GEWEX Process Evaluation Study on Upper Tropospheric Clouds & Convection

GEWEX UTCC PROES

- *provide observational metrics to probe process understanding*
- *advance understanding on feedback of upper tropospheric clouds*

Coordination: **Claudia Stubenrauch & Graeme Stephens**

GDAP meeting, 29 Nov – 1 Dec 2016, Washington, USA

-> GEWEX PROES (Process Evaluation Studies)

NASA obs4mip meeting (April 2014)
-> need to use observations more intelligently to probe process understanding

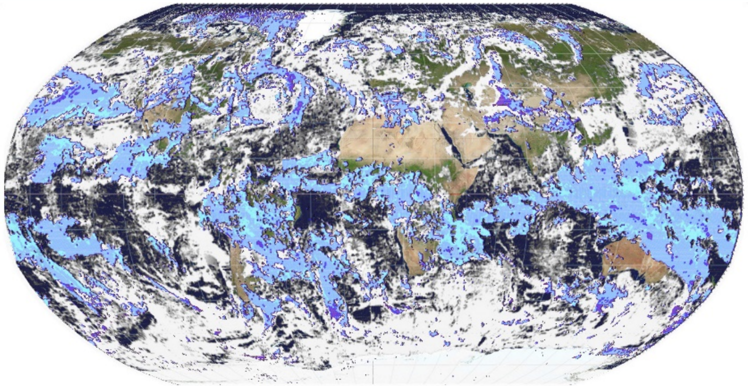
(Stephens, Jakob & Tselioudis GEWEX News Nov 2015)

5 GEWEX-related PROES activities developing:

- **Upper Tropospheric Clouds & Convection** (lead *C. Stubenrauch, G. Stephens*) – SPARC - WCRP Grand Challenges
- **Ice mass balance** (lead *E. Larour, S. Nowicki*), GEWEX - CLiC
- **Radiative Kernels for Climate** (lead *B. Soden*)
- **Mid-latitude storms** (lead *G. Tselioudis, C. Jakob*)
- **Soil moisture climate** (lead *S. Seneviratne*)

under umbrella of GDAP *(-> changing acronym)* ???

UTCC PROES : Motivation



dark -> light blue,
according to decreasing ε_{cld}

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

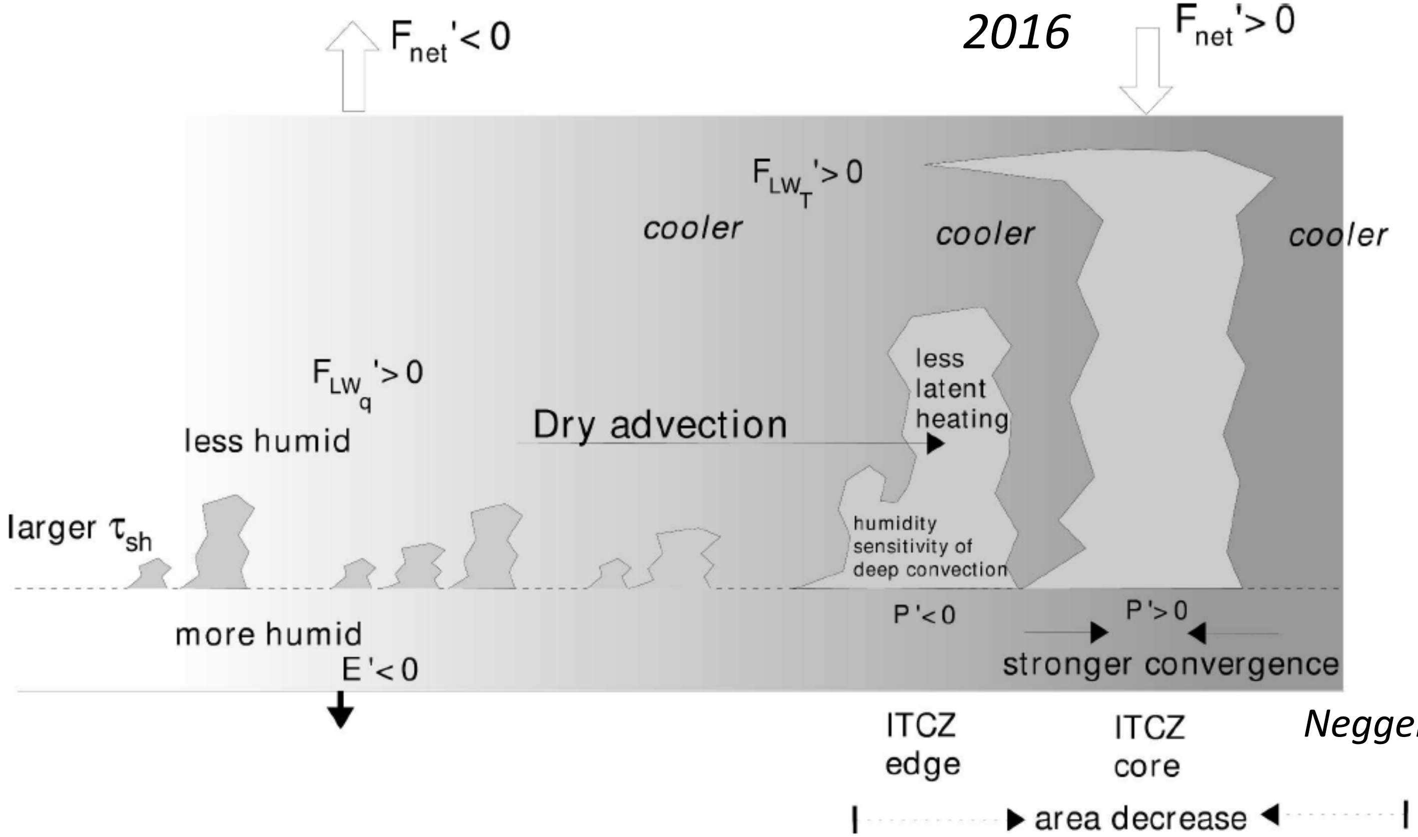
How do cirrus change in warming climate? -> rad. heating -> atm. Circulation

What is the role of cirrus in modulating the Earth's climate?

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

Interconnections: shallow cumulus – deep convection

from Seiji Kato's talk at IRS 2016



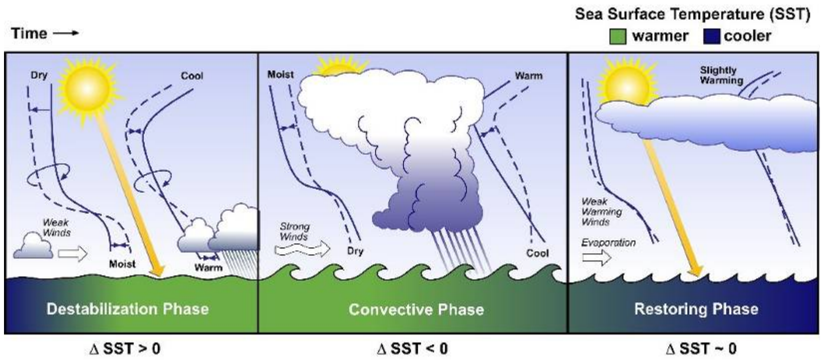
Neggers et al. 2007

More humid boundary layer -> more shallow cumulus
-> dryer free troposphere -> narrower ITCZ
-> stronger precipitation by deep convective clouds

Other feedback hypotheses

- **Thermostat** (*Ramanathan & Collins 1991*) : warmer environment creates thicker Ci anvils -> subsequently cooled by more reflective Ci (negative feedback)

- **Humidistat** (*Stephens et al. 2004, Lebsock et al. 2010*) : self-regulating radiative – convective feedback mechanism in 3 phases :



- **IRIS effect** (*Lindzen et al. 2001*) : warmer environment -> increase in precip. efficiency -> decrease of anvil area (negative feedback)

- **Stability IRIS effect** (*Bony et al. 2016*) : warmer environment -> anvils rise

-> increase in static stability-> reduction of convective outflow

enhanced convective aggregation -> increased IRIS effect *(Mauritsen & Stevens 2015)*

including cloud-radiative effects -> narrowing of rainy areas

1. GEWEX UTCC PROES meeting

Paris, 16 *Nov 2015*

Feedback hypotheses

*V. Ramaswamy, **T. Mauritsen, S. Bony***

Ressources

1) observations: cloud systems and atmospheric environment

*W. B. Rossow, H. Masunaga, D. Bouinol, **R. Roca, G. Sèze, S. Protopapadaki, C.-K. Teo***

2) including the atmospheric flow: Cirrus origin and life cycle

J. Luo, B. Legras, R. Plougonven, A. Podglajen

3) processes and parameterizations (parcel, CRM, GCM)

Small scale process modelling *S. van den Heever*

Large scale development / evaluation of parameterizations (LMDZ, CNRM, ETHZ)

C. Risi, C. Rio, , J.-B. Madeleine, B. Gasparini

4) Radiative transfer

*T. L'Ecuyer ,**C. Stubenrauch***

next day: Discussion on Synergetic data base

J. Luo, G. Stephens, G. Sèze, S. Protopapadaki, S. Stubenrauch

interested in cirrus -> anchor data base to AIRS upper tropospheric cloud systems

GEWEX UTCC PROES discussions at IRS

Auckland, 17 *Apr 2016*

V. Ramaswamy (GFDL), A. Baran (MetOffice), D. Bouniol (CNRM), R. Roehrig (CNRM), B. J. Sohn (Seoul Univ.), S. Kato (Nasa Langley), H. Okamoto (Kyushu Univ.), M. Wendisch (Univ. Leipzig), S. Kinne (MPI-M), C. Stubenrauch (LMD)

1) parse the thematic question into specific actionable questions

2) see how these can be addressed within CFMIP activities

presentation at CFMIP conference attracted CRM community

3) LMDZ tests cloud system simulator to assess convection / detrainment / microphysics schemes

2) make an inventory of variables needed & sources, uncertainties

3) build synergetic data bases to address each of the questions
instead of one synergetic data base which includes all information

Why using IR Sounders to derive cirrus properties?

TOVS, ATOVS, AIRS, CrIS, IASI (1,2,3), IASI-NG

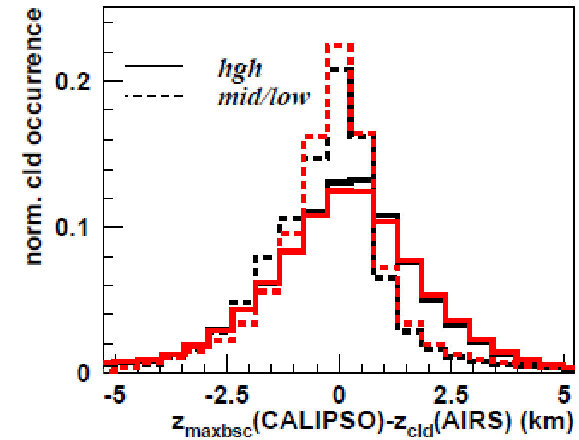
>1979 / ≥ 1995 ≥2002 / ≥ 2012 ≥2006 / ≥ 2012 / ≥ 2020

7:30 AM/PM 1:30 AM/PM 9:30 AM/PM

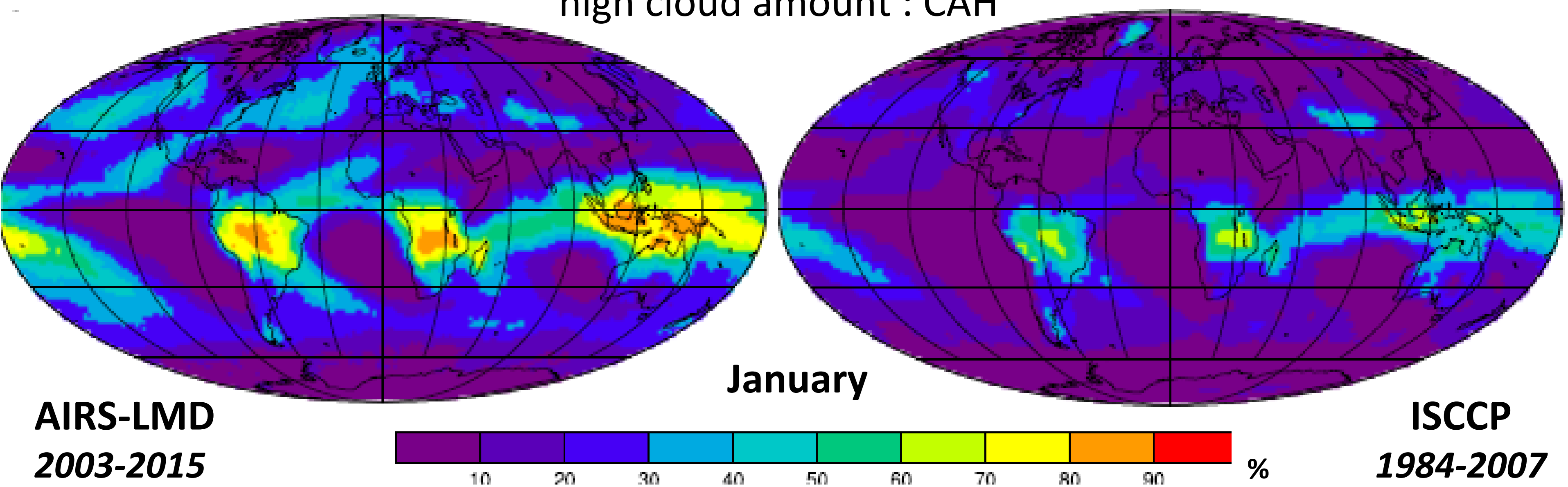
- long time series & good areal coverage
- good IR spectral resolution -> sensitive to cirrus

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

cloud height evaluation with CALIPSO



high cloud amount : CAH



reanalysis V2

from GEWEX Cloud Assessment Database

Identification of mesoscale high cloud systems (1)

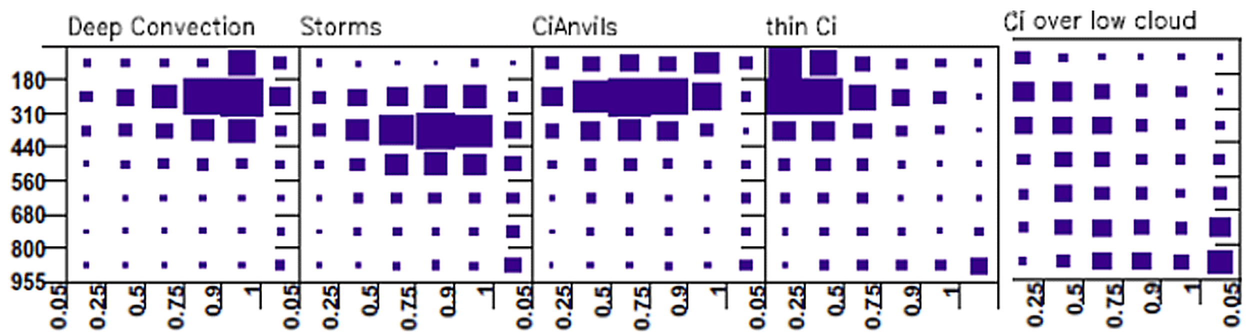
clouds are extended objects, driven by dynamics -> organized systems

Method 1: 'Weather States'

build clusters by occurrence of cloud classes per mesoscale grid (2.5 / 2°)

-> ISCCP (*e.g. Tselioudis et al. 2013*), **($p_{cld} - \tau_{cld}$) histograms**

-> AIRS ($p_{cld} - \varepsilon_{cld}$) histograms



Comparison with ISCCP:

good agreement, thin Ci & Ci over low cld often indicated by ISCCP as fair weather (WS7)

distinct vertical & horizontal structures & radiative effects

observational radiative-convective feedback (e.g. Tselioudis & Rossow 2010, *Lebsock et al. 2010*)

tropical convection (e.g. *Rossow et al. 2005, Jakob & Schumacher 2008, Tan et al. 2015*)

very valuable for model evaluation (e.g. *Gehlot & Quaas 2012*)

but no information of system size

Identification of mesoscale high cloud systems (2)

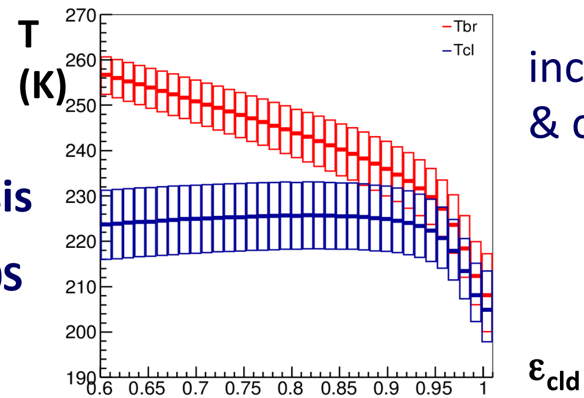
Method 2: merge adjacent footprints containing cold clouds using $T_B^{IR\ window}$

Machado & Rossow 1993	**(<245 K, Cb < 218 K),**
Yuan & Houze 2010	**(<260 K, Cb from AMSR-E rain rate),**
Fiolleau & Roca 2013	**(< 233 K, Cb from TRMM rain rate) ….**

T_B^{IR} depends on T_{cld} & on ε_{cld}, whereas T_{cld} & ε_{cld} are independent variables:

AIRS analysis

30N-30S



increasing T_B^{IR} threshold includes opaque clouds with $T_{cld} \sim T_B^{IR}$ & clouds with colder T_{cld} & smaller ε_{cld}

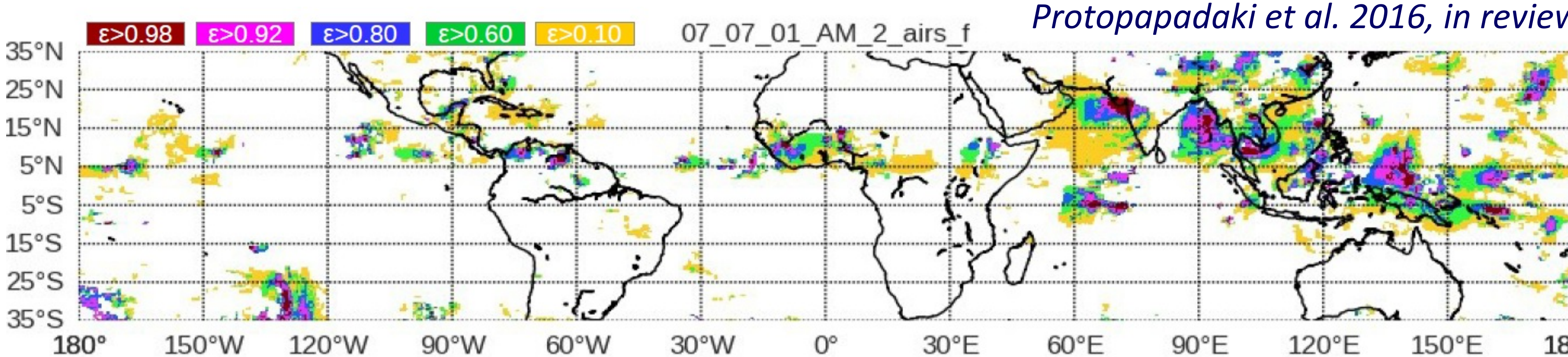
215K / 233K / 245K / 260K
0.98 / 0.92 / 0.8 / 0.6

-> study thick anvils

life cycle studies

Method 3: merge adjacent footprints containing high clouds (p_{cld}) from AIRS

Protopapadaki et al. 2016, in review

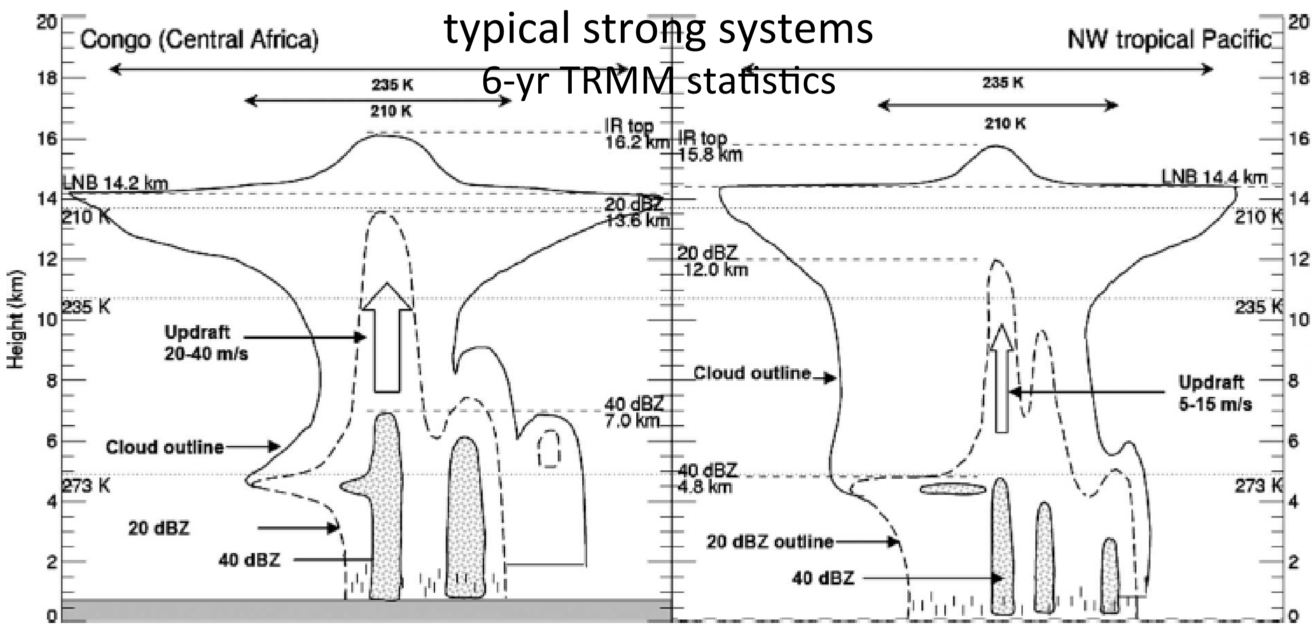


proxies of convective intensity - strength – depth

vertical updraft : TRMM / CloudSat Echo Top Height *(Liu & Zipser 2007, Takahashi & Luo 2014)*
Level of Neutral Buoyancy : soundings / max mass flux outflow *(Takahashi & Luo 2012)*
area of heavy rainfall : CloudSat-AMSR-E-MODIS *(Yuan & Houze 2010)*
width of convective core (CC): CloudSat *(Igel et al. 2014)*
cold cloud top : T_B^{IR} *(Machado & Rossow 1993)*, T_{cld} *(Protopapadaki et al. 2016)*
mass flux : ERA-Interim + Lagrangian approch *(Tissier et al. 2016),*
A-Train + 1D cld model *(TissierMasunaga & Luo 2016),*

land : large updraft & CC, large ETH (large particles at high altitude), small systems
ocean: smaller updraft & CC, large systems

typical strong systems
6-yr TRMM statistics



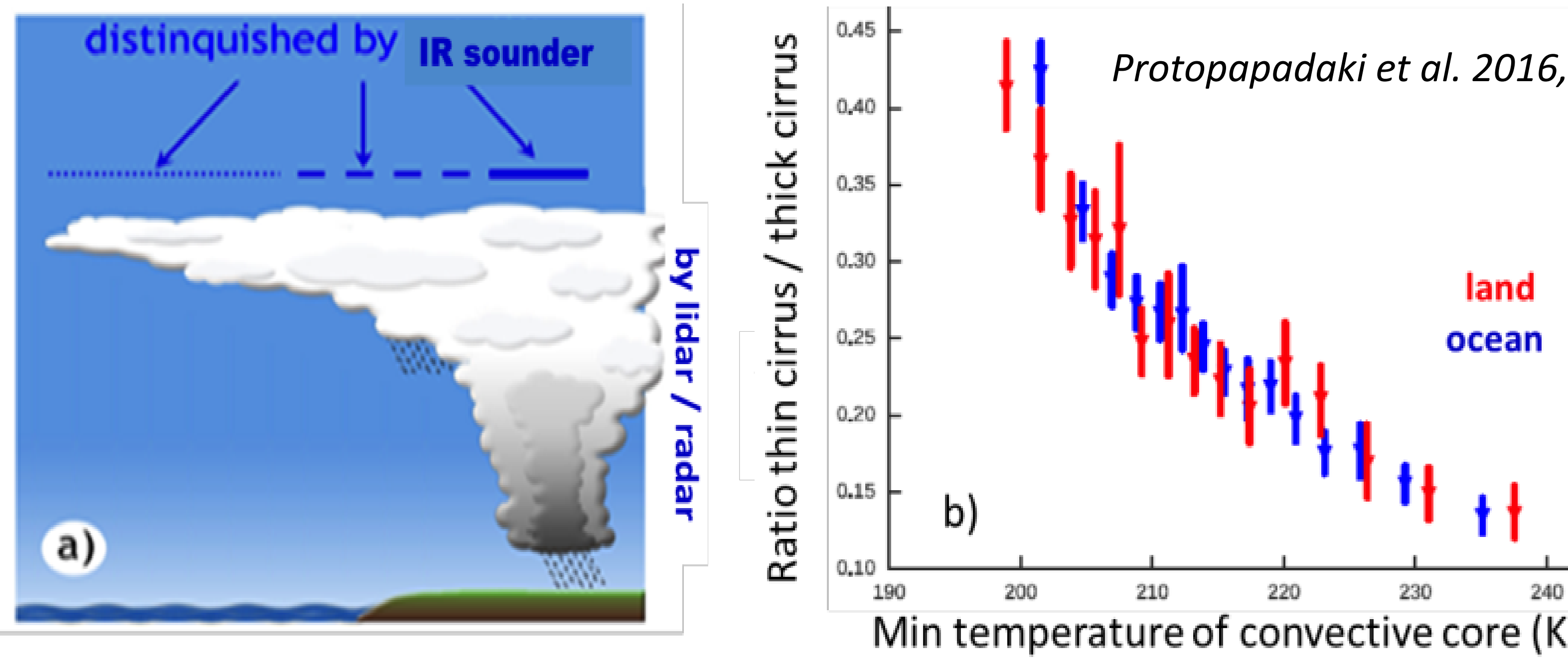
Liu & Zipser 2007

observational metrics
to probe process understanding

How do the anvil properties change with convective strength?

Cloud system approach:

study properties of UT systems (size, thin to thick anvil, etc) as function of their convective strength (proxies: T_{min} / size of convective core)



behavior can be studied by CRM models

and can be used for climate model evaluation *(optimal spat. res. 0.5°)*

UTCC PROES Synergies

Horizontal structure data:

AIRS cloud systems
surface precipitation from AMSR-E/TRMM/GPCP
environmental state data from reanalyses
MODIS-CERES convective cloud objects (initial spat. res. 1 km -> 20km)
UTH from AIRS-AMSU/MLS
δD from MIPAS
fluxes from CERES

Horizontal – vertical hybrid data:

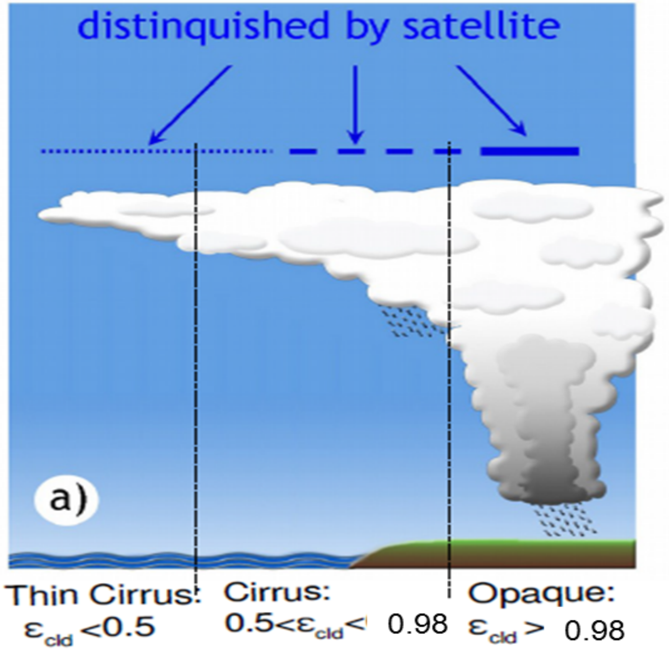
- AIRS - vertical structure, microphysics & heating rates from CALIPSO-CloudSat
- CloudSat convective systems *(Takahashi & Luo)* - AIRS convective cloud systems

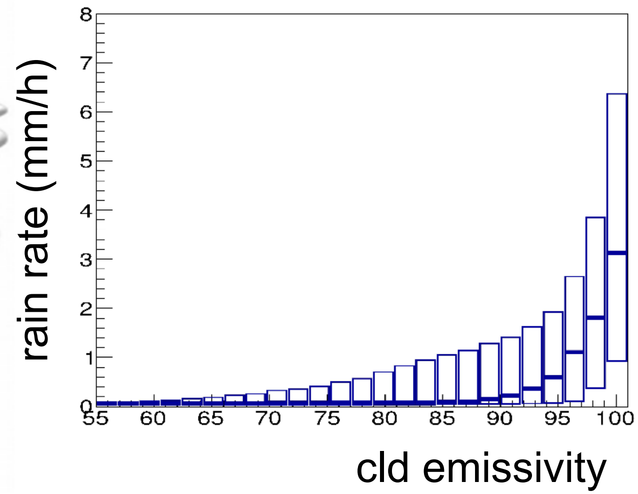
Time dimension for life cycle analysis :

AIRS-IASI-GridSat-ISCCP-Megha-Tropiques

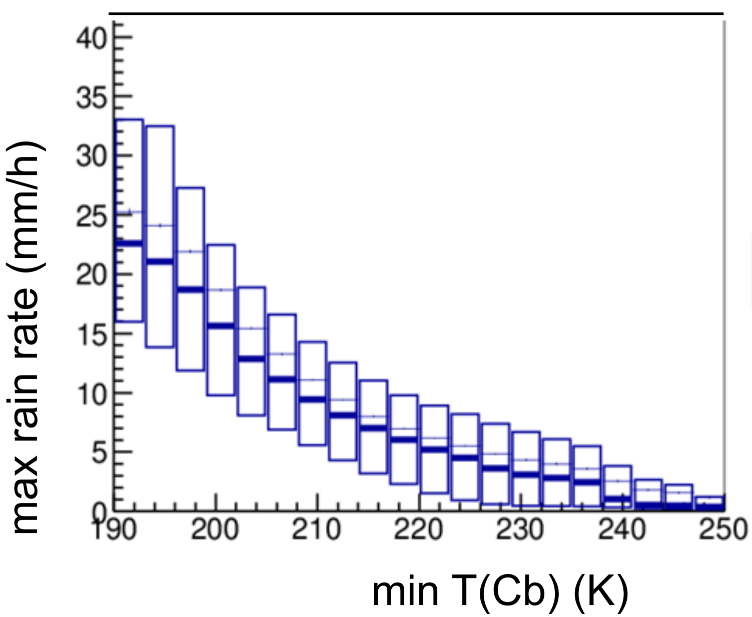
IR Sounder proxies of convection & strength:

AIRS-AMSR-E Synergy





high RR for ε_{cld}>0.98
-> convection



colder systems have a higher max RR
-> convective strength

T_{min} of convective core -> proxy of convective strength

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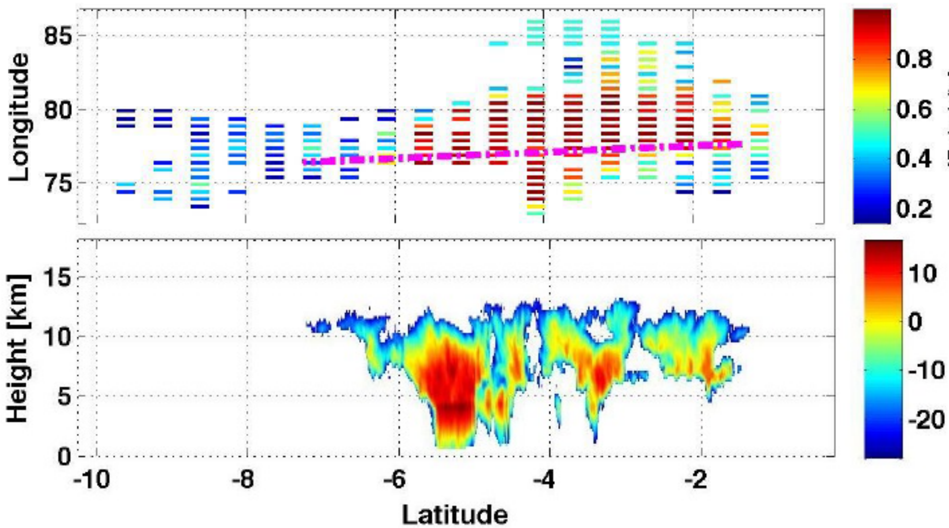
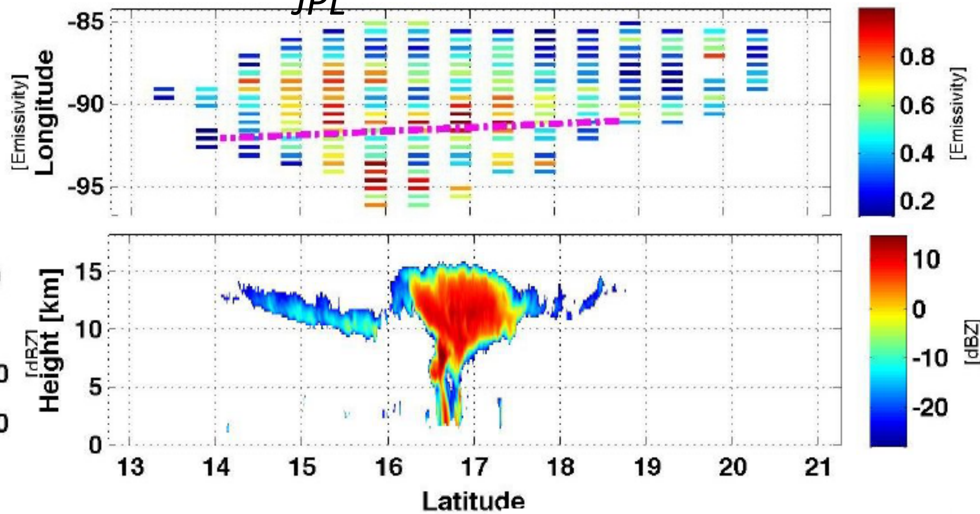
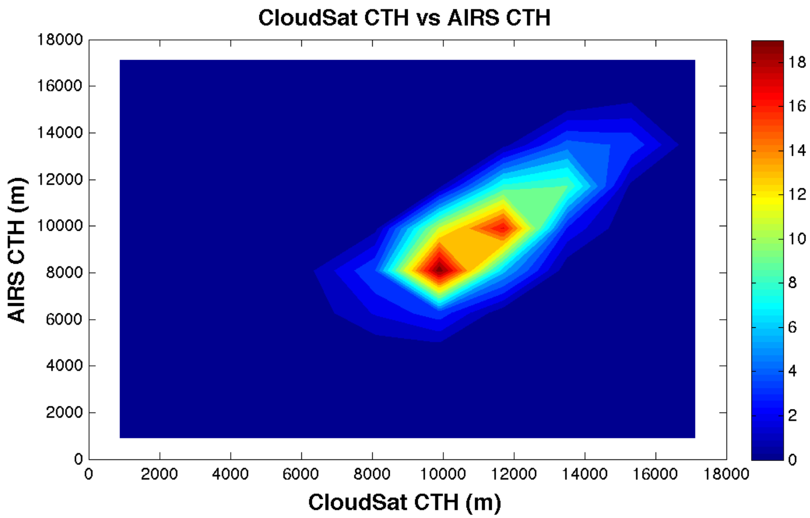
AIRS – CloudSat synergy on convective cloud systems

collaboration with *Hanii Takahashi, JPL*

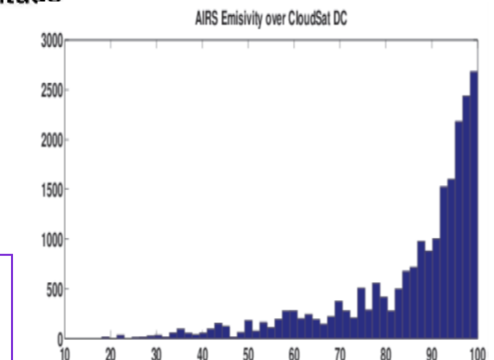


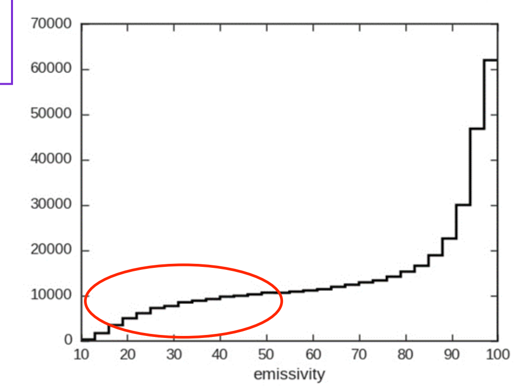




AIRS adds to horizontal dimension

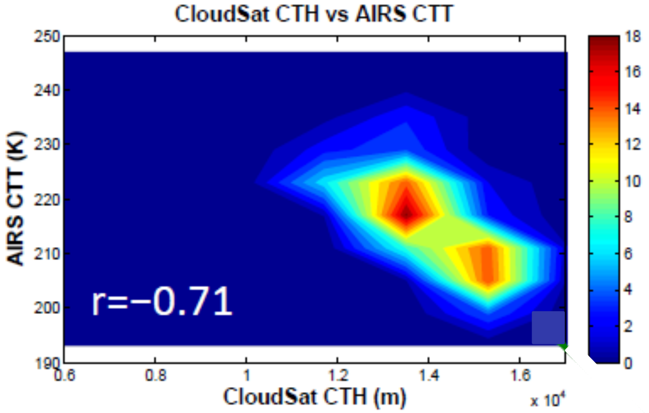
AIRS extends convective systems beyond emissivity of 0.5

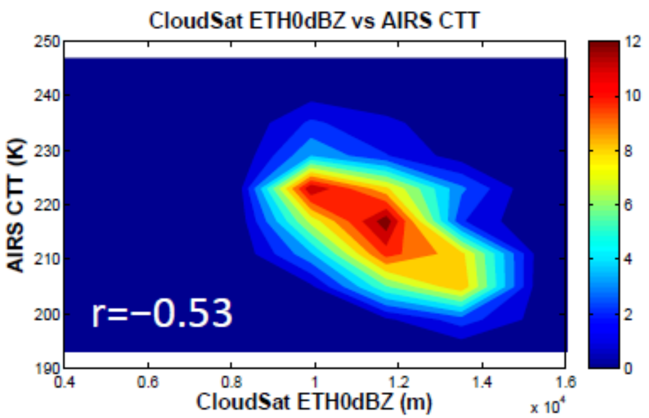


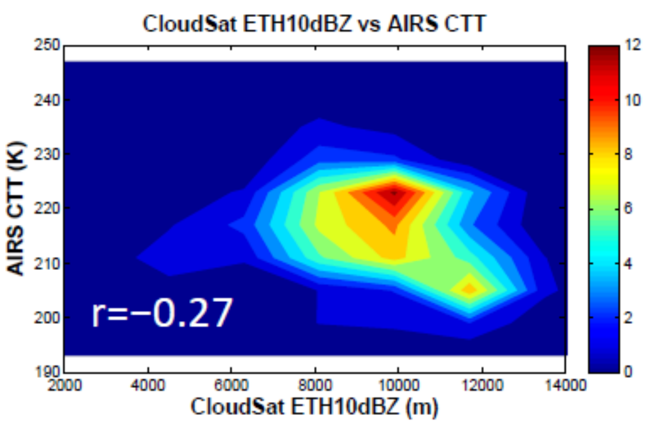


good correlation between AIRS & CloudSat cloud height : r=0.73

AIRS – CloudSat synergy : convective cores





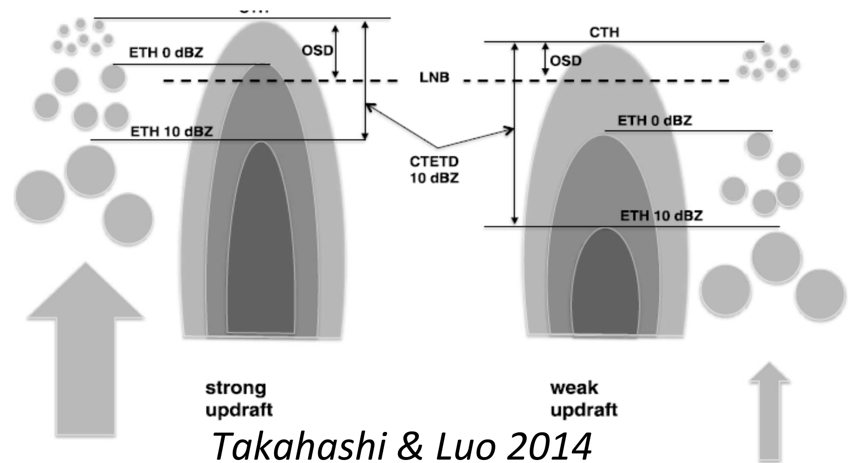


collaboration with *Hanii Takahashi, JPL* *very preliminary*

How does AIRS Tmin compare to CloudSat proxy of convective strength ETH ?

Cloud Top Height (CTH)

Radar Echo Top Height (ETH)



Takahashi & Luo 2014

T_{min} correlates well with CTH, but less with ETH

next: consider different life cycle stages, combine with atmospheric environment…

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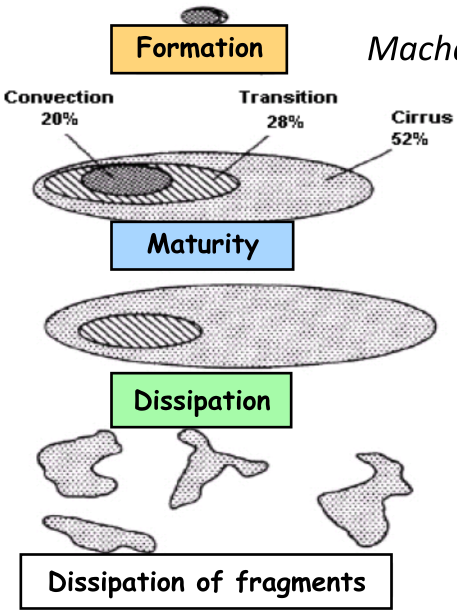
Proxies for life stage of convective system

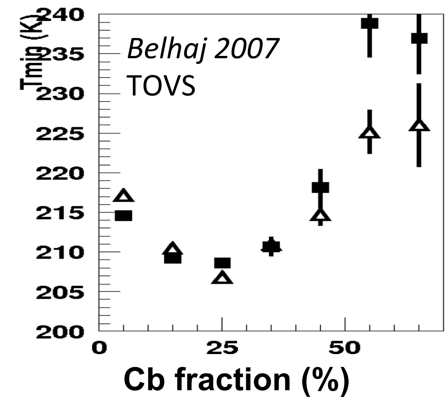


Machado & Rossow 1993

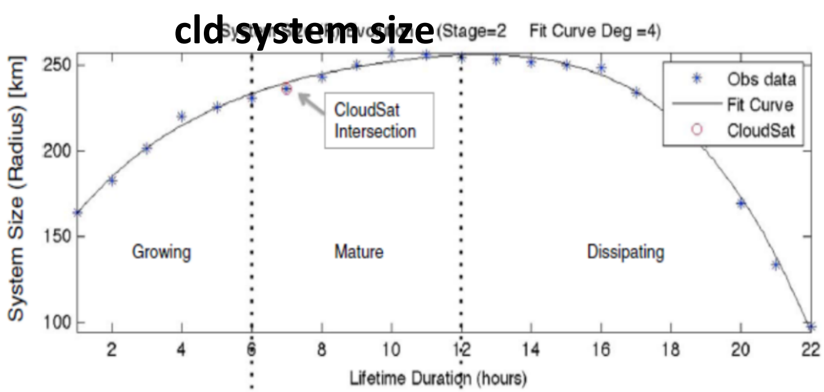
convective core fraction within system

Formation (Cb>40%): ***small size, warm***
Maturity (10-30% Cb): ***max size, min temperature***
Dissipation (Cb<10%): ***small size, slightly warmer***

in agreement with *Futyan & DelGenio 2007* over Africa

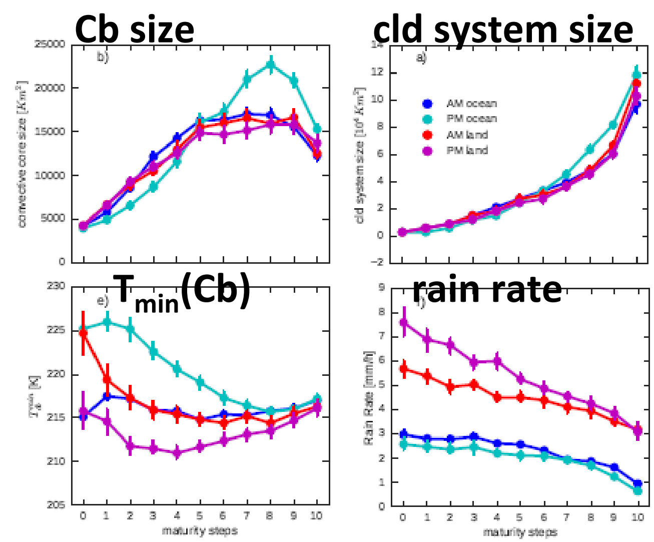


max of convection over land (ocean) 16-18h (during night)
problem: most polar sunsynchroneous observations do not catch this



anchor CloudSat to ISCCP-CT database:
use $TB(IR)_{min}$ & r(conv system) to follow development

Takahashi & Luo 2014



use Cb fraction as proxy of maturity

Protopapadaki et al. 2016

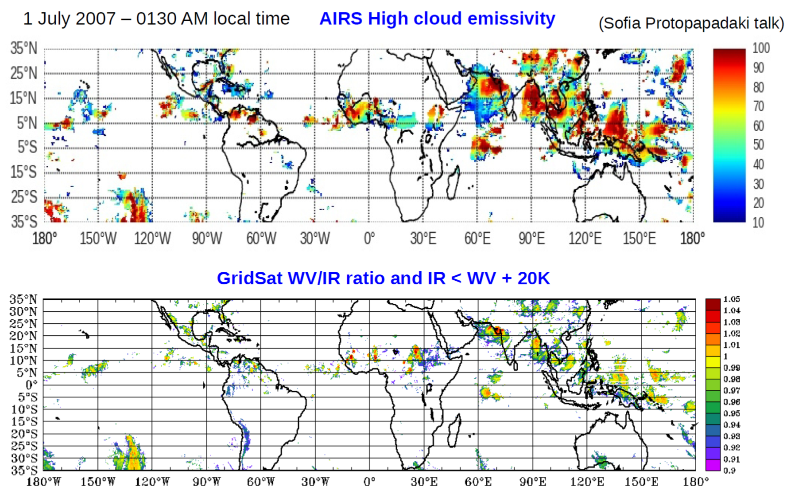
Synergies to analyze system life evolution

A-Train - geostationary data – TRMM – Megha-Tropiques

GridSat data :
gridded ISCCP B1 data: 0.07°
IR window, IR water vapor, 8 km res.
3-hourly 1980-now,
available at NOAA

≥ 2009 1-hourly geostationary data
available at AERIS

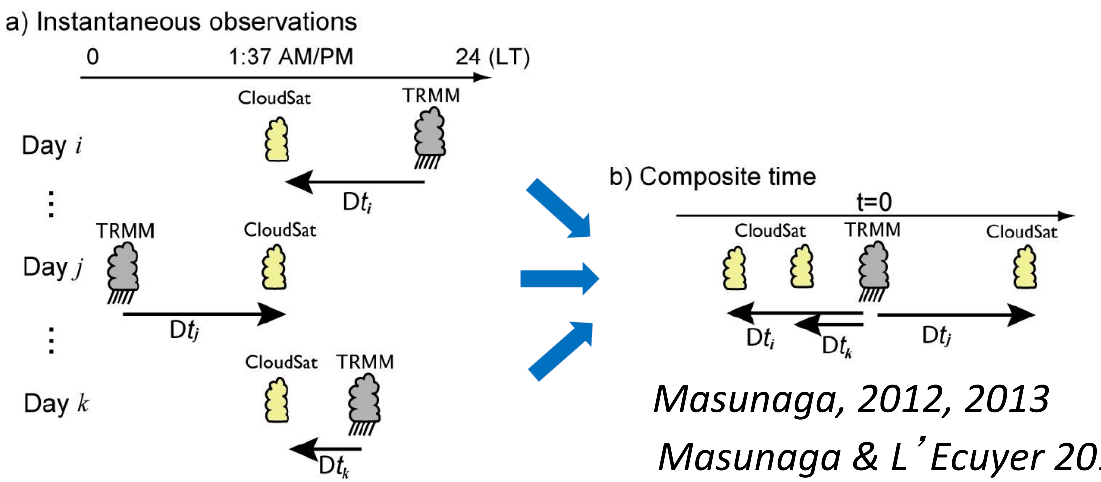
G. Sèze, UTCC PROES meeting
29 Apr 2016, Paris



Composite observations w. r. t. convective life stages

(H. Masunaga, J. Luo, R. Roca)

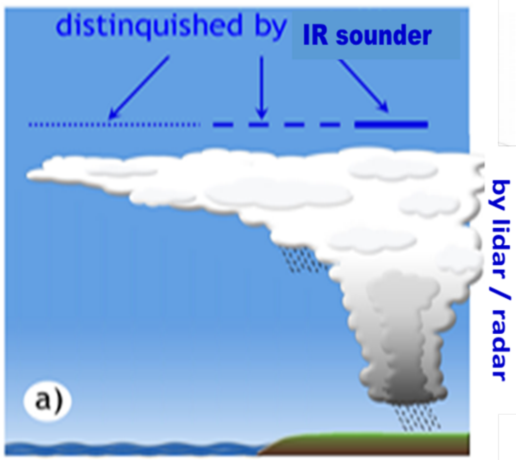
J. Luo, UTCC PROES meeting
29 Apr 2016, Paris

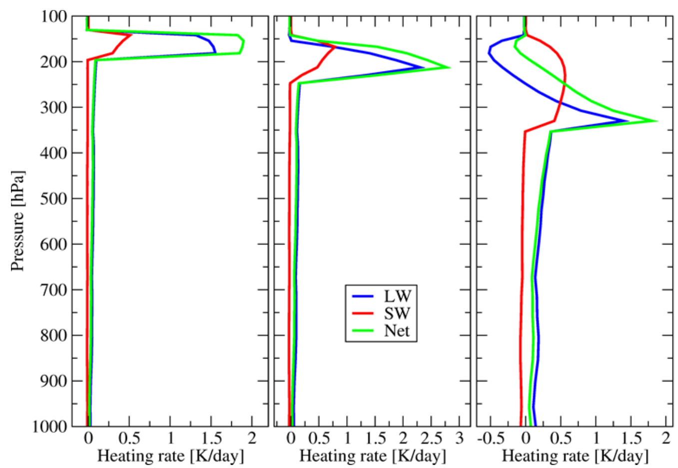


Masunaga, 2012, 2013
Masunaga & L'Ecuyer 2014

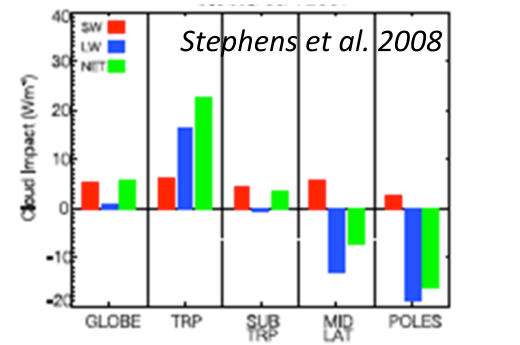
Vertical structure of UT cloud systems and their radiative heating

in tropical convective regions more than 50% of the total heating is contributed by UT heating due to cirrus *(Sohn 1999),* which then induces a widespread impact on the large-scale tropical atmospheric circulation





high clouds dominate heating in tropics,
low clouds determine cooling at high lat.



Goal: gain a better understanding of relation between
convection and heating induced by cirrus anvils

Heating depends on areal coverage, cloud emissivity distribution, vertical structure (multiple layering & microphysics)

determine radiative fluxes & heating rates
by categorizing vertical structure wrt cloud emissivity, height, IWP

cirrus heating w. r. t. their origin

What types of cirrus are most responsible for heating the atmosphere and thus influential to climate sensitivity?

- How much of the heating can be traced to convectively generated cirrus ?
- How much of the variability of UT heating is governed by variability in areal coverage, emissivity and microphysics ?

AIRS UT cloud systems, not including convective cores:
Are they dissipating convective systems or in situ formed ?

-> Lagrangian approach (backtracking) *(B. Legras)*

atmosph./cloud properties & radiative transfer model
-> cirrus heating rates

vertical layering, vertical IWC / De profiles important
parameterization as fct of IWP (e.g. *Feofilov et al. ACP 2015*)

compare to CloudSat-lidar heating rates

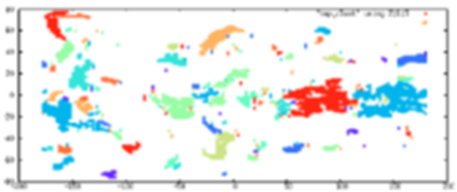
Evaluation strategies for cirrus systems in climate models

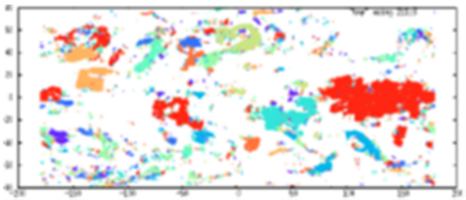
separate evaluation of cirrus systems
originating from convection & large-scale forcing

- ➢**LMDZ: thermodynamical approach (*Hourdin et al. 2013*)**
- ➢**ECHAM-HAM: microphysical scheme accounting for aerosol-cloud interactions (*Kuebbeler et al. 2014*)**

'simulator' of high cloud systems
for evaluation of convection schemes / detrainment / microphysics in GCMs

(M. Bonazzola, C. Risi)





compare horizontal extent & life time of Ci anvils in relation to convective strength, expansion & contraction of tropical convective systems in relation to conv. strength & cirrus heating

next GEWEX UTCC PROES meeting

CUNY, New York, *28-29 Mar 2017* *hosted by Johnny Luo*

Preparation of synergetic data to be in a form that could be adopted to start to evaluate relations between UT clouds and convection in models.

1)outline what we have data wise
2)investigate what specific new diagnostics can be used for evaluating modelling at different scales
(CRM which resolve convection and GCM which use parameterizations)
3)discuss data analysis methods to be investigated to take into atmospheric flow (separate cirrus originating from convection and in-situ) and system evolution
....

Participants inscribed so far:

Observations / radiative transfer : J. Luo, W. B. Rossow, H. Masunaga, T. L'Ecuyer, E. Jensen, H. Takahashi, G. Stephens, C. Stubenrauch, E. Zipser (?), C. Schumacher (?)

CRM modelling : S. van den Heever, W.-T. Chen

Climate modelling : T. Del Genio (GISS), R. Ramaswamy, L. Donner (GFDL), B. Gasparini (ETHZ), U. Burkhardt (DLR)

Summary & Outlook

motivation: ***advance on understanding feedback of UT clouds***

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

focus on

1) tropical convective systems &

2) 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, e

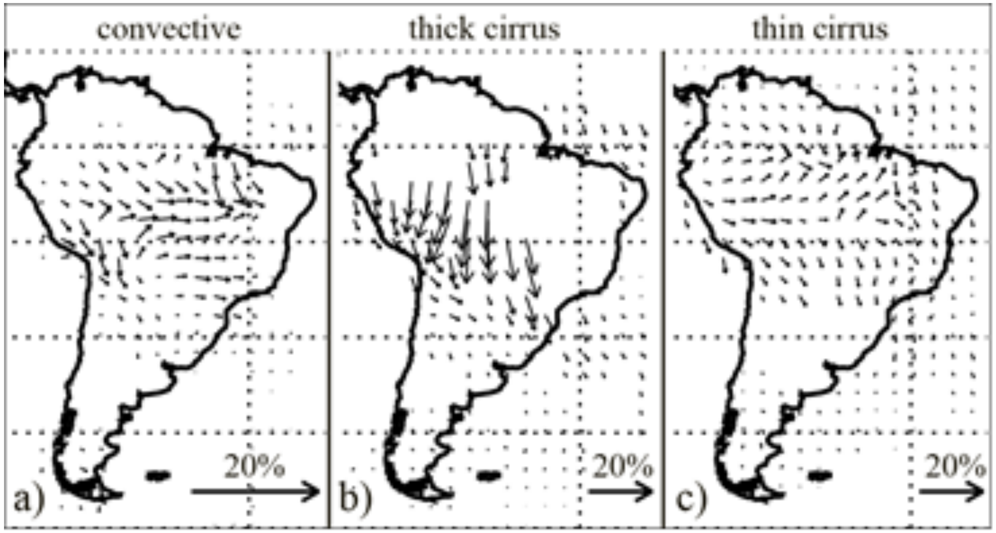
- **first relationships between convective strength & anvil properties**
- **prepare synergetic data,** incl. vertical dimension & atmosph. environment
- **determine heating rates**
- **investigate how cloud systems behave in CRM studies**

& in GCM simulations ***(under different parameterizations of convection/detrainment/microphysics)***

Diurnal cycle of high clouds

synergy AIRS – IASI

Feofilov et al., in preparation



↓ 24h00 → 18h00

↑ 12h00 ← 6h00

Amplitude & time of max high cloud amount
a) opaque (ε_{cld} > 0.95), b) thick cirrus (0.95 > ε_{cld} > 0.5), c) thin cirrus (ε_{cld} < 0.5)

Deep convection max in early evening,
anvils (thick cirrus) continue development during night,
thin cirrus in early afternoon, partly from dissipation of convective systems