Entrainment and Tropical Cumulus Congestus Cloud Growth

Michael P. Jensen[1], Tami Toto[1], Katherine Towey[1,2,3,4]

[1]Brookhaven National Laboratory [2] DOE Science Undergraduate Laboratory Internship

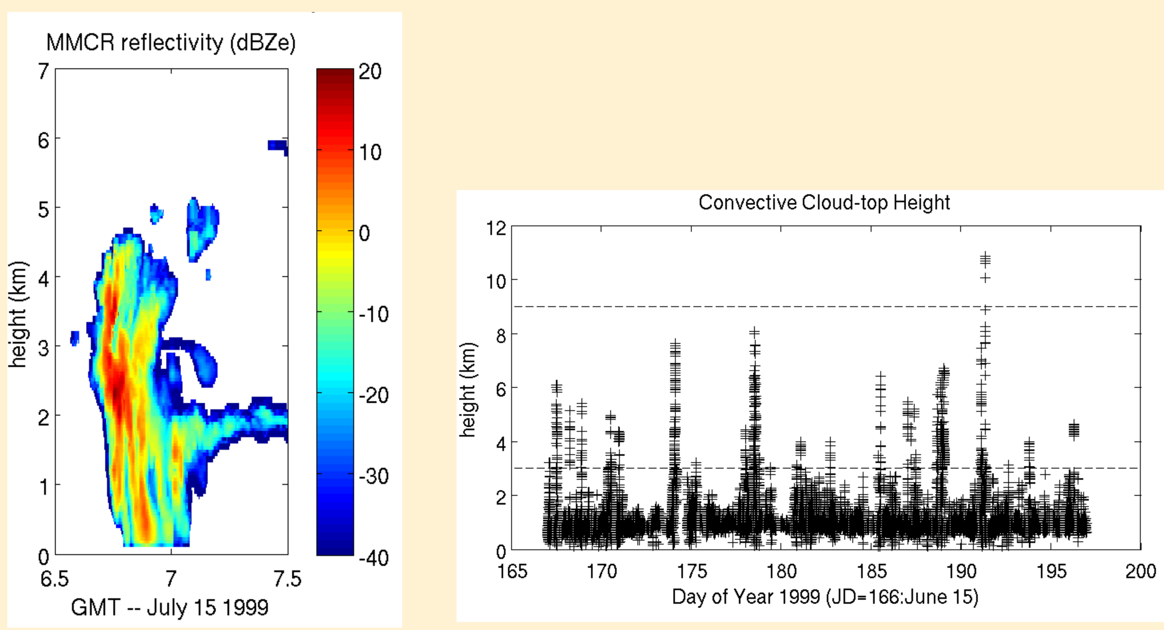
[3] State University of New York at Albany [4]Plymouth State University

Corresponding author: Mike Jensen, mjensen@bnl.gov, (631) 344-7021

ABSTRACT

We use observations from the ARM Climate Research Facility on Nauru Island in the tropical Western Pacific to revisit the growth of cumulus congestus clouds and the factors that control their lifecycle (Jensen and Del Genio 2006, hereafter JD06). We revisit the relative importance of freezing level stability and mid-tropospheric dry layers in limiting the growth of cumulus congestus clouds considering only "terminal" congestus clouds (Luo et al. 2009). Cloud radar-observed Doppler velocities are used to are used to determine the growth state ("terminal" vs. "transient") of cumulus congestus clouds. Preliminary results support the original conclusions from JD06 that bulk entrainment rate decreases as a function of congestus cloud-top height and the mid-level humidity is the critical factor limiting congestus cloud growth.

INTRODUCTION



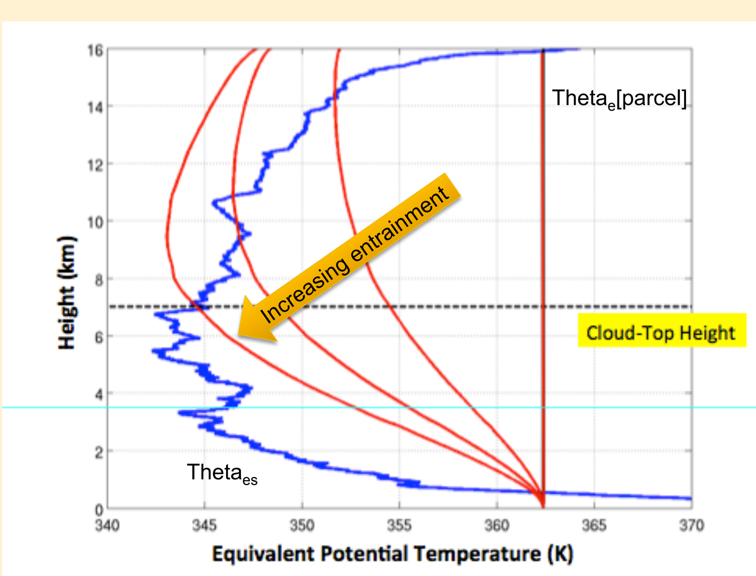
Observations of cumulus congestus at the Nauru Island site (Fig. 1 JD06).

Proposed factors limiting further growth:

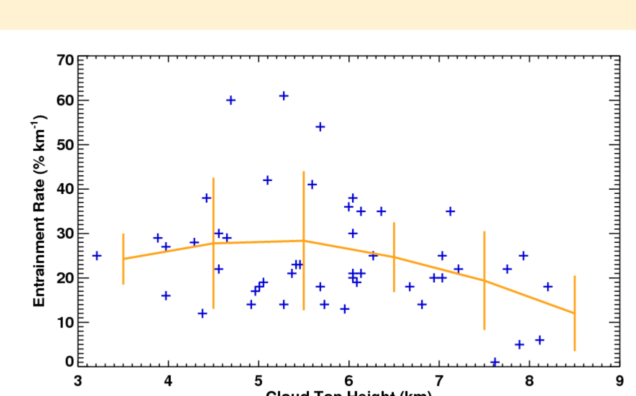
1. Differences in cloud depth function of CAPE
2. Weak stable layers at freezing level
3. Intrusions of dry air in the mid-troposphere

(Redelsperger at al. 2002)

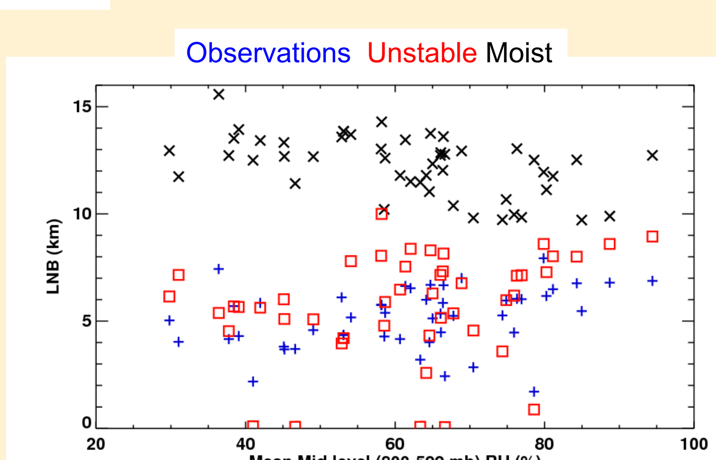
PREVIOUS WORK



- Simple "entraining plume" model used to estimate bulk entrainment rate
- 67 cumulus congestus cases at Nauru (1999-2002)
- Investigate impact of freezing-level stability and mid-tropospheric humidity on modeled cloud-top height



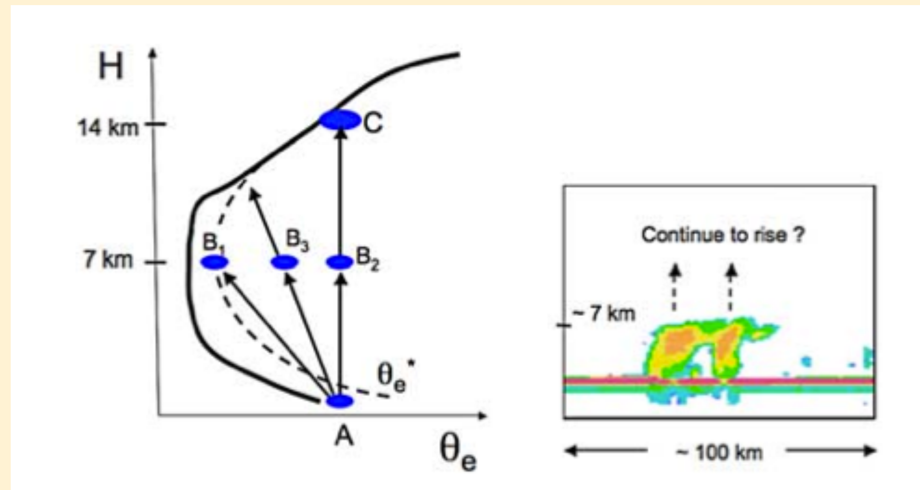
- Estimated bulk entrainment rates decrease as a function of cloud-top height



- Little change in level of neutral buoyancy (LNB) using unstable freezing level sounding

- Significant changes in LNB using moist mid-level sounding

TERMINAL vs. TRANSIENT CONGESTUS



(From Luo et al. 2009)

- Snapshot of cloud does not provide lifecycle context
- Luo et al. (2009) use CTH and CTT to infer growth stage of observed congestus
- 42% (over tropical oceans) and 36% (over tropical land) are transient

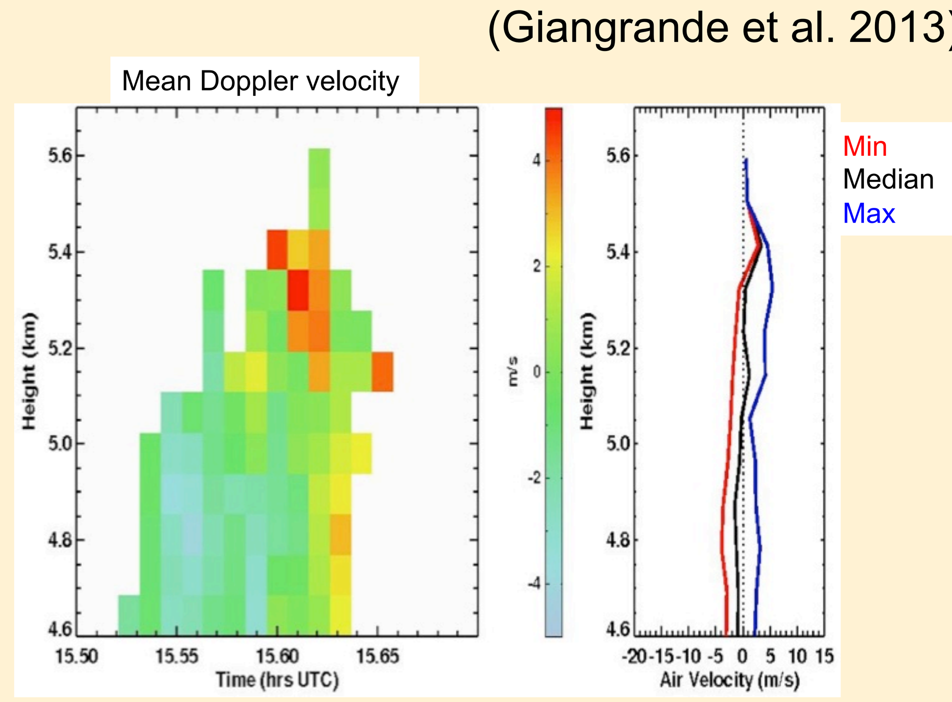
Question: Can we determine terminal vs. transient from surface-based ARM measurements?

Question: How does this impact the results of Jensen and Del Genio (2006)?

TERMINAL vs. TRANSIENT FROM ARM OBSERVATIONS

- Doppler velocity from vertically pointing cloud radar
- Account for hydrometeor fall-speed using $V_f = aZ^b$

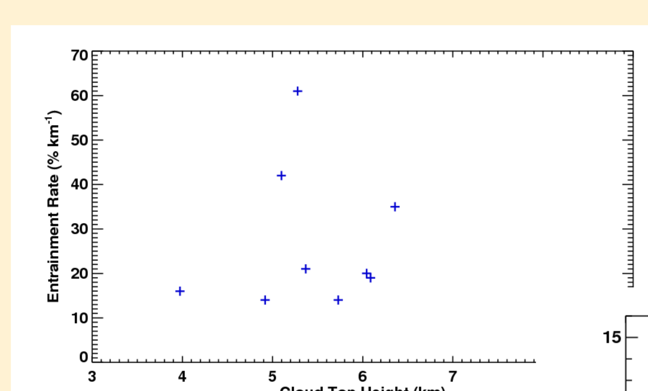
(Giangrande et al. 2013)

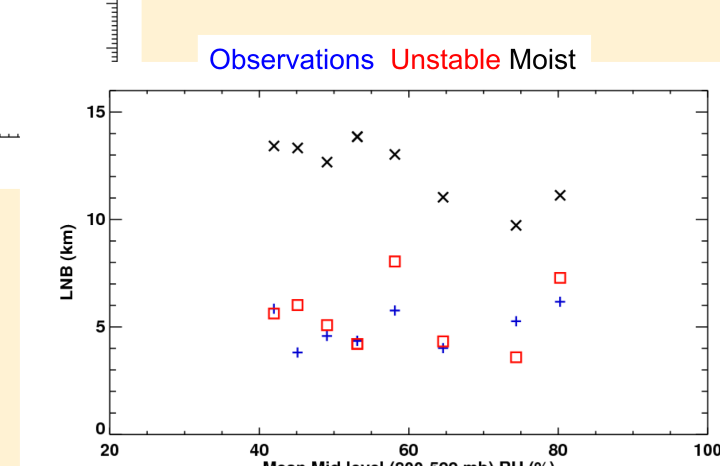


Growth criteria based on:

- Fraction of cloud-top (1 km) pixels moving upward
- Slope of median vertical velocity with height
- Absolute magnitude of mean cloud-top vertical velocity

Of the original 67 cases from JD06 only 9 (13%) were classified as "terminal"



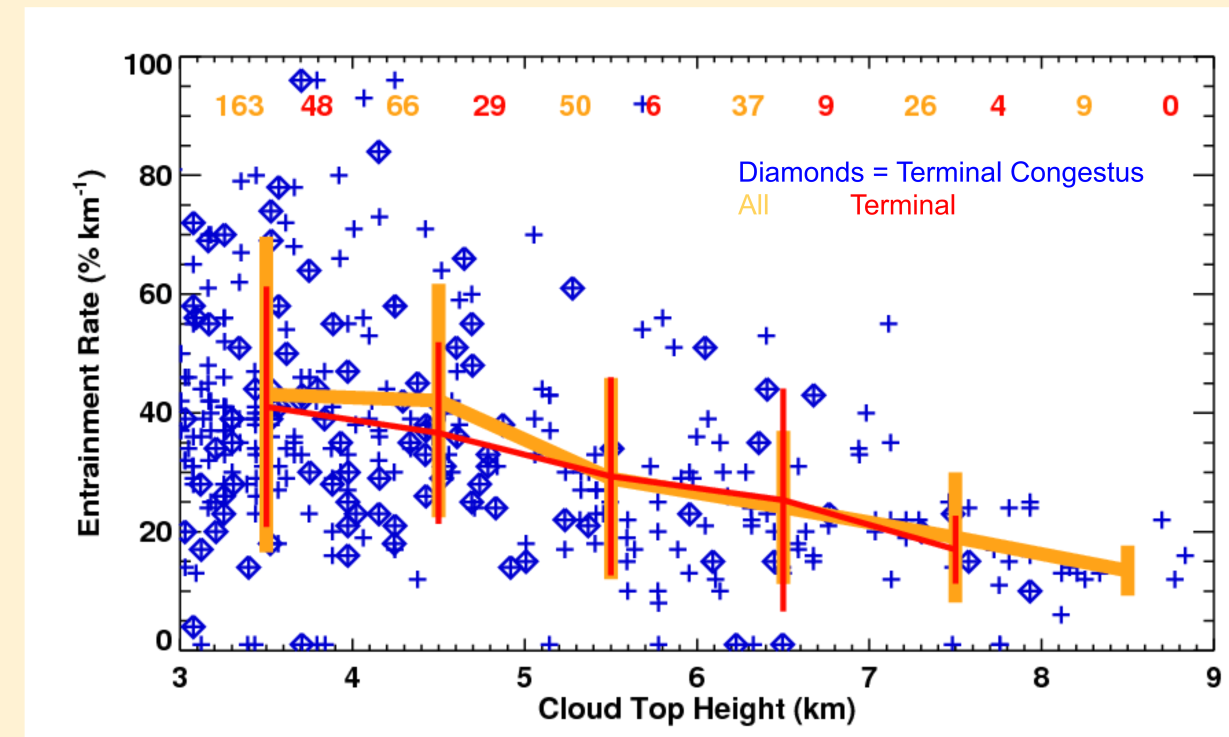


AUTOMATED CONGESTUS IDENTIFICATION

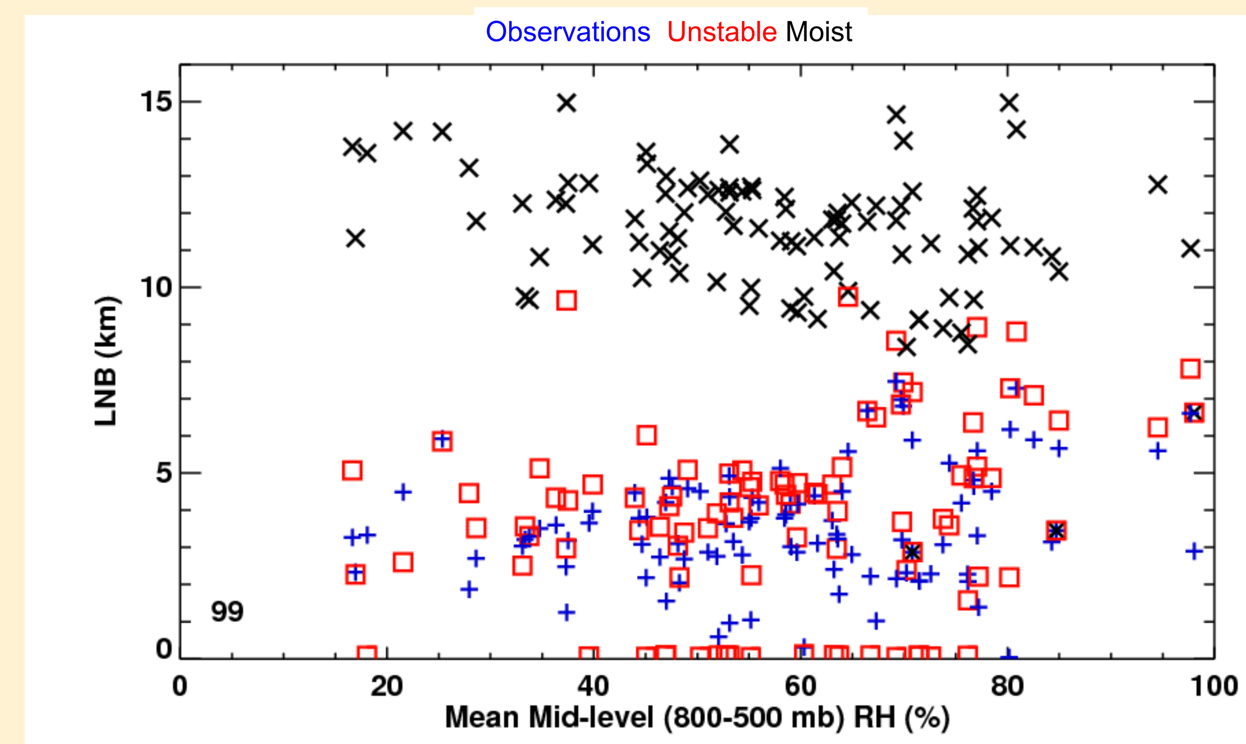
- Simplified detection and spread algorithm
- ARSCL median CBH < 1 km
- 3 km < CTH < 9 km
- 60 sec. minimum duration
- Radiosonde launch within previous 6 hours

EXTEND TO ADDITIONAL CASES 1999-2008

Automated routine identified 355 total cumulus congestus cases, 99 (28%) terminal



- Similar trend between entrainment rate and CTH
- As expected, entrainment rates are overestimated when transient congestus are included



- Supports conclusion of JD06 that mid-level humidity is most significant factor limiting congestus cloud-top heights.

WHAT DO WE DO NEXT?

- **Extend to all cases observed at Tropical ARM sites**
  - Manus (1999-2014)
  - Darwin (2002-2014)
  - Niamey, Niger (2006)
  - Gan Island, Maldives (2011)
  - Manacapuru, Brazil (2014-2015)
- **Evaluate sensitivty of results to:**
  - Automated cumulus congestus mask
  - Fall-speed relationship
  - Terminal/Transient criteria
- **Re-evaluate correlations between environmental characteristics and entrainment rate**
- **Investigate new methods for determining entrainment rate**

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