Measuring Turbulent Flows over a Forested Hill

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1 Introduction

The effect of complex terrain on air flow has been widely studied and the theory surrounding the problem under idealized conditions is well developed (e.g. Jackson and Halt, 1975). The central features of turbulent flows through forest canopies are also well documented (e.g. Kaimal and Finnigan, 1994 and Finnigan, 2000). However, despite the fact that a significant portion of the world’s mountains is forested the interactions between the air flow and canopy over complex terrain have not yet been fully investigated. The intent of this work is to introduce a field campaign conducted by the University of Leeds in the winter 2006-07 in collaboration with the Forestry Commission, the University of Edinburgh and the UK Met Office. The measurements collected will provide a dataset for validating some of the latest model developments and theories surrounding the problem of canopy air flow interaction over complex terrain and will also be useful for improving numerical weather prediction schemes and estimating wind damage to commercial forests.

2 Theory

An analytical model created by Finnigan and Belcher (2004) has predicted the following unique effects in boundary layer flows over a hill covered with a canopy:

- The pressure gradient associated with the flow over a hill causes additional perturbations to the flow within the canopy.
- The pressure gradient within the canopy is partly balanced by the canopy drag. In the upper reaches of the canopy downwards turbulent transport of momentum is also important.
- Deep within the canopy this balancing of the pressure gradient will produce maximum streamwise winds on the upwind slope of the hill while in the upper reaches of the canopy the maximum streamwise winds are near the crest of the hill.
- In the lower reaches of the canopy the lee of the hill the pressure gradient causes decreased wind speeds and, if the canopy is sufficiently deep this leads to flow separation with a reversal.
- The presence of a canopy on a hill will decrease the expected speedup over the hill due to the extra turbulent mixing within the canopy and the maximum velocity will occur further upwind of the hill crest than on an unforested hill.

3 The Numerical Model

Numerical simulations of flow over a forested hill produced by Ross and Vosper (2004) have provided evidence to support the theories of Finnigan and Belcher (2004). For small hills though the linear theory breaks down. This leads to significant flow into (‘out of the canopy and a shift in the pressure field relative to the hill. The plot in figure 1 illustrates these features including the flow separation within the canopy over the lee slope.

4 Field Campaign

The field campaign took place on the Scottish island of Arran, located approximately 14 miles off the south-west coast of Scotland (Figure 2.1). The field site is a ridge on the north-east coast of the island, 1.5km in length and varying in height from sea level to 281m. The campaign was run over a period of 8 months from October 2006 to May 2007 with intensive data collection taking place from February until May 2007. The winter and spring months were chosen for data collection because winds at this time of year are stronger and will provide clearer indications of the flow dynamics. The southern end of the ridge is forested with a majority of coniferous trees while the northern end is unforested, allowing a direct comparison between flows over a forested and flows over an unforested hill to be made.

5 Case Study

Initial data analysis has indicated that there is a potentially interesting case study from 27.04.07 with easterly winds and a full data set. The plot in figure 4 shows averaged wind vectors from 7 AWS sites located within the forest. On the eastern slope winds are predominantly easterly aligned with the synoptic flow. On the western sector wind flow separation is indicated by the abrupt change in direction directly below the leeward summit. This flow separation is a ubiquitous feature of both numerical and analytical results for forested hills.

6 Conclusions

The motivation behind this field campaign was to collect a dataset that could validate the latest model developments and surrounds the question of flow over a forested hill. A range of discrepancies exist between the data collected by the numerical models and the field campaign and it would seem to indicate that there is a need for improvements to the models.

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7 References


