PV Snow Losses for the Contiguous U.S.: Gridded Models with Ground-Based Validation

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GroundWork

Modeled Monthly Snow Losses for the CONUS

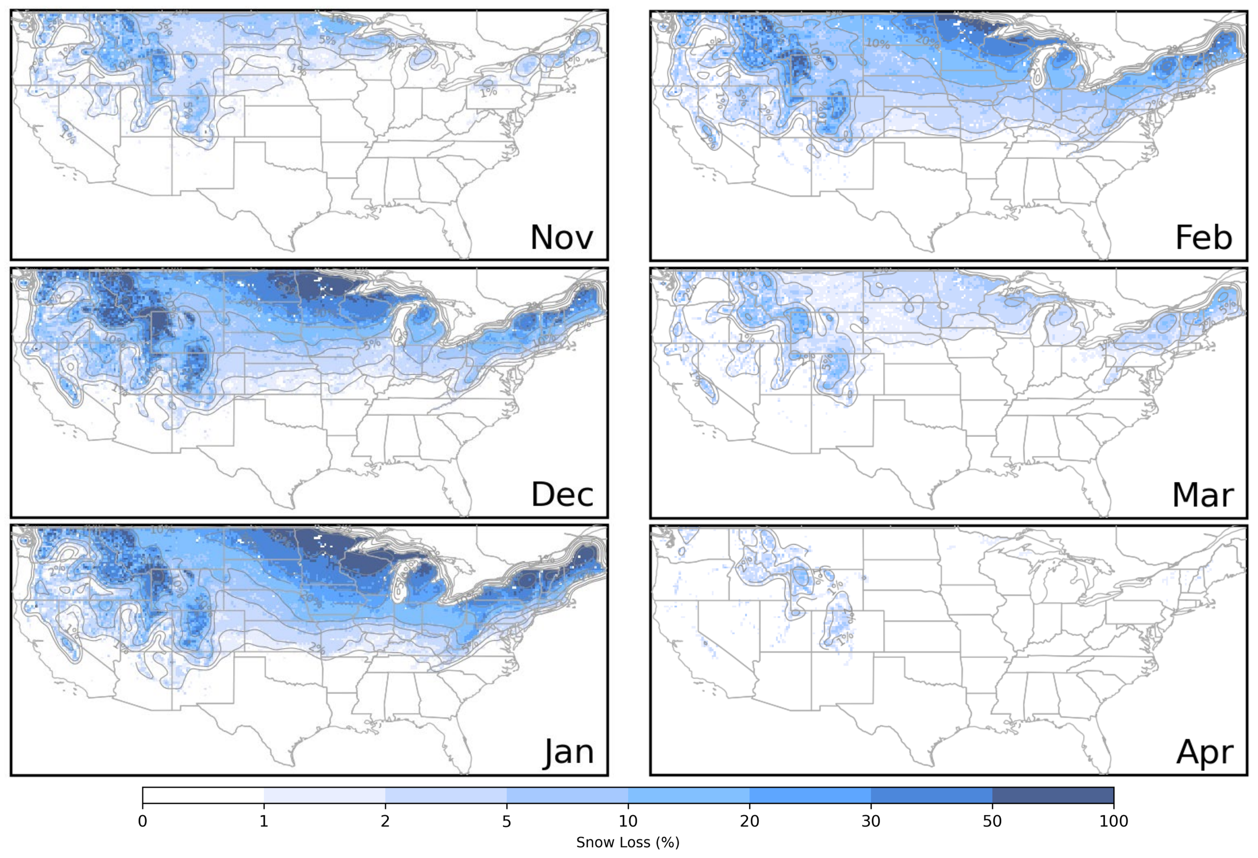

Figure 1. Marion median snow loss computed from NSRDB and SNODAS data 2003 – 2024 for modules at fixed 40-degree tilt. Temperature/POA coefficient -80. Rack-mounted slide coefficient 0.6.

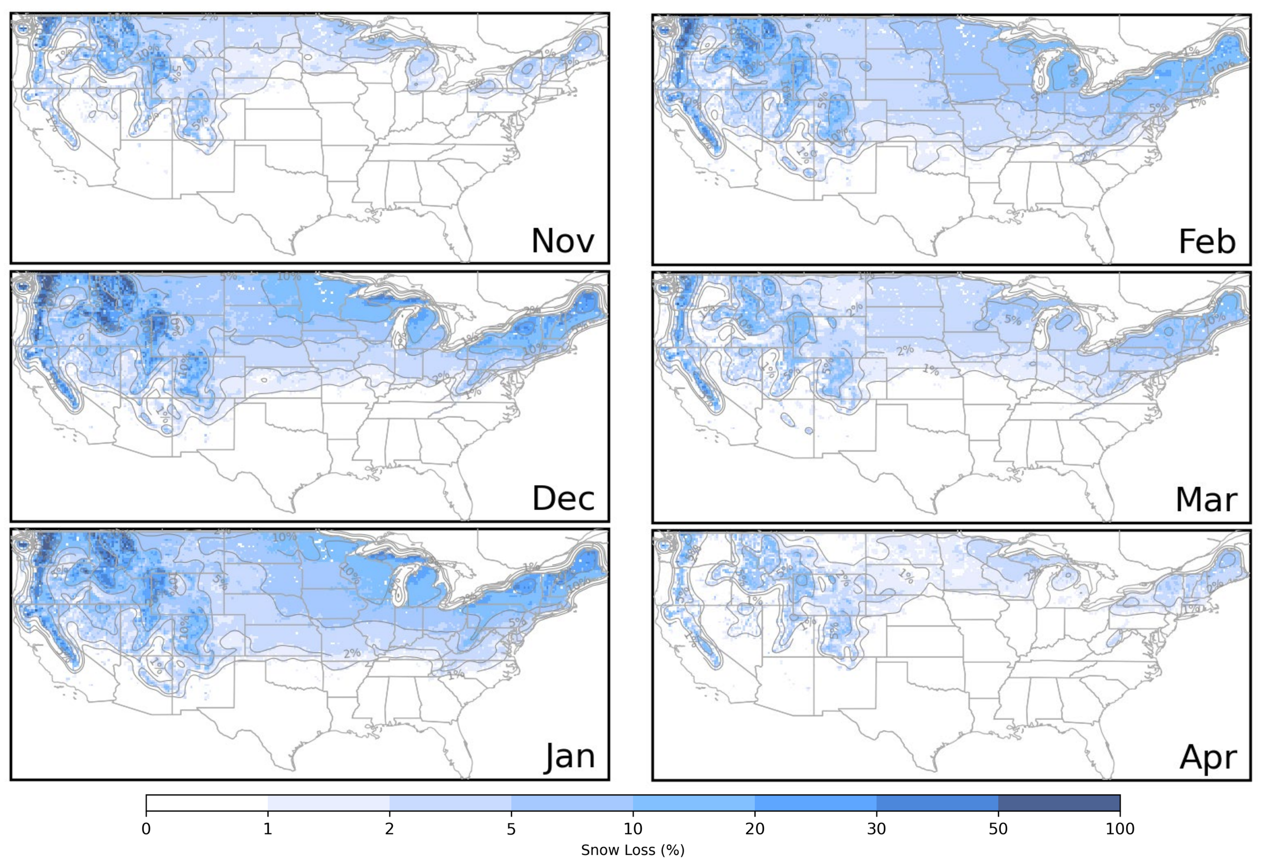

Figure 2. Townsend median snow loss computed from NSRDB and SNODAS data 2003 – 2024 for 2.4-m long modules at fixed 40-degree tilt. Module lower edge is 1 m above the ground surface.

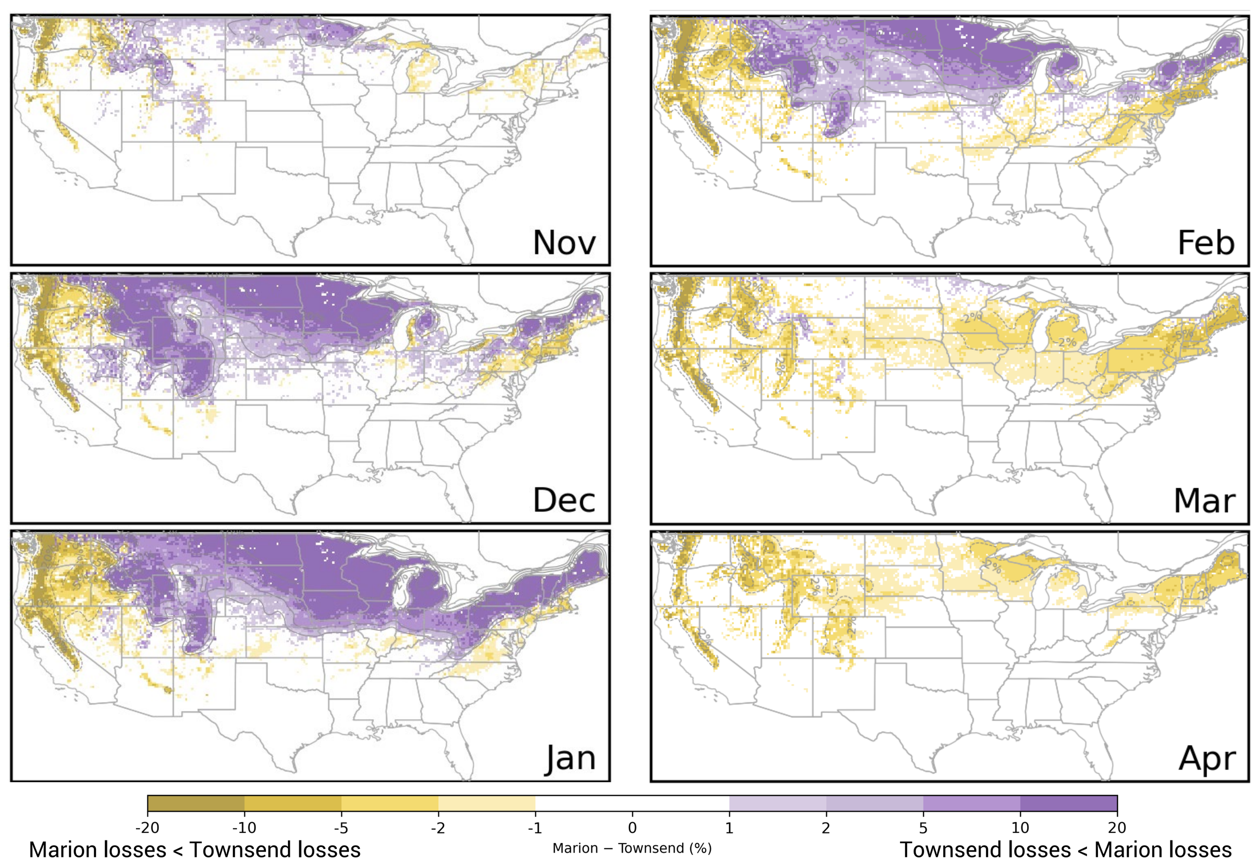

Figure 3. Difference (Marion – Townsend) median snow losses. Losses computed from NSRDB and SNODAS data, 2003 to 2024.

Takeaways

- NSRDB and SNODAS data can be used as inputs to both models in any location in the CONUS.
- Marion generates larger losses under cold conditions, such as in the middle of winter in the northern states. *The Marion model doesn't shed snow when it is extra cold.*
- Townsend generates larger losses with warmer temperatures and more snow, such as the Sierra mountains in the west. *The Marion model sheds snow under warmer temperatures. The Townsend model does not allow snow shedding with large amounts of snow.*
- Further work is needed to diagnose the sources of the deviation between the two models.

GOALS:

1. Generate monthly snow loss maps for the contiguous U.S. using the Marion and Townsend models driven by gridded satellite inputs (NSRDB/SNODAS).
2. Validate modeled snow losses against ground-based measurements.

Model Inputs

Years: 2003 – 2024 (22 years)
0.2 x 0.2 grid spacing (~22 km)

Models Require
POA irradiance
Snow timing and amount
Temperature
RH (Townsend)

NSRDB (product of NLR)
- GHI, DNI, DHI, air temperature, relative humidity
- Hourly values

SNODAS (product of NOAA)
- Snow depth
- Daily values

Modeled vs Measured: Upstate New York

Figure 4. Photographs of soiling kit modules. Soiled module on left side. Cleaned on right side.

TOP: Snow-covered module, 2024-01-17

BOTTOM: Naturally cleaned soiled module, 2024-01-28

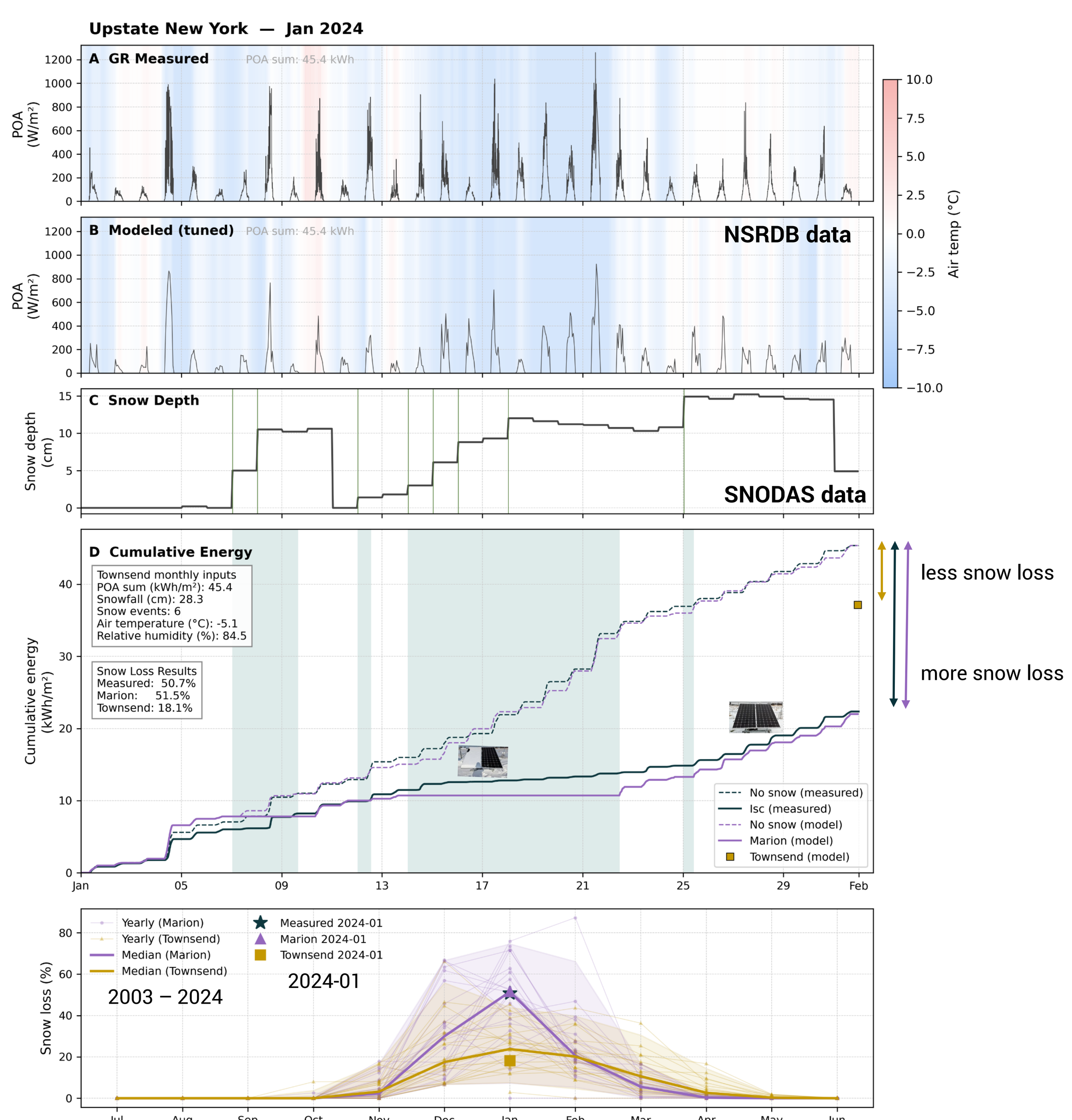

Figure 5. (A, B, C, D) Timeseries of a single month. For *this particular month and location*, snow reduced the cumulative energy to a greater degree in Marion than in Townsend, and Marion better approximated the measured snow loss. (Bottom) measured and modeled losses for January 2024 relative to modeled historic losses.

Measurements

Soiling Kit Module to Pyranometer Tuning Method:

1. **Pyranometer GHI decomposition** — *GHI → DNI, DHI*
2. **Pyranometer GHI transposition** (also done with NSRDB GHI) — *DNI, DHI → POA*
3. **Convert soiled module Isc to effective irradiance** — *Isc → G*
4. **Find valid minutes to perform tuning** — *mask = (SZA < 80) & (winter median G <= G) & (POA > 100) & (Nov – Mar)*
5. **Compute tuning factor** — *k = median(G[mask] / POA[mask])*
6. **Apply tuning factor** — $G_{Adj} = G / k$

Measured Monthly Snow Loss Calculation:

$$Snow\ loss = 1 - \frac{E_{with}}{E_{without}} = 1 - \frac{\sum G_{Adj}}{\sum POA}$$

(A similar equation is used for Marion snow loss.)

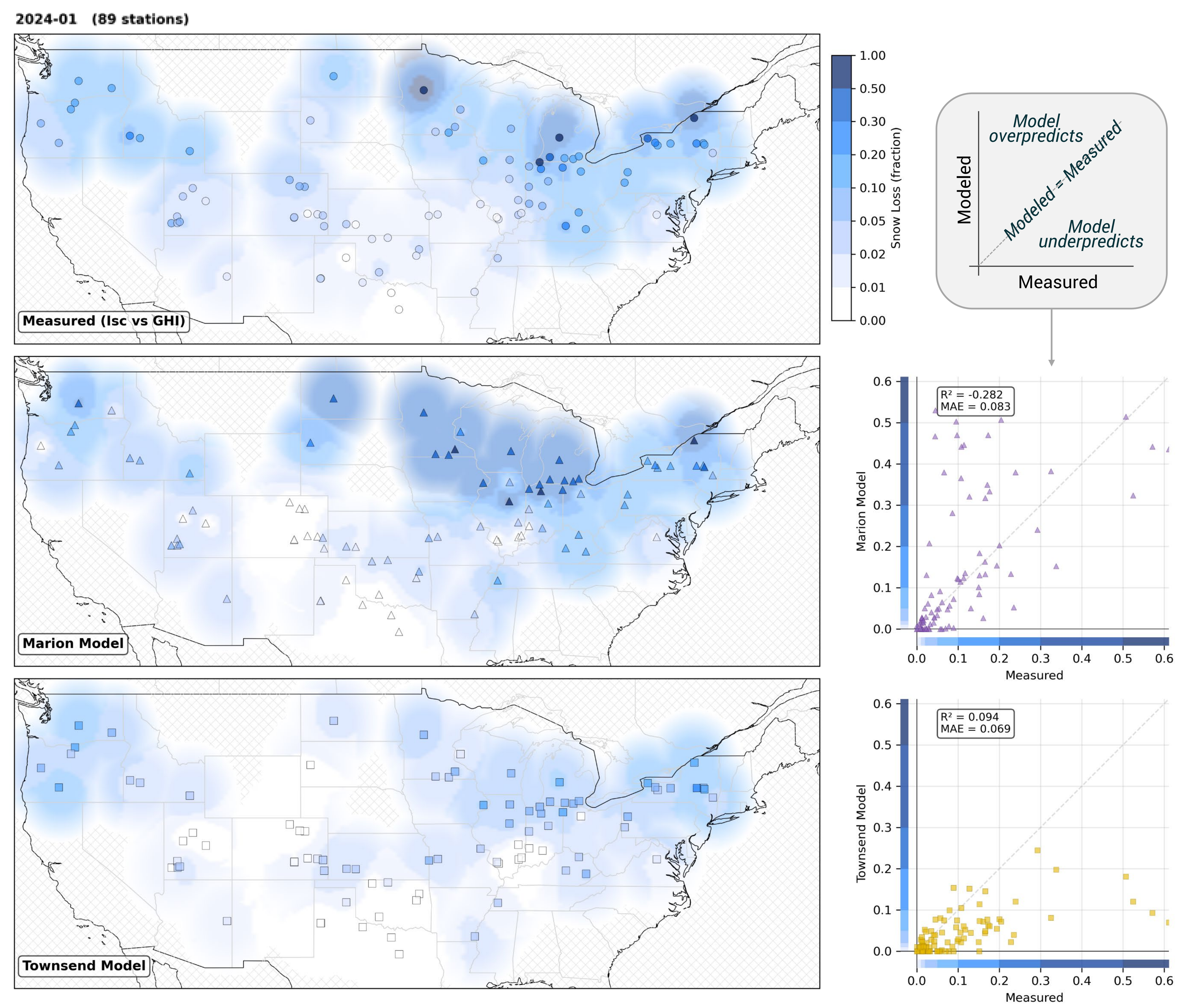

Figure 6. Measured (top) and modeled (middle and bottom) snow loss across 89 validation sites.

Modeled vs Measured by Region

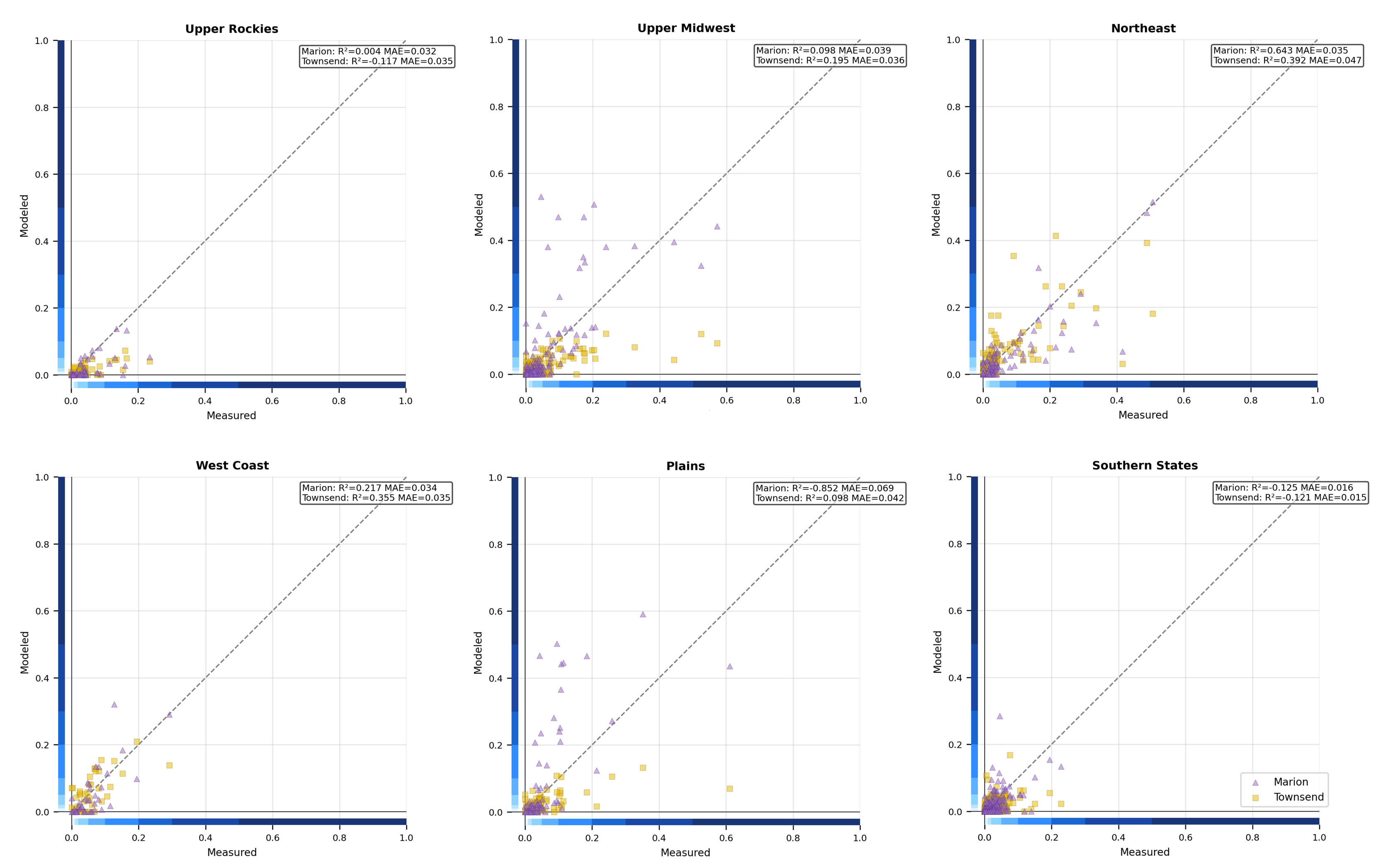

Figure 7. Regional snow loss patterns. Points above the 1:1 line indicate model overprediction; points below indicate underprediction.

Takeaways

- A co-located soiling kit and pyranometer can be used to measure snow losses. Care must be taken to account for dust soiling and when performing Isc and POA transformations.
- Snow loss values using the NSRDB and SNODAS data sets as inputs to the Marion and Townsend models are in the same realm as those using the co-located soiling kit and pyranometer method.
- Validation of the snow loss measurement method and modeling methods using gridded satellite data inputs has been demonstrated.

References

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[2] Townsend L, Powers L. *Photovoltaics and snow: an update from two winters of measurements in the Sierra.* IEEE PVSC 37. 2011. p. 003231–6.
[4] Sengupta, M, Xie Y, Lopez A, Habte A, Maclaurin G, Shelby J, *The National Solar Radiation Data Base (NSRDB)*, Renewable and Sustainable Energy Reviews 89 2018 (June): 51-60.
[4] National Operational Hydrologic Remote Sensing Center. (2004). *Snow Data Assimilation System (SNODAS) Data Products at NSIDC. (G02158, Version 1).* Boulder, Colorado USA. National Snow and Ice Data Center.
[5] Anderson, K, Hansen, C, Holmgren, W, Jensen, A, Mikofski, M, Driesse, A, *pvlib python: 2023 project update.* Journal of Open Source Software, 8(92), 5994, (2023).https://doi.org/10.21105/joss.05994