10th International Cloud Modeling Workshop

Convection in Strong Vertical Wind Shear: The 2 Aug COPE Case

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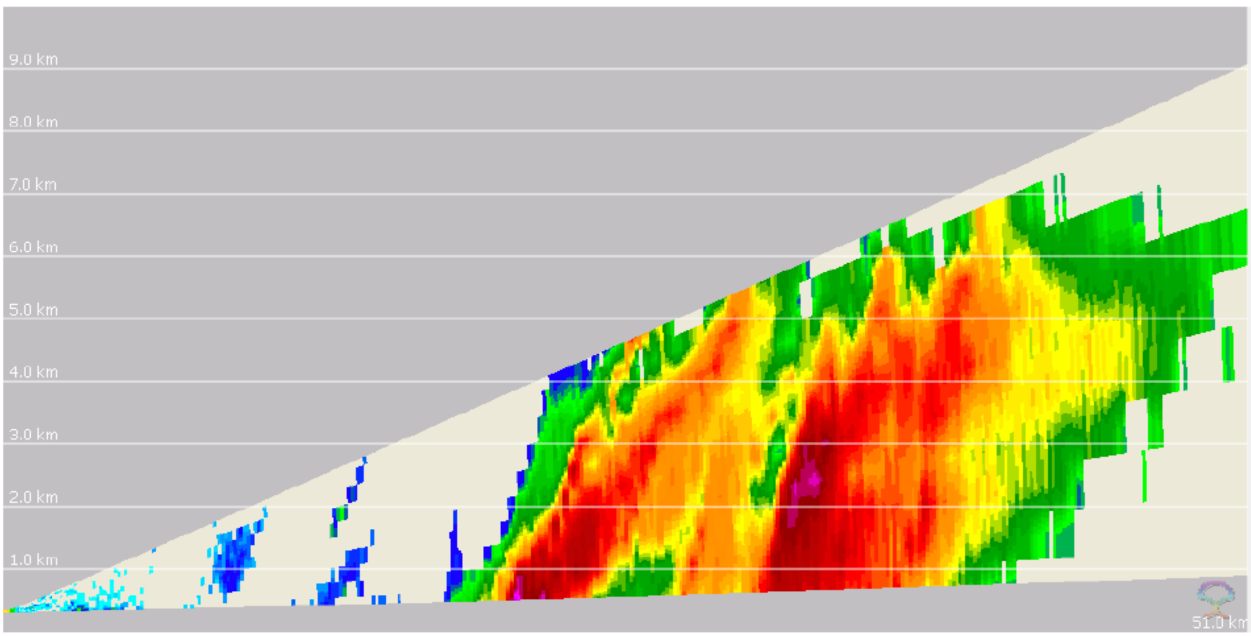

<u>Deadlines</u>:

Confirmation of Participation: ~March 10, 2021

Submission of simulation results to organizers: June 1, 2021

Cloud Modeling Workshop: July 26-30, 2021

Updates to the former version of this document are highlighted in yellow.

Case Overview:

The COnvective Precipitation Experiment (COPE) was conducted in July and August of 2013 in southwestern England. This region has a history of flash flood events in which nearly stationary lines of heavily precipitating convection can develop (e.g., Golding et al. 2005). Thus goal of the field campaign was to collect data on the dynamics and microphysics of convective precipitation, to help improve numerical weather prediction of heavy rainfall events. Several research aircraft and a portable ground-based radar, along with a wind profiler and surface aerosol measurement site, were deployed. A detailed description of the field project and highlights can be found in Leon et al. (2016).

On 2 Aug 2013, convection developed in an unstable environment (surface-based CAPE was approximately 700 J kg^{-1}) with strong vertical wind shear (300-1000 hPa shear was 5 x 10^{-3} s^{-1}). Maximum cloud-top heights were near 8 km and maximum aircraft-sampled updraft speeds ranged from 10 to 20 m s^{-1}. As a result, the clouds leaned substantially with height, as shown in the vertical cross section of two storms shown on the cover page of this document (based on ground-based radar data interpolated to a grid). Despite having greater instability and thus deeper convection than many of the other COPE cases, this case produced minimal precipitation in the convective stage sampled by the aircraft, despite having radar echoes exceeding 60 dBZ, and few ice particles (Jackson et al. 2018, Lasher-Trapp et al. 2018).

The 2 Aug case was one of those simulated and analyzed by Lasher-Trapp et al. (2018). In that study, it was found that the strong vertical wind shear severely limited various precipitation processes, and surface rainfall (Fig. 1). The strong updrafts lofted hydrometeors downstream of the main cloud and reduced the collection of cloud water as they fell. In addition, it was found that a secondary ice production mechanism (rime-splintering, i.e. the Hallet-Mossop process) was also limited by the strong vertical wind shear in the cloud, precluding high ice number concentrations.

The proposed modeling exercise is to conduct simulations of this case with various idealized modeling frameworks to gain insight on:

- ***the effects of strong vertical wind shear on microphysical processes (e.g. collision-coalescence, ice production, riming, rime-splintering, evaporation of falling hydrometeors, etc.)***
- ***the effects of strong vertical wind shear upon different representations of microphysical processes used in numerical models***

This case is interesting for a modeling inter-comparison because the vertical wind shear should highlight variability in dynamical-microphysical interactions among different models, and in microphysical rates across different models. The latter are often dependent upon the terminal velocity relationships and collection efficiencies assumed in the models, both of which this case may highlight. A short line of convective cells are to be initiated in the models, as described later in this document, and the domain-wide evolution of precipitation processes will be analyzed similar to Lasher-Trapp et al. (2018). We intend that a formal publication will be produced from the results.

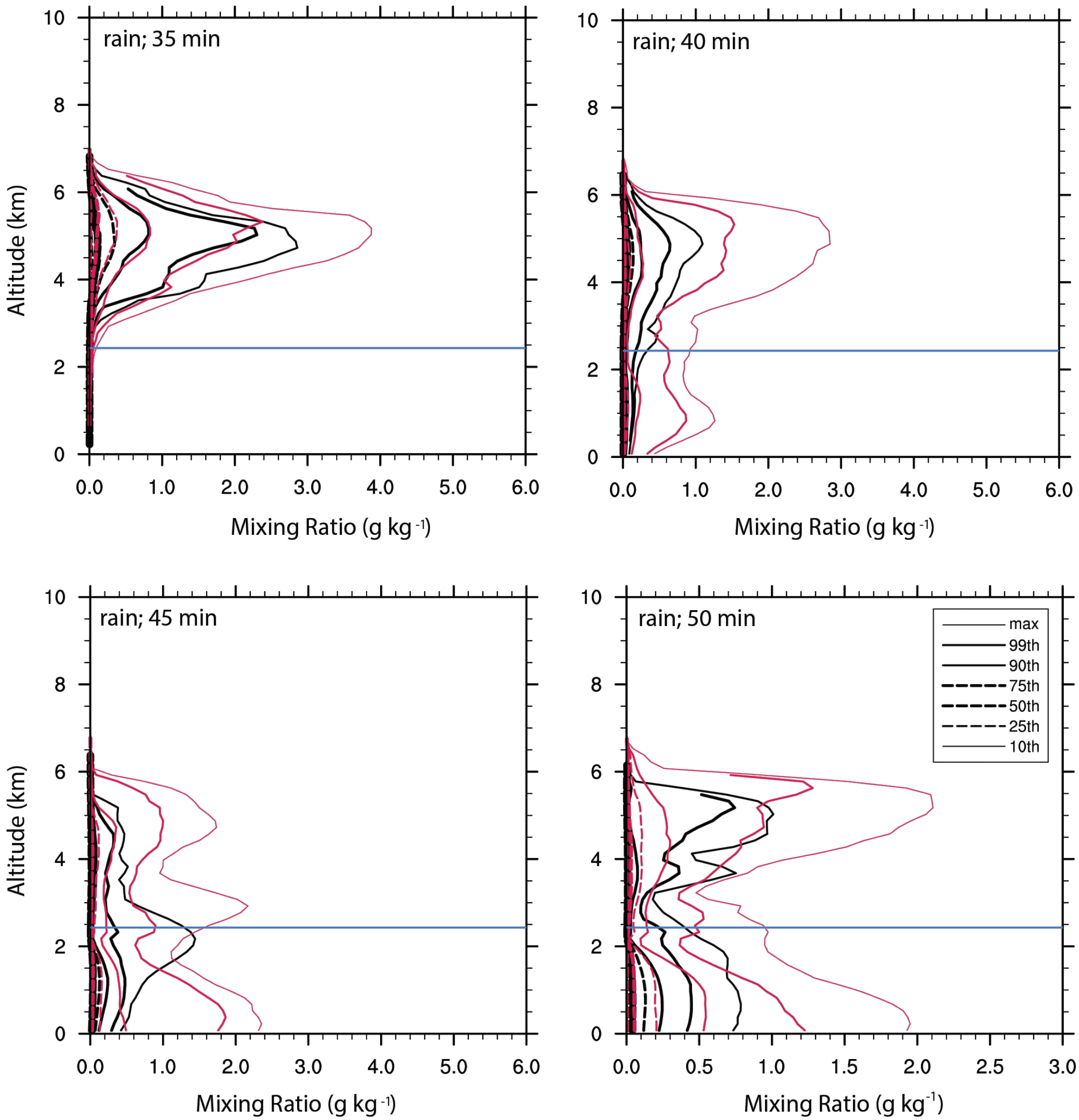

Fig. 1. Contoured frequency by altitude diagrams (CFADs) of rain mass for the 2 Aug control simulation (black) and another 2 Aug simulation with half the vertical wind shear (red). Reducing the vertical wind shear, all else being the same as the control run, greatly increased the surface rainfall. The height of the environmental 0℃ isotherm is shown by a blue horizontal line. Adapted from Lasher-Trapp et al. (2018).

Requested Simulations

To conduct the simulations, the 2 Aug sounding based on the observations, and the modified 2 Aug sounding with half the vertical wind shear (Fig. 2 below), are provided upon request.

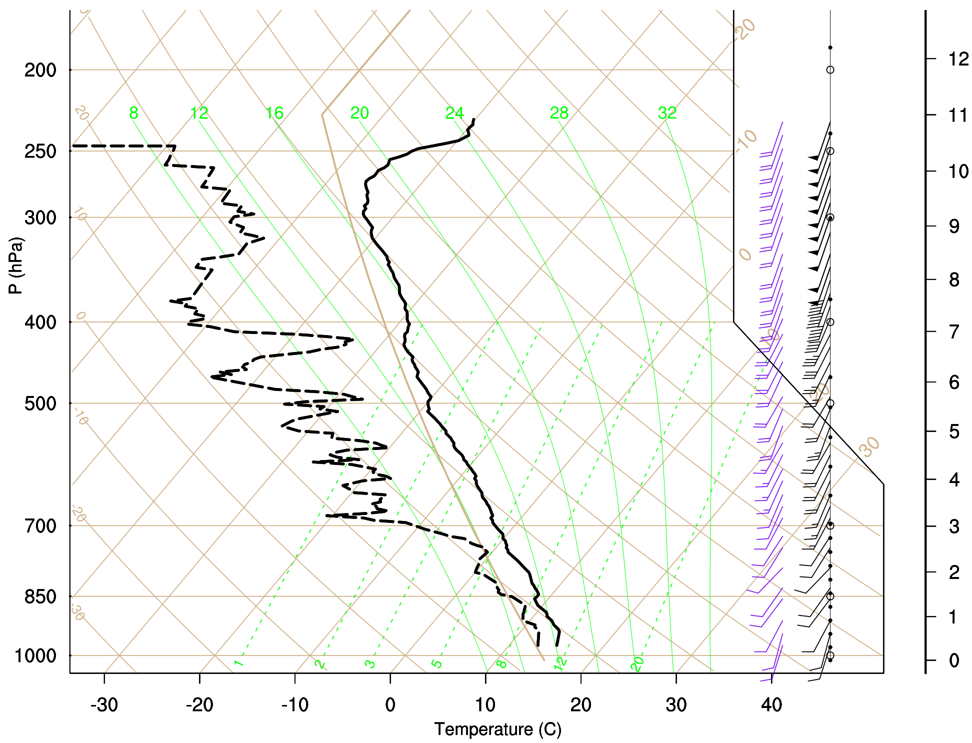

Fig. 2.
Soundings used to initialize the model for the 2 Aug 2013 case. The black sounding and wind profile are the for the "base case". The same thermodynamic sounding, but instead using the purple wind profile, is to model the "reduced wind shear" case. Figure adapted from Lasher-Trapp et al. (2018).

We encourage participation from groups using different bulk, bin and Lagrangian microphysical schemes. For the latter schemes, **if running the models in 2D is necessary, please run them in the N-S plane**, so that the grid is more aligned with the environmental winds.

<u>We request 4 simulations</u>:

1. Base case simulation using supplied 2 Aug sounding with (default) strong vertical wind shear, including rime-splintering, but no other ice multiplication schemes;

2. Same as base case, but with rime-splintering deactivated;

3. Modified sounding (decreased wind shear) case;

4. Same as #3, but with rime-splintering deactivated

Model Configuration for Simulations

Base case setup (#1): (contact Holly Mallinson—*hmm2@illinois.edu*)

- Sounding from 2 August COPE case (supplied); we subtracted out 2 m/s in the W-E direction, and 7 m/s in the N-S direction to help keep storms in the domain
- Domain size: 36 km in east-west direction x 63 km in north-south direction x 10 km depth; 150 m resolution (in all dimensions)—if resources are not available use coarser grid
- Integration time: 2 hours maximum, but depending upon the speed of cloud initiation scheme, may need 1.5 hours or less
- Other secondary ice production besides rime-splintering (Hallet-Mossop) disabled.
- No terrain
- Open (radiative) boundary conditions, or periodic with extended domain
- Coriolis force off
- CCN = 600 cm^{-3} (active at 1% supersaturation)

Modified sounding case setup (#3): (contact Holly Mallinson—*hmm2@illinois.edu*)

All same as "base case setup", except:

- Sounding from 2 August COPE case with reduced vertical wind shear (supplied)

Cloud initiation details, for all simulations:

- Lasher-Trapp et al. (2018) used their own series of Gaussian heat fluxes in the CM1 model. This code is available (for CM1)—contact S. Lasher-Trapp (*slasher@illinois.edu*).
- Participants can also reproduce this effect using a series of 4 warm bubbles:
  - Location: x = 9 km, y = 4,10,16, 22 km initiated at 100, 200, 300, 400 s from model start, respectively, all with radii ~ 2.5 km and depth ~ 1200 m*. NOTE THAT THIS SEPARATION IS ESSENTIAL TO COMPARE AMONG DIFFERENT SIMULATIONS, TO COMPARE/LIMIT THE AMOUNT OF "SEEDING" FROM ONE CLOUD TO ANOTHER.
  - To help gauge the strength of the forcing needed, some cloud tops should reach 8 km, but no higher. Our maximum updraft speeds were ~ 20 m/s at times, but the majority of the time they were ~ 10 m/s. (It is not critical that updraft speeds match our original simulations, but it is important that cloud top heights are in rough agreement, due to the influence on primary ice nucleation.)

**Thanks to Cunbo Han (KIT) for working with us to determine the appropriate bubble depth to reproduce our simulated cloud heights.*

Information to be Submitted to Organizers for Analysis

We request all the following information and model output **by June 1, 2021**:

- Name, and contact information
- Model name, and reference
- Model domain and grid spacing, if different than specified above
- Primary ice nucleation formula, and reference, including contact nucleation (if used), and Bigg freezing (if used)
- Equation for rime-splintering (Hallet-Mossop)
- Other information as requested by Organizers to analyze the results

For each simulation, we require the following output variables, at 1-minute intervals (contact Holly Mallinson for uploading instructions—hmm2@illinois.edu):

Variable Name	Units	Description
p	hPa	pressure
z	m	model grid point heights
T	K	Air temperature
u	m s^{-1}	Perturbation horizontal velocity, east-west
v	m s^{-1}	Perturbation horizontal velocity, north-south
w	m s^{-1}	Vertical velocity (positive = upward)
rho	kg m^{-3}	Dry air density
qv	kg kg^{-1}	Water vapor mixing ratio
qc	kg kg^{-1}	Cloud water mixing ratio
qr	kg kg^{-1}	Rain water mixing ratio
qi	kg kg^{-1}	Cloud ice mixing ratio
qs	kg kg^{-1}	Snow mixing ratio
qg	kg kg^{-1}	Graupel mixing ratio
Nc	kg^{-1}	Cloud droplet number concentration
Nr	kg^{-1}	Raindrop number concentration
Ni	kg^{-1}	Cloud ice number concentration
Ns	kg^{-1}	Snow number concentration
Ng	kg^{-1}	Graupel number concentration
dbz	dBZ	Simulated radar reflectivity[1]
rain	kg m^{-2} s^{-1}	Surface precipitation (liquid, if possible time-integrated)

[1] Radar reflectivity should be computed assuming a 10-cm wavelength radar, and only including the Rayleigh approximation (no Mie scattering considered). Further information can be found, for example, in Bryan and Morrison (2012; p. 223, and references therein).

References

Bryan, G., and H. Morrison, 2012: Sensitivity of a simulated squall line to horizontal resolution and parameterization of microphysics. *Mon. Wea. Rev*., 140, 202–225, doi:10.1175/MWR-D-11-00046.1.MWR-D-11-00046.1.

Jackson, R., J. R. French, D. C. Leon, D. M. Plummer, S. Lasher-Trapp, A. M. Blyth, A. Korolev, 2018: Observations of the microphysical evolution of convective clouds in southwest United Kingdom. *Atmos. Chem. Phys*., https://doi.org/10.5194/acp-2018-437

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Leon, D. C., and Coauthors, 2016: The Convective Precipitation Experiment (COPE): Investigating the origins of heavy precipitation in the southwestern United Kingdom. *Bull. Amer. Meteor. Soc.*, 97, 1003–1020, https://doi.org/10.1175/BAMS-D-14-00157.1.