Modification of Cumulus Entrainment Due to Neighboring Clouds

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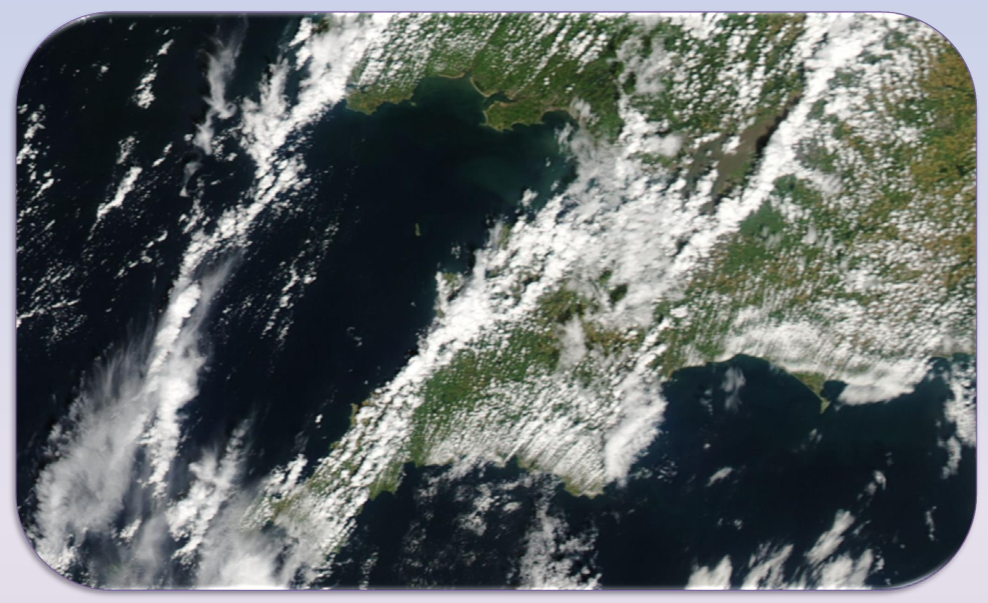
Motivation

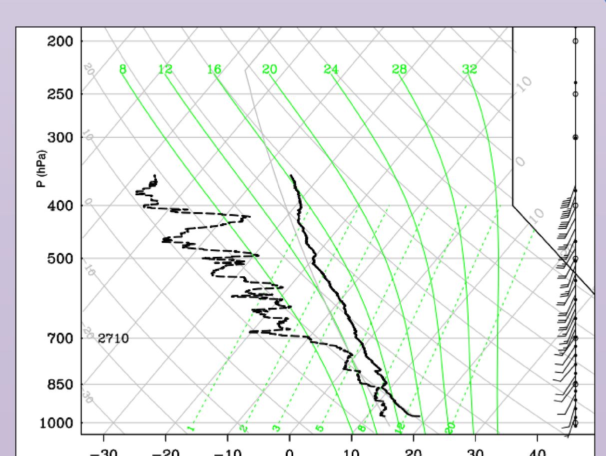
The Convective Precipitation Experiment witnessed cumulus congestus developing parallel to the wind shear vector along convergence lines (below) during August 2-3, 2013 over SW England. These clouds frequently matured in close proximity to a neighboring cloud and produced high (> 32 mm/hr) rainfall rates at the surface. The compact spacing of neighboring clouds may have limited entrainment and thus enhanced precipitation production.



In our research, we explored how neighboring clouds may *mutually alter entrainment and microphysical properties* to increase rainfall at the surface. Using identical cloud forcing, we varied the distance between centers and sequencing of three clouds aligned with a unidirectional wind shear vector.

Simulation

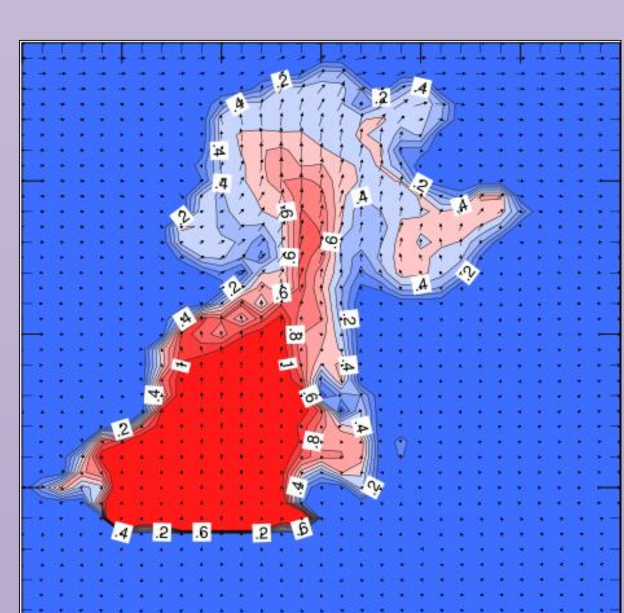
The environment in the Straka Atmospheric Model v. 2012 (50 m grid spacing) was initialized with the 2 Aug sounding (right), with an altered unidirectional wind shear profile. The clouds were forced by a 100 W/m^2 Gaussian heat flux in addition to a small mean flux over the domain.



1538Z Aug 2, 2013 – Davidstowe, UK

Single, Isolated Cloud Characteristics

- Cloud Base ~ 0.9 km AGL
- Cloud Top ~ 5.5 km AGL
- Max updraft speed ~ 19 m/s
- Max cloud water ~ 3.0 g/kg
- Max graupel + hail ~ 6.0 g/kg



Contours indicate the fraction of the adiabatic liquid water content. Mixing occurs prominently near the cloud top circulation.

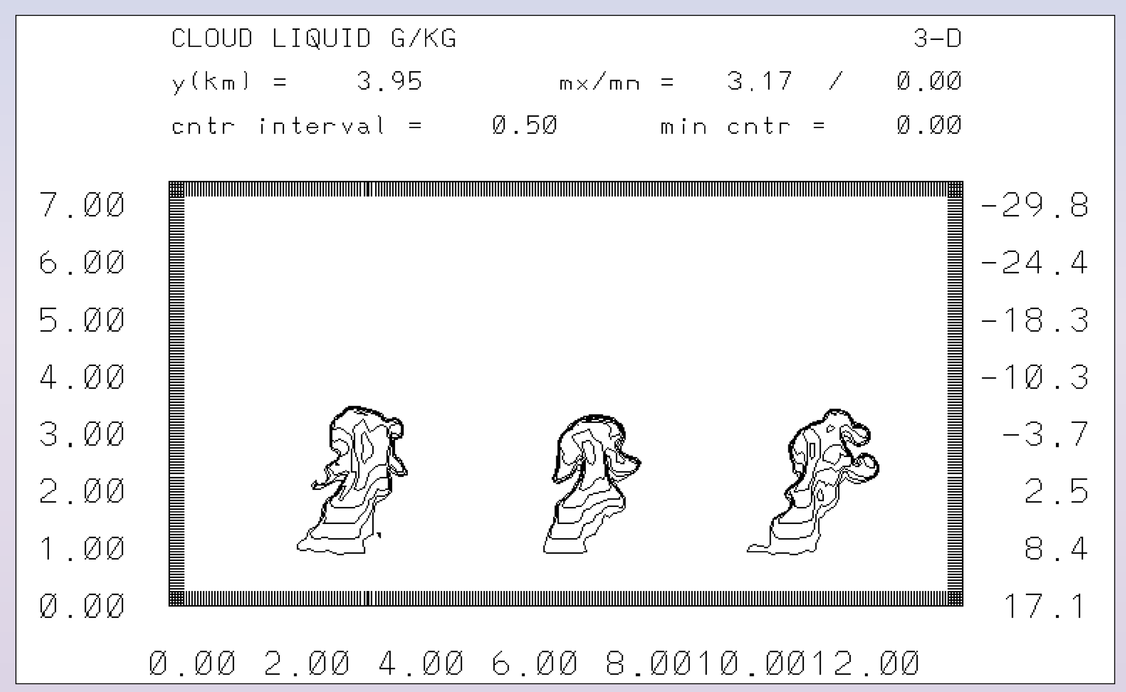
Entrainment Calculations

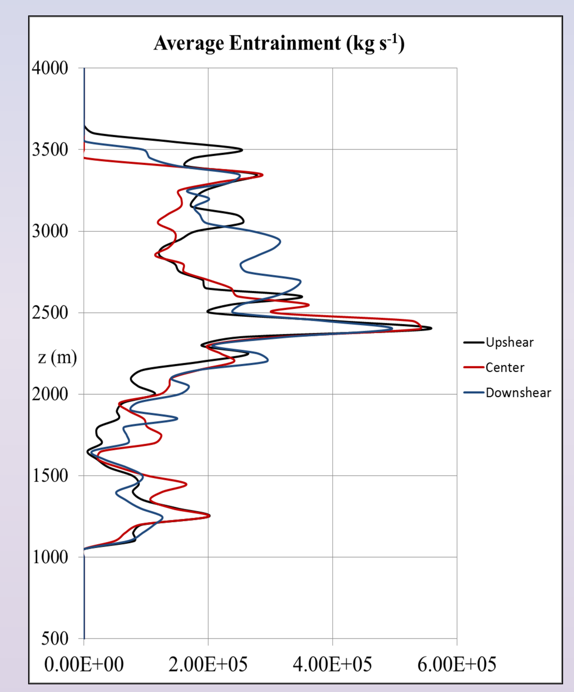
Local calculation of entrainment and detrainment of a fluid may be performed following the method of Dawe and Austin (2011).

Envisioning the cloud in three dimensions, a grid cell is decomposed into 48 tetrahedrons where interpolation allows for the construction of a sub-grid scale isosurface, such as the cloud-environment interface.

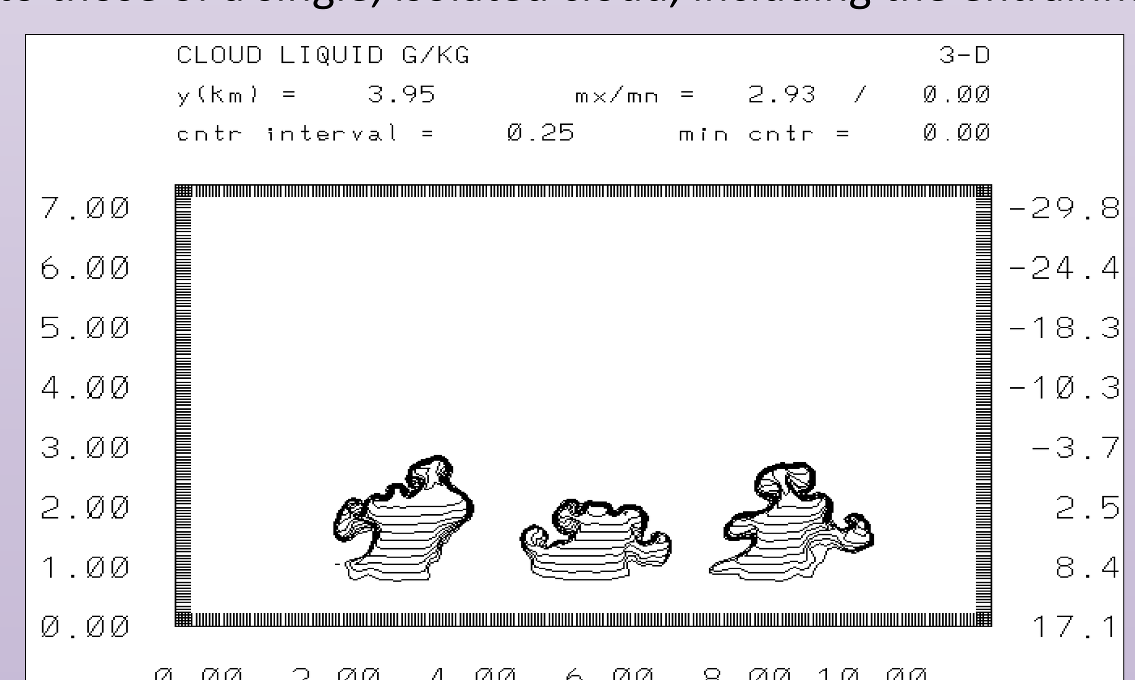
By tracking the interface in time, instantaneous local calculations of entrainment and detrainment may be computed anywhere along the isosurface.

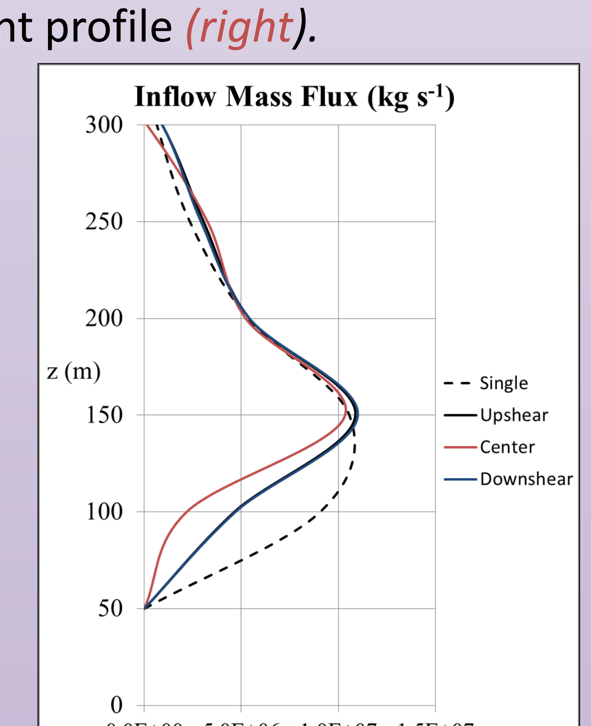
Simultaneous Forcing of Clouds at Different Spacing





Beyond 4000 m spacing *(left)*, each cloud experiences similar dynamics and microphysics to those of a single, isolated cloud, including the entrainment profile *(right)*.

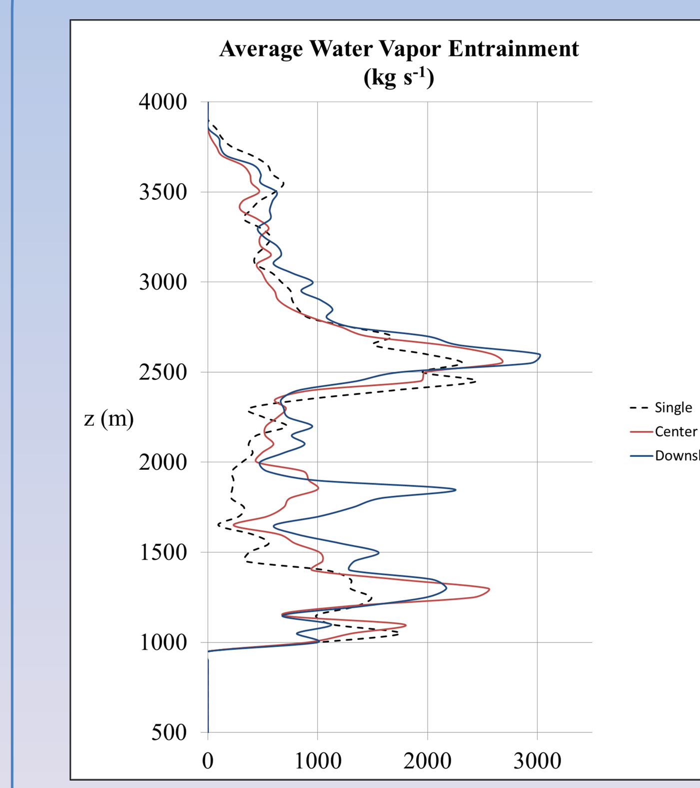




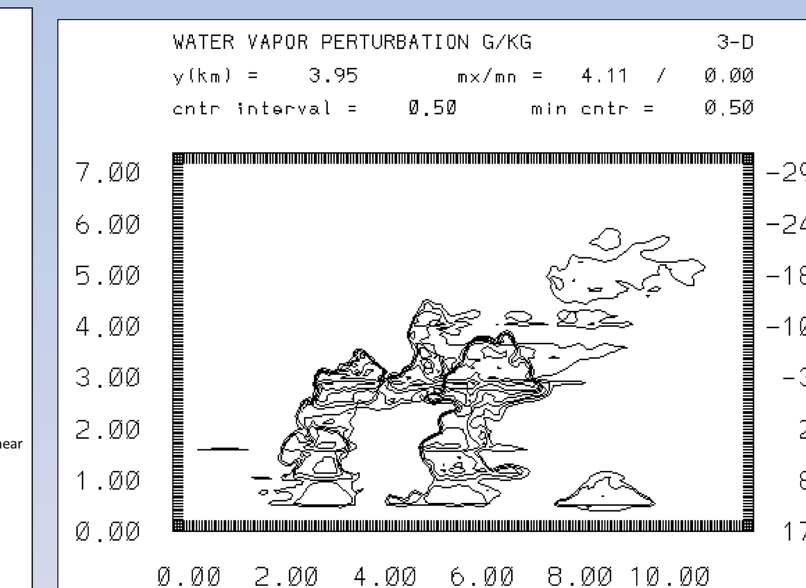
As the spacing between the clouds decreases to 3000 m *(left)*, they develop noticeably slower than a single, isolated cloud. Each cloud inflow is *significantly slowed by interference from the flow patterns of surrounding clouds at low levels (right).*

10 Min Delay Between Forcing

3000 m spacing

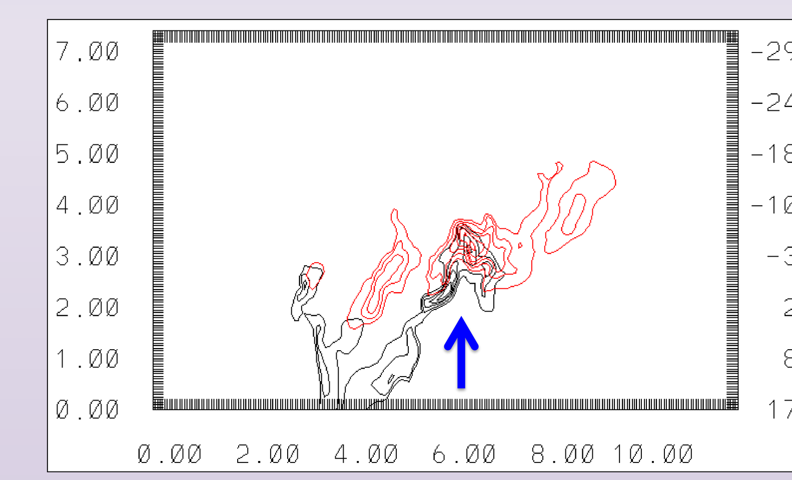


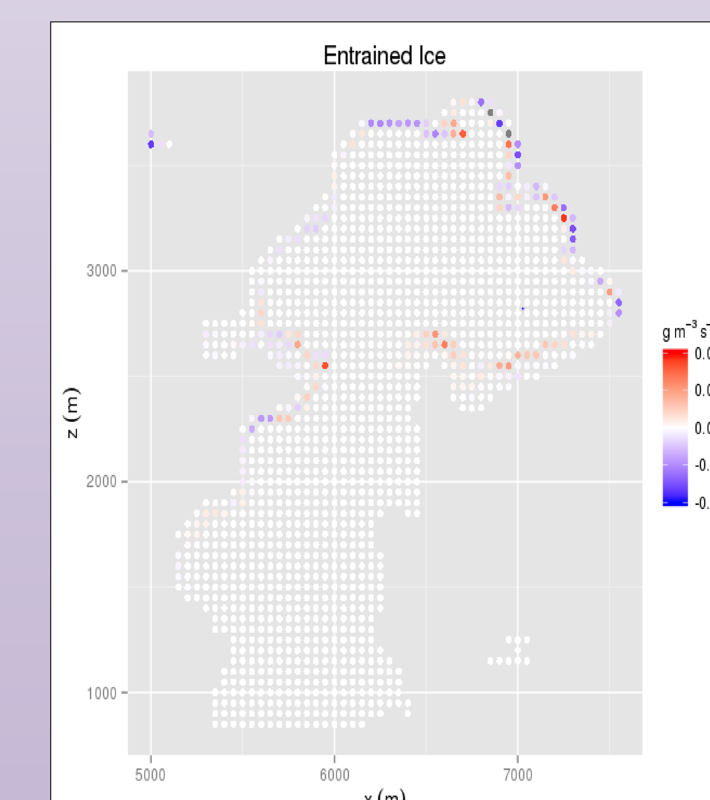
Entrained air is more moist in downshear, newer clouds.

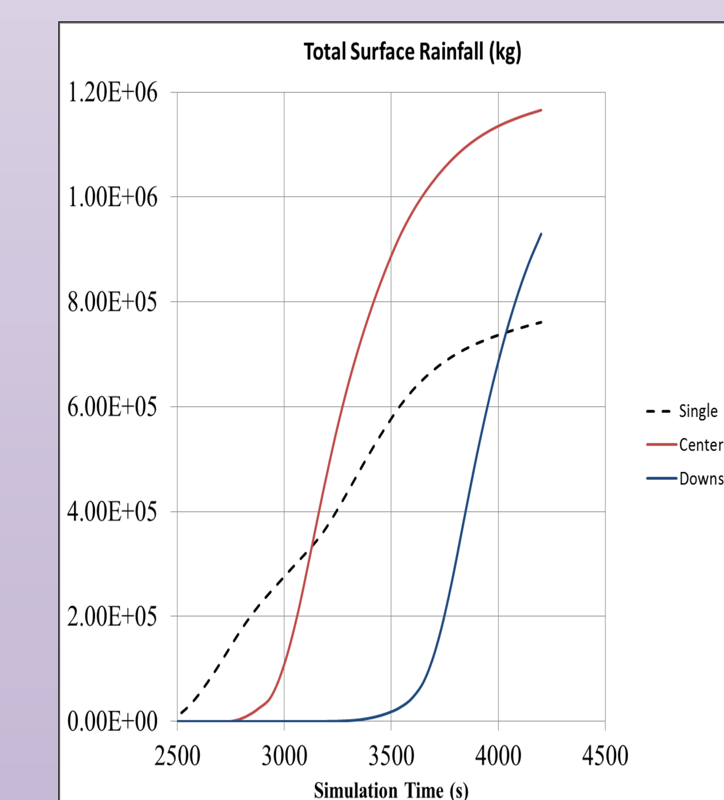


Older clouds moisten the free atmosphere, *weakening the effects of entrainment*, and seed younger, downshear clouds with ice.

Raindrops (right, *black*), formed by the younger center cloud (arrow), encounter graupel (*red*) from the older upshear cloud, and are entrained into its top (below).







Hail embryos are thus produced more quickly in the presence of more moisture and supercooled raindrops, leading to increased rainfall at the surface in the center cloud.

Conclusions & Future Work

- Simultaneous forcing causes low-level inflow to compete with other inflows, reducing the moisture and heat flux into each cloud.
- Delayed forcing along the line of clouds allows subsequent clouds to entrain moist air and ice, leading to significant increases in rainfall output in a sheared environment.
- While the entrainment of ice has clear benefits to rain production, the effect of entraining water vapor from neighboring clouds still needs to be better quantified.

References & Acknowledgements

- National Science Foundation Award # AGS-1230292

- Dawe, Jordan T., Philip H. Austin, 2011: Interpolation of LES Cloud Surfaces for Use in Direct Calculations of Entrainment and Detrainment. *Mon. Wea. Rev.*, **139**, 444–456.