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Seasonal-to-Interannual Prediction of Climate Disasters in China

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- Introduction
- IAP dynamical seasonal-to-interannual climate prediction system (IAP DCP)
- Real-time Predictions and verifications
- Summary

Why Climate Prediction

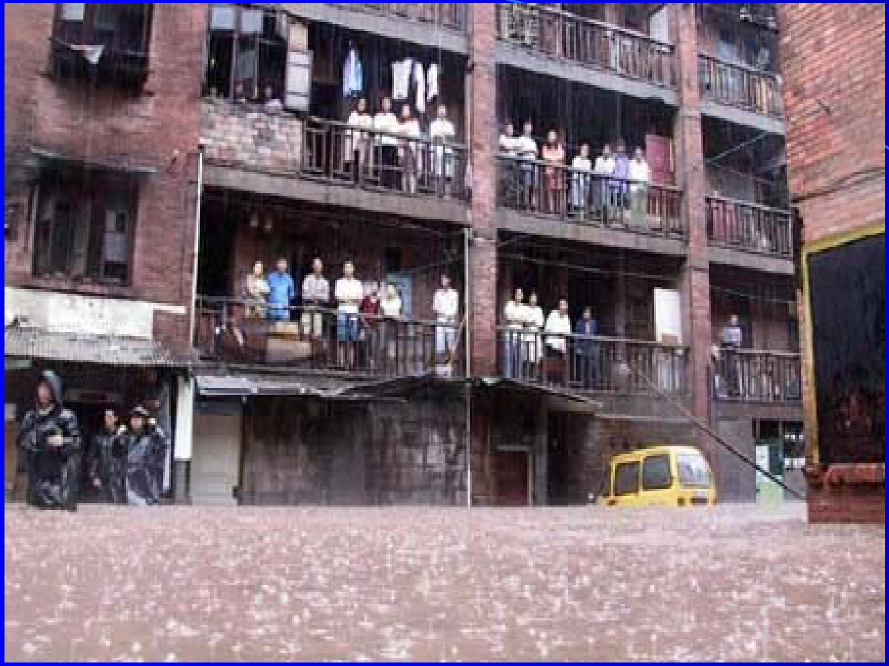
Some floods in 2002

Source: Red Cross

Large climate anomaly such as severe flood and drought can result in heavy losses for the local economy and even human lives

Climate prediction with reasonable skill is of great importance for reducing and even avoiding climate-related disasters.

Floods



Flood over Yangtze River basin

Climatic disasters happen in China frequently

Drought & Dust-storm

Drought over Yellow River basin

China

- 10 billions economic loss annually
- 78 billions economic loss caused by 1991 severe flooding event over Huaihe and Yangtze River more than 5000 dead
- 248 billions loss caused by 1998 severe flooding events over China, more than 3600 dead

International Research Activities on the dynamical climate prediction

- CLIVAR (Study of CLImate VARiability and Predictability)
- SMIP (Seasonal Prediction Model Intercomparison Project --- Phase I & Phase II)
- NSIPP (NASA Seasonal to Interannual Prediction Project)
- PROVOST (PRediction Of Climate Variation On Seasonal to interannual Time scale)
- DEMETER(Development of a European Multimodel Ensemble system for Seasonal to inTERannual prediction)

……

International Research Activities on the dynamical Climate prediction

- International Research Institute for Cliamte Prediction (IRI)   (Initiated in 1994)
- Climate Prediction Center(CPC/NCEP)
- ECMWF (Initiated in 1995)
- UK Met office   (Initiated in 1987, Ward and Folland, 1991))
- CPTEC/Brazil (Initiated in 1995)
- Experimental climate prediction center(ECPC), Scripps Institute of Oceanography
- Korea Meteorology Administration (KMA)
- Japan Meteorology Administration (JMA)

Climate Prediction Activities in China

- **Statistical Climate prediction of summer rainfall anomalies over China can be dated back to 1950s.**
- **First Extraseasonal Prediction by Numerical Climate Models was conducted in 1988 in the Institute of Atmospheric Physics (IAP/CAS)**

Zeng et al., 1990

China's Contribution

- **Establishment and improvement of IAP Dynamical Climate Prediction System (IAP DCP)**

  e.g., Li, 1992; Zeng et al, 1997; Lin et al, 1998， Zhou et al. 1998; Zeng et al., 2003 …

- **Dynamical Seasonal Prediction of Climate Anomalies since 1990 by IAP DCP**

  Zeng et al., 1990; Yuan et al., 1996; Zeng et al., 1997; Lin et al., 1998, 1999, 2000; Zhou et al., 2001, …

China's contribution

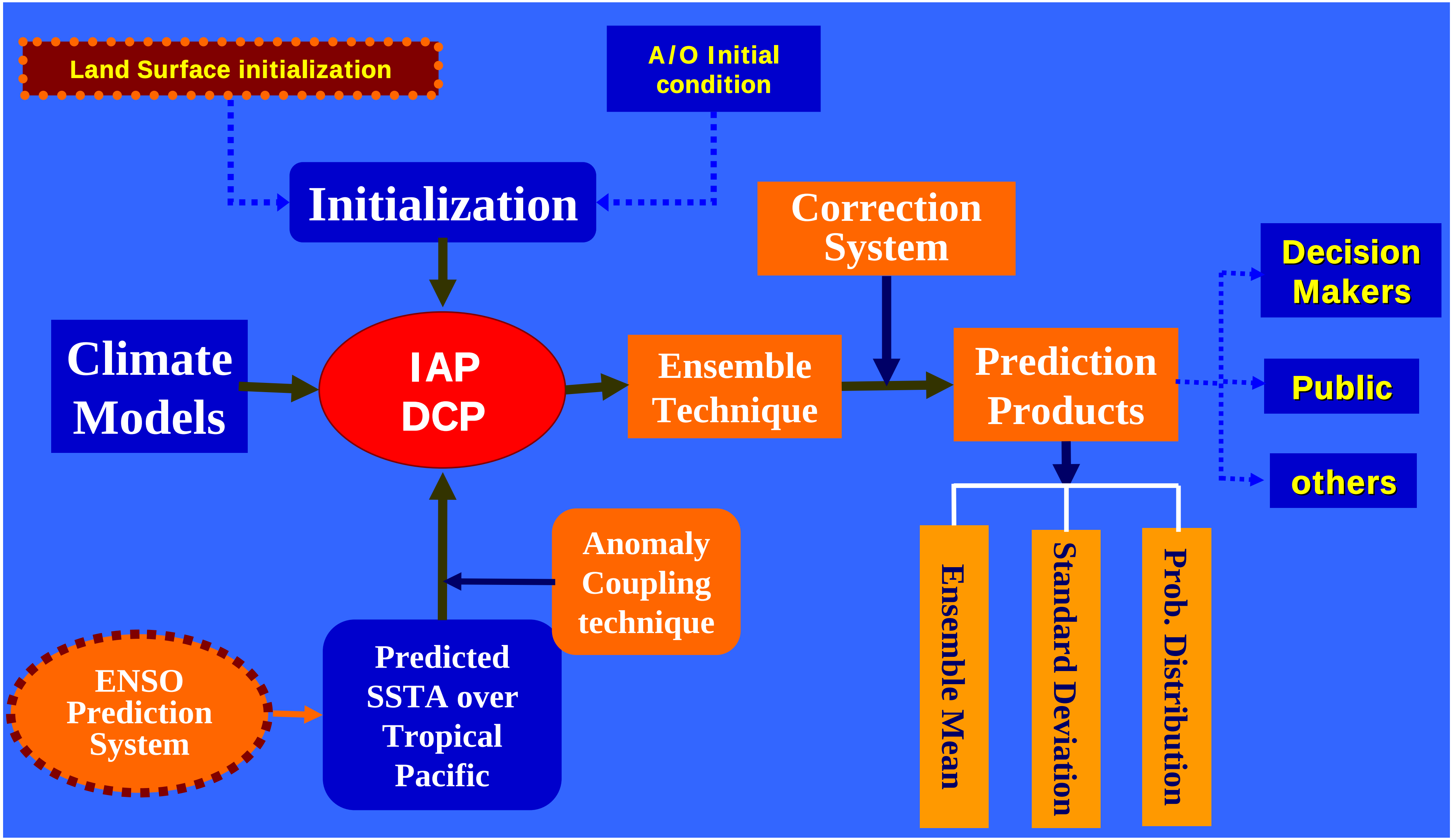
- **National Climate Center (since 1995)**
  - **NCC/CMA T63 AGCM**
  - **RegCM2_NCC**
- **Chinese Academy of Meteorological Science, CMA (CAMS/CMA)**
  - **CCM3□R15L9□□RegCM2 nested model**
  - **……**

IAP Dynamical Seasonal to Interannual Prediction System

Components of IAP DCP

- IAP ENSO Prediction System
  - IAP TOGA-I (AGCM, OGCM, CGCM, LSM ….)
- Anomaly coupling Technique
- Ensemble Prediction Technique
  - Ensemble mean / Standard Deviation / Probability Distribution
- Correction System
- Prediction Products

IAP Dynamical Climate Prediction System



IAP ENSO Prediction System

Model Description

- **IAP 2-Level Atmosphere General Circulation Model**

  Region: Global

  Resolution: 4^o x 5^o in Horizontal Direction

  2 Levels in Vertical

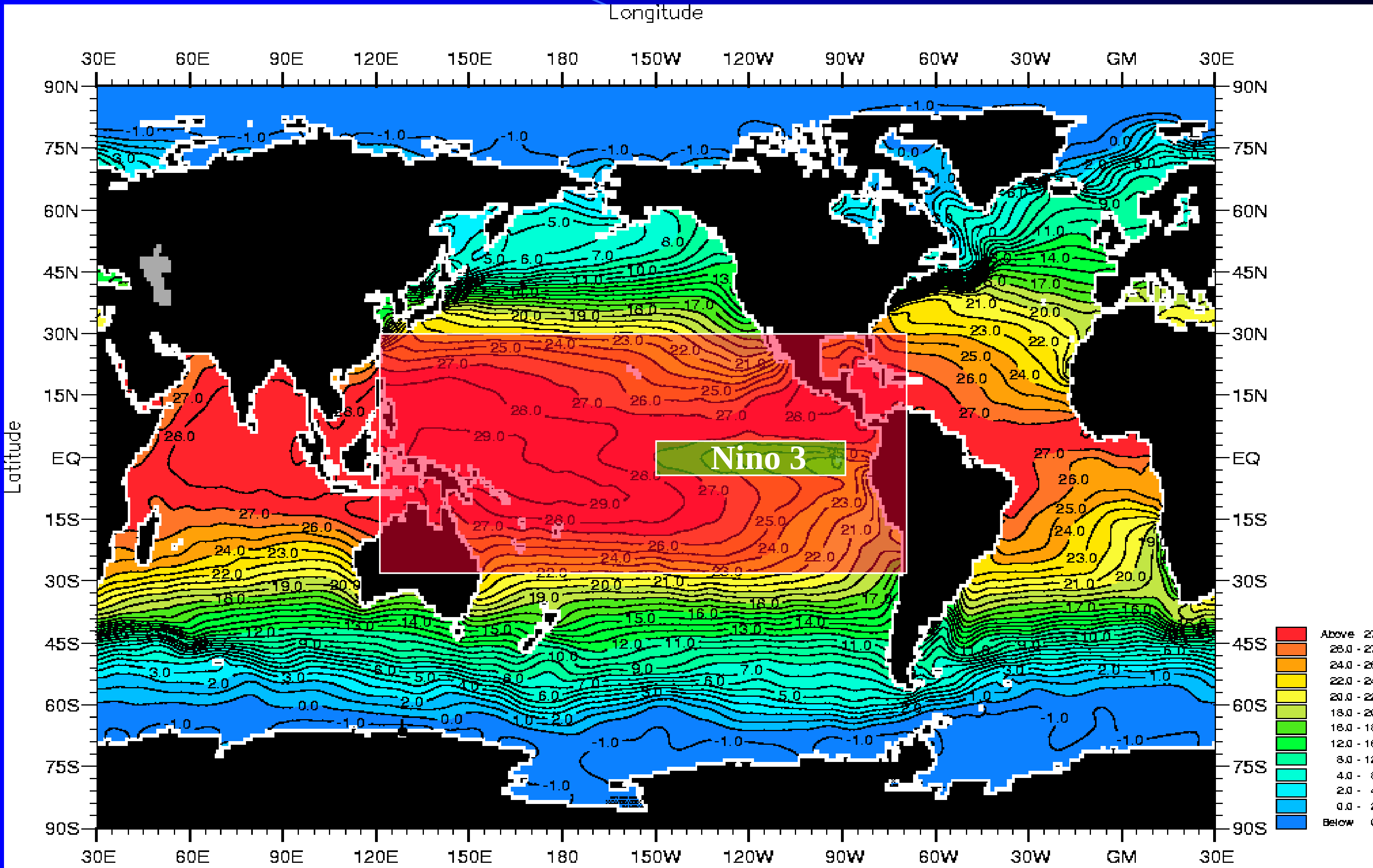
- **Tropical Pacific Ocean General Circulation Model**

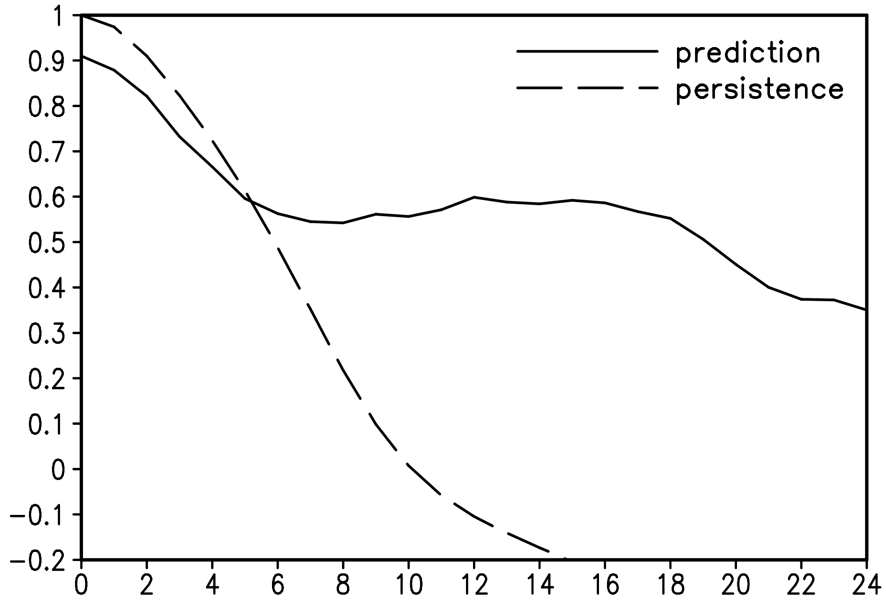
  Region: 120^oE - 70^oW, 30^oS - 30^oN

  Horizontal Resolution: 1^o x 2^o

  Vertical: Unequal 14 Layers from Surface to 4000m Depth

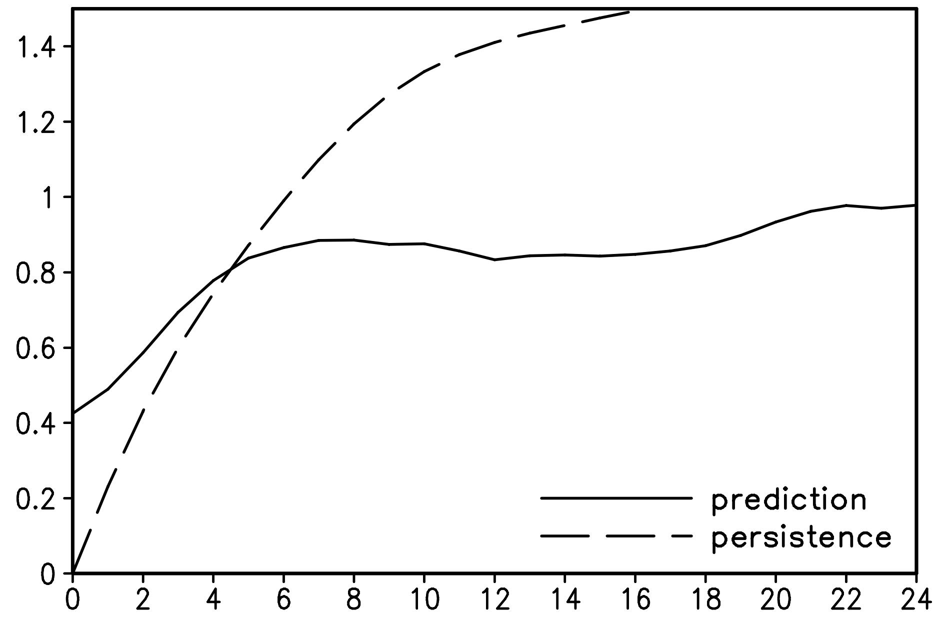
  9 Layers in the Upper 240m


Longitude
30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W GM 30E
90N 75N 60N 45N 30N 15N EQ 15S 30S 45S 60S 75S 90S
Latitude
Nino 3
Above 27.0
26.0 - 27.0
24.0 - 26.0
22.0 - 24.0
20.0 - 22.0
18.0 - 20.0
16.0 - 18.0
12.0 - 16.0
8.0 - 12.0
4.0 - 8.0
2.0 - 4.0
0.0 - 2.0
Below 0.0



Corr. Coef. Between Forecasts (Model and Persistence) and Observation for Nino3 SSTA

RMS Error (^oC) in Nino 3



Integration Scheme

Two-tired Integration:

Step I: Predict the SSTA by a coupled A-O GCM (IAP TOGA-I)

Step II: Integrate the AGCM with different atmospheric initial conditions (ensemble prediction)

Anomaly Coupling technique

- Over Tropical Pacific Region, SSTA used in IAP DCP is the linear combination of Observed initial month SSTA and forecasted SSTA by IAP ENSO prediction system

$$(SSTA)^t=\alpha(t)*[(SSTA)_{to}]+[1-\alpha(t)][K*(SSTA)_{Fcst}]^t$$

Here, n=1,…12, Corresponding to Jan. ~ Dec.

- Over other regions, SSTA is kept as the observed SSTA in initial month.

Ensemble Prediction technique

- Traditional small perturbation method is not suitable for the climate prediction, because climate prediction is far away from the limit of “initial predictability” due to the large uncertainties of current generation climate model.
- The difference in initial conditions should be large enough, so we take initial atmospheric conditions from different days.

Original Correction Method(CM_OLD)

The correction method used in IAP DCP is the so-called "percentage anomaly correction" (Hereafter referred to as "CM_OLD"), which can be expressed as:

$$a' = a + \varepsilon$$

where *a* and *a'* are the uncorrected and corrected prediction of percentage anomaly, respectively, ε is the ensemble mean model bias averaged over the whole hindcast period . If *b* is the observed percentage anomaly, then

$$\varepsilon = \langle b - a \rangle_h$$

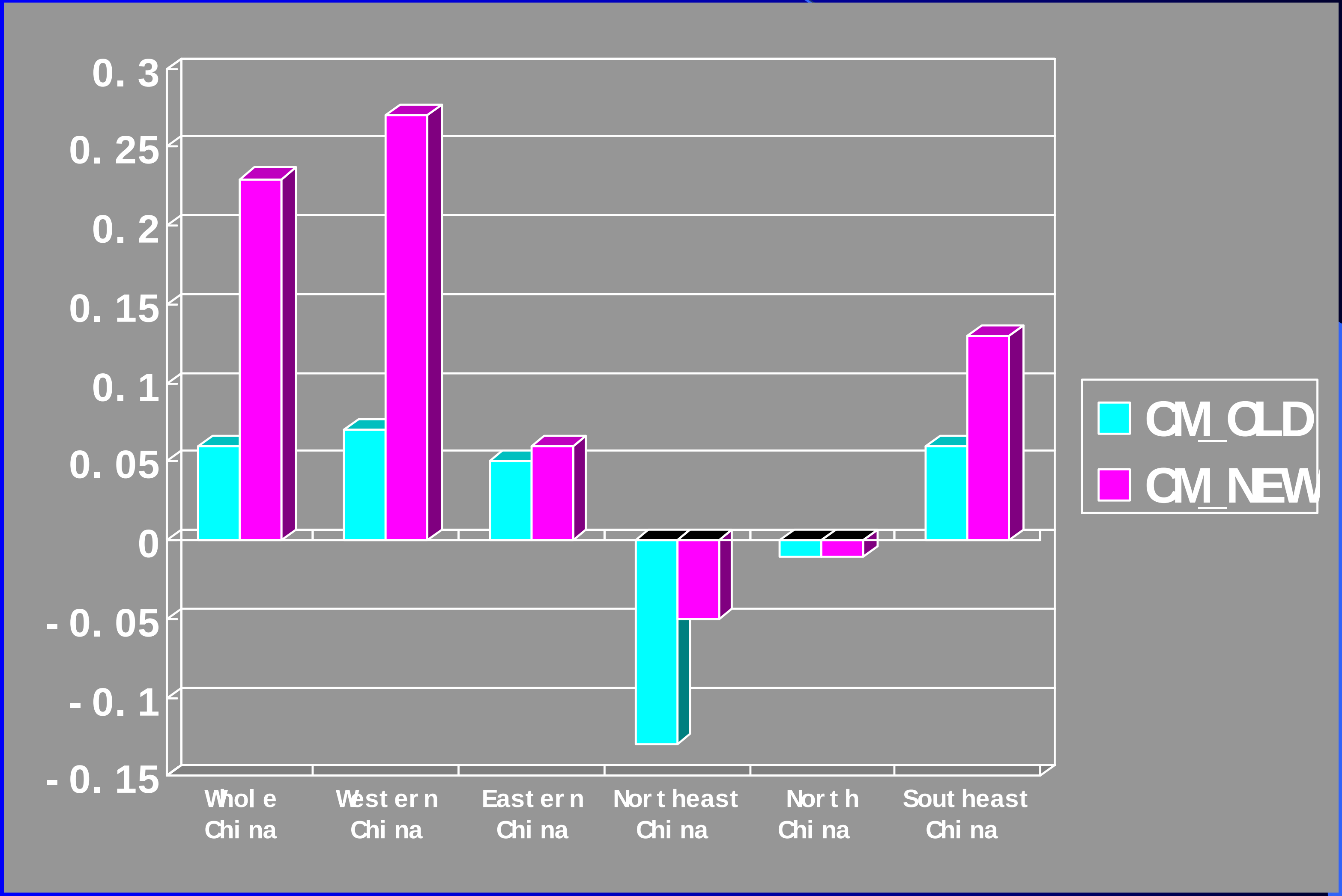
Here, $\langle \cdot \rangle$ means average over the whole hindcast period h corresponds to a sample set of hindcast experiments, here is the hindcast period 1980-2000

New Correction Method (CM_ENSO)

For the New correction method , compare the model systematic errors for three different categories of SST anomalies according to the ENSO cycle

$$\varepsilon_i = \langle b - a \rangle_{h_i} \begin{bmatrix} i = 1, & El\ ni\tilde{n}o\ year \\ i = 2, & La\ ni\tilde{n}a\ year \\ i = 3, & Normal\ year \end{bmatrix}$$

21-year averaged Anomaly Correlation Coefficient (*ACC*) for the predicted and observed percentage rainfall anomalies over China for IAP DCP with “CM_OLD” and “CM_ENSO” correction method respectively.



EOF-based correction method

- Expanding simulated and observed anomalies into a linear combination of EOFs

$$O(x,t) = \sum_n \widetilde{O}_n(t)\phi_n(x)$$

$$F_i(x,T) = \sum_n \widetilde{F}_{i,n}(T) \cdot \varphi_{i,n}(x)$$

- Use multiple linear regression to adjust simulation

$$\widetilde{O}(t) = \sum_n \alpha_{i,n}\widetilde{F}_{i,n}(t) + \varepsilon_{i,n}(t) .$$

$$\widetilde{F}_i^{reg}(T) = \sum_n \alpha_{i,n}\widetilde{F}_{i,n}(T) .$$

$$F_i^{syn}(x,T) = \sum_n \widetilde{F}_{i,n}^{reg}(T) \cdot \phi_n(x)$$

Yun 2004 , Multi-model synthetic superensemble algorithm for seasonal climate prediction using DEMETER forecasts, Tellus

SVD-based correction method

- Use SVD analysis, expanding simulated and observed anomalies into a sequences of coupled modes

$$\mathbf{z}_{\text{sim}}(t) \approx \sum_j u_j(t)\mathbf{g}_j,$$

$$\mathbf{z}_{\text{obs}}(t) \approx \sum_j v_j(t)\mathbf{h}_j,$$

- Use linear regression to adjust simulation

$$v_j = \alpha + \beta u_j + \varepsilon$$

$$u'_j = \alpha + \beta u_j$$

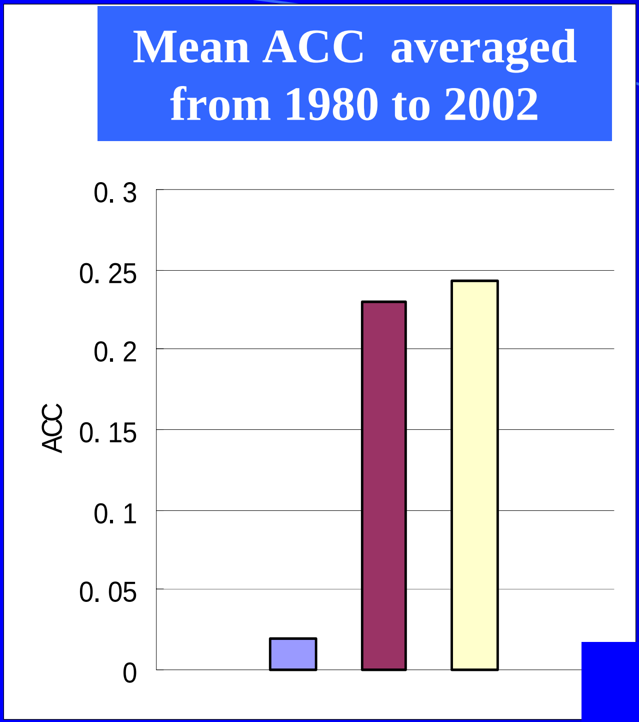
$$z_{sim}' = \sum_j u'_j(t) h_j$$

$$\hat{z}_{sim}'_{(T+1)} = z_{sim}'_{(T+1)} + c(z_{sim\,(T+1)} - z_{sim}'\text{£¨}T+1))$$

$$c = \frac{COV\,(Z_{obs}, (z_{sim} - z_{sim}'))}{VAR\,(z_{sim} - z_{sim}')}$$

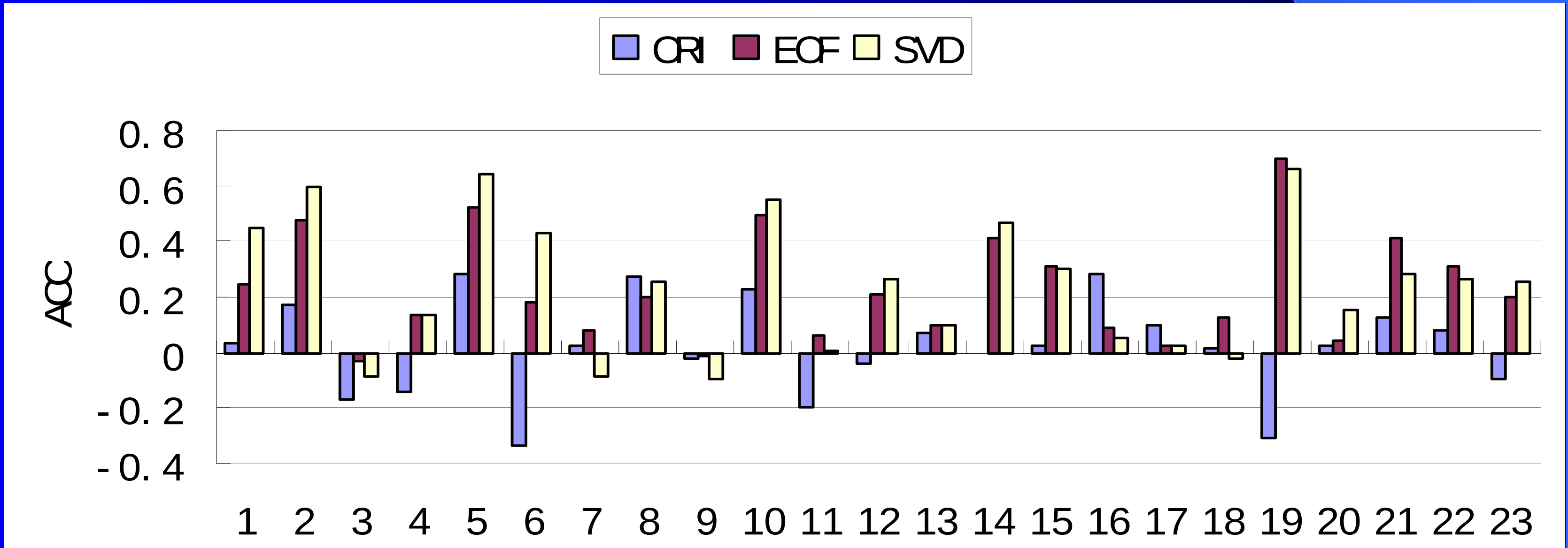
Feddersen 1999 , Reduction of Model Systematic Error by Statistical Correction for Dynamical Seasonal Predictions, J. Climate.

Kharin (2001), skill as a function of time scale in ensembles of seasonal hindcasts, climate Dynamics, 17, 127-141.



The EOF and SVD-based correction methods do have a clear positive impact on skill for summer rainfall anomaly averaged over the whole China

ACC before and after EOF- and SVD-based correction for summer rainfall anomalies over China from 1980 to 2002



Prediction Products (I)

For the ensemble prediction, we have three category of prediction products:

- **Ensemble mean:**

$$< F > = \sum_{i=1}^{n} \gamma_i F_{(i)}$$

- **Standard Deviation:**

$$D^2 = \sum_{i=1}^{n} \gamma_i' \left[F_i' - < F >_{final} \right]^2$$

Prediction Products (II)

Probability Distribution

$$P(F \in F^{(k)}) = \frac{1}{n} N^{(k)}$$

Where:

$F^{(k)}$ is K^{th} regime, for example $F^{(0)}$ indicates positive anomaly of predicted variable F;

$N^{(k)}$ is the number of individual predictions with F_i' $F^{(k)}$, which depends on geographical distribution;

γ_i' , γ_i : impirical probability coefficients

n : total number of ensemble members, for IAP DCP, n=28

Design of Hindcast Experiment

A series of hindcast experiments has been performed by using two versions of IAP AGCM:

1. **IAP AGCM-1.3 □2L, 2°x 2.5°□**
2. **IAP AGCM-2.0 □9L, 4°x 5°□**

Design of Hindcast Experiment

(IAP AGCM1.3)

Climate Model	**IAP AGCM1.3**
Sea surface temperature	$(SST)_c+(SSTA)_{obs}$
Atmospheric initial conditions	Wind, geopotential height, relative humidity are taken from NCEP real-time analysis, and then interpolated into the model grid-point with 2°×2.5° horizontal resolution.
Hindcast period	21 years (1980-2000)
Ensemble Size	Number of days of staring Month for each ensemble (e.g. 31 for January, 28 for February ……) respectively
Duration of integration	1 year (for each ensemble member) Total Integration year: 365x21=7665 yrs
Verification data	Observed rainfall data from 160 stations in China during 1980-2000; NCEP reanalysis data with 2.5x2.5 resolution.

Verification of climate prediction

- **correlation analysis**

Correlation Coefficient:

$$\frac{\sum_{i=1}^{N}(\Delta R_{f,i}-\overline{\Delta R_{f,i}})\times(\Delta R_{o,i}-\overline{\Delta R_{o,i}})}{\sqrt{\sum_{i=1}^{N}(\Delta R_{f,i}-\overline{\Delta R_{f,i}})^{2}\times\sum_{i=1}^{N}(\Delta R_{o,i}-\overline{\Delta R_{o,i}})^{2}}}$$

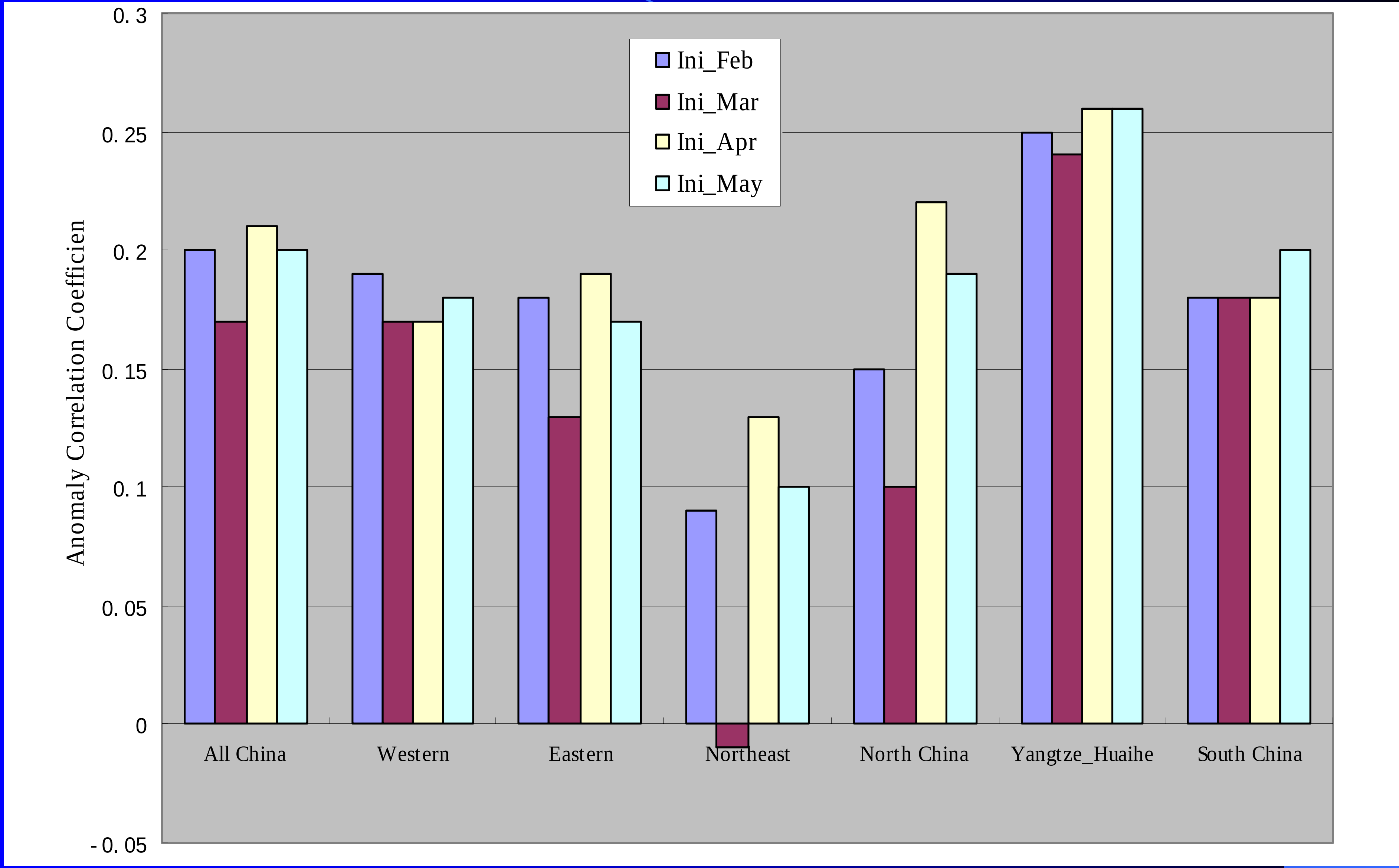
Anomaly correlation coefficient (ACC); Temporal correlations

N: Total number of stations (years) used for evaluation.

$R_{f,i}$ and $R_{f,i}$ are predicted anomaly percentage and long-term mean at the ith station(year), respectively.

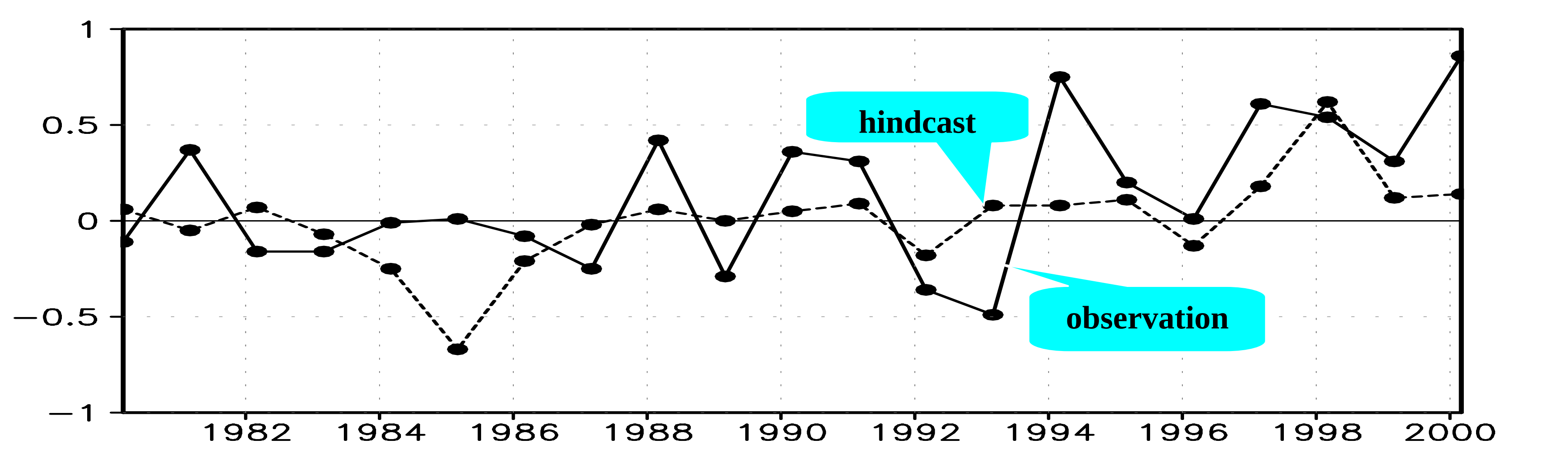
$R_{o,i}$ and $R_{o,i}$ are respective observed anomaly percentage.

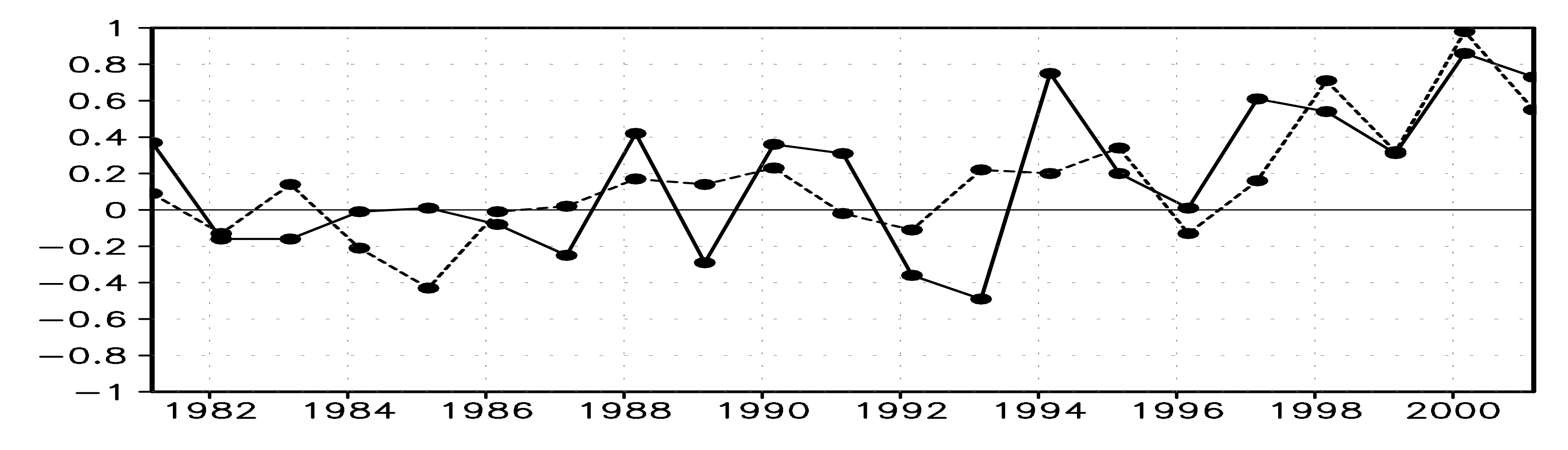
Comparison of ACC for JJA precipitation between observation and prediction by IAP DCP initiated from Feb., Mar., April and may respectively



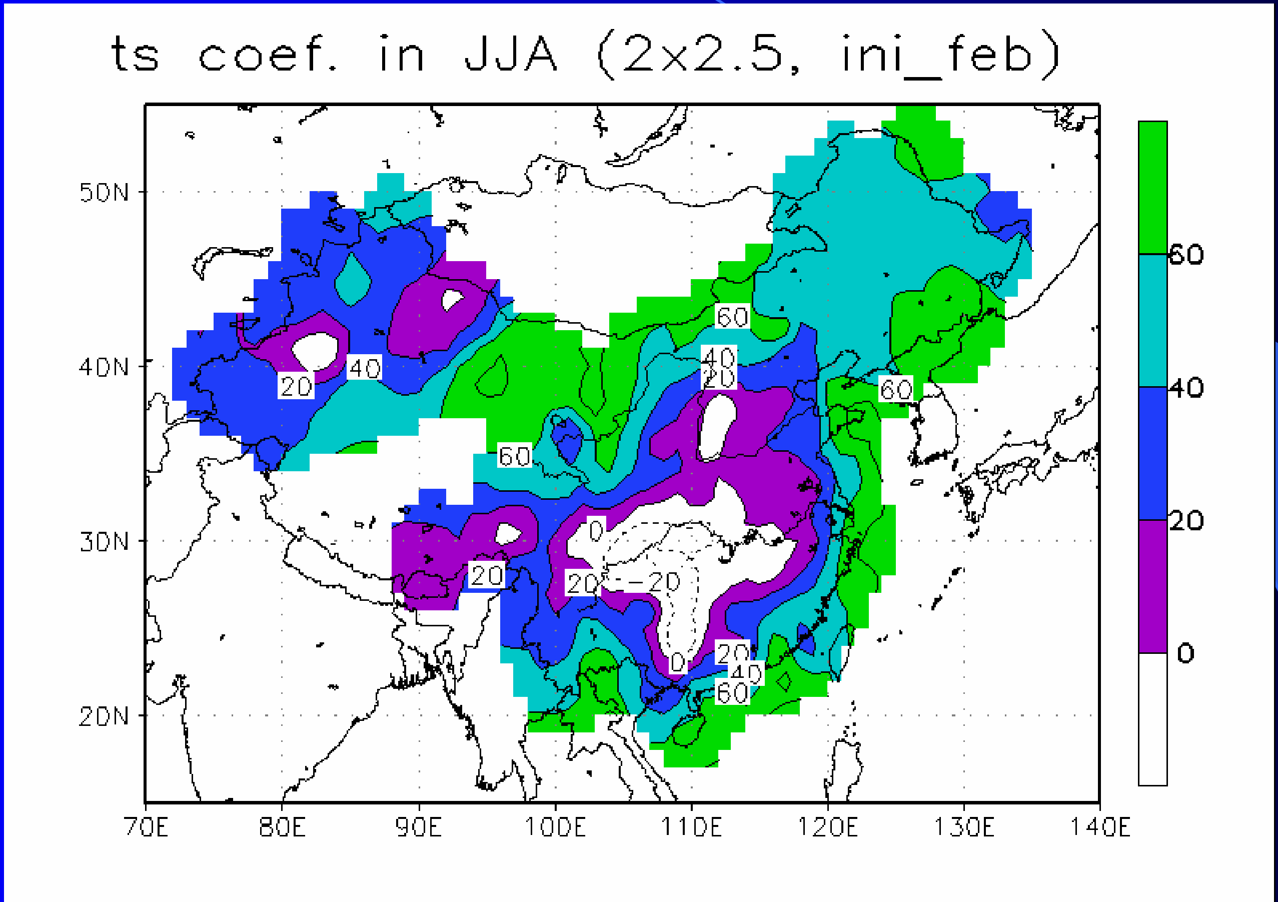
Observed(solid) and Hindcast(dashed) summer temperature anomalies over China

Upper: Initiated from Feb.; Lower: Initiated from preceding October

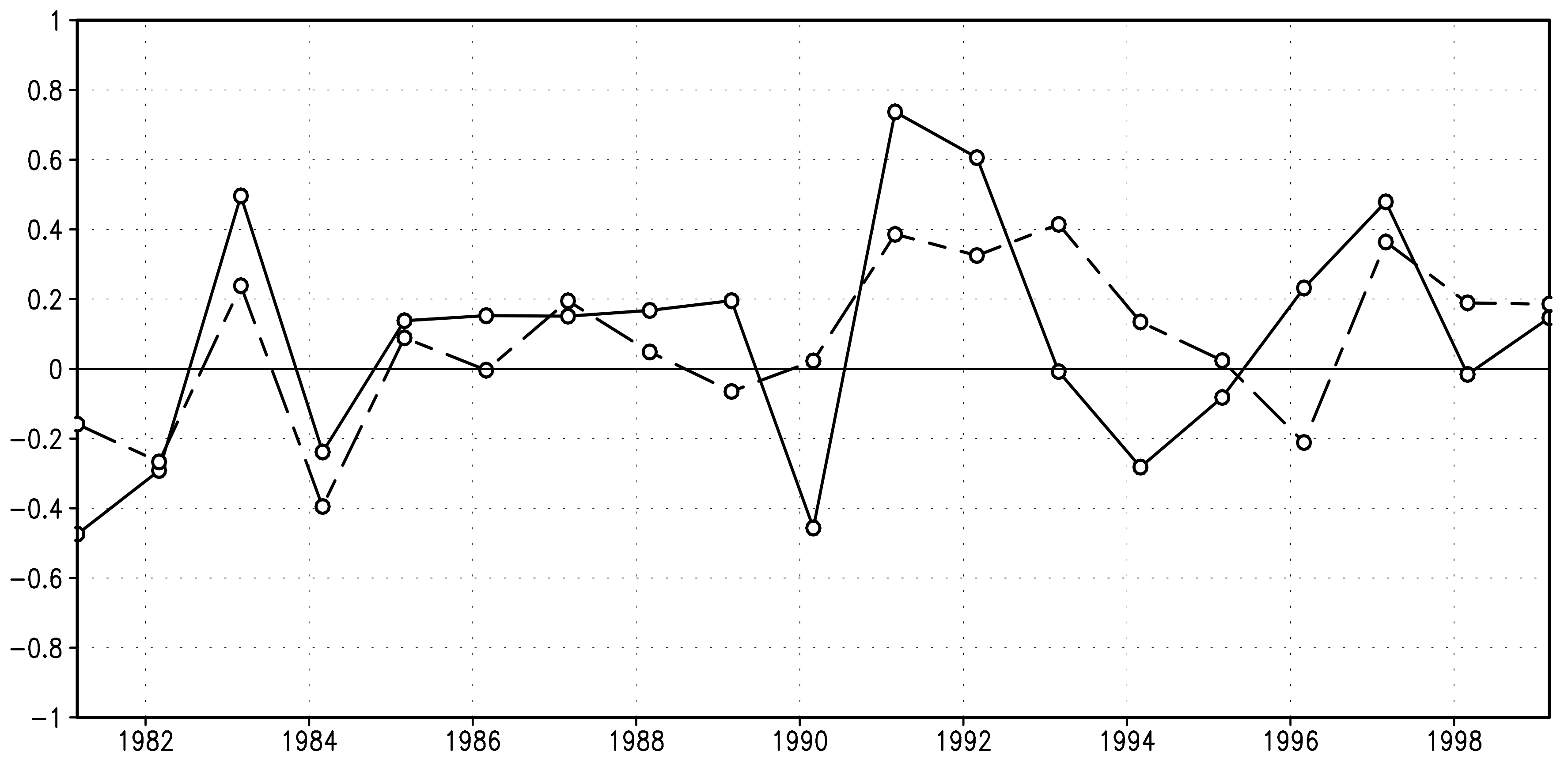




Temporal correlations for JJA temperature between observation and hindcast results (initiated from Feb) by IAP DCP.

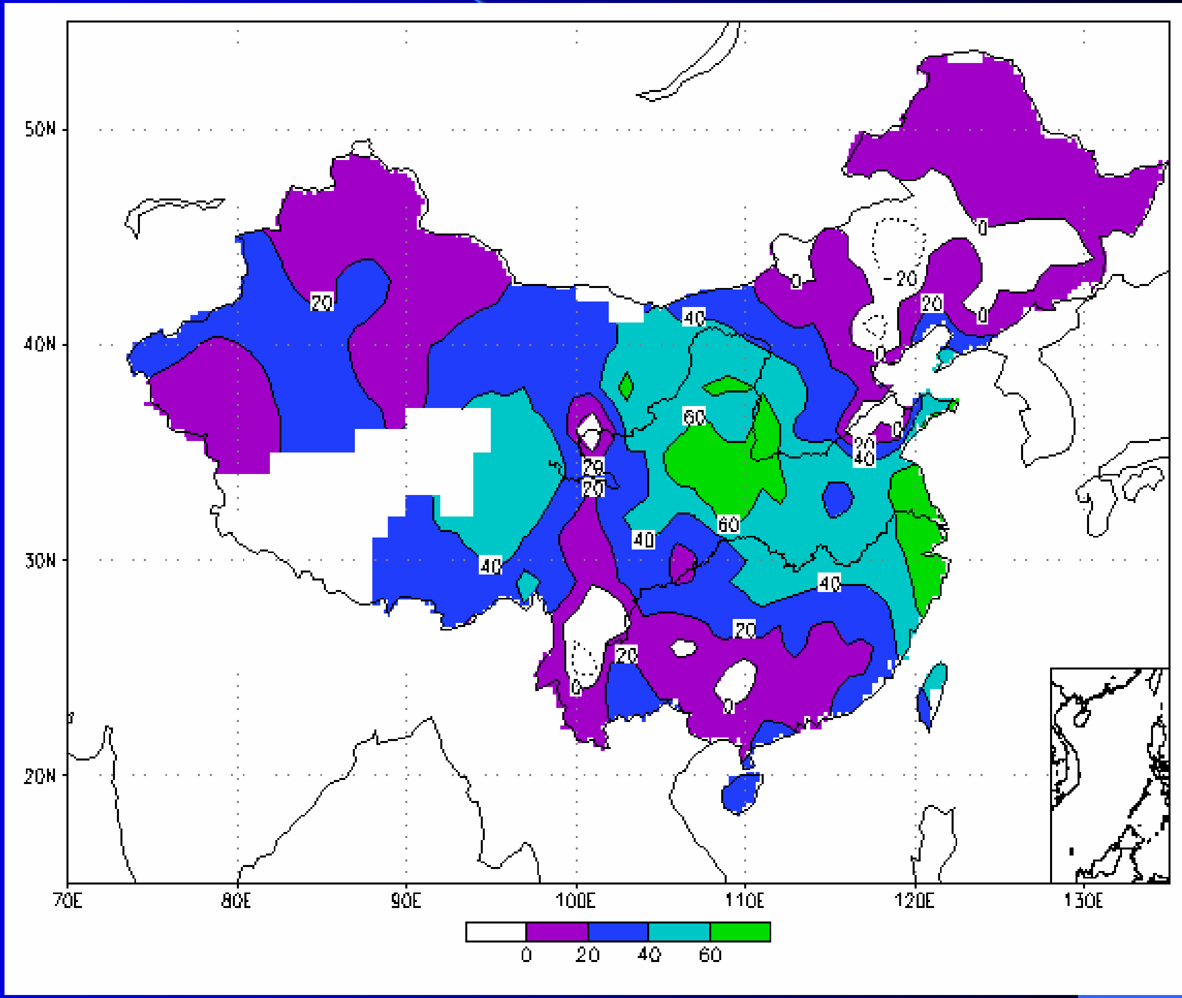


Inter-annual variation of the Anomaly correlation coefficient between the NCEP reanalysis and ensemble hindcast experiments for spring surface wind field averaged over China (Solid line: Zonal wind; Dashed line: Meridional wind)

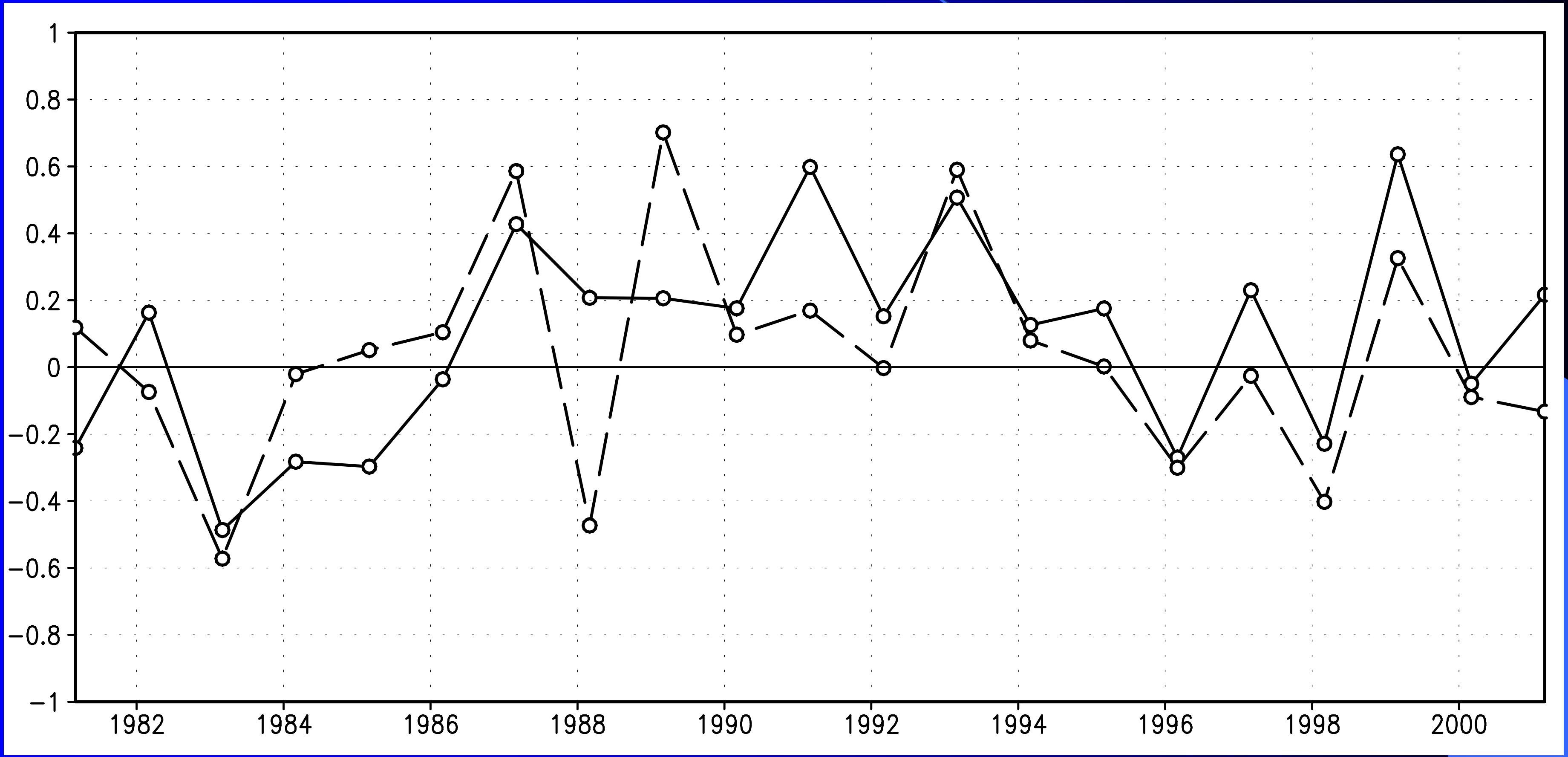


Temporal Correlations for spring surface temperature

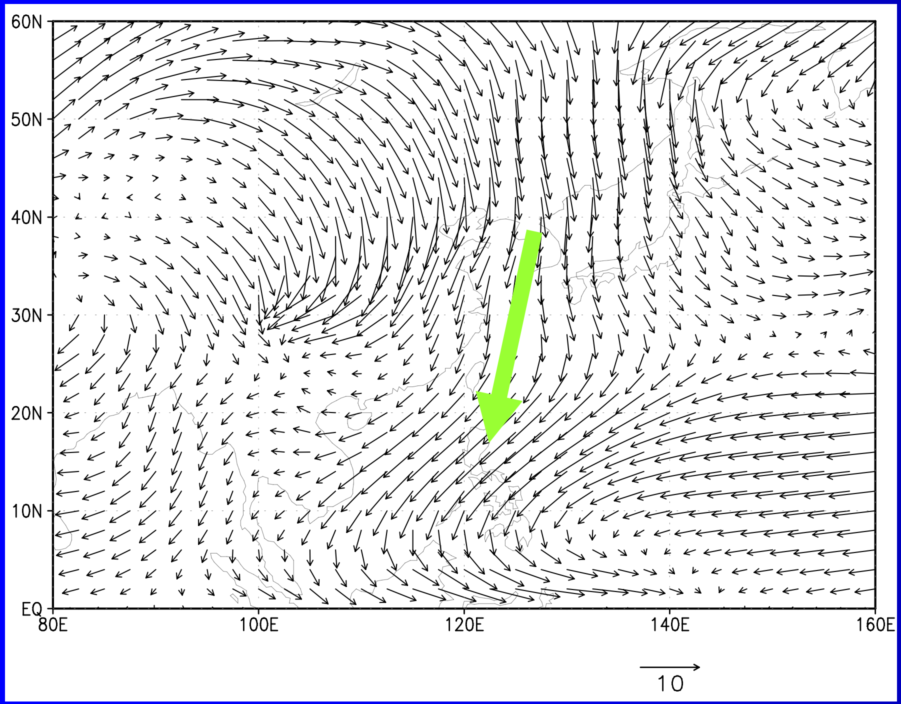
Positive correlations over Most Areas, with high correlation values located in Central part of China. There are 89 stations (out of total 160 stations) with correlations larger than 0.20.



Inter-annual Variation of the ACC for spring precipitation
Solid line: Northwest China□Dashed Line: Northern China

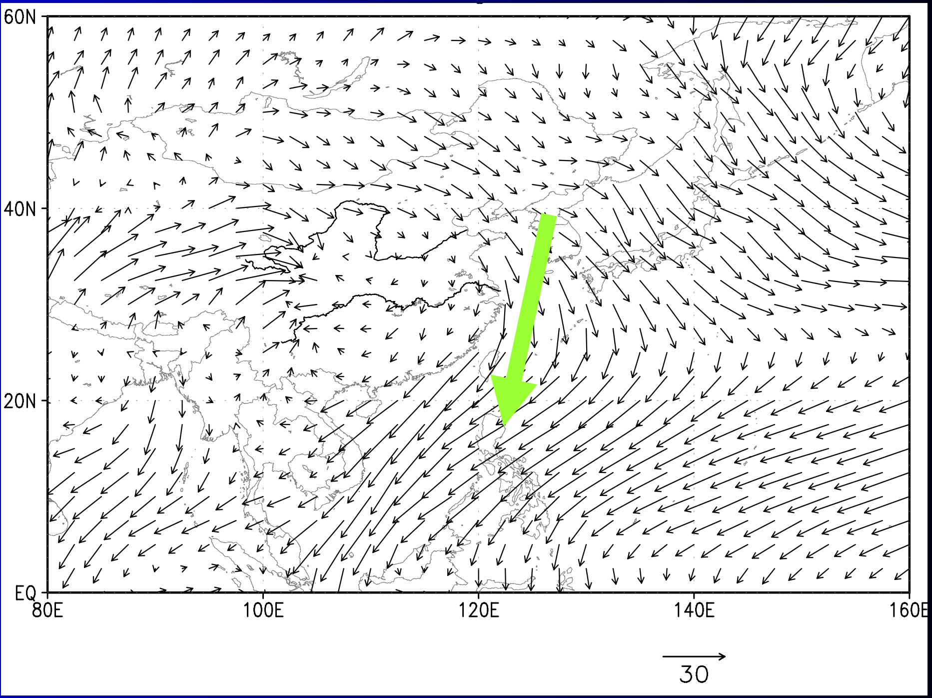


Surface wind climatology for DJF

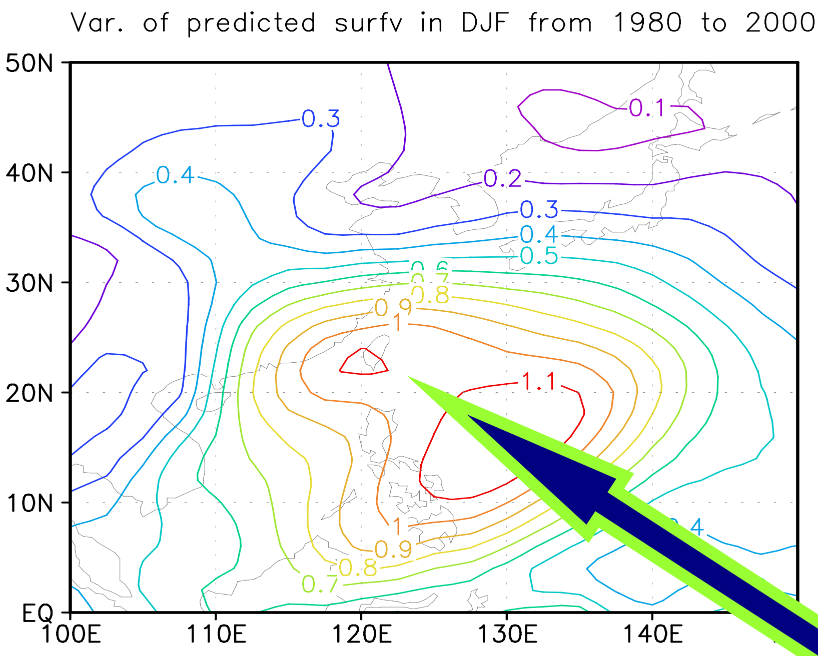


Hindcast Experiment initiated from September (1980-2000)

NCEP Reanalysis (1980-2000)

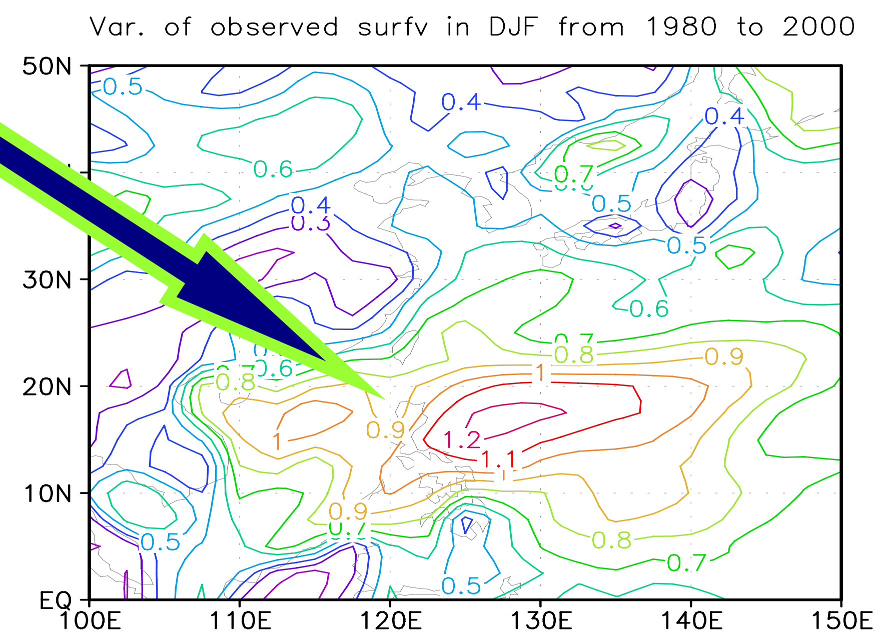


Variability of Meridional wind at surface for DJF



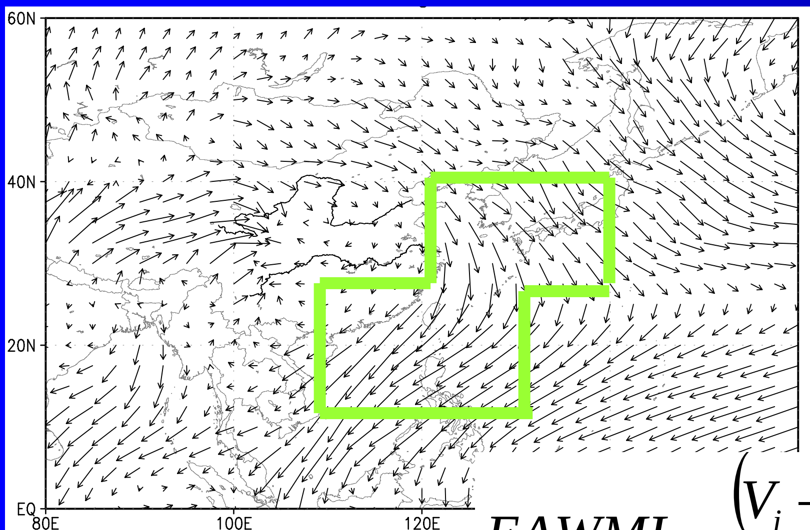
Hindcast Experiment initiated from September (1980-2000)

NCEP Reanalysis (1980-2000)



East Asian Winter Monsoon Index (EAWMI)

- **Averaged v component over the area from the East China Sea to the South China Sea (10-25N, 110-130E) and (25-40N,120-140E)**



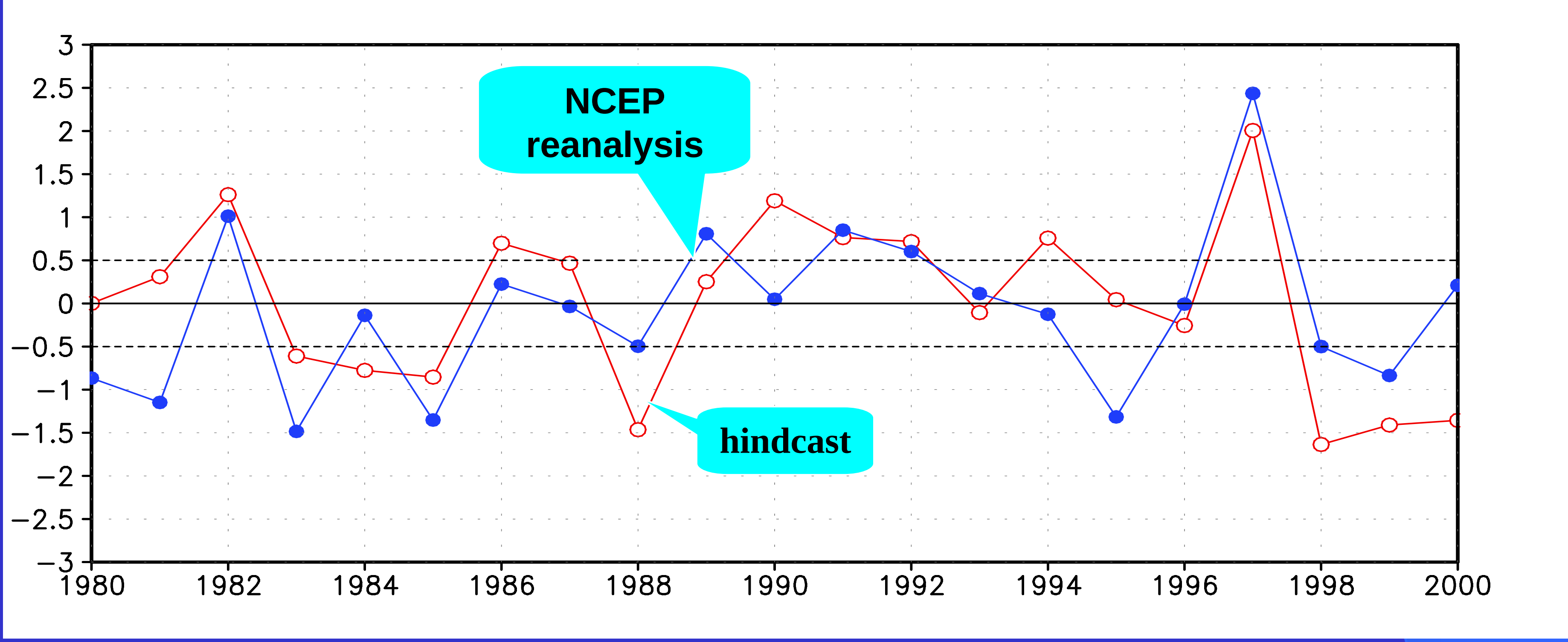
Averaged over December to February for the calculation of EAWMI

$$EAWMI = \frac{\left(V_i - \overline{V}\right)}{\left|\overline{V}\right|}$$

$$EAWMI = \begin{cases} I \geq 0.5 & \text{Weak winter Monsoon} \\ -0.5 \leq I \leq 0.5 & \text{Normal winter Monsoon} \\ I \leq -0.5 & \text{Strong winter Monsoon} \end{cases}$$

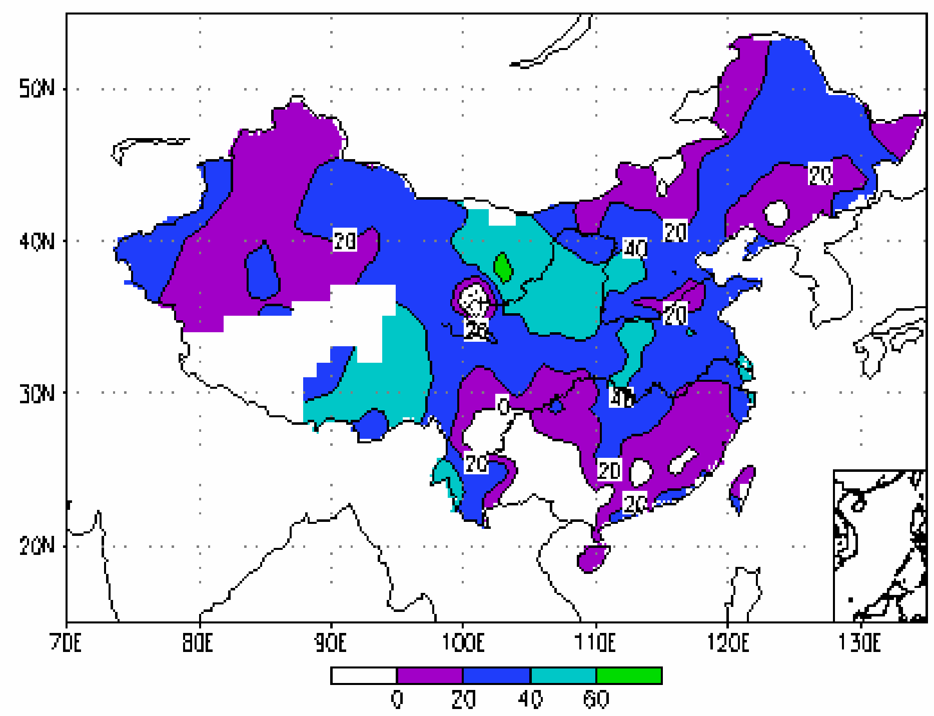
Chen et al., 2000:, AAS, Vol.17., No.1, 48-60.

Interannual Variability of East Asian Winter Monsoon Index
(Chen Wen, 2000)
Red: Hindcast Experiment by IAP AGCM Initiated from September
Bule: NCEP reanalysis;   Correlation: r =0.62

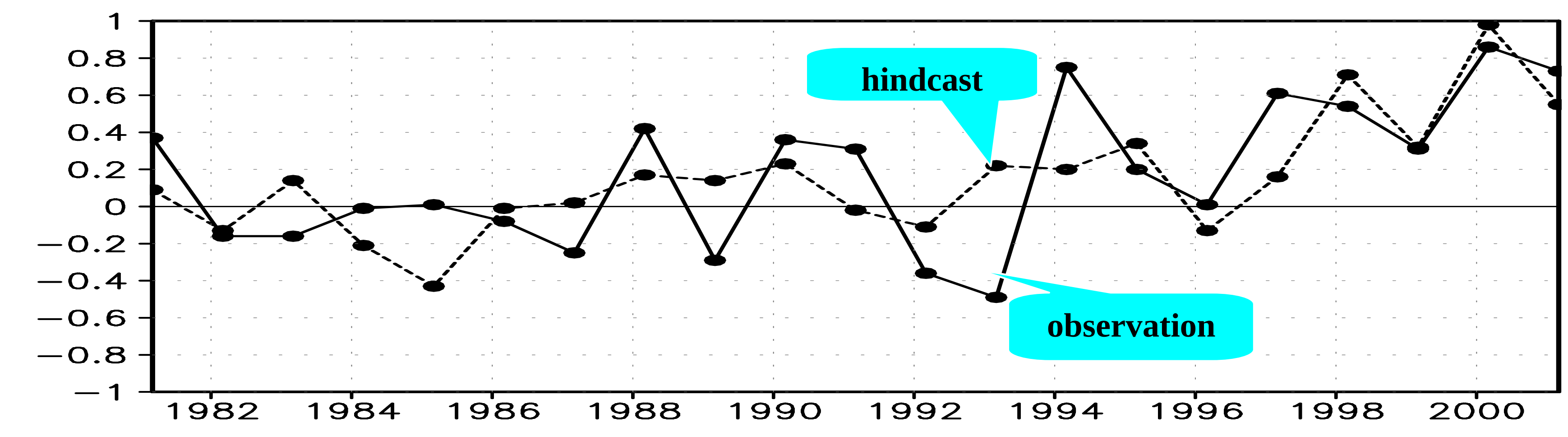


The interannual variation of East Asian Winter Monsoon Index (EAWMI) can be quite well reproduced by the hindcast experiments using IAP DCP.

Temporal Correlations for DJF Temperature between observation and hindcast results

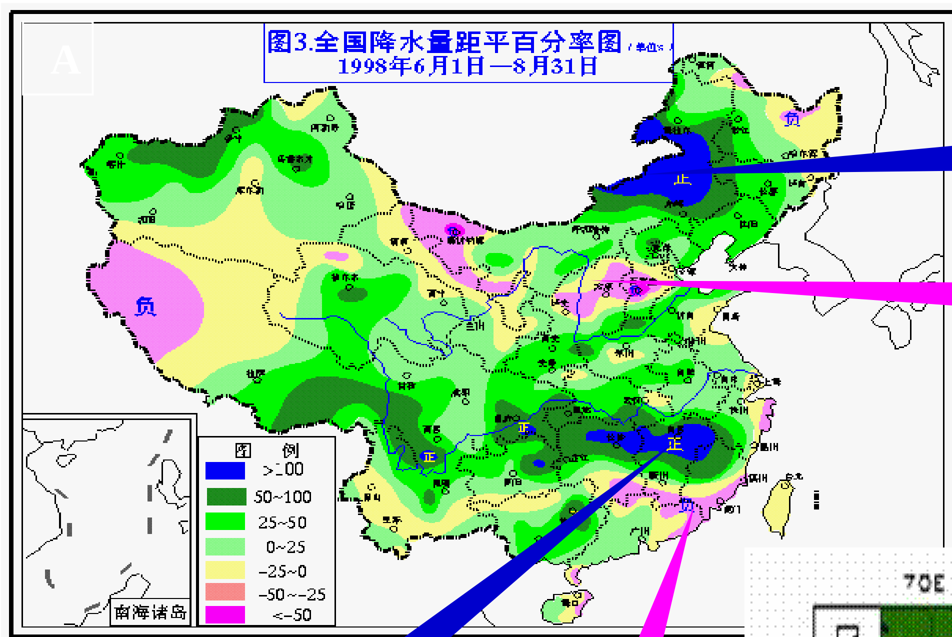


Observed(solid) and Hindcast(dashed) winter temperature anomalies over China



Real-time Predictions and Verifications

Percentage Summer Rainfall Anomaly for 1998

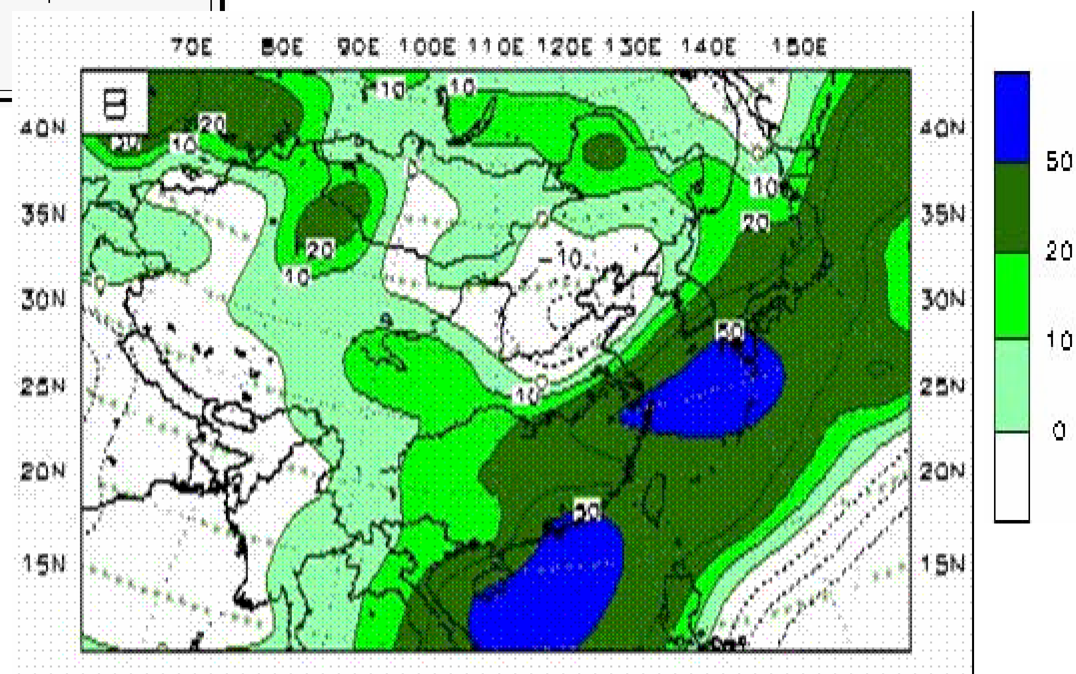


Western Part of Northeast China

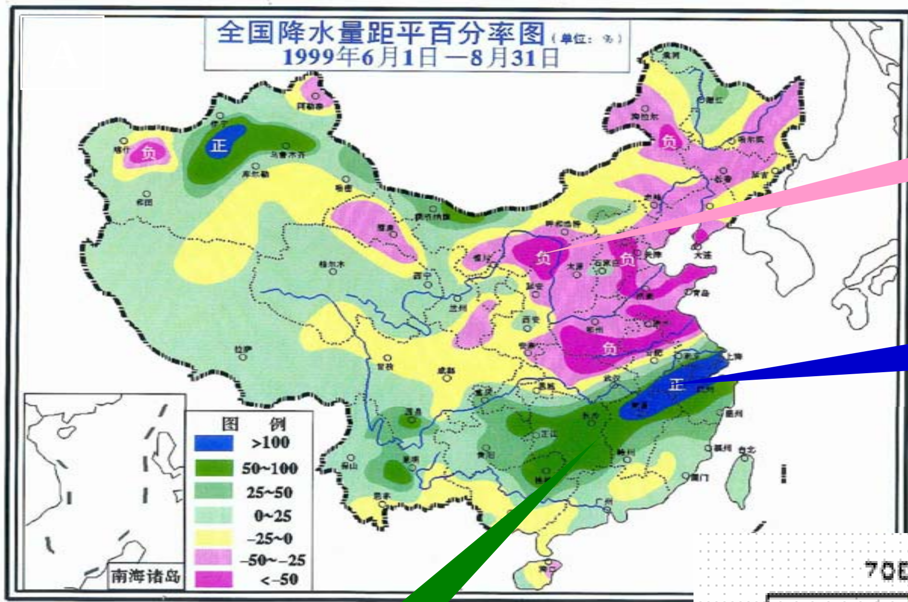
Drought over North China

Severe Flood over Yangtze River Valley

Less than normal in southeastern Coastal Area



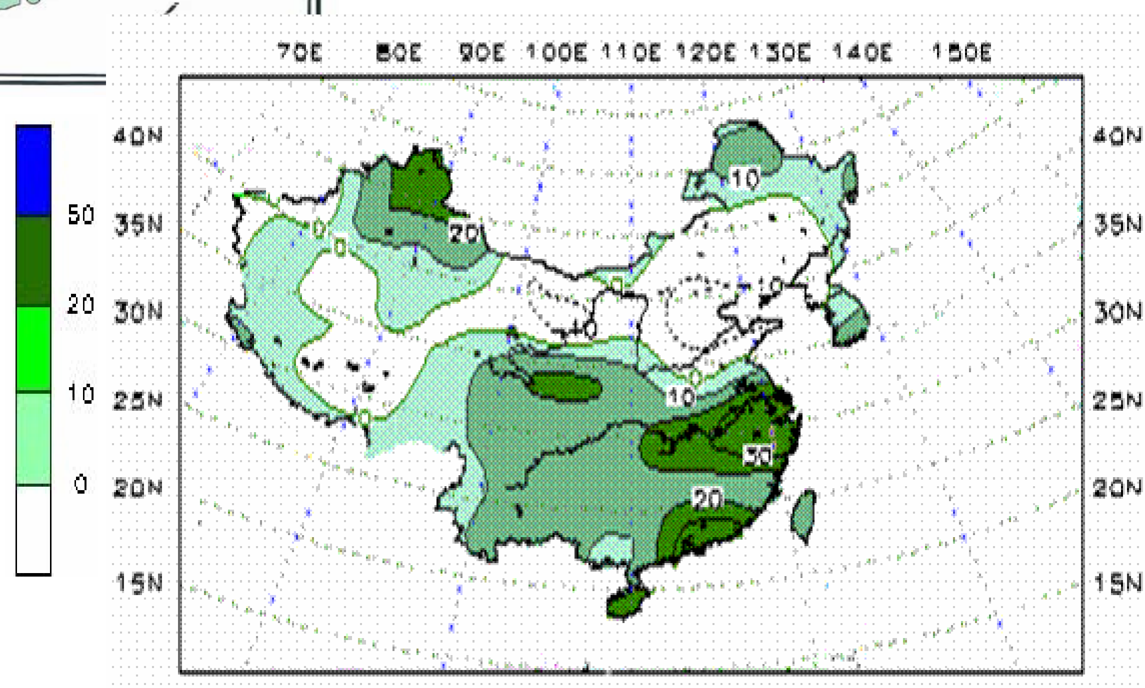
Percentage Summer Rainfall Anomaly for 1999



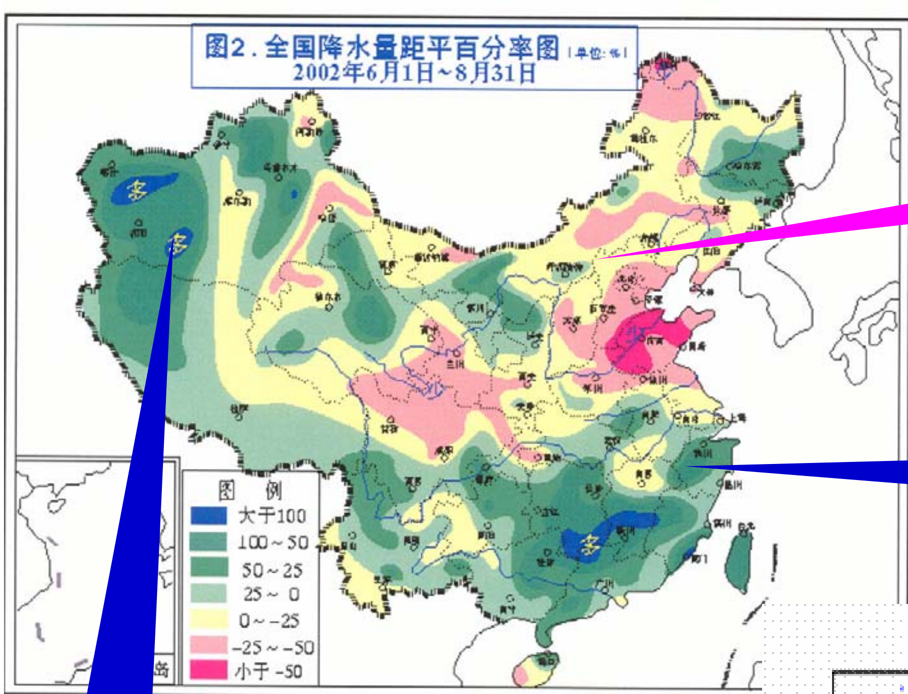
Drought over North China

Flood over Middle and lower reach of Yangtze river valley

Positive Rainfall anomaly over Southern China



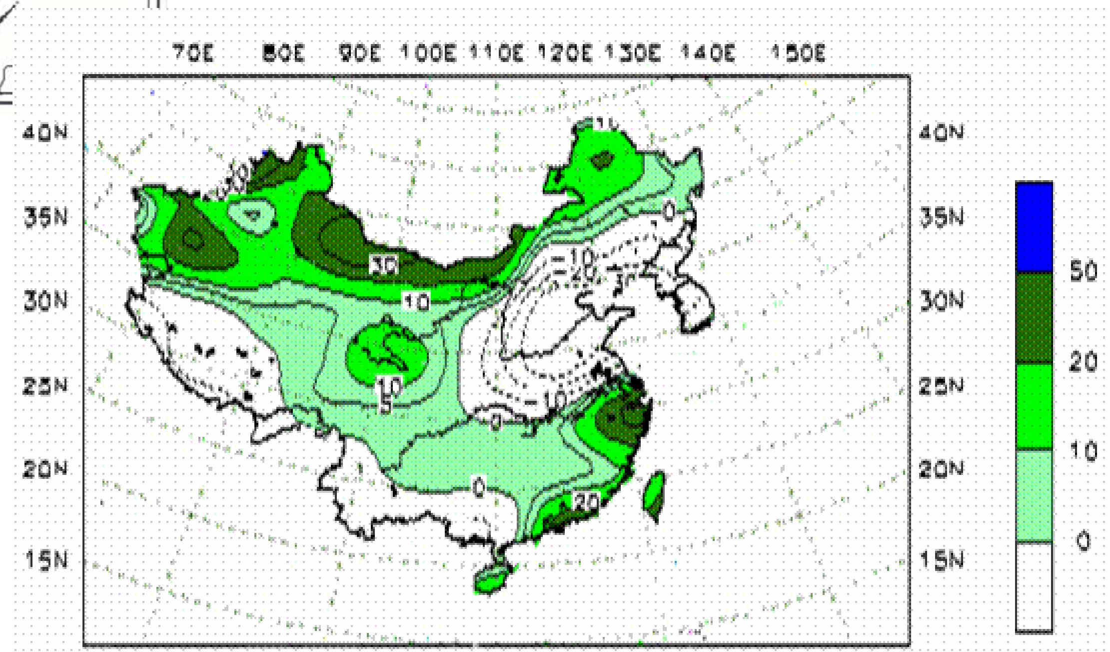
Percentage Summer Rainfall Anomaly for 2002



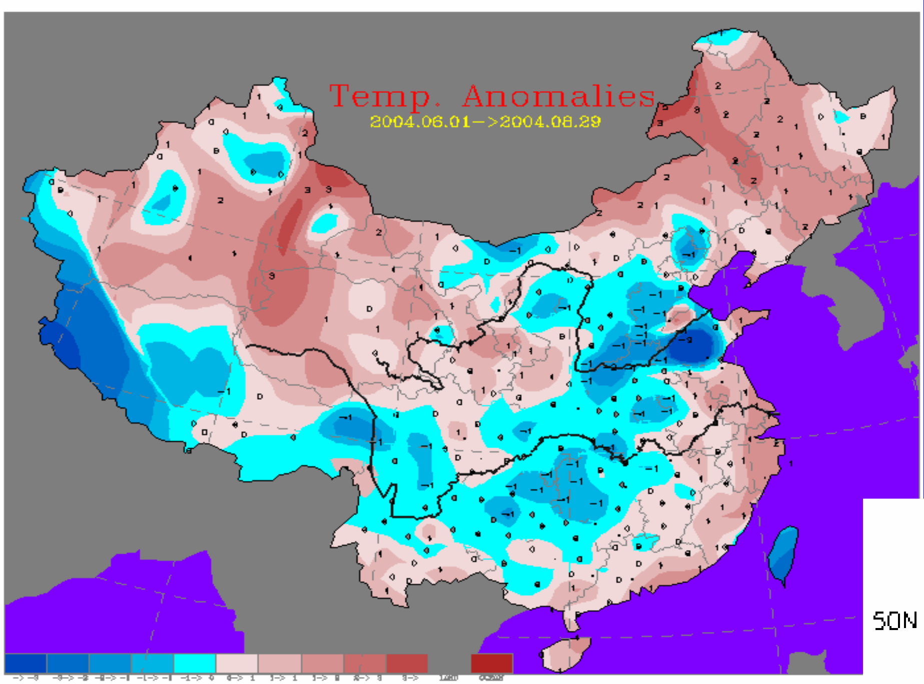
Drought conditions remain over most part of North China

Positive rainfall anomaly over lower reach of Yangtze River

Positive rainfall anomaly over Northwest China



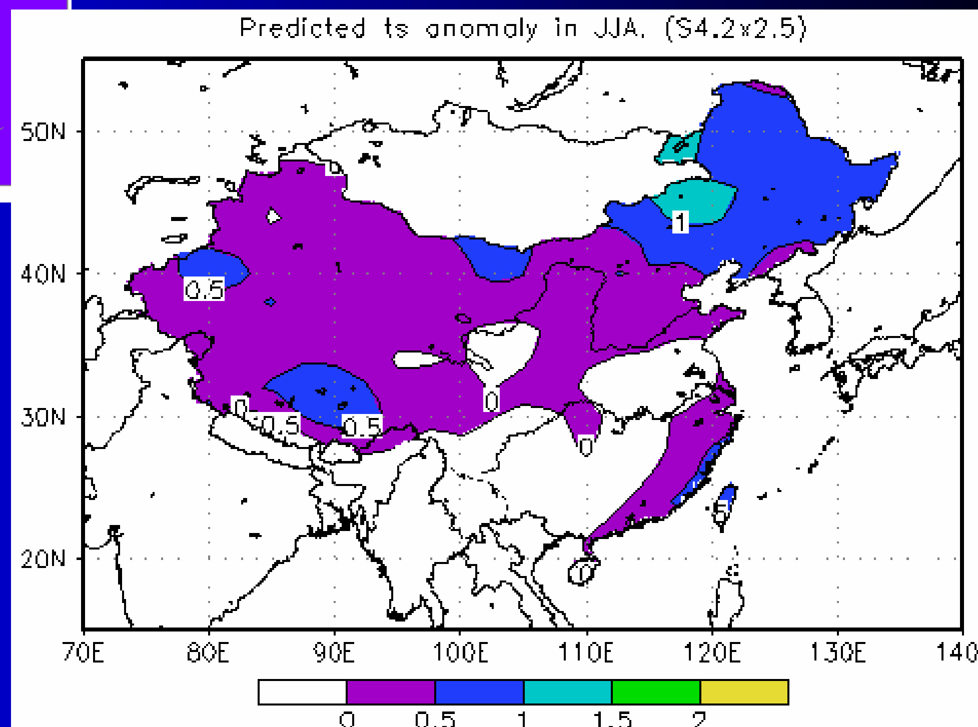
Summer surface air temperature anomaly for 2004



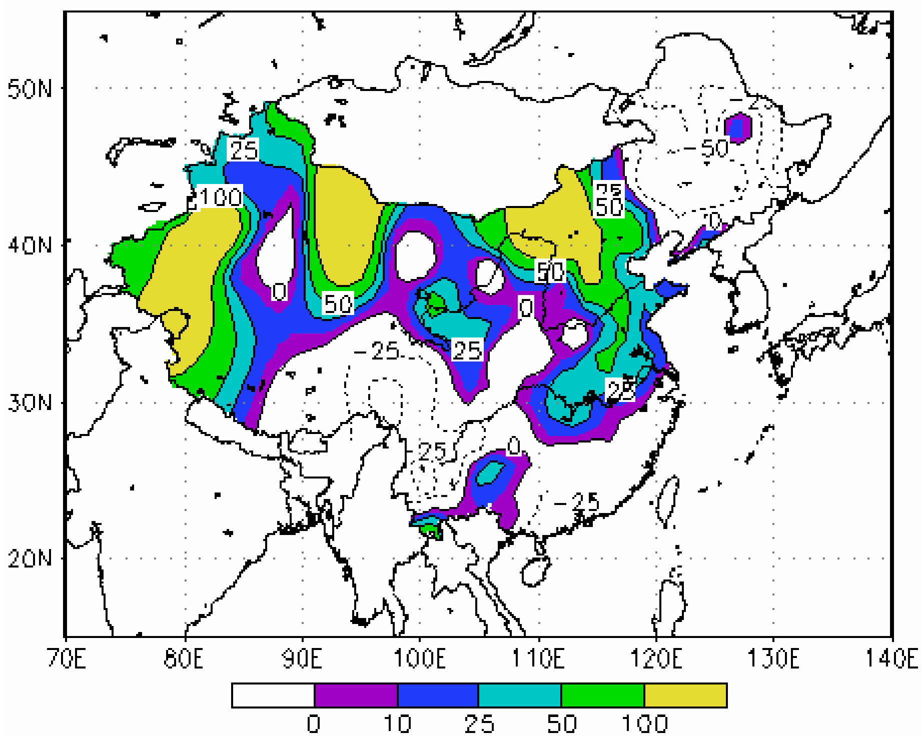
Observation

ACC=0.39

Prediction by IAP DCP

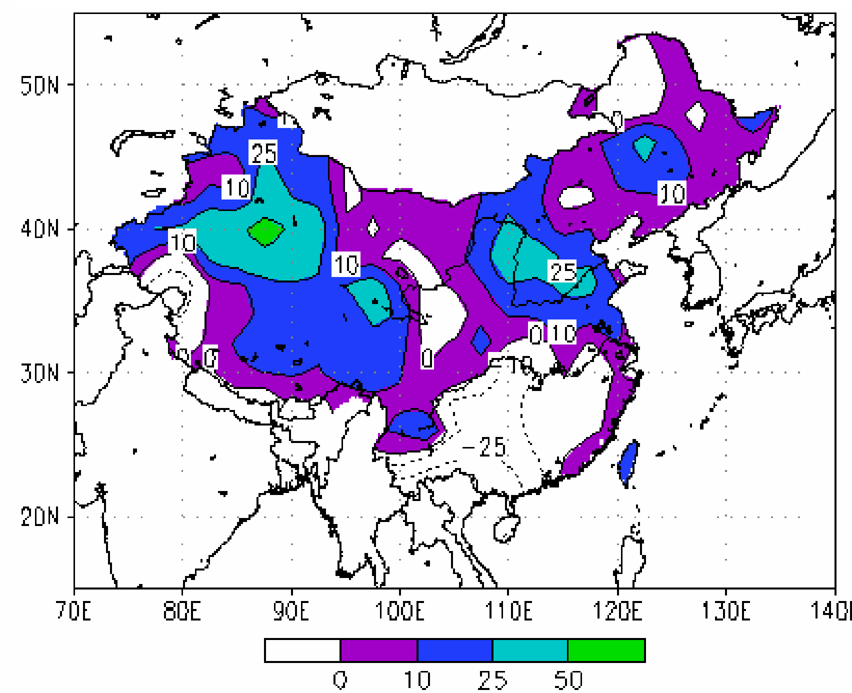


Percentage Spring Rainfall Anomaly for 2003



Observation

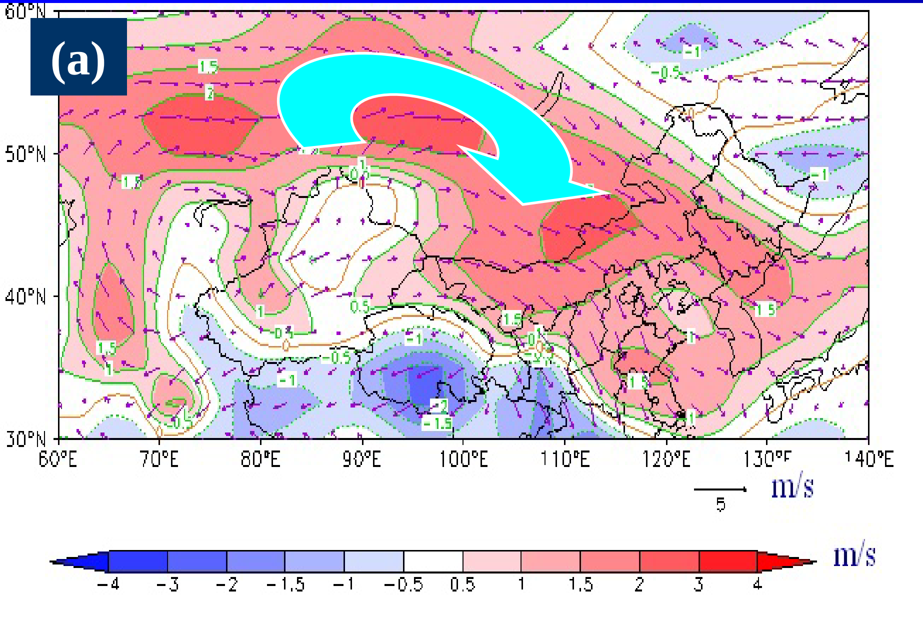
Prediction by IAP DCP

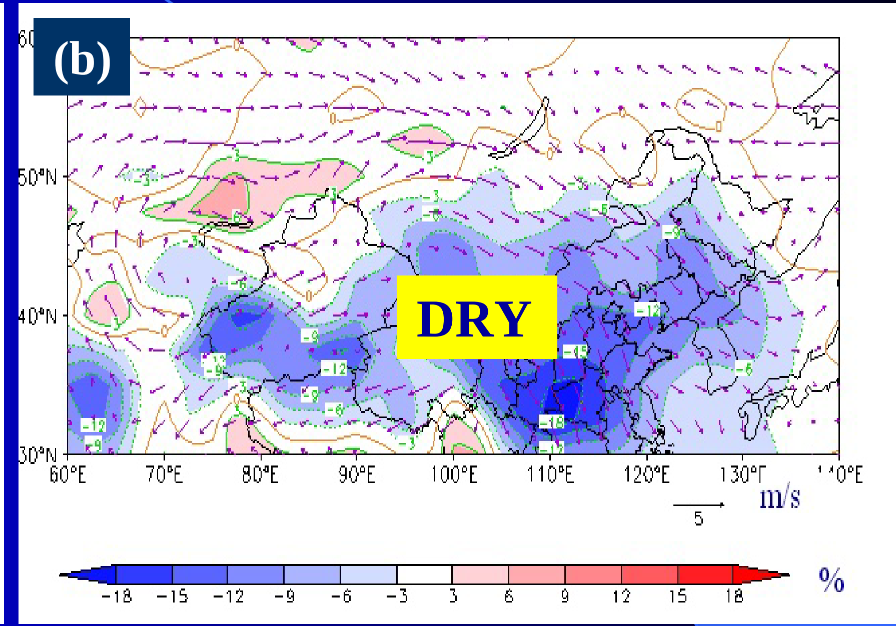


Prediction of the occurrence frequency of dust storm over northwest China

- Through analyzing the NCEP/NCAR reanalysis data, the climatological features related to the spring dust storm activities have been investigated. It's found that the most important factor is the surface wind anomalies over dust source regions and along the dust transportation passage; Meanwhile, the soil moisture anomalies (or surface relative humidity) and surface vegetation cover anomalies may also play roles in the dust storm activities.
- Hindcast results show that, IAP DCP does show certain skill in predicting the anomalies of rainfall, surface wind and temperature over Northern China during Spring time.
- Dynamical prediction of climate condition favorable (or suppressive) for the occurrence frequency of dust storms is encouraging.

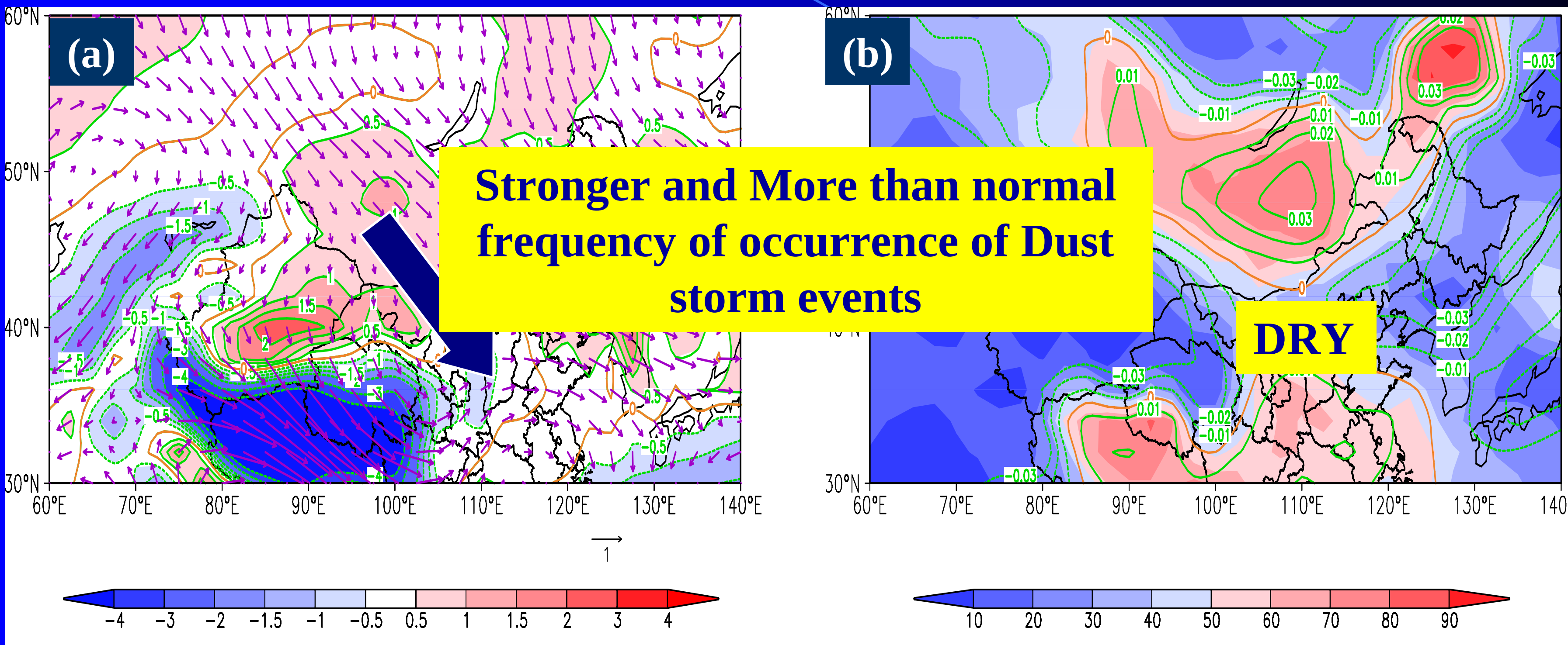
Observed springtime climate anomalies over East Asia (March & April, 2001) Frequent and stronger dust-storm activities)





(a) 850hpa wind anomalies
(b) Anomalies of surface RH (Shaded) and 850hpa wind
Red: positive anomaly,
Blue: negative anomaly.

Prediction by IAP DCP (Mar.& Apr.of 2001)

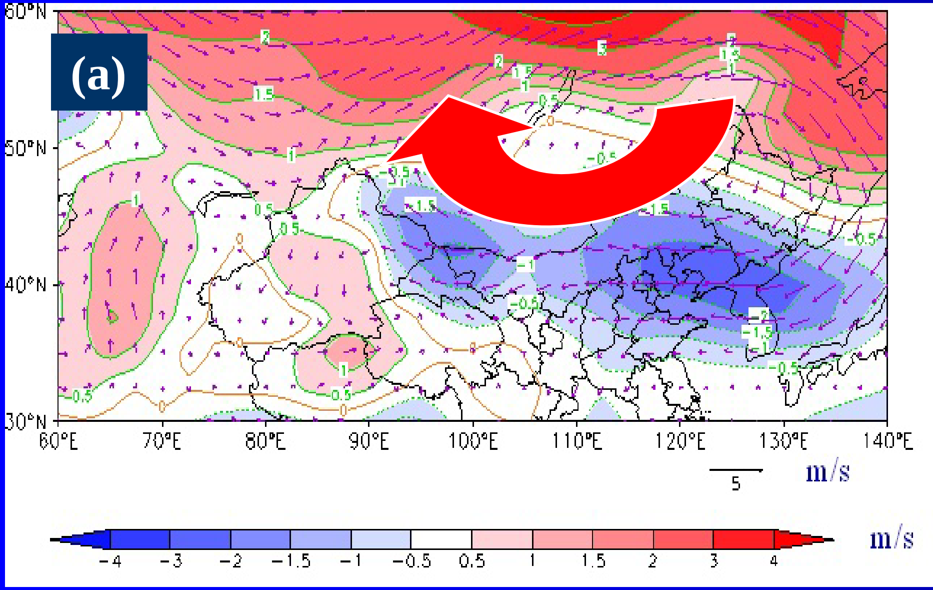


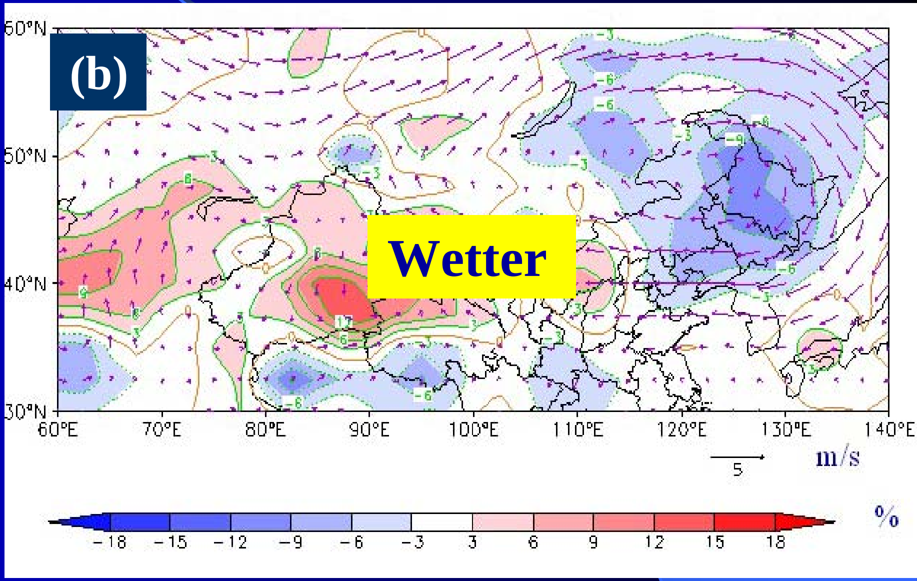
(initiated from Oct. 2000)

(a) 850hpa wind vector and wind speed anomalies (red: positive anomaly, blue: negative anomaly).

(b) Soil wetness anomalies and the probability for positive soil moisture anomalies (red: >50%, blue:<50%)

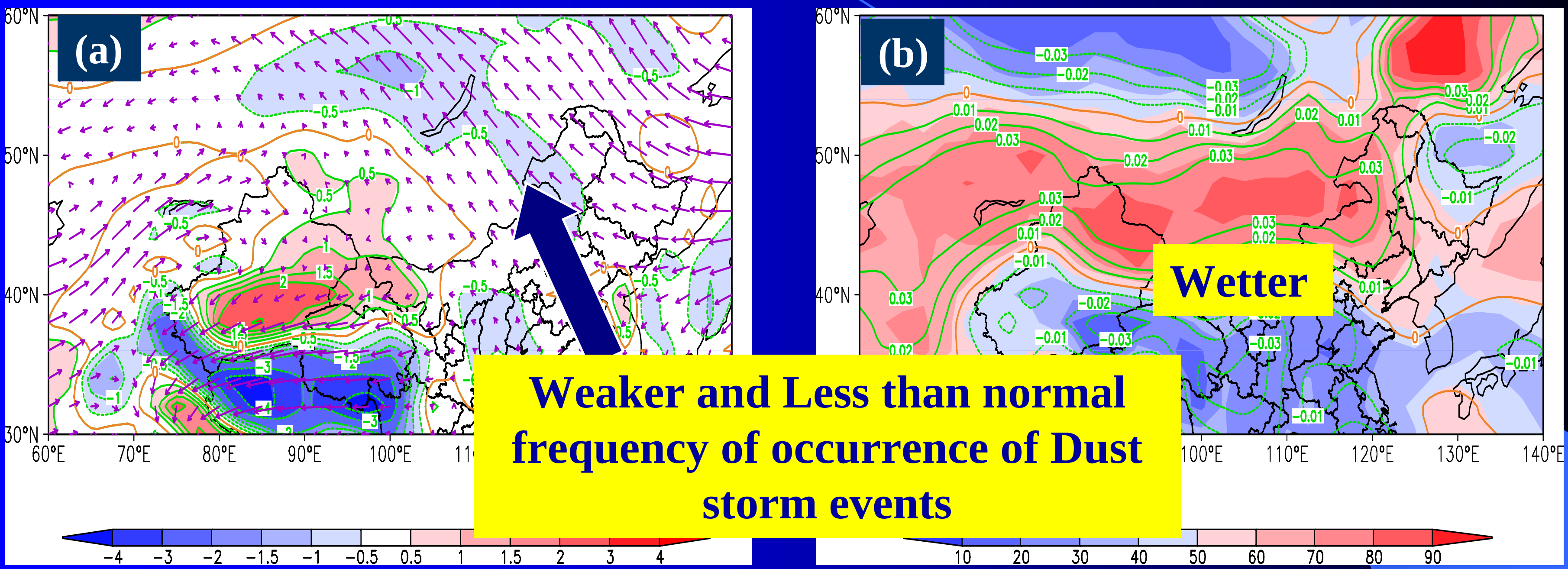
Observed springtime climate anomalies over East Asia (March & April, 2003) （Weak and less dust-storm activities)





(a) 850hpa wind anomalies
(b) 850hpa wind anomalies and surface RH anomalies
Red: positive anomaly,
Blue: negative anomaly.

Prediction by IAP DCP (Mar.& Apr.of 2003)

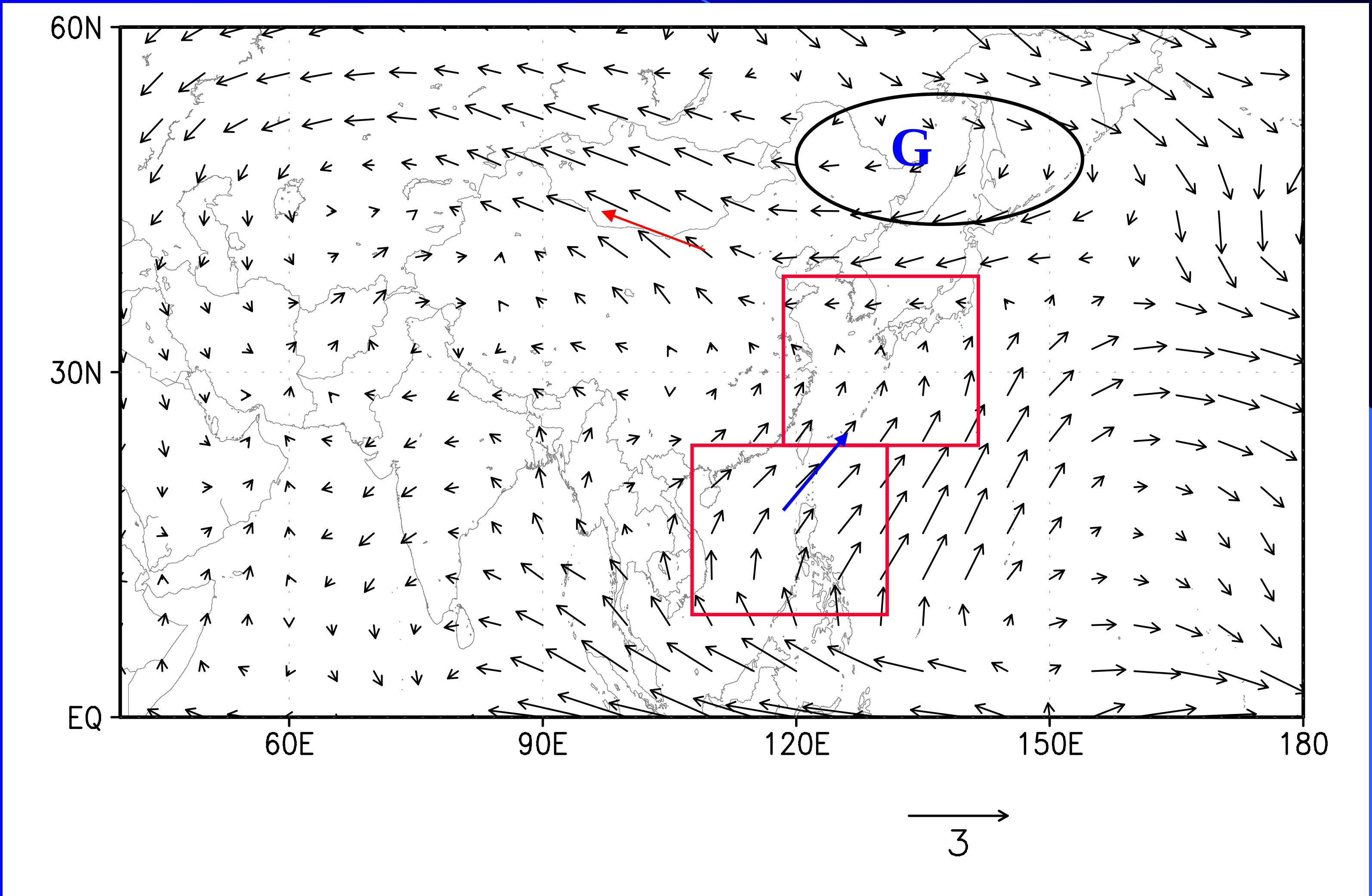


(initiated from Oct. 2002)

(a) 850hpa wind vector and wind speed anomalies (red: positive anomaly, blue: negative anomaly).

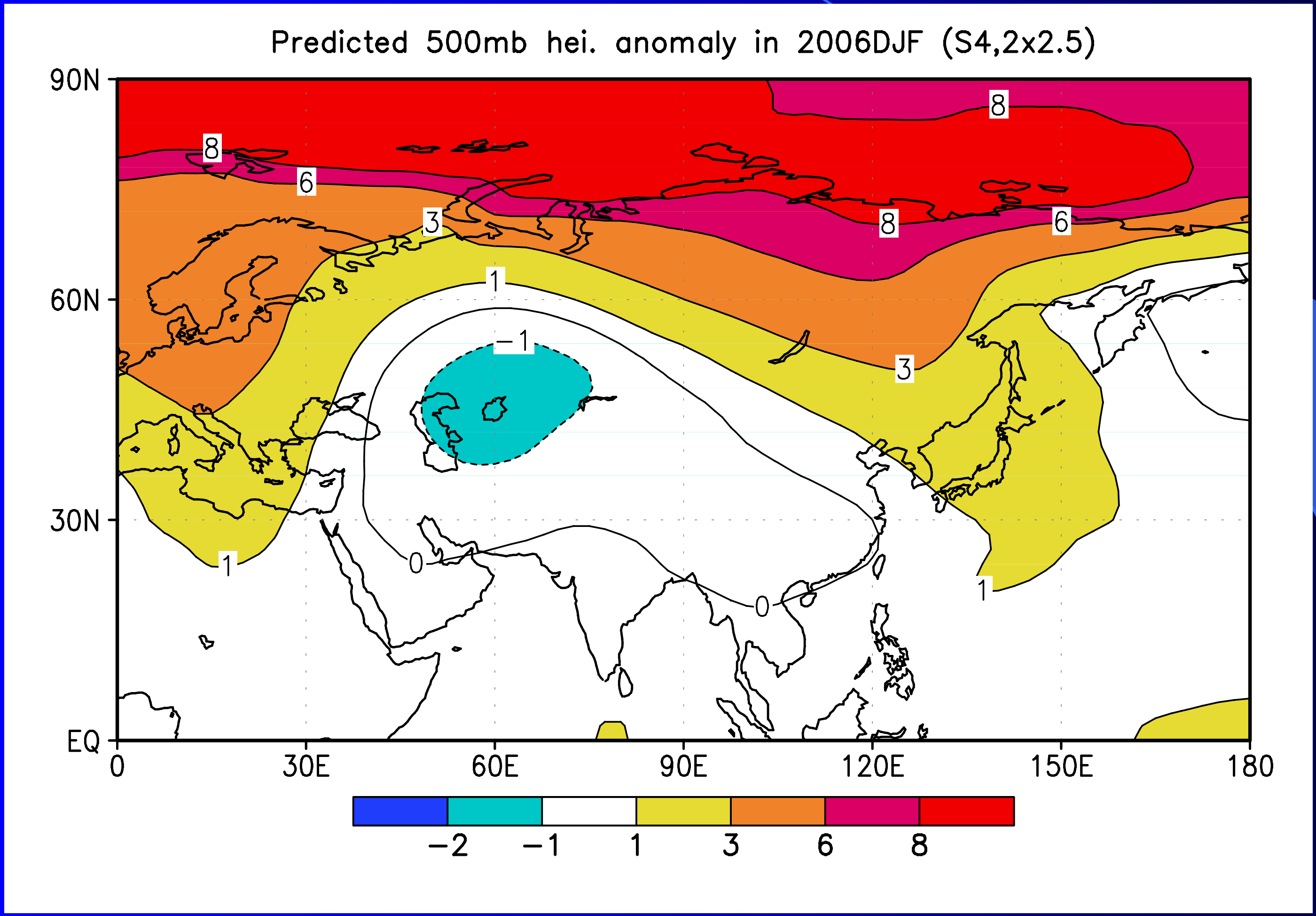
(b) Soil wetness anomalies and the probability for positive soil moisture anomalies (red: >50%, blue:<50%)

Surface Wind Anomaly (DJF, 2006)
Predicted by IAP DCP



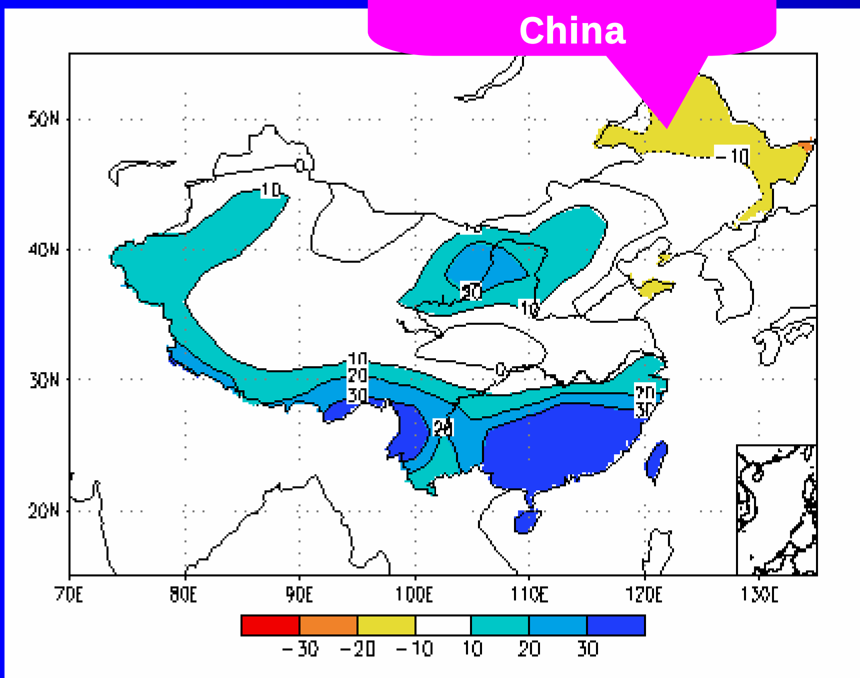
EAWM: weak

500hpa Geopotential Height Anomalies (DJF, 2006) Predicted by IAP DCP (Unit:10gpm)

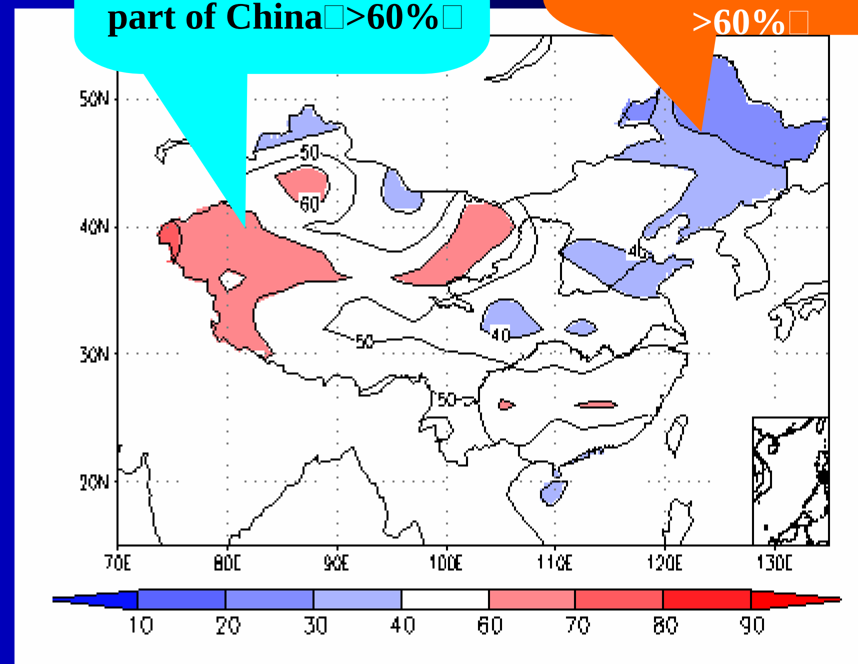


East Asian trough is weak

Percentage Rainfall Anomaly and Probability Distribution with positive anomalies (DJF, 2006)



Distribution of Percentage Rainfall Anomaly

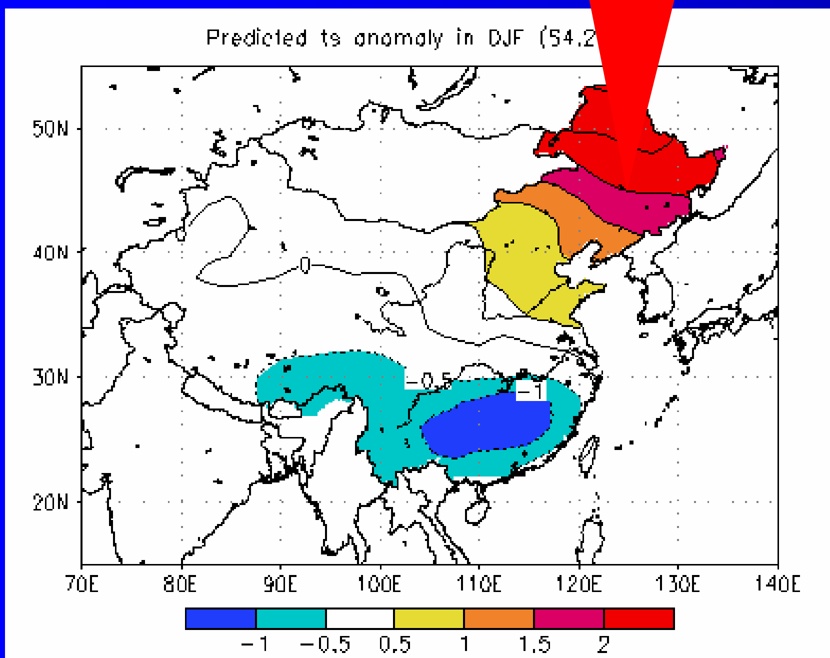


Probability Distribution

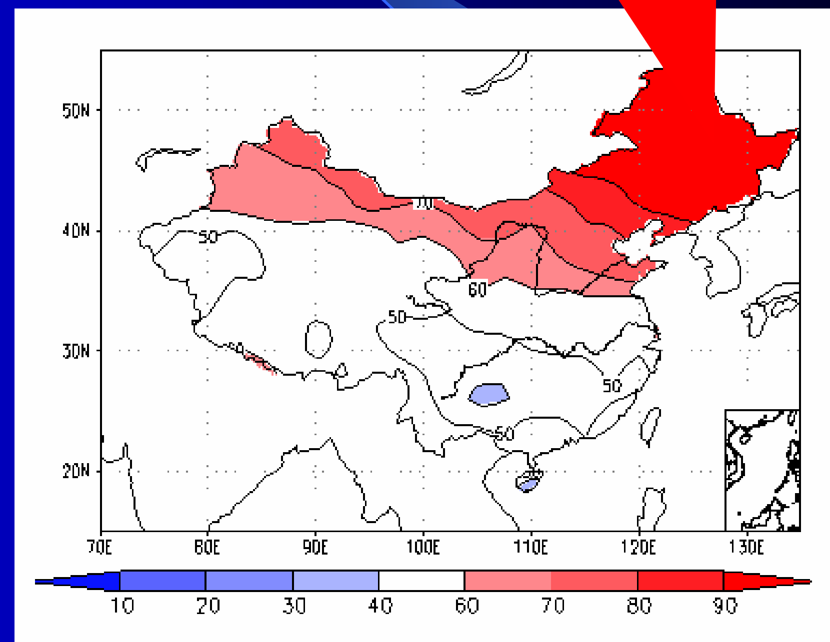
Temperature Anomaly and Probability Distribution with positive temp. anomalies (DJF, 2006)

Warm than normal tem. over Northeast China and North China

Large Probability for positive temp. anomaly over north part of China□>70%□



Temperature Anomaly



Probability Distribution

Summary

- **IAP dynamical seasonal to interannual prediction system has been introduced firstly, then the predictive skill of IAP DCP has been evaluated through different sets of hindcast experiments.**
- **IAP DCP does show certain skill in the prediction of climate anomalies over China, such as Rainfall over Yangtze and Huaihe River valley, temperature over China, EAWM.**

Summary

- **IAP Dynamical Climate Prediction system (IAP DCP) is skillful in the prediction of summer rainfall anomalies over China during recent years, and the occurrence frequency of dust storm over northwest China.**
- **Prediction results have been submitted to decision makers, including MOST, CAS, CMA, …..**

Performance of IAP dynamical Seasonal to interannual prediction system

- **Applications of IAP dynamical seasonal to interannual prediction system to the real time prediction of East Asian monsoon system are encouraging.**
- **However, every of its component should be improved in order to meet the national demand on more accurate climate prediction.**

Future Issues

- Ensemble runs
  - Multi-model ensemble technique
- Correction System
- Extending the geographical range of SST predictions
- Spatial and temporal restrictions
  - Higher resolution model
  - Regional model

Thank You

Why Seasonal Prediction

- Growing demand for reliable seasonal forecasts

Integration Scheme: Two-tiered Fashion