The role of upper tropospheric cloud systems in climate: building observational metrics for Process Evaluation Studies (PROES)

UTCC PROES: on Upper Tropospheric Clouds & Convection

• advance understanding on feedback of UT clouds

Claudia Stubenrauch
Laboratoire de Météorologie Dynamique / IPSL, France

& UTCC PROES Participants

3 Jul 2018, 2nd WCRP meeting on Monsoons & Tropical Rain Belts, Trieste, Italy
UT clouds play a vital role in climate system by modulating Earth’s energy budget & UT heat transport

**Goal:**
- Understand relation between convection, cirrus anvils & radiative heating
- Provide obs. based metrics to evaluate detrainment processes in models
focus on tropical convective systems & cirrus originating from large-scale forcing

- cloud system approach, anchored on IR sounder data
  horizontal extent & convective cores/cirrus anvil/thin cirrus *based on* $p_{cld}$, $\varepsilon_{cld}$
- explore relationships between ‘proxies’ of convective strength & anvils
- build synergetic data (vert. dimension, atmosph. environment, temporal res.)
- determine heating rates of different parts of UT cloud systems
- follow snapshots by Lagrangian transfer -> *evolution & feedbacks*
- investigate how cloud systems behave in CRM studies
  & in GCM simulations *(under different parameterizations of convection/detrainment/microphysics)*

UTCC PROES Strategy

*working group links communities* from observations, radiative transfer, transport, process & climate modelling

meetings: Nov 2015, Apr 2016, Mar 2017
Why using IR Sounders to derive cirrus properties?

TOVS, ATOVS
>1979 / ≥ 1995: 7:30/ 1:30 AM/PM

UT cloud amount  July

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_{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)

stubenrauch et al., ACP 2017

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 ($p_{\text{cld}}$)

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

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)
Synergy with TRMM to analyze system life evolution

Composite observations w. r. t. convective life stages

H. Masunaga
UTCC PROES meeting 2017

Masunaga & L’Ecuyer 2014

20°S-20°N, ocean
2006 – 2009

Evolution of moisture & cloud structures in organized convection

well defined convective cloud column at time of precipitation & then thinning out, but cirrus also around before convection
Goal: relate anvil properties to convective strength

Strategy: need proxies

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

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

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

  \textbf{vertical updraft}: CloudSat Echo Top Height / TRMM

  \textbf{LNB}: soundings / max mass flux outflow (Takahashi & Luo 2012)

  \textbf{heavy rain area}: CloudSat-AMSR-E-MODIS (Yuan & Houze 2010)

  \textbf{core width}: CloudSat (Igel et al. 2014)

  \textbf{mass flux}: ERA-Interim + Lagrangian approach (Tissier et al. 2016)
  A-Train + 1D cld model (Masunaga & Luo 2016)
cloud system size / max rain rate increase with convective depth (colder cloud tops), but land – ocean differences:
at same height continental cloud systems stronger convective rain rate & smaller size
colder cores -> stronger max RR => $T^{cb}_{min}$ proxy for convective strength

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:* $T_{min}^{Cb} / LNB(max \ mass)$

Why?

H1: UT environmental predisposition (at higher altitude larger RH, T stratification)

H2: UT humidification from cirrus outflow

$\rightarrow$ CRM studies
Characteristics of deep convection from CRM simulations

S. van den Heever, UTCC PROES meeting 2017

advance our understanding of environmental impacts on horizontal & vertical scales of tropical deep convection; convective anvil dynamic & radiative feedbacks

Radiative-Convective Equilibrium simulations

R. Storer, water budget studies
UTCC PROES meeting 2017

detrainment higher & broader

Posselt et al. 2012

high cloud fraction

increasing SST -> increased PW, convective intensity (w) & high cloud fraction, decrease in IR cooling -> slowing radiatively driven circulation
UT cloud system approach to assess the LMDZ model

analyze GCM clouds as seen from AIRS/IASI, via simulator & construct UT cloud systems

-> evaluation of GCM convection schemes / detrainment / microphysics

Goal: build coherent $v_m$- De parameterization

nominal fall speed & precipitation efficiency

$$v_m = c \times f(IWC), \quad De = f(T), \quad \varepsilon = f(De, IWC)$$

scaled $v_m$ too small compared to observations

$$v_m = c \times f(IWC, T)$$

Heymsfield et al. 2007

$v_m$ increase with IWC stronger towards warm $T$

Deng & Mace 2008

$v_m$ increase with IWC weaker towards warm $T$

$D_m$ from PSD moment parameterization of Field 2007,

$v_m = f(D_m); \quad De = f(v_m);$ Heymsfield 2013, 2003

Rad. balance via precip. efficiency, UT hum variability

horizontal cloud system emissivity structure sensitive to $v_m, De$
implementing T dependency of \( v_m \rightarrow \) larger spread in \( T_{\text{min}}^{\text{cb}} \), in better agreement to observations integrating \( v_m \) – De very promising: leads to more realistic core size development!

**Next steps:** DM08 without scaling factor & \( \text{De}(v_m) \)
more sensitivity studies on parameters used for radiation balance integrating single scattering properties developed by Baran 2016 from PSD’s of F07
convective – anvil heating

Latent heating from TRMM:
column precipitation & cloud profile

Tropical stratiform rain leads to high peak in heating & cooling below deep convective rain leads to broad atmospheric warming

Sensitivities of TRMM & CloudSat radar

TRMM radar misses 5 km to cloud top & factor of 5 in horizontal extent

TRMM LH – ISCCP RH synergy

Total radiative heating enhances gradient of latent heating at upper levels (e.g., 250 mb), esp. over Africa, Maritime Continent & South America & enhances overall LH by ~20%
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 $\varepsilon_{\text{cl}}$, $p_{\text{cl}}$, vert. layering, thermodyn.

cloud LW heating

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

GEWEX UTCC PROES: cooperations being formed, focusing on tropical convective systems
coord. C. Stubenrauch & G. Stephens
next meeting: 22-23 Oct 2018 in Paris

- 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 \( \varepsilon_{\text{cld}} \), \( p_{\text{cld}} \) 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)