Diagnostics of Tropical Convective Mass Transport

Ian Folkins, Glen Lesins, Toni Mitovski
Department of Physics and Atmospheric Science
Dalhousie University

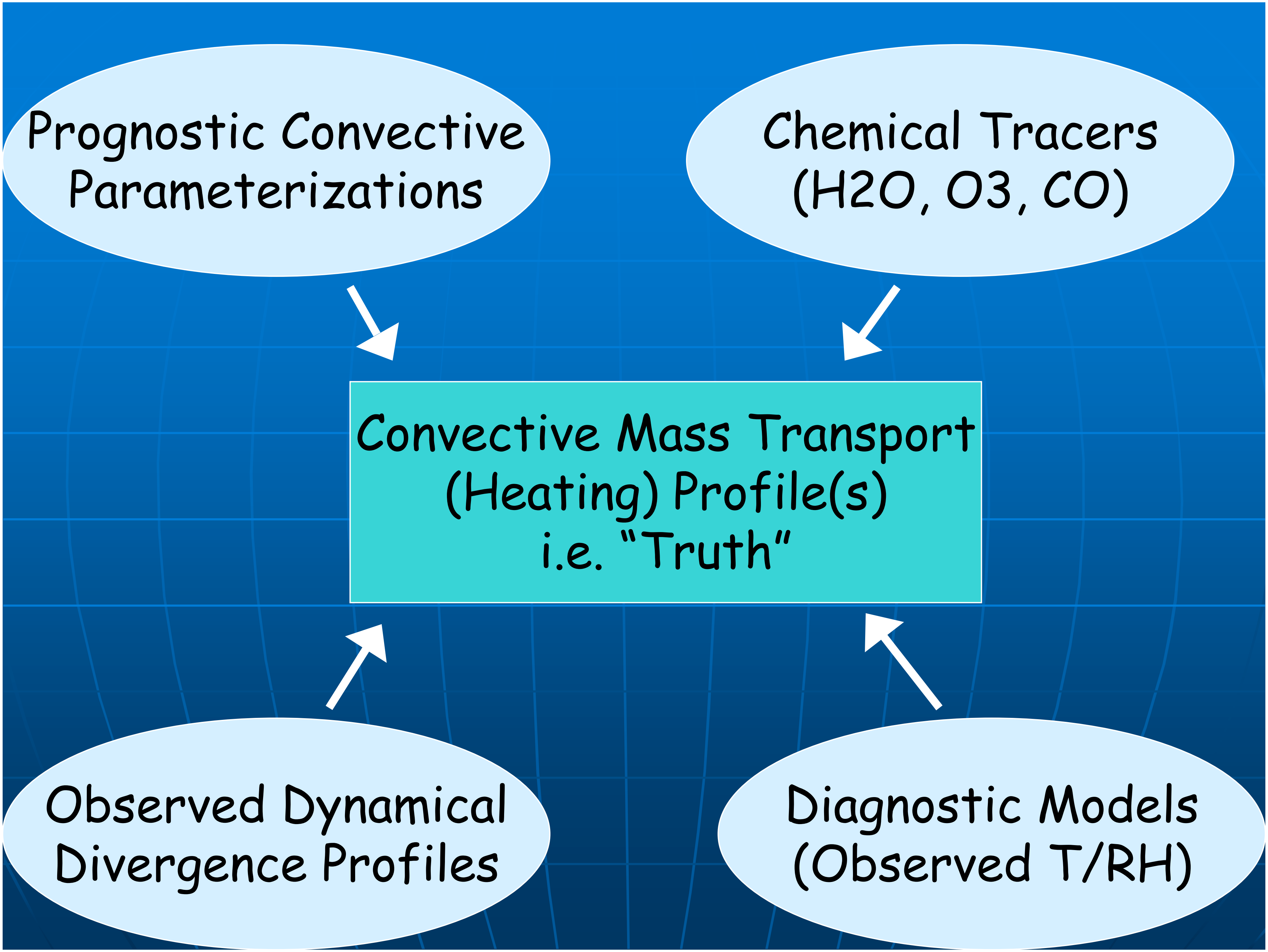
Why is convective mass transport important?

(1) Reflects vertical heating profile of convection

(2) Affects wave generation (stratospheric and tropospheric dynamics).

(3) Affects distribution of water vapor and other greenhouse gases (climate feedbacks).

(4) Probably need to do a better job in convective mass transport to improve tropical rainfall predictability.



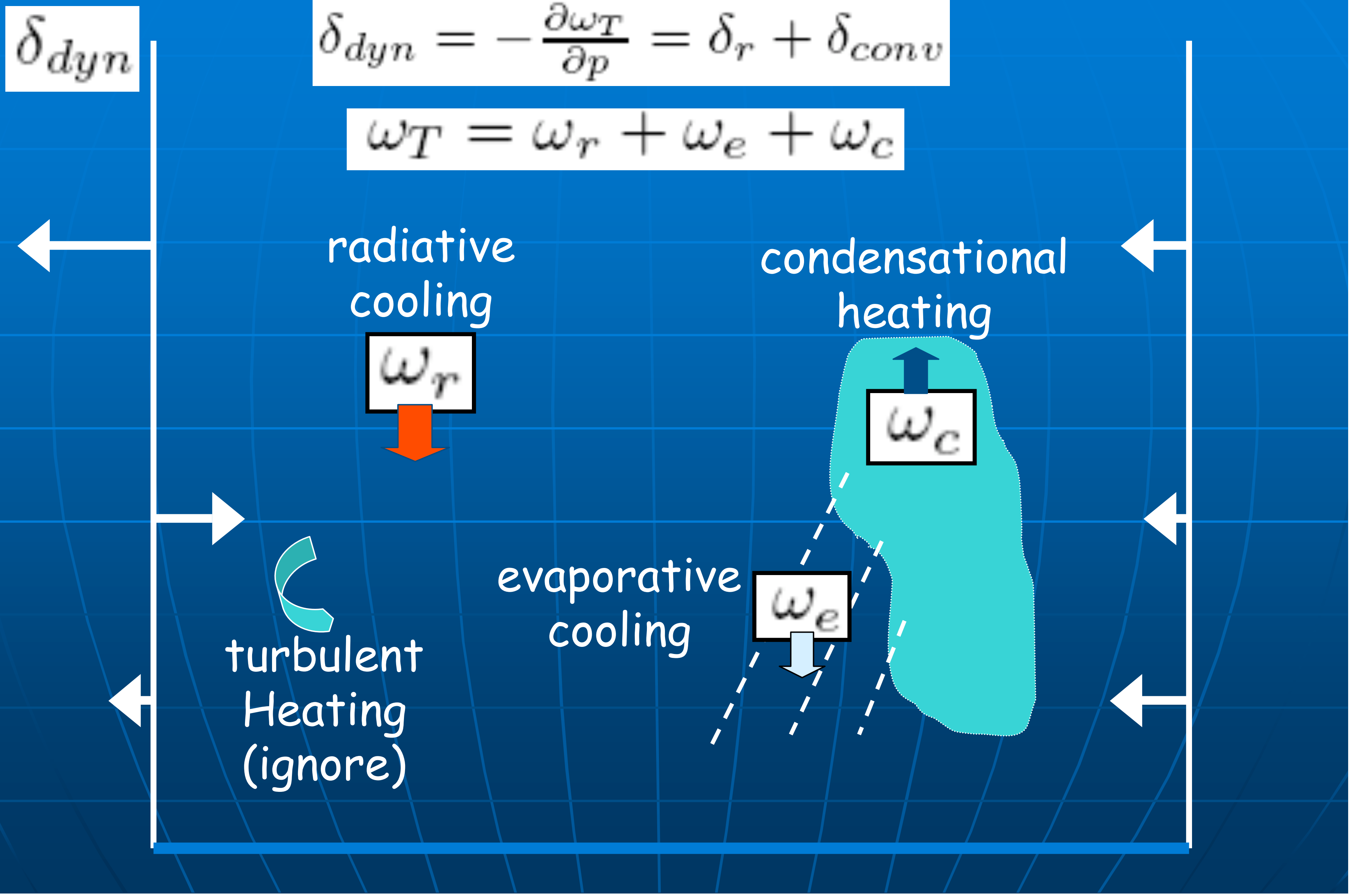
Prognostic Convective Parameterizations
Chemical Tracers (H2O, O3, CO)
Convective Mass Transport (Heating) Profile(s) i.e. "Truth"
Observed Dynamical Divergence Profiles
Diagnostic Models (Observed T/RH)

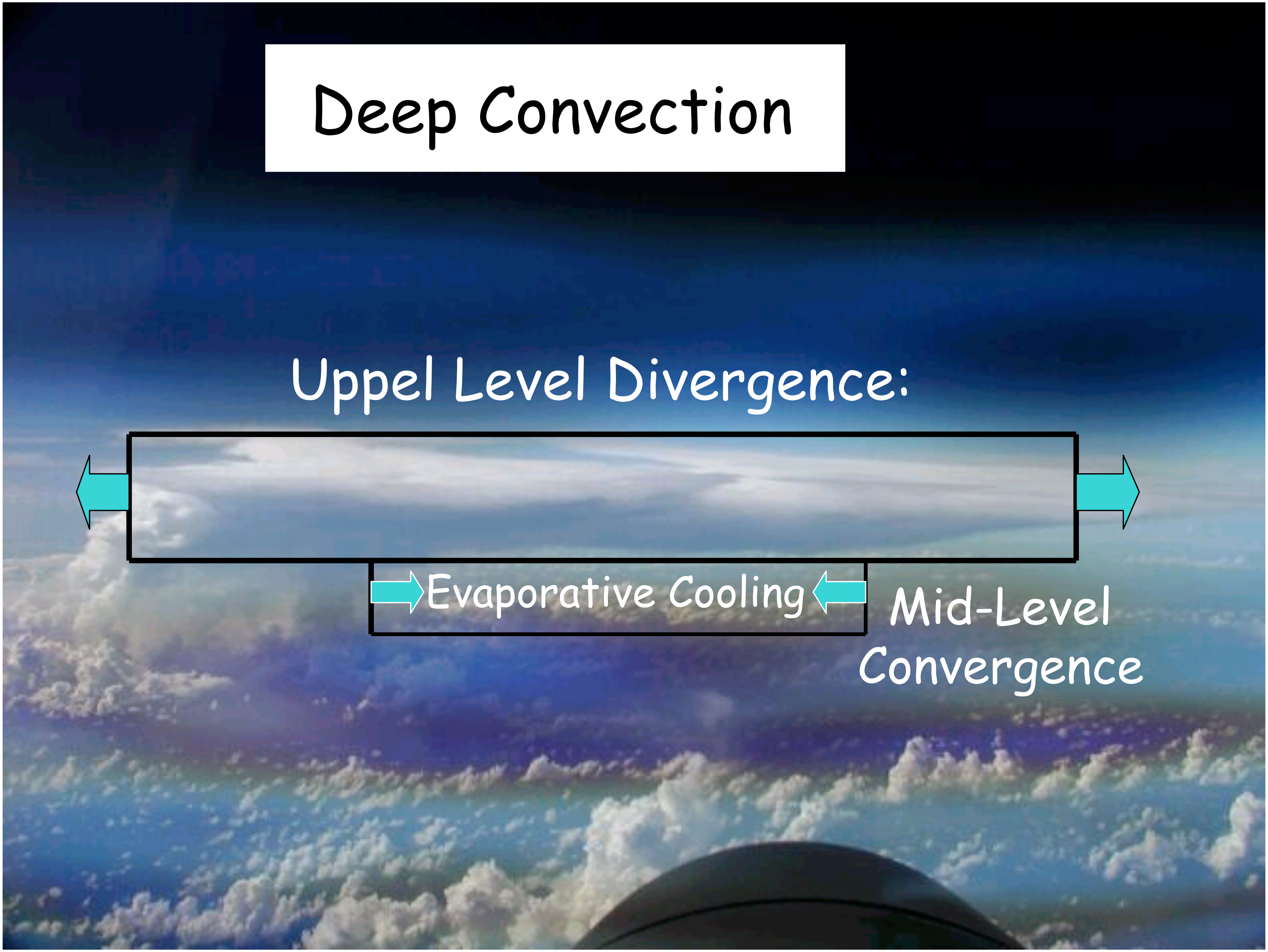
Dynamical Divergence and Convective Mass Fluxes

For fixed PT surfaces, weak horizontal heat flux divergence:

$$\delta_{dyn} = -\frac{\partial \omega_T}{\partial p} = \delta_r + \delta_{conv}$$

$$\omega_T = \omega_r + \omega_e + \omega_c$$





Deep Convection
Uppel Level Divergence:
Evaporative Cooling
Mid-Level
Convergence

Mapes and Houze, JAS, 1995

Deep Outflow Layer

Inflow to feed downdrafts (mainly)

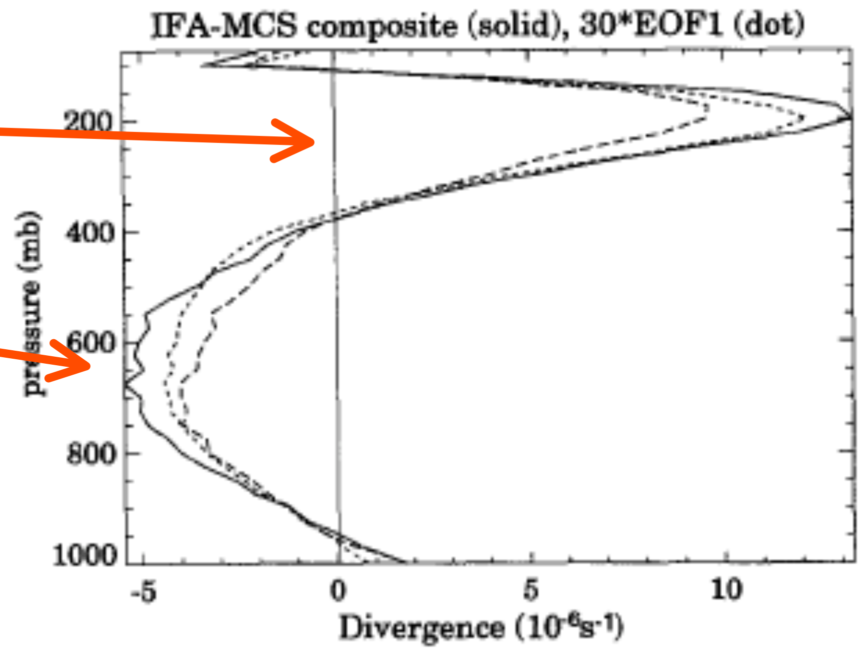


FIG. 13. Average IFA divergence profiles. Solid line: the IFA-MCS composite (Table 1, Fig. 12). Dashed line: the extended life cycle composite (IFA-MCS composite plus times immediately prior and subsequent to the times listed in Table 1). Dotted line: the leading EOF of the 480 IFA divergence profiles, arbitrarily scaled to match the other profiles.

Johnson and Cieslinski, 2000

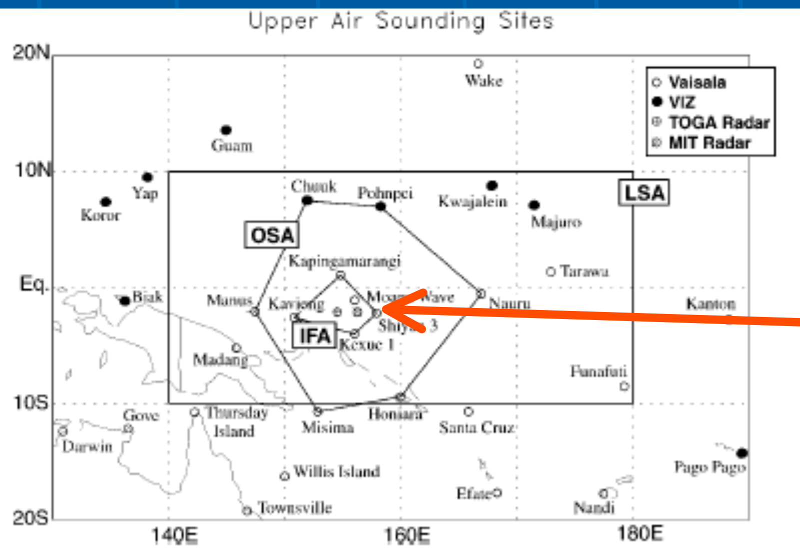


FIG. 1. Upper-air sounding sites in the TOGA COARE region. Large-Scale Array (LSA), Outer Sounding Array (OSA), and Intensive Flux Array (IFA) are indicated. Vaisala sites, open circles; VIZ sites, closed circles.

Rawinsonde wind measurements from the TOGA/COARE IFA when deep convection present

Trimodal cloud top distribution (lidar obs):

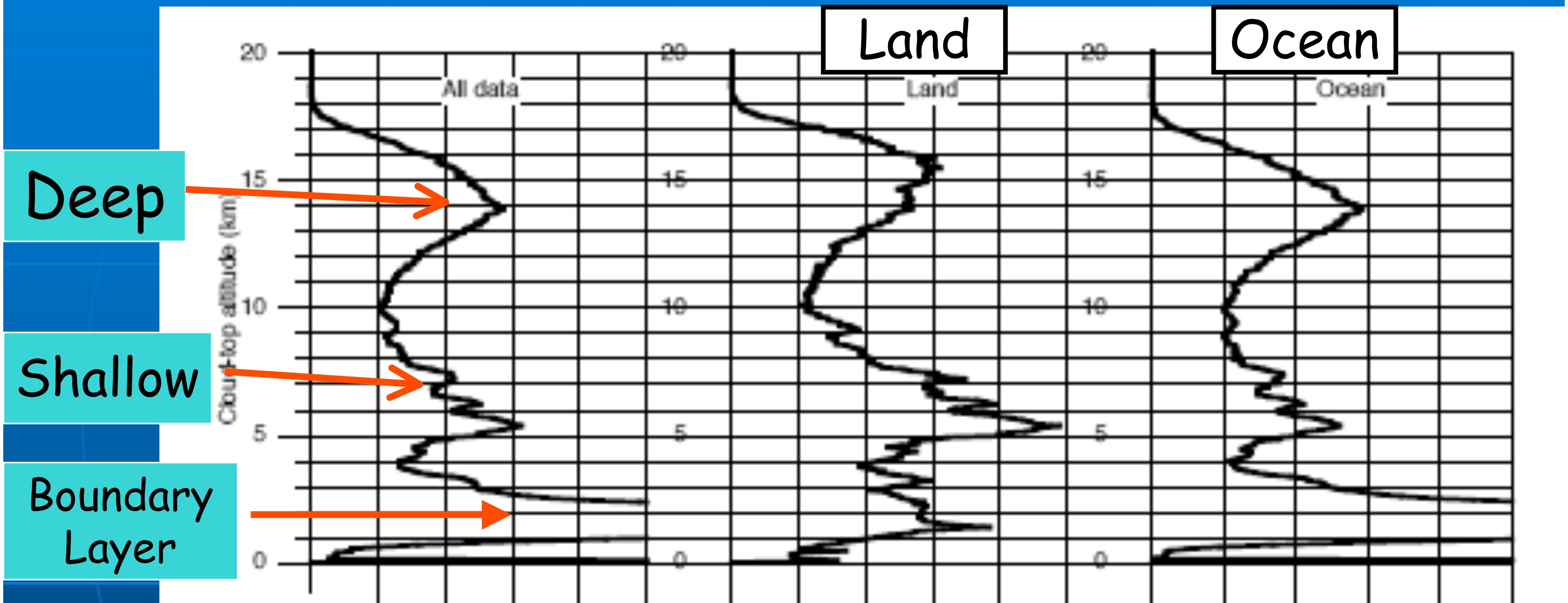


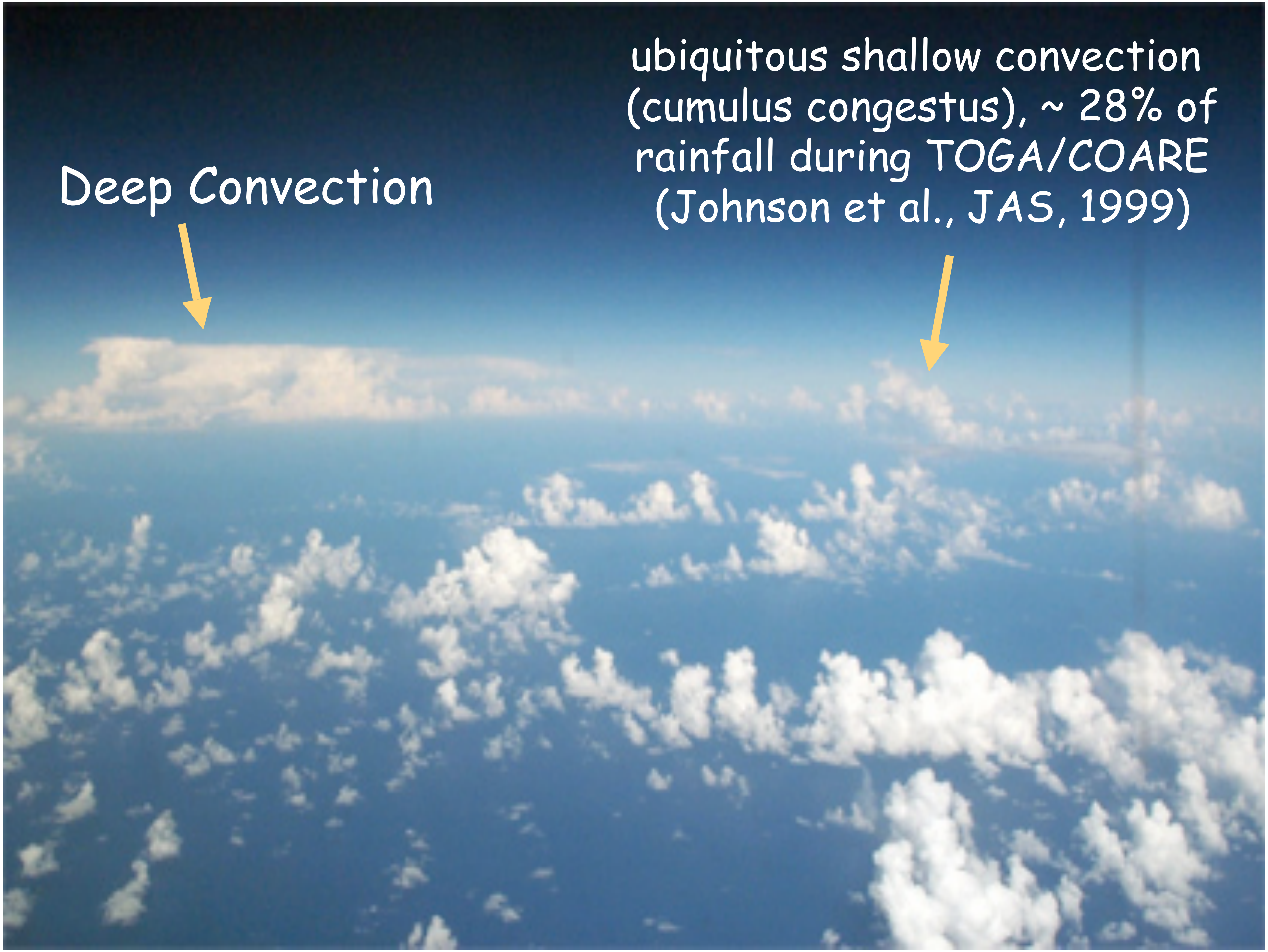
Figure 2. Fraction of GLAS observations (% per km) between 10°S and 20°N that contain a thick-cloud top vs. altitude (km). The solid lines are for thick clouds, and the dashed lines are for thin clouds. The histogram has been constructed using bins of 76.8 m, the native resolution of the GLAS data.

Tropical cloud-top height distributions revealed by ICESat/GLAS

A. E. Dessler*
Dept. of Atmospheric Sciences, Texas A&M University, College Station

S. P. Palm
Science Systems and Applications Inc., Lanham, Maryland

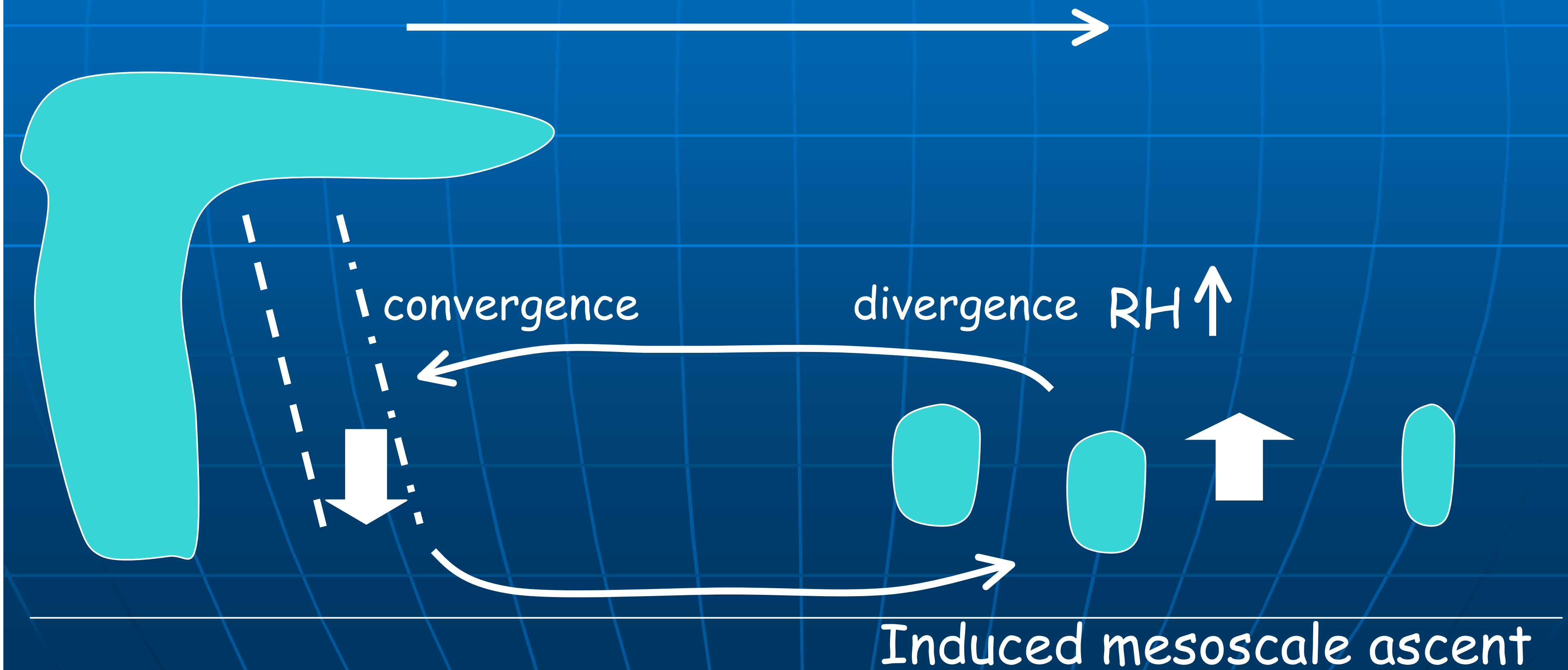
J. D. Spinhirne
NASA Goddard Space Flight Center, Greenbelt, Maryland


Deep Convection
ubiquitous shallow convection (cumulus congestus), ~ 28% of rainfall during TOGA/COARE (Johnson et al., JAS, 1999)

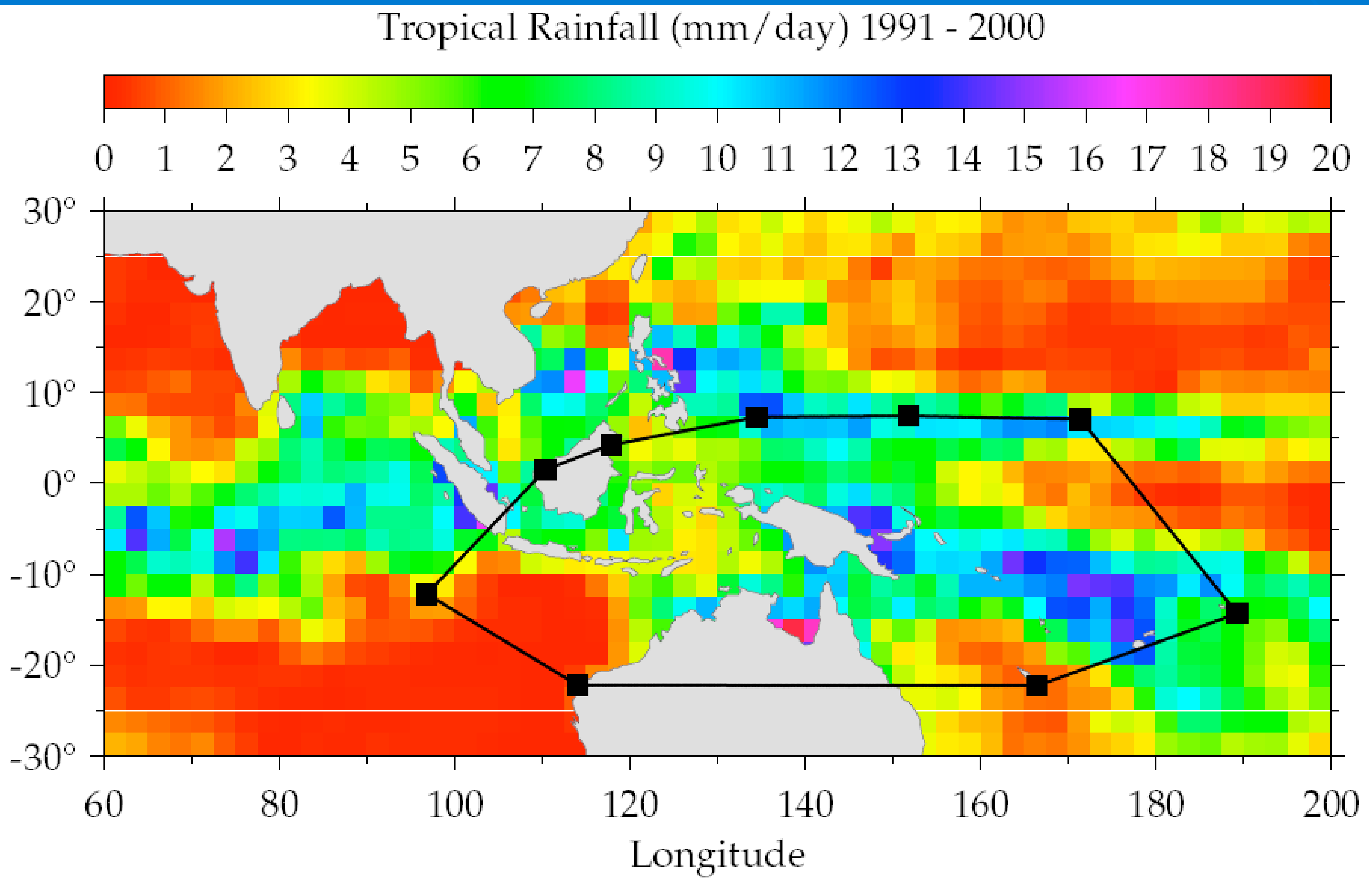
Interaction between shallow/deep convection

- Deep convective rainfall propagates toward shallow convection due to water vapor feedback (reductions in buoyancy due to mixing are extremely sensitive to the RH of the background atmosphere).

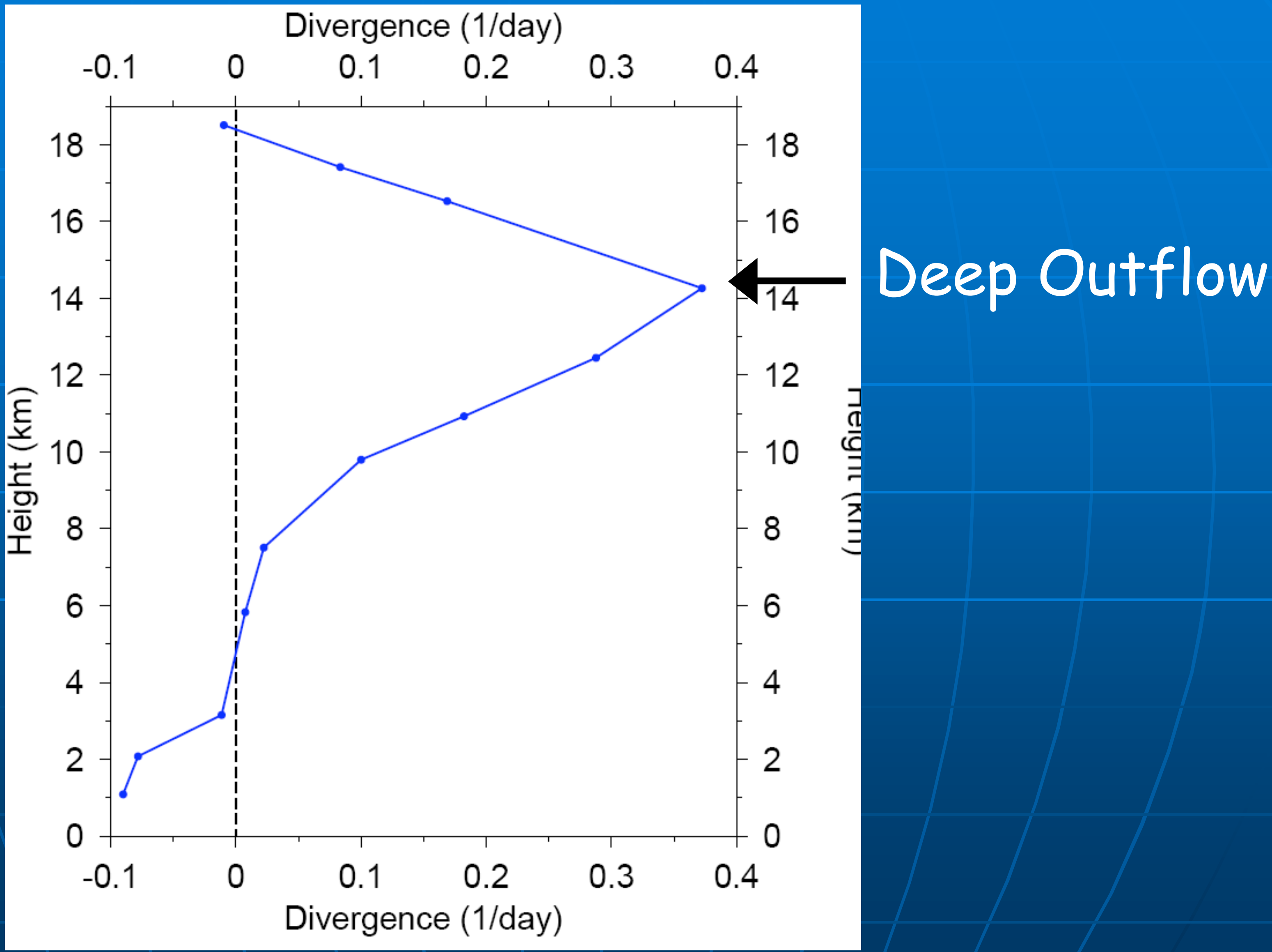
- It has been suggested that the MJO is a water vapor feedback mode with the trade wind circulation biasing the direction of propagation toward the east.



Mean Divergence profile from larger scale Array:



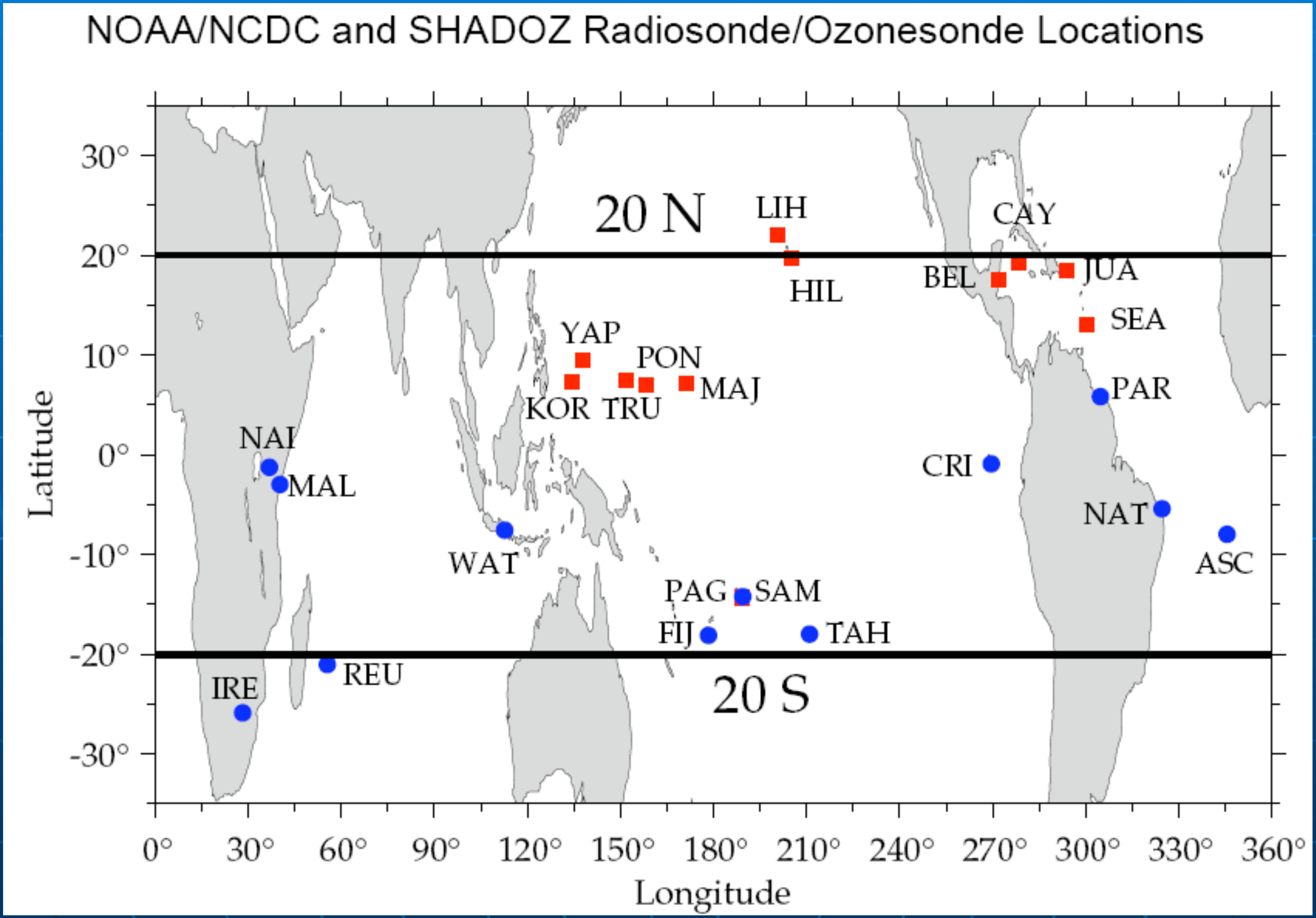
Mean DJF divergence profile from BADC winds for large array:



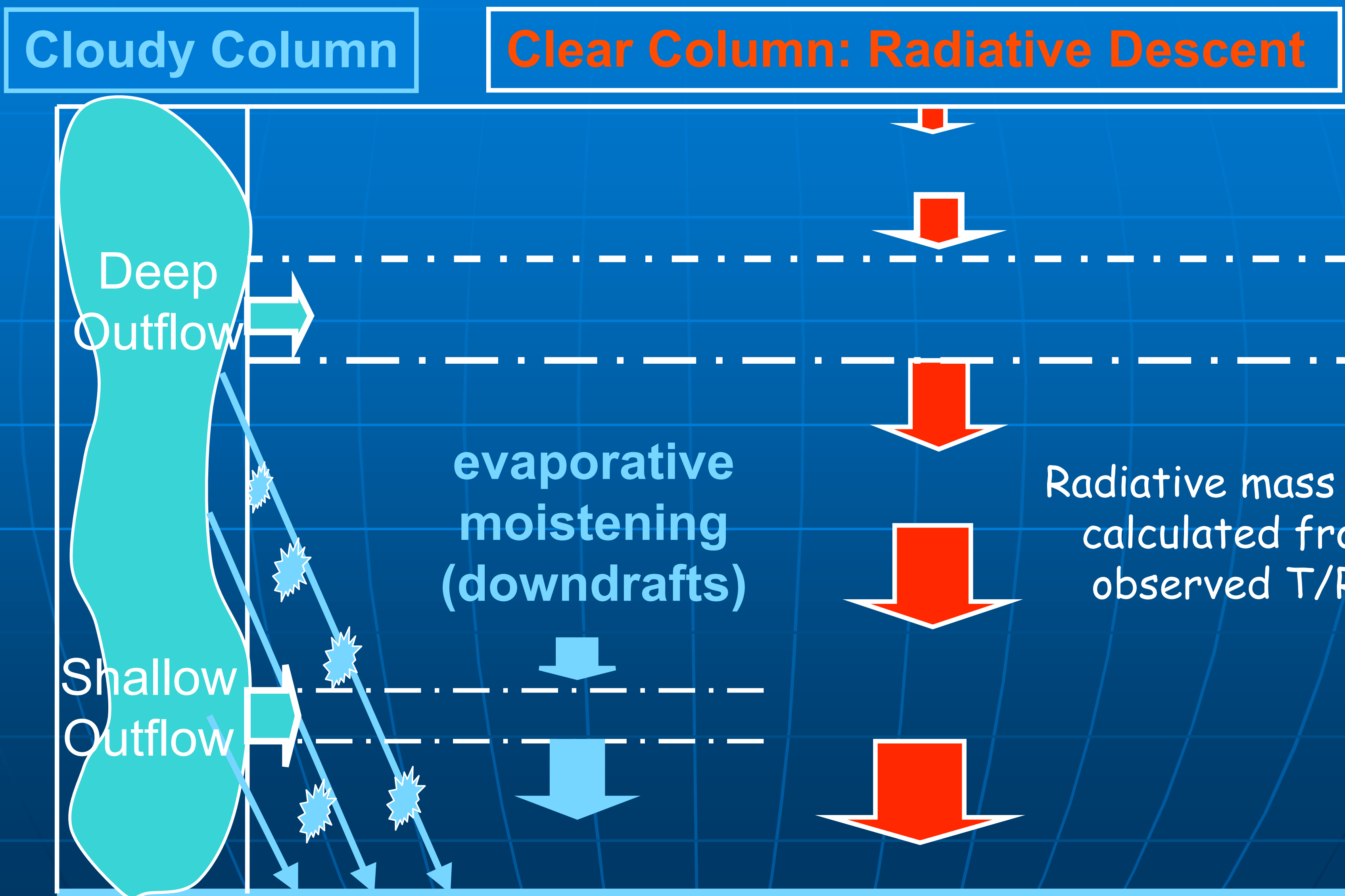
What happens to the shallow outflow mode?

Radiosonde T/RH climatologies used in Two Column Model

(red: SPARC high res; blue: SHADOZ)

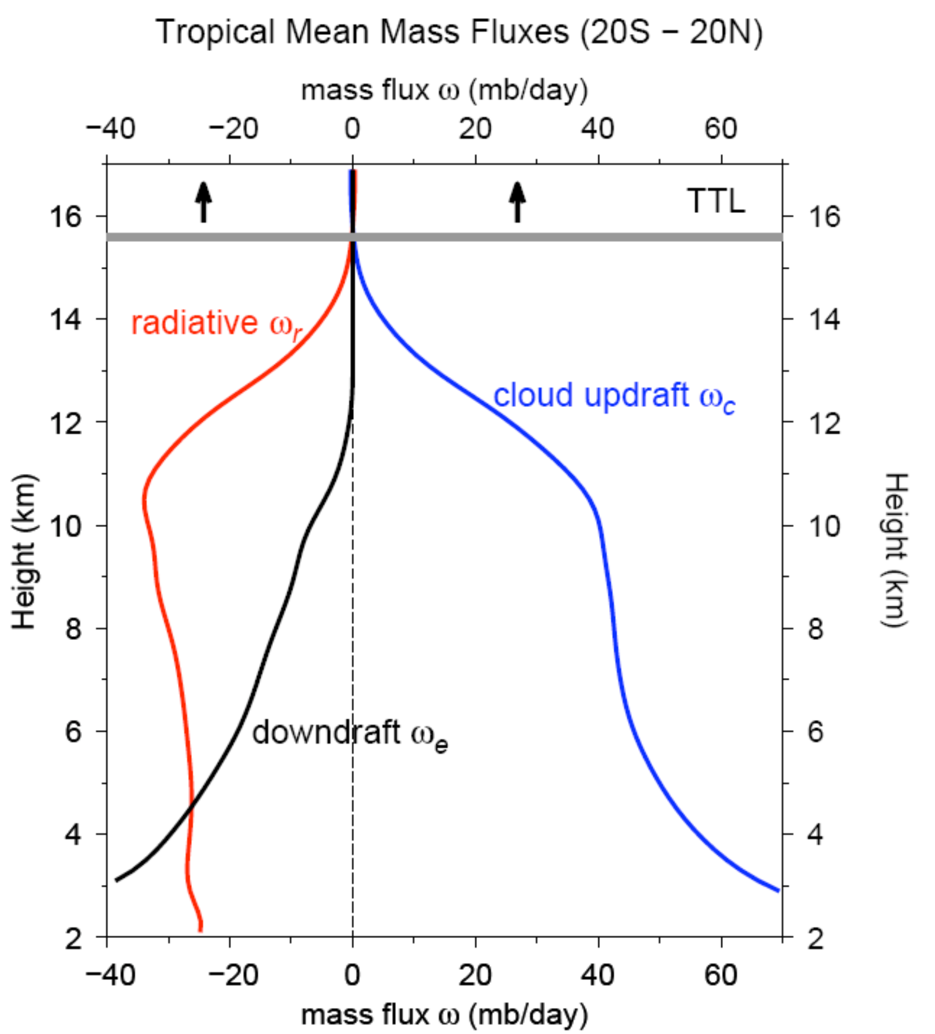


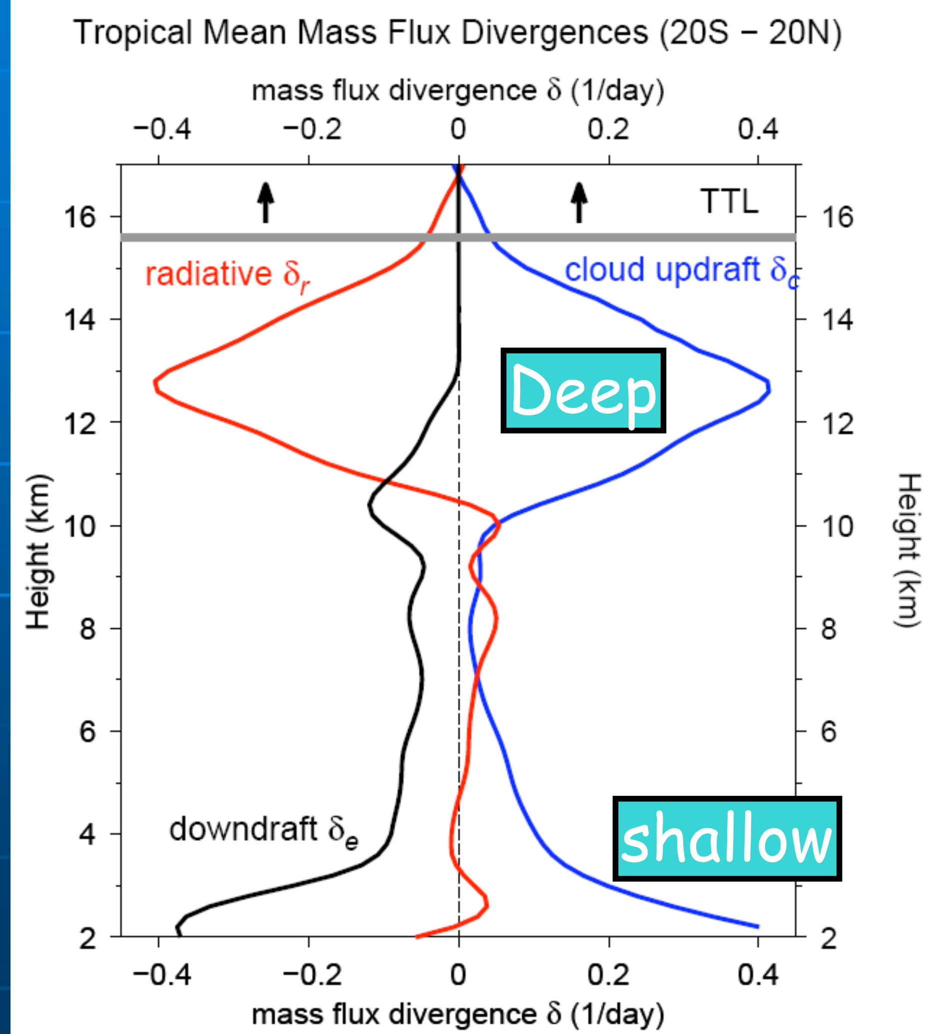
Convective Outflow can be estimated from clear sky mass fluxes (radiative + evaporative).



Two Column Model:

Mass Flux / Mass Flux Divergence



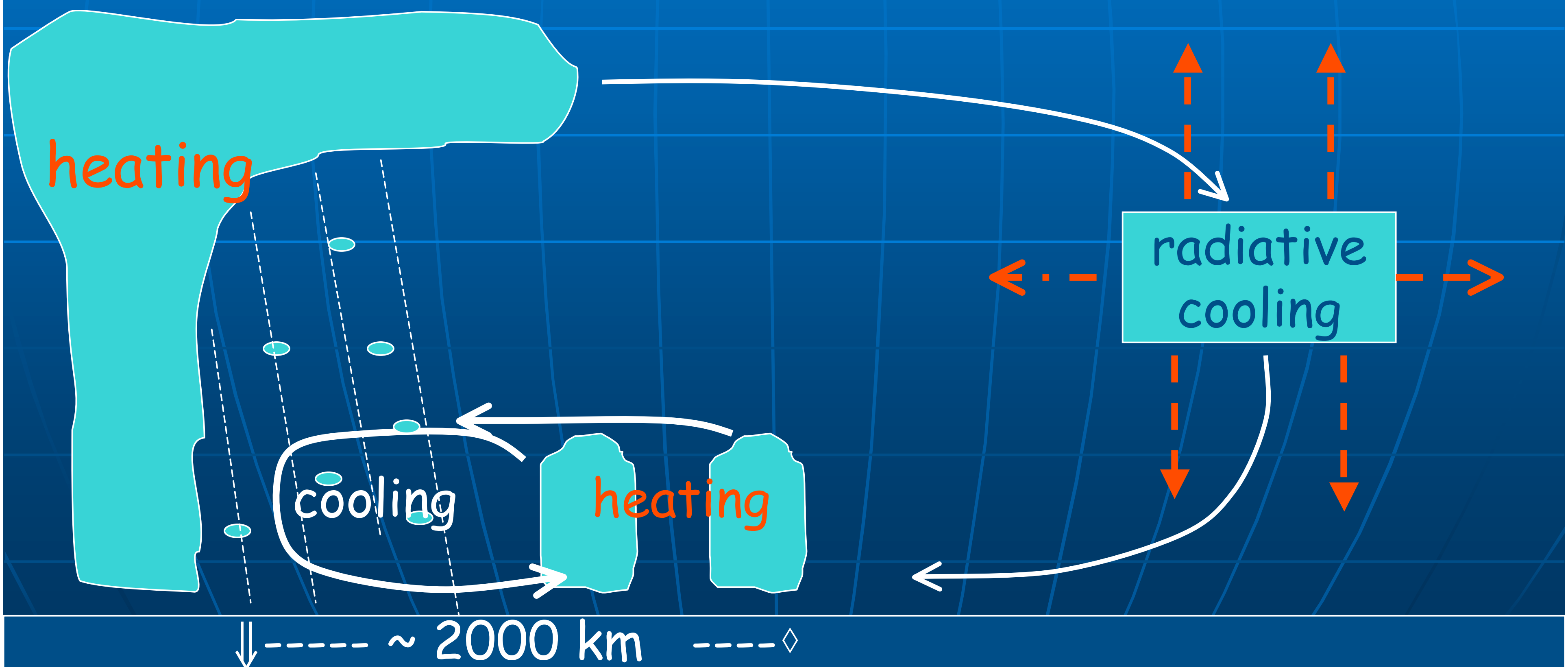


Folkins and Martin, JAS, 2005

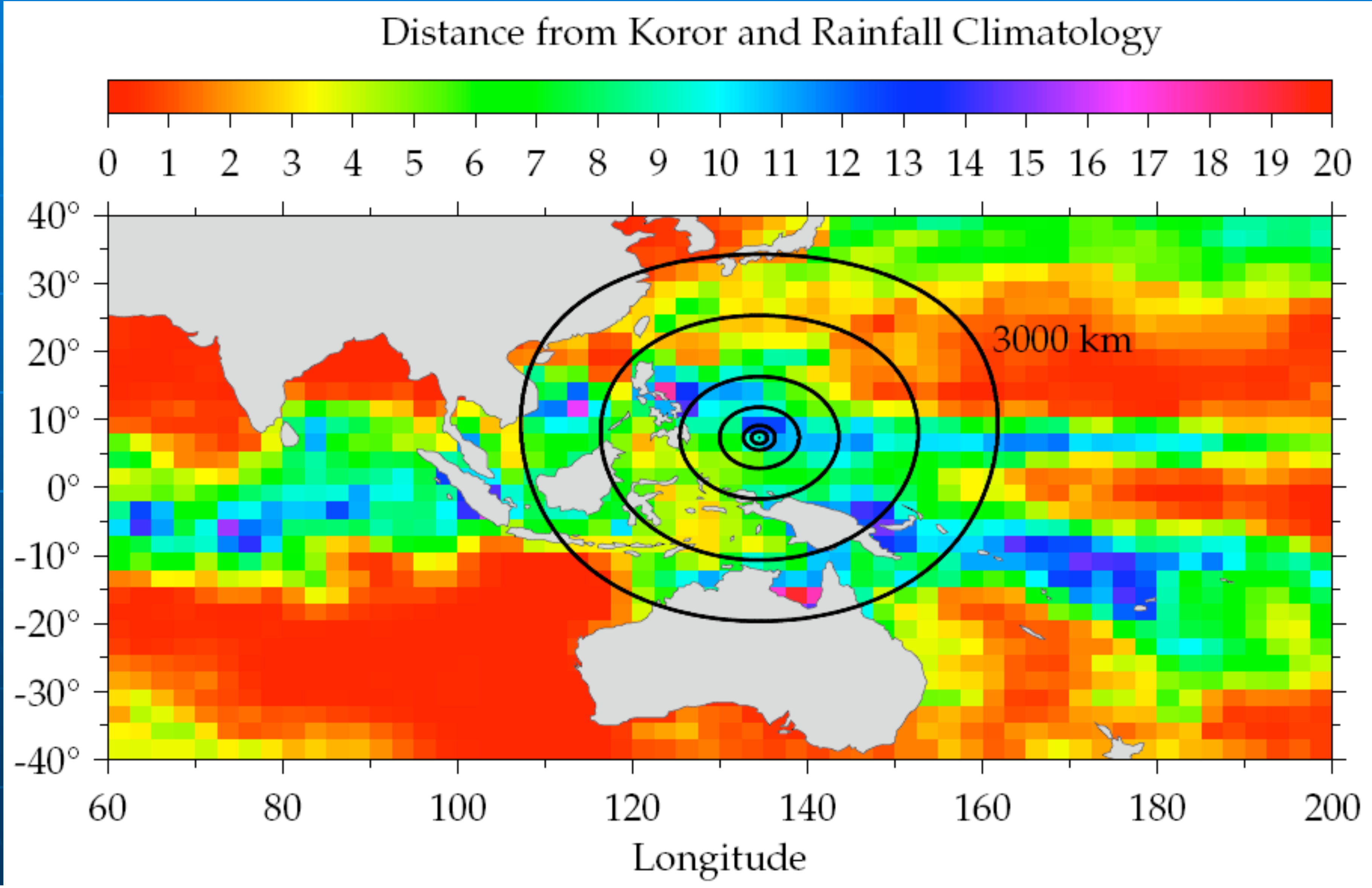
Two Distinct Circulations?

1) Tropical-scale Hadley/Walker circulation: deep condensational heating balances radiative cooling.

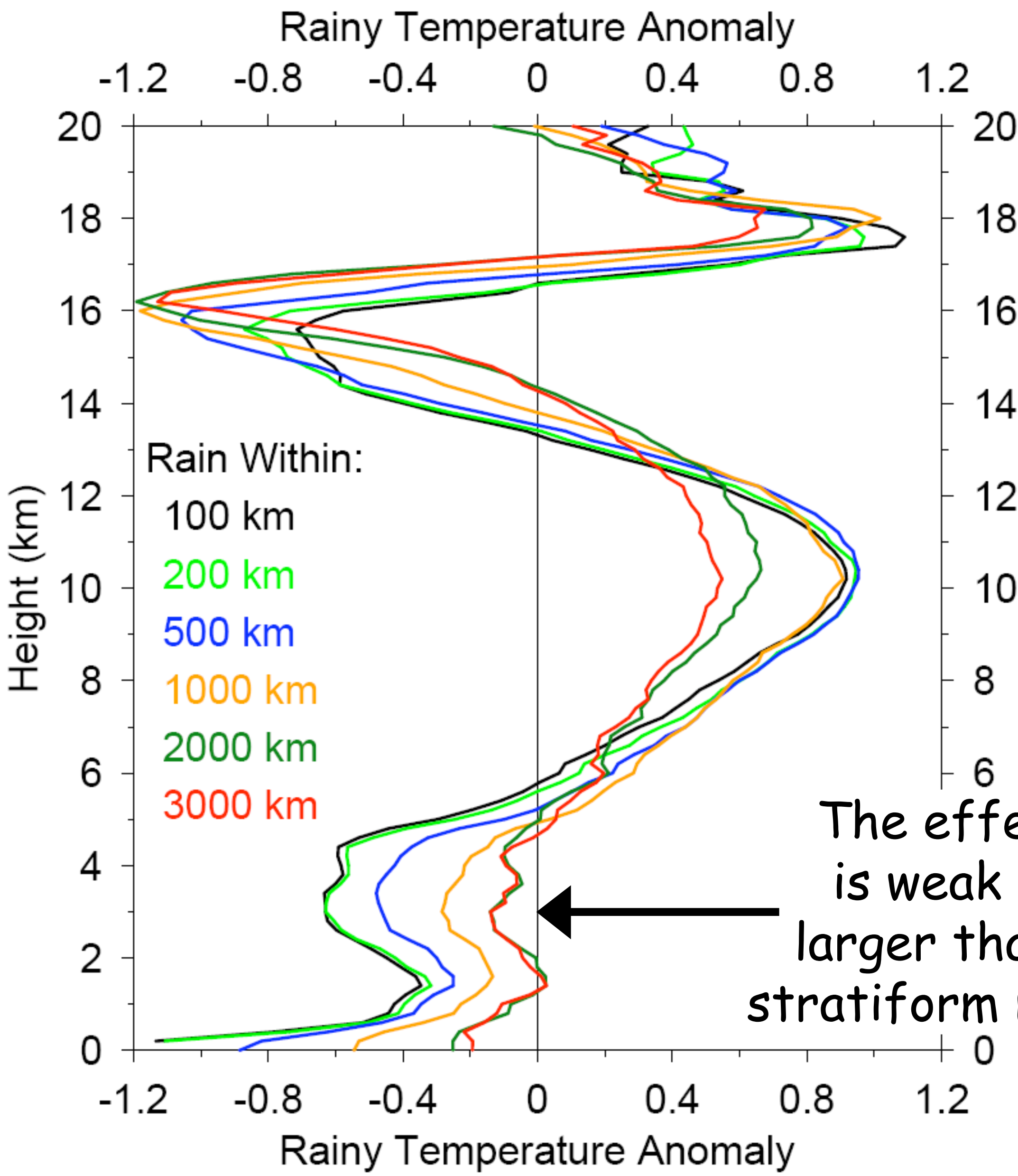
2) Regional scale downdraft/shallow convection circulations: shallow convective heating balances Evaporative cooling.



Relationship between temperature anomalies at Koror and rainfall proximity:



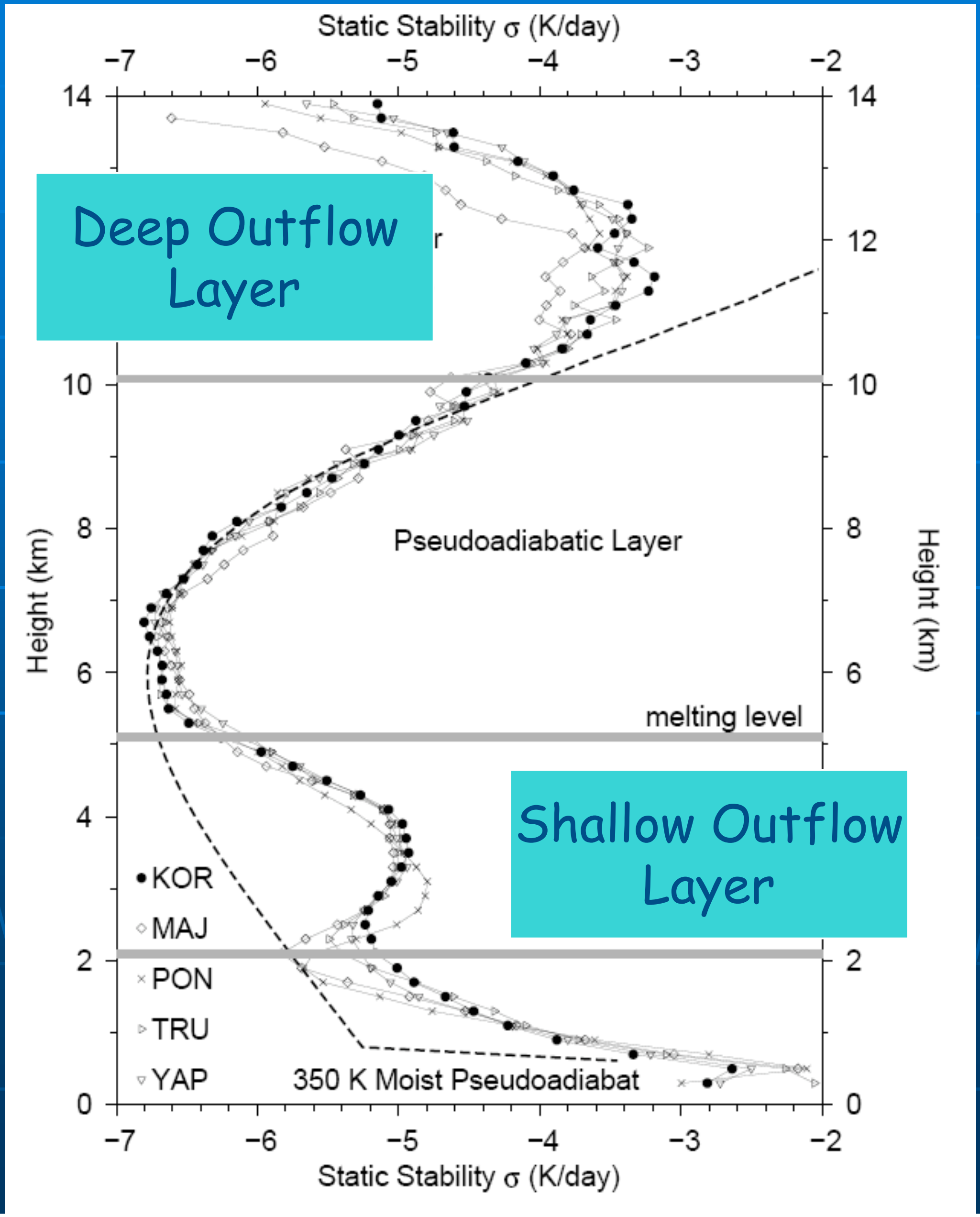
Temperature anomaly for top 10% rainfall bin averaged within circular regions centered at Koror of various radii:

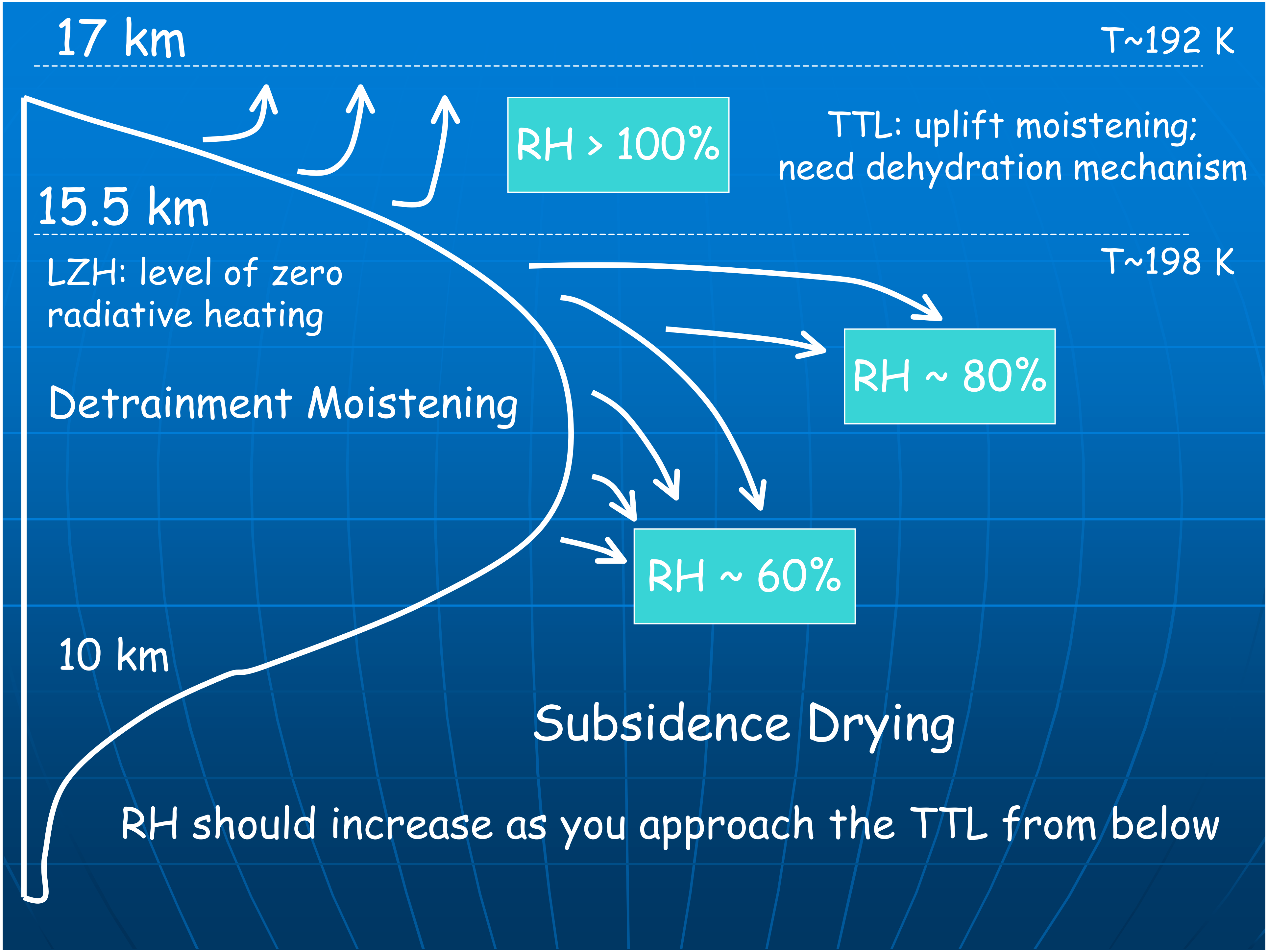


Superposition of full depth tropospheric heating ("convective" mode) plus upper level warming + lower level cooling ("stratiform" mode)?

The effect of rainfall on temperature is weak below 5 km for spatial scales larger than 2000 km: higher wavelength stratiform mode has smaller Rossby radius?

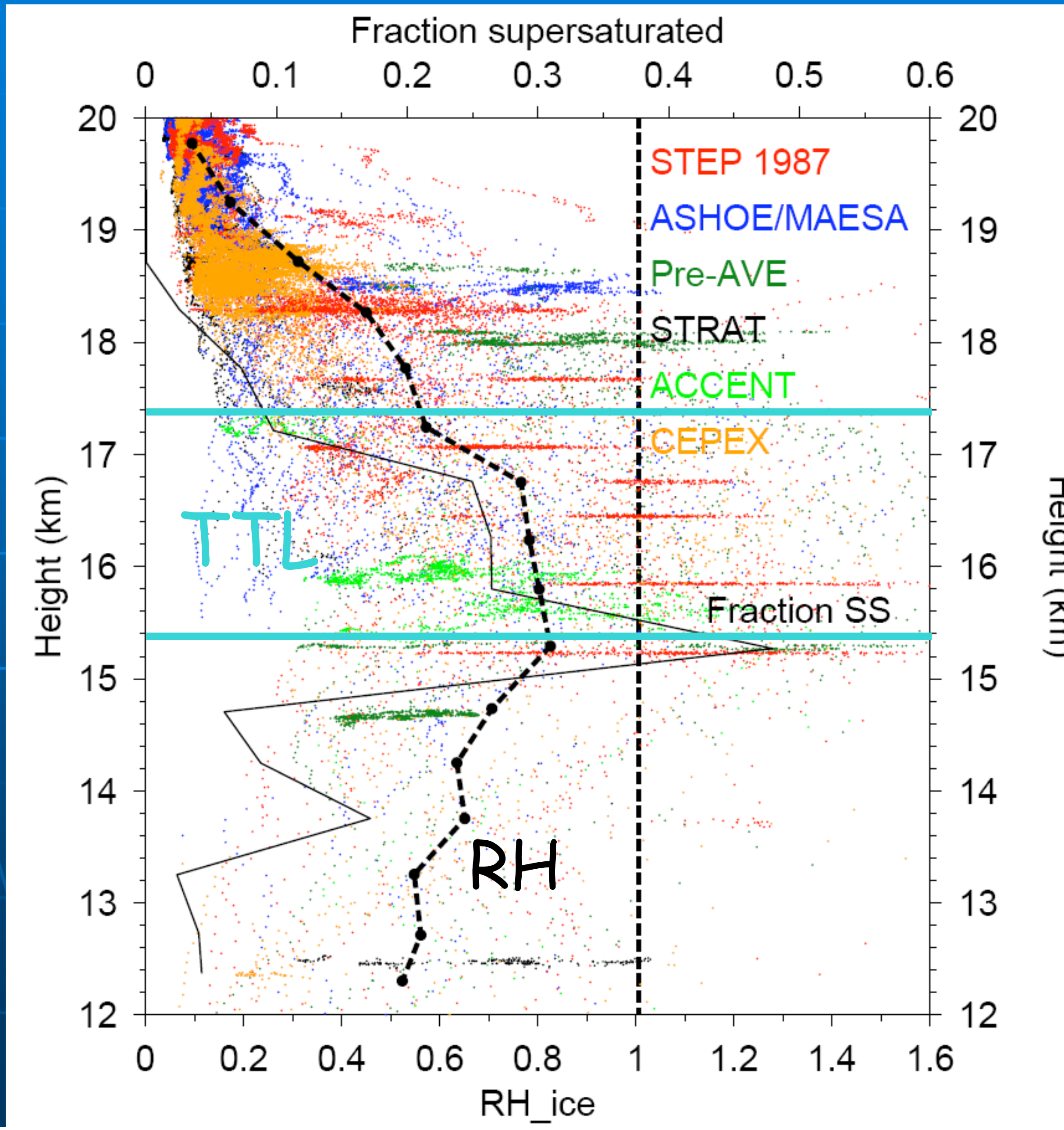
Outflow Layers associated withchanges in stability



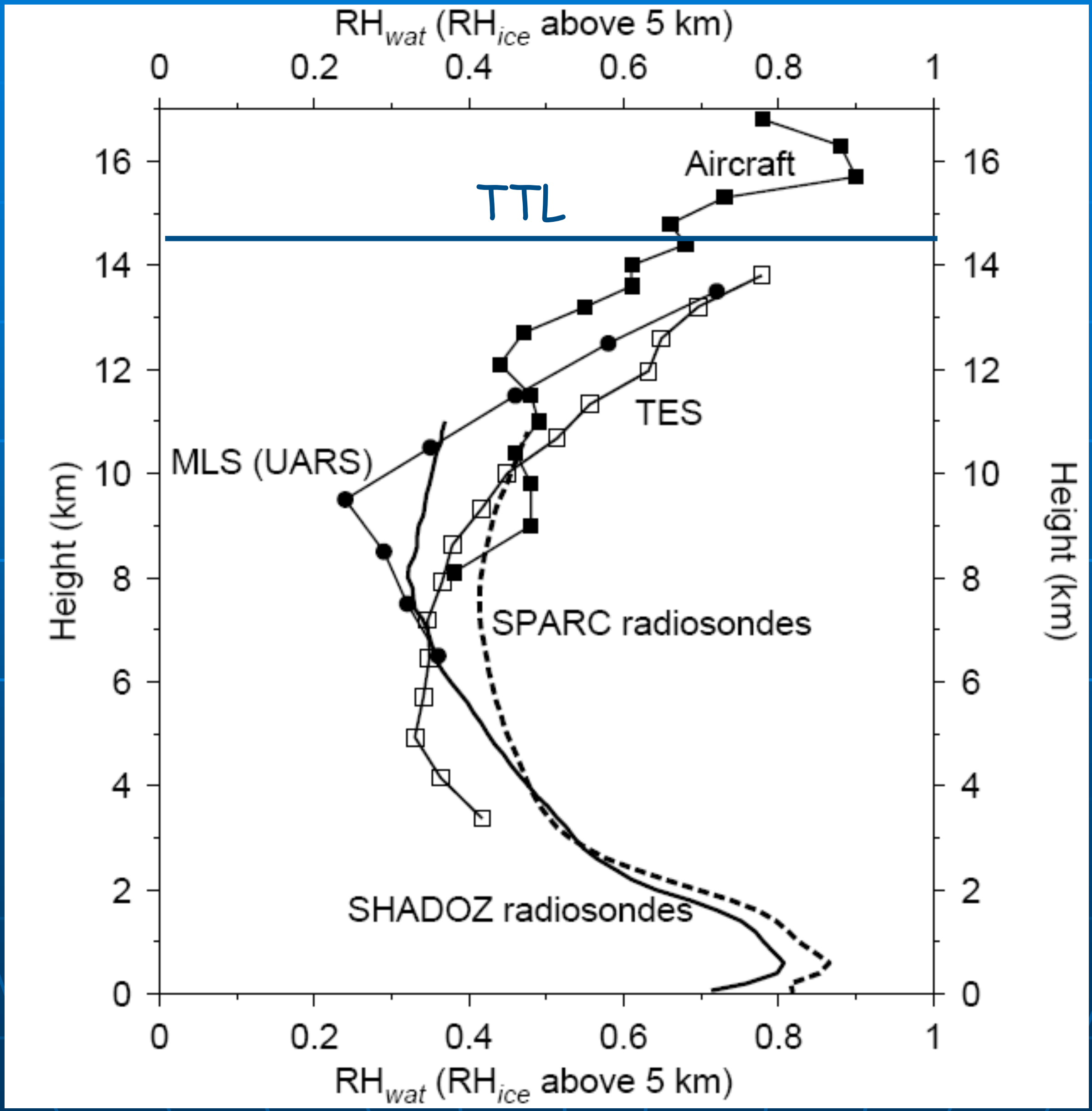


17 km
T~192 K
RH > 100%
TTL: uplift moistening;
need dehydration mechanism
15.5 km
LZH: level of zero
radiative heating
T~198 K
RH ~ 80%
Detrainment Moistening
RH ~ 60%
10 km
Subsidence Drying
RH should increase as you approach the TTL from below

Aircraft measurements of tropical upper tropospheric RH

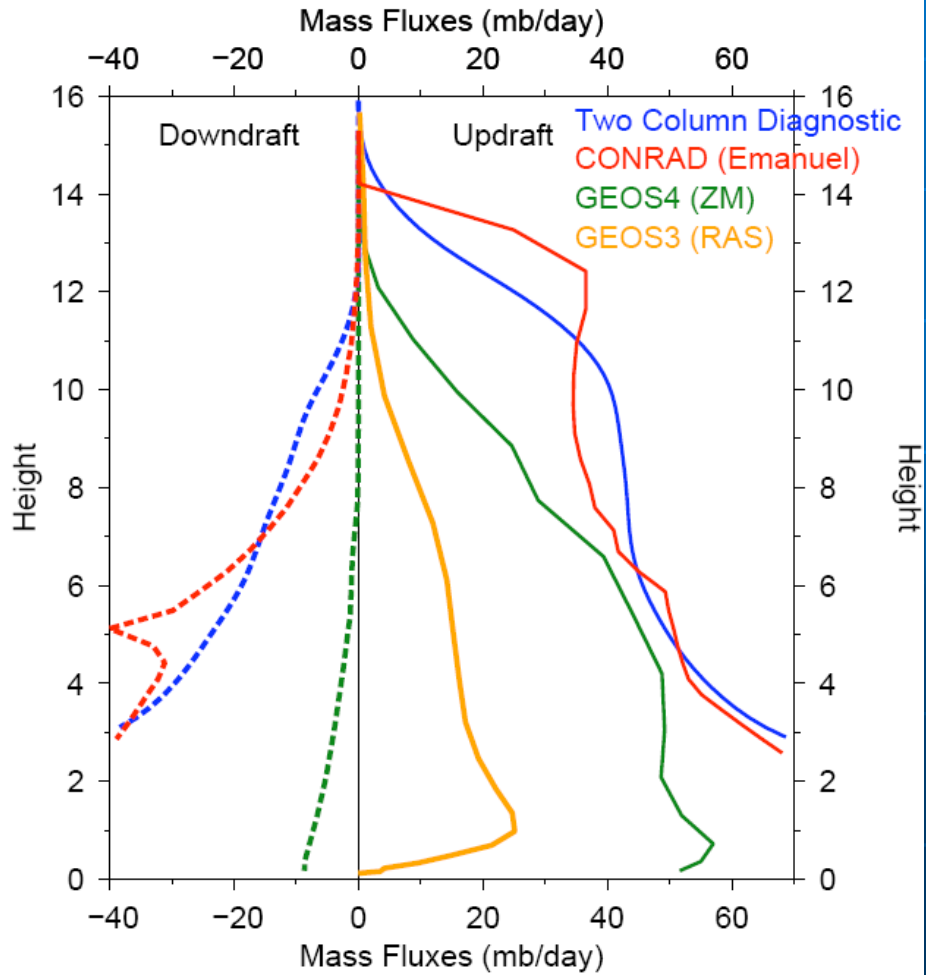


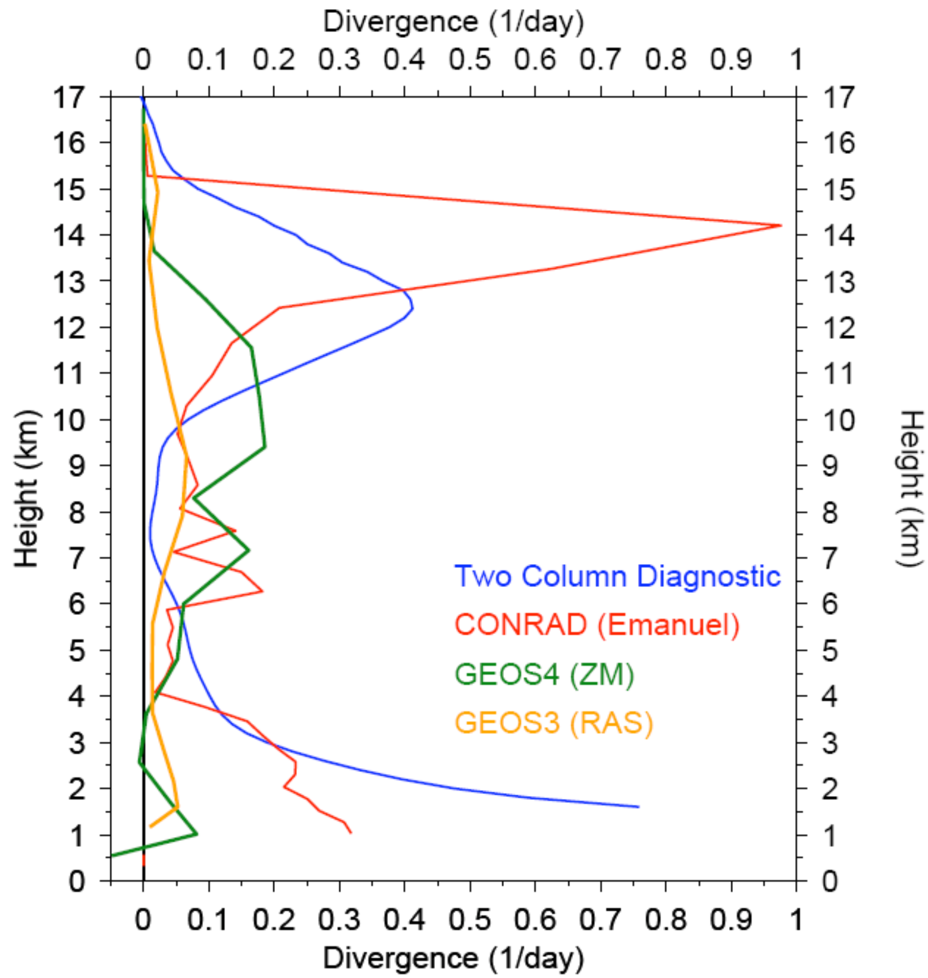
Compilation of Various Tropical Climatologies:



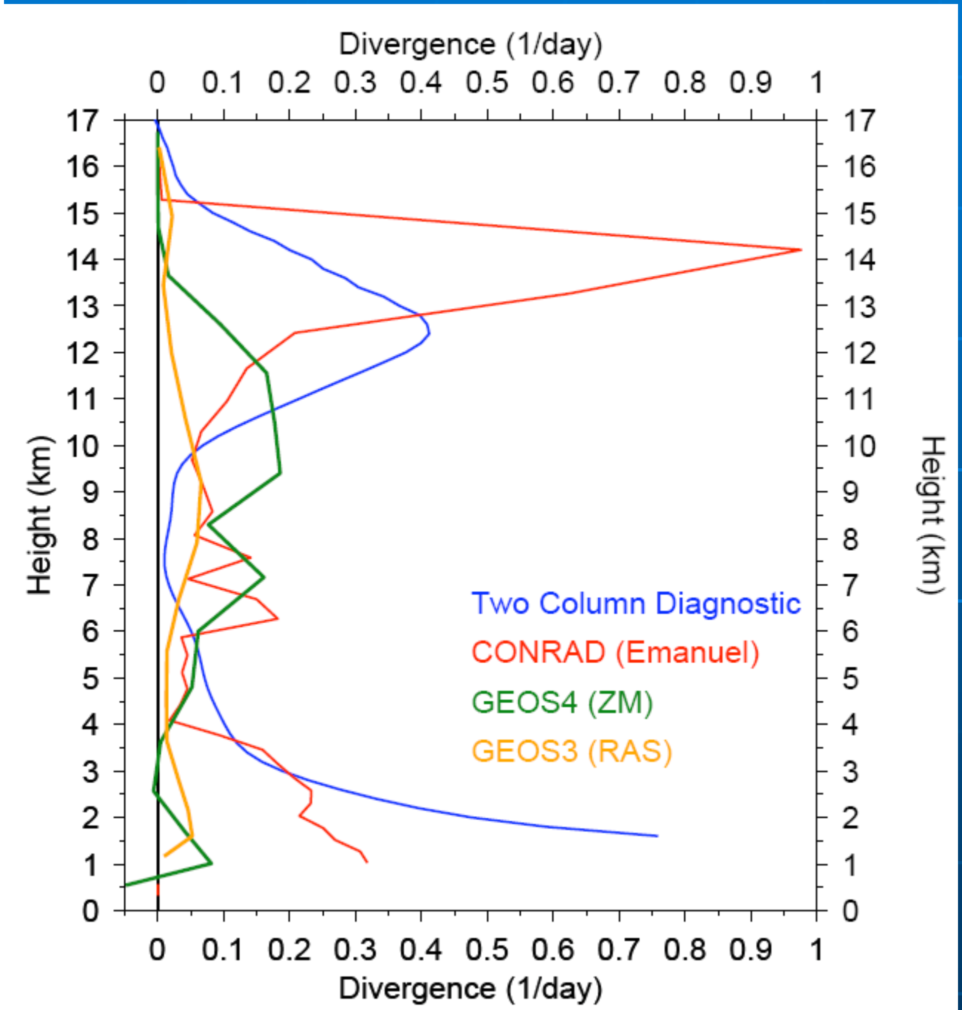
Tropical mean cloud mass flux and divergence profiles from 3 convective schemes

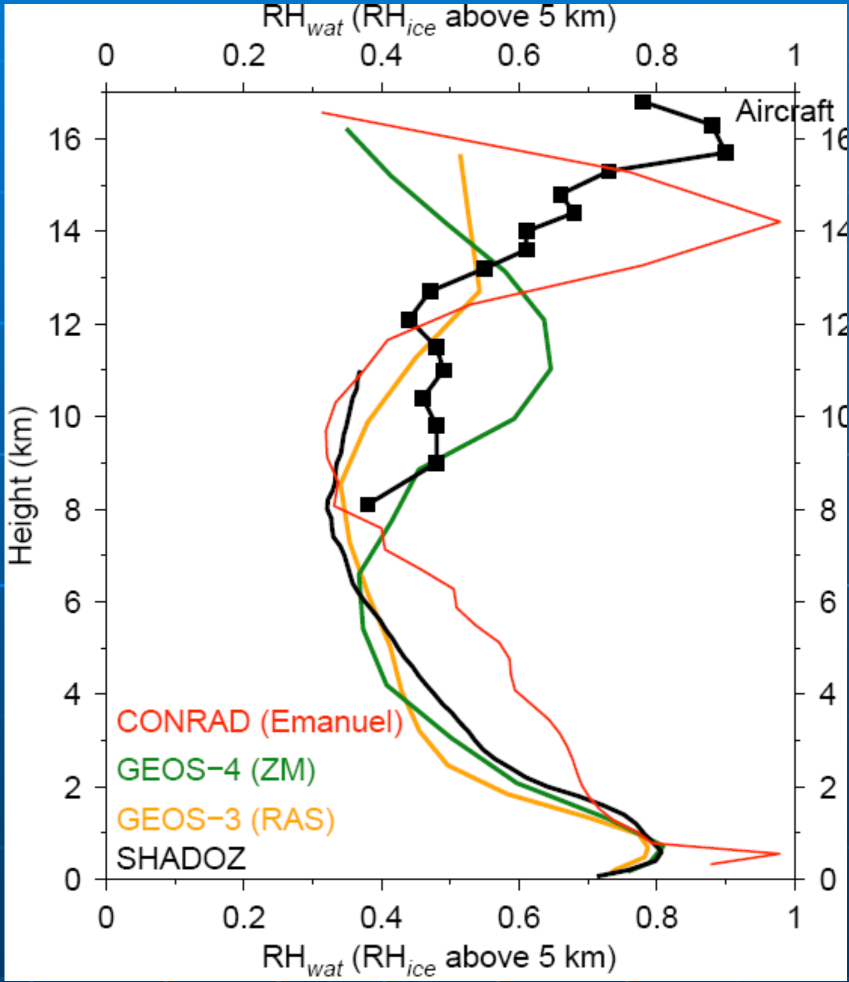
[Emanuel, Zhang and McFarlane (GEOS-4), Relaxed Arakawa Schubert (GEOS-3)]

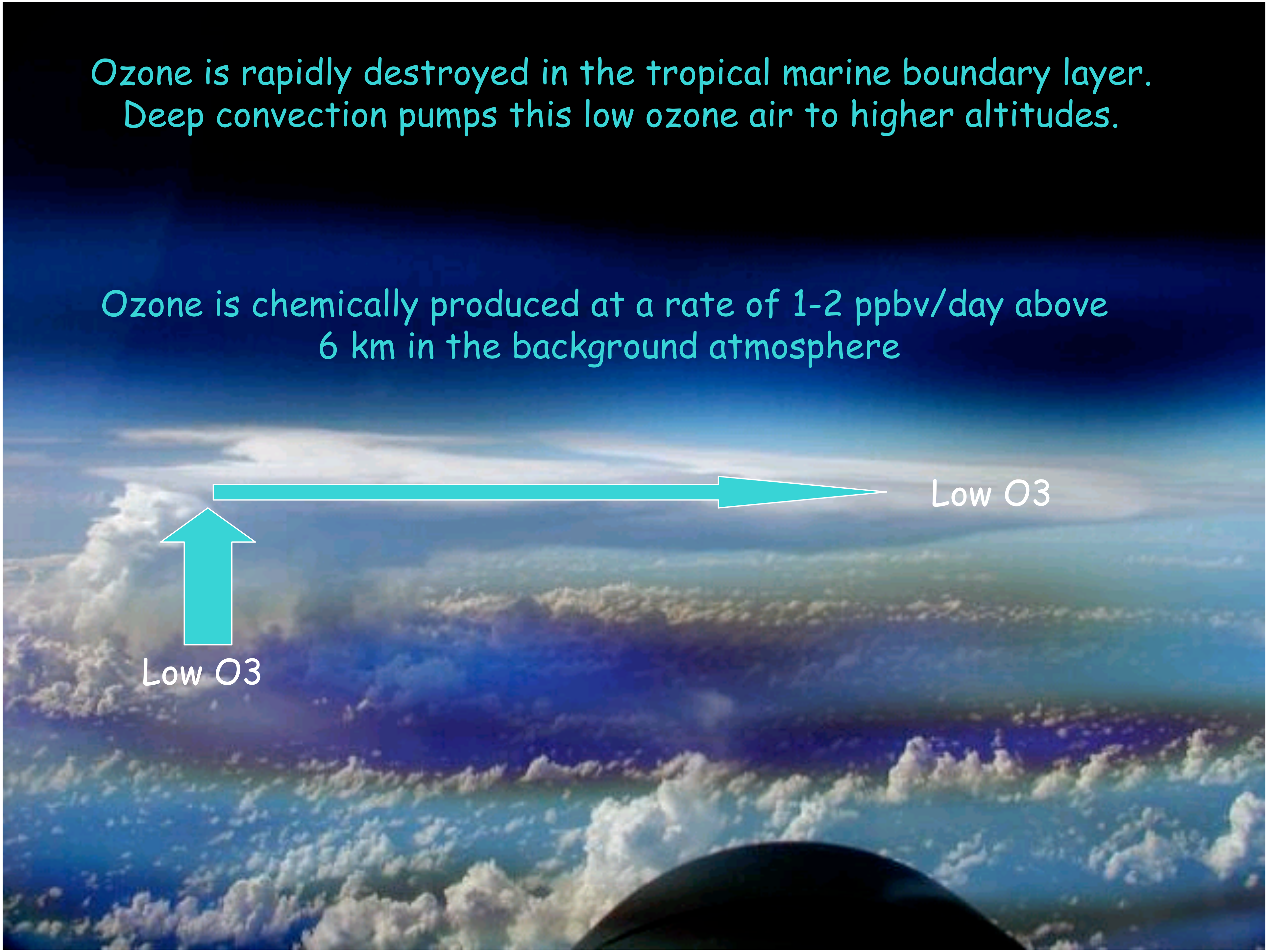




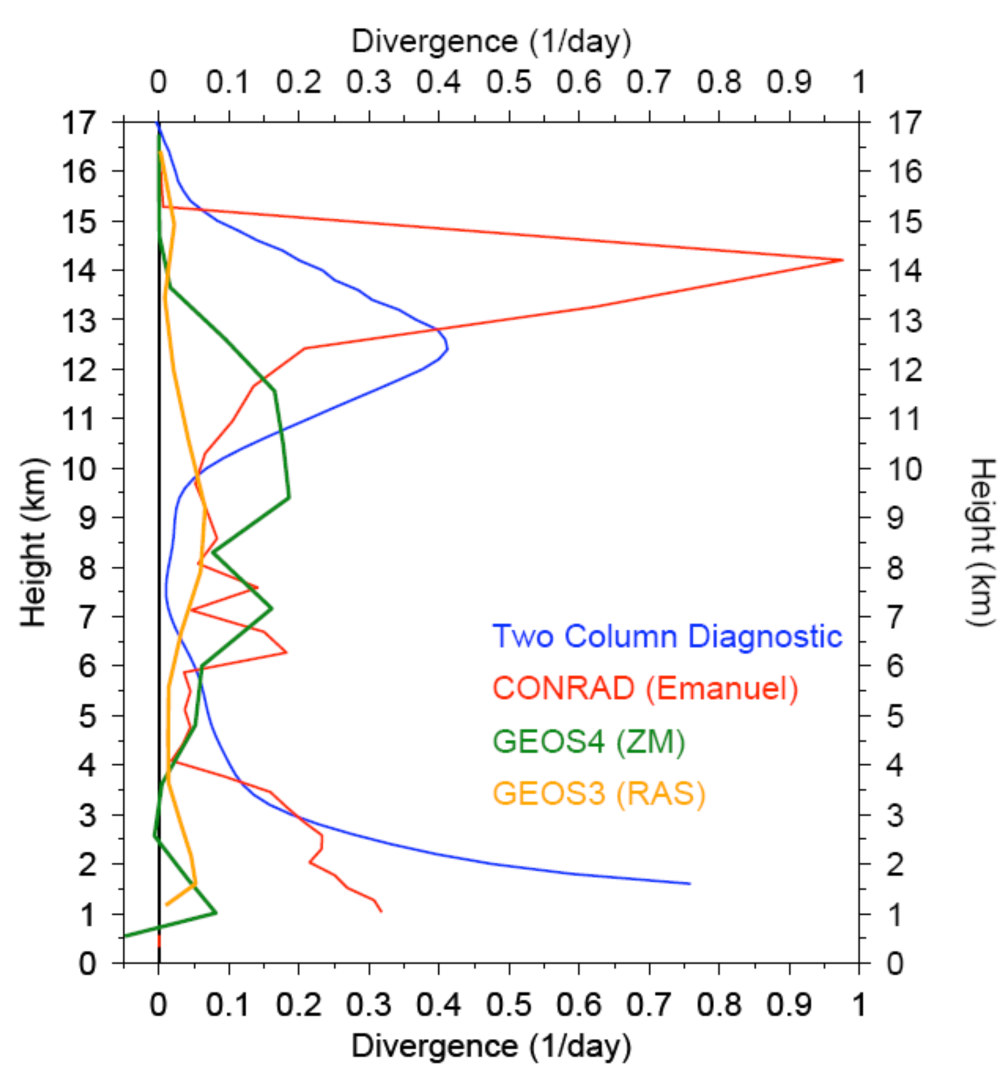
Relative Humidity Comparisons

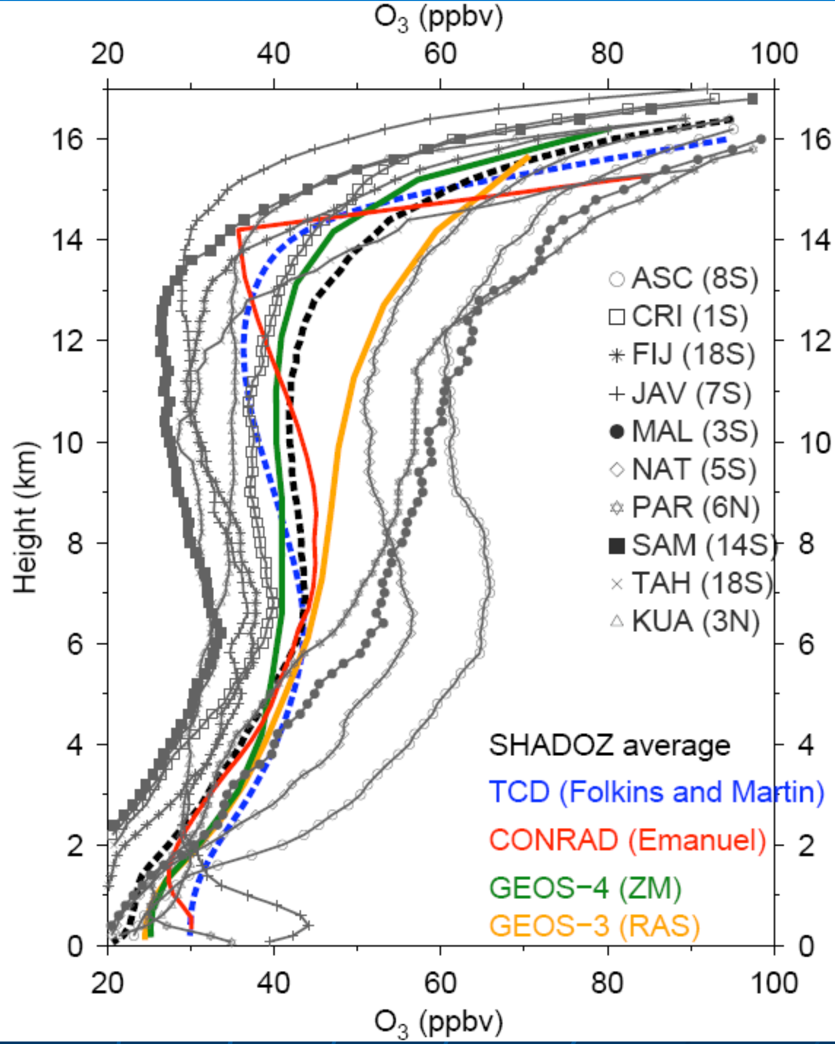





Ozone is rapidly destroyed in the tropical marine boundary layer.
Deep convection pumps this low ozone air to higher altitudes.
Ozone is chemically produced at a rate of 1-2 ppbv/day above 6 km in the background atmosphere
Low O3
Low O3

Ozone Comparisons





GEOS-3(RAS) model lacks upper tropospheric ozone minimum

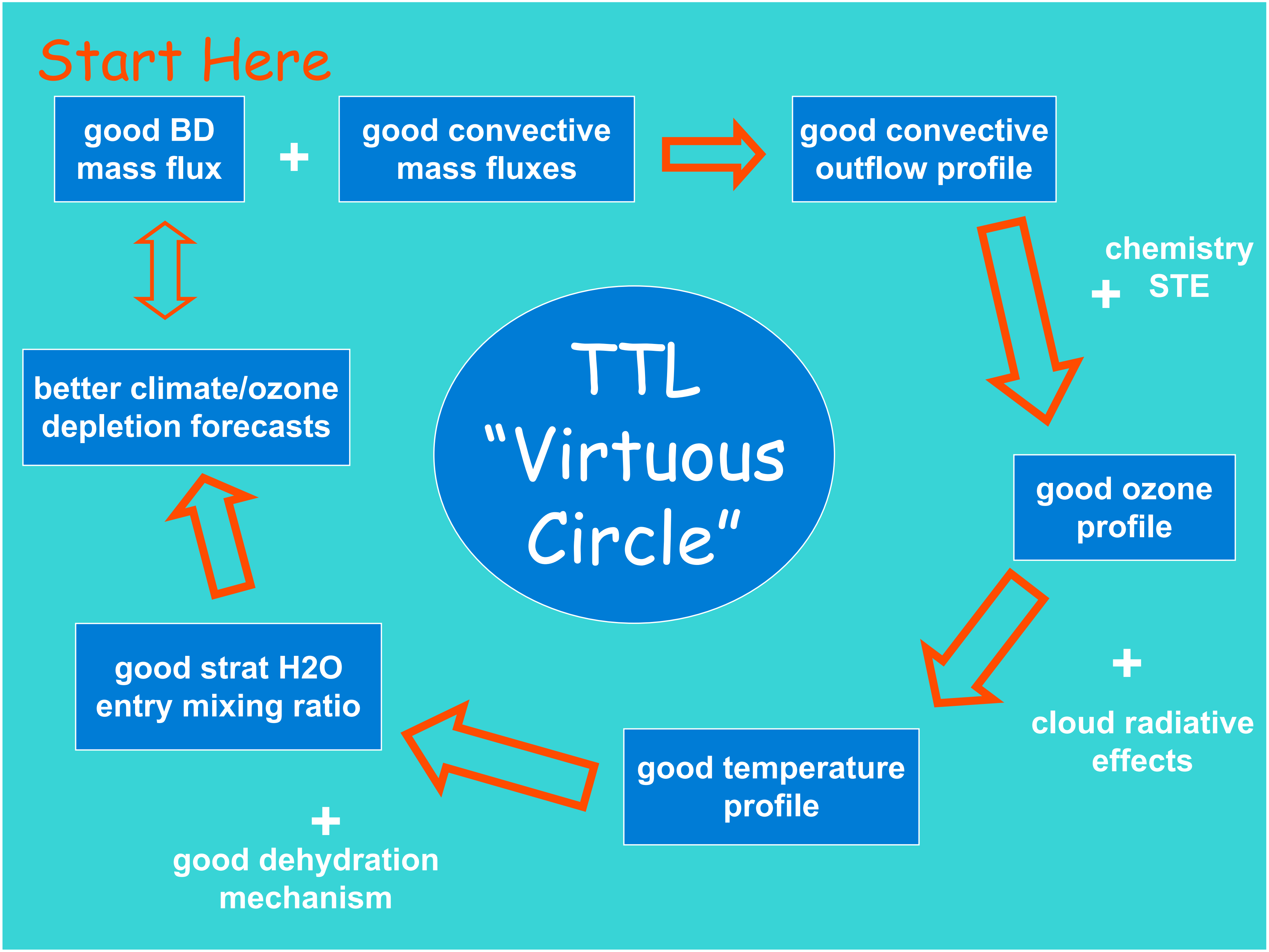
Summary

-The observations are pretty clear: there is a deep outflow mode with a peak near 13 km, and a shallow outflow mode below 6 km.

- In general, convective parameterizations do not seem to exhibit a clear separation between these modes.

- Getting a clear physical separation between the deep and shallow outflow layers is probably key to the problem of tropical predictability.

-Need to compare model predictions of RH/tracers across both outflow layers to test convective schemes (e.g. comparisons with radiosonde RH by themselves are of limited use).

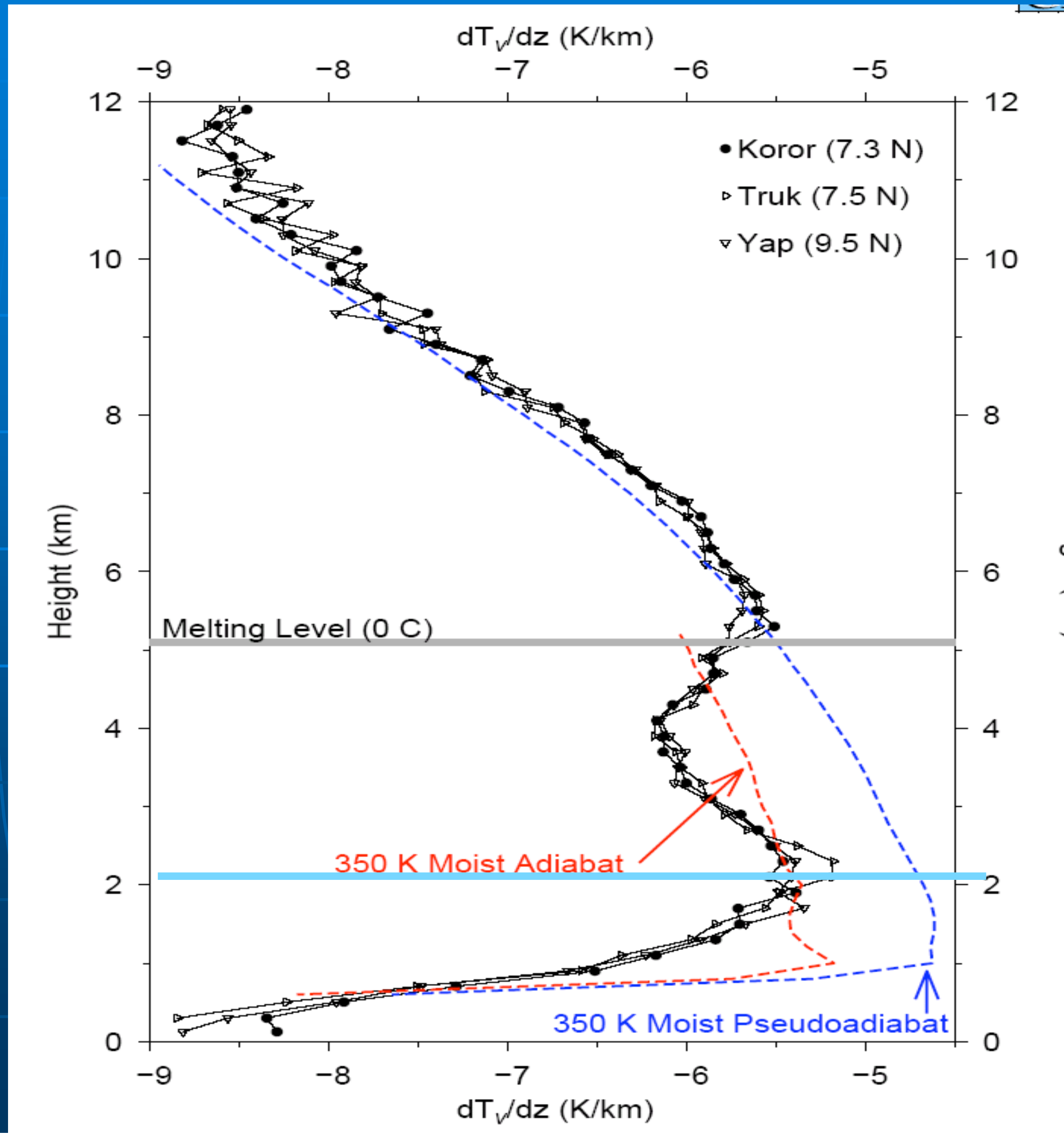

Start Here
good BD mass flux
+
good convective mass fluxes
good convective outflow profile
chemistry
+ STE
good ozone profile
+
cloud radiative effects
good temperature profile
+
good dehydration mechanism
good strat H2O entry mixing ratio
better climate/ozone depletion forecasts
TTL
"Virtuous Circle"

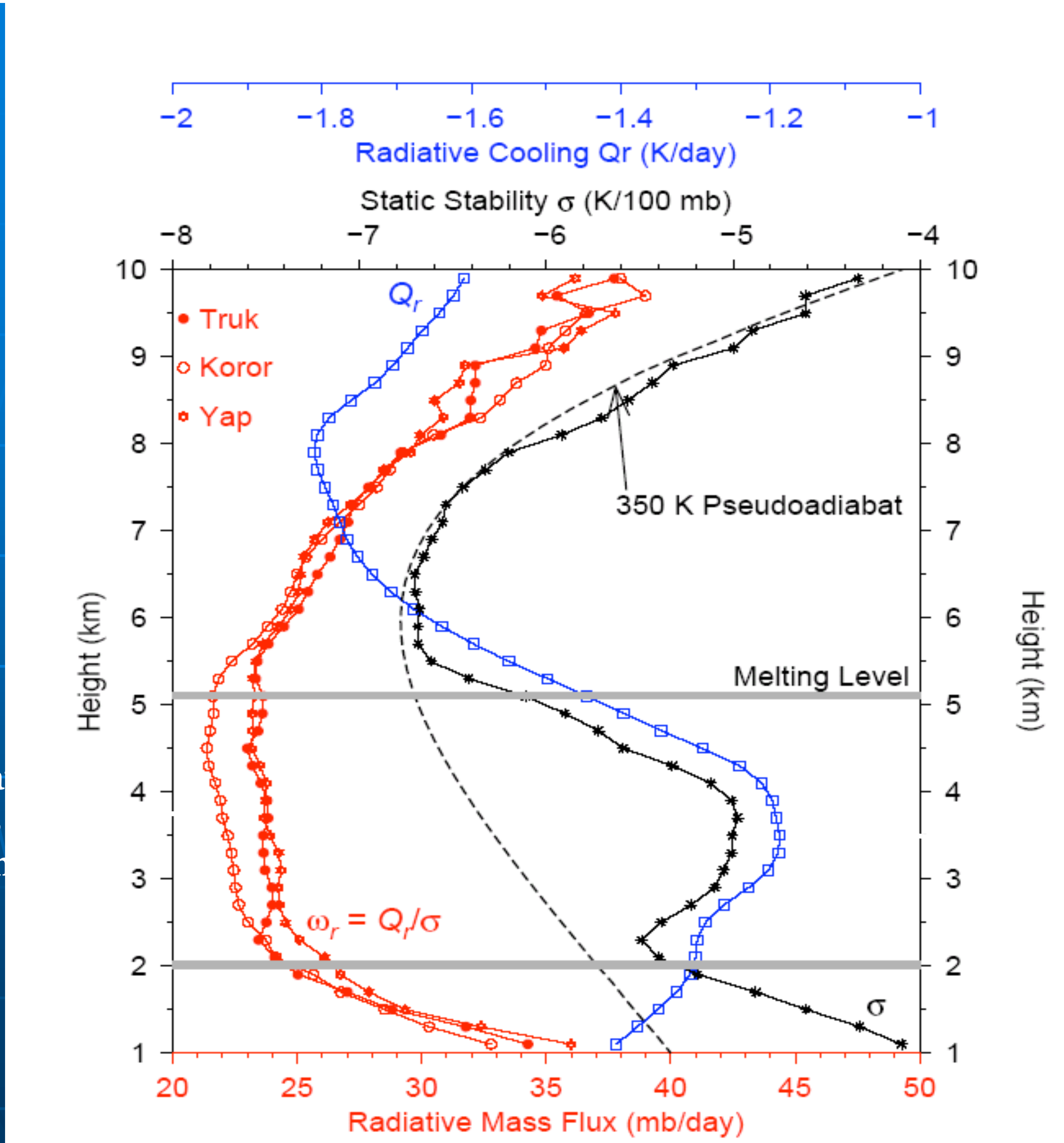
However, the shallow circulation has a distinct temperature structure if you look at lapse rates.

Deep

Shallow

Boundary Layer

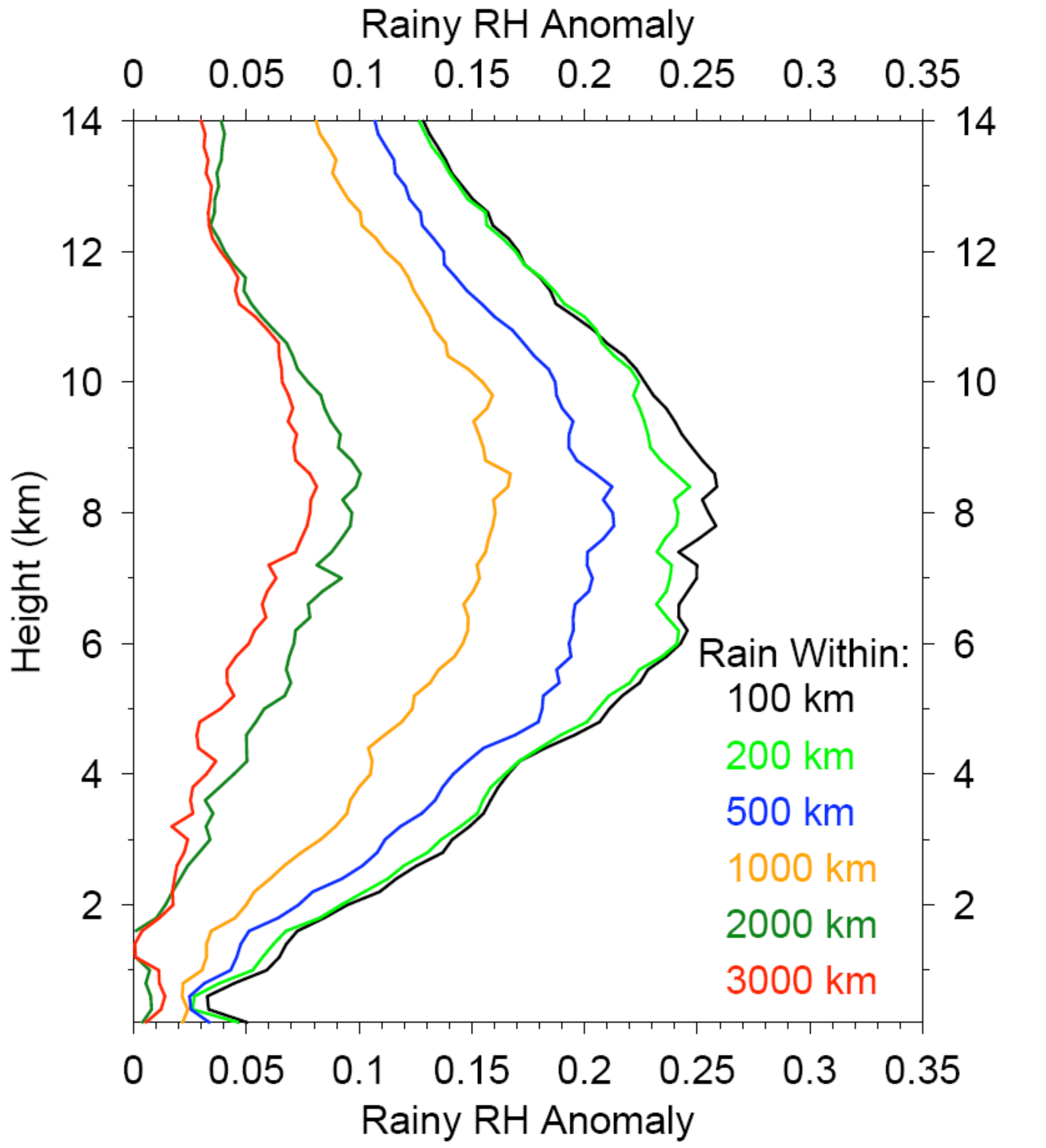




$$\omega = \frac{Q}{\sigma}$$

radia
mass
is con

pse rate 'notch' mimics
vertical variation of
ative heating.


Rainy RH Anomaly
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
14
12
10
8
6
4
2
Height (km)
Rain Within:
100 km
200 km
500 km
1000 km
2000 km
3000 km