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

GEWEX **UTCC PROES: on Upper Tropospheric Clouds & Convection**

- ***advance understanding on feedback of UT clouds***

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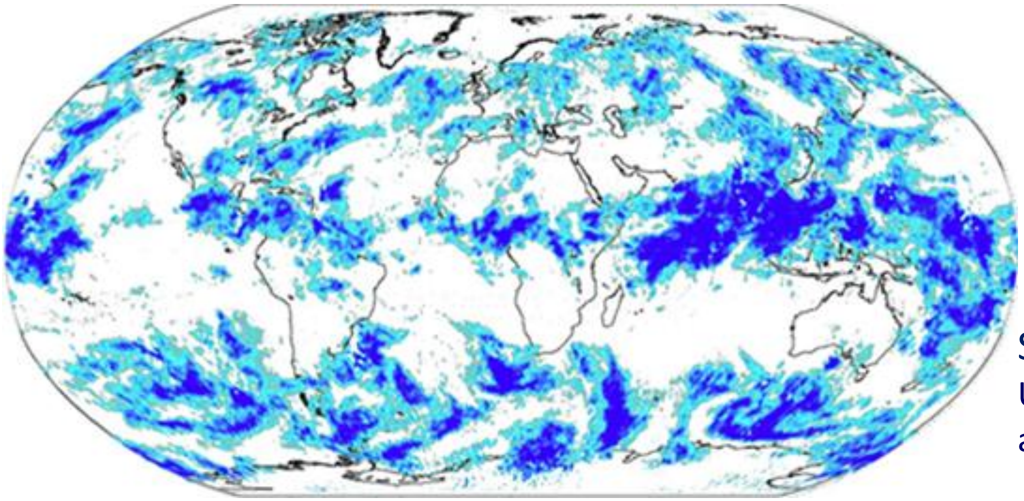
& UTCC PROES Participants

3 Jul 2018, 2nd WCRP meeting on Monsoons & Tropical Rain Belts, Trieste, Italy

Motivation

UT clouds cover 30% of the Earth



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

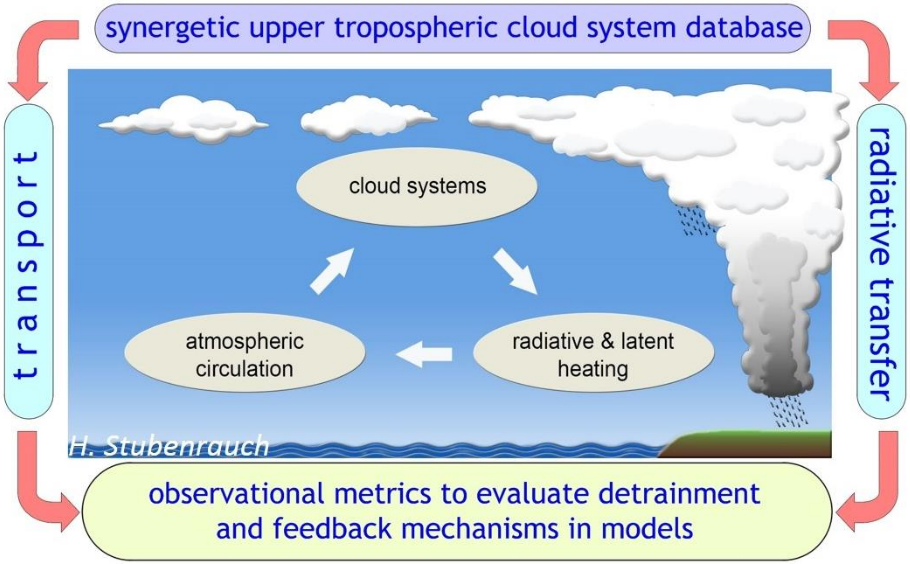
UT clouds play a vital role in climate system by modulating Earth's energy budget & UT heat transport

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

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 obs. based metrics to evaluate detrainment processes in models



UTCC PROES Strategy

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

meetings: Nov 2015, Apr 2016, Mar 2017

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}

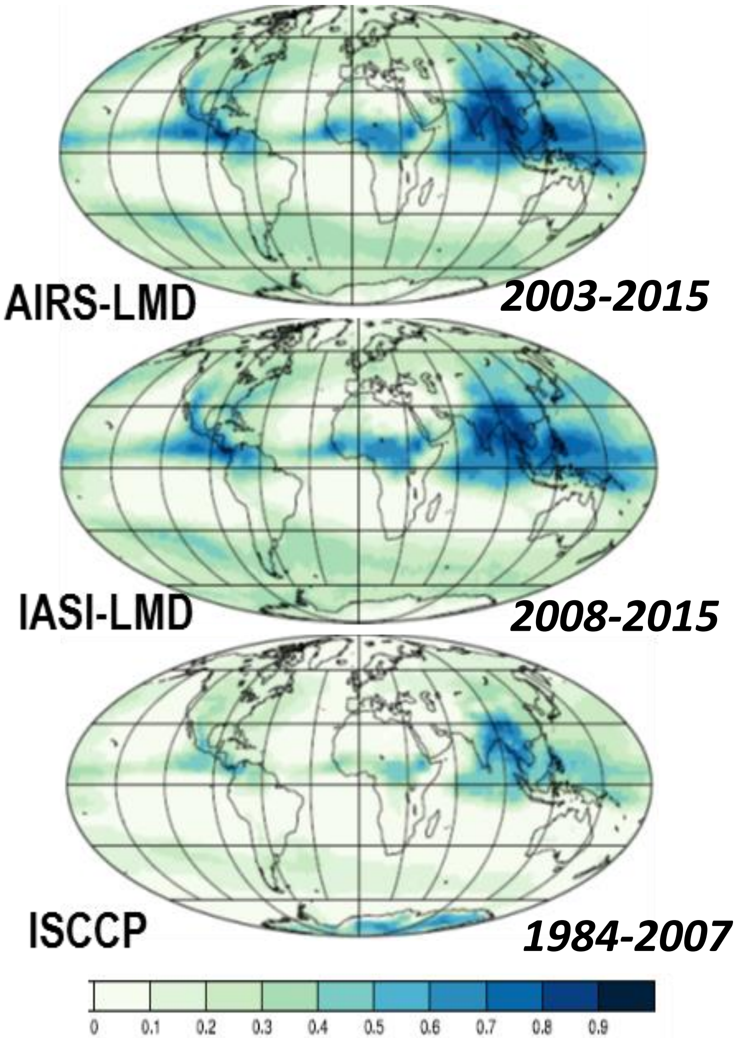
- **explore relationships between 'proxies' of convective strength & anvils**
- **build synergetic data** (vert. dimension, atmosph. environment, temporal res.)
- **determine heating rates** of different parts of UT cloud systems
- **follow snapshots** by Lagrangian transfer -> **evolution & feedbacks**
- **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	AIRS, CrIS	IASI (1,2,3), IASI-NG
>1979 / ≥ 1995: 7:30/ 1:30 AM/PM	≥2002 / ≥ 2012 : 1:30 AM/PM	≥2006 / ≥ 2012 / ≥ 2020 : 9:30 AM/PM

UT 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**

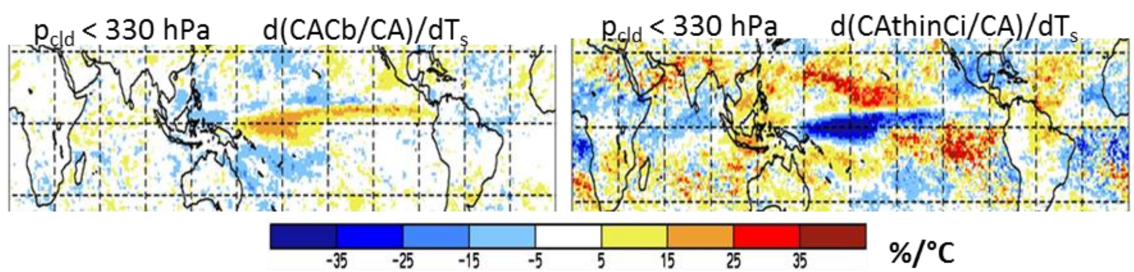
day & night, COD_{vis} > 0.2, also above low clouds

CIRS (Cloud retrieval from IR Sounders):

Stubenrauch et al., *J. Clim. 1999, 2006; ACP 2010,* ***ACP 2017***

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

Stubenrauch et al., ACP 2017



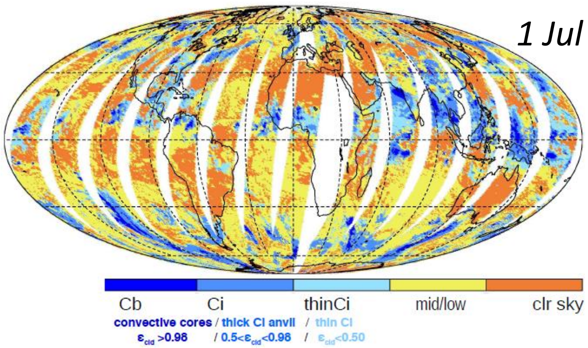
Changes in occurrence of Cb & thin Ci clouds relative to all clouds per °C warming show different geographical patterns
slight tropical increase in Ci, thCi rel to all clouds

-> change in heating gradients

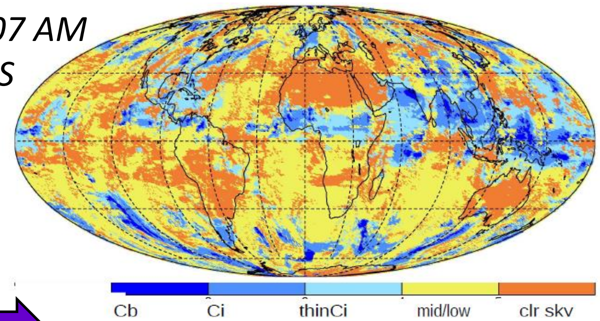
From cloud retrieval to cloud systems

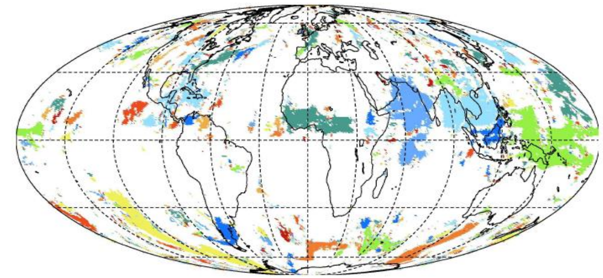
clouds are **extended objects**, driven by dynamics -> **organized systems**

Method: 1) group adjacent grid boxes with high clouds of similar height (p_{cld})



1 Jul 2007 AM
AIRS



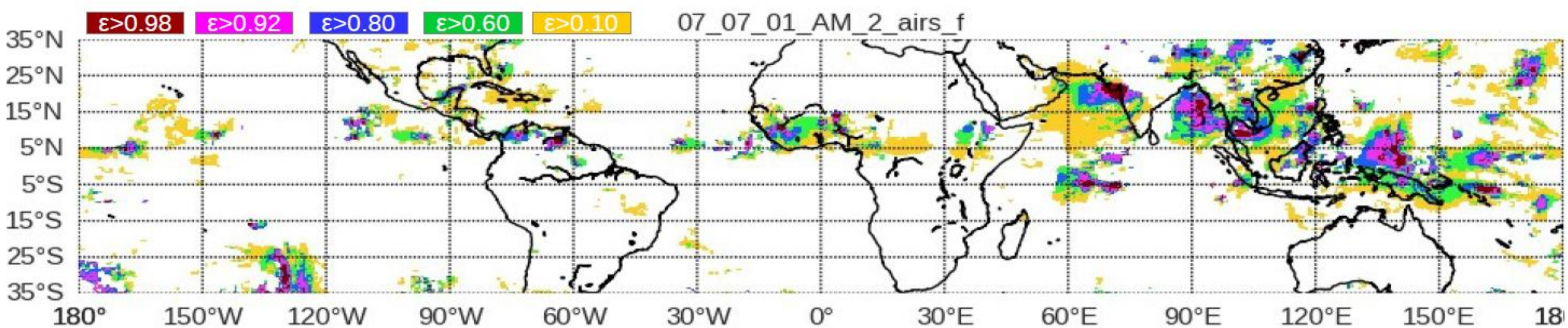


fill data gaps using PDF method

build UT cloud systems

Protopapadaki et al. ACP 2017

2) use ε_{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)*

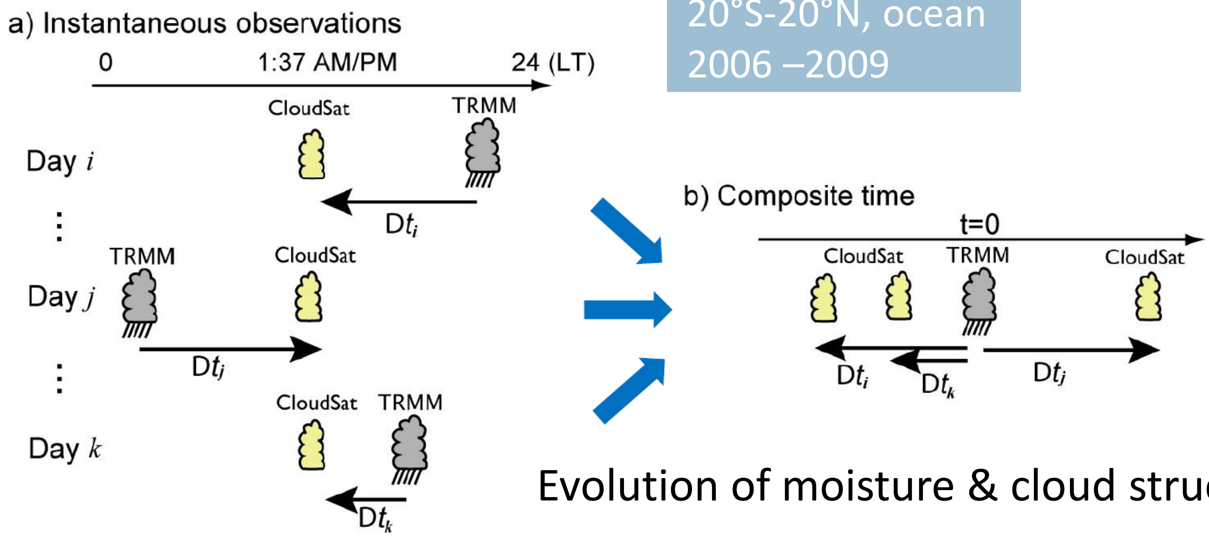
Synergy with TRMM to analyze system life evolution

Composite observations w. r. t. convective life stages

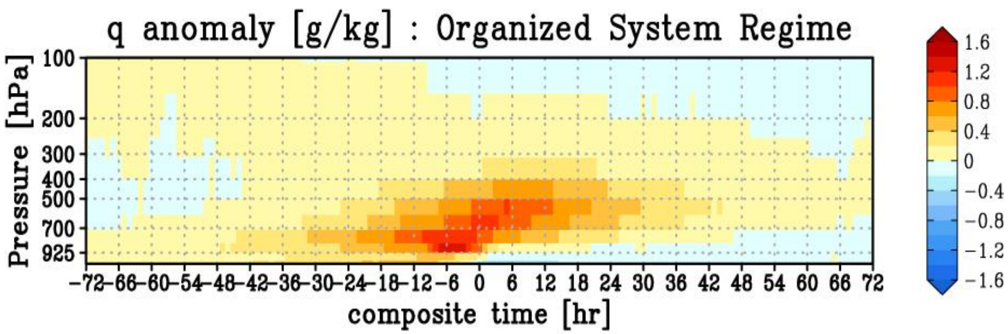
H. Masunaga
UTCC PROES meeting 2017

20°S-20°N, ocean
2006 –2009

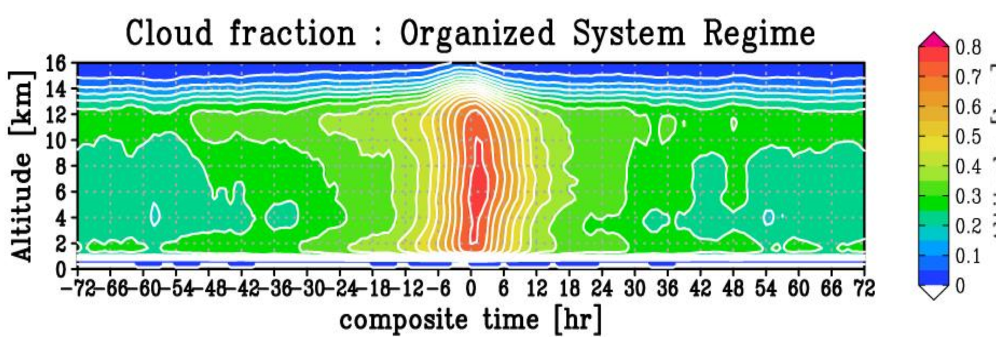
Masunaga, 2012, 2013
Masunaga & L'Ecuyer 2014

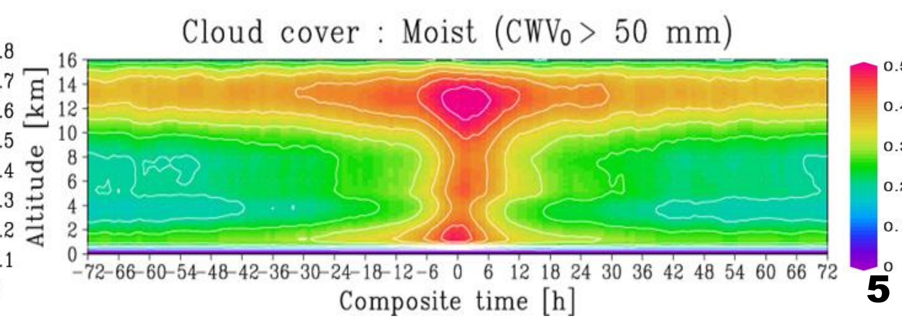


Evolution of moisture & cloud structures in organized convection



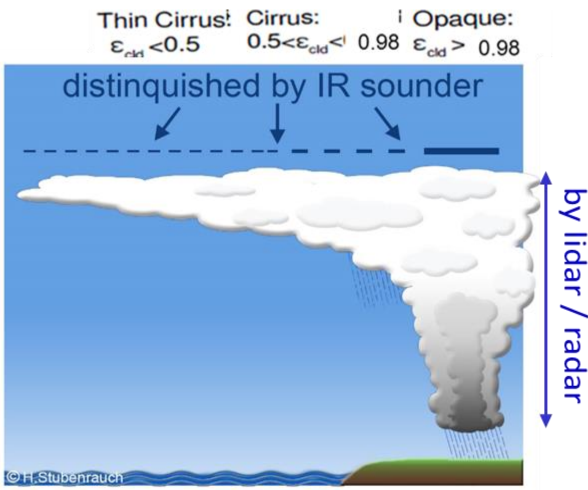
well defined convective cloud column at time of precipitation & then thinning out, but cirrus also around before convection





Goal: relate anvil properties to convective strength

Strategy: need proxies



- to identify convective cores

  $\varepsilon_{cld} > 0.98$ *(compared to AMSR-E rain rate)*

- to identify mature convective systems

  system core fraction : 0.1 – 0.3 *(reaching max core size)*

- 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* / TRMM
  / conv mass transport *(Takahashi & Luo 2014 / Liu & Zipser 2007, Mullendore et al. 2008)*

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

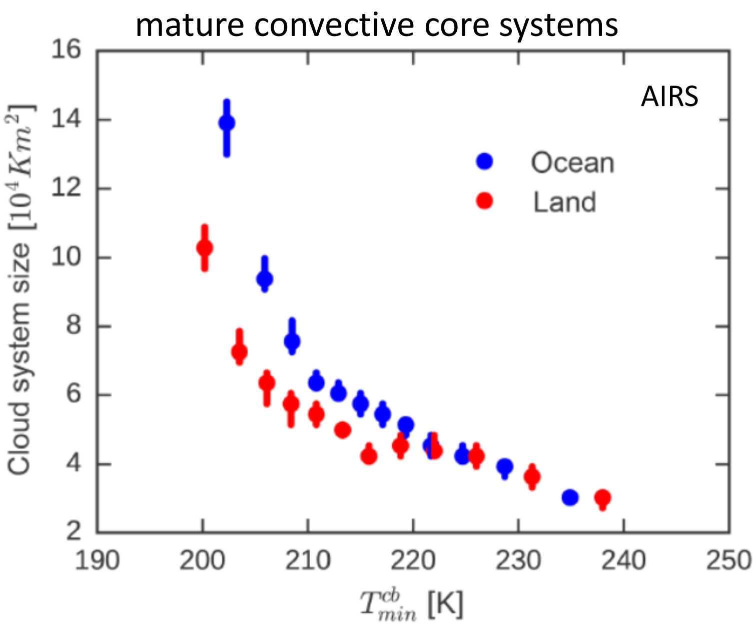
  heavy rain area: CloudSat-AMSR-E-MODIS *(Yuan & Houze 2010)*

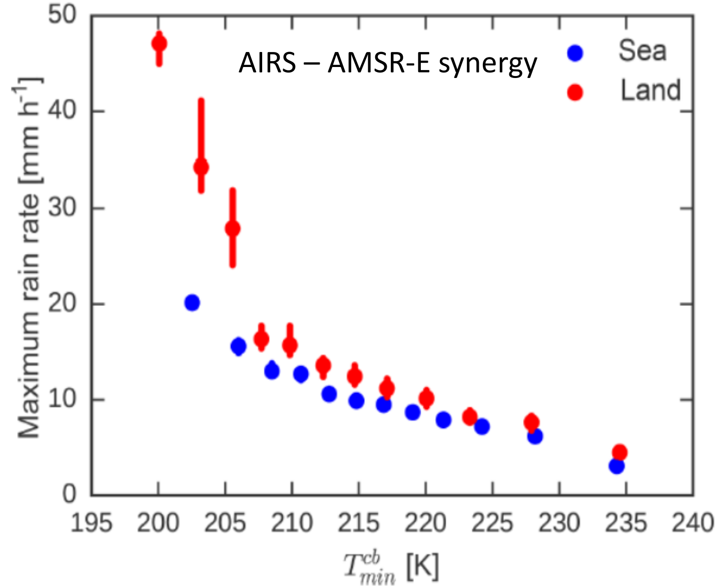
  core width : CloudSat *(Igel et al. 2014)*

  mass flux : ERA-Interim + Lagrangian approch *(Tissier et al. 2016)*
  A-Train + 1D cld model *(Masunaga & Luo 2016)*

convective strength -> cloud system properties

Protopapadaki et al. 2017





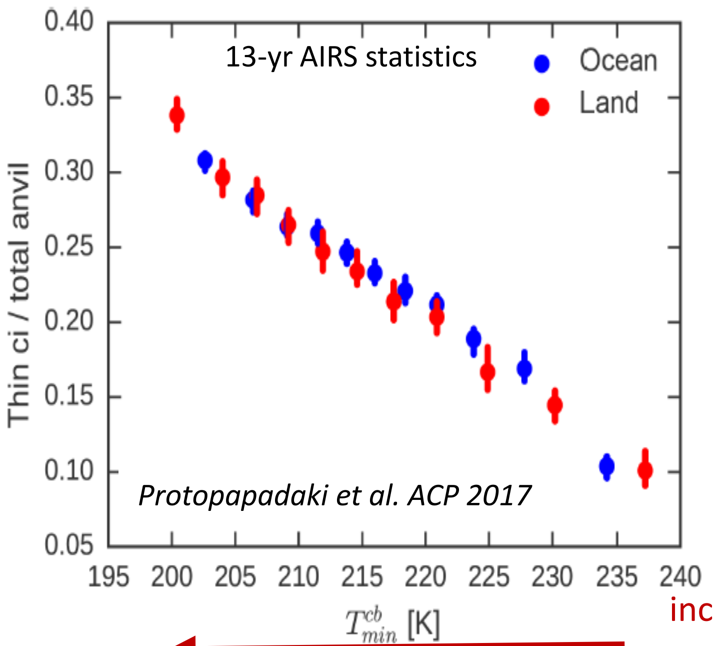
cloud system size / max rain rate increase with convective depth (colder cloud tops), but **land** – **ocean** differences :
at same height continental cloud systems stronger convective rain rate & smaller size

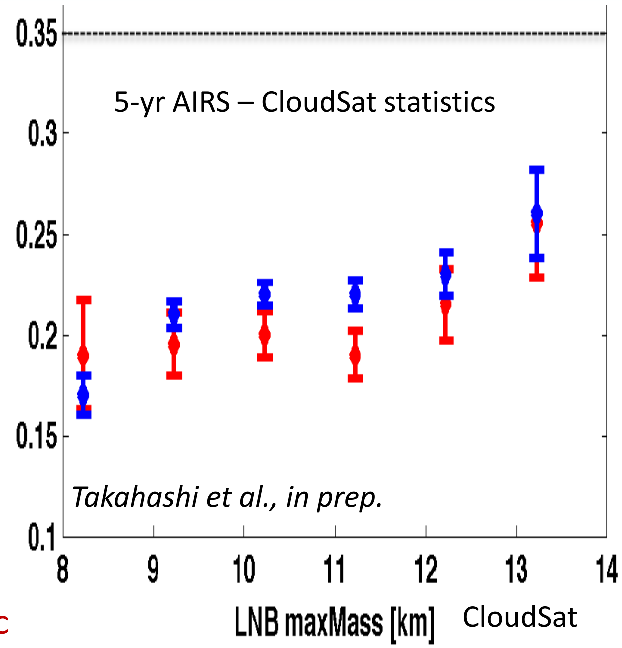
colder cores -> stronger max RR => T^{cb}_{min} proxy for convective strength

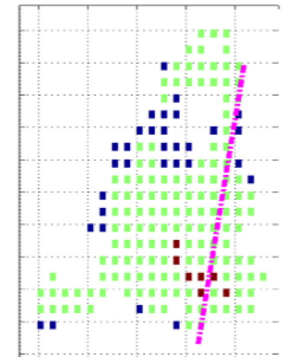
TRMM study ***(Liu et al. 2007)***:
larger updraft & convective cores, but smaller cloud systems
smaller updraft & convective cores, but larger cloud systems

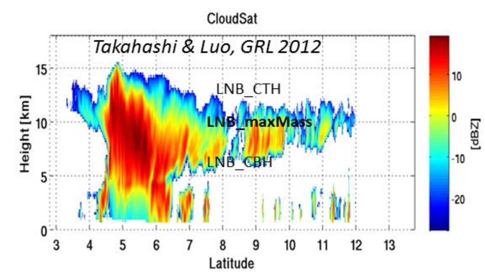
CloudSat study (***Takahashi et al. 2017***):
less entrainment - stronger entrainment

convective strength -> anvil properties









inc convective strength

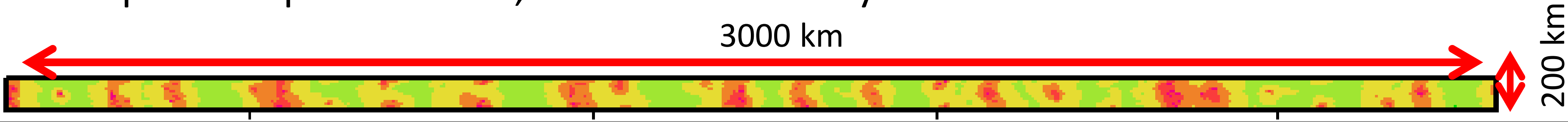
Mature convective systems: increase of thin Ci with increasing convective strength !
similar land / ocean
relation robust *using different proxies : T_{min}^{Cb} / LNB(max mass)*

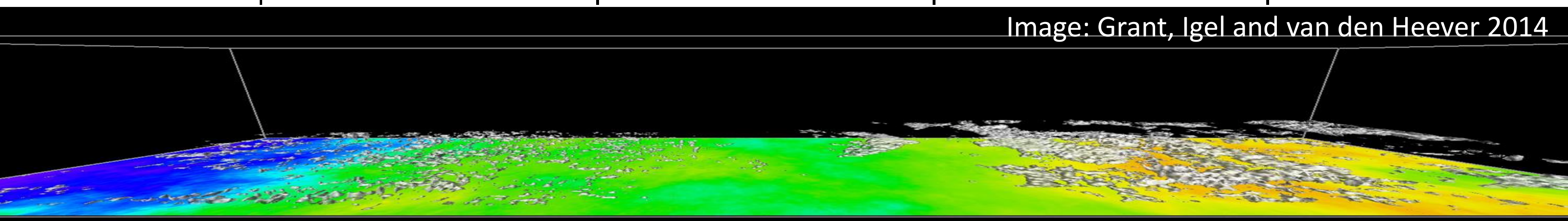
Why ?
H1: UT environmental predisposition (at higher altitude larger RH, T stratification)
H2: UT humidification from cirrus outflow
-> CRM studies

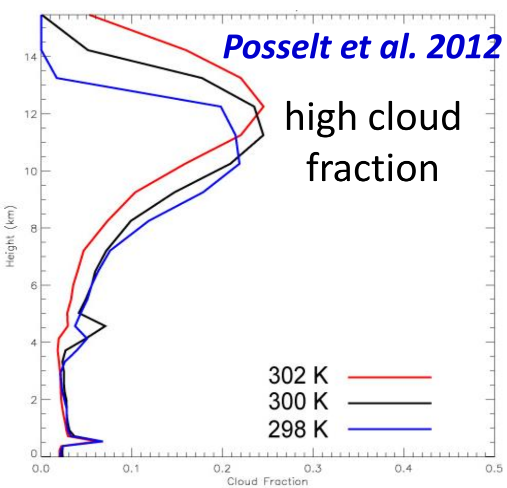
Characteristics of deep convection from CRM simulations

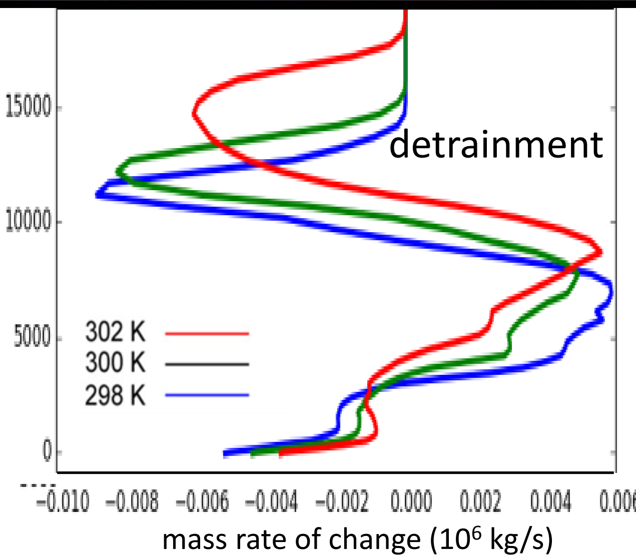
***S. van den Heever**, UTCC PROES meeting 2017*

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

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

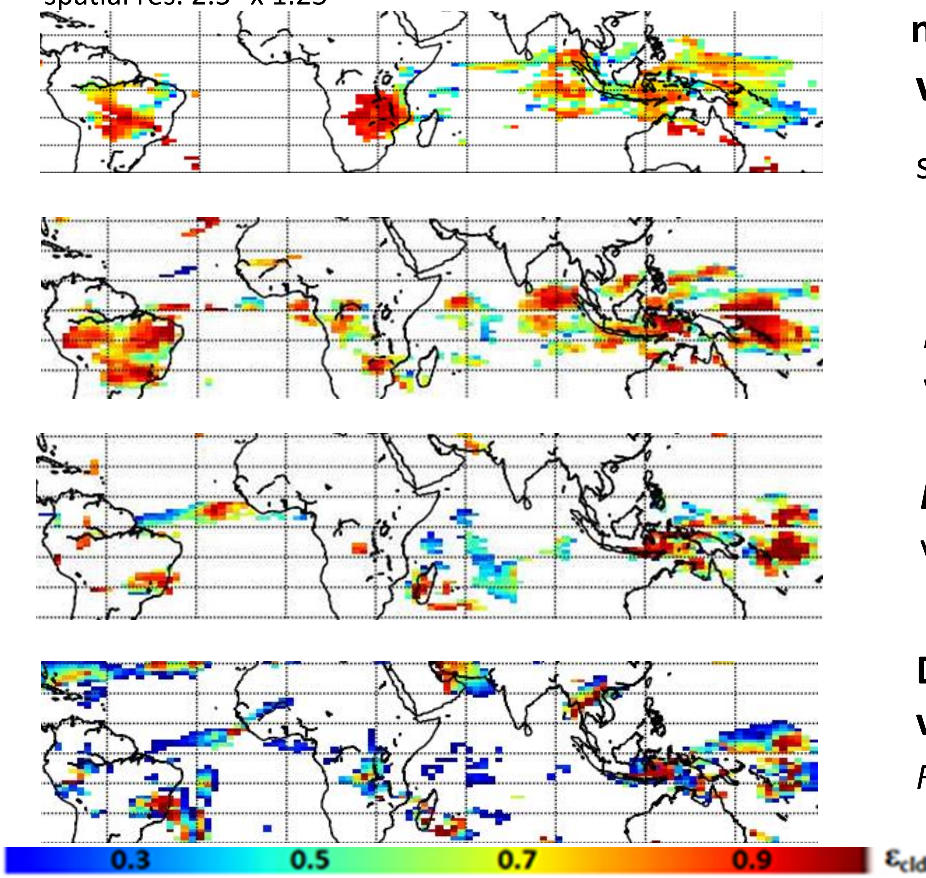
M. Bonazzola, LMD

& construct UT cloud systems

-> evaluation of GCM convection schemes / detrainment / microphysics

Goal: build coherent v_m- De parameterization

spatial res. 2.5° x 1.25°



nominal fall speed & precipitation efficiency

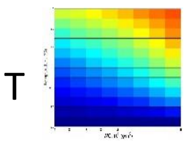
$$v_m = c \times f(IWC), \qquad De = f(T), \varepsilon = f(De, IWC)$$

scaled v_m too small compared to observations

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

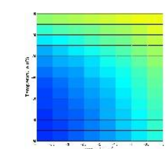
Heymsfield et al. 2007

v_m increase with IWC *stronger* towards warm T



Deng & Mace 2008

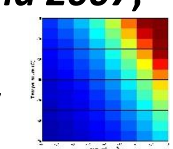
v_m increase with IWC *weaker* towards warm T



D_m from PSD moment parameterization of *Field 2007*,

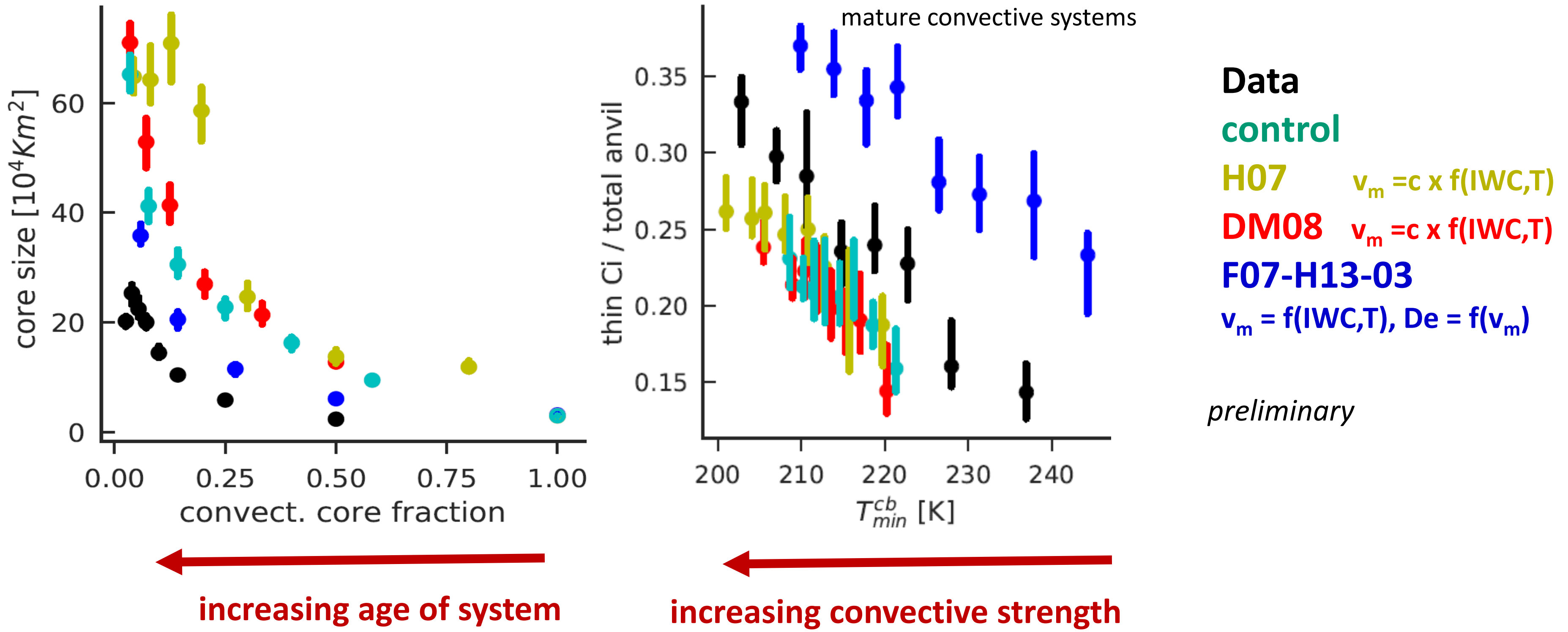
$v_m = f(D_m)$; $De = f(v_m)$ *Heymsfield 2013, 2003*

Rad. balance via precip. efficiency, UT hum variability



horizontal cloud system emissivity structure sensitive to v_m, De

process-oriented UT cloud system behaviour



implementing T dependency of v_m -> larger spread in T^{cb}_{min}, in better agreement to observations
integrating v_m –De very promising: leads to more realistic core size development !

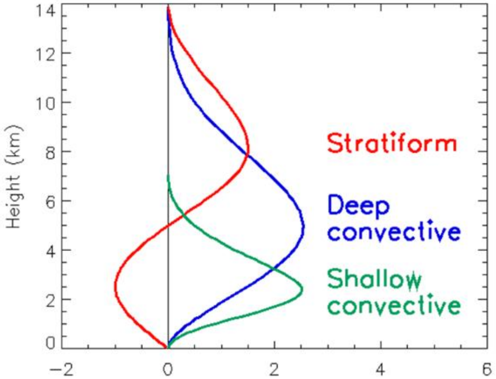
Next steps: DM08 without scaling factor & De(v_m)
more sensitivity studies on parameters used for radiation balance
integrating single scattering properties developed by Baran 2016 from PSD's of F07

convective – anvil heating

latent (LH) – radiative (RH)

C. Schumacher
UTCC PROES meeting 2017

Schumacher et al. 2004



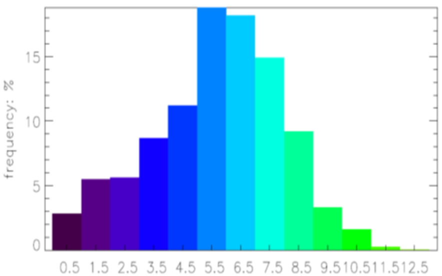
Latent heating (K/day)

latent heating from TRMM :
column precipitation & cloud profile

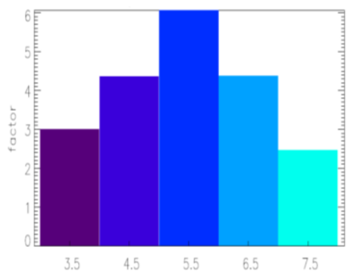
tropical stratiform rain leads to high peak in heating & cooling below
deep convective rain leads to broad atmospheric warming

Sensitivities of TRMM & CloudSat radar

Li & Schumacher 2010



depth of missed echo top (km)



echo base height (km)

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

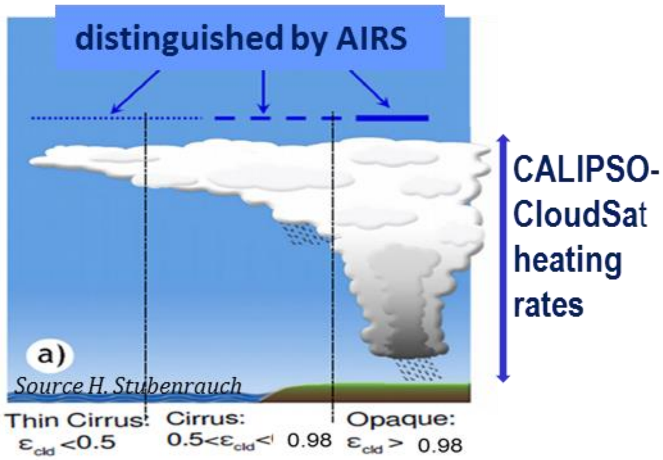
TRMM LH – ISCCP RH synergy

Li et al. 2013

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



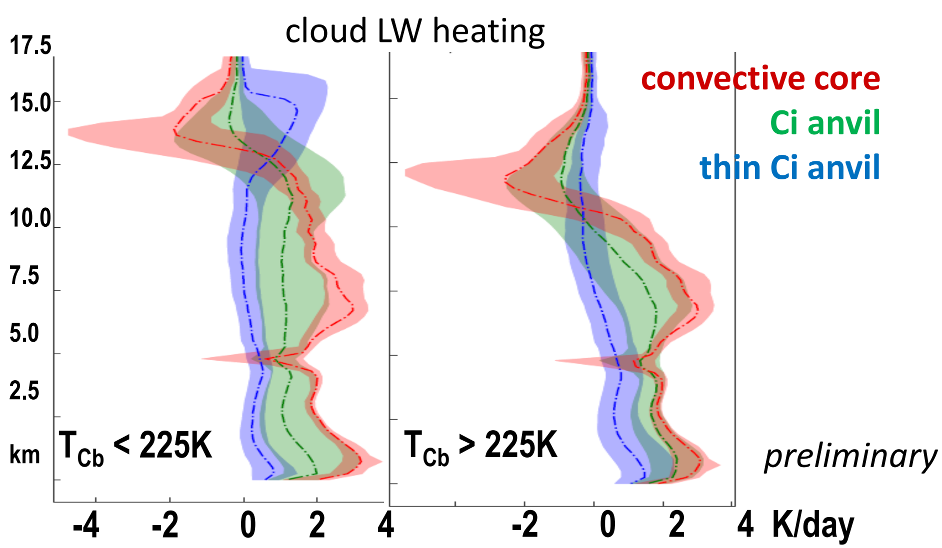
Heating will be affected by:

- 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 ε_{cld}, p_{cld}, vert. layering, thermodyn.



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 *https://gewex-utcc-proes.aeris-data.fr*

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 ε_{cld}, p_{cld} shows clear distinction**

  thin Ci heating larger for colder systems

- ❑ **propogate 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)*