Centre for Energy and Environmental Markets

UNSW THE UNIVERSITY OF NEW SOUTH WALES SYDNEY • AUSTRALIA



Wind Energy Forecasting: Overview, Challenges and Australia's Contribution

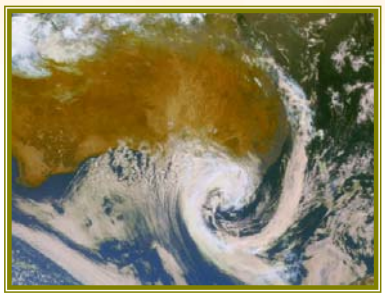
By

Merlinde Kay

AMOS bimonthly seminar series 1st August 2007

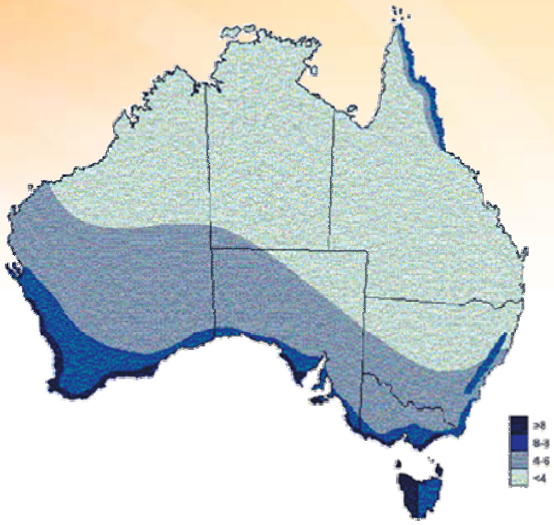
Outline

- Introduction
- Overview of Wind Energy and Forecasting
- Wind Farms in Australia
- Wind Statistics
- Challenges in Wind Energy and Forecasting
- Weather Systems and Events of Importance
- Preliminary Work
- Australia's Contribution



Introduction

- As wind power emerges as a significant component of energy markets around the world, Australia's major wind resources mean that it is well placed to harness greater wind energy within the electricity industry.



http://www.pmc.gov.au/publications/energy_future/chapter2/5_prospectivity.htm

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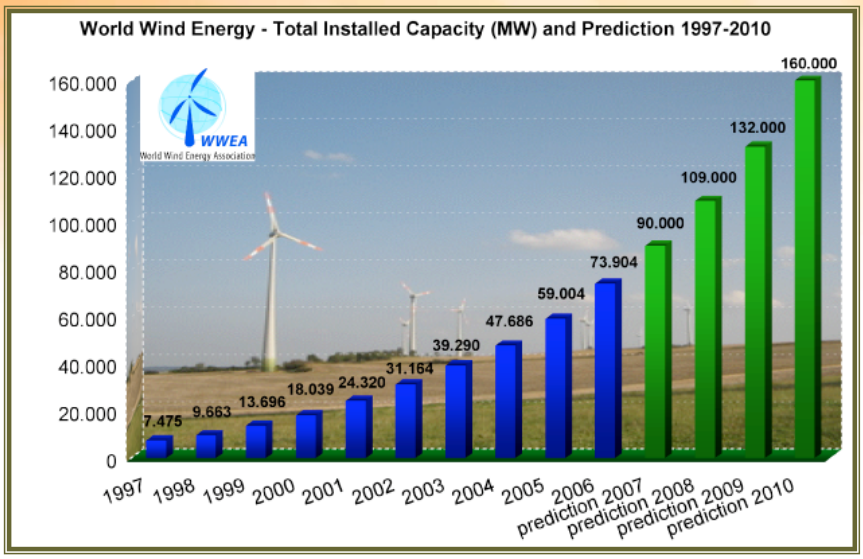

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Ranking total 2006	Country	Additional capacity 2006	Growth rate 2006	Total capacity end 2006	Total capacity end 2005	Ranking total 2005
		[MW]	%	[MW]	[MW]	
1	Germany	2.194	11,9	20.622	18.428	1
2	Spain	1.587	15,8	11.615	10.028	2
3	USA	2.454	26,8	11.603	9.149	3
4	India	1.840	41,5	6.270	4.430	4
5	Denmark	8	0,3	3.136	3.128	5
6	China	1.145	90,9	2.405	1.260	8
7	Italy	405	23,6	2.123	1.718	6
8	United Kingdom	610	45,1	1.963	1.353	7
9	Portugal	628	61,4	1.650	1.022	11
10	France	810	106,9	1.567	757	13
11	Netherlands	336	27,5	1.560	1.224	9
12	Canada	768	112,4	1.451	683	14
13	Japan	354	34,0	1.394	1.040	10
14	Austria	146	17,8	965	819	12
15	Australia	238	41,1	817	579	15
16	Greece	183	31,9	756	573	16
17	Ireland	147	29,6	643	496	18
18	Sweden	54	10,6	564	510	17
19	Norway	55	20,4	325	270	19
20	Brazil	208	729,6	237	29	34
	Rest	730	48,4	2.238	1.508	
TOTAL		**14.900**	**25,3**	**73.904**	**59.004**	

Introduction

- As wind power emerges as a significant component of energy markets around the world, Australia's major wind resources mean that it is well placed to harness greater wind energy within the electricity industry.

- The ability to accurately predict weather events that rapidly change wind energy production from one or more wind farms would reduce the costs of integrating wind energy into power systems and increase the commercial viability of wind energy in competitive electricity markets.

- In response to this we are working on numerous strategies to analyse and initiate a methodology to improve forecasting of events that lead to large changes in wind energy production (ie., too little or too much wind and rapid changes in wind speed and direction).

An Extreme Event

Wind Farms in Australia

Region	Installed Under Construction
WA	199 MW
SA	388 MW 289 MW
NSW	17 MW
Vic	134 MW 192 MW
QLD	12 MW
Tas	67 MW 75 MW Studland Bay

Total Installed: 817MW
Under Construction: 556 MW

http://www.auswea.com.au/auswea

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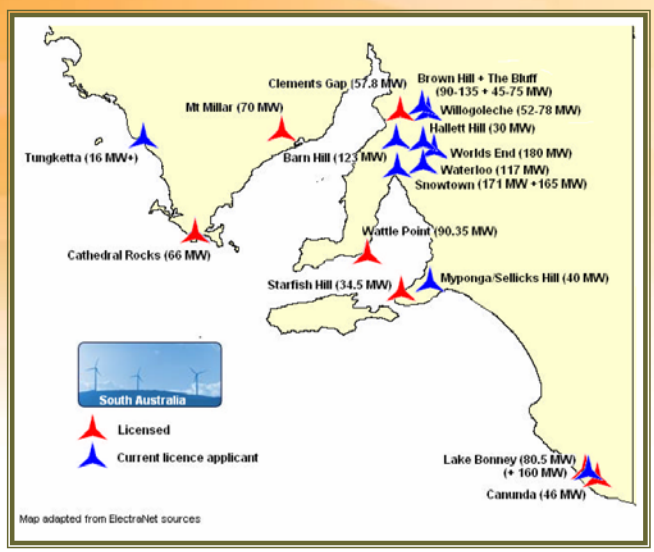

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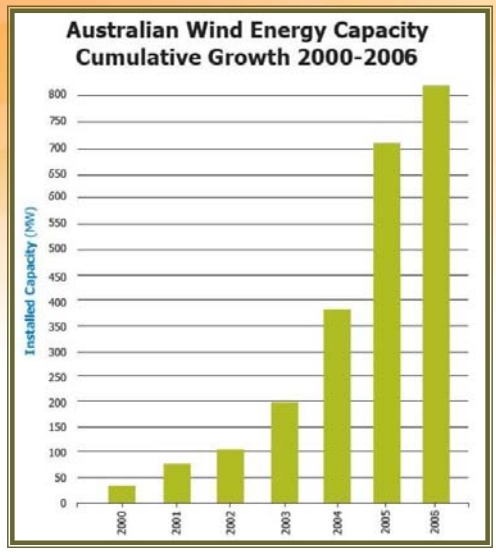

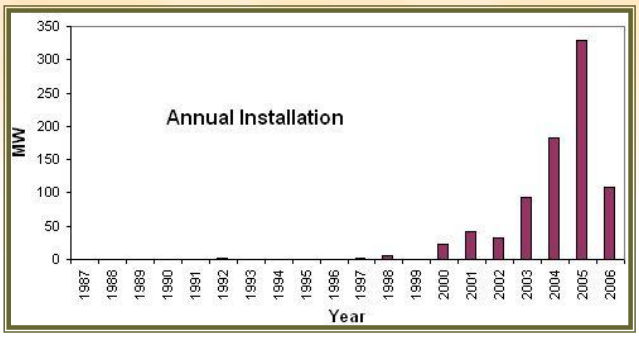

http://www.auswea.com.au/auswea/downloads/Tradewinds_report.pdf

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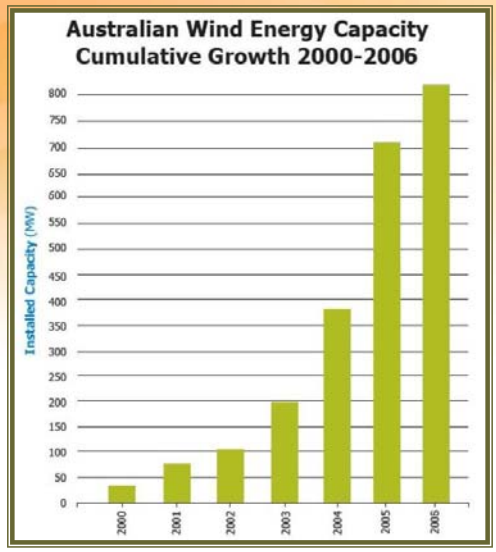

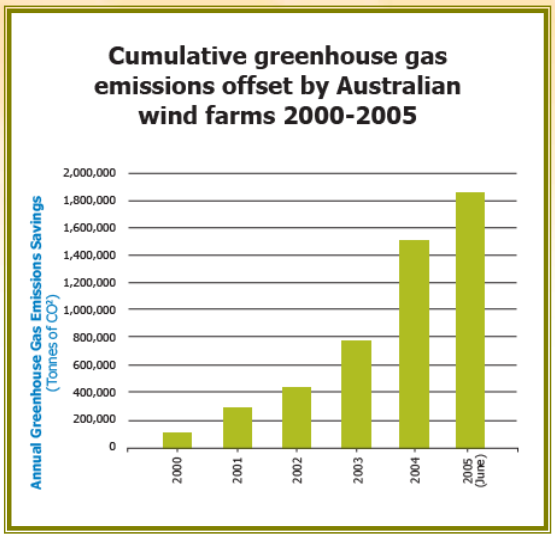

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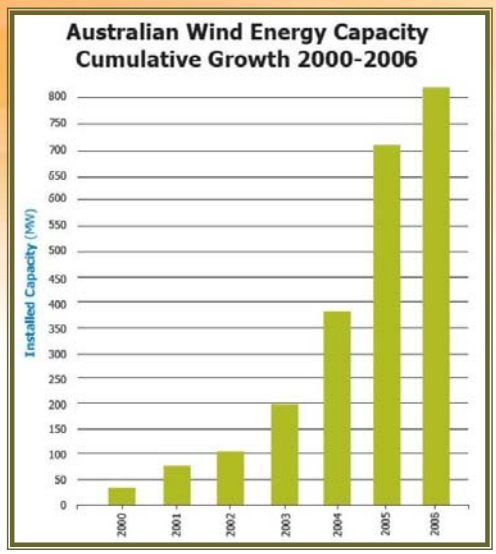

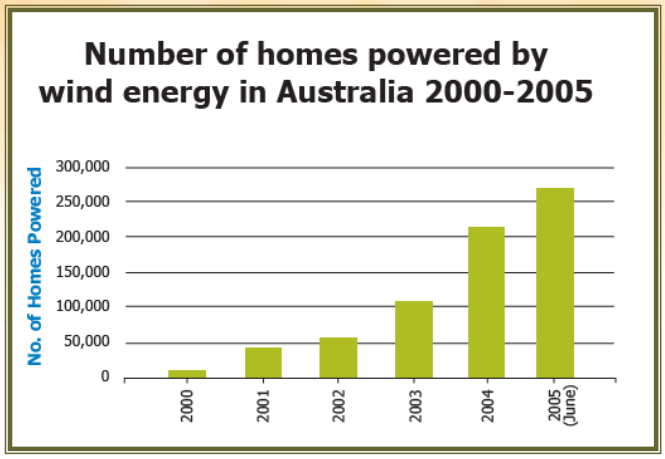

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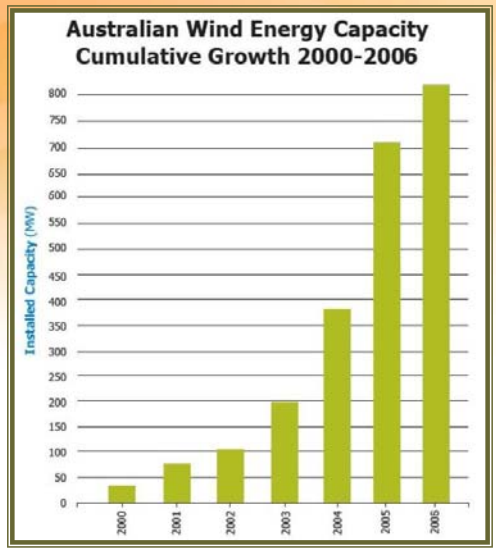

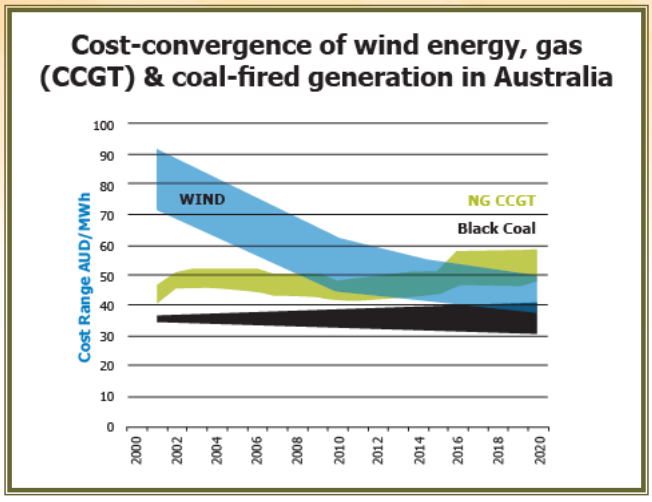

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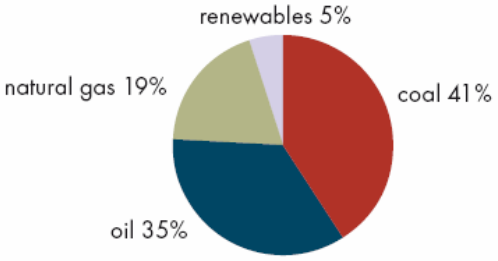
Wind Energy Statistics

E primary energy consumption, by fuel, 2004-05 Australia



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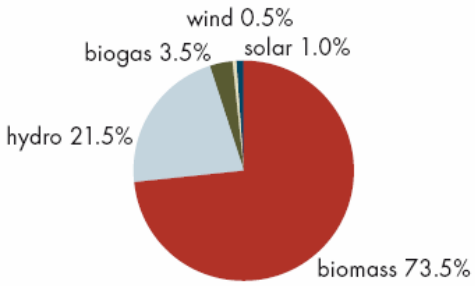
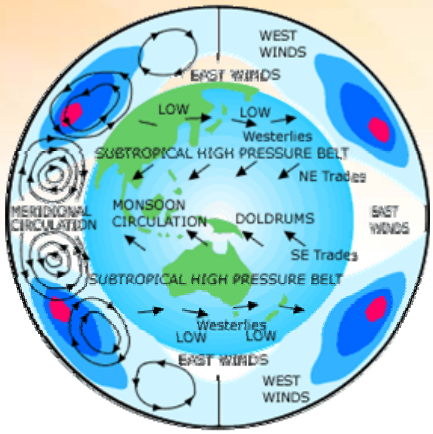


http://www.abareconomics.com/publications_html/energy/energy_06/energyupdate_06.pdf

Converting Wind Energy into Electricity

- The sun heats the earth's surface unevenly, creating differences in air temperature and subsequent differences in air pressure.
- The result is ***wind***.



Converting Wind Energy into Electricity

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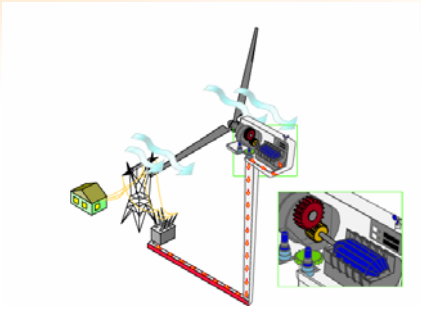
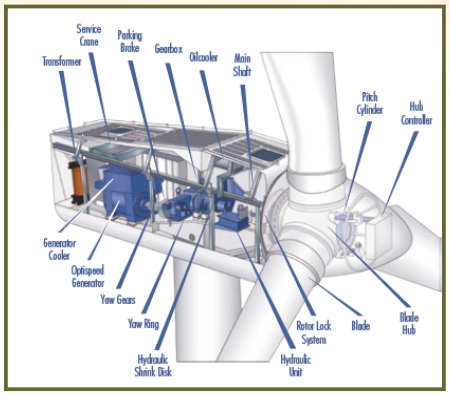
- The result is ***wind***.
- The wind turns the turbine blades, which drives a generator to produce electricity.
- This electricity travels through a transformer and into the local electricity network through transmission lines that distribute electricity to homes.





http://www1.eere.energy.gov/windandhydro/wind_animation.html

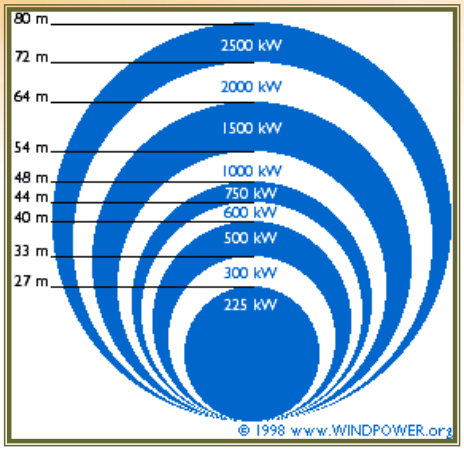
http://www.stanwell.com/PDF/Toora%20Fact%20Sheet.pdf

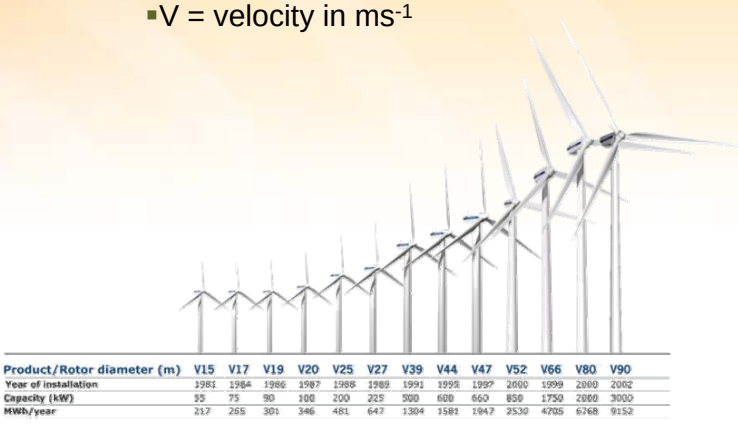
The Wind Power Formula

- The power of the wind is the cube of the wind speed.
- The Wind Power Formula:

$$P = \frac{1}{2}\rho v^3 \pi r^2$$

- Where P = Power in Watts
- ρ = density of dry air in kgm^{-3}
- r= radius of the rotor in metres
- V = velocity in ms^{-1}

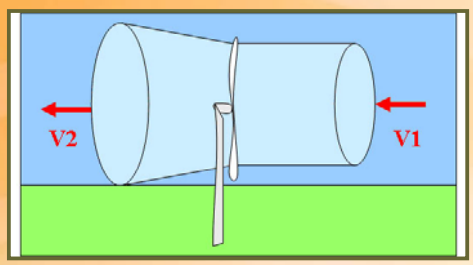


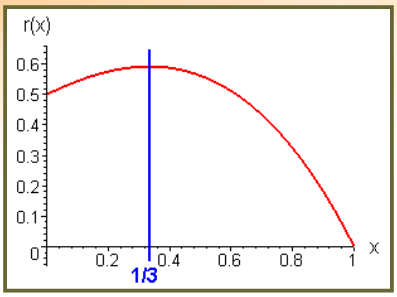


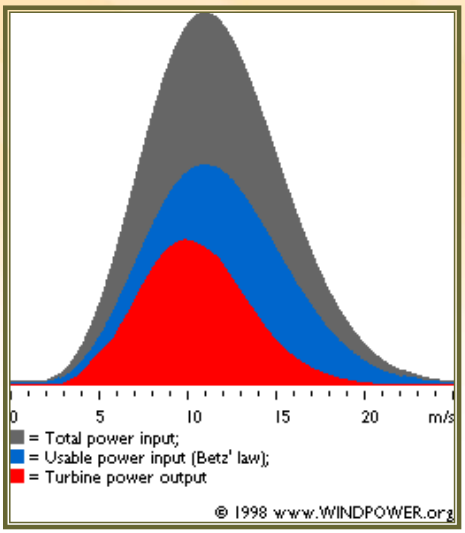
Product/Rotor diameter (m)	V15	V17	V19	V20	V25	V27	V39	V44	V47	V52	V66	V80	V90
Year of installation	1981	1984	1986	1987	1988	1989	1991	1993	1997	2000	1999	2000	2002
Capacity (kW)	55	75	90	100	200	225	500	600	660	850	1750	2000	3000
MWh/year	217	265	301	346	481	647	1304	1581	1947	2530	4705	6768	9152

http://scruss.com/talks/02006/bcs/pics/vestas-turbine_size.jpg

Power Density to Power Output



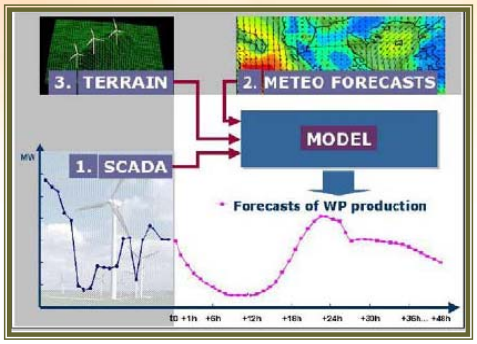




- **Betz' Law :** Betz' law says that you can only convert less than 59% of the kinetic energy in the wind to mechanical energy using a wind turbine.

Overview of Wind Energy Forecasting

- Many short-term (up to 72 hours ahead) wind energy forecasts are based on numerical weather prediction (NWP) models to determine the expected behaviour of the wind.
- The weather data supplied by an NWP is transformed into wind power forecasts using ***statistical*** and/or ***physical*** approaches.

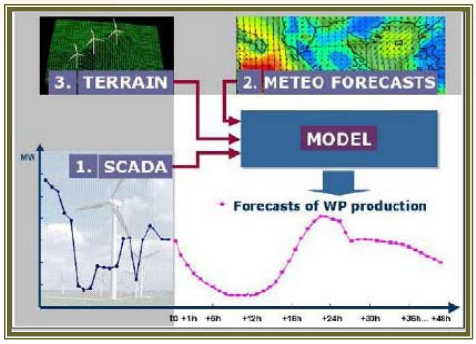


http://anemos.cma.fr/download/ANEMOS_D1.1_StateOfTheArt_v1.1.pdf

Overview of Wind Energy Forecasting

The statistical approach

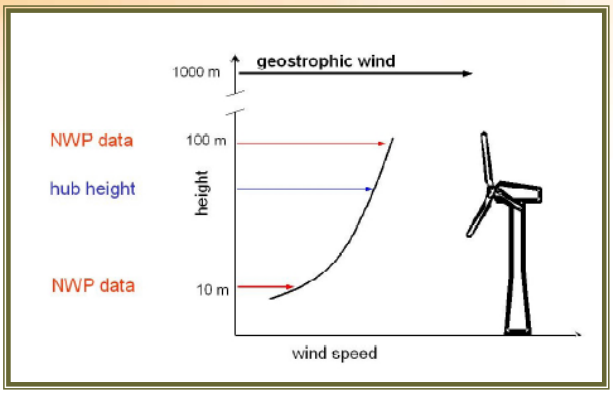
- The ***statistical*** approach is based on previous observations of actual wind speed and direction, or wind generation – it ignores the meteorological details and completely relies on data analysis.
- An advantage of this approach is that predictions can be adapted to the location of the wind farm thereby reducing systematic errors.
- A disadvantage is that it does not predict rare atmospheric conditions suitably well.

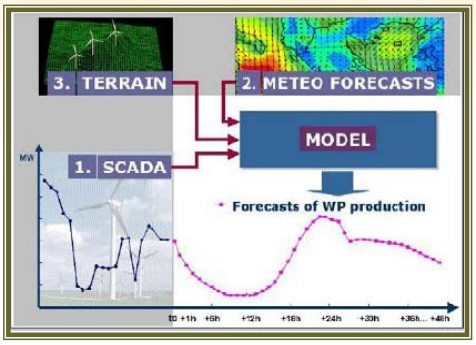


Overview of Wind Energy Forecasting

The Physical Approach

- Physical approaches use methods from boundary layer meteorology and choose parameterizations based on detailed physical descriptions of the boundary layer.
- One problem that can arise here is that often NWP's are run with a coarse resolution which can not take into account more localized effects for specific wind farms.





Challenges Faced in Wind Energy Forecasting

- Establishing a framework for maximizing the value of wind energy requires forecasting.
- There is a large range of forecasting challenges which pose complex and interesting problems that we are looking to identify and solve.

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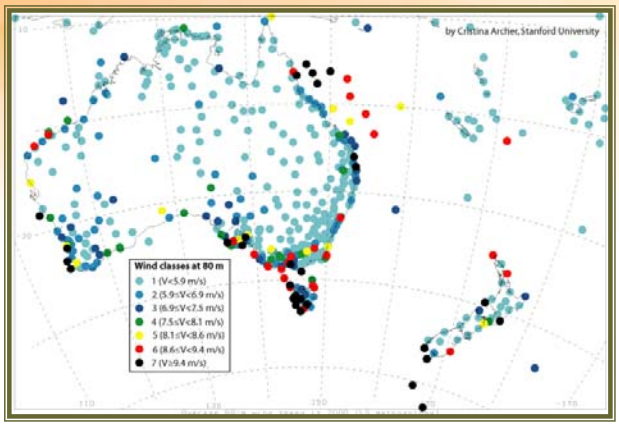
- ***The appropriate location***



- Archer, C.L., amd Jaconson, M.Z. (2005), Evaluation of global wind power, J. Geophys Res., vol 110, D12110.

Challenges Faced in Wind Energy Forecasting

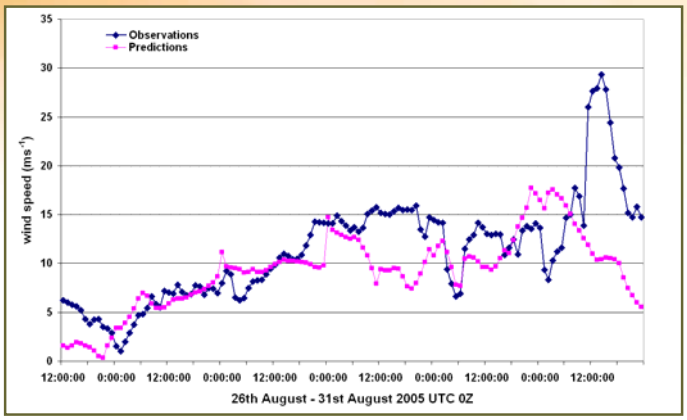
- There are many challenges one faces in maximising the value of wind power:
  - The Great Australian Bight is an open bay stretching approximately 2000 km, opening onto the Southern Ocean that spans the coastline of two Australian states – Western Australia and South Australia.
  - South Australia (SA) currently contributes 51% of Australia's total wind energy production (Auswind) hence this region is an area of importance that can pose different challenges compared to similar regions in the Northern Hemisphere.

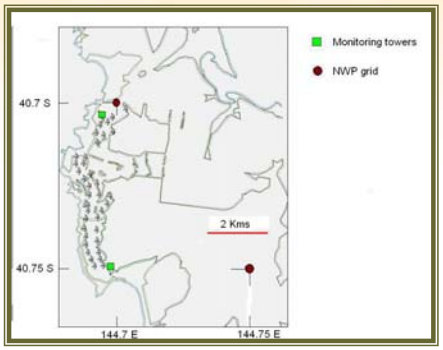
Challenges Faced in Wind Energy Forecasting

- There are many challenges one faces in maximising the value of wind power:
  - Are NWP models a useful tool by themselves, and how well can they make an accurate/useful wind forecast?
  - Is ensemble forecasting an appropriate strategy?
  - Besides a NWP, what type of models will be the most advantageous to use, and/or what type of statistical methods could be applied to improve or make a forecast?
  - What is the best way to convert a forecast of atmospheric behaviour into a forecast of the output of a set of wind farms?

Numerical Weather Prediction

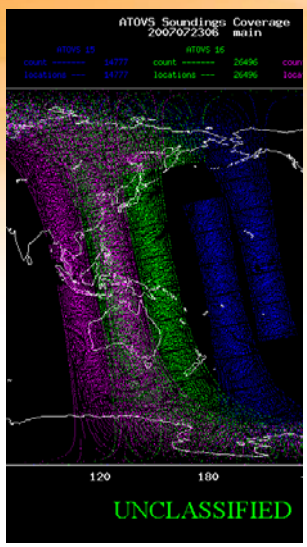
- The ability of an Numerical Weather Prediction model (NWP) to make an accurate/useful wind forecast: Most NWP's *are not* geared towards detailed wind predictions, especially in the context of wind power and the electricity market. **The question to answer here is are they a useful tool by themselves?**

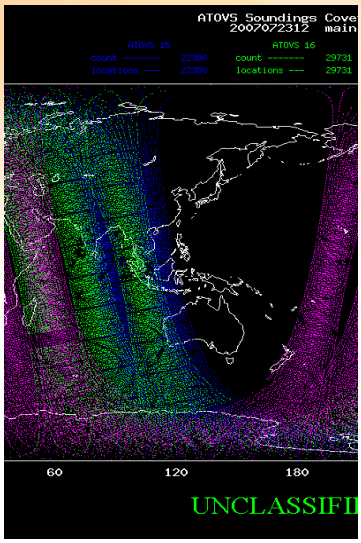


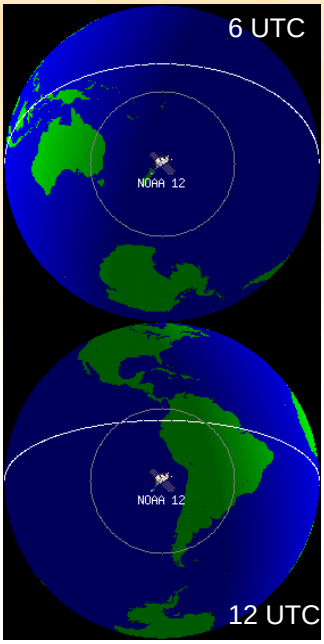


Data and Forecast Horizon

- Access to data: **Will additional data sources contain any information of use to forecasting for the wind energy sector?**
- **Timing issues of when data is delivered.**







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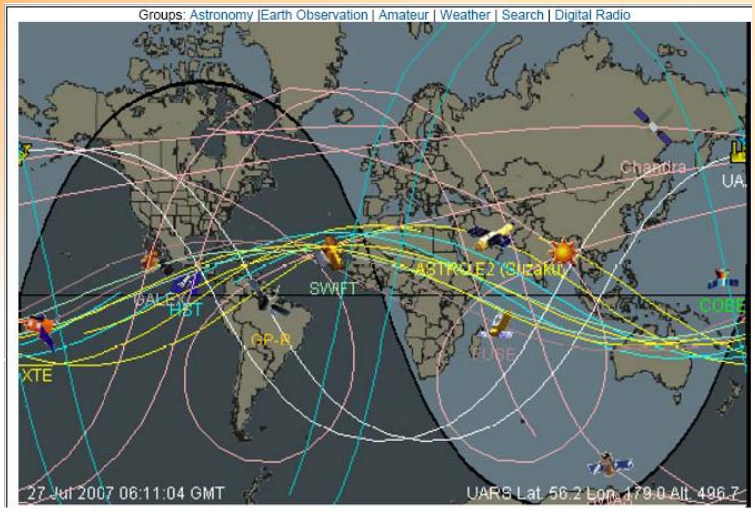
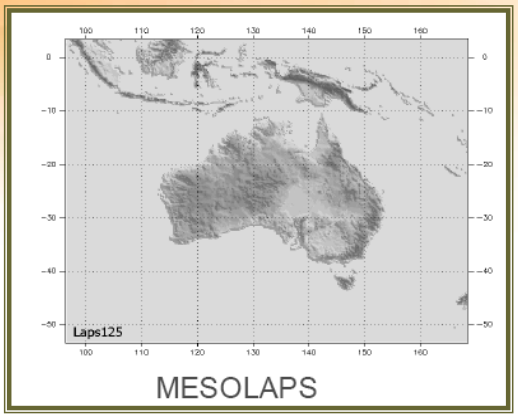
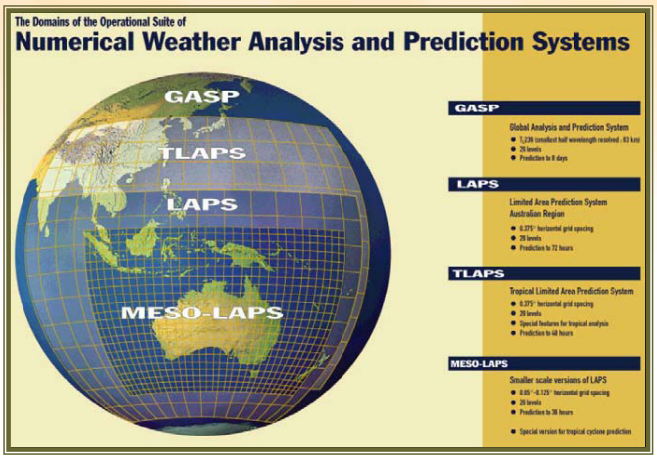


Regional and Small Scale Requirements

- The resolution of the NWP model is of great importance, and also produces challenges in wind energy forecasting such as:
  - **The task of distinguishing between regional and small scale forecasts.**





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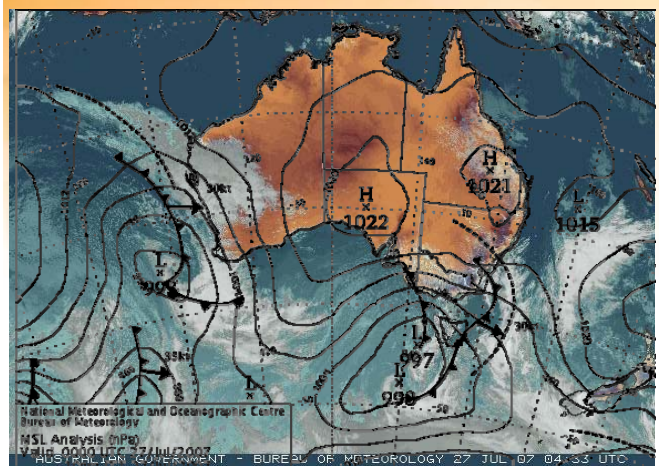
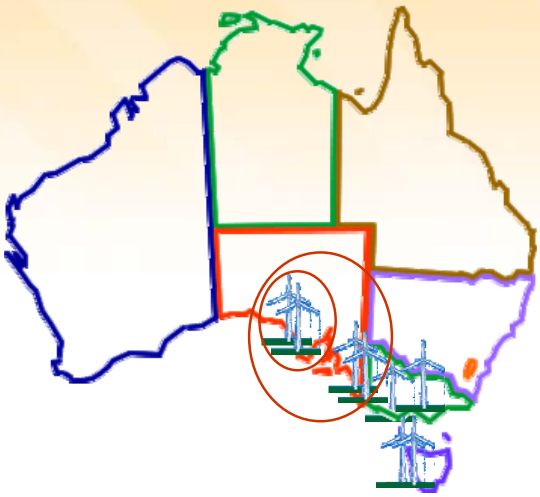
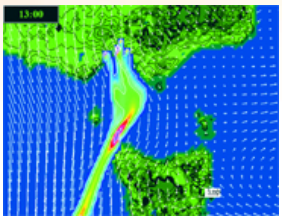




What is the 'best' model/method to utilize?

- **What type of models will be the most advantageous to use?**
  - A new model from the BMRC WLAPS looks promising.
  - The current wind energy forecast provider WEPROG is using a 75 member multi-scheme ensemble method.
  - Besides a typical NWP could The Air Pollution Model (TAPM) provide a more useful forecast [1]?

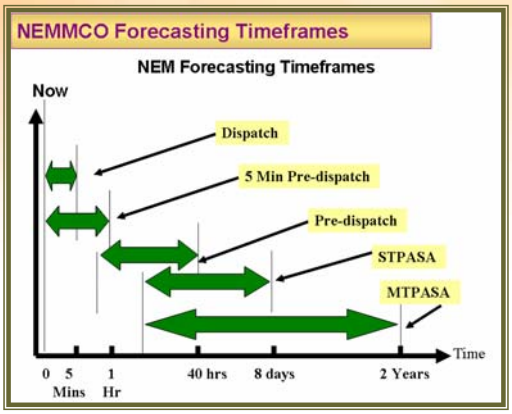


- **What type of statistical methods (PCA, time series analysis etc) could be used to make a forecast?**

- [1] Craine, S., Massie, R., vander Schoor, K., Cohen, W., Bateman, B., Peterson, J., and Langford, S. (2004), Wind Resource Atlas for Southern Australia. *Wind Engineering*, **28**, 4, pp. 355-366.
- http://www.cmar.csiro.au/research/tapm/

The National Electricity Market Requirements

- The National Electricity Market Management Company (NEMMCO)'s regional aggregation requirements leads us to ask:
  - **What type of forecast is best for the timeframes required?**

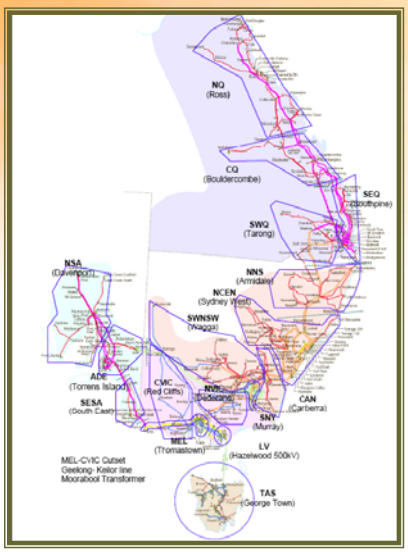


PASA: Projected Assessment of System Adequacy

AWEFS functional requirements ROI from NEMMCO website http://www.nemmco.com.au/

The National Electricity Market Requirements

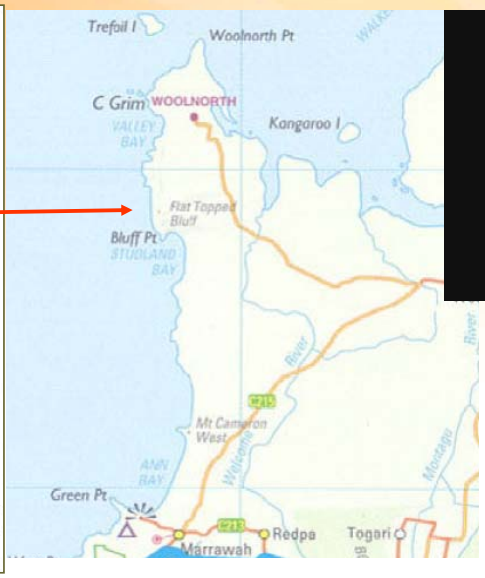
- **What is the best way to produce a forecast that can incorporate individual and aggregated wind farms?**

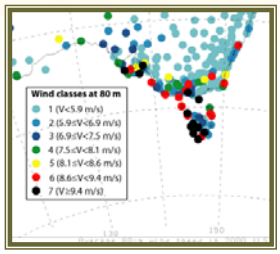


AWEFS functional requirements ROI from NEMMCO website
http://www.nemmco.com.au/

Basslink is the 360km electricity interconnector between Tasmania and Victoria. It is the world's longest HVDC sub-sea cable. Basslink can provide up to 600MW of hydro electricity to mainland Australia and over 300MW of electricity into Tasmania.

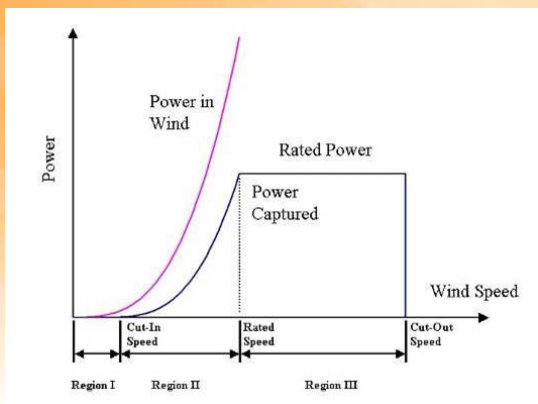
Woolnorth Wind Farm in Tasmania





http://www.hydro.com.au/Documents/Corporate/Woolnorth1.mpg

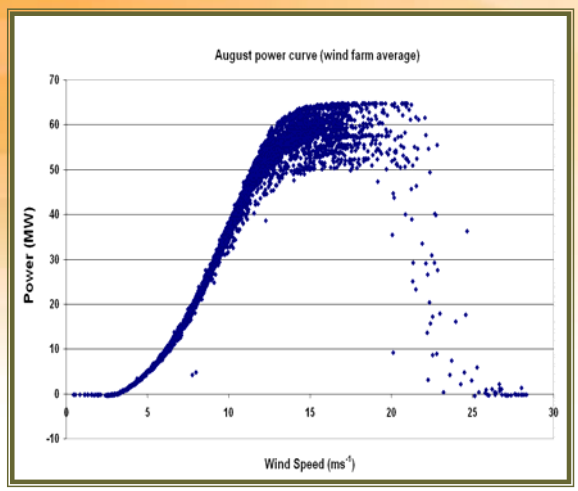
The Power Curve

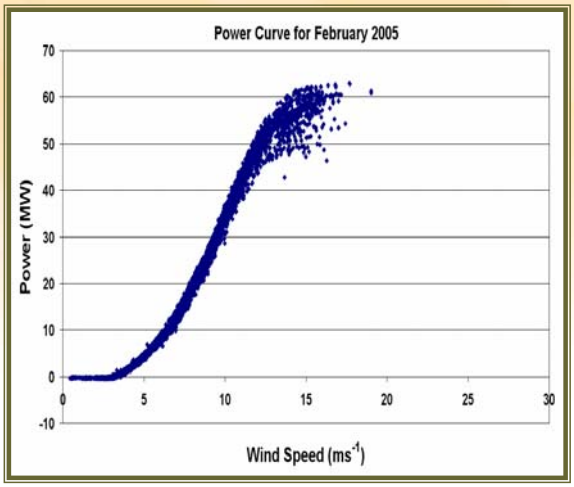


An example Power curve showing the cut-in and cut-out speeds:
Region I: 3 - 5ms^{-2}
Region II: rated power at ~15ms^{-1}
Region III: Cut out Speed 25ms^{-1}

http://home.clara.net/darvill/altenerg/wind.htm

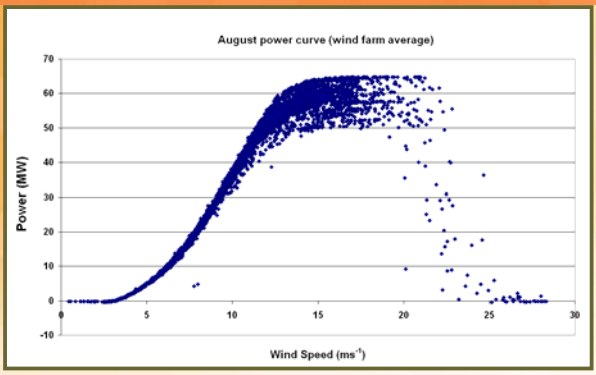
The Power Curve for Woolnorth

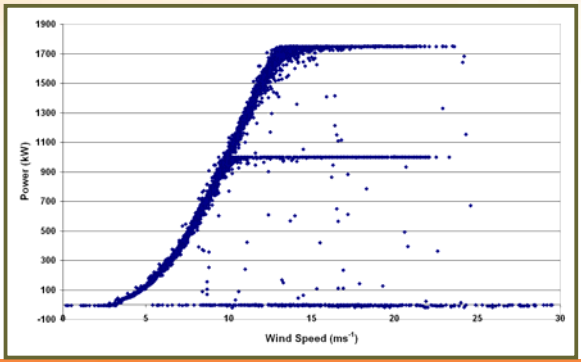


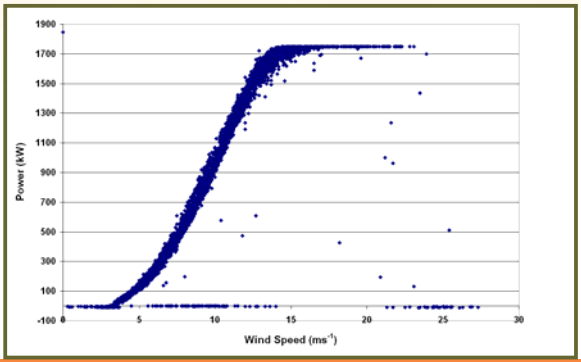


Power curve for the average of the wind farm for August and February 2005, showing the cut-in and cut-out speeds:
Region I: approximately 4 ms^{-2}
Region II: rated power at ~15ms^{-1}
Region III: Cut out Speed between 22 – 25ms^{-1}

The Power Curve for Woolnorth







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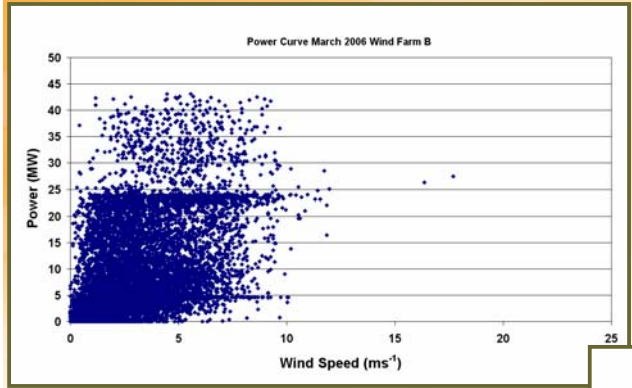
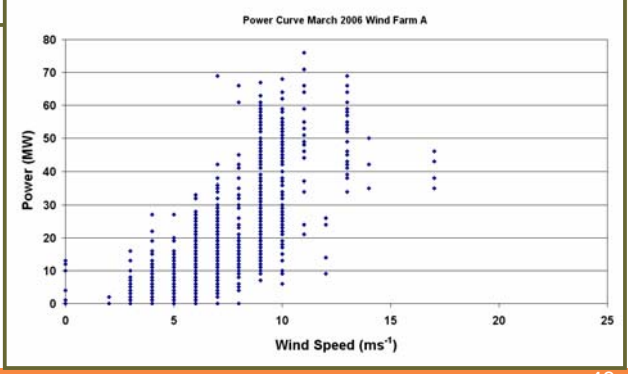
Power Curves from SA illustrating BAD Data





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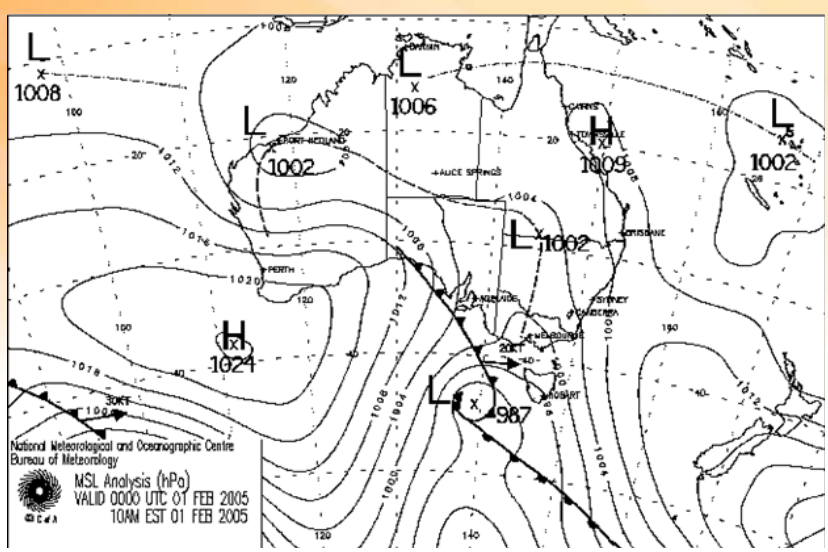
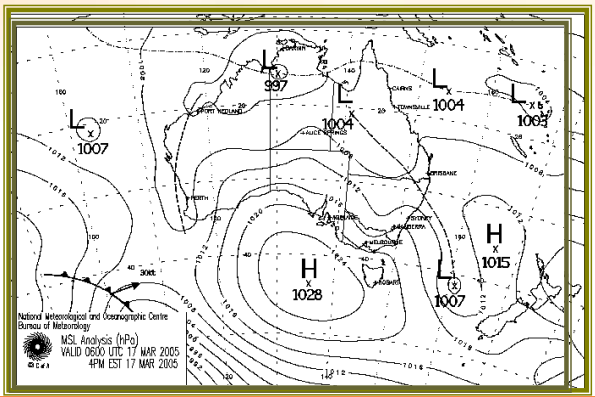
Synoptic Situations of Interest

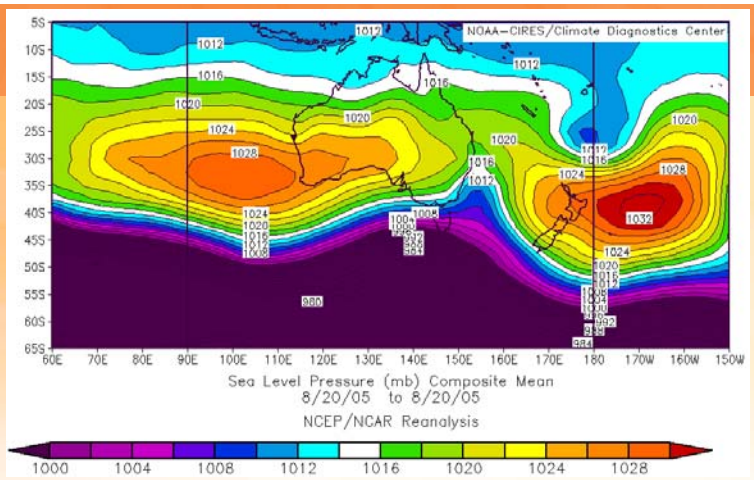


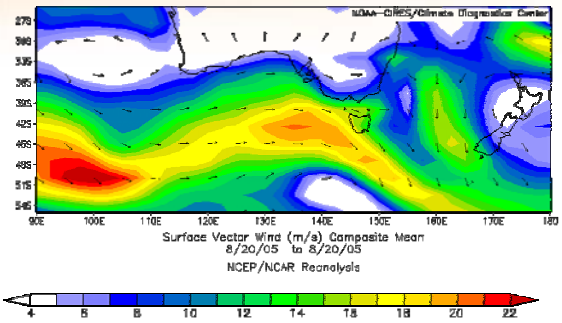
http://www.deh.gov.au/soe/2001/atmosphere/atmosphere02-1.html

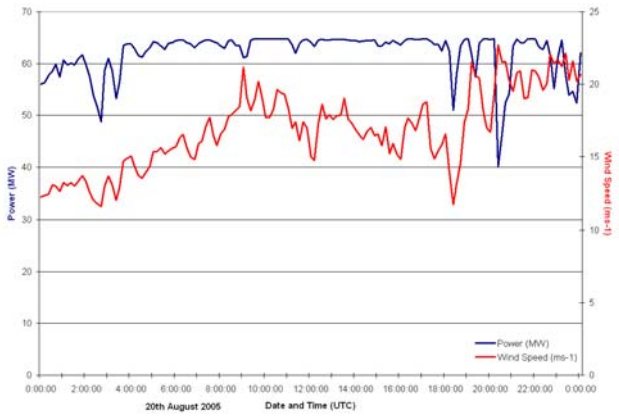
Synoptic Features identifiable with Large Swings

- ***Fronts:*** the narrow boundary zone between two air masses where there is a difference in density.
- ***Troughs:*** have the potential of intensifying rapidly with the result being ***stronger winds***.
- Unstable low pressure systems
- The transition between low and high pressure systems (particularly observable in Autumn)









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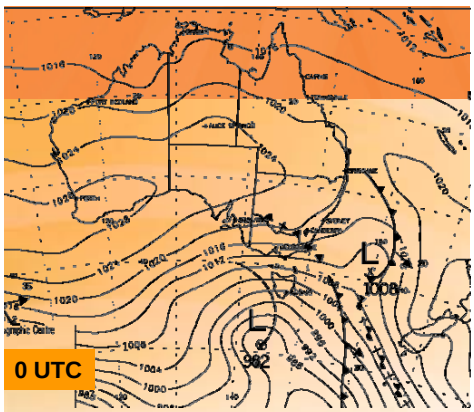

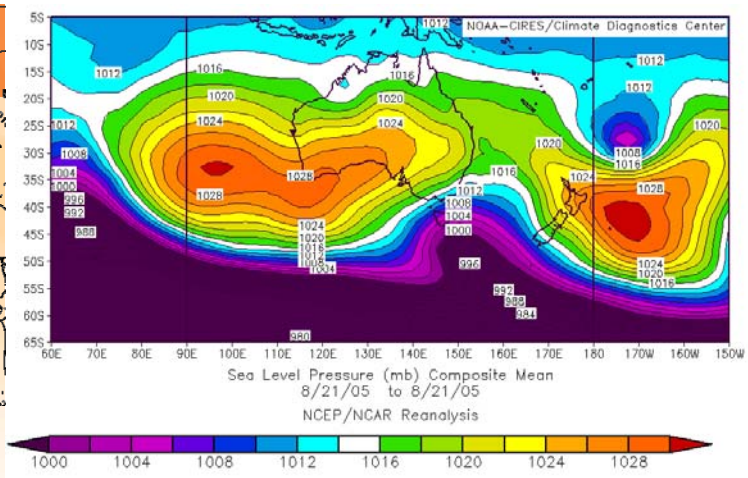

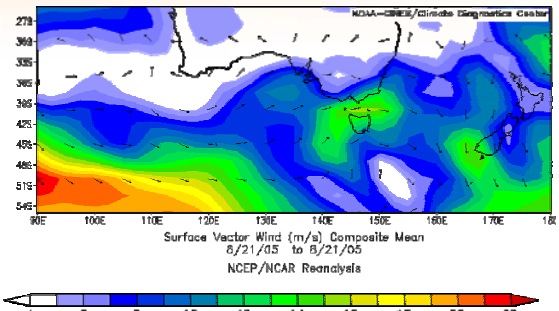

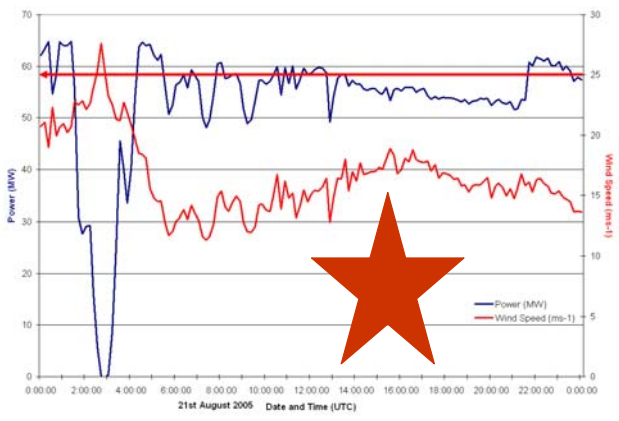

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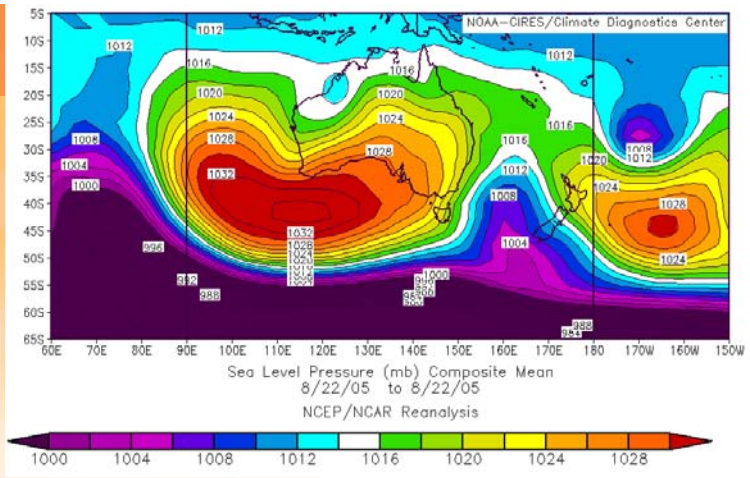

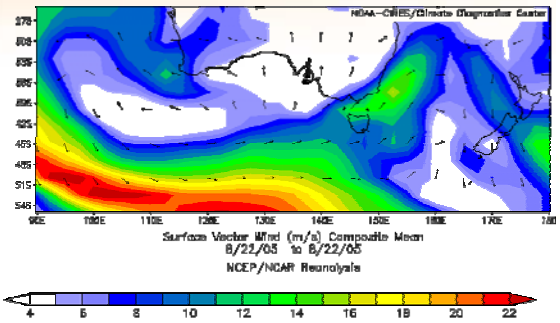

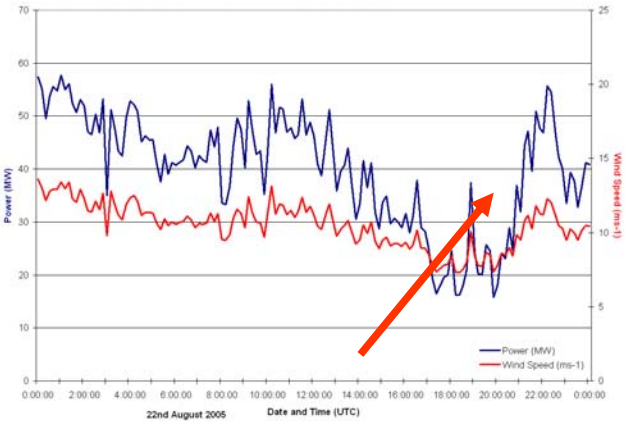

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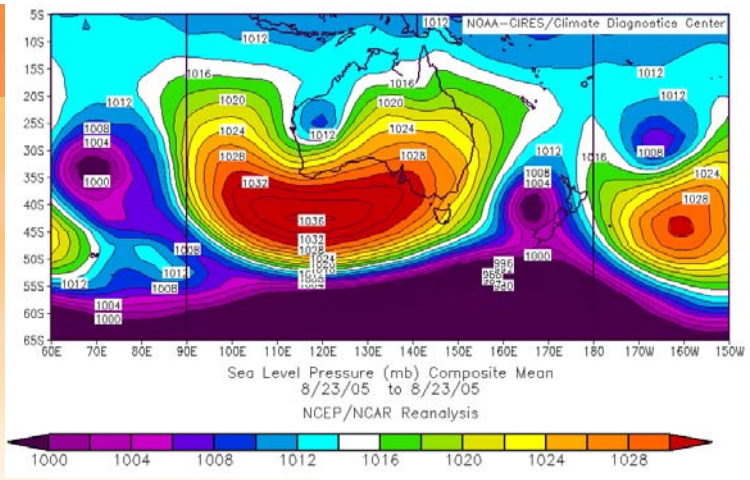

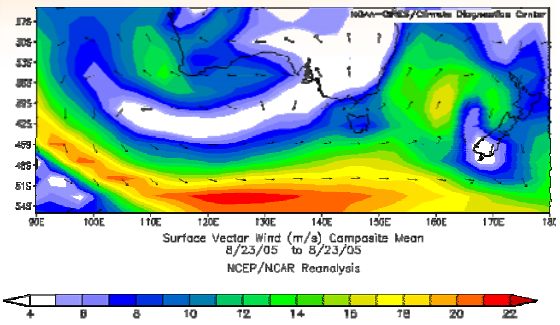

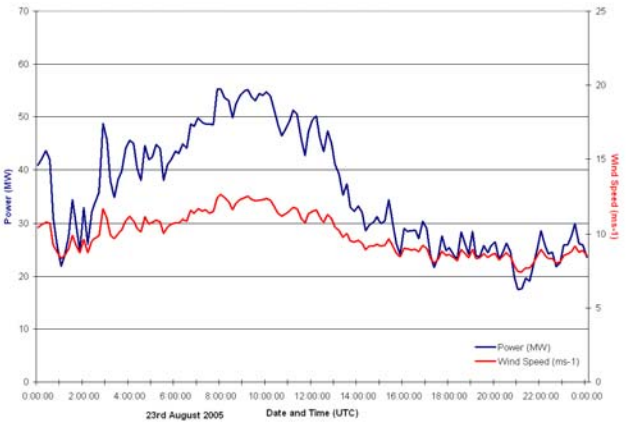

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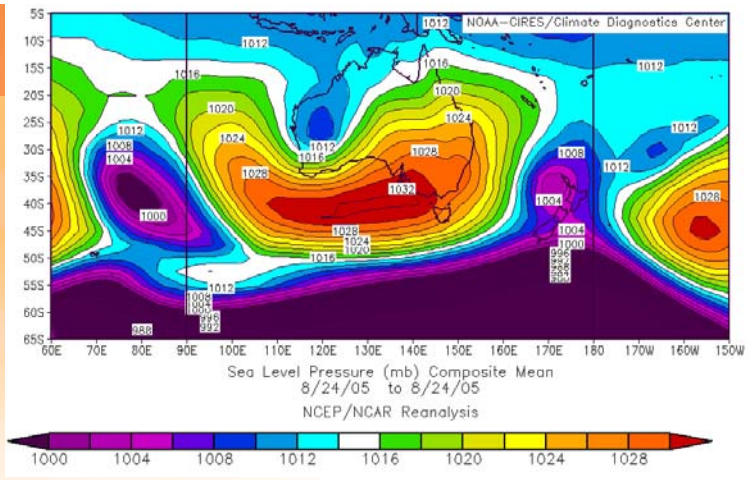

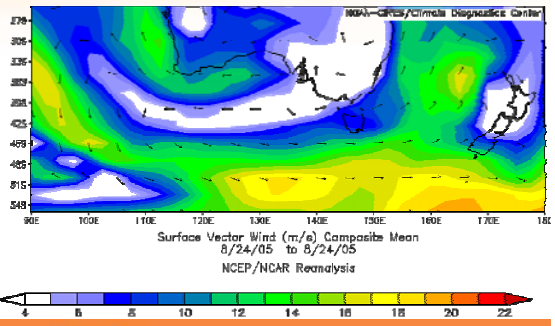

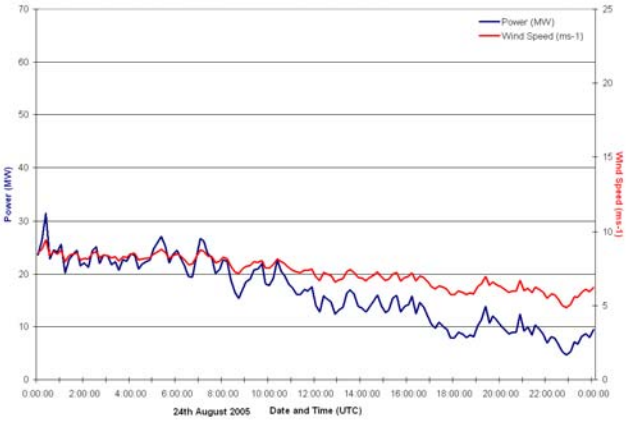

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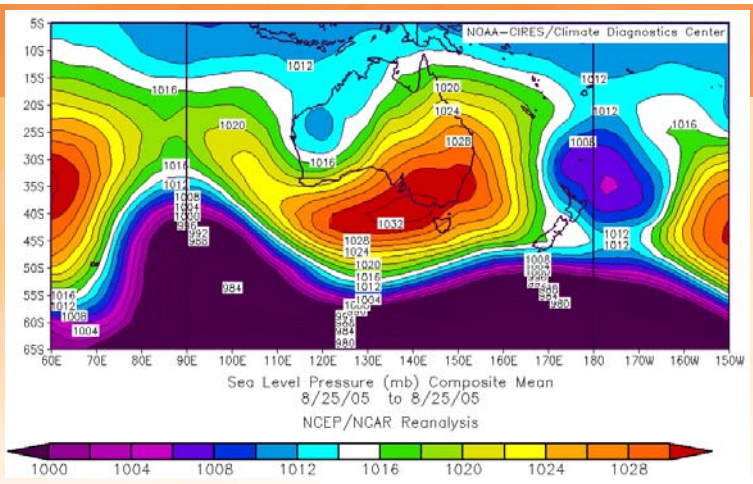

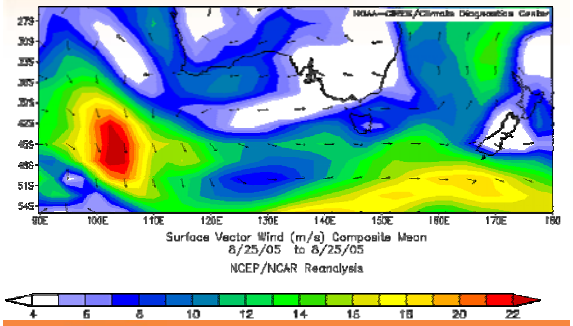

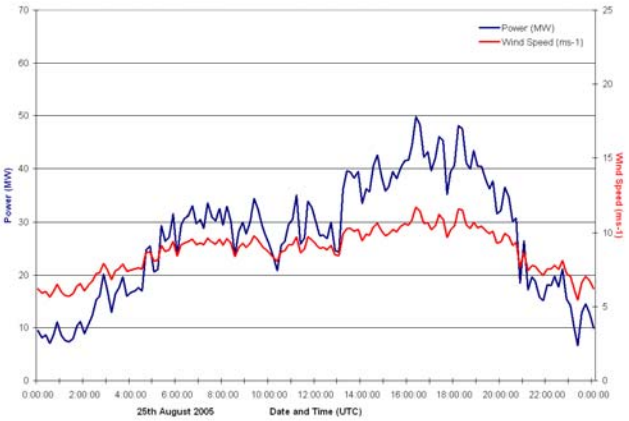

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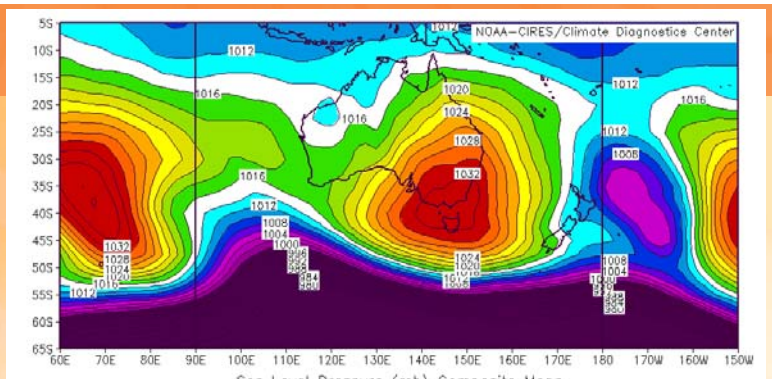

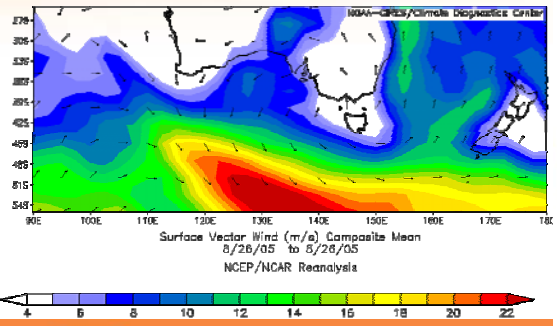

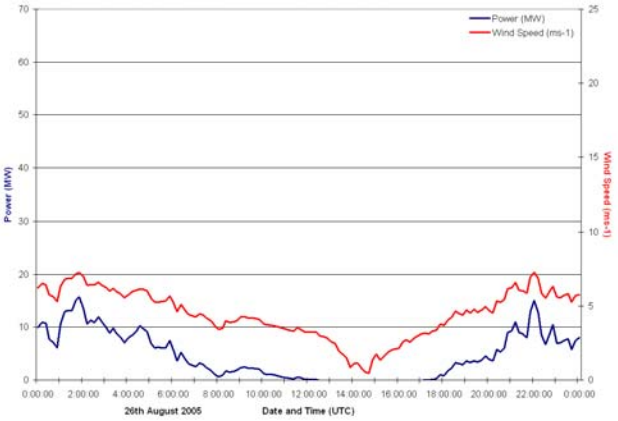

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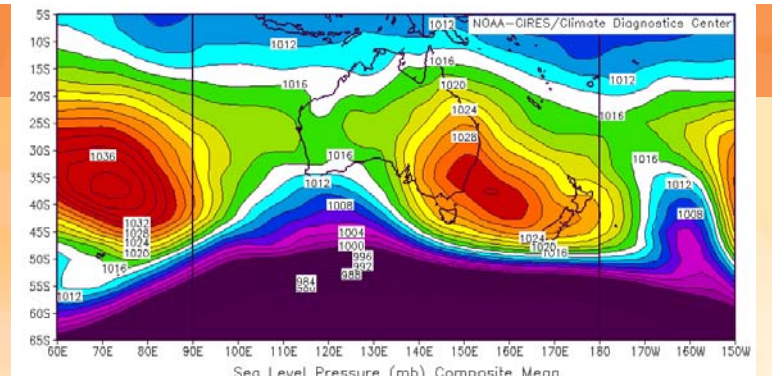

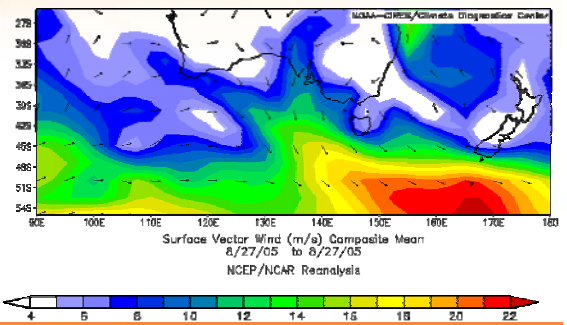

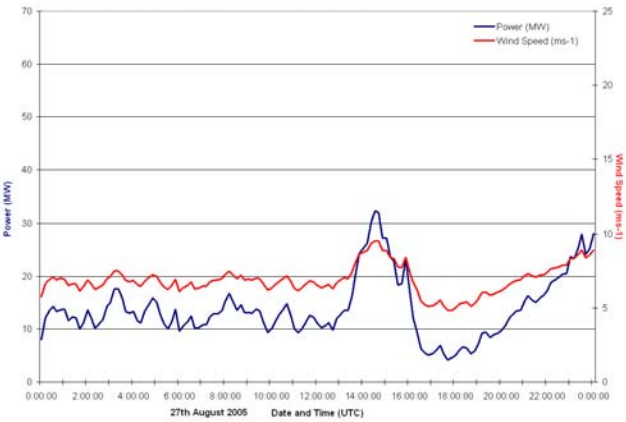

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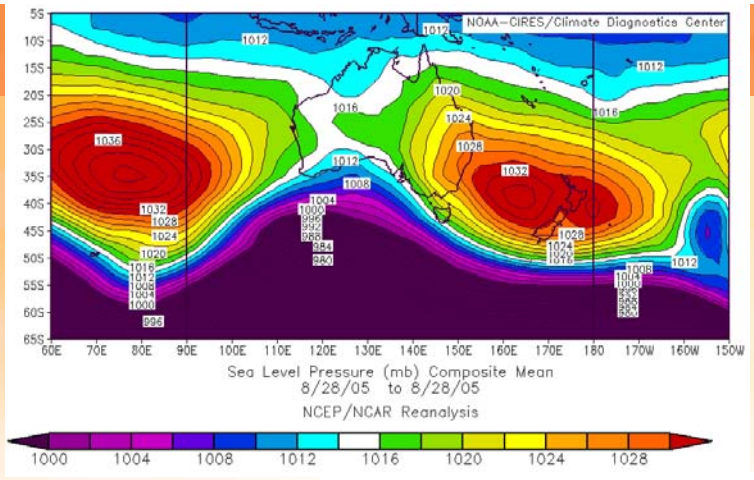

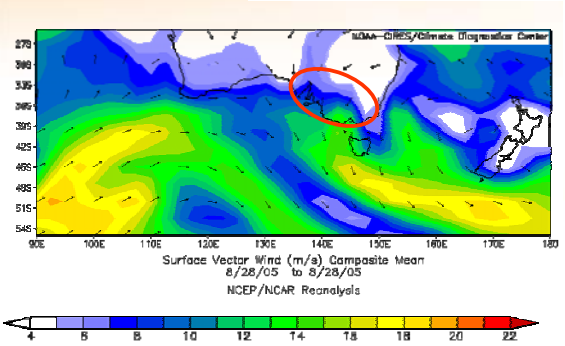

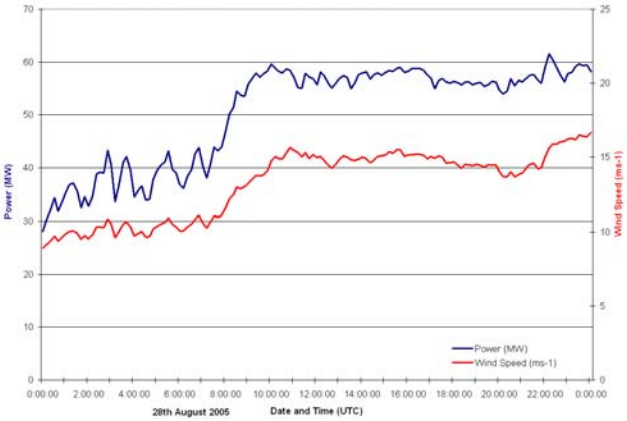

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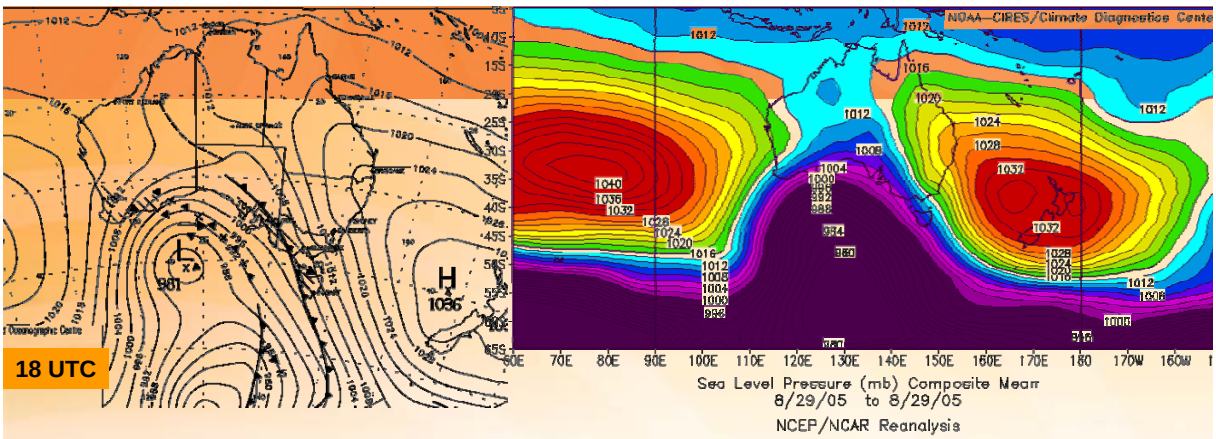

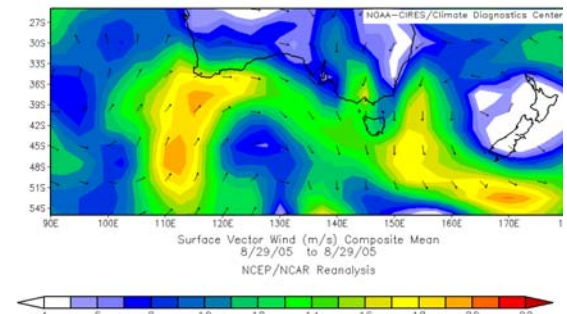

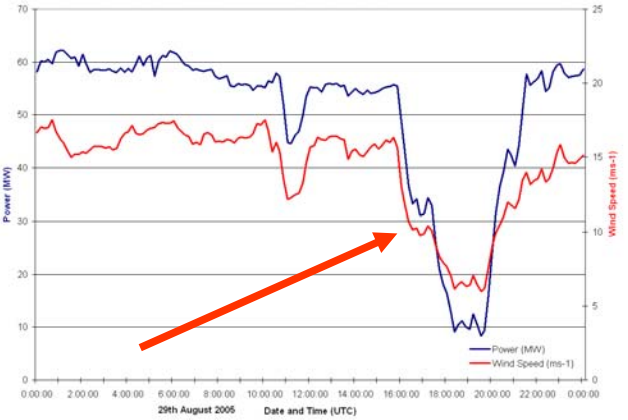

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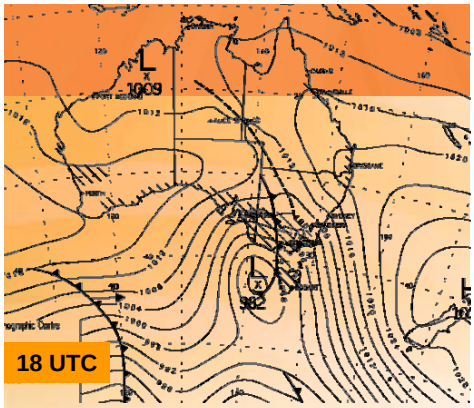

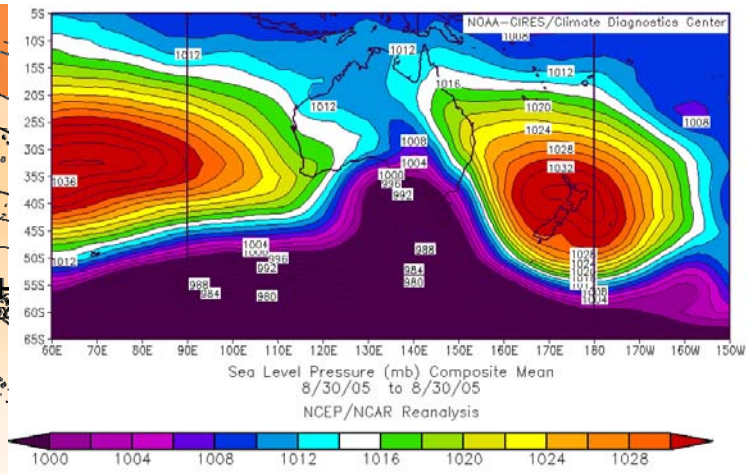

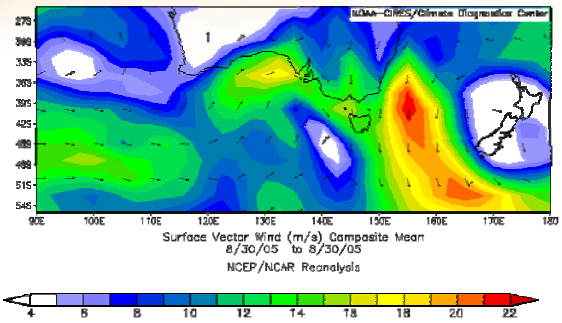

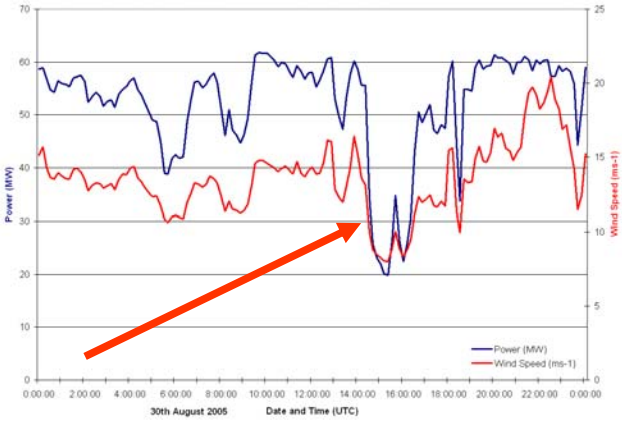

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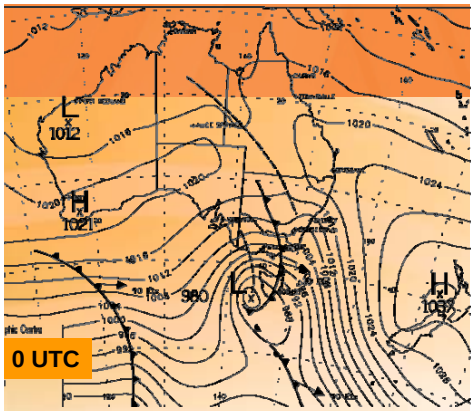

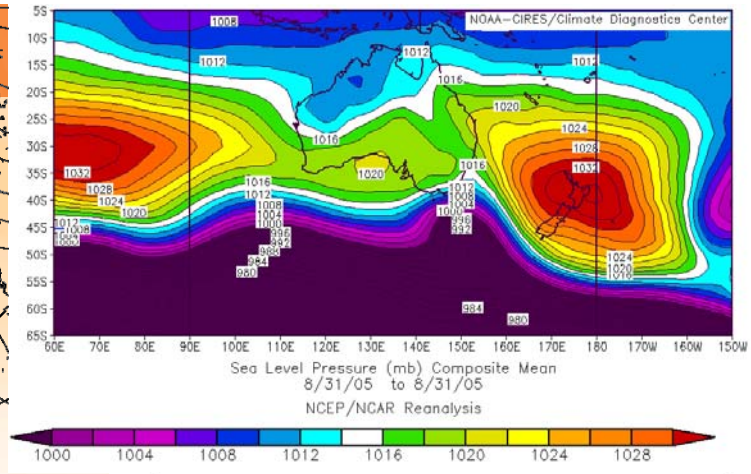

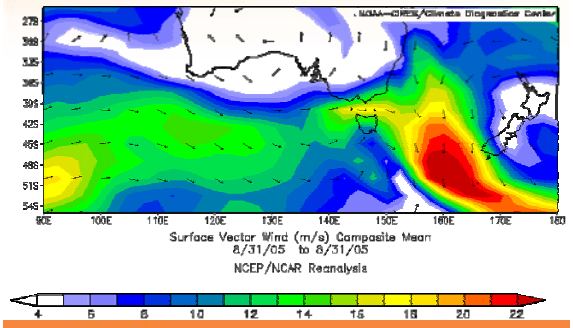

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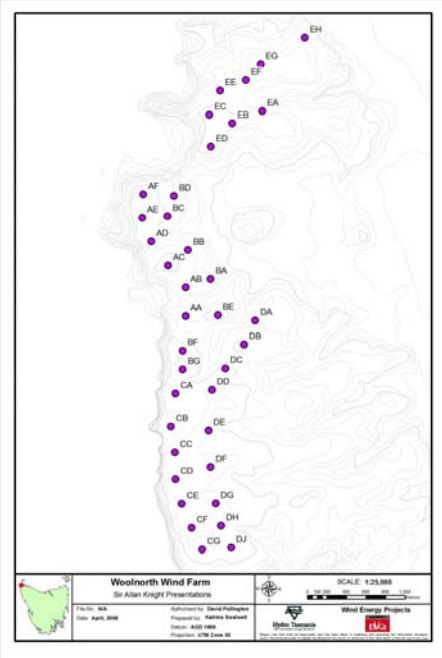
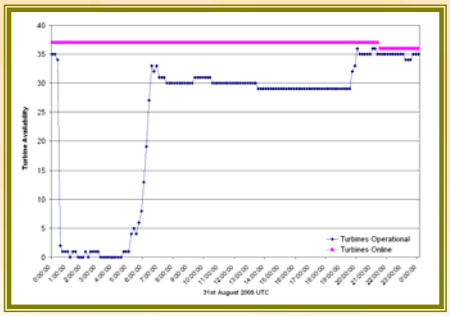
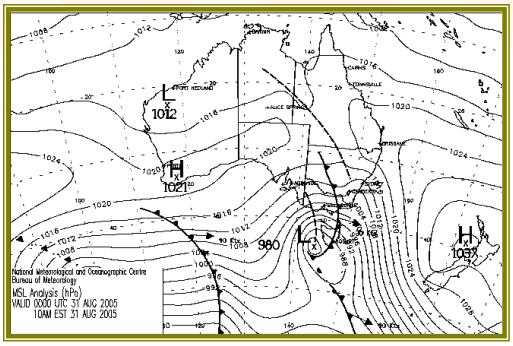
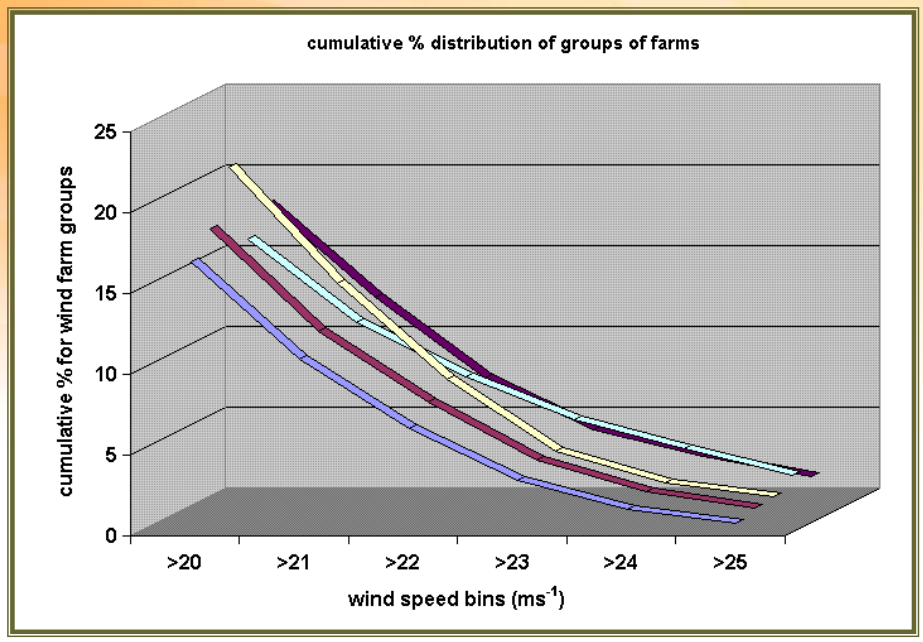
Turbine Availability Compared to Synoptic Situation







Woolnorth Wind Distribution for August 2005



Comparing NEMMCO Power Demand in August to the Output from Woolnorth

- An interesting question to ask is: **During peak demand times (Figure 2), would the wind power from Woolnorth have been available at peak times?**

Figure 1: Power and wind speed over a 24 hour period

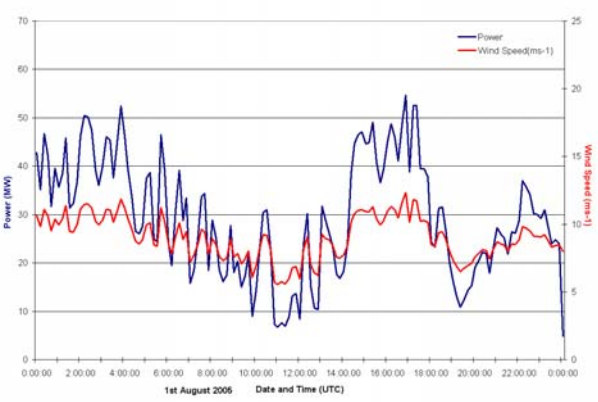
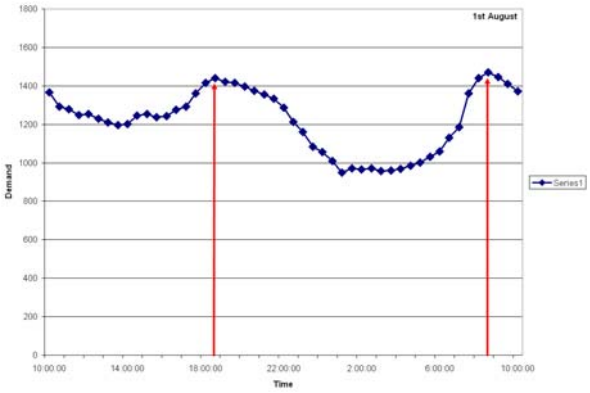
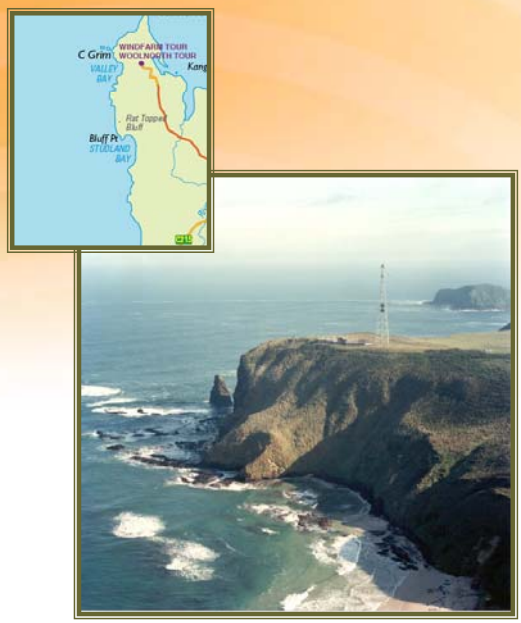


Figure 2: 30 minute power demand for Tasmania



demand data for Tasmania http://www.nemmco.com.au/

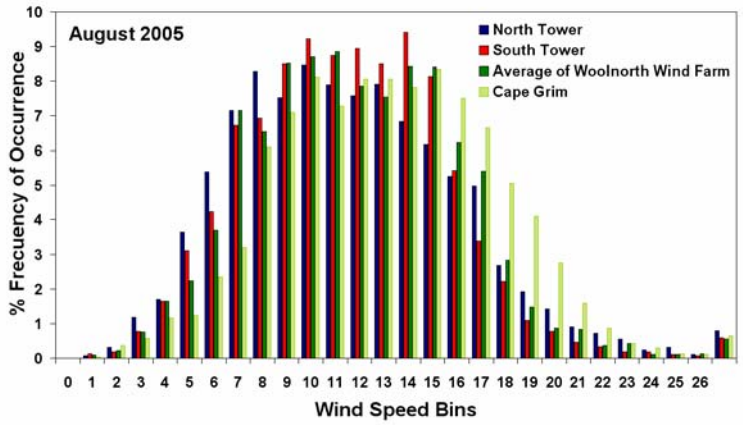
Cape Grim Baseline Station

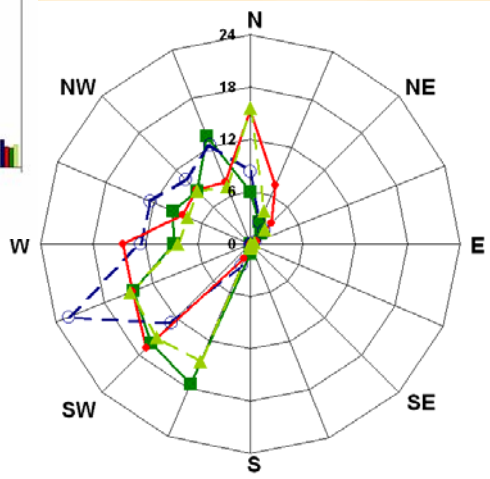


©David Whillas, CSIRO Atmospheric Research 1989

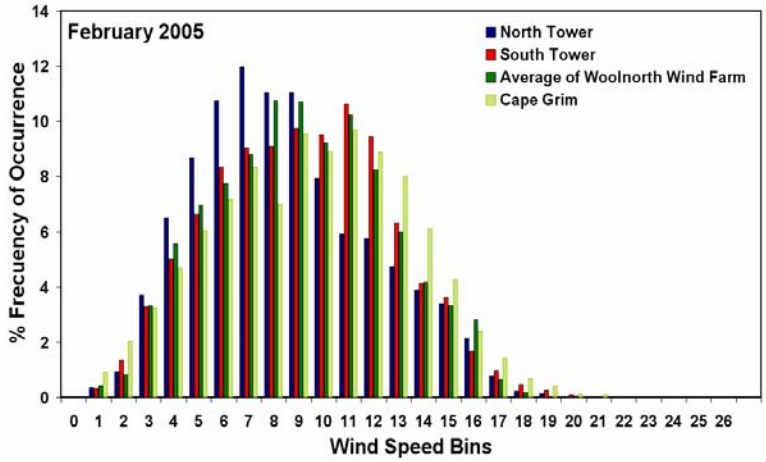
- To investigate the true nature of the weather and atmospheric conditions that approach Woolnorth, one needs access to detailed meteorological measurements.
- The Cape Grim Baseline Air Pollution Station is situated approximately 2.1 km north of the top of the Woolnorth windfarm, and has measurements of meteorological parameters including wind speed and direction, rainfall, temperature, humidity and air pressure.

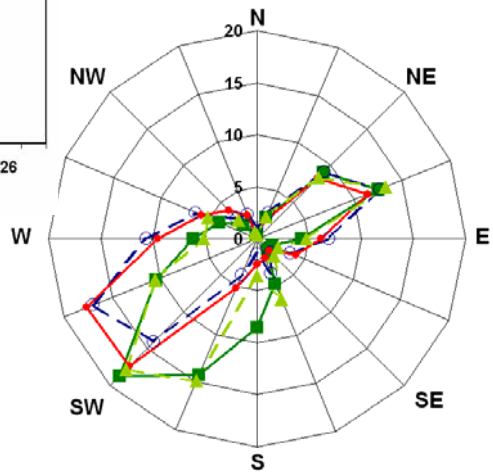
Cape Grim and Woolnorth – August 2005





Cape Grim and Woolnorth – February 2005



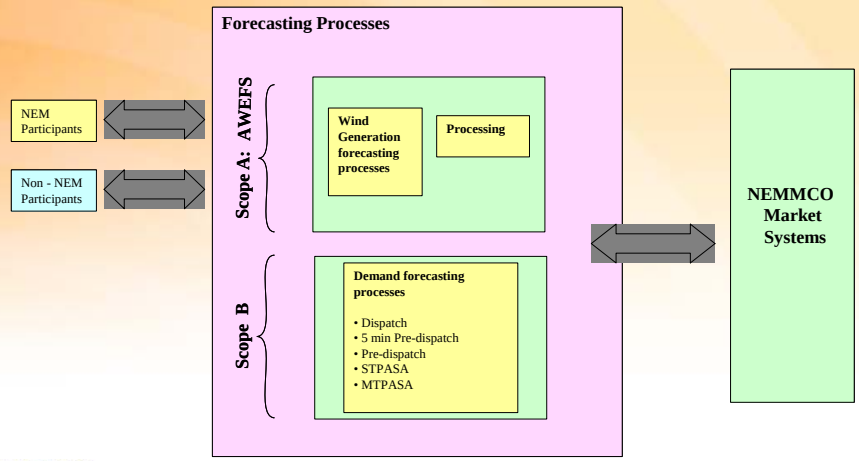


Australian Wind Energy Forecasting System - AWEFS

- Financed by the Australian Greenhouse Office (AGO)
- Forecasts for short to long term time frames
- Collection and Analysis of data
- Multiple forecasters will provide feeds of weather forecast information into AWEFS
- Outputs from AWEFS will include:
  - Forecasts of wind generation in MW for each Probability of Exceedance (POE) 10, 50 and 90% for each forecasting time frame
  - met data :eg wind speed, direction, temp pressure
- Should be able to identify forecast intervals affected by extreme weather. A warning alarm system could be a potential indicator.

Australian Wind Energy Forecasting System - AWEFS

Potential Scope(s) and data flows



Dispatch	5 minutes ahead
Pre-dispatch	Up to 40 hours ahead
STPASA	Up to 7 days ahead
MTPASA	Up to 2 years ahead
SOO	Up to 10 years ahead

Australian Wind Energy Forecasting System - AWEFS

Required For	POE	Frequency	Resolution	Number of intervals	Max. time to produce	Latest time by which outputs must be received (time prior to start of first dispatch or trading interval)	Forecasting Objective
5 minute dispatch	50%	5 minutes	5 minutes	1	< 10 secs	40 seconds	Individual wind farms, forecast areas, and NEM regions
5-minute pre-dispatch	50%	5 minutes	5 minutes	24	< 30 secs	90 seconds	Individual wind farms, forecast areas, and NEM regions
Pre-dispatch	10% 50% 90%	30 minutes	30 minutes	Variable - Current calendar day and 1-2 following calendar days	< 3 minutes	60 seconds	Individual wind farms, forecast areas, and NEM regions
ST PASA	10% 50% 90%	2 hours	30 minutes	8 calendar days starting from the next calendar day	< 3 minutes	60 seconds	Forecast areas and NEM regions
MT PASA	10% 50% 90%	Weekly	Daily	735	10 minutes	60 seconds	Forecast areas and NEM regions

Future Directions

We are attempting to answer some of these questions:

- Initial work has been on classifying what synoptic weather events are correlated to rapid changes in wind power.
- On a smaller scale, how did the position of the turbines affect the amount of wind power it produced.
- What useful information can we obtain from a NWP forecast?
- **I have been concentrating on the Woolnorth wind farm, and have acquired 5 years of minute observational data from Cape Grim. I am hoping to be able to correlate some of the wind farm observations at Woolnorth with the data from Cape Grim to see if there is some sort of pattern or a way to produce a type of forecast.**
- **Nesting of TAPM within a new NWP model**
- **Investigating parameters in the upper atmosphere such as potential vorticity.**
- **The announcement of AWEFS….. And the winner is……?????**

Acknowledgements

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