8.2 EXPLORING VARIABILITY OF MODEL RESULTS IN THE GEWEX ATMOSPHERIC BOUNDARY-LAYER STUDY (GABLS)

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1. INTRODUCTION

Within the GEWEX Atmospheric Boundary Layer Study (GABLS) intercomparisons are organized for the performance of boundary-layer schemes. Sofar this has been done by using a prescribed surface temperature in one-dimensional (column) models (see Cuxart et al, 2006; Svensson and Holtslag, 2006). It appears that the results for both the first and second GABLS study show a significant variability in the surface fluxes and atmospheric profiles, despite the relatively simple boundary condition and the forcing conditions. This is directly related to the different parameterizations of the various models (Holtslag, 2006).

In stead of prescribing the surface temperature, one may also consider to prescribe the surface heat flux. However, in particular for night time conditions over land, the surface heat flux depends strongly on the surface layer turbulence. In addition, the surface temperature and the surface heat flux are strongly related (Van de Wiel et al, 2003; Steeneveld et al, 2006a).

Thus in reality neither the surface temperature nor the surface heat flux are true external boundary conditions. Therefore in this paper we address surface feed-back by solving the surface energy balance. As such we investigate to what extent the degree of variability among the models is influenced by this. The set up of the second GABLS intercomparison case is used to study three diurnal cycles of the boundary layer over land under clear skies.

2. SET-UP INTERCOMPARISON AND MODEL DESCRIPTION

In the current study we use a state-of-the-art, first order closure model and vary the parameters in the turbulence scheme for both stable and unstable conditions in a reasonable range to mimic the apparent variability among boundary layer models. As such first model runs are performed with a prescribed surface temperature as inspired by the observations and described in the GABLS-II case description (Svensson and Holtslag, 2006). Secondly, the model runs are repeated, but then using an interactive prognostic equation for the surface temperature.

In this paper we utilize the coupled land surface-boundary layer model by Duynkerke (1991). The reference model set up has 50 logarithmically distributed layers. Compared to the reference second GABLS study, the surface boundary condition for specific humidity has been altered by introducing a constant canopy resistance of 800 s m^{-1}. Below is a brief discussion of the model assumptions. For details we refer to Duynkerke (1991) and Steeneveld et al (2006b).

a) Turbulence parameterization

The turbulent fluxes of momentum and heat are described by local diffusion for both the surface layer and the SBL. The eddy diffusivity *K* is given by (*x* = heat or momentum):

$$K_x = \frac{\ell^2}{\phi_m \phi_x}\left|\frac{\partial \vec{V}}{\partial z}\right| \qquad (1)$$

Here the length scale ℓ is given by:

$$\frac{1}{\ell} = \frac{1}{kz} + \frac{1}{\lambda_0} \qquad (2)$$

with κ = 0.4 the Von Karman constant, λ_0 the asymptotic mixing length (infinite in the reference case).

The stability functions for unstable conditions are given by:

$$\phi_x(\zeta) = \frac{kz}{X_*}\frac{\partial \overline{X}}{\partial z} = \left(1 - \gamma_x \frac{z}{L}\right)^{-1/4} \qquad (3)$$

and for stable conditions by:

$$\phi_x(\zeta) = \frac{kz}{X_*}\frac{\partial \overline{X}}{\partial z} = 1 + \beta_x \zeta\left(1 + \frac{\beta_x}{\alpha_x}\zeta\right)^{\alpha_x - 1} \qquad (4)$$

In Eqs. (3) and (4) $\zeta = z/\Lambda$ and Λ is the local Obukhov length. For the reference model we have β_m = 5, β_m = 7.8, $\alpha_m = \alpha_h$ = 0.8, γ_m = 15 and γ_h = 20.

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b) Soil and land surface scheme

In the interactive model cases the soil temperature evolution is calculated by the diffusion equation (using a grid length of 1 cm) and we calculate the heat flux through vegetation G by:

$$G - (1 - f_{veg})K^{\downarrow} = r_g\left(T_{veg} - T_{s0}\right) \qquad (5)$$

In Eq. (5) $K^{\downarrow}$ is the incoming shortwave radiation, T_{veg} represent the the vegetation surface temperature, and T_{s0} the soil temperature just below the vegetation (at z = 0 m). The latter is calculated from the soil diffusion equation. As reference values we have f_{veg} = 0.9 and r_g = 5.9 W m^{-2} K^{-1}.

Subsequently, T_{veg} is computed by solving the surface energy budget for the vegetation layer:

$$C_v \frac{\partial T_{veg}}{\partial t} = Q^* - G - H - L_v E \qquad (6)$$

Here C_v is the heat capacity of the vegetation layer per unit of area (C_v = 2000 J m^{-2} K, Van de Wiel et al., 2003), Q^* the net radiation, H the sensible heat flux and L_vE the latent heat flux. Q^* is calculated by adopting the Garratt and Brost (1981) radiation scheme.

Note that Eqs. (5) and (6) provide a rather strong coupling of the atmosphere to the vegetated land surface for the current parameter setting. This is important to have a realistic feedback.

c) Model parameter settings

Overall 16 model runs are made on basis of two reference runs for coupled and uncoupled cases and each with 7 alternative permutations in some of the parameter settings.

The parameter modifications from the reference values listed above are:

- $\alpha_m = \alpha_h$ = 0.95 (in stead of 0.8)
- $\beta_m = \beta_h$ = 3 or 4.7;
- λ_0 =15, 50, 100, 250 m
- $\lambda_0 = \eta\, u_{*,local} / N$ with η =0.8,1.3,2
- 30 and 20 layers in model set up (in stead of 50)
- $\gamma_m = \gamma_h$ = 16 (in stead of 15 and 20)
- Lapse rate above daytime PBL (various values)

Note that in all model runs the roughness length and the canopy resistance are constant and that the geo-strophic wind is taken at a reference value of 9.5 ms^{-1} (as in Svensson and Holtslag, 2006). To study the impact of wind, additional runs are made with a reduced geo-strophic wind (see below).

3. RESULTS AND DISCUSSION

The model results for all permutations made are presented for friction velocity (Figure 1), sensible heat flux (Figure 2) and boundary- layer height (Figure 3). In each figure the upper frame (a) indicates the results with the uncoupled model (using prescribed surface temperature) and in (b) the results by solving the energy budget equation. The local starting time in the model runs is 14 LT (rather than 16 LT in the GABLS2 runs), and that the duration of all runs is 59 hours (so that the axis of all the figures runs from 14 until 73 hours).

Overall the variety in the upper frames (Figures 1a, 2a, 3a) is rather similar to the variety among different models in the GABLS2 intercomparison study for the uncoupled models. (Svensson and Holtslag, 2006). Thus the range of parameters chosen and their impacts in the current model setting can be used to study the impact of coupling the boundary layer to the land surface.

In the next step, we repeat all model runs and allow for surface feed-back using Eqs. (5) and (6). The results for the coupled model runs are given in the lower frames (Figures 1b, 2b, 3b). Overall the variety is smaller in the coupled cases, in particular for the sensible heat fluxes. Note that during daytime the sensible heat flux is rather similar for all model runs and has a different magnitude than in the uncoupled case. Thus, surface feed-back is influencing the model results and is also able to compensate for some variation in the model parameter values.

The variability in the friction velocities of the first night remains during daytime in the uncoupled runs, but not so much for the coupled case. Thus with the current way of coupling the boundary-layer has a shorter memory.

It also appears that in all of the model runs, the observed friction velocity and the absolute magnitude for the sensible heat fluxes are much smaller than in the observations at night time (not shown). This is mostly related to the applied forcing by the geo-strophic wind. Note that Steeneveld et al (2006b) showed a good performance with the current model and the basic parameter setting using a smaller and time depending wind speed forcing.

Forecasted atmospheric profiles for potential temperature and wind speed magnitude after 12 hours are given in Figure 4 (valid for local night time conditions at 2 am of October 23, 1999). Similar results are found for longer forecasting times during night. However, during day time the variability among the models is typically much less.

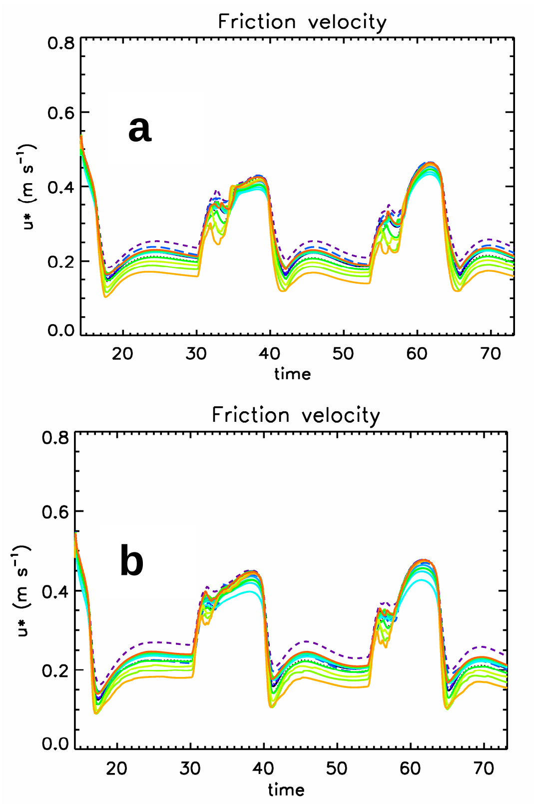

Figure 1:
Modeled variability of friction velocity for a prescribed surface temperature (a) and a coupled energy budget (b).

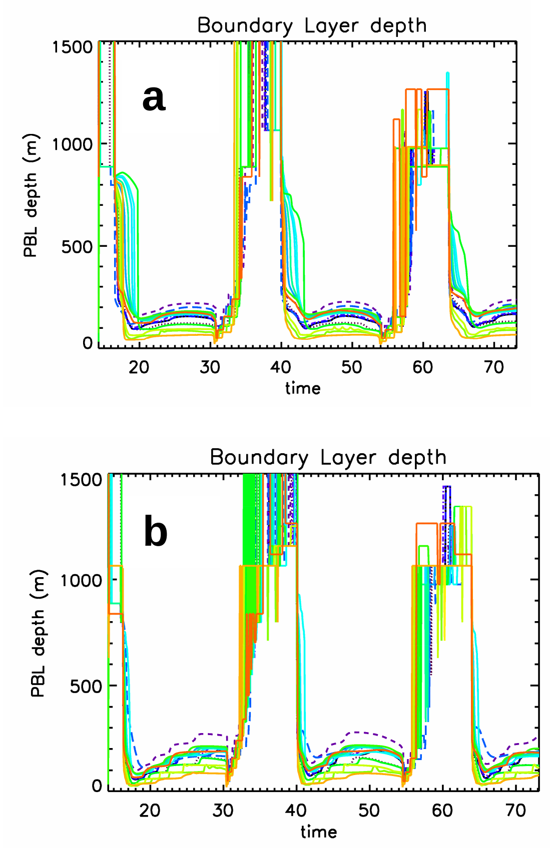

Figure 3:
As Figure 1 for boundary layer depth.

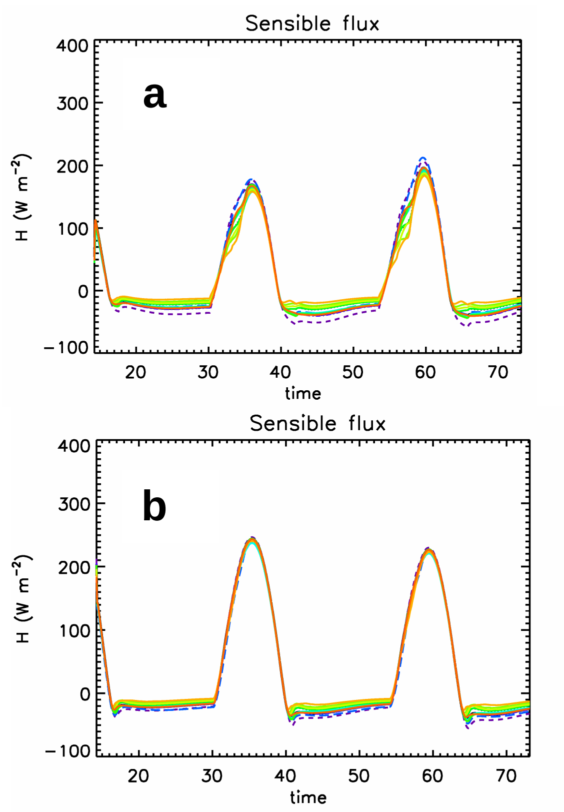

Figure 2:
As Figure 1 for the sensible heat flux.

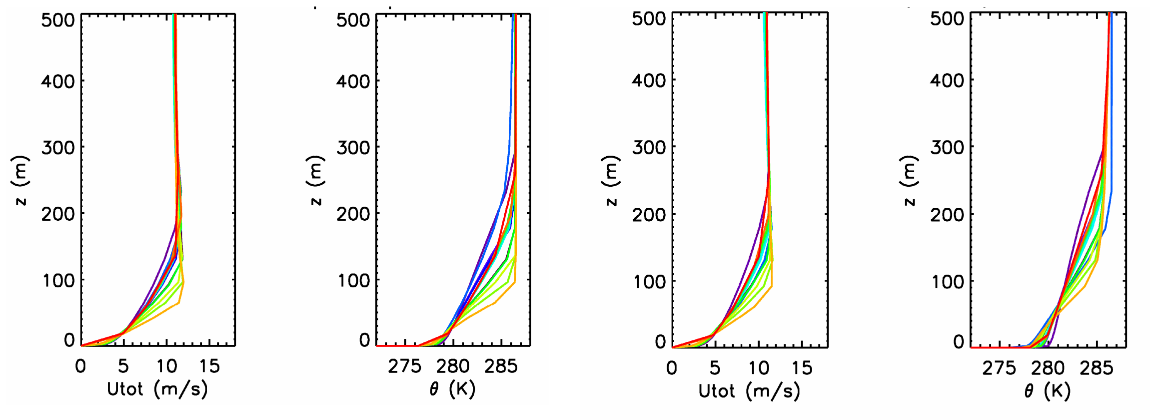

Figure 4:
The profiles of wind speed magnitude and potential temperature up to 500 meters for a 12 hour forecast. Left hand side the results for the uncoupled case and right hand side for the coupled case.

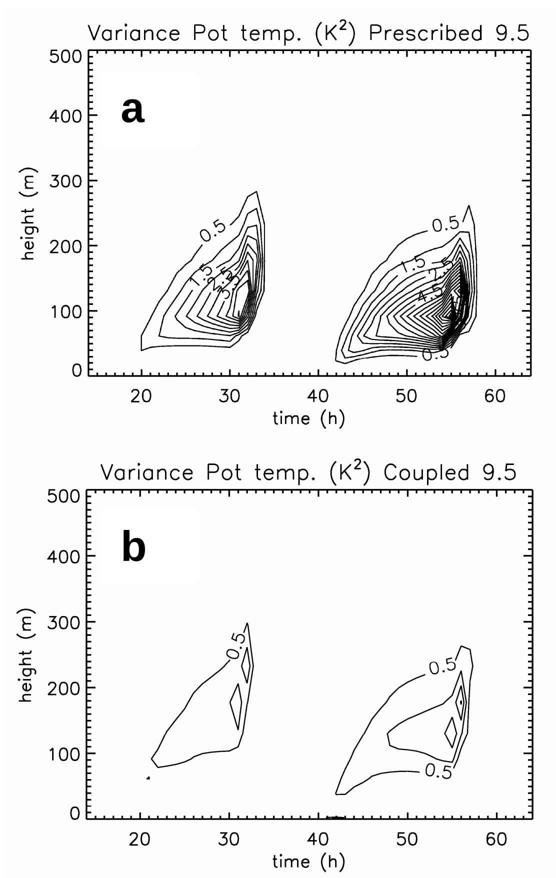

Figure 5:
Contour plot of variance of the predicted potential temperature in a prescribed (a) and coupled (b) case.

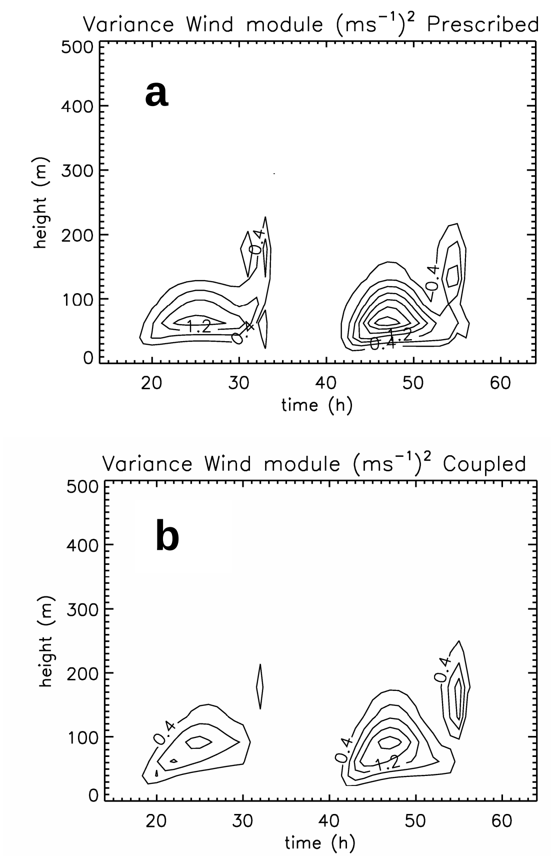

Figure 6:
As Figure 5 for wind speed magnitude.

To illustrate the variability in potential temperature and wind speed magnitude, we have calculated the mean square difference (or variance) of the various model results. Figures 5 and 6 provide the outcome. Again a distinction is made in uncoupled (upper frames) and coupled cases (lower frames). In all figures the variances are plotted for a height up to 500 meter versus the complete forecast period up to 59 hours.

It appears that the strongest variability occurs for potential temperature and wind speed in the stable boundary layer, both for the coupled and uncoupled cases. Note that the variances in the SBL occur over the same depth although with different magnitudes.

It is also clear that the variability increases with forecasting time. In the second night the maximum variance is 11.2 K^2, while in the first night this is only 4 K^2 (factor 3 smaller) for the uncoupled model runs (Fig. 5a). During day time the variance is only significant in the entrainment layer (not shown).

The variability in the model results is rather different for potential temperature and the wind speed magnitude by comparing their results for the coupled and uncoupled cases. For potential temperature the variability decreases with about a factor of 4 for the coupled case in the first night, and for the wind speed magnitude the variance decreases with 30%.

By repeating the model experiments in this paper with a lower geo-strophic wind of 4.8 ms^{-1} (50% of the reference value), we find overall similar characteristics. However, the variance is typically much smaller in the predicted profiles for potential temperature and for the wind speed magnitude (not shown).

4. CONCLUSIONS

In this paper we have studied the impact of coupling the boundary layer to the land surface on the variability in model results. It appears that most of the variability seen in the second GABLS model intercomparison case can be reproduced by taking one model and choosing suitable parameter ranges.

Overall the variety of model results is less when coupled to the land surface. Apparently surface feed back can compensate for some of the variety introduced by changing model parameters. This implies that the evaluation of boundary-layer models is less critical when coupled to the land surface and this is in particular true for the night time boundary layer over land. The implications of these findings for future evaluation studies need further thinking.

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