Level of Neutral Buoyancy, Convective Outflow, Convective Core and Entrainment Rates: A CloudSat Perspective

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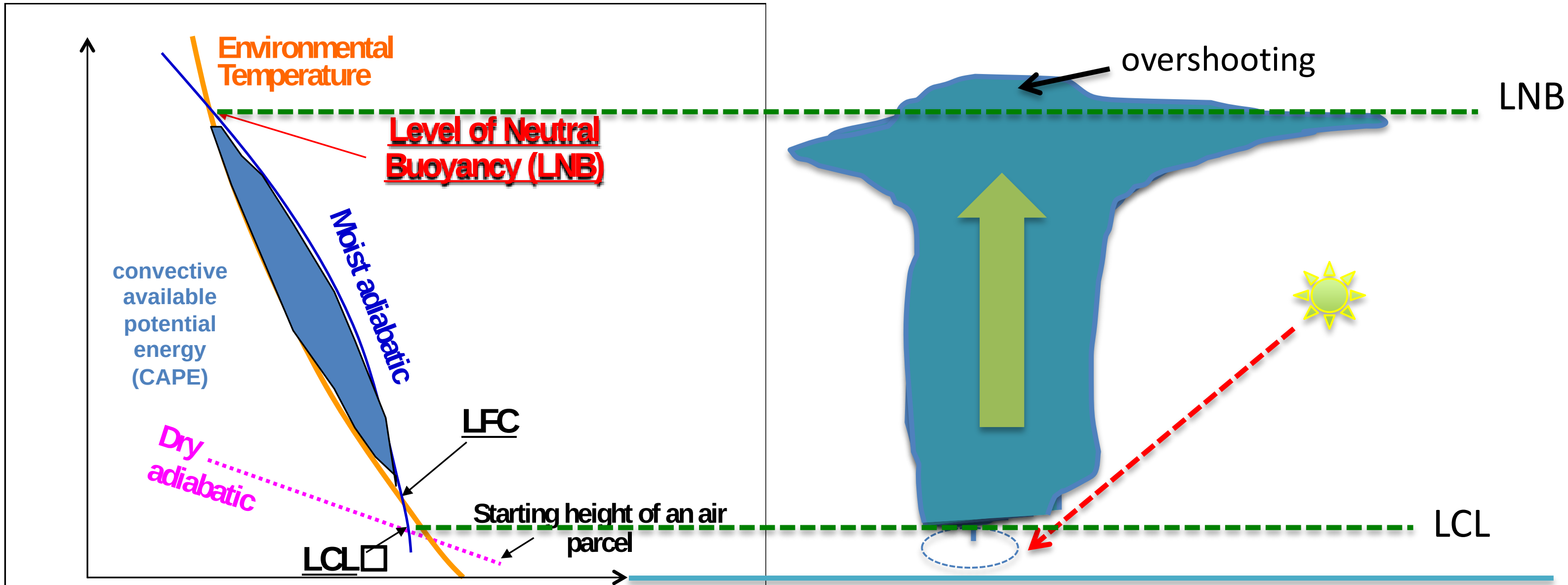
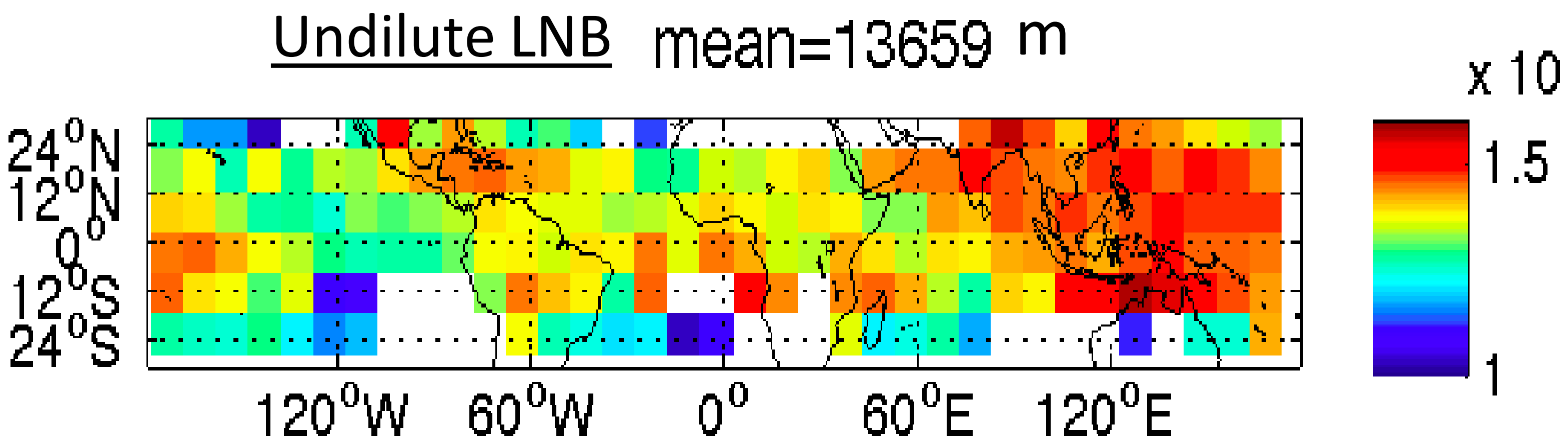
Textbook definition of LNB – Parcel Theory
(pseudo-adiabatic version)



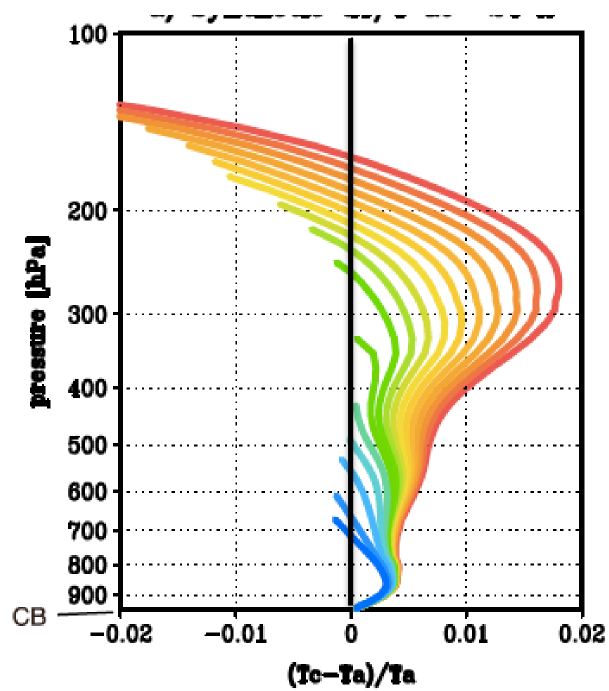
Art of Hanii Takahashi



Source: ECMWF analysis (2006 – 2008)

The question is: how is this version of LNB related to the actual deep convective outflow?

Where exactly do the convective air parcels feel the zero buoyancy?

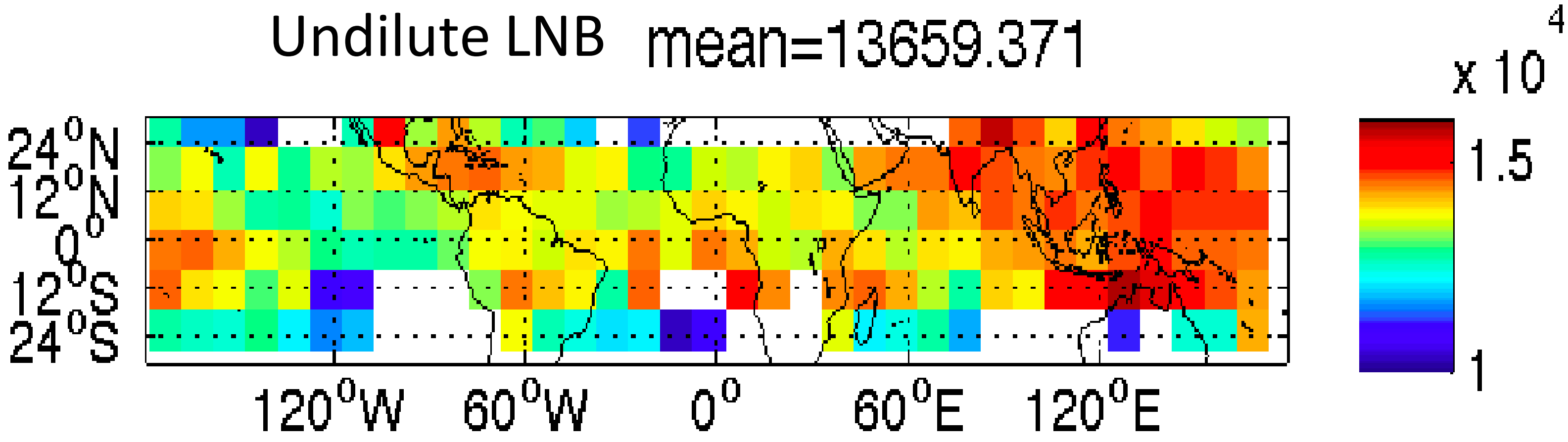


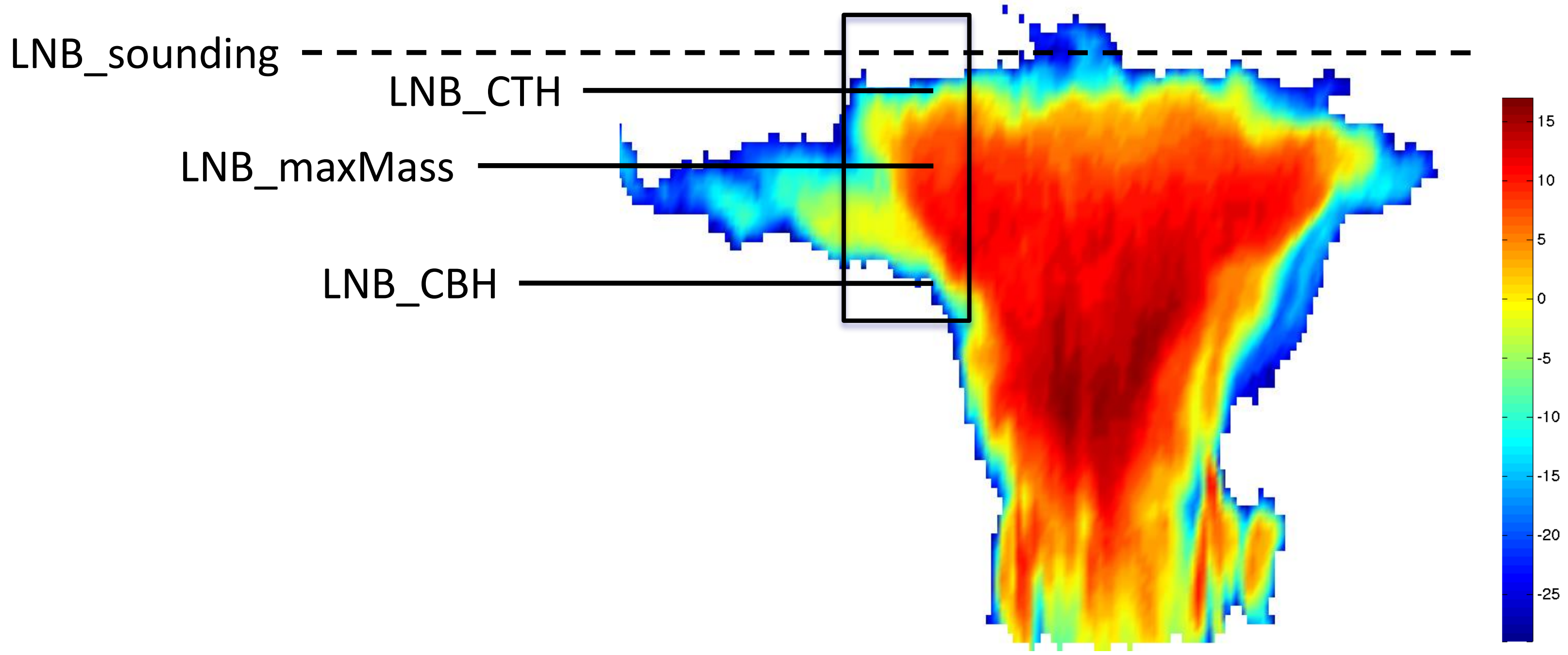
Buoyancy

Parcel model calculation of buoyancy

Different colors designate different entrainment rates: warmer colors, lower entrainment.

Masunaga and Luo (2016)


Undilute LNB mean=13659.371
x 10^4
1.5
1
24°N
12°N
0°
12°S
24°S
120°W
60°W
0°
60°E
120°E


LNB_sounding
LNB_CTH
LNB_maxMass
LNB_CBH
15
10
5
0
-5
-10
-15
-20
-25

Outline

1. A Global Survey using CloudSat Data
2. Regional Variations
3. Relation to Entrainment Rates and Convective Core
4. Summary and Discussions

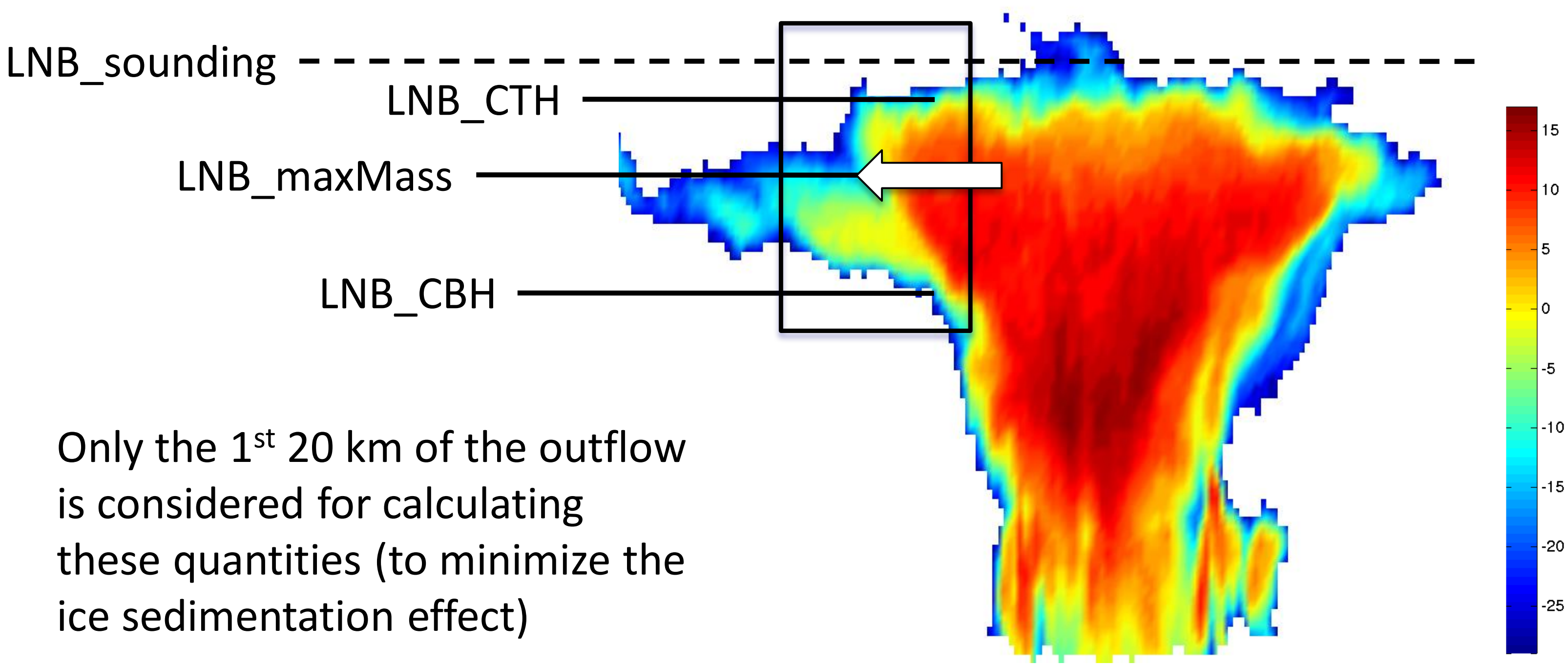
References:

- Takahashi, H. and Z. Luo, 2012: Where is the level of neutral buoyancy for deep convection? *Geophys. Res. Letts*., 39, L15809, doi:10.1029/2012GL052638
- Takahashi, H., Z. J. Luo, and G. L. Stephens, 2017: Level of neutral buoyancy, deep convective outflow and convective core: new perspectives based on 5 years of CloudSat data, *J. Geophys. Res*., Atmos., 122, doi: 10.1002/2016JD025969

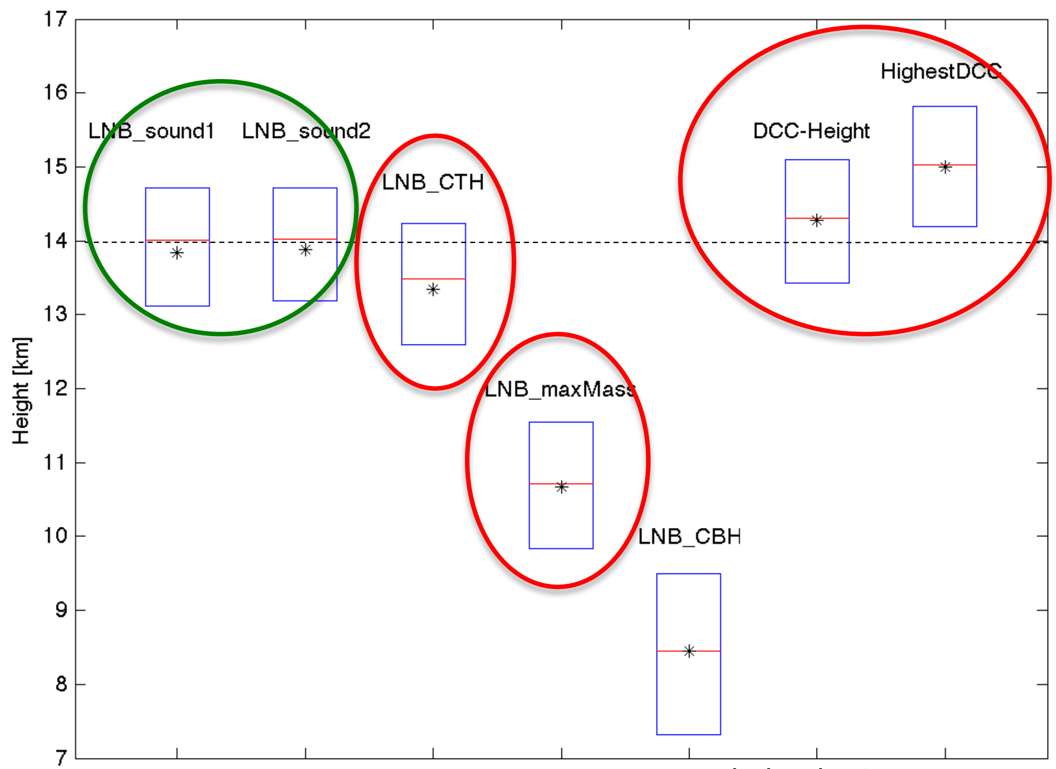
Methodology

This is our target: <u>a mature deep convection</u>

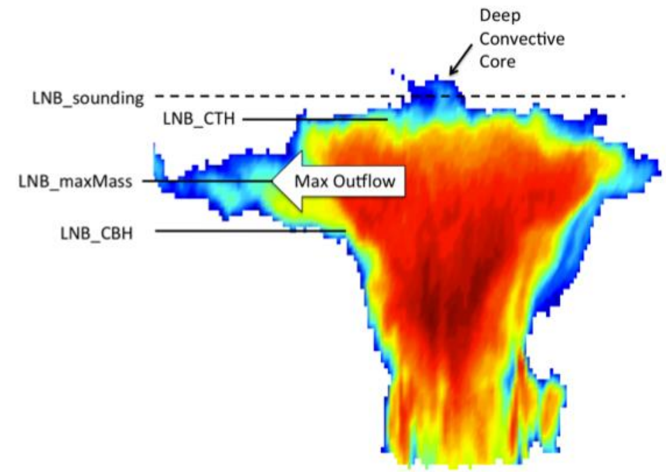
Well-developed anvil and outflow will "betray" where convective motions loses steam (neutral buoyancy)



Only the 1st 20 km of the outflow is considered for calculating these quantities (to minimize the ice sedimentation effect)



Takahashi & Luo 2012



Based on 4008 convective objects from CloudSat data (2006-2008)

Land-Ocean Differences

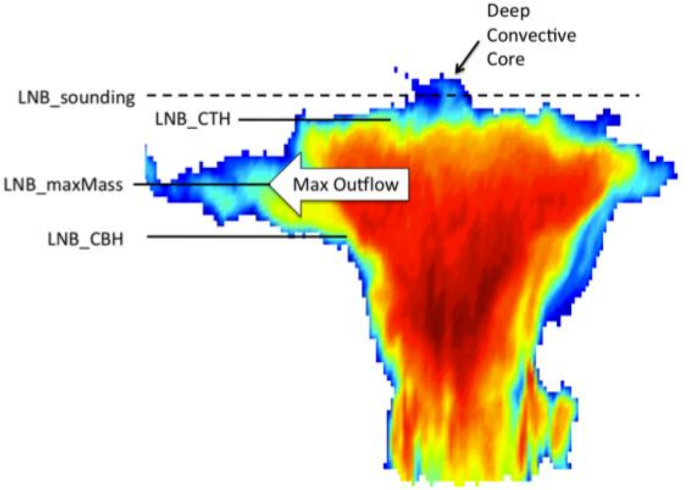
Takahashi & Luo 2012

Median (STD)	LNB_sounding1	LNB_sounding2	LNB_CTH	LNB_maxMass	LNB_CBH
All	14,219 (1,203)	14,247 (1,163)	13,406 (1,365)	10,680 (1,342)	8,409 (1,495)
Ocean	14,229 (1,141)	14,234 (1,135)	13,293 (1,358)	10,548 (1,315)	8,272 (1,473)
Land	14,185 (1,388)	14,268 (1,254)	13,756 (1,327)	11,141 (1,337)	8,783 (1,527)
Median (STD)	**DCC-Height**	**Highest DCC**	**System Size**	**DCC Size**	**Number of Cases**
All	14,237 (1,194)	14,951 (1,204)	159.5 (159.7)	11 (25.7)	4008
Ocean	14,125 (1,168)	14,841 (1,186)	167.2 (165.1)	9.9 (25.1)	3087
Land	14,654 (1,198)	15,373 (1,176)	139.7 (136.5)	14.3 (27.5)	909

- LNB_sounding is similar between land and ocean; however, LNB_observation (LNB_CTH, LNB_maxMass, LNB_CBH) is consistently higher (by ~ 500 m) over land than over ocean.

- The height of the core is higher over land.

- Ocean convective systems are larger, but their cores are smaller



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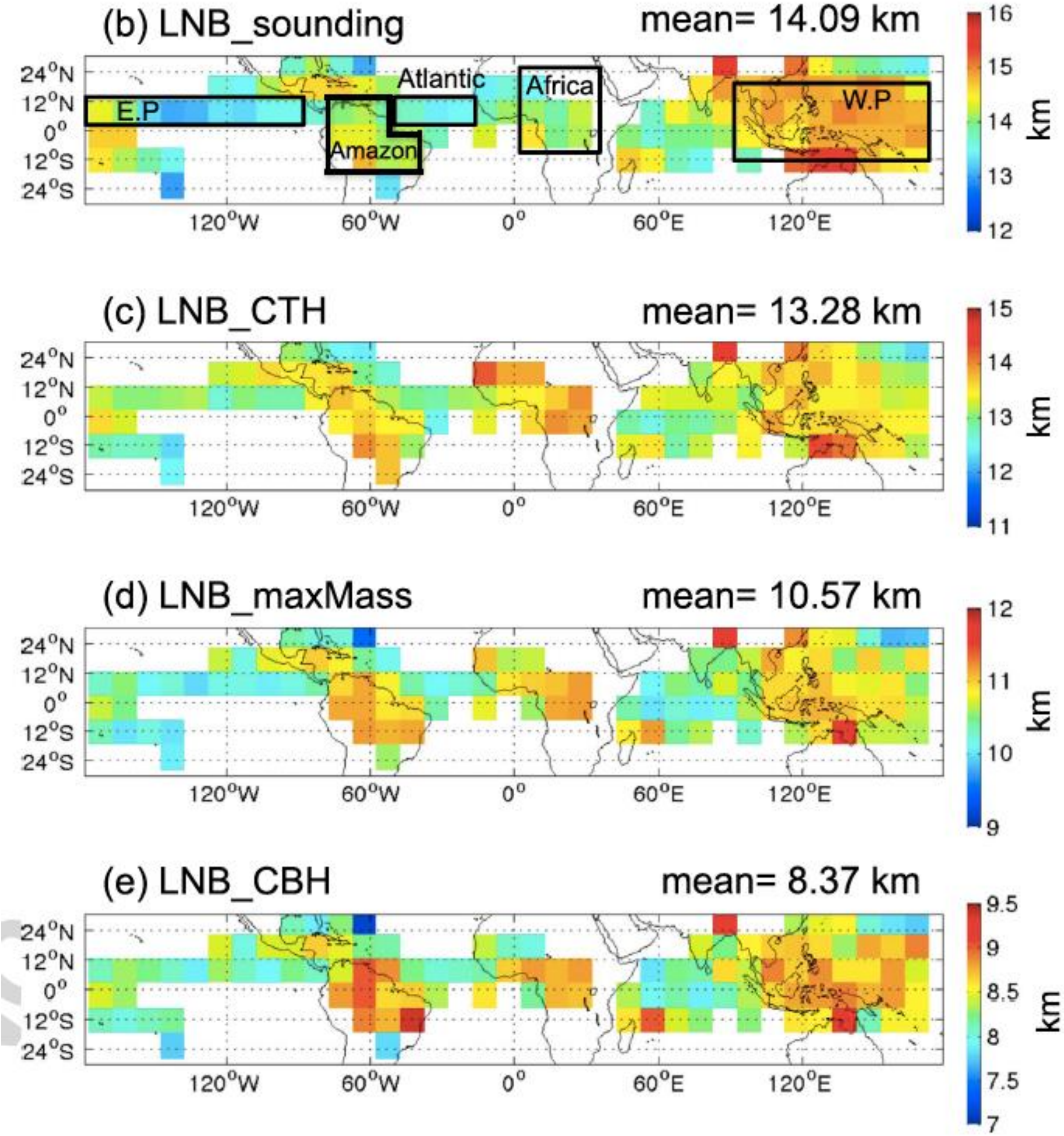
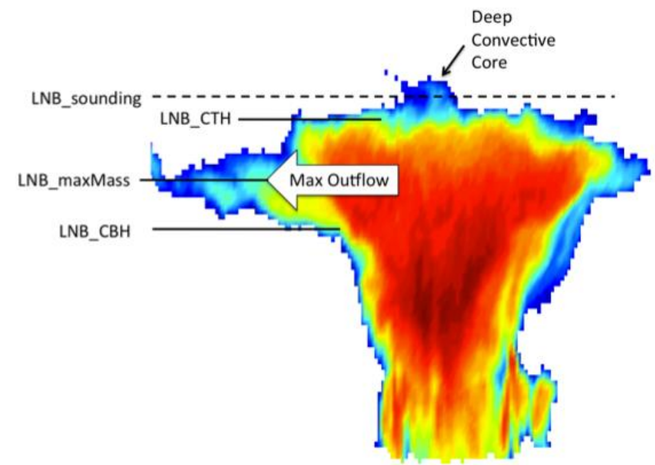
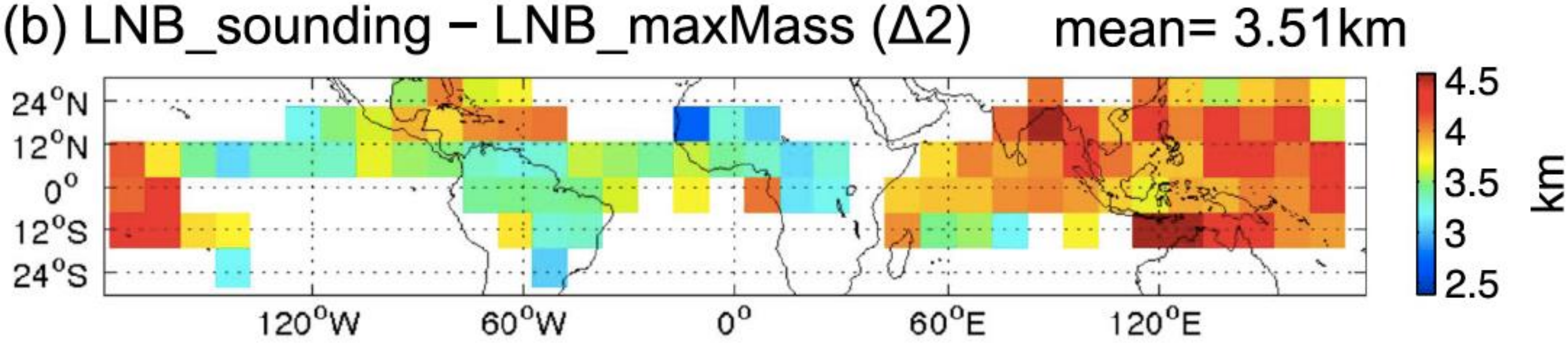


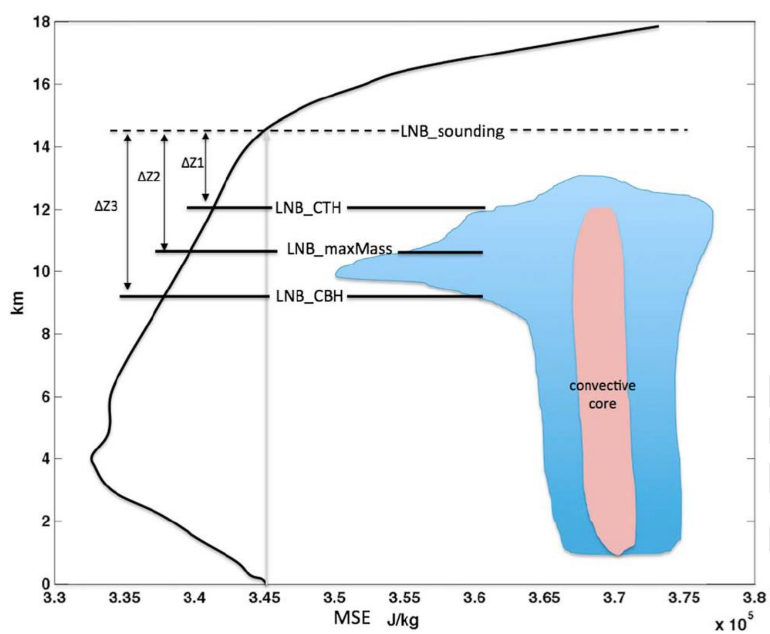


Now based on 5-yrs of data and 7320 cases

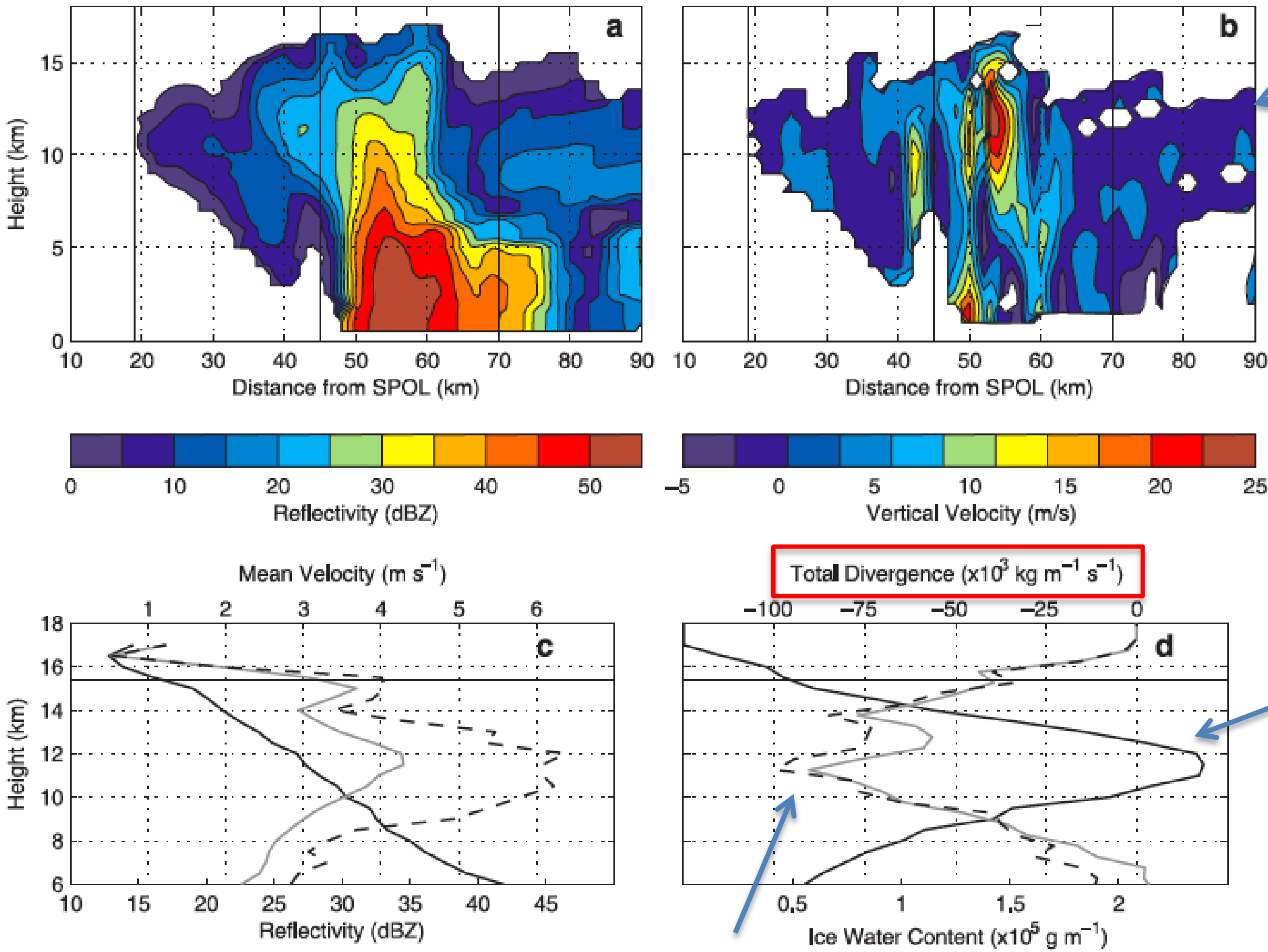
Takahashi et al. (2017)



(b) LNB_sounding − LNB_maxMass (Δ2)
mean= 3.51km
24°N
12°N
0°
12°S
24°S
120°W
60°W
0°
60°E
120°E
4.5
4
3.5
3
2.5
km



LNB_sounding
ΔZ1
ΔZ2
ΔZ3
LNB_CTH
LNB_maxMass
LNB_CBH
convective core
km
MSE J/kg
x 10^5

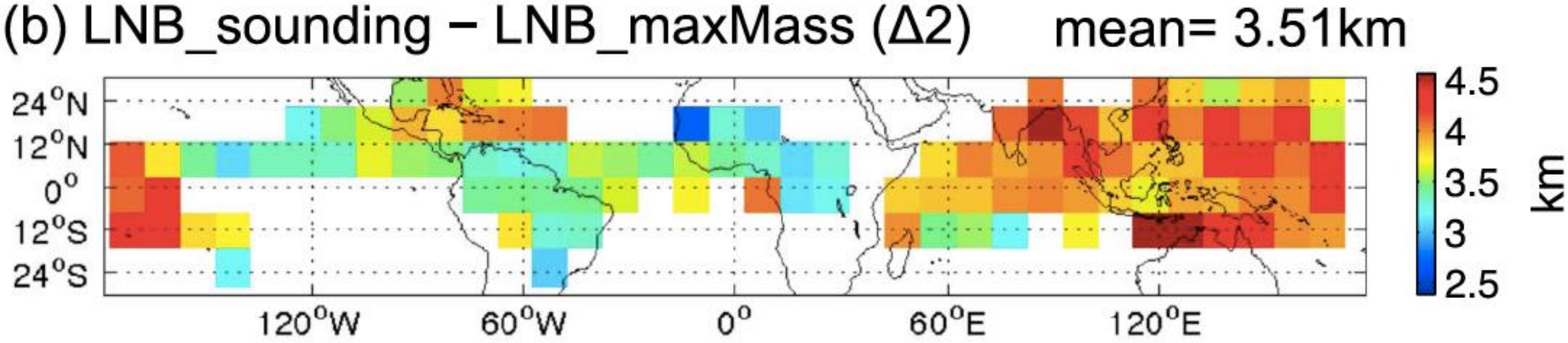


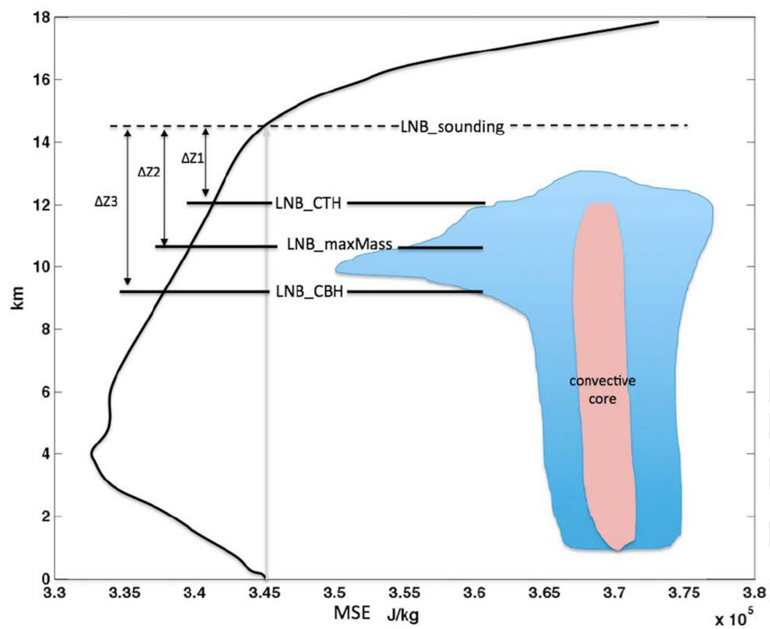
Vertical velocity

Divergence Inferred from the vertical velocity

IWC Inferred from radar reflectivity

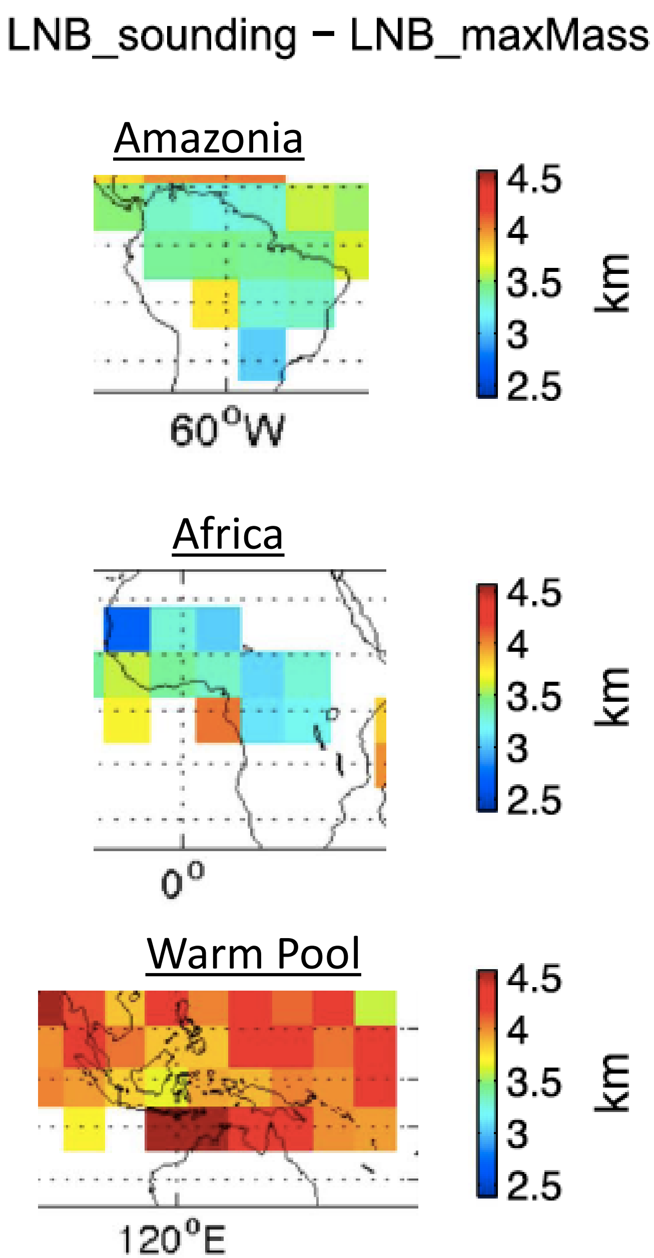
Mullendore et al. (2009)

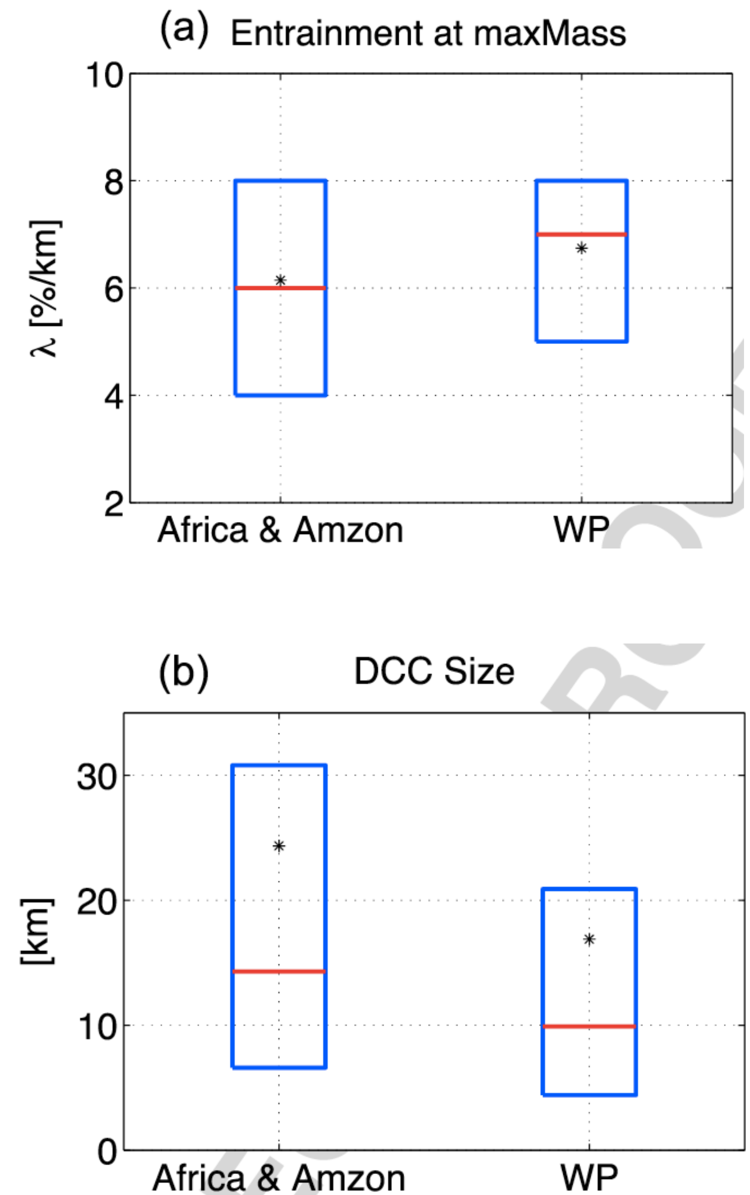




There are a number of ways to explain the regional differences in Δ2 (LNB_sounding – LNB_maxMass).

Here we interpret the Δ2 as indicating *the magnitude of entrainment dilution.*


LNB_sounding − LNB_maxMass
Amazonia
60°W
Africa
0°
Warm Pool
120°E
4.5
4
3.5
3
2.5
km


(a) Entrainment at maxMass
λ [%/km]
10
8
6
4
2
Africa & Amzon
WP
(b) DCC Size
[km]
30
20
10
0
Africa & Amzon
WP

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MODELS OF PRECIPITATING CUMULUS TOWERS

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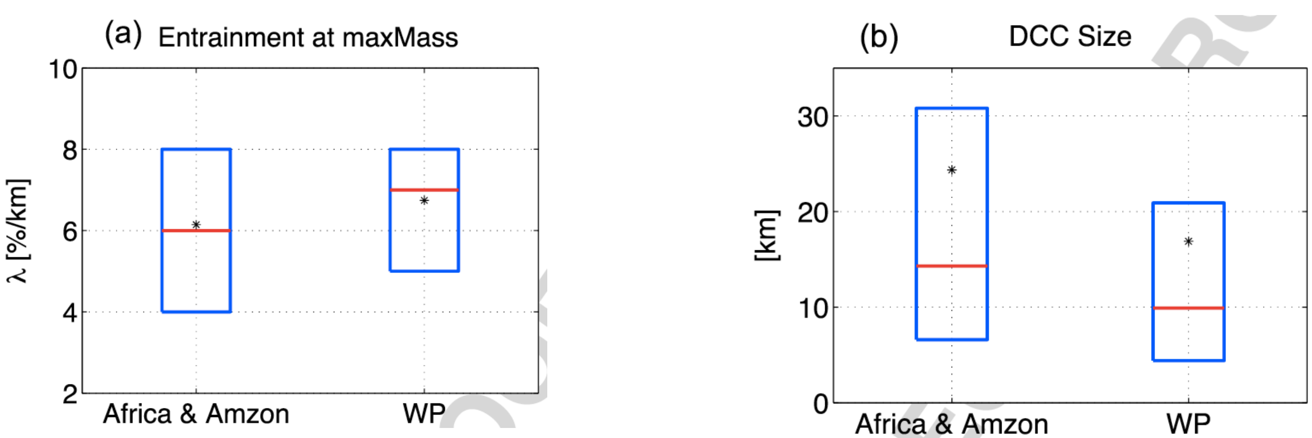
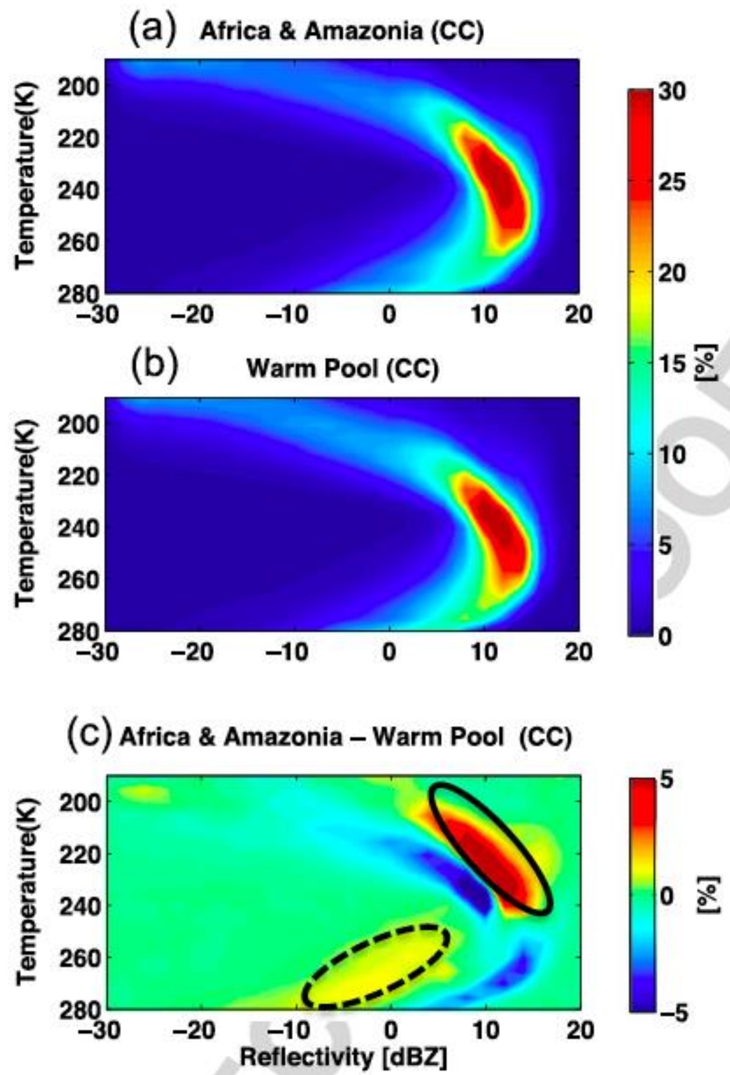
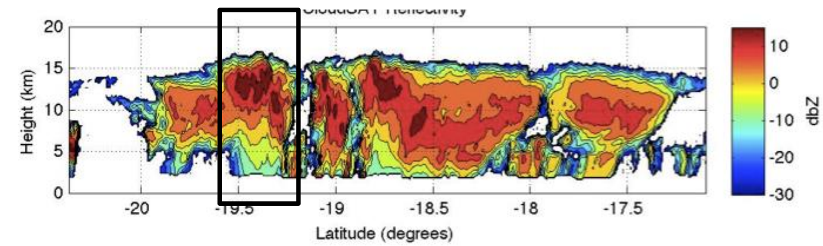
Atmospheric Physics and Chemistry Laboratory, ESSA, Miami, Fla.

$$\frac{1}{M}\frac{dM}{dz}\simeq\frac{0.2}{R} \text{ (laboratory result)}$$

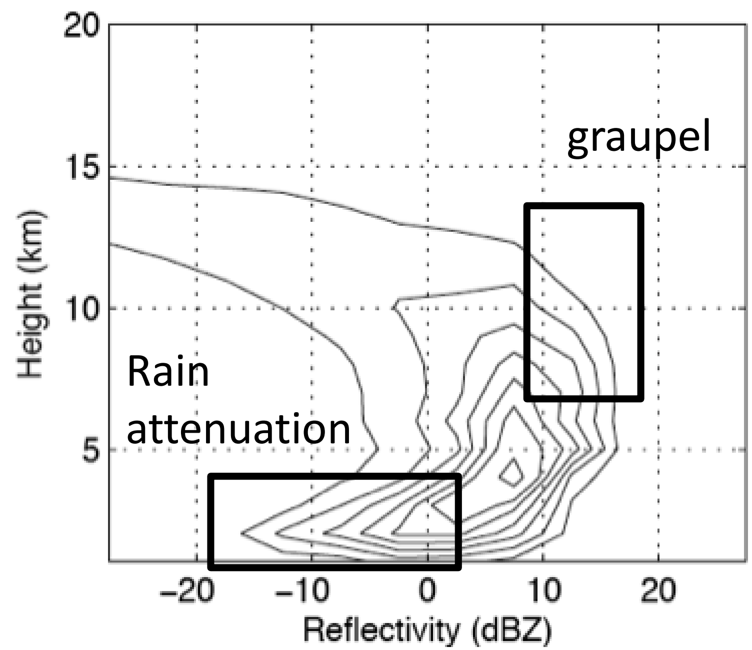
$$\frac{1}{M}\frac{dM}{dz}=\frac{9}{32}\frac{K_2}{R} \text{ (theoretical result)}$$





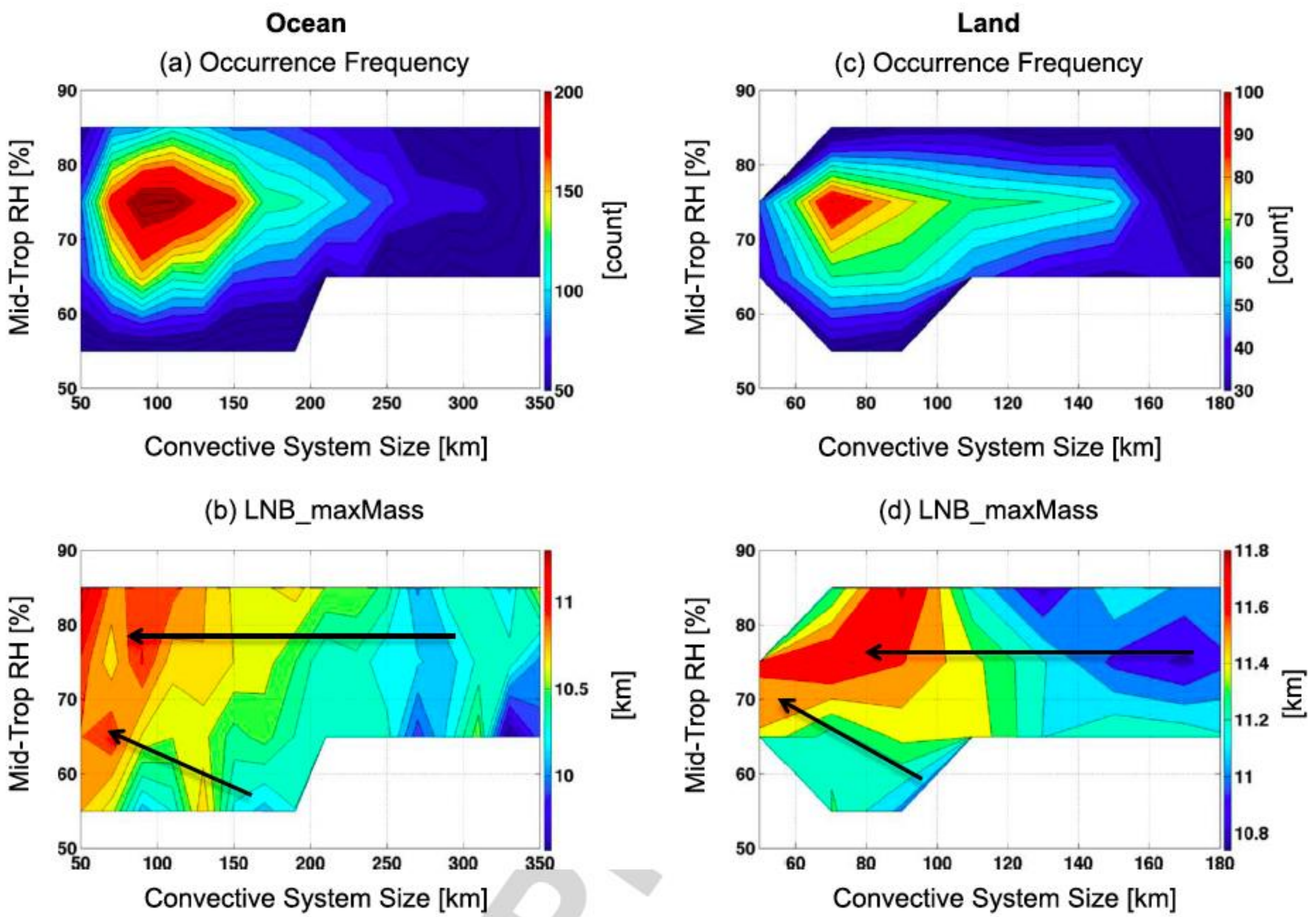


Contoured frequency by altitude diagram (CFAD)



Dependence of LNB_maxMass on

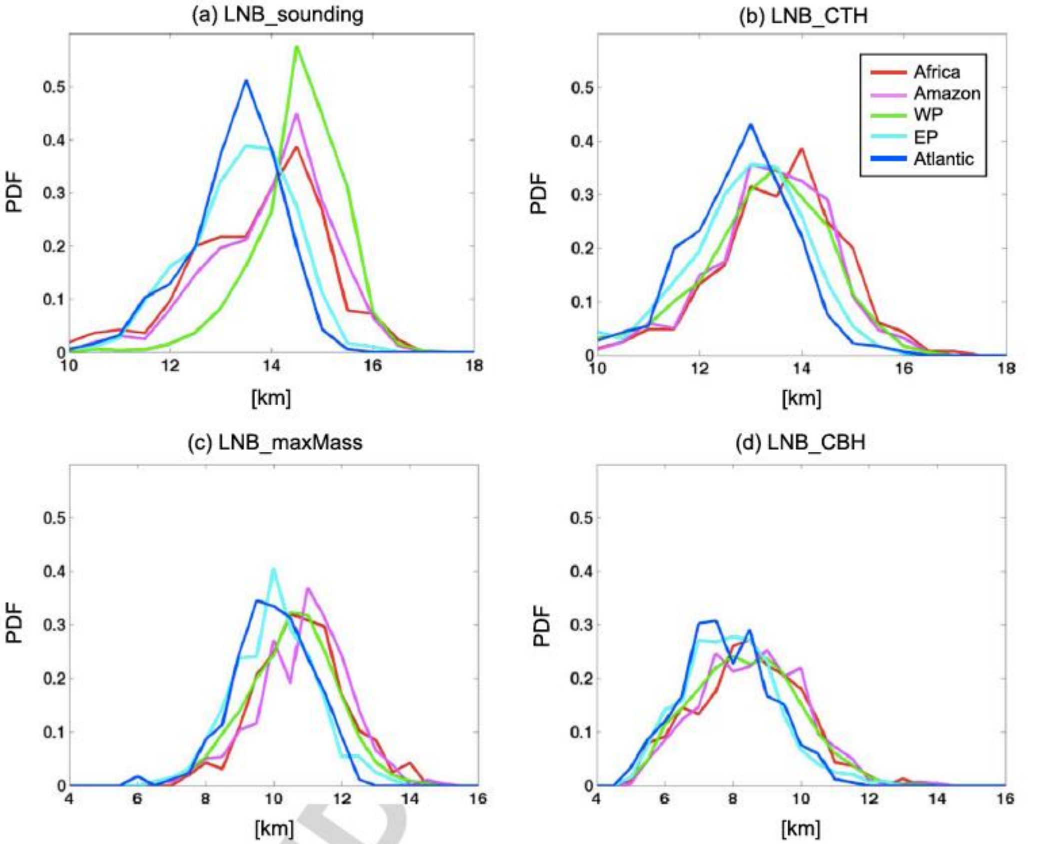
1) convective system size
2) Environmental conditions (e.g., mid-tropospheric RH)

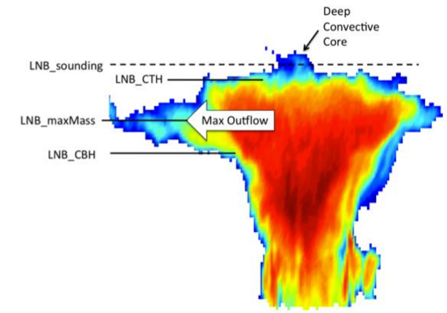


Summary

1. Deep convective outflow is almost always lower than the undilute LNB (LNB_sounding). However, there is little correlation between LNB_sounding and the actual outflow height.
2. The difference between LNB_sounding and LNB_maxMass is smaller over land than over ocean, which can be interpreted as indicating the land convection is less diluted.
3. We observed a negative relationship between convective entrainment rate and convective core size.
4. CloudSat CPR observations show that DCC is stronger over land than over ocean
5. LNB_maxMass depends on convective system size and environmental RH in such a way that …

Backup slides





- <u>LNB_sounding ranking</u>: WP(14.9km), Amazonia (14.5km), Africa (14.2km), East Pacifc (13.8km), and Atlantic ITCZ (13.7km)
- <u>LNB_maxMass ranking</u>: Africa (11.1km), Amazonia (11.3 km), WP (10.9km), East Pacific (10.3km), and Atlantic ITCZ (10.3 km)