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Effects of Snowfall on PV Systems

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Snow on PV

- How do we measure the effects of snow on PV?
- How can we distinguish snowfall effects from other system losses?
- How can we predict the effects of snowfall on distributed systems?
- What effects do snowfall losses have on PV system design?

Measuring Snow Losses

- A baseline is needed for comparison, data from a snow covered panel can look like the output from a heavily overcast day

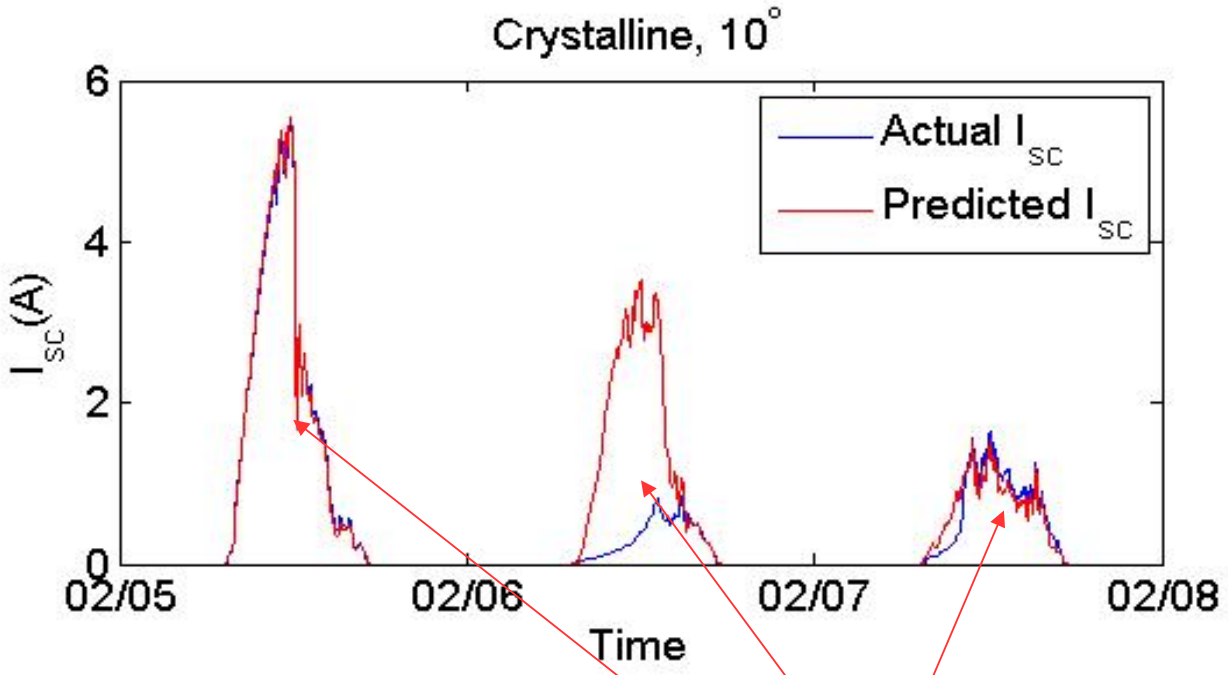
- Two possible methods:
  - Set up a test site with identical modules. Clean one set regularly and measure the difference in outputs between the two sets.

  - Measure irradiation with a heated and ventilated pyranometer. Use a PV performance model to simulate expected output and calculate the difference between simulated and actual output. (chosen methodology)

Townsend et al, 2011

CVF 3 heated and ventilated enclosure
Source: Kipp & Zonen

Measuring Snow Loss



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Results

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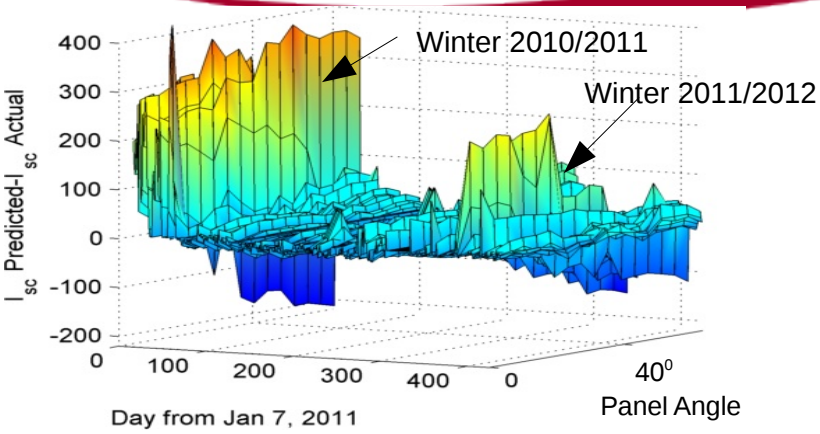
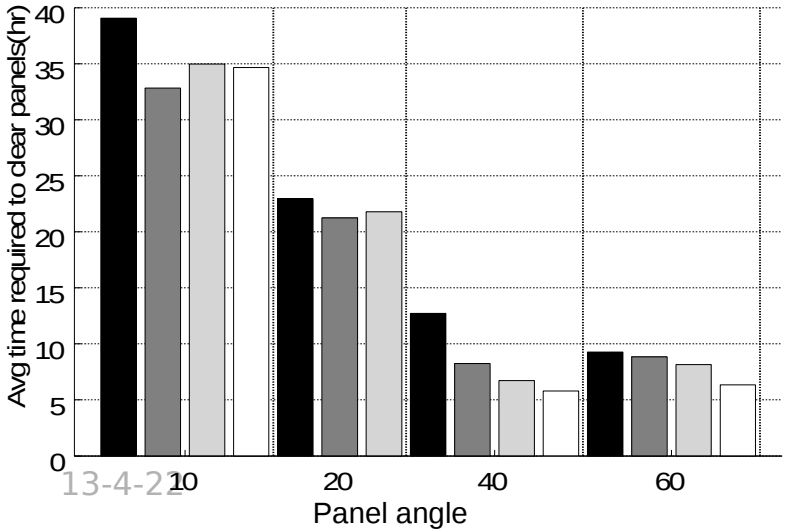
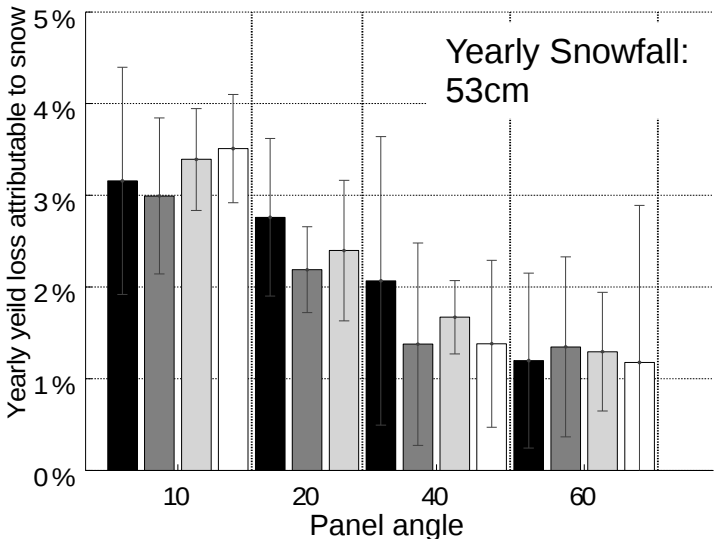
- The presented results are from the winters of 2010/2011 and 2011/2012
- 3D plot shows the difference between modelled and actual PV output for the two winters.
- Time to clear and yearly loss are based on 2010/2011 data



2010/2011 time to clear

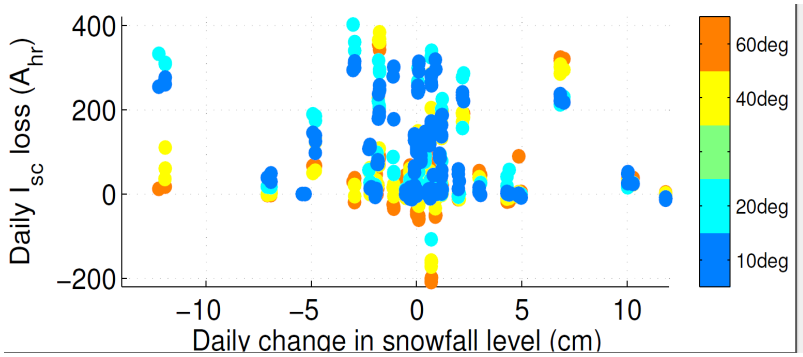


2010/2011 yearly I_{sc} yield loss



Prediction

- Daily snowfall does not correlate well with daily snow loss
- Snowfall is a very complex phenomenon
- Esp. at lower angles, snowfall from the previous day will increase the chances of snow adhering.
- Therefore a time series modeling technique is used, based on a parametric fit to an empirical, lag 1 Moving Average equation

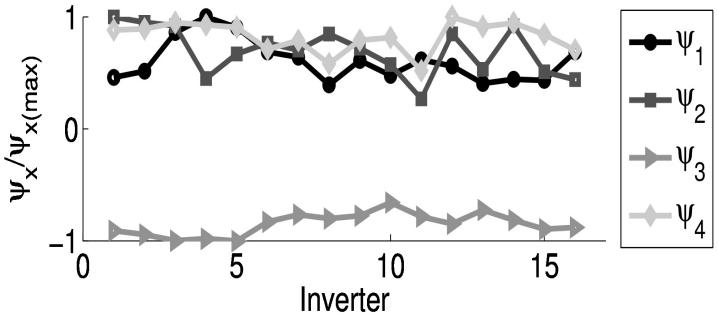


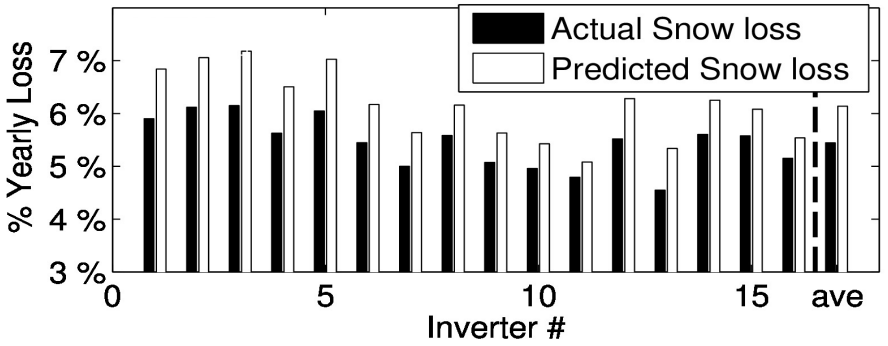
$$\hat{I}_{sl} = \psi_1 * \bar{S}_t + \psi_2 * \bar{G}_t + \psi_3 * \bar{T}_t + \psi_4 * \bar{S}_{(t-1)}$$

- G_t -daily mean irradiation (W/m^2)
- T_t -daily mean panel temperature
- S_t- daily snowfall at day t and (t-1)
- $\psi_1 \ldots \psi_4$ - Parametric coefficients

Prediction

- Coefficients found by minimizing least squares error
- Applied to distributed sites (8MW, multiple inverters), the outputs were fairly stable between individual inverters





- Coefficients from one site were able to predict snow losses at another, similar site

Prediction

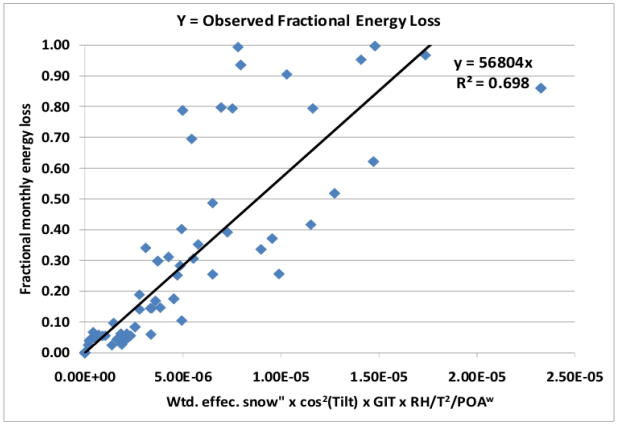
- Alternative method using the BEW engineering methodology:
  - Based on data from Truckee, CA (39^{0}N 120^0 W, 200” snowfall)

$$loss\% = C_1 \times Se^{'} \times cos^2(tilt) \times GIT \times \frac{RH}{T_{air}^2 \times POA^0.67}$$

$$Se = \frac{S \times (1 + 1/N)}{2}$$

$$GIT = [1 - C_2 \times exp(-\gamma))]$$

$$\gamma = \frac{R \times Se^{'} \times cos(tilt)}{\frac{(H^2 - Se^{'2})}{2} \times tan(P)}$$

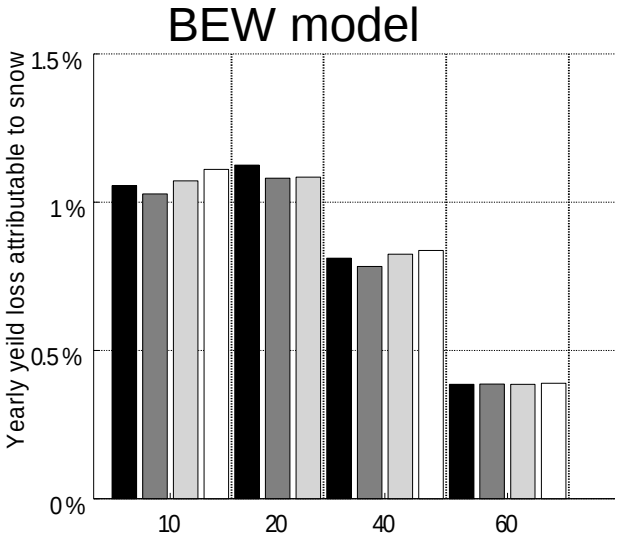


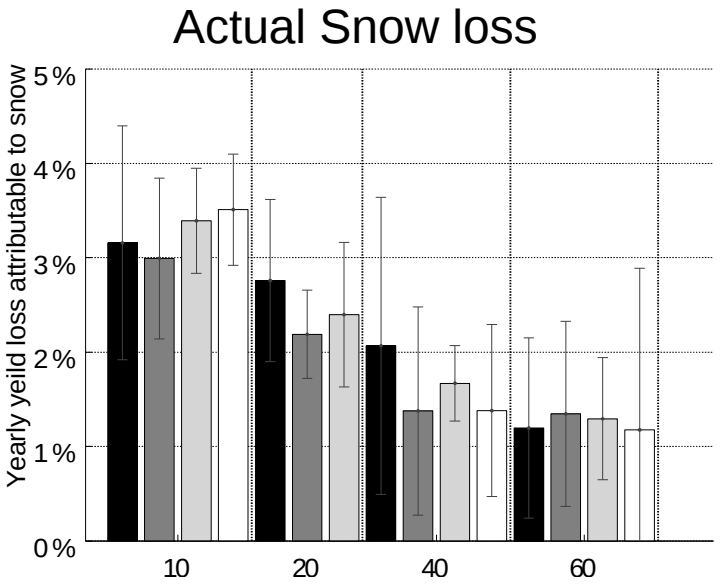
Source: Townsend et. Al, 2011

RH- Relative Humidity
T- Temperature
Tilt- Module tilt angle
N- Number of snow events/month
POA- Monthly plane of array irradiation (kWh/m^2)
P- Piled snow angle (assumed 40^0)
H- Drop height from array edge to ground
S- Monthly snowfall
Se'- 6 wk rolling average of Se

BEW Methodology

- Provides a more generalized view of snowfall losses
- Begins to account for ground interference from snow piles
- Loses some sensitivity at lower levels of snowfall



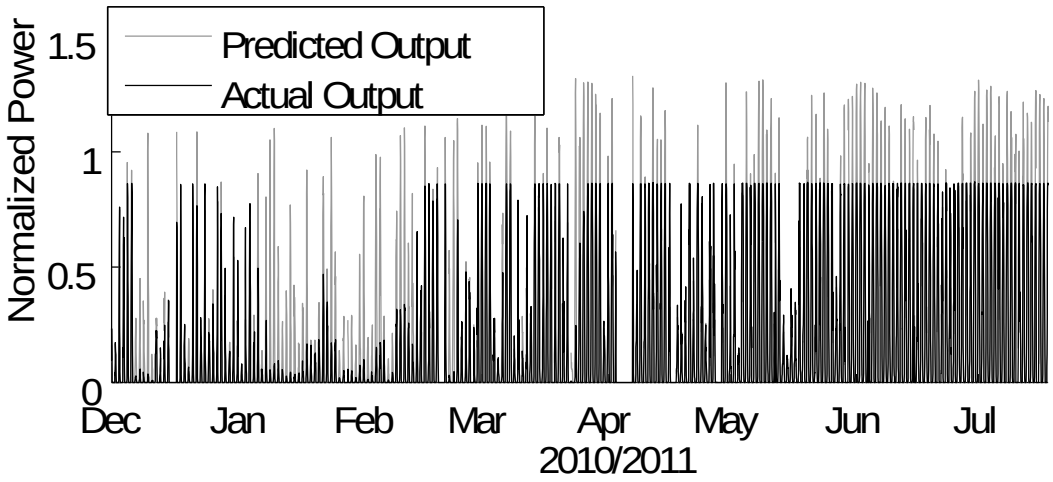


PV Design Lessons

- Improved prediction of snow losses can improve P90 estimates
- Snow loss should be included in array angle optimizations (albedo effects)
- Where possible **leave space available for snow to clear**
- Snow losses can be amplified by DC overrate, especially on low-profile rooftop systems (Commercial rooftop)

DC Overrate

- Typical DC overrate profile seen below (20% overrate):



- DC clipping will tend to bias PV output to the winter months. Therefore, same absolute energy loss due to snowfall on a DC clipped system will result in a higher % yearly loss
- Especially on commercial rooftops, where snow losses can be very large, this can have a significant impact.

Snow on PV

- Measured snow losses in Kingston ON were on the order of 1%-3% yearly
- Two models are being developed to predict the effects of snowfall on PV systems
- More data is required to increase confidence in models, and to allow integration into PV modeling packages

Thank you

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Further Reading

- Rob W. Andrews, Andrew Pollard, Joshua M. Pearce, The effects of snowfall on solar photovoltaic performance, Solar Energy, Volume 92, June 2013, Pages 84-97, ISSN 0038-092X, 10.1016/j.solener.2013.02.014.
- Andrews, R.W.; Pearce, J.M., "Prediction of energy effects on photovoltaic systems due to snowfall events," Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE , vol., no., pp.003386,003391, 3-8 June 2012
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- Rob W. Andrews, Andrew Pollard, Joshua M. Pearce, A new method to determine the effects of hydrodynamic surface coatings on the snow shedding effectiveness of solar photovoltaic modules, Solar Energy Materials and Solar Cells, Volume 113, June 2013, Pages 71-78, ISSN 0927-0248, 10.1016/j.solmat.2013.01.032.
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