AESO Wind Power Forecasting Pilot Project
Pre-Conference Session

Calgary, 24th April 2007

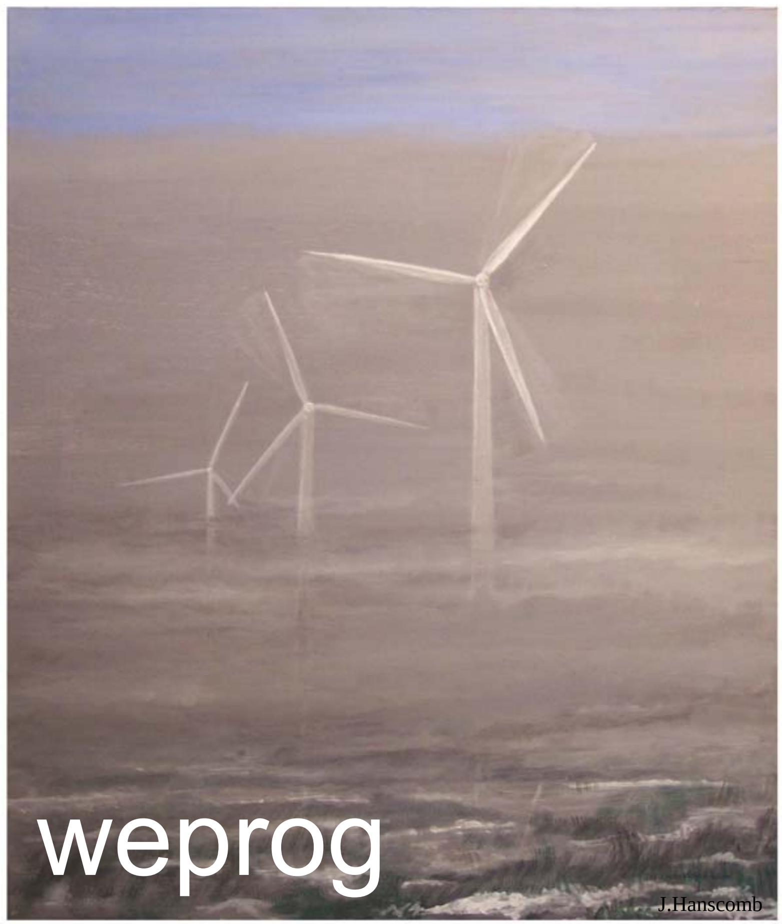

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Table of Contents

- Short Introduction to WEPROG and the MSEPS
- Setting up Forecasting for the AESO Pilot Project
- Experiments with the historical data
- Preliminary Results from the Experiments
- Examples
- Conclusions so far..

What is the MSEPS ?

A

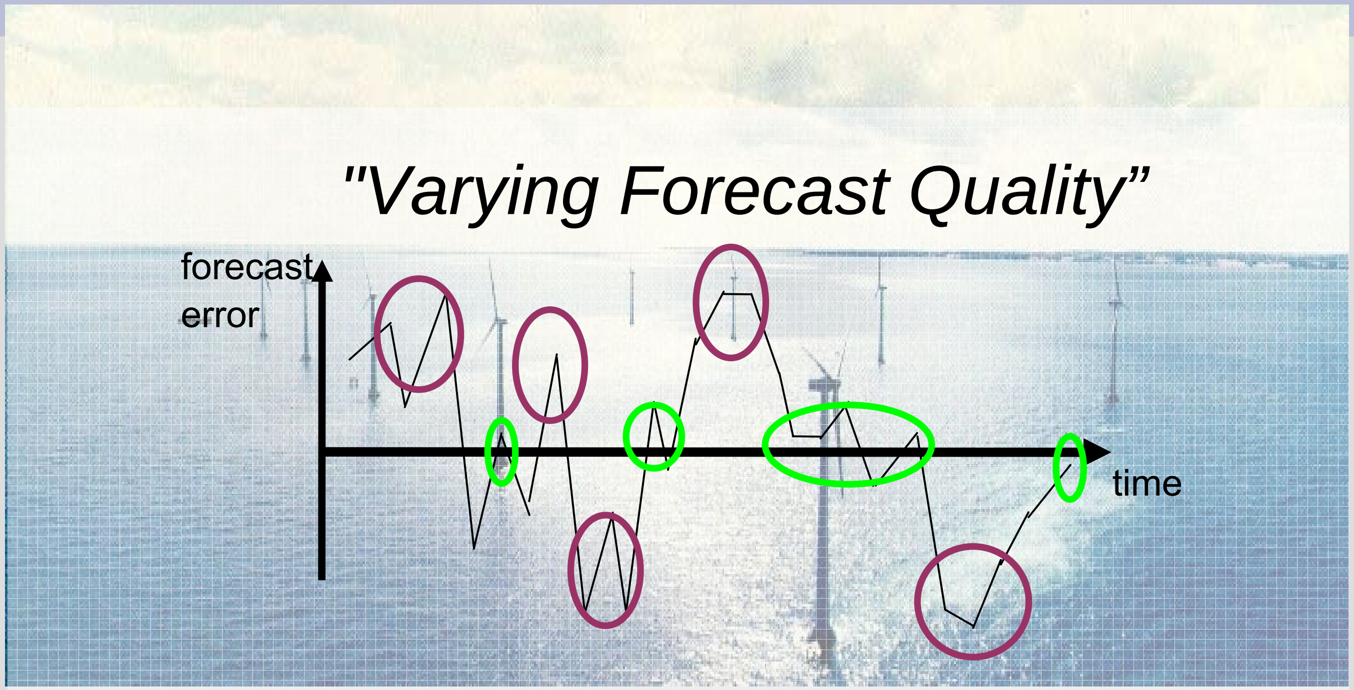
Multi-Scheme

Ensemble Prediction

System

Wind Energy is one out of many possible applications

The basic thought behind the Multi-Scheme EPS



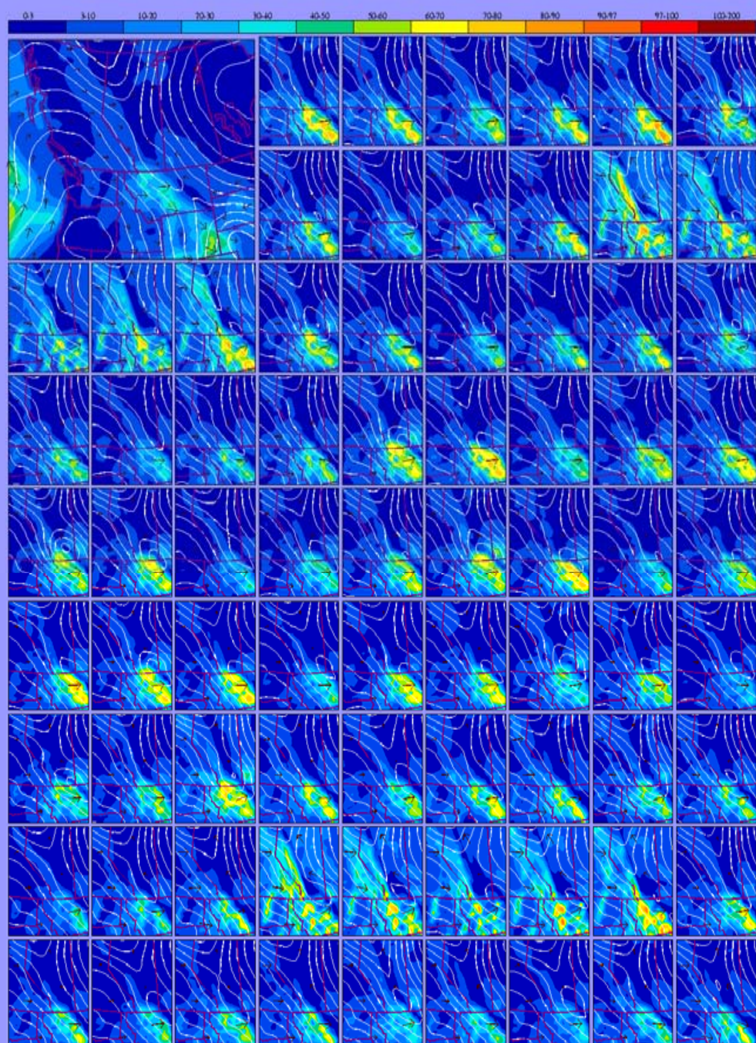
The background

- the weather changes fast between predictable and non-predictable
- subjective methods are not sufficient to estimate predictability
- the commercial world suffers from various prediction mistakes

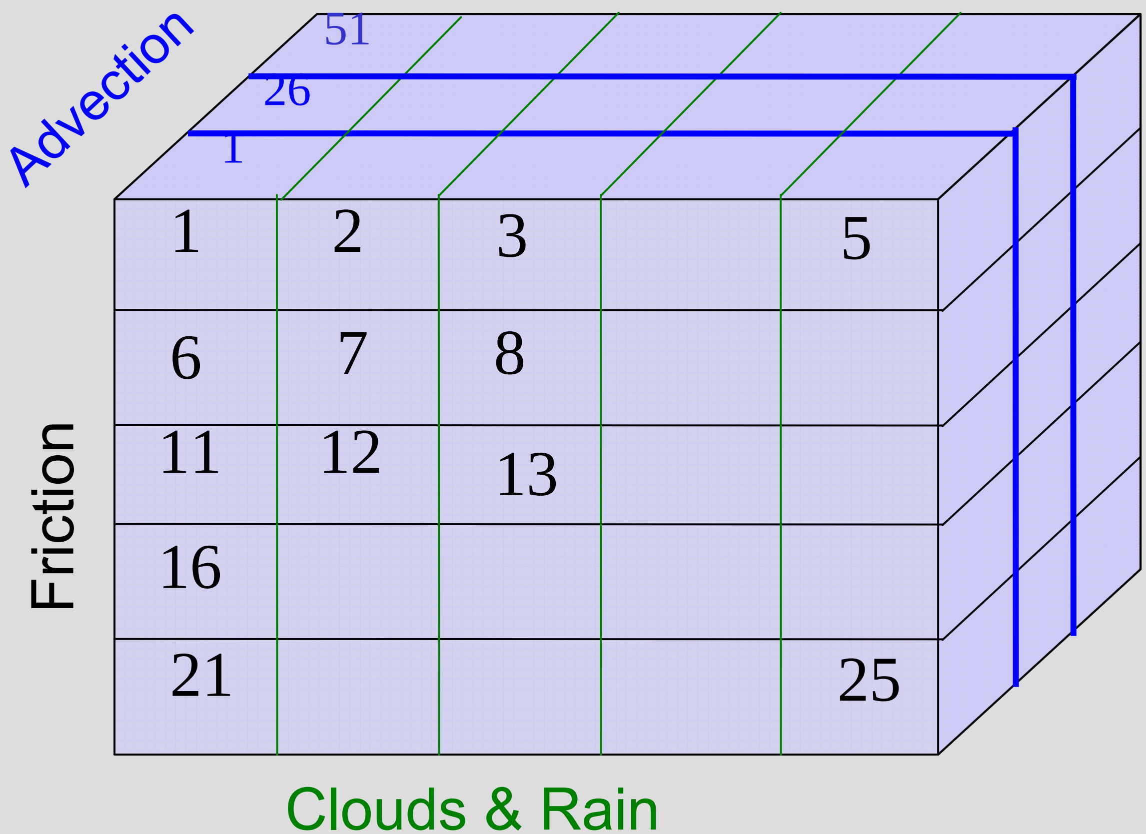
The method

- run a large number of different independent model configurations
- evaluate the uncertainty directly on the final product

The 75 MSEPS model configurations



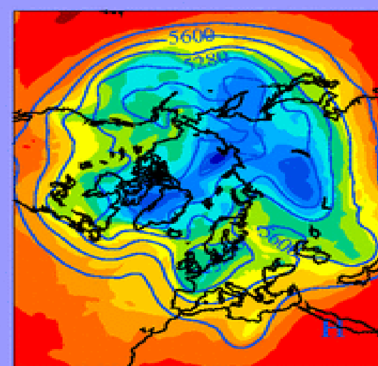
Example 72h wind power potential forecast for Alberta – 2007/04/07 12UTC +72h



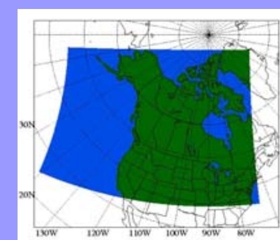
MS-EPS system with embedded weather dependent Applications

Global ANALYSIS every 6 hours from 2 different sources

MS-EPS hemispheric



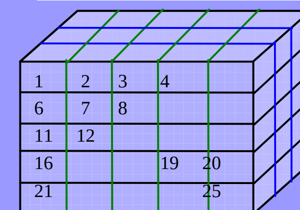
Limited Area MSEPS



Analysis data

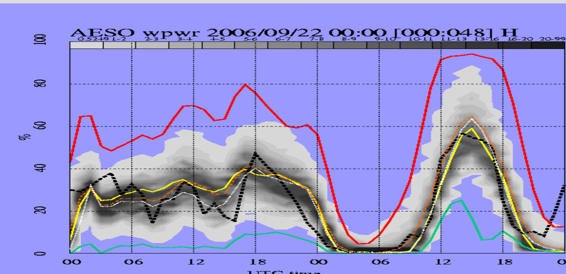
Boundary data

First guess data



processing 75 times the pwr application

PMT filter

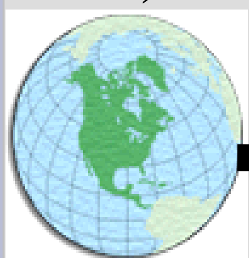


Graphics

End-User Specific Products

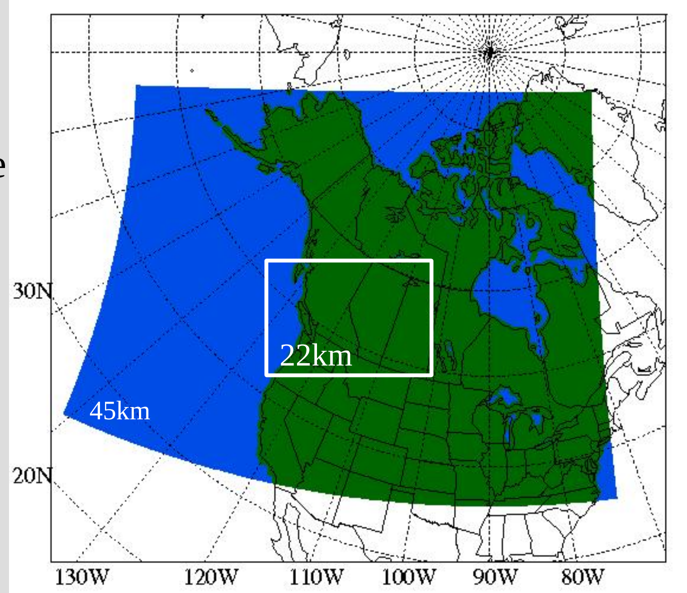
Setup of WEPROG's MSEPS for the AESO Pilot Study

Global Analysis (State Estimate)



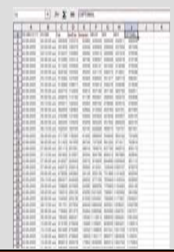
every 6 h

Large-scale and nested MSEPS setup



MSEPS 45km		MSEPS 22km		
1	-->	1		
2	-->	2		
3	-->	3		
4	-->	4		
5	-->	5		Min
.	-->	.	<-->	Max
.	-->	.		Optimal
.	-->	.		Mean
.	-->	.		
73	-->	73		
74	-->	74		
75	-->	75		

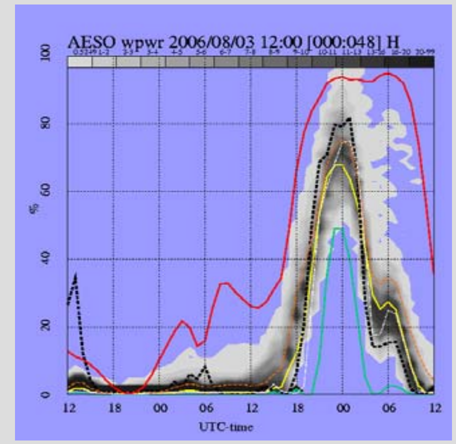
every hour



Data delivery to Phoenix Server

\+

graphics production

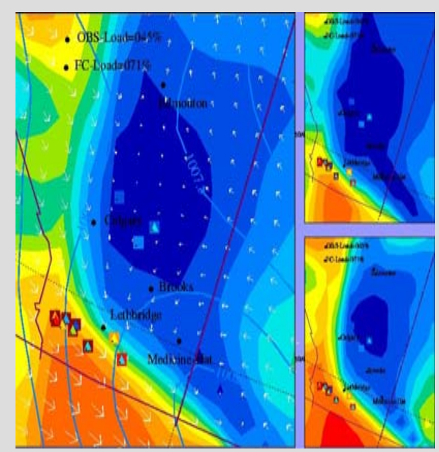


every 10min

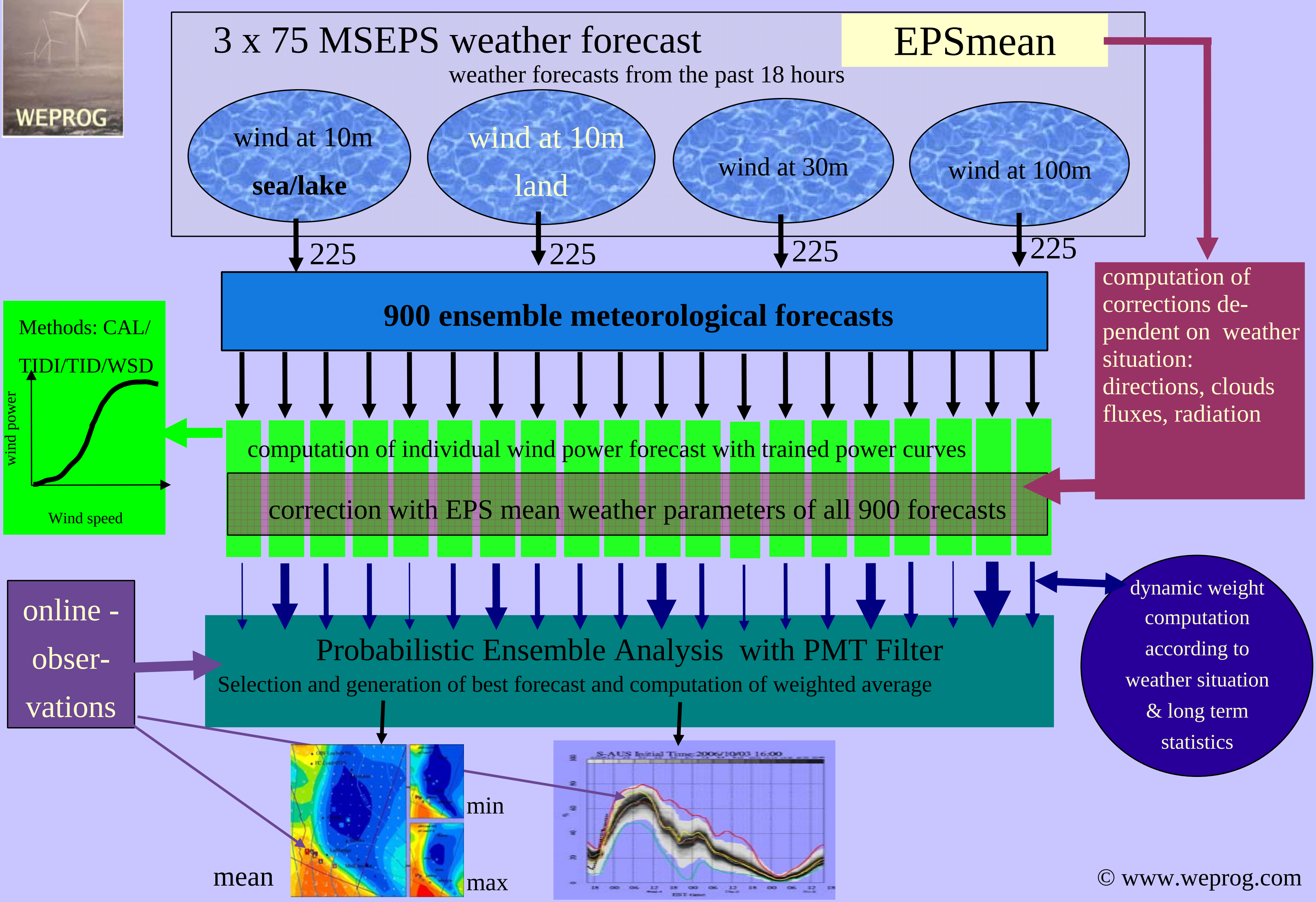
Phoenix Server observation update

met data

pwr data



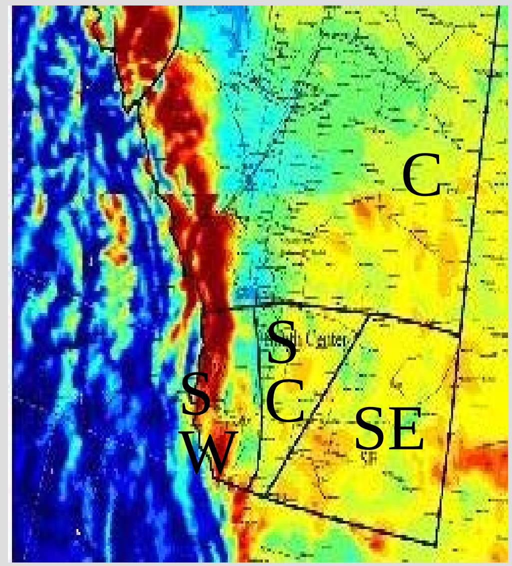
WEPROG's 900 member MSEPS Power Prediction



Experiments & Training with historic met & power data

Summary of conducted experiments in the pre-operational study:

- Relationship between wind direction and wind generation
- Generation Frequency in comparison
- Estimation accuracy from measure wind speed to wind power generation
- Forecast Error Analysis– where is the bulk of the forecast error coming from ?
- Large-scale model versus nested model
- The “lee wave problem” of the Rocky Mountains – or the influence of the Chinook winds on the forecast accuracy



Directional Performance and Power Distribution for SW + SC Wind Facilities

Note:

- Period Jan-Dec 2006
- All numbers from 12 hour predictions
- Forecast error in Unit [% of installed capacity]
- Power generation is relative to the total predicted for 2006
- Mean generation is relative to peak for each wind direction

Mean Generation: 17%

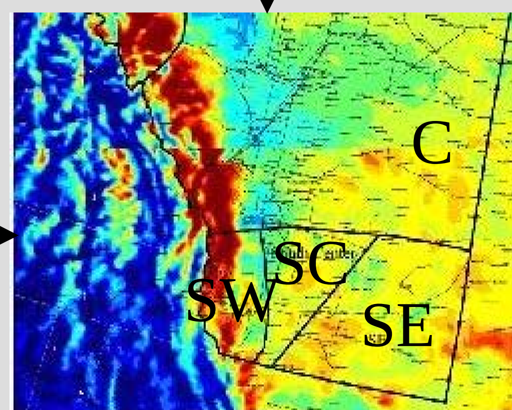
Power Generation: 9.5%

Forecast error: 8.5%

Power Generation: 83%

Forecast error: 12.8%

Mean generation 45%



Power Generation: 3.4%

Forecast error: 3.2%

Mean Generation 4.2%

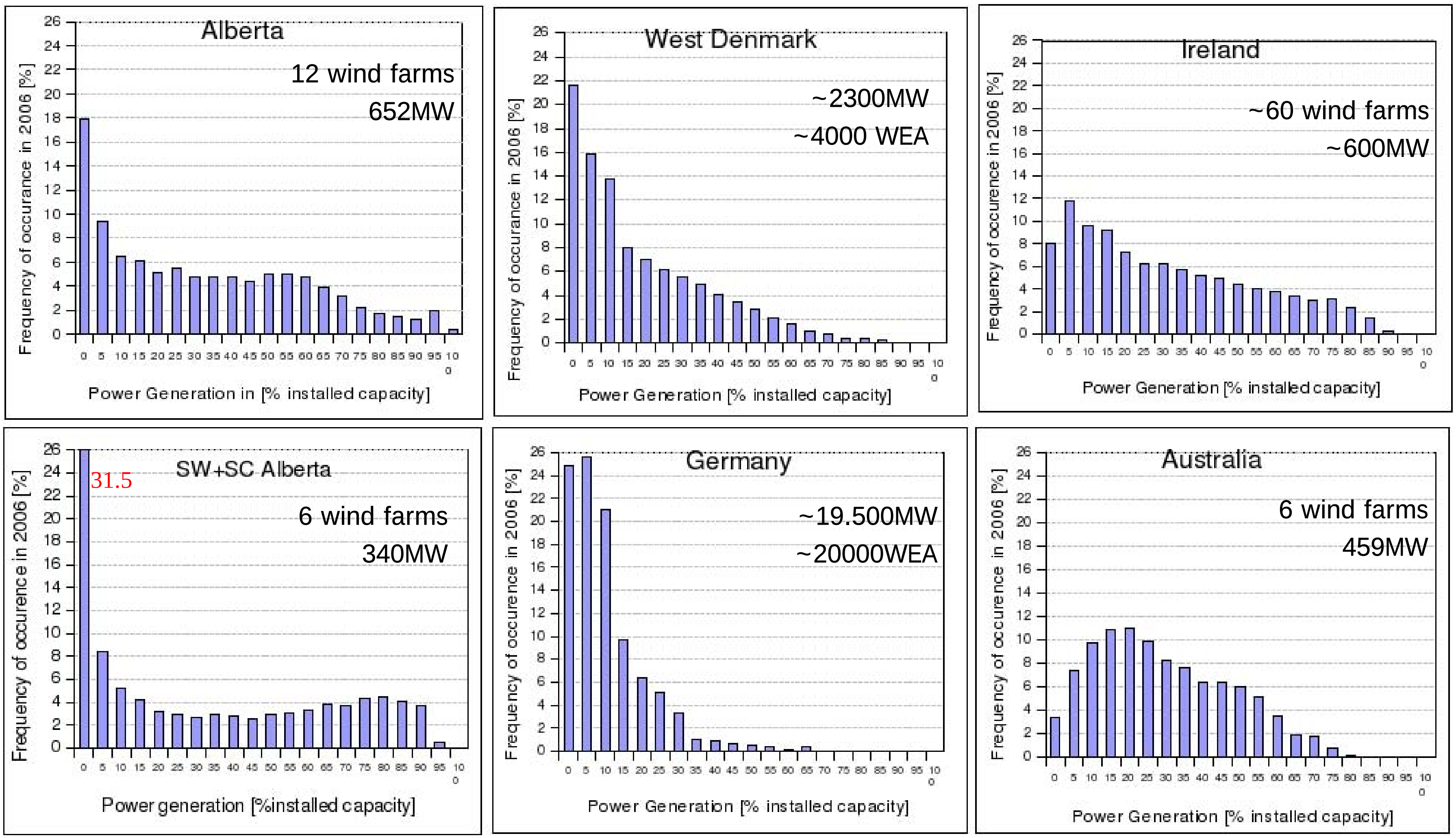
Power Generation 3.4% of total

Forecast error: 3.8%

Mean Generation 4.6%

The forecast generation and error takes place in periods with westerly flow. Other wind directions contribute very little to total generation and error.

Frequency Distribution in 5% Power Generation bins for various Countries



Grid security optimized Wind Power Prediction Techniques with the MSEPS Ensemble

Optimisation for minimum RMS/MAE error implies a smoothing of the forecast. High grid security requires that the TSO has probabilistic forecasts of the expected ramp rates without inherent smoothing.

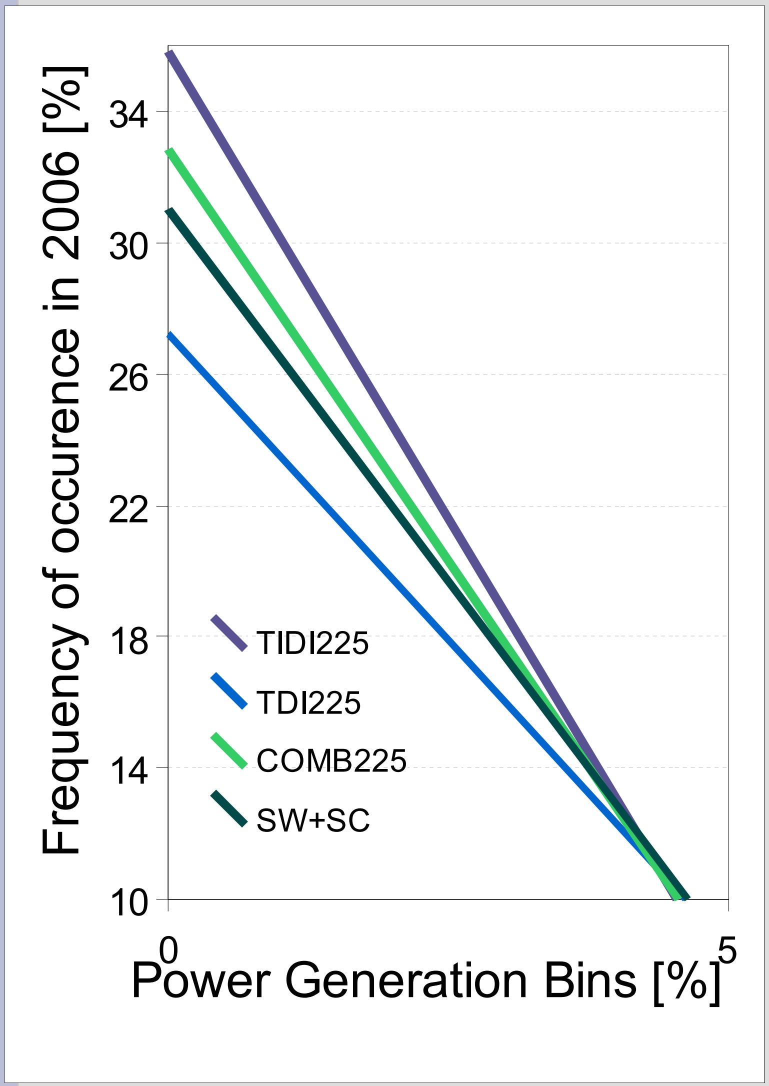
CODE Name	Calibration - Level	Ensemble member usage	Power curve estimation technique	Convergence speed	Optimization target
TIDI	facility level	wind speed,dir*	Sorting	fast	security
TDI	facility level	wind speed,dir*	LS minimization	slow	low error
COMB	facility level	wind speed,dir*	LSminimization,sorting	slow	low error,security

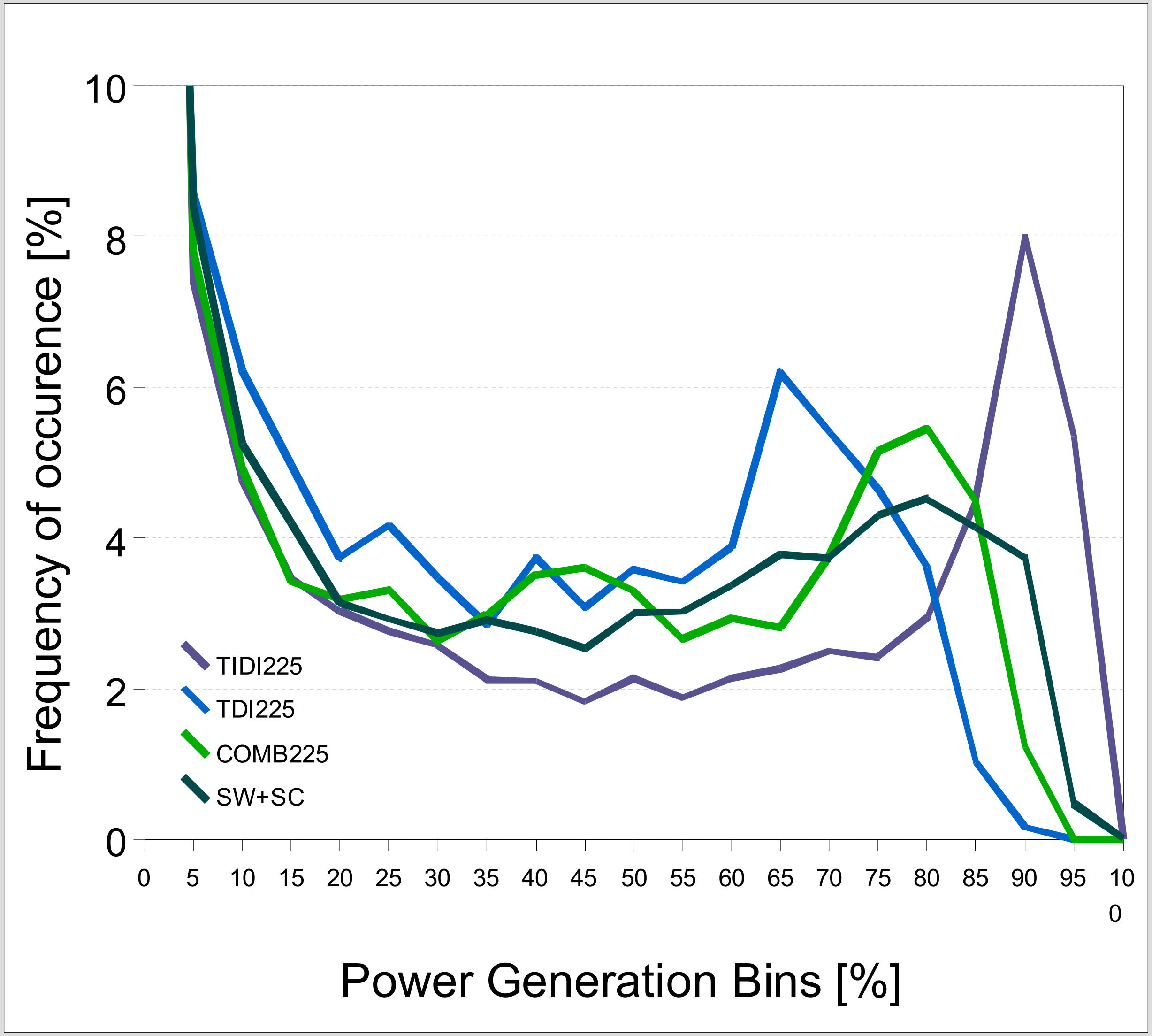
* all other weather parameters are taken from the EPS mean forecast

Sorting => power curve determined by numerical sorting algorithm to ensure little bias

LSMinimization => least square minimization - power curve estimated with paired measurements and forecasts

Frequency Distribution of the Different Power Prediction methods in 5% Power Generation bins





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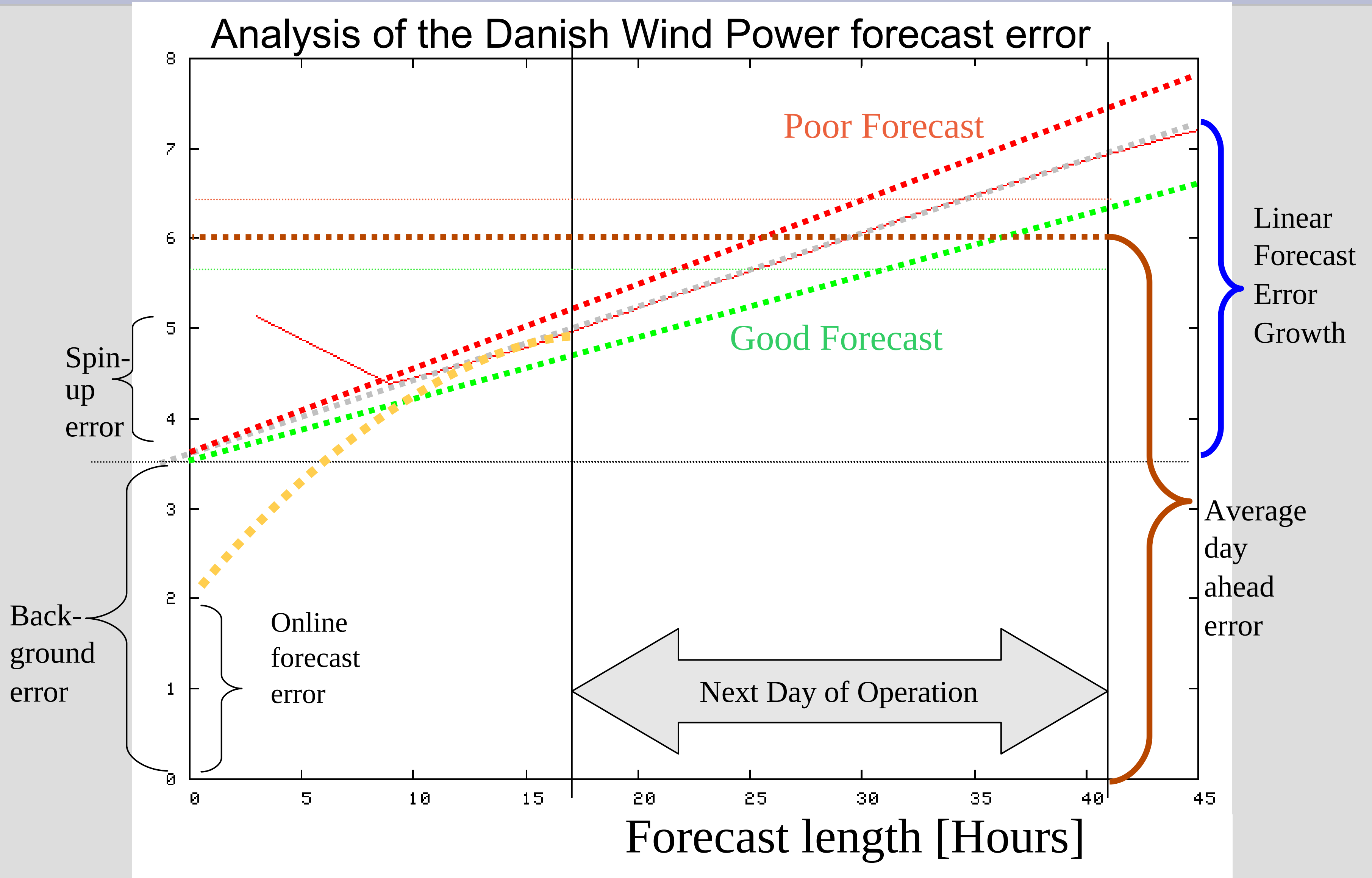
Wind Power Forecast Error Decomposition



How accurate can the Wind Power be Estimated from the measured Wind speed ?

Data set from a wind farm in Alberta:

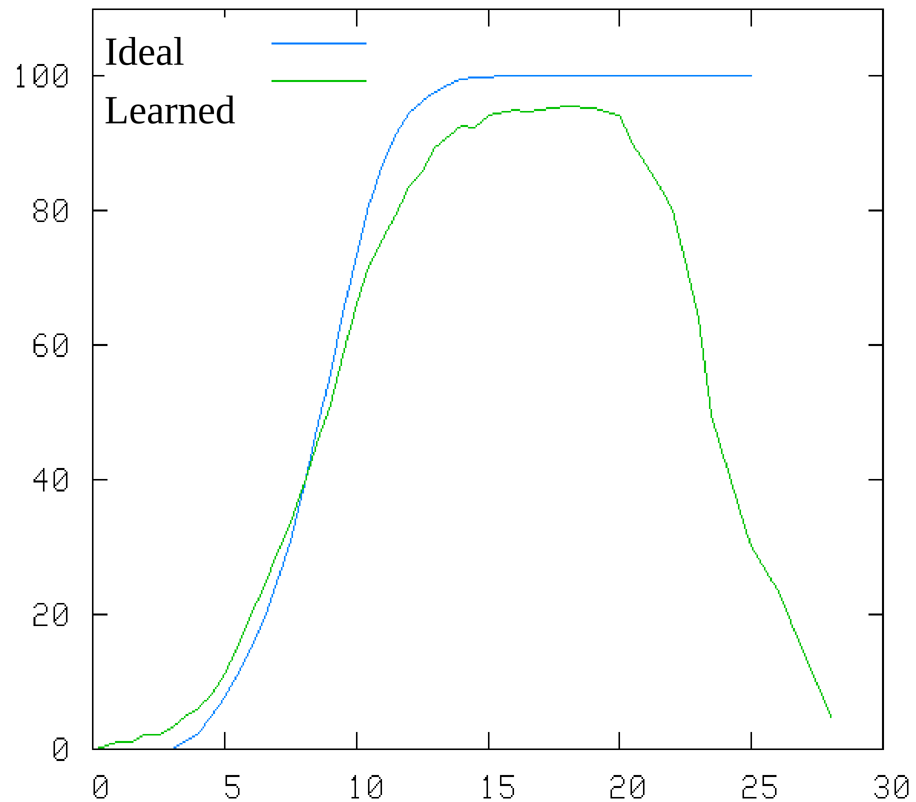
- 1 year data set of wind speed from met tower
- 1 year power measurement
- 10 minute time resolution

Two Estimation Methods

- "Ideal" is a standard power for a single turbine
- A "learned" power curve

Statistical results

	Learned	Ideal
Mean ABS. Error	10.78%	11.52%
RMS	16.30%	18.71%
Correlation	0.90	0.89



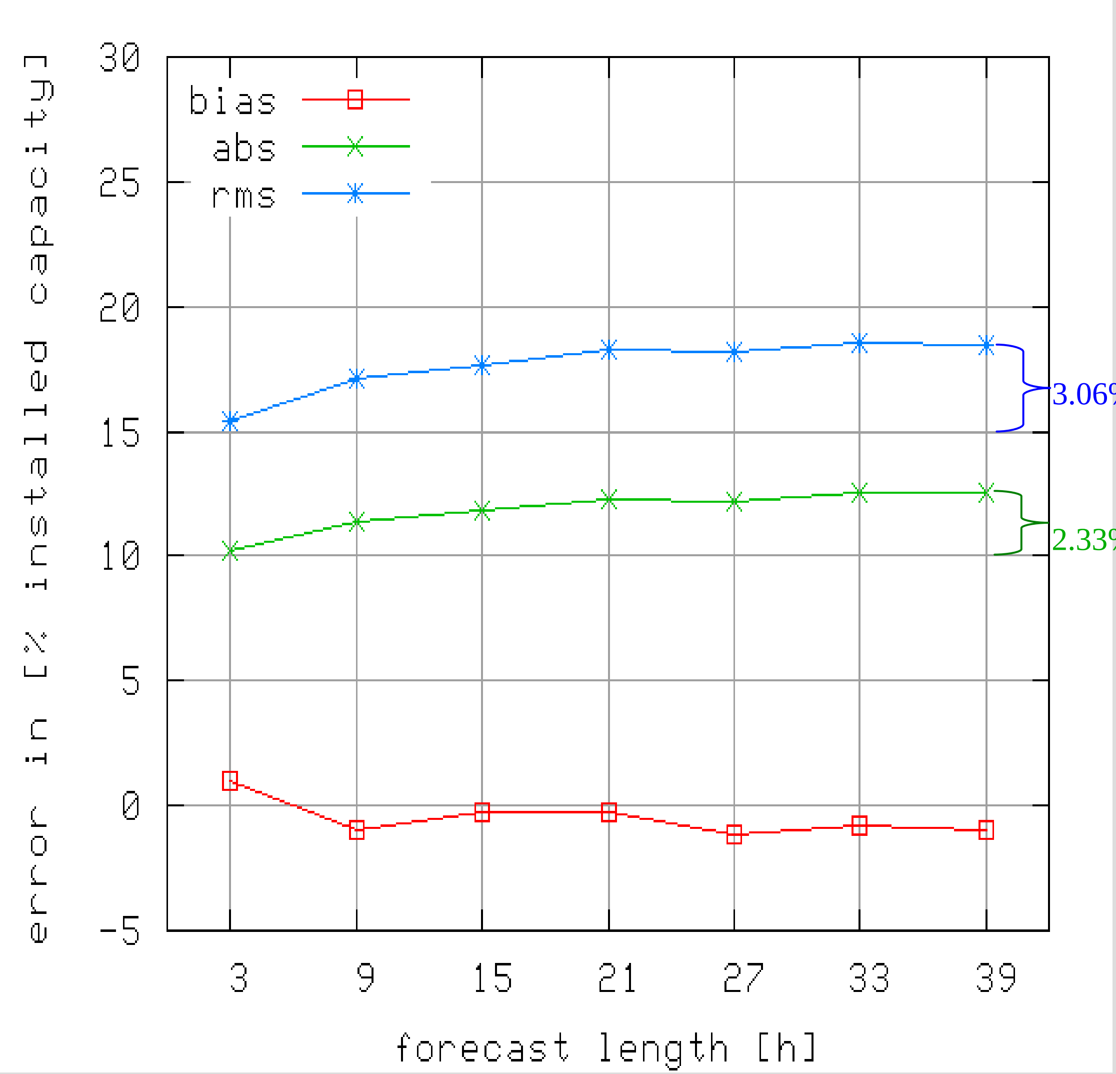
The estimation error for a single wind farm is considerable and indicates that we must expect difficulties in getting under 10% mean abs. error in forecast mode. The same technique would result in less than 7% error for a wind farm in the western part of Denmark.

Estimating the Forecast error growth from wind facilities in SW+SC

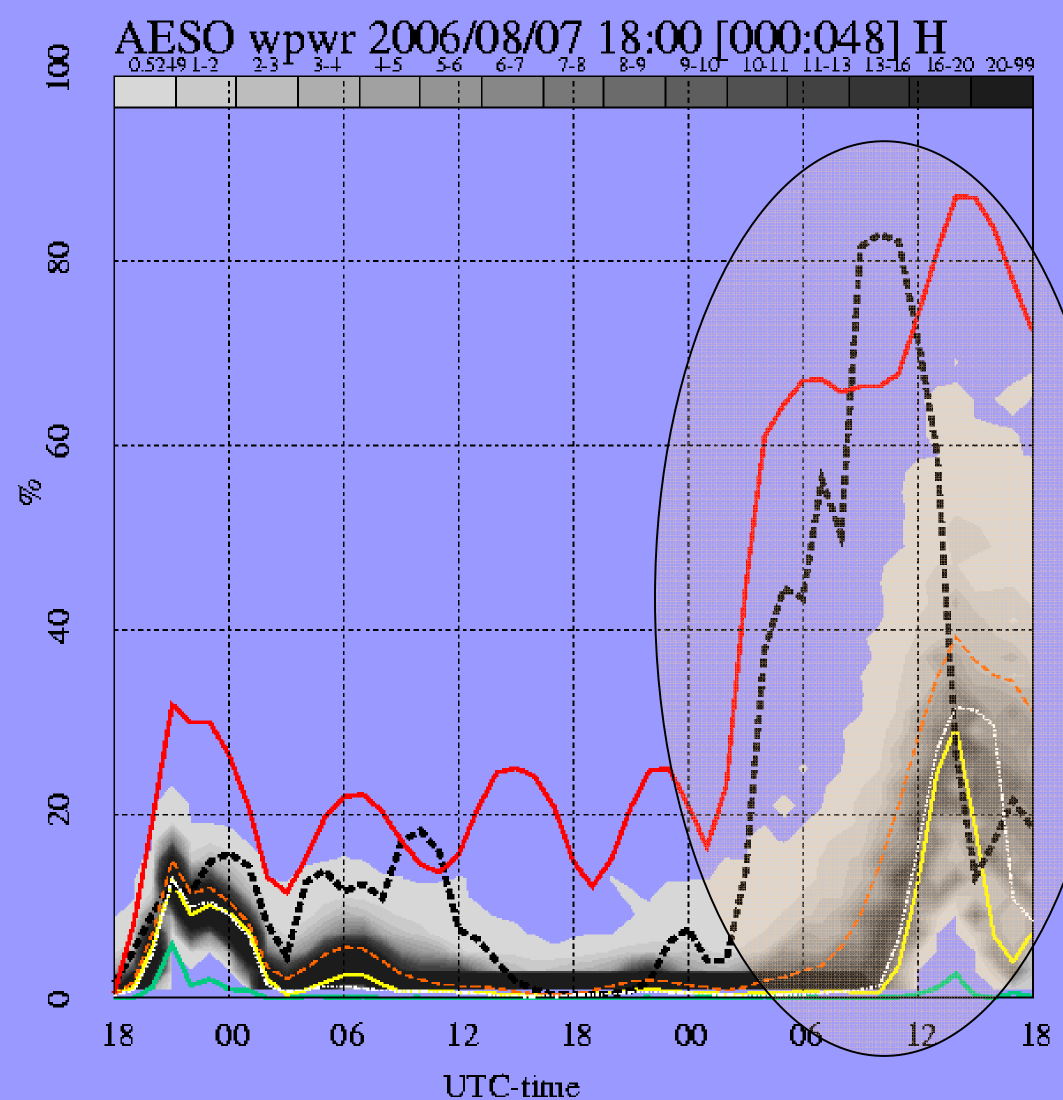
Statistics details:

- Period: Jan-Dec 2006
- Prediction method: COMP
- High resolution nested model
- Facilities covered South West (3)and South Center (2)

*A Mean Absolute Error growth of 2.3% over 2 days is very similar to what is experienced in other areas, but there is **a dominant initial background error of 10%**, which is in fact a typical number for a single wind farm in a flat, but windy terrain.*



Why is it so difficult to predict the wind that generates the wind power in Alberta ?



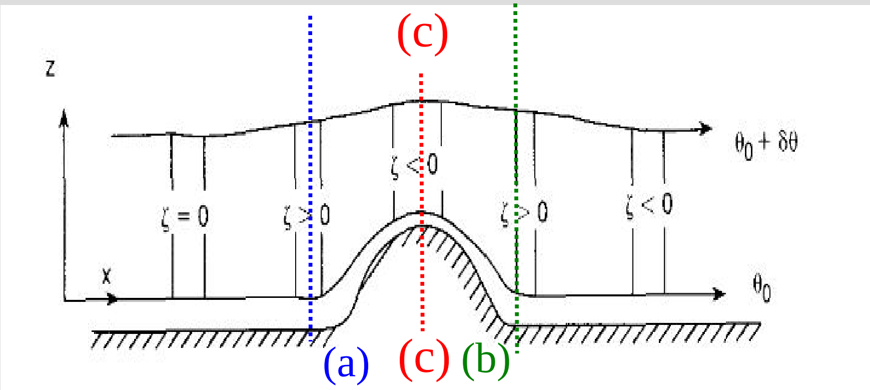
<u>The sources:</u>

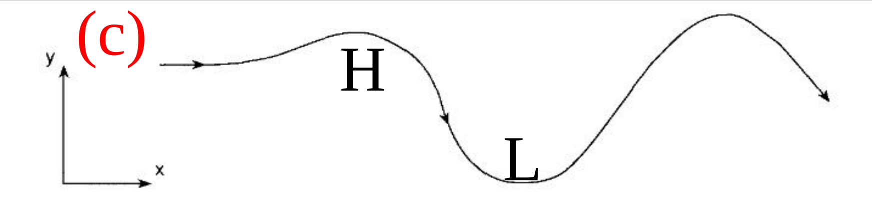
- 83% of the wind energy generation in 2006 was produced by westerly flow.
- The Chinook Winds are most prevalent over the South West and South Center region, especially in a belt from Pincher Creek in the Crowsnest Pass through Lethbridge
- In the Center region, the Bow Valley in the Canadian Rockies west of Calgary acts as a natural wind tunnel funneling the chinook winds.

<u>Our Theory:</u>

There is a large uncertainty associated with the strength and the timing of the Chinook winds.

Using Isentropic Potential Vorticity (IPV) to describe the uncertainty of the Chinook winds





The idealised theory says:

...because of the conservation of **IPV=(f+ζ)*** $\partial\theta/\partial$**p**

- an air column is compressed vertically as it ascends (a)
- an air column expands horizontally over the mountain (c)
- an air column expands vertically again as it descends.

The air-parcel pressure increases on the lee side and the air turns counter clockwise to North-East and creates a low pressure system with upward vertical motion (b)

- the upward motion is compensated by down-drafts of air with high levels of momentum leading to a gusty wind

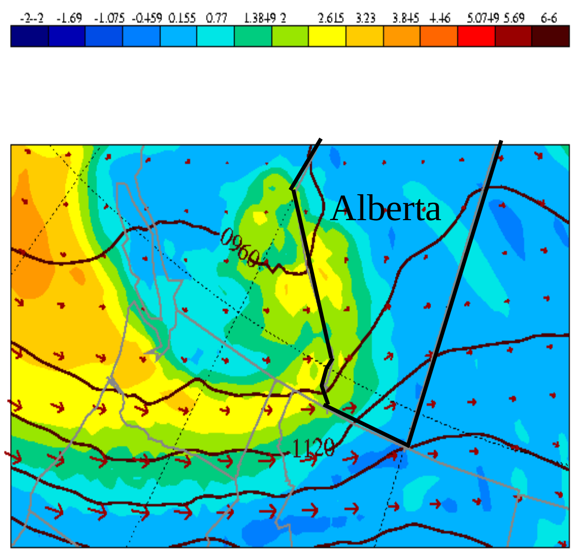
The wind speed on the lee side depends on a number of factors such as:

- the potential vorticity flow from the Pacific (West)
- Latent heat release, when the air is ascending on the west side of the Rockies
- The frictional effects of the Rockies
- the effective height of the mountains - it varies with stability and can be much higher than the physical height

==> these factors imply a high model uncertainty and prompt for an ensemble of weather forecasts

Real Examples of IPV

Horizontal IPV Map



Westerly flow of IPV on an isentropic surface towards Alberta. IPV values above 2 (yellow to red) indicate air with high IPV of stratospheric origin.

The full dark lines are isolines of the Montgomery stream function.

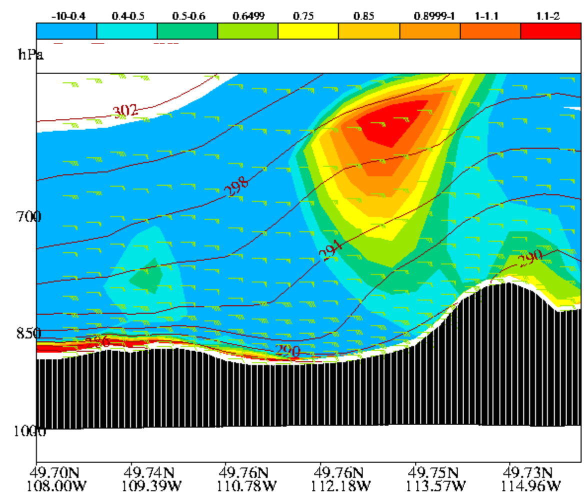
IPV is seldom used in forecasting, but often used in theoretical studies in meteorology o the large scale weather pattern.

The most important feature of IPV in a wind power context is the ability to warn about sudden changes of the weather.

Strong IPV near the surface connected to IPV above is an indicator of a dramatic change in the wind power generation.

IPV result in changes of the wind speed of 10m/s in one minute. An attempt to forecast such changes explicit will result in a high level (a double punishment), but a probabilistic forecast with an ensemble add confidence.

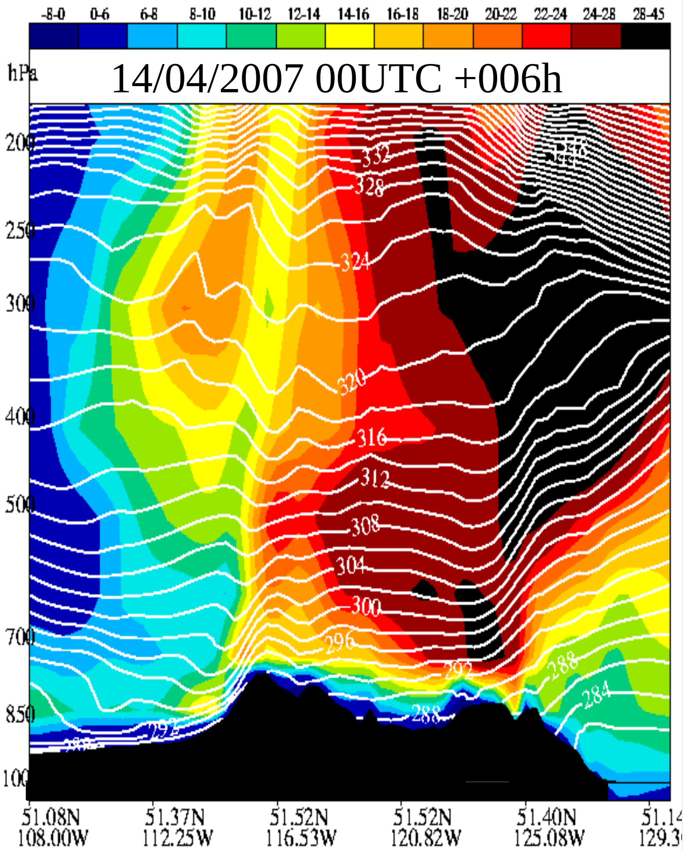
IPV Crossection

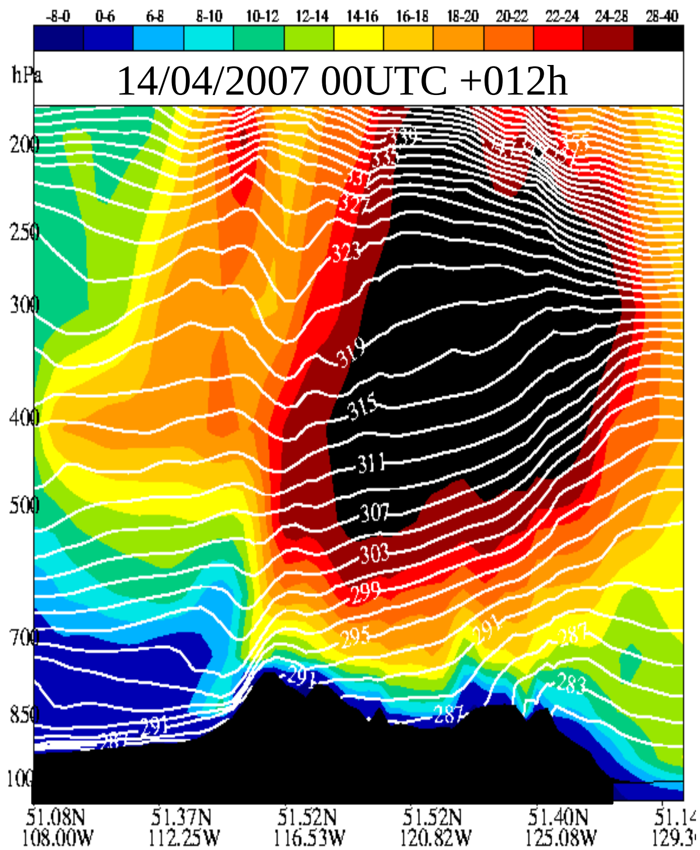


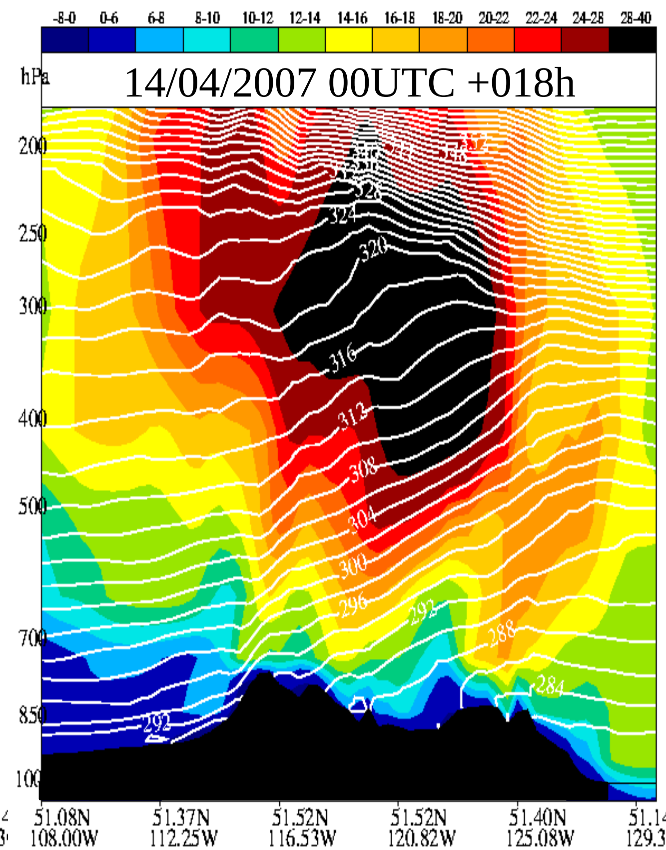
Crossection of potential temperature isolines. These are material surfaces for adiabatic frictionless motion. Thus, no airparcel can cross an isoline and the flow is along these surfaces.

The shading shows the IPV and therefore the area with strong risk of a sudden change in the wind generation.

The Complexity of the Flow across the Mountains

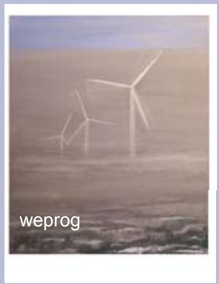






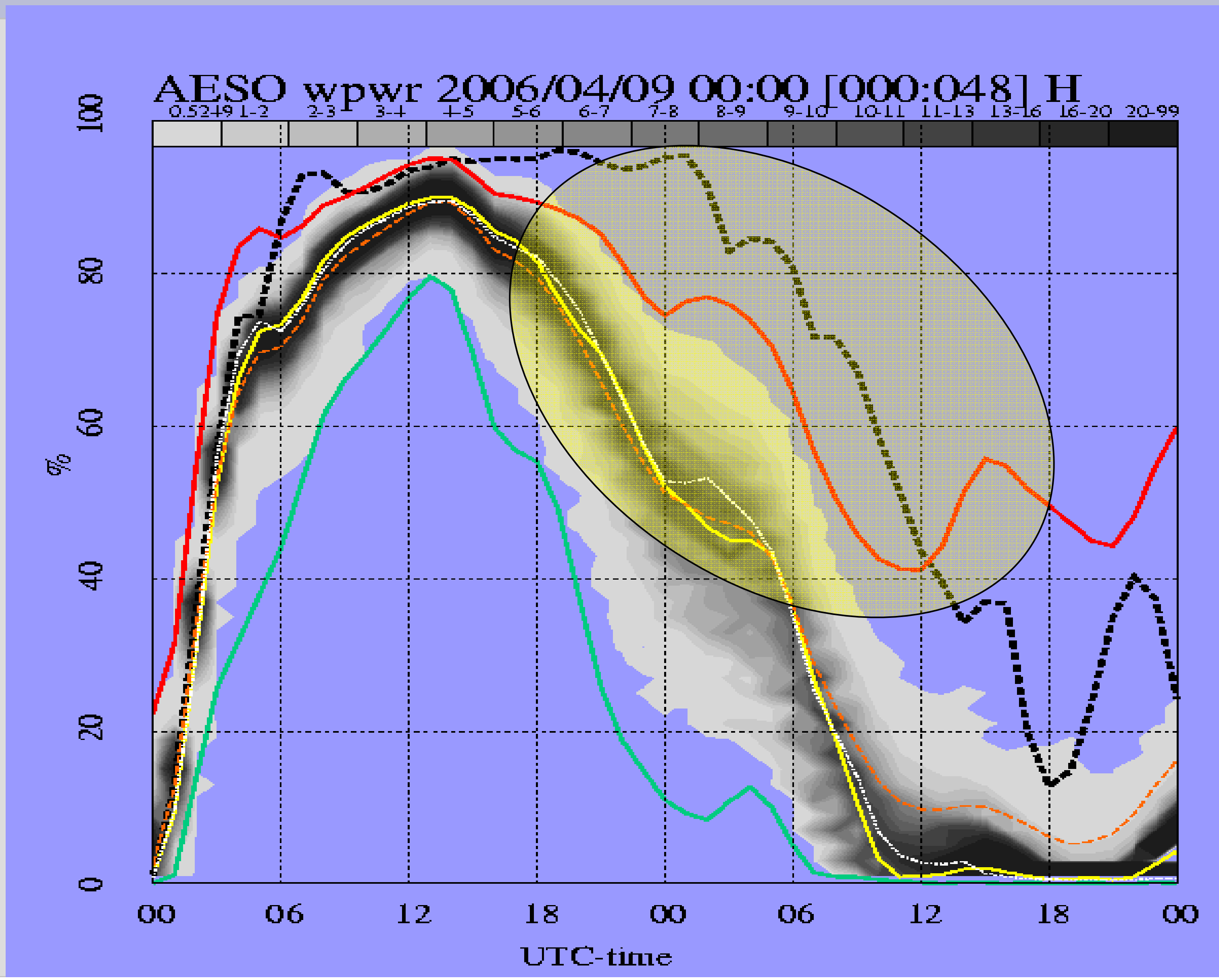
The wind speeds are shown as colour and the isentropes as white iso-lines. The left figure shows a Chinook in Alberta as the isentrope from Alberta can be followed back to an altitude of about 4.5km in the Pacific region.

Note, that the Chinook is fully broken down on right figure again.



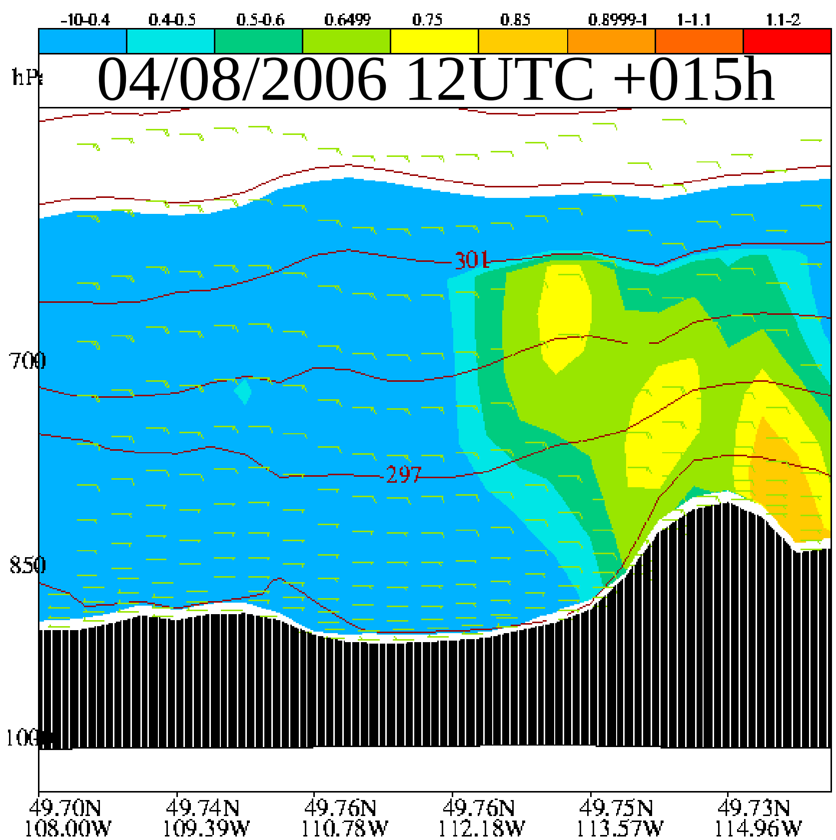
A case study: 9th April 2006

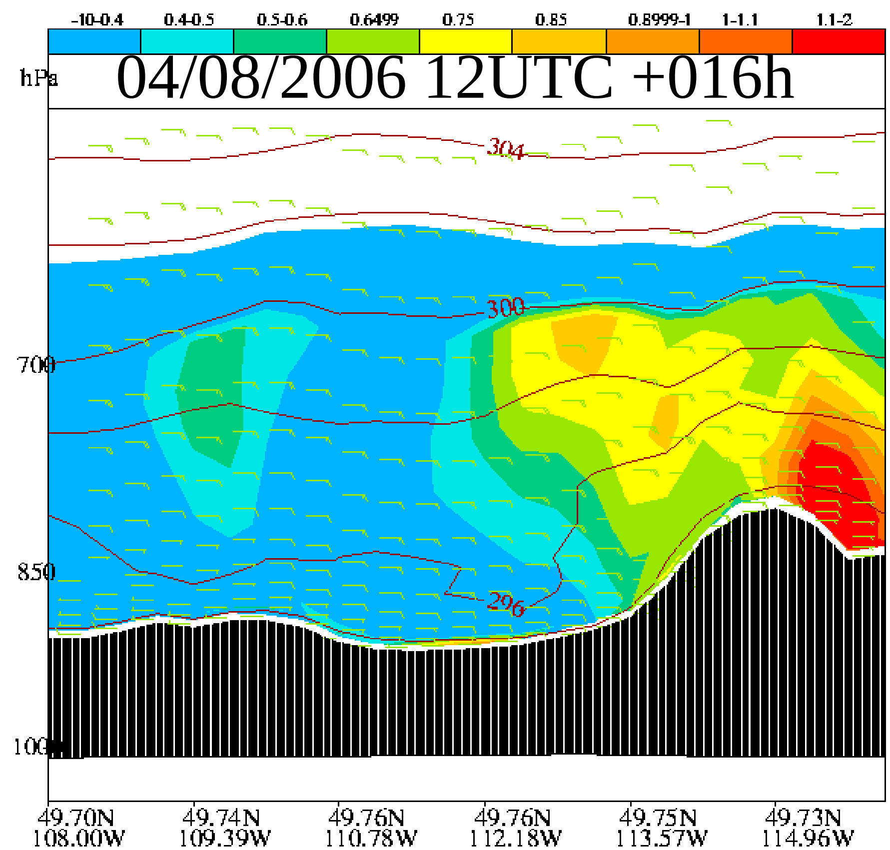
Analysis of a Forecast with too little Ensemble Spread



A case study: 9th April 2006

Using IPV to describe the uncertainty of the Chinook winds





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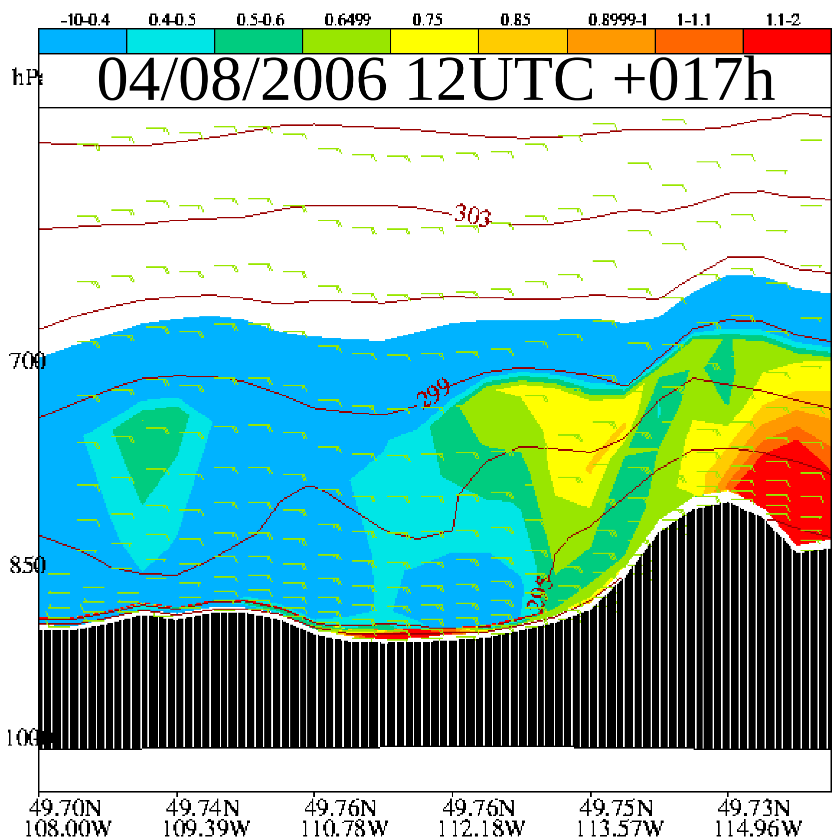

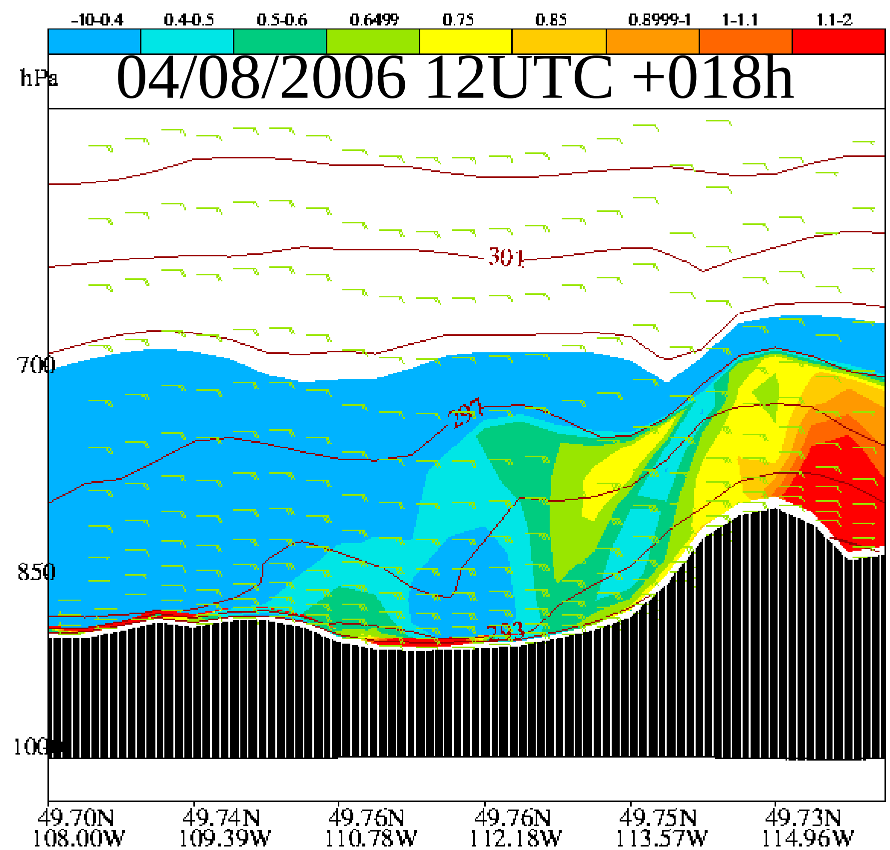

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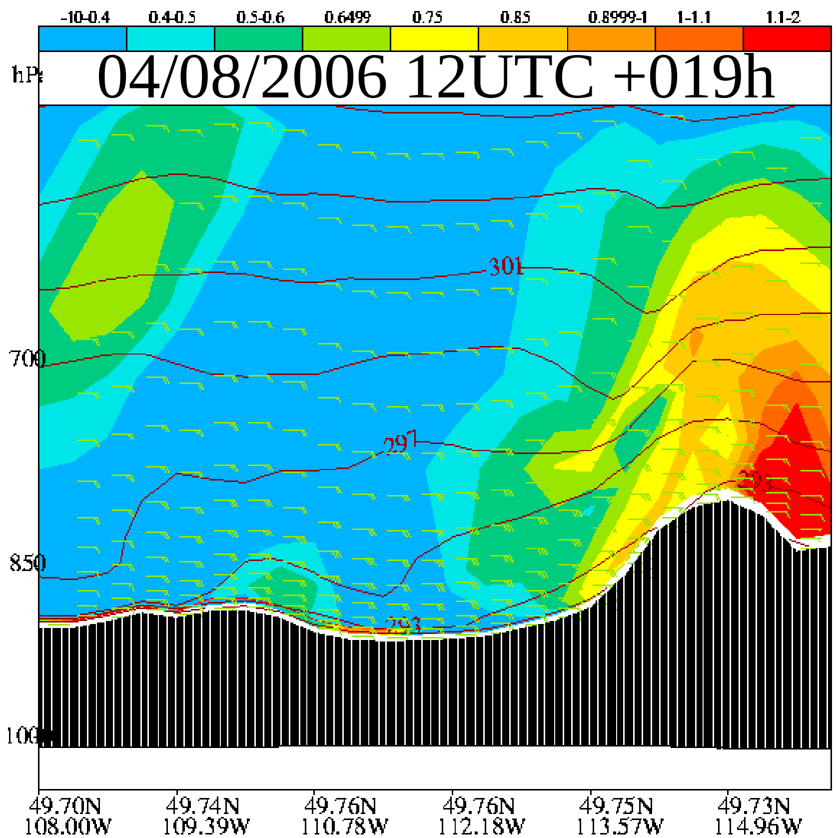

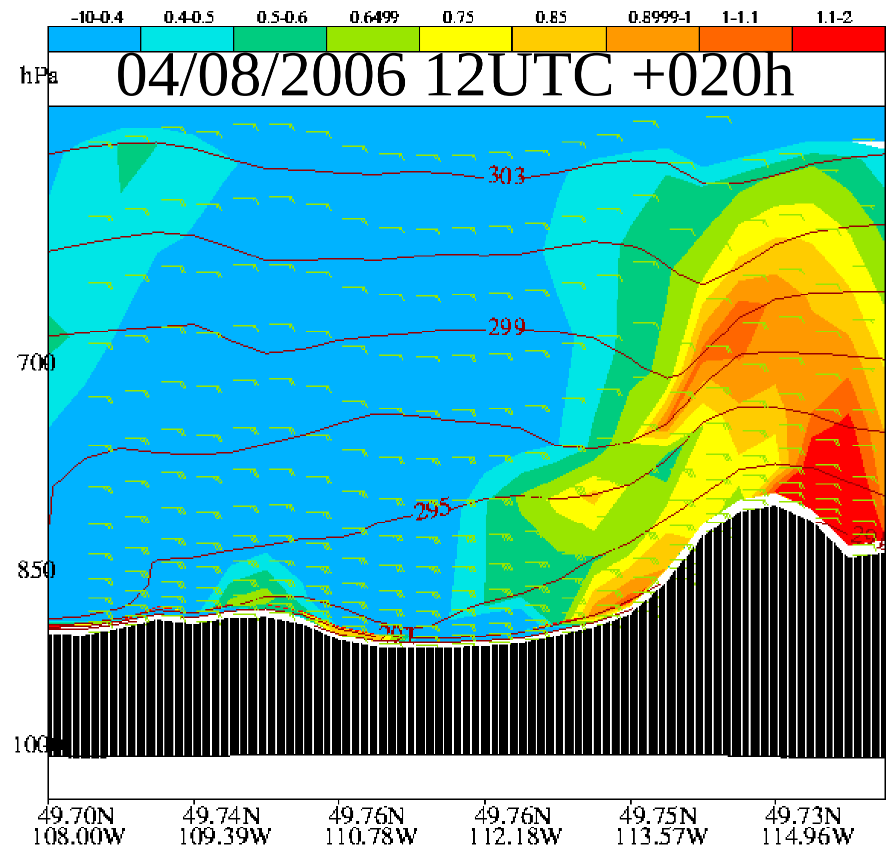

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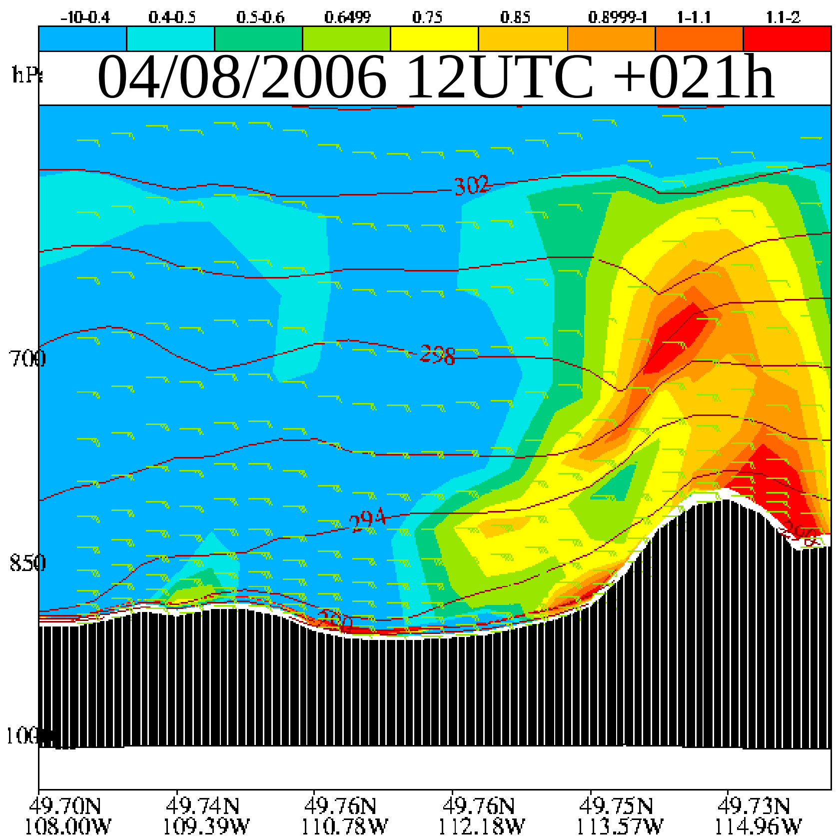

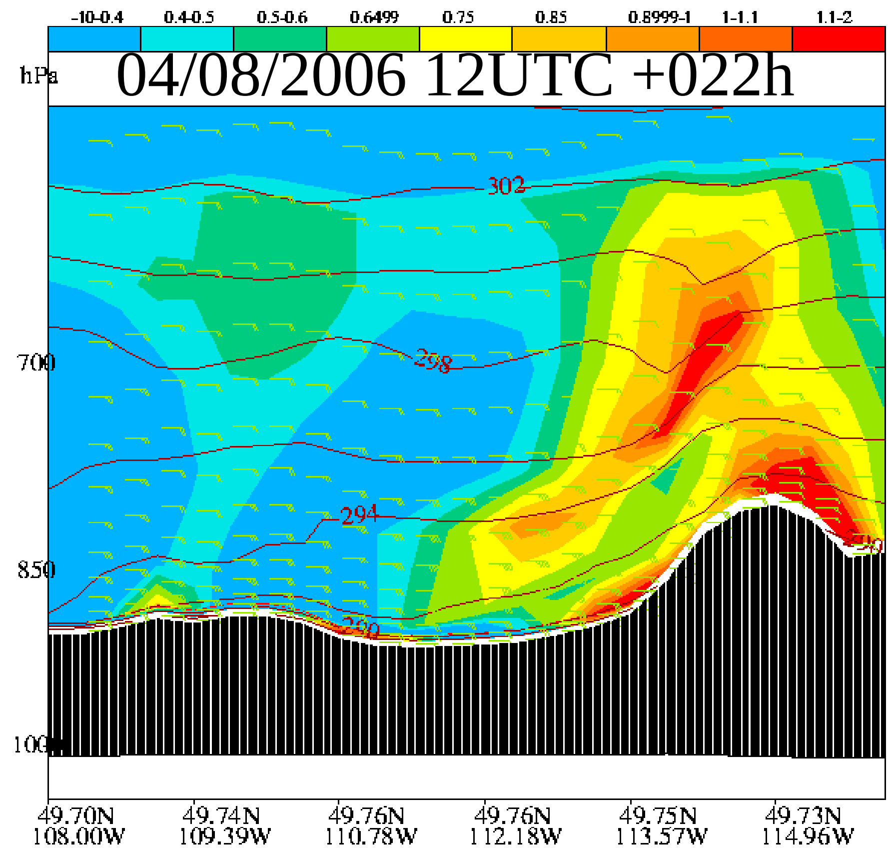

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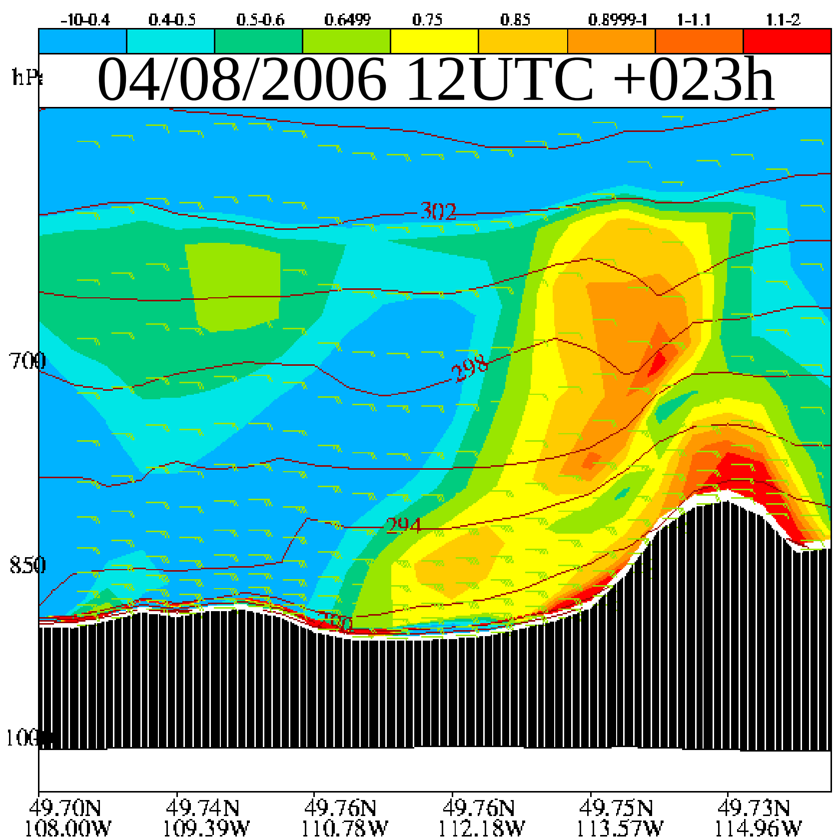

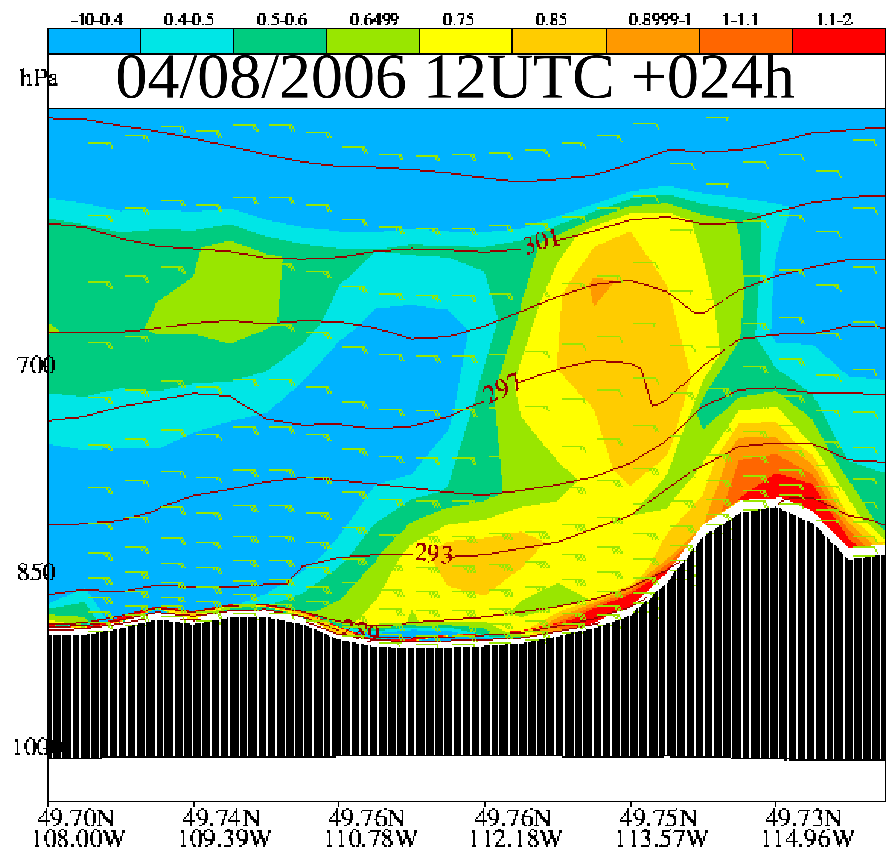

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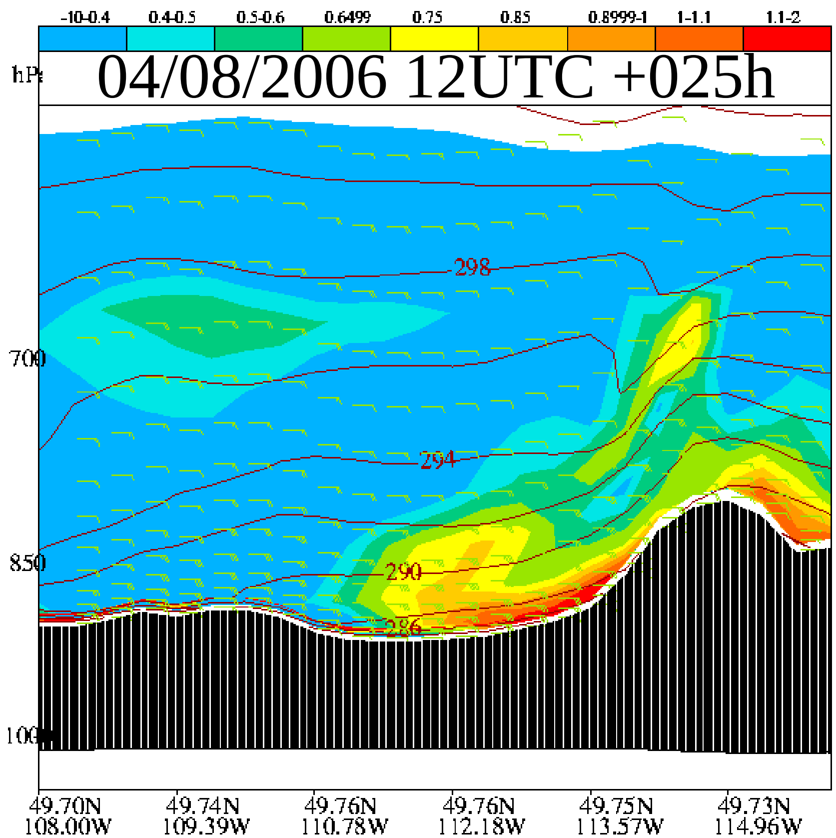

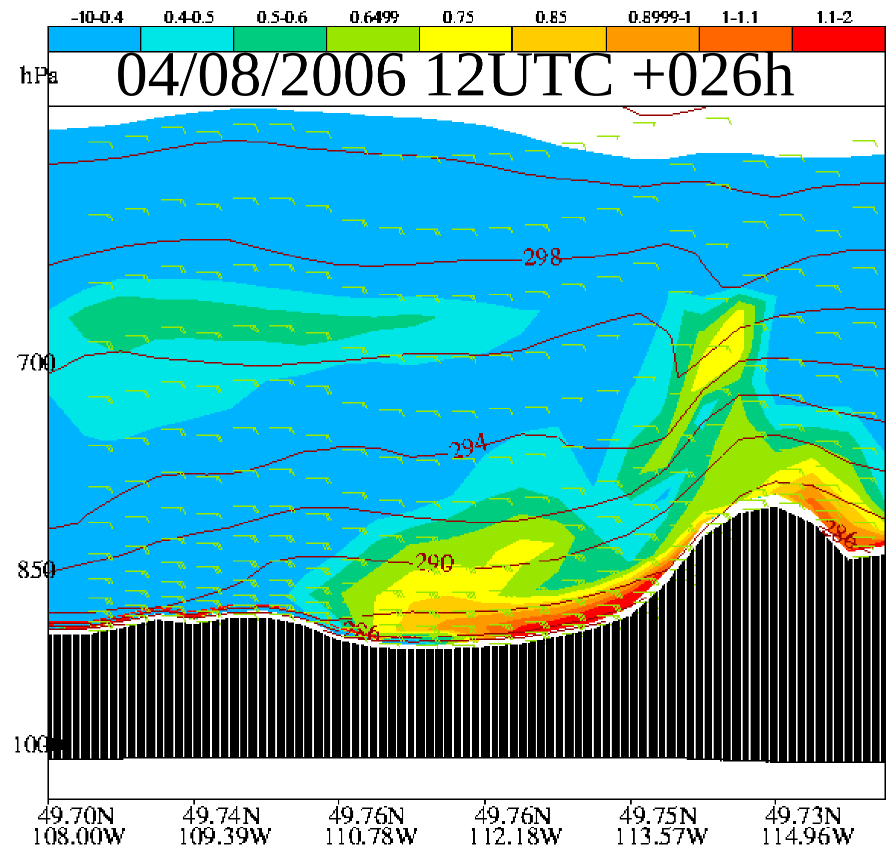

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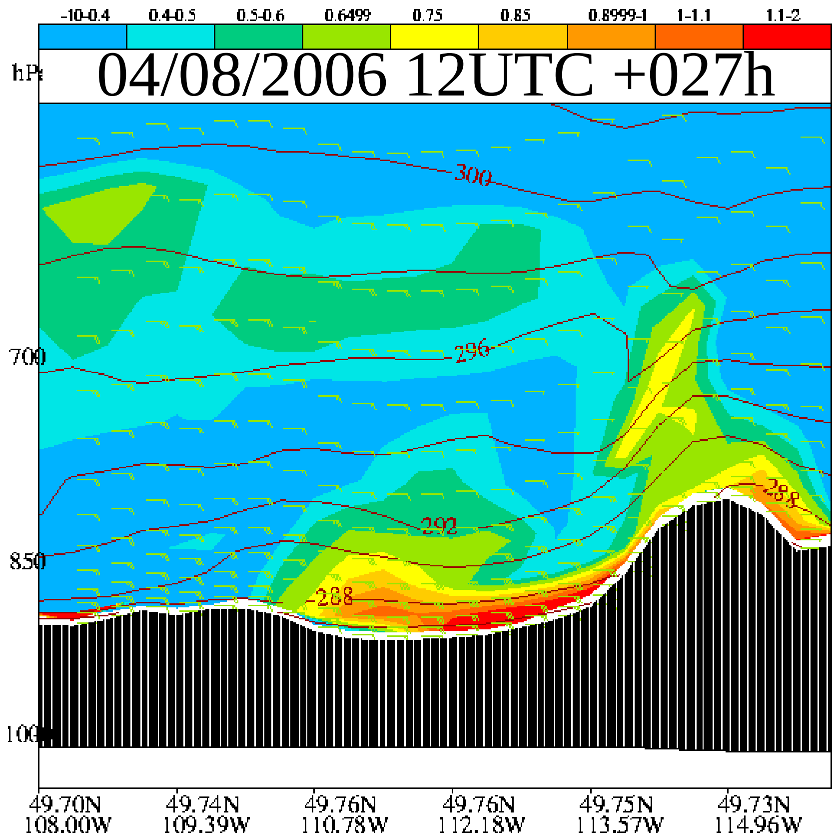

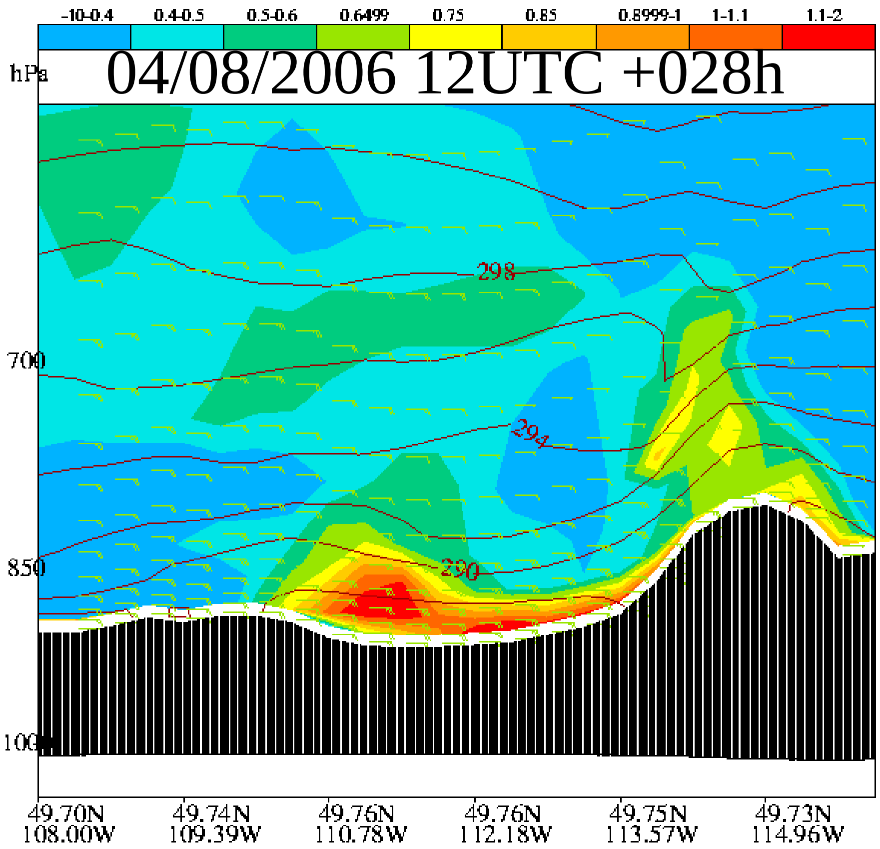

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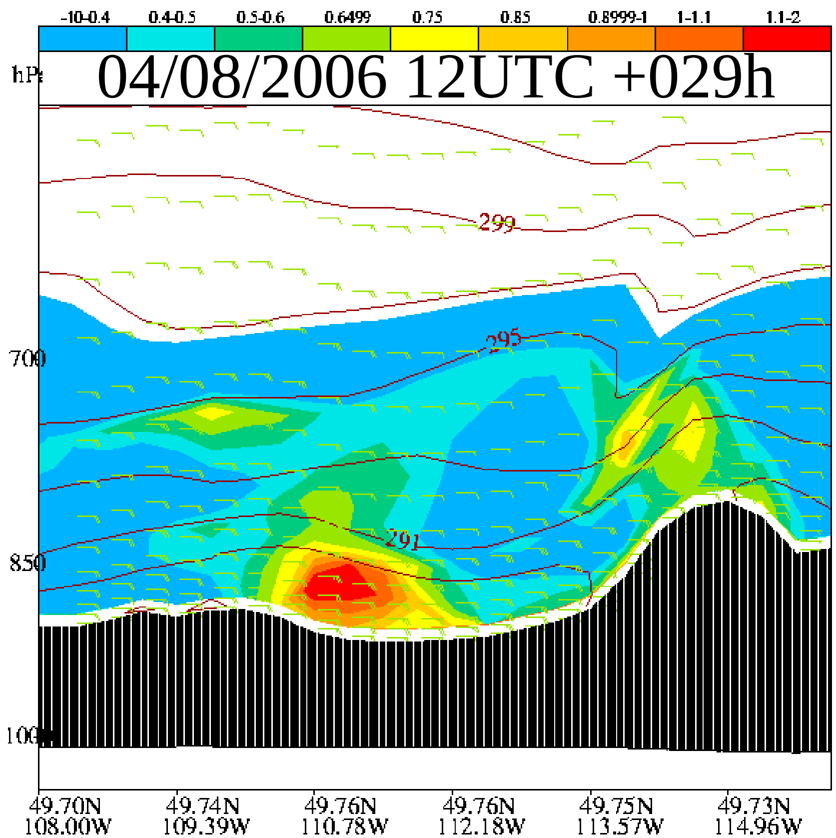
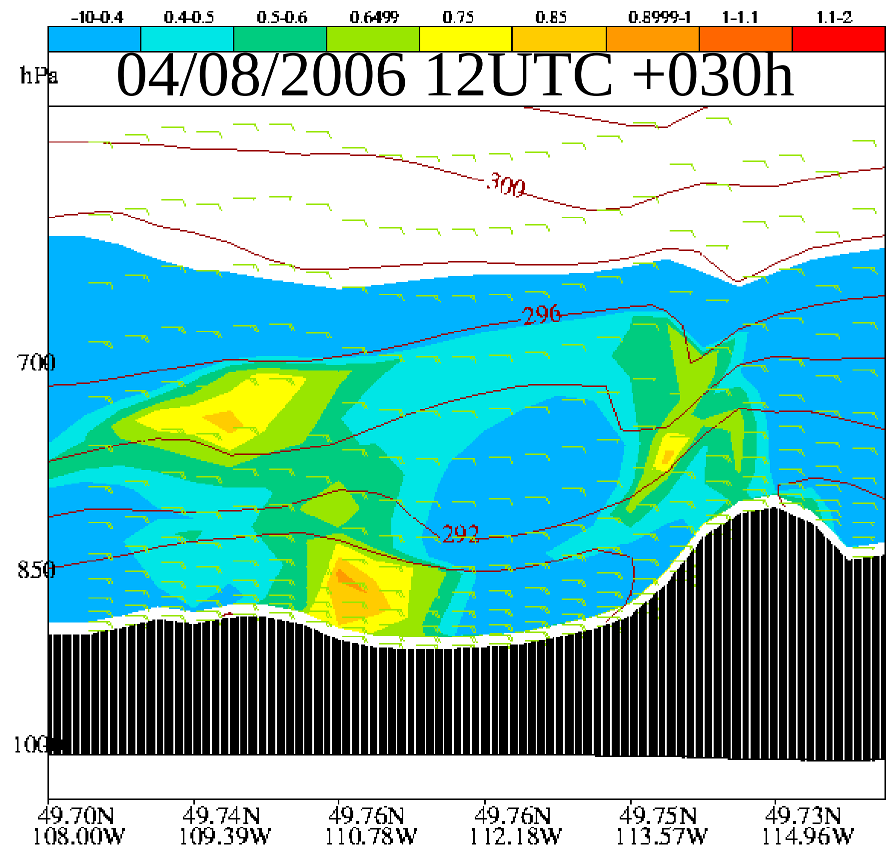
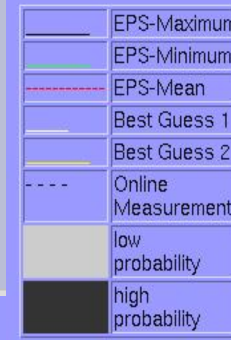
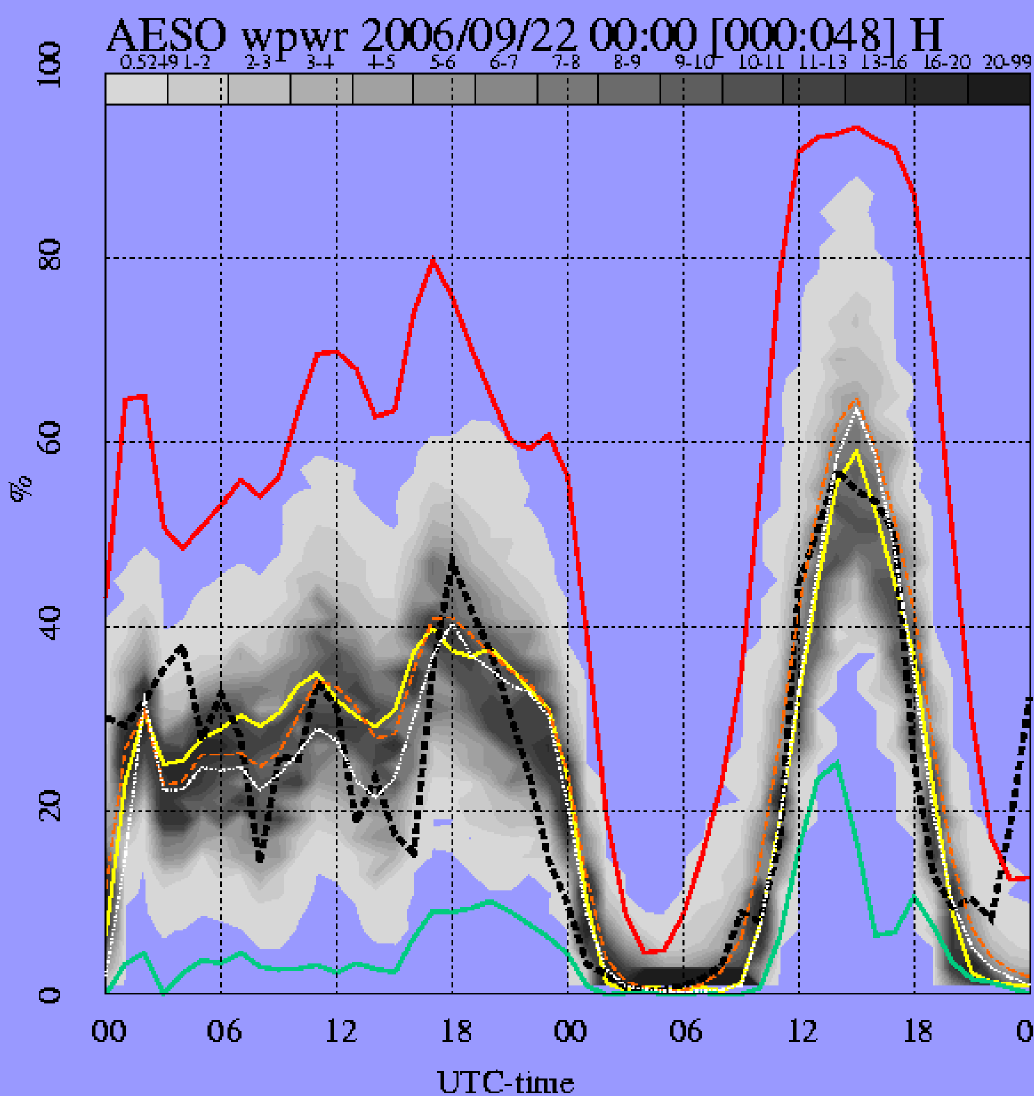
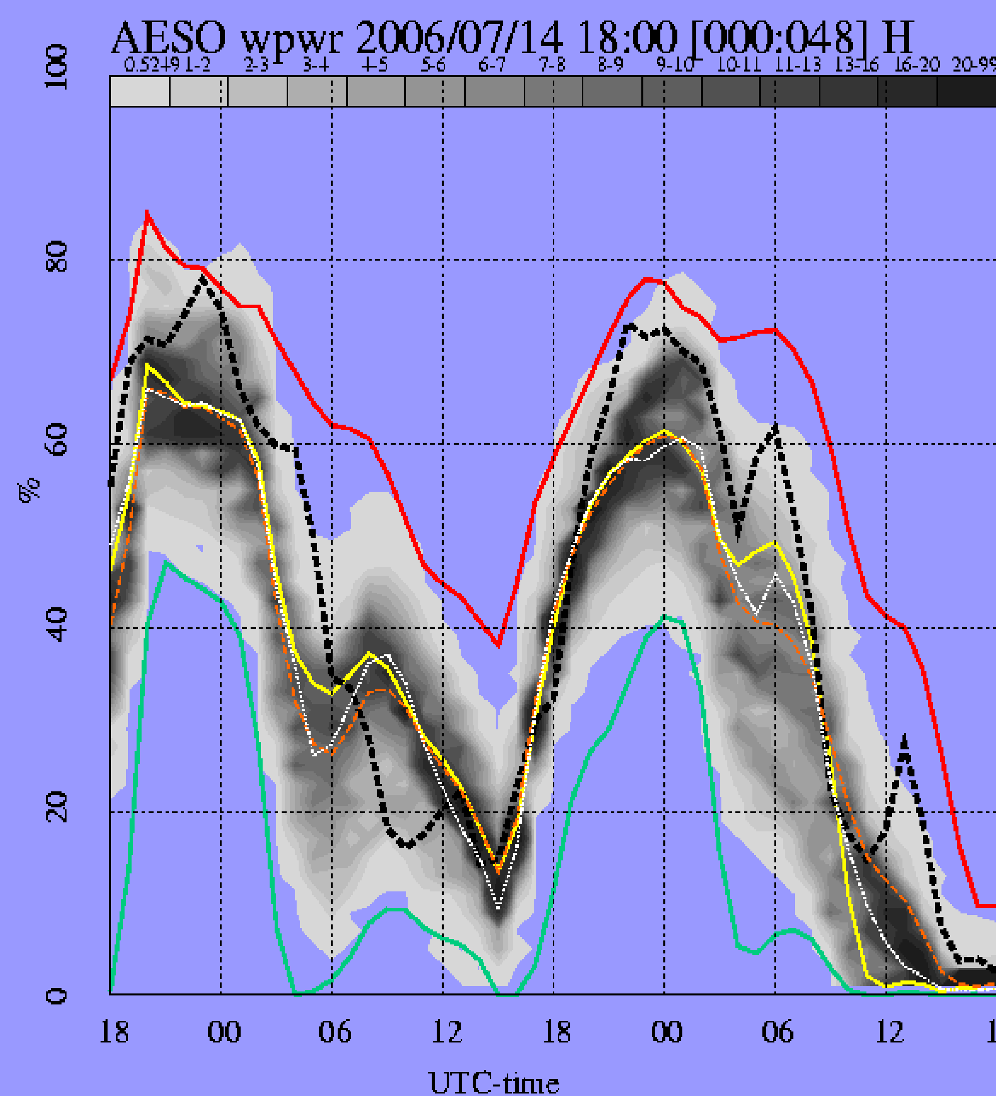




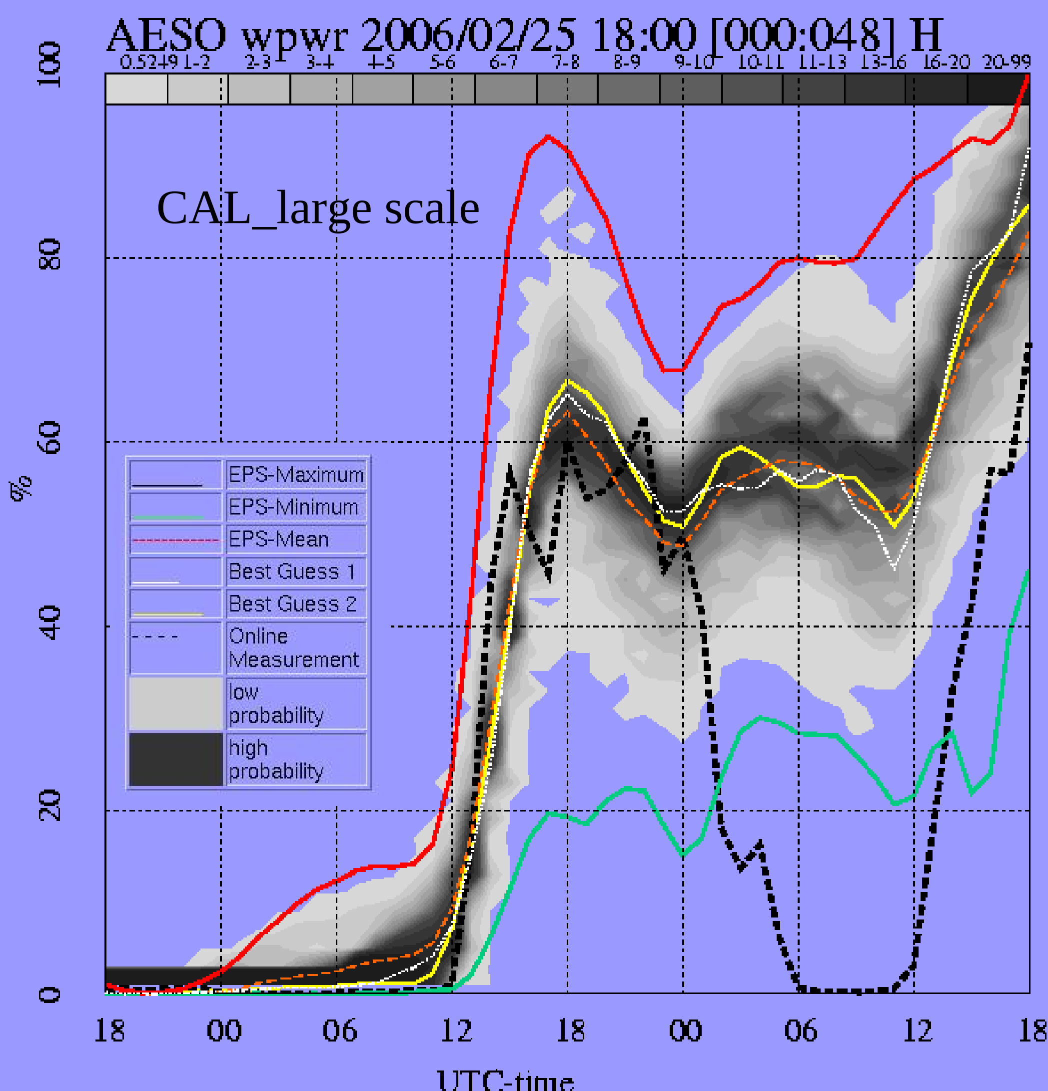
Examples of good predictions with high uncertainty

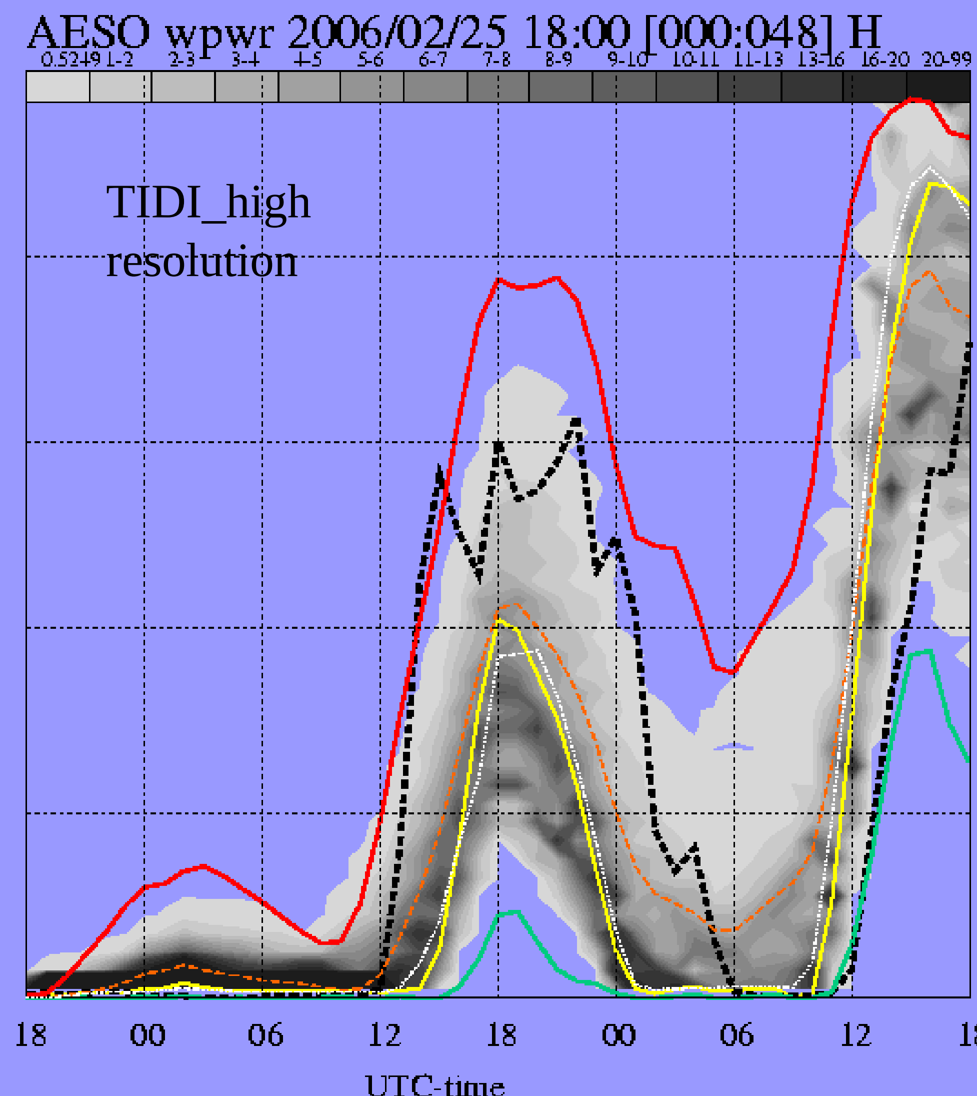






Examples of the difficulty in predicting wind power in Alberta





MSEPS Reserve Prediction

Background:

- The uncertainty is sometimes very low and sometimes very high. A constant reserve would consequently be inefficient and expensive.
- Full coverage of all forecast errors is expensive and there is always of risk of non-weather related accidents during the operation

Optimization Scenarios: (R=Reserve, G=generation,FC= Forecast, LB=no generation,UB=full generation)

<u>Scenario 1: StaticReg</u>

- 1 forecast's error statistics over 1 year determines the upper limit for reserve allocation
- Actual Reserve allocation is limited by the forecast, i.e. FC+R < UB, FC-R > LB
  - R is chosen to secure that FC-R < G < FC+R is historically always valid (here: 90%)

<u>Scenario 2: DertemFC</u>

- R is chosen as a fixed reserve allocation for upward and downward ramping (here +/-11%)

<u>Scenario 3: Security</u>

- Reserve is computed from the Difference between Minimum and Maxiumum of the Ensemble

<u>Scenario 4: Economic</u>

- Optimisation to reduce unused reserve allocation (here: 70% of Scenario 3)

MSEPS Reserve Prediction: Example

Data description:

- 1-year data for SW+SC
- 12-18 hour forecast issued every 6th hour
- High resolution COMB forecast

Statistics without reserve prediction

	Forecast [%rated capacity]
Bias (FC)	-2.10
Mean absolute Error (FC)	11.60
RMS (FC)	16.80
Correlation (FC)	0.85

Optimisation	Scenario 1 StaticReg [% rated capacity]	Scenario 2 DetermFC [% rated capacity]	Scenario 3 Security [% rated capacity]	Scenario 4 Economic [% rated capacity]
Reserve Predictor	75% reserve	Reg=FC+/-11	max-min	0.7*(max-min)
Bias (FCR)	0.00	-0.85	-0.50	-0.80
Mean Absolute Error (FCR)	0.00	4.54	1.40	2.50
RMS (FCR)	0.00	10.15	5.40	7.22
Correlation (FCR)	1.00	0.95	0.99	0.97
Required UpReg (7)	4.70	4.70	4.70	4.70
Required DownReg (8)	6.80	6.80	6.80	6.80
Predicted UpReg (9)	4.70	2.84	4.20	3.83
Predicted DownReg (10)	6.80	4.10	5.80	5.13
Unpredicted UpReg (7-9)	0.00	1.80	0.50	0.87
Unpredicted DownReg (8-10	0.00	2.70	1.00	1.67
Unused Regulation	32.30	3.30	9.30	5.67
Effective cost*	15.90	10.80	11.40	10.83
Hours covered by reserve	100.00	64.50	85.10	76.00

FC = Forecast of wind power alone

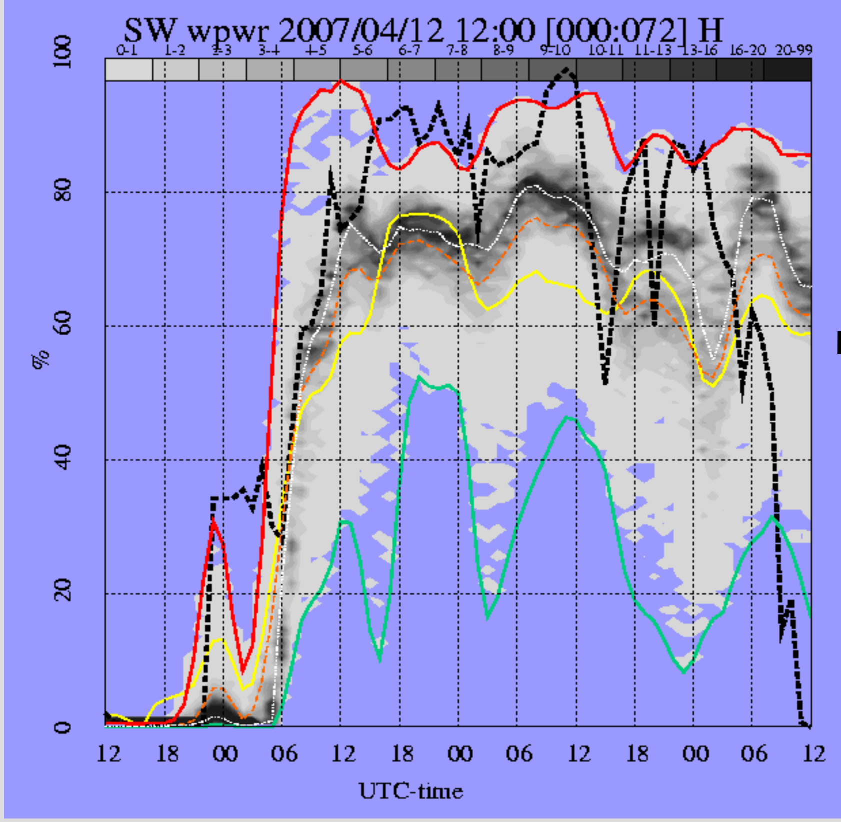
FCR = Forecast + Reserve allocation

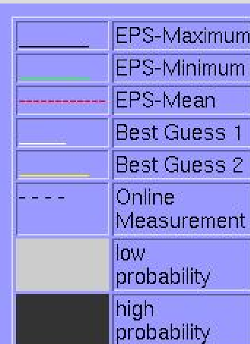
*Assumed relative cost of various types of reserve:

- urgent=1.0%
- unused passive = 0.1%
- allocated according to prediction in advance =0.6%

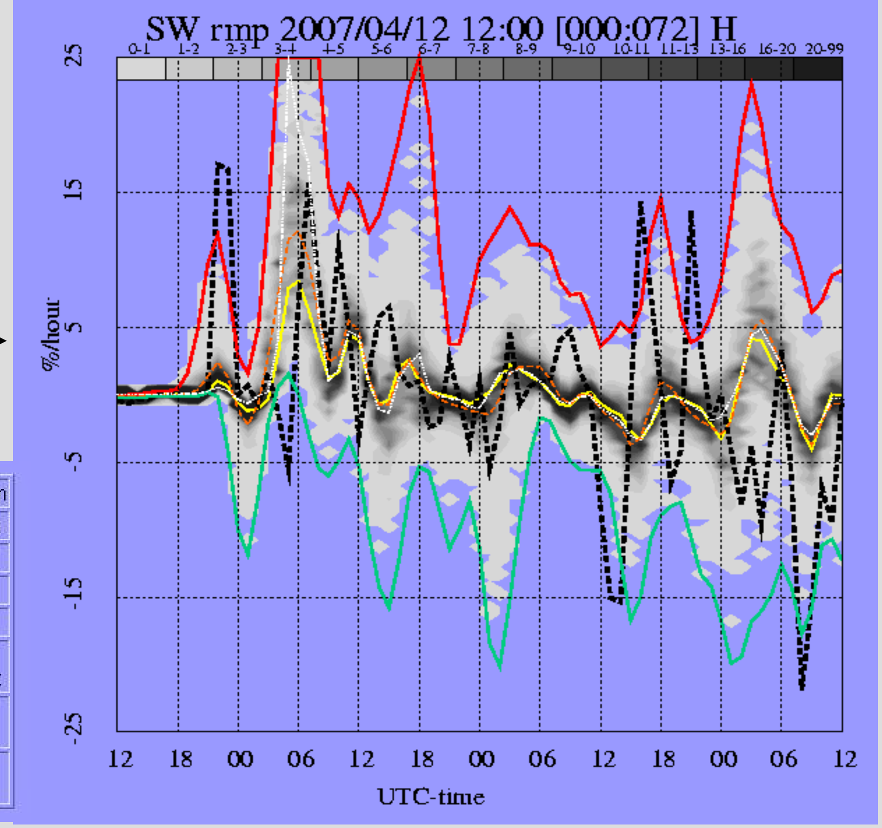
MSEPS Ramp Rate Prediction

wind power generation for the SW area





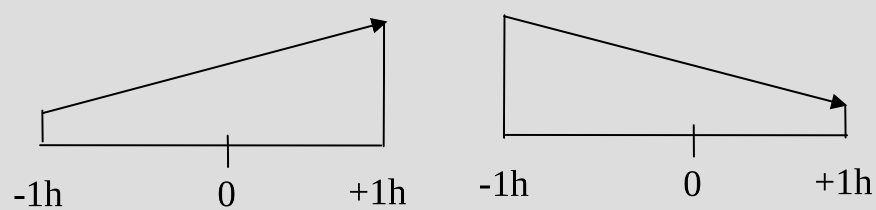
expected ramp rate for the SW area



The ramp rate is computed with the EPS:

for every of the 75 forecasts, we compute the change

in power generation over a 2 hour window



Preliminary Results from 2006 of wind power predictions for Alberta

The five wind farms in SW+SC have together an error level, that is similar to a single wind farm in a flat but windy terrain

The error increase with respect to forecast length is not higher than elsewhere in the world, although the terrain is very complex.

Improved modelling of the flow across the mountains is likely to be the key to increase the quality of the predictions

The poor correlation between estimated wind power from met tower measurements and actual power generation is an indicator of the high variable conditions

Multiple smaller wind farms will give more accurate predictions than fewer large wind farms.

A final Chinook Sample

from the 14th April 2007 00UTC +08H

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