Interdecadal Modulation of ENSO Teleconnections

Alexander Gershunov and Tim P. Barnett
Climate Research Division, Scripps Institution of Oceanography,
University of California, San Diego, La Jolla, California

ABSTRACT

Seasonal climate anomalies over North America exhibit rather large variability between years characterized by the same ENSO phase. This lack of consistency reduces potential statistically based ENSO-related climate predictability. The authors show that the North Pacific oscillation (NPO) exerts a modulating effect on ENSO teleconnections. Sea level pressure (SLP) data over the North Pacific, North America, and the North Atlantic and daily rainfall records in the contiguous United States are used to demonstrate that typical ENSO signals tend to be stronger and more stable during preferred phases of the NPO. Typical El Niño patterns (e.g., low pressure over the northeastern Pacific, dry northwest, and wet southwest, etc.) are strong and consistent only during the high phase of the NPO, which is associated with an anomalously cold northwestern Pacific. The generally reversed SLP and precipitation patterns during La Niña winters are consistent only during the low NPO phase. Climatic anomalies tend to be weak and spatially incoherent during low NPO–El Niño and high NPO–La Niña winters. These results suggest that confidence in ENSO-based long-range climate forecasts for North America should reflect interdecadal climatic anomalies in the North Pacific.

1. Introduction

The existence of quasi-decadal variability in the Pacific sector climate (e.g., Latif and Barnett 1994, 1996; Mantua et al. 1997; Minobe 1997) has important implications for long-range climate prediction in North America. The spatial manifestations in climate variables around the North Pacific sector associated with the North Pacific oscillation (NPO) are qualitatively similar to those of ENSO. Characterizing the high NPO phase are the anomalously deep Aleutian low, cold western and central North Pacific, and warm eastern Pacific coastal waters, as well as anomalous warming in the central and eastern tropical Pacific. Reversed climatic conditions characterize the low NPO phase. The response of the Pacific sector climate to ENSO is qualitatively similar but relatively stronger in the Tropics and weaker in the midlatitudes (Mantua et al. 1997; Zhang et al. 1997). This similarity of climatic responses to ENSO and NPO suggests that the more slowly evolving NPO can modulate ENSO-related climate predictability over North America, especially in the west. The expected form of this modulation is a stronger climate response to El Niño (La Niña) during those epochs marked by a high (low) phase of the NPO. We hypothesize that this would correspond to a synergetic (constructive) match of NPO and ENSO phases (warm ENSO–high NPO or cold ENSO–low NPO), while the opposite (destructive) match would tend to weaken the effects of either mode's influence on the North American climate. The purpose of this paper is to show that this is indeed the case.

ENSO signals in the North American climate have been documented by many researchers (e.g., Ropelewski and Halpert 1986, 1996; Kiladis and Diaz 1989; Gershunov and Barnett 1998). The large inter–El Niño or inter–La Niña variability characteristic of these seasonal anomalies has also attracted attention (Kumar and Hoerling 1997; Livezey et al. 1997; Gershunov 1998). This type of interevent variability

Corresponding author address: Alexander Gershunov, Climate Research Division, Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0224.
E-mail: sasha@ucsd.edu
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necessarily undermines ENSO-related long-range climate predictability, statistically based predictions being especially vulnerable. Some of this variability may be due to details of the forcing such as timing, magnitude, and spatial characteristics of the tropical Pacific SST anomaly. Some may be due to the inherent and unpredictable internal atmospheric variability (e.g., Lau 1997). A portion of this variability may be due to the modulating influence of non-ENSO interannual and longer-period coherent climatic modes (e.g., Mann and Park 1996). Observational evidence suggests a strong influence of the NPO on North American circulation, precipitation, and temperature (Latif and Barnett 1994, 1996; Mantua et al. 1997). For example, over western North America, the northwest tends to be dry and the southwest tends to be wet during the high phase of the NPO with a reversed pattern occurring during the low phase. The spatial similarity of NPO-related anomalies to those forced by ENSO suggests that the NPO may modulate ENSO signal stability as well as magnitude. This possibility is also addressed by our analysis.

It is important to understand that the focus of this paper is the effect of ENSO–NPO interference on North American climate, not the effect of ENSO and NPO on each other. To be sure, ENSO and NPO appear to be related. Mantua et al. (1997) estimate correlation coefficients between unfiltered indices of ENSO and NPO to have magnitudes between about 0.3 and 0.4. There is a profusion of theories on possible physical linkages between the tropical and North Pacific (e.g., Enfield and Allen 1980; Gu and Philander 1997; Lysne et al. 1997; Pierce et al. 1998, manuscript submitted to *J. Climate*). These theories do not agree on the direction of causality, they do not agree on whether the primary connection is oceanic or atmospheric, and they certainly do not agree on the physics involved.

This paper, however, does not take part in the debate on ENSO–NPO physics. In fact, results and conclusions presented below hold regardless of the physical mechanisms, or even direction of causality or lack thereof, involved in the ENSO–NPO association. The ENSO and NPO indices used here are independent of each other, chosen to maximize predictability of each one separately from the other. The thrust of this paper is toward the practical goal of long-range climate prediction based on well-established knowledge of the climate system. The term "modulation" as used in the title refers to the influence of long-lived North Pacific anomalies on the strength and stability of North American ENSO-related climate signals. It does not imply a causal relationship between ENSO and NPO.

In what follows, after a brief description of the data and general analytic approach in section 2, we describe the NPO modulation of ENSO-related North American climate anomalies. Low-level atmospheric circulation represented by the sea level pressure (SLP) field over the North Pacific, North America, and the North Atlantic is considered in section 3. The precipitation field over the contiguous United States as represented by the frequency of heavy daily precipitation (HPF) is considered in section 4. NPO modulation of ENSO signal magnitude and stability is considered for both SLP and HPF. Results are summarized and discussed in section 5.

2. Data and methods

Interdecadal NPO-related regime shifts have been confirmed by independent analyses to have occurred in 1925, 1947, and 1977 in various SST, SLP, and proxy indices from around the North Pacific (e.g., Mantua et al. 1997; Minobe 1997). This separates our period of record (1933–93) into three epochs: 1933–46 and 1977–93, marked by the high phase of the NPO, and 1947–76, marked by the low phase. Parenthetically, Mantua et al. (1997) use the name, PDO (Pacific Decadal Oscillation) for the same phenomenon we call NPO. Although consideration of interannual NPO shifts would slightly strengthen the results presented below, interannual variations in the NPO are ignored here because they are unpredictable at present. The interdecadal NPO component, however, even if currently unpredictable with dynamical methods, tends to be persistent.

ENSO extreme winters are defined to occur when December, January, and February (DJF) NIÑO 3.4 (5°N–5°S, 120°–170°W) detrended SST is more than 0.8 standard deviations ($0.8\sigma \approx 0.6$°C) away from the long-term mean. While high enough to exclude questionable events, this threshold provides an adequate number of ENSO cases when subcomposited by NPO phase (see Table 1). Detrended DJF NIÑO 3.4 SST was chosen as the ENSO index for two reasons: 1) NIÑO 3.4 SST anomalies are well known to exert a strong influence on extratropical circulation during boreal winter (Graham and Barnett 1995), and 2) interannual NIÑO 3.4 SST anomalies are most skillfully predicted by hybrid coupled models for DJF (Barnett et al. 1993). Besides being more amenable to skillful pre-

TABLE 1. Classification of winters based on phases of ENSO and NPO.

	High NPO	Low NPO
El Niño	1940, 1941, 1942, 1980, 1983, 1987, 1988, 1992	1954, 1958, 1964, 1966, 1969, 1970, 1973
La Niña	1934, 1943, 1984, 1985, 1989	1950, 1951, 1956, 1971, 1972, 1974, 1976

diction, detrended NIÑO 3.4 SST anomalies are independent of epochal NPO shifts considered here.

SLP records for the Northern Hemisphere were obtained from the National Center for Atmospheric Research (dataset ds010.1). (Information on this dataset is available online at http://www.scd.ucar.edu/dss/datasets/ds010.1.html.) Because the North American ENSO signal is more stationary from month to month during January, February, and March (JFM) than during DJF, monthly JFM anomalies were averaged to represent the winter seasons' SLP anomaly. The spatial domain used in our SLP analysis extends from 20° to 70°N over the Western Hemisphere.

Precipitation data were obtained from the National Climatic Data Center. Daily precipitation records at 168 stations in the contiguous United States were selected for long and reasonably continuous records. Station locations are denoted by dots in Fig. 1. Sixty-one winters (JFM 1933–93) of data are available for these locations. Heavy rainfall events are defined for each location as those days with rainfall totaling above the 75th percentile of the 61-winter rainy day climatology at that station. For every winter, HPF is recorded. These heavy rainfall events make up most of the seasonal total rainfall and, not surprisingly, results obtained with HPF are similar to those obtained with total seasonal precipitation. We chose HPF to represent the precipitation field because while HPF is closely related to total seasonal rainfall amount, it carries special societal importance because of its direct relation to flood risk. HPF is also a good candidate for statistical prediction because, at least in the western United States, sensitivity of daily precipitation frequency to ENSO tends to increase for more extreme precipitation events (e.g., Cayan et al. 1998, manuscript submitted to *J. Climate*). Moreover, HPF is expected to be less sensitive to rain gauge biases than is total seasonal precipitation amount.

Of the 61 winters used in this study, 27 ENSO active winters are composited according to ENSO and NPO phase combination (see Table 1).

The general approach is to illustrate the effect of NPO on ENSO teleconnections by compositing SLP and HPF according to ENSO phase and further by NPO phase. For both variables, signal strength and stability are considered. Circulation signals (SLP) are considered on a spatial domain including North America and adjoining oceans. This is northward and downstream of the tropical and North Pacific forcing centers, respectively. Precipitation signals are considered within the contiguous United States. All anomalies are constructed relative to the 1933–93 base period.

3. SLP

a. Analysis procedure

To illustrate the nature of NPO influence on ENSO teleconnections, we describe signal strength and signal stability, or consistency from one winter to another within a composite. SLP signal strength is measured by composite anomaly means, while stability is expressed by intracomposite standard deviations. The standard deviations are expressed as percentage of local climatological standard deviation computed from the entire 61-winter climatology. Signal is separated from noise by statistical significance assessment via bootstrap resampling (Efron 1982). The approach is sensitive to composite size and is described in a simi-

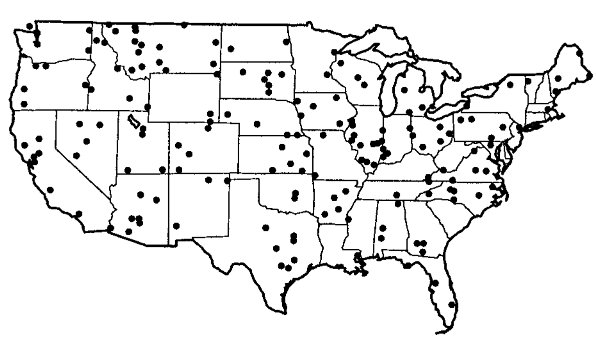

FIG. 1. Dots represent station locations for 168 stations used in this study.

lar context in Gershunov and Barnett (1998) and Gershunov (1998). SLP signal strength and stability results are presented in Figs. 2 and 4, respectively.

b. Results

The left panels of Fig. 2 display the mean SLP anomaly for the El Niño composite and subcomposites according to NPO phase, as indicated. The El Niño signal over the North Pacific consists of an anomalously deep Aleutian low with low pressure anomalies stretching and diminishing toward the southeast along the west coast of North America. Further compositing by NPO phase reveals that the Pacific sector El Niño SLP signal is determined primarily in El Niño winters occurring during the high phase of the NPO. In such winters, the Aleutian low as well as the anomalously low SLP along the West Coast are almost twice that for all El Niño years. By contrast, El Niño

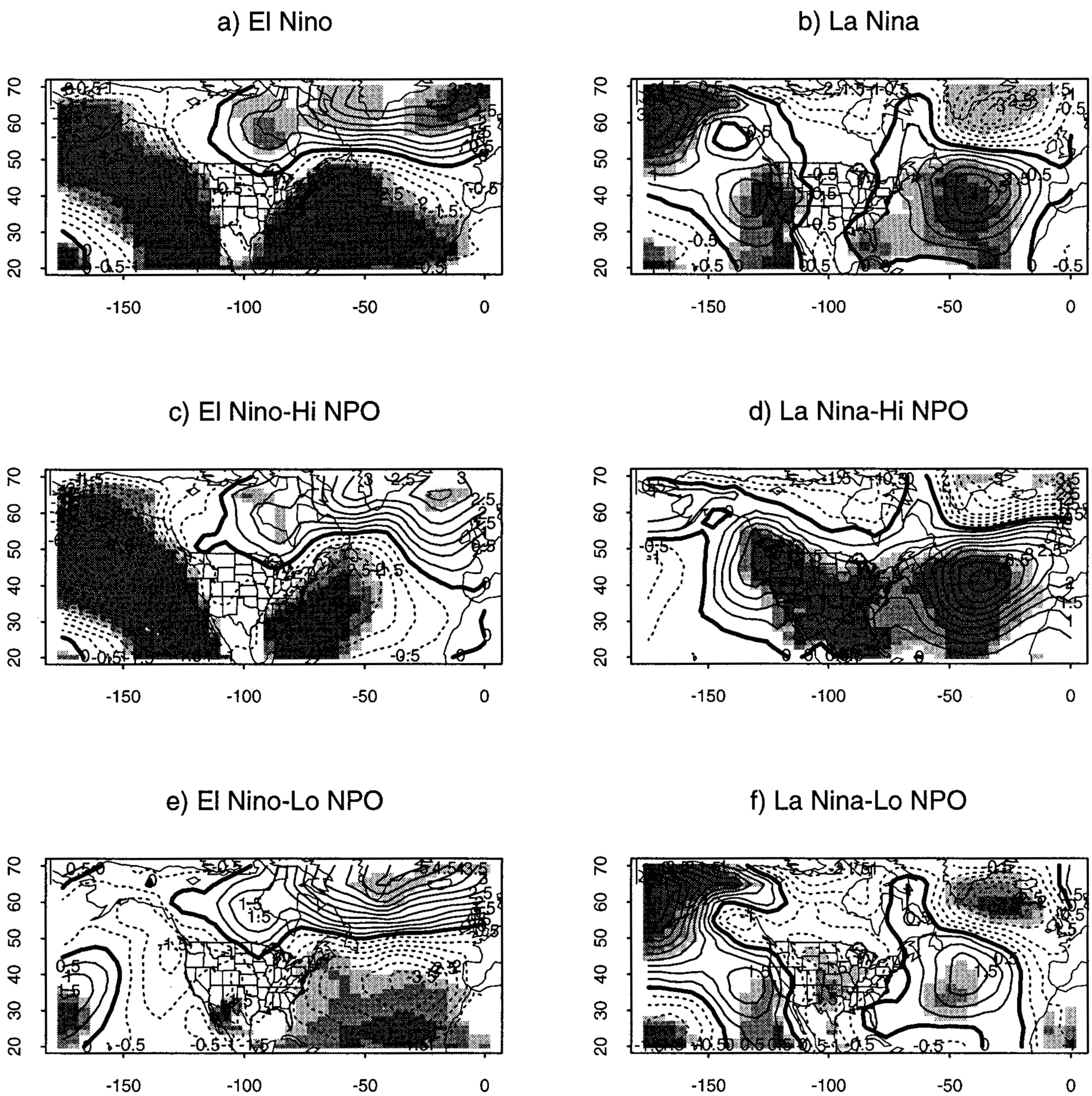

FIG. 2. Mean SLP anomalies for the (a) El Niño and (b) La Niña JFM composites expressed in millibars. Middle panels [(c) and (d)] present the same information for El Niño and La Niña composites subcomposited by the high NPO phase, while lower panels [(e) and (f)] represent the low NPO subcomposites. The zero line is thickened. Thin contours are drawn at 0.5-mb intervals. Negative contours are dashed and positive contours are solid. Values significant at $\alpha = 0.1$, 0.05, and 0.01 are lightly, medium, and darkly shaded.

winters ocurring during the low phase of the NPO exhibit a rather different and mostly insignificant SLP anomaly pattern in the eastern North Pacific.

During La Niña winters (Fig. 2b) a pattern roughly inverse of the El Niño pattern is evident. The positive SLP anomaly in the North Pacific, however, is not centered on the climatological position of the Aleutian low, but is rather pushed out to the Bering Sea and along the U.S. west coast [see Hoerling et al. (1997) for an investigation of the physics responsible for the nonlinearity of ENSO teleconnections]. Further compositing by NPO phase reveals that the North Pacific La Niña signal is associated with winters occurring during the low phase of the NPO (Fig. 2f). A moderately significant low SLP anomaly emerges over the central United States. The La Niña pattern occurring during NPO's high phase (Fig. 2d) is relatively distorted in the North Pacific–North American sector. The center of the anomalously high SLP occurs in the Pacific Northwest corner of the United States. The whole contiguous United States is characterized by statistically significant high pressure anomalies merging with the stronger anomaly in the Azores high.

It is apparent that the typical El Niño and La Niña SLP anomalies in the North Pacific–North American sector occur preferentially during winters characterized by the high and low NPO phases, respectively. This is the constructive ENSO–NPO phase relationship. In the opposite, or destructive, phase pairings the typical ENSO signals tend to be seriously distorted. This is expected to have direct implications for ENSO-related predictability over the contiguous United States.

A relationship between ENSO, NPO, and SLP over the North Atlantic is suggested in Fig. 2. The North Atlantic oscillation (NAO) is associated with changes in surface westerlies over the North Atlantic and is a primary determinant of European climate (e.g., Hurrel 1995). The typical NAO signature in the SLP anomaly field is a dipole between the strengths of the Bermuda–Azores high and the Icelandic low. The NAO appears to be in a positive phase (stronger westerlies) during La Niña winters, especially those occurring during the high NPO phase. The negative NAO phase is observed during El Niño winters, especially those occurring during the low NPO phase. Why are destructive ENSO–NPO phase combinations associated with more significant NAO excursions? This important question is beyond the scientific and geographic scope of this paper. Preliminary results indicate a weak contemporaneous relationship between ENSO and NAO. This relationship is reflected in Figs. 2a and 2b. NPO and NAO indices suggest a lagged relationship with the NPO leading by several years. A weak contemporaneous relationship is manifested in Figs. 3a and 3b. NAO has an apparent tendency to be in the same phase during El Niño (La Niña) as during low NPO (high NPO) phases. However, when ENSO extreme years are removed from the composites, high NPO winters are no longer associated with coherent North Atlantic SLP anomalies (Fig. 3c). A rigorous investigation of the links between ENSO–NPO and NAO is deferred to a future paper.

Figure 4 examines the stability of the SLP signals. Intracomposite SLP anomaly standard deviation relative to the climatological standard deviation is displayed in percent in the same format as the SLP anomalies in Fig. 2. These standard deviations reveal that the Aleutian low SLP anomaly (especially its northwestern extent) exhibits superclimatological stability (i.e., lower than climatological variability) during El Niño winters but significantly so only during the high NPO phase years. The same can be said for the subclimatological stability around the west coast of the United States. This is due to the large intracomposite differences between the southeastern extension of the Aleutian low SLP anomaly. The Gulf Coast SLP anomaly also tends to be less stable during El Niño–high NPO winters.

The high SLP anomaly observed during La Niña winters tends to be stable during both phases of the NPO right along the U.S. west coast, but with larger and more spatially coherent significance during the constructive phase (low NPO). The highly localized (and statistically insignificant) low SLP anomaly in the eastern Gulf of Alaska occurring during the constructive phase also appears to be very stable. The Azores high anomaly, although also weak, similarly tends to be very stable during La Niña–low NPO winters.

To summarize, examination of Figs. 2 and 4 generally suggests that the major North Pacific–North American El Niño and La Niña SLP anomalies expected to affect the U.S. climate tend to be both stronger and more stable during constructive ENSO–NPO phase pairings. Destructive phase pairings, however, may be associated with anomalous winters in Europe and eastern North America through their association with the NAO.

4. HPF

a. Analysis procedure

The processing of HPF data is described in detail by Gershunov (1998). Quantiles for HPF are derived

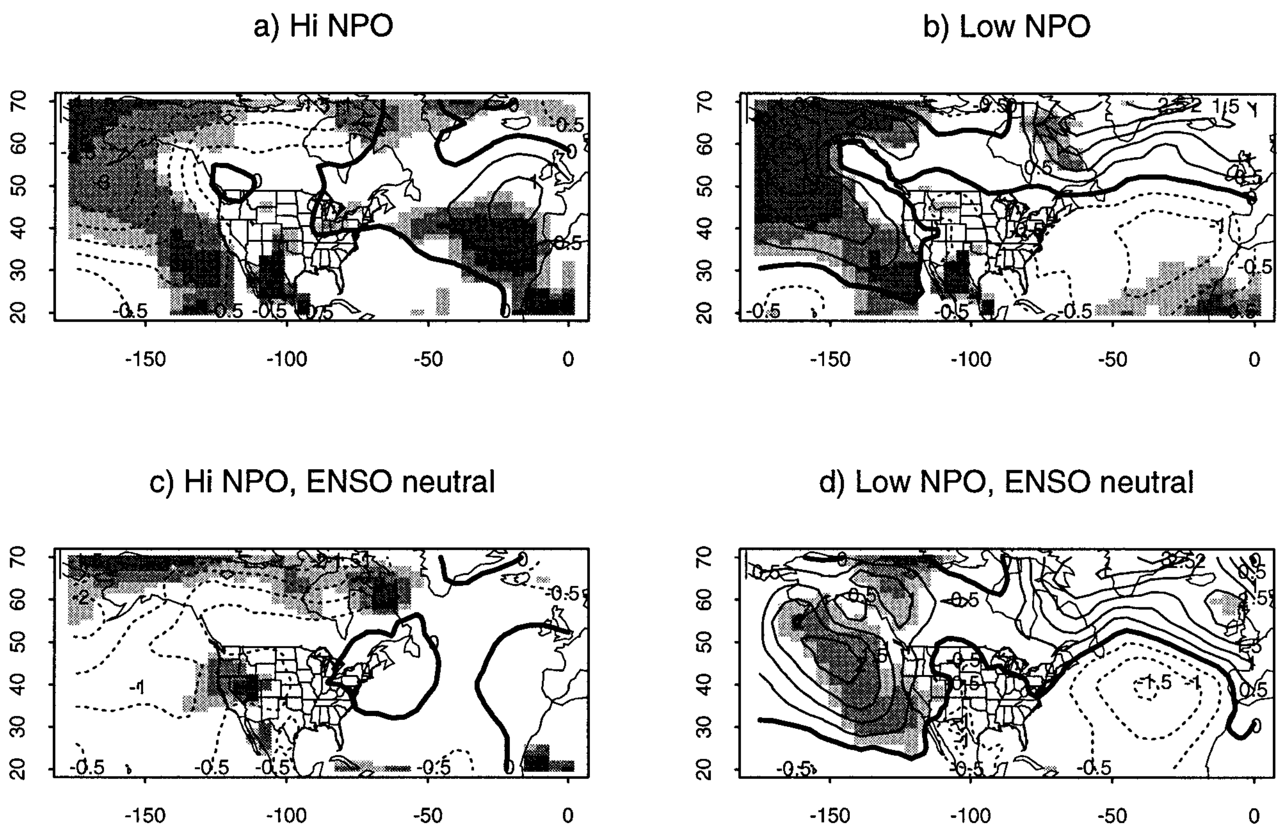

FIG. 3. SLP anomalies for the (a) high and (b) low NPO JFM composites including ENSO extreme years. (c) and (d) Same as (a) and (b) but with ENSO extreme winters excluded. Note that the composite pattern displayed in (c) is calculated by excluding eight El Niño winters and only five La Niña winters (see Table 1). Contours and shading are as in Fig. 2.

at each station from the 61-yr climatology. Each seasonal value is then ranked according to its respective climatological probability of being larger than another observation from the same empirical probability density function. This quantile transformation is done to ensure that a specification based on a composite mean frequency will not be artificially biased toward higher values. The composite means represent signal magnitude and are displayed in quantile units in Fig. 5.

Specification skill and stability is assessed via cross-validated proportion of the intracomposite variance (R^2_{cv}) explained by the composite mean. Skillful specification is indicative of repeatable conditions from one winter to another within a composite. The R^2_{cv} is used here to assess stability because of the measure's direct usefulness in assessing potential predictability (Gershunov 1998). HPF is a variable we want to be able to predict. Areas with potential predictability are those characterized by some appropriate combination of signal magnitude and stability. The R^2_{cv} for HPF composites is displayed in Fig. 6.

b. Results

Consider the El Niño HPF signal (left panels of Fig. 5). A zonally uneven north–south gradient separates the wet southwest and southeast from the dry northwest and northeast. Subcompositing by NPO phase produces a similar but stronger pattern during the constructive (high NPO) phase. Because of the reduction in degrees of freedom, higher signal magnitude is not everywhere reflected in higher statistical significance; however, the similarity of Figs. 5a and 5c is evident. The pattern of the destructive phase (Fig. 5e) is generally similar, especially in the eastern United States, but rather weak and confused in spatial detail, particularly in the western and central United States. Just about the only significant and spatially coherent part of the signal is evident along the southeastern and Gulf coasts during the destructive phase. The pattern correlation coefficient between the canonical El Niño pattern shown in Fig. 5a and subcomposite El Niño anomalies during high (low) phases of the NPO displayed in Fig. 5c (Fig. 5e) is 0.89 (0.70), corresponding to 79% (49%) of spatial variability shared.

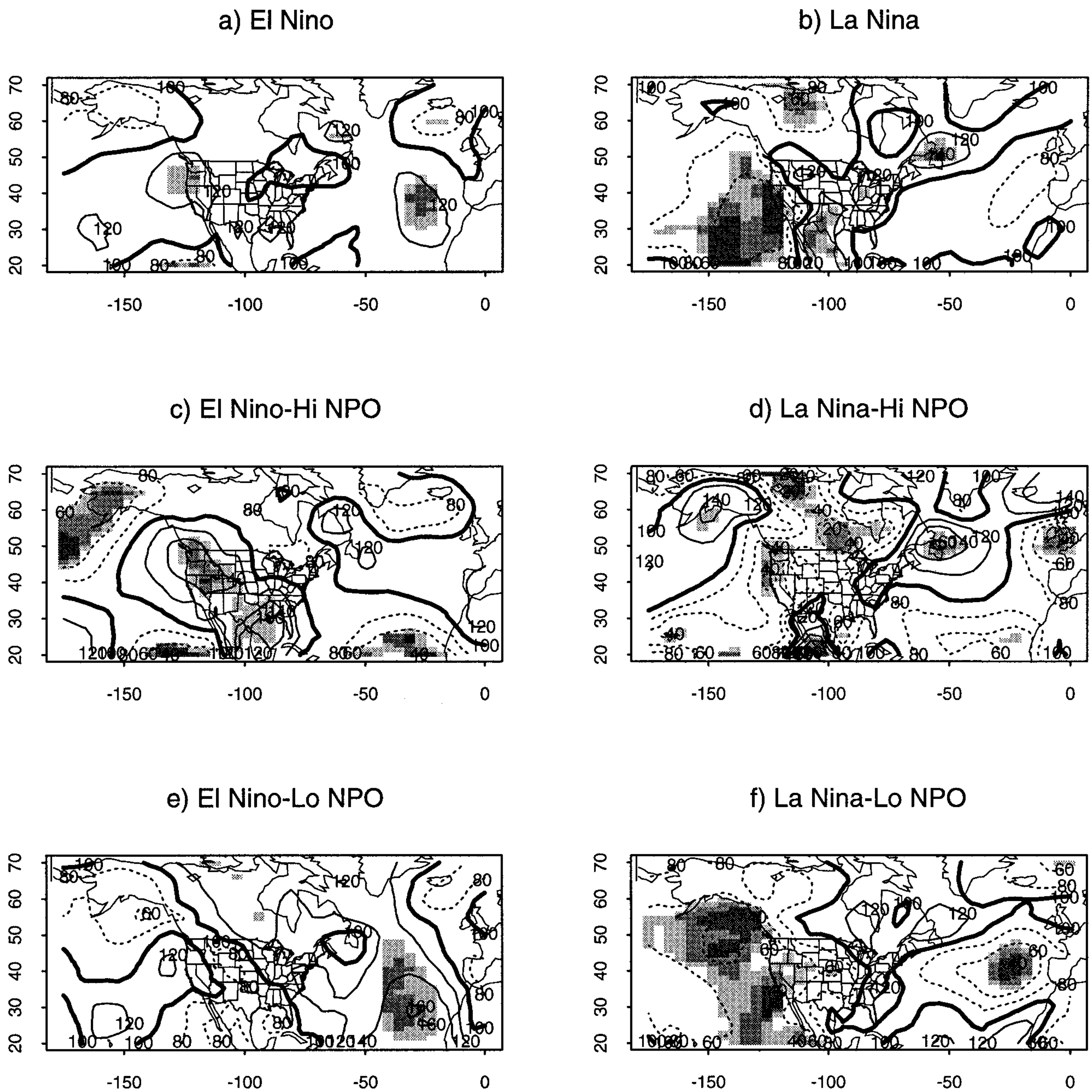

FIG. 4. SLP intracomposite standard deviation for the (a) El Niño and (b) La Niña JFM composites expressed in millibars. Subcompositing in middle [(c) and (d)] and lower [(e) and (f)] panels is the same as in Fig. 2. Intracomposite standard deviations are expressed as percentages of the climatological standard deviations. The 100% contour is thickened. Smaller contours are dashed, larger contours are solid; all are drawn at 20% intervals. Statistical significance is represented by shading as in Fig. 2.

The La Niña HPF pattern is largely the inverse of the El Niño pattern (cf. Figs. 5a and 5b). The inverse patterns differ mainly in that the opposite signal is stronger in the southwest and weaker in the northeast. Compositing by NPO phase reveals an accentuated La Niña signal during the constructive phase (Fig. 5f) and a rather weak and spatially incoherent signal during the destructive phase (Fig. 5d). The pattern correlation coefficient between the canonical La Niña pattern shown in Fig. 5b and subcomposite La Niña anomalies during high (low) phases of the NPO displayed in Fig. 5d (Fig. 5f) is 0.38 (0.86), corresponding to 14% (74%) of spatial variability shared.

Examination of Fig. 6, moreover, reveals that most of the significant HPF anomalies are also stable or consistent from one winter to another within a particular

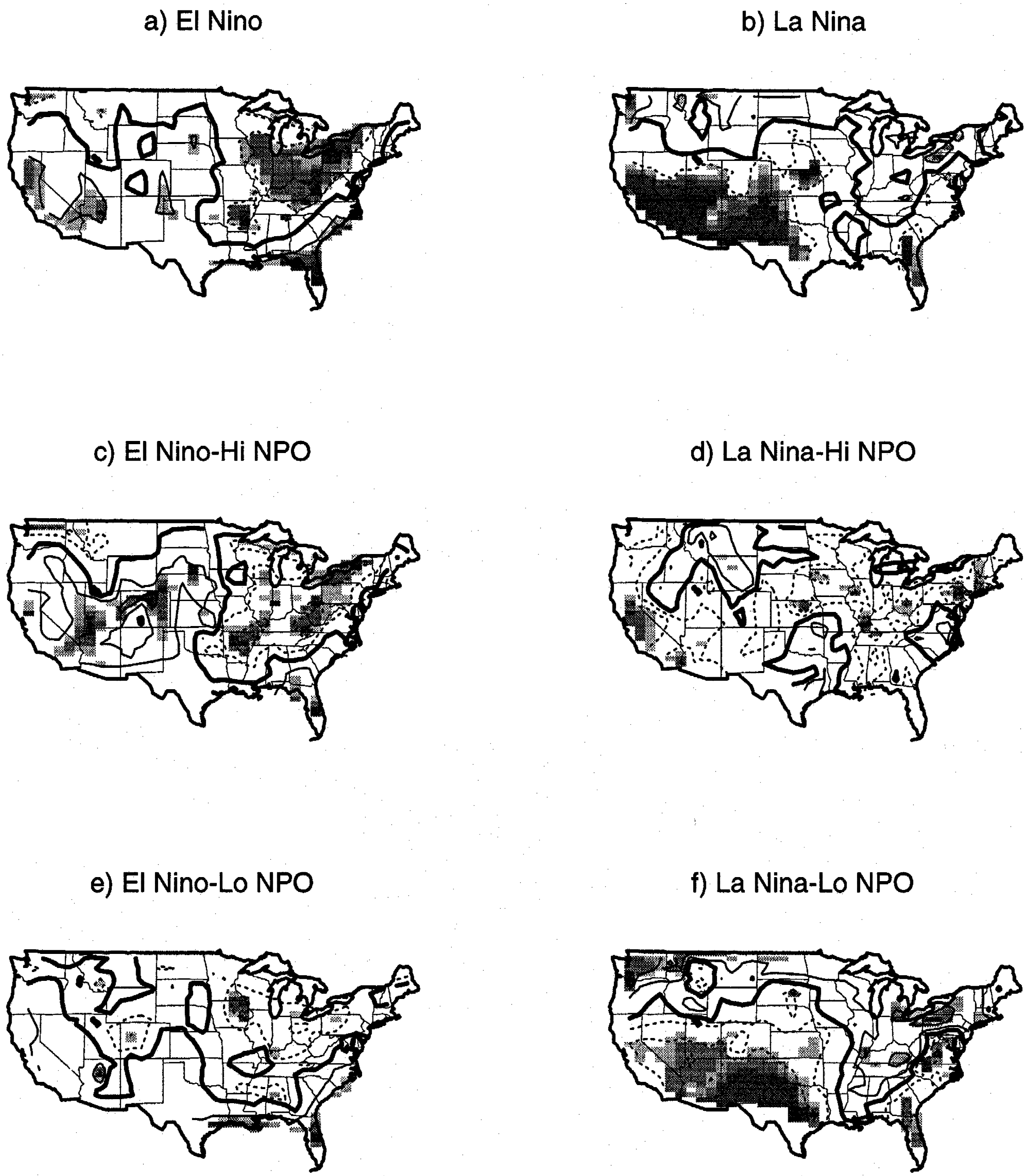

FIG. 5. HPF for the (a) El Niño and (b) La Niña JFM composites expressed as quantiles of the local 61-yr climatologies. Subcompositing in middle [(c) and (d)] and lower [(e) and (f)] panels is the same as in Fig. 2. The 0.5th quantile (median) is thickened. Thin contours are drawn at 0.1 intervals below (dashed) and above (solid) the median. Statistical significance is represented by shading as in Fig. 2.

composite. This leaves signal strength and stability associated with ENSO, with minor local exceptions, largely attributable to the constructive ENSO–NPO interactions. An example of a local exception to this rule is the strong and stable dryness in central California during La Niña–high NPO winters.

These results are consistent with SLP results presented above both in their main thrust suggesting po-

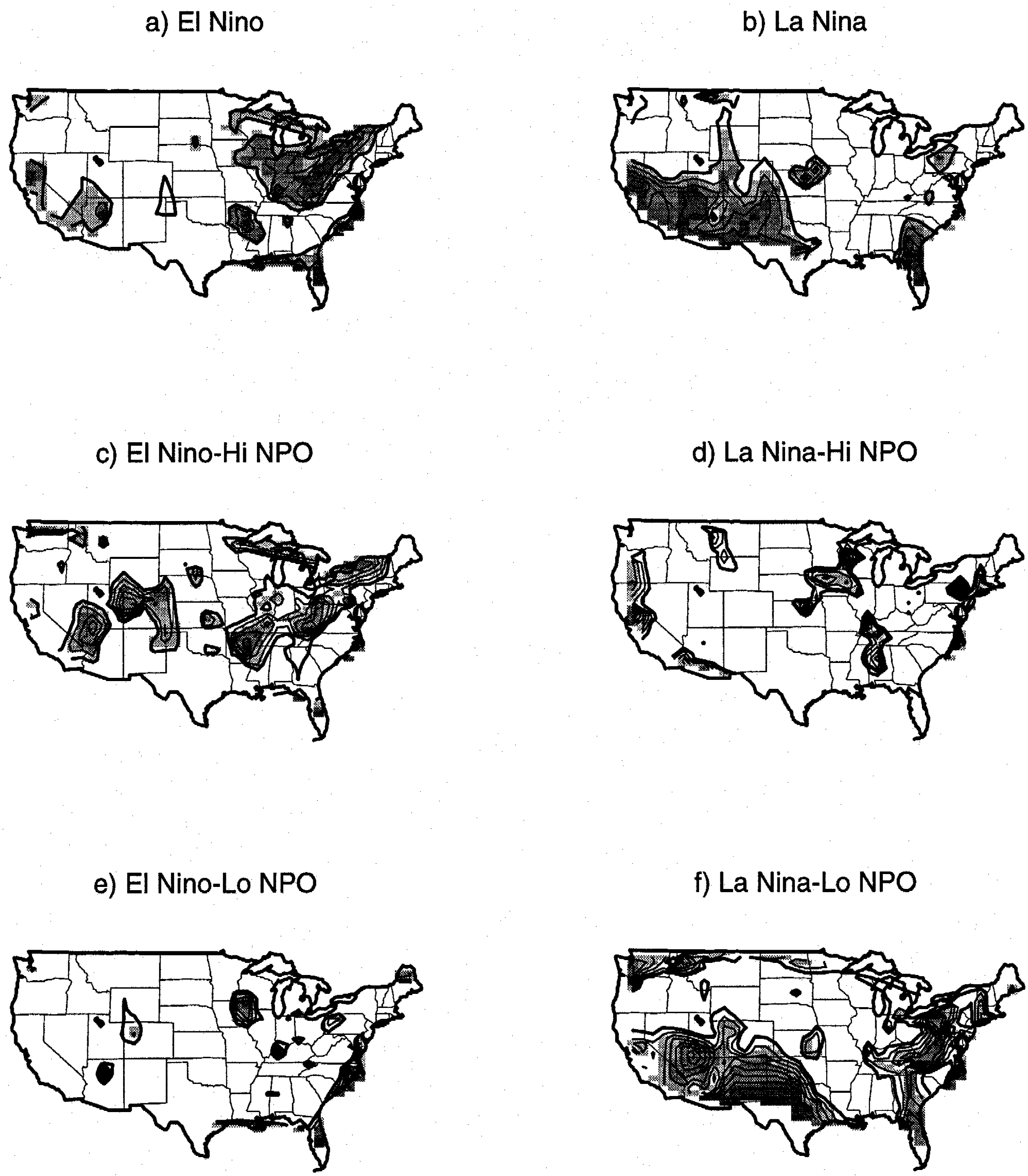

FIG. 6. Cross-validated proportion of variance (R^2_{cv}) in the JFM HPF explained by the phase model for (a) El Niño and (b) La Niña winters. Subcompositing in middle [(c) and (d)] and lower [(e) and (f)] panels is the same as in Fig. 2. Positive values are contoured at 0.1 intervals. The zero contour is thickened. Statistical significance is represented by shading as in Fig. 2.

tential predictability during constructive ENSO–NPO phase winters and in their spatial agreement. For example, the accentuated high frequency of heavy rainfall in the northwest during La Niña–low NPO winters (Fig. 5f) is consistent with the existence of a localized and stable low SLP anomaly in the eastern Gulf of Alaska (Figs. 2f and 4f).

5. Summary and conclusions

Documented ENSO teleconnections to North America (e.g., Ropelewski and Halpert 1986, 1996; Kiladis and Diaz 1989; Gershunov and Barnett 1998) are complicated by large inter–El Niño or inter–La Niña variability (Kumar and Hoerling 1997; Livezey et al. 1997; Gershunov 1998). While some of this variability may be due to details of the tropical Pacific forcing and some to the inherent and unpredictable internal atmospheric variability, a significant and potentially predictable portion appears to be due to the non-ENSO interannual and longer-period coherent modes of climate variability. We presented evidence that the NPO modulates ENSO teleconnections affecting North America. El Niño (La Niña) signals are strong and stable during the high (low) NPO phase. Alternatively, signals tend to be weak, spatially incoherent, and unstable during the El Niño–low NPO and La Niña–high NPO phase combinations. Given the importance of signal strength and stability in determining climate predictability, we expect high (low) NPO epochs to be conducive to El Niño– (La Niña–) related predictability. In other words, our confidence in any North American ENSO-based climate forecast that resembles canonical El Niño or La Niña patterns should be conditioned on NPO phase.

Although the present study is purely empirical, these results are relevant to the problem of ENSO-based climate forecasting with dynamical models. These so-called two-tiered forecasting schemes (Bengtsson et al. 1993; Barnett et al. 1994) commonly involve forcing an atmospheric general circulation model (AGCM) with a tropical Pacific SST anomaly forecasted with a dynamical, statistical, or hybrid model of ENSO, while climatological SSTs are prescribed elsewhere. Given a strong tropical Pacific SST anomaly, a realistic AGCM will produce an ensemble mean North American climate response similar to the observed canonical ENSO anomaly. Such AGCMs forced with the strong and well-predicted 1997/98 tropical Pacific warm anomaly correctly predicted the strong and typical El Niño climate signal in North America (e.g., Mo et al. 1998). Our results raise the question, "Would the 1997/98 North American winter AGCM forecasts have been so successful if the NPO had not been in its high phase?" An alternative question is, "If a strong La Niña event develops in the winter of 1998/99, as currently forecast by most models, and if the North Pacific persists in its cold phase, can we be confident in any North American climate forecast resembling canonical La Niña conditions?" The empirical results presented here certainly suggest that we should not have much confidence in such a forecast. It seems imperative that the state of the NPO be reckoned in all ENSO-based forecasts for the North American winter climate, whether statistical or dynamical. Some operational climate forecasting groups have begun to include persisted North Pacific SST anomalies in the forcing field of their ENSO-based AGCM prediction schemes (L. Goddard 1998, personal communication). At present, however, it is not known whether AGCMs are able to successfully simulate the North American climatic manifestations of the ENSO–NPO interference. A study examining several GCMs in this regard is forthcoming.

How does the NPO modulate the consistency and strength of El Niño anomalies? The strongest atmospheric manifestation of the NPO is in the strength of the Aleutian low (Mantua et al. 1997; our Fig. 3), which is also well known and shown here to be affected by ENSO teleconnections. We hypothesize that a deeper Aleutian low shifts the storm track southward while El Niño provides an enhanced eastern tropical Pacific moisture source for the storms to tap. Alternatively, a weaker Aleutian low during the low phase of the NPO paired with La Niña steers cyclonic storms farther north, increasing precipitation in the northwest while the less frequent storms passing over the southwest tend to be drier than normal because less moisture is available from the eastern tropical Pacific. This paradigm is generally consistent with observed precipitation anomalies in the western United States.

The atmospheric pressure anomaly in the Aleutian region is sensitive to ENSO phase. Therefore, its magnitude, as determined by the NPO may be reduced during low NPO–El Niño and high NPO–La Niña winters. It should not be surprising, therefore, that such NPO–ENSO combinations produce confused SLP signals and spatially incoherent, unstable precipitation signals. Furthermore, storms, even if dislodged farther south during the high NPO phase, would tend to be drier during La Niña winters because of the reduced eastern tropical Pacific moisture source. The more northerly storm track during low phases of the NPO puts most storms somewhat out of reach of the enhanced tropical moisture source during El Niño winters. The storms that do wander farther south in such winters probably tend to be wetter. This may help explain the spatially incoherent SLP anomaly patterns over the northeastern Pacific and HPF anomaly patterns over the contiguous United States during winters characterized by destructive ENSO–NPO phase combinations.

Less general and more locally rooted theories may hold on regional scales and other low-frequency modes are likely important modulators of interannual variability in other parts of the world. Lacking good physical understanding of most of these documented interannual and lower-frequency modes (e.g., Mann and Park 1996), we are far from being able to physically forecast their evolution. However, the timescales involved in the evolution of quasi-decadal coupled climatic modes, such as the NPO, make them amenable to persistence forecasting with lead times comparable to seasonal lead times of skillful ENSO forecasts (e.g., Barnett et al. 1993). The central implication of this paper is that stratification of ENSO-based statistical forecasts by NPO phase should greatly enhance the accuracy of such forecasts, particularly in the western and central United States.

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