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

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UT clouds play a vital role in climate system by modulating Earth’s energy budget & UT heat transport. They often form mesoscale systems extending over several hundred kilometres, as outflow of convective / frontal systems or in situ by large-scale forcing.

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 observational metrics to probe process understanding
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 $p_{cld}$ & $E_{cld}$
- explore relationships between ‘proxies’ of convective strength & anvils
- build synergetic data, incl. vert. dimension & atmosph. environment
- 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)
Why using IR Sounders to derive cirrus properties?

- **TOVS, ATOVS**
  - >1979 / ≥ 1995: 7:30/ 1:30 AM/PM
  - high cloud amount July

- **AIRS, CrIS**
  - ≥2002 / ≥ 2012 : 1:30 AM/PM
  - Ø long time series & good areal coverage
  - Ø good IR spectral resolution -> sensitive to cirrus
    - day & night, COD > 0.2, also above low clouds

- **IASI (1,2,3), IASI-NG**
  - ≥2006 / ≥ 2012 / ≥ 2020 : 9:30 AM/PM

**CIRS (Cloud retrieval from IR Sounders):**
- AIRS / IASI climatologies -> French data centre AERIS
- HIRS climatology -> EUMETSAT CM-SAF (DWD)

Changes in relative amount of high opaque & thin Ci clouds per °C warming show different geographical patterns
-> UT cloud feedbacks

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

fill data gaps using PDF method
build UT cloud systems

2) use $\varepsilon_{\text{cld}}$ 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)
convective strength -> cloud system properties

proxies to describe convective strength:

**core temp.** \( T_{\text{min}}^{Cb} \) (Protopapadaki et al. 2017), \( T_{B}^{IR} \) (Machado & Rossow 1993)

**vertical updraft**: CloudSat Echo Top Height (Takahashi & Luo 2014) / TRMM (Liu & Zipser 2007)

**Level of Neutral Buoyancy**: 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 approach (Tissier et al. 2016)

A-Train + 1D cld model (Masunaga & Luo 2016)

Cloud system sizes increase with convective strength, but **land – ocean differences**: larger updraft & CC, smaller systems - smaller updraft & CC, larger systems

Liu et al. 2007

**typical strong convective systems** (6-yr TRMM statistics)

Congo (Central Africa)

NW tropical Pacific

Liu et al. 2007

**colder systems have a larger max rain rate**

AIRS – AMSR-E synergy

\( \text{min } T(Cb) \) (K) Protopapadaki et al. 2017
**Mature convective systems:**
increase of thin Ci with increasing convective strength!
similar land / ocean

**relation robust using different proxies:**
$T_{\text{min}}^{\text{Cb}} / \text{LNB}(\text{max mass})$
Diagnostics for UT cloud assessment in climate models

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

-> evaluation of GCM convection schemes / detrainment / microphysics

Spatial res. 2.5° x 1.25°

LMDZ UT cloud systems

Horizontal cloud system emissivity structure sensitive to fall speed

LMDZ behaviour closer to observations, when fall speed is reduced (longer lasting cirrus)
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)

use nadir track info on vertical structure to propagate properties across UT cloud systems

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

cloud LW heating

convective core
Ci anvil
thin Ci anvil

T_{Cb} < 225K
T_{Cb} > 225K

km

preliminary

clear distinction of heating associated with each category

Thin Ci heating increases with convective strength
WG meetings: Nov 2015, Apr 2016, Mar 2017 -> first cooperations

focus on
1) tropical convective systems       2) cirrus originating from large-scale forcing

- synergetic cloud system approach based on IR sounder data
  powerful tool to study relation between convection & anvil properties
  & to evaluate GCM parameterizations

  of convection/detrainment/microphysics

- investigate how cloud systems behave in CRM studies

- classification of heating rates (A-Train synergy) encouraging
  -> extend to UT cloud systems & integrate into feedback studies

  using Lagrangian transport & advanced analysis methods
GEWEX UTCC PROES WG

Coordination: C. Stubenrauch & G. Stephens; next meeting: end Sept or mid Oct 2018 in Paris

Observations / radiative transfer:
G. Stephens, H. Takahashi (NASA JPL), C. Stubenrauch, S. Protopapadaki, G. Sèze (LMD),
J. Luo, W. B. Rossow (CUNY), H. Masunaga (Nagoya Univ.), Roca (LEGOS), D. Bouniol (CNRM),
T. L’Ecuyer (Uni Wisconsin), S. Kato (NASA Langley), C. Schumacher (Texas Univ),
G. Mace, E. Zipser (Utah Univ), E. Jensen (NASA Ames), M. Krämer (FZ Jülich), A. Baran (MetOffice)
C. Kummerow (CSU), B. J. Sohn (Seoul Univ), H. Okamoto (Kyushu Univ)

Lagrangian transport, UTLS cirrus:
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Small scale process modelling:
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W.-T. Chen (Nat Taiwan Univ), B. Kärcher (DLR)

Climate modelling:
T. Del Genio, G. Elsaesser (GISS), R. Ramaswamy, L. Donner (GFDL), B. Gasparini (ETHZ), U. Burkhardt (DLR),
T. Mauritsen (MPI), M. Bonazzola, J.-B. Madeleine, C. Rio, C. Risi, S. Bony (LMD), R. Roehrig (CNRM)

Thank you