STORM-BASED ESTIMATION OF DESIGN GROUND SNOW LOAD FOR SOLAR PANELS

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Outline

Design Snow Load

Snow water equivalent **(SWE)** has its primary application in the development of load standards for building design.

Design snow load is the weight of snow with a mean recurrence interval (MRI) of 50 years.

Numerous studies have been done to determine design snow load at state and national level:

- Montana: Theisen et al. [2004]
- Utah: Bean et al. [2018]
- Colorado: DeBock et al. [2017], Liel et al. [2017]
- Conterminous United States: Bean et al. [2021]

Design Snow Load

Like with roof of buildings, solar panels must be designed to support the maximum weight of snow.

A stand-lone solar panel mounted at a steep angle promotes the shedding of snow.

This shedding phenomenon leads to a critical difference compared to traditional roofing systems that assume that accumulated snow persist for longer periods.

Design Snow Load

Issue: The current design loads in **ASCE 7-22** fail to consider the snow-shedding properties of solar panels. These design loads model the peak, season-long accumulation of snow.

Fix: This paper addresses the issue by requiring a change in the temporal scale of snow measurements considered.

- We evaluate short-term rather than season-long accumulation of snow.
- We mimic the shedding phenomena of the snow accumulation process by defining and extracting storm-level accumulations.

Data Description

Data set: Daily snow depth (SNWD) and SWE measurements used in this analysis were collected from 6,245 weather stations across USA.

- Source - National Oceanic and Atmospheric Administration's (NOAA) Global Historical Climatology Network (GHCND).
- Period - 1858 to 2021 (164 snow years).
- Stations Filters: At least 50% measurement coverage from station inception and 10 or more snow years.
- Weather stations:
  - SNOTEL - 428 stations
  - COOP - 5,566 stations
  - FOS - 251 stations

Missing Data in Snow Measurements

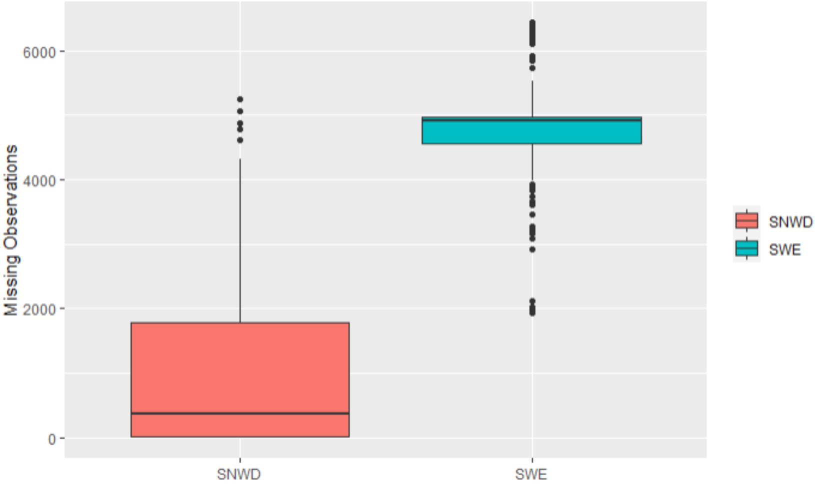


Figure 1: Missing observations of snow measurements

Data Imputation

SNWD Imputation: Using information of stations within a 100,000 meter radius and an elevation difference of 100 meters.

SWE Imputation: Missing daily SWE measurements are estimated using a storm-level random forests density model.

- The model is trained on all available stations to ensure consistency with observed snow densities in the USA.
- Predictor variables include climate and non-climate variables.

Daily Change Method

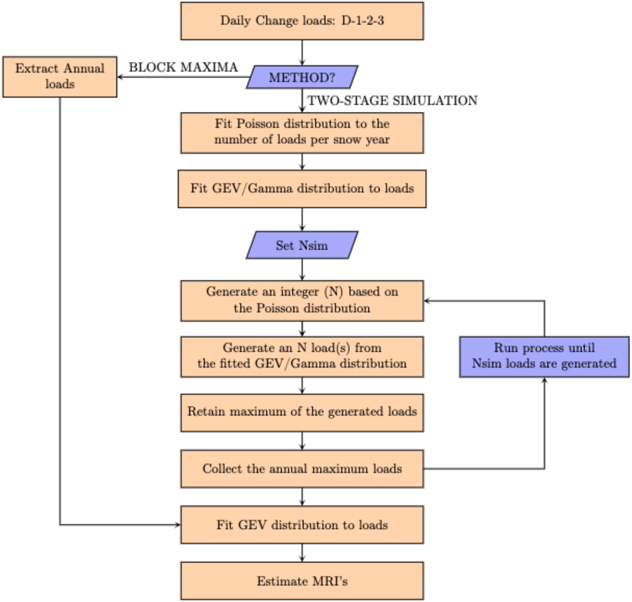
To mimic the shedding phenomenon of solar panels let's assume daily sequential changes in SWE:

$$\{\Delta SWE_t\}_{t=2}^{n} = (SWE_t - SWE_{t-1}) \tag{1}$$

Single-day (D1) Change method: The single-day method retains positive observations from Equation 1.

Multi-day Change method: Addresses changes in assumption (like no sunlight exposure or sticky snow) about the rate at which snow is shed on solar panel.

Key to our methodology: Using snowfall days to separate legitimate snow accumulations from random perturbations.


Daily Change loads: D-1-2-3
METHOD?
BLOCK MAXIMA
Extract Annual loads
TWO-STAGE SIMULATION
Fit Poisson distribution to the number of loads per snow year
Fit GEV/Gamma distribution to loads
Set Nsim
Generate an integer (N) based on the Poisson distribution
Generate an N load(s) from the fitted GEV/Gamma distribution
Retain maximum of the generated loads
Collect the annual maximum loads
Run process until Nsim loads are generated
Fit GEV distribution to loads
Estimate MRI's

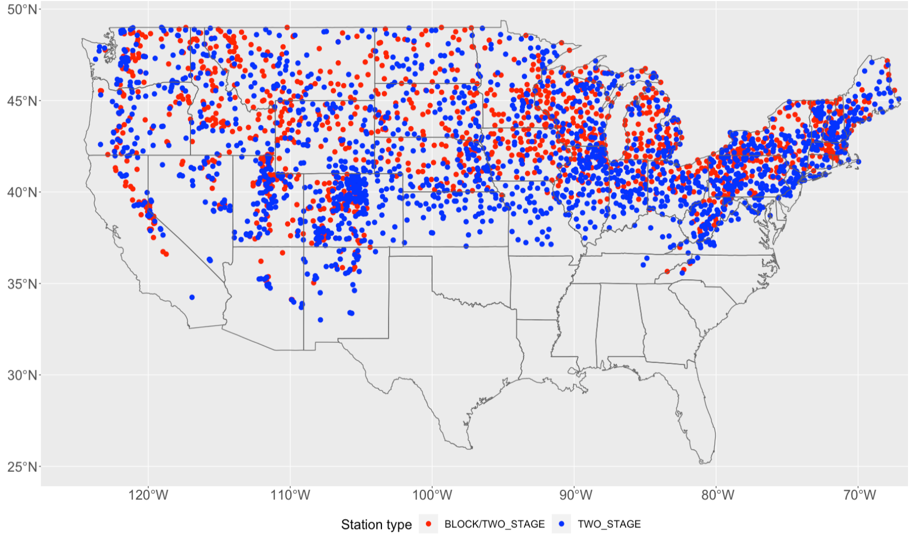


Figure 2: Final weather stations for MRI estimation

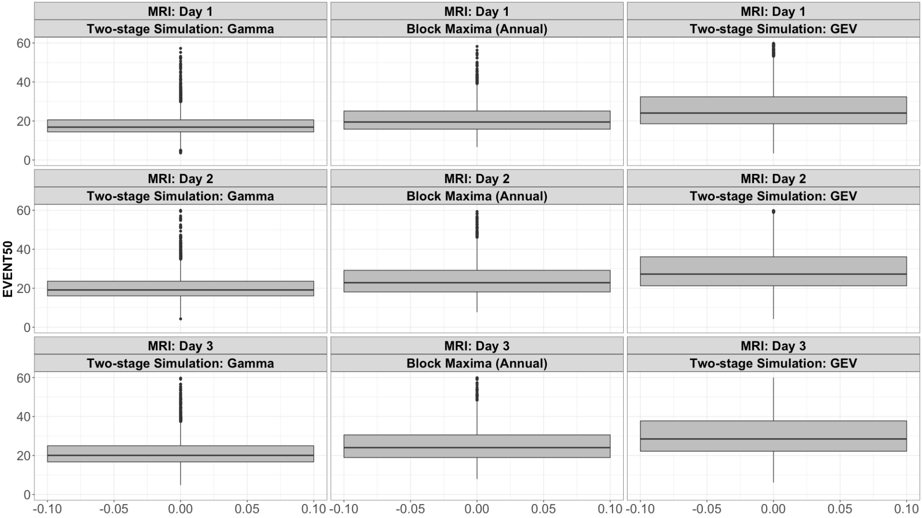


Figure 3: Day 1-2-3 MRI values per fitting approach

Spatially Continuous Prediction Map

- Regional generalized additive models (RGAMs) integrates generalized additive models and spatial partitioning into a single framework.
- The framework accomplished by **remap** r package [Wagstaff, 2021] allows for mapping between measurement locations.
- Variables used for mapping include:
  - Elevation
  - Mean temperature of the coldest month (30-year average)
  - Winter precipitation (30-year average)
  - Latitude and Longitude

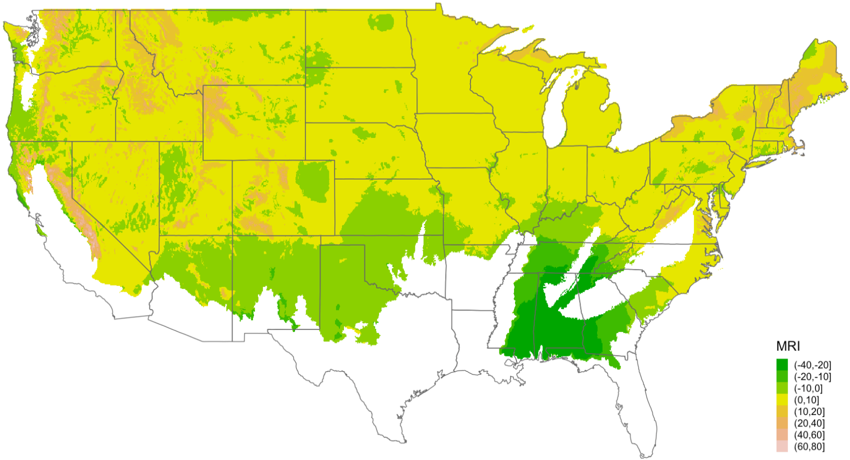


Figure 4: Difference plot between GEV two-stage simulation and block maxima approach for the Day-1 method. Values are measured in pounds per square foot(psf).

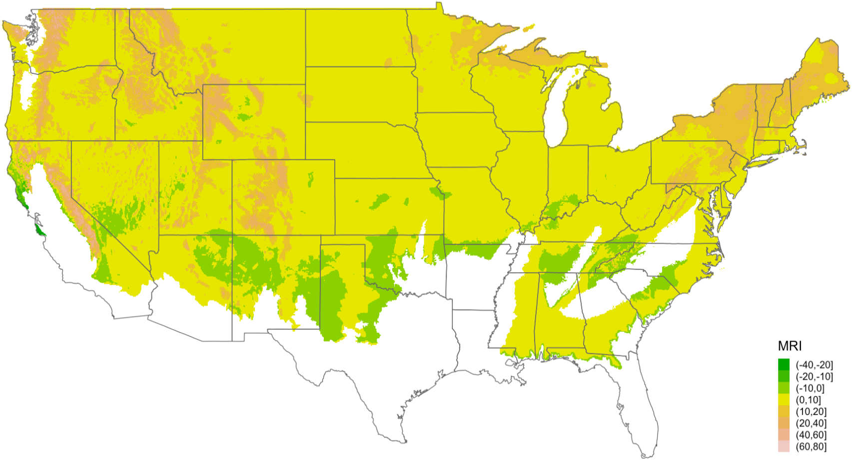


Figure 5: Difference plot between GEV two-stage simulation and gamma two-stage simulation approach for the Day-1 method. Values are measured in pounds per square foot(psf).

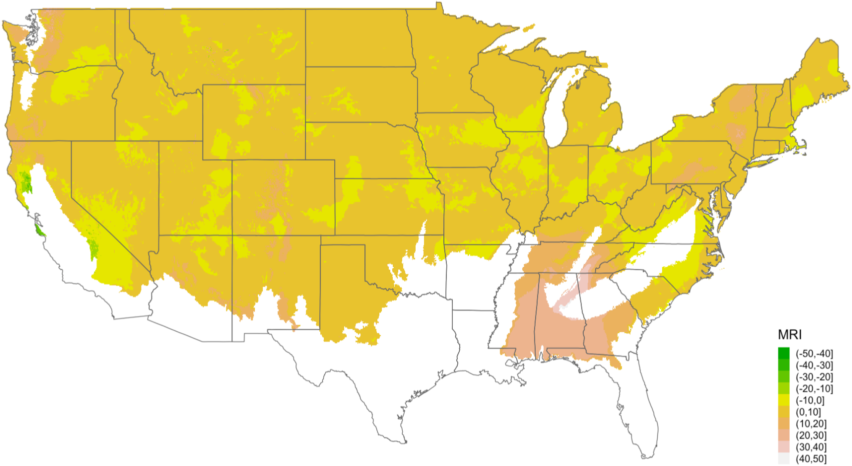


Figure 6: Difference plot between block maxima and gamma two-stage simulation approach for the Day-1 method. Values are measured in pounds per square foot(psf).

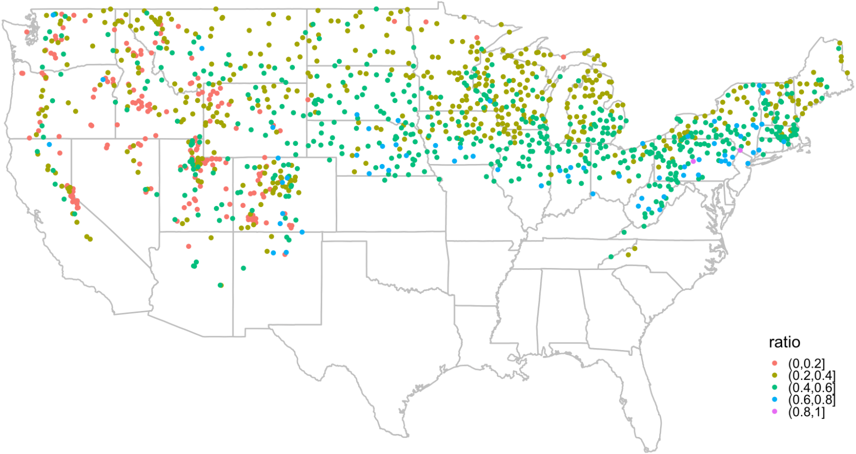


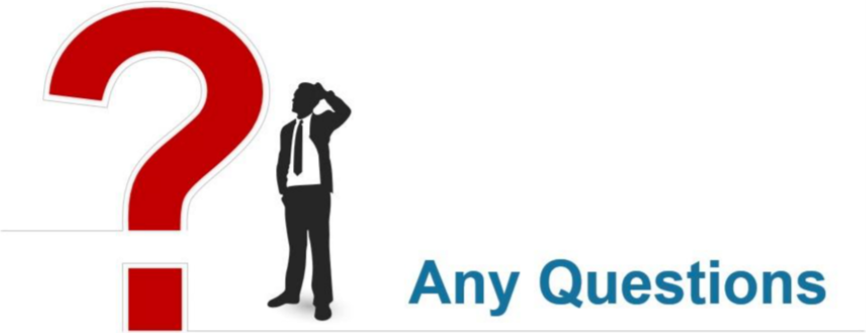
Figure 7: MRI ratio plot of Day-1 block maxima approach to peak, season-long accumulation block maxima approach. Stations have a least 30 observations.

Conclusion

- The GEV two-stage simulation approach produces larger MRI values on an average than the Block Maxima approach(traditional standard).
- The difference in MRI values between the various approaches are predominantly within a $\pm$ **10 psf** across the USA.
- Comparing traditional roof systems MRIs to solar-specific MRIs, MRI ratios turn out to be lower in mountainous stations.

Limitations and Future Work

- Long computational time for Day 2 and 3 data extraction.
- Explore a Bayesian framework (MCMC - Metropolis-Hastings algorithm) to synthetically generate daily snow loads and assess with the two-stage simulation approach.
- Determine Solar-specific design snow load based on uniform risk (safety index) rather than on uniform hazard (constant return period).


Any Questions

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