CLASSIFYING ICE WATER CONTENT PROFILES OF HIGH-LEVEL CLOUDS FROM AIRS/CALIPSO/CLOUDSAT OBSERVATIONS TO BETTER ASSESS CLOUD RADIATIVE EFFECTS

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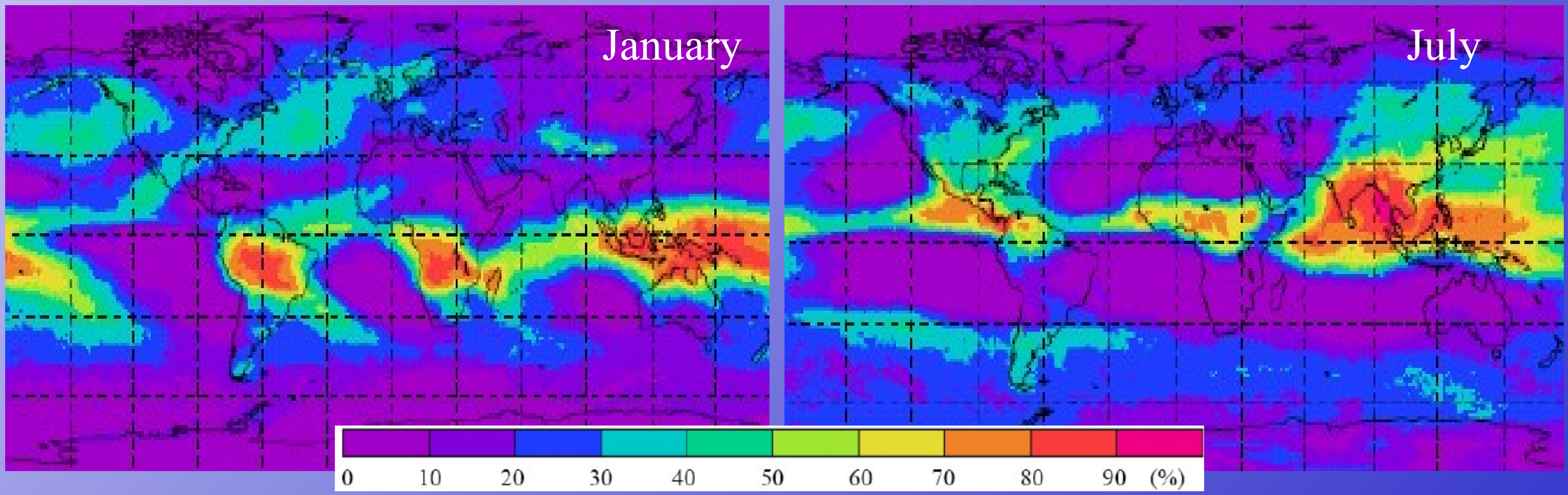
High-level clouds

- High-level clouds: $P_{cloud} < 440$ hPa
- 40-50% (including subvisible Ci) of all clouds
- Tropics: 60%, NH midlatitudes: 40%, SH midlatitudes: 30%
- 10% more high-level clouds over land than over ocean
- Opaque clouds: $\varepsilon_{cld} > 0.95$ 11%
- Cirrus: $0.5 < \varepsilon_{cld} < 0.95$ 44%
- Thin Cirrus: $\varepsilon_{cld} < 0.5$ 45%

  (from AIRS, *Stubenrauch et al., ACP 2010)*

High level cloud amount



How does IWC(z) affect radiative energy balance?

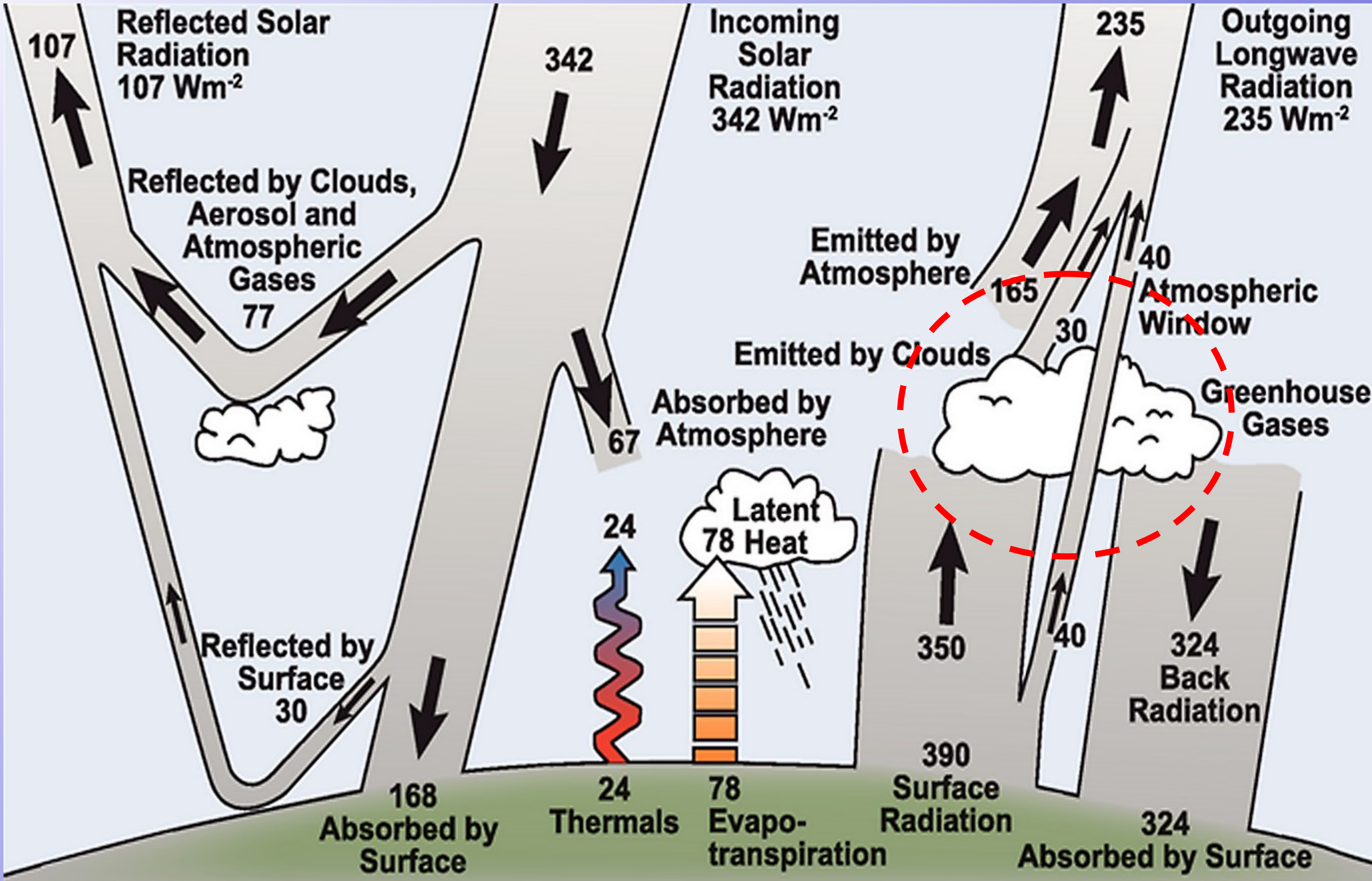
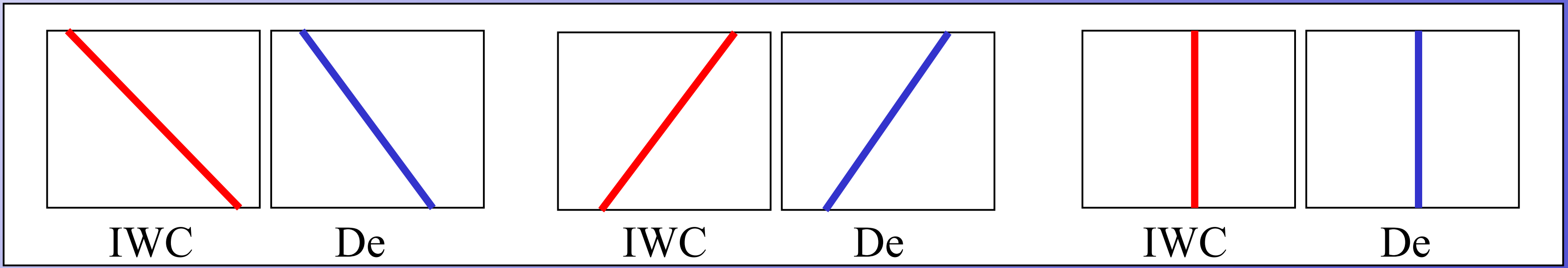


Image credit: IPCC, http://www.ipcc.ch

Motivation

- Knowledge of cloud amount and IWP may be not sufficient for calculating radiative transfer in ice clouds.
- The same IWP can have different IWC(z) profiles
- Applications in GCMs: radiative flux calculations
- Retrieval of bulk microphysical properties (De, IWP) from infrared satellite observations.



Experimental information available for studies:

- Active instruments (radar/lidar) provide IWC(z) & De(z) since 2006
- A-Train synergy (AIRS-CALIPSO-CloudSat)

A-Train Synergy: Level 2 data

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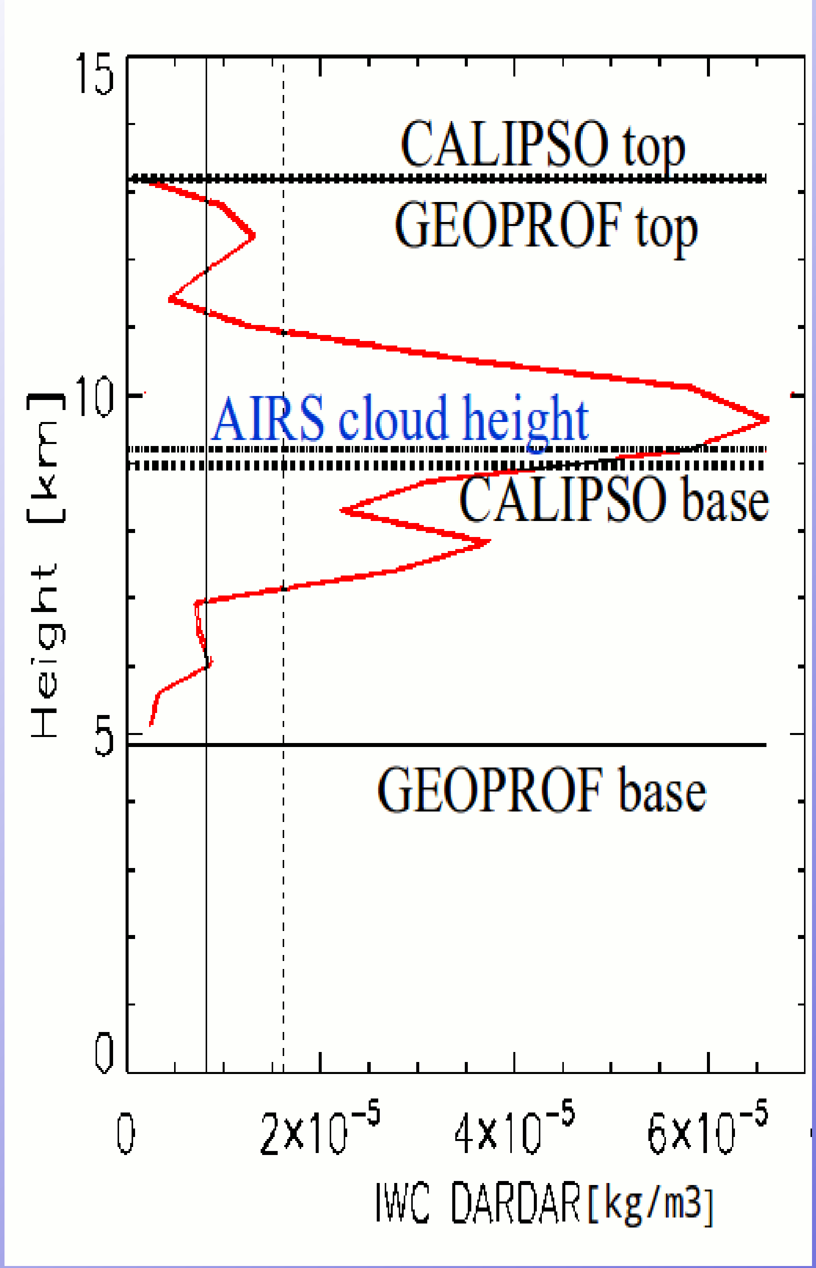
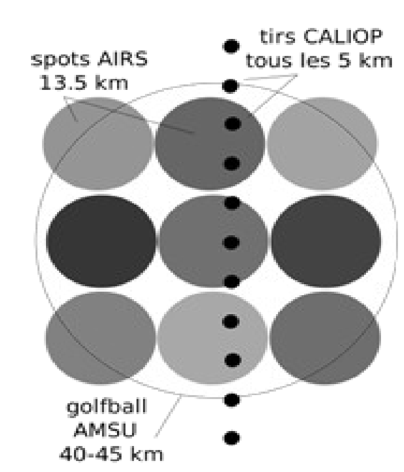


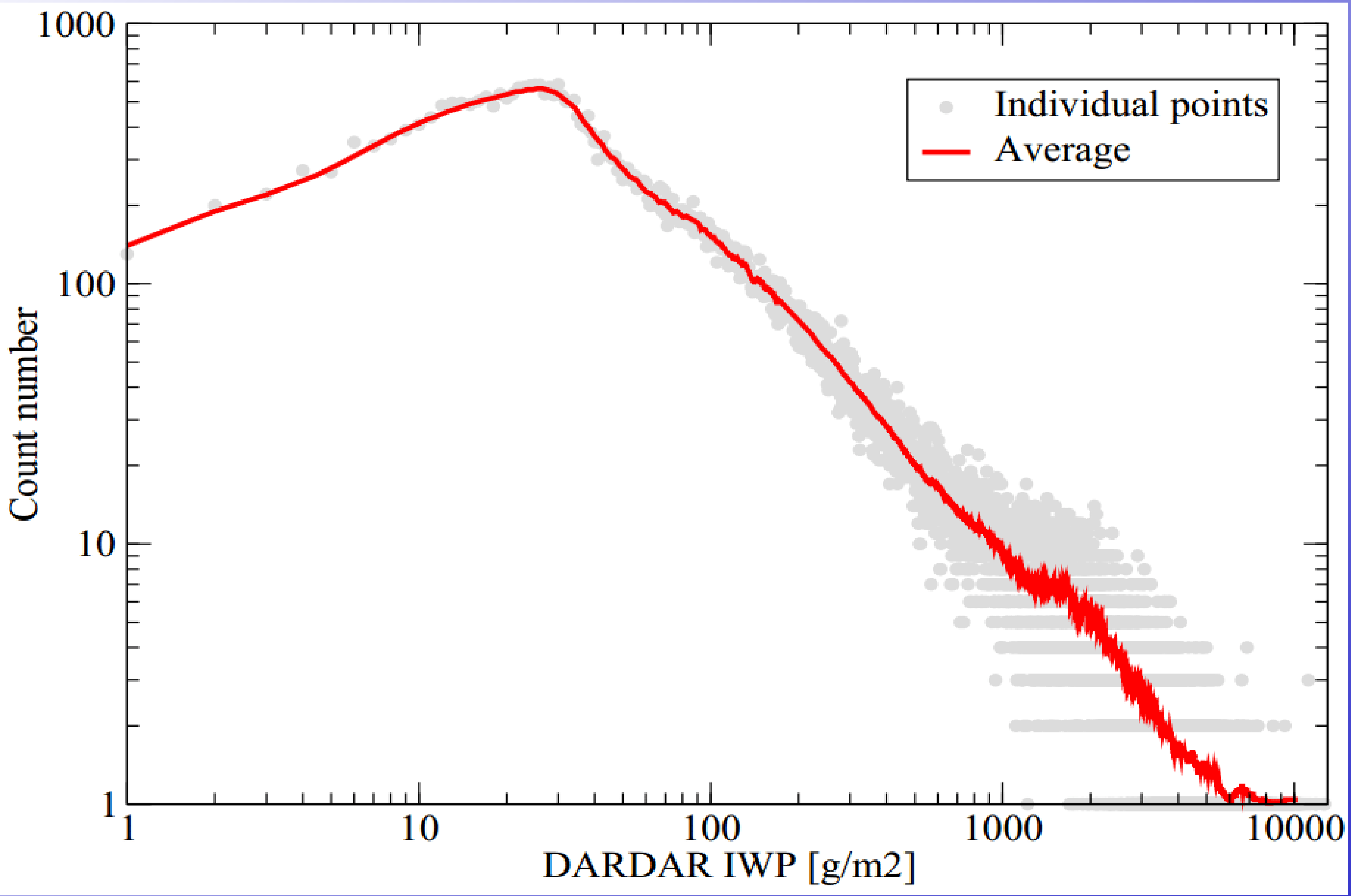
- **AIRS-LMD** *(Stubenrauch et al. 2010)* : P, ε of uppermost cloud -> cloud types De, IWP of semi-transparent cirrus, aggregates/column
- **CALIPSO V3 5km** *(Winker et al. 2012)* : sub-visible Ci, cloud top, apparent base, thermodynamical phase
- **Lidar-Radar GEOPROF V4** *(Mace et al. 2009):* number of cloud layers, cloud top & base height
- li**DAR**rad**DAR** *(Delanoë and Hogan 2010)* : retrieval profiles of thermodynamical phase, IWC(z), De(z).
- **ERA-Interim reanalyses**: winds, H_2O column



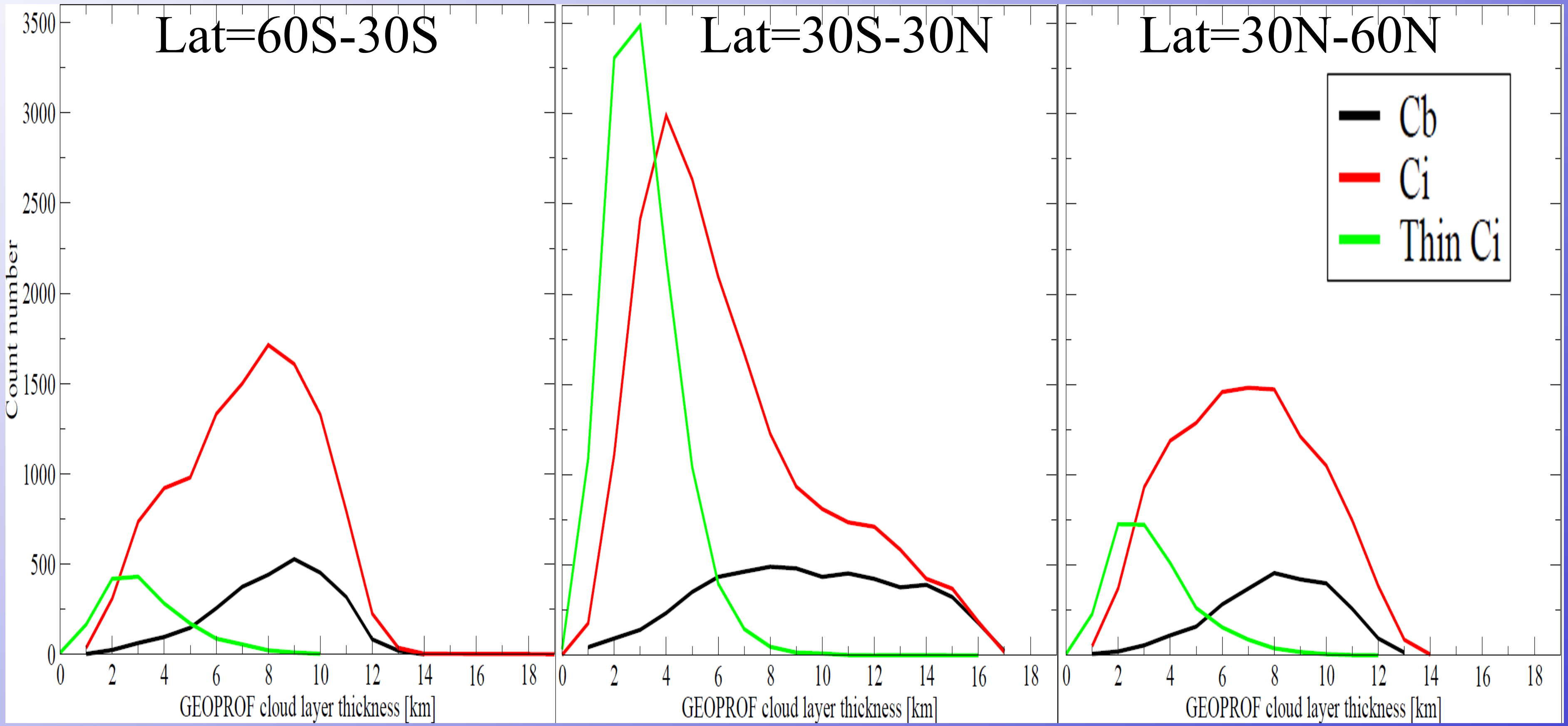
Observation parameters:

- AIRS has 9 × 13.5 km spots per "golf ball"
- CALIOP's footprint is 300 m, 5 km apart
- same orbit, good spatio-temporal overlaps

DARDAR Ice water paths

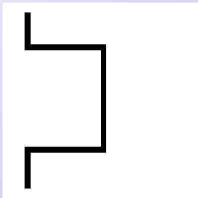


A-Train synergy: vertical extent of different cloud types

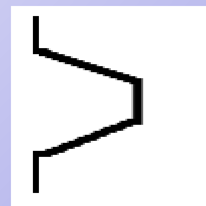


- vertical extent increases from thin Ci to optically thicker high-level clouds
- clouds thicker in SH than in NH midlatitudes (& in winter than in summer)
- vertical extent of thin Ci limited to about 5 km
- climatology of cloud vertical extent per cloud type is an important input for Earth radiation budget

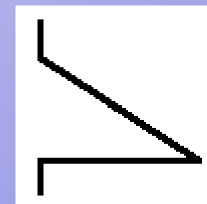
Classification of IWC(z)



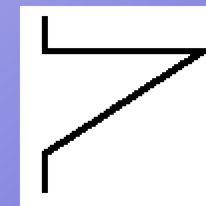
Boxcar



Trapezoid

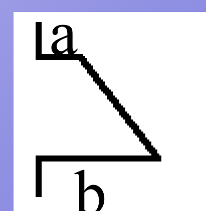


Lower triangle



Upper triangle

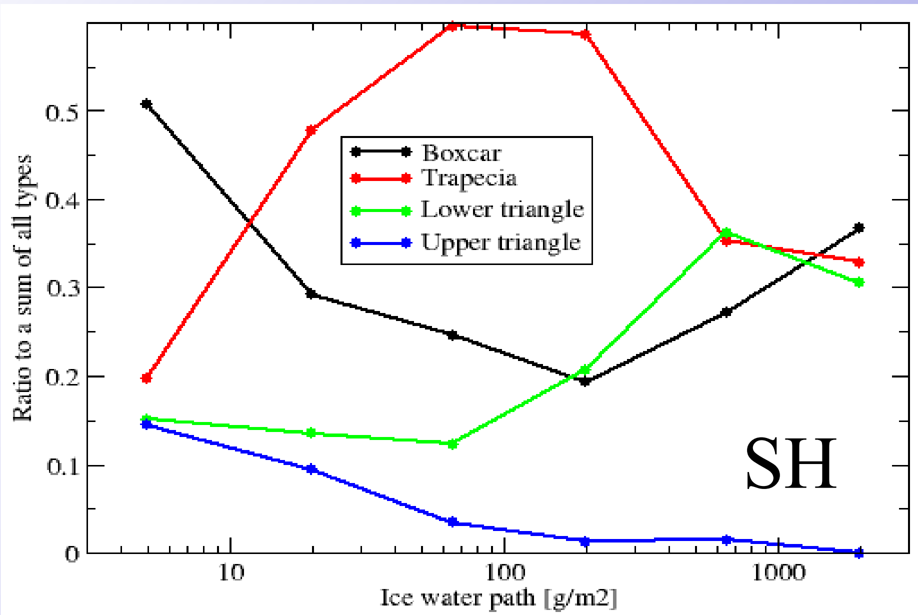
Classification of De(z)

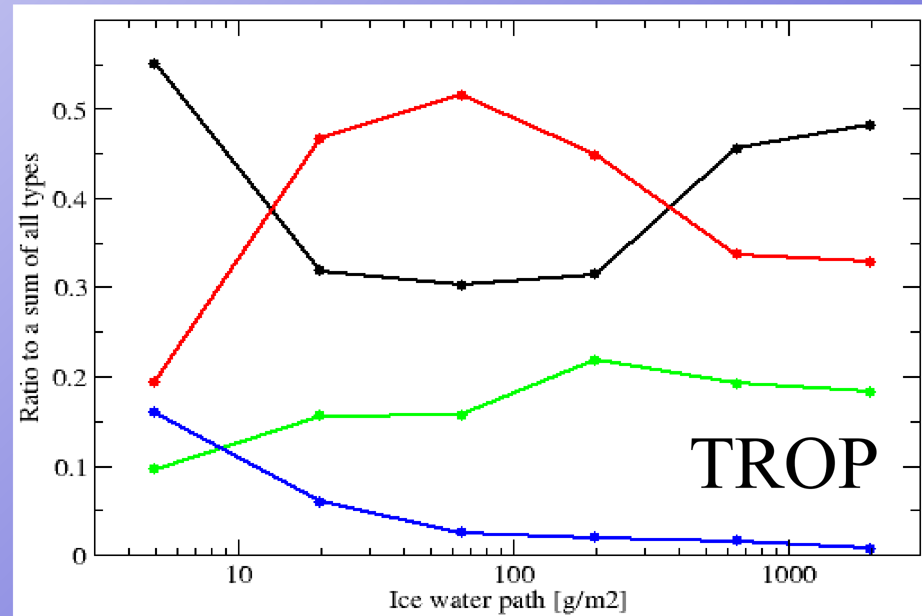


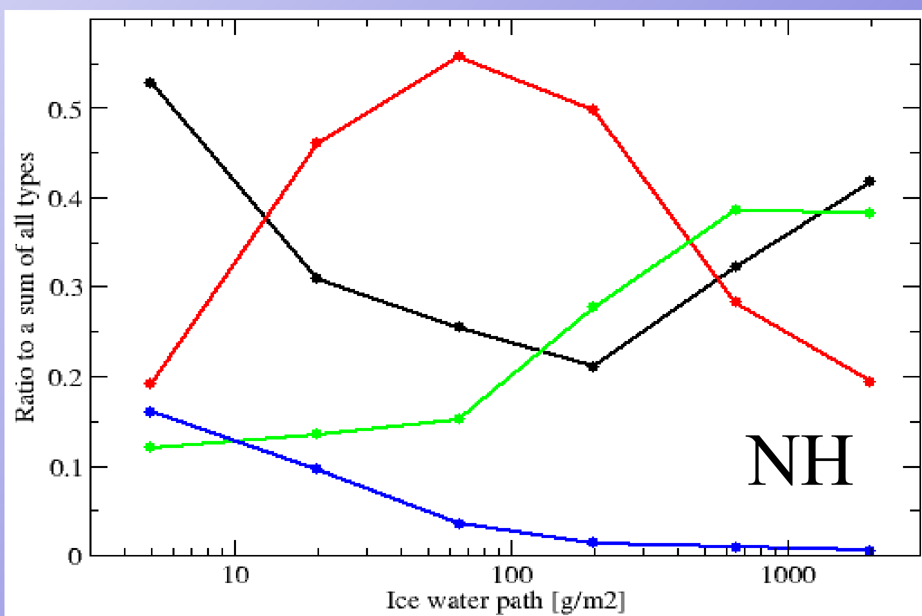
a:b = 1:2, 2:3, 3:4

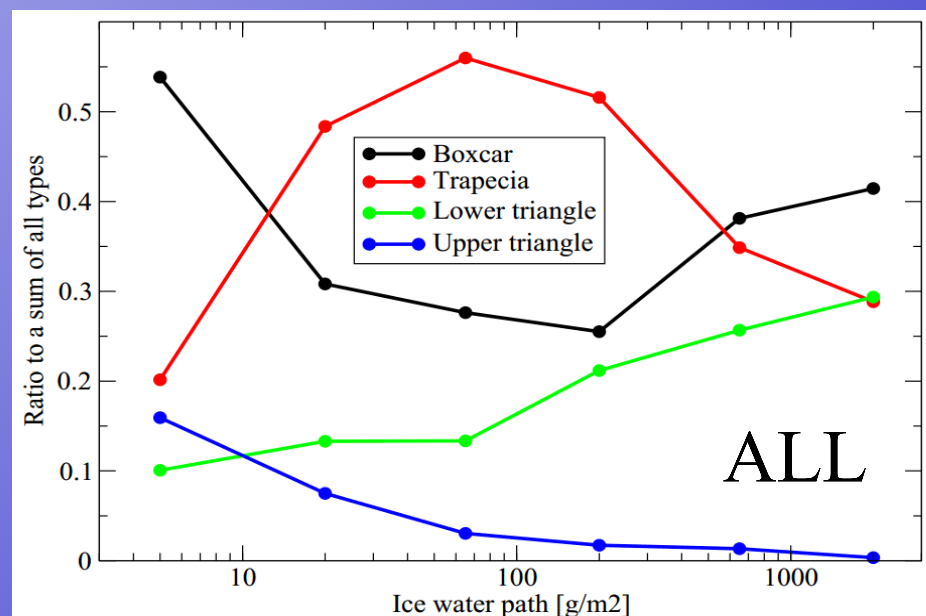
Profile types vs latitude/longitude, IWP, w,u,v, H_2O, etc?

IWC(z) type dependence on IWP







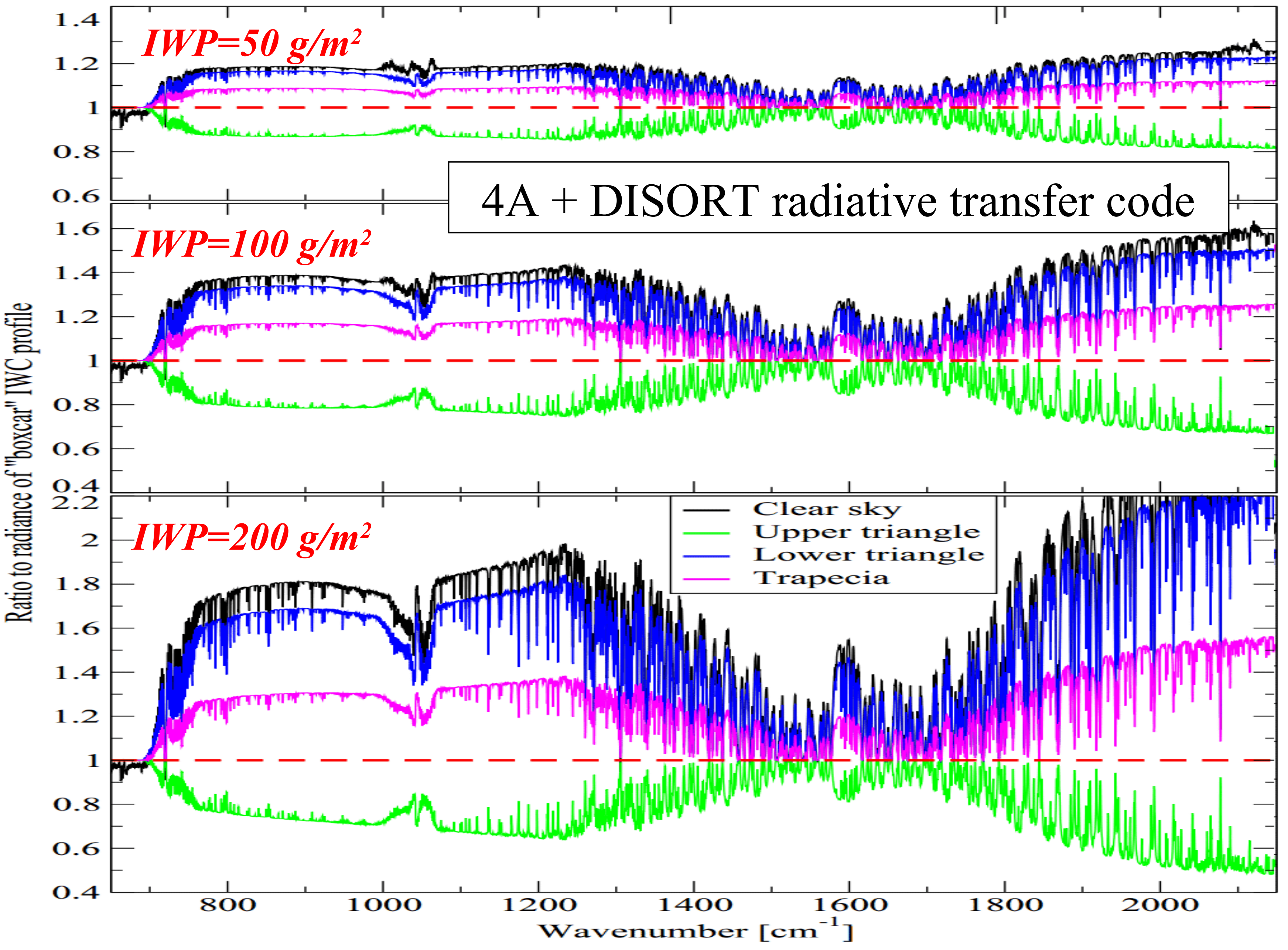


Vertical IWC profile type statistics

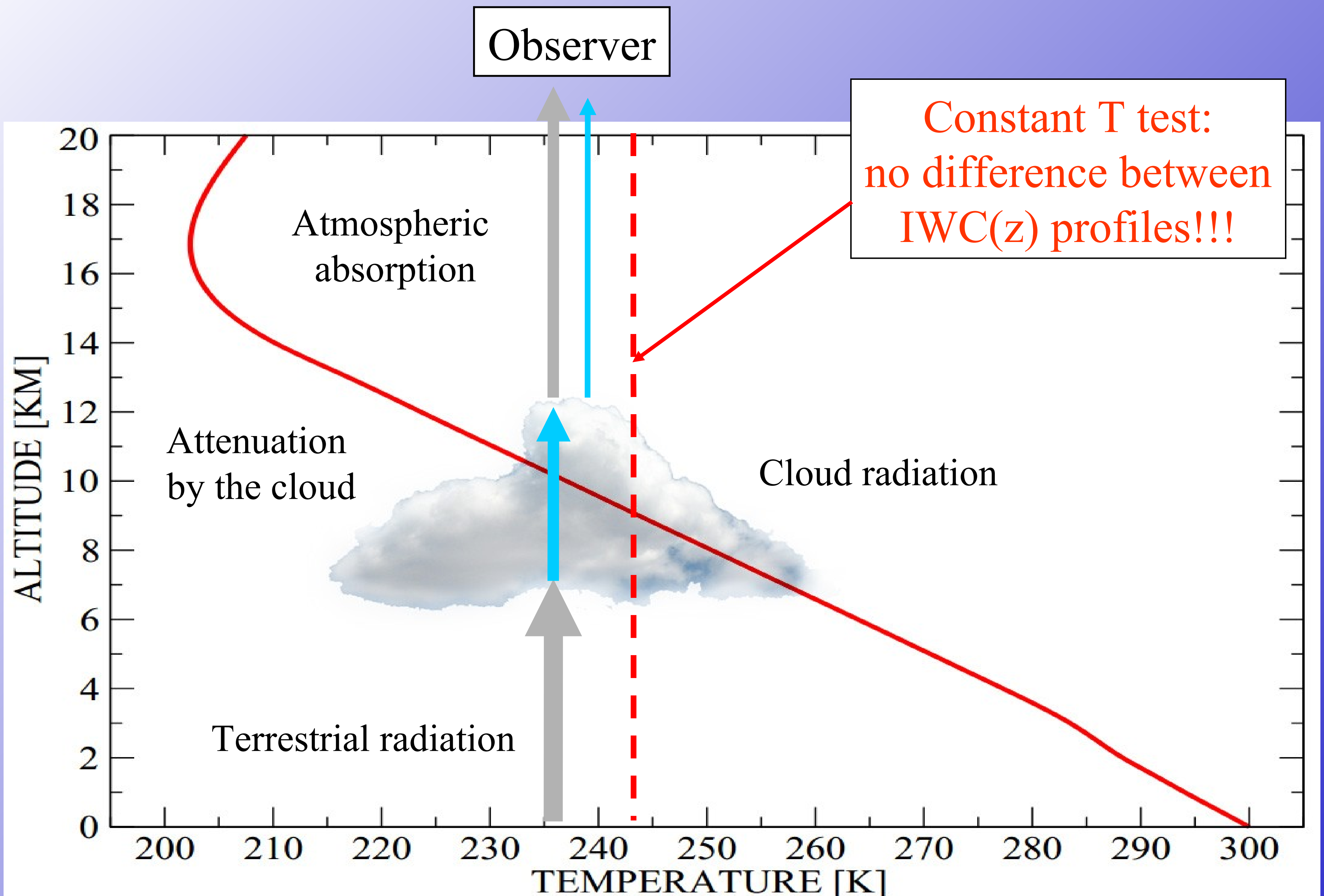
IWP (g/m2)	boxcar	trapecia	lower triangle	upper triangle	Histogram value
0-10	**54%**	**20%**	**10%**	**16%**	**51%**
10-30	**31%**	**48%**	**13%**	**8%**	**29%**
30-100	**28%**	**56%**	**14%**	**3%**	**17%**
100-300	**26%**	**51%**	**21%**	**2%**	**3%**
300-1000	**38%**	**35%**	**26%**	**1%**	**<1%**

- "Boxcar" and trapecia correspond to 80% of the profiles !
- Lower triangles increase with IWP from 10 to 26%
- Upper triangles only for IWP < 30 g/m2
- Only strong vertical wind affects upper/lower triangles

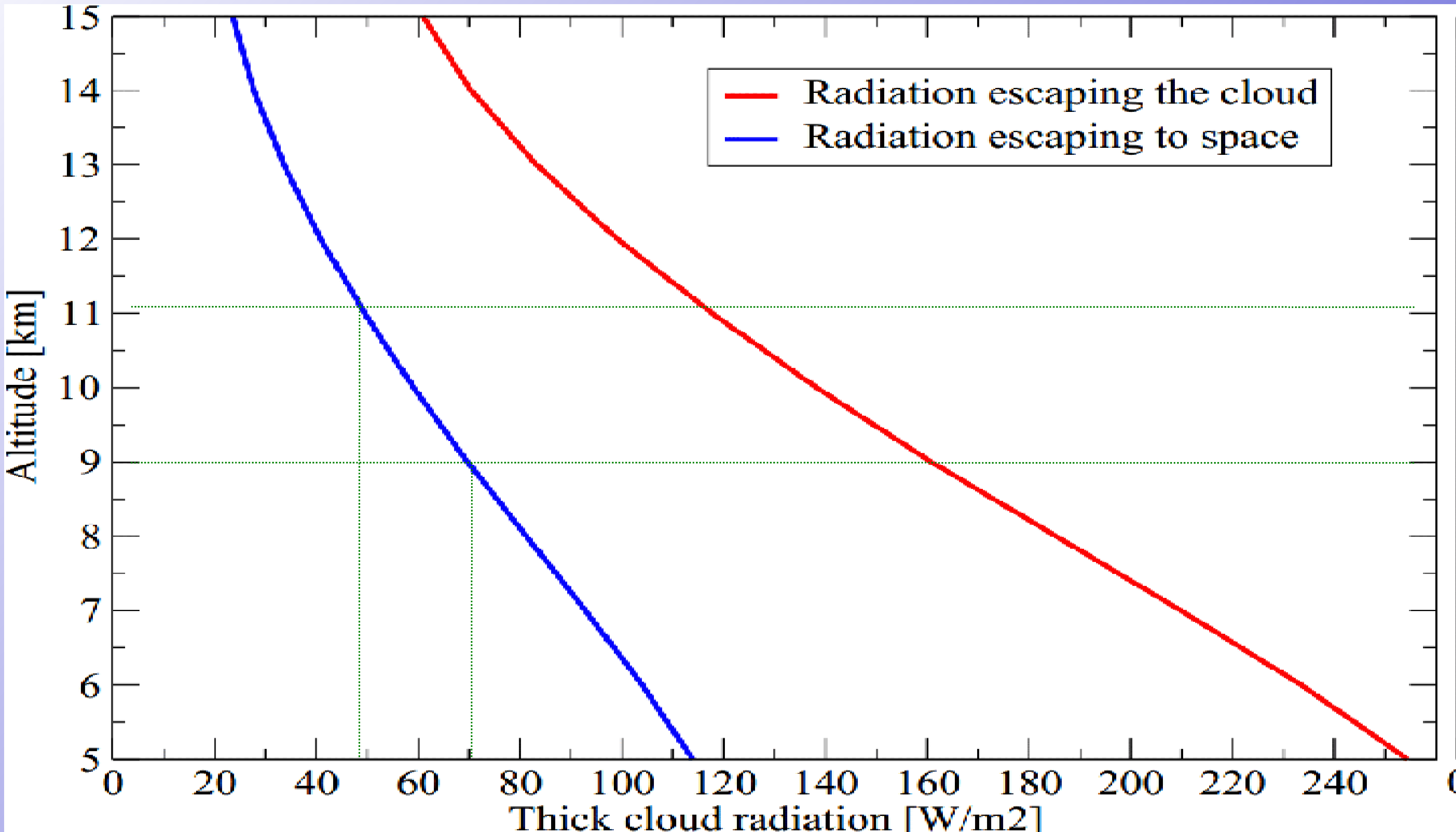
Radiative effects: comparing to boxcar profile



Radiative effects: explanation



Radiative effects: cooling the atmosphere



- For lower triangles vs boxcar cloud type, ΔZ_{eff} = 2-3 km
- Optically thick clouds: ~20-30 W/m^2 stronger cooling of atmosphere
- If averaged over all clouds, the effect reduces to ~2 W/m^2 extra cooling

Conclusions

- IWC(z) profiles analyzed for 3 years of global observations: the results for the upper ice cloud do not depend on a number of cloud layers/type below.

- 80% of the clouds can be represented by boxcar / trapezoid

- Lower triangle clouds ratio increases while the ratio for upper triangle clouds decreases with IWP increase

- Radiative effects of different IWC(z) profiles are explained by thermal radiation of the cloud and T(z) variation

- Energetic effect of using boxcar cloud type instead of real distributions is underestimation of atmospheric cooling rate by ~2 W/m2

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