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Numerical modelling of wind flow over a complex topography

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ABSTRACT

Numerical modelling of wind flow over complex dune topography is an ambitious prospect. There is an increasing need to understand wind flow over complex topography for land planning purposes to enable prediction of sediment transport at a particular site. New surveying techniques permit the rapid development of digital terrain models, however a stumbling block is the ability of Computational Fluid Dynamics (CFD) to emulate the wind flow over such a landscape. To overcome these difficulties, it is important to establish the parameters within which such simulations can operate. This paper details an initial two-dimensional numerical model developed in order to test various modelling assumptions against experimental field wind data. Mason Bay, Stewart Island, New Zealand was chosen as an undisturbed but accessible experimental site with a prevalent on-shore wind perpendicular to a simple foredune and a complex down-wind parabolic dune system. A complex topographical two-dimensional model with vegetation represented as a roughness was compared against field data along a transect dissecting a dune system.

This paper establishes that:

* Replicating the roughness patterns at the surface is important
* The inlet profile should be duplicated with care
* Modelling only a portion of the domain can have an effect on the flow patterns due to outflow effects
* There is a modelling decision to be made between the complexity of the topography and the sophistication of the turbulence model and degree to which vegetation and sand transportation are modelled.

The long-term aim is to instil confidence in numerical techniques so that such technology can be used for predictive purposes.

Software availability

This paper applies FLUENT supplied by Fluent Inc, 10 Cavendish Court, Lebanon, NH 03766, USA. Tel: +1 603 643 2600; fax: +1 603 643 3967: purchased through LEAP Australia, Suite 20, 74–78 The Corso, Manly, NSW 2095, Australia. Tel: +64 28966 7888; fax: +64 28966 7899.

1. Introduction

Predicting wind flow over sand dunes, by experimental or numerical means, has been the goal of many researchers (Hesp et al., 2005; Wood, 2000; Takahashi et al., 2005), often with a view to predicting sand transport. Previous work has often involved isolated dunes, and some issues associated with such predictions, including a generalised application of techniques to a complex topography, are not addressed. The effect of varying surface roughness on the wind flow, due to vegetation cover and modelling the physically diverse geometry with limited computational power also need to be considered. Researchers have had to overcome or circumvent these factors using a series of assumptions and simplifications such as idealised shapes, simplified fluid and turbulence modelling and blanket roughness values (Kim et al., 2000; Parsons et al., 2004). Often the prediction of sand transport over the dune system is the ultimate goal, however there is no acceptable universal model. The results of these research projects make a useful contribution, but there are difficulties in applying simplified models to a real-life complex topography with varying vegetation cover, taking into account all factors (van Dijk et al., 1999). Few management agencies are in a position to undertake or

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fund field-based studies of wind flow and associated sedimentation. The nature of information required has to be understood as no numerical modelling will give accurate point wind flow data but can give comparison datasets, for example to investigate a changing dune morphology. In these circumstances, the results of site-specific investigations of flow over dunes, usually involving only a small section of the relevant landscape, can be difficult to interpret in terms of the larger scale management imperatives (Parker and Kinnersley, 2004).

This paper examines the efficacy of Computational Fluid Dynamics (CFD) as a tool in coastal dune management, with a focus on flow over a foredune. This numerical method has the advantage of flexibility, in that it allows the comparison of multiple scenarios. For example the comparison of the effect of various re-vegetation options and dune morphologies on hinterland flows may be possible. The first aim of any planned use of numerical software such as CFD should be to ensure that it is providing predictions that tally within a reasonable error to those patterns found in the field. The experiment design was developed considering a building block approach for the numerical modelling (AIAA, 1998). This is where a complex problem is broken down into subsystems that can aid in the understanding and future modelling. These subsystems are more complex than unit or benchmark problems and have moderately complex flow physics, multiple relevant flow features, large experimental uncertainty and some initial and boundary conditions are measured.

The motivation was to better understand the wind and in future the particulate flow over complex surfaces because of the variety of environments where these attributes are significant. Such circumstances range from modelling the spread of pollutants within cities, the containment or spread of insecticide sprayed on a farm within a rural setting, through to the drifting and build up of snow around obstacles for construction, recreation or ecological purposes. All of these environments have different physical processes which interact with the fluid flow and the application of simplified geometries is not sufficient for predictive purposes. Numerical modelling in two and three dimensions in such situations presents a major step forward, as they have the potential to provide a viable and flexible predictive set of tools to aid in decision making and the testing of future scenarios. This focus here is then on a complex coastal dune as an ideal system, where we have tested, developed and refined numerical modelling approaches with a view to their subsequent wider application.

Therefore this paper assesses the two-dimensional validation of CFD software with experimental field wind data obtained as part of a wider programme, from a complex dune system at Mason Bay, Stewart Island, New Zealand. The emphasis in this stage of the project is to predict the wind flow over a vegetated complex topography, without sand transport. The focus of this subsystem work is the complexity of the topography and therefore the initial modelling uses a standard turbulence model and a roughness treatment at the surface to represent vegetation to reduce the complexity of the flow physics. The areas of interest investigated are then the pattern of roughness on the complex dune surface, the effect of the inlet velocity profile and the partitioning of the domain. Once these have been established it then allows the issues with modelling the complexity of the topography to be isolated and highlighted and is a step in the process of interrogating the wider problem and introducing more complex flow physics.

2. Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) has been used in traditional engineering such as in the aerospace and automotive industries for the past 40 years. It uses the Navier–Stokes and continuity equations that emulate the velocity and pressure distribution over time and space within a fluid space (Shaw, 1992). These equations are then discritised and solved on a mesh that covers the fluid space of interest. Limited computer capacity requires that various assumptions are made due to the complex non-linear nature of the equations, such as the use of different models for turbulence and wall roughness and there is often a compromise made between physics and geometry complexity. The commercial finite volume

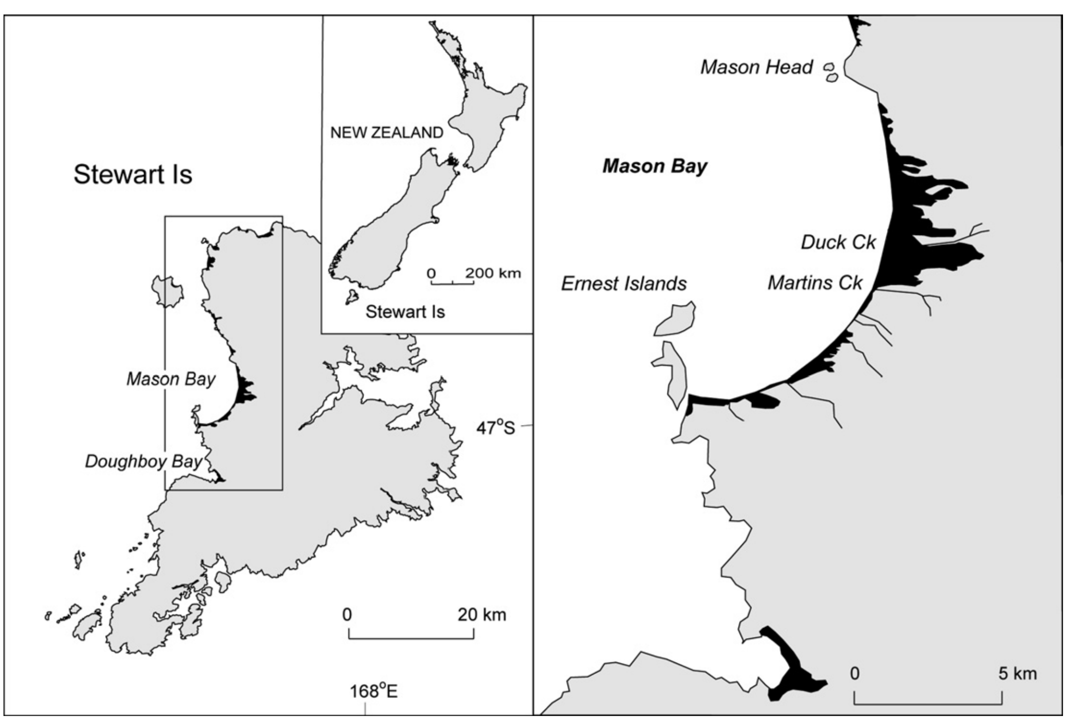

Fig. 1. Location of Mason Bay, Stewart Island, New Zealand.