Evaluation of parcel model estimated cloud top height of deep convective clouds with active sensor observation

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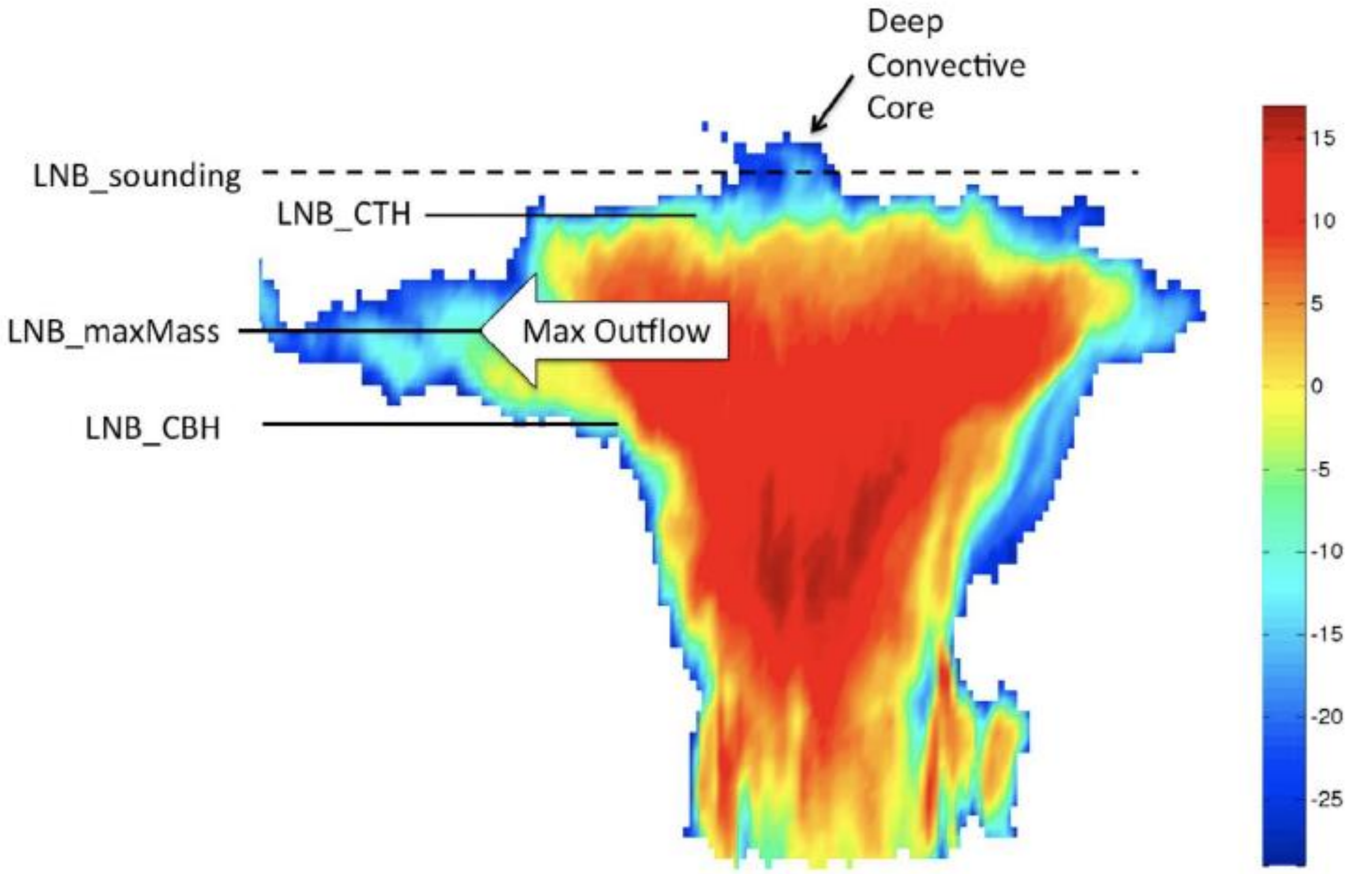
Pre-Launch EarthCARE Science and Validation Workshop

Deep convective cloud cloud top height



Takahashi and Luo, 2012, GRL

Motivations

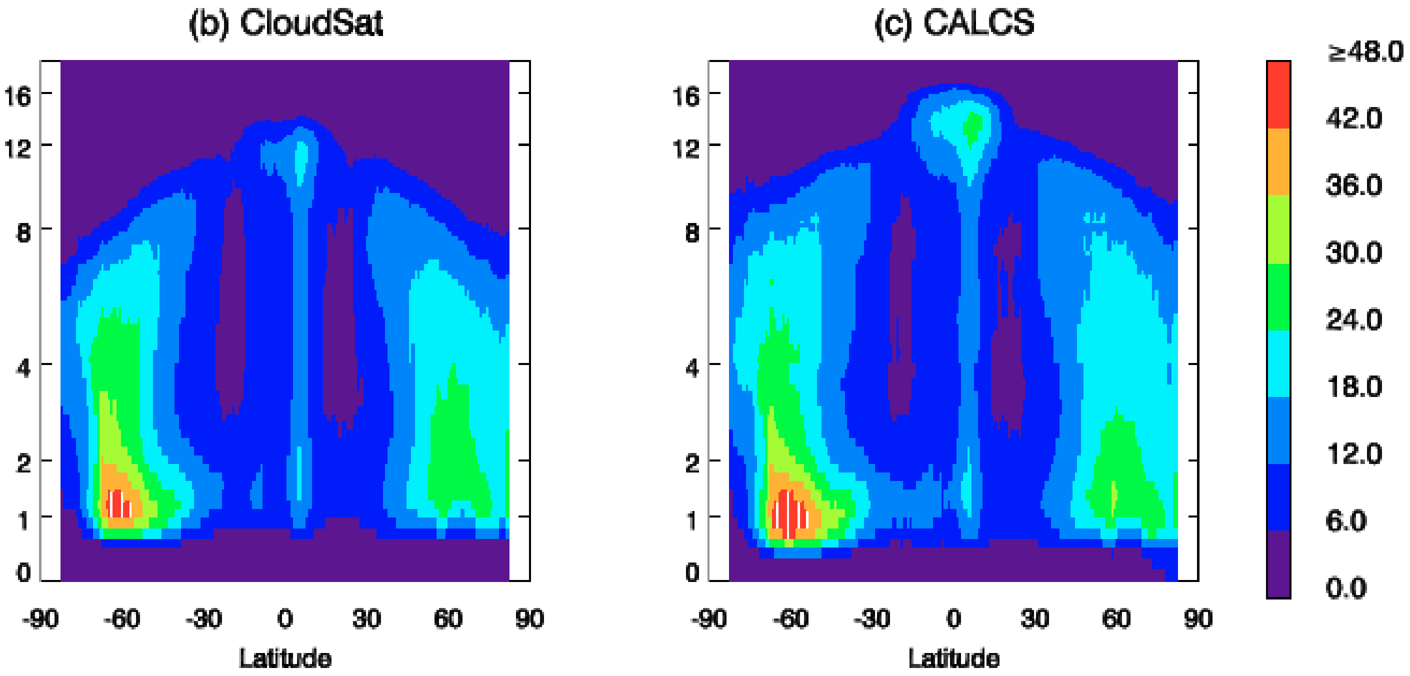
- How well can a parcel model predict deep convective cloud height?
- What is the uncertainty in outgoing longwave irradiance when the cloud top height predicted by a parcel model is used?

Outline of this talk

- Deep convective cloud objects
- Cloud top height of deep convective clouds derived from CALIPSO and CluodSat observations
- Comparison of observed cloud top height with the level of neutral buoyancy as a function of CAPE
- Uncertainty in outgoing TOA longwave irradiance

Data set used in this study

- MERRA-2 (MERRA2_300.inst3_3d_asm_Nv.YYYYMMDD.nc4)
- Version 4 CALIPSO and R05 CloudSat used in CCCM (Version D1)
- July 2006 through June 2010 (4 years of data)
- CALIPSO-CloudSat merged cloud profiles



Ham et al. 2021

Deep convective cloud objects

Cloud objects are derived from daytime MODIS Aqua observations

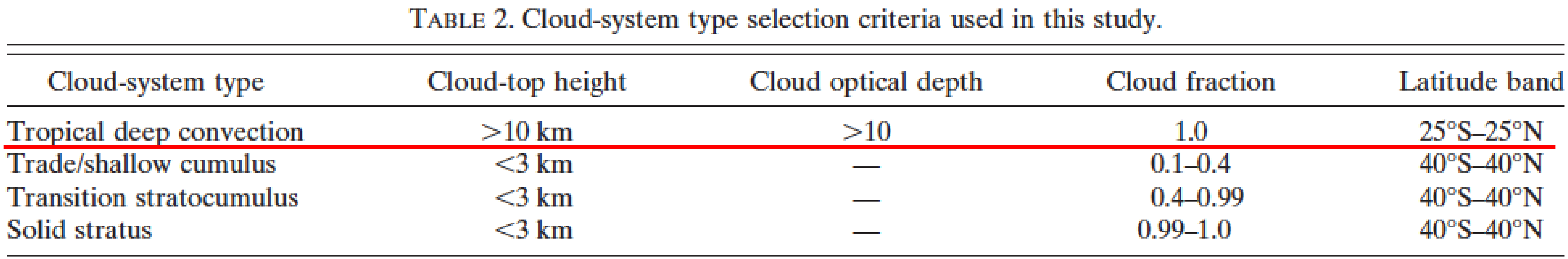
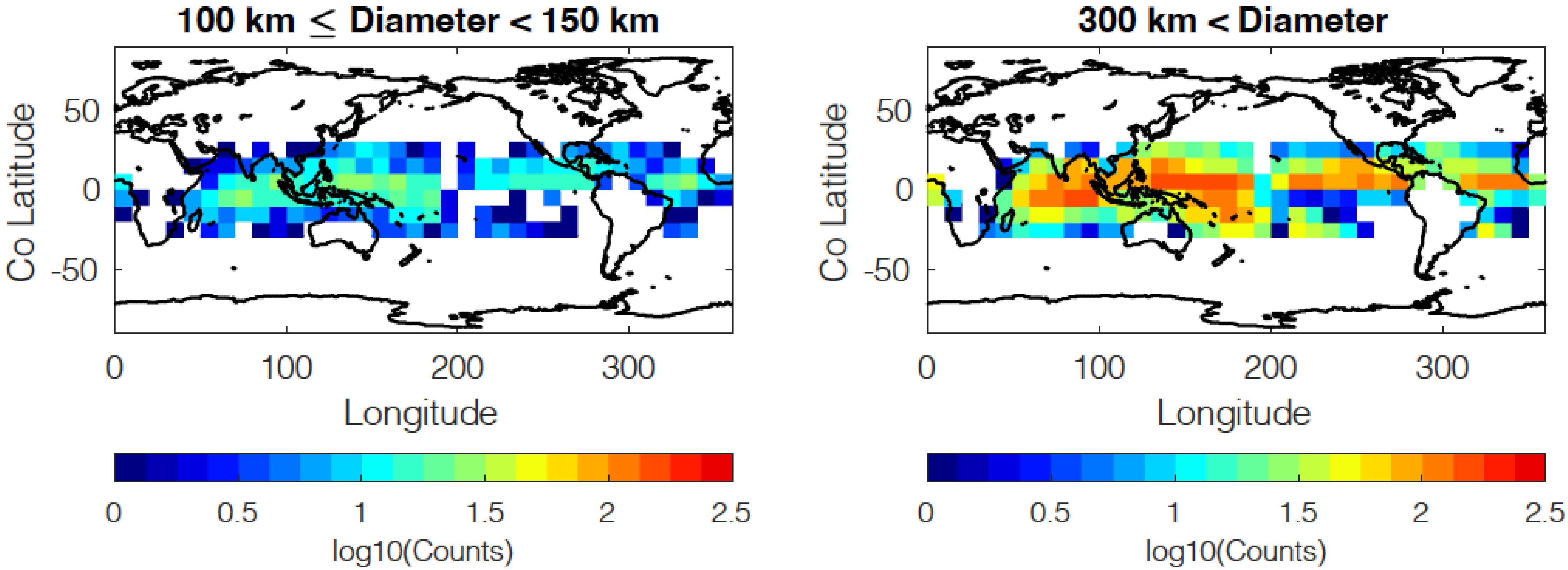


TABLE 2. Cloud-system type selection criteria used in this study.

Cloud-system type	Cloud-top height	Cloud optical depth	Cloud fraction	Latitude band
Tropical deep convection	>10 km	>10	1.0	25°S–25°N
Trade/shallow cumulus	<3 km	—	0.1–0.4	40°S–40°N
Transition stratocumulus	<3 km	—	0.4–0.99	40°S–40°N
Solid stratus	<3 km	—	0.99–1.0	40°S–40°N

Xu et al. 2005 J. Climate

Geolocation of daytime small and large deep convective cloud objects

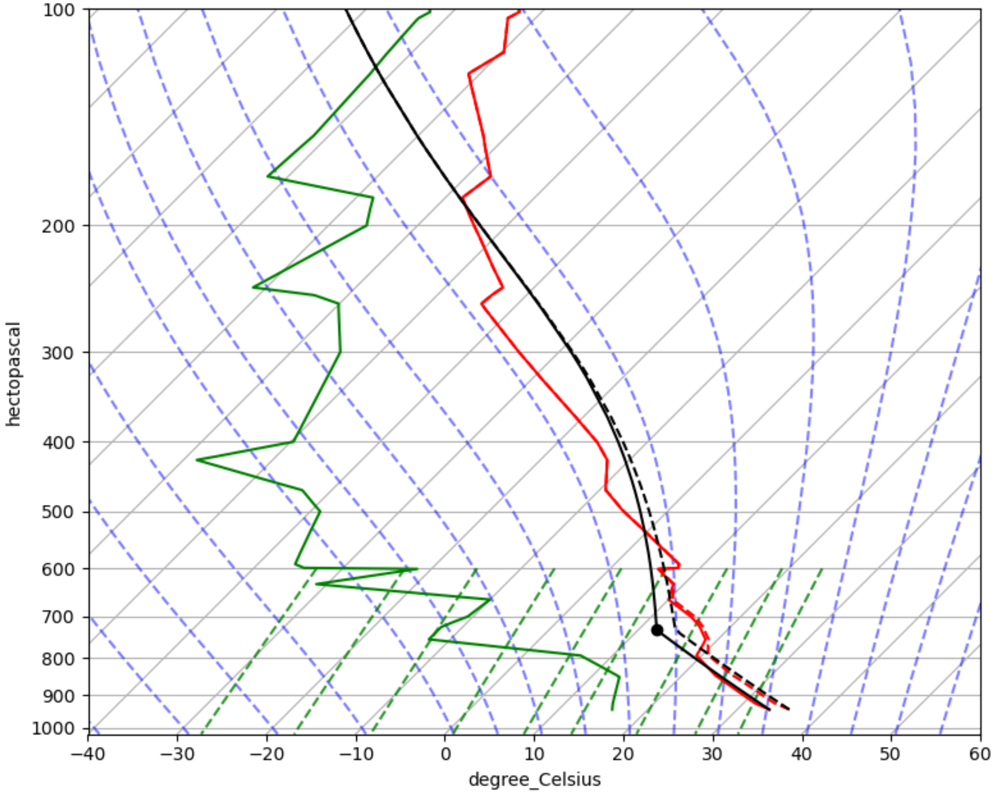


There is no significant regional difference where smaller and larger deep convective clouds occur.

Convective available potential energy (CAPE)

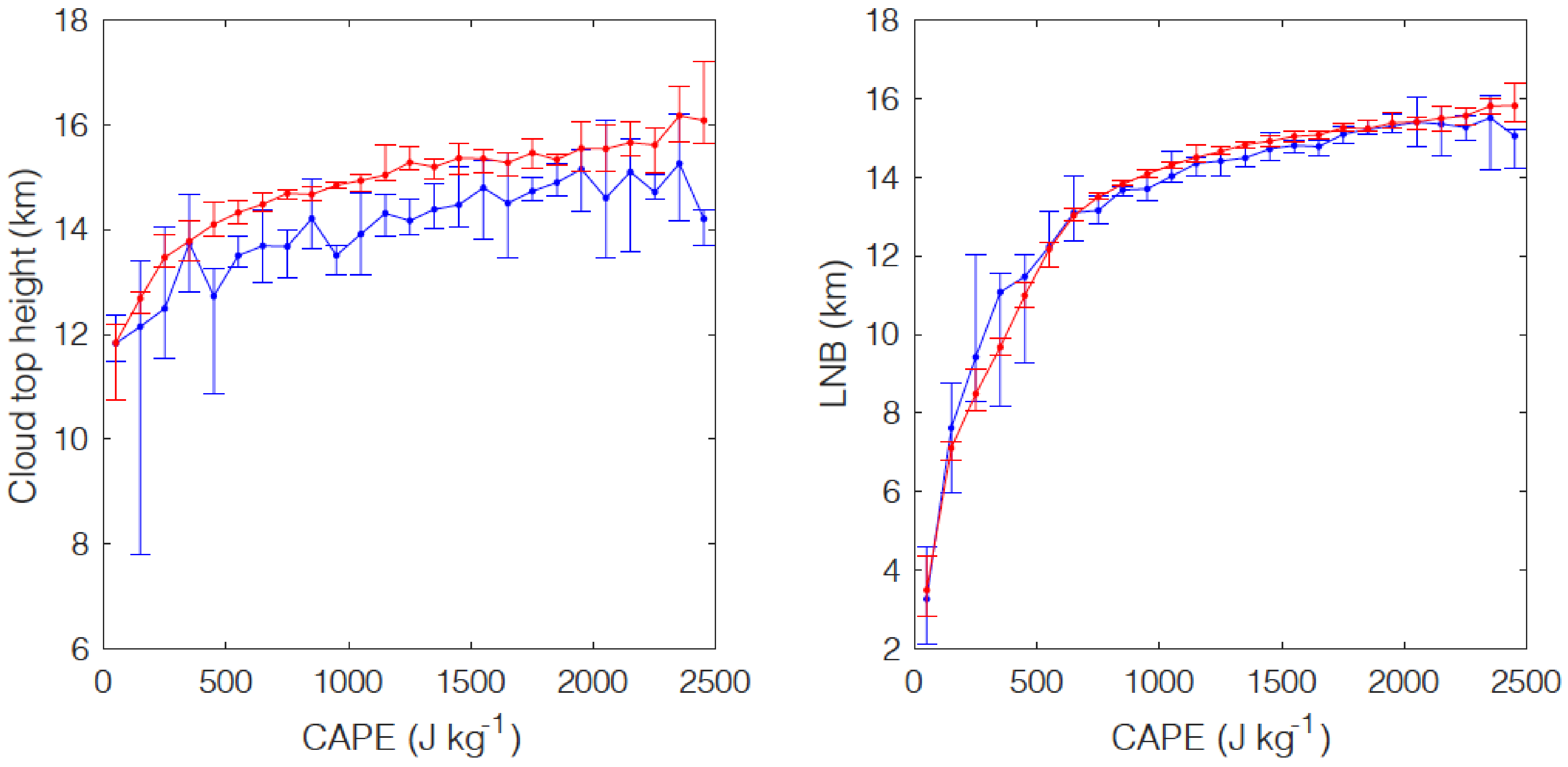
- CAPE is computed with MERRA-2 temperature and water vapor profiles inside cloud objects
- Buoyancy integrated from the level of free convection (LFC) to the level of neutral buoyancy (LNB)
- CAPE is the maximum work done by buoyancy

CAPE = $-R_d \int_{LFC}^{LNB} \left(T_{v,parcel} - T_{v,env}\right) d\ln p$



Deep convective clouds over ocean

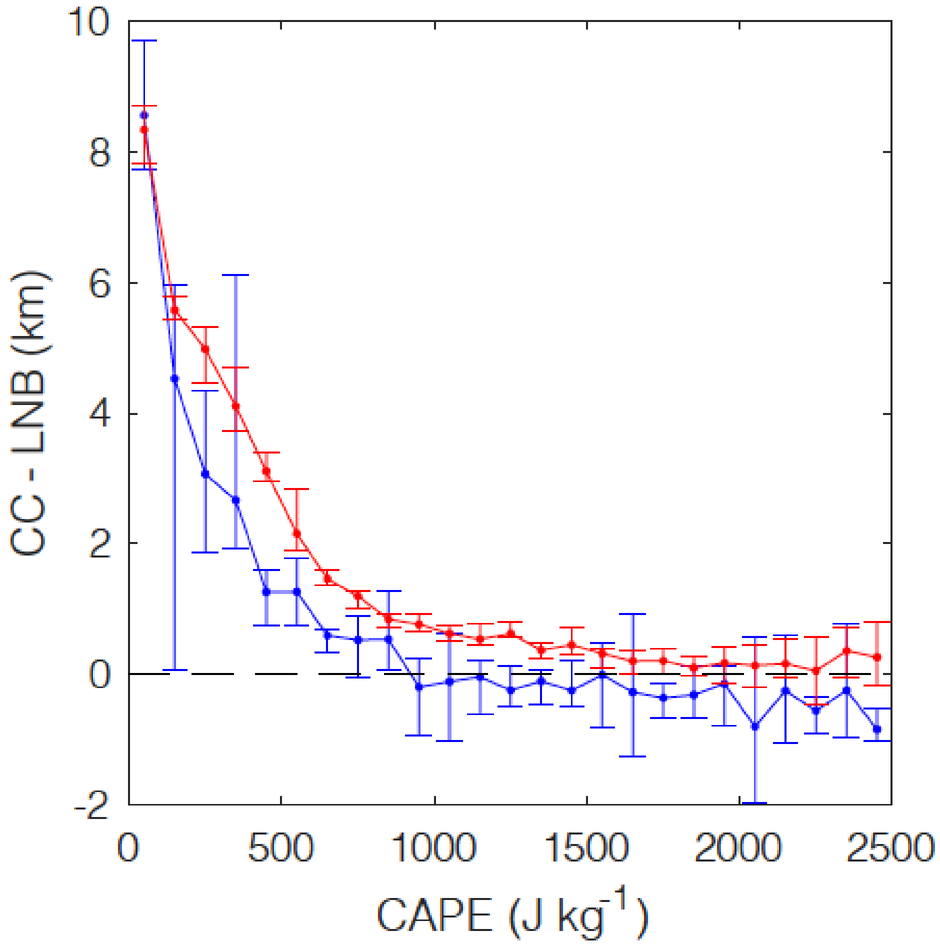
Red: Equivalent diameter > 300 km (large DCC)
Bleu: 100 < equivalent diameter < 150 km (small DCC)



- Cloud top height increases with CAPE.
- Large DCC cloud top is 0.84 km higher than small DCC cloud top when CAPS is larger than 1000 J kg^{-1}

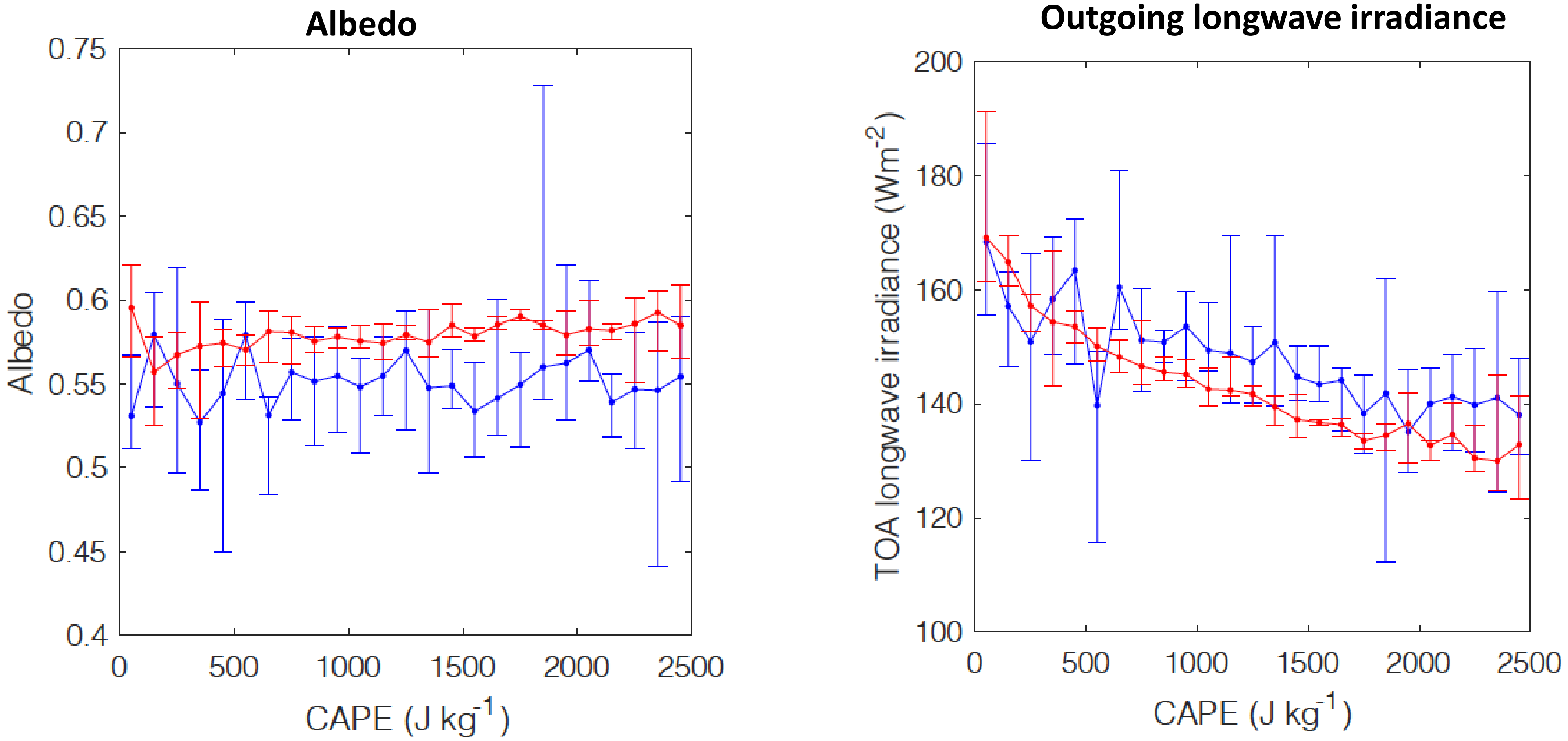
Error bars indicates min and max values among cloud objects

Comparison with level of neutral buoyancy



- Level of neutral buoyancy: equivalent potential temperature is equal to the environmental temperature
- Small DCC cloud top height is lower than LNB by 0.02 km when CAPE is larger than 1000 J kg^{-1}
- Large DCC cloud top height is higher than LNB by 0.38 km when CAPE is larger than 1000 J kg^{-1}

TOA albedo and outgoing longwave irradiance



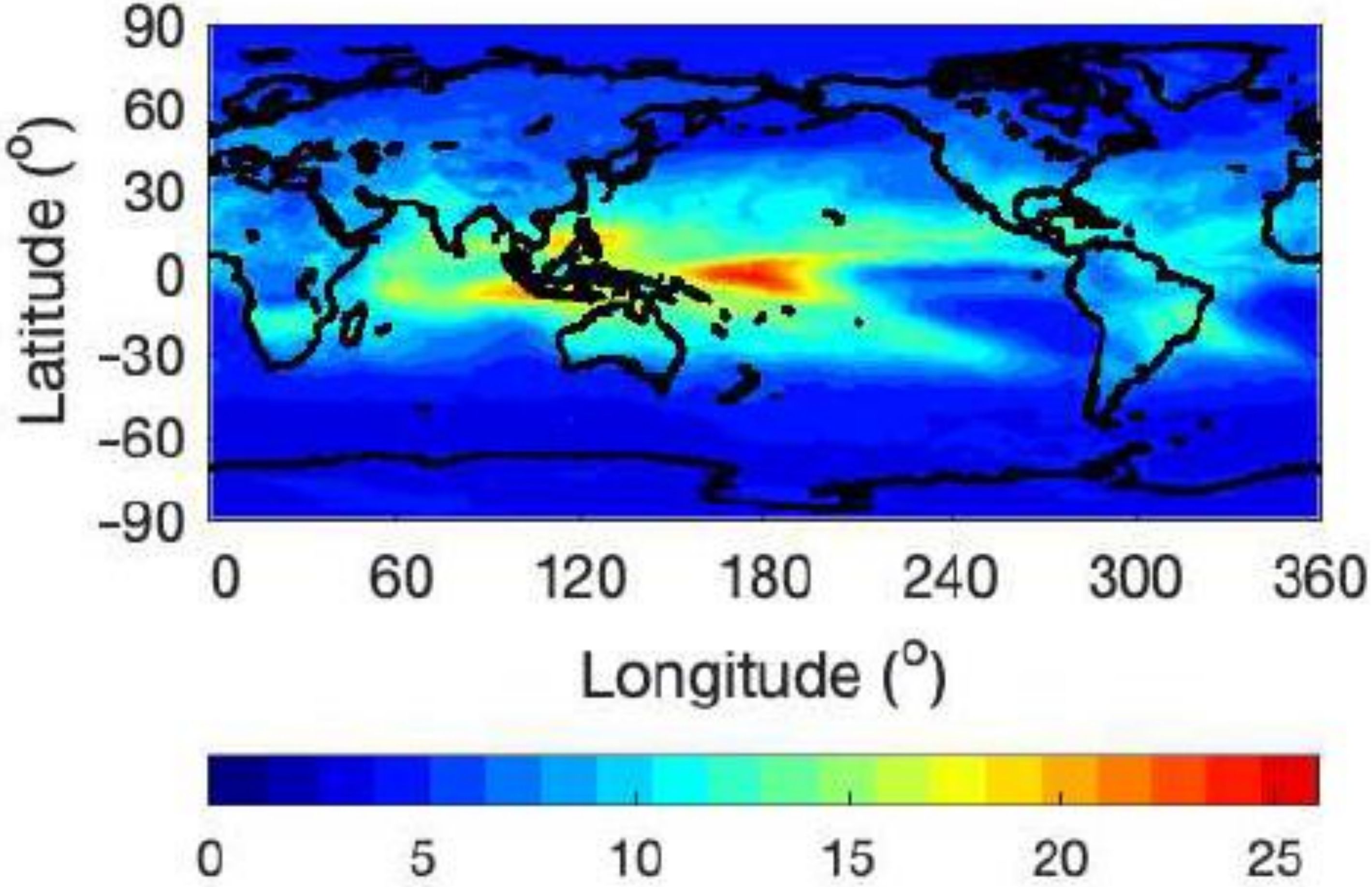
Rate of decreasing OLR with height

Small deep convective clouds: 10.9 Wm^{-2} km^{-1}

Large deep convective clouds: 11.6 Wm^{-2} km^{-1}

If we use LNB is lower by 400m, using LNB overestimate outgoing longwave irradiance by ~4 Wm^{-2}.

Standard deviation of TOA longwave anomalies



A 4 Wm^{-2} bias is about 20% of the monthly mean TOA upward longwave irradiance variability for tropical western/central Pacific

Summary and conclusion

- Mean observed cloud top height is 0.38 km higher (0.02 km lower) than the level of neutral buoyancy for large (small) convective clouds with CAPE larger than 1000 J kg^{-1}.
    - Mean cloud top height estimated by a parcel model is within 400 m from observed cloud top heights.
- Large DCC mean cloud top is higher than the level of neutral buoyancy and small DCC cloud top height is lower than the level of neutral buoyancy for a given CAPE
- The rate of decreasing upward longwave irradiance with height is 10.9 Wm^{-2} km^{-1} for small deep convective cloud objects and 11.6 Wm^{-2} km^{-1} for large deep convective cloud objects.
- Because the upward longwave irradiance decreases approximately 11 Wm^{-2} km^{-1}, the -0.4 km cloud top height bias is ~+4 Wm^{-2} in the upward longwave irradiance bias.
- Do observations of vertical velocity, higher resolution of temperature and humidity reduce the bias?

backups

Entropy production within deep convective clouds

When water vapor condenses under saturated conditions in thermal equilibrium, the process is isentropic.

Other processes changes entropy

Entropy source	**Expression**	**Conditions**	**Entropy change (W kg^{-1} K^{-1})**
Diffusion $\dot{s}_{dif}$ of temperature by air-hydrometeor (liquid) conduction	$\frac{r_i c_l (T_l - T)^2}{T_l T \tau_{cl}}$	Liquid water content 5 g m^{-3} Air temperature 265 K Hydrometeor temperature 275 K Conductive time scale 100 s	5.7×10^{-4}
Diffusion $\dot{s}_{dif}$ of kinetic energy through air-hydrometeor drag force (rain drops)	$r_l \frac{V_{Tl}^2}{\tau_{vl} T}$	Liquid water mixing ratio 0.3×10^{-3} Terminal velocity 10 ms-1 Rain rate 10 mm hr-1	1.1×10^{-4}
Diffusion $\dot{s}_{dif}$ of temperature in moist air	$\frac{k_T}{\rho_a T^2} (\nabla T \cdot \nabla T)$	Conductivity $32 \times 10^{-4} W m^{-1} K^{-1}$ Temperature gradient 10 K m^{-1}	6.9×10^{-6}
Radiative heating	$\frac{\dot{q}_{rad}}{T}$	Radiative heating 1 K day^{-1} Air temperature 273 K	4.2×10^{-5}