Large-eddy Simulations of Stable Boundary Layers in Complex Terrain

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The topic of this research focused on the dynamics of simple slope flows (Skyllingstad, 2003) and their representation in mesoscale models (Skyllingstad et al. 2003). Slope flows have some of the characteristics of decoupled flows that are the subject of this proposal. For example, they have an elevated jet structure with turbulence forced by strong shear above the jet. However, unlike the flows that are of interest in this proposal, slope flows are usually fully turbulent and are characterized by weakly stable conditions. As an example, we present a plot of the downslope velocity produced by the LES model (Figure 1). Above the jet, turbulent eddies are produced in the weakly stratified, sheared flow. These appear as small-scale variations in the downslope velocity.

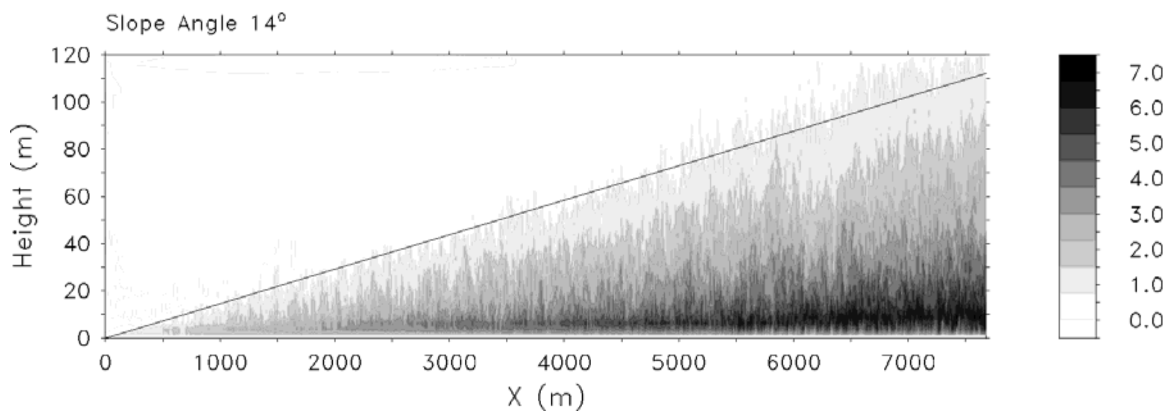

Figure 1. Downslope velocity as a function of distance from the top of the slope as simulated by the LES model for a 14^o slope with 30 W m^{-2} surface cooling. Also shown is the predicted slope depth from a bulk layer model.

In our first VTMX study, slope flow experiments were conducting using both LES and the Advanced Regional Prediction System (ARPS) mesoscale model, using nearly identical forcing and slope characteristics. The idea behind these experiments was to use the LES resolved turbulence fields to diagnose possible problems in the Mellor-Yamada type 1.5 turbulence closure that is used in ARPS. An example from one of our experiments is presented in Figure 2 showing the average slope flow wind speed and potential temperature analysis (taken from Skyllingstad 2002; Skyllingstad et al., 2003). Although some of the differences between the LES and ARPS simulation can be attributed to vertical resolution differences, these comparisons show that above the down slope jet core, the ARPS model over predicts vertical mixing, while decreasing the strength of the flow maximum and increasing the surface temperature. These differences can be traced back to the turbulence closure as is discussed in the next section of this proposal.

Simulations of a compound angle slope show how changing slope angle strongly affects the strength of katabatic flows. Both ARPS and the LES show that slopes with a steep upper slope followed by a more shallow lower slope (concave shape) generate a rapid acceleration on the upper slope followed by a transition to a slower evolving structure characterized by an elevated jet over the lower slope. In contrast, a case with uniform slope having the same total height change yielded a more uniform slope flow profile with stronger winds at the slope bottom. Less available potential energy in the compound-angle case dramatically decreases the flow kinetic energy in comparison with the uniform slope example. Analysis of the total energy budget of the slope flows indicates a consistent structure where a significant fraction of the potential energy generated at the top of the slope was transported down slope and converted into kinetic energy near the slope base.

Comparisons were also made between the LES model and simulations performed by S. Zhong using the Regional Atmospheric Modeling System (RAMS) and indicated significant differences between the two approaches. Most notable are the stronger downslope velocities and deeper

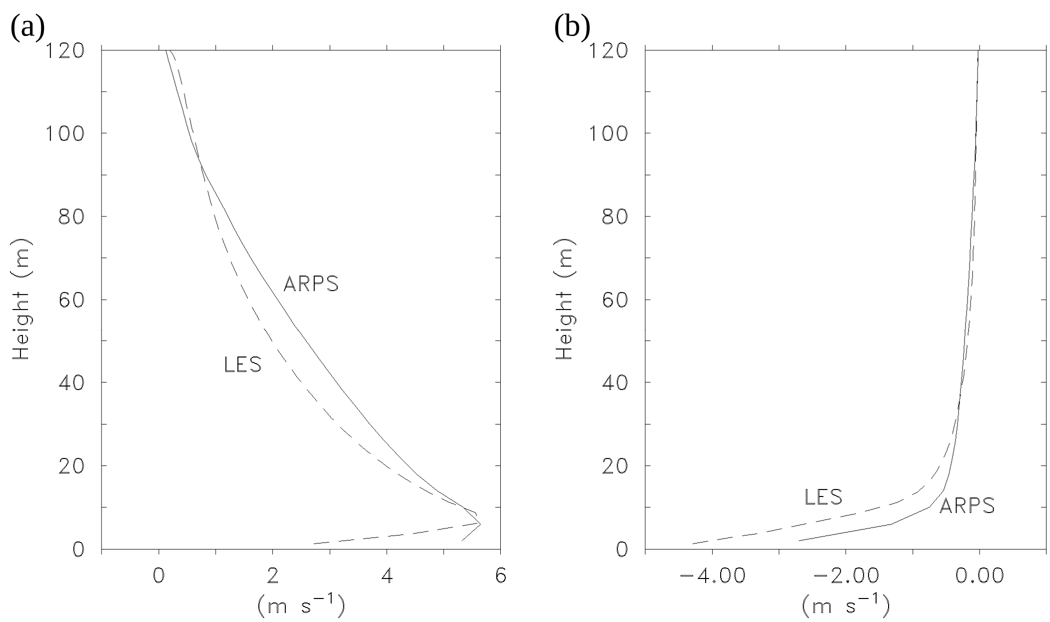

Figure 2. Horizontally averaged (a) downslope velocity and (b) potential temperature taken from a distance between 6240 m and 7320 m from the top of the slope. Solid line represents the ARPS solution, dashed line the LES results.

slope flow depth indicated in the RAMS simulations.

References

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