Decadal Change in East Asian Monsoon Climate System: Natural Variability versus Anthropogenic Forcing

Xiu-Qun YANG
xqyang@nju.edu.cn

Institute for Climate and Global Change Research,
School of Atmospheric Sciences,
Nanjing University, Nanjing 210093, CHINA
Schematic illustrating progression from initial value problems with daily weather forecasts at one end, and multidecadal to century projections as a forced boundary condition problem at the other, with seasonal and decadal prediction in between

Why emphasize the decadal change?

Natural signature vs. anthropogenic forcing

(Meehl, et al. BAMS, 2009)
Issues

◆ What is the observed decadal change in East Asian monsoon climate system?
◆ Can such a decadal change be considered as natural variability (say, the PDO’s impact)?
◆ What is the role of increased CO2 and aerosols?
Climatological East Asian Monsoon (EAM)

Winter (DJF)

Summer (JJA)

Courtesy of JP LI
Interdecadal variabilities of 9-yr running averaged precipitation in eastern China since 1900

Northern China

Yangtze River valley

Southern China

1980s

Courtesy of ZB SUN
Decadal weakening of East Asian summer monsoon and southward shift of rainbelt in China

EASM Index: Standardized 850hPa and surface v-component (110 °- 125 °E, 20 °- 40 °N)

NCEP/NCAR

1951-78

ERA-40

1979-92

Observed

1993-04
Decadal change of EASM rainfall (1948-2004) over whole East Asian domain

Post-1976 minus Pre-1976
Decadal change of EASM rainfall (1948-2004) over whole Asian domain

Epoch 1978-98 minus 1949-77

Sun & Yang, 2012
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◆ Summary
Possible causes responsible for the weakening of the EASM

Forcing of ENSO-like tropical decadal mode

Forcing of monopole decadal mode

Weakening of EASM

Warming TIO

Reduced land-sea Thermal Contrast?

More snow cover depth

Southward shift of Stormtrack, jet stream?

Midlatitude air-sea interaction

Cooling NP

Forcing of ENSO-like tropical decadal mode

Coastal wavetrain?
Basin-scale air-sea interaction signatures in the Pacific

El Niño/Southern Oscillation

Pacific Decadal Oscillation

Interannual Signature

Decadal-to-interdecadal Signature
Basin-scale pattern of PDO

Warming in the tropical Indian and Pacific Oceans, while cooling in the North Pacific
Relationship among precipitation in northern China, SOI, IPO and PDO
Atmospheric thermal anomalies related to EASM’s weakening

Yang and Zhang, 2011

V850 vs Temp (500-200hPa)  -  ERA-40
Diabatic heating anomalies related to EASM’s weakening

Yang and Zhang, 2011

Vertically-integrated diabatic heating - ERA-40

EOF Mode(1) Qp 13.90%
Simulated response of EASM to historical SSTs with CAM3/NCAR

Li, Dai and Zhou, Clim Dyn, 2010
SST anomalies related to EASM’s weakening
PDO-related SSTA pattern

Yang and Zhang, 2011
Relative role of SSTA in each tropical basin in EASM’s weakening

Yang and Zhang, 2011

SSTA only in the tropical eastern Pacific (TPO-only)

Precipitation change

Diabatic heating change

CCM3-simulated decadal change with prescribed observed SST for 1949-98
Post-77 minus pre-1977
Relative role of SSTA in each tropical basin in EASM’s weakening

Yang and Zhang, 2011

SSTA only in the Tropical Indian Ocean (TIO-only)

Precipitation change

Diabatic heating change

CCM3-simulated decadal change with prescribed observed SST for 1949-98
Post-77 minus pre-1977
Opposite effect of TIO SSTA and TPO SSTA on the EASM

CCM3-simulated decadal change of the EASM with prescribed observed SST for 1949-98
Post-77 minus pre-1977

Yang and Zhang, 2011
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- Summary
Increased anthropogenic forcing in East Asia

Urbanization induces rapid land use/cover change and aerosol increase in China

What is role of anthropogenic forcing in east Asia?
Uncertainties in RF estimation are mostly due to regional human activities.
The EASM index change in six coupled climate models for scenario SRES A2

Most of models show an intensified EASM

(Jiang & Wang, 2005)
The EASM precipitation change simulated by climate model with different scenarios of emissions

(Wei, 2005)

Increased precipitation in northern China, rather than along Yangtze River valley.
22 coupled climate models (IPCC AR4)

Simulated precipitation change by $-0.6\% \sim 14\%$, mainly over northern China, Korea and Japan, associated with an enhanced EASM.

(Kripalani et al., 2006)
Regional climate model

Doubling of CO₂ concentration induces a weakened EA winter monsoon, 
BUT an enhanced EA summer monsoon

(Spring, Summer, Autumn, Winter)

(Chen, Pollard and Barron, JC 2004)
Regional climate model

Doubling of CO2 concentration induces an increased precipitation in northern China

(Chen, Pollard and Barron, JC 2004)
Previous simulation with aerosol’s direct effect

Menon et al., 2002

BC-induced increased summer rainfall in southern China, decreased rainfall in northern China
Previous simulation with aerosol’s direct effect

Enhanced Indian monsoon by the mechanism of “elevated heat pump” of Tibetan Plateau.

East Asia (Mei-yu) rain belt shifted north westward, suppressing rainfall over East Asia and the adjacent oceanic regions.

Lau, 2006

Fig. 6 Spatial distribution of JJA anomalies in the Asian monsoon region due to aerosols for precipitation (mm day$^{-1}$), and sea level pressure (hPa) and 850 hPa winds (ms$^{-1}$).
Model: CAM5, released by NCAR. A new generation NCAR AGCM, including aerosol module and aerosol’s indirect effect.

Emissions: in year 1850 and 2000 for IPCC AR5, representing aerosol emissions for Pre-industry (PI) and Present day (PD) (Lamarque, 2010), respectively.

Experiment design: 2 paralleled experiments are run for 10 years for PI’s and PD’s emissions, respectively.

Aerosol’s effect: defined with difference between PD and PI
Aerosol-Cloud Interactions in NCAR CAM5

2-moment Modal Aerosol Module (Liu et al. 2010)
   Prognostic mass and number concentration of 7 and 3 aerosol modes (log-normal function size distributions)
   Internal mixing of aerosol components within mode and external mixing between modes
2-moment stratiform microphysics (Morrison & Gettelman 2008; Gettelman et al. 2010)
   Prognostic ‘cloud mass’ and ‘cloud droplet number’ (G-function size distributions)
   Diagnostic ‘precipitation mass’ and ‘precipitation droplet number’
Cloud liquid droplet activation (Abdul-Razzak & Ghan 2002)
Cloud ice crystal nucleation (Liu et al. 2007)
   Homogeneous freezing on Sulfate
   Heterogeneous nucleation on Dust
Aerosol effects on convective clouds through microphysics not included
Current simulation with aerosol’s direct and indirect effects

Microphysics and modal aerosols permit the study of aerosol indirect effects
Change in Aerosol Optical Depth (AOD) between Present day (PD) and Pre-industrial day (PI)
Changes in Asian summer monsoon

Surface temperature

850hPa wind & Precipitation

Precipitation (mm/day) and Wind (850mb)

Vertically-integrated temperature
Change in surface air temperature: Simulation vs. Observation
surface cooling over central China

Simulated, aerosol-induced

Observed trend

Trends of JJA Maximum Temperature

1961–2005
Change in tropospheric air temperature: Simulation vs. Observation

Tropospheric cooling north of 30N in East Asia

Simulated, aerosol-induced

Vertically-integrated temperature
Clear Sky Solar Radiation Change

TOA

Surface

Atmosphere
Cloud change and short wave cloud forcing

Vertically-integrated low cloud fraction

Vertically-integrated total cloud fraction
Aerosol’s radiative effect

Change in net heating rate:
QRS+QRL+DTV+DCOND

Vertically-integrated temperature

Change in precipitation and 850hPa wind

Precipitation(mm/day) and Wind(850mb)

Land-sea thermal contrast reduced
EASM weakened

Vertically-integrated temperature

Change in net heating rate:
Pd - PI QRS+QRL+DTV+DCOND
Aerosol’s cloud-microphysical effect

CCN at $S=0.1\%$

Cloud droplet number concentration

Cloud droplet effective radius

In-cloud liquid water content
Aerosol’s cloud-microphysical effect

Cloud droplet effective radius

Change in precipitation and 850hPa wind

Precipitation (mm/day) and Wind (850mb)
Issues

◆ What is the observed decadal change in East Asian monsoon climate system?

◆ Can such a decadal change be considered as natural variability (say, the PDO’s impact)?

◆ What is the role of increased CO2 and aerosols?

◆ Summary
The East Asian summer monsoon (EASM) has been experiencing a considerable decadal weakening since the end of 1970s with a significant southward shift of increased precipitation in East Asia.

Such a decadal change has caused serious consequences by increasing drought and/or flooding and altering water resource distribution, which can affect the sustainable development in East Asian region.

The EASM weakening is closely related to the tropical ocean warming. Its role exhibits considerably basin-dependent. The tropical eastern Pacific warming tends to weaken EASM, while the tropical Indian ocean warming plays an opposite role.
Summary

◆ Most of the IPCC AR4 models show that the increased CO2 tends to enhance the EASM, which can not be used to explain the observed EASM weakening.

◆ The state-of-the-art model with aerosol direct and indirect effects shows that increased anthropogenic aerosols tend to weaken East Asian summer monsoon with precipitation shifted to southern China and adjacent oceanic regions by reducing land-sea thermal contrast, which is mostly caused by the aerosol’s radiative effect.

◆ The model also shows that the increased anthropogenic aerosols tend to reduce the precipitation over most of the land areas, especially over Southeast Asian sub-continents, which is mostly related to aerosol’s cloud-microphysical (indirect) effect (i.e., the decreased droplet effective radius).
Thanks