INDUSTRY PERSPECTIVE - DEVELOPERS

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VP TECHNOLOGIES

14TH DECEMBER 2010

res AMERICAS
powering change

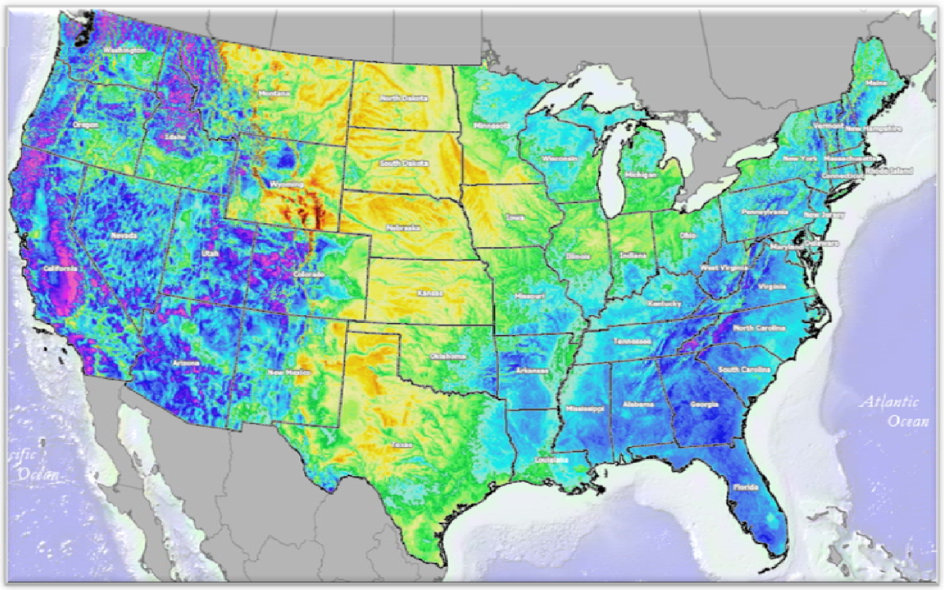
Renewable Energy Systems Americas

- Established in 1982
  - ➢Family Owned
- Over 300 North American employees
- 4,100 MW constructed to date in US (>10% of US)
  - ➢40 projects
  - ➢About 40% of this developed by RES
- 22 member Technical Team has sited over 2,000MW of operational plant
- 1,000 MW under construction
- 226 MW Ownership in two projects in US

Resource Assessment

Finding Wind: The Mesoscale Wind Model

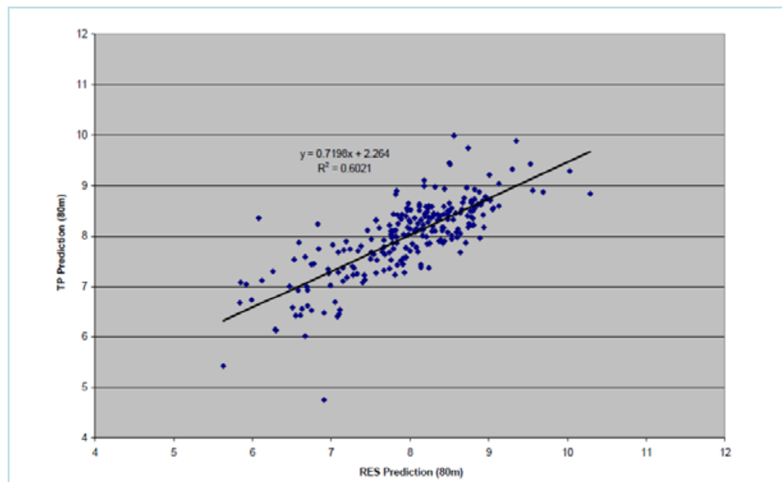
- Most Developers use a mesoscale model to estimate a region's wind potential
- 'Out of the box' std uncertainty of 5 to 7% on mean wind is typically claimed
- Accuracy of maps improving as vendors adjust to more and more measured data



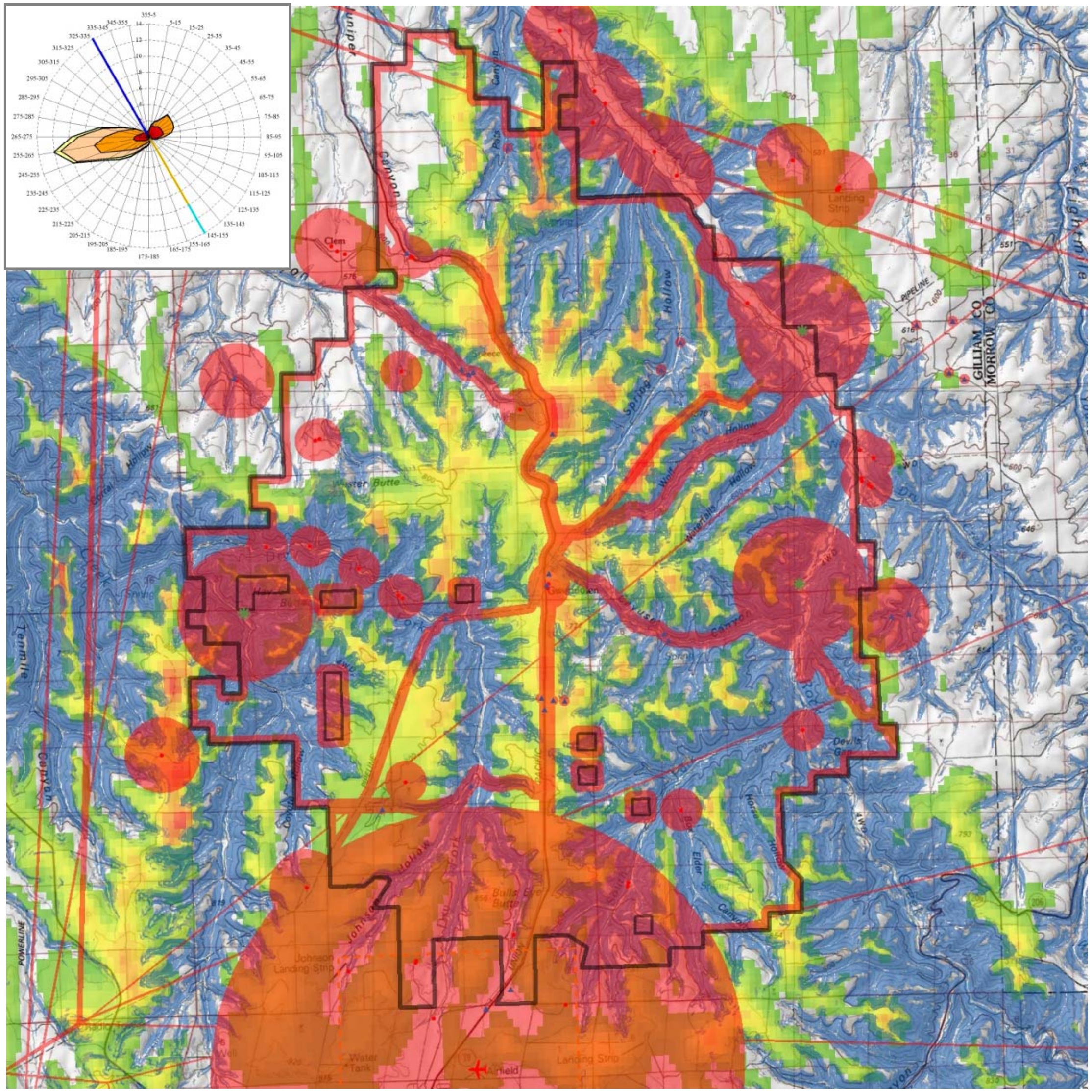
Courtesy AWS Truewind
http://navigator.awstruewind.com/support_samples.cfm

Outputs:

- Wind statistics compiled on a 1 - 5km grid
  - ➢ Average wind speed
  - ➢ Wind direction 'rose'
  - ➢ Wind distribution 'shape', etc



Preliminary Site Design



Research land ownership

- Not always interested!
- Project boundary

Determine site constraints

- 'Setback' map

Determine ease of construction

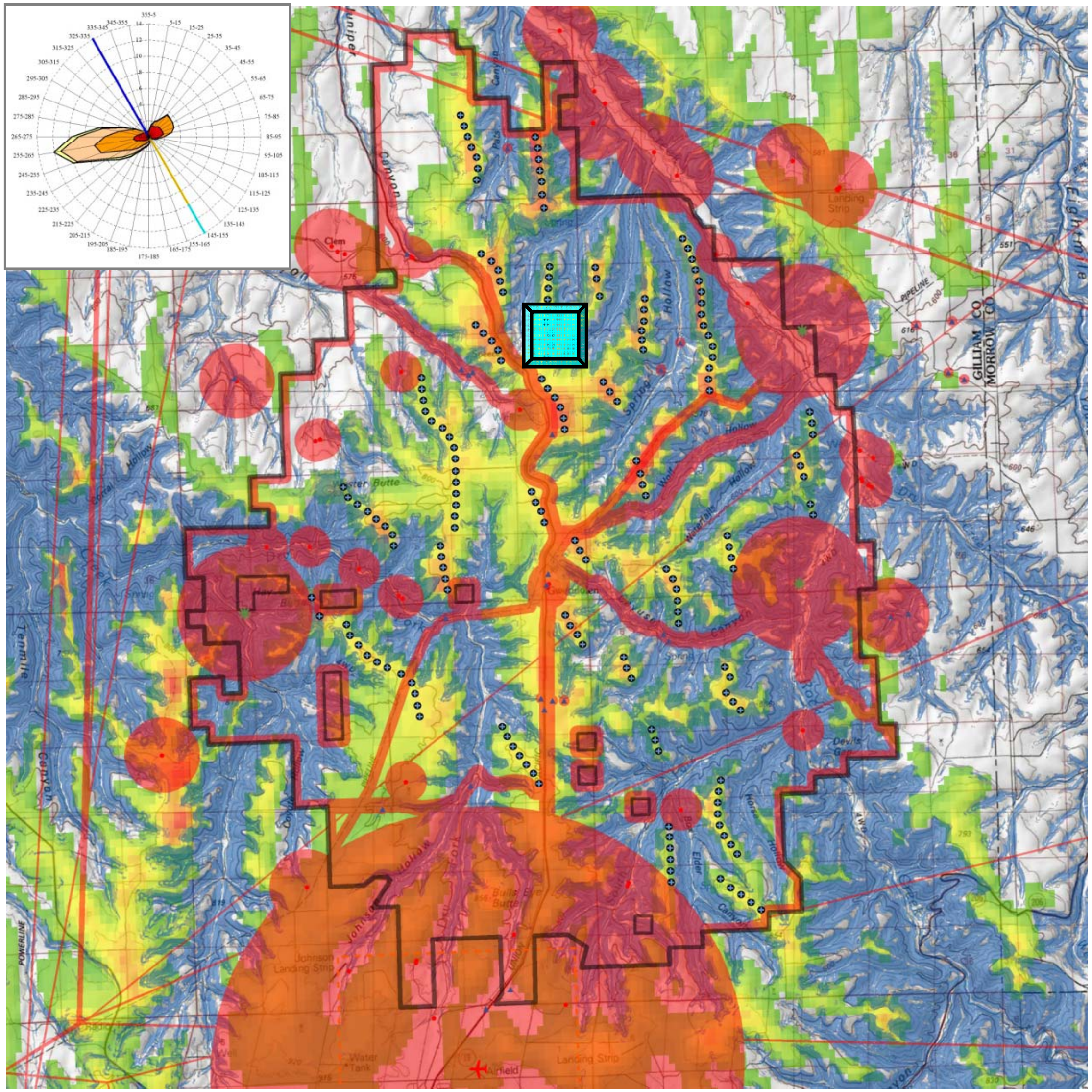
- Color topography by slope
- − Blue (too difficult)
- − Gray (marginal)

Overlay wind map

Estimate wind direction

- Mesoscale model or airport

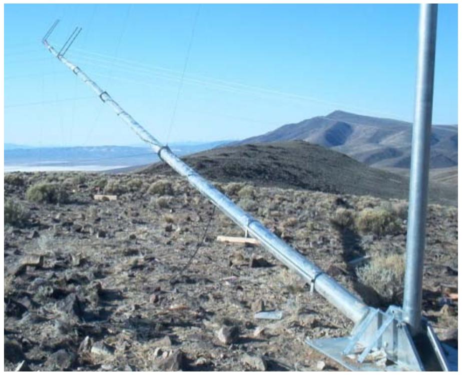
Preliminary Site Design



Next Steps:

- Produce a preliminary layout
- Select a mast location
  - Representative of turbines

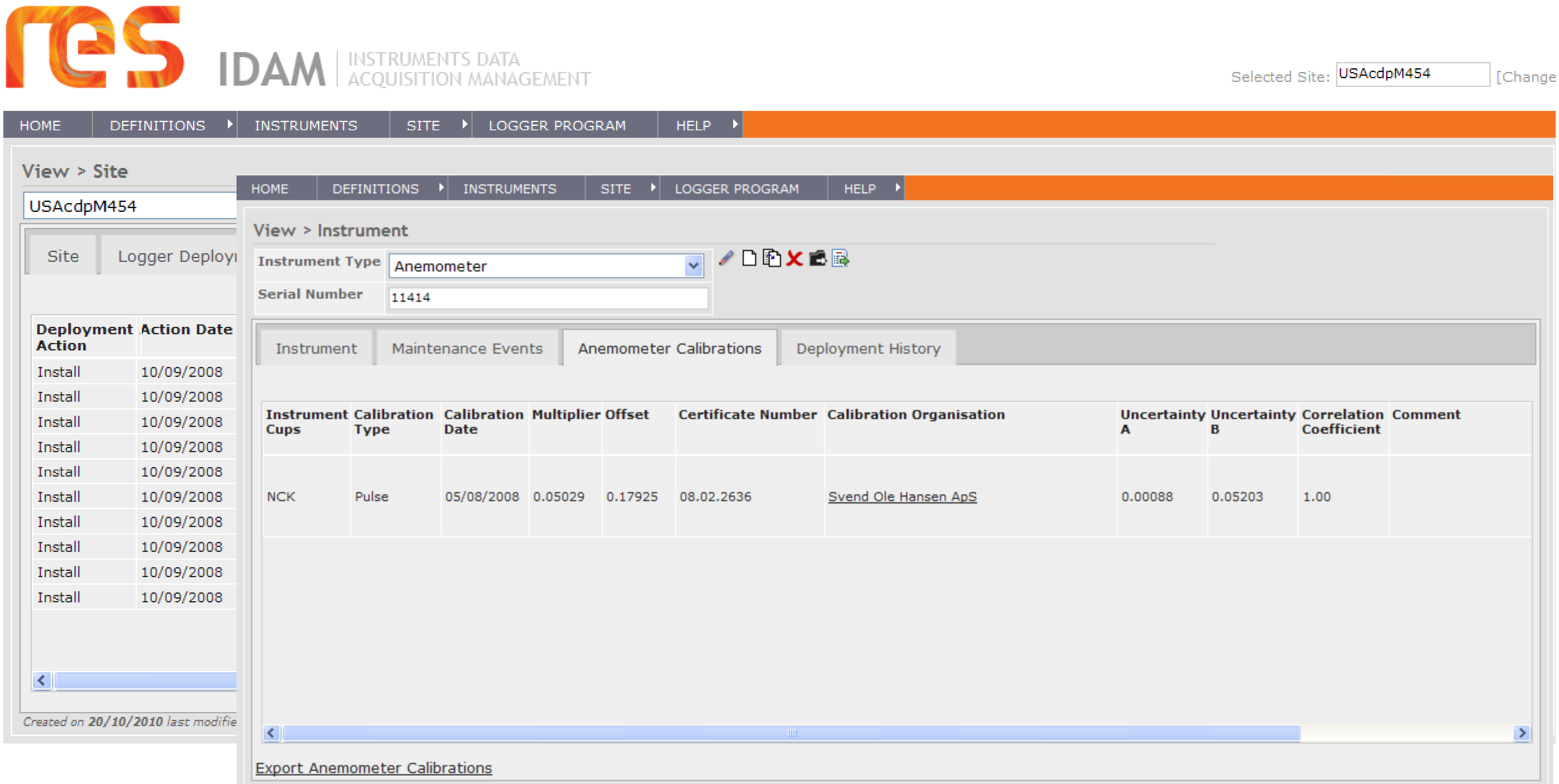
Measuring the Wind- *Mast Installation*



Typical set up includes

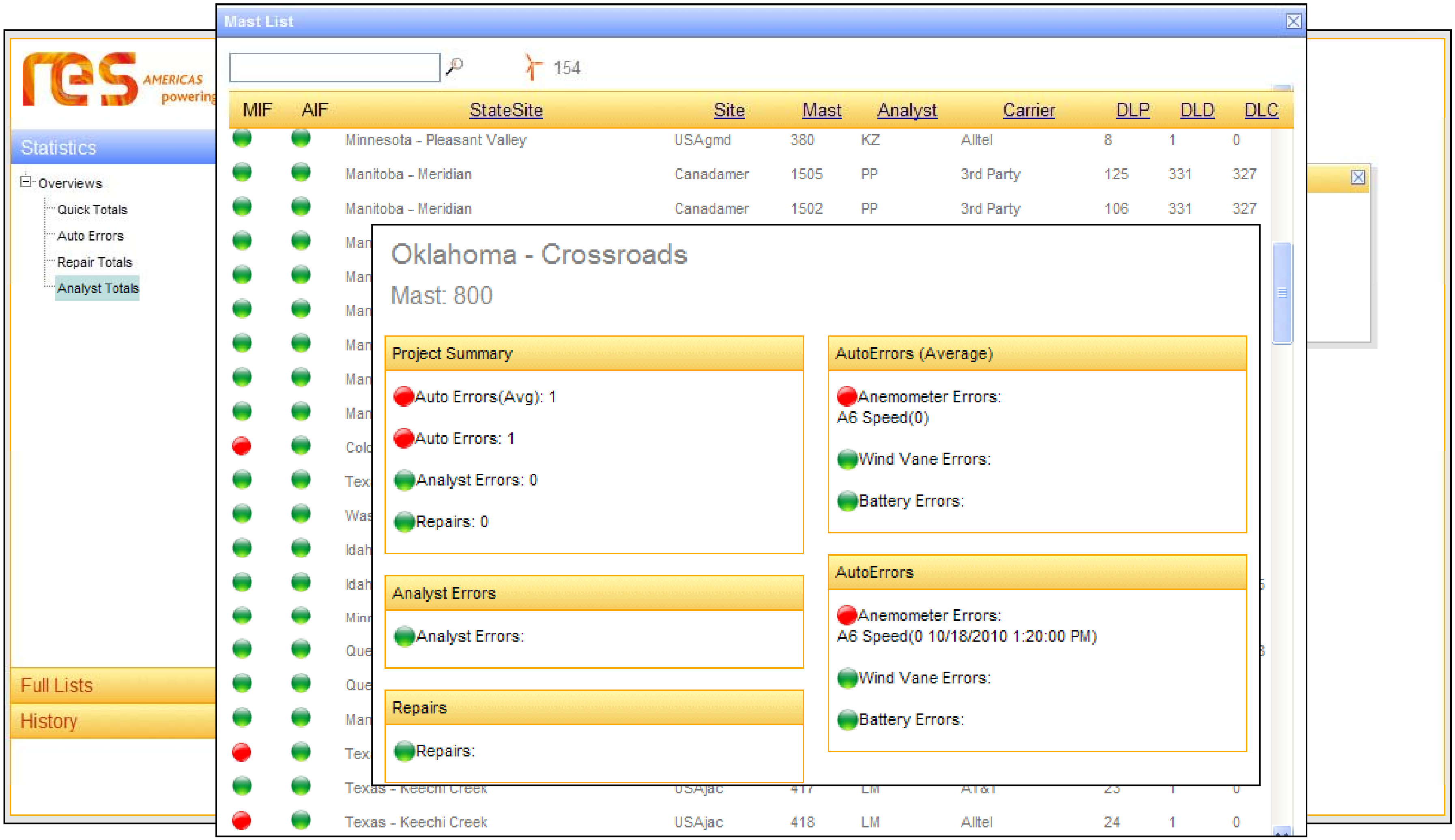
- Anemometers at 3 or 4 levels
- Wind vanes, Temperature & Pressure sensors
- Logger, solar panel, communications
- Purpose built / in-house designed generator for cold weather sites

Quality Control of Instrument Deployment



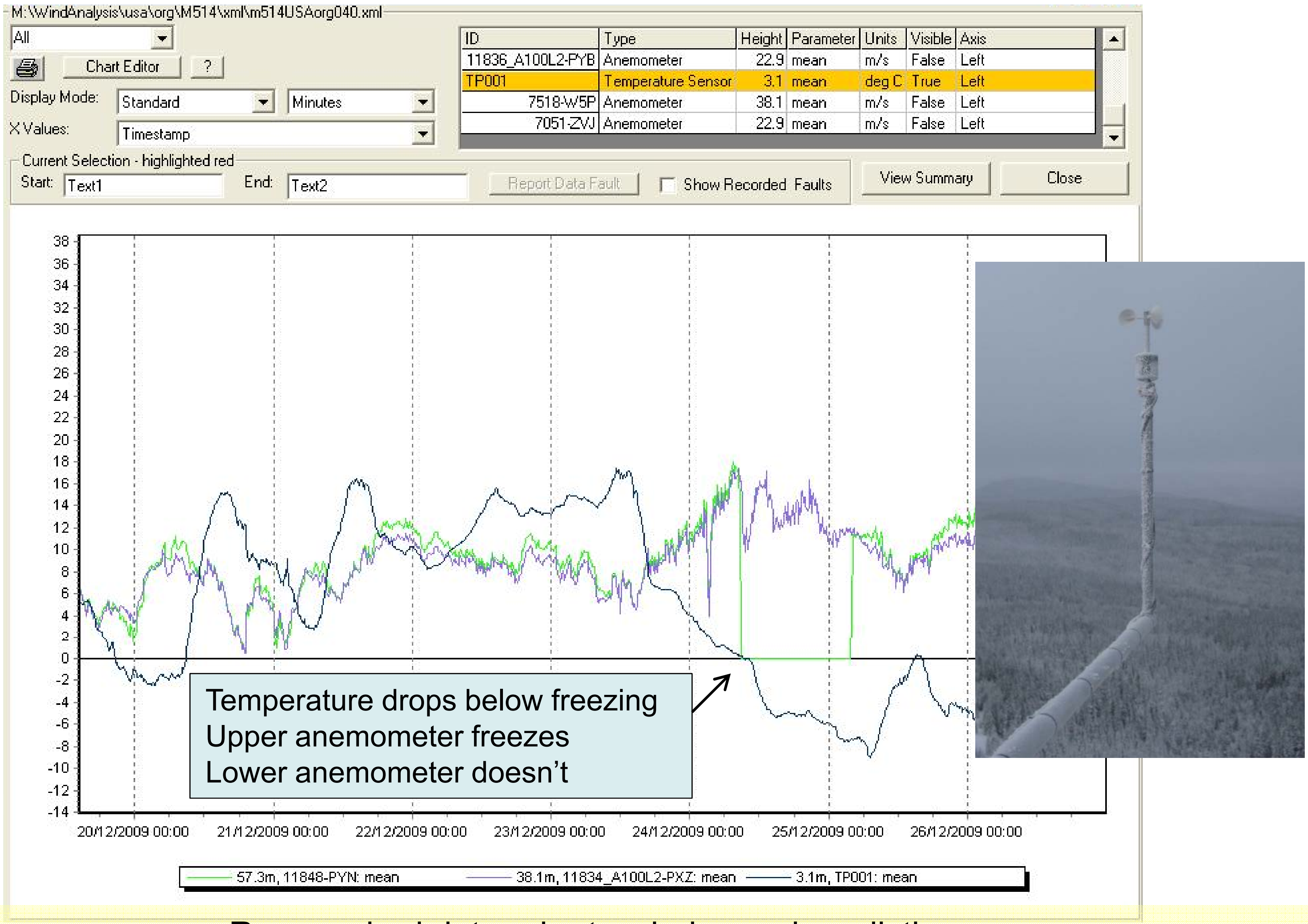
Extremely important to record every detail of what was installed, when it was installed, height, orientation, distance from tower, calibrations and service history of your instrumentation

Mast Data Manager



Flag any potential failures & problems immediately after files are downloaded

Quality Control

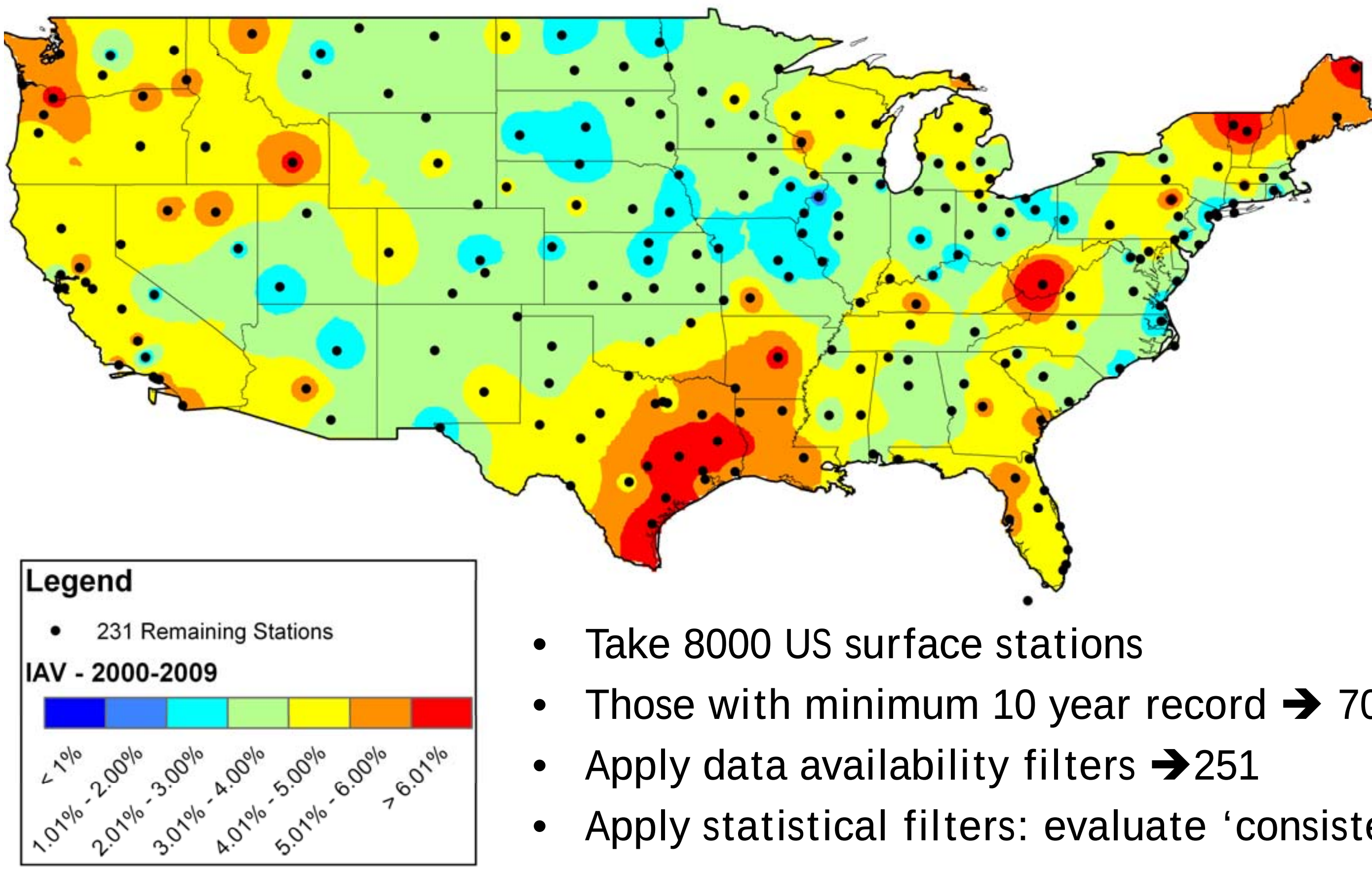


Remove bad data prior to wind speed predictions

Predicting the Long Term Wind Climate

Wind resource varies from year to year: "Inter Annual Variation"

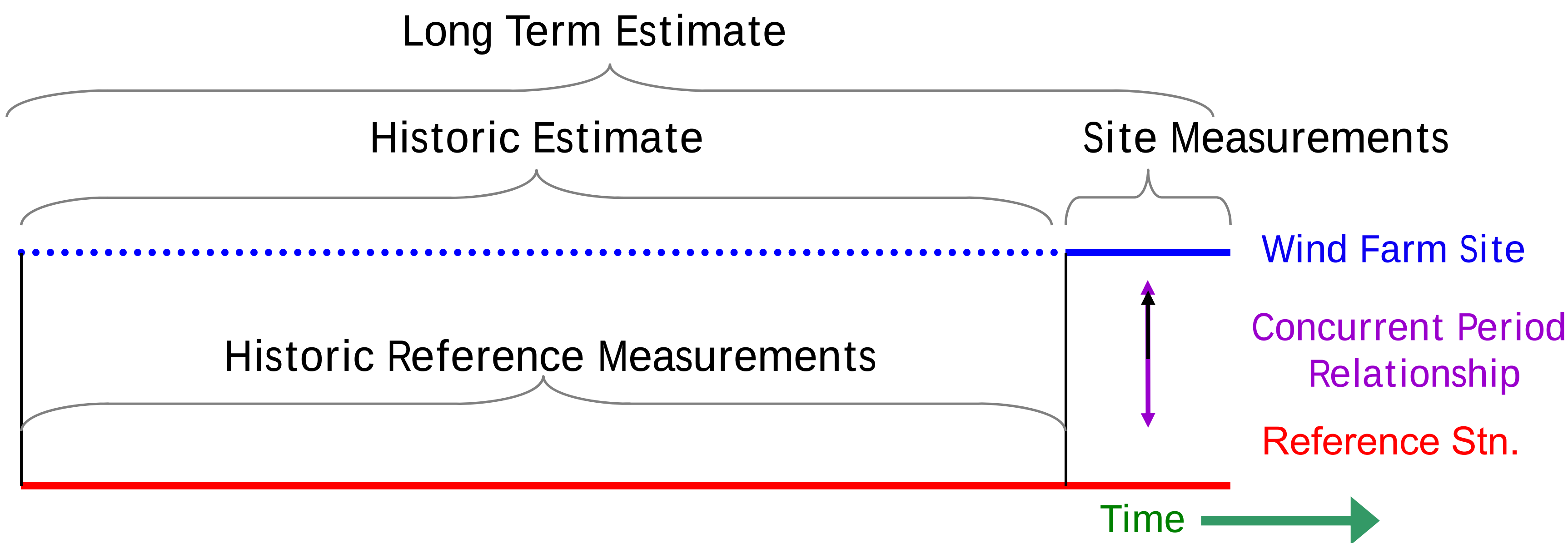
Defined as standard deviation of annual mean wind speed

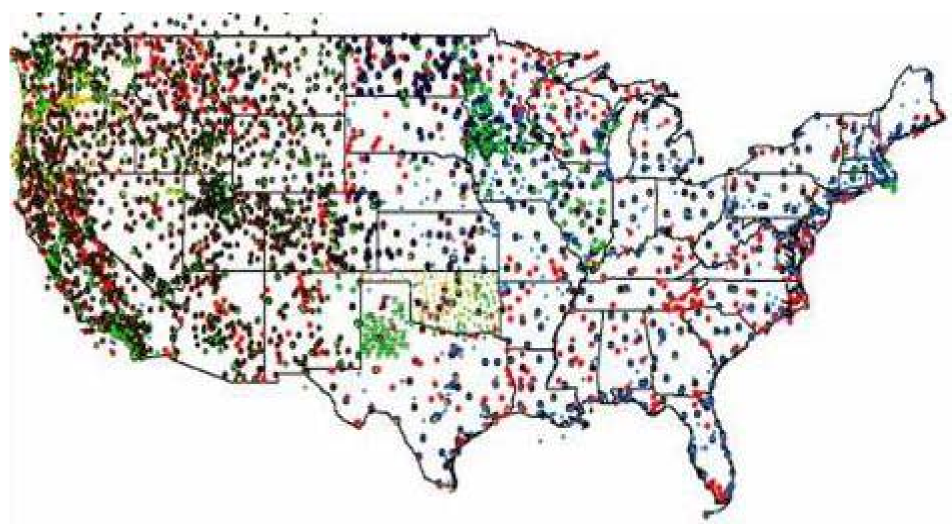


- Take 8000 US surface stations
- Those with minimum 10 year record ➔ 700 stations
- Apply data availability filters ➔251
- Apply statistical filters: evaluate 'consistency' ➔231

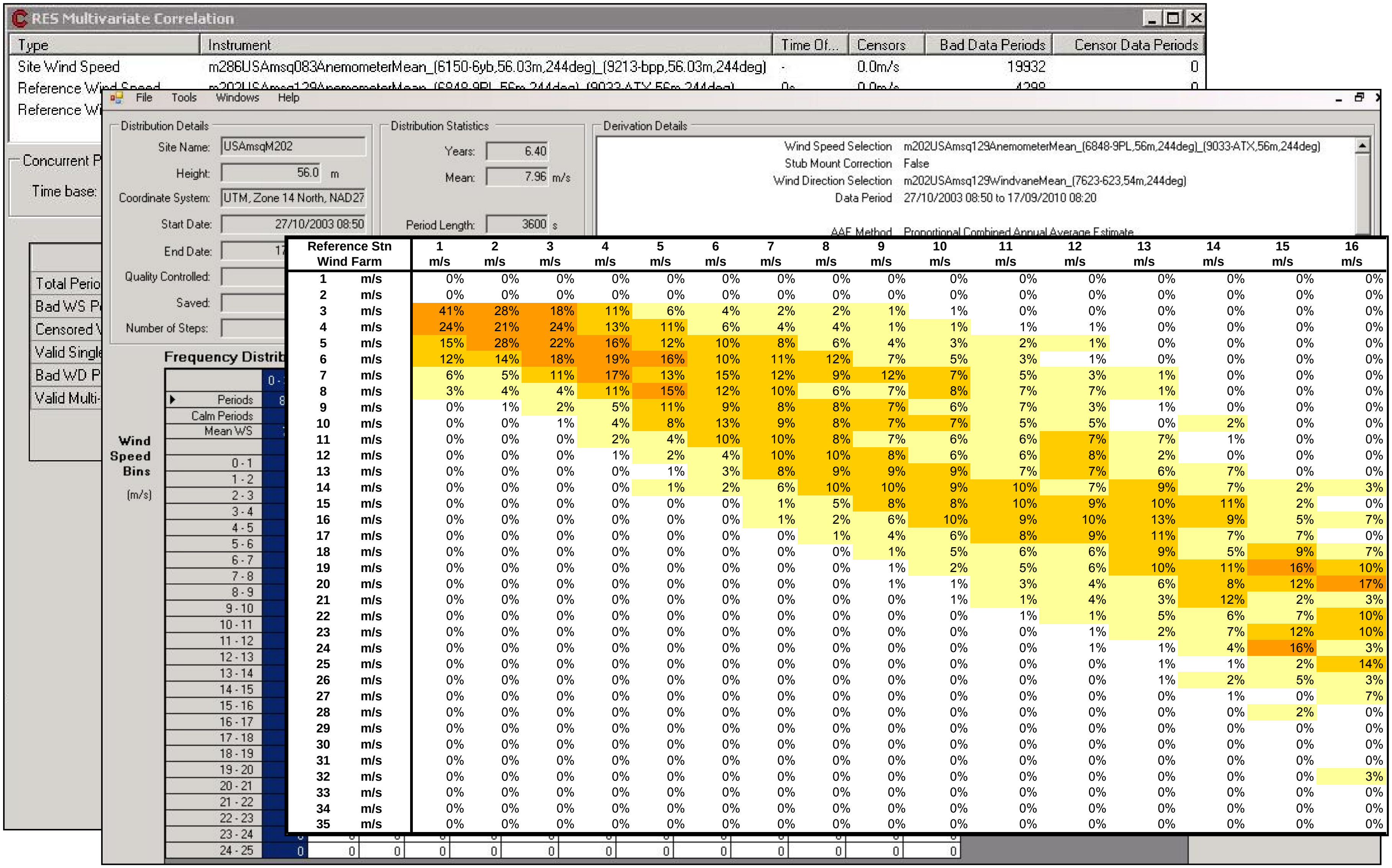
More variation requires a longer measurement campaign for a given uncertainty

Measure Correlate Predict (MCP)





MCP Software



Reference Stn / Wind Farm		1 m/s	2 m/s	3 m/s	4 m/s	5 m/s	6 m/s	7 m/s	8 m/s	9 m/s	10 m/s	11 m/s	12 m/s	13 m/s	14 m/s	15 m/s	16 m/s
1	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	m/s	41%	28%	18%	11%	6%	4%	2%	2%	1%	1%	0%	0%	0%	0%	0%	0%
4	m/s	24%	21%	24%	13%	11%	6%	4%	4%	1%	1%	1%	1%	0%	0%	0%	0%
5	m/s	15%	28%	22%	16%	12%	10%	8%	6%	4%	3%	2%	1%	0%	0%	0%	0%
6	m/s	12%	14%	18%	19%	16%	10%	11%	12%	7%	5%	3%	1%	0%	0%	0%	0%
7	m/s	6%	5%	11%	17%	13%	15%	12%	9%	12%	7%	5%	3%	1%	0%	0%	0%
8	m/s	3%	4%	4%	11%	15%	12%	10%	6%	7%	8%	7%	7%	1%	0%	0%	0%
9	m/s	0%	1%	2%	5%	11%	9%	8%	8%	7%	6%	7%	3%	1%	0%	0%	0%
10	m/s	0%	0%	1%	4%	8%	13%	9%	8%	7%	7%	5%	5%	0%	2%	0%	0%
11	m/s	0%	0%	0%	2%	4%	10%	10%	8%	7%	6%	6%	7%	7%	1%	0%	0%
12	m/s	0%	0%	0%	1%	2%	4%	10%	10%	8%	6%	6%	8%	2%	0%	0%	0%
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14	m/s	0%	0%	0%	0%	1%	2%	6%	10%	10%	9%	10%	7%	9%	7%	2%	3%
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17	m/s	0%	0%	0%	0%	0%	0%	0%	1%	4%	6%	8%	9%	11%	7%	7%	0%
18	m/s	0%	0%	0%	0%	0%	0%	0%	0%	1%	5%	6%	6%	9%	5%	9%	7%
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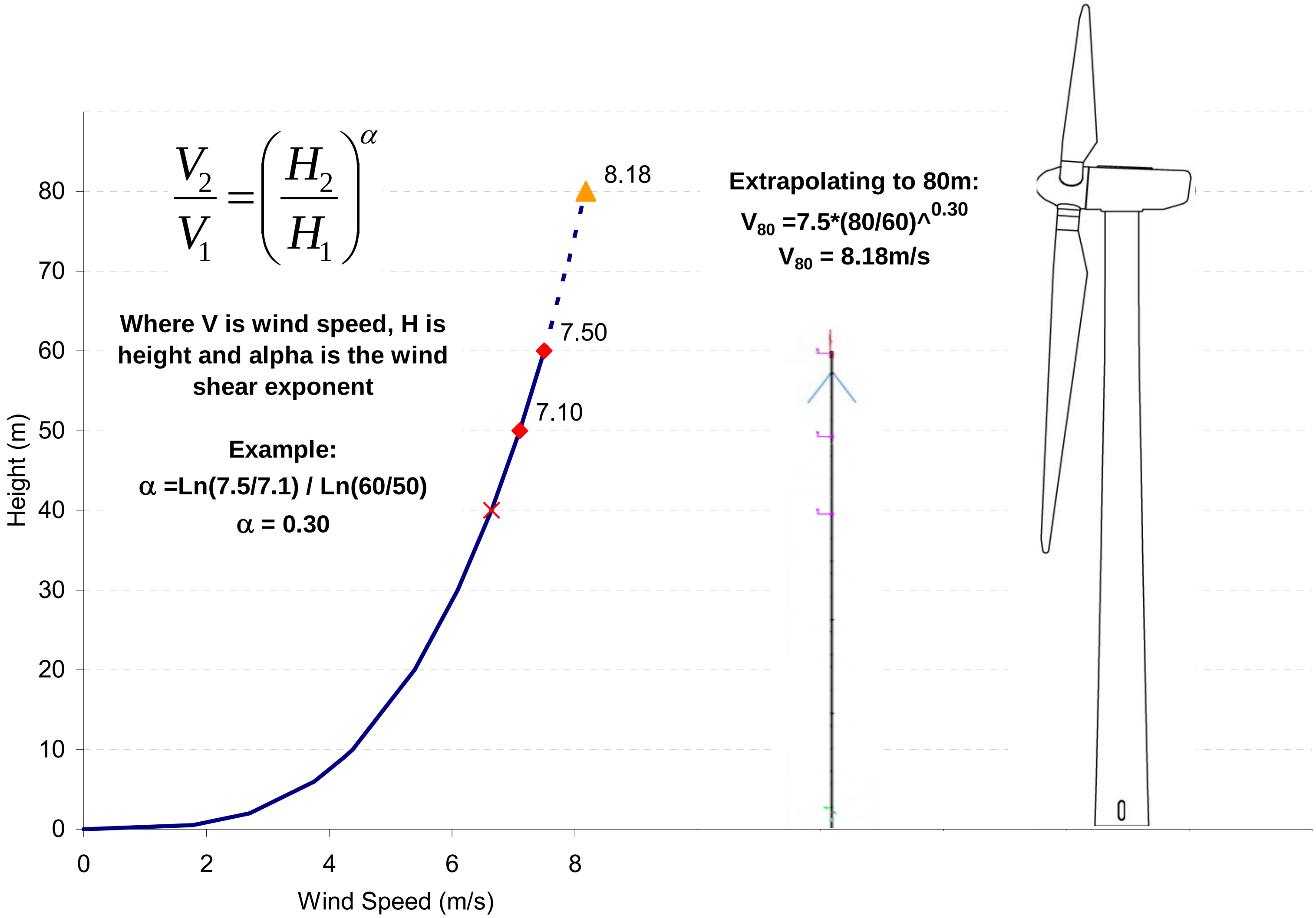
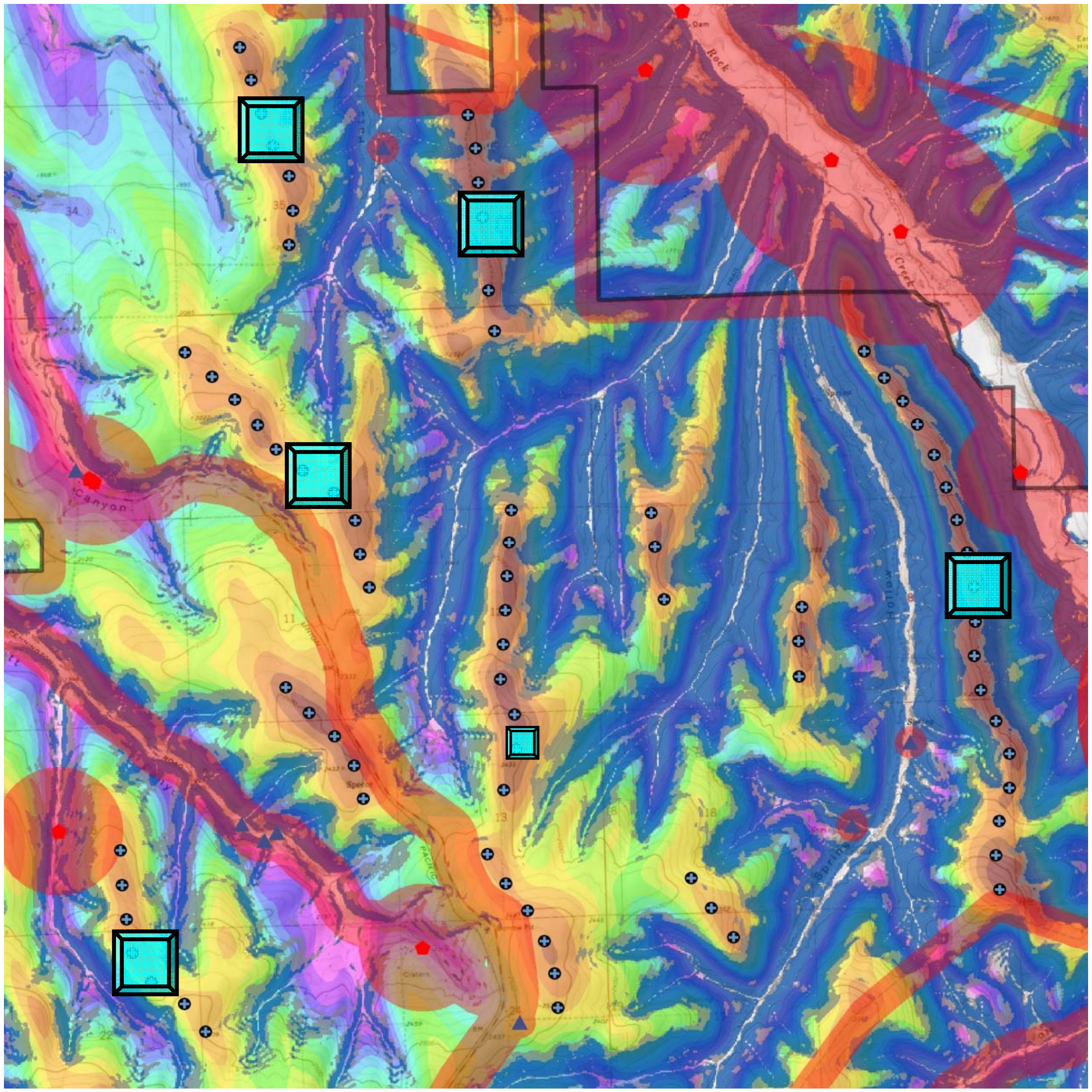
26	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	5%	3%
27	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	7%
28	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%
29	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%
33	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
34	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35	m/s	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Wind Shear Corrections

"Wind shear" describes how the wind increases (or decreases) with height above ground



Layout Design & Energy



Once we have a predicted wind frequency distribution and wind rose, we can run a localized wind flow model

- Greater topographic resolution
- Based on actual wind conditions rather than mesoscale model

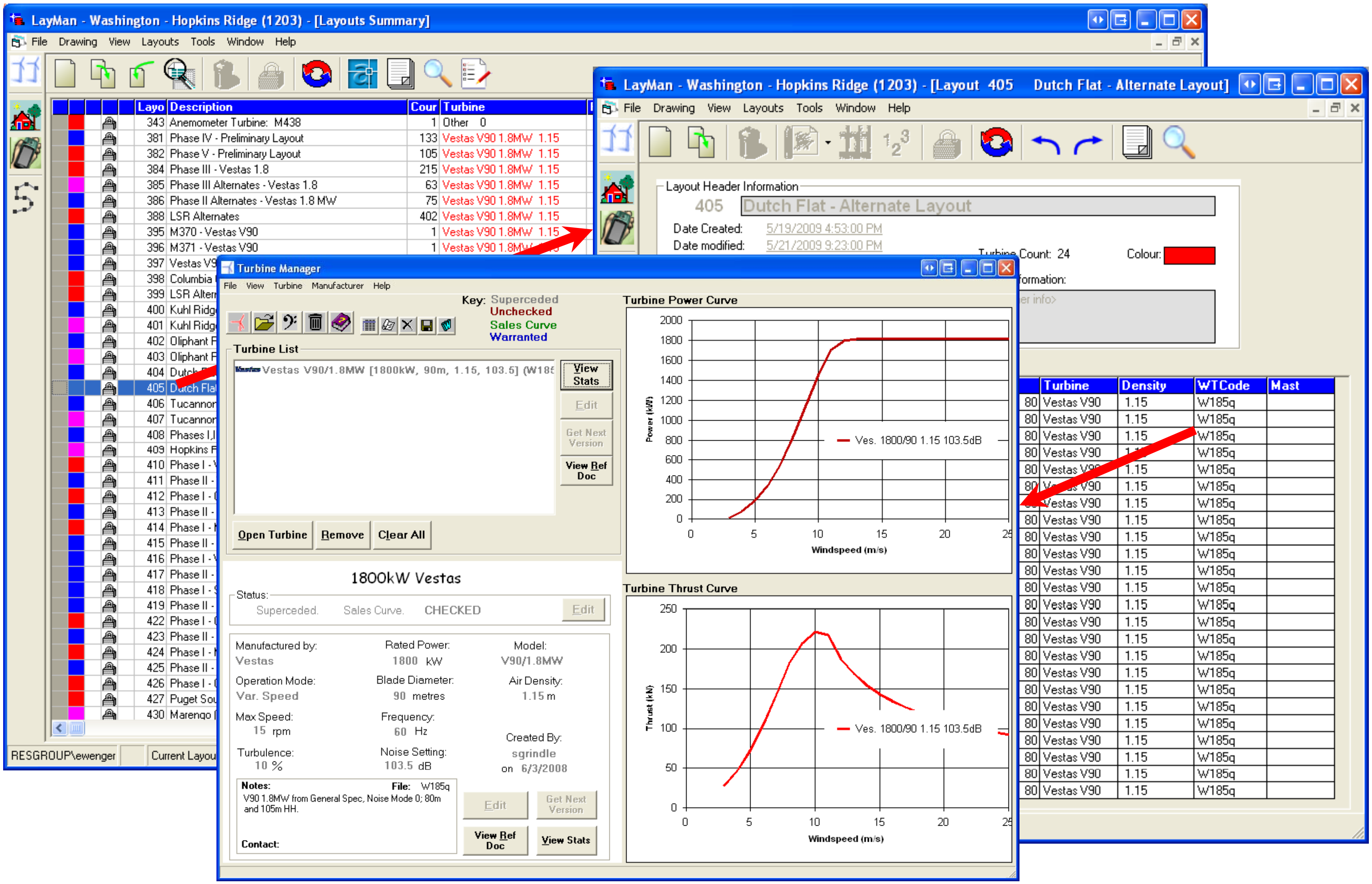
This allows us to optimize the layout for maximum energy production….

….while observing the established site constraints

Additional masts are installed to verify the wind flow model

Energy Yield Calculation & Optimization

Control of Layouts and Turbines



Energy Calculation Summary

Predicted Wind Climate

+

Turbine Layout

+

Wind Shear

+

Wind Flow Model

Orography Model | **Roughness Model**

→

Predicted Wind Climate at Turbine Locations at Hub Height

+

Power / Thrust Curve

+

Wake Model

↓

Gross Energy Yield

+

Loss Adjustment

↓

Net Energy Yield

Air density, turbulence distribution, shear distribution, 1 in 50 year 3 sec gust, inflow angle, temperature distribution, etc

What went wrong?
(That we now account for)

Underperformance: Some of the historic reasons

- 'Stub (top) mounted' anemometers introduced an anemometer speed-up
  - 2 to 5% on wind speed. (Perrin et al 2006, Saba 2002)
- Anticipated curtailment is not included in a consultant wind report
  - A separate study is required – this was not the wind consultant's problem
- ASOS stations had a historic discontinuity when they became automatic
  - Stations began measuring lower wind speeds after the change. This led to over-prediction of historic wind speed. Was not picked up straight away
- Turbine availability has been much lower than assumed for some vendors & sites
- Air density is lower at hub height than at average ground elevation
  - Small (obvious) effect, but was not accounted for historically
- Turbines were placed in silly locations (by inexperienced developers)
  - Simple wind models tend to underestimate in complex terrain. It won't necessarily be as windy as the model says, particularly if mast is at top of hill and turbine is at bottom
- Personal belief: wind resource community 'over-correcting' itself in some areas

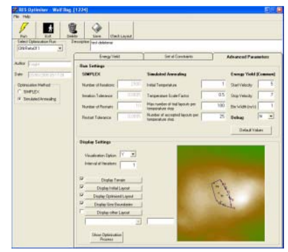
Where the focus shouldn't be

Energy Optimizers

Energy Optimization Software: A bad idea in practice

- RES has developed various optimization software over the years

SIMPLEX ALGORITHM (> 10 years ago) → **GENETIC ALGORITHM** (8 years ago) → **SIMULATED ANNEALING** (7 years ago) → **SOFTWARE DISCONTINUED** (2010)

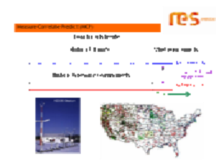


- Why did we discontinue it?
  - Complex site constraints
    - Software could deal with this, but very time consuming entering all into software
    - Inevitably some 'real world' constraint missed (less value in the optimization)
      - Contractual: E.g. Landowner 'A' has stipulation of minimum MW
      - ALTA survey (late in dev. cycle) reveals pipelines, easements, microwaves, etc
      - Many times governed by noise constraints: Complex analysis in itself
  - Wake models and wind flow models don't have required level of accuracy
    - See following slides: Can't do an optimization if the inputs (models) aren't correct
  - Many layouts end up 'designing themselves' and when they don't ….
  - …. an experienced practitioner can get extremely close to the optimized solution

MCP
(Measure Correlate Predict)

M.C.P. Methods

- MCP tends to produce estimates that are within expected uncertainty if:
  - Have at least one year of site data
  - Seasonality is accounted for
  - The reference station has a consistent record (Most important)



GENERALLY: LITTLE LEFT TO LEARN WITH MCP METHODS

- Having stated the above, improvement required in the following:
  - Sub-year predictions (first mast installed only)
    - Measurements at >=60m are correlated with a 10m reference station
      - Problem: Relationship varies seasonally (& diurnally, but not relevant here)
      - Possible solution: Correlate with 60m Mesoscale time series (but problems exist)

NEED FOR BETTER SUB-YEAR PREDICTIONS (FIRST MAST)

What challenges remain?

Wakes

Wake (Array) Effects

- Offshore wind studies suggest that wake losses are greater than anticipated when there are multiple rows of turbines
- Does the same apply onshore?

NEED TO BETTER UNDERSTAND ONSHORE WAKES

Courtesy Energy Northwest

Remote Sensing
New benefits, but new problems too

Remote Sensing: Lidar & Sodar

- SODAR = SOnic Detection And Ranging. LIDAR = LIght Detection And Ranging
- Enable wind measurements at heights greater than standard towers

ZephIR LIDAR

Windcube LIDAR

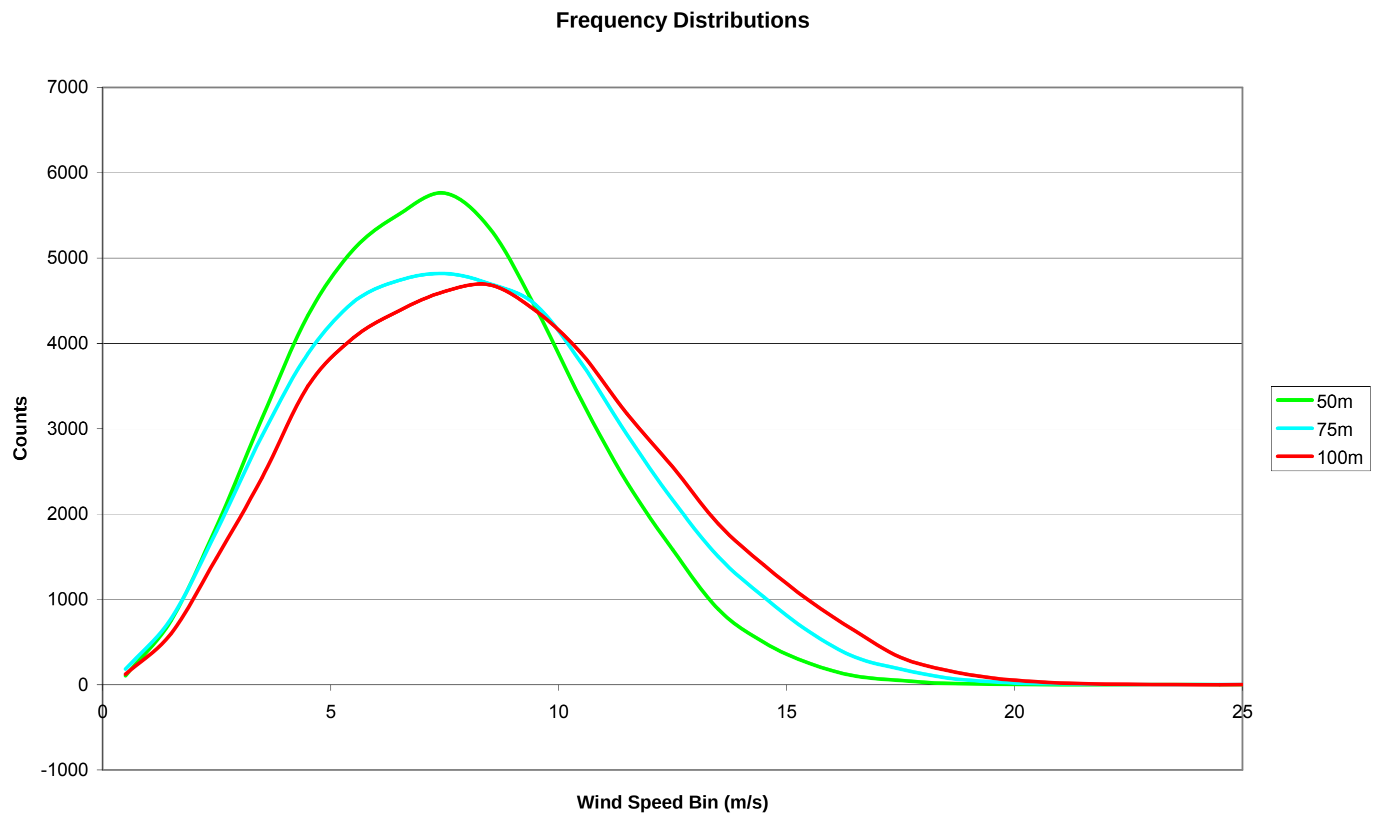
AQS SODAR

Triton SODAR

Lockheed LIDAR

- Currently used primarily to compliment, not replace traditional towers
  - This is changing. One tower + several shorter campaigns
- RES has experience with all of the above and owns Windcubes and Tritons
  - Cost of SODAR comparable to tower. LIDAR significantly more (~4 times)

Distribution Kurtosis and Skewness



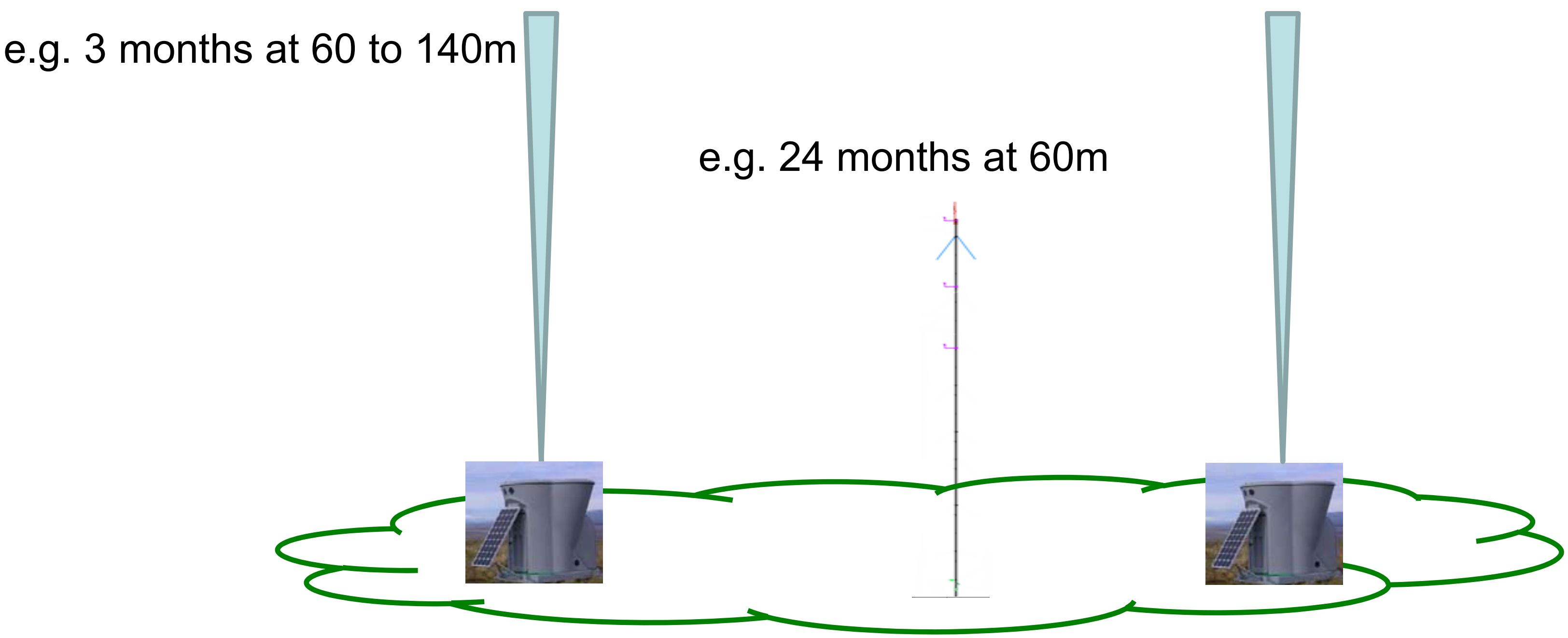
- Kurtosis and Skewness both decrease with height above ground
- How predictable is this?

SODAR & LIDAR PROVIDE OPPORTUNITY TO LEARN

Prediction of distributions with very short records

- In future likely to have multiple, short (3 month) campaigns (lower cost vs. mast)
- These distributions will be over a range of heights (most different height to mast)
- Creates challenges in the predictions at Remote Sensing locations:

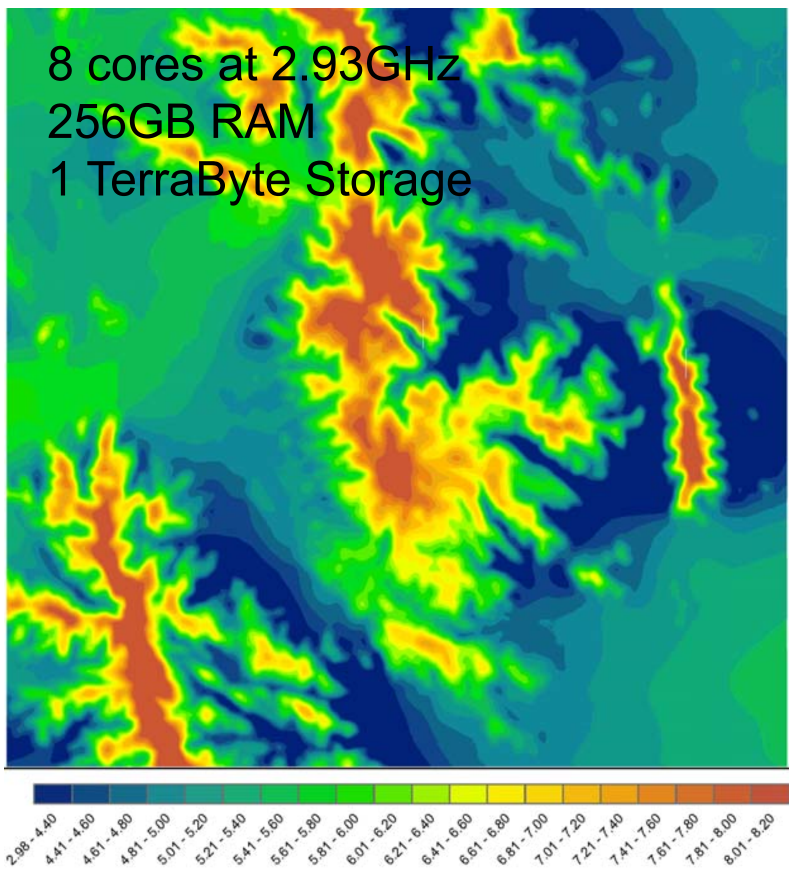
1) ACCOUNT FOR SEASONAL VARIATIONS DUE TO SPATIAL VARIATION IN PREDICTION
2) ACCOUNT FOR DISTRIBUTION SHAPE CHANGING WITH HEIGHT (ALSO WITH SEASON)
3) BE AWARE THAT LOTS OF BRIEF HUB HEIGHT(+) CAMPAIGNS COULD BE A RETROGRADE STEP COMPARED WITH SAME NUMBER OF SHORTER TOWERS WITH A LONGER RECORD

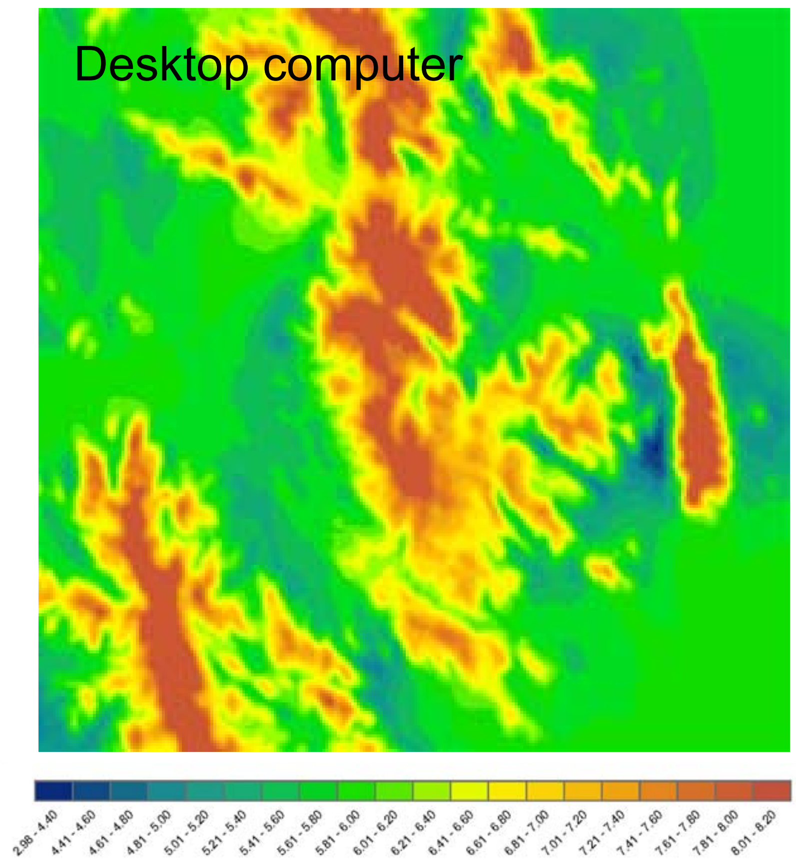


CFD: Some shortcomings

Advanced Wind Speed Modeling: CFD, LES, RANS, etc

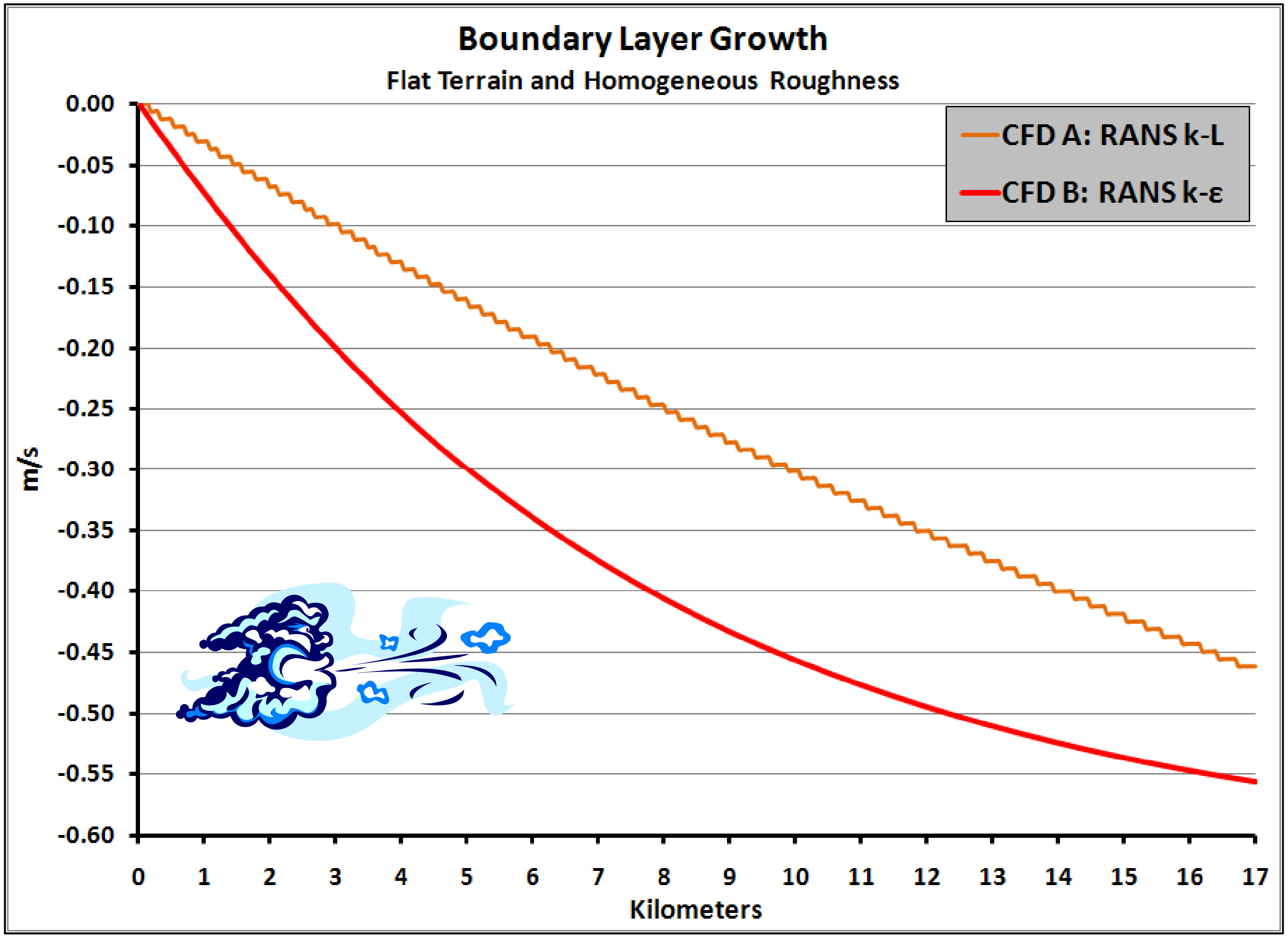
- Traditionally industry has used 'WAsP' or 'MS3DJH'
- With increases in computing power industry has begun to look at more advanced models
- CFD Particularly useful for turbine siting (turbulence & shear)





CFD Boundary Layer Growth (60m a.g.l.)

Applied 8m/s wind speed at normalization point at 0.0km

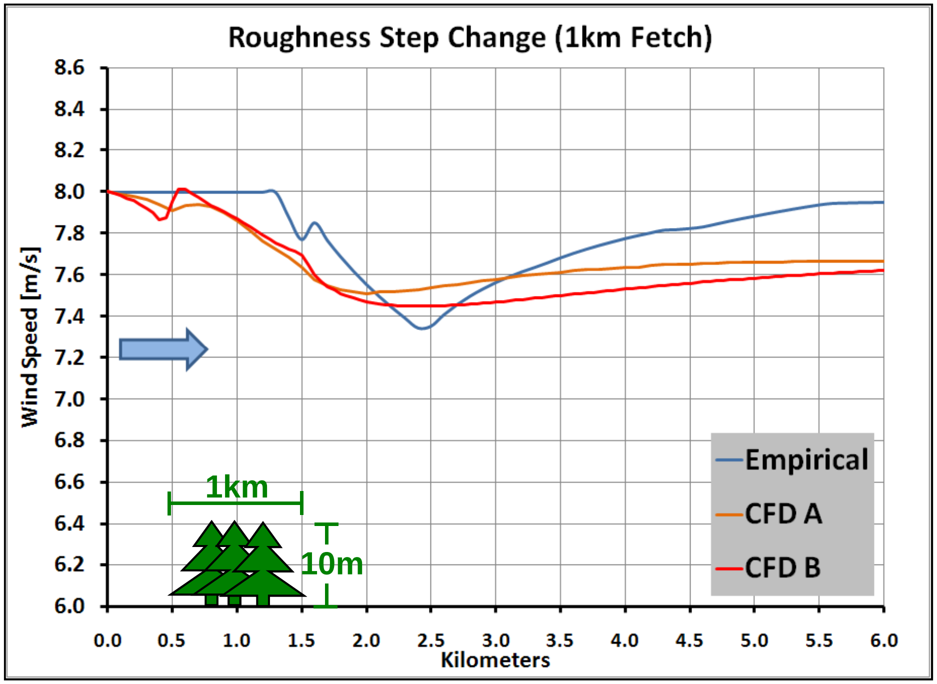


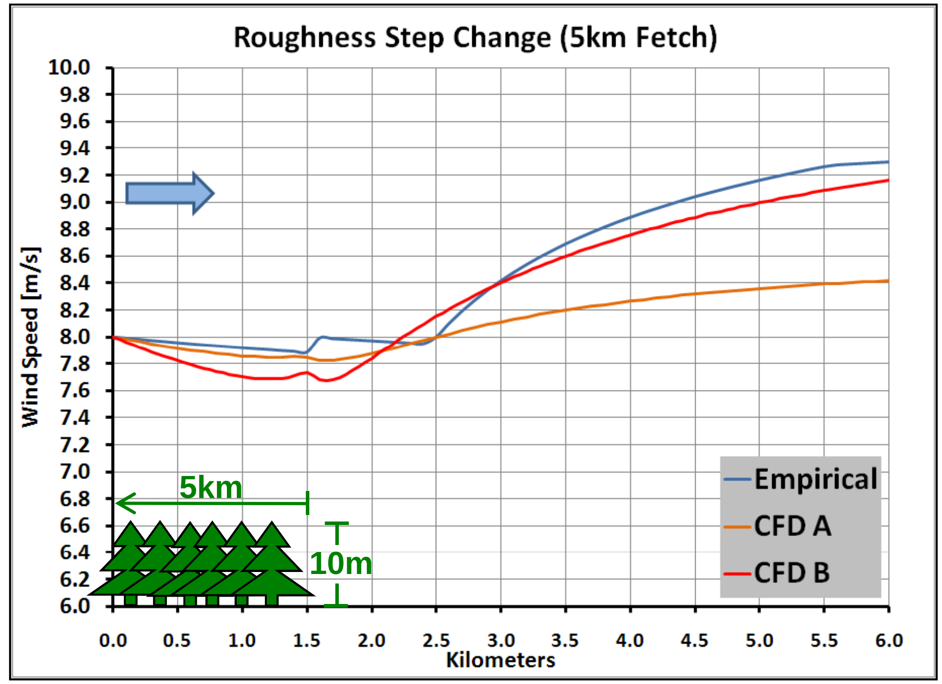
- **Surface roughness extracts momentum from mean flow**
- **Conservation of Mass demands BL growth**
- **~0.50m/s reduction in horizontal wind speed over 17km**
- **Too much momentum extracted**

NEED TO CORRECT FOR BOUNDARY LAYER GROWTH IN CFD

With thanks to Matt Smith

Idealized Roughness Step Change Cases (60m a.g.l.)





- Normalized to 8m/s at 0.0km (to minimize BL growth effect of previous slide)
- BL growth ~0.2m/s over 6km. Does not account for total disparity.
- Significant differences between Empirical (European Wind Atlas equations) and CFD results in 1km fetch case
- CFD B in better agreement with Empirical model for 5km fetch case, but not CFD A

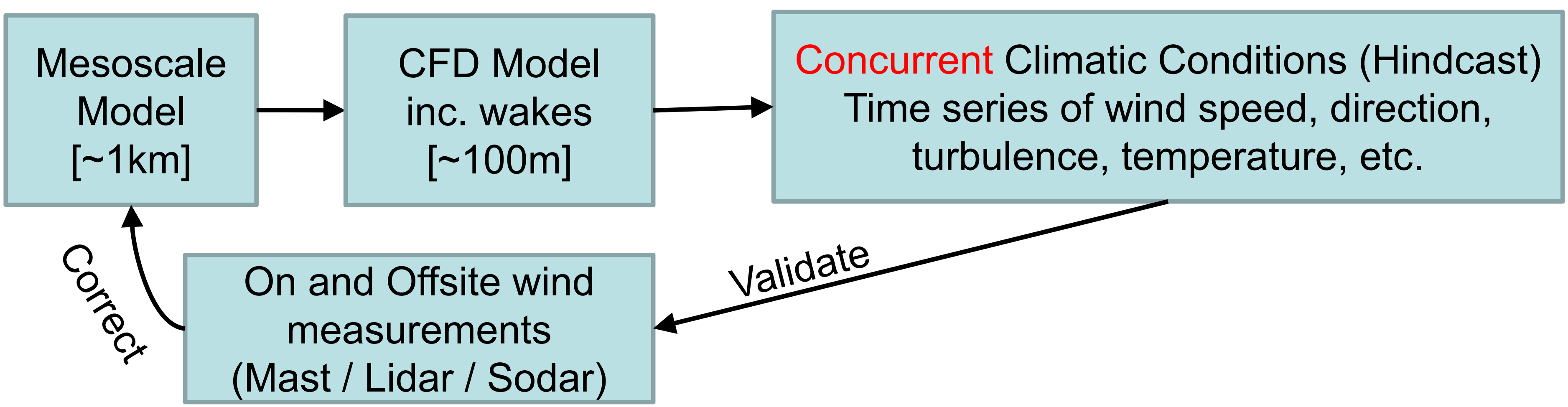
NEED TO ALIGN (AGREE ON) CANOPY MODELS

With thanks to Matt Smith

The ultimate model is Time series based

Time Series Energy Prediction

- Today every 'energy' model takes a distribution approach
- Need to take a Time Series approach to modeling
- Hindcast for existing wind farms to understand the conditions under which models perform poorly and enable refinement of models



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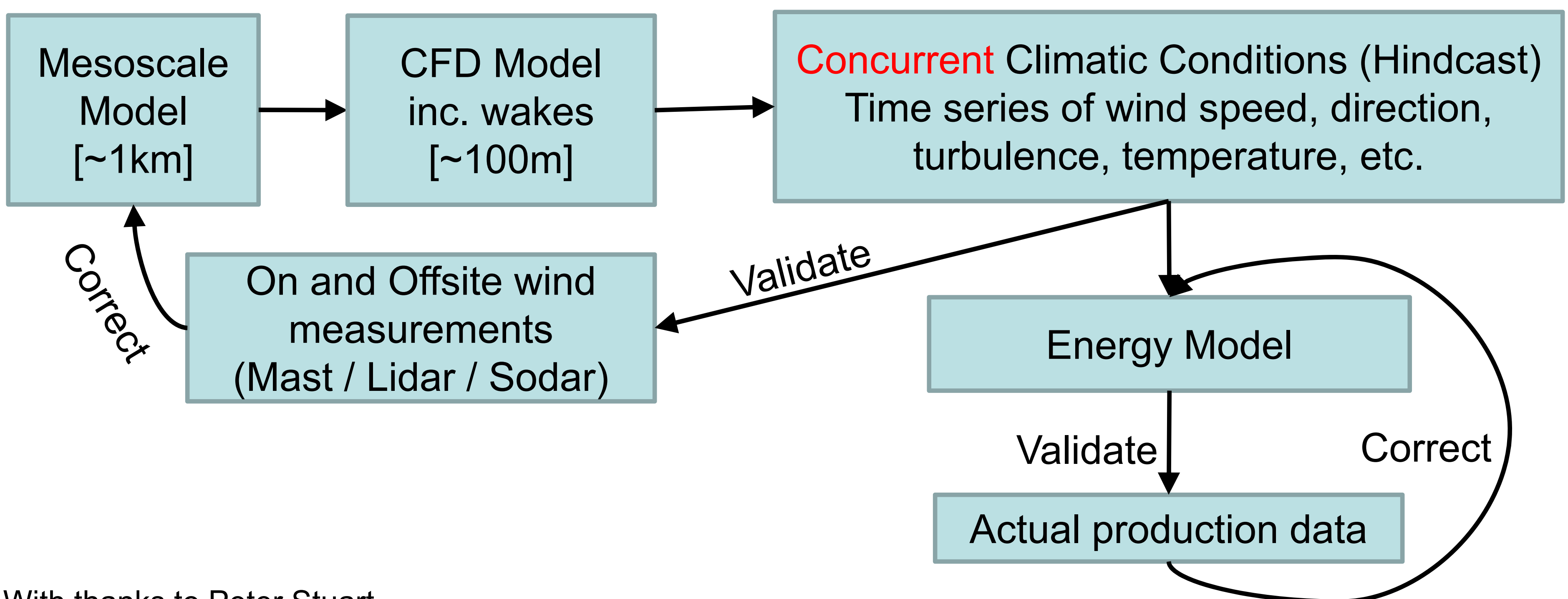
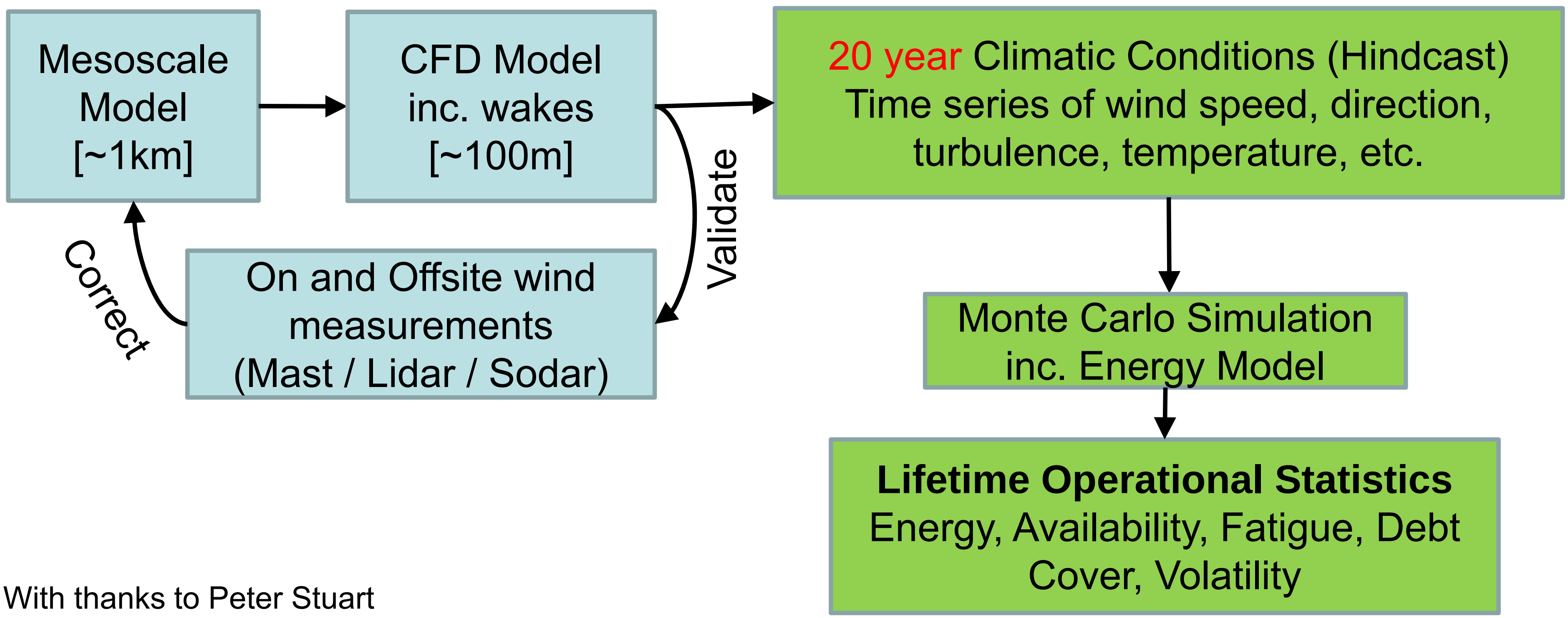


With thanks to Peter Stuart

Time Series Energy Prediction

- Today every 'energy' model takes a distribution approach
- Need to take a Time Series approach to modeling
- Hindcast for existing wind farms to understand the conditions under which models perform poorly and enable refinement of models
- 20 year forecast (actually still a hindcast) of conditions at proposed wind farm site



With thanks to Peter Stuart

THANK YOU

ANDREW OLIVER, PhD. VP TECHNOLOGIES
With thanks to Matt Smith and Peter Stuart

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