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MONTHLY AND SEASONAL NUMERICAL FORECASTS BY USING THE ANOMALY OCEAN-ATMOSPHERE COUPLED FILTERED MODEL

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ABSTRACT

Case experiments of monthly predictions of eight winter months during 1976—1977 and 1982—1983 El Nino events are performed by using a three-layer anomalous filtered model (AFM), in which transient Rossby waves are filtered. The results show that this model predicts successfully the large-scale patterns of the monthly mean surface temperature anomalies. The correlation coefficients between observations and predictions are basically higher than those of persistence predictions. By comparison with the anomalous general circulation model (AGCM) the AFM gives almost the identical results, but the computation time required for running the AFM is nearly 100 times less than that required for running the AGCM. It is also shown that the results of the three-layer model are better than those of the one-layer model. In the meanwhile, four seasonal forecasts are also carried out by using the same model. It seems that the AFM possesses potential ability in predicting large-scale circulation anomalies.

On the basis of the works done during the last decade and of the results in this paper, the predicting ability of the AFM is summed up in the last section.

I. INTRODUCTION

According to the two basic ideas first suggested by Chao et al.[1-3], i. e., the prediction of anomalies is sufficient for long-range forecasting and as "high-frequency noises" the transient Rossby waves can be filtered out, an anomalous atmosphere-ocean/land coupled filtered model (AFM) has been developed. A great number of experiments[4,5] for predicting monthly surface temperature anomalies and 500 hPa anomalous geopotential heights have been made by means of such one-level model. All the results show that these models are promising and that since the time required is considerably short it is worthy of being used for long-range numerical forecasts, especially when powerful computers are not available. As there is only one level in the atmosphere, however, the surface temperature anomalies have to be calculated by using dynamic quantities evaluated at 500 hPa. It is obvious that certain errors would be brought in the calculations. Furthermore, the effects of atmospheric baroclinicity and the adjustment between upper and lower layers were inevitably restricted. One of the improving approaches is naturally to increase the number of layers in models, thus we use a three-layer model for the atmosphere.

II. THE MODEL

Reynolds stress terms which are expressed in terms of horizontal turbulent transfer based on mixing length theory, are taken into account in the anomalous vorticity equation, i.e.

$$\frac{\partial}{\partial t}(\Delta\phi')+\frac{1}{f}J(\bar{\Phi}+\phi',\Delta\phi')+J\left(\phi',\ f+\frac{1}{f}\Delta\bar{\Phi}\right)=f^2\frac{\partial\omega'}{\partial p}+k'\nabla^4\phi'. \tag{1}$$

The first law of thermodynamics for the atmosphere is

$$\frac{\partial}{\partial t}\left(\frac{\partial\phi'}{\partial p}\right)+\frac{1}{f}J\left(\bar{\Phi}+\phi',\frac{\partial\phi'}{\partial p}\right)-\frac{R}{pf}J(\phi',\bar{T})-\frac{\partial}{\partial p}(k+k_r)\frac{\partial^2\phi'}{\partial p^2}$$

$$+\frac{1}{\tau_r}\frac{\partial\phi'}{\partial p}=-\tilde{\sigma}_p\omega'-\frac{R\varepsilon_Q}{p\rho C_p}. \tag{2}$$

The last term in the above equation, i. e. the heat exchange of condensation, may be expressed as[6]

$$\frac{\varepsilon_Q}{\rho C_p}=-\frac{L}{C_p}H_bD_b\gamma\left(\frac{\partial\ln\bar{e}_s}{\partial T}\right)_0\left(\frac{\partial q_s}{\partial T}\right)_0T'_s, \tag{3}$$

where

$$D_b=(\mathrm{div}\mathbf{V})_b.$$

Eliminating ω' from Eqs. (1) and (2) and using following approximation

$$k'\nabla^4\phi'\approx-k\nabla^2\phi', \tag{4}$$

we obtain the diabatic anomalous potential vorticity equation:

$$\frac{\partial}{\partial t}\left(\Delta+\frac{f^2}{\tilde{\sigma}_p}\frac{\partial^2}{\partial p^2}\right)\phi'+\frac{1}{f}J(\bar{\Phi}+\phi',\Delta\phi')+J\left(\phi',f+\frac{1}{f}\Delta\bar{\Phi}\right)$$

$$+k\Delta\phi'-\delta_1k^*T'_s=\frac{f^2\partial G}{\tilde{\sigma}_p\partial p}, \tag{5}$$

where

$$G=-\frac{1}{f}J\left(\bar{\Phi}+\phi',\frac{\partial\phi'}{\partial p}\right)+\frac{R}{pf}J(\phi',\bar{T})+\frac{\partial}{\partial p}(k+k_r)\frac{\partial^2\phi'}{\partial p^2}-\frac{1}{\tau_r}\frac{\partial\phi'}{\partial p}, \tag{6}$$

$$k^*=fRH_bD_b\frac{L}{C_p}\gamma\left(\frac{\partial\ln\bar{e}_s}{\partial T}\right)_0\left(\frac{\partial q}{\partial T}\right)_0\frac{\partial}{\partial p}\left(\frac{1}{p\tilde{\sigma}_p}\right), \tag{7}$$

$$\delta_1=\begin{cases}1, & D_b<0,\\ 0, & D_b>0.\end{cases} \tag{8}$$

Considering that $\omega'=0$ and there is no condensation taking place on both upper and lower boundaries (i. e. the right side of Eq. (2) vanishes), we have

$$p=p_s,\quad \frac{\partial}{\partial t}\left(\frac{\partial\phi'}{\partial p}\right)-G=0, \tag{9}$$

$$\frac{\partial\phi'}{\partial p}=-\frac{R}{p_s}T'_s, \tag{10}$$

$$p\to0,\quad \frac{\partial}{\partial t}\left(\frac{\partial\phi'}{\partial p}\right)-G=0, \tag{11}$$

$$\frac{\partial \phi'}{\partial p}=0, \tag{12}$$

Like the corresponding equation in Ref. [1] the predicting equation of the anomalous surface temperature is

$$z=0, \quad \frac{\partial T_s'}{\partial t}+\left(\frac{\delta}{D_Q}+\frac{1}{D_s}\right)\frac{k_s}{h}T_s'+k_sH_1+\frac{k\tau_r}{D_s}\,\frac{k_s}{h}H_2'=\frac{-s_0l_b\zeta_{0g}'}{w_0\rho_sC_{ps}k_s}, \tag{13}$$

where

$$D_Q=\rho_sC_{ps}k_s/L\rho k_T\gamma\frac{\partial \ln \bar{e}_s}{\partial T}\cdot\frac{\partial q_s}{\partial T}, \tag{14}$$

$$D_s=\rho_sC_{ps}k_s\sqrt{k\tau_r}/\rho C_pk_T. \tag{15}$$

III. NUMERICAL SCHEMES

The difference scheme of Eq. (13) is

$$T_s'^{t+\delta t}=\left[1-\delta t\frac{k_s}{h}\left(\frac{\delta}{D_Q}+\frac{1}{D_s}\right)\right]T_s'^{t}+\delta t\left[k_sH_1+\frac{k\tau_r}{D_sh}H_2+\frac{S_0l_bb(\Delta\phi')_b}{w_0\rho_sC_{ps}k_s}\right]^t. \tag{16}$$

Taking the surface temperature and geopotential height anomalies in the preceding month as the initial fields and one month as a time step, we can get the anomalous surface temperature for the present month from Eq. (16). The geopotential height anomalies can be then calculated from Eq. (5) and its boundary conditions.

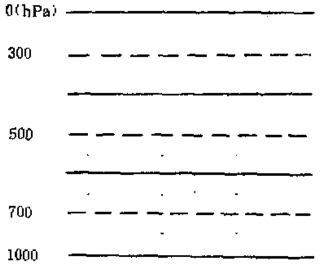


Fig. 1. Vertical configuration for the atmosphere.

Eq. (5) can be rewritten at the three levels illustrated in Fig. 1. Filtered out the transient Rossby waves by omitting the partial derivative with respect to time in Eq. (5), it becomes an adaptive equation which can be solved by the method of overrelaxation:

$$\frac{1}{D^2}\frac{\partial \phi_i'}{\partial t}=\frac{1}{f}J(\bar{\phi}+\phi',\Delta\phi')_i+J\left(\phi',f+\frac{1}{f}\Delta\bar{\phi}\right)_i+k\Delta\phi_i'$$
$$-\delta_ik^*T_s'-\frac{f^2}{\tilde{\sigma}_p}\left(\frac{\partial G}{\partial P}\right)_i, \tag{17}$$

where D is a quantity with a dimension of length. The polar stereographic projection is used and the horizontal grid spacing is taken as 540 km. Arakawa Jacobian has also been employed in the calculations.

IV. THE EXPERIMENTS OF MONTHLY FORECASTS

Eight examples of monthly forecasts during the winter months in 1976—1977 and 1982—1983 El Nino events are given in this section. Their correlation coefficients between observations and predictions as well as persistences of monthly prediction are listed in Table 1.

From Table 1 it can be seen that the prediction of the surface temperature is superior to the persistence for most of the cases except January and February 1983. As to the predictions of geopotential height, five of them are better than, two are equivalent to and one (case Feb. 1983) is worse than, the persistence. It is worth noticing that whether the prediction is successful or not does not depend entirely on the continuity of the circulation pattern. For instance, the prediction is better than the persistence in cases 3 and 8, however it is worse in case 7, in spite of the good continuity of the circulation between the successive months (i. e. the persistence is high) in all the cases. On the other hand, the persistence of geopotential height fields is negative in cases 1 and 4, but the predictions are not too bad, with the correlation between observations and predictions being about 0.3.

Table 1. Comparisons of the Correlation between Observations and Predictions as well as Persistences of Monthly Prediction

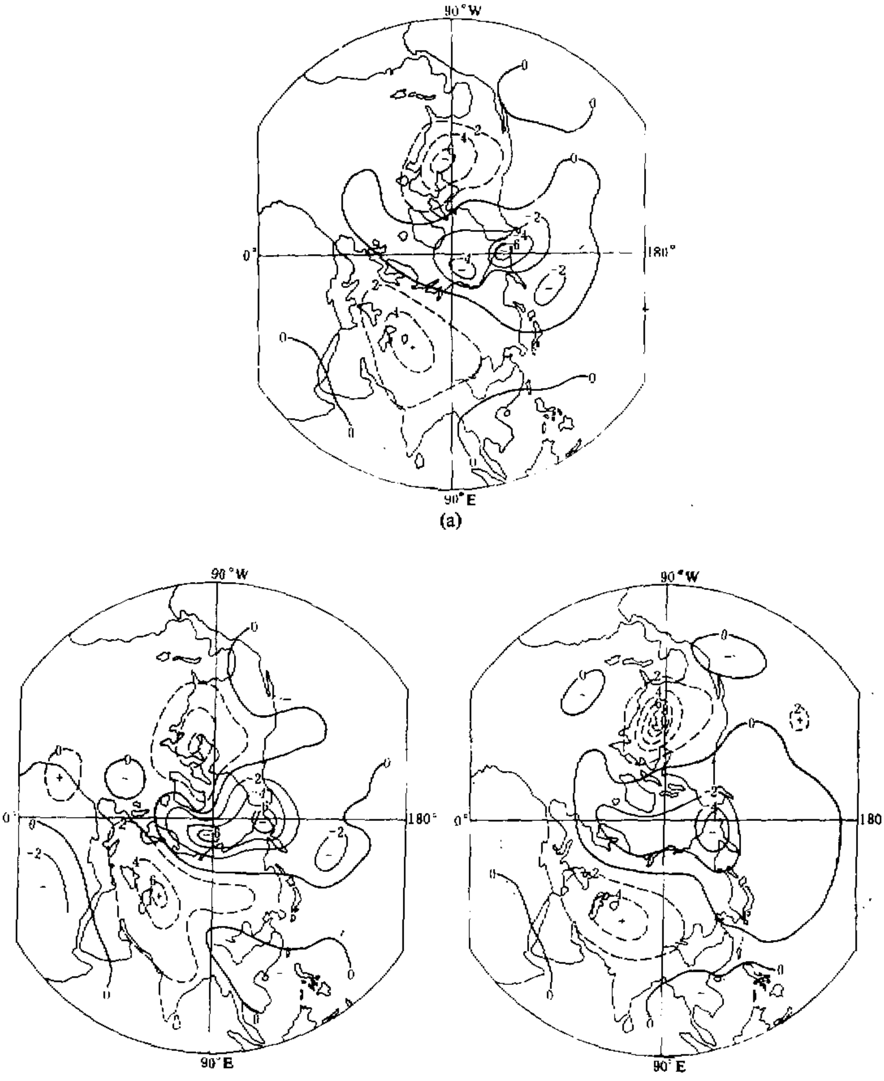
	Cases	T_S'		ϕ'					
				700 hPa		500 hPa		300 hPa	
		A*	B*	A	B	A	B	A	B
1	Nov.—Dec., 1976	0.42	0.39	0.28	−0.15	0.31	−0.10	0.27	−0.17
2	Dec. 1976—Jan. 1977	0.41	0.19	0.48	0.38	0.58	0.01	0.64	0.28
3	Jan.—Feb., 1977	0.56	0.25	0.61	0.47	0.70	0.53	0.66	0.42
4	Feb.—March, 1977	0.59	0.31	0.27	−0.14	0.32	−0.12	0.38	0.15
5	Nov.—Dec., 1982	0.60	0.47	0.26	0.20	0.34	0.42	0.16	0.15
6	Dec.1982—Jan. 1983	0.48	0.56	0.27	0.35	0.23	0.12	0.33	0.38
7	Jan.—Feb., 1983	0.44	0.51	0.17	0.61	0.40	0.58	0.21	0.36
8	Feb.—March, 1983	0.62	0.56	0.51	0.44	0.47	0.22	0.53	0.46
	Average	0.52	0.41	0.35	0.27	0.42	0.21	0.40	0.25

*A stands for the predictions and B the persistences.

On the average, the predictions of both surface temperature and height fields are superior to the persistances.

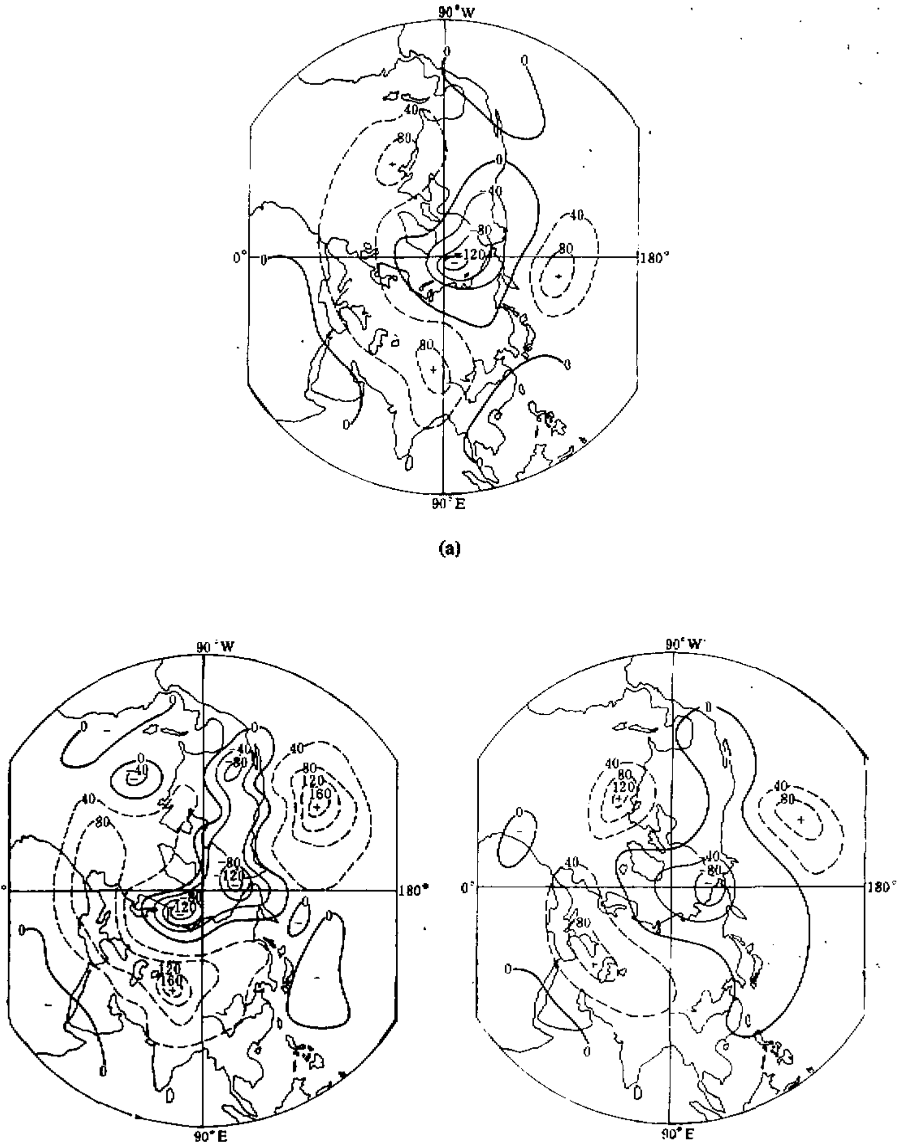
By taking the prediction of Feb. 1977 from the one-layer model[5] as an example, the correlations between observations and predictions for the surface temperature and 500 hPa height fields are 0.36 and 0.42 respectively, but the corresponding correlations given by the three-layer model of this paper are 0.56 and 0.70 respectively. Obviously the predicting ability of the latter is better than that of the former.

The predictions (shown in chart (a)) of the anomalous surface temperature and 500 hPa height fields for March 1977 are illustrated in Figs. 2 and 3 respectively. Only the 700 hPa anomalous height fields for March 1983 is given in Fig. 4 in order to save space. For the sake of making comparison, the observations (shown in chart (b)) are also given in these figures.



(b) (c)

Fig. 2. Anomalous fields of earth's surface temperature, March 1977. Chart (a) is the monthly prediction, (b) is the observation and (c) is the seasonal prediction.



(a)

(b)

(c)

Fig. 3. As in Fig. 2 except for 500 hPa height.

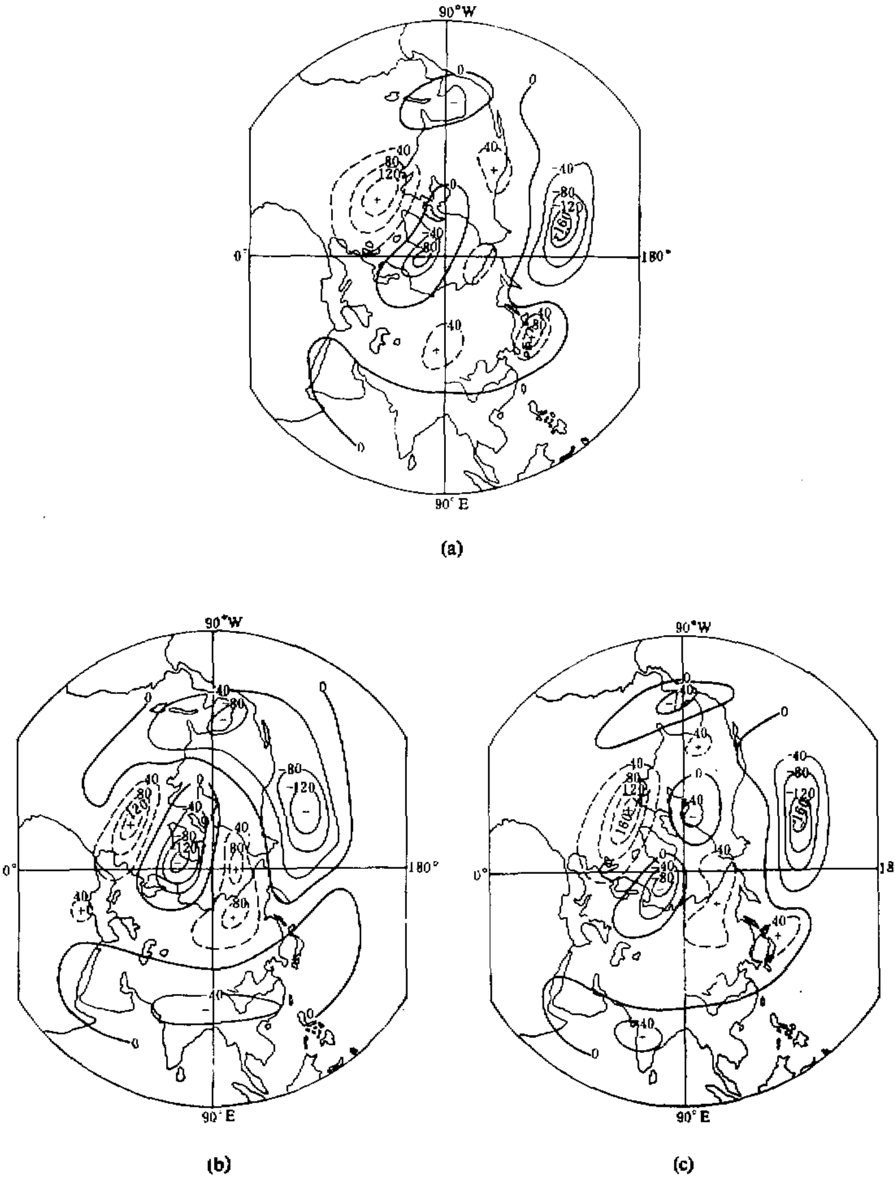


Fig. 4. Anomalous fields of 700 hPa height, March 1983. Chart (b) is the observation. Charts (a) and (c) are the predicted results by AFM and AGCM, respectively.

V. THE COMPARISON WITH AGCM

In what has been called the anomalous general circulation model (AGCM), the method to predict anomalous surface temperature is the same as in AFM. Assuming that as an external source the surface temperature fields are taken to be constants, we integrate Eq. (5) straightforwardly and take a monthly mean to predict the anomalous geopotential heights.

The time step is taken as two hours. Six cases of predictions are performed by the AGCM. Results predicted by the AFM and AFCM are listed in Table 2.

Table 2. Comparison of the Correlation between Observations and Predictions by AFM and AGCM

Cases		ϕ'_{700hPa}		ϕ'_{500hPa}		ϕ'_{300hPa}	
		AGCM	AFM	AGCM	AFM	AGCM	AFM
1	Dec. 1976—Jan. 1977	0.56	0.48	0.54	0.58	0.60	0.64
2	Jan.—Feb., 1977	0.68	0.61	0.67	0.70	0.65	0.66
3	Feb.—March, 1977	0.29	0.27	0.35	0.32	0.38	0.38
4	Dec. 1982—Jan. 1983	0.24	0.27	0.29	0.23	0.39	0.33
5	Jan.—Feb., 1983	0.20	0.17	0.36	0.40	0.28	0.21
6	Feb.—March, 1983	0.67	0.51	0.50	0.47	0.51	0.53
	Average	0.42	0.39	0.46	0.45	0.47	0.46

As shown in Table 2, the predicting ability of AGCM is almost the same as that of AFM. However the former results seem to be slightly better than the latter, especially for 700 hPa height. The computation time required for the AGCM is 188 minutes but only two minutes for the AFM. Clearly it is much more economical to run the AFM.

The pattern of 700 hPa height in March 1983 predicted by the AGCM is depicted in Fig. 4 (c).

VI. THE ABILITY OF SEASONAL FORECASTS

Four experiments of seasonal forecasts are carried out, in which the monthly anomalous surface temperature in the preceding three months is taken as the initial field.

Two different step lengths, one month and three-month, have been tested in our experiments. It is shown that using one-month step length would make the adjustment of the parameters more complicated and waste more computation time. On the other hand, the reults given by three-month step length are not too bad. So we adopt threemonths as step length in the final calculations.

The correlation between observations and forecasts as well as the persistences (the correlation between observations of the predicted month and three months ago) is listed in Table 3. Three of cases are successful, i. e. their correlations are not only higher than those of persistence but also close to 0.3. Only the prediction of height fields in Feb. 1983 fails.

Figs. 2 (c) and 3 (c) give the seasonal predictions of the anomalous surface temperature and of 500 hPa height in March 1977 respectively. Their patterns are similar to the observations (chart (b)).

As shown in Table 3 and the charts, it can be seen that the seasonal forecasts in the sense of average are promising. The AFM seems to have potential ability in predicting large-scale circulation anomalies.

Table 3. Comparisons of the Correlation between Observations and Seasonal Predictions or Persistences

Cases		T'_S		ϕ'_{700hPa}		ϕ'_{500hPa}		ϕ'_{300hPa}	
		A*	B*	A	B	A	B	A	B
1	Nov. 1976—Feb. 1977	0.46	0.39	0.58	−0.17	0.74	−0.13	0.76	−0.03
2	Dec. 1976—March 1977	0.36	0.02	0.16	−0.10	0.29	−0.05	0.34	0.07
3	Nov. 1982—Feb. 1983	0.15	0.15	−0.03	0.18	−0.09	0.06	−0.09	−0.27
4	Dec. 1982—March 1983	0.45	0.44	0.36	0.31	0.40	0.39	0.48	0.41
	Average	0.36	0.25	0.28	0.06	0.34	0.07	0.38	0.05

*A stands for the predictions and B the persistences.

It is also shown from the experiments that the prediction of the anomalous geopotential height depends mainly upon the external sources (the anomalous surface temperature here) and not upon its initial fields. However, the prediction of anomalous surface temperature is intimately related to its initial fields. It is easy to understand that owing to the fact that thermal inertia of the surface temperature (especially the sea temperature) is relatively large and the memory of the atmospheric motion is rather weak, the effect of the initial fields would not be important after enough time and the atmospheric state should adapt itself to the external sources through the adjustment of various processes in the atmosphere.

VII. SUMMARY AND CONCLUSION

As one of the approaches of the long-range numerical forecast the AFM has given rise to various comments[7—9] by colleagues at home and abroad, since the concept and the physical basis of developing AFM were presented in 1977[1] and the first example of monthly forecast was published in 1979[2]. Any long-range forecasting method, just as there are two sides to everything, has its advantages and disadvantages. In this section we would like to make discussions based on the works in the last decade and the results in this paper.

The advantages of an anomalous model are evident. They can avoid predicting the climate fields, which have not been numerically simulated very well as yet, and make use of observed monthly mean climate state as the known fields. In this way, the effect of the climate fields on the evolution of anomalous fields can be taken into account, no matter how they are formed. There is no doubt that the AGCM is better than the usual GCM for the long-range numerical forecasts although people prefer GCM to AGCM.

Actually, a comparative experiment was carried out by Navarro and Miyakoda[12]. Using GCM and AGCM, they attempted to predict an anomalous circulation field which had been given in advance as a reference. In GCM, when zonal wave numbers were taken to be 30 (i. e. $m=30$), the "prediction" is close to the reference, but if $m=15$, the predicted pattern is almost opposite to the reference. Even if $m=15$ in AGCM, however, the result is still as good as that when $m=30$ in GCM.

To develop a strict AGCM is difficult. When we average the atmospheric motion equations in time (e. g. one month), the Reynolds stress terms must emerge due to the presence of the nonlinear terms. How to deal with these terms is still a problem in classical turbulent theory. We may neglect these terms as we did in our early papers[1-5] and also use the conventional method, in which the Reynolds terms can be parameterized by the turbulent diffusion terms of the anomalous components, as in the case of this paper. It is well known that the Reynolds terms only act as the diffusing and smoothing factors in the evolution of anomalous fields. It is shown from Navarro and Miyakoda that the Reynolds terms in the anomalous model have no obvious effects on the phase of the anomaly patterns, but make the amplitudes weak in some degree. If the effects of Reynolds terms are simply like that in all circumstances, it would be fortunate in making long-range forecasts with the AGCM. Otherwise it would be impossible for us to make the equations closed just like in the case of classical turbulent theory.

A contentious problem is to filter Rossby waves. Since there do exist Rossby waves in both atmosphere and oceans and, as is well known, they play a good role in the short-range forecasts, it is easy to dispute with the effects of the transient Rossby waves on the long-range numerical forecasting. This problem has been theoretically discussed by Egger[9] in terms of a simplified model. In his opinion, if the fast-varying disturbances (considered as Rossby waves) are filtered out, the interactions between high and low frequency components are also filtered out, so the predicted results would be seriously distorted. The model used by Egger, however, was not an anomalous model. As Chou Jifan[11] has pointed out, Egger overestimated the relative errors caused by filtering Rossby waves. Another problem to be worth discussing is: what errors would be introduced into monthly and seasonal forecasts by filtering planetary and long waves which play a very important role in the long-range weather processes and retaining only quasi-steady stationary Rossby waves? (We call the stationary Rossby waves as "quasi-steady" because the heating of earth's surface and the climate fields of atmospheric circulation vary slowly with time.) The errors caused by filtering transient Rossby waves can be estimated through numerical experiments. Navarro and Miyakoda[12] pointed out that the predicted large-scale anomalous patterns by both AFM and AGCM were comparable except amplitudes. In this paper, the predicted phases and amplitudes of circulations are similar to observations. Even in the case of one-layer model the amplitudes are also not weak. The key is to choose the most appropriate parameters so as to prevent the amplitudes from being stronger in some cases or weaker in others. Moreover, the AFM is economical and can be used as "a quick look", as Navarro and Miyakoda said, to determine the positive and negative area of predicted pattern.

As far as some technical aspects are concerned, the AFM do have to be improved. Our fifty examples of the monthly forecasts including the eight cases in this paper show that the results of the surface temperature and the geopotential height in the polar region are poor. It seems that the effect of feedback between ice albedo and temperature should be taken into account in the model. A simple method may be utilized, by which the albedo is taken as a function of temperature, as it is used in "energy balance climate model"[13, 14]. On the average, the predicted results in Asia are not as good as those in America[9]. It may be caused by omitting the presence of the Tibetan Plateau. Furthermore, the interactions between the cloudiness and the radiation should also be included, for they affect not only the formation of climate but also the monthly and seasonal forecasts. It is also necessary to develop a tractable scheme of parameterization in order to save a large amount of labour.

The last theoretical problem is the interaction between the atmospheric circulation at mid-latitudes and in the tropics, especially during El Nino events. As shown from analyses[15] and theories[16], when El Nino or the Southern-Oscillation occurs near the equator, the atmospheric circulation at mid-latitudes will be severely adjusted. This has been also confirmed by perennial statistical facts[17]. The quasi-geostrophic model used in this paper, however, is not applicable to the tropics. The years considered in the present paper are just El Nino years. But all the predictions are comparable or superior to the persistence except for the case of Feb. 1983. Now a question arises: what is on earth the ratio between the response of the atmospheric circulations at middle latitudes to the sea surface temperature in the equatorial area and their response to the local temperature or, how much time on earth does it take to allow the variation of the SST in the equatorial ocean to have a significant influence upon the atmospheric circulations at the middle latitudes? Anyway, to include the physical processes predominating in the tropics into this model will be helpful.

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