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Roughness length and displacement height dependent on stability: single-column experiments

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Roughness length and displacement height

The so-called roughness length (z_0) and displacement height (d_0) are parameters characterizing the drag exerted on a turbulent flow over a rough surface. Increasing roughness implies a stronger drag, and increasing values of z_0 and d_0. For a given static stability, increasing z_0 implies a reduced wind shear, while increasing d_0 is associated with an upward shift of the velocity-profile. Both effects act to reduce the velocity at a given height above the surface.

Zilitinkevich et al. (2008), hereafter Z08, demonstrate that z_0 and d_0 both depend on the stability of the flow. Stable (unstable) stratification reduces (increases) z_0 and increases (decreases) d_0 relative their neutral values, by hindering (facilitating) the penetration of eddies into the layer between the roughness elements.

Experiments

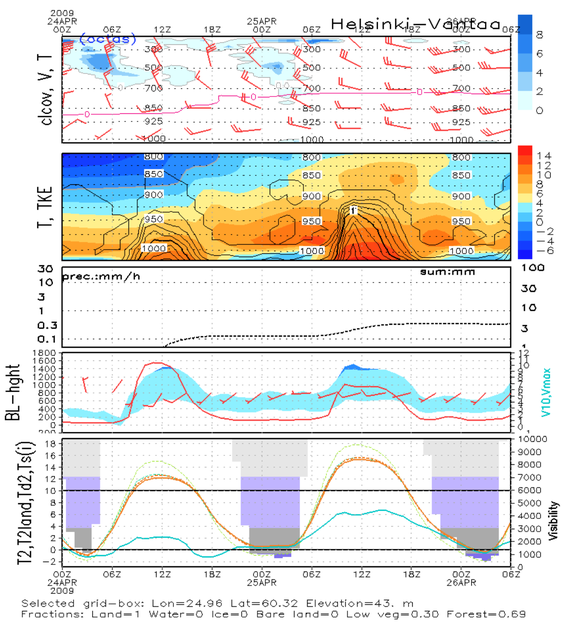
At present, the aerodynamic parameters in HIRLAM do not depend on stability, and d_0 is actually ignored, except for in the new forest scheme, where it appears in the diagnostic 10-m wind speed, but does not influence the surface drag in any way. The two main questions addressed in this study are thus:

1. Impact of introducing d_0 (Exp. Z00)

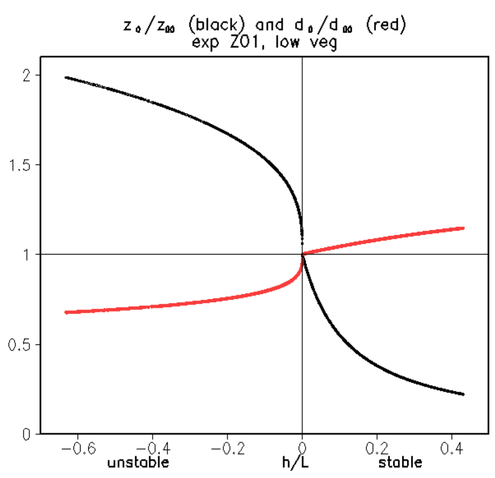
2. Impact of allowing z_0 and d_0 to depend on stability (Exp. Z01)

The "o1d" single column HIRLAM distribution, containing surface schemes of the "newsnow" branch, was used in the study. The displacement height was introduced simply by replacing the height of the lowest model level, h_N by h_N-d_0 in the definition of the drag-coefficients in routine phys/surcof_land.F, and in the diagnostic 10 m wind speed in routine phys/surdia.F. The stability-dependence of z_0 and d_0 was implemented as described in Z08, and the value of d_0 in neutral stratification, d_{00}, was , still following Z08, defined in terms of the neutral roughness length: $d_{00}= 20z_{00}$.

A family of model runs were performed for scenes of snow-free low vegetation and forest without any orographic effects. The runs were initialized by a HIRLAM reference forecast for Helsinki airport, valid on 12 UTC of the 25th of April 2009.

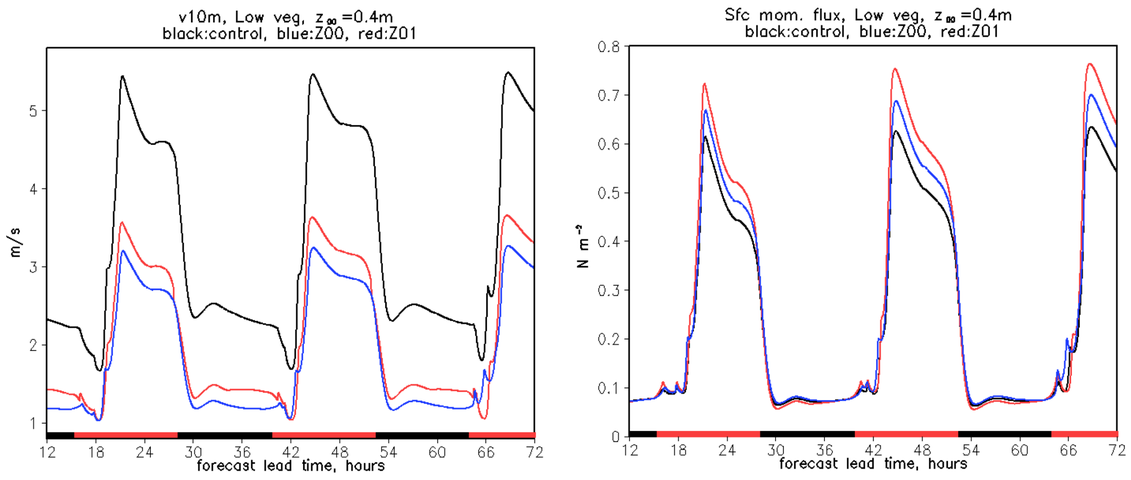


HIRLAM reference forecast providing the initial conditions for the single-column experiments. The meteorological situation was dominated by an almost stationary ridge associated with moderate westerly flow and fine weather with a pronounced diurnal cycle.



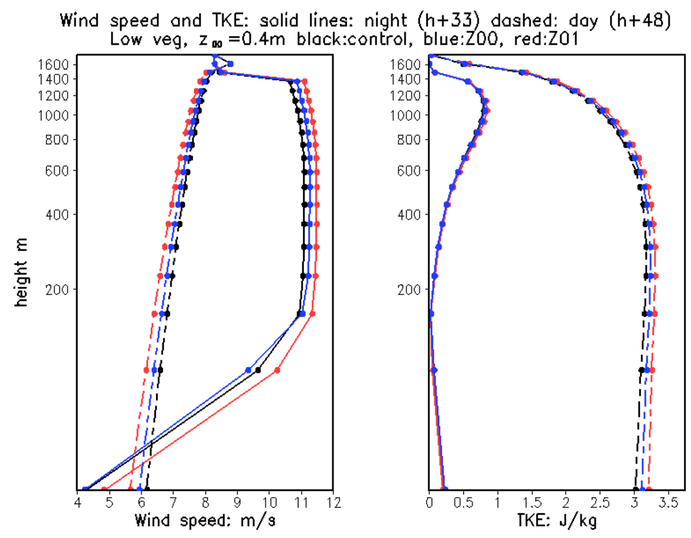
Dependence of the aerodynamic parameters on stability, expressed as the ratio of vegetation height to Obukhov length (h/L). Data from hours 12-72 of exp. Z01 over low vegetation. Z_{00}=0.4 m d_{00}=8 m. The difference in temperature between surface and lowest model level ranges from -3.5 to 4.5 K.

Results



Wind speed (left) and surface momentum flux (right) in three experiments. Red (black) colour at the x-axis indicates unstable (stable) stratification.

Introducing a displacement height (exp. Z00) drastically reduces the wind speed at 10 m above ground and increases the day time surface drag. In comparison, the dependence on stratification (exp. Z01) is less important for the 10 m wind speed, and counteracts the impact of the displacement height. For the surface drag, by contrast, accounting for stratification is as important as introducing d_0. Similar effects prevail over forest (not shown). The influence of the displacement height rapidly diminishes with decreasing roughness, and is hardly visible at z_{00}-values in the centimetre-range, although an effect of the variable stratification can still be discerned.



Vertical profiles of wind speed and turbulent kinetic energy at hours h+33 (night time, solid lines) and h+48 (day time, dashed lines). The lowest model level is at 30 m.

In the mixed layer, accounting for stratification is as least as important than just introducing a displacement height. In day time a reduction in wind speed and an increase in turbulent kinetic energy can be seen throughout the mixed layer. Consistently, the nocturnal maximum in the upper boundary layer is stronger in the modified experiments than in the control.

Conclusions

- Introducing a displacement height has a large impact. It should be noted, that the neutral roughness length of 0.4 m for "low vegetation" is large compared to values typically quoted in the literature, although typical in HIRLAM. Could it be, that large values of the roughness length are used in the model to compensate for a missing displacement height?
- A positive bias in the 10-m wind speed compared to SYNOP-observations, especially at night, is a long-standing systematic error in HIRLAM forecasts. Introducing a displacement height would seem to help, but such a change should probably be accompanied by an adjustment of the roughness-values in order to moderate the impact.

Reference

Zilitinkevich, S., I. Mammarella, A. Baklanov, and S. Joffre, 2008: The effect of stratification on the aerodynamic roughness length and displacement height. *Boundary-Layer Meteorology*, **129**, 179-190.

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