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A Model for Estimating Snow Albedo Changes Due to Time and Temperature

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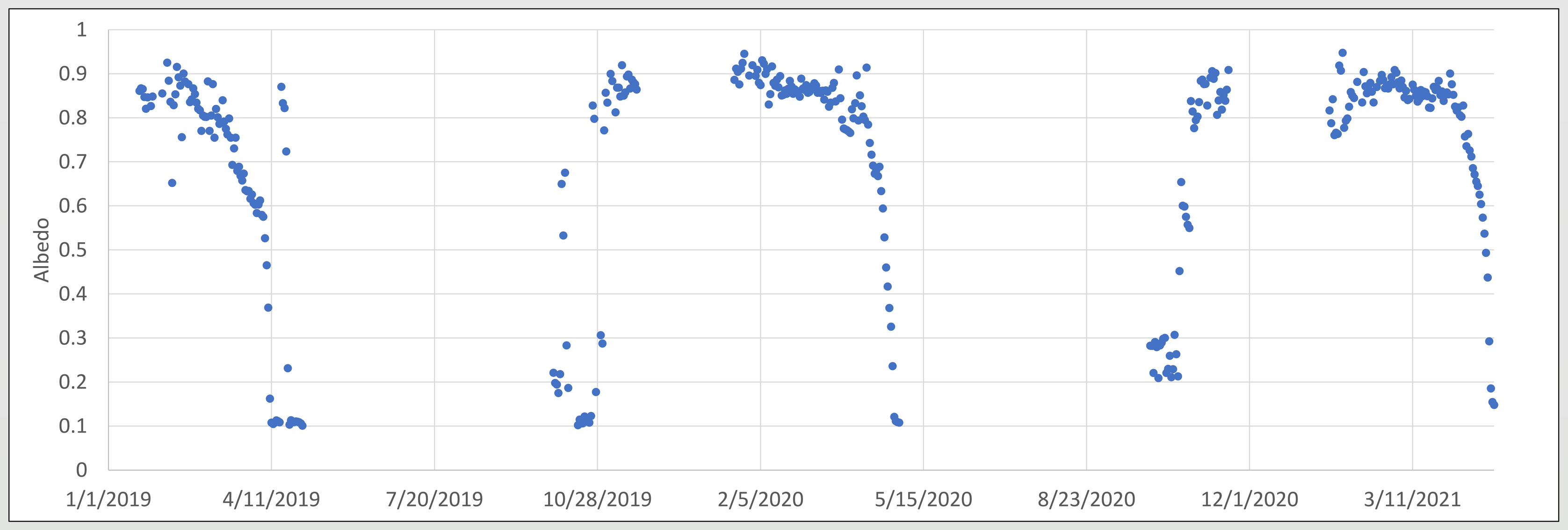
Abstract

Typical modeling of snow albedo in PV performance models alters snow ground albedo between two states, typically 0.2 and 0.8, when snow is not present or present, respectively, on the ground. However, the albedo of snow on the ground changes as snow melts and compacts over time [1], leading to actual snow albedos in a range between the albedo of newly fallen snow and the albedo of the underlying surface. Researchers at Sandia National Laboratories and the University of Alaska, Fairbanks have sought to model this change in albedo as a function of time and temperature, as is common in snowmelt models [2]. We expect that improvements in modeling snow albedo will improve PV system performance modeling in locations which experience frequent snow.

Background

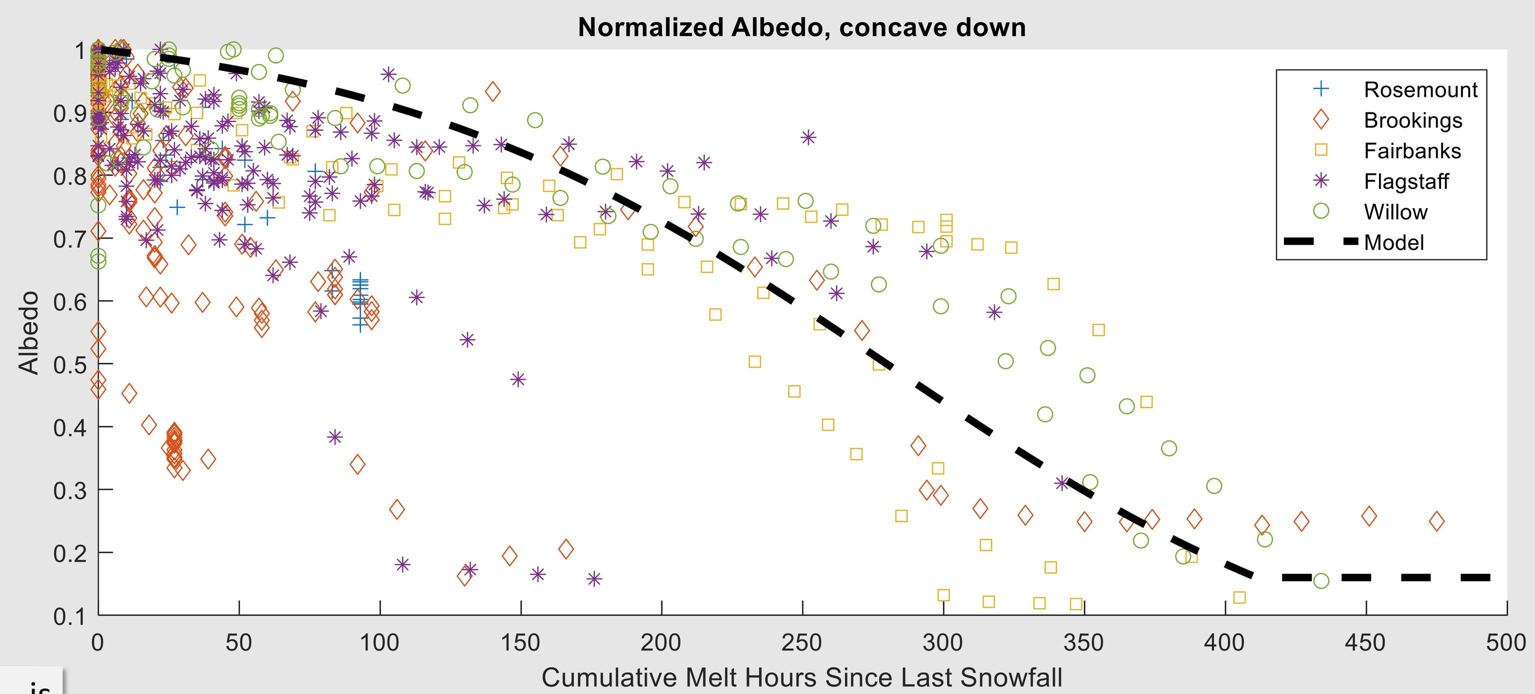
In 2022, we presented data that show albedo is frequently between the typically-used values of 0.2 and 0.8 [3]. In Fairbanks, 32% of October-April days had average albedo between these values. The number of days with in-between albedo increase for Flagstaff, AZ with 36% and Brookings, SD with 68%. Most of these days occur toward the beginning and end of the snowy season as the snow melts.

To address these time periods, we presented a snow-albedo model in which snow albedo changed as a function of "melt-hours" (hours with ambient temperature above 0 °C) experienced at the site. In the proposed model, snow albedo is set to an initial value when snowfall occurs. As melt-hours are accumulated, we note that the snow albedo reduces according to two different regimes. The reduction regime is determined by the amount of snow on the ground in the 3 days prior to snowfall. In the 'concave down' mode, all 3 days before a snow event have snow depth greater than or equal to 10 cm. In the 'exponential decay' mode, at least one of the 3 days before a snow event had snow depth less than 10 cm. We believe that the difference in albedo change modes is due to the likelihood of snow melting to partially reveal underlying ground cover.

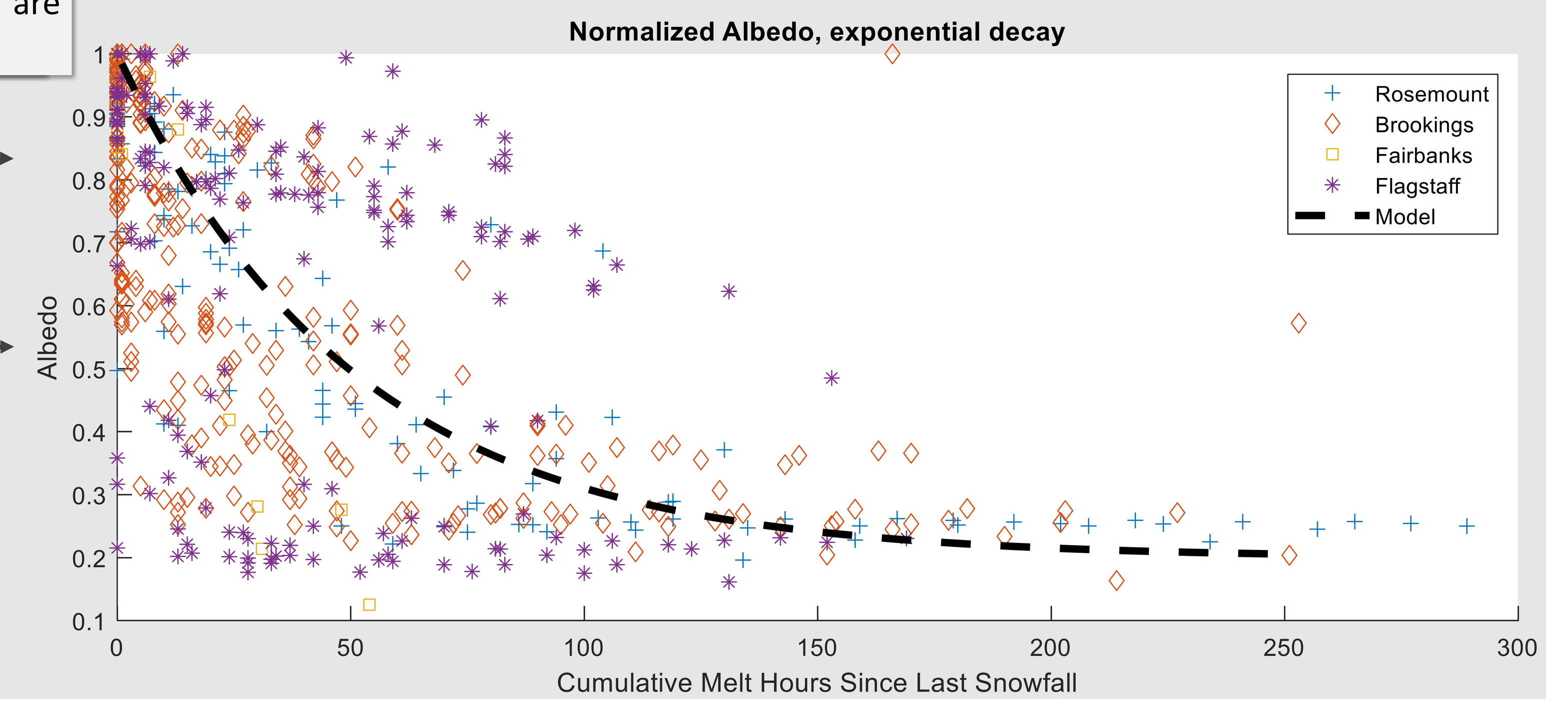


32% of days between October and April have average albedo between 0.2 and 0.8 in Fairbanks, AK.

"Concave down" albedo change mode where snow for all prior 3 days was greater than or equal to 10 cm. Note that a limit is applied here to show the effect of the underlying ground albedo acting as a minimum.

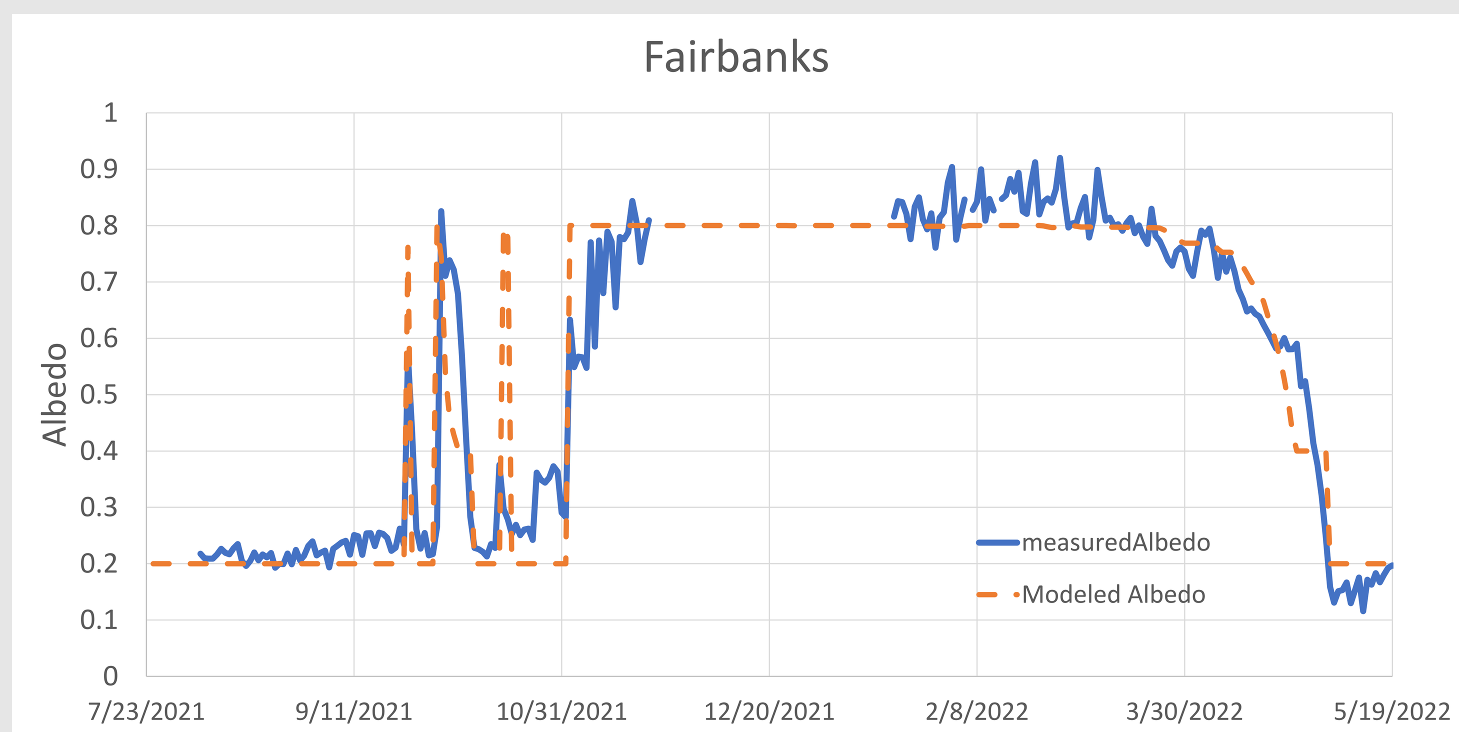


Here, measured albedo is normalized by the maximum albedo of each snow event. Multiple snow events are shown for each site.



"Exponential decay" albedo change mode, where snow for the prior 3 days was not always greater than 10 cm.

Early validation efforts show promising results, in predicting the decline of snow albedo at the end of the snow season. Time periods where the sun elevation is less than 5 degrees have been removed due to difficulty of albedo measurement.



Results & Discussion

Continued analysis of the different snow albedo change modes has yielded a pair of equations that approximately follow the measured albedo data at the 6 sites used for reference data.

The primary equation for the "concave down" model is:

$$A_{Norm} = \frac{1.0982}{1 + e^{0.011(MH-280)}} - 0.05$$

The primary equation for the "exponential decay" model is:

$$A_{Norm} = 0.2 + 0.8e^{-0.019804 \times MH}$$

These normalized values are multiplied by the maximum expected albedo for the site (e.g., 0.8) to determine the expected true albedo of the site.

Our improved model not only captures realistic changes in snow albedo values throughout the winter, but it relies on widely-available data in PV performance modeling. The model **requires** only time-series data of daily snow depth (on the ground) and hourly ambient temperature. Optional inputs may be used to further customize the model based on the site, if desired. These optional inputs include the albedo of underlying ground, the minimum albedo of snow, the albedo of fresh snow, the snow depth where ground cover is visible, and the required snow depth change required to trigger a new snow event.

Initial validation efforts which compare the model output to measured snow albedo show that the improved model predicts snow albedo more accurately than a simple binary value model, with the most improvement shown early and late in the winter where new snow may not persist for long periods of time.

Conclusion

We have successfully completed an improved model for predicting the albedo of snow as the snow melts and settles over time. The model uses only the commonly-available data of ambient temperature and snow depth.

We are in the process of more fully validating the model and comparing the performance against the widely-used binary-value model, but early results show improvement, especially early and late in the snowfall season.

We are currently writing a paper that provides more details of the model itself, the model generation process, and the validation results. We have completed encoding the model in MATLAB and will release the model to the PV modeling community through PV_LIB.

References

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SAND No.SAND2023-03132C