GEWEX Process Evaluation Study on Upper Tropospheric Clouds & Convection

GEWEX UTCC PROES

advance understanding on feedback of UT clouds

large-scale modelling necessary to identify most influential feedback mechanisms

-> models should be in agreement with observations

- *understand relation between convection, cirrus anvils & radiative heating*
- *provide observational metrics to probe process understanding*

Claudia Stubenrauch

Laboratoire de Météorologie Dynamique / IPSL, France

GEWEX Data and Assessment Panel meeting
9 – 12 Oct 2017, Boulder, USA

GEWEX UTCC PROES participants

Coordination: Claudia Stubenrauch & Graeme Stephens

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

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:

B. Legras, A.-S. Tissier, A. Hertzog (LMD)

Small scale process modelling :

S. van den Heever (CSU), R. Storer (NASA JPL), R. Plougonven, C. Muller (LMD),

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)

GEWEX UTCC PROES highlights 2017

- **2nd GEWEX UTCC PROES meeting**

hosted by Johnny Luo, at City College, University of New York, 28 – 29 March 2017

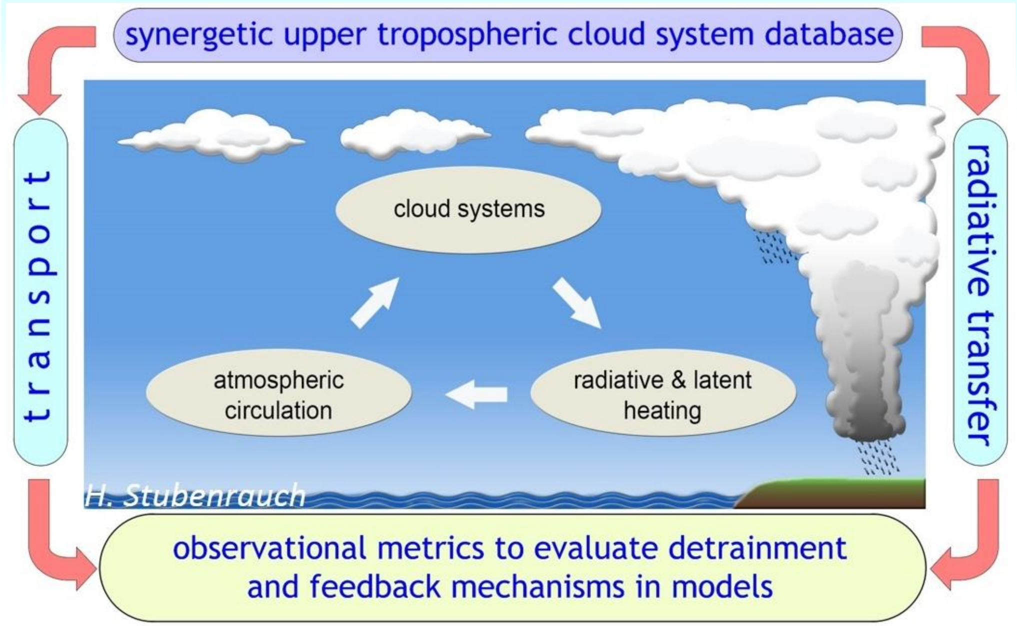
vivid discussions about synergies & cooperations (funding dependent):
data, CRM studies & climate model parameterizations

- **article in GEWEX Newsletter May 2017**
- **AGU session,** convened by H. Takahashi, R. Storer
- **build UTCC PROES website,** in cooperation with French data centre AERIS
  goals, talks of the meetings, references

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)*

IR Sounders to derive UT cloud properties

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

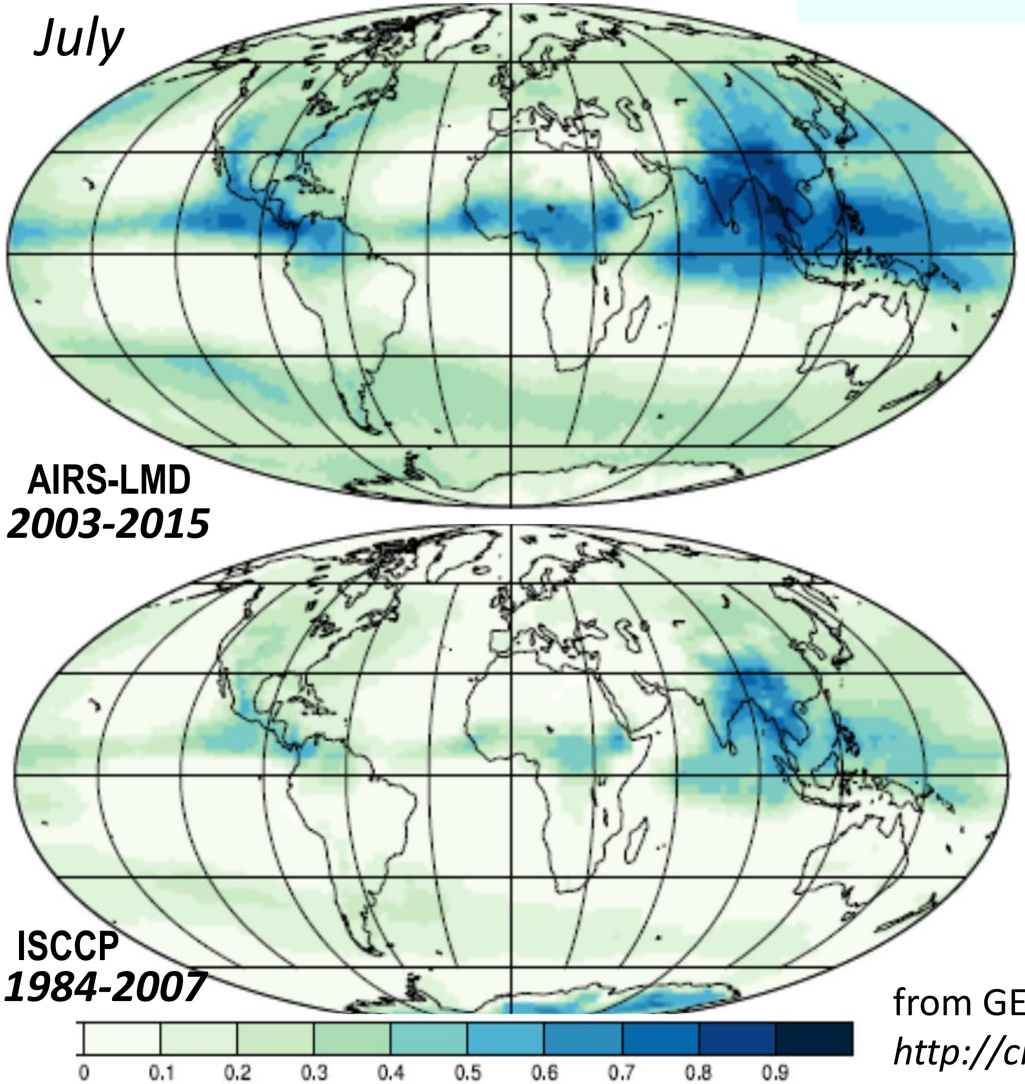
AIRS, CrIS
≥2002 / ≥ 2012 : 1:30 AM/PM

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

- long time series & good areal coverage
- **good IR spectral resolution -> sensitive to cirrus**
  day & night, COD > 0.2, also above low clouds

UT cloud amount

July



CIRS (Cloud retrieval from IR Sounders):

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

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

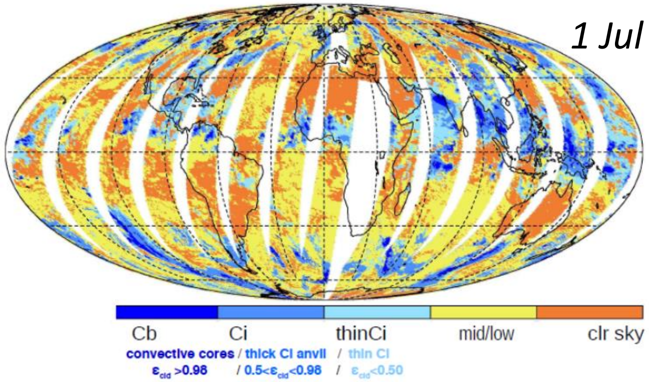
from GEWEX Cloud Assessment Database
http://climserv.ipsl.polytechnique.fr/gewexca

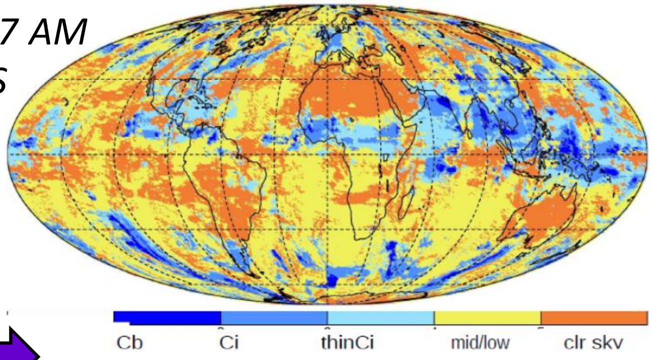
From cloud retrieval to cloud systems

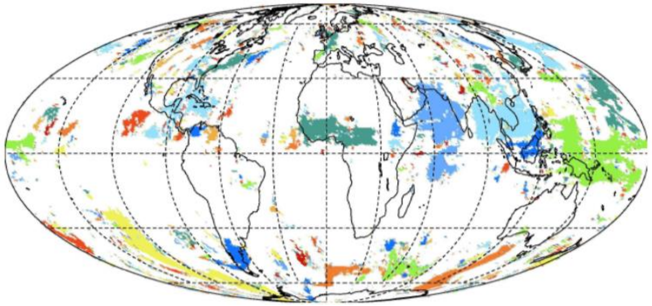
clouds are **extended objects**, driven by dynamics -> **organized systems**

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

1 Jul 2007 AM
AIRS





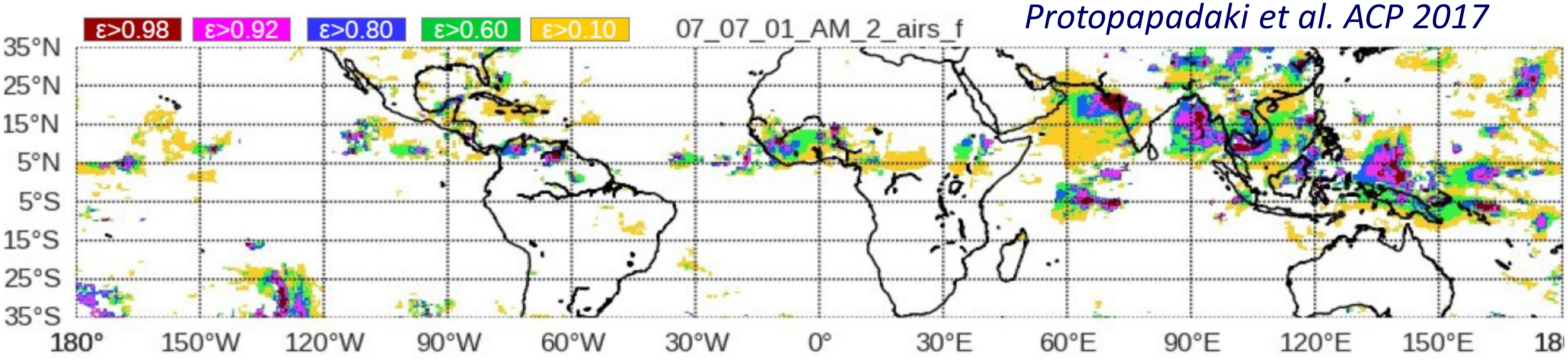


fill data gaps using PDF method

build UT cloud systems

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

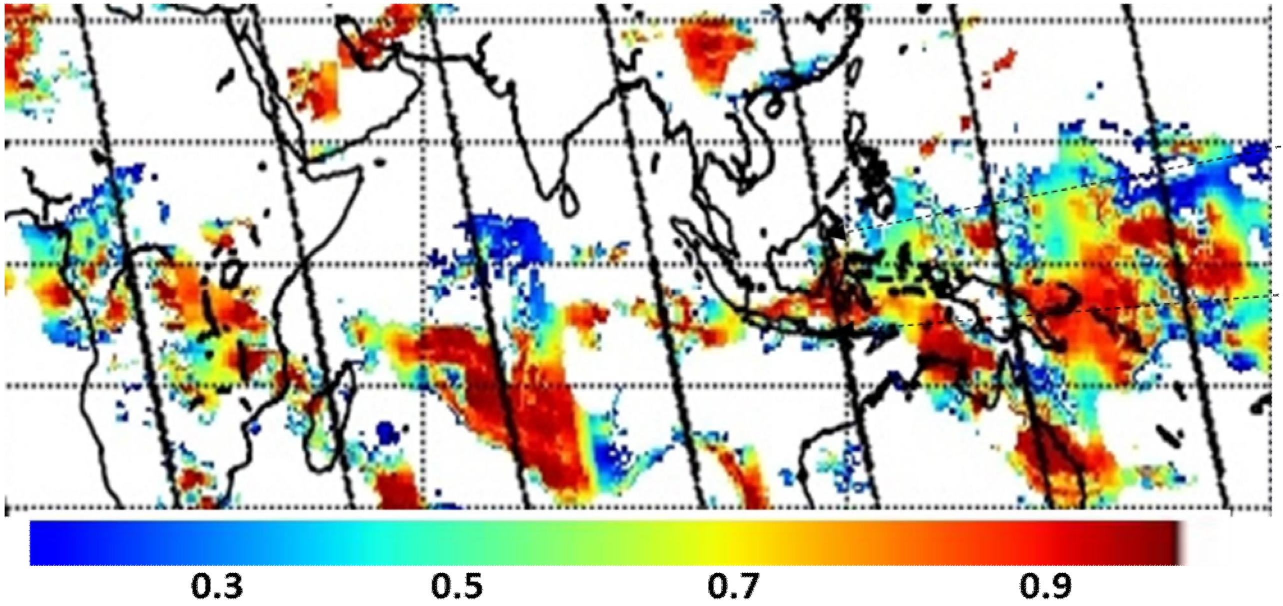
Protopapadaki et al. ACP 2017



30N-30S: UT cloud systems cover 20%, those without convective core 5%

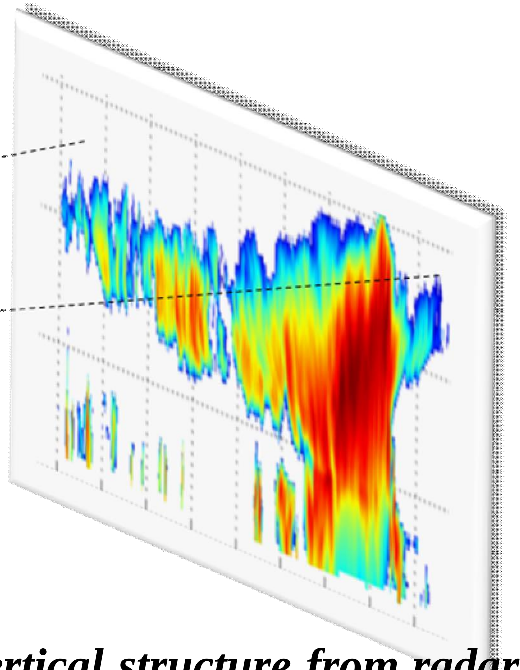
50% of these originate from convection *(Luo & Rossow 2004, Riihimaki et al. 2012)*

Observation synergies



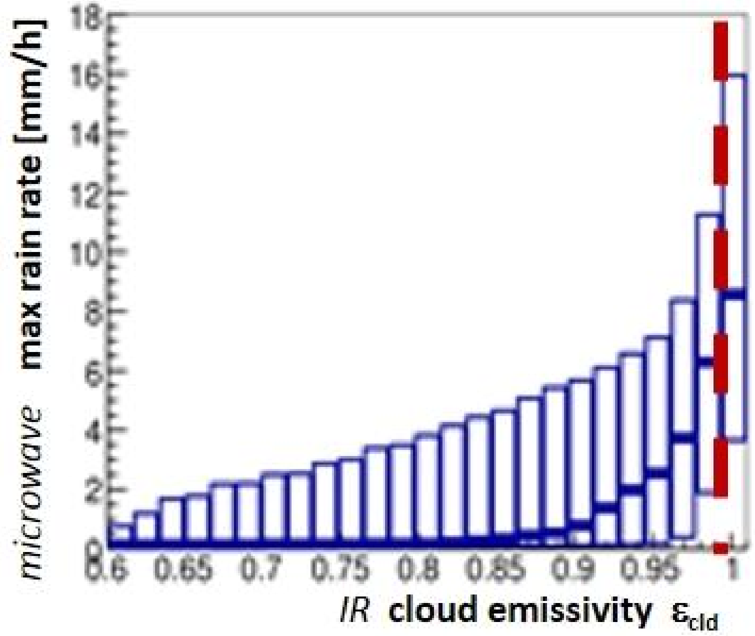
horizontal emissivity structure of UT cloud systems

compared to other studies, IR sounders add thin cirrus ($0.1 < \varepsilon_{cld} < 0.5$)



vertical structure from radar-lidar:

radar reflectivity of convective system



A-Train synergy (1h30 AM / PM)

AIRS – CALIPSO – CloudSat – AMSR-E

microwave imager - IR sounder synergy:

definition of convective core : $\varepsilon_{cld} > 0.98$

Goal: relate anvil properties to convective strength

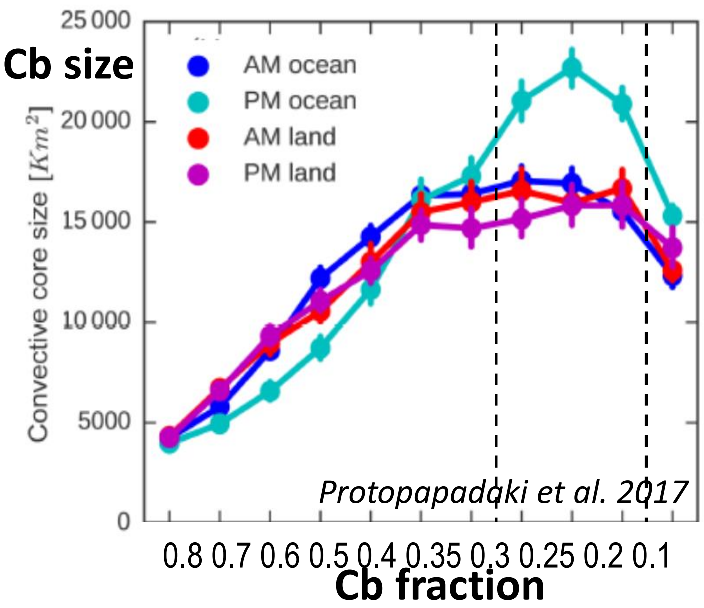
Strategy: need proxies

- 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)*



Protopapadaki et al. 2017

- 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)*

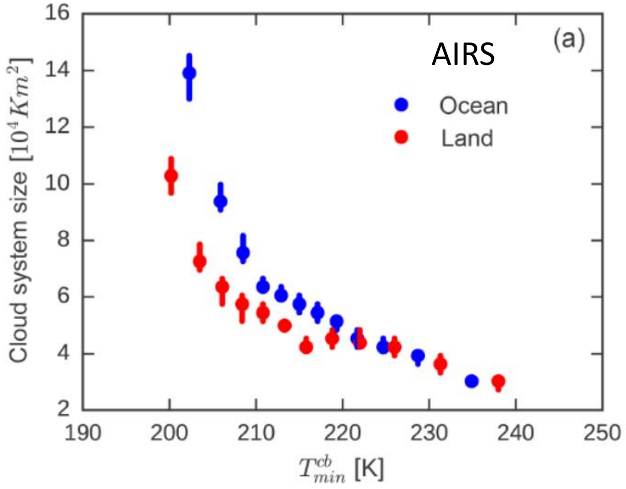
  core width : CloudSat *(Igel et al. 2014)*

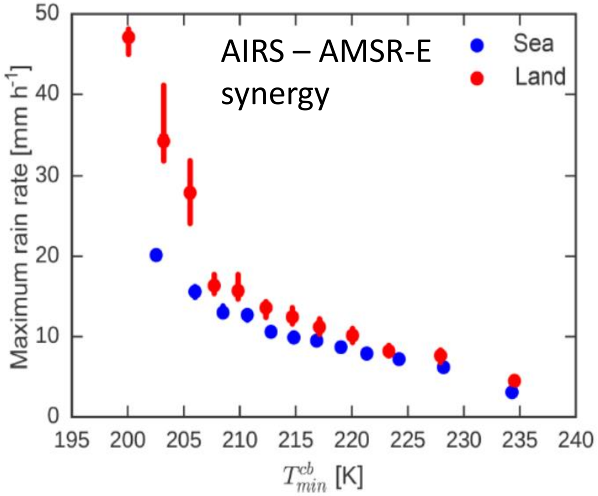
  mass flux : ERA-Interim + Lagrangian approch *(Tissier et al. 2016)*

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

convective strength <-> cloud system properties

cloud system size / **max rain rate** increase with convective strength, but land – ocean differences



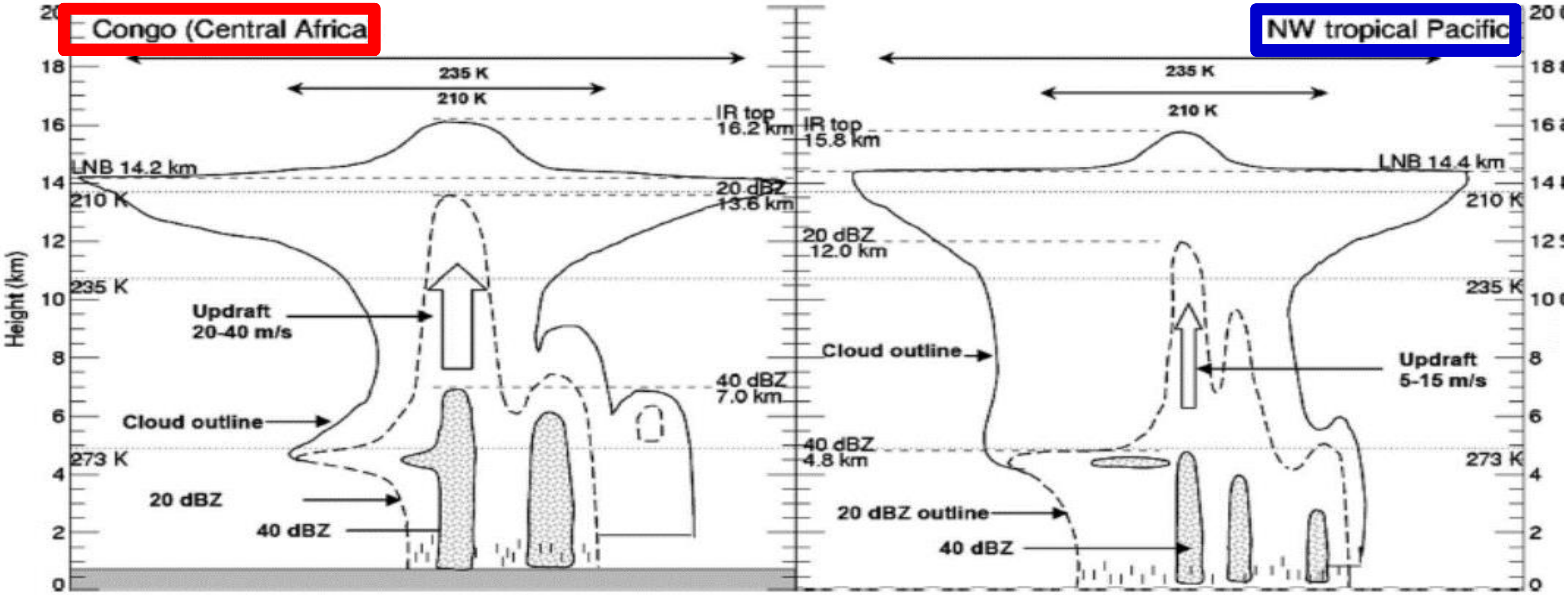


mature single convective core systems

Protopapadaki et al. 2017

Liu et al. 2007

typical strong convective systems (6-yr TRMM statistics)



larger updraft & CC, smaller systems - smaller updraft & CC, larger systems

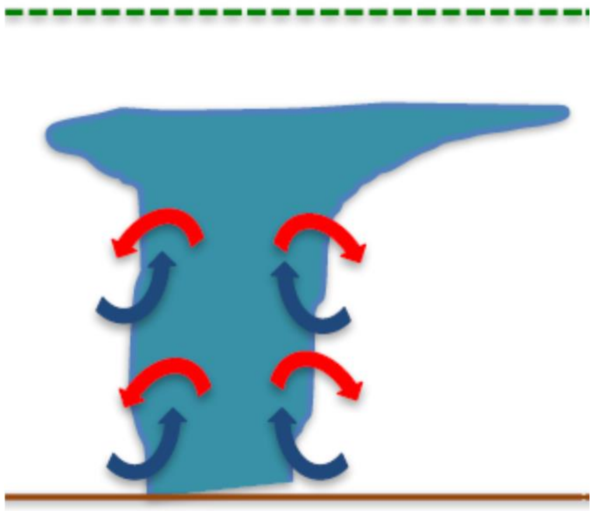
less entrainment

stronger entrainment

Takahashi et al. 2017

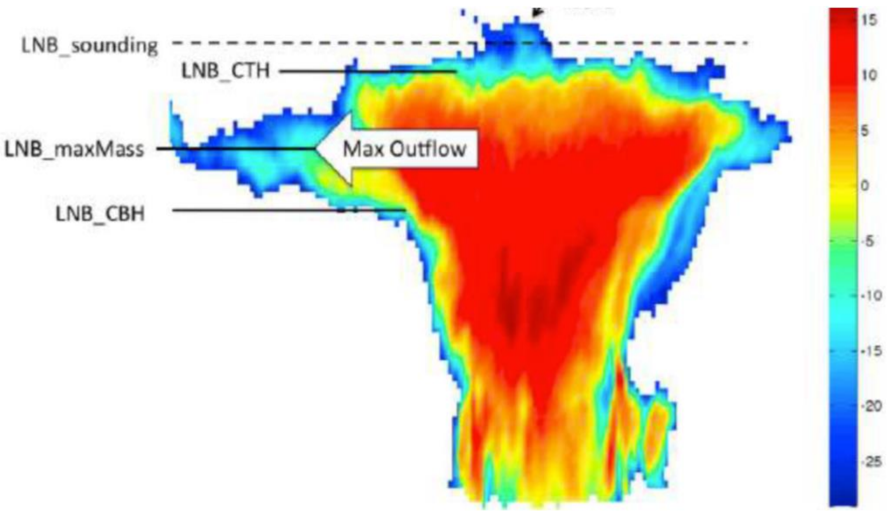
land -ocean convective entrainment

Takahashi et al. 2017



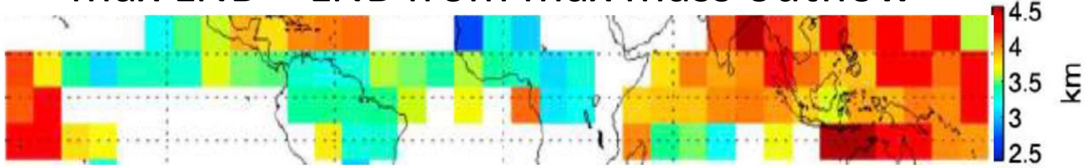
LNB from sounding:
max height
(no air mass interaction)

convective entrainment
affects buoyancy

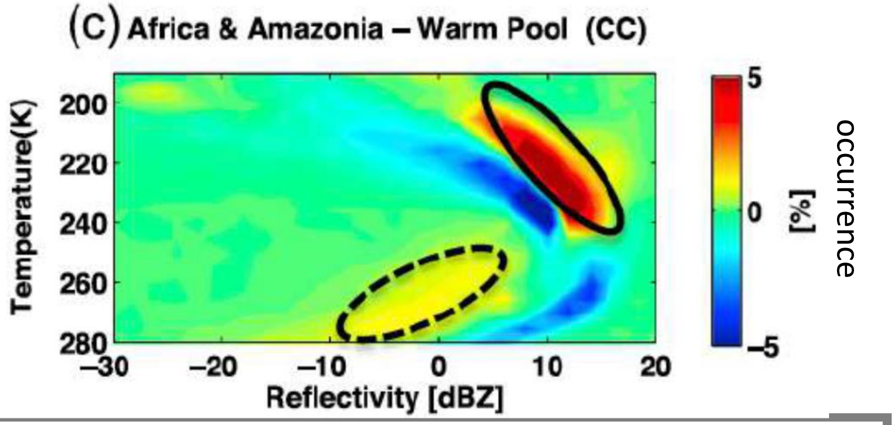


convective cloud objects from 5-yr CloudSat statistics
Takahashi & Luo 2012

max LNB – LNB from max mass outflow



measure of magnitude of entrainment effect



more attenuation due to
heavy rain over land

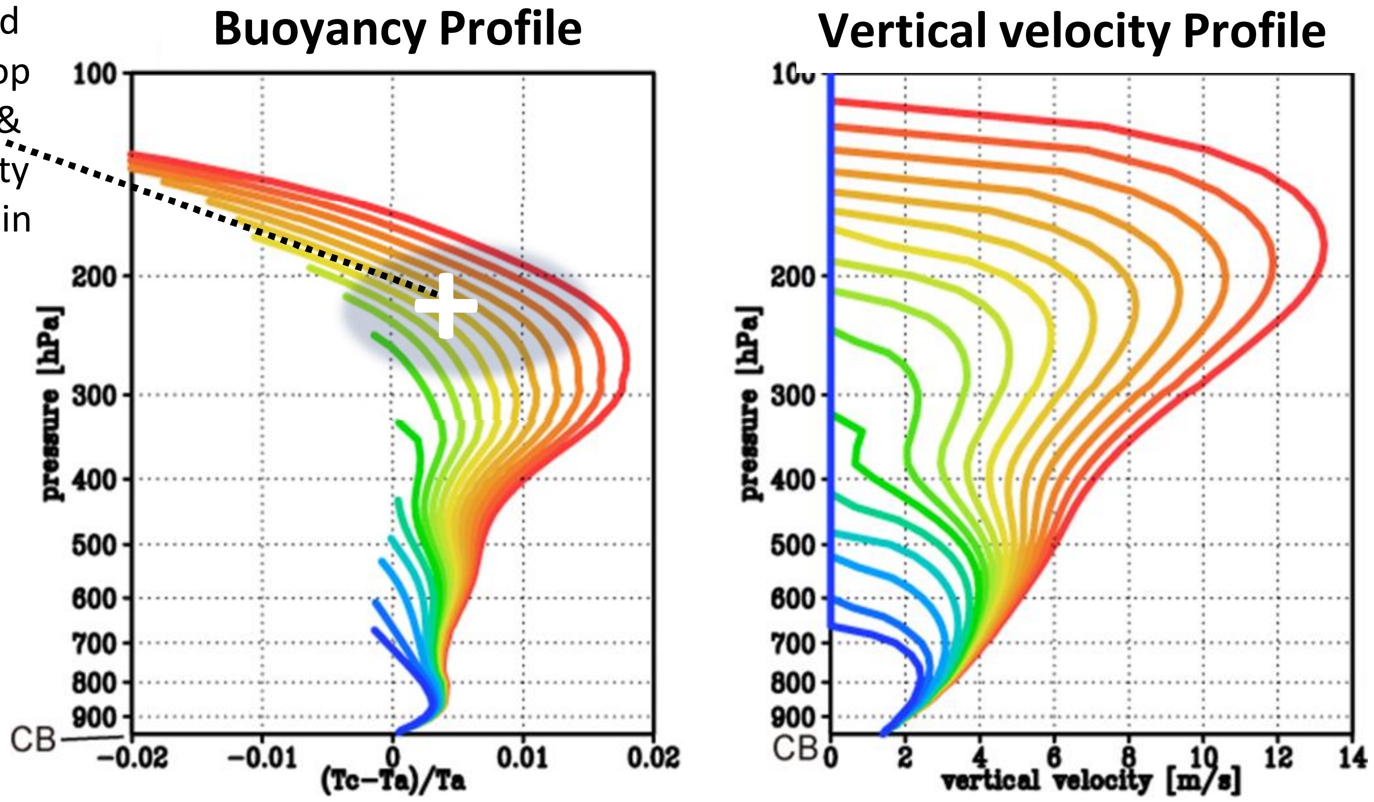
- ➢ Warm Pool more diluted than tropical land regions
- ➢ higher LNB(max mass outflow) associated with moister midtroposphere (reduced entrainment dilution) & smaller systems
- ➢ Tropical continental systems less entrainment => more intense convective cores

convective entrainment & vertical velocity

Masunaga & Luo 2016

Entraining ambient air will slow down convective updraft

Simulations constrained by cloud top buoyancy & vert velocity from A-Train synergy



Forced by AIRS sounding

single column plume model

Plume entrainment rates from 0 km^{-1} to 0.4 km^{-1}

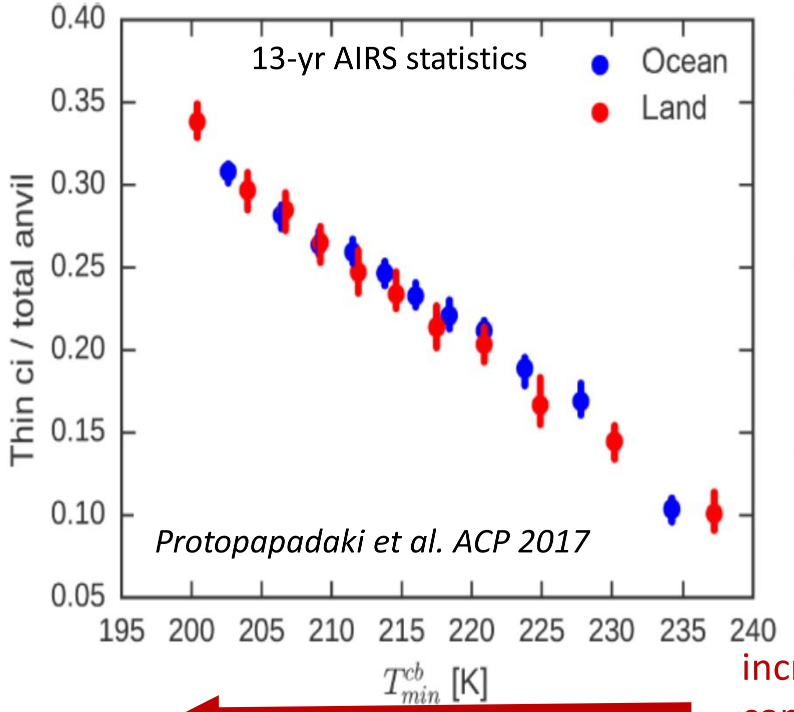
increasing entrainment leads to smaller climate sensitivity

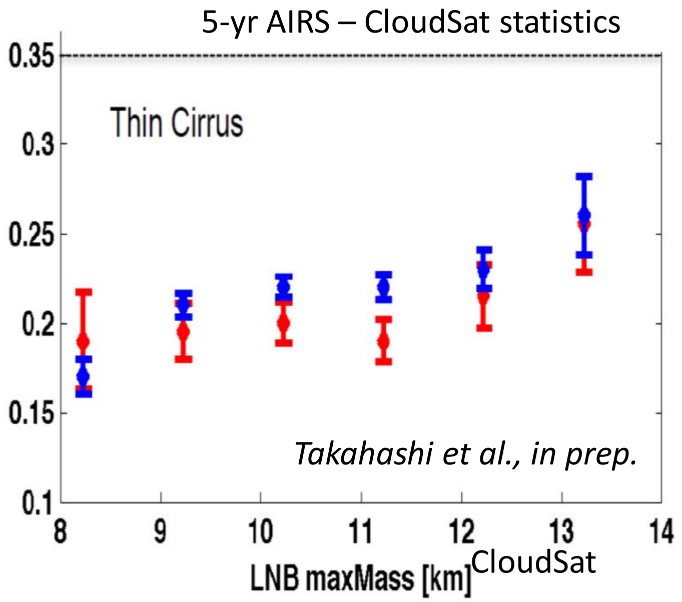
(Zhao et al. 2014, Sanderson et al. 2010)

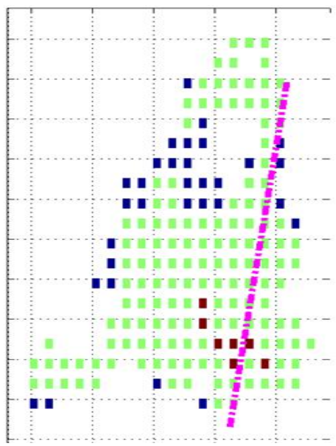
mechanisms not yet understood

L. Donner
UTCC PROES
meeting 2017

convective strength -> anvil properties

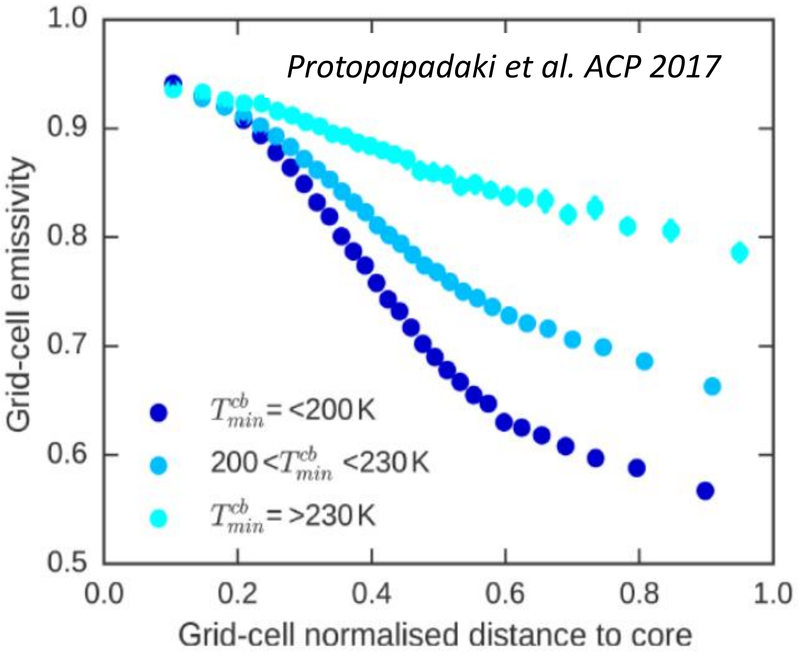






CloudSat

increasing
convective strength



Mature convective systems:

increase of thin Ci with increasing convective strength !

similar land / ocean

slope of ε_{cld} decrease with distance to core increases

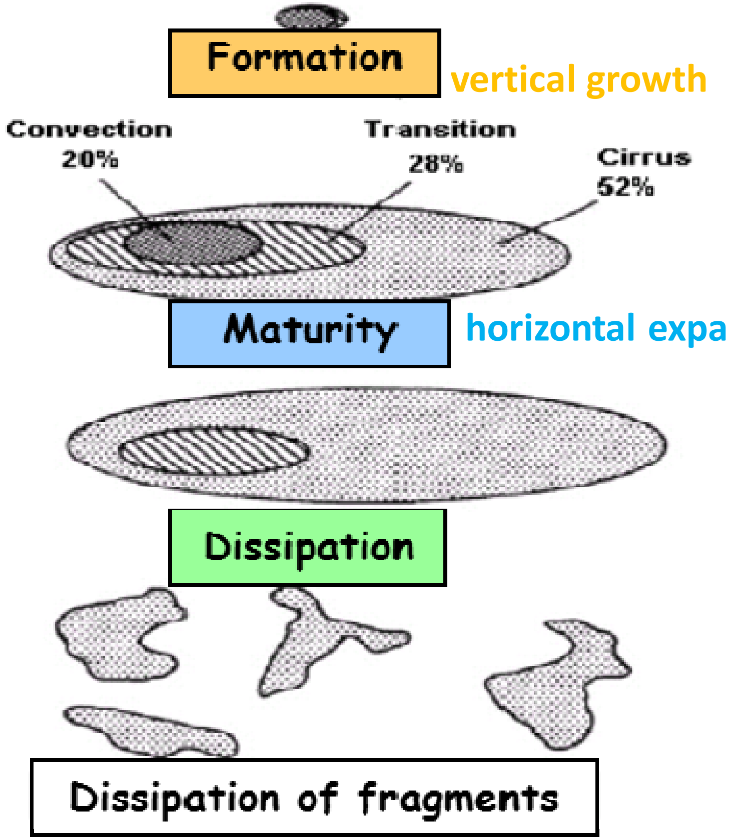
relation robust *using different proxies :*

T_{min}^{Cb} / LNB(max mass)

Life cycle of deep convective cloud systems

max of convection over **land** / **ocean** : **16-18h** / **early morning**
problem: most polar sunsynchroneous observations do not catch this

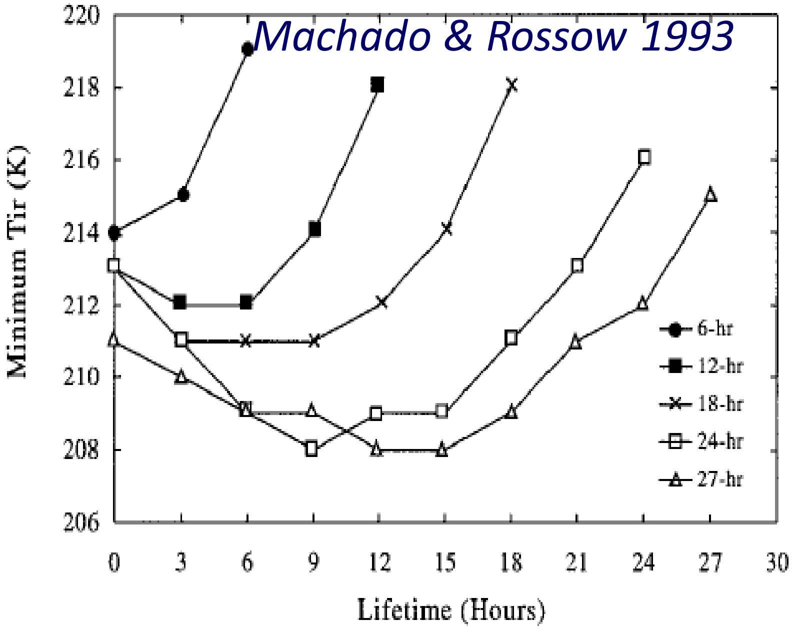
-> use good time resolution of geostationary satellite imagers
& track cold convective cores with T_B^{IR}; however T_B^{IR} depends on T_{cld} & on ε_{cld}



vertical growth

horizontal expansion

track all cold clouds (T_B^{IR} < 245K), sufficiently large (> 45 km)
with ≥ 1 convective cloud (< 218 K)



Machado & Rossow 1993

coldest systems reach longest life-times

-> synergy AIRS/IASI + geostationary satellite imagers *(for ex. HIMAWARI, G. Sèze)*

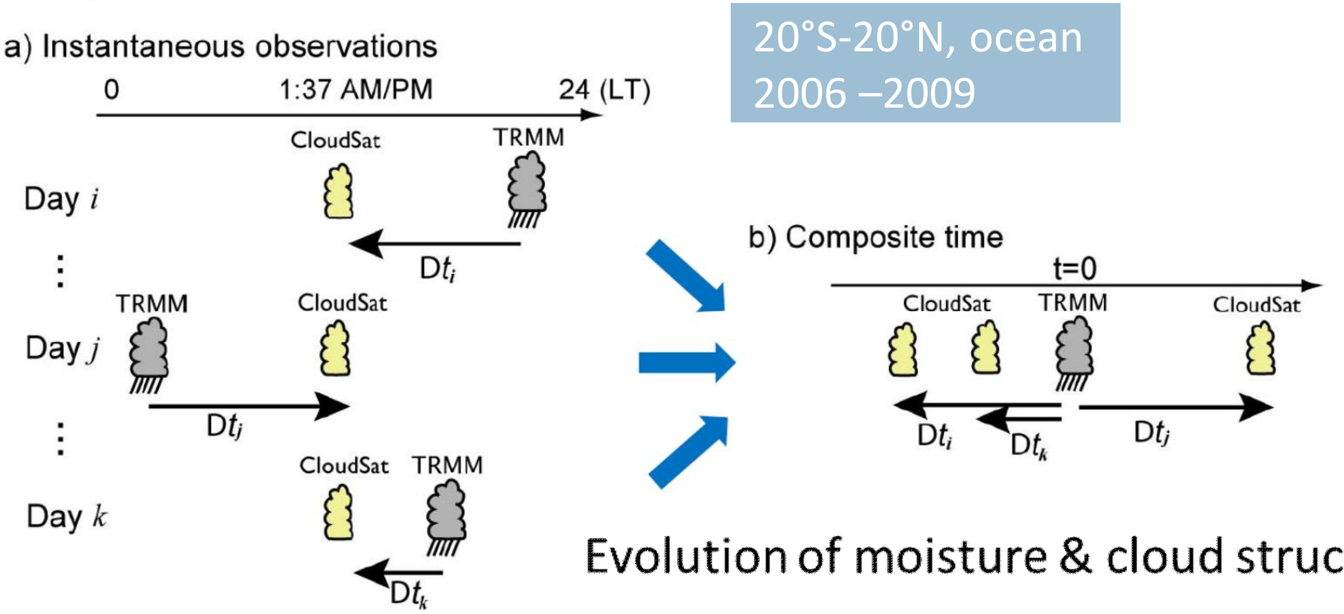
Synergy with TRMM to analyze system life evolution

Composite observations w. r. t. convective life stages

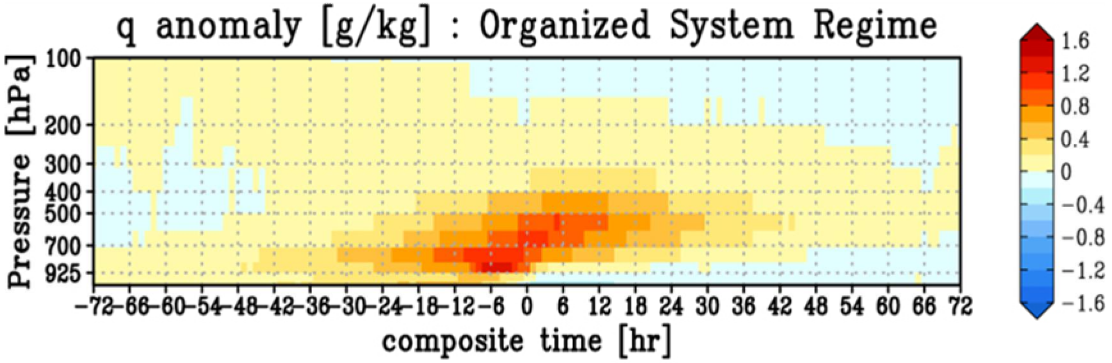
H. Masunaga
UTCC PROES meeting 2017

20°S-20°N, ocean
2006 –2009

Masunaga, 2012, 2013
Masunaga & L'Ecuyer 2014



Evolution of moisture & cloud structures in organized convection

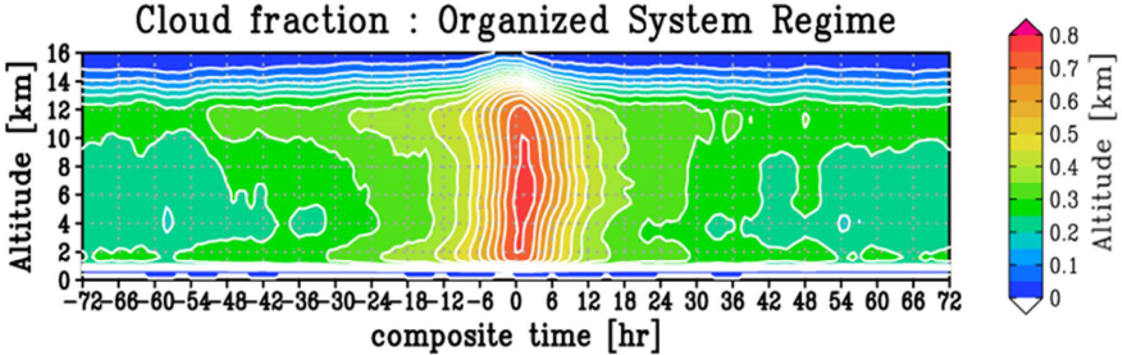


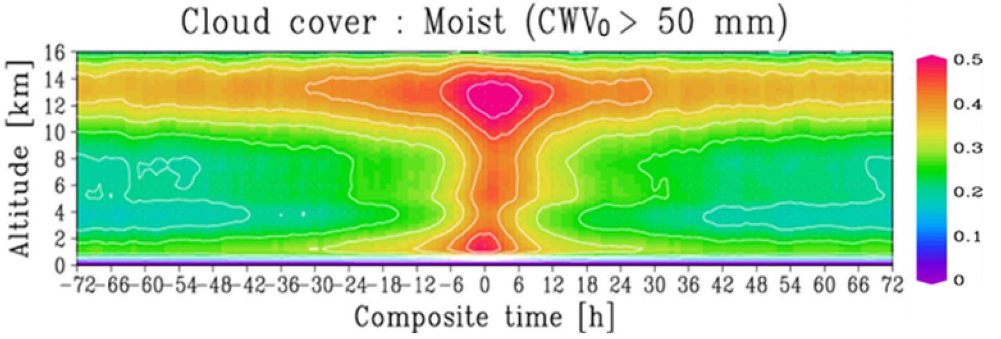
well defined convective cloud column at time of precipitation & then thinning out,

but cirrus also around before convection

Radiative impact on convection ?

seminar at CSU



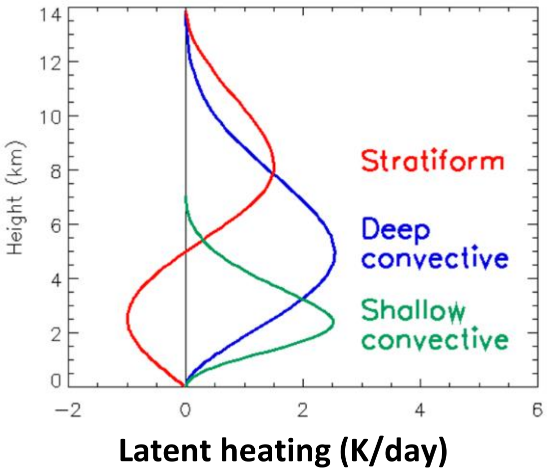


convective – anvil heating

latent (LH) – radiative (RH)

C. Schumacher
UTCC PROES
meeting 2017

Schumacher et al. 2004

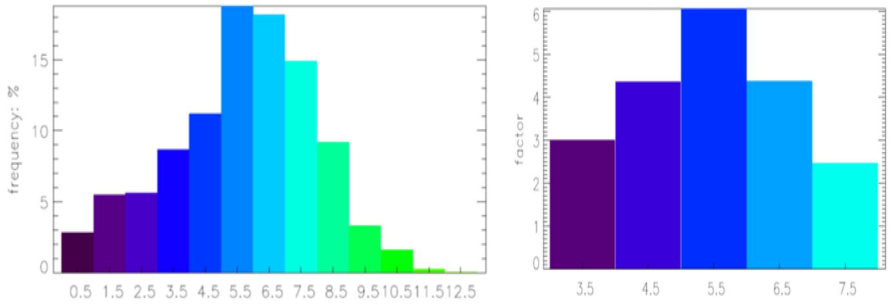


latent heating from TRMM :
column precipitation & cloud profile

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

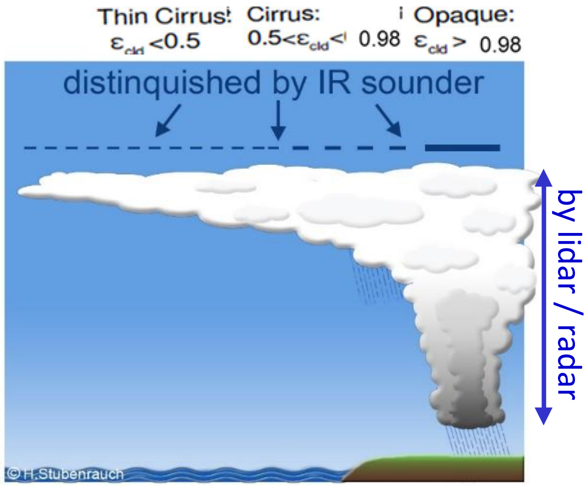
total radiative heating enhances gradient of latent heating at upper levels (e.g., 250 mb),
esp. over Africa, Maritime Continent & South America
& enhances overall LH by ~20%

heating rates of UT cloud systems (1)

critical to feedbacks : cirrus radiative heating in upper troposphere

- Cirrus anvils might regulate convection as they stabilize the atmospheric column by their heating *(Stephens et al. 2008, Lebsock et al. 2010)*

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

Challenges:

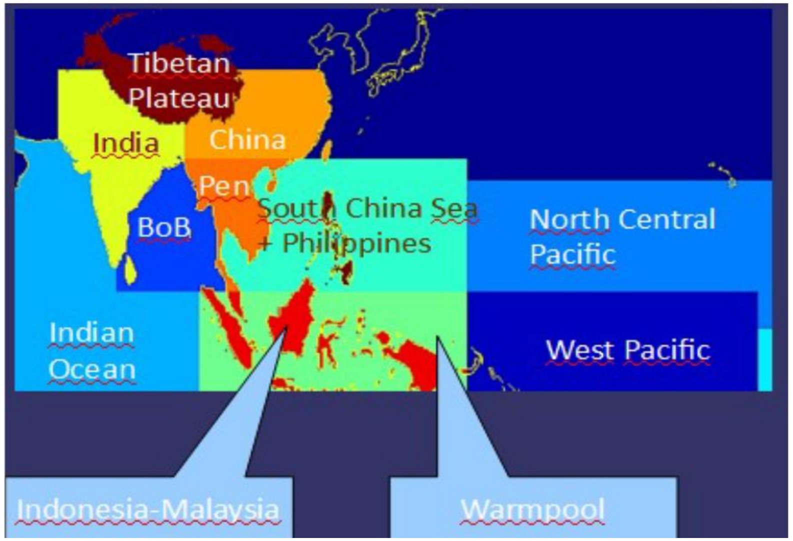
- IWP, vertical profile of IWC
- ice crystal habit, size distribution -> SSP
- retrieval uncertainties in IWC / De profiles
- multiple cloud layering

1) **assess existing radiative heating rates**
2) **sort FLXHR-LIDAR heating rates …**
3) **compute heating rates …**

*by categorizing **cloud types** wrt ε_{cld} & vertical structure*
by *categorizing **atmospheric situation*** wrt T & H_2O profiles

Glance on actual heating rates

B. Legras, 2017

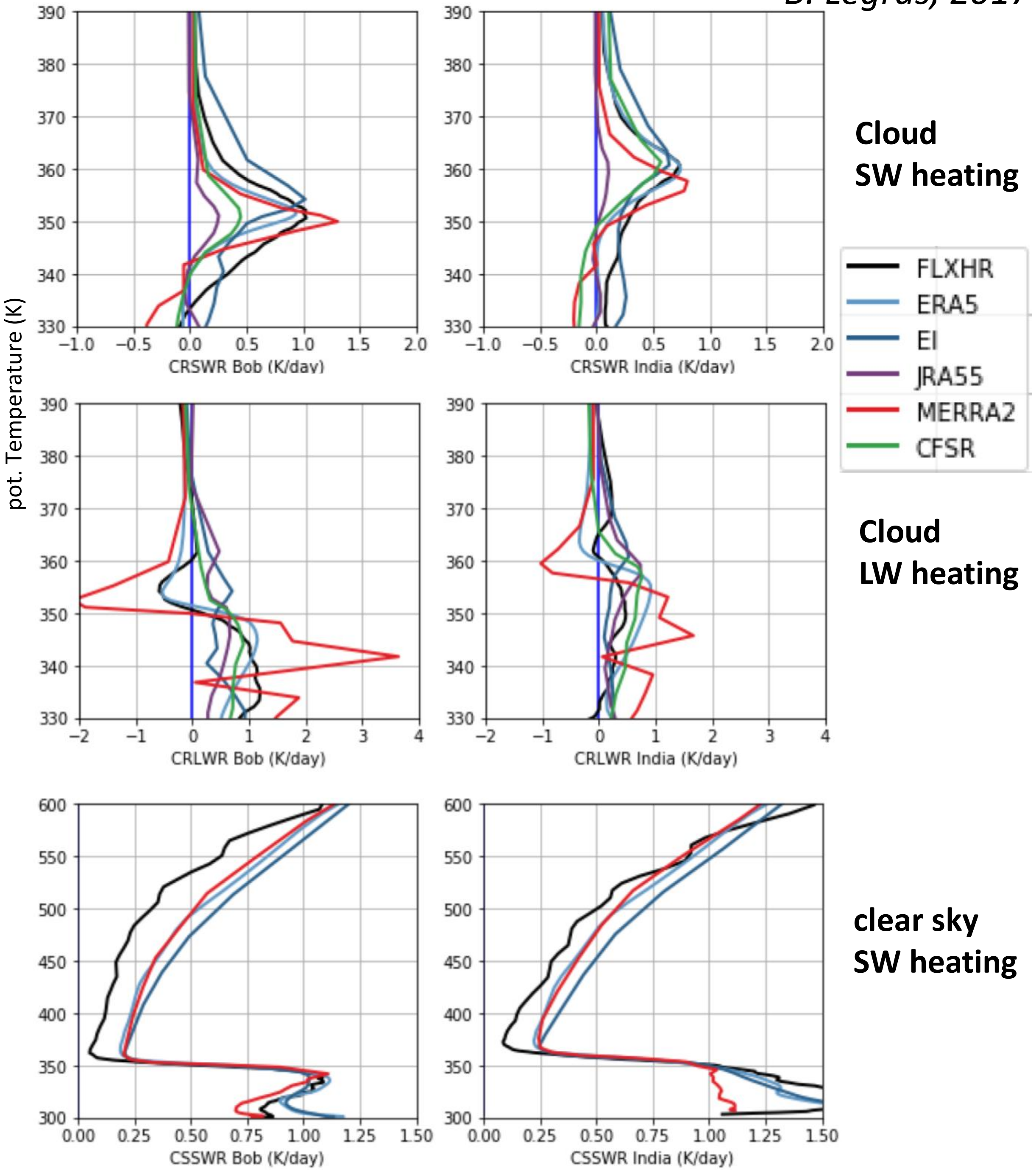


Reanalysis cloud heating rates disagree over convective regions, esp. over Asian monsoon region

Tissier & Legras ACP 2016

Obs. cloud heating rates disagree:
Johansson et al. 2015 (FLX-LIDAR)
-> warming above clr sky LZRH
Yang et al. 2016 (CALIPSO)
-> cooling above 16km

B. Legras, UTCC PROES meeting
29 Apr 2016, Paris



Cloud SW heating

Cloud LW heating

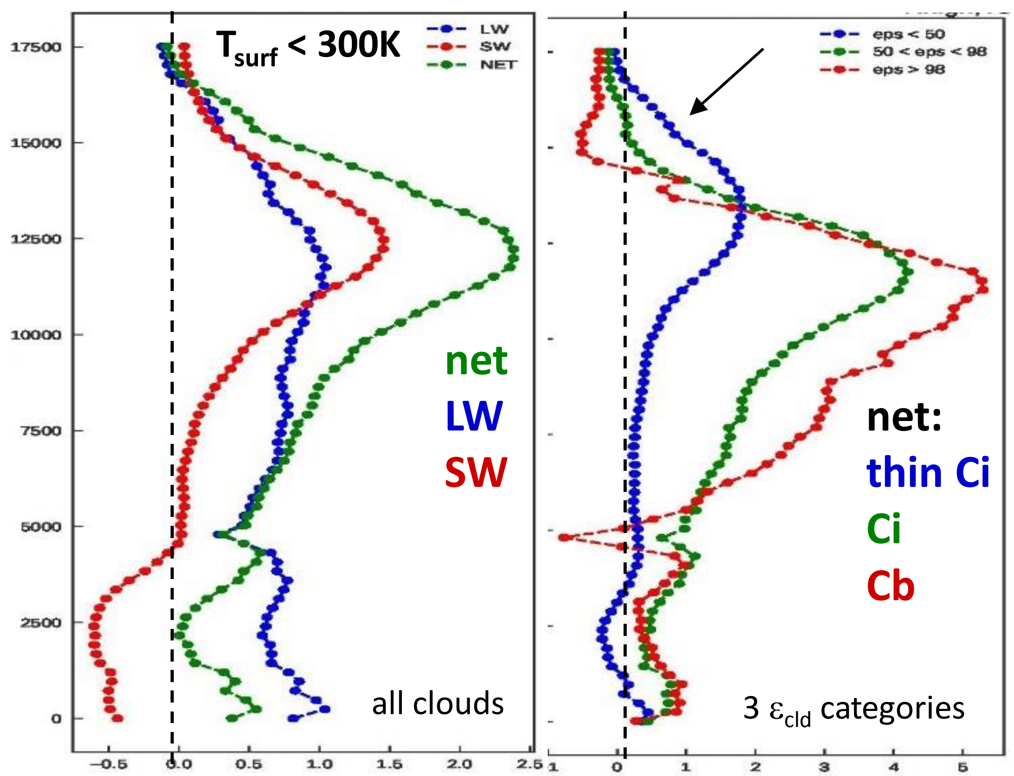
clear sky SW heating

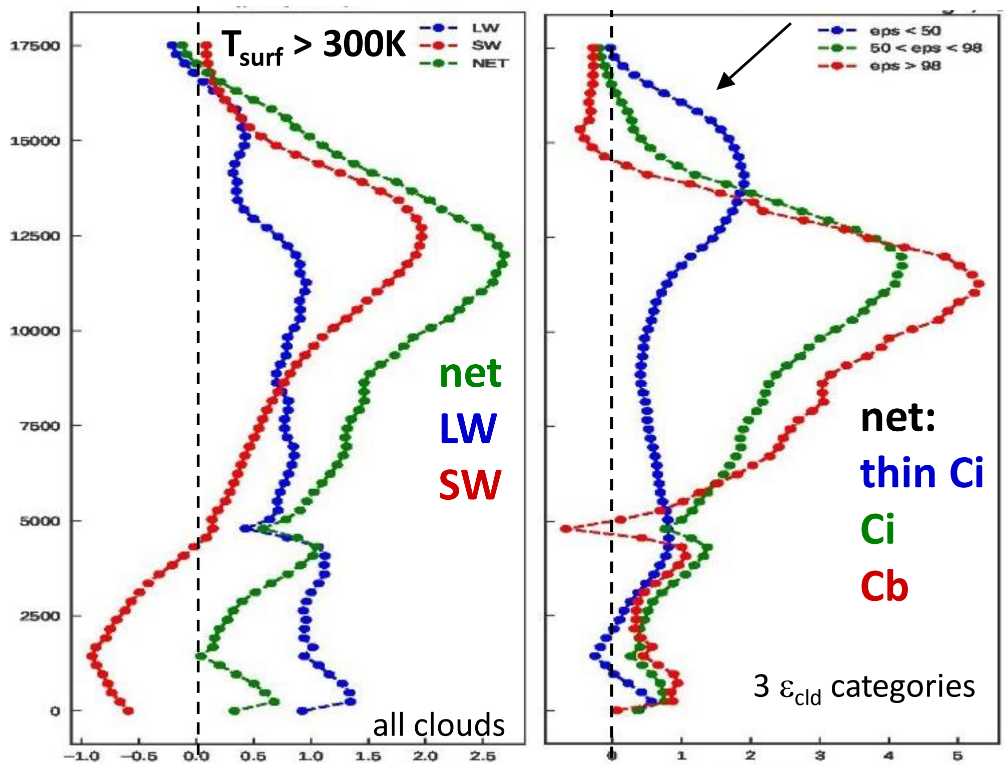
heating rates of UT cloud systems (3)

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

preliminary





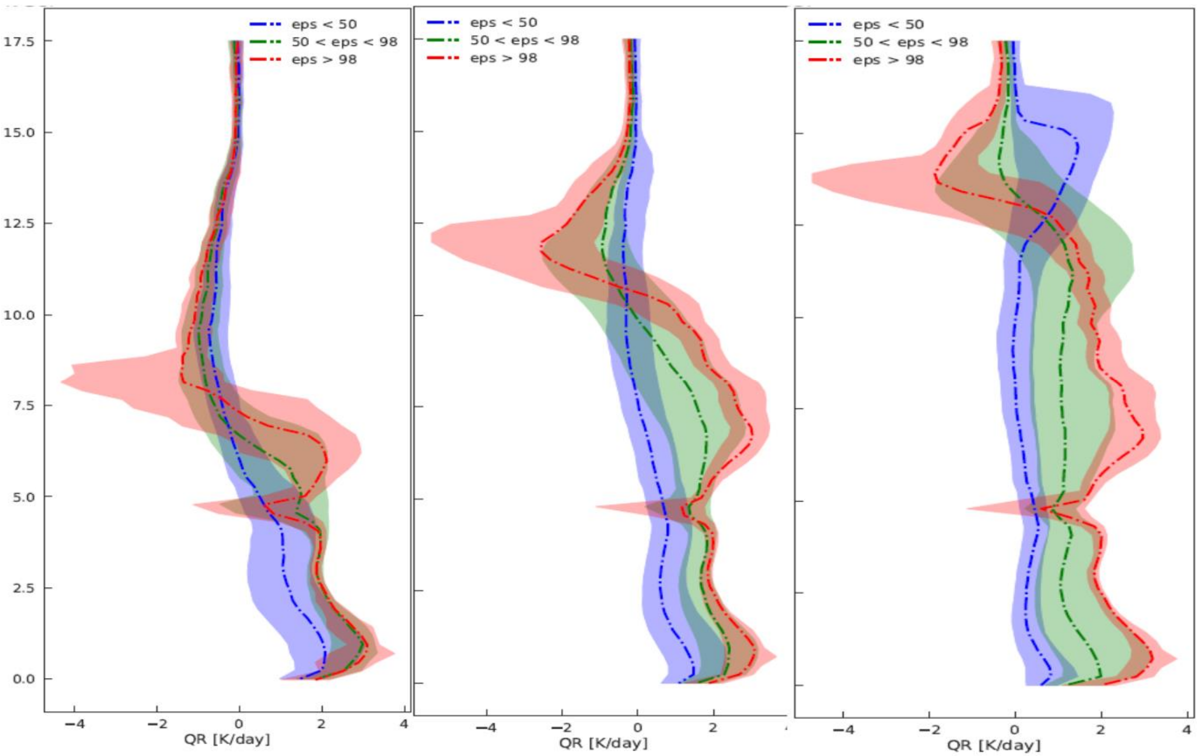
K/day

warmer T_{surf} -> UT cloud net heating occuring in thicker layers

heating rates of UT cloud systems (4)

AIRS UT cloud systems collocated to Lidar-CloudSat FLXHR heating rates wrt to ε_{cld}, p_{cld},

AIRS p_{cld} : 330 - 440 hPa p_{cld} : 200 -330 hPa p_{cld} : 86 - 200 hPa *nadir track statistics* *preliminary*



LW heating cloud – clear sky

convective core

Ci anvil

thin Ci anvil

K/day

clear distinction of heating associated with each category

Next steps:

- refine categories, wrt atmospheric environment (meteorological reanalysis ERA5)
- expand heating rates across UT cloud systems

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

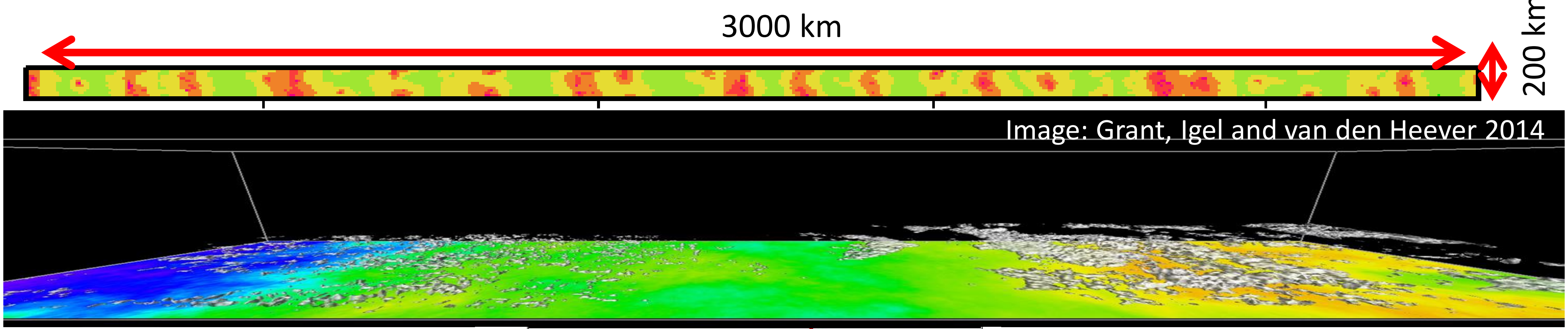
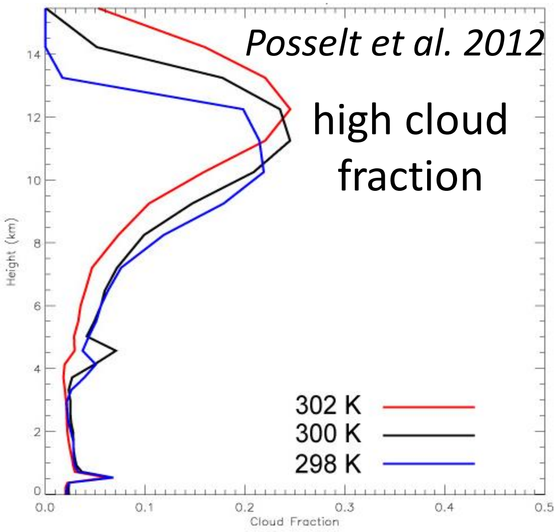
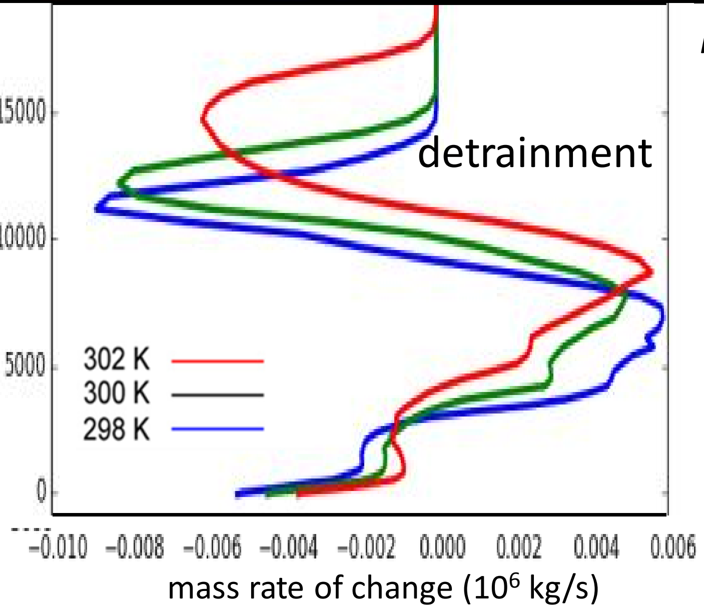


Image: Grant, Igel and van den Heever 2014

Radiative-Convective Equilibrium simulations


Posselt et al. 2012



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

Challenge to simulate (organized) convection

A. Del Genio, G. Elsaesser

GEWEX PROES meeting March 2017

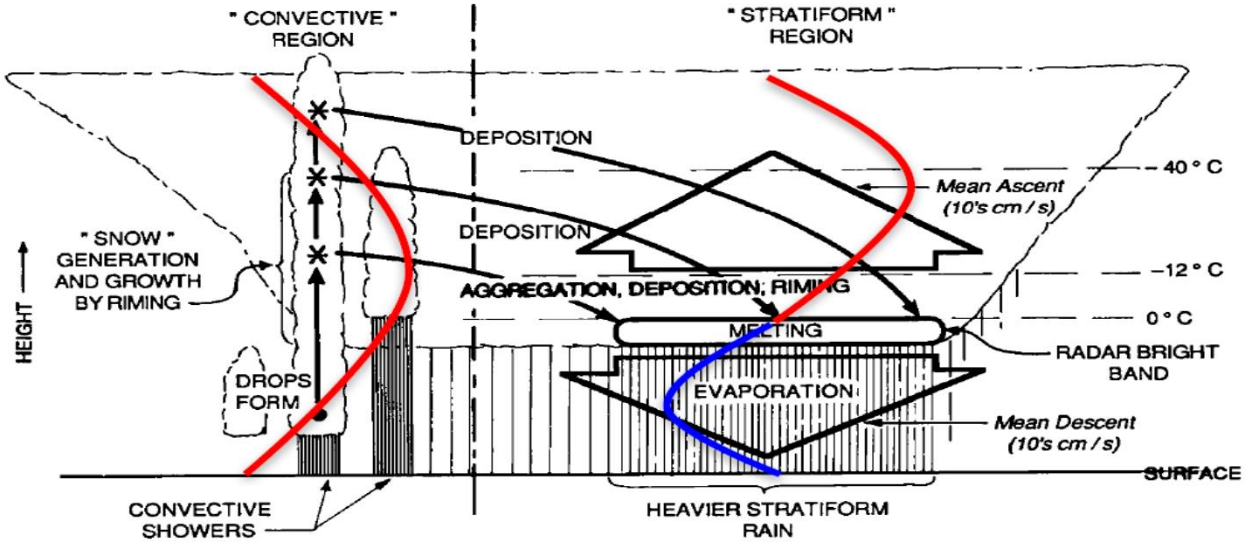


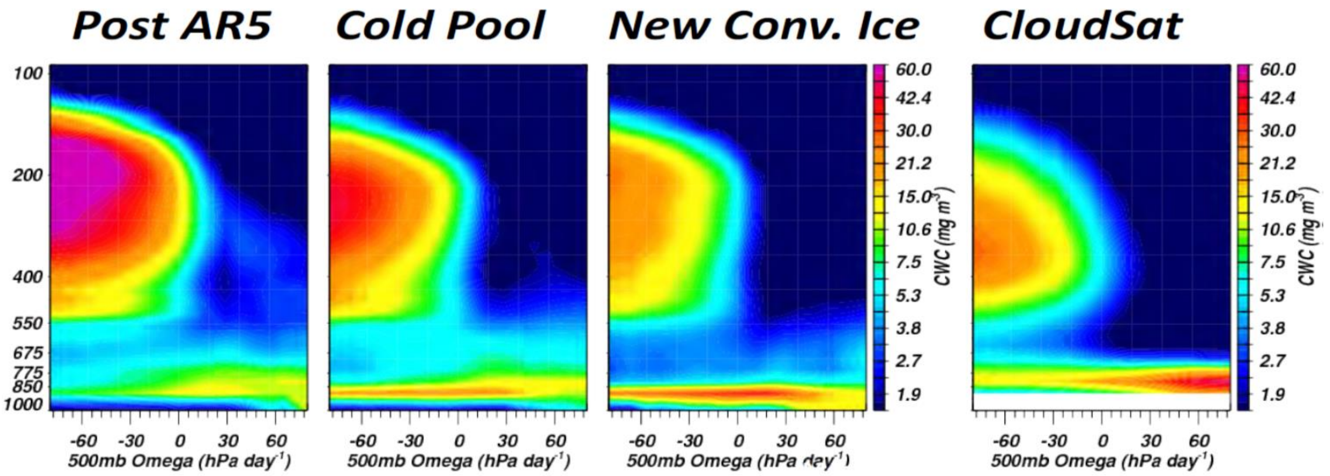
Figure 2. Schematic diagram of the precipitation mechanisms in a tropical cloud system. Solid arrows indicate particle trajectories (adapted from Houze 1989).

GISS GCM

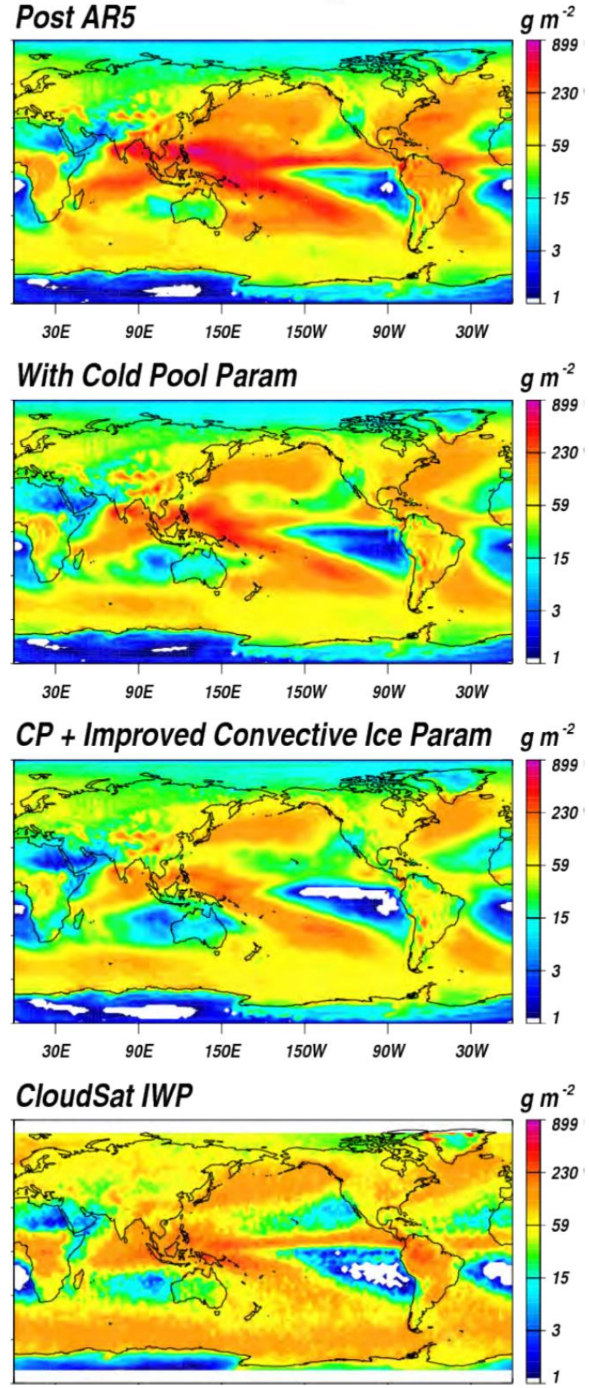
Cold pools *(Del Genio et al. 2015)*

Convective ice parameterization *(Elsaesser et al. 2017)*

Microphysics (*Morrison, Gettelman 2015)*

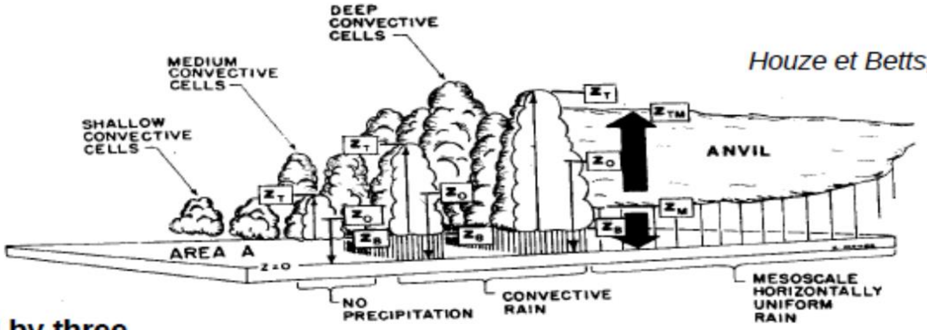


need to simulate entire convective life cycle…



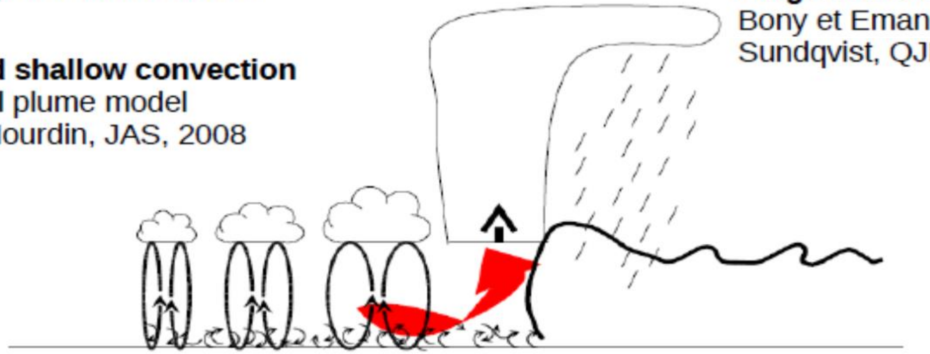
Convection & UT clouds in LMDZ climate model

convection
C. Rio
UTCC PROES
meeting 2015



Houze et Betts, RGSP, 1981

Handled by three different parameterizations



Large-scale condensation
Bony et Emanuel, JAS, 2001
Sundqvist, QJRMS, 1978

Dry and shallow convection
Thermal plume model
Rio et Hourdin, JAS, 2008

Deep convection and associated cold pools
Emanuel, JAS, 1991 revisited by
Grandpeix et Lafore, JAS, 2010

UT clouds
J.-B. Madeleine
UTCC PROES
meeting 2015

(1) Formed by large-scale advection and deep convection (anvils) ; in this latter case they depend on the detrainment of water vapor and maximum precipitation efficiency $\boxed{\varepsilon_{max}}$

[Emanuel & Živković-Rothman 1999 ; Bony & Emanuel 2001; Rio et al. 2012 ; Grandpeix & Lafore 2010]

(2) Phase based on temperature using $\boxed{x_{\mathrm{liq}} = \left(\frac{T - T_{\mathrm{ice}}}{T_0 - T_{\mathrm{ice}}}\right)^{n_x}}$

(3) Precipitation mass flux $(\rho w_{iw} q_{iw})$ computed using ice particle fall velocity

$w_{iw} = \gamma_{iw} w_0$ with $w_0 = 3.29(\rho q_{iw})^{0.16}$ and $\boxed{\gamma_{iw}}$ a tuning coefficient

[Zender and Kiehl, 1997 ; Heymsfield and Donner, 1990]

Diagnostics for UT cloud assessment in climate models

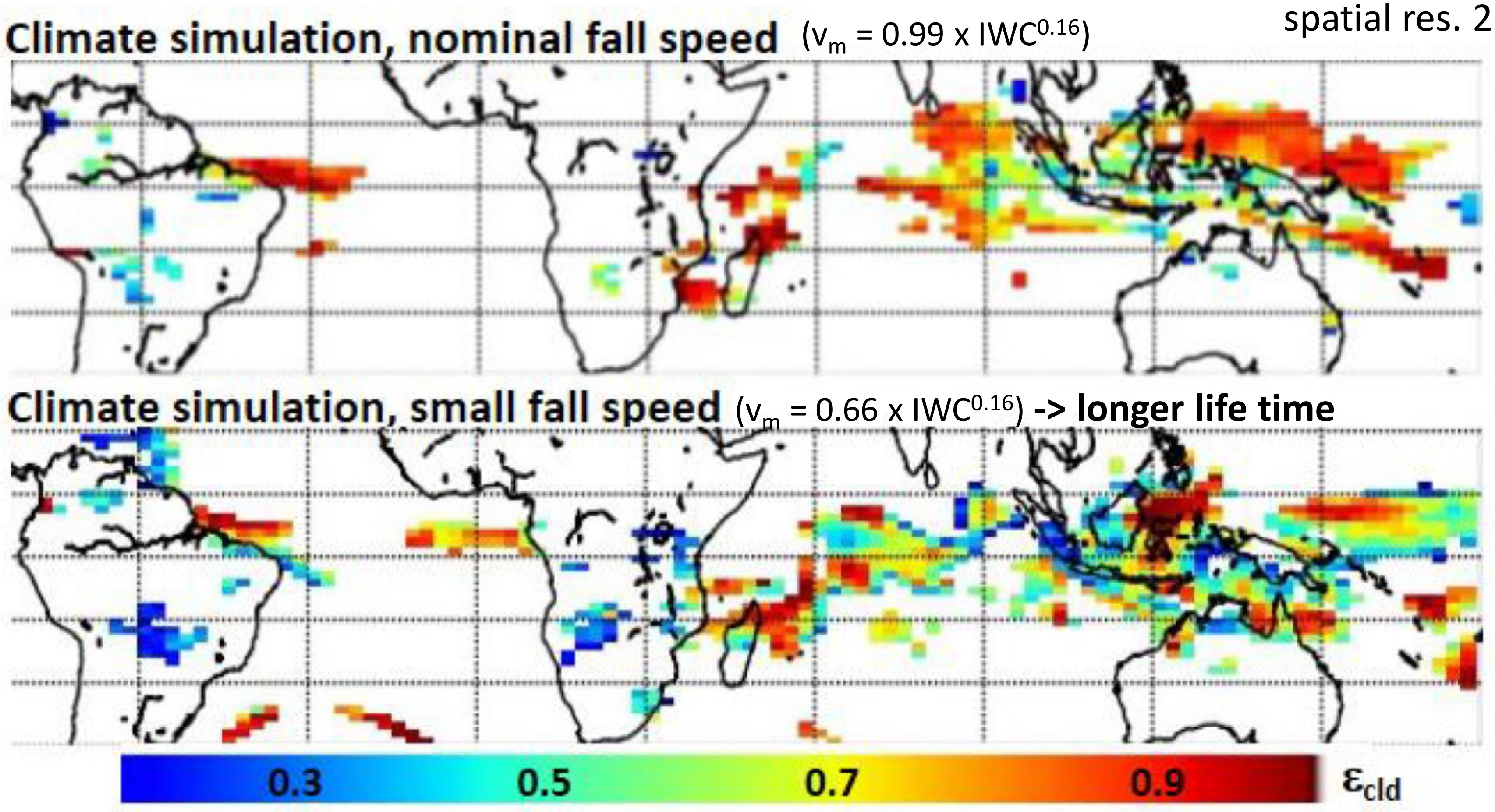
M. Bonazzola, C. Stubenrauch, S. Protopapadaki

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

-> evaluation of GCM convection schemes / detrainment / microphysics

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

spatial res. 2.5° x 1.25°

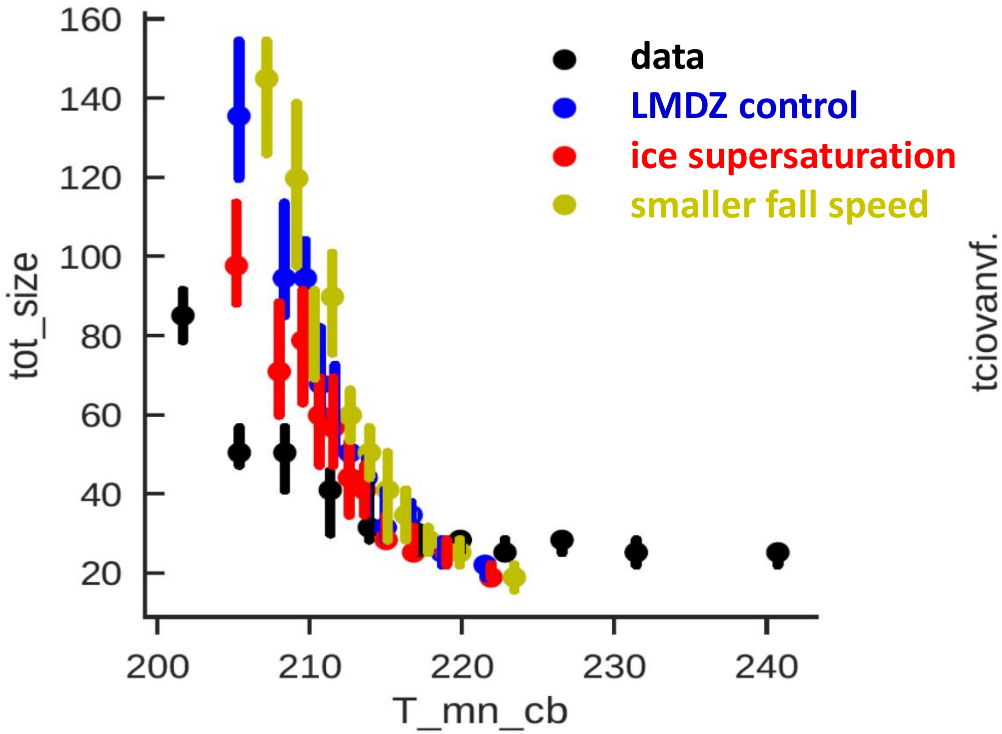

Climate simulation, nominal fall speed ($v_m = 0.99 \times IWC^{0.16}$)

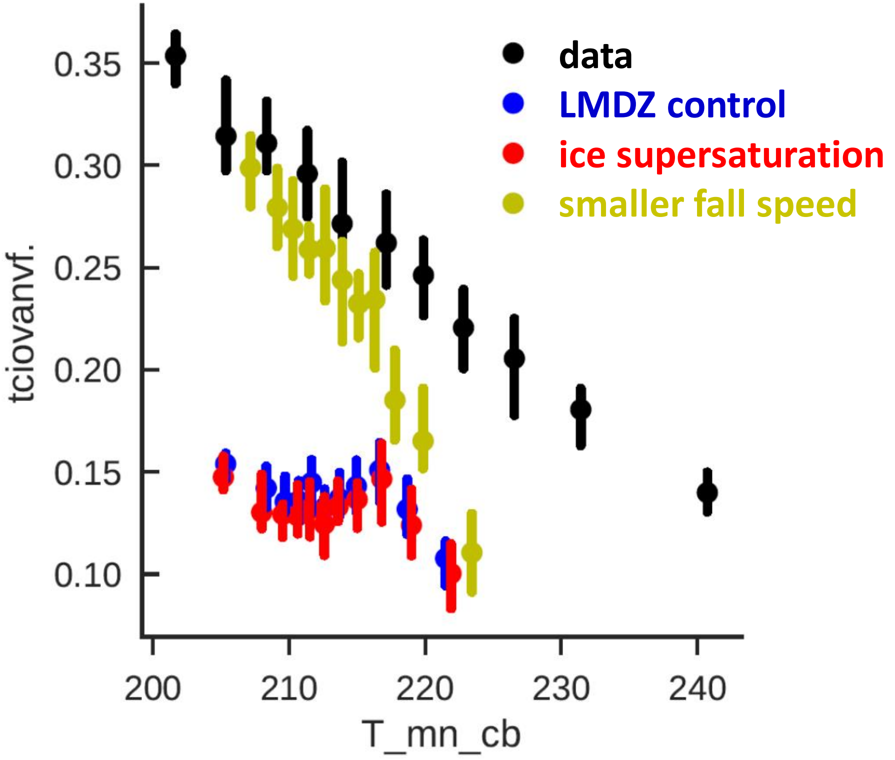
Climate simulation, small fall speed ($v_m = 0.66 \times IWC^{0.16}$) **-> longer life time**

horizontal cloud system emissivity structure sensitive to fall speed

observational metrics to probe process understanding

How do the anvil properties change with convective strength?





- **UT cloud system size increases with convective strength**

  LMDZ cloud system size increases stronger than obs,
  including ISS leads to smaller systems, in better agreement to obs

- **thin Ci over anvil area increases with convective strength**

thin Ci over anvil area much too small for LMDZ and no correlation between 205-215K
reducing the fall speed (longer life time of cirrus) leads to an increase with convective strength

Summary & Outlook

working group *(meetings: Nov 2015, Apr 2016, Mar 2017 -> vivid discussions)*

cooperations being formed (depending on funding), focus on tropical convective systems

- **synergetic cloud system data based on IR sounder data**
  powerful tool to study relation between convection & anvil properties
- **relation between convective strength & anvil properties:**
  change in emissivity structure -> can be used to constrain models
- **classification of vertical structure & heating rates (A-Train synergy)**
  -> extend to UT cloud systems & integrate into 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)*
- **assessment of heating rates ?**

next meeting: autumn 2018 (Paris)