East Asian Summer Monsoon in a Warming World: Forcing from GHG, Aerosol and Natural variability

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WCRP-JNU Training School on Monsoon Variability in Changing Climate
15-21 Jan 2017, Juju National University
Outline

- Background
- Natural variability driven by PDO
- Response to GHG and aerosol forcing
- Detectable Anthropogenic Shift toward Heavy Precipitation over Eastern China
- Summary
What is a Stronger Summer Monsoon?

Monsoon: a seasonal reversal of surface wind
Without monsoon, EA would be covered by deserts

However, monsoon has been weakening in the 2\textsuperscript{nd} half of 20\textsuperscript{th} century
Decadal Changes of summer rainfall (After BCC, 2010)

Monsoon Weakening

1970S
Changes of EASM: Local Pattern

EA summer monsoon circulation index

JJA Rainfall anomalies

South-to-North Water Diversion Project

Transport water from YZ river to N. China by channels

http://www.nsbd.gov.cn/zx/english/
South-to-North Water Diversion Project

(http://www.nsbd.gov.cn/zx/english/20070308/)
Why did the monsoon show a weakening tendency:

Possible Mechanisms

- Tibetan Plateau thermal forcing,
- internal variability,
- global warming, etc.
- PDO
- Aerosol forcing,
- Up to now: No consensus.

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PDSI index in N. China and PDO index over the 20th century

EEMD analysis of PDSI and PDO indices

**AMIP-type simulation is used to understand the driving of SST**

<table>
<thead>
<tr>
<th></th>
<th>CAM3 (T85)</th>
<th>CAM3 (T42)</th>
<th>AM2.1 (FV)</th>
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<tr>
<td>GOGA</td>
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<tr>
<td>ATM</td>
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</tbody>
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**Definition of EASM Index:**

Normalized zonal wind shear between 850 and 200 hPa averaged within (20-40N,110-140E)  (After Han and Wang, 2007)

Land-Sea Thermal Contrast change


Reanalysis

Global SST-forcing

Tropical SST-forcing

Precipitation: Mean State and Inter-decadal change

GFDL AM2.1

(a) AM2.1 GOGAI
1950-1976 mean

(b) CAM3 GOGAI
1950-1976 mean

NCAR CAM3

(c) AM2.1 GOGAI

(d) CAM3 GOGAI
Data diagnosis reveals an out of phase change of E. Asian summer monsoon circulation and PDO at inter-decadal time scale. This relationship is evident in both the past 50 yrs and the 20th century.

When driven by historical SST, the AGCMs are able to reproduce to weakening tendency of E. Asian summer monsoon circulation. The response is dominated by the tropical lobe of PDO/IPO.

The simulation of monsoon rain band changes remains to be a challenge.

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Trend in Sunshine Duration (1954-1998) (Kaiser and Qian, 2002)

Most stations: -2 to -3 %/decade
Average: -1.0%/decade
Black carbon

Δ Precipitation (mm/d)  Experiment A

Menon et al. (2002): Science
### Model and Experiments

#### Definition of EASM Index:

Normalized zonal wind shear between 850 and 200 hPa averaged within (20°-40°N, 110°-140°E) (After Han and Wang, 2007)


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</table>
Weakness of the Experiment:

Stand alone AGCM and only the direct effect of aerosol is considered

New CMIP5 models

We examined the responses of East Asian summer monsoon (EASM) to natural (solar variability and volcanic aerosols) and anthropogenic (greenhouse gases and aerosols) forcings simulated in the 17 latest Coupled Model Intercomparison Program phase 5 (CMIP5) models with 105 realizations.
The details of 17 CMIP5 models

<table>
<thead>
<tr>
<th>No.</th>
<th>Model</th>
<th>Institute</th>
<th>Atmospheric resolution (lat*lon)</th>
<th>Member (35)</th>
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<tr>
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<td>CanESM2</td>
<td>CCCma/Canada</td>
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<td>GFDL-ESM2M</td>
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<td>MIROC-ESM</td>
<td>MIROC/Japan</td>
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<th>No.</th>
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<th>Natural forcings</th>
<th>Anthropogenic forcings</th>
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<td>SOLARIS</td>
<td>A</td>
</tr>
</tbody>
</table>

S: Sato et al. (1993); E: Emission is given; A: Ammann et al. (2003); C: Concentration is given.
## Details of three sets of CMIP5 experiments

<table>
<thead>
<tr>
<th>Experiment description</th>
<th>CMIP5 label</th>
<th>Major purposes</th>
<th>Short name</th>
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<tbody>
<tr>
<td>Past ~1.5 centuries (1850–2005)</td>
<td>historical</td>
<td>Evaluation</td>
<td>All-forcing</td>
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<tr>
<td>historical simulation but with GhG forcing only</td>
<td>historicalGHG</td>
<td>Detection and attribution</td>
<td>GHG-forcing</td>
</tr>
<tr>
<td>historical simulation but with natural forcing only</td>
<td>historicalNat</td>
<td>Detection and attribution</td>
<td>Natural-forcing</td>
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- **According to Taylor et al. (2009), anthropogenic-forcing** is estimated by All-forcing run minus Natural-forcing run.
- **Aerosol-forcing** is estimated by Anthropogenic-forcing run minus GHG-forcing run. 105 realizations are analyzed.

Multi-variate EOF1 of SLP and 850 hPa winds

• EOF1 features a weakening during 1958-2001, recovered since 1990s.

• Above features are evident in the simulation.

The observed southward shift of East Asian subtropical jet (EASJ) has been reproduced in all-forcing runs but with weaker magnitude.

- The southward shift of western part is attributed to aerosol-forcing, while the southward shift of eastern part is attributed to natural-forcing.
- The EASJ has intensified in the GHG-forcing runs.

The linear trends of surface air temperature (58-01)

- Aerosol forcing has led to the cooling over C. China

Higher SLP in N. China and surface cooling in central China

Surface cooling → weaker land-sea thermal contrast and higher SLP. →
Weakened monsoon circulation.
The specified external forcing agents only account for **25.6%** of the observed monsoon weakening.
The linear trends of precipitation during 1958-2001

• Weakness: CMIP5 models are unable to reproduce the precipitation anomalies due to their low resolutions

Point # 2

- The observed weakening trend of low-level EASM circulation during 1958–2001 is *partly and weakly* reproduced under all-forcing runs. A comparison of separate forcing experiments reveals that the aerosol forcing plays a primary role in driving the weakened low-level monsoon circulation.

- The preferential *cooling over continental East Asia* caused by aerosol affects the monsoon circulation through reducing the *land-sea thermal contrast* and results in *higher sea level pressure* over northern China.

- The increasing GHG forcing is favorable for an enhanced monsoon circulation.

- The models still failed in the simulation of monsoon rainband changes.

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Objectives

Are the observed changes in the amount distributions of Eastern China precipitation caused by external forcings and thus detectable?

Observation and Model Data

**Observation**: daily Rain-gauge data from CMA

**CMIP5 20c historical climate simulation**:

- **ALL forcing run**: 11 models, 54 ensemble members
- **ANThropogenic forcing**: 6 models, 26 members
- **GHG forcing**: 10 models, 34 members
- **AA forcing**: 8 models, 22 members
- **NATural forcing**: 11 models, 37 members
- **PI control**: 10 models, ~6000 yrs

Optimal fingerprinting Method

Optimal fingerprinting--Total least squares detection method

\[ y = \sum_{i=1}^{m} (X_i - \nu_i) \beta_i + \nu_0 \]

• \(y\), observed trend, a rank-\(n\) vector, where \(n\) is the number of daily precipitation intensity bins, with \(n=20\) used in this analysis;

• \(X\), fingerprints or anomalous signals, model simulated climate responses to external forcings, a matrix with one column for each external climate forcing;

• \(\nu_i\), sampling noise, estimated from the preindustrial control simulations and intra-ensemble differences;

• \(\nu_0\), noise in the observations

• \(\beta\), scaling factors, inconsistent with 0 indicate a detectable signal, consistent with 1, then the model-simulated response patterns are consistent with the observed changes.
Trend of PDF in precipitation amount

Observation: a shift toward heavier precipitation
Simulation: The observed shift is well simulated with anthropogenic forcings.
**Light precipitation**: daily precipitation falls into the lowest 35% intensity bins.

**Decreasing trend in observed light precipitation.** The simulations with GHG forcing show similar behavior as the observations.
Heavy precipitation: daily precipitation falls into the top 10% intensity bins.

Observation: increasing trend in heavy precipitation

Simulations: Similar behavior as the observations in the simulation with GHGs.
The observed decrease in light precipitation mainly come from the contribution of GHG forcing. Anthropogenic aerosols partly offset the contribution of the GHGs.
The observed increase of heavy precipitation is dominated by the GHG forcing.
ANT forcing determines the forced changes in the ALL forcing run.

The detected responses in ALL and ANT forcing runs are dominated by GHG forcing.

Solid symbols: best estimates of regression coefficients ($\beta$);

Solid error bars: 5-95% uncertainty ranges of $\beta$;

Dashed error bars: 5-95% uncertainty ranges of $\beta$ when the internal variability is doubled.
The detectable effect of **ANT forcing** can be separated from **NAT forcing**.

The detectable effect of **GHG forcing** can also be separated from **AA forcing**.
◆ The anthropogenic forcing has a detectable and attributable influence on the amount distribution of daily precipitation over EC during the second half of the 20th century.

◆ The observed shift from weak precipitation to intense precipitation is due primarily to the contribution of GHG forcing, with AA forcing offsetting some of the effects of the GHG forcing.

◆ Increasing of moisture and changes of monsoon circulation, resulting mainly from GHG-induced warming, favors heavy precipitation over eastern China.
Summary

1. The weakening tendency of EASM during 1950-2000 is driven by the interdecadal changes of Tropical Ocean SSTA, which is a tropical lobe of IPO/PDO.

2. A comparison of CMIP5 separate forcing experiments reveals that the aerosol forcing has driven a weakened monsoon circulation, while the emission of GHG is favorable for a stronger monsoon circulation.

3. The anthropogenic forcing has a detectable and attributable influence on the amount distribution of daily precipitation over EC during the second half of the 20th century.
Some further readings


http://www.lasg.ac.cn/staff/ztj

THANKS
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