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Wind and Wind Hazard Related Research at NIWA

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Abstract

In recent years NIWA has expanded its research activities to more actively include work focused around wind and wind hazards, notably numerical weather prediction (NWP), wind energy forecasting, design wind consulting and vulnerability and risk assessments associated with wind hazards.

In this paper, the results of a recently completed project (previously introduced at AWES14 in August 2010) that re-examined the calculation methods employed in the AS/NZS 1170.2:2002 Structural Design Actions code to estimate the hillshape multiplier, M_t, over New Zealand's hilly and often mountainous terrain are presented. It is found that the code, in its current state, tends towards conservative estimates of design winds and struggles to differentiate between sheltered and exposed sites.

Further, the paper provides an overview of the tools that NIWA has developed over recent years to further its wind and wind hazard forecasting capabilities and showcases some results.

Introduction

NIWA operates a Natural Hazards Centre which, in association with its partners in the Natural Hazards Platform (a multi-party research platform funded by the New Zealand Ministry for Science and Innovation) coordinates and promotes all of the hazard related work carried out into the major hazards New Zealand is susceptible to - including flooding, landslides, coastal erosion, earthquakes, tsunami and wind - with the aim of reducing the vulnerability of New Zealand communities and infrastructure to these natural hazards.

Wind hazards, primarily in the form of wind storms and tornados, have recently been the focus of an increased research effort within NIWA, particularly since the implementation of two key research tools; the EcoConnect multi-hazard environmental forecasting system and the Gerris computational fluid dynamics (CFD) model. Alongside these tools, NIWA is also leading, together with GNS, the development of RiskScape, a multi-hazard loss modelling tool. Wind storms are one of six perils that RiskScape currently covers. An ability to do real time loss modelling or damage forecasting is an addition we are working on. The aim is to use forecasts of maximum wind gust from the EcoConnect numerical weather prediction models as input to the RiskScape model.

In this paper, we describe some recent research results that make use of these tools where they are used to further our understanding of the design wind component of the AS/NZS 1170.2:2002 Structural Design Actions code. We conclude by providing an overview of the key tools NIWA has at its disposal to conduct wind engineering and wind hazard related work.

Re-visiting the AS/NZS 1170.2:2002 Code

One of the major natural hazards in New Zealand is wind storms. In the past few years alone, New Zealand has experienced a number of costly severe wind storms, including the 2008 Greymouth storm that featured downslope winds with gust speeds up to 160km/h, and the March 2010 Wellington wind storm event that saw a maximum recorded wind gust speed of 220km/h. Both events led to considerable property damage.

A key influence on the severity of these events was the effect the local terrain had on the wind field. To investigate this further, a recently completed project, a collaborative effort between NIWA, GNS, Opus International Consultants and the University of Auckland, looked at the wind speed-up effects in the lowest 100m of the atmosphere over the Belmont Regional Park during a north-westerly wind event.

This region (Figure 1), particularly the tops of the hills, is the site of many transmission line pylons and thus understanding how the terrain influences the near-surface wind field is vital for assessing the suitability of the AS/NZS 1170.2:2002 Structural Design Actions code and its handling of the terrain hillshape multiplier, M_t, in estimating the design wind speeds needed to ensure the resilience of these structures and reducing the vulnerability of New Zealand's built infrastructure to wind damage in general.

Figure 1. Aerial view of Belmont Regional Park, looking towards the west. Transmission line pylons can be seen along the ridge running north-south.

The assessment was done by comparing wind speed-up factors, relative to observed winds at Wellington Airport. The hillshape multiplier, M_t, at nine separate locations of varying elevation and thus differing levels of exposure along a transect of the Belmont Regional Park were estimated. For each of the locations, the speed-up and M_t estimates were made using the following methods;

- 5m anemometer observations,
- the AS/NZS 1170.2:2002 Structural Design Actions code,
- the WAsP (www.wasp.dk) analysis package,
- very high resolution (40m) CFD modelling, and
- 1:2000 scale-model wind tunnel modelling.

Figure 2 shows the hillshape multipliers at each of the mast locations as calculated from the different methods.

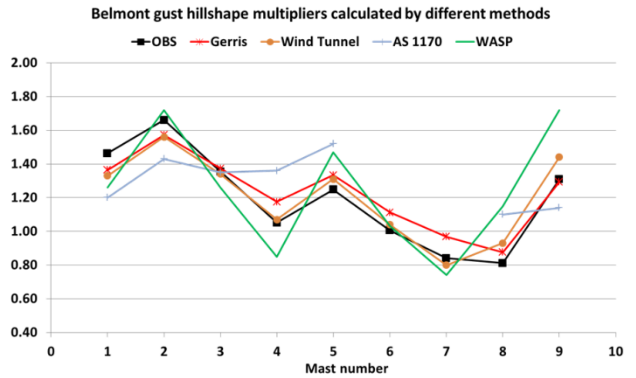

Figure 2. Plot of hillshape multipliers for each of the nine mast locations as calculated from each of the estimation methods. Values for the Design Actions code speed-ups were not calculated for the very sheltered locations 6 and 7.

It is found that the best estimation of speed-up factors, and hence more accurate hillshape multiplier estimation, comes from very high resolution CFD modelling with Gerris and the highly detailed scale-model wind tunnel methods. This result is perhaps not surprising for this particular location given the likely importance of near surface terrain effects such as eddy shedding over upstream hills on wind speed-up or speed-down. However, these two methods are generally also the most costly, particularly if a single site calculation only is required. If more than ten calculations were required in a 10km square then the Gerris and wind tunnel methods would be much more cost competitive. Use of the WAsP model, which calculates a potential flow solution, slightly adjusted for friction effects, while capturing the varying nature of the observed hillshape multiplier across all the mast sites, has a tendency to both over- and under-estimate by up to 15%. The Design Actions code method struggled to differentiate between more and less sheltered sites.

NIWA's Wind Engineering Tools

NIWA has at its disposal a number of tools to help with its wind-related research. In addition to the use of the WAsP (Wind Atlas Analysis and Application Program developed by the Riso laboratory in Denmark), NIWA has the EcoConnect hazard forecasting system, which makes use of the UK Met Office Unified Model^{TM} (aka MetUM), and the NIWA-developed Gerris CFD model. Both of these are under active development and are garnering a wide user-base both within New Zealand, and in the case of Gerris, internationally. The RiskScape model for analysing the impacts of hazards is also available and is garnering a wide user-base amongst local hazard managers interested in assessing hazard exposure.

EcoConnect

Recognising that New Zealand's major natural hazards are driven by the weather, EcoConnect (Uddstrom et al, 2007) is NIWA's attempt to provide a multi-hazard forecasting system that, starting from forecast output from a NWP model, produces a full suite of weather and hazards forecasts of wind, rain, snow, temperature, river flow, sea state and sea level for up to 48 hours in advance. Figure 3 is a flow diagram of how the EcoConnect system is configured.

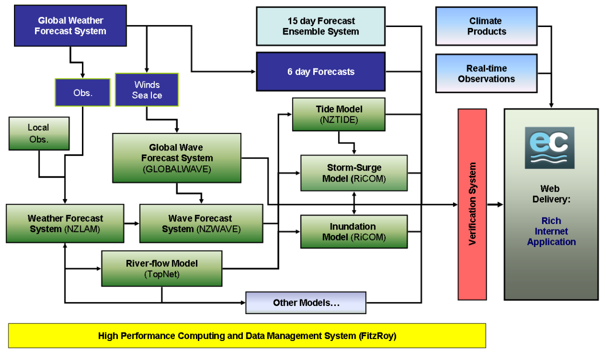

Figure 3. NIWA's EcoConnect hazards forecasting system is a combination of multiply linked models, featuring a verification and fully capable web-delivery system. The arrows in the schematic indicate the primary direction of information flow between system components.

The primary driving model of the EcoConnect suite is the locally configured New Zealand Limited Area Model (NZLAM) (Uddstrom et al, 2011). This NWP model is based on the MetUM (Davies et al, 2005), a non-hydrostatic, semi-implicit semi-lagrangian model that is under active development and in operational use at the UK Met Office and, more recently, by other research and meteorological services around the world. The model is fully data-assimilating, making use of observations from conventional surface stations, ships, buoys, weather balloons, aircraft and numerous satellites. Within EcoConnect, NZLAM is run four times a day out to 48 hours ahead with a 12km horizontal resolution and 70 vertical levels, the lowest at 10m above ground level and three in the lowest 100m of the atmosphere.

Recent work has led to the development of a much higher resolution NWP model to be run inside the EcoConnect suite. The New Zealand Convective, or NZCONV model (Uddstrom et al, 2011), features a 1.5km horizontal resolution and greater vertical resolution, with 5 model levels in the lowest 100m of the atmosphere and the lowest level at just 2.5m above the surface. Presently, NZCONV is run just once a day out to 36 hours ahead. Eventually, the NZCONV model is planned as a replacement for the NZLAM. A key feature of NZCONV is its ability to more properly resolve the complex terrain of New Zealand, particularly the deep glacial valleys of the Southern Alps and the high mountain tops that dominate both the South and North Islands. Figure 4 is a comparison of the South Island orography as represented in the NZLAM 12km model and the new NZCONV 1.5km model.

Being able to use such a detailed orography dataset in the driving NWP model for the EcoConnect suite means forecasting downslope winds and other meteorological fields such as temperature and precipitation should be much improved, particularly for locations such as Queenstown whose weather is often influenced by the local orography.

The NZCONV model has real potential for improving the forecasts of damaging wind events over New Zealand well ahead of time so that appropriate mitigation measures can be put in place ahead of time. Furthermore, wind forecast output from NZCONV will be one of the primary inputs into the new RiskScape wind hazard maps described later in this paper.

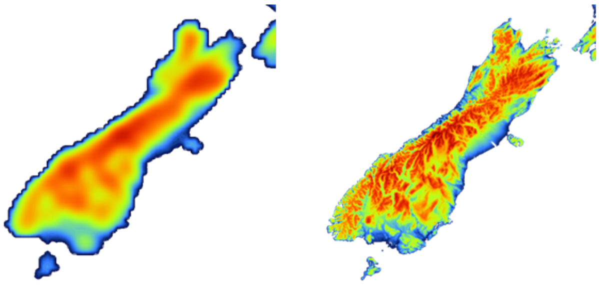

Figure 4. Comparison of the orography field over the South Island of New Zealand used in the 12km NZLAM model (left panel) and from the newly developed 1.5km NZCONV model (right panel), where both the major alpine ridges are resolved and the key features of the South Island's intermountain geography are evident. For reference, Mt Cook has an altitude of 3754m. The NZLAM dataset has Mt Cook at 1675m and NZCONV at 2820m.

Development work on NZCONV is still ongoing and data assimilation is still to be included, with operational implementation planned for mid-2012.

High Resolution Nesting Suite

A key advantage of the semi-implicit, semi-lagrangian dynamical core of the MetUM is the ability to run the same model over a wide variety of horizontal and temporal timescales with minimal changes to the model's set up. Taking advantage of this, NIWA has begun to implement a very high resolution nested suite that runs versions of the model at continuously increasing horizontal resolutions of 40km, 12km, 4km, 1.5km, 333m and 111m.

Even with the most powerful supercomputers, running a model at sub-kilometre scale resolutions is not feasible for an operational set up but is a valuable tool for research purposes, particularly when investigating isolated events. The local implementation of this suite is still very much a work in progress but results from its use at the UK Met Office have proved incredibly promising.

As an example, the nesting suite has been used to simulate TC Megi that struck the Philippines on 18th October 2010, with an observed minimum central pressure of just 885hPa and peak winds of 225kph. Figures 5 and 6 below show the performance of the different resolution models at forecasting the central pressure and peak wind speeds of the cyclone.

From Figure 5, the 40km (Global), 12km and 4km forecasts show only a small deepening compared to observations. The 1.5km forecast, however, very closely follows the observed deepening of the low pressure, reaching a minimum of 905hPa. A similar scenario is also seen with the forecasts of 10m peak wind speed (Figure 6), albeit with the 4km forecasts this time showing a marked improvement on the 40km and 12km forecasts. Once again the 1.5km simulations perform the best and in the days prior to landfall, forecast winds that are quicker than those observed. At the time of writing, TC Megi simulations at 333m and 111m resolutions are still ongoing.

While such a suite is not suited to daily operations, its use in forecasting extreme events, which may initially be flagged by forecasts from NIWA's NZLAM and NZCONV models, will prove valuable. For use over New Zealand, the 12km and 1.5km models in the suite can be replaced with the NZLAM and NZCONV models respectively, or, the suite can be configured to ignore some of the coarser resolution set ups entirely. For example, if an NZCONV forecast were to indicate the possibility of a strong wind event sometime in the coming 36 hours (the forecast period of NZCONV), the nesting suite can be quickly configured to run just the 333m and 111m models over the region of interest taking the NZCONV forecast output as the initial conditions.

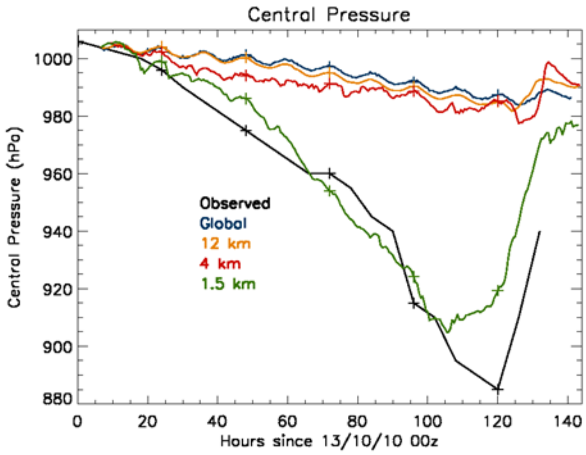

Figure 5. Time series of the central pressure of TC Megi as forecast by each of the different resolution models used in the nesting suite in the 5 days leading up to when TC Megi made landfall on 18th October 2010.

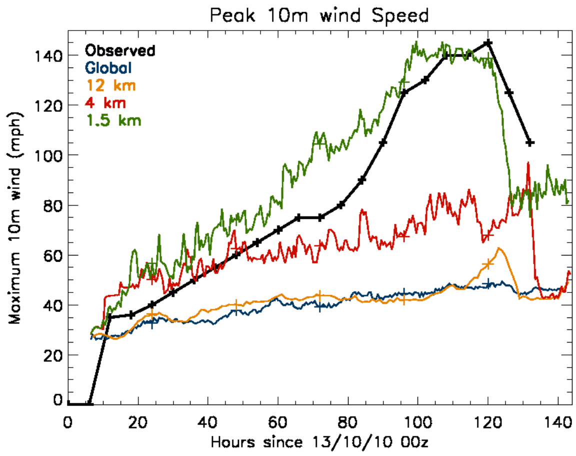

Figure 6. Time series of the 10m peak wind speeds as forecast by each of the different resolution models used in the nesting suite in the 5 days leading up to when TC Megi made landfall on 18th October 2010.

At NIWA, the nesting suite will be used, in the first instance, to simulate the May 2011 Auckland and June 2011 New Plymouth tornados and also the January 2011 TC Yasi event that devastated the northern Queensland region around Innisfail, Tully and Cardwell.

Furthermore, because the nesting suite makes use of the MetUM, the output from the very high resolution models can also easily be imported into the RiskScape model for the generation of wind hazards maps with very little extra technical effort required.

Gerris

Gerris (Popinet, 2003) is a Computational Fluid Dynamics (CFD) model developed at NIWA and distributed under the Free Software GPL license that has begun to accumulate a large and diverse international user community. Gerris solves the time-dependent incompressible Euler equations in both 2D and 3D and has been used in the past to solve problems ranging from von Karman vortex streets, flows around heated cylinders, modelling tides in the Cook Strait and more recently, modelling the severe Greymouth downslope wind storm event of July 2008 (Revell et al, 2009), as well as being used in the Belmont Regional Park hillshape multiplier experiment previously described in this paper.

A key feature of Gerris is its use of an adaptive grid. This allows the highest levels of resolution to be applied to the areas of interest only, saving on the overall computational resource required to perform a simulation. Coupled with a very high resolution digital terrain elevation dataset (DTED), Gerris has proved highly capable when applied to both metrological- and engineering-based wind problems. Figure 7 below is an example of the highly adaptive mesh set up for a Gerris simulation over the Wellington region. The highest levels of resolution are along the coastlines and in the lowest vertical levels. close to the model surface.

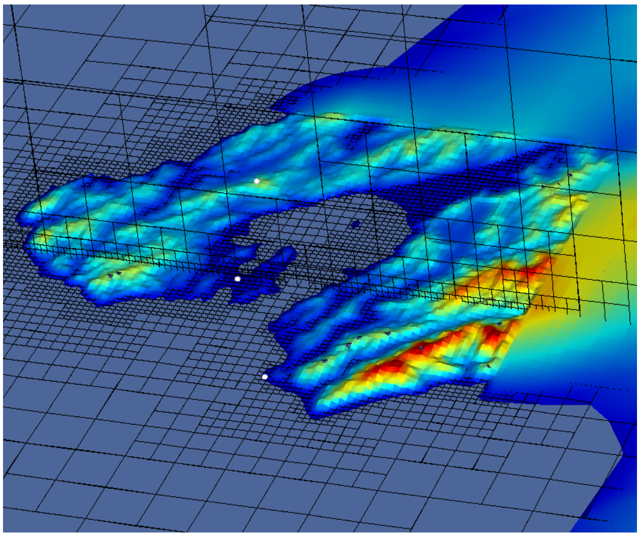

Figure 7. Map showing the initial mesh configuration for a Gerris simulation over the Wellington region. The Wellington topography is coloured according to height above sea level, taken from a 100m resolution DTED.

Recent developments have allowed Gerris to be forced using wind field data from the NZLAM and NZCONV models. Wind fields from these models are applied at specified time intervals over a prescribed region and at a well-defined spatial-scale. This is usually the same resolution as the driving model and, for consistency, is also the coarsest resolution used in the Gerris simulations.

With an appropriate DTED, Gerris will allow us to simulate extreme wind events, such as the Greymouth storm on spatial scales approaching 10's of metres, scales not yet reached with the MetUM simulations. Its use is thus envisaged as a tool for forecasting likely peak wind speeds for extreme wind storm events that are first identified in the coarser resolution NZLAM and NZCONV operational forecasts, as well as for further work focussed on investigating issues with the Structural Design Actions code, particularly for winds over complex terrain and flow around buildings.

RiskScape

RiskScape (www.riskscape.org.nz) is a joint venture between NIWA and GNS that comprises an easy-to-use tool for analysing risks and impacts from multiple hazards, including wind. Its principal objective is to convert hazard exposure information, in the form of forecasts or historical data, into some measure of the likely impacts, such as costs, infrastructure loss and human impacts, on a region or locality.

Output from the RiskScape model is used to enable hazard managers to make informed decisions about the "4 R's" of emergency management: reduction, readiness, response and recovery.

Current work is focussed on the inclusion of maximum gust wind speed from NZCONV as an input to the RiskScape model, from which it will be possible to generate wind hazard maps and do real time loss modelling, in addition to its current wind hazard capabilities (Reese and Reid, 2006).

Within RiskScape, post event surveys are also undertaken. These provide valuable information as to the ability of New Zealand's building stock to withstand severe wind events, such as tornados, and thus inform future versions of the loadings code as to recommended building standards. In February 2011, two NIWA meteorologists took part in the TC Yasi post event damage survey in collaboration with GeoScience Australia.

Conclusions

In this paper the results of a recently completed project that investigated the suitability of the AS/NZS 1170.2:2002 Structural Design Actions code at estimating hillshape multipliers over complex terrain. High resolution CFD modelling or scale-model wind tunnel experiments were found to give the best results compared to observations, with the Design Actions code shown to perform poorly in general. In some locations, application of the code would have led to a speed-down of the wind speed rather than the observed speed-up.

This paper has also described the collection of tools that NIWA has at its disposal for undertaking wind-related research, ranging from forecasting and studying wind-related meteorological events via the use of the EcoConnect suite and NZLAM and NZCONV models, through to the use of Gerris for wind engineering focussed work. Together, these tools comprise a substantial wind engineering toolbox that allows NIWA to contribute to further developing the loadings code, as applied to New Zealand terrain and in mitigating potentially costly damage due to severe wind-related meteorological events.

Acknowledgments

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