The Correlation between Temperature and Precipitation in the United States and Europe

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ABSTRACT

The correlation between seasonal mean temperatures and precipitation totals is computed at some 98 North American and European stations. Negative correlation is most frequent in summers, while negative and positive correlation appear about equally in other seasons. Normalized cospectra show that these correlations do not, in general, reflect a relationship common to a single time scale but rather one that is prevalent at all time scales.

1. Introduction

Evidence that there is a correlation between temperature and precipitation over the United States has been reported by several authors. In particular, it has been found that in the midwestern states wet summers are usually cool summers and vice versa (Hamrick and Martin, 1941; Gilman, personal communication, 1976), reflecting a negative correlation. Blair (1931) studied the relationship between winter temperature and

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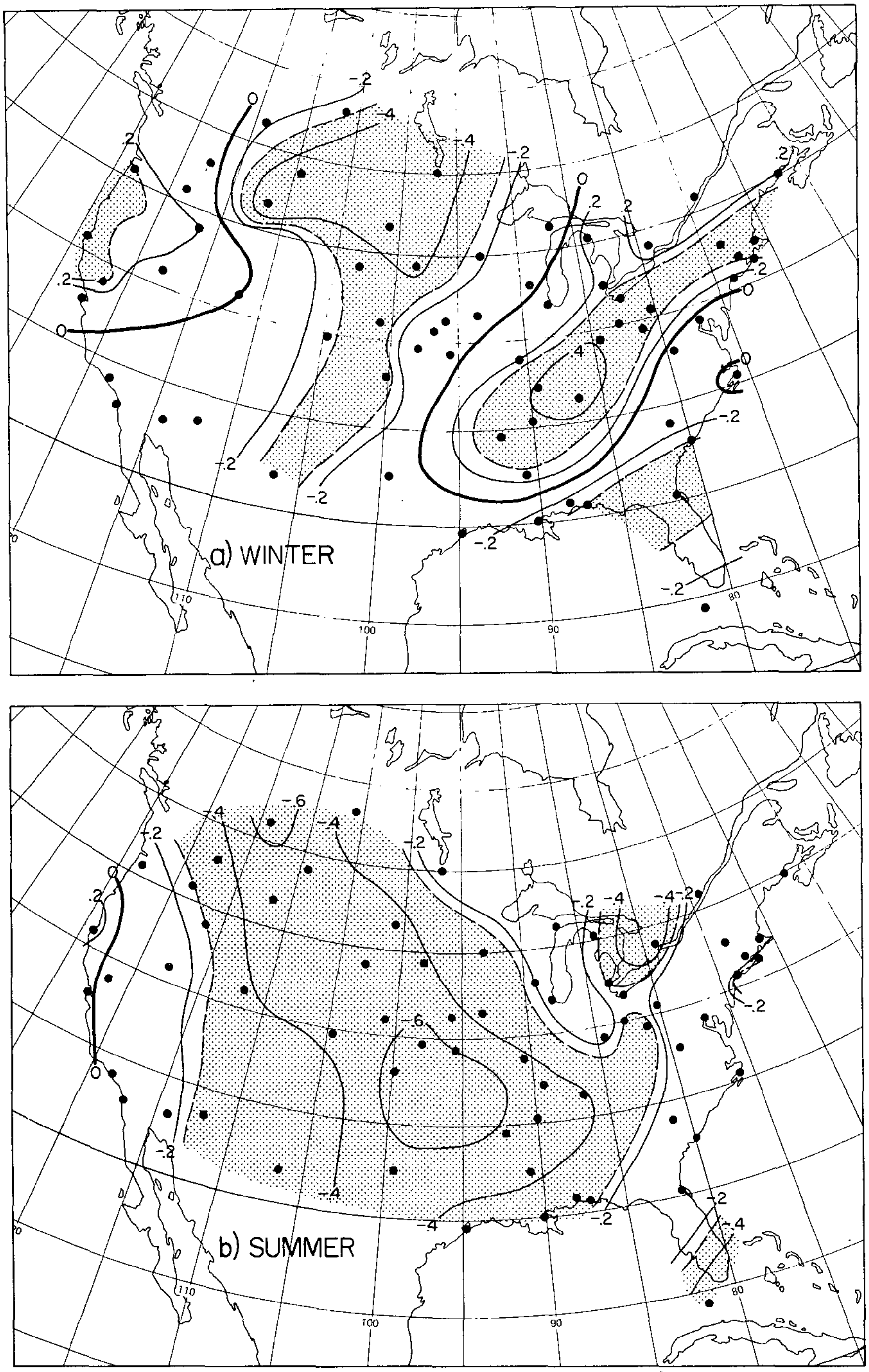


FIG. 1. Total correlation between seasonal mean temperature and precipitation totals for North America for (a) winter and (b) summer. The 95% significance level is 0.25; significant areas are shaded.

winter precipitation over the United States, and found regions of positive and regions of negative correlation. Crutcher (1976) has further defined these relationships by computing correlations between monthly average temperature and precipitation at 42 stations in the United States for each month of the year for the period 1906–48. These correlations are important in furthering our knowledge of climate. It is of interest, for example, to establish whether or not they reflect a relationship common to variations occurring to all, or at only a limited range of time scales.

Here we intend to complement earlier studies of the relationship between temperature and precipitation totals by computing the correlation between seasonal mean temperature and precipitation for stations in North America and Europe. In addition the cospectrum,

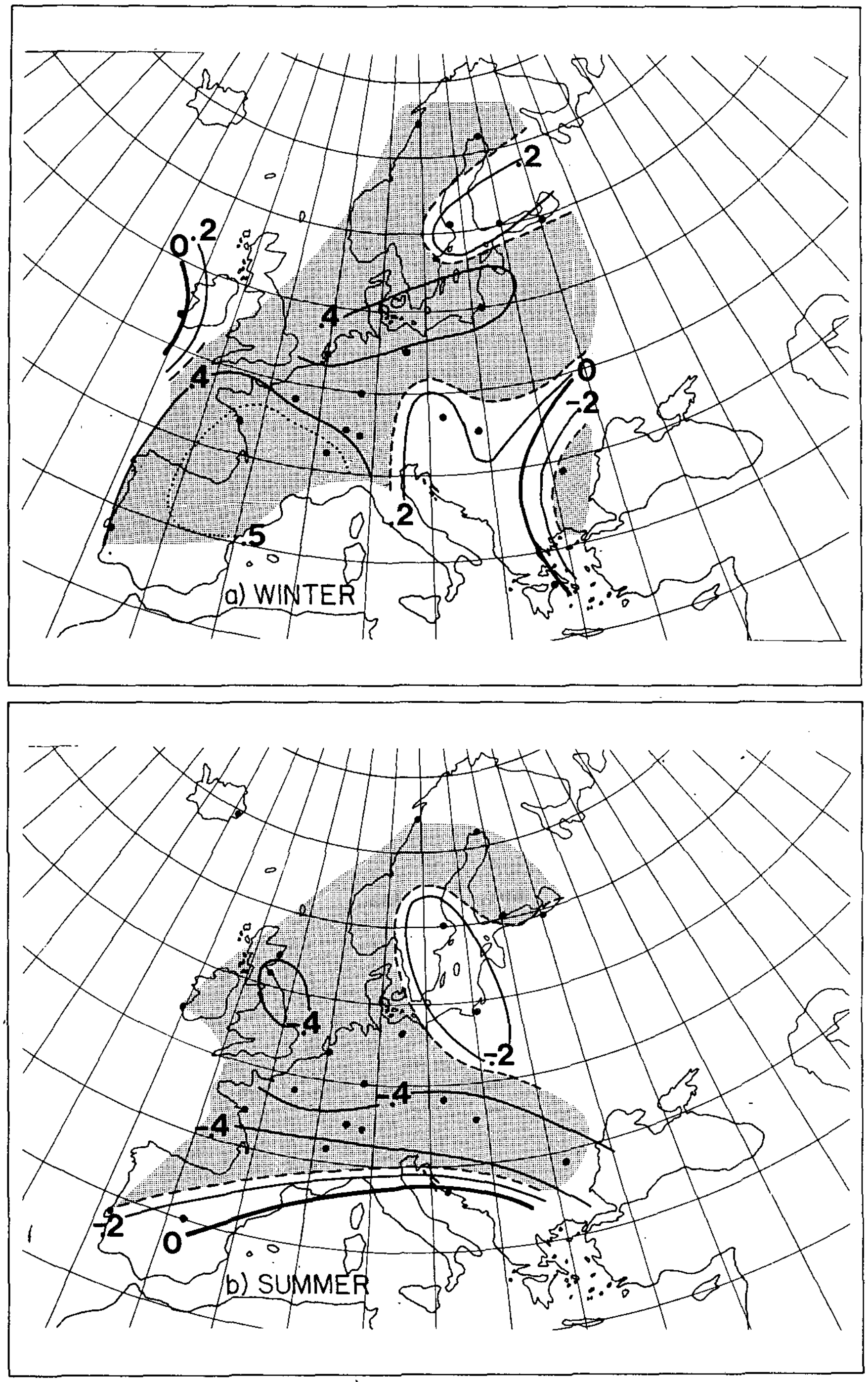


FIG. 2. As in Fig. 1, except for Europe.

or the in-phase part of the cross-spectrum, of the seasonal temperature and precipitation series is computed in order to describe the contribution from various time-scale variations to the total correlation. In particular, we are interested in determining whether the correlations between temperature and precipitation reflect a relationship that is common to variations at all frequencies or one that is favored in a limited frequency band.

2. The data

Time series of seasonal temperature means and precipitation totals are determined for North American and European stations by averaging monthly values collected for *World Weather Records*. Winter values are determined from December, January, February; spring from March, April, May; and so on. For each station we consider the 64-year time series from 1897 to

1960. If there are any missing temperature or precipitation data at a station for this 64-year period the station is not included in the analysis. After elimination of stations with missing data a maximum of 72 stations in North America and 26 stations in Europe are considered (the number of stations varies only slightly from the latter numbers according to season under consideration).

3. Results

a. Total linear correlation between temperature and precipitation

Fig. 1 illustrates the total correlation between the seasonal mean temperature and precipitation totals during the 64-year period for North America for winter and summer seasons. The equivalent distributions for Europe are shown in Fig. 2. The 95% significance level for the total correlation is approximately ±0.25 and areas where the correlation exceeds this limit are shaded in each of the maps.

For the winter season over North America (Fig. 1a) the plains states have a significant negative correlation; that is, during the 64-year period, cold winters were usually wet winters and vice versa. In two areas, however, there is a significant positive correlation: the northern California and Oregon coast and an area from New England south-westward to the lower Mississippi valley. These two areas of positive correlation were found for each of the months December, January and February in the correlations computed by Crutcher (1976). Blair (1931) also found the same relationship and suggested that the distribution of positive and negative correlations was associated with the tracks of cyclones and the relationship of temperature and precipitation within the various sectors of the cyclone. Since more data are available now it is likely that the causes of the temperature-precipitation correlations could be better defined in terms of their relation to cyclone tracks; further studies of the topic are required. This study merely reports the observed correlations.

In the summer (Fig. 1b) only one small area on the Pacific coast has a positive correlation and there is a large area over the west and midwest that extends into the eastern states where the correlation is negative and significant at the 95% level. Over a large part of the United States, therefore, cool summers are usually wet summers and vice versa, a feature which has been shown before, as mentioned in the Introduction.

The distribution of correlations in spring and autumn (not shown) is most similar to the winter pattern, except the positive correlation south of the Great Lakes is considerably reduced in these two seasons, and there is no evidence of positive correlation on the Pacific coast in spring.

Over Europe in winter (Fig. 2a) the majority of the area considered has a significant positive correlation. Only one station has significant negative correlation. The pattern is therefore somewhat different from that over North America, where a large area of negative correlation occurs in the middle of the continent.

In summer the area of significant negative correlation is larger (Fig. 2b), covering most of Europe except the Mediterranean. In Europe, as in North America, therefore, cool summers are usually wet and vice versa. Along the California coast and in the Mediterranean area this does not appear to be the case, however.

In spring (not shown) the correlations are primarily negative and therefore resemble summer more than winter. The distributions of correlations for Europe in the autumn (not shown) differ from all of the other maps primarily because of the absence of any large areas of significant correlation. That is, over Europe during the 64-year period there is little relation in the autumn between the seasonal mean temperature and total precipitation.

b. Contribution from various time scales to the total correlation

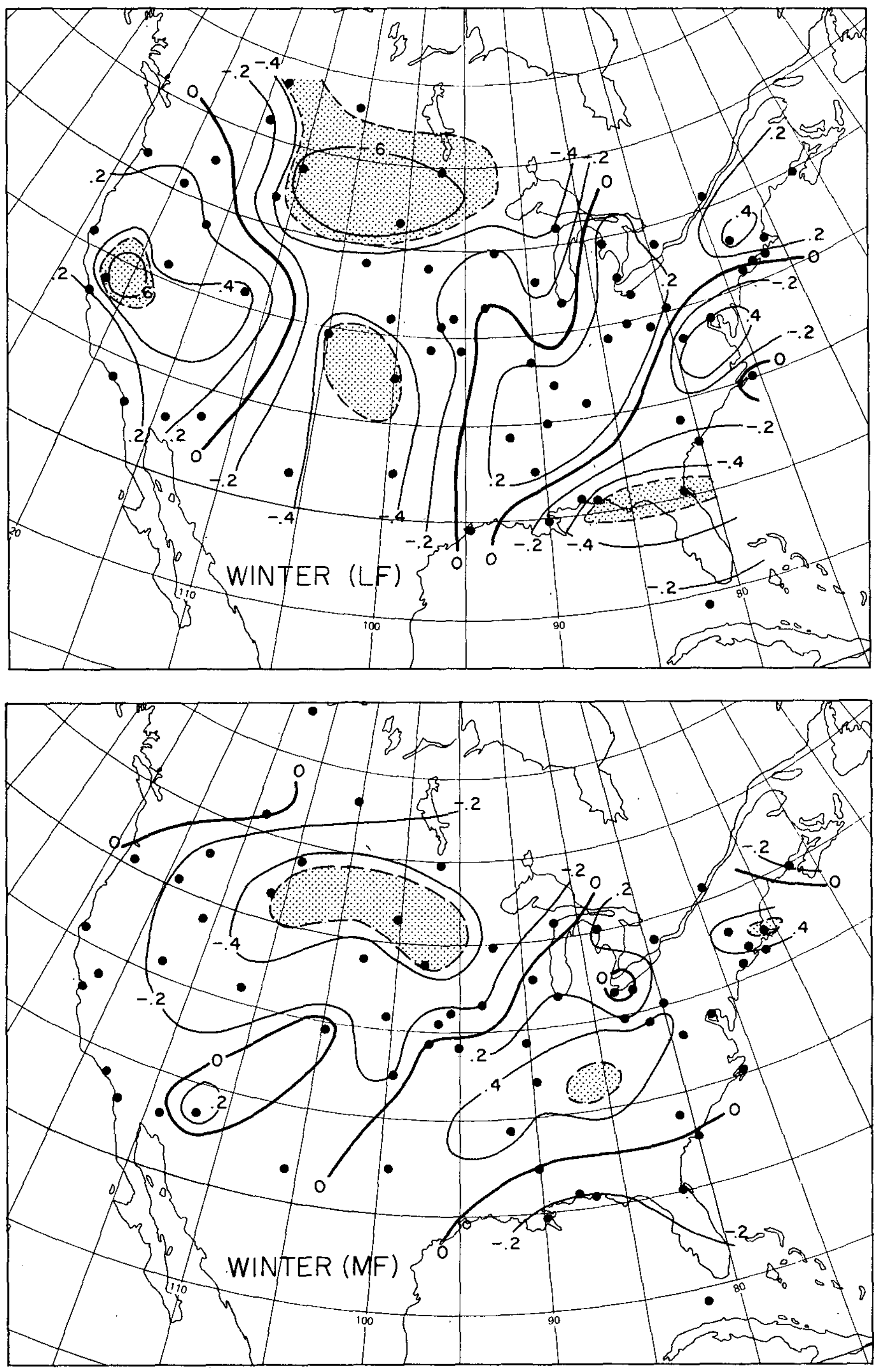
To assess something of the contributions of various time scales to the correlation, the cospectrum or in-phase part of the cross spectrum between temperature and precipitation was estimated. Cospectra were computed by first expanding the seasonal temperature and precipitation values into a Fourier series and then multiplying the in-phase parts of corresponding harmonics together. The average of these products over harmonic numbers 0 to 10, 11 to 21 and 22 to 32 are estimates of the cospectra and the contribution to the total covariance at time scales longer than 6.4 years (low frequencies), between 3.0 and 5.8 years (medium frequencies) and between 2 and 2.9 years (high fre-frequencies), respectively. These three frequency-smoothed cospectral estimates were normalized by dividing by the square root of the product of similarly frequency-smoothed estimates of the temperature and precipitation spectra. It should be noted that although the cospectra themselves give the decomposition of the zero-lag covariance with frequency (see, e.g., Jenkins and Watts, 1968, p. 345), the normalized cospectra give a similar decomposition of the correlation coefficient only if the individual temperature and precipitation spectra are white (constant spectral density at all frequencies).

Fig. 3 shows the normalized cospectra for winter over North America. The 95% significance limits are approximately ±0.45,[2] and the areas with values $\geqslant 0.45$ or $\leqslant -0.45$ are shaded. Although there are local

[2] The variance of the normalized cospectrum is assumed to be inversely proportional to the degrees of freedom (df). Averaging estimates from 11 harmonics provides approximately 22 df but the tapering procedure used reduces this number by about 10%. The 95% limits are then taken to be $1.96/20^{\frac{1}{2}} \approx \pm 0.45$. To assure that this is a reasonable approximation 1500 similarly normalized cospectra were computed for 64-member series of random numbers; 4.8% of these normalized cospectral values fell outside the ±0.45 limits.

exceptions, the overall pattern of each frequency band bears a strong similarity to the total correlation of the winter season (Fig. 1a), i.e., variations on each of the time scales contributes to the total correlation. One can draw similar conclusions regarding the spring, summer and autumn seasons (not shown).

Similarly, the positive correlation evident over most of Europe in the winter as well as the negative correlation just west of the Black Sea (Fig. 2a) is reflected in all three frequency bands for that season (not shown). Also the negative correlation that predominates over most of Europe in summer (Fig. 2b) is evident in all three summer frequency bands. Similar correspondence is found in spring and autumn. Although there are some local exceptions that may have physical importance, we conclude that at most European stations all



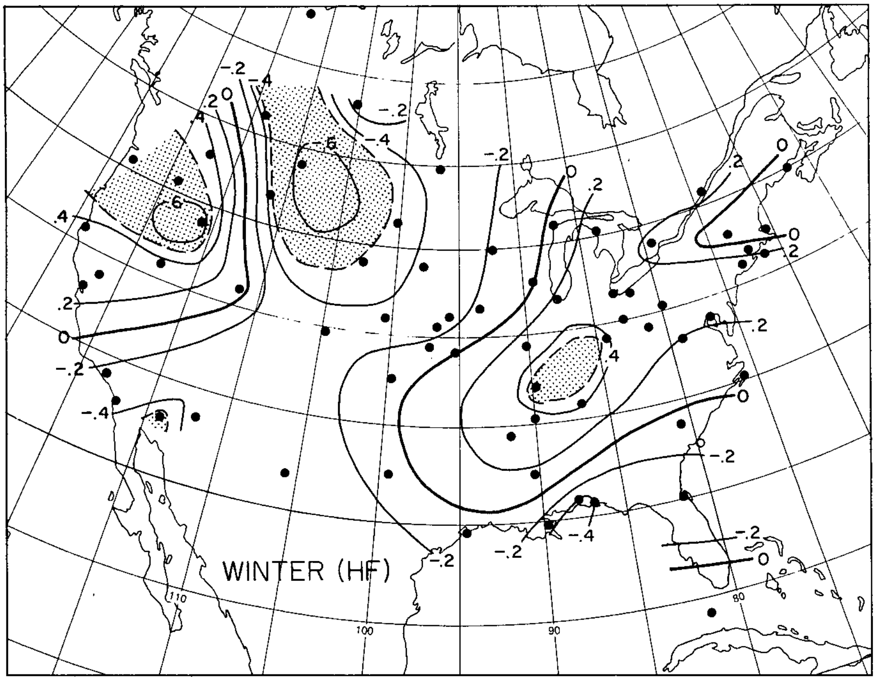


Fig. 3. Normalized cospectra for winter over North America for (a) low frequency (LF, longer than 6.4 years), (b) medium frequency (MF, 3.0–5.8 years), (c) high frequency (HF, 2.0–2.9 years). The 95% significance level is ±0.45; significant areas are shaded.

three frequency bands contribute to the linear correlation of temperature and precipitation in all four seasons.

4. Conclusions

Over most areas summer temperature and precipitation tend to be negatively correlated. In other seasons patterns of correlation are more complex with large areas of both positive and negative correlation. It seems likely that these patterns occur on all time scales since the normalized cospectra, showing the contribution to the total correlation from low-, medium- and high-frequency variations, in general have the same distribution as the correlations. That is, we conclude that the correlations do not reflect a "signal" at any preferred frequency.

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