Precipitation Science from Space and Synergy with Aerosol, Clouds and Climate Studies

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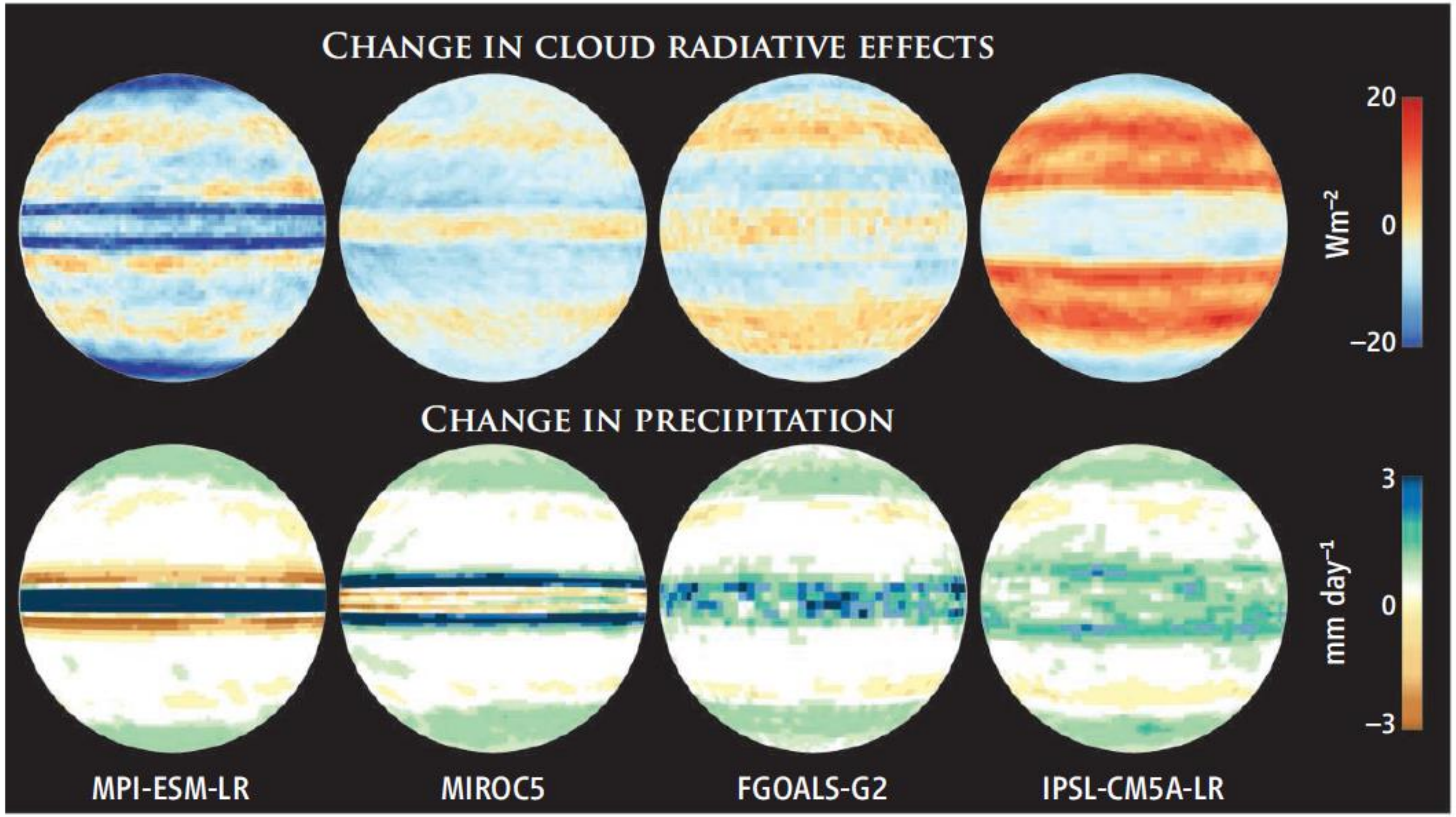
The response patterns of clouds and precipitation to 4℃ warming aqua-planet climate model experiments

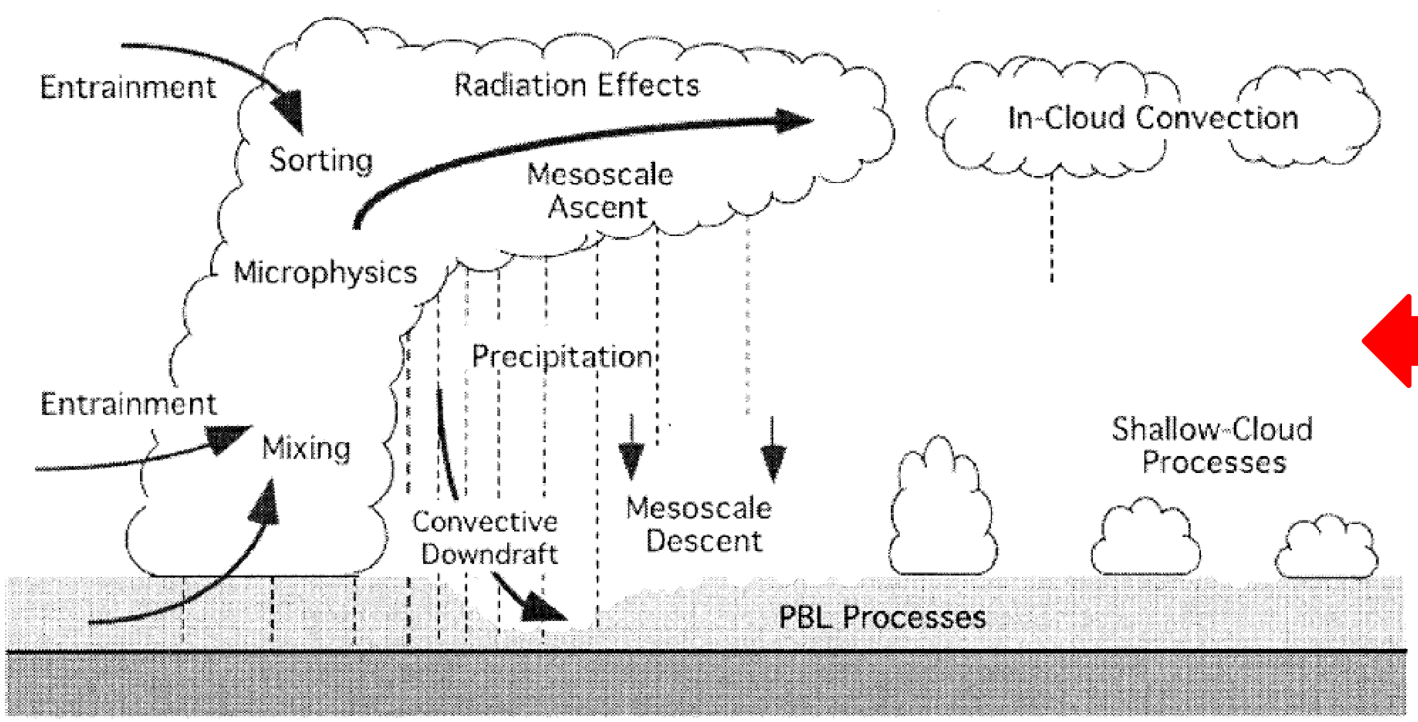


Wide variation. The response patterns of clouds and precipitation to warming vary dramatically depending on the climate model, even in the simplest model configuration. Shown are changes in the radiative effects of clouds and in precipitation accompanying a uniform warming (4°C) predicted by four models from Phase 5 of the Coupled Model Intercomparison Project (CMIP5) for a water planet with prescribed surface temperatures.

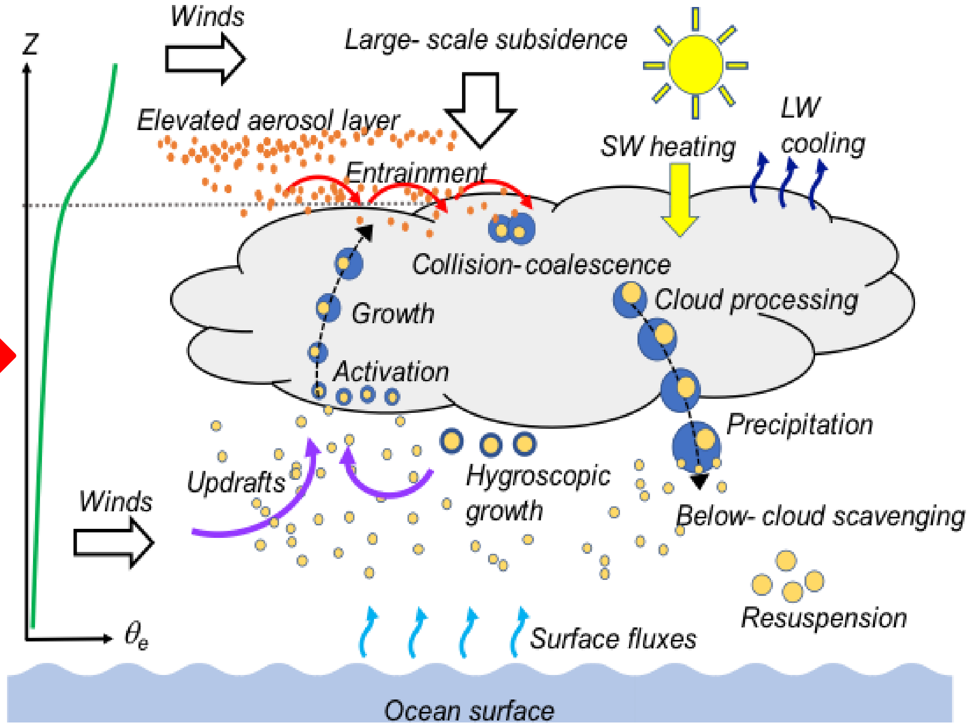
What Are Climate Models Missing?
Bjorn Stevens and Sandrine Bony
Science **340**, 1053 (2013);
DOI: 10.1126/science.1237554

Uncertainties in Formulating Cloud and Associated Processes

UNCERTAINTIES IN FORMULATING CLOUD AND ASSOCIATED POCESSES



ACTIVATE



Arakawa 2004

Sorooshian et al. 2019 BAMS

Convective Parameterization
✓ How to trigger? How to heat?

Aerosol-Cloud-Meteorology Interactions

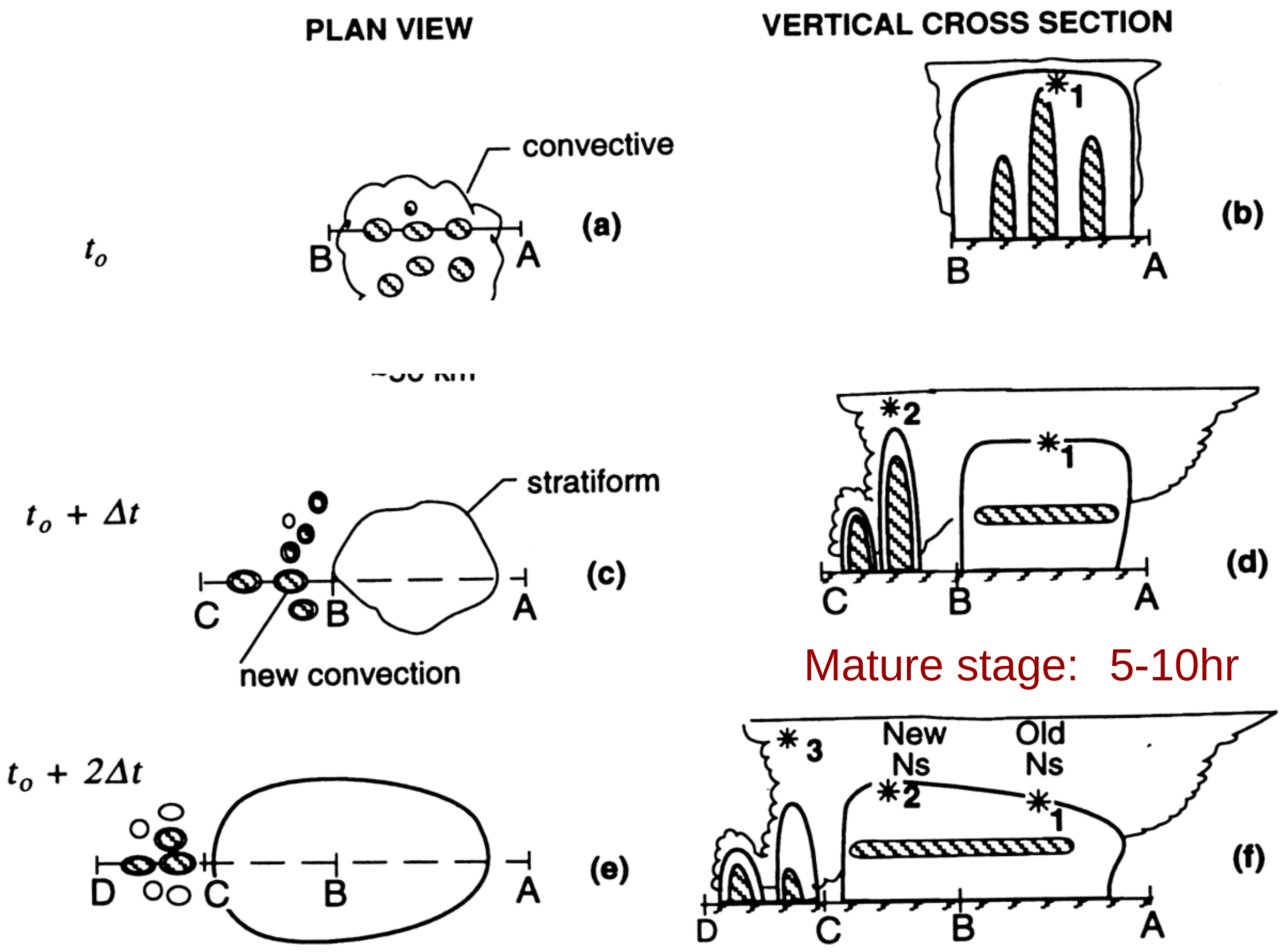
Spread of CCN, Hydrometeors, Microphysics
Cloud Area, Height, (Optical) Depth..

Advances in Precipitation Science with TRMM/GPM

- Characteristics of precipitation systems and their environments
  - Extreme precipitation
  - Mesoscale Convective Systems vs Scattered Convection
- Quantification of convective latent heating
- Detection of precipitation microphysics
  - Liquid/Solid phase
  - Flags for Heavy Ice Precipitation, Graupel Hail
- Improvement of NWF with precipitation assimilations
- High spatial-temporal resolution precipitation maps
- Field experiments for validations

Since 1997!

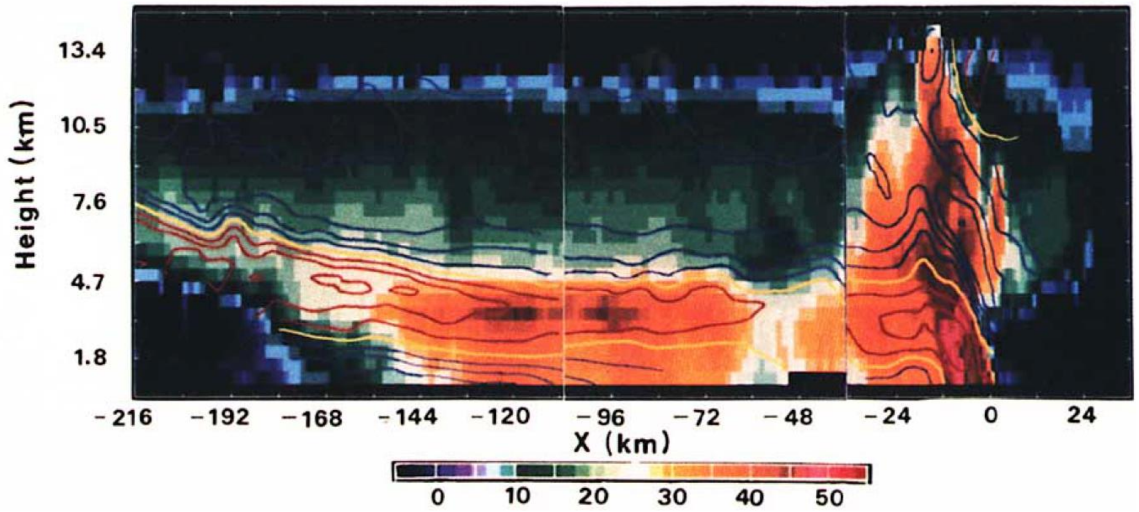
Mesoscale Convective System (MCS)



Mature stage: 5-10hr

Leary and Houze (1979)

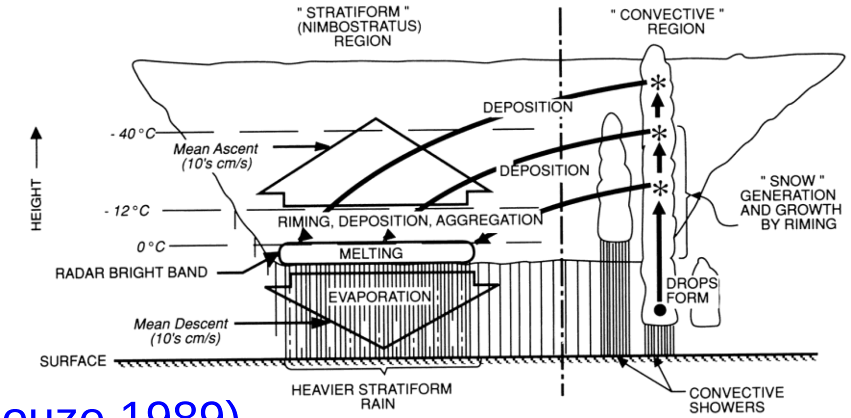
Radar Reflectivity and Doppler velocity



Houze (1980)

Radar Meteorology revealed the structures of Mesoscale Convective Systems, by identifying convective precipitation and stratiform precipitaion, as well as Doppler velocity observations.

Diabatic Heating Associated with MCS



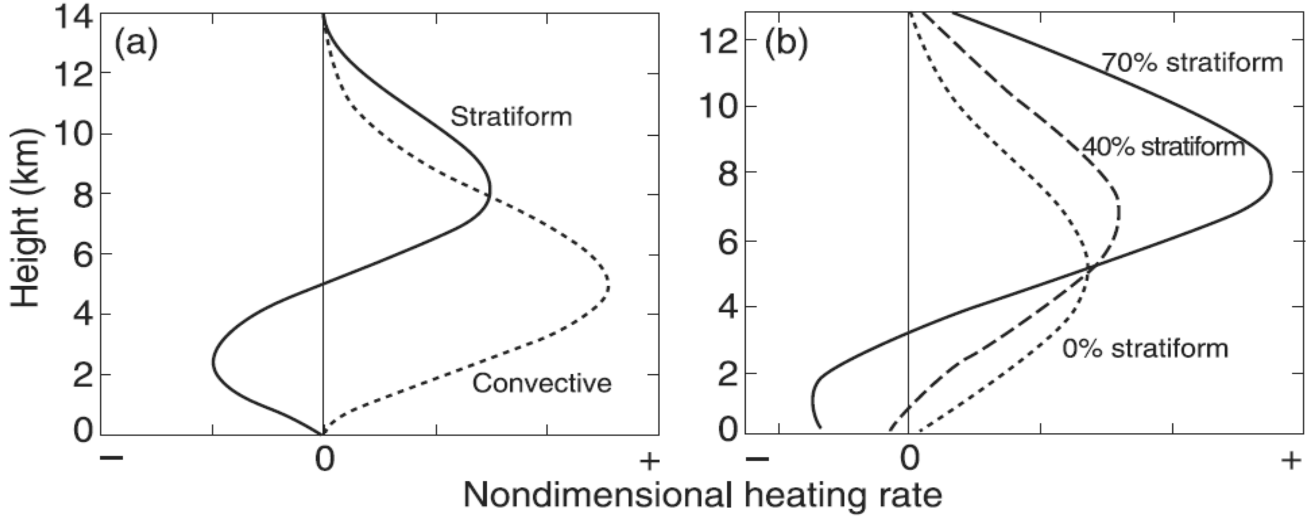
(Houze 1989)

Diabatic Heating (LH+RH) generates circulation

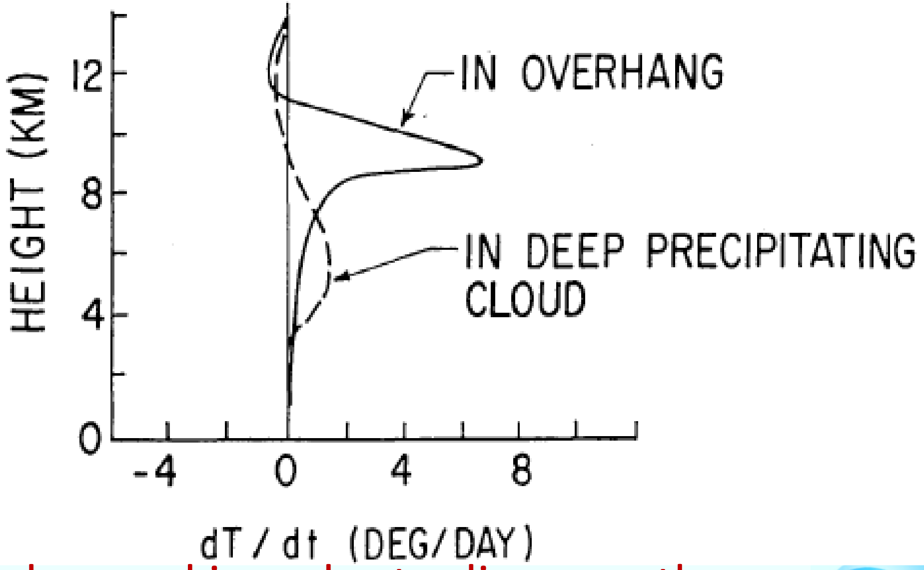
$$\rho \frac{\mathrm{D}P}{\mathrm{D}t} = \zeta \cdot \nabla Q - \nabla \times \mathbf{F} \cdot \nabla \theta$$
$$= \nabla \cdot (\zeta Q - \mathbf{F} \times \nabla \theta),$$

P: Potential vorticity, Q: Diabatic Heating,
F: Frictional forces, zeta: absolute vorticity

Latent Heating (Schumacher et al. 2004)



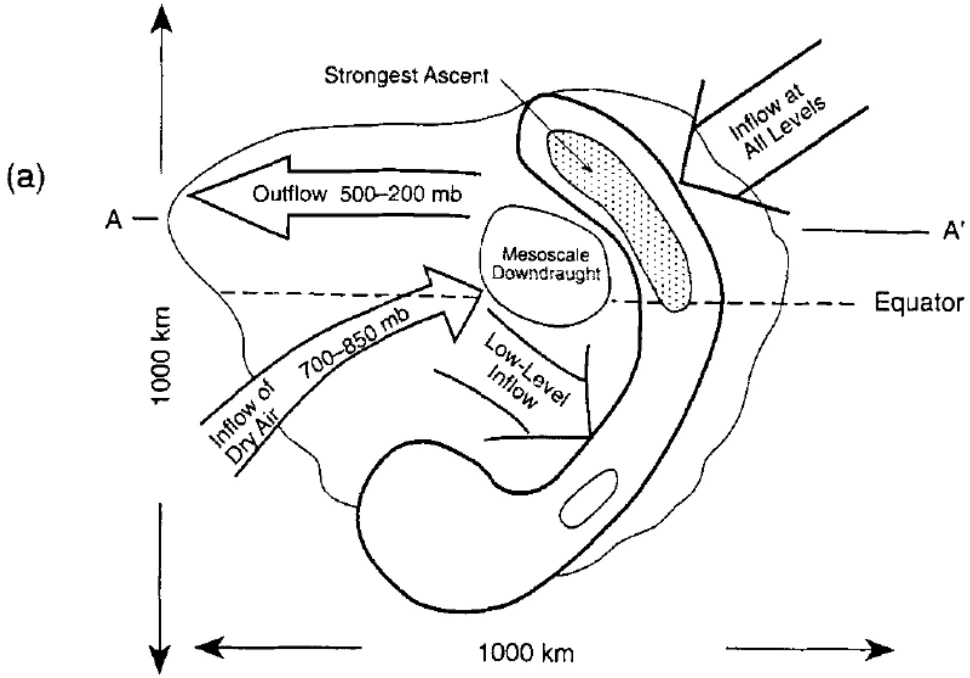
Radiative Heating (Webster and Stephens,1980)



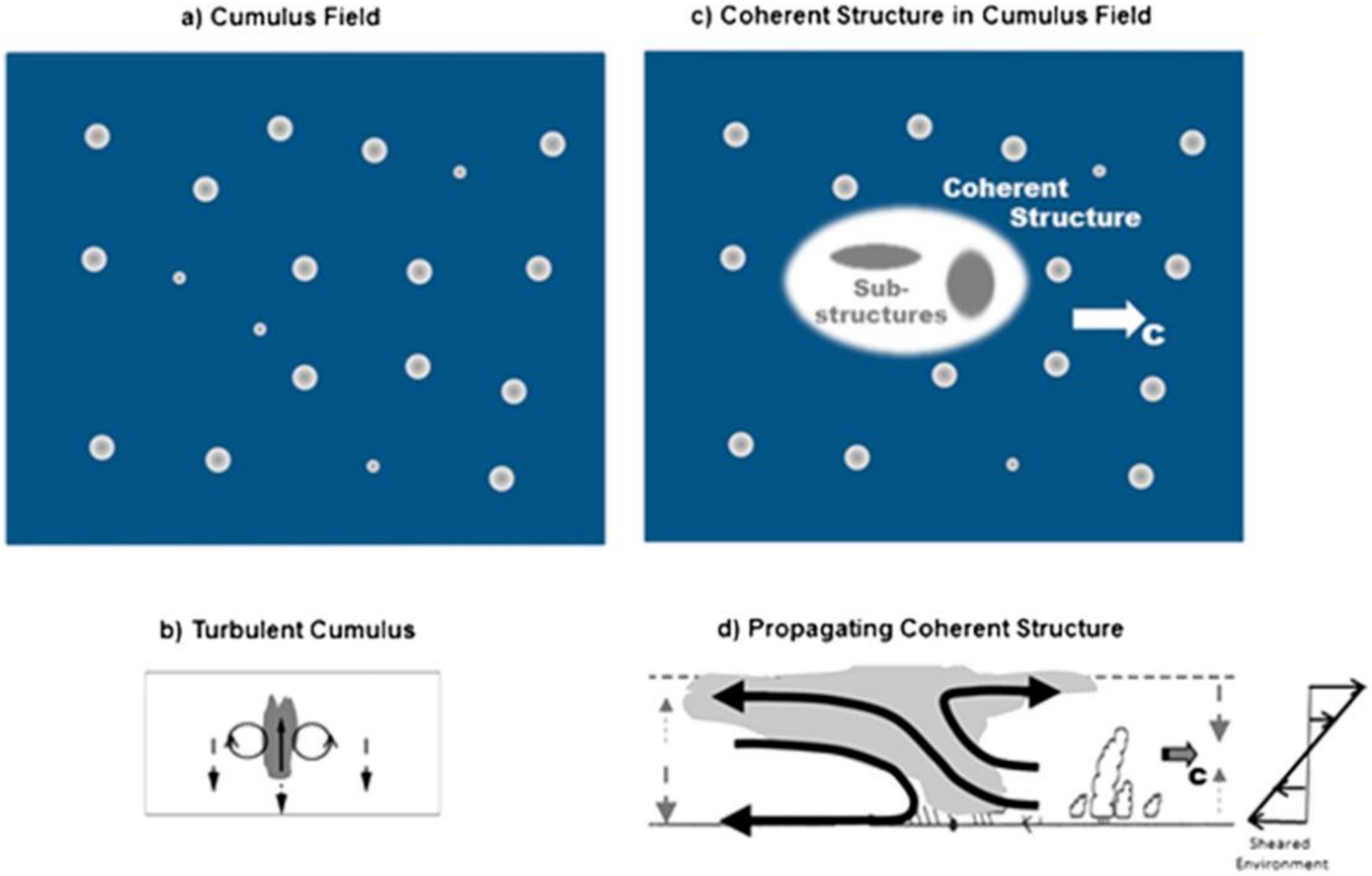
It is essential to know the precipitation properties (conv/strat) and cloud spread in order to diagnose the diabatic heating associated with MCS

Different Regimes of Overturning

(Cumuloninbus vs MCS)



(Moncrieff and Klinker, 1997)

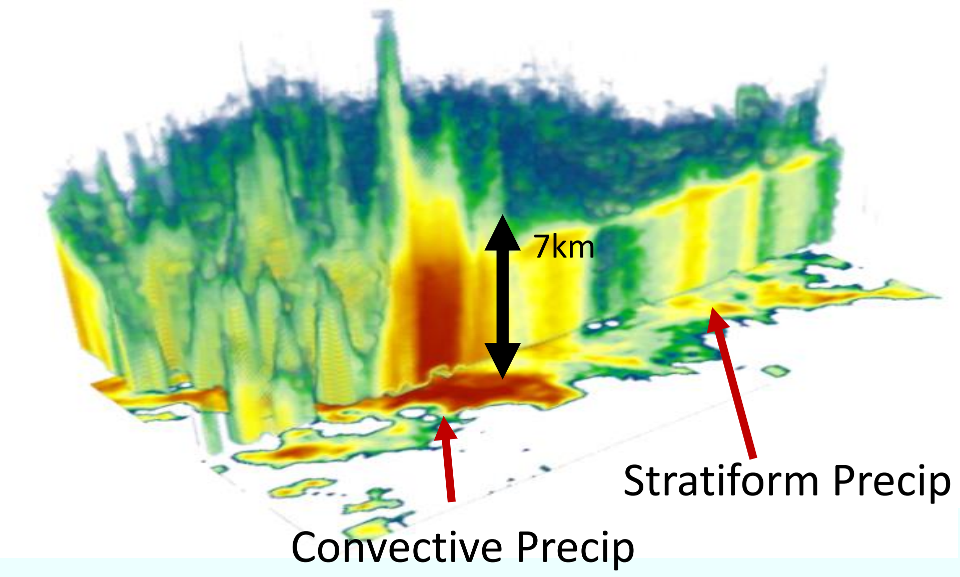


(Moncrieff and Waliser, 2015)

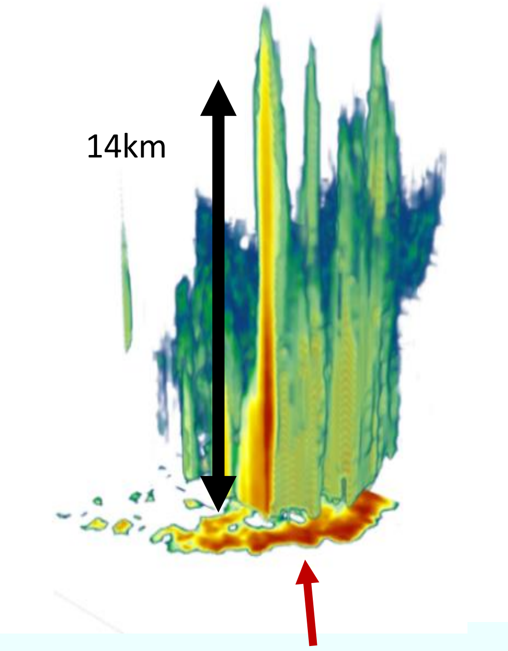
Precipitation Events observed from TRMM PR / GPM DPR

The appearance of space-borne precipitation radars on TRMM in 1997 and followed by GPM satellite in 2014 has enabled us to observe hundreds of millions of precipitation events in 3D from space

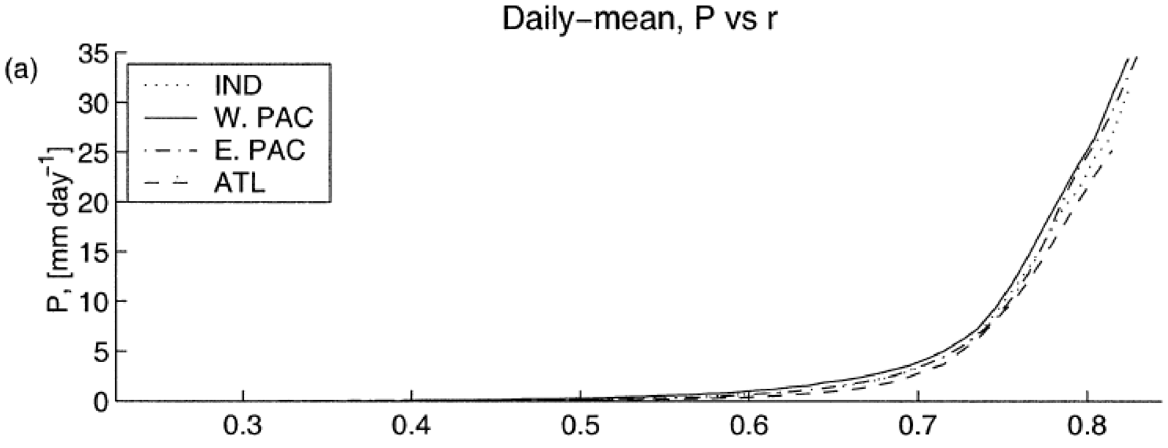
Organized Convection (MCS)



Thunderstorm Convecction



Atmospheric Moisture and Precipitation

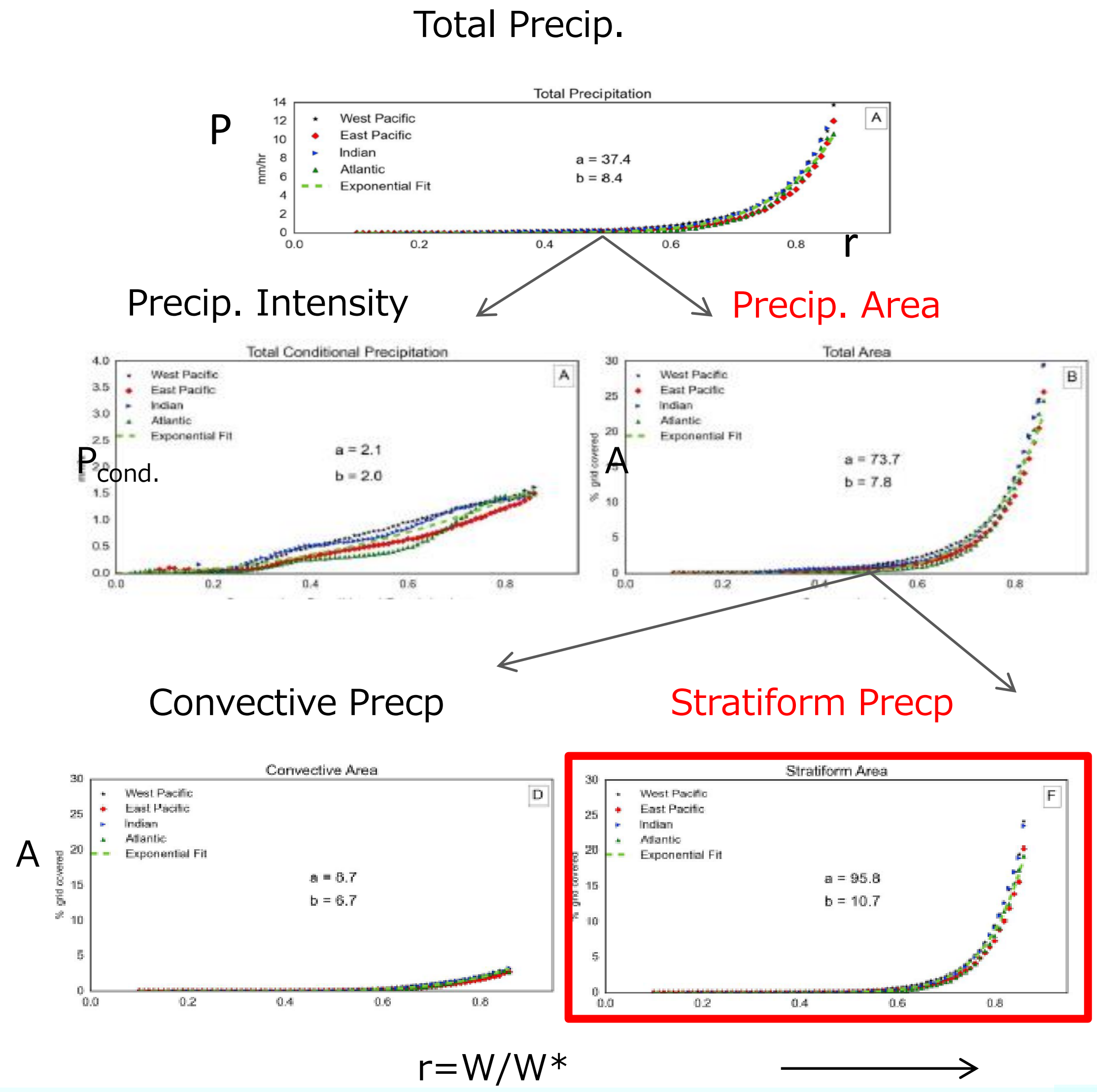


Column Relative Humidity r＝W/W*

Bretherton et al. (2004)

Left: Bretherton et al. 2004 showed a rapid pick up of precipitation with increasing column relative humidity.

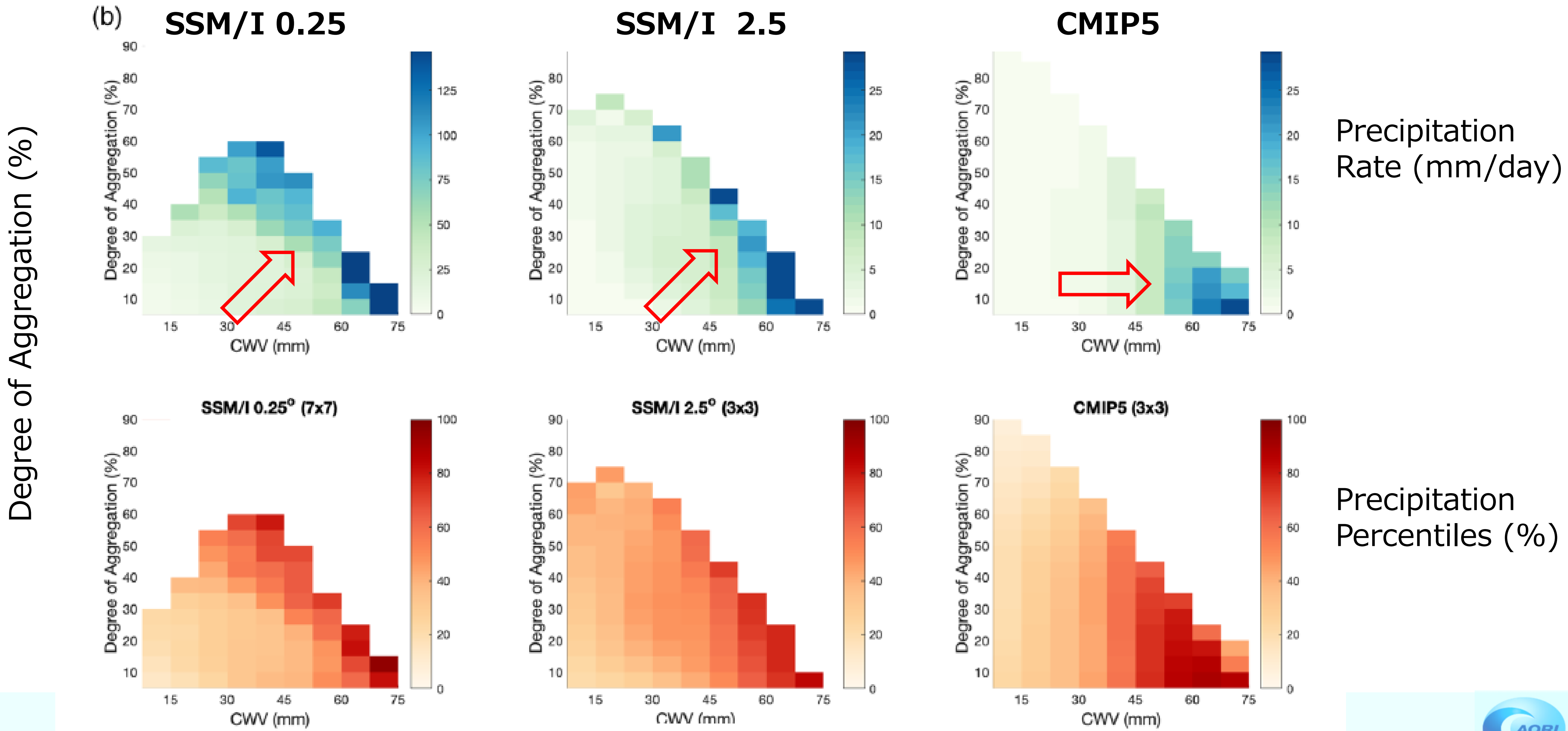
Right: Utilizing TRMM PR data, AS15 showed that it is attributable to organized mesoscale precipitation systems which rapidly increase with increasing column relative humidity r.



→ Emphasized the significant increase of MCS with column relative humidity

Ahmed and Schumacher (2015) with TRMM PR

Precipitation Dependence on CWV and Degree of Aggregation

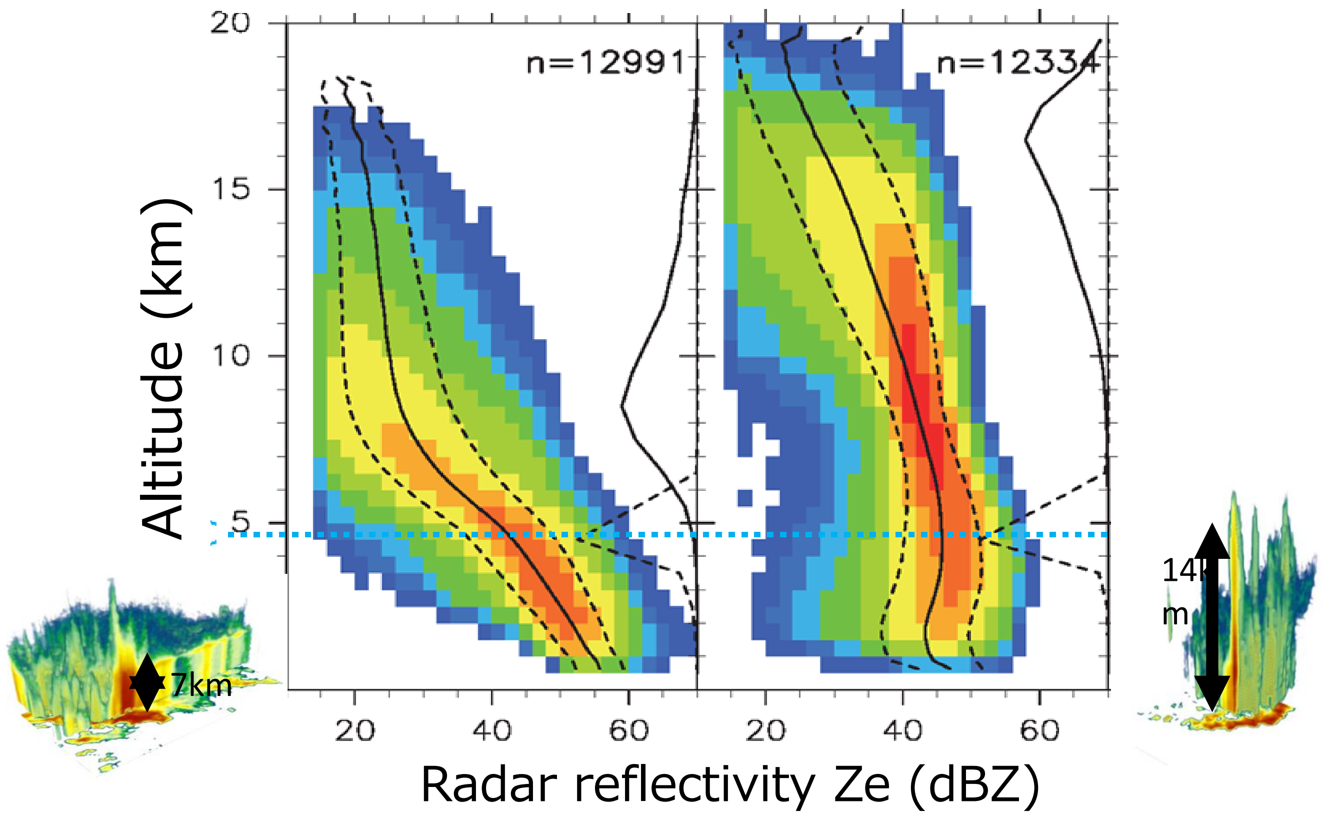


(Dai and Soden, 2020)

Ze-Height PDFs for Extreme Rainfall vs Extreme Convection
2001.9-2012.8 (Hamada et al. 2015, Nature Comm)

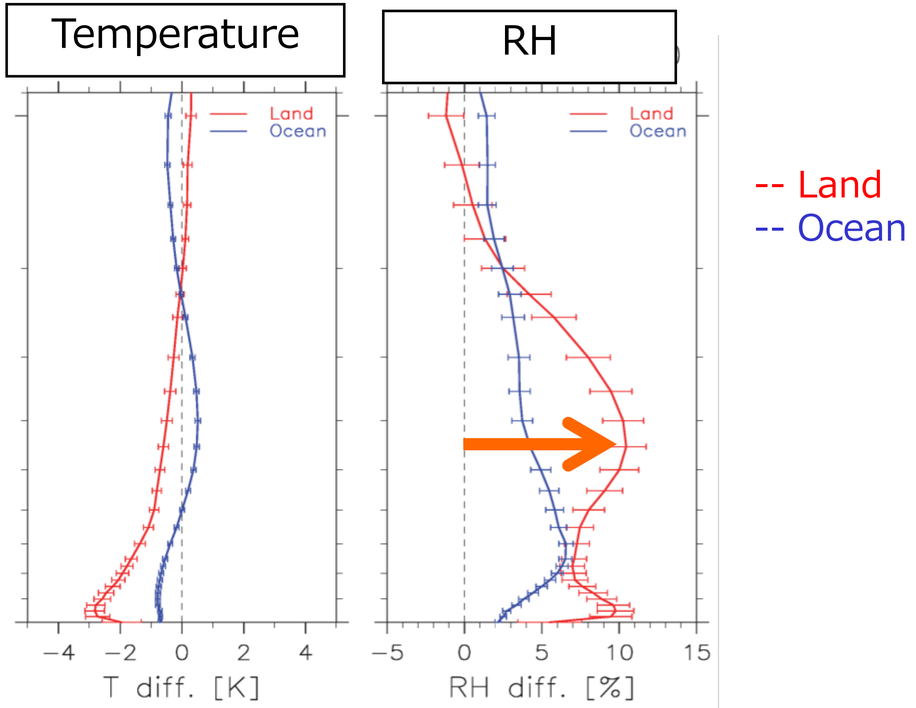
35N-35S Land, 99.9% in each 2.5deg grid 85 million events

Extreme Rain Extreme Conv



Differences in Env. Conditions

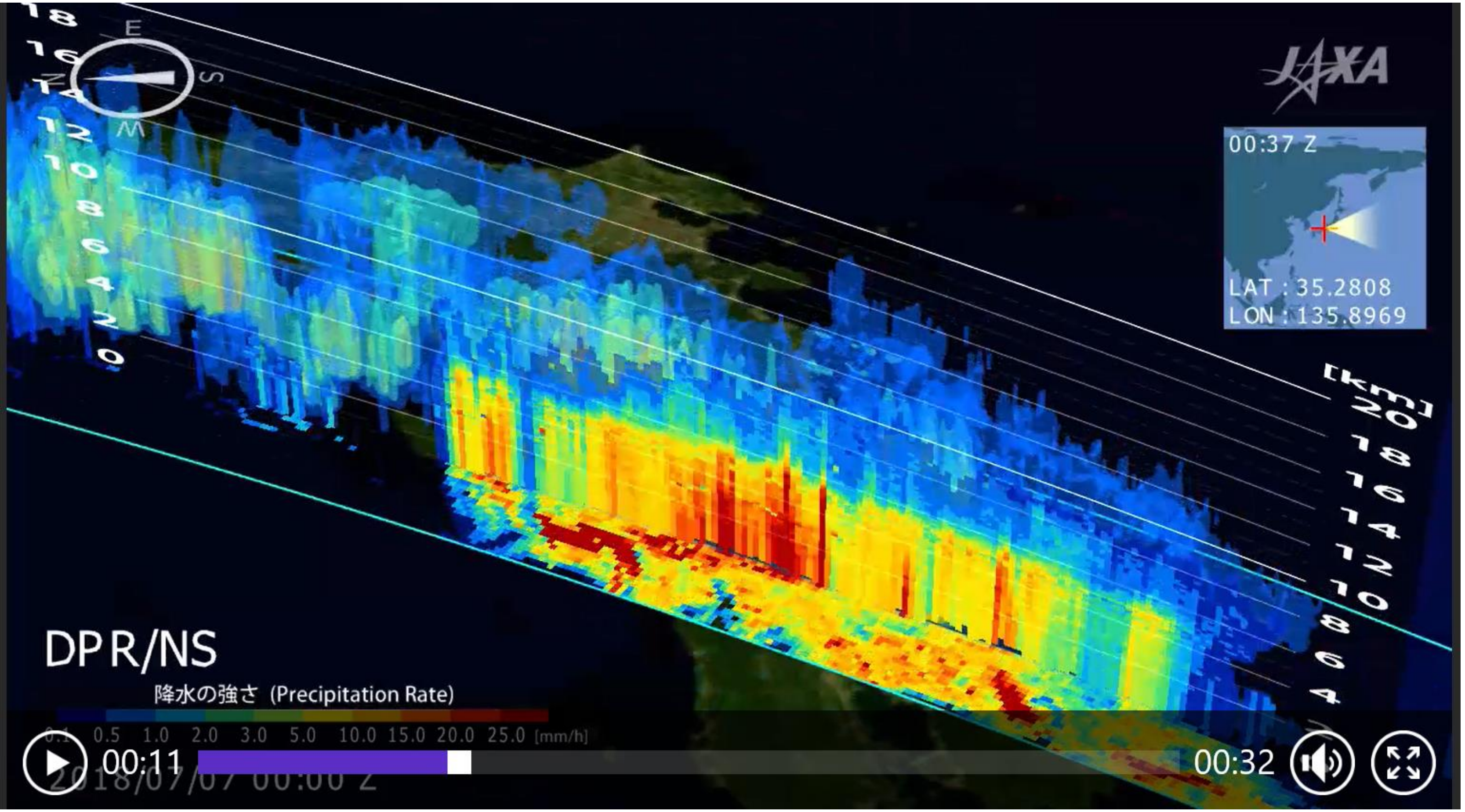
(Ext-Rainfall) – (Ext-Convection)

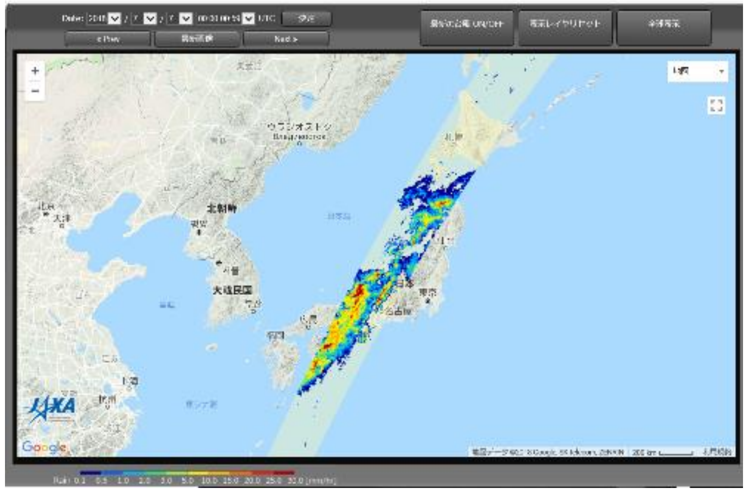


- Heaviest rainfalls are not linked to Tallest convections
- Heaviest rainfalls contain more warm-type rain, in more stable and moister environments, associated with more organized systems (Hamada et al. 2015; Hamada and Takayabu, 2018)

GPM DPR observed the Heavy Rainfall in July 2018

9:38JST, July 7, 2018



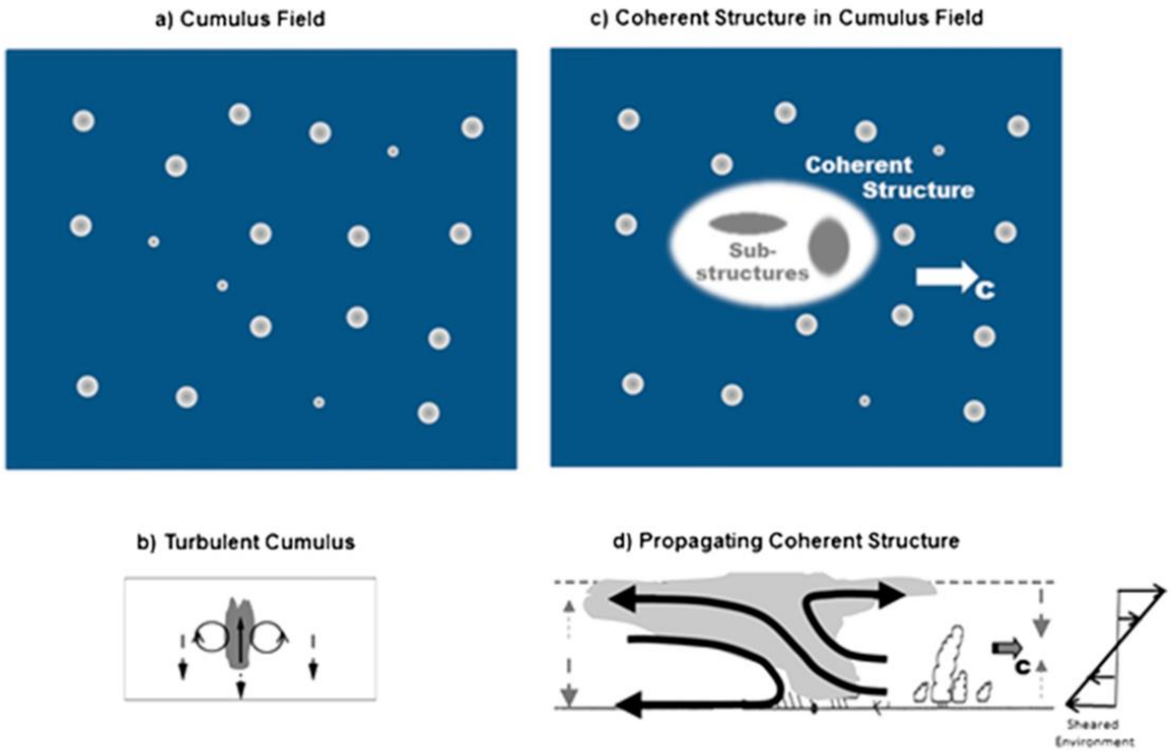


Precipitation tops beyond 10km are scarcely observed

JAXA提供

Large-scale effects with scattered convection vs MCS

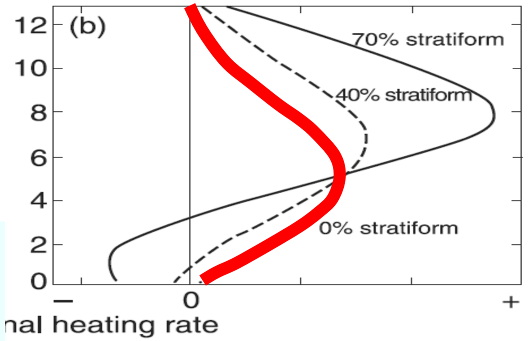
Unstable Atmosphere　　Deep Moist Atmosphere

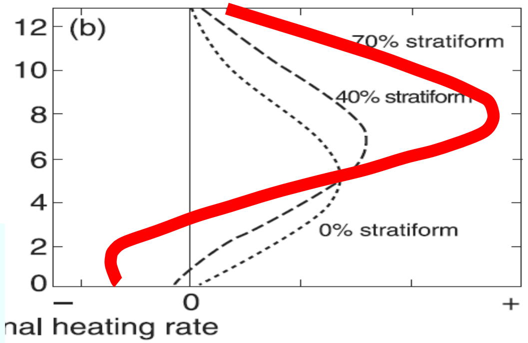


(adopted from Moncrieff and Waliser, 2015)

Cloud coverage, Cloud microphysics
→ Radiative Heating

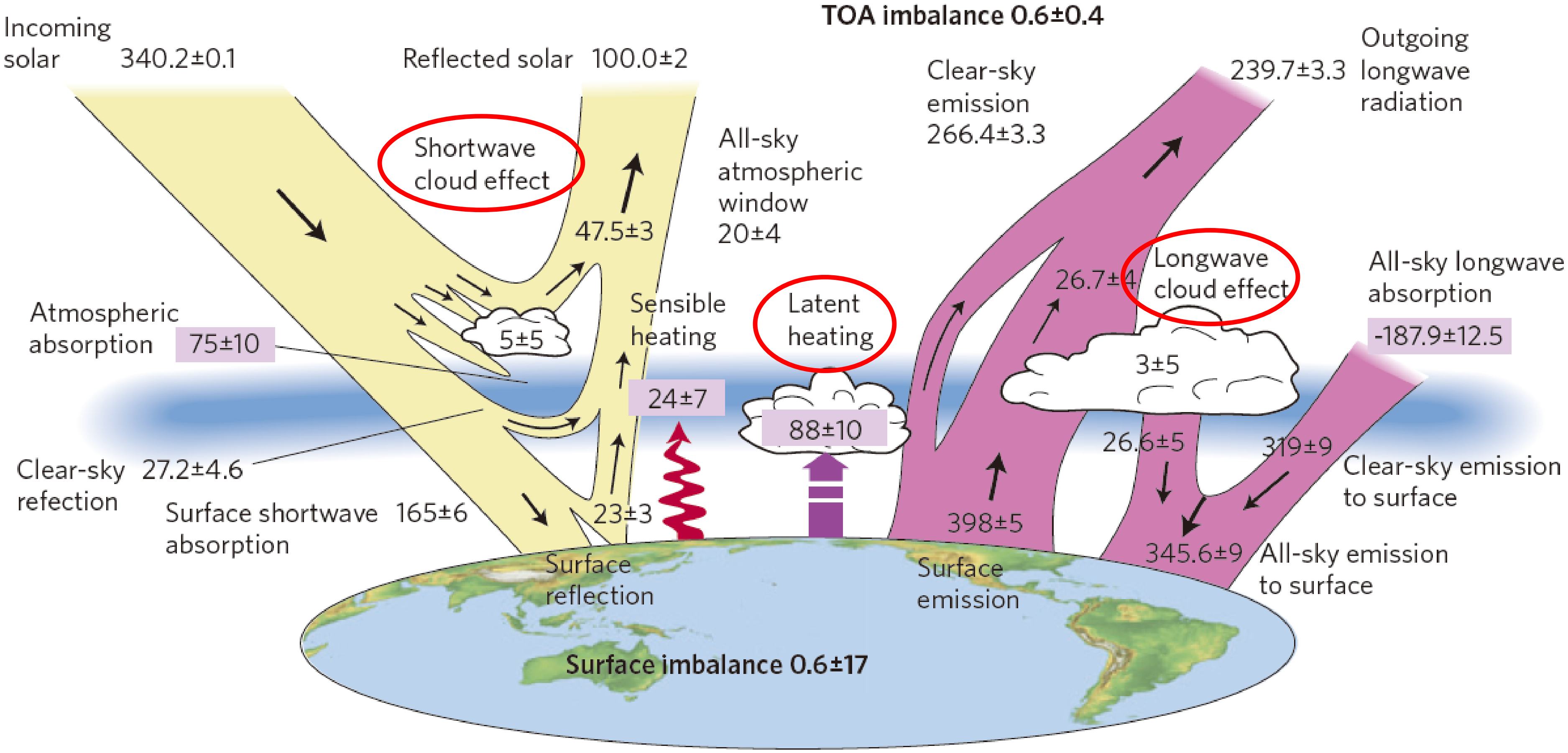
Convective overturning
→ Temperature, Moisture, and Momentum Adjustment





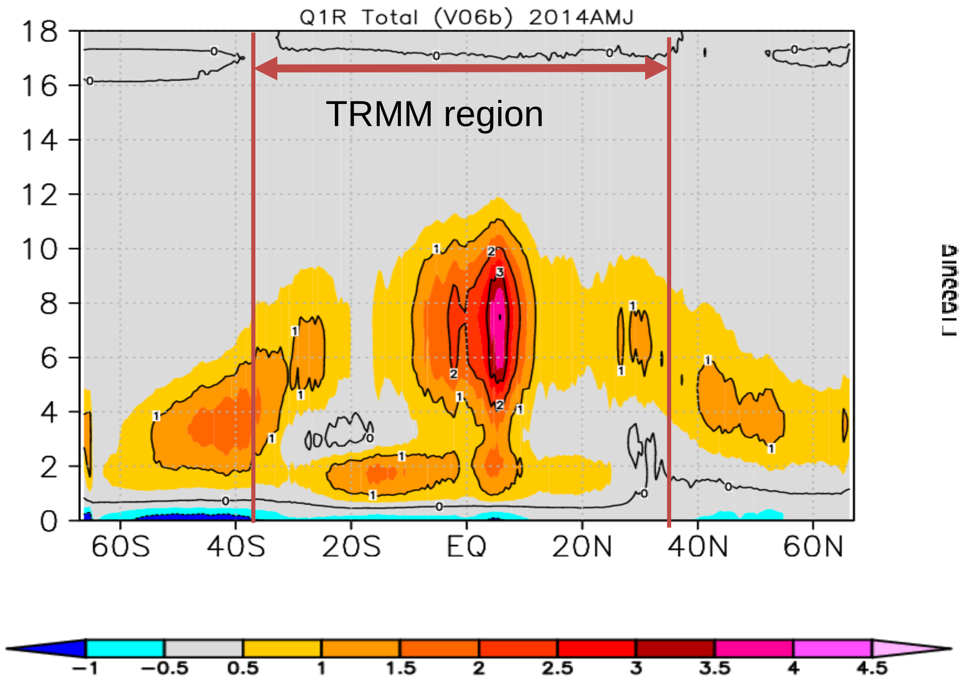
Cloud type organization
→ Latent Heating

Global Energy Budget (Stephens et al. 2012)



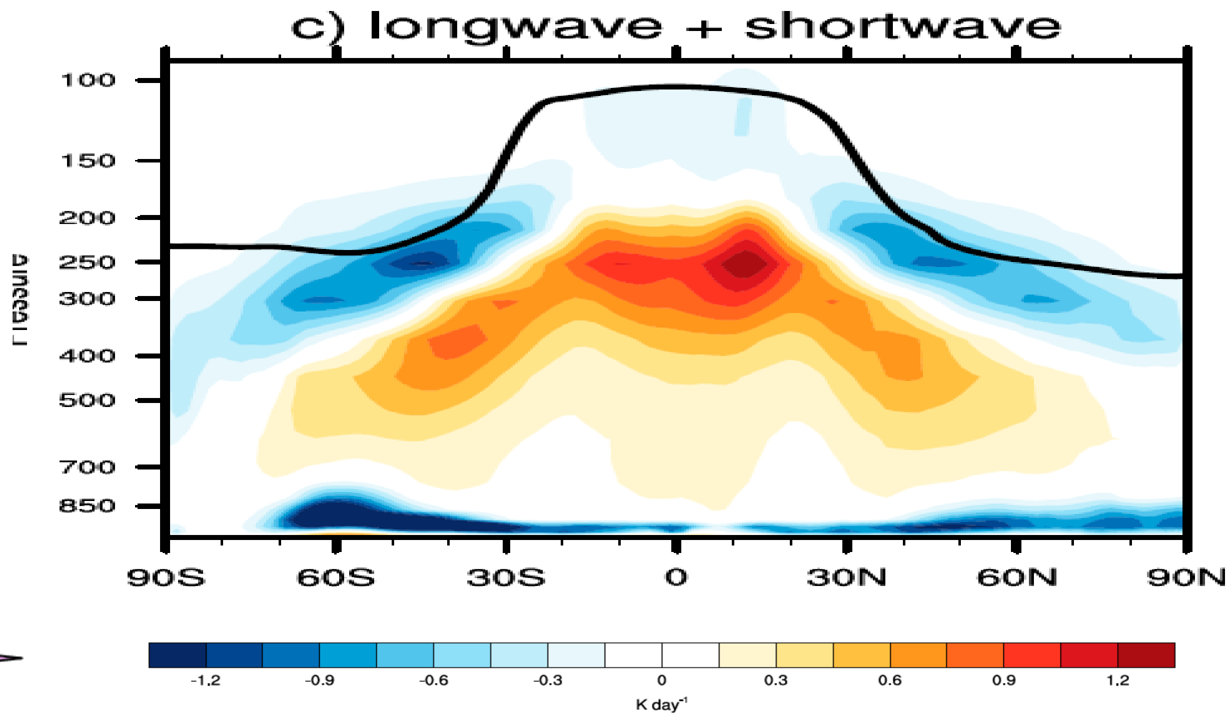
Convective Heating and Radiative Heating

GPM SLH V06 Q1-QR

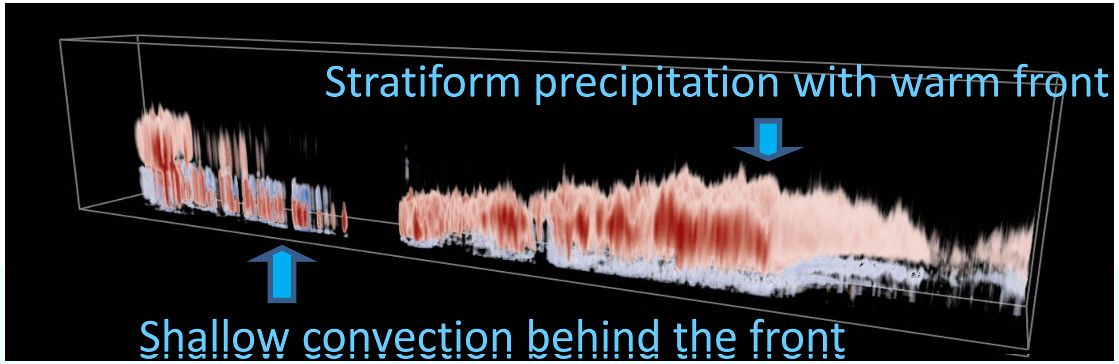


(Takayabu et al. 2019, AOGS)

Cloud Radiative Effect



(Li et al. 2015) Model Simulation



From Precipitation Science to Cloud-Precipitation Science
→Extend quantification of Latent Heating to total diabatic heating (LH+Radiative H) with breakdowns into individual cloud-precip systems

EarthCARE and ACCP

Summary

- We made a big advance in precipitation science with 3D precipitation observations from space.
- As an example, we have emphasized the differences in scattered precipitation and MCS, linked to unstable atmosphere and deep moist atmosphere, respectively.
- The differences in these two regimes extend to various large-scale effects.
- In order to represent effects of cloud-precipitation systems in climate variability, process studies with breakdowns to individual cloud systems will be essential.
- EarthCARE and ACCP observations are awaited.