Atmospheric Modeling Over the Mackenzie, Kuparuk and Lena Watersheds: A Contribution to the NSF ARCSS Freshwater Initiative

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INTRODUCTION

In an effort to understand the Arctic freshwater cycle we are participating in a multi-disciplinary collaborative project that is funded under the NSF ARCSS Freshwater Initiative and that is being led by L. Hinzman (Collaborative Research: Detection and attribution of changes in the hydrologic regimes of the Mackenzie, the Kuparuk and the Lena River Basins). This project combines detailed field measurements with state-of-the-science hydrologic and atmospheric modeling to study multiple small watersheds within the larger Mackenzie, Kuparuk, and Lena watersheds.

The atmospheric modeling portion of this project is using the Polar MM5 atmospheric model to simulate the atmospheric state over both the large watersheds and the smaller watersheds, which are the focus of the field measurement portion of the project. The atmospheric model will be one-way coupled to detailed hydrologic modeling efforts, and will allow us to begin to assess feedback processes between atmospheric and land hydrologic processes.

Project Goals

Goals for the atmospheric modeling portion of this project include:

- Conduct multi-year, multi-scale atmospheric model simulations over the Mackenzie, Kuparuk, and Lena watersheds and over sub-watersheds
- Validate the atmospheric model simulations with available meteorological observations of the near surface atmospheric state
- Provide atmospheric forcing data to the hydrologic modeling portion of the project
- Evaluate the sensitivity of the atmospheric model to changes in model horizontal resolution and determine the impact of this sensitivity on simulated hydrologic processes
- Perform case studies of atmospheric events that help shape the annual hydrologic cycle in the research watersheds
- Evaluate feedback processes between atmospheric simulations and hydrologic simulations, with an emphasis on the role of soil moisture

Atmospheric Model Setup

The Polar MM5 is being used to perform the atmospheric model simulations for this collaborative project. The Polar MM5 has been developed specifically for high latitude atmospheric modeling (Bromwich et al. 2001; Cassano et al. 2001), and has been applied over the Antarctic and Greenland ice sheets, the Arctic pack ice, and most recently over Arctic land areas. The model physical parameterizations include a 1.5 order turbulence closure parameterization (ETA PBL), a cloud microphysics parameterization that has been modified for polar applications, and a longwave radiation code (RRTM) that is appropriate for cold-climate simulations. For this project the atmospheric model is coupled to the NOAH land surface mode.

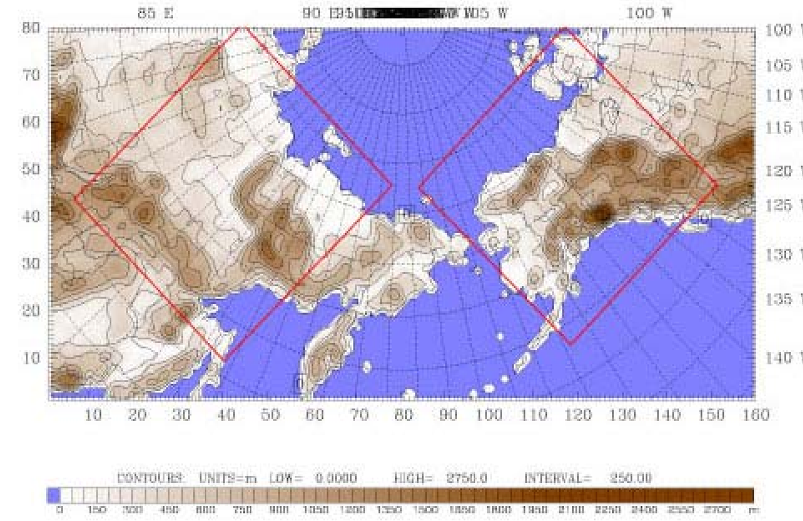

Figure 1. Location for 50 km atmospheric model domains.

The Polar MM5 has been setup to perform simulations over the Mackenzie, Kuparuk, and Lena watersheds (Fig. 1), with a horizontal resolution of 50 km. These atmospheric model simulations are initialized and forced at the lateral boundaries by European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric analyses. Sea ice is specified from satellite observations, and the initial land state (soil temperature and moisture) is taken from the NCEP/NCAR Reanalysis product. Simulations on the 50 km atmospheric model domains have been completed for the time period September 1998 through September 2000. Preliminary results from these simulations will be shown below.

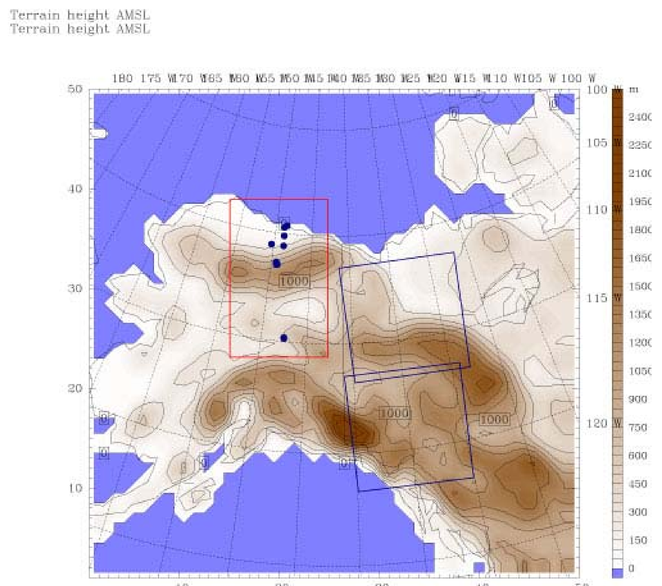

Figure 2. Mackenzie and Kuparuk watershed 50 km atmospheric model domain terrain. The 10 km Kuparuk watershed model domain is shown by the red box. The tentative 10 km atmospheric model domains for the Mackenzie sub-watershed domains are shown by the blue boxes. The blue dots indicate the location of meteorological observations in the Kuparuk and Caribou Poker Creek watersheds.

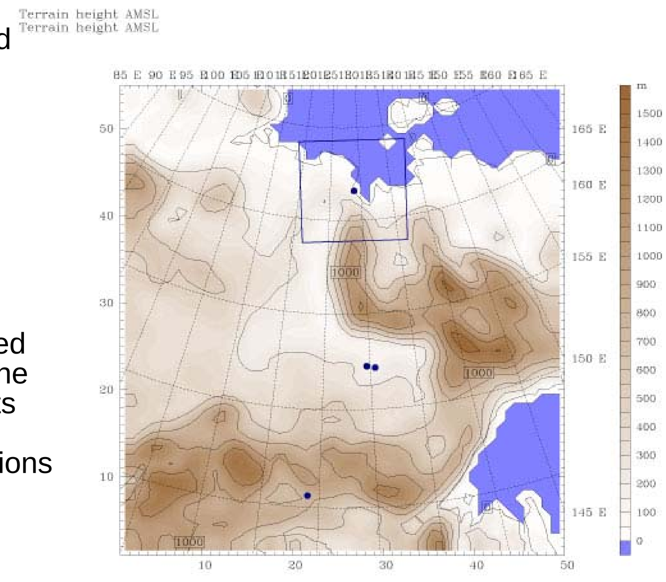

Figure 3. Lena watershed atmospheric model domain. The tentative 10 km Tiksi model domain is shown by the blue box. The blue dots indicate the location of meteorological observations made as part of the GAME-Siberia project.

We are also running one-way nested atmospheric model simulations at higher horizontal resolution (10 km horizontal grid spacing), over smaller model domains. These smaller, higher resolution model domains are shown in Figure 2 (Mackenzie and Kuparuk sub-watersheds) and Figure 3 (Lena sub-watersheds). The initial and lateral boundary conditions for these simulations are taken from the coarser, 50 km, Polar MM5 simulations. Simulations on the 10 km domains will be conducted for the September 1998 through September 2000 time period.

Even higher resolution atmospheric simulations may be conducted at later stages of this project, with horizontal grid spacing of 2-3 km. These computationally expensive simulations will only be run for time periods of a few months, but will allow us to assess scaling issues, particularly as related to providing atmospheric forcing data to the high resolution hydrologic model.

Results and Model Validation

Upper Kuparuk Watershed

Figure 4. Overview of meteorological observation site in the Upper Kuparuk watershed.

The Water and Environmental Research Center (WERC) at the University of Alaska – Fairbanks has been making hydrologic and atmospheric observations in the Kuparuk watershed on the North Slope of Alaska since 1992 (Kane et al. 2000). Meteorological observations at 11 sites in the Kuparuk watershed are being used to evaluate the Polar MM5 atmospheric simulations conducted as part of the current ARCSS FWI project.

Comparisons of the modeled and observed near surface air temperature and downwelling atmospheric longwave radiation at the Upper Kuparuk meteorological site (Fig. 4) are shown in Figures 5 and 6. For both figures the modeled and observed time series show good agreement over the entire annual cycle. Large differences in the modeled and observed temperature are evident between days 494 and 514 (Fig. 5). It is thought that this difference reflects a delayed melting of the snow pack in the model simulation, due in part to the coarse 50 km model resolution which results in a difference in elevation between the observation site and the nearest model grid point of over 100 m. The greater elevation of the model grid point is also the likely explanation for the slightly cooler simulated temperatures compared to the observed temperatures. It is expected that better agreement will be found for the 10 km atmospheric model simulations, which will provide for improved representation of the complex topography along the northern slope of the Brooks Range.

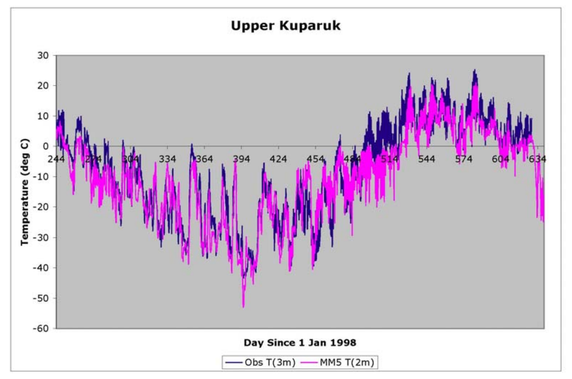

Figure 5. Modeled and observed near surface air temperature at the Upper Kuparuk meteorological site for September 1998 through September 1999.

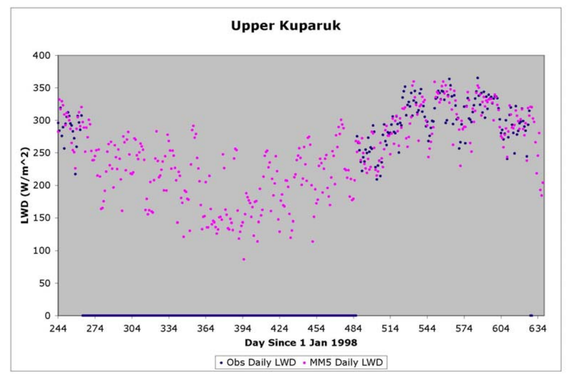

Figure 6. Modeled and observed downwelling atmospheric longwave radiation at the Upper Kuparuk meterological site for September 1998 through September 1999.

One feature to note in Fig. 6 is that during the winter months (days 264 to 484) no observations of downwelling longwave radiation are available, while the atmospheric model is able to provide a continuous time series of all near surface atmospheric variables and fluxes. This illustrates one advantage of the atmospheric model – the ability to provide continuous, uninterrupted time series of the atmospheric state.

Tiksi – Lena Watershed

Figure 7. Meteorological observation tower at Tiksi field site in the Lena watershed.

Atmospheric and hydrologic measurements have been made in the Lena watershed as part of the GAME-Siberia (GEWEX (Global Energy and Water Cycle Experiment) Asian Monsoon Experiment) project. Evaluation of the 50 km Polar MM5 atmospheric model simulations over the Lena watershed have begun by comparing modeled and observed data at Tiksi, Russia (Fig. 7) (Yabuki and Kodama 2003), near the mouth of the Lena River.

Time series of modeled and observed near surface air temperature (Fig. 8) and snow depth (Fig. 9) at Tiksi for September 1998 through September 1999 are shown as examples of the model performance in this region. The modeled and observed temperature time series in Figure 8 show good agreement, and in particular the model time series successfully depicts a number of significant changes in observed temperature during the 13-month period (e.g. the period around day 384). The modeled snow depth also shows good agreement with the observations (Fig. 9), especially during the middle of the winter and in the timing of the final snowmelt in the spring. The snow depth observations at the beginning and end of winter indicate a substantially deeper snow pack than was modeled. Analysis of this discrepancy is under way, and may reflect sub-grid scale variability not resolved with the 50 km grid spacing.

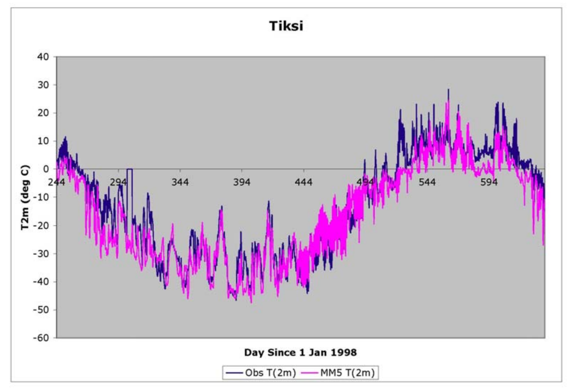

Figure 8. Modeled and observed 2-m air temperature at the Tiksi meteorological site for September 1998 through September 1999.

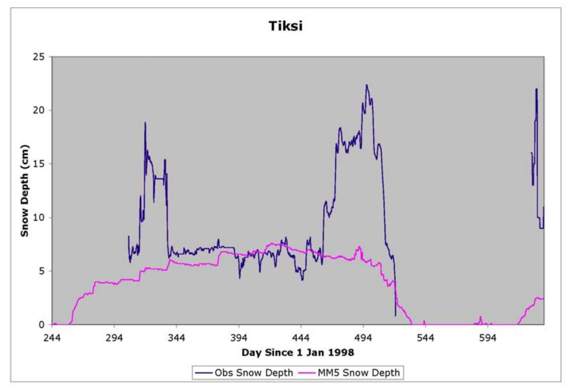

Figure 9. Modeled and observed snow depth at the Tiksi meteorological site for September 1998 through September 1999.

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Conclusions and Plans for Future Work

Two years of 50 km grid spacing atmospheric model simulations (September 1998 through September 2000) over the Mackenzie, Kuparuk, and Lena watersheds have been completed. Good agreement between the modeled and observed near surface atmospheric state has been found for these simulations, although some differences are evident. Some of these differences may be due to the relatively coarse atmospheric model grid spacing of 50 km. Additional atmospheric model simulations using a horizontal grid spacing of 10 km are underway, and may help to explain some of the differences between the modeled and observed data.

Over the next year we will begin to provide our collaborators with atmospheric model data for use in forcing the hydrologic model. We will also begin a more detailed analysis of the atmospheric model results, with an emphasis on case studies of atmospheric events that could have a large impact on the annual hydrologic cycle in the study watersheds.

References

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