Creating a consistent historical NASA POWER solar radiation dataset to support renewable energy, building energy efficiency and agro-climatology decisions

POWER Prediction Of Worldwide Energy Resources

https://power.larc.nasa.gov

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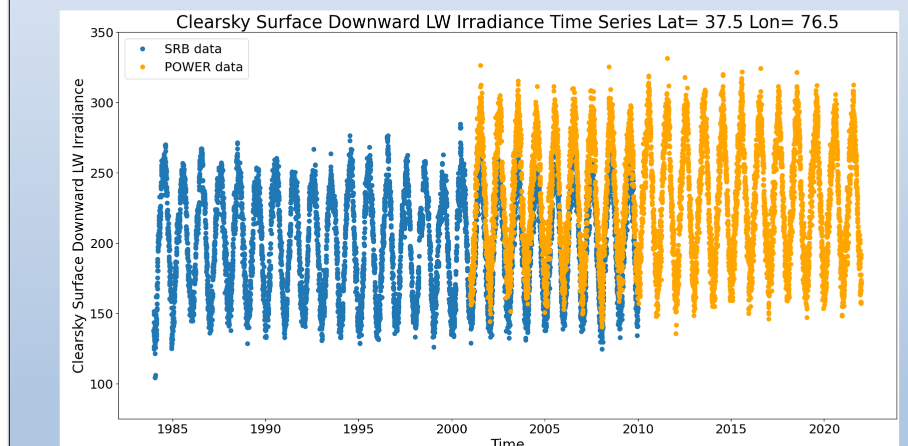
Introduction

- Prediction of Worldwide Energy Resources (POWER) project provides solar and meteorological dataset to support renewable energy, building energy efficiency and agricultural needs.
- POWER longwave and shortwave irradiance data are derived from Global Energy and Water Cycle Experiment Surface Radiation Budget (GEWEX SRB R4-IP) and Clouds and the Earth's Radiant Energy System Synoptic 1 degree (CERES SYN1Deg). These datasets are integrated to produce a single long term time series.
- **Problem Statement:** POWER data users have reported discontinuities (bias) between these two datasets for the years overlapping the observations. The presence of bias from the change in data source introduces a significant long-term trend in the time series which can have significant impacts on accuracy of energy yield estimates hindering informed decision making and misleading conclusions hence, it is important to bias correct the solar irradiance dataset that are used to assess potential of solar energy resources in a region.



- The goal of this work is to utilize bias correction techniques to retain the underlying trend while eliminating any systematic errors and biases to enhance the reliability and usefulness of the data.
- Some of the existing methods used to eliminate bias for stochastic variable are Linear Adaptation, Model Output Statistics (Multiple linear regression), Quantile mapping (CDF Matching), and Measure-Correlate-Predict which has been used in previous studies for similar parameters and have given good results.
- We adapt one of these approach to remove the systematic bias and also, present validation of the bias corrected data against ground truth.

Data Sources

POWER provides several solar and thermal infrared radiation parameters through the website:

Category	Parameters	Source	Statistics Available
Solar Parameters	Top-Of-Atmosphere Shortwave Downward Irradiance	CERES (SORCE, TSIS)	Climatology, Monthly, Daily, Hourly
	Top-Of-Atmosphere Shortwave Direct Normal Radiation	CERES (SORCE, TSIS)	Climatology, Monthly, Daily, Hourly
	All Sky Surface Shortwave Downward Irradiance (horizontal), Diffuse Horizontal*, Direct horizontal*, Direct Normal Irradiances* (* refers to the bias corrected all-sky fluxes)	CERES SYN1Deg Ed4	Climatology, Monthly, Daily, Hourly
	Clear Sky Surface Shortwave Downward Irradiance (horizontal), Diffuse Horizontal, Direct horizontal, Direct Normal Irradiances	CERES SYN1Deg Ed4	Climatology, Monthly, Daily, Hourly
	All Sky Shortwave Upward Irradiance, Clear Sky Shortwave Upward Irradiance	CERES SYN1Deg Ed4	Climatology, Monthly, Daily
	All Sky and Clear sky Spectral Fluxes: PAR, UVA, UVB and an UV Index	CERES SYN1Deg Ed4	Climatology, Monthly, Daily, Hourly
	Insolation Clearness Index, Clear-sky clearness index	CERES SYN1Deg Ed4	Climatology, Monthly, Daily, Hourly
	Clear Sky/All Sky Normalized clearness index	CERES SYN1Deg Ed4	Hourly
	Surface Albedo	CERES SYN1Deg Ed4	Climatology, Monthly, Daily, Hourly
	Solar Zenith Angle, Various solar geometry parameters	CERES SYN1Deg Ed4	Hourly, Climatology
Thermal Infrared Irradiance	All Sky and Clear-sky Surface Longwave Downward Irradiance	CERES SYN1Deg Ed4	Climatology, Monthly, Daily, Hourly
	All Sky Longwave Upward Irradiance, Clear Sky Longwave Upward Irradiance	CERES SYN1Deg Ed4	Climatology, Monthly, Daily

Satellite Derived Radiation Data

CERES SYN1Deg

- The CERES Synoptic 1 degree data product integrates derived fluxes from geostationary satellites to account for regional diurnal flux variations in between Terra and Aqua CERES measurements.
- CERES SYN1Deg has the spatial resolution of 1° latitude and 1° longitude and provides global coverage of shortwave and longwave irradiance from January 1, 2001, to few months within Near-Real time.

GEWEX SRB

- The SRB release 4 dataset integrates data products from cloud, aerosol, atmosphere, ocean surface, and land surface projects to produce a long-term time series of TOA and surface radiative estimates.
- GEWEX SRB R4-IP features full global coverage of shortwave and longwave irradiance from January 1, 1984, to December 21, 2009, with the spatial resolution of 1° latitude and 1° longitude. The length of this series allows overlap with the CERES products which has same spatial resolution.

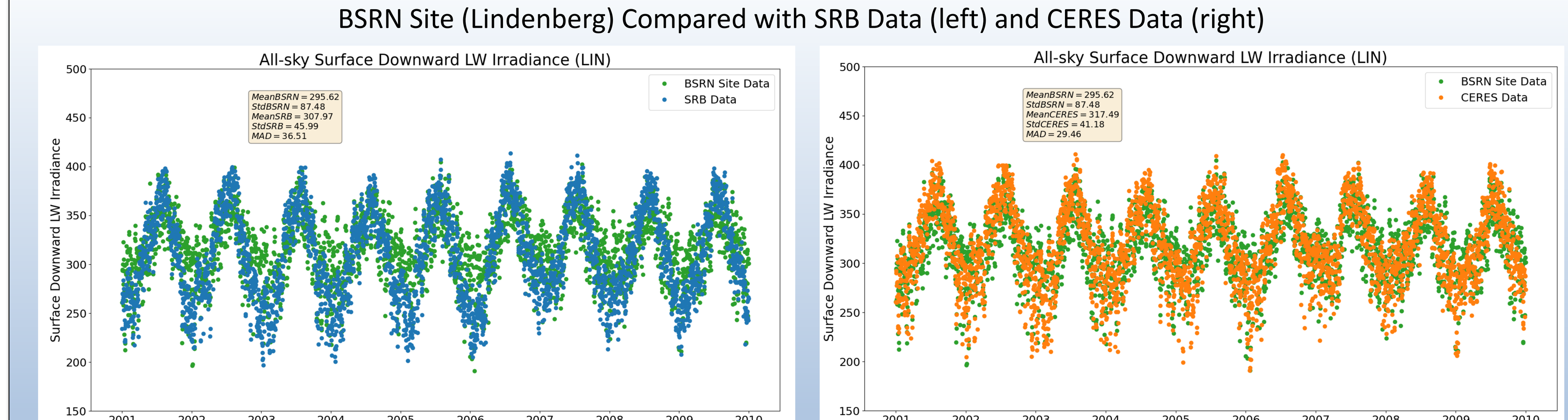
These two-irradiance datasets are merged within the POWER system at the data availability to form a single long-term time series. As a result, there is a discontinuity at the merge point in the shortwave clear-sky/all-sky and longwave clear-sky/all-sky irradiances. Reason for the bias are the different meteorological inputs to the radiative transfer algorithm used to calculate the irradiances that govern the outgoing longwave and shortwave such as water vapor, skin temperature and cloud properties.

Ground Measured Data

Baseline Surface Radiation Network (BSRN)

- BSRN is a radiometric network established by World Climate Research Program (WCRP) that provides ground-based observations to support climate research.
- Systematic SRB-BSRN and CERES-BSRN comparison for co-located daily shortwave and longwave radiation fluxes are done to validate and choose a reference to train the model for bias correction.

BSRN Site (Lindenberg) Compared with SRB Data (left) and CERES Data (right)

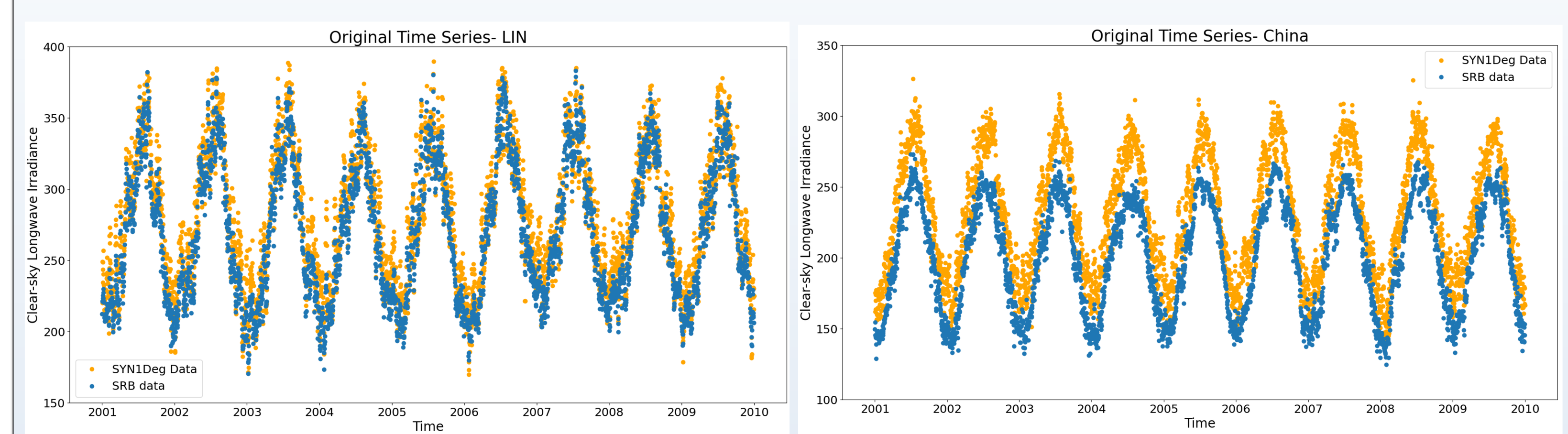


Comparison of statistical metrics show that the all-sky downward longwave ground measured irradiance data is more similar to all-sky surface downward longwave CERES SYN1Deg irradiance as compared to SRB irradiance data. The SRB dataset is adjusted using CERES as a reference.

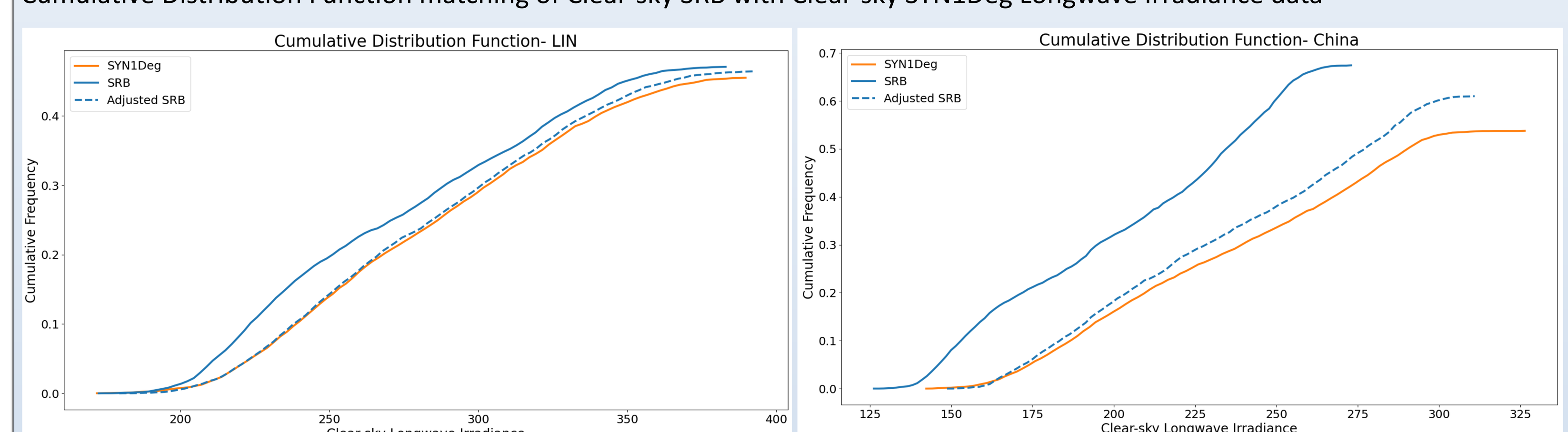
Methodology

- Different bias correction techniques including multiple linear and non-linear regressions, were explored for this work among which quantile mapping effectively removed the bias consistently over different surfaces.
- Limited availability of interacting factors that capture site specific differences adequately caused the regression method to fail for bias removal.
- Quantile mapping is a simpler approach that assumes the bias is relative to historical observations and will be constant throughout.
- Main idea is to adjust the statistical distribution (Cumulative Distribution Function) of SRB irradiance with the CERES, thus correcting for any biases in the SRB data.
- Effectiveness of this approach depends on the quality and representativeness of the data used to estimate the Cumulative Distribution Function
- Overlapping time period between CERES and SRB data (2001- 2009) is used as a training dataset to correct the bias.

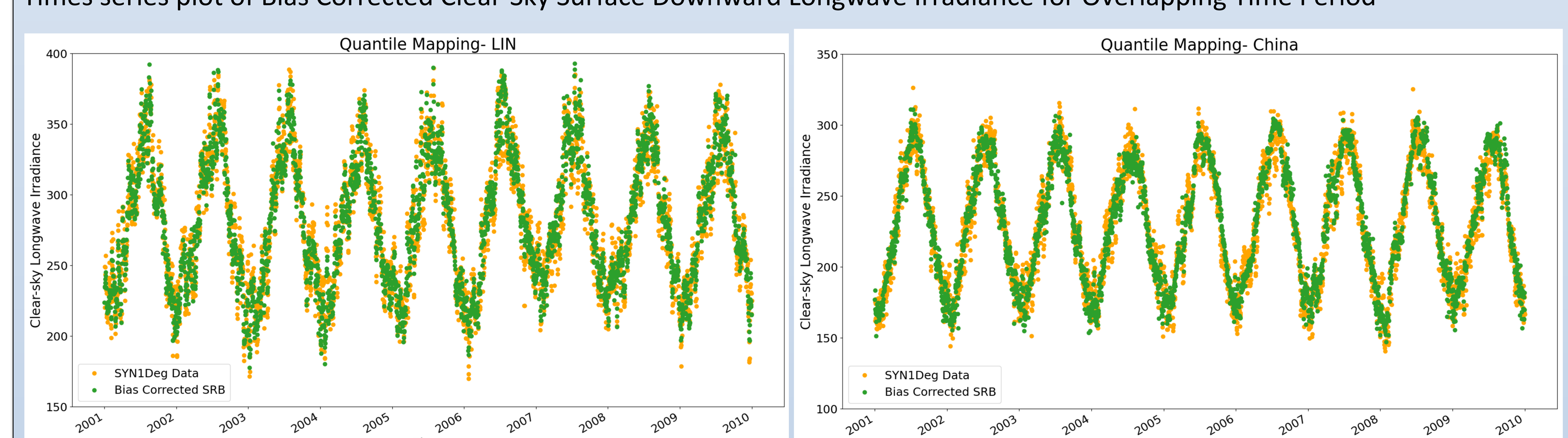
Time Series plot of Clear-sky Surface Downward Longwave Irradiance for Overlapping Time Period



Cumulative Distribution Function matching of Clear-sky SRB with Clear-sky SYN1Deg Longwave Irradiance data



Times series plot of Bias Corrected Clear-Sky Surface Downward Longwave Irradiance for Overlapping Time Period

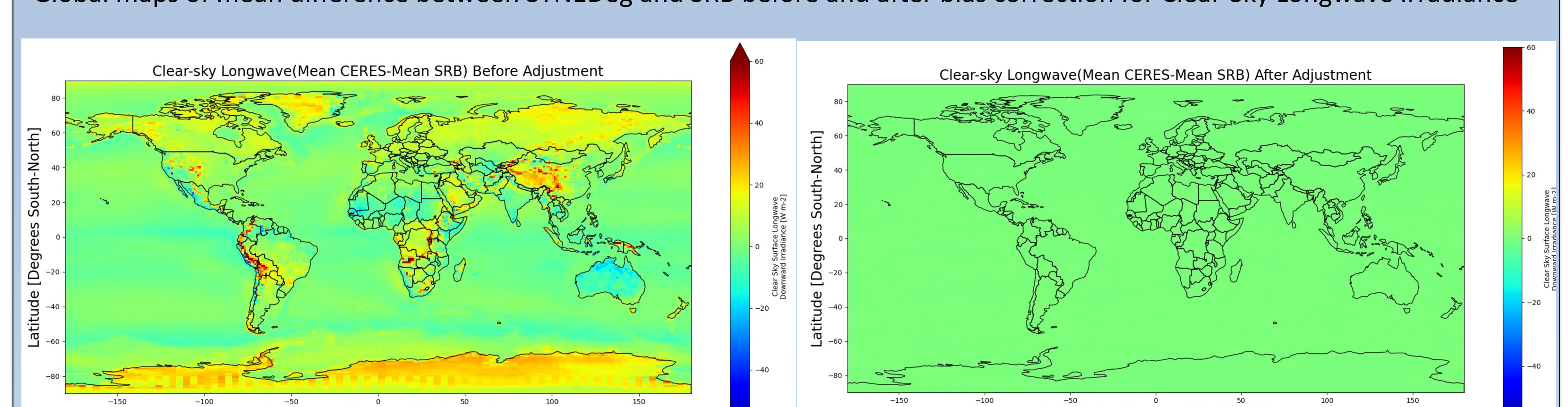


RMSE and MAD Comparison of BSRN sites data before and after bias adjustment

Surface Type	BSRN Sites		Lat/Lon Coordinate	Root Mean Squared Error (W/m^2)		Mean Absolute Deviation (W/m^2)	
				Before Correction	After Correction	Before Correction	After Correction
Grass	Alice Springs, Australia	ASP	23.79S/133.8E	20.19	15.99	16.92	11.77
	Billings, USA	BIL	36.6N/97.5W	15.24	12.83	12.21	9.69
	Bondville, USA	BON	40.06N/88.36W	15.75	15	12.11	10.99
Desert	De Aar, S. Africa	DAA	30.67S/23.99E	18.02	13.56	14.64	10.45
	Sede Boqer, Israel	SBO	30.85N/34.77E	11.29	10.01	8.72	7.46
	Gobabeb, Namibia	GOB	23.56S/15.04E	13.96	13.52	11.01	10.4
Tundra	Barrow, USA	BAR	71.32N/156.6W	11.7	9.17	9.15	6.67
	Alert, USA	ALE	82.49N/62.42W	5.37	5.08	4.12	3.57
	Ny-Ålesund, Norway	NYA	78.92N/11.92E	16.76	5.12	15.48	3.49
Water	Bermuda, Bermuda	BER	32.3N/64.76W	9.56	8.74	7.72	6.27
	Syowa, Antarctica	SYO	69S/39.58E	22.28	9.85	19.26	7.65
	Granite Island, USA	GIM	46.72N/87.41W	17.18	14.27	13.09	9.09

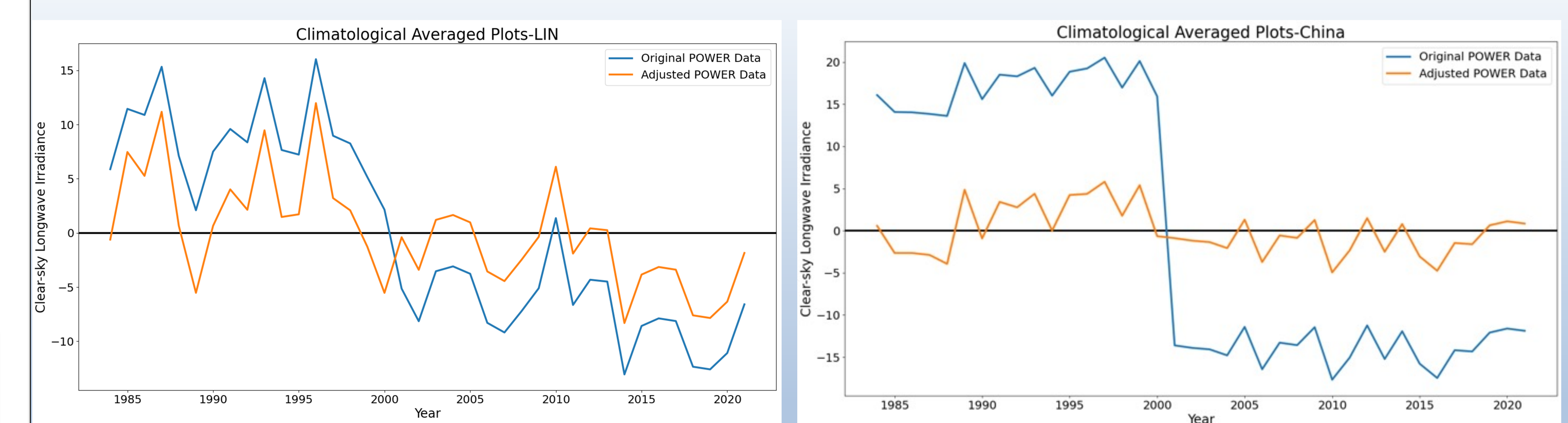
- Cumulative Distribution Function's of SRB and SYN1Deg is rescaled in a way that CDF of SRB matches with CDF of SYN1Deg.
- After the CDF matching the RMSE between the two dataset is reduced from 14.6 $[W/m]^2$ to 8.86 $[W/m]^2$ (LIN) and 31 $[W/m]^2$ to 11 $[W/m]^2$ (China).

Global maps of mean difference between SYN1Deg and SRB before and after bias correction for Clear-Sky Longwave Irradiance



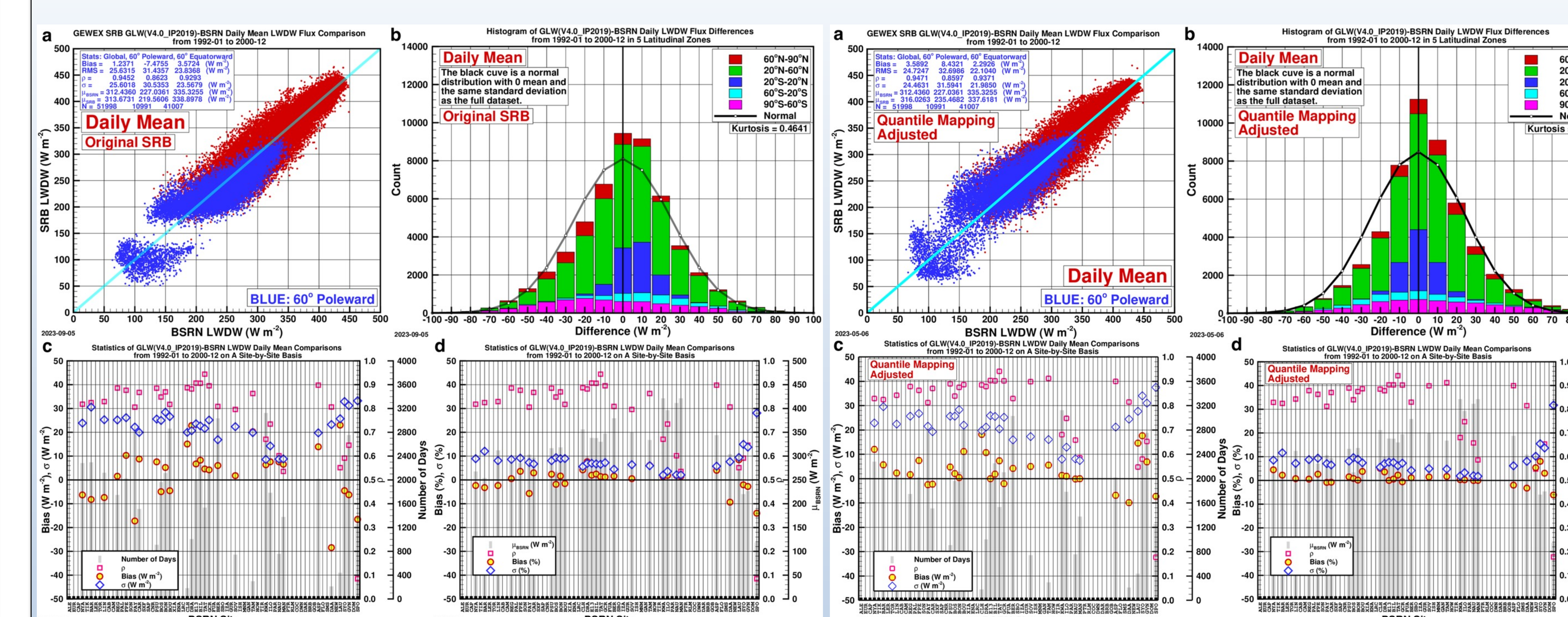
- Global maps visually convey the impact of the bias adjustment process, highlighting the regions where the discrepancies have been minimized.
- Quantile mapping effectively brought the SYN1Deg and SRB datasets into closer agreements across each grid box throughout the globe.

Anomaly Plots before and after adjustment of overall time series from POWER



- The effectiveness of the quantile mapping can also be visualized by comparing before and after adjustment of anomaly plots.
- Here the anomaly plots are the difference between the overall mean and annual mean.
- Anomaly plots indicate that the seasonal patterns and underlying trends of the time series is preserved even after the bias removal.

Validation



Comparison statistics of SRB daily mean longwave surface downward irradiance before and after bias adjustment for data points 60° equatorward only

Time Scale	Bias	RMS	ρ	σ	μ_{SRB}	N
GEWEX SRB longwave original						
Daily Mean	3.57	23.83	0.9293	23.56	338.89	41,007
GEWEX SRB longwave adjusted using quantile mapping						
Daily Mean	2.29	22.10	0.9371	21.98	337.61	41,007

- The comparison of SRB daily mean longwave surface downward fluxes with the BSRN in the zone "60° equatorward" where most data points are located shows appreciable improvement.
- In the "60° poleward" zone, the bias changes its sign, and the magnitude of the bias becomes slightly larger, leading to an increased global bias after adjustment. This observation suggests that the reference SYN1Deg may not represent the absolute truth.
- Despite the global bias, the standard deviation of the site-by-site bias is reduced after the adjustment.

Conclusion

- The performance of quantile mapping is evaluated by using metrics such as Root Mean Squared Error (RMSE) and Mean Absolute Deviation (MAD) and the results indicate that this approach significantly improves accuracy of solar irradiance dataset especially for the weather conditions associated with high cloud cover and extreme irradiance values at water and tundra sites.
- The bias corrected data that is made available through POWER V10 has been validated using the BSRN surface site data and the results indicate that the adjusted longwave and shortwave fluxes agree better with the site data.
- Overall, quantile mapping approach removes the bias and improves the reliability of all sky/clear sky longwave irradiance data. Although not shown, the results are similar for all sky/clear sky shortwave solar irradiance data
- The findings from this study has important implications for solar energy system design, agricultural planning, and climate modeling community and the data can be assessed through POWER website.
- Reducing uncertainties and biases in solar irradiance dataset, quantile mapping can enable better planning and operation of solar energy systems, leading to increased efficiency and cost-effectiveness.
- This work also contributes to the statistical post-processing techniques in the renewable energy domain and highlights the potential of NASA POWER dataset as a valuable resource for solar energy research and applications

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Questions?

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