JP2.7 INVESTIGATING THE CLIMATIC EFFECTS OF THE NAO OVER GREENLAND USING POLAR MM5

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1. Introduction

The climatic significance of the Greenland ice sheet has long been recognized. Greenland represents a sizeable barrier to the large-scale atmospheric flow, and is thus an important orographic source of Northern Hemisphere (NH) planetary wave activity. In addition, the sharp thermal contrast between the ice sheet and the adjacent ocean creates a strong baroclinic zone in which the genesis of synoptic scale storm systems is favored (Putnins, 1970). Recent years have seen a renewed scientific interest in the climate of this region, spawned mainly by the realization that climatically-induced fluctuations in ice sheet mass balance may have implications for environmental change, especially for the future variability of global sea level (e.g., Gregory and Oerlemans, 1998; Huybrechts and de Wolde, 1999).

Studies of Greenland's climate have been greatly aided by numerical models. The utility of these models lies in their ability to fill in spatial and temporal gaps in observational datasets, allowing for the creation of a more complete climate picture. Models also permit one to investigate ice sheet climate in the context of future global change. Current global climate models (GCMs) run at resolutions of 100 – 250 km are unable to adequately represent Greenland's complex topography, and thus exhibit significant regional biases in their simulation of the present-day climate state (e.g., Ohmura et al., 1996; Box et al., 2004). Also, GCM physics may not be attuned to ice sheet environments (Thompson and Pollard, 1997), further limiting the extent to which these models can be used reliably for certain types of high latitude applications. These GCM shortcomings can be overcome with the aid of high resolution, polar-specific regional climate models (RCMs), and several RCM studies over Greenland have been reported as of late in the literature (e.g., Bromwich et al., 2001; Cassano et al., 2001; Box and Rinke, 2003; Box et al., 2004). While these studies have yielded extremely valuable insights into various aspects of Greenland's climate, they are somewhat restricted in the sense that the RCMs that they employed were run for relatively short periods of time, a few months to a decade at most. Model simulations of these durations are insufficient for generating robust statistics on the interannual variability of climate in this region, especially if certain large-scale atmospheric circulation regimes are undersampled in the experiments, as may be the case for the negative phase of the North Atlantic Oscillation (NAO) in the 1990's-restricted RCM investigations referenced above.

In the current work, we utilize an approach that specifically targets periods of time that were characterized by opposite polarities of the NAO. Principal component (PC) analysis is used to identify representative high and low NAO months from the recent part of the observational record, and then the detailed climate over Greenland for these months is simulated with the Polar Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) Fifth-Generation Mesoscale Model (Polar MM5). Polar MM5 (henceforth, PMM5) is forced at its lower and lateral boundaries with data from the European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year reanalysis (ERA-40). Since variability in the NAO is most pronounced in wintertime (Thompson and Wallace, 2000), we perform January simulations of high and low NAO conditions. The NAO, in this case, is viewed as a useful proxy for interannual climate variability over Greenland, in that its extremes represent two distinctly different, dominant states of the large-scale atmospheric circulation. By examining the response of the PMM5 model to high and low NAO forcing, therefore, we can more aptly characterize this variability in terms of its potential magnitude and spatial attributes, and do so without the computational expense of continuous multiyear RCM runs.

2. Experiment Setup

The PMM5 domain employed in the present study encompasses the entire Greenland ice sheet and is comprised of 100 grid points in the north-south direction and 110 grid points in the east-west direction, centered at 71°N latitude and 30°W longitude (Fig. 1). Horizontal grid spacing is set at 40 km, which has been deemed adequate to resolve Greenland's terrain over all but the steepest ice margins (Cassano and Parish, 2000). In the vertical, the model uses a total of 23 levels, with increased resolution near the surface. The model top is specified at a constant pressure of 10 hPa.

The initial conditions and the boundary conditions for the model experiments are obtained from the ERA-40 dataset at a spatial

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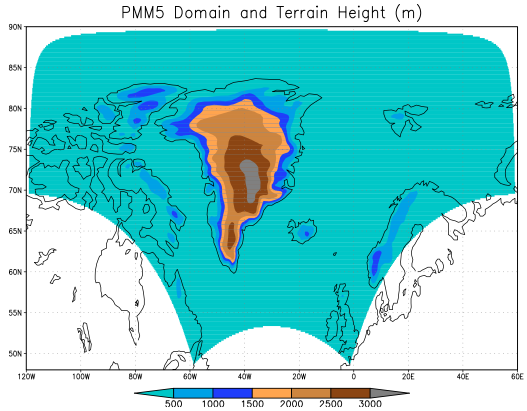

Figure 1. PMM5 domain (shaded region) and terrain height (m). Terrain data are acquired from the United States Geological Survey (USGS) at a resolution of 10 arcmin (~ 19 km).

resolution of 2.5° latitude by 2.5° longitude. Large-scale fields include air temperature, *u* and *v* wind, relative humidity and geopotential on pressure levels, and sea level pressure (SLP), sea surface temperature (SST), snow depth and fractional sea ice at the surface. Atmospheric data at the lateral boundaries of the PMM5 domain are updated every 6 hours, with the model solution at the four nearest grid points simultaneously relaxed (linearly) toward ERA-40.

In order to select representative high and low NAO months, we apply empirical orthogonal function (EOF) analysis to ERA-40 SLP data. We define the NAO as the leading EOF of the NH (20° - 90°N) Atlantic sector (90°W - 90°E) monthly-mean (January) SLP anomaly field, and then use the corresponding EOF (PC) time series (or NAO index) to identify contrasting NAO regimes. The months that are chosen are characterized by an NAO index more than plus or minus one standard deviation from the long-term (1958 – 2002) January mean. Each simulation is initialized at 0000 UTC on 31 December and is run until 0000 UTC on 1 February, with the first 24 hours of this period excluded from forthcoming analyses to allow for the effects of model spin-up.

3. Results

Here, we highlight selected fields for the months of January 1983 (positive NAO) and January 1985 (negative NAO). Figure 2 shows the monthly mean 2 m air temperature (in K) from the model (Fig. 2a,c) and reanalysis (Fig. 2b,d). Over Greenland, the two are remarkably similar; however, the 2 m temperature of the air overlying the water masses to the north and west of Greenland is noticeably colder in ERA-40 than in PMM5. It seems likely that the former solution is too cold in these areas, as this is a known bias in the ERA-40 dataset over ice-covered oceans in the Arctic and Antarctic, a problem related to the assimilation of HIRS (High Resolution Infrared Radiation Sounder) radiances (Betts and Beljaars, 2003).

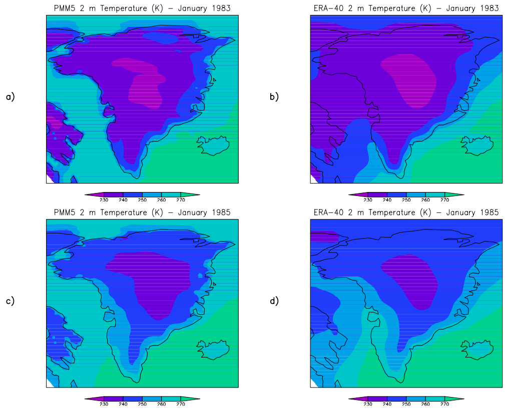

Figure 2. Monthly mean 2 m air temperature (K) for January 1983 from a) PMM5 and b) ERA-40; c) and d) are the same, but for January 1985.

In Figure 3, PMM5 and ERA-40 total monthly accumulated precipitation (in cm) is depicted. While the overall structure of precipitation patterns is quite alike in both the model and reanalysis, PMM5 is considerably wetter during both months. It is not immediately apparent which of these fields is more realistic though, as ERA-40 precipitation is itself a model-derived product. However, in all likelihood, PMM5 precipitation amounts are excessive, particularly during January 1985. Previous work (Cassano et al., 2001) has demonstrated that the model overestimates precipitation along the steep margins of the Greenland ice sheet, a bias likely explained by imprecision in the calculation of the horizontal pressure gradient force over rough terrain (Box et al., 2004). Future versions of PMM5 will seek to ameliorate this problem.

Finally, in Figures 4 and 5, we display monthly means of 10 m zonal wind and SLP, respectively. As was the case for precipitation, zonal wind patterns appear rather similar in PMM5 and ERA-40. Particularly evident is the strengthening of the high latitude westerlies in the high phase of the NAO relative to the low phase (lower portion of Fig. 4a,b relative to Fig. 4c,d). PMM5 wind fields exhibit substantially more fine structure over Greenland than ERA-40, to be expected given the regional model's higher resolution. Model-simulated monthly mean SLP also compares very well with observations (see Fig. 5). Noteworthy are the relatively low pressure in the vicinity of the Icelandic low off

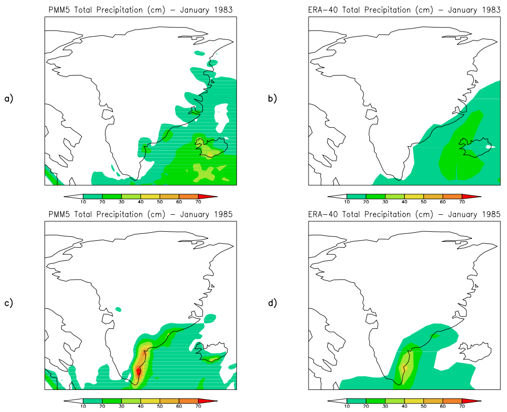

Figure 3. As in Fig. 2, but for total monthly accumulated precipitation (cm).

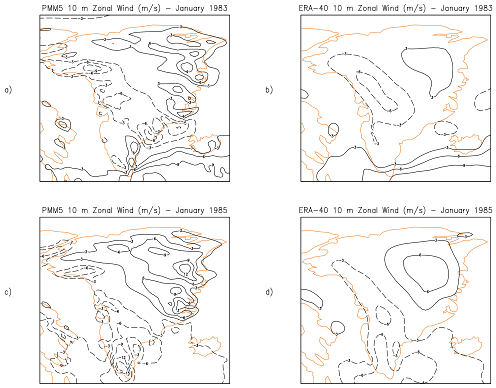

Figure 4. As in Fig. 2, but for monthly mean 10 m zonal wind (m/s). Contour interval is 3 m/s, with negative contours dashed and the zero contour excluded.

southeast Greenland during the high phase of the NAO, and the ridging over the ice sheet during the low phase (both of which are expected).

4. Summary

The PMM5 RCM has been used to simulate the climate state over the Greenland ice sheet for conditions typical of both the high and low phase of the NAO. For the two months of model results analyzed here, PMM5 shows skill in reproducing observed monthly mean patterns of 2 m air temperature, precipitation, 10 m zonal wind and SLP, although the simulated precipitation totals are probably excessive. Differences in the aforementioned climate fields between January 1983 and January 1985 are consistent with what would be anticipated to accompany a shift in NAO regimes. 2 m temperatures over Greenland are generally colder during the former month (Fig. 2), resulting from enhanced northerly flow around a strengthened Icelandic low during the NAO's high phase. The opposite phase of this mode is typified by blocking in the vicinity of Greenland, causing synoptic storm systems to be diverted northward across the ice sheet. (In contrast, the high phase of the NAO is characterized by a dominant storm track that lies to Greenland's southeast.) This behavior is suggested by the relatively higher simulated precipitation amounts along the southeastern coast in January 1985 compared to January 1983 (Fig. 3). 10 m zonal wind and SLP differences between the two months are also readily explained on physical grounds within the framework of the NAO paradigm, as noted in Section 3. Thus, PMM5 appears to capture several of the well-known features of NAO-related climate variability in the Greenland region. An aim of future work will be to establish the robustness of the simulated patterns over a larger number of high and low NAO months.

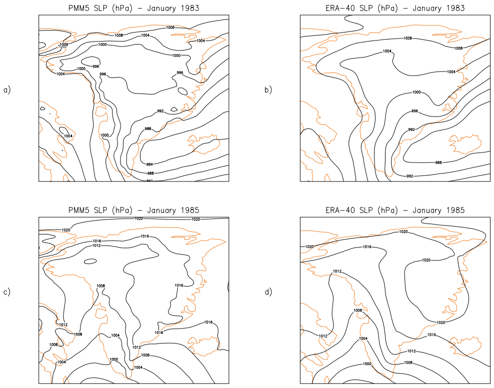

Figure 5. As in Fig. 2, but for monthly mean SLP (hPa). Contour interval is 4 hPa.

5. References

Betts, A. K., and A. C. M. Beljaars, 2003: ECMWF ISLSCP-II near-surface dataset from ERA-40. *ERA-40 Project Report Series No. 8*.

Box, J. E., D. H. Bromwich, and L. –S. Bai, 2004: Greenland ice sheet surface mass balance 1991 – 2000: Application of Polar MM5 mesoscale model and in situ data. *J. Geophys. Res.*, **109**, doi:10.1029/2003JD004451.

Box, J. E., and A. Rinke, 2003: Evaluation of Greenland ice sheet surface climate in the HIRHAM regional climate model using automatic weather station data. *J. Clim.*, **16**, 1302 – 1319.

Bromwich, D. H., J. J. Cassano, T. Klein, G. Heinemann, K. M. Hines, K. Steffen, and J. E. Box, 2001: Mesoscale modeling of katabatic winds over Greenland with the Polar MM5. *Mon. Wea. Rev.*, **129**, 2290 – 2309.

Cassano, J. J., J. E. Box, D. H. Bromwich, L. Li, and K. Steffen, 2001: Evaluation of Polar MM5 simulations of Greenland's atmospheric circulation. *J. Geophys. Res.*, **106**, 33,867 – 33,889.

Cassano, J. J., and T. R. Parish, 2000: An analysis of the nonhydrostatic dynamics in numerically simulated Antarctic katabatic flows. *J. Atmos. Sci.*, **57**, 891 – 898.

Gregory, J. M., and J. Oerlemans, 1998: Simulated future sea-level rise due to glacier melt based on regionally and seasonally resolved temperature changes. *Nature*, **391**, 474 – 476.

Huybrechts, P., and J. de Wolde, 1999: The dynamic response of the Greenland and Antarctic ice sheets to multiple-century climatic warming. *J. Clim.*, **12**, 2169 – 2188.

Ohmura, A., M. Wild, and A. Bengtsson, 1996: A possible change in mass balance of Greenland and Antarctic ice sheets in the coming century. *J. Clim.*, **9**, 2124 – 2135.

Putnins, P., 1970: The climate of Greenland, in *Climates of the Polar Regions, World Surv. Of Climatol.*, vol. 12, S. Orvig, Ed., (Elsevier Sci., New York), 3 – 112.

Thompson, D. W. J., and J. M. Wallace, 2000: Annular modes in the extratropical circulation. Part I: Month-to-month variability. *J. Clim.*, **13**, 1000 – 1016.

Thompson, S. L., and D. Pollard, 1997: Greenland and Antarctic mass balances for present and doubled atmospheric CO_2 from the GENESIS version-2 global climate model. *J. Clim.*, **10**, 871 – 900.