REGIONAL CLIMATE SIMULATION FOR THE PAN-ARCTIC REGION USING MM5

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1. INTRODUCTION

The watersheds surrounding the Arctic Ocean are significant contributors to the hydrologic cycle of the Northern Hemisphere's polar region. The land-based hydrologic cycle for this pan-Arctic region and its resultant freshwater discharges to the Arctic Ocean may play an important role in determining the Ocean's thermal and salinity gradients, thereby affecting sea ice, regional ocean-circulation dynamics, and the formation of Atlantic deep water. Multi-year feedback links may exist that couple river discharge, ocean ice and temperature distributions, and the region's atmospheric circulation (e.g., Mysak, 1995). The river flow also delivers to the Arctic Ocean dissolved constituents and sediments that could affect oceanic primary production and CO_2 uptake.

Global general circulation model (GCM) simulations show that the pan-Arctic region may be highly sensitive to global warming, with relatively large temperature increases, especially in winter (IPCC, 1995). Because the region's hydrologic cycle can affect the formation of sea ice, cloud cover and ultimately North Atlantic deep water, climate change in this region may in turn have global impact. Furthermore, climate warming in the pan-Arctic may also produce substantial thawing of permafrost and, as a consequence, alter the carbon cycle.

We have adapted MM5 for pan-Arctic simulation to evaluate interactions among processes controlling the land region's hydrologic cycle and freshwater input to the Arctic Ocean. One could use a GCM for such study, but model errors at lower latitudes could contaminate Arctic simulation and thus interfere with our analyses. Using a limited-area model allows us to specify pan-Arctic boundary conditions fairly accurately from reanalyses. This abstract describes adjustments made to MM5 for this purpose and gives a comparison of model performance with a wide variety of observations.

2. MODEL AND DATA

In order to simulate the coupled land-atmosphere hydrologic cycle of a region that experiences seasonally frozen soil, we have coupled to MM5 (Version 2) the Land Surface Model (LSM) of Bonan (1996). We have also coupled to MM5 a simple thermodynamic sea-ice model that evolves in conjunction with atmospheric input and specified, temporally varying sea-surface temperatures. The structure of the coupling has been chosen to ease adapting the fully coupled model for parallel-processor computation, an effort currently underway. From the suite of MM5's physical parameterizations, we have used the Grell cumulus convective scheme (Grell et al., 1991, 1993), the adaptation of Blackadar's Planetary Boundary Layer model (Zhang and Anthes, 1982), the explicit treatment of cloud water, rainwater, snow, and ice for resolved precipitation physics (Dudhia, 1989), and CCM2 radiation.

The model domain covers the major Arctic watersheds of Asia and North America (Fig. 1). The lateral boundaries were also chosen so that much of the external forcing of the model comes from regions that are fairly well observed. Simulations reported here used horizontal resolution of 120 km on a polar stereographic projection. One-month test computations using 60-km resolution produced no significant differences from coarser resolution runs, so we retained 120-km resolution for economy. The model's vertical structure is fairly standard: 23 sigma levels with model top at 100 hPa and 9 levels in the layer $\sigma = [0.7,1.0]$.

We performed a series of simulations for October 1985 and July 1986 to calibrate the model versus observations and then performed a one-year simulation from October 1985 – September 1986 to validate model performance. This was a year of relatively large sea-ice changes near river mouths, implying a significant input of river discharge resulting land-atmosphere interaction. The NCEP/NCAR Reanalysis (Kalnay et al., 1996) provided initial and lateral-boundary conditions, with the latter updated every 12 hours. Before starting the long simulation, we also spun-up initial soil temperature and moisture by repeated simulation of September 1985.

Model development was guided by a wide variety of observations from sources such as the Historic Arctic Rawinsonde Archive (Kahl et al. 1992), the TOVS Pathfinder Path-P Daily Arctic Gridded

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Atmospheric Parameters (TOVS, 1999), the Polar Radiation Fluxes archive (Key, 1998), the Xie-Arkin (1997) precipitation data set based on surface observations and satellite retrievals, and the NCEP/NCAR Reanalysis. Analysis focused on behavior in three broad regions (Fig. 1).

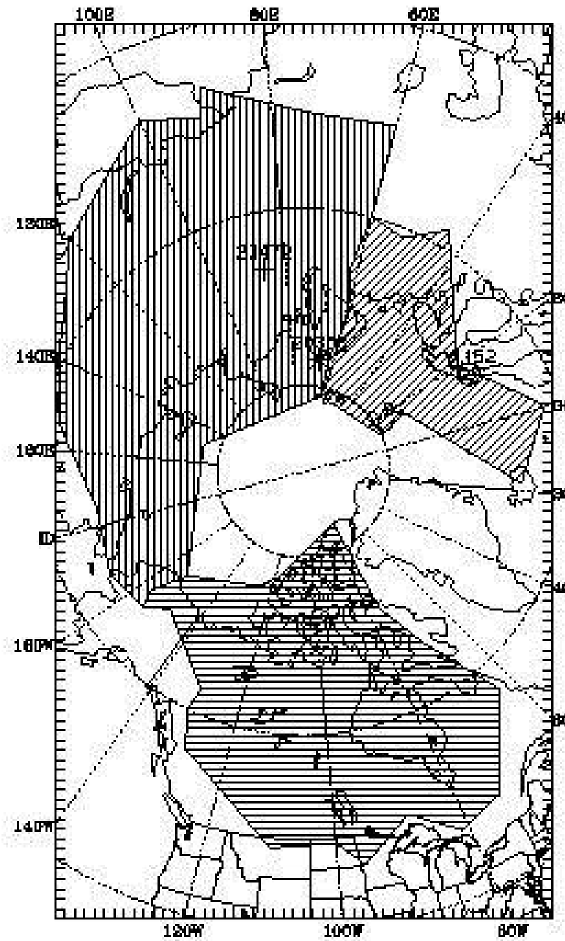

Fig.1: Model domain and subregions for analysis [vertical line: Asian Arctic Watershed; horizontal line: North American Arctic Watershed; diagonal line: European Arctic Watershed.]

3. SOME RESULTS

Model behavior, especially precipitation, was sensitive to simulated cloud cover. The one-month test simulations showed that cloud-cover diagnosis using the standard scheme based on relative humidity was inadequate. Comparison of model-produced cloud ice (C_I) and liquid water (C_L) with cloud cover climatology led to the adaptation of a scheme giving 90% cloud cover in a model layer whenever the layer's C_I or C_L passed pre-specified thresholds that were constant in space and time. This produced marked improvement in cloud cover and precipitation (Fig. 2) simulation.

The model's surface temperature and incident solar radiation reproduced observations fairly well (e.g., Figs. 3 and 4). The model also simulated atmospheric circulation well and could compare better with HARA observations than the reanalysis (Fig. 5).

A current shortcoming of the model is that its annual cycle of runoff does not show a springtime maximum as observed in river discharge records. The model's annual cycle of (precipitation-evapotranspiration) compares well with observed estimates (not shown). However, although the model appears to produce reasonable snow amounts, too much spring snowmelt is infiltrating the soil rather than flowing into overland runoff. Some alteration of LSM's maximum infiltration rate or hydraulic conductivity may be necessary when soil is frozen to avoid this behavior.

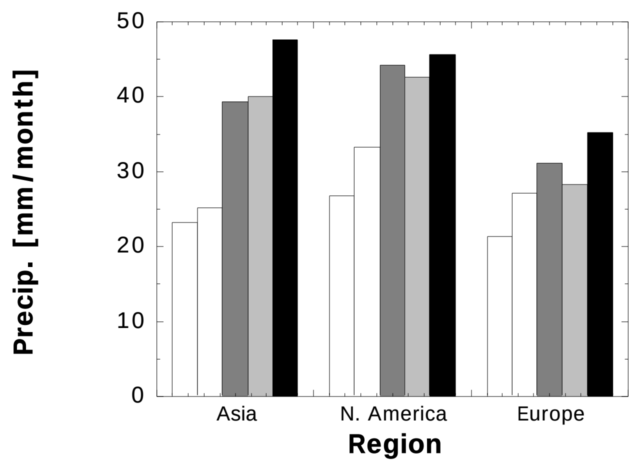

Fig.2: July 1986 precipitation using relative humidity based cloud schemes (unshaded) and cloud-water threshold schemes (shaded) and observed (solid)

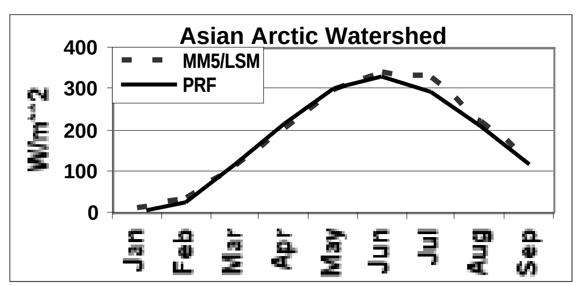

Fig.3: Monthly mean surface incident shortwave radiation for Jan.-Sept., 1986 from MM5/LSM and the Polar Radiation Fluxes archive.

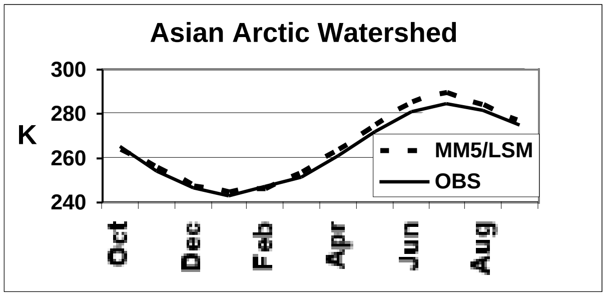

Fig.4: Asian watershed's monthly mean 2-meter air temperature for Oct. 1985 -Sept., 1986.

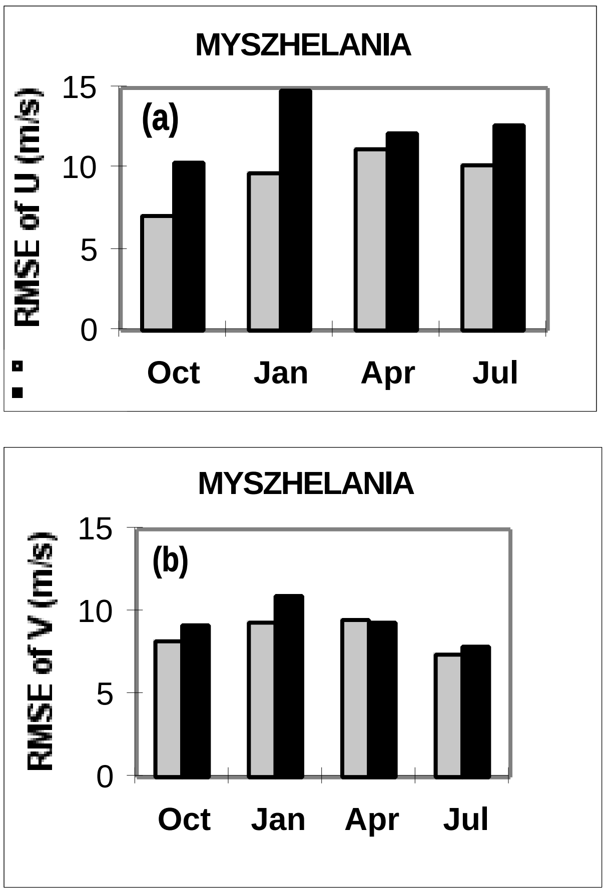

Fig. 5: Root mean square error vs. HARA observations in 850 hPa winds at a site in Russia for (a) zonal wind and (b) meridtional wind. [Hatched=MM5/LSM; Solid=NCEP/NCAR Reanalysis]

4. CONCLUSIONS

A version of MM5 adapted for pan-Arctic simulation of the hydrologic cycle performs fairly well in a one-year simulation. Further improvements in spring runoff generation are needed to give a better match with the observed annual cycle of water flow through the land-atmosphere system.

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