Entrainment Rates in Non-Precipitating Cumulus from Cloud Radar Observations

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ASR PI meeting – Entrainment Breakout

Potomac, MD

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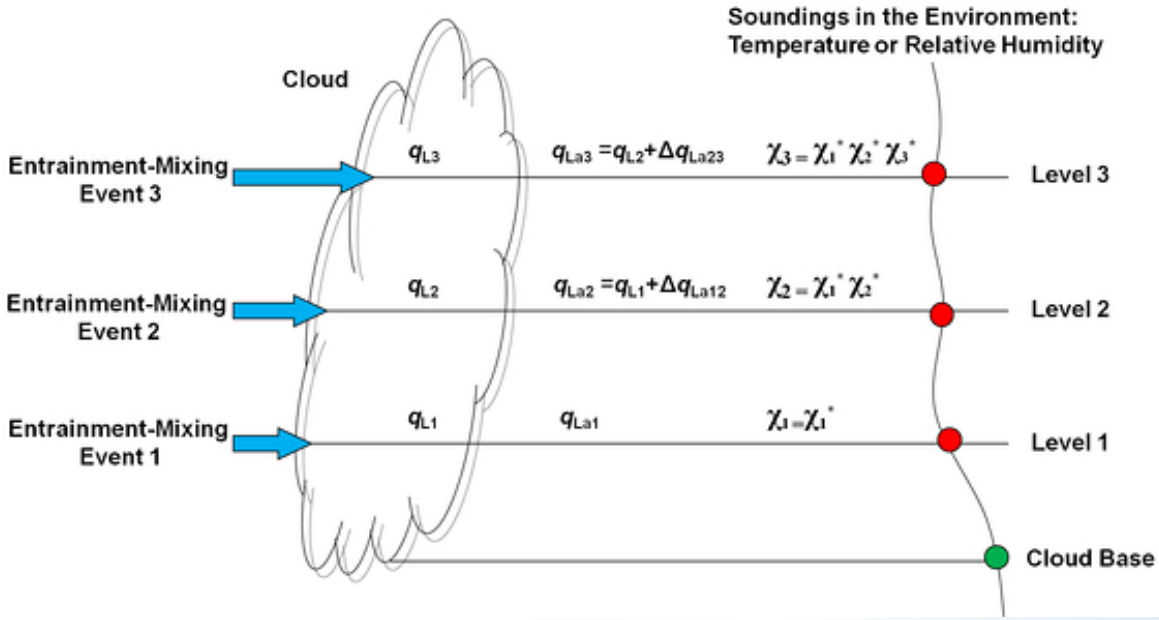
New approach for estimating entrainment rate in clouds (Lu et al. 2012, GRL)

Inputs required:
Cloud Base Height
Cloud Base Temp.
Environment Temp.
Environment Water Vapor
LWC profile



Mixing Processes

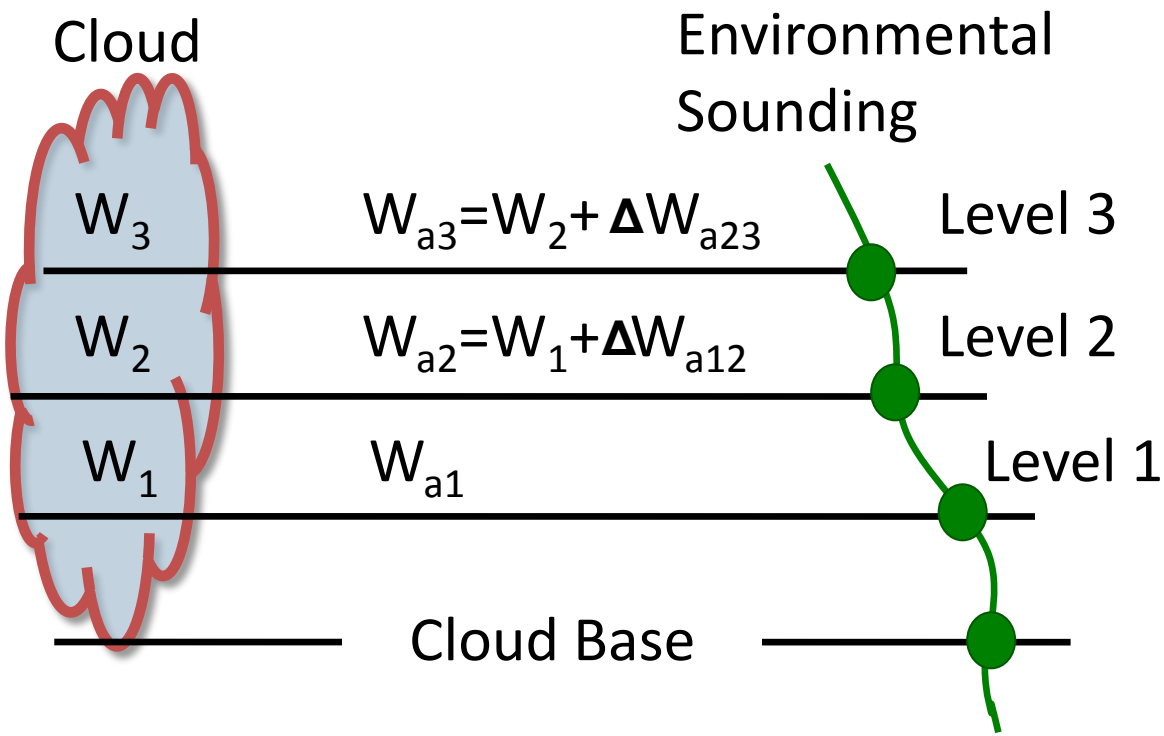
$c_p T = c_p T_a \chi^* + c_p T_e (1-\chi^*) - L_v (q_{La} \chi^* - q_L)$ (Conservation of Energy)

$q_L + q_{vs}(T) = \chi^* [q_{vs}(T_a) + q_{La}] + (1-\chi^*) q_{ve}$ (Conservation of Total Water)

- Does not require in-cloud measurements of temperature and water vapor → potential for remote sensing
- Estimates a PROFILE of entrainment rate

Extending to incorporate MM-radar observations

- Recent advances in retrieving vertical air motions from vertically-pointing mm-radar
- Apply to ARM SGP cloud radar observations



Additional constraints

$a = g * (Tv - Tv_e) / Tv_e$ (Acceleration of the relative adiabatic parcel)

$\chi^* = W_2 / W_{a2}$ (Mixing Fraction)

Assumptions: W=0 for entrained air

Drag is negligible, No “drizzle” (falling drops) contribution

First Applications to ARM Observations

Initial focus on non-precipitating, shallow cumulus clouds

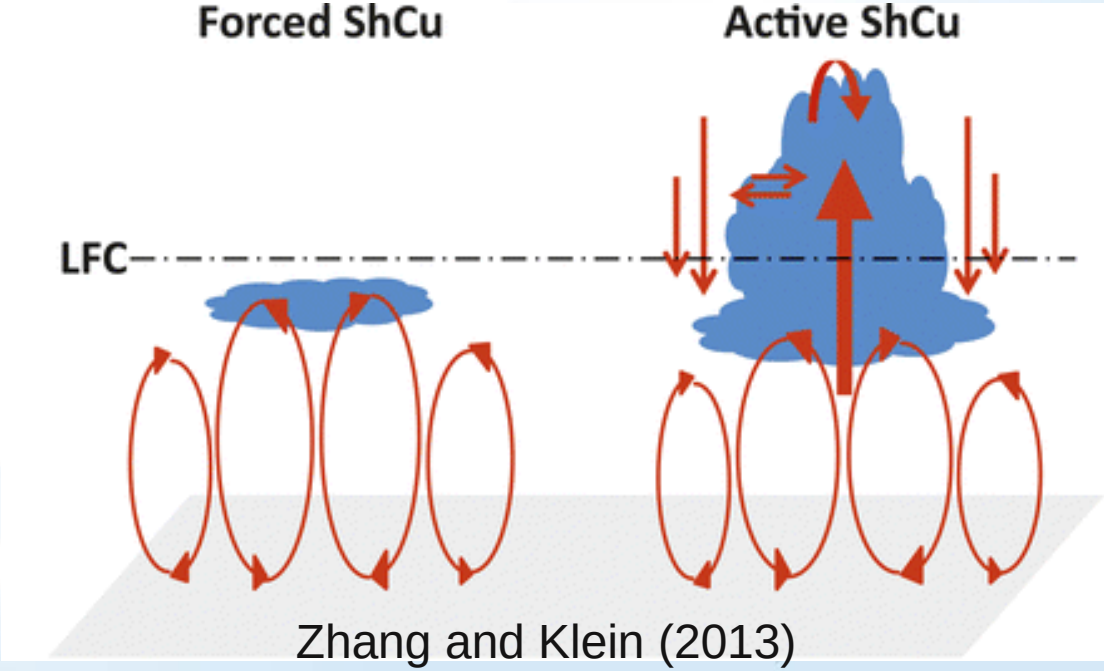
ARM Southern Great Plains Site in north-Central Oklahoma

Important observations:
35 GHz vertically pointing cloud radar
Microwave Radiometer (for LWP)
Radiosonde profiles of temperature and humidity

Case Selection:

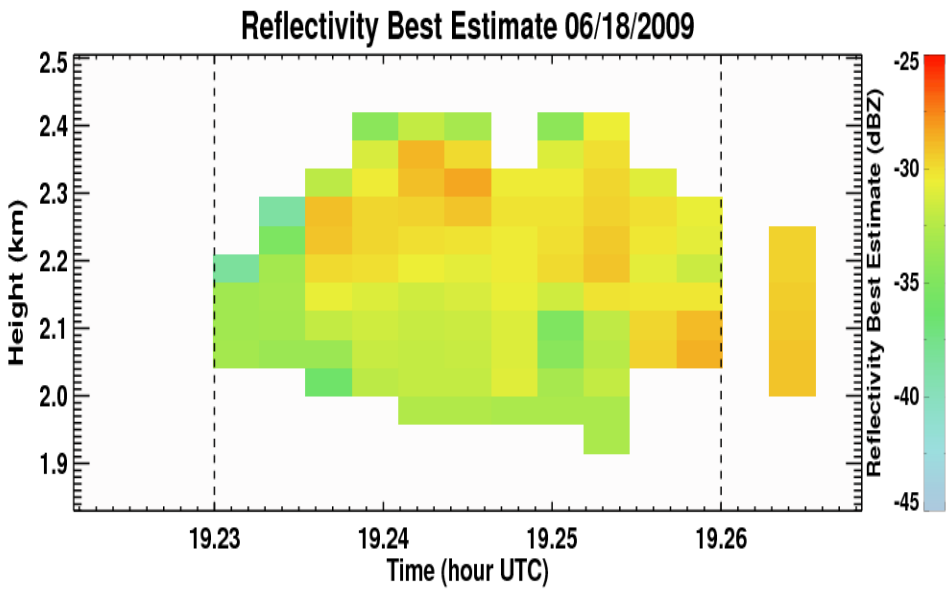
LWP > 100 g/m2

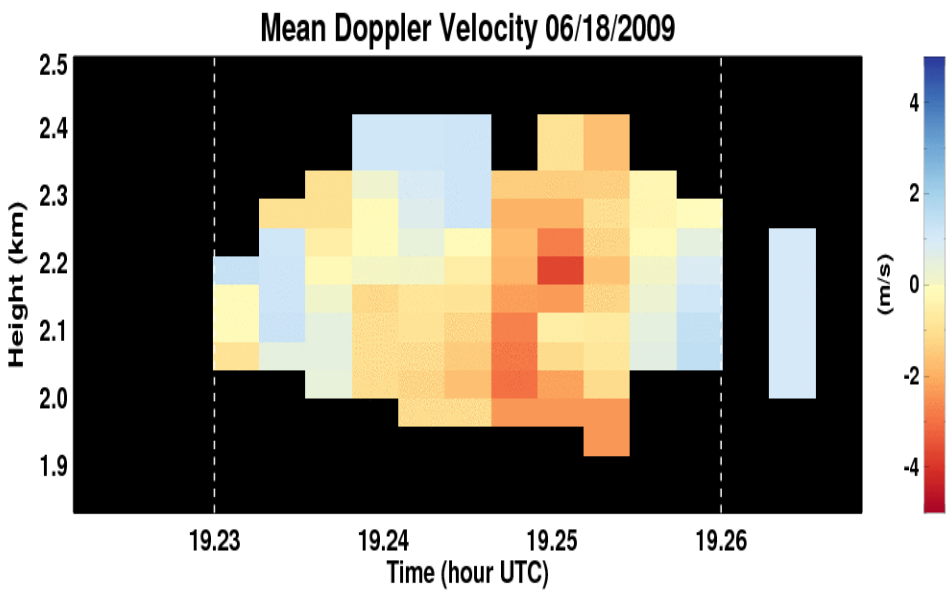
Cloud thickness > 500 m

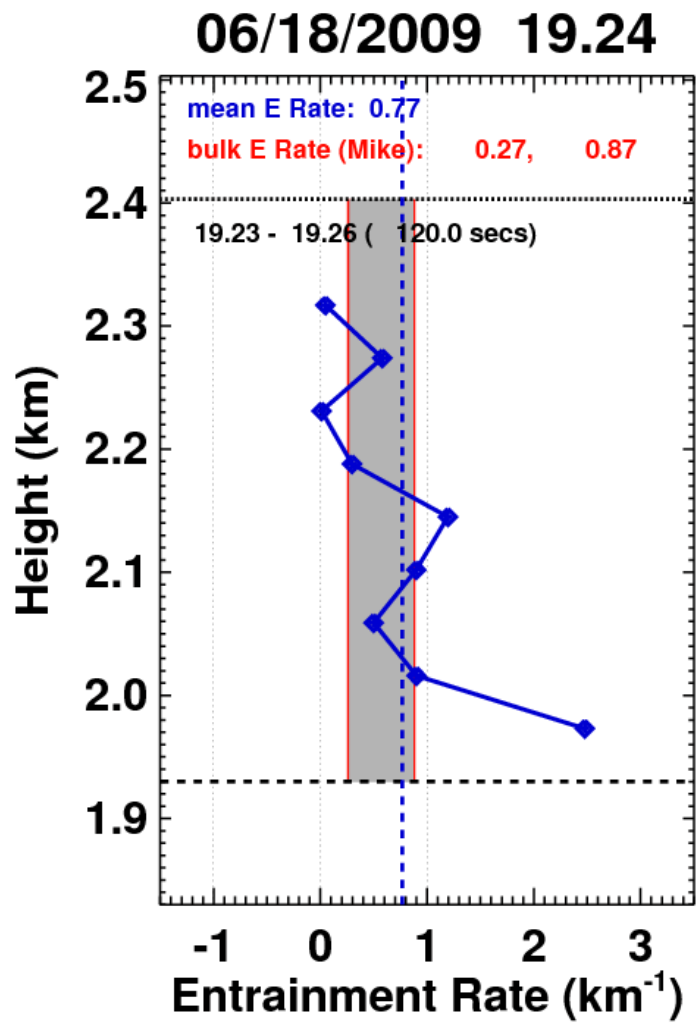


Zhang and Klein (2013)

Example Estimate of Entrainment Rate Profile







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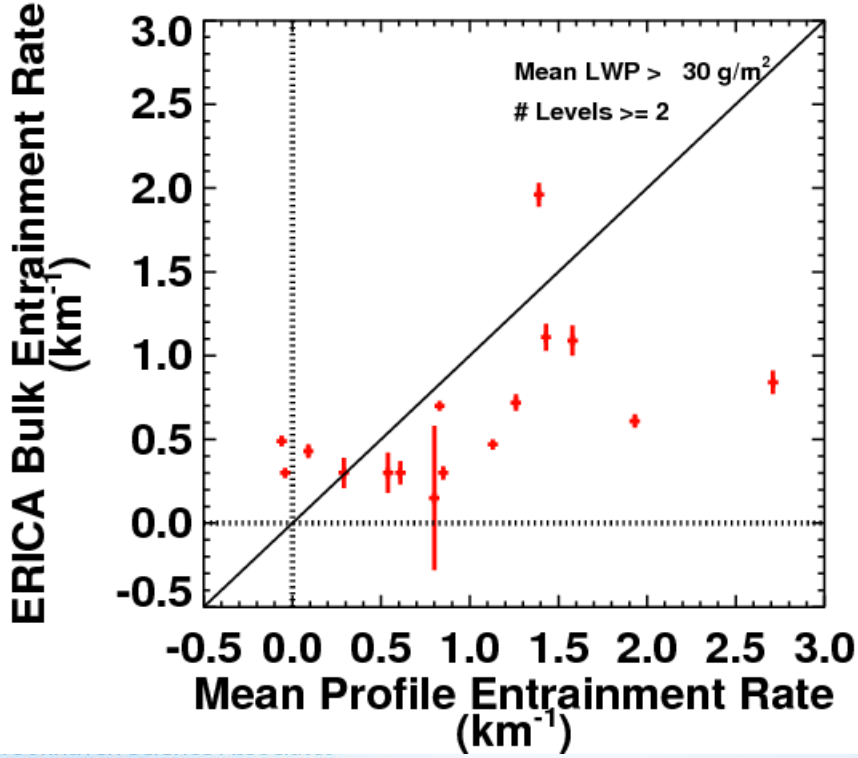
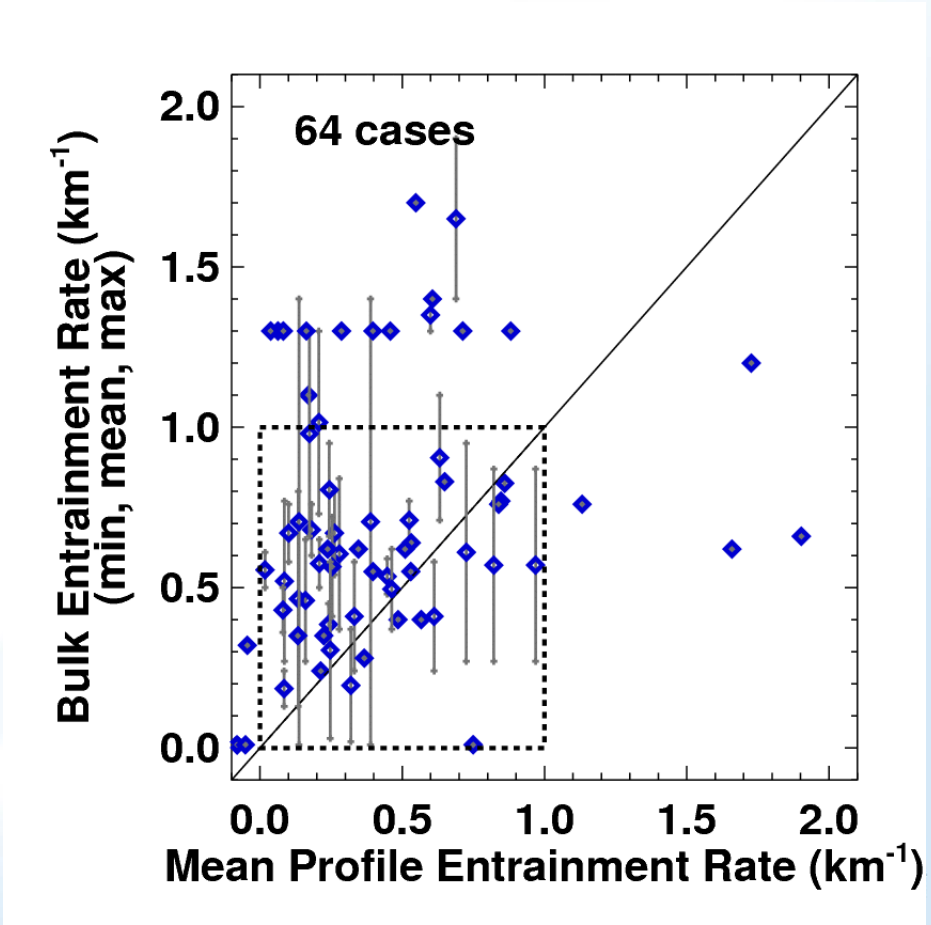
Comparisons to bulk entrainment estimates

Jensen et al. 2006 – Entraining Plume Model, Linear Mixing, CTH constraint

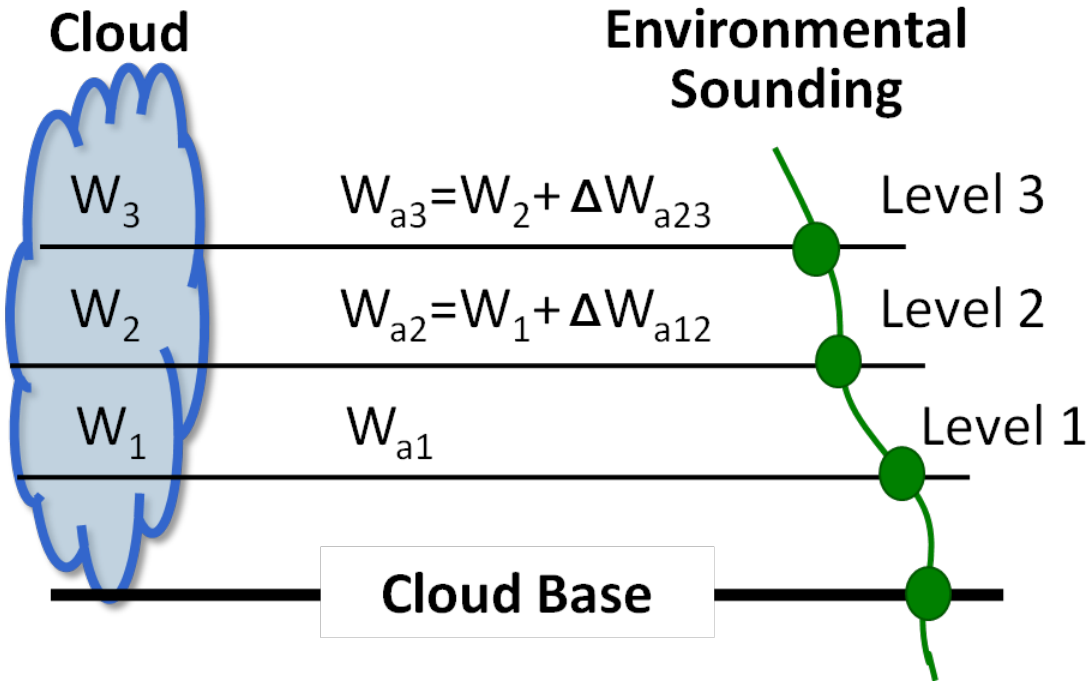
Wagner et al. 2013 – Entrainment Rate in Cumulus Algorithm (ERICA), Explicit Mixing Parcel Model (EMPM), Suite of ARM instruments, optimal estimation technique, LWP constraint.





Where do we go from here?

- More validation
- Extend to additional ARM sites (TWP, Azores)
- Extend beyond non-precipitating cases



Non-Precipitating Shallow Cumulus → **+ Spectral Decomp.** → **Precipitating Cumulus** → **Wind Profiler** → **Deep Convective Clouds**

Provides needed observational constraints of convective cloud entrainment rate for models

Summary

- Building on Lu et al. 2013 we use mm-wave radar vertical velocity observations to retrieve profiles of entrainment rate for non-precipitating cumulus clouds

- Validated against two separate methods of estimating bulk entrainment from remote sensing. Initial results are promising but more validation needed

- Future research will extend to additional validation, additional ARM sites, precipitating cumulus and deep convection