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An Enhanced Snow-Shedding Model: the Module Frame as a Key Variable

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Abstract

Snow sliding is one of the primary methods of natural snow removal from PV modules. In this paper, we evaluate and add to an existing model for predicting snow sliding from PV modules and the rate at which that sliding occurs. Specifically, we look at the impact of the module frame on snow shedding, presenting shedding data from two side-by-side arrays that are identical except one set of modules are frameless while the other set has aluminum frames. This team has previously shown that frameless PV modules shed snow faster than framed PV modules, but the difference in the rate of snow shedding was based on a single winter of data (2018-2019). This study augments that earlier work with data from the 2021-2022 and 2022-2023 winter seasons.

Background

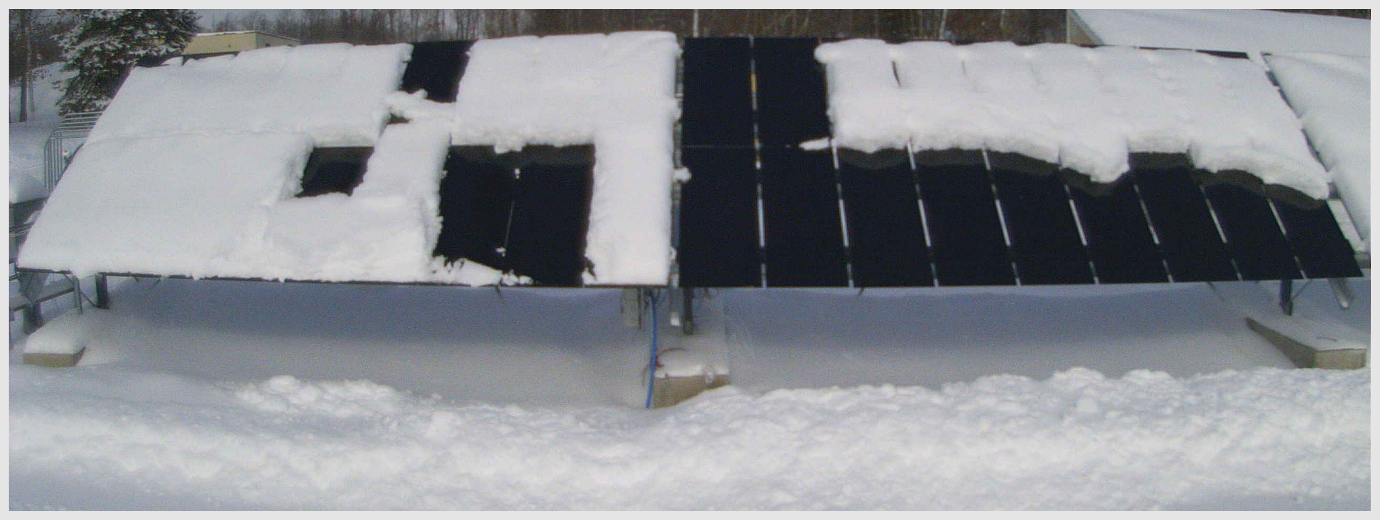
As photovoltaic (PV) installations in northern regions accelerate, the effect of snow accumulation on PV systems and the resulting loss of energy production have become increasingly popular areas of research. Marion, et. al developed one of the first models to estimate the rate of snow shedding from PV modules via sliding as a function of temperature, irradiance, tilt angle, and mounting configuration [1].

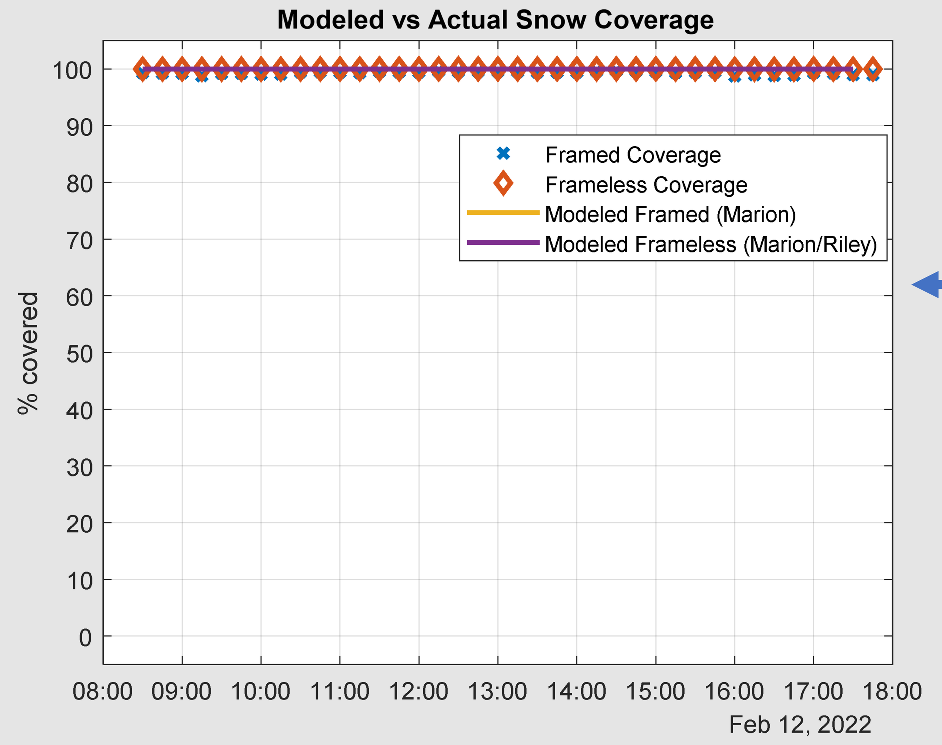
In 2019, this team proposed that sliding rates of snow on PV are also affected by the presence or absence of a frame on the PV modules. For modules which were otherwise identical, the lack of a frame caused snow to shed approximately 50% more quickly [2]. However, this estimate was developed using data from only a single winter, and the team sought to validate the increase in snow shedding with data from more recent winters.

The PV system under study was relocated from Williston, VT to Calumet, MI in 2019. A camera captured images of the system every 15 minutes. The red, green, blue (RGB) pixel values from the module images were automatically classified into two categories via k-means clustering, which were then labeled them as 'snow' and 'non-snow'. Then, the percent coverage for each module was quantified as the percentage of 'snow' pixels. The individual module coverage was averaged to produce the average snow coverage of each PV system.

The Marion shedding model was revised to better either framed or frameless modules, implementing a 50% faster shedding rate for frameless modules. The model was then run in the base form (Marion) and in the improved form (Marion/Riley) and the results are here compared with the snow shedding observed via image analysis.

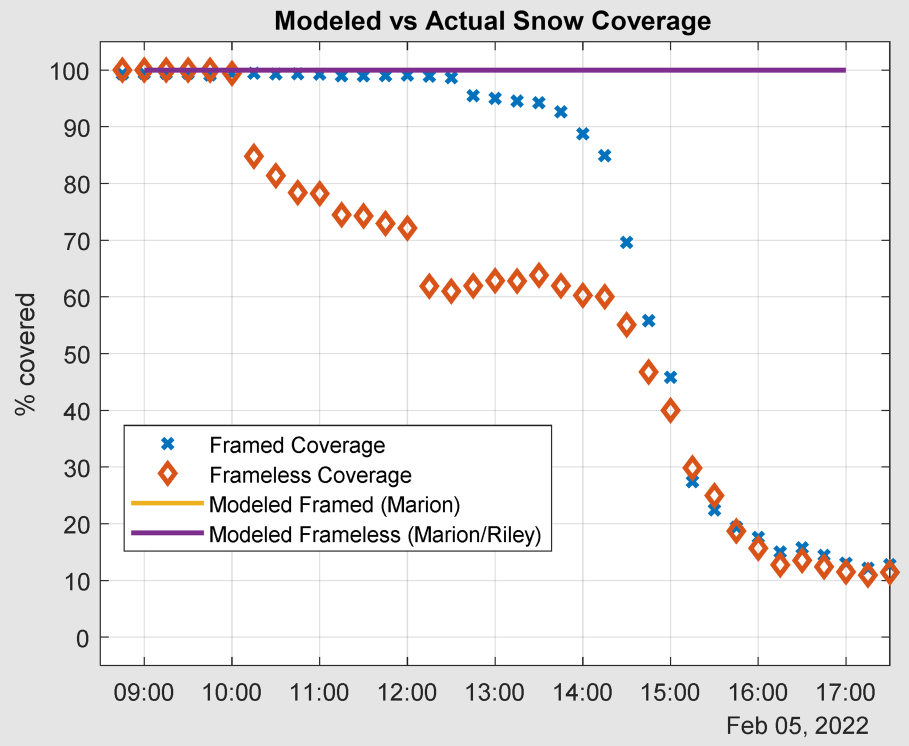
The PV system under test at MTU in Calumet, MI. Framed PV modules on the left and frameless PV modules on the right.

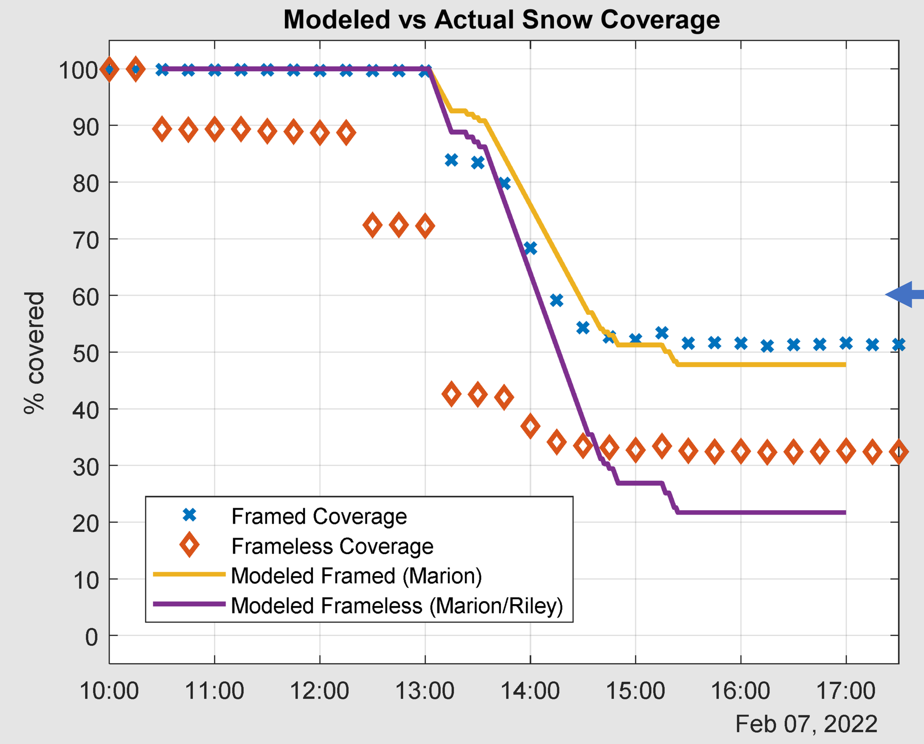




The Marion model correctly models the lack of shedding in conditions that are cold with low irradiance. The improved model similarly predicts a lack of snow sliding in these conditions.

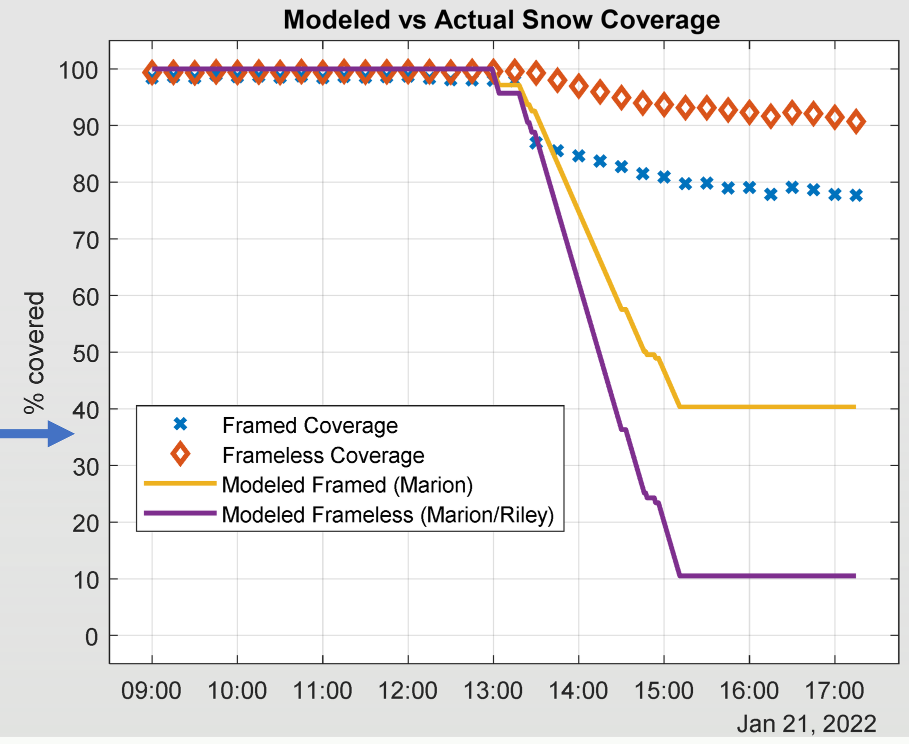
As expected from the data in the original model report, the model can produce false negatives (snow slides without being predicted to slide) as shown here. In this case, snow slides from frameless PV earlier than framed PV.





In 75% of cases where the actual shedding rates of framed and frameless modules differed, the frameless PV modules shed more quickly. The modified model accurately reflects this faster shedding.

In 25% of cases where the actual shedding rates of framed and frameless modules differed, the framed PV modules shed more quickly. In these cases, the modified model caused larger errors than the standard model.



Results & Discussion

The data shown here present several cases where the snow shedding models correctly or incorrectly predict snow shedding. We observed several false positive (snow doesn't slide when predicted by the model) and false negatives (snow slides without being predicted to slide by the model) in our data set, and this is expected given the data in [1].

When actual snow sliding rates differed between the framed and frameless PV modules, the snow shed more quickly from frameless PV modules 75% of the time. In these majority of cases, increasing the sliding rate produces a model that more accurately reflects reality. However, we acknowledge that changing modeled the rate at which snow slides from a module due to lack of a frame, does not capture the observed phenomena of snow sliding earlier (or more easily). We expect that additional work will need to be completed in order to determine the cause for earlier shedding, and alterations to the underlying slide/no slide model will be required. In the 25% of cases where the framed PV shed more rapidly than frameless PV, the modified model produces larger errors than the standard Marion model.

The cause of differences in shedding rate is not fully understood, although we do know that snow shedding is a complex chemical-physical phenomenon with difficult-to-model interactions between snow particles, PV module temperatures, and surface interactions.

Conclusion

Additional snow accumulation and shedding data has shown that the original Marion model and the modified Marion/Riley model perform well at locations other than those where the model was developed. Both models are susceptible to both false negatives (snow slides without being predicted to slide) and false positives (snow doesn't slide when expected).

As we have now validated, under most circumstances, frameless PV modules shed snow more quickly than framed PV modules. We speculate the difference is due to the additional inertia required for snow to slide over the physical barrier posed by a frame. The actual rate of shedding for frameless modules, however, is difficult to determine as there is wide variability between the observed shedding and modeled shedding of snow. Our proposal of a 50% increase in shedding rate for frameless modules produces modeled shedding rates that better approximate the rates observed.

Snow sliding remains to be somewhat difficult to predict, and changes to the slide rate *alone* may not capture all of the snow shedding differences between a given set of modules. Further refinements to the original equations that estimate sliding as a function of temperature and irradiance may be required to adequately capture the differences in PV modules' tendency to shed snow via sliding.

1. B. Marion, R. Schaefer, H. Caine, G. Sanchez, "Measured and modeled photovoltaic system energy losses from snow for Colorado and Wisconsin locations," in *Solar Energy*, vol. 97, pp. 112-121, 2013.
2. D. Riley, L. Burnham, B. Walker, J. Pearce, "Differences in Snow Shedding in Photovoltaic Systems with Framed and Frameless Modules," in *46th IEEE Photovoltaic Specialist Conference*, 2019.

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