P.3.28 MODELING TURBULENT AIRFLOW IN MOUNTAINOUS REGIONS

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1. INTRODUCTION

The influence of orography on the mean flow is an important research topic due to wide ranging applications in areas such as science, engineering, aviation, agriculture, and recreation. Mountainous regions affect weather patterns on local, regional, and synoptic scales, resulting in weather phenomena unique to mountainous regions like orographic enhancement of precipitation, mountain-induced gravity waves, and valley flows. Turbulence caused by orographic distortion of the mean flow is of significant concern to the aviation community. Aircraft experience more turbulence over mountainous regions than over flat terrain by about an order of magnitude (Wallace and Hobbs, 1979).

To obtain a greater understanding of orographic flows, numerical modeling is necessary. Much of the research in orographic flows has centered on numerical modeling studies (Kaimal and Finnigan, 1994), and higher order closure schemes are necessary to examine the turbulent structure of the flow in detail. A model developed at the University of Leeds, UK, is used in two idealized cases to study turbulent flow in mountainous regions.

2. MODELING

The mesoscale numerical model is non-linear, anelastic, and in terrain-following coordinates. For greater boundary layer resolution, the model domain is stretched along the vertical axis. The lower boundary consists of a no-slip logarithmic wind velocity profile, the upper boundary is a rigid-lid, and the lateral boundaries are radiative.

First order and second order turbulent closure schemes are used, depending on the particular application. The first order turbulent closure is a combination of a first-order scheme from Lilly (1962) and a mixing-length scheme from Blackadar (1962). To obtain detailed results of the turbulent structure, the second-order closure of Wyngaard (1975) for stable atmospheric boundary layers can be applied to a limited number of cases. Second order closure schemes account for turbulent processes thought to be important in mountainous regions such as rapid distortion (where turbulence is not in local equilibrium), turbulent advection, and turbulent rate of strain (Kaimal and Finnigan, 1994). Unfortunately, second order closure schemes require large amounts of computer power and usually have limits in their usefulness to a particular range of meteorological (or engineering) conditions.

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3. RESULTS

Two idealized two-dimensional model simulations are shown below, both of which use bell-shaped hills to provide forcing. The first case is for a trapped mountain wave regime and the second case is for vertically propagating mountain waves. The first order closure scheme is used in the trapped case, while the second-order closure scheme is used in the propagating wave case.

3.1 Case 1: Trapped Gravity Waves

Under certain conditions, propagating mountain waves can become trapped below a vertical level. In a trapped mountain wave regime, the downwind slope sometimes experiences strong winds and rotors may form in the boundary layer (Kaimal and Finnigan, 1994). Rotors are hazardous to the aviation community, resulting in numerous aircraft accidents and occasional fatalities (Doyle and Durran, 2002).

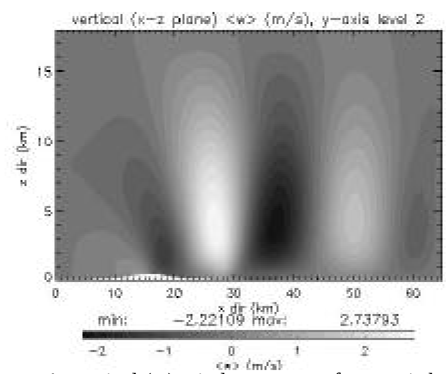

Figure 1: vertical (w) wind component for case 1 showing the trapped mountain waves.

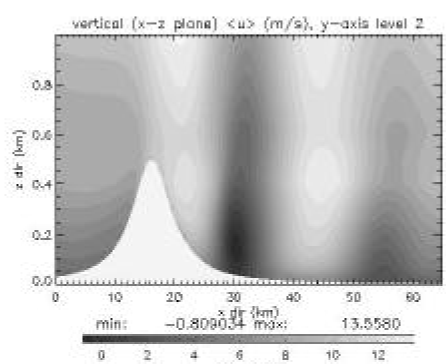

Figure 2: horizontal (u) wind component in the lowest 2 km. A rotor is evident in the negative region of u located on the x-axis at about 30 km.

Model results using the first order turbulent closure scheme for a two-dimensional idealized trapped gravity wave case are shown above. The bell-shaped hill has a peak height of 500 m and half-width 4000 m, the Richardson number (RI) is a constant of ~8, and u at the surface is 10 $m\ s^{-1}$ in the initial mean profile (Wurtele et al., 1987).

Trapped mountain waves can be seen in Figure 1, which shows the vertical wind component w throughout the model domain. The horizontal wind component u in the lowest kilometer is shown in Figure 2, where a rotor is located in the region where u is minimum (about 30 km on the x-axis in the figure). Local values of RI are at a minimum (~.05) in the region of the rotor, which indicates turbulence. Primarily due to high wind shear, minimum values of RI also extend in the surface layer over the lee slope and between 40 and 50 km on the x-axis.

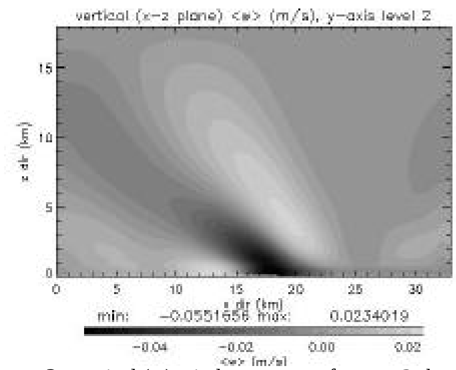

Figure 3: vertical (w) wind component for case 2 showing the propagating mountain wave field.

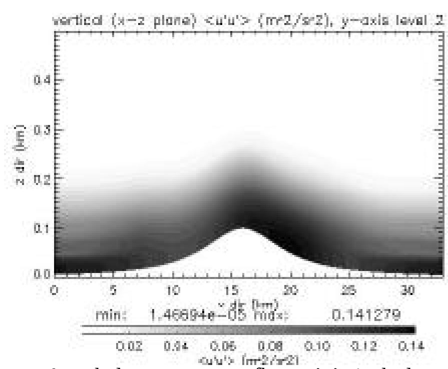

Figure 4: turbulent momentum flux <u’u’> in the lowest 500 m. Maximum values of <u’u’> are located in the wake region just behind the hill.

3.2 Case 2: Propagating Gravity Waves

The second order turbulent closure scheme is used to resolve the turbulent structure around the hill. In this case, the hill height is 100 m, hill half-width 4000 m, static stability N = .0025 s^{-1}, and u = 2.5 $m\ s^{-1}$. The propagating mountain waves are evident in Figure 3, which shows w for the model domain. The turbulent momentum flux <u’u’> is shown in Figure 4 for the lowest 500 m, where maximum values are apparent over the lee slope in the wake of the hill.

4. CONCLUSIONS AND FUTURE WORK

Numerical modeling is necessary for a greater understanding of the general structure of turbulent flow in mountainous regions. A mesoscale orographic model capable of resolving orographic and boundary layer processes has been developed at the School of the Environment, University of Leeds, Leeds, UK, which can be used with both first and second order turbulent closure schemes. Modeling studies indicate that turbulent rotors can form in the wake regions of mountains during a trapped mountain wave event, and that turbulence tends to be at a maximum in the wake region of small hills. This model is also being used to study other idealized cases as well as field experiments using real atmospheric profiles, which will then be compared with corresponding aircraft wind and turbulence measurements.

5. ACKNOWLOGEMENTS

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6. REFERENCES

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