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Large-Eddy-Simulation of an off-ice airflow during BASIS

Dieter Etling[1)], Guido Harbusch[1)] and Burghard Brümmer[2)]

[1)] *Institute of Meteorology and Climatology, University of Hannover, Herrenhäuser Str. 2, D-30419 Hannover, Germany*
[2)] *Meteorological Institute, University of Hamburg, Bundesstr. 55, D-20146 Hamburg, Germany*

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The boundary layer modification for the case of an off-ice airflow during the BALTEX-BASIS field experiment is simulated by means of a Large Eddy Simulation (LES) model. Model results are compared with aircraft observations for turbulent fluxes of momentum, heat and moisture.

Introduction

One goal of the BALTEX Air-Sea-Ice-Study (BASIS) was the investigation of atmospheric boundary layer modification due to variable sea ice conditions. In the area between ice covered sea and open water, the strongest modification can be expected. This is especially true for on-ice and off-ice air flow. The latter case exhibits the most dramatic boundary layer change, because very cold air is flowing over warmer water leading to substantial upward sensible and latent turbulent heat fluxes. These types of cold air outbreaks have been investigated quite often by field measurements and numerical simulations. As an example we might quote the recent papers by Brümmer (1997), Hartmann *et al*. (1997) or Renfrew and Moore (1999).

During the BASIS field-experiment, one case of an off-ice flow was covered by a low-flying research aircraft which obtained measurements of turbulent fluxes near the ice and water surface (Brümmer *et al*. 2001). This allowed us to evaluate the performance of a Large-Eddy-Simulation (LES) model with respect to boundary layer modification.

Large Eddy-Simulation models are by now quite common for boundary layer research (e.g. Agee and Gluhovsky, 1997). In contrast to mesoscale models, like the operational HIRLAM model, only subgrid-scale turbulence is parameterised and all large-scale eddies are resolved explicitly in these models. This demands grid resolutions as low as 10–30 m in all directions. LES models have been applied to the problem of polar boundary layers, e.g. flow over leads or sea ice, by Glendening (1995) or Weinbrecht and Raasch (2001).

Here we report simulations performed with the LES model of the University of Hannover within the BALTEX-BASIS project. The model is described in detail in Raasch and Schröter (2001) and has been applied to the boundary layer development over variable sea-ice concentrations by Raasch and Harbusch (2001).

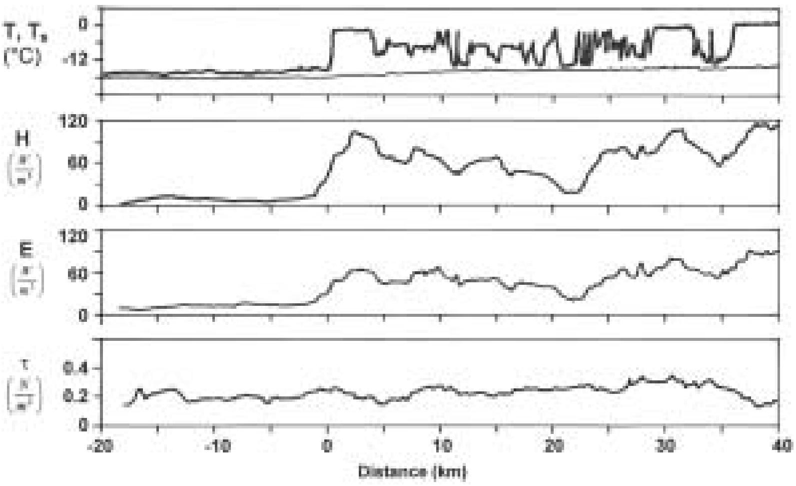

Fig. 1. Aircraft observations for day 5 March 1998 of surface temperature T_s (thick line), air temperature T, sensible heat flux H, latent heat flux E and shear stress τ. All data except for T_s are taken at flight level 30 m above ground.

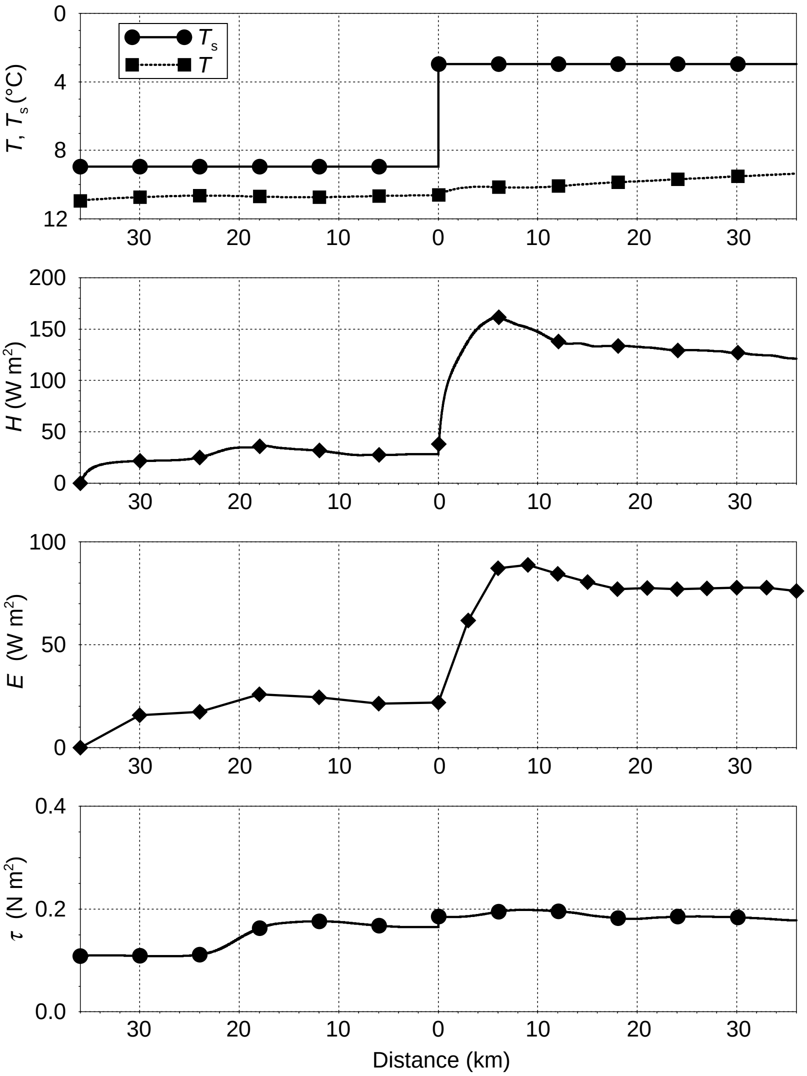

Fig. 2. Results of the LES model for surface temperature T_s , air temperature T, sensible heat flux H, latent heat flux E and shear stress τ. All data (except for T_s) are taken at z = 30 m height, corresponding to mean flight level of the research aircraft (observations in Fig. 1).

Model results

The purpose of this study was to simulate the development of the boundary layer during the off-ice flow situation in the BALTEX-BASIS field experiment on 5 March 1998. On this day, the near-surface wind speed was about 10 m s^{-1} and the wind direction was from about 5° forming an angle of about 35° with the ice edge. As aircraft measurements have been performed for this flow configuration, a comparison between simulations and observations was possible. Details of the flight track and the measurements are given in Brümmer *et al*. (2001) and Vihma and Brümmer (2002). In the model simulations only a part of the total flight was investigated, covering a flight path of about 35 km over ice and water respectively. Due to the periodic lateral boundary conditions and small grid size of the LES model it was not possible to treat the off-ice flow situation as a spatial problem over the whole observation distance of 70 km as e.g. in the simulations by Vihma and Brümmer (2002). Instead, the model domain (a box of 3 × 3 km horizontally and 2 km in the vertical with a grid size of $\Delta x = \Delta y = \Delta z = 10$ m) was moving with the mean boundary layer wind as observed on this day. The spatial change in surface conditions (from ice to sea ice to open water) was simulated by a temporal variation of the lower boundary condition. In this case, the surface temperature as observed by the aircraft (Fig. 1, top) was prescribed at the lower boundary of the model domain (Fig. 2, top). The surface roughness length was taken as $z_0 = 1$ mm over the ice and as $z_0 = 0.1$ mm over the water. These are typical values observed during the BASIS experiment (Vihma and Brümmer, 2002).

The model run was initialised with the observed vertical profiles of wind, temperature and humidity as measured near the research vessel Aranda (the initial temperature profile is shown in Fig. 3). The first part of the flight track was then simulated by applying a small air-ice temperature difference of $\Delta T = 2$ K (Fig. 2) at the lower boundary. The "ice edge" was introduced to the model by a surface temperature jump of $\Delta T = 8$ K, which corresponds to the average surface temperature observed by the aircraft (Figs. 1 and 2, top). This is of course a simplification of the real situation that showed variations in the surface temperature. But the main aspect of the LES simulations was to capture the principle development of the boundary layer during this off-ice flow situation.

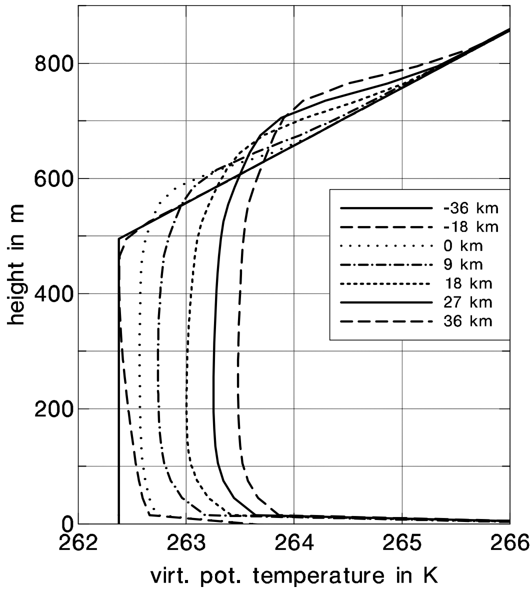

Fig. 3. Vertical profiles of the virtual potential temperature at various horizontal positions as simulated by the LES-model.

The effect of increased surface temperature on air temperature at a flight level of about 30 m and on turbulent fluxes of sensible and latent heat as well as on surface shear stress as observed by the aircraft is shown in Fig. 1. The measurements have been smoothed with a gliding mean over a 4-km flight distance. The results from the LES model simulations are displayed in Fig. 2. For comparison, the temperature jump ("ice-edge") in the model at horizontal position 0 km in Fig. 2 is equivalent to the observed jump at $x = 0$ km in Fig. 1.

The simulated sensible heat flux increased from about 30 W m^{-2} over the ice to about 150 W m^{-2} after the "ice edge". The observed values were somewhat lower with about 120 W m^{-2} after the surface temperature jump. The simulated latent heat flux compared quite well with the observations, with about 20 W m^{-2} over the ice and about 90 W m^{-2} after the "ice edge". In contrast to measurements (Fig. 1), results derived from the LES model looked very smooth (Fig. 2). This can be attributed to the fact that the observed surface temperature after the ice edge was quite variable, while it was kept constant in the model simulations.

In general, the temporal (spatial) development of fluxes as well of air temperature was captured quite reasonably by the model simulations. A better agreement could be obtained, if the small-scale variations of the surface temperature as observed (Fig. 1, top) would also be applied to the model boundary condition.

Concerning the development of the vertical boundary layer structure, model results for virtual potential temperature are given in Fig. 3. Due to the increased surface heat flux, the boundary layer was heated by 1.4 K and the capping inversion was increased from about 500 m at the Aranda station to about 750 m at 36 km downwind the “ice-edge”. The aircraft measurements showed a temperature increase of 2 K and an inversion height of about 700 m at the end of the flight leg (Vihma and Brümmer 2002). These differences between model results and observations could be due to too strong vertical mixing near the inversion by the model.

Conclusions

An LES model has been applied to an off-ice airflow case as observed during the BASIS field experiment. The boundary layer modification was simulated by following the air mass trajectory with observed surface temperature as lower boundary condition in the model domain. Despite the well-known limitations of the LES approach for spatially varying surface conditions, the development of observed air temperature, sensible and latent heat flux and shear stress were simulated in reasonable agreement with the aircraft observations.

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