On the Contribution of Major Warming Episodes in the Tropical East Pacific to a Useful Prognostic Relationship Based on the Southern Oscillation

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ABSTRACT

It is known that the Southern Oscillation Index (SOI) and the mean sea surface temperature off the Peru Coast are highly coherent and that variations of the latter are dominated by infrequent warming episodes. The present study examines the relative contribution of these warming episodes to the covariance of statistically significant correlations between the fall SOI and winter mean 700 mb heights in the Northern Hemisphere. The degree of dominance of the warming episode years in this context is evaluated by Monte Carlo methods.

It was found that, for the 30-year period studied, data pairs following tropical east Pacific warming events contributed disproportionately to major correlation maxima in much of the Northern Hemisphere. Such covariance concentrations, however, were found to be fairly likely outcomes (probability > 9%) if groups of years are chosen at random from the appropriate covariance arrays. Thus, we conclude that the influence of the fall SOI upon the subsequent winter mean 700 mb height distribution is a rather pervasive one, not limited to tropical east Pacific warming situations.

In contrast to other areas, correlation maxima in the North American sector received disproportionately small covariance contributions from the warming episode years. In northwest Canada, the contribution of those years was small and opposite in sign to the total covariance.

1. Introduction

Studies over the course of many years have described the association of the Southern Oscillation not only with the weather and atmospheric circulation over substantial portions of the globe, but also with the sea surface temperature in the tropical east Pacific. A succinct historical survey of this extensive literature may be found in Rasmusson and Carpenter (1982).

The present study is prompted by two lines of development in these studies. In the first place, the application of Monte Carlo methods to the significance testing of correlation fields (Livezey and Chen, 1983) has permitted a more secure evaluation of the statistical significance of lag relationships between the Southern Oscillation Index (SOI) and the subsequent atmospheric circulation (Chen, 1982). Secondly, a close relationship has been found between fluctuations of the SOI and the average sea surface temperature (SST) anomalies near the Peru coast (Berlage, 1966; Rasmusson and Carpenter, 1982). Since SST variations in the tropical east Pacific are dominated by moderate to strong warming events occurring, on the average, about once every four years (Ramusson and Carpenter, 1983), the question arises as to whether the statistically significant lag relationships involving the SOI have resulted largely from these same, relatively infrequent situations.

The purpose of this paper is to examine the degree of dominance of a statistically significant SOI predictive relationship by tropical east Pacific warming events. Our approach is to dissect the correlation computation to reveal the relative contribution of the covariance in various segments of the data sample to the linear correlation coefficient. We then evaluate the uniqueness of these covariance concentrations by determining the likelihood that they could be matched by random drawings of years. It is to be emphasized that we will be dealing with correlation coefficients of established statistical significance and that our results pertain only to a particular data sample.

Since lag relationships of the type studied are being reintroduced into operational long-range prediction, the answer to the question posed has some immediacy. Beyond this, it is felt that the simple methodology proposed may be of general interest.

2. Procedure and results

To examine the contribution of the covariance in definable components of a particular dataset to the correlation between two variables, the equation for the linear correlation coefficient can be written as follows:

$$r_{xy} = \frac{\overline{xy}}{s_x s_y} = \frac{1}{N s_x s_y} \sum xy$$
$$= \frac{N_1}{N}\left(\frac{\sum_1 xy}{N_1 s_x s_y}\right) + \frac{N_2}{N}\left(\frac{\sum_2 xy}{N_2 s_x s_y}\right), \qquad (1)$$

where r is the linear correlation coefficient, x and y are departures of the two variables from sample means, s_x and s_y are standard deviations and N_1 and N_2 are the number of cases in subsets 1 and 2 of the total data sample. The terms in parentheses on the right side of Eq. (1) can be viewed as the contribution per unit of data in each subset to the correlation coefficient, which is the frequency-weighted sum of these contributions. We will use this framework to examine the relative contribution of years with tropical east Pacific warming events to a prime SOI predictive relationship.

During 1950–76, warming events were taken to be instances with spring or summer peak monthly mean sea surface temperature anomaly near the Peru Coast (ship track 1 of Rasmusson and Carpenter, 1982) equal to or greater than 2°C above normal. By this definition, warming events occurred in 1951, 1953, 1957, 1965, 1969, 1972 and 1976. These are the same years subsequently designated as "warm episode years" by Rasmusson and Carpenter (1983), who also extended consideration through 1979 with no further warm episode additions.

Chen (1982) has shown that both summer and fall SOI (mean sea level pressure difference between Tahiti and Darwin) are significantly related to the mean 700 mb height anomaly field in the Northern Hemisphere during the following winter. His fall-to-winter correlation field (Fig. 1) is the basis for the present study. Correlation coefficients based on data from fall 1950 through winter 1980 are given in column (a) of Table 1 for selected locations near major centers of correlation in Fig. 1. According to Chen (personal communication, 1983), apart from the statistical significance of the entire correlation field of Fig. 1, the correlations at the specific locations indicated in Table 1 are also locally significant although the correlations at 35°N, 140°W and 65°N, 115°W are only marginally so at the 5% level.

Column (c) of Table 1 provides the contribution per unit of data to the correlation when only fall–winter data pairs following the seven warm episodes in the tropical east Pacific are considered, while column (b) pertains to the remaining 23 data pairs. (Note that values exceeding one are a possible outcome in columns (b)–(e) since these values are not correlation coefficients.) When examined in this way it is clear that, at most of the locations considered, the data pairs following warm episodes generally contributed disproportionately to the strength of the relationships. This is especially true in the Pacific sector. On the other hand, in the North American sector the seven data pairs following warm episodes contributed little; in fact, at 65°N, 115°W the impact of that part of the record was small and opposite in sign to the substantial

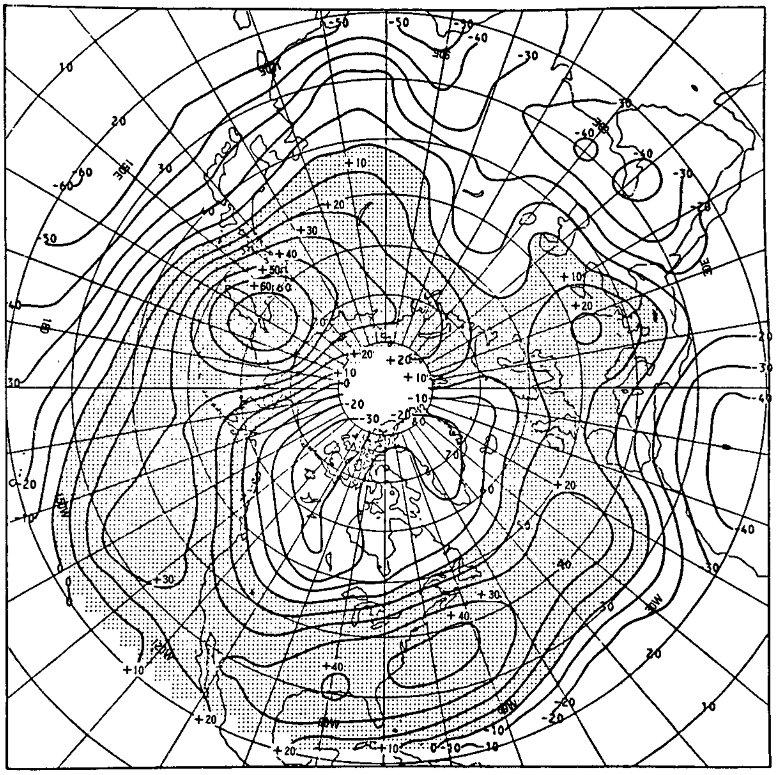

FIG. 1. Correlation between the fall Southern Oscillation Index and the winter mean 700 mb height, fall 1950–winter 1979 [after Chen (1982)].

TABLE 1. Contribution per unit of data to the correlation of fall Southern Oscillation Index with the subsequent winter mean 700 mb height at selected locations for various data groups, fall 1950–winter 1980. Linear correlation coefficient column (a) is the frequency-weighted sum of component contributions per unit of data from either columns (b) and (c) or columns (d) and (e) taken together.

(a) Linear correlation coefficient, total record (30 years),
(b) Partial record (23 years) excluding data pairs following seven warm episodes in the tropical east Pacific,
(c) Partial record (7 years) consisting of data pairs following seven warm episodes in the tropical east Pacific,
(d) Partial record (16 years) with the two consecutive data pairs following warm episodes in the tropical east Pacific excluded,
(e) Partial record (14 years) consisting of the two consecutive data pairs following warm episodes in the tropical east Pacific.

	Number of years				
Location	(a) 30	(b) 23	(c) 7	(d) 16	(e) 14
Pacific sector					
60°N–160°E	0.68	0.58	1.01	0.47	0.91
20°N–160°E	−0.57	−0.46	−0.91	−0.63	−0.49
35°N–140°W	0.36	0.31	0.53	0.12	0.64
North American sector					
65°N–115°W	−0.36	−0.53	0.22	−0.44	−0.26
35°N–70°W	0.44	0.51	0.21	0.53	0.33
South Eurasia/North Africa sector					
25°N–0°	−0.46	−0.39	−0.66	−0.42	−0.50
30°N–50°E	−0.42	−0.37	−0.58	−0.34	−0.50
20°N–100°E	−0.56	−0.53	−0.63	−0.45	−0.67

contribution from the remaining 23 years. Finally, comparing columns (a) and (b), it is apparent that the essence of the fall to winter relationships surveyed was inherent to the non-warm episode years at all locations studied.

Sea surface temperature analyses (Rasmusson and Carpenter, 1983) indicate that tropical east Pacific warm episodes are characteristically followed by colder than normal water commencing the following spring. With this in mind, the analysis of Table 1 was reworked assuming that the warm SST episodes define a two-year SST regime. Column (e), Table 1 is the contribution per unit of data to the correlation when only the two consecutive fall–winter data pairs following each of the seven warm episodes are considered while column (d) deals with the remaining 16 data pairs. In general, these results are similar to those stemming from the previous analysis. However, it now becomes apparent that, for this limited sample, the strength of

TABLE 2. Contributions to covariance between departures from their 30 year means of the fall Southern Oscillation Index and the winter mean 700 mb height at 60°N, 160°E (year pertains to SOI; warming episode contributions are indicated by asterisks).

1950	−28.29	1965	178.24*
1951	55.73*	1966	19.77
1952	1.46	1967	−7.56
1953	−6.05*	1968	18.78
1954	1.32	1969	15.91*
1955	121.92	1970	85.25
1956	40.84	1971	46.55
1957	21.35*	1972	61.09*
1958	14.35	1973	126.73
1959	−16.69	1974	7.04
1960	−6.14	1975	40.45
1961	−6.13	1976	2.27*
1962	40.91	1977	17.84
1963	74.39	1978	17.83
1964	18.90	1979	−9.73

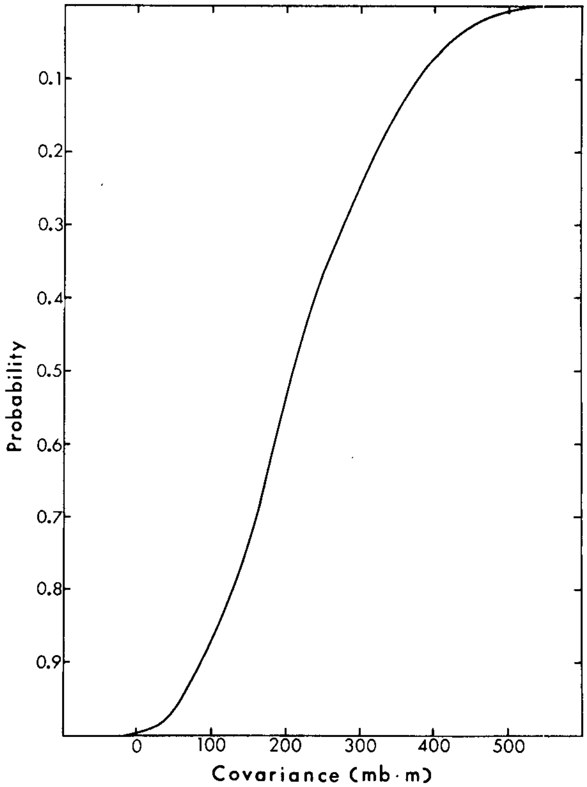

FIG. 2. Probability of exceeding a given contribution to the covariance between fall SOI DN and winter mean 700 mb height DN at 60°N, 160°E from groups of seven years chosen at random.

TABLE 3. Covariance concentrations of the data groupings of Table 1, together with the probability that each extremity could be exceeded by chance (in parentheses).

	Number of years					
Location	(b) 23		(c) 7	(d) 16		(e) 14
Pacific sector						
60°N-160°E	617.79	(0.190)	328.54	353.07	(0.171)	595.26
20°N-160°E	−174.84	(0.156)	−106.67	−166.92	(0.373)	−114.59
35°N-140°W	321.16	(0.315)	166.84	83.76	(0.096)	404.69
North American sector						
65°N-115°W	−448.99	(0.032)	57.01	−258.41	(0.324)	−133.57
35°N-70°W	402.06	(0.251)	51.63	292.95	(0.288)	160.74
South Eurasia/North Africa sector						
25°N-0°	−181.22	(0.309)	−91.50	−133.84	(0.440)	−138.88
30°N-50°E	−148.52	(0.322)	−70.88	−96.82	(0.334)	−122.58
20°N-100°E	−141.77	(0.408)	−50.83	−83.65	(0.293)	−108.95

the correlation in the east Pacific (35°N, 140°W) received a large contribution from the two consecutive data pairs following each of the seven warm episodes.

Given the disproportionate covariance contribution of certain segments of the 30 year record to the significant correlations studied, it remains to be seen whether those years dominate the correlations. It may be that a particular data series abounds in covariance contributions of a particular sign, making it relatively easy to obtain groups of years with a substantial aggregate of covariance. We will conclude that a particular group of years dominates a correlation if a substantial concentration of covariance due to those years is not likely to be equaled by a random drawing of groups of years. This problem can be readily treated by the use of Monte Carlo methods.

As an example, consider the results of Table 1 at 60°N, 160°E. The correlation between the fall SOI and the following winter mean 700 mb height at this location is 0.68, the highest value within the study area. Furthermore, columns (b) and (c) of Table 1 evidence a strong concentration of positive covariance in the warming episode years, as can be also seen from the covariance array of Table 2. We note, however, that several large positive covariance contributions from nonwarming episode years are scattered throughout the record. In fact, only three of the ten largest positive contributions came from warming episode years. To evaluate the likelihood of a chance covariance concentration as large as that due to the seven warming episode years, we randomly select 1000 different groups of 7 from the 30 covariance contributions of Table 2. This results in the probability distribution shown in Fig. 2. From this it can be seen that the likelihood of a covariance concentration exceeding that of the seven warming episode years (328.54; see Table 3) by a random drawing of groups of seven years is about 19%. Thus, we conclude that the large positive covariance concentrations of those years was not an unusual property of this particular covariance array and that the correlation was not dominated by the seven warming episode years.

A similar Monte Carlo procedure was followed to evaluate the covariance contributions due to the other data grouping of Table 1. These results are summarized

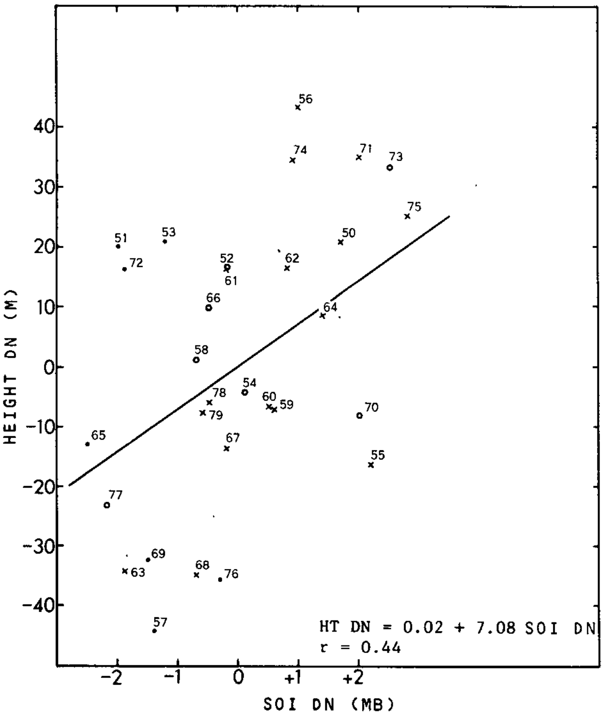

FIG. 3. Scatter diagram of fall SOI anomaly versus winter mean 700 mb height anomaly at 35°N, 70°W, fall 1950–winter 1980. Points are identified by year of fall. First (second) fall–winter data pairs following moderate to strong warming episodes in the tropical east Pacific are indicated by dots (open circles) and remainder of years by crosses. Line of linear regression and its equation are indicated.

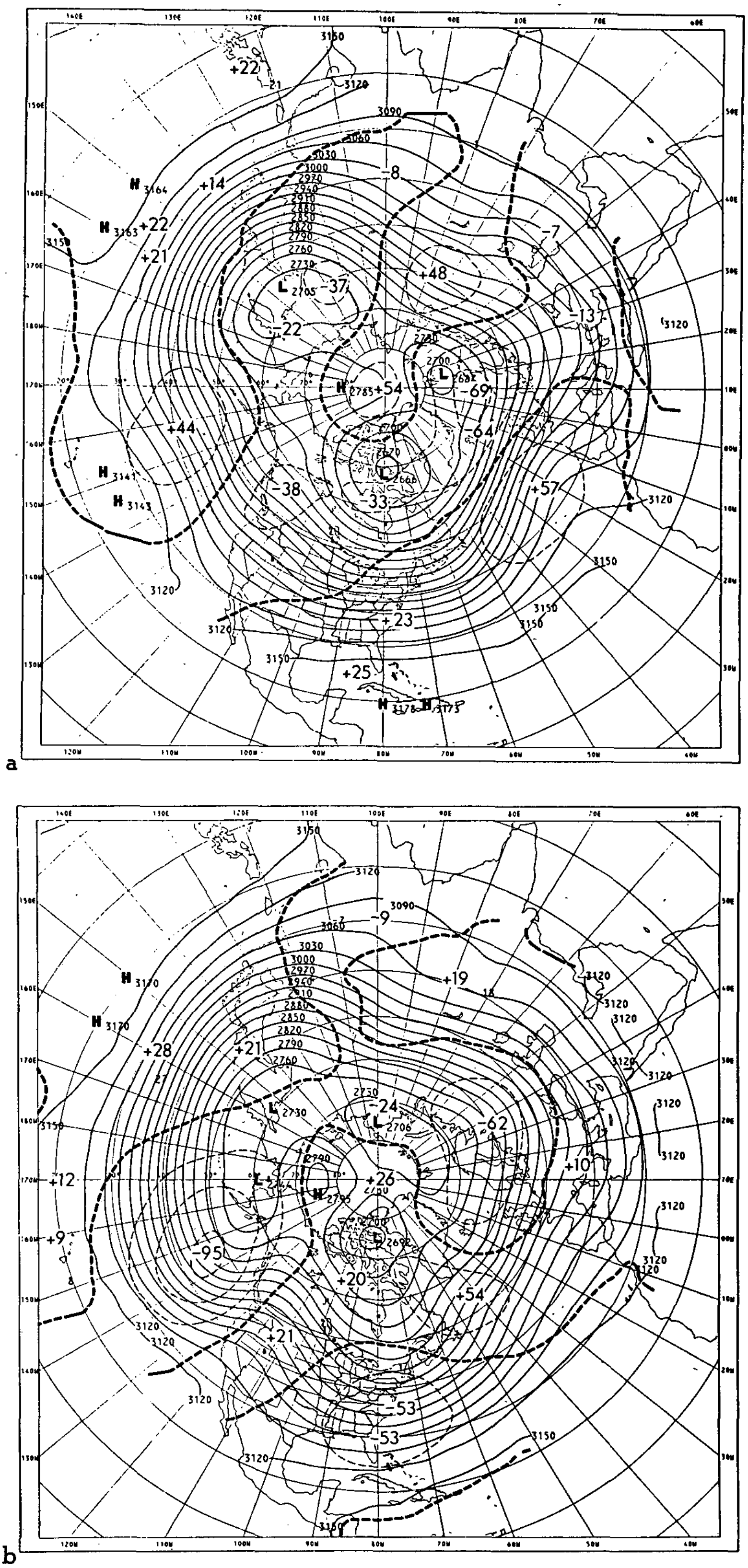

FIG. 4. Winter mean 700 mb height and DN (m) following selected warming episodes in the tropical east Pacific (see Fig. 3) for (a) 1951–52, (b) 1957–58 and (c) 1965–66.

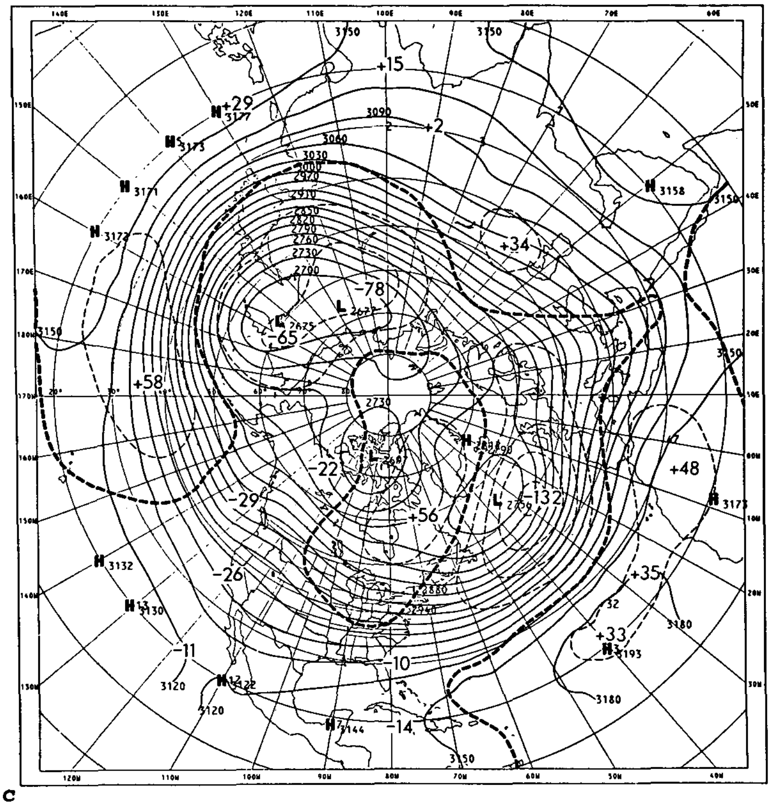

FIG. 4. (*Continued*)

in Table 3. In only one instance did a covariance concentration due to the warming episode years have a chance probability of occurrence of less than 5%. At 65°N, 115°W, there was only about a 3% probability that one could randomly select from the given covariance sample a group of seven years which contributed so little to the observed negative correlation. In all other instances there was a substantial probability of exceeding the covariance contribution of the warming episode years by a random drawing of groups of years. On the basis of this analysis, we conclude that the correlations studied were not dominated by warming episode years but received substantial contributions from other parts of the record.

In the vicinity of the United States, only one of the three correlation centers, that at 35°N, 140°W, received a substantial covariance contribution from the warming episode years. At the other two locations, the contribution of those years was disproportionately small and even, at 65°N, 115°W, opposite in sign from the prevailing correlation. The weak contribution at 35°N, 70°W is further treated in Fig. 3 which is a scatter diagram of fall SOI departure from normal (DN) versus winter mean 700 mb height DN. The large variability of winter mean height at this location following tropical east Pacific warming events (solid dots) is apparent. This is further illustrated in Fig. 4 which shows the Northern Hemispheric height pattern for three such instances. From the foregoing, it appears that the predictive relationship under consideration has very limited applicability in the vicinity of North America immediately following tropical east Pacific warming episodes.

3. Conclusions

For the 30 year period studied, data pairs following tropical east Pacific warming episodes contributed disproportionately to the statistically significant relationship between fall SOI and winter mean 700 mb height in much of the Northern Hemisphere. Such covariance concentrations, however, were found to be fairly likely outcomes (probability > 9%) if groups of years are chosen at random from the appropriate covariance arrays. Thus, we conclude that the influence of the fall SOI upon the subsequent winter mean 700 mb height distribution is a rather pervasive one, not limited to tropical east Pacific warming situations.

In contrast to other areas, correlation maxima in the North American sector received disproportionately small covariance contributions from the warming episode years. In northwest Canada the contribution of those years was small and opposite in sign to the covariance. This was the only situation tested where the covariance contribution of the warming episode years was unlikely (probability $\leqslant 5\%$) from a random selection of years. In the vicinity of the east coast upper-level trough, tropical east Pacific warming episodes were followed by a wide variety of winter outcomes.

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