Convective Processes in the UT/LS

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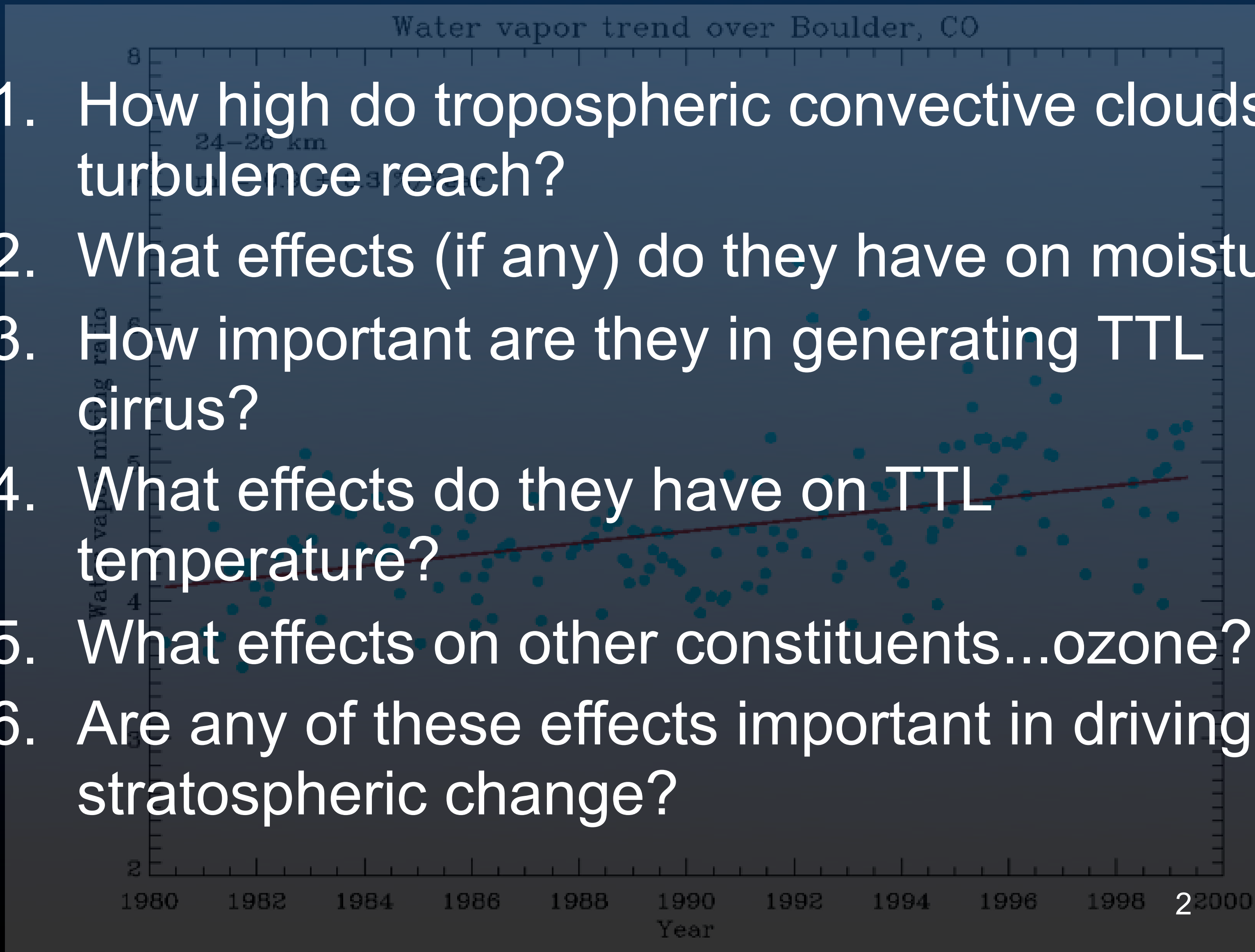
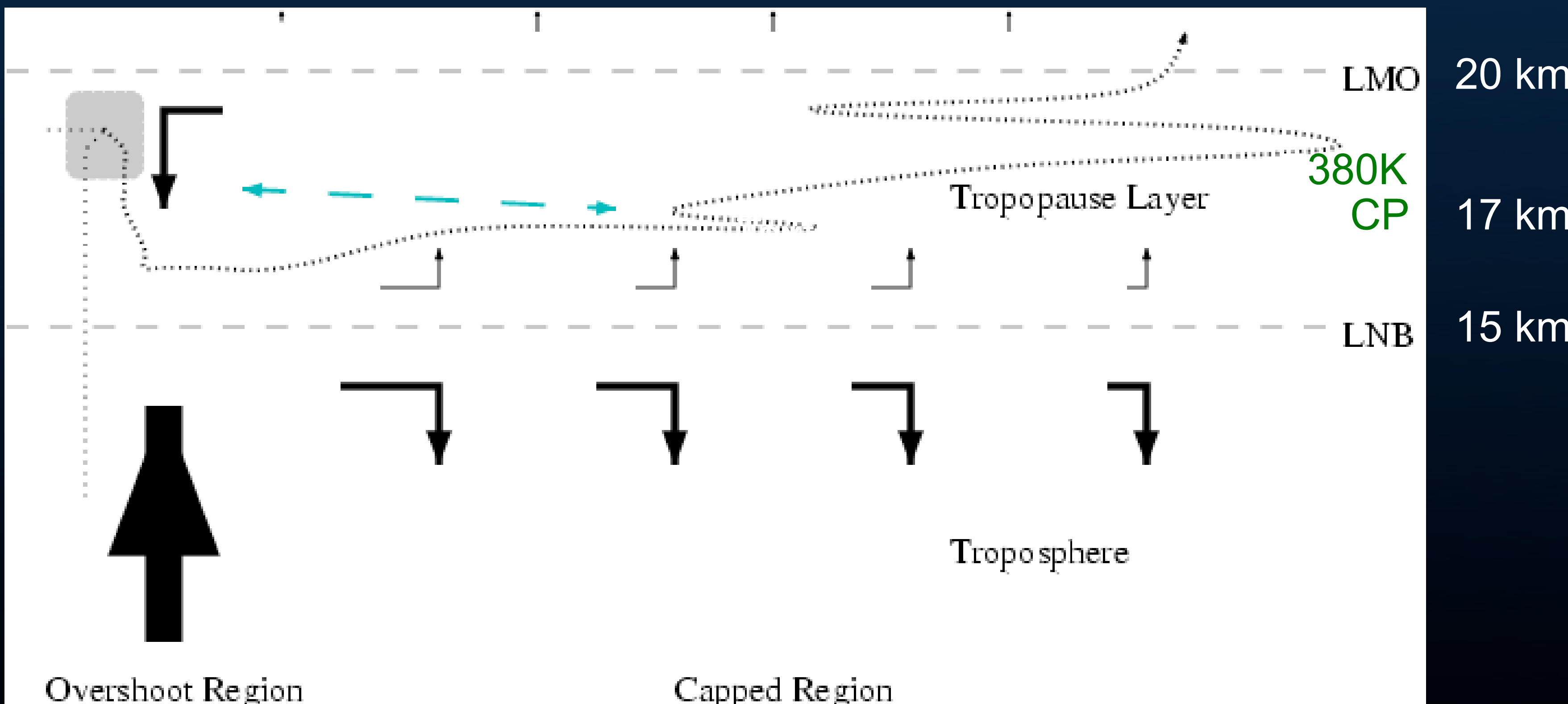
Questions....

1. How high do tropospheric convective clouds/ turbulence reach?
2. What effects (if any) do they have on moisture?
3. How important are they in generating TTL cirrus?
4. What effects do they have on TTL temperature?
5. What effects on other constituents...ozone?
6. Are any of these effects important in driving stratospheric change?



UT vs. LS: lg-scale transport barrier ~15 km

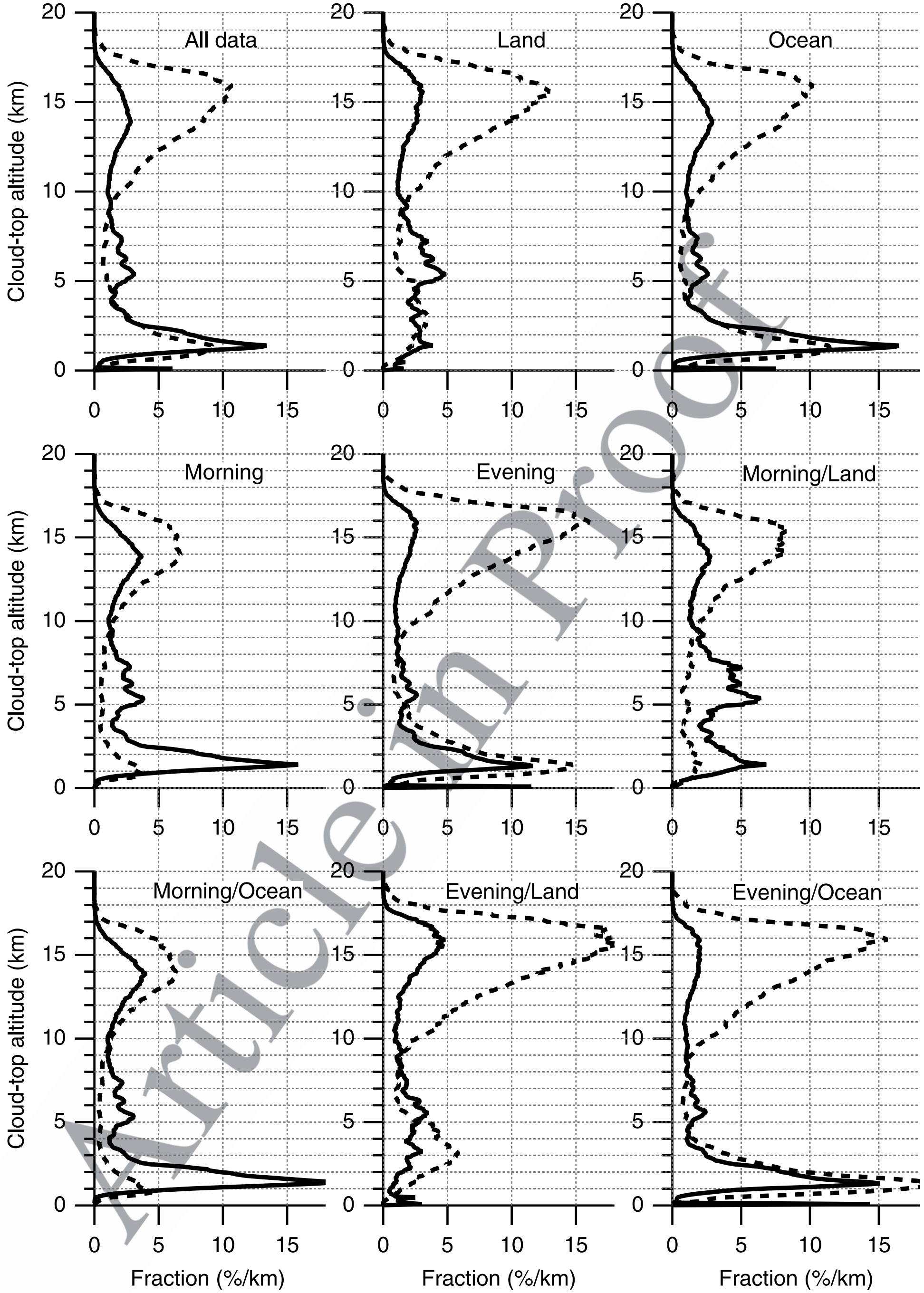


--> UT water vapor probably has little effect on LS

Cloud height

How much cloud penetration is needed to matter?

- Crude scaling argument: cloud contribution to vertical transport ~ convective cloud area (e.g., Gettelman et al. 2002). In Tropics,
  - Tropospheric overturning w ~ 30 hPa/day
  - Stratospheric overturning w ~ 0.1-0.3 hPa/day
  - Tropospheric rain area ~2.5% (Liu and Zipser in press)
    - Clouds matter in stratosphere until area < 0.02%.
- Impact on a constituent will depend also on "contrast" between its tropospheric and ambient value (Dessler and Sherwood 2004).



GLAS thick clouds (Dessler et al, JGR, in Press):

4.7% above 14.5 km

0.34% above 377.5K

0.02% above ~20 km (??)

IR (Gettelman et al 2002)

0.5% above CP (~370K)

20 dbZ from TRMM PR (Liu and Zipser BAMS in press)

0.023% P > 14 km

0.005% P > 380K

... 1/4 of cells in TTL reach the overworld!

Water vapor;
Cirrus

The advection-condensation model of humidity

1. Water vapor capped near saturation in small (cloudy) regions where cooled to saturation;
2. Parcel water vapor mixing ratio conserved during subsequent warming (horizontal transport);
3. Relative humidity determined by amount of parcel warming since last saturation.

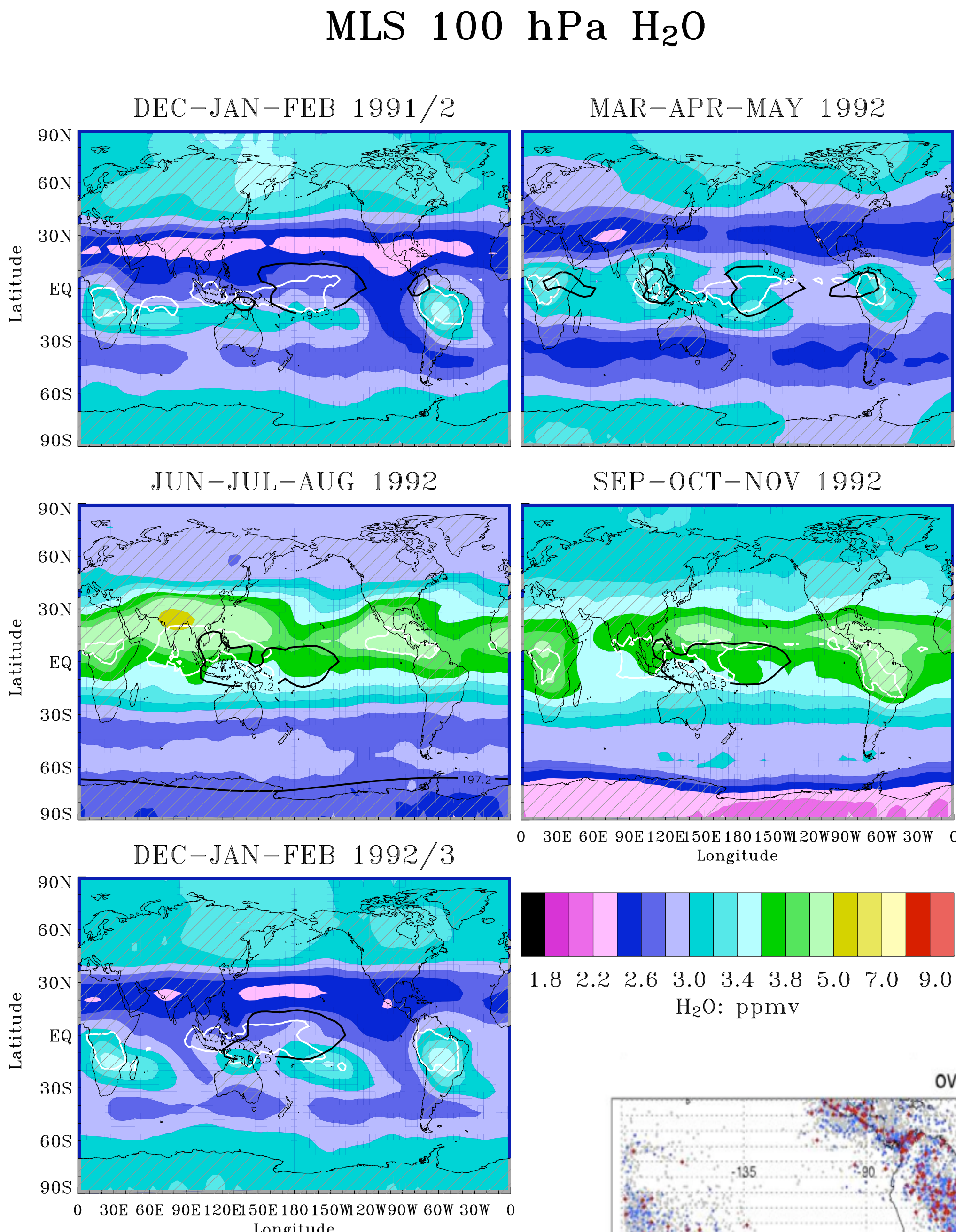
Water vapor field controlled by large-scale wind and temperature fields.

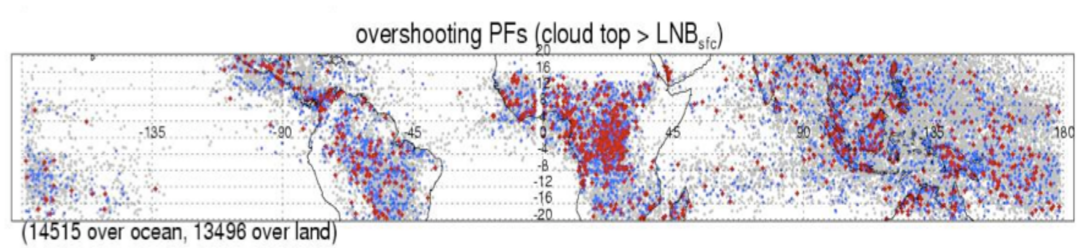
Application of AC:

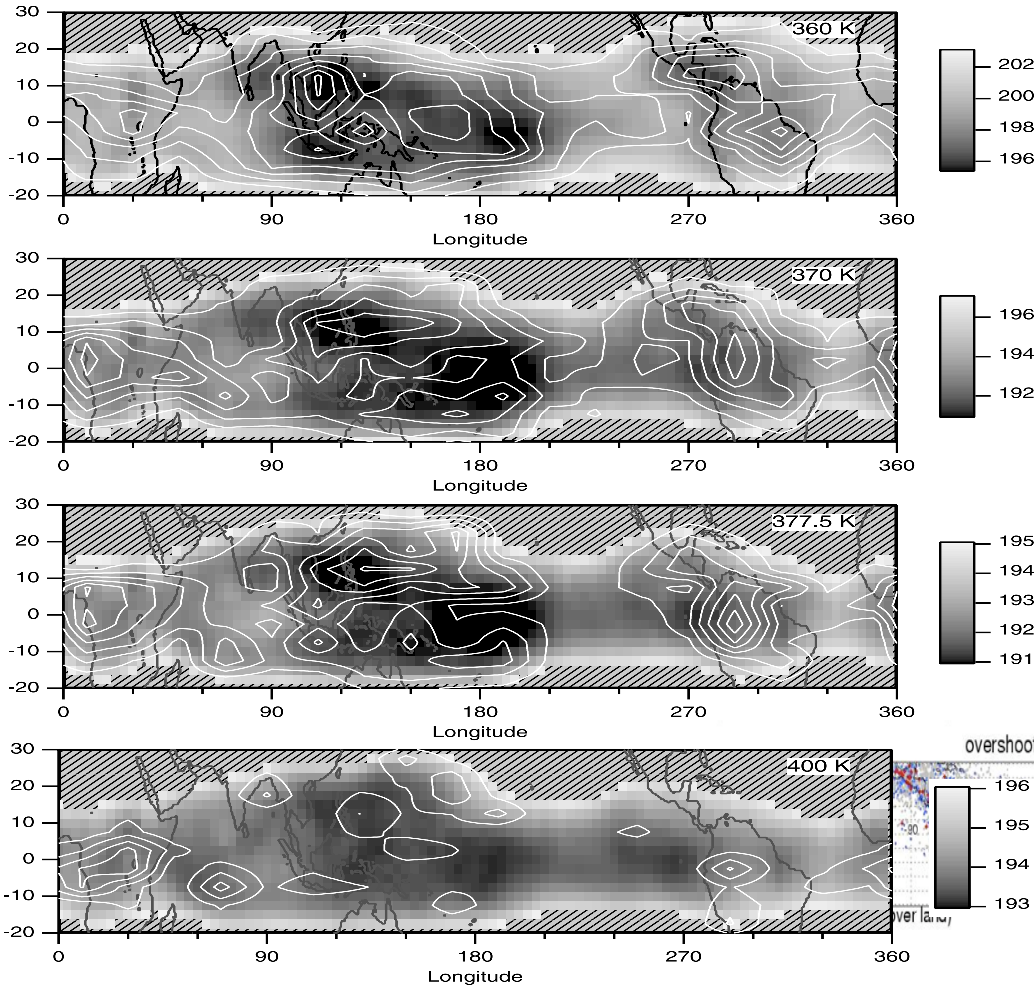
- To stratospheric entry vapor
  - Roughly reproduces seasonal cycle via T
  - Very roughly reproduces horizontal pattern in TTL (Holton and Gettelman 2002)
  - Roughly reproduces interannual variation (Fueglistaler and Haynes 2005)
  - BUT... convective centers clearly inject water to at least 100 hPa level (Read et al 2004)
- To upper tropospheric water vapor
  - Reproduces horizontal pattern

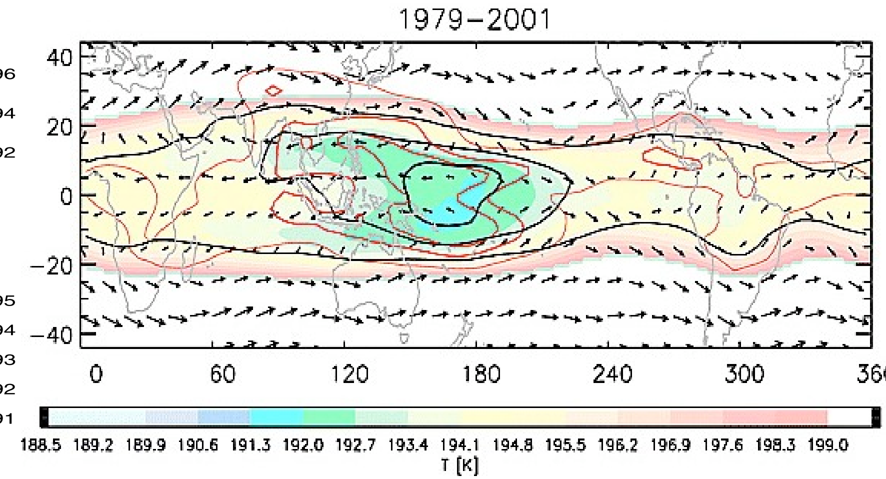
Does this leave any room for microphysical influences on water vapor?

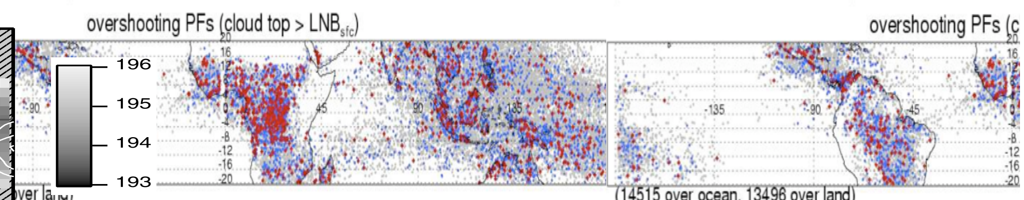
Evidence of convective hydration (Read et al 2004)











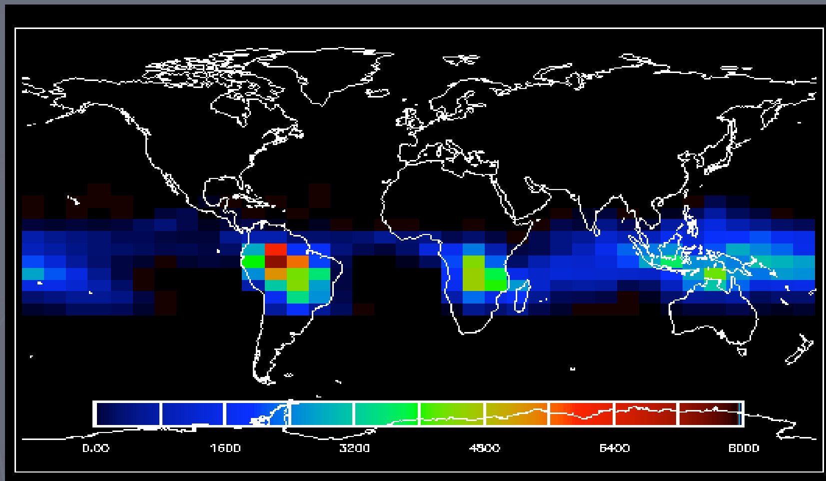
gure 6. Average temperature (K) at 360-, 370-, 377.5-, and 400-K potential temperature based on KMO meteorological fields. Also shown (white contours) is evening TNTC frequency from Figures 1–4.

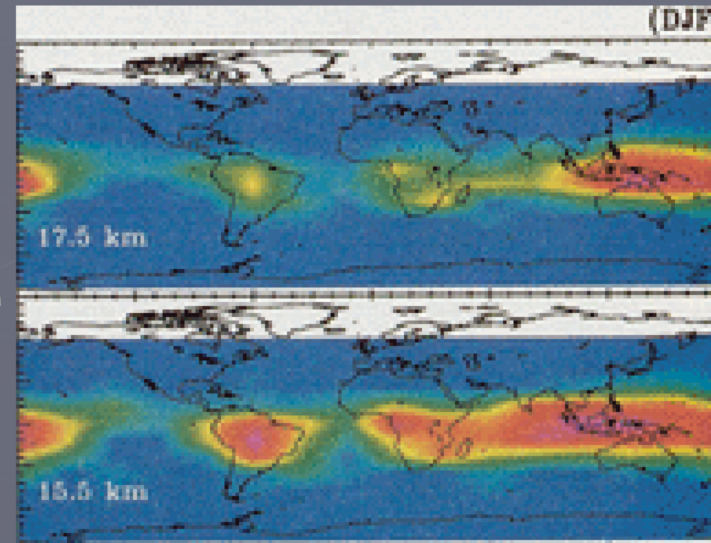
forming more frequently as the temperature

demonstrate the relationship between TNTC and TTL temperature more clearly, we have each GLAS measurement a temperature at 360, and 400 K by interpolating daily UKMO fields to the GLAS measurement locations. In Figure 7, we show the fraction of GLAS measurements that contain a TNTC as a function of local temperature. Throughout the TTL, TNTC frequency increases as the local temperature decreases. This is consistent with our intuition, which suggests that clouds should form more frequently as the temperature decreases. The exception is at the coldest temperatures at 360 K, one sees that TNTC

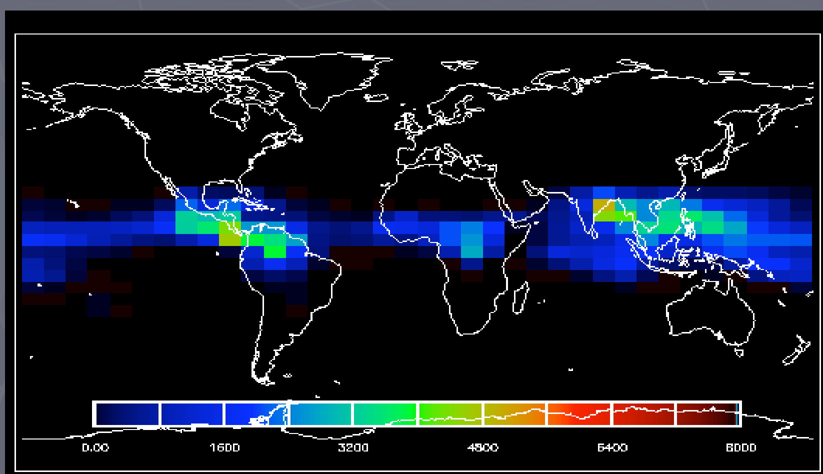
Tropical Cb

% thin cirrus

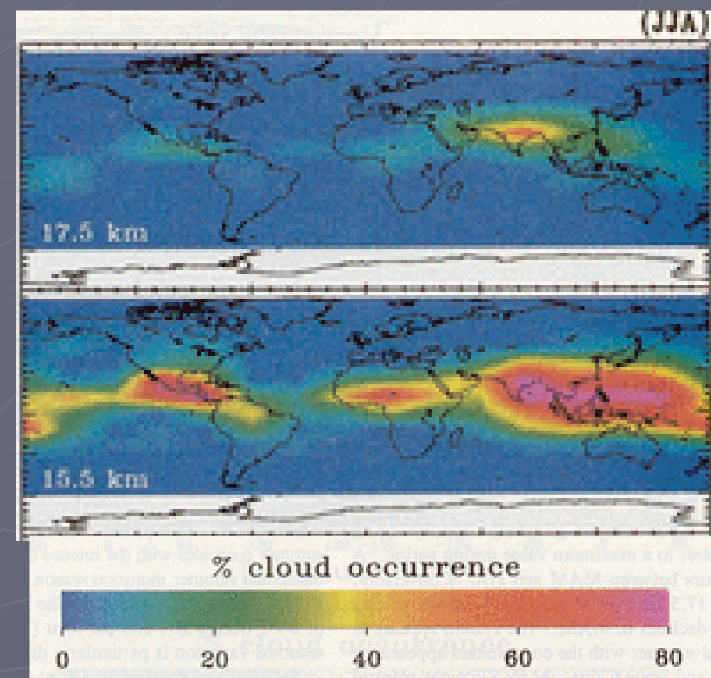


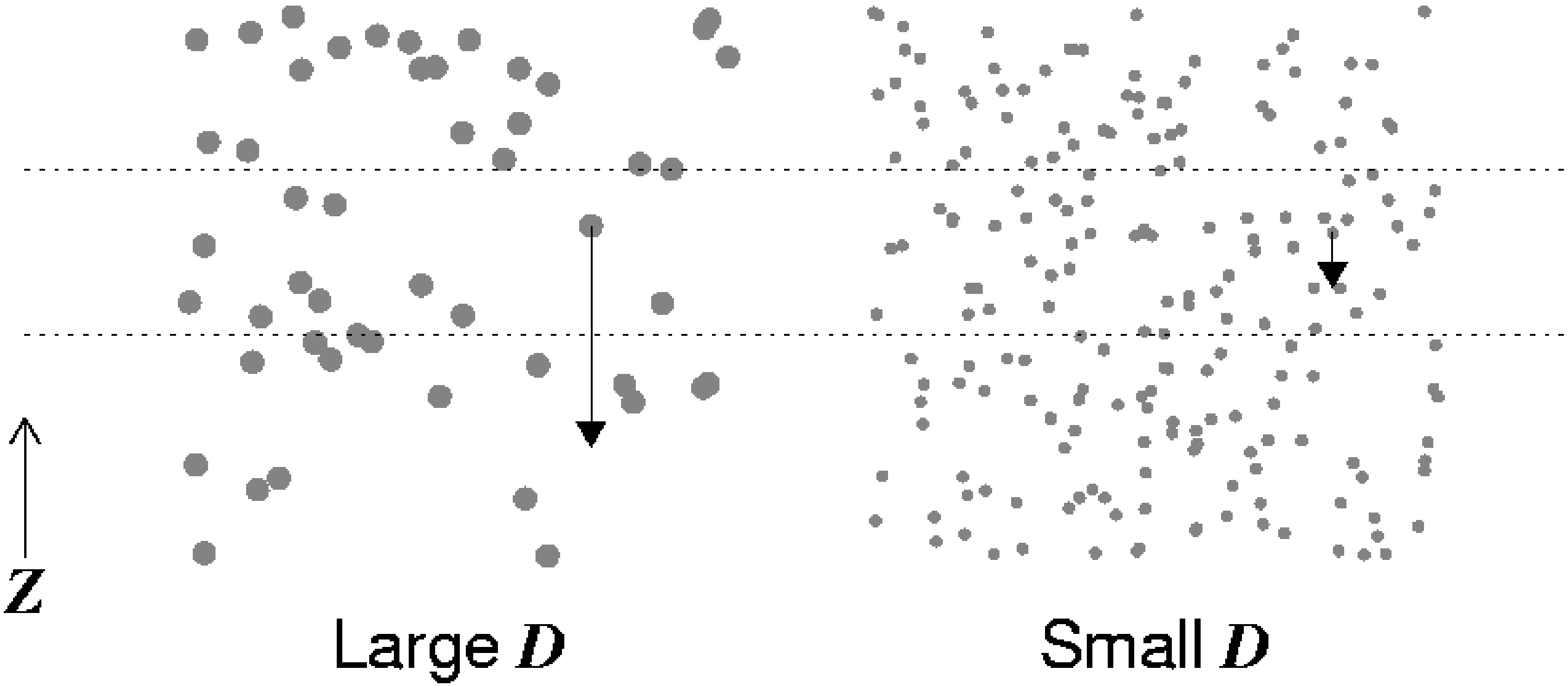


DJF



J
J
A





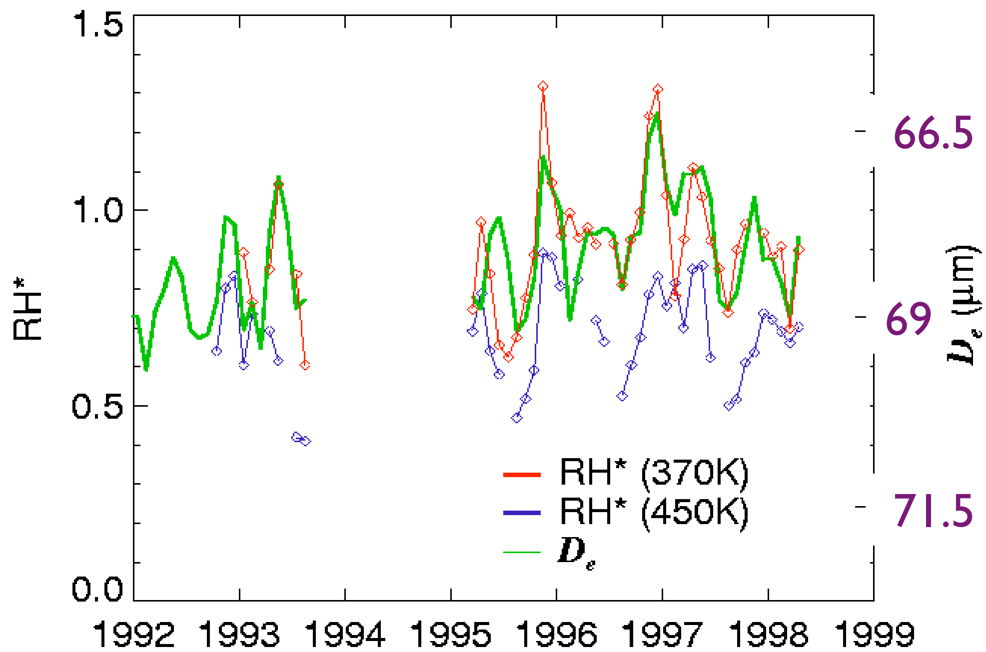
Fall velocity ~ D^2

Evaporation rate per particle ~ D

Mass evaporated per unit vertical distance, per particle ~ D^{-1}

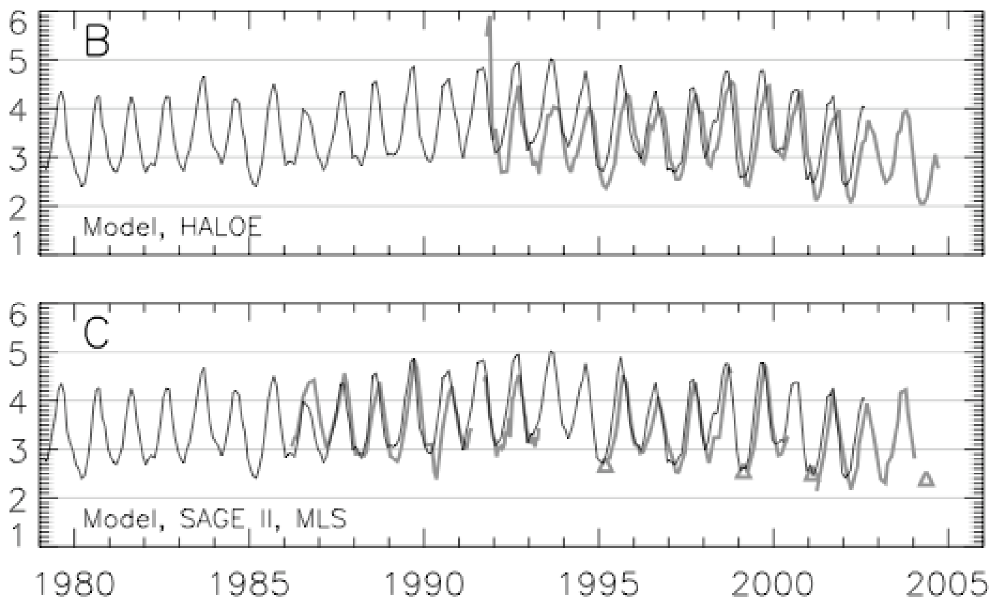
" , per unit particle mass ~ D^{-4}

Tropical mean variations



Sherwood, 2002

“non-T” q



Fueglistaler and Haynes, 2005

full q

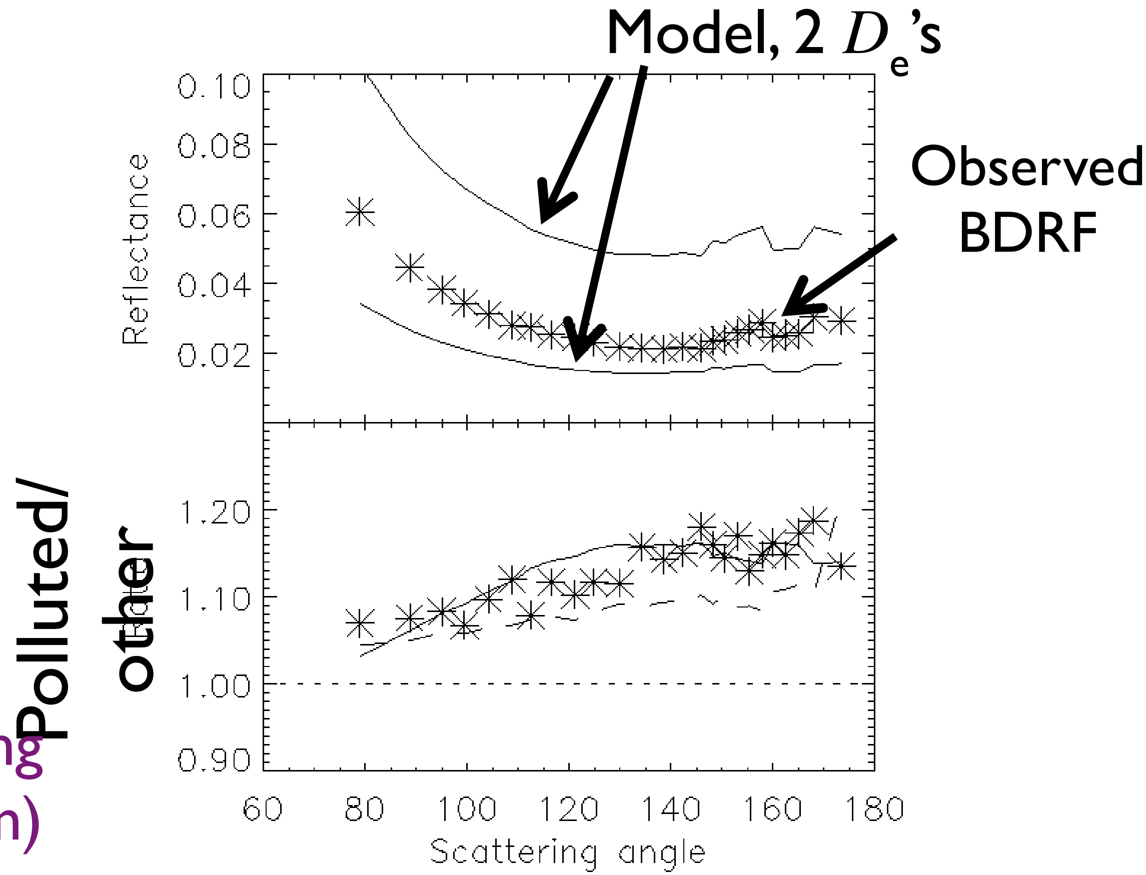
- Fueglistaler and Haynes (2005): microphysics not necessary (r=.7, or .8 with full winds)....30% additional variance explained by full winds.

- Sherwood (2002): 50% additional variance explained by microphysics without full winds (highly significant)

- Notholt et al. (2005) calculate modest impact of sulfate aerosol with in-situ dehydration.

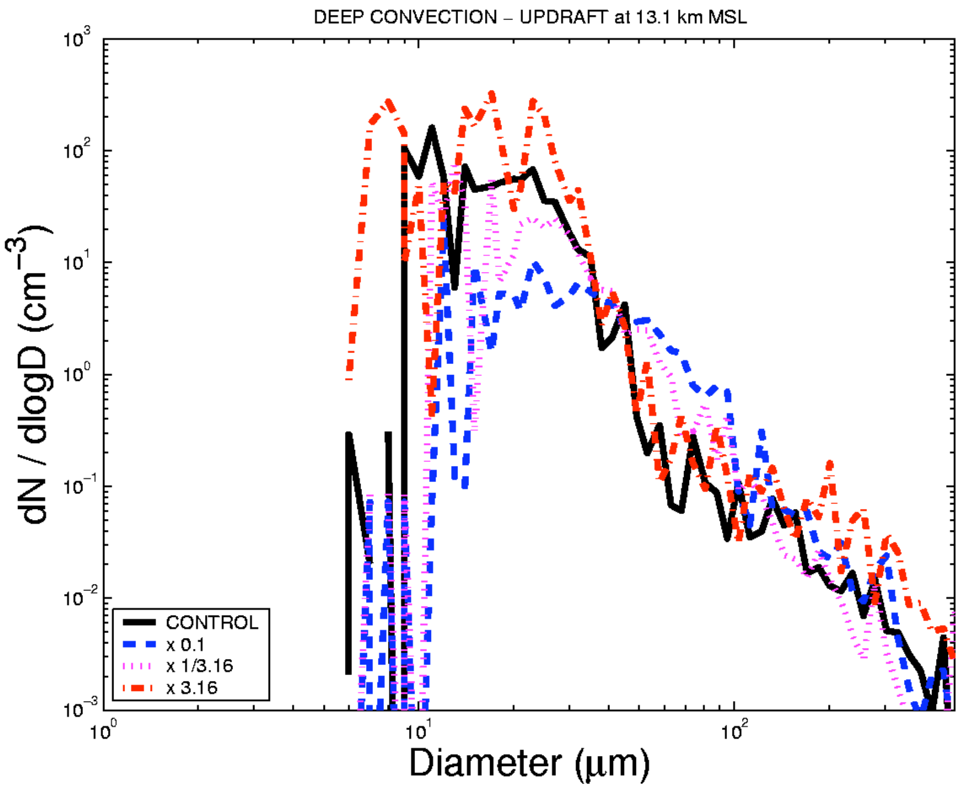
What does small D_e mean in terms of the size distribution?

1. Observations: BDRF different for low-D_e, polluted cases.



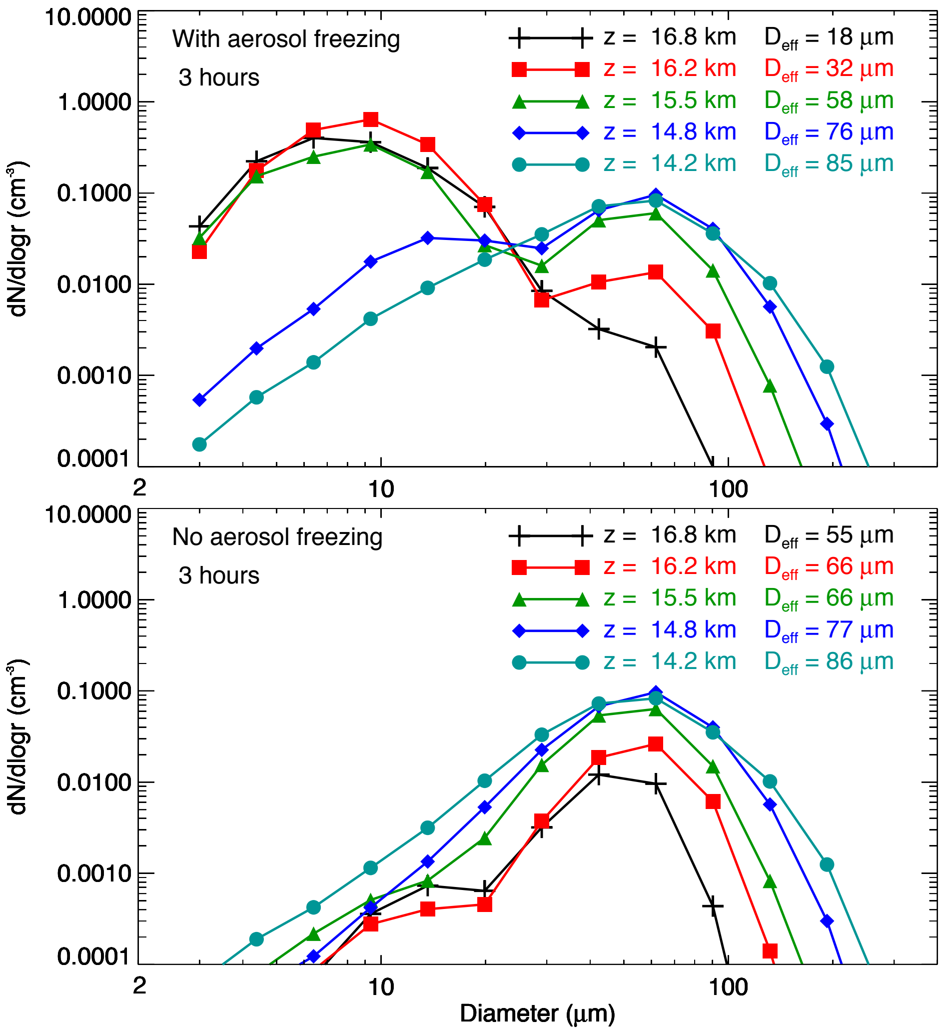
More backscattering --> small (<~20 μm) particles!

2. Explicit Microphysical Model (EMM, Phillips et al 2002, 2004)



CCN factor	D_e (μm)	$< 30\mu$m (cc^{-1})	$< 10\mu$m
3.16	54	83.5	24.4
1.00	71	32.3	4.8
0.32	70	12.1	0.01
0.10	90	2.7	0.01

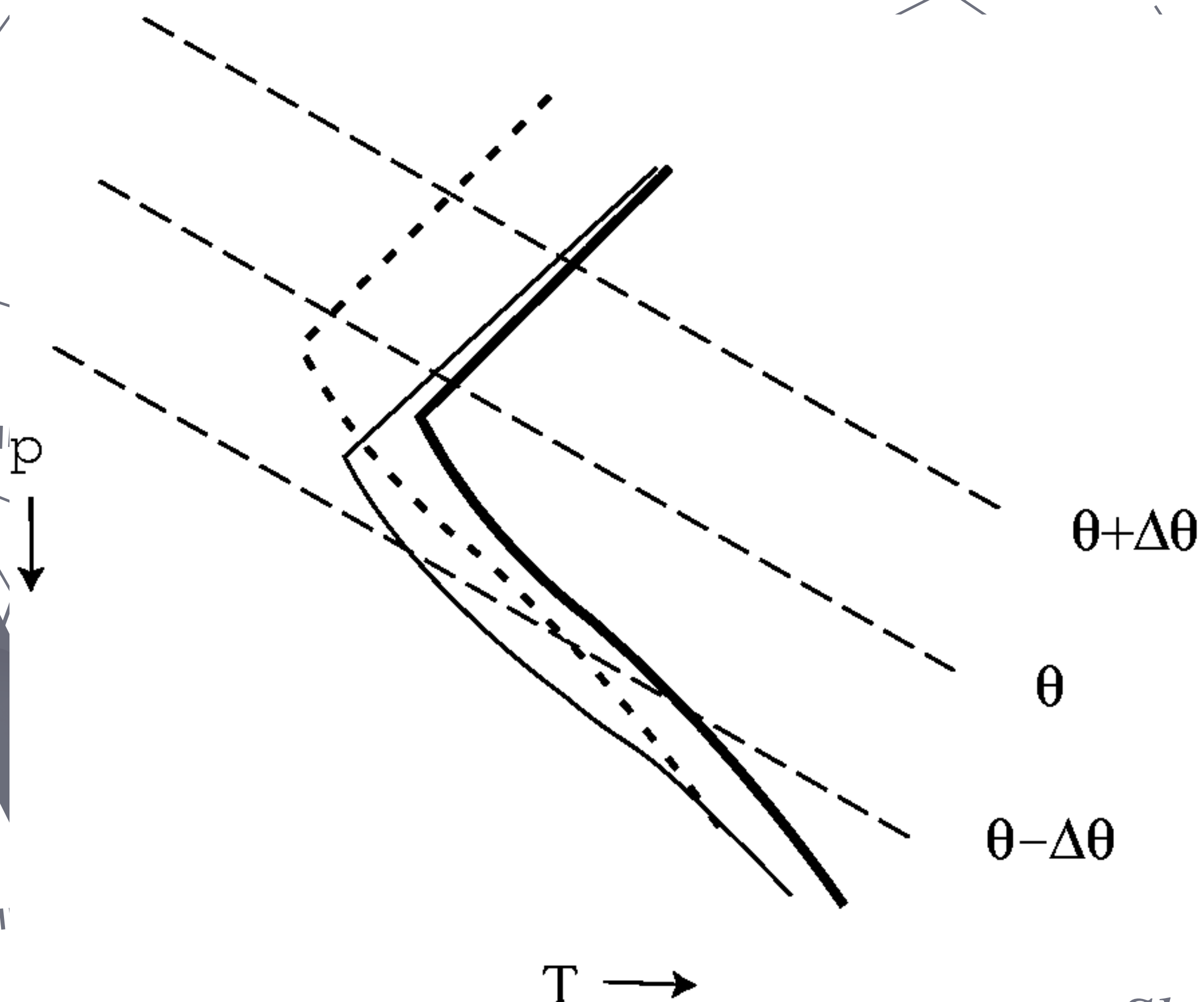
--> many more small particles (shutdown of warm rain)



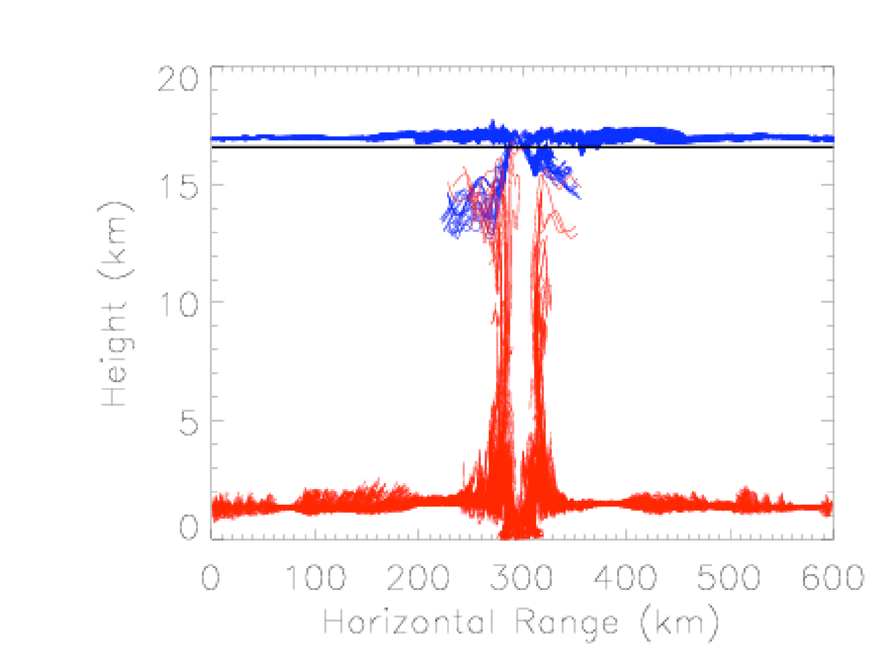
Jensen and Ackerman (2006) report a similar result due to increased *w*; homogeneous freezing (secondary nucleation)

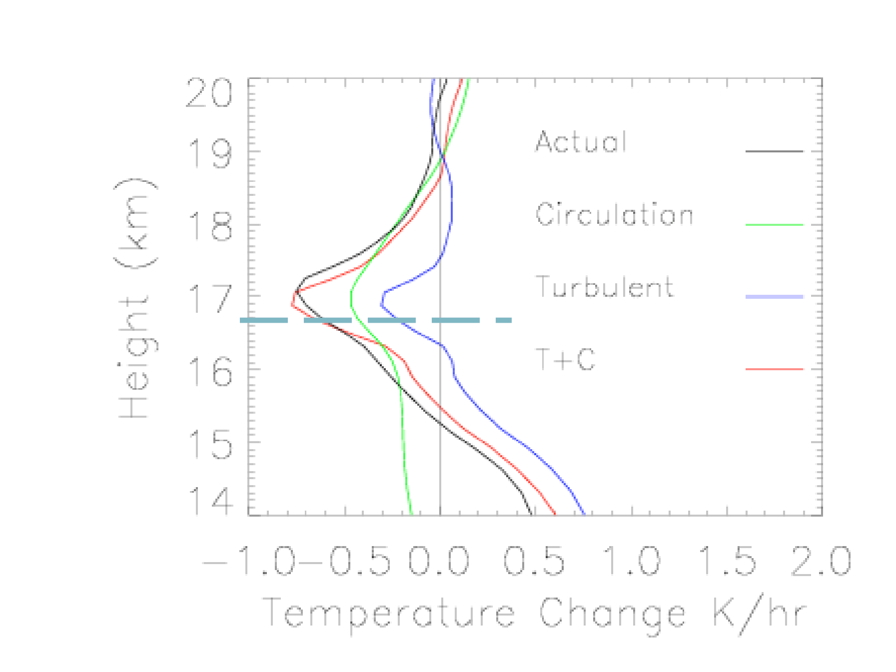
Temperature

Cold point is cooled, lowered by convective events



Sherwood et al. 2003





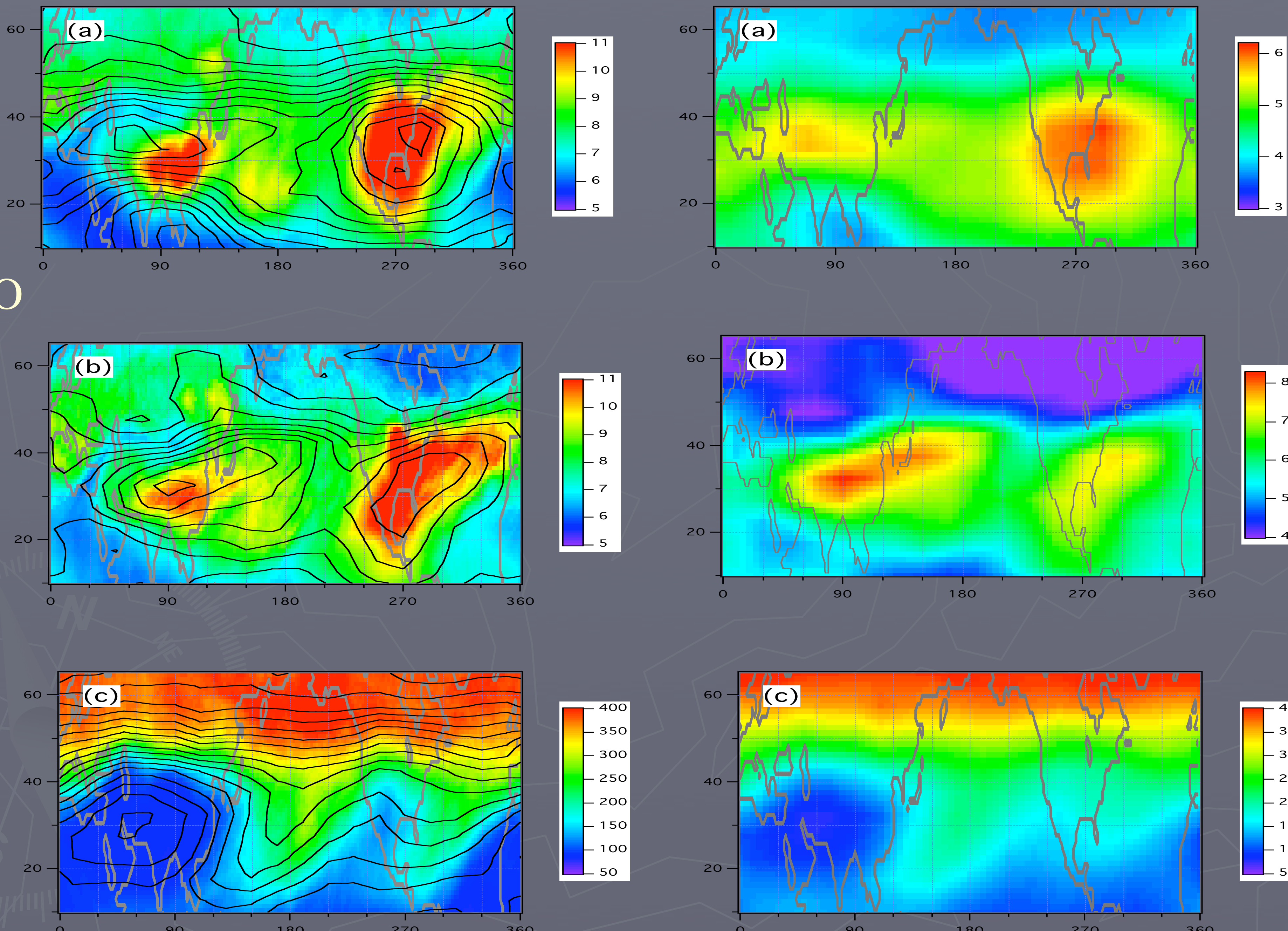
CRM simulations show deep convective cooling around cold point (Kuang and Bretherton 2004) and entrainment of stratospheric air into upper troposphere (Robinson and Sherwood 2006)

Energy Budget Dilemma

- TTL radiative heating is not balanced by Brewer-Dobson upwelling! (esp. over WP)*
- Two hypotheses to explain this:
  - Additional upwelling near tropopause, driven by local momentum fluxes and/or dissipative planetary waves (Highwood and Hoskins 1998, Boehm and Lee 2001) (*supported by 2001 cooling event*)
  - Convective cooling (Sherwood 2000 etc.) (*well tested*)

* Hartmann et al. 2001 explanation does not work!!

Other constituents

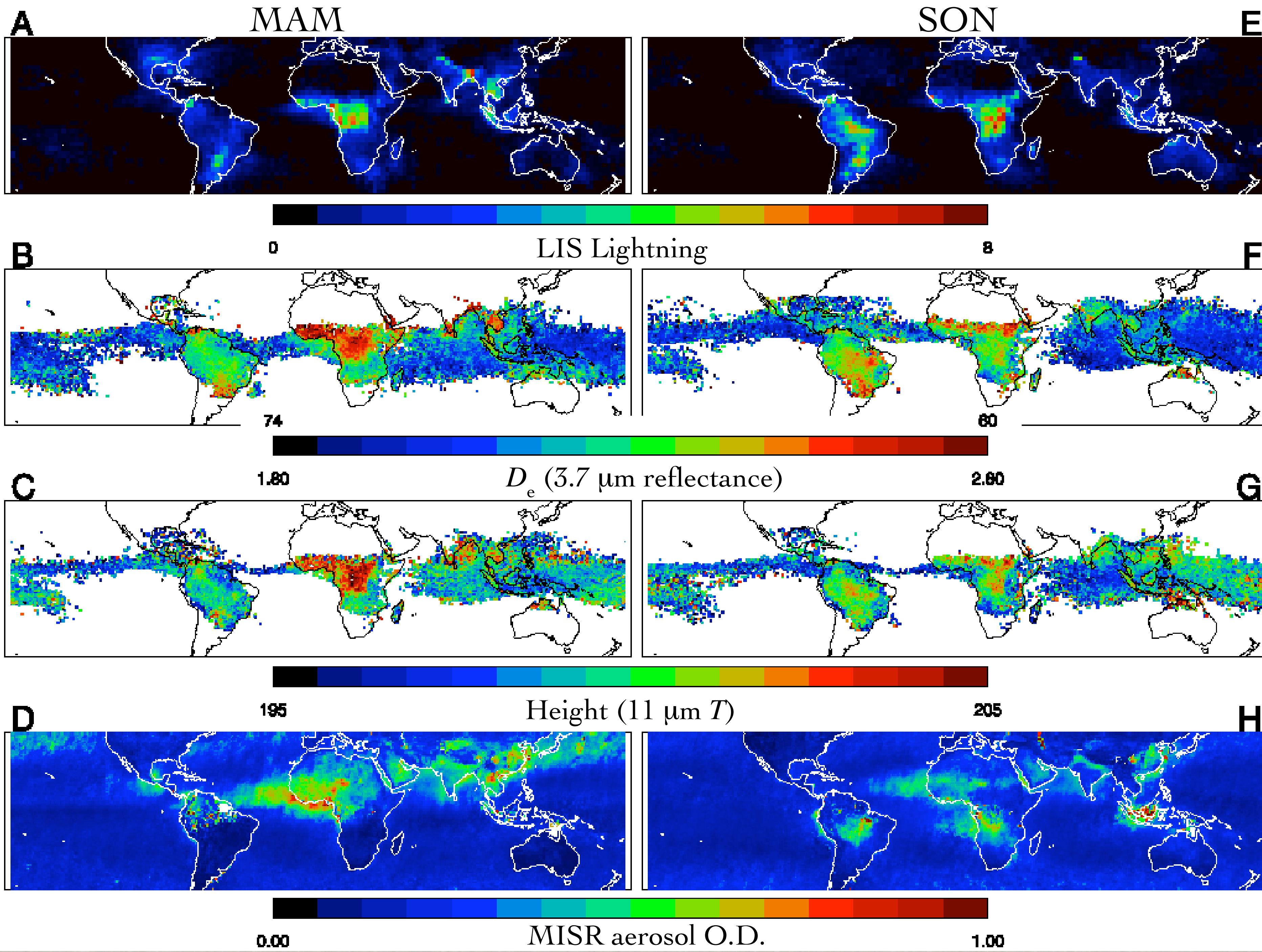


H_2O

O_3

Simulated

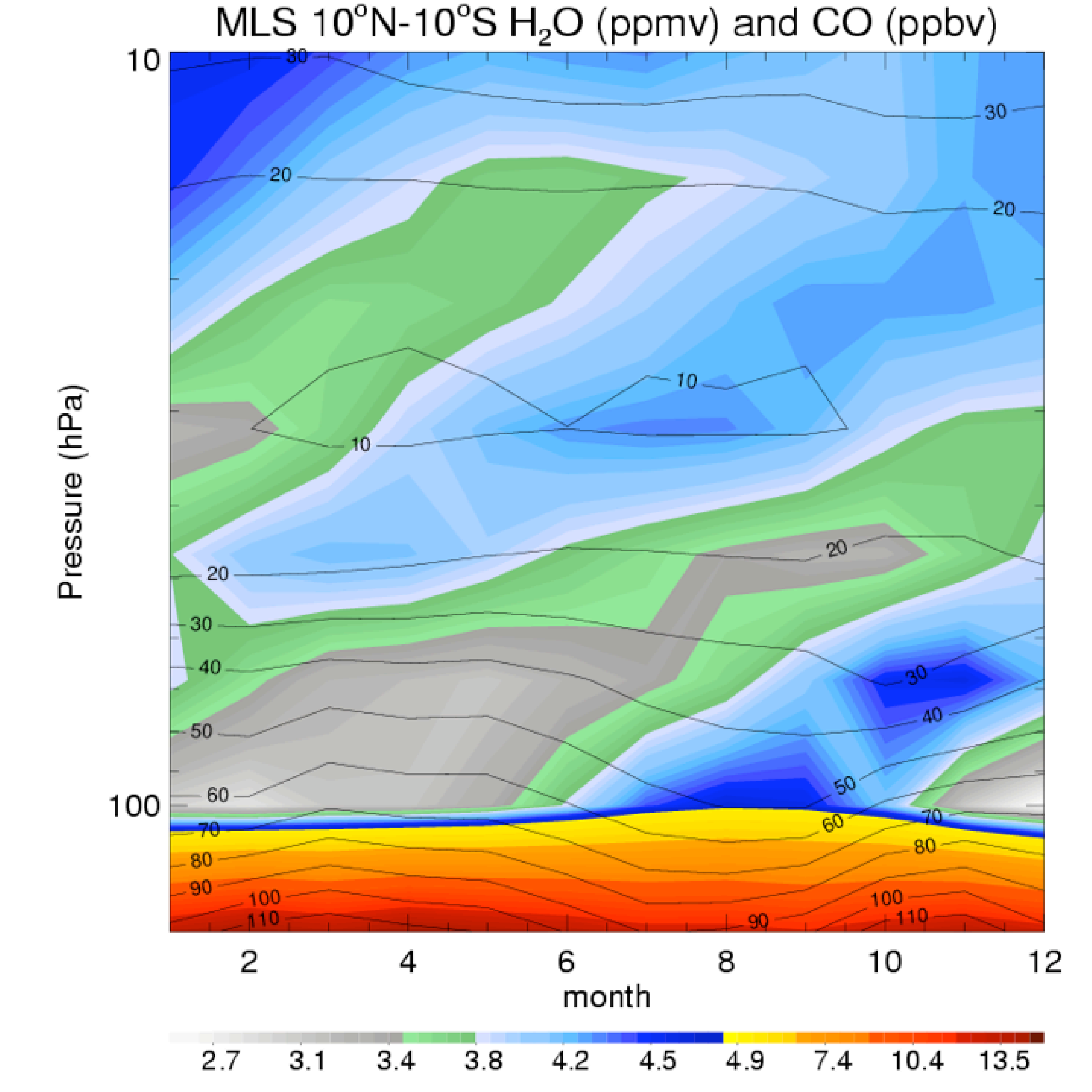
Observed



A
MAM
SON
E
LIS Lightning
0
8
B
F
74
60
De (3.7 µm reflectance)
1.80
2.80
C
G
Height (11 µm T)
195
205
D
H
MISR aerosol O.D.
0.00
1.00

Questions / goals

- Resolve energy budget dilemma M
- Quantify the impact of DCC on TL cirrus amount and characteristics M, D
- Better understand interplay between DCC moistening and in-situ dehydration as air ascends through TTL (can we explain the near-uniform isotopic ratio?) M, D
- Impact of UT, BL aerosol, *w* on DCC tops and outflows D
- Better understanding of DCC vigor M
- Better constraints on mixing at DCC tops D



MLS 10°N-10°S H2O (ppmv) and CO (ppbv)
Pressure (hPa)
10
100
2
4
6
8
10
12
month
2.7
3.1
3.4
3.8
4.2
4.5
4.9
7.4
10.4
13.5

Table 2. Convective intensity proxies of OPFs, MCSs and PFs with flashes over land and ocean.

Liu and Zipser, 2005

		Population (#)	Area (km^2)	Z_{20dBZ} (km)	Z_{40dBZ} (km)	PCT_{85} (K)	PCT_{37} (K)	OPFs with Flashes (%)	Flashes (#)	
Ocean	OPFs 14 km	34567	11695	15.2	6.0	154.7	255.2	37	3	
	OPFs LNB_{sfc}	14515	12431	15.6	6.2	151.1	253.7	41	4	
	OPFs $LNB_{925\&1000}$	14370	12546	15.6	6.2	150.3	253.4	41	4	
	OPFs Z_{trop}	3497	17086	16.9	7.0	133.8	242.6	60	11	6.6/storm
	OPFs Z_{380K}	1600	18082	17.4	7.2	131.8	238.3	66	18	
	MCSs	39255	20465	13.4	5.8	160.6	253.5	27	2	
	PFs with flashes	29659	7080	12.9	6.0	170.3	257.8	100	5	
Land	OPFs 14 km	37422	5309	15.5	7.9	148	247.2	86	17	
	OPFs LNB_{sfc}	13496	5141	15.8	8.1	143.5	245.7	87	18	
	OPFs $LNB_{925\&1000}$	15985	6004	16.0	8.3	137.9	242.1	88	22	
	OPFs Z_{trop}	6144	7281	17.0	10.0	119.5	228.1	92	38	
	OPFs Z_{380K}	3912	7491	17.4	10.7	114.7	223.2	92	47	
	MCSs	21526	14757	14.0	7.2	146.1	242.6	75	20	15/storm
	PFs with flashes	75260	3633	12.8	6.7	183.7	259.5	100	9	

... lightning more prevalent over land, even compared to tropopause-penetrating maritime storms!

... the latter are much taller but the former have more large particles at lower levels