Factors affecting the distribution of tropical precipitation in CMIP5 models and their effects to future projections

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\begin{itemize}
  \item Takayabu et al. (2010; \textit{J. Climate})
  \item Hirota et al. (2011; \textit{J. Climate})
  \item Hirota and Takayabu (in revision; \textit{Climate Dynamics})
\end{itemize}
Studies on Future Climate Projection of the Asian Region Utilizing CMIP5 Multi-Model Ensemble Data (June 2012-March 2015)

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4. Ryuichi Shirooka, JAMSTEC
5. Yoshio Kawatani, JAMSTEC

Succession of Theme2/S-5 project (2007-2012)
CMIP3 intercomparison in phenomena basis
1. Intense precipitation and large-scale environment in the Asia.

2. Seasonal change of Precipitation in the Asia and its relationship to land surface and ocean surface conditions

3. Conveying climate model information to downscaling studies

4. Effect of tropical convection to precipitation in the Asia

5. Stratosphere-troposphere circulation and Asian climate

CMIP5

Future Projection

Evaluations based on Meteorological Consistency

Obs. Data

Obs. Data

Obs. Data

Obs. Data

Obs. Data

CMIP5

Historical Run

Downscaling (SOSEI Project)

Exchange info

Extract more accurate information about future projection of atmospheric phenomena related to precipitation and clouds in the Asian Region

Project Structure
Factors affecting the distribution of tropical precipitation in CMIP5 models and their effects to future projections

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• Takayabu et al. (2010; \textit{J. Climate})
• Hirota et al. (2011; \textit{J. Climate})
• Hirota and Takayabu (in revision; \textit{Climate Dynamics})
Background

Proper representation of precipitation over tropical oceans are essential for accurate simulation of atmospheric general circulation.

Tropical precipitation is controlled by SST
• Cumulus convection is enhanced with higher SST

Humidity in mid-troposphere
• Observations suggest the significant suppression of deep convection from the entrainment of dry environmental air.

(e.g. Yonenama and Fujitani 1995; Numatuti et al., 1995: Brown and Zhang, 1997: Sherwood, 1999; Bretherton et al. 2004; Takayabu et al. 2010, JC)
While congestus responds linearly to SST, obedient to low-level instability, deep rain is controlled by another factor.

When heating profiles are stratified with vertical velocity, we can see mid-tropospheric dryness associated with subsidence strongly suppresses deep convection.
Well known biases in climate models

**Double ITCZ (DI) bias**
- SST
- Convective parametrization
  - Sensitivity of deep convection to the mid-tropospheric humidity. (Hirota et al. 2011, JC)
  
**DI index** (Bellucci et al. 2010)
  Precipitation (150-100W, 20S-Eq)

**Cold Tongue (CT) bias**
- Ocean Model Resolution
- Trade winds (Meehl et al. 2001)
  
**CT index**
  SST (180-150W, 3S-3N)
CMIP5 precipitation

TRMM

precipitation maps for various models:

- HadGEM2-CC
- CCSM4
- MIROC4h
- GFDL-CM3
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- HadCM3
- inmcm4
- CanESM2
- CNRM-CM5
- NorESM1-M
- bcc-csm1-1
- MRI-CGCM3
- GISS-E2-R
- GISS-E2-H

The color bar represents [mm/day] ranging from 1 to 8.5.
Objectives

- Examine reproducibility of tropical precipitation by comparing CMIP3 and CMIP5 dataset, focusing on DI & CT biases.
- Discuss its relationship to
  - Sensitivity of cumulus convection to environmental conditions
  - Ocean model resolution
- Examine the effects of a model selection based on physical factors to the future projection.
Data

Climate Models
CMIP5 (historical; RCP45)
CMIP3 (20C3M; A1b)

Obs.
TRMM PR2A25 /HadISST/JRA25

Current Climatology: 1981-2000
(TRMM: 1998-2007)
Future projection: 2081-2100
Season: All Year
Domain: Tropical oceans (30S-30N)

(Model with flux adjustment in CMIP3 are excluded.)
CMIP5 VS CMIP3
Taylor score for precipitation distribution (30S-30N ocean)

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

**CMIP3**
- **LowScoreModels**
- **HighScoreModels**

**CMIP5**
- **LowScoreModels**
- **HighScoreModels**

Average=0.60

Average=0.64
Double ITCZ bias stands out in CMIP3/LSM
DI index = 3.80 mm/day (>> 1.40 mm/day in observation)

Cold tongue bias stands out in CMIP5/LSM
CT index = 26.5 °C (<< 27.9°C in observation)
Scores for Double ITCZ and Cold Tongue

In CMIP5 ensemble,

- Number of models with severe double ITCZ is reduced.
- Cold tongue bias stands out, since CT index remains similar.
WHAT CONTROLS THE DOUBLE ITCZ BIAS?
Precipitation (TRMM PR) in RH600-Tsfc diagram

Precipitation tends to be more sensitive to RH600 than to SST

Precipitation Sensitivity Index:
Taylor score of RH600-Tsfc diagram referring to this observation
CMIP5 Intercomparison with Precipitation Sensitivity Index

TRMM PR vs JRA25

Good models are sensitive to the RH600. Poor models are either more sensitive to SST or PDF is not good.

5 High Score Models in the Precipitation Sensitivity Index

5 Low Score Models in the Precipitation Sensitivity Index
Comparison of Precipitation Distribution against Precipitation Sensitivity Index

5 High Score Models in the Precipitation Sensitivity Index

We can see much improved ITCZ structure in selected models
Proper representation of the sensitivities is important for improving DI.
WHAT CONTROLS THE COLD TONGUE BIAS?
Possible causes: Higher resolution models can simulate tropical instability waves (Robert et al. 2011), or circulations & thermal structure in the equatorial Pacific (Zheng et al. 2012) more accurately.
Selection of Models for Future Projection

Methodology:
An average of 5 Good models selected as
- Good representation of prcp sensitivity to RH600 & Tsfc
- Higher ocean model resolution
are compared with the all CMIP5 model ensemble average.

Previous Studies show
Weakening of Walker circulation.

<table>
<thead>
<tr>
<th>Model</th>
<th>Rep of prcp sensitivity</th>
<th>Ocn model Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIROC5</td>
<td>0.86</td>
<td>1.07</td>
</tr>
<tr>
<td>GFDL–ESM2G</td>
<td>0.85</td>
<td>0.93</td>
</tr>
<tr>
<td>MIROC–ESM</td>
<td>0.85</td>
<td>1.15</td>
</tr>
<tr>
<td>NorESM1–M</td>
<td>0.84</td>
<td>0.73</td>
</tr>
<tr>
<td>CSIRO–Mk3–6–0</td>
<td>0.84</td>
<td>1.88</td>
</tr>
<tr>
<td>MIROC–ESM–CHEM</td>
<td>0.83</td>
<td>1.15</td>
</tr>
<tr>
<td>FGOALS–s2</td>
<td>0.80</td>
<td>0.96</td>
</tr>
<tr>
<td>HadGEM2–CC</td>
<td>0.79</td>
<td>0.91</td>
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<tr>
<td>MPI–ESM–LR</td>
<td>0.79</td>
<td>1.08</td>
</tr>
<tr>
<td>inmcm4</td>
<td>0.78</td>
<td>0.73</td>
</tr>
<tr>
<td>GFDL–ESM2M</td>
<td>0.78</td>
<td>0.95</td>
</tr>
<tr>
<td>CanESM2</td>
<td>0.78</td>
<td>1.15</td>
</tr>
<tr>
<td>CNRM–CM5</td>
<td>0.77</td>
<td>0.78</td>
</tr>
<tr>
<td>MRI–CGCM3</td>
<td>0.67</td>
<td>0.70</td>
</tr>
<tr>
<td>bcc–esm1–1</td>
<td>0.64</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Red = 5 selected good models
Blue = 5 low resolution models
Strikethrough = 5 models not sensitive to RH600
Significantly larger weakening of Walker circulation is projected in the Selected average.
Summary

- Compared to CMIP3, Taylor skill score for distribution of tropical precipitation of CMIP5 models is slightly improved.
  - Double ITCZ bias is reduced, but Cold Tongue bias remained.
- Double ITCZ bias is closely related to sensitivity of deep convection to mid-tropospheric humidity.
  - A Precipitation Sensitivity Index is proposed.
- Cold Tongue bias is related to Ocean model resolution.
- Selection of models based on evaluations of physical factors is effective and results in significant differences in future projection: larger weakening of Walker Circulation in this case.

Hirota and Takayabu (in revision; Climate Dyn.)
Messages

• Selection of the models should be based on understanding of physical factors causing the biases.

• Selection of a climate model ensemble based on physical factors works effectively to reduce the current climate simulation biases, and results in significant differences in future projections of general circulations.
Thank you
Research Subjects
Various Phenomena related to precipitation change in the Asia

1. Intense precipitation and large-scale environment in the Asia.
2. Seasonal change of Precipitation in the Asia and its relationship to land surface and ocean surface conditions
3. Conveying climate model information to downscaling studies
4. Effect of tropical convection to precipitation in the Asia
5. Stratosphere-troposphere circulation and Asian climate
Convective Heating vs RH at 600 hPa

In CMIP3 models without DI, deep convection is more sensitive to the mid-tropospheric humidity (Hirota et al. 2011, JC).

→ Similar results in CMIP5
Background

Proper representation of precipitation over tropical oceans are essential for accurate atmospheric general circulation.

Tropical precipitation is controlled by SST

• Cumulus convection is enhanced with higher SST

Humidity in mid-troposphere

• Entrainment of dry environmental air to convection effectively suppresses deep convection (Takayabu et al. 2010, JC; ...).

Well known biases in climate models

• Double ITCZ bias
• Cold tongue bias
Double ITCZ bias

- SST bias
  - Coastline
  - Upwelling
  - WISHE
  - low level cloud
    (Mechoso et al. 1995; ...)
- Convective parametarization
  - Sensitivity of deep convection to the mid-tropospheric humidity is too weak.
    (Hirota et al. 2011, JC; ...).

Double ITCZ Index (Bellucci, 2010):
Precipitation averaged over southeastern Pacific (150-100W,20-0S)
Cold tongue bias

- Tropical instability waves (Robert et al. 2009)
- Ocean circulations & thermal structure (Zheng et al. 2009)
- Trade winds (Meehl et al. 2001)

Cold Tongue Index:
SST over the equatorial central Pacific (180-150W,3S-3N)
(SST bias over entire tropical oceans is removed.)
Convective Heating vs RH at 600 hPa

In CMIP3 models without DI, deep convection is more sensitive to the mid-tropospheric humidity (Hirota et al. 2011, JC).

Sensitivity of deep convection to humidity is increased from CMIP3 to CMIP5.
Ocean resolution?

high <= Resolution of ocean model => low (degree)

GISS_E_R & GISS_AOM with ~4deg. are excluded.
Ocean resolution?

SST of EC Pac. (180-150W, 3S-3N) dev. from trop.

Resolution of ocean model (degree)

CMIP3

CMIP5

Resolution of ocean model (degree)

corr = 0.41

corr = -0.70

Stronger <= cold tongue => weaker

Resolution of ocean model (degree)
マルチモデル間EOF

EOF1 (20%)

EOF2 (14%)

ダブルITCZインデックス

EOF1 ⇌ DI index
EOF2 → Cold Tangue
EOF1

CMIP3 (28%)

CMIP5 (20%)

PC大

PC小

PC大

PC小
EOF2

CMIP3 (16%)  

CMIP5 (16%)

PC大  

PC小  

PC大  

PC小
10-year mean Q1-QR & SST  JJA 98-07

Deep Organized Systems

(Takayabu et al. 2010)