Comparison of Sea Level Pressure Reconstructions from Western North American Tree Rings with a Proxy Record of Winter Severity in Japan

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ABSTRACT

Reconstructions of winter (December–February) sea level pressure (SLP) from western North American tree-ring chronologies are compared with a proxy record of winter severity in Japan derived from the historically documented freeze dates of Lake Suwa. The SLP reconstructions extend from 1602 to 1961 and freeze dates from 1443 to 1954. The instrumental and reconstructed SLP for the 20th century reveal two distinct circulation regimes (teleconnection patterns) over the North Pacific that appear to be associated with severe and mild winters and, consequently, with early and late freezing of the lake. The reconstructed SLP anomaly map for severe winters prior to 1683 shows a pattern similar to those in the instrumental and reconstructed records of the 20th century. The analysis reveals that the reliability of the reconstruction may vary with the configuration of the actual SLP pattern as the mild winter pattern is not as well reconstructed as the severe winter pattern. That result illustrates the importance of testing the reliability of a reconstruction within the context of the intended interpretation. This analysis demonstrates how different types of proxy climate data can be compared and verified.

1. Introduction

Dendroclimatology has made significant advances in recent years as a variety of climate reconstructions have become available (Stockton and Meko, 1975, 1983; Cook and Jacoby, 1977; Fritts *et al.*, 1979; Jacoby and Cook, 1981; Cropper, 1982; Hughes, *et al.*, 1982). One can place confidence in the correctness of these climatic reconstructions when they can be shown to agree with independent instrumental data and other information on past climate. Demonstration of agreement between different paleoclimatic data sets adds to the credibility of their information content and different kinds of comparisons can be made to validate the information over various geographical regions and time scales.

Climate reconstructions from tree-ring chronologies have been developed by multivariate regression techniques (Fritts, 1976; Fritts *et al.*, 1979). A statistical model of the relationship between spatial arrays of tree-ring chronologies (predictor) and climatic data (predictand) is constructed and applied to data over the model calibration period to calculate a transfer function. The transfer function is then applied to the predictor variables outside of the calibration period to reconstruct past climate. This approach involves several assumptions which may significantly affect the reliability of the resulting reconstructions. It is, therefore, essential that the model and its reconstruction be tested over a period independent of that used for calibration, a process called verification (Gordon, 1982).

One objective test of the reliability of a reconstruction is a comparison with instrumental data identical to that used in the calibration but over an independent time period. However, rigorous testing of the reconstruction in that way is not always possible due to the short length of available instrumental records. In that situation, subsample replication techniques over the calibration period can provide statistical verification of the general structure of the model, but not of its final calibrated form (Gordon, 1982). Of course, this technique cannot be used as a measure of reconstruction performance outside the calibration period. The subsample approach was applied to the SLP reconstructions to select the reconstruction used in this analysis (Fritts and Lough, 1985).

Even if independent instrumental data are available to verify a reconstruction, verification is often limited to periods with climatic conditions similar to those used for calibration. Comparison with other proxy or historical records of climate becomes necessary to assess the reconstruction's reliability over longer time scales. Comparison of many independently derived proxy climate records (e.g., Williams and Wigley, 1983) is important for establishing a spatially detailed and reliable picture of climatic variations prior to instrumental records.

A number of factors can make this comparison a difficult task. Proxy series provide an incomplete record of climate variations and different series are likely to portray different climatic variables. Many proxy series represent an integration of a number of climate parameters, although one parameter may be more important than the others. In addition, the direction of climatic variation may vary according to the geographical region considered (van Loon and Williams, 1976a, 1976b; Jones and Kelly, 1983; Williams and Wigley, 1983).

The process is facilitated by the fact that associations between the climates of different regions—teleconnections—occur because of the large-scale patterns of the atmospheric circulation, and these can provide a basis for comparing different instrumental and proxy climate series. Evidence of similar linkages should be expected in the proxy records, although the statistical association would be anticipated to be less than that found in the instrumental record due to the loss of climate variance in the reconstruction process.

The present work describes an attempt to verify a dendroclimatic reconstruction of SLP for the North Pacific by using a proxy record of winter severity in Japan: freeze dates for Lake Suwa published by Arakawa (1954). The SLP reconstruction is evaluated for its ability to identify average atmospheric circulation patterns that would produce severe and mild winters in Japan.

2. Data

a. Reconstructed sea level pressure

Winter (December–February; hereafter DJF) SLP over the North Pacific was reconstructed as departures from the mean pattern of the instrumental record for the period 1899 to 1970. Sixty-five tree-ring chronologies from western North America (Fritts and Shatz, 1975) were used as statistical predictors of winter SLP at 96 grid points between 100°E and 80°W longitude, 20° and 70°N latitude. Several transfer function models were calibrated over the period 1899–1963 using multivariate regression techniques described by Fritts (1976) and Lofgren and Hunt (1982). The SLP reconstructions used were developed in a manner described by Fritts *et al.* (1979). They represent an average of reconstructions from three models of different structures which had the best calibration and verification statistics (Fritts, 1982). An anomaly map of estimated SLP was obtained for each winter from 1602 through 1961. Problems with the reliability of the early instrumental pressure data (Trenberth and Paolino, 1980) may affect the reconstructions along the northern margin of the grid.

Because there were insufficient independent SLP data, verification of the three models was performed using subsample replication techniques over the calibration period (Gordon, 1982). The average explained variance (adjusted for loss of degrees of freedom) was 29.4%. Only 28% of the pressure grid points had positive reduction of error statistics. Thus both calibration and verification statistics indicate considerable lack of precision in the individual grid point reconstructions. However, it is still possible that the reconstructed variance is sufficient to define large-scale patterns of climatic variation despite errors at individual grid points.

b. Freeze dates of Lake Suwa

Freeze data for Lake Suwa (36°N latitude and 138°E longitude, elevation, 759 m) in central Japan are available for the period 1443 to 1953, though many freeze dates are missing between 1683 and 1923 (Arakawa, 1954). Frequently, both the date of freezing of the lake surface and the date of the ice fracture were recorded. The latter refers to the cracking and deformation of the ice surface which typically occurs several days after freezing and is caused by mechanical stresses related to the diurnal freeze/thaw cycle. The deformations are quite dramatic and their occurrence was often recorded when the date of freezing was not.

Arakawa (1957) and Gray (1974) used the freeze data to estimate Japanese winter temperature variations. More recently, the freeze data have been critically examined by Tanaka and Yoshino (1982) and they found the dates to be a valid proxy record of Japanese winter temperatures. The correlation of 0.54 ($n = 31$) between the date of freeze and local instrumental winter (DJF) air temperatures (Tanaka and Yoshino, 1982) provides a measure of the quality of the freeze record as a proxy climate indicator. A cold or severe winter is linked to early freeze dates and a warm or mild winter to late or no freezing.

The most extreme freeze dates are likely to be the most reliable indicators of winter severity. Thus, the freeze dates were examined to select those dates which could be considered extreme. Figure 1 shows that the distribution of both the freeze and the fracture dates is skewed and the freeze dates are more closely clustered around the mean. On average, the fracture date is eight days after the freeze date, but the relationship between the freeze and fracture date is not homogeneous throughout the data set. Prior to 1680, fracture occurred two to four days after freezing; after about 1680, the fracture date lags further behind the freeze date; and, in the 20th century, the differences between freeze and fracture dates exhibit an increased variability. Ar-

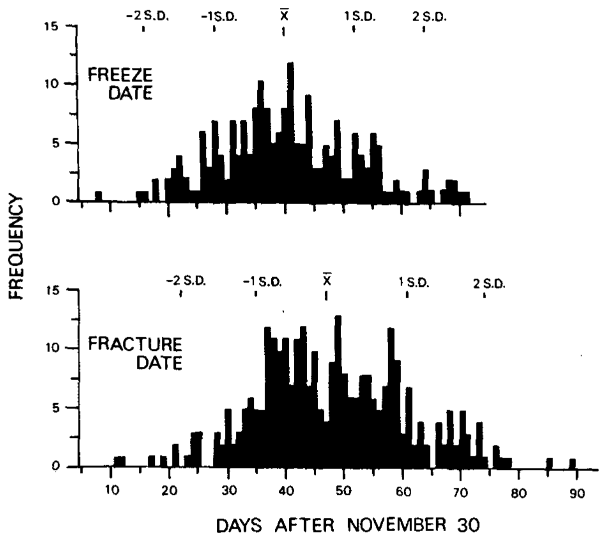

FIG. 1. Frequency distribution of freeze and fracture dates of Lake Suwa, Japan for the period 1602–1954. Dates are expressed as number of days after November 30. Note that there is some doubt as to the reliability of the freeze dates for the period 1683–1923 and of the fracture dates for the whole period.

akawa (1954) indicates that both the freeze and fracture dates from 1683 to 1923 *may* be inferior to the other data due to changes in the traditional ceremonies at Lake Suwa (see also Tanaka and Yoshino, 1982). It was, therefore, decided to restrict our analysis to the most reliable freeze dates—prior to 1683 and after 1923. Fracture dates were disregarded because of their inconsistent relationship to freeze dates. We adopted the convention of assigning the year of the January month to the winter season.

The distribution of the freeze dates (Fig. 1) suggests that an extreme early freeze occurs with a value one standard deviation below the mean and an extreme late freeze, two standard deviations above the mean. Winters when the lake did not freeze are always classified as mild. The classification of winters on those criteria appears in Table 1. This is a somewhat *ad hoc* classification method but, given the quality of the data, a more rigorous approach is not warranted.

3. Results

Given the availability of reliable freeze dates, their relationship with the SLP field can be tested over two time periods: first, 1924–54, for which both instrumental and reconstructed SLP data exist, and second, 1602–82, for which only the reconstructed data are available.

The instrumental SLP anomalies from the period 1924–54 were first evaluated to determine whether distinct SLP anomalies are associated with the severe and mild winters, as defined by the lake freeze data. The SLP anomalies for the extreme years in each category were averaged and mapped (Fig. 2, top panel). Severe winters are associated with a strengthened Aleutian Low and mild winters with lower than normal pressure in the Siberian arctic and higher than normal pressure in the central North Pacific.

Anomaly maps (not shown) similar to those shown in Fig. 2 were also obtained when winter instrumental temperatures at the nearby station of Matsumoto (36°N, 136°E) were used to classify winter severity. The anomalous northwesterly air flow resulting from a strengthened Aleutian Low and the anomalous southwesterly flow linked with an anomalous low over Siberia and a high over the North Pacific are consistent with severe and mild winters, respectively, in Japan. Changes in the pressure distribution involving the Siberian High and Aleutian Low are well-known meteorological features affecting Japanese winters (Yoshino, 1977). The grid points (marked by dots in the figure) that are statistically different (at the 95% confidence level) from the 1899 to 1970 mean are not necessarily near Japan and are most often in the northern half of the grid. This suggests that differences in Japanese winter temperatures are related to large-scale circulation features particularly at northern latitudes.

The question of whether results such as those presented in Fig. 2 are statistically meaningful has been

TABLE 1. Years of extreme winters in Japan inferred from the freeze dates of Lake Suwa and the correlation of reconstructed sea level pressure anomalies with the average anomaly pattern in the instrumental sea-level pressure data.

Severe		Mild	
Year	r	Year	r
	1924–54		
1927	0.46	1932	0.58*
1936	0.75*	1935	0.53
1946	0.29	1941	−0.10
1948	−0.31	1949	0.50
	1602–82		
1606	0.74*	1647	−0.20
1607	0.43	1672	0.03
1610	−0.06	1678	0.13
1612	0.27		
1615	0.74*		
1617	0.79*		
1621	0.52		
1629	0.78*		
1631	0.65*		
1635	0.84*		
1642	0.79*		
1659	0.43		
1665	0.75*		
1666	0.66*		
1669	−0.35		
1673	−0.64		
1680	−0.68		
1681	−0.43		

* Indicates correlation coefficients greater than 0.58 which can be considered statistically significant at the 95% confidence level.

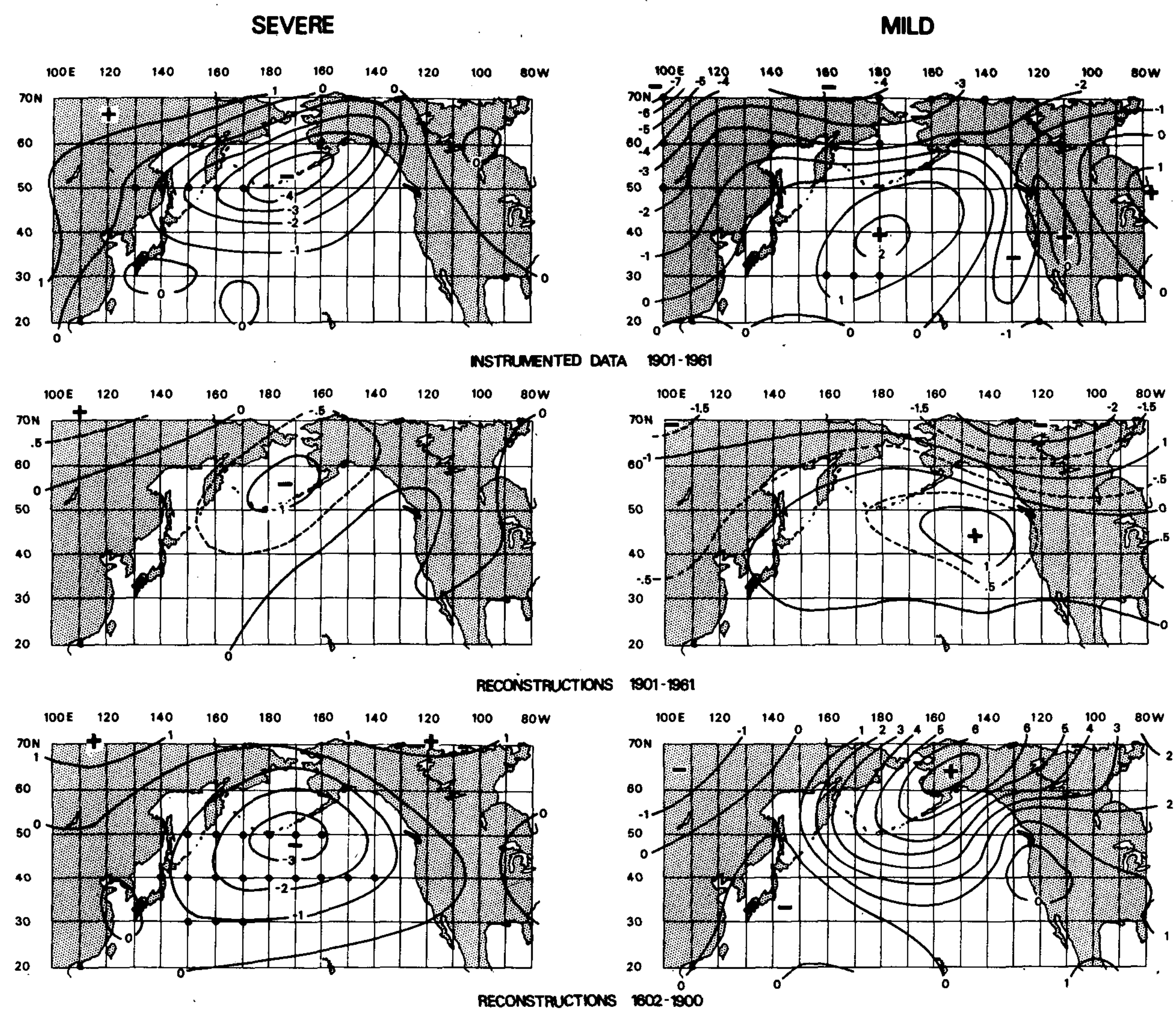

FIG. 2. The winter sea level pressure anomalies in the instrumental and reconstructed record averaged for winters which were classified as severe and mild, on the basis of the freeze date of Lake Suwa. Heavy circles indicate anomalies that are significantly different from the 1899–1970 mean at the 95% confidence level.

discussed by Livezey and Chen (1983). For the mild and severe cases, the percentages of grid points with significant statistics are 12.5 and 8.3% of the total, respectively. Those figures are very close to the value of 9.4% expected by chance, when the binomial distribution is used to determine the collective significance of a finite set of 96 individual grid points. We further tested the effects of spatial correlations between grid points in our data set by performing simulations of the map averaging process. The simulations suggest that 22.5% of the grid points would have to show significant statistics to obtain statistically meaningful map patterns for four-year averages of instrumental SLP anomalies. None of the results presented here (Fig. 2) passes this test. However, the physical consistency of our results, whether derived from instrumental winter temperature data or lake freeze data, argues for the existence of a real—albeit weak—relationship between winter SLP patterns and the severity of Japanese winters. It is not surprising that there should not be a strong field relationship between *local* temperature variations and *large-scale* pressure fluctuations.

The reconstructed SLP anomalies (Fig. 2, middle panel) averaged over the same severe and mild winters closely resemble those for the instrumental data in the areas of the Aleutian Low and Siberia. There are discrepancies both in the location of the anomaly centers and in their magnitudes. The reconstructions for the mild winters are particularly poor in that regard. The overall patterns are similar and exhibit high correlations between the reconstructed and instrumental pressure patterns in each category; for the severe winter pattern the correlation is 0.55, and for the mild winter pattern, 0.69.

The significance of correlations between the instrumental and reconstructed SLP anomaly maps was evaluated by taking into account the number of effective degrees of freedom in the map data sets. The first 17 principal components of the instrumental SLP data explain 95% of the total variance and, therefore, could be said to contain 17 degrees of freedom. On average, the reconstructed SLP data are based upon 12 principal components and would contain as many degrees of freedom. Using the more conservative of these figures we conclude that maps, such as presented in Fig. 2, are significantly correlated at the 95% confidence level for correlations of 0.58 or greater. Even from that conservative view, the reconstructed mild winter patterns are significantly correlated with the corersponding instrumental patterns and the severe patterns are very nearly so. High correlations would, of course, be expected because the reconstructions are calibrated with the instrumental data from the 20th century. The reliability of the reconstruction can only be truly evaluated by examining the reconstructed SLP distribution for years independent of the calibration period.

Figure 2 (bottom panel) shows the average reconstructed SLP anomalies for years classified as severe and mild in the period 1602–82. The features associated with the severe winters in the instrumental data are clearly present in the reconstructed pressure anomalies. The large area of below-average (and statistically significant) anomalies in the vicinity of the Aleutian Low extends 20° further south than the area identified in the instrumental data. The correlation of 0.75 between the instrumental and reconstructed maps indicates that the reconstructions identify features similar to those present in the instrumental data. The mild winter pattern is reconstructed very poorly (correlation of 0.02 with the instrumental map). (Note, though, that because of the severity of the 17th century, there are only three mild winters in this sample. A larger sample may be needed to reveal the signal; see below.)

Table 1 includes the correlations of the reconstructed SLP anomaly pattern for each selected extreme winter with the average anomaly pattern in the instrumental 20th century SLP data. Four winters were classified in each category in the 20th century but only one out of the four was significant in the severe case and one out of four significant in the mild case. This implies that averaging is needed to isolate the large-scale pressure pattern associated with local variations in Japanese temperatures from the background noise. Nine of the eighteen winter reconstructed SLP anomaly patterns for 1602–82 were positively and significantly correlated with the average pattern of the instrumental data. No case was statistically significant in the small mild winter sample during the same time period. Considerable variability can be noted in the individual correlation coefficients, but the average reconstructed severe winter pattern is well correlated with the pattern in the instrumental data.

4. Conclusions

The comparison of reconstructed and instrumental winter SLP distributions (Fig. 2) demonstrates that the reconstructed SLP anomalies reflect variations in the large-scale surface circulation patterns which can be linked with severe Japanese winter temperatures. From this result it is evident that, at least in severe winters of this type, the large-scale features of the SLP reconstructions in the North Pacific are consistent with another proxy climatic indicator, and can thus be considered reliable.

The Lake Suwa freeze dates are an indicator of severe or mild winter temperatures in Japan produced by identifiable surface circulations over eastern Asia and the North Pacific. Reconstructions of SLP anomalies derived from the North American tree-ring data lack precision at individual grid points. However the *average* pattern of reconstructed pressure anomalies is consistent with features in the average patterns of instrumental pressure data in years associated with early freeze dates and severe winters. A consistent relationship is not found for late freeze dates and mild winters and this needs to be investigated further. Although this may simply be a product of the small sample size during the 17th century, it is possible that the severe winter SLP distribution has an effect on western North American climate (where the tree-ring chronologies are located) that is not reciprocated by the mild winter pattern. The greater complexity of the SLP pattern over western North America found in the average of the mild winter cases (Fig. 2, top) may support this possibility. The severe winter SLP pattern is reliably reconstructed, but the mild winter pattern is not. It is concluded that the SLP reconstructions may be reliable only for some situations, in this case circulations involving an intensified Aleutian Low. Although the average large-scale circulation patterns are shown to be reliable, the reconstructions lack precision in terms of the magnitude and positioning of circulation features in specific winters.

A reliable *spatially* detailed picture of past climate variations can only be obtained by comparing proxy records from different regions. As climate variations are regionally complex, simple matching of trends will be inadequate. This study has demonstrated how different sources of proxy climate information from different regions can be compared by making use of *known* relationships between the regions considered. Reasonable teleconnections can be established from the instrumental data base and then be used to test the reconstructions.

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