Horizontal emissivity structure of UT cloud systems & resulting heating
(A-Train synergy)

T2.4 – UT cloud systems: Determination of their 3D structure & their radiative effects

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Monsoon Clouds over Bangladesh (Archive: NASA, International Space Station)
Motivation & Approach

**advance our understanding on UT cloud feedback**

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

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 anvis?

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

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

**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
link anvil structure to convective depth

Protopapadaki et al. ACP 2017

15 years AIRS; tropical UT cloud systems ($p_{\text{clad}} - p_{\text{tropopause}} < 250$ hPa or $p_{\text{clad}} < 440$ hPa); convective core (Cb): $\varepsilon_{\text{clad}} > 0.98$; mature systems: Cb fraction within system 0.1 – 0.3

Deeper convective cores -> stronger max rain rate
-> $T_{\text{min}}^{\text{Cb}}$ good proxy for convective strength

Deeper convection leads to relatively more thin cirrus within larger anvils (similar land / ocean)
relation robust using different proxies:
$T_{\text{min}}^{\text{Cb}} / \text{LNB(max mass)}$

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?
How do tropical UT clouds change with global $T_{surf}$?

Stubenrauch et al. ACP 2017

Changes in occurrence of Cb & thin Ci relative to total cloud per °C warming show different geographical patterns -> change in heating gradients

& UT cloud systems?

av. coverage of all UT cloud systems: 25.6%  
79% of coverage from convective systems, 6% from thin ci systems  
48% of convective systems are cold convective systems ($T_c < 210K$)

dcov/d$T_s = -1.3 \pm 0.6 \% / ^\circ C$

d[ cov_{coldConv}/cov_{conv} ]/d$T_s = +18 \pm 5 \% / ^\circ C$

d(thci/anv)/d$T_s = 0.041 \pm 0.008 / ^\circ C$

d$T_c/dT_s = -2.1 \pm 0.5 ^\circ C / ^\circ C$

d$\epsilon_c/dT_s = -0.035 \pm 0.005 / ^\circ C$

warming ->
larger area covered by cold convective systems & more thin ci within anvil

15 years AIRS; tropical UT cloud systems ($p_{cld} < 440$ hPa); convective core (Cb): $\epsilon_{cld} > 0.98$
Contrast cold (*La Nina*) & warm (*El Nino*) tropics

Jan 2008 $\Delta T_{\text{surf}} = -0.46^\circ$C

Jan 2016 $\Delta T_{\text{surf}} = +0.47^\circ$C

Warmer El Nino period:
larger area covered by cold convective systems & more thin ci within anvil
1) **along nadir tracks:**
categorize CloudSat FLXHR-lidar vertical structure & heating rates wrt cloud type \((p_{\text{clld}} \& e_{\text{clld}})\), for different atmospheric situations

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 sampled along track

AIRS UT clouds collocated to Lidar-CloudSat FLXHR heating rates wrt to $\varepsilon_{\text{cl},r}$, $p_{\text{cl},r}$

tropics, AIRS $p_{\text{cl}} < 200$ hPa, nadir track statistics

warmer $T_{\text{surf}}$ -> UT cloud net heating occurring in thicker layers

slightly larger thin cirrus heating
heating rates of UT cloud systems, sampled along track

AIRS UT cloud systems collocated to Lidar-CloudSat FLXHR heating rates wrt to $\varepsilon_{\text{cl}, \text{p}}$

- Clear distinction of heating associated with each category
- Cold convective systems have a larger thin Ci heating
2) expand vertical structure across UT cloud systems via deep machine (ANN) learning

spectacular progress in automation of finding most appropriate weights used in the ANN layers (weights are modified to reduce difference between actual & desired outputs)

TensorFlow framework to train deep learning models using Keras python library

**AIRS – CloudSat-CALIPSO synergy along the track (2007-2010):**
X = cloud properties from AIRS & environmental properties from ERA (including horizontal organization)
F(X) = vertical cloud extent or HR

train, validate & test non-linear regression models -> test feasibility
2a) cloud vertical extent via deep learning

1) **Explore relevant variables**: $c_{\text{cl}}$, $p_{\text{cl}}$, $c_{\text{cl}}$ uncertainty, $p_{\text{cl}}$ uncertainty, $\chi^2_{\text{min}}$, spat. $T_B$ var., 9 $c_{\text{cl}}$ (8-11$\mu$m), OLR, column $H_2O$, land fraction, $p_{\text{surf}}$, $T_{\text{surf}}$, $p_{\text{tropopause}}$, $T$ profiles, $H_2O$ profiles $c_{\text{cl}}$ - $p_{\text{cl}}$ PDFs + clear sky frequency over 2° x 2° (43 variables)

2) **Develop models**: for Cb, Ci, thin Ci, lower clouds, clear sky

   random sampling for training (80%), validation (10%) & testing (10%), determine nb of iterations & check overfitting

- Results improve if initial cloud info extended by atmospheric info and/or spatial cloud organization & separate models for cloud types
- Best results for thin cirrus & low clouds (as their extent is lower)
- Optically opaque clouds: bimodal $\Delta z$ distribution; not yet well caught by prediction
  -> need to explore other variables (vertical velocity, etc...)
2a) cloud vertical extent via deep learning

1) **Explore relevant variables**: $\varepsilon_{\text{cld}}, p_{\text{cld}}, \epsilon_{\text{cld\ uncertainty}}, p_{\text{cld\ uncertainty}}, \chi^2_{\text{min}}, \text{spat. } T_B \text{ var., }$
9 $\varepsilon_{\text{cld}} (8\text{-}11 \mu m), \text{OLR, column } H_2O, \text{land fraction, } p_{\text{surf}}, T_{\text{surf}}, p_{\text{tropopause}}, \text{T profiles, } H_2O \text{ profiles}$
$\varepsilon_{\text{cld}} - p_{\text{cld}} \text{ PDFs + clear sky frequency over } 2^\circ \times 2^\circ \text{ (43 variables)}$

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2b) Cloud radiative LW heating rates via deep learning

results improve when initial cloud info extended by atmospheric info

no overfitting, mean absolute error $\leq 0.5$ K/day!

$\varepsilon_{\text{cld}}$ critical variable => models per cloud type

very promising, but needs deeper assessment
Prediction errors < 0.3 K/day
prediction error LW HR PM slightly smaller than AM
prediction error SW HR slightly smaller than LW HR
El Nino (warm) – La Nina (cold)

CAH (AIRS-CIRS)

Thin Ci fraction

Cb fraction

OLR (AIRS-NASA)

LW HR p < 210 hPa

LW HR 210 hPa-500 hPa

LW HR p > 500 hPa

Feedbacks -> ‘regional Intensification of hydrological cycle’

Stephens et al. 2018

RH 200-500 hPa (AIRS-NASA)

Next step: compare HR’s of moistening and drying regions sampled by CALIPSO-CloudSat and using wider sampling of AIRS-ERA predicted HR’s
Summary & Outlook

- synergetic UT cloud system approach based on IR sounder data powerful tool to study relation between convection & anvil properties
  
  *warming might lead to more cold convective systems with relatively more thin cirrus* 
  
  *this affects then the heating gradients*

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

- Expansion of LW heating rates across UT cloud systems via deep learning:  
  
  *first results show a very good reproducibility for separate models of Cb, Ci, thin Ci, lower clouds and clear sky*

- Improvements:  
  
  1) atmospheric thermodynamic & dynamic variables of ERA5  
  2) new NASA CloudSat-lidar data for training

- Study impact of cirrus heating on large-scale circulation:  
  
  *couple observed radiative heating rates with latent heating rates & force GCM to quantify climate system dynamical response to atmospheric heating*

- Postdoc CDD 3 years (2 yrs TOSCA EECLAT-IASI & 1 yr ANR TTL-Xing): *Friederike Hemmer*
GEWEX Process Evaluation Study on Upper Tropospheric Clouds and Convection (UTCC PROES)

advance understanding on feedback of UT clouds

  goals, meeting presentations, references, links

- 3rd GEWEX UTCC PROES meeting, Sorbonne University, Paris, 22 – 23 Oct 2018
  30 participants with contributions on:
  Observational analyses of mesoscale convective systems, Water vapor & convective transport, Process studies, Climate variation & feedbacks, Parameterizations & model diagnostic studies
**UTCC PROES Strategy**

**meetings:** Nov 2015, Apr 2016, Mar 2017, Oct 2018

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

**focus on tropical convective systems** & cirrus originating from large-scale forcing

- Cloud System Concept, anchored on IR sounder data
  (horizontal extent & convective cores/cirrus anvil/thin cirrus **based on** $p_{cld}$, $e_{cld}$)
  -> **relationships between anvil properties & convective strength**

- **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**)