Evaluation of the Stable Boundary Layer processes in the Global Environmental Multiscale (GEM) Model over the Arctic Ocean during SHEBA

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1. Introduction

Coupled Global Climate Models (CGCMs) participating in the Phase 2 of the Coupled Model Intercomparison Project (CMIP2) simulate poorly the projected Arctic amplification of climate change near the surface over the Arctic ocean (e.g. Holland and Bitz, 2003). Also, Tjernström *et al.* (2004) report that climate models participating in the Arctic regional climate model intercomparison project (ARCMIP) represent poorly the stably stratified Arctic boundary layer surface turbulent fluxes of heat, momentum and moisture that couple the lower atmosphere with the ice-covered Arctic Ocean. The first goal of this research is to evaluate the GEM model simulated near-surface climate and turbulent processes by comparing them to those observed during the Surface Heat Budget of the Arctic Ocean (SHEBA) year. The second goal of this study is to evaluate the sensitivity of GEM simulations to stability functions and roughness length parameterizations.

2. Model experiment

A simulation was made with GEM on a limited area grid of 70x80 grid boxes centered at a longitude of 156 °W and a latitude of 67 °N with a horizontal resolution of 0.5 degree. 53 vertical levels are used with the top of the model located at 10 hPa. The model integration began in September 1996 and ended in October 1998 with a 30 minutes time step. A spin-up period of one year was included before comparing GEM with the SHEBA observations (Persson *et al.*, 2002) that started in October 1997 and ended a year later. Lateral boundary conditions were supplied from ERA-40 at every 6 hours and the surface boundary conditions of ice fraction and sea-surface temperature (SST) were prescribed from the AMIP II data set. It is worth mentioning that the surface skin temperature distribution was obtained from a surface heat budget computation and wasn't prescribed from the Advanced Very High Resolution Radiometer (AVHRR) used by Tjernström *et al.* (2004) in order to give more degrees of freedom to the model.

3. Results

Comparisons of simulated near-surface state variables with SHEBA observations are shown in Figures 1(a) to (c). The surface wind comparison (Figure 1(a)) suggests large errors occur under calm conditions, with GEM systematically overestimating the wind speed by an average of 1.14 m/s for all conditions observed during the SHEBA year. Surface air temperature and specific humidity (Figures 1(b) and 1(c) respectively) are reasonably well simulated considering that surface temperature wasn't prescribed in the model. Temperature errors are lower in summer as they are constrained around 0 °C during the melting season. The GEM model has an overall warm bias of 0.53 °C in comparison with SHEBA observations.

The comparison of simulated surface turbulent fluxes with SHEBA observations (Figures 1(d) to (f)) showed that like most of the ARCMIP models, GEM overestimates the friction velocity (momentum flux) with a bias of 0.066 m/s for all conditions and the largest errors during calm conditions. Large errors are found for the simulated sensible and latent heat fluxes. The observed mean sensible heat flux is -1.92 W/m^2 while the mean simulated flux is -1.59 W/m^2. The latent heat flux is largely overestimated (bias of 4.03 W/m^2) in the GEM model like in most of the ARCMIP models. Even if the sensible heat flux amplitude is small compared with the other components of the surface heat budget, such errors could be affecting the low-level cloud cover by transporting moisture upward and, indirectly, affecting the radiative budget at the surface.

3. Summary and discussion

In order to understand the origin of modelling errors and possibly to improve the representation of the

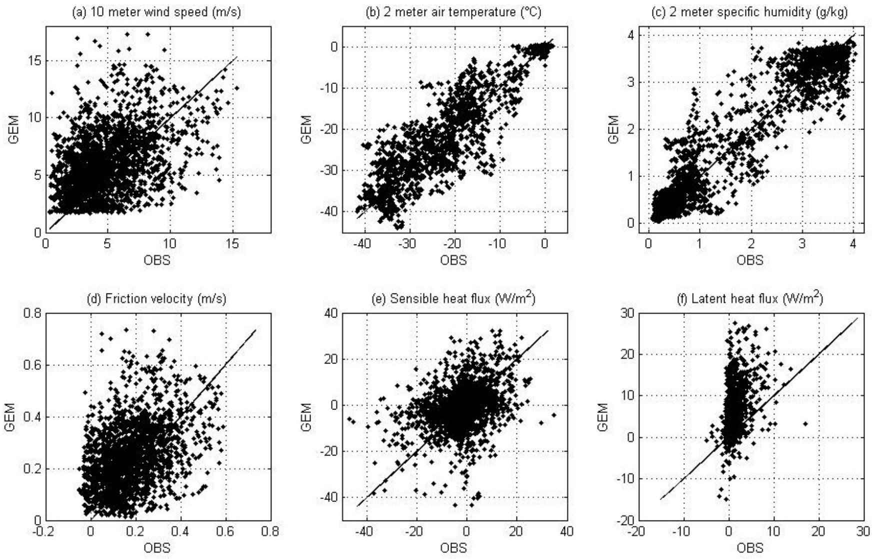

Fig. 1 – Scatter plots of observed (horizontal axis) versus modelled (vertical axis) near-surface (a) wind, (b) air temperature, (c) specific humidity and surface turbulent fluxes of (d) momentum (friction velocity), (e) sensible heat and (f) latent heat. The scatter plots are based on 3 hourly mean time series for the October 29^{th} 1997-October 1^{st} 1998 period. Positive fluxes of sensible and latent heat are in the upward direction and friction velocity is equal to the square root of the surface turbulent flux of momentum.

interaction between the atmosphere and the ice-covered Arctic Ocean, parameterisation of turbulent processes must be evaluated in more detail. GEM and most of the ARCMIP models use a surface layer scheme similar to the well-known Louis (1979) scheme based on Monin-Obukhov similarity theory with surface fluxes of momentum, heat and moisture computed by the generic formula $\overline{w'\chi'}_s = -C_\beta V_s(\overline{\chi}_{ref} - \overline{\chi}_s)$ where χ is u, v, q_v or θ the potential temperature, C_β is the transfer coefficient for χ, V_s is the average 10 meter wind speed, $\overline{\chi}_{ref} - \overline{\chi}_s$ is the average vertical gradient of χ (where β is m, h or v for momentum, heat and moisture respectively) between the surface and a reference level. In this formulation, the transfer coefficient depends on roughness length $z_{0\beta}$. In GEM, roughness lengths are prescribed to a constant value of 0.16 mm for momentum (z_{0m}), heat (z_{0h}) and moisture (z_{0v}) over sea-ice. The transfer coefficients depend also on a stability function ϕ_β that depends on the gradient Richardson number Ri with $\phi_m = 1 + \alpha Ri$ in the stable regime and $\alpha = 12$ (Delage, 1997). The stability function for heat and moisture is calculated by $\phi_h = Pr_t \phi_m$ where Pr_t is the turbulent Prandtl number (equal to one by default in GEM). The sensitivity of GEM to different parameterizations of $z_{0\beta}$, Pr_t and α will be evaluated in future work. Analysis of observations of Prandtl and Richardson number made by the Atmospheric Surface Flux Group (ASFG) (Grachev *et al.*, 2008) during the SHEBA year and associated observations of the stability functions ϕ_β could allow us to improve the quality of the simulations once the sensitivity is to those parameters is established.

4. References

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