Paper No. 29

EFFECT OF A PACIFIC SEA SURFACE TEMPERATURE ANOMALY ON THE CIRCULATION OVER NORTH AMERICA

J. Shukla and B. Bangaru, *Massachusetts Institute of Technology, Cambridge, Massachusetts, Sigma Data Services Corporation, c/o Goddard Space Flight Center, Greenbelt, Maryland*

ABSTRACT

During the fall and winter of 1976-77, sea surface temperature (SST) in the north Pacific was characterized by abnormally cold temperatures in the central and western portions of the north Pacific with a warm pool located off the west coast of the U. S. (Figure 1). Namias (1978) has suggested that the north Pacific SST anomalies may have been one of the multiple causes of the abnormally cold temperatures in eastern North America during the 1976-77 winter. This study attempted to test this hypothesis by conducting a numerical experiment with the GLAS general circulation model.

INTRODUCTION

The model used in the present study is the one described earlier by Somerville et al. (1974) and Stone et al. (1977). A modified version of the model has also been presented in the proceedings by Halem et al. (1978). The experiments were performed by first integrating the GLAS GCM for 45 days with the climatological mean SST and the observed initial conditions valid for January 1, 1975. This integration is referred to as the Control run (C). The climatological SST field was then changed by adding a time invariant anomaly field and therefore, although the climatological SST varied with season, the imposed anomaly field remained constant with time. The structure of the imposed SST anomaly was the same as shown in Figure 1, but the numerical values were exaggerated by considering them in °C rather than °F. The model was integrated again for 45 days and will be referred to this run as the Anomaly run (A).

Control Run C and Anomaly Run A were further repeated with their respective boundary conditions in SST but the initial conditions in u, v, T, and surface pressure were randomly perturbed. The spatial variation of the random perturbations corresponded to Gaussian distributions with zero means and standard deviations of 1°C in temperature, 4 m/s in horizontal wind components and 3 mb in surface pressure over land points and 2°C in temperature, 8 m/s in horizontal wind components, and 6 mb in surface pressure over ocean points.

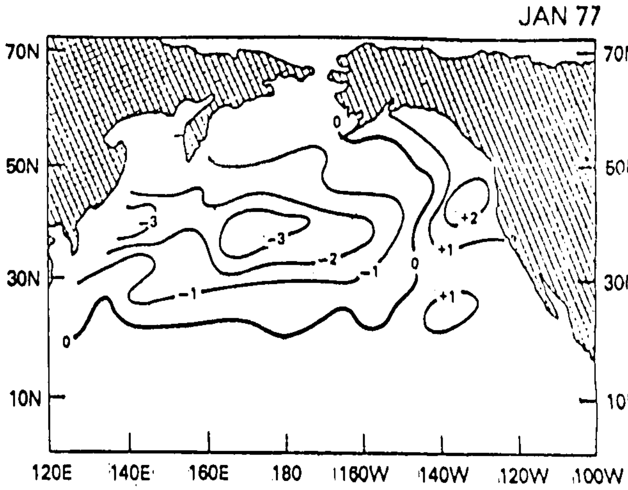

Fig. 1. Observed sea surface temperature anomaly (°F) during January 1977.

These runs are referred to as Initial Condition Perturbation Runs C_1 and A_1 for Control (C) and Anomaly (A), respectively. Four additional Initial Condition Perturbation Runs were already made by Spar et al. (1978) which are referred to as C_2, C_3, C_4, and C_5. The atmospheric parameters for the six runs are referred to as C, C_1, C_2, C_3, C_4, C_5, as the mean control (Cm) and the average of two anomaly runs A and A_1 as mean anomaly (Am). In order to assess the response of the imposed SST anomaly on the atmospheric circulation, the differences between the mean control and the mean anomaly runs averaged for the period between day 15 through day 45 are examined and the magnitude of the differences is compared with respect to the standard deviation among the mean monthly values for the six control runs for this period.

Figure 2a shows the differences between the mean anomaly and the mean control runs for the 700 mb temperature. The largest differences are found along the International Date Line, which is the longitude of maximum negative anomaly in SST, and the eastern parts of Canada, and the northern U. S. A positive anomaly is found over Greenland. Occurrence of colder 700 mb temperatures over the cold anomaly and warmer 700 mb temperatures over the warm anomaly can be explained by considering the radiative, sensible and latent heat fluxes. A detailed examination of the model-generated heat fluxes showed that the evaporation and convective cloudiness decreased over the cold anomaly. Reductions in the moisture and the sensible heat flux, which reduces the convective clouds, causes a reduction in the latent heat of condensation and this can also cause cooling of the atmospheric temperatures. Consistent with the decrease in the convective

TEMPERATURE AT 700 MB (DIFF)

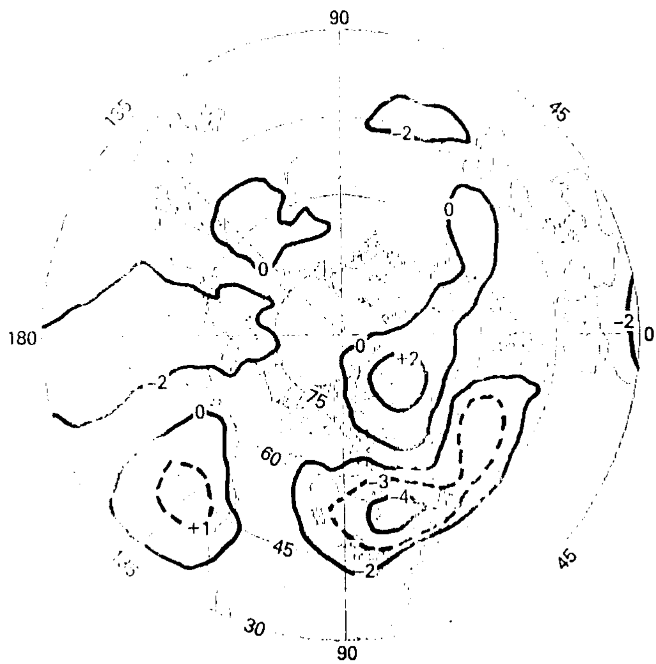

Fig. 2a. Temperature at 700 mb (Difference).

cloudiness, it was also found that the solar flux at the surface increased but the long wave flux at the surface decreased. Since the sea surface temperatures were prescribed, this feedback does not operate in the model. It should be noted, however, that the net effect of these diabatic heat sources and sinks is such that the heat source (sink), which is initially confined to the lower boundary, finally extends into the troposphere.

The most interesting feature in this figure is the coldest 700 mb temperatures centered around 50N, 75W. This is clear evidence of the downstream response of the model to the SST anomalies in the Pacific. Figure 2b shows the ratio of the differences and the standard deviations among the six control runs. These ratios are the signal-to-noise ratio. Two areas of maximum signal to noise are found, one over the anomaly itself and the other centered around 50N, 75W. The positive temperature anomalies over Greenland were found to have a signal-to-noise ratio less than two.

In the earlier numerical experiments with the NCAR model (Kutzbach et al. [1977], Chervin et al. [1976]) no significant downstream effect was noticed. Although the two general circulation models are not identical (especially with regard to their simulation of the transient eddies), in GLAS' opinion, the primary reason a downstream effect was observed in the GLAS model was due to the nature of the spatial structure of the SST anomaly.

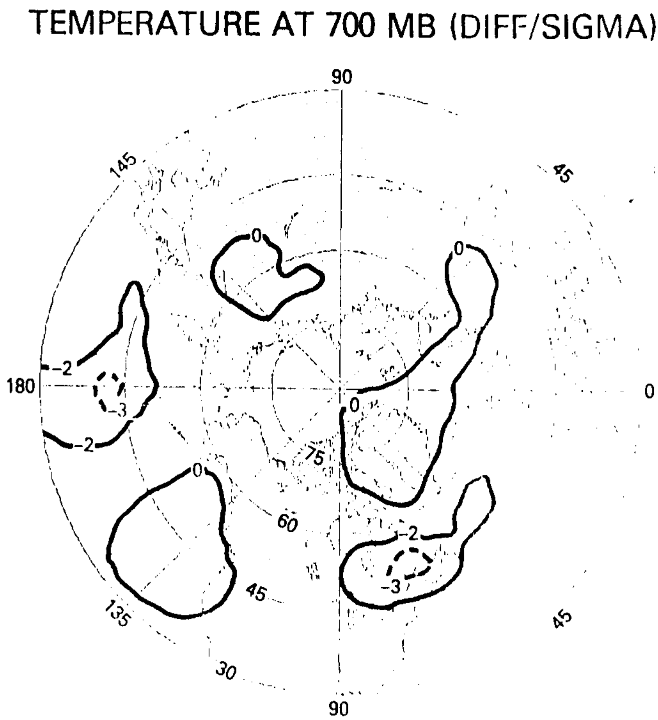

Fig. 2b. Temperature at 700 mb (Difference/Standard Deviation).

The results of these numerical experiments support the hypothesis by Namias that the SST anomalies over the Pacific during the 1976-77 winter may be one of the contributing factors towards very cold temperatures over the northeast U. S. and warm temperatures over the Alaska region. Since this was not a coupled ocean-atmosphere model, SST anomalies were assumed to persist for the whole period of integration. This assumption is justified byu the observed fact that the SST anomalies do persist for a time period ot several months.

These results show clear evidence of a downstream response of the model atmosphere to the imposed SST anomalies over the Pacific. It is interesting to note that for some levels the downstream effect away from the anomaly is more than the effect over the anomaly itself. Since the natural variability of the mid-latitude atmosphere is rather large, the standard deviation among six predictability runs was calculated and the ratios of the mean differences to the standard deviations indicated that the downstream effects are indeed significant.

The results of the present study suggest that the downstream orographic barriers may contribute to amplify the SST-generated atmospheric perturbations. In other words, an orographically forced atmospheric flow regime may be more sensitive to further modification by the perturbations generated by the SST anomalies. This qualitative conjecture is suggested by those numerical experiments in which it is found that the effects of the north Pacific SST anomalies are most prominent on the western and the eastern sides of the North American continent. This is of special significance for the winter of 1976-77 because, as pointed out by Namias (1978), the anomalous flow pattern over North America was in phase with the normal winter flow pattern. Therefore, this was interpreted as an inphase amplification of the normal winter circulation, which is orographically and thermally forced by the mountains and the mean heat sources and sinks. The purpose of this numerical experiment was not to simulate the actual events of the 1976-77 winter but only to examine the effects of similar SST anomalies on the model atmosphere. It should be noted that the atmospheric conditions in the mean control run corresponded to the winter of 1975.

Detailed examination of the model-simulated daily charts indicated that in general the anomaly runs did not show a persistent blocking pattern near the west coast of the U. S. as observed during the 1976-77 winter. However, there were periods of 3-5 day duration in which the ridge over the west coast of the U. S. was highly intensified and such events were more frequent in the anomaly run compared to the control run. Blocking situations do occur but they do not last too long. It is not clear whether this is a manifestation of some model deficiency or it is because the model integrations are not performed long enough for several interannual cycles.

References

Chervin, R. M., W. M. Washington, and S. H. Schneider, 1976: Testing the statistical significance of the response of the NCAR general circulation model to north Pacific Ocean surface temperature anomalies. J. Atmos. Sci., 33, pp. 413-423.

Halem, M., J. Shukla, Y. Mintz, M. L. Wu, R. Godbole, and Y. Sud, 1978: Climate comparisons of a winter and summer numerical simulation with the GLAS general circulation model. Proceedings at the JOC Study Conf. on Climate Models, April 3-7, Washington, DC.

Kutzbach, J. E., R. M. Chervin, and D. H. Houghton, 1977: Response of the NCAR general circulation model to prescribed changes in ocean surface temperature, Part 1: Mid-latitude changes. J. Atmos. Sci., 34, pp. 1200-1213.

Namias, J., 1978: Multiple causes of the North American abnormal winter 1976-77. Mon. Wea. Rev., 106, pp. 279-295.

Somerville, R. C. J., P. H. Stone, M. Halem, J. E. Hansen, J. S. Hogan, L. M. Druyan, G. Russell, A. A. Lacis, W. J. Quirk, and J. Tenenbaum, 1974: The GISS model of the global atmosphere. J. Atmos. Sci., 31, pp. 84-117.

Spar, J., J. J. Notario, and W. J. Quirk, 1978: An initial state perturbation experiment with the GISS model. Mon. Wea. Rev., 106, pp. 89-100.

Stone, P. H., S. Chow, and W. J. Quirk, 1977: The July climate and a comparison of the January and July climates simulated by the GISS general circulation model. Mon. Wea. Rev., 105, pp. 170-194.