Analyzing the Pacific-North American teleconnection pattern and its relationship to climate using RegCM3, a high resolution regional climate model

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Introduction

The Pacific-North American (PNA) teleconnection pattern is widely recognized as a robust feature of Northern Hemisphere atmospheric circulation, and more specifically represents the structure of the quasi-stationary wave field over the North Pacific and North America. The PNA is a strong control of inter- and intra-annual climate variability over North America. This study presents an assessment of the influence of the PNA on past, present, and future climate and surface hydrology in North America.

The Models

The GCM output used here is from the ECHAM5/MPI present climate (20C) and IPCC A2 SRES runs, which span the years 1860-2100. Here we use the output from ECHAM5 to analyze the PNA and to drive the regional model, RegCM3, which is run on a much finer 50-km grid. This study present results from both ECHAM5 and RegCM3 for the entire 240 year period.

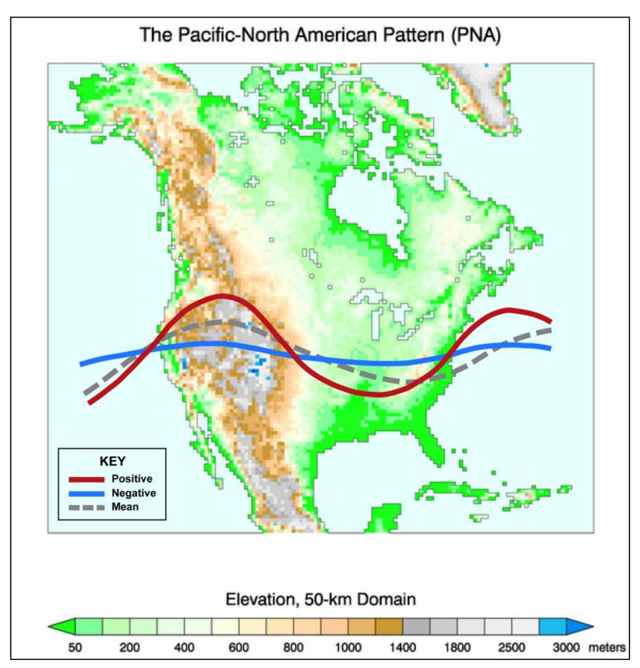


Figure 1 The Pacific-North American teleconnection positive (red line), negative (blue line), and mean state (gray line) patterns. The map shows the elevation and 50-km domain used in the RegCM3 simulations. *Figure adapted from Leathers et al., 1991.*

Methods

We examine spatial and temporal changes in the PNA pattern and index over the length of the 240 year model runs for the DJF winter season. The PNA index and spatial pattern are based on the modified linear pointwise method from Wallace and Gutzler (1981) and "modified" by NCEP/CPC, and a rotated principle component analysis (RPCA) (Barnston and Livezey, 1987), respectively.

We apply a modified linear pointwise method to compute a monthly index value based on a linear combination of standardized 500-hPa geopotential height anomalies:

$$\mathrm{PNA} = [z^*(15\text{-}25°\mathrm{N}, 180\text{-}140°\mathrm{W}) - z^*(40\text{-}50°\mathrm{N}, 180\text{-}140°\mathrm{W}) + z^*(45\text{-}60°\mathrm{N}, 125\text{-}105°\mathrm{W}) - z^*(25\text{-}35°\mathrm{N}, 90\text{-}70°\mathrm{W})],$$

where z^* is the mean standardized height anomaly the over the specified region. The index value is a measure of the spatial structure of the PNA pattern: a positive index value corresponds to more meridional flow at 500 hPa, whereas a negative index indicates more zonal flow (Fig. 1 above). The PNA index is computed using the ECHAM5 global simulation, and the computed index is used to analyze patterns and changes in North American climate in the RegCM3 simulations.

References

Barnston, A. G. and R. E. Livezey (1987). Classification, seasonality, and persistence of low-frequency atmospheric circulation patterns. *Mon. Wea. Rev.*, **115**, 1083-1126.

Leathers, D. J., B. Yarnal, and M. A. Palecki (1991). The Pacific/North American teleconnection pattern and United States climate. Part I: Regional temperature and precipitation associations. *J. Climate*, **4**, 517-528.

Wallace, J.M. and D.S. Gutzler (1981). Teleconnections in the geopotential height field during the Northern Hemisphere winter. *Mon. Wea. Rev.*, **109**, 784-812.

Methods (cont.)

We use a rotated principle component analysis (RPCA) to identify the PNA spatial pattern within the ECHAM5 GCM. The ten leading EOF modes are computed from a correlation matrix of seasonally standardized 500-mb height anomalies for all longitudes between 20–90°N and the EOFs are rotated according to the Varimax criterion.

The RegCM3 domain does not extend to include all four points that are used to compute PNA index. We thus rely on the global ECHAM5 output to calculate the index. We computed a index using three of the four points that fall within the RegCM3 domain to verify the PNA is present in the RegCM3 simulation. The two indices show comparable frequency and amplitude.

Results

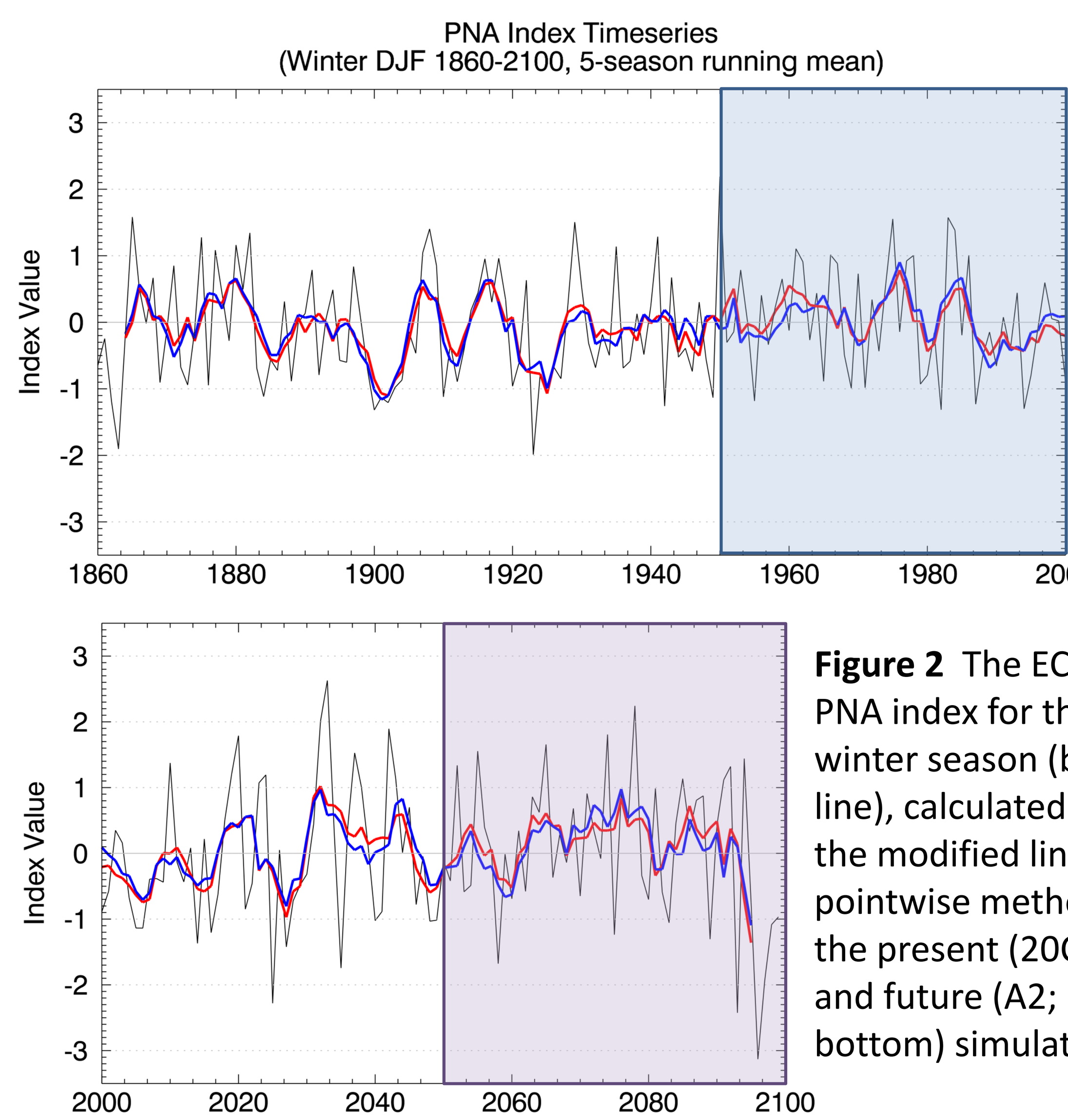


Figure 2 The ECHAM5 PNA index for the DJF winter season (black line), calculated using the modified linear pointwise method, for the present (20C; top) and future (A2; bottom) simulations.

The smoothed 5-season running mean is shown for ECHAM5 (red) and RegCM3 (blue). The RegCM3 smoothed index is calculated with three of the four points in the index equation, explaining the deviations from the ECHAM5 smoothed line. Both indices were de-trended for the A2 years 2001-2100 to account for the effects of global warming. The boxed sections highlight the time periods used in the correlation analysis, 1950-2000 (blue) and 2050-2099 (purple).

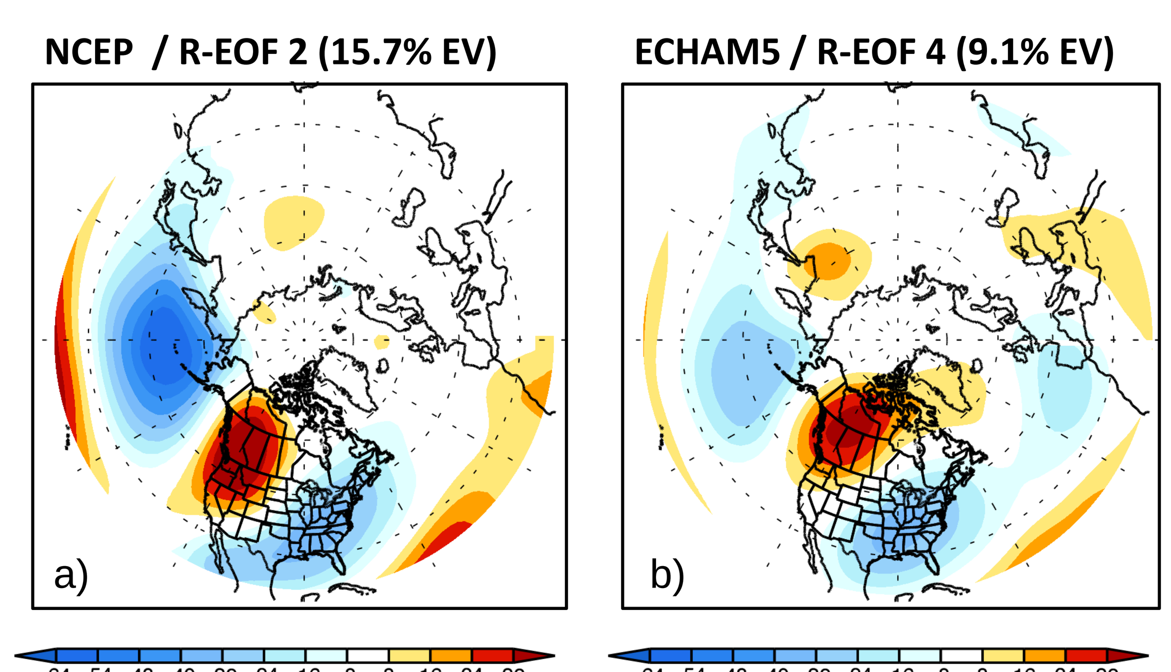
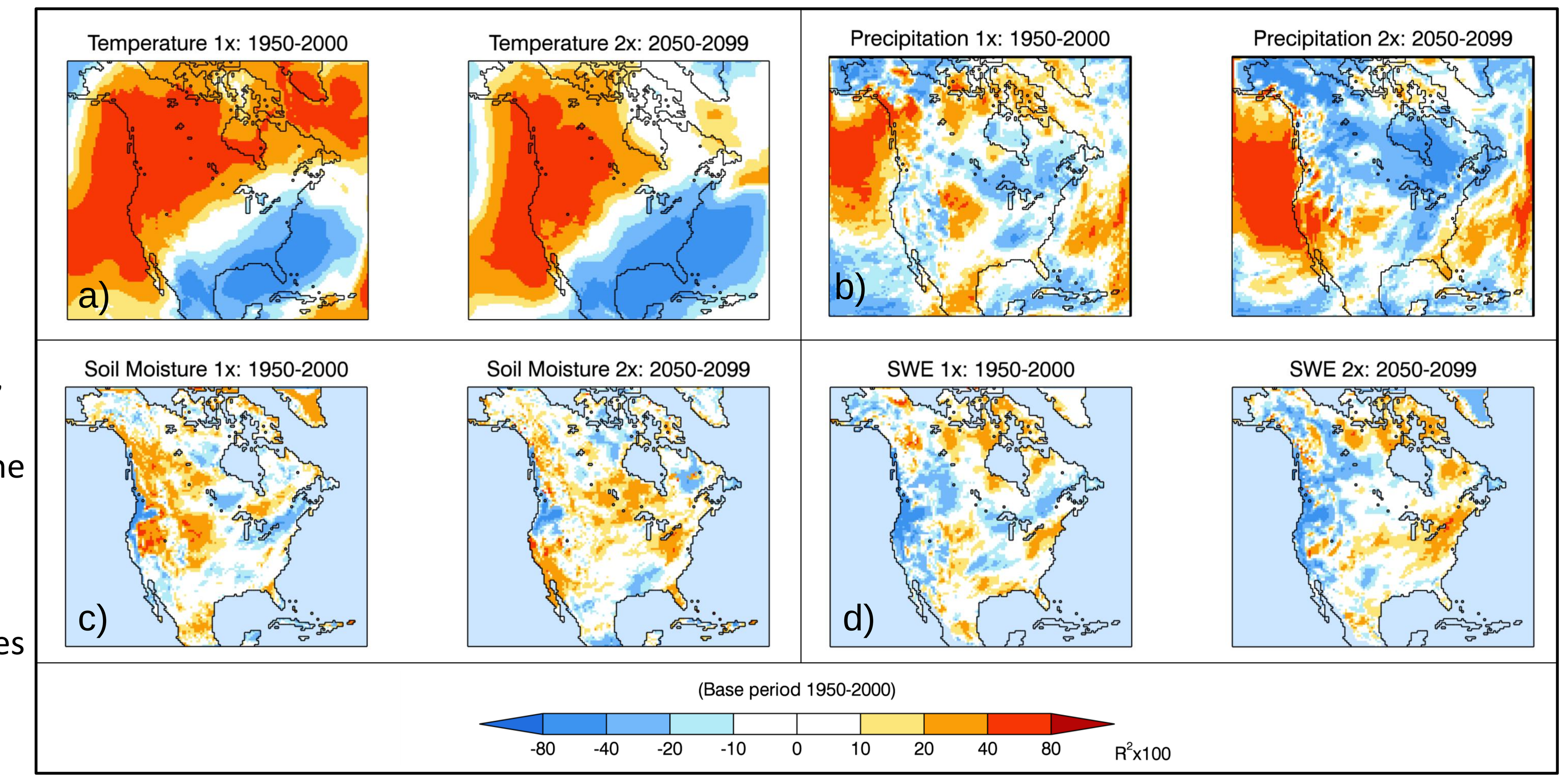
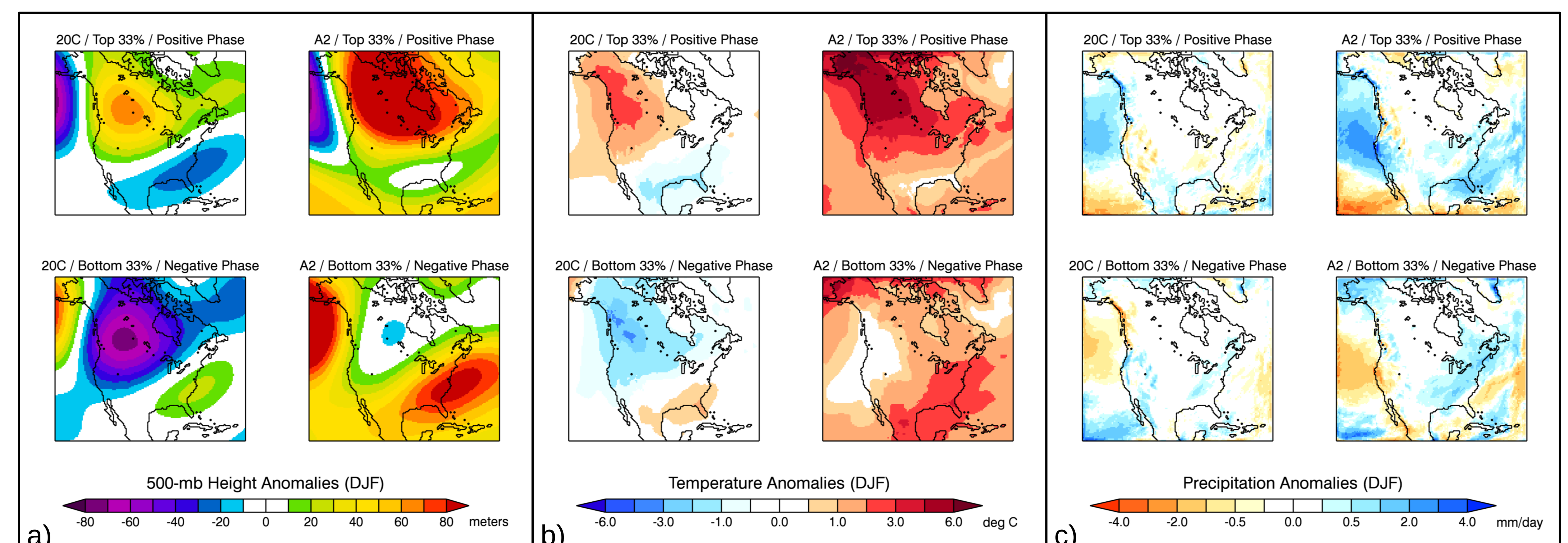


Figure 3 A rotated-EOF analysis of winter (DJF) standardized 500-mb height anomalies for the years 1950-2000 reveals the Pacific-North American teleconnection for a) NCEP/NCAR Reanalysis and b) ECHAM5. The patterns displayed here are for the positive phase of the PNA.

Results (cont.)

Figure 4 Correlations between the PNA index and selected surface field anomalies for present (1950-2000, "1x") and future (2050-2099, "2x") scenarios as simulated by the RegCM3. The variables shown are a) 2-meter air temperature, b) precipitation, c) soil moisture, and d) snow water equivalent (SWE). The plotted values are the temporal correlation between the PNA index and the anomaly value at each grid point for the given time period. The anomalies are departures from the 1950-2000 climatological base period.





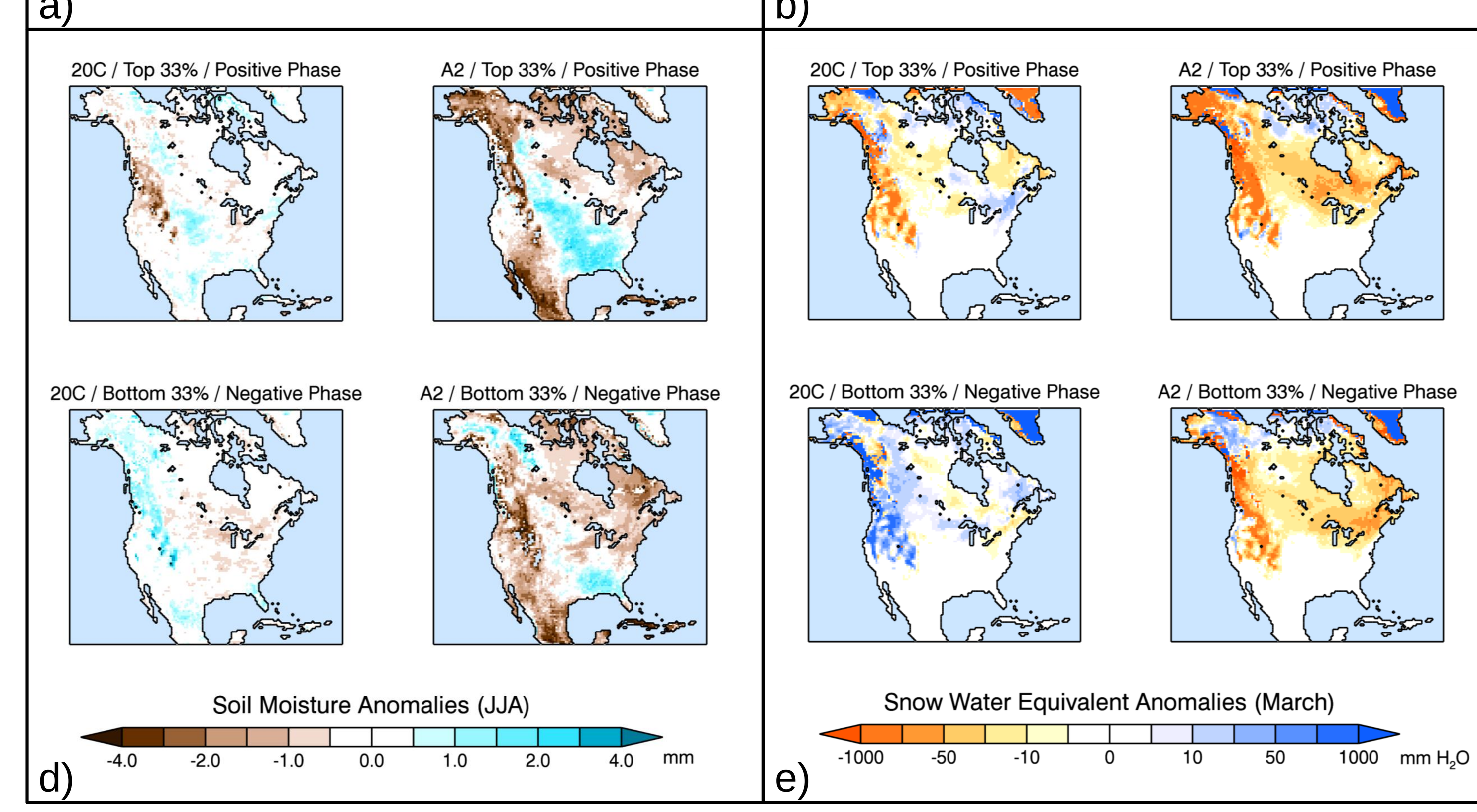


Figure 5 Composite anomaly maps for the top 33% (top row of each figure) and bottom 33% (bottom row) of PNA index values for both the 20C (1860-2000; left side) and A2 (2001-2099; right side) periods. The variables are a) 500-mb height, b) 2-m air temperature, c) precipitation, d) soil moisture, and e) snow water equivalent (SWE). To highlight the interplay of winter PNA phases with season-ahead responses we map winter (DJF) anomalies for height, temperature, and precipitation, summer (JJA) anomalies for soil moisture, and March anomalies for SWE.

Discussion

The Pacific-North American teleconnection is expressed as a robust pattern in both the ECHAM5 global and RegCM3 regional climate models. Figure 2 displays a PNA index time series of a similar frequency and magnitude to that calculated from observations. The spatial pattern emerges as a leading mode in a rotated-EOF analysis, also consistent with observations (Fig. 3). The PNA index is highly correlated with North American climate, notably temperature and precipitation. Positive and negative PNA patterns lead to distinct changes in the anomalies of these and other climate variables. The effects of global warming are evident, particularly in Figures 5a-b where the geopotential heights and temperatures both increase in the A2 plots, however the spatial patterns remain in tact. Soil moisture and SWE (Figs. 5c,d) show a complete reversal in sign between the 20C and A2 scenarios under a negative PNA pattern, indicating that the effects of global warming outweigh the effects of the PNA on North American climate.

Acknowledgements

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