Cloud Growth and Entrainment Rates in Shallow Cumulus and Congestus During GoAmazon 2014/2015

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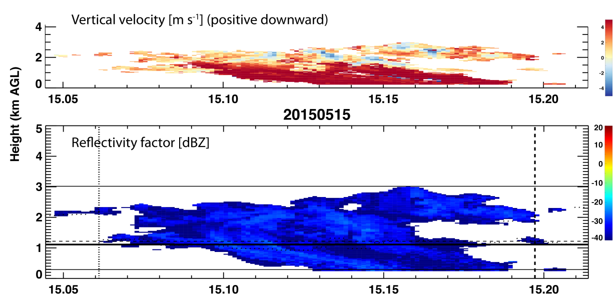
Motivation and Objective

- For convective clouds of all depths, cloud growth and entrainment are closely intertwined. Our overarching scientific question is, “Do entrainment and detrainment rates vary across different shallow convection environments?”
- Our early efforts in addressing this question focus on calculating estimates of entrainment rate for shallow cumulus and congestus clouds sampled during the Green Ocean Amazon 2015/5 (GoAmazon14/5) campaign.
- We apply the Jensen and Del Genio (J. Cim. 2006) bulk method to estimate entrainment rates consistent with thermodynamic sounding profiles and cloud depth obtained from the W-Band ARM Cloud Radar (WACR).

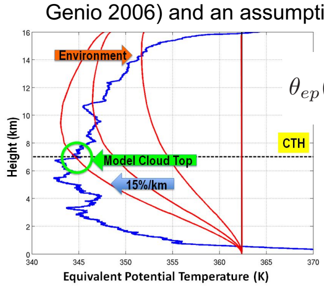
Background

- Shallow cumulus clouds were identified from W-Band ARM Cloud Radar (WACR) observations, with the criteria of cloud-top heights (CTH) below 3 km.
- Shallow cumulus were further classified as active or forced, with the active having a thickness greater than 300 m (Zhang and Klein, JAS, 2013).
- Clouds with CTH between 3 and 9 km were classified as congestus clouds.
- For the Manacapuru, Brazil site during the GoAmazon 2014/5 campaign, we found 102 active shallow cumulus clouds and 792 congestus clouds.
- Four radiosondes launched at the site per day serve to quantify the thermodynamic profile of the atmosphere.



Methods

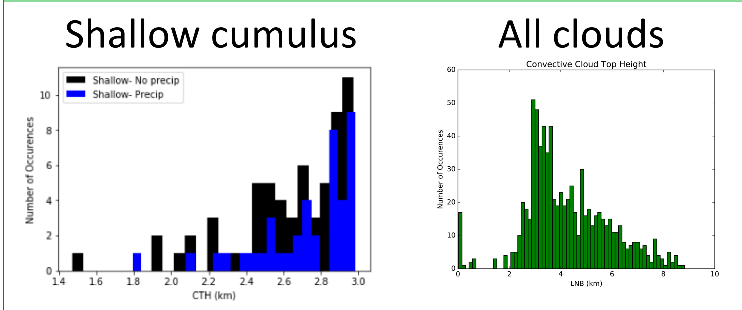
- An entraining plume model was used to estimate the entrainment rate based on observed CTH (Jensen and Del Genio 2006) and an assumption of pseudoadiabatic ascent.

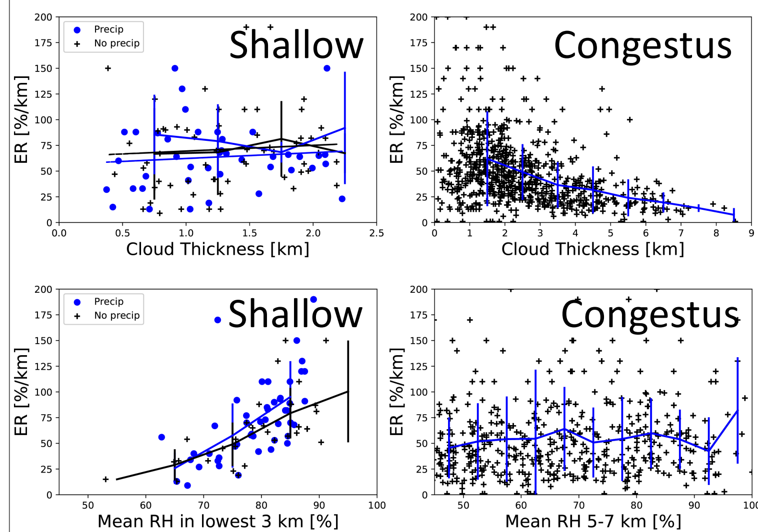


$$\theta_{ep}(z+\Delta z) = \left[\frac{\theta_{ep}(z) + \varepsilon \Delta z \theta_e}{1+\varepsilon \Delta z}\right]$$

- The method iteratively finds a single entrainment rate consistent with a plume rooted in the boundary layer that attains a level of neutral buoyancy at the observed cloud-top height.

Controls on Entrainment Rate





We performed multiple linear regression to identify the factors explaining the greatest amount of variance in entrainment rate:

Shallow

Variable	R^2
RH	0.4158
shear	0.019
CAPE (less than 5km)	0.0068
cloud thickness	0.0067
CIN	0.0041

Congestus

Variable	R^2
Cloud thickness	0.1295
RH	0.0183
CIN	0.0087
CAPE	0.0014
shear	0.0014

Conclusions

- Entrainment rates in congestus are negatively correlated with cloud thickness, reminiscent of entrainment formulations that scale as ~1/*H*.
- Shallow cumulus entrainment rates are a strong function of environmental humidity, but of opposite sign of what one would expect.
- Precipitation in shallow cumulus reduces entrainment rate relative to nonprecipitating clouds.
- Retrieved entrainment rates appear to be smaller (factor of ~5–10) than LES (e.g., Siebesma et al. 2003). Is this from using the maximum cloud-top height in calculation or an artifact of a single entrainment value?
- Future observational estimates of entrainment rates for non-precipitating clouds will include the Jensen et al. (2013) buoyancy-based approach that uses vertical motion obtained from cloud radar and evaluating these entrainment retrieval methods from LES output.

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