Towards physical validations of numerical models with satellite data

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Outline

1. Double ITCZ bias in CMIP5 models and entrainments in cumulus parameterization
   -- physical validation for climate models

2. Observation of extreme rainfalls
   -- a challenge for CRM

1. Double ITCZ bias in CMIP5 models and entrainments in cumulus parameterization

physical validation for climate models

TRMM-derived Shallow and Deep heating

- Takayabu et al. (2010; *J. Climate*)

Data

1. 3D Q1-QR data from the TRMM PR based Spectral Latent Heating (SLH) database Dec. 1997-Nov.2007

   Shige et al. (2004, 2007, 2008, 2009)

2. RH and dp/dt : Japanese Reanalysis (JRA25 and JCDAS), SST : NOAA OISST

Apparent Heat Source (Yanai et al. 1973)

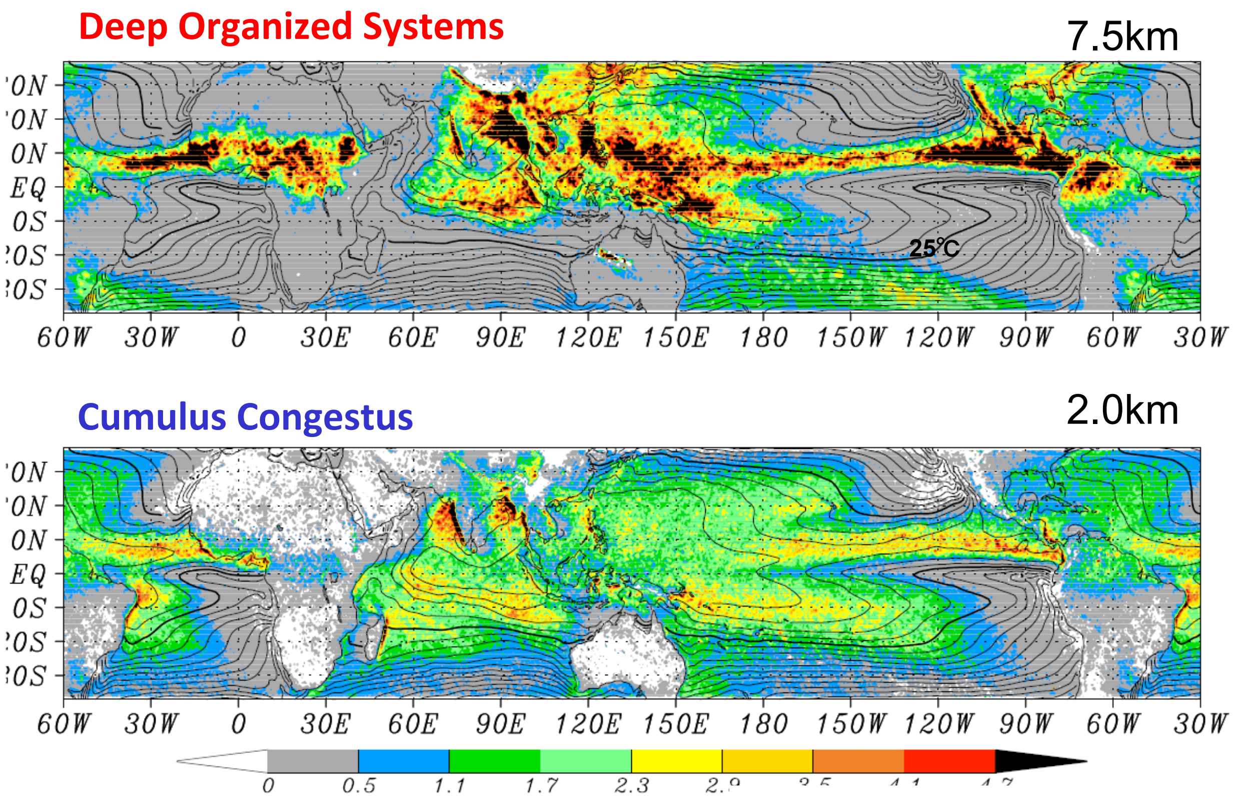
$$Q1 \equiv \frac{D\bar{s}}{Dt} = \frac{\partial \bar{s}}{\partial t} + \bar{v} \bullet \nabla \bar{s} + \bar{\omega} \frac{\partial \bar{s}}{\partial p}$$

$$= QR + L(\bar{c} - \bar{e}) - \nabla \cdot \overline{s'v'} - \partial / \partial p \, \overline{s'\omega'}$$

where $s = CpT + gz$ dry static energy

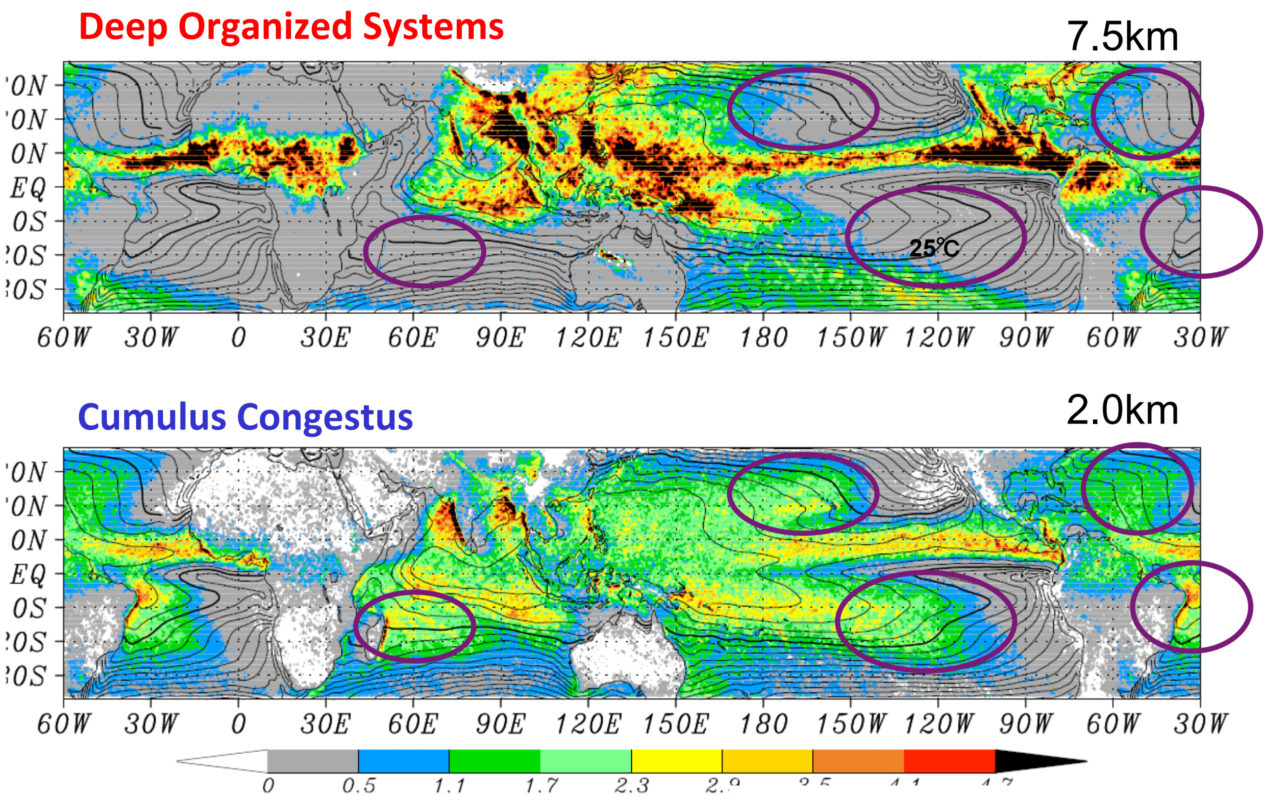
$\bar{\ }$: grid mean, $'$: deviation from the grid mean

TRMM PR Q1-QR & NOAA SST JJA 98-07



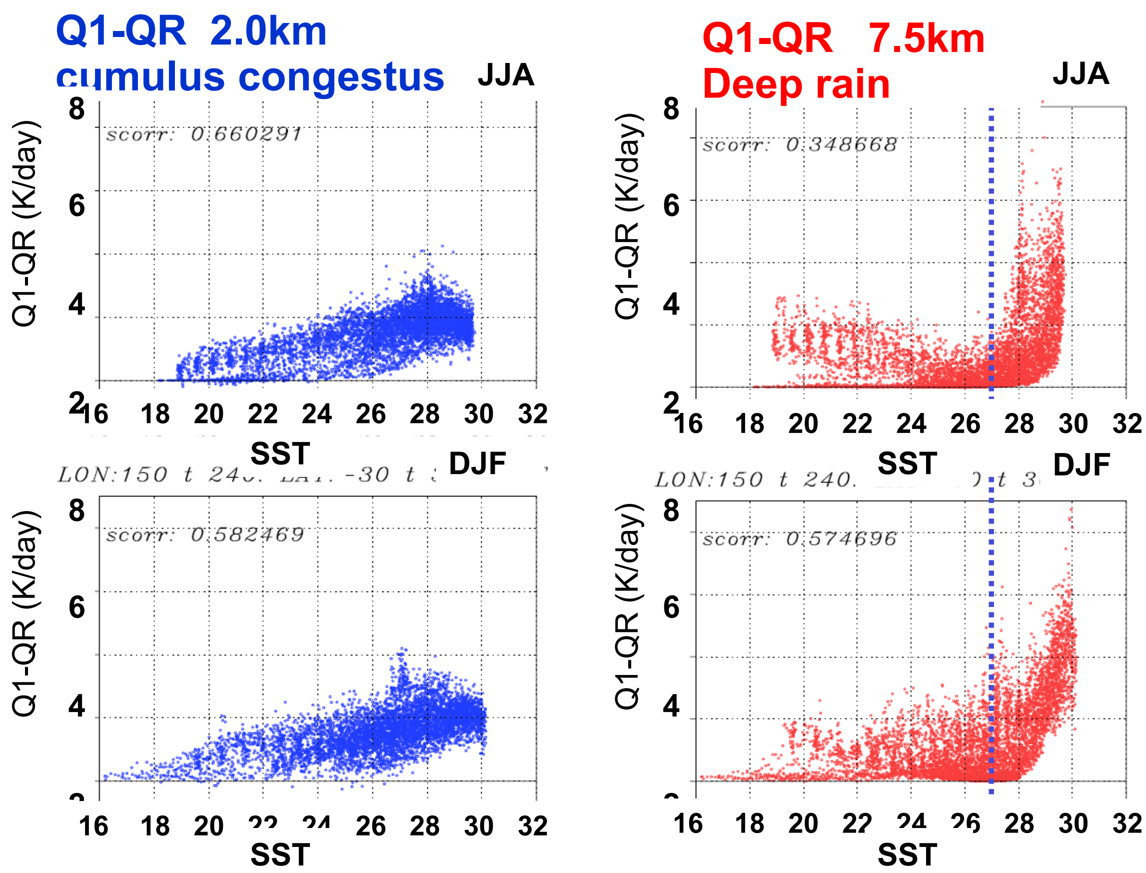
(Takayabu et al. 2010, J. Climate)

TRMM PR Q1-QR & NOAA SST JJA 98-07



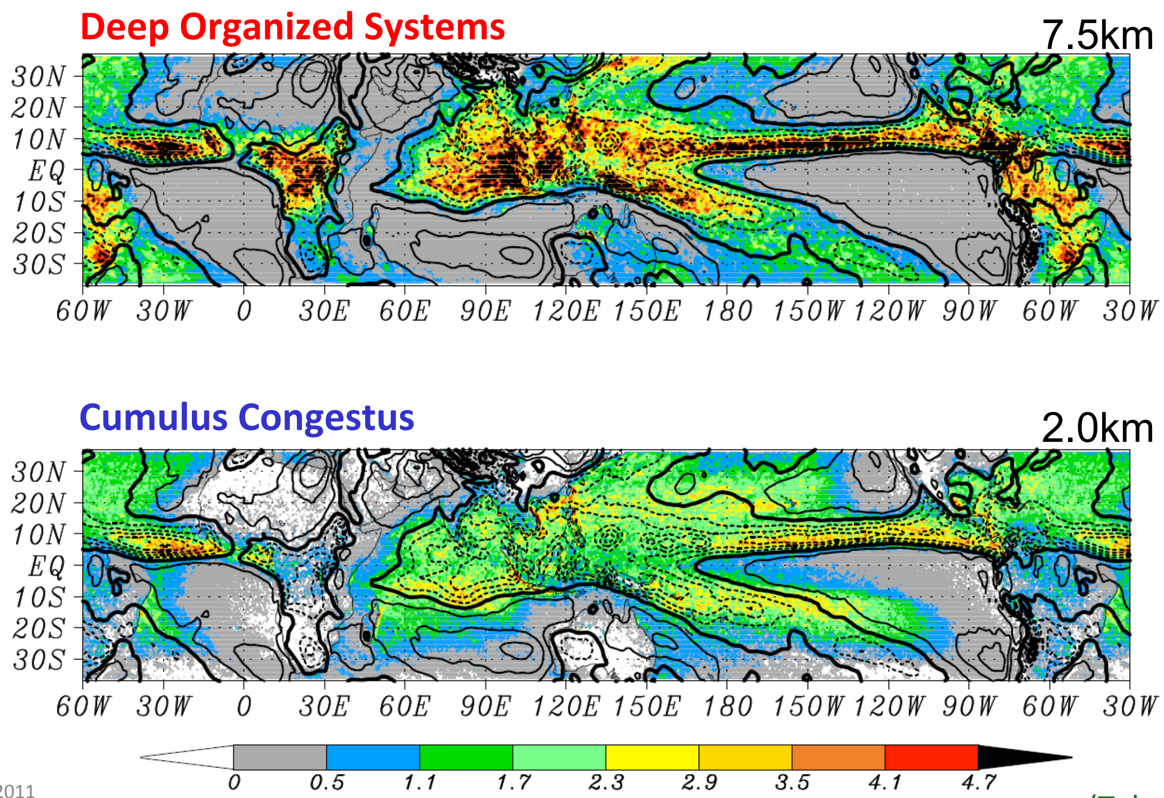
(Takayabu et al. 2010, J. Climate)

TRMM Q1-QR vs. SST 97-05 30N-30S Pacific



(Takayabu et al. 2010)

TRMM PR Q1-QR & JRA-ω500 JJA 98-07

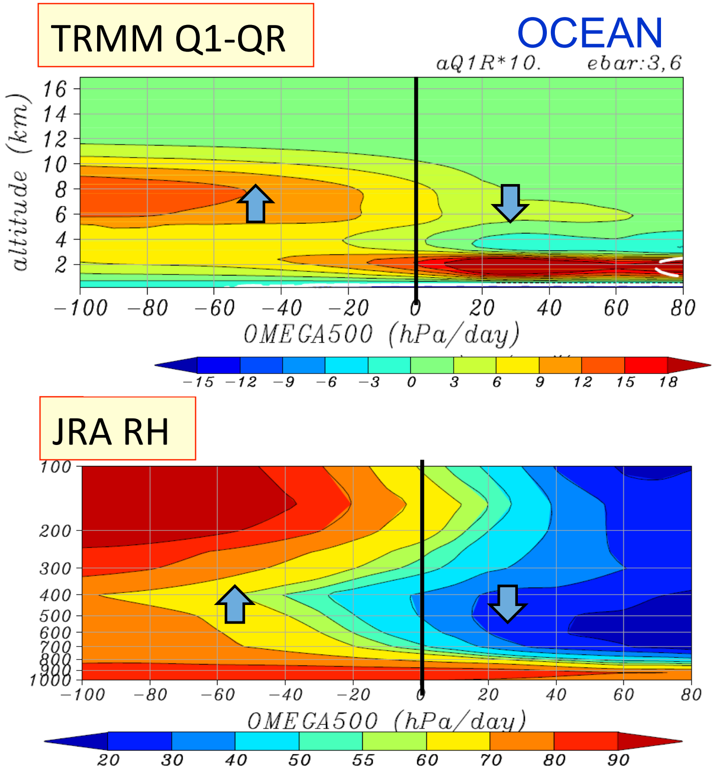


AOGS 08/08/2011

(Takayabu et al. 2010)

Cond-Mean Q1-QR & RH stratified with **dp/dt** 500hPa. 30N-30S

(Takayabu et al. 2010)



We can clearly see a distinct bimodality of Q1-QR with deep and congestus heating.

Deep heating is effectively suppressed with the large-scale subsidence.

Subsidence regions have very dry layer in the middle troposphere (~600 hPa)
→ Entrainment of dry air reduces buoyancy of convection
→ suppression of deep convection

Implications: Large-scale control of rainfall type

- Precipitation distributions over tropical oceans are strongly influenced not only by SST but also by mid-tropospheric humidity.

- Distinct congestus regime is found where SST is moderately high, but mid-level is dry associated with a large-scale subsidence.

Double ITCZ bias in CMIP5 models and MIROC5 simulations

- Hirota et al. (2011; *J. Climate*)
- Hirota and Takayabu (2012, J. Meteor. Soc. Japan)
- Hirota and Takayabu (2013; *Climate Dynamics*)
- Hirota et al. (2014, *J. Climate*)

Data:

CMIP5 (historical runs)
  17 models w/o flux adjustments

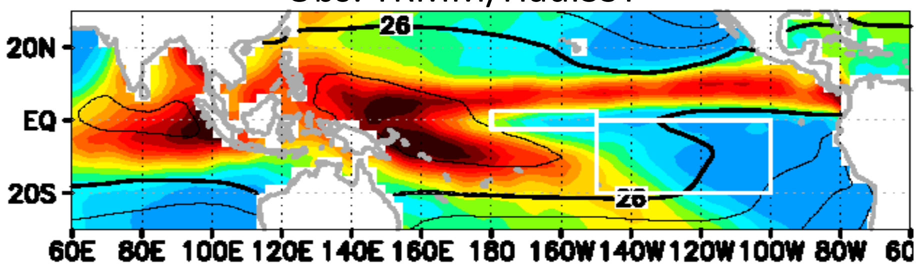
$TRMM_{PR2A25}$/HadISST/JRA

CMIP5
CNRM-CM5
CSIRO-Mk3-6-0
CanESM2
FGOALS-g2
FGOALS-s2
GFDL-ESM2G
GFDL-ESM2M
HadGEM2-CC
MIROC-ESM-CHEM
MIROC-ESM
MIROC4h
MIROC5
MPI-ESM-LR
MRI-CGCM3
NorESM1-M
bcc-csm1-1
inmcm4

Double ITCZ bias

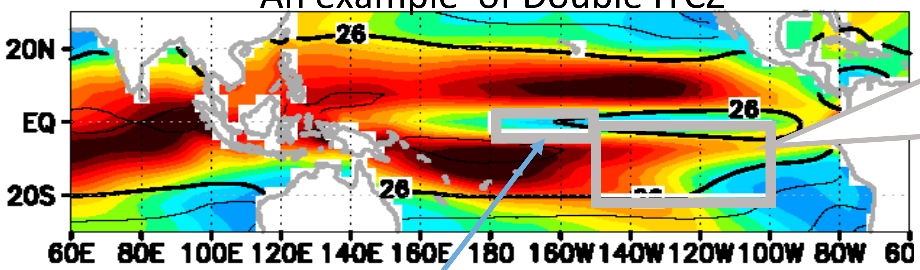
Precip(color) & SST(contour)

Obs: TRMM/HadISST



Many climate models overestimate precipitation over the southeastern Pacific along the equator

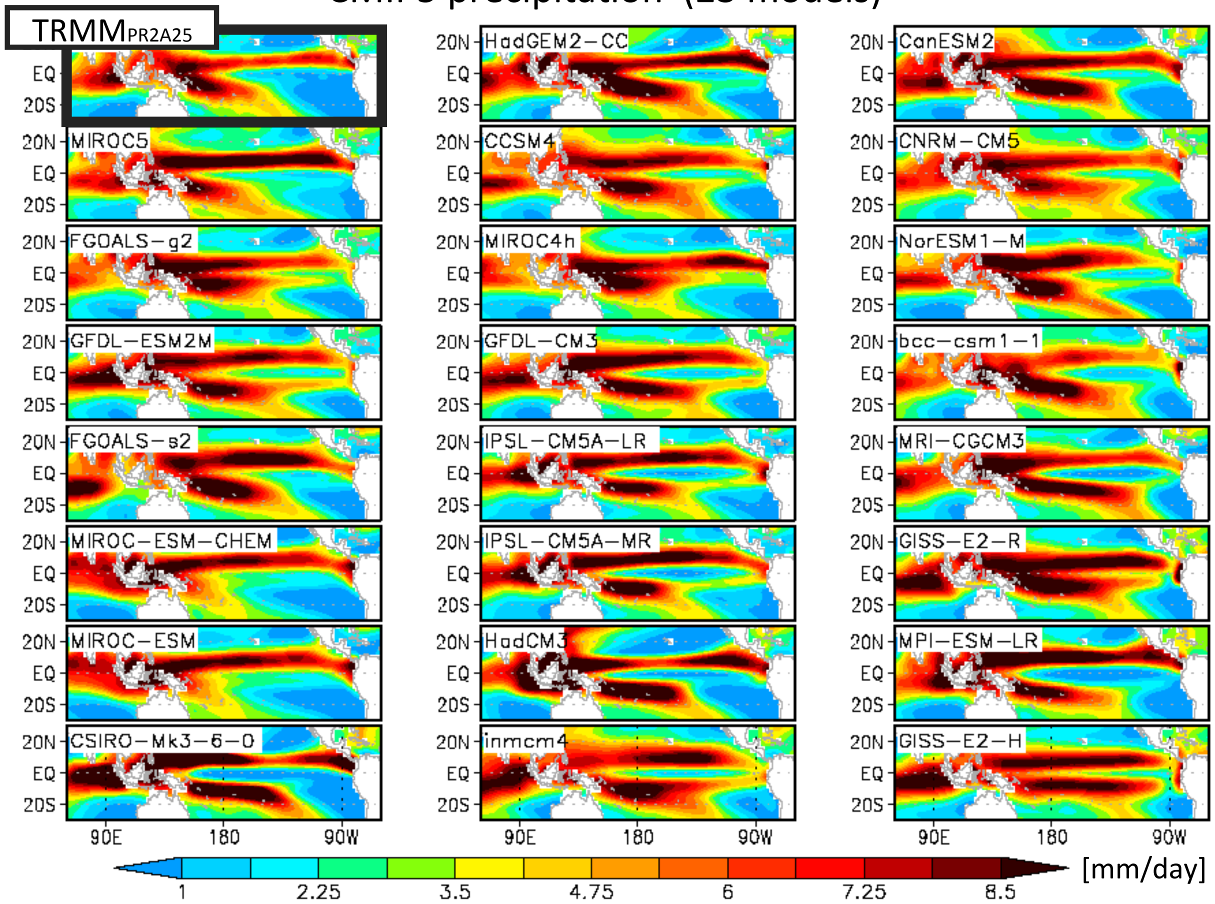
An example of Double ITCZ



Double ITCZ Index (Bellucci, 2010): Precipitation averaged over southeastern Pacific (150-100W,20S-Eq)

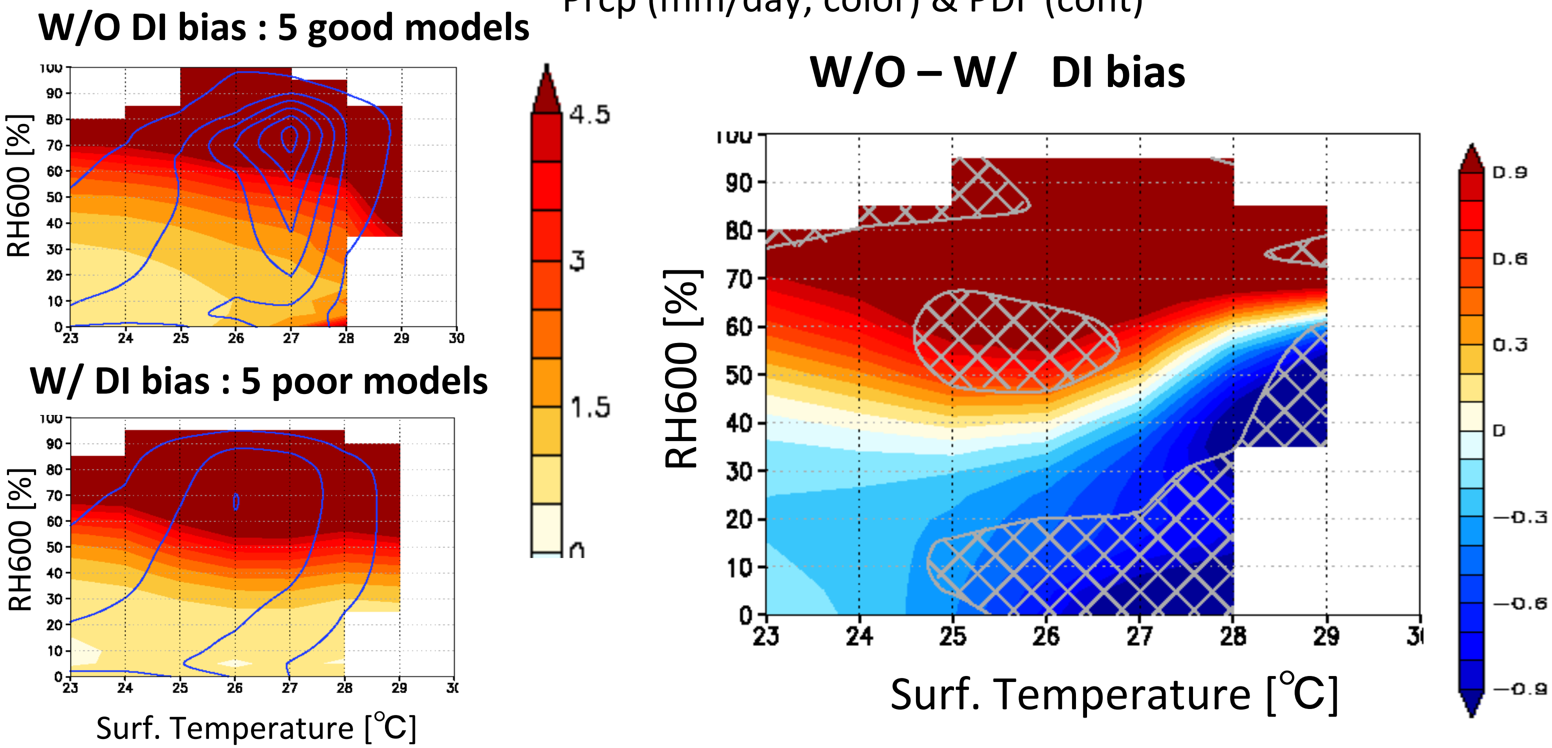
(cold tongue bias)

CMIP5 precipitation (23 models)



Cond-mean Precipitation against RH600 & Surf Temp.

Prcp (mm/day; color) & PDF (cont)



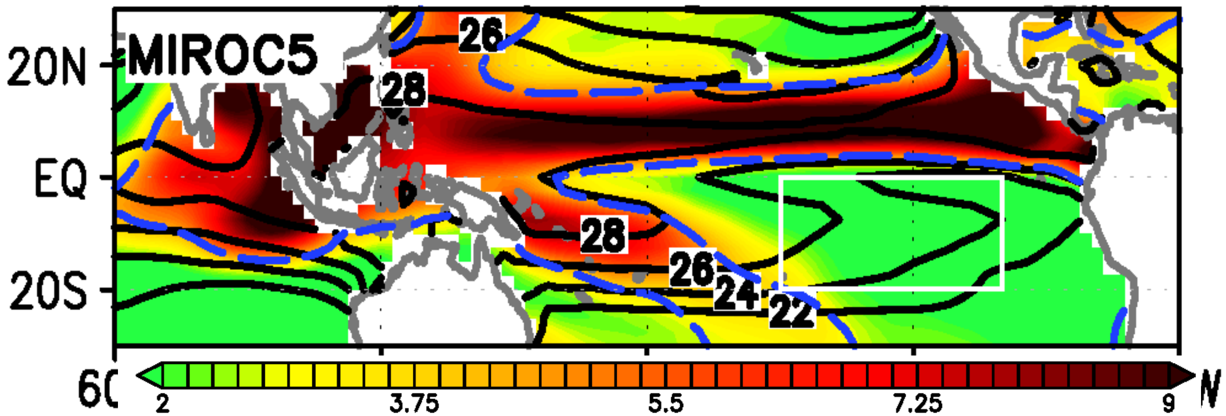
Double ITCZ bias is more sensitive to RH600 than to Tsurface

Summary 1:

- The Double ITCZ bias in CMIP5 models is closely related to sensitivity of precipitation to mid-tropospheric humidity

Investigate roles of entrainments in cumulus schemes with MIROC5 simulations

Precipitation, SST, and dp/dt500 of MIROC5



MIROC5 (AORI UTokyo/NIES/JAMSTEC) is equipped with Chikira-Sugiyama's new convective scheme with a state-dependent entrainment (Chikira and Sugiyama, 2010). This model shows a good performance. Deep convection is largely suppressed with subsidence over moderately warm SST regions.

$$\epsilon = C_\epsilon \frac{aB}{\hat{w}^2}.$$

(Hirota et al., 2011, J. Clim.)

In order to confirm if this entrainment scheme is really mitigating the DI problem, Nagio performed AGCM experiments.

Model : AGCM component of MIROC5 (T42L40)

(AORI/NIES/JAMSTEC; Watanabe et al. 2010)

Experiments:

- Standard (**Ctl**) Chikira and Sugiyama (2010)
- No Entrainment (**NoEnt**)
- Original Arakawa & Schubert (**AS**)
- RH-threshold (**ASRH**) Emori et al. (2001)

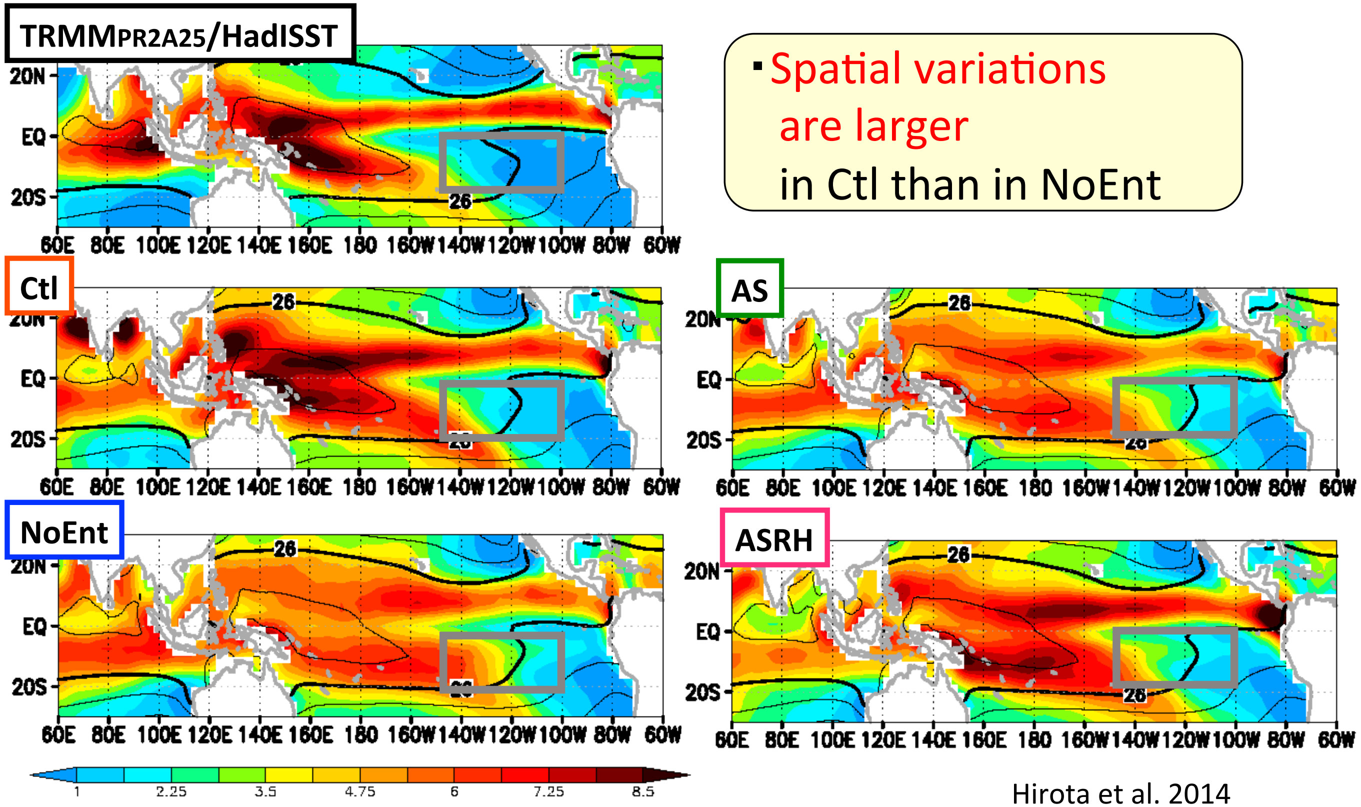
  Inhibit convection when cloud layer RH < 80%

$$\epsilon(z) = C_\epsilon \frac{aB(z)}{\hat{w}_c(z)^2}$$

state dependent

Precipitation distribution

precipitation (color; mm/day) & SST (contour; ℃)

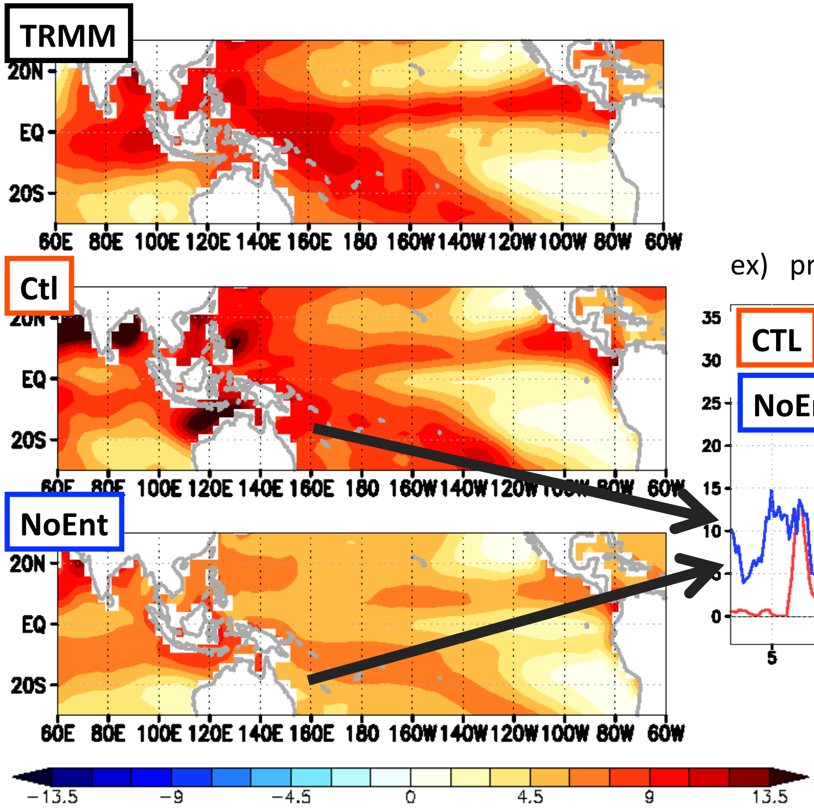


- Spatial variations are larger in Ctl than in NoEnt

Hirota et al. 2014

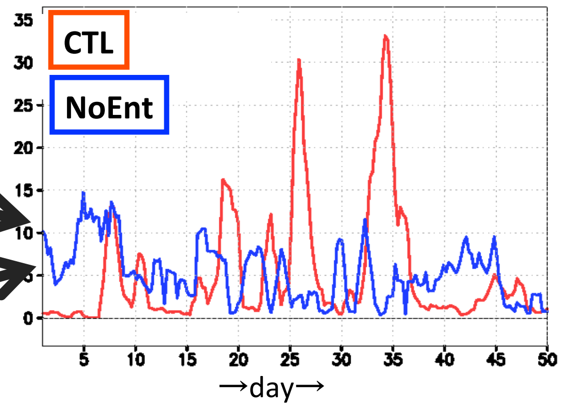
Temporal variations

Standard deviation of 6 hourly precip (color; mm/day)



We see more temporarily organized precipitation for control case, than very frequent and weaker precipitation in no-entrainment runs.

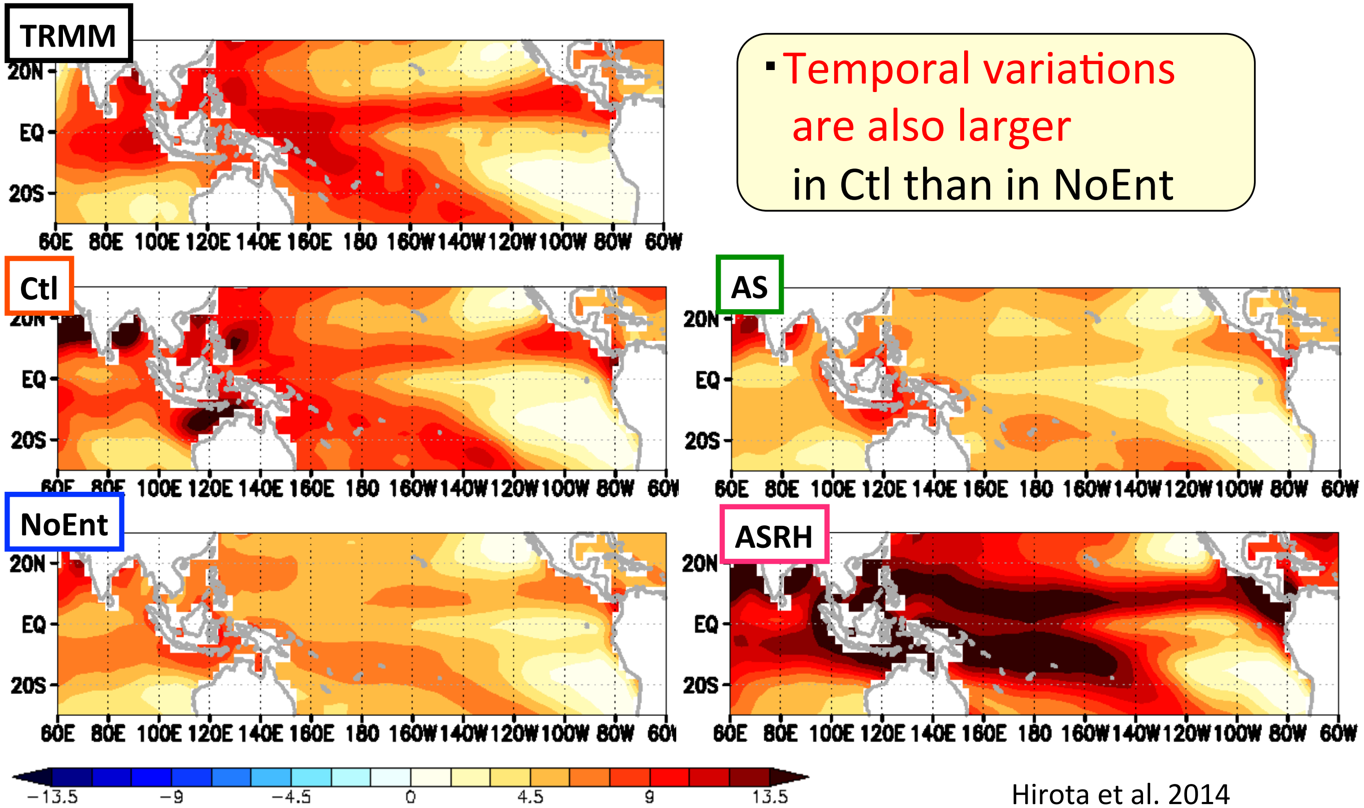
ex) prcp time series (mm/day (160E,18S)



Hirota et al. 2014

Temporal variations

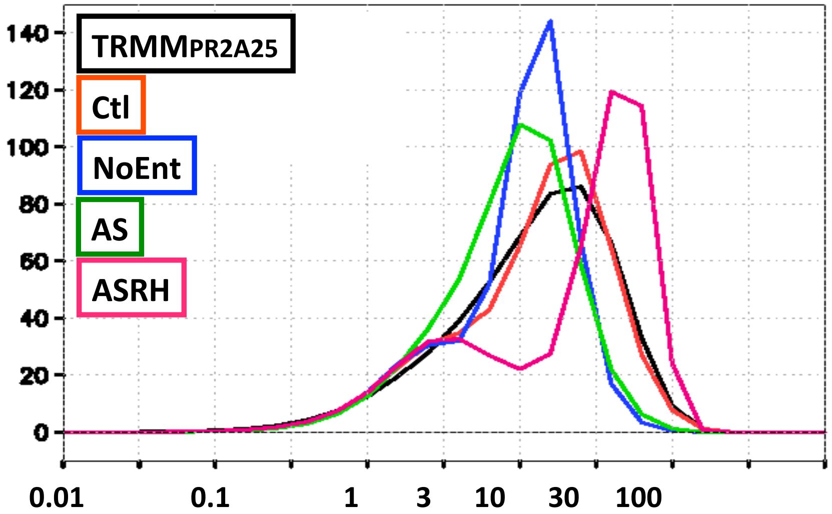
Standard deviation of precip (color; mm/day)



- Temporal variations are also larger in Ctl than in NoEnt

Hirota et al. 2014

Contribution to total precipitation (30S-30N)



precipitation intensity [mm/day]
(using 6hourly snapshot data on 2.5×2.5 deg grids)

- **Ctl ~ TRMM**
- **NoEnt &AS** underestimate strong precip.
- **ASRH** overestimates strong prcip

Hirota et al. 2014

Summary 2:

AGCM

- Chikira-Sugiyama's Entrainment enhances spatial & temporal variations.
  - Better spatial distribution & mitigated double ITCZ
  - Better temporal variations and intensity PDFs.

AOGCM (not shown)

- The double ITCZ bias is amplified in a coupled model with NoEnt convection.
- Oceanic feedbacks may be also playing a role to suppress DI in the real world.

2. Observation of extreme rainfalls

a challenge for CRM

Characteristics of precipitation extremes analyzed with 17 years of TRMM observation

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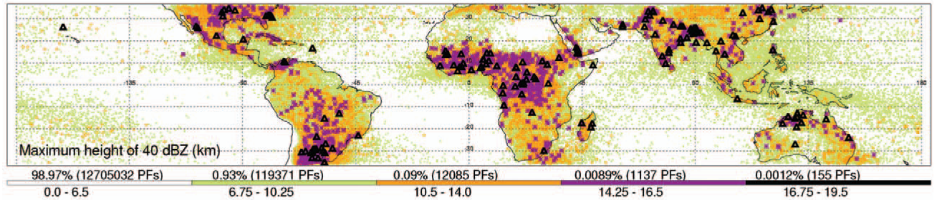
AORI, Univ. Tokyo

With Ed Zipser, *Univ Uta,* C. Liu, *Texas A&M*

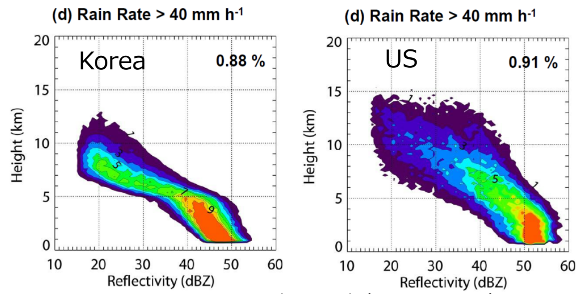
- Hamada, A., Y. Murayama, and Y. N. Takayabu, 2014: J. Climate
- Hamada, A., Y. N. Takayabu, C. Liu, and E. J. Zipser, 2015: Nature Comm

Preceding studies on extreme rainfall

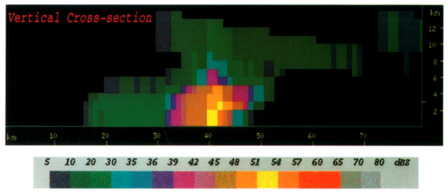


Zipser et al. (2006)

- Zipser et al. (2006): The world's most intense convection from TRMM PR/TMI
- Sohn et al. (2013): Heavy rainfall over Korea is associated with relatively shorter clouds
- Smith et al. (1996): Flash flooding storms with less severe convection and little lightning in US
- McCollum et al. (2000): Rainfall intensity in Eq. Africa is not large for its tall rain top height
- Shige et al. (2013): Heavy orographic rainfall exhibits lower RTH



Sohn et al. (2013, MWR)



Flush flood storms: Smith et al. (1996)

Objectives

- Describe the regional characteristics of extreme rainfall, globally.
- Compare the structures of extreme rainfall and extremely tall convection.
- Study the preferred environments for extreme rainfall and extreme convection

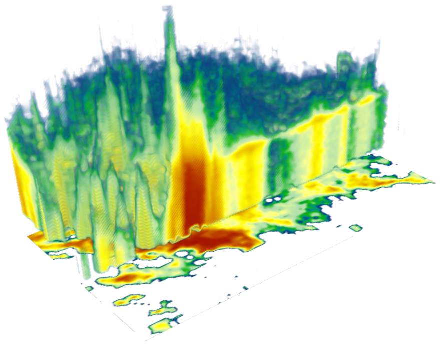
Data

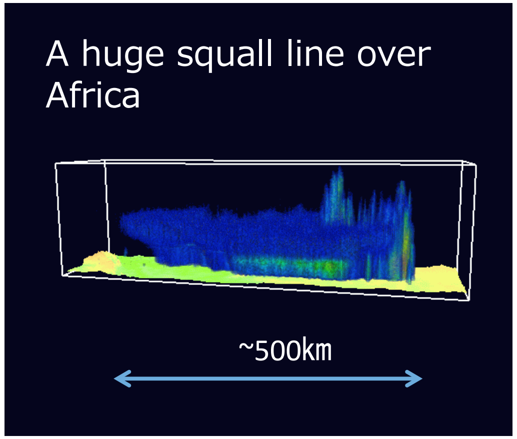
- TRMM PR 2A25 ver.7   Sep2001-Aug2012 (11yrs)
  - A removal filter for false-extreme was applied

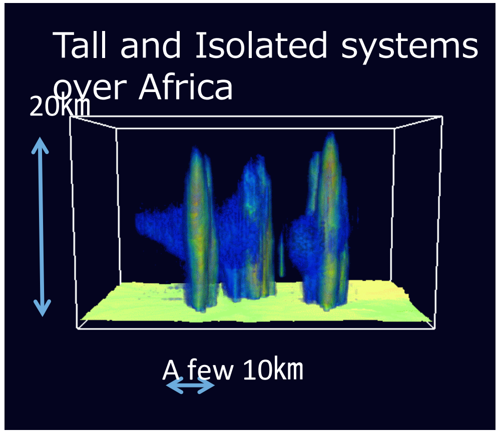
  (Hamada and Takayabu 2014, JAMC)
- ERA-interim 1.5°, 6-hourly

Definition of Regional Extreme Rainfall Events

1. Define “rainfall events” as contiguous rain-certain areas with TRMM PR 2A25.
2. Accumulate rainfall events for 2001-2012 in every 2.5degx2.5deg grid ~ 85 million events
3. Define Extreme (99.9%) Rainfall Events in terms of maximum near-surface precipitation



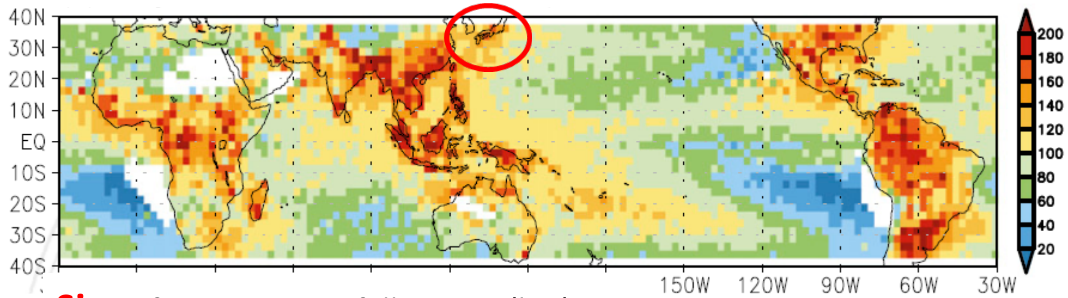




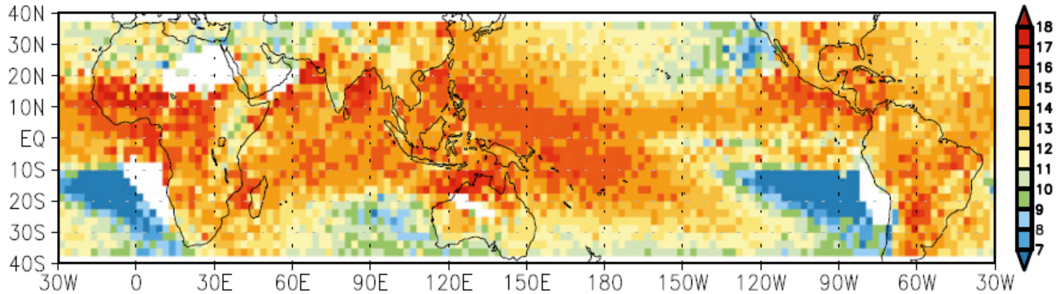
Characteristics of Regional Extreme Rainfall

Hamada, Murayama, Takayabu (2014, J. Clim)

Intensity of Extreme (99.9%) Rainfall events (mm/hr)



Size of Extreme Rainfall events (km)

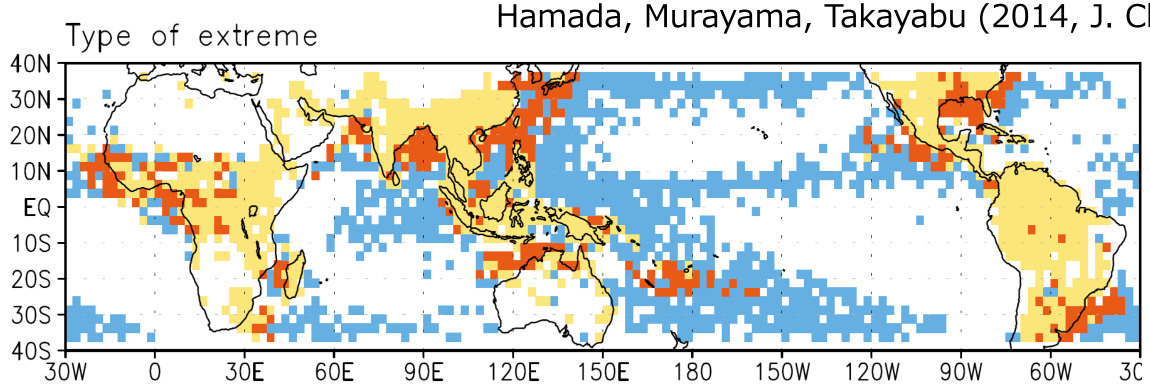


Characteristics of extreme rainfalls in each 2.5x2.5 deg grid are studied.
Intensity of "extreme rainfall" varies from region to region.

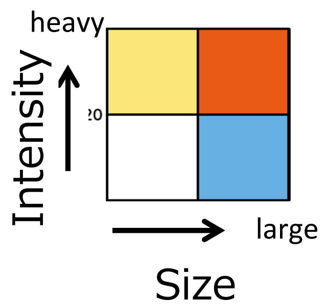
Three types in terms of extreme rainfall

2001-2012

Hamada, Murayama, Takayabu (2014, J. Clim)

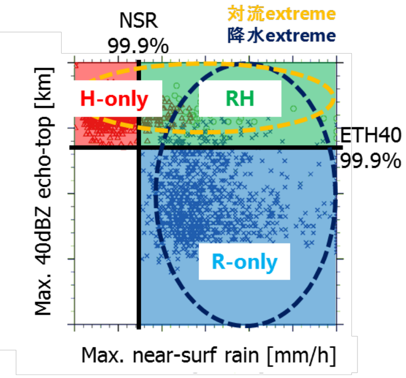


- Regions are categorized into three types in terms of extreme rainfall characteristics
- Regions around Japan and Korea are characterized with relatively heavy and large "extremes".



Definition of R-extreme & H-extreme

1. Define Rainfall events as contiguous rain-certain areas with TRMM 2A25.
2. Accumulate rainfall events for 2001-2012 in each 2.5degx2.5deg grid > 80 million events
3. Define Extreme Events in 3 types in each 2.5degx2.5deg grid
   - R-only extreme: Extreme (99.9%) events in terms of maximum near-surface precipitation
   - H-only extreme: Extreme events (99.9%) in terms of maximum 40dBZ echo top heights.
   - RH extreme: satisfies both R- and H- thresholds.



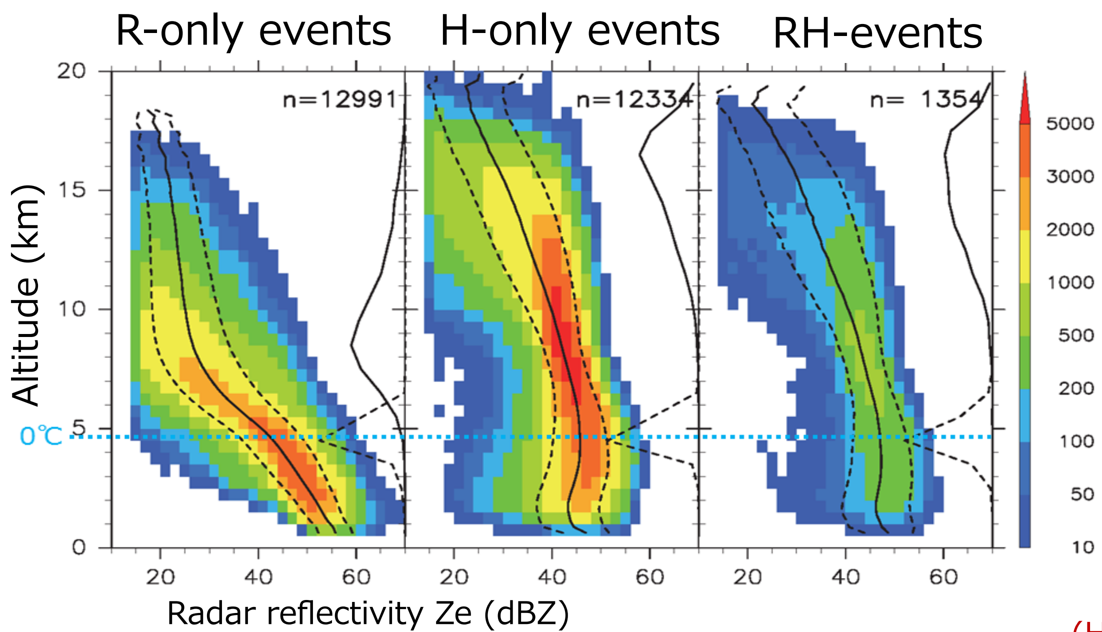
:more than 95% are convective

Hamada, A., Y. N. Takayabu, C. Liu, and E. J. Zipser, 2015: Weak linkage between the heaviest rainfall and tallest storms. Nat. Commun., Vol. 6 (6213), doi:10.1038/ncomms7213.

Ze-Height PDFs for Extr. Rainfall & Extr. Convection 2001.9-2012.8

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

85 million events

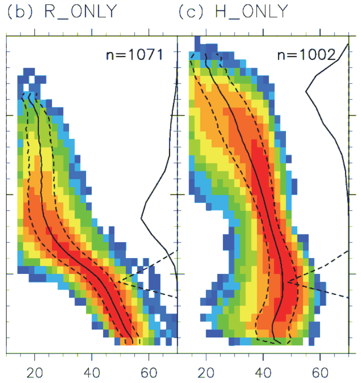


(Hamada et al. 2015)

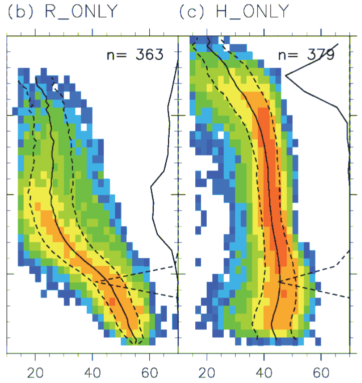
- Heaviest rainfall comes from systems different from tallest convection events.

Contrasting PDFs in different regions

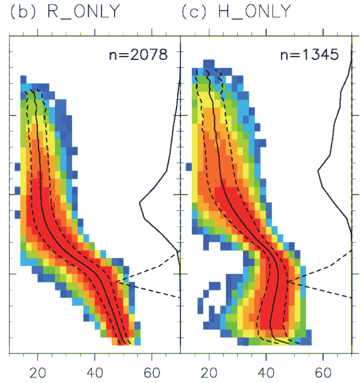
Amazon



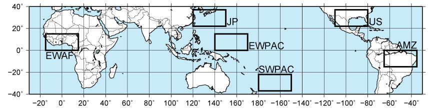
Eq. Africa



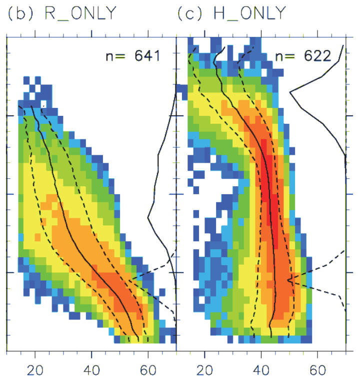
Eq. W. Pacific



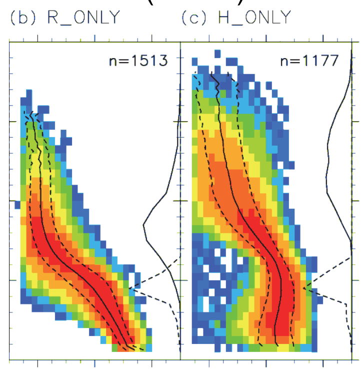
- Same irrespective of regions
- Extreme rain rate is mostly associated with moderate systems, even in the regions like USA where severe convective storms are dominant



USA

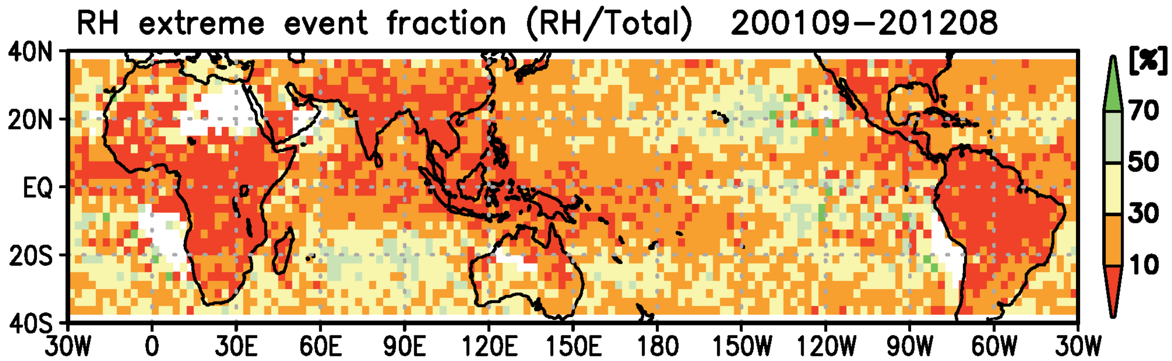


JP (Ocean)



Hamada et al. 2014 submitted

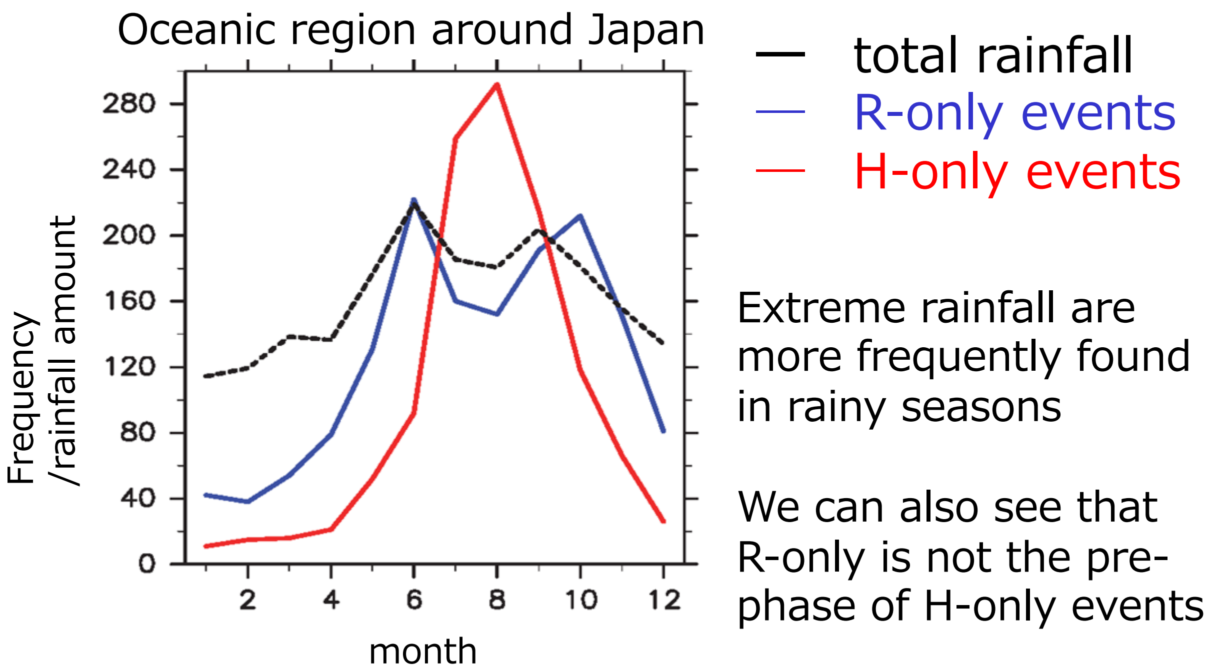
Fraction Map of RH-extreme events



- Only a small fraction of rainfall events satisfies both thresholds for extreme rainfall and extreme convection .
- Land: <30% everywhere, <10% deep tropics
- Ocean: Mostly < 30%, slightly higher in suppressed regions

(Hamada et al. 2015)

Seasonality of Extreme Events



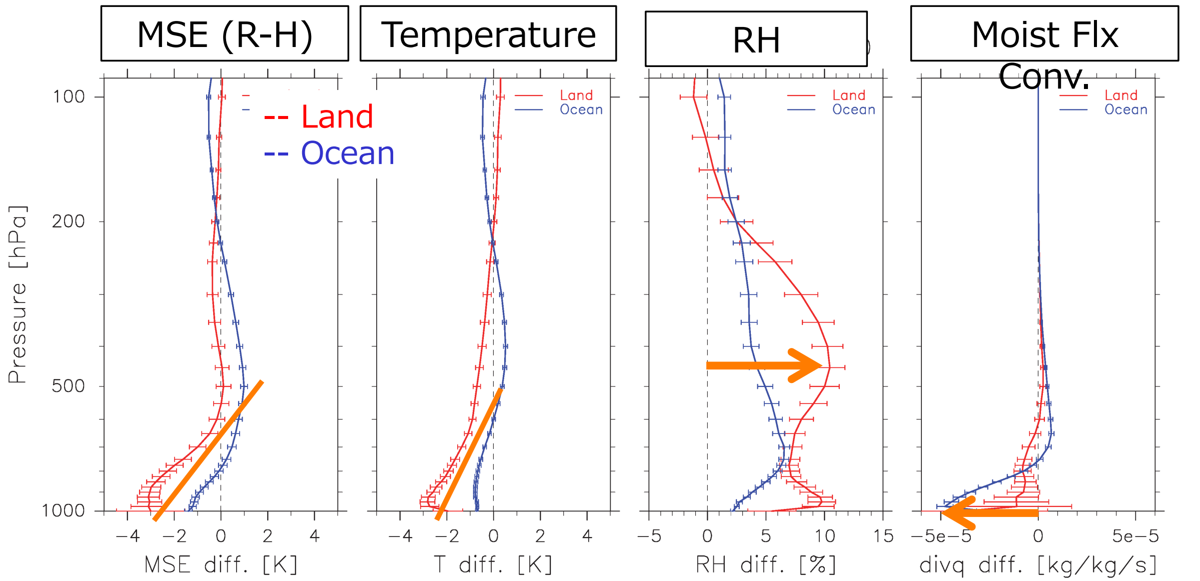
Extreme rainfall are more frequently found in rainy seasons

We can also see that R-only is not the pre-phase of H-only events.

(Hamada et al. 2015)

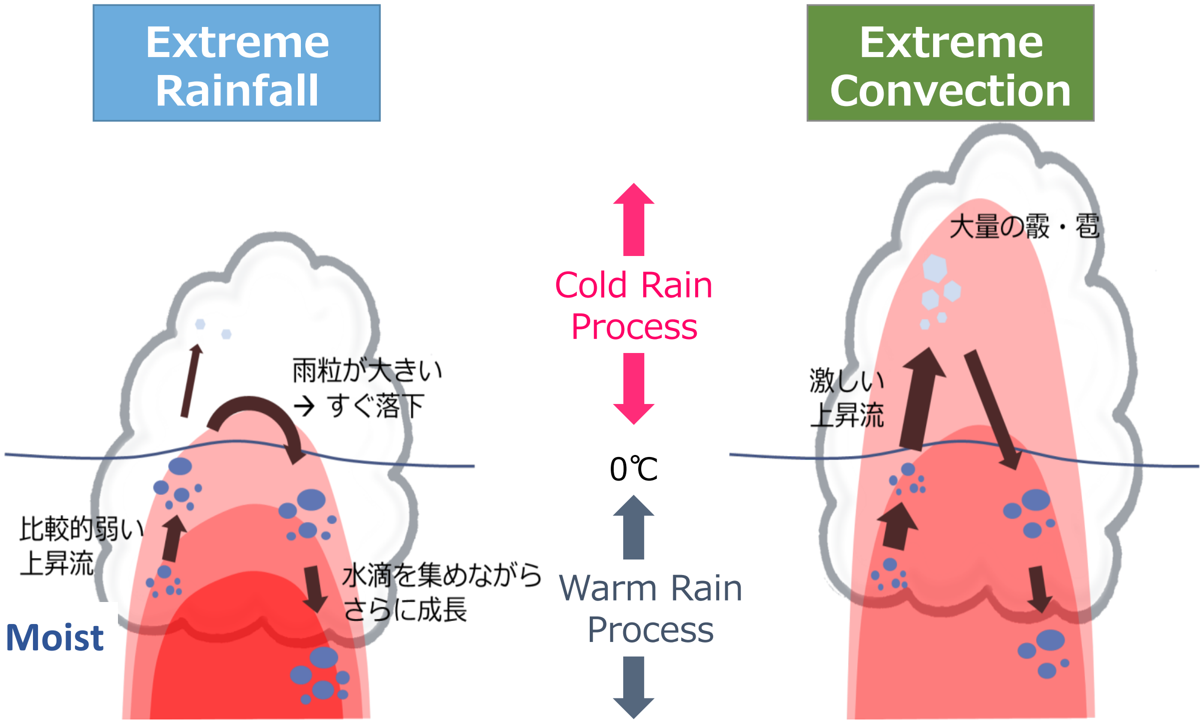
R-H Differences in the environments

(Hamada et al. 2015, Nature Comm)



More extreme rainfalls are found with moist mid-lower troposphere, while more extreme convections are associated with larger atmospheric instability

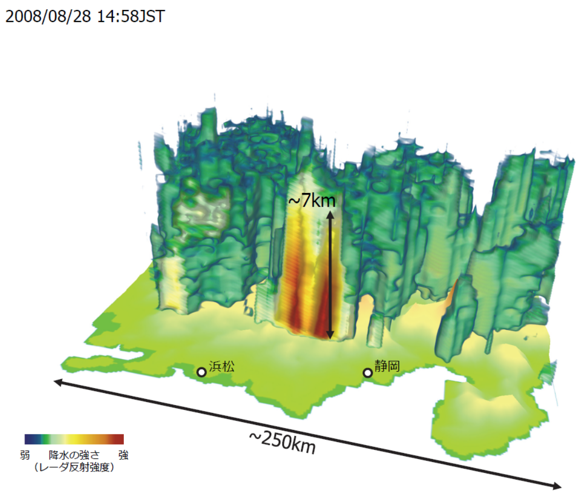
Characteristics in Precipitation Process



Significance of warm rain processes in moister environment is indicated for extreme rainfalls in TRMM observation regions. Extreme conv. is found in more unstable environments.

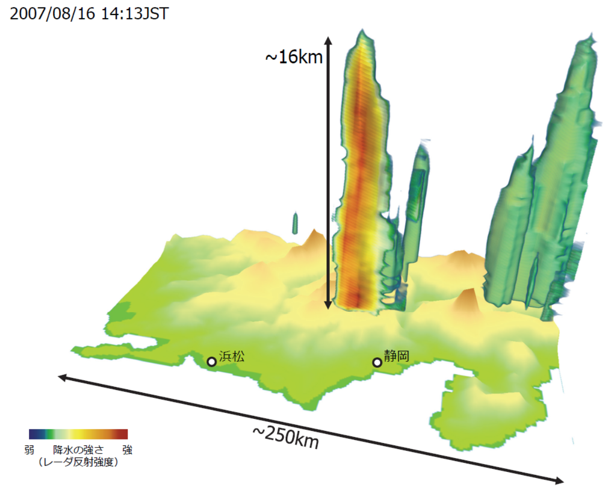
Examples of R-only and H-only over Japan

Extreme Rainfall



Torrential rainfall in the end of August 2008

Extreme Convection

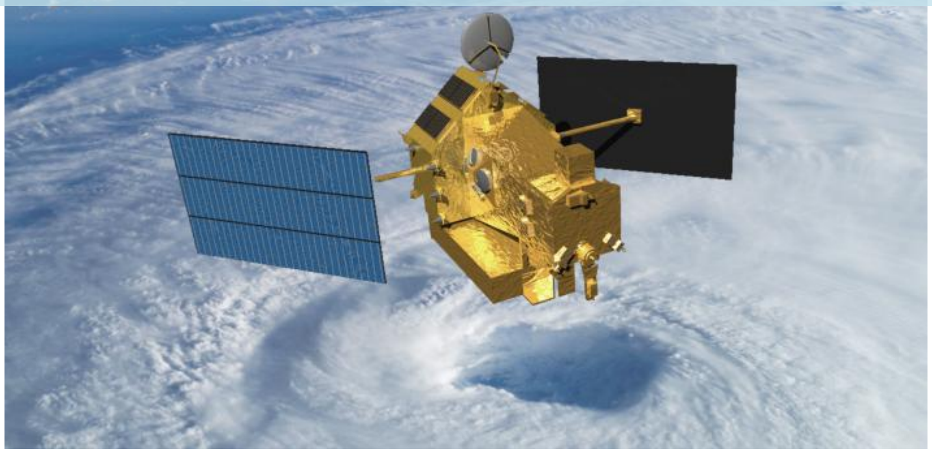


Hottest day in August 2007

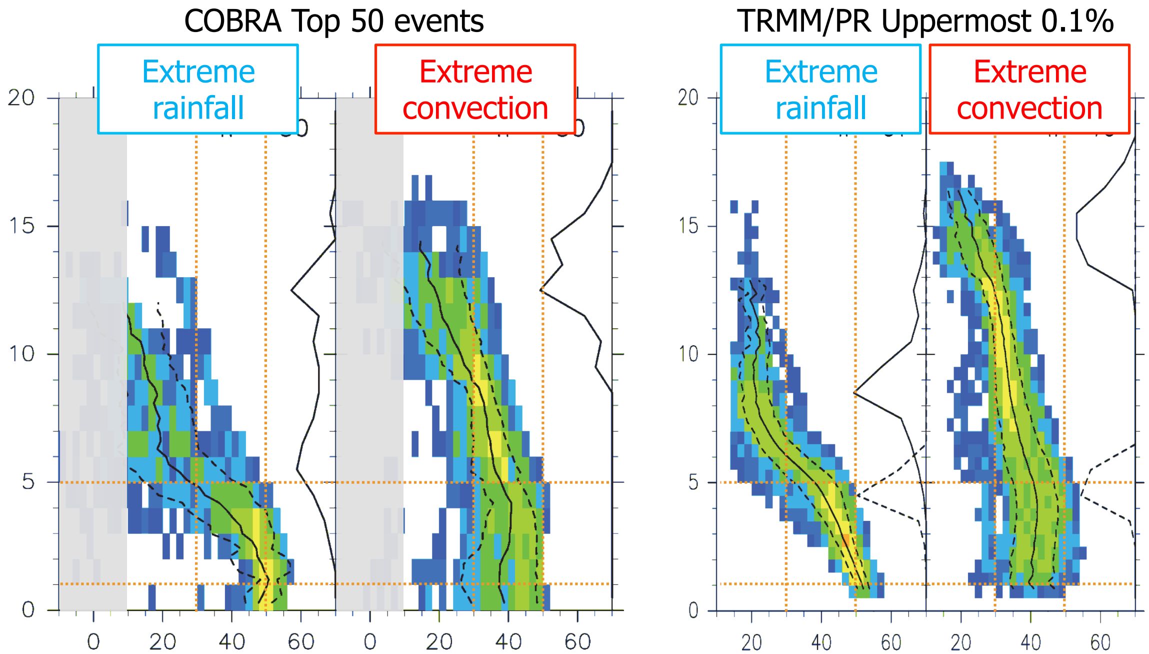
Summary 3

- Heaviest rainfalls (R-extremes) are scarcely associated with tallest convections (H-extremes). This is quite universal over all TRMM regions.
- Significance of warm rain processes is indicated with extreme rainfall, under a very moist condition in the mid-to-lower troposphere with relatively moderate instability.
- These points may be a challenge for state-of-the-art CRMs.

Thank you



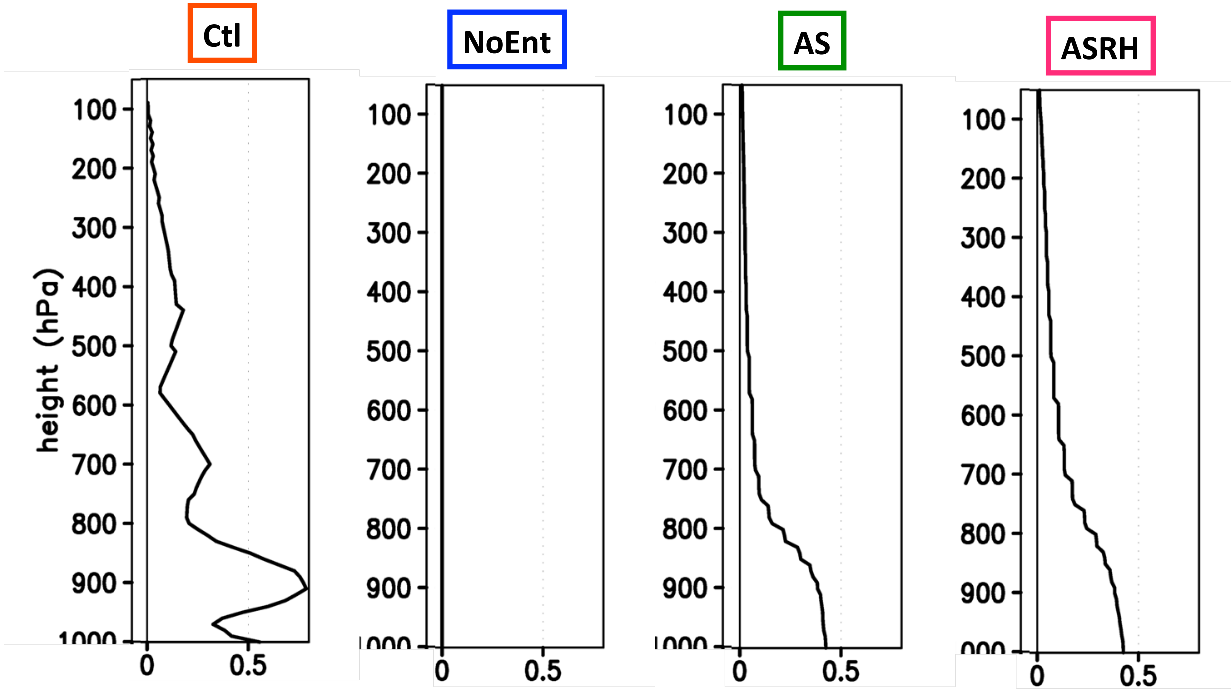
Comparison with a Ground-based Radar COBRA in Okinawa



- Extreme rainfall: Both exhibit "low-echo centroid" structure
- Extreme convection: Ze well corresponds in the mid-low troposphere; PR > COBRA in the upper troposphere
- RH-extreme events: COBRA 8%, TRMM 18%

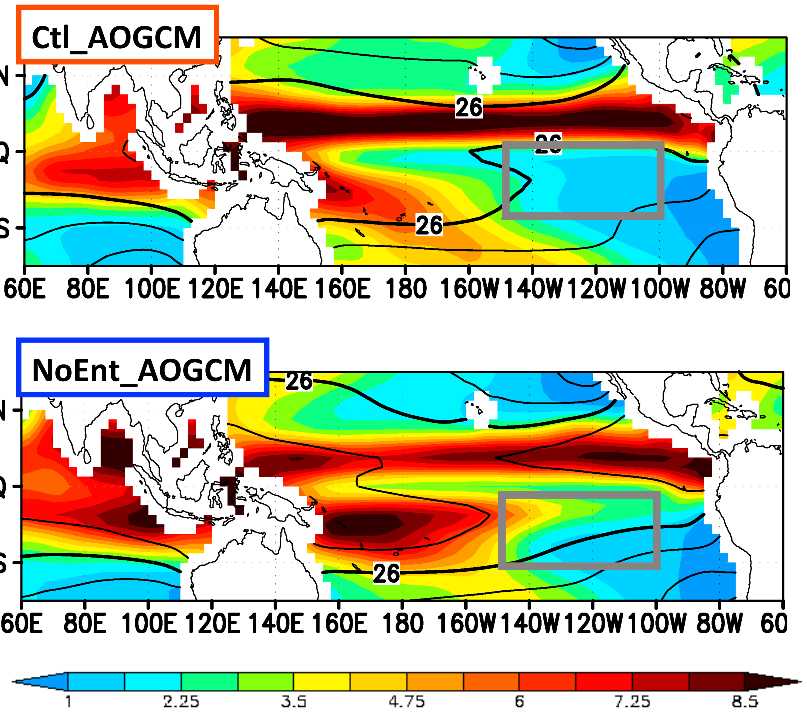
→ Attenuation issue has qualitatively small effect; Not affected by surface clutter

Vertical profiles of entrainment rate (km^{-1}; 30S-30N)



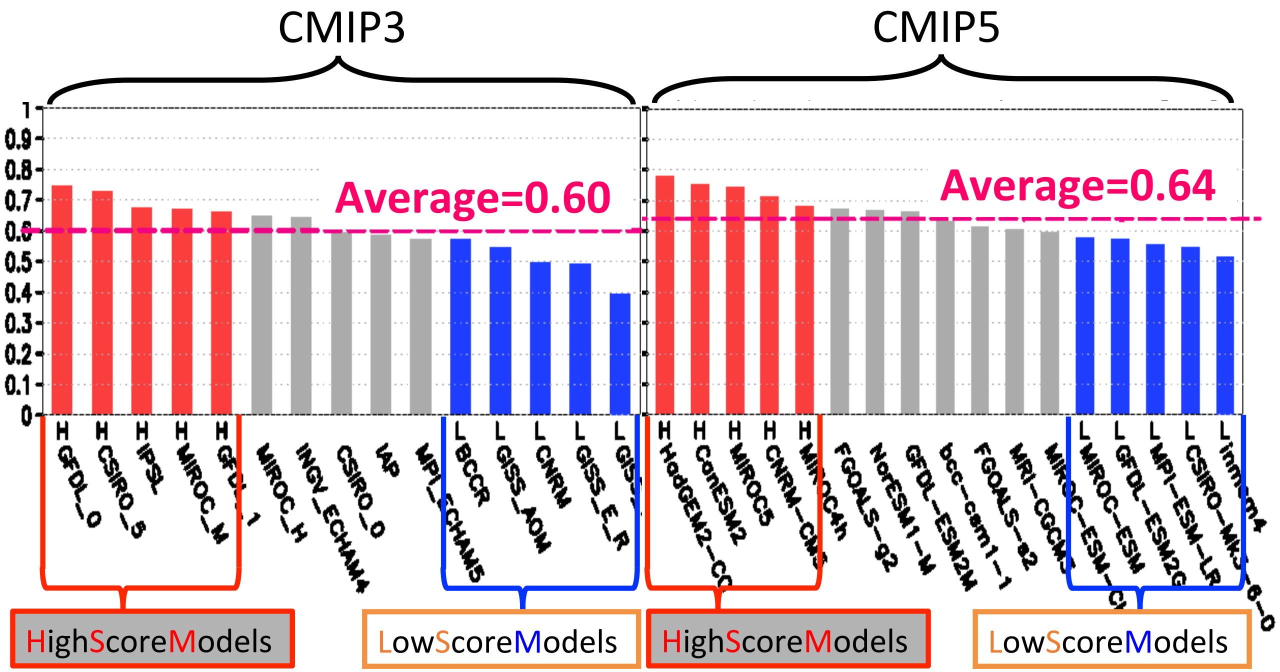
The entrainment rate of the **Ctl** in the lower troposphere is significantly larger than those of the **AS** and **ASRH**.
(Chikira and Sugiyama, 2010).

The double ITCZ bias is amplified in Coupled Models.
Oceanic feedbacks may be also playing a role.

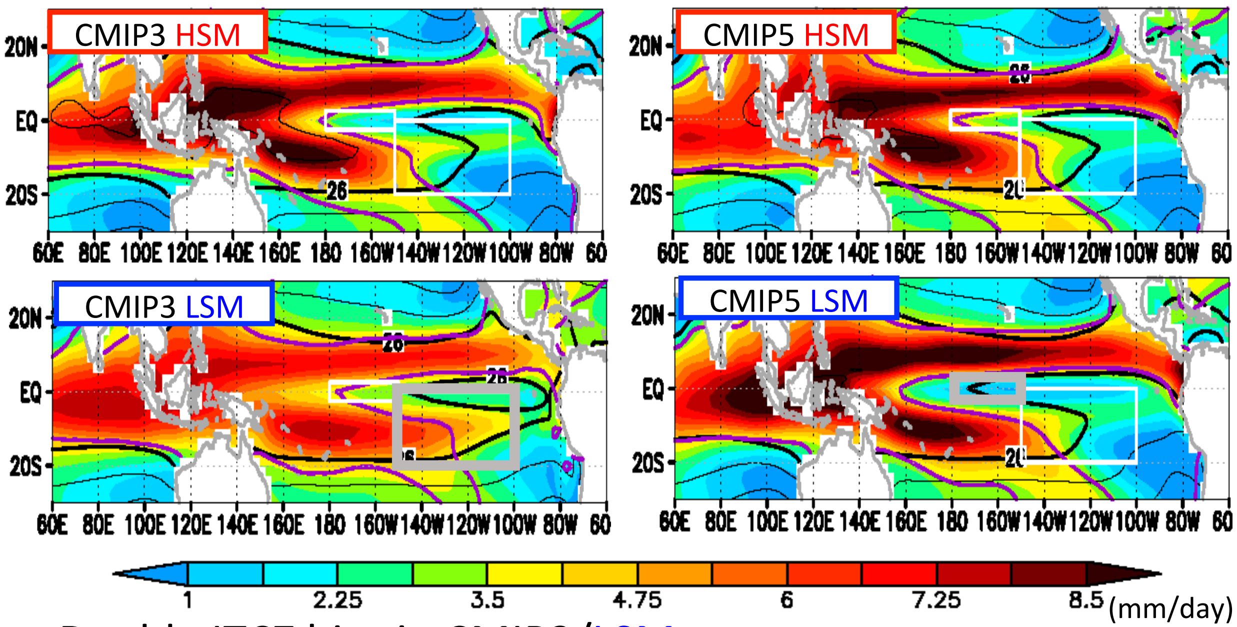


Taylor score for precipitation distribution (30S-30N ocean)

$$S \equiv \frac{(1+R)^4}{4(SDR + 1/SDR)^2}$$ (Taylor, 2001)



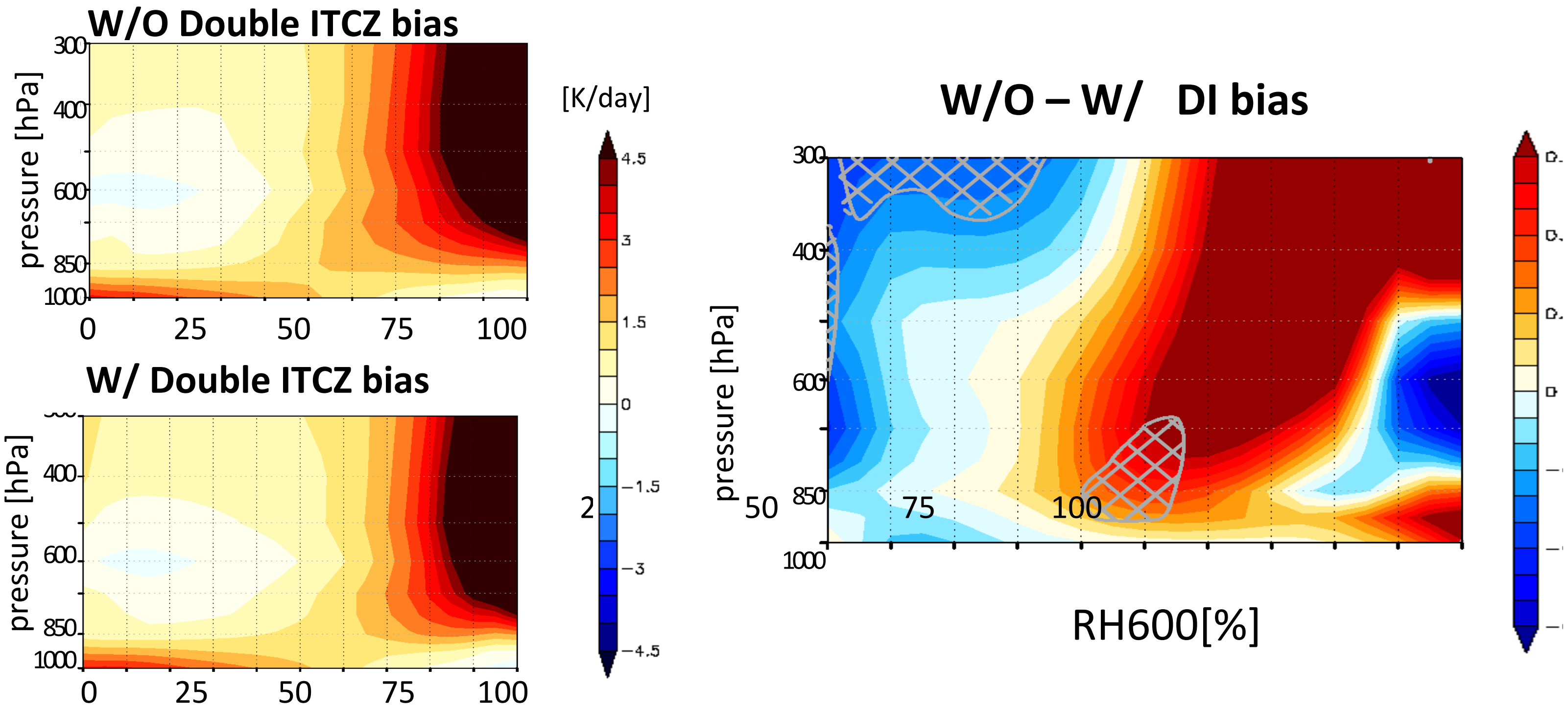
CMIP3 vs CMIP5



- Double ITCZ bias in CMIP3/LSM
  DI index = 3.80 mm/day (**>>** 1.40 mm/day in observation)
- Cold tongue bias in CMIP5/LSM
  CT index = 26.5 ℃ (**<<** 27.9℃ in observation)

Convective Heating vs RH at 600 hPa

Deep convection is more sensitive to the mid-tropospheric humidity



DATA TRMM Spectral Latent Heating (Shige et al. 2004, 2007, 2008, 2009)

- Three dimensional Q1-QR from the TRMM SLH database, generated in TRMM PR2A25 original resolution and gridded into monthly, 0.5degx0.5deg: L3LH, Dec.1997-Nov.2007

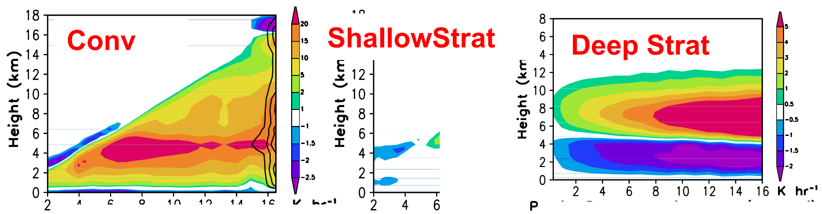
Apparent Heat Source

$$Q1 \equiv \frac{D\bar{s}}{Dt} = \frac{\partial \bar{s}}{\partial t} + \bar{v} \bullet \nabla \bar{s} + \bar{\omega}\frac{\partial \bar{s}}{\partial p} = QR + L(\bar{c} - \bar{e}) - \nabla \cdot \overline{s'v'} - \partial / \partial p \, \overline{s'\omega'}$$

where $s = CpT + gz$ dry static energy (Yanai et al.1972)

- Japanese Reanalysis (JRA25) and JCDAS, ERA40
- NOAA OI-SST (up to 2005)

SLH tables based on GCEM simulation



Rain Top Height

Melting level precip.

JCK-091109