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Visual forecasting tool for large, rapid changes in wind power generation

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17th August, 2009

www.ceem.unsw.edu.au

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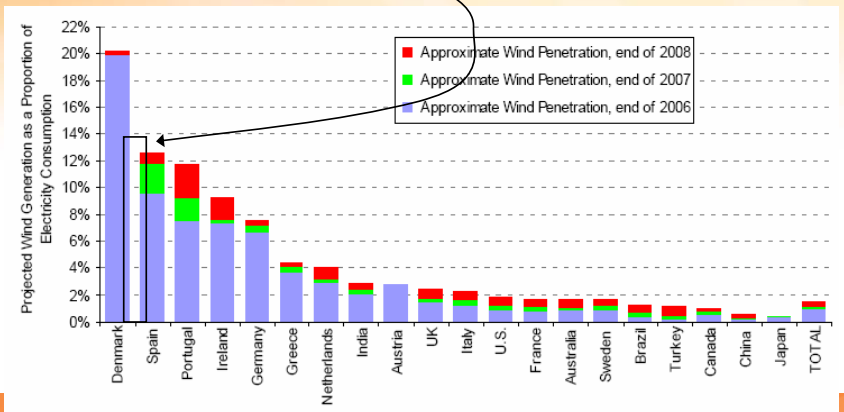
Wind Energy Integration

- Many of the power systems in these countries are interconnected to other countries
- The Australian power system is not even connected east to west!
- Take South Australia on its own… (data source www.aemo.com.au for 2008-9 financial year)



Source: Berkeley Lab estimates based on data from BTM Consult and elsewhere

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Wind Energy Integration

- South Australia currently has around 75% of Australia's wind power installations
  - Good wind, SA government pro-wind
  - But on the end of the NEM network
- Australian Government to expand Renewable Energy Target to increase non-hydro renewable energy capacity by 5 times
- This is expected to be largely met by wind power
- Many discussions around integrating wind into South Australia and the rest of Australia

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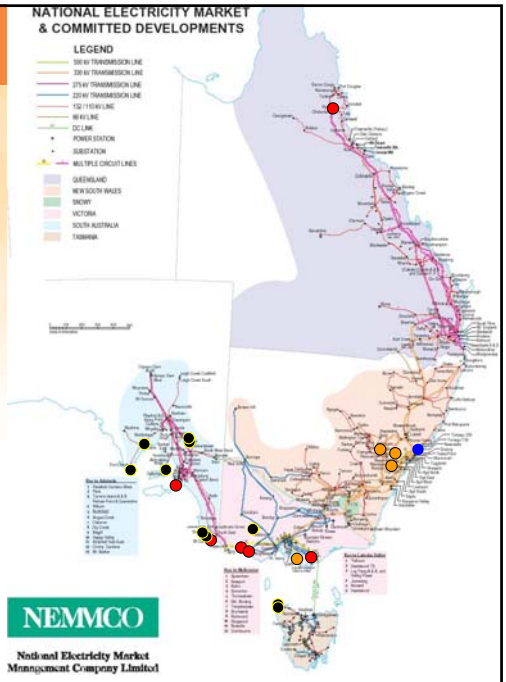
Wind Energy in Australia

- 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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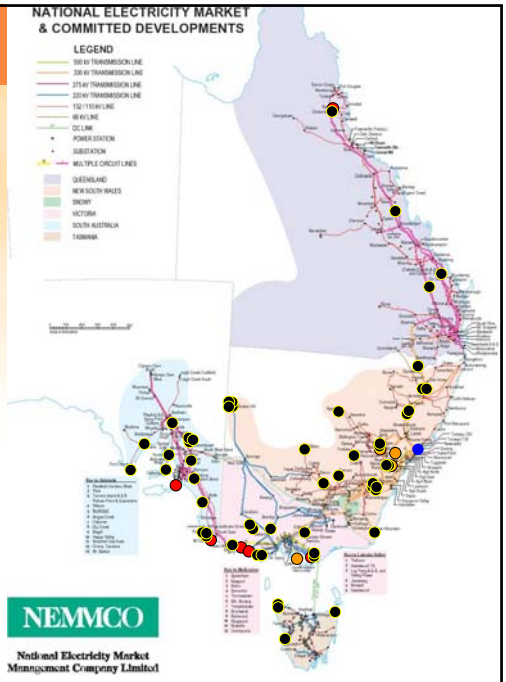
Wind Energy in Australia

- National Electricity Market (NEM) →
- Wind Farms in 2015? →

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



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Wind Energy Integration

- The wind power resource:
  - Wind farm power generation may follow a daily pattern for some periods of the year
    - Eg. Sea breezes at coastal sites during Summer
    - Eg. Strong winds overnight at inland sites
  - However in general, and certainly at an aggregated level in a power system, wind generation is different every day since it depends on the weather
  - Extreme temperatures (very hot or cold) are often associated with calm weather (not windy). This is because the fundamental cause of wind is resolve temperature differences!

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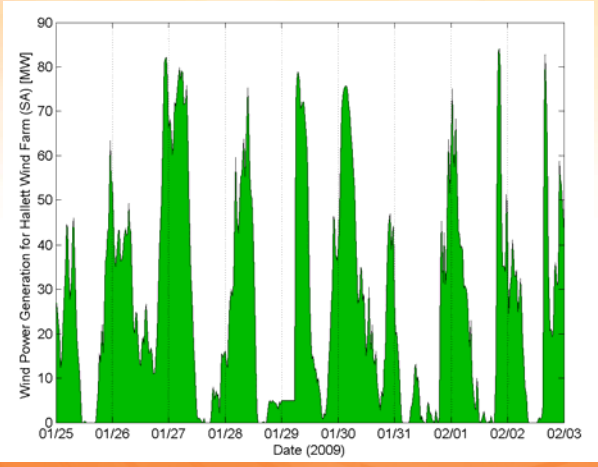
Wind Energy Integration

- The wind power resource:
  - Highly variable

Single wind farm in SA



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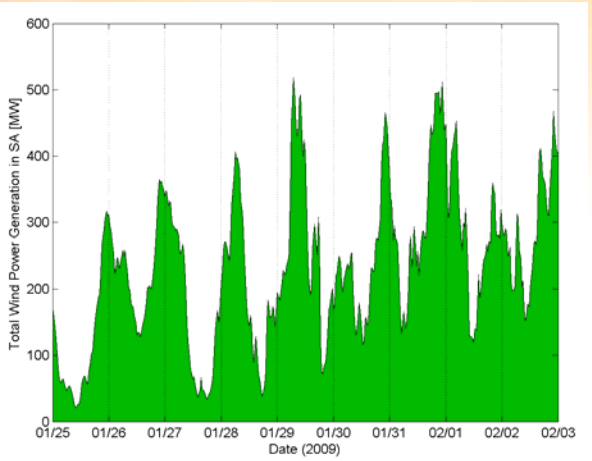
Wind Energy Integration

- The wind power resource:
  - Highly variable
  - But better with diversity

Total of 9 wind farms in SA



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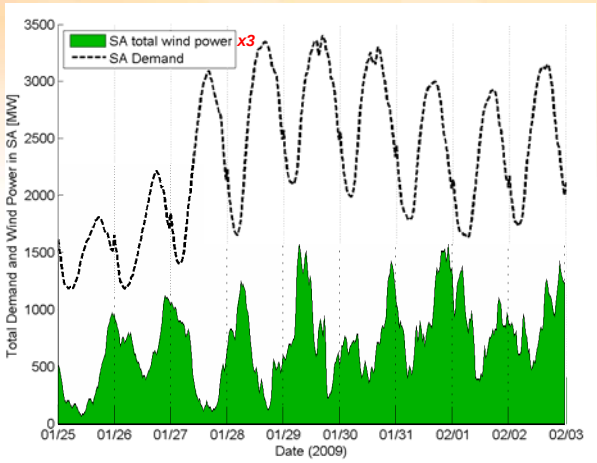
Wind Energy Integration

- The wind power resource:
  - Highly variable
  - But better with diversity
  - Still often anti-correlated with demand

Total wind power plus Demand in SA



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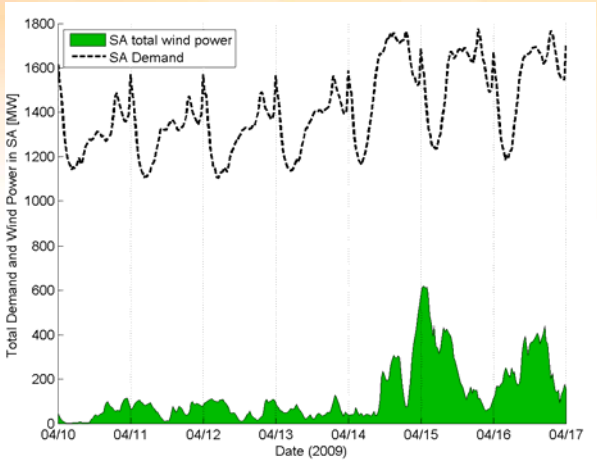
Wind Energy Integration

- The wind power resource:
  - Highly variable
  - But better with diversity
  - Still often anti-correlated with demand, but not always
  - In fact overall correlation is just -0.03



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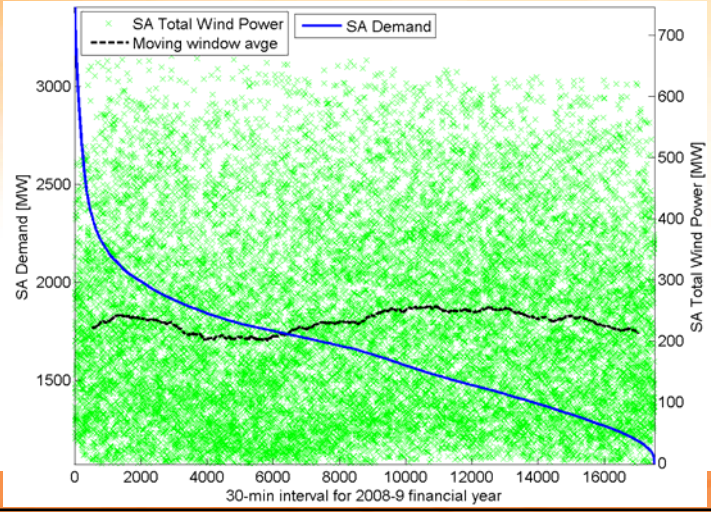
Wind Energy Integration

- Wind power is not correlated in SA *(nor anti-correlated)*



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Wind Energy Integration

- Some issues:
  - Windy places are typically not where people live
    - Wind farms need good transmission to transport the power
  - Since there is no fuel cost for wind AND wind generators often get additional green energy credits, when there is wind power the electricity market prices become lower (or even negative) thus showing a lower value for wind power

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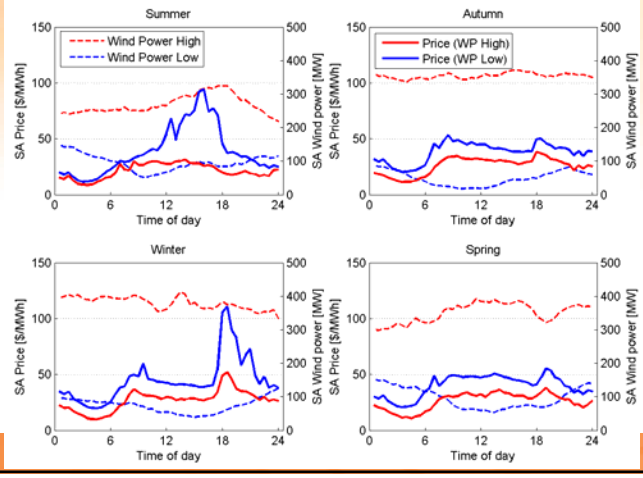
Wind Energy Integration

Average daily profiles of price in South Australia for 2008-9 during "high wind" (highest 25% of wind power cases over all working days) and during "low wind" (lowest 25%) days (after truncating price between $0 and $415/MWh)



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Wind Energy Integration

- Some issues:
  - Windy places are typically not where people live
    - Wind farms need good transmission to transport the power
  - Since there is no fuel cost for wind AND wind generators often get additional green energy credits, when there is wind power the electricity market prices become lower (or even negative) thus showing a lower value for wind power
    - But is this the 'true' value of wind? Wind has these different (and external) circumstances compared with the other generators
  - Coal generators are inflexible in that they cannot start-up quickly (need 6 hours). Hence for wind to replace coal generation need good wind forecasts out to at least 6 hours ahead
  - With 20% wind energy in a system, Denmark have experienced situations where they produce more wind power than the total demand. Without storage, this excess wind power can only be wasted or exported

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Wind Energy Integration

- Some changes we could make to facilitate wind:
  - Improve wind forecasting
  - Control electricity demand more
    - Eg. Control off-peak water heating more as well as other appliances
    - Controlled charging of millions of plug-in electric vehicles

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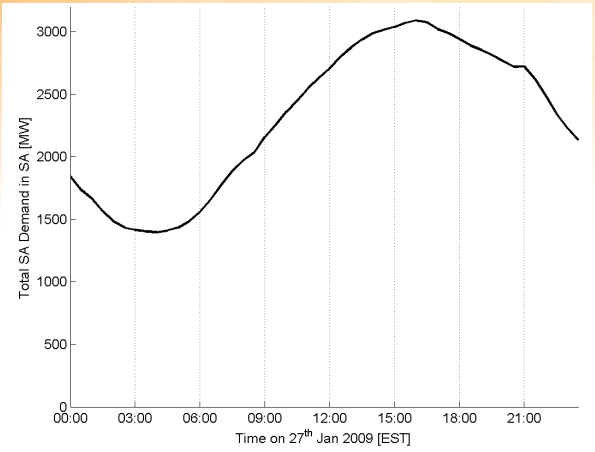
Wind Energy and Plug-in vehicles

- A 'bad' day in SA during 2009 heat wave



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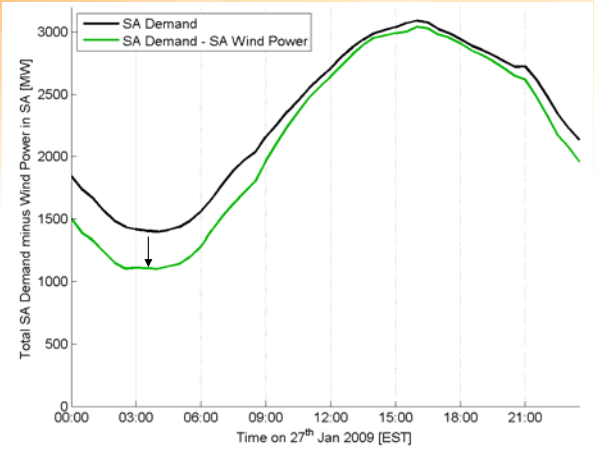
Wind Energy and Plug-in vehicles

- A 'bad' day in SA during 2009 heat wave



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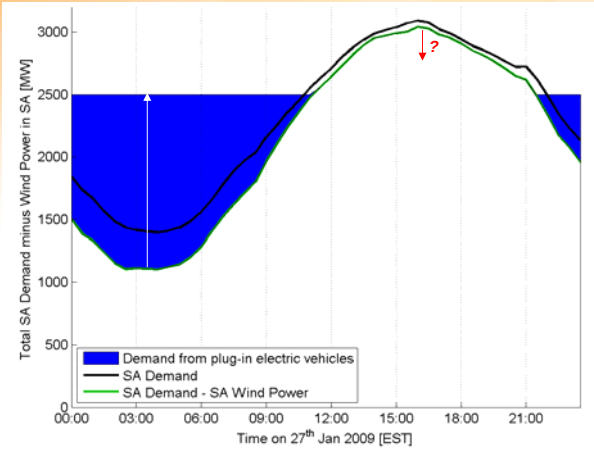
Wind Energy and Plug-in vehicles

- A '*normal*'? day in SA during 2009 heat wave



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Wind Energy Forecasting is required

- In general, *renewable* energy forecasting (wind, solar, etc.) is required
- Electricity demand is already routinely forecast by power system operators
  - Major deviations from the daily patterns due to regular human activities are due to temperature extremes (eg. heat wave in SA requiring lots of air conditioning)

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Wind Energy Forecasting

- Regardless of how much storage/plug in vehicles are available in the power system, wind forecasts could be required in two forms:
  - An overall amount of wind power over the next 12 hours to decide how much controllable power reserves are required (eg. Hydro) (or plan car battery recharging)
  - Forecasts of potential large rapid changes in wind power. The power system operator would need to ensure that the power system can react quick enough so that the supply/demand balance can be maintained, subject to transmission constraints

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My PhD in Wind Energy Forecasting

- Focussed on forecasting potential large rapid changes in wind power generation
- PhD is now published and available online: http://unsworks.unsw.edu.au/vital/access/manager/Repository/unsworks:5018
- Numerical Weather Prediction (NWP) models are the best tool we currently have to forecast the weather more than a few hours ahead

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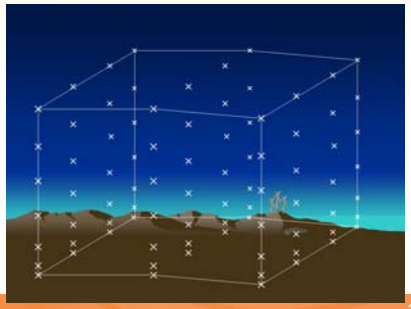
My PhD in Wind Energy Forecasting

- NWP models
  - Usually run by Bureaus of meteorology
  - Large amounts of measurements from satellites and surface based instruments are collected to estimate the current state of the atmosphere on a grid
  - Then model forward in time solving the equations of motion in response to known disturbances (eg. Sun's heat, Coriolis force)



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My PhD in Wind Energy Forecasting

- Discovered that NWP models are:
  - Good at predicting the evolution of large-scale synoptic weather features and their impact on surface winds
  - But there is no consistent mapping of these NWP weather features to a location in the physical world largely due to misplacement errors of these features
    - Eg. When do weather forecasts say that the cool change will arrive at precisely 4:20pm? They usually give an estimate: "sometime in the afternoon".
- Found a way to present the forecast wind fields from NWP models that gives useful information on the nature of potential changes in wind

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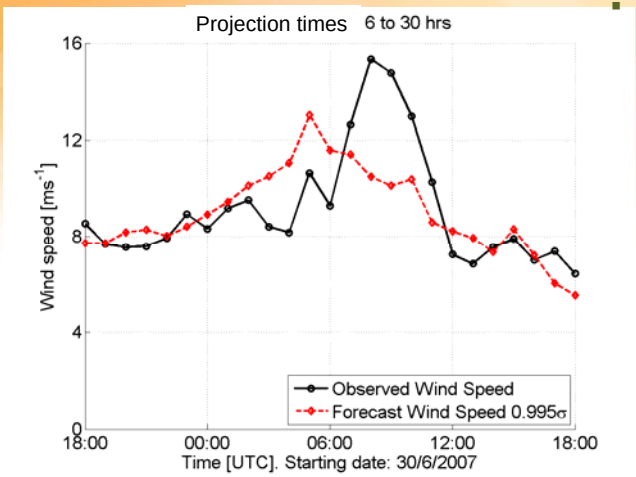
Typical time-series forecast from NWP system



- **Before we knew the observations (black), how did we know what caused this peak in the forecast and how certain can we be about it?**
  - **Is the peak consistent across the region or is it a small feature in the NWP forecast?**
  - **Is there the possibility of an aliasing (sampling) error?**

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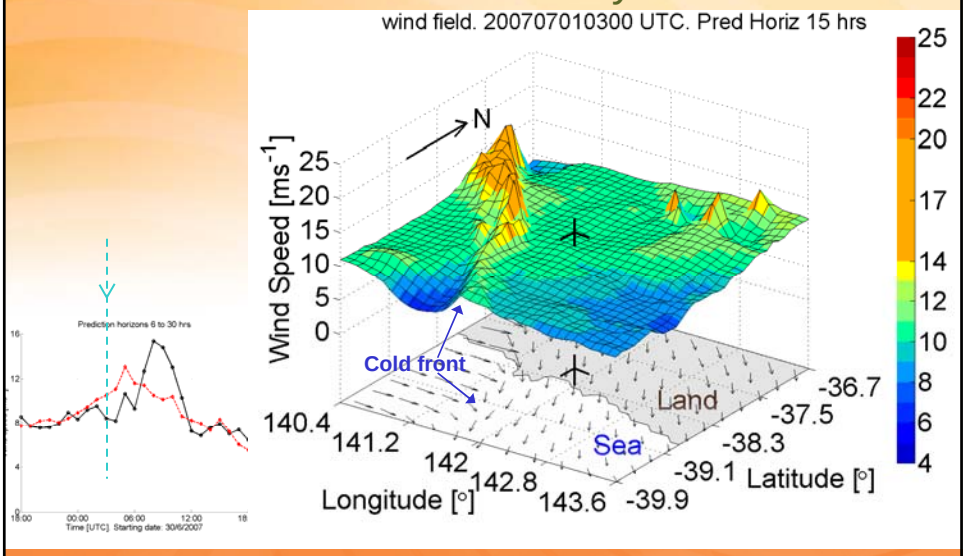
Cold Front on 1st July 2007



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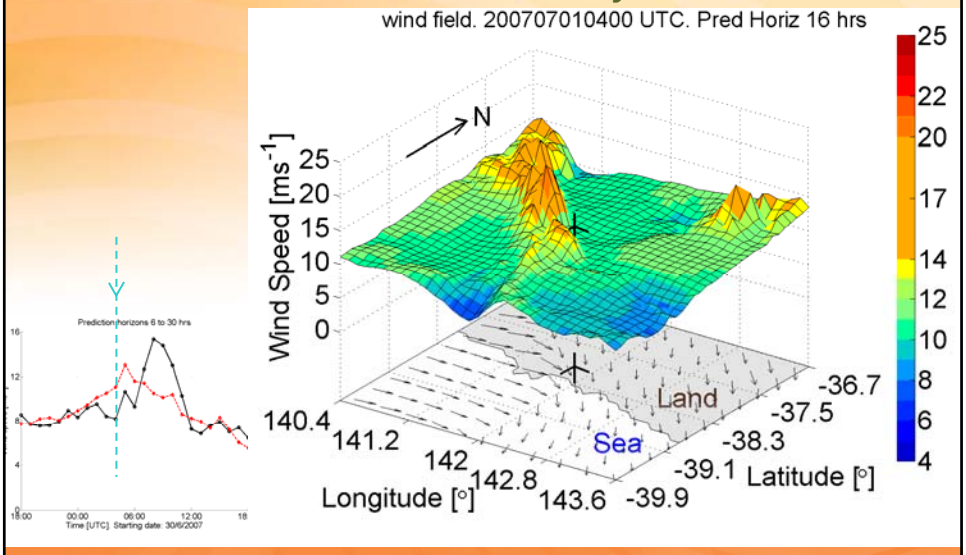
Cold Front on 1st July 2007



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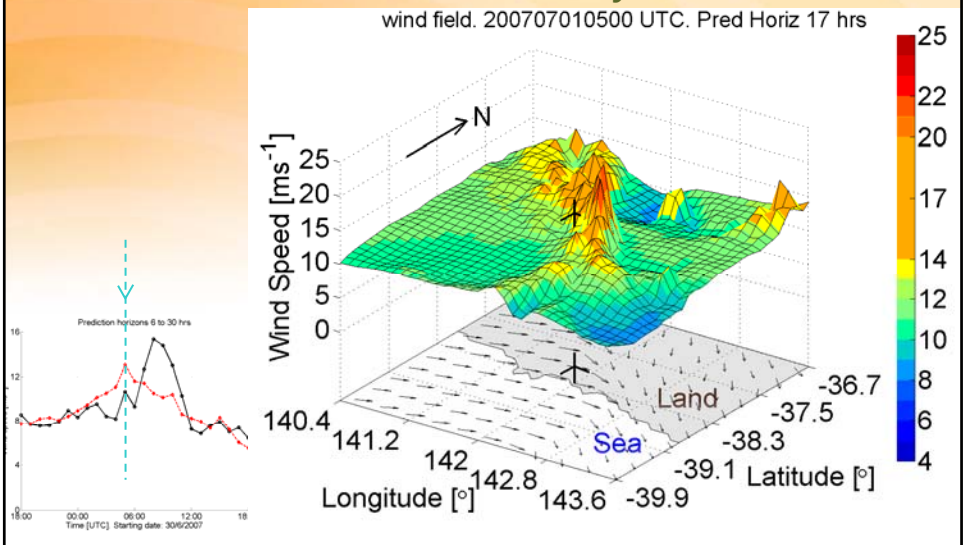
Cold Front on 1st July 2007



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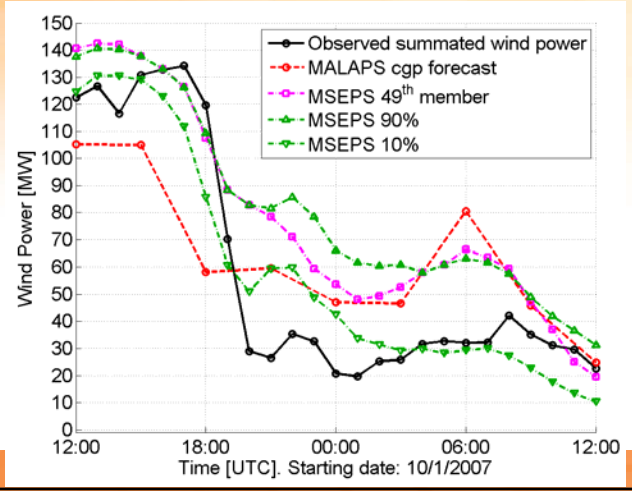
10th January event: cold front

Drop in summated wind power from 3 wind farms

Time-series forecasts (single & probability from NWP ensembles) & actual observations



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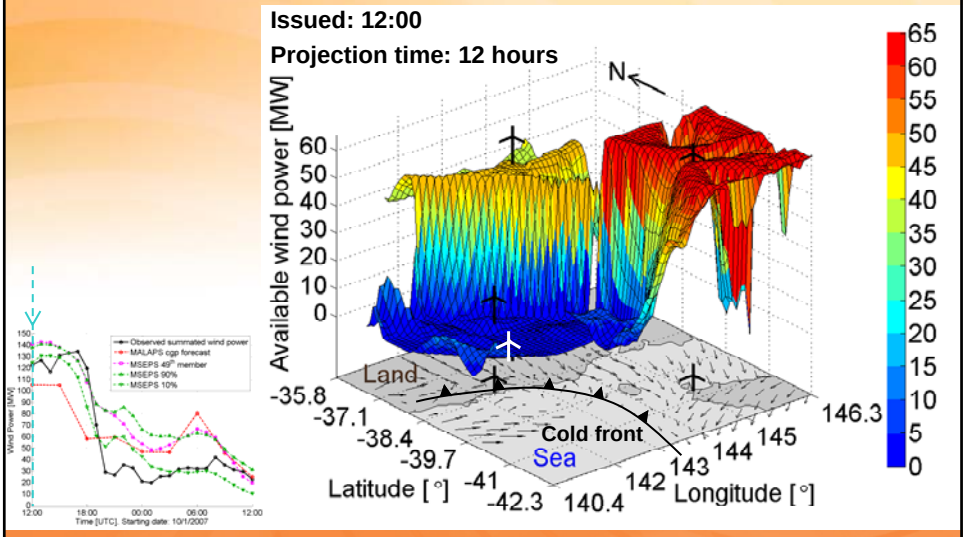
Cold Front on 10th January 2007



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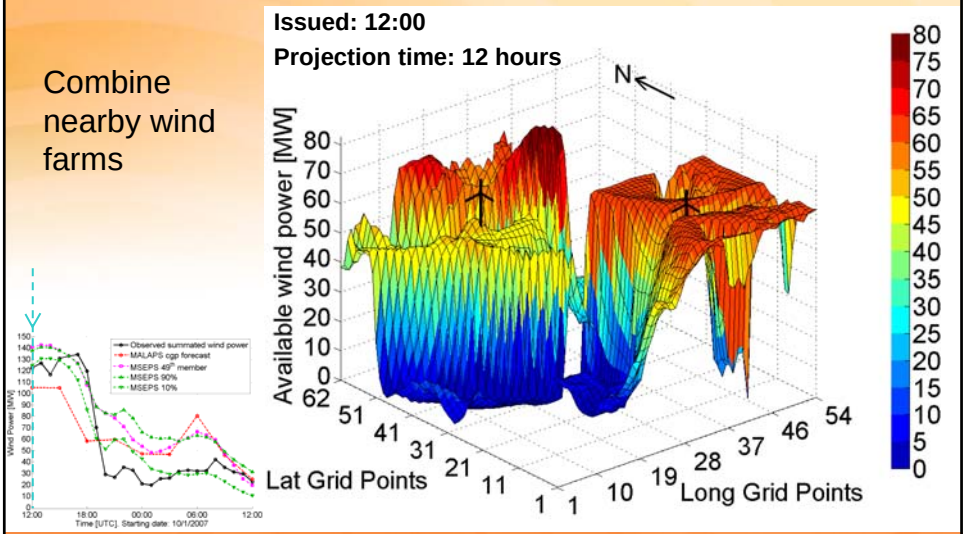
Cold Front on 10th January 2007

Combine nearby wind farms



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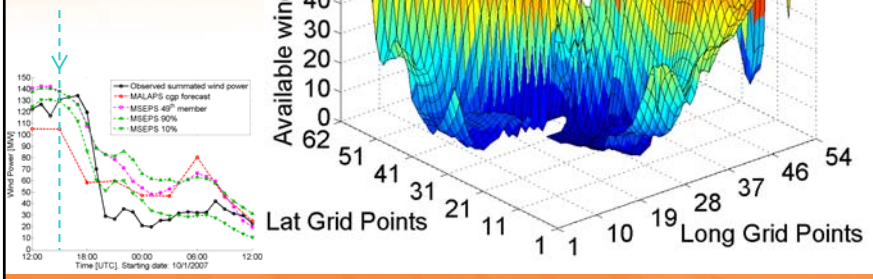
Cold Front on 10th January 2007

Issued: 15:00

Projection time: 15 hours



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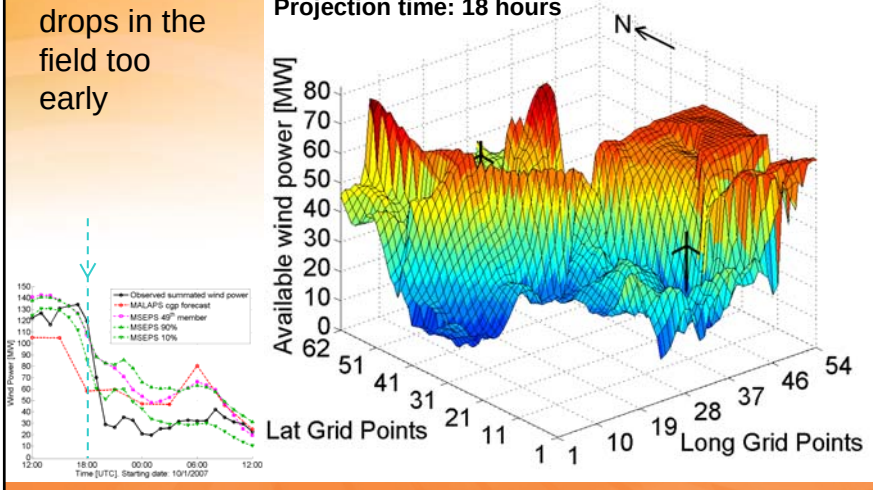
Cold Front on 10th January 2007

Bluff Point drops in the field too early

Issued: 18:00

Projection time: 18 hours



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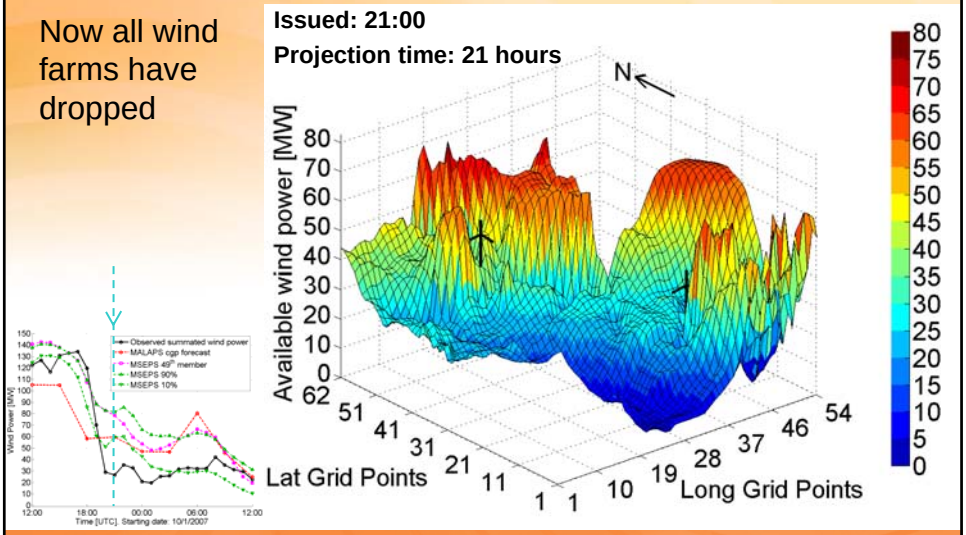
Cold Front on 10th January 2007

Now all wind farms have dropped



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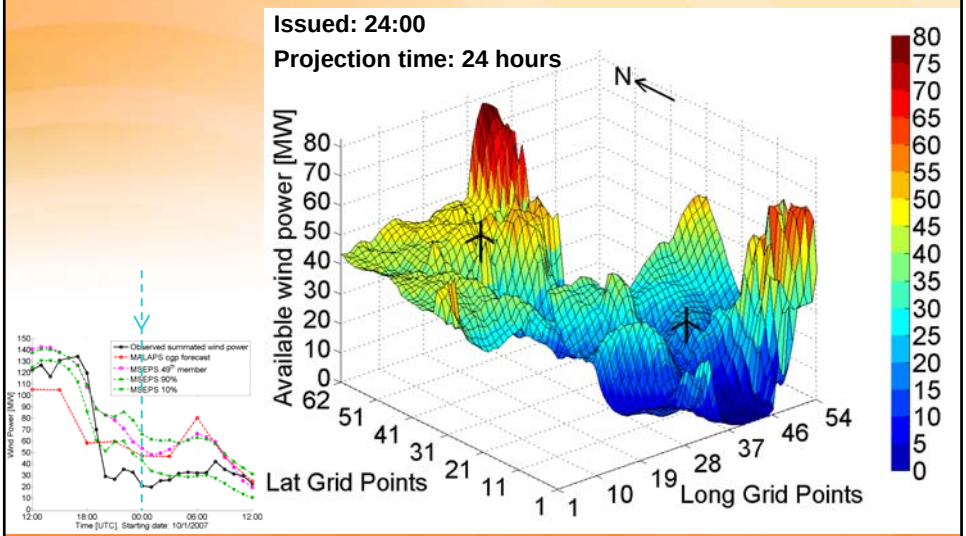
Cold Front on 10th January 2007



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But, in the control room…

- Power system operators have told us they have limited time in the control room to study wind field visualisations
- They have indicated they need more determinative and aggregated forecast outputs in a time-series format
- They can also benefit from other simple tools such as an alarm condition based on a reasonable probability of a large, rapid change in wind power generation

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One-year post doc project

- The Challenge:
  - Maintain as much of the information gained through forecast wind fields by displaying this information in a time-series format
- Techniques:
  - Pattern recognition to estimate the speed and direction of the wind features in the field
  - Based on this estimated propagation velocity, extract time-series traces from wind field assuming different misplacement error possibilties

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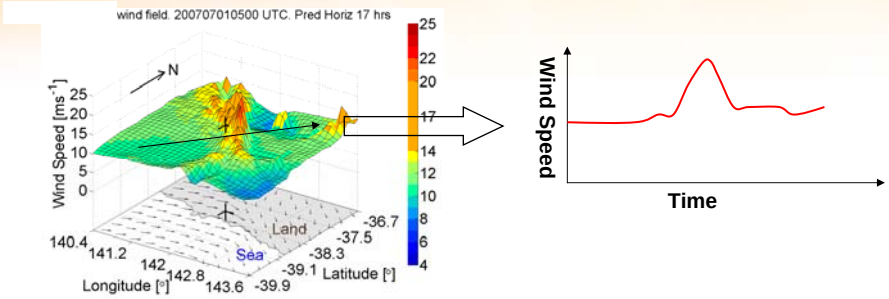
Extracting time-series traces

- Example of time-series trace:
- Note that speed and direction of wind feature propagation is not the same as wind speed and direction!



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Extracting time-series traces

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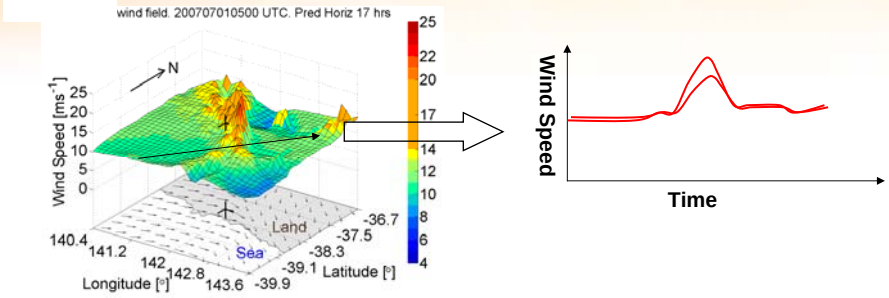

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Extracting time-series traces

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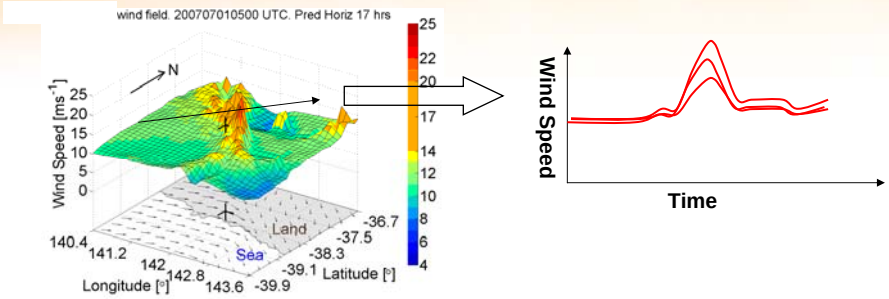

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Further work in Wind Energy Forecasting

- Converting the wind fields back to time-series information retaining (most of) the gained forecast information
  - Looking at ways to present aggregated information
- Using observations to adjust the forecast wind fields reducing some uncertainty due to misplacement

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Thank you & Questions

- Supervisors: Iain MacGill and Hugh Outhred
- Collaboration with Jeff Kepert (Bureau of Meteorology)
- Data providers:
  - BMRC - MALAPS
  - Pacific Hydro Pty Ltd. (wind farm developer)
  - Roaring 40s Pty Ltd. (wind farm developer)

BMRC Bureau of Meteorology Research Centre

PacificHydro

Roaring40s THINKING ENERGY

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