SURFACE ROUGHNESS AND LOCAL WINDS

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Abstract: By numerically simulating atmospheric flow, the impact of surface friction on winds that are canalized by a mountain is investigated. The simulations show that in the case of wind that is accelerated by orography, surface friction has a significantly stronger wind-breaking effect than if mountains have not accelerated the wind. These results are particularly encouraging for plans to change the local wind climate in Iceland by massive growing of trees.

***Keywords** – surface roughness, corner wind, surface friction, idealized flow, local winds*

1. INTRODUCTION

Strong and persistent winds are an important factor in the climate of many mountainous regions. These winds affect the lives of people in a multitude of ways: The environment may be improved locally by winds that provide fresh air in areas where air pollution is a problem. The winds may also have a negative impact through soil erosion or by hampering the growing of trees or other agricultural products. In some regions windstorms regularly cause damages on structures and lead to costly building standards. The wind has also a chilling effect on people and animals and this is by most humans considered to reduce the quality of life in temperate and cold climates.

In this paper, the impact of friction at the surface of the earth on local orographic winds is examined and compared to the impact friction has on winds over flat land. The numerical simulations used for this purpose are described and their results presented. The physical background for the response of the wind to surface friction is discussed and the paper concludes with a remark on the relevance of the results for planting of trees to reduce the wind.

2. NUMERICAL SIMULATIONS

The airflow around an elliptic mountain has been simulated numerically to investigate the impact of surface friction on a corner wind originating at the edge of an elongated mountain. The primitive equations that govern atmospheric flow are solved with the help of a numerical model MM5 (Grell et al. 1995) and the effect of surface friction is parameterized according to Hong and Pan (1996). In the simulations the surface friction is varied by changing the roughness length z_o from 0.001 m to 1 m, corresponding to the roughness range from flat and bare ground or water up to the roughness of pine forest (Wieringa, 1993).

At the lower boundary, there is either a 3000 m high Gaussian shape mountain ridge with an aspect ratio $L_y / L_x = 24$ km / 8 km = 4 or flat ground. The entire simulation domain is 180 km x 180 km with 40 terrain-following sigma levels in the vertical. The horizontal resolution is 3 km. The initial atmosphere and the boundary conditions feature constant stability N= 0.01 s^{-1}. The initial wind speed and the wind speed at the boundaries are 15 ms^{-1} in simulations with the mountain, but 25 ms^{-1} in the simulations with flat ground. The flow speed is compared after 3 hours of simulation, corresponding to 20.3 non-dimensional time units (t*=Ut/Lx) for the simulations with a mountain. At that time the flow is sufficiently stationary for comparison between simulations of different roughness.

In the simulations with the mountain, the non-dimensional mountain height or the inverse Froude number Nh/U is 2.0 and the Rossby number U/fL_x is 15.6. For these values of the governing non-dimensional numbers, the low-level flow should be expected to be blocked and diverted around the mountain edges, slightly more to the left than to the right. Downstream of the mountain there should be a wake with relatively little wind and vortices with areas of return flow (u<0).

3. RESULTS

The surface flow past the mountain is shown in Fig. 1. On the upstream side, the airflow is blocked and slow, while on both sides of the mountain where the low-level flow escapes the upstream blocking there is significant speed-up of the flow. As expected, the deflection of the upstream flow is to a slightly greater extent directed to the left than to the right, but the differences in wind speed between the two sides of the mountain are small. Immediately downwind of the mountain crest there is a local wind maximum which is associated with the mountain waves that are active even though the upstream flow is blocked. Strong mountain waves are basically above the mountain and the associated strong surface winds do not extend far downstream. Instead, there is a large wake with slow reversed flow. On each side of the wake the corner winds extend far away from the mountain, and in fact their downstream extension appears only to be limited by the boundary of the simulation domain. The maximum wind speeds at 10 m above the ground in the left corner wind (facing downstream) are given in Fig. 2 that presents the key result of this study. The figure shows the maximum simulated wind for different values of the surface roughness. As expected, the surface wind speed is reduced as surface roughness is increased. The wind speed decreases not far from linearly with log (z_o) in the case of a corner wind as well as over flat land, but the slope of the corner wind curve is greater. For z_o=1 m the wind speed is almost the same in both cases, while for z_o=0.001 m the corner wind is more than 20% stronger than the wind over flat land.

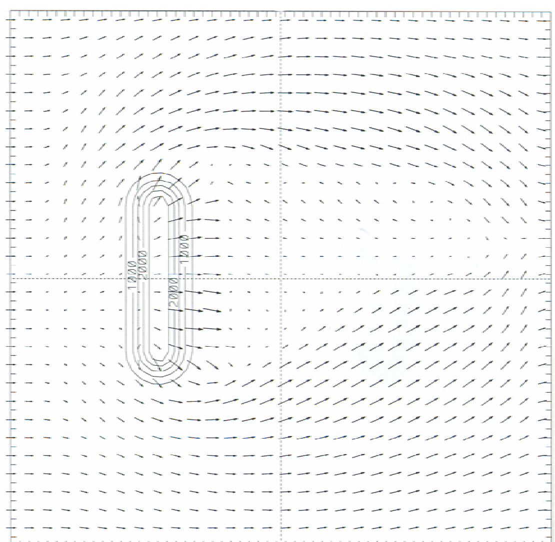

Figure 1. Surface flow in a numerical simulation with z_o = 0.001 m

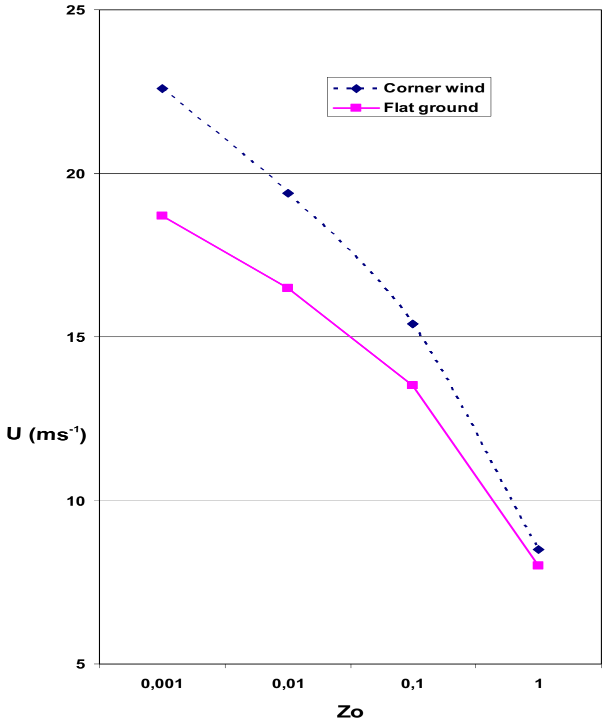

Figure 2. Maximum wind speeds at 10 m above the ground in simulations of a corner wind and flow on flat ground for different values of surface roughness.

4. DISCUSSION AND CONCLUSIONS

A plausible explanation for the different response of the wind to increased surface roughness could be related to different vertical profiles of the wind. Over flat land there is a regular increase in wind speed with altitude, while the corner winds have a maximum at low levels and a reverse vertical shear close to mountain top level as illustrated in Fig. 3. Increased surface roughness leads to more vertical mixing of horizontal momentum through the whole boundary layer. In the case of a corner wind, both upward as well as downward mixing of horizontal momentum reduces the jet, while over flat land only downward mixing of the momentum leads to lower wind speeds at the level where the corner wind is strongest. Other factors may also be of importance; over flat land, the wind above the surface layer is close to geostrophic, while in the corner wind there is no such balance of forces. If a corner wind that is basically driven by a high pressure anomaly on the upstream side of the mountain is by some means stopped in the lee of the mountain, there is no reason for it to start up again. On the other hand, the wind over flat land is driven by a large scale pressure gradient, to which it tends to adjust. The upstream pressure anomaly is also known to be sensitive to surface friction (Ólafsson and Bougeault, 1997, fig.7). On rough surface, the pressure anomaly is much less than on a free-slip surface, suggesting that the roughness on the upstream side of the mountain may be important for the strength of the corner winds. Increased roughness on the upstream side may however act both ways, since for situations close to blocking it could help block the flow, that would otherwise not be blocked and consequently, the corner wind would become stronger than if the flow was not blocked.

5. CONCLUSION

The results of the experiments indicate that an increase in surface roughness may have a greater decelerating effect on the surface winds if the winds have been accelerated at the edge of a mountain, than if the winds have not been influenced by mountains. Enthusiastic forest growers may find this encouraging and worth further investigation.

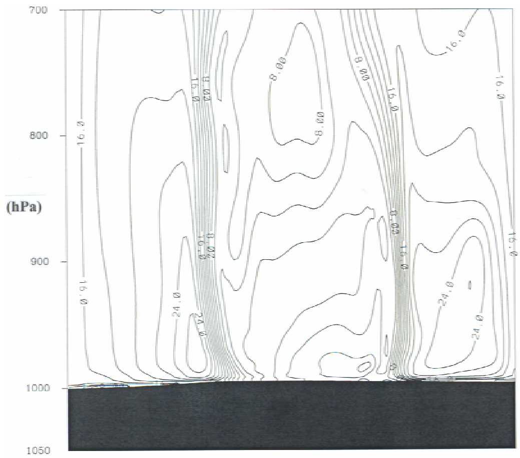

Figure 3. Wind speed (ms^{-1}) in a cross section along the dashed vertical line in Fig. 2. The flow is out of the page.

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