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# ACCURATE MODELING OF ALBEDO IN WINTER

*Snow is an ever-changing substrate*

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2024 Photovoltaic Modelling Collaborative Workshop



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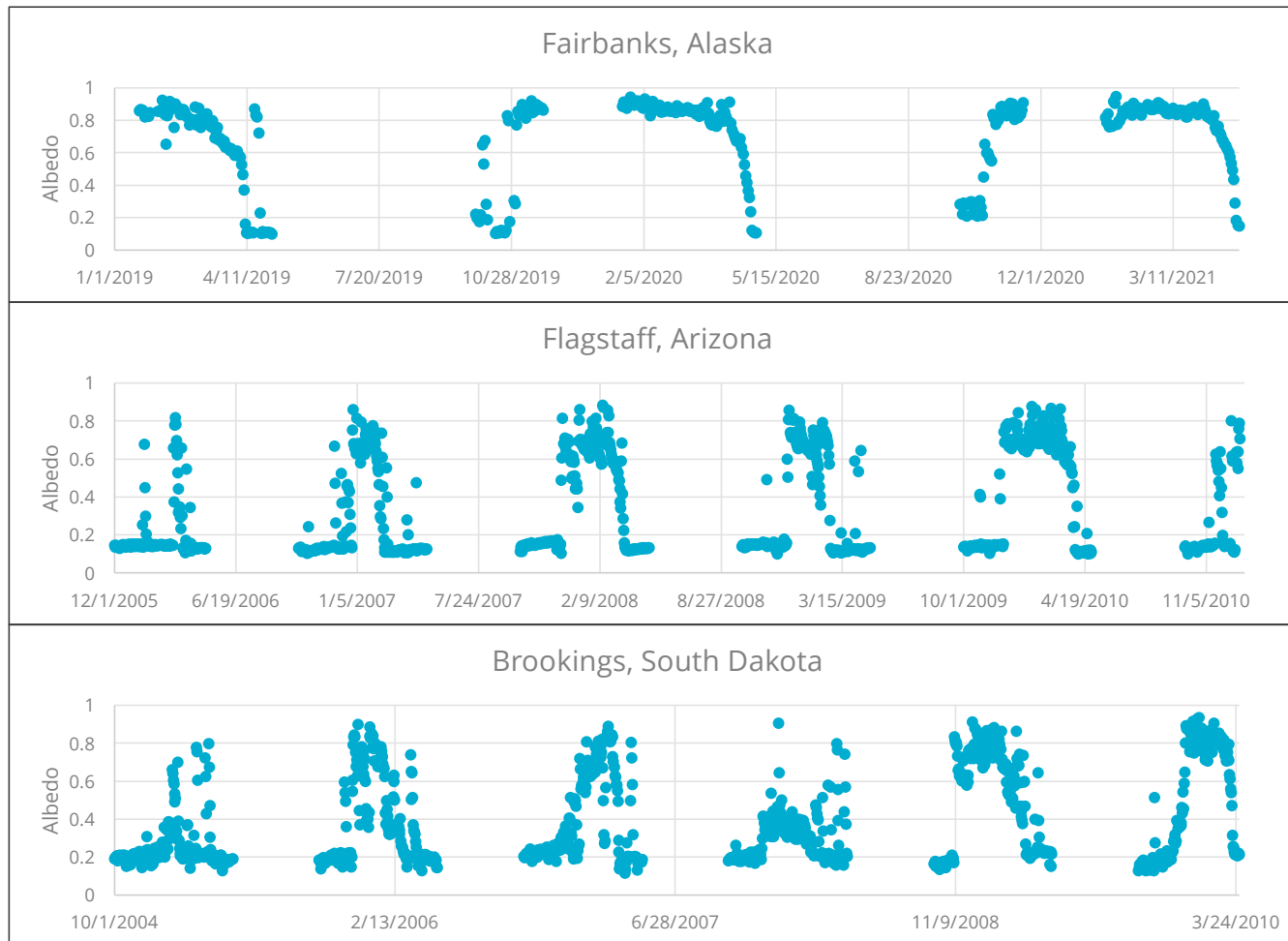
# MOTIVATION

## SNOW ALBEDO



- Snow albedo (reflectivity) changes
  - Snow morphology, age, and density
  - Particulate accumulation
  - Melting down to the (presumably) darker surface below
- It is an important factor in PV performance estimation in locations that receive snow
  - Bifacial PV
  - High tilt PV or tracked PV
- It is traditionally modeled as one of two values, e.g. 0.8 when snow present, 0.2 otherwise
  - A binary model
- Snow-melt models are fairly common in estimating snow pack and water runoff
  - The albedo portion of these models is usually a minor component, but requires more complicated inputs

## THE BINARY MODEL LEAVES SOMETHING TO BE DESIRED



**32% of** days between October and April had avg albedo between .2 and .8 (excludes days when sun was <5 degrees)

**36% of** days between October and April had avg albedo between .2 and .8.

**68% of** days between October 1 and April 30 had avg albedo between .2 and .8.



## GOALS FOR OUR MODEL

- More accurately estimate snow albedo as the snow changes, melts, compacts over time
  - Compared to a binary model
- Uses easy-to-find inputs and easy to calculate
  - The slightly better model you use is better than the complicated model you don't use
- Many of the existing snow-melt models use (among other things) a factor of time and temperature
  - This gives us a starting point



DEVELOPMENT



## DEVELOPING THE MODEL

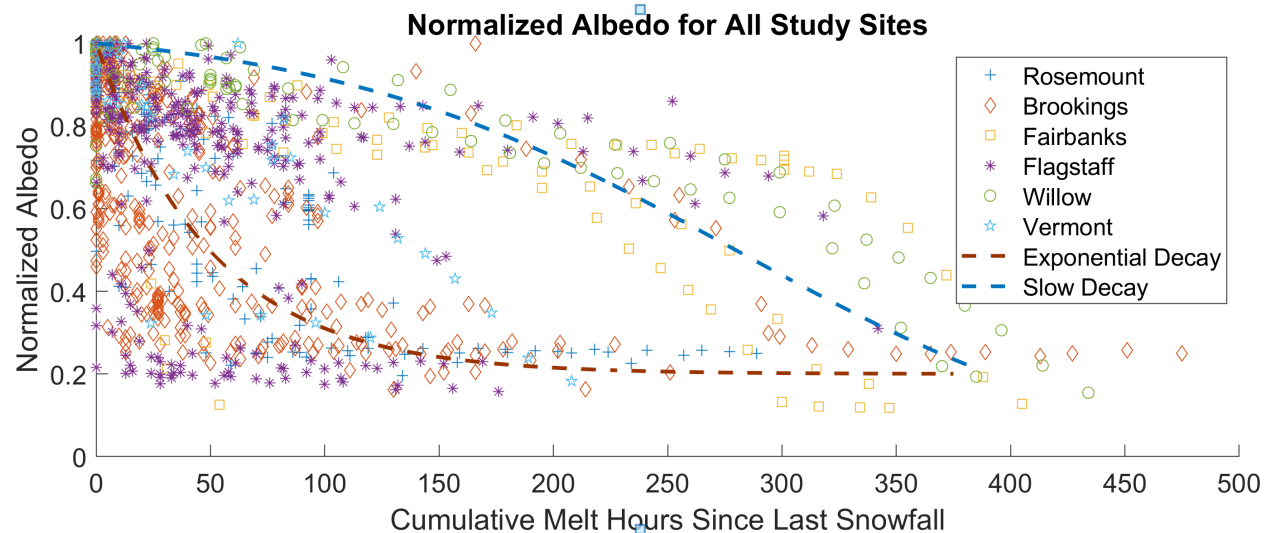
- Some data measured by us, some from the AmeriFlux data network
  - Snow depth (daily or more frequently)
  - Ambient temperature (hourly or more frequently)
  - Albedo (hourly or more frequently)
- 6 sites used in “training” data
  - Fairbanks, AK
  - Willow, AK
  - Fairlee, VT
  - Brookings, SD
  - Flagstaff, AZ
  - Rosemount, MN
- Data cleaning was required

<https://ameriflux.lbl.gov/data/data-policy/>



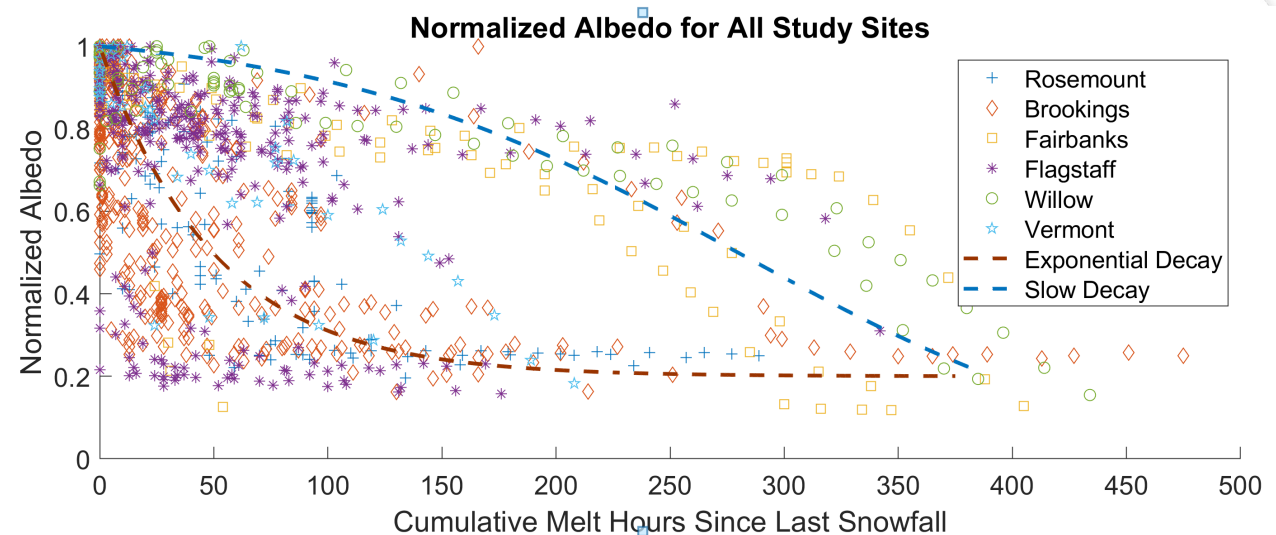
## EVENT CLASSIFICATION

- “Snow events” classified as periods of 3 or more days without new snow fall
- Within each snow event, sum the number of hours where the hourly temperature is  $> 0^{\circ}\text{C}$ 
  - A “melt-hour”
- Normalize the albedo within each event such that the maximum normalized albedo = 1
- Plot the normalized albedo of snow as a function of the number of hours with temperature  $> 0^{\circ}\text{C}$

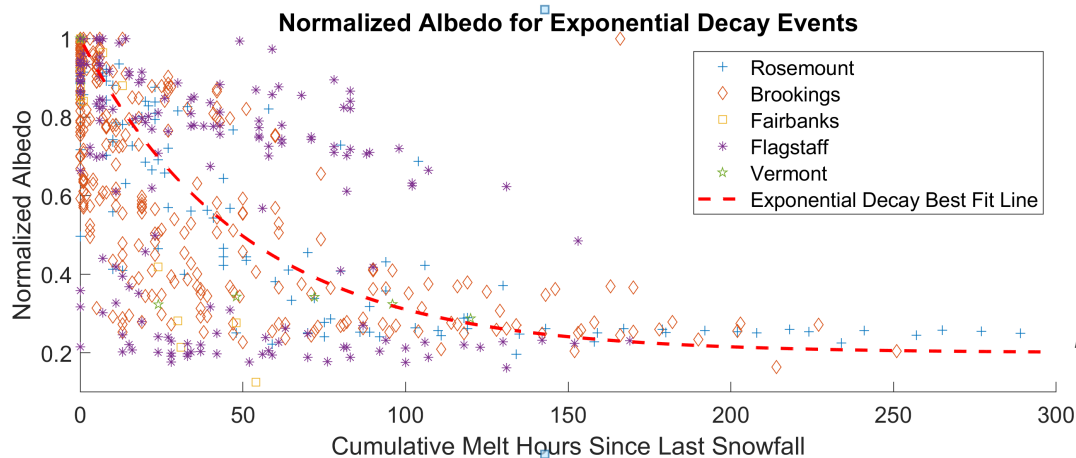
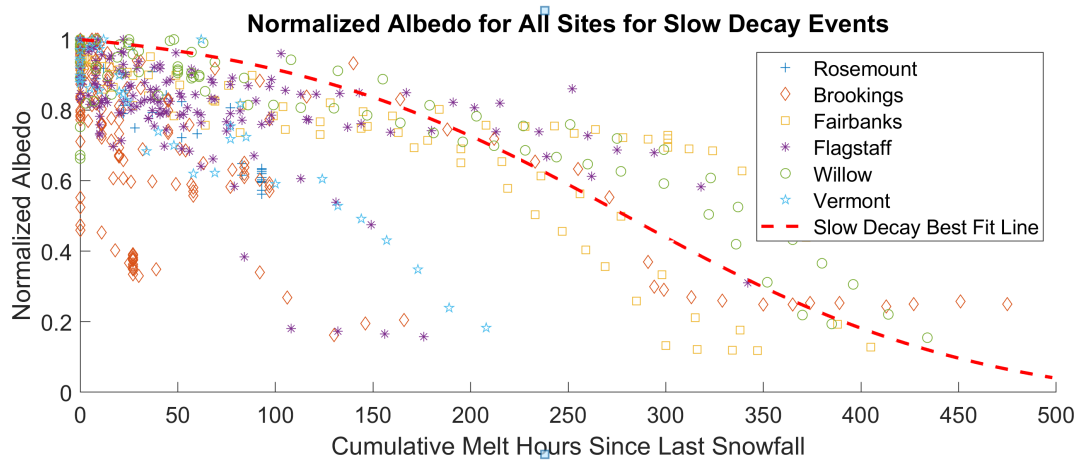


## SEPARATING THE EVENTS

- Two event types
  - “Exponential Decay”
  - “Slow Decay”
- Amount of snow on ground on the day prior to the start of the event determines which event type
  - $> 10$  cm = Slow Decay
  - $< 10$  cm = Exponential Decay



# SEPARATING THE EVENTS



$$\beta_{SD} = \frac{1.0982}{1 + e^{0.011 \times (M - 280)}} - 0.05$$

- $\beta$  is the albedo reduction factor for the “slow decay” or “exponential decay” modes
- $M$  = accumulated melt hours since last snowfall

$$\beta_{ED} = 0.2 + 0.8 \times e^{-0.019804 \times M}$$

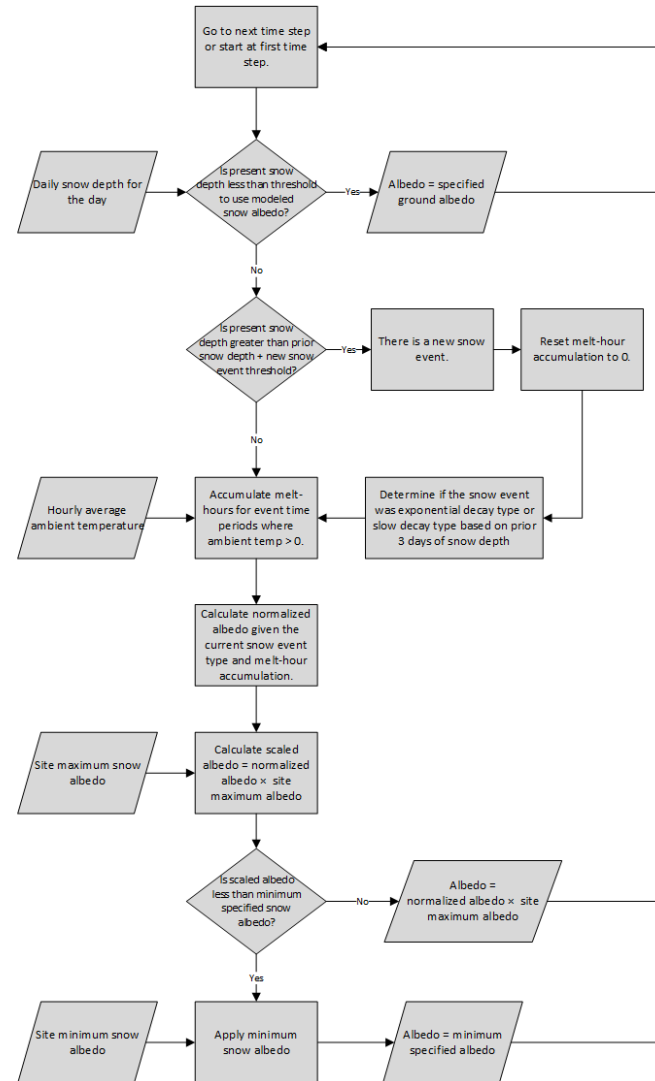




# MODEL DESCRIPTION & OPERATION

# THE INPUTS AND OUTPUTS OF THE ALBEDO CHANGE MODEL (AKA MELT-HOUR MODEL)

- Required Inputs
  - Daily snow depth
  - Hourly average ambient temperature
- Optional inputs
  - Site maximum albedo (default = 0.8)
  - Site minimum snow albedo (default = 0.4)
  - Site albedo without snow (default = 0.2)
- Outputs
  - Modeled albedo



## MODEL OPERATION IN A NUTSHELL

- Step through the process for each time step:

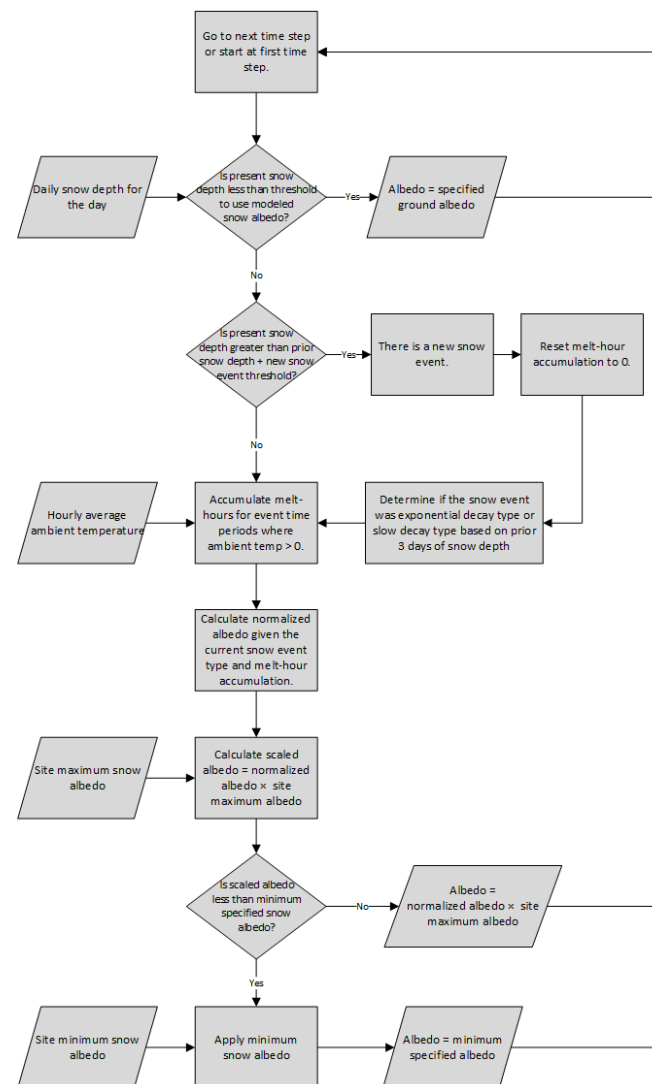
- Did it snow?

- No

- Accumulate melt-hours
      - Calculate albedo reduction factor from melt-hour accumulation
      - $\text{Albedo} = \text{reduction factor} \times \text{maximum site albedo}$
      - Apply filters

- Yes

- Reset melt-hour accumulation
    - Determine which type of snow event it will be based on snow on ground over the past 3 days
    - Accumulate melt-hours
    - Calculate reduction factor
    - Calculate Albedo
    - Apply filters





DOES IT WORK?

## LOOKS LIKE IT WORKS

- Compared the traditional binary model and the melt-hour model against the measured albedo
- RMSE and Mean Absolute Percent Error (MAPE) improve at all locations in the training data set
  - No surprise there
- RMSE and MAPE improve at all locations in the validation data set
  - Includes 2 locations that were not in the training data

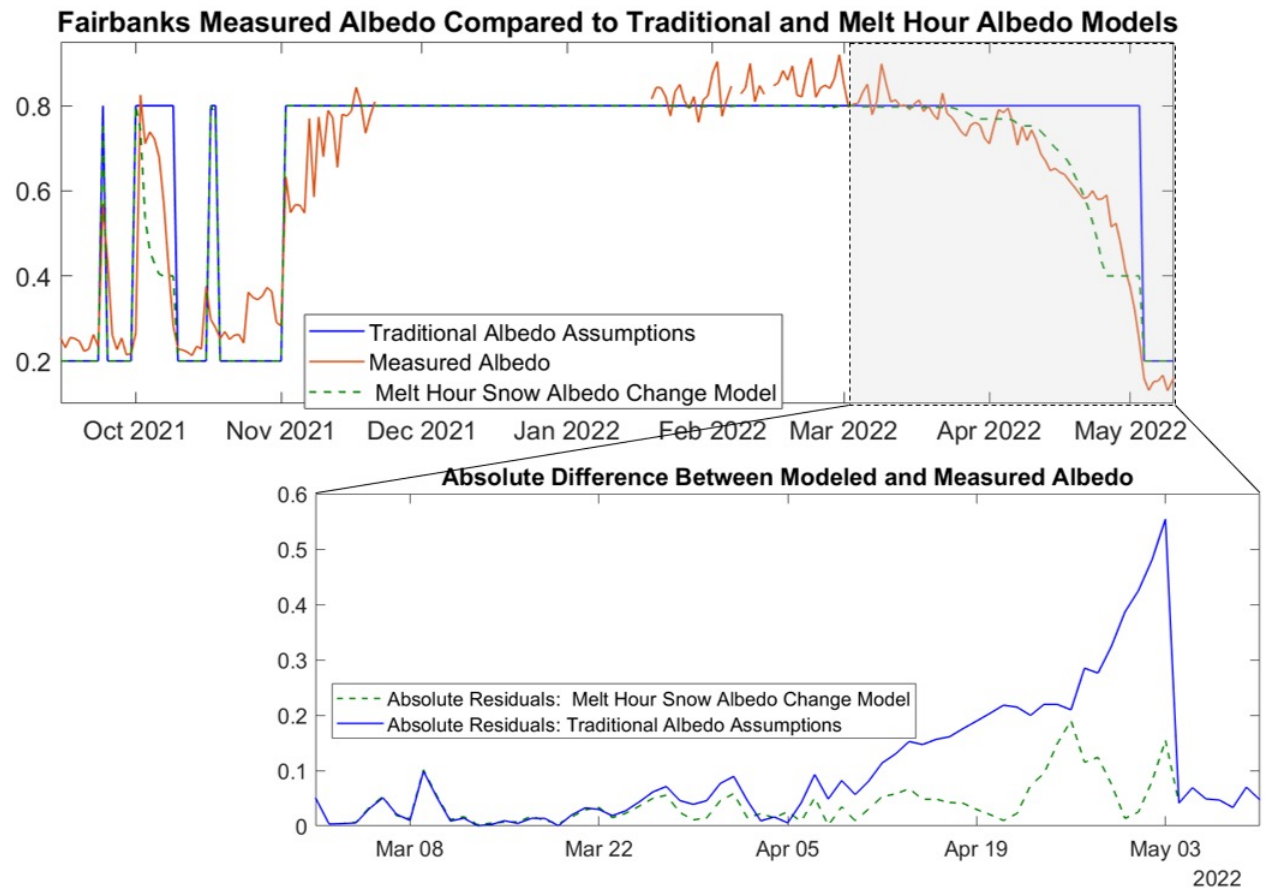
| Training Data Set   |                |                 |                    |                     |
|---------------------|----------------|-----------------|--------------------|---------------------|
| Location            | RMSE M-H Model | RMSE Trad Model | MAPE M-H model (%) | MAPE Trad model (%) |
| Fairbanks, AK 19-21 | 0.0857         | 0.0969          | 18.3954            | 19.7871             |
| Flagstaff, AZ       | 0.1137         | 0.1241          | 48.2178            | 49.8154             |
| Rosemount, MN       | 0.1431         | 0.1584          | 27.8605            | 30.2037             |
| Brookings, SD       | 0.1392         | 0.1463          | 23.2169            | 24.042              |
| Fairlee, VT 20-21   | 0.0893         | 0.2001          | 18.8632            | 39.4351             |

| Validation Data Set   |                |                 |                    |                     |
|-----------------------|----------------|-----------------|--------------------|---------------------|
| Location              | RMSE M-H Model | RMSE Trad Model | MAPE M-H model (%) | MAPE Trad model (%) |
| Fairbanks, AK 21-22   | 0.0835         | 0.1118          | 12.1099            | 15.6022             |
| <b>Haines, AK *</b>   | 0.1806         | 0.2158          | 57.1033            | 64.2638             |
| <b>Houghton, MI *</b> | 0.1604         | 0.1729          | 75.4356            | 78.3075             |
| Fairlee, VT 21-22     | 0.0812         | 0.0863          | 12.9847            | 13.7809             |

## TIME SERIES VIEW OF THE VALIDATION DATA, FAIRBANKS



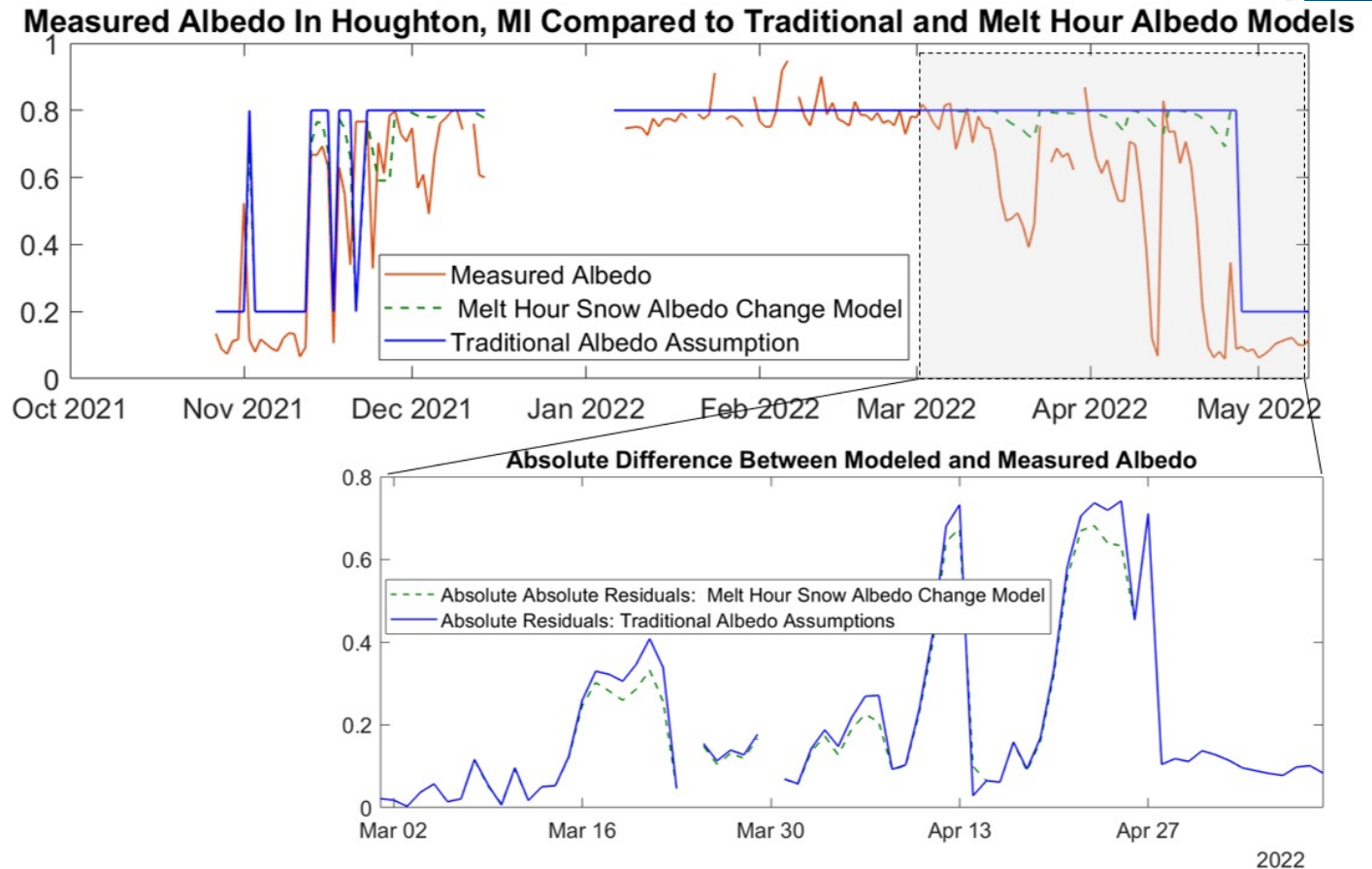
- Most of the improvement is found in the “shoulder seasons”
  - Melting snow gradually reveals the underlying terrain



## TIME SERIES VIEW OF THE VALIDATION DATA, HOUGHTON



- Again, the “shoulder season” shows the most improvement from advanced albedo modeling
- Note that Houghton was not in the training data set





WHAT'S THE  
EFFECT ON PV?



## IRRADIANCE MODELING

- SAM used to estimate irradiance in Fairbanks, AK
  - Front side irradiance at 60 degree tilt
  - Rear side irradiance at 60 degree tilt
  - Front side irradiance +  $0.8 \times$  rear side irradiance at 60 degree tilt
    - Approximate effective irradiance for bifacial PV modules with 0.8 bifaciality
- 3 different data sets *differing only in the albedo*
  - Modeled albedo using the measured albedo values – reference values
  - Modeled albedo using melt-hour model
  - Modeled albedo using traditional binary model

## FRONT POA INSOLATION

- Positive values indicate that the model under-predicted insolation relative to the measured albedo

| Front POA Insolation |                   |                                           |                 |                                           |
|----------------------|-------------------|-------------------------------------------|-----------------|-------------------------------------------|
| Month                | Traditional Model |                                           | Melt-hour Model |                                           |
|                      | % Error           | Absolute Difference (kWh/m <sup>2</sup> ) | % Error         | Absolute Difference (kWh/m <sup>2</sup> ) |
| October              | -0.94             | -0.43                                     | 0.34            | 0.16                                      |
| November             | -0.25             | -0.07                                     | -0.31           | -0.09                                     |
| December             | 0                 | 0                                         | 0               | 0                                         |
| January              | 0.05              | 0.01                                      | 0.05            | 0.01                                      |
| February             | 0.19              | 0.04                                      | 0.2             | 0.04                                      |
| March                | -0.2              | -0.3                                      | -0.11           | -0.17                                     |
| April                | -2.56             | -5.4                                      | 0.23            | 0.48                                      |
| <b>Total</b>         |                   | <b>-5.4</b>                               |                 | <b>2.51</b>                               |



## REAR POA INSOLATION

- Positive values indicate that the model under-predicted insolation relative to the measured albedo
- Rear POA is more strongly influenced by albedo than Front POA
- Rear POA is likely to be a smaller proportion of energy generation in many situations
  - Requires Bifacial PV
  - Tilt dependent

| Rear POA Insolation |                   |                                           |                 |                                           |
|---------------------|-------------------|-------------------------------------------|-----------------|-------------------------------------------|
| Month               | Traditional Model |                                           | Melt-hour Model |                                           |
|                     | % Error           | Absolute Difference (kWh/m <sup>2</sup> ) | % Error         | Absolute Difference (kWh/m <sup>2</sup> ) |
| October             | -13.18            | -1.15                                     | 4.9             | 0.43                                      |
| November            | -5.06             | -0.21                                     | -6.22           | -0.25                                     |
| December            | 0.71              | 0.01                                      | 0.68            | 0.01                                      |
| January             | 1.5               | 0.05                                      | 1.53            | 0.05                                      |
| February            | 1.96              | 0.12                                      | 2.01            | 0.12                                      |
| March               | -1.72             | -0.63                                     | -0.91           | -0.34                                     |
| April               | -19.32            | -12.89                                    | 1.84            | 1.22                                      |
| <b>Total</b>        |                   | <b>-13.29</b>                             |                 | <b>5.95</b>                               |

## SUMMARY OF IRRADIANCE MODELING

- The traditional binary model tends to greatly over-estimate insolation
- The albedo change model tends to under-estimate insolation, by a smaller margin than the binary model
- As seen in the model residuals, the largest differences in modeled irradiance are seen in the early and late months of the winter season





WHAT'S NEXT?

## UP NEXT

- Publish
- Incorporate into pvlib-python
  - Code written to implement the model (thanks Norman Jost!)
  - Feature request generated, awaiting a pre-print

## CONCLUSION AND CONTACT

- The melt-hour (albedo change) model
  - Improves upon albedo estimation of snow relative to the traditional binary model
  - Requires only easily-obtained inputs
  - Is tunable for each location if other factors are known (e.g., ground cover albedo)
  - Is almost ready to be used in your applications

THANK YOU

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