Validation of Industry Snow Losses

PVPMC 2022

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August 24, 2022

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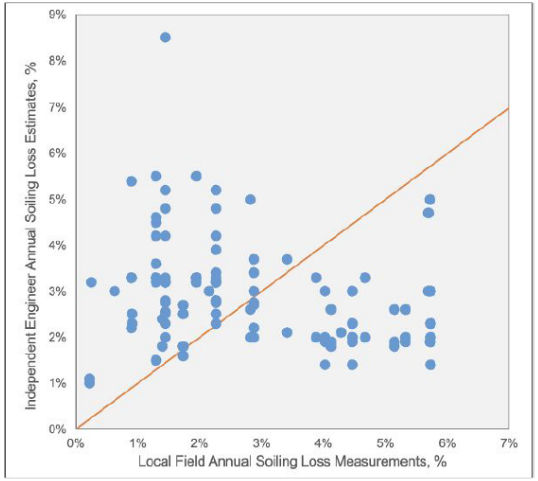
Agenda

Overview

Figure 1. Soiling Loss Variance – IE vs. Field Measurements



Source: Fracsun ARES soiling station hardware from 40 locations; compared to IE estimates

- Snow losses can have significant impact on level of energy generation.
- Snow losses can have high variance year-to-year.
- Snow loss models therefore can be crucial to predicting both the loss amounts and the variability of losses for a given location.
- We compared 55 operational losses to two snow loss models; 29 sites with 1+ years concurrent.
- Leading industry snow loss models may differ several percent both annually and monthly.
- Snow models primarily studied using fixed tilt ground and rooftop settings; more single-axis tracker study (and SCADA data) for comparison may be beneficial to future analyses.

Figure 1: KWH Analytics (2021). “Solar Risk Assessment: 2021: Quantitative Insights from the Industry Experts” pp. 15.

Snow Loss Model Studies

Model	**BEW / Townsend**	**MTU / Queen's University / Andrews**	**NREL / Marion**	**Proprietary (e.g., SunPower PVsim)**
Research Studies	• Powers, Newmiller & Townsend, 2010 • Townsend & Powers, 2011	• Andrews et al., 2012 • Andrews et al., 2013	• Marion et al., 2013 • Ryberg & Freeman, 2017	• e.g., Gun et al. (SunPower), 2018
Characteristics	Empirical monthly	5-minutely operational timeseries	Hourly timeseries	Varies
PV systems used in derivation	Ground-mounted fixed tilt (0º, 24º, 39º)	Various rack-mounted fixed tilt (5º-60º)	Roof- and ground-mounted fixed tilt (15º-35º)	Varies
PV system locations	Truckee, CA	Ontario, Canada	WI, CO	Varies

Operational Snow Losses from SCADA

Waterfall of Losses

Resource Availability

- Quantify the effect of actual insolation vs proforma expectation on energy output

As-Built Capacity and Degradation

- Quantify the effect of as-built observed generation capacity vs nameplate
- Quantify the effect of degradation over period of analysis

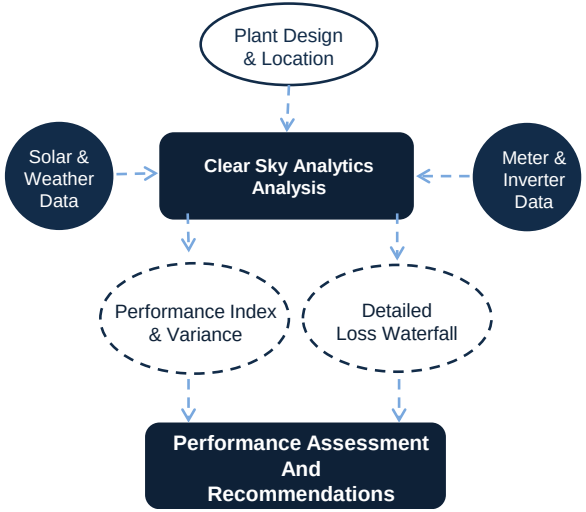
Other Externalities

- Forced Curtailment
- Grid Outages
- **Snow**

Addressable Losses

- Inverter outages
- Other AC outages
- DC outages
- Tracker outages
- Soiling abatement
- Tracker set up
- Inverter set up
- Plant control

Analysis of SCADA Data from Operational PV Plants



Resource and production data

↓

Data curation and repair

↓

Generate expected output for each period using PVLIB and proprietary models of plant

↓

Compare actual vs expected output to determine a Performance Index and quantify loss for each period

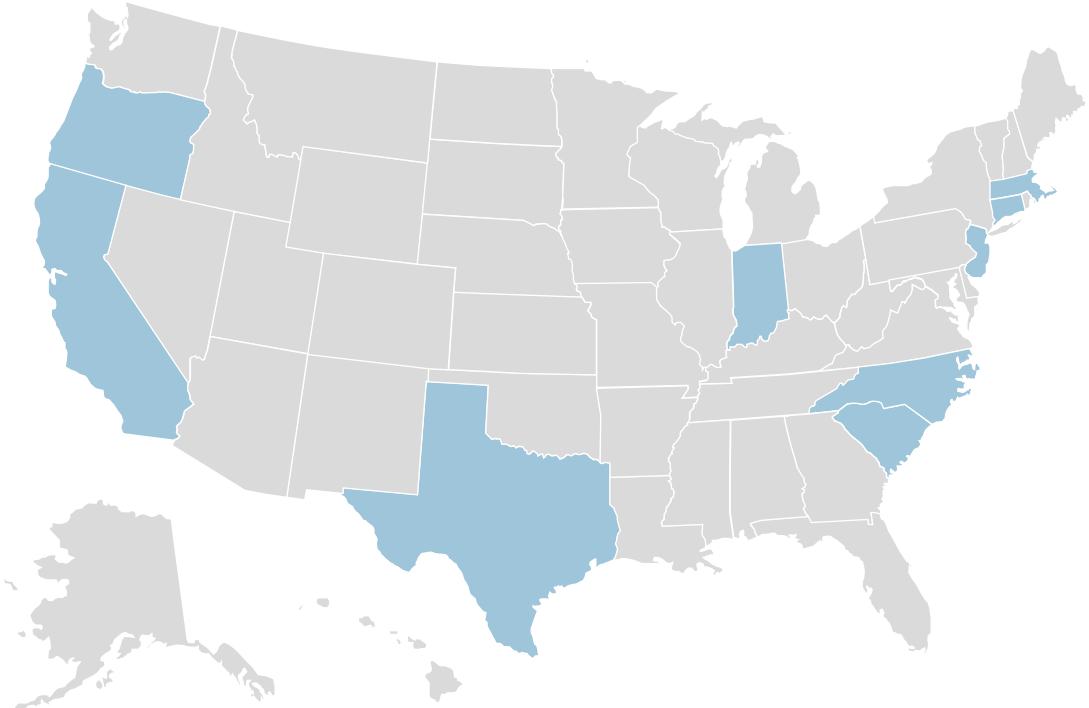
↓

Algorithmically attribute losses into a waterfall of root causes (one of which is Snow)

Determining Snow Loss

Identify and quantify loss due to snow/ice by algorithmically identifying periods where Performance Index drops uniformly and significantly across the site during a period consistent with snow accumulating and sticking (cloudy and freezing) and then similarly recovers uniformly and significantly in a manner consistent with snow melting or sliding.

Map of SCADA locations

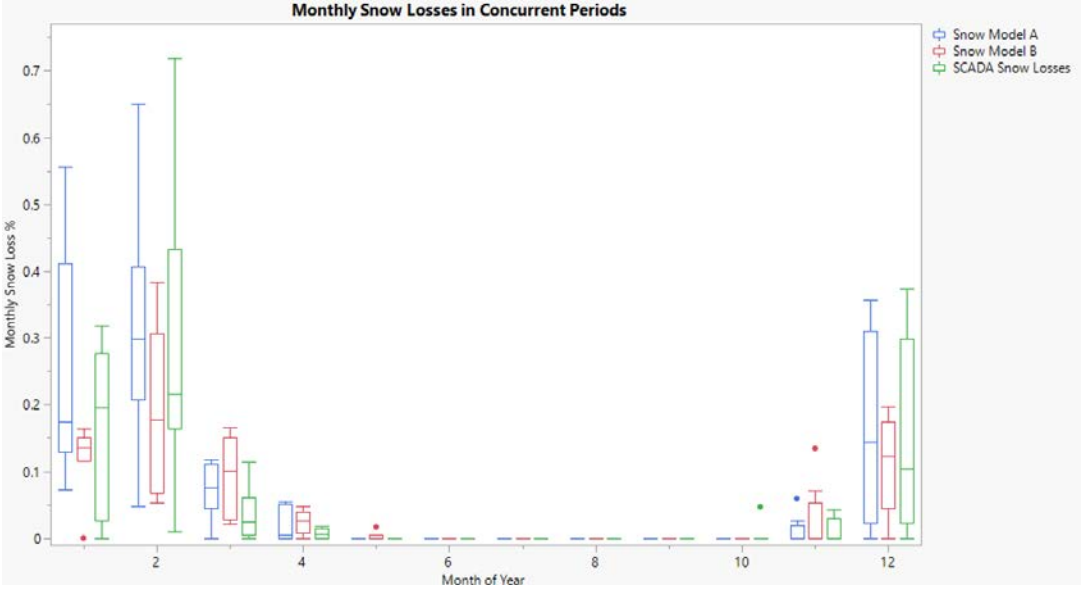


- 55 operational solar projects with provided SCADA data in the states to the right.
- These sites do not cover all snow environments in the US, but are a sample used for comparison purposes here.
- Not all sites experienced SCADA snow losses, however most sites experienced moderate to low snow losses.

Snow Modeling Sensitivities

Year-to-Year Snow Loss Variability

- Year-to-year snow variability is significant!
- Right: one site with 7+ years of SCADA data demonstrates range of losses for each calendar month.
- TMY based snow losses may not have P50 snow loss conditions present and may be biased.
- For this study, losses were modeled using timeseries data starting in Jan 1998 and ending in Dec 2020, where available.



Data Quality and Availability

- For some models, measured snow fall or snow depth may be required.
- NOAA stations used here with the following attributes:
  - Significant number of years of usable data recovery (>10, most over 15).
  - Nearby to the site (<40km).
  - Minimal elevation differences where possible (<50m).
- Models may be improved by on-site measurements to tune long-term datasets to hyperlocal conditions, however:
  - Model testing with small variations to temperature and other variables did not reveal significant sensitivity.
  - Therefore, further testing for this hypothesis was not tested further at this time.

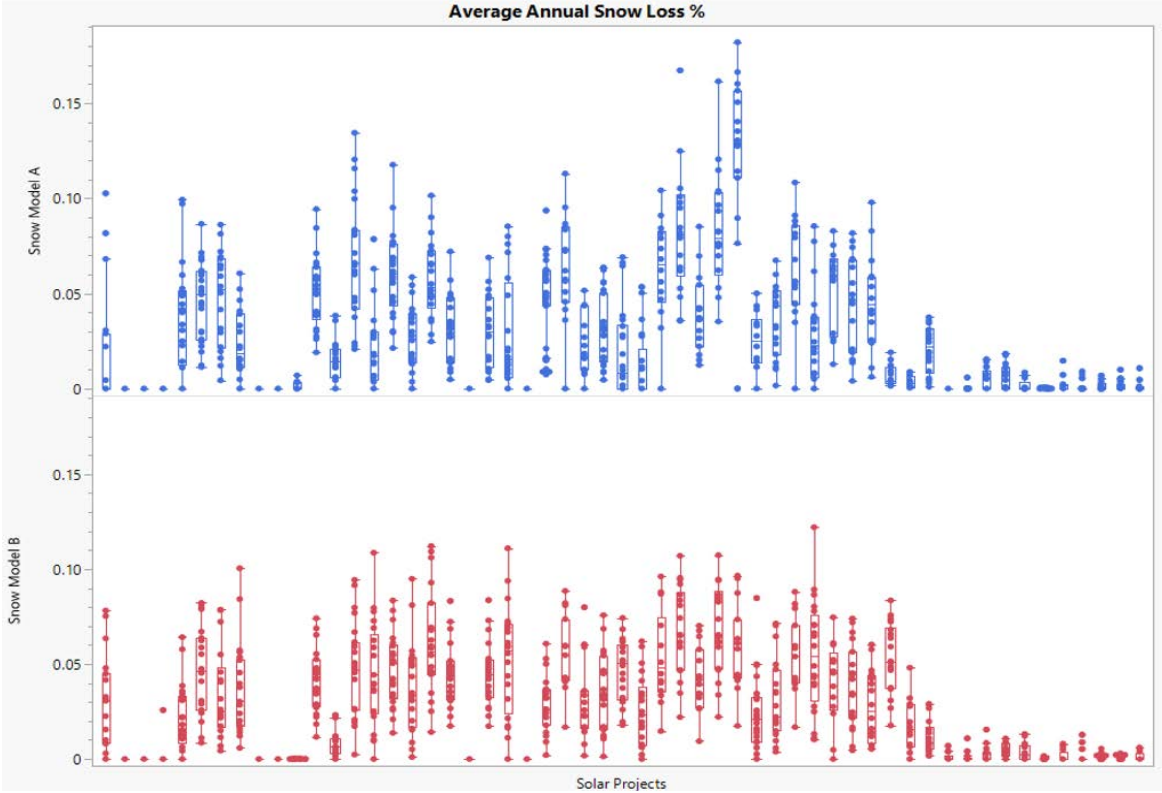
PV System: Fixed Tilt vs. Single Axis Trackers

- The majority of snow models were studied and derived from fixed tilt systems.
- For hourly (or finer temporal resolution) modeling, one can substitute in timestamp-specific panel angle.
- For daily (or greater) temporal modeling:
  - Flat tilt (0º) is likely to over-predict loss, as snow sliding will not be modeled.
  - Absolute maximum panel angle was used in this analysis to simulate snow shedding angle.
  - Maximum achieved angle (for backtracking systems) may be an alternative depending on planned tracker operational strategy.

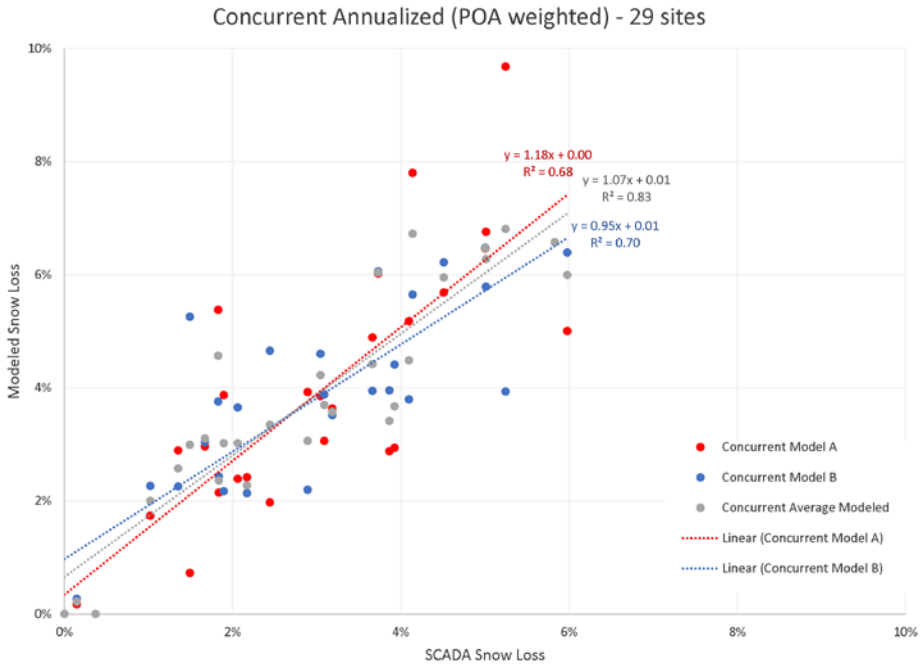
Validation of Snow Losses

Variability in Annual Modeled Snow Loss at 55 Sites

- Two snow loss models used for comparison purposes.
- Long-term timeseries (typically 15+ years) losses calculated.
- Annual modeled snow loss averages for each year at each site plotted to the right.
- Note the significant differences in annual values at each site as well as variation at different sites!

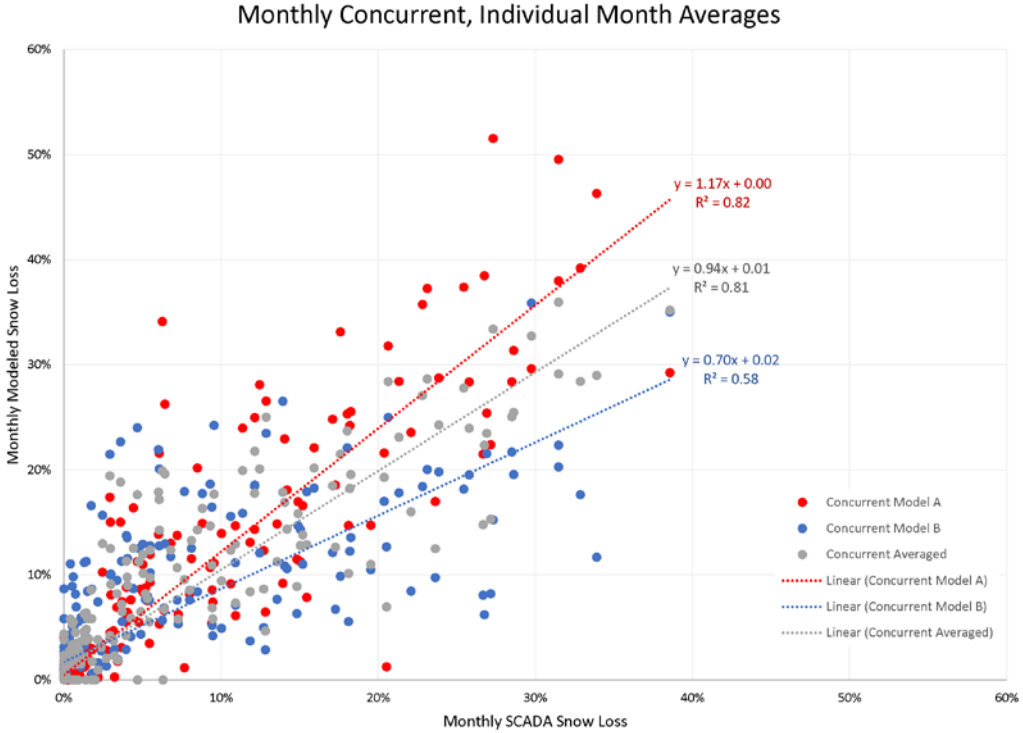


Annualized Concurrent Losses for 29 Sites



- 29 sites with 1+ years concurrent modeled and SCADA losses.
- For each site, the average loss for the concurrent period and calendar month of the year was computed, then POA-weighted with average monthly POA per site for annualized values.
- These models show a clear linear relationship with slopes close to 1; when models were averaged monthly and compared, R^2 improved significantly due to a diversity of models reducing statistical noise.
- Average annual modeled losses around 1% greater than SCADA, +/- 1.2% STD

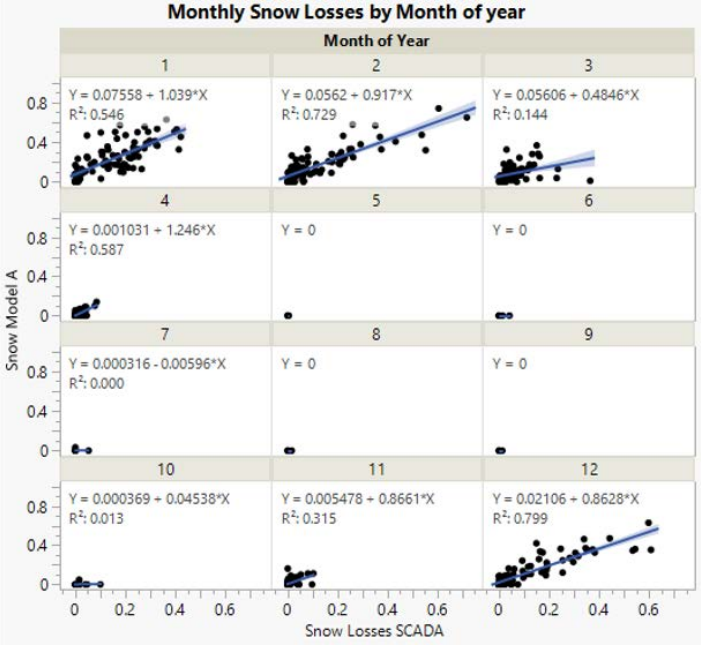
Calendar Month Concurrent Losses for 29 Sites



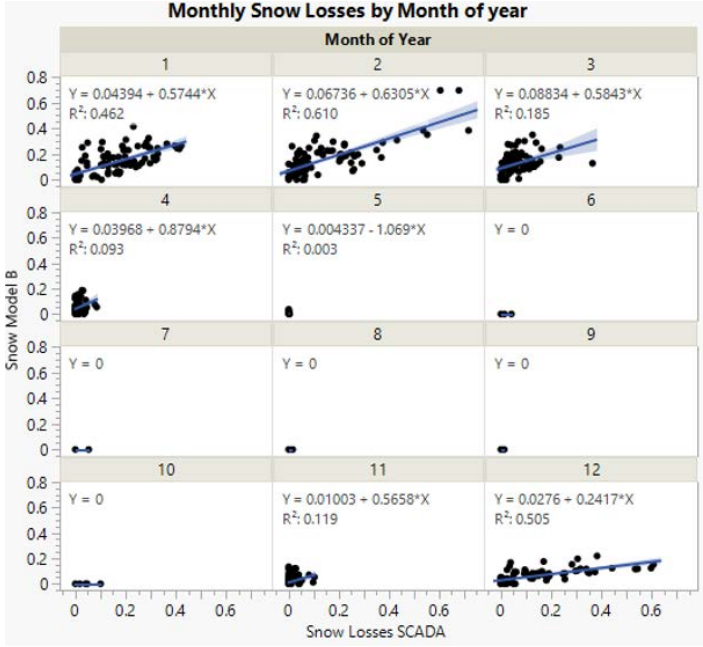
- 29 sites with 1+ years concurrent modeled and SCADA losses.
- For each site, the average loss for the concurrent period and calendar month of the year was computed and compared.
- Both models have a fair amount of scatter monthly, and differing regressions; average of both models still improves but less drastically than annually.

Total Monthly Comparison by Month of the Year

Model A



Model B



Conclusions

Results and Conclusions

- Models performed best on annualized POA-weighted, which is the closest analog to applied loss in an energy estimate.
- Models had fair scatter for annualized months and specific months, however this is a less essential metric than annualized as heavy snow months are typically lowest in POA/energy production.
- Models appear to perform best in moderate to high snow conditions; low snow months benefit from long-term averaging.
- Statistical noise from an individual model can be mitigated by averaging monthly with another model of similar quality.
- Additional data points for single-axis trackers would benefit our understanding of modeling for these systems.

Future Work

Future Work and Ideas

Model Tuning

- Model Validation suggests strong correlation between models and SCADA, but an overall offset persistent in more than one model.
- Additional study may be used to determine if constants applied in each model can be refined or are variable for certain conditions.

Long-Term Correlation

- Long-term modeled losses at a site with SCADA losses may be able to be correlated during concurrent periods, resulting in a long-term, site-specific, loss adjustment.
- Benefit to operational analysis and determining future losses.

Single-Axis Trackers

- More SCADA data for diverse system setups could be obtained and used for analysis.
- Backtracking and true-tracking may have different conditions for snow shedding vs fixed tilt.
- Snow stow benefits (and conditions for such benefits) may also be added to modeling.

Questions?

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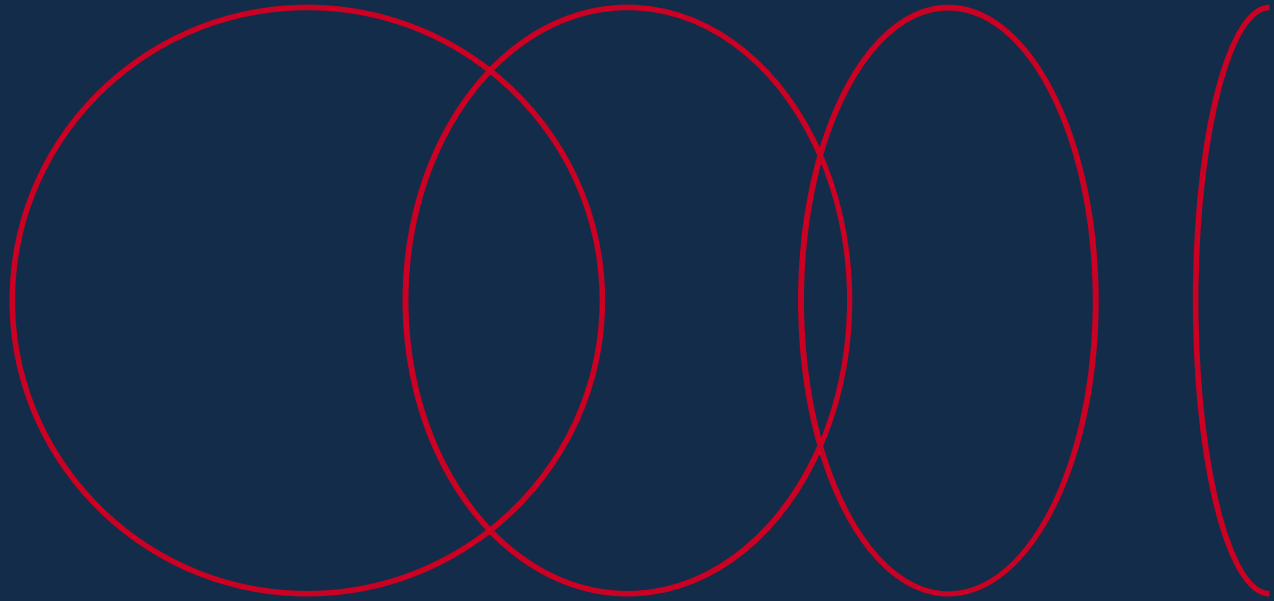

Thank you

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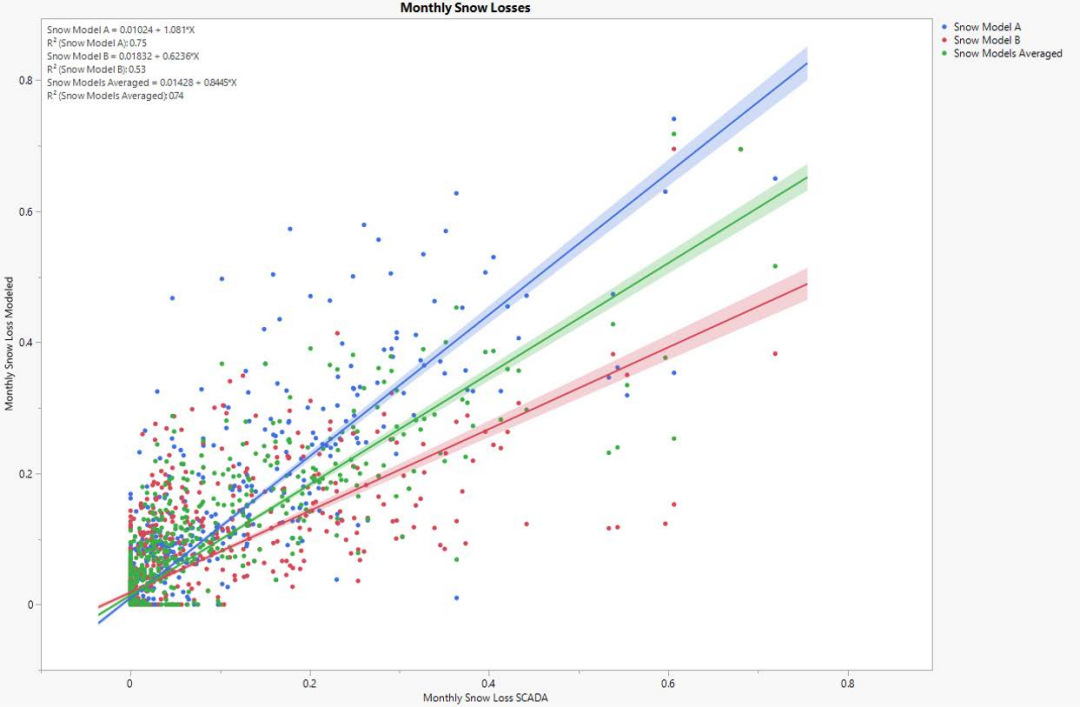
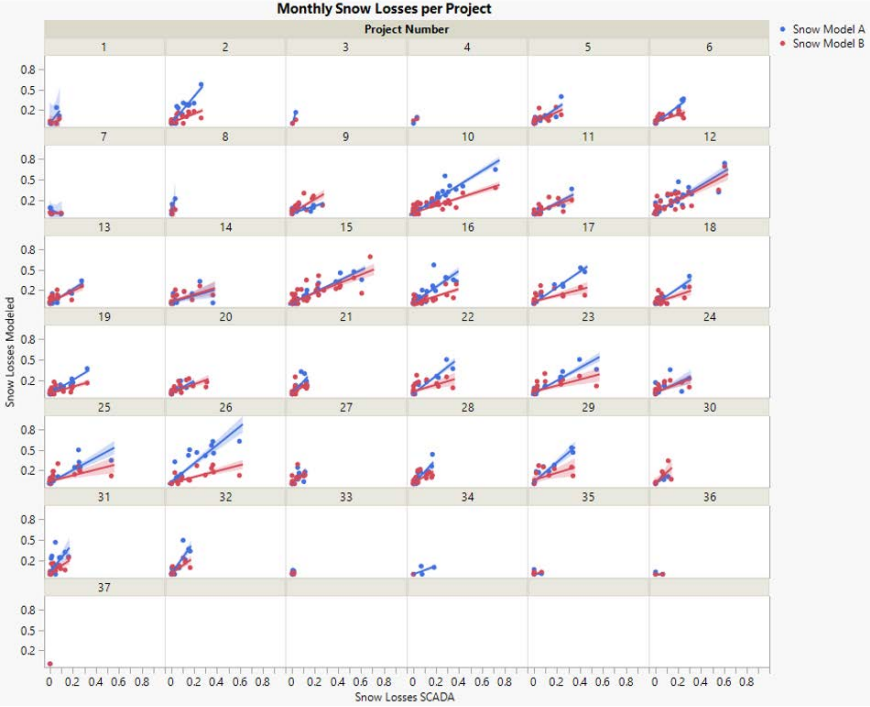
Monthly Correlation Across 55 Sites



Modeled vs SCADA Snow Losses Per Project



Total Monthly Comparison by Type of System