EMS Annual Meeting Abstracts
Vol. 11, EMS2014-260, 2014
14th EMS / 10th ECAC

Evaluation of the Weather Research Forecasting model for three contrasting sites over snow in stable conditions with light winds

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Modeling the atmospheric stable boundary layer (SBL) is challenging, especially over snow-covered surfaces. For example in the Arctic, many global and regional climate model outputs diverge from one another, as well as from observations e.g. for near surface variables such as temperature, wind speed and humidity. The SBL is governed by many small-scale physical processes, such as turbulent mixing, the coupling of the atmosphere with the underlying medium, radiation, the presence of clouds or fog, subsidence, advection, gravity waves and drainage and katabatic flows. These physical processes and their interactions are either not completely understood, or are represented incompletely.

This study evaluates the full three dimensional (3D) and the Single Column Model (SCM) versions of the Weather Research and Forecasting (WRF) model for stable, low wind speed conditions over snow-covered surfaces for three contrasting terrains. The studied sites are Cabauw in the Netherlands (snow over grass), Sodankylä in Finland (snow over a needle leaf forest) and Halley (snow over ice shelf). To study the physical and dynamical processes in more detail, the SCM was driven by realistic forcings of the WRF 3D field. Several sets of SCM forcings were tested: A. no advection, B. varying geostrophic wind in time, C. wind advection on top of B, D. temperature and moisture advection on top of C, and E. forcing the SCM field to the 3D field above a threshold height.

The 3D-WRF forecasts for near surface wind speeds performed surprisingly well, but near-surface temperatures and specific humidity were overestimated for Cabauw and Sodankylä, and underestimated for Halley. The best results for the WRF SCM were obtained when wind, temperature and moisture advection is prescribed (set D). A prescription of the surface characteristics inspired by local observations regarding the snow cover and vegetation fraction, improved the SCM 2m temperature forecasts. All three study sites had in common that the forecasted temperature and moisture inversions are underestimated, though this aspect improved when advection was prescribed. Finally, so called process diagrams are used to identify whether model sensitivities for the boundary layer mixing, the longwave downwelling radiation and land surface coupling are well represented compared to observations.

Overall we conclude that the SBL over snow with low wind speeds can be forecasted to a good approximation with WRF if all processes are taken into account at high atmospheric resolution and when land surface characteristics are accurately prescribed.