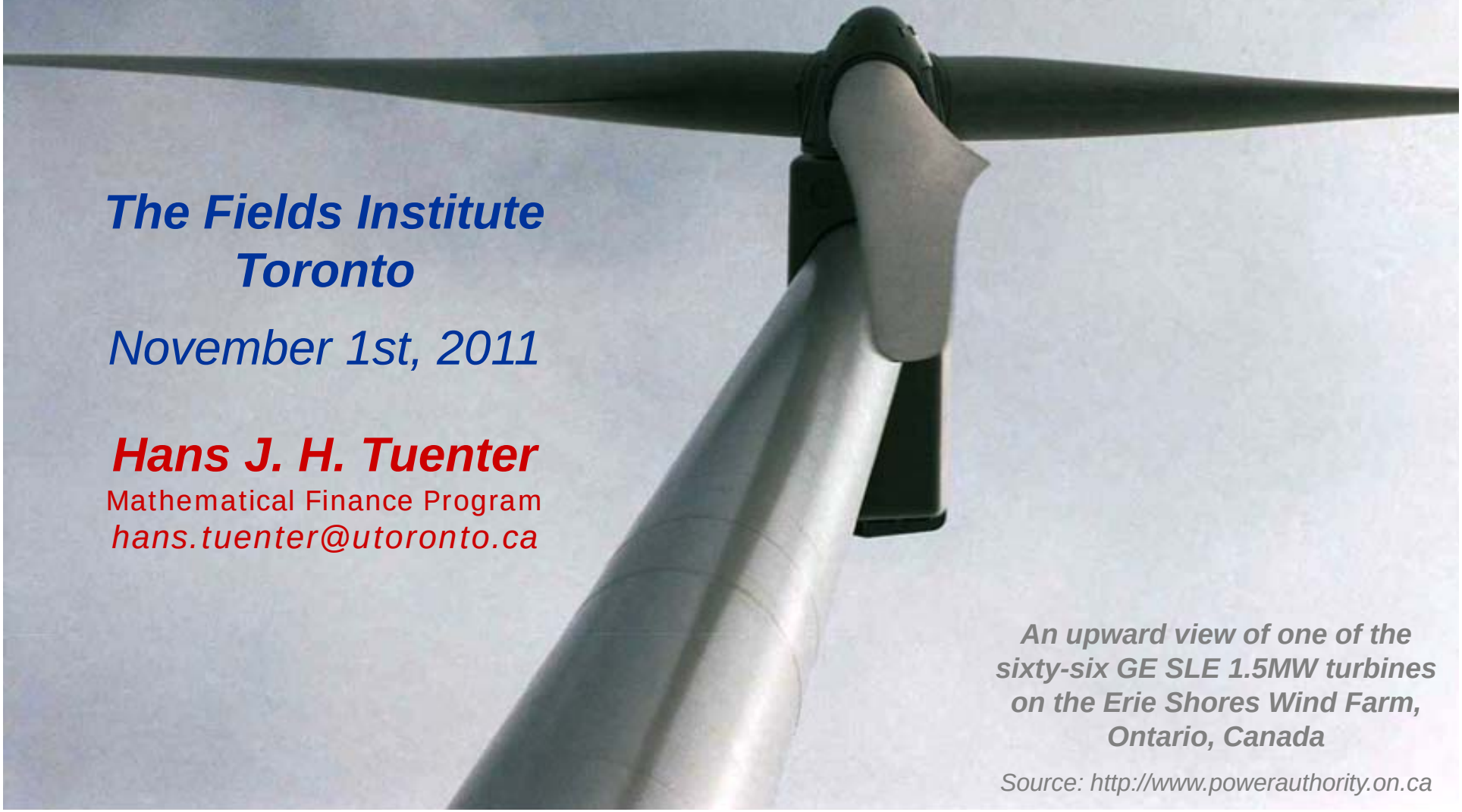
WIND ENERGY

Modeling and Forecasting of Wind Energy



The Fields Institute Toronto

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An upward view of one of the sixty-six GE SLE 1.5MW turbines on the Erie Shores Wind Farm, Ontario, Canada

Source: http://www.powerauthority.on.ca

Installed Capacity — May 2011

ONTARIO POWER GENERATION

Why does it matter?

- Wind is “must run” and displaces other generation.
- Coal is being phased out in Ontario. This reduces the buffer between base-load generation and higher priced generation.
- The Green-Energy-Act (GEA) and its FIT program has and will dramatically increase the share of renewables in Ontario’s generation portfolio. Most of this is wind energy.

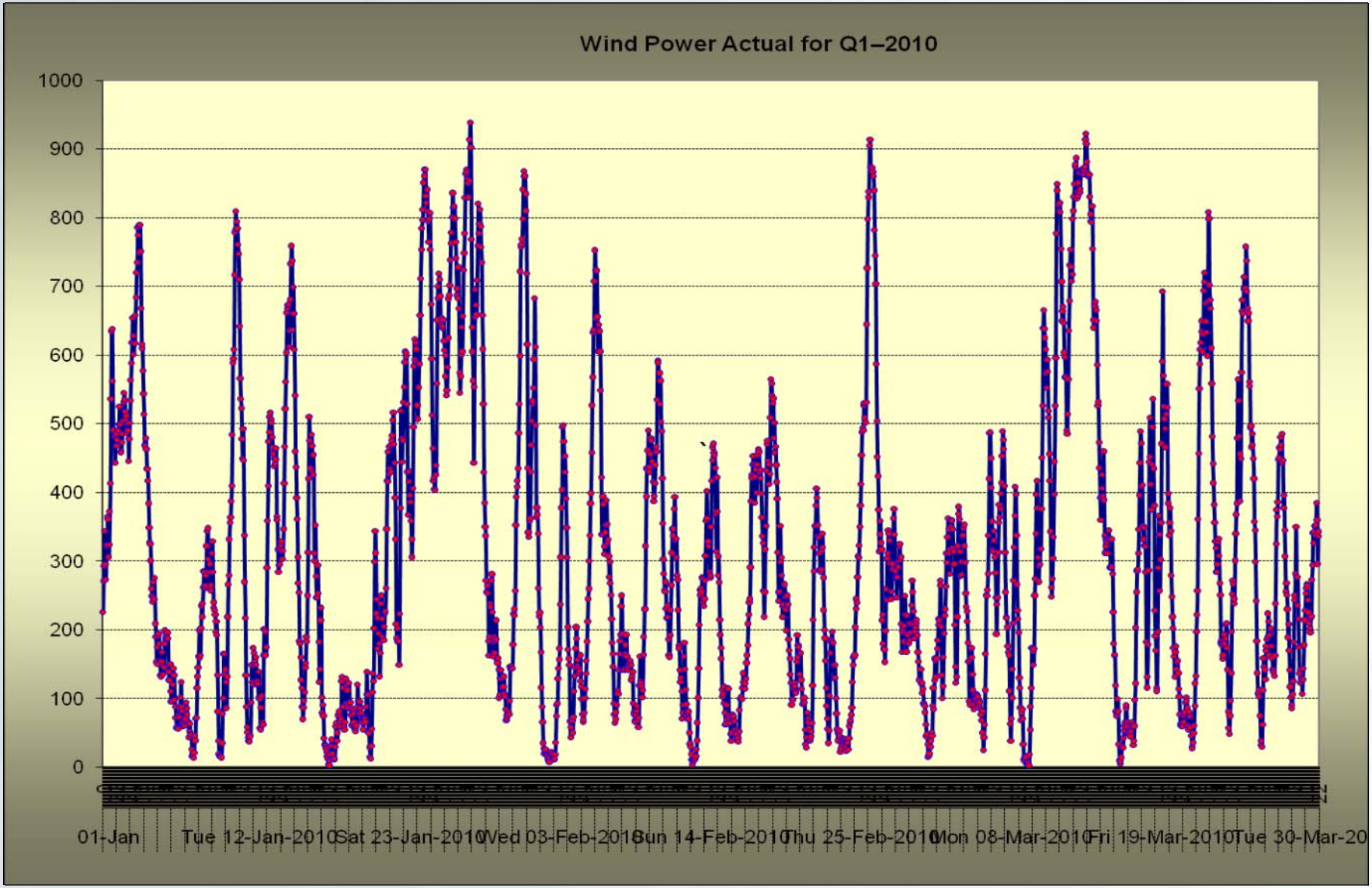
Forecasting

- **Long-term** wind-energy forecasting.
  System planning. Diversified wind portfolio.
- **Short-term** wind-energy forecasting.
  Operational purposes. Meteorological forecasts.

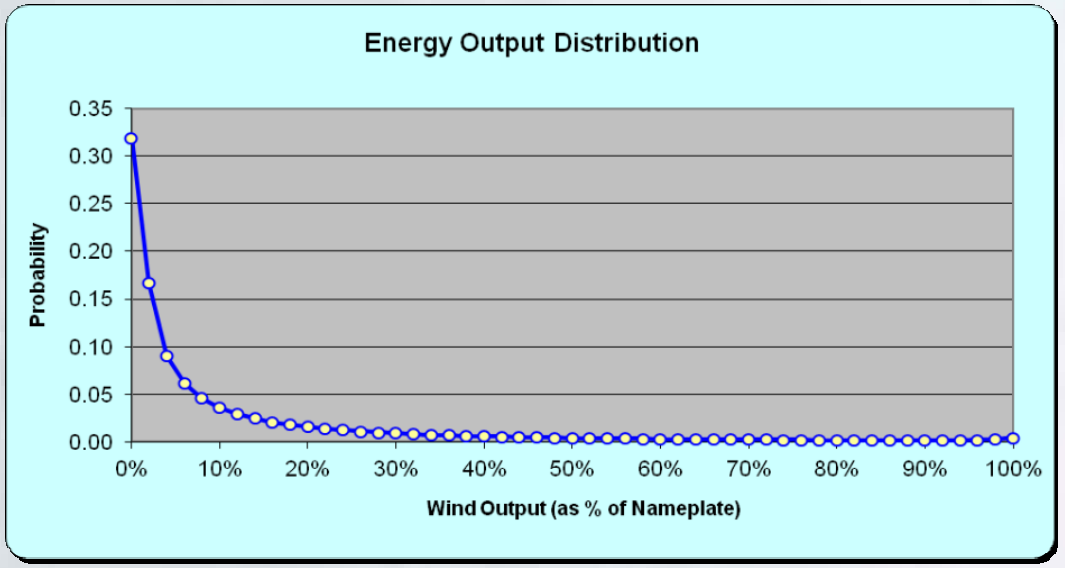
Modeling wind-energy directly is difficult.

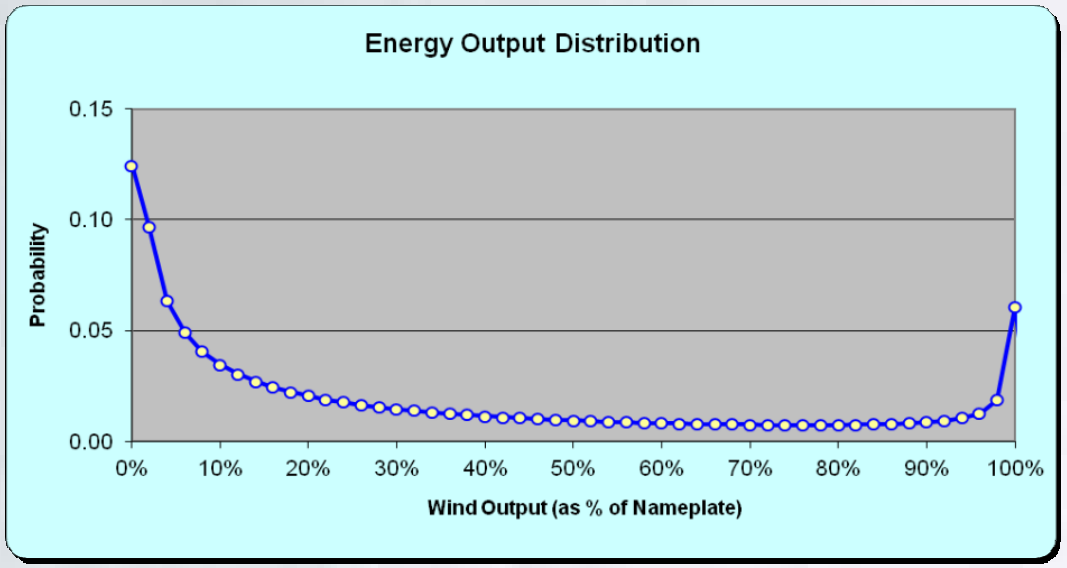
Needs a fundamental model.

Wind-Power Time-Series

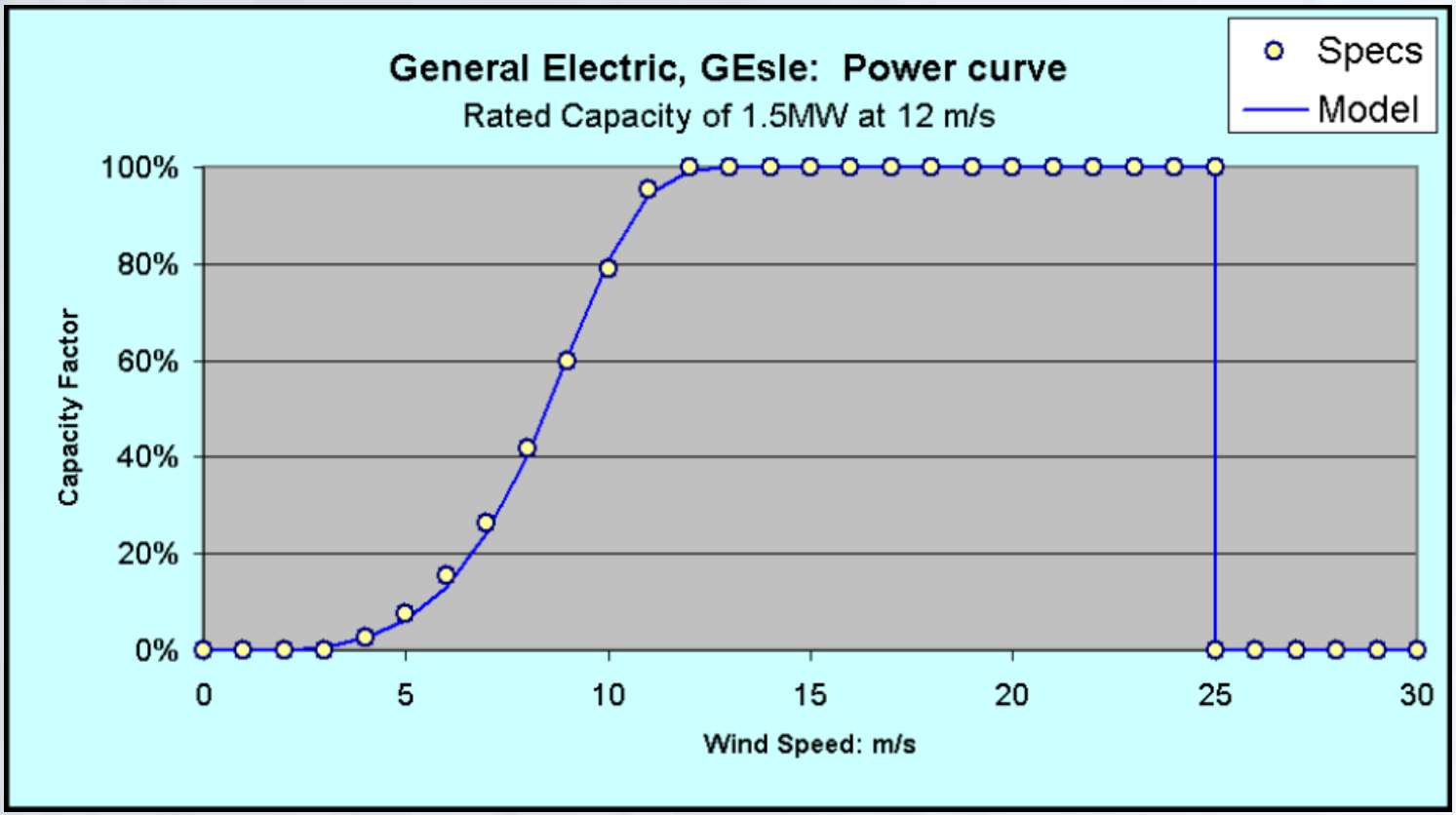


Distributions: Summer vs Winter

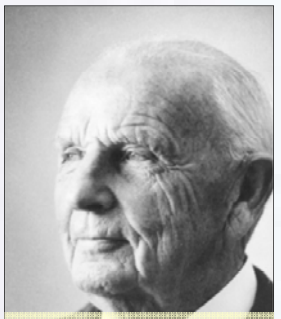




Wind Speed to MW



Albert Betz
(1885—1968)

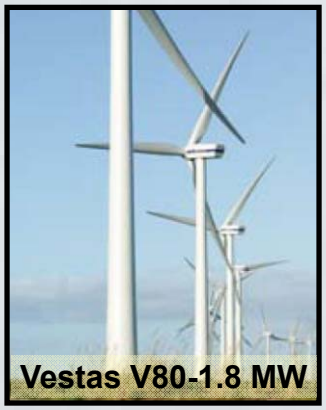


Waloddi Weibull
(1887—1979)

Power curves are calibrated to a parametric, family of continuous curves and provide a close fit to the (discrete) power curves provided by the manufacturer. *Much faster conversion of wind speed to power*.

Wind Speed to MW

ONTARIO POWER GENERATION

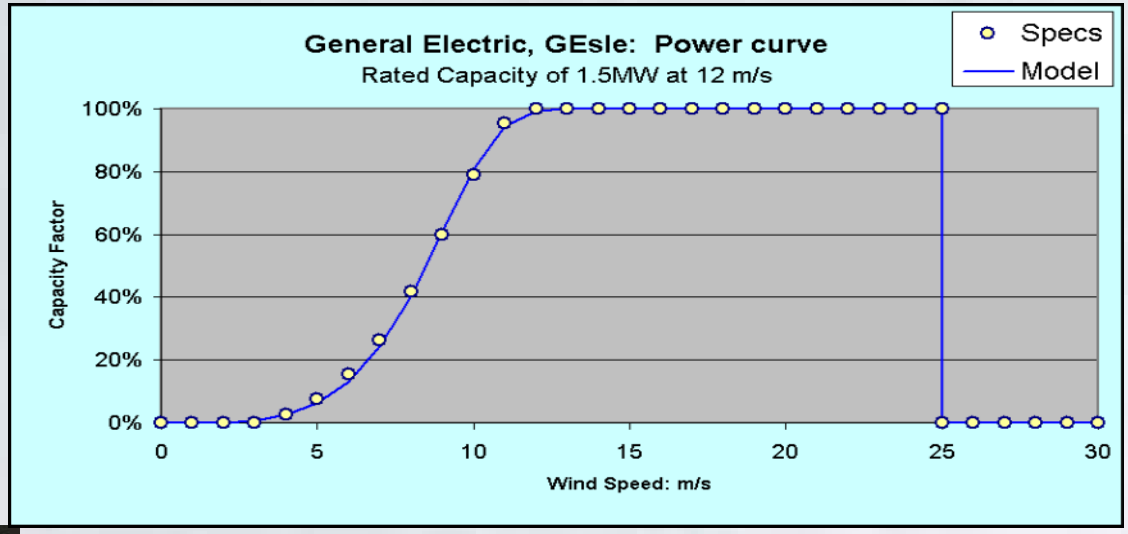


Wind Turbine	Cut-in speed and Cut-out speed	Wind Farm(s)	Total MW
GE sle 1.5	Cut-in: 3.5 m/s Cut-out: 25 m/s	Prince I & II(1.5 MW × 126) ErieShores (1.5 MW × 66) Melancthon I & II (1.5 MW × 133)	487.50 MW
ENERCON E82	Cut-in: 2 m/s Cut-out: 28 m/s	Ripley (2 MW × 38)	76.00 MW
Vestas V80 -1.8 MW	Cut-in: 4 m/s Cut-out: 25 m/s	Kingsbridge (1.8 MW × 22)	39.60 MW
Vestas V82 -1.65 MW	Cut-in: 3.5 m/s Cut-out: 20 m/s	Leader A & B (1.65 MW × 121)	199.65 MW
Siemens SWT-2.3-82	Cut-in: 4 m/s Cut-out: 25 m/s	Kingsbridge II (2.3 MW × 69) Kruger (2.3 MW × 44) Wolfe Island (2.3 MW × 86)	457.70 MW

Conversion — Wind Speed to MW

ONTARIO POWER GENERATION

— Turbine and Wind Farm data —									
	Erie Shores	Prince Farm	Melanc thon	Kings bridge	Enbridge	Ripley	Kruger	Wolfe Island	TOTAL
Name Plate MW	99	189	199.5	39.6	181.5	76	101.2	197.8	1083.6
Turbine Type	GE 1.5 sle	GE 1.5 sle	GE 1.5 sle	Vestas V80	Vestas V82	ENERCON E82	Siemens 2.3 MW Mark II	Siemens 2.3 MW Mark II	
Cut-In Speed	3.5	3.5	3.5	4	3.5	2	4	4	
Cut-Out Speed	25	25	25	25	23.5	28	25.3	25	
Scalar	10	10	10	10	10	10	10	10	
k	3.7283	3.7283	3.7283	3.6962	3.3767	3.3194	3.6644	3.6644	
c0	0	0	0	0	0	0	0	0	
c1	0.95079	0.95079	0.95079	1.1694	1.0609	0.7247	0.80428	0.80428	
c2	0.66104	0.66104	0.66104	0.050262	0.48568	0.77042	0.15627	0.15627	

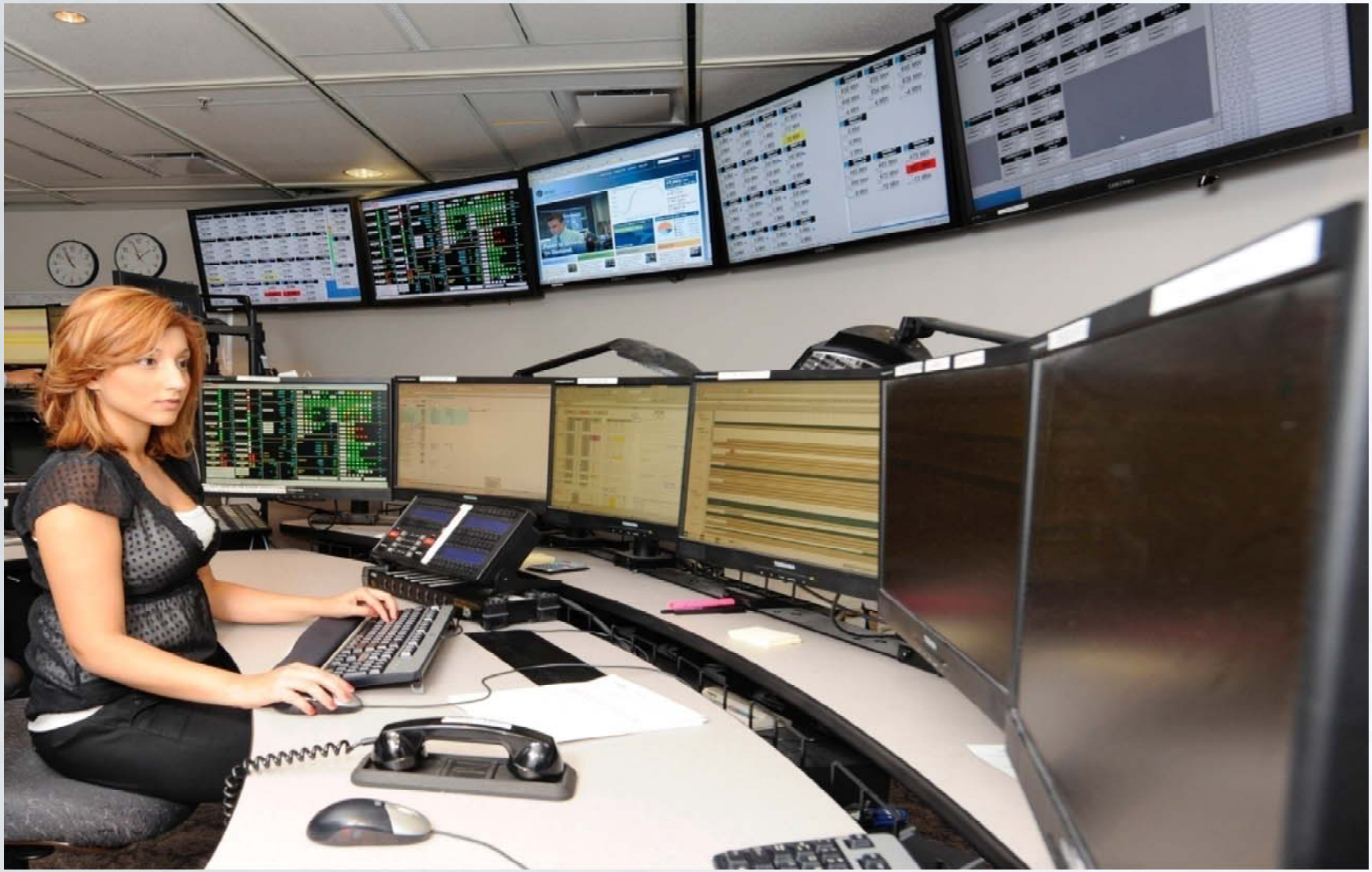


- Each and every wind speed is fed through a specific turbine power-curve.
- Power-curve model developed in-house.

The IESO Control Room

OPG's Control Room

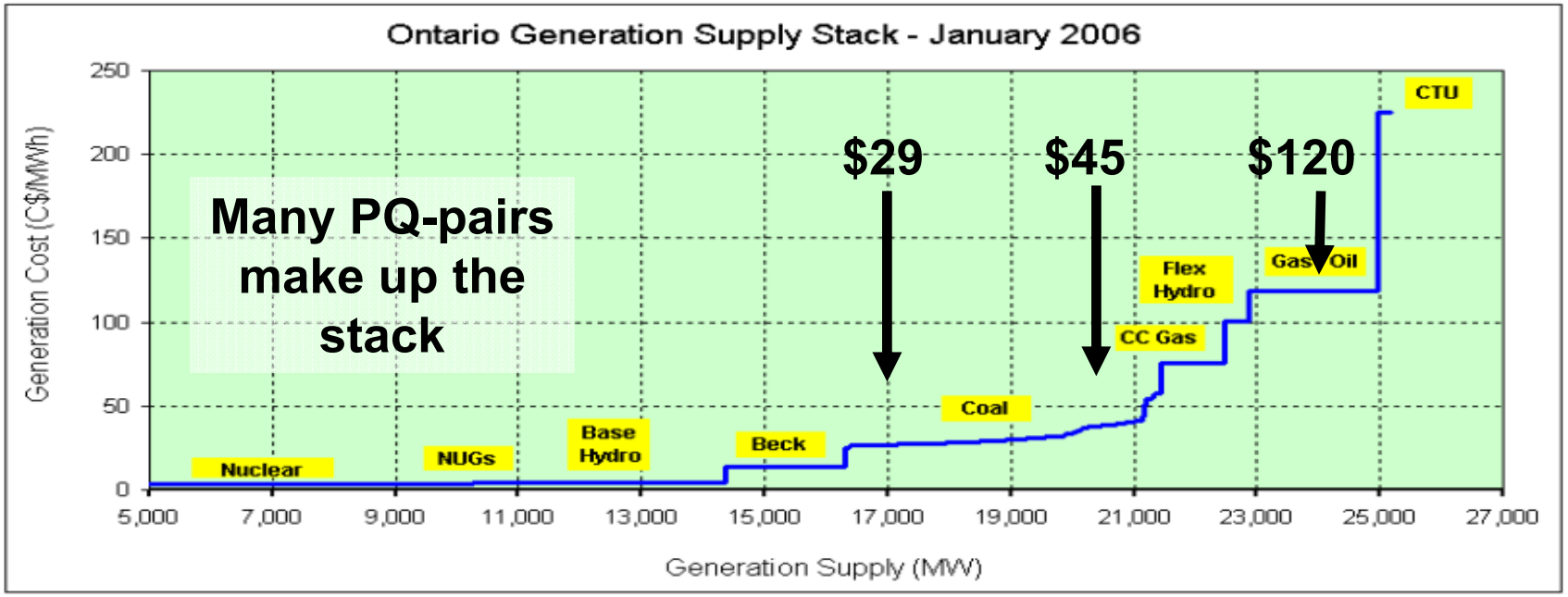
ONTARIO POWER GENERATION



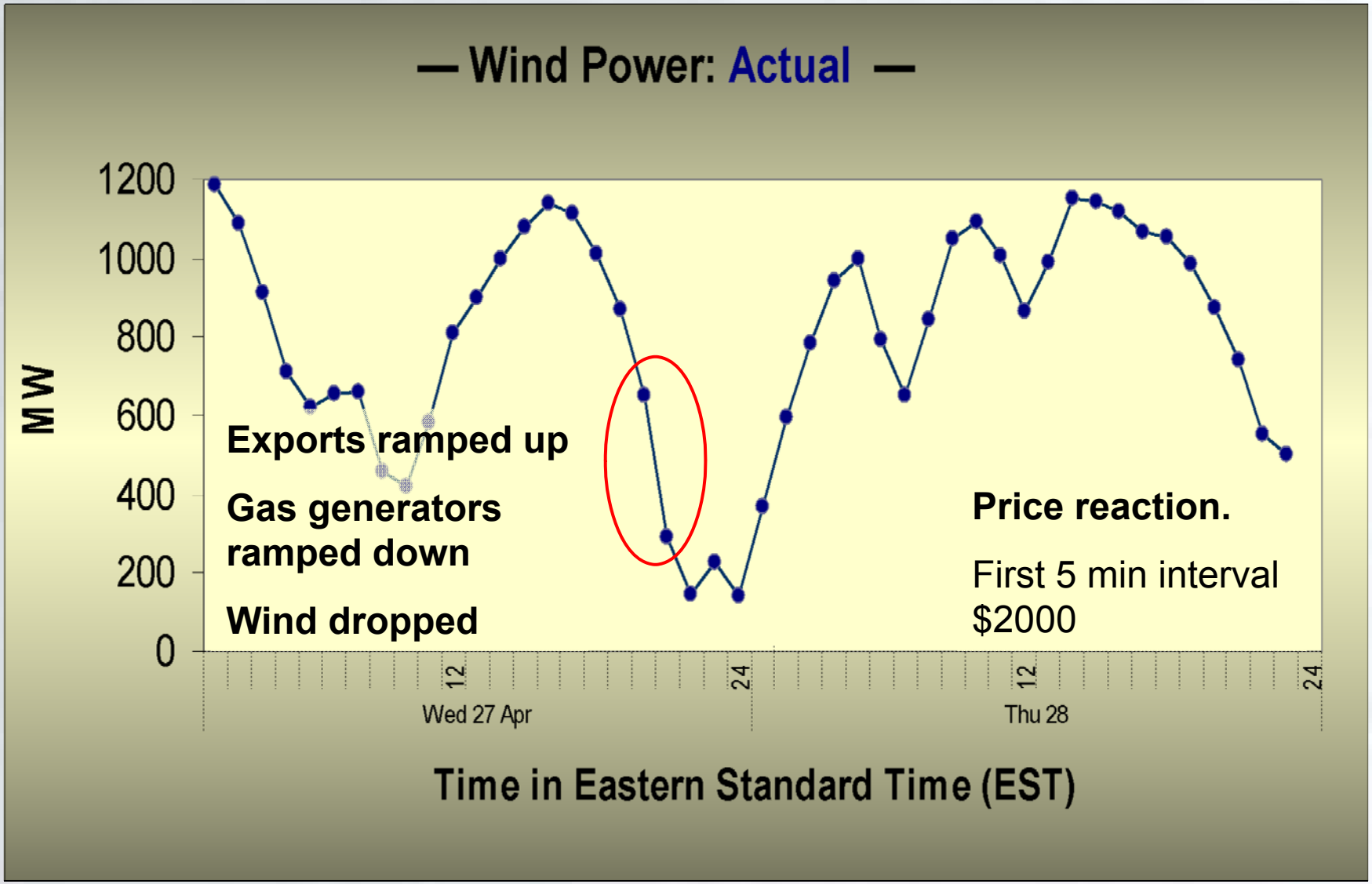
PQ-pairs & The Stack

Electricity Markets 101

100MW Unit	Laminations (example)				
Price	$20	$30	$40	$60	$100
Quantity	10MW	50MW	20MW	10MW	10MW



Sudden Drop in Wind Power



Global Forecasting System

- Resolution 0.5 X 0.5 degree latitude/longitude
- 60 observations at 3hr intervals
- Updated every six hours at 00Z, 06Z, 12Z and 18Z
- Forecasts are free
- Wind speeds and direction at various pressure levels

NOAA

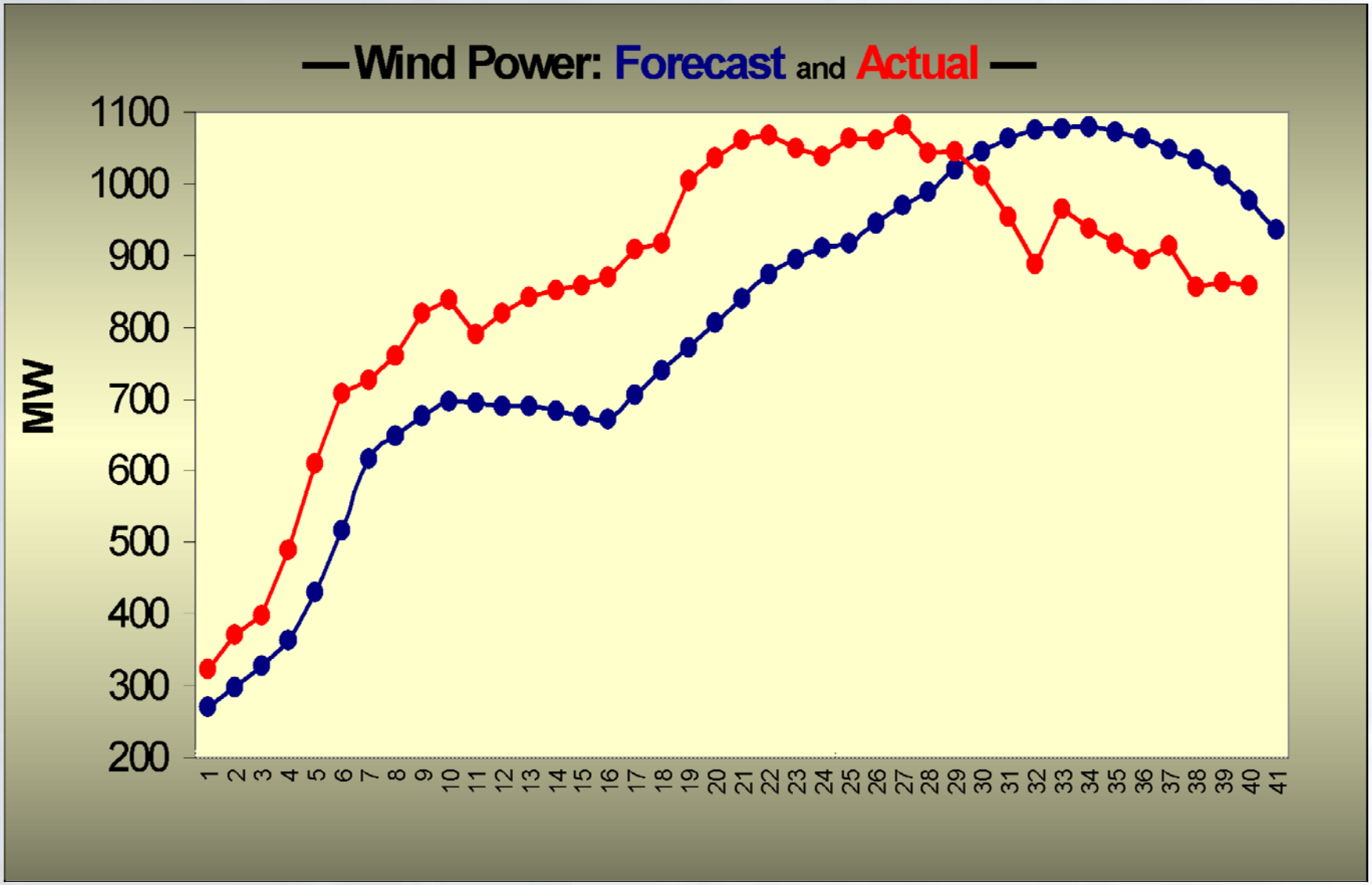
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

Implementation

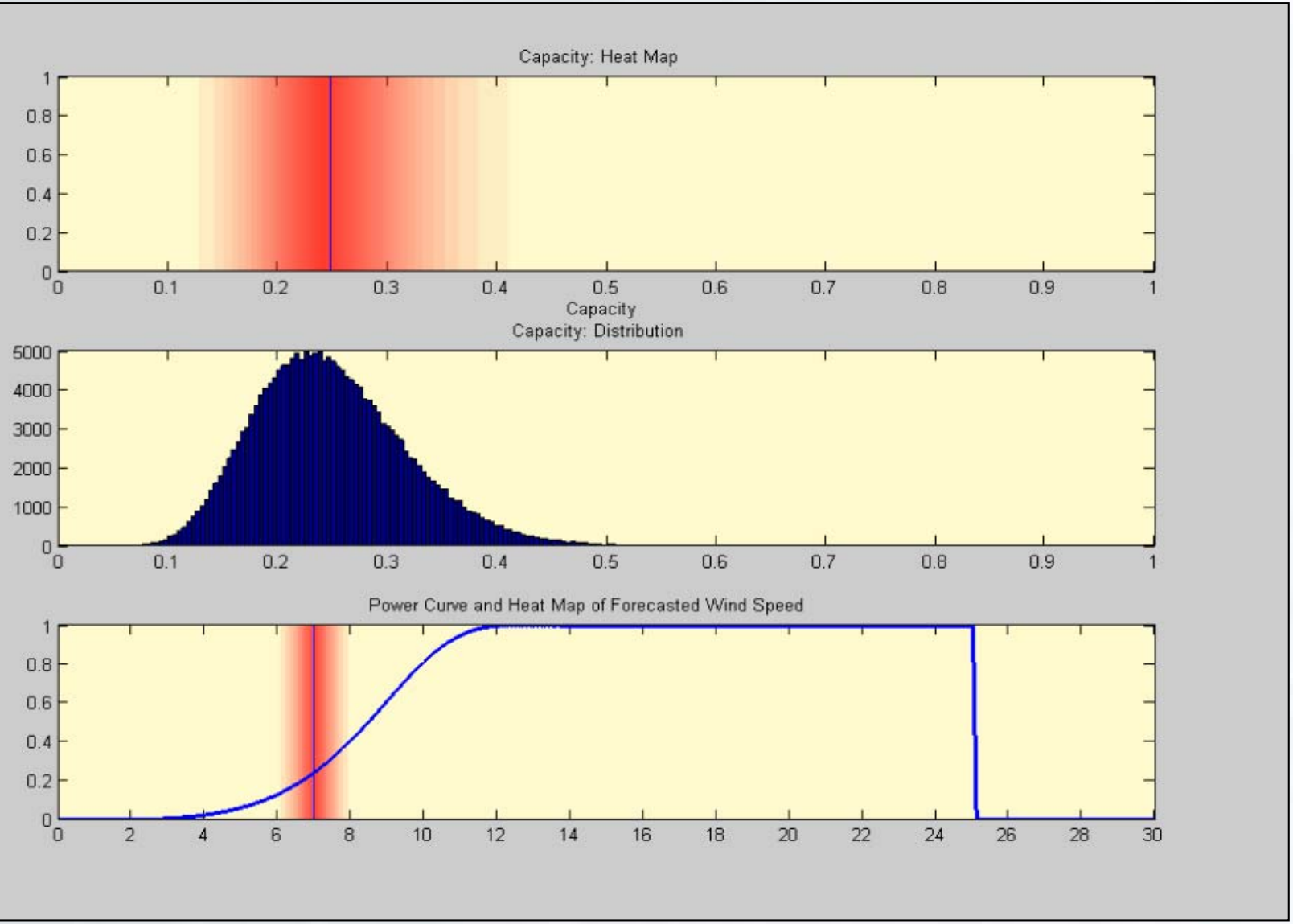
- Determine a profile from the wind speed at various pressure levels. Proxy for wind speed at turbine height.
- Convert wind speeds to energy using a power curve.
- Impute implied wind speeds from recent, actual energy.
- Calibrate, and adjust forecasts.
- Feed adjusted wind speeds through a power curve.

GFS mb-v	→	Raw MW
Implied v	←	MW Actual (IESO)
↓		
Adjusted v	→	Adjusted MW

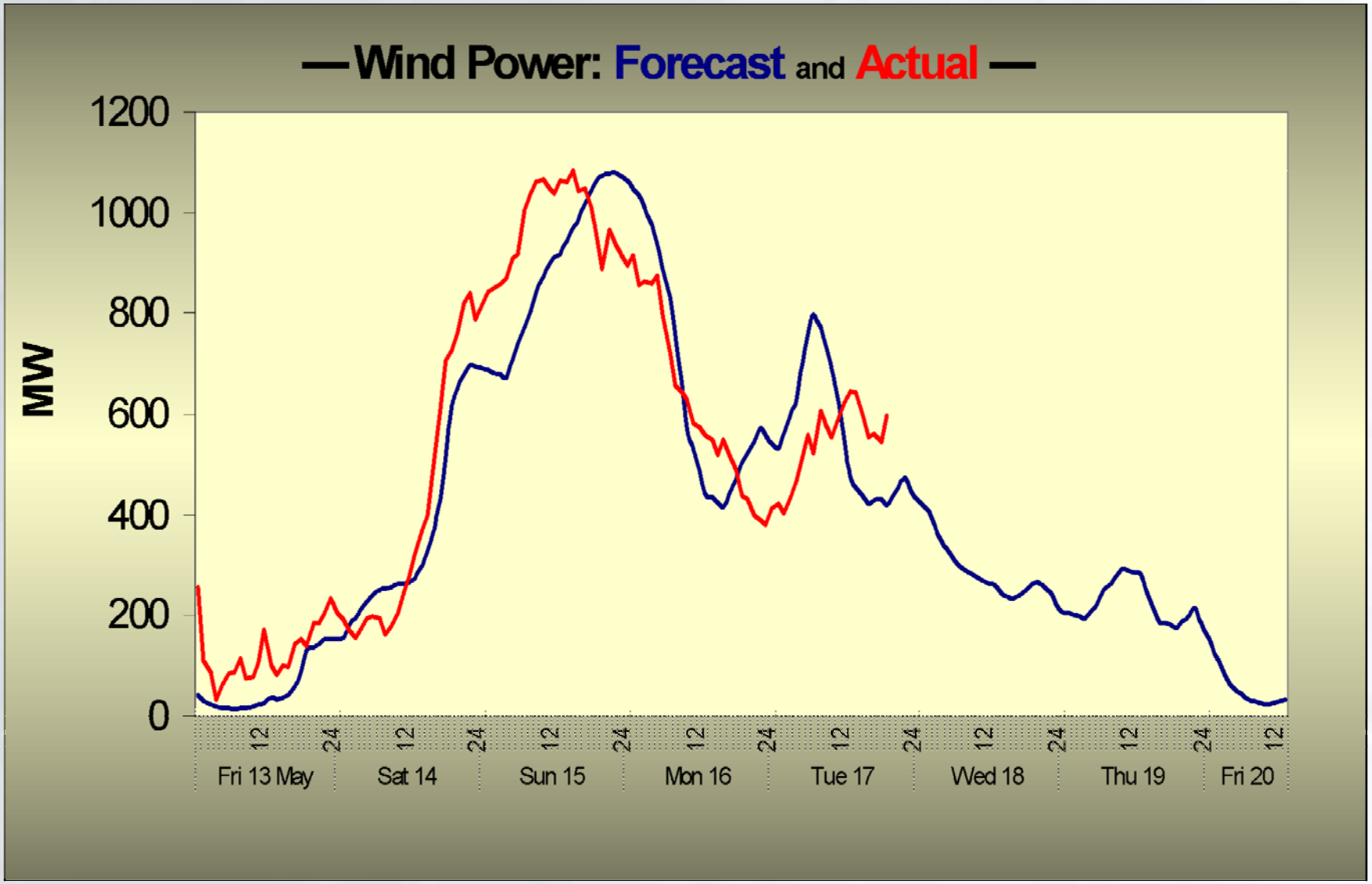
Accuracy of Wind Forecasts



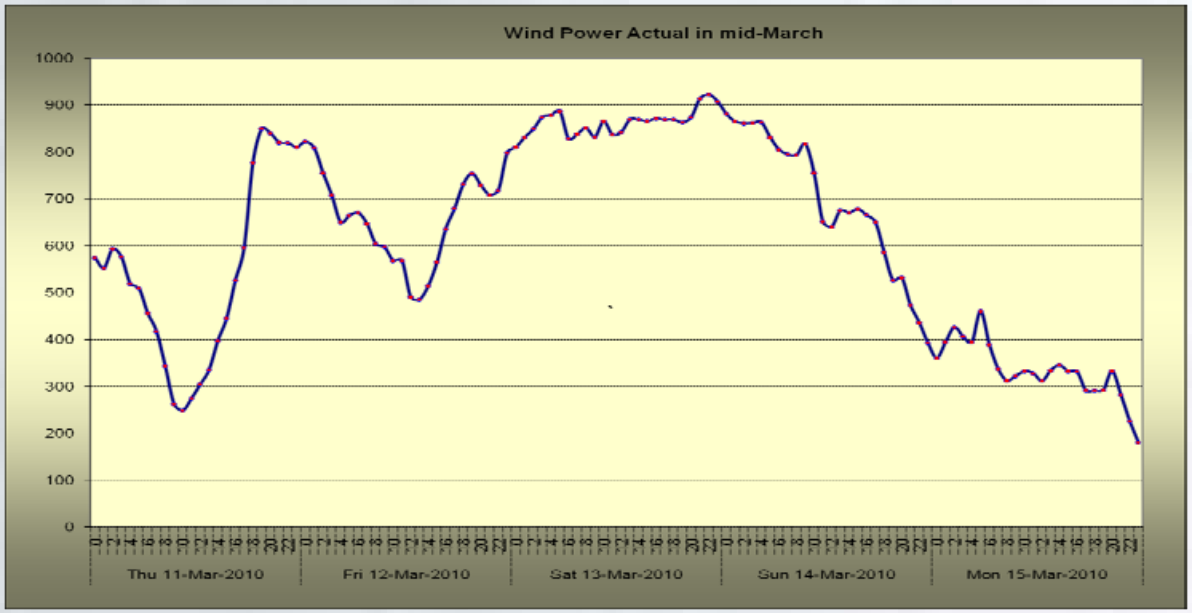
Propagation of Uncertainty

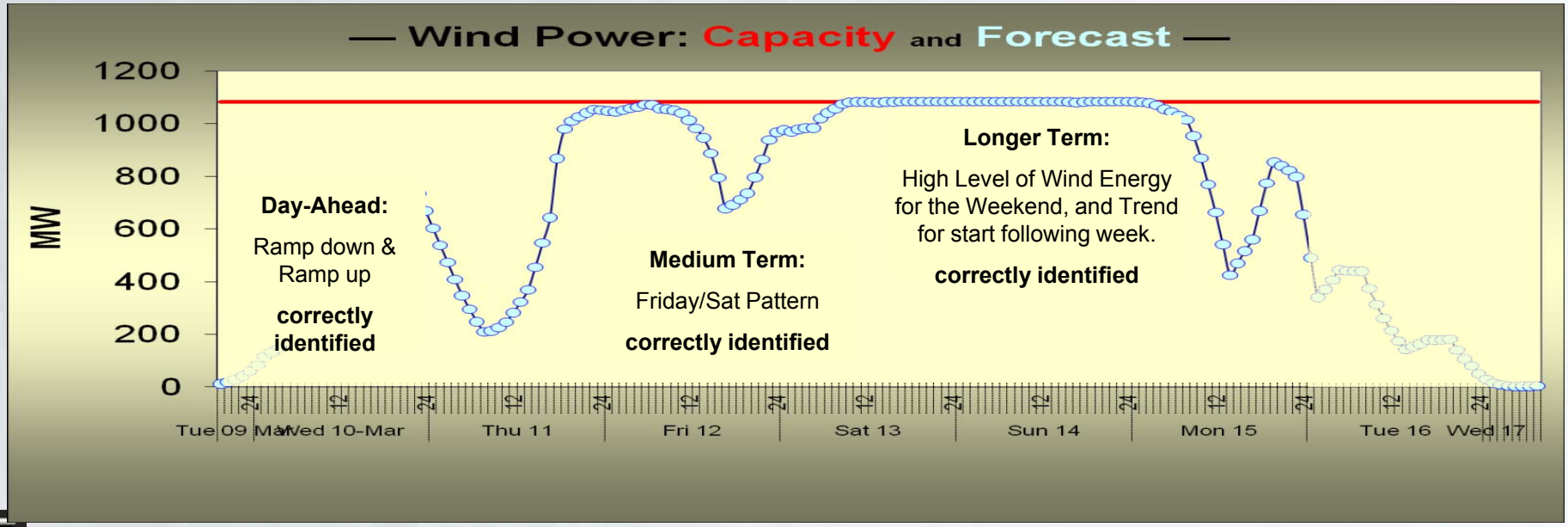


— a Week in May —

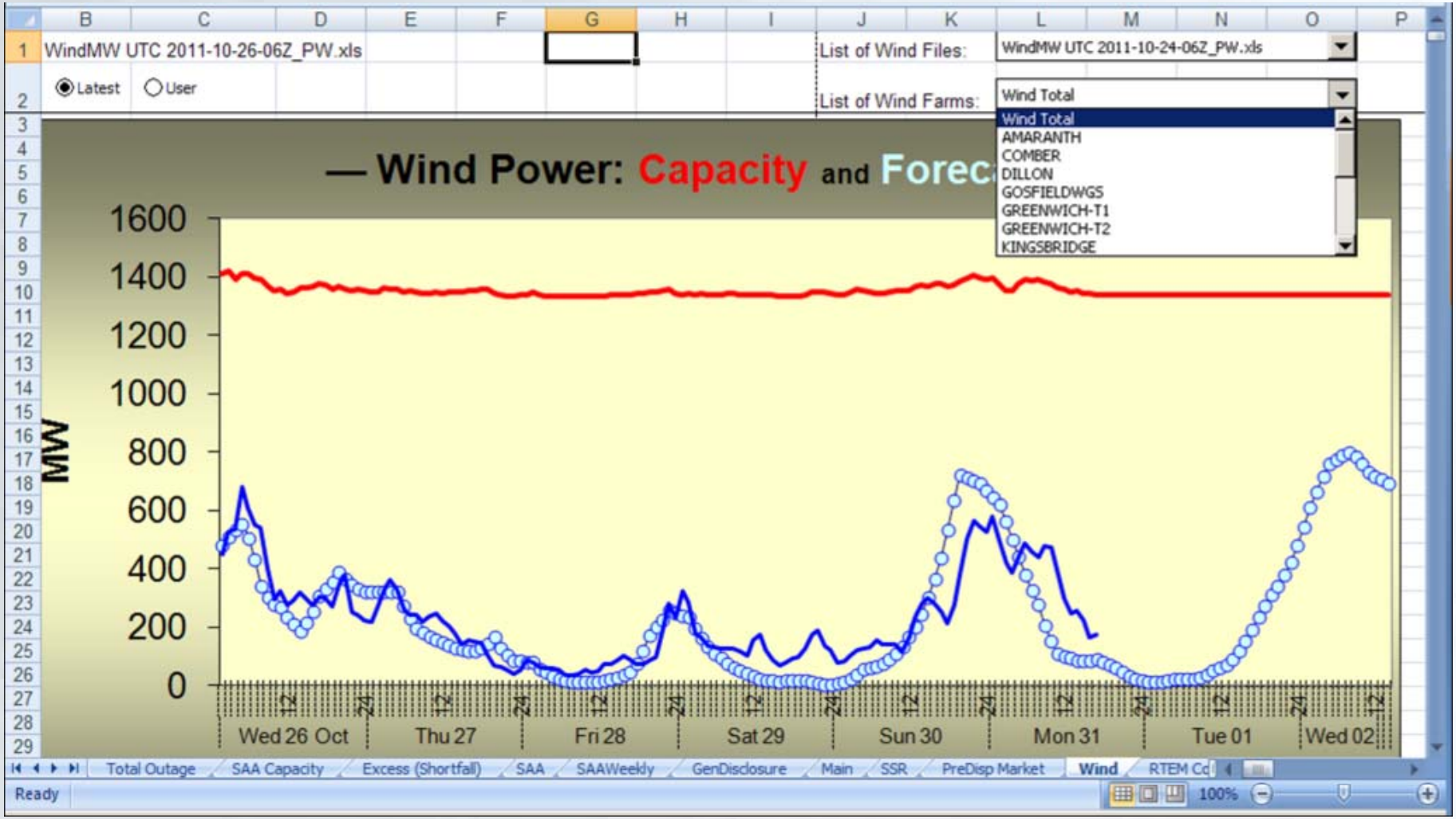

—Wind Power: Forecast and Actual —
MW
1200
1000
800
600
400
200
0
12
24
Fri 13 May
Sat 14
Sun 15
Mon 16
Tue 17
Wed 18
Thu 19
Fri 20

Usage of Forecasts





Implementation: KISS



Conclusion

- Raw forecasts give a good indication of the pattern and shape of wind energy.
- Provides an early indication of ramp events and periods of high and low wind energy.
- However, needs local information to scale raw forecasts to improve the MW-accuracy of the forecast.
- Clients need to be educated in the methodology for a successful implementation.