Towards a complete Description of Tropical Upper Tropospheric Cloud Systems & Diabatic Heating from Synergistic Satellite Observations

Linking convective organization & atmospheric heating

within the framework of GEWEX UTCC PROES

Process Evaluation Study on Upper Tropospheric Clouds & Convection

Claudia Stubenrauch[1],

Giulio Mandorli[1], Xiaoting Chen[1], Thomas Fiolleau[2]

[1]Laboratoire de Météorologie Dynamique / IPSL, Paris, France

[2]Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, Toulouse, France

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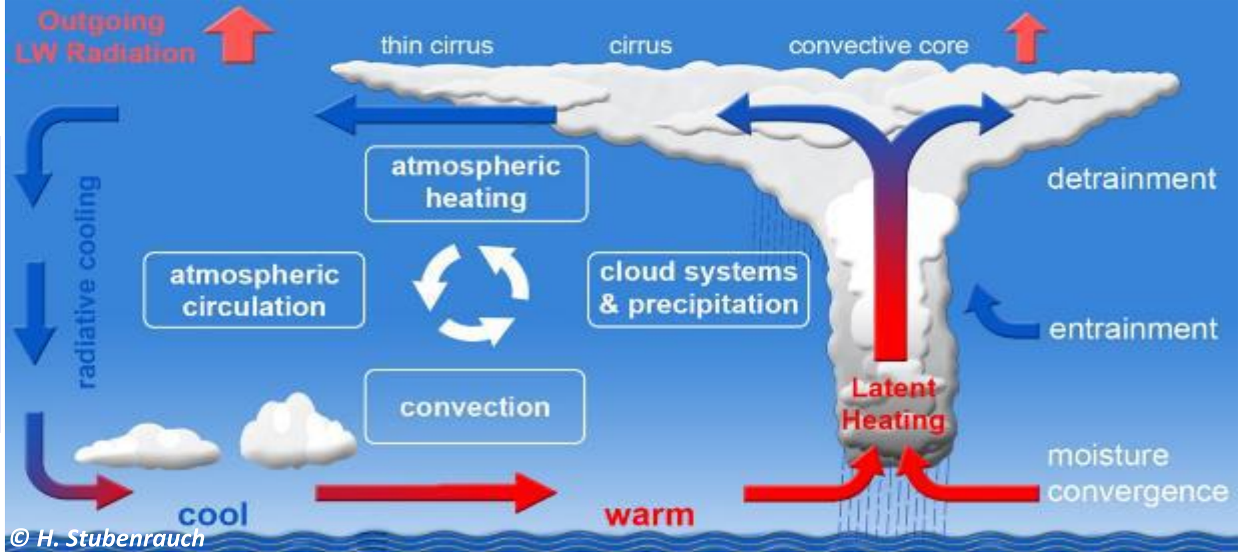
Motivation & approach

Climate warming :

change in tropical convective intensity & organisation ?

-> size & emissivity structure of cirrus anvils

-> heating gradients -> large-scale circulation



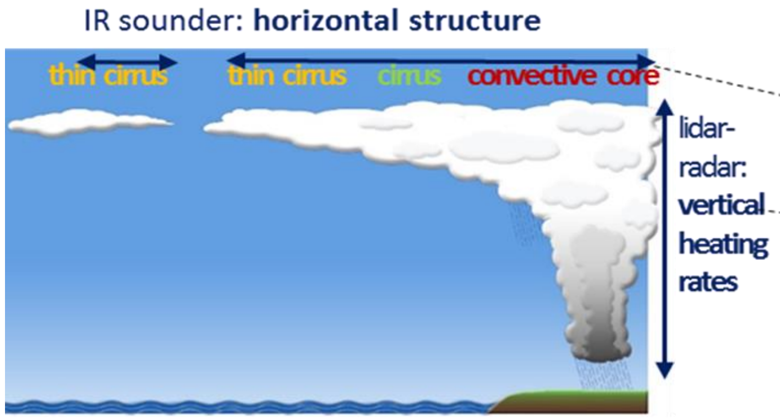
To advance our understanding on UT cloud feedbacks, we are coupling

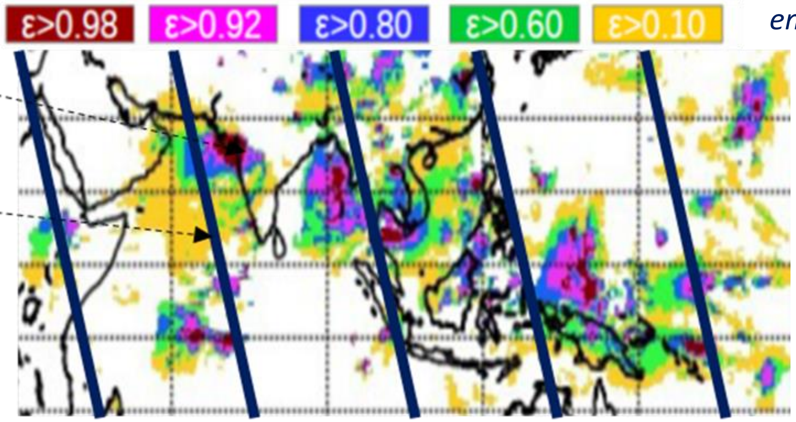
- **cloud-top properties**: from IR Sounder, ***sensitive to Ci*** *(day-night) & good instantaneous coverage (Stubenrauch et al. ACP 2017)*
- **Eulerian Cloud System Concept**: *relating cirrus anvil properties to convection (Protopapadaki et al. ACP 2017)*
- **vertical structure & rain areas within UT clouds**: from CALIPSO-CloudSat & ML *(Stubenrauch et al. 2023)*
- **3D diabatic heating**: **radiative** from CALIPSO-CloudSat & ML & **latent** from TRMM & ML
- **Lagrangian Convection Tracking**: based on cold T_B^{IR} *(Fiolleau et al. 2020)* & precipitation *(Takahashi et al. 2021)*
- **metrics of convective organisation**: *(Mandorli & Stubenrauch 2023)*
- **simulation experiments**: study changes in atmospheric circulation for different situations of convective organization

-> quantify dynamical response of climate system to atmospheric heating

3D snapshot reconstruction using synergistic data & Machine Learning

add vertical structure & precipitation





emissivity structure of UT cloud systems

vertical structure & precipitation:

1) CloudSat-lidar on narrow nadir tracks

2) TRMM radar : small coverage at specific LT

LT within 20 min of 1h30 AM

expand vertical structure & precipitation across AIRS / IASI swaths via ANN:

1) develop regression & classification models based on **Artificial Neural Networks (ANN)**, training on collocated data *(AIRS-CloudSat-lidar 2007-2010, AIRS-TRMM 2004-2015, IASI-TRMM 2007-2015)*

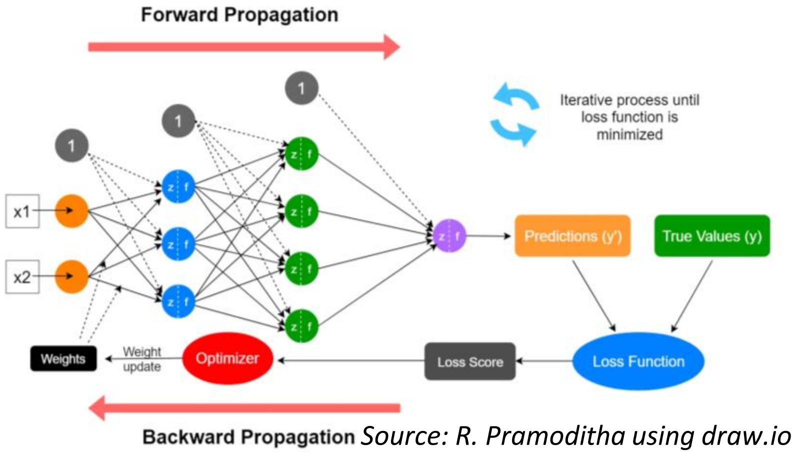
2) apply these models on the whole CIRS data record *(2004-2018)*

use derived atmospheric properties *(similar for AIRS & IASI)* **:**

X : CIRS cloud variables & ERA-Interim atmosphere, surface

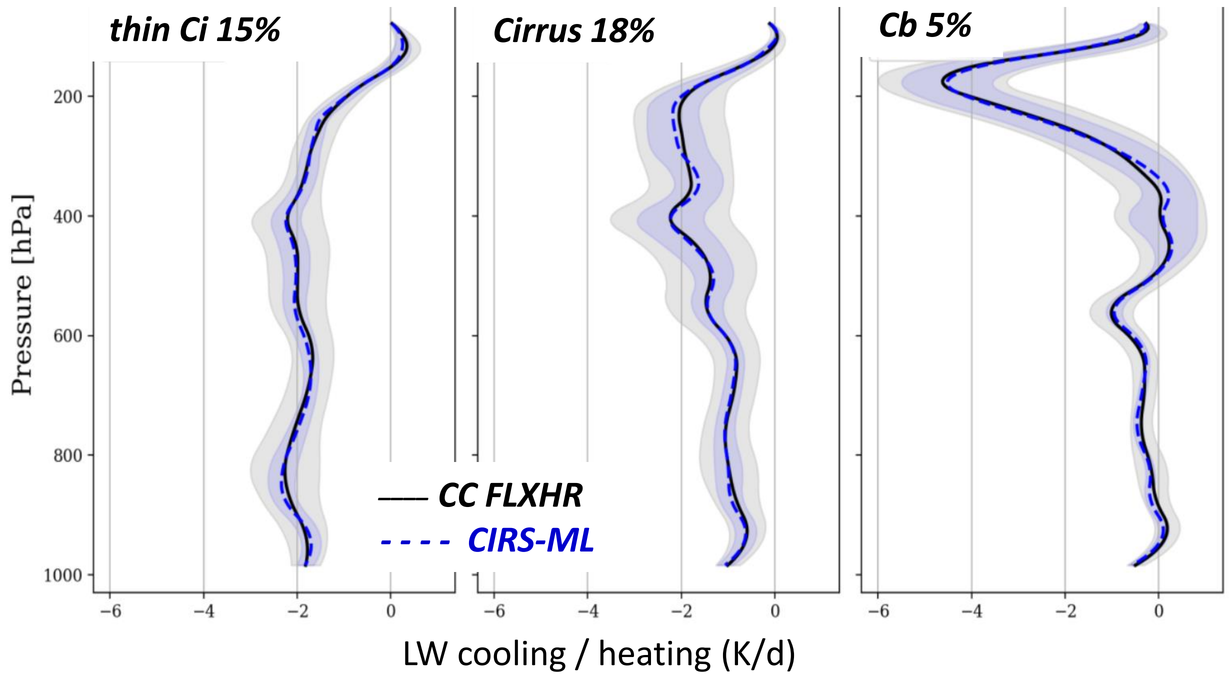
F(X) : CloudSat-lidar radiative heating rates, Z_{top} & Z_{top}-Z_{base}, cloud layering, rain rate from *NASA FLXHR v4*, *GEOPROF*, *PRECIP-column*

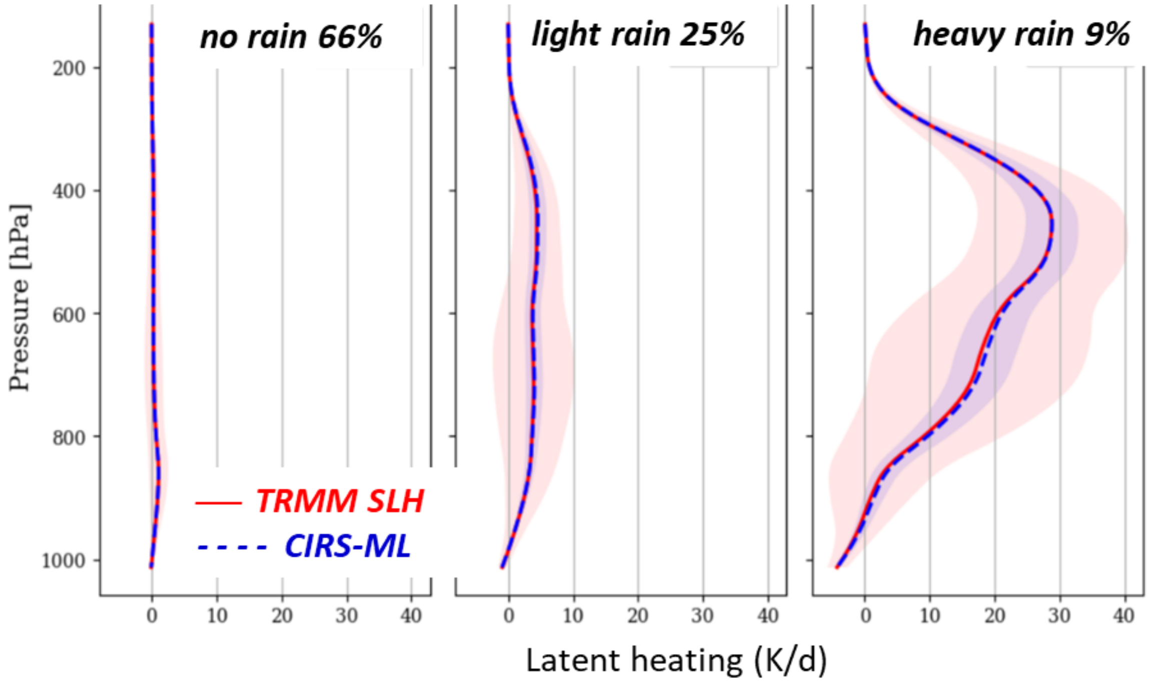
TRMM latent heating rates from *NASA SLH v6*



Source: R. Pramoditha using draw.io

Development of scene-dependent ANN models





radiative heating rates from ANN trained over 8 scenes:
Cb / Ci / mid-low clds / clr sky x ocean / land

ocean	clouds	clr
LW HR	0.79 K/d	0.34 K/d
SW HR	0.45 K/d	0.22 K/d

MAE

Large scewness of precipitation rate distribution
-> classification

- **no / light / heavy rain** *accuracy 65 - 70%*

latent heating rates from ANN trained over 12 scenes:
UT clds / mid-low clds x no rain / light rain / heavy rain x ocean / land

RH: well predicted means & variability

LH: well predicted means & underestimated variability

snapshots of horizontal structures

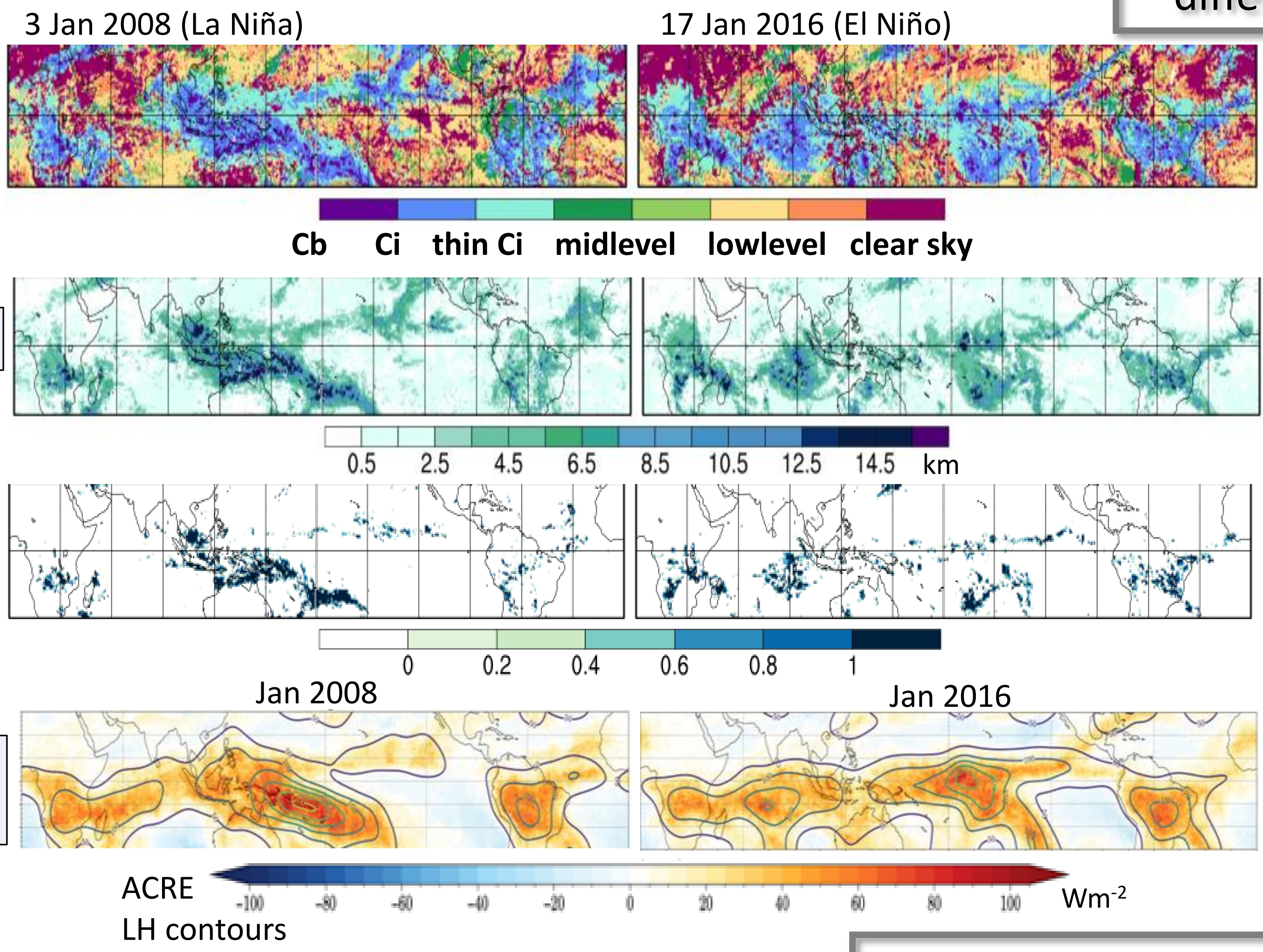
different for La Niña - El Niño

cloud type

vertical extent

RainRate > 0 fraction

radiative & latent heating



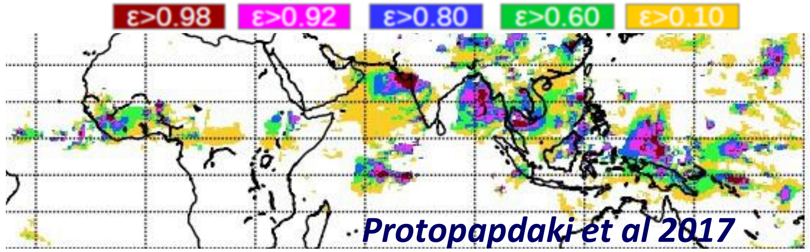
ANN

vertically integrated LH & ACRE well aligned !

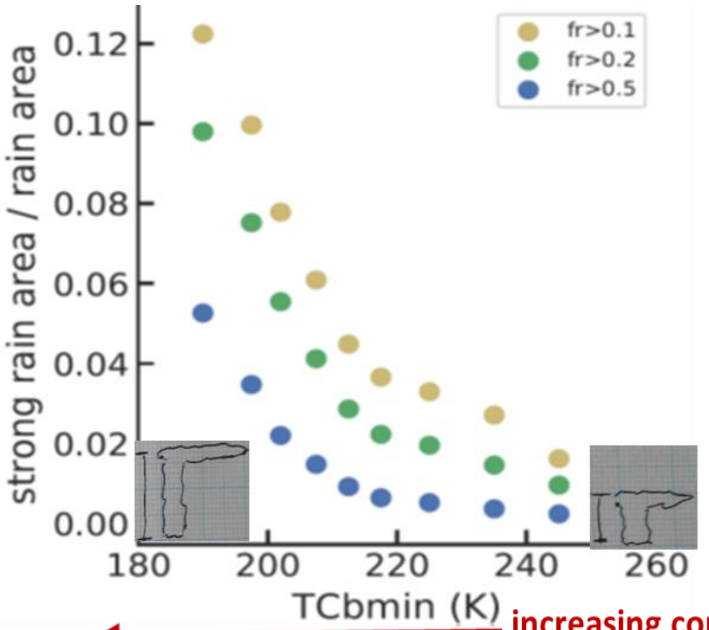
Process-oriented behaviour of mesoscale convective cloud systems

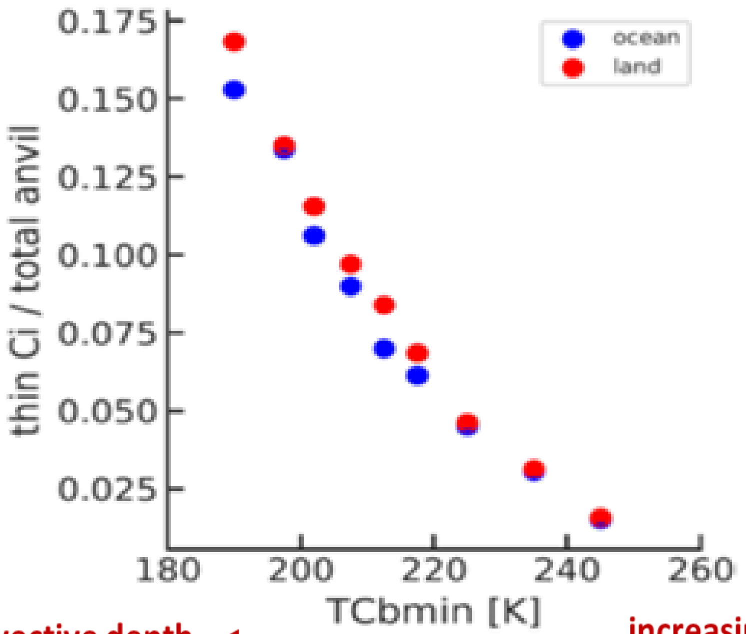
Stubenrauch et al. ACP 2023
Stubenrauch et al. JAMES 2019

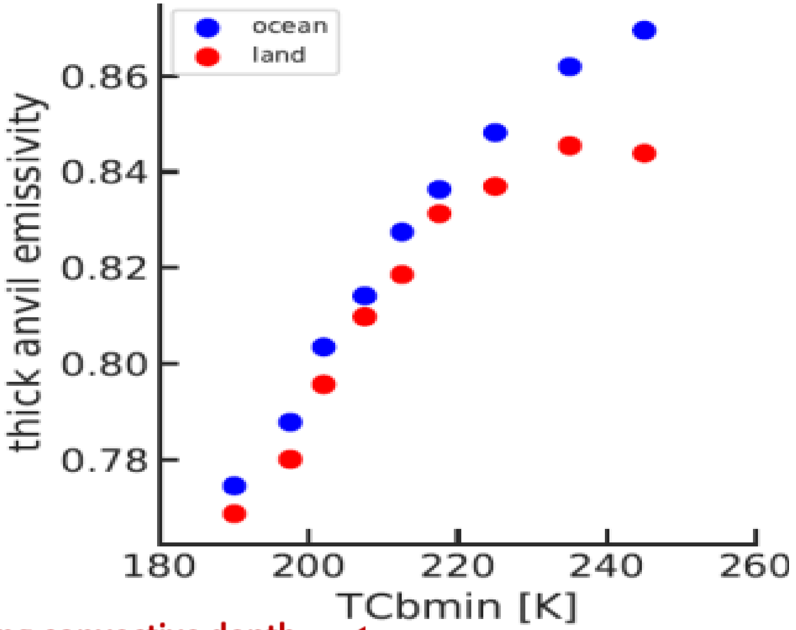
Eulerian Cloud System Concept using p_{cld} & ε_{cld}



proxy for convective depth: min T within core of mature systems
Mature MCSs: convective core fraction 0.2-0.4







increasing convective depth

increasing convective depth

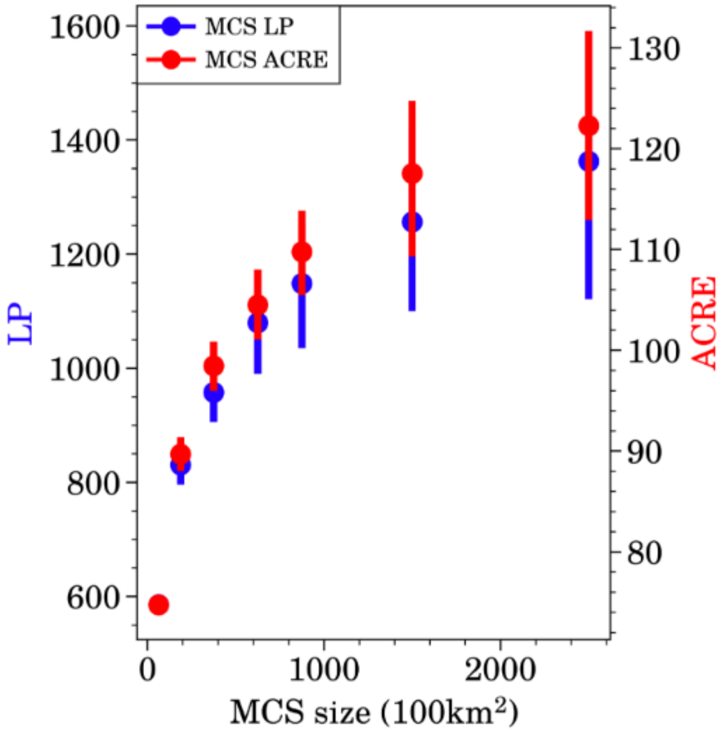
Deeper convection leads to:

larger heavy rain areas | larger areas of surrounding thin Ci | slightly thinner anvils

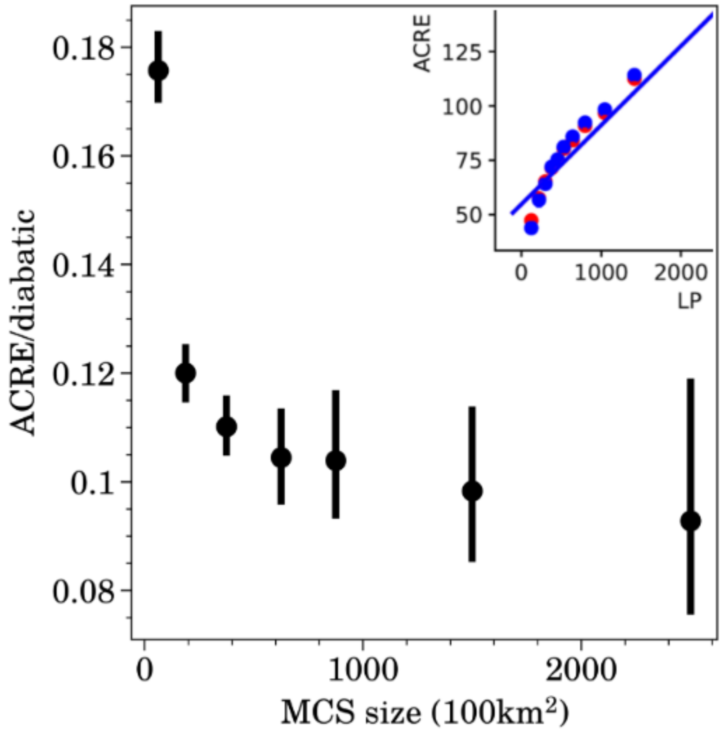
Relation between LH & RH in mesoscale convective cloud systems

Chen et al. 2024, in preparation

proxy for convective organization: MCS size



radiative enhancement: ACRE/(ACRE+LH)



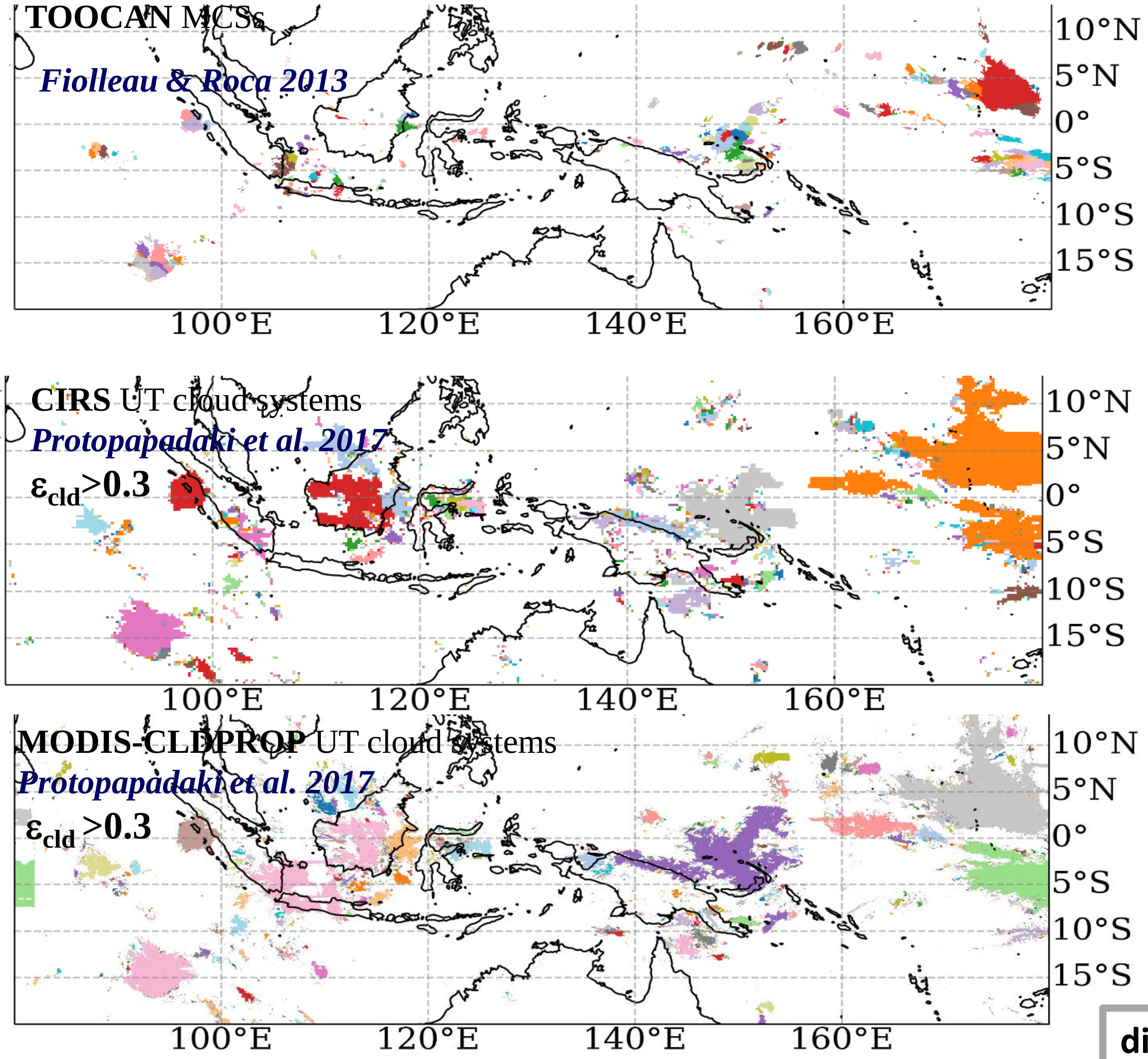
Both LH & ACRE increase with MCS size

however, ACRE increases more slowly

CIRS-ML Synergy with Lagrangian convection tracking

combine MCSs from tracking to anvil properties

Snapshot at 1:30PM , 4 Jan 2016



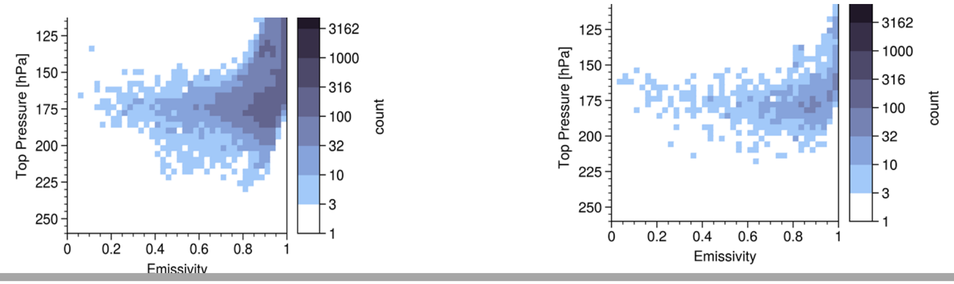
How is Cirrus & its heating related to deep convection & its organization ?

***TOOCAN**: cold mesoscale convective systems*
fine spatial & temporal resolution
tracking yields life time & stage, maturity size

-> cold T_B (& precipitation) tracking miss anvil parts

***CIRS-ML**: large envelopes of UT cloud systems with additional information (HR, LH, thin Ci & anvil properties)*

***MODIS**: much better spatial resolution than CIRS: still large envelopes of UT cloud systems !*



dissipating stage: *long-living MCSs* thicker & higher than *short-living MCSs*

Conclusions & Outlook

- **Synergy of different satellite instruments provides a more complete picture of clouds**

- **complete 3D snapshots & longer time series by ML**
  -> convective organization & process studies

- **Eulerian Cloud System Concept allows**
  - to study relationships between convection & anvils
  - process-oriented evaluation of GCM parameterizations

- **Synergy of UT cloud envelopes & Lagrangian MCS Concept adds life time & life stage**
  - to study relationship between convection & thinner parts of anvils

- **Radiative enhancement of LH seems to decrease with MCS size**

Investigate relationship between latent & radiative heating & its effect on atmospheric circulation in dependence of convective organization in climate simulations *in cooperation with L. Li, LMD*

CIRS-ML 3D cloud structure dataset distributed at *https://gewex-utcc-proes.aeris-data/fr/data*

2004-2018: on AIRS swath at 1:30 AM & PM, spatial resolution of 0.5°, netCDF format

general

UTC time
T_{surf}
p_{surf}
solar zenith
$p_{tropopause}$

CIRS cloud retrieval

T_{cld}
p_{cld}
ε_{cld}
most frequent scene:
UT cld, mid-low cld, clr sky
cld type fractions:
Cb, Ci, thin Ci, mid-low

Stubenrauch et al. ACP 2017

vertical structure

z_{cldtop}
z_{cldtop} - $z_{cldbase}$
for each cld type

Rain Rate classification

Rain Rate indicator
fractions of
no, light, heavy rain

radiative heating

SW heating rate
LW heating rate
at 22 pressure levels

clr sky monthly mean
SW heating rate
LW heating rate
at 22 pressure levels

CIRS-ML trained on CloudSat-CALIPSO GEOPROF, PRECIP-column & FLXHR

Stubenrauch et al. ACP 2023

Stubenrauch et al. ACP 2021

TOOCAN Tracking of organized convection (> 2012) at ***https://toocan.ipsl.fr/*** *Fiolleau & Roca 2013*