Non-Gaussian Turbulent Flow over a Coastal Escarpment

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Keywords: *Escarpment flow, non-Gaussian turbulent flow field, high resolution measurements*

Introduction

The stochastic nature of wind, in many cases, poses challenges for wind power prediction and effects loading on the wind turbine blades and structure. In homogenous isotropic turbulence, the probability density functions (PDFs) have shown to be approximated well by a Gaussian distribution [1] [2]. Thus, in wind power forecasting models and studies on wind turbine loads in the atmospheric boundary layer (ABL), it is common practice to employ the assumption that the ABL wind speed is an ergodic random process.

As the installed capacity of wind energy continues to increase, it is becoming more commonplace to choose sites in complex terrain. Complex terrain is characterized by large, abrupt changes in surface characteristics such as elevation or roughness. Typical examples of complex terrains are steep mountains, forest canopies or coastal escarpments—the last being the main objective of this paper. These types of topographies can be very advantageous in terms of wind energy production due to increased wind resources, but can significantly affect both the mean and turbulent characteristics of the local flow field. Non-Gaussian velocity fields have been identified in areas of complex terrain. The horizontal wind velocity near forest canopy edges have shown to have a positive skewness and thus a departure from Gaussian behavior [3] [4]. Flow downstream of escarpment edges have typically shown to have Gaussian PDFs of the longitudinal velocity component near the surface [5] [6]. Escarpments can generate complex spatial-temporal structures such as separation regions and shedding vortices [7]. In addition, there is speculation of non-Gaussian intermittency of the flow in the zones of recirculation although, to date, there is no definite confirmation of such flow behavior [8]. The motivation for this study is to help identify this potentially intermittent behavior of the turbulent velocity field in recirculation regions downstream of escarpments and to further aid the improvement of wind power forecasting models based off of near surface measurements.

Site Description and Methodology

A full-scale field campaign was conducted to investigate the near surface flow field over the coastal escarpment in Prince Edward Island, Canada seen in Figure 1. The surrounding area has long stretches of flat open terrain which is bound by an escarpment on the west side of the island as seen in Figure 1 (top right). Spurious forest canopies are also present to the East and Southeast of the

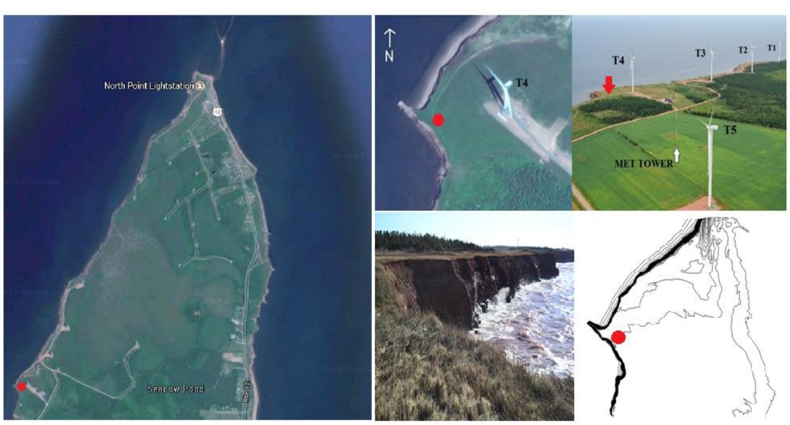

Figure 1: Measurement location (red marker) with an image and contour plot of the escarpment. Top right image photographed by WEICan and contour plots supplied by government of P.E.I.

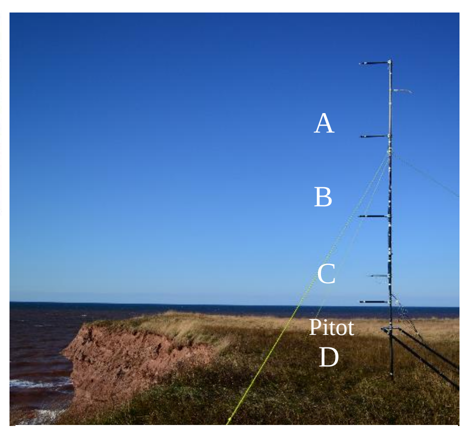

Figure 2: Cobra Probe array at 3.11 m from the edge of the escarpment

measurement site and the open water fetch is greater than 55 km to the west. The surface flow near the edge of the escarpment has been investigated using both a scanning LiDAR and arrays of Cobra probes. Cobra probes, which are four-holed pressure probes capable of resolving all three components of the mean and fluctuating velocities as well as the static pressure within a ±45° cone of acceptance, were used to measure the flow characteristics close to the escarpment as depicted in Figure 2.

Results and Future Work

Table 1 identifies each cobra probe in Figure 2 and its corresponding time series statistics for a sampling period from 12:30 p.m. to 12:35 p.m. on November 11, 2015. It should be noted that probe D, due to the limitations of Cobra probes in regions of reverse flow, is not included as the data set contained many invalid values. A pitot tube is also deployed at a height of 2.13 m above probe D (Figure 2). Here, the D'Agostino-Pearson test is used to quantitatively identify if the turbulent flow field at each probe location deviates from a normally distributed population. Moreover, skewness (γ) and kurtosis (κ) of the PDF of each probe were compared to a normal distribution in Figure 3. It is evident from the skewness and kurtosis values in Table 1 as well as the PDFs from each of the probes that deviations from a normal distribution (red curves in Figure 3) were encountered and hence the turbulent flow field at this location up to a height of 6.02 m is non-Gaussian. This non-Gaussian behaviour is particularly pronounced for probe C, which, interestingly, is the closest (valid) measurement to the surface. This result indicates that the small scale features of terrain play an important role in the non-Gaussianity of the atmospheric flows very close to the surface.

Further analysis of the time series data from multiple configurations at distances downstream of the escarpment edge will be done to characterize the extent of the non-Gaussian turbulent flow field at this site. Additional results will be presented at the conference.

Cobra Probe	Z (m)	$\bar{U}$	σ_u	γ	κ
A	6.02	10.9	8.3	-0.58	3.92
B	4.56	10.7	9.7	-0.50	3.84
C	3.06	11.1	13.1	-1.44	7.64

Table 2: Height and five minute statistics of the Cobra probe array in Figure 2.

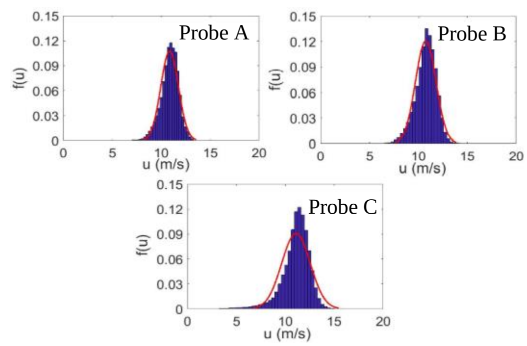

Figure 3: PDFs of cobra probes in arrangement depicted in Figure 2.

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