Wind Resource Engineering

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UBC, Vancouver

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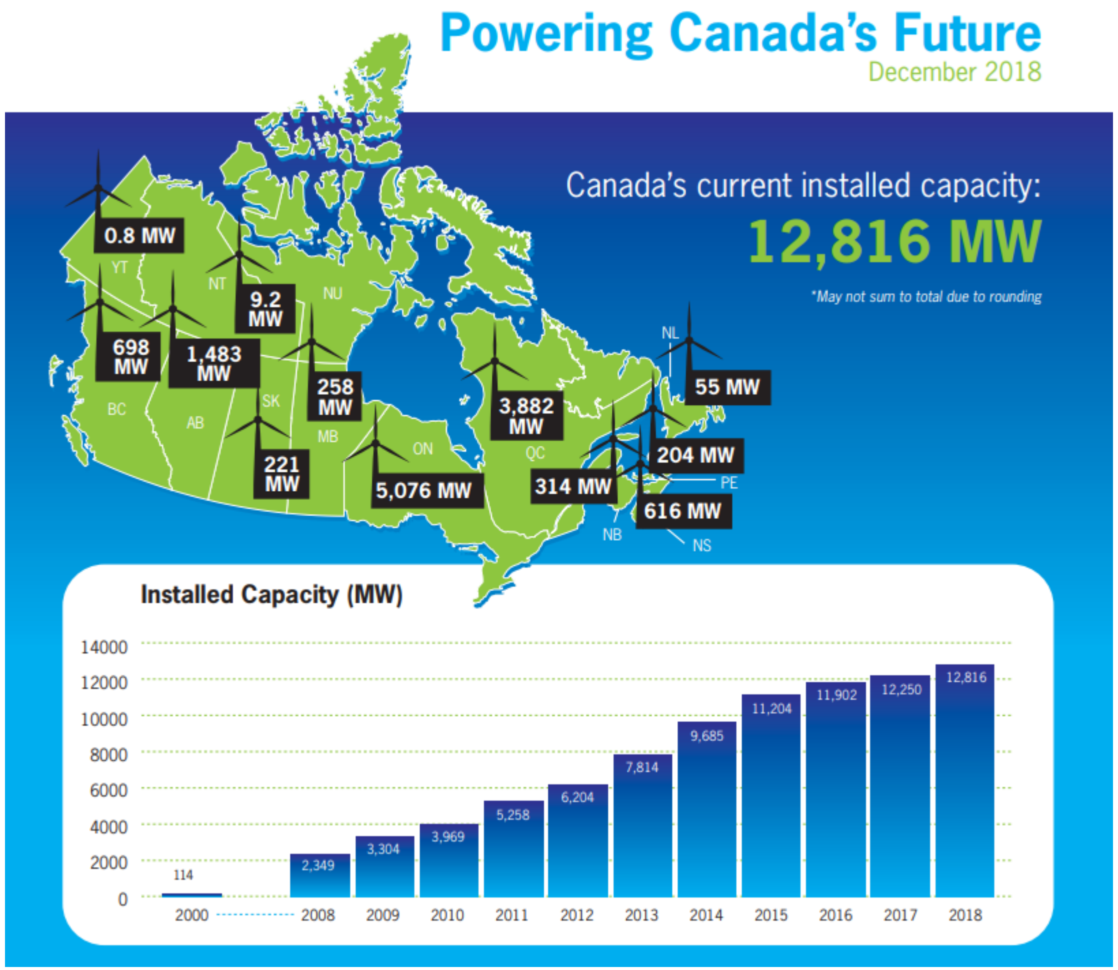
Overview

Whirl-wind tour: A branch of Engineering in 20-minutes

1. Economics of Wind
2. What is Wind Resource Engineering
   - *Finding a place to start (Scouting)*
   - *Measuring the atmosphere (Meteorological Campaign)*
   - *Vertical wind speed profile (Shear)*
   - *Measure-Correlate-Predict (MCP)*
   - *Wind Flow Modelling*
   - *Layout Optimization*
   - *Name Plate Capacity Optimization*
3. Market Integration

Introduction: Market Overview

- How much wind in Canada?
  - *648.4 TWh -> 4.7% total*
  - *Power vs. Energy*
- Where are new projects being built?



https://canwea.ca/wp-content/uploads/2019/02/powering-canadas-future-web.pdf

Introduction: Electricity Markets

How feasible in wind as an energy source?

- Where are the opportunities?
  - *Replacing coal*
    - requires a partner for grid stability.
  - *Cheap source of supplemental energy.*
- What are the economics?
  - *Trends in Electricity Rates*
    - $140/MWh => $37/MWh
  - *Compared to Competition*
    - Solar vs Wind vs Run of River
  - *Market Integration*
    - Quality of Power
  - *Are subsidies required?*

Alberta REP

Round	Name Plate Capacity	Rate ($/MWh)
REP 1 (2018)	595.6 MW	$37.00
REP 2 (2019)	362.9 MW	$38.69
REP 3 (2019)	400.8 MW	$40.14
Total	1359.3 MW	$38.38

https://www.aeso.ca/market/renewable-electricity-program/rep-results/
https://www.nrcan.gc.ca/energy/facts/electricity/20068

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What is Wind Resource Engineering?

How much energy will a wind farm deliver to the grid?

1. ***Scouting*** *=> Where to start*
2. *Designing a Wind Farm*
   - **Design data collection strategy** (Meteorological Masts/Remote Sensing)
   - Assess wind resource (**Shear, MCP, Wind Flow Modelling**)
   - **Optimization of layout and Name Plate Capacity (NPC)**
   - Evaluate turbine technologies, hub height, cold weather packages, de-icing systems, etc.
   - Climate Suitability
3. *Financing*
   - Estimate Energy
   - Minimizing uncertainty => uncertainty determines lending rate
4. *Post-construction true-up*
   - Based on SCADA data (10-minute) and invoices (monthly).
   - Power performance testing

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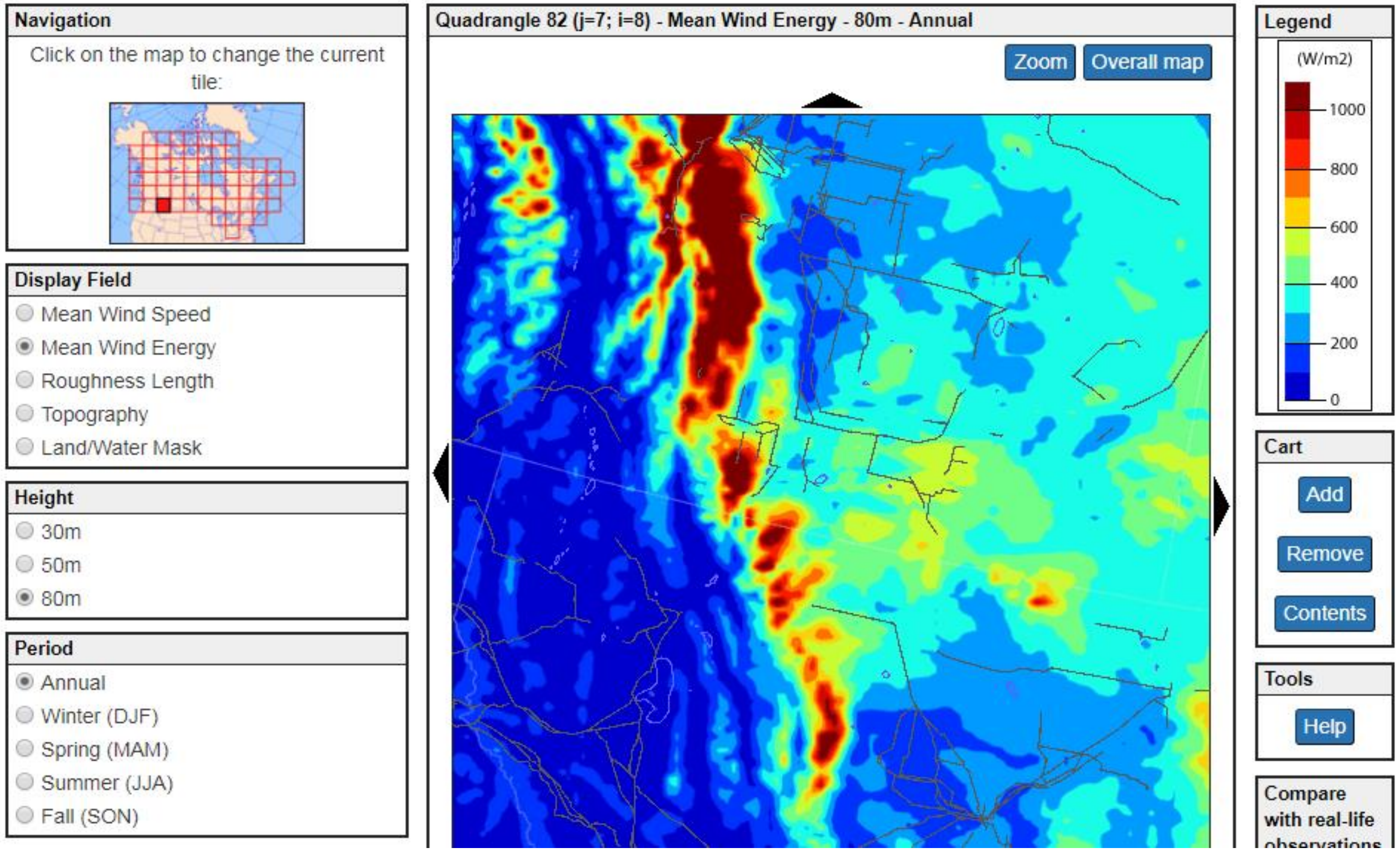
Scouting

Where best to place a wind farm?

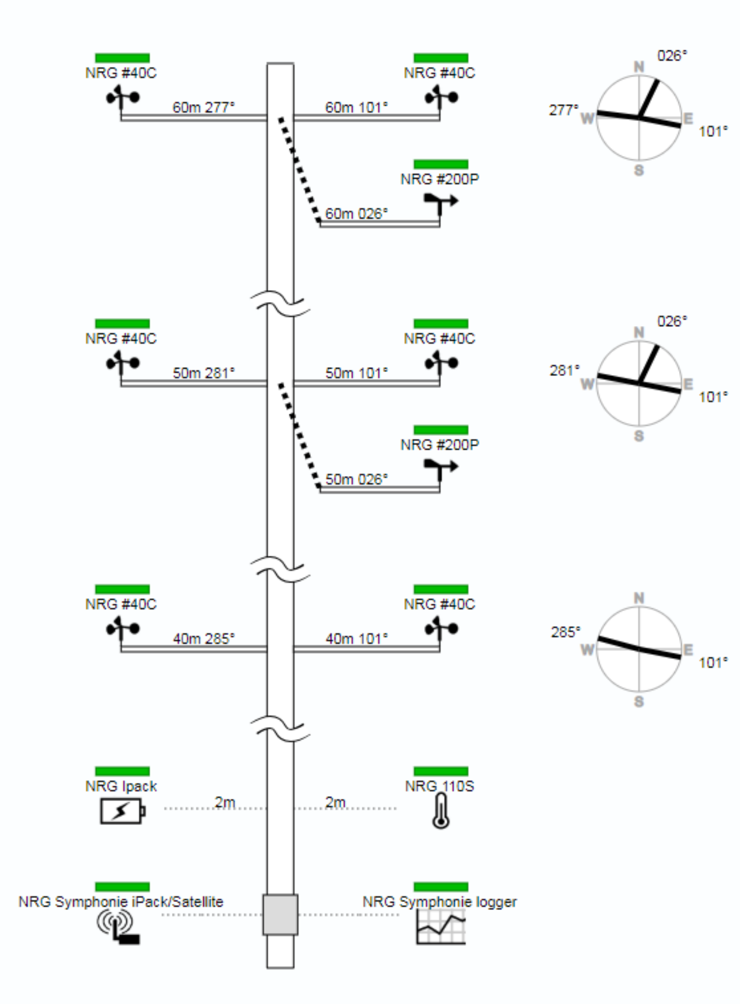
1. *Transmission (-)*
2. *Constraints (+)*
3. *Politics (-)*
4. *Climate Suitability*
   - Gust
   - Fatigue (TI)
   - Corrosion
   - Earth quakes
5. *Economics (+)*
   - Better turbines
   - Better analysis
   - Cheaper financing



http://www.windatlas.ca/maps-en.php

Design Measurement Campaign

How to measure on-site wind speeds?



https://ws1.windserver.com/

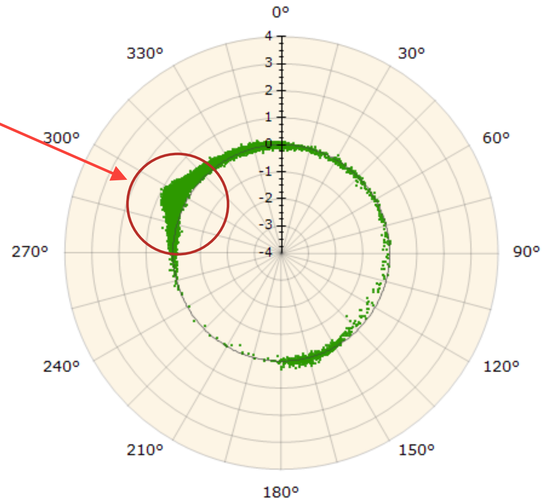
- Where to place towers?
  - *Where are wind flow models poor?*
- What instruments?
  - *Wind speed => how many heights?*
  - *Wind direction*
  - *Temperature*
    - Differential temperature?
  - *Barometric Pressure*
  - *Relative humidity*
- How tall a tower?
- Remote sensing?
- How long should the measurement campaign be?

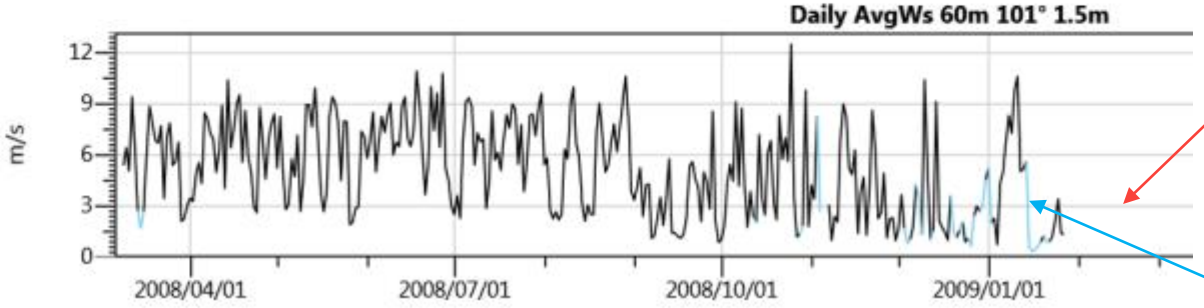
Measuring the Weather

How to quality control measurements?

- Quality control
  - *Sensor health*
  - *Icing detection*
  - *Set-up errors*
- Common problems
  - *Flow distortion => short booms*
  - *Sensor Drag => sensor wear*
  - *Timestamp off-set*
  - *Missed icing*

Sensor A – Sensor B





https://ws1.windserver.com/

Shearing: Profile

What is the vertical wind speed profile of the atmosphere?

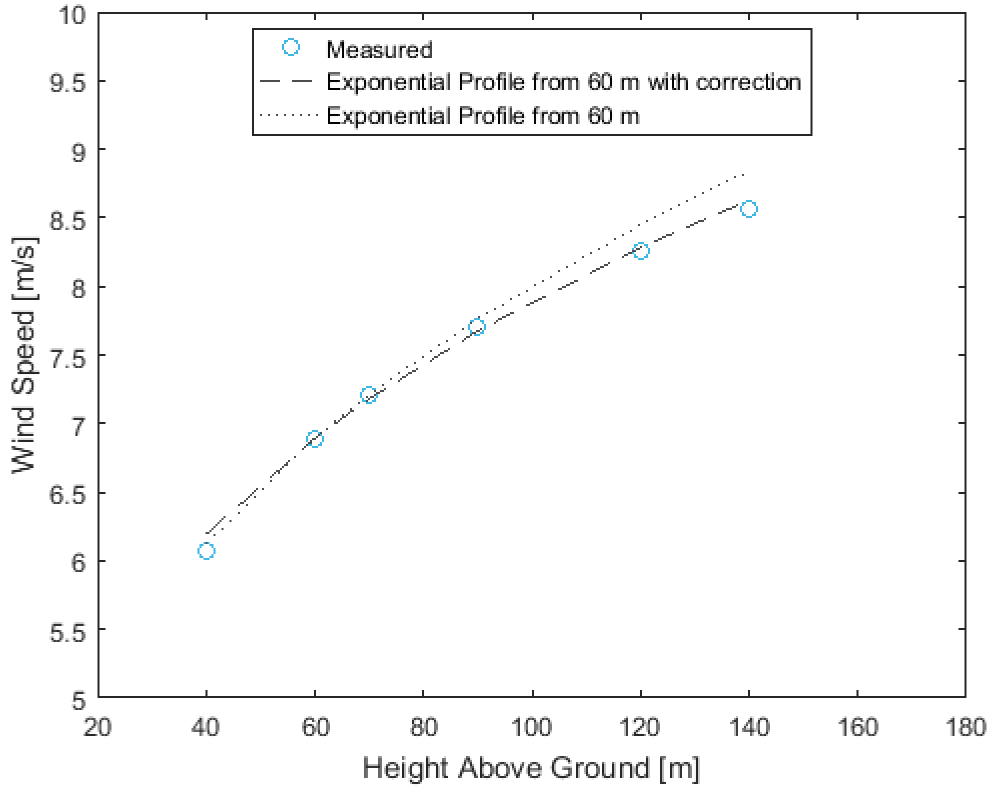
1. *Assume profile*
   - Exponential or Power Law:

$$\frac{u}{u_r} = \left(\frac{z}{z_r}\right)^{\alpha}$$

   - Log Law:

$$u_z = \frac{u_*}{\kappa}\left[\ln\left(\frac{z-d}{z_0}\right) + \psi(z, z_0, L)\right]$$

   - Measure multiple heights, fit profile and extrapolate.
2. *Remote Sensing*
   - Actually measure profile
   - Expensive => short-term
   - Seasonality

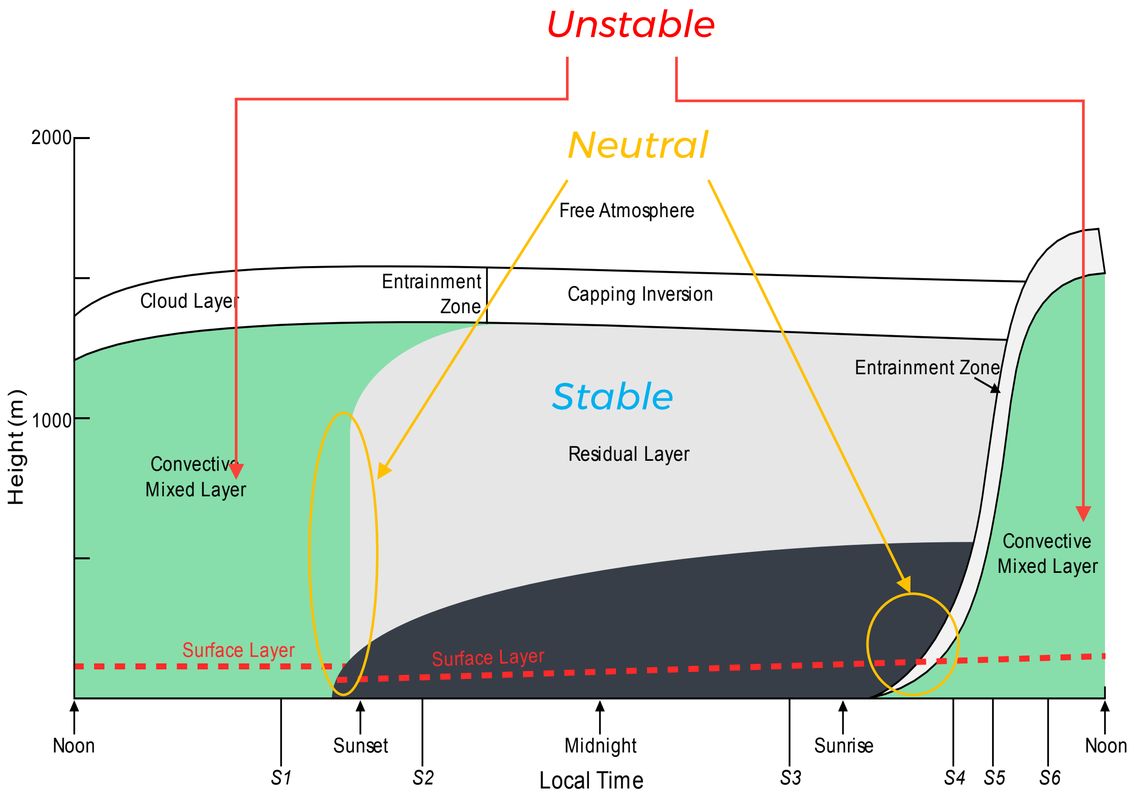


https://en.wikipedia.org/wiki/Log_wind_profile
https://en.wikipedia.org/wiki/Wind_profile_power_law

Shearing: Stability

How does the vertical profile change over-time?

1. *How does stability change the profile?*
   - Stable vs neutral vs unstable
   - Seasonal profile, diurnal profile, directional profile.
   - Stability is terrain dependent
2. *Need a better model*
   - Reduced uncertainty, reduced financing costs
   - Shorter masts relative to hub height
3. *Economics*
   - The taller a tower, the more expensive
   - Turbines have increased in height, old campaigns are no longer suitable



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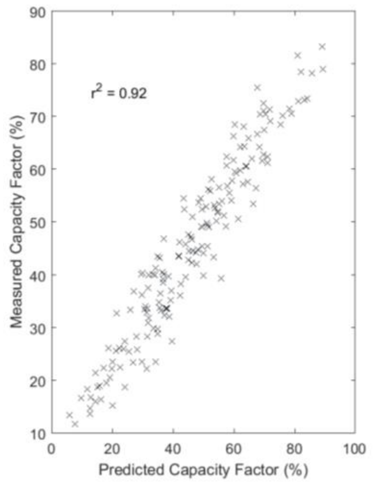
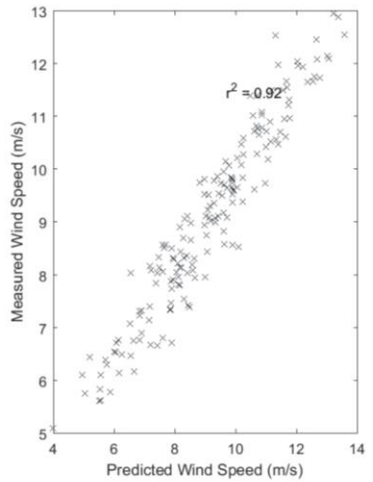
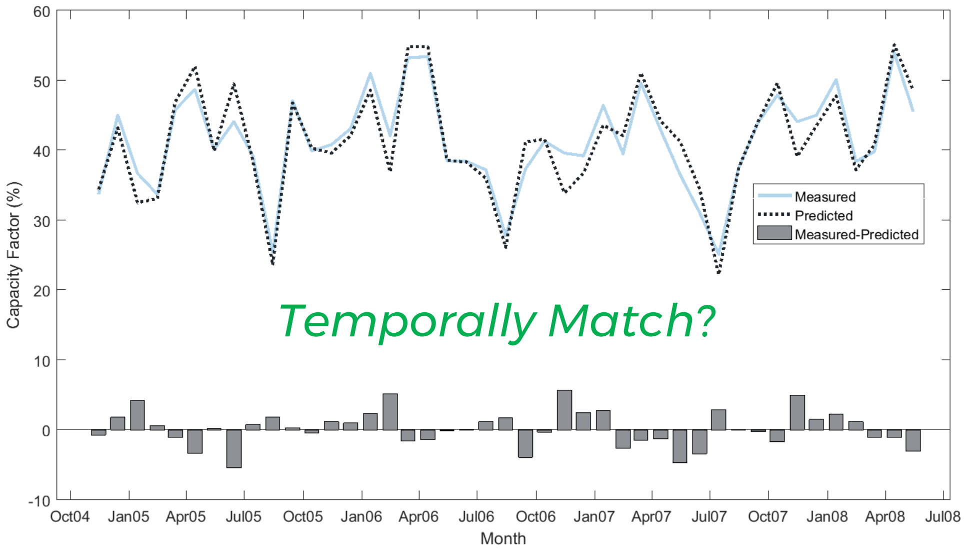
Measure, Correlate, Predict (MCP)

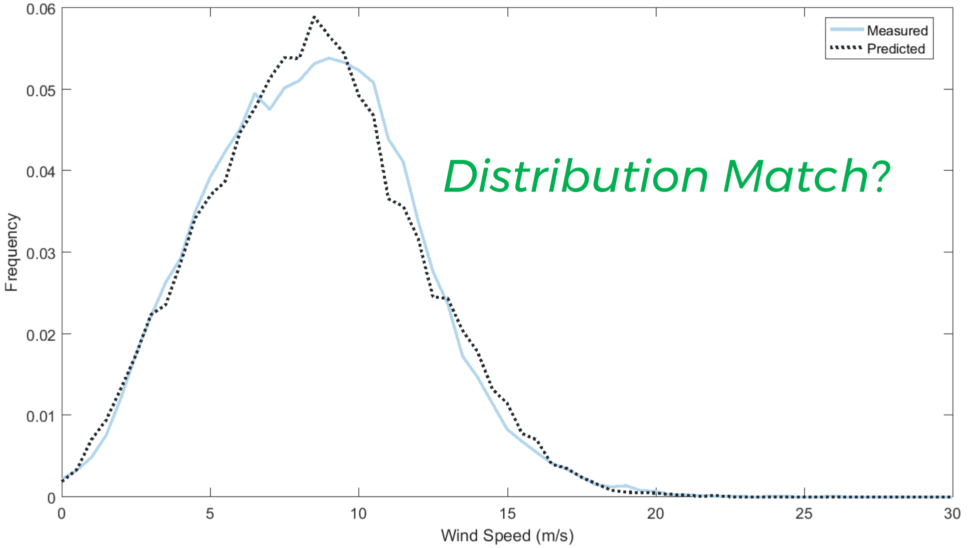
How to correct short-term measurements to the long-term?

1. *Suitable long-term reference: Environment Canada, ERA5 or MERRA2*
2. *Strong correlation -> representative*
3. *Long-term correct: temperature, pressure, relative humidity, wind speed, wind direction, stability?*





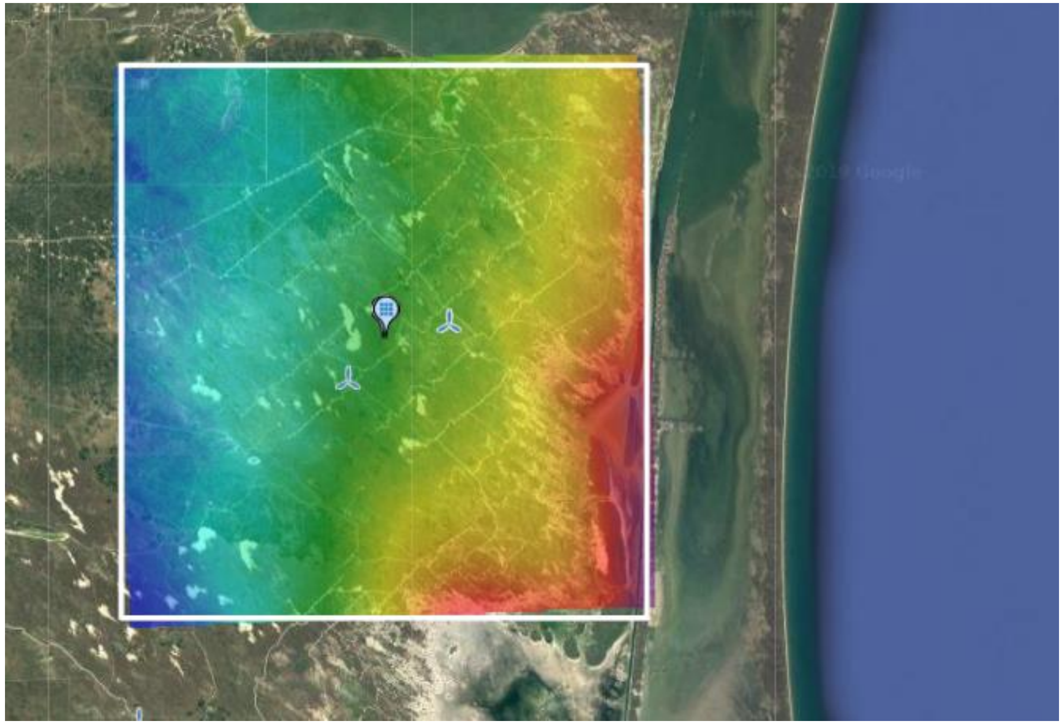




Global Meso-Scale Models

How to spatially and temporally model the atmosphere?

1. *Micro-scale (<10 km)*
   - Examples: CFD, WAsP
   - Accounts for: terrain & roughness
   - Weather phenomena must be measured
2. *Meso-scale (10-1000 km)*
   - Examples: ERA5, Vortex
   - Accounts for: geostrophic winds, thunderstorms, land-sea breezes, squall lines, etc.
   - Accurate over a much larger distances.
3. *Climatic vs Timeseries*
   - Correlation of losses
   - Correlation of air density
   - Correlation with prices

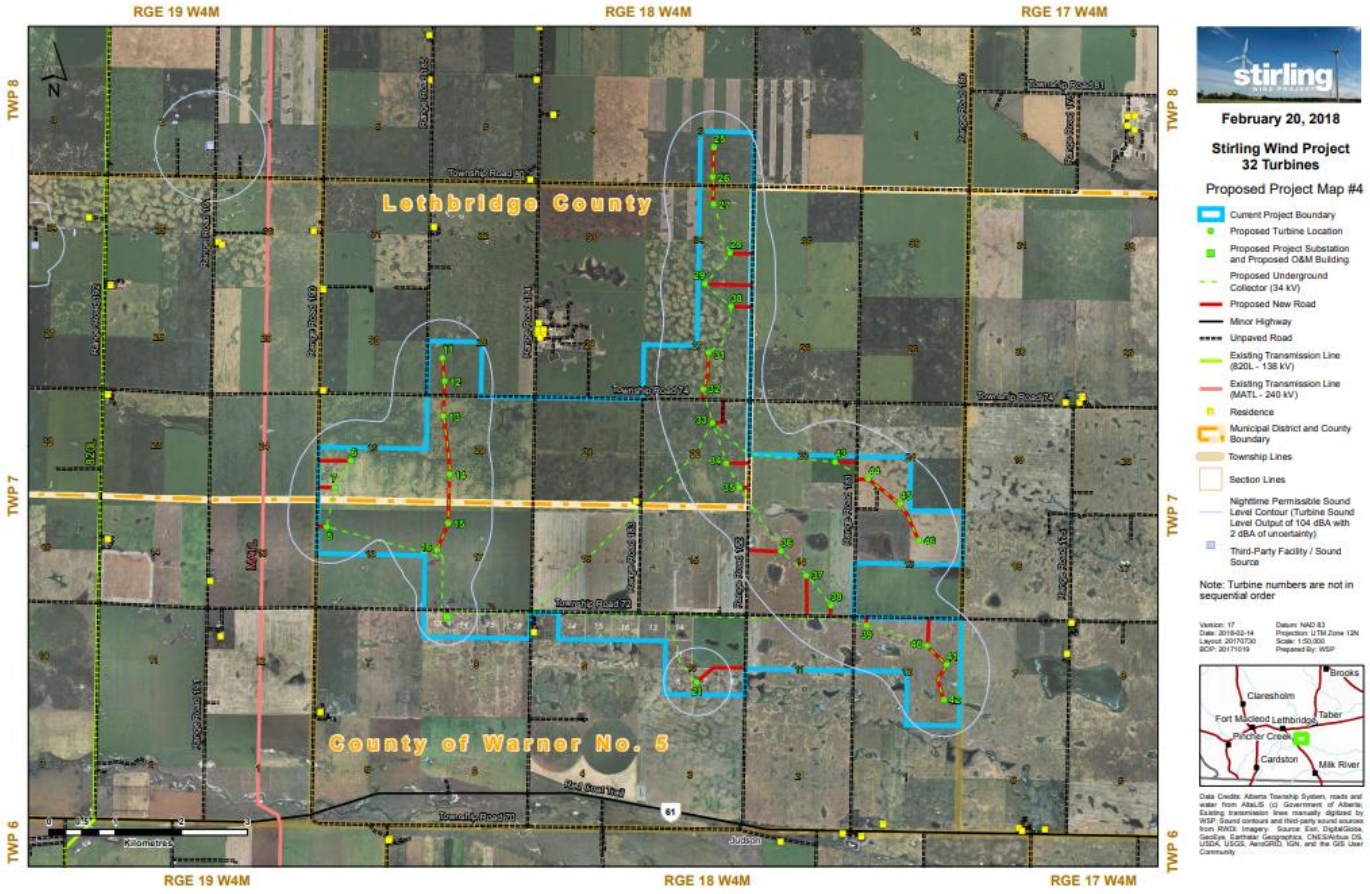


Vortex: http://interface.vortexfdc.com/

Layout Optimization

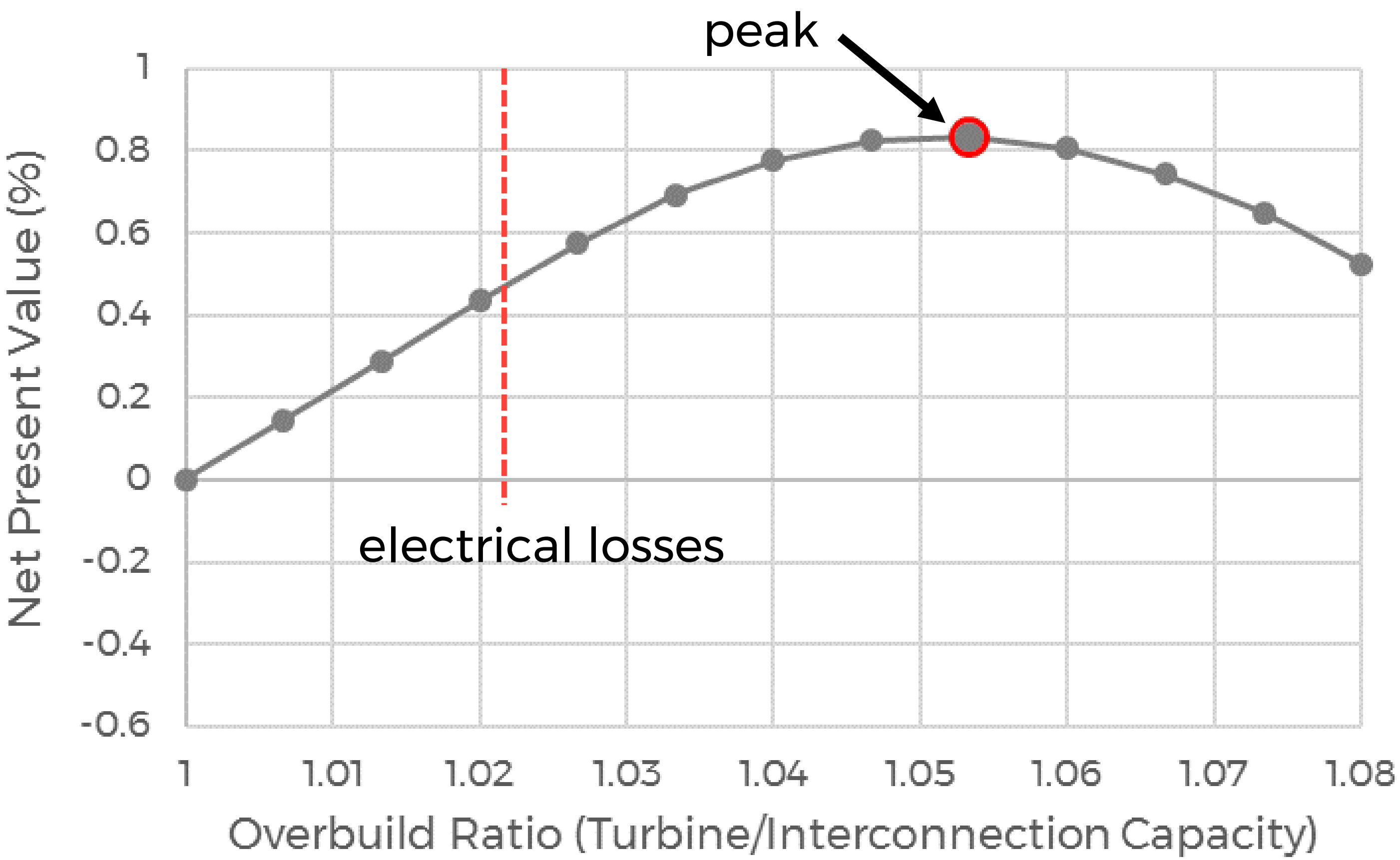
Where should turbines go and what type of turbine should be used?

1. *Turbine Selection*
   - Climate Suitability (survivability)
   - Sound Output
   - Maximum Energy
2. *Placement*
   - Constraints
   - Inter-connection costs
   - Resource (Energy)
   - Wake losses
   - Icing losses (elevation dependent)
3. *Optimizer*
   - Inter-related considerations: Sound, wake, energy
   - Discontinuous – constraints add hard edges.
   - Mixed mode: Different power curves



Stirling Wind Project: http://stirlingwind.com
Open House Posters: http://stirlingwind.com/wp-content/uploads/2016/12/Stirling-Wind-Project-October-Open-House-Boards.pdf

Case Study: Impact of Over-build



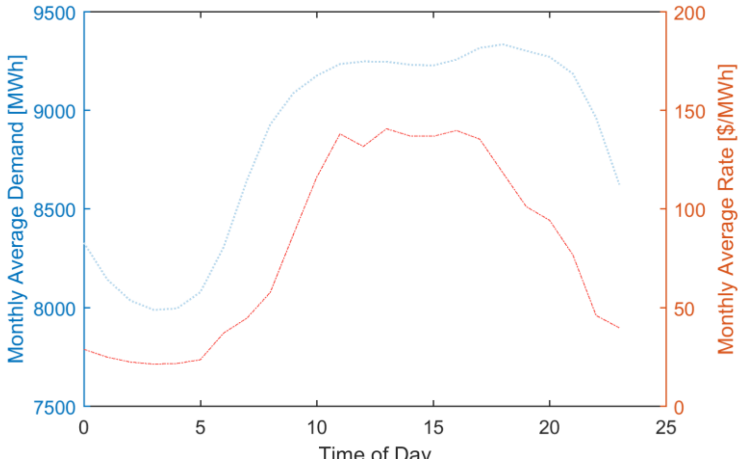
- Assumptions
  - *CAPEX: $1.6M/MW*[1]
  - *2.2% Electrical Losses (peak)*
  - *47 $/MWh offtake*
  - *44.4% Net Capacity Factor*
- Peak return at 1.053 overbuild
  - *(e.g. 158/150 turbines)*
  - *Curtailment of 0.31%*
  - *NPV +0.8% over base case*

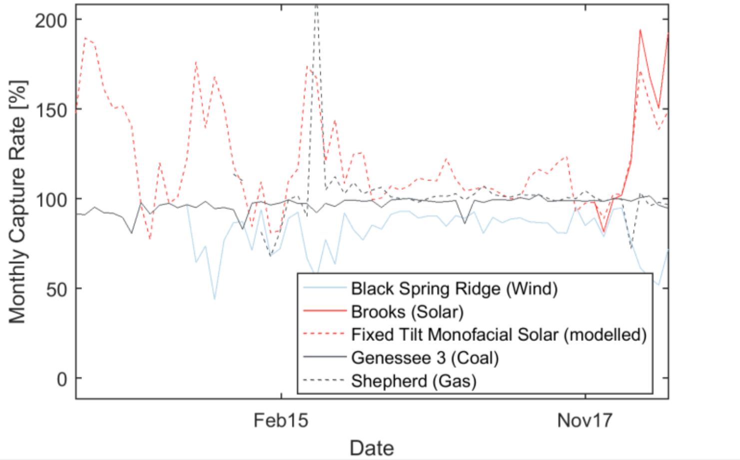
[1] NREL: 2018 Annual Technology Baseline (Case 3), www.atb.nrel.gov
Slide from: Errol Halberg, « Maximizing Project Economics Through Project Capacity Overbuild » AWEA Wind Resource & Project Energy Assessment Conference 2018

Energy Markets: Wind Integration

How to spatially and temporally model the atmosphere?

1. Market demand fluctuates
   - *Typically low at night*
   - *High during day/evening*
2. In AESO market, price fluctuates from negative to $999/MWh
   - *Pro-cyclist would be paid $0.02/hour, $0.30/hour at maximum rate*
3. Wind tends to produce at low demand
   - *Storage: battery, hydro or load shifting*
4. Hydrocarbons match load closely
5. Solar tends to produce at high demand





http://ets.aeso.ca/ets_web/ip/Market/Reports/CSDReportServlet

Final Notes:

— Wind is economically competitive, even considering intermittency.

— Wind power is an established industry, but still relatively young.

— There are many areas that the science of WRA can improve.

Questions

wsp.com