Understanding Spatial and Temporal Variability in Satellite-based Surface Solar Radiation Using BSRN Station Data

Maya Niyogi[1], Dr. Falguni Patadia[2], Neha Khadka[3], Taiping Zhang[3], J. Colleen Mikovitz[3], Dr. Paul Stackhouse[2]

[1]Johns Hopkins University, [2]NASA Langley Research Center, [3]Analytical Mechanics Associates

PRESENTED AT:

INTRODUCTION AND LITERATURE REVIEW

Introduction:

Many communities rely on city-specific solar radiation data when making decisions--for example, contractors can use NASA satellite city irradiation data to understand annual solar radiation patterns, make predictions about future behavior, and then choose which materials (radiators, heating units, etc.) are best suited for the building they're working on.

A question then arises: is the satellite data of a high enough resolution that solar irradiation variations city-wide are captured? Can we rely on the satellite data to relay accurate information about the city variations, especially when dealing with a scale as small as (ex.) building?

Research Question:

While BSRN ground stations measure various solar radiation parameters as ground truth, their limited coverage makes it difficult to use BSRN station data over the continental US. NASA satellite data is global but at a very coarse resolution. Does the POWER satellite data (with its current resolution) capture the solar radiation variations within cities?

Three Papers of Importance:

1. The Validation of the GEWEX SRB surface shortwave flux data products using BSRN measurements: A systematic quality control, production, and application approach (Zhang et al)

- Describes validation process of GEWEX satellite data against BSRN ground stations

2. Spatial Representativeness of Surface-Measured Variations of Downward Solar Radiation (Schwartz et al 2017)

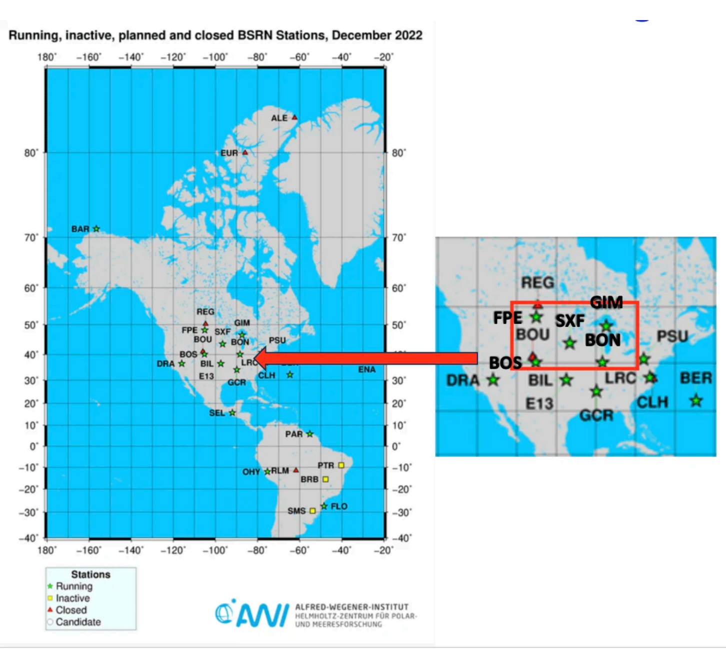
- Derived relationship between stations within latitude and longitude grid boxes
- Discussed representativeness of station's measurements for surrounding terrains/area contained in boxed grid

3. From Point to Area: Worldwide Representativeness of Monthly Surface Solar Radiation Records (Schwarz et al 2018)

- Studied how topology can affect representativeness of station values for grid area

DATA SOURCE AND REGION OF FOCUS

Region of Focus:



Schwarz et al (2017) and Schwarz et al (2018) studied station data in regards toresolution required for accurate reflection of radiation levels in surrounding areas and of land features by captured radiation levels.

Both studies emphasized the importance of station density and chose their region of choice (Europe) due to its high station density.

Since the area of focus is the United States, region selected is the red box (left). 5 active stations within this region collect data (BOS, FPE, SXF, BON, GIM), resulting in high station density within this 30° x 10° grid.

Ground Station Data:

Baseline Surface Radiation Network (BSRN) collects and processes data used to validate many satellite data sets

- 76 total stations worldwide
- About 13-15 actively covering continental US
  - Number reporting can vary

Each active ground station had different periods of data collection, so made data frame collating all 5 stations' data

- Compiled along the intersection of dates collected
- The new data frame shows dates for when all stations collected data or had an entry
  - Not a Number (NaN) considered a valid entry

Boulder (BOS)'s dates of collection range from 8-1995 to 4-2020 and Granite Island (GIM)'s dates of collection range from 10-2018 to 12-2022.

All stations had data entries from 10-2018 to 11-2019. Calculations were done referencing an interpolated version of this table's compiled information (below).

time	DLM_BOS	latitude_BOS	longitude_BOS	DLM_FPE	latitude_FPE	longitude_FPE	DLM_SXF	latitude_SXF	longitude_SXF	DLM_BON	latitude_BON	long
2018-10-01	334.2757	40.1333	-105.2333	312.3271	48.3167	-105.1	345.6271	43.73	-96.62	364.7458	40.0667	
2018-10-02	345.1021	40.1333	-105.2333	321.9667	48.3167	-105.1	358.9576	43.73	-96.62	389.7667	40.0667	
2018-10-03	337.2507	40.1333	-105.2333	275.2931	48.3167	-105.1	345.4298	43.73	-96.62	391.2882	40.0667	
2018-10-04	307.2146	40.1333	-105.2333	272.3868	48.3167	-105.1	286.3716	43.73	-96.62	396.4597	40.0667	
2018-10-05	301.8007	40.1333	-105.2333	284.1979	48.3167	-105.1	333.4194	43.73	-96.62	395.7062	40.0667	
...	...	...	...	...	...	...	...	...	...	...	...	
2019-11-26	262.8007	40.1333	-105.2333	224.7459	48.3167	-105.1	297.1069	43.73	-96.62	321.2687	40.0667	
2019-11-27	202.0236	40.1333	-105.2333	267.9840	48.3167	-105.1	285.5868	43.73	-96.62	314.5118	40.0667	
2019-11-28	226.4715	40.1333	-105.2333	280.9445	48.3167	-105.1	286.2201	43.73	-96.62	307.0528	40.0667	
2019-11-29	274.7153	40.1333	-105.2333	297.9285	48.3167	-105.1	302.2569	43.73	-96.62	322.6875	40.0667	
2019-11-30	242.4951	40.1333	-105.2333	286.5971	48.3167	-105.1	NaN	43.73	-96.62	336.9036	40.0667	

426 rows × 15 columns

Satellite Data:

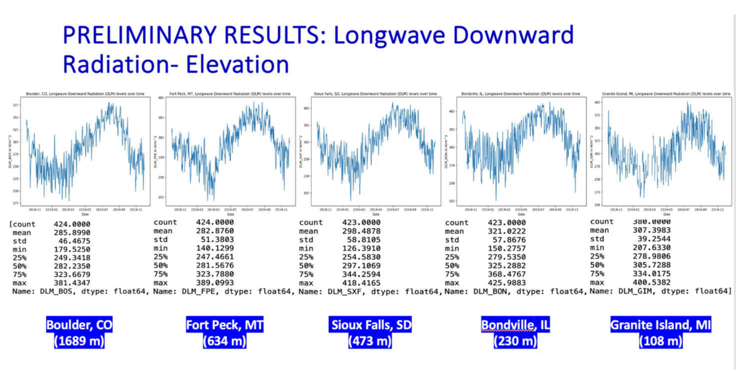
Satellite data accessed via NASA's POWER Project AWS DataStore

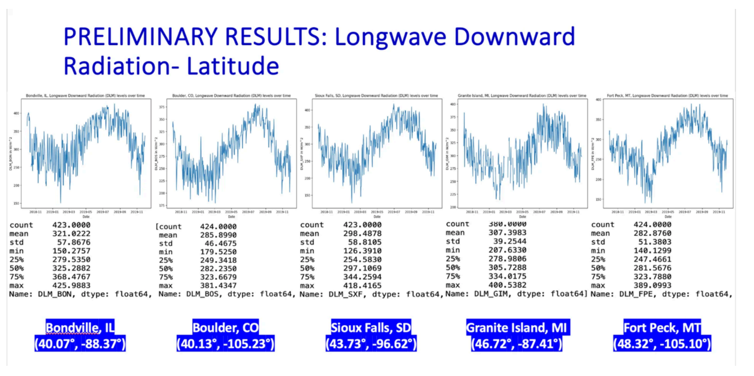
- Time period of focus was October 2018 – November 2019
- Data derived from CERES SYN1deg data set
- Parameters studied: All Sky Surface Shortwave Downward Irradiance (ALLSKY_SFC_SW_DWN) and All Sky Surface Longwave Downward Irradiance (ALLSKY_SFC_LW_DWN)

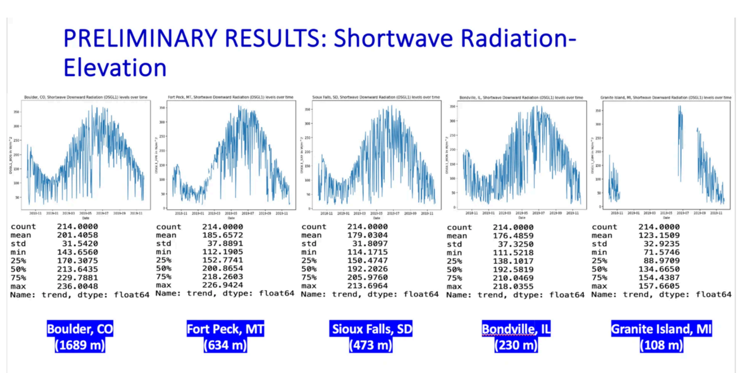
Continental United States mapping data accessed via US Census Bureau's TIGER/Line shapefiles and related database (2022 shapefile)

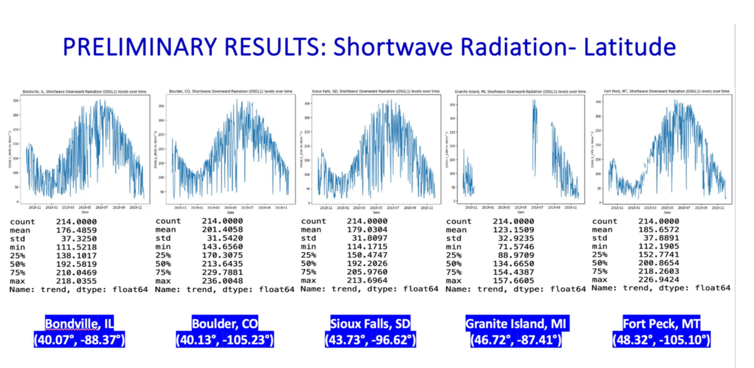
Ground data from BSRN's ground station collection data sets

PRELIMINARY RESULTS









Satellite vs Ground Data Statistical Analyses:

RESULTS: Differences Between Daily All-Sky Longwave Ground and Satellite Values (1 Oct 2018 – 30 Nov 2019)

STATION	BOS	FPE	SXF	BON	GIM
MEAN BIAS DIFFERENCE (w/m^2)	17.60 w/m^2	-3.52 w/m^2	1.18 w/m^2	6.03 w/m^2	3.38 w/m^2
MEDIAN BIAS DIFFERENCE (w/m^2)	17.80 w/m^2	-2.79 w/m^2	1.09 w/m^2	5.42 w/m^2	1.70 w/m^2
SKEWNESS	-0.0443	-0.1836	0.0291	0.1621	0.2647
AVERAGE FRACTIONAL BIAS DIFFERENCE	7.05 w/m^2	-1.56 w/m^2	0.04 w/m^2	2.12 w/m^2	1.50 w/m^2
RMSE	285.22 w/m^2	283.05 w/m^2	299.76 w/m^2	321.76 w/m^2	305.43 w/m^2
NMSE	0.2251	0.0577	0.0252	0.0487	0.2432

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Mean Bias Difference: Measure of systematic difference. A positive value indicates that, on average, the ground data set tends to record values X w/m^2 larger than the satellite data set.

Median Bias Difference: Measure of central tendency of differences. A positive value indicates that, on average, the ground data set tends to record values X w/m^2 larger than the satellite data set when looking at the central tendency of differences.

Skewness: A positive skewness indicates a slight rightward skewness; on average, there tend to be more instances where the ground data set is recording higher values than the satellite data set. Ranges from 0 to 1.

Average Fractional Bias Difference: If positive, it suggests that, on average, the ground data set is relatively about X times higher than the satellite data set. Average fractional bias difference looks at relative magnitude of the differences.

RMSE: Measure of average magnitude of the differences between corresponding values in the ground data set and satellite data set. Typically want a smaller value

NMSE: Measure of agreement between two datasets, normalized against the ground data set's variance. Ranges between 0 and 1, and a lower score is better.

DISCUSSION

Results: BSRN Ground Stations Longwave and Shortwave Daily Temporal Patterns (1 Oct 2018 - 30 Nov 2019)

Longwave Ground Data:

No easily-predictable pattern between stations and their measurements

- South → North: Can't claim equatorward stations have higher levels
- Elevation: (excluding FPE) as elevation decreases, DLM levels increase
- 1000 m difference between BOS and FPE, FPE recorded 3 W/m^2 less

Shortwave Ground Data:

No easily-predictable pattern between stations and their measurements

- Can't claim equatorward relationship
- Location= large influence on shortwave radiation, so would expect there to be distinct relationship if no confounding variables
- Can see a relationship based on station elevation and measurements

Results: All-Sky Longwave Daily and All-Sky Shortwave Daily Distributions (Satellite vs Ground Data) (1 Oct 2018 - 30 Nov 2019)

Longwave Daily:

- Except for Fort Peck, we see that ground stations tend to record higher All-Sky Longwave values
  - Difference between ground and satellite values tends to vary by less than 20 w/m^2, and in most places by less than 10 w/m^2
- Except for Boulder and Granite Island (NMSE ≤ 25%), agreement between ground station data and satellite data is good (NMSE ≤ 5%)

Shortwave Daily:

- Sioux Falls and Granite Island have ground stations that tend to record lower All-Sky Shortwave values
- Boulder, Fort Peck, and Bondville have ground stations that tend to record higher All-Sky Shortwave values
  - Here, these values all tend to vary by less than 5 w/m^2
- Except for Boulder (NMSE ≤ 15%), agreement between ground station data and satellite data is good (NMSE ≤ 5%)

NEXT STEPS

Future Work:

Clear Sky Data

BSRN data sets don't include Clear Sky Shortwave measurements, so need to use an independent data set from NASA

- Data set includes values until 2017, so future analyses will need to include a different time interval for comparisons

Austin and Houston City Data

Austin and Houston have ground data stations that collect measurements on various solar and dust parameters (via UT Austin's Bureau of Economic Geology)

- Analyses until now have been over a more general region with varying topography
- Focusing on Austin and Houston specifically will aid in analyses focusing on a more compact region and analyses focusing more on cities

STATION VS SATELLITE IMAGES

[VIDEO] https://www.youtube.com/embed/XZY_pWgHvxg?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

AUTHOR INFORMATION

Maya Niyogi is a third-year student at Johns Hopkins University studying Applied Mathematics, Statistics, and Economics. She can be reached via email at mniyogi1@jh.edu or Linkedin at https://linkedin.com/in/mayaniyogi.

TRANSCRIPT

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