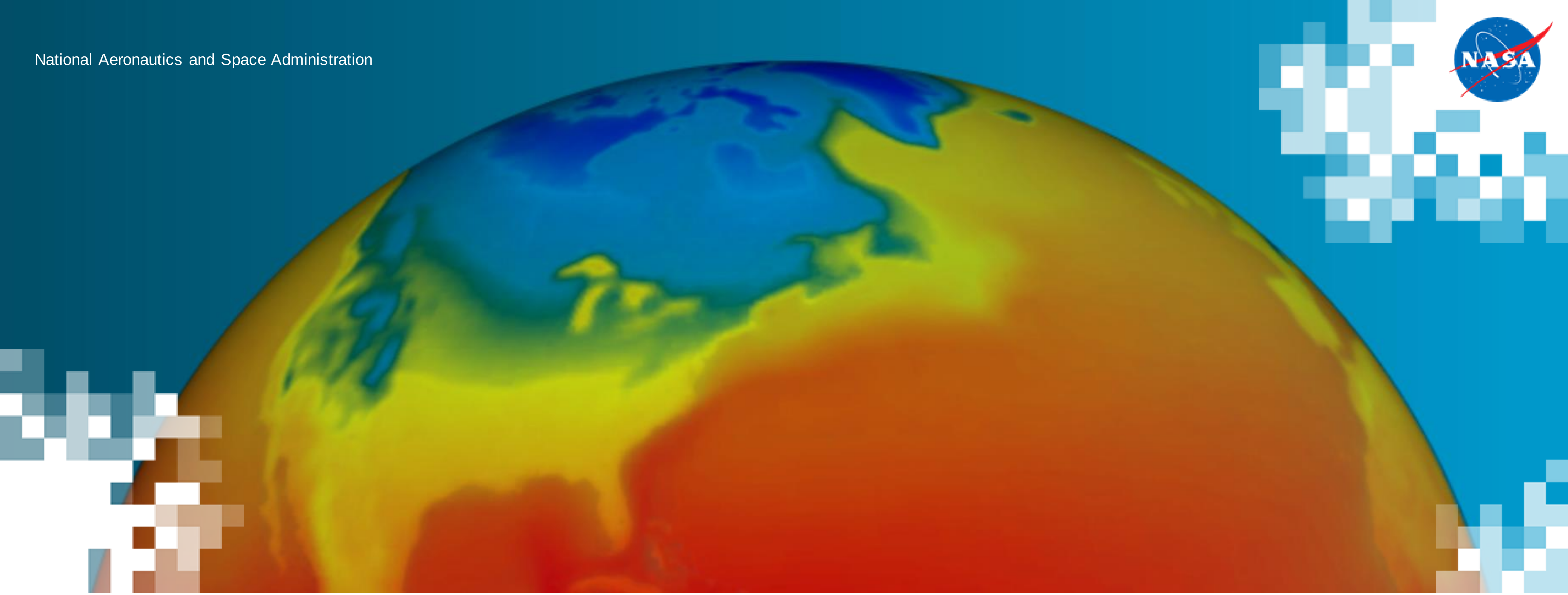
National Aeronautics and Space Administration



How to Utilize NASA Resources for Energy Efficiency and Renewable Energy Applications

Collaboration between NASA POWER for NASA ARSET

June 22, 2021

What are POWER GIS Web Services?

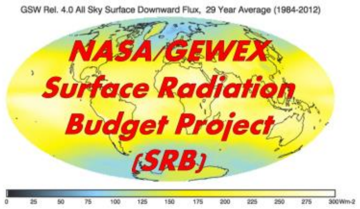
What is POWER's Purpose?

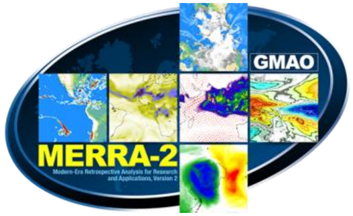
- POWER stands for "Prediction of Worldwide Energy Resources" project funded by NASA to help facilitate the usage of NASA Earth observations, analysis, and modeling to answer key societal questions.
- POWER aims to improve the nation's public/private capability for integrating environmental data from NASA Earth observations and research, *particularly surface solar irradiance*, to support increased:
  - renewable energy development,
  - building energy efficiency and sustainability, and
  - agroclimatology applications.

Photo Credits: nrdc.org, solvay.com, harvestreturns.com

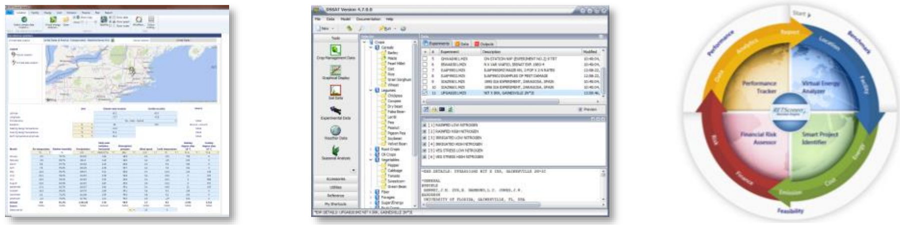
How is the POWER GIS Web Services Improved?

Data Providers Interaction and Planning



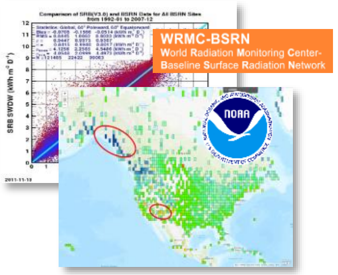


User Interaction/Partnerships/Requirements Capture

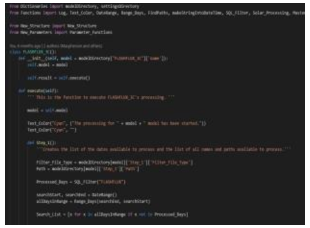


POWER
Prediction Of Worldwide Energy Resources

Data Processing, Customization and Integrity



Data Validation & Documentation



Coding, Processing & Storage

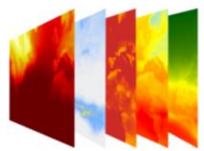
Technology Partners

Public Discovery & Data Distribution

POWER Website

APIs

Web Mapping Services



Data Access Viewer

Community-Specific Reports

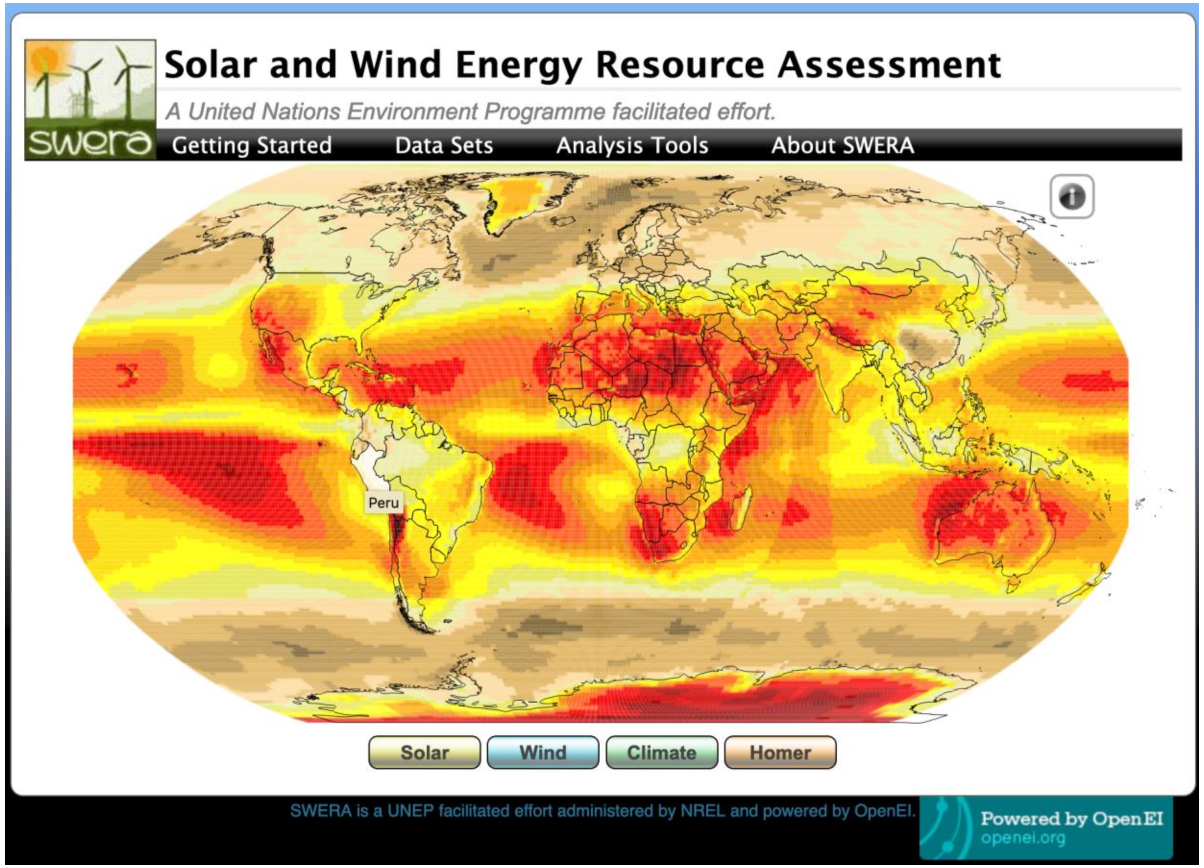
Available on Beta!

OPeNDAP®: is a registered trademark of the Advanced Software for Remote Data Retrieval.

What is POWER's approach to building community relationships?

Collaboration and Partnership Building: Governmental and Professional Organizations

- National Renewable Energy Laboratory (NREL, US Dept of Energy)
  - Historically NASA supplied data where there were no surface observations
- RETScreen® (Natural Resources Canada)
  - Integration of the POWER Data into the RETScreen® software enabling world-wide access to data without the need for a surface site to conduct analysis.
- ASHRAE© (formerly American Society of Heating, Refrigeration and Air-Conditioning Engineers):
  - Demonstrate usefulness of NASA EO
  - Enable public access globally of the ASHRAE climatic design conditions report using POWER Data.



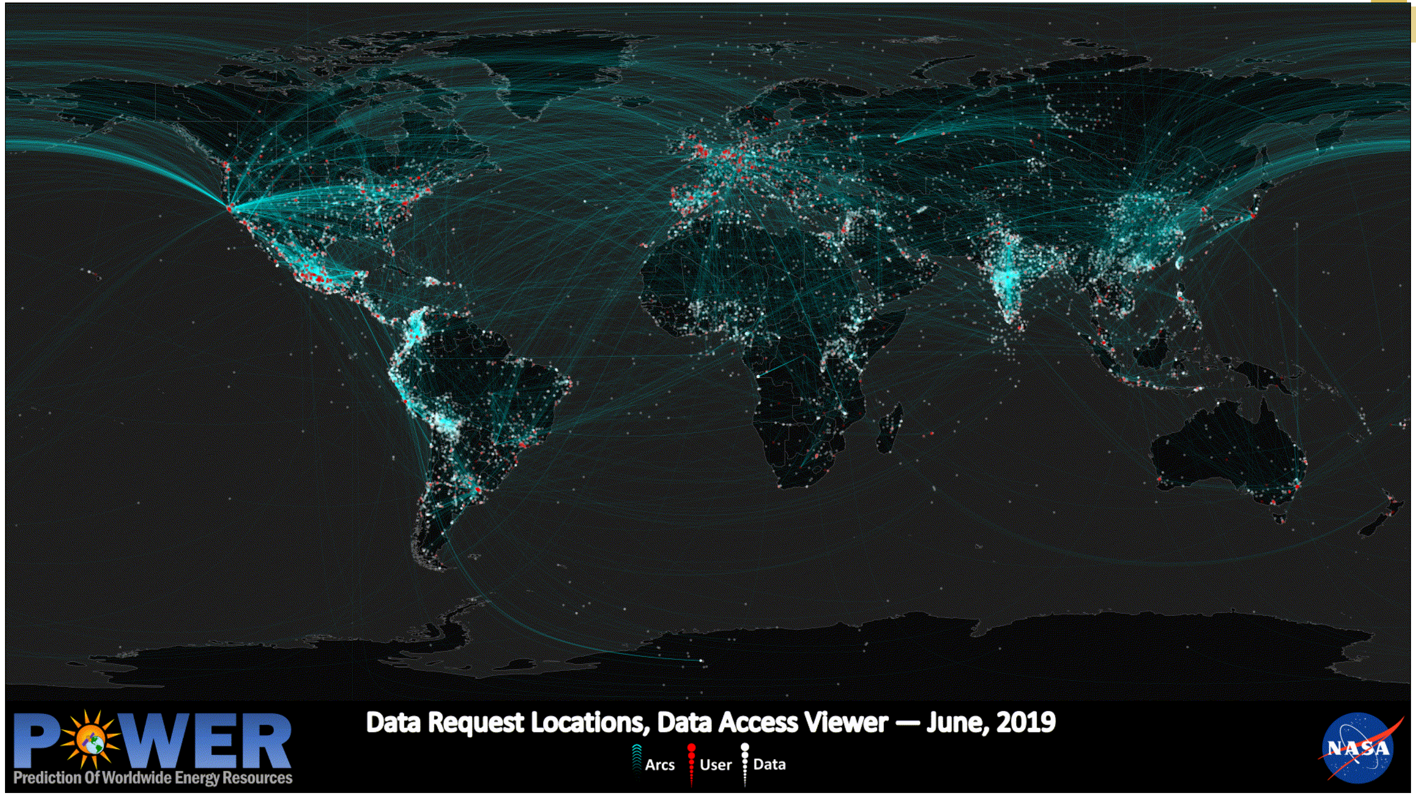
SWERA was early collaboration between NREL, USGS and NASA (https://openei.org/apps/SWERA//).

ASHRAE®: is a registered trademark of the American Society of Heating, Refrigeration and Air Conditioning Engineers
RETScreen®: is a registered trademark of the Government of Canada

How often is POWER being used?

POWER Web Services Portal collects a variety of information to understand data requests and changes of the user base while maintaining free and anonymous access.

- *track overall usage by collecting key measures of data requests and unique users (I.e., metrics)*
- *Also, track orders by data set source, user community and parameter.*



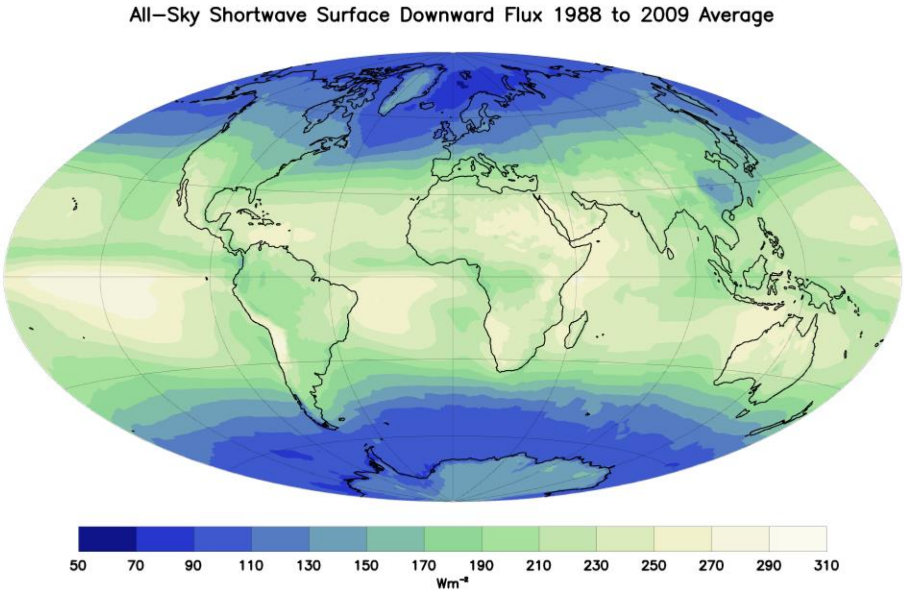
Monthly Cumulative - Metrics Information		
Requests	Unique Users (IP Based)	Data Volume (GB)
06/01/2019 to Present	06/01/2019 to Present	06/01/2019 to Present
148,997,987	276,425	16,003 GB

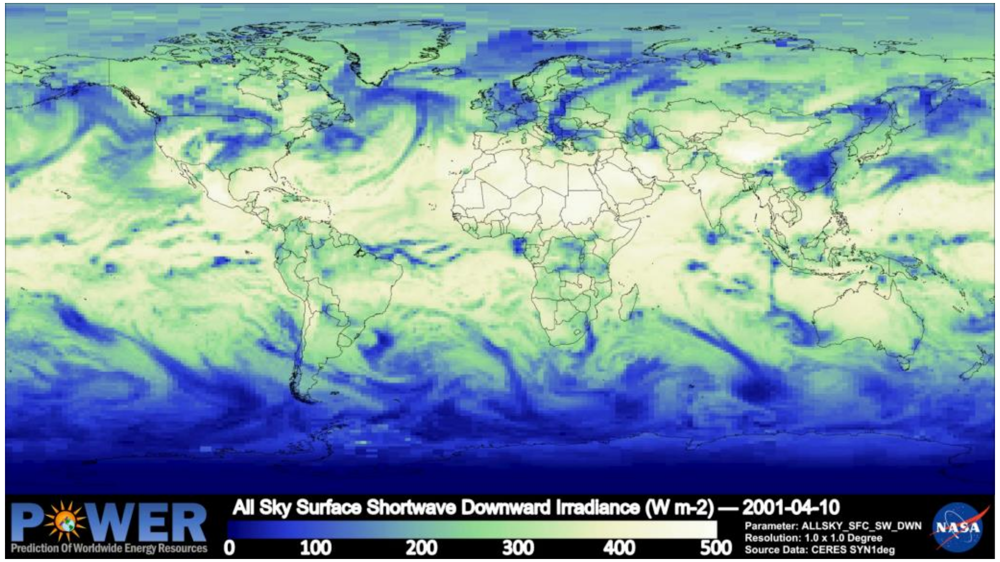
Cumulative - Geospatial Services		
	Before	After
	1999/06/01 to 2018/04/30	2018/05/01 to Present
Requests	35,988,533	180,052,616
Data Volume (GB)	3,612 GB	22,004 GB

What Sorts of Data Help Enhance POWER's Utility?

Time Averaged versus Time Series

- Some users require statistics from long-term averaged data parameters
  - Useful for feasibility and engineering studies for large numbers of renewable energy projects
  - POWER beta now allows users to choose years for long-term averages
- Some users require time series data products
  - Useful for modeling energy systems with observed variability
  - Useful for monitoring building energy efficiency performance
  - POWER beta now allows up to hourly averaged data products but also features daily, monthly, annual time series statistics





Using the Climatological Averages

POWER's Value Added Products Enhance Usage

Base and Derived Parameters for POWER GIS

All parameters are available globally at the source data resolution.

Climatological Base Parameter	Climatological Value Added
• All-Sky & Clear-Sky Surface Solar Insolation on Horizontal Surface • Surface Reflected Solar Flux • All Sky Downward Longwave Radiative Flux • Top-Of-Atmosphere Insolation • Air Temperature at 2 m, 10 m • Specific Humidity at 2 m, 10 m • Surface Dewpoint at 2 m • Surface Pressure • Surface Skin Temperature • U, V, Wind Speed, & Wind Direction at 2 m, 10 m, and 50 m • Precipitation	• Solar geometry, Surface albedo, Direct Normal, Diffuse, • **Tilted surface solar parameters including optimal angle/irradiance computations** • 3-hourly solar fluxes and cloud parameters, • **No-sun Days (Black-sky days), min insolation over day periods for battery backup** • Heating/Cooling Degree Days (for 0^{o} C, 10^{o} C, 18.3^{o} C standards) • Skin Temperature max/min/range, Frost Days, • Total Column Precipitable Water • ASHRAE® Building Climate Thermal & Moisture zones • Wind Roses by Energy classes

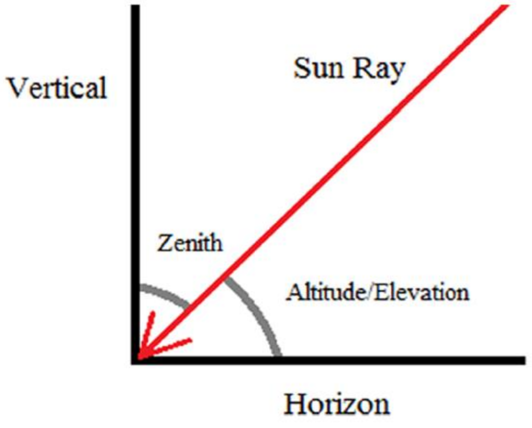


Fig. 6. Zenith and altitude angles.

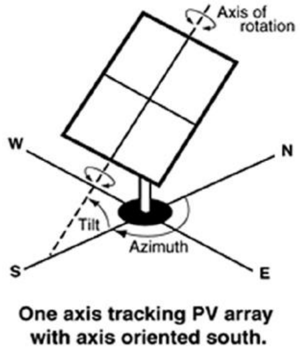


Fig. 7. Tilt angle (pveducation, 2019).

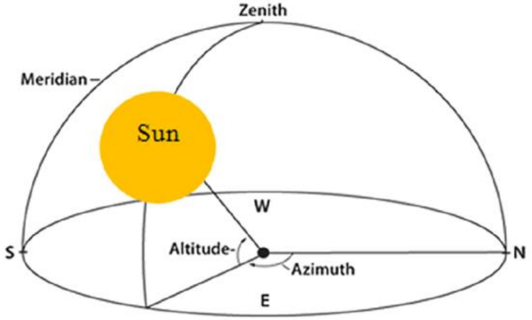
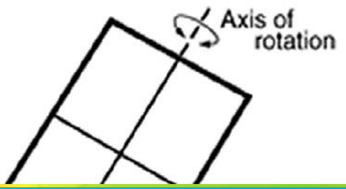


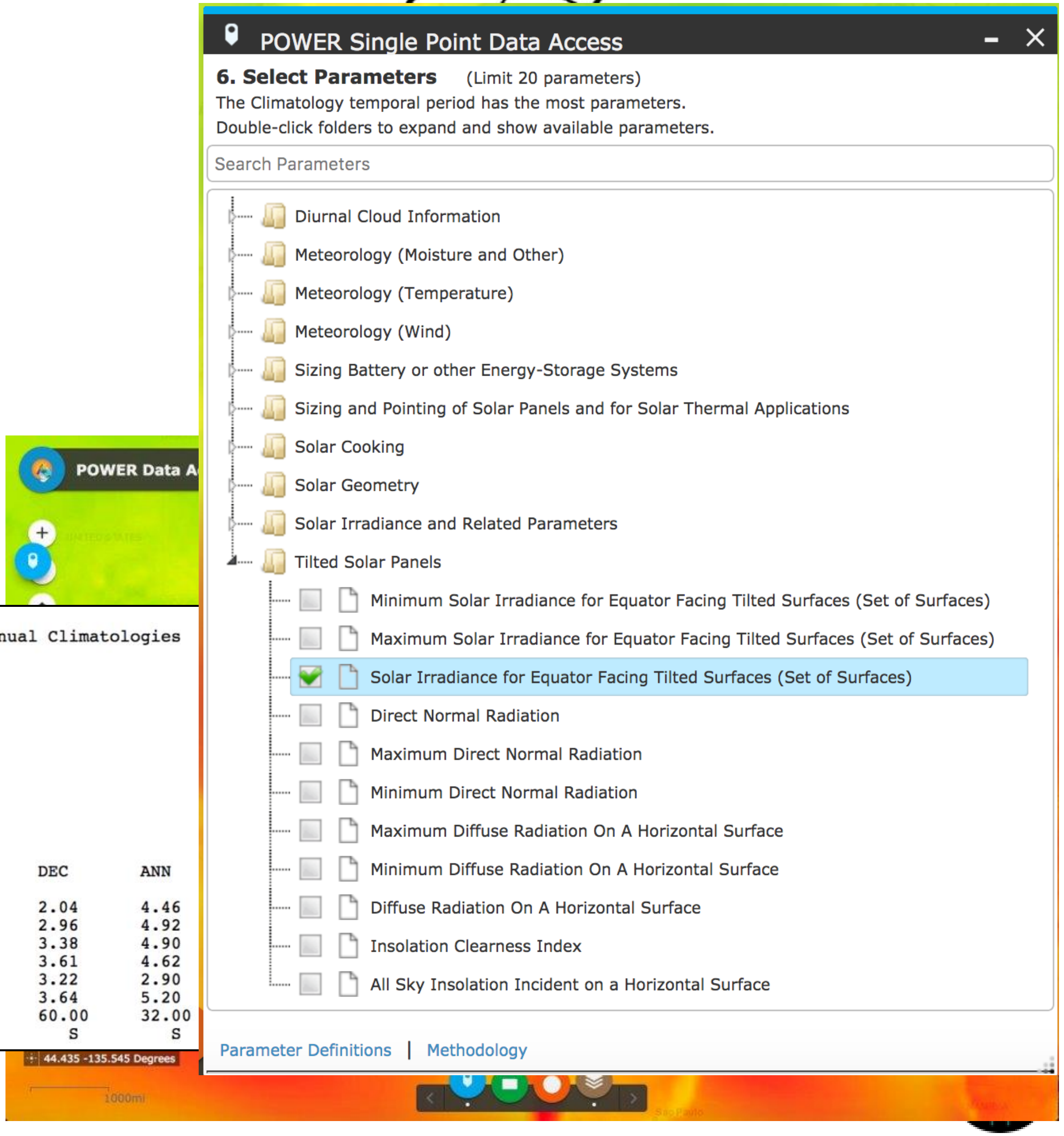
Fig. 8. Azimuth and altitude angle (Sidek et al., 2014).

Awasthi et al., 2020, Energy Reports

What is Equator Tilted Surface Irradiance?

- Solar panel surface tilted toward the equator at an angle equivalent to location latitude (a first estimate for a solar panel)
- Currently uses an industry standard parameterization for climatological average solar irradiance (improved in new version)
- Tilted irradiance provided for a set of angles
- Output tables including an optimal tilt angle and corresponding irradiance





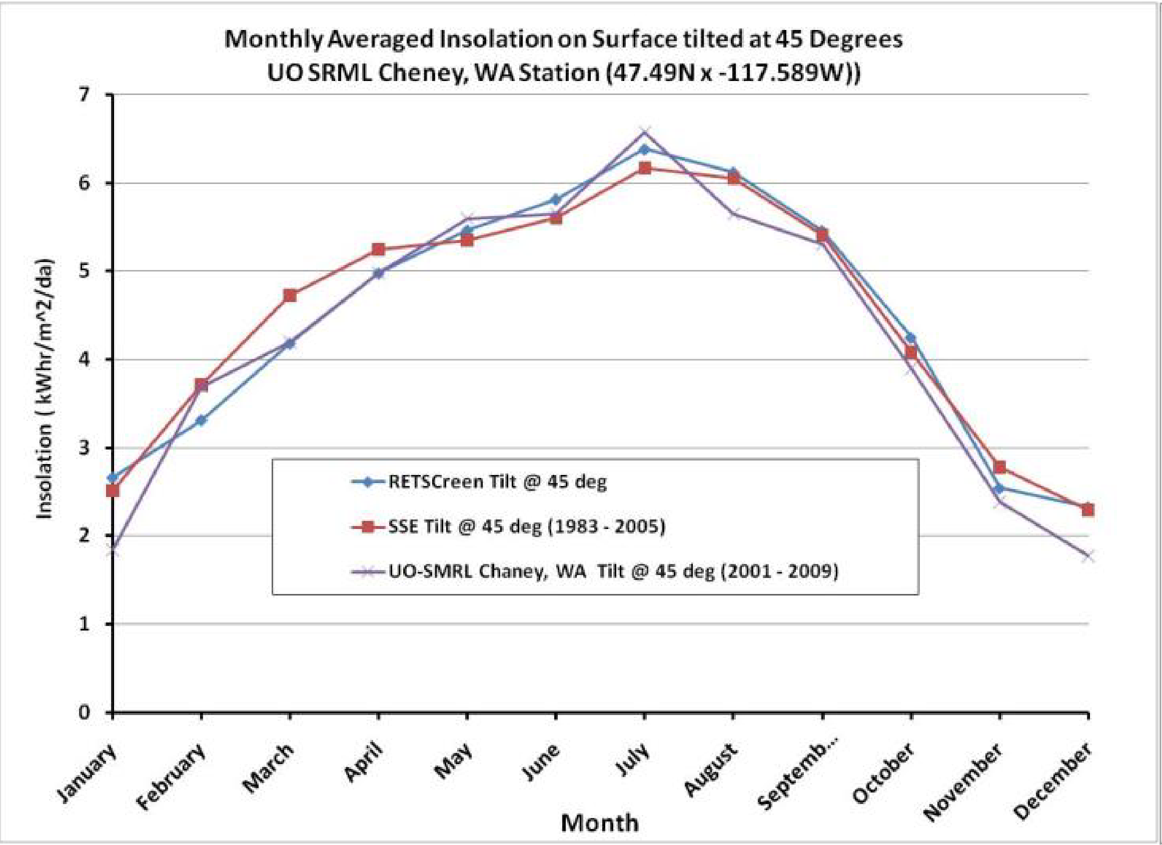
NASA/POWER SRB/FLASHFlux/MERRA2/ 0.5 x 0.5 Degree Climatologies
22-year Additional Solar Parameter Monthly & Annual Climatologies (July 1983 - June 2005), 30-year Meteorological and Solar Monthly & Annual Climatologies (January 1984 - December 2013)
Location: Latitude 37.9624 Longitude -74.7246
Elevation from MERRA-2: Average for 1/2x1/2 degree lat/lon region = 0.26 meters Site = na
Climate zone: na (reference Briggs et al: http://www.energycodes.gov)
Value for missing model data cannot be computed or out of model availability range: -999
Parameter(s):
SI_EF_TILTED_SURFACE SRB/FLASHFlux 1/2x1/2 Solar Irradiance for Equator Facing Tilted Surfaces (Set of Surfaces) (kW-hr/m^2/day)
SI_EF_OPTIMAL SRB/FLASHFlux 1/2x1/2 Solar Irradiance Optimal (kW-hr/m^2/day)
SI_EF_OPTIMAL_ANG SRB/FLASHFlux 1/2x1/2 Solar Irradiance Optimal Angle (Degrees)
SI_EF_TILTED_ANG_ORT SRB/FLASHFlux 1/2x1/2 Solar Irradiance Tilted Surface Orientation (N/S Orientation)
Note(s):
Northward facing tilted surfaces are designated negative (-)

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
-END HEADER-													
SI_EF_TILTED_SURFACE_0	2.17	2.86	4.21	5.54	6.27	6.67	6.48	5.89	4.93	3.76	2.65	2.04	4.46
SI_EF_TILTED_SURFACE_22	3.01	3.58	4.85	5.82	6.18	6.40	6.30	6.02	5.52	4.73	3.67	2.96	4.92
SI_EF_TILTED_SURFACE_37	3.37	3.83	4.95	5.62	5.71	5.79	5.74	5.70	5.54	5.05	4.12	3.38	4.90
SI_EF_TILTED_SURFACE_52	3.54	3.87	4.78	5.12	4.97	4.93	4.94	5.09	5.24	5.08	4.32	3.61	4.62
SI_EF_TILTED_SURFACE_90	3.05	2.99	3.22	2.74	2.22	1.99	2.07	2.52	3.26	3.87	3.68	3.22	2.90
SI_EF_OPTIMAL	3.55	3.88	4.96	5.83	6.33	6.68	6.51	6.06	5.57	5.11	4.32	3.64	5.20
SI_EF_OPTIMAL_ANG	57.00	47.00	35.00	20.00	8.00	4.00	6.00	15.00	30.00	46.00	56.00	60.00	32.00
SI_EF_TILTED_ANG_ORT	S	S	S	S	S	S	S	S	S	S	S	S	S

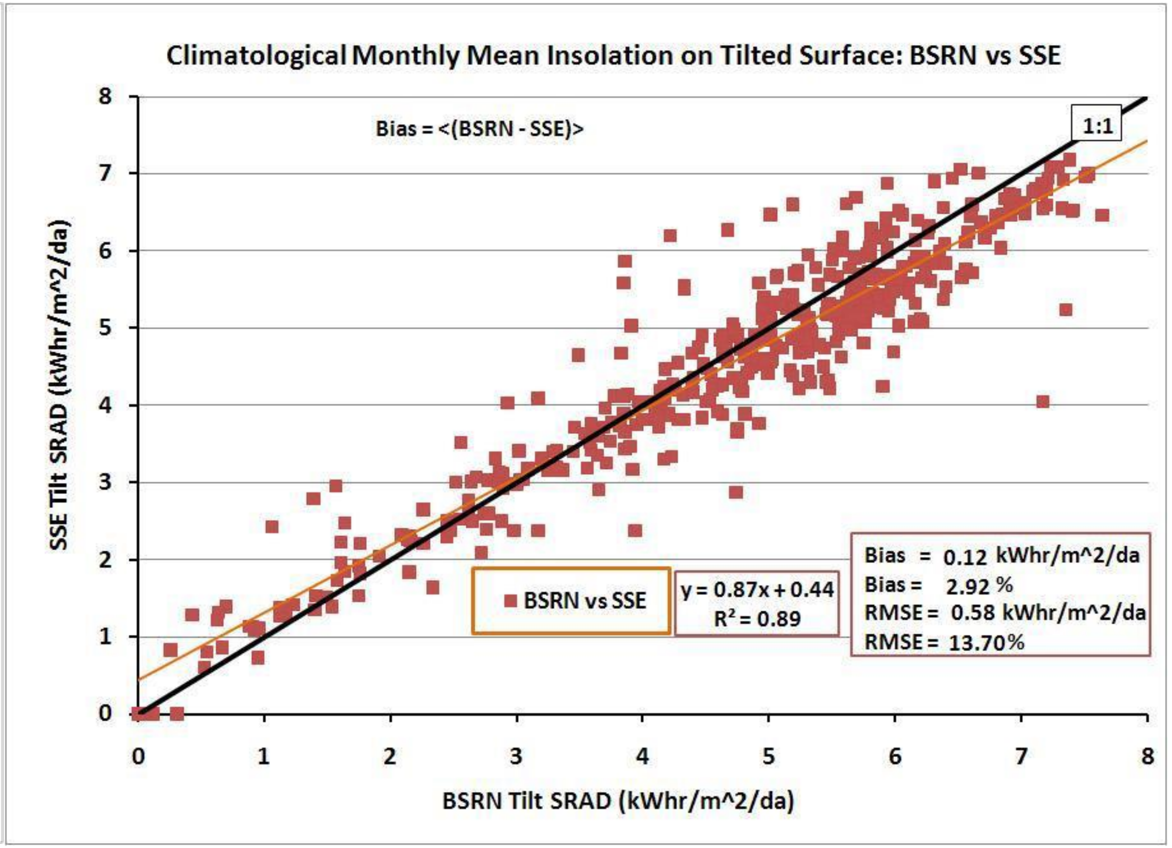
Assessment of Equator Tilted Surface Irradiance

Assessing tilted surface irradiance is very hard due to scarce measurements. Here we obtained some tilted surface measurements and also devised a technique to estimate using standard measurements giving < 3% bias and 14% RMS at monthly average.

Monthly Validation against Titled surface irradiance from University of Oregon Site



Monthly Validation against BSRN sites using diurnal variation of sun and surface albedo



Information found in the POWER methodology documentation

BSRN = Baseline Surface Radiation Network
SSE = Surface Solar Energy

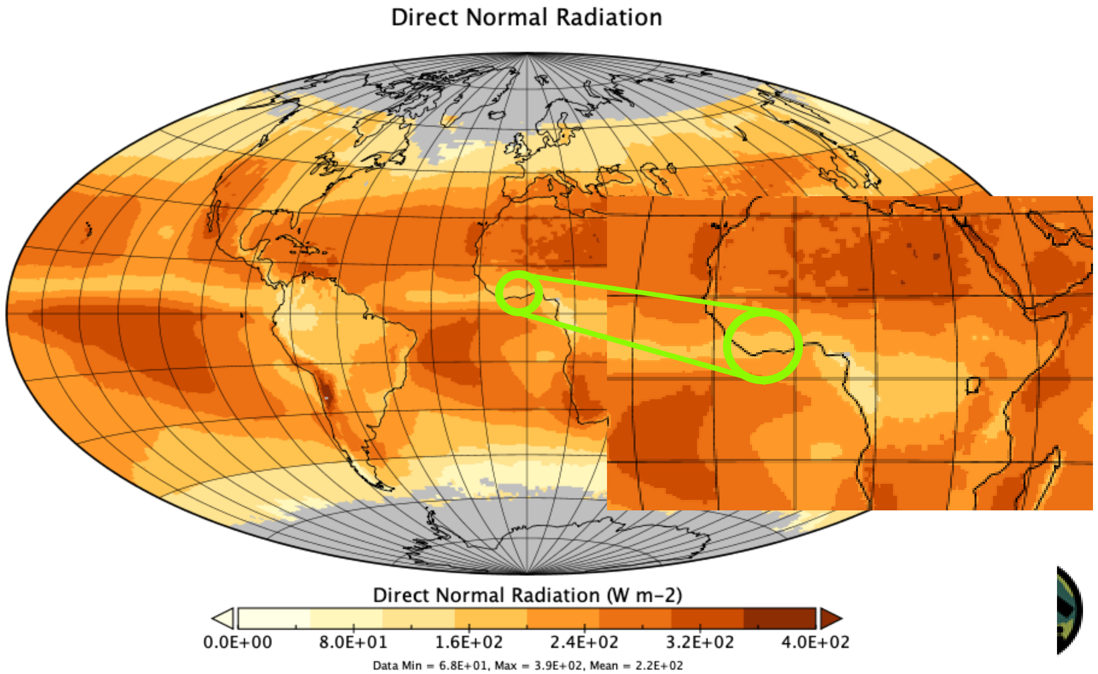
How can long-term solar averages be used?

Evaluation of an African Community Solar Panel System

- A community solar power project in a remote village in West Africa appeared to be working poorly.
- A solar consultant investigated using insolation data from the “**POWER Single Point Data Access**” application on POWER’s “**Data-Access-Viewer”**. Sample data:

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
DNR	6.13	5.88	5.04	4.29	4.12	3.54	2.97	2.84	3.35	4.09	4.65	5.67	**4.37**
DNR_MAX	7.53	7.42	5.7	4.78	4.68	4.3	4.04	3.56	3.99	4.7	5.05	7.13	**5.24**
DNR_MIN	4.97	4.81	4.42	3.85	3.47	2.76	2.3	2.27	2.59	3.57	3.88	4.51	**3.62**

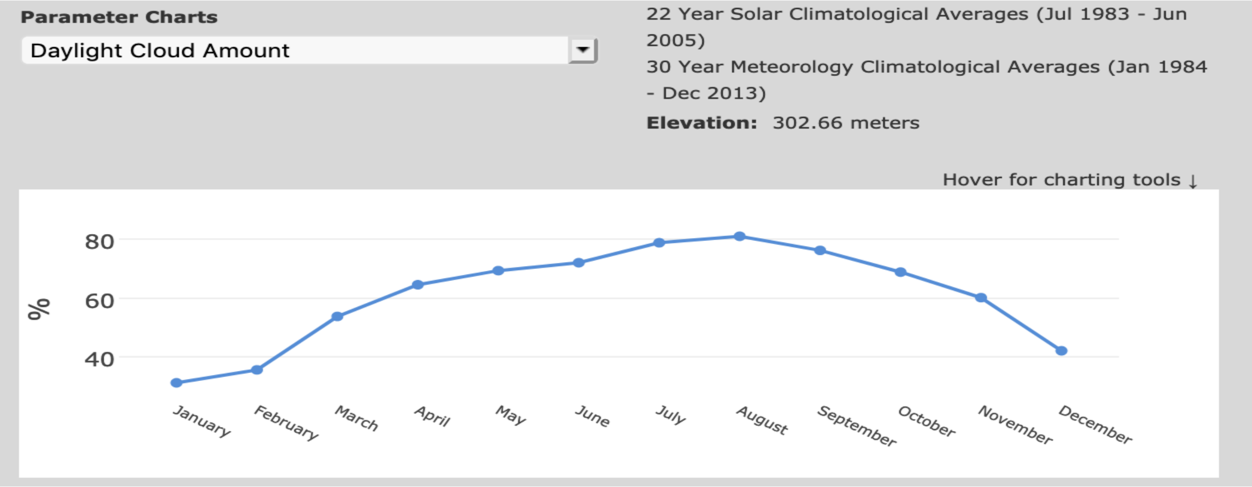
- Going to the “**POWER Layer List**” application that features image services, the consultant was also able to do a quick visual survey of solar energy potential in the whole region.



How can long-term solar averages be used?

Evaluation of an African Community Solar Panel System

- The long-term annual averaged daytime cloud amount >60%; with 9 of 12 climatological month averaged > 50%
- Despite the tropical location, frequent cloud cover significantly lowered the Direct Normal Radiation (DNR) which is needed for the efficient operation of photovoltaic modules.
- POWER's DNR data revealed that the solar array was actually performing up to specifications, though not up to expectations.
- Local management made the necessary adjustments to power usage and billing and were able to move forward better informed.

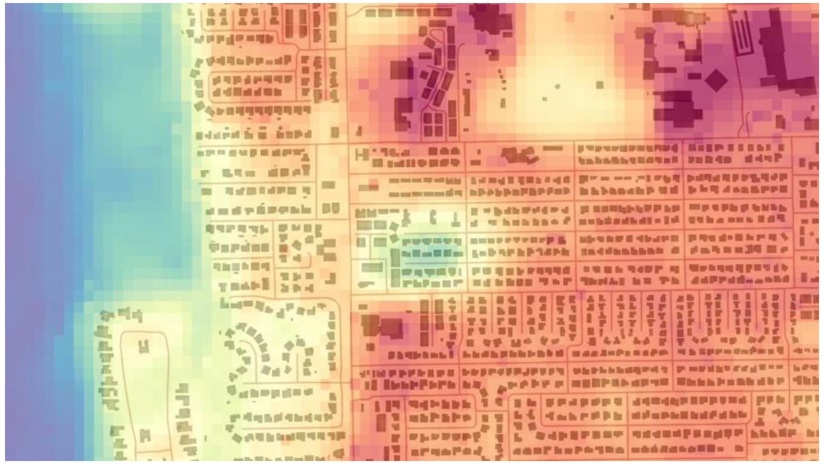


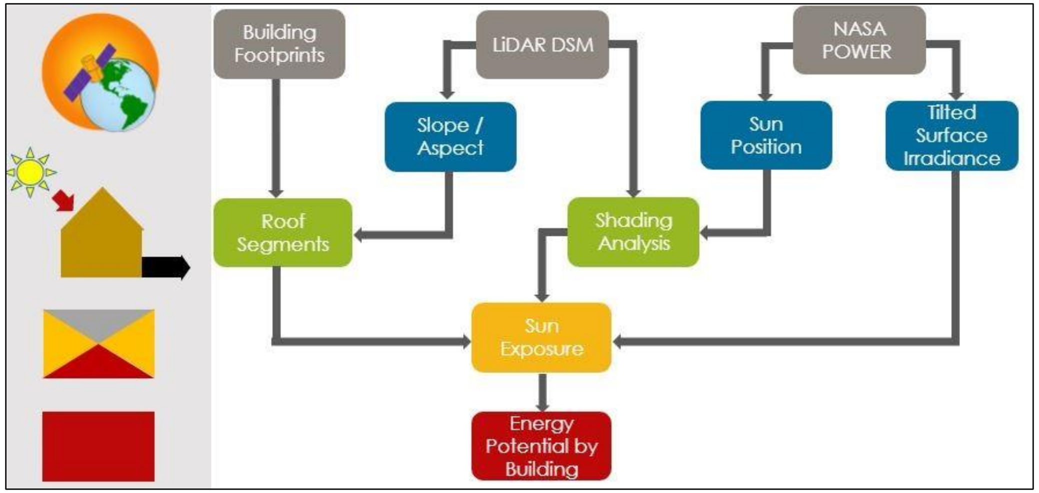
Lives touched by NASA data – a community water system with solar-powered pumps is in the plans, which will make this strenuous method of transporting water obsolete. (photo credit: Friesen Energy)

How can solar irradiance parameters be used?

DEVELOP Satellite Beach Energy (Solar Roofs)

- The City of Satellite Beach, Florida, has committed to supplying 100% of its energy use from renewable energy, primarily solar, by the year 2050.
- The team estimated rooftop solar power potential using a high-resolution Light Detection and Ranging (LiDAR) dataset and the NASA Prediction of Worldwide Energy Resources (POWER) dataset to assist Satellite Beach in reaching their solar renewable energy goals.





How can wind parameters be used?

Optimal wind farm placement

- On land wind technology now has a comparable levelized cost of electricity to fossil fuels
- Wind speeds can be used along with terrain maps to find the best placement
- Temporal variation can further refine that placement

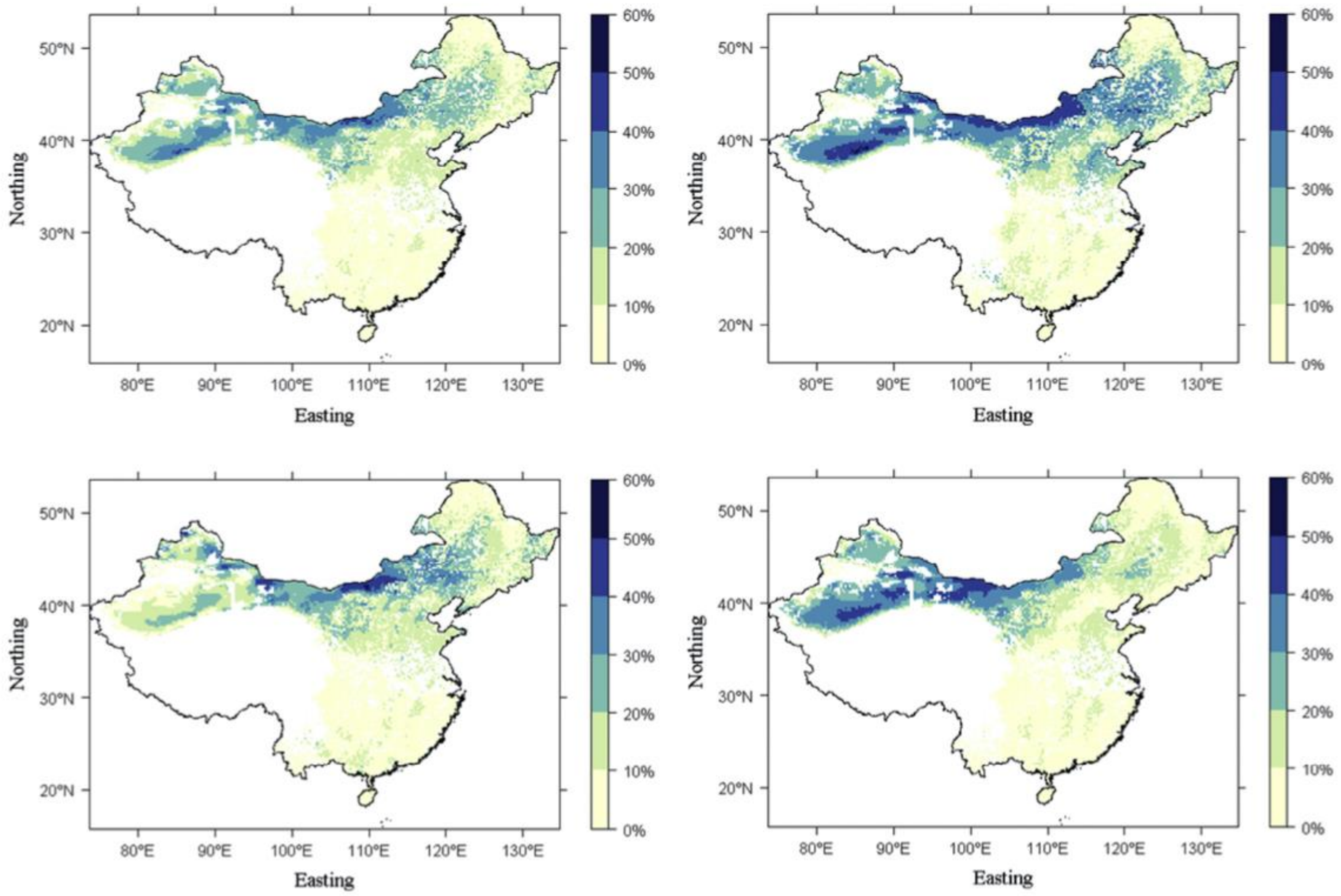
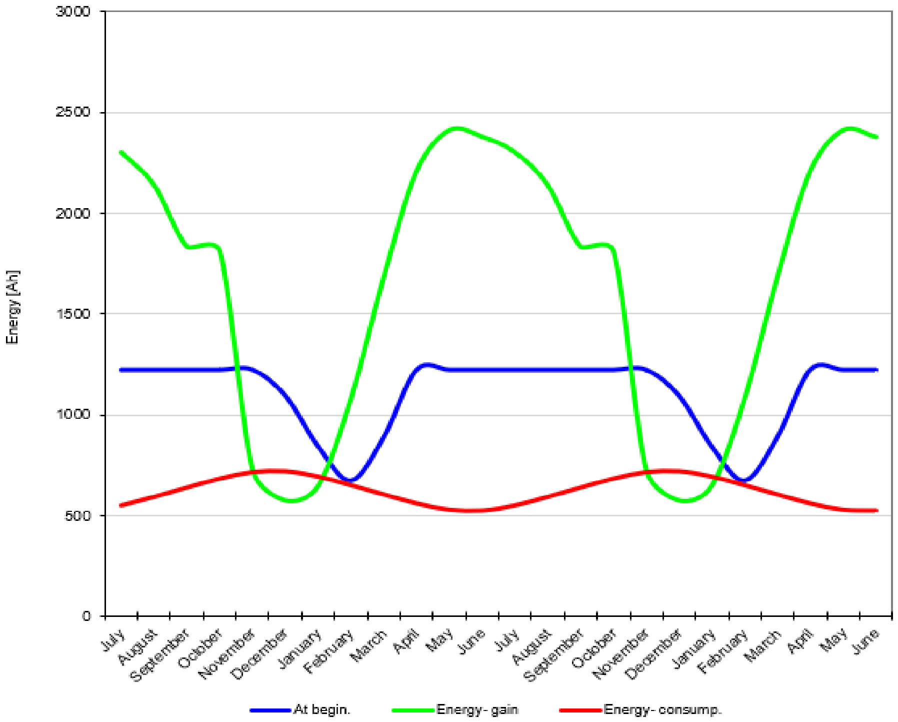


Figure 5: from Bosch et at., 2017 showing seasonal variation of average capacity factor in China

Maritime Usage of POWER Climatological and Time Series Data

Autonomous energy systems needed for remote marine structures

- To support renewable energy for remote navigation aids, IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) publishes a solar and storage system design guide and sizing tool—which relies on NASA POWER for the core inputs.
- POWER global data and specialized parameters integrate into IALA's tool in ways that other irradiance-only datasets cannot.
- Sample critical Inputs are:
  - Daily global all-sky insolation
  - Long-term statistics:
    - "black-sky days" parameter informs battery backup decisions using daily irradiance variability
    - tilted irradiance estimates including optimal tilt angle estimates

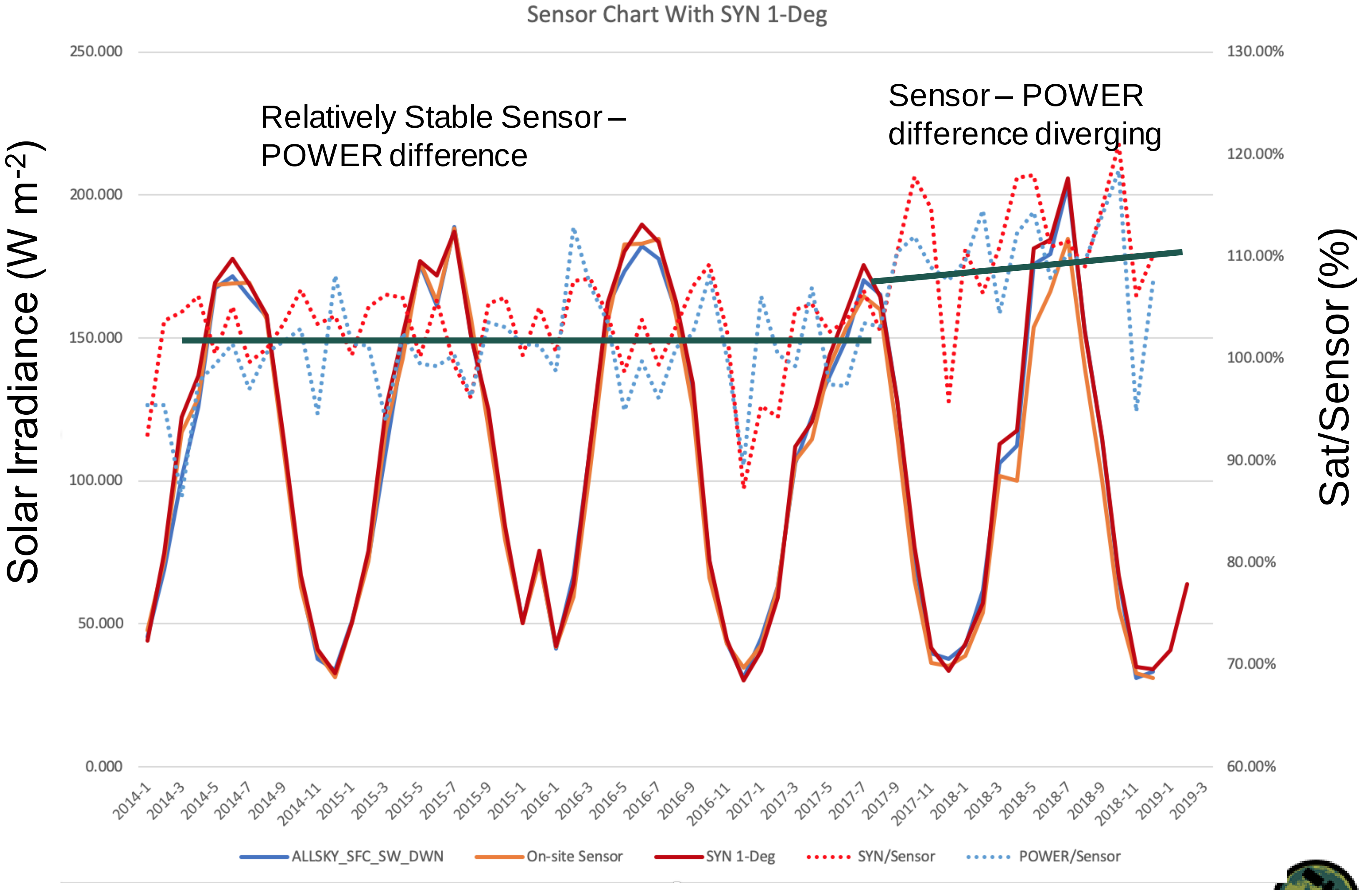


(Courtesy ICF POWER Use Case Report, 2021)

How Can Near-Real Time Parameters by used?

Solar Panel Installation Monitoring

- User manages 50 solar panel sites producing 5.3 MW of power.
- Reads POWER low latency and sensors to help monitor performance
- Noted divergence > 5% with POWER surface irradiance
- Used CERES SYN1Deg (new POWER Beta) and EBAF (not shown) to evaluate for trend; none found
- After several additional months divergence reached 50%
- User concluded sensor was bad

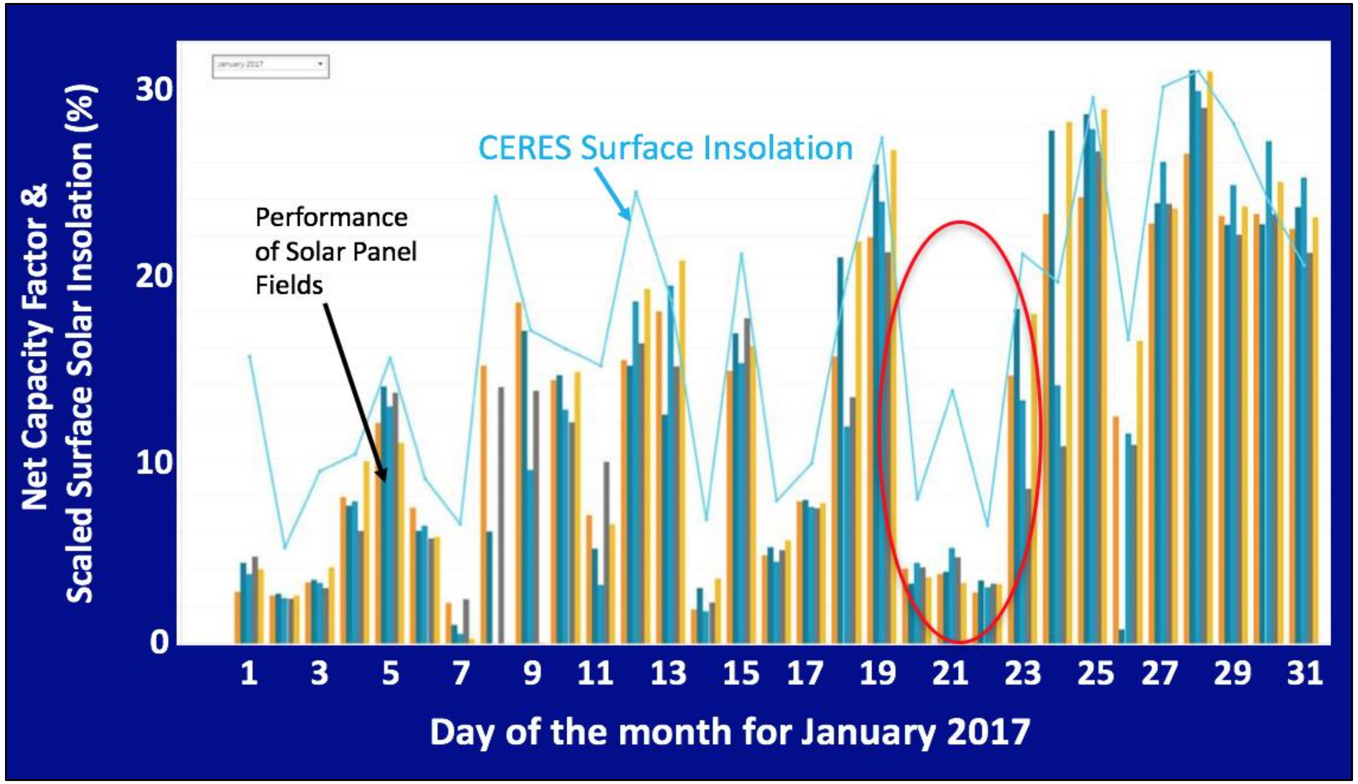


How can solar irradiance parameters be used?

Solar Photovoltaic Panel Array Monitoring

- A Customer First Renewables' consultant obtains POWER's near-real time solar irradiance from CERES FLASHFlux (~6-7 days).
- These data are compared to the energy produced from five solar photovoltaic (PV) panel array fields monitored in North Carolina, US.
- The variability of solar field electrical output is compared to day-to-day solar irradiance values to assess performance and identify potential system problems.

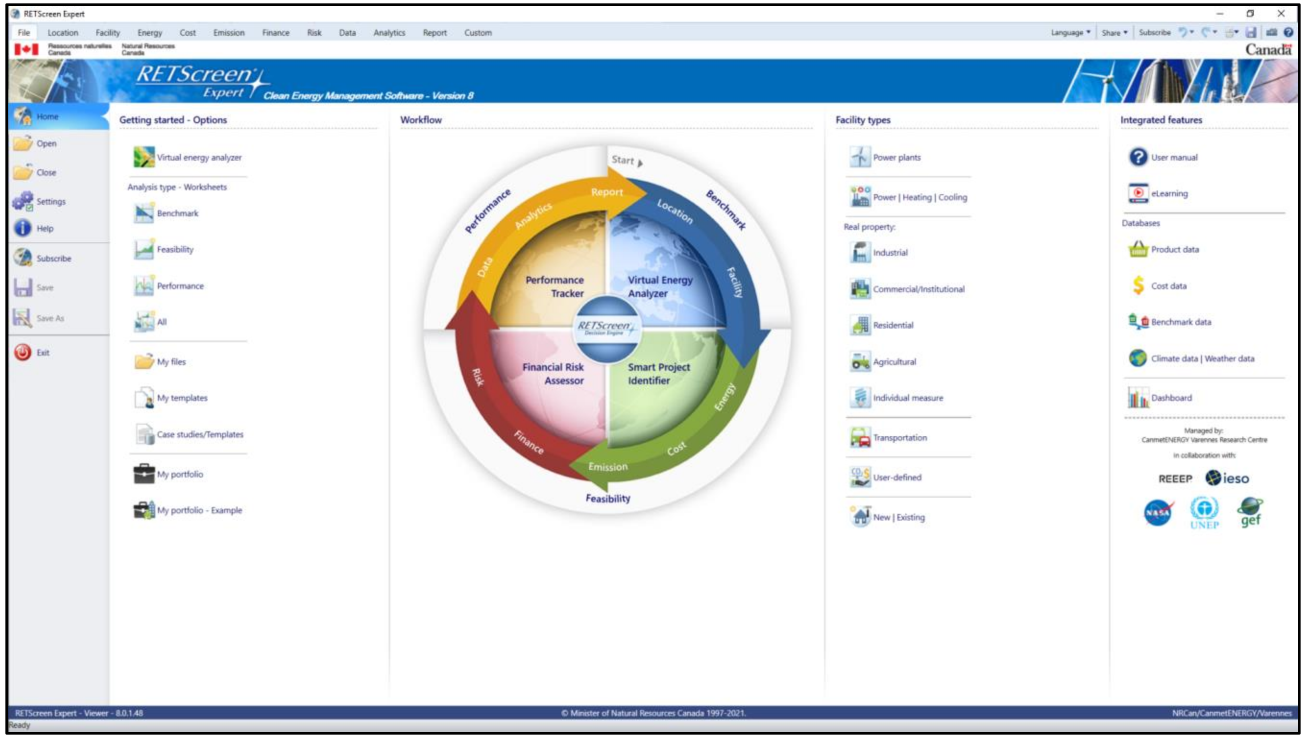
Does PV panel electrical output properly correspond to sunlight conditions?



The RETScreen® Partnership

- The POWER project has had a partnership with RETScreen® for over 20 years where POWER provides global data as:
  - Climatological averages that are embedded in the software
  - Near-real time obtained via a direct connection to POWER

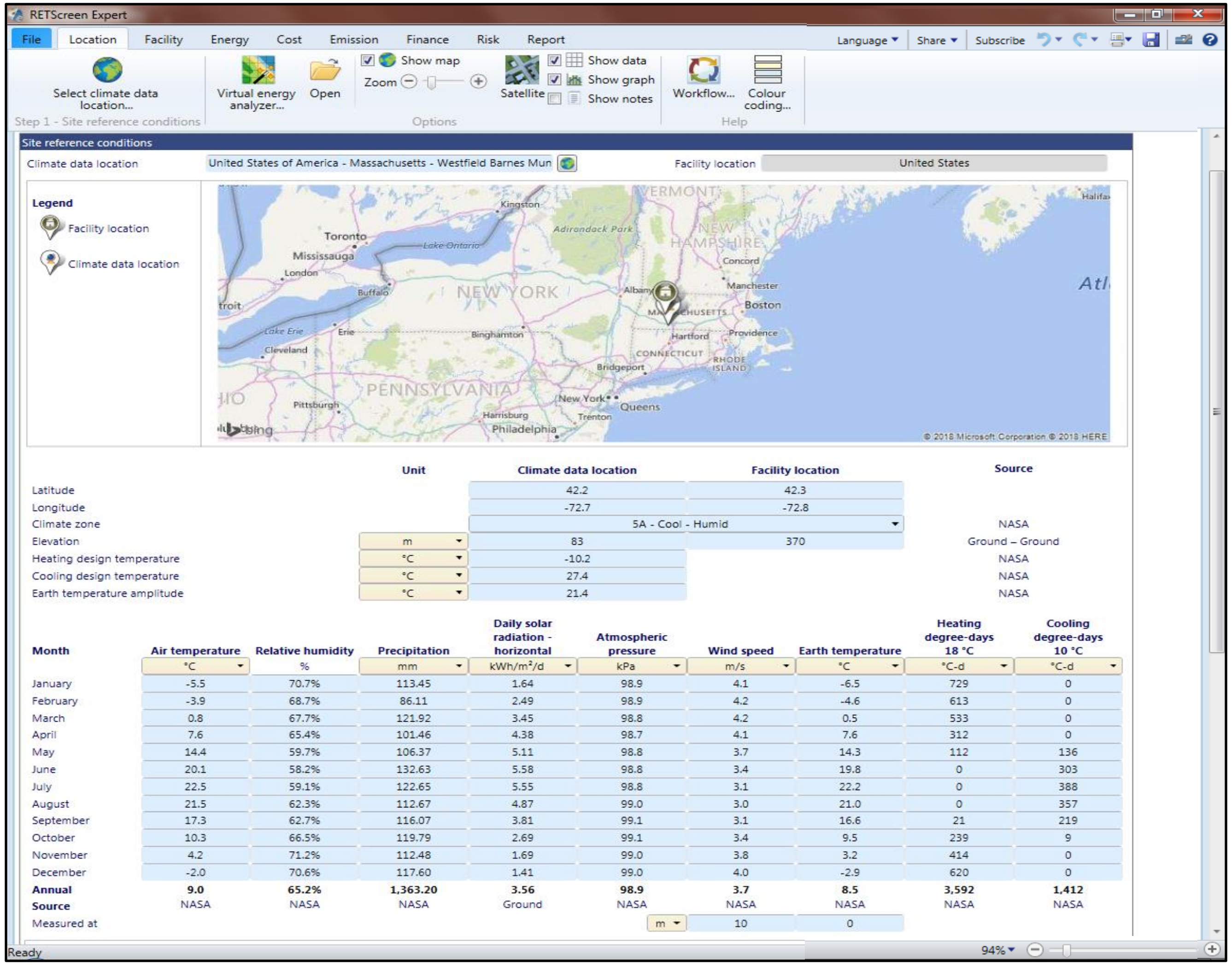
- **World's leading clean energy decision making software**
  - Benchmark, feasibility, performance, and portfolio analysis
  - Energy efficiency, heating and cooling, power generation and cogeneration
  - 36 languages covering 2/3 of world's population
  - 700,000+ registered users



RETScreen®: is a registered trademark of the Government of Canada

RETScreen®'s Integration of POWER Data

- A RETScreen® Expert "climate data" input screen is shown; if surface measurements are unavailable RETScreen uses POWER provided estimates
- Parameters include long-term averages by month of multiple parameters such as (embedded):
  - Surface temperatures
  - Precipitation
  - Winds
  - Solar Irradiance
- Similar parameters for energy monitoring applications requiring the near-real time data stream directly accessed through POWER's API



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RETScreen® and POWER Applications: Solar Technologies

Solar Wall – Wicked Joe Coffee

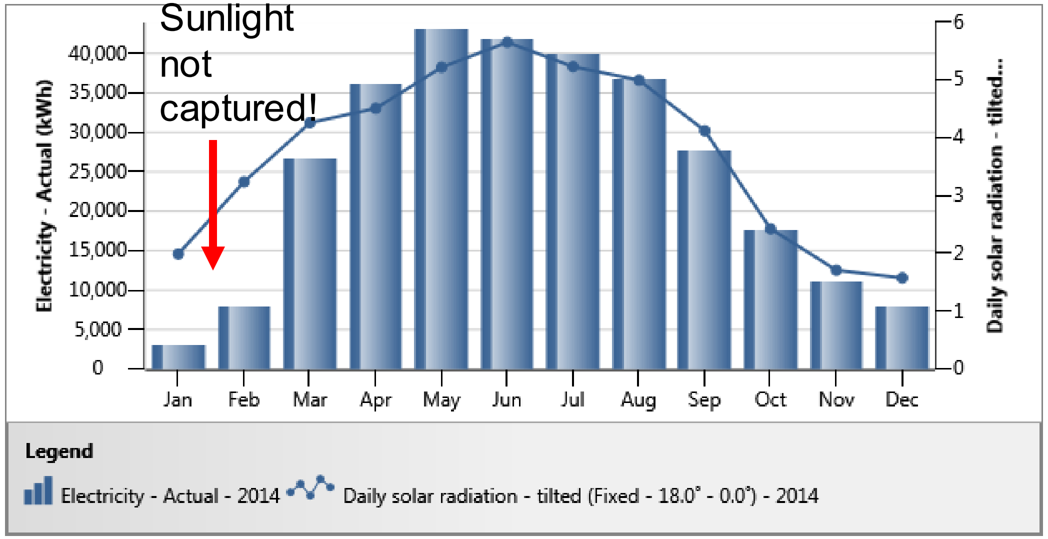
- Wicked Joe is a family-owned coffee company that wanted to use sustainable business practices
- Their facility was 20,000 sq ft (1858 sq m) and the company wanted to save heating costs
- They assessed renewable technologies to meet their needs; considering their Maine location in the Northeastern US
- The builders utilized RETScreen© and POWER data to determined that a glazed solar wall would capture 40% more heat.
- The company reports cost savings of approximately $10,000 per year.

See more at Space for US

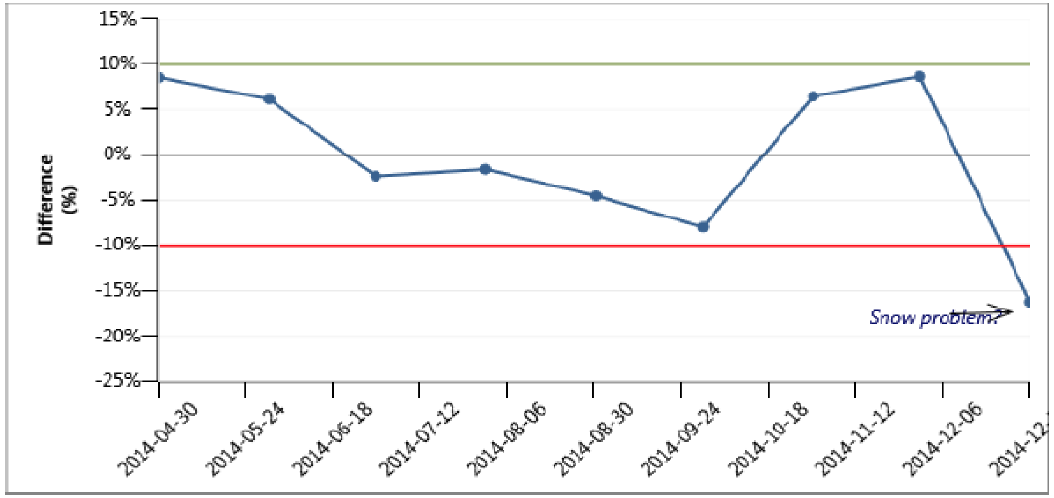
RETScreen®: is a registered trademark of the Government of Canada

RETScreen® and POWER Applications: Solar Power Plant

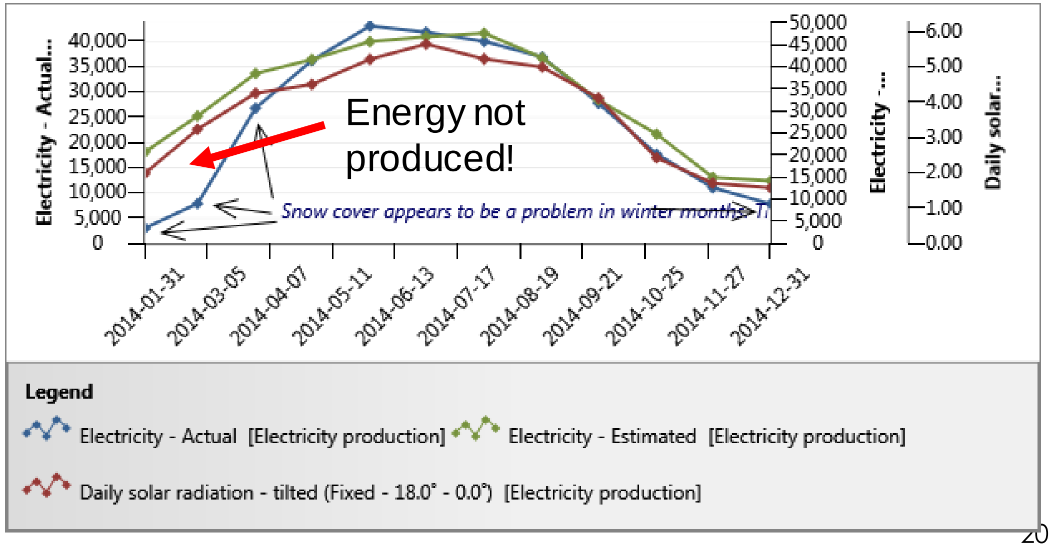
Should this solar power plant pay to have snow cleaned off their panels in winter?



Control chart (Baseline)



Monthly electrical output compared to monthly averaged solar irradiance (corrected with tilt parameterization) from CERES FLASHFlux via POWER.

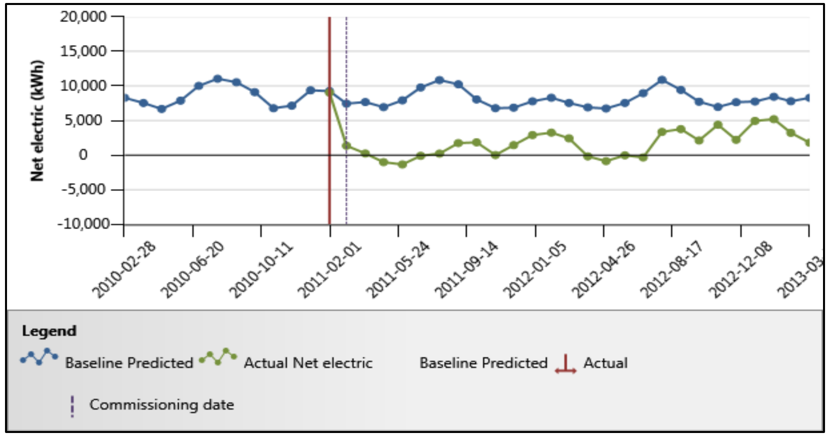


RETScreen® and POWER Applications: NASA LaRC Solar Panel

NASA EO Data and/or Surface Measurements

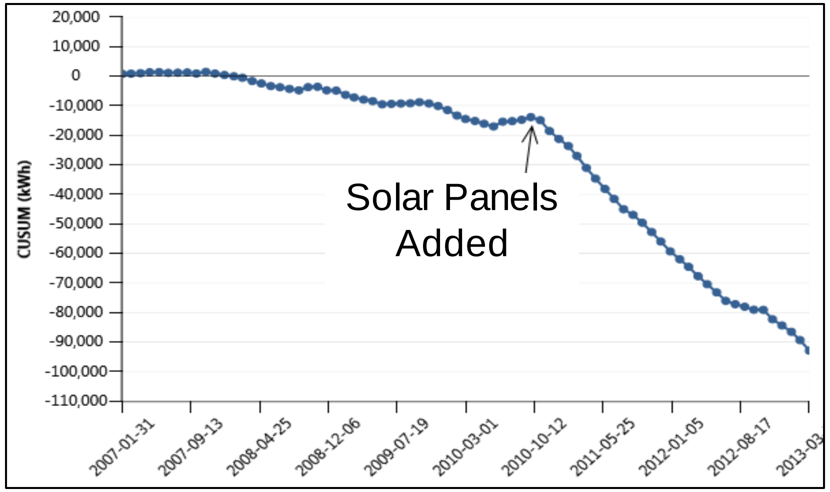
CERES FLASHFLux → NRT Time Series POWER API Services → RETScreen Energy Analysis Application

Net Savings 160 MWh (2/10–3/13)

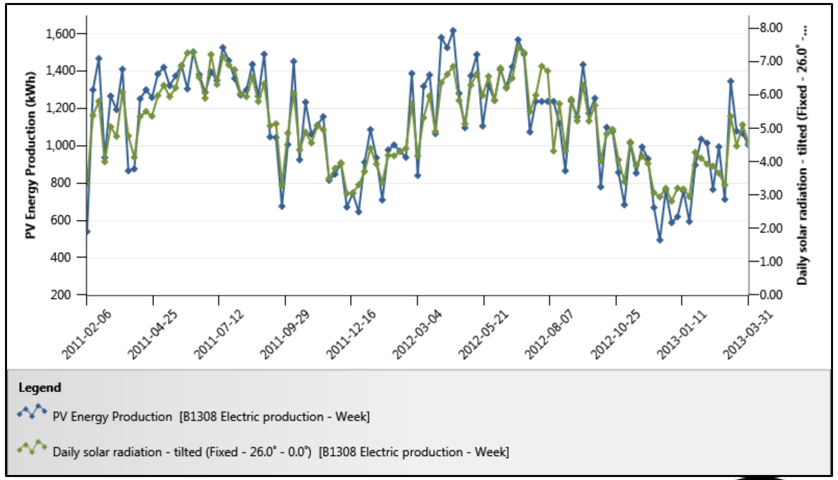


Four building energy assessments working with center energy management officials and RETScreen.

Steady state RETScreen regression models provide for energy performance analysis (NASA TMs available).



Solar Panel Electrical Output (kWh)

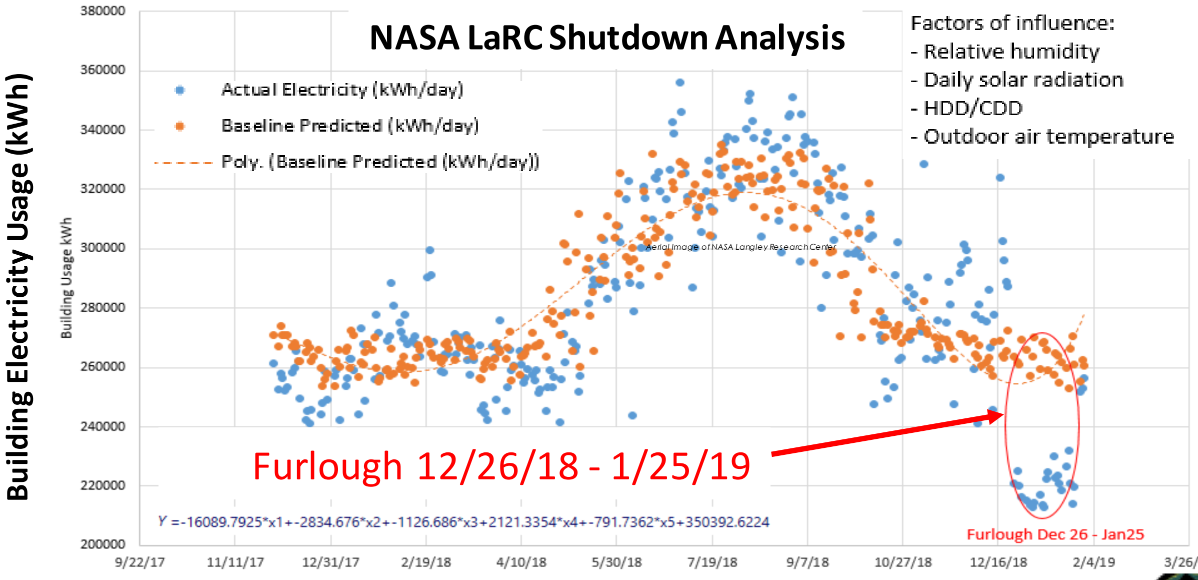


RETScreen® and POWER Applications: NASA Building Energy

Building Energy Usage Monitoring: How much energy would have been used if all buildings were at normal capacity?

- NASA Langley's Center Operations uses data from POWER and RETScreen to monitor energy usage for the entire center relative to weather and sunlight conditions.
- These are used to make an accurate estimate of the electrical energy **not** used during the 2019 Furlough by normalizing to weather conditions.
- NASA's Office of Infrastructure is using RETScreen® and POWER NASA-wide to help assess building energy efficiency.

Aerial Image of NASA Langley Research Center

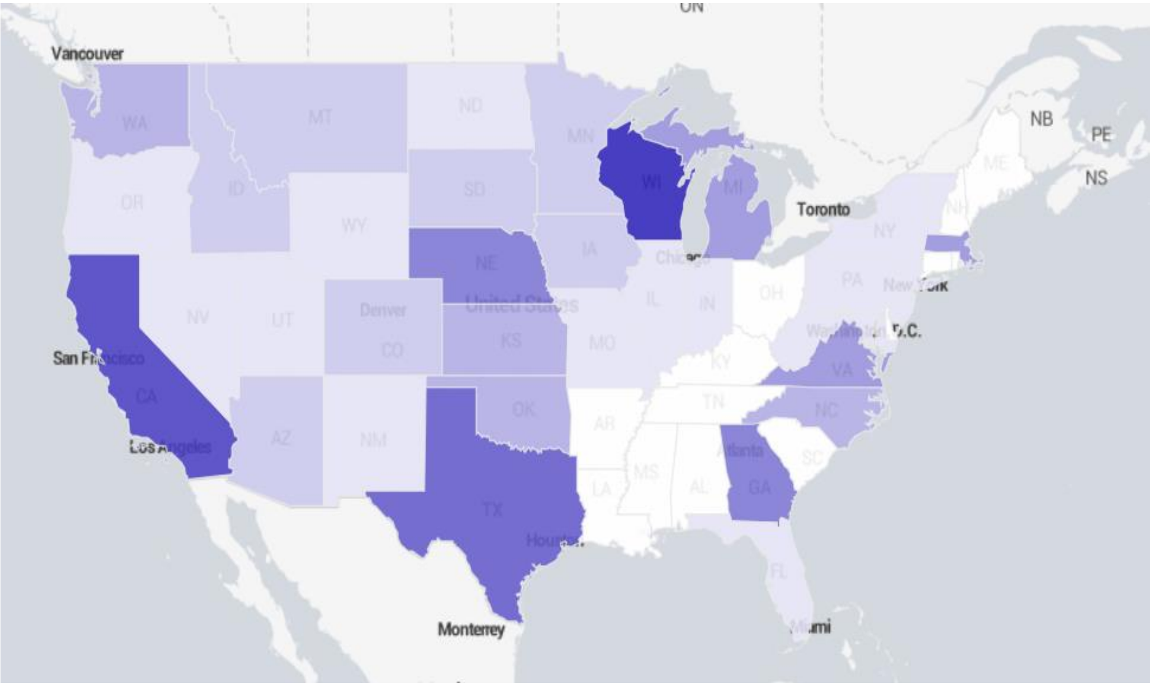


RETScreen®: is a registered trademark of the Government of Canada

RETScreen® /POWER Applied Science Benefits the U.S.

- **Michigan:** University of Michigan uses RETScreen to monitor building energy efficiency and greenhouse gas emission(UMich Link). (uses POWER low latency data products)
- **Alaska:** U.S. Department of Agriculture Analyzes Wood Heating in Alaska with RETScreen (AL Link)(uses POWER daily long-term time series data product streams)
- **Massachusetts and Minnesota:** RETScreen used to developed renewable energy heating and cooling scenarios for policy incentive programs including solar hot water heating, biomass heat and advanced heat pump technologies (MA link & Mn link). (uses POWER climatology data).
- **Hawaii:** Department of Education implementing program to use RETScreen at all education buildings/schools (uses POWER low latency data products)

US Distribution of Early POWER-GIS Beta Adopters (API data requests Q1 2018)



- **Wisconsin:** RETScreen is used extensively for the State's Focus on Energy solar hot water incentive program for businesses. Also, using RETScreen potential projects are evaluated for savings and educational training and feasibility analysis are conducted (WI link 1 & WI link 2) (uses POWER/SSE climatology data from GEWEX SRB, CERES, GMAO).

RETScreen®/POWER Applied Science Benefits the World

- **Canada/US:** Renewable energy engineers use daily solar irradiance to assess performance of multiple solar systems for clients of RETScreen® users in Ottawa region (e.g., others include MIT, Lockheed Martin, Corning, Johnson Controls)
- **Canada:** 3M Company manages 200+ facilities using RETScreen® and POWER low latency data: "The NASA datasets we use are critical to our energy analysis since they are used as major variables that predict our energy use."
- **Spain:** Solar geometry and Solar Noon and Daylight Hours to design solar streetlights. – Pilar Pérez Oliván, Asesora Luminotécnica, Navarra
- **Peru:** Provider of solar systems in Peru and uses the POWER data to check amount of sun at a specific point. – Chavier E. Solano Isaya, Product Manager, Energía Solar y Automatización

- **Argentina:** Sizing and Pointing of Solar Panels in the new POWER data portal. Área Técnica , Goodenergy, Buenos Aires
- **Belgium:** "We've been using the NASA database for Nokia's Renewable Energy solutions dimensioning." – Nokia, Antwerpen

POWER and ASHRAE©

What are key parameters for building energy efficiency?

- Critical parameter for building systems is the heating and cooling degree days (HDD/CDD)
- POWER uses MERRA-2 to define long-term HDD/CDD

Heating Degree Days:

$$HDD = \sum (T_{base} - \langle T_i \rangle)^{+}$$

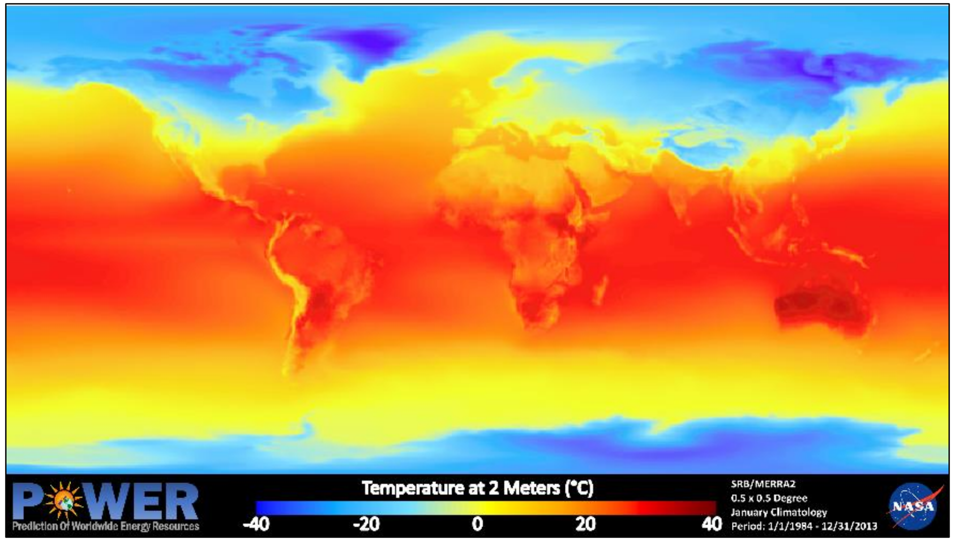
$$T_{base} = 18.3^{o}C\ (65^{o}F)$$

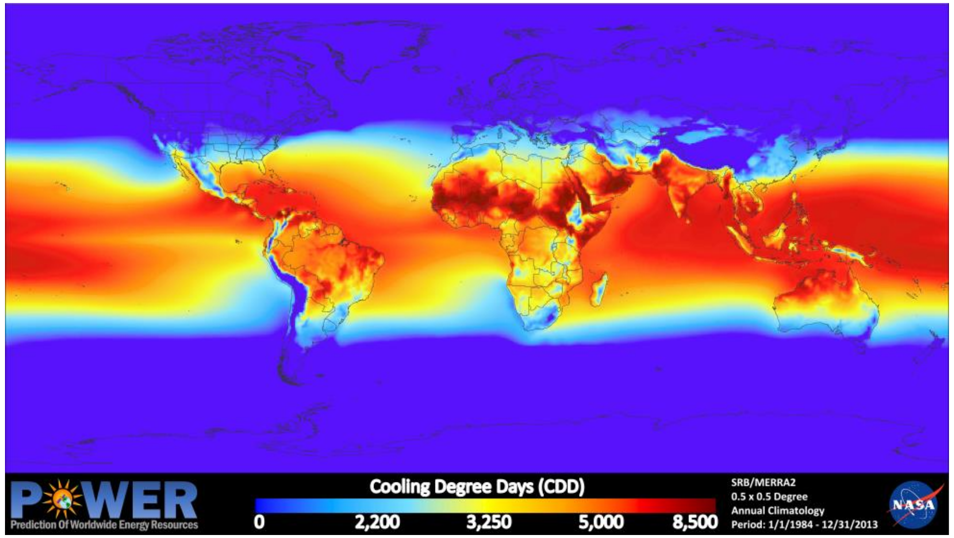
Cooling Degree Days:

$$CDD = \sum (\langle T_i \rangle - T_{base})^{+}$$

$$T_{base} = 10^{o}C\ (50^{o}F)$$

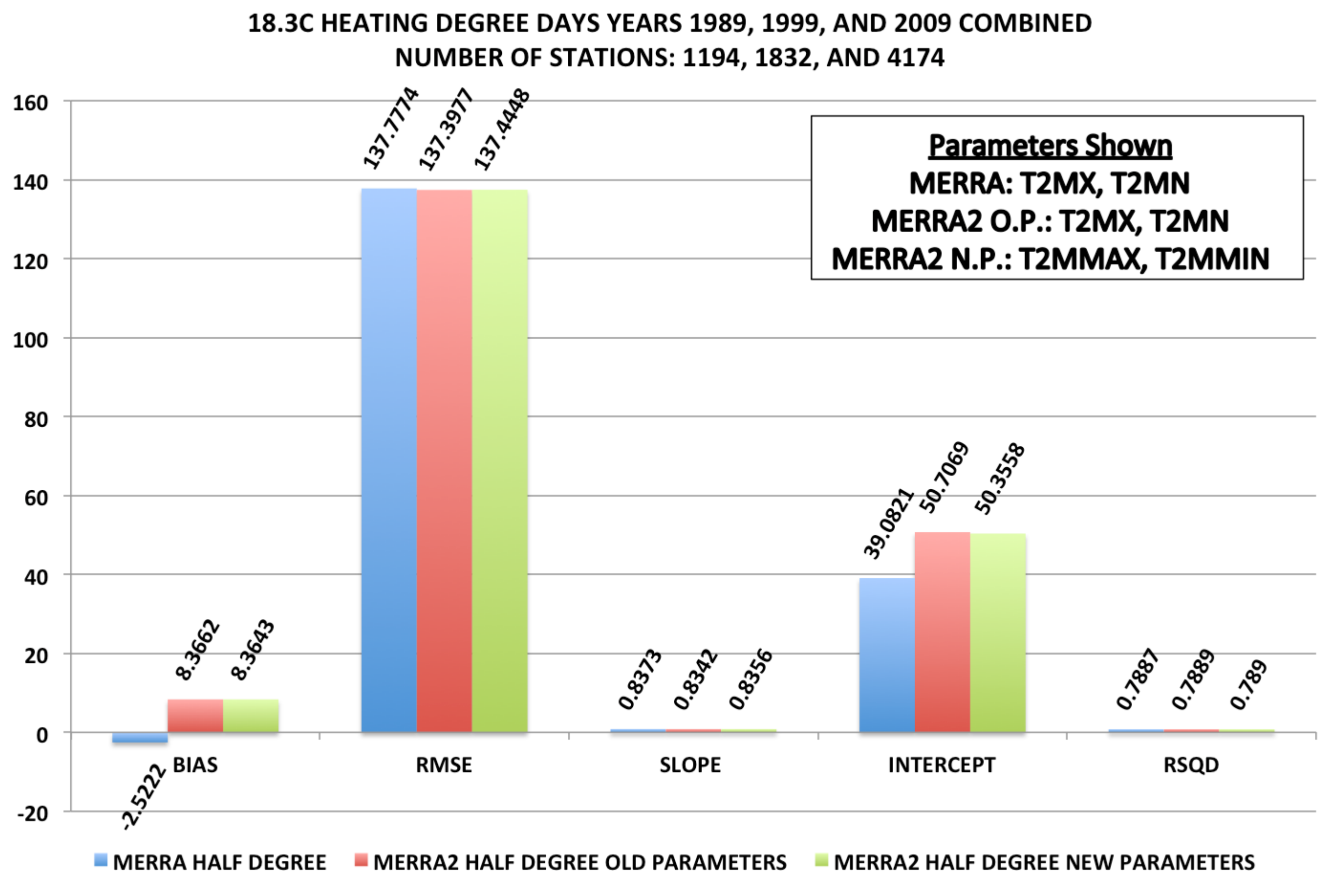
$^{+}$ *Positive definite: negative values are not included in sum*

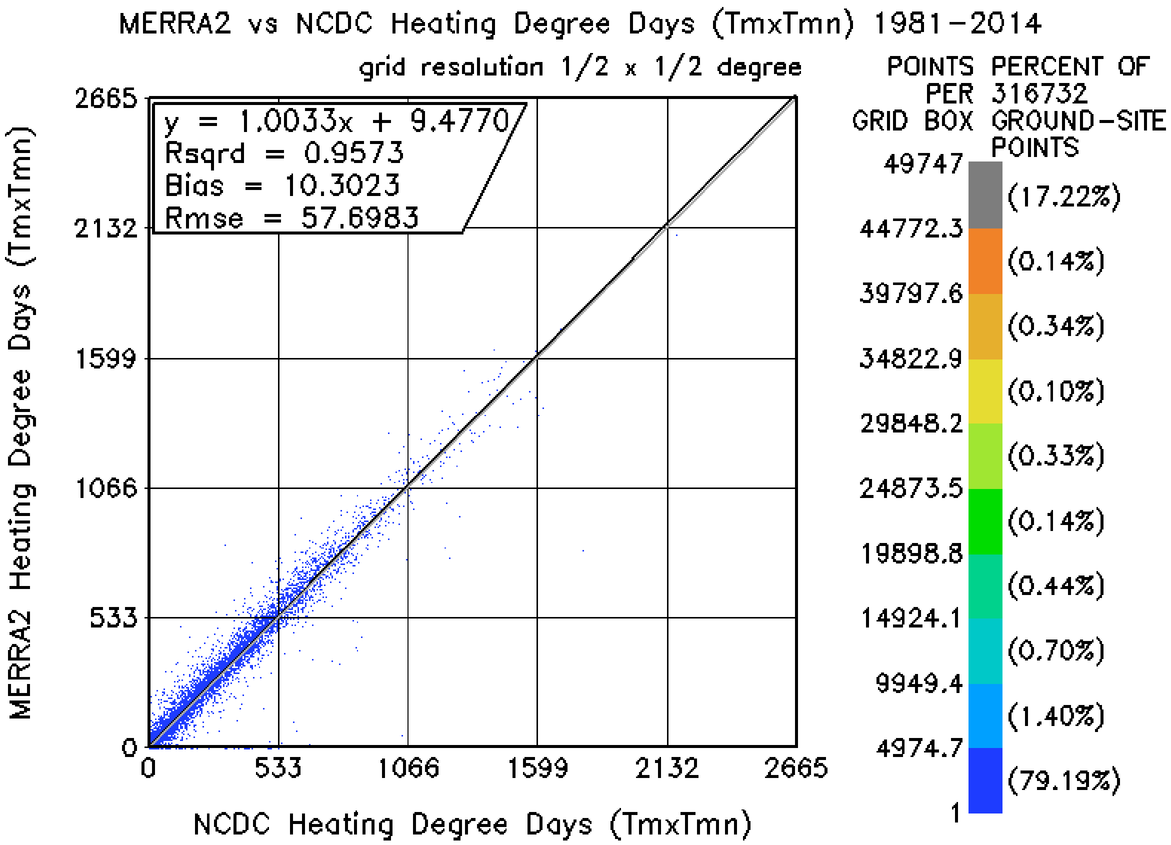




Global Validation of MERRA-2 Heating Degree Days

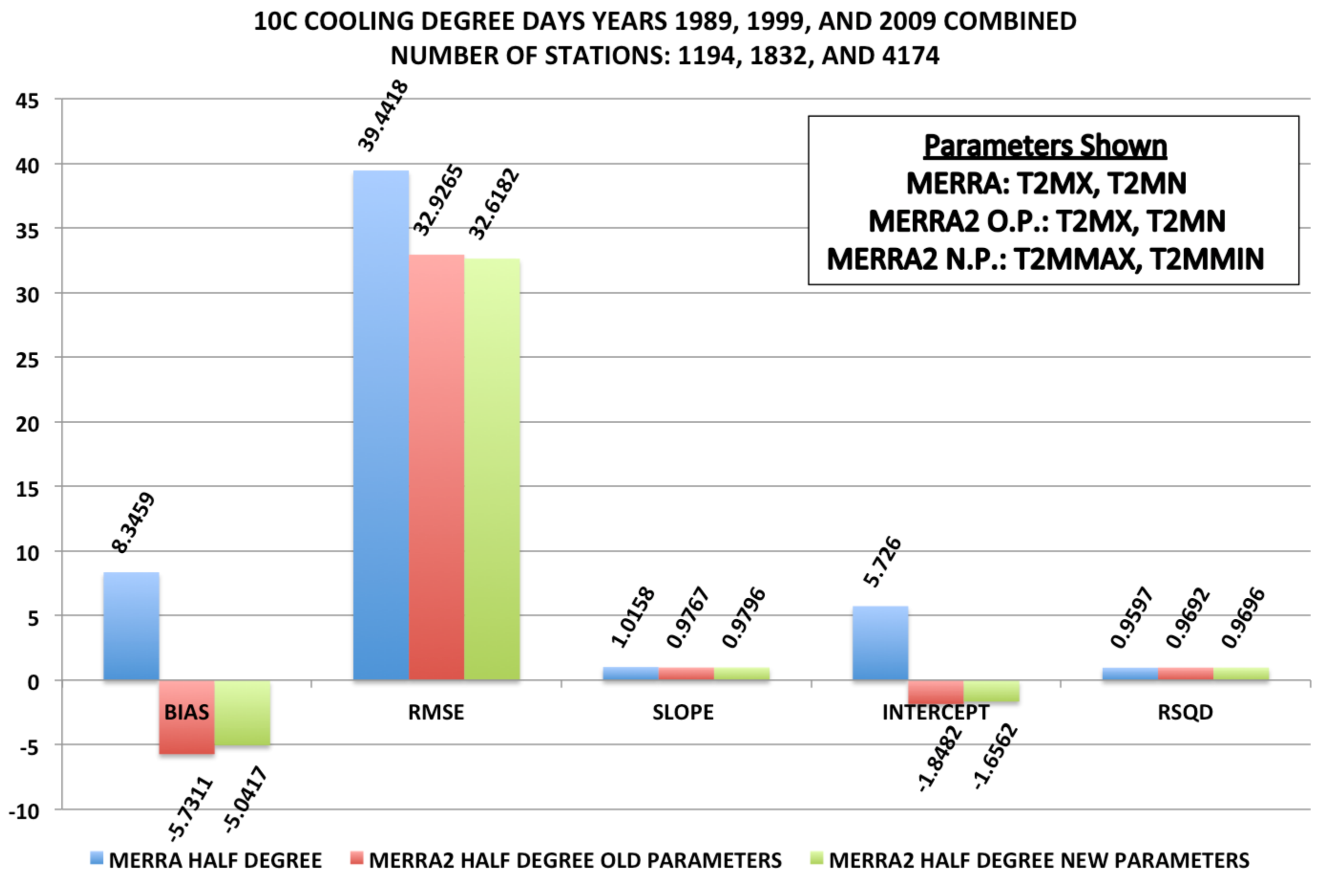
1981-2014, every 3rd year

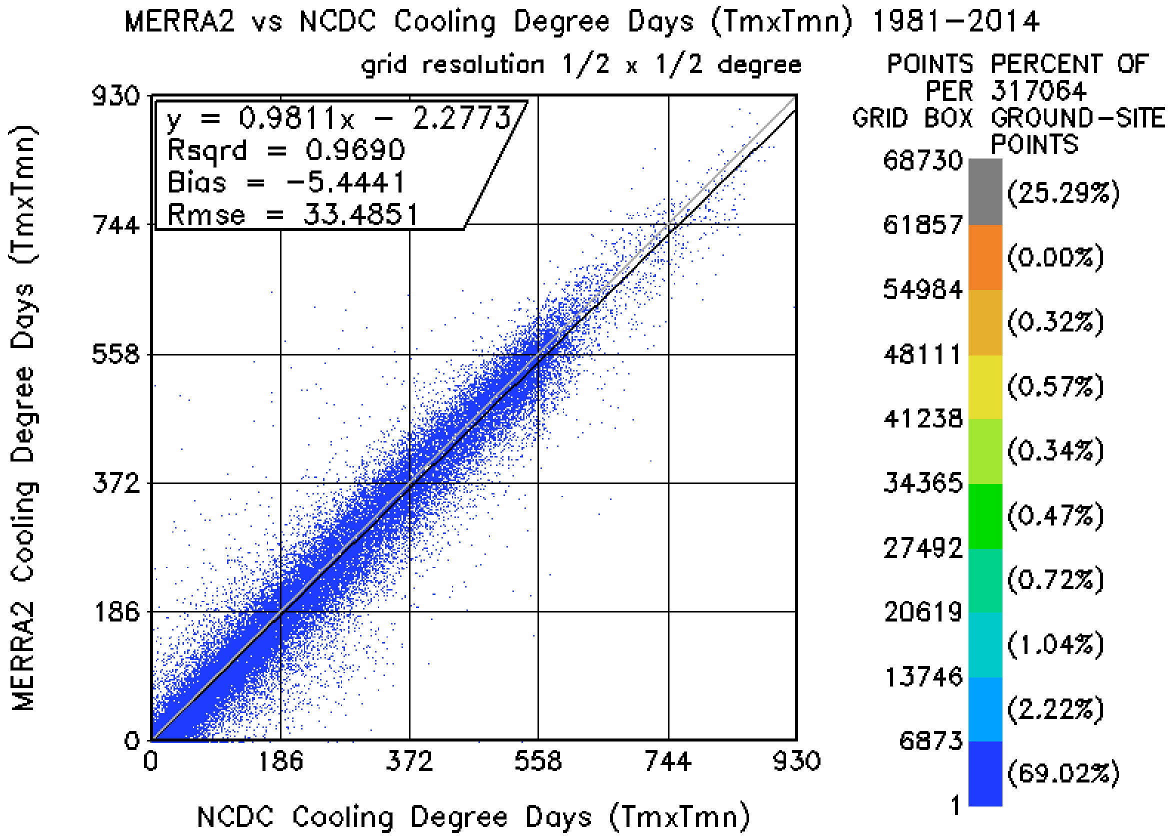




Global Validation of MERRA-2 Cooling Degree Days

1981-2014, every 3rd year





ASHRAE© and POWER: Building Climate Zone Definitions

- Climatological annual HDD/CDD are used by ASHRAE to define Building Climate Zones
- Dry/humid/marine zones are determined using monthly and annual precipitation using MERRA-2
- Used by government officials to determine building code standards in US and around the world
- POWER provides maps /data for long-term building climate zones and variability

Table A-3 Climate Zone Definitions (taken from Proposed Addendum b to Standard 169, Climate Data for Building Design Standards).

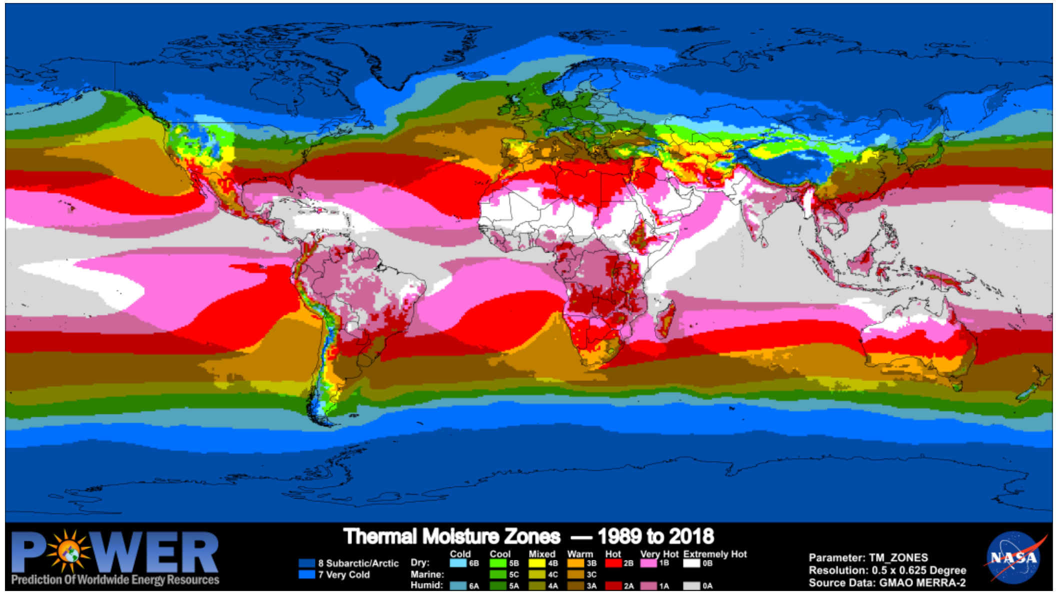
Thermal Zone	Name	I-P Units	SI Units
0	Extremely Hot – Humid (0A), Dry (0B)	10,800 < CDD50ºF	6000 < CDD10ºC
1	Very Hot – Humid (1A), Dry (1B)	9000 < CDD50ºF ≤ 10,800	5000 < CDD10ºC ≤ 6000
2	Hot – Humid (2A), Dry (2B)	6300 < CDD50ºF ≤ 9000	3500 < CDD10ºC ≤ 5000
3A and 3B	Warm – Humid (3A), Dry (3B)	4500 < CDD50ºF ≤ 6300 AND HDD65ºF ≤ 3600	2500 < CDD10ºC < 3500 AND HDD18ºC ≤ 2000
3C	Warm – Marine (3C)	CDD50ºF ≤ 4500 AND HDD65ºF ≤ 3600	CDD10ºC ≤ 2500 AND HDD18ºC ≤ 2000
4A and 4B	Mixed – Humid (4A), Dry (4B)	2700 < CDD50ºF ≤ 6300 AND 3600 < HDD65ºF ≤ 5400	1500 < CDD10ºC < 3500 AND 2000 < HDD18ºC ≤ 3000
4C	Mixed – Marine	CDD50ºF ≤ 2700 AND 3600 < HDD65ºF ≤ 5400	CDD10ºC ≤ 1500 AND 2000 < HDD18ºC ≤ 3000
5A and 5B	Cool– Humid (5A), Dry (5B)	1800 < CDD50ºF ≤ 6300 AND 5400 < HDD65ºF ≤ 7200	1000 < CDD10ºC ≤ 3500 AND 3000 < HDD18ºC ≤ 4000
5C	Cool – Marine (5C)	CDD50ºF ≤ 1800 AND 5400 < HDD65ºF ≤ 7200	CDD10ºC ≤ 1000 AND 3000 < HDD18ºC ≤ 4000
6A and 6B	Cold – Humid (6A), Dry (6B)	7200 < HDD65ºF ≤ 9000	4000 < HDD18ºC ≤ 5000
7	Very Cold (7)	9000 < HDD65ºF ≤ 12600	5000 < HDD18ºC ≤ 7000
8	Subarctic/Arctic (8)	12600 < HDD65ºF	7000 < HDD18ºC

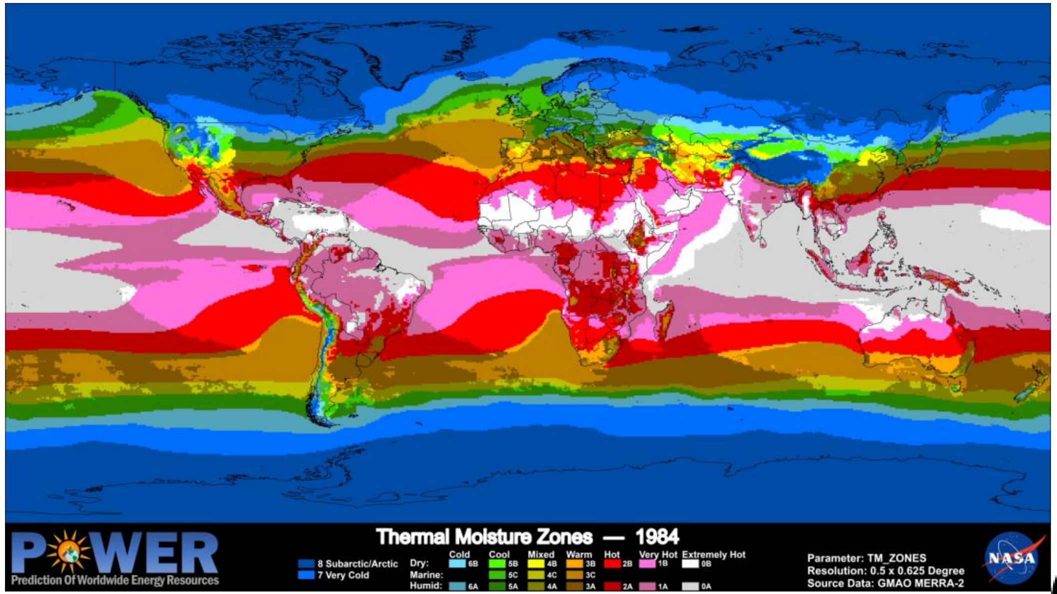
The criteria for dry and humid are similar but not identical to those enumerated in Table 2B above.

ASHRAE© Building Climate Zones

Illustrating Climate Variability

- Using MERRA-2, POWER creates ASHRAE Building Climate Zone maps for world
  - Demonstrated to ASHRAE which subsequently used MERRA-2 for Quadrennial Handbooks
- Also, created “rolling” climate zones from 4-year means to illustrate the changes in time from 1984 through 2019.
  - POWER Beta uses a Custom Zones API endpoint to create these maps.
  - Also, developed a series of python tools to convert to time-enabled the zones as ShapeFiles, Image Services, Feature Services, and GeoTIFFs, and Videos.





ASHRAE© Collaboration

Climate Design Conditions Report

- New (and still being finalized), this report provides statistical meteorological and solar information important the sizing of various building systems such as heating and air conditioning
- ASHRAE provides this report for specific surface sites
- POWER GIS Web Services (beta) allows estimates anywhere in the world for a customized time period and location through the DAV ordering tool
- The long-term statistics utilize hourly values of temperature, humidity, wind, precipitation and solar parameters
- Statistics include percentile values as measure of extremes, conditional probabilities and long-term average values by annual and month

POWER Climatic Design Conditions (MERRA-2 and SRB/CERES)

Latitude: 29.6106 | Longitude: -82.2603 | Elevation: 28.3 | StdPres: 14.68 | Time Period: 2014 - 2019 | Note: 0.5 x 0.5 Degree Gridded Data

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB 99.6%	Heating DB 99%	Humidification DP/MCDB and HR 99.6% DP	99.6% HR	99.6% MCDB	99% DP	99% HR	99% MCDB	Coldest month WS/MCDB 0.4% WS	0.4% MCDB	1% WS	1% MCDB	MCWS/PCWD to 99.6% DB MCWS	PCWD
1	-0.2	1.8	-5.6	0.0		-3.2	0.0		2.7		2.7			

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB 0.4% DB	0.4% MCWB	1% DB	1% MCWB	2% DB	2% MCWB	Evaporation WB/MCDB 0.4% WB	0.4% MCDB	1% WB	1% MCDB	2% WB	2% MCDB	MCWS/PCWD to 0.4% DB MCWS	PCWD
7	12.5	35.8		34.7		33.6		28.4		28.1		27.8			

Dehumidification DP/MCDB and HR 0.4% DP	0.4% HR	0.4% MCDB	1% DP	1% HR	1% MCDB	2% DP	2% HR	2% MCDB	Enthalpy/MCDB 0.4% Enth	0.4% MCDB	1% Enth	1% MCDB	2% Enth	2% MCDB	Extreme Max WB
35.8	20.0		25.3	20.0		25.0	20.0								29.6

Extreme Annual Design Conditions

Extreme Annual WS 1%	2.5%	5%		Extreme Annual Temperature Mean Min	Mean Max	Standard deviation Min	Standard deviation Max	n-Year Return Period Values of Extreme Temperature n=5 years Min	n=5 years Max	n=10 years Min	n=10 years Max	n=20 years Min	n=20 years Max	n=50 years Min	n=50 years Max
6.0	5.2	4.5	DB	-3.6	37.4	1.8	1.6	-4.9	38.6	-6.0	39.6	-7.0	40.5	-8.3	41.7
			WB	-5.4	29.2	2.9	0.4	-7.5	29.5	-9.2	29.7	-10.8	29.9	-12.9	30.1

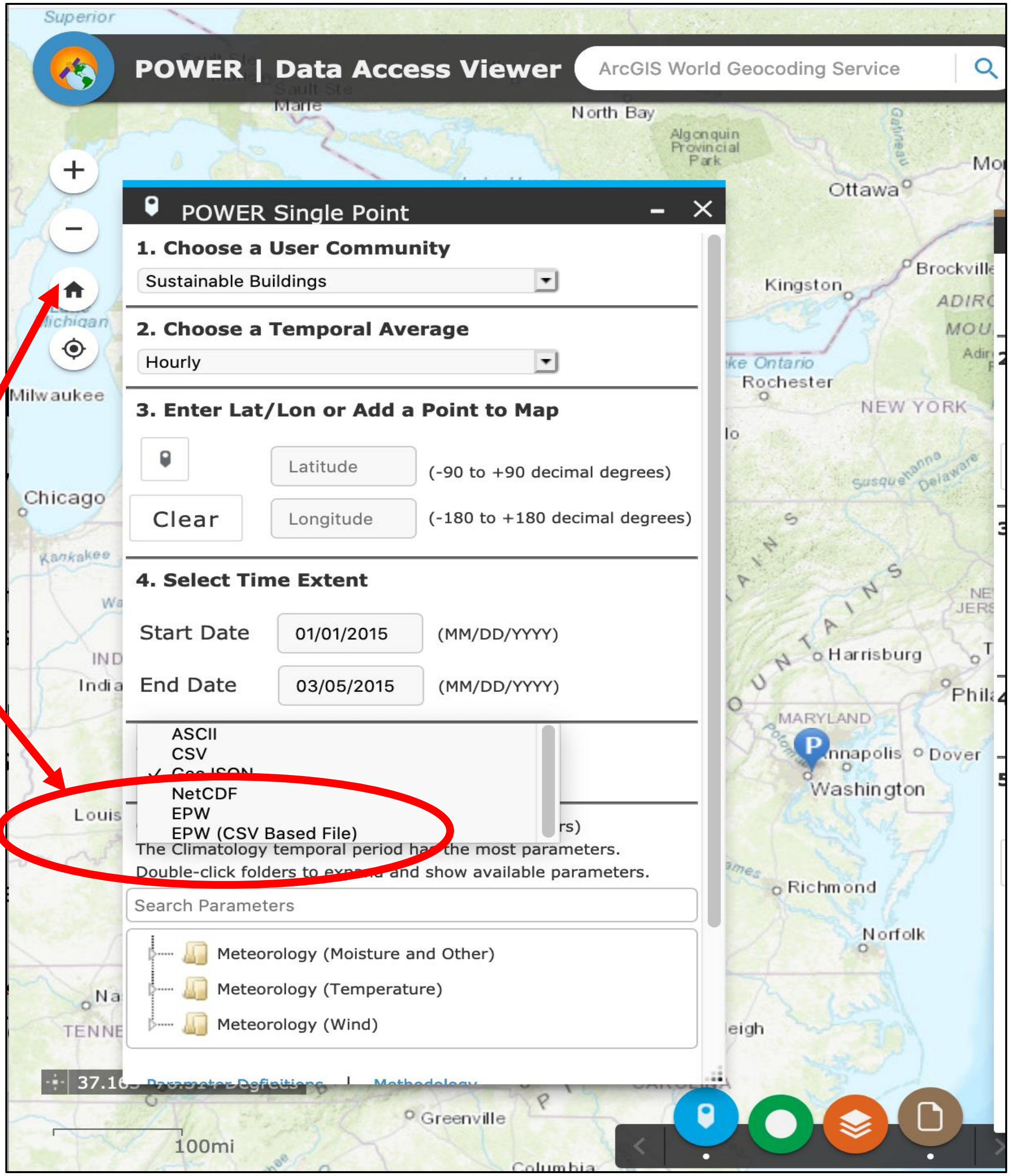
Monthly Climatic Design Conditions

			Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours		DBAvg	21.2	11.5	15.3	17.3	21.3	25.1	27.1	27.9	27.5	26.0	22.3	17.2	15.6
		DBStd	0.7	2.2	3.0	1.8	1.3	1.1	0.9	0.8	0.4	0.8	1.4	2.1	2.1
		HDD10.0	59	40	8	2	0	0	0	0	0	0	0	3	6
		HDD18.3	535	204	95	63	8	0	0	0	0	0	8	61	95
		CDD10.0	4302	100	168	240	350	475	524	563	555	495	397	235	199
		CDD18.3	1747	7	20	45	109	218	275	306	298	246	148	44	31
		CDH23.3													
		CDH26.7													
Wind		WSAvg	2.3	2.7	2.6	2.6	2.6	2.3	2.0	1.7	1.9	2.1	2.6	2.4	2.5
Precipitation		PrecAvg	811	53	44	45	41	45	86	77	145	173	38	44	31
		PrecMax	1383	125	94	146	99	108	202	156	268	394	92	101	80
		PrecMin	3	3	2	1	2	1	3	5	3	1	2	2	5
		PrecStd	637	48	39	53	41	40	76	68	123	155	37	46	27
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB		15.2	18.2	19.3	22.9	26.8	28.1	29.4	28.1	27.1	24.3	20.2	19.1
		MCWB		11.2	16.0	15.2	18.4	19.4	23.0	23.8	24.2	23.4	20.1	17.7	16.3
	2%	DB		15.0	18.1	19.2	22.9	26.7	28.1	29.3	28.1	27.1	24.3	20.1	18.9
		MCWB		11.0	15.9	15.2	18.4	19.4	23.0	23.8	24.2	23.4	20.0	17.5	16.0
	5%	DB		14.4	18.1	19.2	22.9	26.5	28.1	29.1	28.0	27.0	24.2	19.7	18.5
		MCWB		10.7	15.8	15.1	18.3	19.4	23.0	23.8	24.2	23.3	19.8	17.1	15.5
	10%	DB		13.6	17.9	19.2	22.8	26.2	28.1	28.7	27.9	26.9	24.0	19.1	17.9
		MCWB		10.1	15.7	15.0	18.1	19.4	23.0	23.8	24.2	23.1	19.5	16.5	14.6

ASHRAE© and POWER: Custom Formats

Industry Standard EPW Format

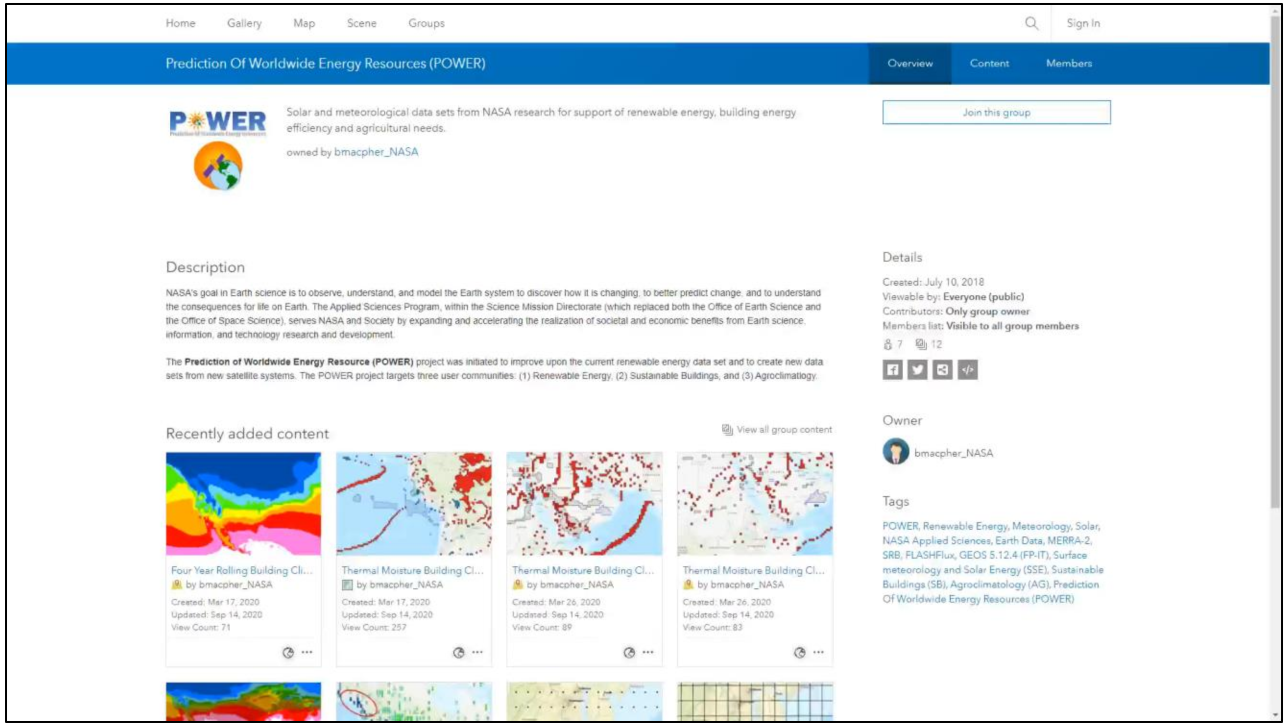
- New in POWER GIS (beta) is the hourly EPW (EnergyPlus Weather) format:
  - Developed for hourly modeling on building systems
  - Used explicitly as input for the EnergyPlus software and many other similar tools
- Available through DAV under "Sustainable Buildings" group
  - Available for user specified location
  - From Jan 1, 2001 to Dec 31, 2019
- EPW contains numerous parameters including temperature, humidity, solar irradiance, solar illuminance, cloudiness, etc. (18 now; +6 later)
- EPW formats in two options: raw and CSV compatible.



POWER Geospatial Data Services

ArcGIS© Image and Feature Services allow users to efficiently interact with the POWER data in GIS applications.

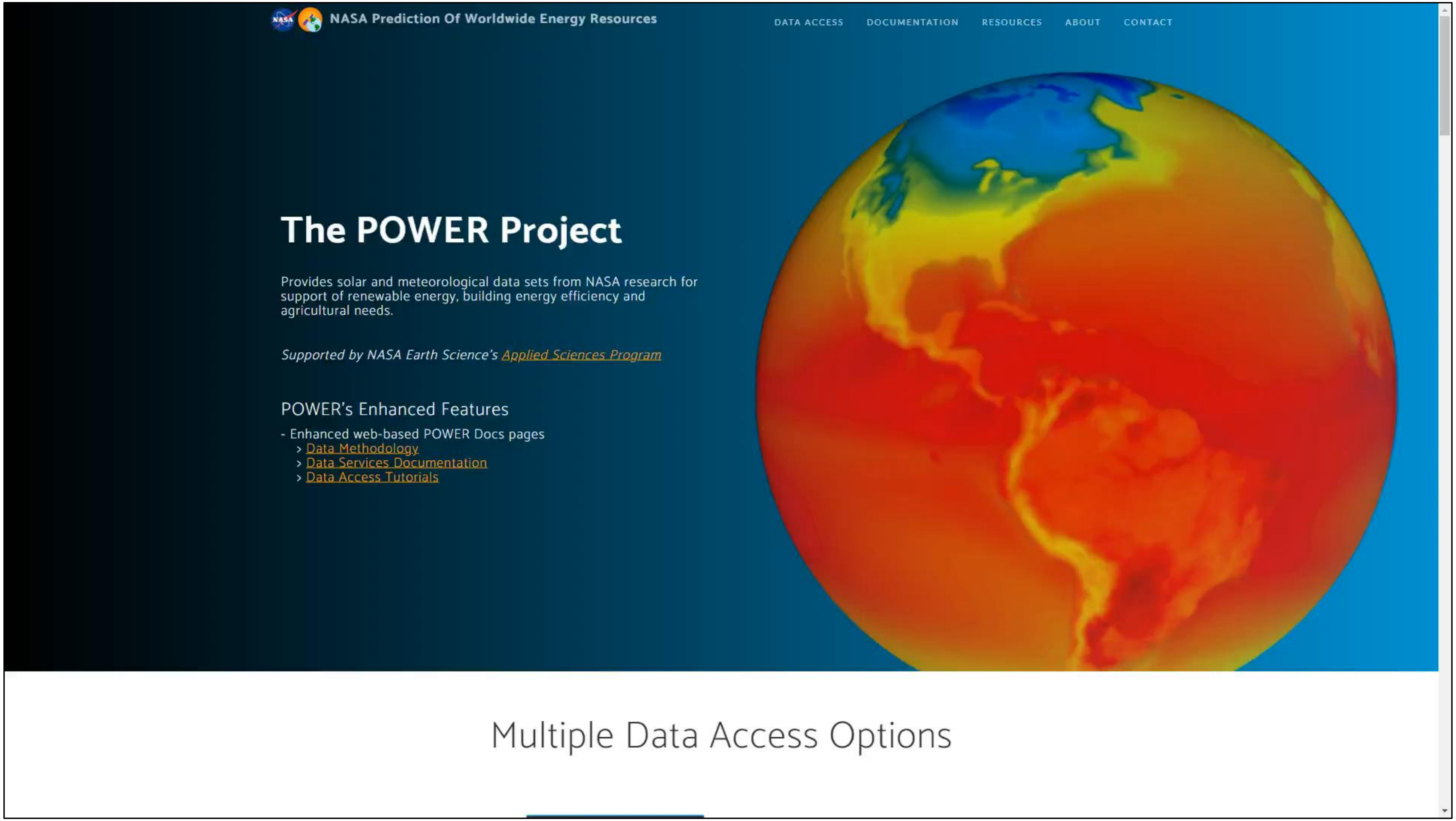
- Allows for direct connection to data services in GIS desktop and web-based applications
- Provides Open Geospatial Consortium (OGC©) compliant services.
- Availability in multiple data portals NASA ArcGIS© Online, ASDC, and the Esri© Living Atlas



Hyperlink: [NASA AGOL - POWER]

ArcGIS®: is a registered trademark of the Environmental Systems Research Institute, inc.
OGC©: is a registered trademark of the Open Geospatial Consortium
Esri®: is a registered trademark of the Environmental Systems Research Institute, inc.

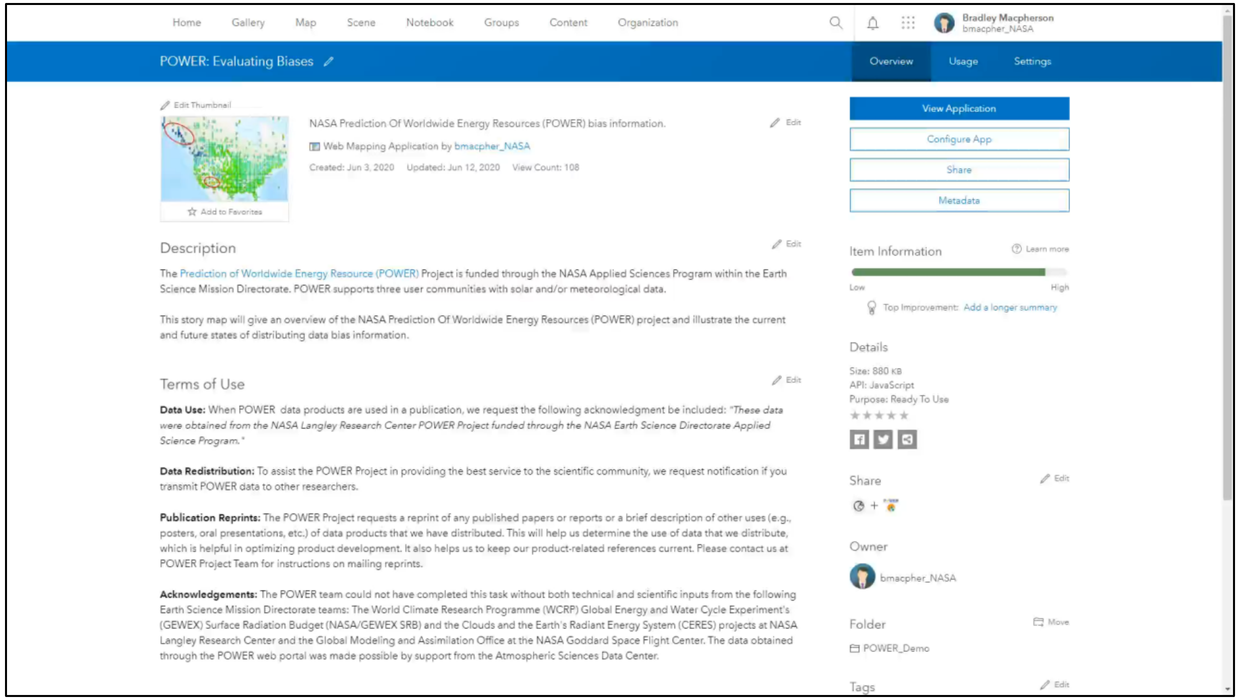
POWER Geospatial Data Services – Video



POWER: Tools and Analytics

Story Map Evaluating Biases

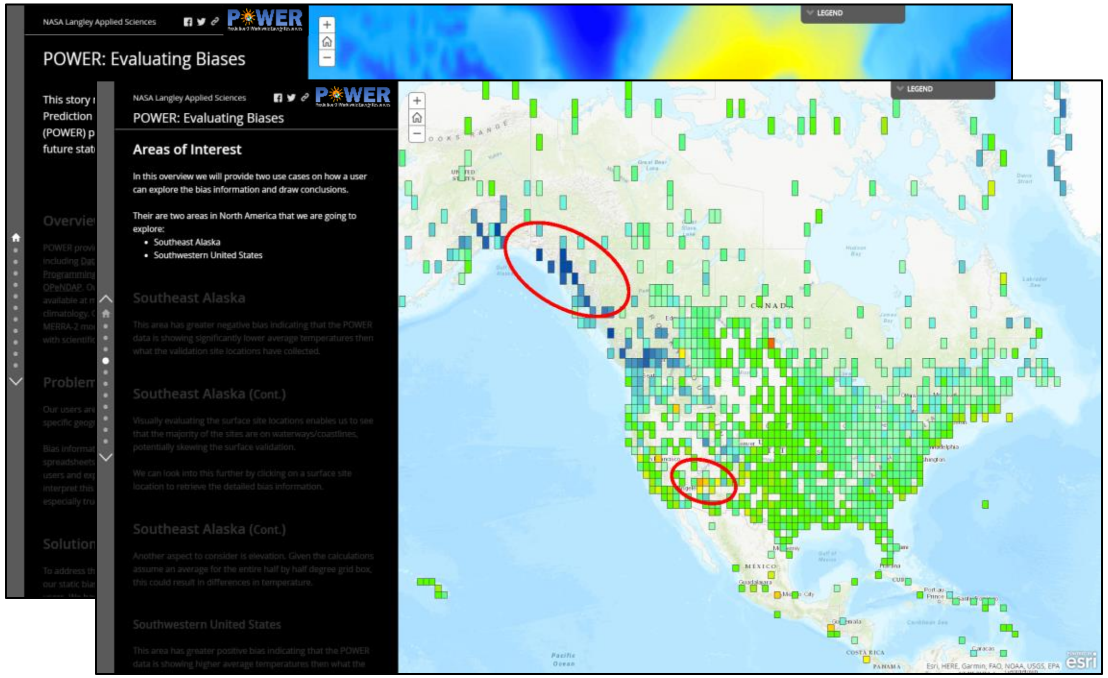
- **Key Features:**
  - Allow users to navigate through a spatially enabled presentation enhanced with multi-media, narratives, and interactive GIS content
  - Provides a thorough overview, allowing users to develop their own conclusions from the underlying data.
  - Available on NASA AGOL, alleviating the need for users to have additional software

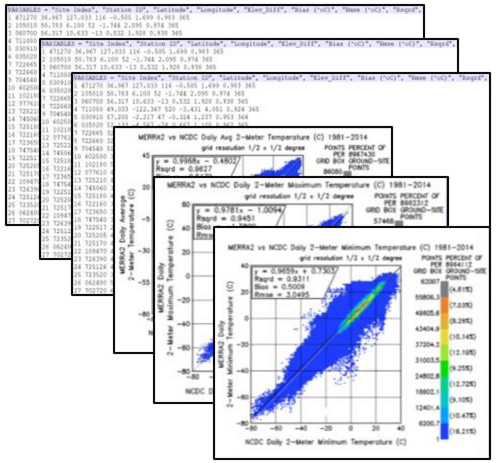


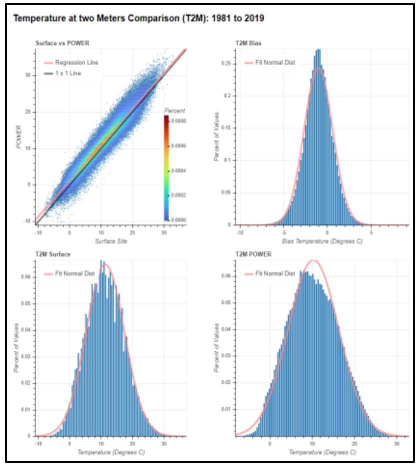
Hyperlink: [Evaluating Biases]

POWER Analysis – Bias Mapping

- The spatially enabled bias data then is used to create maps and conduct spatial analysis
- Have developed and released an example StoryMap® used to identify areas of regional bias
- This procedure will be used to validate the next version of the POWER Data Archive where the bias data will be hosted as web maps and standard text-based reports.
- The official bias information is in the POWER Methodology documentation hosted on the POWER Website.

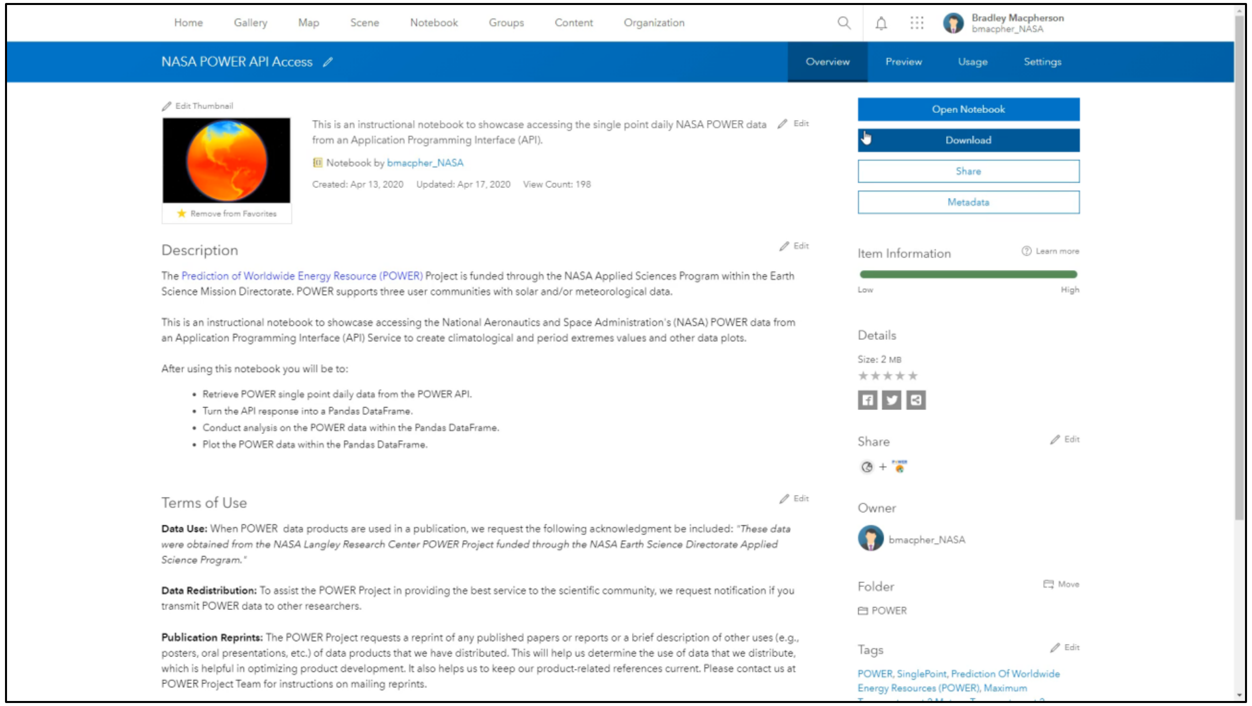






Analytics with Jupyter Noteboks

- **Key Features:**
  - The POWER project has some Jupyter® notebooks currently available to conduct climate anomalies detection
  - Allow users to interact with the POWER API in a Jupyter® Notebook without the need for additional software.
  - Provides step by step instructions on how to use the new data services and tools
- Presented at the ASDC Data Presentation for 2020 DEVELOP Fellow Class on April 22nd, 2020



Hyperlink: [NASA POWER API Access]

Jupyter®: is a registered trademark of the Jupyter Project

What Have We Learned?

NASA Earth Observations (EO) data products through POWER are used to address energy related data needs.

- The POWER GIS Web Services provides parameters that have been developed in collaboration with:
  - NASA science projects: CERES, GMAO
  - renewable energy and energy efficiency engineers and researchers
  - organizations such as DOE/NREL and ASHRAE
  - partnerships with decision support providers such as NRCan RETScreen®
- Parameters provided are long-term averages and time series available from daily to annual
  - the next version (currently in beta) to include hourly parameters from January 2001
- Long-term averaged products include “value added” products like tilted solar irradiance and “black sky days” to better enable decisions in solar panel configuration and battery backup systems
- Multiple applications were demonstrated through including:
  - solar panel technologies and configurations,
  - solar monitoring, and
  - building energy performance monitoring.
- ASHRAE Building Climate Zones including a depiction of their variability show the value of geospatial services and analytic capabilities possible using GIS and other analytic tools
- The upcoming new version of POWER GIS Web Services is under continual development and will enable new applications.
- NASA research and community feedback will lead to continual improvement and development

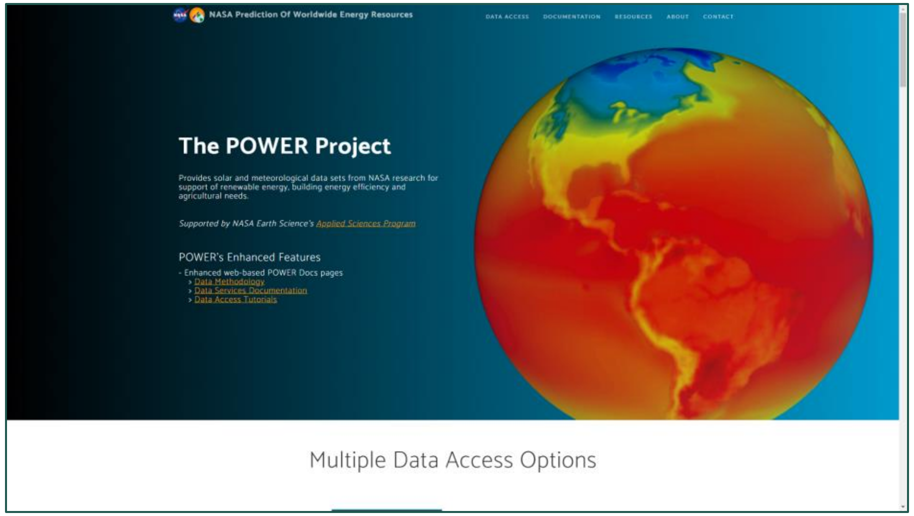
Thank You!

Find us at: https://power.larc.nasa.gov/

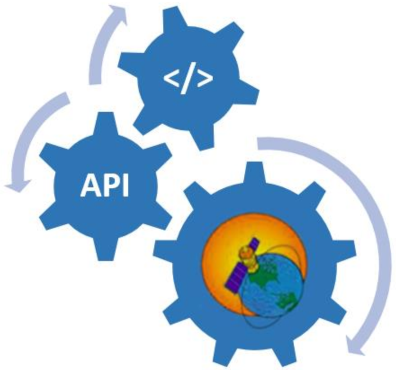
Email us at: larc-power-project@mail.nasa.gov

How do you access POWER data?

- POWER provides an integrated services suite to efficiently access environmental data, pre-computed analysis reports for management of energy production, and monitoring energy efficiently systems, as source data for modeling software.
- The POWER data can be accessed form the:
  - Application Programming Interface (API)
  - Data Access Viewer (DAV)
  - Geospatial Services



APIs



Data Access Viewer

Geospatial Services