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

UTCC PROES: on Upper Tropospheric Clouds & Convection
Å ***advance understanding on feedback of UT clouds***

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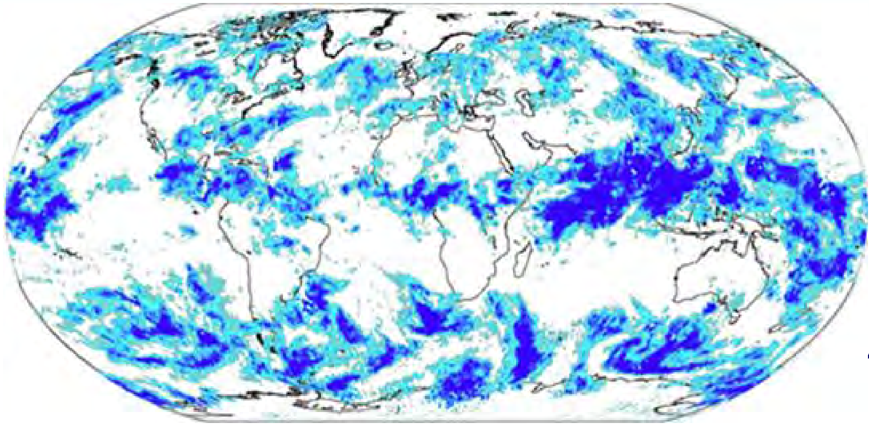
G. Stephens & UTCC PROES Participants

Clouds, Properties / Climate Feedbacks: Symposium to celebrate Bill Rossow's science contributions
6-8 June 2017, Columbia University, New York, USA

Motivation



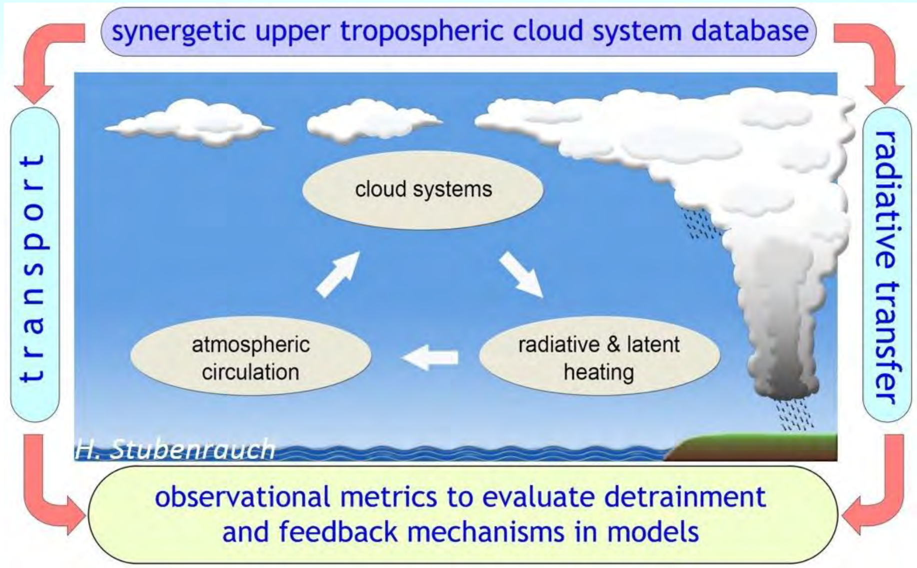
Snapshot AIRS-CIRS
UT clouds: dark -> light blue,
according to decreasing ε_{cld}

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.
Cirrus form as outflow of convective / frontal systems
or in situ by large-scale forcing

How does convection affect UT clouds & vice versa?
Critical to feedbacks: cirrus radiative heating -> atmospheric circulation

Goals: understand relation between convection, cirrus anvils & rad. heating
provide obs. based metrics to evaluate detrainment processes in models



UTCC PROES Strategy

meetings: Nov 2015, Apr 2016, Mar 2017

***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 approach, anchored on IR sounder data**

horizontal extent / convective cores/cirrus anvil/thin cirrus ***based on*** p_{cld}, ε_{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)*

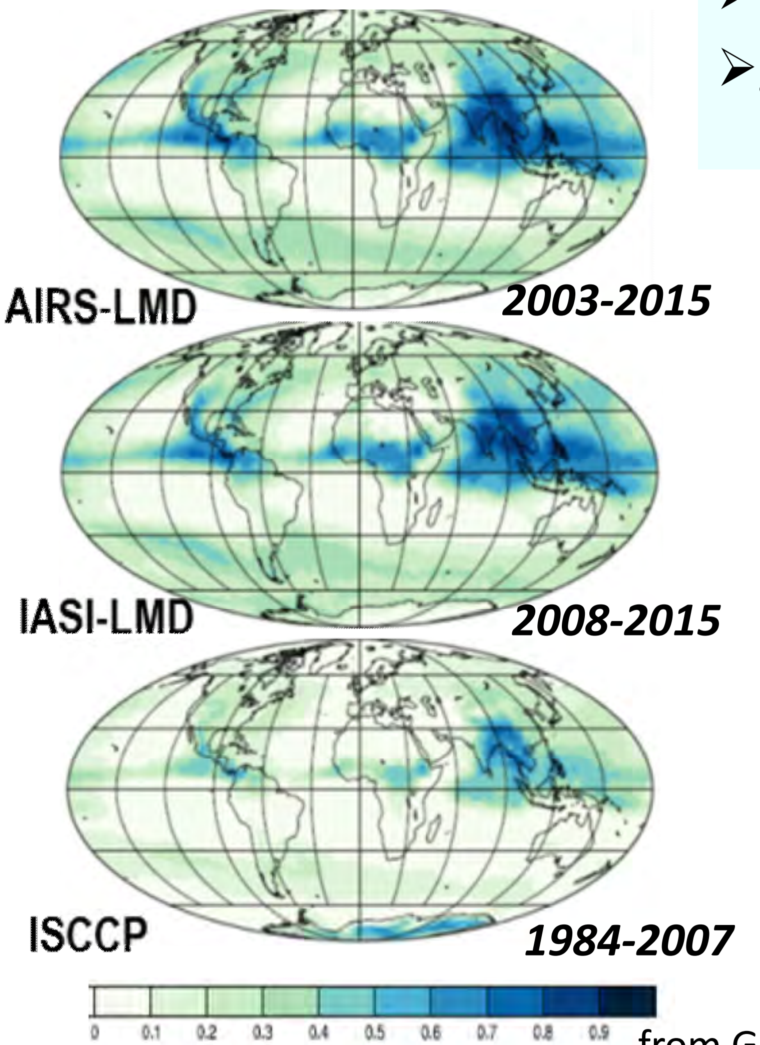
Why using IR Sounders to derive cirrus properties ?

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

high cloud amount July



from GEWEX Cloud Assessment Database
Stubenrauch et al. BAMS 2013

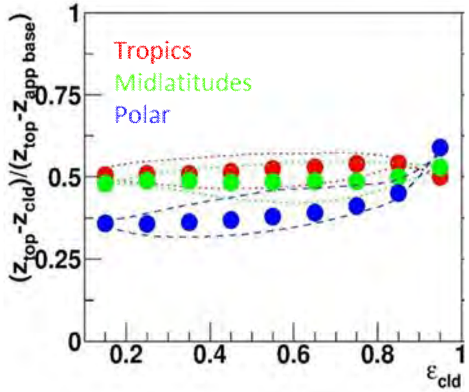
- long time series & good areal coverage
- **good IR spectral resolution -> sensitive to cirrus**

  day & night, COD > 0.2, also above low clouds

CIRS (Cloud retrieval from IR Sounders):

ATBD*: Feofilov & Stubenrauch 2017* (DOI: 10.13140/RG.2.2.15812.63361)
Stubenrauch et al., J. Clim. 1999, 2006; ACP 2010, ACPD 2017
AIRS / IASI climatologies -> French data centre AERIS
HIRS climatology produced by EUMETSAT CM-SAF (DWD)
Hanschmann et al. 2017, in prep.

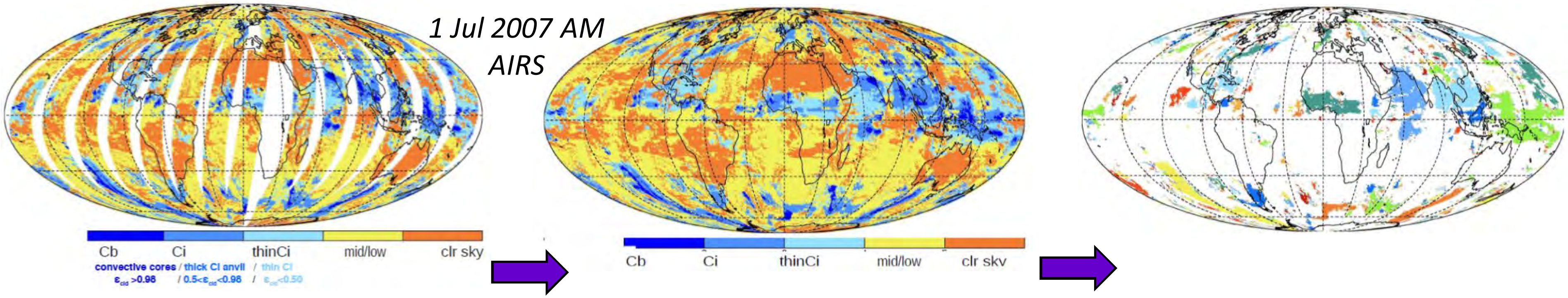
cld height ≈ middle between top & base (or apparent base)
independent of ε_{cld}
A-Train synergy



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})

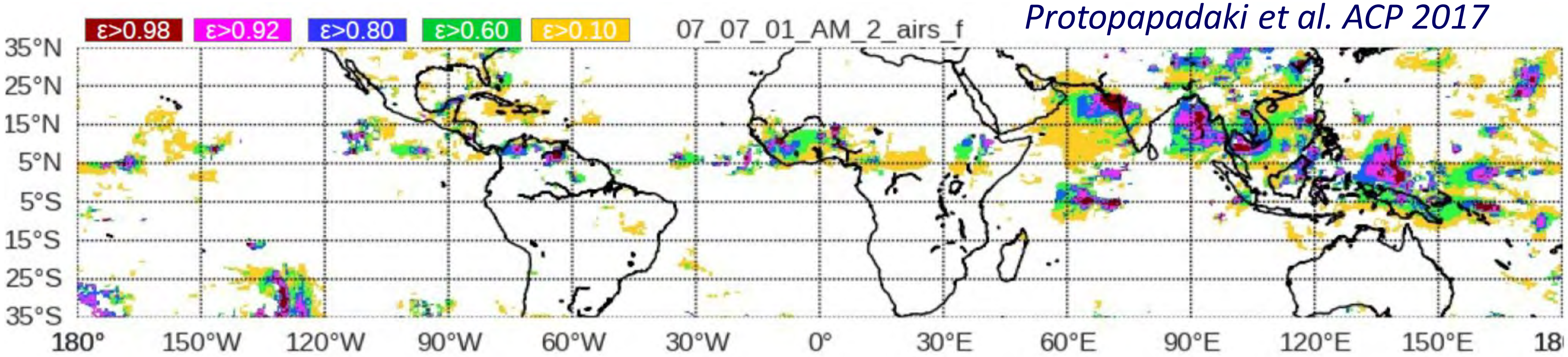


fill data gaps using PDF method

build UT cloud systems

2) use ε_{cld} to distinguish convective core, thick cirrus, thin cirrus

Protopapadaki et al. ACP 2017



relate cloud system properties to convective strength

proxies to describe convective strength:

core temp. : T_{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)*

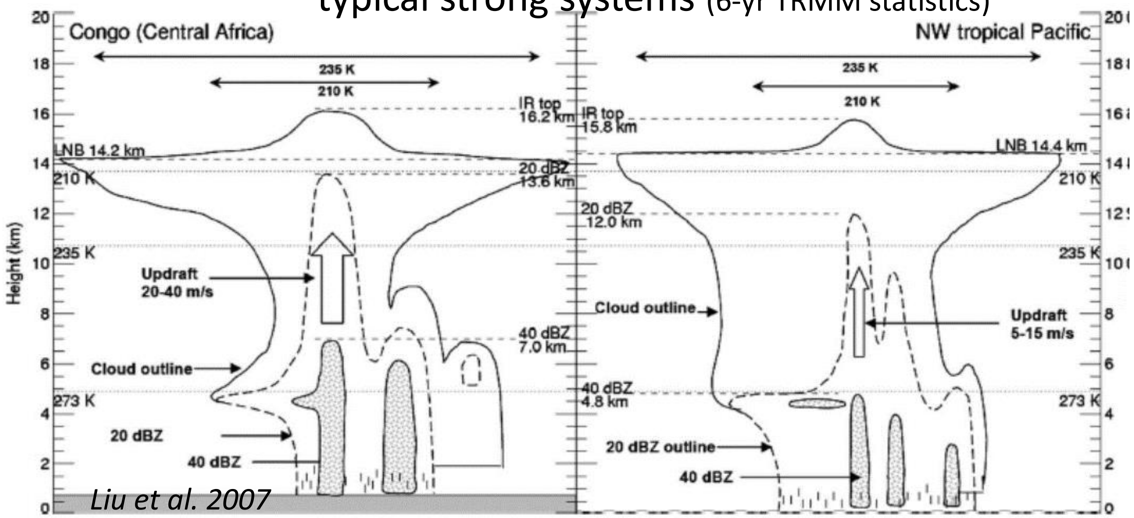
core width : CloudSat *(Igel et al. 2014)*

mass flux : ERA-Interim + Lagrangian approch *(Tissier et al. 2016)*

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

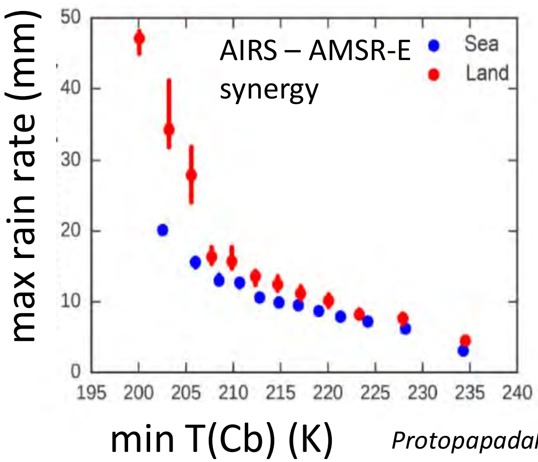
Cloud system sizes increase with convective strength, but **land – ocean** differences :
larger updraft & CC, smaller systems - **smaller updraft & CC, larger systems**

typical strong systems (6-yr TRMM statistics)



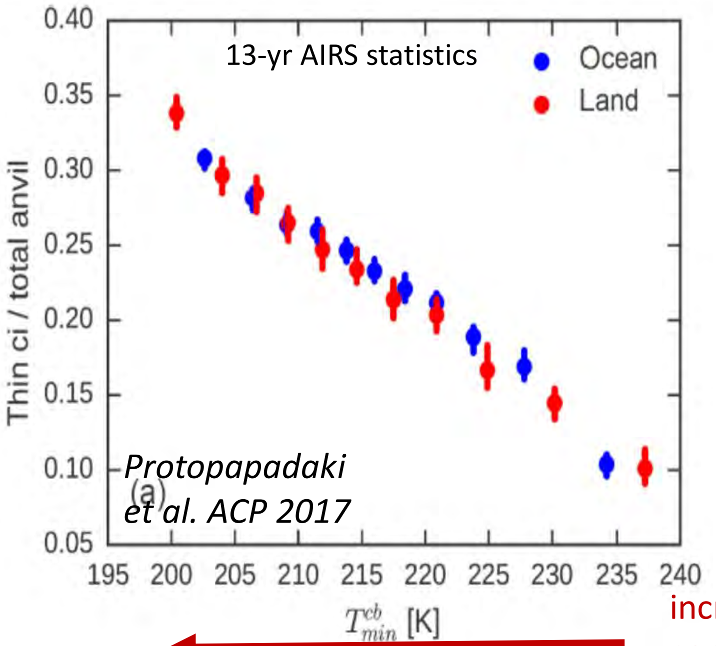
Liu et al. 2007

colder systems have a larger max rain rate

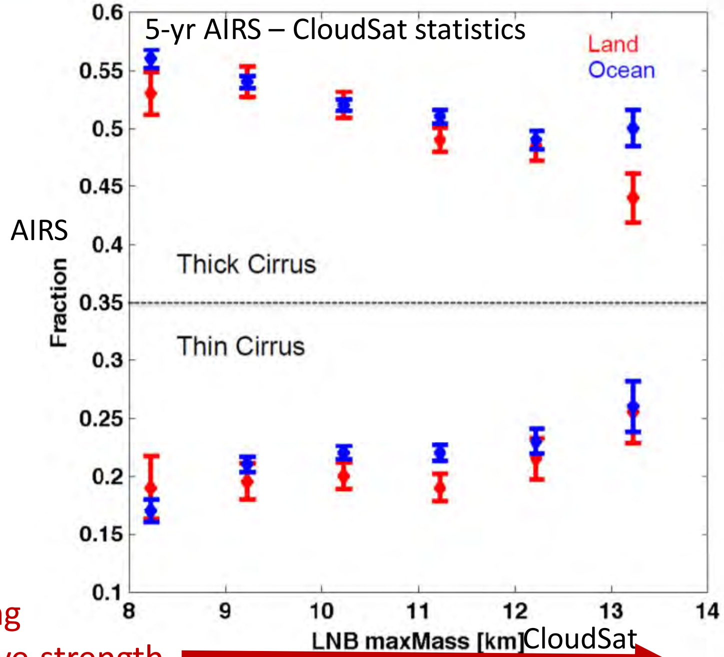


Protopapadaki et al. 2017

relate anvil properties to convective strength



Protopapadaki et al. ACP 2017



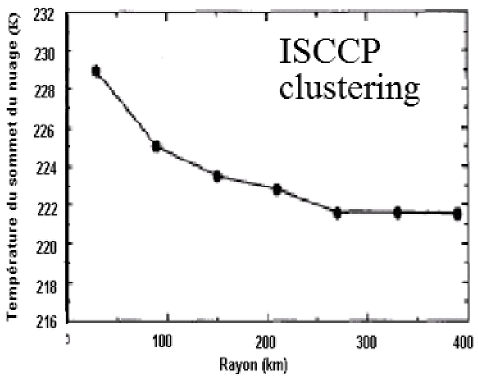
Takahashi et al. 2017, in prep.

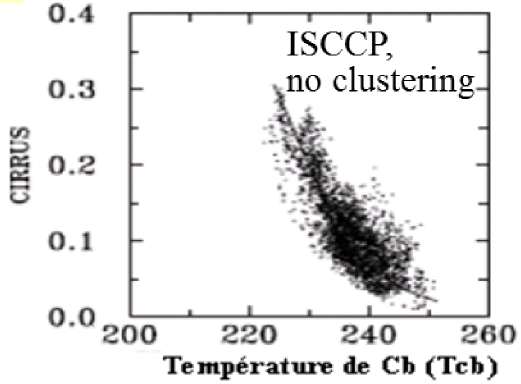
increasing convective strength

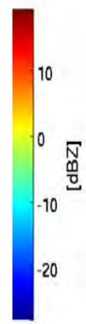
Properties of convective cells -> horizontal extension of cirrus anvils ?

Machado & Rossow Mon. Weath. Rev. 1993

Ch. Chou & J. D. Neelin, GRL 1999

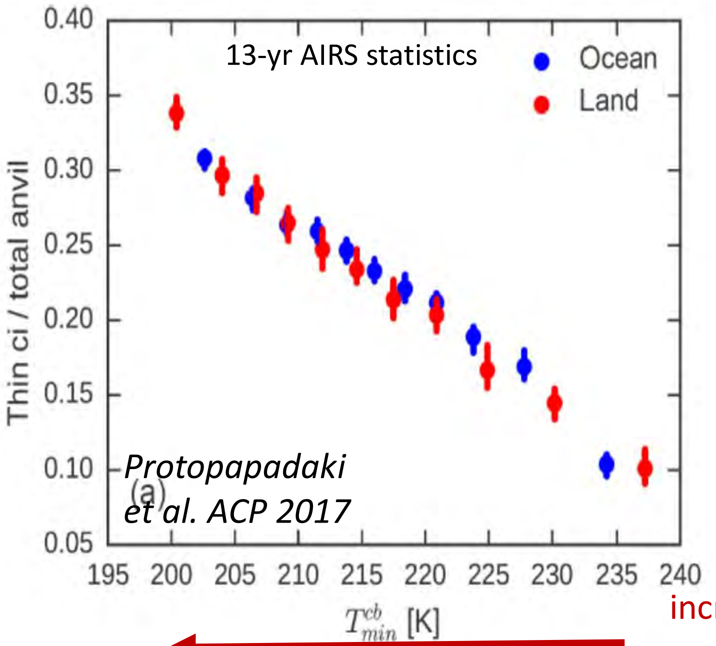


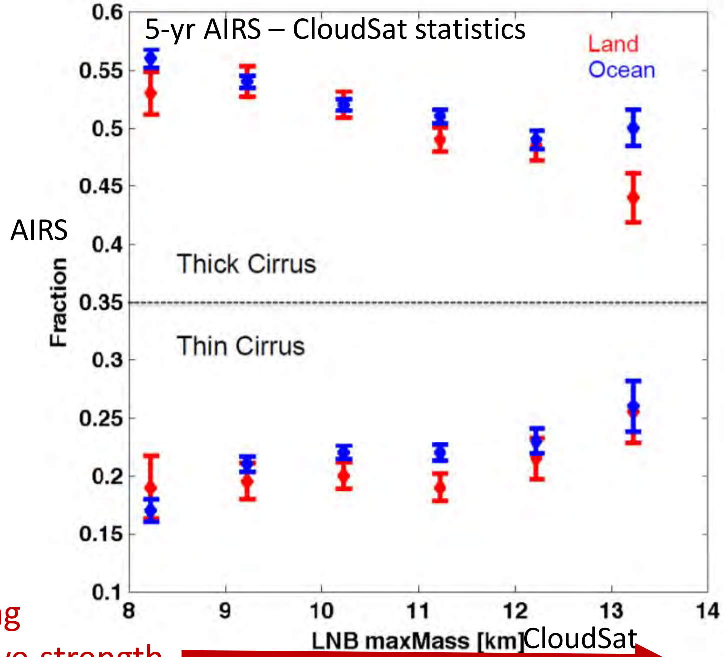




cluster size and cirrus amount increasing with decreasing T_{Cb}

relate anvil properties to convective strength



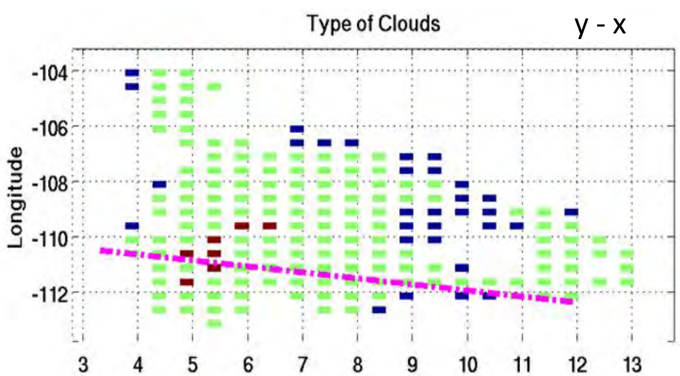


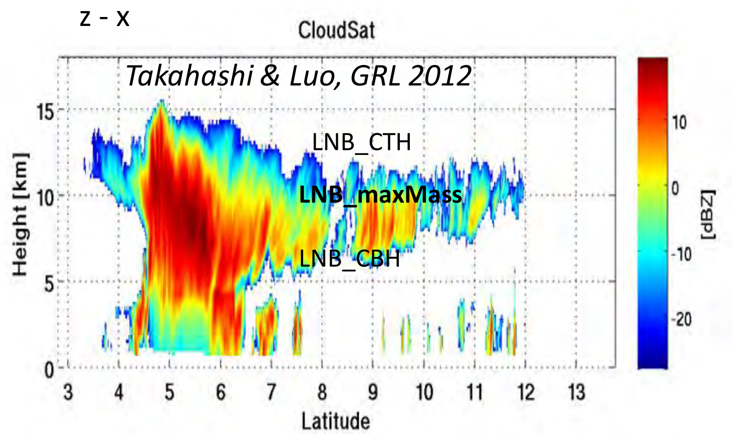
Takahashi et al. 2017, in prep.

increasing convective strength

in-(de-)crease of thin (thick) Ci with increasing convective strength

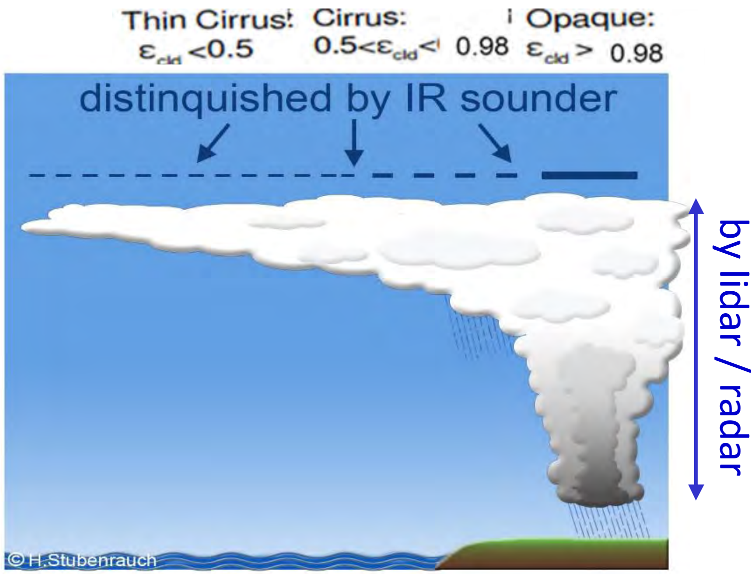
relation robust using different proxies : T_{min}^{Cb} / LNB(max mass)





heating rates of anvil parts (1)

tropical convective regions: > 50% of total heating UT heating due to cirrus *(Sohn 1999)*
-> widespread impact on large-scale tropical atmospheric circulation

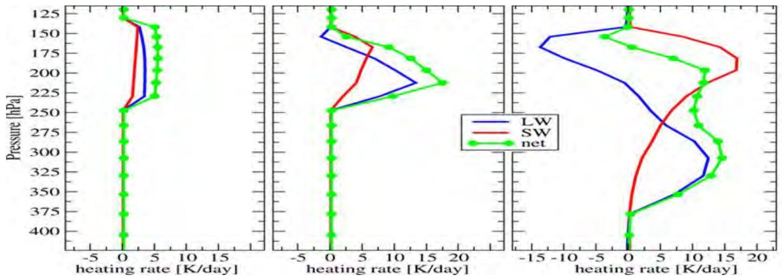


Heating will be affected by:

- 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

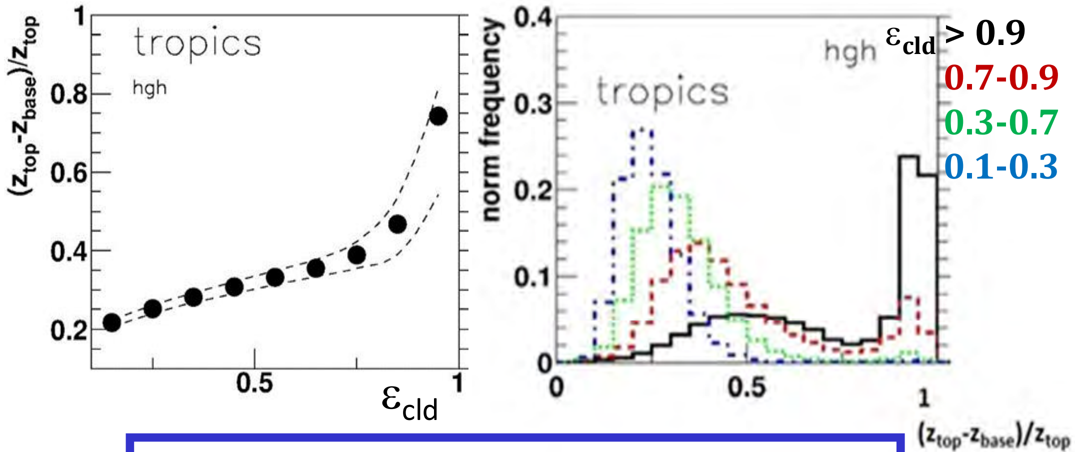
typical UT heating computed by RRTM



IWP= 10, mostly const De = 30,
30, trapezium 50,
300 gm^{-2} increas. IWC profile 80 µm

ε_{cld} dependent IWC profiles (Feofilov et al. ACP 2015)

1) **determine heating rates using categorization of vertical structure wrt to ε_{cld}, p_{cld}**

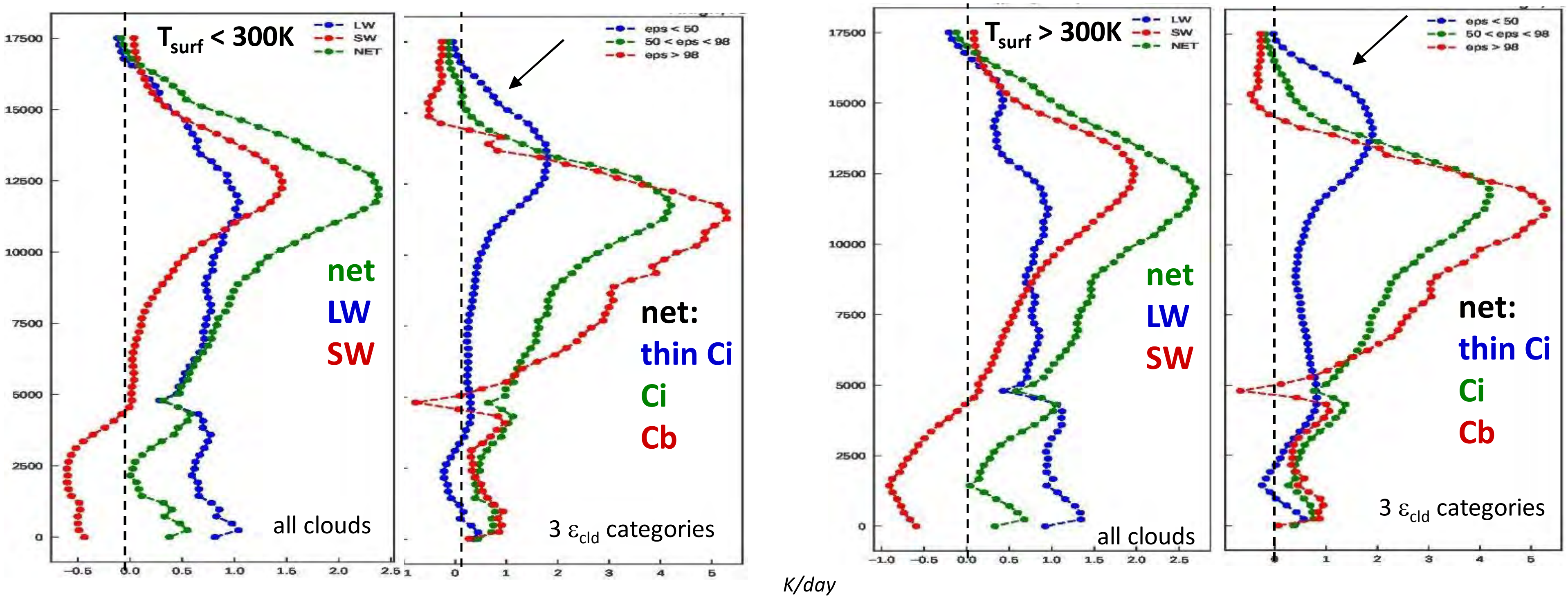


vertical extent increases with to ε_{cld}
next step: decrease distribution widths by stratifying wrt dynamics, humidity,T, etc

heating rates of anvil parts (2)

2) categorize Lidar-CloudSat FLXHR heating rates wrt to ε_{cld}, p_{cld}, vert. layering, thermodyn.

tropics, AIRS p_{cld} < 200 hPa, nadir track statistics *very preliminary*



warmer T_{surf} -> hgh cld net heating occuring in thicker layers

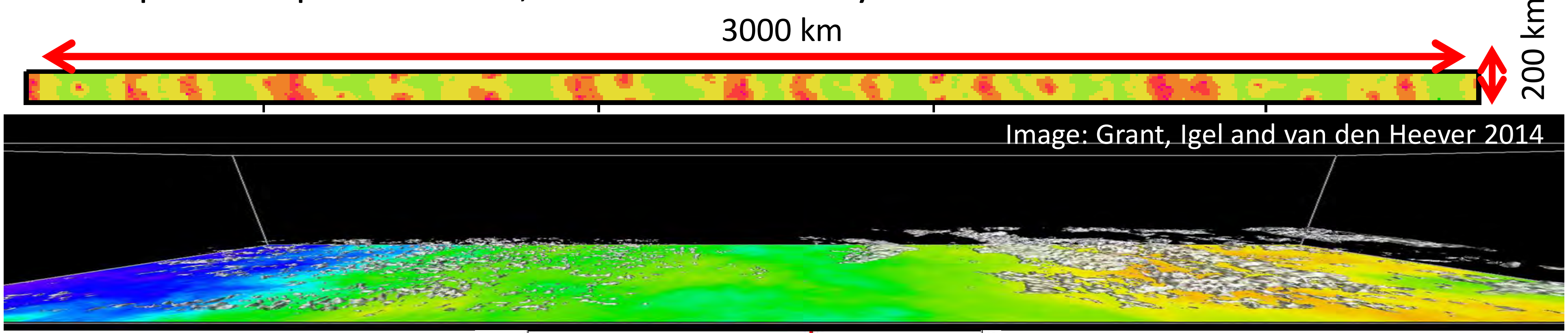
Next steps: analyze AIRS-CALIPSO-CloudSat track in combination with AIRS UT cloud systems, investigate ocean / land differences; study sensitivities to microphysical assumptions

FLXHR heating rates lie within 0.2 (LW) / 0.15 (SW) K/d (ARM comparison, *Protat et al. 2014)*

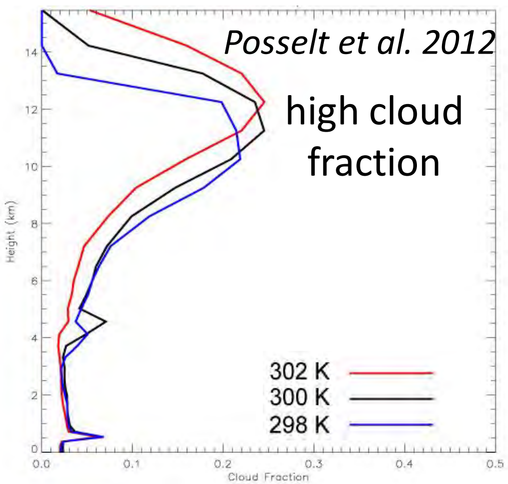
Characteristics of deep convection from CRM simulations

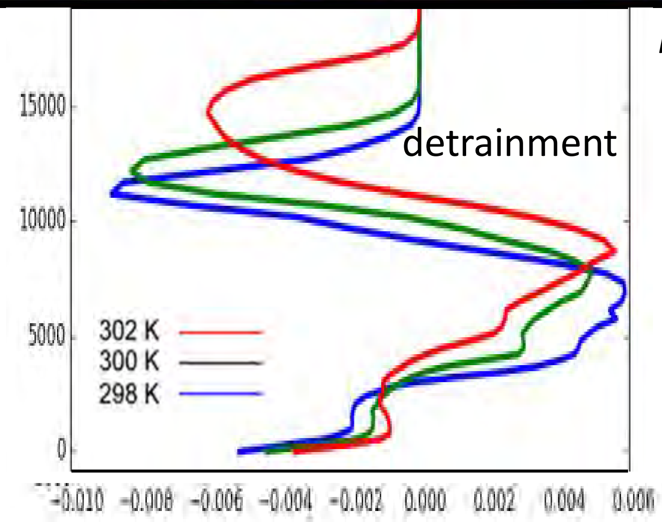
S. van den Heever, UTCC PROES meeting March 2017

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 March 2017

detrainment higher & broader

increasing SST -> increased PW, convective intensity (w) & high cloud fraction, decrease in IR cooling -> slowing radiatively driven circulation

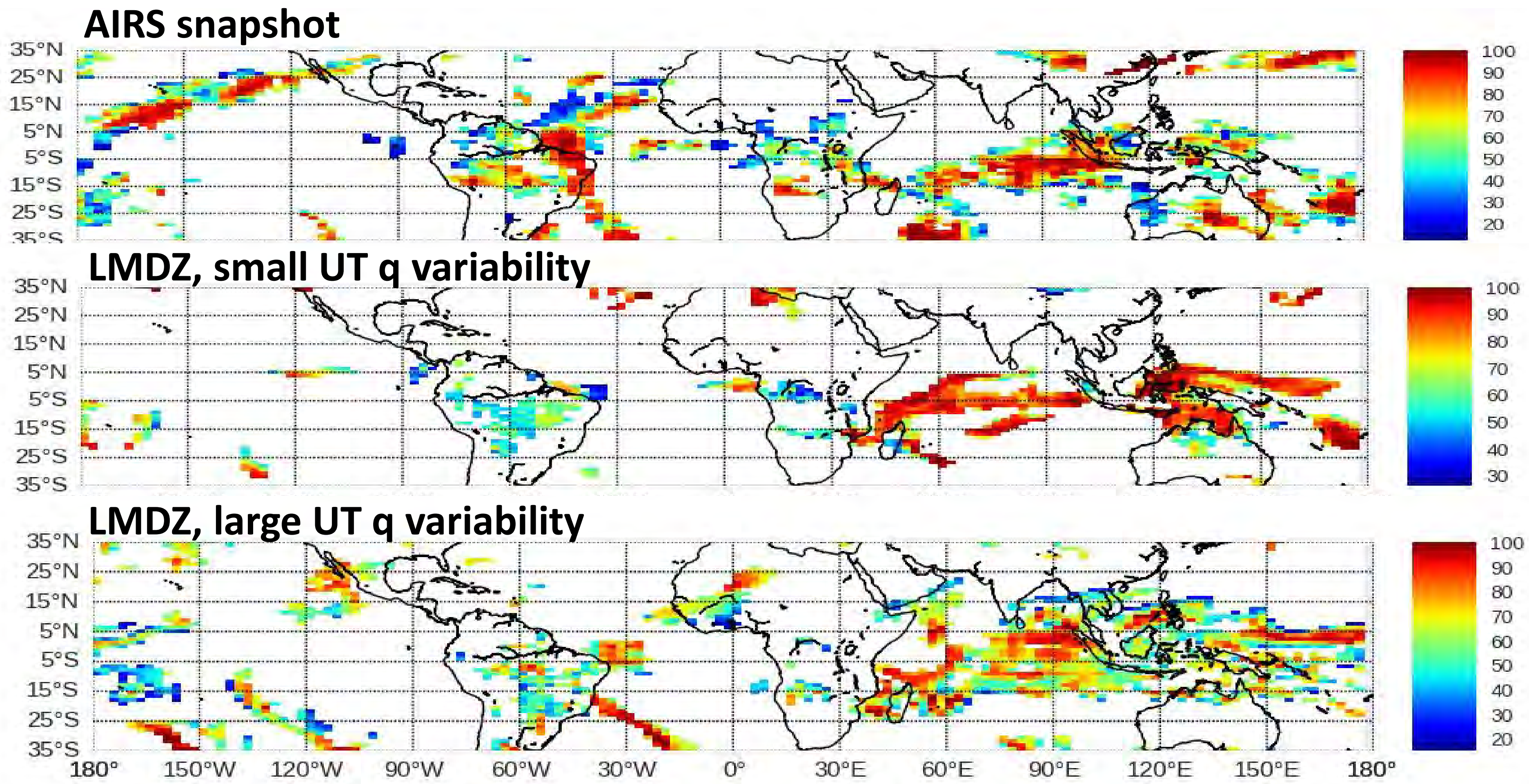
Diagnostics for UT cloud assessment in climate models

M. Bonazzola, S. Protopapadaki, C. Stubenrauch

simulate GCM clouds as seen from AIRS/IASI & construct UT cloud systems

-> evaluation of GCM convection schemes / detrainment / microphysics

allows to assess horizontal extent & emissivity structure of UT cloud systems



UT q variability might be compared to AIRS climatology of *Kahn et al. 2009, 2011*

Summary & Outlook

working group *(meetings: Nov 2015, Apr 2016, Mar 2017, autumn 2018)*

focus on

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

- **relation between convective strength & anvil properties:**
  change in emissivity structure
  -> might be used to constrain models

- **classification of vertical structure & heating rates (A-Train synergy)**
  -> extend to UT cloud systems & to other observation times
  & integrate into observational feedback studies
  using Lagrangian transport & advanced analysis methods

- **investigate how cloud systems behave in CRM studies**
  & in GCM simulations ***(under different parameterizations of convection/detrainment/microphysics)***