Untangling the role of upper tropospheric clouds in the modulation of the Earth’s climate

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UT clouds cover 40% of the Earth

UT clouds play a vital role in climate system by modulating Earth’s energy budget & UT heat transport.

Convective tropical regions: > 50% radiative heating by cirrus (Sohn 1999)

UT clouds often form mesoscale systems extending over > 1000 km, as outflow of convective / frontal systems or in situ by large-scale forcing.
height & amount of UT clouds constrained by clear sky mass & energy budget

large-scale modelling necessary to identify most influential feedback mechanisms => models should be in agreement with observations

Goals: - understand relation between convection, cirrus anvils & radiative heating
  - provide obs. based metrics to evaluate detrainment processes in models
Why using IR Sounders to derive cirrus properties?

- **TOVS, ATOVS**
  - >1979 / ≥ 1995: 7:30/ 1:30 AM/PM
- **AIRS, CrIS**
  - ≥2002 / ≥ 2012 : 1:30 AM/PM
- **IASI (1,2,3), IASI-NG**
  - ≥2006 / ≥ 2012 / ≥ 2020 : 9:30 AM/PM

- long time series & good areal coverage
- good IR spectral resolution -> sensitive to cirrus
day & night, COD\textsubscript{vis} > 0.2, also above low clouds

**CIRS (Cloud retrieval from IR Sounders):**

- AIRS / IASI cloud climatologies -> French data centre AERIS
- HIRS cloud climatology -> EUMETSAT CM-SAF (DWD)

**Changes in occurrence of Cb & thin Ci clouds relative to all clouds per °C warming show different geographical patterns**
- slight tropical increase in Ci, thCi rel to all clouds
- change in heating gradients

from GEWEX Cloud Assessment Database
Stubenrauch et al. BAMS 2013
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 ($p_{\text{clld}}$)

![1 Jul 2007 AM AIRS](image)

- fill data gaps using PDF method
- build UT cloud systems

2) use $\varepsilon_{\text{clld}}$ to distinguish **convective core, thick cirrus, thin cirrus** (only IR sounder)

![Protopapadaki et al. ACP 2017](image)

30N-30S: UT cloud systems cover 25%, those without convective core 5%

50% of these originate from convection *(Luo & Rossow 2004, Riihimaki et al. 2012)*
Goal: relate anvil properties to convective strength

**Strategy:** need proxies

- to identify convective cores
  \[ \varepsilon_{\text{clld}} > 0.98 \]  
  (compared to AMSR-E rain rate)

- to identify mature convective systems
  \[ \text{system core fraction} : 0.1 – 0.3 \]  
  (reaching max core size)

- to describe convective strength
  \[ \text{core temp.} : T_{\text{min}}^{Cb} \]  
  (Protopapadaki et al. 2017)
  \[ T_{\text{B IR}} \]  
  (Machado & Rossow 1993)

**vertical updraft:** CloudSat Echo Top Height / TRMM
/ conv mass transport  
  (Takahashi & Luo 2014)  
  / Liu & Zipser 2007, Mullendore et al. 2008)

**LNB:** soundings / max mass flux outflow  
  (Takahashi & Luo 2012)

**heavy rain area:** CloudSat-AMSR-E-MODIS  
  (Yuan & Houze 2010)

**core width:** CloudSat  
  (Igel et al. 2014)

**mass flux:** ERA-Interim + Lagrangian approch  
  (Tissier et al. 2016)
  A-Train + 1D cld model  
  (Masunaga & Luo 2016)
cloud system size / max rain rate increase with convective strength, but land – ocean differences: at same height continental cloud systems stronger convective rain rate & smaller size

TRMM study (Liu et al. 2007):
larger updraft & convective cores, but smaller cloud systems
smaller updraft & convective cores, but larger cloud systems

CloudSat study (Takahashi et al. 2017):
less entrainment - stronger entrainment
**Mature convective systems:**
increase of thin Ci with increasing convective strength!
similar land / ocean

**relation robust using different proxies:**
\[ T_{\text{min}}^{\text{Cb}} / \text{LNB(max mass)} \]
UT cloud system approach to assess the LMDZ model

analyze GCM clouds as seen from AIRS/IASI, via simulator (M. Bonazzola) & construct UT cloud systems

-> evaluation of GCM convection schemes / detrainment / microphysics

spatial res. 2.5° x 1.25°

nominal fall speed & precipitation efficiency

\[ v_m = f(IWC), \quad De = f(T), \quad \varepsilon = f(De, IWC) \]

scaled \( v_m \) too small compared to observations

\( v_m \) adapted from Heymsfield et al. 2007

\( v_m \) increase with IWC stronger towards warm T

\[ v_m = f(IWC, T) \]

\( v_m \) adapted from Deng & Mace 2008

\( v_m \) increase with IWC weaker towards warm T

horizontal cloud system emissivity structure sensitive to fall speed
UT cloud system behaviour in climate models

cloud system size ($10^4$ km$^2$)

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thin Ci/tot anvil

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introducing T dependency -> larger system size & thin Ci/tot anvil, in better agreement with observations

increasing age of system

increasing convective strength

weakening of $v_m$ increase with IWC towards warm T seems to be in better agreement with observations

Next: integrate & test De parameterization coherent with $v_m$
heating rates of UT cloud systems

UT heating due to cirrus -> impact on large-scale tropical atmospheric circulation

Heating will be affected by:
- areal coverage
- emissivity distribution
- vertical structure of cirrus anvils (layering & microphysics)

propagate nadir track info on vertical structure across UT cloud systems

AIRS – CloudSat – CALIPSO synergy

categorize NASA CloudSat FLXHR-LIDAR heating rates wrt to $\varepsilon_{cld}$, $p_{cld}$, vert. layering, thermodyn.

clear distinction of heating associated with each category
thin Ci heating increases with convective strength
Summary & Outlook

- AIRS & IASI cloud climatologies will be distributed by AERIS & be part of an updated GEWEX Cloud Assessment database *(end 2018)*

- synergetic UT cloud system approach based on IR sounder data powerful tool
  1) to study relation between convection & anvil properties:  
     *emissivity structure of mature systems changes with convective strength: more surrounding thin cirrus*
  2) for process based metrics to evaluate GCM parameterizations linked to convection/detrainment/microphysics *(fallspeed – De)*

- categorization of heating rates *(A-Train synergy)* wrt to $e_{cld}$, $p_{cld}$ shows clear distinction  
  *thin Ci heating larger for colder systems*

- propagate heating rates across UT cloud systems & integrate into feedback studies using Lagrangian transport & advanced analysis methods

- investigate mechanisms leading to emissivity structure in CRM RCE studies *(large domain)*

**cooperations within GEWEX working group UTCC PROES**

PROcess Evaluation Study on Upper Tropospheric Clouds & Convection *(coord.: Stubenrauch & Stephens)*


next meeting : 22-23 Oct 2018 in Paris