Vol.10 No.1 Advances in Atmospheric Sciences February 1993

Numerical Study for Potential Predictability of Short–Term Anomalous Climate Change Caused by El Nino

Ni Yunqi (倪允琪), *Lin Wuyin* (林武银)
Department of Atmospheric Sciences, Nanjing University, Nanjing 210008
Wang Wanqiu (王万秋), *Yuan Chongguang* (袁重光)
Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100080
and *Zhang Qin* (张勤)
Department of Meteorology, Nanjing Institute of Meteorology, Nanjing 210044

Received April 2, 1992; revised June 11, 1992

ABSTRACT

In this paper, the two–layer IAP model with sea surface temperature anomalies in the equatorial central–eastern Pacific is used to investigate potential predictability of global short–term anomalous climate change caused by El Nino via the "switching" experiments. The experimental results show that short–term anomalous climate change in the tropics is mainly caused by instantaneous response of tropical atmosphere to SSTA in the tropics. The effective period of this kind of anomalous climate is shorter and about monthly scale. In the high latitudes, the anomalous climate is mainly caused by the lag response of atmosphere to SSTA in the tropics. The strongest influence appears in the month after a half year when the SSTA in the tropics disappears. Therefore, potential predictability of short–term anomalous climate change may be reached to one year; anomalous climate change in the middle–latitudes is not only affected by instantaneous response to SSTA in the tropics, but also by lag response to that. Therefore, short–term climate change prediction with monthly time scale can be not only done by using SSTA in the tropics, but also prediction of short– term climate after a half year can be done and its effective predictable period may be reached to one year.

I. INTRODUCTION

The low frequency variability—El Nino appearing in the tropical Pacific associated with oscillated phenomena—southern oscillation is a typical event resulting from interaction between ocean and atmosphere. It has an important influence on short–term change(including monthly, seasonal and annual time scales) of global climate, for example, 1982–83 El Nino is a strongest warming event of sea water in the equatorial Pacific in the century. As a result, it caused global climate anomaly. Therefore, the meteorologists are very much concerned with the problem whether the short–term anomalous climate change caused by El Nino can be predicted or not.

Since the problem of predictability is proposed, Lorenz (1963, 1969, 1982, 1984) did a number of researches on it. The conclusion is theoretical upper–limitation of predictability about two weeks. Thus,is there any practical significance for short–term climate prediction with monthly, seasonal and annual time scales? It is very clear that this kind of predictability differs from predictability of weather forecast proposed by Lorenz. According to this idea, Shukla (1981a and 1981b) and Miyakoda (1982) did some researches on predictability of monthly mean atmospheric state. Their conclusion is that the tropical atmosphere possesses stronger potential predictability under anomalous external forcing in the tropics. Chervin (1986) studied this problem with NCAR GCM. He compared variance calculated by the results from 20 year integration of the model without non-seasonal external forcings with those from observation. It was found that variance in the model is not significantly smaller in the middle latitudes than observed variance. Therefore, he suggested that there was a little potential predictability of seasonal mean state in the United States. Chervin (1986) analyzed the results from 15 year integrations of the model with monthly mean sea surface temperature for 180 months (Oort, 1983, May 1958–April 1973 including three El Nino events) and monthly mean SST of the above data set, respectively. The statistical test of both variances showed that there was potential predictability in the tropics other than in the middle latitudes. The above results seem to show that it has possibility of predicting short–term climate with monthly time scale or longer in the tropics, but it is much more difficult to do it in the middle–high latitudes. However, forecasters use sea surface temperature anomalies in the tropics in summer to predict change of atmospheric state in middle latitudes (such as China) in next winter or vice versa. It seems to show that it is not impossible to predict an influence of tropical external forcing anomaly on the middle–latitudes atmosphere with monthly, seasonal time scales. The key problem is that it is necessary to consider the lag relationship between tropical sea surface temperature anomaly and middle latitude atmosphere. Based on the above idea, a GCM is used to study lag response of atmosphere to tropical SSTA and investigate short–term climate change resulting from El Nino, especially the predictability in the middle–high latitudes in this paper. It is shown that our result is quite different from the prvious conclusions and further verifies the physical basis of statistical relationship between the tropical SSTA in the previous period and the middle–latitude atmosphere change in the later period.

II. BRIEF DESCRIPTION OF THE MODEL AND EXPERIMENTAL SCHEMES

In this paper, two–layer global grid primitive equation model (named as IAP GCM) developed by Institute of Atmospheric Physics, Chinese Academy of Sciences is used.

In this model, the top of the model is placed at 200 hPa with two layers in the vertical but the absorption of short–wave radiation by ozone in the stratosphere is considered; grid box is 4° × 5° with latitude– longitude coordinate in the horizontal; description of variables is the C–grid mesh scheme. Solar short wave radiation, long wave radiation from underlying surface and atmosphere, large–scale condensation and small scale cumulus convection heating process, heat, moisture and momentum turbulence exchange between atmosphere and underlying surface are considered in the model. Temperature and wetness of soil are respectively predicted by using heat and moisture budget equations. Sea surface temperature and sea ice cover from observation are input into the model and snow cover on ground is predicted by using snow quantity equation. The underlying surface is divided into nine types and albedo on the ground is calculated according to type of ground and with or without snow cover. The integrated time step of the model is 7.5 minutes.

Detail description of this model can be read in the paper written by Zeng Qingcun et al (1989).

Zeng et al (1989) used the above model without non–seasonal external forcings to integrate for 25 years. This 25–year simulation results are defined as “natural climate change series of the model atmosphere”. At the same time, the simulated results from a period of this series, that is, from November 1 of the fifth model year to January 31 of the seventh model year, may be thought as a parallel run without non–seasonal external forcings and referred to as a control experiment named as “experiment C”.

The numerical experiment with anomalous sea surface temperature is referred to as “experiment A". The integrated procedure is divided into four steps:

The first step, the sea surface temperature in equatorial central– eastern Pacific is gradually increased (switching on category). The model with simulation on October 31 of the fifth model year as initial condition and SST with daily increased by 0.1°C in the region I(see Fig.5) is integrated for 10 days. As a consequence, the sea surface temperature in the region I is increased by 1°C; in the following time, SST in the region II is daily increased by 0.1°C and the model is again integrated for 10 days. At this time, SST in the region II is increased by 1°C while SST in the region I is increased by 2°C; then, the same procedure is continued in the region III and after the model is integrated for the third 10 days, SST in the region III is increased by 1°C, increased by 2°C in the region II and by 3°C in the region I. In other words, after the model is integrated for the first month, the sea surface temperature anomalies in the equatorial central–eastern Pacific are completely input into the model, and non–seasonal external forcing SSTA needed during the period when the model with anomalous sea surface temperature is integrated is obtained.

The second step, the period that the model with SSTA in the equatorial central–eastern Pacific is continually integrated. The model with SSTA in the equatorial central–eastern Pacific superimposed on the December climatological SST is integrated for one month.

The third step, the period that the sea surface temperature is gradually decreased to the normal (switching off category). The SST in the model is daily decreased by 0.1°C since January 1 of the next year. The procedure decreased SST is similar to the procedure increased SST described as above but the direction is opposite. The SST in the whole tropical Pacific is recovered to climatological state in February after the model is integrated for the third month.

The fourth step, the model with monthly mean climatological SST is continually integrated for one year till January 31 of the seventh model year.

The results simulated by the model with anomalous sea surface temperature from November 1 of the fifth model year to January 31 of the sixth model year may be viewed as simulated results from the simultaneous response of atmosphere to anomalous sea surface temperature while the results from February 1 of the sixth model year to January 31 of the seventh model year as the results from lag response of atmosphere to anomalous sea surface temperature.

We calculate monthly mean geopotential height at 500 hPa from "natural climate change series of model atmosphere", then calculate mean square difference σ_C and σ_A for each month from experiment C and experiment A, respectively, where σ_A and σ_C are defined as

$$\sigma_A = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\varphi_i^A - \bar{\varphi}_i)^2} \quad \text{and} \quad \sigma_C = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\varphi_i^C - \bar{\varphi}_i)^2} ,$$

n is total grid number in the computed area and index i denotes the ith grid, bar denotes mean state. Finally, the ratio of signal to noise for each experimented month is obtained, which is indicative of potential predictability of global or regional short–term climate change caused by El Nino.

III. ANALYSIS OF THE RATIO OF THE SIGNAL TO NOISE IN THE GLOBAL AND VARIOUS LATITUDINAL ZONES AND POTENTIAL PREDICTABILITY OF SHORT– TERM CLIMATE CHANGE

According to the above simulated results, σ_C, σ_A and the ratio of the signal to noise for

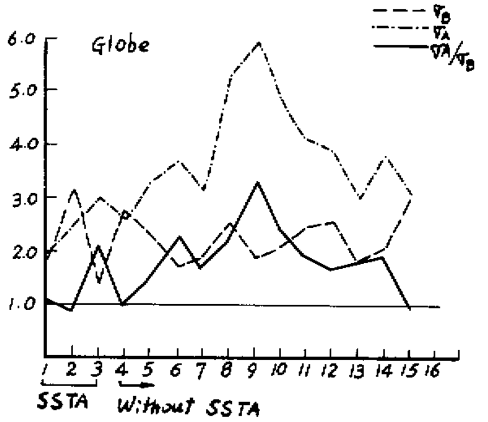

Fig.1. Month to month variation chart of global mean ratio of signal to noise.

each month is calculated in terms of global mean (see Fig.1), and the ratio of signal to noise in various latitudinal zones, that is, tropical zone (25°S–25°N), the middle latitudes (25°S–60°S and 25°N–60°N) and the high latitudes (60°S–90°S and 60°N–90°N) are respectively given in Fig.2, Fig.3 and Fig.4.

Fig.1 shows that in terms of global mean, the maximum ratio of signal to noise appears in the month next to the month when the sea surface temperature anomalies are the strongest. The ratio of signal to noise reaches 2.06. It is more significant that the maximum ratio of signal to noise does not appear in the period of instantaneous response but in the sixth month after the sea surface temperature anomalies disappear, that is July of the sixth model year. The maximum ratio of signal to noise reaches 3.13. Furthermore, the ratio of signal to noise which is greater than 1.0 persists almost one year even after the sea surface temperature anomalies are recovered to normal. It is clearly shown that anomalous sea surface temperature has not only a instantaneous influence on atmosphere but also a lag influence on atmosphere, and the latter is stronger than the former. The time scale of the persistent influence may reach one

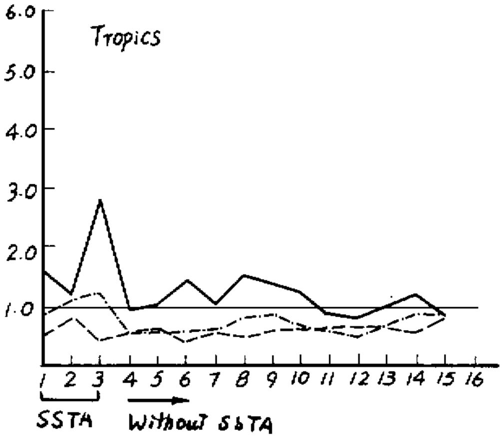

Fig.2. Month to month variation chart of mean ratio of signal to noise in lower latitudes (25°S–25°N).

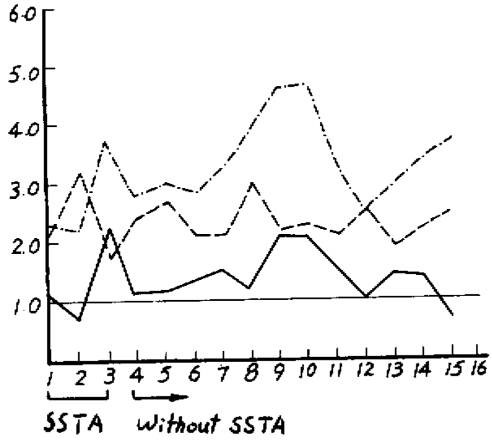

Fig.3. As in Fig. 2 except for middle latitudes (25°S–60°S, 25°N–60°N).

year. The month with the strongest influence of SSTA is in the last month of a half year after the sea surface temperature anomalies disappear (for example, SSTA appears in winter but the strongest influence exists in summer in this experiment). These results are consistent with forecaster's experience and analysis of lag relationship between sea surface temperature anomalies and geopotential height anomalies.

Fig. 2 represents monthly variation of the mean ratio of signal to noise in the tropical region. The characteristics in Fig.2 obviously differs from those in Fig.1. The maximum ratio of signal to noise appears in the month next to the month when the sea surface temperature

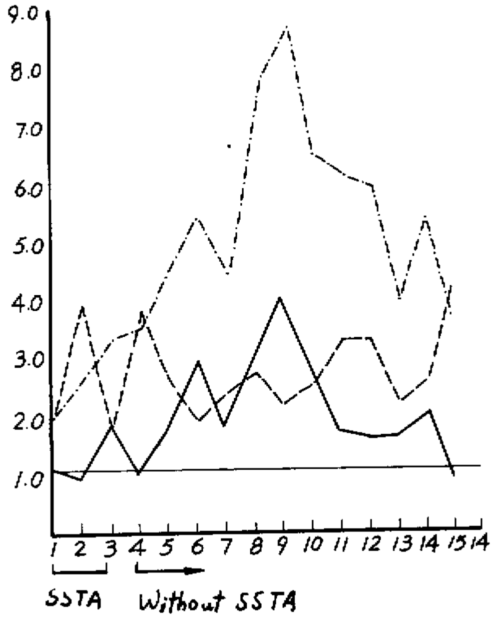

Fig.4. As in Fig.3 except for high latitudes (60°S–90°S, 60°N–90°N).

anomalies in the tropics are the strongest during the period of instantaneous response and not during the period of lag response, and the instantaneous response in the tropics is much stronger than the lag response. It is also shown that during the lag response, the months when the ratio of signal to noise is greater than 1.0 are only six months, which is only half time length appearing in Fig. 1. These results clearly indicate that in the tropics, atmospheric response to tropical sea surface temperature anomalies mainly is instantaneous response of atmosphere and lag response is much weaker compared with it. Therefore, the strongest potential predictability is in the month next to the month when SSTA is the strongest and its potential predictability may persist a half year but potential predictability during the lag response period is obviously weakened.

Fig.3 and Fig.4 give the monthly variation of mean ratio of signal to noise in middle-latitudes and high-latitudes, respectively. Comparing Fig.2 with Fig.3 and Fig.4, it can be found that during the instantaneous response period, the ratio of signal to noise is decreased with increase of latitude regardless of the strongest instantaneous response in various latitudinal zones appearing in the month next to the month when the SSTA is strongest; during the lag response period, however, the ratio of signal to noise is increased with increase of latitude, that is, the largest appearing in high latitudes, the next largest in middle latitudes and the smallest in lower latitudes, and the strongest lag response appears in the fifth month after the SSTA disappears in the tropics but it is lagged by one month, that is in the sixth month, in middle and high latitudes; the ratio of signal to noise which is greater than 1.0 in middle-high latitudes persists about one year, which is much longer than persistent time in lower latitudes. The above results clearly suggest that the effect on anomalous climate change in the tropics mainly is an instantaneous influence of tropical forcing while in high latitudes, mainly is a lag influence of tropical forcing with one year of the lag time scale; in middle latitudes, however, both the instantaneous and the lag influence on anomalous climate change are equally significant.

IV. CHARACTERISTICS OF SPATIAL DISTRIBUTION OF THE RATIO OF SIGNAL TO NOISE AND POTENTIAL PREDICTABILITY OF ANOMALOUS CLIMATE CHANGE IN THE AREAS RELATED TO THEM

Fig.5 represents the spatial distribution of the ratio of signal to nosie in November of the fifth model year, that is, the first month when the sea water in the equatorial central-eastern Pacific is warming. Fig.5 clearly shows that the ratio of signal to noise in the whole tropics is much larger than 1.0 and maximum values located in equatorial eastern Pacific and equatorial western Pacific. Apparently, the former is over the warm water area and the latter is a

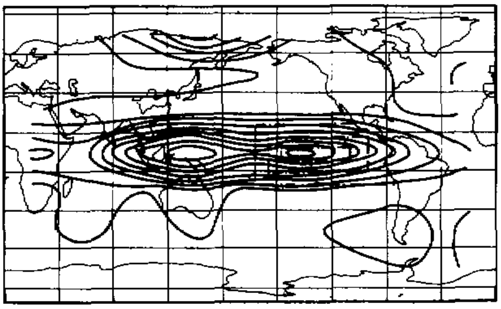

Fig.5. Spatial distribution of the ratio of signal to noise in November of the fifth model year.

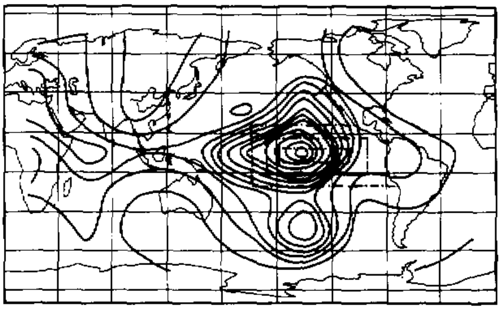

Fig.6. As in Fig.5 except for January of the sixth model year.

larger value area of the ratio of signal to noise resulting from anomalous change of equatorial east–west circulation, which includes India and southern Asia. However, the ratio of signal to noise is smaller than 1.0 or close to 1.0 in middle–high latitudes except for northeastern Asia. In December of the fifth model year (the second month during sea water is warming), basic characteristics of spatial distribution of the ratio of signal to noise are similar to those in the previous month (not shown), in which the large value area still is located in the tropics except for that the ratio of signal to noise reaches above 2.0 in the central area of Asia. In January of the sixth model year (the month when SSTA is gradually decreasing, see Fig. 6), the spatial distribution of the ratio of signal to noise is obviously changed. The ratio of signal to noise is larger than 1.0 not only in the whole Pacific, but also in the most area of South America, Europe and Africa, although it is still larger than 1.0 in the tropics and the center located in equatorial central–eastern Pacific. Obviously, the ratio of signal to noise in middle latitudes is enhancing. The above results have shed much light on that the instantaneous forcing of warming sea water mainly has an influence on the tropics and influence scope of instantaneous forcing extended to the whole Pacific region in the month next to the month when SSTA is the strongest, especially obviously increased in middle latitudes. It is interesting that the area of strong ratio of signal to noise does not appear immediately in the equatorial Pacific in the month when anomalous sea surface temperature in the tropics disappears. The area where the ratio of signal to noise is larger than 2.0 mainly appears in the north of northern Pacific, eastern tropical Indian Ocean, North Atlantic and southeastern polar area of South Pacific (see Fig. 7). After that time (from March of the sixth model year to January of the seventh year), there no longer exists a large area where the ratio of signal to

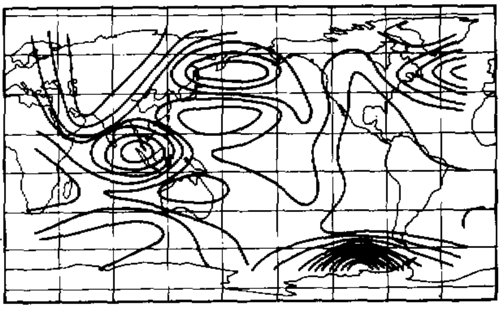

Fig.7. As in Fig.5 except for February of the sixth model year.

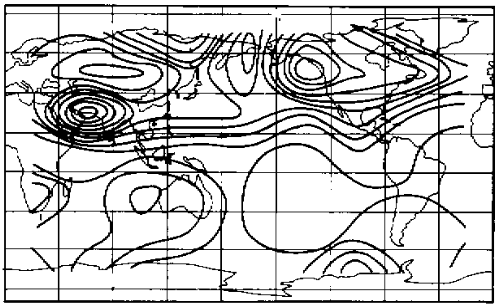

Fig.8. As in Fig.5 except for August of the sixth model year.

noise is much larger than 1.0 in the tropics.

In the light of the above, the potential predictability in the tropics completely depends on the instantaneous forcing influence of sea surface temperature anomalies in the tropics. Its effective predictable length is limited in the months when the SSTA exists in the tropics and potential predictability is quickly weakened once the SSTA disappears in the tropics. However, there is stronger potential predictability in middle latitudes in the month next to the month when the SSTA in the tropics is the strongest, especially the Pacific, Europe and Africa.

The ratio of signal to noise in middle–high latitudes is increasing with increase of the lag time. Fig. 8 gives spatial distribution of the ratio of signal to noise in the seventh month after the SSTA in the tropics disappears (that is August of the sixth model year). This picture clearly shows that the ratio of signal to noise less than or close to 1.0 appears in the tropical region, South Pacific and South Atlantic while areas with maximum ratio of signal to noise are North America with the center located in the west coast of North America, Indian monsoon area and East Asian monsoon area with the center located in the Bay of Bengal and eastern Asian area. In the Southern Hemisphere, the large value areas of the ratio of signal to noise are located in Australia and south of Africa. Obviously, Asian monsoon area (including Indian monsoon, East Asian monsoon, Mascarene high and Australian high) and North American continent are strongly affected by lag influence (lagged by a half year) of the SSTA forcing in the equatorial central–eastern Pacific. Thereafter, it can be conjectured that it has strong potential predictability for predicting monsoon change and climate change in North America after a half year using sea surface temperature anomalies in equatorial central–eastern Pacific in the previous period. Spatial distribution of the ratio of signal to noise for each month (not shown) further indicates that it may be predicted for short–term climate change in middle–high latitudes in the later period by using sea surface temperature anomalies in the tropical ocean in the previous period, and its effective prediction length may reach about one year.

V. DISCUSSION AND CONCLUSION

In this paper, the 25 year simulation results by using the IAP model without non–seasonal external forcings are defined as natural climate change series of the model and "switching" experiment with sea surface temperature anomalies in the equatorial central–eastern Pacific has been done to investigate potential predictability of anomalous global short– term climate change caused by El Nino. The experiment clearly shows that there are two types of influences of sea surface temperature anomaly in the equatorial central–eastern Pacific on atmosphere: one is the influence of instantaneous forcing; another is the influence of lag forcing. Anomalous short–term climate change in the tropics can mainly arise as a result of instantaneous forcing influence with influence time scale responding to persistent time of anomalous external forcing. Therefore, the predicting effective period of this kind of anomalous climate is comparatively short and it is responding to persistent time of external forcing. Anomalous climate in high latitudes can be mainly caused by lag influence of tropical SSTA and the strongest influence month is lagged by a half year after the anomalous sea surface temperature disappears. Thus, it is possible to predict the anomalous climate phenomena in high latitudes after a half year using SSTA in the tropics in the previous period. Thereafter, it can be conjectured that the potential predictability of anomalous short–term climate is determined by the lag influence of sea surface temperature anomaly in the tropics associated with one year of persistent time; anomalous climate in middle latitudes is not only affected by instantaneous forcing influence of sea surface temperature anomaly in the tropics, but also by its lag forcing influence. Furthermore, it is possible to do prediction of short–term climate with monthly time scale using SSTA in the tropics but also prediction of short–term climate after a half year.

The above results seem to show that the tropical external forcing may generate the low–frequency signal with various frequencies, and instantaneous influence of tropical external forcing on the atmosphere is related to climate signal with comparatively high frequency caused by the external forcing and the lag influence on the atmosphere can arise as extra–low frequency signal caused by external forcing. Results also suggest that it needs about over one month when the extra–low frequency signal propagates from the tropics to middle–high latitudes (compared Fig.2 with Fig.6). The above results also indicate that the atmosphere has stronger memory capability for climate signal caused by external forcings. Furthermore, memory capability of atmosphere seems to be related to frequency of climate signal. The lower the frequency of climate signal is, the stronger the atmospheric memory capability is; the memory capability of atmosphere seems to be also related to latitude. The higher the latitude is, the stronger the atmospheric memory capability is. Obviously, weaker memory capability of the lower latitudinal atmosphere is due to active tropical convection and unstable tropical atmosphere. It is noteworthy that the lag influence of the tropical external forcing lagged by six month in various latitudes reaches the strongest but in high latitudes, the phenomenon is more apparent. This fact seems to indicate that the tropical froced signals are amplified and they are stronger in lower latitudes and weaker in higher latitudes for signal with higher frequency while the amplification is stronger in higher latitudes than in lower latitudes for the signal with lower frequency. The former is characterized by stronger instantaneous forcing influence of tropical external forcing in the tropics and the latter characterized by stronger lag influence in high latitudes. According to the above analyses, it may be viewed that potential predictability of anomalous short–term climate change is based on self–memory capability of atmosphere for climate signals caused by tropical external forcings (related to frequency of climate signals and latitudes) and strong or weak degree of amplification of this climate signal.

In the light of the above, the global anomalous short–term climate change caused by El Nino is a synthesized reflection of state change of a complicated ocean–atmosphere coupled model with different memory capability for climate signals with various frequency. In this paper, numerical study for potential predictability of the short–term climate change is investigated and very significant results are obtained but for really understanding predictability of global short–term anomalous change caused by El Nino, the following two dynamical questions still open:

1) dynamical characteristics and significance (including propagation and amplification of extra–low frequency climate signal) reflected by atmospheric memory capability with climate signals caused by external forcings;

2) a number of studies for instantaneous response of atmosphere to tropical external forcings have already been done (Webster, 1981; Simmons, 1982; Keshavamurty, 1982; Ni et al., 1990a,b), however, lag responses of atmosphere to tropical external forcings were never noticed, which is a very important aspect of atmospheric external dynamics; and further studies about this problem will get benefit from further efforts to study prediction of short–term anomalous climate change caused by anomalous external forcings.

We are grateful to the Open Lab of Atmospheric Sciences and Geophyisical Fluid Dynamics, Institude of Atmospheric physics Chinese Academy of Sciences and its director, Prof. Zeng Qingcun for his support.

REFERENCES

Chervin, R. M. (1986), Interannual variability and seasonal climate predictability, *J. Atmos. Sci.*, **43**: 233–251.

Keshramurty, R. N. (1982), Response of the atmosphere to sea–surafce temperature anomalies over the equatorial Pacific and the teleconnections of the Southern Oscillation, *J. Atmos. Sci.*, **39**: 1241–1259.

Lorenz, E. N. (1963), The predictability of hydrodynamic flow, *Trans.* New York Academy of Sciences, Ser. II, 25, 409–433.

Lorenz, E. N. (1969), Three approaches to atmospheric predictability, *Bull. Amer. Meteor. Soc.*, **50**: 345–349.

Lorenz, E. N. (1982), Irregularity: A fundamental property of the atmosphere, *Tellus*, **36A**: 98–111.

Miyakoda, K and Chao Jiping,*(1982), Essay on dynamical long range forecasts of atmospheric circulation, *J. Met. Soc. Japan*, **60**: 292– 308.

Ni Yunqi, Lin Wuyin, (1990), Numerical study of short–range climate oscillation with various time scales forced by El Nino during the Northern summer, *Acta Meteorologica Sinica*., **4(3)**: 305–324.

Ni Yunqi, Lin Wuyin and Ning Dongmei. (1990), Numerical study of the short–term climate oscillations forced by El Nino during the Northern winter, *Acta Meteorologica Sinica*., **4(5)**: 552–566.

Oort, A. H. (1983), Global atmospheric circulation statistics, 1958– 1973. NOAA Professional Paper No.14, U. S. Government printing office, Washington D. C., 180pp.

Shukla, J., (1981a), Dynamical predictability of monthly means, *J. Atmos. Sci.*, **38**: 2547–2572.

Shukla, J., (1981b), Predictability of monthly means: Part II, Influence of the boundary forcings, *Proceedings of ECMWF Seminar on problems and prospects in long and medium range weather forecasting*, 261–312.

Simmons, A. J. (1982), The forcing of stationary wave motion by tropical diabatic heating, *Q. J. R. Met. Soc.*, **10**: 503–534.

Webster, P. J. (1981), Mechanisms determining the atmospheric response to sea surface temperature anomalies, *J. Atmos. Sci.* **38**: 554–571.

Zeng Qingcun, Zhang Xuehong, Liang Xinzhong, Yuan Chongguang and Chen Shengfang (1989), Documentation of IAP Two Level Atmospheric General Circulaiton Model, DOE / ER / 60314–H1, Prepared for United States Department of Energy, 383pp.