Dynamic Snow Loss Model and Validation

PVPMC 2018 – Albuquerque, NM

Defne Gun, Greg Kimball, Mike Anderson | May 2, 2018

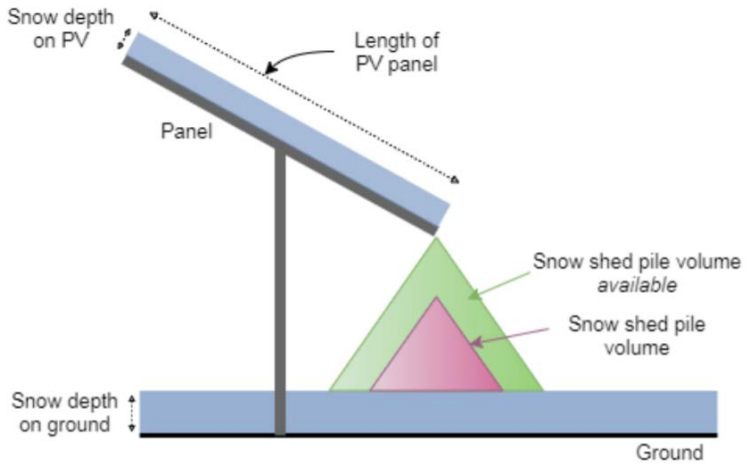
Modeling Impact of Snow on PV Production

- Snow coverage on PV panels can significantly decrease annual energy production
- In snowy climates, production losses can be 5% or more depending on:
  - Local snow behavior
  - System configuration
  - O&M practices

- SunPower's dynamic snow loss model predicts the impact of snow on production using:
  - Location specific time-series snow depth data
  - System type and characteristics

Snow Model Overview

- SunPower's snow model was developed based on basic engineering principles and validated against operational site data
- The snow loss model translates ground snow depth data to snow depth on PV through:
  - Snow accumulation
  - Snow dispersion through melting or sliding
- The methods for accumulation and melting are based on equations from Bill Marion's model
- SunPower's model adds a method to account for snow sliding off a module which is especially critical for ground systems



Snow Model Overview

- Accumulation $\Delta SD_{PVaccum} = \Delta SD_G \times cos\beta$ $(\Delta SD_G > 0)$
  - ΔSD_G = change in snow depth on the ground, and
  - β = slope of the PV from horizontal

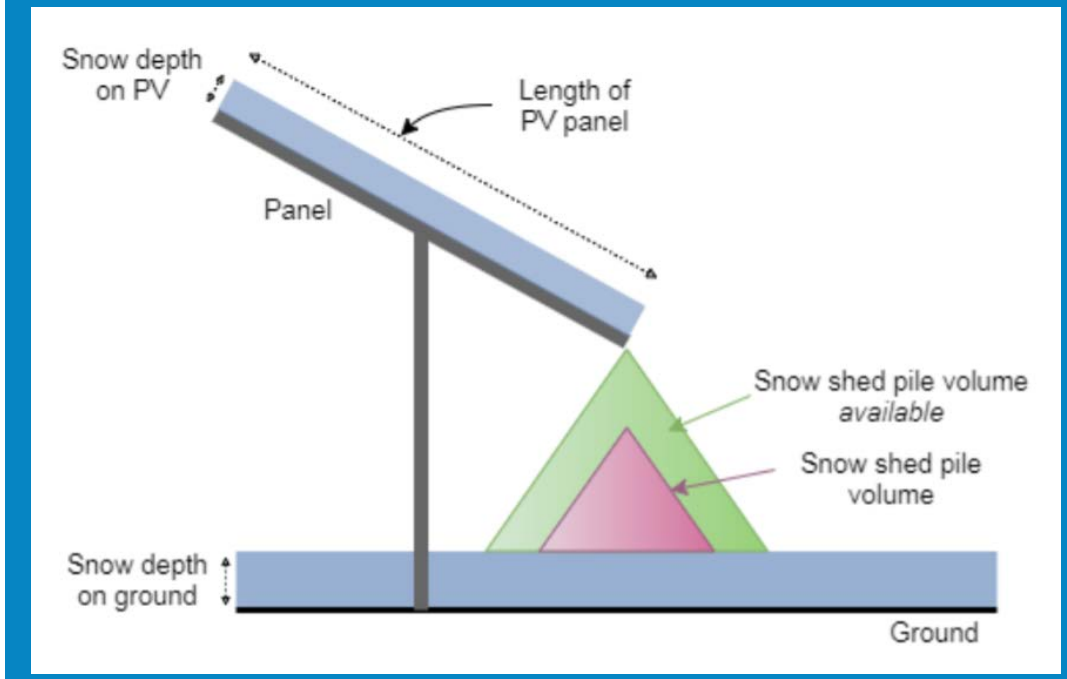
- Melting $\Delta SD_{PVmelt} = \Delta SD_{Gmelt} \times \frac{cos\theta}{cos\theta_z}$ $(\Delta SD_G < 0)$
  - θ = incidence angle between the sun and normal to the PV (at solar noon)
  - θ_z = incidence angle between the sun and normal to the ground (zenith angle, evaluated at solar noon)

- Combined

  $SD_{PV} = SD_{PVprevious} + \Delta SD_{PVaccum} + \Delta SD_{PVmelt}$
  - SD_{PV} = current snow depth on the PV
  - $SD_{PVprevious}$ = previous snow depth on the PV

Sliding

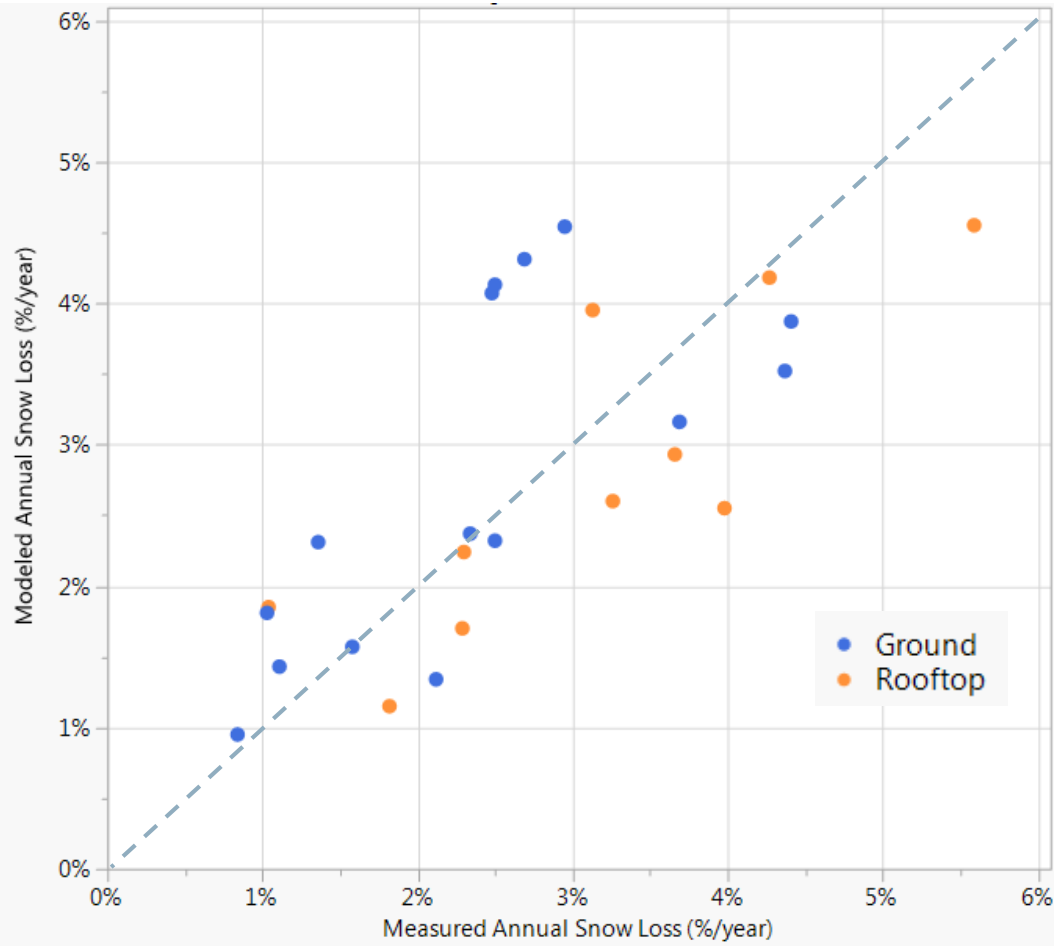
- Sliding is assumed to occur beyond a critical tilt angle of 5°
- Past this threshold, snow will slide off the module at the end of the day if there is sufficient room for it to collect below the array



Snow Model Validation

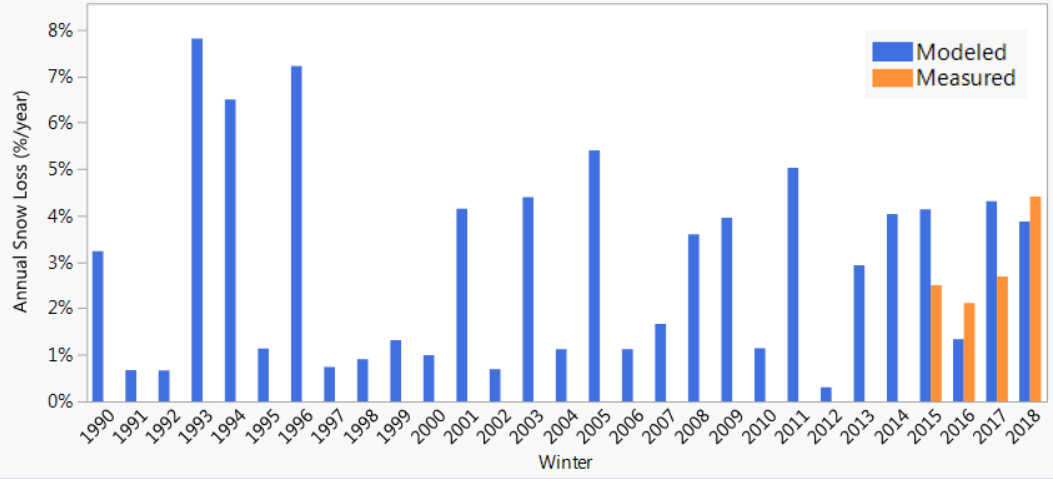
- Annual snow losses for 10 sites were quantified using measured power data
  - These sites consisted of 5 rooftop and 5 ground fixed-tilt sites in snowy climates
  - Several systems have up to four years of operation data
- Measured snow losses were compared with the snow model output using historical snow depth data from Global Surface Summary of the Day (GSOD)
- Measured snow losses up to 6% were observed
  - MBE: 0.08%
  - RMSE: 0.90%

Measured vs Modeled Annual Snow Losses for 10 sites (with multiple site-years)



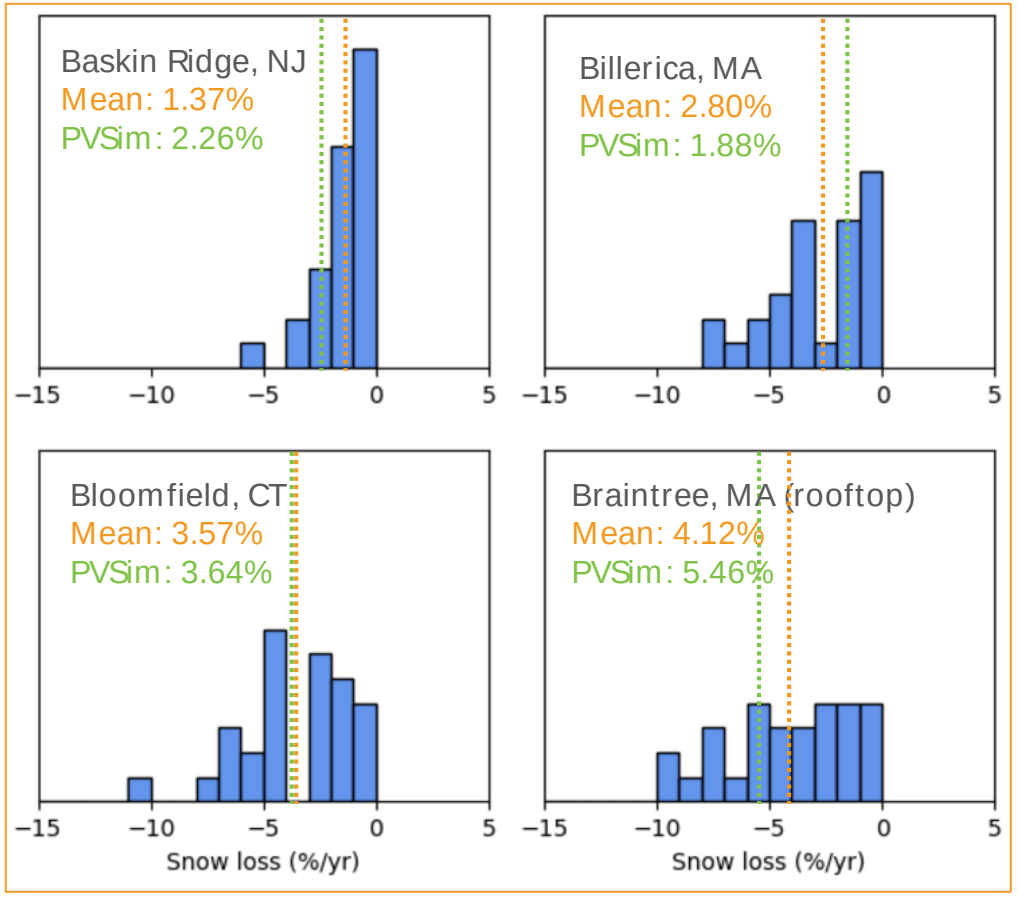
Inter-annual Variability

Modeled Snow Losses over 30 Years for a Ground System in MA



- (Right) – A long term study was done for 4 sites using 30 years of historical GSOD snow data. Each plot shows the distribution of yearly snow loss and the PVSim value given by running the snow model using “typical” snow data from Meteonorm
- (Top) Modeled snow loss values over 30 years are shown for a single site (25 degree fixed tilt system) in Massachusetts

Modeled Snow Loss over 30 years



Comparison with Other Snow Models

- Conclusions/key takeaways
  - SunPower model works as well for ground and roof systems
  - The addition of sliding mechanics improved snow loss estimates particularly for ground systems
  - Inter-annual variability in snow depth results in significant year-to-year snow losses
    - Standard deviation of annual snow losses using 30 years of snow data is close to 2%

Model	Implementation	Reported Accuracy
Townsend	Excel	1.4%-4.4% (MBE)*
Marrion	Scripting	0.2%-1.6% (MBE)*
Andrews	Scripting	0.5%-1.5% (MBE)*
SunPower	PVSim	0.08% (MBE)

*from SolarPro Magazine." *Modeling Losses Due to Snowfall*

Models Referenced

- Andrews, R.W., Pollard, A. & Pearce, J.M., 2013. The effects of snowfall on solar photovoltaic performance. Solar Energy, 92, pp.8497. https://doi.org/10.1016/j.solener.2013.02.014.
- Townsend, T. & Powers, L., Photovoltaics and snow: An update from two winters of measurements in the sierra. 2011 37th IEEE Photovoltaic Specialists Conference, pp.32313236. http://ieeexplore.ieee.org/document/6186627.
- Marion, B.; Schaefer, R.; Caine, H., & Sanchez, G. Measured and modeled photovoltaic system energy losses from snow for Colorado and Wisconsin locations. Solar Energy, 97 112-121. (2013). http://doi.org/10.1016/j.solener.2013.07.029

Thank You

Let’s change the way our world is powered