High-Risk Scenarios for Wind Power Forecasting in Australia

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Abstract

This paper presents preliminary results from a wind power forecasting study of potentially high-risk scenarios for power systems in the context of the Australian National Electricity Market (NEM). This paper focuses on the two Australian States of highest wind penetration to date, South Australia and Tasmania. Firstly, a study is made of the wind climate of these two States affecting the wind power output at various wind farms. Techniques to identify specific instances of high-risk scenarios are explored combining aggregated wind power and meteorological observations with known inherent power system constraints. An assessment is made of the performance of two technically different, commercially available forecasting systems. Further work is planned to expand on these findings and develop ramp forecasting techniques as a complement to traditional approaches.

Keywords: wind power prediction, wind energy forecast, ramp, extreme event, rapid changes, large swing, power system security

1. Introduction

Power system and electricity market operators are increasingly concerned about large, rapid changes ("ramps") in aggregated wind farm output, as they may be costly to balance in the market or affect power system security. This is particularly true in Australia due to the large geographic extent of the power system (4000km long) with wind farms currently being concentrated in a few, high wind, regions in relatively weak areas of the grid.

Ramps in aggregated wind power output can be considered as high-risk events, and this is where an accurate wind power forecast is particularly valuable. This risk is specified by the wind power forecast clients, such as the power system operator and market participants. For example in the Australian power system, forecasting extreme events (ramps) may assist in determining frequency control ancillary services (FCAS) requirements. [1], and also help participants to better manage their unit commitment decisions. A range of security (technical) and commercial risks are relevant. Such risks can be evaluated as a combination of scenario type, probability and consequence; utilising a combination of engineering and economic models. It is critical that there is ongoing communication between wind power forecast providers, clients and researchers, since the situation is always changing, due to new installations, transmission upgrades, and so on.

Techniques to identify specific instances of high-risk scenarios are explored, combining aggregated wind power and meteorological observations with known inherent power system constraints. Operational, situation dependent power system constraints are not included as these are not considered the responsibility of the wind power forecast provider. Rather, a wind power forecasting system could provide forecasts of all ramps and the power system operator would then decide what action is required given the current circumstances in the power system operation.

To the author's knowledge, there are three organisations looking specifically at predicting ramps in wind power output. Weprog in Denmark have a scheme to make a ramp forecast from their Multi-Scheme Ensemble Prediction System (MSEPS) and this is being trialled operationally in Alberta [2].

AWS Truewind (USA) is currently engaged in a research effort to optimise forecast performance for large ramp events in both the hours-ahead and day-ahead modes [3]. They are developing a forecast system that uses a phenomenon-switching approach in which the forecast system configuration is automatically switched when the probability of a particular phenomenon is estimated to be high.

The Californian Independent System Operator (ISO) also has a project looking at ramp forecasting tools for real-time operations, and ramp mitigation strategies [4].

Section 2 summarises all the data used to obtain the results in this paper. Section 3 presents a summary of the wind climate for the South Australian wind farms by relating the power observations to MSLP analyses. Section 4 discusses briefly the identification of high-risk events and includes one example.

Section 5 looks at the performance of two different commercially available forecasting packages during some high-risk events. Section 6 introduces a new wind power forecasting methodology with a focus on high-risk events. This includes some very preliminary results. Finally there is a conclusion and acknowledgments.

2. Summary of Data

The following summarises the data used for the results in this paper.

The wind farm observation data used in this paper is for 5 wind farms in South Australia (which cannot be identified for confidentiality reasons) and the 37 turbine, 64.5 MW Roaring 40s Woolnorth Bluff Point wind farm in Tasmania. This data was obtained with a resolution of 5 or 10 minutes and was averaged to hourly data by averaging the observations made during the previous hour leading up to and including the current hour. At each of these wind farms (except one in South Australia), wind speed and direction observations are also available. The data used for Woolnorth is the average of the observations made on the turbine towers. The wind speeds are measured with sonic anemometers. The source of the wind speed and direction observations at the South Australian wind farms is not known for sure, but is likely to be a meteorological (met) tower located on site and measuring at hub height.

Two wind power forecasting systems are featured in this paper, the Wind Power Prediction Tool (WPPT) and the Weprog Multi-Scheme Ensemble Prediction System (MSEPS).

WPPT is a statistical forecasting system which combines recent power observations with a wind speed and direction forecast from a Numerical Weather Prediction (NWP) system. WPPT is owned by Danish company ENFOR and described in detail in [5, 6]. Hydro Tasmania organised the installation of WPPT for the Woolnorth wind farm in 2005. The NWP forecast feed is obtained from the Australian Bureau of Meteorology MesoLAPS model with 12.5 km resolution [7]. The forecast used is at 10m height above the model terrain at a nearby grid point to Woolnorth. Details of this setup can be found in [8, 9].

The MSEPS is owned by Danish/German company Weprog, see [10-12] for details. The system is currently running operationally for the National Electricity Market Management Company (NEMMCO). Forecasts are made for 6 wind farms in South Australia (including the 5 referred to in this paper) and Woolnorth. Weprog provide many different forecasts for a given wind farm with different objectives. The forecasts used in this paper are from Weprog's so-called "optimal" method. These forecasts are described as the statistical best guess [13]. Weprog also make forecasts optimised for ramps but these are not available for Australia at this stage.

In addition to this, the Australian Bureau of Meteorology has recently developed a new NWP system WLAPS [14, 15], with a focus on wind forecasts for the wind energy industry. WLAPS has been run in test mode for two 6 week periods in 2005/6, and has been running operationally since October 2006. In this paper, some of the forecasts from this system are shown from the two 6 week periods.

Finally, the MSLP analyses shown in this paper are from the LAPS NWP analyses [16] publicly available from the Australian Bureau of Meteorology website.

3. The wind climate for South Australian wind farm power output

To date, more than half of Australia's wind power, 388 MW, is installed in a concentrated area in the state of South Australia (SA). This amount means that on average these wind farms produce 9% of South Australia's total energy use [17]. Figure 1 shows the locations of 5 of these wind farms on the MSLP charts. In the broad sense of the Australian National Electricity Market (NEM), these are installed at one end of the power system, which extends some 4000km east and then north along Australia's coast to Port Douglas in northern Queensland. With more wind farms to be installed in South Australia in the near future, wind power forecasting is becoming more important.

The following presents a summary of the wind climate for the behaviour of the wind power output from 5 wind farms in South Australia, and how it relates to MSLP analyses over the Australian region. Two common weather regimes are observed over one year (August 2005 to July 2006)), occurring around 70 times each:

Regime 1. One high pressure system lies south or over Western Australia and another to the south-east of South Australia. There is typically a cold front between these two highs with an associated low pressure system to the south.

The power varies during these periods depending on the strength of the low pressure system and front in the southern ocean, if it reaches far enough to the north so that the wind farms receive some high winds.

Regime 2. A high pressure system lies in the Bight south of SA and moves slowly to the east. The wind farm power is typically near zero except Jan-March when sea breezes can give some periodic power to some of the wind farms. The length of time that regime 2 can last is seen to be longer in May and June than in other months. The longest observed was a period of 9 days where the total power of the 5 wind farms remained less than 14% of rated power.

In general, the wind situation switches between the two regimes, as the high pressure systems move to the east. Regime 1 typically lasts for around 2 days and regime 2 lasts for 2-3 days. Figure 1 (centre) shows a selection of 6 days of aggregated wind power output for the 5 wind farms in March 2006. The regimes taking place during this period are indicated. The plot shows generally higher power during regime 1, but with some variability. As labelled on the figure, during regime 2 one wind farm produced significant power which wind direction data indicates is a probably a sea breeze (note: the time shown on the plot is UTC and without daylight saving, South Australia is 9.5 hours ahead of UTC).

Other common events that are observed during the year of data include:

- A front or trough causing dips in the wind farm power output. This sometimes affects many wind farms simultaneously (such as the example on 12 March in Figure 1) and at other times occurs at each or most of the wind farms in sequence. This occurs at least 11 times and can be seen in all months except April, May and June.
- A weak high pressure system over inland Australia, north of the wind farms allows frontal systems from the southern ocean to reach far enough north for the give wind energy to the wind farms to produce power. This is observed commonly in July and August but also occasionally from October to December. High pressure systems over inland Australia is known to be a winter phenomenon.
- Sea breezes were observed between January and March, occurring only during regime 2.

It is observed that a ramp in wind power is much more likely in regime 1 than in regime 2. Thus this study signifies the possibility that there may be some periods of time where a forecasting system can predict that a ramp in wind power is very unlikely to occur. A forecast such as this alone is useful for a power system operator.

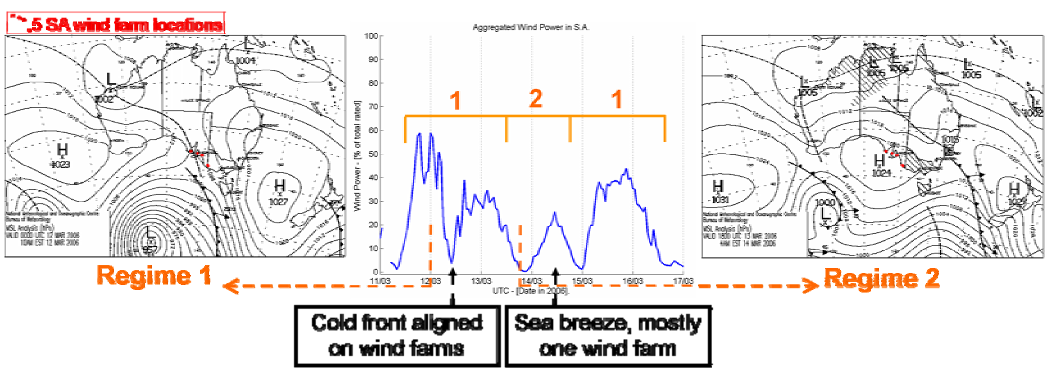

Figure 1: Aggregated wind power from 5 wind farms in South Australia for 6 days in March 2006 (centre). Two MLSP charts are shown (left and right), with their corresponding times indicated on the power plot. 5 dots of the MSLP plots on the south coast of Australia indicate the locations of the 5 wind farms. Some features on the power plot are explained in the boxes below the figure.

4. Identification of high-risk events

For demonstration purposes, potential high-risk scenarios have been identified using hourly-averaged wind power observations. Wind speed changes occurring on this time scale should be within the scope of what a typical NWP model with a 10-20 km resolution can forecast. Ramps in wind power have been defined as situations where the change in aggregated wind power within 3 hours exceeds a specified threshold (eg. 75% of rated power).

A previous study was made assessing the types of ramps occurring at Woolnorth [8, 9]. These were categorised into wind speed ramps from fronts, troughs and low pressure systems, as well as high wind speed shut downs.

An example of an interesting, rare high-risk event is shown in Figure 2, below. The figure shows the observed wind power and wind speed for 3 wind farms in South Australia and Woolnorth in Tasmania. The period shown is from 20:00 on 29th August to 8:00 on 31st August 2005 UTC, where a deep low and associated front moves across all 4 of the farms in succession. As it does this, it causes a few hours of high wind speeds which trigger high wind speed shut-down at a few but not all wind farms. The shut-down is most extreme when it reaches Woolnorth as shown in the figure which shuts down completely for 4 hours. The MSLP analyses are shown for every 6 hours during the period, labelled by numbers on the charts and axes to show the time they were made.

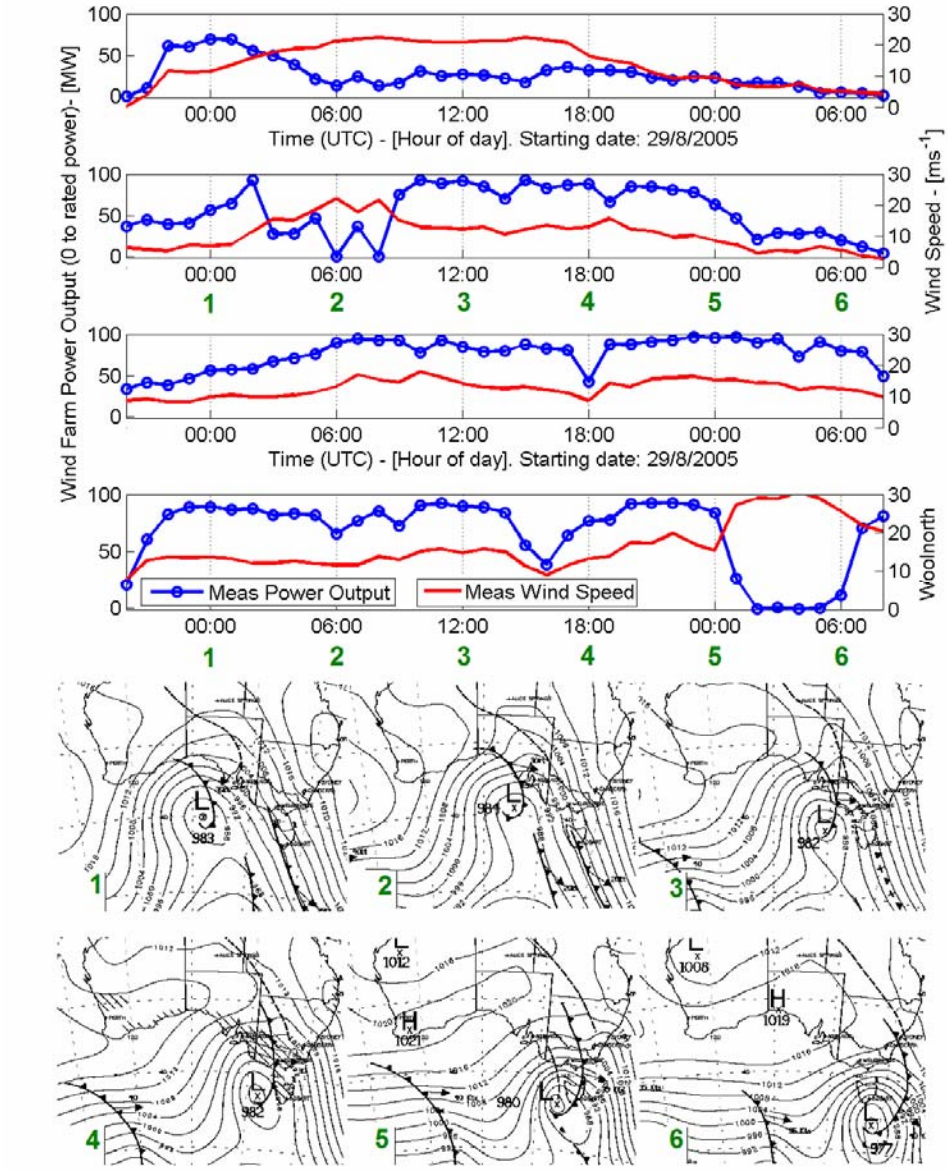

Figure 2: Example of a rare high-risk scenario as a front and deep low caused shut-down (>25 m/s wind) at various Australian wind farms as it moved over 36 hours. The numbers on the MSLP analyses shown correspond to the 6 time stamps numbered on the wind speed/power plots.

5. Traditional forecast performance

Forecasting systems based on NWPs and learning algorithms may not forecast ramps in wind power well because:

- The spatial resolution of NWPs may be too coarse,
- The events are too rare to support an effective learning process,
- Forecasts of these events may mistime or smooth out a ramp, or mask the event completely.

Figure 3 (upper) shows an example of a ramp event at Woolnorth, with the wind power forecasts made by Weprog and WPPT. The lower plot shows the wind speed and direction observations with the corresponding forecasts of Weprog and MesoLAPS. Both the wind power and speed forecasts show that the ramp rate was underpredicted. The fact that the slopes of the wind speed forecasts are slight indicates that the NWP models failed to capture the severity of this event at Woolnorth. Since both the Weprog and WPPT forecasts used, employ statistical methods to optimise the wind power forecast for overall error, it is likely that they worsen this effect because of uncertainty in the timing of such events.

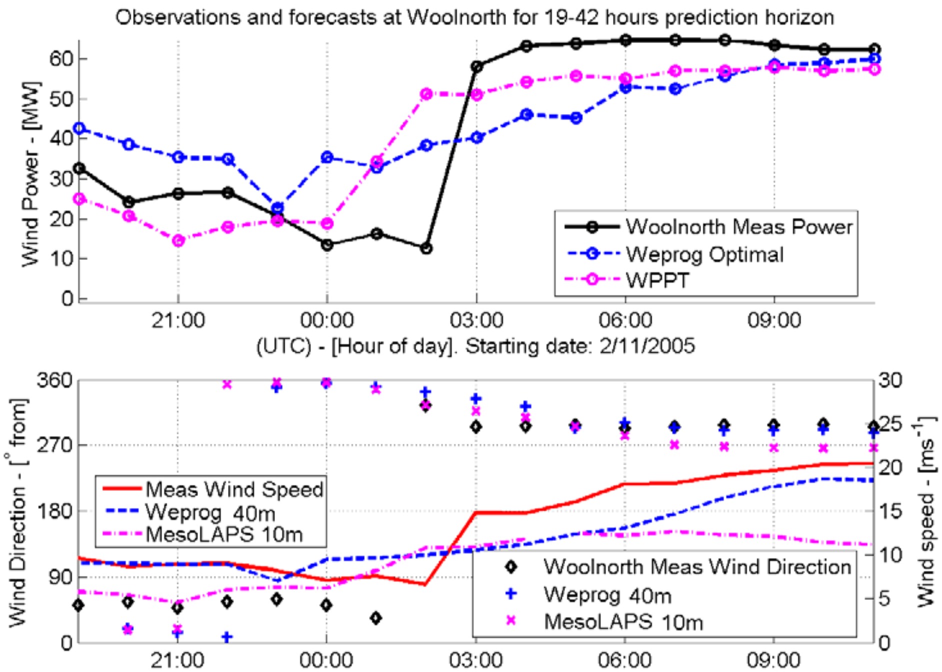

Figure 3: Example of forecasting smoothing of a high-risk scenario at the Woolnorth wind farm in Tasmania, with the forecasts from Weprog and WPPT/MesoLAPS. The upper plot shows the wind power observations and forecasts, and the lower plot shows the wind speed and direction observations and forecasts. The heights of the wind speed and direction forecasts above the NWP model level are also shown.

The forecast error over one year is compared for Weprog and WPPT in the following. The RMSE is used and this is decomposed into the bias (BIAS), the standard deviation bias (SDBIAS) and the dispersion (DISP) so that $RMSE^2 = BIAS^2 + SDBIAS^2 + DISP^2$ [18]. DISP represents the error that is irremovable with time independent statistical techniques.

These error measures are shown in Figure 4 comparing Weprog using two different prediction horizons; 7-30 hours and 19-42 hours. WPPT is only shown for 19-42 hours. The error measures are shown on the left plot for the whole year of data (where all of the forecasts and observations used are available simultaneously) and for two subsets of this data in the other plots. The subset used in the middle plot is for the periods during which there is a detected ramp (see section 4). The start and end of these periods is determined manually for each case and is typically only 4 or 5 hours. The subset used in the right plot is for the same periods used in the middle plot plus an extra 6 hours before and after those periods.

Figure 4 shows that the statistical optimisation methods used by Weprog and WPPT are working well since the BIAS, and to a lesser extent the SDBIAS are minimised for the whole year. In agreement with intuition the SDBIAS is larger for the period during ramps than for the whole period. DISP has the main contribution to the RMSE for the whole period and during ramps. Weprog and WPPT have similar RMSE during ramp periods, but only Weprog improves significantly for periods ±6 hours. Overall, the plot demonstrates that forecasts with prediction horizons of 19-42 hours are not as accurate during ramps than in general. Weprog at 7-30 hours prediction horizon has lower RMSE for ramps ±6 hours than for whole year, probably due to extended periods of zero and full rated periods before and after ramps, which would have a low forecast error.

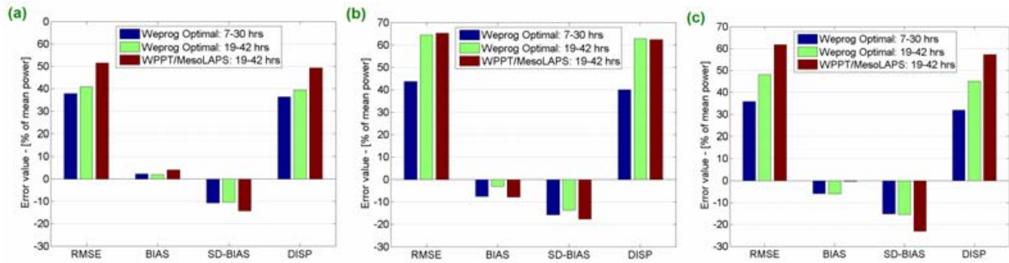

Figure 4: RMSE, BIAS, SD-BIAS and DISP (dispersion) at Woolnorth for 2 different forecasting systems, the Weprog MSEPS and WPPT. Weprog is shown for two different prediction horizon ranges: 7-30 hours (left bar) and 19-42 hours (middle bar). WPPT is shown for 19-42 hours (right bar). The error is calculated for the whole 1 yr period (a), during periods of 11 ramps (b) and during the 11 ramp periods with 6 hours before and after as well (c).

6. A complimentary ramp forecast

Traditionally, Bureaus of Meteorology and their Numerical Weather Prediction (NWP) systems have had a focus on forecasting weather at the surface of the earth as this is the region that directly affects traditional human activities. Additional Bureau services have been added in more recent times such as upper air forecasting for the aviation industry. However the main foci for many weather Bureaus have been on forecasting rainfall, temperatures 2m above the surface and to a lesser degree, wind speeds at 10m above the surface. Consequently, the Australian Bureau of Meteorology's large computer data storage systems are designed to store surface forecast variables from NWP models at a 1 hour resolution (this includes rainfall, 2m temperature and 10m winds among many others things) but store all forecasts at model levels above the surface (typically from 10m to many km) at only a 6 hour resolution. Many current commercially available wind energy forecasting packages (eg. [6, 18]) use a single grid point, 10m wind forecast from an NWP to predict the wind power for one wind farm. Statistical and/or physical approaches are used to convert the 10m wind forecast to a wind energy forecast. In theory this requires scaling of the 10m wind speed to hub height (typically at 50-80m) and conversion through the power curve of the wind turbines. The problem with using winds at 10m height in the NWP models is that 10m winds are heavily influenced by the local topography, yet NWP models represent the topography very coarsely. Furthermore, since the topography is poorly represented, it may be that nearby grid points have a better representation of the current wind behaviour than the closest ones to the wind farms, and that this would be situation dependent (at least dependent on wind direction). Finally, due to the nature of the coarse horizontal resolution of NWP systems, it is conceivable that broader weather systems associated with large scale horizontal momentum would be better modelled than smaller unstable situations with a high level of vertical momentum. There has already been much work published discussing how High pressure systems are predicted better by NWP systems than Low pressure systems (eg. [19]). In consideration of these ideas, assuming that the power curve and height scaling of the wind speed is done with precision, the aforementioned method of forecasting wind energy is only valid if:

1. The topography within many grid points of the wind farm is relatively homogenous (such as the ocean or very flat land),
2. The weather situation is a broad systems with mostly horizontal momentum.

To date, none of Australia's wind farms to date are installed in locations satisfying point 1, and many large changes in wind power output occur in weather situations different to that of point 2.

We are exploring ramp forecasting techniques that use dispersed 3-D information from the NWP rather than only information from the grid point nearest to a wind farm. We expect that these techniques would complement rather than replace traditional approaches. Figure 5 shows an impression of some grid points in an NWP model, with a couple of wind farms shown on the terrain. Three close vertical columns of grid points are shown and the two other columns in between are intended to look further away. In the case of WLAPS these vertical columns are 10km apart in the horizontal plane. WLAPS has 61 levels in the vertical, and in the figure only the lowest 6 are shown. For WLAPS the first few levels are approximately 10, 40, 70, 110 and 150m above the model's representation of the terrain, although these vary slightly with pressure. At each grid point, WLAPS makes forecasts of the u, v and w components of wind, temperature, humidity and geopotential height. It is intended to look at all this information see what could be useful for predicting ramps in wind power.

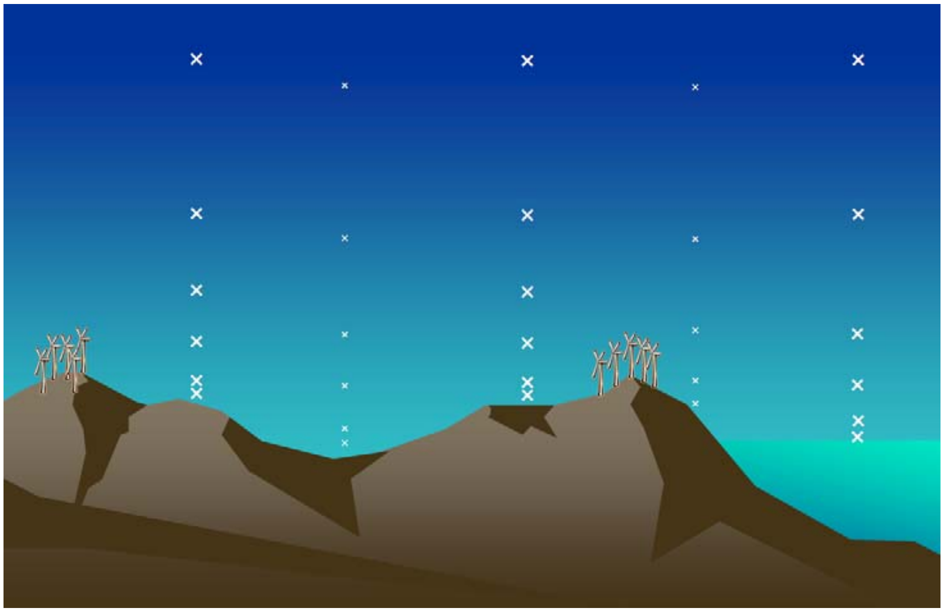

Figure 5: Diagram of the locations of some NWP grid points around a couple of wind farms.

Very early research looking into the WLAPS forecasts at the BMRC suggests that there is valuable forecast information to be gained from higher NWP model levels than 10m. Figure 6 compares the detailed topography at the Woolnorth wind farm site with the representation of the topography at the WLAPS grid points. A striking contrast between the two topographies is the height above sea level where the wind turbines are installed. The nearby grid points to the Woolnorth wind farm are either in the sea (with an elevation of 0m) or on land with an elevation of 10m. However the actual elevations of the turbine sites are all around 100m. One could say that the hill the turbines are installed on cannot be resolved in the model, just as the turbine towers themselves cannot be resolved. This means that, as far as the model is concerned the wind turbines are installed with towers as high as the hill and the towers combined minus the elevation of the grid point used (of course, the hill affects the wind captured by the turbines differently to the arbitrary situation of replacing the hill with taller turbine towers, but these effects cannot be modelled in WLAPS). For example, a wind turbine installed at 100m elevation in reality has a hub height above model level at the closest land grid point (with elevation 10m) of 50+100-10 = 140m. This is a long way from a surface wind speed forecast at 10m.

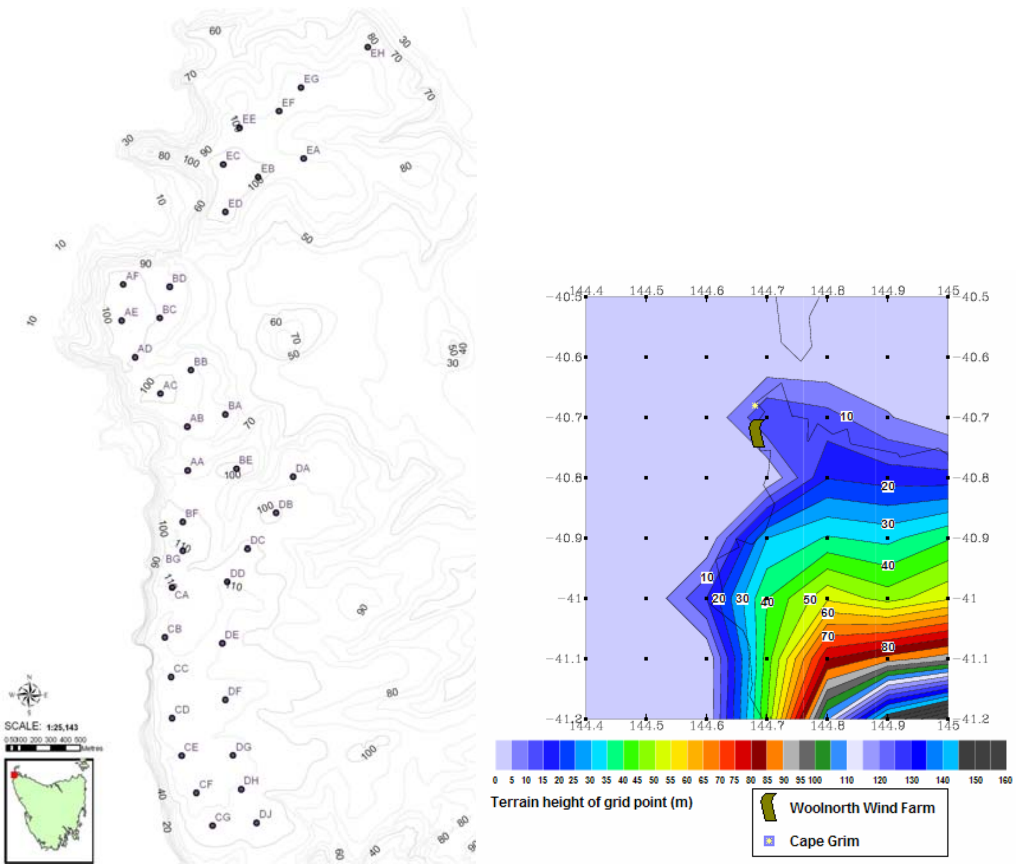

Figure 6: (a) The detailed topography of the Woolnorth site with the turbine layout. (b) The representation of the topography at the Woolnorth site in WLAPS with the WLAPS grid points, the Woolnorth wind farm area, and the Cape Grim Baseline Air Pollution Station shown for reference.

The following 3 figures show some preliminary results from case studies using WLAPS forecast data. The case studies are of ramp events occurring in 3 quite different synoptic situations. For each case the figure shows the broad synoptic situation as made by the Bureau's LAPS analysis [7], with the observations and various forecasts of the wind speed from WLAPS over a couple of days. The wind speed observations are an average of the wind speeds measured by the sonic anemometers mounted on each turbine. All the WLAPS forecasts are at the closest land grid point to the wind farm, at 40.7°S and 144.7°E as shown in Figure 6, except one as labelled at 28km SW (at 40.9°S and 144.5°E). The forecasts are taken from initialisation times at 12 UTC, and their prediction horizons vary from 12 to 35 hours. The 10m forecasts and observations have a 1 hour resolution whereas the model level forecasts have a 6 hour resolution (as explained above). The model levels chosen are at sigma levels 0.9972, representing the closest model level to 50m height, and 0.9841 representing the closest model level to 150m. These model levels forecasts will be hereby referred to as the 50m and 150m forecasts.

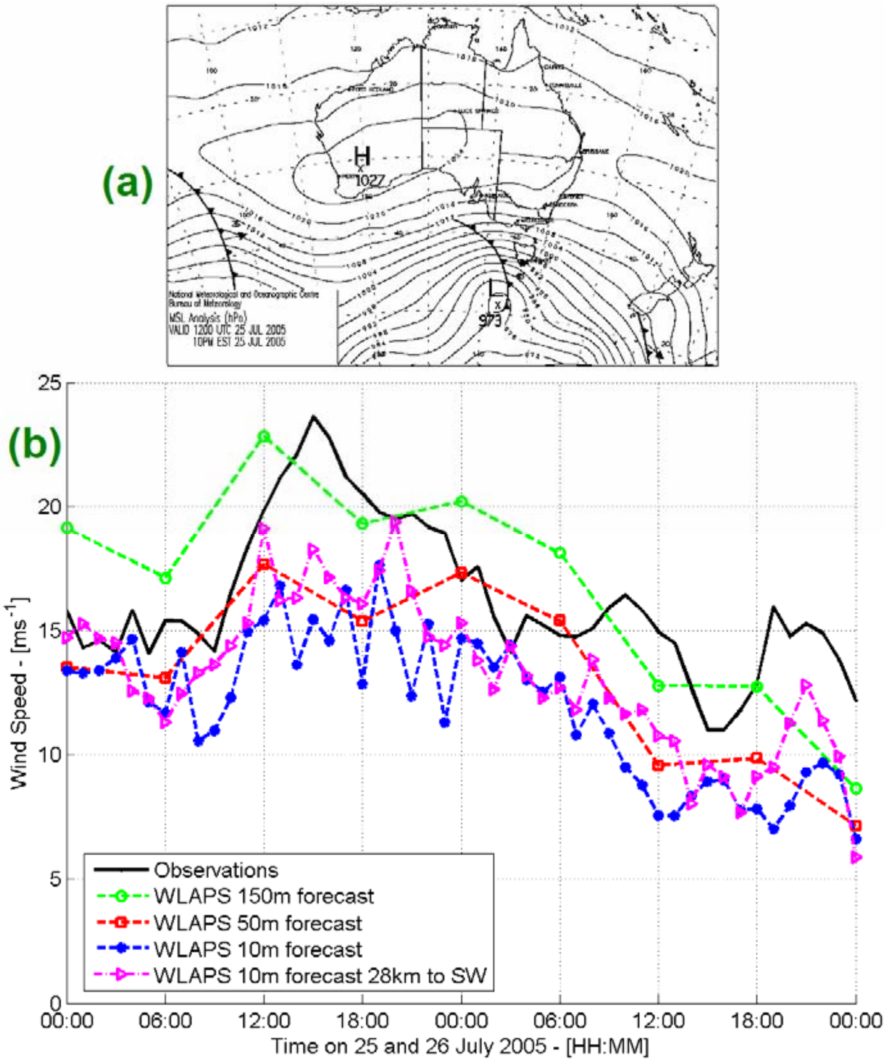

Figure 7: A ramp event at Woolnorth wind farm caused by a front. (a) A BoM's LAPS MSLP analysis just before the event. (b) WLAPS wind speed forecasts at various heights and locations compared with the observations for the event.

The first case study is of a frontal system causing a wind speed ramp at Woolnorth in broad scale westerly flow – see Figure 7(a). The wind speed observations and WLAPS forecasts are shown for this event in Figure 7(b). The example shows that the event is predicted quite well by the model with the major features and their ramping rates and is best captured by the 150m forecast. Note that the timing of the peak is unfortunately not available at a higher resolution than 6 hours at the model levels, although closer to an uncertainty of 1 hour would be more useful from a power system security or market perspective for an event such as this. The hourly 10m wind forecast at the same land grid point is unfortunately not very correlated with the observations. The 150m forecast also has a much closer magnitude to the observations than the 10m or 50m forecasts. The wind directions are predominantly from WSW (not shown) and are also predicted well for this event, at 150m as well as at 10m. The 10m forecast from a nearby grid point in the sea, 28 km SW of the other is also shown in Figure 7(b). This forecast is clearly much more correlated to the observations than the 10m wind at the closest land grid point. These are positive early signs into the possibility that improvements wind power prediction can be made by utilising more information from an NWP than one grid point at one height.

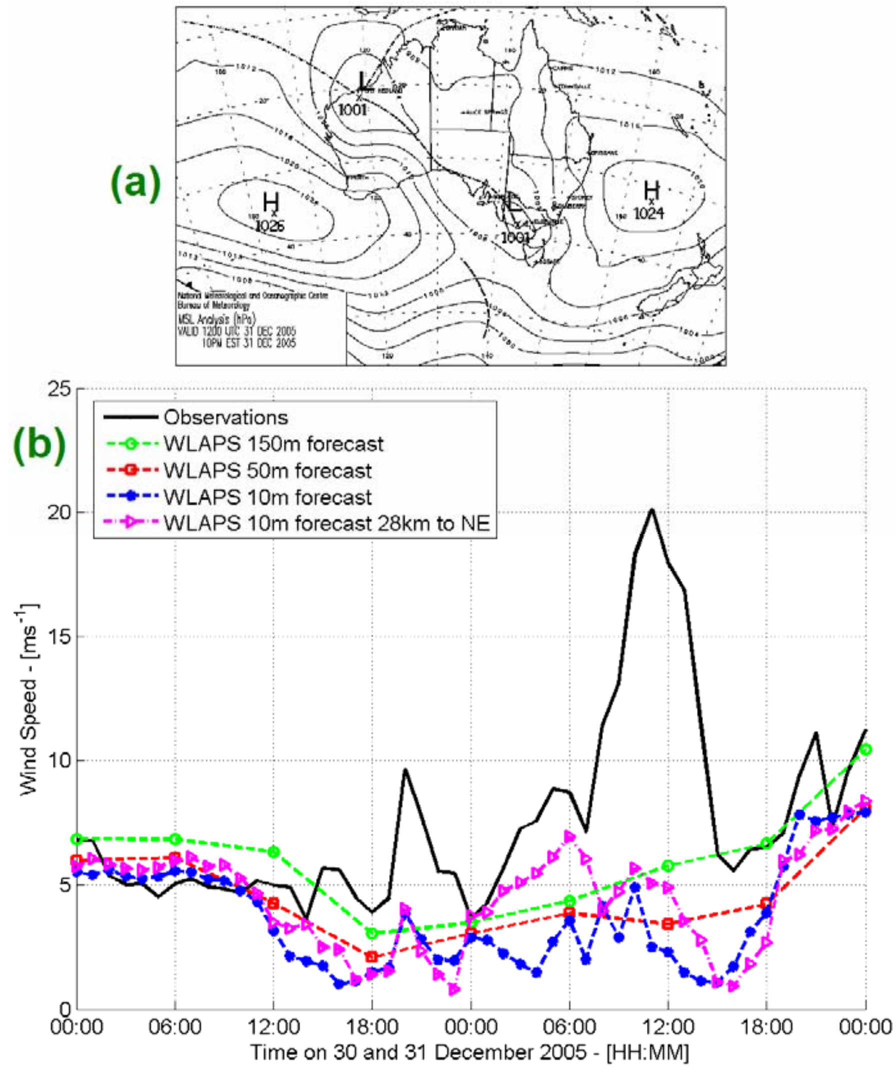

Figure 8: A ramp event at Woolnorth wind farm caused by a low pressure system. (a) and (b) are as in Figure 7.

Figure 8(a) shows the MSLP analysis before a low pressure system moves close to Woolnorth – a very different situation to the first case study above. In this case, the wind directions (not shown) are again predicted close to the observations for all shown model heights and this is a good indication that there is no timing error with the event. However the wind speeds have a major peak at 11:00 on 31 December which is not predicted well by any forecast shown. The closest forecast of this peak is at the nearby grid point 28km NE of the main grid point used, which like the previous case is also in the ocean (see Figure 6(a)). Also like the previous case, this is upstream from the wind farm, since the wind directions at the time of the peak are from around the NE. Further study is required into the vertical nature of low pressure systems such as these, as well as its precise movements to ascertain why the model got it wrong here. This includes looking at the model's prediction of the position of the high pressure systems as this influences the movement of the centre of the low.

The final example is at the Cathedral Rocks wind farm in South Australia. It is a coastal wind farm where the topography is similarly too complex to be resolved well in WLAPS (not shown). The four nearest grid points to the wind farm are at 0 (sea), 5, 15 and 25m above sea level whereas the turbines are all installed at around 100m elevation in reality. The grid point of reference used is a few km NW of the wind farm at 34.8°S and 134.6°E, at which the model terrain is represented at 25m above sea level. The other grid point featured in the figure is 30km south of this reference grid point. In this case study, the weather system is what appears to be a broad scale, stable, high pressure system (see Figure 9(a)). However, as shown in the observations in Figure 9(b), a ramp in wind speed occurs over 3 hours from 10:00 to 13:00 UTC. This ramp is not due to a sea breeze since the wind directions change to be from the NE (the opposite direction than the sea) as the ramp occurs and the event is in winter (August). Even though the event is unobservable from the broad scale MSLP, the WLAPS 150m forecast captures the event quite well. Interestingly in this case, the 50 and 10m forecasts have the right trend but have much too slow ramp rates. Further investigation is needed to work out why this is. During the event, the wind direction is from the north, so the 10m wind forecast from a nearby grid point in the sea south of the farm is also shown. As with the above cases, the level of this 10m wind speed forecast is closer to the observations when the land grid point 10m wind speed forecast under-predicts.

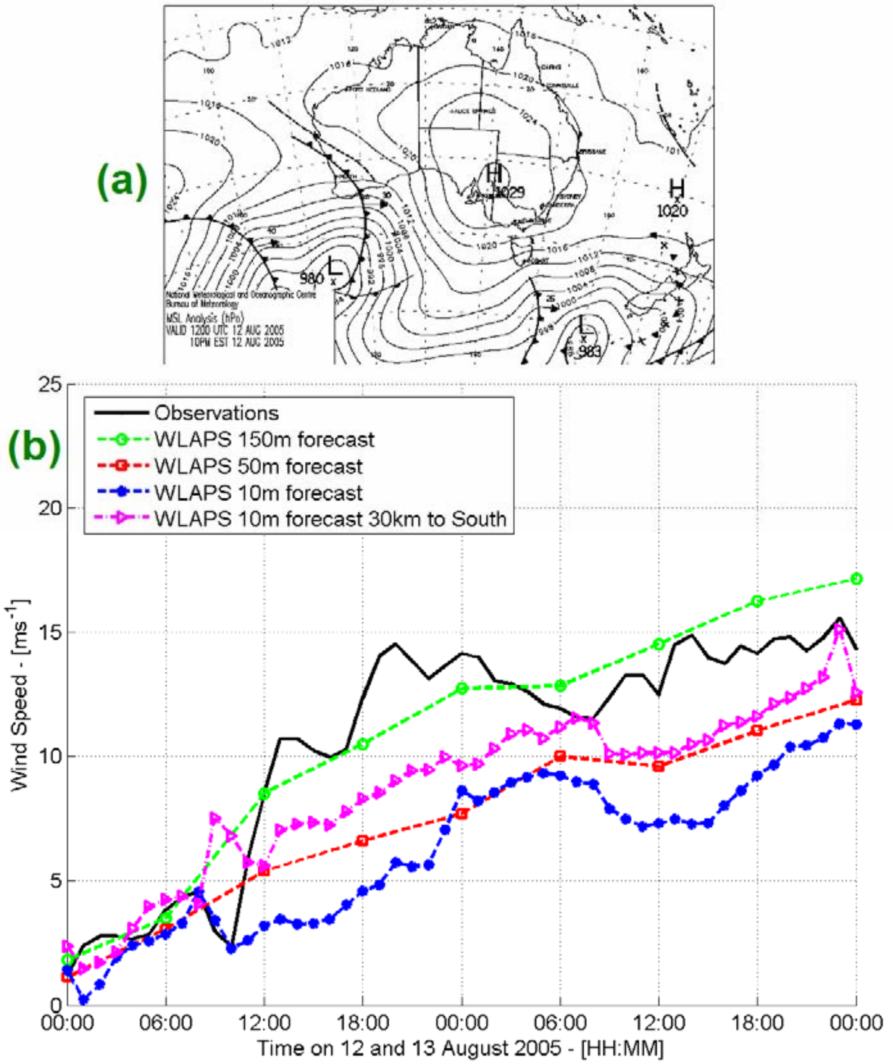

Figure 9: A ramp event at the Cathedral Rocks wind farm in South Australia occurring during a high pressure system. (a) and (b) are as in Figure 7.

The initial case studies on WLAPS show some promising results. Much more in depth research is planned for coming months to attempt to answer, among many, the following questions.

1. What do NWP systems forecast well for wind power prediction and what do they not forecast well. The answer is likely to be dependant on weather situation, grid point location, model level height, and individual wind farms.
2. Using the knowledge from question 1 above, what kind of strategy arises to make a wind energy forecast, particularly for large changes in wind power output.

7. Conclusions

As the penetration of wind power increases in a region of a power system, the prediction of large, rapid changes (ramps) in wind power output becomes more critical to manage power system security and market stability. Studies on the weather patterns relating to ramps in wind power for some of Australia's wind farms show that there are potentially frequent periods where it is possible to accurately predict that a significant ramp will not occur. During other periods, accurate prediction of ramps, including their timing is not a trivial task. It is likely that the techniques to optimise a forecast to reduce the overall error will be different to the techniques used to optimise the predictions of ramps. In section 6 some case studies on an NWP model have been made which indicate that there could be useful information to gain from NWP forecasts at different grid points near to the wind farm, especially at appropriate heights above the model terrain. It is intended to investigate this further and to consider looking at other forecast variables than wind speed and direction, as well as if there can be situation dependency on which grid points and variables are useful. This is likely to be weather situation dependent also.

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