Asian Monsoon in a Global Perspective

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Outline

1. Background

2. Overview of GM

3. Responses to external forcings

4. Concluding remarks
The majority of Asian people lives in the southern and eastern part of the continent: a monsoon region with more than 2 billion population.
Monsoon in Asia: Supply of water resources for more than one billion people

Subtropical regions of the world are arid/semi-arid regions except for EA
Monsoon, manifested by wind & rainfall
Seasonal Migration of Tropical Convergence Zone (TCZ)

Annual evolution of daily mean Winds at 850 hPa and Precipitation

Courtesy: Roxy Mathew Koll
Monsoon, manifested by wind & rainfall
Seasonal Migration of Tropical Convergence Zone (TCZ)

Annual cycle of Indian rainfall

Courtesy: Roxy Mathew Koll
East Asian monsoon: Tropical & subtropical parts due to the existence of WPSH

Zhou, T., D. Gong, J. Li, B. Li, 2009: Detecting and understanding the multi-decadal variability of the East Asian Summer Monsoon -- Recent progress and state of affairs. Meteorologische Zeitschrift, 18 (4), 455-467
Why are there monsoons?

Monsoon Annual Cycle – Robust?

- land-sea thermal contrast ($T_s/P_s$ gradient)
- Orography (Tibet – elevated heat source)
  (East Africa – frictional force on cross-equatorial flow)
- Earth’s rotation (Coriolis force)
- Moisture from the tropical Indian Ocean

Courtesy: H. Annamalai
ITCZ – The Global Tropical Conveyor

Semi-Permanent Pressure Systems: January

Semi-Permanent Pressure Systems: July

White lines: Average sea-level pressure
White arrows: Surface wind-flow patterns

Courtesy: Raghu Murtugudde
We should obviously be able to relate the ITCZ to rainy seasons on land.

Courtesy: Raghu Murtugudde
**Figure 6a.** Mean upper tropospheric (200–500 mbar) temperature (degrees Celsius) for the boreal summer (JJA), and boreal winter (DJF), averaged between 1979 and 1992. The boreal summer plot is based on calculations first made by *Li and Yanai* [1996]. Mean columnar temperatures warmer than $-25^\circ$C are shaded.
Boreal winter monsoon

- **H**: High pressure
- **L**: Low pressure
- **Blue Arrow**: Boreal winter monsoon air flow
- **Red Arrow**: Boreal summer monsoon air flow
- **Blue Line**: Nonmonsoon airflow
- **Orange Area**: Boreal winter rainy season
- **Green Area**: Boreal summer rainy season

Courtesy: Raghu Murtugudde
Indian Flood

Reuters

http://assets-cdn.ekantipur.com/images/third-party/natural-disaster
Pakistan Flood

Wuhan Railway Station
Extreme rainfall in Beijing: July 21, 2012

Northern suburb of Beijing

Beijing Subway
Heat Wave in China: Aug 2013
Heat Wave in China: Aug 2013

Shanghai
2008 Jan. cold surge and frozen disasters snowstorm in S. China

From Jan 10 to Jan 31, 2008:
10 provinces affected, 60 people died.
Economic loss more than 53.79 billion RMB
(6 RMB=1 USD)
Monsoon deep convection: S&T interaction, Cloud & Radiation feedback

Bony et al. 2015 Nature Geoscience
Space and time scales in the monsoon

- **Weather**
  - Diurnal cycle
  - Thunderstorms
  - Monsoon depressions

- **Climate Variability**
  - MJO/BSISO
  - ENSO & IOD
  - Monsoon/annual cycle
  - PDO & AMO

- **Climate Change**
  - GHG emissions
  - Aerosol emissions
  - Ice melt?

- **Increasing temporal and/or spatial scale**
  - Hours
  - Days
  - Weeks
  - Months
  - Years
  - Decades
  - Long-term and centuries

Courtesy: Andy Turner
We focus on the monsoon responses to external forcing agents.
1. Background
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1. Monsoon Prec. Intensity:
   (a) **Annual Range**: Local summer Minus Local Winter Prec.
   
   $$\text{AR (Annual Range)} = \text{PR}_{\text{JJA}} - \text{PR}_{\text{DJF}} \text{ (in North Hemisphere)}$$

   $$\text{PR}_{\text{DJF}} - \text{PR}_{\text{JJA}} \text{ (in South Hemisphere)}$$

   (b) **Area averaged local summer Pr at each grid within the present monsoon domain**

   **NHMI**: NH-JJA “monsoon” precipitation
   **SHMI**: SH-DJF “monsoon” precipitation
   **GMI**: NHMI + SHMI

2. Monsoon Domain: **AR >180mm and >35% Total annual rainfall**

   (Wang and Ding 2006 GRL)
Global monsoon domains defined by rainfall

(Wang and Ding 2006 GRL)
Global monsoon domains defined by wind

Defined based on wind
Li and Zeng (2003, 2005)
Seasonal cycles of regional monsoon rainfall

![Maps of regional monsoon rainfall](image)

Courtesy: Raghu Murtugudde
Global monsoon changes
Each regional monsoon has its own characteristics due to its specific land-ocean configuration and orography, and due to differing feedback processes internal to the coupled climate system.

There is coordination among regional monsoons: brought about by the annual cycle of the solar heating.

There are connections in the global divergent circulation and thereby global monsoons: due to mass conservation.
The downward trend in the ISMR

monsoon droughts?

Courtesy: Roxy Mathew Koll
The downward trend in the ISMR

Figure 1 | Summer monsoon precipitation trends for the years 1901-2012. Observed trend in precipitation (mm day$^{-1}$ 112 year$^{-1}$) in (a) IMD and (b) CRU datasets, during June-September, for the years 1901-2012. Contours denote regions significant at the 95% confidence level.

Roxy et al. 2015, Nature Communications
Downward trends in East Asian and African monsoons

Hoerling et al. (2006) J. Climate

Zhou et al. (2009) Meteorologische Zeitschrift
Linear trend in summer rainfall in the post--1950 period is plotted at 0.5 mm/day/century interval in the 0.5° resolution CRU TS 3.1 data; zero-contour is omitted. The South-Flood North-Dry pattern is manifest.

Changes of East Asian and global monsoon

Changes of land monsoon area and total rainfall (1948-2003)

Regional monsoon rainfall changes


Monsoon Area  Intensity  Amount

Changes of global land monsoon precipitation

Global and NH land monsoon:
1) upward trend during 1901-1950s (95% confidence)
2) downward trend from 1950s to 1980s (95% confidence)
3) Recovering since the 1980s

(Zhang and Zhou, 2011, Clim Dyn.)
The corresponding observational ARI shows increasing tendency for 1979-2011.

All five reanalysis datasets show similar but stronger increasing trends than the observation.

All five reanalysis can reproduce the observed positive anomalies in Australian monsoon region and northern part of Asian region.

Changes of global land monsoon precipitation

**global land and ocean**: upward trend for 1979-2009 (95% confidence level)

(Wang et al. 2012 Clim Dyn.)
The GM saw decadal variability in the 20th century, with a strengthening trend prior to the 1950s, a weakening trend during the 2nd half of the century.

An enhanced trend of Global land monsoon is witnessed since the 1980s up to present.
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GHG & Aerosols
The red, green, blue, and yellow lines are for the ensemble-mean all-forcing (ALL_F), aerosol-only (AERO), greenhouse gases and ozone-only (WMGGO3), and natural forcing-only (NAT) CM3 historical integrations, respectively.
Spatial patterns of the 1950–1999 least-squares linear trends of the June-September average precipitation [mm day$^{-1}$ (50 years)$^{-1}$]
Observations show that South Asia underwent a widespread summertime drying during the second half of the 20th century, but it is unclear whether this trend was due to natural variations or human activities.

A series of climate model experiments is used to investigate the South Asian monsoon response to natural and anthropogenic forcings. The observed precipitation decrease can be attributed mainly to human-influenced aerosol emissions.

The drying is a robust outcome of a slowdown of the tropical meridional overturning circulation, which compensates for the aerosol-induced energy imbalance between the Northern and Southern Hemispheres.

These results provide compelling evidence of the prominent role of aerosols in shaping regional climate change over South Asia.

Bollasina et al. 2011 Science
How about the East Asian summer monsoon?
<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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<td>BCC/China</td>
<td>64*128</td>
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<tr>
<td>2</td>
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<td>BNU/China</td>
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<td>CCCma/Canada</td>
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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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</thead>
<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>
</tr>
</tbody>
</table>

• 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.

Linear trends of SLP and 850 hPa winds (1958-2001)

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.

Detection and Attribution as Forensics

Detection: finding something out of the ordinary – a "signal" emerging from the noise

Attribution: determining the cause of the detected trend

Volcanoes, Solar, CO₂ Emissions
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
- PIcontrol: 10 models, ~ 6000 yrs

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.

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 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.
Volcanic aerosols
Summer climate after large volcanic eruptions

Changes under Global warming
The global monsoon area will expand mainly over the central to eastern tropical Pacific, the southern Indian Ocean, and eastern Asia.

GMP: global monsoon total precipitation

- GMP shows an increase in the RCP4.5 scenario and more so in the RCP8.5 scenario
- Monsoon-related precipitation will significantly increase in a warmer climate

Future change ratio of Pav, SDII, R5d and DD over E. Asia

Blue: RCP4.5  Red: RCP8.5

shading: Precipitation
vector: vertically integrated water vapor flux

1. The global monsoon area defined by the annual range in precipitation is projected to expand mainly over the central to eastern tropical Pacific, the southern Indian Ocean, and eastern Asia.

2. The global monsoon precipitation intensity and the global monsoon total precipitation are also projected to increase. Indices of heavy precipitation are projected to increase much more than those for mean precipitation.

3. The projected increase of the global monsoon precipitation can be attributed to an increase of moisture convergence due to increased surface evaporation and water vapor in the air column although offset to a certain extent by the weakening of the monsoon circulation.
THANKS

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