5A.10

Mesoscale simulations of cold season Alaskan atmosphere-surface interactions using PSU/NCAR MM5 model coupled to the NOAH-LSM land surface model

Jing Zhang and Jeffrey S. Tilley

Geophysical Institute, University of Alaska-Fairbanks, Fairbanks, AK

1. Introduction

The effects of snow cover on atmospheric circulation and climate, including temperature anomalies, precipitation patterns and hydrological processes have been widely studied (e.g.,Namias 1985; Barnett et al.,1998). In these and other studies, snow cover and snow melt have been found to play important roles in the surface energy budget, turbulent fluxes in the atmospheric boundary layer, and the hydrologic cycle. In addition, frozen soil can dramatically affect the partitioning of rainfall and snow meltwater between infiltration and runoff (e.g., Lynch-Stieglitz 1993) as well as the evapotranspiration(e.g.,Tilley and Lynch 1998). As such, frozen soils and those undergoing freeze/thaw processes figure strongly into the annual groundwater and runoff budgets (e.g., Aguado 1985), thereby feeding back into the regional and global hydrologic cycles.

Obviously, all these processes are particularly important for Arctic and subArctic continental regions which contain permafrost and have frozen active layers and large snow covered areas during the long winter season. To obtain realistic depictions of land-atmosphere-ice exchange processes in regional Arctic model simulations, it is necessary for the model to account for such winter season processes. Recently, such processes have been included in a land surface scheme (referred to hereafter as NOAH-LSM; Koren et. al 1999) developed jointly by NCEP, Oregon State University, the Air Force Weather Agency, and NOAA's Office of Hydrology.

In this study, we couple the NOAH-LSM scheme to version 3 of the PCU/NCAR Mesoscale Model MM5. (e.g., Chen and Dudhia 2000). We then examine simulation results for a cold season case study period to determine the effectiveness of the new scheme compared to the standard MM5v3 land surface model (Chen and Dudhia 2000) which contains simpler treatments of frozen soil and snow cover processes.

2.Description of Land Surface Models

A complete description of the MM5v3 Land Surface Model (LSM) can be found in Chen and Dudhia (2000). Here we provide a brief summary of the key features relevant to this study. LSM features four soil layers and a single canopy layer. A total depth of 2 meters is chosen for the soil in order to reasonably simulate daily and seasonal variability of the soil moisture and soil temperature fields. Depths of the soil layers are assumed to be 0.1, 0.3, 0.6 and 1 meter proceeding downward from the top layer, respectively. Roots from vegetation (prescribed from one of several available databases) extend to a depth of 1 meter. Soil moisture and soil temperature are computed prognostically from equations describing hydraulic conductivity and heat conduction, respectively. The surface temperature is defined to reflect a combination of the bare soil and the canopy temperatures within a grid cell and is computed diagnostically with a surface energy balance relation.

Subfreezing soil temperatures have no effect on soil ice formation, which is essentially ignored. Whenever there is snowfall, snow accumulates on the ground surface and the surface albedo is adjusted with a canopy-dependent factor. The insulating effect of snow cover on the underlying soil is considered by calculating the heat flux between surface and the soil with a constant snow thermal diffusivity.

If snow cover is present and the surface temperature is above the freezing point, snowmelt is allowed. However, the snowmelt (and variation of snow properties, if any) is assumed to occur uniformly in space and time for the grid cells under consideration.

Such treatment is, unfortunately, inconsistent with observations which indicate that snow density can vary from 0.1-0.5 gcm^{-3} depending on snow age and compactness. Snow albedo also can vary from 0.5 for wet, dirty snow to ~ 0.8 for new, dry snow. Observations also indicate that the variability in snow properties influences the processes of snow accumulation and ablation directly and thus should be included in land surface schemes.

In addition to the processes included in the Chen and Dudhia (2000) LSM, the NOAH-LSM scheme includes the temporal variability in snow processes as well as ice formation within the soil and the effects of soil ice on the soil water diffusivity, water potential and thermal conductivity. In particular, snow density in NOAH-LSM varies with snow temperature, snow melt and snow accumulation. Fractional snow coverage is allowed to account for the effect of patchy snow.

.Corresponding Author Address:
Dr. Jeffrey S. Tilley,Geophysical Institute,
University of Alaska-Fairbanks
903 Koyukuk Dr,. P.O. Box 757320
Fairbanks, AK 99775-7320 email: jeff@gi.alaska.edu

Affected by this patchy snow, surface albedo is snowdepth dependent. For the frozen soil, NOAH-LSM first accounts for the energy source/sink from phase transitions (liquid water <->ice) in the soil temperature equation. Then the frozen water is removed from total soil water in soil moisture transfer equation and the soil heat capacity, thermal conductivity and water potential are modified from their previous values. Other details of NOAH-LSM not described here can be found in Koren et al.(1999).

3. Model Configuration and Experiment Design

For this study we have coupled the NOAH-LSM scheme to the Penn State/NCAR Mesoscale model MM5v3 in order to examine the performance of the NOAH-LSM scheme in a high latitude setting with permanently frozen soils overlain by a seasonally freezing and thawing active layer with a depth of generally 50 cm or more. The domain of the simulations is shown in Figure 1. We utilize a model grid resolution of 45km for these initial tests on a computational grid of 41 x 47 x 23 vertical layers. A model timestep of 150 s is used.

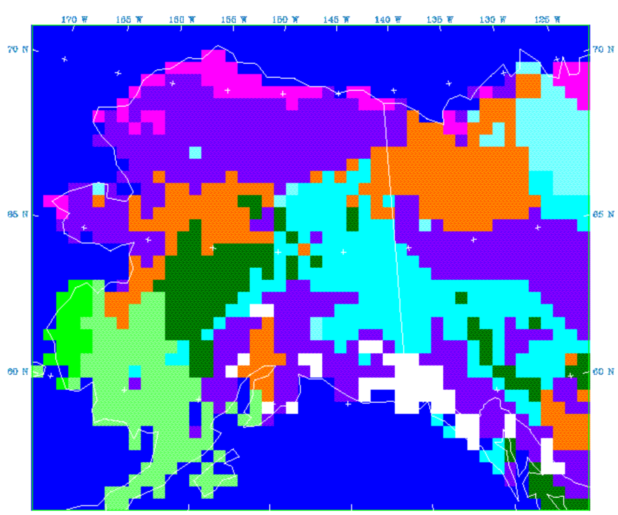

Figure 1. Domain and vegetation depiction used in the modeling experiments. The vegetation classes follow the USGS classification scheme. Darker colors indicate tundra types, lighter colors indicate forests or mixed tundra/forest vegetation, white indicates glacial ice.

In all simulations, we employed the following MM5v3 physical parameterizations: the Dudhia (1989) simple ice microphysics scheme; the Grell (1993) cumulus scheme; the MRF planetary boundary layer scheme (Hong and Pan 1996); and a simple cloud radiative cooling scheme . NCEP/NCAR reanalysis data are used to provide initial and boundary conditions to the modeling system. No additional observations are ingested for these experiments.

We perform two different experiments for the case under consideration: one with the standard MM5v3/ LSM system (referred to hereafter as the LSM experiment) and one with the coupled MM5/NOAH-LSM (referred to hereafter as the NOAH-LSM experiment).We conduct both simulations for a fall season case study period of 30 September-3 October 1999. This period begins with snow cover over part of the model domain and includes additional precipitation as rainfall in southwestern and southcentral Alaska.

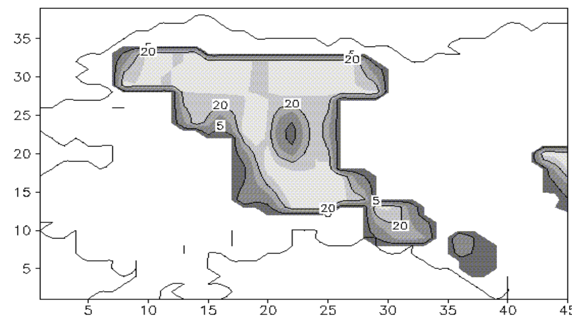

Figure 2. Initial snow cover (cm) at 00 UTC 30 Sept. 1999 over the domain of interest, from NCEP/NCAR Reanalysis data

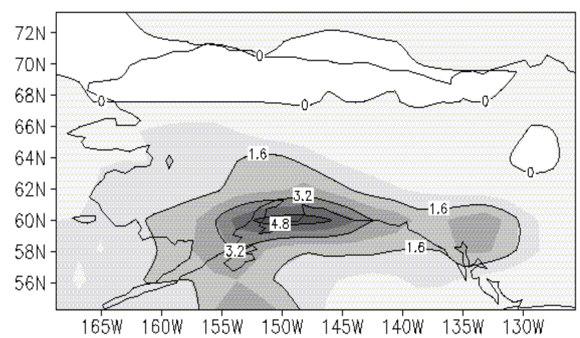

Figure 3. Total accumulated precipitation (cm) from 00 UTC 30-Sept -00 UTC 3 October over the domain of interest, from NCEP/NCAR Reanalysis data.

4. Modeling Results

Figure 2 illustrates the initial NCEP/NCAR reanalysis snow cover present over the domain at the start of the simulation period (00 UTC 30 September 1999). At this time snow covers only the Brooks Range and the eastern interior sections of Alaska. Figure 3 depicts the total precipitation during the period. Precipitation mainly occurred over the southcentral and southwestern sections of Alaska. Based on the mean surface temperature during this period (not shown) and a check of available station data, the majority of the precipitation that fell during this period was in the form of rain except at the extreme northern part of the precipitation shield in the vicinity of Norton Sound and the Koyukuk valley. Therefore, there was little change in snow cover at the end of the study period over the main precipitation area. In fact, the largest change in snow cover over the period appeared to occur over the Yukon Territory, apparently from precipitation that was not well captured in the Reanalysis dataset. Due to this discrepancy we interpret the Reanalysis data with some caution in what follows but feel that the majority of that data are of sufficient quality for our purposes in this study.

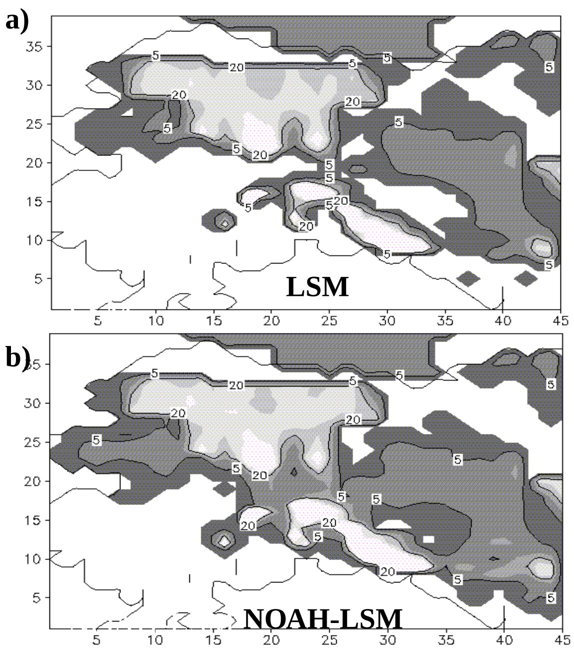

Figure 4. Snow cover (cm) at 00 UTC 3 Oct 1999 as simulated by a) the LSM simulation, and b) the NOAH-LSM simulation

The simulated precipitation (not shown) by both model systems are quite similar and are reasonably consistent with the Reanalysis data, with the exception that the amount of simulated precipitation is somewhat larger. This is not an unexpected result. The MM5 model will be able to resolve mesoscale precipitation events on a much finer grid than the Reanalysis, which will tend to smooth out local areas of heavier precipitation as part of the analysis procedure to the relatively coarser grid. As a result, the accumulated snow cover by MM5/LSM (Fig.4a) and MM5/NOAH-LSM (Fig.4b) at the end of simulation period is larger than the Reanalysis over southern and southeastern Alaska. However, neither simulation captures the magnitude of the increase in snow cover over the Yukon territory seen in the Reanalysis data, though both simulations produce snowfall in that region. By carefully comparing the snow cover among the two simulations and the reanalysis, and taking into account the extreme similarity among the LSM and NOAH-LSM simulated precipitation, it is evident that more snowmelt occurs over the central domain in the LSM simulation than in the NOAH-LSM simulation. Below we briefly consider some of the potential physical reasons behind these differences.

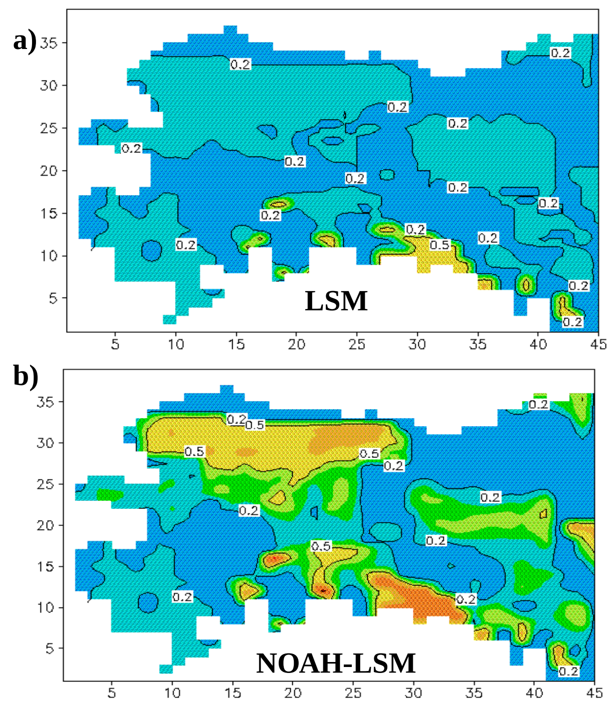

Figure 5. Surface Albedo at 00 UTC 3 Oct 1999 as simulated by a) the LSM simulation, and b) the NOAH-LSM simulation

Figures 5a and 5b show the surface albedo for the LSM and NOAH-LSM simulations, respectively, at 00 UTC 3 October. A large difference is evident between the simulations, notably in the interior areas of Alaska, reflecting the resultant difference between the snow-depth dependent albedo (larger for greater snow depth) in NOAH-LSM and the constant snow albedo in LSM. The lower albedo in the LSM simulation will allow for more shortwave radiant energy to be absorbed by the snow pack and thereby promote increased sublimation and/or melting during daytime clear sky periods, as this case study period occurs close enough to the autumnal equinox to allow for significant daytime heating from shortwave radiation if skies are mostly clear. Further, in the LSM scheme the surface skin(snow) temperature is set constant at 273.16K once snowmelt begins. Thus, once the lower albedo in the LSM simulations has promoted enough radiant energy absorption for snowmelt to commence, any additional energy gain will be completely directed into further snowmelt and accelerate the melting process. By contrast, in NOAH-LSM, even once snowmelt begins the skin temperature can change, allowing for excess energy to be involved in processes other than a phase change to liquid water. The potential contrast in snow melt rates is illustrated in Figure 6. The figure shows, for an interior Alaska grid point that experiences snow melt in both simulations, the change in the water equivalent snow depth with time in each simulation. While the snow melt rate is fairly steady in the NOAH-LSM simulation, once snow melt begins in the LSM simulation it continues at a rapid, accelerating pace until all the snow cover is removed.

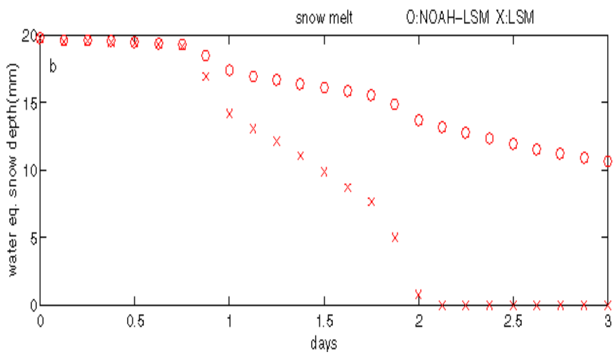

Figure 6. Comparison of snow melt rates for an interior Alaskan grid point over the course of the simulations using the LSM (circles) and NOAH-LSM (crosses) schemes.

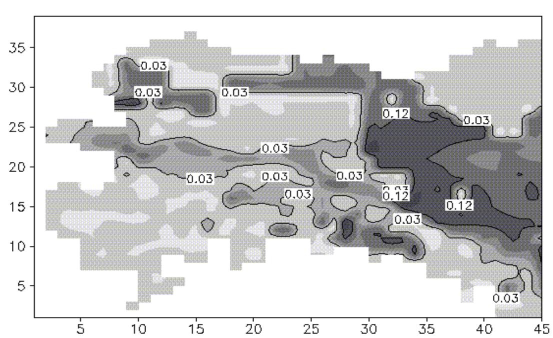

Figure 7. Difference in volumetric upper layer (0-10 cm) soil moisture predicted for 00 UTC 3 Oct 1999 between the NOAH-LSM and LSM simulations. Lightest shading indicates greater soil moisture in the LSM simulation; all other shadings indicate greater moisture in the NOAH-LSM simulation.

Another important difference between the LSM and NOAH-LSM schemes is the treatment of frozen soil and how such soil figures into the soil layer water balances. Figure 7 shows the difference in simulated upper layer soil moisture between the NOAH-LSM and LSM simulations. Generally positive differences (greater soil moisture in NOAH-LSM) prevail over most of the domain, with the largest differences over the topography of the Brooks Rage, Alaska Range and smaller ranges in Alaska and the Yukon Territory. When compared with the reanalysis dataset (not shown), the NOAH-LSM values are in better agreement than the LSM values, thus the differences represent an improvement in the NOAH-LSM simulation.

Soil temperatures are subfreezing over nearly all of the areas with positive differences. These differences can be largely attributed to fact that since the soil water cannot freeze in the LSM scheme, more soil water is available in the LSM simulation for both runoff and evapotranspiration. Indeed, both runoff and evapotranspiration (not shown)are larger in the LSM simulation, with runoff especially larger over the Brooks Range and the Yukon Territory. We will explore other hydrological consequences of this difference at the conference.

5. References

Aguado, E., 1985: Radiation balances of melting snow covers at an open site in the Central Sierra Nevada, California, *Water Resour. Res*., **21**, 1649-1654.

Barnett,T.P., L.Dumenil, U.Schlese, E.Rooeckner, and M. Latif, 1989: The effect of Eurasian snow cover on regional and global climate variations, *J.Atmos.Sci*., **46,** 661-685.

Chen, F., and J. Dudhia, 2000: Coupling an advanced land-surface/hydrology model with the Penn State/NCAR MM5 modeling system. Part I: Model description and implementation. [submitted to the *Monthly Weather Review*, 2000].

Dudhia, J., 1989: Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. *J. Atmos. Sci.*, **46**, 3077-3107.

Grell, G., 1993: Prognostic evaluation of assumptions used by cumulus parameterizations. *Mon. Wea. Rev.*, **121**, 764-787.

Hong, S.Y., and H.-L.Pan, Nonlocal boundary layer vertical diffusion in a medium-range forecast model, Mon. Wea. Rev., 124, 2322-2339.

Koren, V., J.Schaake, K.Mitchell, Q-Y.Duan, F.Chen and J.M.Baker, 1999: A parameterization of snowpack and frozen ground intended for NCEP weather and climate models, *J.Geophys.Res*., **104,** 19569-19585.

Lynch-Stieglitz, M.1994: The development and validation of a simple snow model for the GISS GCM, *J.CLimate*, **7(12),** 1842-1855.

Namias, J.,1985: Some empirical evidence for the influence of snow cover on temperature and precipitation, *Mon. Weather Rev.*, **113,** 1542-1553.

Tilley, J. S. and A. H. Lynch, 1998: On the applicability of current land surface schemes for Arctic tundra: An intercomparison study. *J. Geophys. Res*, **103 (D22)**, 29051-29064.

Acknowledgments: This work is sponsored by the Department of Defense through Johns Hopkins University under the University Partnering for Operational Support Initiative.