**Validation of simulated Planetary Boundary Layer (PBL) structure using a new surface layer module with SHEBA observations.**

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## 1. Introduction

Improving model simulations of the current Arctic environment is a necessary step in assessing future Arctic climate scenarios under global change conditions. Improving the representations of surface-exchange processes between snow/sea-ice and the atmosphere is one area of needed attention. This project is an effort to develop better surface representations of surface energy balance and temperature in the Arctic region, and to determine the efficacy of using a sophisticated surface-layer scheme in MM5.

## 2. Model and observation descriptions

The NOAA/ETL Advanced Canopy Atmosphere Soil Algorithm (ETL/ACASA) is based on a prototype developed by Pyles (2000) for MM5 V2 at the University of California, Davis. The ACASA model incorporates a Reynolds-averaged, diabatic, third-order representation of turbulent statistics and calculates the surface-layer microenvironment in a multi-layer context (Pyles 2000, Meyers 1985), with twenty atmospheric layers in the current experiment. The advantages of ACASA have been shown in 1-D offline tests (Pyles et al. 2000).

ETL/ACASA incorporates several new modifications that render it more generally applicable to the Earth's surface than earlier versions. The fourth-order surface temperature solution technique in ETL/ACASA has been modified from the original Paw U and Gao (1988) formulation to achieve more accurate results for situations where temperatures are between 158 and 373 K. Soil/sea ice and snow physics, adapted from the mesoscale analysis and prediction system scheme (MAPS) (Smirnova et al. 2000), have been modified for general applicability. Heat transfer in snow and/or soil and sea ice is handled using a 1-D thermal diffusion approach, and moisture transport calculations include both vertical diffusional and gravitational effects (Smirnova et al. 2000). For this experiment, the hydraulic conductivity was assumed to be negligible for sea-ice, and the thermal conductivity and heat capacity are assumed to be constant at 2.5 s m$^{-2}$ and 1.96 (10$^{6}$) J kg$^{-1}$, respectively. The number of soil/ice layers, as well as the maximum number of snowpack layers, is now adjustable.

The theoretical framework for all PBL models used here is based on gradient diffusion, or *k*-theory, described with the following formulation:

$$\partial\alpha / \partial t = \partial / \partial z(k_\alpha(\partial\alpha / \partial z - \gamma_\alpha)),$$

where $t$ is time (s), $z$ is the height above ground (m), alpha is the quantity being mixed (wind velocity, temperature, humidity, etc.), $k_\alpha$ is the turbulent diffusion coefficient (sm$^{-1}$), and $\gamma_\alpha$ is a countergradient term (defined later) which is 0 in most cases. The main difference between these schemes lies in how $k_\alpha$ and $\gamma_\alpha$ are defined in the Blackadar (Grell et al. 1995), MRF (Hong and Pan 1996), Gayno-Seaman (Shafran et al. 2000) and Eta (Janjic 1990, 1994) schemes.

Though how $k_\alpha$ values are defined varies between schemes, generally they are functions of turbulence length scales and vertical wind shear (or turbulence kinetic energy). The turbulence length scale, $\ell$ (m), in each of the formulations except Gayno-Seaman (see Ballard 1991), is defined as $\ell = (\lambda_0 + kz) / kz\lambda_0$, where $k$ in this case is the von Karmann constant (0.4) and $z$ is the height above ground (m). The background mixing length ($\lambda_0$ (m)) is defined differently in each of the three schemes, adding to differences in PBL evolution.

For the Blackadar and Eta models, $\gamma_\alpha$ is 0 for all quantities at all levels (countergradient contributions are ignored). For the Gayno-Seaman and MRF schemes, $\gamma_\alpha$ is defined for potential temperature $(\theta)$ at levels below 1.2 times the height of the mixed-layer ($h$) as: $\gamma_\alpha = b\overline{w'\theta'} / w_* h$, where $\overline{w'\theta'}$ is the surface heat flux, b=5, and $w_*$ is a convective velocity scale which differs in definition between these two schemes.

ETL/ACASA is coupled to each of the four schemes described above to estimate surface momentum, heat and moisture fluxes every 30 minutes. Specifically, surface-layer values of sensible heat flux, moisture flux, and friction velocity (root mean square of the vertical momentum flux), and surface (skin) temperature from ETL/ACASA are used by each PBL scheme as the lower boundary condition for these quantities. In addition, ETL/ACASA values of Monin-Obukhov length and bulk Richardson number are used by each scheme to estimate PBL height. The Gayno-Seaman scheme also requires surface-layer turbulence kinetic energy, which is calculated by ETL/ACASA from the sum of the three velocity variance components. ETL/ACASA also provides surface albedo values since those in MM5 are prescribed.

MM5 values of air temperature, humidity, wind speed, pressure, land use type, precipitation and downwelling long- and short-wave radiation from the lowest sigma-layer were used to drive ETL/ACASA.

In this experiment, snow was initialized to 22cm at each grid point where the initial soil and air temperatures were below 273 K. For sea ice points, initial temperature values were linearly interpolated from oceanic temperatures of –1.8 C (below 2.2m) to MM5 climatological values near the top of the snowpack. Climatological values for soil temperature were used to initialize the land points.

Observed data used in these comparisons are from the Surface Heat Budget of the Arctic Ocean Experiment (SHEBA). An ice station, centered on the Canadian icebreaker *Des Groseilliers*, was established in the Beaufort Sea in October 1997 and allowed to drift with the pack ice until October 1998. Uttal et al. (2001) and Persson et al. (2002) give a more complete description of the field program, data processing, and the accuracy of the measurements.

## 3. Experimental Method

For this investigation, MM5 was run for eight days beginning 00Z Jan 15, 1998. MM5 was driven with initial and boundary conditions from NCAR/NCEP Reanalysis fields interpolated to 60km horizontal grid spacing. The number of vertical layers in each simulation was 50, with the lowermost sigma-layer at 2m above the surface. Having 30 layers within the lowermost 1 km of the atmosphere was necessary to resolve the persistent, shallow inversion layer in the wintertime arctic environment. The physics packages chosen for each simulation are: RRTM long- and short-wave radiation, simple ice microphysics, and the Grell convection scheme.

In this investigation, four 8-day simulations were performed, each using a different PBL scheme with ETL/ACASA as the surface-layer flux and temperature scheme (described later). Hourly values of model and observed potential temperature are compared. For diagnostic purposes, hourly simulated and observed values of surface sensible heat flux, friction velocity, skin temperature, air temperature (2m) and wind speed (2m) were also compared.

## 4. Results and conclusion

Figure 1 shows time vs. height plots of potential temperature and Brunt-Vaisala frequency for each of the four MM5 simulations. In general, these simulations show the utility in coupling between each PBL scheme and ETL/ACASA. Though ETL/ACASA was used in each simulation, results in Figure 1 show differences resulting from the choice of PBL scheme.

Comparison of the model results and observations indicates that these simulations appear sensitive to choice of the vertical mixing routine. In particular, the use of Blackadar with ETL/ACASA generates the tightest and shallowest inversion layer, while the MRF scheme allows for more deep vertical mixing. For longer simulations over wider regions, such differences may evolve to a point where coupled feedbacks with additional atmospheric processes such as cloud formation contribute to greater divergence between the simulations than is evident in this preliminary experiment.

Since the only differences in the design of each MM5 simulation lie in the choice of PBL scheme to which ETL/ACASA is coupled, the primary source of these differences likely originates in how the turbulent length scales and vertical diffusion are handled in each PBL scheme. Work is currently underway to isolate these differences and explain them in the context of each scheme's mathematical formulations mentioned briefly in Section 2. We will be presenting the results from this enquiry during our presentation.

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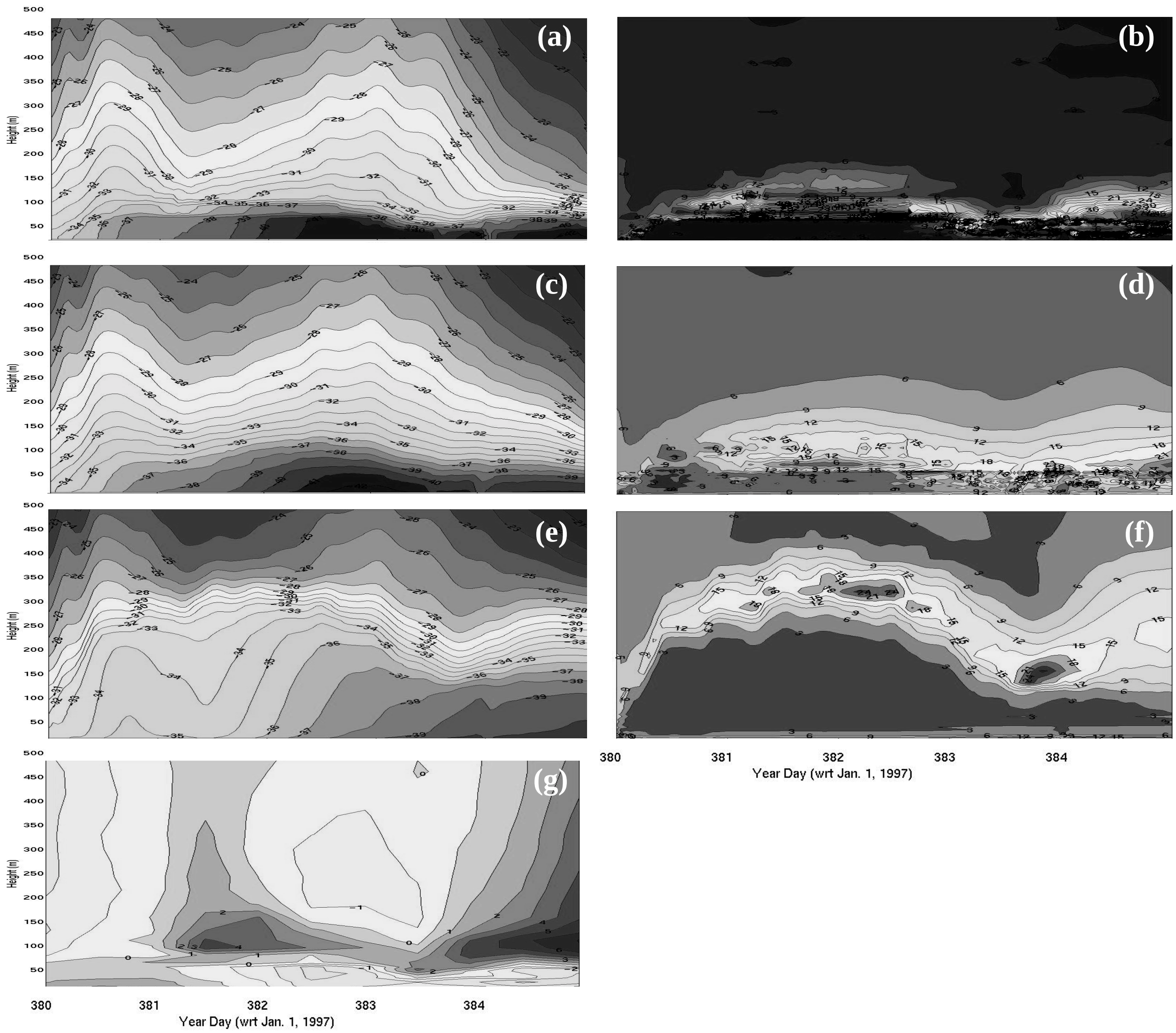

Figure 1: January 15-23 time vs. height diagrams of MM5 simulated potential temperature (K) (a,c,f) and Brunt-Vaisala frequency ($s^{-1}$) (b,d,e). Panels (a) and (b) are for MM5-Blackadar-ETL/ACASA, (c) and (d) are for MM5-Eta-ETL/ACASA, and (e) and (f) are for MM5-MRF-ETL/ACASA. Panel (g) is time vs. height difference between MM5-Blackadar-ETL/ACASA and observed temperature (K).