

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

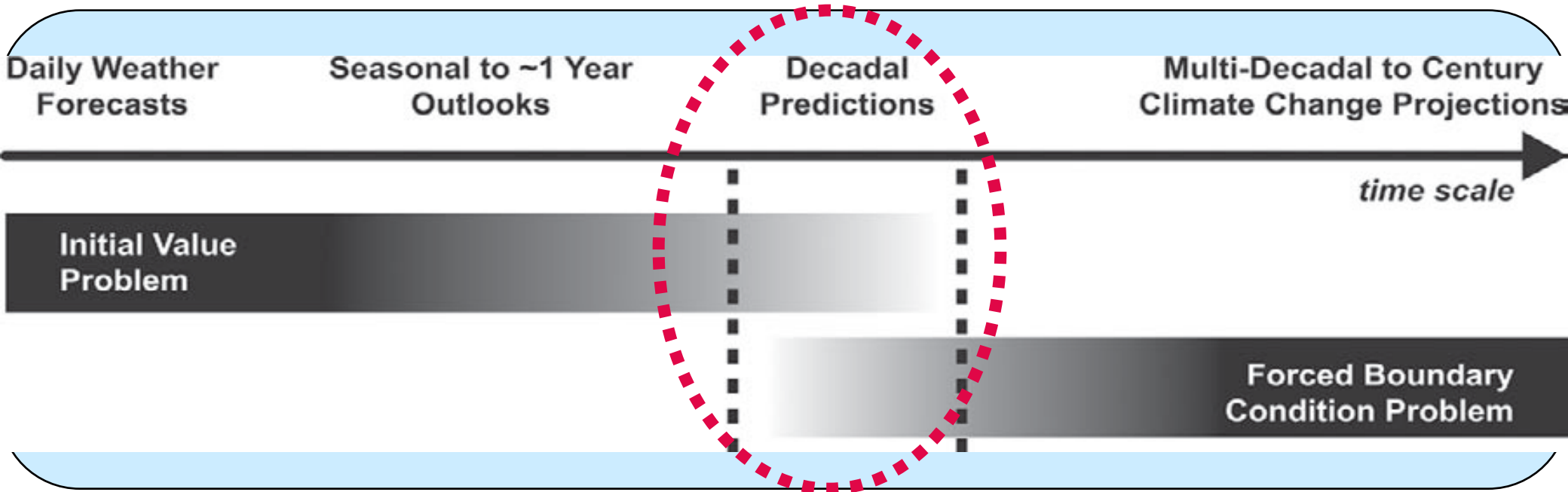
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School of Atmospheric Sciences,
Nanjing University, Nanjing 210093, CHINA**

Why emphasize the decadal change?

Natural signature vs. anthropogenic forcing

Meehl, et al. BAMS, 2009



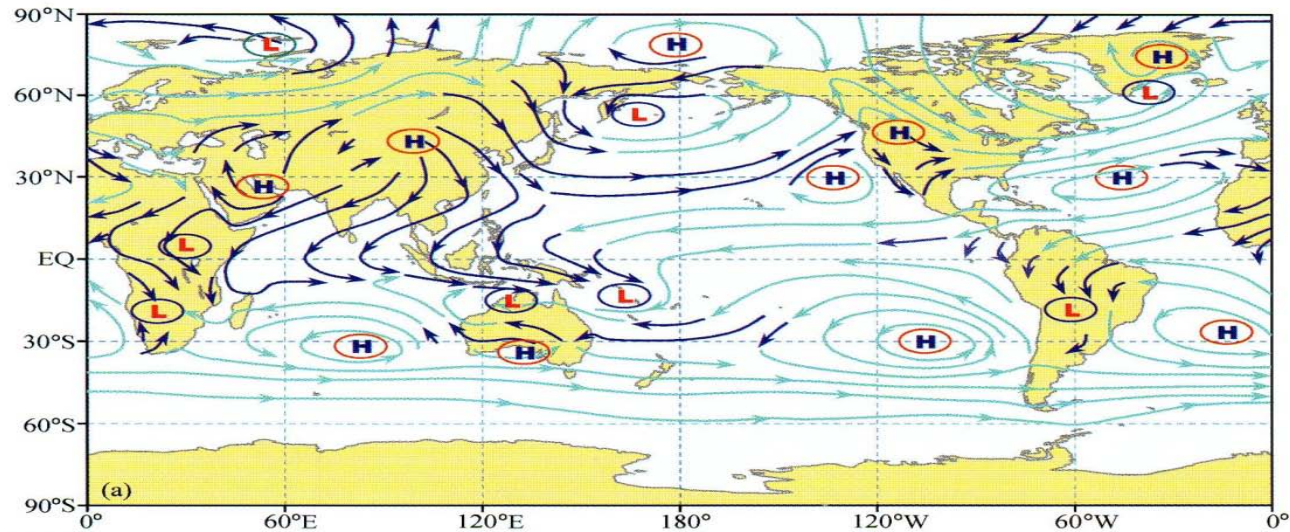
Schematic illustrating progression from initial value problems with daily weather forecasts at one end, and multidecadal to century projections as a forced boundary condition problem at the other, with seasonal and decadal prediction in between

Issues

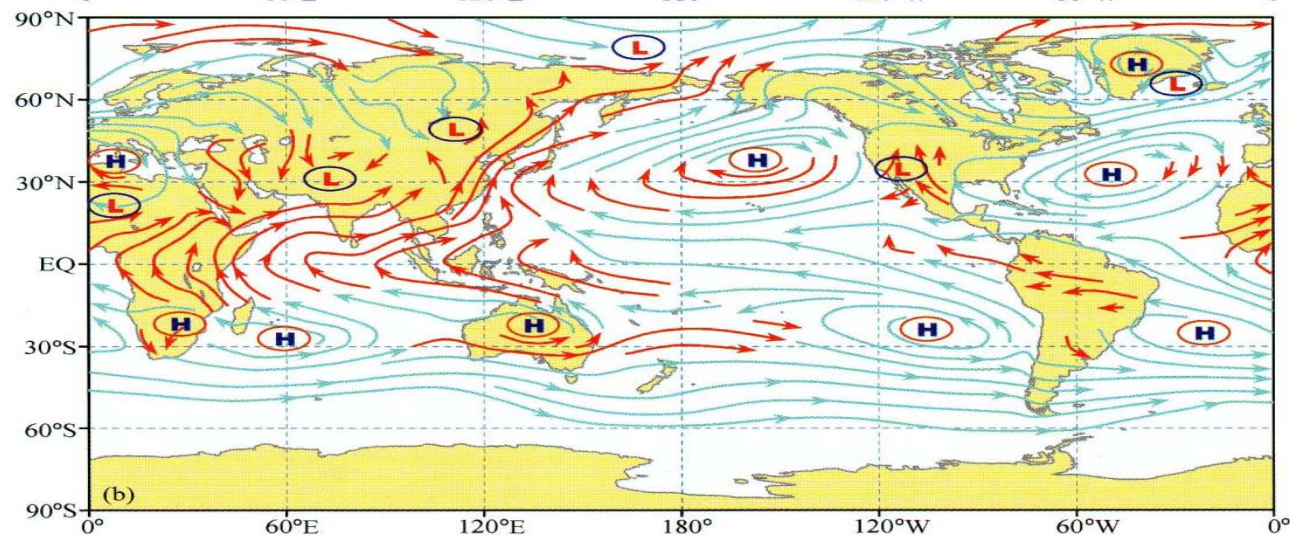
- ◆ **What is the observed decadal change in East Asian monsoon climate system ?**
- ◆ **Can such a decadal change be considered as natural variability (say, the PDO's impact)?**
- ◆ **What is the role of increased CO₂ and aerosols?**
- ◆ **Summary**

Climatological East Asian Summer Monsoon

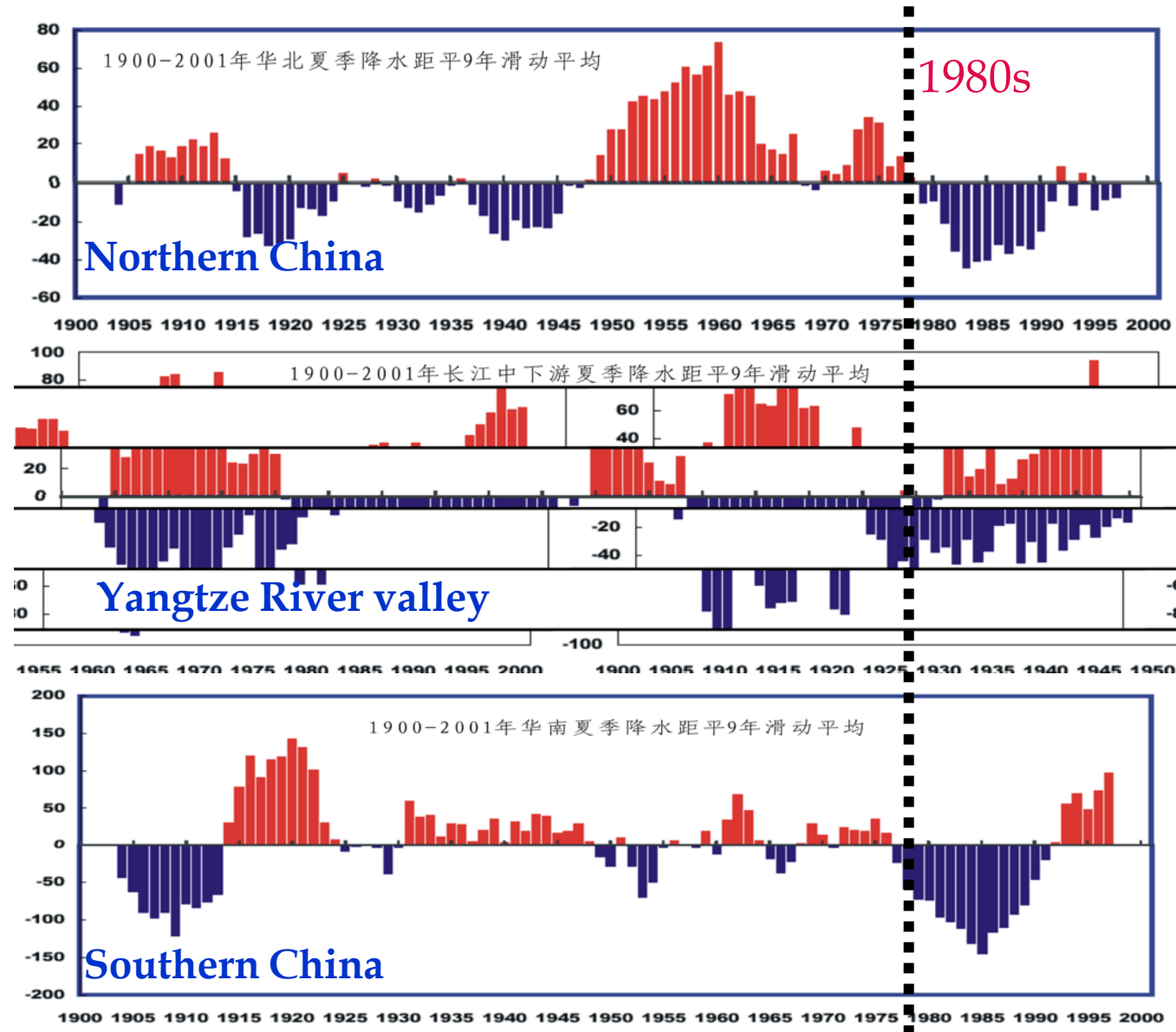
Winter
(DJF)



Summer
(JJA)



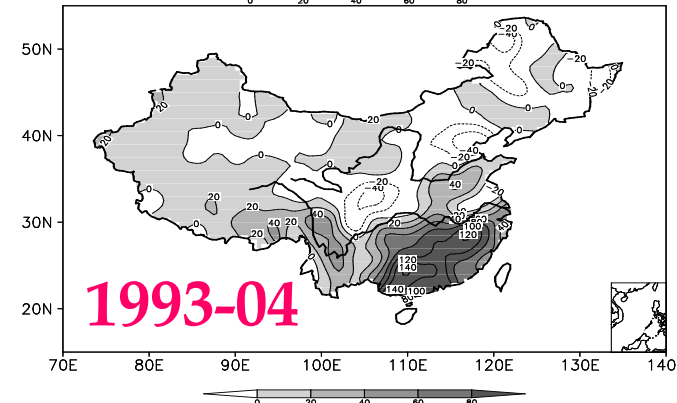
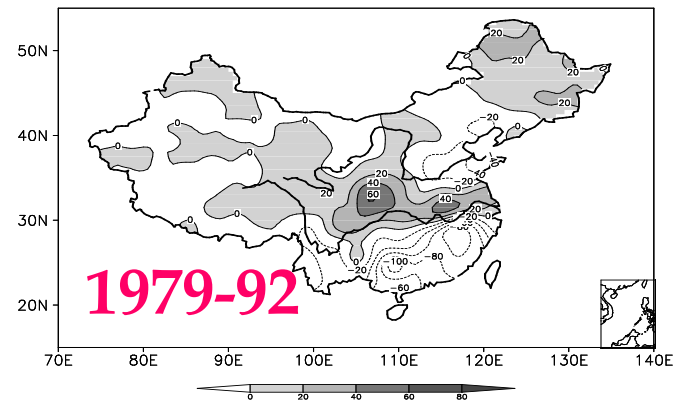
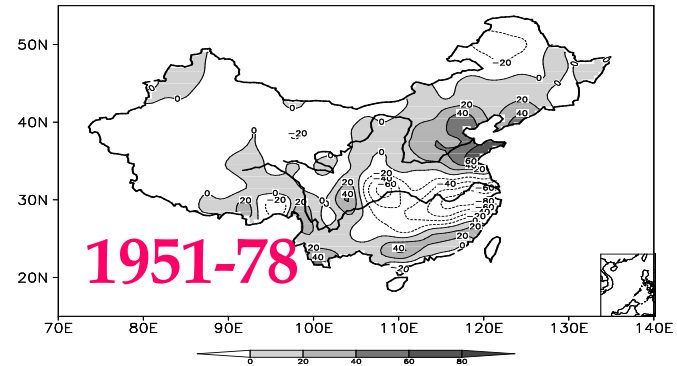
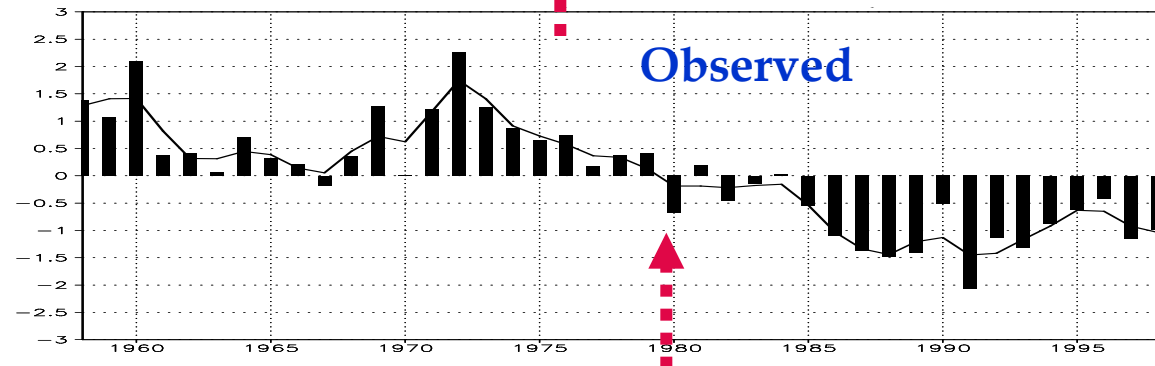
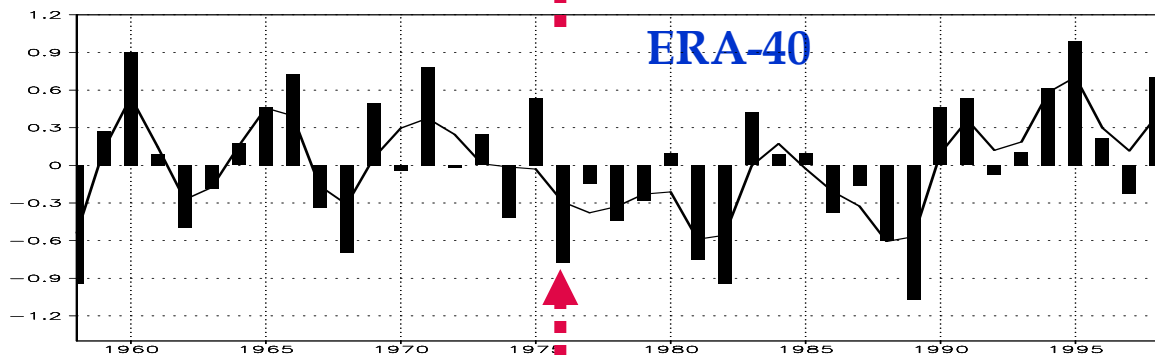
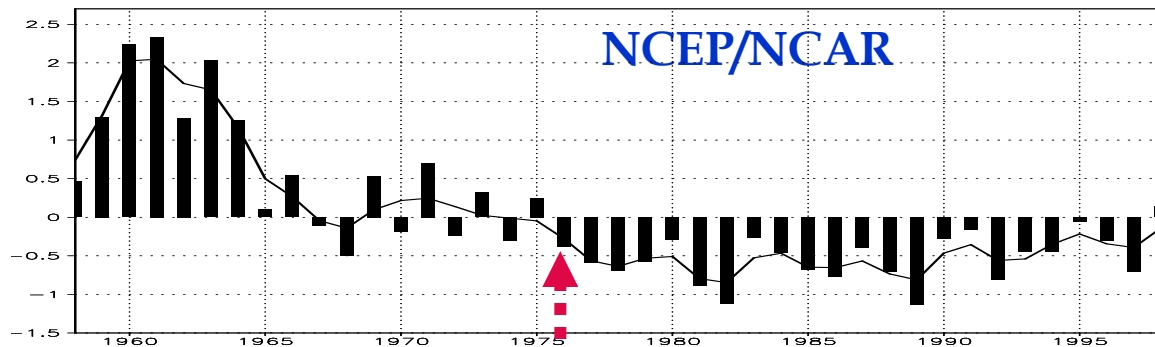
Interdecadal variabilities of 9-yr running averaged precipitation in eastern China since 1900



Sun, 2006

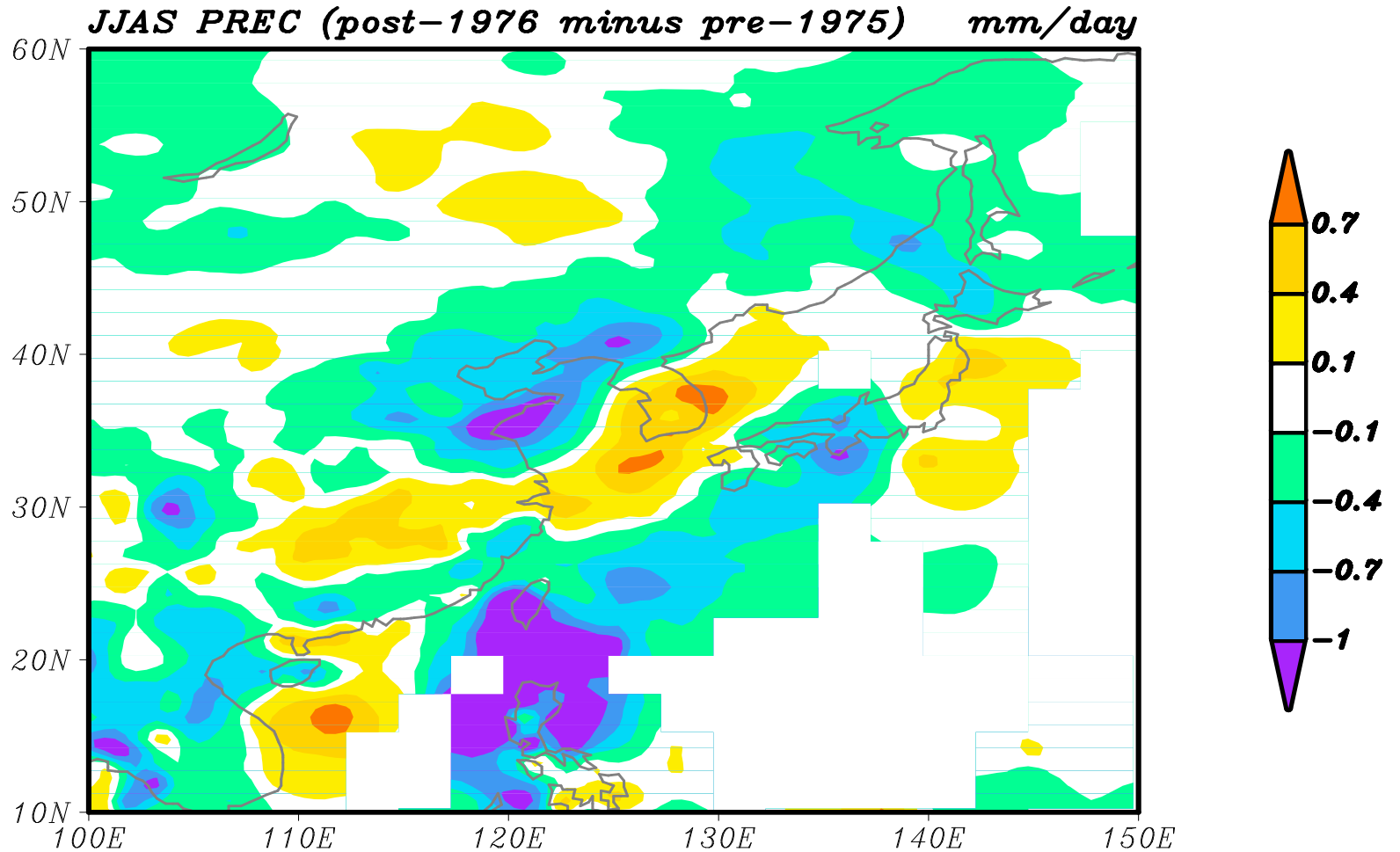
Decadal weakening of East Asian summer monsoon and southward shift of rainbelt in China

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



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

Post-1976 minus Pre-1976



Persistent flooding/drought is one of challenges for the sustainable development in China

Persistent raining (2008)

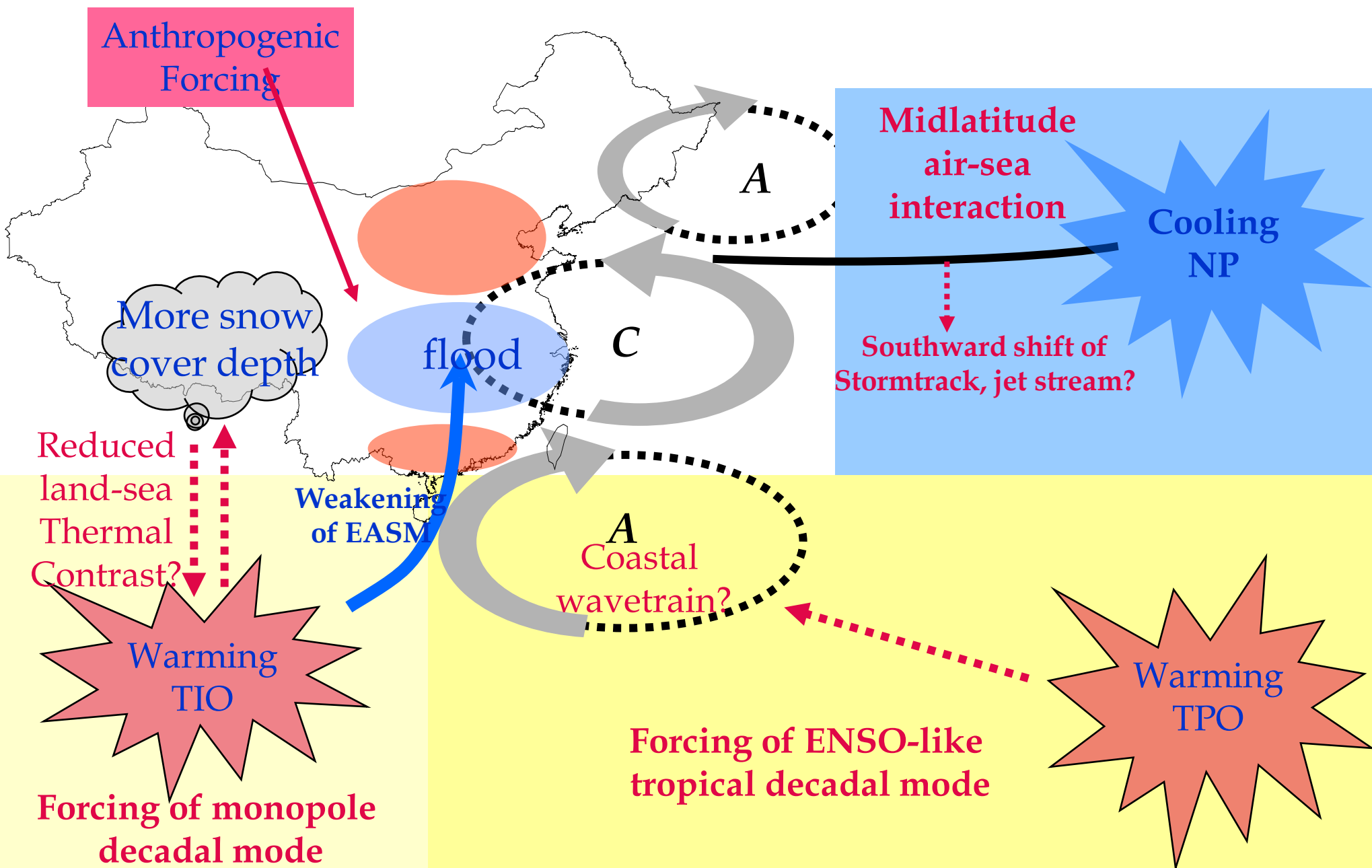
Persistent drought (2009/2010/2011)



Issues

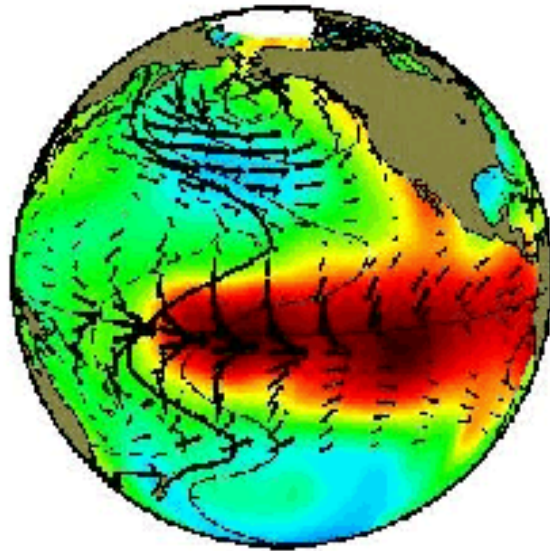
- ◆ What is the observed decadal change in East Asian monsoon climate system ?
- ◆ Can such a decadal change be considered as natural variability (say, the PDO's impact)?
- ◆ What is the role of increased CO₂ and aerosols?
- ◆ Summary

Possible causes responsible for the weakening of the EASM

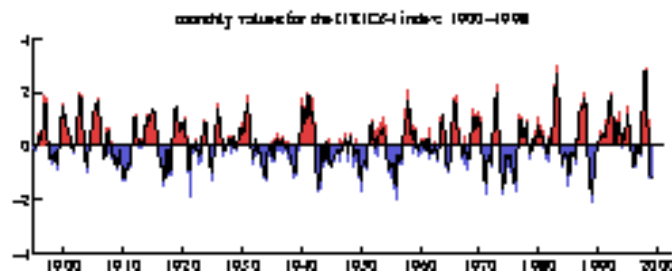
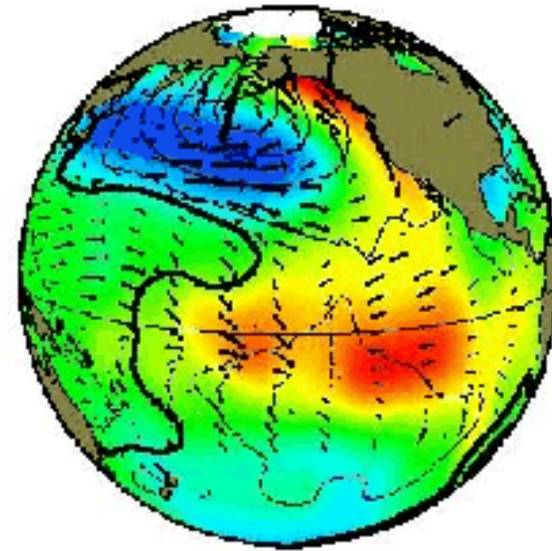


Basin-scale air-sea interaction signatures in the Pacific

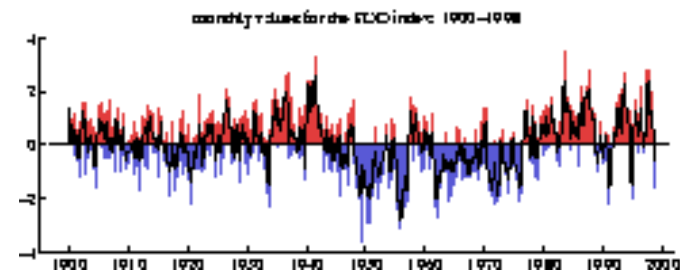
El Niño/Southern Oscillation



Pacific Decadal Oscillation



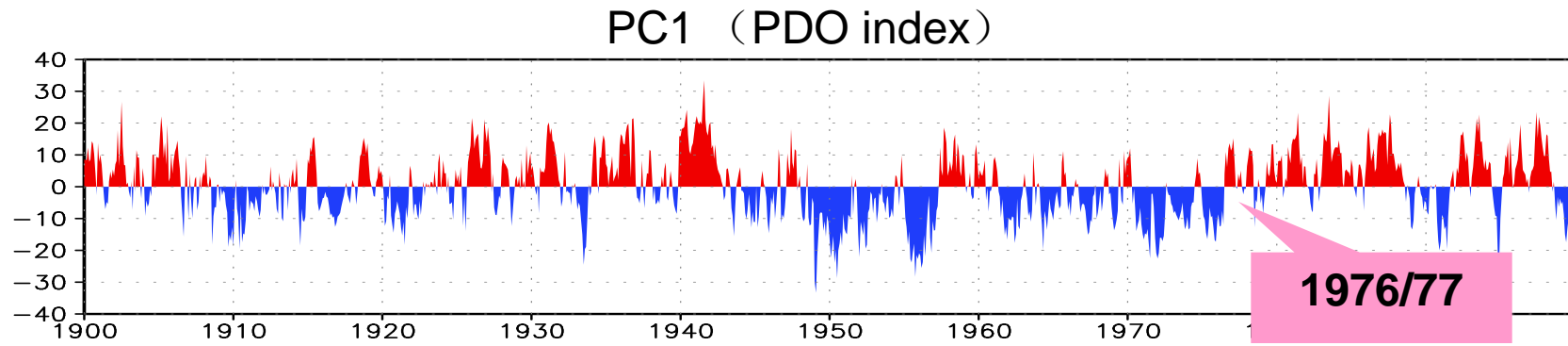
Interannual Signature



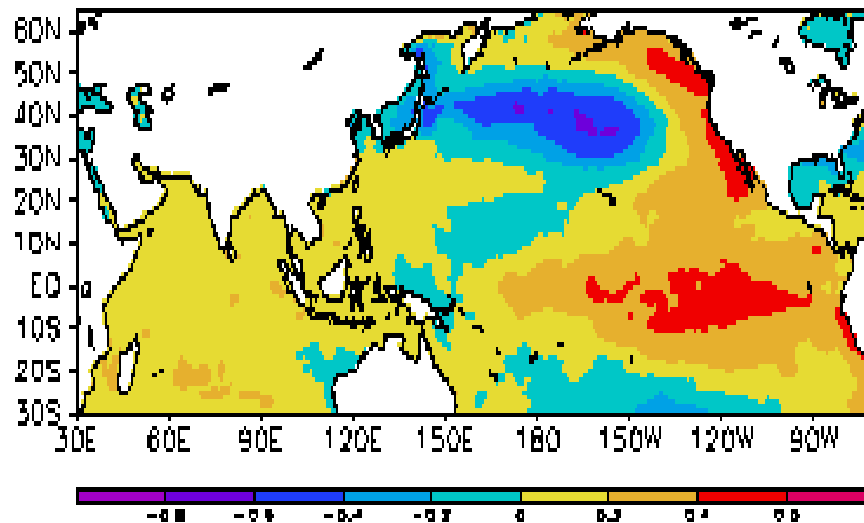
Decadal-to-interdecadal Signature

Basin-scale pattern of PDO

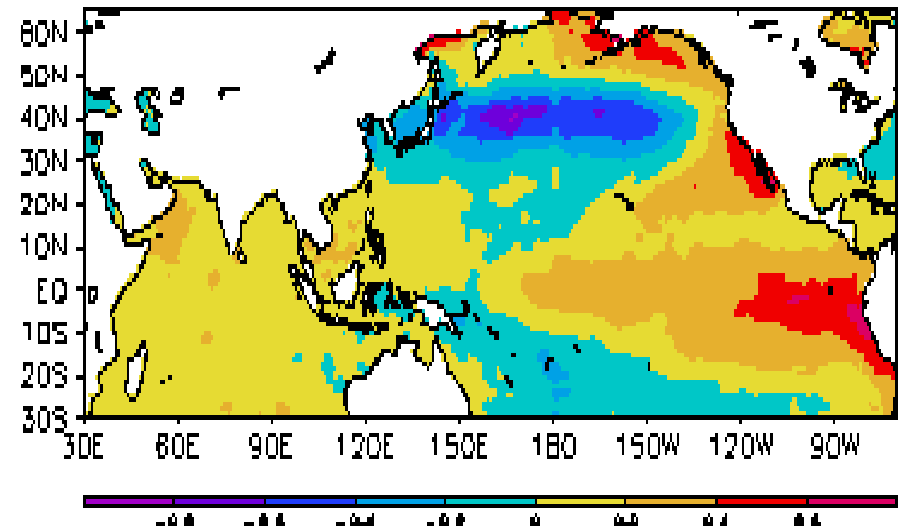
Warming in the tropical Indian and Pacific Oceans,
while cooling in the North Pacific



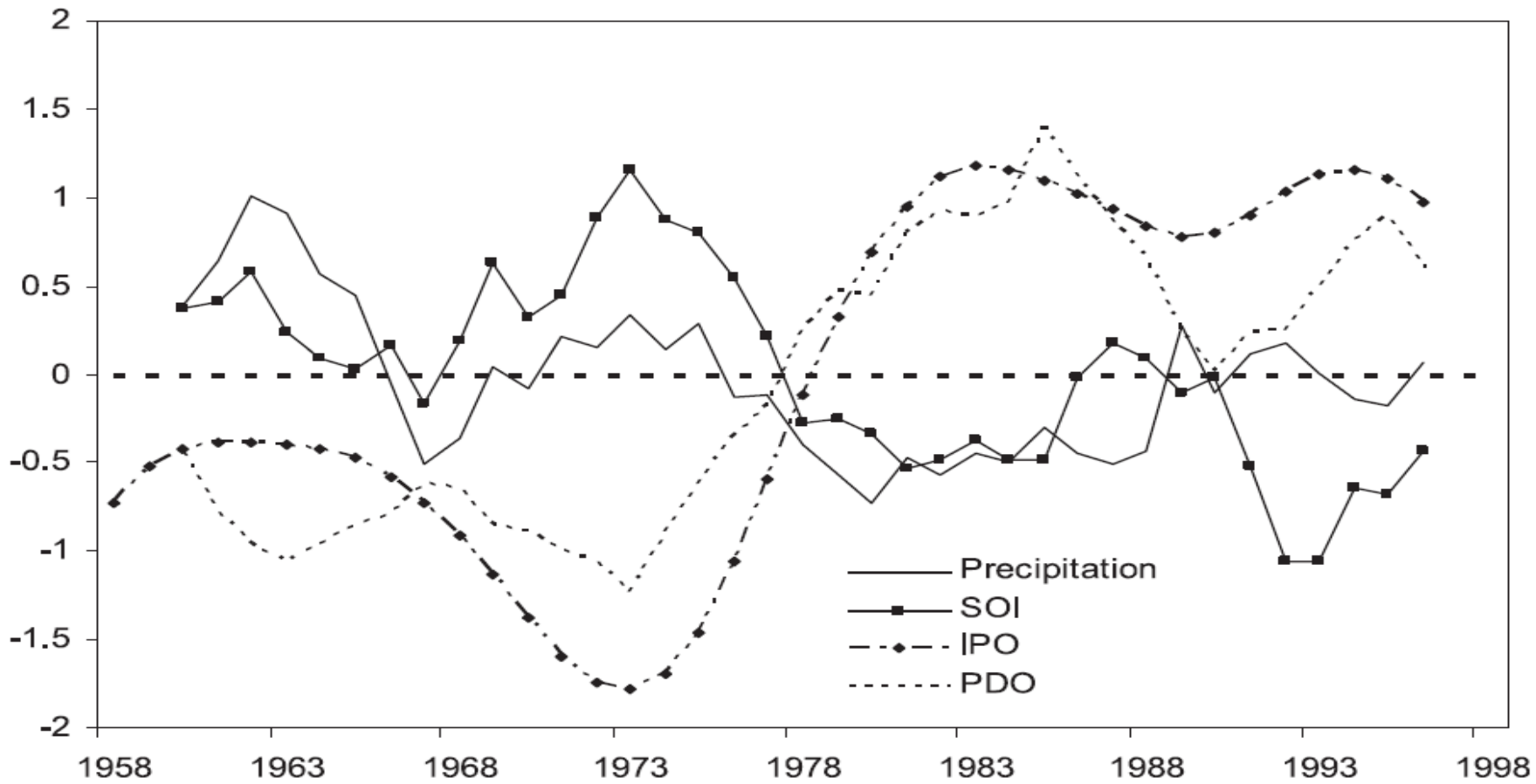
Regression of SSTA on PDO index (DJF)



Regression of SSTA on PDO index (JJA)



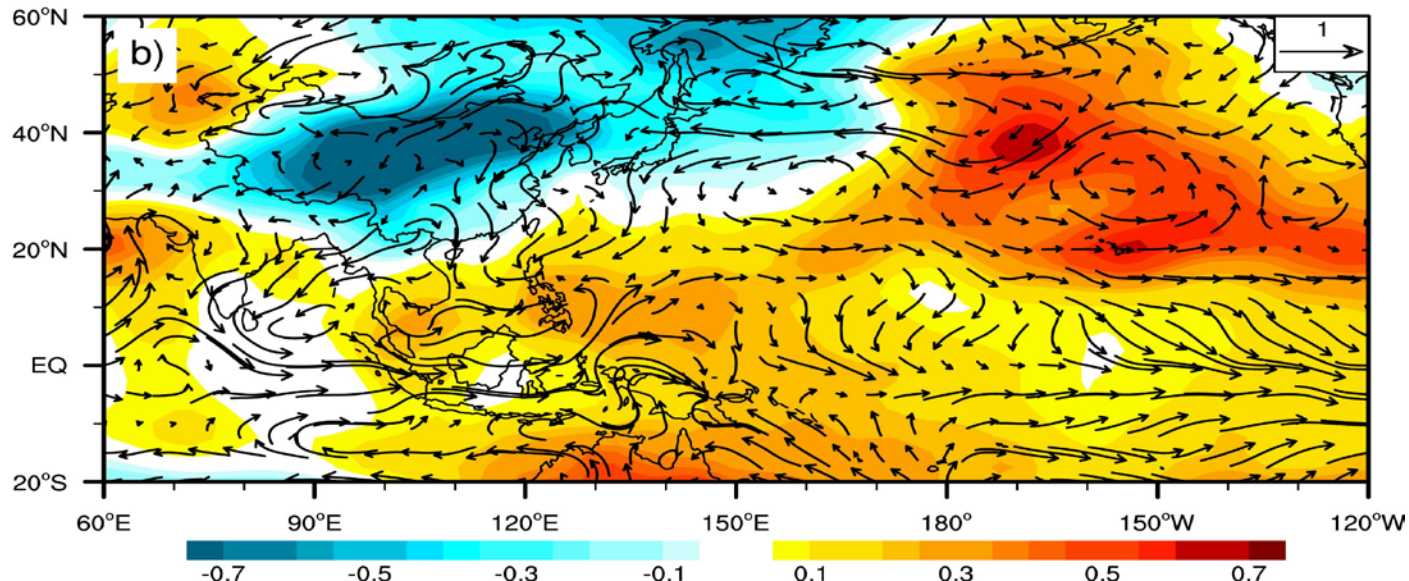
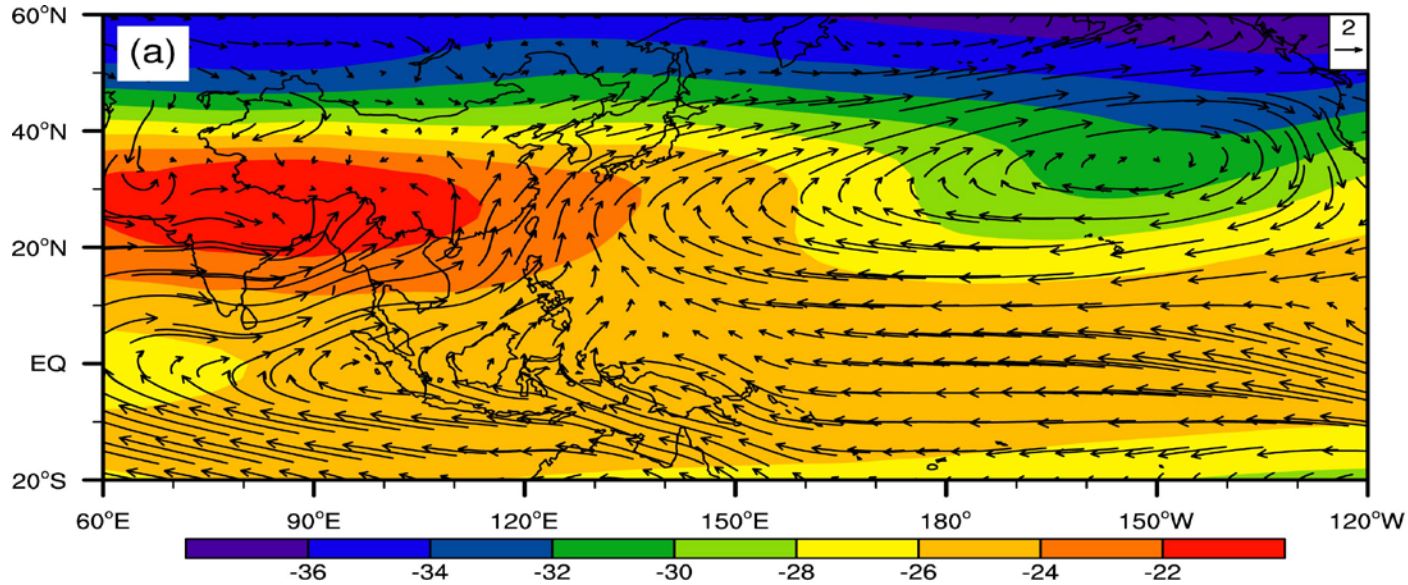
Relationship among precipitation in northern China, SOI, IPO and PDO



Atmospheric thermal anomalies related to EASM's weakening

Yang and Zhang, 2011

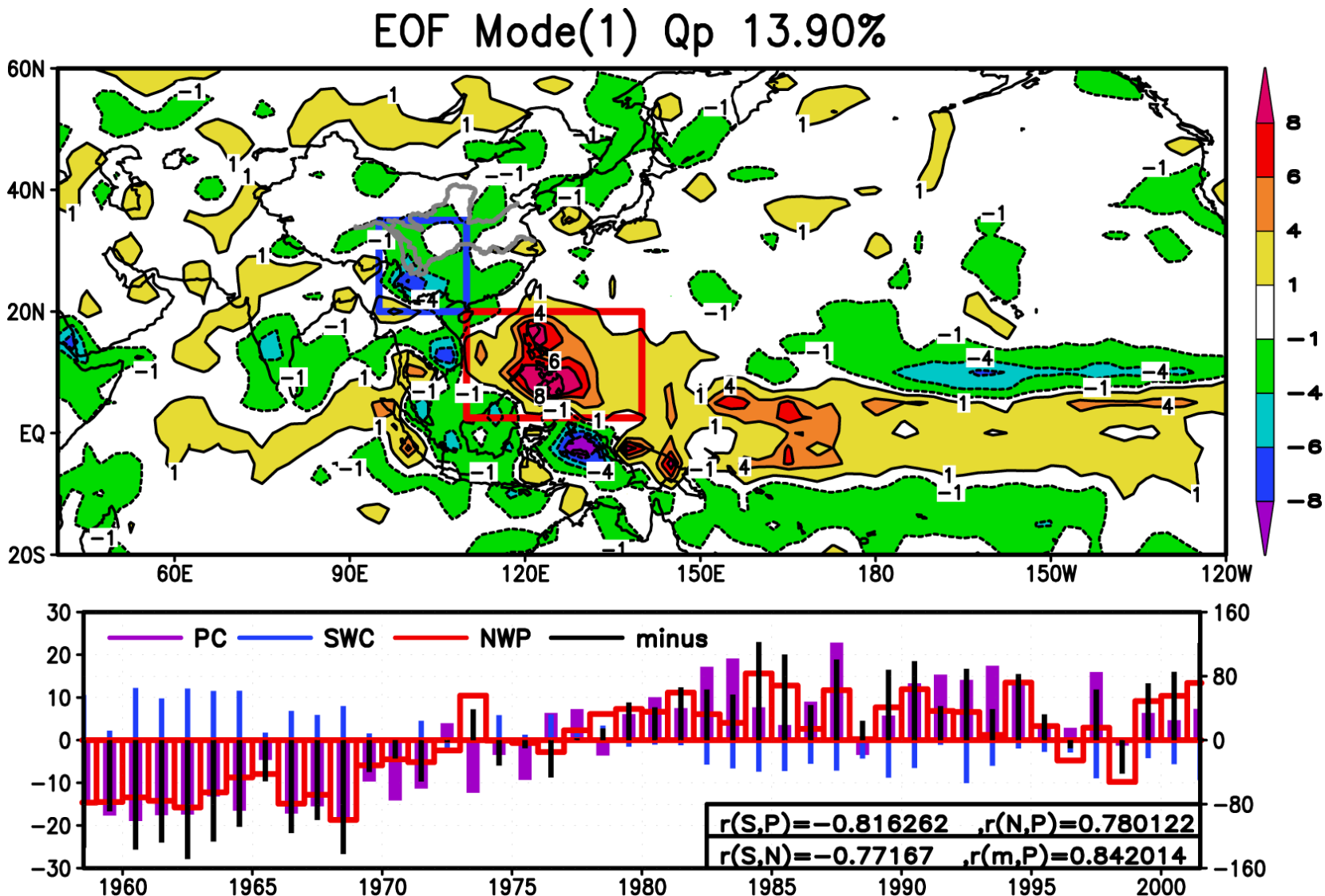
V850 vs Temp (500-200hPa) - ERA-40



Diabatic heating anomalies related to EASM's weakening

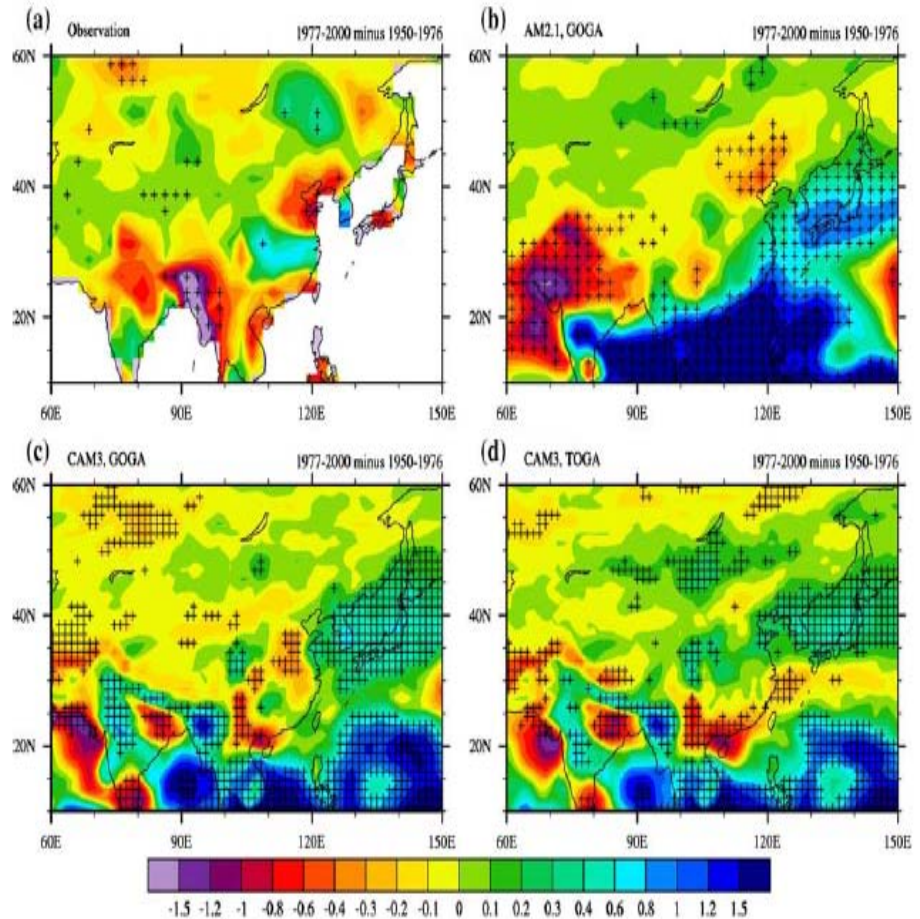
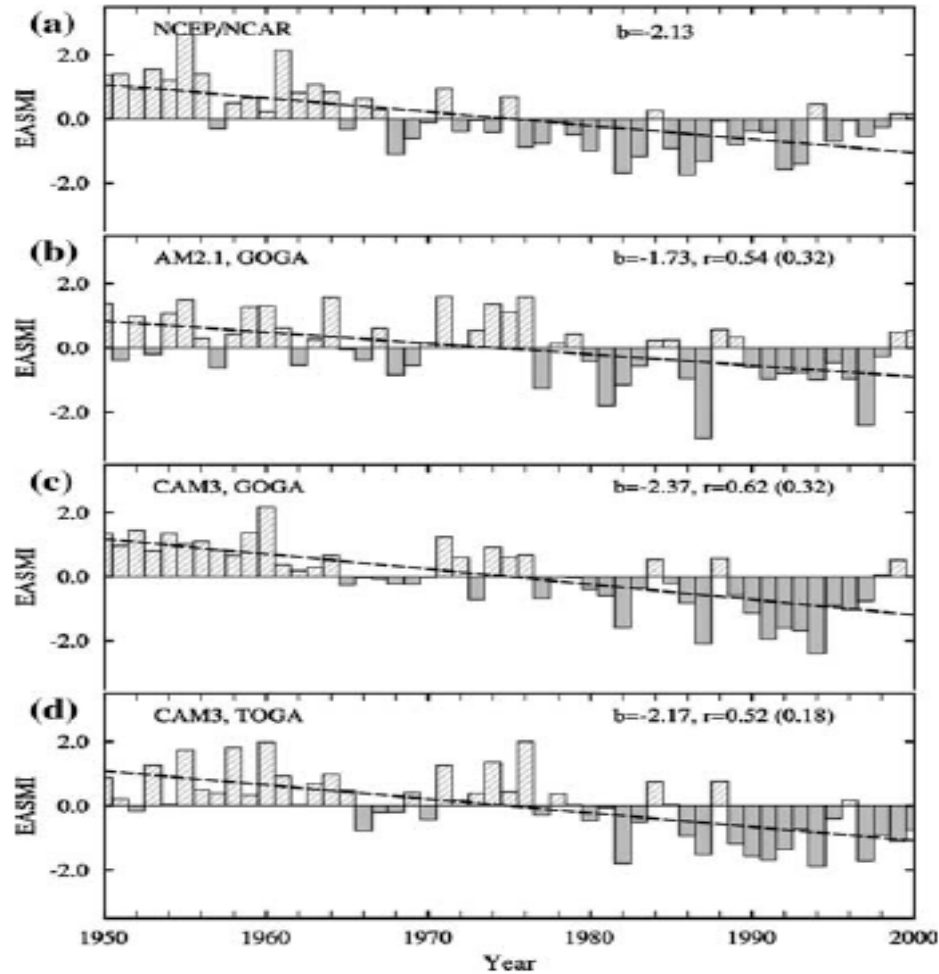
Yang and Zhang, 2011

Vertically-integrated diabatic heating - ERA-40



Simulated response of EASM to historical SSTs with CAM3/NCAR

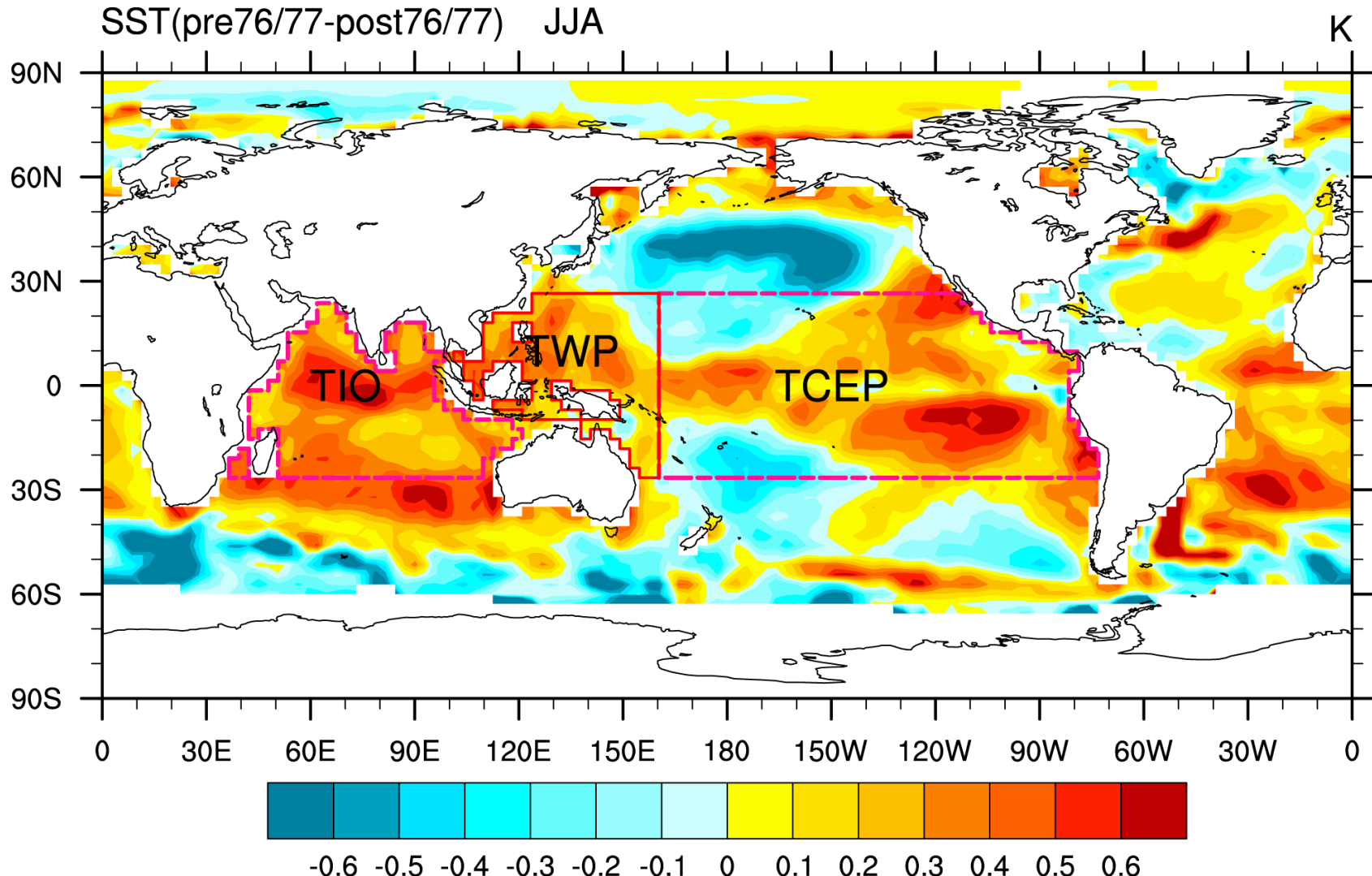
Li, Dai and Zhou, Clim Dyn, 2010



SST anomalies related to EASM's weakening

PDO-related SSTA pattern

Yang and Zhang, 2011

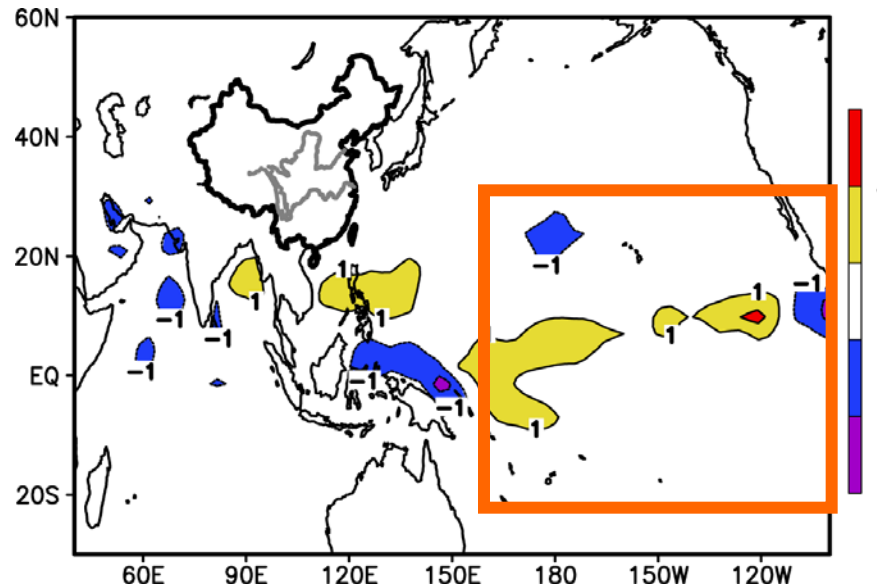


Relative role of SSTA in each tropical basin in EASM's weakening

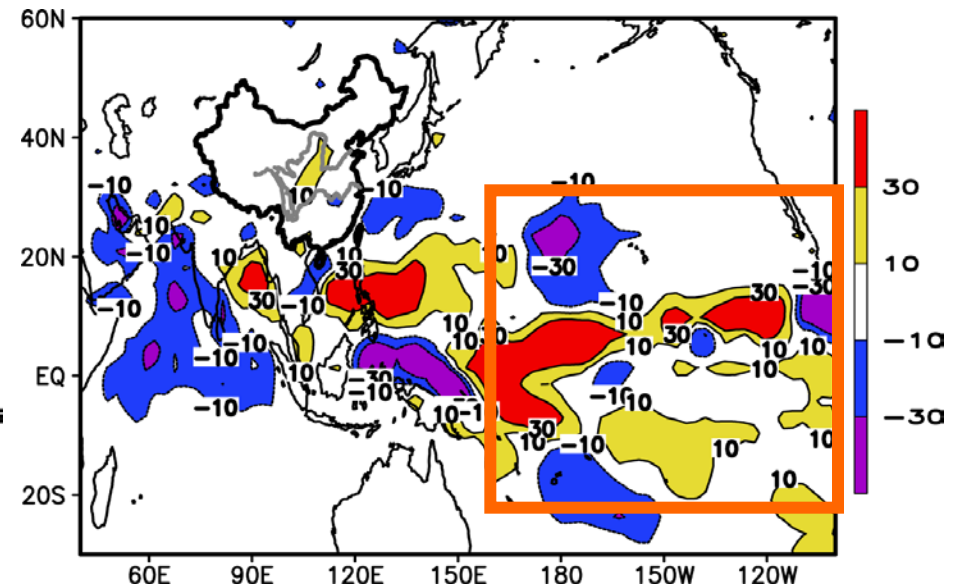
Yang and Zhang, 2011

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

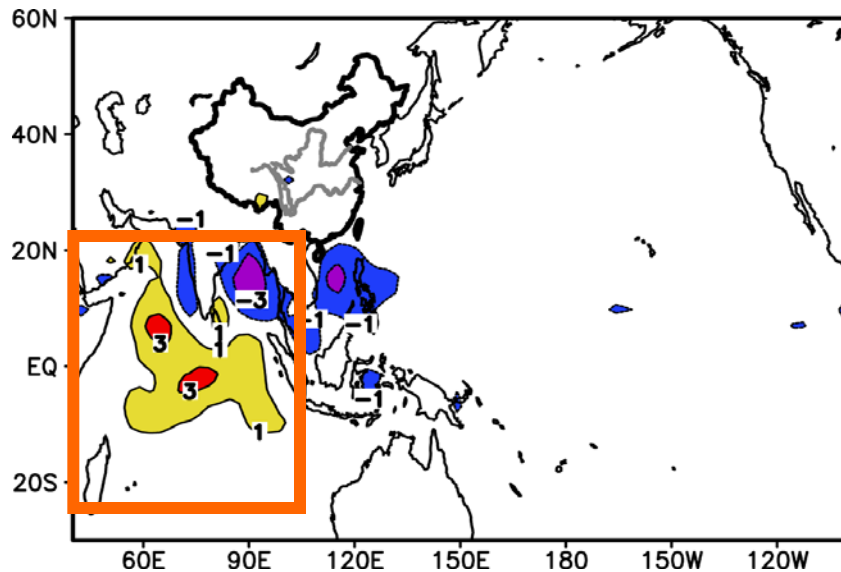
Post-77 minus pre-1977

Relative role of SSTA in each tropical basin in EASM's weakening

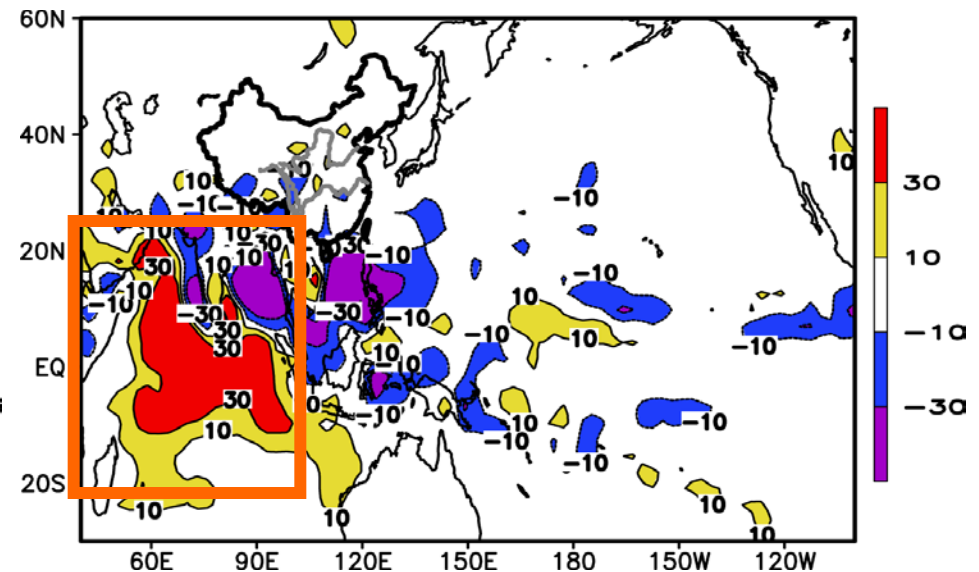
Yang and Zhang, 2011

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

Precipitation change



Diabatic heating change

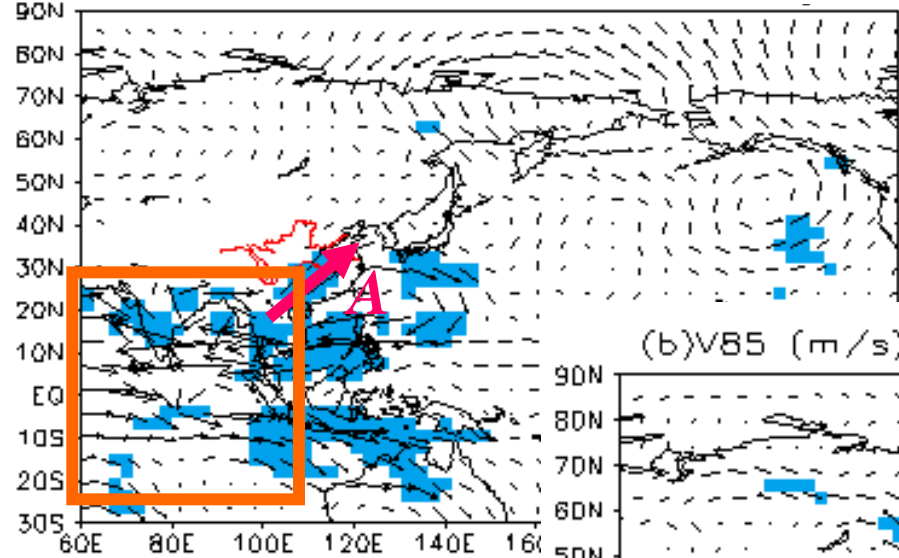


CCM3-simulated decadal change with prescribed observed
SST for 1949-98
Post-77 minus pre-1977

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

TIO SSTA only

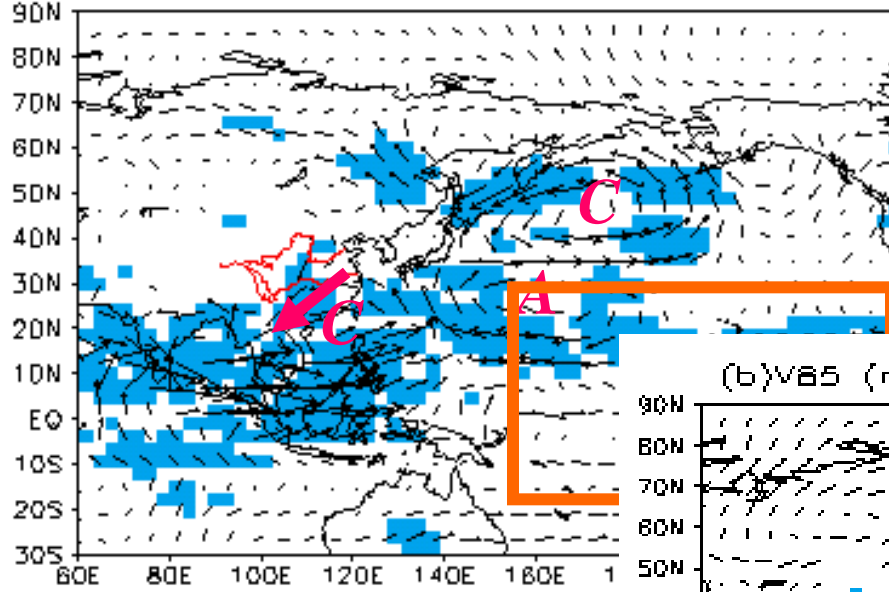
(b) V85 (m/s) [JJA]



Enhanced EASM

TPO SSTA only

(b) V85 (m/s) [JJA]

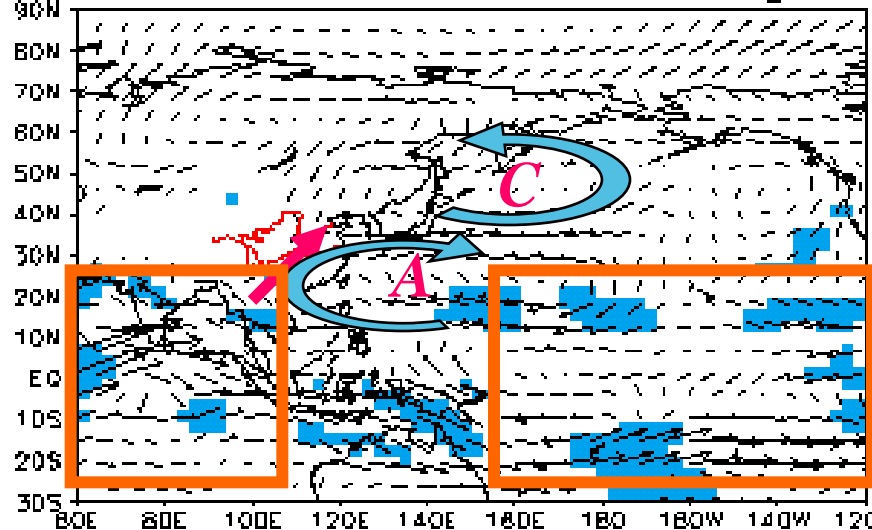


Weakened EASM

Yang and Zhang, 2011

TIO+TPO SSTA

(b) V85 (m/s) [JJA]



Opposite effect of TIO SSTA and TPO SSTA on the EASM

Issues

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- ◆ 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

Increased anthropogenic forcing in East Asia

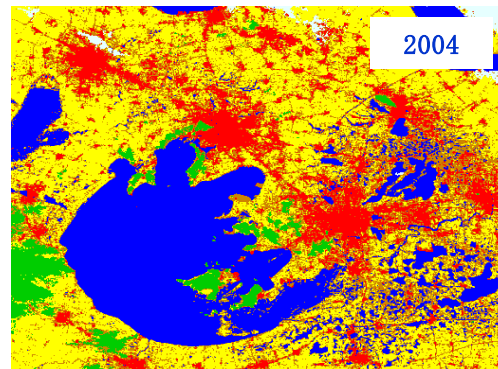
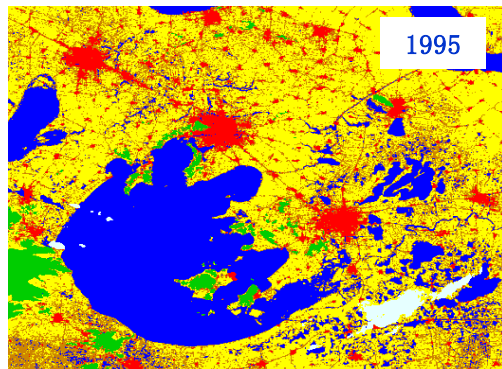
Urbanization induces rapid land use/cover change and aerosol increase in China

What is role of anthropogenic forcing in east Asia?

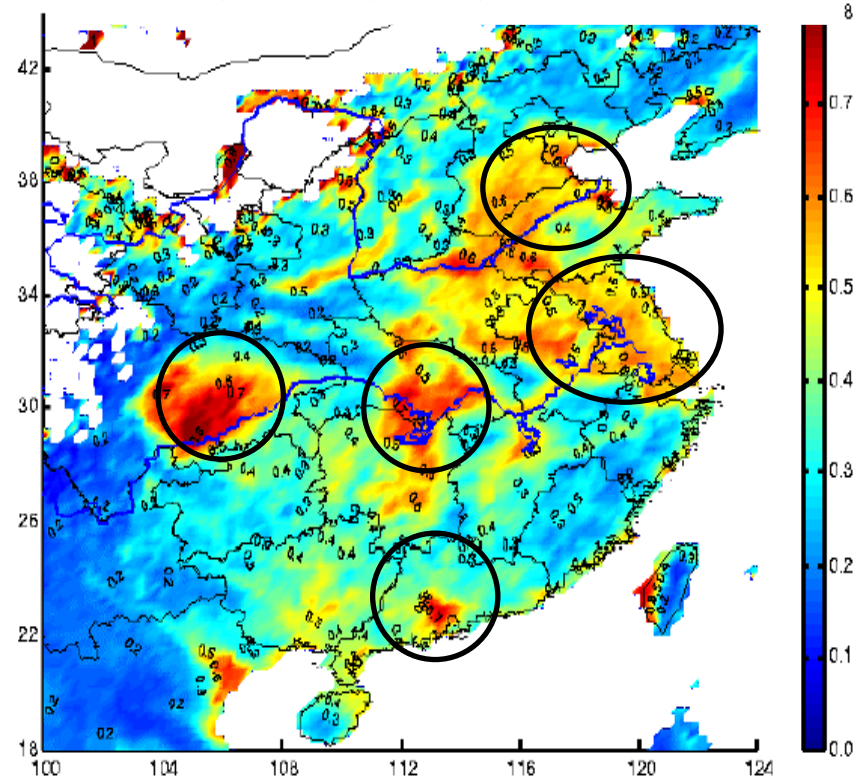
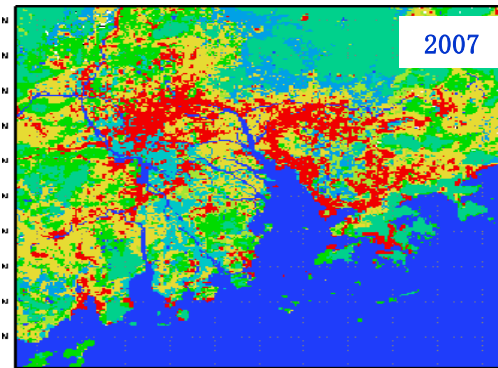
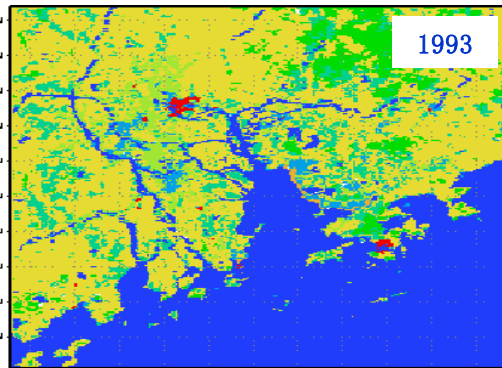
东部土地利用/覆盖快速扩张 (LUCC)

2007年秋季月平均气溶胶光学厚度 (AOD)

苏锡常



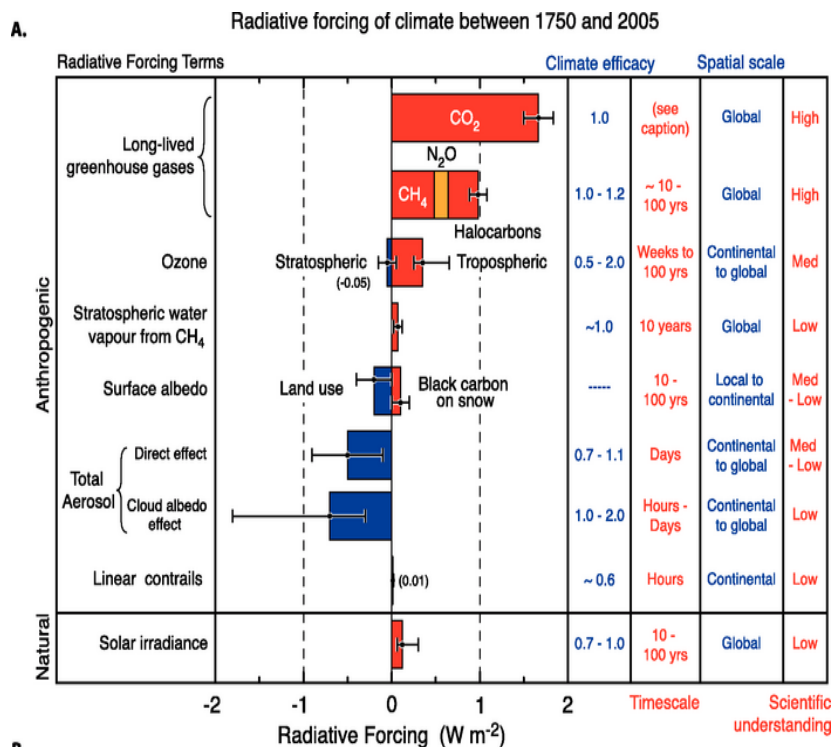
珠三角



Uncertainties in RF estimation are mostly due to regional human activities

IPCC/AR4估计的全球平均的辐射强迫及其不确定性

IPCC/AR4估计的对流层顶和表面全球辐射强迫空间分布

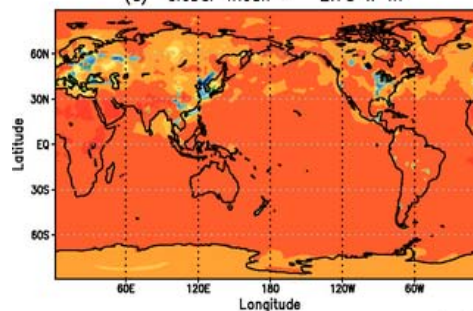


GFDL CM2.1模式

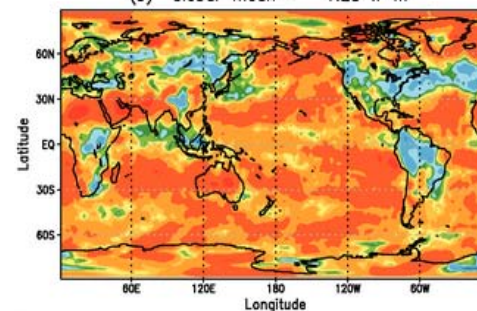
Radiative Forcing

MIROC+SPRINTARS模式

(a) Global-mean = 2.78 W m⁻²

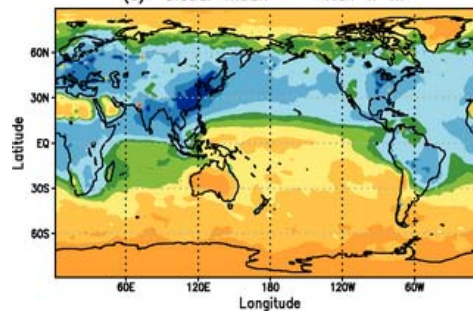


(b) Global-mean = 1.28 W m⁻²

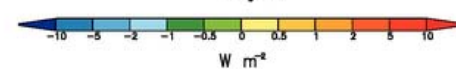
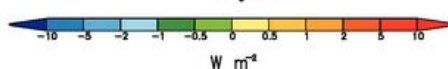
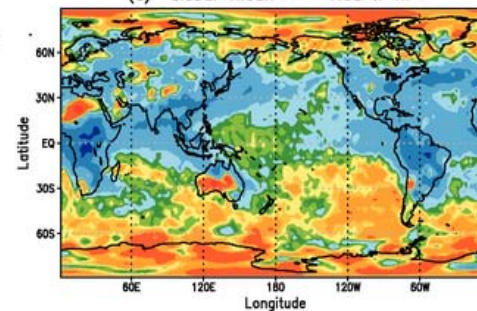


Surface forcing

(c) Global-mean = -1.01 W m⁻²



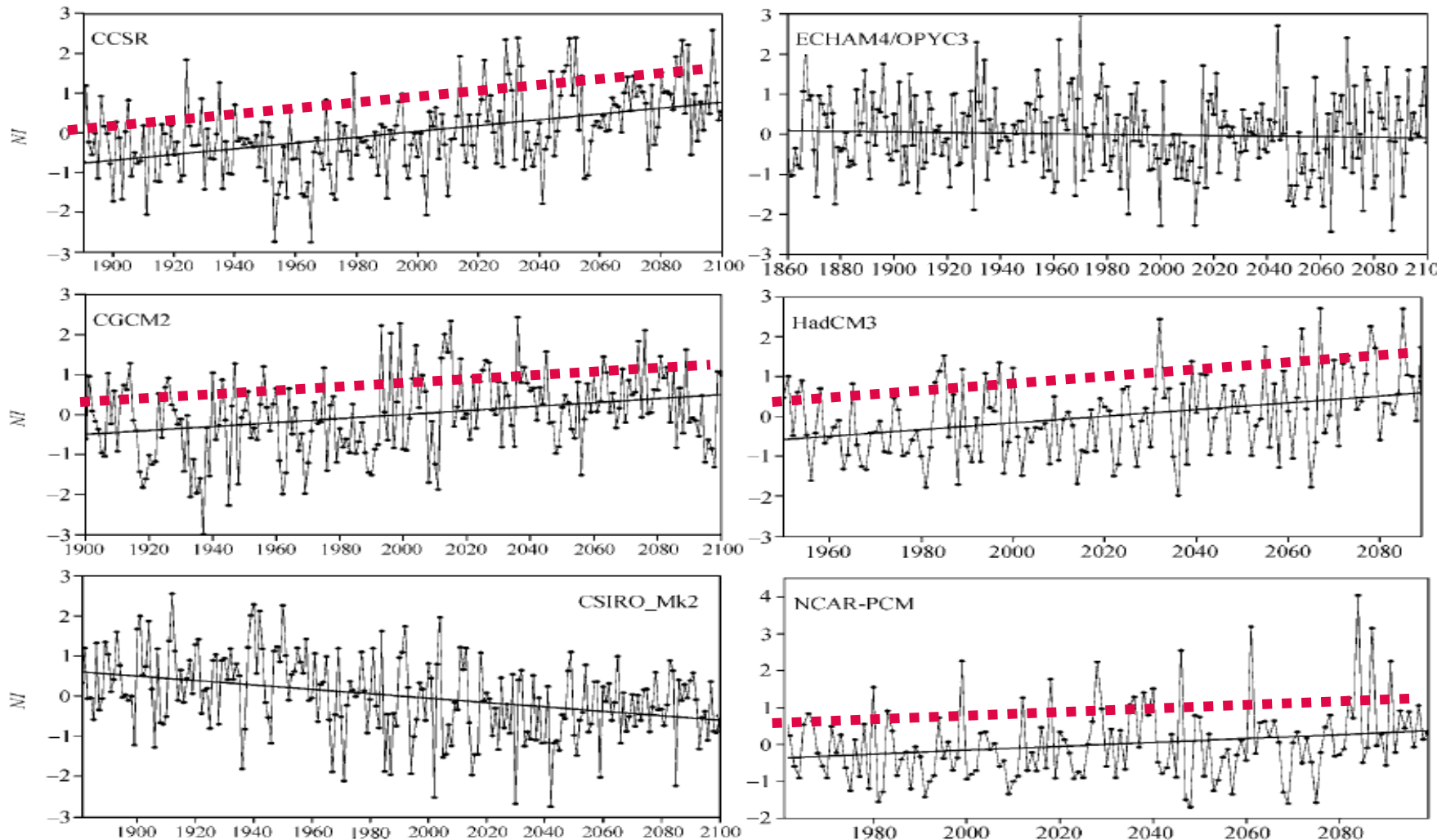
(d) Global-mean = -1.58 W m⁻²



B.

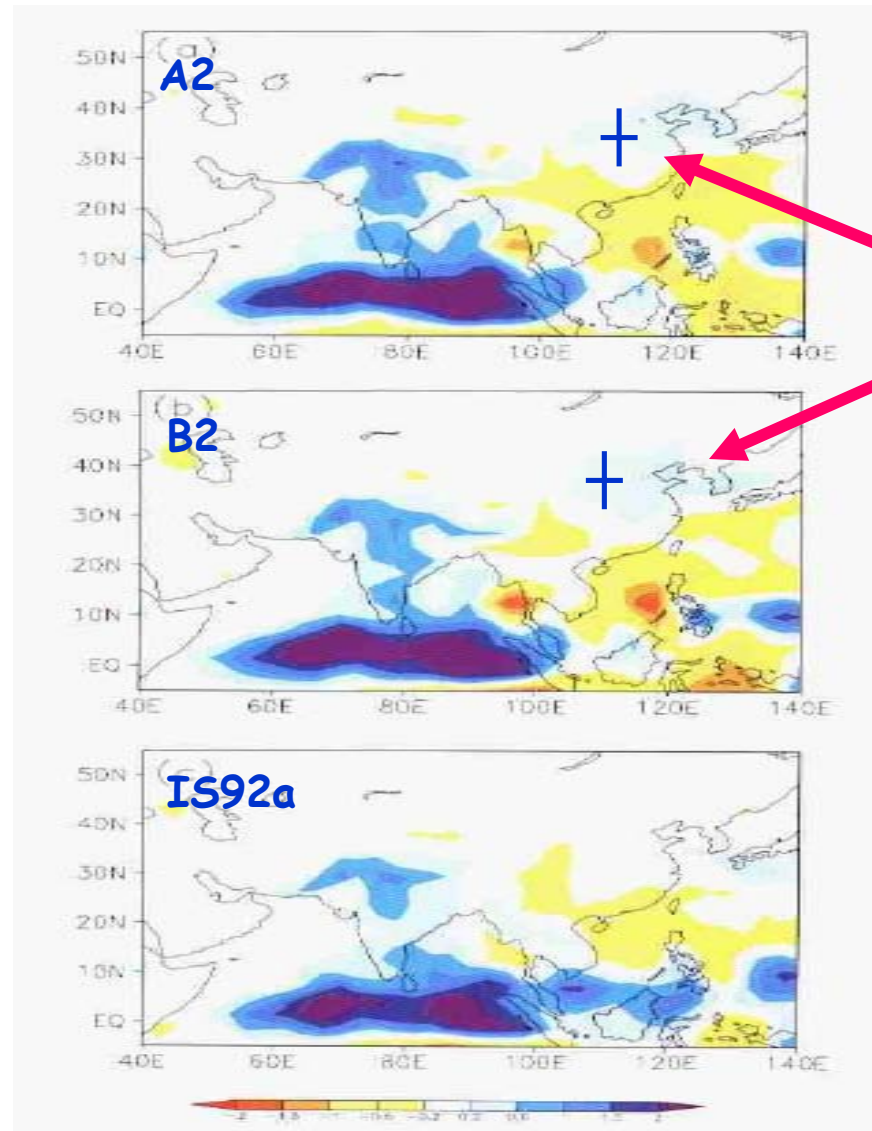
The EASM index change in six coupled climate models for scenario SRES A2

Most of models show an intensified EASM



(Jiang & Wang, 2005)

The EASM precipitation change simulated by climate model with different scenarios of emissions



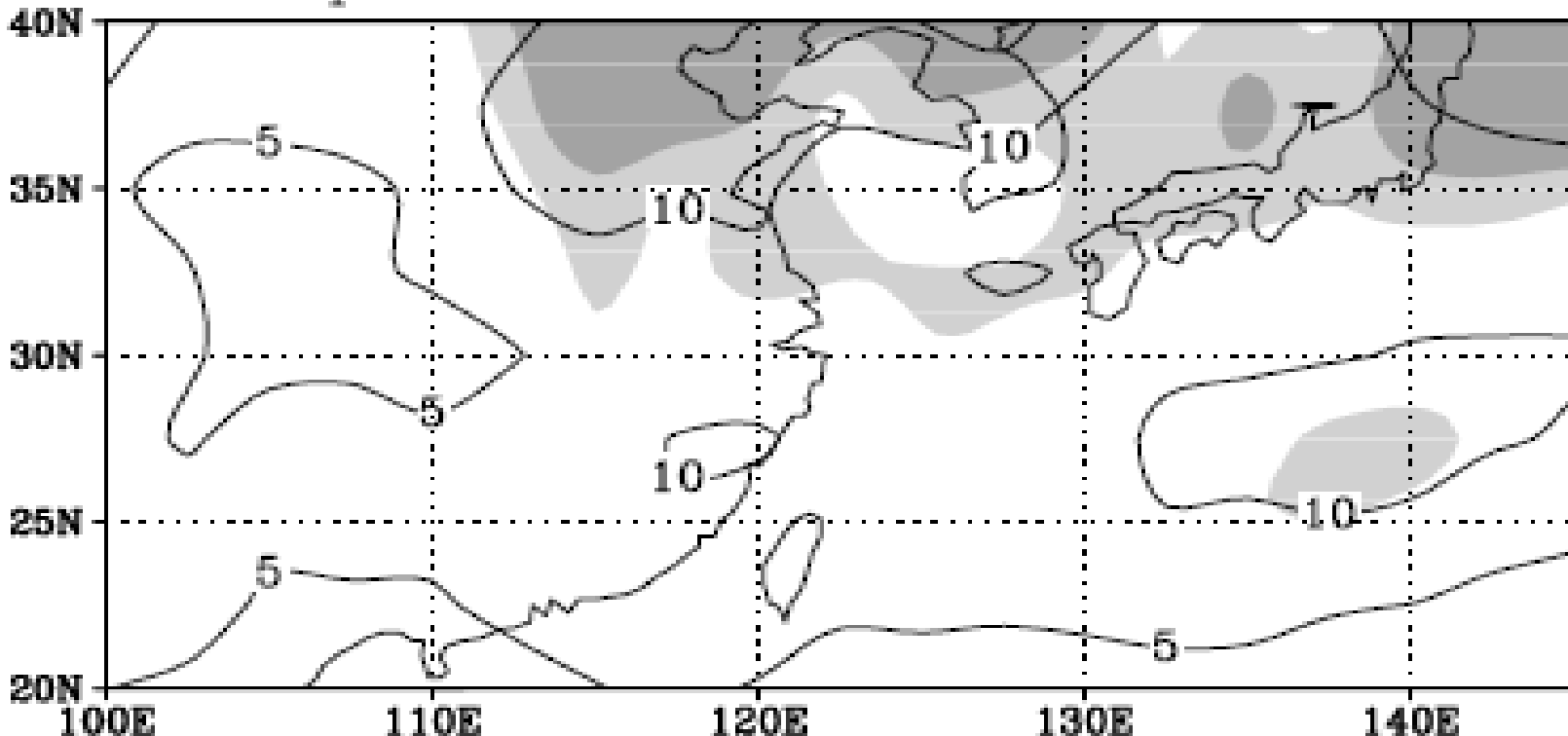
Increased precipitation in northern China, rather than along Yangtze River valley

(Wei, 2005)

22 coupled climate models (IPCC AR4)

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

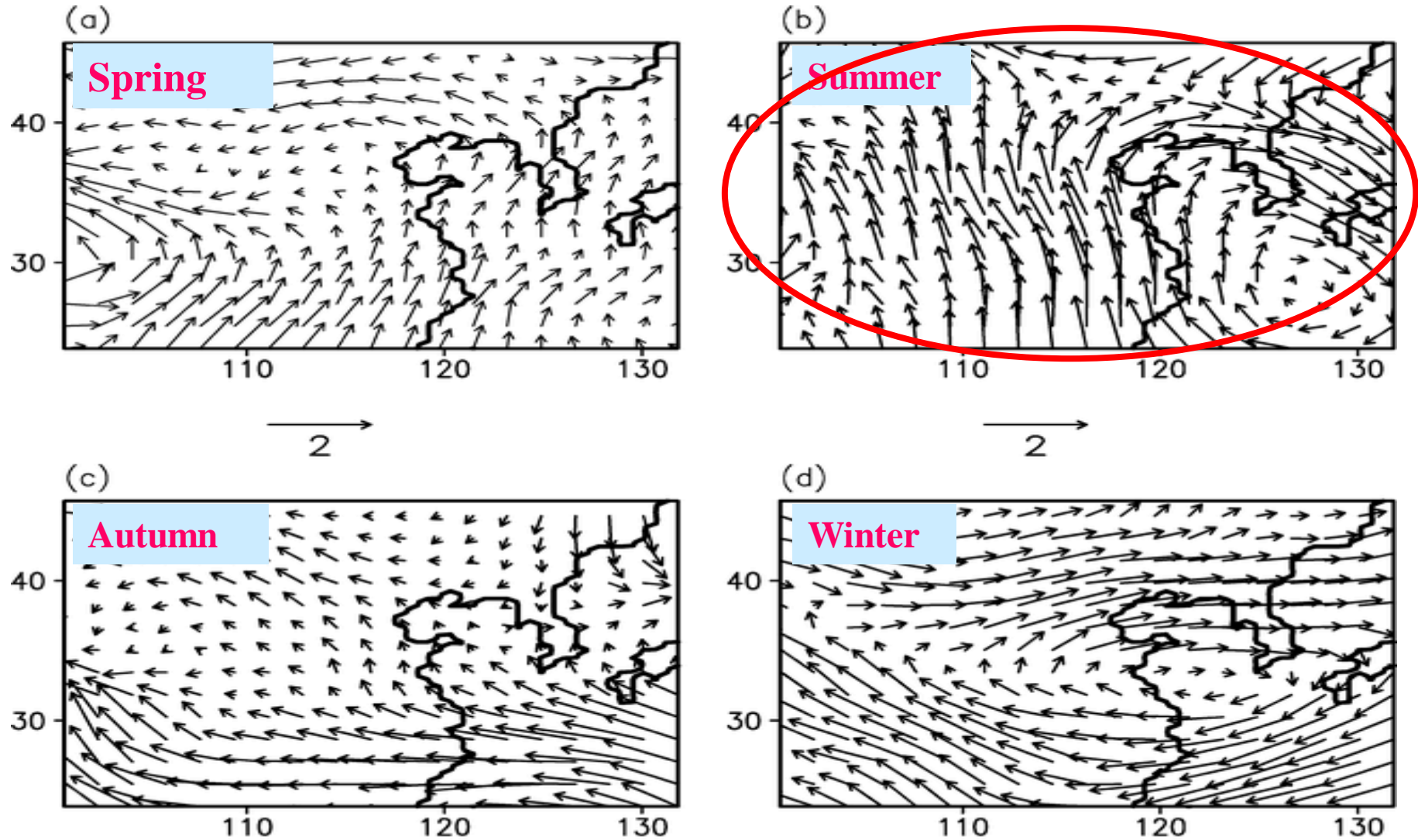
Multi-Model Ensemble Patterns: Difference
1pctto2x-20c3m
percent increase and t-value



(Kripalani et al, 2006)

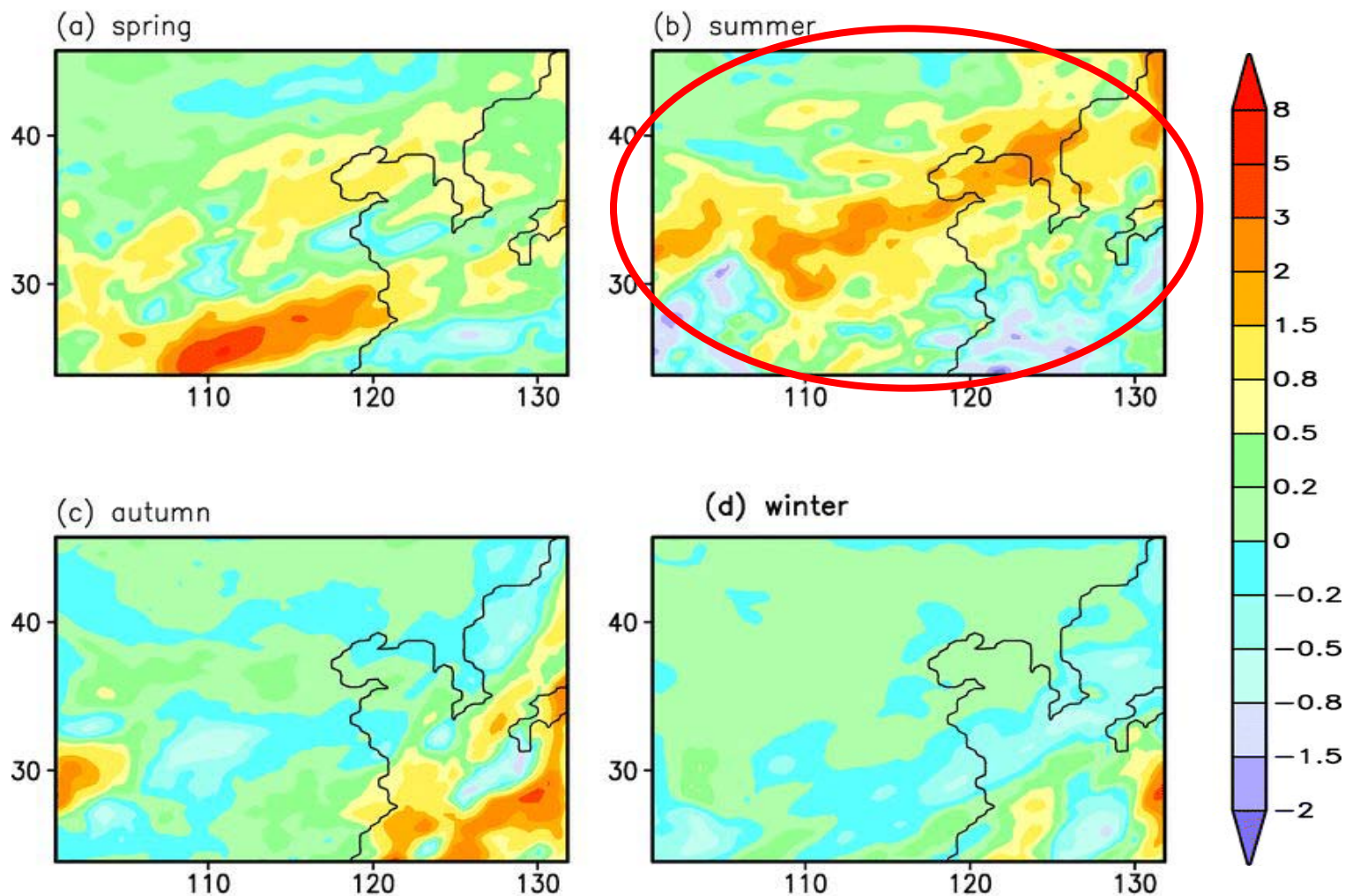
Regional climate model

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



Regional climate model

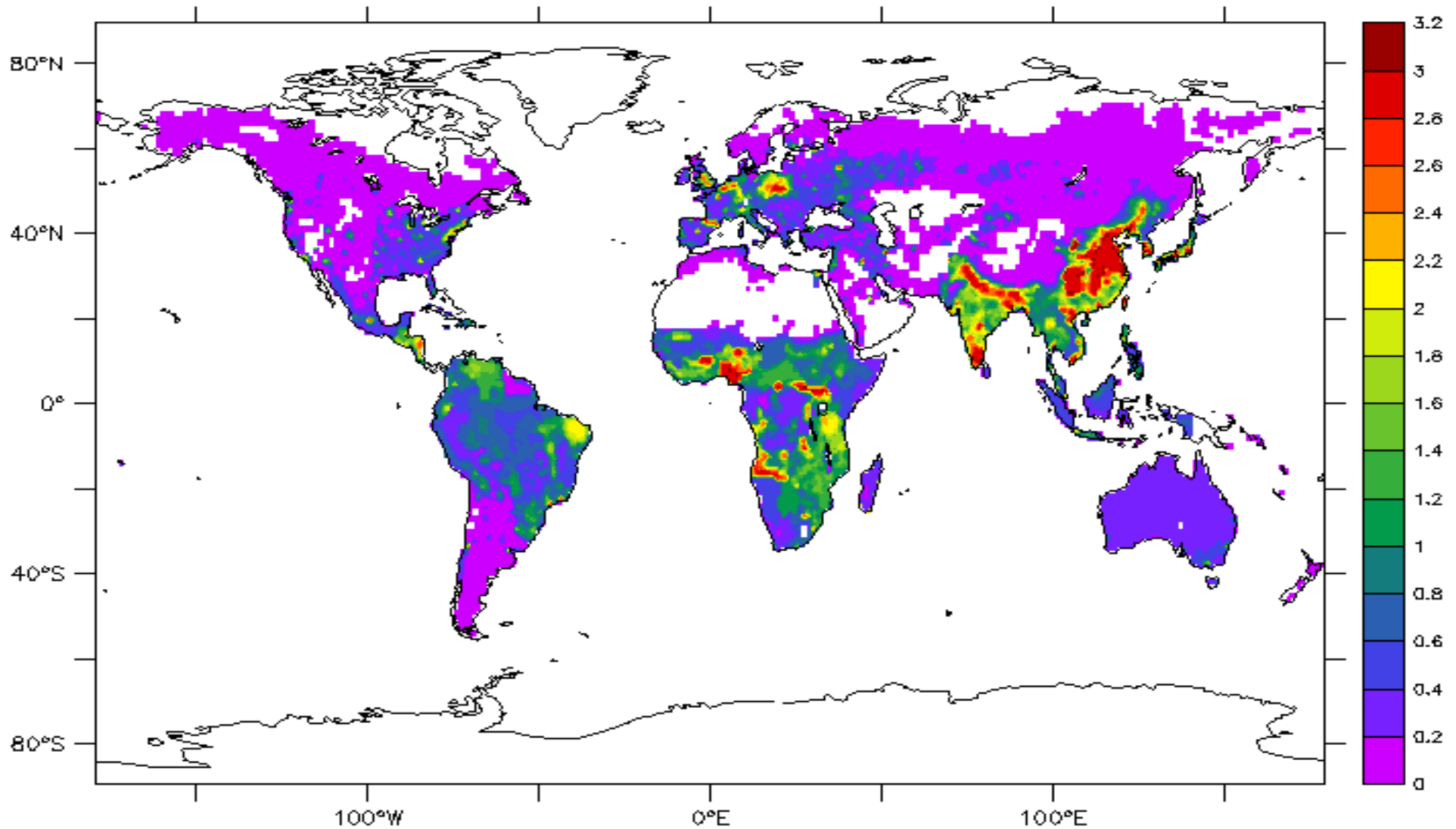
Doubling of CO₂ concentration induces an increased precipitation in northern China



(Chen, Pollard and Barron, JC 2004)

Global BC Emissions

(Tami Bond, 2002)



Previous simulation with aerosol's direct effect

Menon et al., 2002

BC-induced increased summer rainfall in southern China, decreased rainfall in northern China

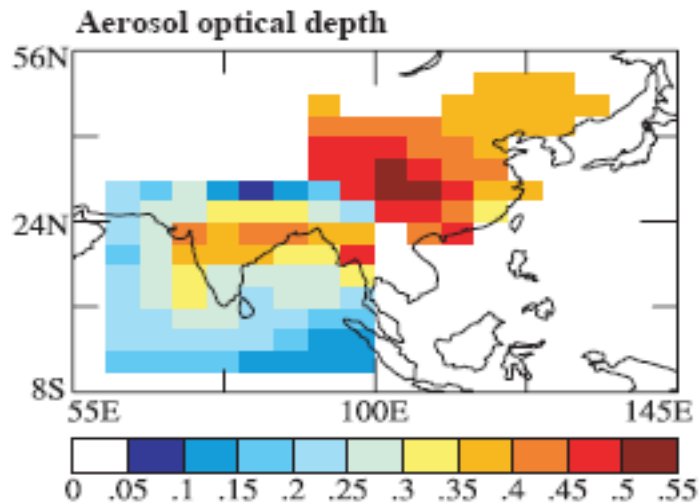
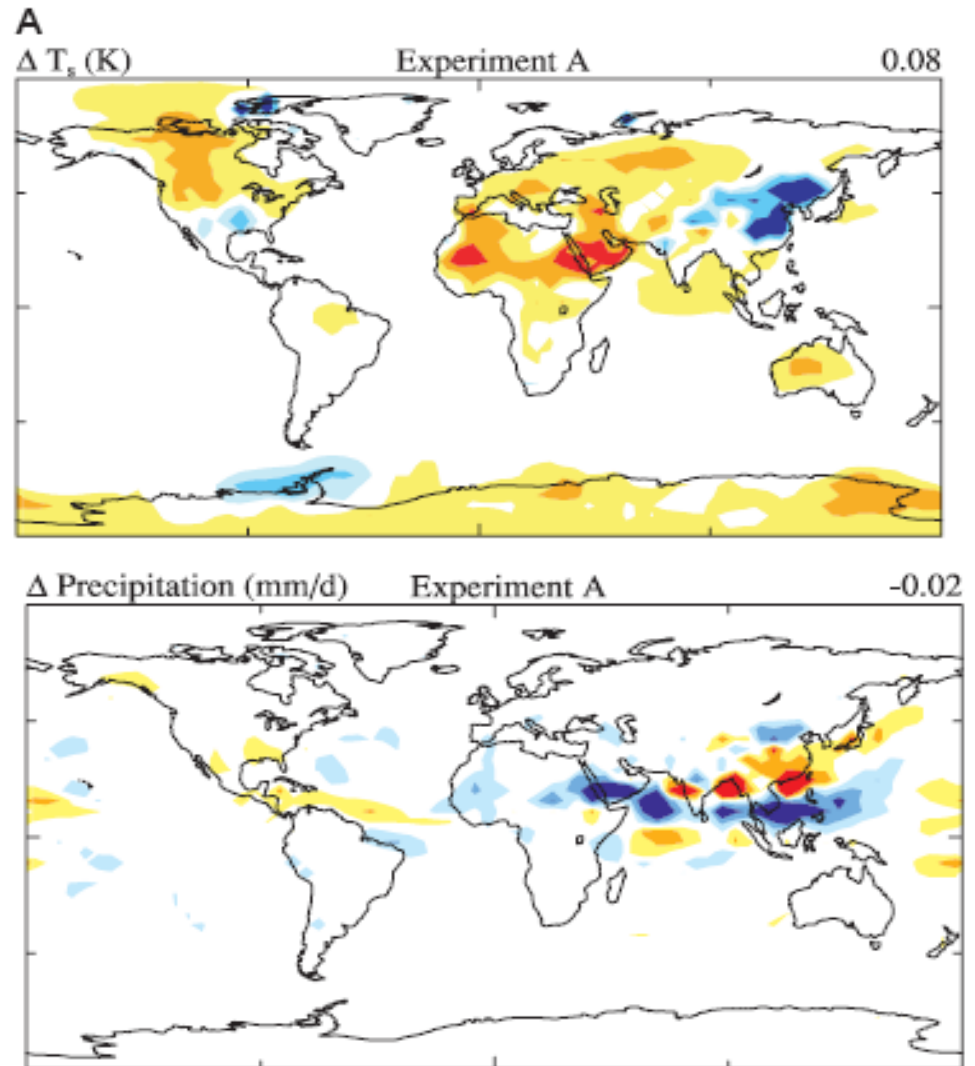


Fig. 1. Incremental aerosol optical depth $\Delta\tau_{aer}$ ($0.55 \mu\text{m}$), which is used to drive the climate change simulations. Latitude and longitude are denoted.



Previous simulation with aerosol's direct effect

Lau, 2006

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.

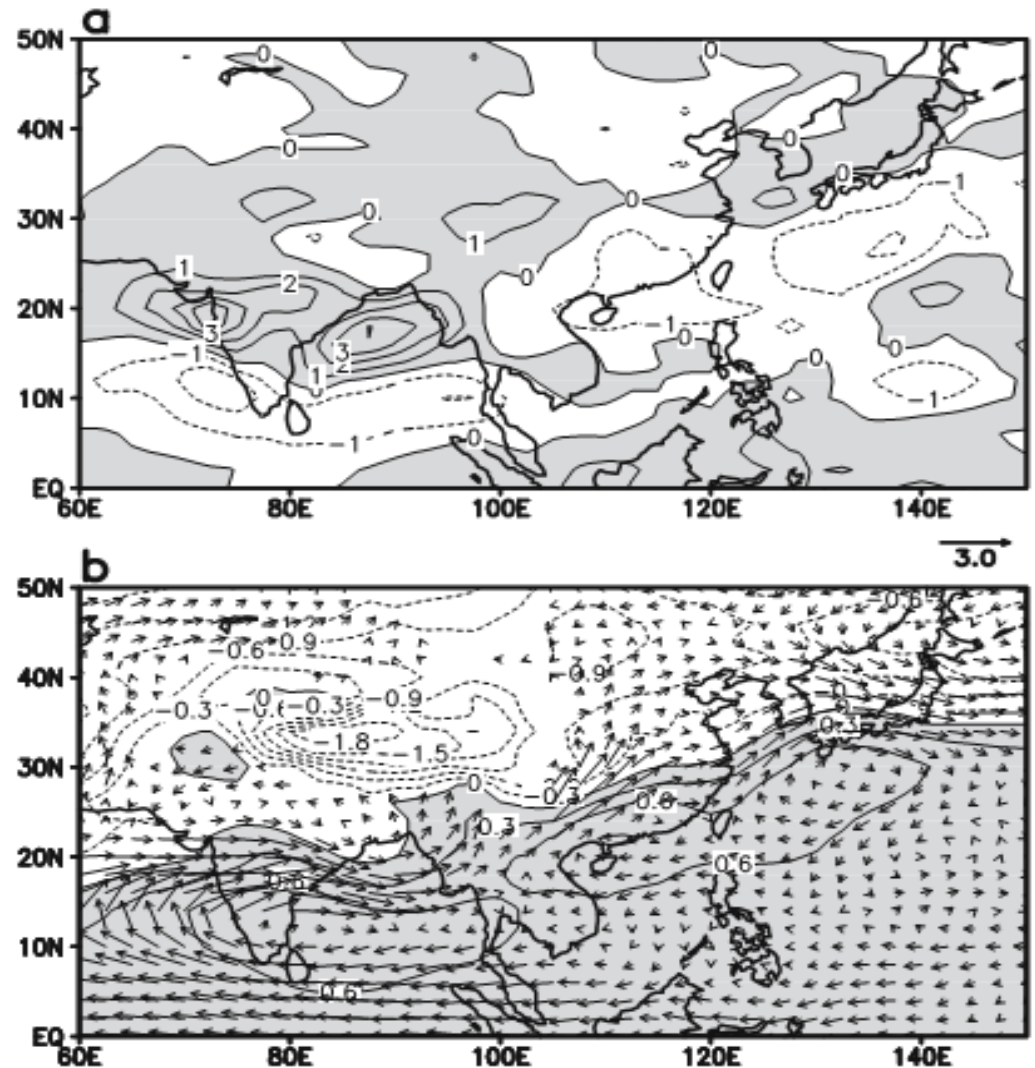


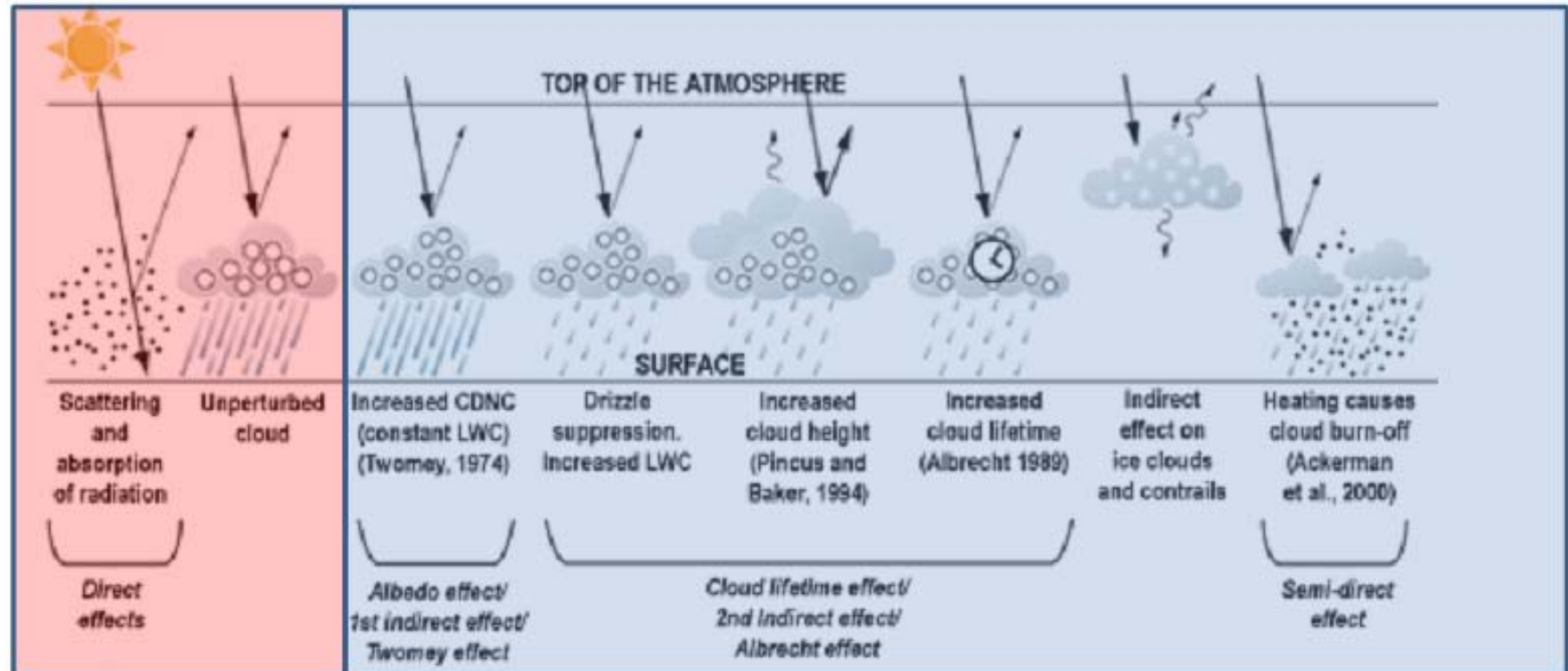
Fig. 6 Spatial distribution of JJA anomalies in the Asian monsoon region due to aerosols for a precipitation (mm day^{-1}), and b sea level pressure (hPa) and 850 hPa winds (ms^{-1})

Current simulation with aerosol's direct and indirect effects

Microphysics and modal aerosols permit the study of aerosol indirect effects

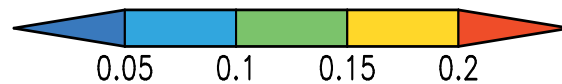
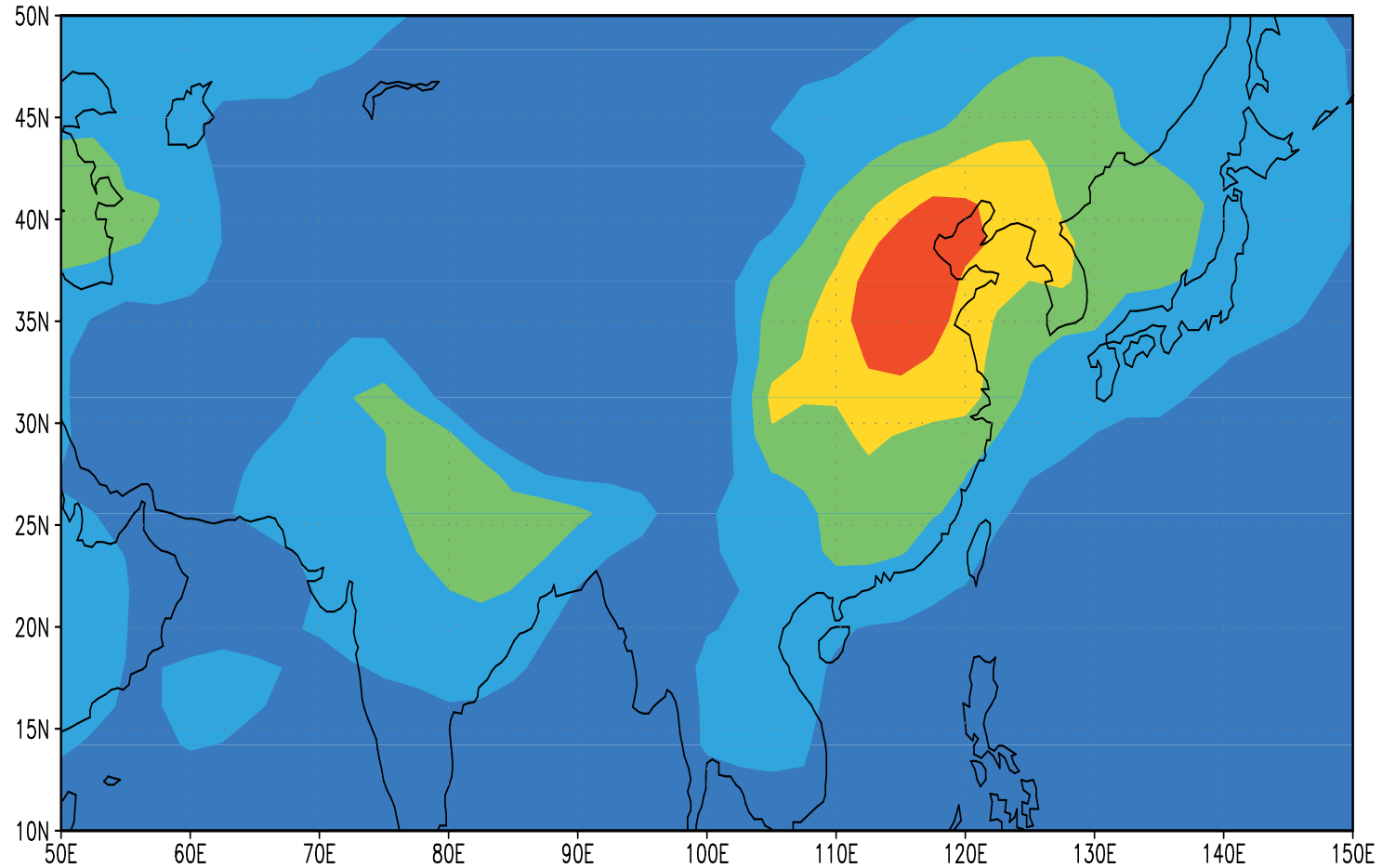
CAM4

CAM5



Change in Aerosol Optical Depth (AOD) between Present day (PD) and Pre-industrial day (PI)

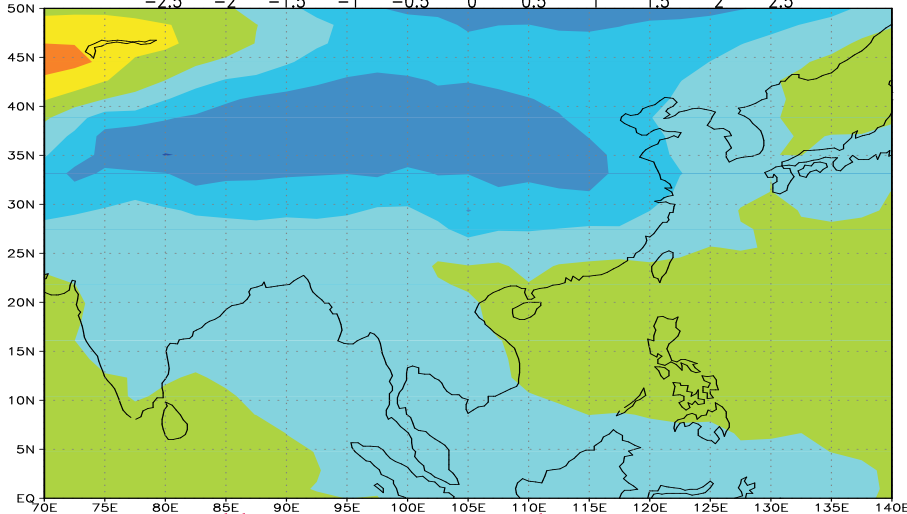
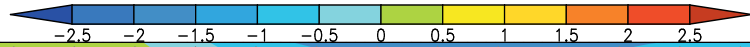
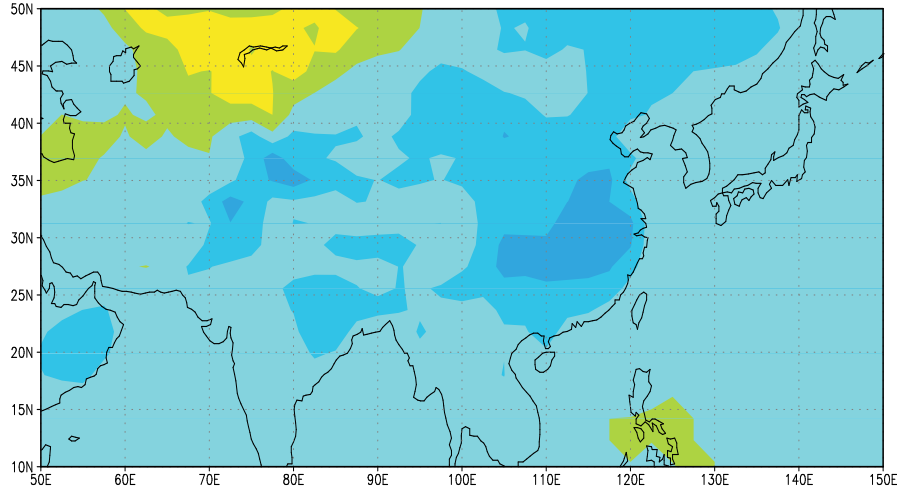
PD-PI Aerosol Optical Depth (JJA)



Changes in Asian summer monsoon

Surface temperature

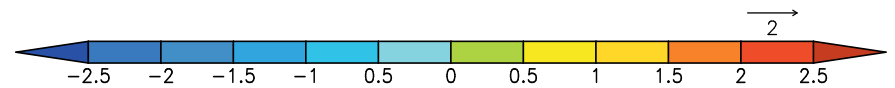
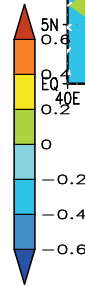
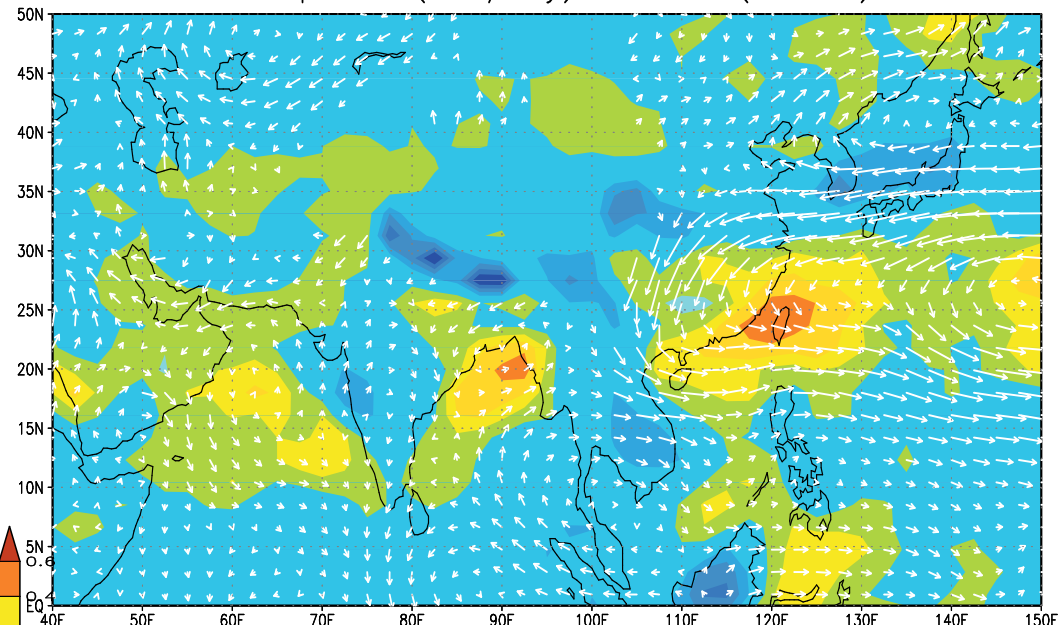
PD - P1ts



Vertically-integrated temperature

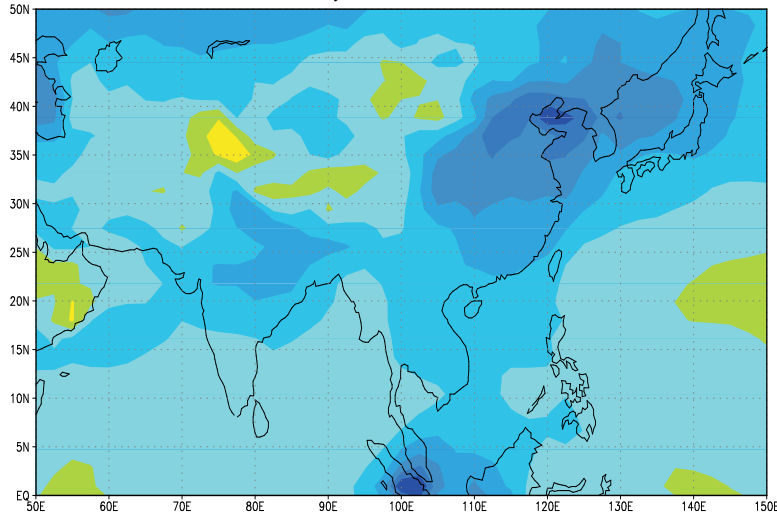
850hPa wind & Precipitation

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



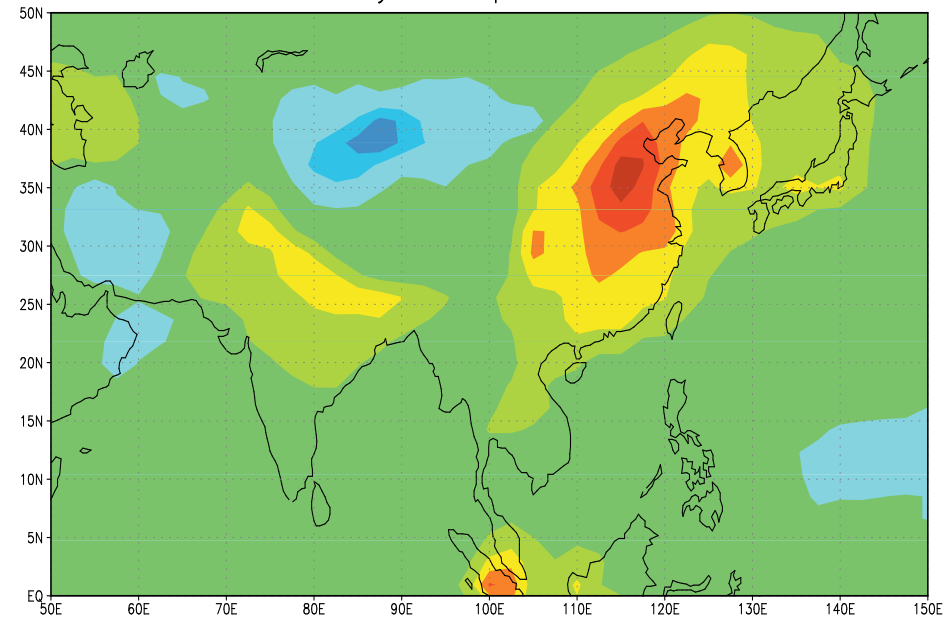
Changes in Radiative Forcing

**Net Solar Radiation
at TOA**

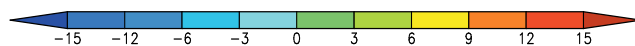
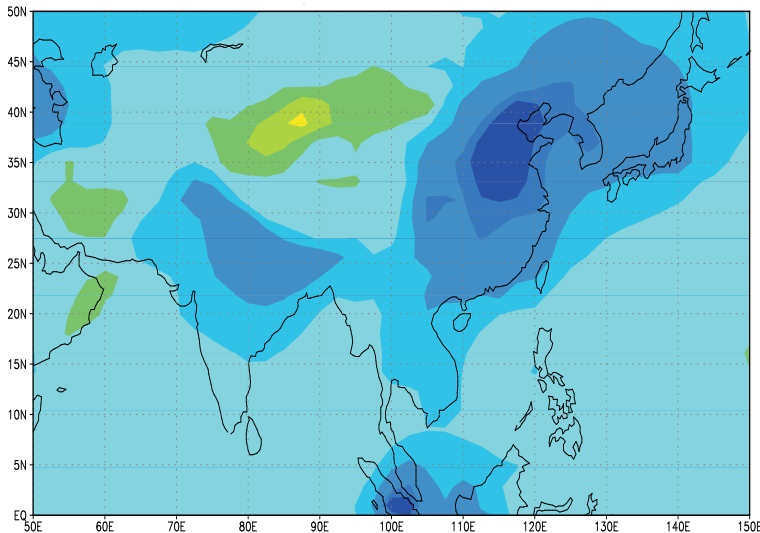


**Clear sky solar radiation
for atmosphere**

Clear Sky atmosphere Solar flux



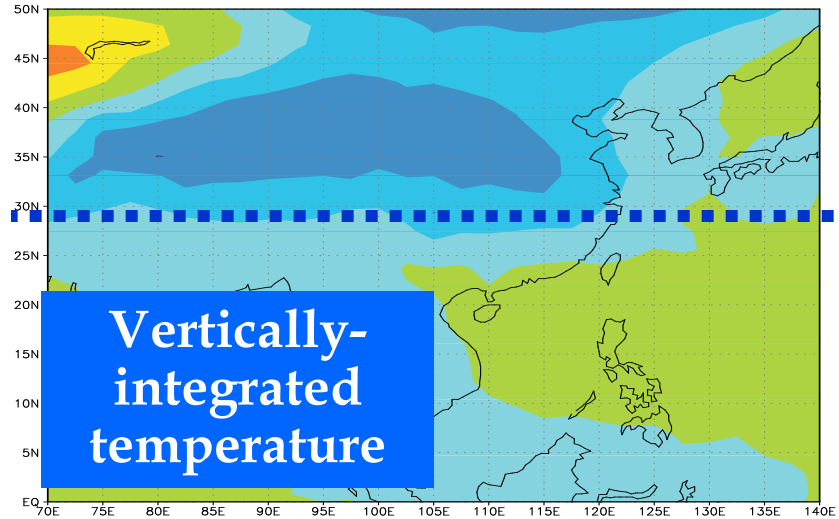
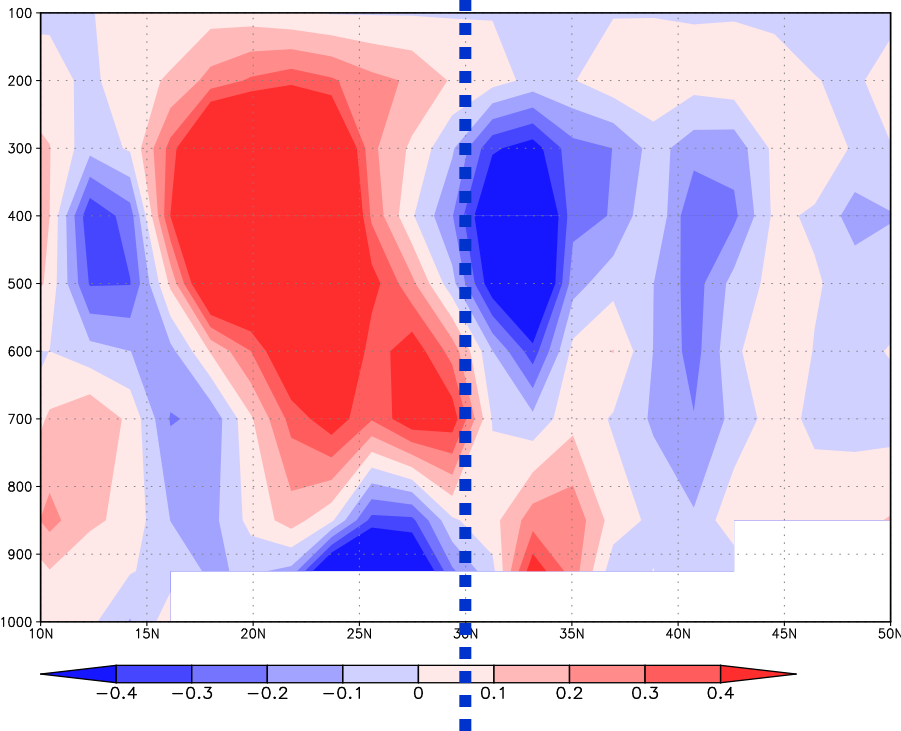
**Net Solar Radiation
at surface**



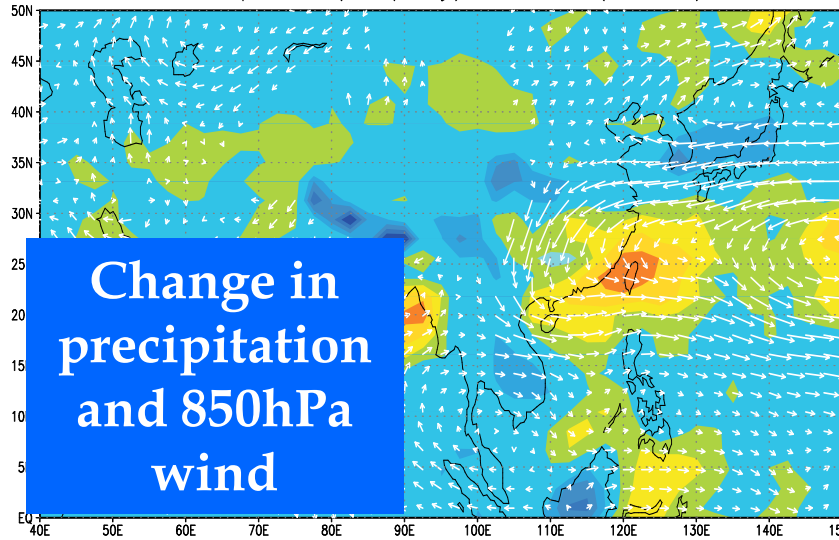
Aerosol's radiative effect

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

$P_d - P_i$ QRS+QRL+DTV+DTCOND

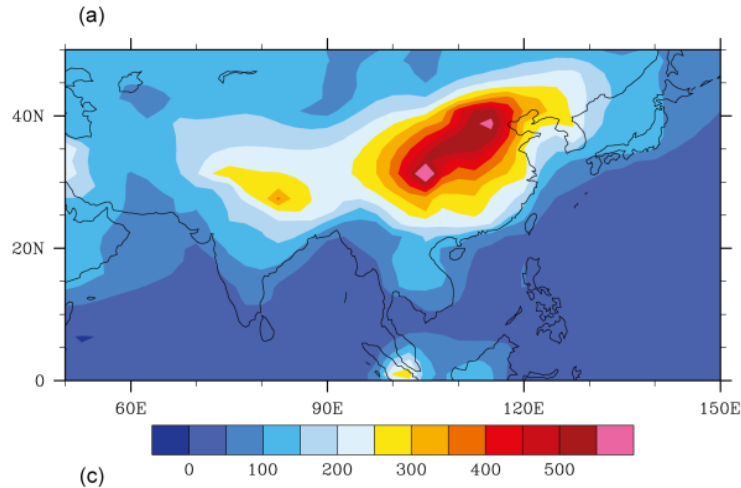


Precipitation(mm/day) and Wind(850mb)

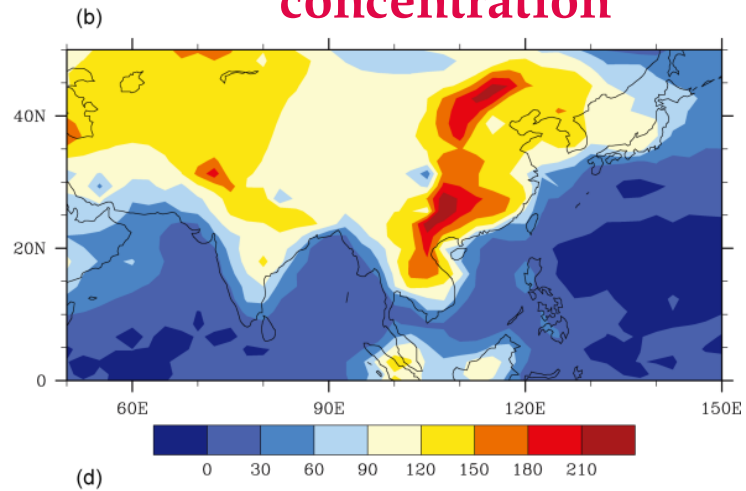


Aerosol's cloud-microphysical effect

CCN at $S=0.1\%$



Cloud droplet number concentration

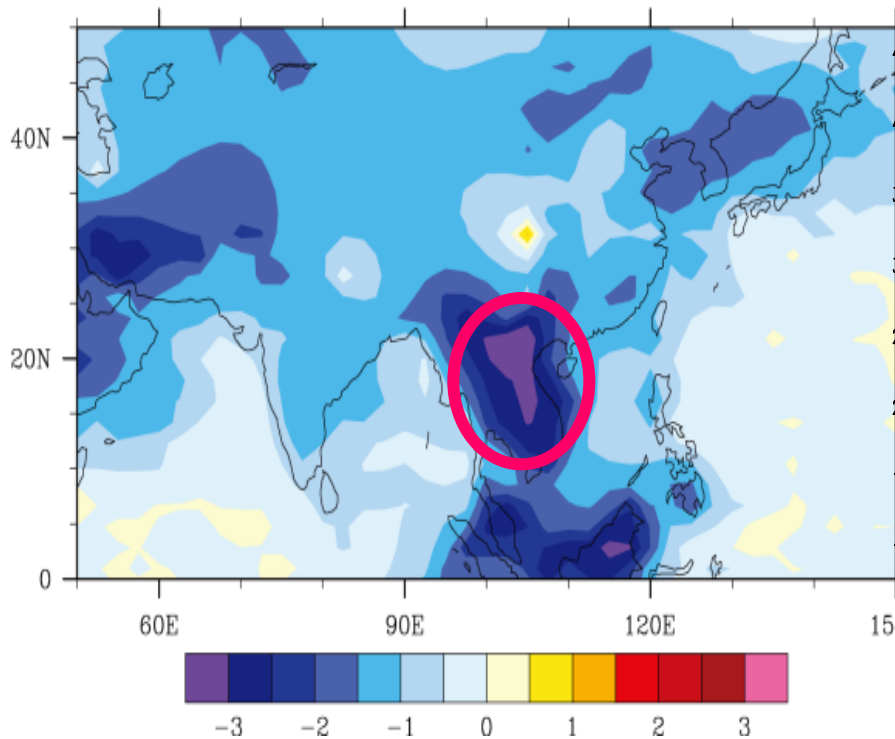


Cloud droplet effective radius

In-cloud liquid water content

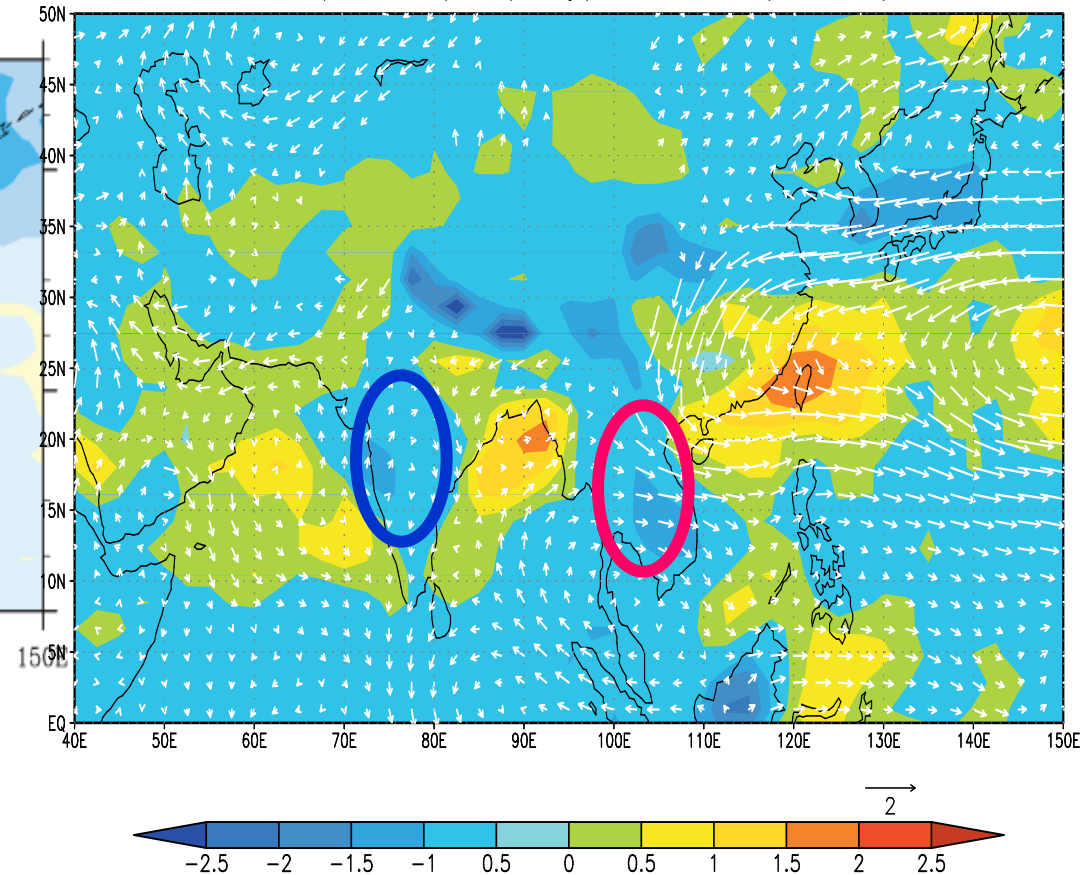
Aerosol's cloud-microphysical effect

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**

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-continent, which is mostly related to aerosol's cloud-microphysical (indirect) effect (i.e., the decreased droplet effective radius).



**Thanks for your
attention**