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

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[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]
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)

<table>
<thead>
<tr>
<th>Land-ocean thermal contrast</th>
<th>Large-scale circulation</th>
<th>Climate variability</th>
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<td>(e.g., Zhou &amp; Zou, 2010)</td>
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<td>SST and air-sea coupling</td>
<td>Moist convection</td>
<td>Orography</td>
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<td>(e.g., Bollasina &amp; Nigam, 2009; Levine et al., 2013; Levine &amp; Turner, 2012; Marathayil et al., 2013; DeMott et al., 2011)</td>
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<td>Land surface flux</td>
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<td>(e.g., Samson 2016; Terry et al., 2017)</td>
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- 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]
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 each year 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]
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]
Observed Occurrence of Precipitation Objects by Size

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

Pre-onset:
- Mostly over land (S- and M-size)

Post-onset:
- Over ocean mainly L-size
- Over land mainly M-size

[Chen et al., 2019, JMSJ, in revision]
Insufficient Sensitivity of Precipitation to Column RH

- 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]
Zonal Vertical Profile of $Q_v$ and Cloud Fraction

Ocean Mean Subsidence Profile

Coastal Convection, Basin-scale Circulation, and Ocean CWV

Evolution of Ocean Mean CWV

[Chen et al., 2019, JMSJ, in revision]
Similar bias may exist over other coastal monsoon regions

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

- 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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NCAR CAM5 Asian Monsoon (AMIP simulation)

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

Monsoon onset: Pentad at FA = 0.2

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

Based on Sperber and Annamalai [2014 CD]
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
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, ERA-I**
- **CAPT DAY3**

### Column RH

- **CAPT Day 3 Q1-QR & w**

### TRMM Q1-QR & ERA-I 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 precip – 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)

Excluding 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
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 = $\sqrt{\text{Area of precipitating object}}$

S (<100km), M (100-300km) and L (>300km)
10-day evolution of OLR, **no vertical wind shear imposed**
10-day evolution of OLR, with vertical shear (low-level westerly)

(blue=high cloud top)