Alaska Wind Program Highlights

Canada-US Clean Energy Dialogue

Oct. 1, 2015

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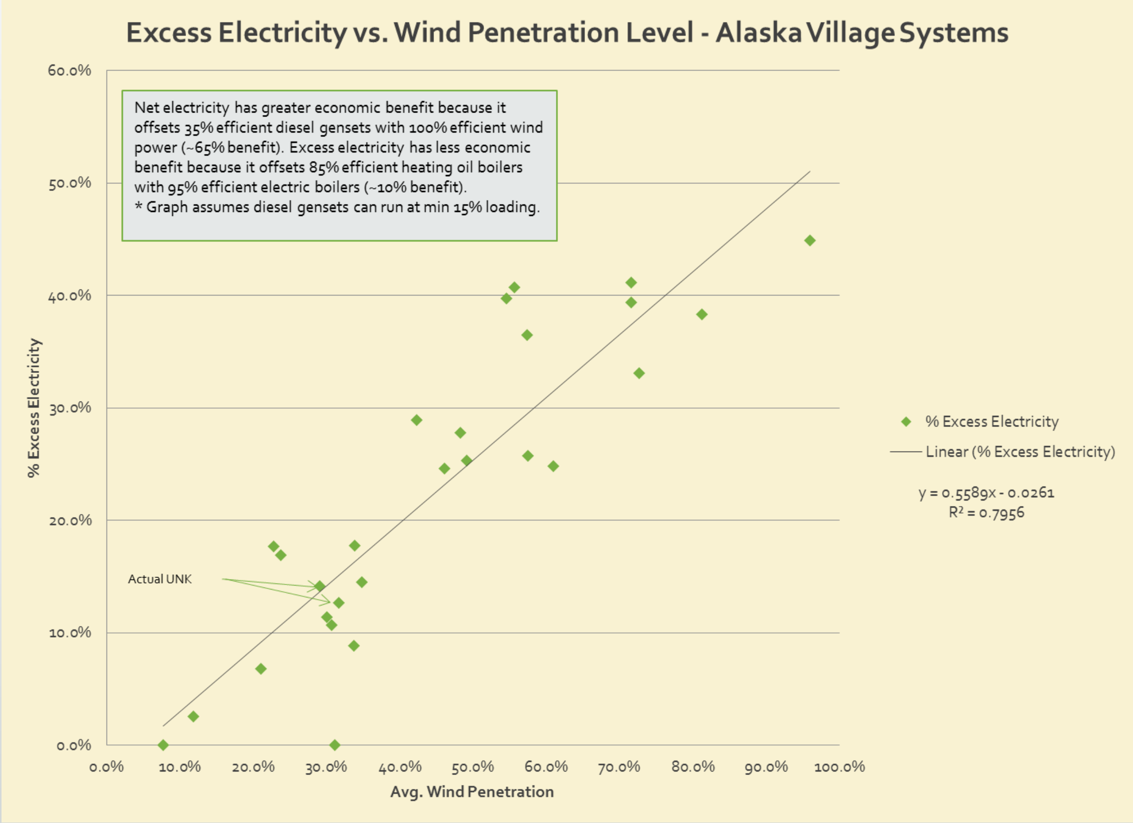
Secondary Heat Loads – Critical to Project Success

- Failing to fully consider, model and design secondary loads in hybrid wind systems ensures a 15-20 point gap from expected annual energy production.



- New wind penetration classes:

Penetration Class	Operating Characteristics	Instantaneous Penetration	Average Penetration
Very Low	Diesel runs full time Wind power reduces net load on diesel All wind energy goes to primary load No supervisory control system	<60%	<8%
Low	Diesel runs full time At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading or wind generation is curtailed. Requires relatively simple control system	60% - 120%	8%-20%
Medium	Diesel runs full-time At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading. More complex secondary load control system is needed to ensure that heat loads do not become saturated during extended windy periods.	120%-300%	20%-50%
High	Diesels may be shut down during high wind availability Auxiliary components are required to regulate voltage and frequency Requires sophisticated control system	300%-900%	50%-150%

- Impacts of curtailment:

Installed Wind Capacity (kW)	Total Wind Energy Produced (kWh)	Excess Electricity	Net Elec kWh	Net Thermal kWh	Control Method	Fuel Savings @ $4.5.gal	Potential Benefit
300 (Hi Pen)	888,180	292,307	595,873	292,307	Elec Boiler or ETS units	$240,274.89	100.00%
300 (Hi Pen)	888,180	292,307	595,873	0	Turbine max setpoint	$206,263.73	85.84%
300 (Hi Pen)	888,180	292,307	595,873	0	Non value dump load	$206,263.73	85.84%
300 (Hi Pen)	489,227	0	489,227	0	Curtailment	$169,347.31	70.48%
300 (Hi Pen)	888,180	262,731	625,449	0	15-min Batt/FW storage	$216,501.58	90.11%
200 (Med Pen)	592,117	107,310	484,807	107,310	Elec Boiler or ETS units	$180,303.78	100.00%
200 (Med Pen)	592,117	107,310	484,807	0	Turbine max setpoint	$167,817.81	93.08%
200 (Med Pen)	592,117	107,310	484,807	0	Non value dump load	$167,817.81	93.08%
200 (Med Pen)	396,716	0	396,716	0	Curtailment	$137,324.77	76.16%
200 (Med Pen)	592,117	90,975	501,142	0	15-min Batt/FW storage	$173,472.23	96.21%

*Max wind = village demand – min diesel loading + diversion load

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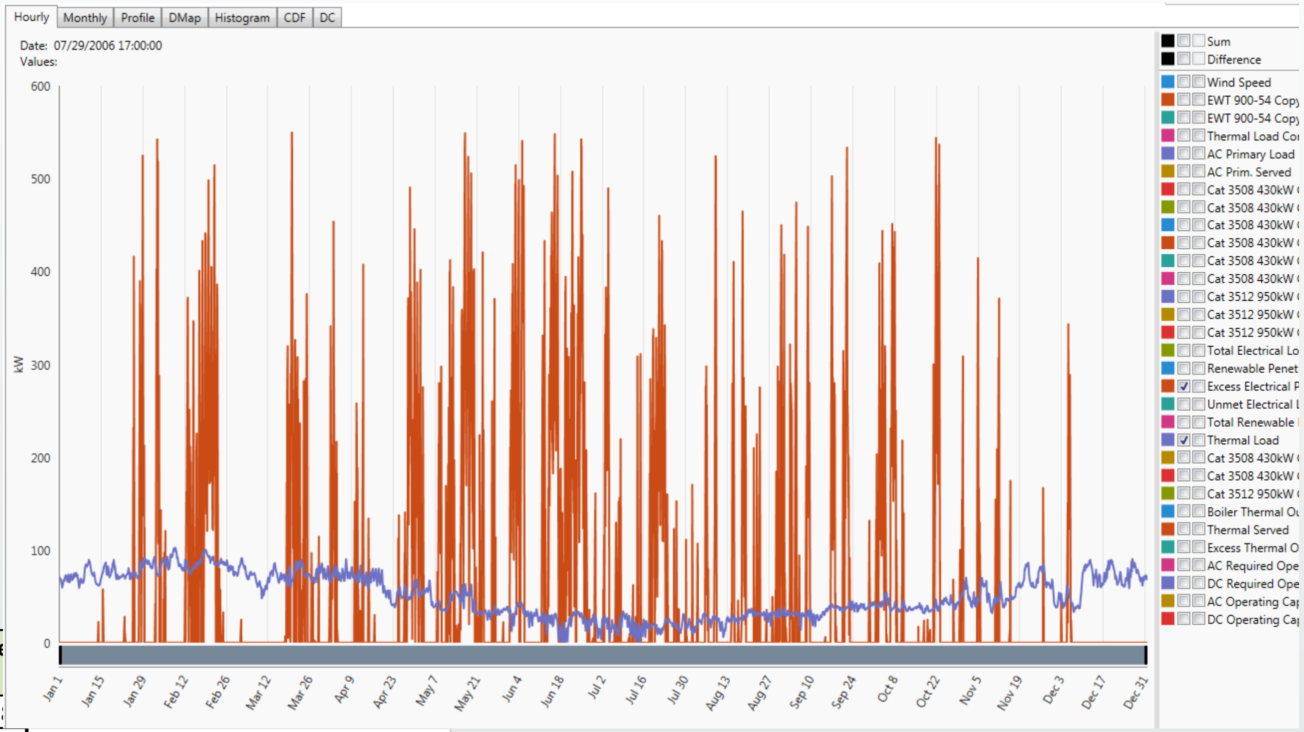
Modeling of Thermal Systems

- Simply comparing annual heat demand with annual excess energy leads to significant error in system design.
- While the health clinic in this village consumes almost twice as much energy over the course of a year, the heat load is much less variable than and doesn't coincide with the excess wind. Additional heat loads must be added to the system design to avoid significant curtailment of wind turbines.



^^ Poorly matched excess vs. heat load

Community building/load	Connected to HR Loop?	Current annual heating oil consumption*	Thermal mass - Equiv. gals. of storage	MMBTU Equiv	kWh Equiv	Average kW		
Public Works-HEMF	Y	19,216		2,652	743,163	84.		
Sewer Plant	Y	13,695		1,890	529,639	60.46	Estimate 20% of total load is unmet	
School	N	116,800		16,118	4,517,240	515.67	1840000	
PSO	N	6,348		876	245,502	28.03	100000	<BTU/Hr
Health clinic	N	14,219		1,962	549,925	62.78	224000	<BTU/Hr
Water plant	N	11,426		1,577	441,904	50.45	180000	<BTU/Hr
Fire Station	N	16,758		2,313	648,126	73.99	264000	<BTU/Hr
Power plant	Y	1,625		224	62,847	7.17	Estimate 20% of total load is unmet	
				0	0	0.00		
				0	0	0.00		
Totals		200,087		27,612	7,738,346	883.3	331,107	**<<Excess kWh from HOMER**

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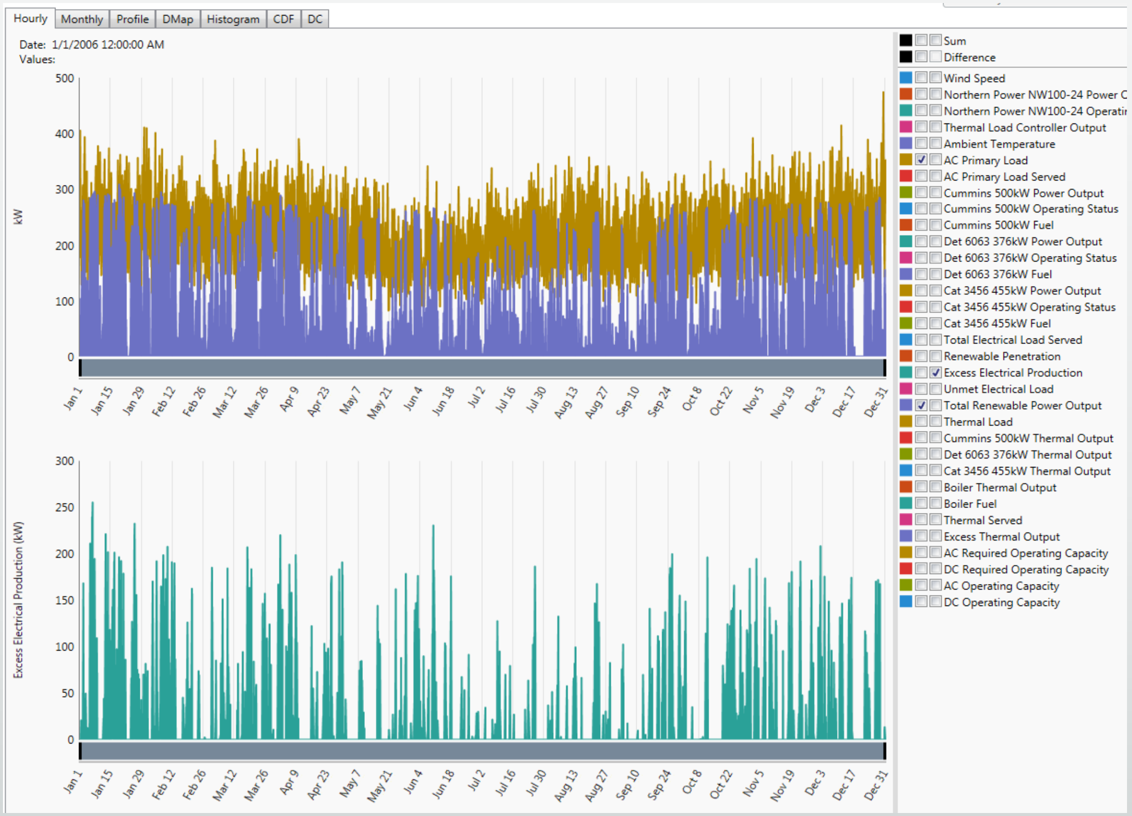
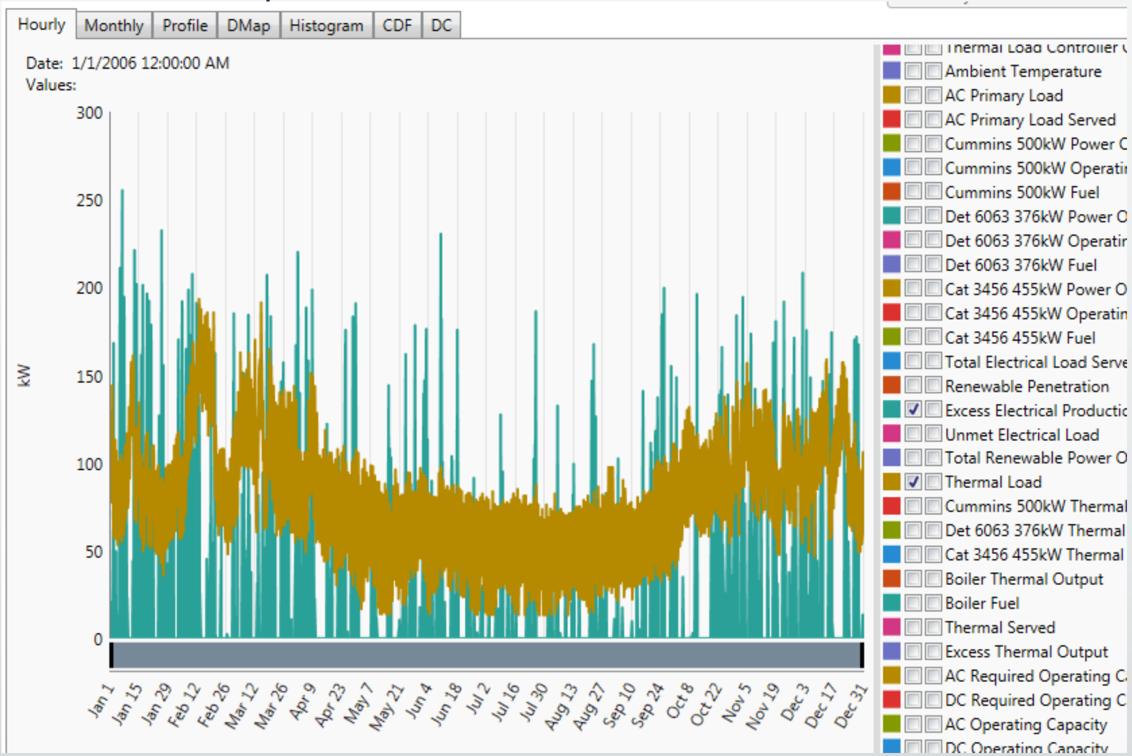
Detailed modeling of electric load, heat load and wind energy

- Because wind energy is variable, there are times throughout the year when there is more energy available (turquoise = excess) from the wind turbines (purple) than the current net* village electrical load (gold).



- Thermal loads (gold) for buildings and facilities in a community can make use of this excess wind energy (turquoise) to supplement other sources (power plant heat recovery or oil-fired boiler). Reasonably well-matched excess and load:



*Max wind = village demand – min diesel loading + diversion load

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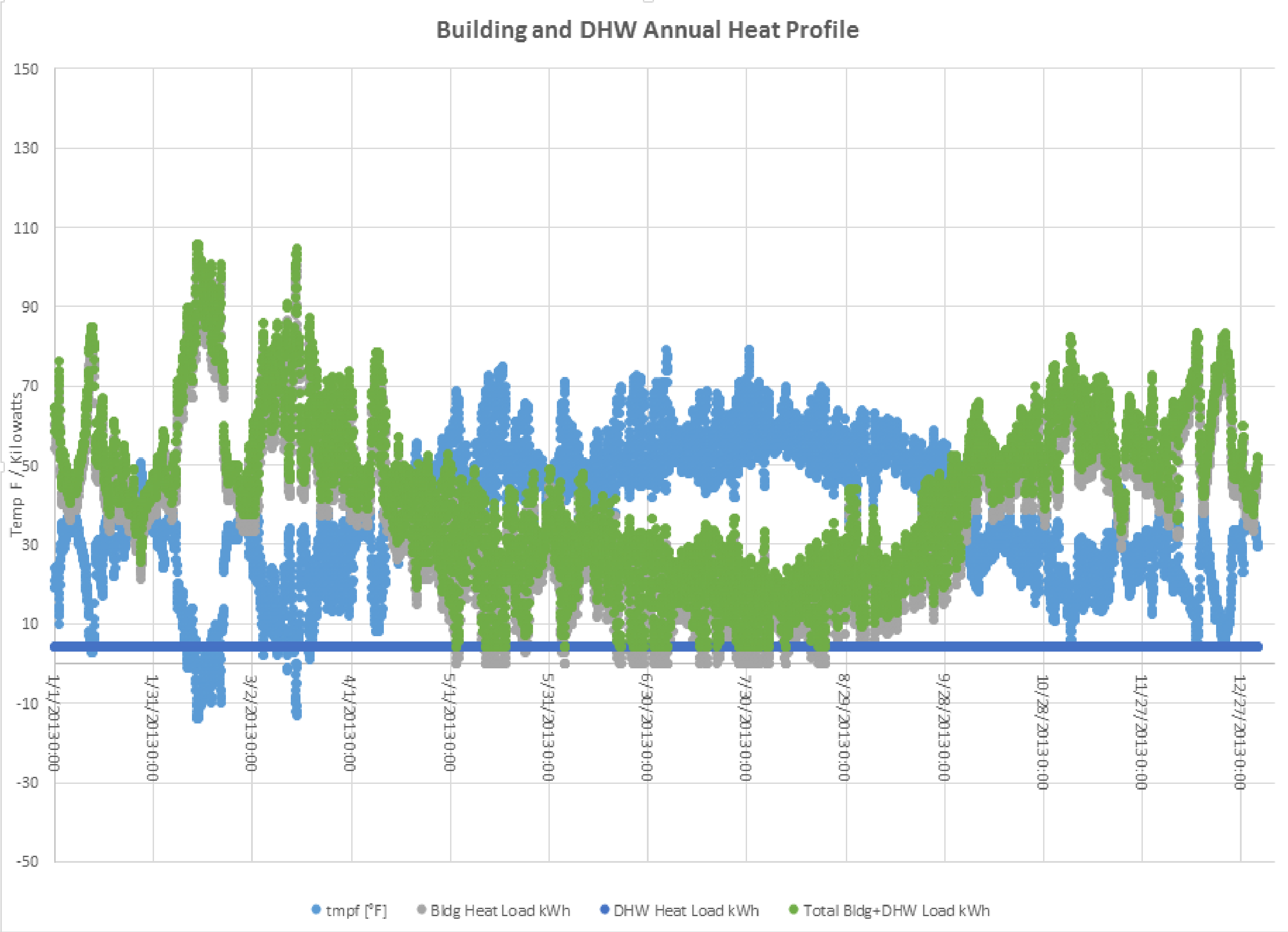
Modeling building thermal loads is easy



Pull records on annual fuel deliveries for large community buildings. AKWarm estimates work too.

Total annual building heat loss = total heating fuel consumed per year minus boiler inefficiency

AEA can pull ASOS/AWOS data to build an hourly temperature profile for the community and calculate hourly delta T and equivalent hourly heating oil gallons or kilowatt-hours.

Most village buildings do not harness significant passive solar gain, so the model can remain simple.

The model doesn't need to be exact – just good enough to compare relative loads vs. excess power.

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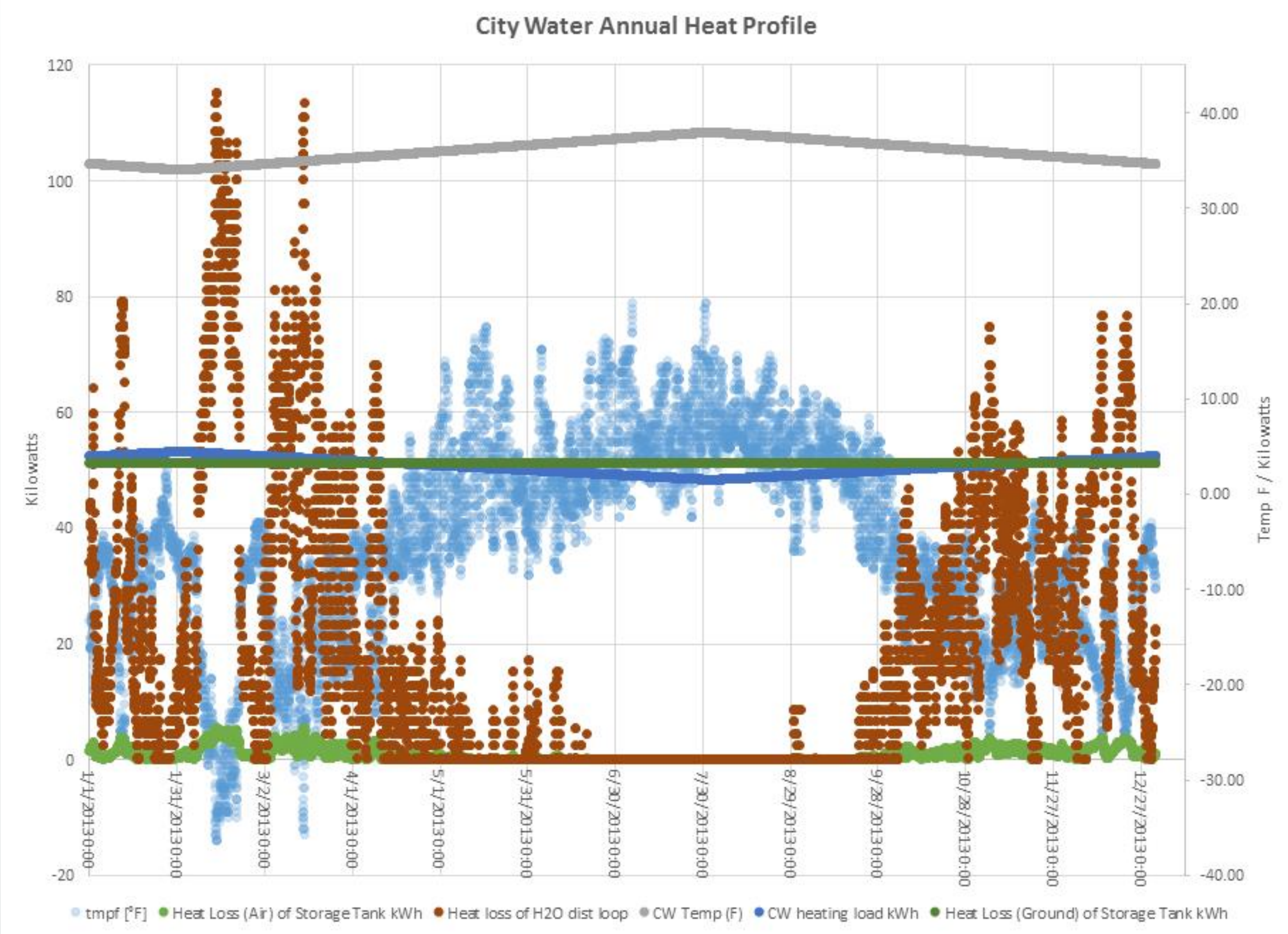
Water Systems: More Complex to Model



There are more factors to model, but we can still answer the question: "Will the heat loads connected to our system even have a theoretical chance of taking all the power we can give them?"

We still need to know the annual fuel consumption, but should also consider as many of the following additional factors: coldest/warmest water temperature at source, storage tank size and insulation, length diameter and insulation of circ. loop pipe, washeteria dryers and DHW load.

Systems with storage tanks offer a buffer to take more heat now for possible benefit later.

Do buildings and water systems already connect to a waste heat loop? Does proximity to the power plant allow this?

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Limitations to the method and model

- The model is far from perfect, but attempts to simulate a typical year for thermal load and excess wind energy. Think ballpark, not section/row/seat.
- Understand that the diurnal thermal profile (warmest during the day and coolest at night) is greatly diminished near and above the Arctic Circle (Lambert's Law) both during the winter and the summer. Atmospheric blocking of solar energy is also magnified at higher latitudes for longer periods of the day (Beer's Law).
- An efficient passive-solar building design will deviate more from the model – but only when the sun angle is above the atmosphere-blocking level (Beer's Law) and facing the primary windows. This may impact new schools or hospitals, but we don't presently have any passive-solar water treatment or sewer plants built in the Arctic. Passive-solar buildings must also have unobstructed southern exposure to maximize their benefit.
- Very drafty buildings can consider a wind-chill-based Delta T calculation rather than straight temperature.
- For structures combining building heat with water heat, an estimate will need to be made on the portion of fuel attributed to each function. Diurnal profiles for water heating will be driven by both Delta T as well as time-of-day usage.
- The farther away a building is from the reference AWOS station, the less accurate the model. In small villages, this shouldn't be a problem. In large metropolitan areas like Anchorage or Fairbanks where inversion layers can affect parts of the city, but not others, temperatures could be off by as much as 20 degrees F at certain times.
- Consider opportunities to implement heat pumps or dispatchable electric loads.

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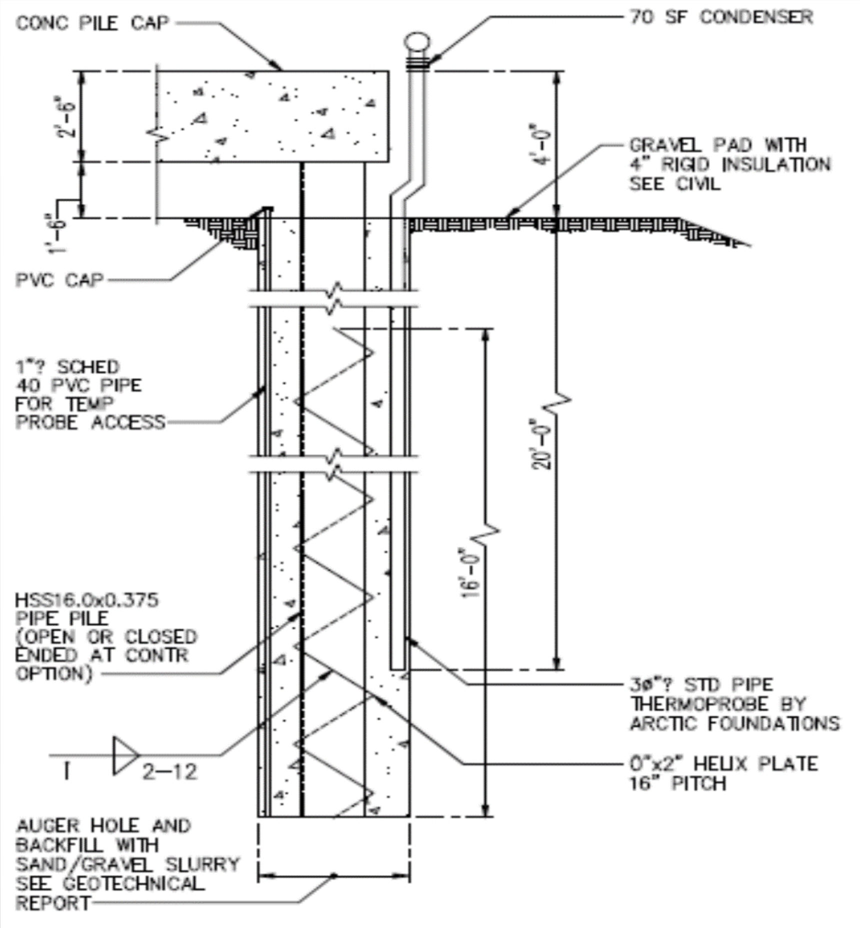
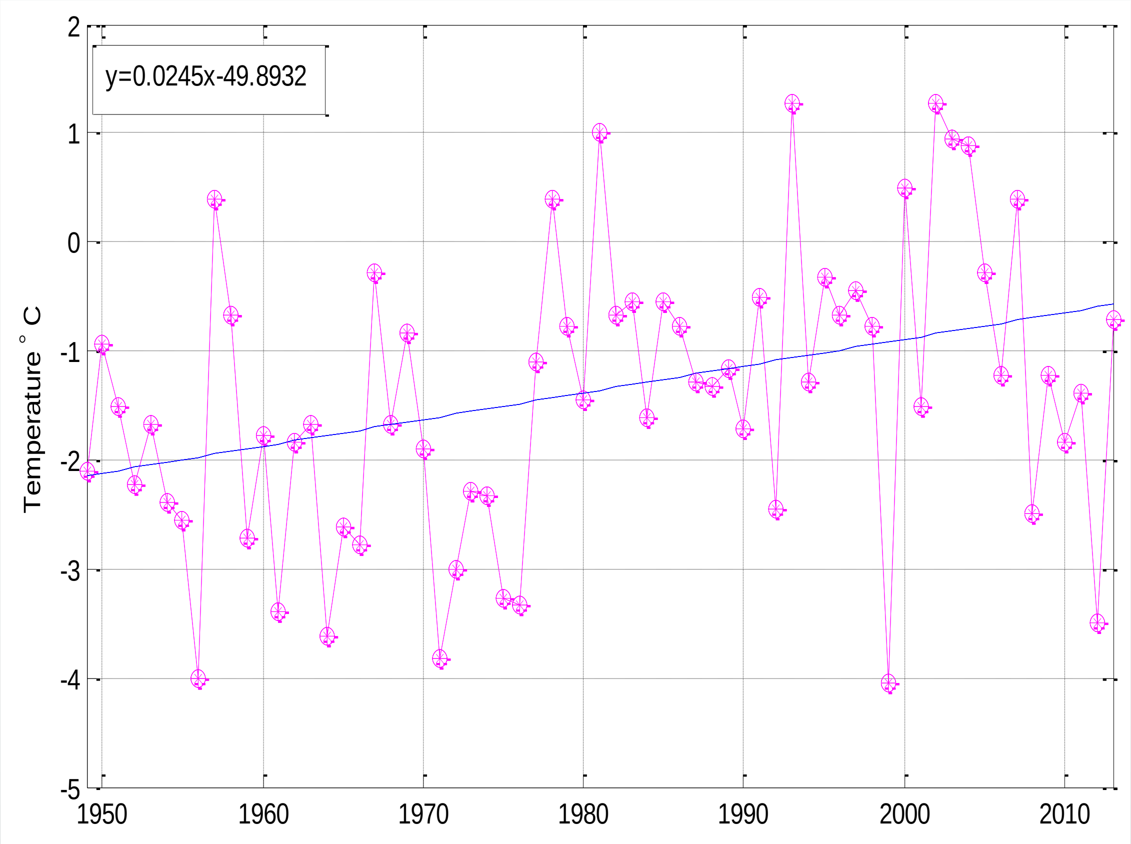
Typical Permafrost Foundation – Thermopile with Concrete Cap

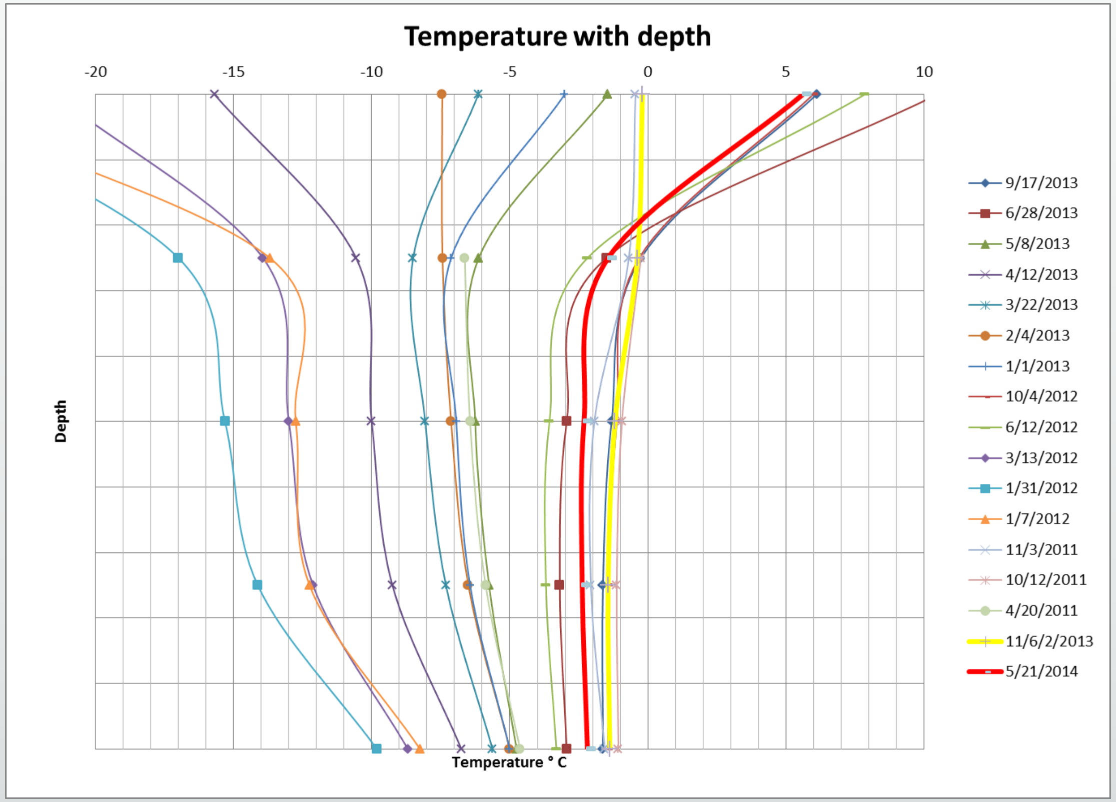


Warm Permafrost is a Concern

- Bethel Avg Temperature

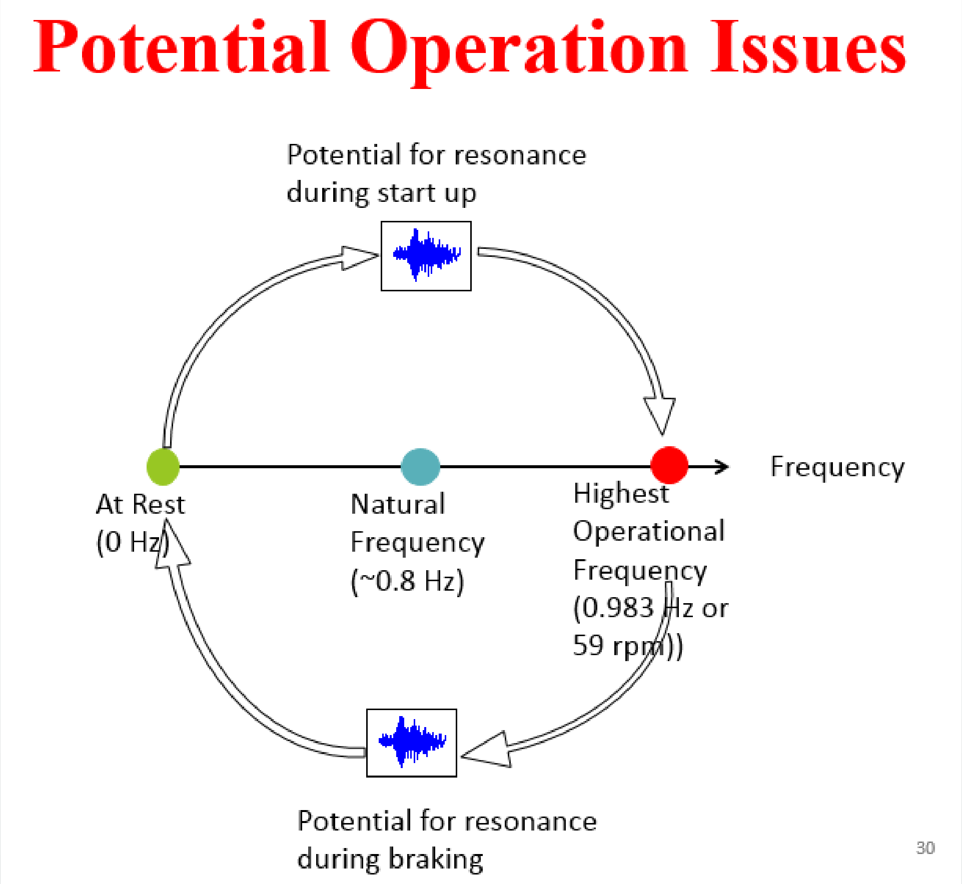


- 2013-14 warmest on record



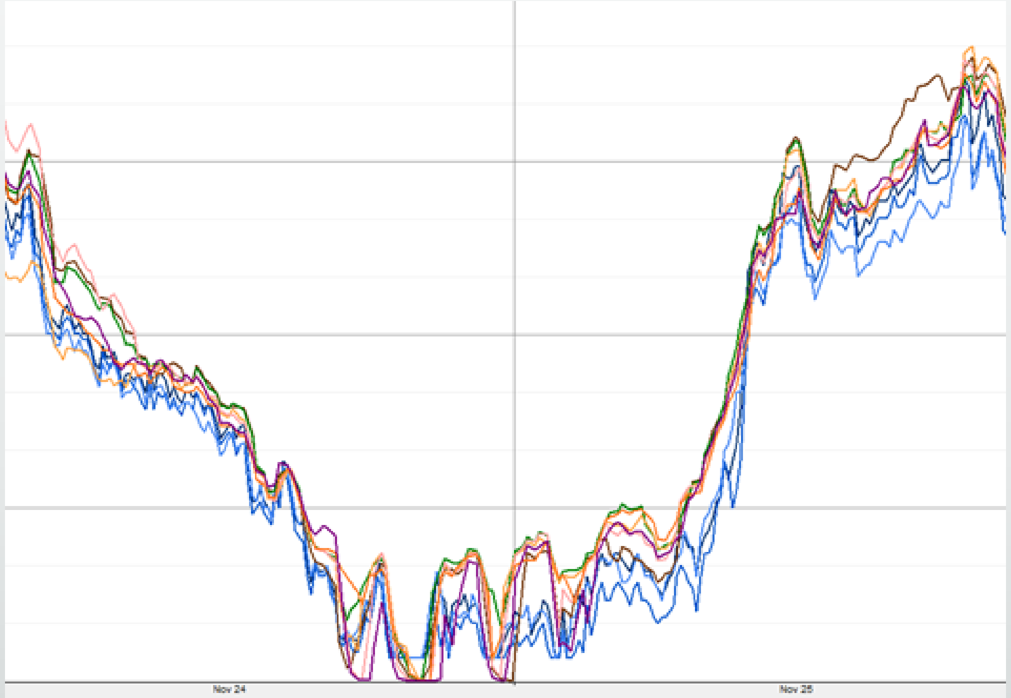
Vibration Monitoring

- Sensor configuration

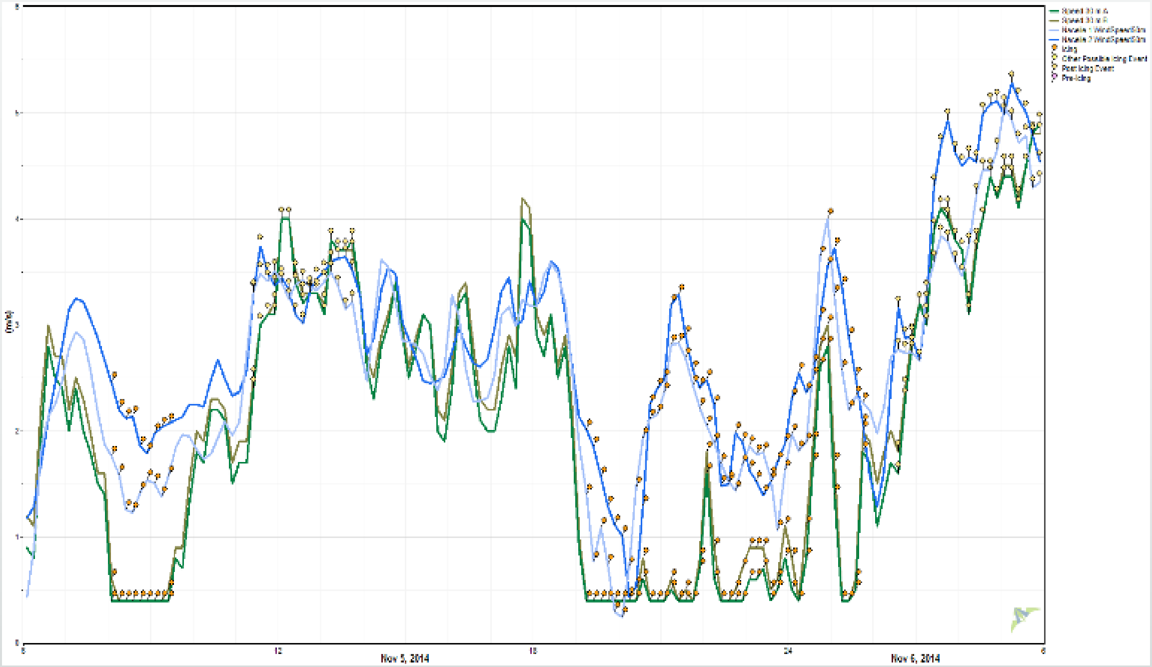


Icing Study

- Snapshot of Unalakleet met tower (blue hues) and wind turbine anemometers (all other colors) showing variation but with major wind speed shifts in sync.

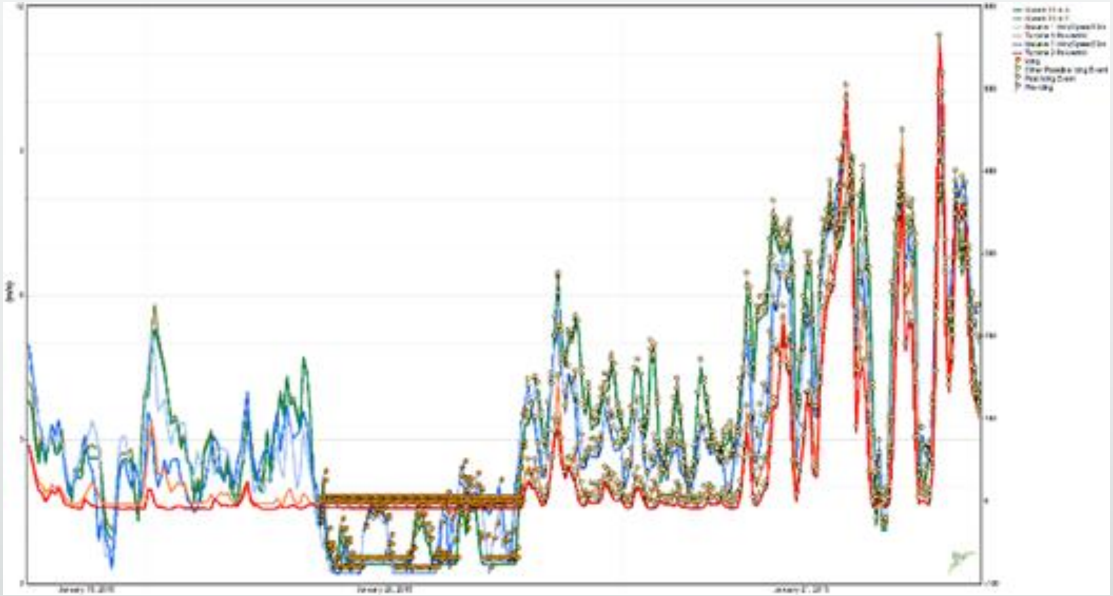


- Nov. 5 & 6 very weak and weak icing signals in Nome. Met tower anemometers (green and olive) follow nacelle 1 and 2 (light and dark blue) heated anemometers. Heated anemometers still indicate light winds when cup anemometers indicate no wind, but not in the range where the wind turbine will produce power.

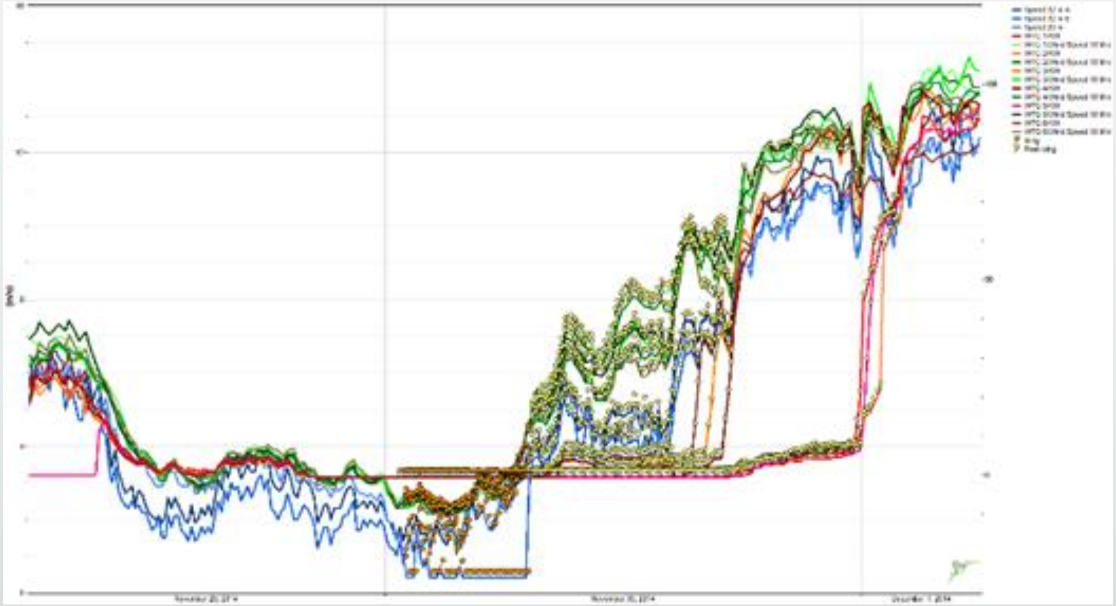


Icing Impact on Wind Turbine Output

- Weak icing signal in Nome. Met tower anemometers (green and olive) follow nacelle 1 and 2 (light and dark blue) heated anemometers. Wind turbine output (orange and red) has stopped during the icing period and resumes when wind speeds increase.



- Unalakleet post-icing event showing met tower anemometers (blue) flat lined during the icing period and then lagging the nacelle anemometers (green) for 10 hours. Wind turbine production (red) is zero during the icing period and post-icing for 8-16 hours.



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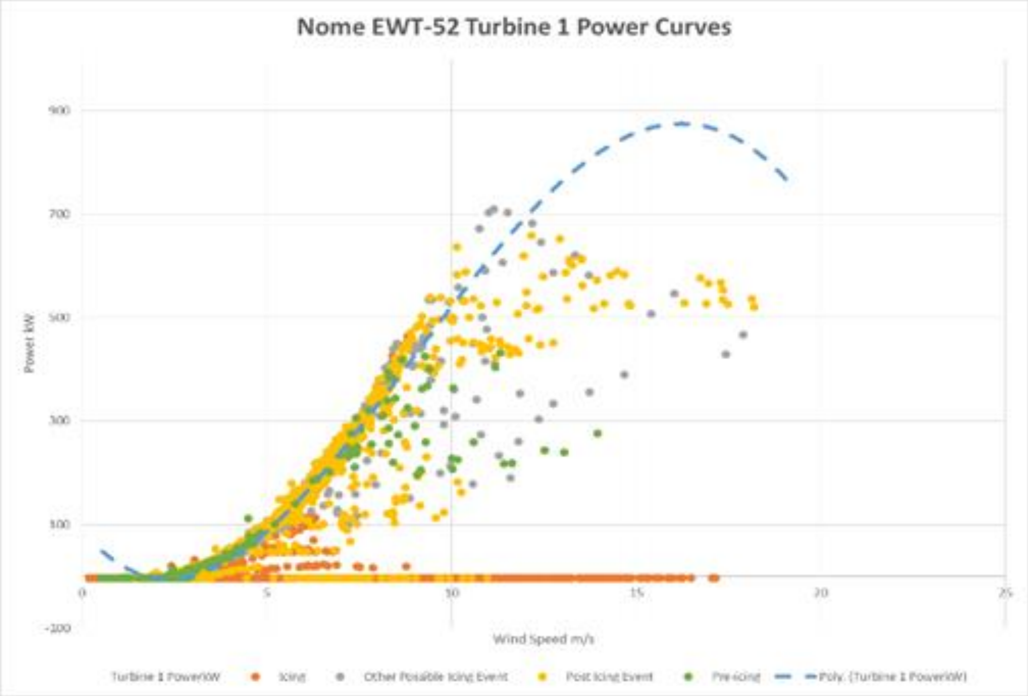
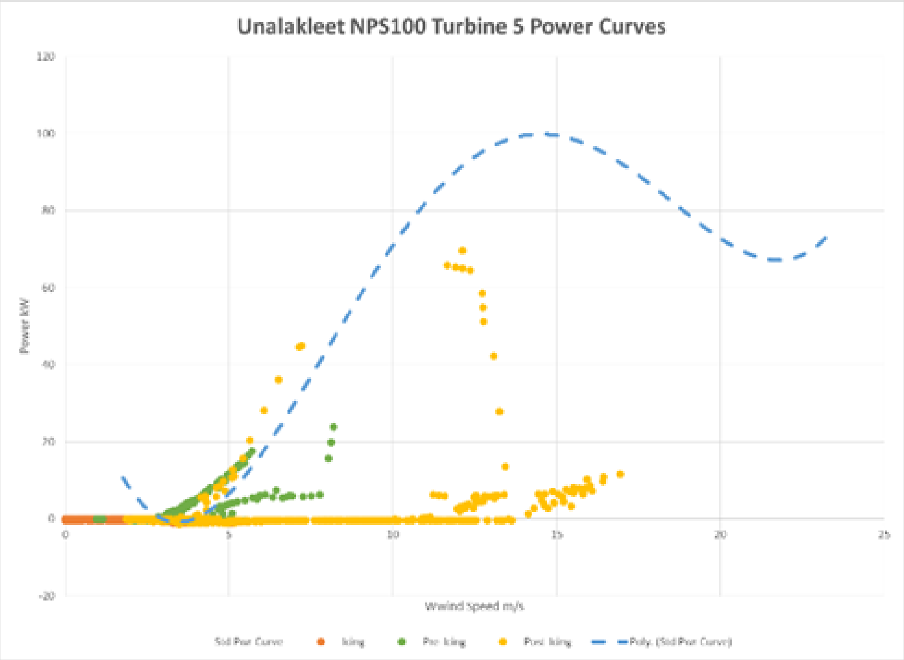
Icing Impact on Wind Turbine Output

- Nome EWT-52 turbine #1 showing overlayed power curves for non-flagged (blue) periods, met tower icing events (orange), pre-icing reduced power production (green), post-icing reduced power production (yellow) and other possible events where no met tower icing was observed (grey).



- Unalakleet NPS-100 turbine #5 showing overlayed power curves for non-flagged (blue) periods, met tower icing events (orange), pre-icing reduced power production (green), post-icing reduced power production (yellow). Icing (orange) is masked by other plots/curves, but is essentially flat-lined at zero power output with wind speeds of 5 m/s or less.



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Icing Impact on Wind Turbine Output

- When encountered in met tower data sets, icing data should be left "as-is" rather than deleting and resynthesizing the data values. The original data accurately represents the wind conditions in the case of hoar frost and represents the expected wind turbine output in the case of hoar frost and rime ice. Tables below show the expected error in energy production forecasting using the delete/synthesize method for the study period.

Month	Northern Power 100-21 As-Is Net Energy (kWh)	Northern Power 100-21 Synth Net Energy (kWh)	% Over Predict
Nov	35,350.09	37,973.64	7.42%
Dec	34,174.90	34,007.83	-0.49%
Jan	22,413.74	24,641.39	9.94%
Overall	*91,938.77*	*96,622.85*	*5.09%*

Month	EWT DW52-900 As-Is Net Energy (kWh)	EWT DW52-900 Synth Net Energy (kWh)	% Over Predict
Oct	61,517.94	62,763.83	2.03%
Nov	215,488.39	223,382.88	3.66%
Dec	173,155.42	185,837.06	7.32%
Jan	119,517.95	162,307.41	35.80%
Feb	47,984.71	96,752.52	101.63%
Overall	*617,664.94*	*731,044.75*	*18.36%*

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SpiDAR Evaluation

- Cold-weather evaluation to test equipment accuracy and survivability.
- Light detection and ranging system weighs 60 kg.
- Remote power module weighs 375 kg.
- Deployed at Delta Wind Farm – Latitude 64 deg
- Very limited winter performance data due to warranty troubleshooting and repair.
- Stable performance since reinstall in May 2015

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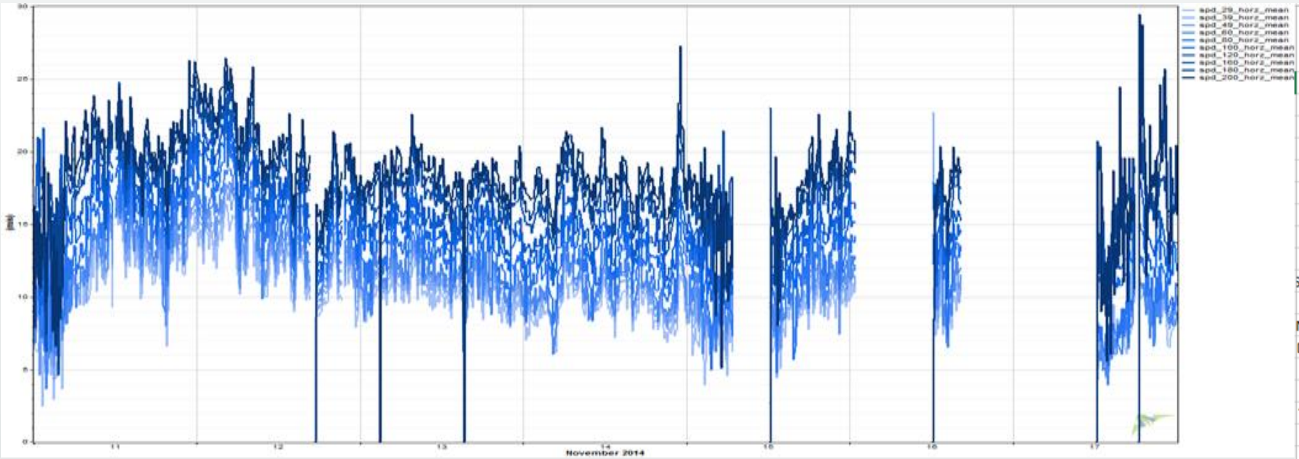
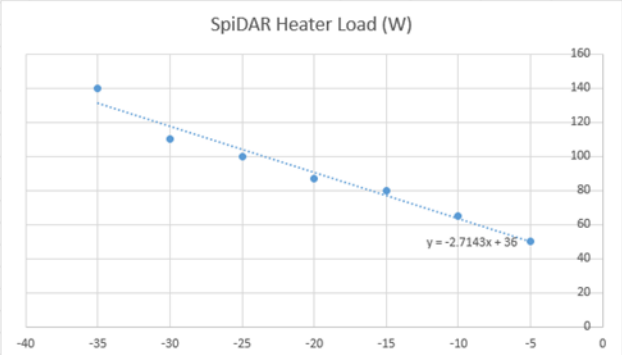
SpiDAR Power Pack Capabilities

- After several sunny days of operation following the field install at Delta Wind Farm, the unit went offline on an overcast day. Similar outages were experienced the following week.
- An on-board heater consumes more power than the nominal 35W to run the LIDAR system. 1-min average loads of 89W were observed with instantaneous peaks of 305W. Power pack is only usable 5 months per year.



Month	Solar Radiation	AC Energy Generated by 560W Ppack	SpiDAR Load No Heater	SpiDAR Monthly kWh Load with Heater	SpiDAR Avg kW Demand	
	kWh / m2 / da	kWh	kWh	kWh	kW	
January	1.17	21	26.04	83.65205533	77.43556	Yellow denotes power deficit for the month
February	2.73	42	23.52	76.5310523	71.25141	
March	4.18	66	26.04	74.47917016	65.10641	
April	5.05	76	25.2	67.79889958	57.25659	
May	5.26	80	26.04	53.89832537	37.44399	
June	5.05	74	25.2	51.24	35	
July	4.96	74	26.04	52.08	35	
August	4.36	64	26.04	52.08419858	35.00564	
September	3.84	56	25.2	52.06740404	36.1121	
October	2.05	33	26.04	53.73352857	37.22248	
November	1.35	22	25.2	79.85248155	73.45764	
December	0.67	12	26.04	90.97985773	87.28476	
Annual	3.39	620	306.6	788.3969732		

Temp C	SpiDAR Heater Load (W)	Calculated
-5	50	49.5715
-10	65	63.143
-15	80	76.7145
-20	87	90.286
-25	100	103.8575
-30	110	117.429
-35	140	131.0005
-40	140	144.572



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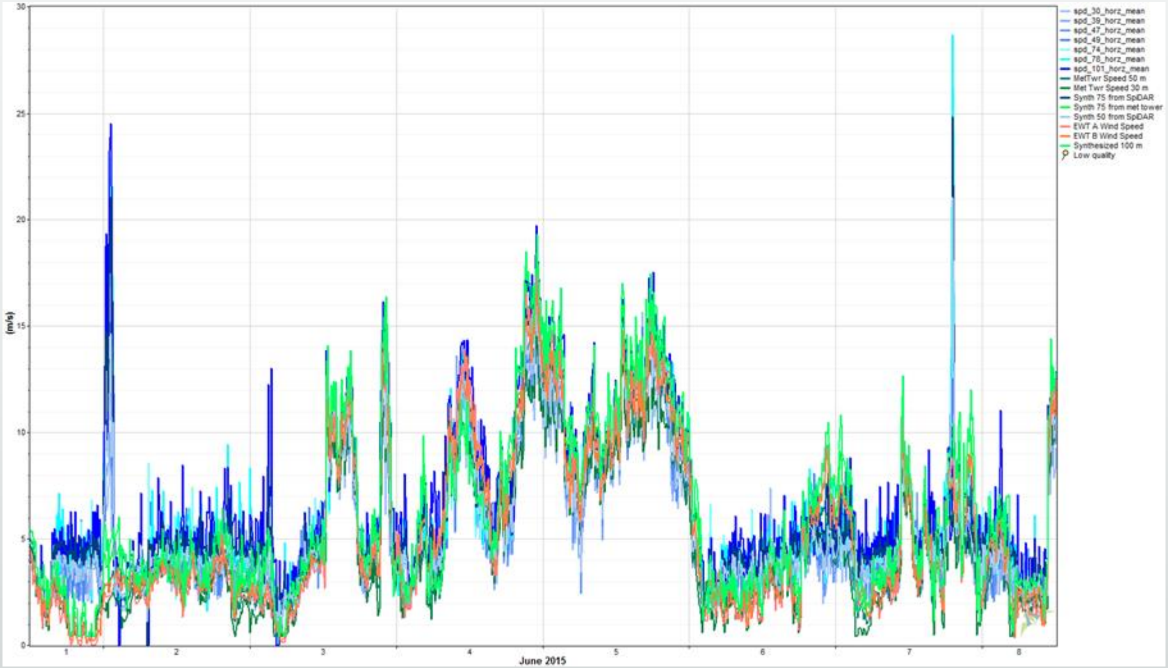
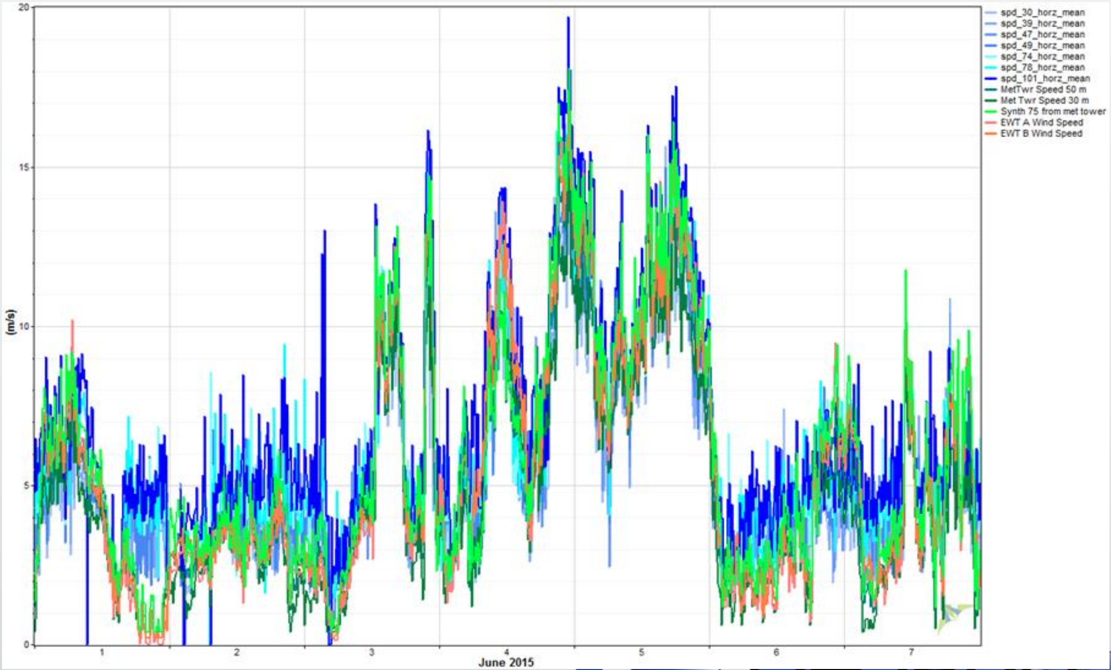
SpiDAR Data Accuracy

- SpiDAR data were compared to the reference data sets from the met tower at 30 meters (speed) and 50 meters (speed and direction) and the EWT turbines nacelle met station (speed and direction).

- Trend charts of 5030 rows of data indicated 27 10-minute records that contained outlier data which were subsequently deleted. Only the most extreme outliers were screened on the initial pass to assess data quality without preconceived limits. Pre and Post outlier removal is below.





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SpiDAR Data Accuracy

- Performing a Pearson correlation of 10-minute time-paired data, the results showed high correlation on temperature and average wind speed data between the SpiDAR and the met tower or wind turbine anemometers.

SpiDAR Parameter	Turbine A	Turbine B
Temperature Correlation	0.91145643	0.910117
78m Mean Speed Corr.	0.91963936	0.926535

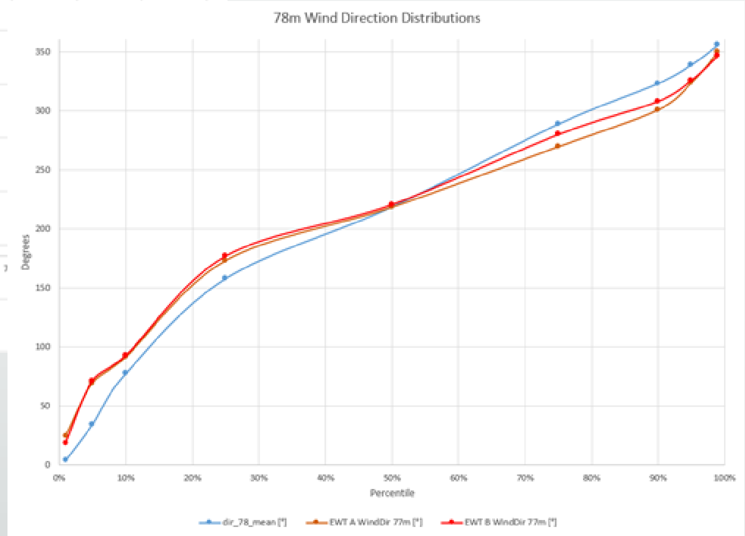
SpiDAR Parameter	Met Tower
30m Mean Speed Corr.	0.92407087
49/50m Mean Speed Corr.	0.93535584

- Correlation drops in the wind speed standard deviation and wind direction measurements.

SpiDAR Parameter	Turbine A	Turbine B
78m Dir Mean Corr.	0.4057454	0.511491

SpiDAR Parameter	Met Tower
30m Std Dev Corr.	0.15814643
50m Std Dev Corr.	0.0947984
49/50m Dir Mean Corr.	0.52879759
49/50m Dir Std Dev Corr.	0.21900335

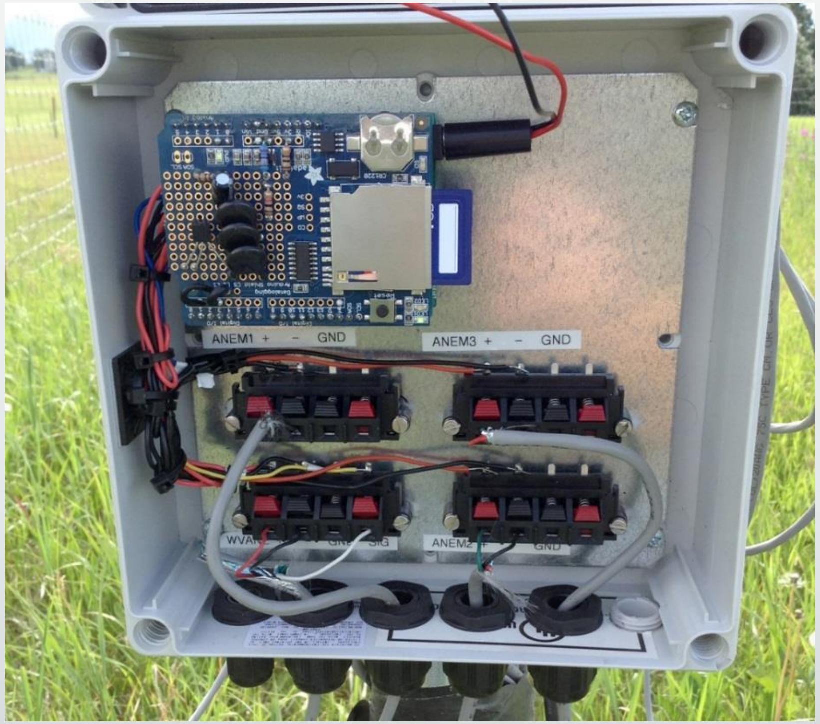
- An analysis of the distributions of wind direction show better overlap than the Pearson correlation of step-by-step changes.



Wind Datalogger for Alaska

- RFP issued with $20k to seed development of datalogger specifically designed to meet the needs of wind resource assessment in remote Alaska.
- Current offerings (12-15 data channels at $1800+ per unit) targeted at large wind farm resource assessment market.
- Winning design proposal has 3 anemometer channels and 1 vane, on-board temperature sensor, 1-min logging interval of date & time, min, max, average and std. dev for anemometer/vane and min, max, avg for temperature. .CSV format.
- Data cable inputs are spring-clip, providing for fast and reliable connection in harsh weather installations.
- Halus Power Systems is designer, manufacturer and supplier.
- Unit sells for $500-$650 depending on exact configuration/options.

- Datalogger unit at field test site in Palmer, AK showing controller board with SD card, spring-clip connectors and water-tight seals around cable intrusions.



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Optional Buckland photos

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Rich Stromberg
907-771-3053 (desk)
rstromberg@aidea.org

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