Statistical Downscaling of Climate Models for Solar Resource Assessment

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1. INTRODUCTION

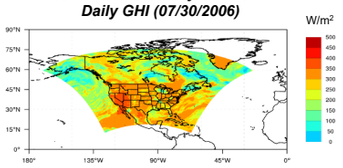
- Assessing solar energy resources under future climate scenarios has been highlighted to understand potential impacts of future climate change in solar generation on the power sector.
- Climate model projections have been recognized by the renewable energy community as a useful data set to analyze the impacts of future climate change on renewable resources.
- However, spatial and temporal resolutions of the GCMs (e.g., ~100 km and daily for spatiotemporal resolution) are too coarse for regional climate studies.
- Usually, regional solar resource assessments under future climate are performed using downscaled general circulation models (GCMs) using either-
  - regional climate models (RCMs) or
  - statistical/machine-learning based approaches.
- The main purpose of this study is to **develop statistical methods within an efficient framework** for downscaling future climate data sets tailored for solar energy applications.
- The **National Solar Radiation Database (NSRDB) (Sengupta et al. 2018)** is used to build and calibrate the statistical downscaling models with:

1) Bias-correction, 2) Temporal downscaling, and 3) Spatial downscaling

2. DATA

RCM Data

CanRCM4 forced by CanESM2 Daily GHI (07/30/2006)

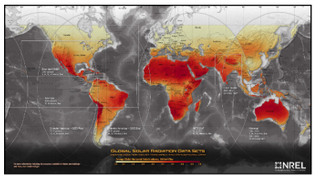


Feature	Specification
Forcing data (GCM)	CanESM2
Spatial resolution	0.22°
Temporal resolution	Daily
Variable	GHI
Data period	2006-2100
Scenarios	RCP4.5 and RCP8.5

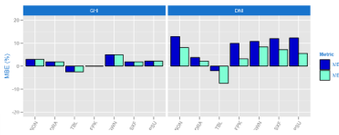
- RCM-based climate projections obtained from the North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX; https://na-cordex.org/) are used as inputs to the proposed statistical methods.
- We selected daily GHI simulated by the Canadian Regional Climate Model 4 (CanRCM4) forced by the second-generation Canadian Earth System Model (CanESM2).

Satellite-derived Observations

NSRDB



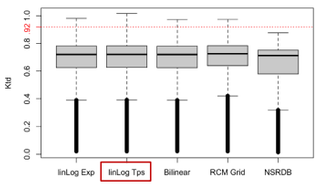
Mean Bias Error (MBE) for NSRDB compared to surface observations



- In order to be comparable with the RCM spatial resolution (0.22°), the 4-km NSRDB was averaged and aggregated to a 20-km grid.
- Jiménez et al. 2022 demonstrated that the accuracy of NSRDB is sufficient for regional model evaluation (e.g., WRF-Solar).

Regridding RCM Data to NSRDB Grid

Clear-sky index for different regridding methods

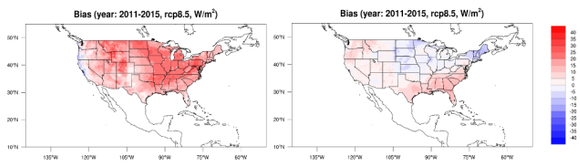


- Regridding RCM data (0.22° spatial resolution) to the 20-km NSRDB grid is the first step in downscaling the climate projections of solar irradiance.
- The uncertainty associated with this step was studied in Bailey et al. (2022) using a Bayesian hierarchical model.
- Bailey et al. (2022) showed that any uncertainty attributable to the regridding step in downstream modeling is negligible.
- We selected thin-plate splines (TPS) as a final spatial analysis method to regrid the RCM outputs to the 20-km grid.

3. BIAS CORRECTION

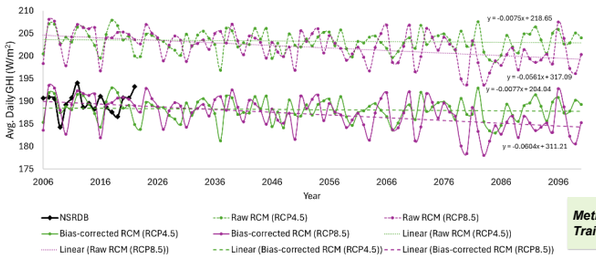
- We employed a bias correction technique based on quantile mapping (McGinnis et al. 2015) to reduce bias of RCM GHI.
- The quantile mapping method efficiently reduced the warm bias of RCM GHI for most regions across CONUS and produced a GHI bias within ± 20 W/m² in an out-of-sample application.

Raw RCM ***Bias corrected RCM***



95-years Bias-corrected GHI Projections

Daily GHI (2006-2100; RCP4.5 and RCP8.5)

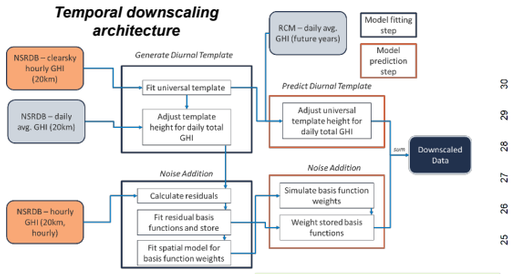


- The bias-correction method applied to the raw RCM conserves both the trend and pattern of the raw RCM GHI.
- This indicates that the quantile mapping reduces the bias of RCM GHI without adversely impacting the RCM's ability to represent future projections of solar irradiance trend and variability.

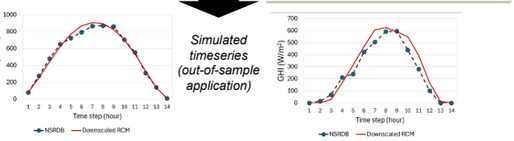
Method: *Quantile mapping*
Training period: *2006-2020 (15 years)*

4. TEMPOROAL AND SPATIAL DOWNSCALING

Temporal downscaling architecture



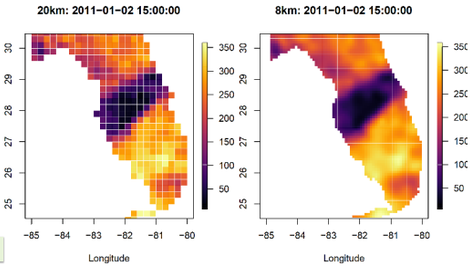
Training: *1998-2020 NSRDB data (23 years)*



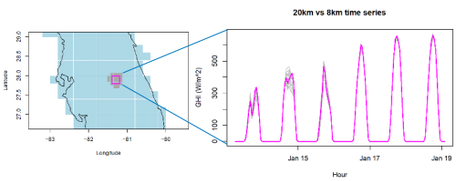
Simulated timeseries (out-of-sample application)

- Bias-corrected daily GHI is used as input to the temporal downscaling model.
- Significant effort was made to produce hourly-scale clouds representative of NSRDB cloud distributions.
- We developed 1) the diurnal template model and 2) the residual basis functions and trained the models using the NSRDB data.
- Spatially correlated cloud patterns are also considered through spatial model simulating noise.
- MBE of downscaled GHI is less than 3% against the NSRDB (for CONUS).

Spatial downscaling



Downscaled timeseries



- We developed a spatial model based on TPS to downscale the 20-km RCM data to 8-km resolution.
- The downscaled data notably enhances the spatial resolution, leading to increased detail and smoother transitions between pixels.

5. SUMMARY

- A statistical method was developed to correct biases of future projections of GHI simulated using RCMs and to downscale daily–20-km RCM GHI to hourly–8-km resolution GHI.
- The NSRDB data sets were used to calibrate the RCM output (from CanRCM4) and validate the downscaled GHI projections for CONUS.
- MBE for the downscaled hourly GHI was calculated to be 3% when compared to the NSRDB.
- The long-term solar radiation data set that covers entire CONUS will be publicly available.

REFERENCES

Bailey, M.D., Nychka, D., Sengupta, M., Habte, A., Xie, Y. and Bandyopadhyay, S., 2023. Regridding uncertainty for statistical downscaling of solar radiation. Advances in Statistical Climatology, Meteorology and Oceanography, 9(2), pp.103-120.

McGinnis, S., Nychka, D. and Mearns, L.O., 2015. A new distribution mapping technique for climate model bias correction. In Machine Learning and Data Mining Approaches to Climate Science: Proceedings of the 4th International Workshop on Climate Informatics (pp. 91-99). Springer International Publishing.

Sengupta, M., Xie, Y., Lopez, A., Habte, A., Maclaurin, G. and Shelby, J., 2018. The national solar radiation data base (NSRDB). Renewable and sustainable energy reviews, 89, pp.51-60.

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