Centre for Energy and Environmental Markets AEMO UNSW

Presenting NWP forecast information on potential large rapid changes in wind power generation

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www.ceem.unsw.edu.au

Talk outline

- **PART 1**

  Overview on the wind power forecast spatial fields approach to wind power forecasting using NWP forecasts from multiple grid points

- **PART 2**

  Preliminary results for the prototype wind power forecasting tool currently being developed for AEMO

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Project background

- Australian Government funded CEEM to undertake research to facilitate the uptake of wind energy in the Australian National Electricity Market, including:
  - Nick Cutler's wind forecasting PhD, completed in 2009
- Australian Energy Market Operator (AEMO) funding current project to further develop Nick's PhD wind forecasting techniques into a prototype extreme events wind forecasting model.
- If successful, this could be an enhancement to AEMO's Australian Wind Energy Forecasting System (AWEFS)

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Value of wind forecasting

- Wind power generation has been shown in a pre-vious study to have an effect on spot prices in SA*
- Wind forecasts (0-24 hours lead time) can allow better spot price forecasts, and in turn allow:
  - Generators to optimise their bidding strategies
  - Demand-side response groups to better capitalise on price spikes
- Power system operators can use wind power forecasts to plan for potential large disturbances
- Slow-start generators can better plan their unit commitment

*See http://www.crawford.anu.edu.au/research_units/eerh/pdf/EERH_RR38.pdf

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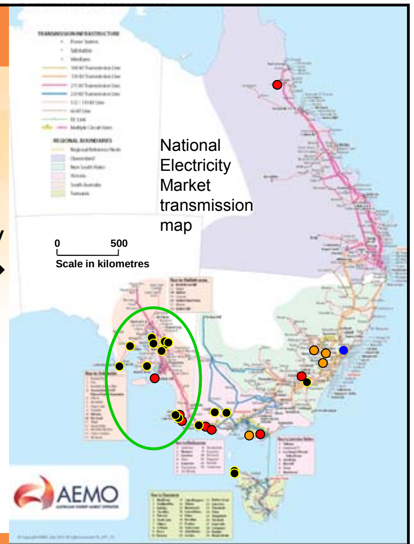
Wind Energy in Australia

- National Electricity Market (NEM) →
- Wind Farms currently installed in the grid →

Legend:
Wind farm size
- 0-1 MW
- 1-10 MW
- 10-50 MW
- > 50 MW



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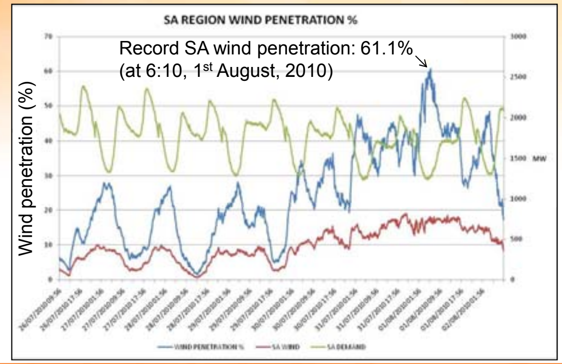
Growing wind penetration in the NEM

- Lead by South Australia:



(Peter Biddle, AEMO)

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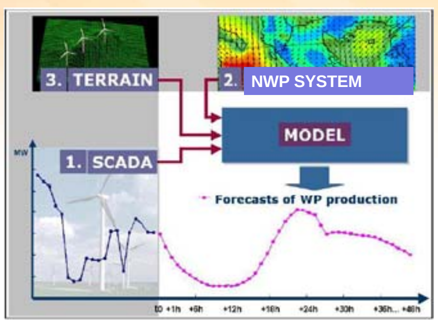
Wind Energy Forecasting Conventional Approach

- SCADA: recent observations
- "NWP " is Numerical Weather Prediction
- "Model" usually contains:
  - "Power curve"
  - Other statistical transformations



(Giebel G, 2003)

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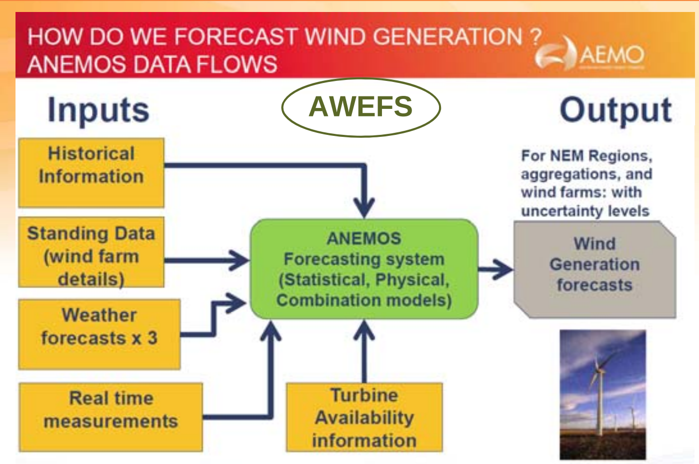

(Slide 8 from AWEFS Overview presentation: http://www.aemo.com.au/electricityops/0260-0007.pdf)

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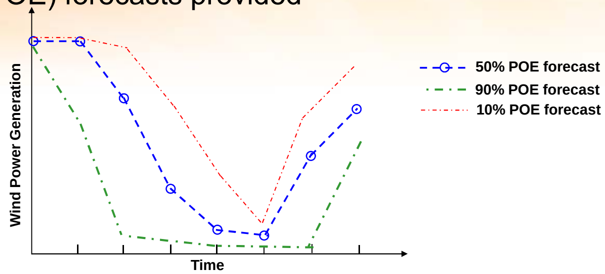
AWEFS – special features

- Forecasts every 5 mins up to 2 hours, then every 30 mins to 6 days, then daily up to 2 years
- 10%, 50% and 90% Probability Of Exceedance (POE) forecasts provided



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AWEFS – special features

- Forecasts every 5 mins up to 2 hours, then every 30 mins to 6 days, then daily up to 2 years
- 10%, 50% and 90% POEs provided
- An extensive wind farm power observation SCADA data set, including wind turbine availability
- Researcher access server
  - And researcher wind farm data access agreements with wind farm data owners
  - Scope for enhancements including beyond Phase B of the AWEFS project

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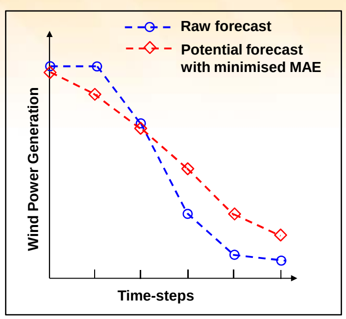
Wind Forecast Performance Assessment

- Systems often designed to minimise average amplitude error, such as mean absolute error (MAE)
- Two potential issues:
  - Temporal sampling and temporal averaging of data
  - Treats forecast errors as independent
    - Large rapid changes with timing uncertainty could be smoothed out



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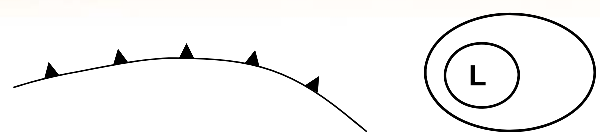
Outcomes from the PhD thesis (1)

- For the Australian wind farms we have studied, large, rapid changes in wind power are largely caused by horizontally propagating synoptic weather phenomena:
  - Eg. Cold fronts and low pressure systems



Outcomes from the PhD thesis (2)

- For the Australian wind farms we have studied, large, rapid changes in wind power are largely caused by horizontally propagating synoptic weather phenomena
- For a particular wind farm, past observations are unlikely to be a good guide to forecast large rapid changes
- Numerical Weather Prediction (NWP) systems are a better source of information for forecasting significant changes in the weather

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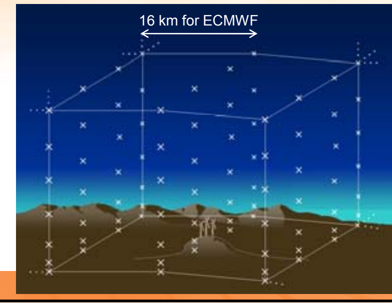
NWP systems (1)

- Represent the atmosphere on a relatively coarse horizontal grid
  - ECMWF global model horizontal resolution is 16 km (increased from 25 km this year) with 91 vertical levels



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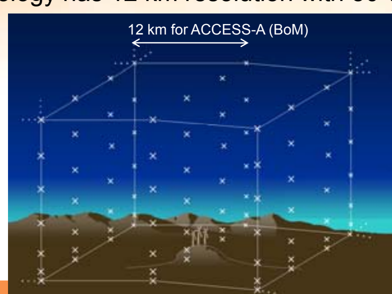
NWP systems (2)

- Represent the atmosphere on a relatively coarse horizontal grid
  - The new local NWP model from the Australian Bureau of Meteorology has 12 km resolution with 50 vertical levels



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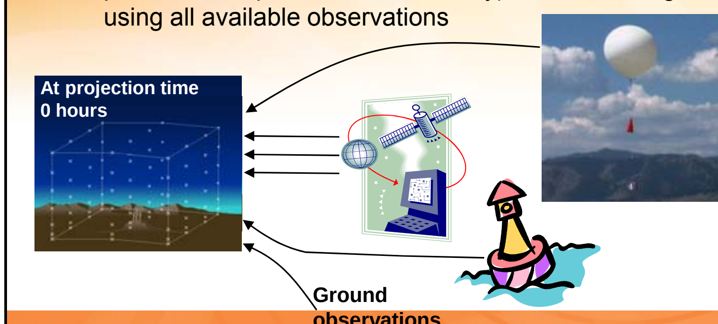
NWP systems (3)

- Forecast is produced in two steps:
  - 1. **Estimate initial state** of the atmosphere (wind, pressure, temperature and humidity) on the model grid using all available observations



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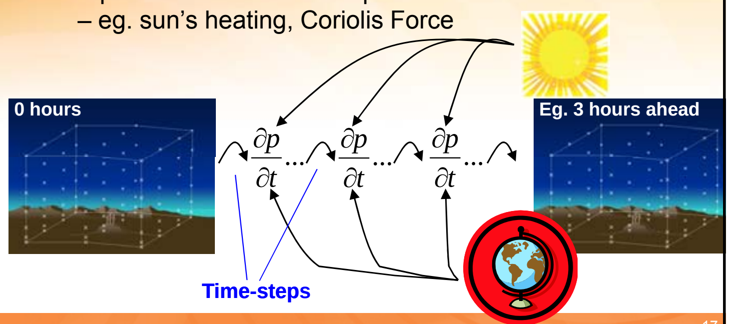
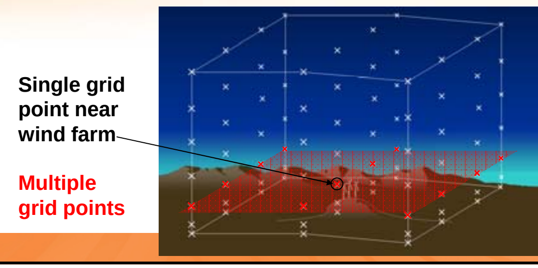
NWP systems (4)

- Forecast is produced in two steps:
  - 2. **Run model forward** in time, solving simplified equations of motion in response to known disturbances – eg. sun's heating, Coriolis Force



NWP systems (5)

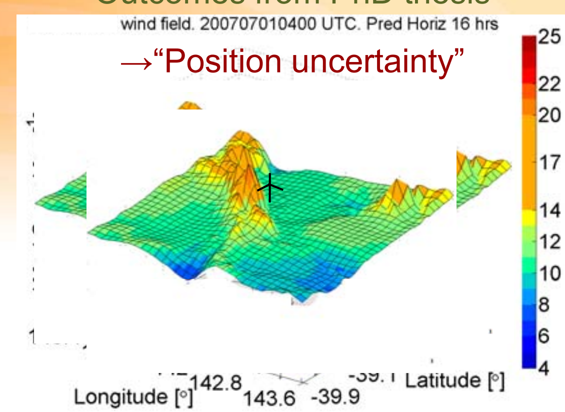
- Conventional use of NWP information: take forecast at a single grid point (or interpolation of grid points) near location of interest at each time step
- Alternatively, could utilise multiple grid points



NWP systems (6)

- Strengths and weaknesses for wind power forecasting
  - Cannot directly model fine-scale detailed topographic effects on the wind due to coarse resolution
    - Fortunately, large aggregated changes in wind power are not likely to be caused by these effects
  - Good at forecasting broad synoptic weather phenomena (such as cold fronts and low pressure systems) and how they affect near-surface winds out to around 48 hours ahead
  - Uncertain in the timing, or more generally the precise position of such synoptic weather phenomena as they propagate in time

Outcomes from PhD thesis



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Outcomes from PhD thesis

- Identified that conventional time-series forecast derived from a single grid point may be missing useful information in NWP system
  - Position uncertainty during large rapid changes could imply significantly different plausible scenarios to single grid point forecast
- Developed technique to display multiple grid point information from NWP systems to characterise wind forecast uncertainty due to position uncertainty
  - Problem: the wind at each grid point is influenced by the local topography →

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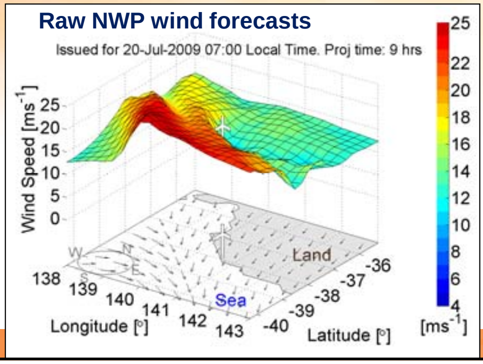
PhD outcomes: Terrain standardisation method

- Develops relationships between grid points based on historical data to standardise effects of topography



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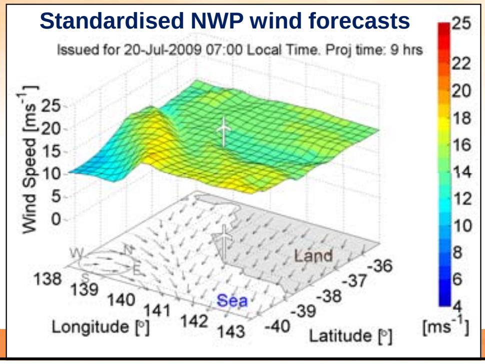
PhD outcomes: Terrain standardisation method

- Develops relationships between grid points based on historical data to standardise effects of topography



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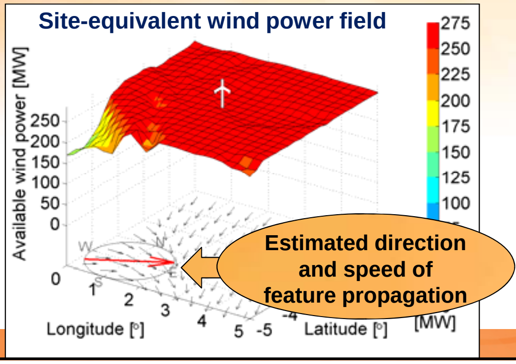
PhD outcomes: Convert wind field to wind power

- Develops relationships between historical forecasts and observations to create:



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PhD outcomes: animation of wind power forecast fields

- Potential forecasting tool for the control room
- They help the user to visualise different plausible scenarios for wind power generation
- An example for SESA:
  - Summated wind power generation from Lake Bonney 1, Lake Bonney 2 and Canunda (total rating 286 MW)
  - Large rapid change event on 8 December 2009

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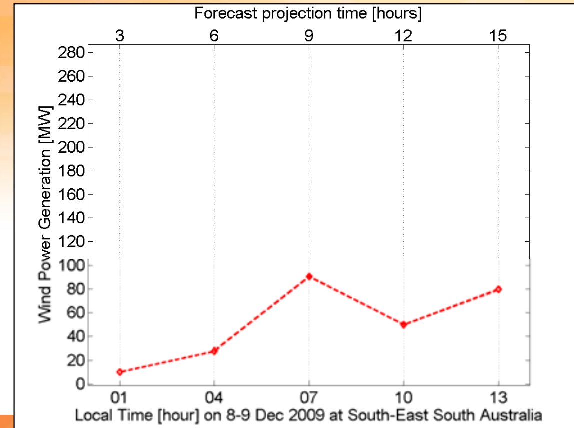
Second event, the single grid point forecast



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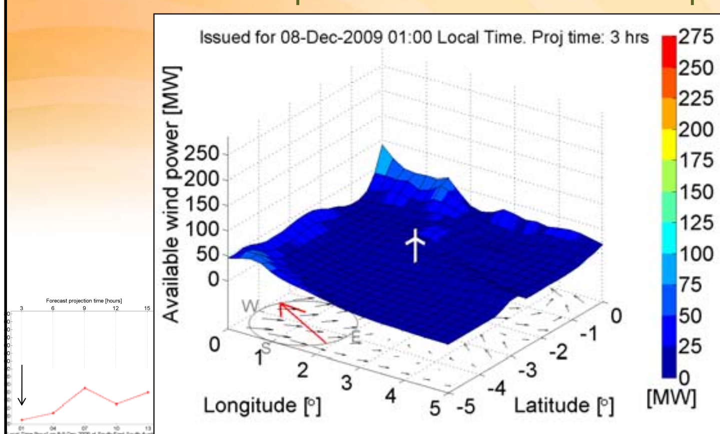
Animation of wind power forecast fields example



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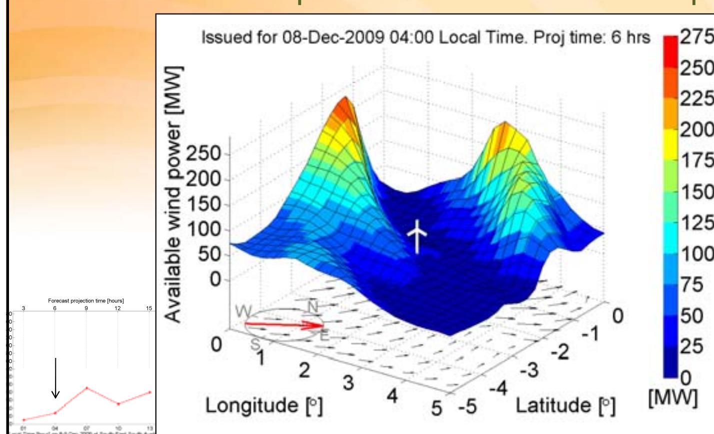
Animation of wind power forecast fields example



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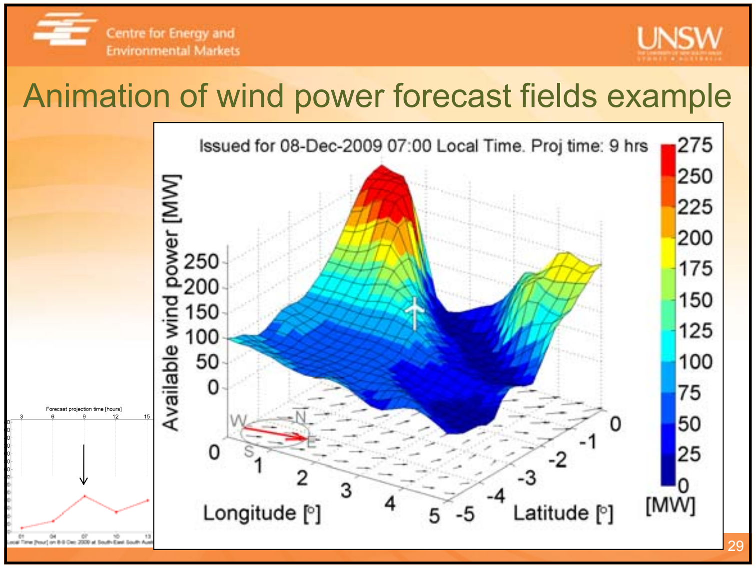

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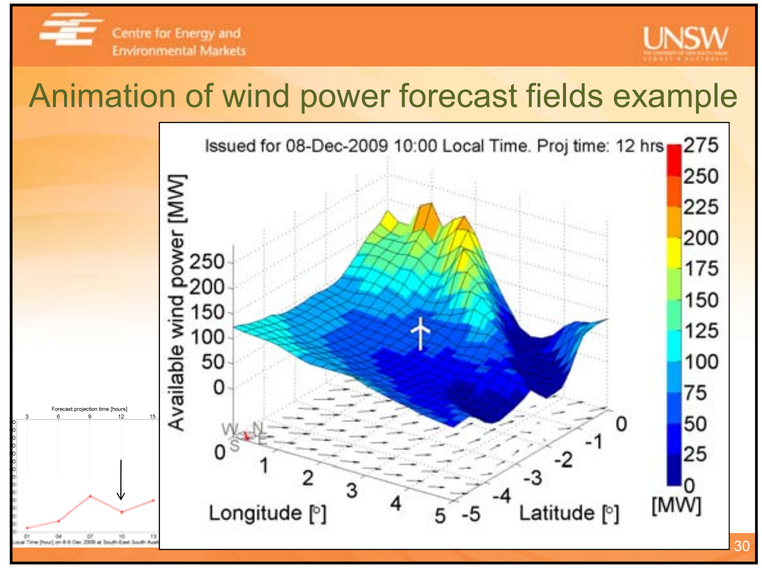
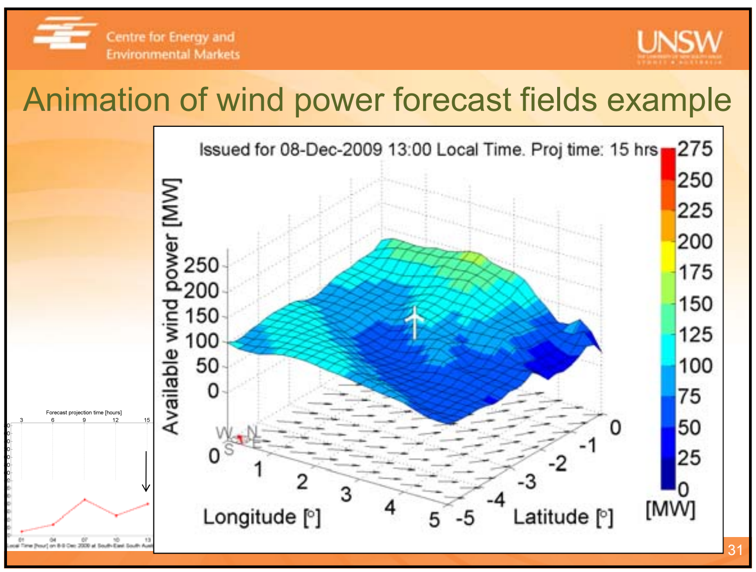
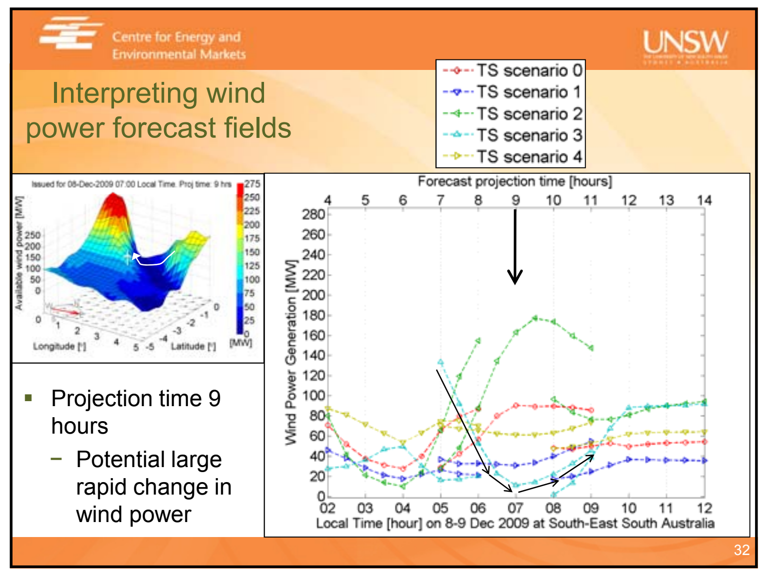
UNSW
Animation of wind power forecast fields example
Issued for 08-Dec-2009 07:00 Local Time. Proj time: 9 hrs
Available wind power [MW]
Longitude [°]
Latitude [°]
[MW]
29



Centre for Energy and Environmental Markets
UNSW
Animation of wind power forecast fields example
Issued for 08-Dec-2009 10:00 Local Time. Proj time: 12 hrs
Available wind power [MW]
Longitude [°]
Latitude [°]
[MW]
30



Centre for Energy and Environmental Markets
UNSW
Animation of wind power forecast fields example
Issued for 08-Dec-2009 13:00 Local Time. Proj time: 15 hrs
Available wind power [MW]
Longitude [°]
Latitude [°]
[MW]
31



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UNSW
Interpreting wind power forecast fields
TS scenario 0
TS scenario 1
TS scenario 2
TS scenario 3
TS scenario 4
Forecast projection time [hours]
Wind Power Generation [MW]
Local Time [hour] on 8-9 Dec 2009 at South-East South Australia
Projection time 9 hours
Potential large rapid change in wind power
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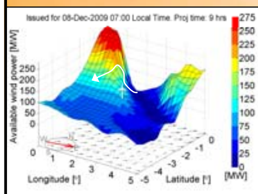
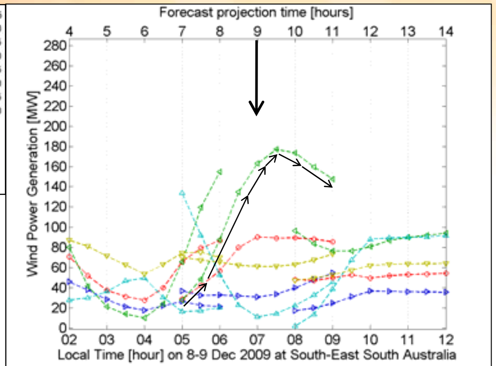
Interpreting wind power forecast fields

TS scenario 0
TS scenario 1
TS scenario 2
TS scenario 3
TS scenario 4



- Projection time 9 hours
  - Potential large rapid change in wind power



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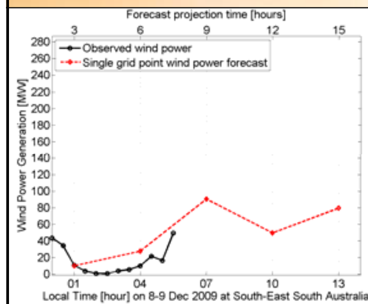
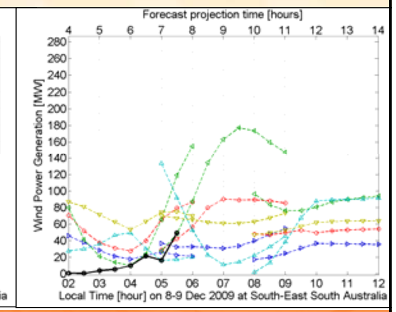
Interpreting wind power forecast fields

- Observations up to 5:30

Observed wind power
TS scenario 0
TS scenario 1
TS scenario 2
TS scenario 3
TS scenario 4





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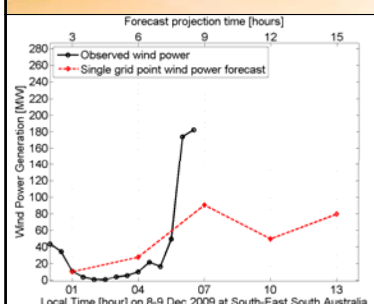
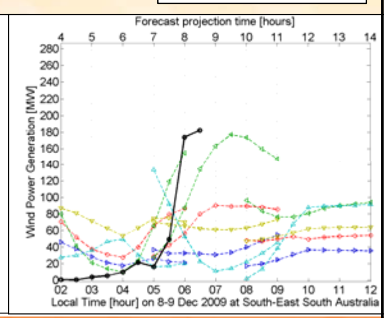
Interpreting wind power forecast fields

- Observations up to 6:30

Observed wind power
TS scenario 0
TS scenario 1
TS scenario 2
TS scenario 3
TS scenario 4





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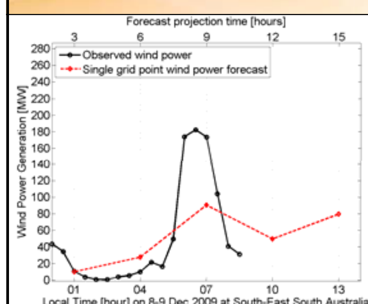
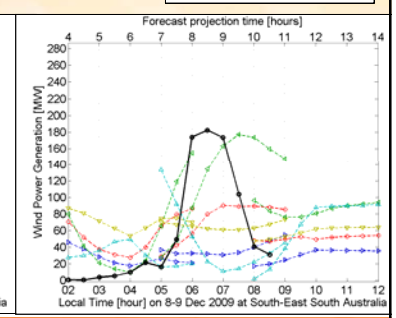
Interpreting wind power forecast fields

- Observations up to 8:30

Observed wind power
TS scenario 0
TS scenario 1
TS scenario 2
TS scenario 3
TS scenario 4





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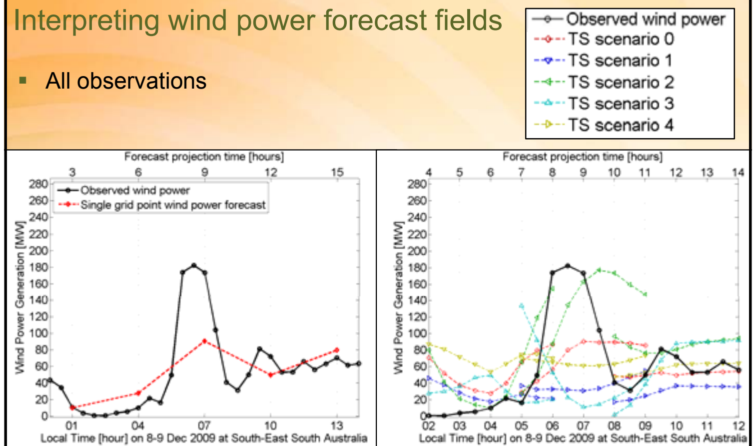
Interpreting wind power forecast fields

- All observations



Animated wind power field versus NWP ensembles

Animated spatial fields	NWP Ensemble
Data currently exists in AWEFS	More expensive to purchase
Single NWP model typically has a higher spatial resolution	Typically has lower spatial resolution
Highlights chronological behaviour	If used for single grid point scenarios, they are subject to sampling error
Scenarios based on misplacement errors from one plausible evolution of the atmosphere	Could characterise different evolutions of the atmosphere
Can show very different scenarios within a short forecast horizon, with a more sensitivity during the events of interest: large rapid changes	May not provide very different scenarios in the first 24 hours because it can take some time for the ensemble members to differ

PART 2

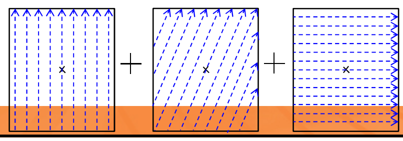
The prototype forecasting tool for AEMO

- The prototype tool is specified to provide information in two steps:
  - Raise **alerts** when there is the possibility of a large rapid change occurring within a forecast horizon of 48 hours
  - For each alert, **presentations of** the available **forecast information** is to be provided highlighting plausible multiple scenarios for wind power generation, in 2 forms:
    - An animation of successive wind power spatial fields,
    - A time-series plot showing multiple scenarios, with an indication of their associated probability.
  - These presentations would only be assessed by the operators if they deem the alert to occur at a critical time (eg. other constraints in the network)

Alerting without an estimated propagation speed/dir

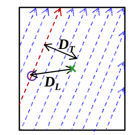
- From experience:
  - Assume propagation speed is 5 grid points/hr north-south (or around 140 km/h, fixed)
  - Assume propagation direction has a westerly component with one of nine evenly spaced possibilities, i.e.

  - With one grid point spacing for potential displacements, this gives 158 traces in each wind power field, eg.



Alerting without an estimated propagation speed/dir

- Ranking the alerts:
  - For each detection we have:
    - ***S***: The size of the large rapid change (how much larger than the threshold is it?)
    - D_T: The perpendicular distance of the trace from the central grid point (cgp).
    - D_L: The distance from the cgp to the detected large rapid change



Alerting without an estimated propagation speed/dir

- These values are converted linearly to weights, w:
  - For D_T = 0, the weight based on distance is 1 up to 1.5 hours in each direction (because 3 hours between fields) and then decreases linearly:

$$w_{D,D_T=0} = \begin{cases} 1 & D_L \in [0, 210]\text{km} \\ [1, 0.28] & D_L \in [210, 357]\text{km} \end{cases}$$

  - For $D_T > 0$, the weight decreases with D_T by 0.001/km.

$$w_D = w_{D,D_T=0} - 0.001 \times D_T$$

  - The weight based on size of change varies from 1 to 2 from the large rapid change threshold up to the maximum change (rated power).

$$w_S = [1, 2], S = [\text{change threshold, rated power}]$$

Alerting without an estimated propagation speed/dir

- The weights are multiplied together to get the total weight for a detection: $w_{\text{detection}} = w_D \times w_S$
- These weights are then classified into two types:
  - HWS: high wind speed cut-out
  - CWS: change in wind speed
- The weights for each type are added together to get the total weighting for each field, for each large rapid change type
- In addition to the HWS weighting, also made weighting based on number of grid point wind speeds > 19 ms^{-1} in the field with weights reducing with greater distance from the cgp. This is then scaled to be within same range as the HWS weights.

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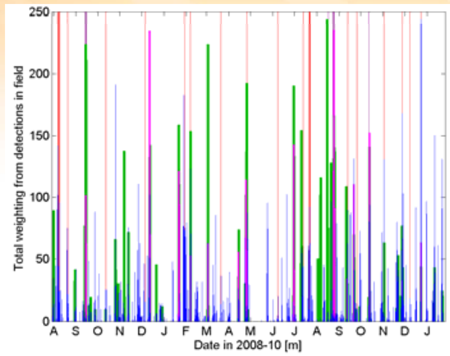
Results: SESA changes by 150 MW in 30 mins

- Detections vs observed event
  - Red: observed CWS event
  - Purple: observed HWS event
  - Blue: w_{CWS}
  - Pink: w_{HWS}
  - Green: $w_{HWS,\ WS>19}$



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Preliminary results
SESA changes by 150 MW in 30min

- 1.5 years of data: 548 days
- Grouped weightings further into periods of consecutive weightings – 1 event can be detected in multiple consecutive fields but only occur once
- Results are tuned to minimise number of missed events – a good place to start

Statistic	CWS	HWS	$HWS_{WS>19}$
Percentage of 3-hour time steps alerted	25%	1%	2.2%
Number of events alerted (by considering alerted consecutive fields as one event)	250	18	47
Number of events occurred	23	9	9
Number of missed events	2/23	1/9	0/9

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Preliminary results

Maximum changes observed for all alert- and non-alert periods, with probability based on weighting for each alert-period

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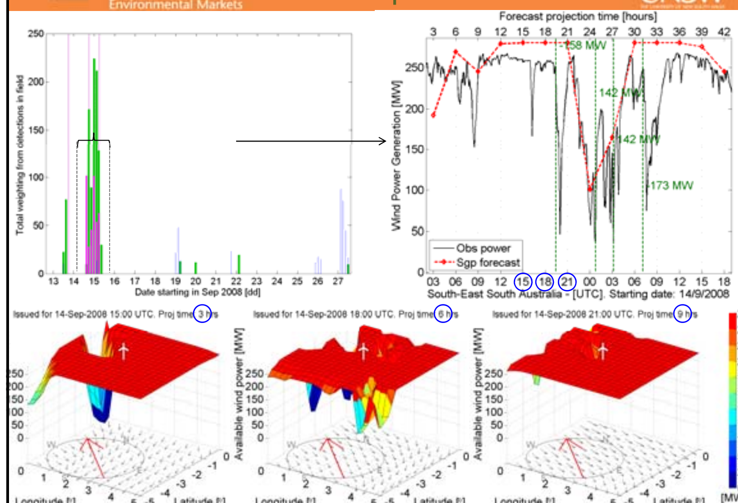
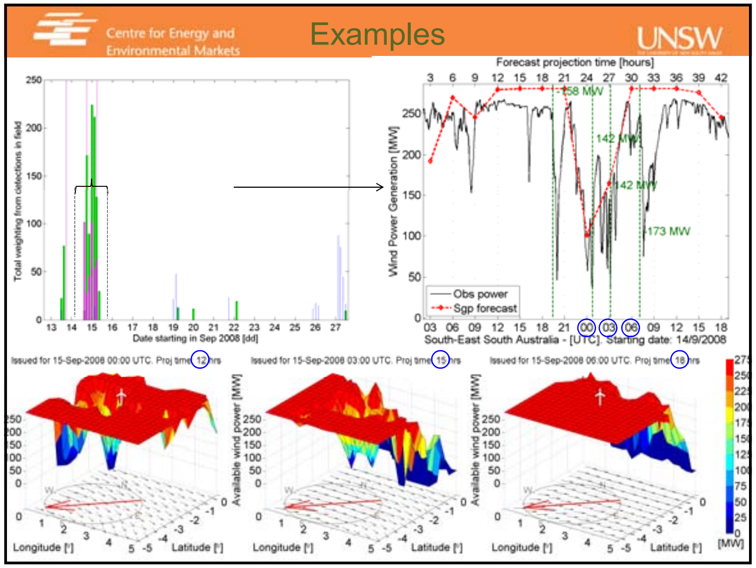
Examples

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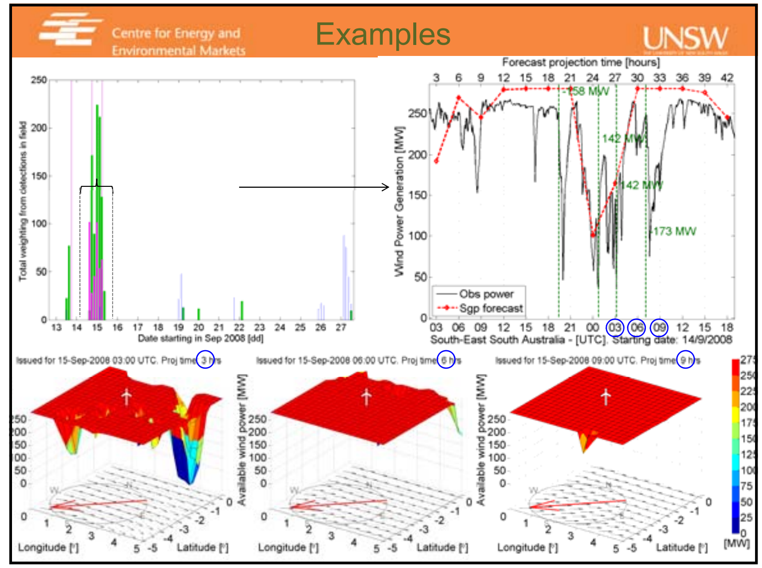
Examples
UNSW
Forecast projection time [hours]
Obs power
Sgp forecast
Wind Power Generation [MW]
158 MW
142 MW
142 MW
173 MW
South-East South Australia - [UTC]. Starting date: 14/9/2008
Date starting in Sep 2008 [dd]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UNSW
Forecast projection time [hours]
Obs power
Sgp forecast
Wind Power Generation [MW]
158 MW
142 MW
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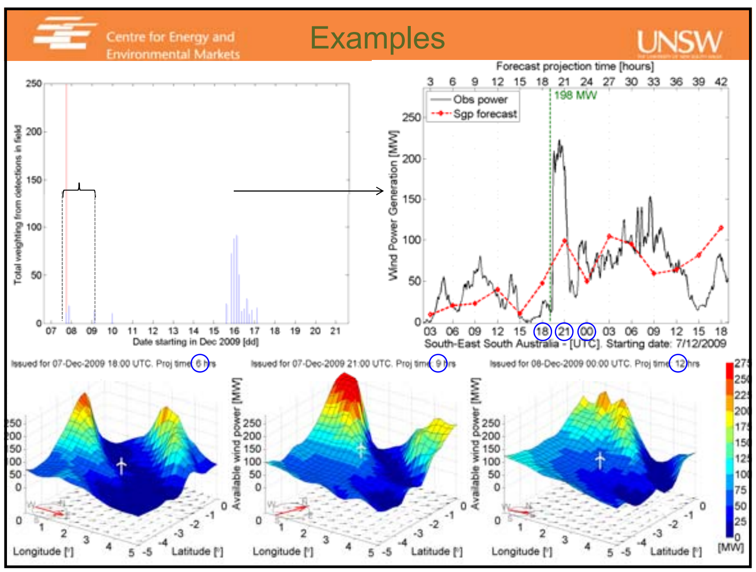
173 MW
South-East South Australia - [UTC]. Starting date: 14/9/2008
Date starting in Sep 2008 [dd]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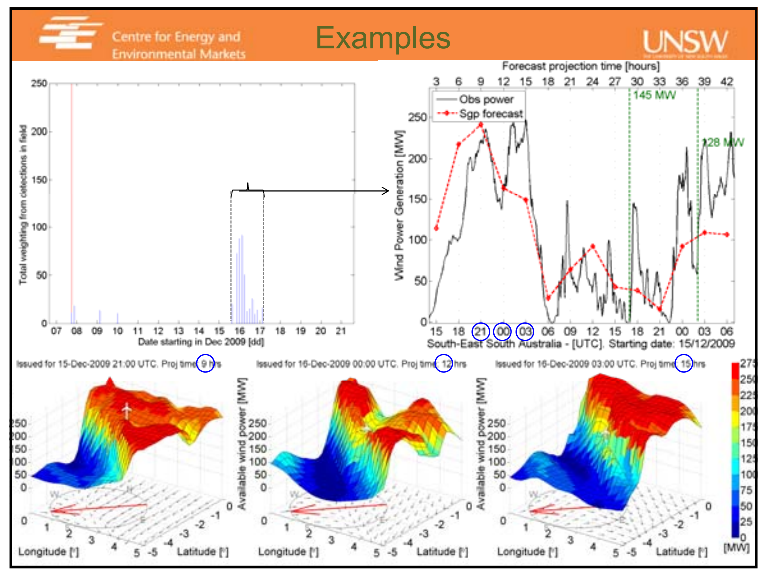
Examples
UNSW
Forecast projection time [hours]
Obs power
Sgp forecast
Wind Power Generation [MW]
198 MW
South-East South Australia - [UTC]. Starting date: 7/12/2009
Date starting in Dec 2009 [dd]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Examples
UNSW
Forecast projection time [hours]
Obs power
Sgp forecast
Wind Power Generation [MW]
145 MW
128 MW
South-East South Australia - [UTC]. Starting date: 15/12/2009
Date starting in Dec 2009 [dd]

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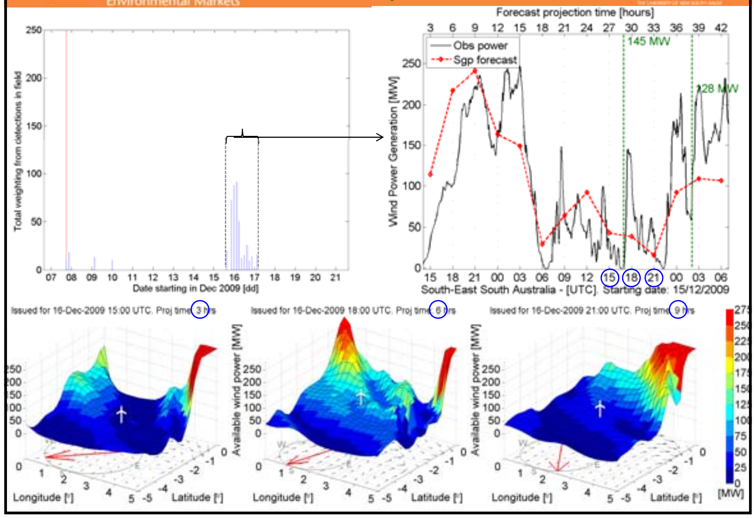
Examples



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Preliminary results

Woolnorth changes by 100 MW in 30 mins

- Same period of 1.5 years of data: 548 days
- Grouped weightings further into periods of consecutive weightings again

Statistic	CWS	HWS	$HWS_{WS>19}$
Percentage of 3-hour time steps alerted	36%	4%	8%
Number of events alerted (by considering alerted consecutive fields as one event)	229	55	123
Number of events occurred	8	18	18
Number of missed events	0/8	5/18	2/18

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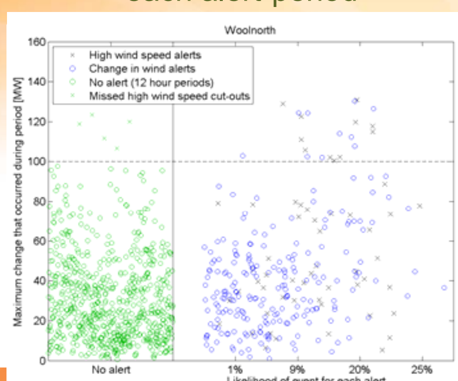
Maximum changes observed for all alert- and non-alert periods, with probability based on weighting for each alert-period



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Further work

- Estimating speed and direction of propagation:
  - Refining the method.
  - Using hourly NWP data – will try to test this using the new BoM ACCESS models.
- Finding suitable ways to aggregate relatively distant wind farm sites.
- Showing different tunings of the results, optimising for less alerts but more missed events

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