# Evaluating the bias of South China Sea summer monsoon precipitation associated with fast physical processes using climate model hindcast approach

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Jul 18, 2019 CPPC, MetOffice, Exeter, UK

[Chen et al., 2019, J Clim]
[Chen et al., 2019, JMSJ, in revision]

# Motivation:

## Bias of East Asian Summer Monsoon in NCAR CAM5 AMIP simulation

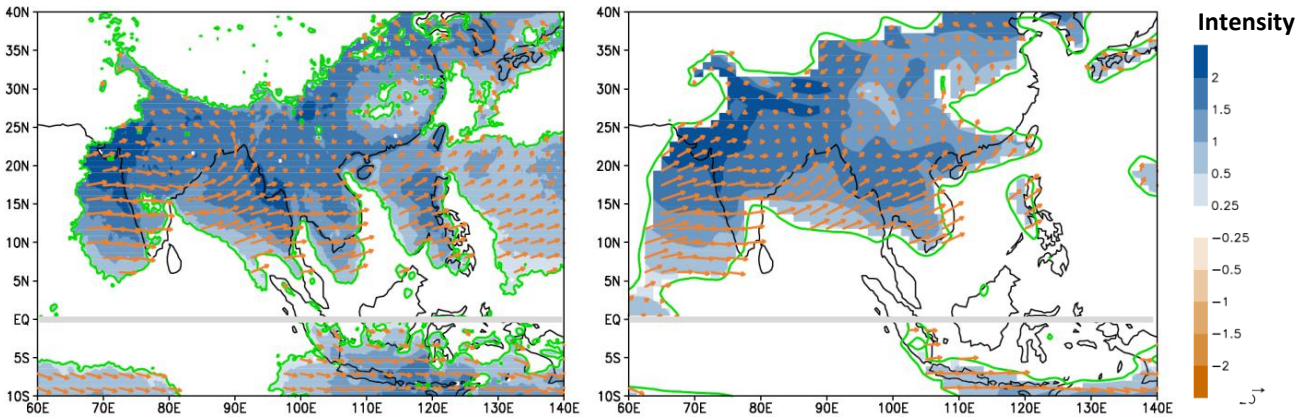
- **weaker intensity**
- **earlier onset (by 4-6 pentads)**
- **longer duration (by 5-10 pentads)**

**[Chen et al., 2019, JC]**

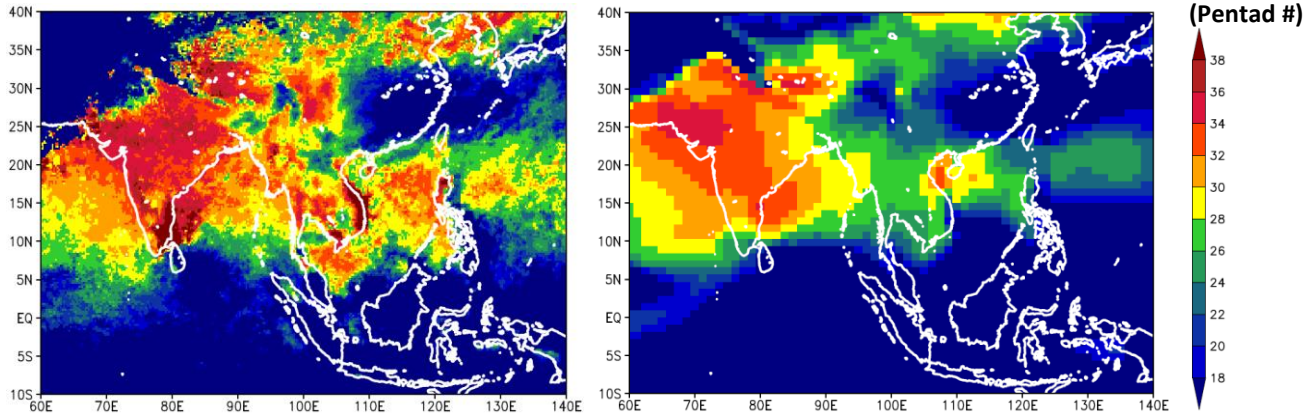
**TRMM 1998-2012** | **CAM5 AMIP 1998-2012**

**Monsoon Domain & Intensity**

Wang and Ding (2008); Wang et al., (2011); Kim et al., (2011)

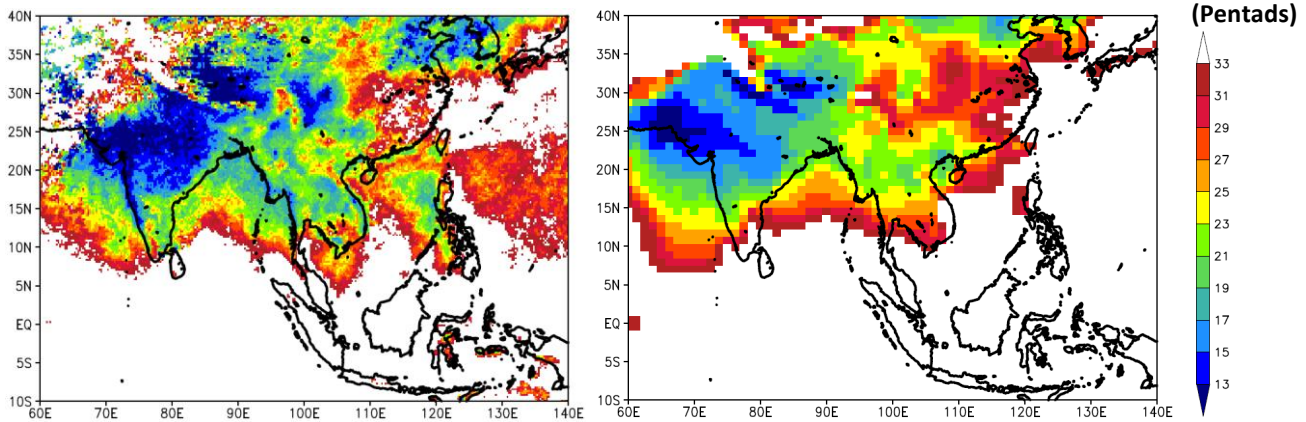



**Monsoon Onset**




**Monsoon Duration**

Sperber and Annamalai (2014)



# The challenges of improving monsoon simulations in global models

- **In AMIP/CMIP simulations, monsoon bias can be amplified/damped by interactions among various components in the climate system, emerging at multiple time scales (days~decadal)**

**Land-ocean thermal contrast**
(e.g., Zhou & Zou, 2010)

**SST and air-sea coupling**
(e.g., Bollasina & Nigam, 2009; Levine et al., 2013; Levine & T urner, 2012; Marathayil et al., 2013; DeMott et al., 2011)

**Land surface flux**
(e.g., Samson 2016; Terry et al., 2017)

**large-scale circulation**
(e.g., Bollasina & Nigam, 2009; Gadgil & Sajani, 1998; Sperber & Palmer, 1996)

**Moist convection**
(e.g., Bush et al., 2015; Mukhopadhyay et al., 2009; Rajendran et al., 2002; Slingo et al., 1994)

**Climate variability**
(e.g., Lin et al., 2008; Li et al., 2015; Song & Zhou, 2014; Zhou et al., 2009)

**Orography**
(e.g., Boos & Hurley, 2012; Wu, Chou, et al., 2017; Wu, Freychet, et al., 2017; Wu & Hsu, 2016)

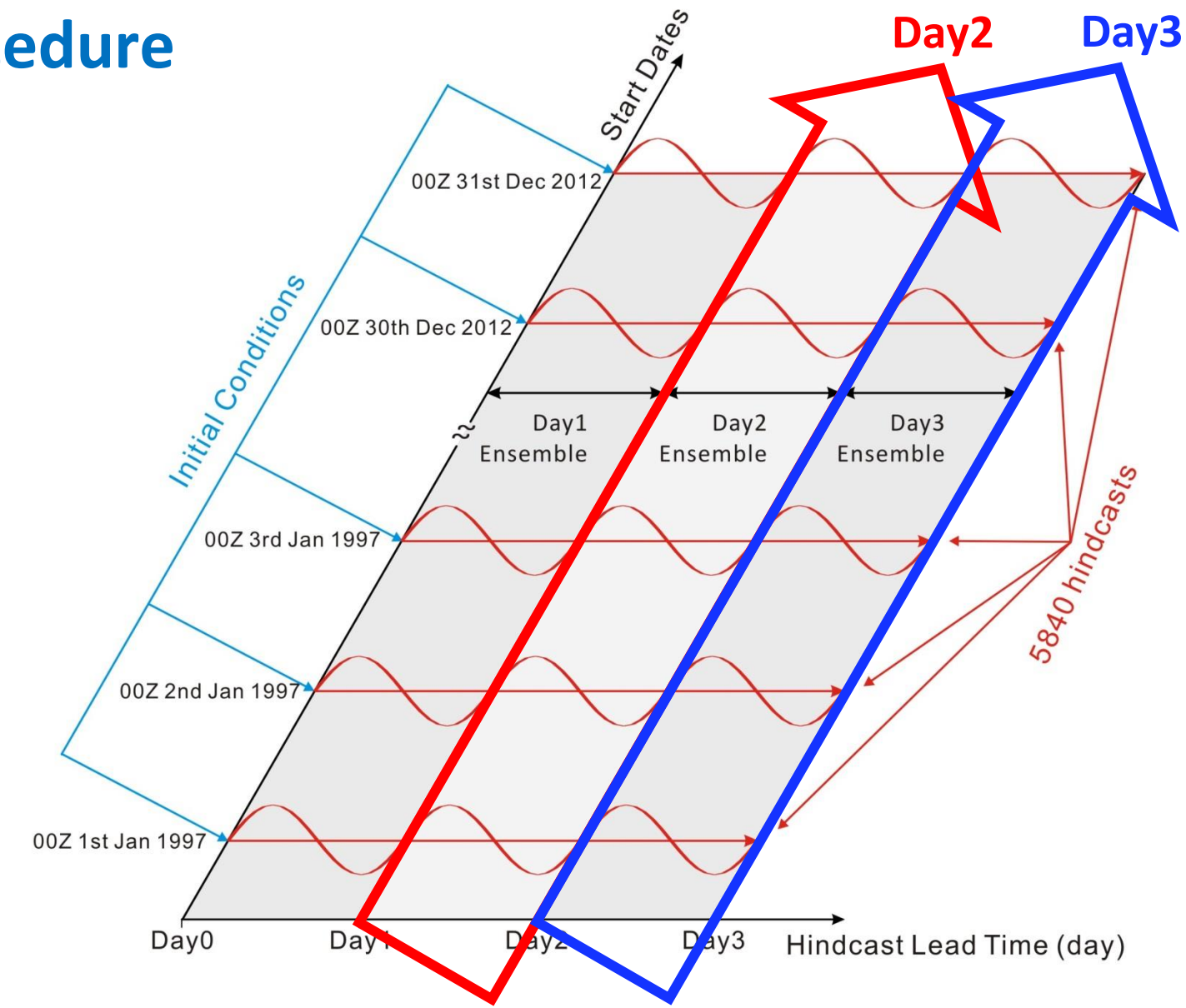
- **What we often do to reduce bias: Tuning the parameterizations (and hope it works….)**

***Can we diagnose the biases arisen from the "fast" physics (convection, cloud, radiation), before they interact with the "slow" process (circulation, etc.)?***

# Identifying model biases caused by fast processes: The Multi-Year Hindcast Procedure

- To diagnose biases associated with interactions of only the fast physics (< 3 days), given a well-constrained, actual large-scale state

- To establish robust model systematic biases by comparing to long-term observations




**[Ma et al., 2013; 2015, JAMES]** *(a.k.a TransposAMIP)*

# The Cloud-Associated Parameterizations Testbed (CAPT) Hindcast Experiment Design

- 3-day long hindcast simulations starting every day at 00Z for the period of 1998 – 2012
- CAM5.1/CLM4.0 (~ 1 x 1 degree and 30 vert. levels)
- Atmospheric initial state variables: mainly ERA-Interim and also from a nudging run
- Land initial conditions: offline land simulation forced with atmospheric reanalysis and observations

**[Ma et al., 2015, JAMES]**

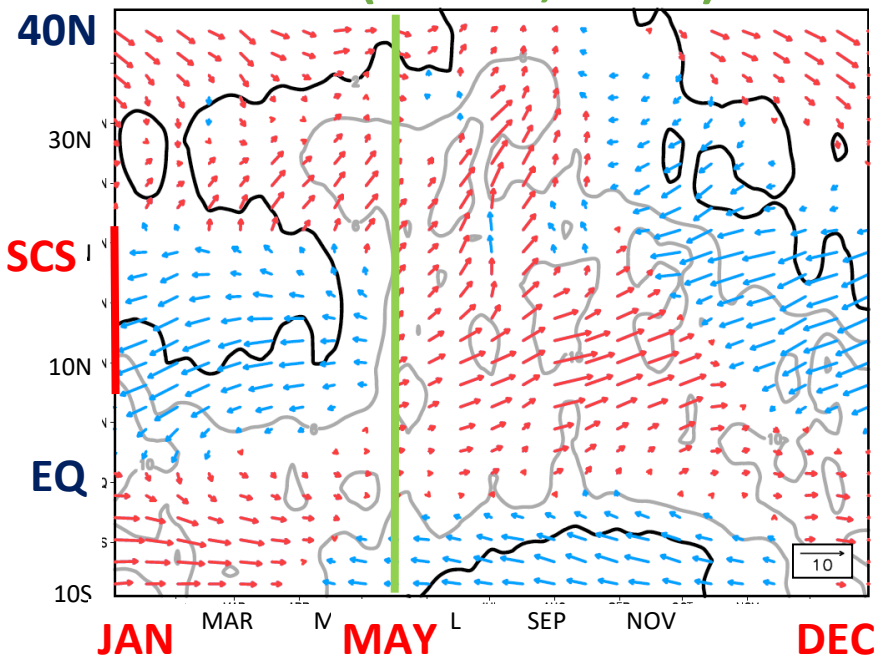
# Evolution of SCS-EA Summer Monsoon

**The CAPT multi-year hindcast:**

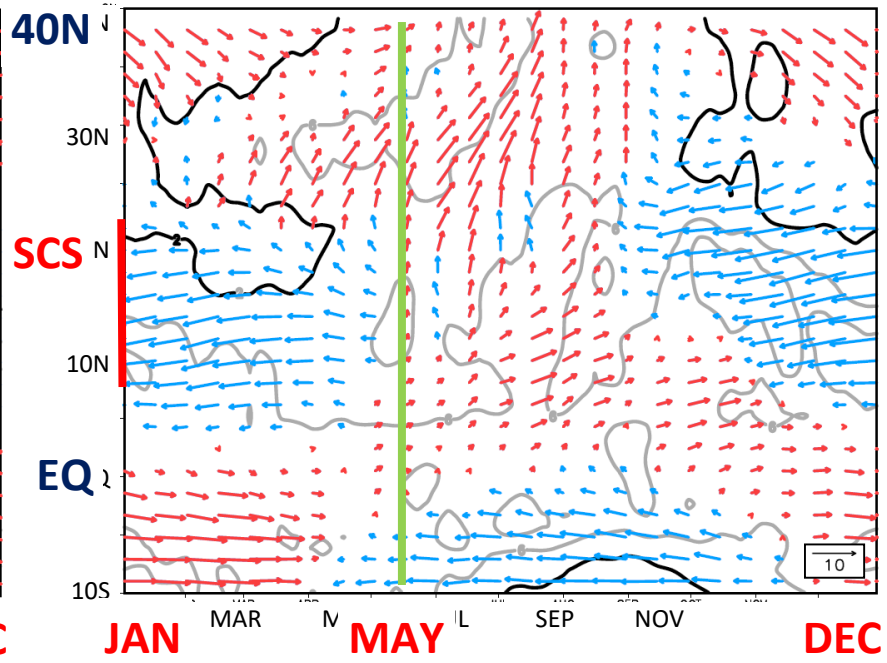
- **Well-constrained winds**
- **Similar precipitation bias as in AMIP but closer to observation**
- **Earlier onset in SCS**
- **Weaker post-onset rainfall**

**[Chen et al., 2019, JC]**

OBS (TRMM, ERA-I)




CAM5 AMIP

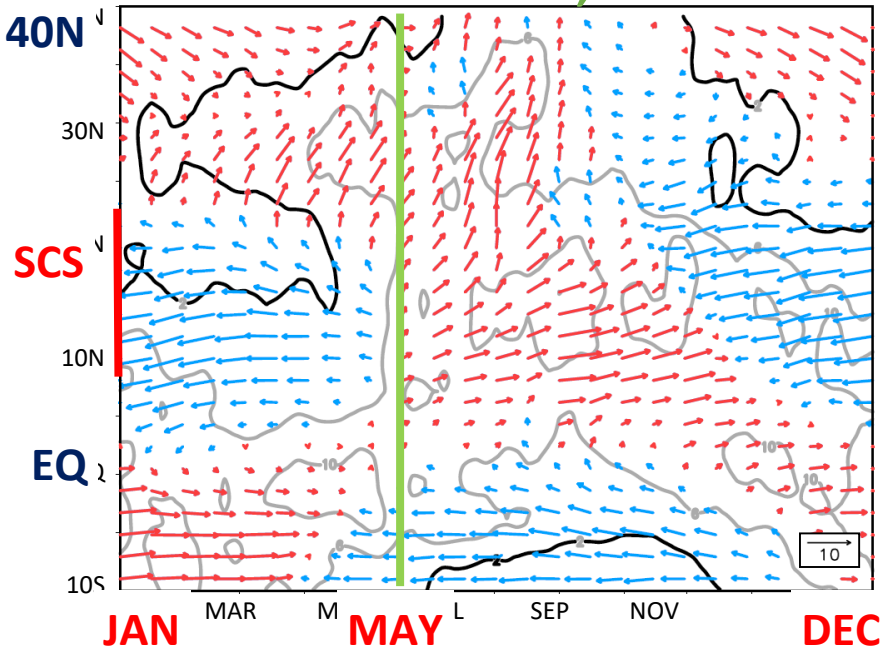



Climatology 1998-2012
Zonally averaged over **110-120E**

Contour: Precipitation
**(black= 2 mm/d)**

Vector: 850 hPa winds > 1 m/s
(red = $u_{850} > 0$)

CAPT Hindcast, DAY3



# Evaluation of model biases using SCS Monsoon Onset Composites

- SCS summer monsoon onset index:
  - $U_{scs}$ (averaged over 5-15N, 110-120E) [Wang et al. 2004 JCLI]
    - In the onset pentad $U_{scs} > 0$ m/s
    - In the subsequent four pentads, $U_{scs} > 0$ in at least three pentads and mean $U_{scs}$ of the accumulative four pentads > 1 m/s

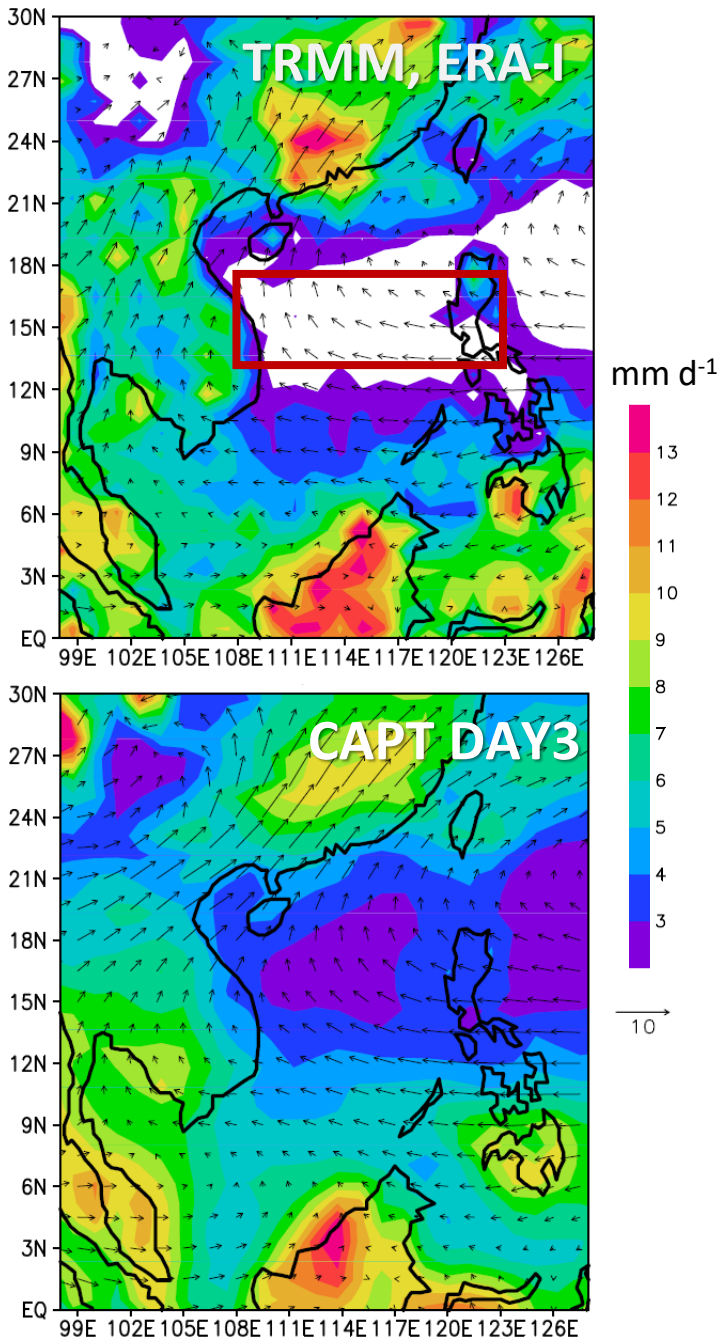
- Calculate $U_{scs}$ from ERA-I to determine the monsoon onset date <u>each year</u> between 1998 and 2012:
  **Pre (post) -onset composites: two pentads before (after) onset date**

# Pre-onset Bias: Land-ocean contrast of precipitation and local circulation

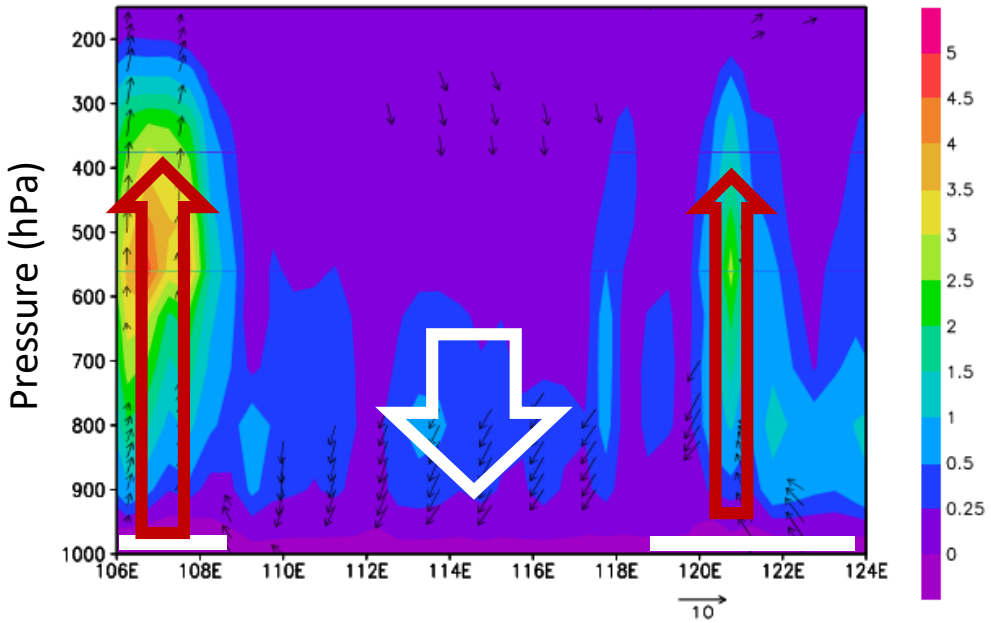
- **Much weaker land-ocean contrast in hindcast**
- **Anomalous subsidence over ocean associated with strong land convection (diurnal cycle) is weaker**

Conditional sampling for days with subsidence over open ocean in ERA-I

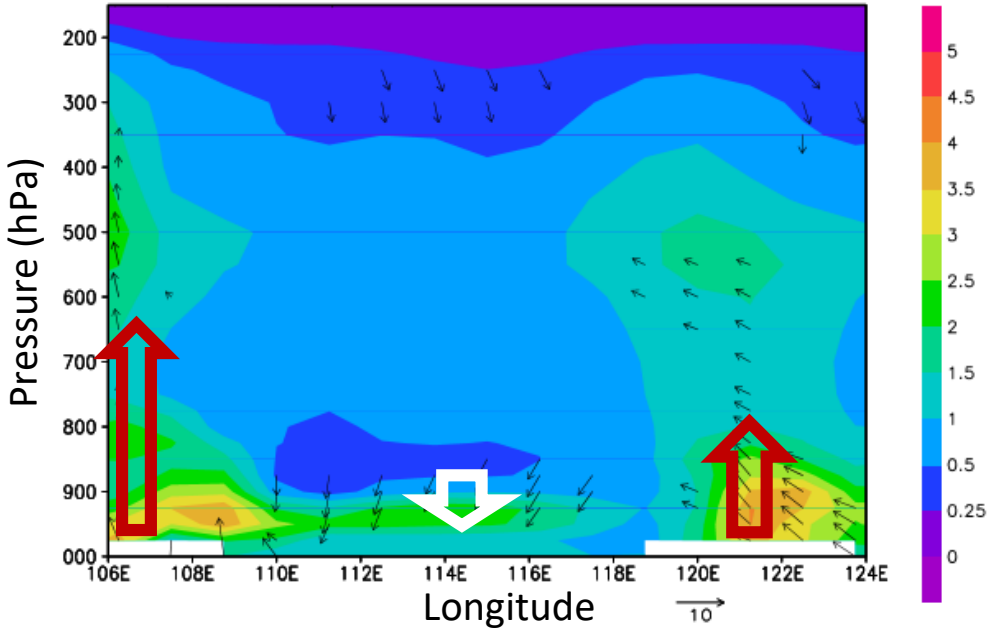
**[Chen et al., 2019, JC]**




## TRMM Q1-QR & ERA-I ω



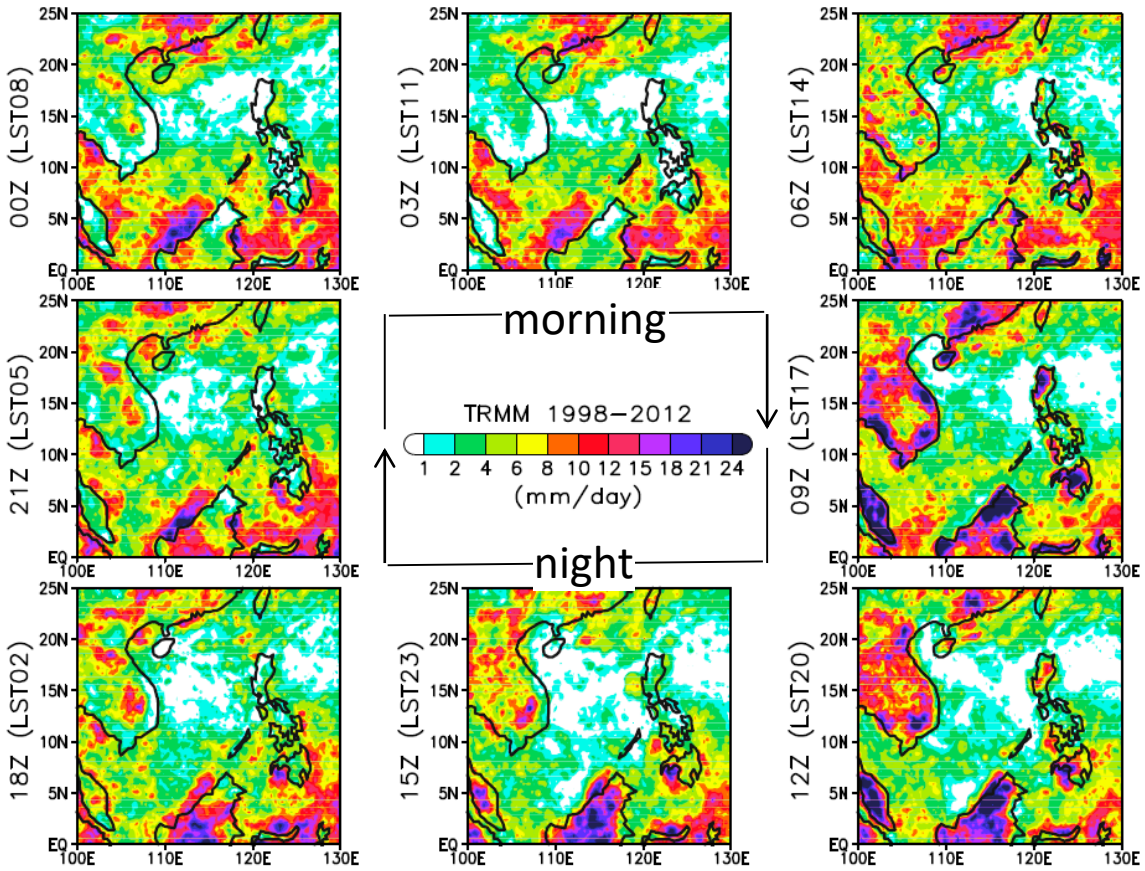

## CAPT Day 3 Q1-QR & ω



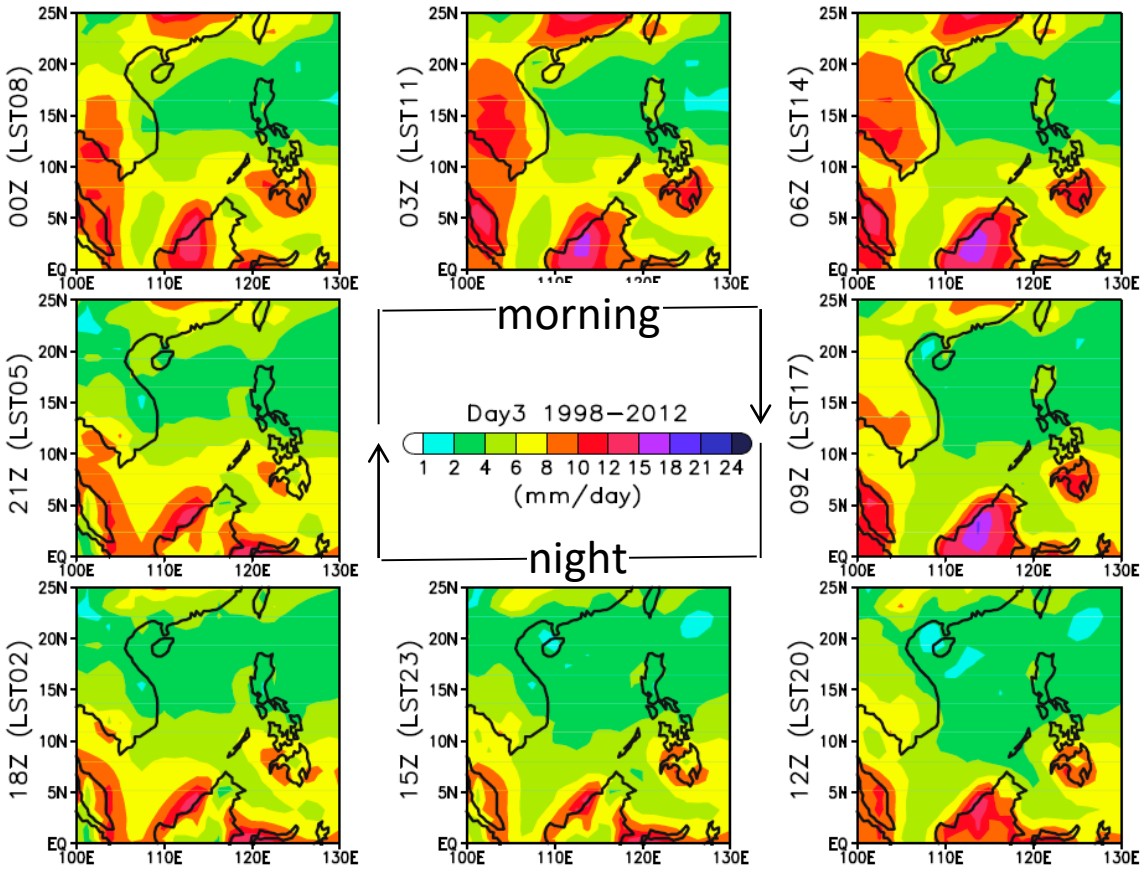
# Bias in Diurnal Cycle of Convection over Land

- **Weaker amplitude, earlier peak time**
- **Longer duration but weaker rainfall**
- **Land DC biases are similar both pre- and post-onset**

## Pre-onset, TRMM




## Pre-onset CAPT Day3

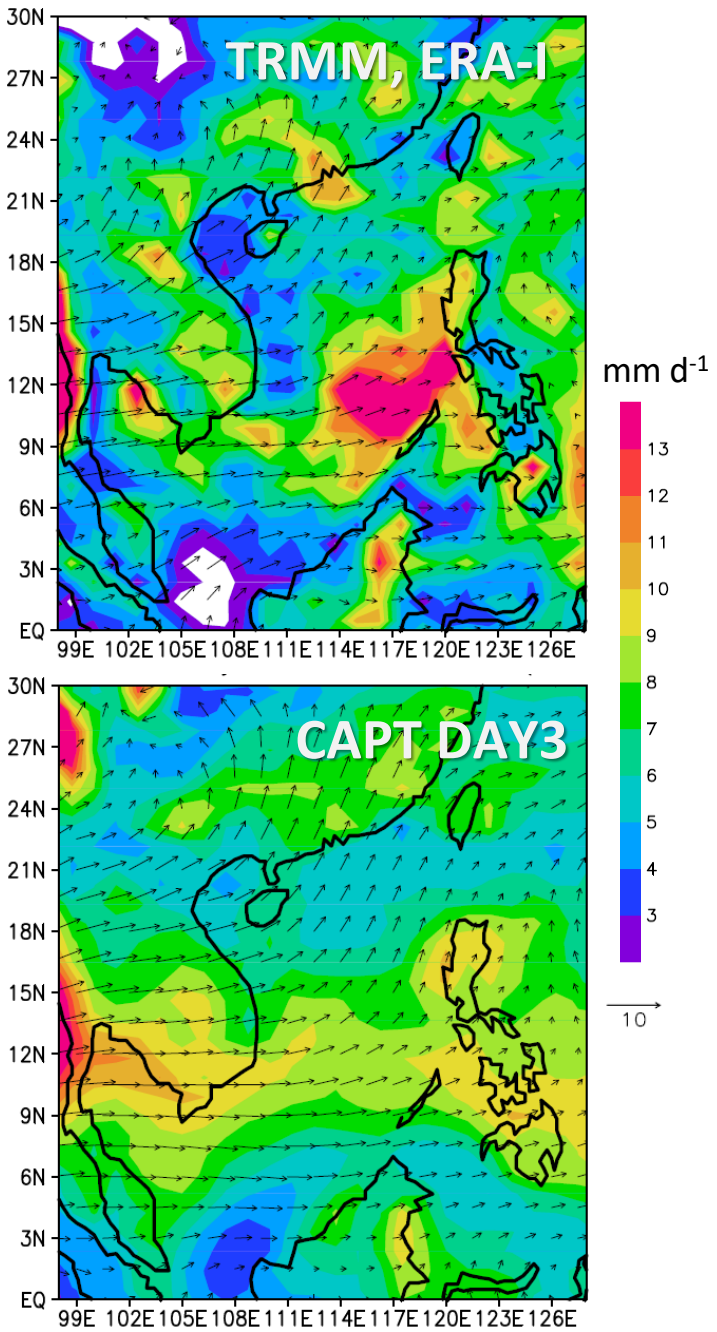


# Post-onset Bias: Costal organized convection system

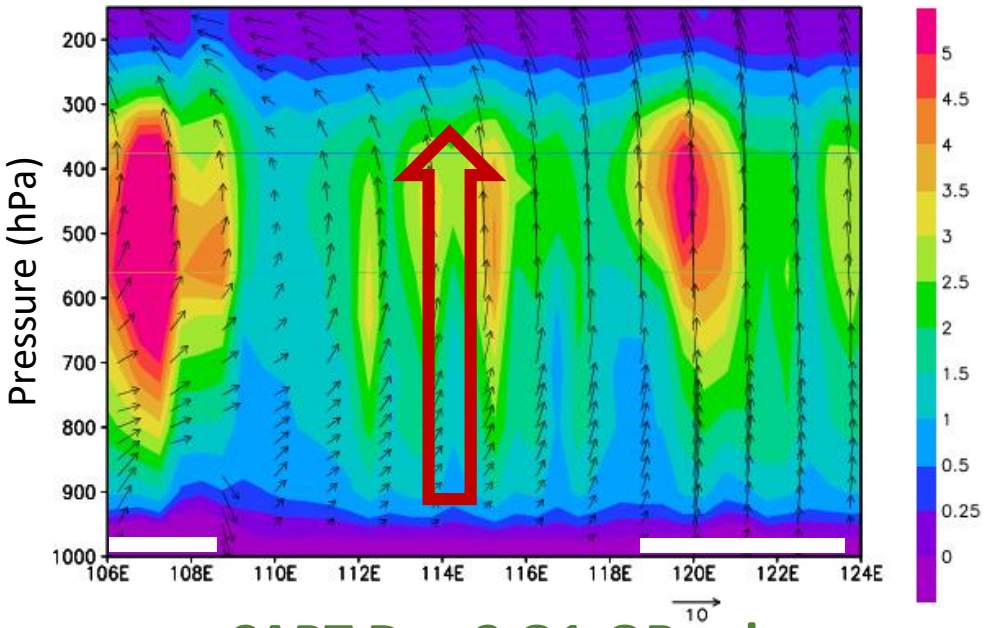
- **Rainfall over W Philippines weaker and less concentrated (smaller E-W gradient)**
- **Less organized costal convection system, with strong upper level heating (stabilizing effects)**

Exclude year 2006 due to TC

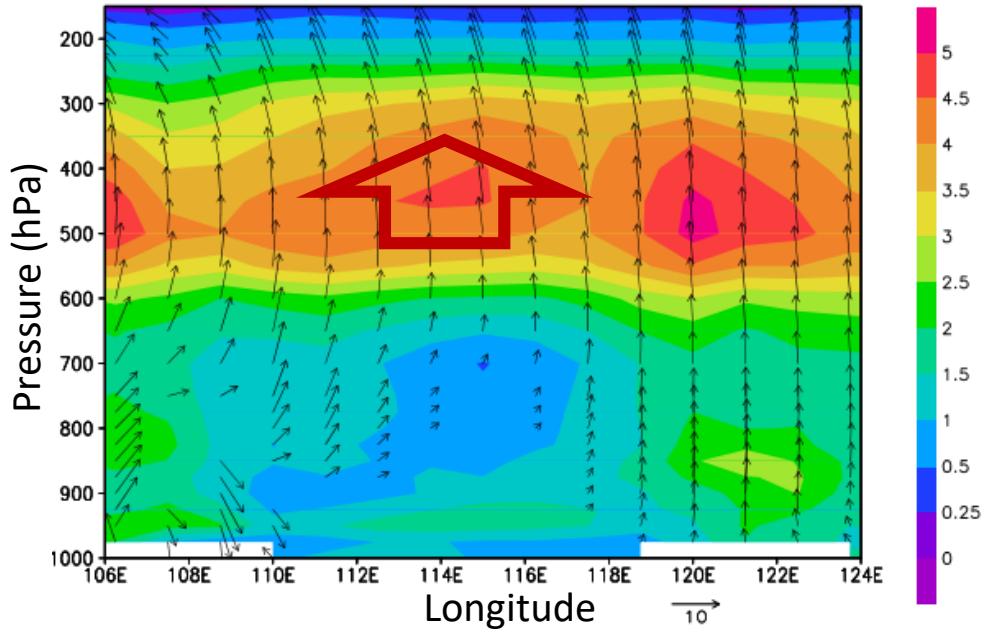
**[Chen et al., 2019, JC]**




## ERA-I Q1-QR ω'




## CAPT Day 3 Q1-QR ω'

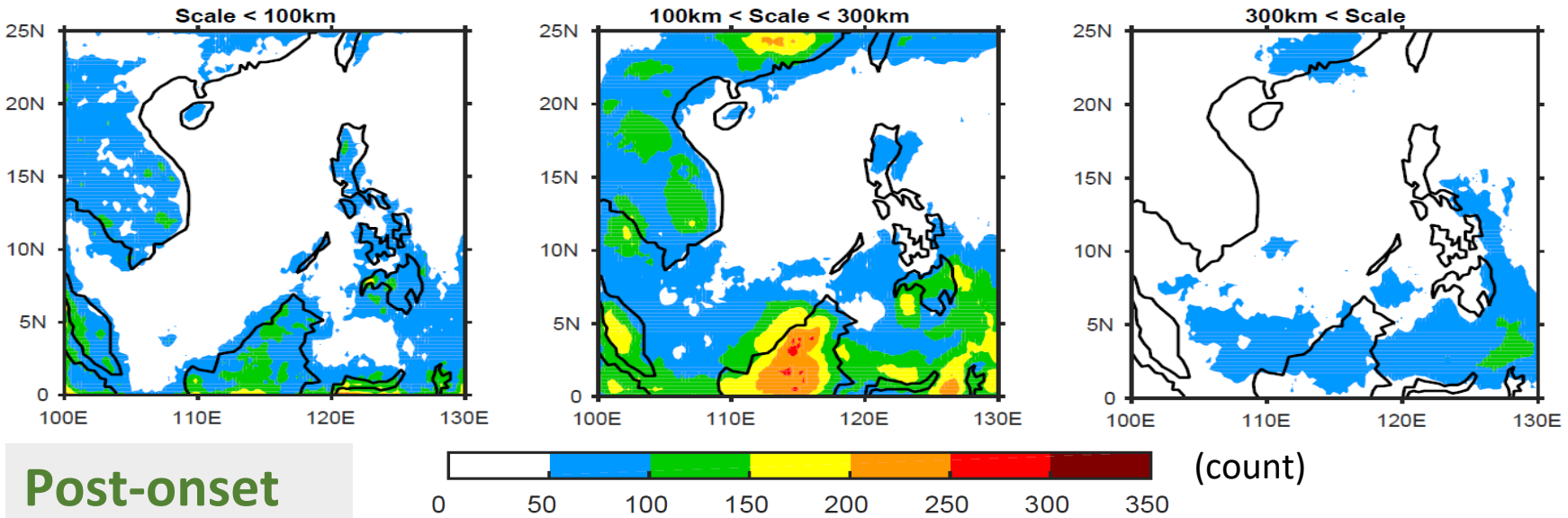


# Observed Occurrence of Precipitation Objects by Size

[Chen et al., 2019, JMSJ, in revision]

**S (<100 km)** **M (100-300 km)** **L (>300 km)**

## Pre-onset

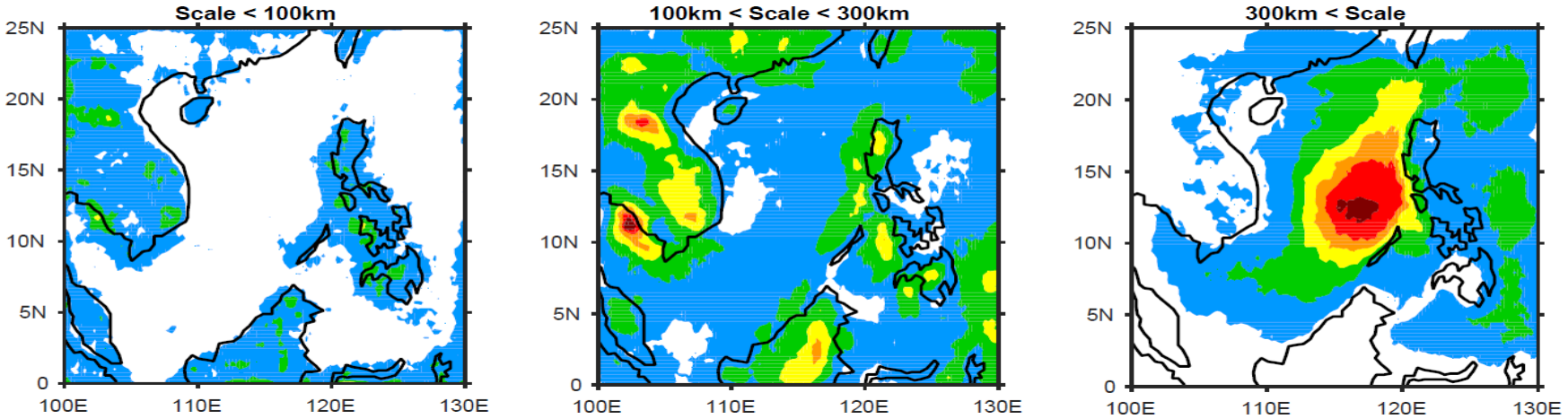



(TRMM 3B42 1998-2015)

Pre-onset:

- Mostly over land (S- and M-size)

## Post-onset




Post-onset:

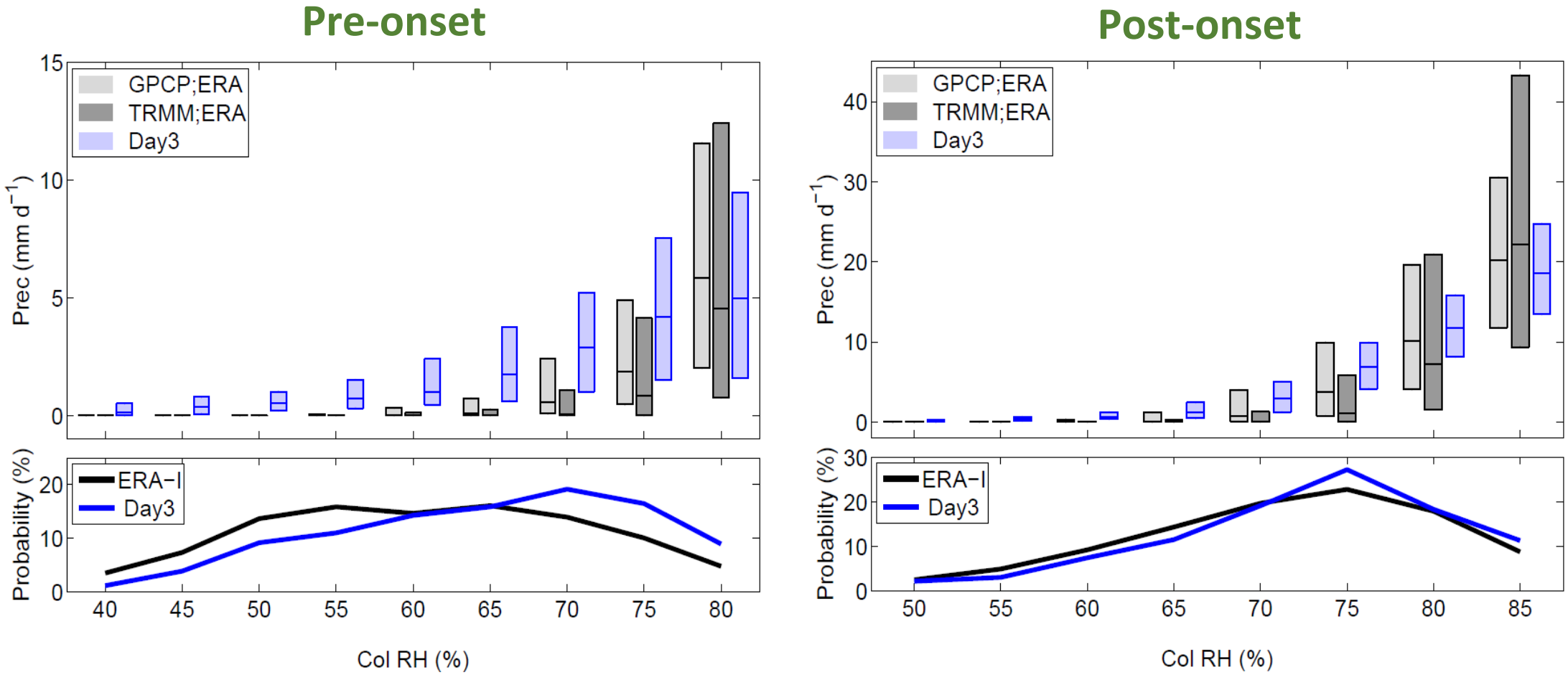
- Over ocean mainly L-size
- Over land mainly M-size

# Insufficient Sensitivity of Precipitation to Column RH

Statistics over SCS ocean areas

**CRH vs. Precip**

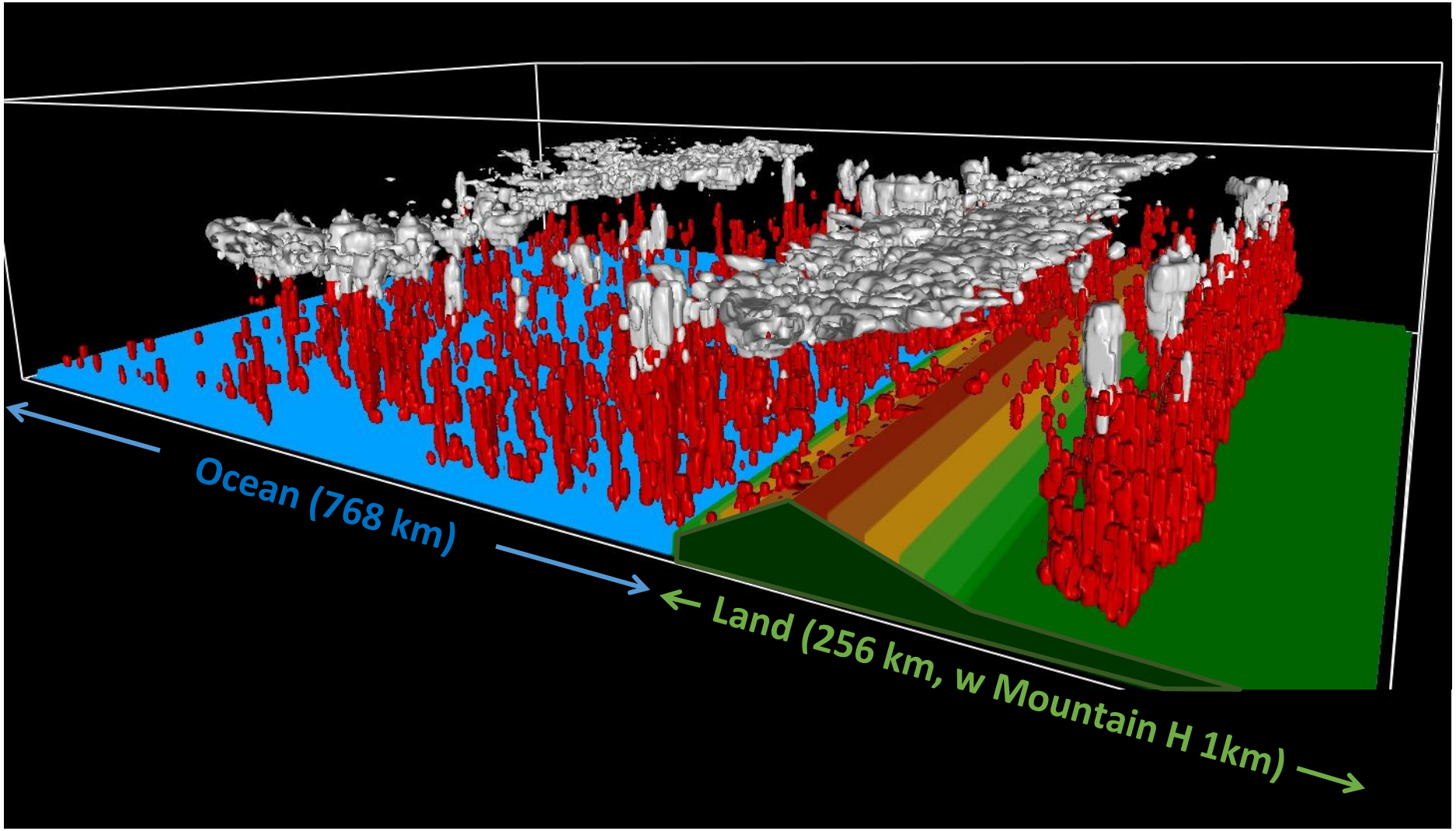
**PDF of CRH**




- **Similar bias in CRH-precip during pre- and post-onset**
- **Rainfall variability is overestimated in dry environment (<75%), and underestimated in moist environment (>75%)**

# Idealized Cloud-Resolving Simulations over Coastal Areas

- 3D cloud-resolving **Vector Vorticity Model (VVM) with interactive land surface model** [Jung and Arakawa 2008; Wu and Arakawa, 2011; Chien and Wu, 2016; Lin, 2016]
- **Idealized** ocean-land-orography configuration similar to the actual scale of the SCS basin
- 10-day simulations with solar forcing to generate diurnal cycle; dx=2km; 45 layers stretched to 30km



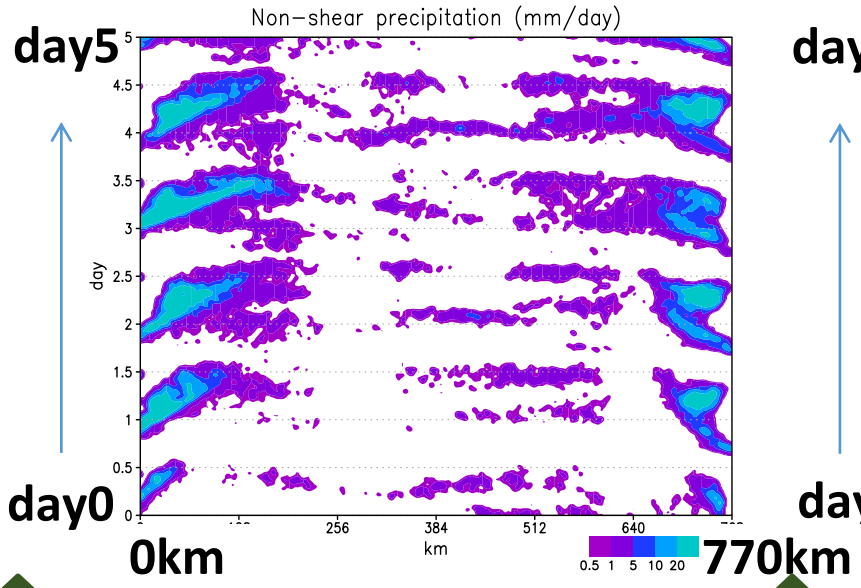

- **Sensitivity to background vertical wind shear: No shear vs. Shear (weak low-level westerly)**

# Idealized VVM Cloud-Resolving simulations:

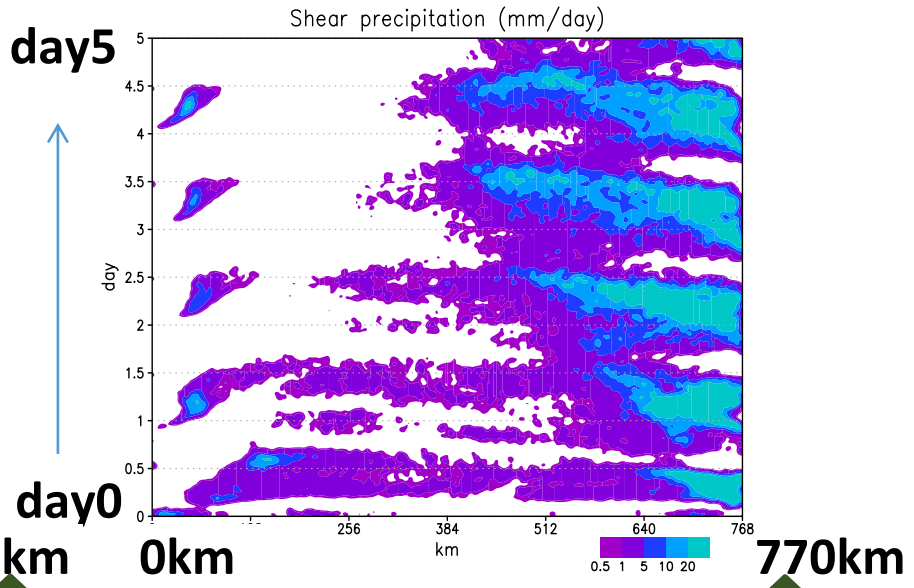
# Response of Coastal Convection to Low-level Wind Shear

[Chen et al., 2019, JMSJ, in revision]

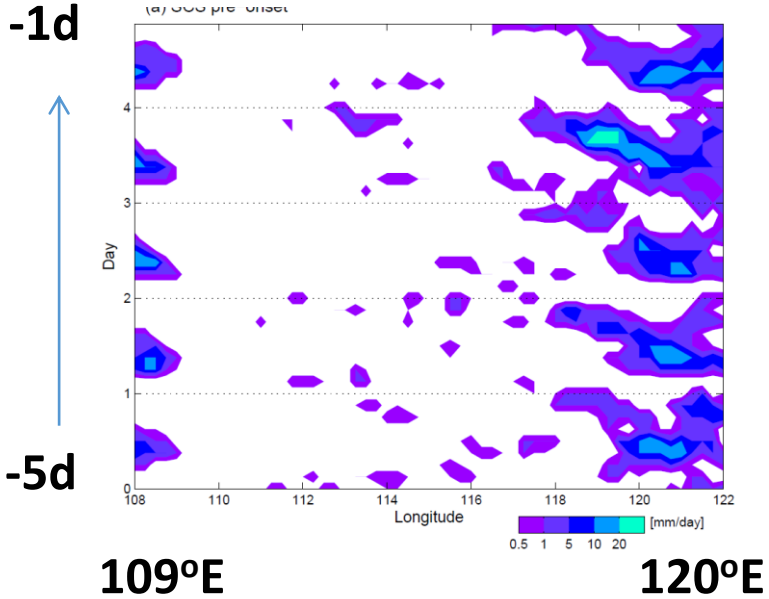
## CRM, no shear

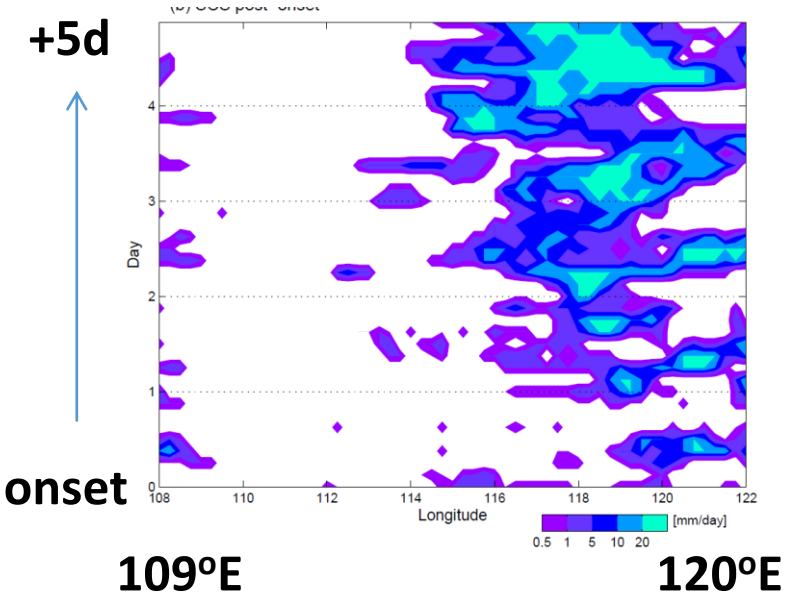



## CRM, with shear (low-level westerly)



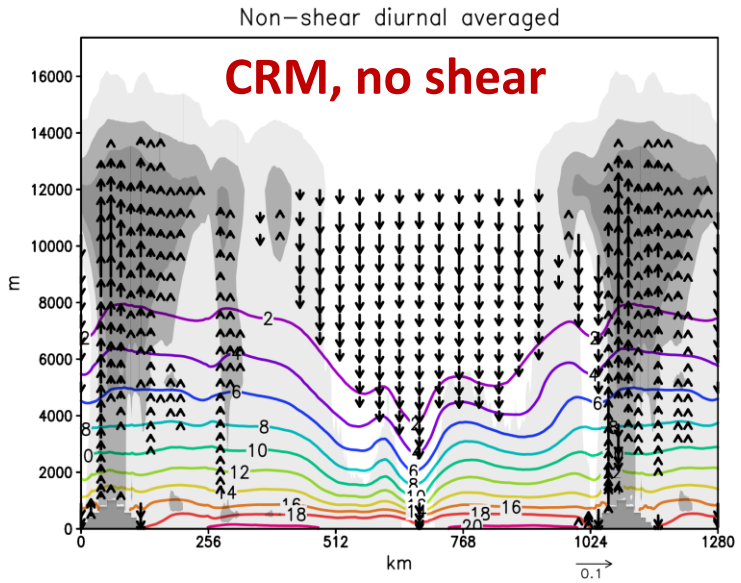

## Observed SCS Coastal Precipitation (TRMM, example of 2014)

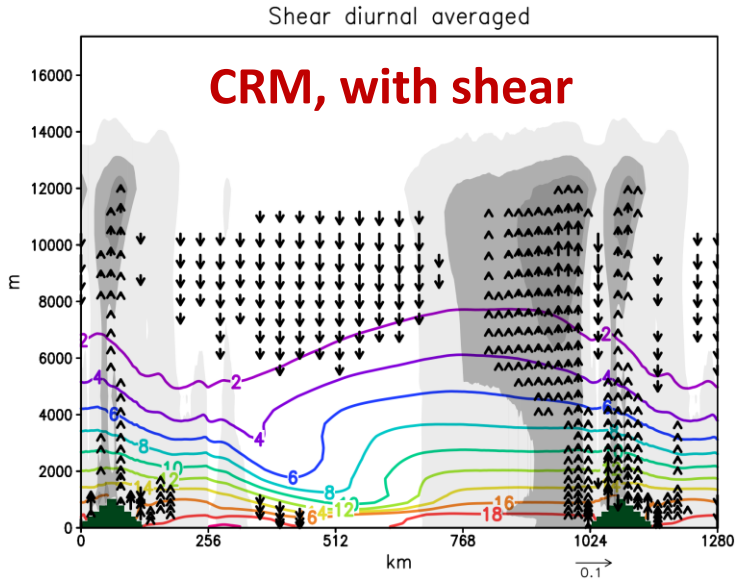


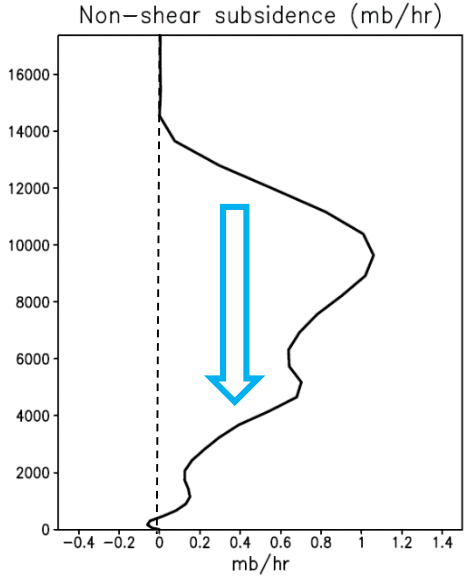
# Coastal Convection, Basin-scale Circulation, and Ocean CWV

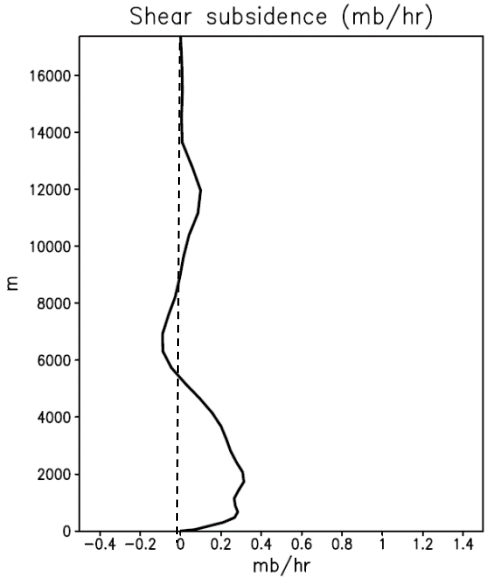
## Zonal Vertical Profile of $Q_v$ and Cloud Fraction



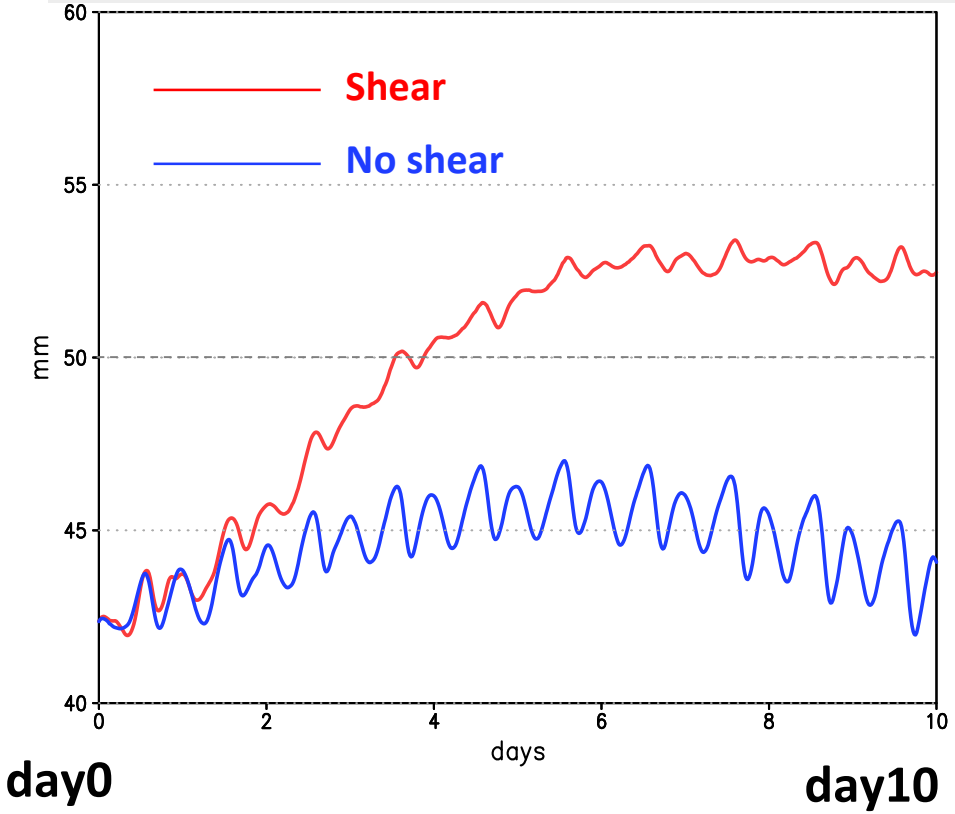




## Ocean Mean Subsidence Profile



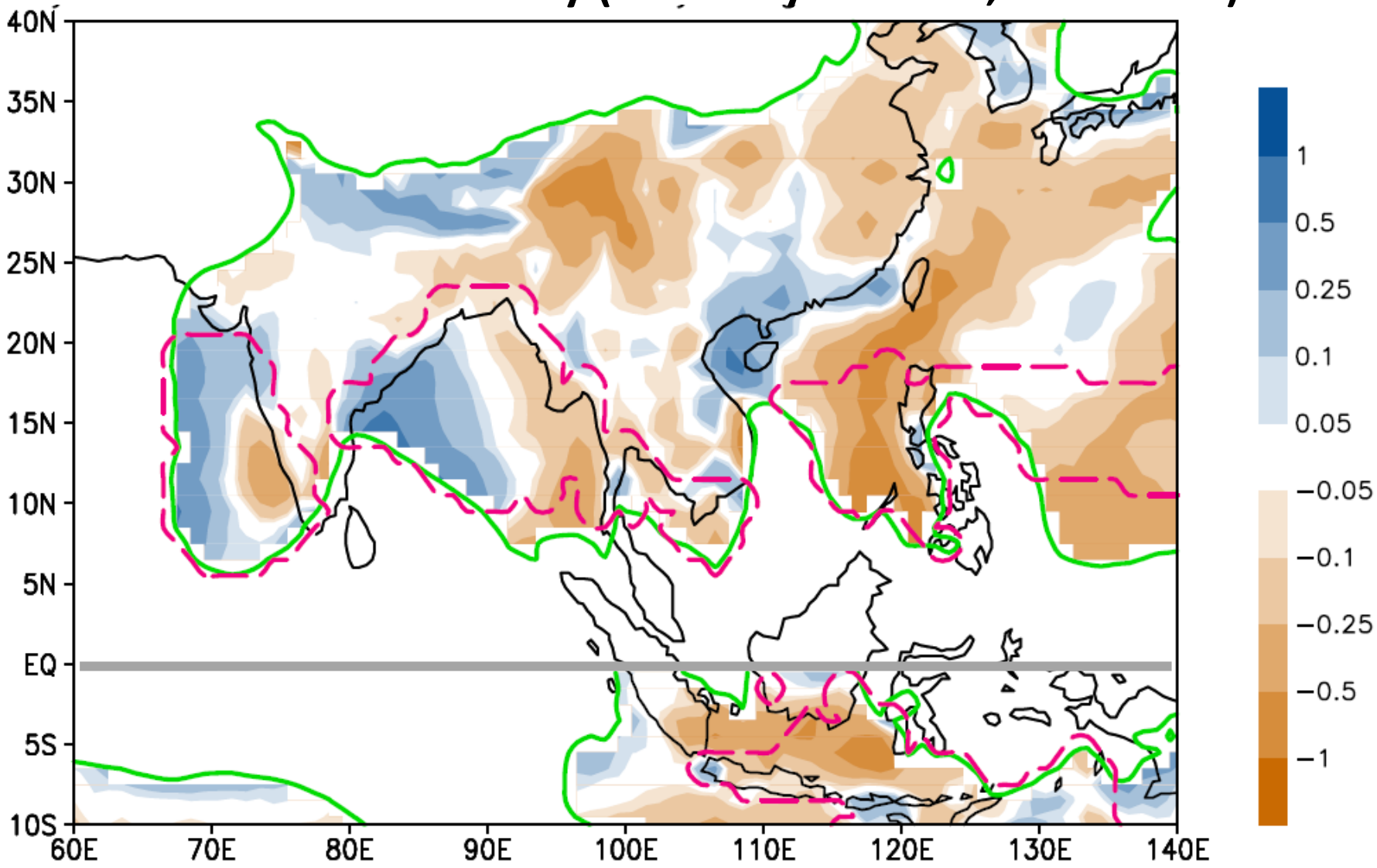

## Evolution of Ocean Mean CWV




[Chen et al., 2019, JMSJ, in revision]

# Similar bias may exist over other coastal monsoon regions

**Bias of monsoon intensity (CAPT day3 – GPCP, 1998-2012)**




- Pre-monsoon environment with very warm SST (>28°C) suppressed by prominent low-level subsidence

**Green lines:**
**GPCP Monsoon domain (annual range > 2.5 mm/day)**

**Pink dashed lines:**
**ERA-Int SST>28°C & 1000~500hPa MAX w > 0.01 Pa/s in spring**

- **Monsoon intensity = annual range of precip/ annual mean precip**

# Conclusions

- SCSSM precipitation in NCAR CAM5 is evaluated using the **CAPT hindcast** framework to identify biases due to **interactions of fast physical processes**
  - Pre-onset: too weak land-ocean convection contrast and the associated local circulation
  - Post-onset: organized coastal convection is not well represented
  - Biases in diurnal cycle and sensitivity to moisture of cu parameterization
- **The influence of land convection on basin-scale circulation, and the effect of coastal convection on the ocean moistening**
  → representation of coastal convection in GCMs may be the key for simulating a more realistic monsoon onset transition.

- Ongoing work:
  - Sensitivity tests of cu parameterization under the hindcast framework
  - Idealized CRM simulations to explore the sensitivity of moistening time-scale to SST, wind shear intensity (altitude), and land surface type and terrain.

# Thank you for listening!

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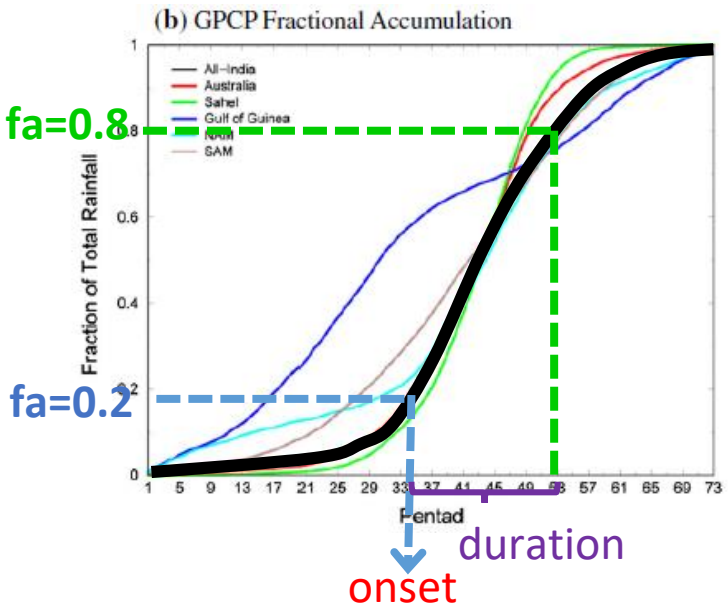
**Funding Source: Ministry of Science and Technology, Taiwan**


- Chen W.-T., C.-M. Wu, and H.-Y. Ma (2019), Evaluating the bias of South China Sea summer monsoon precipitation associated with fast physical processes using climate model hindcast approach, J. Climate, https://doi.org/10.1175/JCLI-D-18-0660.1

- Chen, W.-T, C.-M. Wu, W.-M. Tsai, P.-J. Chen, and P.-Y. Chen (2019), Role of coastal convection to moisture buildup during the South China Sea summer monsoon onset, J. Meteor. Soc. Japan, in revision

# NCAR CAM5 Asian Monsoon (AMIP simulation)

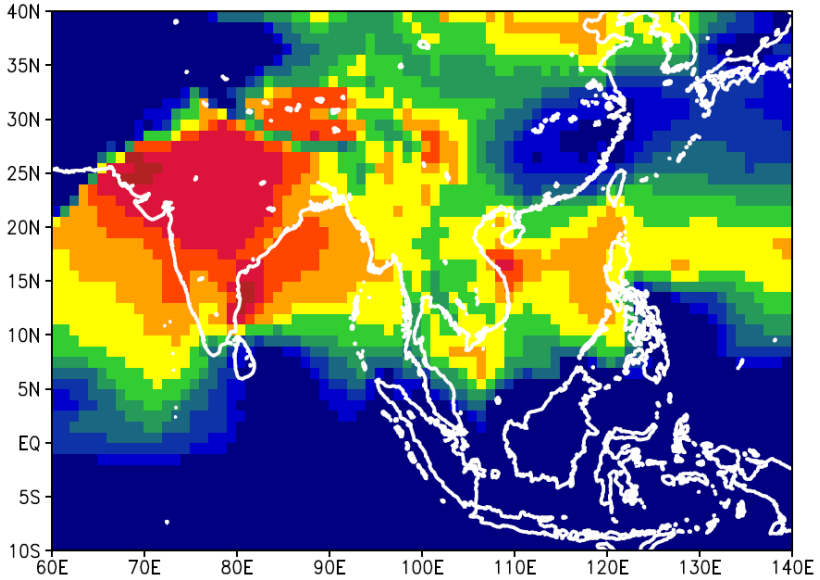
- **Onset and Duration based on fractional accumulation of rainfall**
- **EASM in CAM5 AMIP: "too early, too weak"**



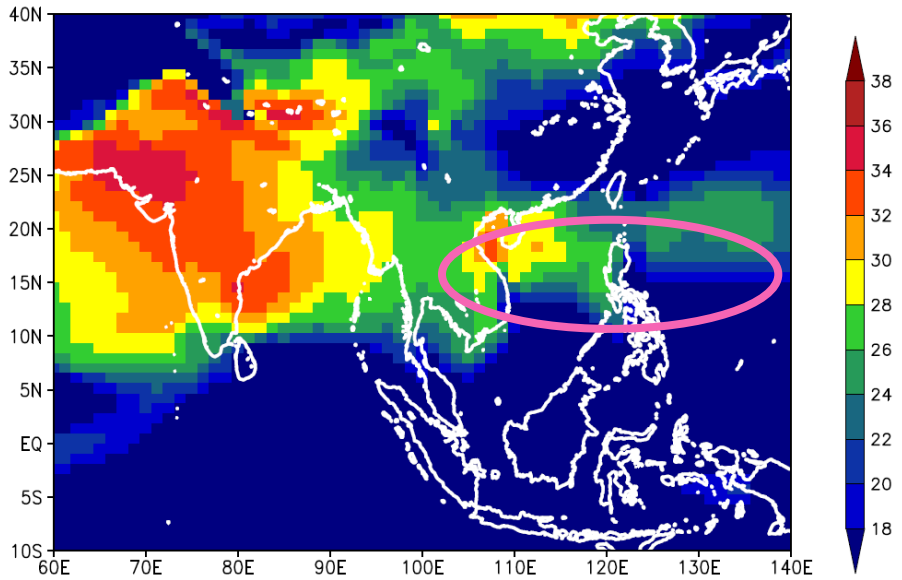

Based on Sperber and Annamalai [2014 CD]

## Monsoon onset: Pentad at FA = 0.2

OBS (GPCP), 1998-2012

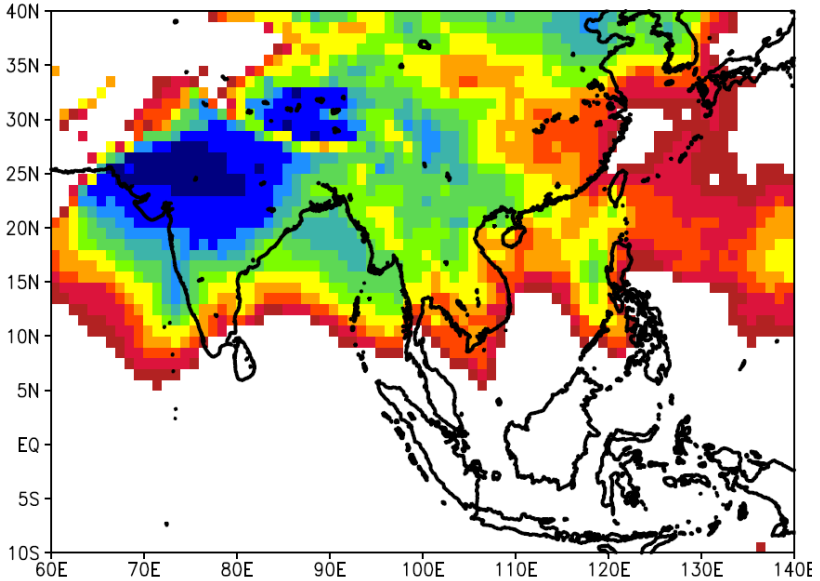


CAM5 AMIP, 1998-2012

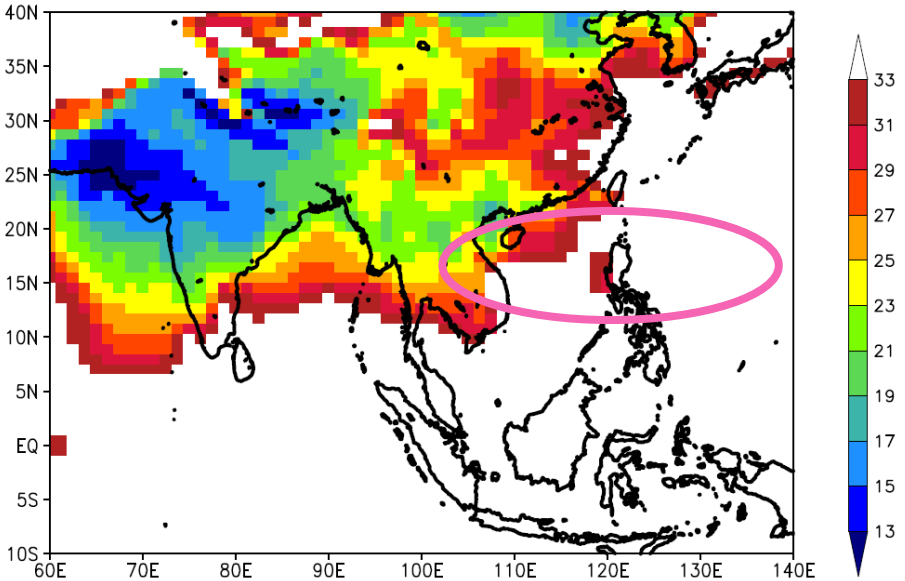


## Monsoon duration: Pentads from FA=0.2 to FA= 0.8

OBS (GPCP), 1998-2012

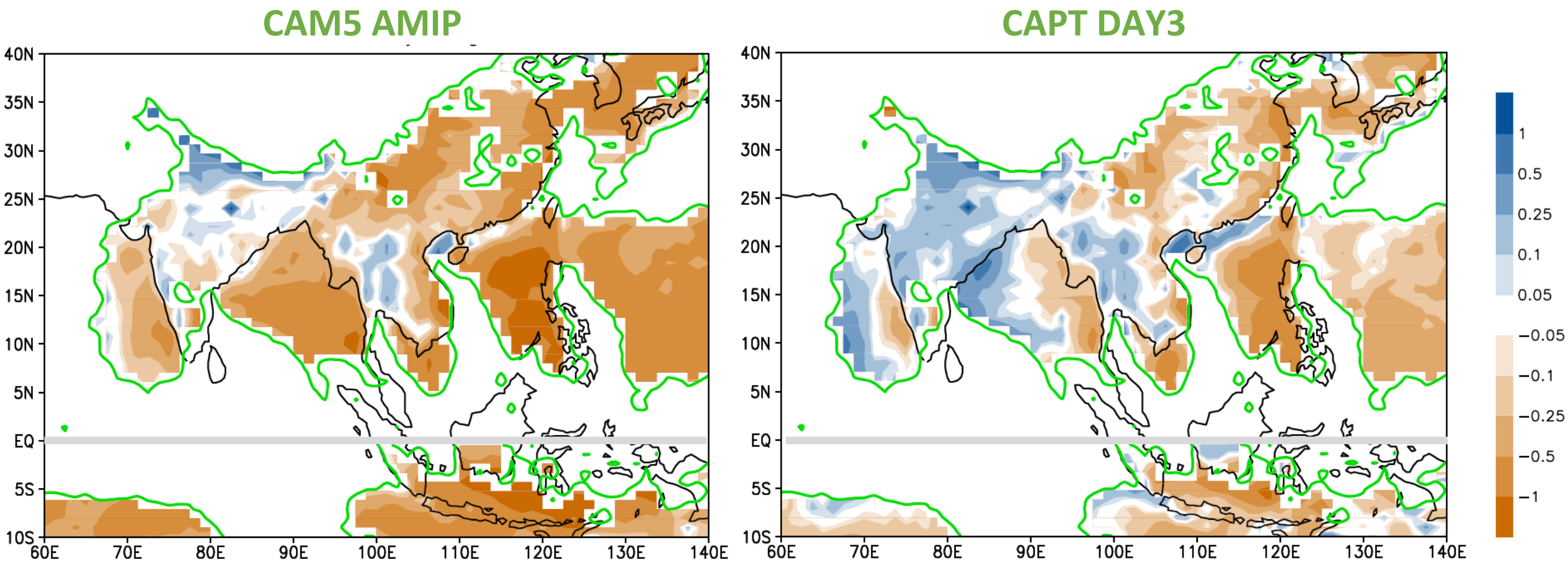


CAM5 AMIP, 1998-2012



# Bias in Asian Monsoon Intensity: CAM5 AMIP vs. CAPT

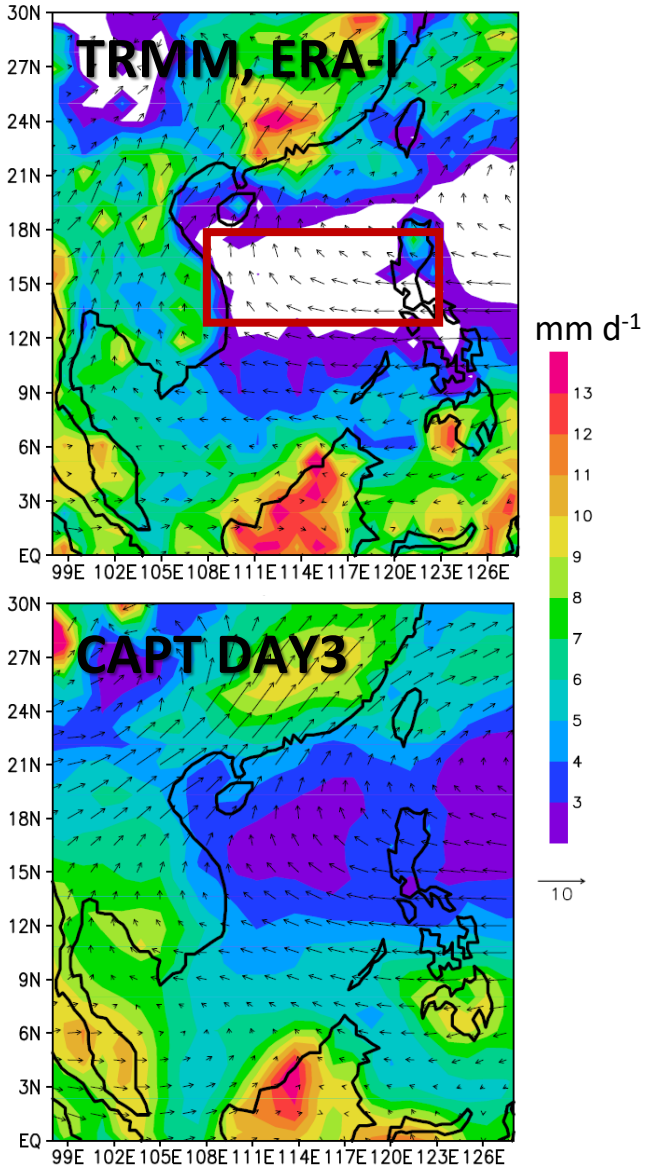
- CAPT: “Dipole patterns” with suppressed (enhanced) seasonal contrast over the windward (leeward) side of SCS, BoB, and India



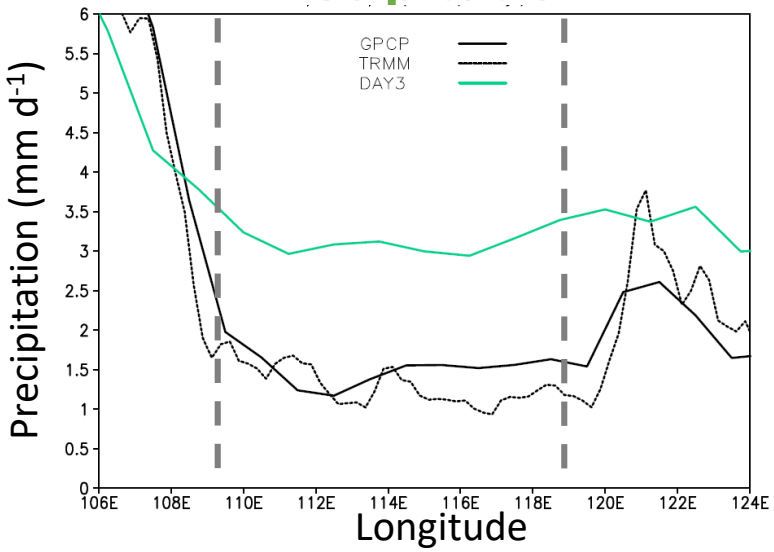

**Bias of monsoon intensity (color shading) relative to TRMM 3B42 within observed monsoon domain (green line)**

# Pre-onset: Land-ocean contrast of precipitation, moisture, and local circulation

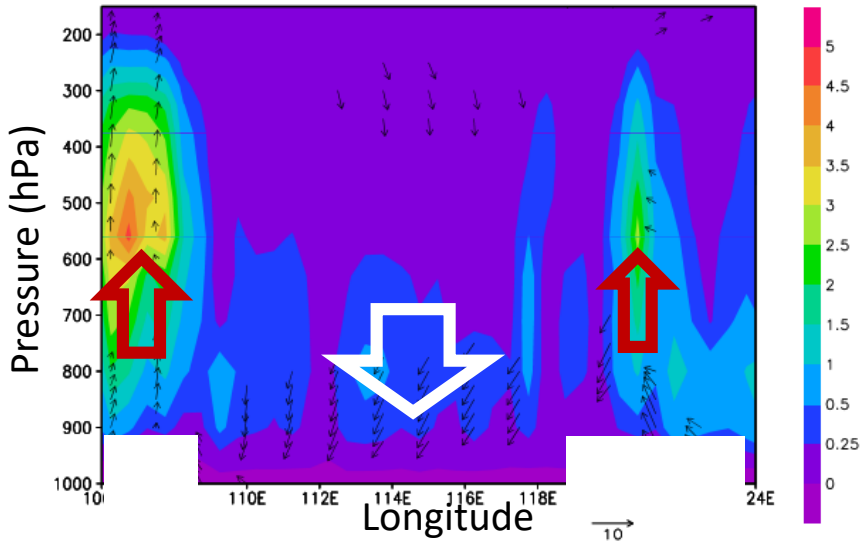
- **Much weaker land-ocean contrast in hindcast**
- **Anomalous subsidence over ocean associated with strong land convection (diurnal cycle) is weaker**



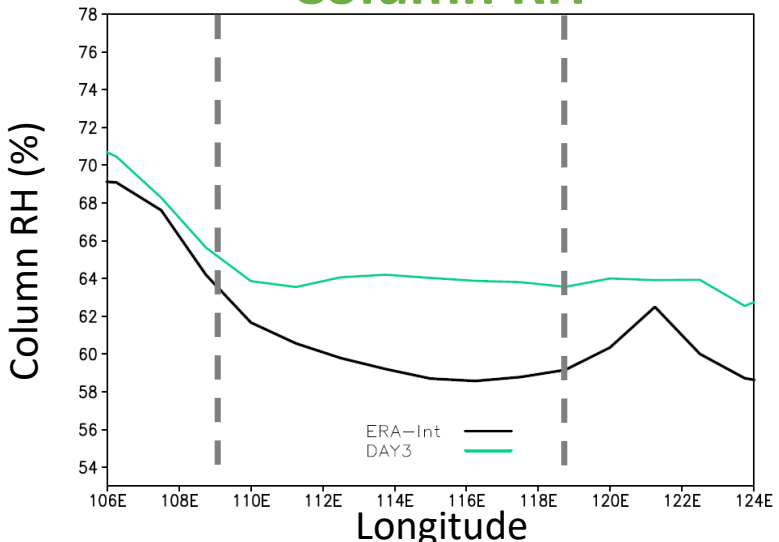

## Precipitation



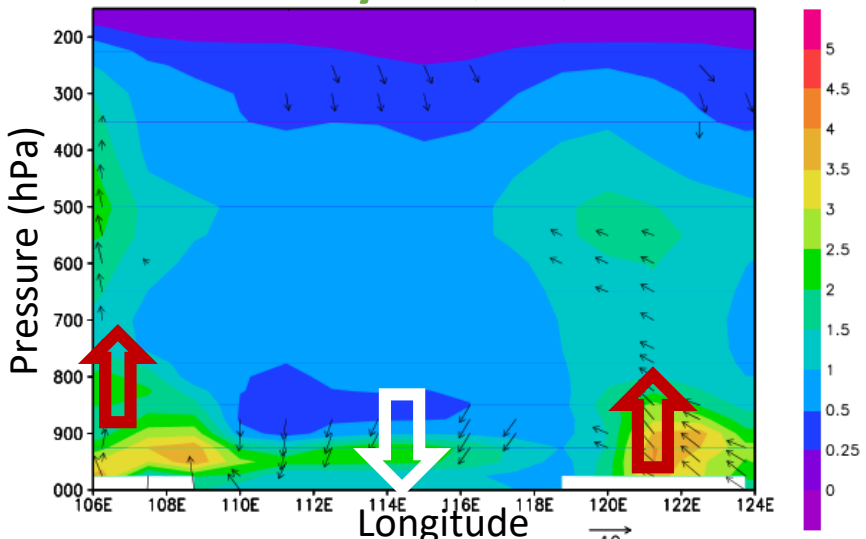

## TRMM Q1-QR & ERA-I w




## Column RH




## CAPT Day 3 Q1-QR & w

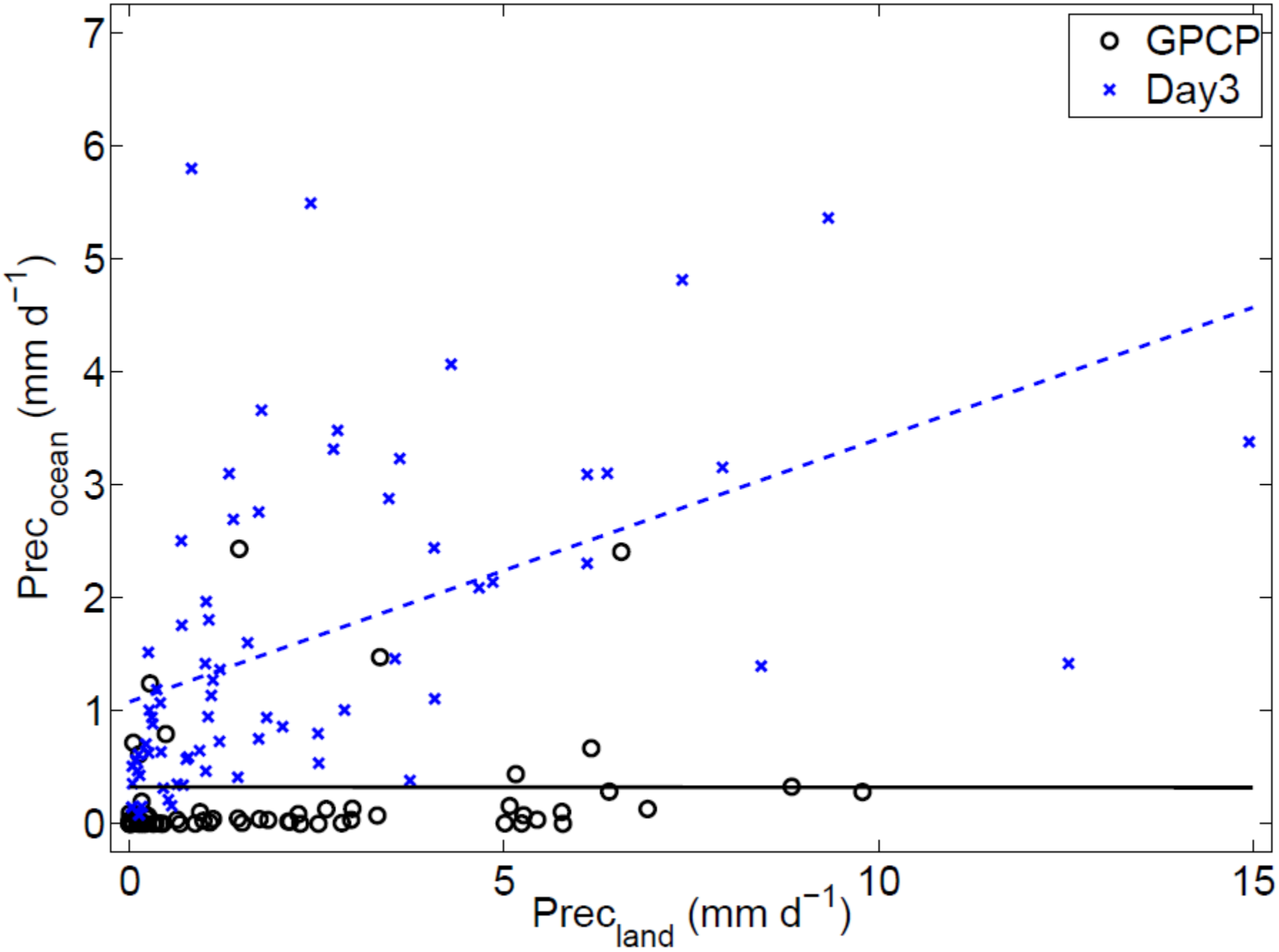



Conditional sampling for days with subsidence over open ocean in ERA-I

**Pre-onset daily mean precipitation over Philippine land vs. over SCS ocean, only for the days when SCS ocean areas exhibit low-level subsidence:**

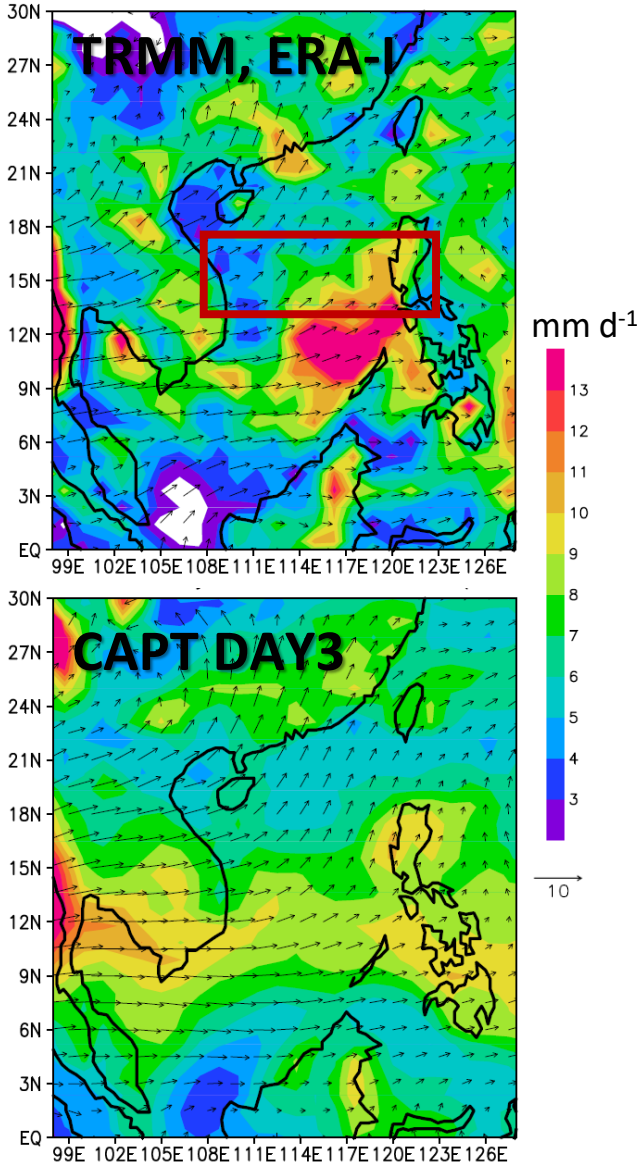
**Observation:**
**strong land precip – low/no ocean precip**

**CAPT:**
**strong land precipt – strong ocean precip**

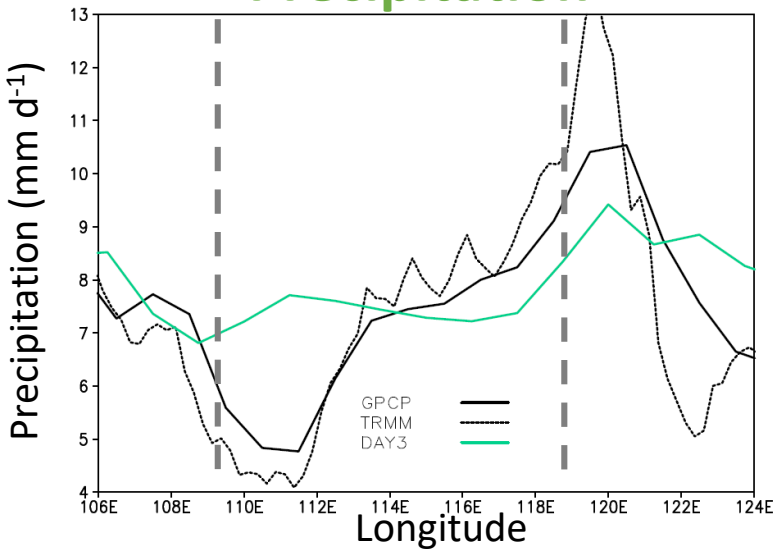


# Post-onset: Costal organized convection system

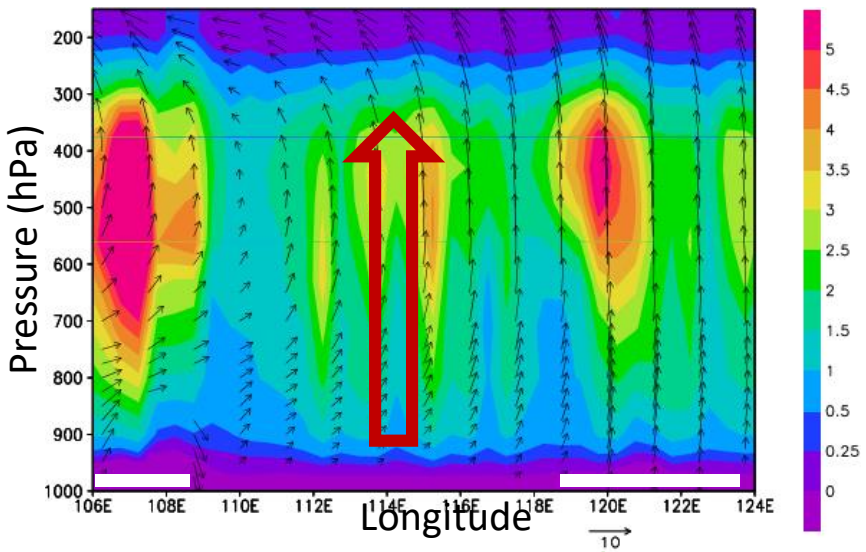
- **Rainfall over the W Philippines weaker and less concentrated in hindcast (smaller E-W gradient)**
- **Less organized costal convection system;, with strong upper level heating (stabilizing effects)**



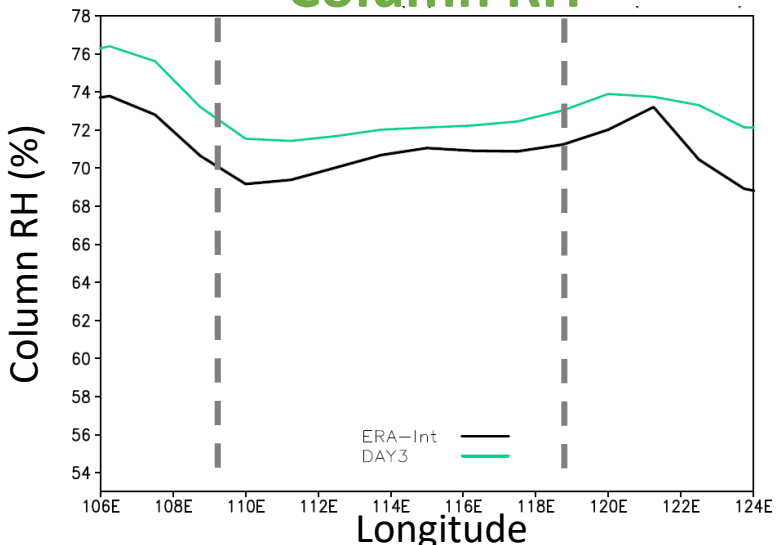

## Precipitation



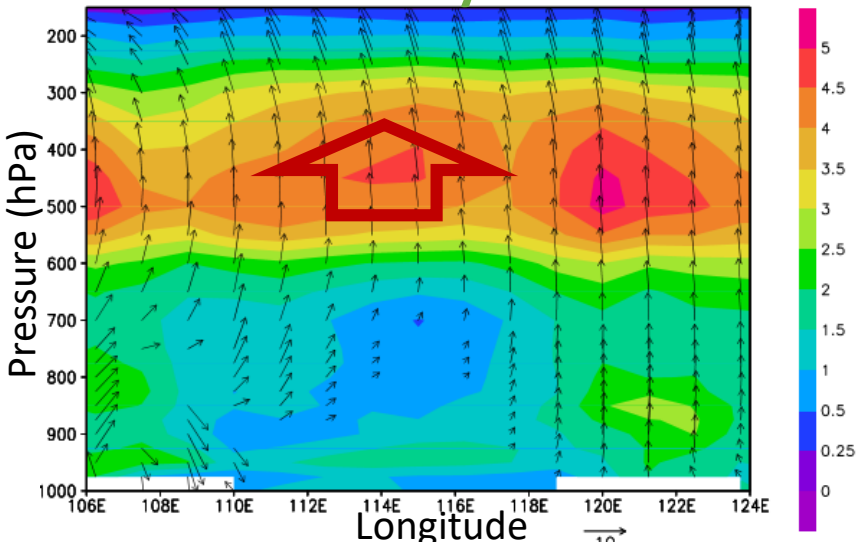

## ERA-I ω'




## Column RH




## CAPT Day 3 ω'




Exclude year 2006 due to TC

# Diurnal cycle of Convection over land is under-simulated

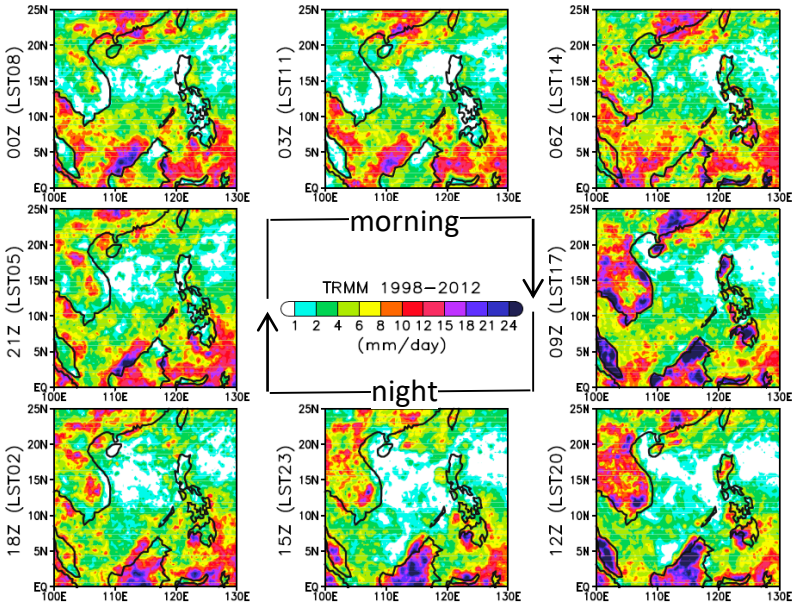
**Land DC biases are similar pre- and post-onset**

- **Weaker amplitude**
- **Earlier peak time**
- **Longer duration but weaker rainfall**

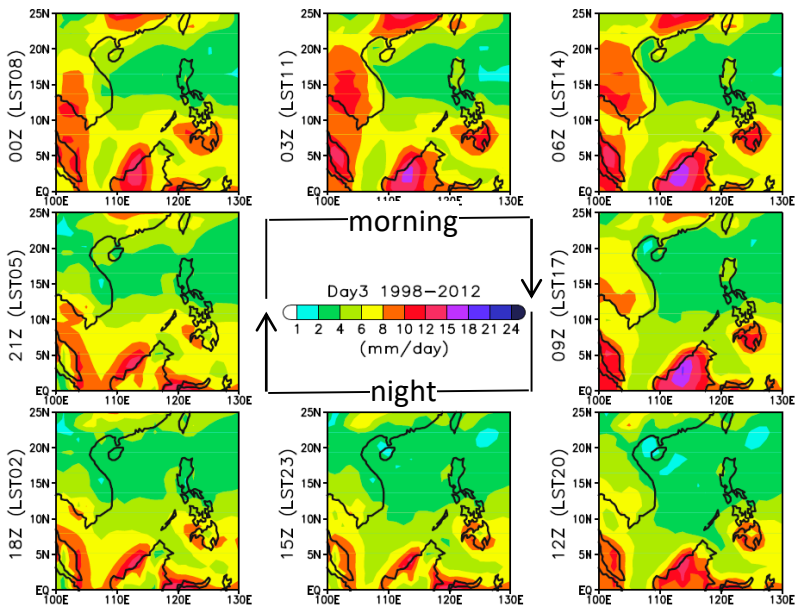
**Bias in post-onset coastal system DC**

- **No E-W contrast**

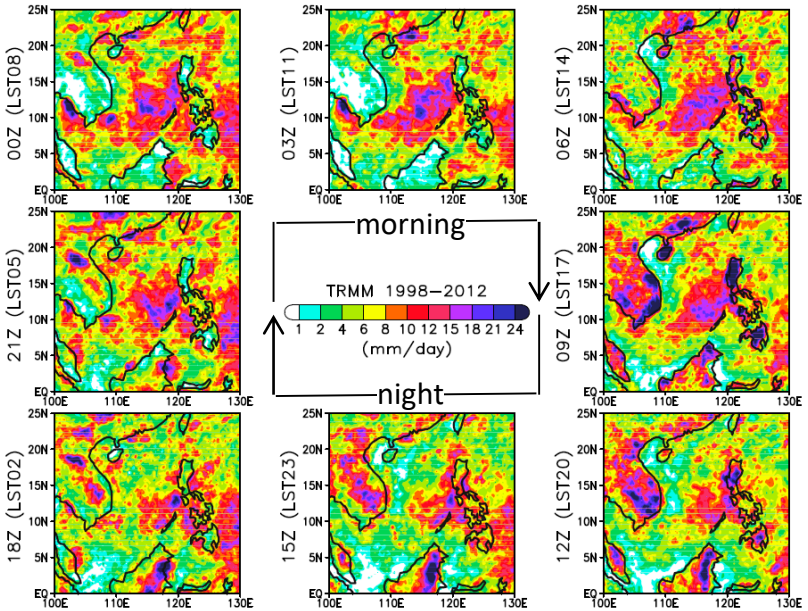
## Pre-onset, TRMM



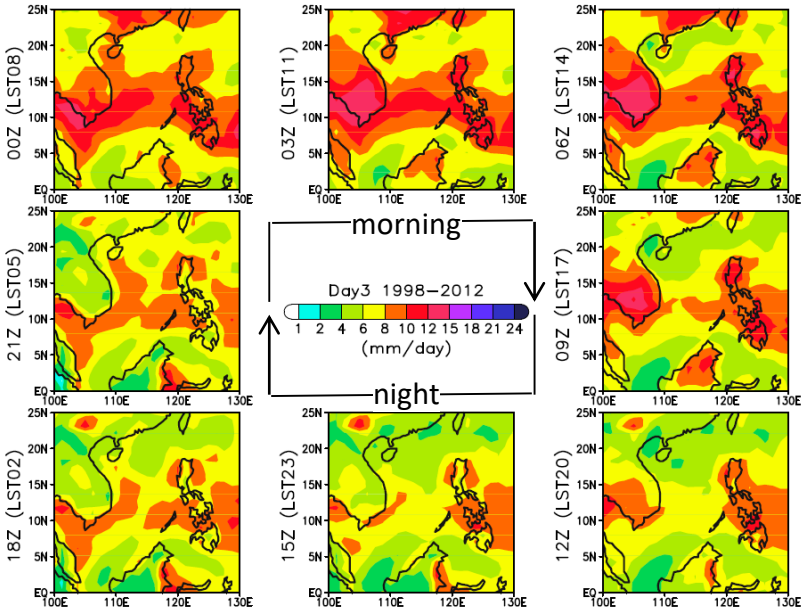

## Pre-onset CAPT Day3




## Post-onset, TRMM

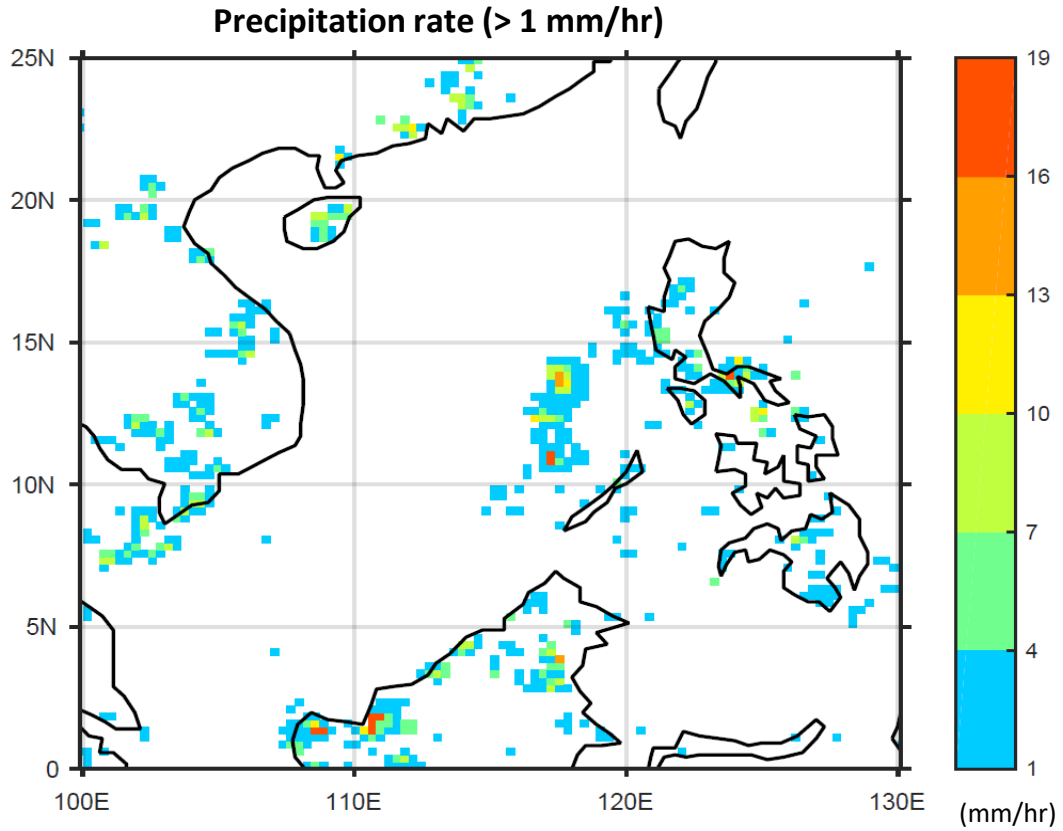


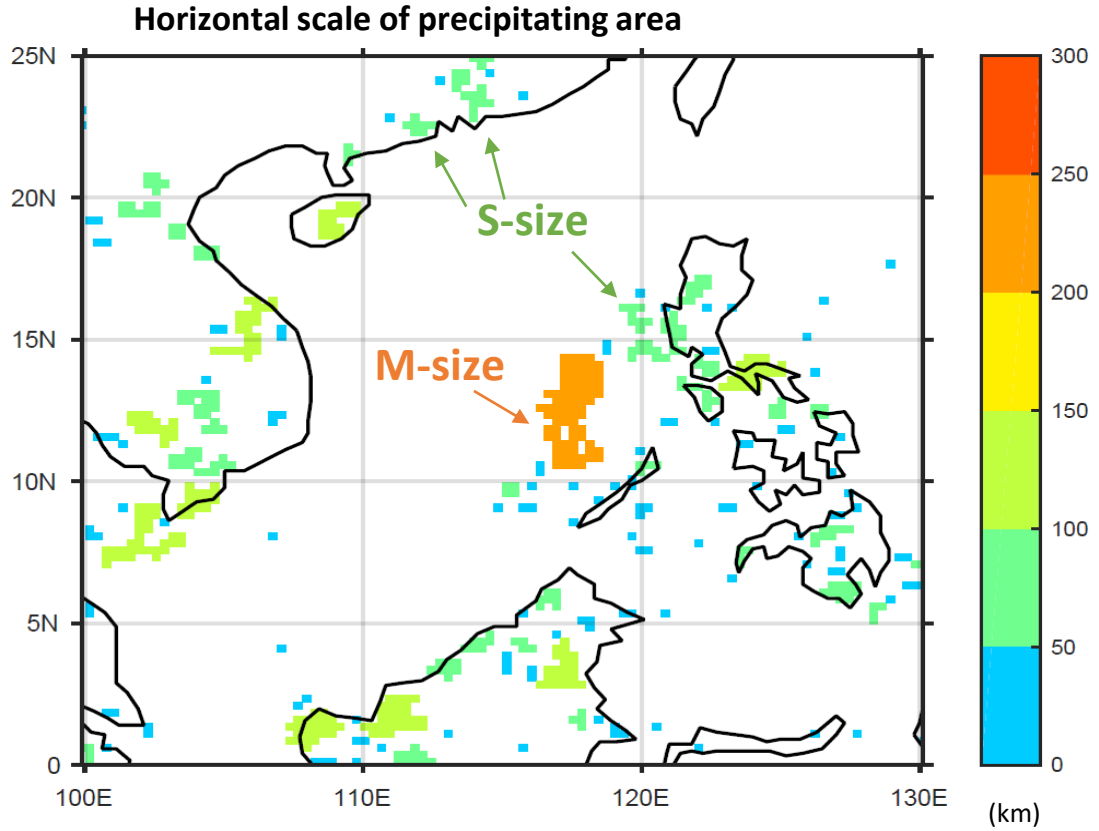

## Post-onset, CAPT Day3



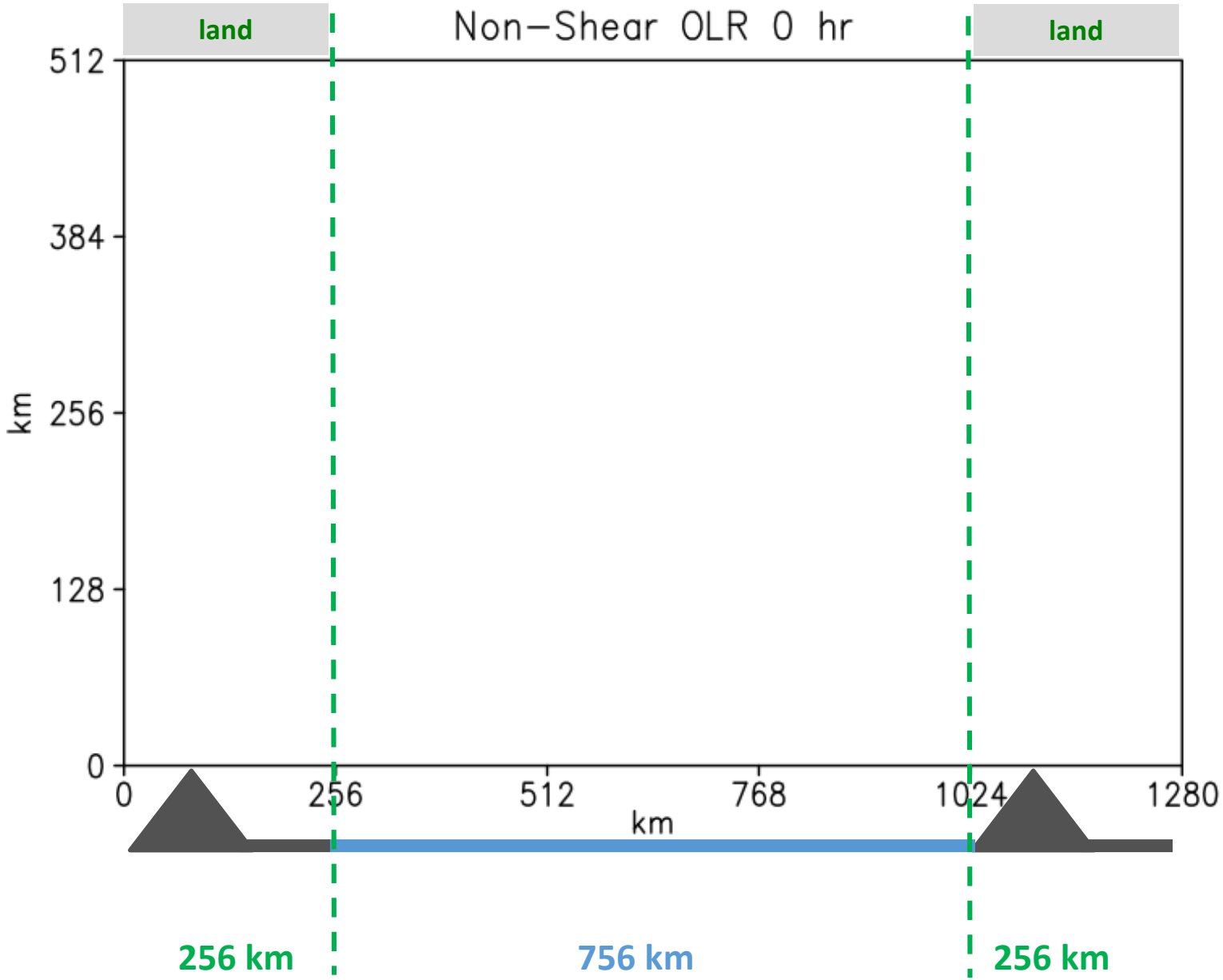
# Quantify the size of precipitating objects in TRMM 3B42

- Identify object-based precipitating systems (OPS) by contiguous TRMM 3B42 pixels with precip. **> 1 mm/hr** using the four-way connection segmentation method [Tsai and Wu, 2016]
- Horizontal size scale = $\sqrt{Area\ of\ precipitating\ object}$
  S (<100km), M (100-300km) and L (>300km)



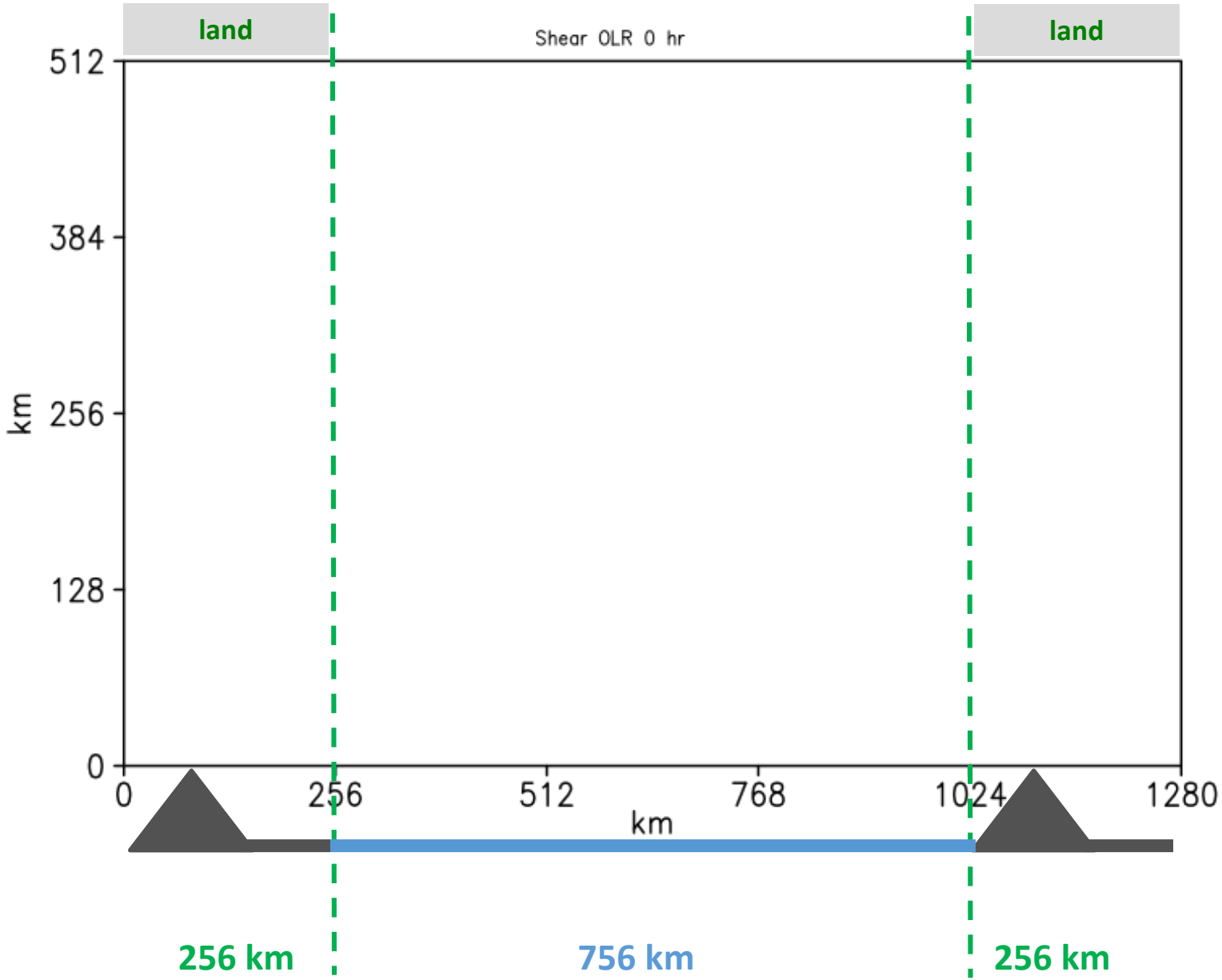



# 10-day evolution of OLR, no vertical wind shear imposed




(blue=high cloud top)

# 10-day evolution of OLR, with vertical shear (low-level westerly)




(blue=high cloud top)