Why can't SBL models reproduce the near-zero heat flux at high wind speeds?

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Abstract

Many observations taken at different surfaces show that heat fluxes approach zero for high wind speeds, as the temperature gradients tend to be destroyed in such situations. However, this process is not observed in numerical models used to reproduce the nocturnal boundary layer flow.In this work, it is proposed a model that uses an alternative scheme, with an air layer at the lower boundary, with the purpose of testing whether it drives near-zero fluxes and thermal gradients under intense winds.

Introduction

Many observations taken at different surfaces show that heat fluxes approach zero for high wind speeds, as the temperature gradients tend to be destroyed in such situations. However, this process is not observed in numerical models used to reproduce the nocturnal boundary layer flow. In these models, it is usually possible to discern a maximum of the absolute heat flux at intermediate stabilities, but not the vanishing flux at the neutral limit. The main reason for such behavior is that, differently from what happens in the real world, the model atmosphere near the surface is never truly neutral, because a stable thermal gradient is always present, regardless of wind speed.

In this work, it is proposed a model that uses an alternative scheme, with an air layer at the lower boundary, with the purpose of testing whether it drives near-zero fluxes and thermal gradients under intense winds.

Model equations

The prognostics equations solved by this model are:

$$\frac{\partial u}{\partial t} = f(v - v_G) - \frac{\partial \overline{u'w'}}{\partial z}\ , \tag{1}$$

$$\frac{\partial v}{\partial t} = f(u_G - u) - \frac{\partial \overline{v'w'}}{\partial z}\ , \tag{2}$$

$$\frac{\partial \theta}{\partial t} = -\frac{\partial \overline{w'\theta'}}{\partial z}\ , \tag{3}$$

$$\frac{\partial e}{\partial t} = S_S u_*^2 + \frac{g}{\Theta}\overline{w'\theta'} + \frac{\partial}{\partial z}\left[\frac{K_E \partial e}{\sigma_E \partial z}\right] - c_\varepsilon \frac{u_*^3}{l_m}\ . \tag{4}$$

$$\frac{\partial \overline{w'\theta'}}{\partial t} = -\overline{w'^2}\frac{\partial \theta}{\partial z} + (1 - c_2)\overline{\theta'^2}\frac{g}{\Theta} - c_1 \frac{u_*}{l_m}(\overline{w'\theta'})\ . \tag{5}$$

$$\frac{\partial \overline{\theta'^2}}{\partial t} = -2\overline{w'\theta'}\frac{\partial \theta}{\partial z} - C_{\theta'^2}\frac{u_*}{l_m}\overline{\theta'^2}\ . \tag{6}$$

The stable boundary layer (SBL) is limited by its top $h = 50$ m and the ground surface ($z = 0$), which in this model is replaced by a layer of air. Between these two limits, we consider 5 levels with the first one fixed at $z = 5m$ and the others fixed at $z = 10$ m, $z = 20$ m, $z = 30$ m and $z = 40$ m. The prognostic equations for the wind components and potential temperature are calculated at these levels. Given that such evaluation demands estimating the turbulent flux divergences, variables TKE, heat flux and potencial temperature variance are evaluated at intermediate levels zi between the main levels z. Boundary conditions $u(t,h) = u_G$, $v(t,h) = v_G$, $\theta(t,h) = \Theta$, where $\Theta = 300K$; $u(0,z_j) = u(0,z_{j-1}) + (u_G - u(0,z_0))/5$ and $v(0,z) = v_G = 0$, where $u(o,z_0) = 0.1m/s$; $\bar{e}(0,zi) = 0.005m^2/s^2$

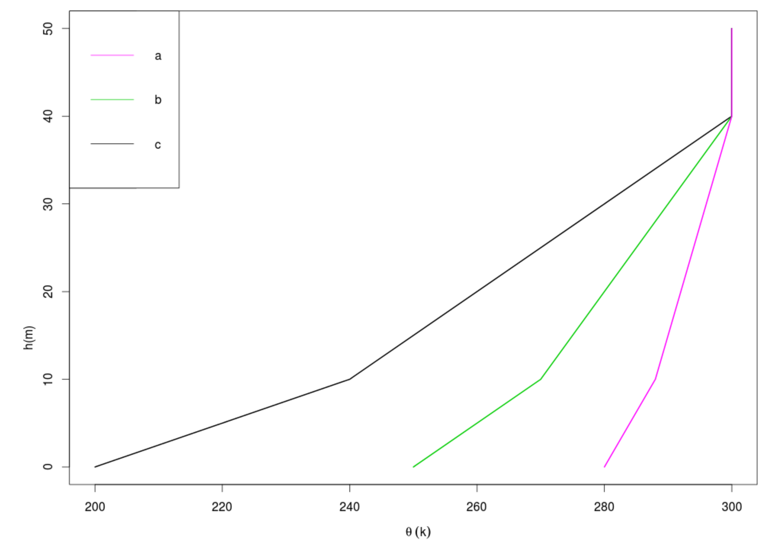

Figure 1 : This figure shows the initial potencial temperature profiles (a, b and c) used in the simulations.

Results

In all cases, VTKE stays at its minimum value for mean wind speeds lower than a vertically dependent threshold. Once the threshold is reached, a linear relationship between VTKE and the mean wind speed occurs. Such a behavior is qualitatively similar to the hockey stick patern observed by Sun et al.(2012). Models such as those proposed by Costa et al. (2011) and by Maroneze (2016) also presented this qualitative correspondence with the hockey stick theory.

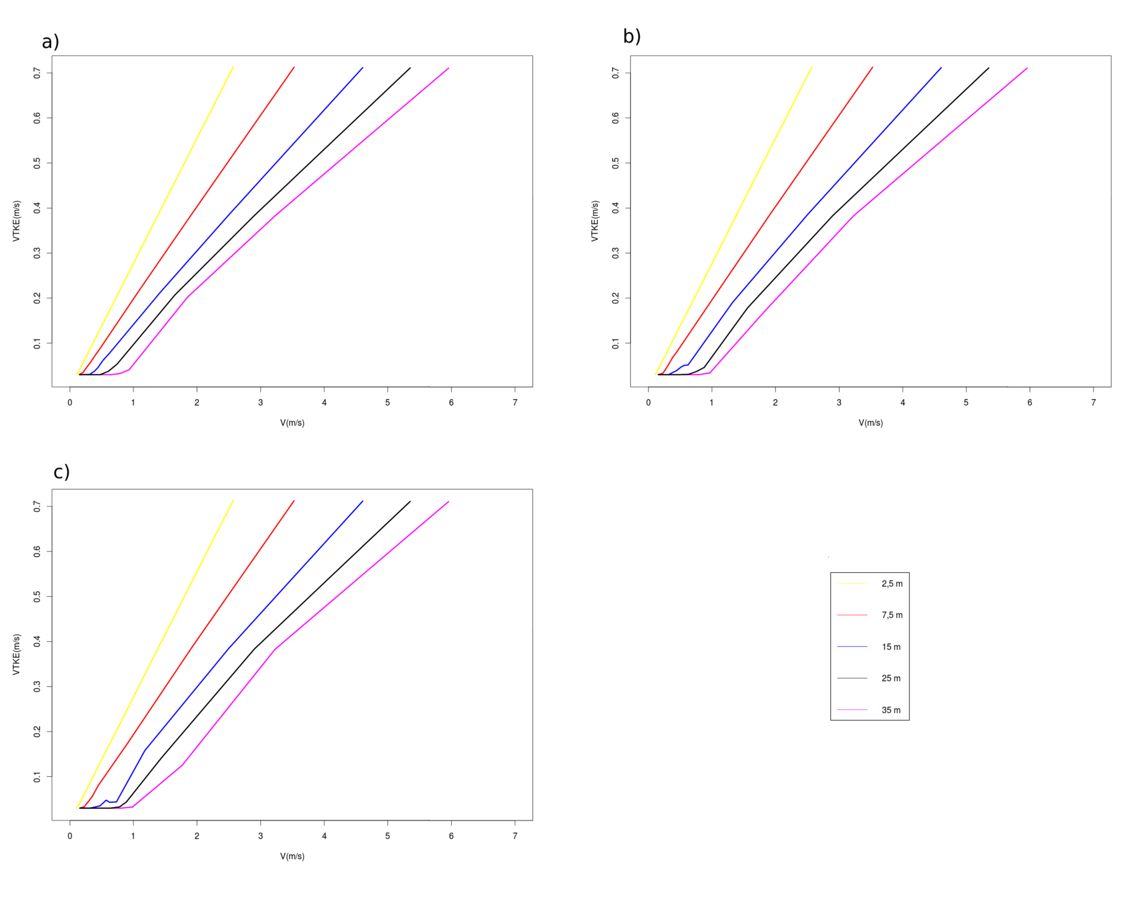

Figure 2 : This figure show the relationship between VTKE and mean wind speed simulated using the model that use a alternative scheme for all initial thermal profiles connsidered (a, b and c).

The heat flux tends to zero under intense winds, following observations in that regard (figure 3). In initial conditions b and c, the model produces a maximum of absolute heat flux under intermediate values of mean wind speed, therefore determining two distinct regimes, one with heat fluxes increasing with wind speed and another where the flux decreases with wind speed. In case a, when the initial thermal gradient is extremely large, this distinction is not apparent, as the absolute heat flux decreases monotonically with wind speed.

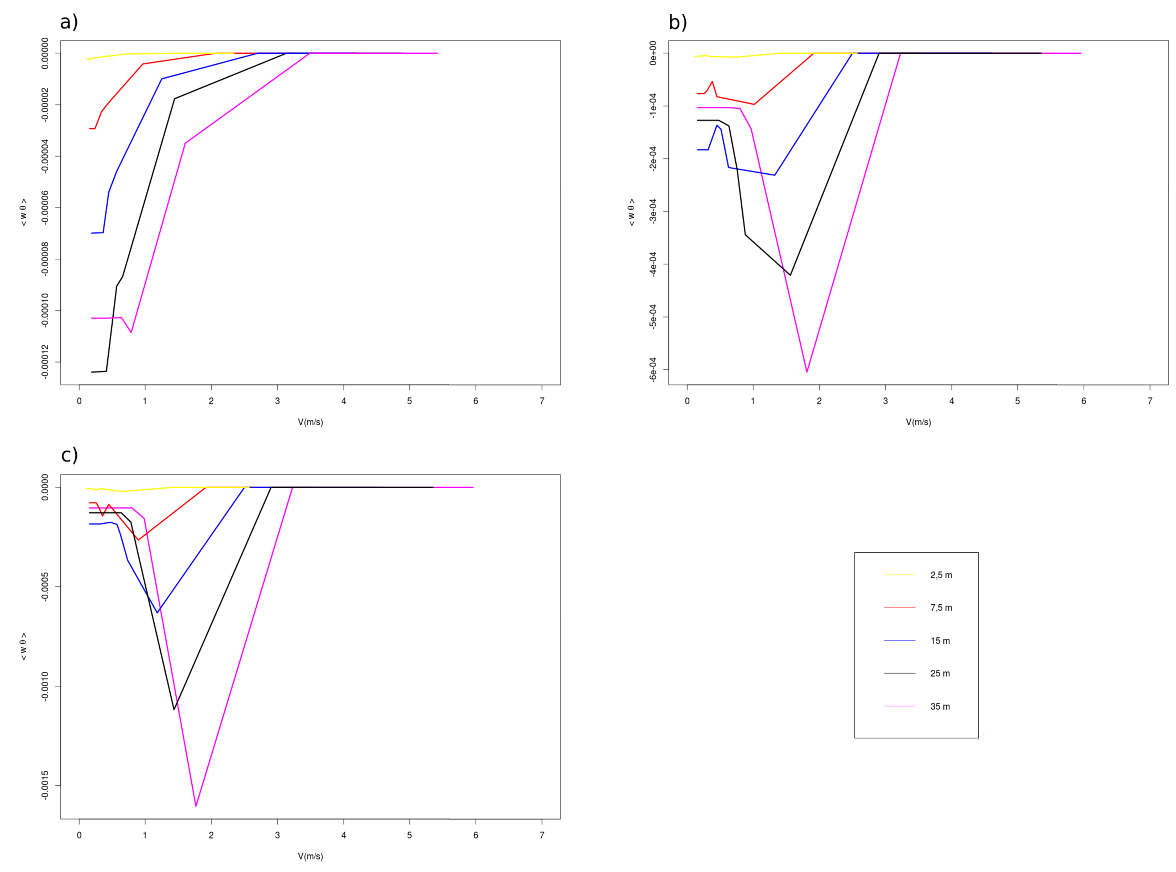

Figure 3 : This figure show the relationship between heat flux and mean wind speed simulated using the model that use a alternative scheme for all initial thermal profiles connsidered (a, b and c).

The thermal gradient destruction under intense winds can be seen in figure 5. In all cases, under very intense winds the thermal gradient is totaly destroyed, but the wind speed necessary to cause it differed among the intial thermal profiles considered. It is also interesting to notice that the model indicates the occurence of shallow mixing for wind speeds not intense enough to totaly destroy the thermal gradients.

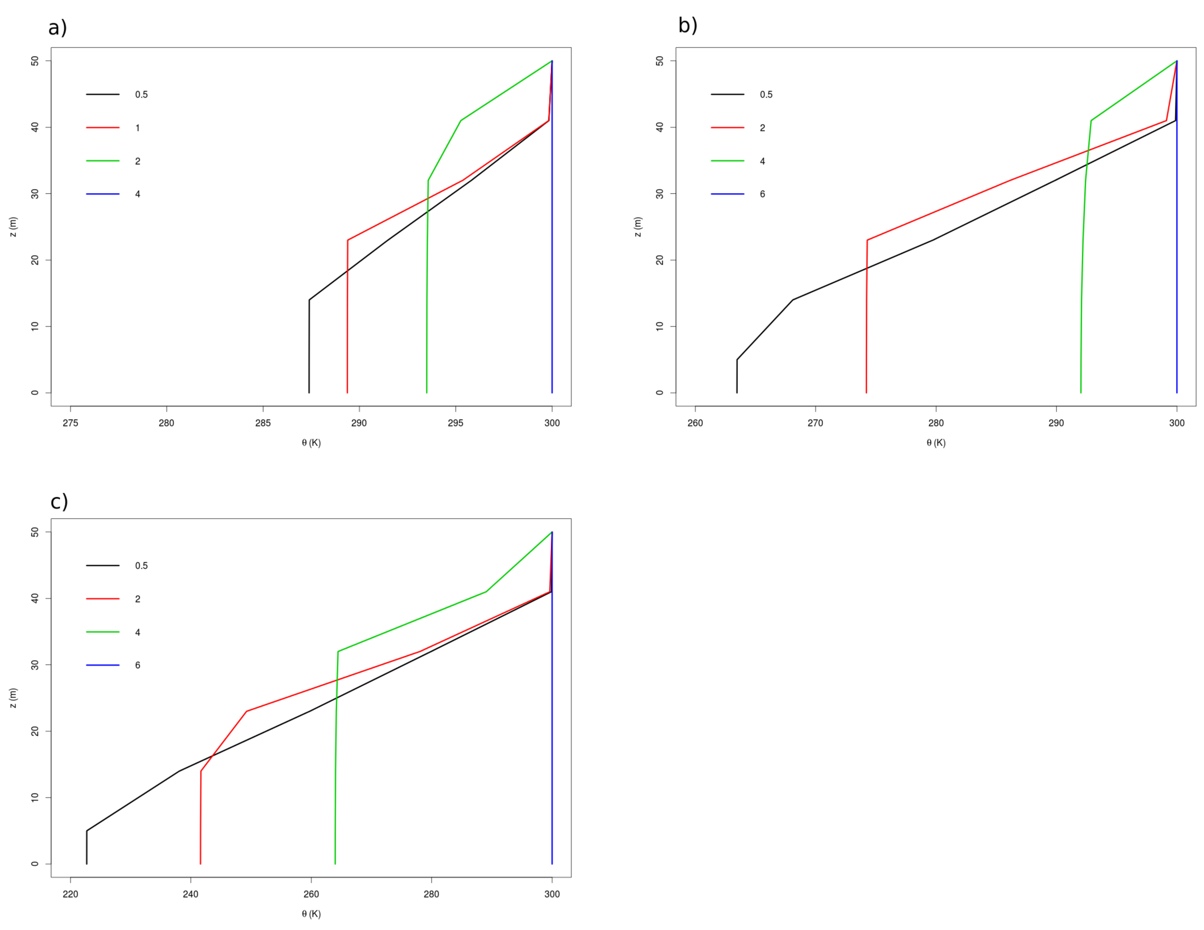

Figure 4 : This figure show the mean vertical profile potencial temperature in the last two hours of the simulation for all initial thermal profiles connsidered (a, b and c).

Final considerations

The results of the present study suggest that the inability of schemes commonly used to simulate the interaction between the surface and the lower atmosphere to totally destroy the thermal gradient is related to the way the soil and surface properties are parameterized. It is shown that the use of an alternative scheme usinga layer of air as lower boundary condition, fluxes and thermal gradients tend to zero under intense winds. Furthermore, the relationship between turbulence and wind speed in such idealized scheme reproduces the double-regime behavior observed by Sun et al. (2012).

The conditions presented here are highly idealized, with exceedingly large thermal gradients and, nevertheless, the magnitude of the simulated fluxes is small. Therefore, the study must be seen as an exercise with the purpose of understanding what is necessary to remove the model thermal gradients under intense winds. The development of a scheme that is able to do that under realistic conditions is a task for future work.

References

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