NOTES AND CORRESPONDENCE

Interdecadal and Interannual Variations over the North Pacific Simulated by a Set of Three Climate Experiments

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(Manuscript received 22 March 1996, in final form 12 September 1996)

ABSTRACT

A set of three climate experiments is performed using a T42 GCM version of the Japan Meteorological Agency global model to examine extratropical interdecadal and interannual variations over the North Pacific region associated with the anomalous SST forcing in the Tropics. Three independent 34-yr integrations from January 1955 to December 1988 are forced by the same SST boundary condition observed on the global scale.

The set of these integrations provides clear evidence that the tropical SST impact upon the wintertime extratropical model atmosphere in the North Pacific is very significant. It is also concluded that the abrupt change of midlatitude circulation regime that occurred in the winter of 1976/77 was primarily caused by very localized tropical heating in the central Pacific. This anomalous SST forcing was most likely responsible for persistent negative height anomalies over the central North Pacific during at least the period from 1977 to 1983, which formed a part of the extratropical wave train traversing the North Pacific and North America, which produced warm temperature anomalies along the west coast of North America, as well as western Canada. However, an increase in observed wintertime surface temperature over northern Eurasia at almost the same period can little be explained by anomalous SST forcing from the Tropics. The internal variability of the extratropical atmosphere itself is suggested to contribute much more to the circulation regime over the Eurasian continent.

1. Introduction

In order to explore the predictability of seasonal forecasts using atmospheric GCMs, an ensemble of long-term simulations utilizing the GCMs forced with observed global SSTs has very recently been performed (e.g., Kumar and Hoerling 1995; Kumar et al. 1996; Stern and Miyakoda 1995). They show that the SST impact on the total variance of the extratropical atmosphere is relatively small, despite the large impact of SST on the total variance of the tropical atmosphere, which means that the seasonal forecast in the extratropics is not easy due to less potential predictability. This issue is also reviewed by Palmer and Anderson (1994). Likewise, an evaluation of SST-forced atmospheric variability in the extratropics is made by Harzallah and Sadourny (1995), who performed an ensemble of seven independent 19-yr simulations with observed SSTs, although they do not highlight the seasonal forecasts.

Multiple GCM simulations presented above are of less than 20-yr integration because they focus mainly upon seasonal and/or interannual timescales. If we try to perform longer-term simulations than about 30 yr, what new finding could we obtain from those climate simulations? One benefit, as Kumar et al. (1996) mentioned, is that the evaluation of SST-forced extratropical atmospheric variability is expected to be more realistic than that by short-term climate simulations because it is based on averages over many ENSO events. The other is that it would allow us to understand to what extent interdecadal variations appearing in the extratropical circulation are influenced by SST forcing. The emphasis of this study is mainly upon the latter issue, although both issues are considered.

One of the main concerns with the interdecadal scale is an abrupt change in the midlatitude circulation regime over the North Pacific in the winter of 1976/77. This phenomenon has been well simulated by several GCMs (Graham 1994; Lau and Nath 1994; Graham et al. 1994;
Kawamura et al. (1995). Some of them conclude that it basically results from tropical SST anomalies on the interdecadal scale. Kawamura et al. (1995, hereafter referred to as KSS) also demonstrate that the polarity of the Pacific–North American (PNA) pattern is indicative of definite interdecadal variability due to tropical SST forcing, but observed PNA has a more evident interdecadal-scale trend than that simulated. Of course, we cannot deny that deficiencies of the GCM might lead to the discrimination between simulation and observation. According to previous GCM studies, however, tropical SST impact on the extratropical model atmosphere is likely to be different due to the internal variability of the extratropical atmosphere itself, even though the tropical SST forcing is quite similar. Lau and Nath (1994) show, in fact, that one out of four independent realizations is remarkably different from the other realizations in terms of the extratropical response of the model atmosphere. This is suggestive of the importance of ensemble climate experiments for examining the interdecadal and interannual variations in the extratropics using an atmospheric GCM. The objectives of this study are to 1) follow up the conclusions presented by KSS, who have examined interdecadal and interannual variations in the northern extratropics by performing a single 34-yr realization with a GCM employing observed SSTs, and 2) to discuss upper-tropospheric geopotential height and surface air temperature anomaly patterns associated with the abrupt change in the extratropical circulation regime in the winter of 1976/77, based on a set of three climate experiments.

2. Experimental design

The model utilized for this research is a T42 GCM version of the Japan Meteorological Agency global model (JMA-GSM89). The horizontal resolution is equivalent to approximately 2.8° lat × 2.8° long. A set of three independent 34-yr integrations from January 1955 to December 1988 has been performed employing prescribed global SSTs. The three independent simulations are named the R1, R2, and R3 experiments for convenience. The overall features of R1 have already been documented by KSS. The initial conditions for R2 and R3 are given by the last atmospheric states simulated in R1 and R2, respectively. A brief explanation of the model and experimental design is given by KSS.

3. Results

To begin with, Fig. 1 shows the differences in simulated wintertime (December–February) sea level pressure for the period 1977–1986 versus that for the period 1967–76, which are obtained by the three independent simulations. Comparisons with observations are also made. If we take a look at the Aleutian low region, we find that all three experiments produce negative anomalies over that region, but their anomalies are considerably different in terms of magnitude. Highly significant negative sea level pressure anomalies can be seen in the R1 and R3 runs, which are also comparable in magnitude to that observed. Yet we cannot find any significant anomalies in and around the North Pacific region in the R2 experiment. This feature certainly indicates that one out of three independent simulations is obviously different from the other experiments, even on the decadal scale, as for the extratropical atmosphere. The above result leads us to investigate how the model atmosphere in the Tropics responds to the same SST forcing in each realization.

Three interannual time series of wintertime 200-hPa geopotential height anomalies over the central equatorial Pacific region (10°N–10°S, 170°–140°W), where tropical responses to SST anomalies are evidently strong (see Fig. 9 of KSS), are exhibited in Fig. 2a. It is clearly found that all the three experiments exhibit the same tropical SST forcing, which coincides well with the observed Southern Oscillation index (not presented). This supports the previous studies (e.g., Lau 1985; Stern and Miyakoda 1995; Kumar and Hoerling 1995) showing that SST has a crucial impact on the total variance of the tropical atmosphere. By contrast, if we highlight 500-hPa geopotential height variations over the North Pacific region (35°–55°N, 170°E–140°W) as an indicator of the extratropical response of the model atmosphere (Fig. 2b), the situation is quite different. The time series of 500-hPa geopotential height anomalies derived from the three realizations seem to be independent of each other. Actually, we cannot find any significant correlations between the time series. Based on the three real SST experiments, we estimated the ratio of SST-forced variance to the total variance of monthly mean 500-hPa height anomalies in the corresponding region to clarify to what degree the SST forcing affects interdecadal and interannual variability in the extratropical circulation. The methodology proposed by Rowell et al. (1995) and Harzallah and Sadourny (1995) is applied for the estimation. It is found, as a consequence, that the SST-forced variance there accounts for only about 10%–20% of the total variance. We consider that the internal variability of extratropical model atmosphere itself reaches 80%–90% in this region, it seems reasonable that each interannual time series behaves almost independently. Yet, we cannot deny the substantial contribution of tropical SST forcing to the interannual and interdecadal variations of the extratropical atmosphere. In fact, the cross correlations between tropical and extratropical responses in the R1, R2, and R3 runs, which are computed from the time series shown in Figs. 2a and 2b, are −0.69, −0.46, and −0.66, respectively. Although the correlation in R2 is comparatively low, all the three coefficients surpass the 95% confidence level with respect to statistical significance. Furthermore, if we take three-run averages of the height anomaly data, the interannual variations of the wintertime 500-hPa
geopotential height field over the North Pacific region are found to coincide quite well with those of 200-hPa height field over the central equatorial Pacific \((r = -0.81)\), which is one of the good indicators of the tropical response of the model atmosphere, as shown in Fig. 2c. This provides clear evidence that the impact of the tropical SST upon the extratropical atmosphere is very significant. In particular, the persistence of the anomalous 500-hPa height fields since the winter of 1976/77 is well simulated in terms of the set of three experiments, which is substantially governed by the anomalous SST forcing in the Tropics. The area mean 500-hPa geopotential height over the North Pacific region \((35^\circ - 55^\circ N, 170^\circ E - 140^\circ W)\) is quite well correlated with the PNA teleconnection index defined by Wallace and Gutzler (1981). Actually, if we take three-run averages of both sets of data, the correlation between them is \(-0.95\), which shows that the area mean 500-hPa height in the North Pacific that we defined is a good indicator of dominance of PNA, as well as the North Pacific (NP) index proposed by Trenberth and Hurrell (1994). These facts support the major conclusion presented by KSS that the tropical forcing is primarily responsible for the abrupt change in the extratropical circulation regime in the winter of 1976/77 via the prominence of the PNA mode.

Let us note that another feature of interest is included in Fig. 2b. As stated earlier, the three time series of simulated 500-hPa geopotential height anomalies have no correlations with each other. However, if we focus specifically on the period 1977–83, which corresponds quite to the period II defined by KSS, it is clearly seen that all three realizations show a very similar tendency for persistent negative height anomalies. This tendency disappears after the winter of 1982/83. Compared with the other periods, the period of 1977–83 is viewed as a very curious period because the three time series of simulated 500-hPa height anomalies do not seem to be independent of each other during this period. Figure 3 presents the wintertime 200-hPa geopotential height anomaly patterns averaged over the period 1977–83 for each experiment. Also shown is three-run mean 200-hPa height anomaly pattern (Fig. 3a). In Fig. 3a, a major response of the tropical atmosphere is characterized by

![Fig. 1. (a) Difference in the observed wintertime sea level pressure for the decade 1977–86 vs the decade 1967–76, where 1976 refers to the period from December 1975 to February 1976. Contour interval is 1 hPa, and shading denotes negative values. (b) As in (a) but for the R1 experiment. (c) As in (a) but for the R2 experiment. (d) As in (a) but for the R3 experiment. The regions where values are different from zero at the 5% level of statistical significance using a t test are denoted by dots.](image-url)
positive height anomalies over the central equatorial Pacific. The tropical response, with a dominant positive anomalous area in both hemispheres, is somewhat asymmetric with respect to the equator, and the anomalies around the Hawaiian islands are more significant than those located in the Southern Hemisphere. At any rate, it should be noted that the significant response of the tropical atmosphere is due to very localized heating in the central equatorial Pacific.

Associated with the tropical SST forcing is the establishment of prominent negative height anomalies over the North Pacific region near 40°N, 160°W, amounting to ~60 m (see Fig. 3a). Positive and negative height anomalies are also evident over northwestern Canada and the southern United States, respectively. These two positive and two negative anomalous centers coincide well with the four action centers used in defining the PNA index. Thus, the 200-hPa height anomaly pattern exhibits a well-organized extratropical wave train, with two embedded cyclonic cells and two anticyclonic cells emanating out of the localized tropical heating in the central Pacific. We emphasize here that the above features are well simulated by all three independent experiments, although slight differences are seen, especially in terms of magnitude. It is shown in Fig. 1 that the R2 run is different from the other two experiments, but if the period of 1977–83 is particularly concerned, R2 is also successful in simulating negative anomalies over the North Pacific region, with almost the same magnitude of around ~60 m (Fig. 3c). It is most likely that the tropical SST forcing during the period from 1977 to 1983 is at least responsible for persistent negative height anomalies over the North Pacific, which form a part
of the extratropical wave train traversing the North Pacific and North America.

No remarkable anomalies can be seen over the Eurasian continent, as shown in Fig. 3a, although weak negative anomalies are indicated over central Eurasia. In fact, each independent simulation produces a considerably different anomaly pattern, as for the Eurasian continent. This is consistent with the inference that the extratropical response of the model atmosphere to SST anomalies in northern winter tends to be fairly strong (weak) in the regions of the Western (Eastern) Hemisphere, as presented by KSS (their Fig. 13). A much greater contribution of internal variability to the model atmosphere in the extratropics over the Eurasian continent is expected.

Our attention is next focused on the wintertime surface air temperature anomaly patterns averaged over the same period in each run, as revealed in Fig. 4. If we take a look at the three-run mean temperature anomaly pattern (Fig. 4a), distinctive positive temperature anomalies are distributed along the west coast of North America, as well as western Canada, together with a maximum value of about +1°C over Alaska. Of particular interest is that each simulation demonstrates the positive temperature anomalies around Alaska, with almost the same magnitude. The increase in temperature along the west coast of North America is probably attributed to the northward intrusion of advected warmer air in that area, associated with deepened Aleutian lows (e.g., Cay- and Peterson 1989; Trenberth 1990), as stated already in KSS. By contrast, weak negative temperature anomalies are indicated over northern Eurasia (Fig. 4a), but each realization fails to produce a similar temperature anomaly pattern over northern Eurasia. This is evidently associated with the differences in the dynamic structure of extratropical circulation, as inferred from Fig. 3.

4. Summary

The conclusions from this study are summarized in the following.

- The wintertime extratropical response over the North Pacific due to the tropical SST forcing is more clearly shown by a set of three climate experiments. It is strongly supported that the abrupt change of the mid-latitude circulation regime that occurred in the winter of 1976/77 resulted from very localized tropical heating in the central Pacific.
- The anomalous tropical SST forcing is most likely responsible for persistent negative height anomalies over the North Pacific during at least the period from 1977 to 1983, which form a part of the extratropical wave train traversing the North Pacific and North America. This wave train, which is identified with PNA, results in warm temperature anomalies along the west coast of North America, as well as western Canada.
Although all three independent realizations certainly indicate that simulated interdecadal and interannual variations of the extratropical atmosphere are correlated significantly with the same tropical SST forcing, the three time series of simulated 500-hPa height anomalies, which are used as an indication of the extratropical response, have never had any significant correlations between each other since the internal variability of the extratropical atmosphere itself contributes a great deal to the total variance estimated by the set of experiments.

From observations, it is known that the circulation regime that occurred in the winter of 1976/77 persisted until about 1988 (e.g., Trenberth and Hurrell 1994). Our simulations indicate, on the other hand, that the anomalous SST forcing from the Tropics contributes substantially to the maintenance of the abnormal circulation regime over the North Pacific during at least the period from 1977 to 1983. The discrimination between observation and simulation might be attributed to deficiencies in the GCM that was used in the present study. However, as documented in KSS, it is also possible that even though tropical SST forcing is quite similar, the extratropical response of the model atmosphere to anomalous SSTs is considerably different due to the internal variability of the extratropical atmosphere itself. Actually, we showed some model response features in Fig. 1 and Fig. 2b. If we look at Fig. 2b once again, only the R3 experiment is seen to demonstrate persistent negative anomalies until 1988, in contrast with the other two independent simulations. The internal variability is expected to have a crucial effect on this difference. The present study suggests that the observed persistent circulation regime over the North Pacific region from post-1983 to about 1988 cannot necessarily be explained by anomalous SST forcing from the Tropics, which is clearly distinguished from the period of 1977–83.

As exemplified in Fig. 2c, a considerable reduction in the estimated internal variance due to the three-run averaging process is suggested because the two time series are well correlated with each other. It is thus anticipated that our findings, obtained by a limited number of simulations, will essentially be unchanged even if many more simulations are performed. We are aware, of course, that the length of the simulations and the number of parallel simulations are both crucial to es-
timating a realistic extratropical response to the SST forcing. Much work needs to be done before completely understanding of the internal modes in the extratropical circulation is reached.

Acknowledgments. We would like to thank Dr. Kanzaburo Gambo and Dr. Tomonori Matsuura for stimulating discussions. We are grateful to the anonymous reviewers for their helpful comments, which led to an improved presentation of the manuscript. This research was supported by the Japan Science and Technology Agency through the project study of disaster predictions in global hydrologic processes. Computations were performed with the Cray Y-MP2E/264 supercomputer of the National Research Institute for Earth Science and Disaster Prevention.

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