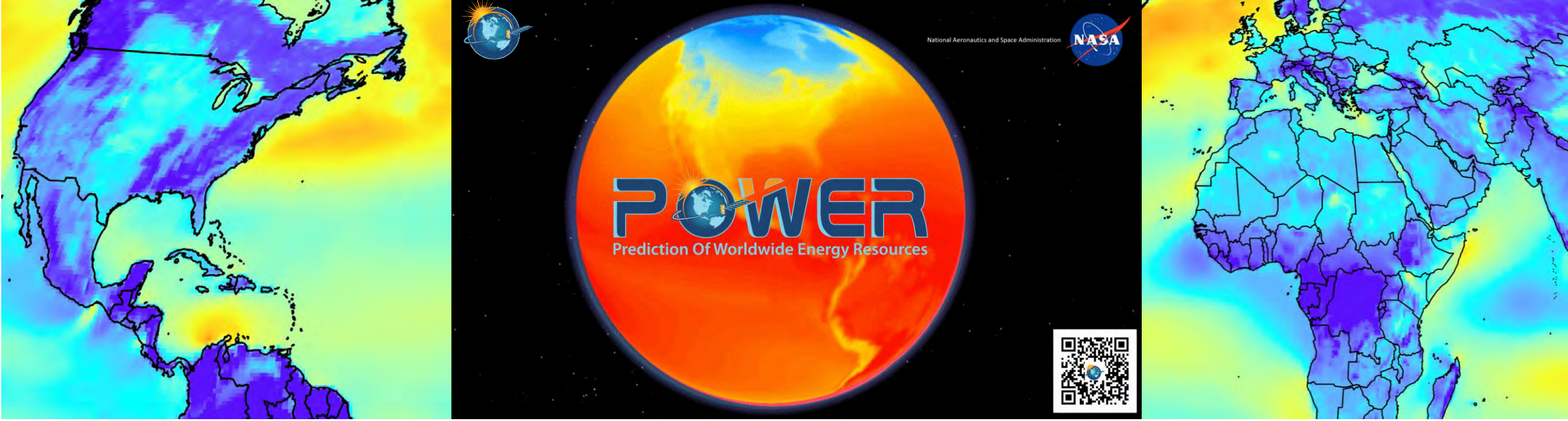


Taking Earth Science to Actionable Decisions in Renewable Energy, Sustainable Infrastructure and Agroclimatology Sectors

Falguni Patadia | NASA Langley Research Center, Hampton, VA

POWER Principal Investigators: Dr. Paul W. Stackhouse, Jr. & Dr. Falguni Patadia – National Aeronautics and Space Administration (NASA)
Team Members:
• Bradley Macpherson, A. Jason Barnett, Madison Broddle, Christopher Higham, Claire Baldacci, Ben Landes, & Valeria Green – Booz Allen Hamilton (BAH)
• Taiping Zhang, Colleen Mikovitz, Bradley Hegyi, & Neha Khadka – AMA, Inc. (AMA)

What is POWER?

The **Prediction Of Worldwide Energy Resources (POWER)**[1] Project aims to improve the capability for integrating environmental data from NASA Earth Observations (EO), regarding surface solar irradiance and related parameters, into decision making processes regarding energy and agriculture

As a NASA Applied Sciences project, POWER creates application ready datasets and improves the accessibility and usage of EO data supporting community research in **three focus areas**

National Aeronautics and Space Administration

1 Renewable Energy Development

Assisting in Energy System Design

POWER's Renewable Energy Web Data Services provide access to parameters specifically tailored to inform the design of solar and wind powered renewable energy systems

2 Building Energy Efficiency & Sustainability

Informing Building Energy Efficiency

POWER's Sustainable Buildings Web Data Services provide industry-friendly parameters for the buildings community in customized formats for input to building decision support tools.

3 Agroclimatology Applications

Enhancing Food Security

POWER's Agroclimatology Web Data Services are designed to provide web-based access to industry-friendly parameters formatted for input to crop models contained within agricultural decision support tools.

POWER | COMMUNITY OF USERS

National Aeronautics and Space Administration

Joe

I want to adopt ***green energy*** for my new facility. Will it be ***cost effective?***

Jill

I want to plan on when to sail my drone with payloads ? Will there be ***enough sunlight*** to power the drone ?

Joshua

I want to implement ***green energy solutions*** in my manufacturing facilities. Can I ***monitor the performance*** over time

Margaret

I want to ***model the maize yield*** response to Nitrogen Fertilizer Intervention

Ben

I want to ***determine the optimal solar water pump configuration*** for our customers

POWER | 100% User Needs Driven

National Aeronautics and Space Administration

- **Finding** the Datasets

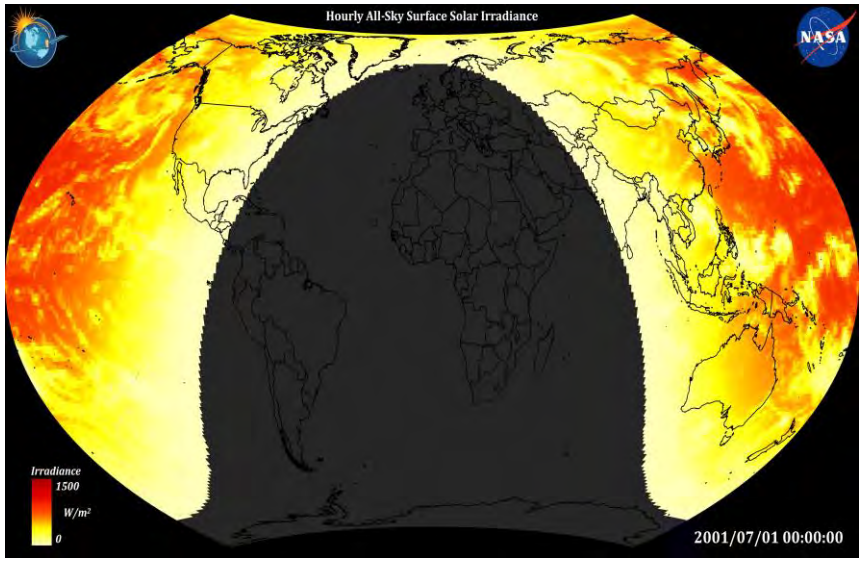
POWER | 100% User Needs Driven

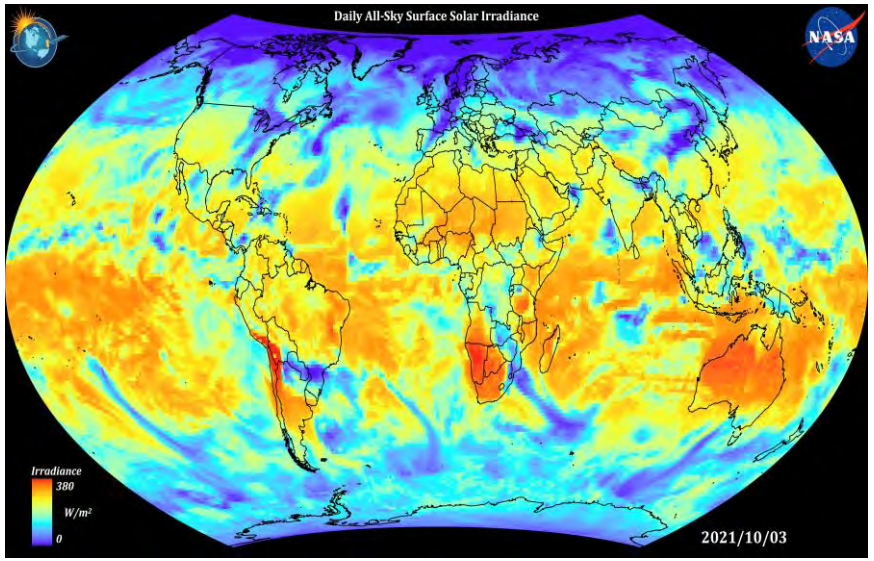
National Aeronautics and Space Administration

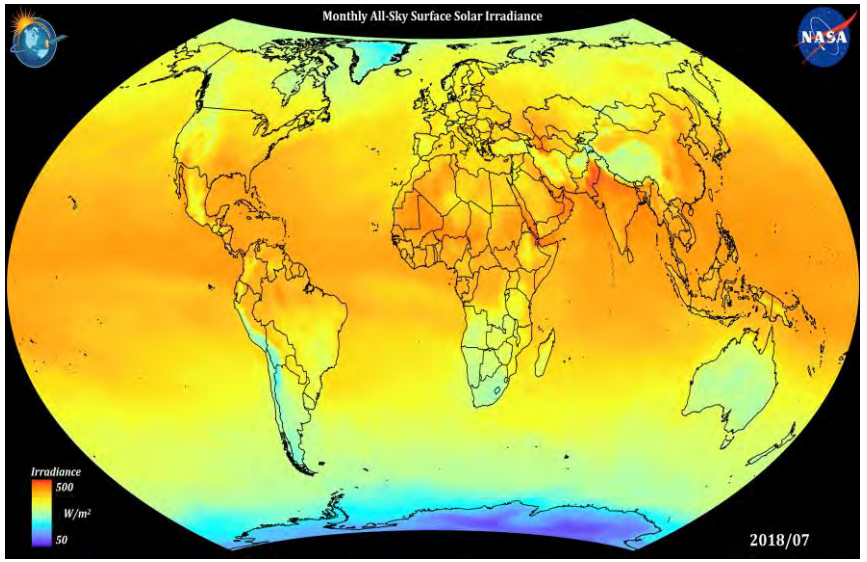
Data Products | Global Surface Solar Radiation

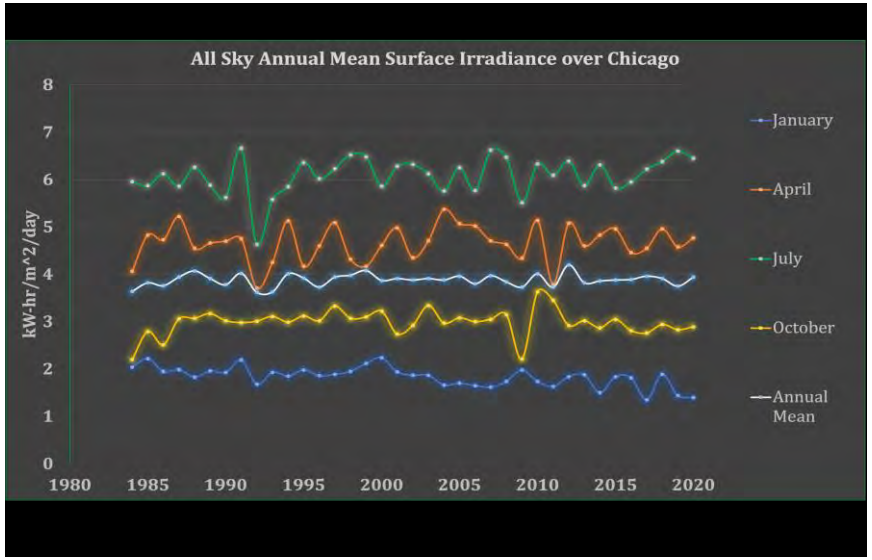
National Aeronautics and Space Administration

- Hourly since 2001
- Daily, monthly back to Jan 1984
- Latency within 3-4 days (solar 5-6 days)









Data Source | Global Surface Solar Radiation

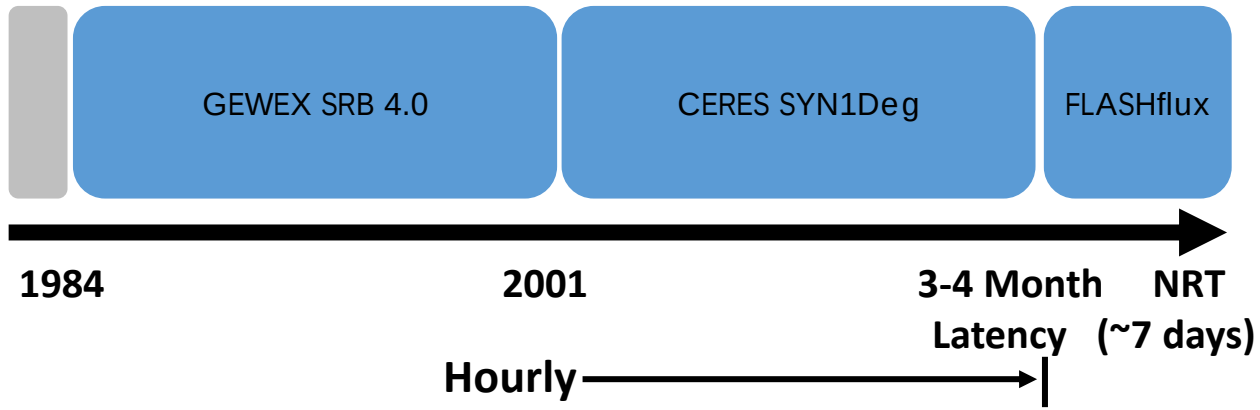
National Aeronautics and Space Administration

Source	Temporal Span		Temporal Average		Description
	Start	End	Input	Output	
GEWEX SRB 4.0	Jan 1, 1984	Dec. 31, 2000	Daily	Daily, Monthly, Annual, Multi-year	Satellite analysis from global cloud imagers (from geosynchronous and polar orbiters satellites) using radiative transfer lookup tables
CERES SYN1Deg (Ed 4A)	Jan 1, 2001	End of SYN1Deg (current)	Hourly	Hourly, Daily, Monthly, Annual, Multi-year	Satellite analysis from CERES convolved with MODIS for scene and TOA fluxes, then uses radiative transfer with additional input from geosynchronous satellites and other inputs to produce surface fluxes
CERES FLASHFlux	End of SYN1deg (current)	Near Real Time	Daily	Daily, Monthly, Annual, Multi-year	Satellite analysis of CERES (reflected solar) and MODIS (cloud imager) measurements (on Terra and Aqua satellites) providing daily averaged estimates of radiative fluxes within 5-6 days of real-time.

Production System:

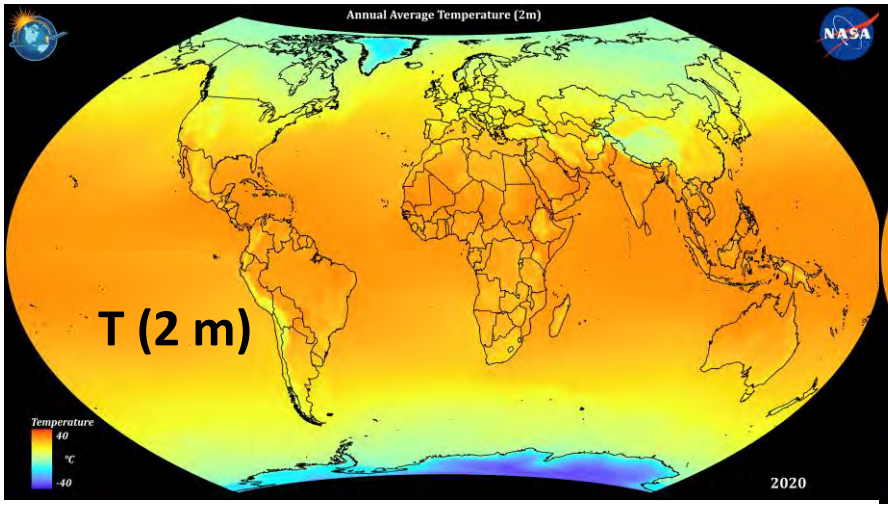
- Daily solar data products from 1984 provided through 7 days of real-time at 1 Deg resolution
- SRB to CERES SYN1Deg, to FLASHFlux
- Hourly from 2001 through 3-4 months of observation

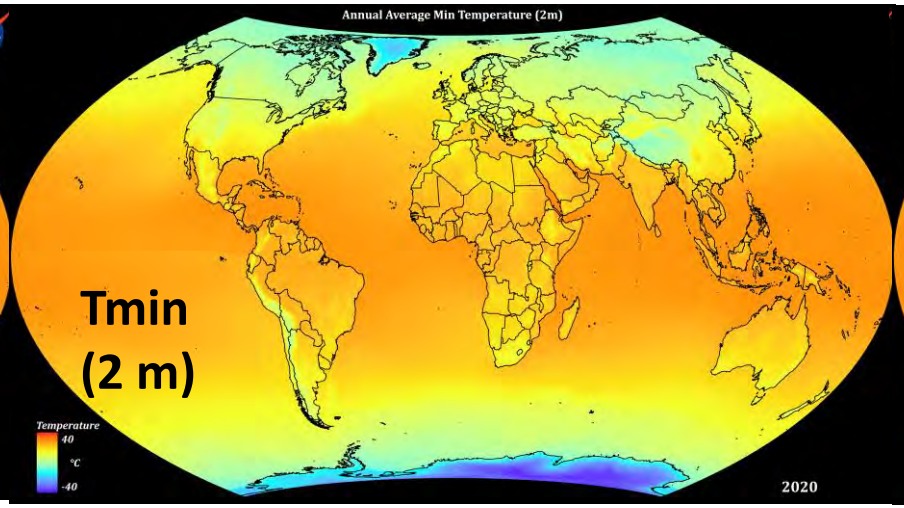
Production Data Timeline

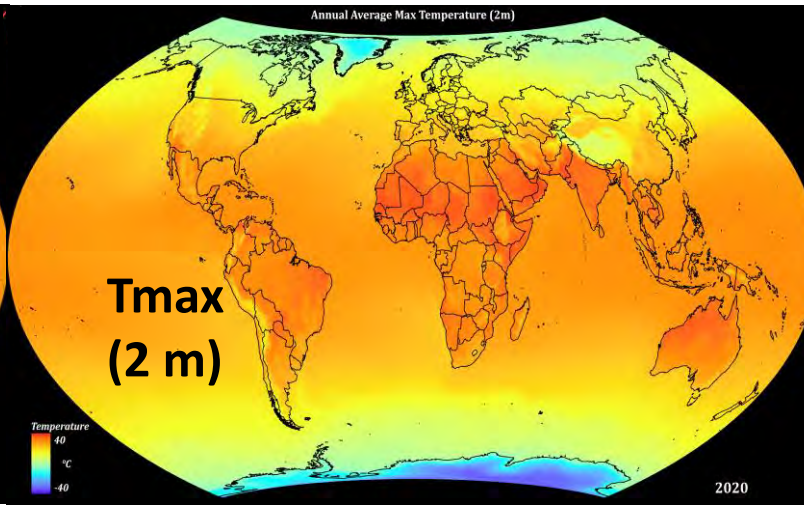


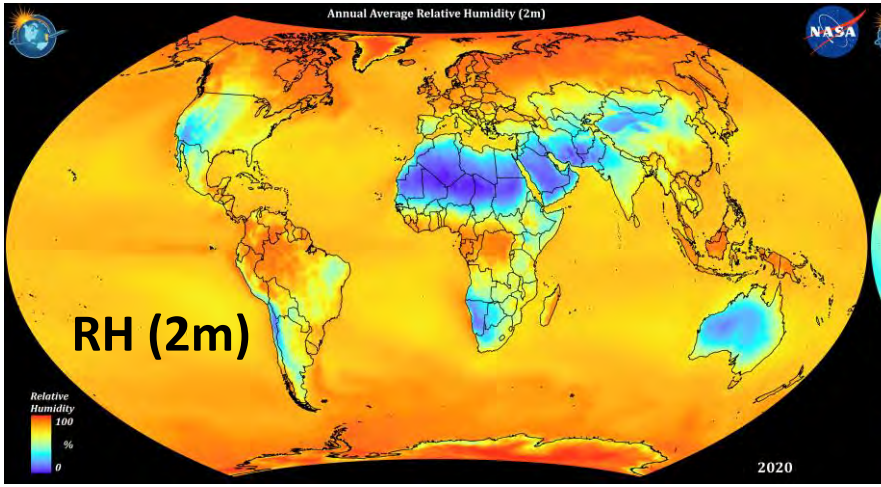
Data Products | Global Surface Meteorology

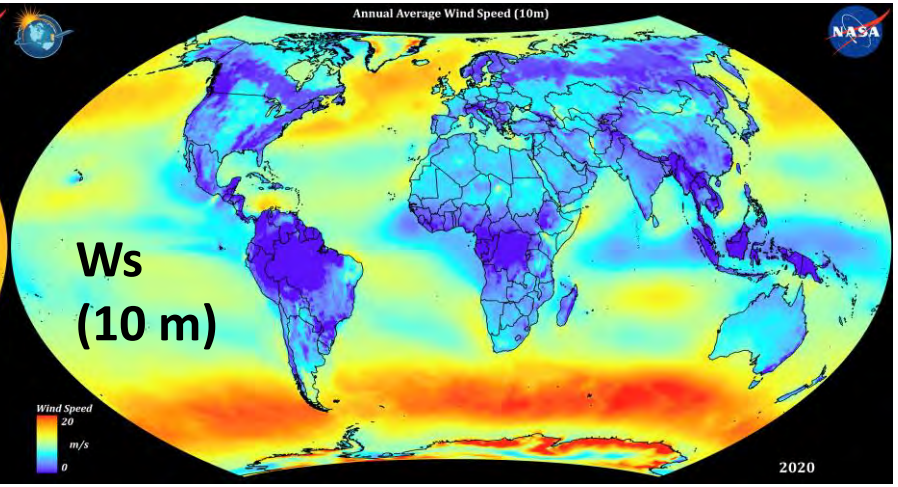
National Aeronautics and Space Administration

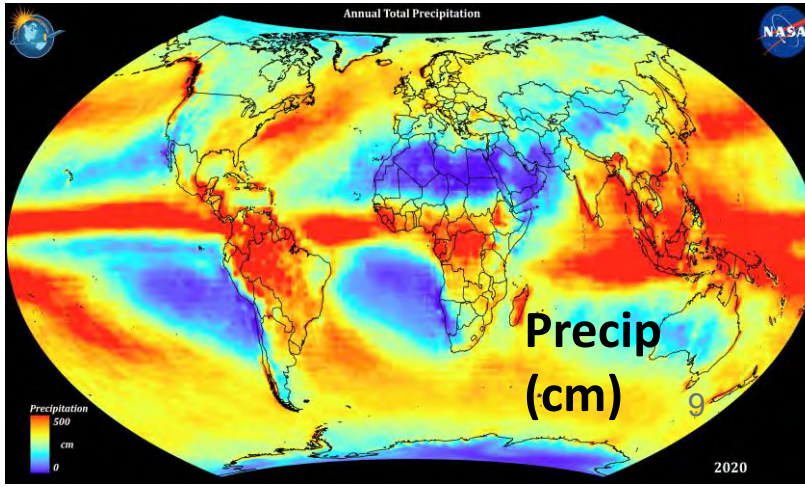












Data Source | Global Surface Meteorology

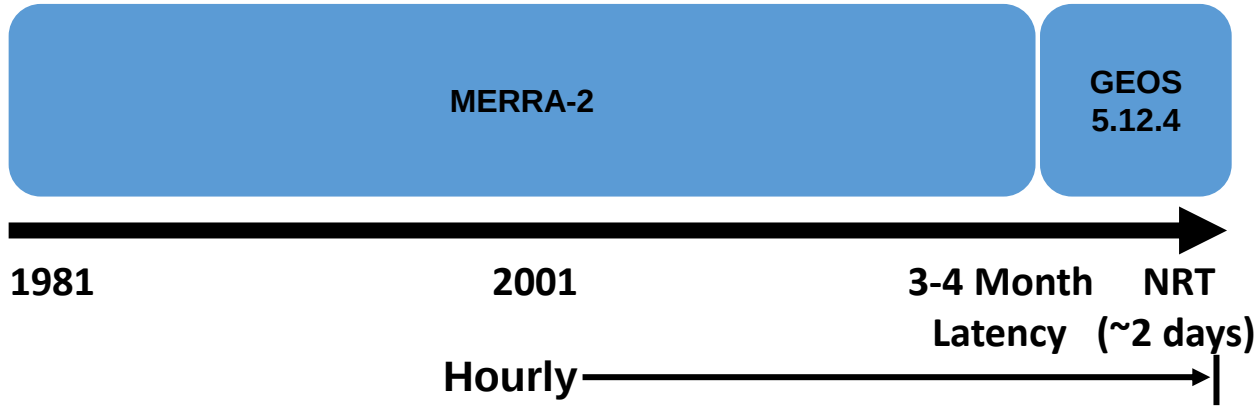
National Aeronautics and Space Administration

Source	Temporal Span		Temporal Average		Description
	Start	End	Input	Output	
MERRA-2	Jan. 1, 1981	End of MERRA-2 (current)	Hourly	Hourly, Daily, Monthly, Annual, Multi-year	Atmospheric reanalysis with assimilated observations (1-2 months behind real time)
GMAO FP-IT (GEOS 5.12.4)	End of MERRA-2	Near Real Time	Hourly	Hourly, Daily, Monthly, Annual, Multi-year	Atmospheric reanalysis with assimilated observations with less assimilated observations, available within 2 days of real-time
IMERG	Jan 1, 2001	Near Real Time	Daily	Daily	The Multi-satellite Retrievals for GPM (IMERG) algorithm provides estimates of precipitation in UTC time at 10 km resolution, available within 2 days of real-time.

Production System:

- Daily surface meteorology data products from 1981 provided through 3 days of real-time
- MERRA-2 to GEOS 5.12.4
- Data is at ~half degree spatial resolution

Production Data Timeline



POWER | Understanding User Barriers

National Aeronautics and Space Administration

- [x] **Finding** the Datasets
- [ ] **Data Interpretation |** Data Quality and Data Limitations

Joshua

I want to implement green energy solutions in my **manufacturing** facilities and monitor the performance over time

POWER | RELIABLE LATEST VERSION OF DATASETS

EARTH SCIENCE
APPLIED SCIENCES

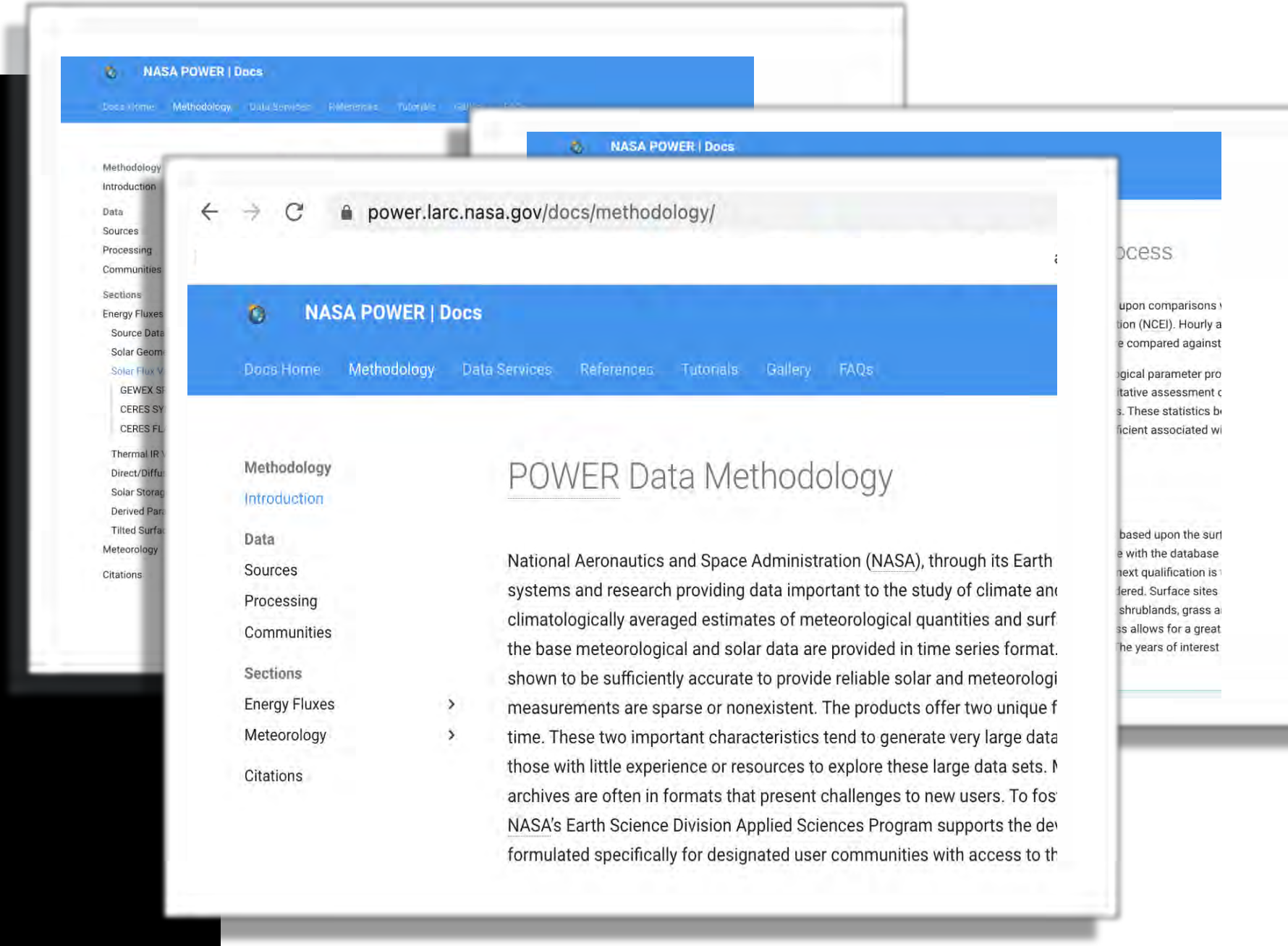
How Is Data Parameter Quality Determined ?

EARTH SCIENCE
APPLIED SCIENCES

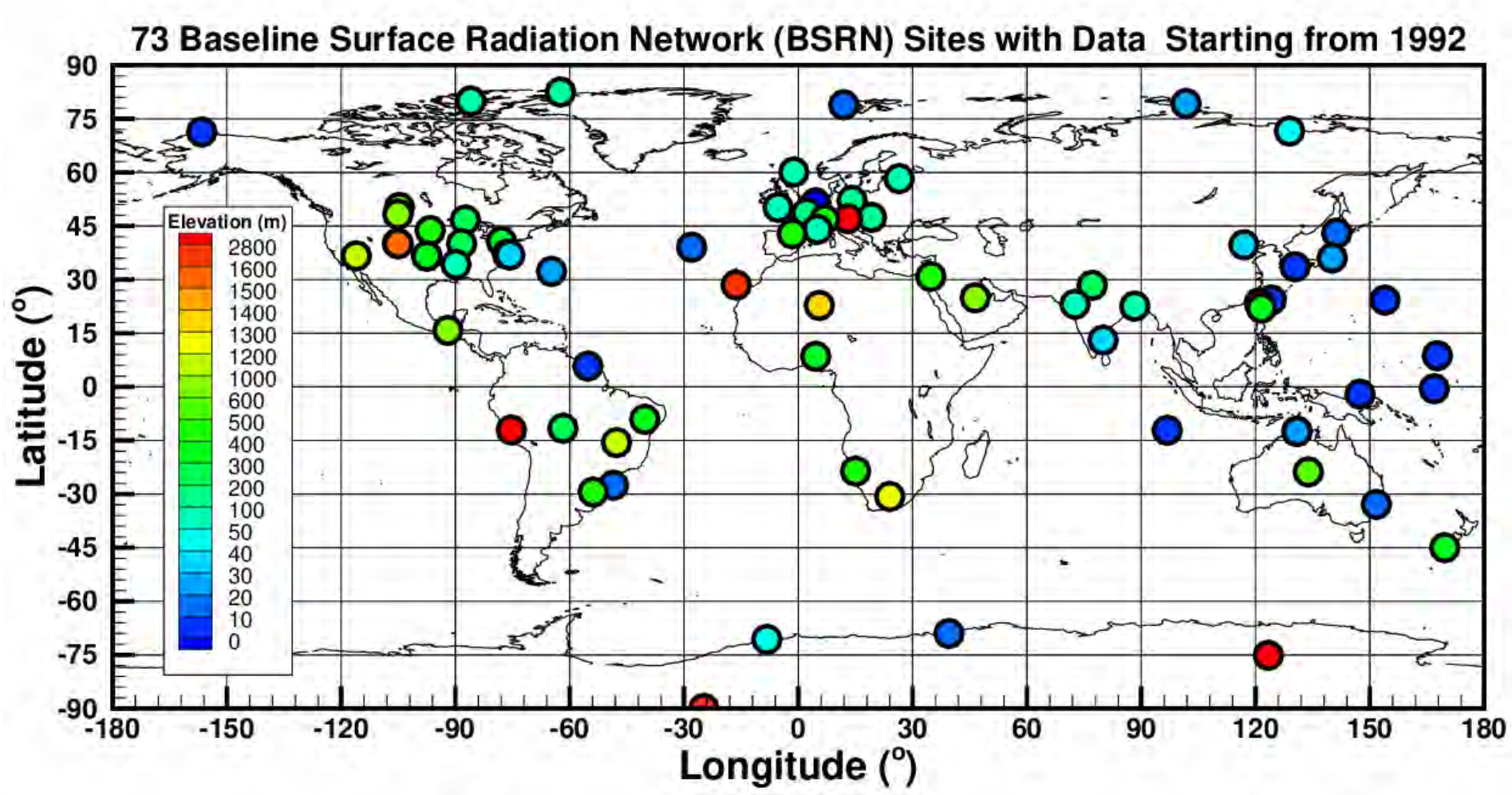
POWER uses surface measurements to characterize data product uncertainty

Validation at various temporal scales (up to hourly) and assessments for value-added products as observations available

See "Methodology Documentation" pages for more information and statistics



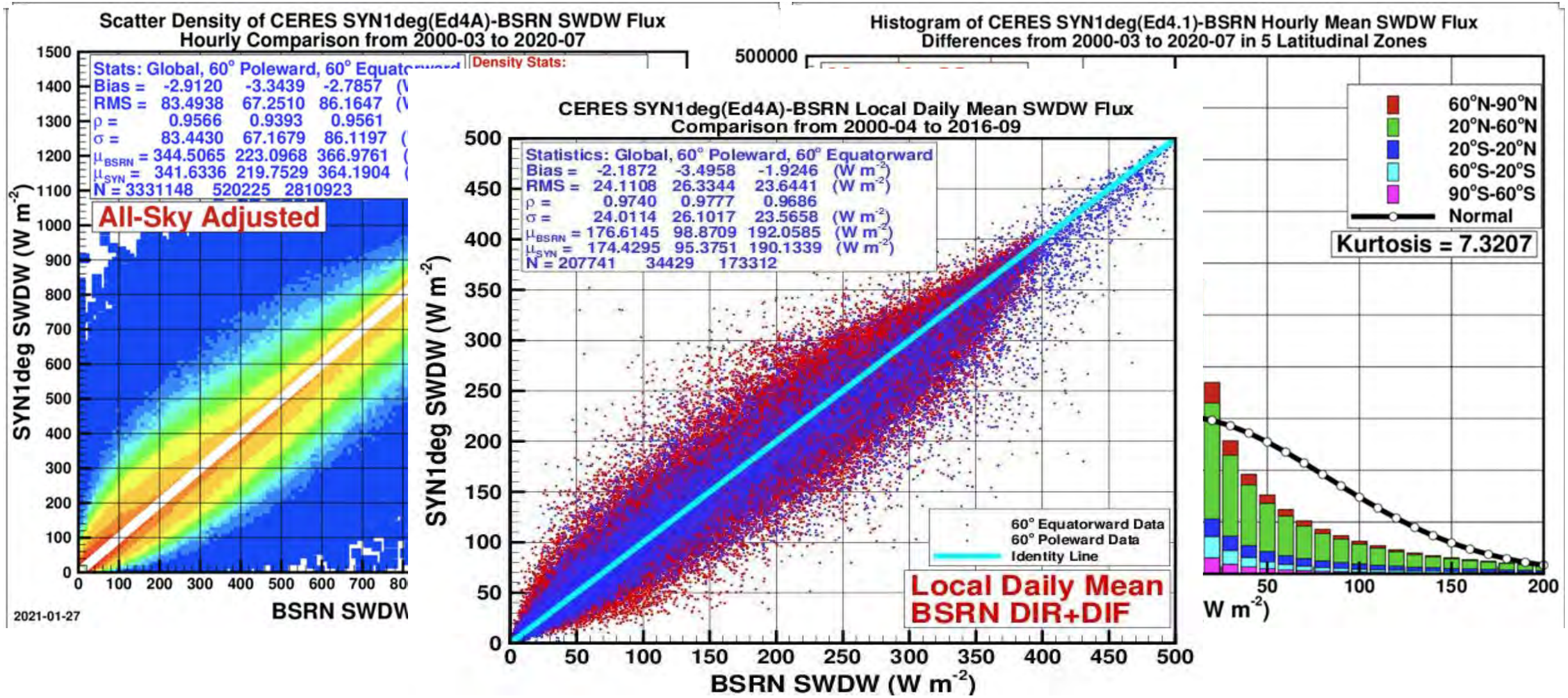
POWER | EVALUATING CERES SYN1DEG HOURLY FLUXES



Uses Zhang *et al*., (2013) to process and quality control measurements

POWER | VALIDATION OF CERES SYN1DEG HOURLY SURFACE SOLAR IRRADIANCE

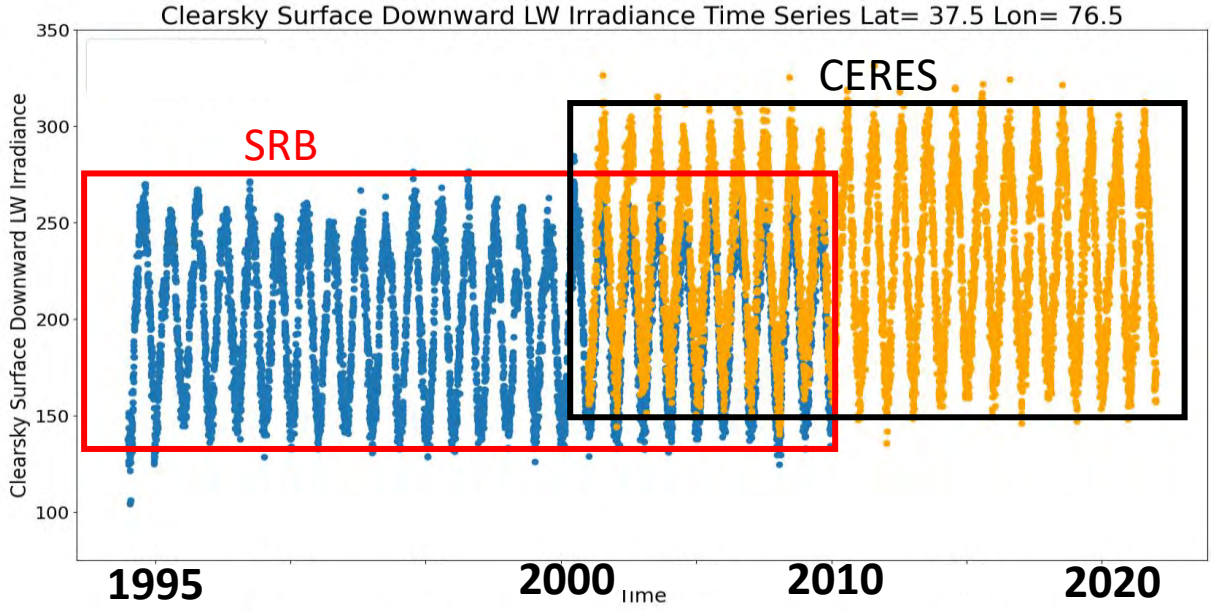
(Shortwave – SW or Global Horizontal Irradiance - GHI)

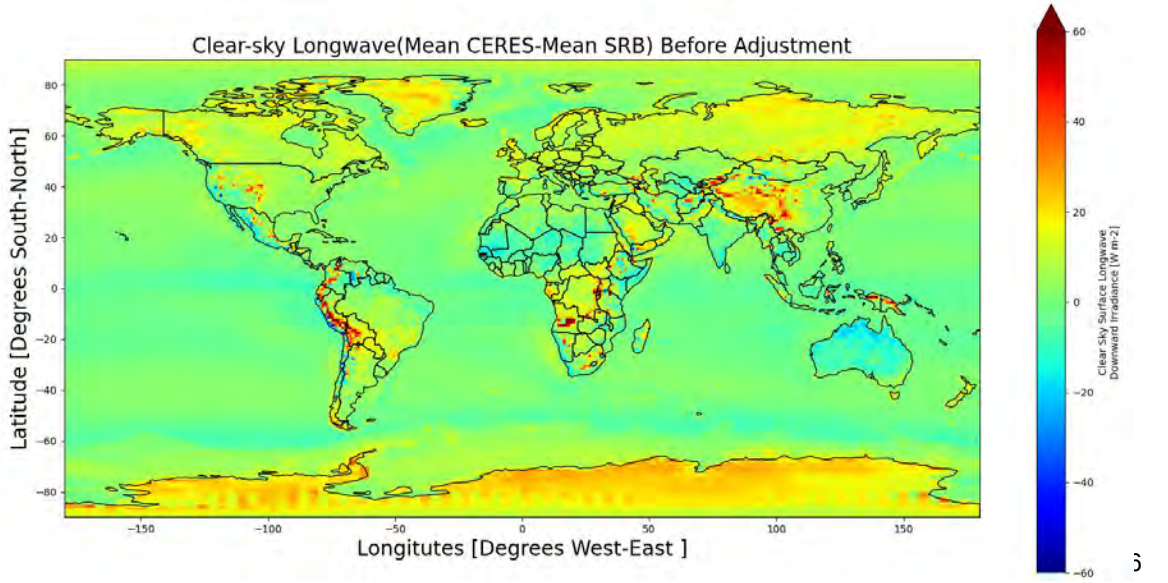


POWER | EVALUATING DOWNWARD LW FLUX TIME-SERIES

National Aeronautics and Space Administration

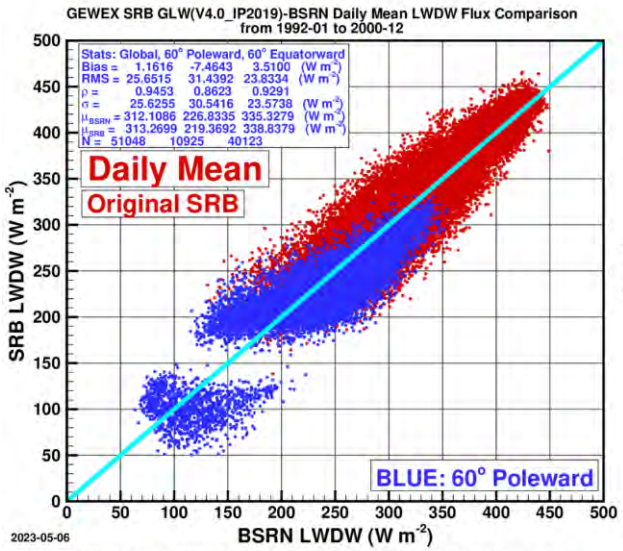
- Building Designers use downward LW to estimate building cooling as a function of time
- In the 1995 to 2020 data record, there is a discontinuity between SRB and CERES LW Flux
- Biases are region dependent though
- Our users are most interested in trends, variability and ranges (min-max) for their assessments
- We applied quantile mapping using overlapping years (2000-2010) to generate bias correction coefficients (1x1 Deg)

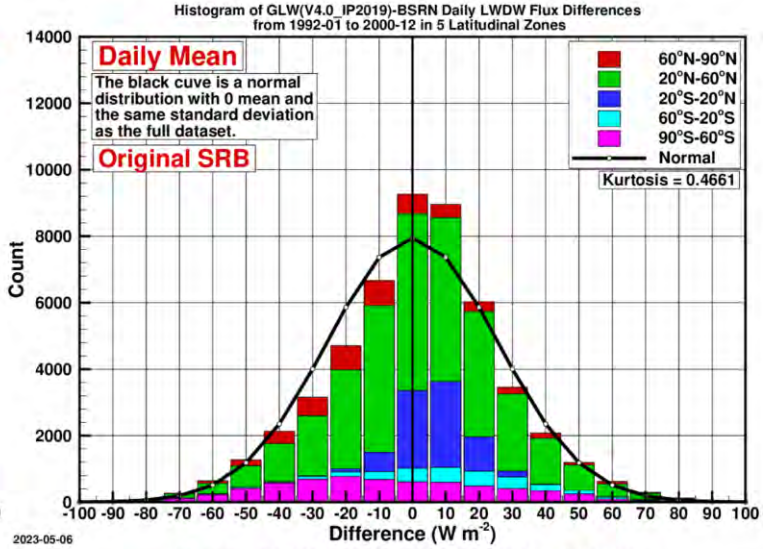


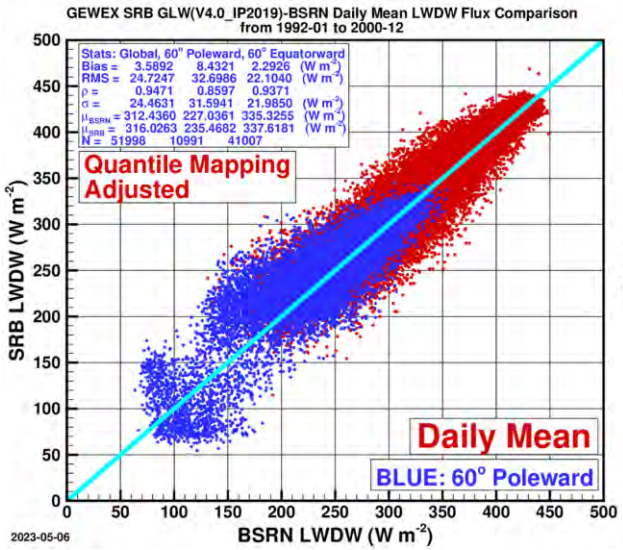


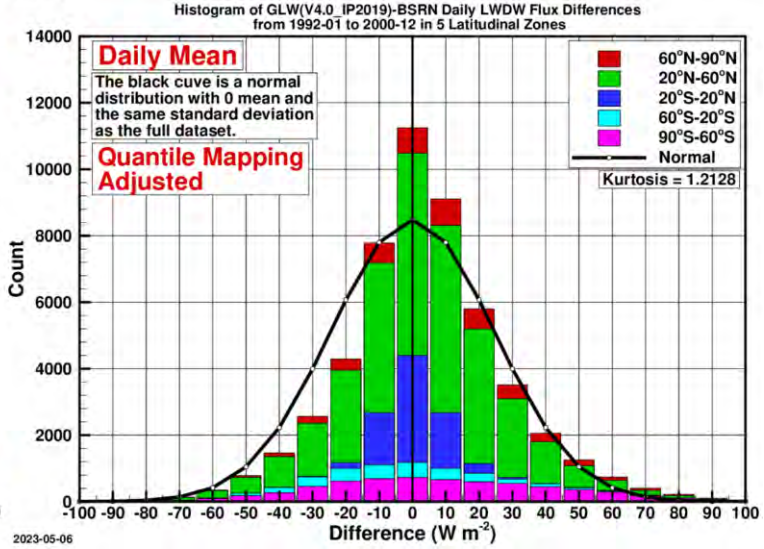
POWER | VALIDATING CORRECTED LW FLUX TIME-SERIES

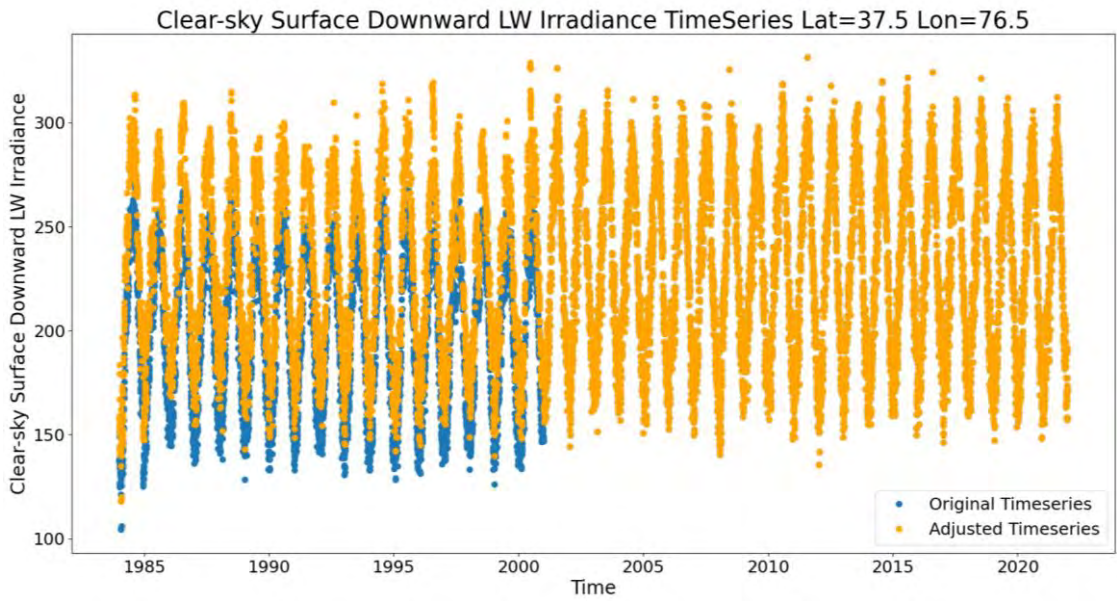
National Aeronautics and Space Administration



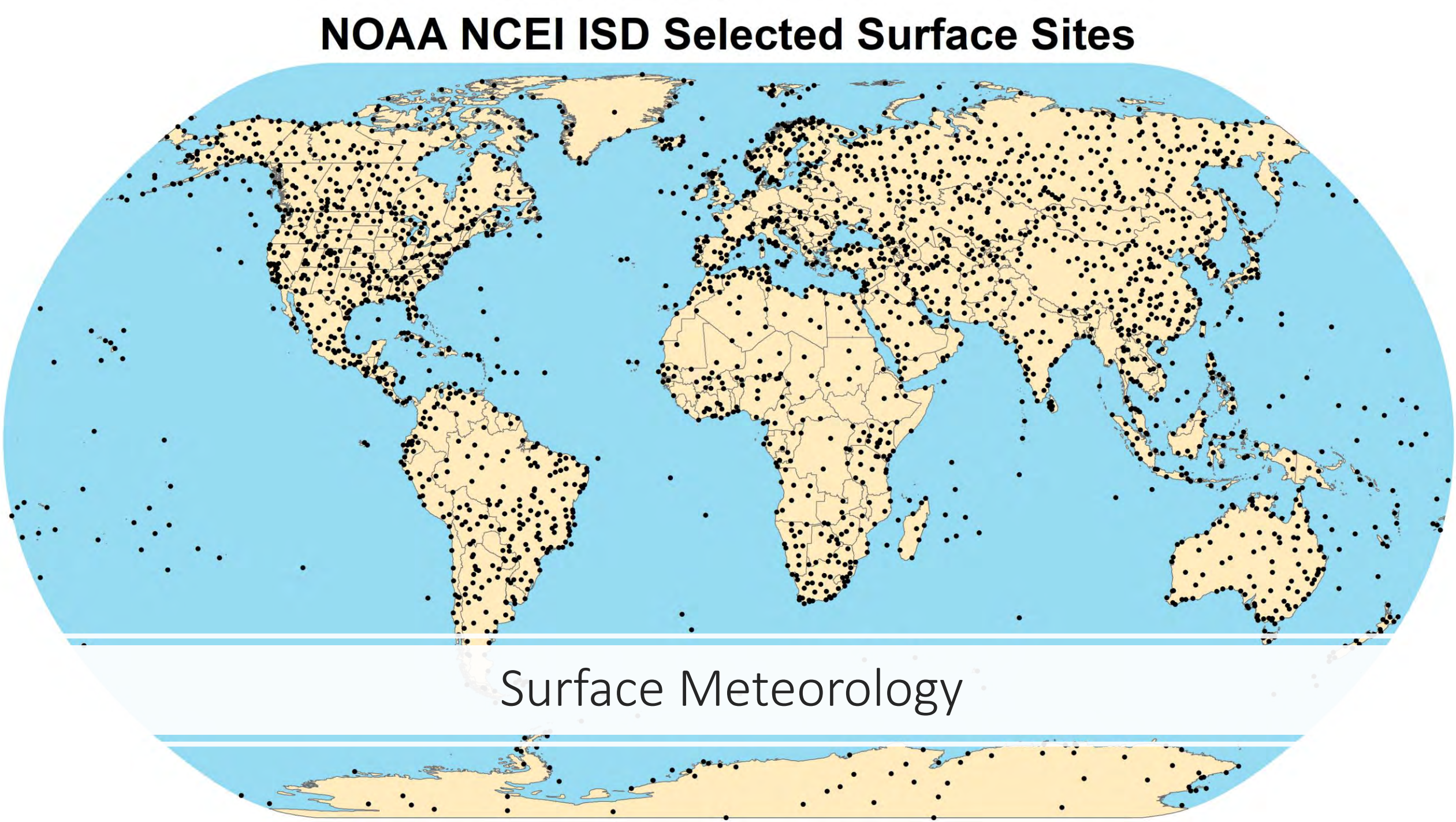








- Longwave show improvement at sites equatorward of 60°
- Quantile mapping removed the discontinuity; variability in data and range is preserved

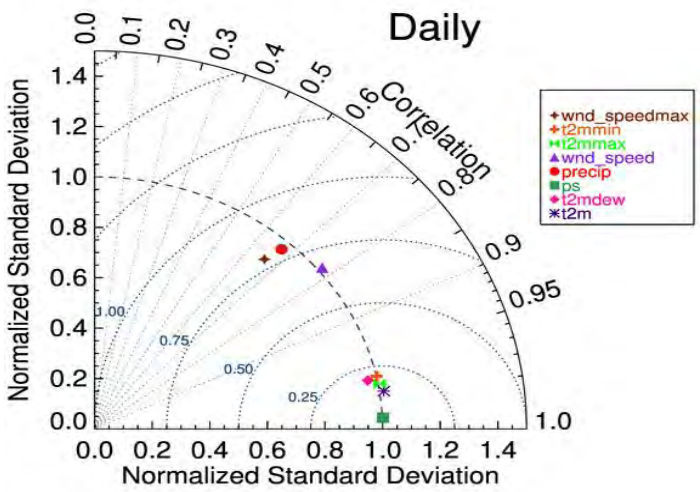


Surface Meteorology

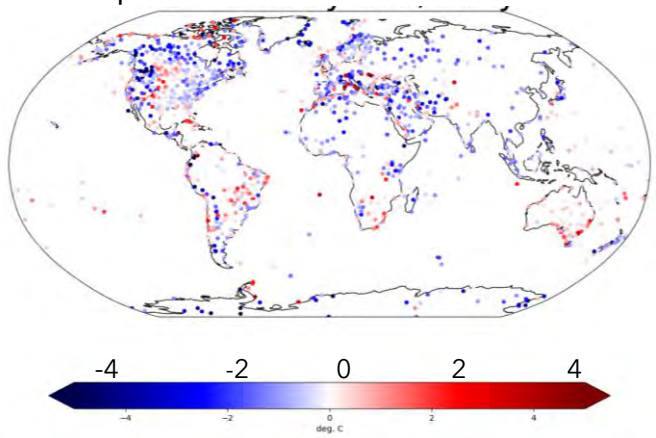
National Aeronautics and Space Administration

POWER | VALIDATING SURFACE METEOROLOGY | GLOBAL STATS

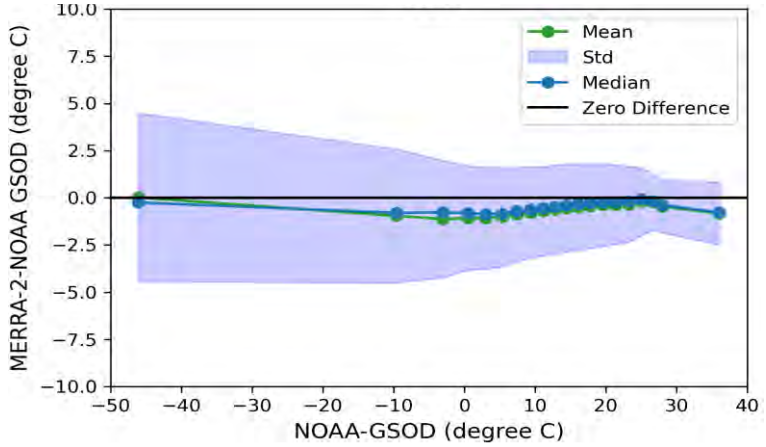
Merra-2 Daily Mean fields



2m Daily Temperature: Bias Comparison from 1981 - 2020



2m Daily Temperature Differences



Primary source of surface meteorology in POWER is MERRA-2

- Well documented system
- Extensively validated by scientific and applied science communities

In context of POWER users, we focus on verifying validation results in scientific literature and adding time-series validations

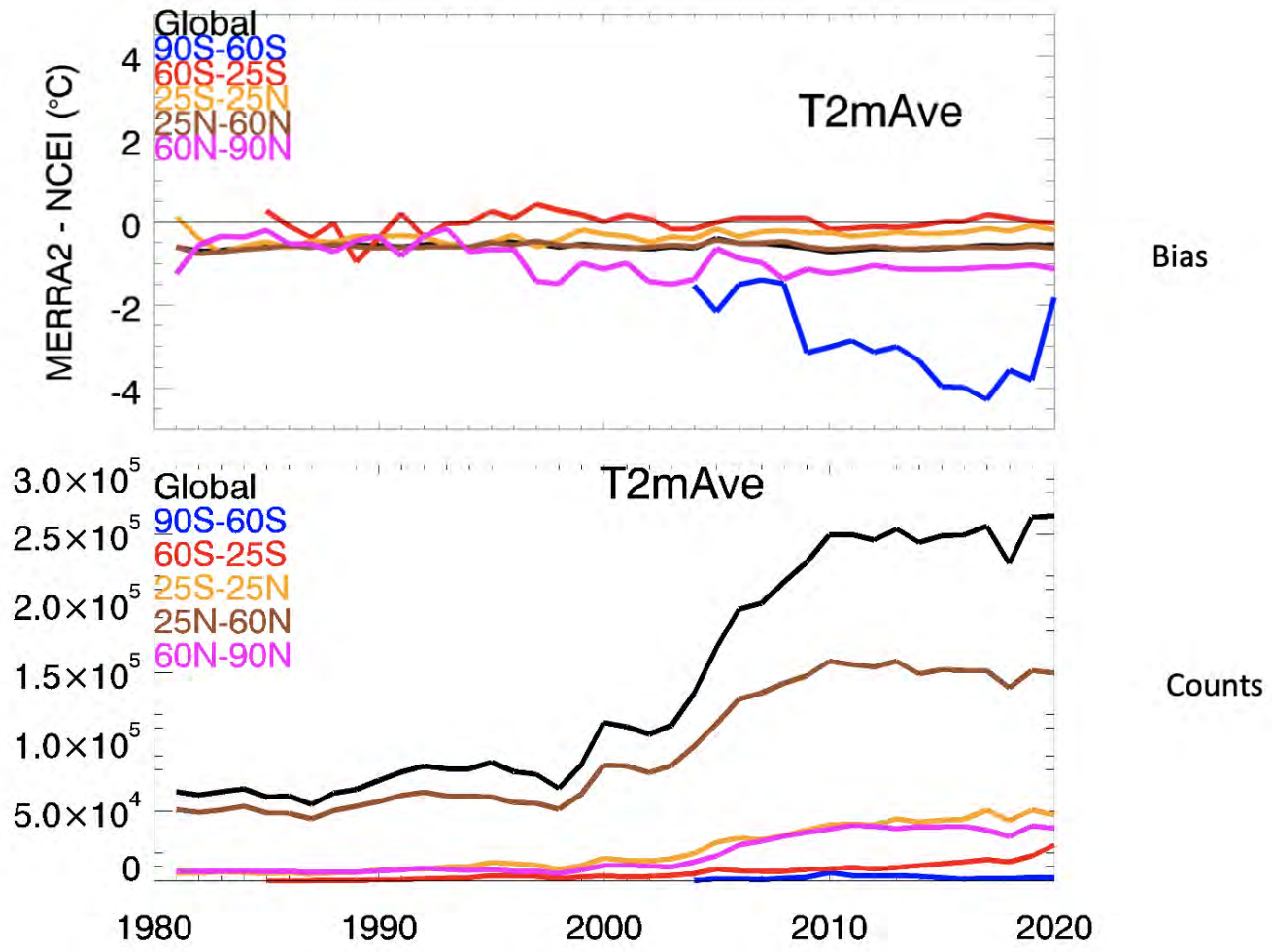
- Bias of temperature and dew point under 5% of mean value; varies little year to year in 4 decades of site comparisons
- Wind speed & Precip have higher RMS by percentage; Dependence on field magnitude & these can be highly variable within the 1 Deg grid

POWER | Surface Meteorology Validation Over Time

WHY POWER TEAM VALIDATES DATA?

- Number of surface stations have increased over time
- More max and min temperatures reports than mean temperature
- More analysis TBD with same set of long-term site data

Temperature changes over Antarctica, if real, it has implications



POWER | UNDERSTANDING USER BARRIERS

National Aeronautics and Space Administration

- ☑ **Finding** the Datasets
- ☑ **Data Interpretation** | Data Quality and Data Limitations

Looks like Joshua should be all set to implement energy efficient solutions and performance monitoring system for their facilities ?

Joshua

I want to implement green energy solutions in my facility and monitor its performance over time

POWER | BARRIERS | HOW WILL USERS OBTAIN NASA DATA?

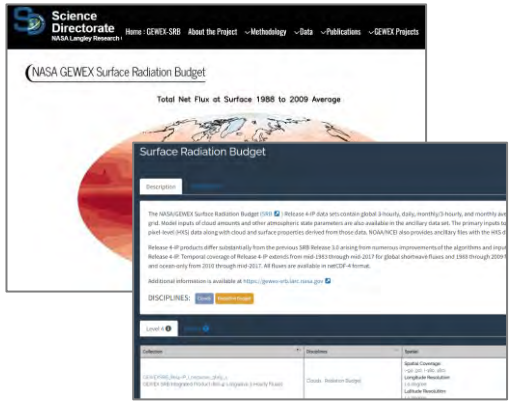
National Aeronautics and Space Administration

Average Amount of Sunshine (All Sky Surface Shortwave Downward Irradiance) in a single location over the past 35+ years - Climatological Monthly/Annual Average

Identify the Correct Source to span time range of interest	Determine where and How to download Each Granule	Ensure space required to download and time	Understand file formats (NetCDF & HDF) and identify correct parameter

GEWEX SRB (1/1/84 - 2000)

SRB Website



ASDC Data Page

OPeNDAP Granule Subsetting

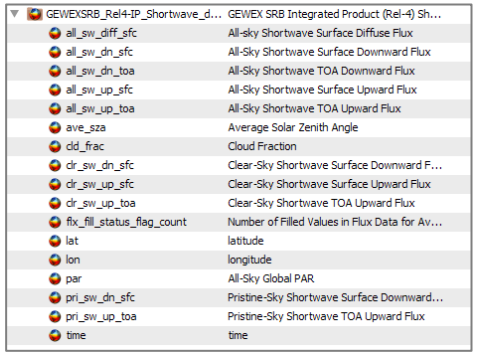
Earthdata Search Granule Download

ASDC Granule Direct Download

Download All 408

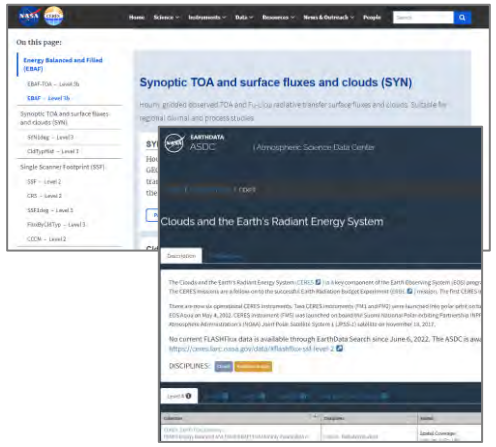
Size per file: ~20MB

Total: 8160 MB (8 GB)



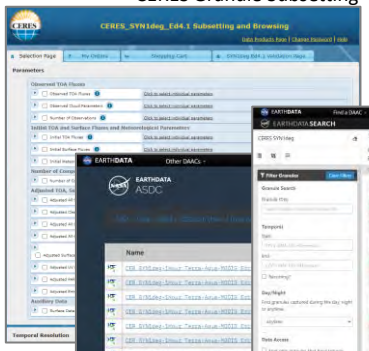
CERES Syn1Deg (1/1/2001 – 2020)

CERES Website

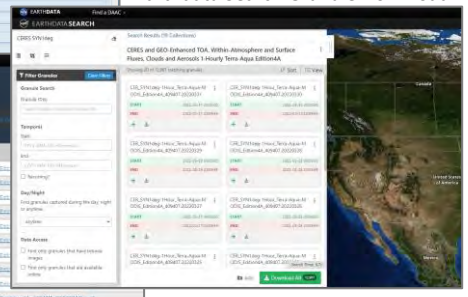


ASDC Data Page

CERES Granule Subsetting



Earthdata Search Granule Download



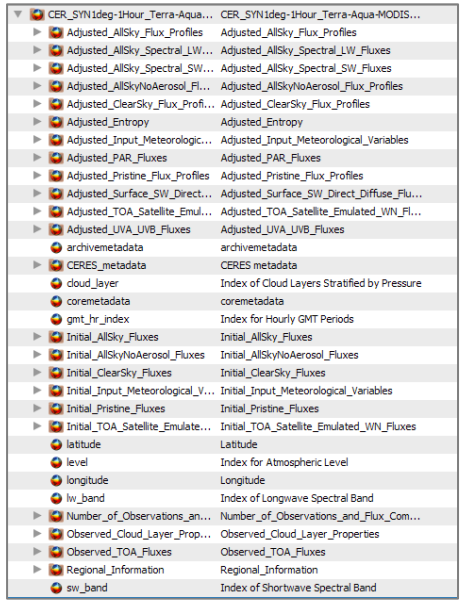
ASDC Granule Direct Download

Download 13k+ files

Download All 12,967

Size per file: ~700MB

Total: 9,076,900 MB (9 TB)

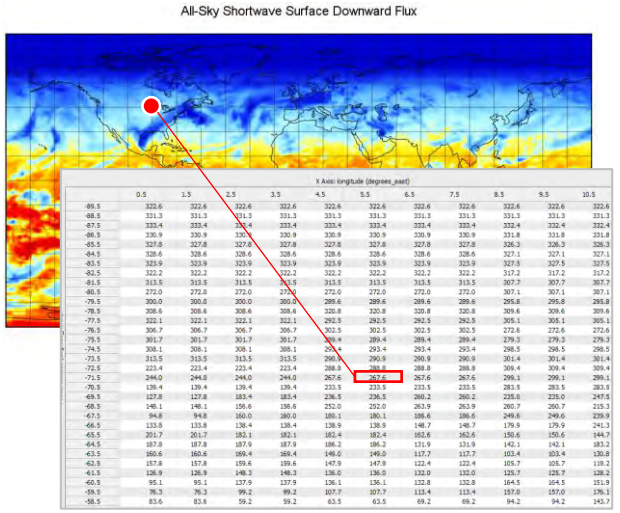


POWER | USER BARRIERS | DERIVED PARAMETERS AND FORMATS

National Aeronautics and Space Administration

Average Amount of Sunshine (*All Sky Surface Shortwave Downward Irradiance*) in a single location over the past 35+ years - Climatological Monthly/Annual Average

Identify your location within each file for 1 degree x 1 degree grid and adjust for data quality issues



GEWEX SRB (1/1/84 - 2000)

CERES Syn1Deg (1/1/2001 – 2020)

Convert units to local solar hours (kWhr/M²/day)

```
short_all_sw_dn_sfc(time=28, lat=180, lon=360);
  :units = "W m-2";
  :_FillValue = -10000S; // short
  :standard_name = "surface_downwelling_shortwave_flux";
  :long_name = "All-Sky Shortwave Surface Downward Flux";
  :scale_factor = 0.1f; // float
  :valid_range = 0.0f, 475.0f; // float
  :_ChunkSizes = 1U, 180U, 360U; // uint
```

```
:units = "W m-2";
```

CERES hourly – convert to local solar 3 days

CERES hourly average to days

Data at Various Temporal Scales

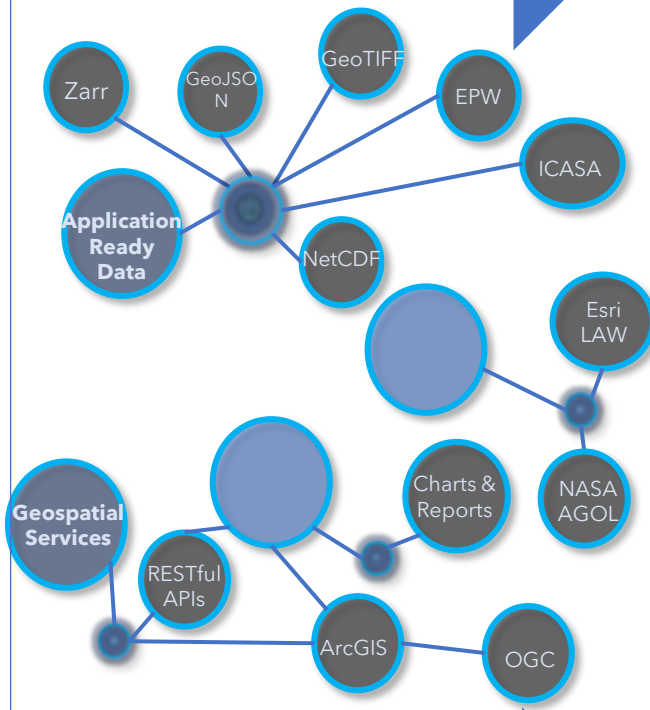
Monthly Average
Average days for each month (30 x 12 x 35+) for each year

Annual Average
Average across all months for each year (12 x 35+)

Monthly Climatological Avg
Average each of the 12 months across 35+ years.

Annual Climatological Average
Average all annuals across 35+ years.

Convert Output to Application Ready Format



POWER | Understanding User Barriers

National Aeronautics and Space Administration

- ☑ **Finding** the Datasets
- ☑ **Data Interpretation |** Data Quality and Data Limitations
- ❑ **Processing the Datasets** to extract the Exact Parameter of interest
- ❑ Derived Parameters / **Value-Added Data** (Units, Formats)

POWER | Understanding User Barriers

National Aeronautics and Space Administration

- ✅ **Finding** the Datasets
- ✅ **Data Interpretation** | Data Quality a
- ✅ **Processing the Dataset** ameter of interest
- ✅ Derived P **Data** (Units, Formats)

Is th

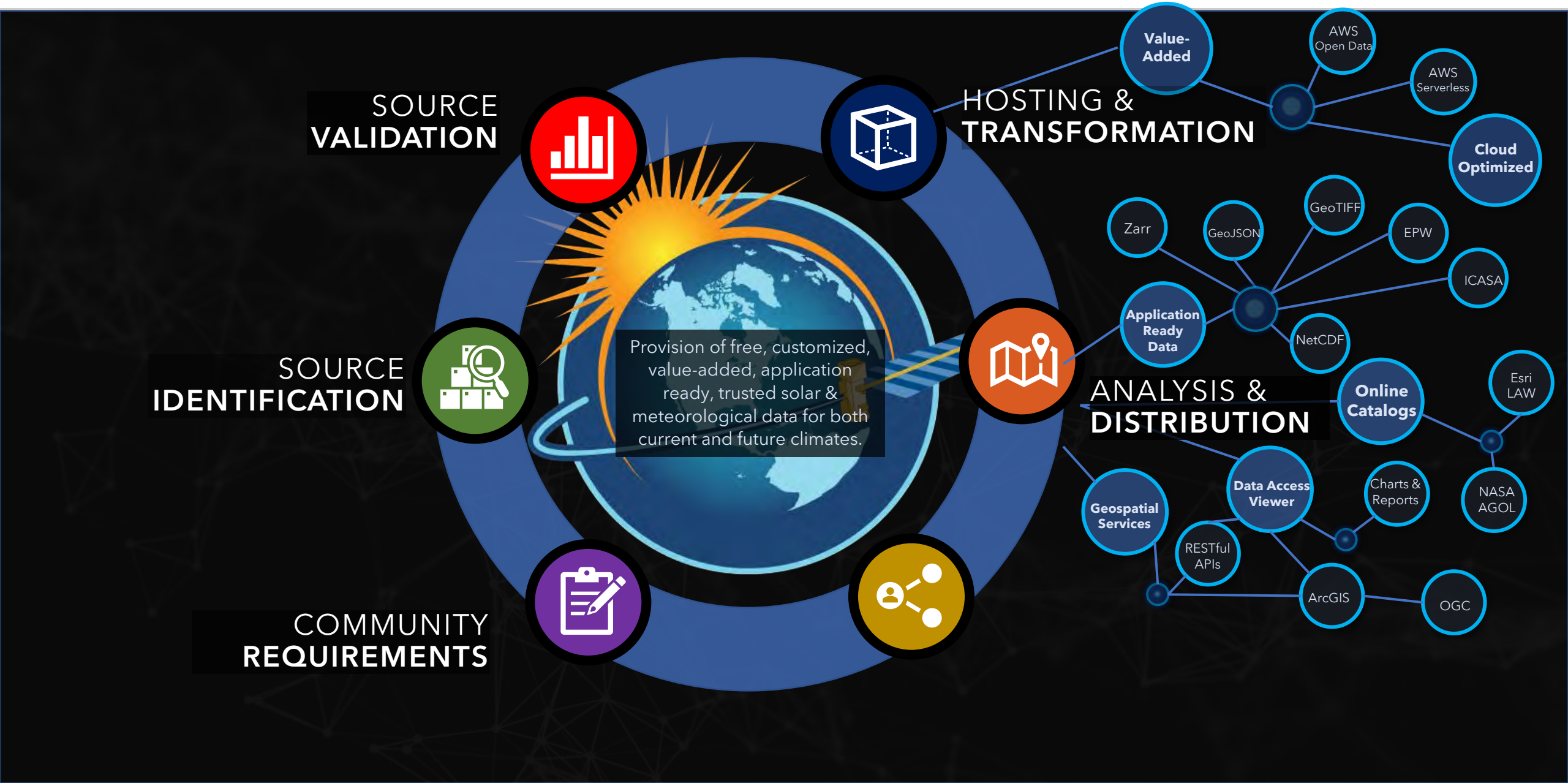
NO

Beyond Data Needs is **Data Accessibility**

❑ Different users require **access** to the **same data** in **different ways!**

Beyond Data Needs | Breaking Accessibility Barriers

National Aeronautics and Space Administration



POWER | UNDERSTANDING USER BARRIERS

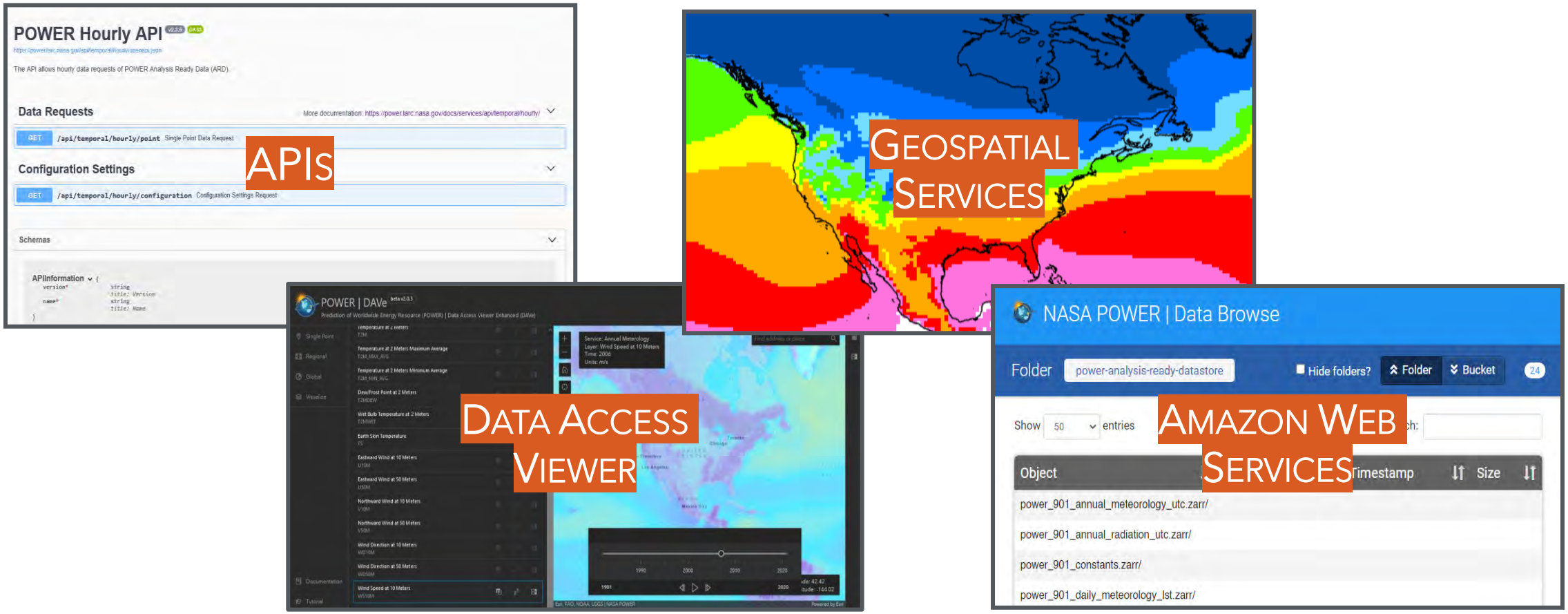
National Aeronautics and Space Administration

- ☑ **Finding** the Datasets
- ☑ **Data Interpretation |** Data Quality and Data Limitations
- ☑ **Processing the Datasets** to extract the EXACT Parameter of interest
- ☑ Derived Parameters / **Value-Added Data** (Units, Formats)
- ☑ Different users require **access** to the **same data** in **different ways!**

POWER | Services for Data access

EARTH SCIENCE
APPLIED SCIENCES

Different users require different ways to access the same data



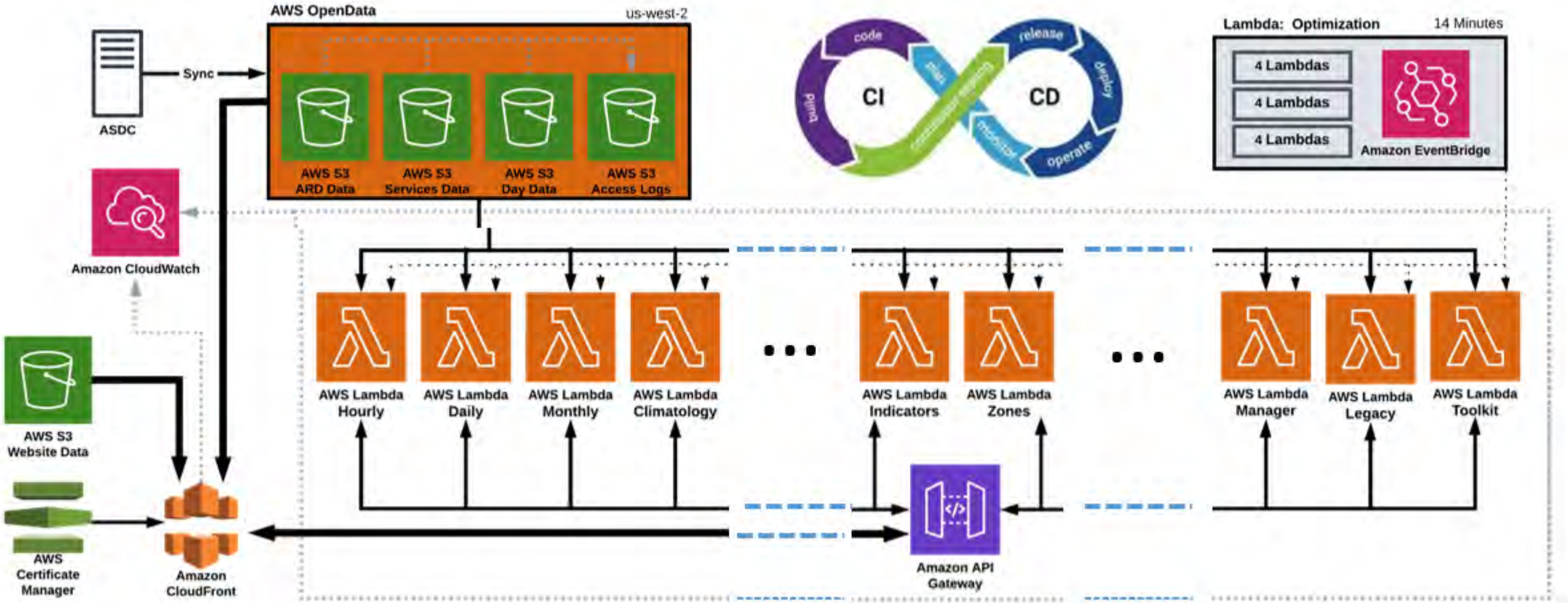
Creating trusted, value-added, easy-to-use Application Ready Data & Services

How does POWER utilize the cloud?

Cloud-based POWER interface increases reliability and reduces delivery wait times for data orders

Cloud Architecture (AWS – NASA's MCP ATO)

The POWER version three architecture that is currently in production is fully cloud optimized and hosted in AWS using serverless technology. This architecture includes all the previous functionality with the addition of enhanced analytics capabilities and direct access to the complete POWER Data archive in AWS S3 as Analysis Ready Cloud Optimized (ARCO) Zarr datasets. All with improved system reliability!



Jupyter Notebooks & POWER ARD on AWS

Jupyter Notebooks:

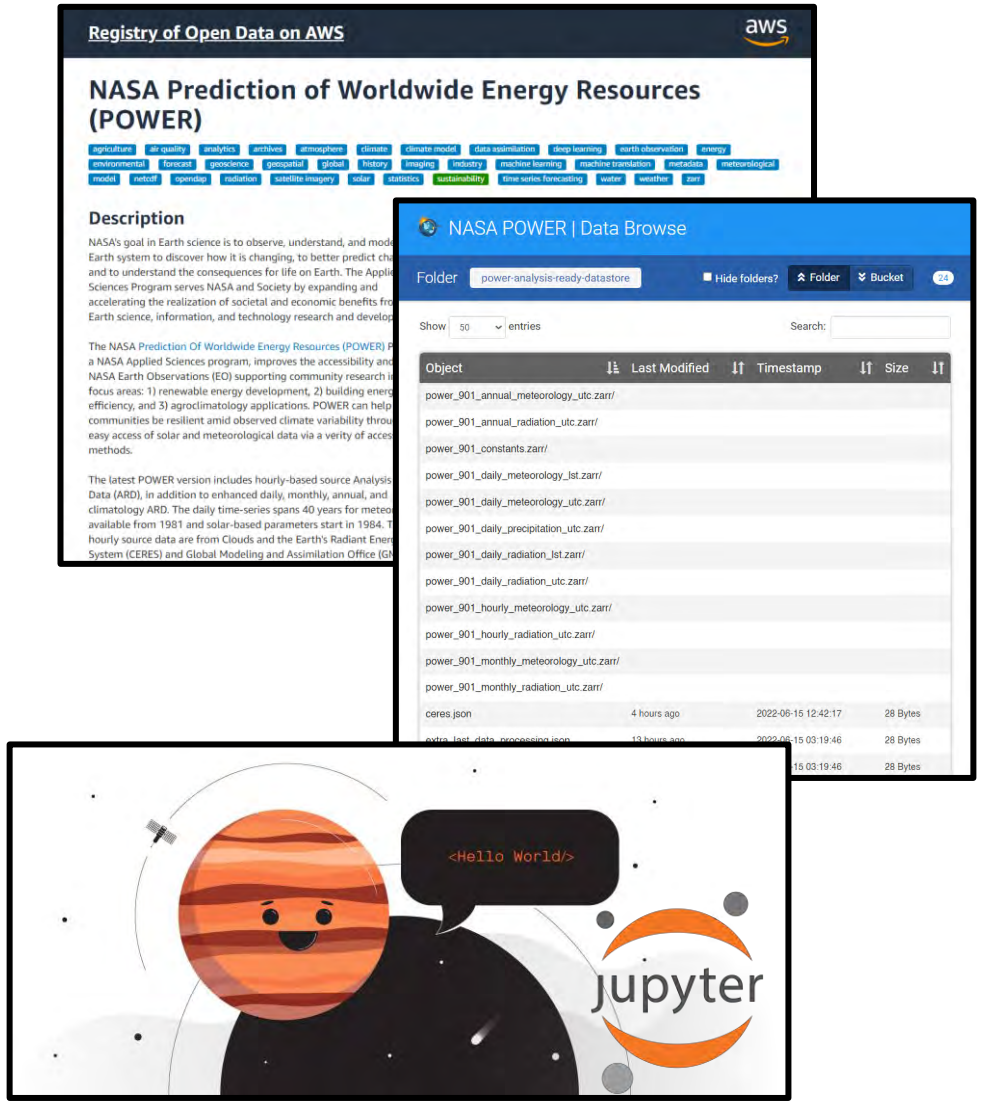
- The POWER project Jupyter® notebooks are available to help assess parameter (ARD) variability over time
- Allow users to interact with the POWER API in Jupyter Notebooks without the need for additional software.
- Provides step by step instructions on how to use the new data services and tools

Link: POWER Knowledgebase

Key Features:

- The POWER AWS allows users to directly access the POWER Analysis Ready Data (ARD) of ~8.5TB.

Link: POWER on AWS's Open Data Registry



POWER | Data Access Viewer (DAV)

EARTH SCIENCE
APPLIED SCIENCES

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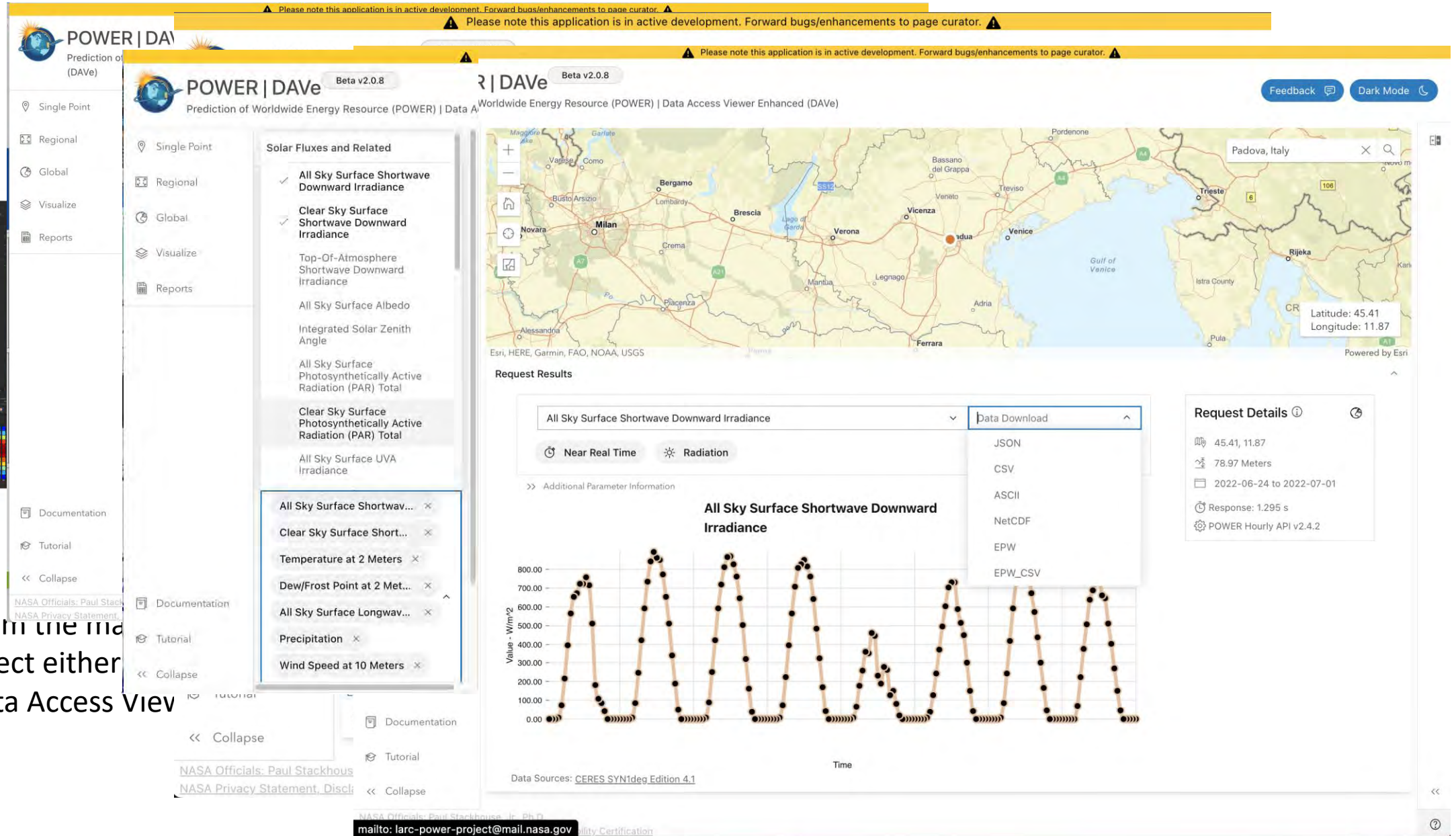
Data Access Viev



Analytic Data Services | Reports

Building Climatic Design Conditions

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	HR	MCDB	Humidification DP/MCDB and HR 99% DP	HR	MCDB	Coldest month WS/MCDB 0.4% WS	MCDB	1% WS	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	MCWB	1% DB	MCWB	2% DB	MCWB	Evaporation WB/MCDB 0.4% WB	MCDB	1% WB	MCDB	2% WB	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	HR	MCDB	1% DP	HR	MCDB	2% DP	HR	MCDB	Enthalpy/MCDB 0.4% Enth	MCDB	1% Enth	MCDB	2% Enth	MCDB	Extreme Max WB
35.8	20.0		25.3	20.0		25.0	20.0								29.6

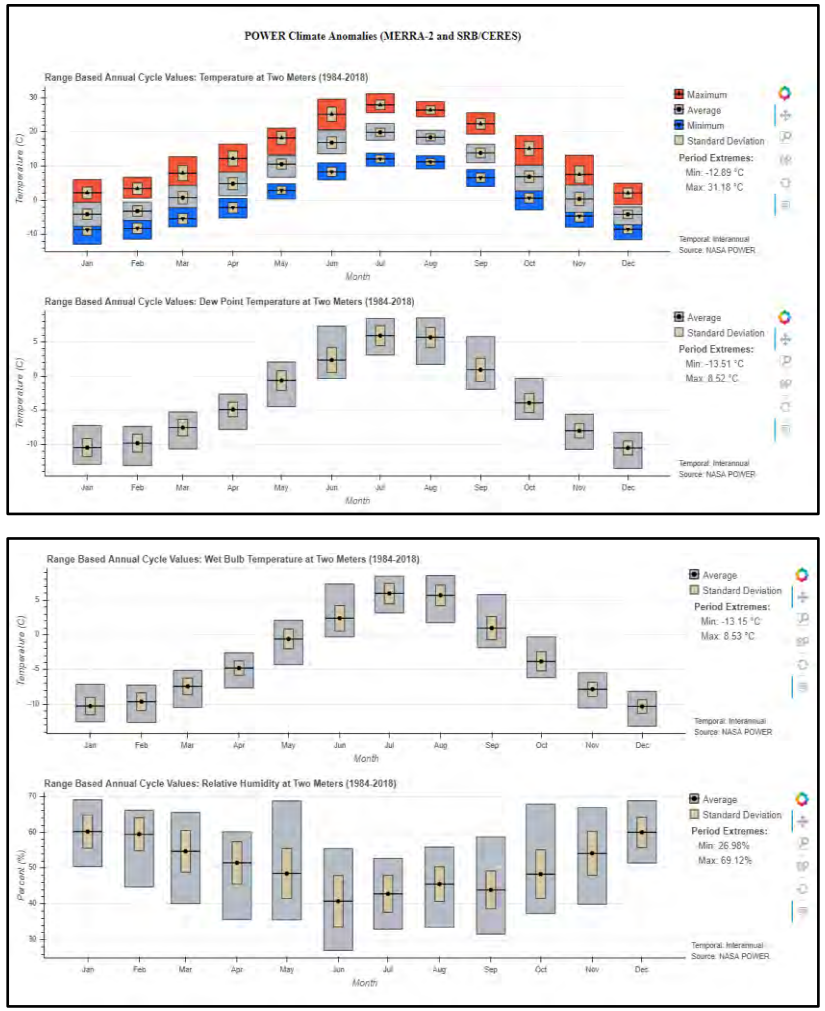
Extreme Annual Design Conditions

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	
	0.4% 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	
	2% 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	
	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	
	10% 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	
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4% WB	11.2	16.0	15.2	18.4	19.4	23.0	23.8	24.2	23.4	20.1	17.7	16.3	
	0.4% MCDB	15.2	18.2	19.3	22.9	24.1	26.5	27.9	27.7	27.1	24.3	20.2	19.1	
	2% WB	11.0	15.9	15.2	18.3	19.3	23.0	23.8	24.2	23.4	20.0	17.4	16.0	
	2% MCDB	15.0	18.1	19.3	22.8	24.1	26.5	27.9	27.7	27.1	24.1	20.1	18.9	
	5% WB	10.7	15.8	15.1	18.0	19.2	23.0	23.8	24.2	23.3	19.8	17.0	15.5	
	5% MCDB	14.4	18.1	19.2	22.6	24.1	26.5	27.9	27.7	27.0	23.8	19.7	18.5	
	10% WB	10.1	15.6	14.9	17.5	19.0	22.9	23.8	24.2	23.1	19.4	16.2	14.6	
	10% MCDB	13.6	18.0	19.2	22.4	24.1	26.5	27.8	27.6	26.9	23.3	19.1	17.9	
Mean Daily Temperature Range	5% DB MDBR	11.5	11.8	12.5	12.3	12.1	9.5	9.0	8.4	8.4	10.2	11.6	10.7	
	5% DB MCDBR													
	5% WB MCWBR													
	5% WB MCDBR													
Clear Sky Solar Irradiance	taub													
	taud													
	Ebn,noon													
	Edn,noon													
All-Sky Solar Radiation	RadAvg	3.2	3.94	5.02	5.97	6.45	5.84	5.43	5.38	4.79	4.48	3.53	2.95	
	RadStd	1.12	1.42	1.53	1.64	1.6	1.72	1.65	1.44	1.44	0.99	1.05	0.94	

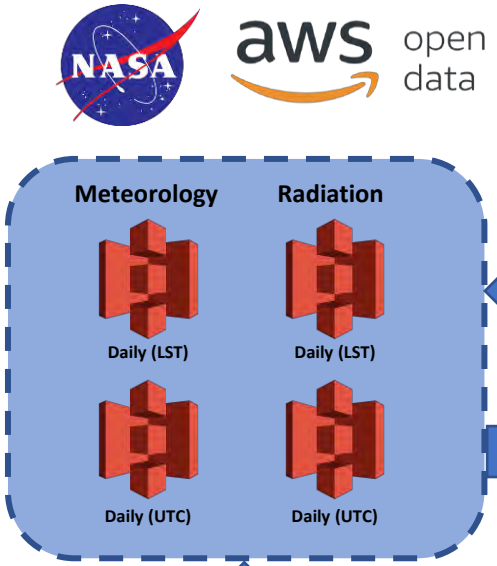
Climate Variability and Anomalies Report



Windrose Report Table by NREL Classes

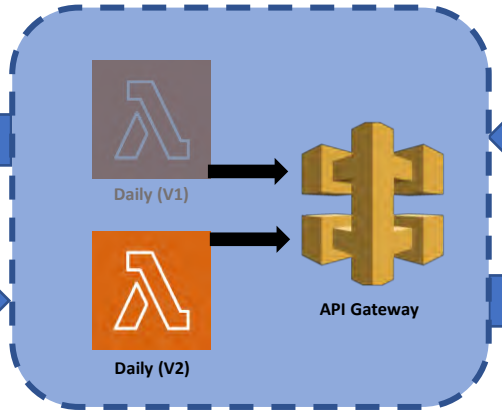
```
-BEGIN HEADER-
NASA/POWER Wind Rose MERRA2/GEOS 5.12.4 (FP-IT) 0.5 x 0.5 Degree Daily Averaged Data
Dates (month/day/year): 01/01/1984 through 12/31/2018
Single Point Total
Location: Latitude  38.9531   Longitude -77.028
Elevation from MERRA-2: Average for 1/2x1/2 degree lat/lon region = 83.32 meters   Site = na
Value for missing model data; cannot be computed or out of model availability range: -999
Parameter(s):
    WR10M     Wind Rose at 10 meters (percent)
                  CLASS_1: 0-1.5 m/s
                  CLASS_2: 1.5-3.0 m/s
                  CLASS_3: 3.0-4.4 m/s
                  CLASS_4: 4.4-5.1 m/s
                  CLASS_5: 5.1-5.6 m/s
                  CLASS_6: 5.6-6.0 m/s
                  CLASS_7: 6.0-6.4 m/s
                  CLASS_8: 6.4-7.0 m/s
                  CLASS_9: 7.0-9.4 m/s
                  CLASS_10: 9.4+ m/s
    WR50M     Wind Rose at 50 meters (percent)
                  CLASS_1: 0-1.5 m/s
                  CLASS_2: 1.5-3.0 m/s
                  CLASS_3: 3.0-5.6 m/s
                  CLASS_4: 5.6-6.4 m/s
                  CLASS_5: 6.4-7.0 m/s
                  CLASS_6: 7.0-7.5 m/s
                  CLASS_7: 7.5-8.0 m/s
                  CLASS_8: 8.0-8.8 m/s
                  CLASS_9: 8.8-11.9 m/s
                  CLASS_10: 11.9+ m/s
    WD_PCT     Wind Direction Percent (percent)
    WD_AVG     Wind Direction Average Wind Speed (m/s)
DIRECTION      This consists of 16 22.5 degree swaths; the center point being defined. (degrees)
CLASS          The NREL Wind Classifications with enhanced low-end wind levels that have different cutoffs for 10m and 50m Heights.
PARAMETER DIRECTION  CLASS_1  CLASS_2  CLASS_3  CLASS_4  CLASS_5  CLASS_6  CLASS_7  CLASS_8  CLASS_9  CLASS_10  WD_PCT  WD_AVG
-END HEADER-
    WR10M     000.0     1.59     4.03     1.60     0.33     0.16     0.03     0.05     0.02     0.03     0.00     7.83     2.50
    WR10M     022.5     1.73     3.86     0.94     0.10     0.00     0.02     0.00     0.01     0.00     0.00     6.66     2.15
    WR10M     045.0     1.42     4.07     1.27     0.09     0.02     0.01     0.00     0.00     0.00     0.00     6.87     2.28
    WR10M     067.5     1.53     4.69     2.89     0.41     0.10     0.04     0.02     0.01     0.00     0.00     9.68     2.64
    WR10M     090.0     1.44     3.77     1.69     0.16     0.06     0.02     0.01     0.01     0.00     0.00     7.15     2.42
    WR10M     112.5     1.33     2.56     0.77     0.09     0.03     0.01     0.01     0.00     0.00     0.00     4.80     2.15
    WR10M     135.0     1.01     1.71     0.41     0.11     0.00     0.01     0.00     0.00     0.00     0.00     3.25     2.06
    WR10M     157.5     1.15     1.76     0.39     0.03     0.00     0.00     0.01     0.01     0.01     0.00     3.36     1.95
    WR10M     180.0     1.00     1.64     0.51     0.09     0.02     0.02     0.02     0.00     0.00     0.00     3.29     2.14
    WR10M     202.5     1.06     2.07     0.63     0.09     0.02     0.02     0.01     0.00     0.01     0.00     3.91     2.18
    WR10M     225.0     1.17     1.99     0.79     0.09     0.08     0.02     0.02     0.02     0.04     0.00     4.22     2.31
    WR10M     247.5     1.19     1.94     0.80     0.13     0.03     0.02     0.02     0.02     0.03     0.00     4.18     2.33
    WR10M     270.0     1.13     2.64     1.34     0.13     0.08     0.04     0.03     0.02     0.02     0.00     5.42     2.48
    WR10M     292.5     1.23     3.30     2.03     0.41     0.23     0.09     0.08     0.03     0.09     0.00     7.49     2.82
    WR10M     315.0     1.60     3.56     3.49     0.95     0.48     0.24     0.26     0.21     0.25     0.02    11.05     3.28
    WR10M     337.5     1.51     4.01     3.13     1.02     0.45     0.27     0.17     0.10     0.20     0.01    10.86     3.14
    WR10M       ALL    21.09    47.60    22.68     4.23     1.76     0.86     0.71     0.46     0.68     0.03   100.02
    WR50M     000.0     0.63     1.85     3.79     0.59     0.41     0.16     0.23     0.15     0.13     0.01     7.95     4.12
    WR50M     022.5     0.46     1.73     3.75     0.53     0.16     0.11     0.03     0.02     0.01     0.00     6.80     3.77
    WR50M     045.0     0.54     1.63     4.06     0.65     0.21     0.09     0.07     0.02     0.01     0.00     7.27     3.87
    WR50M     067.5     0.41     1.66     5.24     1.18     0.61     0.34     0.23     0.13     0.13     0.00     9.93     4.51
    WR50M     090.0     0.52     1.48     3.81     0.56     0.20     0.15     0.09     0.06     0.04     0.00     6.90     4.00
    WR50M     112.5     0.37     1.45     2.44     0.24     0.06     0.05     0.04     0.05     0.02     0.00     4.72     3.57
    WR50M     135.0     0.39     1.08     1.45     0.13     0.07     0.06     0.02     0.00     0.00     0.00     3.21     3.33
    WR50M     157.5     0.47     1.18     1.44     0.06     0.04     0.01     0.00     0.01     0.03     0.00     3.24     3.10
    WR50M     180.0     0.46     1.09     1.49     0.15     0.07     0.02     0.02     0.01     0.02     0.00     3.32     3.24
    WR50M     202.5     0.43     1.18     1.81     0.17     0.10     0.04     0.02     0.01     0.03     0.01     3.80     3.49
    WR50M     225.0     0.47     1.31     2.01     0.17     0.12     0.07     0.02     0.05     0.05     0.01     4.28     3.57
    WR50M     247.5     0.42     1.20     1.83     0.27     0.12     0.05     0.02     0.02     0.07     0.00     4.01     3.64
    WR50M     270.0     0.55     1.31     2.63     0.45     0.16     0.07     0.05     0.10     0.04     0.01     5.37     3.87
    WR50M     292.5     0.58     1.35     3.39     0.74     0.35     0.31     0.22     0.18     0.24     0.02     7.38     4.52
    WR50M     315.0     0.62     1.53     4.21     1.30     0.86     0.62     0.56     0.58     0.70     0.07    11.04     5.23
    WR50M     337.5     0.54     1.71     4.32     1.06     0.81     0.58     0.53     0.61     0.59     0.05    10.80     5.07
    WR50M       ALL     7.86    22.74    47.67     8.25     4.35     2.73     2.15     2.00     2.11     0.18   100.02
```

How do POWER's APIs work?



Data Request

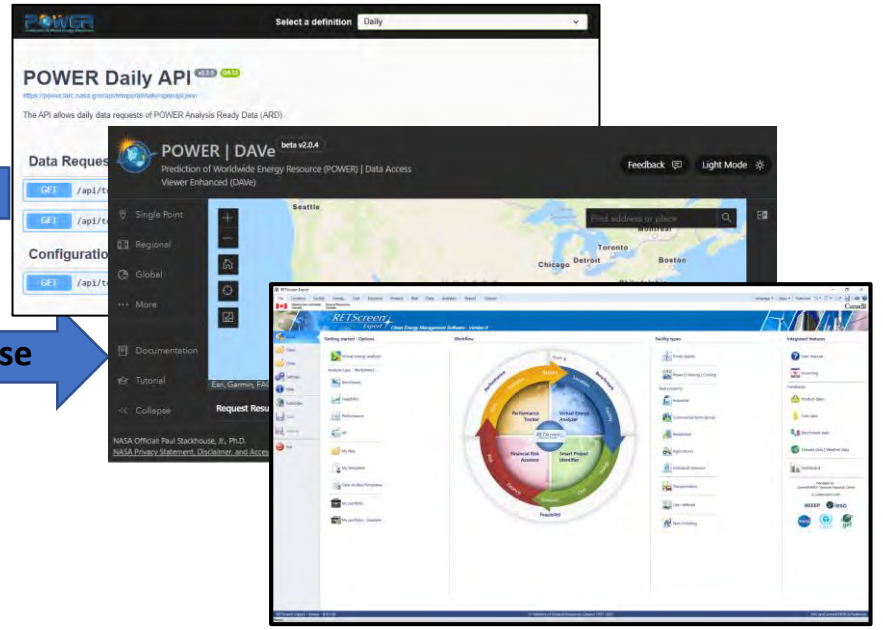
Data Response



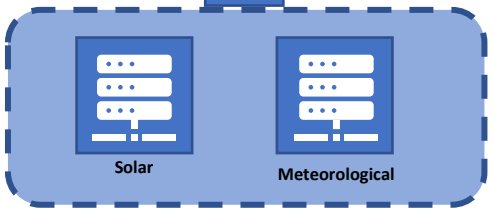
API Request

API Response

Data Request Sources



Data Updates



POWER's API System

The POWER Project APIs support programatic access to the entire data catalog. The APIs provide community specific data products for independent use, directly embeed into applications, and for POWER Data Access Viewers.

Hosting in AWS Lambda:
The microservices provide data at all temporal levels including hourly, system endpoints, and all the analytical reports.

Geospatial Feature & Image Services

POWER provides Esri® ArcGIS Image and Feature Services that allow users to efficiently interact with the POWER data in Geographic Information System (GIS) applications and related tools.

Image Services: new image services for annual radiation, annual meteorology, monthly radiation, and monthly meteorology.

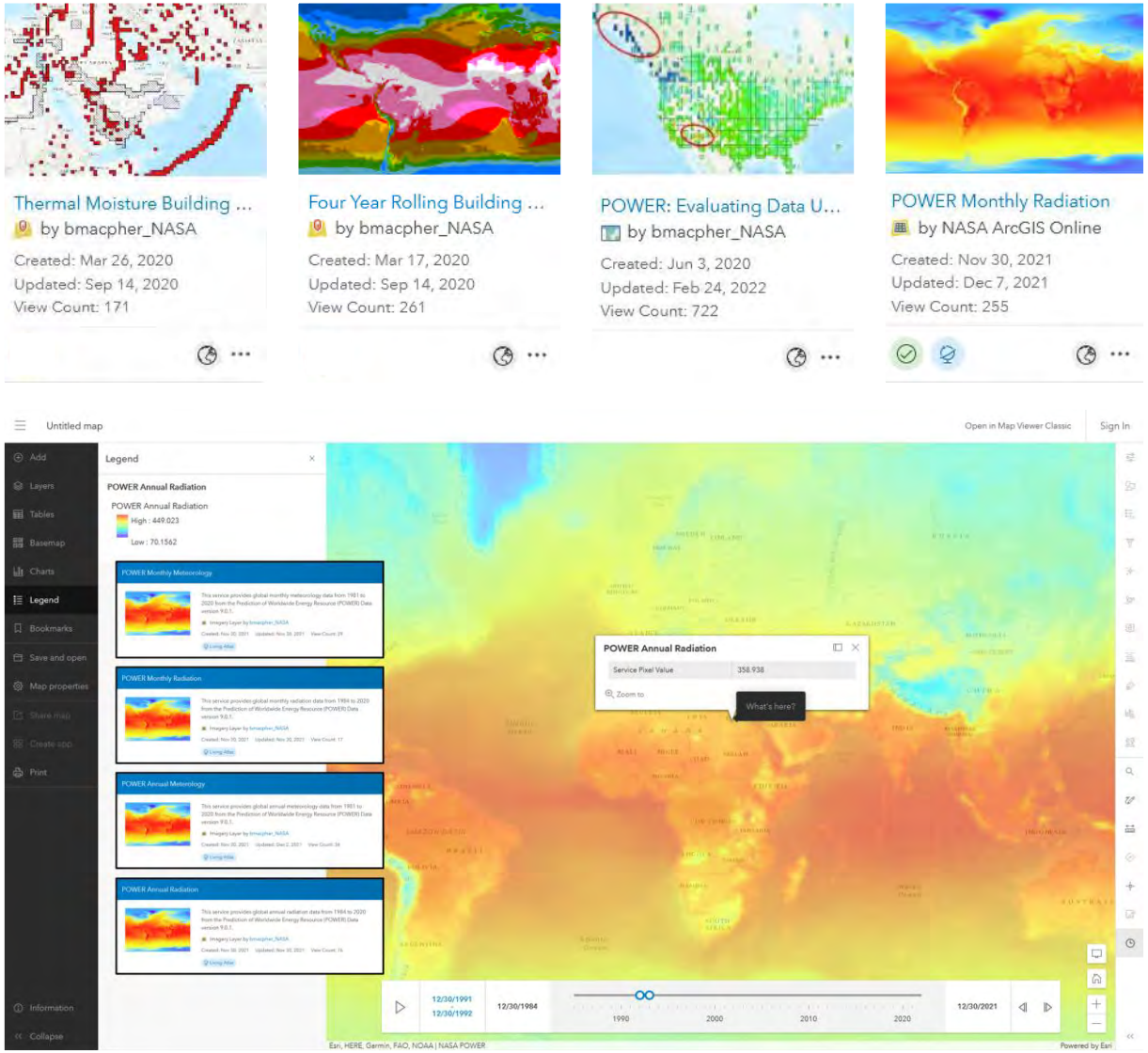
Feature Services: global long-term ASHRAE® building climate thermal-moisture zones, 4-year rolling thermal zones, and period differences

Available on:

Esri Living Atlas of the World

NASA ArcGIS Online (AGOL)

NASA ArcGIS Enterprise



POWER evolved with User Needs

Tech

Data

LaRC ASDC, DOE
*NREL, **RETScreen®***
International

*USGS, **ASHRAE***

Sustainable Building Community

DSSAT *IEA*

Near Real Time (NRT) Data Availability

ESRI

Web-Based Data Visualization, API, & GIS Capability Added

Total Data Requests Exceeds 360 Million

1997-1999

Surface Meteorology & Solar Energy (SSE)

2004

2006

Daily Time-Series Data & Agriculture Community

2008

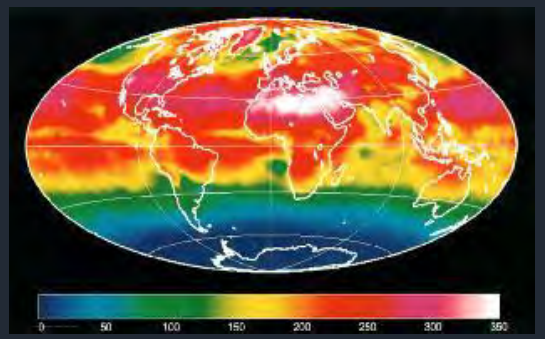
2012

Enhanced Climatology Data Availability

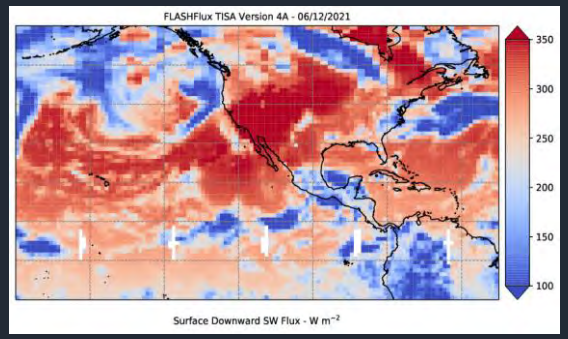
2018

2021-2022

Hourly (2021) & Cloud Based (2022)

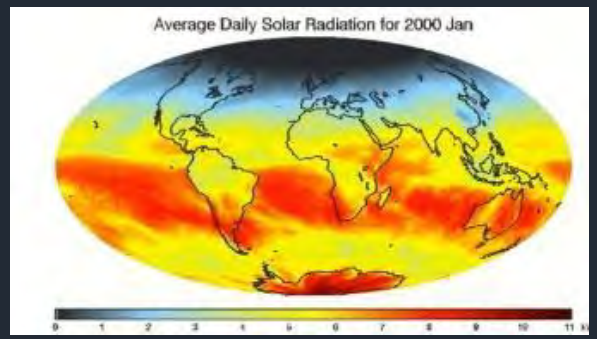


WCRP SRB v1

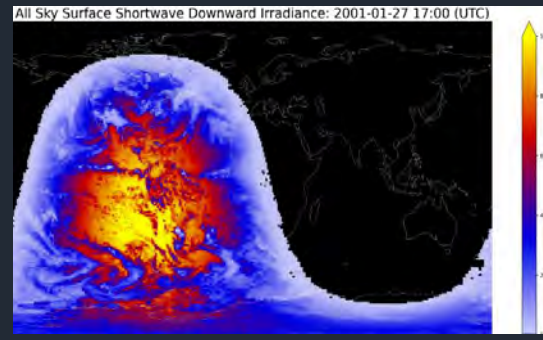


CERES FLASHFlux

Total Data Requests exceeding 326 million



WCRP/GEWEX SRB v2.5

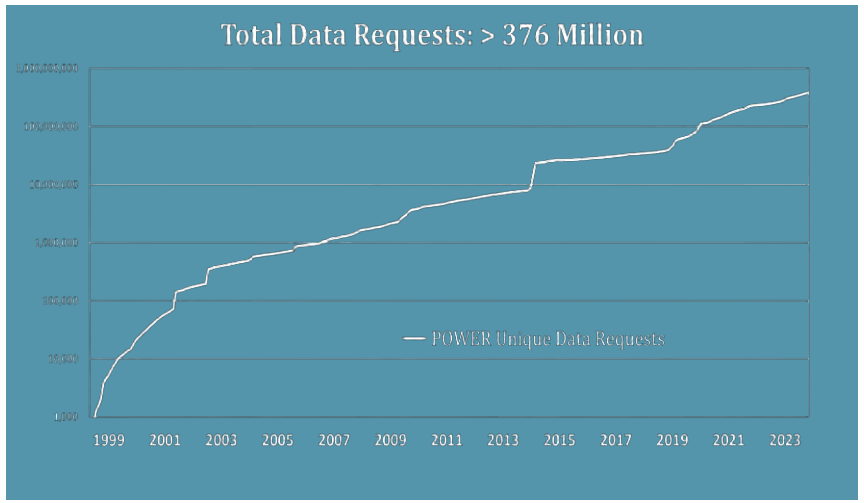


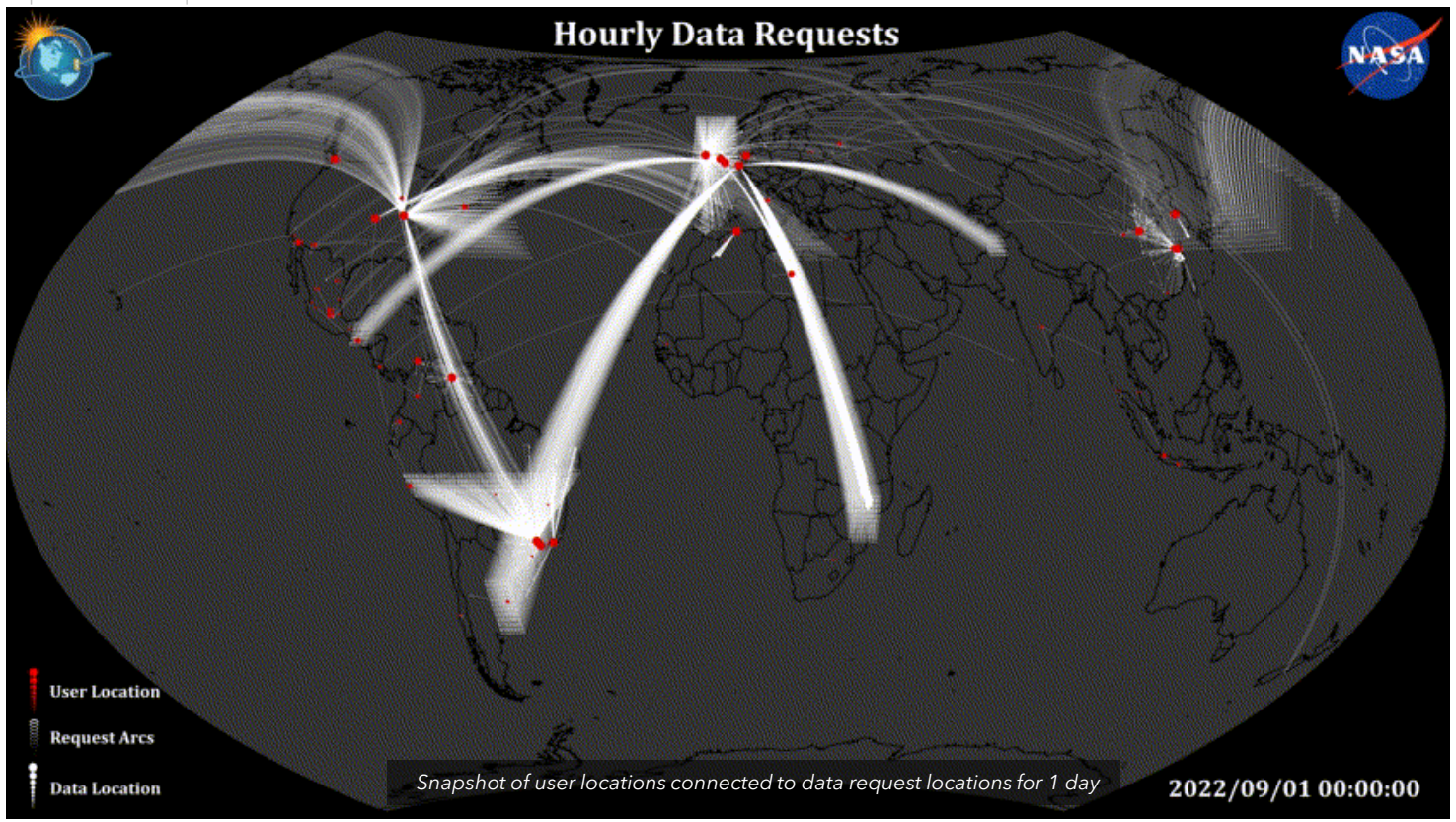
CERES SYN1Deg

POWER Users | Impact of Modern Technology Adoption

EARTH SCIENCE APPLIED SCIENCES

POWER fulfills
7+ million data requests
for over
30,000 unique users
per month





Before Geospatial Services	
1999/06/01 to 2018/05/01	
Requests	35,988,533
Data Volume	3,612 GB
The data volume is available from 6/01/2019	

After Geospatial Services	
2018/05/01 to Present	
Requests	340,264,728
Data Volume	110.46 TB
Unique Users	734,389

https://power.larc.nasa.gov

POWER | Revisiting Community of Users

National Aeronautics and Space Administration

Joe

I want to adopt green energy for my new facility. Will it be cost effective?

Jill

I want to plan on when to fly my drone with payloads ? Will there be enough sunlight to power the drone ?

Joshua

I want to implement green energy solutions in my facility and monitor its performance over time

Margaret

I want to model the maize yield response to Nitrogen Fertilizer Intervention

Ben

I want to determine the optimal solar water pump configuration for our customers

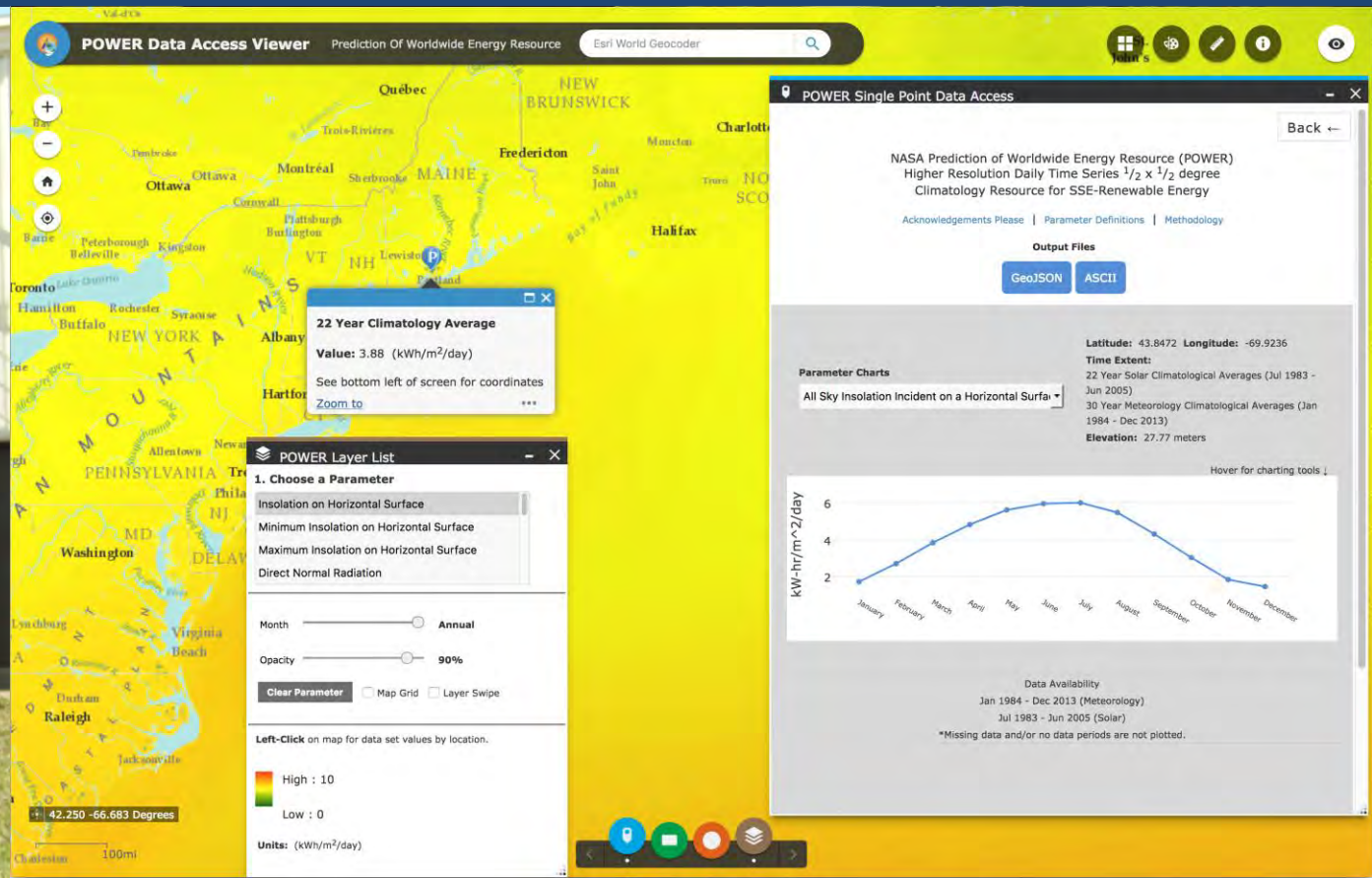
Renewable Energy Development

Wicked Joe Organic Coffees

"The benefits of solar, in our view, go far beyond the financial considerations or return on investment. While some regions may have 'more optimal' conditions for solar, we believe that any place where the sun shines is a good place for solar."

–Bob Garver, Wicked Joe Founder

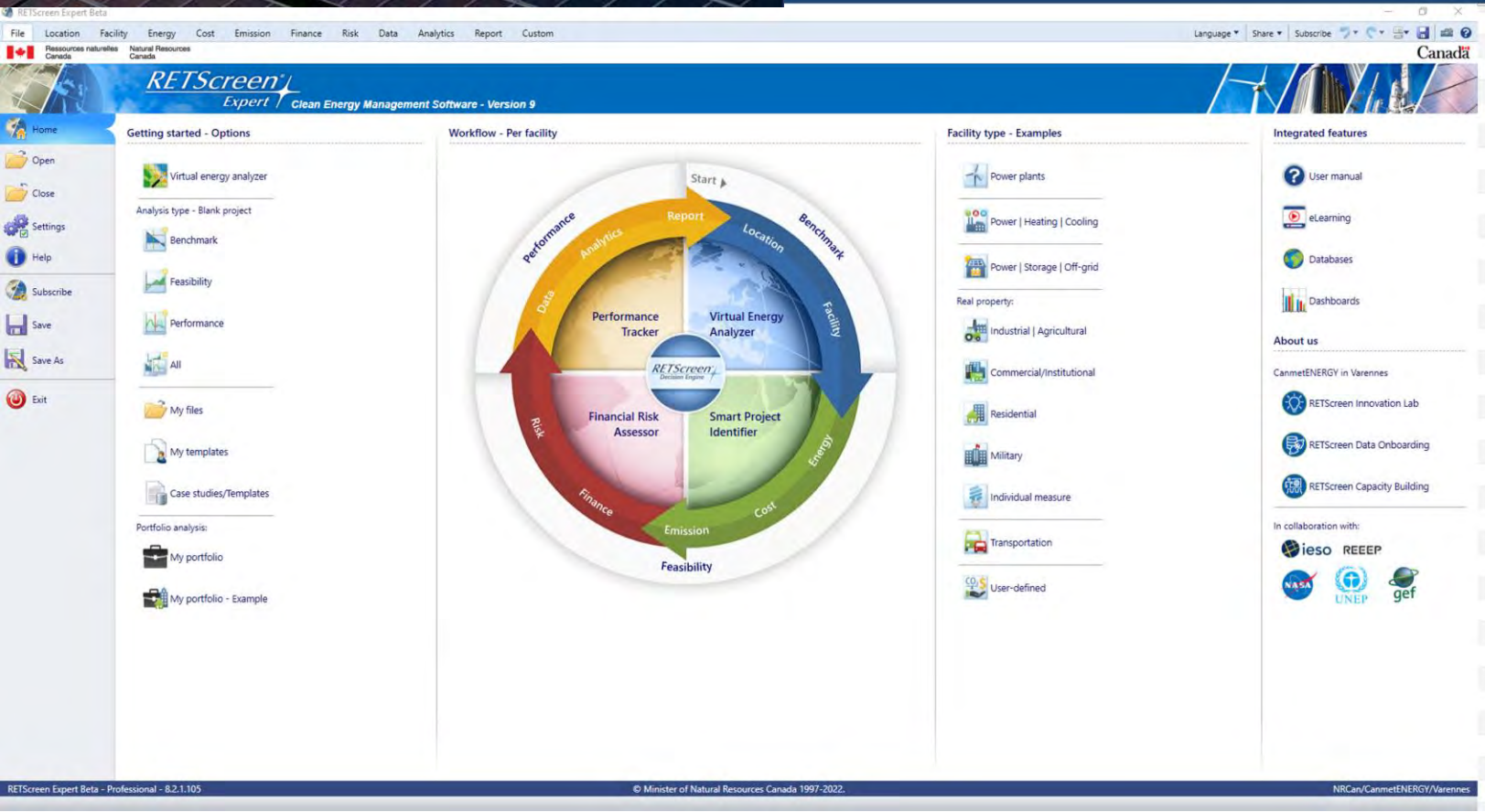
Wicked Joe Coffee utilized RETScreen™ and POWER data to determine that a glazed solar wall would result in 40% more heat savings of approximately $10,000 per year.

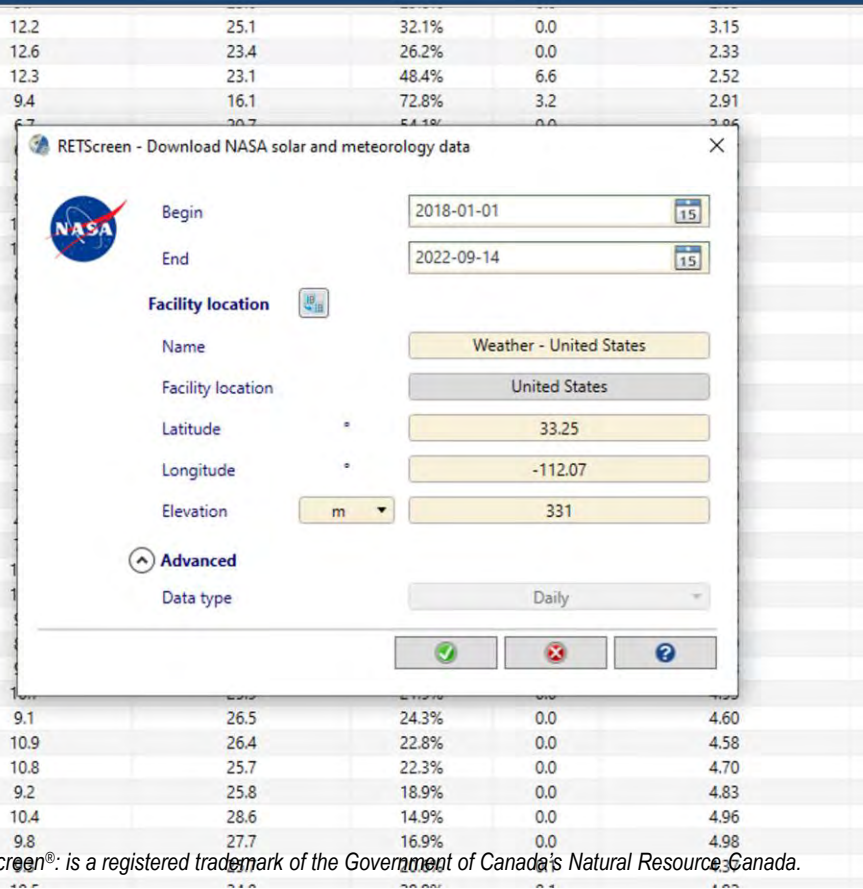


Natural Resources Canada's RETScreen® Clean Energy Management Software Platform

World's leading clean energy decision making software for benchmark, feasibility, performance, and portfolio analysis related to nergy efficiency, heating and cooling, power generation and cogeneration,with 732,000+ registered users.

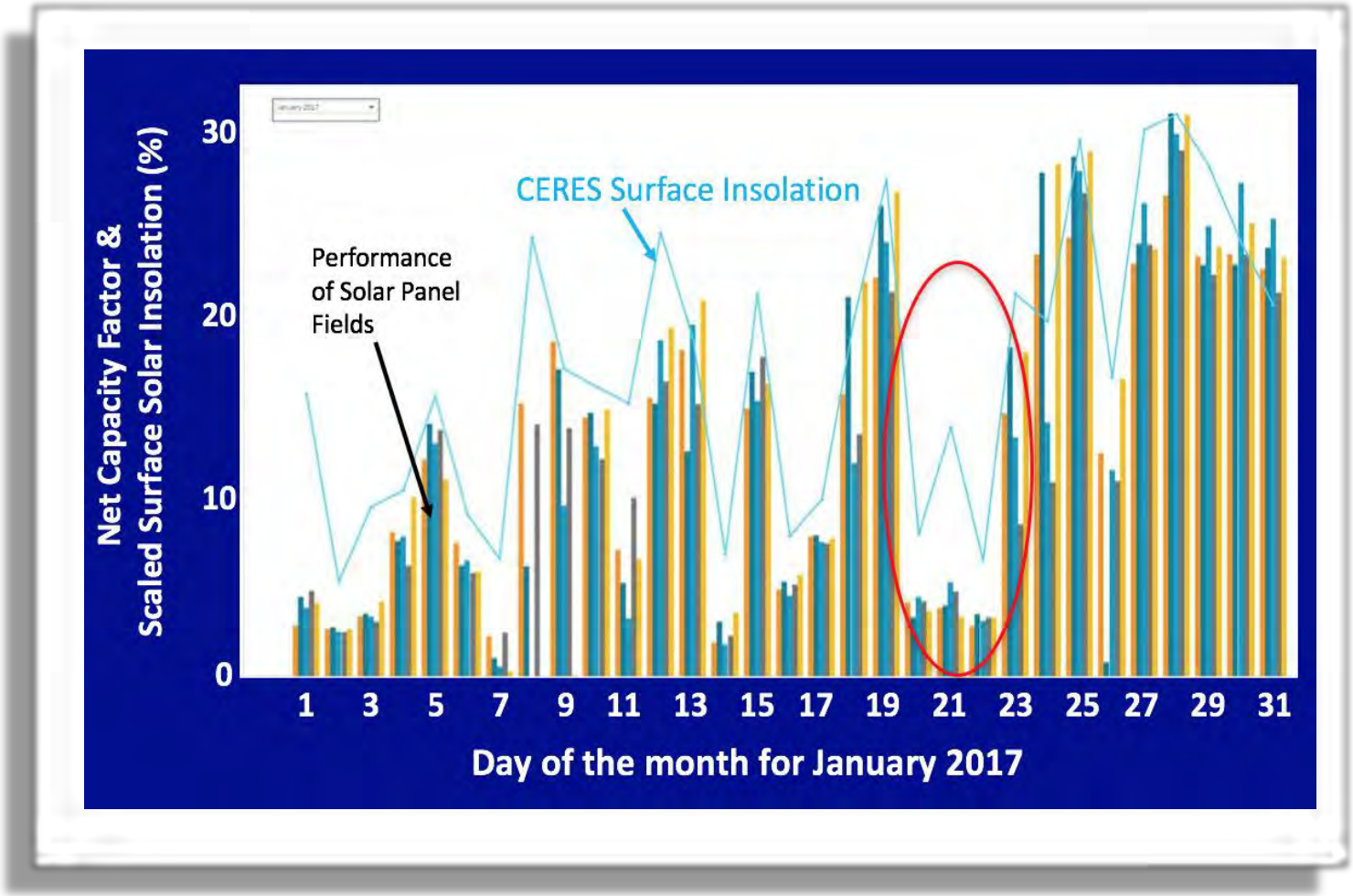
POWER provides global data as climatological averages that are embedded in the software and near-real time data obtained via a direct connection to POWER.





CustomerFirst Renewables Is Using Data from POWER to Monitors Five Solar Fields in North Carolina

Variability of Solar Radiation is used to assess performance of solar panels and identify potential system problems

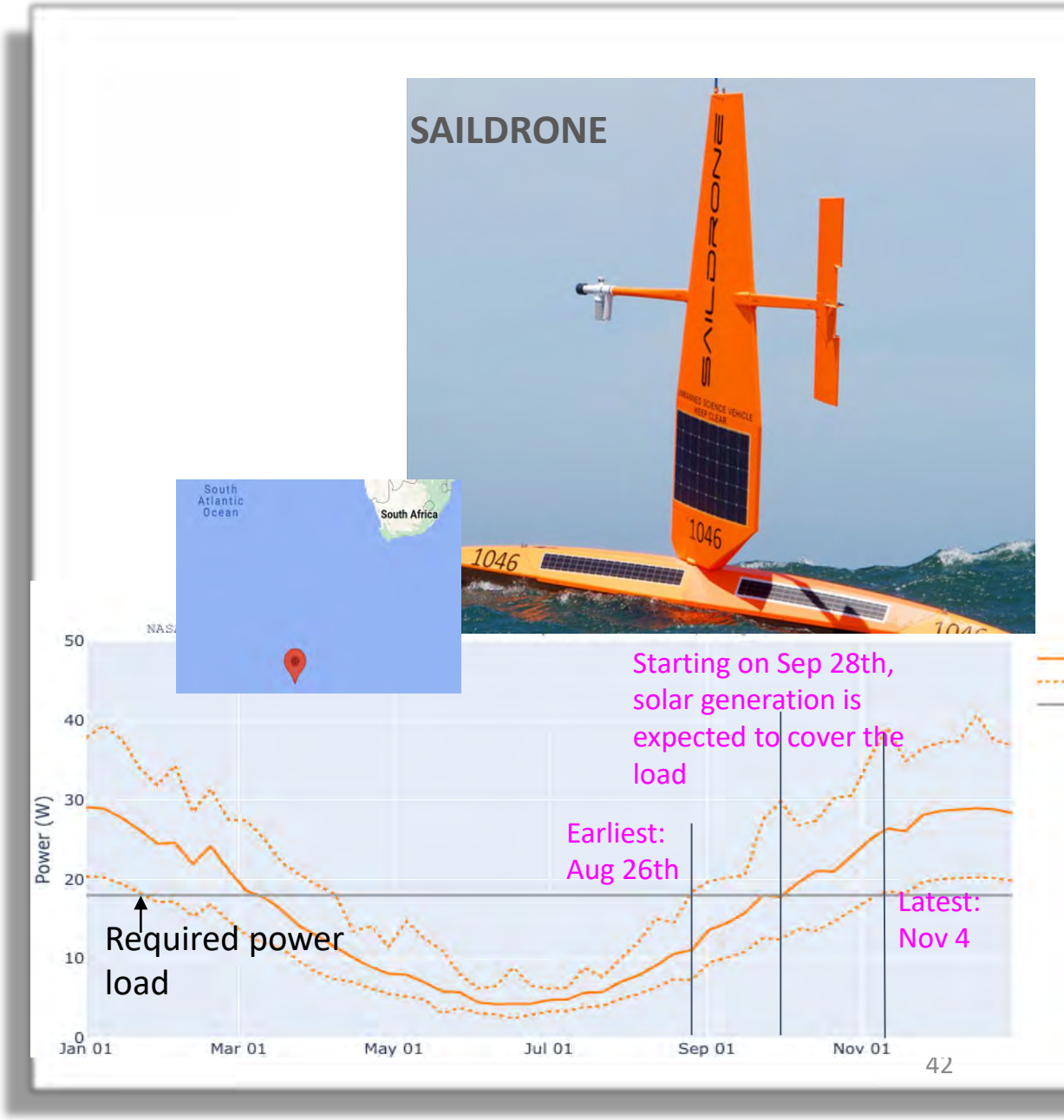


SAILDRONE is using Data from POWER to determine viable operations season and make strategic engineering tradeoff decisions

Hourly Solar Radiation

Intensity of solar radiation determines how much electricity can its drone's solar panels generate

- Prioritize adding solar or reducing loads on drone ?
- Modify contract to support a mission?

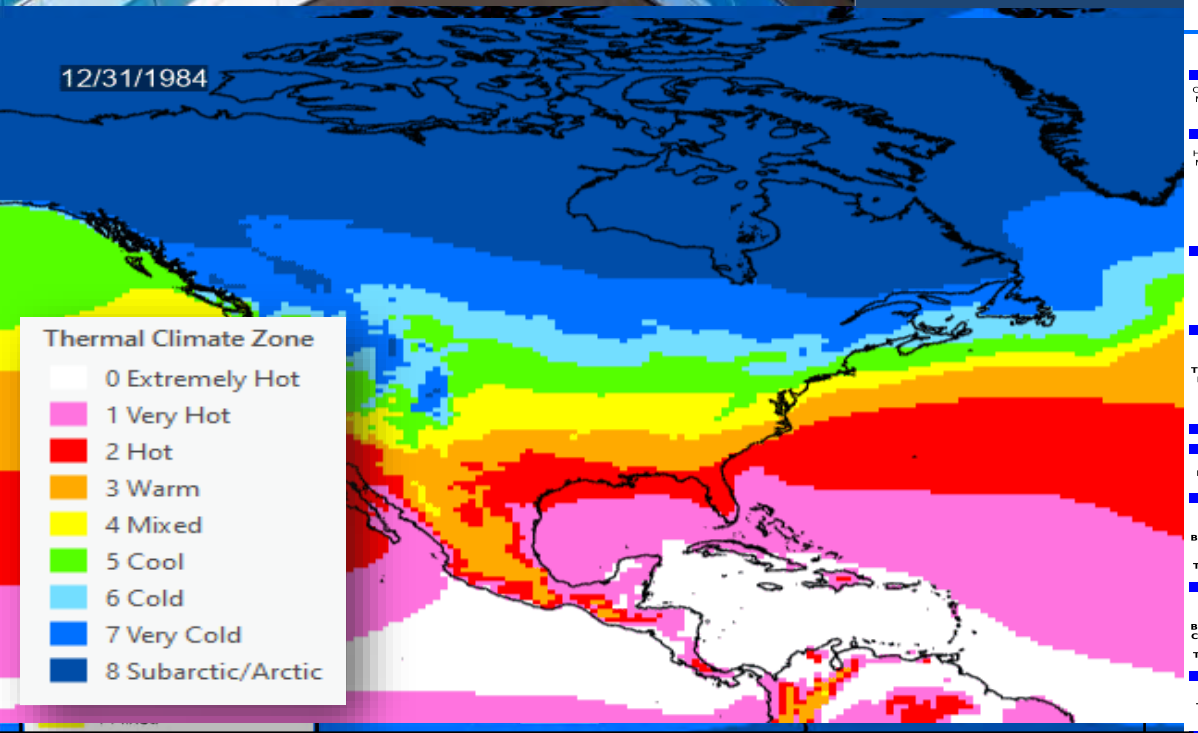


Building Energy Efficiency & Sustainability

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

The POWER project is working with ASHRAE professional association to make their Climatic Design Conditions report available to the public with POWER data globally.

Using MERRA-2, POWER creates Global ASHRAE Building Climate Zone maps, as well as"rolling" climate zones from 4-year means to illustrate the changes in time from 1984 through 2021.



POWER Rolling Climate Thermal Zones
1984 to 2021

Building Climatic Design Conditions

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 DP 99.6%	HR 99.6%	MCDB 99.6%	DP 99%	HR 99%	MCDB 99%	Coldest month WS/MCDB WS 0.4%	MCDB 0.4%	WS 1%	MCDB 1%	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	MCWB 0.4%	DB 1%	MCWB 1%	DB 2%	MCWB 2%	Evaporation WB/MCDB 0.4% WB	MCDB 0.4%	WB 1%	MCDB 1%	WB 2%	MCDB 2%	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 DP 0.4%	HR 0.4%	MCDB 0.4%	DP 1%	HR 1%	MCDB 1%	DP 2%	HR 2%	MCDB 2%	Enthalpy/MCDB Enth 0.4%	MCDB 0.4%	Enth 1%	MCDB 1%	Enth 2%	MCDB 2%	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	Max	Standard deviation	Min	Max	n-Year Return Period Values of Extreme Temperature n=5 years Min	Max	n=10 years Min	Max	n=20 years Min	Max	n=50 years Min	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
	0.4% 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
	2% 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
	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
	10% 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
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4% WB		11.2	16.0	15.2	18.4	19.4	23.0	23.8	24.2	23.4	20.1	17.7	16.3
	0.4% MCDB		15.2	18.2	19.3	22.9	24.1	26.5	27.9	27.7	27.1	24.3	20.2	19.1
	2% WB		11.0	15.9	15.2	18.3	19.3	23.0	23.8	24.2	23.4	20.0	17.4	16.0
	2% MCDB		15.0	18.1	19.3	22.8	24.1	26.5	27.9	27.7	27.1	24.1	20.1	18.9
	5% WB		10.7	15.8	15.1	18.0	19.2	23.0	23.8	24.2	23.3	19.8	17.0	15.5
	5% MCDB		14.4	18.1	19.2	22.6	24.1	26.5	27.9	27.7	27.0	23.8	19.7	18.5
	10% WB		10.1	15.6	14.9	17.5	19.0	22.9	23.8	24.2	23.1	19.4	16.2	14.6
	10% MCDB		13.6	18.0	19.2	22.4	24.1	26.5	27.8	27.6	26.9	23.3	19.1	17.9
Mean Daily Temperature Range	5% DB MDBR		11.5	11.8	12.5	12.3	12.1	9.5	9.0	8.4	8.4	10.2	11.6	10.7
	5% DB MCDBR													
	5% WB MCWBR													
	5% WB MCWBR													
Clear Sky Solar Irradiance	taub													
	taud													
	Ebn,noon													
	Edn,noon													
All-Sky Solar Radiation	RadAvg	3.2	3.94	5.02	5.97	6.45	5.84	5.43	5.38	4.79	4.48	3.53	2.95	
	RadStd	1.12	1.42	1.53	1.64	1.6	1.72	1.65	1.44	1.44	0.99	1.05	0.94	

ASHRAE STANDARD

ANSI/ASHRAE Standard 169-2021
(Supersedes ANSI/ASHRAE Standard 169-2020)
Includes ANSI/ASHRAE addenda listed in Appendix C

Climatic Data for Building Design Standards

See Appendix C for approval dates.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. Instructions for how to submit a change can be found on the ASHRAE® website (https://www.ashrae.org/continuous-maintenance).

The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 180 Technology Parkway NW, Peachtree Corners, GA 30092. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

 ISSN 1041-2336

Approved American National Standard ANSI www.ansi.org

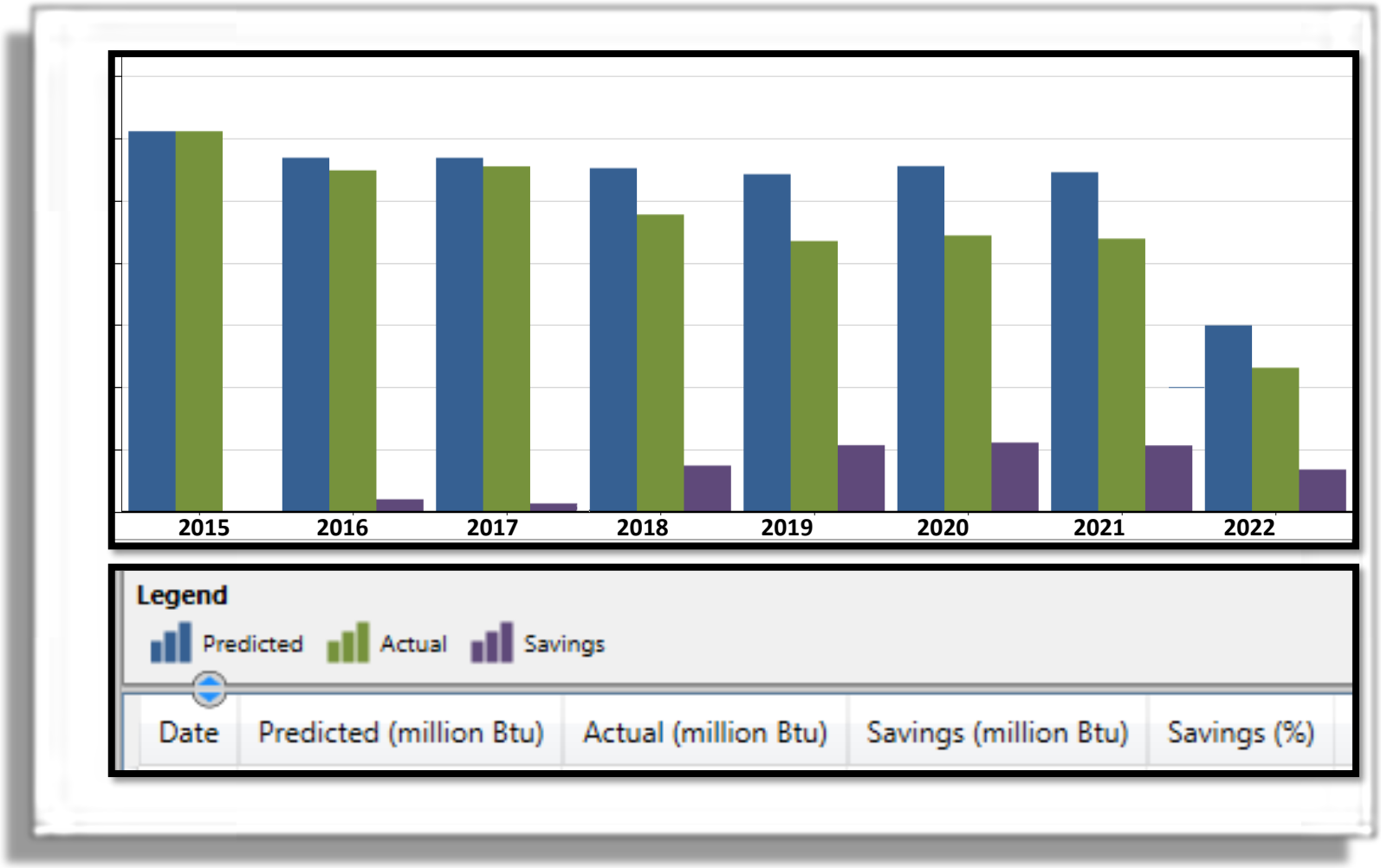
Includes Web-based access to climatic data, design conditions, figures, and tables.
(Requires Adobe Acrobat® and Microsoft Excel®)

3M Company implements strategies to increase energy efficiency and reduce carbon emissions in the manufacturing facilities it manages

Time series data used for retrofitting decisions

Monitoring and assessment of post decision implementation

Using RETScreen® Clean Technology tool and time series data (verify ISO 50001 energy standards)



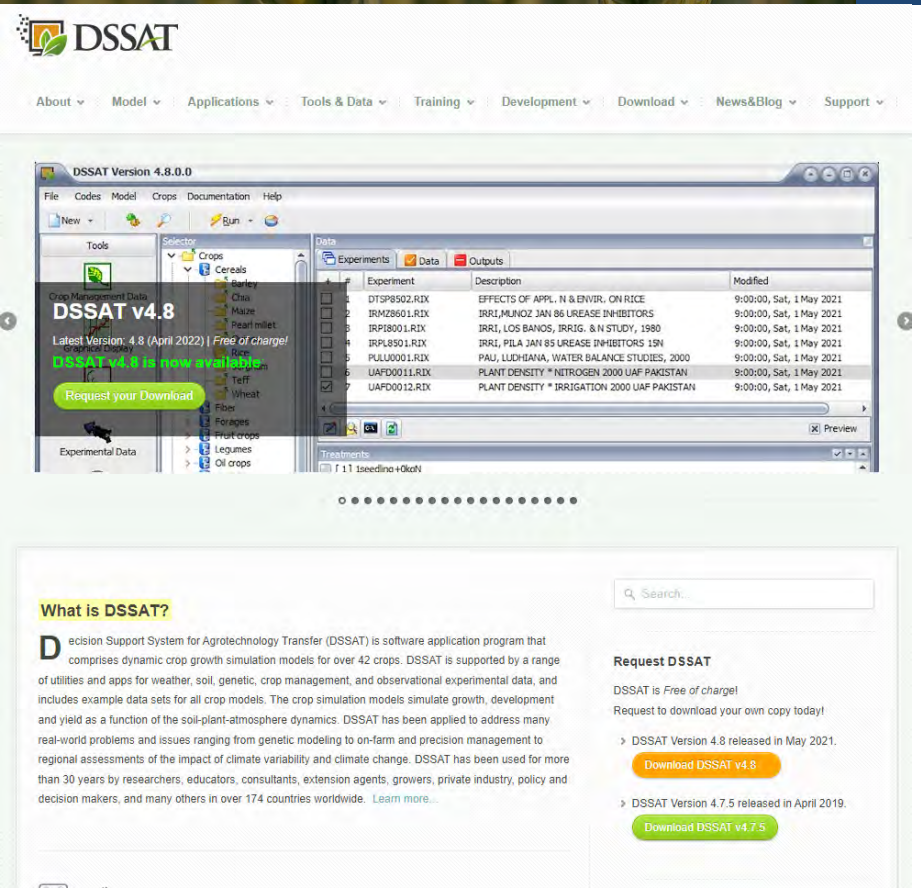
Agroclimatology Applications: Partners

Decision Support System for Agrotechnology Transfer (DSSAT)

POWER data supports the Decision Support System for Agrotechnology Transfer (DSSAT) tool, an agriculture ecosystem by the Global Food Systems Institute & Department of Agricultural and Biological Engineering at the University of Florida (UF).

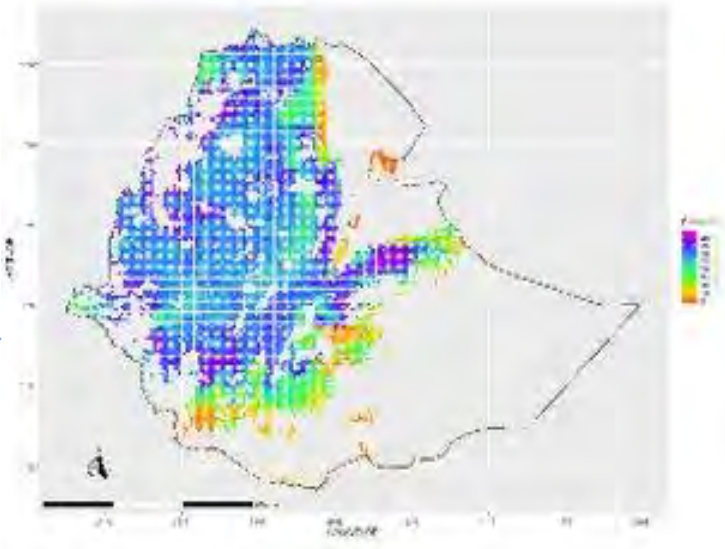
The DSSAT tool can be used for:

- Modeling crop yield prediction
- Estimating crop maturity dates
- Harvest progression over time
- Assessing the potential impact of climate change on global food security



The Ministry of Agriculture in Ethiopia used DSSAT to model the maize yield response to Nitrogen Fertilizer Intervention

Historical (34 year) and Near-Real-Time solar and weather data from NASA POWER was used in DSSAT



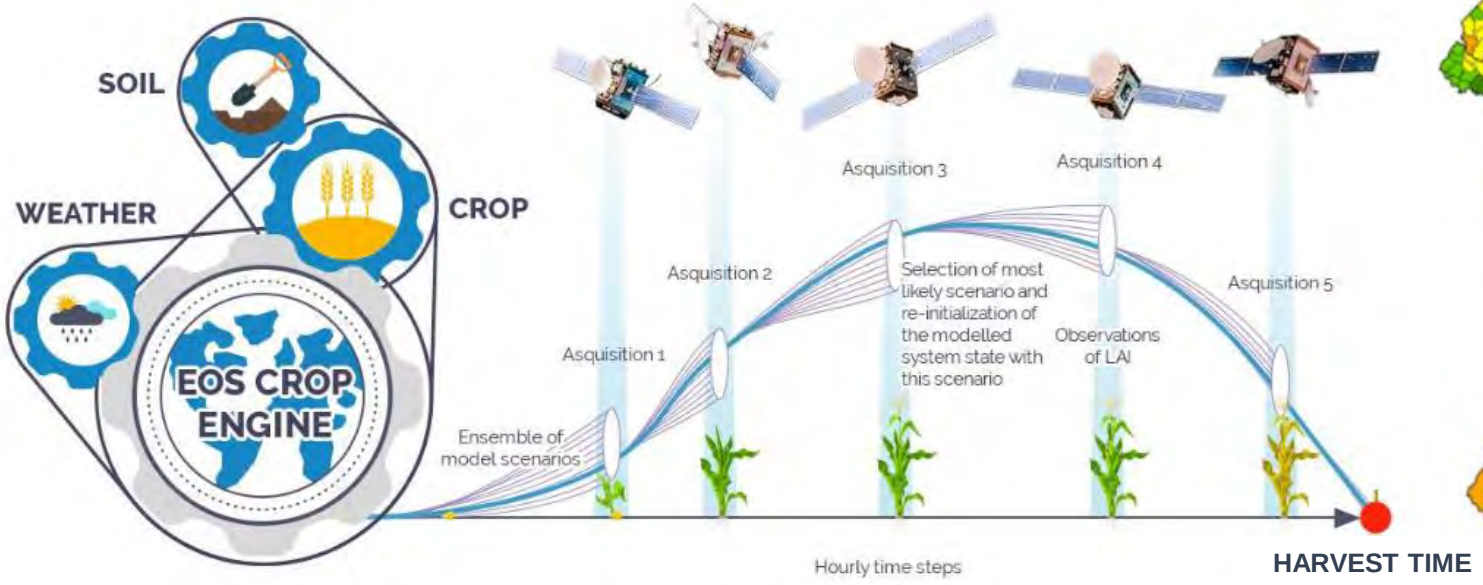
Absolute difference in maize yield after additional fertilizer application

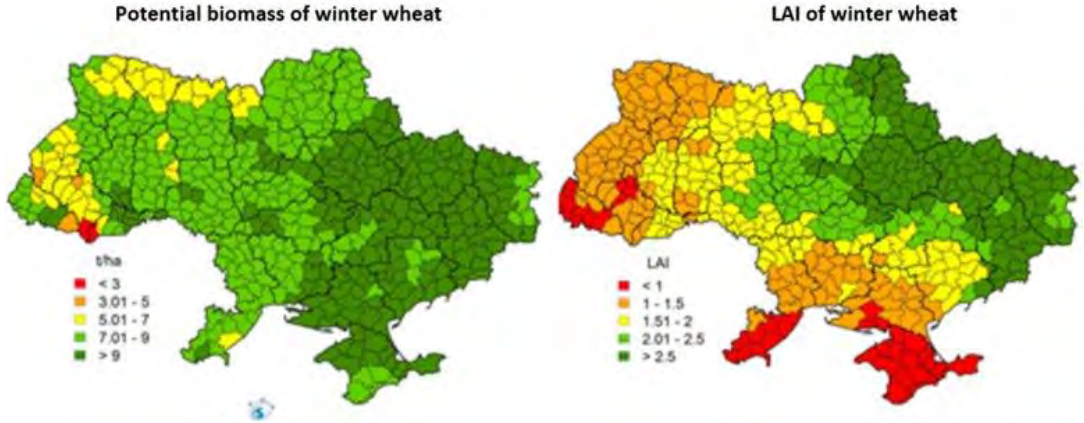
Agroclimatology Applications

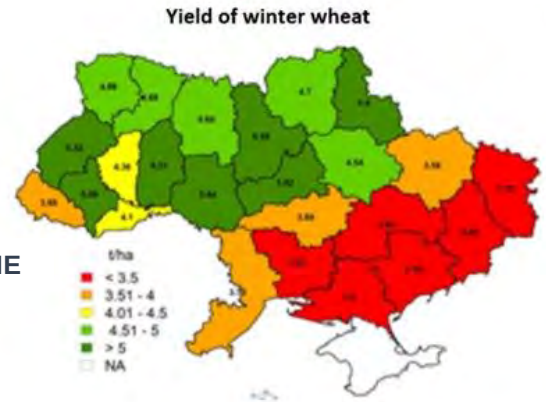
Earth Observing Satellite Data Analytics (EOSDA)

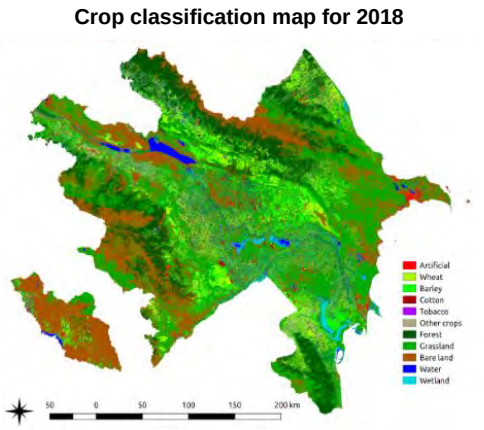
The main focus of EOSDA is the global agricultural sector, providing reliable information of crop development, crop disease, and yield forecast to their clients. These outcomes are very dependent on weather, so accurate estimation of past and current weather is very important.

EOSDA developed crop growth monitoring system that runs operationally from independent modules that are integrated to monitor crop behaviour and produce crop yield forecasts, where NASA POWER meteodata is a key input.



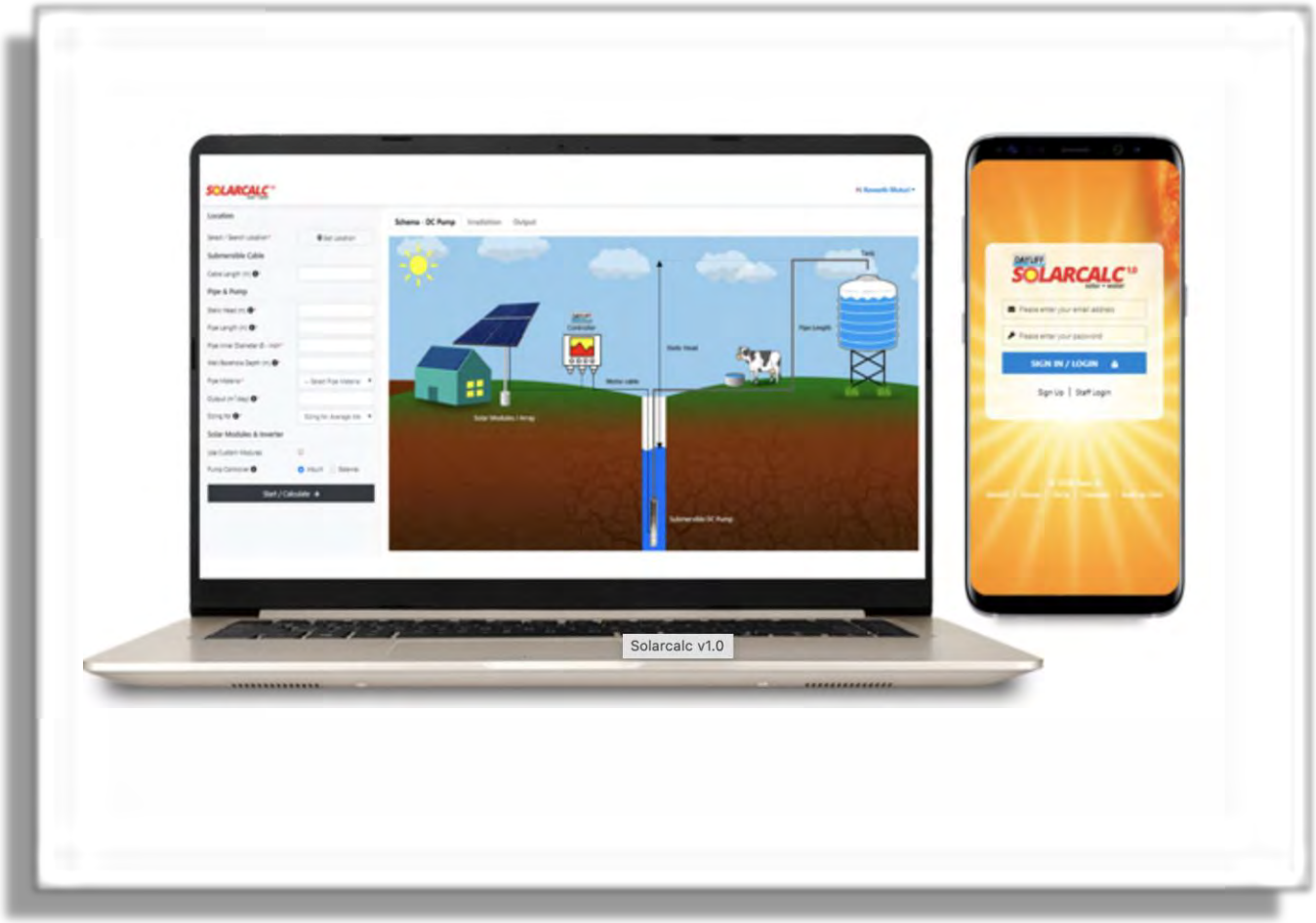






The **Davis & Shirtliff Group** in East Africa uses **SolarCal** to determine the optimal solar water pump configuration for their customers

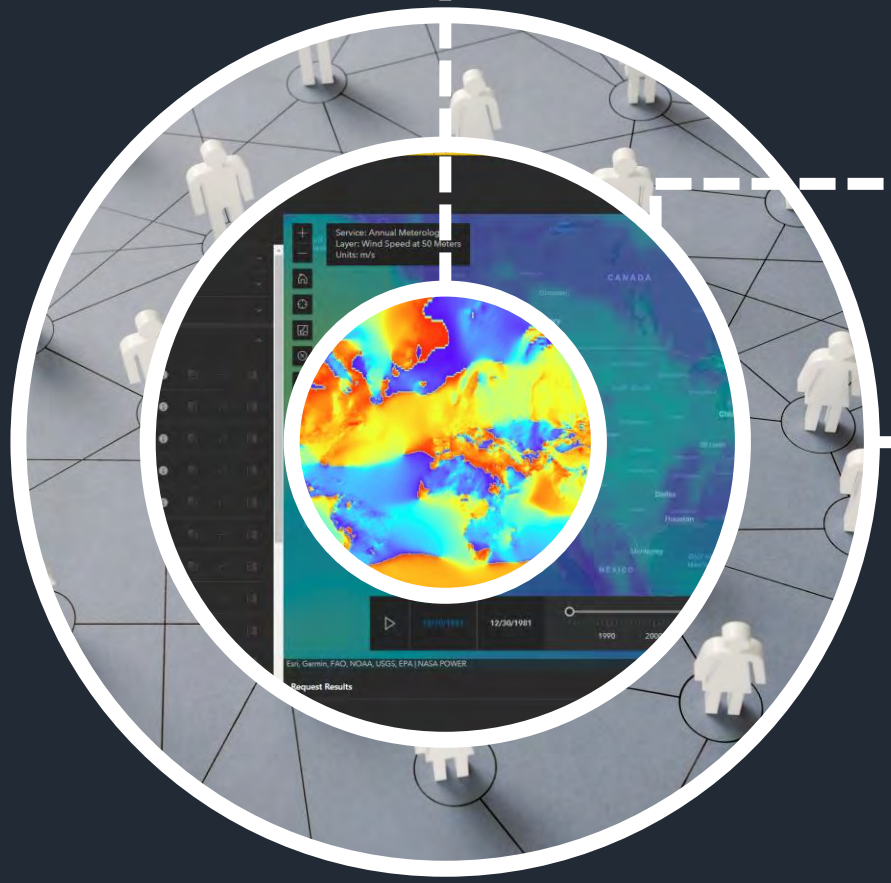
D&S developed an application called **'SolarCalc'** that uses data from POWER to compute how many solar panels (including their arrangement) are needed to power different types of Solar-powered Water Pumps



What are POWER's Impacts on the Community?

Roadmap | POWER's Future Plan

EARTH SCIENCE
APPLIED SCIENCES



New & Improved Datasets from Providers (SMAP, TEMPO, including predictive data!)

Enhanced Data Production Technologies

Increased User Community Engagement & Communication
(e.g Validation Tool PRUVE)

Roadmap | Climate Data Services

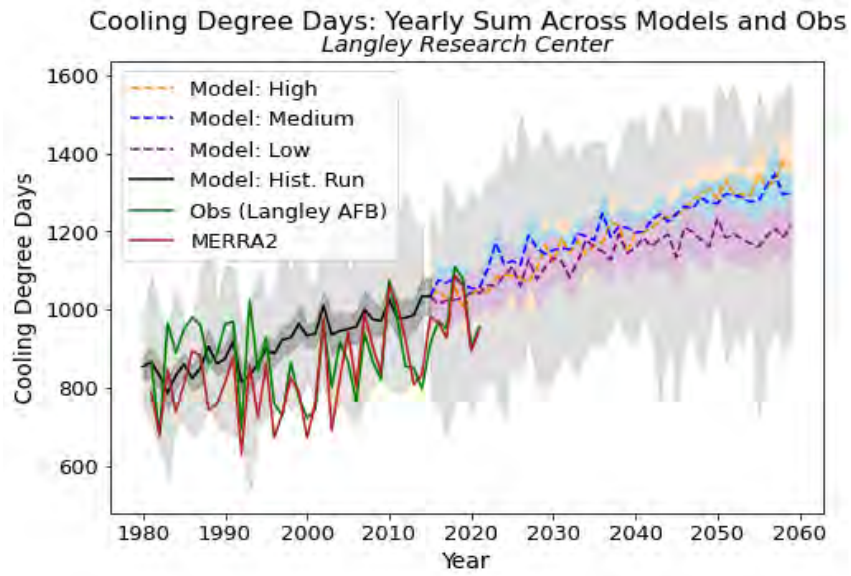
EARTH SCIENCE APPLIED SCIENCES

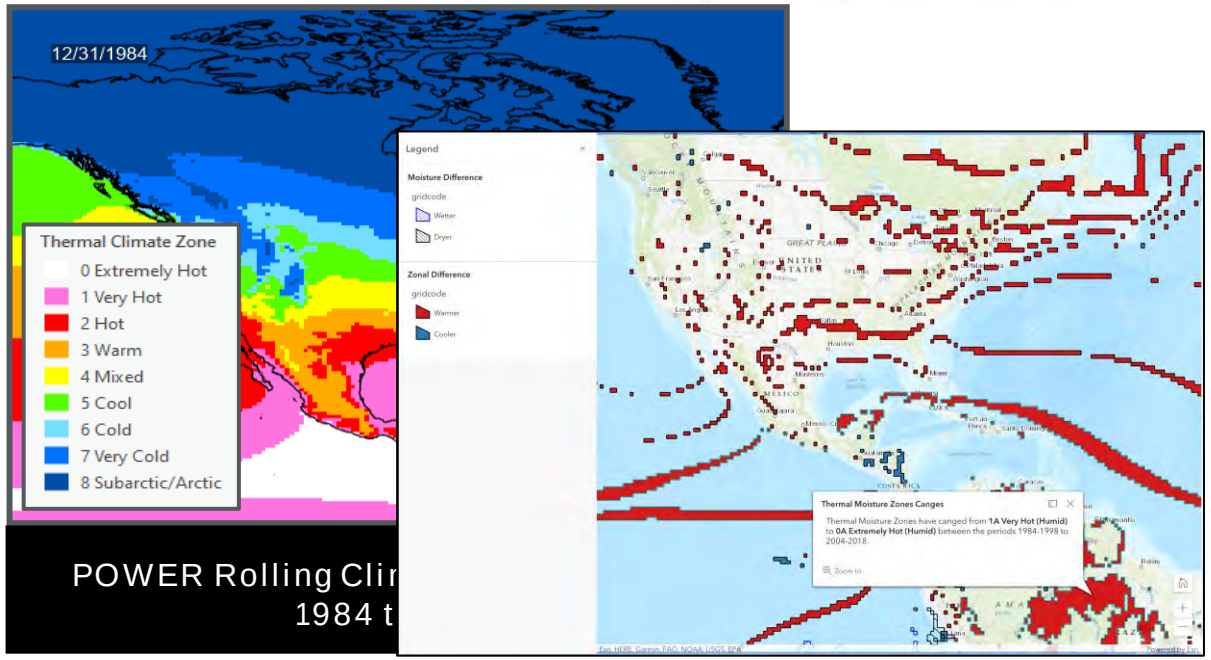
NASA-wide project to assess building system sustainability for operations, maintenance and planning according to Federal regulations

Assess and utilize NASA Earth Exchange (NEX) Global Downscaled Data Product from CMIP6 model data products:

- 22 of 26 models utilized; runs out to 2100
- 3 SSPs processed
- 60°S-90°N, all longitudes; downscaled to 20 km; daily temporal resolution
- 9 parameters including: T, Tmin, Tmax, RH (q), Wind Speed, Precip, SWdown, Lwdown

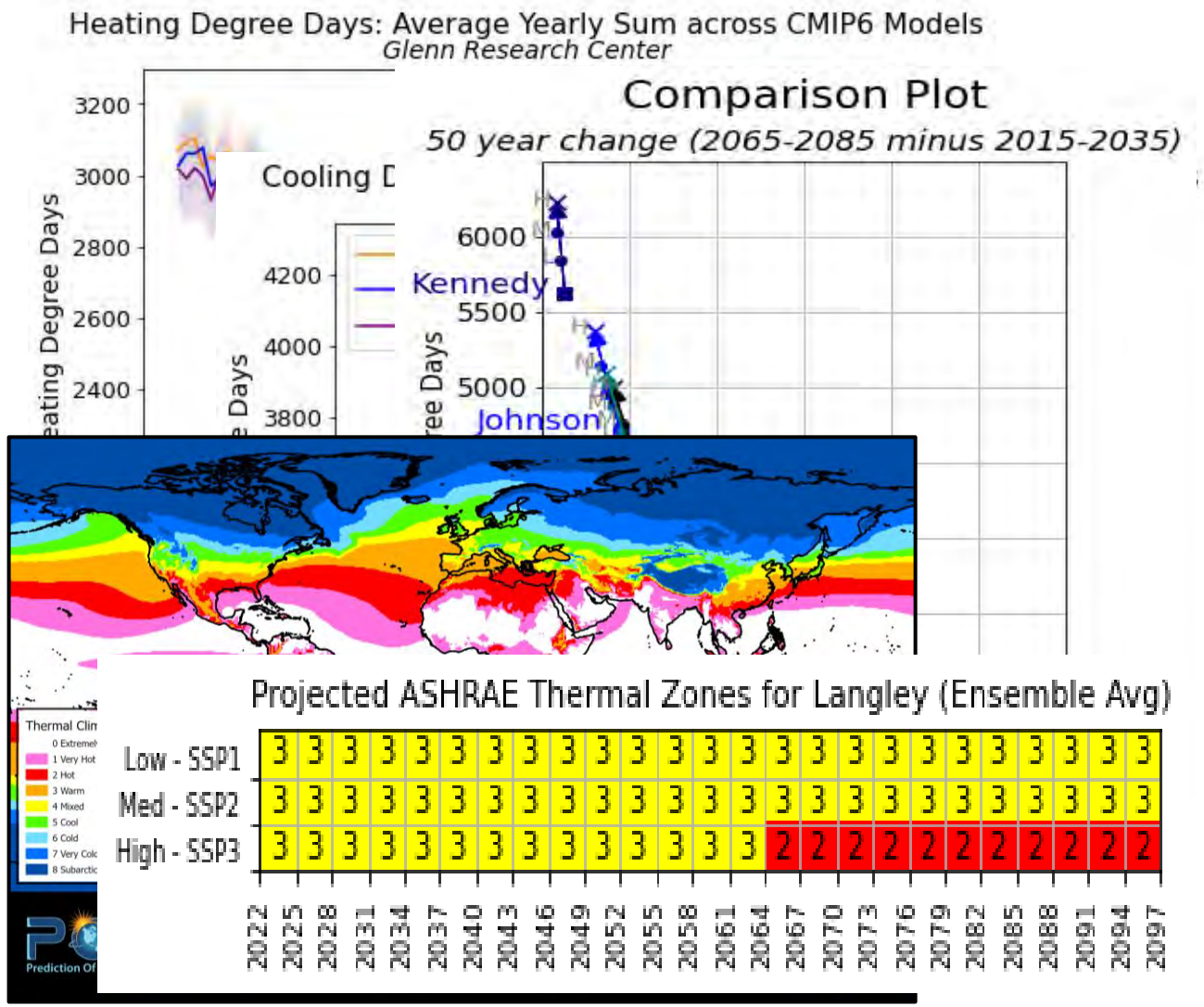
22 Member Ensemble for each SSP processed to assess CCD/HDD at each center





Time Series Usage: Climate Projections Analysis for Sustainability Assessments

- **Produce long time series to capture scenario changes**
  - Apply bias correction (using surface obs and POWER data for each parameter)
  - Input into decision support tool
  - Estimate differences in energy, GHG load and cost for archetypical and/or specific buildings
- **Utilize CDD/HDD/Precipitation to create maps of estimate global building climate zones**
  - Can assess changes in climate zone changes relative to individual and/or ensembles of models



Roadmap | Online Data Validation Tool (PRUVE)

EARTH SCIENCE APPLIED SCIENCES

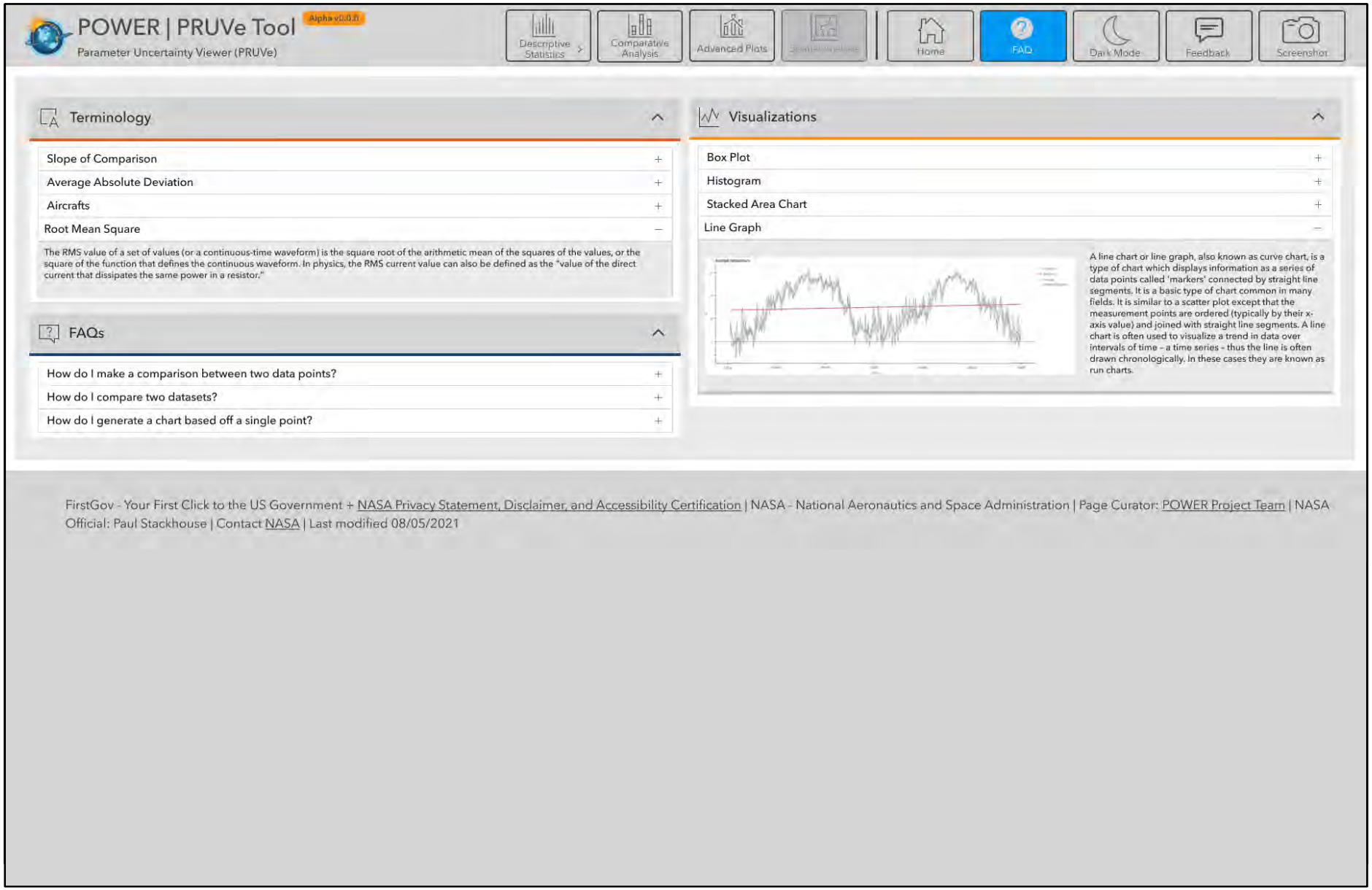
Currently working on a new web-application called PaRameter Uncertainty ViEwer (PRUVE)

A system built on **open-source frameworks** to support the computation, discoverability, and visualizations of data uncertainty.

Key Features:

- No-coding access
- Prototype to include ~3,000 surface sites
- Dynamic data visualization available for each site
- Creates maps, plots, and conducts spatial analysis on the fly
- User selectable point based descriptive statistics
- User selectable site based intercomparison
- Advanced custom plotting for specific use cases

The PaRameter Uncertainty ViEwer (PRUVE)



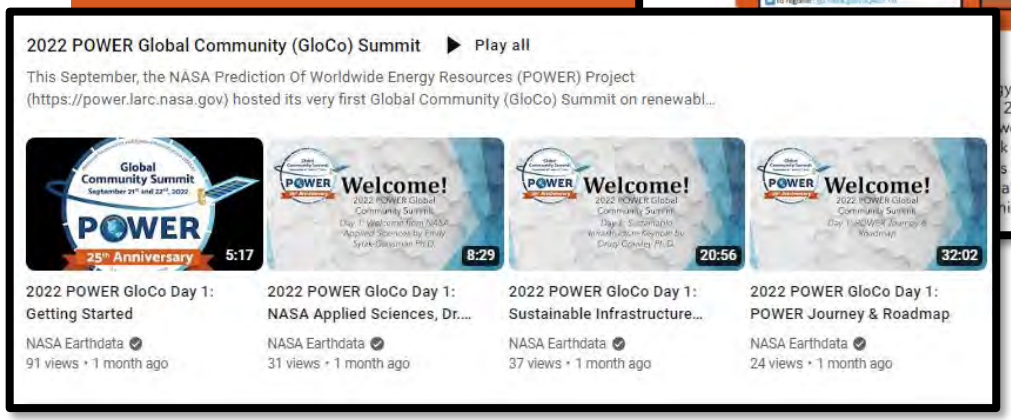
User Engagement | 2nd Annual Global Community Summit (GloCo)

National Aeronautics and Space Administration

SAVE THE DATE : October 11-12th, 2023

The POWER GloCo Summit is a **FREE** two-(half) day hybrid event on **October 11-12th, 2023**, hosted by the NASA POWER Project Team.

Stay tuned for more GloCO announcements, including information for how to submit a lightning talk presentation, soon!



- Learn more about the NASA POWER Project
- Watch new product capability demonstrations
- Engage in community-driven breakout sessions
- Hear how users are utilizing NASA POWER products

Connect with POWER & Learn More

Explore POWER's docs & learning resources!

➥ Esri® ArcGIS StoryMap
➥ POWER Services Dashboard
➥ API Landing Pages
➥ Methodology Docs

https://power.larc.nasa.gov/

Submit your user stories & POWER-featured publications!

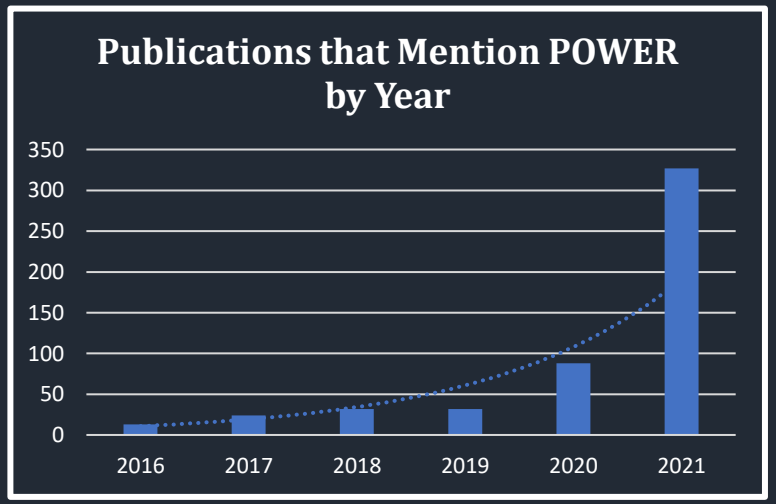
➥ The team keeps a list of presentations, papers, & projects that have used POWER Data.

Energy Webinars

Reach out to POWER directly!

larc-power-project@mail.nasa.gov

falguni.patadia@nasa.gov



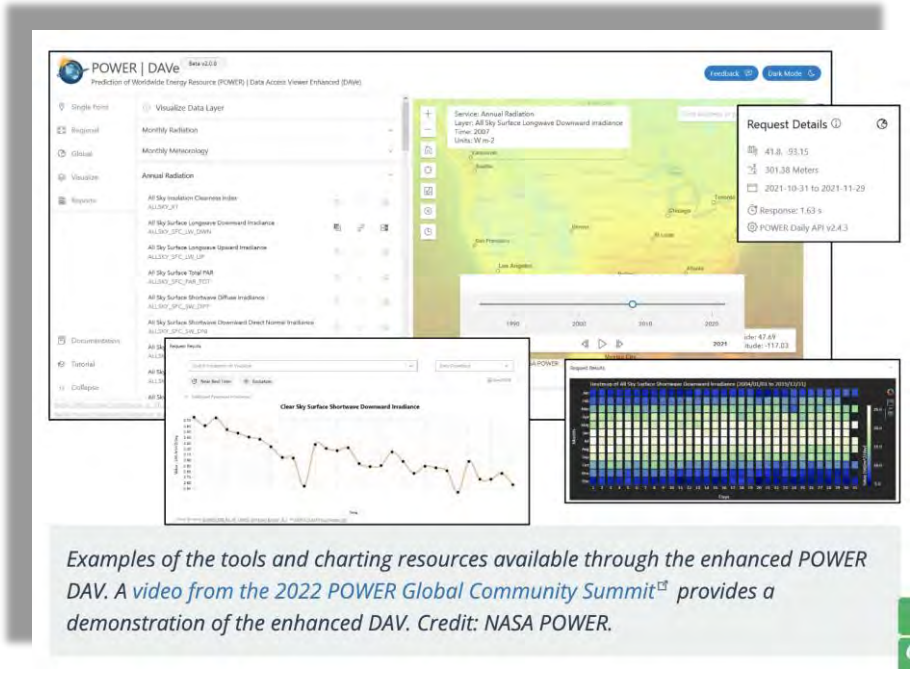
Thank you!

Email: larc-power-project@mail.nasa.gov
Website: https://power.larc.nasa.gov

Principal Investigators: Dr. Paul W. Stackhouse, Jr. & Dr. Falguni Patadia – National Aeronautics and Space Administration (NASA)
Co-Investigators:

- Bradley Macpherson, Madison Broddle, Christopher Higham, Claire Baldacci, & A. Jason Barnett – Booz Allen Hamilton (BAH)
- Taiping Zhang, Colleen Mikovitz, Bradley Hegyi, & Neha Khadka – Science Systems and Applications, Inc. (SSAI)

https://www.earthdata.nasa.gov/learn/articles/power-overview



Examples of the tools and charting resources available through the enhanced POWER DAV. A video from the 2022 POWER Global Community Summit provides a demonstration of the enhanced DAV. Credit: NASA POWER.