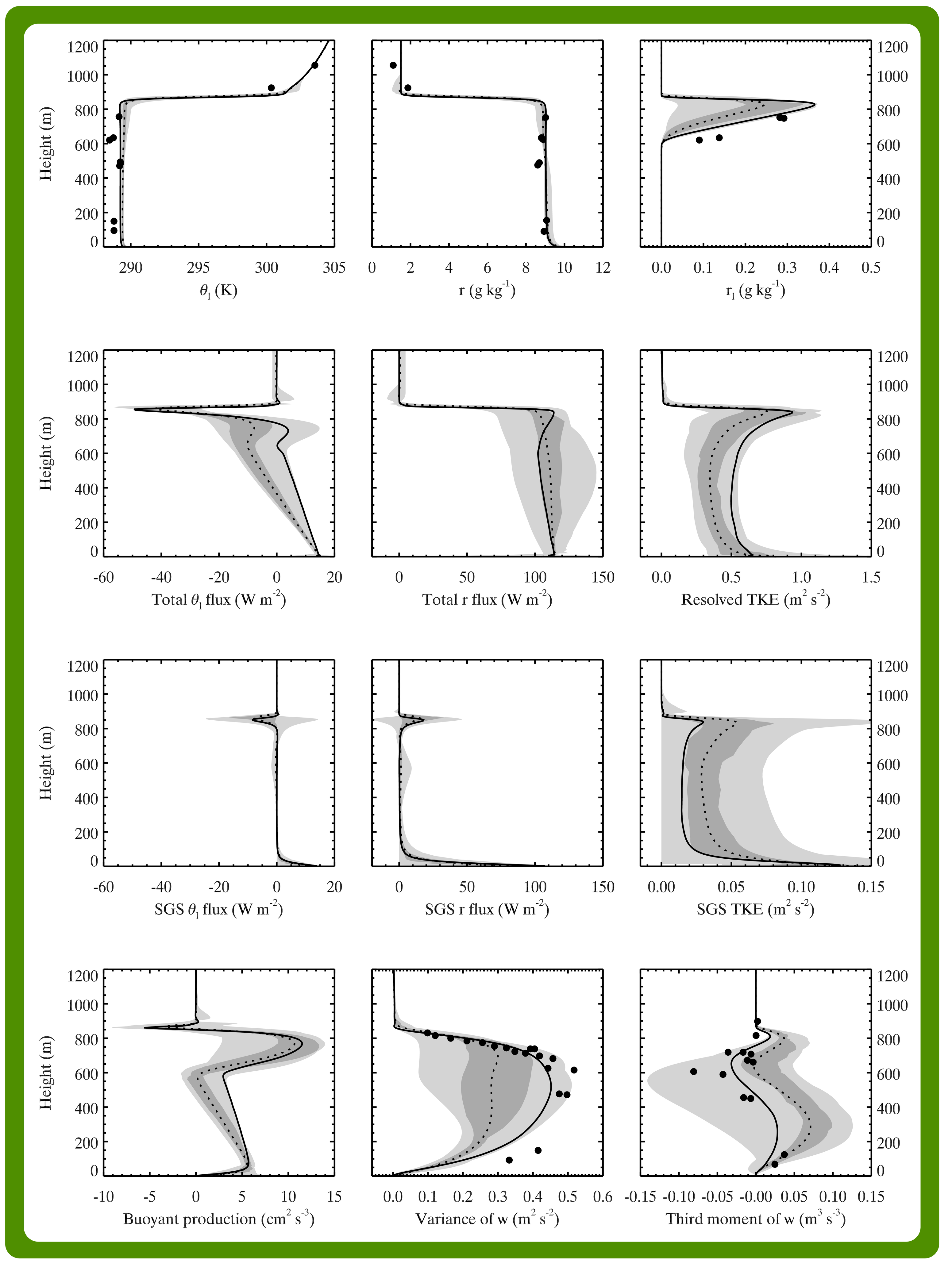
LEFT: Snapshot picture of the liquid water path and a cross-section cloud water mixing ratio at the green dotted line on the LWP picture. The line contours show vertical velocity. The downdrafts (updrafts) are colored red (green), the black contour is the zero isoline. The contour lines are drawn every 0.5 m s^{-1}. Narrow downdrafts and broad updrafts are consistent with radiatively driven turbulence. Downdrafts tends to exist at cloud holes (cloud water depleted region).

RIGHT: The power spectrum of the vertical velocity at ~800 m. The inertial subrange appears at ~400 m wavelength. The slope is steeper than $\kappa^{-5/3}$ for the scale smaller than 6Δx (Bryan et al. 2003).



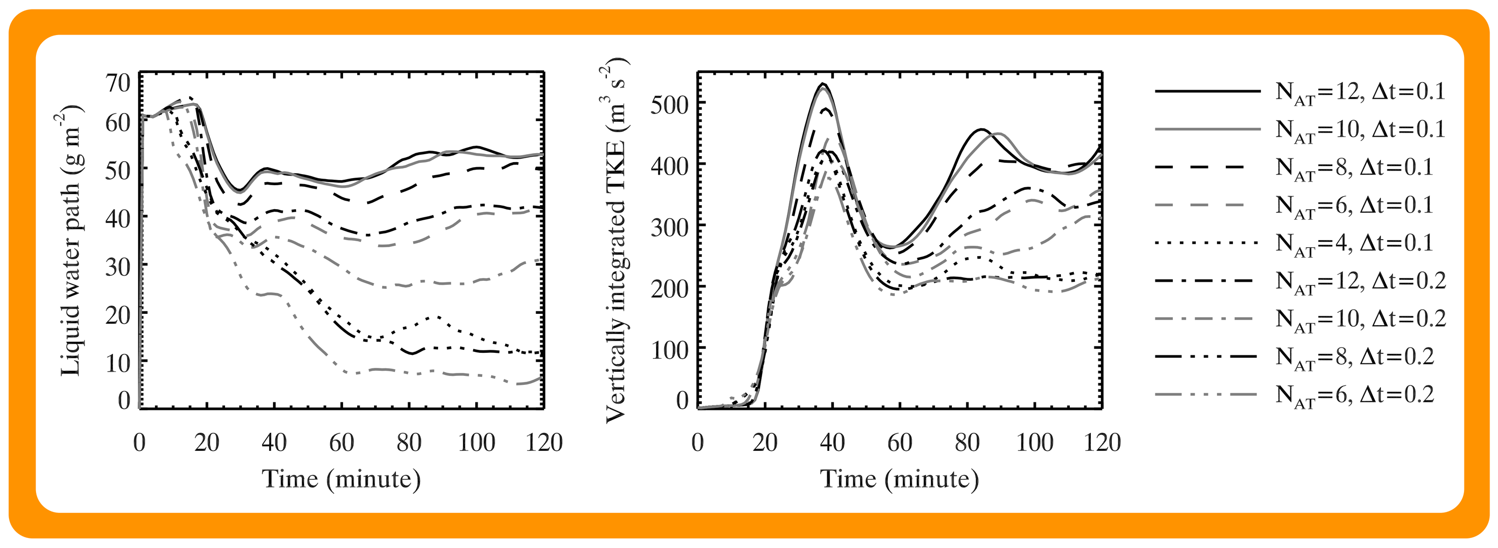


LEFT & RIGHT: Comparison with the GCSS ensemble members. The solid lines are the ARW-LES results, and dotted lines are the GCSS ensemble mean. The dark shading covers the first and third quartile, and the light shading covers the entire ensemble range. The black-filled circles show the observational values. Three cloud base heights for ARW-LES are an isoline of the 0.0001, 0.001, 0.01 g kg^{-1} cloud water mixing ratio from the lowest to the highest cloud base height. θ_l is liquid water potential temperature, r is total water mixing ratio, r_l is cloud water mixing ratio, and w is vertical velocity. The vertical profiles are hourly means of the fourth hour.

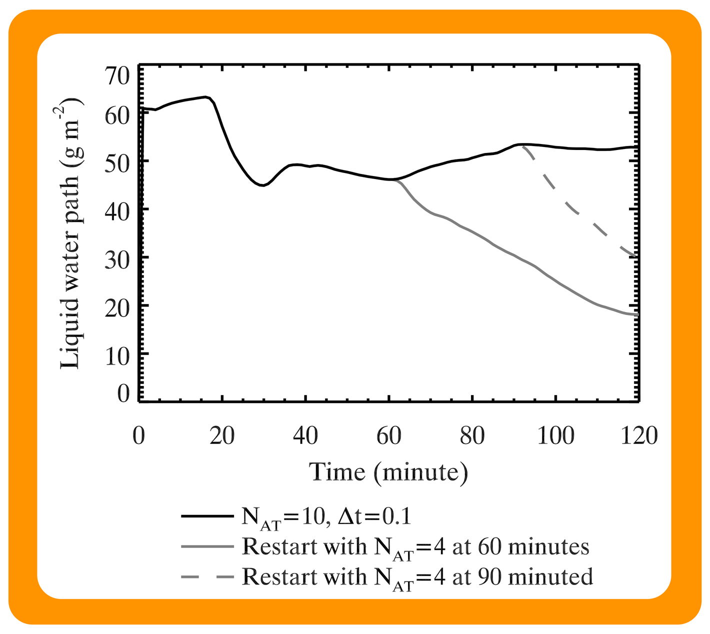


Sensitivity to the acoustic time step

Being a compressible model, ARW uses a time-split scheme of Klemp et al. (2007) to integrate both physical mode (low frequency) and acoustic and gravity-wave mode (high frequency). We found that the simulated cloud and turbulence are very sensitive to the acoustic Courant number. For instance, fast cloud dissipation happens with half of the maximum acoustic Courant number for stability.



LEFT: The results of the sensitivity test with various acoustic Courant number. N_{AT} is the number of acoustic time steps per physical time step, Δt. All cases are numerically stable. The results with the same acoustic Courant number, e.g., (N_{AT},Δt)=(6,0.1)=(12,0.2), are similar. The results converge for (N_{AT},Δt)=(10,0.1) and (12,0.1). The largest acoustic Courant number for this convergence is 0.086.



LEFT: The test simulations by restarting with N_{AT}=4 at 60 and 90 minutes with the restart data saved for the run with (N_{AT},Δt)=(10,0.1). The sensitivity immediately appears, thus the excitation of the resolved scale turbulence around 20 minutes is not responsible for the sensitivity.

- This sensitivity has also been observed with DYCOMS-II RF02 (Ackerman et al. 2009). However the convergence appears at larger acoustic Courant number (0.12).

- Does this sensitivity exist for shallow cumulus clouds? A sensitivity test with RICO (vanZanten et al. 2011) is in progress.

New tools

For efficient workflow, we introduced two useful packages: one is the ARW statistics package, which outputs horizontal mean profiles in height coordinate during simulation. The other is the ARW-LES package for easy model setup. The original ARW only outputs a three-dimensional snapshot, which is useful but not optimal. For instance, post-processing could be a huge burden for analysis. Configuring ARW for an idealized simulation requires modification of the source codes, which could easily be a source of errors. These packages are available for the ARW users upon request.

On-going research

Further evaluation of ARW-LES will be carried on by comparing with the turbulence structure of the stratocumulus boundary layer derived from high resolution Doppler lidar measurements during VOCALS campaign.

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