Comparisons between modern East Asian monsoon variability and those found in proxies associated with the Asian-Pacific Oscillation during the past 1000 years

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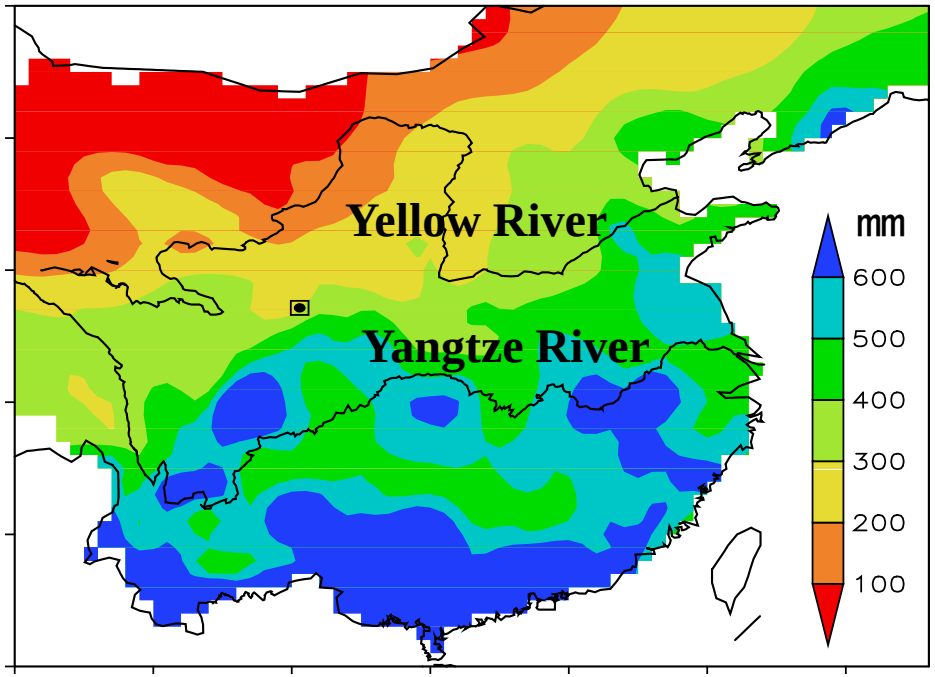
Outline

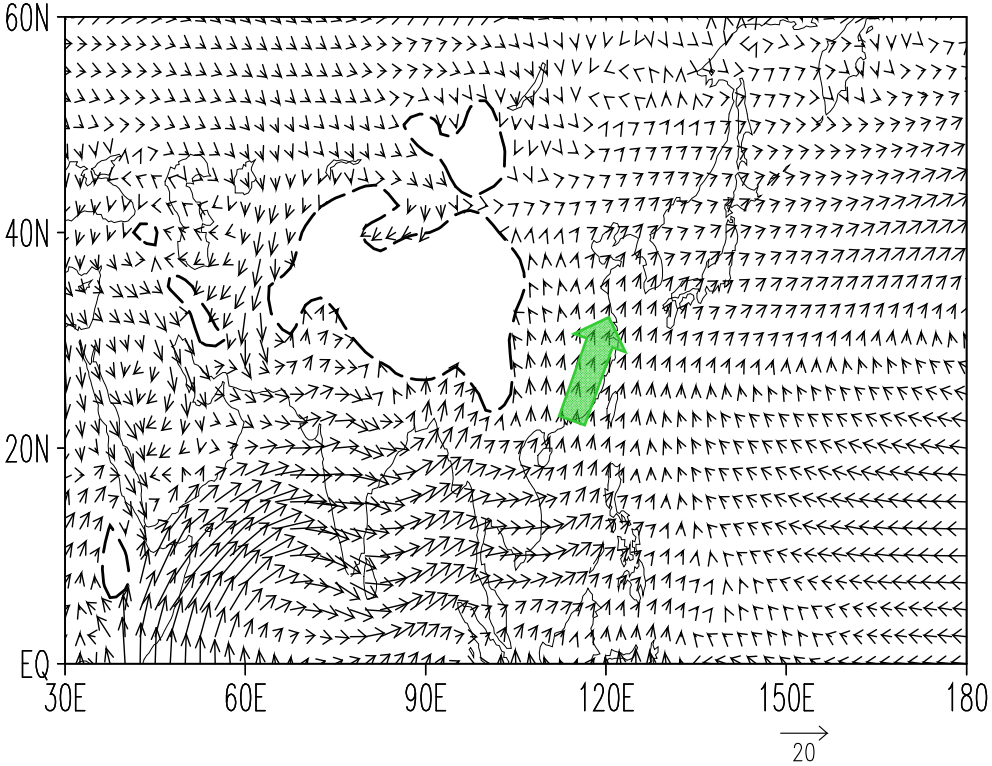
1. **Basic features of East Asian monsoon climate**
2. **Choice of thermal contrast index**
3. **Reconstruction of thermal contrast**
4. **Variability of thermal contrast and precipitation over eastern China**
5. **Summary**

1. Basic characteristics of East Asian monsoon

Climatology of summer rainfall



Climatology of summer low-level wind



- **A change in the lower-tropospheric wind direction is driven by the thermal contrasts between Asian land and its adjacent oceans**
- **A variation between wet and dry seasons is related to the variation in wind**
- **Anomalies of East Asian summer monsoon (EASM) and rainfall are closely related to variations of the thermal contrasts between Asia and the North Pacific**

Flohn 1957; Chen et al. 1992; Webster et al. 1992; Murakami 1994; Li and Yanai 1996; Ding 2004

2. Millennial climate in China

Proxies of temperature and precipitation showed that

- **Climate in China showed the similar phenomena such as the Medieval Warm Period (MWP) and Little Ice Age (LIA)**
- **In MWP (LIA): climate was drier (wetter) in south China and wetter (drier) in North China**
- **Over eastern China: air temperatures in the 9th to 11th centuries were comparable to the present day or slightly lower compared to the present day**

Zheng et al. 1993; Ren et al. 1996, 2005; Yao 1997; Wang et al. 1998, 2000, 2007; Zhang 2002; Yang et al. 2002, 2006; Ge et al. 2002; Li et al. 2005; Tan et al. 2011

- **Clearly, the previous studies paid little attention to reconstructions of thermal contrasts over the EASM region.**
- **It is useful to investigate the EASM features by reconstructing the millennial thermal contrast indices**

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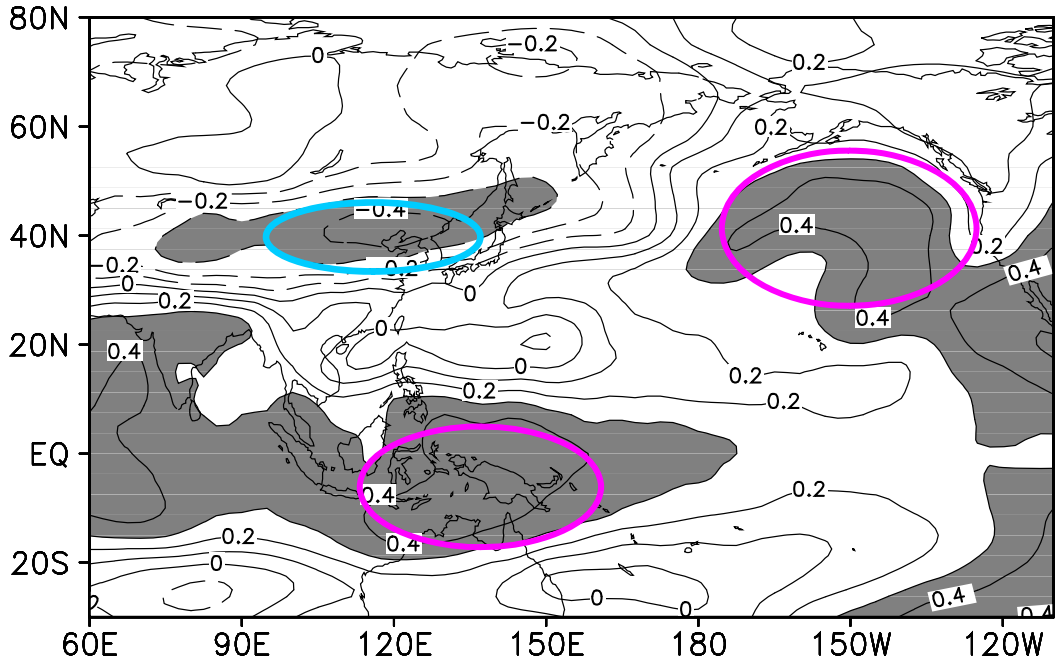
Correlation between summer rainfall in south China and 500-200-hPa temperature (1958-2001)



- **Define a temperature difference between East Asia and the central-eastern North Pacific (tropical western Pacific) as a zonal (meridional) thermal contrast.**

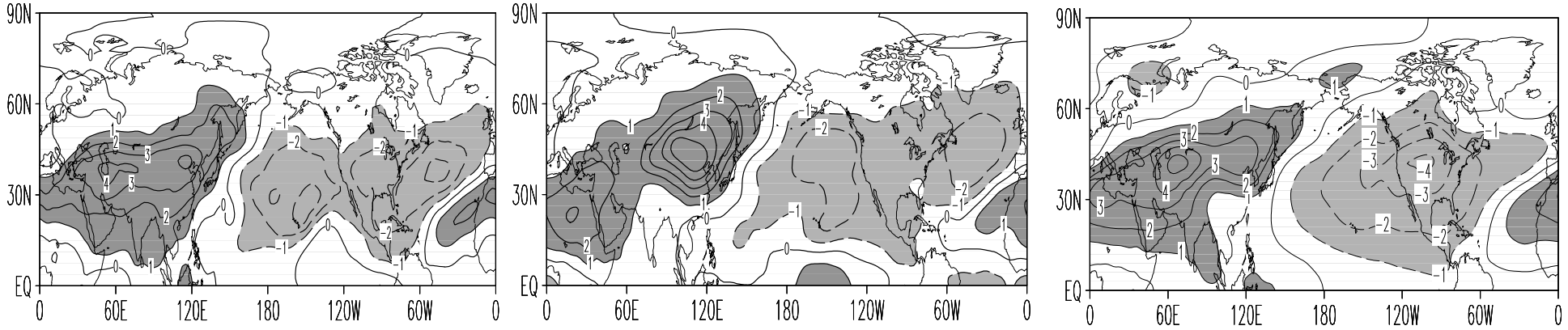
(Zhao, Chen, Xiao, Nan, Zou, Zhou, Acta Meteoro Sin, 2008)

The variation of summer rainfall in South China is associated with thermal contrasts between East Asia and the North Pacific

The thermal contrasts can be indicated by the Asian-Pacific oscillation (APO) index that measures variability of an out-of-phase relationship between Asia and the North Pacific. For a higher APO index, a positive (negative) anomaly of tropospheric *T'* appears over Eurasia (the North Pacific-Atlantic), increasing the east-west contrast between Eurasia and the North Pacific-Atlantic.

APO：EOF1 of tropospheric temperature deviation

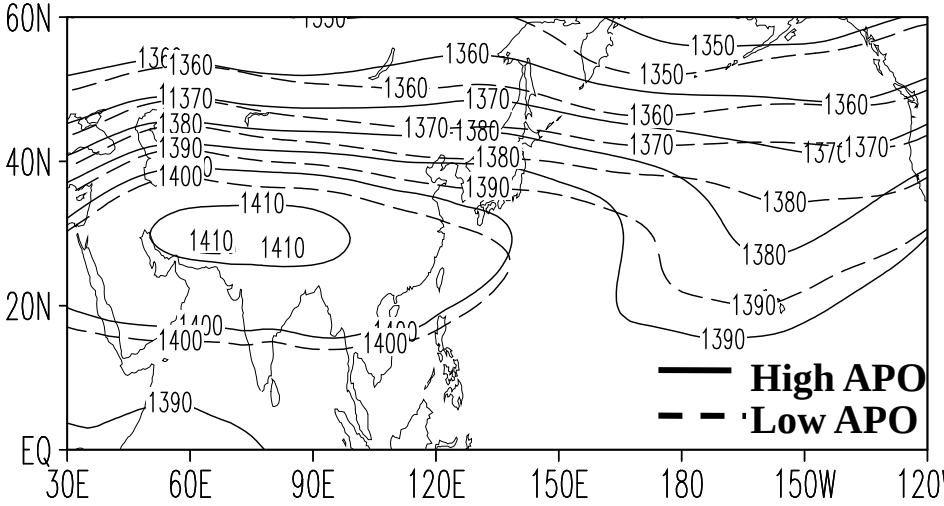
ERA-40 （1958-2002） NCEP （1948-2002） 20th CR （1901-2002）



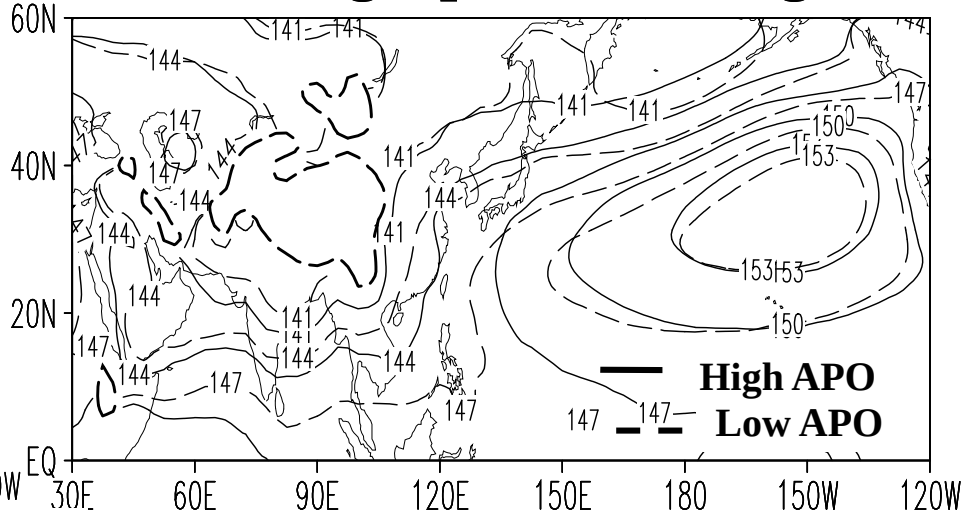
(Zhao, Wang, Zhou, Clim Dyn, 2012)

APO can well indicate changes of atmospheric circulation and rainfall over Asia-North Pacific

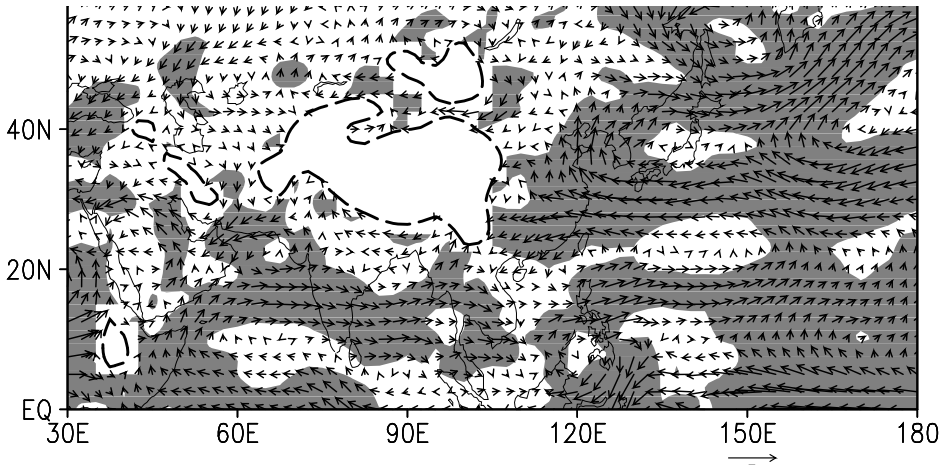
150-hPa geopotential height



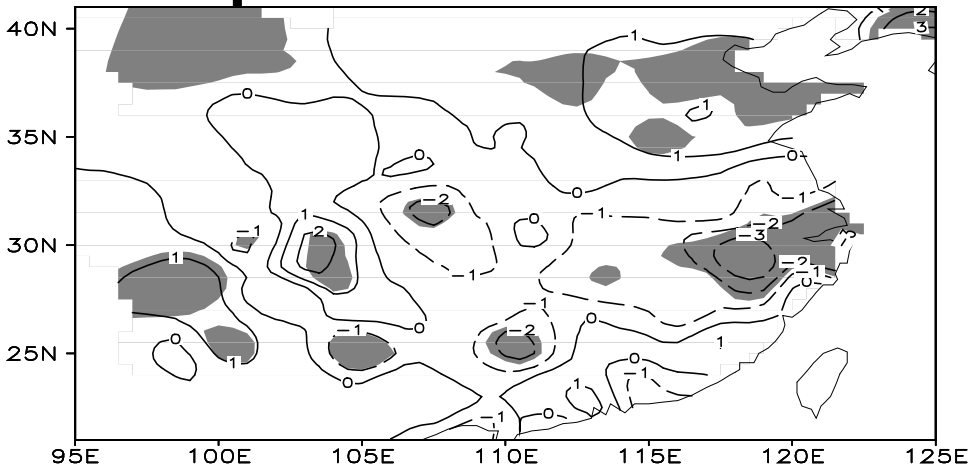
850-hPa geopotential height



Composite 850-hPa wind difference



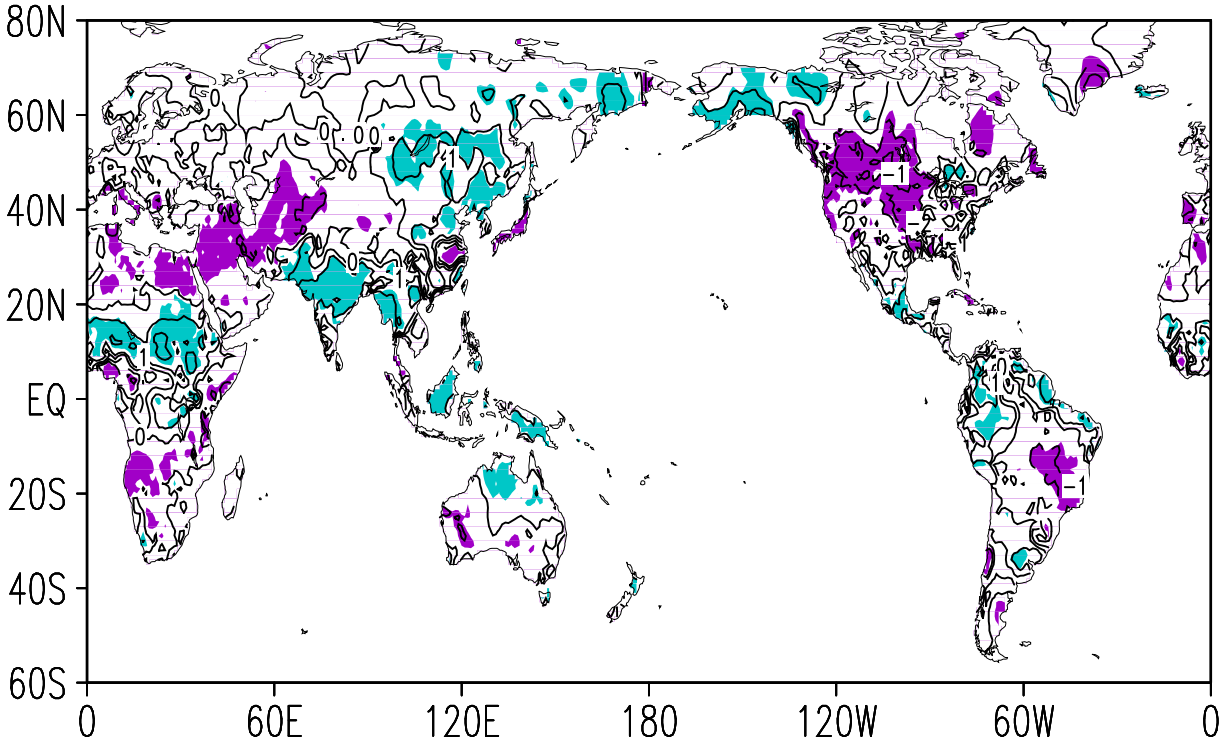
Composite rainfall difference



(Zhao, Zhu, Zhang, Clim Dyn, 2007)

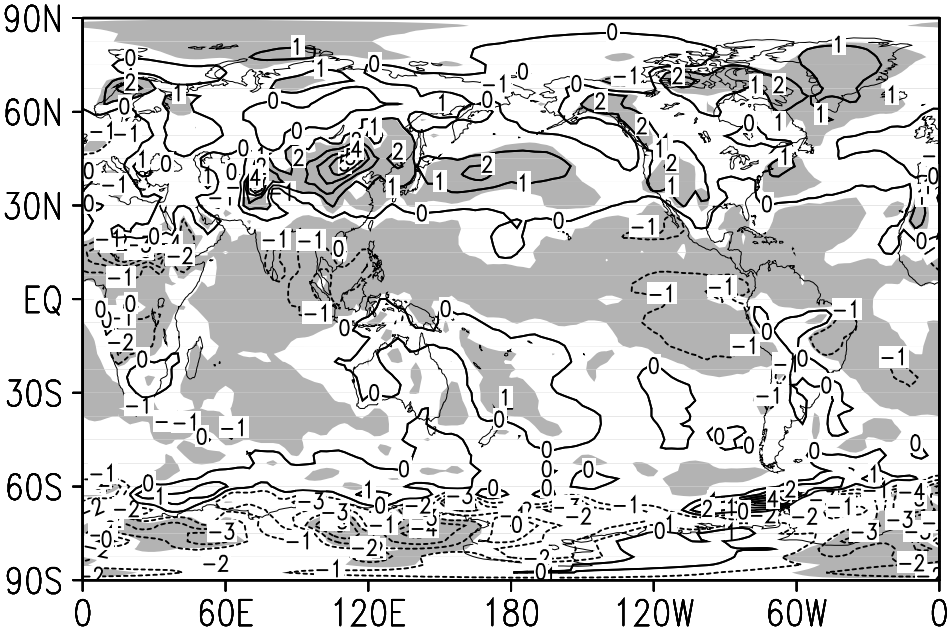
The summer APO index has a correlation of -0.48 (0.43) with rainfall in south (north) China during 1958-2001.

Regressed summer rainfall against APO during 1901-2002

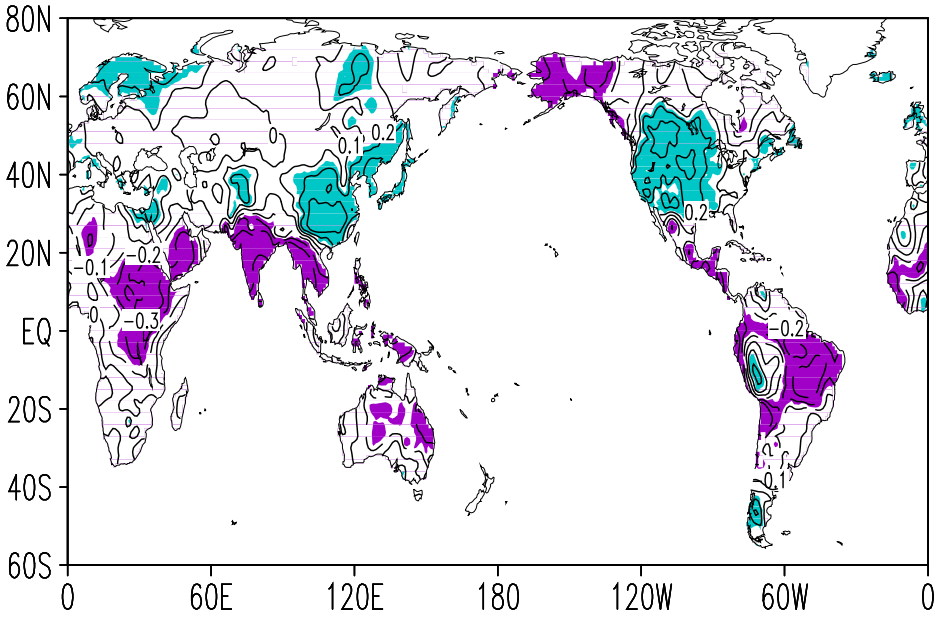


(Zhao, Wang, Zhou, Clim Dyn, 2012)

Composite surface air temperature(1958-2001)



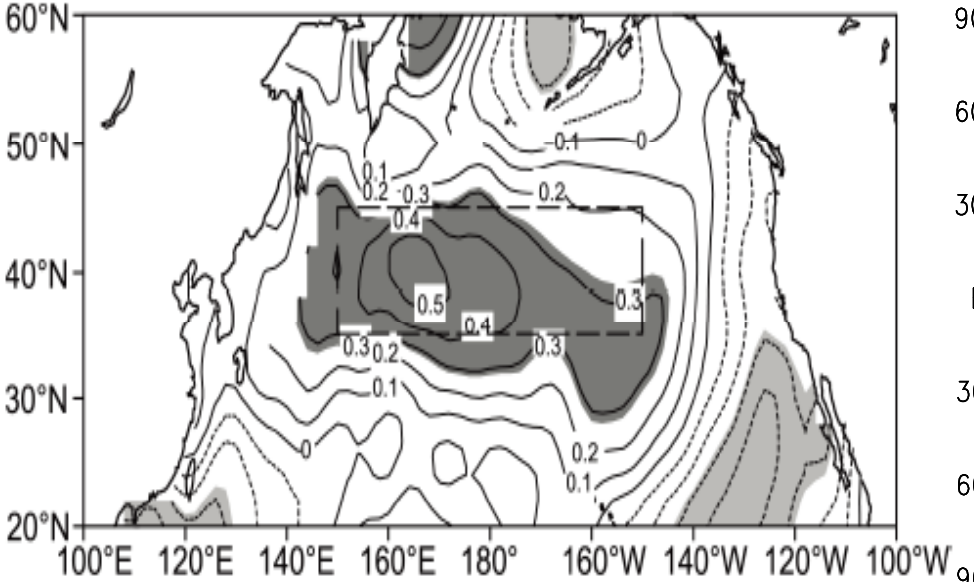
Regressed Air temperature against APO (1901-2002)



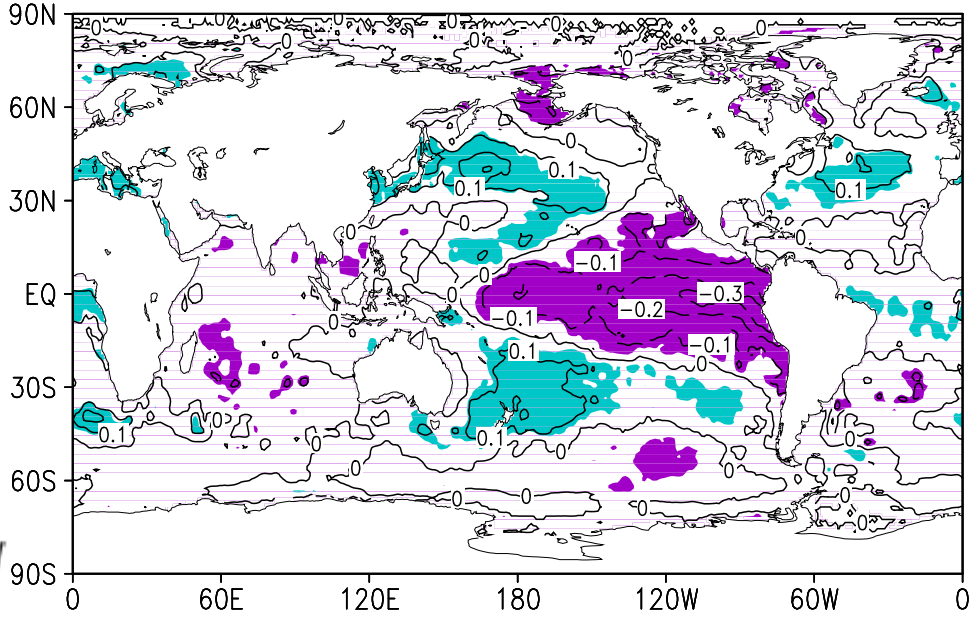
- **APO is related to surface air temperature over East Asia**

(Zhao, Zhu, Zhang, Clim Dyn, 2007; Zhao, Wang, Zhou, Clim Dyn, 2012)

Correlation between SST and APO (1954-2003)



Regressed SST against APO (1901-2002)



- **APO is correlated with the extratropical North Pacific SST that can be indicated by the PDO index, with a correlation of 0.58 between APO and PDO (1954-2003)**

(Zhou and Zhao, Chinese Sci Bull, 2010; Zhao, Wang, Zhou, Clim Dyn, 2012)

In the following section, we use temperatures over East Asia and the North Pacific to reconstruct the APO index.

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1. **Basic features of East Asian monsoon climate**
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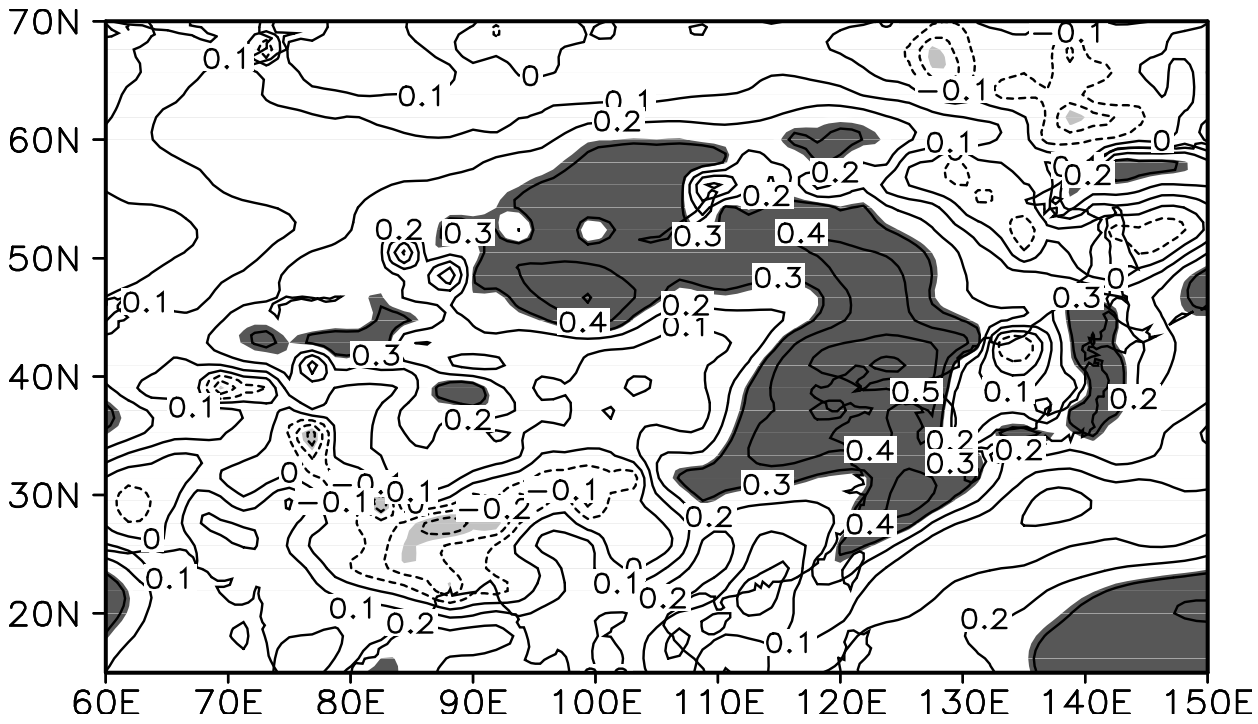
Correlation in summer temperature between Beijing meteorological observation and the NCEP reanalysis（1951-2000)



We may use Beijing temperature to indicate that over East Asia

(Zhou, Zhao, Liu, Chinese Sci Bull, 2009）

1. Data used in reconstruction

- **Reconstructed PDO index: 993-1996 (MacDonald et al. 2005)**
- **Reconstructed summer temperature: BC 665-AD 1985 from stalagmite record in Beijing (Tan et al., 2003)**
- **APO from the NCEP reanalysis : 1951-2000**
- **PDO（1951-2000）: http://jisao. washington.edu/pdo**
- **Beijing meteorological station temperature (1951-2000)**

2. Method of reconstruction

- **Use two sets of data to build a multivariate linear regressed model of summer APO**

  Observational Beijing surface air temperature and PDO

  Reconstructed Beijing temperature and PDO

- **Calibration period : Build the model**

  Verification period: Test the reliability of the model

(Zhou, Zhao, Liu, Chinese Sci Bull, 2009）

3. Model of reconstruction

（1）Reconstructed model from observational data

$$I_{APO} = -0.563 \times I_{PDO} + 0.292 \times T_{Beijing} + 0.259 \qquad (1)$$

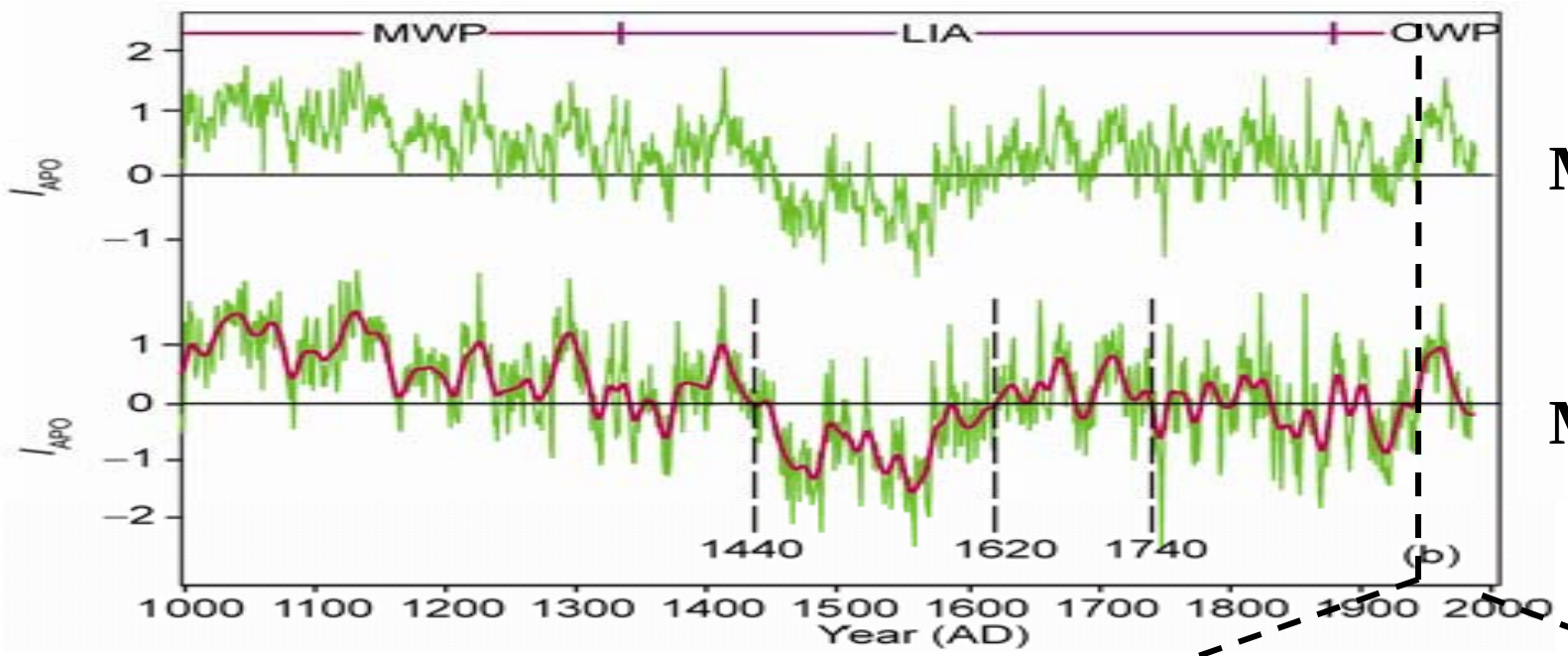
（2）Reconstructed model from proxies

$$I_{APO} = -0.936 \times I_{PDO} + 0.225 \times T_{Beijing} + 0.046 \qquad (2)$$

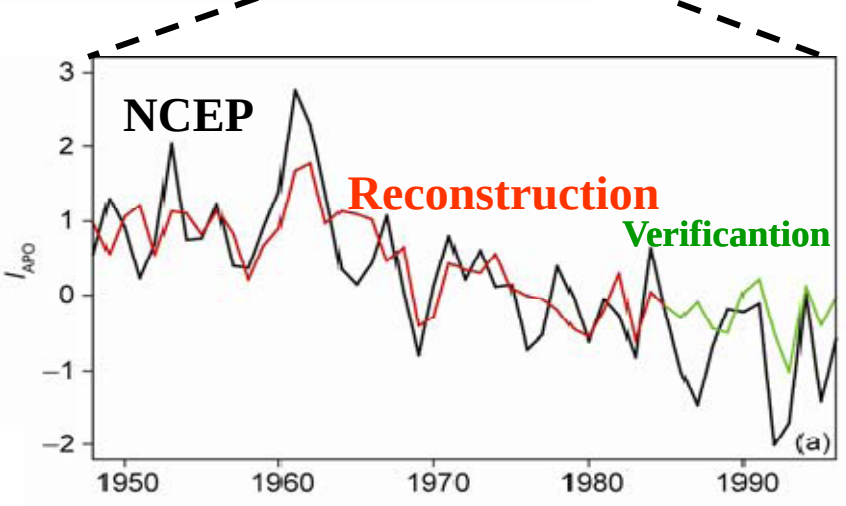
All parameters of these two models and their regressed coefficients are statistically significant.

(Zhou, Zhao, Liu, Chinese Sci Bull, 2009）

4. Comparison of different APO reconstructions

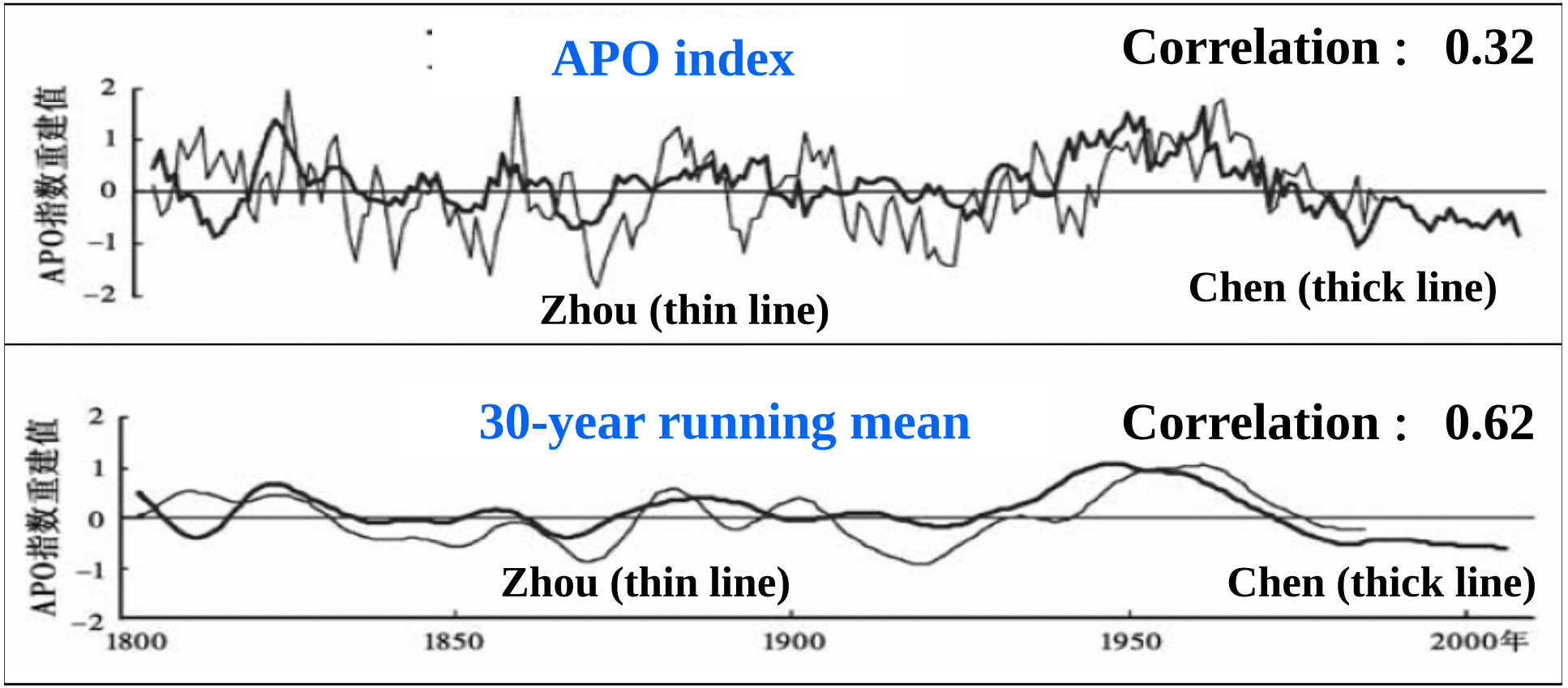


Long-term variations of APO in models 1 and 2 are similar



(Zhou, Zhao, Liu, Chinese Sci Bull, 2009）

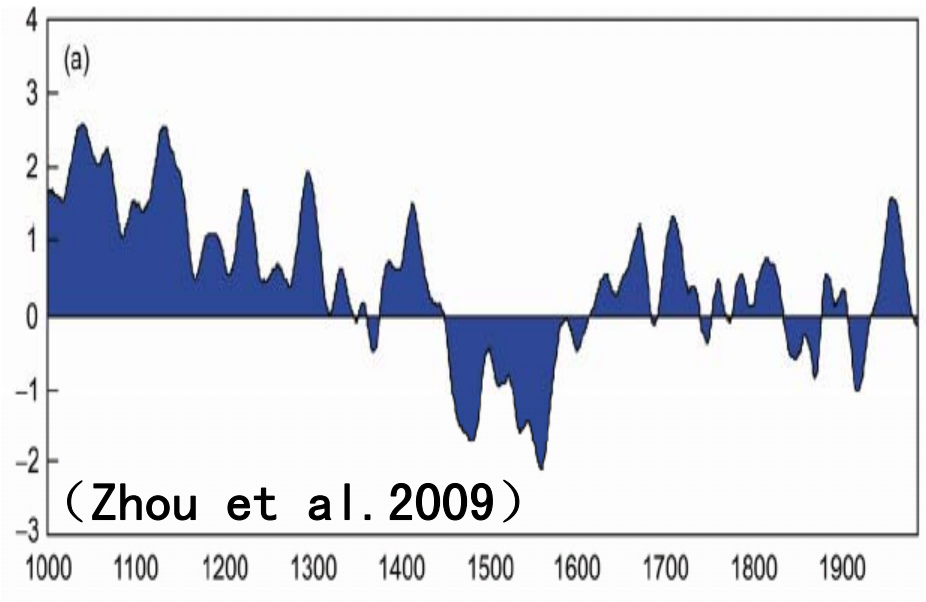
A comparison with Chen's reconstruction in 1800-2000



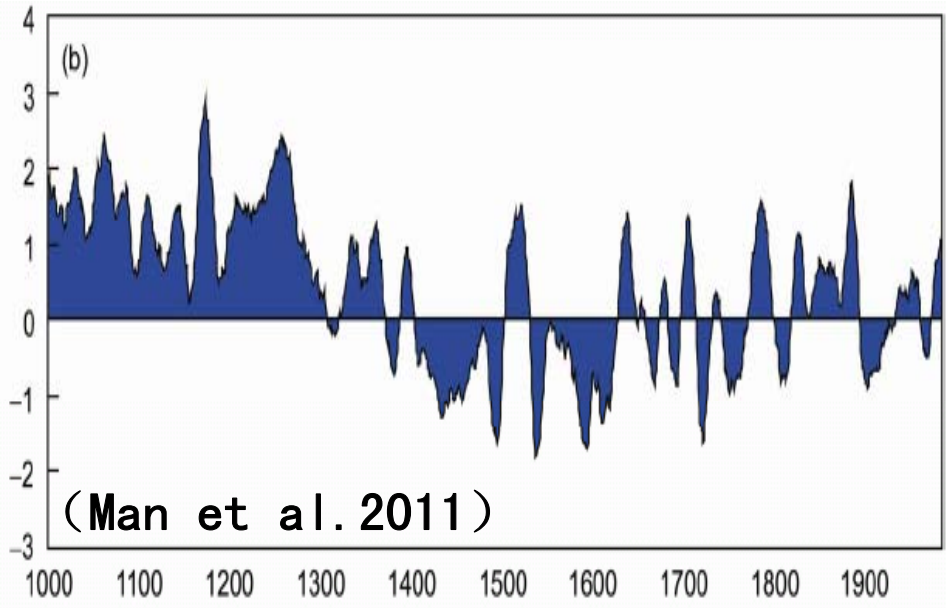
Correlation between our reconstruction and Chen's tree-ring reconstruction: 0.32, 0.62 （Chen et al., 2011）

A comparison with climate model APO in 1000-1985

Our reconstructed APO



F-GOALS Climate model APO



On a centennial scale, the simulated APO had a similar varying feature to our reconstruction, with a correlation of 0.50 for 31-year running mean（Man et al. Chinese Science Bulletin, 2011）

This consistency between our APO and the others suggests the reliability of our reconstruction

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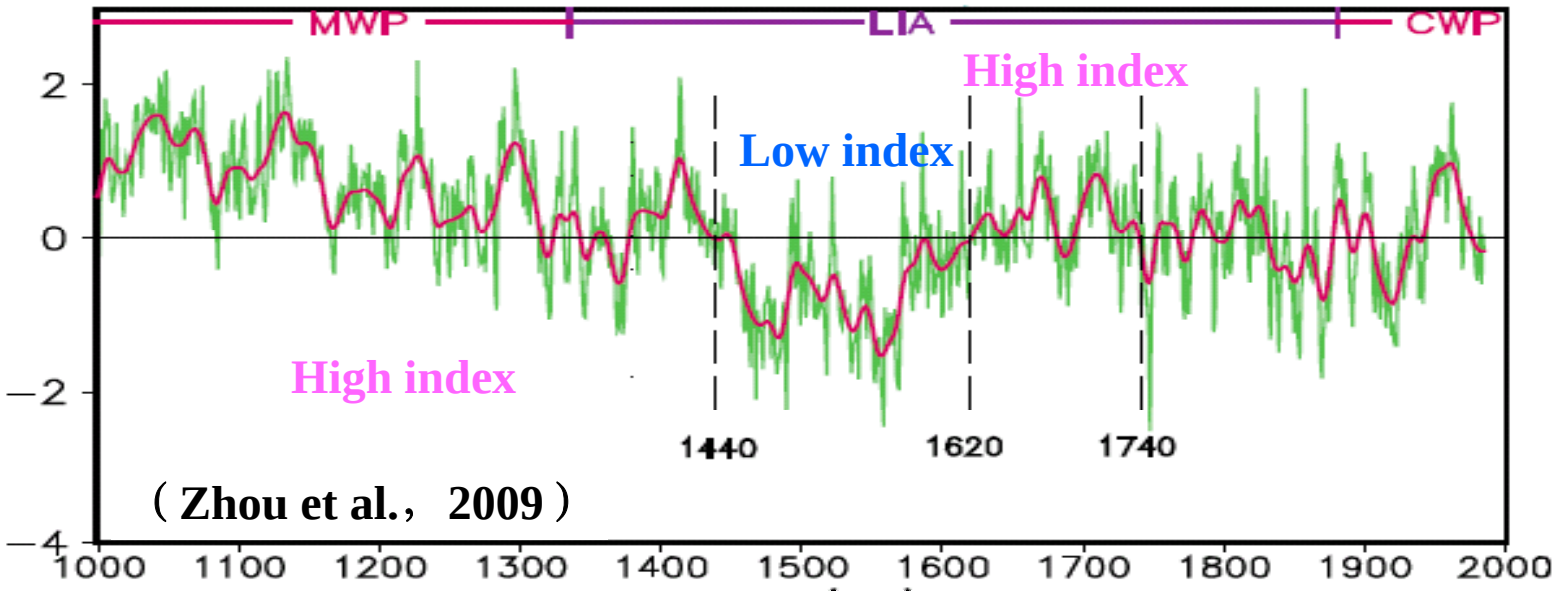
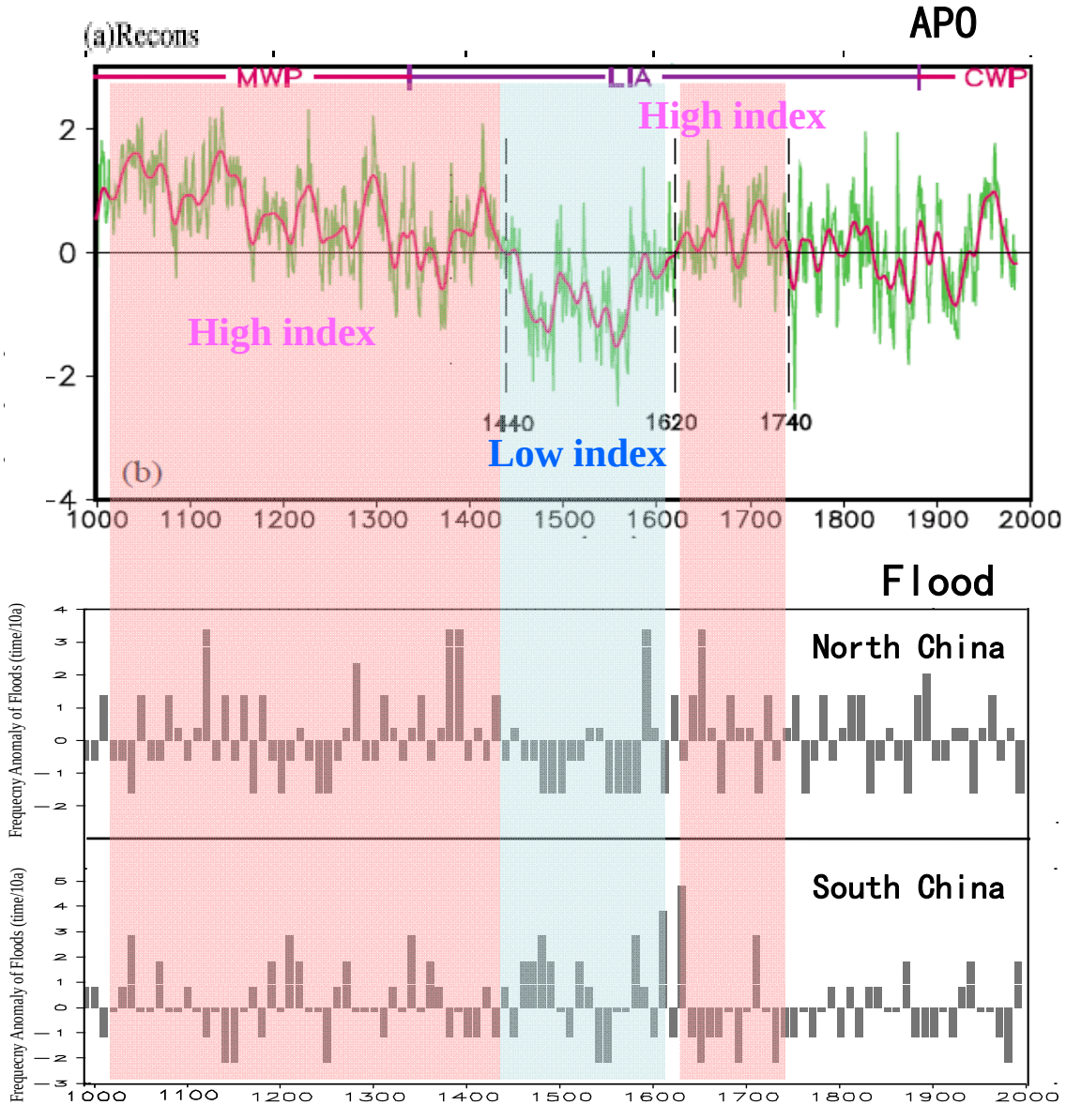
APO



- **In MWP: APO was mainly positive, indicating a strong thermal contrast between Asia and Pacific and a strong EASM.**
- **In LIA: APO was mainly negative and weakest in 1450-1570 , indicting a weak thermal contrast and EASM.**
- **From the variability of the thermal contrast, we might guess that in MWP (LIA), there should be more rainfall in north (south) China and less rainfall in south (north) China.**

Comparison between APO and flood frequency anomaly

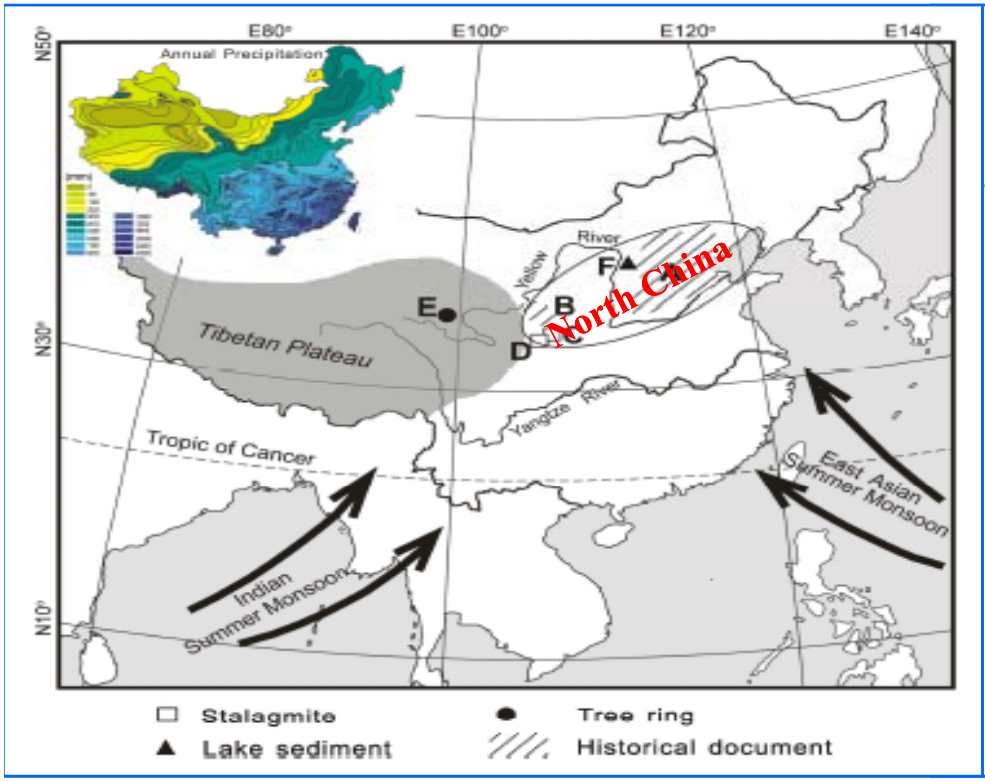


- **In 1000-1440： with high APO, more (less) flood in north (south) China**
- **In 1440-1620： with low APO, less (more) flood in north (south) China**
- **In 1620-1740： with high APO, more (less) flood in north (south) China**

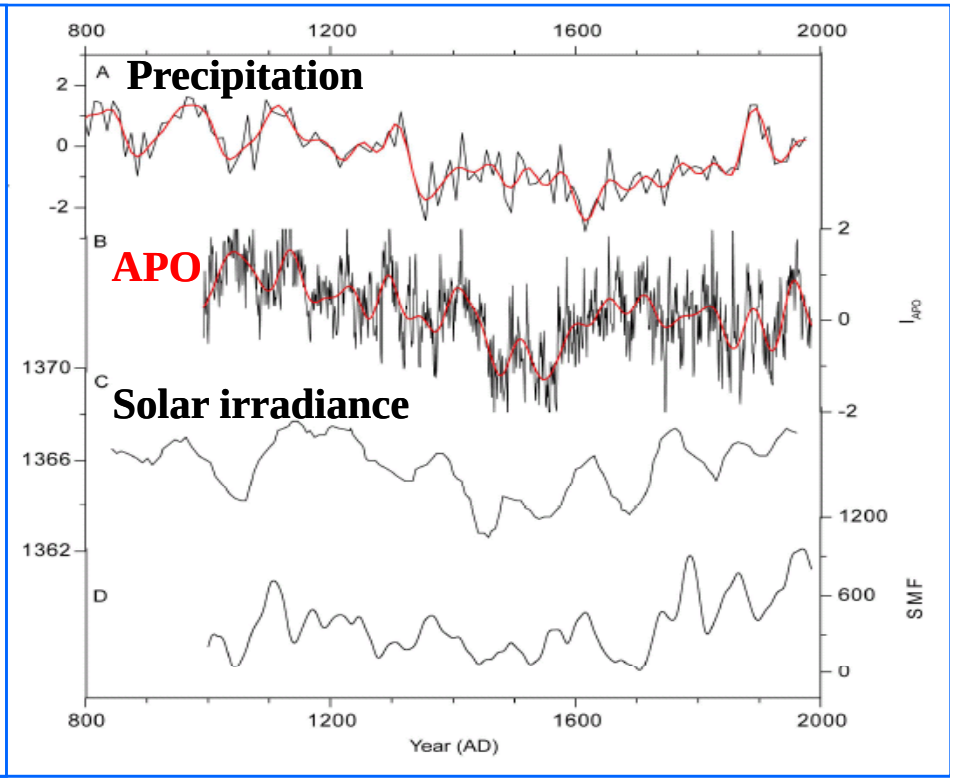
（Zhou et al.,2009, 2011）

On the centennial scale, when APO was higher, there was more (less) rainfall over north (south) China; when APO was lower, vice versa

Location of north China and palaeoclimate sites



Synthesized precipitation index for north China



Tan et al. (2011) synthesized the precipitation records in north China, compared with the reconstructed APO, and found a significant positive correlation of 0.40 in the past millennium

(Tan et al., Climate of the Past, 2011)

Other rainfall evidence in MWP

- **In MWP, there is more proxy evidence that supports a more summer precipitation in north China and a less rainfall in south China (Ren, 1996; Tong, 1997; Cao, 2000; Wu, 2005)**

This consistency between APO and precipitation variations further supports the reliability of our reconstructed APO

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(1)The reconstructed thermal contrast (namely APO) between land and ocean can be used to indicate variability of EASM and rainfall in the past millennium.

(2) In LIA, the thermal contrast was weak and the weakest thermal contrast in the past millennium occurred in 1450–1570. EASM rain belt remained in south China, with less rainfall in north China. This feature corresponded to a weak EASM.

(3) In MWP, the thermal contrast was strong and EASM rain belt moved northwards, with more rainfall in north China. This feature corresponded to a strong EASM.

1000-Year APO index：http://cadata.cams.cma.gov.cn/nianlun

Thanks!