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Understanding and Attributing East Asian Climate Change

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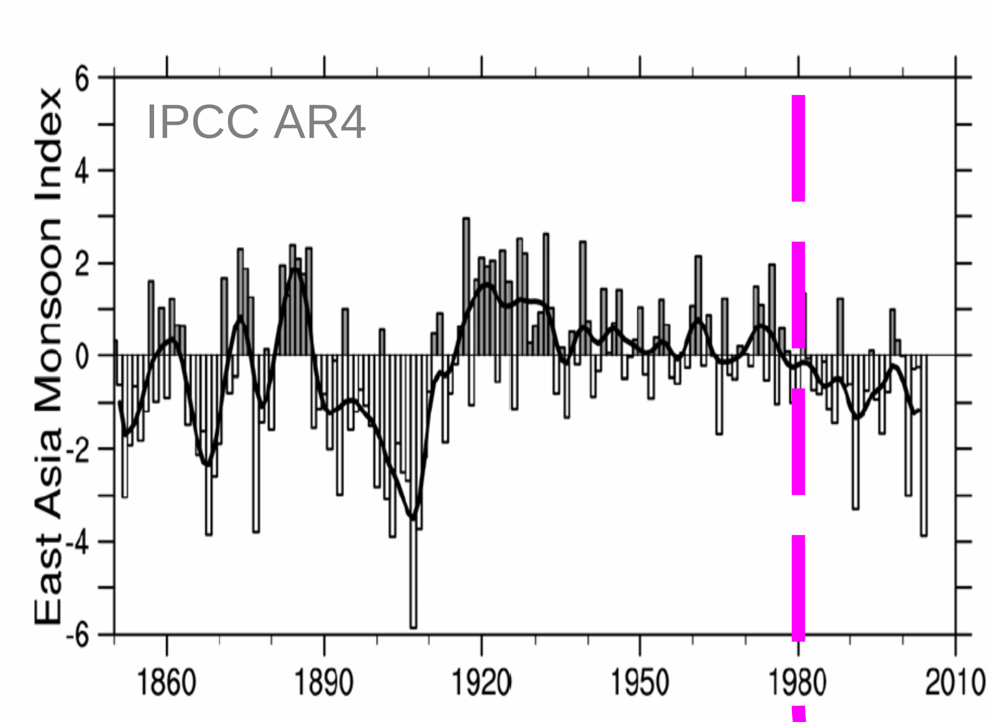
Outline

- Background
- Observational analysis
- Climate modeling
- Summary
- References

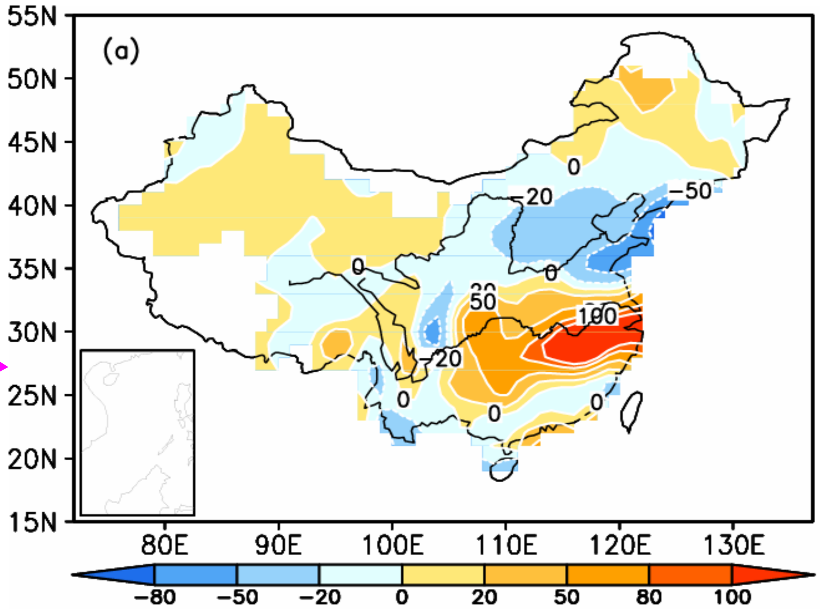
Long-term variation of E. Asian Summer monsoon



East Asian Summer Monsoon Index

(Guo et al. 2003; IPCC AR4)

A trend toward increasing drought in N. China and excessive rainfall in central China along the Yangtze River valley



JJA Trend of Precipitation for 1958-2000 from station data

Trend of summer temperature and precipitation

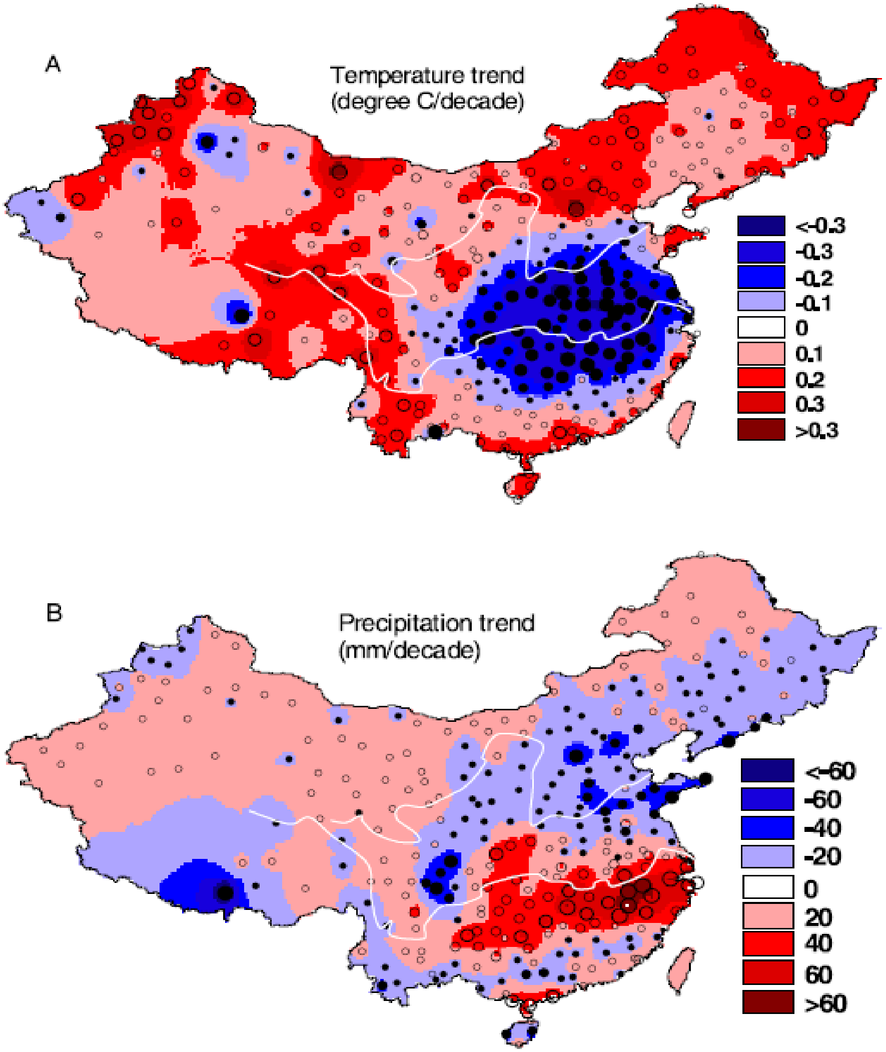


Figure 8. (a) Trend (°C/decade) of summer (JJA) daily maximum air temperature indicating the cooling in south-central China (mid Yellow River Basin to the mid-lower Yangtze River Basin) from 1969 to 2000 and (b) trend of summer precipitation (mm/decade) showing the increasing rainfall in the same area. The main branches of Yellow River (north) and Yangtze River (south) are sketched on both panels.

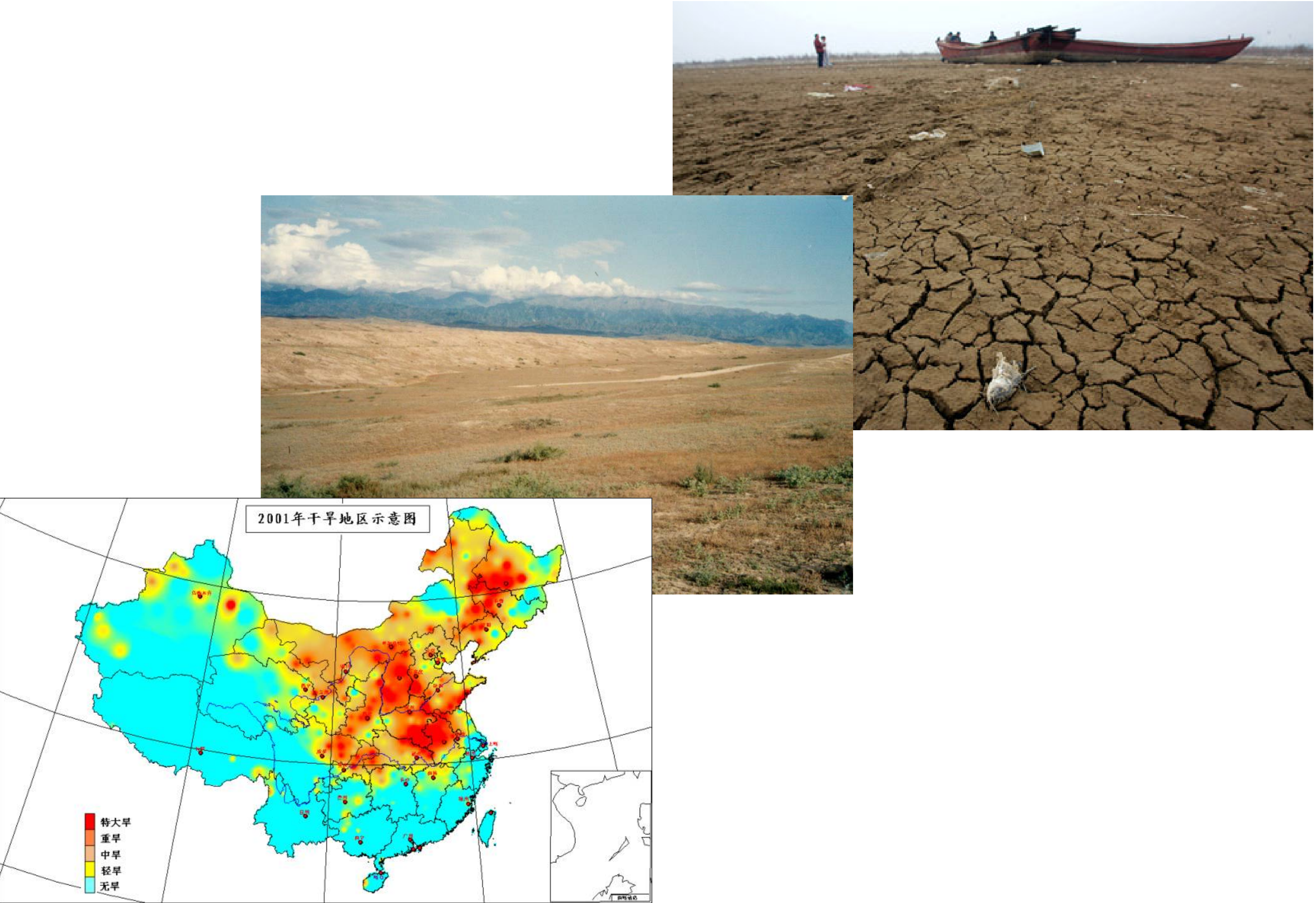
Temperature

Rainfall

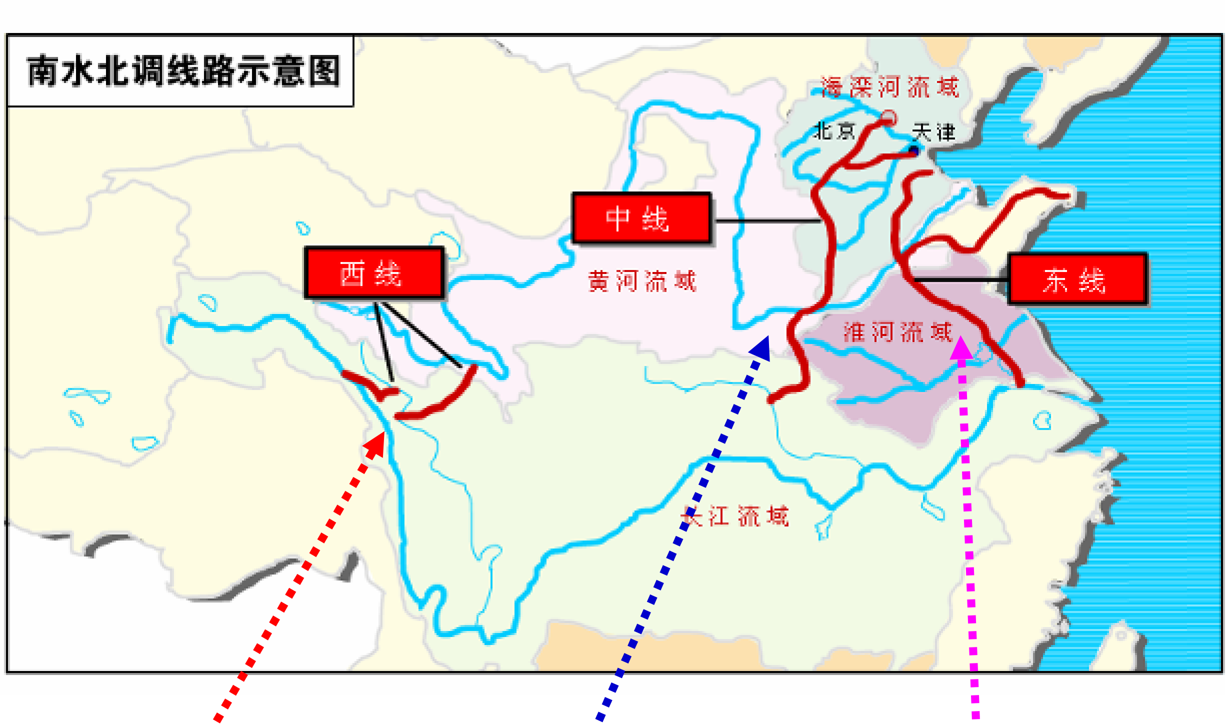
Xu et al. 2006 JGR

South Flood and North Drought

South Flood and North Drought



South-to-North Water Diversion Project



Western Route Project **Middle Route Project** **Eastern Route Project**

http://www.nsbd.gov.cn/zx/english/20070308/

Courtesy of SNWD website

(http://www.nsbd.gov.cn/zx/english/20070308/)

Why “South Flood – North Drought” ?

Why “South Flood – North Drought” ?

-- Natural inter-decadal Variability : (Yu and Zhou 2004 GRL; Li et al. 2005, 2008 J Climate; Xin et al. 2006 J Climate)

-- Tropical Ocean forcing (Zhou et al. 2008 J Climate; Li et al. 2008 Clm Dyn)

-- Snowfall change over the TP (Zhang et al. 2006 J Climate; Zhao et al. 2007 J Cimate)

-- TP plateau warming (Wang et al. 2008 GRL)

-- Aerosol-monsoon interaction ? (Li et al. 2007 GRL; Li et al. 2008 Clm Dyn)

-- Global warming ? (Zhou and Yu 2006 J Climate; Kripalani et al. 2007)

-- Internal variability (Lei et al. 2008, UK-China workshop on climate change)

-- ……

The true story

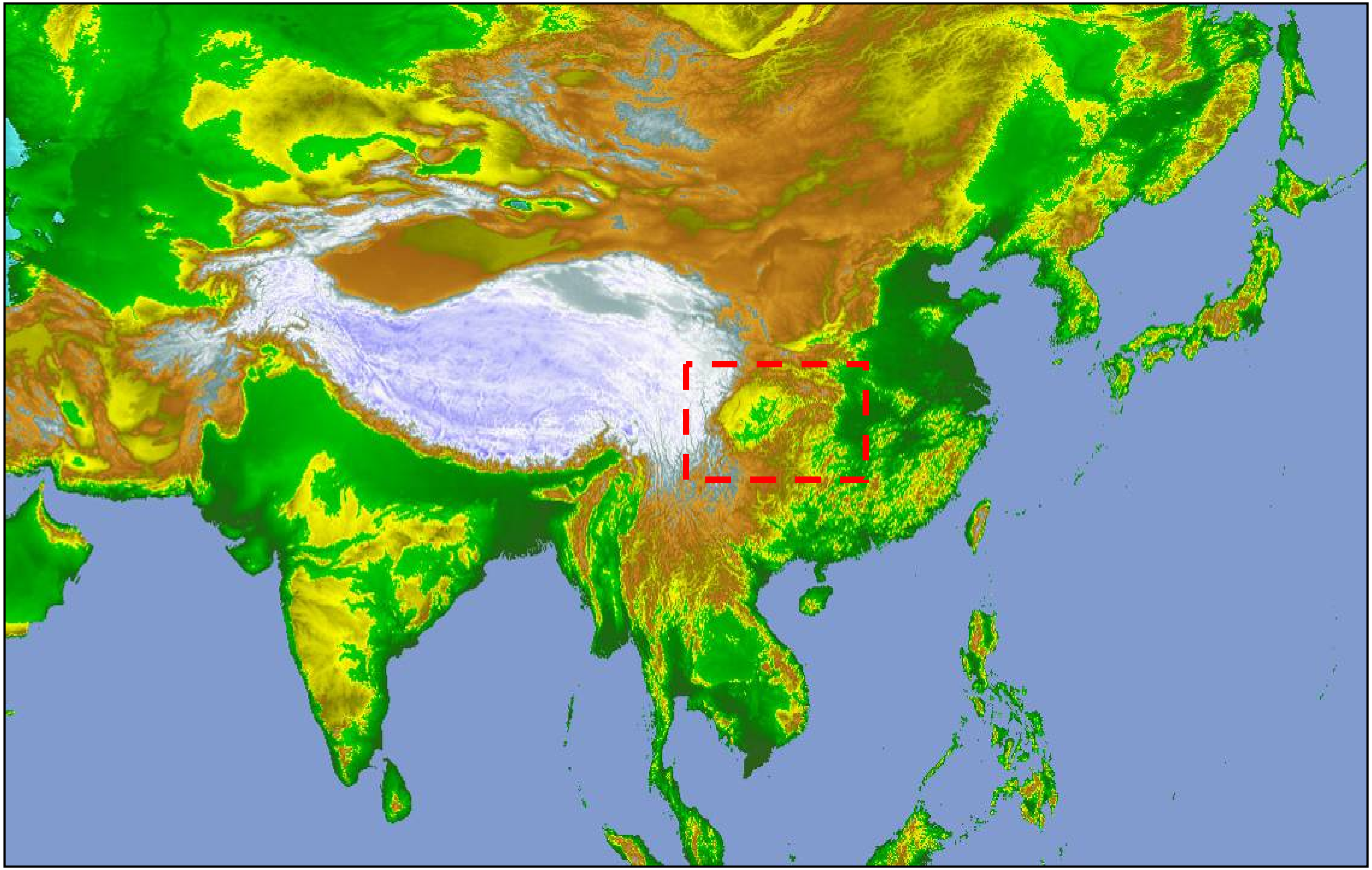
The inter-decadal scale climate transition of E. Asian climate is **not** a regional phenomenon; rather it has a much bigger picture and is a local manifestation of Northern Hemispheric climate transition occurred in the late 1970s .

Point 1:

This interdecadal climate shift has occurred throughout the year. Not only in summer.

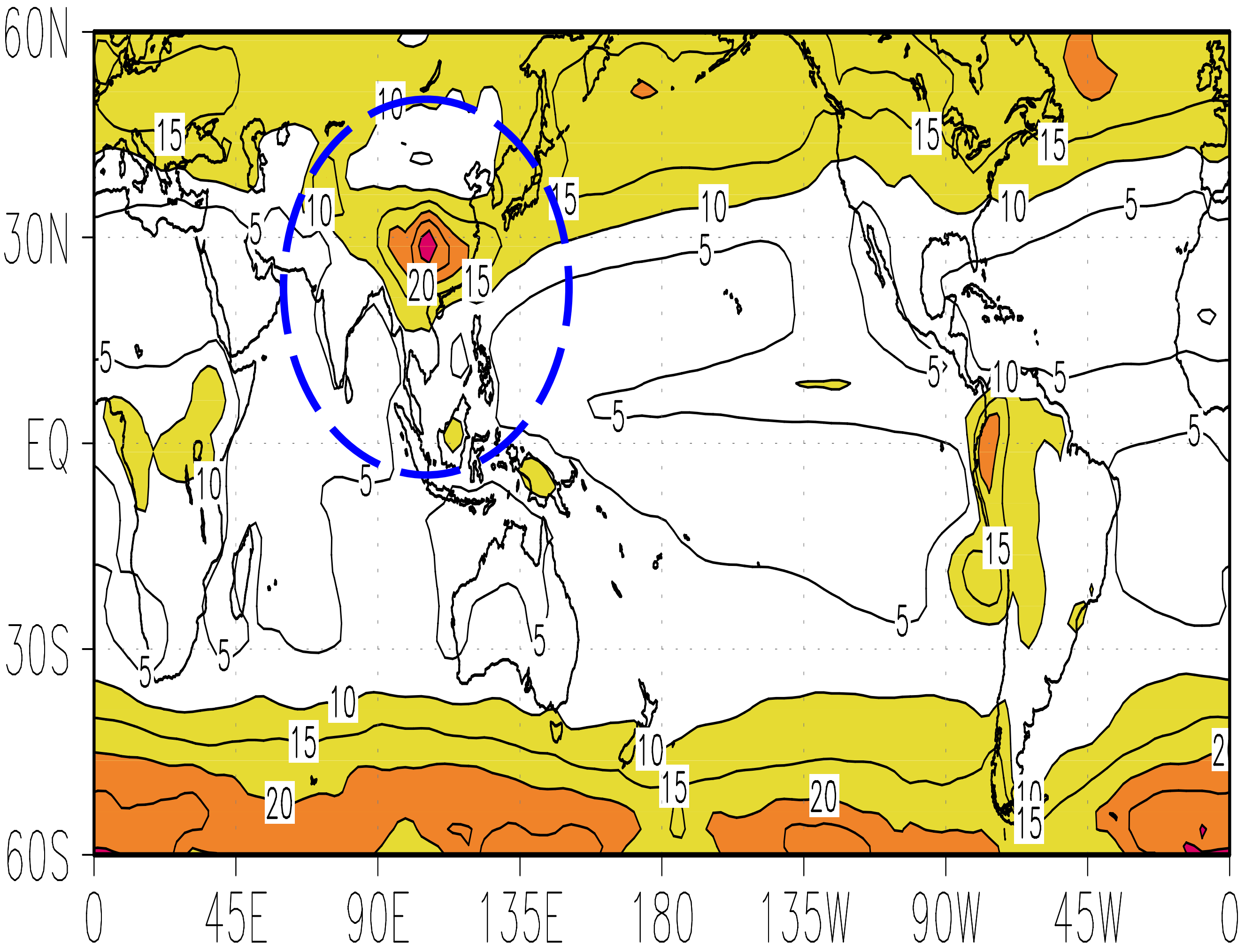
Defense: Two data analyses

Springtime cooling downstream of the Tibetan Plateau

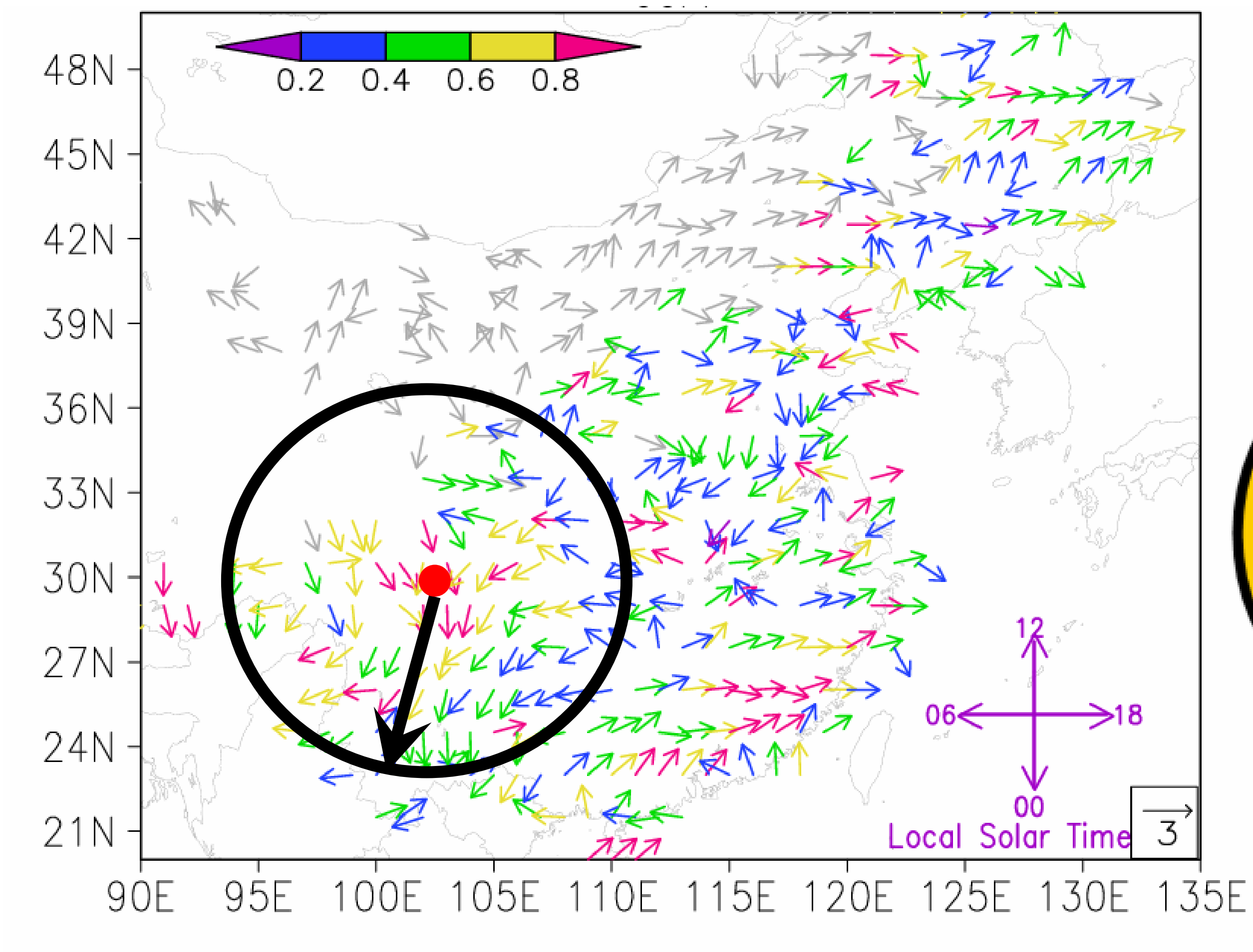


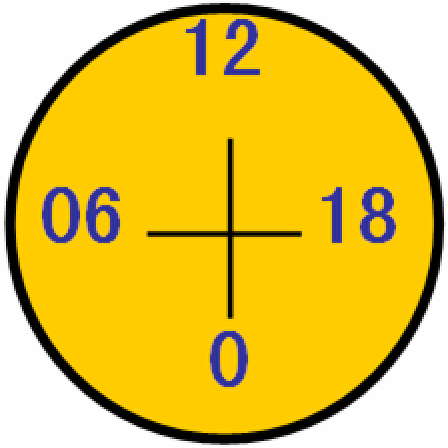
(Evidence-1)

Annual mean stratus cloud based on ISCCP



Diurnal cycle: rains in mid-night





(Yu et al, 2007a,b GRL; Zhou et al. 2008a, J. Climate)

Diurnal cycle documented 1000-yrs ago in Chinese poem

《夜雨寄北》

君问归期未有期，

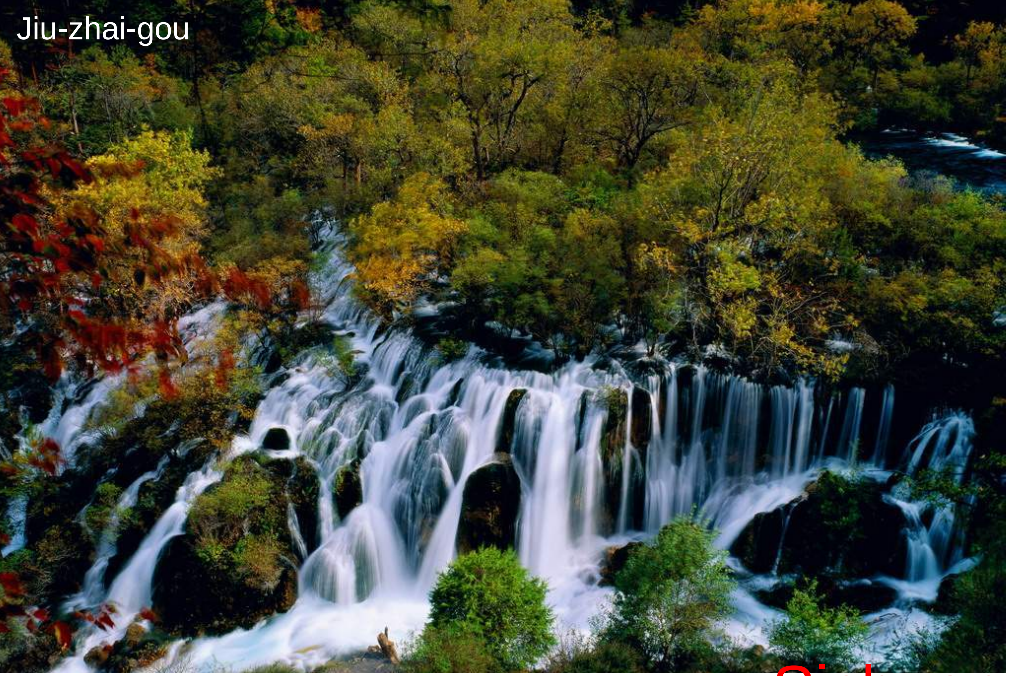
巴山夜雨涨秋池。

何当共剪西窗烛，

却话巴山夜雨时。

——李商隐(813—858)

Sichuan, CHINA


Jiu-zhai-gou

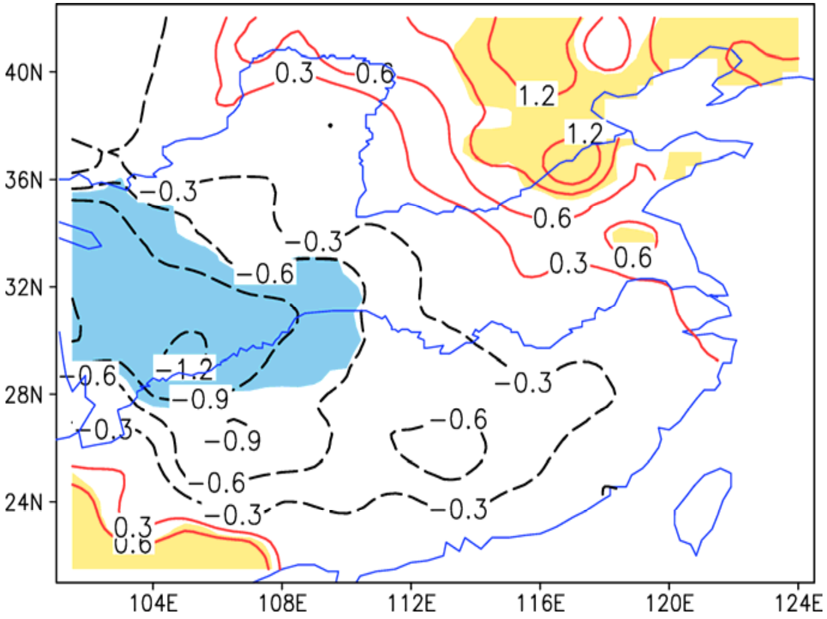

Huang-long


Jiu-zhai-gou


Jiu-zhai-gou

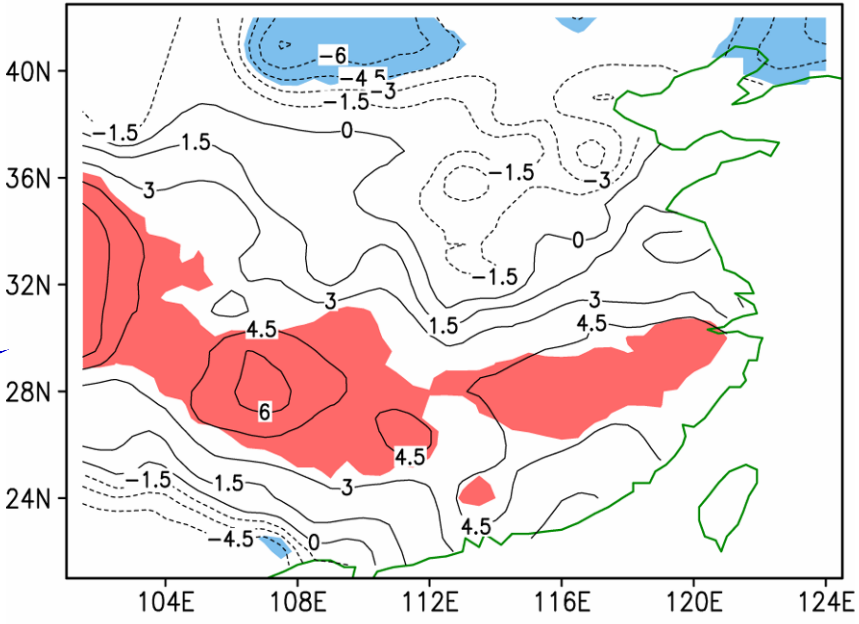
Sichuan

Cooling downstream of the Plateau



Trend of Mar SAT (1951-2000)

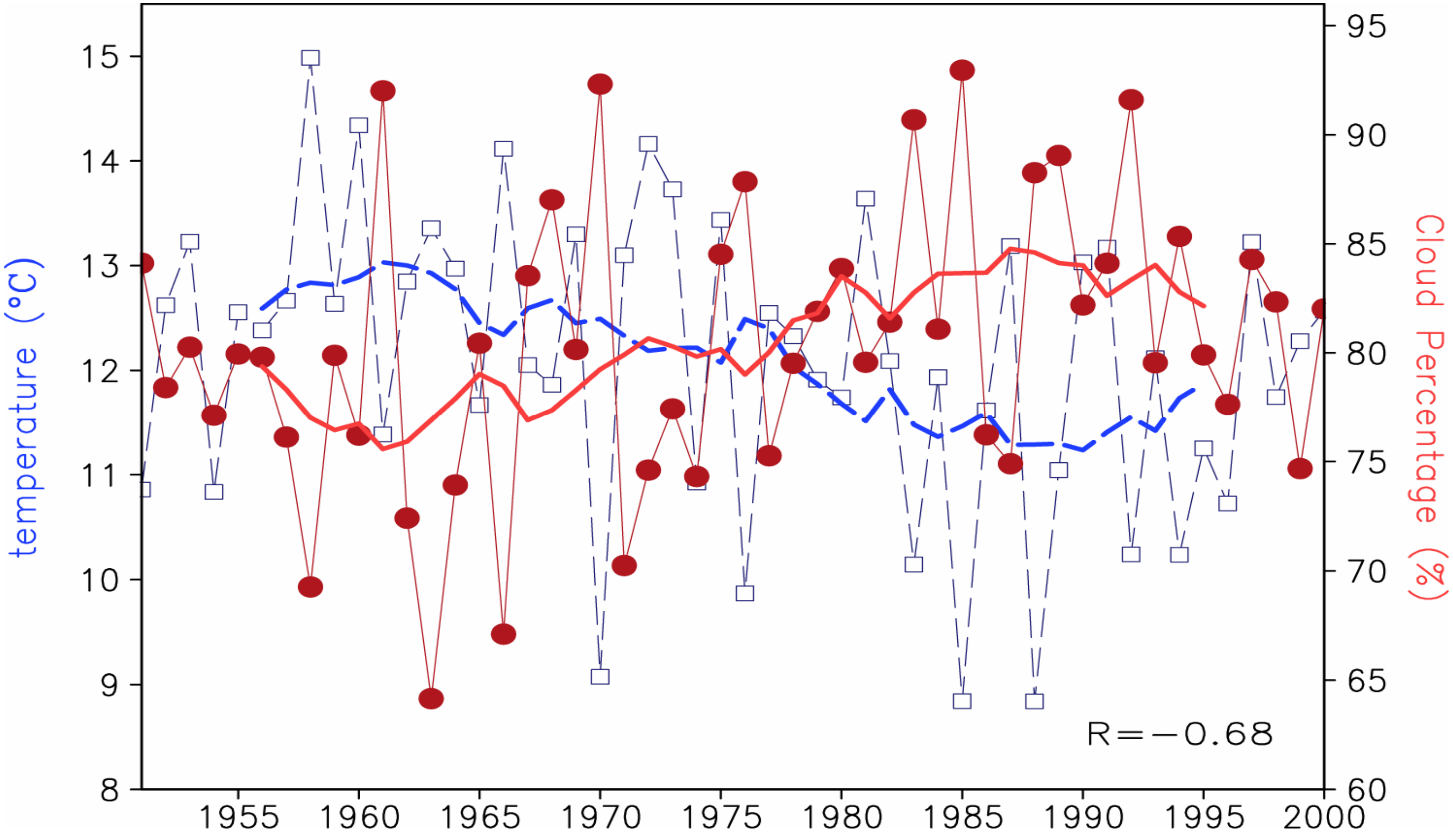
Unit: ℃/ 50years



(1976-2000)-(1951-75) Total cloud

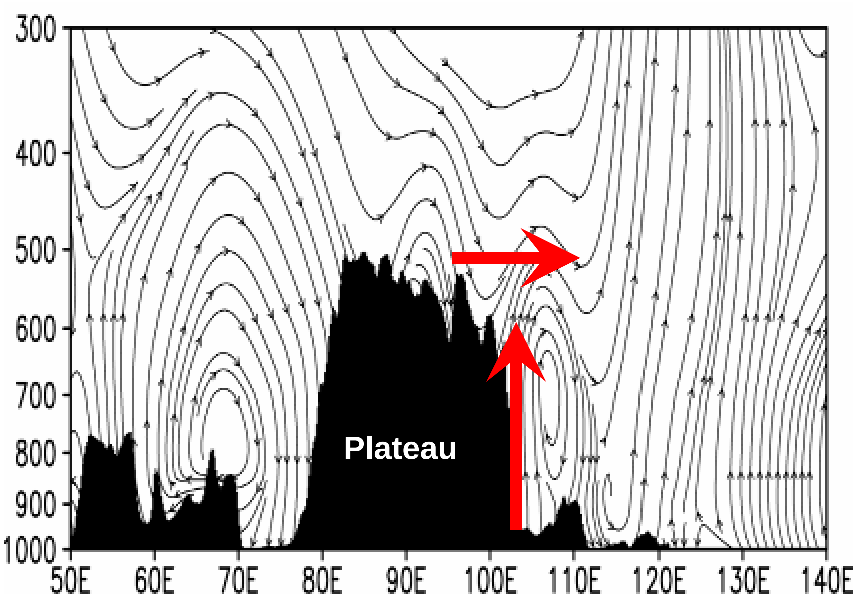
(Li et al. 2005, J. Climate)

Regional average Total cloud （red） and SAT （blue）

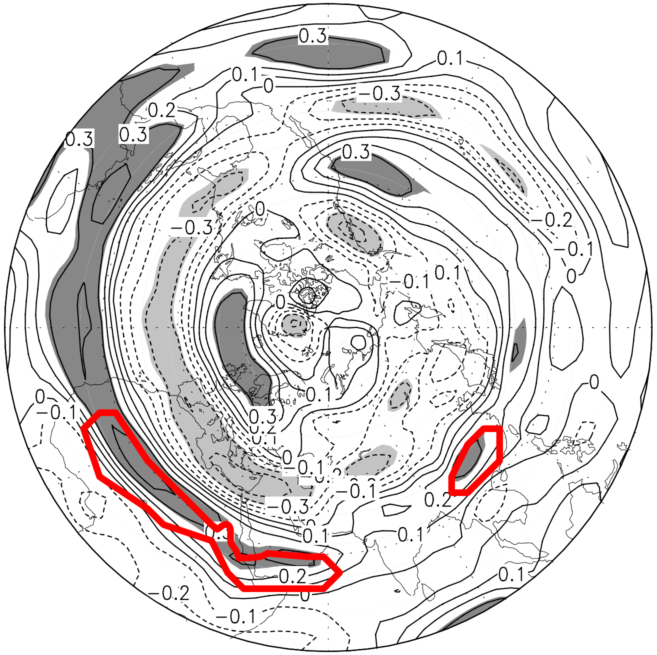


Li et al. 2005, J. Climate

NAO Played Active Role in the Circulation Changes



Vertical circulation changes in March
(1975-1999 minus 1950-1974)

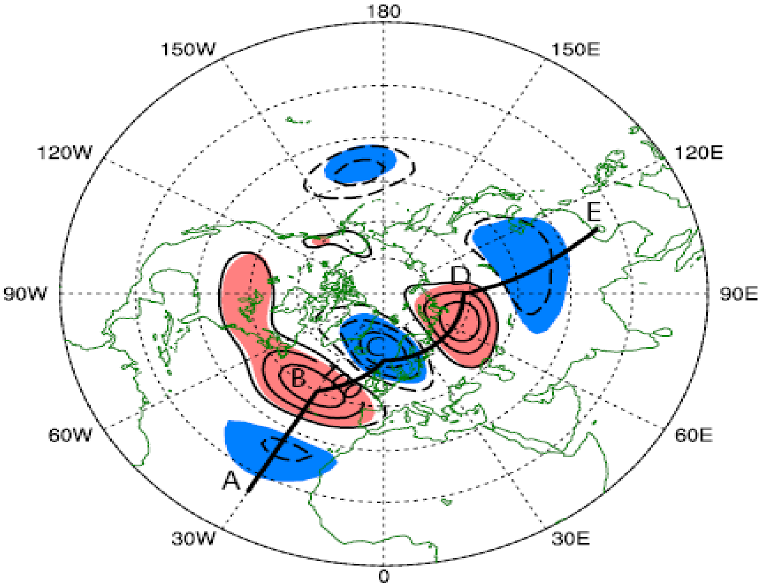


Correlation between Mar
U500 and DJF NAO index

The circulation changes encourage an increase of mid-level cloud.

The “CAP” (zonal wind) is closely related to the NAO.

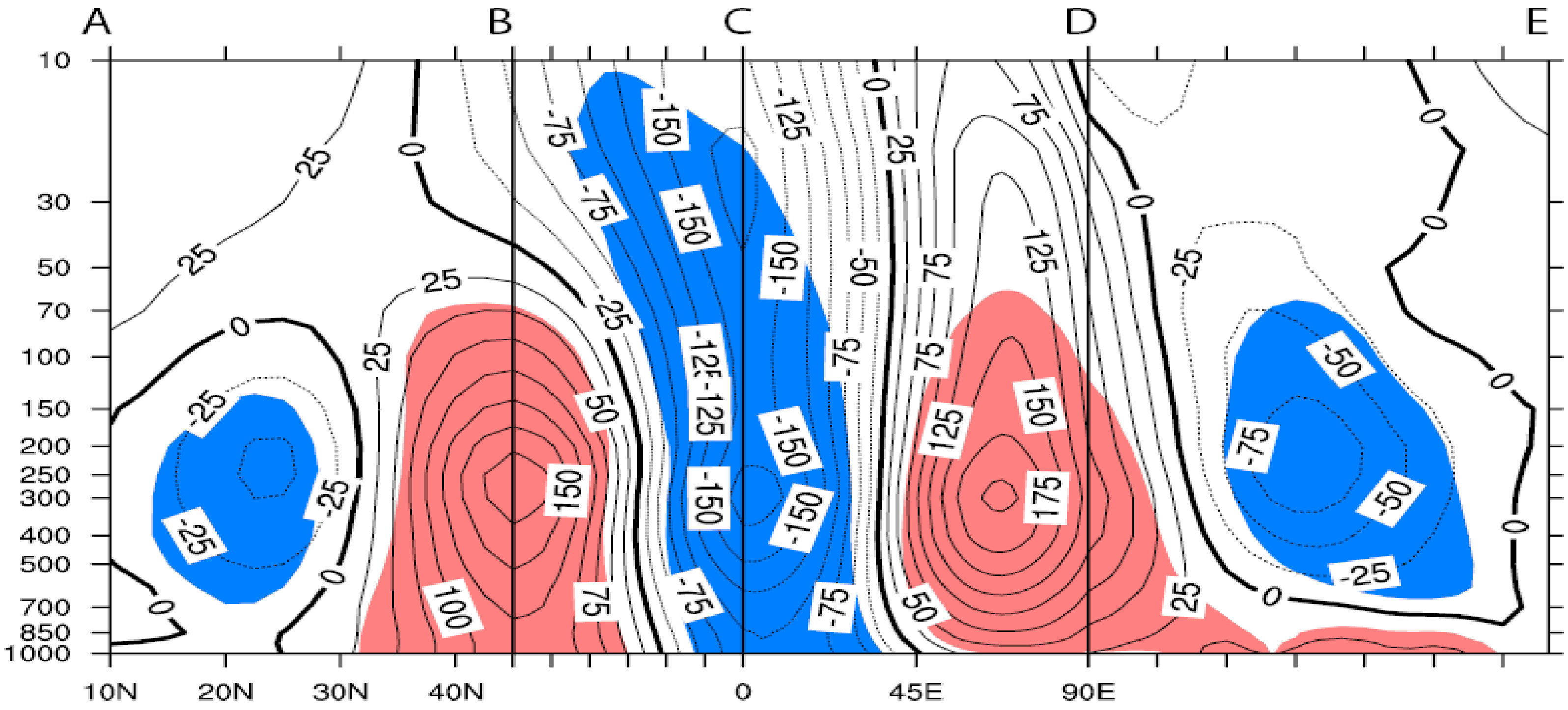
Li et al. 2005, J. Climate



Transection of the March Geo-Height alone the line (ABCDE) through

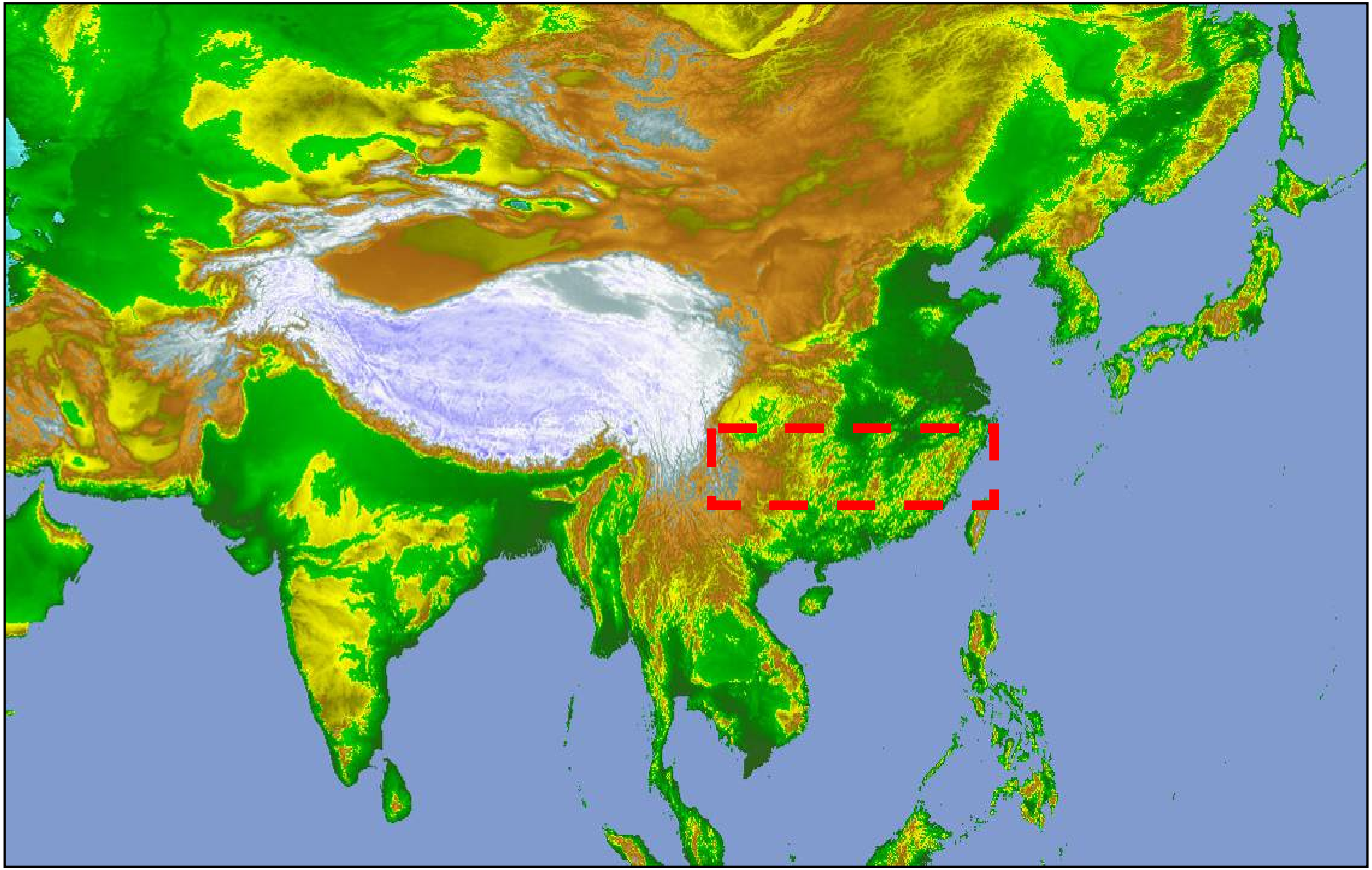
the 5-centers

of NAULEA pattern



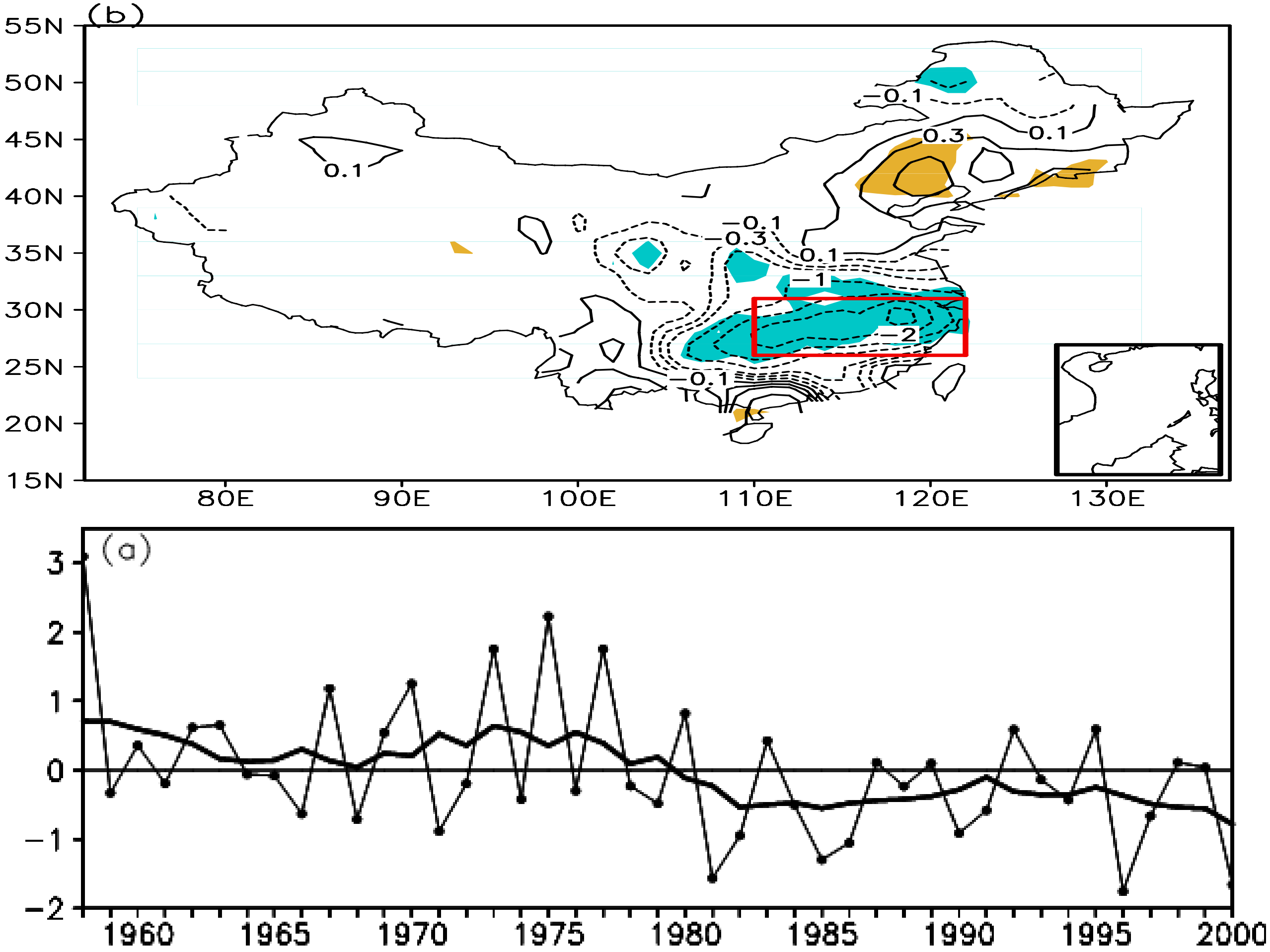
(Li et al. 2008, J. Climate)

Late spring drought in South China



(Evidence-2)

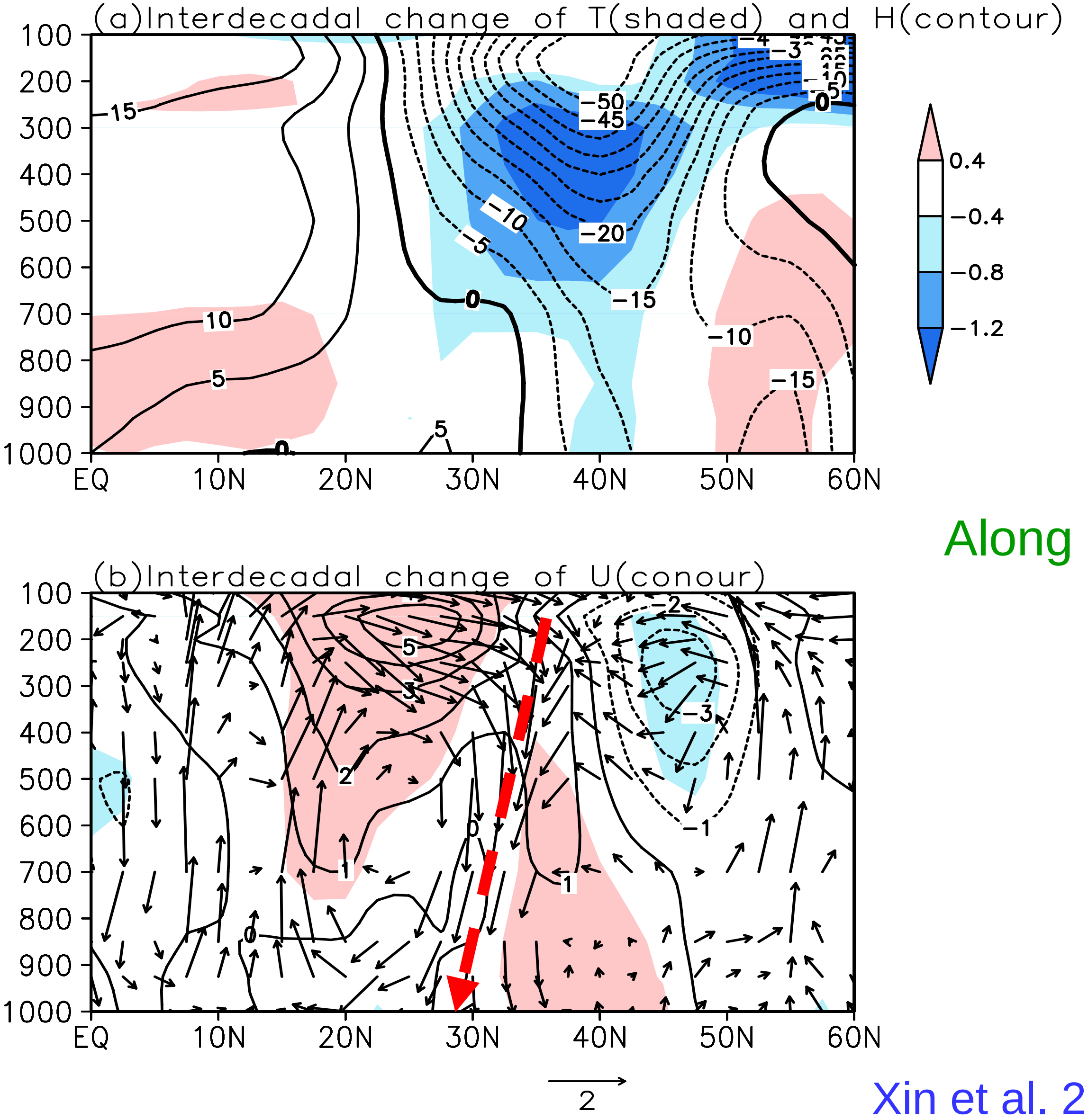
Late Spring Drought in South China



Changes of May rainfall (1975-1999 minus 1950-1974)

Xin et al. 2006 J. Climate

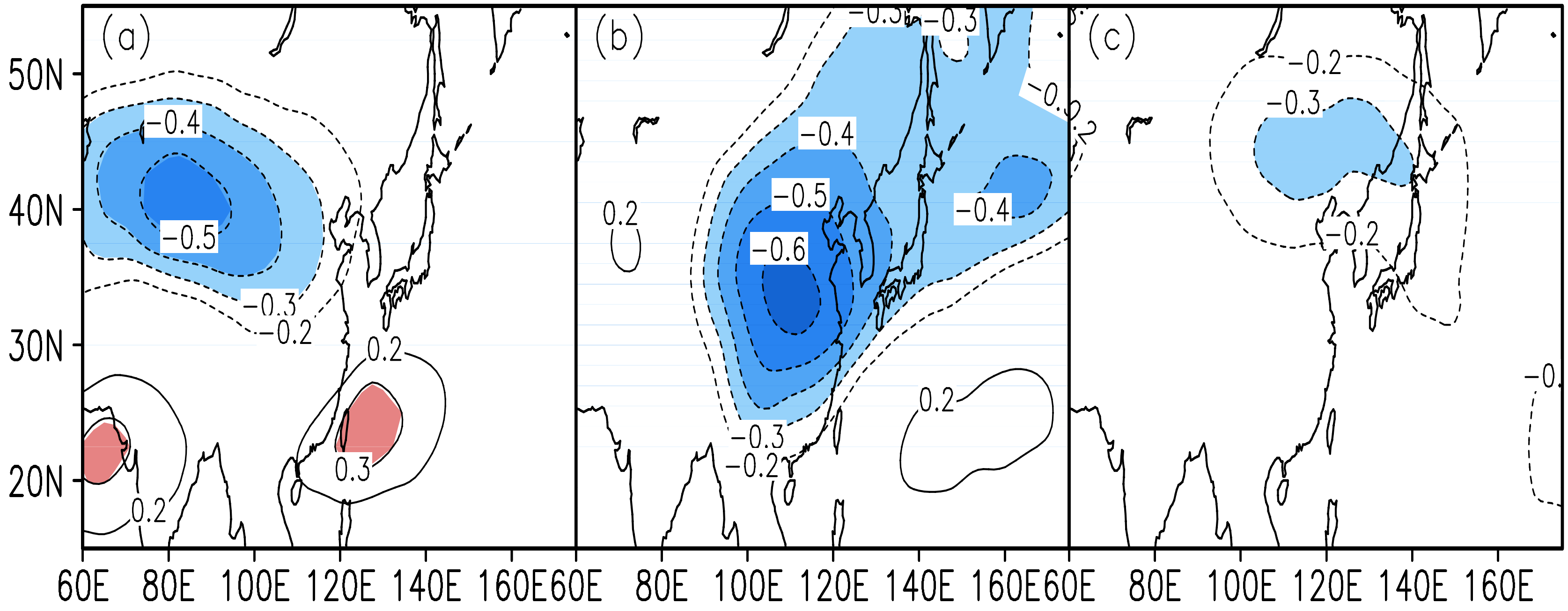
Inter-decadal Change of Temperature (shading), GP Height (contour) and Vertical Circulation



Along 110—125° E

Xin et al. 2006 J. Climate

Correlation between JFM NAO and $T_{500\text{-}200Pa}$



Early April

Late April ～Middle May

Late May

Xin et al. 2006 J. Climate

Point 2

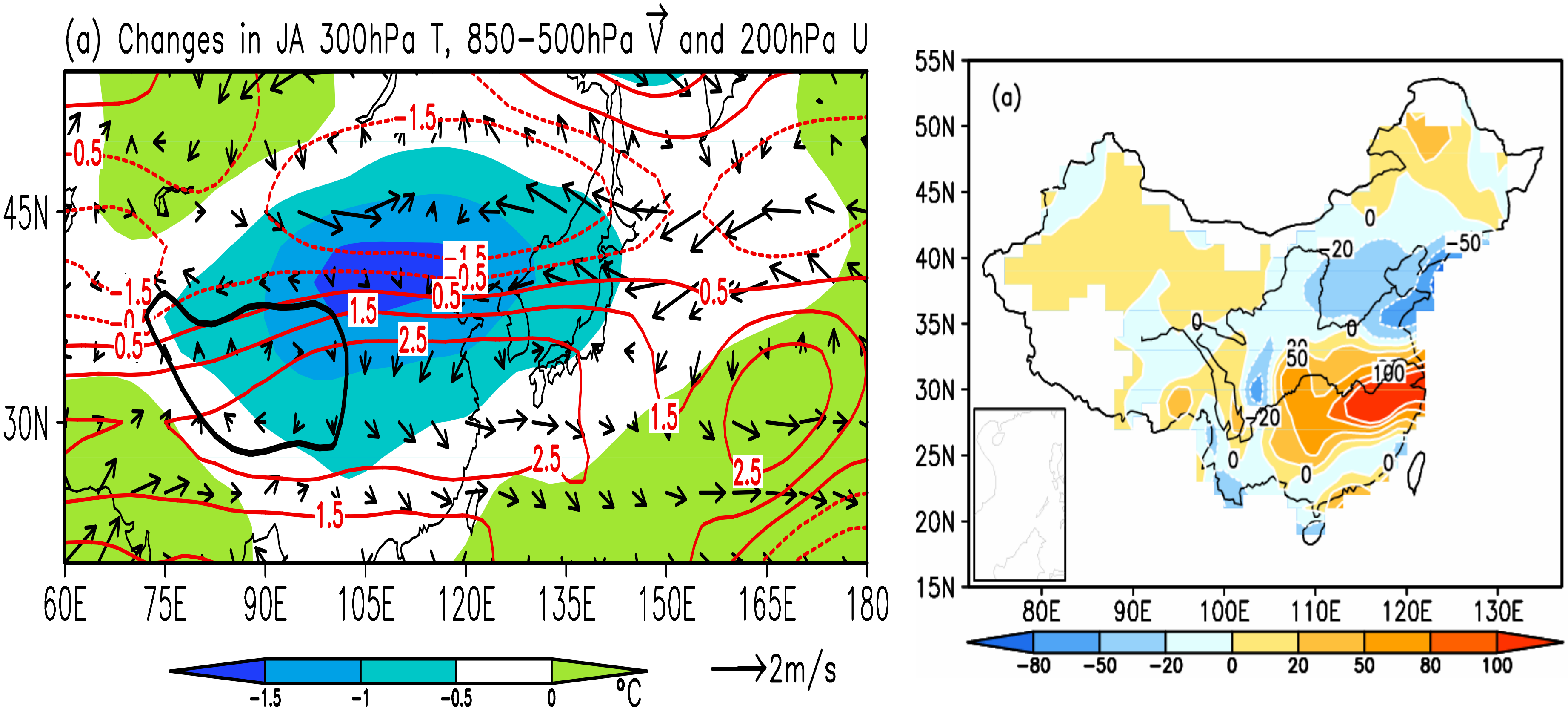
The weakening of EA summer monsoon,

which is part of the interdecadal shift,

has a pronounced 3-D structure.

Defense: Two data analyses

South Flood and North Drought in summer

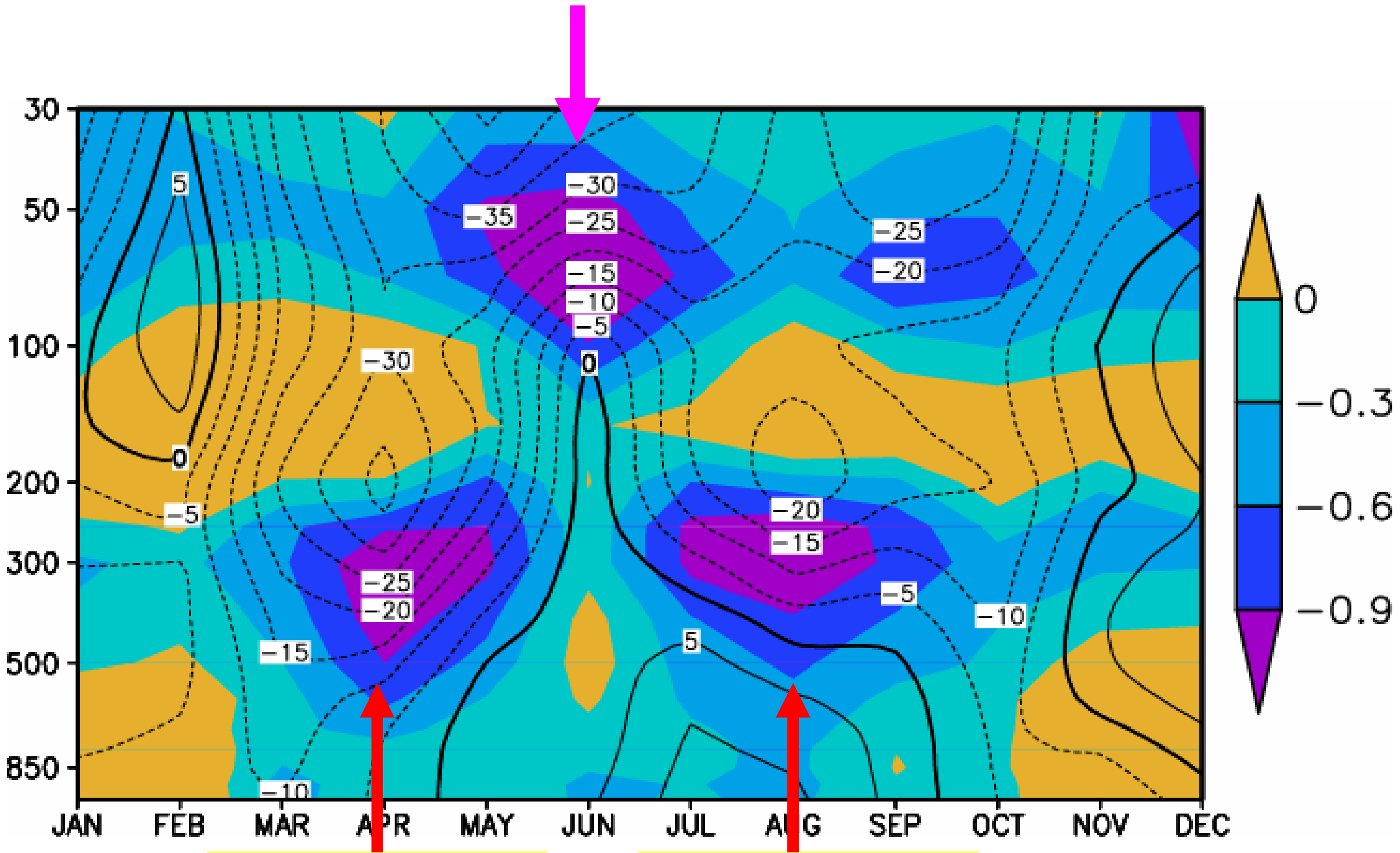


Changes of JA T_{300hPa} (shading), U_{200hPa} (contour) and Surface Wind

(1975-1999 minus 1950-1974)

Yu et al. 2004 GRL

Seasonality of Tropospheric Cooling over E. Asia



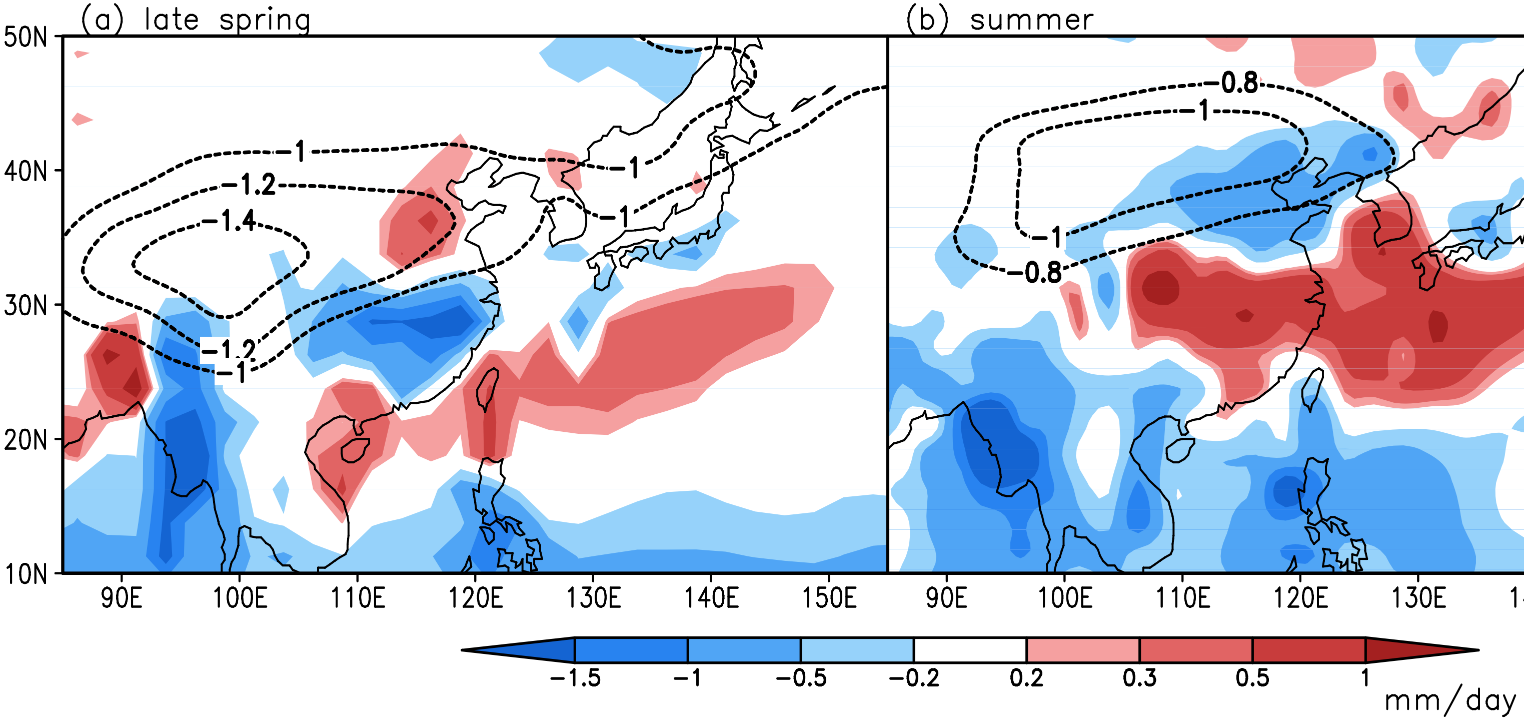
Spring drought

SFND

Time–height cross section of monthly mean **air temperature (shading in units of ℃)** and **geopotential height (contours** in units of geopotential decameter) changes (1980–2001 mean minus 1958–1979 mean) averaged in (30–45°N, 90–120° E)

Yu and Zhou 2007 J. Climate

Changes of T(500-200hPa) and Rainfall (1981-2000 minus 1958-1977)

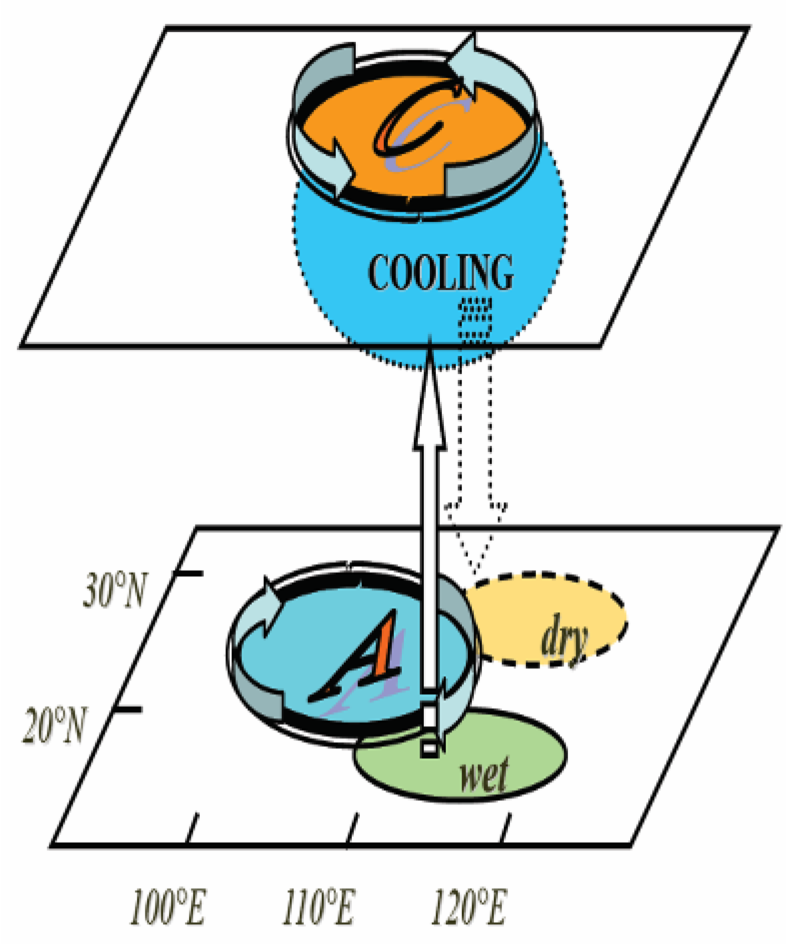


Contour: Temperature Change

Shading：Rainfall Change

Xin et al. 2006 J. Climate

Impact of troposphere cooling on EA monsoon Climate



- Upper troposphere cooling
- The pressure at the uppermost troposphere decrease
- The pressure drop increases poleward pressure gradient force to the south of cooling region
- Enhances the 200hPa subtropical jet through geostrophic balance, between the Coriolis force and pressure gradient force.

- The troposphere cooling-induced mass change enhances lower-troposphere pressure, resulting in an anomalous anticyclone beneath the upper troposphere cooling
- To the east of the AC, anomalous northerly winds increased, signifying a weakening of the EASM.

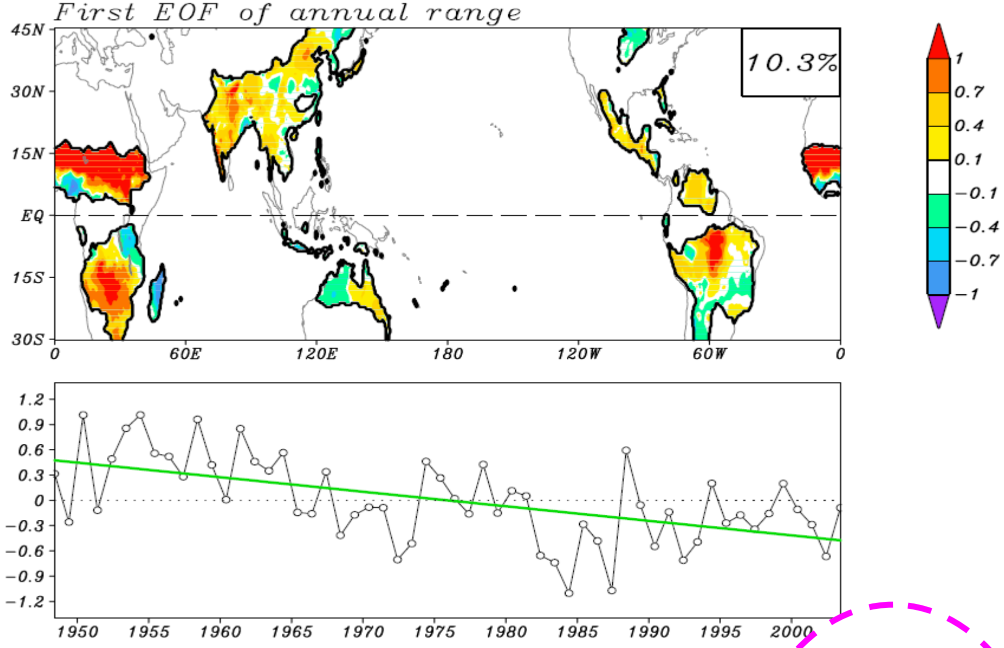
Yu et al.(2004) GRL; Zhou and Yu (2005) JGR; Xin et al. (2006) J. Climate

Point 3

The weakening of EASM is a local manifestation of global land monsoon change, which has s a decreasing tendency due to the warming of Tropical Ocean.

Defense: Two data analysis + 5 sets of numerical Exps.

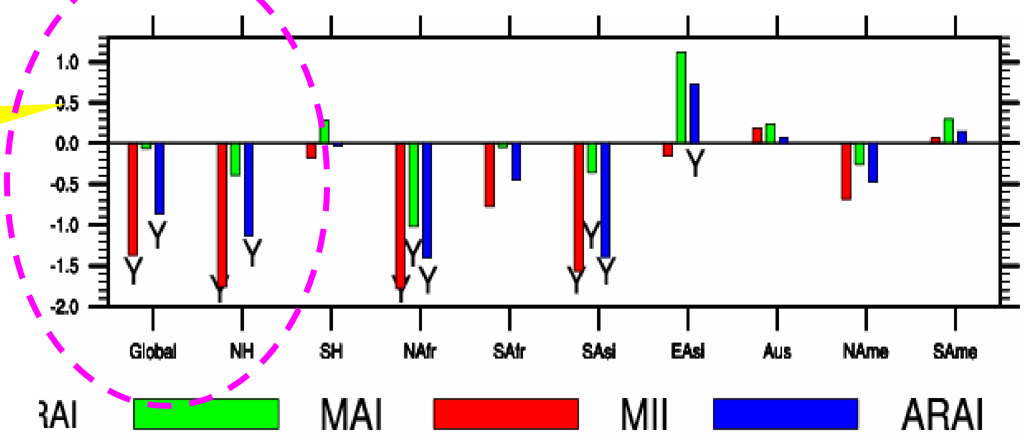
An overall weakening tendency of global land monsoon precipitation in the last 56 years (1948-2003)



The EOF1 of normalized annual range anomalies (upper) and the corresponding PC (lower).

(Wang and Ding, 2006,GRL)

Trend of monsoon rainfall coverage, intensity, and amount

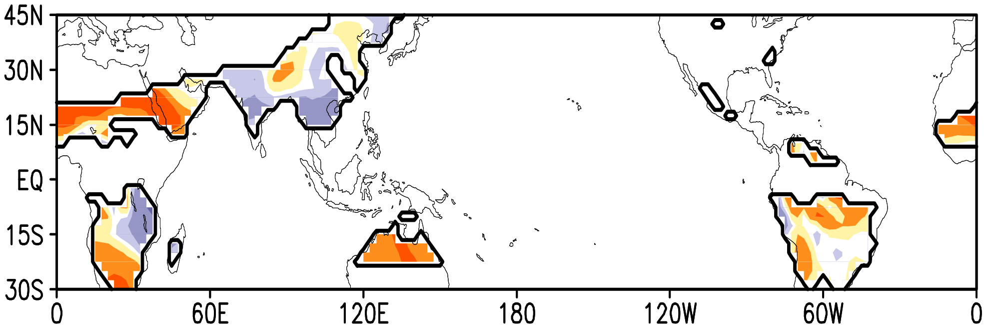


(Zhou et al. 2008 GRL)

Global land monsoon precipitation change simulated by CAM2

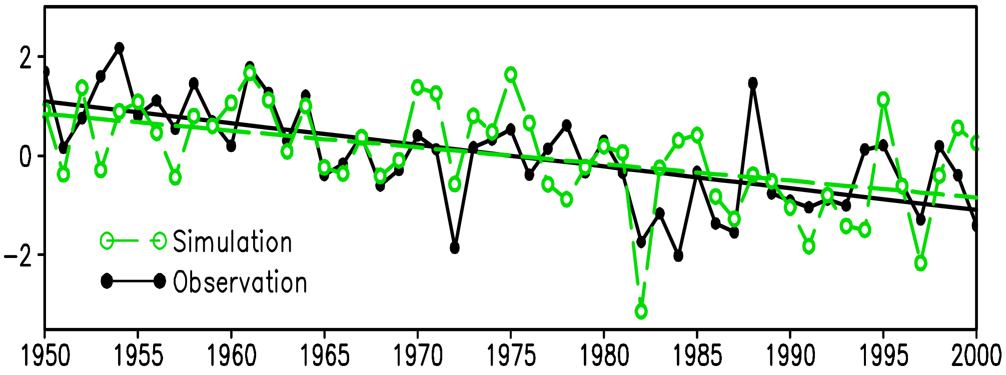
(Global SST-driven, 15 realizations)

(b)First EOF of simulated annual range (20.9%)



(c)Leading principle component

cor=0.60



Rainfall
Anomaly
Pattern

Monsoon
Rainfall
index

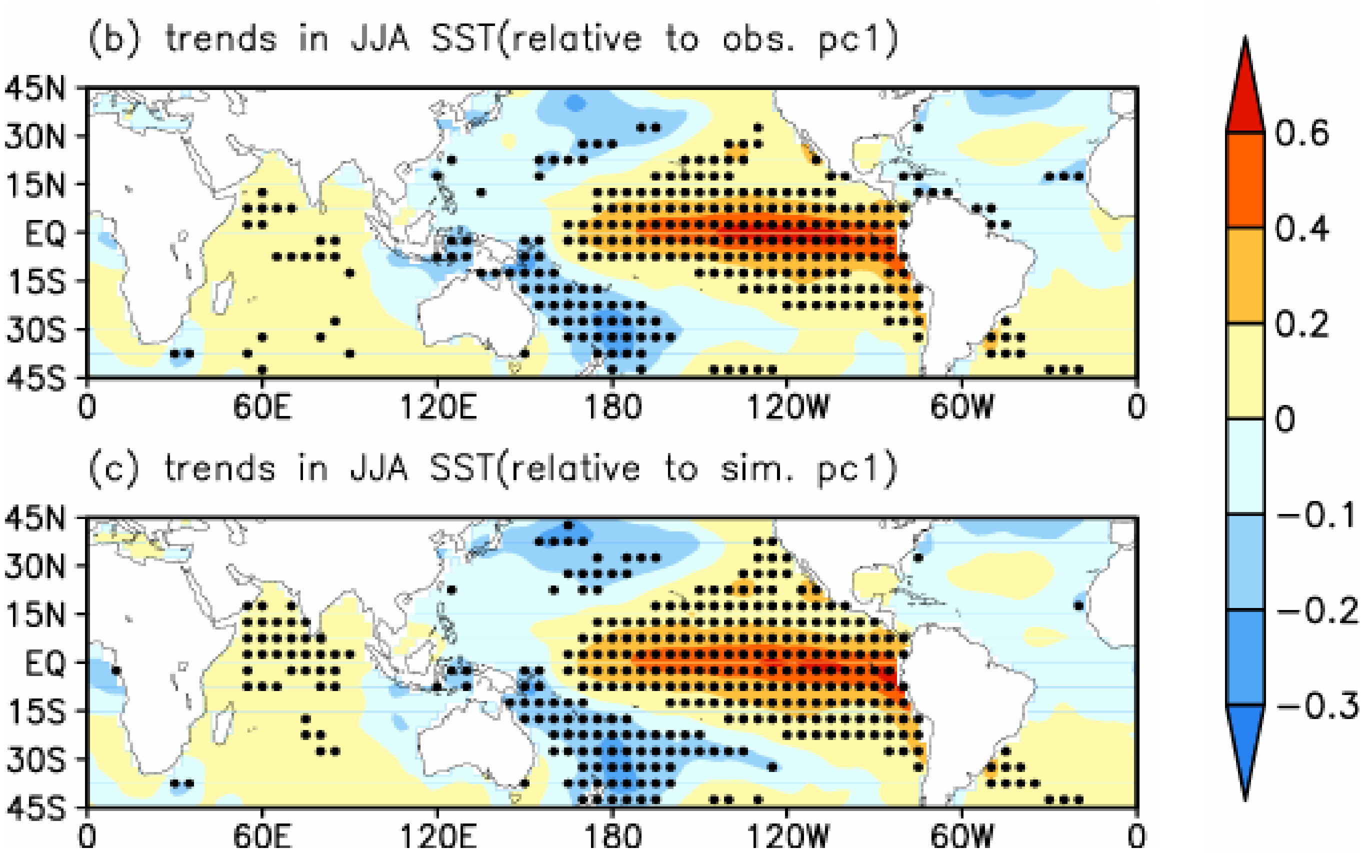
The first EOF of normalized annual range anomalies (upper) and the corresponding principle component or ARI (lower).

Zhou et al. 2008b J. Climate

SSTA congruent with the weakening trend of global land monsoon precipitation

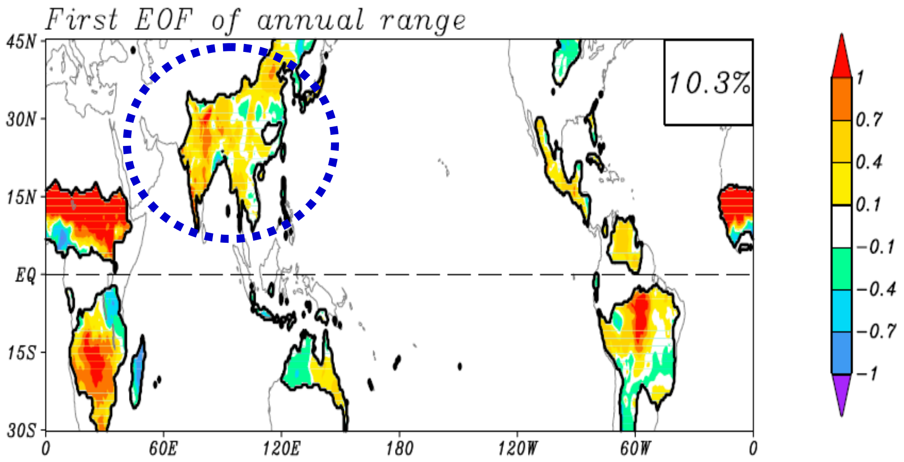
Monson-related in OBS

Monsoon-related in model



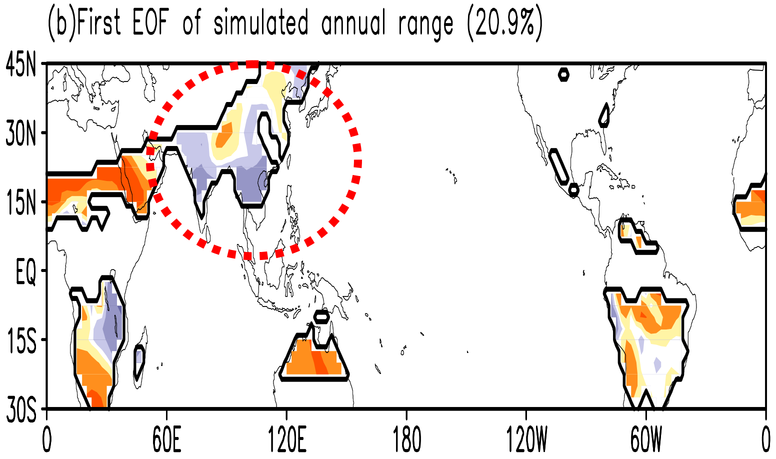
(Zhou et al. 2008b J Climate)

Low skill of East Asian monsoon rainfall



First EOF of annual range

Observation



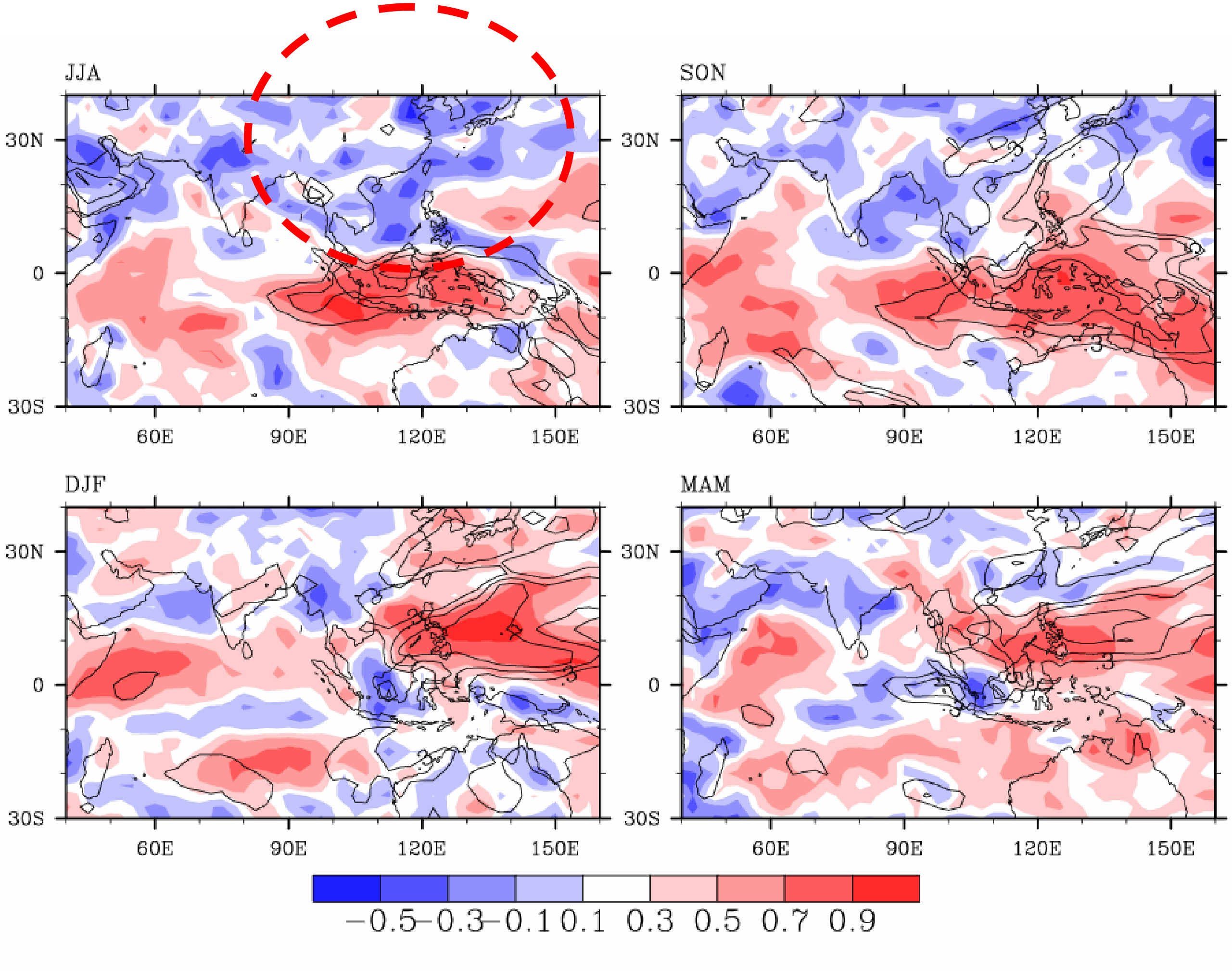
(b)First EOF of simulated annual range (20.9%)

Simulation

Reasons for the un-success:

1. Absence of air-sea coupling in AMIP-type simulation
2. Model bias in precipitation

Correlation of Simulated (AMIP MME) and observed rainfall anomalies



- High skill in tropical region
- Nearly no skill in summertime Asian monsoon area.
- Better in winter

Zhou et al. 2009a, J. Climate

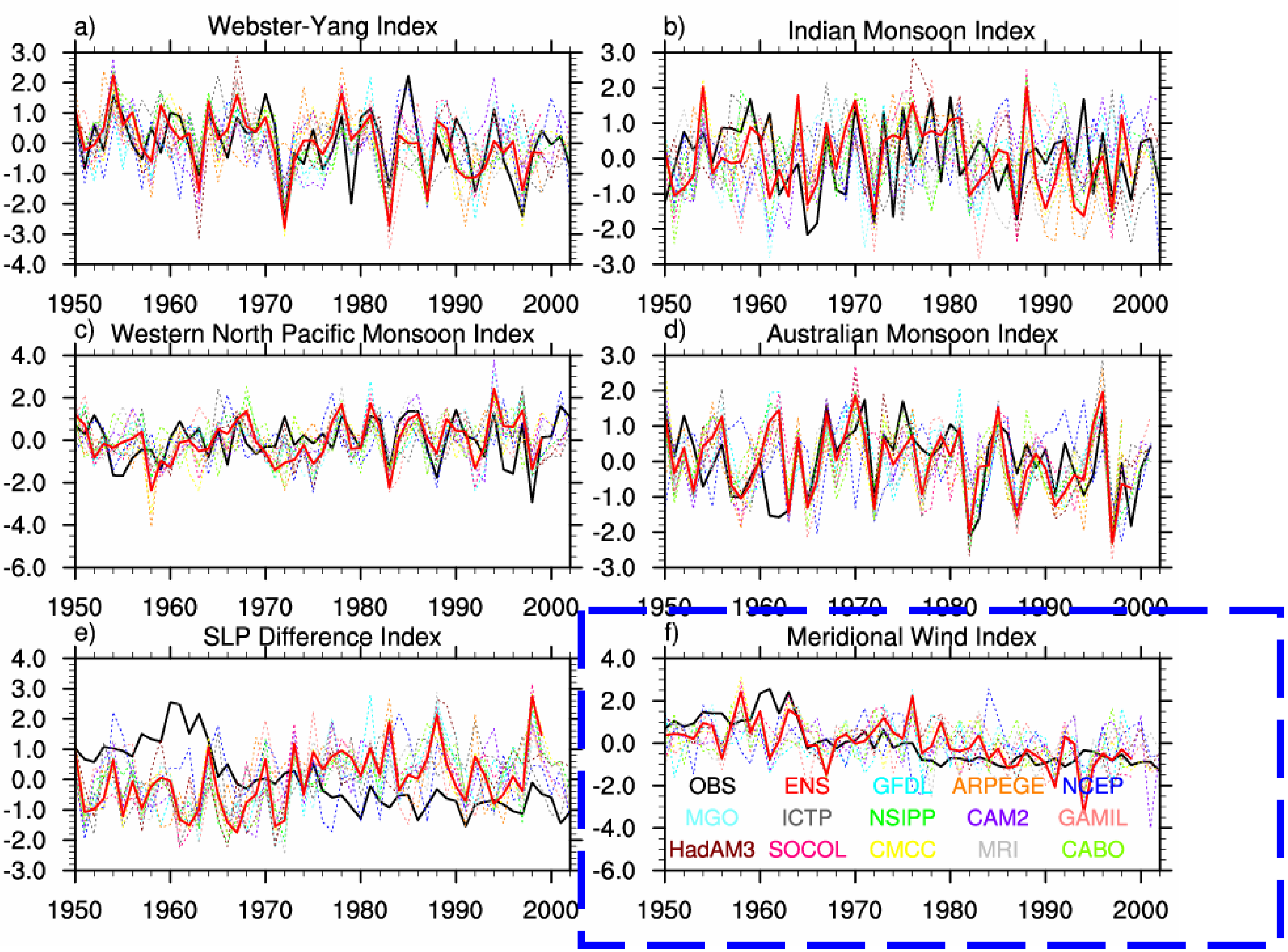
It is not a good idea to examine E. Asian monsoon precipitation change with AMIP-type simulation.

A better way is to focus on monsoon circulation

(3 evidences)

Monsoon circulation indices in CLIVAR C20C models

(Global SST forcing)



Evidence-1: Zhou et al. (2008) Clm. Dyn.

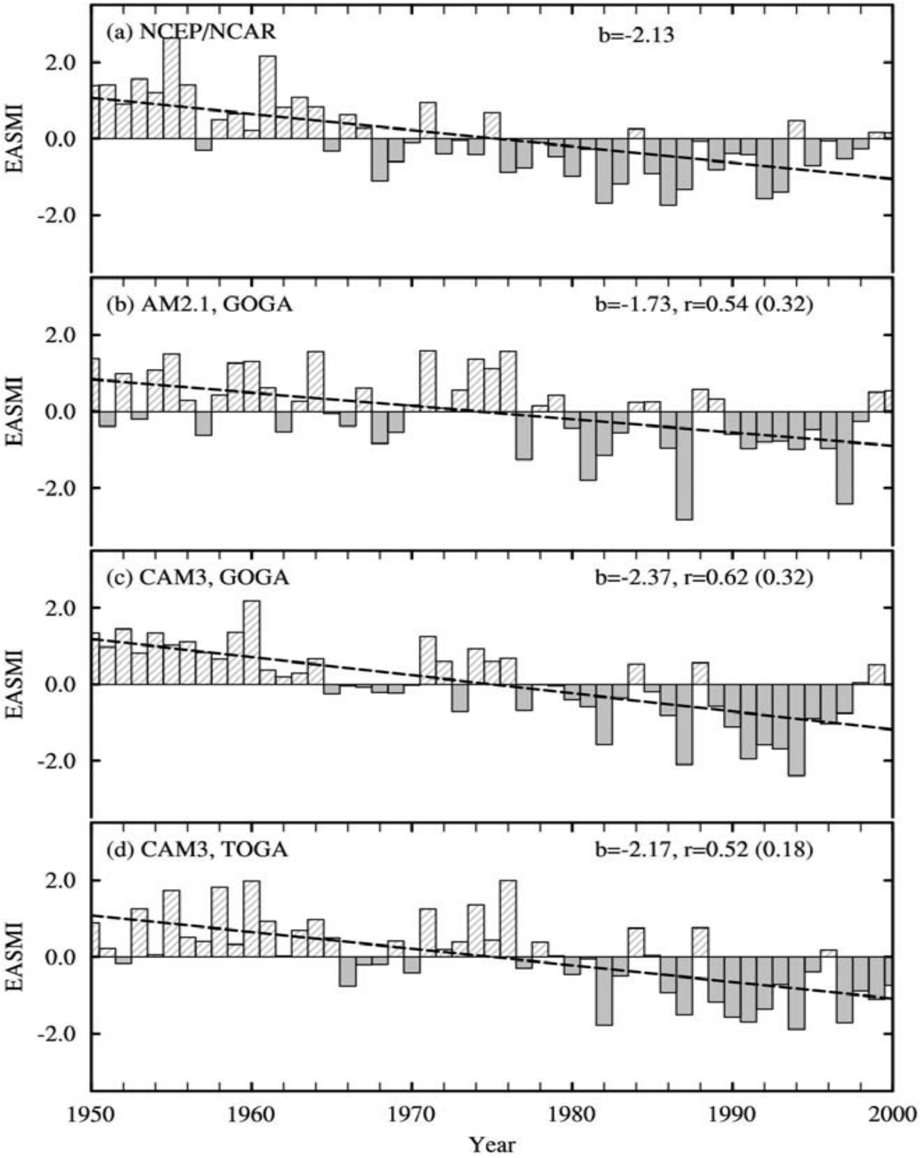
E. Asian Summer monsoon circulation index

NCEP/NCAR

GFDL AM2.1 GOGA

NCAR CAM3 GOGA

NCAR CAM3 TOGA

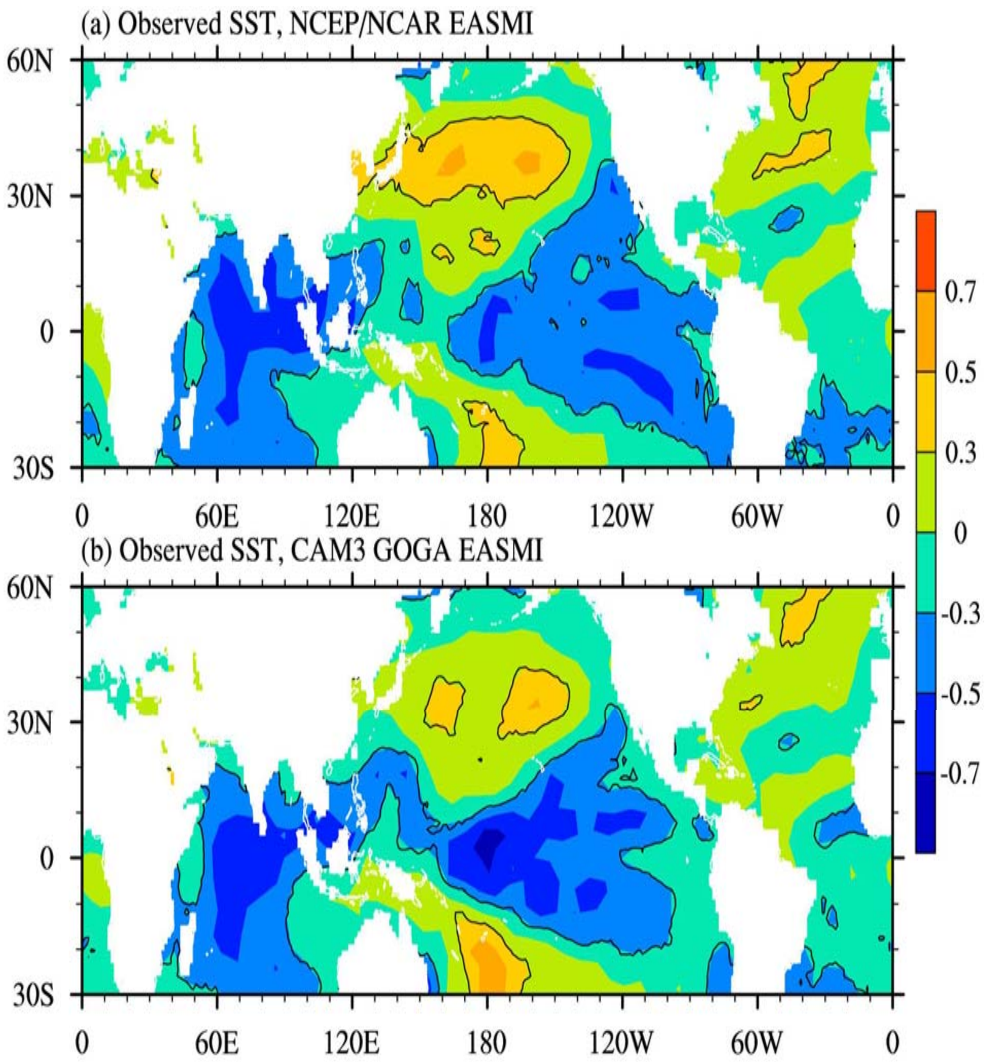


10 realizations

5 realizations

Evdence-2: Li et al. 2008 Clm Dyn

Correlations of SSTA with EASM circulation index



Observation

CAM3 GOGA

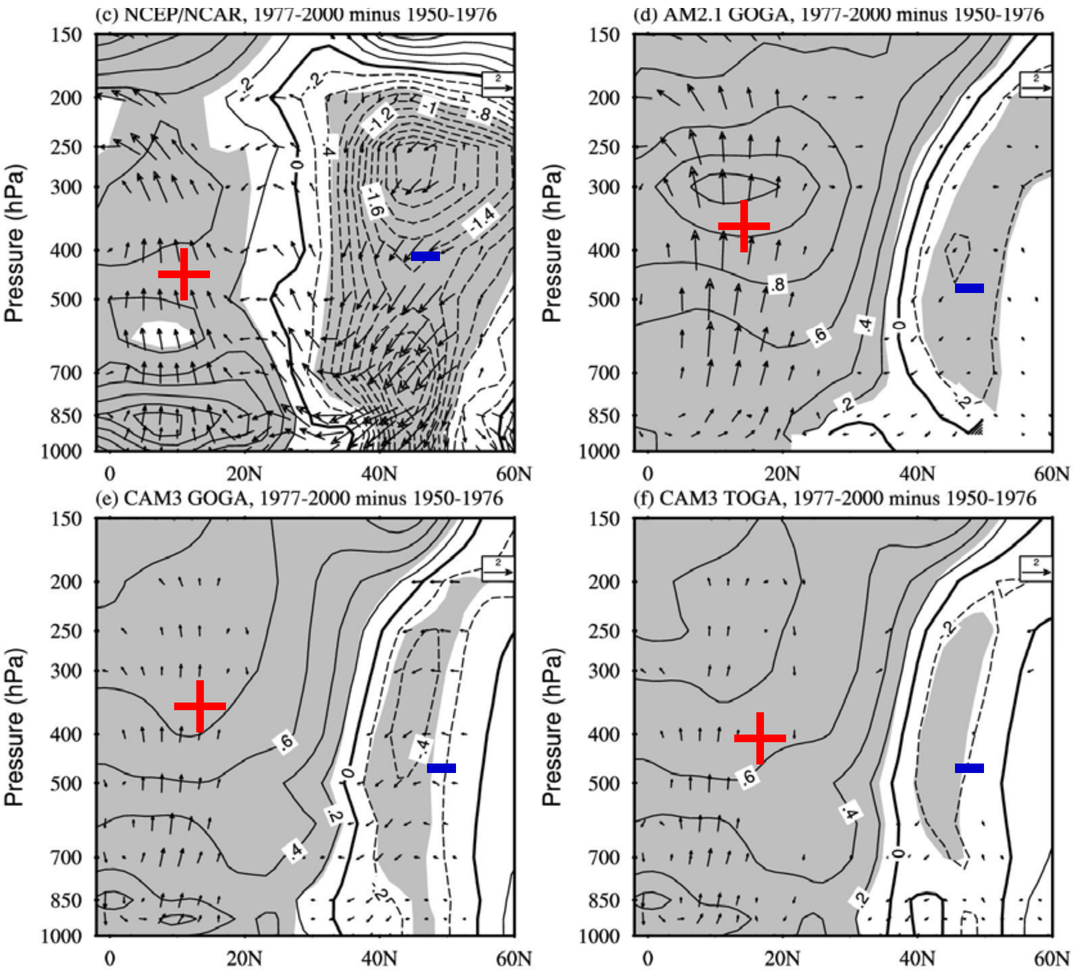
(Li et al. 2008 Clm Dyn)

Land-Sea thermal contrast change

(105° -122° E average T and latitude –height cross-section)

1977-2000
minus1950-1976
NCEP/NCAR

CAM3 GOGA

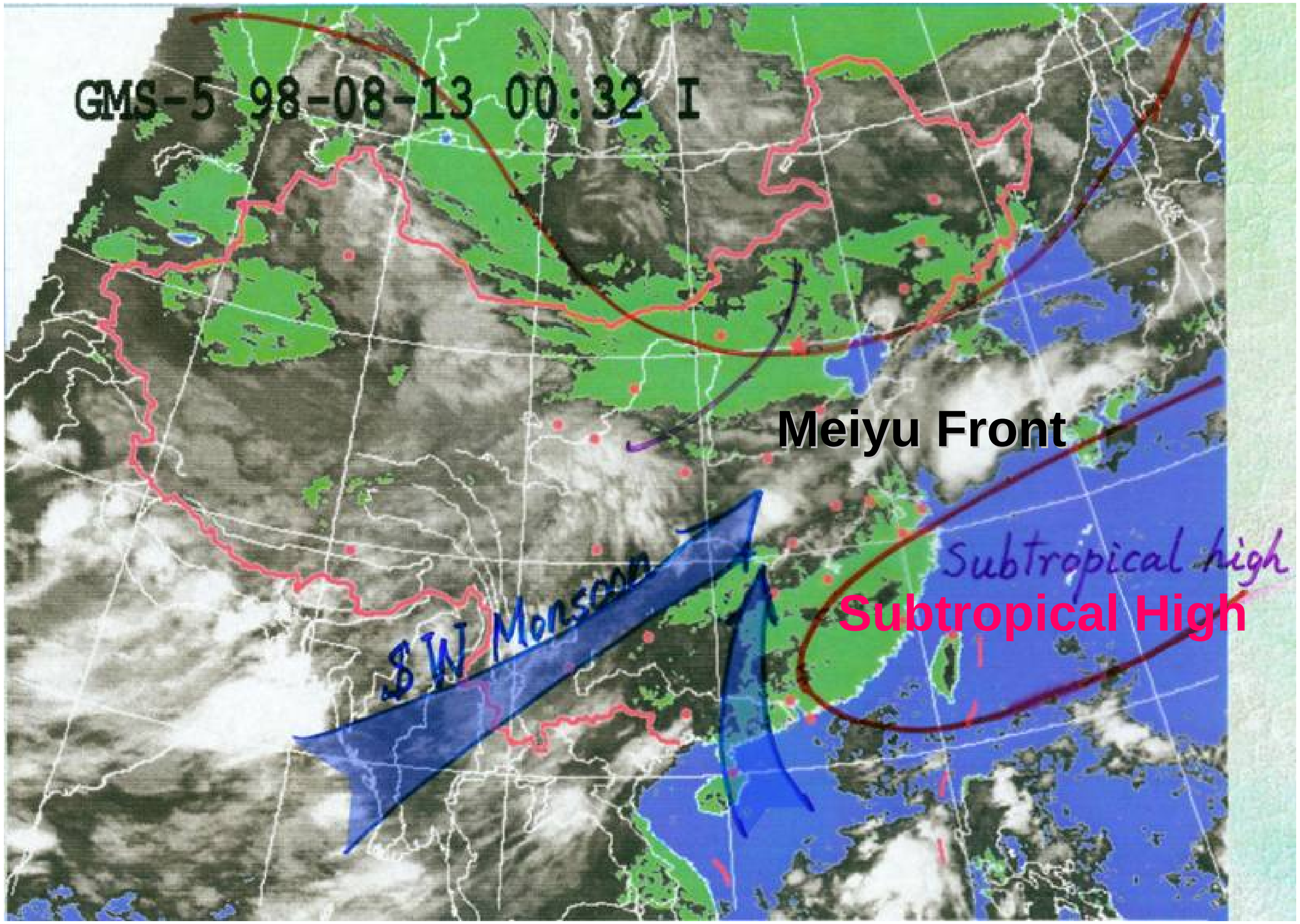


1977-2000
minus1950-1976
AM2.1 GOGA

CAM3 TOGA

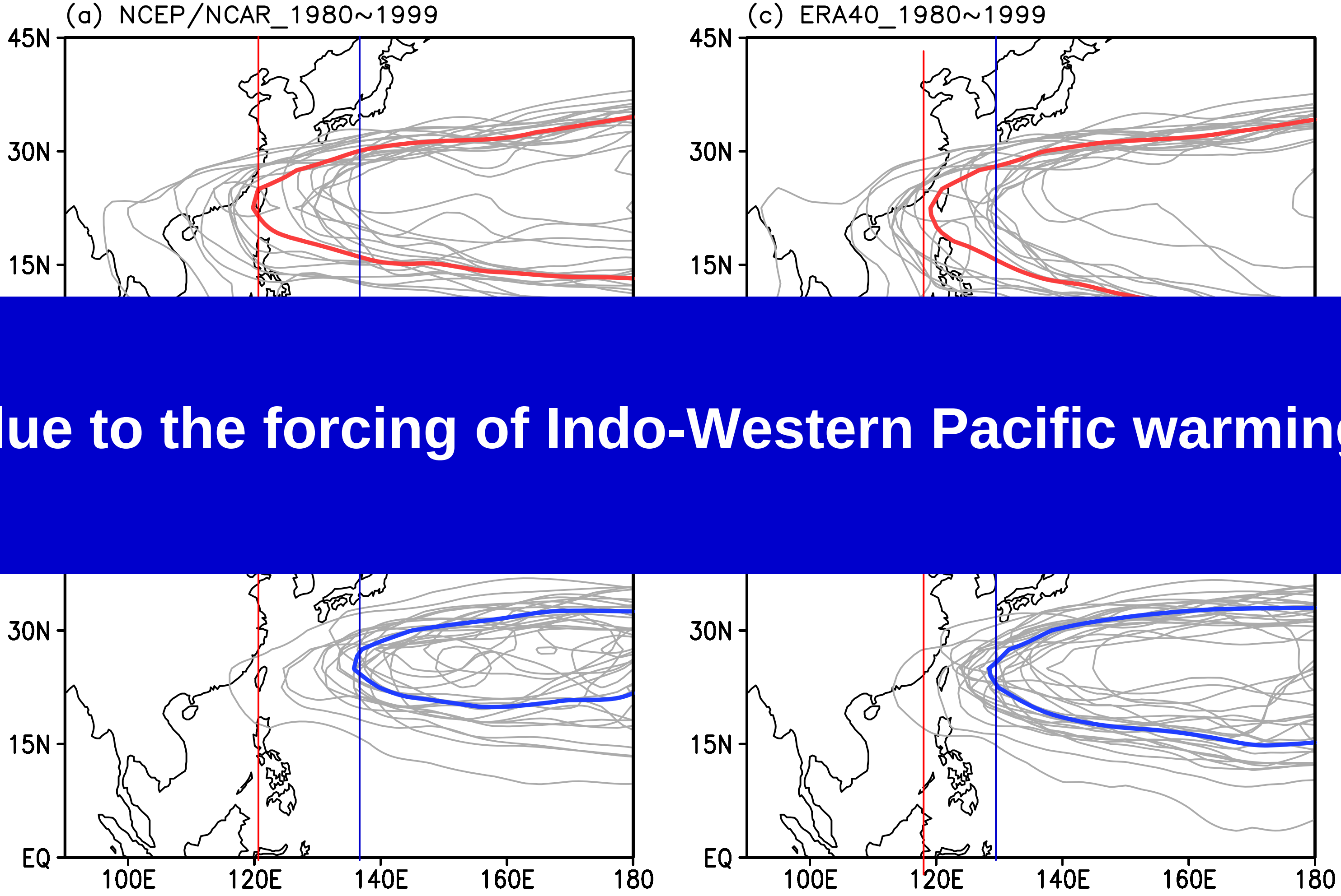
(Li et al. 2008 Clm Dyn)

Evidence-3: Western Pacific Subtropical High change



Courtesy of Huang (2007)

Westward Extension of WPSH



1980-99

It’s due to the forcing of Indo-Western Pacific warming

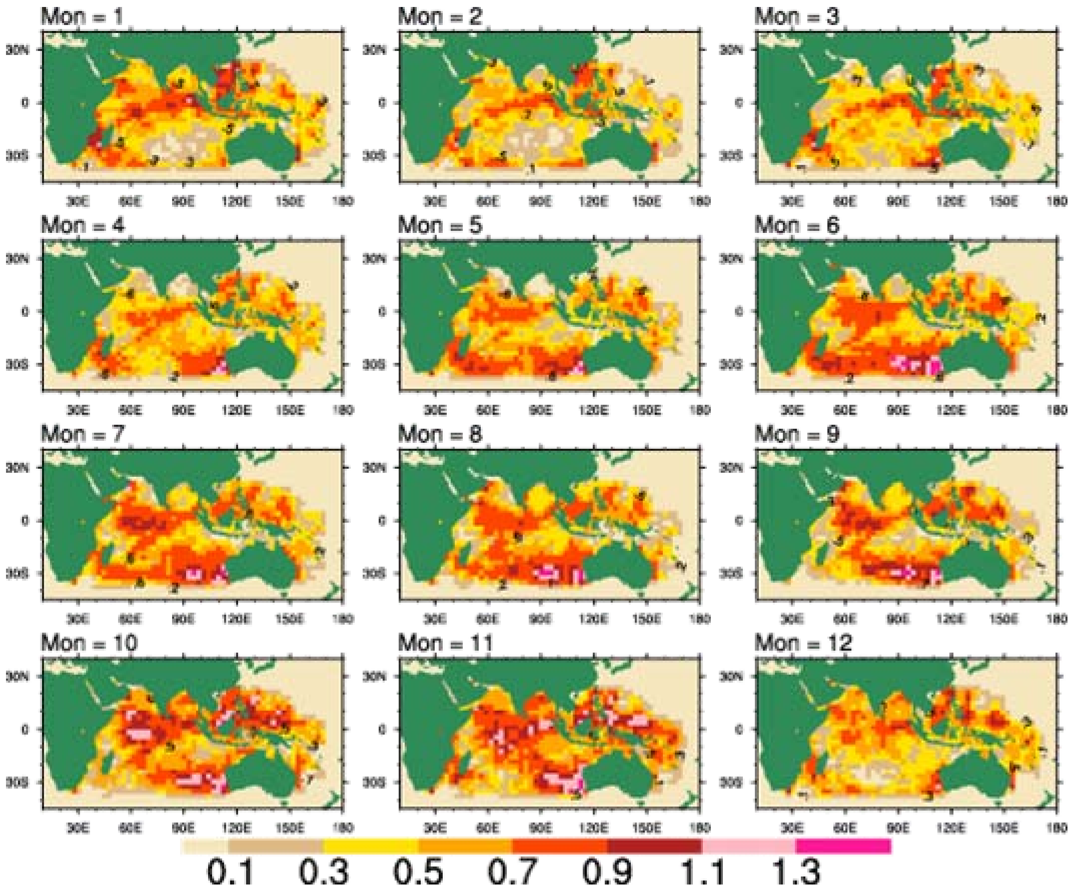
1958-79

NCEP/NCAR

ERA40

Contour lines for 5870 gpm of 500 hPa geo-potential height for each summer

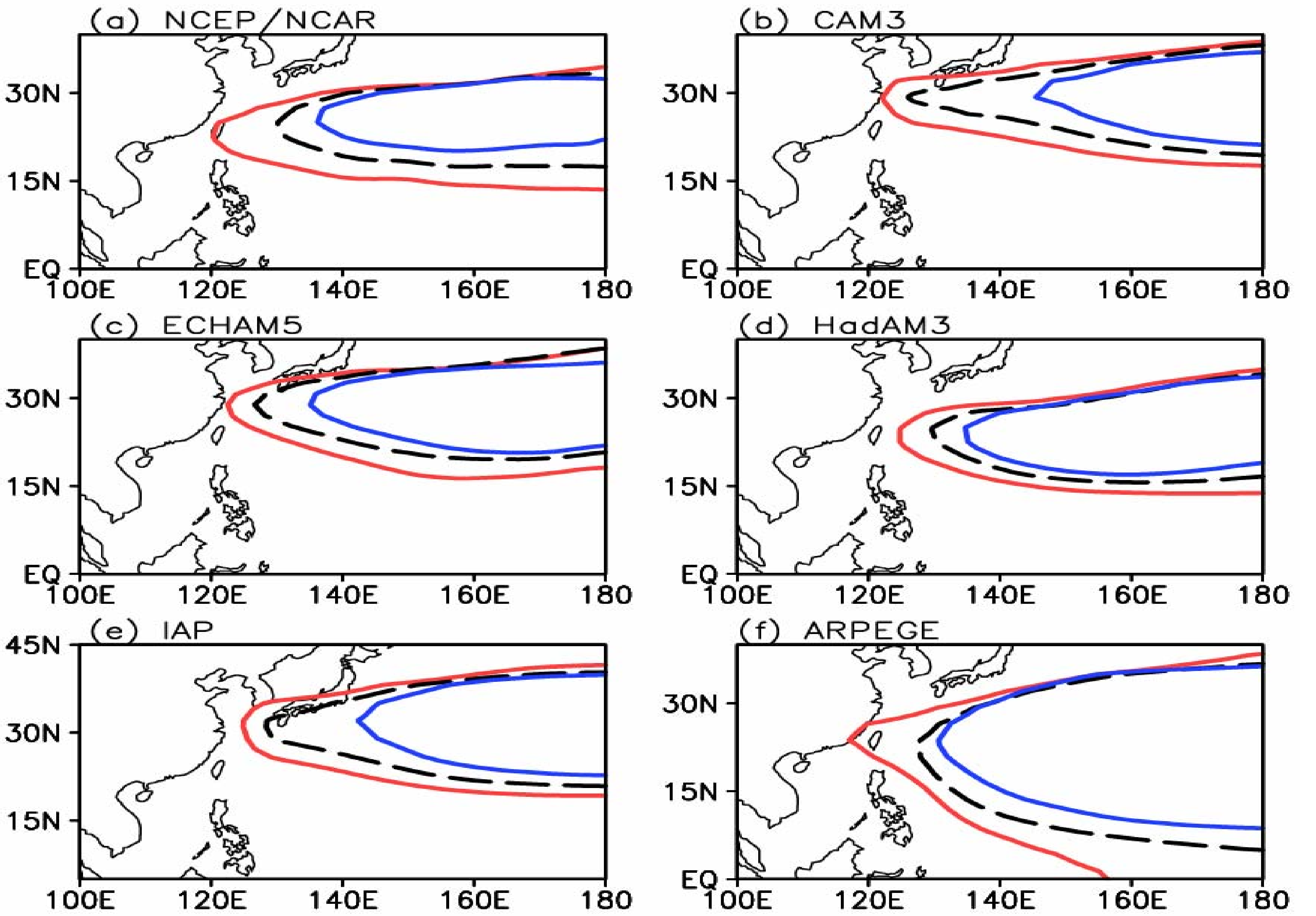
SST trend in Observation（ ºC/50y）



- Warming + Cooling Exps.
- 40 yrs Integration, last 30yrs used in the analyses.

(Zhou et al. 2009b J. Climate)

WPSH in IWP warming, cooling and *control* runs



Zhou et al. 2009b J. Climate

The mechanisms

- Negative heating in central equatorial Pacific due to Walker circulation change

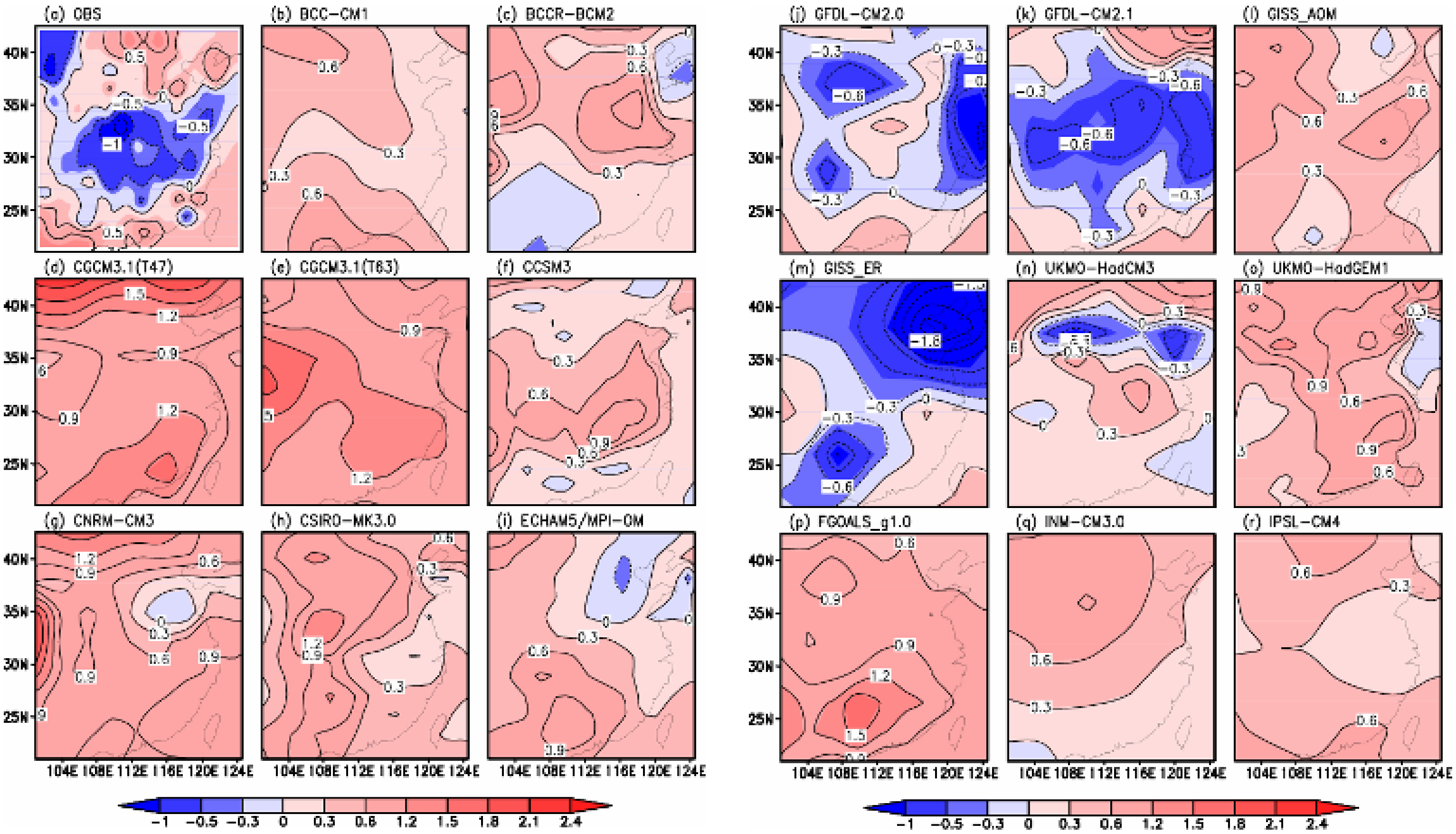
- Sverdrup vorticity balance associated with condensational heating over the warmer SST

Zhou et al. 2009b J. Climate

Does global warming work in monsoon weakening ?

WCRP 20C3M Modeling

Summer SAT trend (1950-1999) in 20C3M of IPCC AR4



Zhou and Yu, 2006 J. Climate

Summary

1. Against the warming trend elsewhere, the downstream of TP has a cooling trend in spring. The positive phase of NAO contributes to the cooling trend by either changing the westerly jet or a NAULEA tele-connection pattern.
2. The spring drought of S. China is partly dominated by tropospheric cooling which is significantly related to the NAO+.
3. The upper troposphere cooling is one factor responsible for the weakending of summer monsoon.
4. The topical Ocean warming is one mechanism for the weakening tendency of global land monsoon rainfall and E. Asian Monsoon Circulation.
5. The westward extension of WPSH is partly driven by the warming of Indo-Pacific Ocean.
6. The CMIP3 models show no evidences signifying the dominance of GHG on the weakening of EASM ***(further detection analysis to confirm this?).***

Some further reading for details of our work

Spring Climate:

1. Li J., R. Yu, T. Zhou, 2008, Teleconnection between NAO and climate downstream of the Tibetan Plateau, ***J. Climate***, 21, 4680-4690
2. Xin X., R. Yu, T. Zhou, and B. Wang, 2006, Drought in Late Spring of South China in Recent Decades, ***J. Climate***, 19(13), 3197-3206.
3. Li J., R. Yu, T. Zhou, et al. 2005, Why is there an early Spring cooling shift downstream of the Tibetan Plateau, ***J. Climate***, 18 (22), 4660–4668
4. Yu R., T. Zhou, 2004, Impacts of winter-NAO on March cooling trends over subtropical Eurasia continent in the recent half century, *Geophys. Res. Lett.,* , 31, L12204, doi:10.1029/2004GL019814.

Summer Monsoon:

1. Zhou, T., L. Zhang, and H. Li, 2008: Changes in global land monsoon area and total rainfall accumulation over the last half century, *Geophys. Res. Lett.,* 35, L16707, doi:10.1029/2008GL034881
2. Yu R., and T. Zhou, 2007, Seasonality and three-dimensional structure of the interdecadal change in East Asian monsoon, ***J. Climate***, 20, 5344-5355.
3. Zhou, T. and R Yu (2005), Atmospheric water vapor transport associated with typical anomalous summer rainfall patterns in China, ***J. Geophys. Res*.,** 110, D08104, doi:10.1029/2004JD005413
4. Yu R., B. Wang, and T. Zhou, 2004, Tropospheric cooling and summer monsoon weakening trend over East Asia, *Geophys. Res. Lett.,* 31,L22212, doi:10.1029 /2004GL021270
5. Yu R., B. Wang and T. Zhou，2004, Climate effects of the deep continental stratus clouds Generated by Tibetan Plateau, ***J. Climate***, 17,2702-2713

Some further reading for details of our work

Model Attributions:

1. Zhou T., R. Yu, J. Zhang, H. Drange et al. 2009a, Why the Western Pacific Subtropical High has extended westward since the late 1970s, *J. Climate*, In Press
2. Zhou, T., B. Wu, and B. Wang, 2009b: How well do Atmospheric General Circulation Models capture the leading modes of the interannual variability of Asian-Australian Monsoon? *J. Climate*, In Press
3. Zhou T., Yu R., Li H., et al. 2008a, Ocean forcing to changes in global monsoon precipitation over the recent half century, ***J. Climate***, 21, (15), 3833–3852
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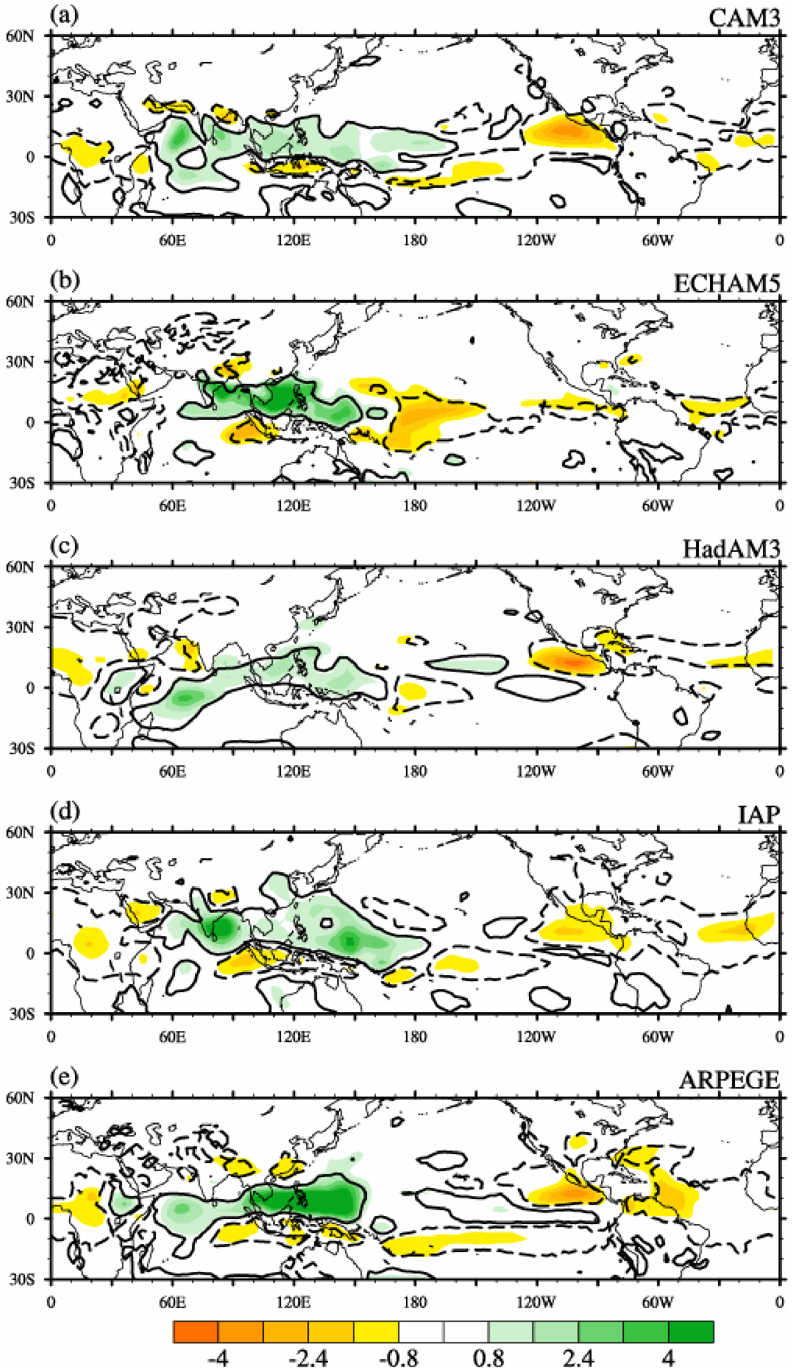
http://web.lasg.ac.cn/staff/ztj/index_e.htm

THANK YOU !

Understanding climate change by climate modeling

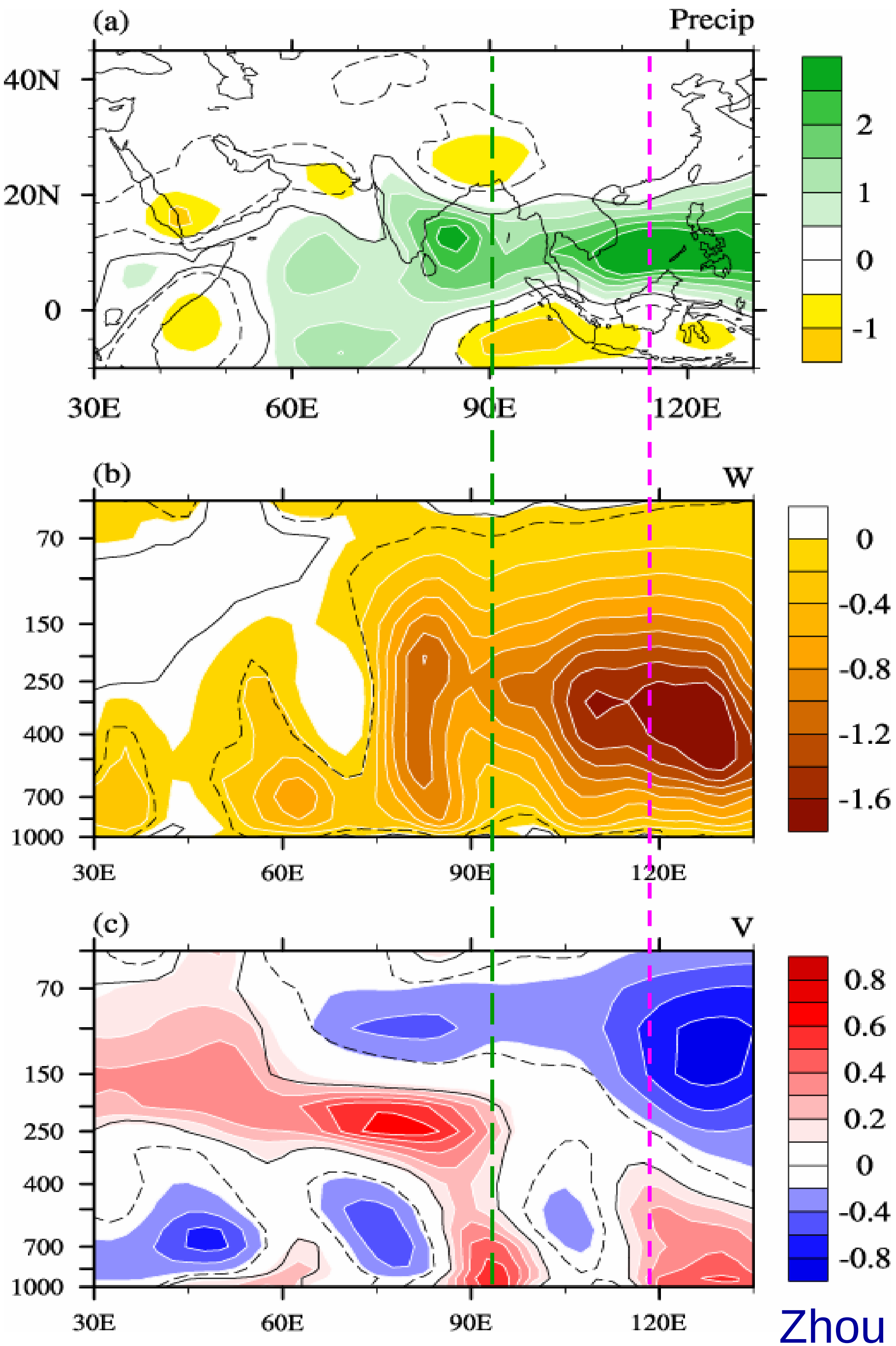
http://web.lasg.ac.cn/staff/ztj/index_e.htm



Negative heat source
in Central Pacific

Zhou et al. 2008b J. Climate, in revision

Multi-model ensemble



Rainfall

$$\beta v \approx f \frac{\partial \omega}{\partial p}$$

Vertical velocity

Meridional wind

0-20° N average

Zhou et al. 2008b J. Climate, in revision

Sverdrup vorticity balance: Poleward anomalous flow

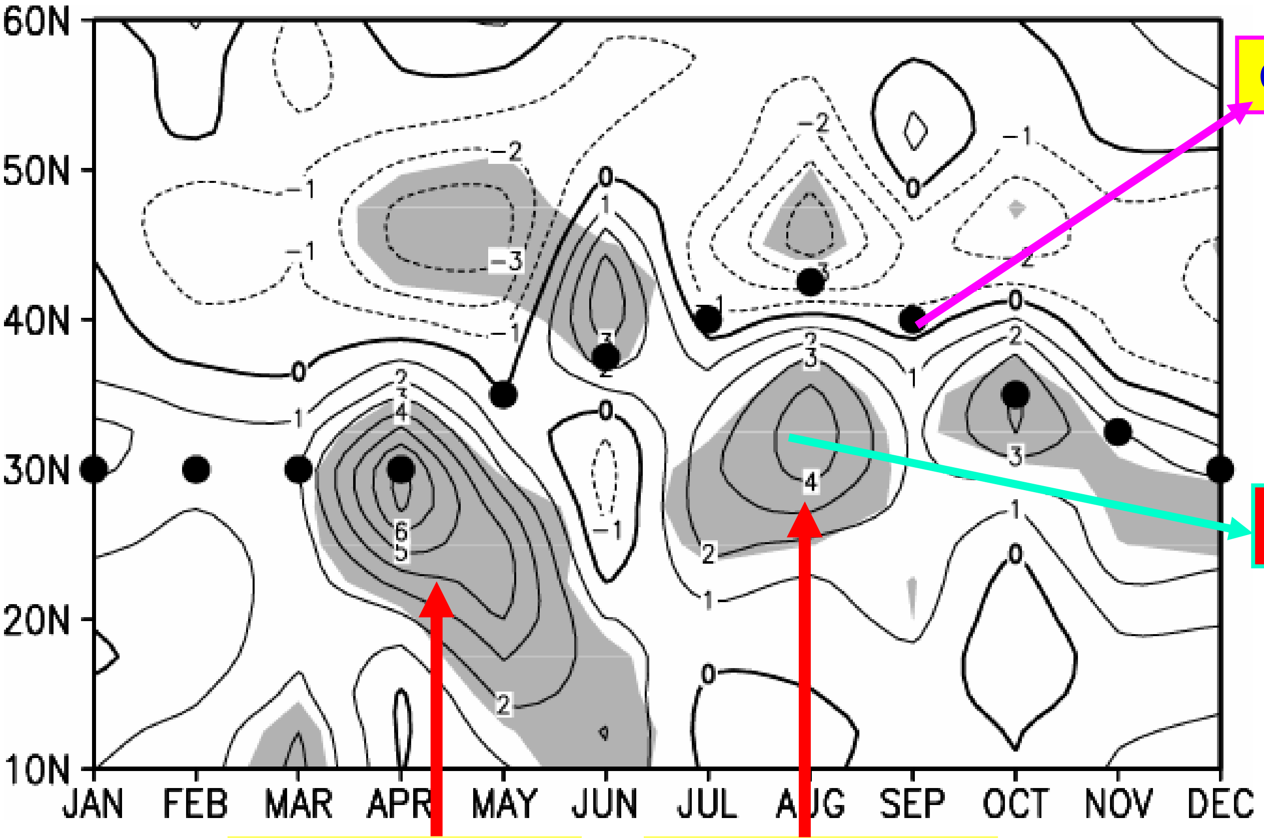
$$\beta v \approx f \frac{\partial \omega}{\partial p}$$

Strong poleward flow at the low level should be seen over the region with maximum ascent.

Where v is meridional wind, omega is the vertical velocity, f is the Coriolis parameter, and beta is its meridional gradient (Rodwell and Hoskins, 2001).

The Sverdrup balance can also be expressed in other forms to emphasize the importance of the vertical distribution of heating (Wu et al. 1999).

Changes of East Asian Westerly Jet



Climate mean position

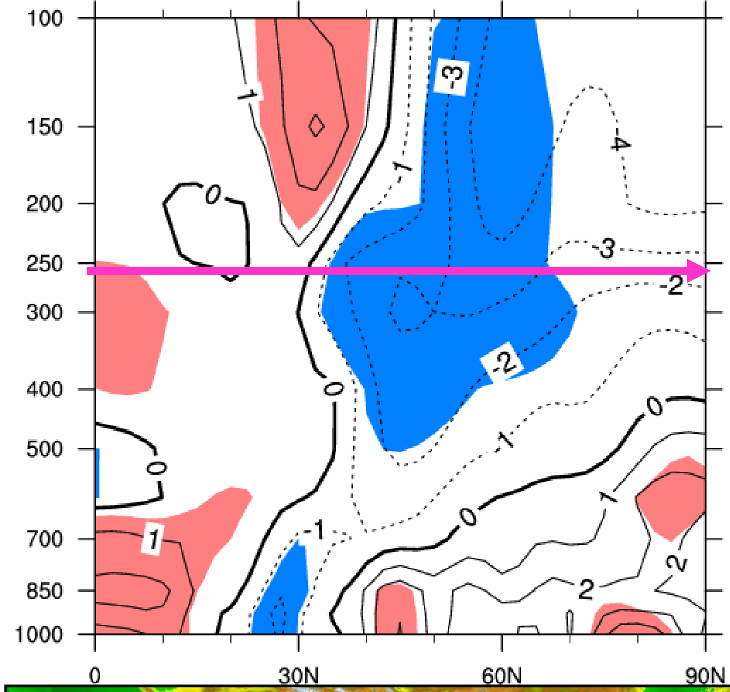
U200 anomaly

Spring drought

SFND

Time–latitude cross sections of 100–120°E monthly mean zonal wind changes at 200 hPa (1980–2001 mean minus 1958–1979 mean; units: m s-1). Heavy dots indicate the climatological locations of the jet axis for different months.

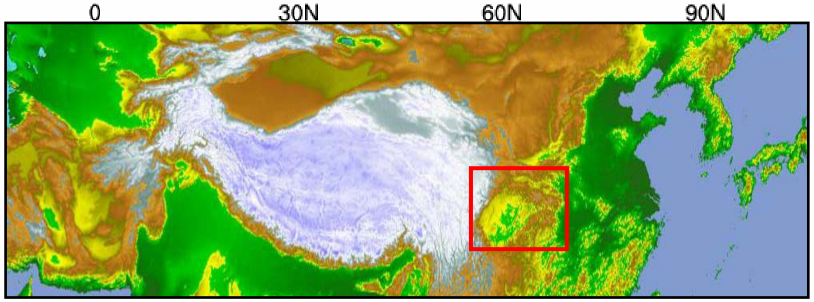
Yu and Zhou 2007 J. Climate



Linear trend of March temperature (1951-2000)

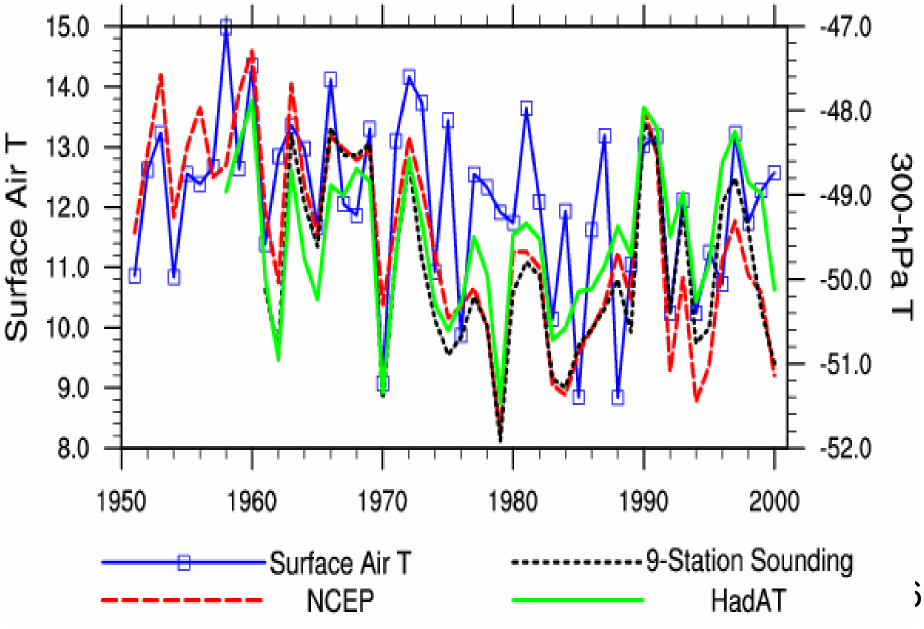
zonally averaged between 100-120ºE

(Li et al. 2008, J. Climate)

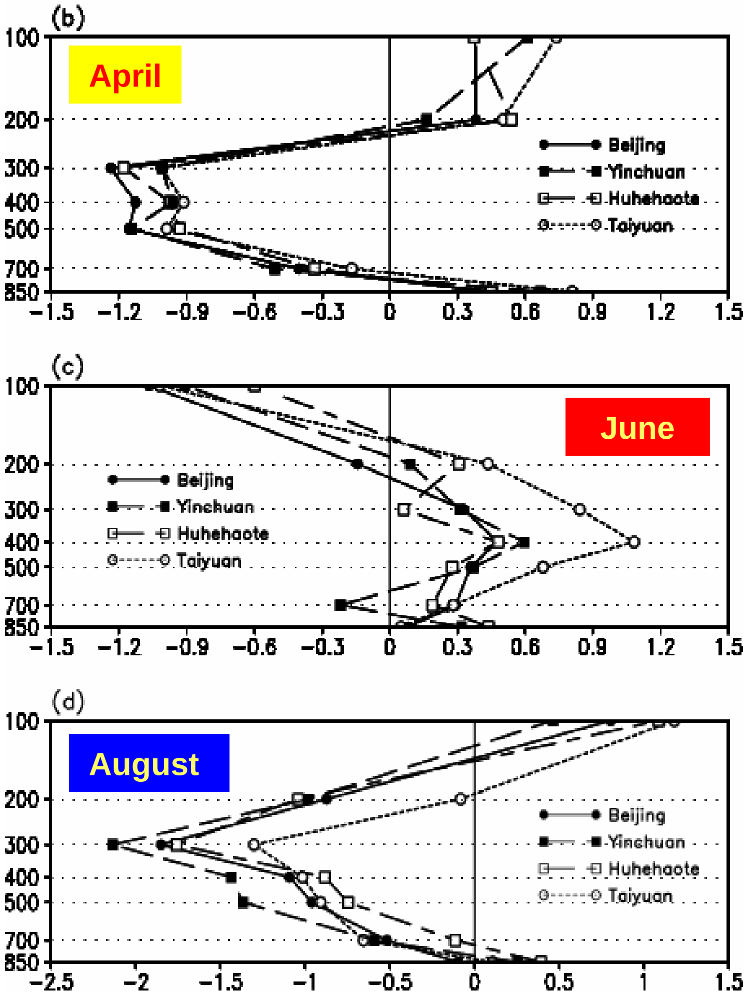


Surface T over EPTP (27-32ºN,103-108ºE)

300-hPa T over (37-43ºN,93-120ºE)



Observed Evidences- A Whole Picture: Seasonality and 3-D Structure of Interdecadal Change in the E. Asian Climate



Vertical profiles of temperature change (1980–2001 mean minus 1958–1979 mean) for four stations, including Huhehaote (40.82°N, 111.68°E), Beijing (39.80°N, 116.47°E), Yinchuan (38.48°N, 106.22°E), and Taiyuan (37.78°N, 112.55°E).

- HadAT has similar cooling
- The cooling in Re-analysis data is real in nature.

After Yu and Zhou (2007)

Aerosol Forcing ?

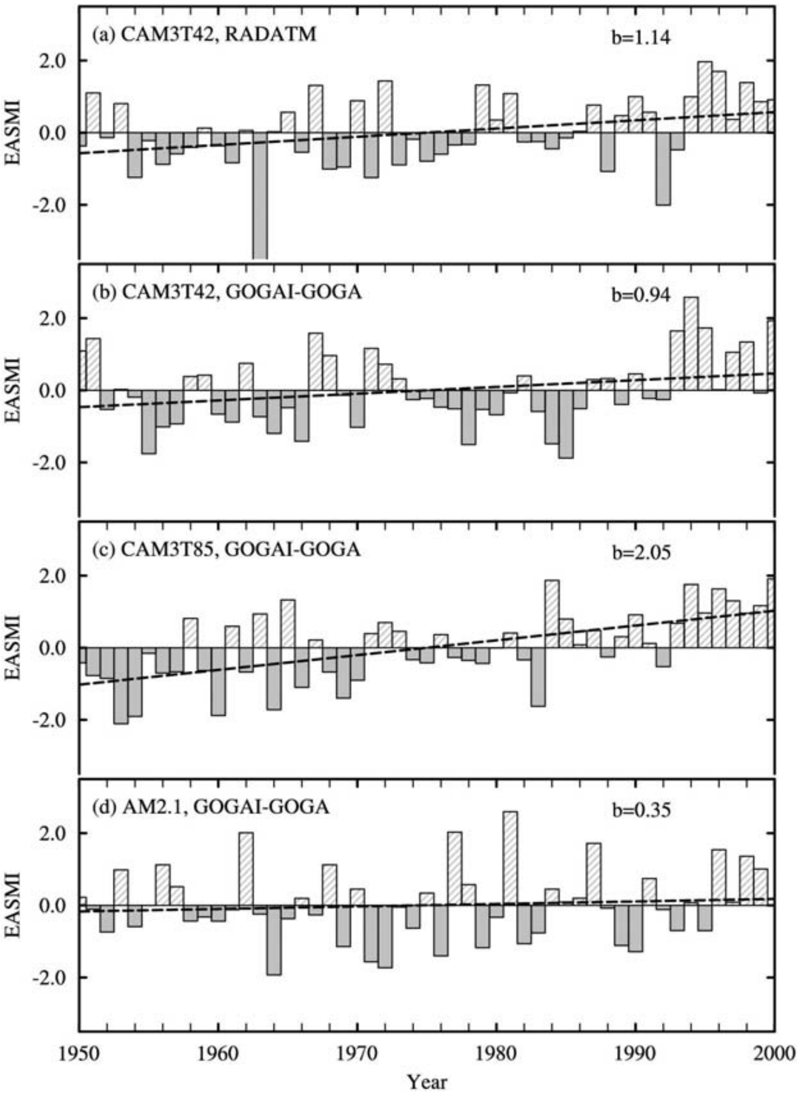
E. Asian Summer monsoon index

CAM3 T42 RADATM

CAM3 T42 GOGAI-GOGA

CAM3 T85 GOGAI-GOGA

AM2.1 GOGAI-GOGA

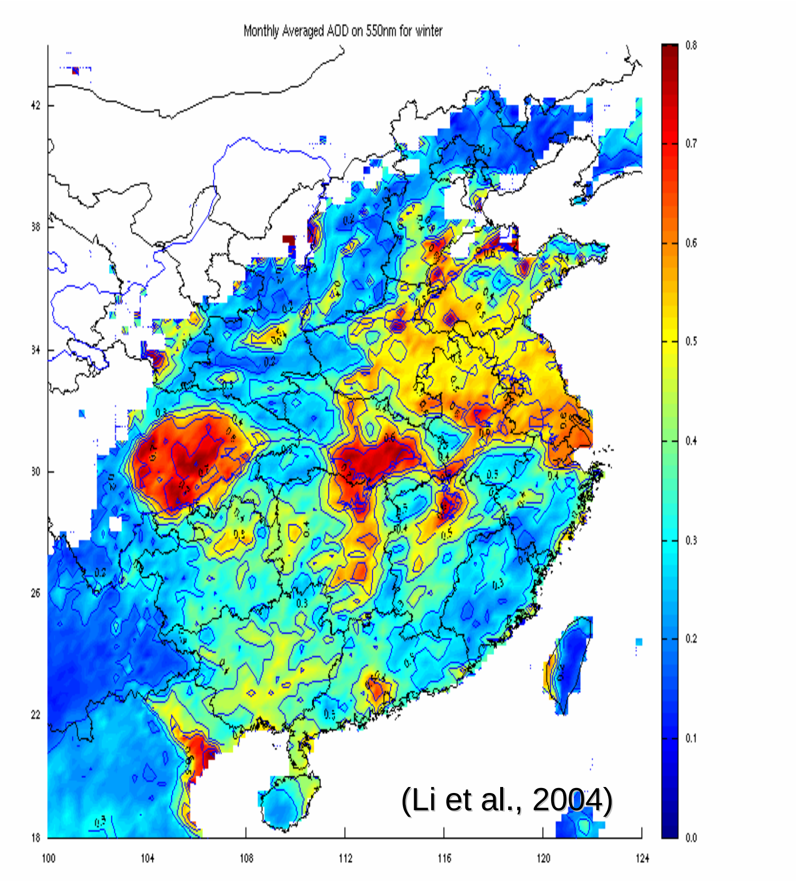


The prescribed aerosol forcing is the same as 20C3M.

(Li et al. 2008 Clm Dyn; consistent with Li et al. 2007 GRL)

1. Zhou T. , H.-H. Hsu, and J. Matsumoto, 2009: ***East Asian, Indochina and Western North Pacific Summer Monsoon***, WMO Report of the International Committee of the 4th International Workshop on Monsoons (IWM-IV), in press
2. Zhou T., D. Gong and J. Li, 2009:East Asian Summer Monsoon: Past, present, and future, ***Meteorologische Zeitschrift***

One Example: arguments on the role of aerosol



(Li et al., 2004)

REPORTS

Climate Effects of Black Carbon Aerosols in China and India

Surabi Menon,[1,2]* James Hansen,[1] Larissa Nazarenko,[1,2]
Yunfeng Luo[3]

In recent decades, there has been a tendency toward increased summer floods in south China, increased drought in north China, and moderate cooling in China and India while most of the world has been warming. We used a global climate model to investigate possible aerosol contributions to these trends. We found precipitation and temperature changes in the model that were comparable to those observed if the aerosols included a large proportion of absorbing black carbon ("soot"), similar to observed amounts. Absorbing aerosols heat the air, alter regional atmospheric stability and vertical motions, and affect the large-scale circulation and hydrologic cycle with significant regional climate effects.

China has been experiencing an increased severity of dust storms, commonly attributed to overfarming, overgrazing, and destruction of forests (*1*). Plumes of dust from north China, with adhered toxic contaminants, are cause for public health concern in China, Japan, and Korea, and some of the aerosols even reach the United States (*2*). Recent dust events have prompted Chinese officials to consider spending several hundred billion yuan (~$12 billion) in the next decade to increase forests and green belts to combat the dust storms (*3*). Such measures may be beneficial in any case. However, we suggest that the observed trend toward increased summer floods in south China and drought in north China (*4*), thought to be the largest change in precipitation trends since 950 A.D. (*4*), may have an alternative explanation: human-made absorbing aerosols in remote populous industrial regions that alter the regional atmospheric circulation and contribute to regional climate change. If our interpretation is correct, reducing the amount of anthropogenic black carbon aerosols, in addition to having human health benefits, may help diminish the intensity of floods in the south and droughts and dust storms in the north. Similar considerations may apply to India and neighboring regions such as Afghanistan, which have experienced recent droughts.

Atmospheric aerosols, which are fine particles suspended in the air, comprise a mixture of mainly sulfates, nitrates, carbonaceous (organic and black carbon) particles, sea salt, and mineral dust. Black (elemental) carbon (BC) is of special interest because it absorbs sunlight, heats the air, and contributes to global warming (*5*, *6*), unlike most aerosols, which reflect sunlight to space and have a global cooling effect (*7*). BC emissions, a product of incomplete combustion from coal, diesel engines, biofuels, and outdoor biomass burning (*8*), are particularly large in China and India because of low-temperature household burning of biofuels and coal (*9*).

It is reasonable to anticipate that human-made aerosols may contribute to climate change in China and India, because both absorbing BC aerosols and reflective aerosols, such as sulfates, reduce the amount of sunlight reaching the ground and thus should tend to cause local cooling. Observed temperatures in China and India in recent decades, unlike most of the world, reveal little warming (*10*); and in some seasons there is cooling, especially in the summer when aerosol effects should be largest. The climate effect of aerosols is complicated, because aerosols have, in addition to their direct radiative effects, indirect effects on cloud properties (*7*, *11*).

Here we report on climate model simulations of the direct radiative effect of aerosols in the region of China and India. We used the Goddard Institute for Space Studies (GISS) SI2000 12-layer climate model, which has been used to study the impact of several forcings on global mean temperature (*12*). Figure 1 shows the (seasonally independent) added aerosol optical depth $\Delta\tau_{aer}$ (0.55 μm) used in our climate model experiments (*13*). Over China, we take $\Delta\tau_{aer}$ (0.55 μm) to be equal to τ_{aer} (0.75 μm) measured in the 1990s (*14*, *15*). Over India and the Indian Ocean, $\Delta\tau_{aer}$ in our experiments is taken from chemical transport model assimilations of satellite measurements (*16*). The resulting radiative forcings at the top of the atmosphere and surface (fig. S1) are ~+6 W m^{-2} and −17 W m^{-2}, respectively, over India and the Indian Ocean, which is comparable to values estimated by others (*17*).

We performed two primary experiments. In experiment A, we added the aerosols of Fig. 1 with aerosol single-scatter albedo (SSA) = 0.85 (*18*), which is representative of measurements from the Indian Ocean Experiment (INDOEX) (*17*) and industrial regions in China. We obtained such relatively "dark" aerosols by including an appropriate amount of BC, with the remainder being sulfate. In experiment B, we removed BC so that SSA = 1, i.e., the aerosols were "white." In both A and B, the sea surface temperature (SST), greenhouse gases, and other forcings were kept fixed at the same values as in the control run, so that the aerosols were the only forcing. Both experiments were run for 120 years.

Figure 2A shows the simulated summer [June, July, and August (JJA)] surface air temperature (T_s) changes. The aerosols with SSA = 0.85 yield cooling in China by 0.5 to 1 K (a consequence of the reduced solar radiation reaching the surface) but warming in most of the world [due to BC heating of the troposphere (*19*)]. Because of the long model run, the cooling in China and even the warming in many distant locations are highly significant (>99%), based on Student's *t* test (fig. S2). The simulated cooling in China is larger than the observed cooling there during the past 50 years (Fig. 2B), when most of the increase in aerosol amount probably occurred. This is as expected, because the simulations exclude the effect of increasing greenhouse gases (*20*).

The BC absorption in China and India causes a significant warming (>0.5 K) in the Sahara Desert region and in west and central Canada, despite the fixed SST. Because aerosols were unchanged outside the China/India region, this warming at a distance seems to be due to heating of tropospheric air over China and India, with dynamical export to the rest of the world, where the warmer troposphere can reduce convective and radiative cooling of the surface. Consistent with observations (*10*, *21*), this warming does not occur over the south central United States, where the observed cooling trend is thought to be driven by warming in the tropical Pacific Ocean (*21*, *22*).

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

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Aerosol optical thickness of 2002

Menon et al. 2002

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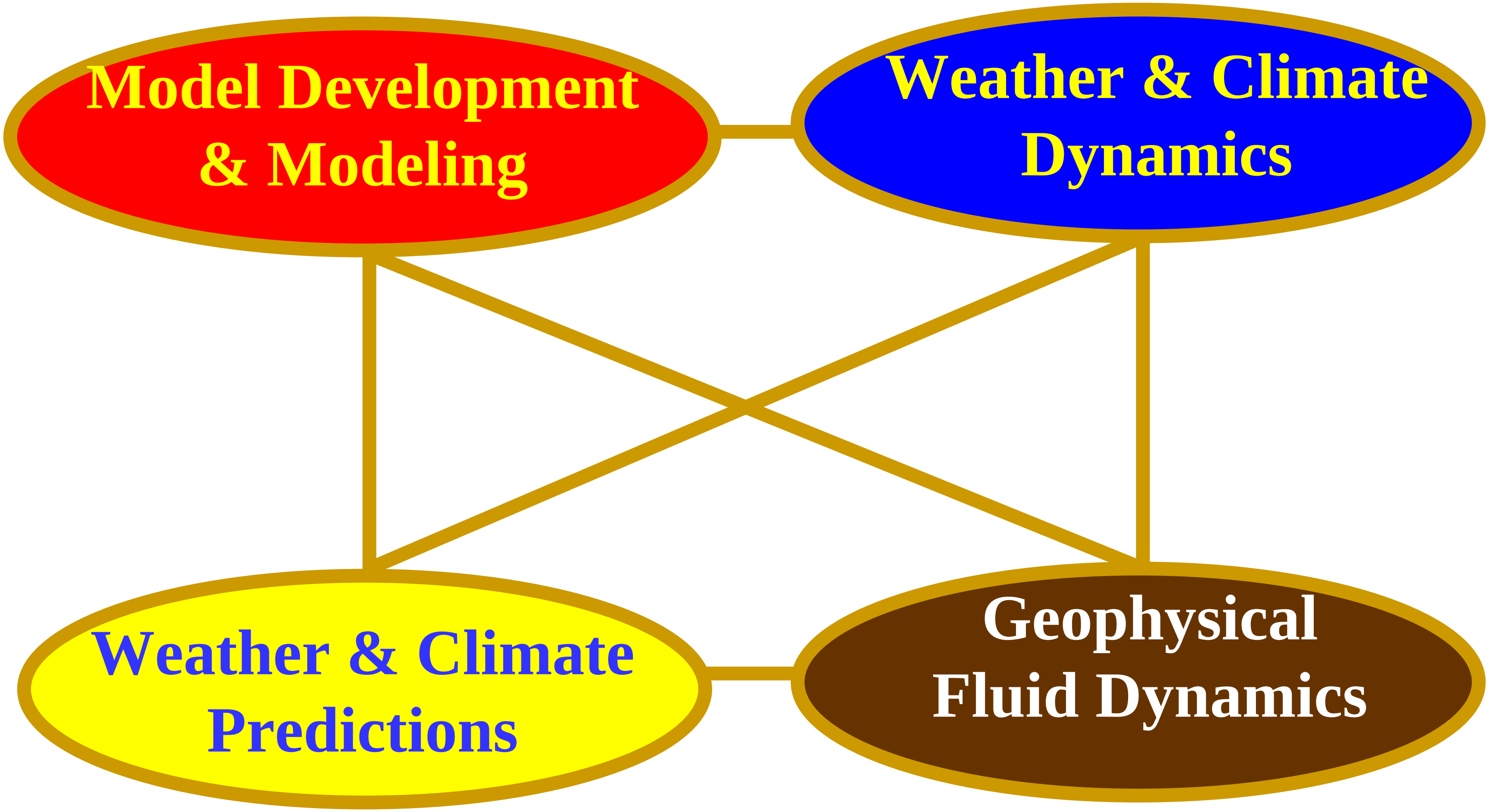


Model Development & Modeling

Weather & Climate Dynamics

Weather & Climate Predictions

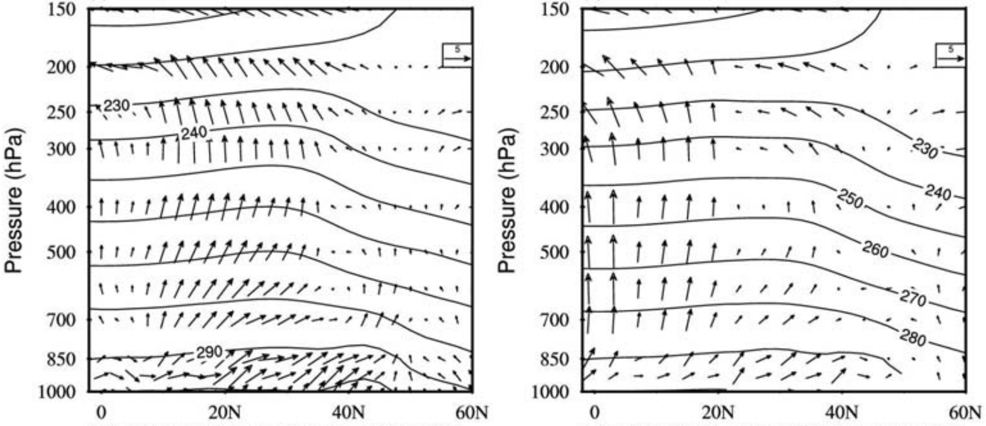
Geophysical Fluid Dynamics

105° -122° E average T and latitude –height cross-section

1950-1976 mean
NCEP/NCAR

(a) NCEP/NCAR, 1950-1976 mean

(b) AM2.1 GOGA, 1950-1976 mean

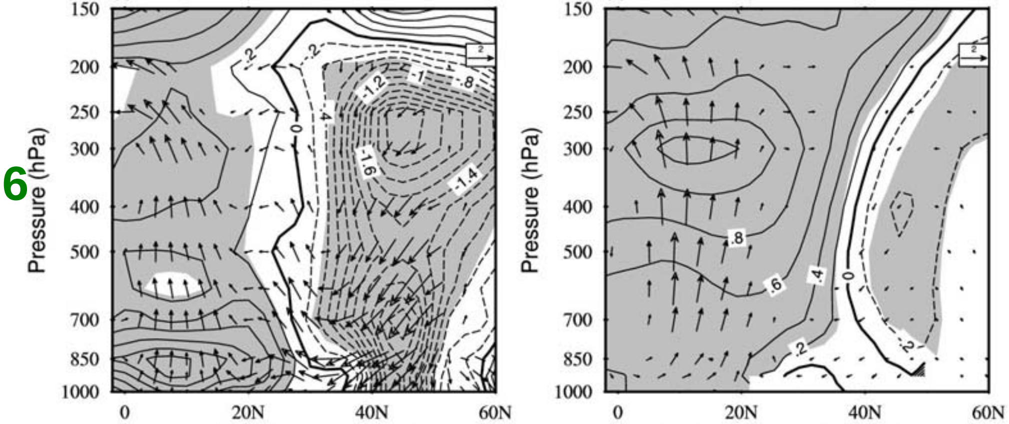


1950-1976 mean
AM2.1 GOGA

1977-2000
minus1950-1976
NCEP/NCAR

(c) NCEP/NCAR, 1977-2000 minus 1950-1976

(d) AM2.1 GOGA, 1977-2000 minus 1950-1976

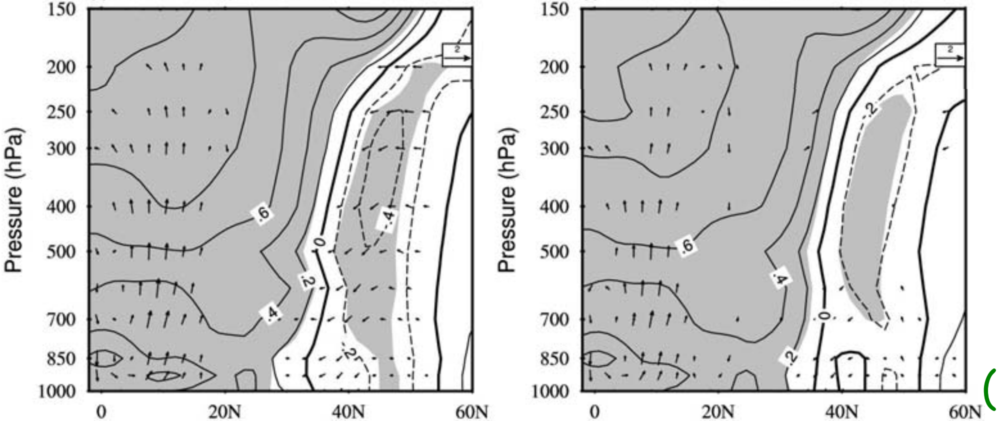


1977-2000
minus1950-1976
AM2.1 GOGA

CAM3 GOGA

(e) CAM3 GOGA, 1977-2000 minus 1950-1976

(f) CAM3 TOGA, 1977-2000 minus 1950-1976



CAM3 TOGA

(Li et al. 2008 Clm Dyn)