Are winds in cities always slower than in the countryside? Modelling the Urban Wind Island Effect

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Introduction

Though the Urban Heat Island has been extensively studied, relatively little is known about **urban** – **rural** wind differences. We investigate the contrast in wind behaviour between the urban and the rural environment, using a straightforward mixed-layer bulk model (Tennekes & Driedonks, 1981; Byun & Arya, 1986; Theeuwes et al., 2015), to identify differences in wind under equal geostrophic forcing, and to find situations where **urban** winds are surprisingly higher than **rural** winds: the **Wind Island Effect (WIE)**.

Model Configuration

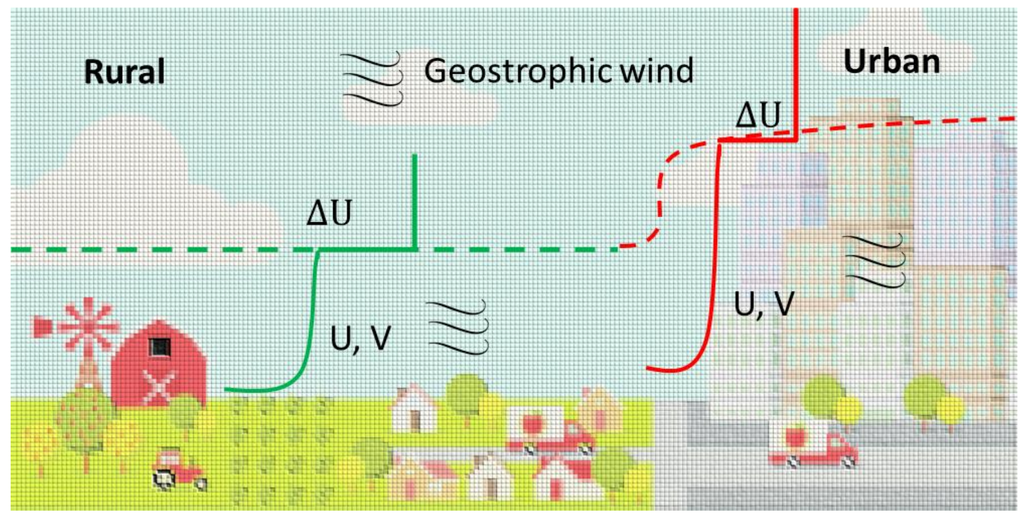

Figure 1. Conceptual outline of the Mixed Layer Model, following Theeuwes et al. (2015). The model contains an uncoupled urban and a rural column, with the same large-scale forcing, but different surface surface properties (initial profiles of U, V, boundary-layer depth, surface roughness).

We use a conceptual mixed-layer slab model coupled to a land-surface model (**Figure 1**). The used mixed layer equations are:

$$\frac{dU}{dt} = f(V - Vgeo) + \frac{1}{h}(\overline{uw_s} - \overline{uw_h})$$

$$\frac{dV}{dt} = -f(U - Ugeo) + \frac{1}{h}(\overline{vw_s} - \overline{vw_h})$$

$$\frac{d\Delta U}{dt} = w_e * \gamma_u - \frac{1}{h}(\overline{uw_s} - \overline{uw_h}) + f\Delta U$$

$$\frac{d\Delta V}{dt} = w_e * \gamma_v - \frac{1}{h}(\overline{vw_s} - \overline{vw_h}) - f\Delta V$$

$$w_e = \frac{dh}{dt} = \frac{T_0 V_*^3 (C_F - C_D \frac{hN}{V_*})}{g\Delta\theta h + C_T T_0 V_*^2}$$

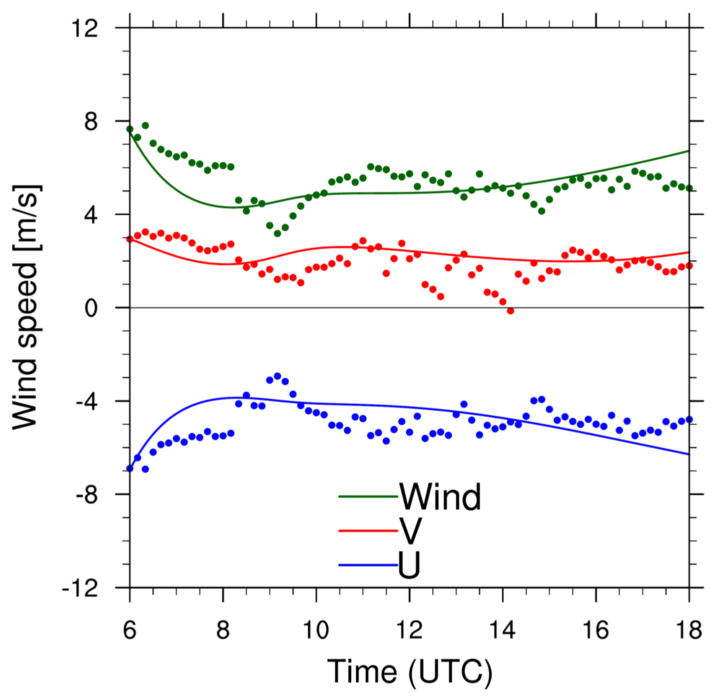

Figure 2. Validation of model wind (U and V) against Cabauw tower observations (markers) of May 4, 2008

The model code is first validated against observations taken at the Cabauw research tower in the Netherlands, for a clear day with moderate winds **(Figure 2)**. The model follows the observed wind speeds well, though the model seems to create too much friction at the start of the simulation. While small-scale fluctuations of the wind cannot realistically be solved by this bulk model, this model was designed to research mean wind behaviour, which it does satisfyingly.

Results

Next, we study the differences in wind behaviour a case during the 2002 BUBBLE urban campaign (Rotach et al., 2005). By varying **urban** surface cover we investigate the sensitivity of the model to the initial values of U, V, boundary-layer depth, to find the optimal conditions for a **WIE** to occur.

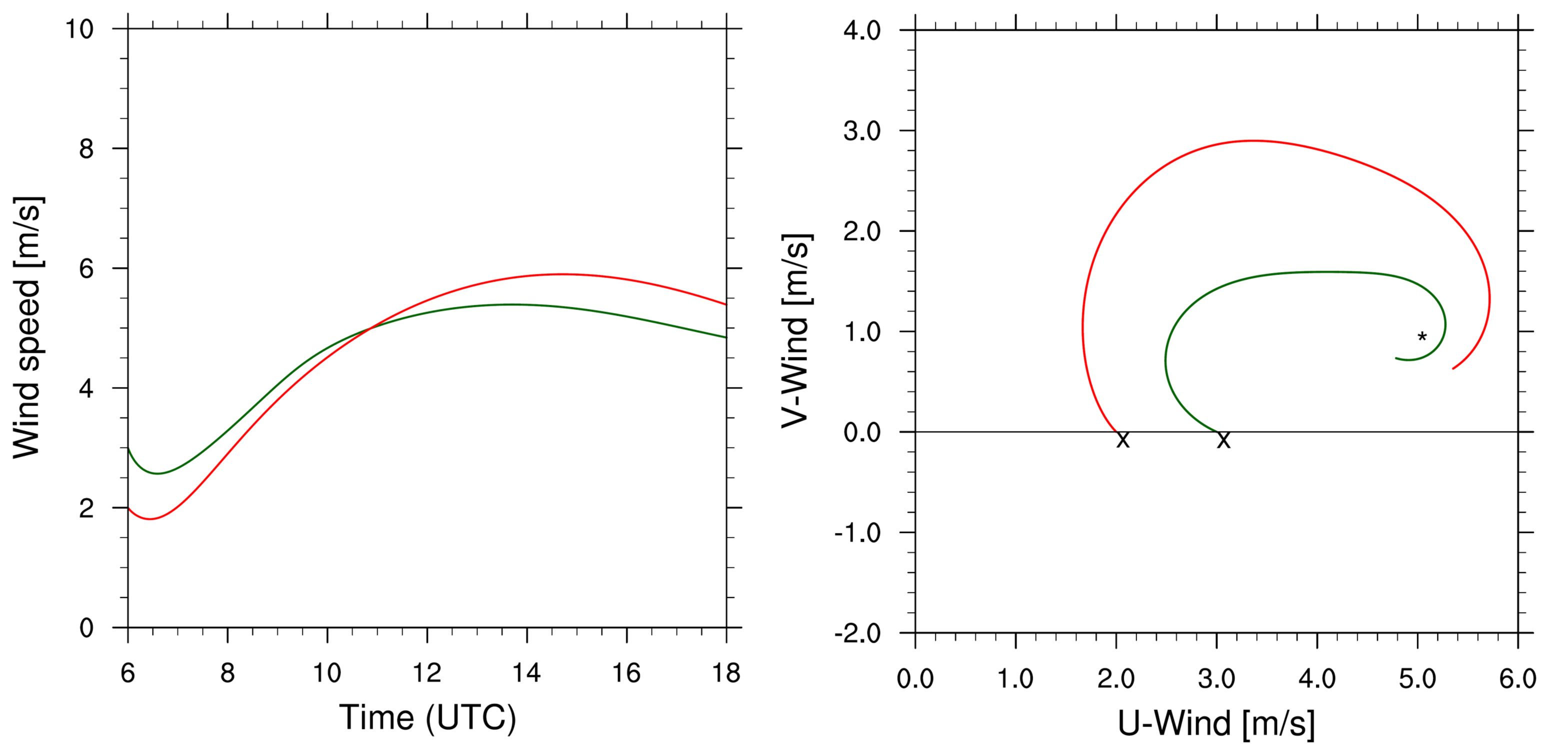

Figure 3. Plots of the urban and rural wind speed.
X's in the hodograph plot mark the initial values; the asterisk marks the geostrophic equilibrium.

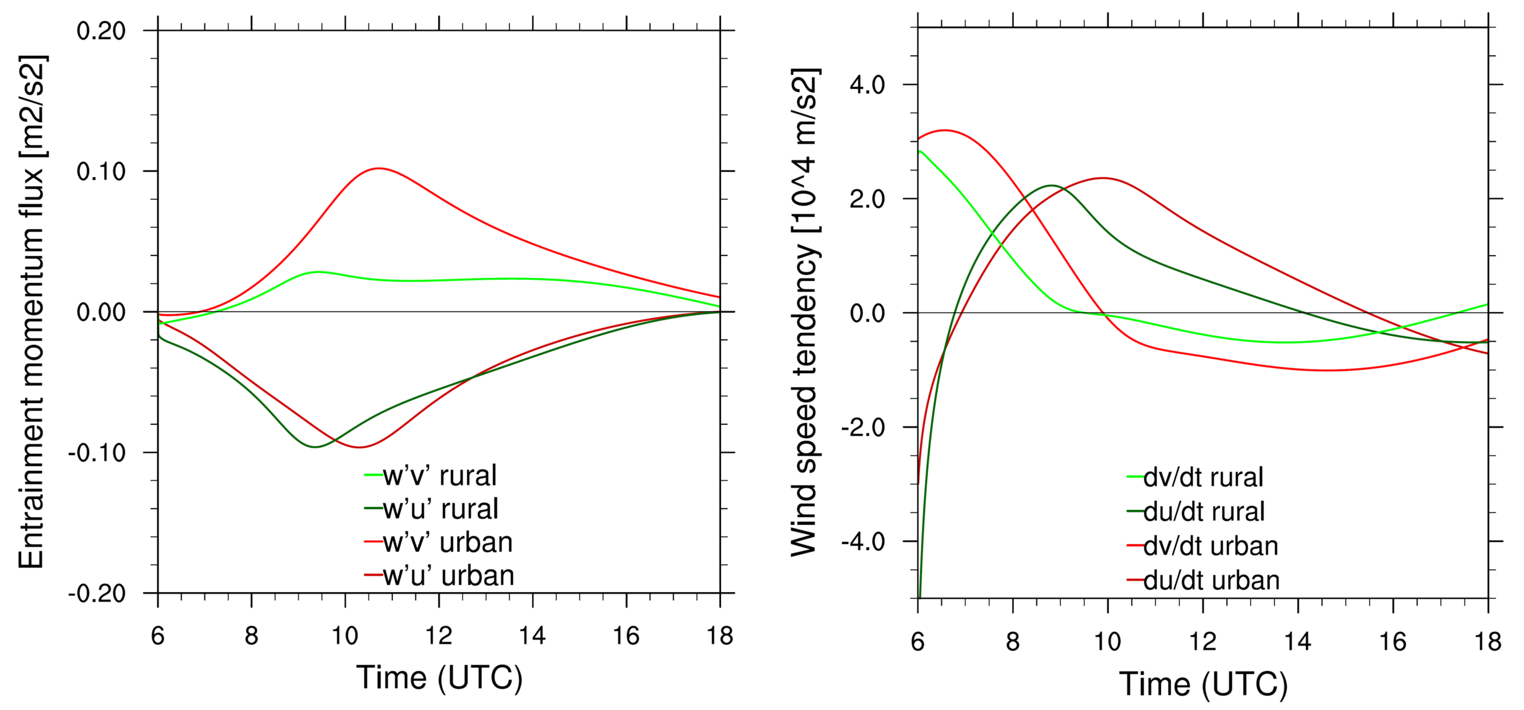

Figure 4. Time evolution of the urban and rural entrainment momentum fluxes (L) and wind speed budget terms (R).

Figure 3 shows the mean wind for the **urban** and **rural** part of the model, for initial ABL depth of 400 m (**urban**) and 100 m (**rural**). The wind in both columns experience an internal oscillation, as is also documented by Byun & Arya (1986). Though the **rural** wind starts at a higher value, the **urban** wind quickly increases in speed and passes the **rural** wind: a **WIE** of ~0.6 ms^{-1}. The higher acceleration of the **urban** wind speed is caused by the entrainment of faster geostrophic wind into the boundary layer (**Figure 4**).

Conclusions

- **Under certain conditions urban wind can be higher than the rural wind: an urban Wind Island Effect (WIE)**
- **Whether a WIE occurs is highlly dependent on the boundary layer depth, initial wind profile, and the geostrophic wind**
- **Higher urban ABL depths combined with low rural ABL depths are the most favourable for a significant WIE to occur**

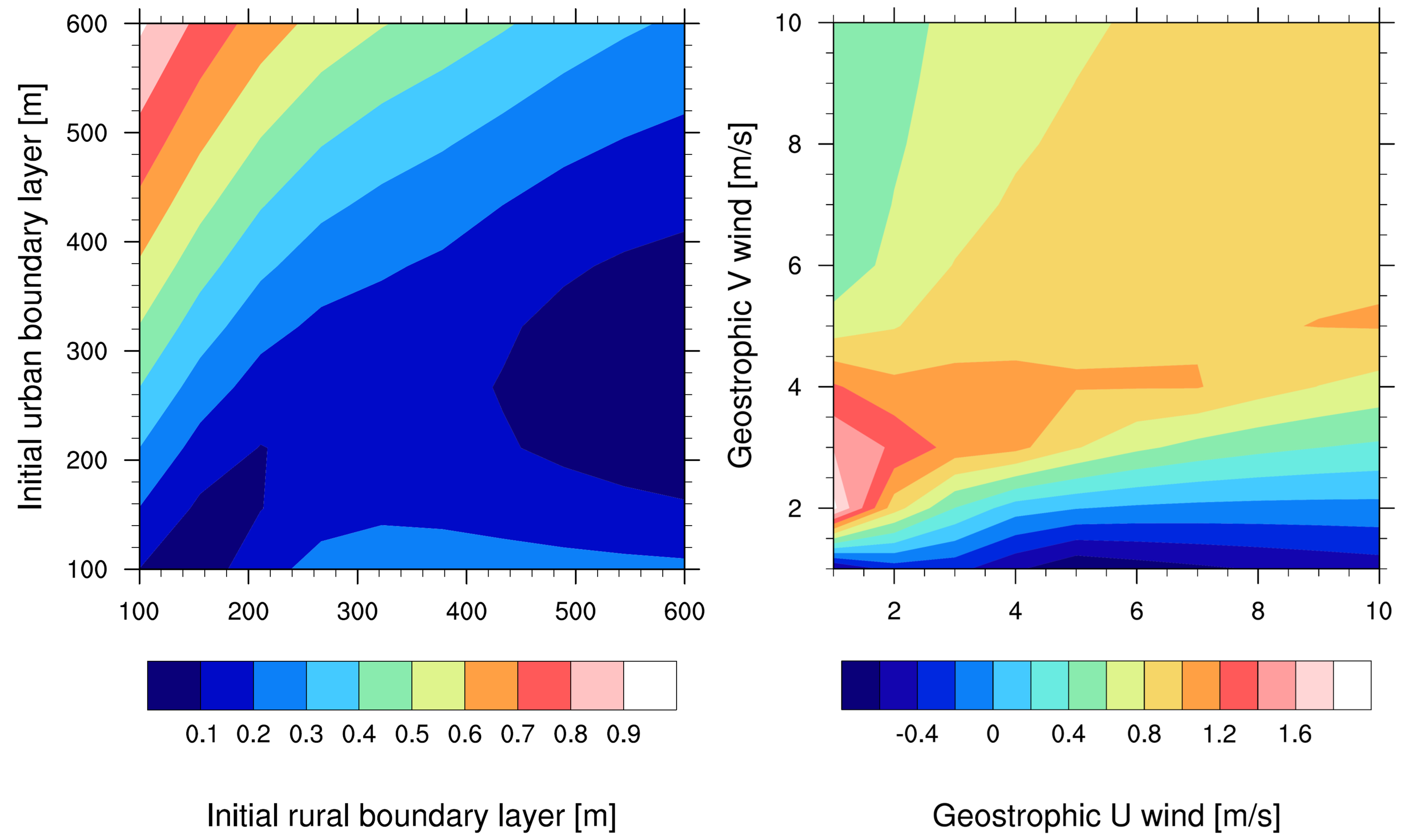

Figure 5. Sensitivity of the maximum WIE [m/s] to initial boundary layer depths (L) and geostrophic wind speed (R). Other initial profiles are equal to those of Figure 2.

Figure 5 shows the sensitivity of the maximum **WIE** to the initial boundary-layer depth, and the geostrophic wind speed. Higher **urban**, with lower **rural** boundary layers, and moderate geostrophic wind speeds are most favourable for the **WIE** to occur.

References

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