The Effects of Convective Clouds on Vertical Scalar Transport

Nicole Ngo[1], Chin-Hoh Moeng[2] and Jeff Weil[2]

[1] SOARS Program and [2]National Center for Atmospheric Research

Overview

In the planetary boundary layer (PBL) (defined as < 1 km above the surface), pollutants travel smaller distances and have longer residence times relative to those in the upper troposphere. This could have global implications if pollutants like NO_x, which generate O_3, a greenhouse gas, are transported into the upper troposphere. Without clouds, the pollutants released near the surface are likely to stay within the PBL (i.e., the smog layer) if there is no deep convection to carry them upward.

The **objective** of this study is to understand how deep convective cloud systems influence the vertical distribution of insoluble species in the troposphere using a Lagrangian approach.

Velocity Field Data

- Used a synthetic flow field numerically generated from a 3-D large eddy simulation (LES) model of a deep convection system generated by Marat Khairoutdinov
- Differences from previous studies is that this LES used a very large numerical domain of 2048 x 2048 x 256 (or 10^9) grid points known as a giga-LES
- We use the velocity field at a time interval of 15 minutes to drive the particles.
- Grid mesh size: 100m in the x- and y- direction, varying in z (50 m below z=1 km).
- We released 2048 particles (12 hours after the cold start) along y at 30 arbitrarily chosen x locations (i.e., total particles: 2048 x 30)
- We found their vertical distributions at 3, 6 and 12 hour after the release (Figs. 3 and 4)

Cloud properties

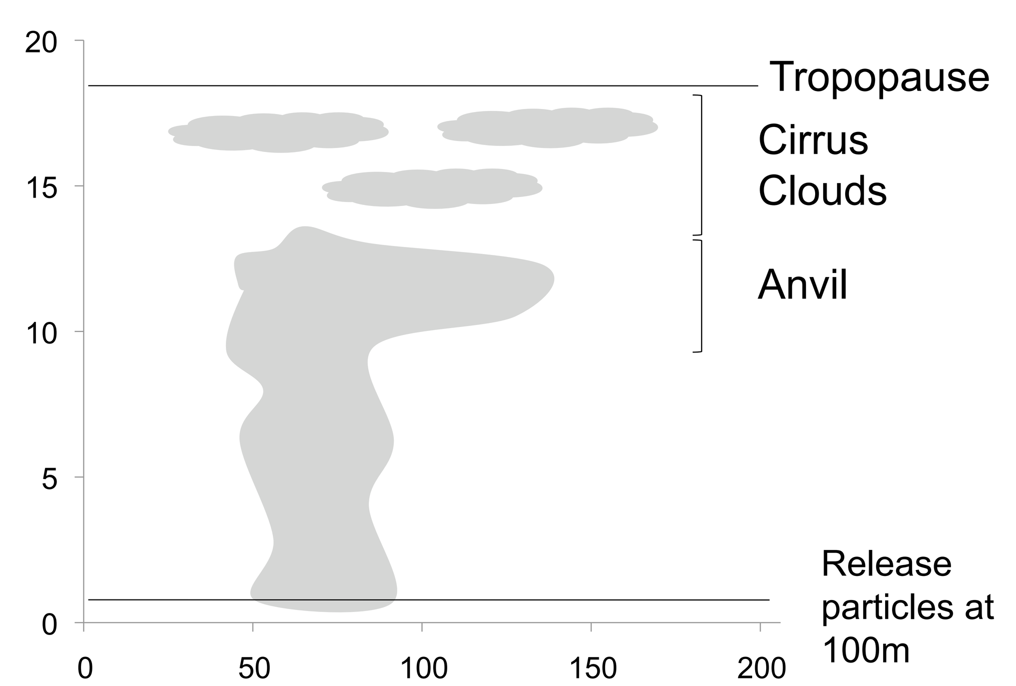

Fig.1. A sketch of a thunderstorm

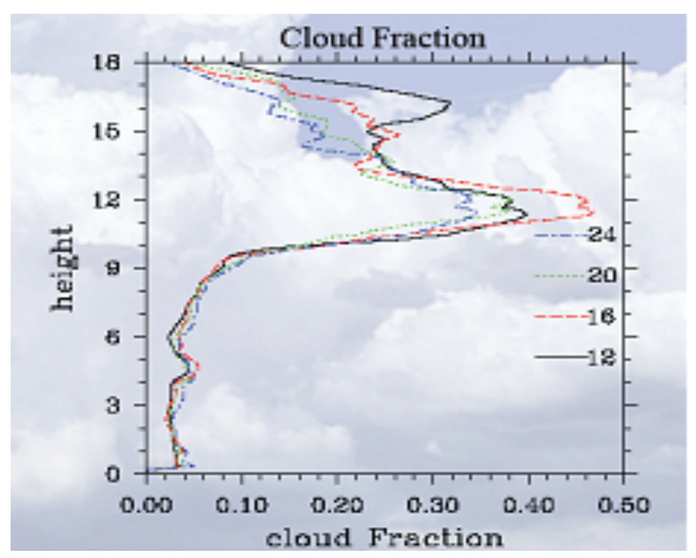

Fig.2. This figure shows cloud fraction in the simulation. Numbers represent hours after the cold start. Note maximum cloud fraction (or anvil) is at about 11 km. (Courtesy of Marat Khairoutdinov)

No need to show Fig. 3 if no space.

Acknowledgements

This work was done under the auspices of the Significant Opportunities in Atmospheric Research and Science (SOARS®) program of the University Corporation for Atmospheric Research, with funding from the National Science Foundation, the U.S. Department of Energy, the National Oceanic and Atmospheric Administration, and Goddard Space Flight Center, NASA.

Special thanks to Chin-Hoh Moeng and Jeff Weil

Lagrangian Particle Dispersion Model

We make 2 assumptions:

1. We are using passive tracers that are tracked using the resolved velocity field from the LES. Here we ignore subgrid scale (SGS) motion (eddies smaller than the giga-LES grid resolution size).
2. Mean concentration is proportional to the particle density at that point on the domain

To find the new particle positions, we used the equations given in the box. The concentration of particles at z, $C(z)$, is found by taking the sum of particles between $z - \mathrm{d}z < z_p < z + \mathrm{d}z$, where $\mathrm{d}z = 25m$.

Particle position at time t:

$$\frac{\mathrm{d}\mathbf{x}_p}{\mathrm{d}t} = \mathbf{u}(\mathbf{x}_p, t) \qquad (1)$$

Change in x and z over time given by:

$$\frac{\Delta x_p}{\Delta t} = u(\mathbf{x}_p, t) \qquad (2)$$

$$\frac{\Delta z_p}{\Delta t} = w(\mathbf{x}_p, t) \qquad (3)$$

We then integrate (2) and (3) to find the new particle positions at time $t + \Delta t$ given the particle coordinates and velocities at t:

$$x_p(t + \Delta t) = x_{p(t)} + u(\mathbf{x}_p, t) \qquad (4)$$

$$z_p(t + \Delta t) = z_{p(t)} + w(\mathbf{x}_p, t) \qquad (5)$$

Results and Discussion

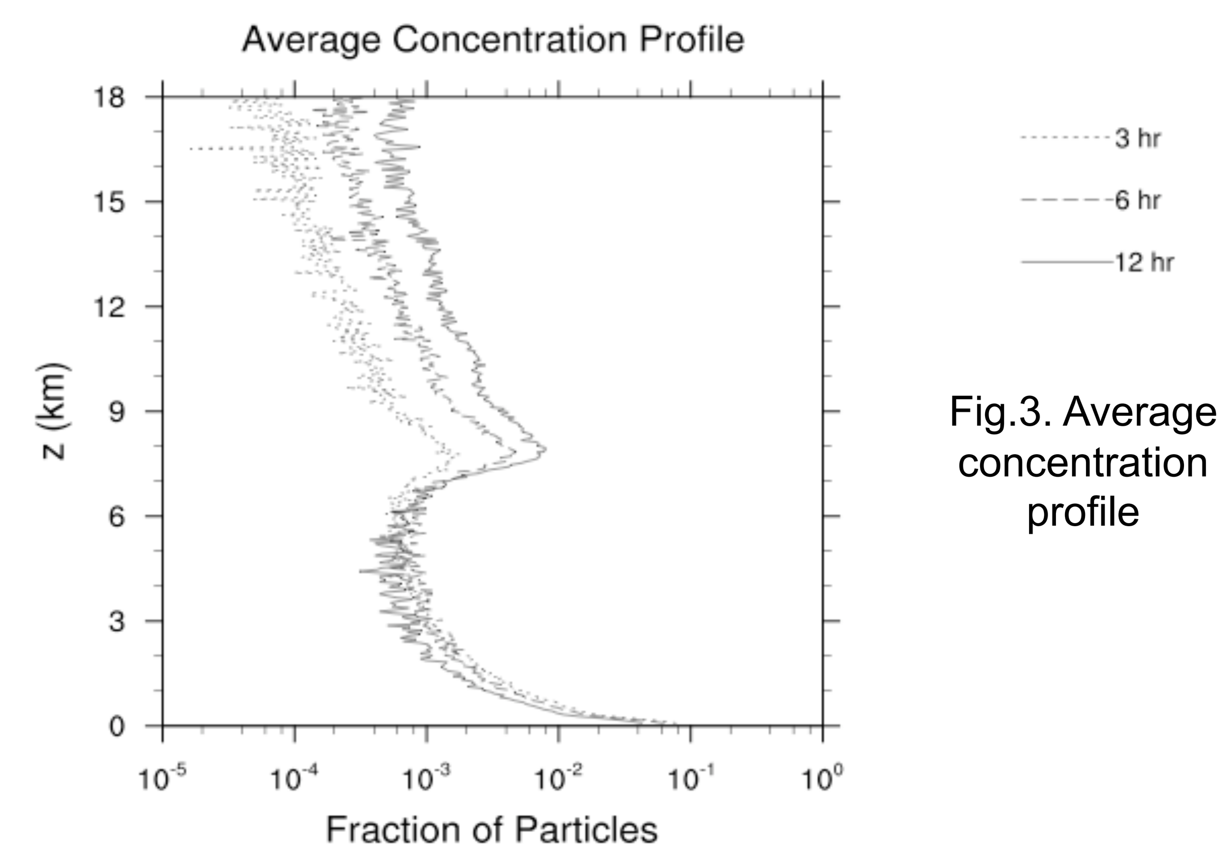

Fig.3. Average concentration profile

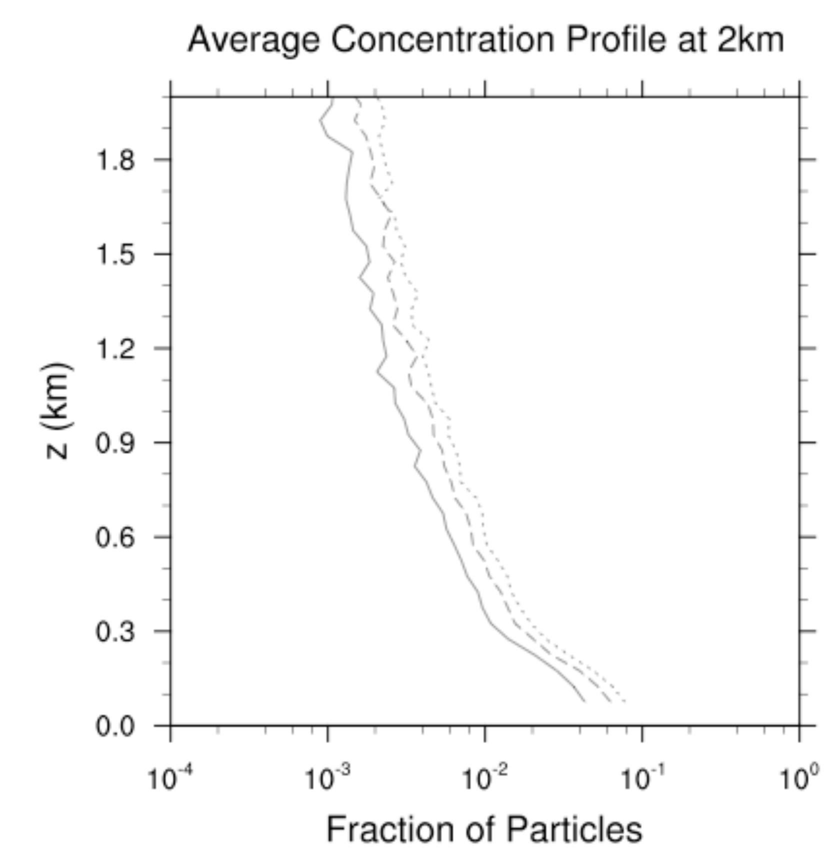

Fig.4 Average concentration profile within 2 km of the surface

Fig. 3 shows a peak around 8-9km at 3, 6 and 12 hour after the particel release. (The non-smoothness of the curves is due to the limited number of particles.)

Comparing this to Fig.2, this peak is ~2-3km below the anvil, which is puzzling. In the data, we found that ~25% of particles remain near the surface at z=25 m, which is the lowest level we set for the particles. This is a result of not accounting for the SGS effect. That is, eddies smaller than the grid mesh size were ignored. These shallow, smaller eddies are important nearer to the surface where turbulent motions are small. In this simulation, the LES was computed over a tropical ocean, so the PBL is quite shallow, only about 300 m. In Fig. 4 we see that a more uniform distribution in the PBL.

Future Research

- In this study, we used a low-order scheme (shown in Eqs. 4 and 5) in computing the particle trajectories, but a higher order scheme may increase accuracy
- Study the soluble species that react to cloud droplets.

References

Moeng, C-H., LeMone, P., Khairoutdinov, M., Krueger, S., Bogenschutz, P., and D. Randall. (2009) “The tropical marine boundary layer under a deep conbvection system: a large eddy simulation study,” *Journal of Advances in Modeling Earth Systems.*