Towards a complete description of clouds: Synergies between geostationary & polar-orbiting, A-Train lidar-radar & passive instruments

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Discussion Outline

- Leo complement at higher latitudes → polar clouds
- Temporal resolution / day-night consistency → diurnal cycle processes
- Cloud System Approach & applications

How to get a more complete cloud picture?

- vertical structure from lidar-radar nadir tracks only
  1) classify along track wrt ISCCP cloud types (Rossow & Zhang 2010)
  2) expand by linking to cloud properties from sounders / radiometers & environment from reanalyses
- complementary databases
- precipitation, aerosols, radiative fluxes, atmospheric state
good temporal resolution vs sensitivity / day-night coherence: *diurnal cycle of high clouds*

- ISCCP is driven towards the diurnal cycle of optically thicker clouds

![Graph showing diurnal cycle of high clouds in different regions](image)

**AIRS-IASI summer**
- ISCCP
- CATS

**NH midlatitudes**

**Tropics**

*Feofilov & Stubenrauch, ACP, 2019, in press*

Database of mean amount, diurnal amplitude & peak time per cloud type
- 1° x 1°, monthly
- 2008-2015

Assume harmonic functions as in Cairns 1995
Getting a complete cloud picture for advancing our understanding on UT cloud feedback

GEWEX PROcess Evaluation Study on Upper Tropospheric Clouds & Convection

critical to climate feedback of UT clouds: cirrus radiative heating in UT

Heating will be affected by:
- areal coverage
- horizontal emissivity structure
- vertical structure (layering)

Climate warming: change in convective intensity & coverage, height of convective systems & emissivity structure of the anvils?

This then affects the heating gradients -> large-scale circulation

Goal: understand relation between convection & radiative heating induced by cirrus anvils

Method:
1) IR Sounders provide cloud height & emissivity; sensitive to cirrus
2) Cloud System Concept relates the anvil properties to processes shaping them
3) expand radar-lidar nadir track vertical structure laterally across UT cloud systems
From cloud retrieval to cloud systems

**Clouds** are **extended objects**, driven by dynamics -> organized systems

**Method:** 1) group adjacent grid boxes with high clouds of similar height ($p_{cld}$)

- Fill data gaps using PDF method
- Build UT cloud systems

2) use $\varepsilon_{cld}$ to distinguish **convective core**, **thick cirrus**, **thin cirrus**

30N-30S: UT cloud systems cover 20%, those without convective core 5%
50% of these originate from convection *(Luo & Rossow 2004, Riihimaki et al. 2012)*
link anvil structure to convective depth

15 years AIRS-CIRS (Stubenrauch et al. 2017); **tropical mature UT cloud systems**; convective core (Cb): \( \varepsilon_{\text{cld}} > 0.98 \); Cb fraction within system 0.1 – 0.3

Deeper convective cores \( \rightarrow \) stronger max rain rate
\( \rightarrow T_{\text{cb min}} \) good proxy for convective depth

Deeper convection leads to relatively more thin cirrus within larger anvils
(similar land / ocean)

**Why?**

H1: UT environmental predisposition (at higher altitude larger RH, T stratification)
H2: UT humidification from cirrus outflow

Does the relationship change in a warmer climate?
UT Cloud System Concept to assess GCM parameterizations

Cloud System Concept relates anvil properties to processes shaping them
-> process-oriented evaluation of detrainment / convection / microphysics parameterizations

Example: Towards coherent bulk ice cloud scheme deduced from thermodynamics in LMDZ

New process-oriented diagnostics based on Cloud System Concept powerful constraint:
more realistic $v_m - D_{eff}$ -> more realistic anvil size & $\varepsilon$ horizontal structure (increasing thin Ci) development
Tuning adjustment of UT sub-grid water variability (RQH) -> larger anvils & more thin cirrus

Stubenrauch et al., 2019

data
control $v_m = 0.3 \times f(IWC)$
$D_e = f(T)$
empirical $v_m(IWC,T) \& D_e(v_m)$
PSDM $v_m \& D_e(v_m)$
PSDM $v_m \& D_e$
link anvil heating rates to convective depth

via a complete 3-D description of UT cloud systems & their environment (from ERA-Interim / ERA5)

1) **along nadir tracks:**
categorize NASA CloudSat-CALIPSO vertical structure & heating rates wrt cloud type \( (p_{\text{cld}} \text{ & } \varepsilon_{\text{cld}}) \) from AIRS-CIRS

2) **expand nadir track info across UT cloud systems & environment:**
develop optimized ‘non-linear regression models’:
deep neural network learning techniques relate most suitable cloud & atmospheric properties from IR sounders & meteorological reanalyses to vertical structure & heating rates
1) heating rates of UT cloud systems, sampled along track

NASA CloudSat-CALIPSO FLXHR heating rates collocated to AIRS-CIRS UT cloud systems; classified by cloud type within systems

- Clear distinction of heating associated with each category
- Cold convective systems have a larger thin Ci heating
2) Expand nadir track vertical structure via deep learning

1) develop optimized ‘non-linear regression models’
2) apply models to AIRS-ERA data (2003 – present) & to IASI-ERA data (evaluate with ARM measurements)

-> extend 3D information for process & climate studies

Cloud LW HRs over tropical band

UT: strong warming of UT by thin Ci, strong cooling above Cb & thick Ci anvil
MT: warming by Cb, thick Ci anvil
LT: warming by Cb, cooling above low clouds (also underneath Ci & thin Ci)
Expanded radiative LW heating rates: specific levels

apply cloud & clear sky models to AIRS-ERA data

Preliminary Jan 2008

1 model over ocean & land separate models ocean / land CloudSat-CALIPSO nadir tracks

- 106hPa
- 200 hPa
- 525 hPa
- 850 hPa

- predicted HRs over whole tropical band similar to nadir track, but giving a much more complete picture -> process studies
- model dependent differences over land (-> more investigation)

UT: strong warming by thin Ci, strong cooling above Cb & thick Ci anvil

MT: warming by Cb & thick Ci, cooling above low clouds

LT: warming by Cb, cooling above low clouds (also underneath Ci & thin Ci)
**Constrain IWC profile shape by IWP**

Collocated AIRS-CIRS – DARDAR data

<table>
<thead>
<tr>
<th>IWP (g/m²) (occurrence)</th>
<th>constant</th>
<th>trapezia</th>
<th>increas</th>
<th>decreas</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10 (18%)</td>
<td>42%</td>
<td>32%</td>
<td>12%</td>
<td>14%</td>
</tr>
<tr>
<td>10-30 (21%)</td>
<td>28%</td>
<td>51%</td>
<td>14%</td>
<td>7%</td>
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<td>25%</td>
<td>55%</td>
<td>16%</td>
<td>3%</td>
</tr>
<tr>
<td>100-300 (17%)</td>
<td>18%</td>
<td>59%</td>
<td>21%</td>
<td>2%</td>
</tr>
<tr>
<td>300-1000 (12%)</td>
<td>13%</td>
<td>53%</td>
<td>33%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Const & trapezia ≈ 80% of all profiles

Lower triangle increases with IWP from 10 to 26% 

Upper triangle only for IWP < 30 g/m² 

Independent of location / season! 

Strong vertical winds only affect lower triangles

**Develop regression models for Δz, nb of layers, IWC & De profiles using AIRS-CIRS (or ISCCP-NG) – lidar-radar synergy**
Complementary synergies

Thomas Fiolleau, UTCC PROES meeting 2018

Mesoscale Convective Systems from geo IR imagers – precipitation from TRMM

Short-lived systems (<12h) only explain <30% of rainfall over ocean & <40% over land

Lifetime duration
max extension, minimum $T_B^{IR}$
initiation, dissipation
propagated distance

Pattern recognition, tracking, $T_B^{IR} < 235K$

Roca et al. 2014

JF Rysman, UTCC PROES meeting 2018

Deep Convection & Convective Overshooting from microwave sounders 1999-2015

based on Hong et al. 2005
Rysman et al. 2017
daily, 0.2°
Occurrence of DC
CO effectively reaches tropopause 50% of time
 UT Cloud System Concept powerful tool to link anvil properties to convection

categorization of heating rates (A-Train synergy) wrt to \( \varepsilon_{\text{cl}d} \), \( p_{\text{cl}d} \) shows clear distinction between cloud types; *stronger thin Ci heating for colder systems*

deep learning together with appropriate cloud & atmospheric variables makes it possible to laterally expand radar-lidar cloud vertical structure

*good prediction of LW & SW heating rate profiles*: within 0.4 K/day

### Implications for ISCCP-NG

Cloud System Approach & Weather States -> process-oriented studies

Vertical structure necessary for radiative flux computation & process studies:

Build vertical structure of ISCCP-NG by collocating with lidar-radar etc &

1) categorize wrt ISCCP-NG cloud properties

2) determine as function of cloud & atm. properties via deep learning