Diagnosis of Anomalous Winter Temperatures over the Eastern United States during the 2002/03 El Niño

LISA GODDARD

International Research Institute for Climate Prediction, Columbia University, Palisades, New York

ARUN KUMAR

NOAA/NWS/NCEP/Climate Prediction Center, Camp Springs, Maryland

MARTIN P. HOERLING

NOAA–CIRES Climate Diagnostics Center, Boulder, Colorado

ANTHONY G. BARNSTON

International Research Institute for Climate Prediction, Columbia University, Palisades, New York

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ABSTRACT

The eastern United States experienced an unusually cold winter season during the 2002/03 El Niño event. The U.S. seasonal forecasts did not suggest an enhanced likelihood for below-normal temperatures over the eastern United States in that season. A postmortem analysis examining the observed temperatures and the associated forecast is motivated by two fundamental questions: what are these temperature anomalies attributable to, and to what extent were these temperature anomalies predictable? The results suggest that the extreme seasonal temperatures experienced in the eastern United States during December–February (DJF) 2002/03 can be attributed to a combination of several constructively interfering factors that include El Niño conditions in the tropical Pacific, a persistent positive Pacific–North American (PNA) mode, a persistent negative North Atlantic Oscillation (NAO) mode, and persistent snow cover over the northeastern United States. According to the simulations and predictions from several dynamical atmospheric models, which were not rigorously included in the U.S. forecast, much of the observed temperature pattern was potentially predictable.

1. Introduction

The eastern United States experienced unusually cold temperatures during the winter season of 2002/03 (Fig. 1a). According to the observed record over the last 50 yr, the seasonal temperatures over much of the United States east of the Mississippi River, from the Gulf Coast to New England, registered below the coldest 20th percentile (Fig. 1c). The cold temperatures and associated winter storms were classified within the top 20 costliest disasters for 2002 and 2003, worldwide. These extreme winter conditions over the eastern United States were purported to have cost 60 lives and approximately $1 billion in insured losses (Swiss Re 2003, 2004).

Also occurring in 2002/03 was a moderate strength El Niño event. As the El Niño event was manifest by mid-2002, and because El Niño events exert substantial influence on the North American climate during boreal winter (Ropelewski and Halpert 1986; Barnston 1994), the official seasonal forecast for December–February (DJF) 2002/03 over the United States relied heavily on canonical patterns of climate anomalies associated with El Niño combined with a projection of trends based on the pattern of warm bias observed over the last 10 yr (Higgins et al. 2000). The resulting forecast for much of

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Corresponding author address: Lisa Goddard, International Research Institute for Climate Prediction, The Earth Institute at Columbia University, 228 Monell Bldg., 61 Route 9W, Palisades, NY 10964-8000.
E-mail: goddard@iri.columbia.edu

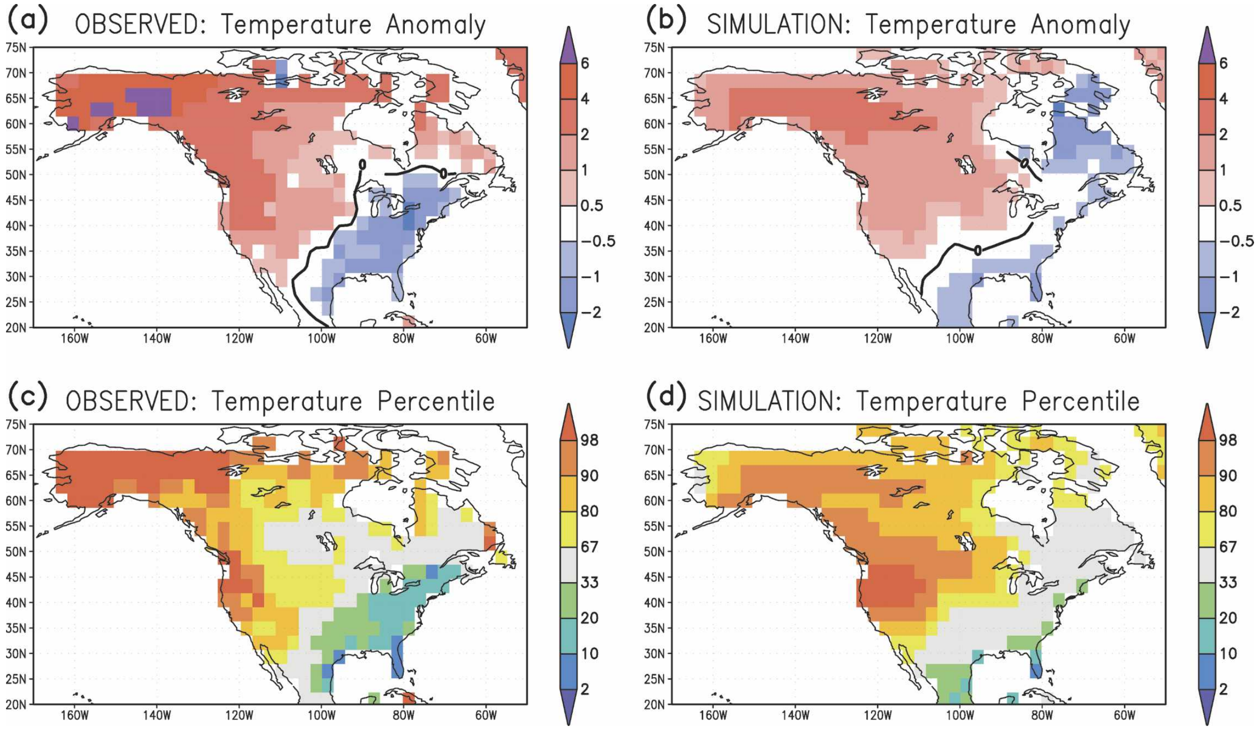

FIG. 1. Anomalous temperature for Dec 2002–Feb 2003: (a) the observed anomaly (°C), (b) the MM simulated anomaly (the zero contour is indicated), (c) the observed percentile of seasonal temperature over the base period for the observations, and (d) the percentile of MM seasonal temperature.

the United States, particularly the northern half of the country, indicated a strong likelihood for above-normal temperatures (Fig. 2). Thus, not only were the eastern U.S. temperatures unusually cold, but the forecasts indicated that the observed outcome was unlikely for most of the region.

A postmortem analysis is conducted of the eastern U.S. temperatures and associated forecast for the DJF 2002/03 season. This analysis addresses two fundamental questions: what are these temperature anomalies attributable to, and to what extent were these temperature anomalies predictable? For any given season, the observed climate is a combination of a boundary-forced signal and internally generated atmospheric noise. The boundary-forced signal constitutes the potentially predictable part of the seasonal climate, arising largely from changes in temperature patterns over the tropical oceans (e.g., Goddard et al. 2001). However, for the climate to be predictable in a real forecast setting, the changes in relevant boundary conditions must also be predictable.

A main motivation of this analysis (i.e., to what factors the U.S. temperature anomalies are attributable) is to understand how much the signal in the atmospheric response departed from the canonical El Niño response pattern, and whether the observed anomalies were consistent with this. Did the particular details of the 2002/03 El Niño lead to differences from the canonical El Niño expectations, or did atmospheric noise dominate the outcome? Being only a single case study, this analysis may be deemed anecdotal, but the justification for this particular case study is that 1) it motivates the analysis of atmospheric response beyond El Niño/La Niña in hopes of improving seasonal climate predictions, and 2) the analysis is part of an evolving activity for the attribution of seasonal climate variability (Barnston et al. 2005) and defines a procedure that could be repeated for other case studies.

2. Data and methods

a. Observations

The air temperature observations over land come from the Climate Anomaly Monitoring System (CAMS) over land (Ropelewski et al. 1985). These monthly averaged data are based on over 6000 station observations, approximately 600 of which are in North America. The station data are interpolated onto a 2° × 2° latitude–longitude grid. This dataset supplies temperature anomalies relative to the 1971–2000 climatological base period.

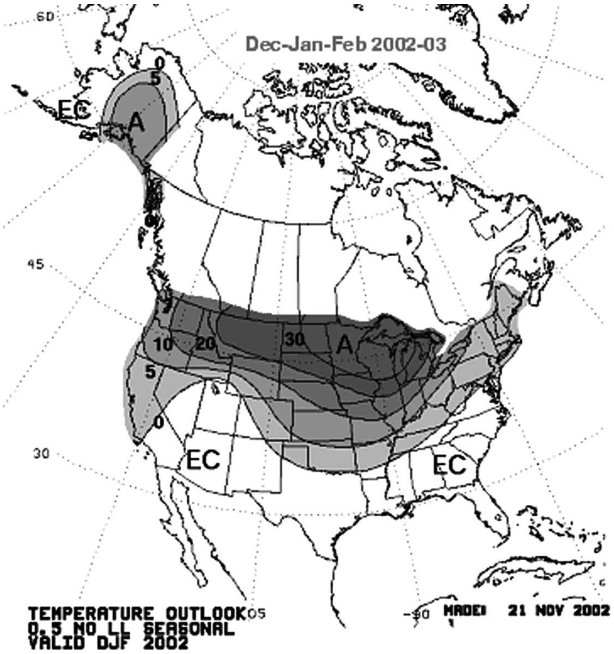

FIG. 2. Probabilistic temperature forecast produced by NCEP's Climate Prediction Center in mid-November 2002 for the December–February 2002/03 season. Contours show probability anomalies for the most likely temperature category with respect to its climatological probability of 33.33%. The possible three categories are above-normal ("A," shaded gray), near-normal ("N"), or below-normal ("B," none on map). EC means "equal chances," implying the climatological probabilities of 33.33% for each of the three categories. For increased likelihood of above- or below-normal, the near-normal category retains its 33.3% probability. Thus, a value of 10 in the gray shading implies forecast probabilities of 43.33% for above-normal, 33.33% for near-normal, and 23.33% for below-normal seasonal temperatures.

Over the oceans, the extended reconstructed SST (ERSST) dataset (Smith and Reynolds 2003) serves to document ENSO variability. The Niño-3.4 SST index (SST anomalies averaged 5°S–5°N; 170°–120°W) represents the overall measure of ENSO variability, and spatial maps of particular El Niño events are used (but not shown) to discern qualitative interevent differences. Consistent with the air temperature over land, the climatological base period of 1971–2000 is used.

To examine the qualitative response of the tropical and extratropical atmosphere to tropical SST forcing, tropical precipitation, and 200-mb geopotential height patterns are examined. These fields are taken from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis (Kalnay et al. 1996). Although true observations of precipitation would be preferable to a reanalysis product, none exists for a comparably long period. Again, anomalies are defined with respect to the 1971–2000 climatological base period.

Snow-cover data over North America is used to examine the possible role of land surface boundary conditions during the winter season. Maps showing gridded fields of the temporal fractional coverage of snow is obtained from the Snow Data Resource Center of Rutgers University Climate Laboratory (more information available online at http://climate.rutgers.edu/snowcover). The snow-cover information comes from the National Oceanic and Atmospheric Administration (NOAA) and is based on shortwave imagery from satellites. Weekly digitized maps are interpreted on the National Meteorological Center limited-area fine mesh grid, with cell resolution ranging from 16 000 to 42 000 km^2. The weekly snow cover is a binary field; the cell is considered snow covered if it has at least 50% coverage. Monthly values indicate percent of time the cell is snow covered by weighting the weekly values according to the days per week falling in the given month. The climatological period for snow cover covers November 1966–May 1999, with a few missing months in the early part of the record.

b. *AGCMs: Simulations and forecasts*

A multimodel ensemble of atmospheric general circulation model (AGCM) simulations and predictions provides the basis for the attribution and predictability assessment of the DJF 2002/03 U.S. temperatures. The terminology employed here is specific and deliberate: *simulations* are model runs forced by observed SSTs; *forecasts* are model runs forced by predicted SSTs. The simulation ensemble indicates to what extent the temperature anomalies are potentially predictable, when the observed SSTs force the models. The forecast ensemble shows the actual model-predicted temperature anomalies over the United States, using one manifestation of predicted SST forcing. The model forecasts result from the real-time seasonal forecast activities at the International Research Institute for Climate and Society (IRI). The simulation runs for the various models are continually updated and are maintained as an ongoing activity used for comparison with the real-time forecasts to assess the difference between potential and actual predictability.

The details of the individual AGCMs are given in Table 1. In all cases, anomalies and tercile definitions are relative to the 1971–2000 climatological base period. The simulation runs are continuous integrations in which the individual ensemble members differ from one another in their initial conditions prescribed at the beginning of the runs (approximately 1950). For the

TABLE 1. The four atmospheric GCMs used in the analysis: the NCAR Community Climate Model (CCM; Hack et al. 1998; more information available online at http://www.cgd.ucar.edu/cms/ccm3), the European Community/Hamburg model of the Max-Planck-Institut für Meteorologie (ECHAM; Roeckner et al. 1996; more information available online at http://www.mpimet.mpg.de/en/wissenschaft/modelle/echam.html), the Geophysical Fluid Dynamics Laboratory (GFDL Global Atmospheric Model Development Team 2004) model, and NASA's Seasonal-to-Interannual Prediction Project (NSIPP) model at the Goddard Space Flight Center (more information available online at http://nsipp.gsfc.nasa.gov/research/atmos/atmos_descr.html).

Model	CCM3.2	ECHAM4.5	GFDL	NSIPP1
Ensemble size	10	24	10	9
Horizontal resolution	T42	T42	2.5° × 2.0°	2.5° × 2.0°
Vertical resolution	18	19	18	34

forecasts, the initial conditions are taken from the restart files of the long runs that extend up to the present. No observed atmospheric data are used for initialization of the forecasts.

For the forecast ensemble, each AGCM uses the same predicted SST anomaly fields, produced at the beginning of November 2002, added to the fields of climatological SST. The predicted SST anomaly fields are constructed from a variety of tools: the tropical Pacific SST anomalies are from the NCEP coupled ocean–atmosphere GCM (Ji et al. 1998), the tropical Atlantic SST anomalies are based on a canonical correlation analysis (CCA) model that uses recent observations of the tropical Pacific and Atlantic SSTs as the predictors (Repelli and Nobre 2004), the tropical Indian Ocean SST anomalies for DJF 2002/03 are based on the observed SST anomalies from October 2002 damped with an *e*-folding time of 90 days, and the midlatitudes also are prescribed observed SST anomalies from October 2002 damped with an *e*-folding time of 30 days. The variety of methods used for SST prediction in the different ocean basins reflects the evolution of IRI's global SST predictions, with the recognition that the chosen statistical tools outperform the available dynamical tools outside the tropical Pacific.

c. *Multimodel combination*

A multimodel (MM) treatment reduces the biases in the simulated and forecast seasonal climate relative to those of the individual AGCMs. It also provides a larger set of realizations for ensemble averaging. For both of these reasons, the skill of MM ensembles generally exceeds that of the individual models (Pavan and Doblas-Reyes 2000; Robertson et al. 2004). Here, the simplest approach to model combination is employed; each of the four models receives equal weight. Using this simple model combination approach, maps are produced of MM ensemble mean, which represent the forced part of the seasonal climate, and of the multimodel three-category probabilities,[1] which quantify the model-perceived uncertainty in the seasonal climate.

3. Results

a. *Model agreement*

The MM simulation ensemble mean, which was forced by observed SSTs, agrees with observations in the general pattern of temperature anomalies (Fig. 1). Table 2 provides measures of quantitative agreement, which are also high for the MM simulation over the United States as a whole. More extreme temperature values are found in the observations as one might expect since the observations represent a combination of the boundary-forced signal and internally generated atmospheric noise. The most notable difference exists over the eastern United States, where the observed temperatures were below the coldest 20th percentile east of the Mississippi River along the entire eastern seaboard (Fig. 1c). The MM ensemble-mean simulation response indicated below-normal temperatures (i.e., coldest 33d percentile) along the entire East Coast, and below 20th percentile over Florida, but the region of cold anomalies did not extend inland (Fig. 1d).

Where model simulations all agree with each other in sign (Fig. 3a), they virtually always also agree with observations (Fig. 3b). That all AGCMs exhibit shifts in their individual ensemble means in the same direction strongly suggests that the real climate system also has an increased likelihood for shifting in the same direction, assuming that the models faithfully represent the real world, or at least do not share common biases.

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[1] The three categories are assumed equiprobable, with tercile boundaries based on data from the 1971–2000 climatological base period. Thus, below normal refers to colder than the 33d percentile, and above normal refers to warmer than the 67th percentile. Tercile boundaries are determined by ranking the data, without the use of any fitting techniques.

TABLE 2. Skill scores for DJF 2002/03 temperature calculated over contiguous United States. (a) Ranked probability skill score (RPSS) is given for three-category probabilistic forecasts, using a reference forecast of climatological probabilities that defines the categories as equiprobable. (b) The Heidke skill score similarly treats three-category forecasts, but as a hit rate, using a reference forecast of random hits. Both scores are constructed using the gridpoint values over the contiguous United States. The western and eastern United States are divided at 90°W, approximately at the Mississippi River. Note: Areas of climatological probabilities are not included in the Heidke skill score.

	United States	Western United States	Eastern United States
(a) RPSS (%)			
CPC forecast	0.16	17.1	−29.3
MM forecast	21.2	25.6	11.3
MM simulation	32.9	45.2	5.0
(b) Heidke (%)			
CPC forecast	−5.5	15.2	−50.0
MM forecast	34.6	50.6	−2.9
MM simulation	32.1	56.1	−24.3

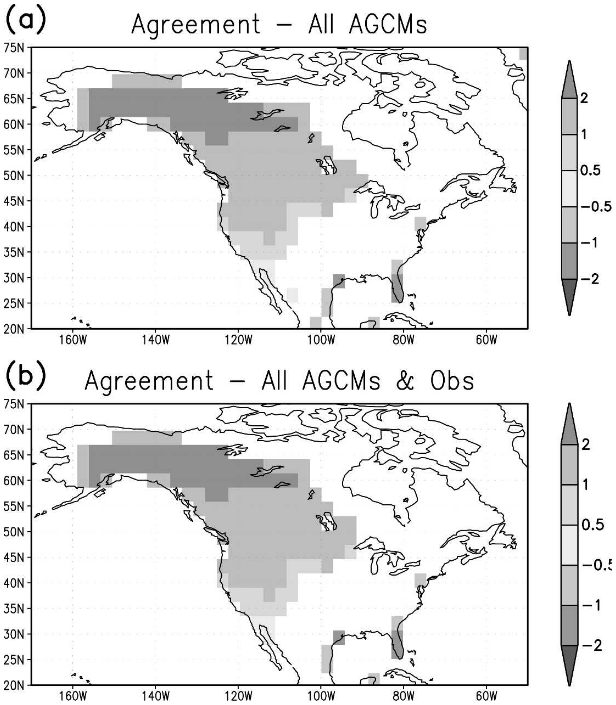

FIG. 3. Temperature anomaly (°C) as shown in Fig. 1b: (a) shaded only for regions where all models agree in sign of the anomaly, and (b) shaded only for regions where all models and observations agree in sign of the anomaly.

b. External/boundary forcing—SSTs

A moderate El Niño event occurred in late 2002/early 2003. If we assume that the tropical Pacific SST anomalies contributed to the pattern of temperature anomalies over the United States in that winter, then we imply that a successful forecast of U.S. temperatures depends on an accurate prediction of the El Niño conditions. The SST anomaly forecast used in this analysis for December 2002–February 2003 (Fig. 4a) closely resembles the observed SST anomaly field over the central equatorial Pacific (Fig. 4b). As a result, the eastward shift in convective heating over the Pacific from the model forecasts, forced with predicted SSTs, also resembles that of the simulations, which were forced by the observed SSTs (not shown). The SST prediction for the tropical Pacific (see section 2b) was obtained from the NCEP coupled model, and it presented an outlook for El Niño very near the middle of the range of a large group of ENSO prediction models. The largest errors in tropical Pacific SST are found in the far eastern equatorial Pacific (Fig. 4c), but these are not likely to have much impact on tropical heating anomalies because the SSTs there are usually far below the convective threshold in DJF. Sizeable errors are also found over the Indian Ocean and Maritime Continent, which may degrade the seasonal climate prediction over North America (Farrara et al. 2000).

Across the United States, the dynamical forecasts and simulations were more skillful than the official Climate Prediction Center (CPC) forecast (Fig. 5; Table 2). The pattern of MM forecast air temperatures anomalies over the United States agrees reasonably well with observations, even though the majority of the skill originates over the western United States. The magnitude of the forecast anomalies was weaker than the observations (Figs. 1a and 5a), but the dominant category indicated in the MM forecast category typically coincides with that of the observations. Where the forecast indicates categorical probabilities of above normal or below normal that notably exceed their climatological value of 33.3%, that category was observed (Figs. 1c and 6b,d). The MM simulation, which used observed SSTs, indicates stronger magnitude temperature anomalies across the United States relative to the MM forecast, which used the predicted SSTs (cf. Figs. 1b and 5a). The principal difference between the boundary conditions for these two sets of model runs were those over the Indian Ocean (Fig. 4), suggesting that Indian Ocean SST anomalies contributed to the strength of the forced temperature pattern over the United States.

Just as the models produce an ensemble of possible outcomes based on one instance of boundary forcing, be it observed or predicted SST, the observations are also effectively drawn from a range of possibilities. It is therefore relevant to examine the probability or likelihood of the event as seen in the models (Fig. 6). For locations where all AGCMs agree in sign (Fig. 3) the

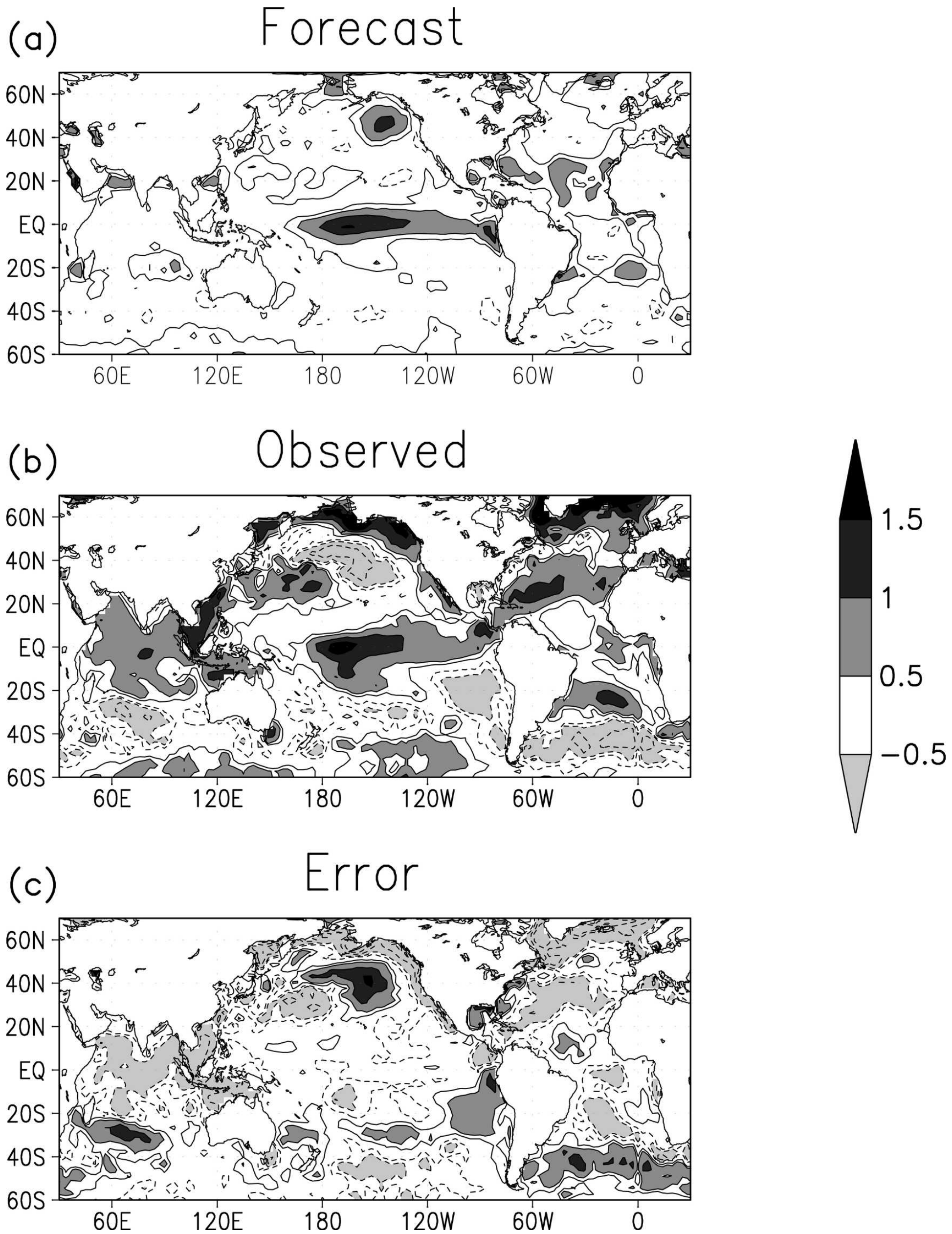

FIG. 4. SST anomalies (°C) for December 2002–February 2003 from (a) a forecast, (b) the observations, and (c) the error in the forecast (i.e., forecast − observed). Data are contoured at ±0.25°, 0.5°, 1.0°, and 1.5°C.

MM simulation indicates that the corresponding above- or below-normal category is more than 50% likely (Figs. 6a,c). In the MM forecast similar, but less sizeable, shifts in the seasonal temperature probabilities are seen over most of the areas (Figs. 6b,d). In general, the strength of the probability shift (i.e., departure from 33.3% for above- or below-normal probabilities) mirrors the strength of the ensemble mean percentile for both the simulation and the forecast.

Having detected a global SST-forced component to U.S. temperature anomalies during DJF 2002/03, we now address the specific role of El Niño. What pattern of temperature anomalies would be expected over the United States in DJF during an El Niño event, and can the models capture that pattern? A comparison of composites over the 10 warmest El Niño events since 1950[2]

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[2] El Niño strength is measured by the Niño-3.4 index, which is the SST anomaly averaged over the central equatorial Pacific box: 5°S–5°N, 170°– 120°W.

indicates that model simulations represent the observed teleconnection pattern qualitatively (Fig. 7). The main feature of the canonical El Niño temperature composite is a zonal pattern, with warmer-than-normal temperatures in the northern United States and cooler-than-normal temperatures across the southern tier. Some bias exists in the models: the zero line lies farther north and the warmest anomalies are found farther to the east in observations. Some of the discrepancy between observed and simulated composites may be due to sampling issues since the composites consist of 530 realizations for the AGCMs and only 10 for the observations. Discrepancy between the observed and simulated composites may also arise from changes in the radiative forcing due to increasing greenhouse gases that are present in nature but not in these model runs. Probabilistic composites of above- and below-normal categorical temperatures show similar patterns but also illustrate the biases more clearly. The spatial biases may be related to spatial biases in the tropical rainfall anomalies or, equivalently, the tropical heating, which is stronger and focused slightly west in models compared to observations. However, the models simulate well the placement and strength of 200-mb height anomalies, with the exception of the extension of nega-

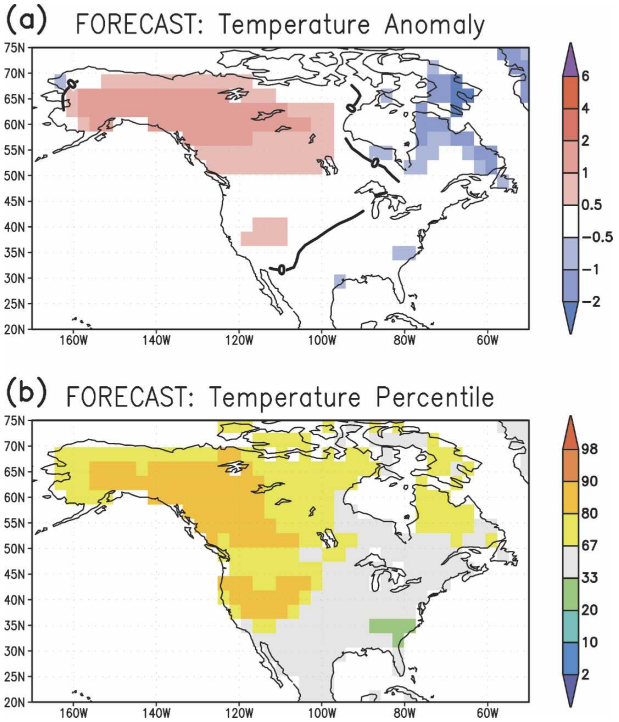

FIG. 5. December 2002–Febuary 2003: (a) temperature anomaly (°C) and (b) temperature percentile from the MM forecast.

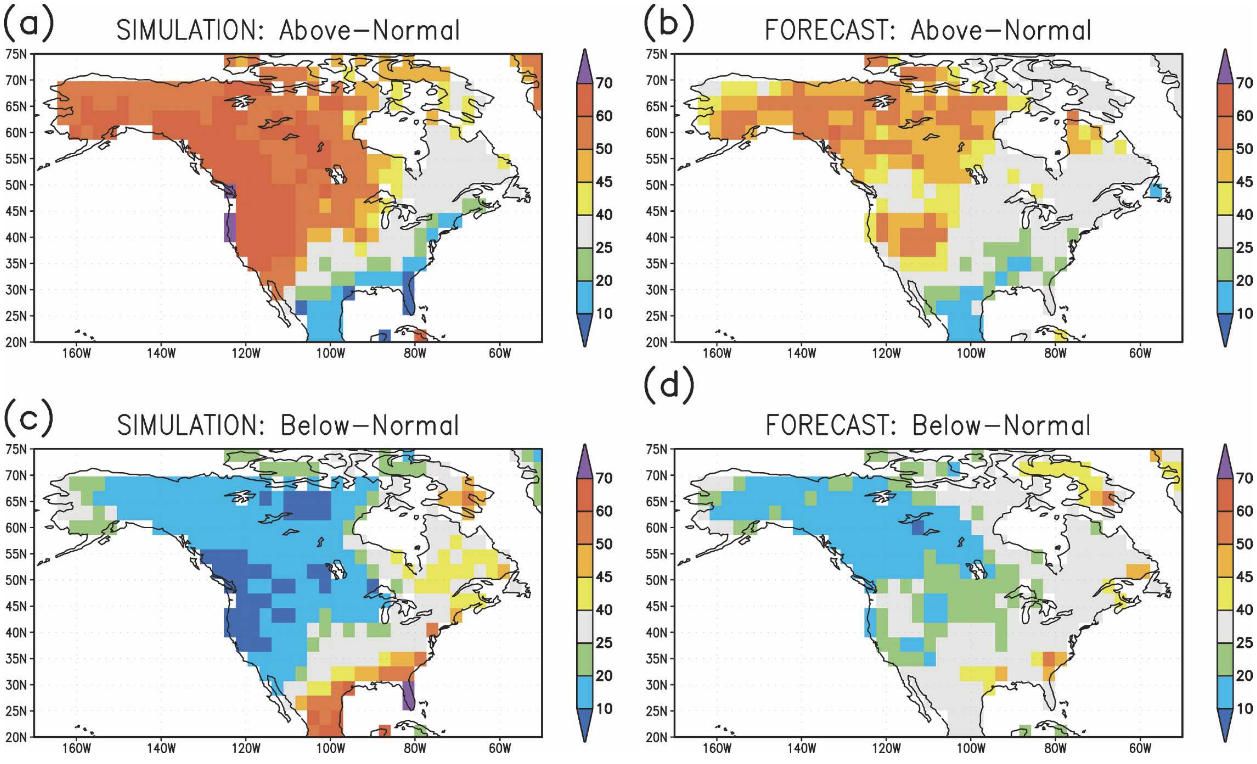

FIG. 6. Temperature probabilities for December 2002–February 2003 for the above-normal category from the MM (a) simulation and (b) forecast, and similarly for the (c), (d) below-normal category. The near-normal category is not shown.

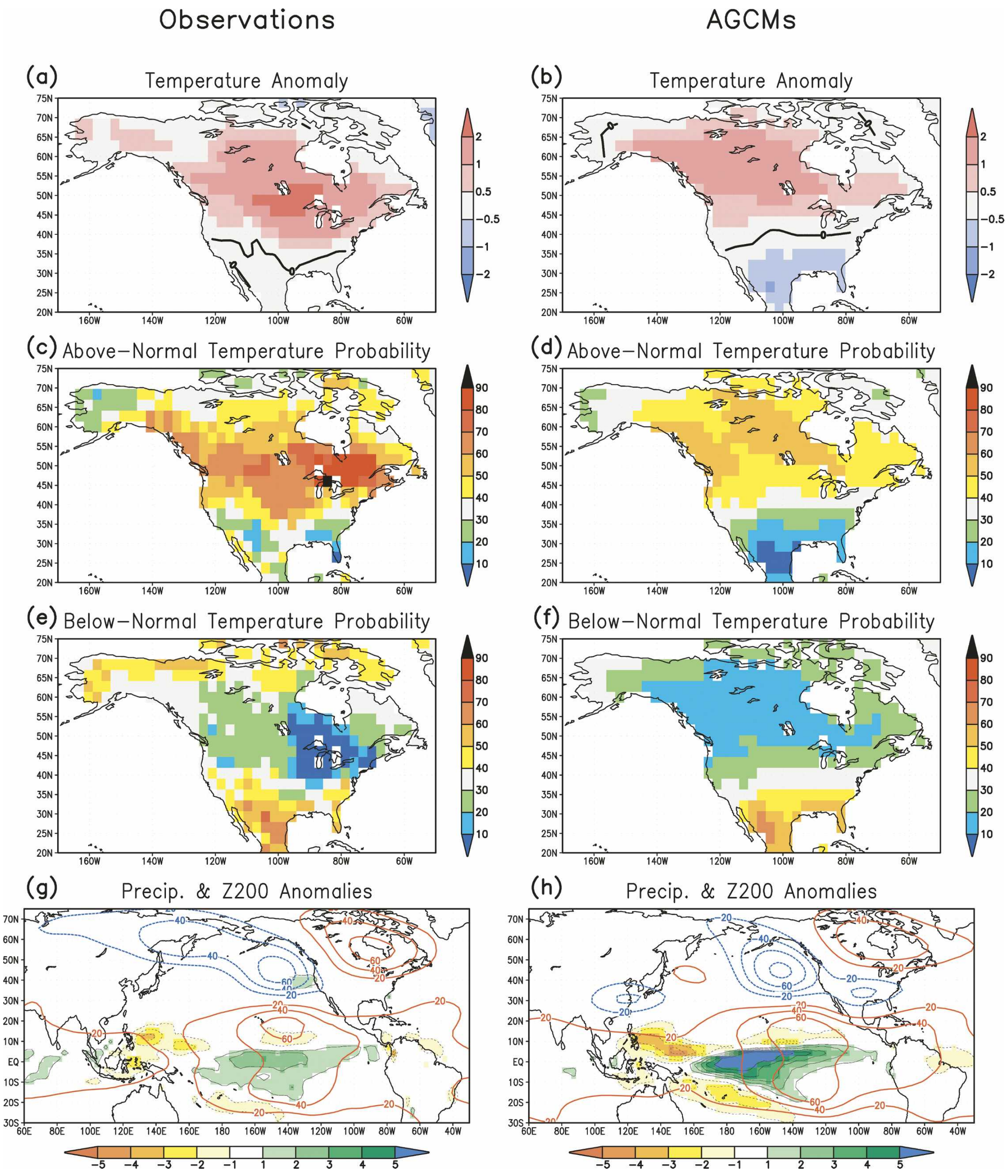

FIG. 7. Composite DJF temperature response from the warmest 10 El Niño events over the period 1950–98: (left) observations and (right) MM simulation. (a), (b) Temperature anomaly (°C). The zero contour is indicated. (c), (d) Frequency of occurrence of the above-normal category. (e), (f) The frequency of occurrence of the below-normal category. (g), (h) The precipitation anomaly (mm day^{-1}) shown in shading, and the 200-mb height anomaly (m) with positive anomalies indicated by the solid red contours and negative anomalies by the dashed blue contours. El Niños considered in the composite are 1957/58, 1965/66, 1968/69, 1972/73, 1982/83, 1986/87, 1987/88, 1991/92, 1994/95, and 1997/98.

tive anomalies over southern United States, which is seen as a robust feature only in the models.

The SST anomalies observed during the El Niño of 2002/03 were focused in the central Pacific. Not all El Niño events share this pattern; some have their strongest SST anomalies in the far eastern Pacific. These two manifestations of SST warming during El Niño are not distinguished in the El Niño composites shown in Fig. 7. Did the particular character of this event suggest that modifications to the canonical El Niño pattern should be expected? If the top 10 El Niños are divided into two groups, those focused in the eastern Pacific and those focused in the central Pacific, then noticeable differences are found in the temperature composites over the United States (Larkin and Harrison 2005). During the central Pacific events the tropical rainfall/heating lies closer to the date line, and the associated 200-mb anomaly pattern over the United States is shifted to the west relative to the canonical pattern (not shown; Hoerling and Kumar 2002). As a result, in DJF below-normal temperatures become more likely in the southeastern United States, up through the mid-Atlantic states, as seen in both the observations (Larkin and Harrison 2005; their Figs. 1 and 3) and the models.

In the specific case of DJF 2002/03 the dynamical models (Figs. 1 and 6) provided a more robust indication of the expected temperature anomaly pattern than the observational composite based on all El Niños. One reason is that they can respond to other unique characteristics of the SST anomalies in the particular season, but a general composite cannot. In terms of the forecast, these unique characteristics of the SST must still be reasonably captured before their impact on the climate can be predicted.

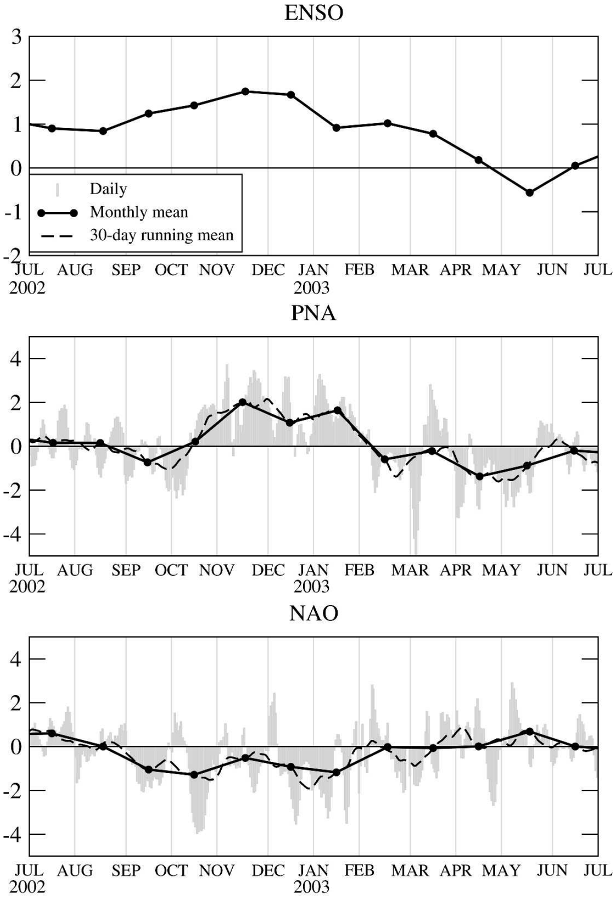

Figure 8

FIG. 8. The index time series: (a) monthly ENSO index of Niño-3.4 (averaged SST anomaly 5°S–5°N, 170°–120°W); (b) daily PNA index (shaded bars), monthly mean (solid line), and 30-day running mean (dashed line); and (c) daily NAO index (shaded bars), monthly mean (solid line), and 30-day running mean (dashed line). (Indices were obtained online at http://www.cpc.noaa.gov/products/precip/Cwink/daily_ao_index/teleconnections.shtml.)

c. Internal versus external forcing

Besides the teleconnection from the moderate El Niño, other patterns of the atmosphere's circulation, perhaps unforced by any boundary anomalies, may also have had some influence on the U.S. temperatures during the winter of 2002/03. The Pacific–North America (PNA) mode was persistently positive, and the North Atlantic Oscillation (NAO) mode was persistently negative from November 2002 to January 2003 (Fig. 8). Both of these circulation patterns, in the polarity they favored during 2002/03, led to negative temperatures over the eastern United States during DJF (Fig. 9).

The PNA pattern can be generated by internal dynamics of the atmosphere or excited by boundary forcing. That tropical SST influences, but does not dominate, the PNA-related variability is evidenced by the projection of the observed global sea surface temperatures on the observed PNA time series, showing a modest 0.5°C region within the central equatorial Pacific (Fig. 9a). Some AGCMs also show PNA-like sensitivity to the convective anomalies associated with SST anomalies in the central equatorial Pacific region (Barsugli and Sardeshmukh 2002). Given that the simulations and forecasts for DJF 2002/03 indicated slightly cooler temperature anomalies along the U.S. east coast than seen in the central Pacific El Niño composites, a PNA-like response in the models was likely excited by the central Pacific SST anomalies.

Similarly, the NAO can arise purely from internal atmospheric noise (Fyfe et al. 1999; Feldstein 2000; Robertson 2001), but it also appears to be modulated by SST and snow boundary conditions (Rodwell et al. 1999; Cohen and Entekhabi 1999; Hoerling et al. 2001).

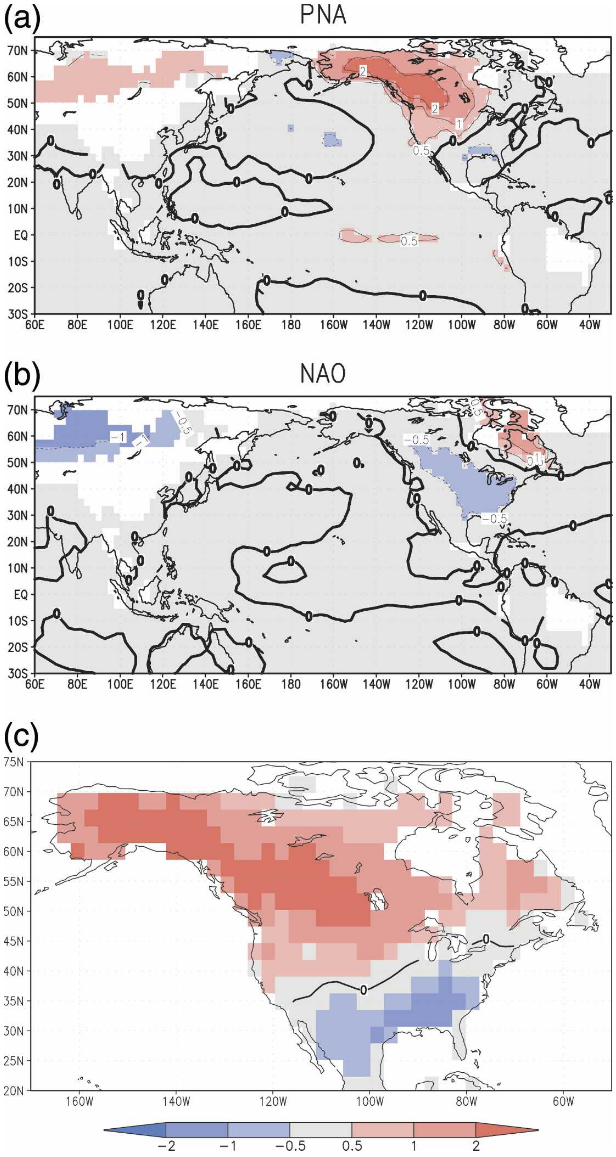

FIG. 9. Regression of DJF seasonal-mean temperature anomalies on DJF seasonal-mean time series of (a) the PNA index and (b) the negative of the NAO index (1950–98). (c) Linear combination of air temperature regression patterns of El Niño, PNA, and NAO weighted by strength of observed indices for DJF 2002/03 (°C). The zero contour is indicated.

The time scale of the NAO is primarily intraseasonal, but can range to interdecadal (Feldstein 2000). At the seasonal time scale the NAO is not robustly associated with SST forcing in the observations (Fig. 9b). While most AGCMs show the NAO to be a mode of variability, some do not retain this structure in the ensemble mean, implying that some models treat it as purely internal to the atmosphere while others show a discernible forced component. In our analysis, it does not appear that the AGCM simulations or forecasts for DJF 2002/03 captured the NAO as a boundary-forced signal.

Given that the simulated/forecast pattern from the AGCMs so resembles the central Pacific El Niño composite, one can conclude that models can, and did, respond to the specific character of the El Niño. That response in the AGCMs may also project on the PNA pattern. The models did not capture the observed persistence in the NAO. However, the models' inability to produce a forced NAO signal does not, in itself, rule out the possibility of a boundary-forced contribution to the NAO in nature.

A simple linear combination of the temperature anomaly patterns from the dominant modes acting in 2002/03 yields an anomaly map very similar to that observed (Fig. 9c). Thus, the observed temperature pattern can be described as externally forced, due primarily to El Niño, with constructive interference from atmospheric noise. However, this attribution still does not capture the strength of cold anomalies in the northeastern United States.

d. Other boundary forcings

Frequent snowfall, and thus persistent snow cover, over the northeastern United States (Fig. 10) can explain the local amplification of cold temperatures. For much of the Northeast, snow cover is climatologically present 30%–80% of the time, depending on location, with more persistent snow cover at higher latitudes. During 2002/03 the snow cover was present 70%–100% of the time from northern Virginia to Canada. The New England states experienced nearly 100% temporal coverage for the entire DJF 2002/03 season. Persistent snow cover can lead to a 1°–2°C seasonal cooling in the eastern United States through the positive feedback from an enhanced albedo (Walsh et al. 1982, 1985; Yang et al. 2001). Additionally, it should be noted that some modeling studies have shown that enhanced snow cover over the Northern Hemisphere midlatitudes can influence the NAO (Gong et al. 2002). Such a reinforcing feedback between the cold temperatures, the snow cover, and the NAO, could explain the apparent persistence of this otherwise internally generated mode of the atmosphere.

Atmospheric models can reasonably represent the continental-scale seasonal cycle and interannual range of snow cover for the Northern Hemisphere (Frei et al. 2003; Kumar and Yang 2003). However, in long AGCM simulations, the fidelity of interannual variability in the pattern of snow cover is related to model skill in simulating midlatitude precipitation patterns, which is not high. Consistent with the ENSO response, in the DJF

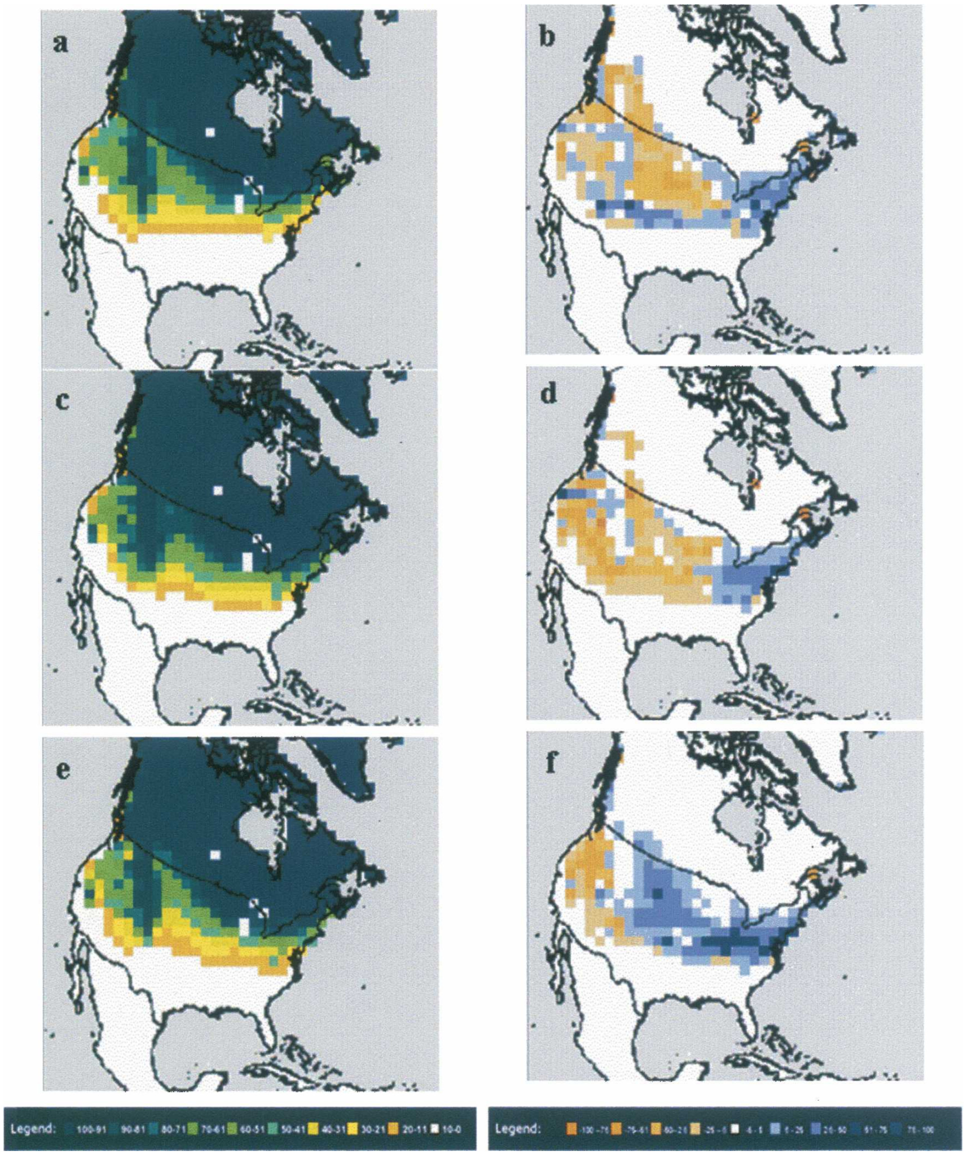

FIG. 10. Gridded snow-cover frequency (% of weeks). The 33-yr climatology for (a) December, (c) January, and (e) February. Departure from normal for (b) December 2002, (d) January 2003, and (f) February 2003.

2002/03 simulations and forecasts the AGCMs indicated negative precipitation anomalies rather than the positive anomalies that were observed (not shown). Therefore, they did not capture this additional source of below-normal temperature, implying that this portion of the anomalous temperatures was not potentially predictable by the tools used here.

The regional enhancement of below-average temperatures from the persistent snow cover completes the attribution of the unusually cold seasonal conditions during DJF 2002/03.

4. Summary and discussion

The Seasonal Diagnostics Consortium of the Applied Research Centers is engaged in near-real-time activity to detect and understand the role of sea surface temperatures (SSTs) in observed climate anomalies (Barnston et al. 2005). The work presented here accepts the challenge of attributing the seasonal temperature pattern observed in 2002/03, and also grabs a unique opportunity to reexamine the real-time forecasts, as well as the forecast process itself.

The unusually cold temperatures experienced in the eastern United States during DJF 2002/03 are attributed to a combination of constructively interfering factors:

1) El Niño conditions in the tropical Pacific;
2) a persistent positive PNA mode;
3) a persistent negative NAO mode; and
4) persistent snow cover over the northeastern United States.

The dynamical model simulations detected a SST-forced signal in U.S. surface temperature for DJF 2002/03, which differed from the canonical El Niño signal, because the largest SST anomalies were focused in the central Pacific, near the date line. The AGCMs agreed closely with observations for that winter for the United States as a whole, with regionally better agreement over the western United States than over the eastern United States (Table 2). Despite the existence of other, possibly nonboundary-forced contributions to the 2002/03 U.S. winter (e.g., NAO), one conclusion drawn from the MM simulations is that the skill of the U.S. temperature prediction could have been increased by use of dynamical tools rather than use of empirical methods involving the canonical El Niño signal and/or recent trends (Table 2).

What comments could be made about the official forecasts in the light of the analysis presented herein? Of course, it is easier to claim forecast success with perfect hindsight than it is to produce an accurate forecast, but possible causes for the failure for the U.S. operational surface temperature outlook (Fig. 2) are worth examining, and could be instructive for future forecast practices.

To follow the reasoning behind the operational forecasts, one should bear in mind that methods for U.S. operational climate forecasting are still largely empirical and rely heavily on the expected state of future SSTs (i.e., the state of ENSO and associated atmospheric response patterns). Even as late as the November 2002, there existed great uncertainty as to how large the amplitude of the El Niño SSTs might become, and how the spatial pattern might evolve. The debate was more than academic; it entailed selecting from materially different response patterns for U.S. temperatures. There was no broad consensus among the participants of the forecast conference call that the Climate Prediction Center (CPC) regularly hosts regarding the existence of different "flavors" for El Niño climate impacts, despite the strong research evidence already existent in the literature for different response patterns for El Niño events focused in the east Pacific versus being confined to the central Pacific (e.g., Hoerling and Kumar 2002; Larkin and Harrison 2005). Furthermore, the suggestion by the dynamical models that below-normal temperature over the eastern United States had a finite possibility of occurrence, or at least that the probability for canonical above-normal temperatures should be relatively low, was also not given much consideration.

The AGCMs can and did respond appropriately to the flavor of the 2002/03 El Niño, in which the largest SST anomalies were focused in the central equatorial Pacific. The AGCMs further responded to the central Pacific SST anomalies by projecting positively onto the PNA pattern and enhancing the below-normal temperature anomalies in the eastern United States. However, the AGCMs did not capture the persistence in NAO seen in observations. The AGCMs also did not account for the persistent snow cover. Nonetheless, some key elements of the observed temperature pattern were potentially predictable, and improved probabilities for the risk of extreme warm and cold categorical temperatures was possible for the eastern United States. For the seasonal forecast of DJF 2002/03 the El Niño pattern in tropical Pacific SST was well predicted. The associated forecast qualitatively resembled the simulations and the observations. In hindsight, we can conclude that much of the potential predictability could have been realized in the real-time forecasts for this season.

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