Estimating Rain Evaporation in Convective Systems from Cold Pool Surface Pressure Perturbations

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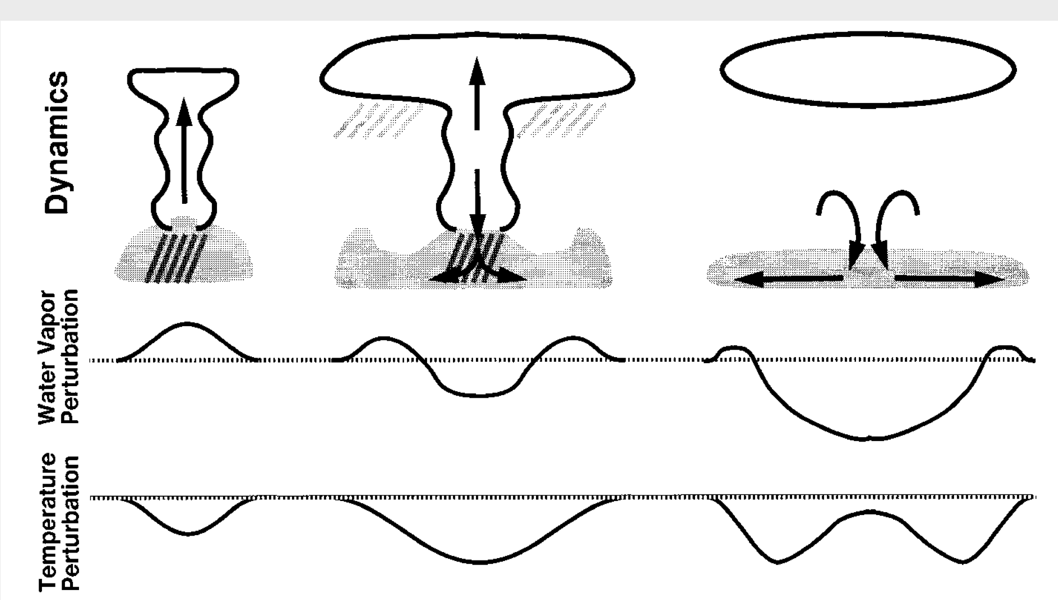
Motivation

Because convective cloud systems generally have strong interactions with boundary layer circulations and thermodynamics, the boundary layer wind and thermodynamic fields contain a great deal of information about convective cloud systems and their interactions with the boundary layer. We are in the process of "retrieving" this information from 15 years of 5-minute Oklahoma Mesonet data and hourly Arkansas Basin River Forecast Center (ABRFC) gridded precipitation data.

We have already demonstrated that estimates of cloud base updraft and downdraft mass fluxes can be retrieved from the surface divergence field. We are currently developing a method to estimate rain evaporation in convective systems from cold pool surface pressure perturbations. In the 1950s, Fujita identified meso-highs in his mesoanalyses and linked them to cold pools produced by rain evaporation (Fujita 1959). We have extended Fujita's (1959) method for estimating rain evaporation from the hydrostatic surface pressure anomaly.



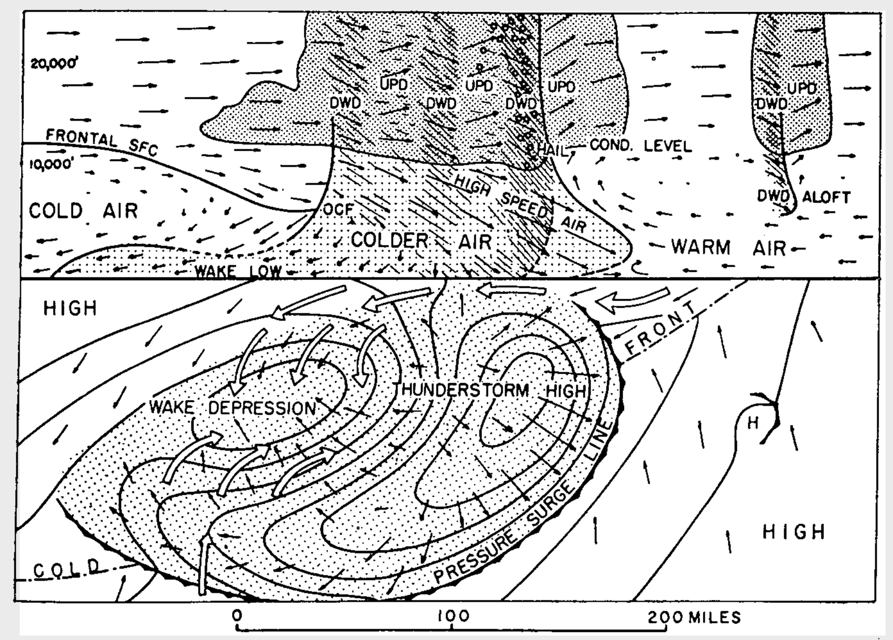
Schematic diagram of cold pool development (Tompkins 2001).

Approach

Early in his career, Fujita noticed that the largest signal in surface weather patterns occurred in connection with deep convection. Through detailed and insightful analyses of surface data, Ted Fujita unraveled many of the mysteries of severe storms.

In a 1959 paper, Fujita proposed that a dome of cold air is produced by the evaporation of raindrops falling beneath the cloud base. He showed that, for a specific scenario, the excess mass of cold air is directly proportional to the the mass of evaporated rain. We show that Fujita's formula for this relationship applies in general.

Results

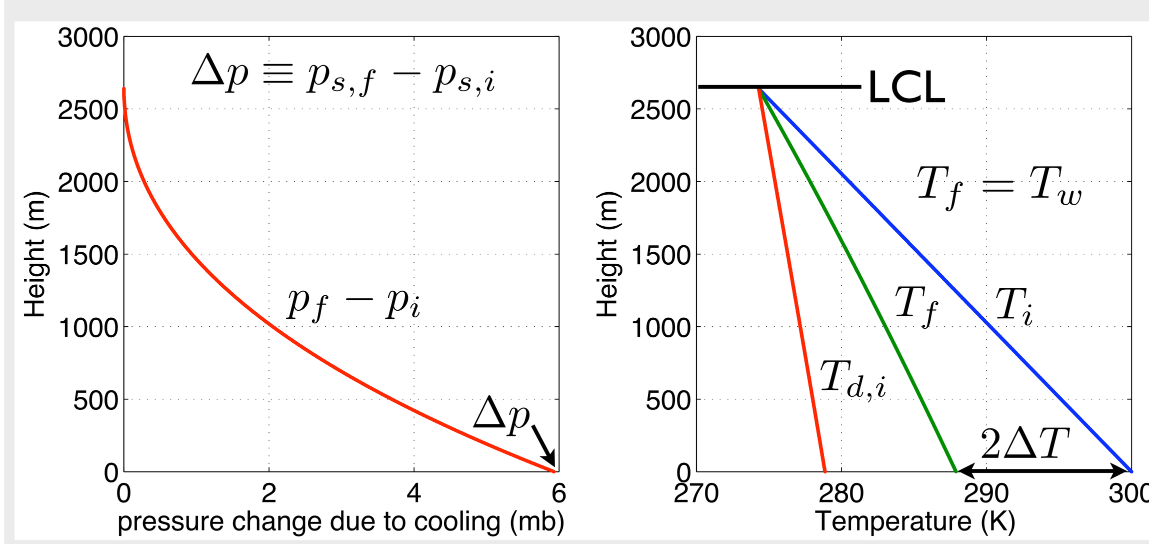


Cold dome and meso-high (Fujita 1955).

We related the surface pressure excess (mass per unit area), Δm, to the mass per unit area of rain evaporated, ΔQ :

$$\Delta m \equiv \frac{\Delta p}{g} = \frac{L_e \Delta Q}{c_p \overline{T_i}} \left[\frac{p_{s,i}}{p_{s,f} - p_t} \log \left(\frac{p_t}{p_{s,f}} \right) \right]$$

Under typical conditions: $\Delta m \approx 9 \Delta Q$

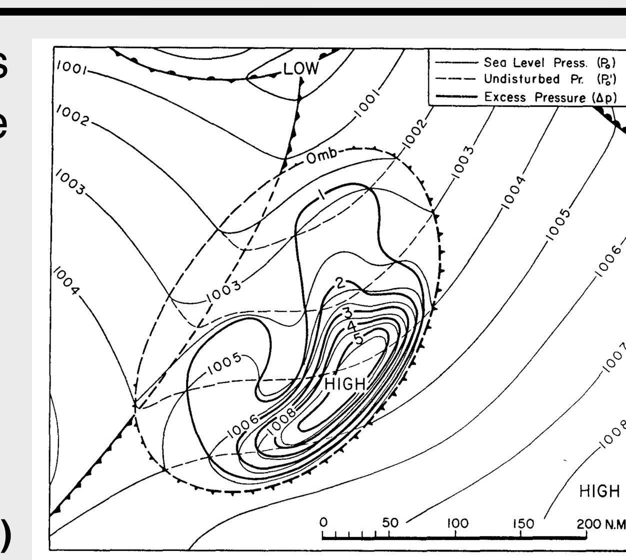


We can estimate the pressure at the top of the cooled column, p_t, from surface measurements of temperature and pressure in the cold pool and in the environment:

$$p_t = p_{s,f} \exp \left(\frac{\Delta p}{p_{s,i}} \frac{\overline{T_i}}{\Delta T} \right)$$

We tested our estimate of the cooled column depth for various scenarios.

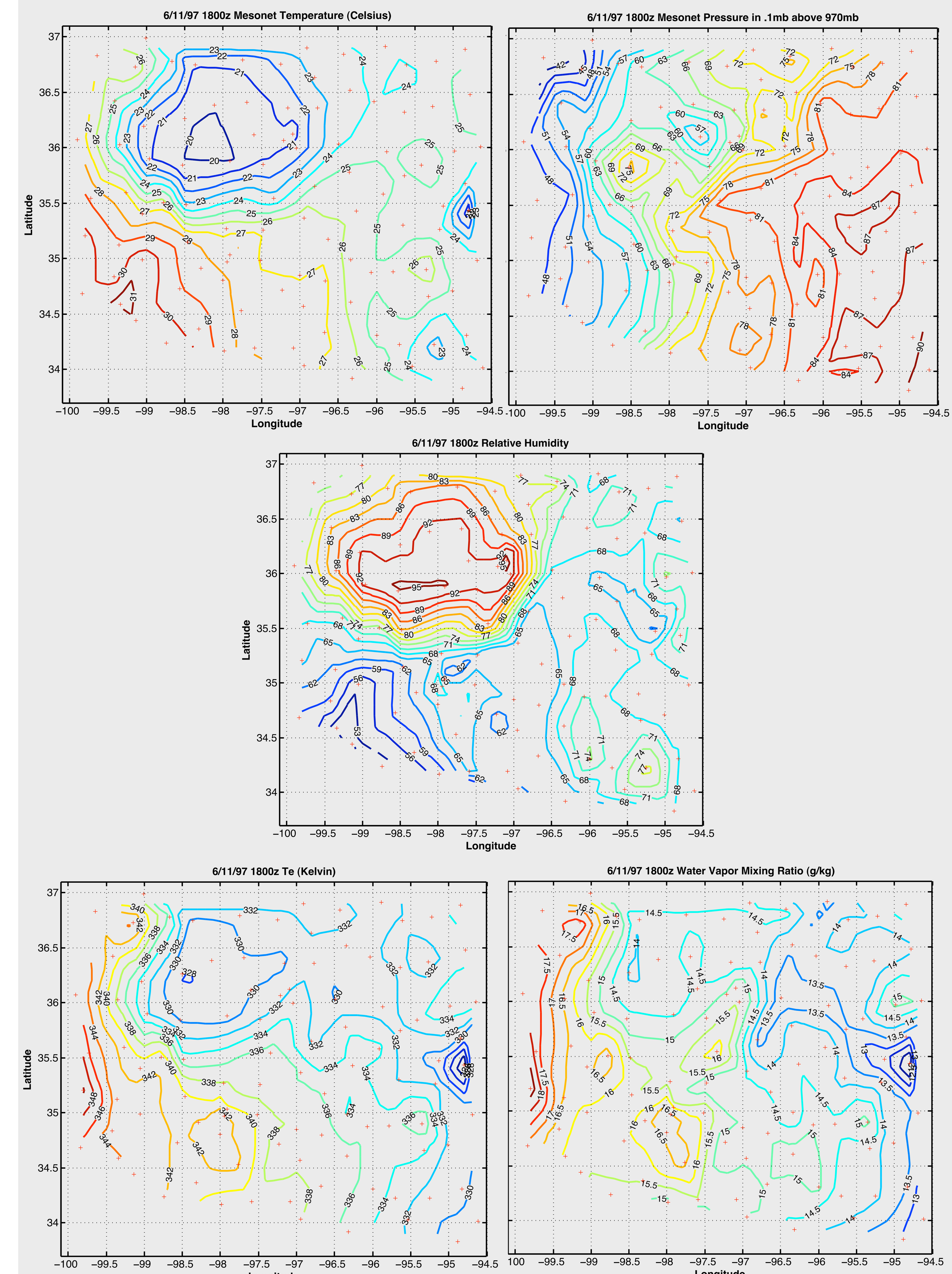
Careful mesoanalysis is required to determine the excess pressure.



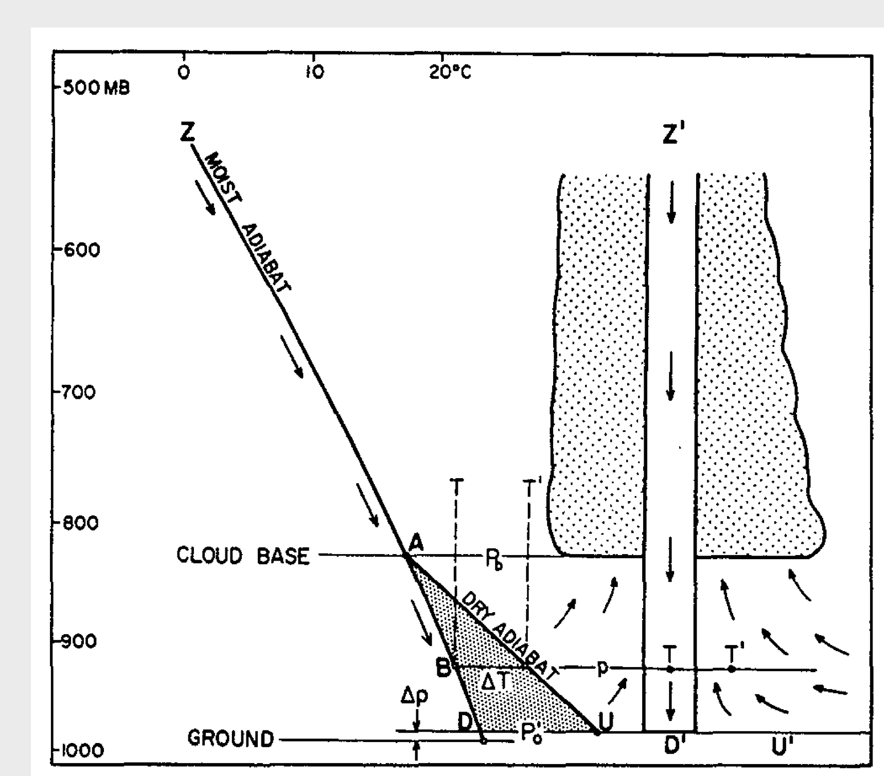
(Fujita 1959)

Results

Processes other than rain evaporation can contribute to changes in surface temperature and pressure.



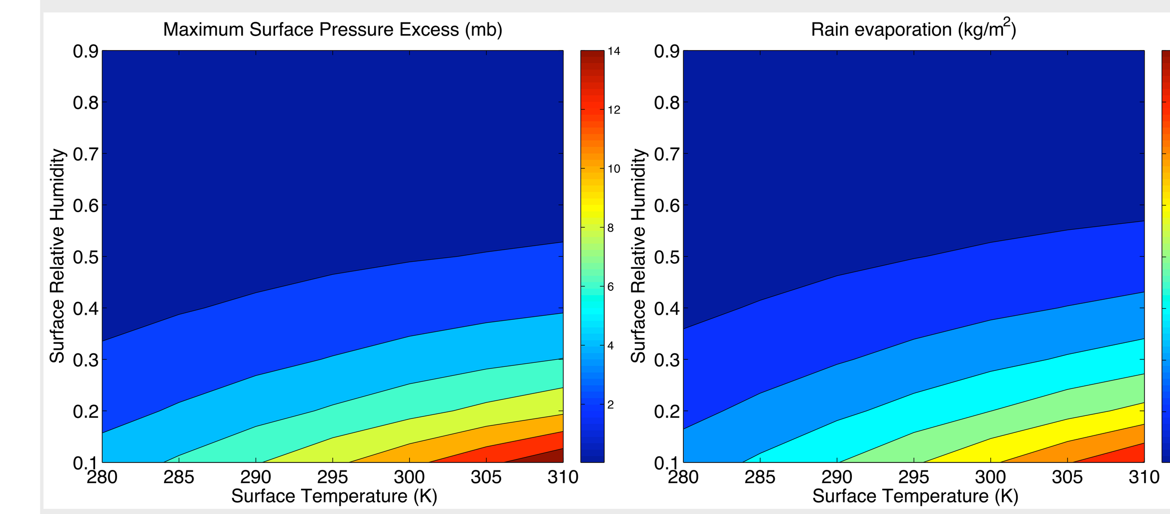
Maximum rain evaporation and pressure excesses occur when a mixed layer is cooled to its wet-bulb temperature at all levels from the surface to the LCL.



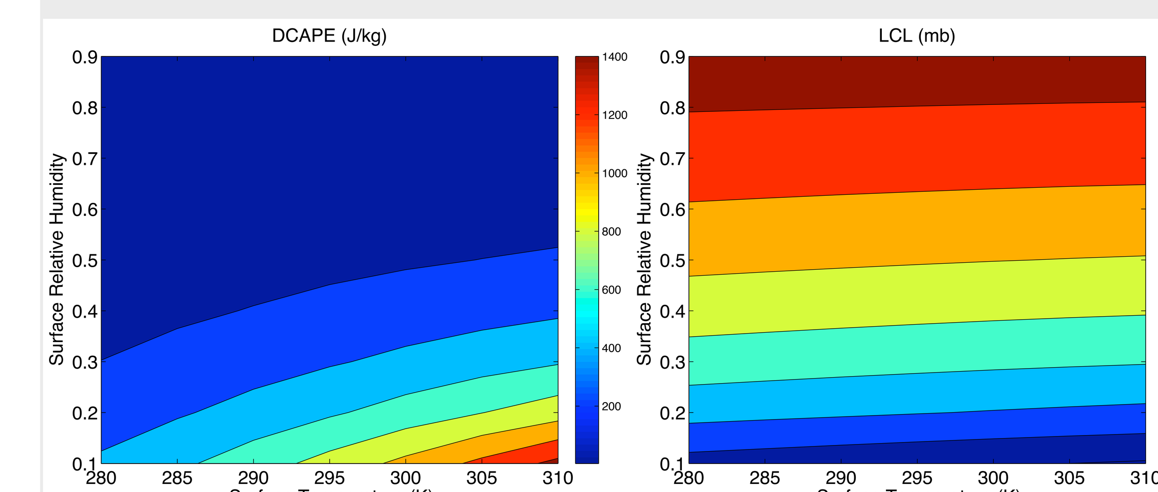
(Fujita 1959)

Results

We calculated the pressure excesses for these conditions for a range of surface temperatures and relative humidities. The pressure excesses are proportional to rain evaporation, as expected.



The pressure excesses are closely related to DCAPE (Downdraft Convective Available Potential Energy), but not to LCL (Lifting Condensation Level).



Plans

- Perform mesoanalyses to determine pressure excesses.
- Compare retrieved rain evaporation to "maximum possible."
- Use CRM simulations to do OSSEs (Observation System Simulation Experiments).

References

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Acknowledgement:
This research was supported by the Office of Science (BER), U.S. Department of Energy, Grant No. DE-FG02-08ER64553.