MEASURING TURBULENT FLOWS OVER A FORESTED HILL

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Abstract: It is widely recognized that turbulent flows are complicated by both the presence of forest canopies and topography. To date most field campaigns and modeling efforts have been designed to address these complications individually. However, the presence of complex terrain within a forested area can change the balance between terms in the momentum equation within and above the forest canopy. On smaller hills in particular, this can lead to flow into the forest over the upwind slope and flow out of the forest as well as enhanced separation over the lee slope. This difference in flow can also lead to an increase in the pressure drag over a forested hill and can have important implications for scalar transport between the forest canopy and the boundary layer above. Recent theoretical and computational work has begun to look specifically at canopy flow processes over complex terrain but there are currently very few field measurements to validate the latest model developments. This work presents data from an intensive measurement campaign undertaken on a forested hillside on the Scottish island of Arran beginning in November 2006. Detailed profiles of turbulence were measured from three tall masts erected at selected points across the ridge. In addition, a large network of automated weather stations was used to reveal spatial variation in the pressure field and to identify other significant features of the flow over a forested hill. An introduction to the project, including a summary of the theory, motivation, methodology and some preliminary results from the field measurements will be discussed.

Keywords: Boundary layer flows, canopy flows, complex terrain, turbulent flow.

1. INTRODUCTION

The effect of complex terrain on air flow has been widely studied and theory surrounding the problem under idealized conditions is well developed (e.g. Jackson and Hunt 1975; Finnigan and Belcher 2004). The central features of turbulent flows through forest canopies are also well documented (e.g. Kaimal and Finnigan 1994; Finnigan 2000. However, despite the fact that a significant portion of the world’s mountainous terrain is forested the interactions between the air flow and canopy over complex terrain have not yet been fully investigated.

Current orographic flow models tend to parameterise terrain surfaces with a roughness length, effectively ignoring the flow processes that take place within the forest canopy. But recent work has shown that the presence of complex terrain within a forested area can affect the balance of the terms of the momentum equation within and above a forest canopy. Theoretical work conducted by Finnigan and Brunet 1995; Finnigan and Belcher (2004) models boundary layer flows over a hill covered with a canopy. This work predicts that the pressure gradient associated with the flow over a hill causes additional perturbations to the flow within the canopy. The flow also demonstrates several previously unrealised features. In a deep canopy the pressure gradient is balanced by canopy drag while in the upper reaches of the canopy downward turbulent transport of momentum and canopy drag will act to balance the pressure gradient. This balancing will produce increased streamwise winds on the upwind slope of the hill. Deep within the canopy on 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. Furthermore, the presence of a canopy on a hill will decrease the expected speed-up over the hill due to the extra turbulent mixing caused by the canopy and that the maximum velocity will occur further up the slope than on an unforested hill.

Some of these features have been demonstrated in wind tunnel investigations conducted by Finnigan and Brunet (1995) and numerical simulations have provided further evidence to support these theories (Ross, Arnold et al. 2004). However to date there are very few field measurements to validate these developments.
The intent of this work is to introduce a unique set of measurements collected by the University of Leeds in the winter 2006-07 in collaboration with the Forestry Commission, the UK Met Office and the University of Edinburgh. The measurements 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. FIELD CAMPAIGN

Leac Gharbh, a ridge on the northeast corner of the Scottish island of Arran was chosen for the location of the field campaign. It is approximately 225m in height and 1.5km long with north-south orientation. The southern end of the ridge is forested with a majority of coniferous trees. The northern end is unforested allowing a direct comparison to be made between the flow over a forested hill and the flow over an unforested hill. Leac Gharbh was chosen because the slope is steep enough to demonstrate flows outside of the linear regime described by Finnigan and Belcher (2004). Furthermore the area is accessible with suitable sites for the erection of turbulence towers.

Figure 1: Map showing Leac Gharbh ridge, circles show sites of tall mast towers. Note central ride where navigation beacons are located. © Crown Copyright/database right 2005. An Ordnance Survey EDINA supplied service.

The field campaign took place from October 2006 through May 2007. Data was collected for a period of two months from March 2007.

2.1 Vertical profiles within and above the forest canopy

Three towers of 18m, 18m and 22m heights respectively, were erected at three separate sites on the ridge as indicated in Figure 1. Canopy height ranges between 8-12 m and is not uniform at any of the three sites. Each tower was mounted with four 3-D sonic anemometers for collecting turbulence information, as well as five temperature sensors and five cup anemometers for characterizing the mean flow. Data was logged at a frequency of 10Hz providing continuous velocity and temperature profiles within and above the canopy. Site one is located on the southwest corner of the central ride, exposed to uphill flows from the south and west. Site two is positioned just off the ride, on the west side, looking out over the sea. The air flows at
site two come uphill off the sea and travel in an easterly direction. Site three is south of site two, about half way up the ridge on the sea side, with exposure to the same air flows.

Figure 2: a) Photo of mast tower at site 1and, b) view looking up at instrument profile on mast.

Figure 3: Photo of AWS located along the coast on the east side of the hill.

2.2 Surface measurements

Surface measurements were made using 14 automatic weather stations (AWS) placed at the sites marked in figure 1. Each AWS collected pressure, temperature and relative humidity data in addition to wind speed and direction using cup anemometers and vanes mounted at 2m. All instruments measured continuously with a 3s sampling interval and data was monitored and recorded using custom built dataloggers. An AWS station was erected close to each turbulence tower to provide a direct comparison. The remaining AWS sites were erected in areas that were thought to provide interesting data with regard to the air flow and its interaction with the canopy and topography. One AWS was erected at sea level along the east coast of the ridge (see Figure 3). A short time series of pressure and temperature and relative humidity data from this particular AWS is shown in Figure 4. A second AWS was placed in the forest directly below turbulence tower two to provide information to link the data from the two turbulence towers. Two AWS were
set up along the south west side but fairly low down from the ridge to provide information on the air flow going around the ridge. The remaining AWS were located in a line along the ridge top, leading north and leaving the canopy cover. These should provide interesting data with regards to the flow over the ridge as well as data for a direct comparison between surface flows within the canopy and surface flows outside of the canopy.

![Graph](image)

**Figure 4:** Example of data available from automatic weather stations (AWS) from the first week of March 2007. The upper time series shows pressure while the lower plot shows relative humidity (small circles, left vertical-axis) and temperature (crosses, right vertical-axis).

3. DATA HANDLING

At the time of going to press, the field campaign is still underway and only a small portion of the dataset is available. The data obtained from this campaign will be used to validate the current theories surrounding turbulent flows in forest canopies over complex terrain.

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REFERENCES


