VERTICAL STRUCTURE OF HIGH-LEVEL CLOUDS FROM SATELLITE OBSERVATIONS: RADIATIVE EFFECTS

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Motivation

• Radiative transfer in semi-transparent clouds: application in GCMs and cloud retrieval algorithms.
• Radiative transfer dependence on IWC(z) and De(z) vertical distributions: same IWP can be formed in a number of ways.
• Source of information - collocated cloud observations
  - passive sounders (TOVS, ATOVS, AIRS, IASI (1,2,3), IASI-NG) vs active sounders (radar/lidar)
  - good coverage vs peculiarities of the vertical structure
• A-Train synergy (AIRS-CALIPSO-CloudSat).
Level 2 data used in this work

**GEOPROF V4** (Mace et al. 2009): based on CloudSat cloud profiling radar and CALIPSO lidar measurements; retrieves cloud top, cloud base, number of cloud layers

**CALIPSO V3 5km**: sub-visible cirrus, H, T, P, cloud type, and thermodynamical phase.

**DARDAR** =liDAR+raDAR: (Delanoë and Hogan, 2010): Optimal estimation retrieval for ice clouds, profiles of thermodynamical phase, IWC, De.

**AIRS**: cloud pressure, IR emissivity of the uppermost cloud, Bulk microphysical properties of semi-transparent cirrus using spectral emissivity differences: De, IWP, aggregates/columns.

Additional data: w,u,v winds and total H₂O (ECMWF)
Example of co-located data
Averaged $IWC(z)$ distributions

Non-linearity: energetic effect of

$$\tau(1hr) + \tau(1hr) \neq 2\tau(1hr) + 0\tau(1hr)$$

Modeling clouds = cloud amount + cloud prof. $IWC(z), De(z)$
Classification of IWC(z) and De(z)

Boxcar  Upper triangle  Lower triangle  Trapecia

\[ \frac{a}{b} = 1:2, \ 2:3, \ 3:4 \]

Profile types vs latitude/longitude, IWP, w, u, v, H_2O, etc?
IWC(z) type dependence on IWP
Radiative effects: comparison to boxcar type

$IWP=100 \text{ g/m}^2$

4A+DISORT radiative transfer code

Ratio to radiance of "boxcar" IWC profile

Wavenumber [cm$^{-1}$]
Radiative effects: varying IWP

IWP=50 g/m²

IWP=100 g/m²

IWP=200 g/m²
Radiative effects: explanation

Observer

Atmospheric absorption

Attenuation by the cloud

Cloud radiation

Terrestrial radiation
Conclusions

• Presence of liquid water in the lower part of the cloud does not change the ratio of IWC(z) types compared to “pure ice” clouds.
• Uppermost clouds in multiple layer systems have different IWC(z) types ratio for IWP>100 g/m².
• “Boxcar” type of IWC(z) profiles dominate at small IWPs and for larger IWPs its ratio becomes equal to that of “trapecia”.
• The number of “upper triangle” shapes is negligible for IWP > 30 g/m².
• The ratio of “lower triangles” increases with IWP and reaches ~25% for IWP>300 g/m².
• IWC(z) profile depends on vertical wind for IWP>300 g/m².
• Radiative effects of different types of profiles are linked with thermal structure of atmosphere and vertical size of the cloud.
Extra slides
• Presence of liquid water in the lower part of the cloud does not change the ratio of IWC(z) types compared to “pure ice” clouds.
• Uppermost clouds in multiple layer systems have different IWC(z) types ratio for IWP>100 g/m².
• “Boxcar” type of IWC(z) profiles dominate at small IWPs and for larger IWPs its ratio becomes equal to that of “hacked box”.
• The number of “upper triangle” shapes is negligible for IWP > 30 g/m².
• The ratio of “lower triangles” increases with IWP increase and reaches ~25% for IWP>300 g/m².
• IWC(z) profile doesn’t depend on w_500 for IWP<300 g/m².
• For IWP>300 g/m², the effects of updraft and downdraft become visible in the number of low triangle and hacked box profiles.
Further analysis

- Cluster analysis using AIRS observations

- $IWC(z)$ versus:
  - size of the cluster
  - type of the cluster
  - position in the cluster

Machado & Rossow, 1993