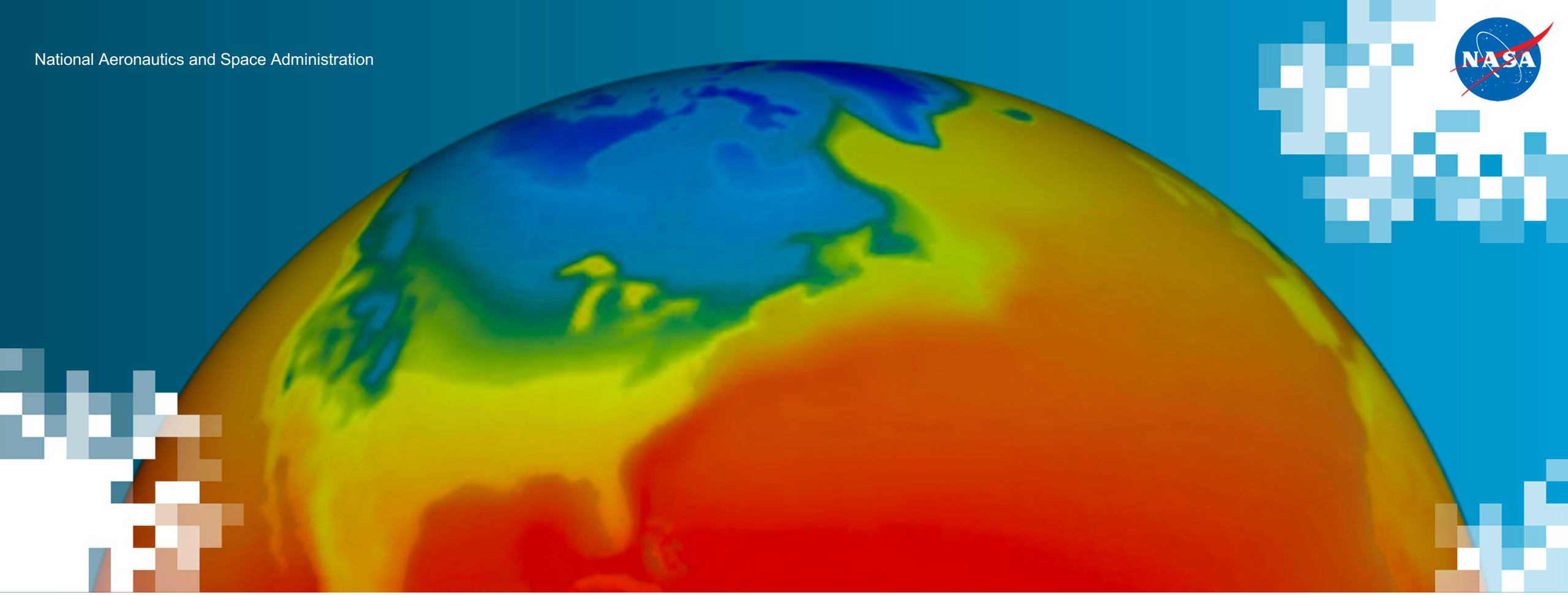
National Aeronautics and Space Administration



# Understanding and Obtaining NASA Data Products Through POWER

Collaboration between NASA POWER and NASA ARSET

June 15, 2021

POWER
Prediction Of Worldwide Energy Resources

# What is POWER?

## What is POWER's Purpose?

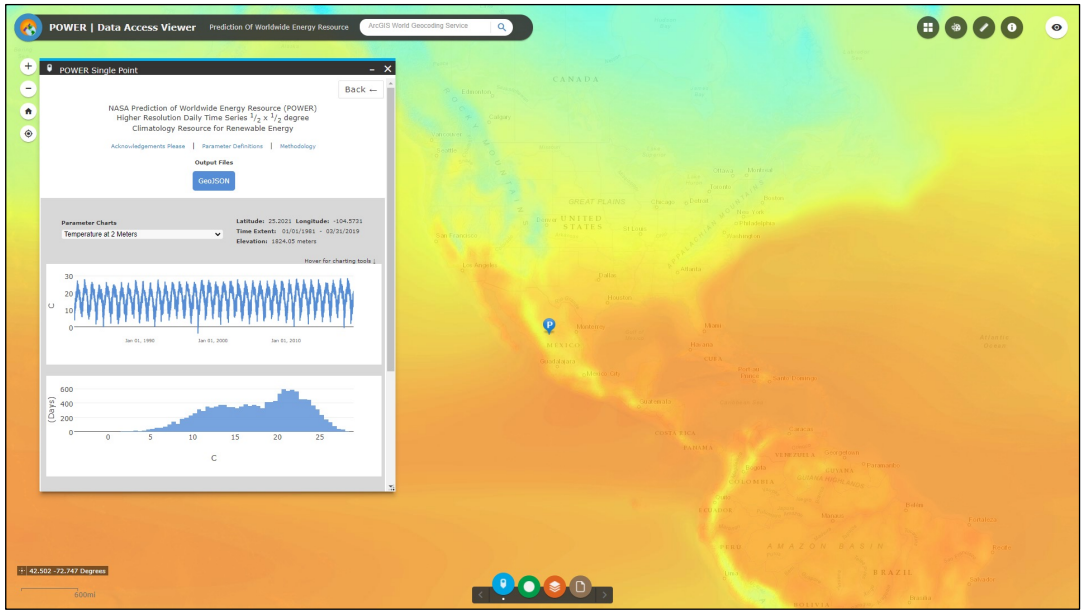
- POWER stands for "Prediction of Worldwide Energy Resources" project funded by NASA to help facilitate the usage of NASA Earth observations, analysis, and modeling to answer key societal questions.
- POWER aims to improve the nation's public/private capability for integrating environmental data from 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*

# What is POWER's role in the community?

## POWER supports the community with:

- Public, open discovery, efficient access, and convenient distribution of NASA Earth Observations data through an integrated services suite.
- Societal benefit area-specific content guided by interaction with and feedback from professional community members and organizations.
- Key partnerships with scientific data providers and user groups providing actionable and community feedback for improved future data products.

# What questions can be answered with Earth Observations made available through POWER Web Services?

- What is typical variability of the sunlight, temperature, and winds over the past 25-30 years in a region?
- What is the anticipated level of production for an installed photovoltaic (PV) field? Is there an optimal tilt angle that considers cloud patterns?
- Is this regional area potentially suitable for wind power generation?
- How can we understand the variability of building environment climate parameters needed to determine current and future building standards?

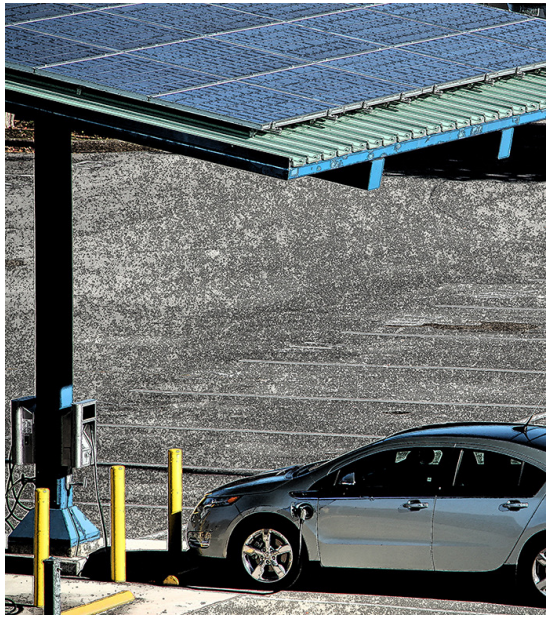


*Photo Credit: NASA Technology Transfer Program*

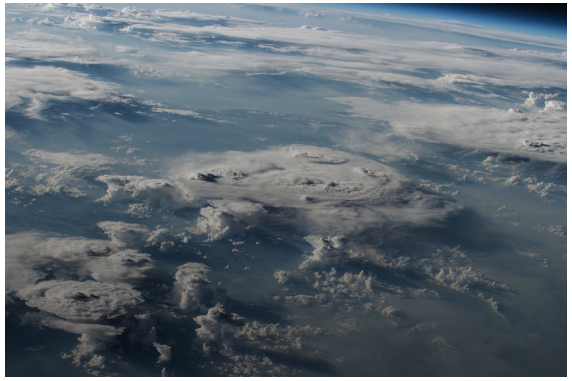


*Photo Credit: NASA CERES*

# What questions can be answered with Earth Observations made available through POWER Web Services?

- How can we determine if incorporating renewable technologies makes sense from an environmental and economic perspective?
- Can I monitor the performance of my building and see if retrofitting renewable technologies is feasible and afterwards effective?
- How can I introduce a class to the principles and effectiveness of implementing solar technologies anywhere in the world?

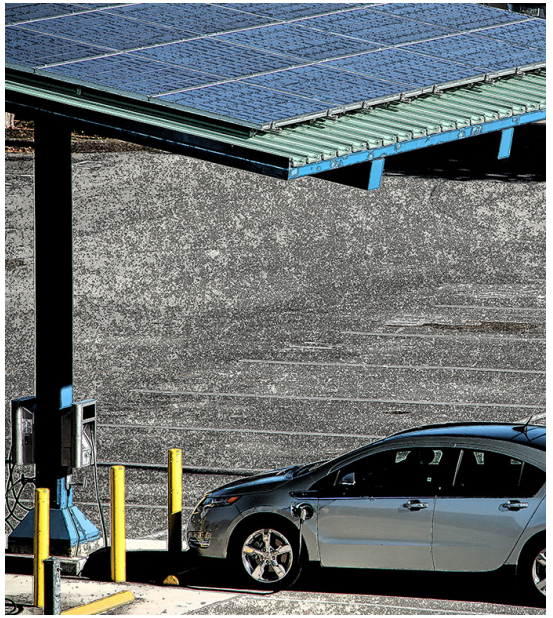


*Photo Credit: NASA Technology Transfer Program*

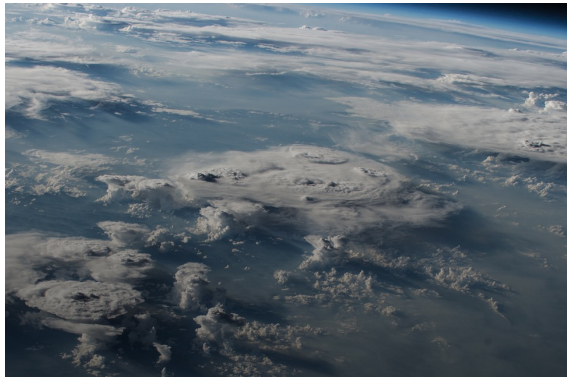


*Photo Credit: NASA CERES*

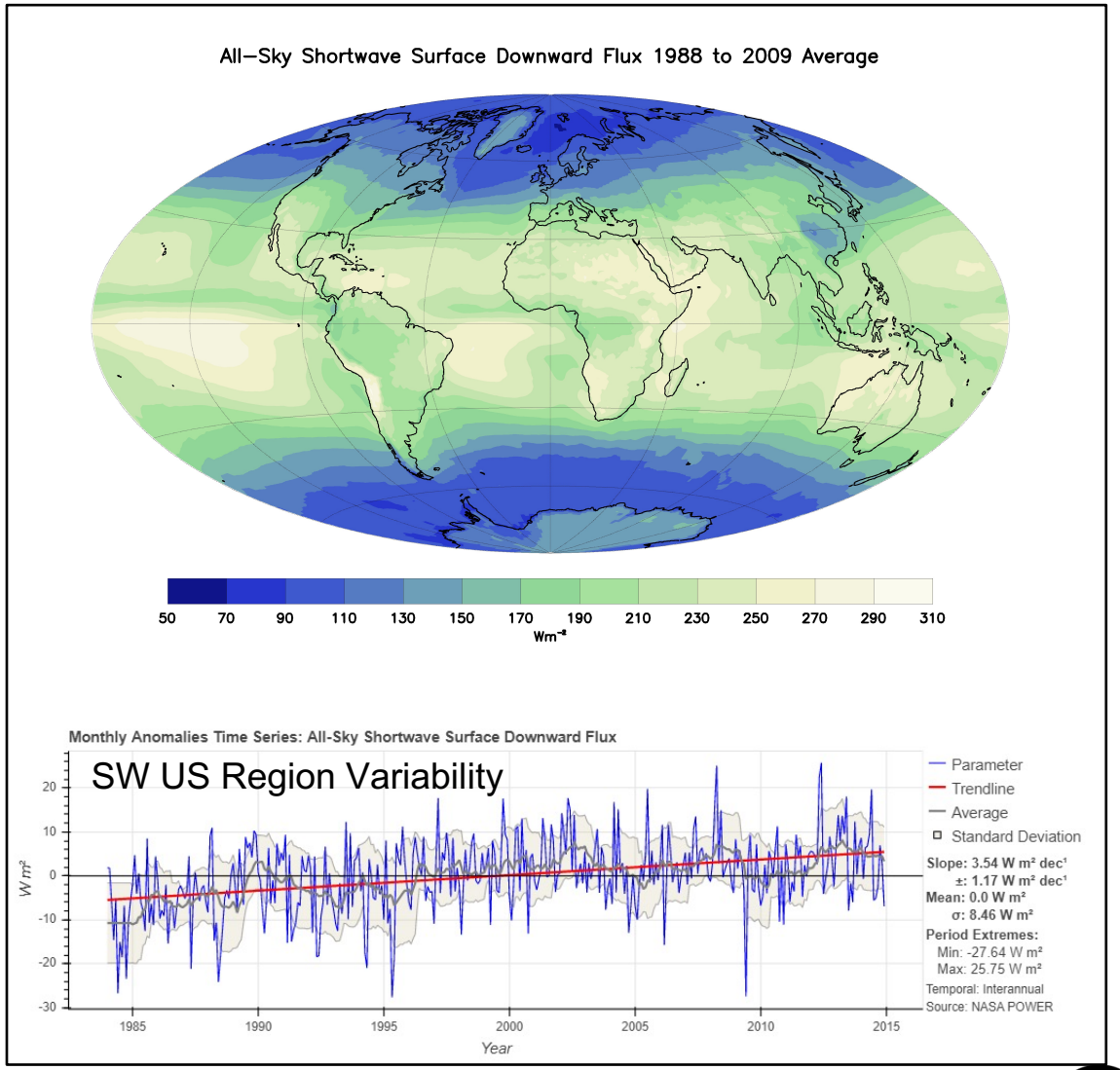
# What information does the community need to answer those and other questions?

Among the most widely needed data are long records to near real-time of:

- Sunlight Information: Solar irradiance and related components (i.e., direct, diffuse, solar angles, surface albedo)
- Surface Temperature and Humidity (max and min T, dewpoint, RH, etc.)
- Wind Speed and Direction
- Cloud Coverage, Thickness, and Type

Time series of parameters are needed including:

- Hourly, Daily, Monthly, Annual
- Long-Term Averages



# What NASA EOs can provide these data parameters?

*The POWER Data Archive uses NASA research and modeling data products plus value added data processing and services to customize parameters for community use.*

Current POWER version at: ***https://power.larc.nasa.gov***

| Source | Temporal Span | | Temporal Average | | Description |
|---|---|---|---|---|---|
| | Start | End | Input | Output | |
| GEWEX SRB 3.0 | July 1, 1983 | Dec. 31, 2007 | Daily | Daily, Monthly, Annual, Multi-Year | Satellite analysis from global cloud imagers (from geosynchronous and polar orbiting satellites) using radiative transfer lookup tables |
| | | | | | |
| CERES FLASHFlux | End of SRB Rel 3 | 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) |
| MERRA-2 | Jan. 1, 1981 | End of MERRA-2 (current) | 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 | Daily, Monthly, Annual, Multi-Year | Atmospheric reanalysis with less assimilated observations, available within 2 days of real-time |

# What NASA EOs can provide these data parameters?

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***Red indicates changes for POWER Beta web site: https://power.larc.nasa.gov/beta***

| Source | Temporal Span | | Temporal Average | | Description |
|---|---|---|---|---|---|
| | Start | End | Input | Output | |
| GEWEX SRB 4.0 | July 1, 1983 | Dec. 31, 2000 | Daily | Daily, Monthly, Annual, Multi-Year | Satellite analysis from global cloud imagers (from geosynchronous and polar orbiting 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) |
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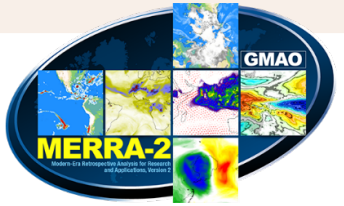
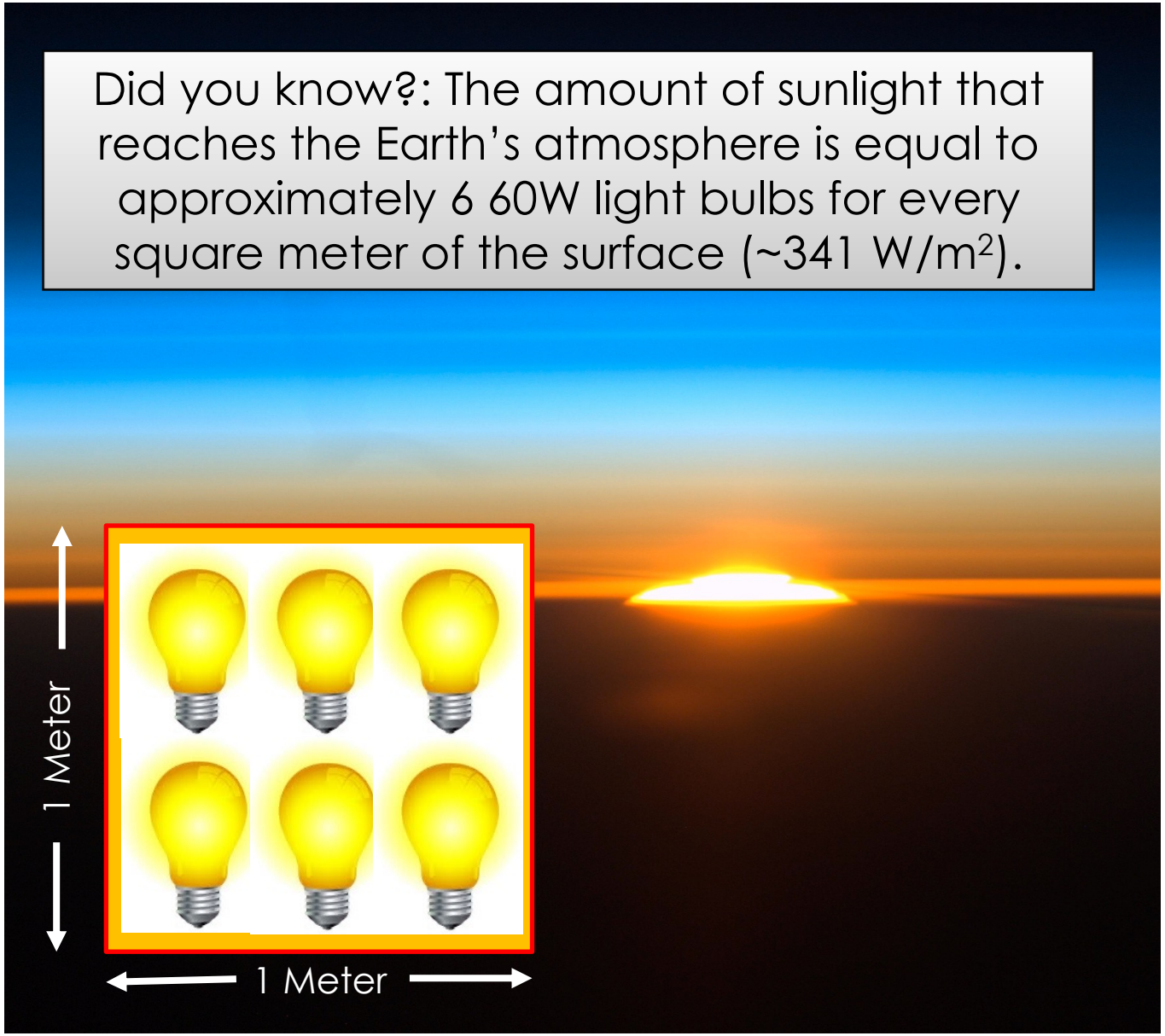


# What is solar irradiance?

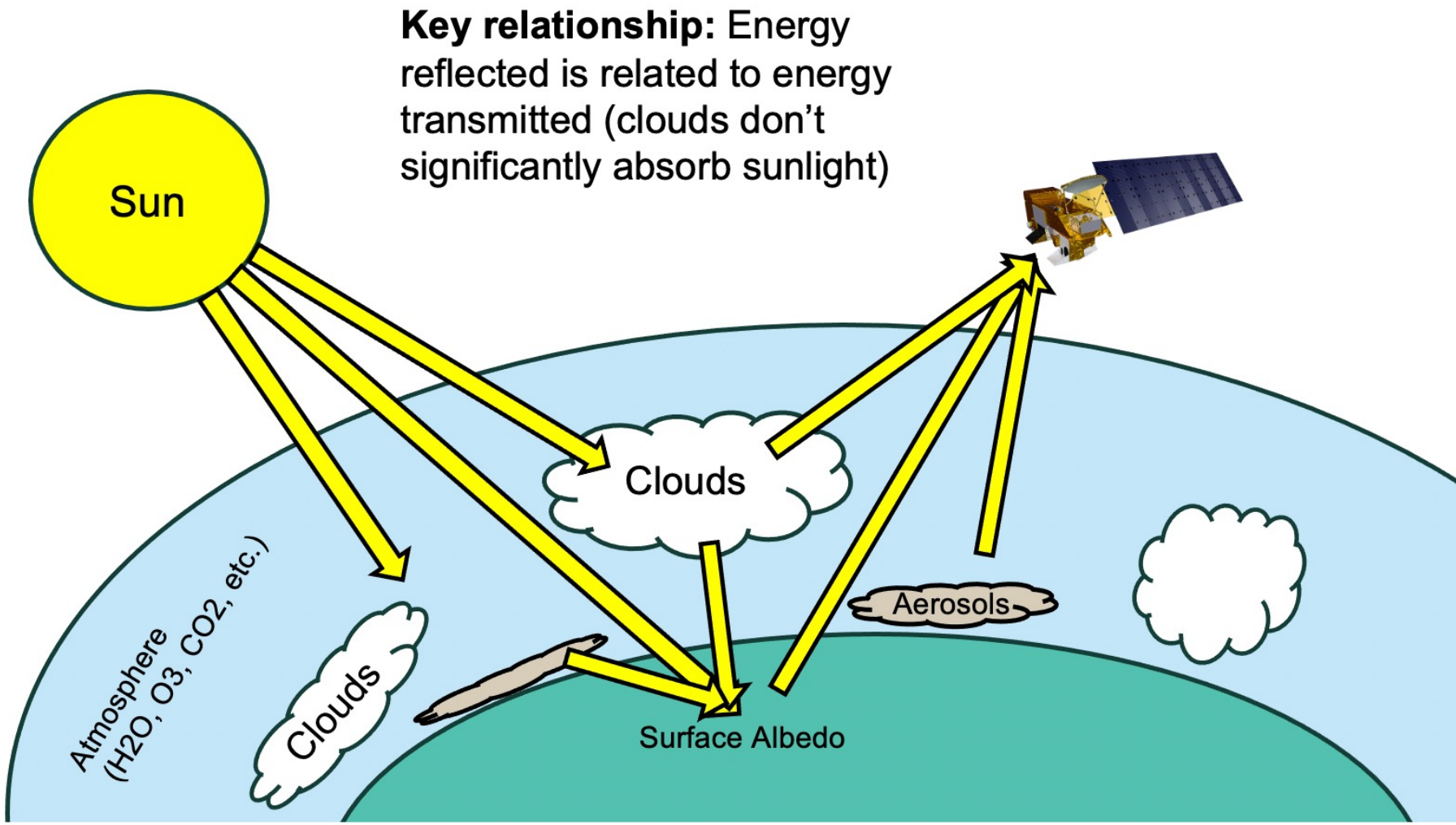
- Solar irradiance is the rate at which solar energy falls onto a surface, per unit area. The units are power per area: Watts per square meter, abbreviated as $W/m^2$.
- Solar irradiance is transmitted through the atmosphere and is vital for understanding climate variability and surface heating.
- Surface solar irradiance is an important factor in the sizing of both solar panels and battery backup systems, solar cooking applications, and building design.



# How is surface solar irradiance calculated from Earth observations?

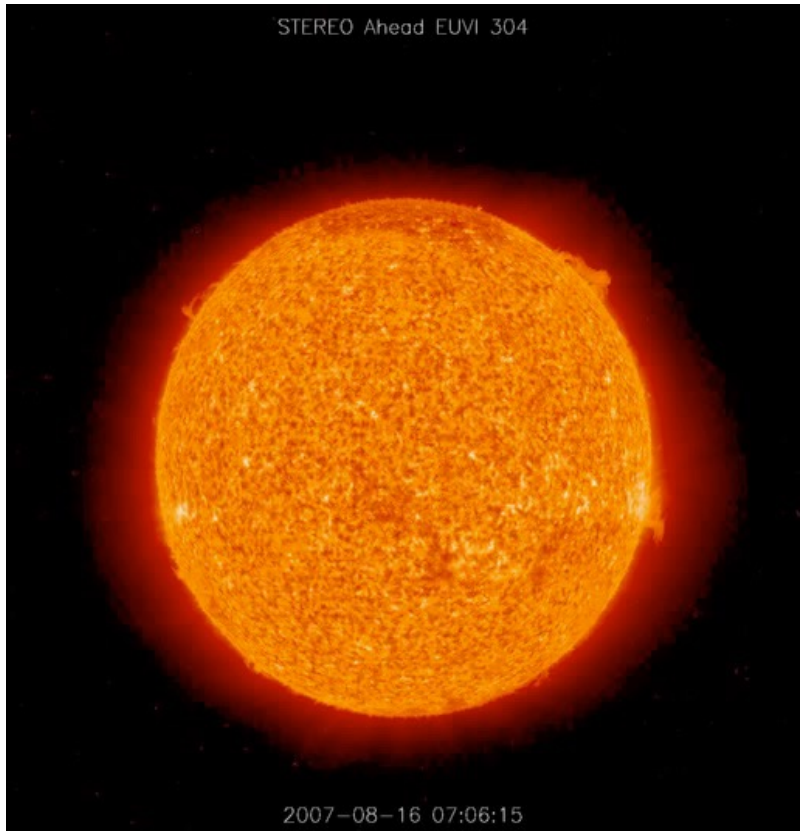
**Need to know the:**

- Amount energy that comes from the sun
- Total received energy for various satellite sensors
- Concentration of atmospheric gases that absorb and scatter light (H2O, O3, CO2, etc.)
- Amount, thickness, and type of clouds and aerosols that reflect, absorb and scatter light
- Reflective nature of the surface (i.e., albedo)

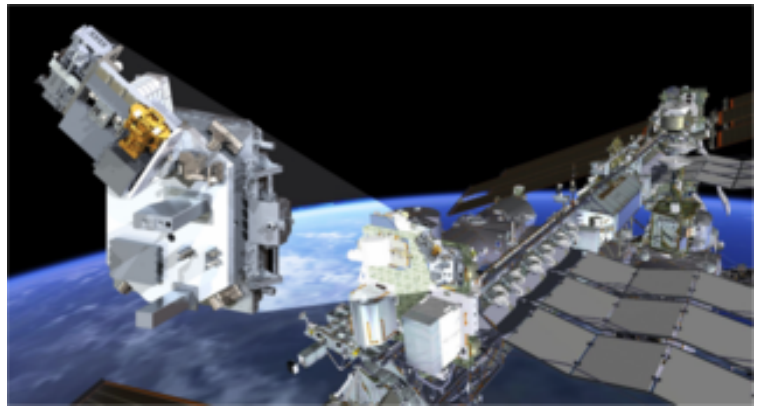


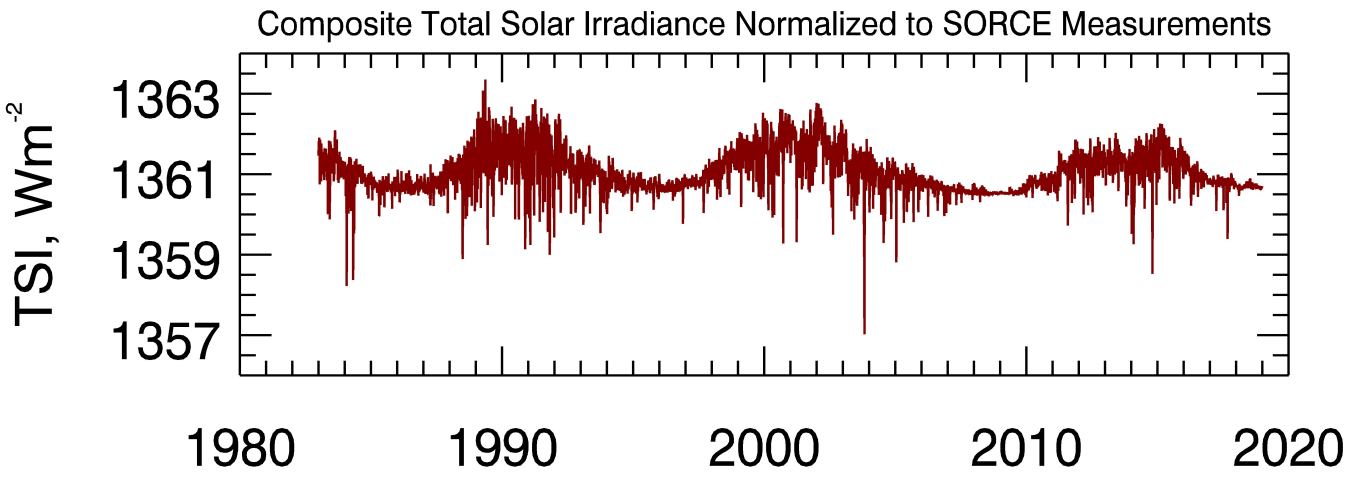
# Estimating solar irradiance at the surface starts at the top!

First, measure the energy from the Sun received at the Top Of Atmosphere (TOA) Total Solar Irradiance (TSI).




NASA's SORCE Mission is now replaced by TSIS-1 on board the ISS.



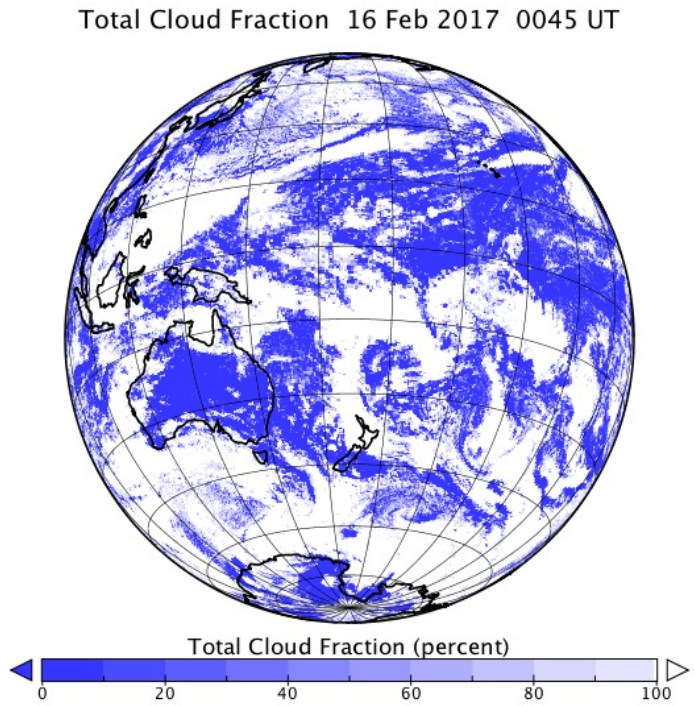



SORCE = SOlar Radiation Climate and Experiment; TSIS = Total and Spectral Solar Irradiance Sensor; ISS = International Space Station

# GEWEX Surface Radiation Budget Project (SRB): Start with Clouds

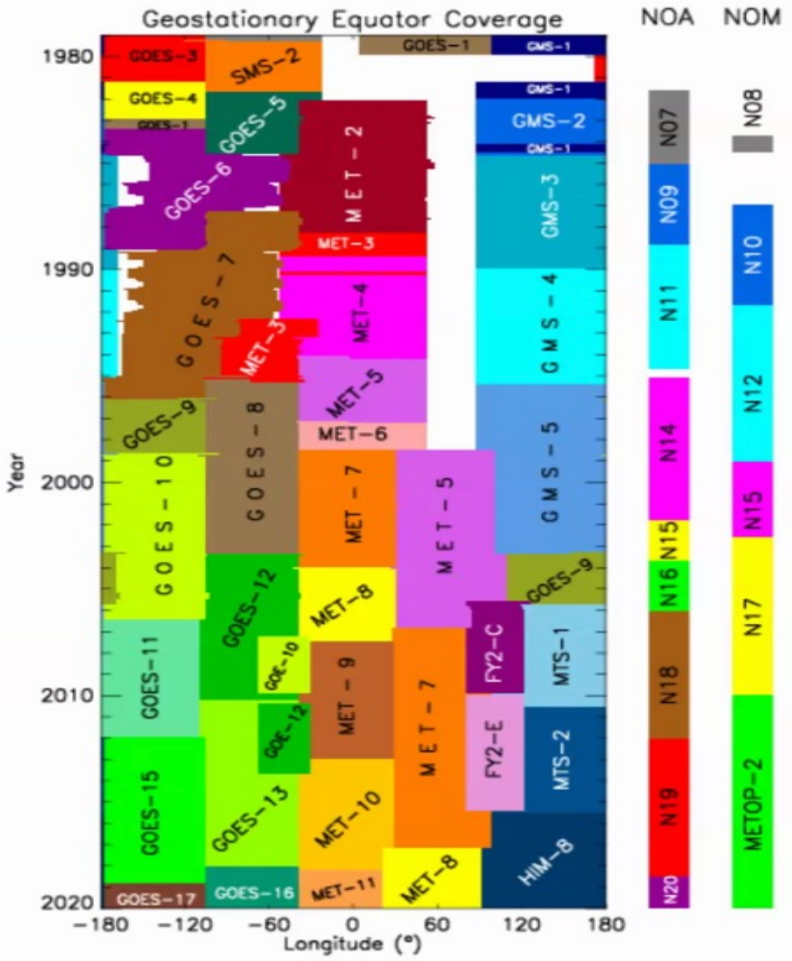
## Obtain 3-hourly Global Cloud Properties from World's GEO and LEO Imagers

- International Satellite Cloud Climatology Project (ISCCP)




*(A global cloud composite example, complements of LaRC SatCORPS for DSCOVR Satellite Mission)*

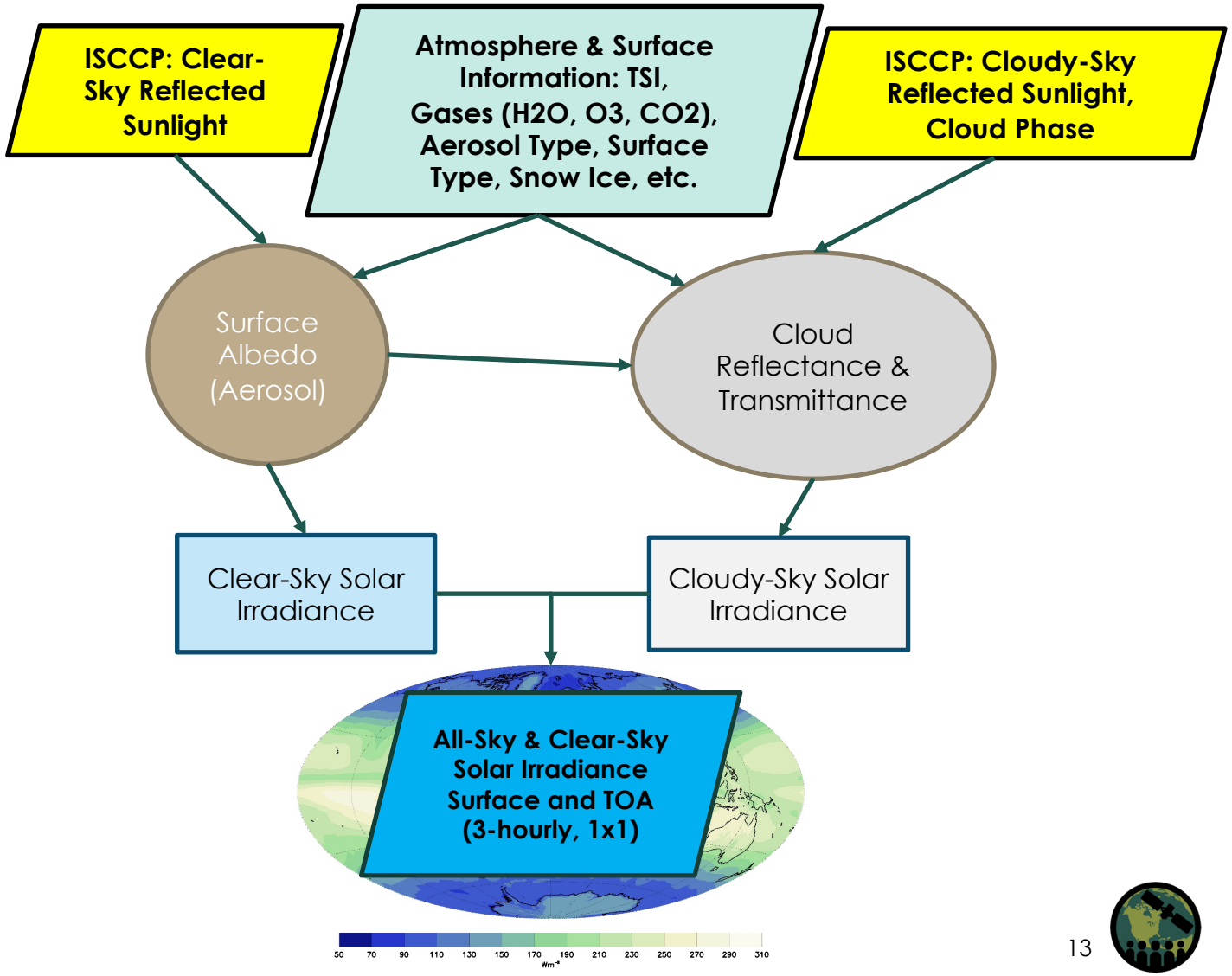
- Multi-satellite imager data cross-calibrated together from both geosynchronous (GEO) and low earth orbit (LEO)
- Satellite visible reflectance/thermal infrared emission, cloud and surface reflectance information output
- Processed globally every 3 hours from July 1984




*Courtesy NOAA NCEI (K. Knapp)*

# GEWEX SRB: Compute the Surface Solar Irradiance

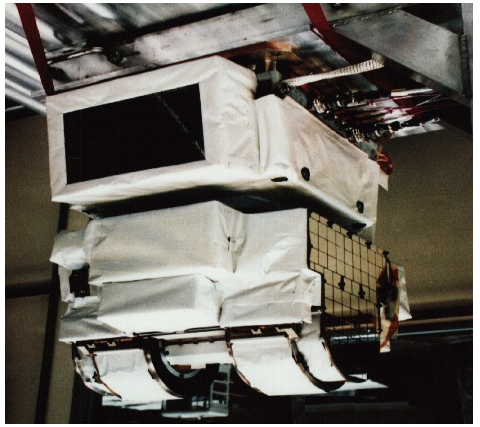
- ISCCP satellite products provide measured reflected sunlight for clear and cloudy skies: cloud detection and phase.
- Other ancillary information including TSI, gases, aerosols, surface types, etc. is input.
- The GEWEX shortwave (SW) model uses an iterative technique to infer the clear and cloudy sky solar irradiance.
  - Estimates albedo from clear-sky using aerosol information
  - Estimates cloud reflectance and transmission of sunlight
  - Computes fluxes given time and location

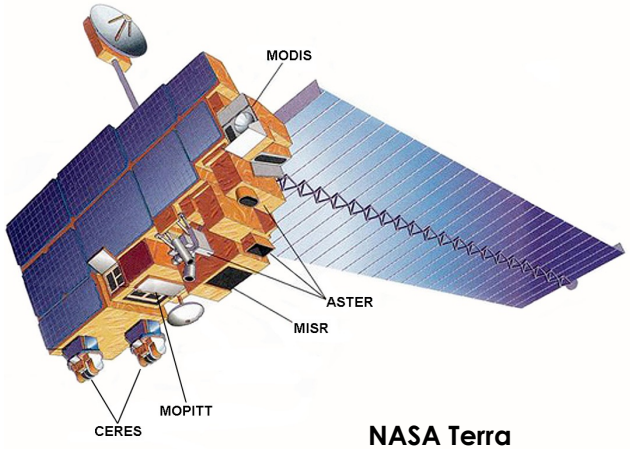


# CERES Top-of-Atmosphere Measurements

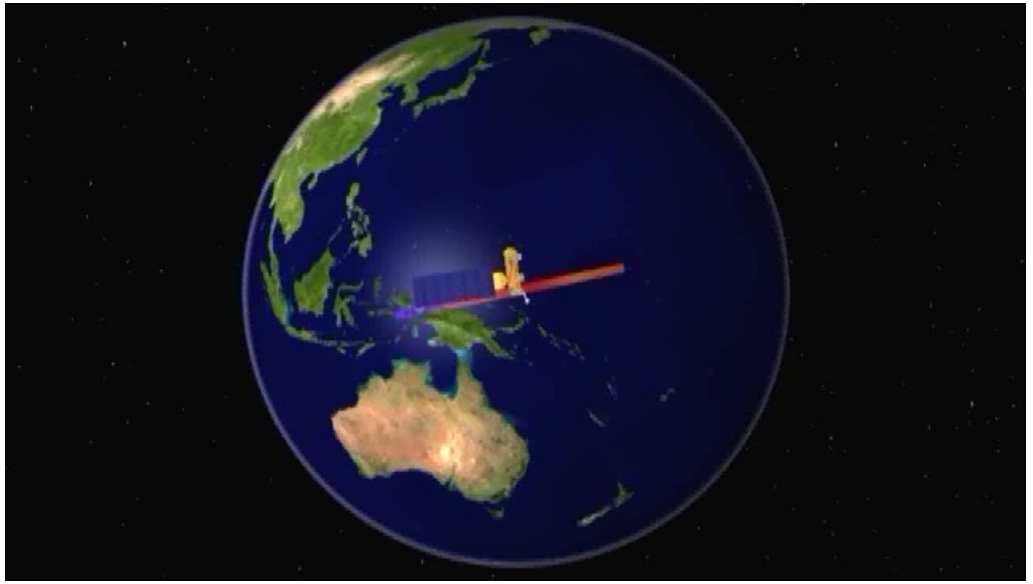
## Clouds and Earth's Radiant Energy System (CERES) Starting in 2000

- CERES measures reflected solar and emitted thermal infrared energy at the top-of-atmosphere to:
  - Monitor balance of energy
  - Determine effects of clouds on climate
  - **Much higher accuracy and stability**
- CERES flies on satellites with imagers used to produce cloud properties (like ISCCP H) but has far better resolution and more spectral channels.
  - Terra (AM overpass): MODIS*
  - Aqua (PM overpass): MODIS
  - NPP (PM overpass): VIIRS**
  - NOAA-20 (PM overpass): VIIRS





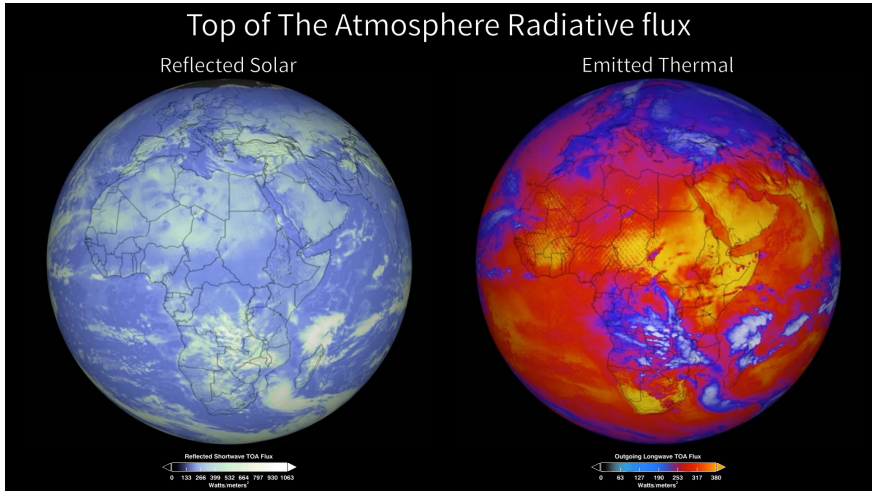
NASA Terra



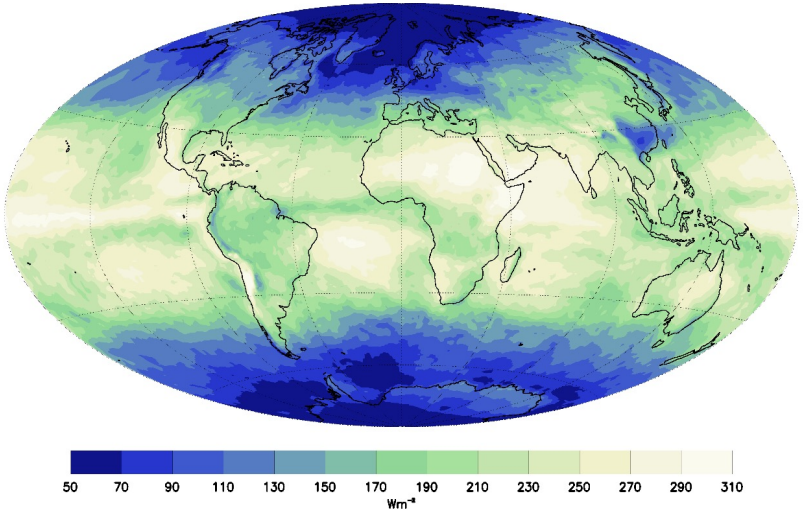
*MODIS = MODerate resolution Imaging Spectrometer
**VIIRS = Visible Infrared Imaging Spectrometer

# CERES Surface Solar Irradiance: SYN1Deg Data Products

- Computed fluxes from CERES SYN1Deg (synoptic 1°x1°) are produced using a radiative transfer model with MODIS and geosynchronous satellite-derived cloud properties.
- SYN1Deg provides hourly surface solar irradiance from March 2000 to within a few months of present.
- SYN1Deg products incorporate:
  - Terra/Aqua using CERES instruments with fused MODIS
  - GEO properties cross-calibrated to MODIS supplement
- Other key inputs include TSI, NSIDC Ice/Snow, surface types, NASA atmospheric reanalysis properties (3D temperature, humidity, ozone), aerosol optical properties, and surface albedo

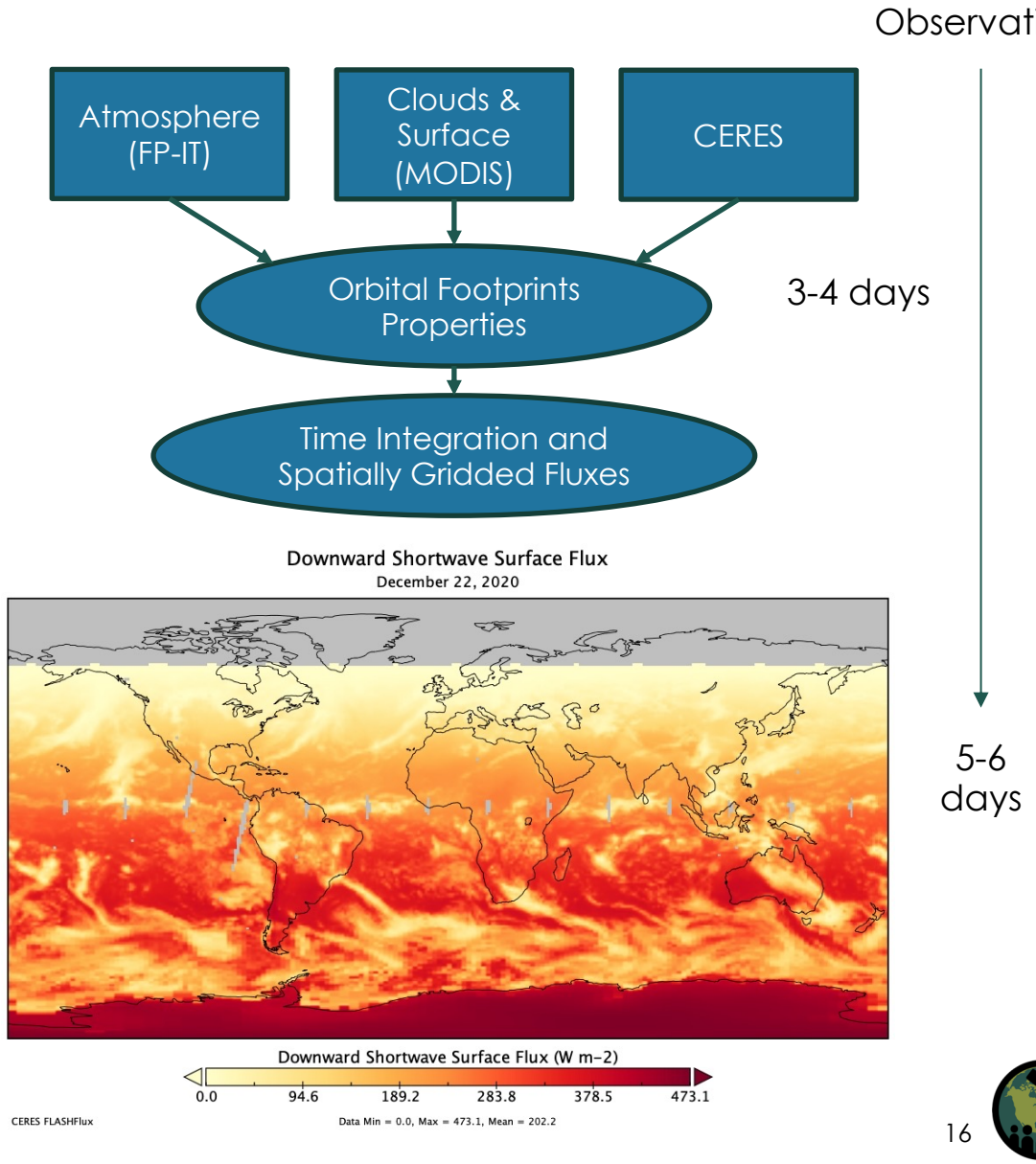



CERES SYN1Deg Surface Solar Irradiance Average



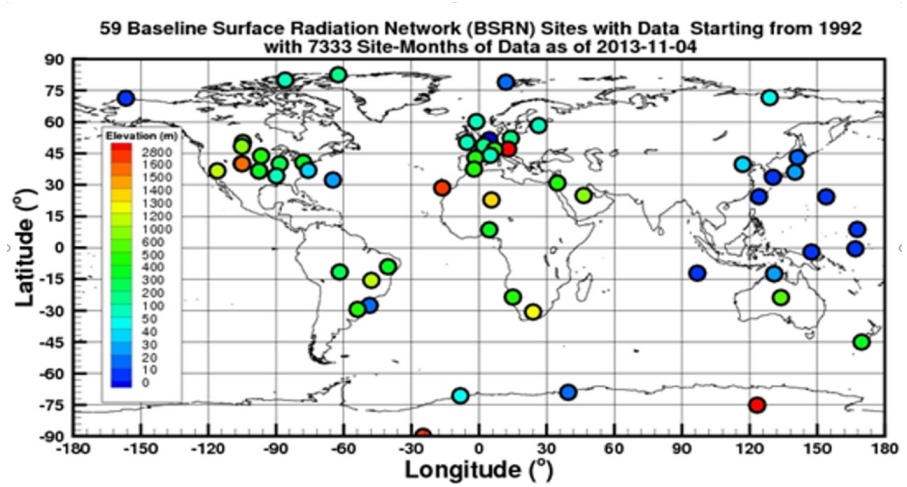
# CERES Near-Real Time: FLASHFlux Data Products

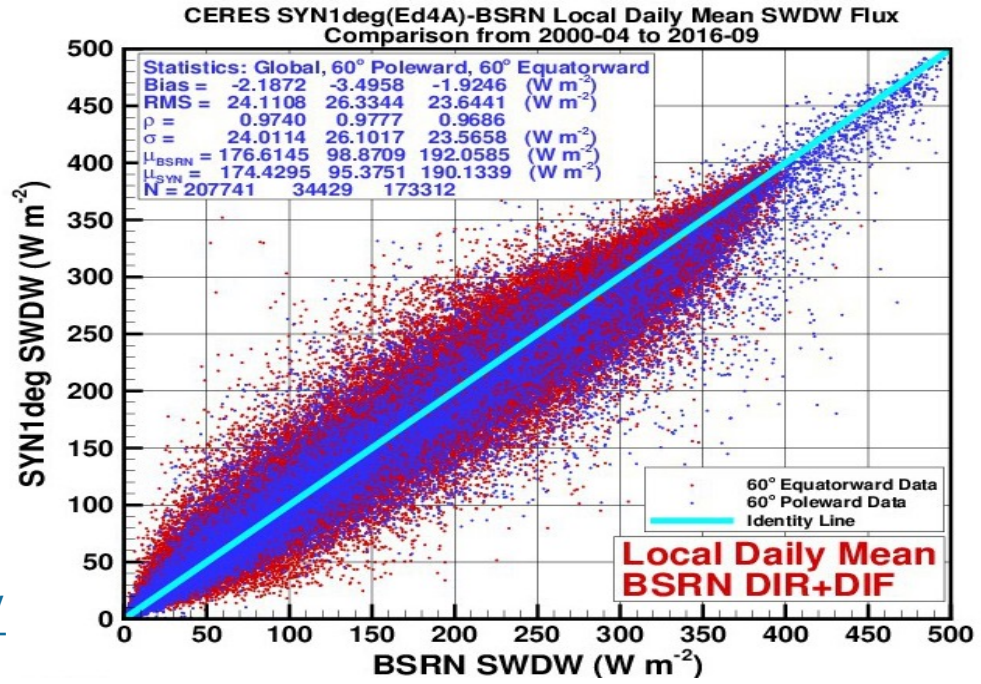
- Due to the needs of POWER data users for the most up-to-date solar irradiance data available, a second CERES Product, FLASHFlux, is utilized.
  - FLASHFlux uses the same inputs as SYN1deg but faster with a **target latency of 7 days.**
  - Data product quality is assessed independently for each source.
  - Day-to-day variability is sufficiently consistent for applications.
  - For the Beta, FLASHFlux data are overwritten with climate quality SYN1deg as soon as the data are available.



# How do we determine solar irradiance data quality?

- Solar irradiance data quality can be evaluated through:
  - Validation by comparison to surface measurements from networks like BSRN, ARM, and GEBA.
  - Ensemble and time averaged statistics are calculated.
  - Comparisons to other datasets such as CERES compared to SRB and/or to other independent data sets.
- See "Methodology Documentation" pages for more information and statistics

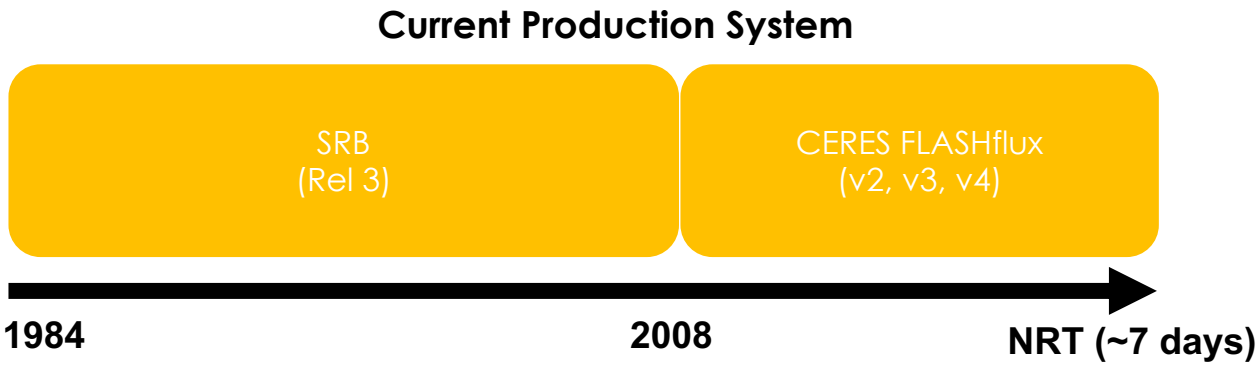


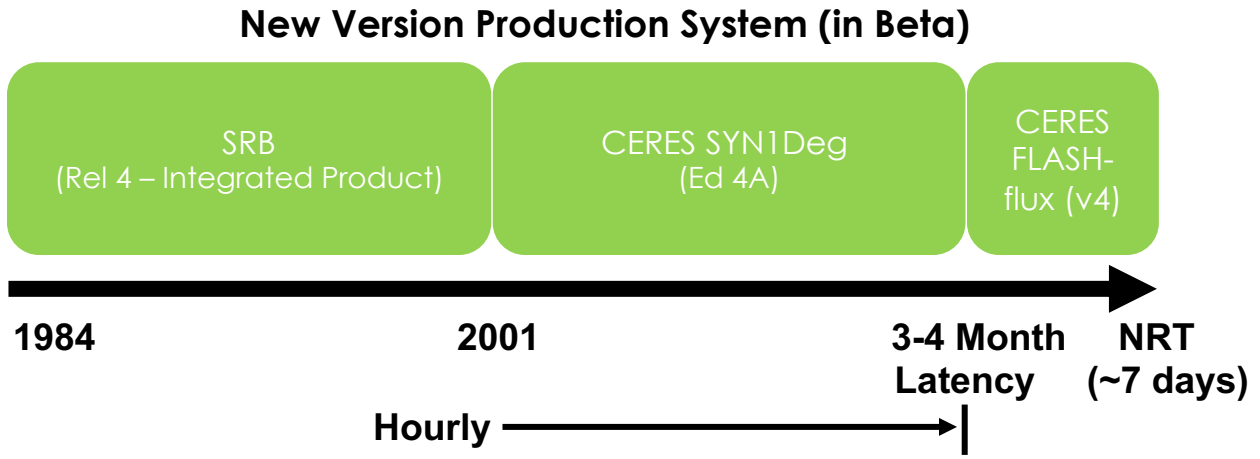

https://power.larc.nasa.gov/docs/methodology/solar/

# Time Span of POWER Solar Data Products

- **Current Version:**
  - Daily solar data products from 1984 provided through 7 days of real-time
  - SRB Rel 3 to CERES FLASHFlux (v4A)
  - MERRA-2 to FP-IT

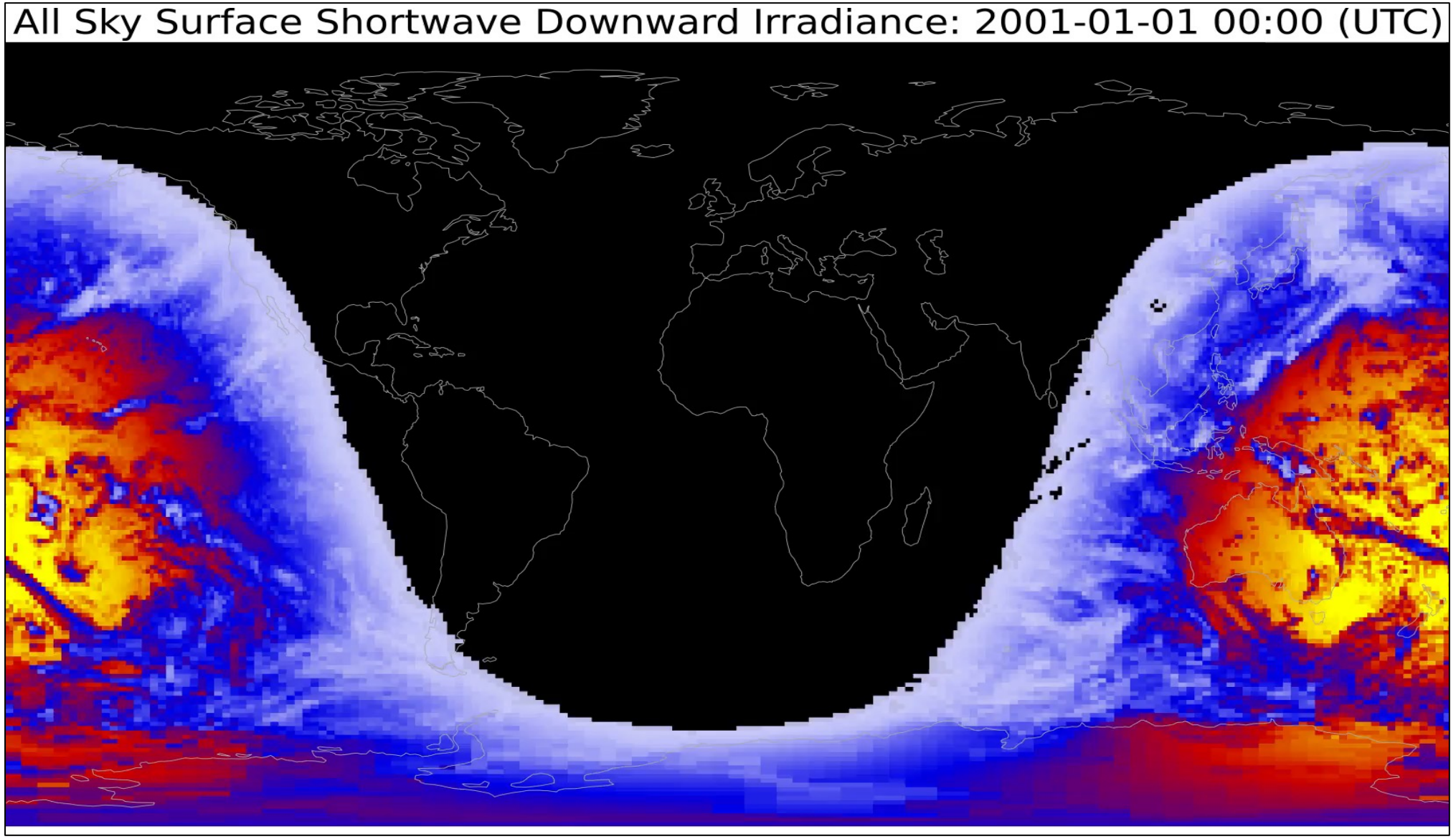



- **New Version Production System:**
  - Daily solar data products from 1984 provided through 7 days of real-time
  - SRB to CERES SYN1Deg, to FLASHFlux
  - Hourly from 2001 through 3-4 months of observation
  - MERRA-2 to FP-IT




*Interpret long time series with caution due to concatenation of data products.*

# Daily Solar Irradiance – Hourly Video

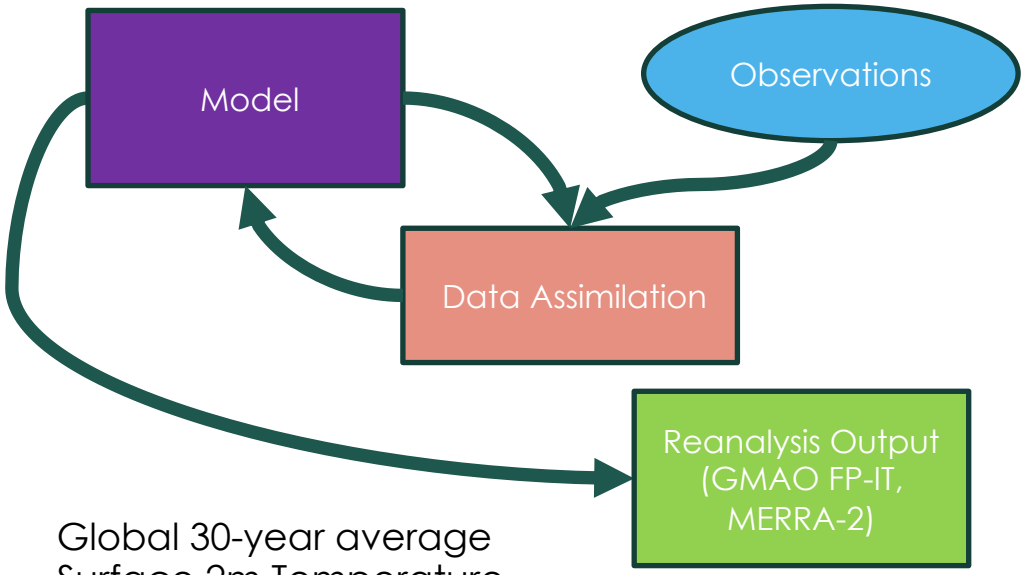


# Where can we obtain surface meteorological parameters?

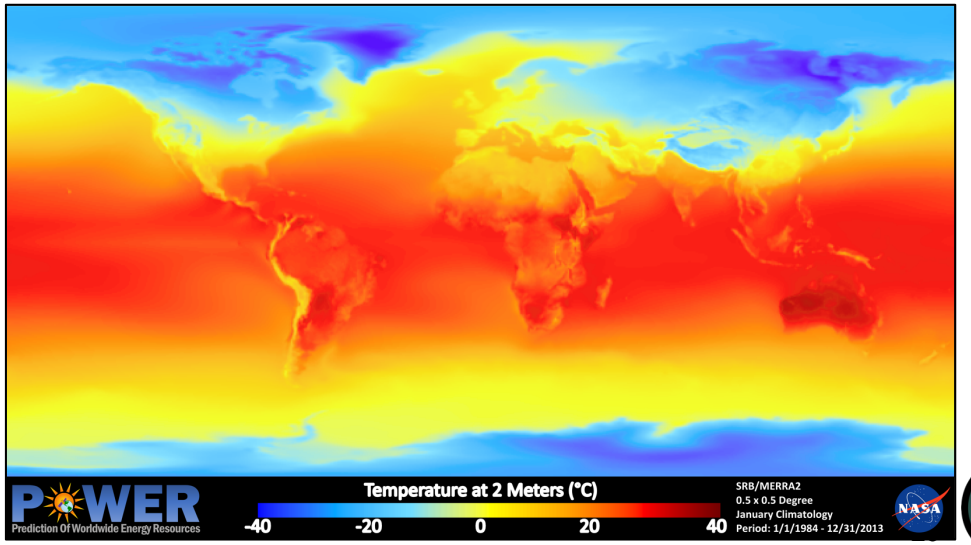
## NASA's Global Modeling and Assimilation Office (GMAO) Data Products

What is an atmospheric data assimilation?

- Global atmospheric models run iteratively.
  - Model 6hr forecasts are adjusted within thresholds to observations
  - Model forecasts rerun to produce products
- GMAO produces:
  - Near real-time (FP-IT; 2 days)
  - Long-term MERRA-2 (Modern Era Retrospective analysis for Research and Applications)
- MERRA-2 has assimilated 50 Billion observations over 40 years.




Global 30-year average Surface 2m Temperature



# What sorts of observations are assimilated?

- Surface measurements including:
  - Weather Stations and Buoys, Ships
- Airborne on radiosondes and commercial aircraft
- Satellites (large variety):
  - Spectral imagers
  - Microwave instruments
  - Atmospheric sounders
  - GPS occultation

*https://svs.gsfc.nasa.gov/search/?search=mccarty*

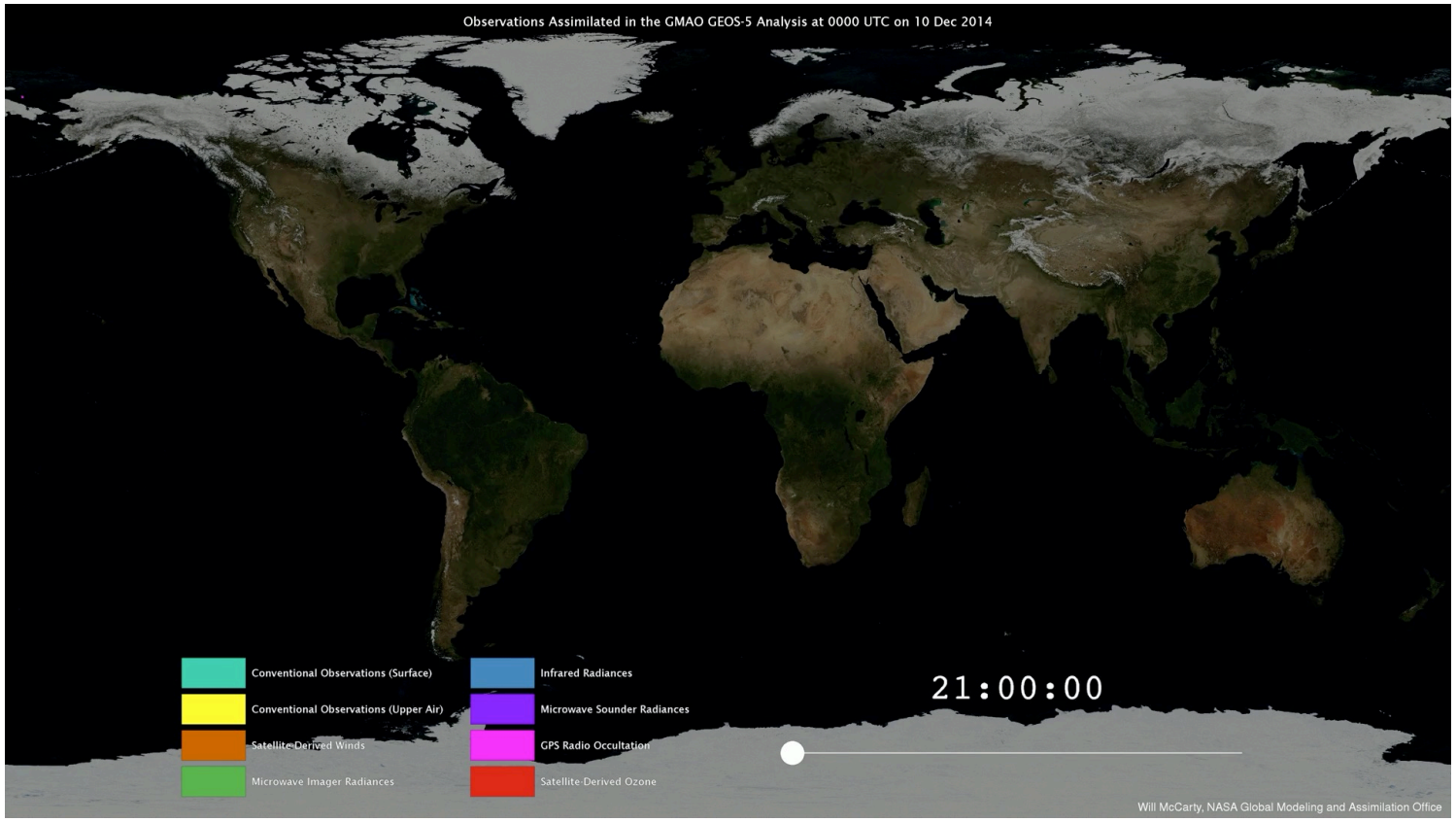



*Photo Credit: NOAA PMEL*

*Photo Credit: wiki commons by Famartin*

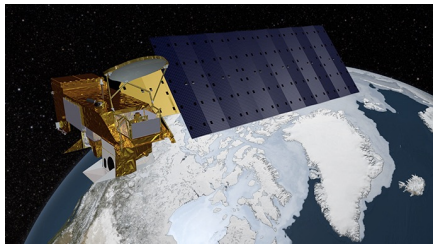
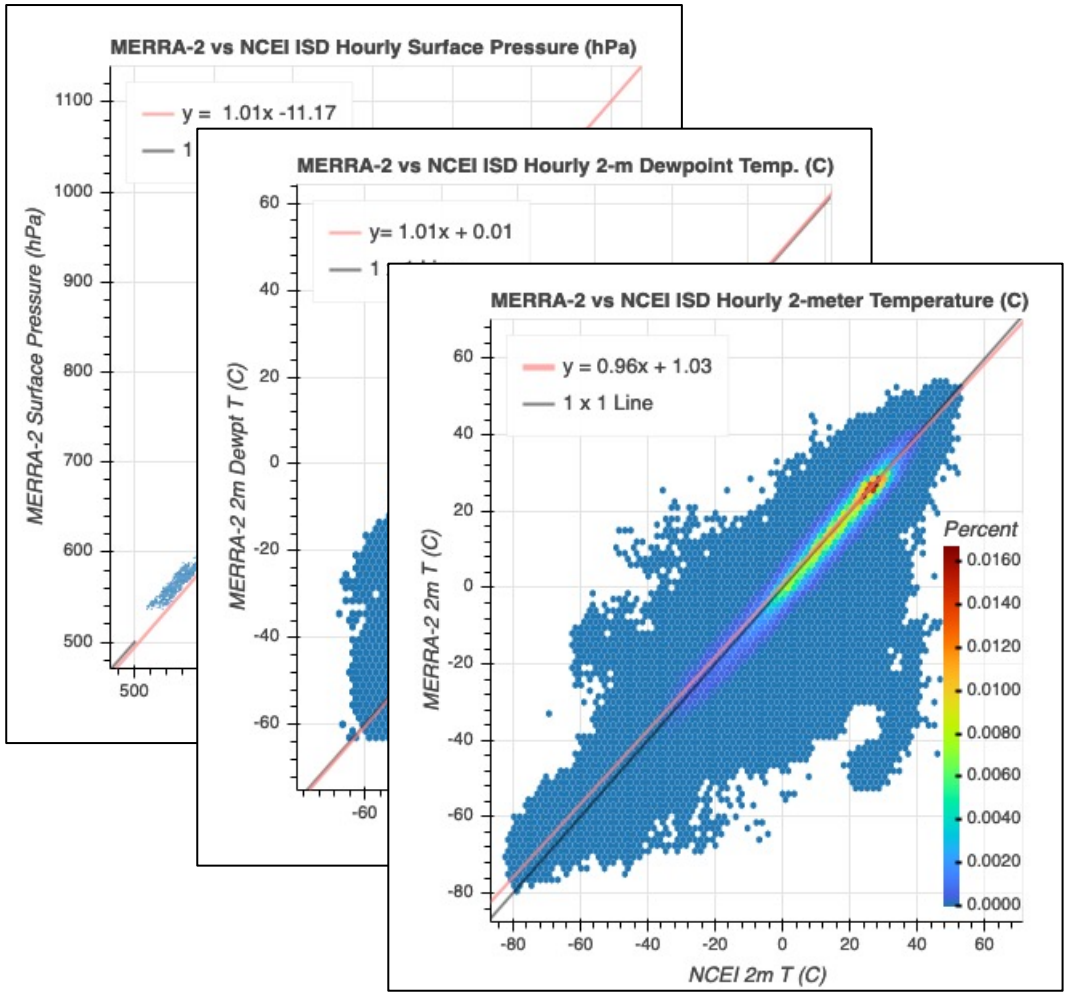


*Photo Credit: NASA Aqua*

# How do we determine MERRA-2 data quality?

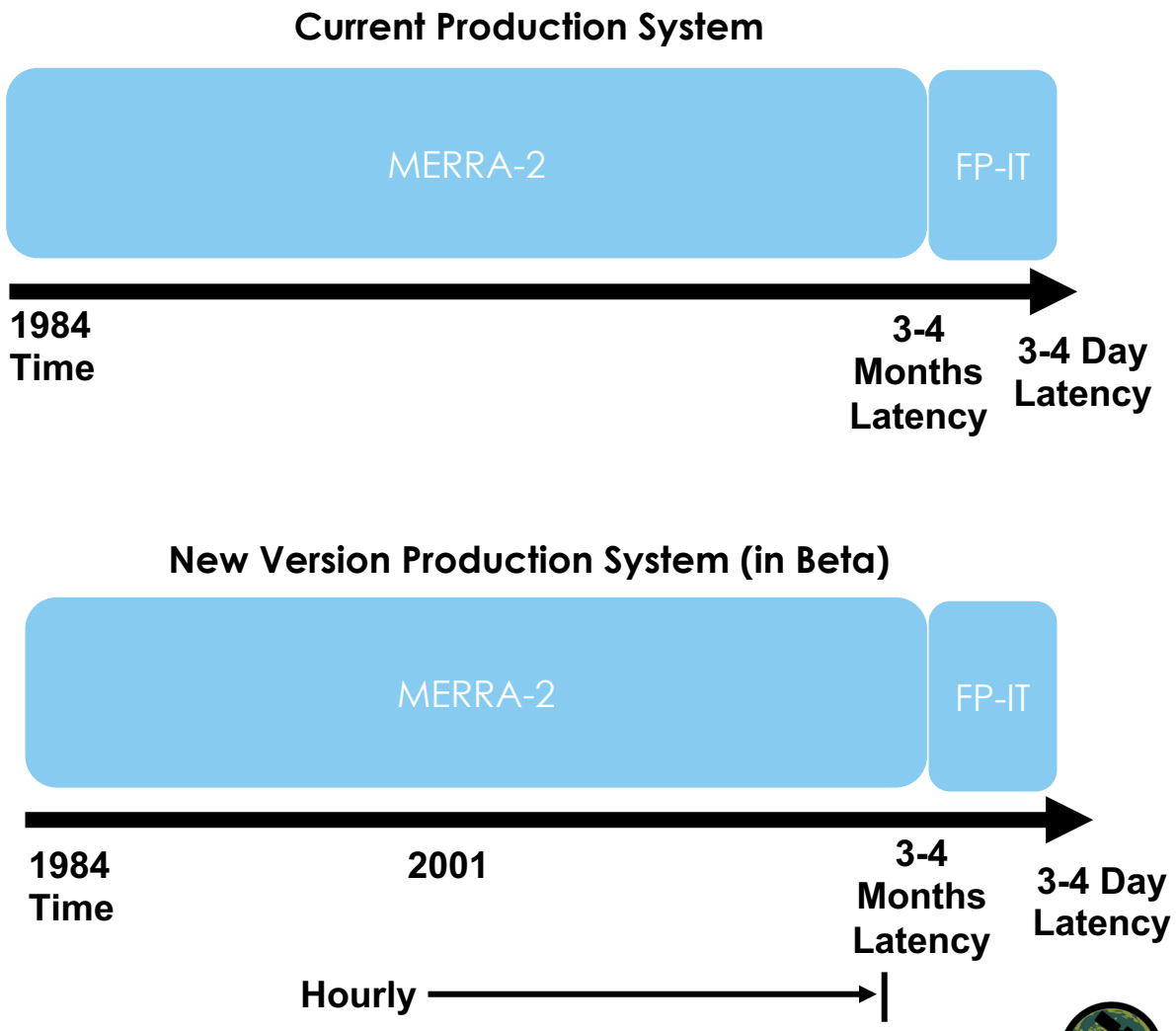
- The POWER Project conducts additional parameter data validation for basic parameters with the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information (NCEI) surface measurements:
  - Global Summary of the Day (GSOD) for daily validation
  - Integrated Surface Database (ISD) for hourly validation
- Producing histograms and scatterplots conducted by month and surface type produced in 4-year blocks and both aggregated and site-specific static reports/histograms




https://power.larc.nasa.gov/docs/methodology/meteorology/

# Time Span of POWER Surface Meteorological Data Products

- **Current Production System:**
  - Meteorological products from MERRA-2 begin Jan 1984 (with solar) to 3-4 months of real-time
  - Near real-time is from a separate assimilation called FP-IT (Forward Processing-Instrument Team)
    - Subset of the parameters for optimization
    - No precipitation adjustments implemented like MERRA-2
    - Available via POWER at 3-4 days latency
- **New Version Production System (Now Beta):**
  - Same as above except:
    - Hourly from Jan 2001 through Long-Term data replaces FP-IT with MERRA-2
    - FP-IT to be replaced by new version within the next year; MERRA-2 within 3-4 years



# Introduction POWER Web Services Portal

NASA Prediction Of Worldwide Energy Resources

DATA ACCESS DOCUMENTATION RESOURCES ABOUT CONTACT

## The POWER Project

Provides solar and meteorological data sets from NASA research for support of renewable energy, building energy efficiency and agricultural needs.

*Supported by NASA Earth Science's Applied Sciences Program*

POWER's Enhanced Features

- Enhanced web-based POWER Docs pages
  - › Data Methodology
  - › Data Services Documentation
  - › Data Access Tutorials

https://power.larc.nasa.gov

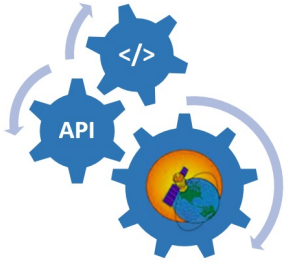
*An interface to obtain and utilize global, long-term solar and surface meteorological resource data.*

*Scalable to any device!*

# POWER Data Access Methods

POWER enhances data discovery, access, and distribution as Analysis Ready Data (ARD) for direct application of inputs to decision to support tools, modeling and forecasting packages, and as inputs to scientific research is provided via three basic services:

**APIs**

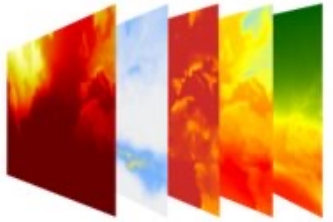



***API:*** *The RESTful Application Programming Interfaces (API) through a single endpoint (i.e., formatted URL string); delivery directly though user browser and/or application.*

**Data Access Viewer**

***Data Access Viewer (DAV):*** *The DAV provides a web map with a simple user interface via widgets that allow users to select community specific parameters, units, time periods, and the output formats (invokes the API).*

**Geospatial Services**

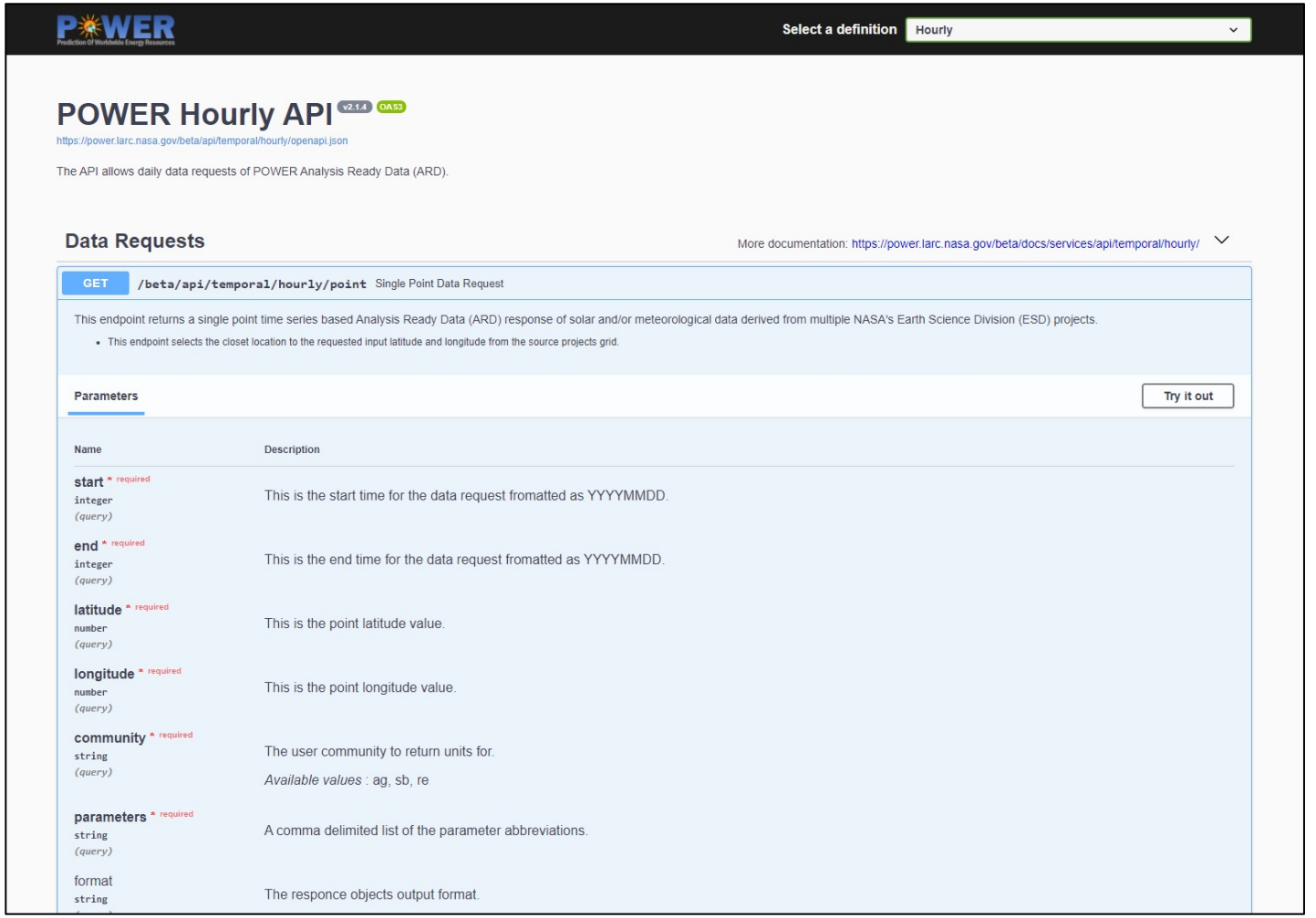


***ArcGIS:*** *The RESTful Esri® ArcGIS® Image and Feature Services that support geospatially-enabled data distribution for direct use in Geographic Information System (GIS) and related tools.*

# What does the POWER Application Programming Interface (API) do?

The POWER API delivers Analysis Ready Data (ARD) for inputs to decision support tools, modeling and forecasting packages, and as inputs to scientific research by providing:

- Complete access to the entire database without any other services.
- Direct integration into external applications; users can submit a request and a response will be returned without leaving their application!
- User specified subsets converted into user community specific units and provides formats like ASCII, ICASA, CSV, GeoJSON, NetCDF, and more!



# What is the POWER Application Programming Interface (API)?

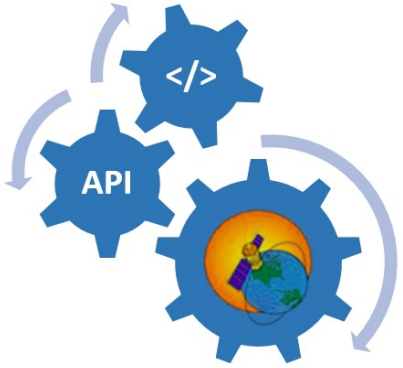
## Example Temporal API Requests

Hourly Point API Request URL

Daily Point API Request URL

Monthly Point API Request URL

Climatology Point API Request URL




## Example for Daily API

**Uniform Resource Locator (URL):**
https://power.larc.nasa.gov/beta/api/temporal/daily/point

**Uniform Resource Identifier (URI):**
?start=20010101&end=20011231&latitude=50&longitude=50&community=sb&parameters= T2M,ALLSKY_SFC_SW_DWN

https://power.larc.nasa.gov/beta/api/temporal/daily/point?start=20010101&end=20011231&latitude=50&longitude=50&community=sb&parameters=T2M,ALLSKY_SFC_SW_DWN


```
{
  "type": "FeatureCollection",
  "geometry": {
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    ]
  },
  "properties": {
    "parameter": {
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        "2001010210": -27.23,
        "2001010211": -23.39,
        "2001010212": -20.3,
        "2001010213": -18.56,
        "2001010214": -17.62,
        "2001010215": -17.86,
        "2001010216": -18.72,
```
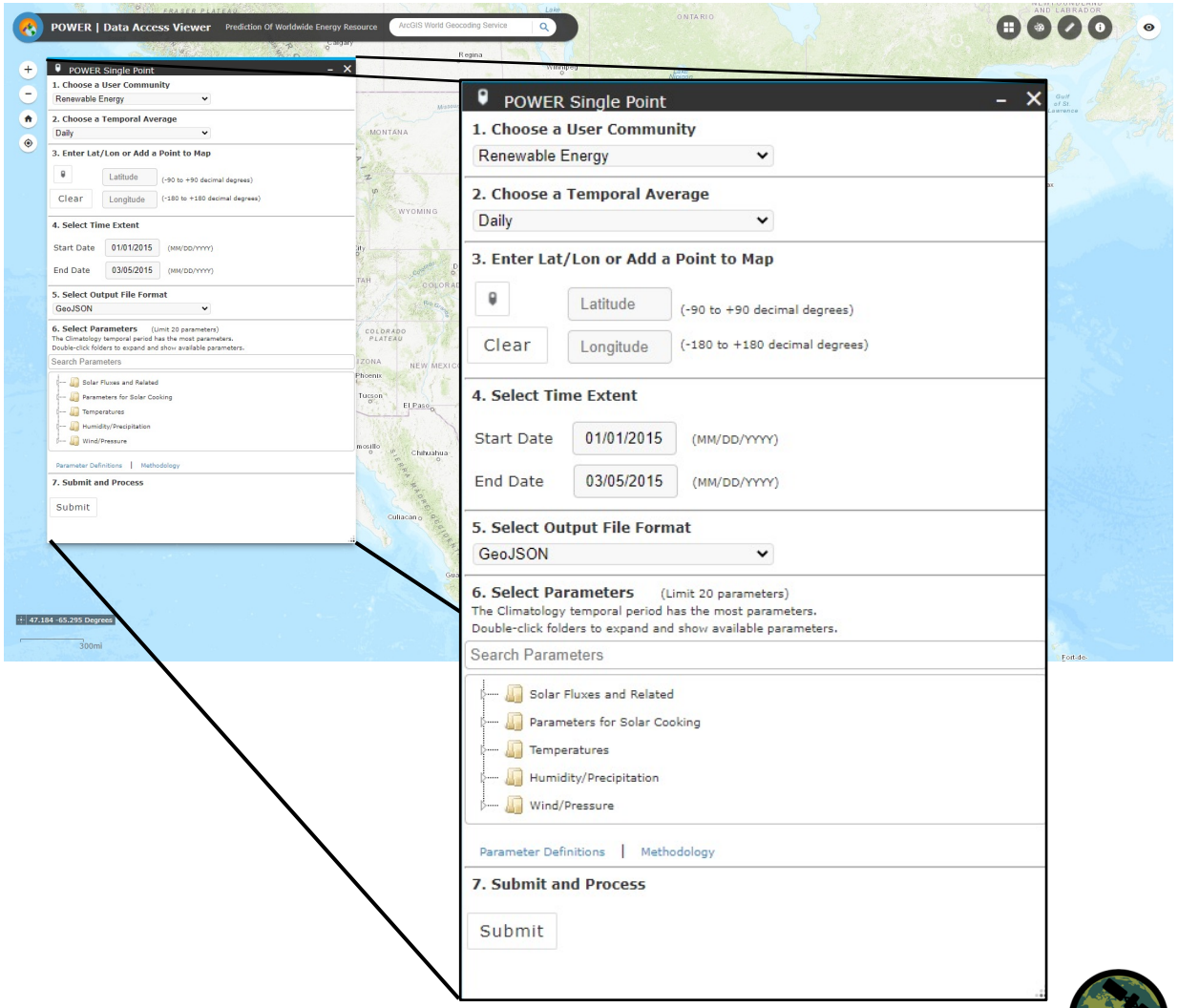
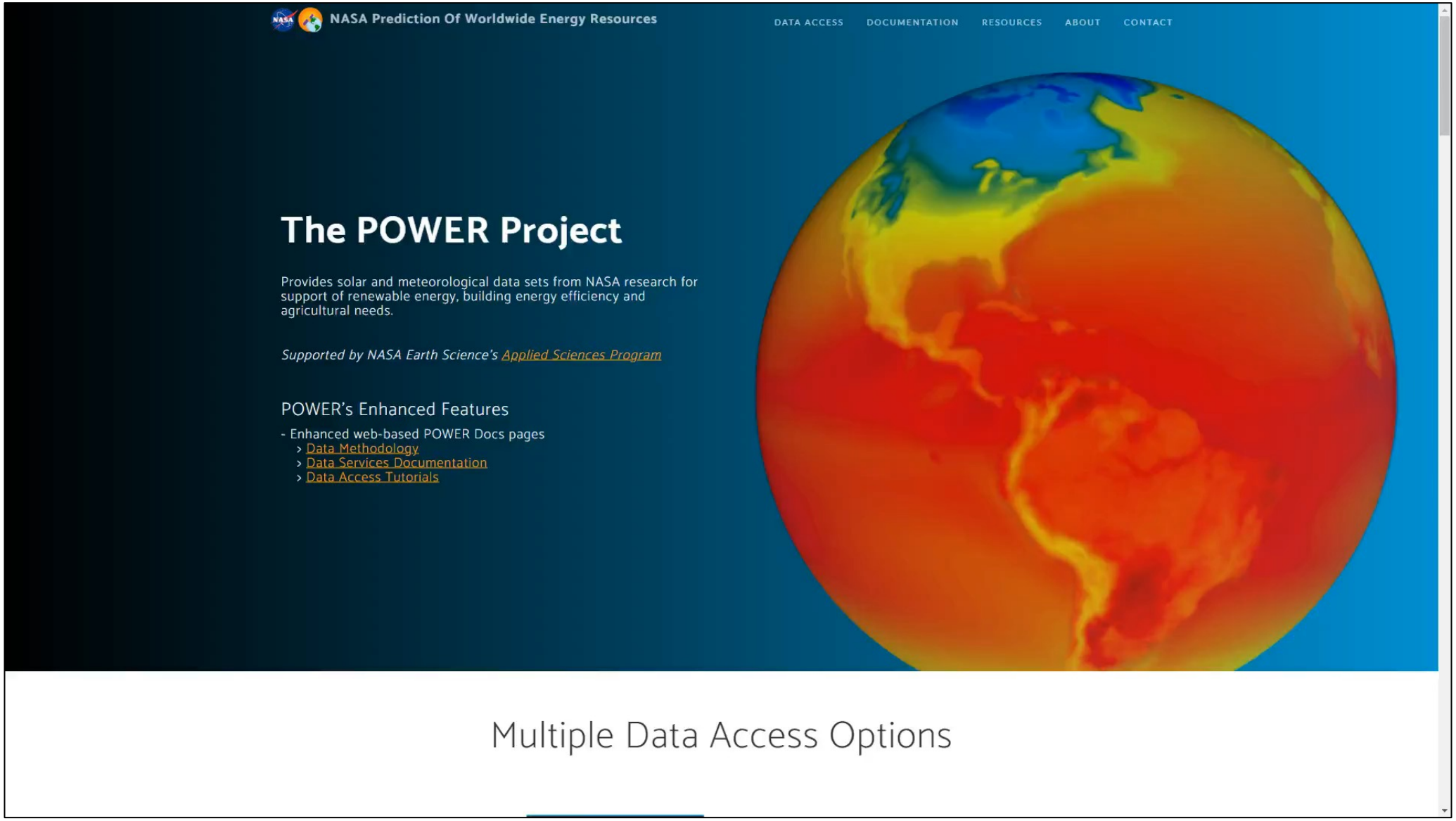

# What is the POWER Data Access Viewer (DAV)?

- Provides a front-end web map with a simple user interface via integrated widgets that is responsive and built for mobile and desktop use
- Allows users to select community specific parameters, units, time periods, and the output formats to efficiently retrieve data from the Application Programing Interface (API)
- Enables users to follow a set of questions (without programming knowledge), to create the API request URL and download the requested data
- Displays global ArcGIS Image and Feature Services of data parameters and provides simple graphing capabilities



# How do you use the POWER Data Access Viewer (DAV)?

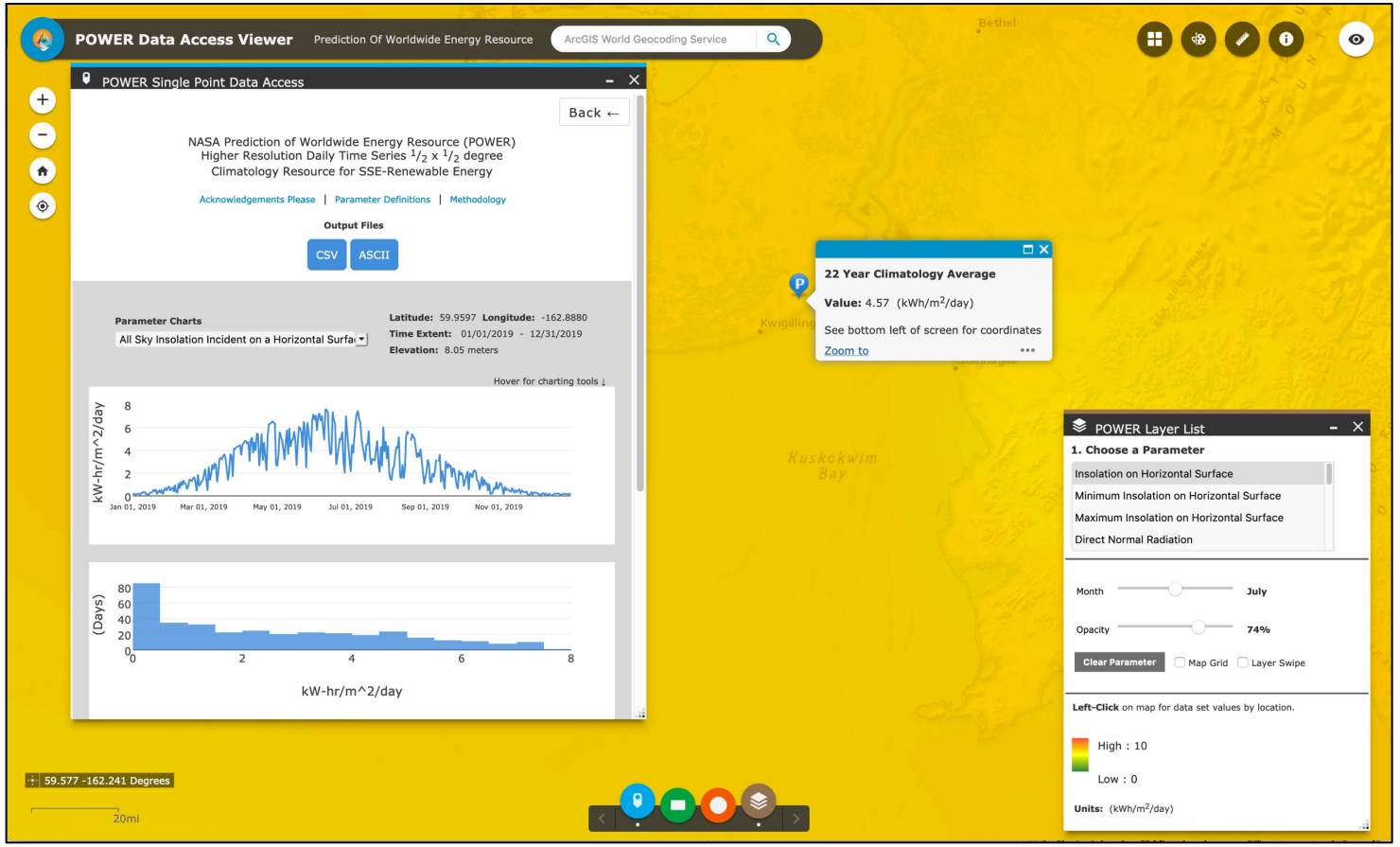


# How do you use the POWER Data Access Viewer (DAV)?

## Layer List Image Services:

- Climatological average maps services for 20+ key variables
- Monthly and annual averages available
- Interactive values displayed for any location when clicked
- Integrated opacity control to view terrain below

Solar Irradiance for July in Kongiganak, Alaska, US



# What GIS Services does POWER provide?

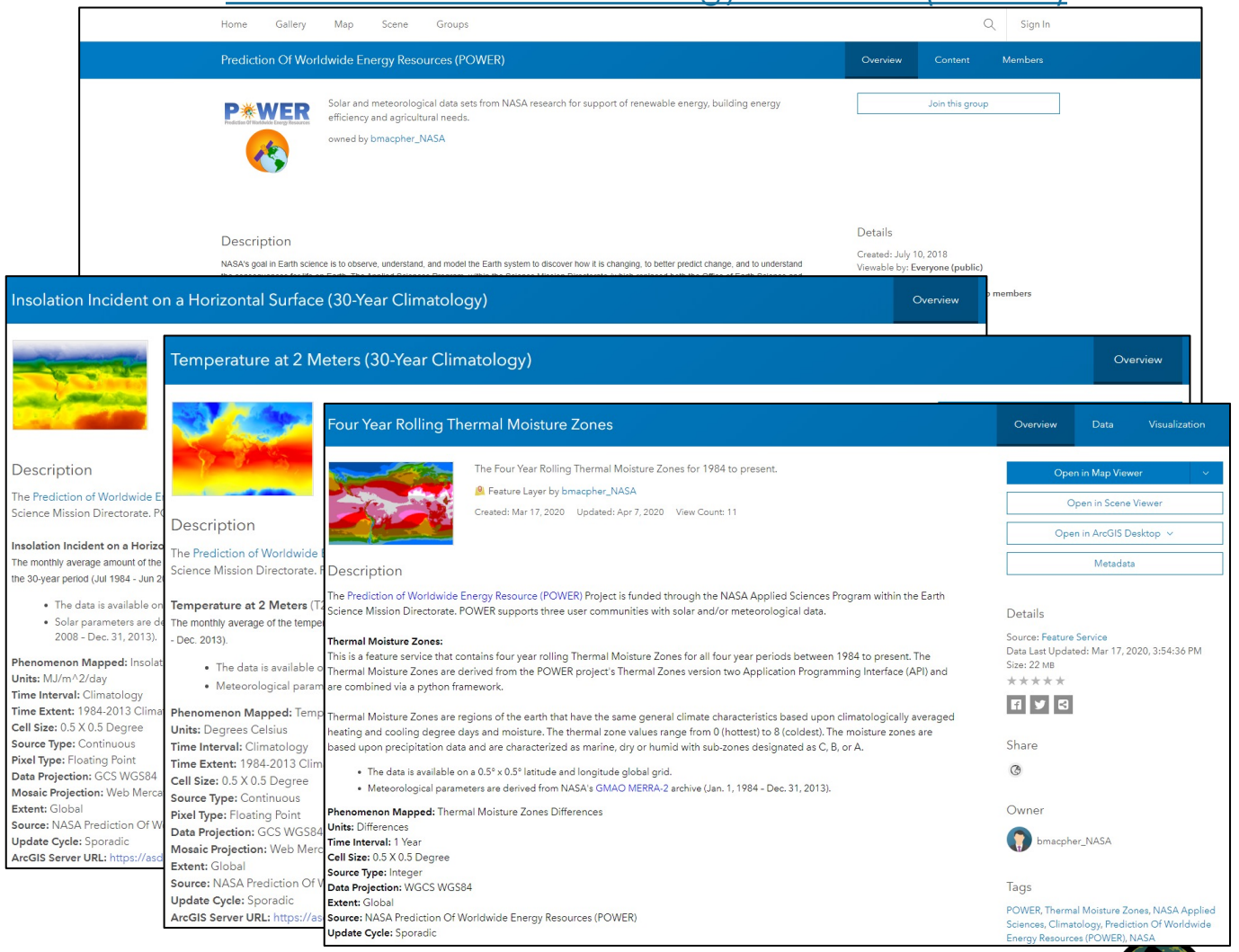
POWER provides Esri® ArcGIS Image and Feature Services that allow users to efficiently interact with the POWER data in Geographic Information System (GIS) applications and related tools.

- **Image Services:** Global climatology-based solar and meteorological parameters
- **Feature Services:** Global long-term ASHRAE® building climate thermal-moisture zones, 4-year rolling thermal zones, and period differences

**Available on:**

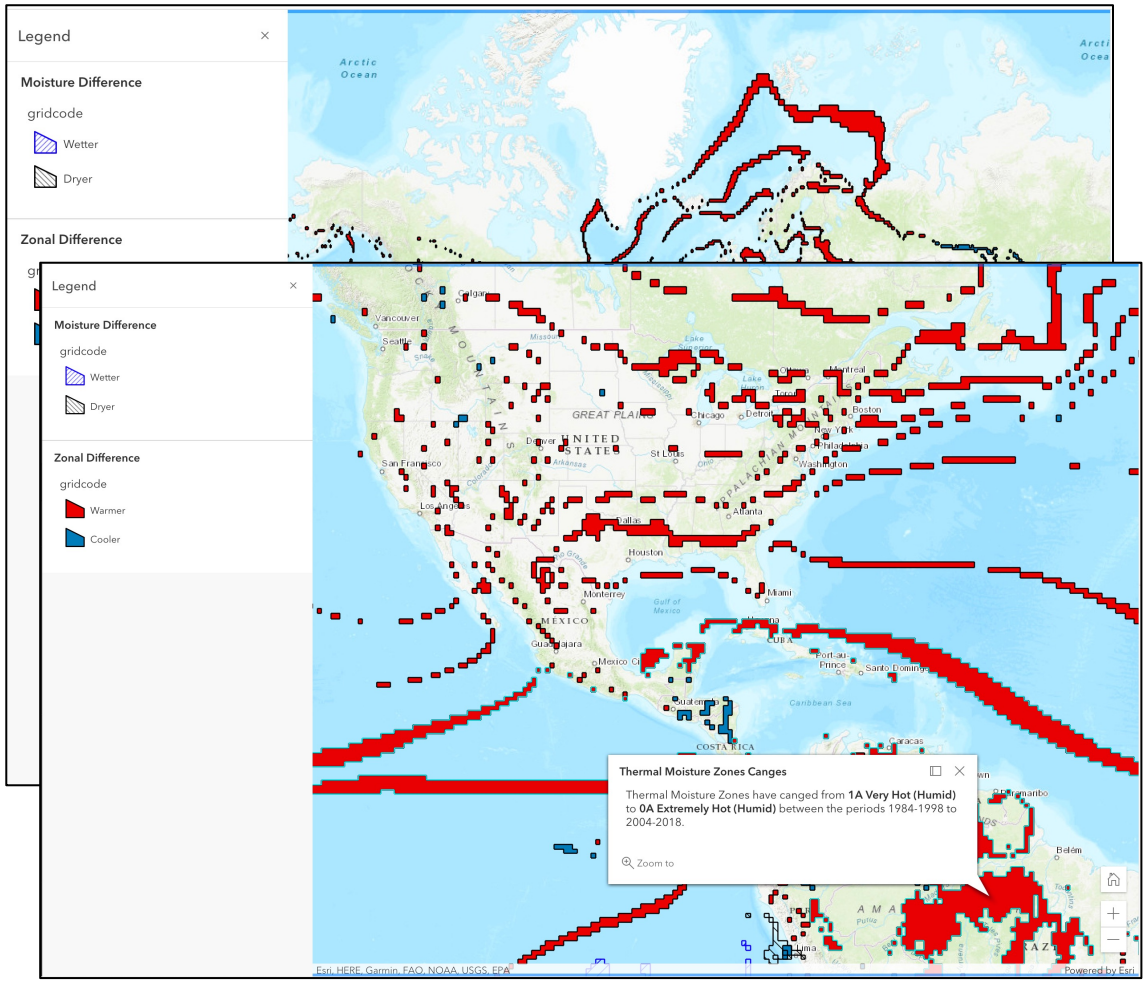
- NASA ArcGIS Online (AGOL)
- ASDC ArcGIS Online
- Esri Living Atlas

Prediction Of Worldwide Energy Resources (POWER)



# What GIS services does POWER provide?

- The Web maps and StoryMaps® allow users to more efficiently explore, modify, and interact with the POWER Data without need for additional software
- Responsive and scalable; built for mobile and desktop use
- Examples:
  - Reviewing regional data quality by comparing to surface measurements
  - Long-term differences in ASHRAE® building climate zones

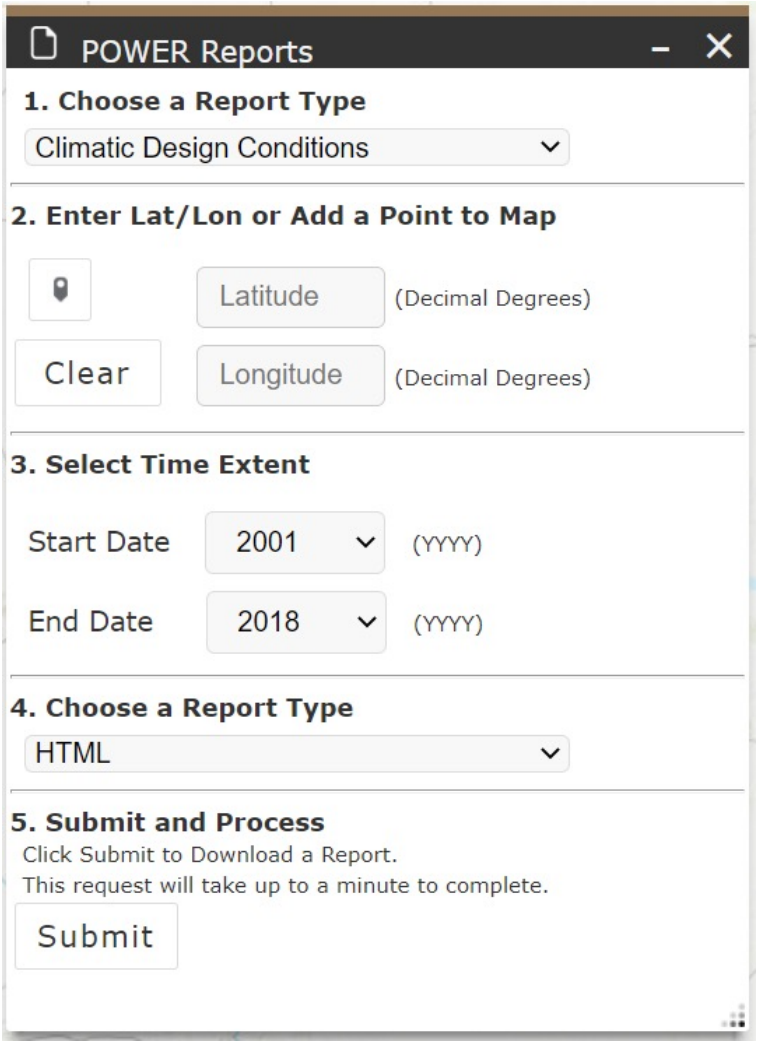


# What are POWER's analytic data services?

*New in power/beta …*

POWER provides single location, user specified time period reports to assess long-term variability:

- **Anomaly Report**
  - Time series plots and climatological assessments
  - ASHRAE® building climate zone indicators change plots for climate monitoring
- **Building Climate Design Conditions Report**
  - Developed with ASHRAE® from the Design Condition report
- **Windrose Report**
  - Average wind speeds reported in tables classified according to NREL using wind energy thresholds






*ASHRAE®: is a registered trademark of the American Society of Heating, Refrigerating and Air-Conditioning Engineers*

# Analytic Data Services – Report Outputs

## 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 | Coldest month 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 | | Standard deviation | | n-Year Return Period Values of Extreme Temperature n=5 years | | n=10 years | | n=20 years | | n=50 years | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | 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 |
| | | 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 |
| 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 |
| | | 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 |
| | | 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 |
| | | 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 |
| | | 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 |
| | | MCDBR | | | | | | | | | | | | | |
| | 5% WB | MCWBR | | | | | | | | | | | | | |
| | | MCDBR | | | | | | | | | | | | | |
| | | 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 | |

## Climate Variability and Anomalies Report

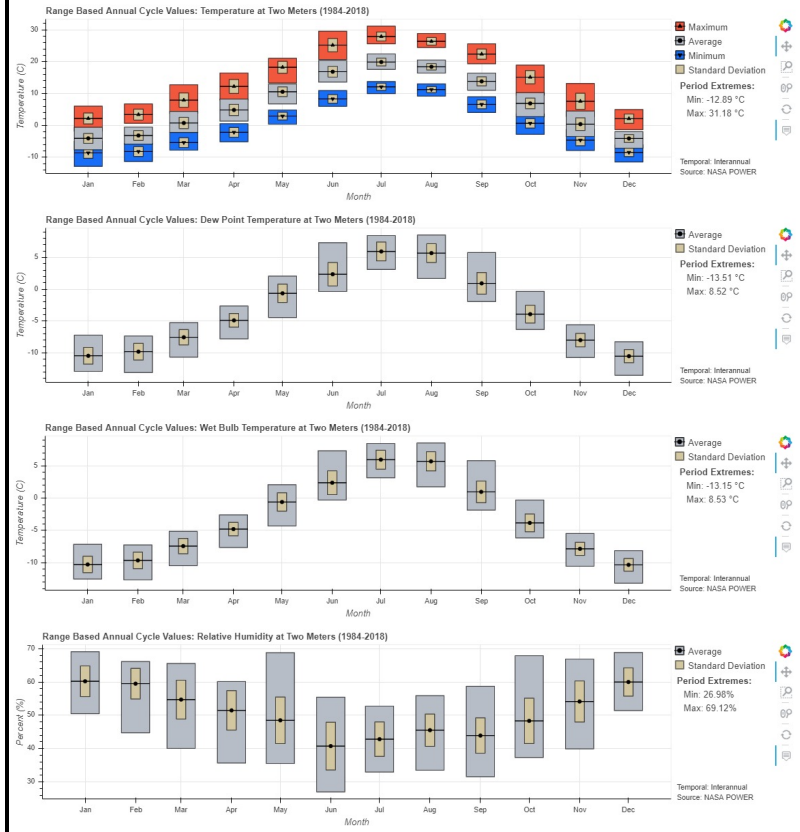
**POWER Climate Anomalies (MERRA-2 and SRB/CERES)**

Latitude: 39.701 Longitude: -105.0212 Elevation: 2297.9m StdPres: -999 Time Period: 1984 - 2018 Note: 0.5 x 0.5 Degree Gridded Data

*The scales of the plots are independent, place take note when comparing values across the plots*

*The base climatology period for the anomalies is the requested time period's climatology (1984 - 2018).*

**POWER Climate Anomalies (MERRA-2 and SRB/CERES)**



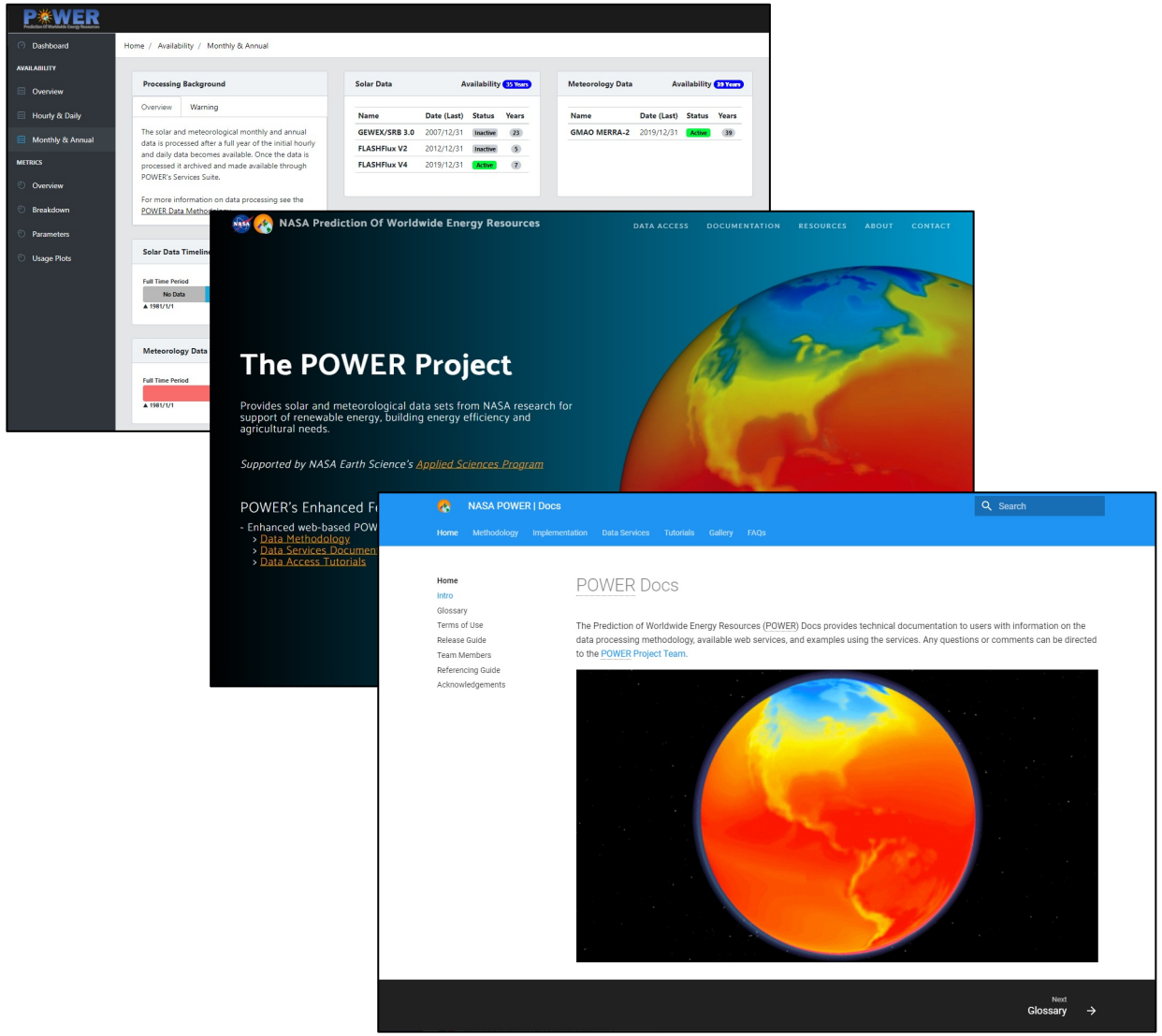

## Windrose Report Table by NREL Classes

```
-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
```

# Where is the POWER documentation?

The POWER Documentation consists of four main sites that are built for both mobile and desktop use:

- **Homepage:** The project overview with links to all POWER resources.
- **Dashboard:** A series of dynamic webpages that provide real-time status information on data processing.
- **Pages:** The API landing pages that use the OpenAPI specification to create interactive pages for the API endpoints.
- **Docs:** The project's documentation and methodology providing accurate and detailed information to users.



# What Have We Learned?

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

- Global solar irradiance estimates are made using specialized measurements:
  - Of the sun from SORCE/TSIS
  - Calculated using information from a combination of NASA CERES instruments and satellite imagers
  - Estimates are made within a week of observation
- Surface meteorological parameters are made available from atmospheric reanalysis from NASA's MERRA-2
  - Estimates of these quantities are available within a few days

- The POWER Web Services Portal:
  - Uses NASA's EO and modeling to customize datasets for energy related applications
  - Spans from 1984 to within a few days of the current time
  - Daily, Monthly, Annual, and Climatological averages provided
  - Data is made available through:
    - API for direct usage
    - DAV for interactive selection
    - Web image and feature services
  - New version features hourly data since Jan. 2001


# Thank You!

**Find us at:** https://power.larc.nasa.gov/
**Email us at:** larc-power-project@mail.nasa.gov

# ACRONYMS

| | |
|---|---|
| **3D** | Three Dimensional |
| **API** | Application Programming Interface |
| **ARD** | Analysis Ready Data |
| **ARM** | Atmospheric Radiation Measurement |
| **ASCII** | American Standard Code for Information Interchange |
| **BSRN** | Baseline Surface Radiation Network |
| **CERES** | Clouds and the Earth's Radiant Energy System |
| **CSV** | Comma Separated Values |
| **DAV** | Data Access Viewer |
| **DSCOVR** | Deep Space Climate Observatory |
| **EO** | Earth Observation |
| **FLASHFlux** | Fast Longwave and Shortwave Flux |
| **FP-IT** | Forward Processing-Investigator Team |
| **GEBA** | Global Energy Balance Archive |
| **GEOS** | Geostationary Operational Environmental Satellite |
| **GEWEX** | Global Energy and Water Exchanges Project |
| **GIS** | Geographic Information System |
| **GMAO** | Global Modeling and Assimilation Office |
| **GSOD** | Global Summary of the Day |
| **ISCCP** | International Satellite Cloud Climatology Project |
| **ISD** | Integrated Surface Database |
| **ISS** | International Space Station |
| **LaRC** | Langley Research Center |
| **MAC** | Max-Planck Aerosol Climatology |

| | |
|---|---|
| **MERRA-2** | Modern-Era Retrospective analysis for Research and Applications, Version 2 |
| **MODIS** | MODerate resolution Imaging Spectrometer |
| **NASA** | National Aeronautics and Space Administration |
| **NCEI** | National Center for Environmental Information |
| **NetCDF** | Network Common Data Form |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NREL** | National Renewable Energy Laboratory |
| **NSIDC** | National Snow and Ice Data Center |
| **PAR** | Photosynthetically Active Radiation |
| **POWER** | Prediction of Worldwide Energy Resources |
| **PV** | Photovoltaic |
| **SatCORPS** | Satellite ClOud and Radiation Property retrieval System |
| **SORCE** | SOlar Radiation Climate and Experiment |
| **SRB** | Surface Radiation Budget Project |
| **TOA** | Top Of Atmosphere |
| **TSI** | Total Solar Irradiance |
| **TSIS** | Total and Spectral Solar Irradiance Sensor |
| **URI** | Uniform Resource Identifier |
| **URL** | Uniform Resource Locator |
| **VIIRS** | Visible Infrared Imaging Spectrometer |
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# POWER Data: What Parameters are Provided?

## Base and Derived Parameters for POWER GIS v2 (Beta)

**All parameters are available globally at the source data resolution.**

### Source Data (Hourly)

- 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

### Daily, Monthly, & Annual

- Clear & Cloudy Clearness Indexes

- Air Temperature Average, Min, Max, Range at 2 m, Wet Bulb
- Temp Frost point at 2 m
- Relative Humidity at 2 m
- Wind speed and Direction at 10m, 50 m
- Max/Min Wind Speed

### Climatological

- Solar geometry, Surface albedo, Direct Normal, Diffuse, Tilted surface solar parameters
- 3-hourly solar fluxes and cloud parameters,
- No-sun Days, min insolation over day periods

- Heating/Cooling Degree Days (for 0° C, 10° C, 18.3° C standards),
- Skin Temperature max/min/range, Frost Days,
- Total Column Precipitable Water
- ASHRAE® Building Climate Thermal
- & Moisture zones

**Source Data:**

- Global Energy and Water Exchange Project (GEWEX) Surface Radiation Budget (SRB)
- Fast Longwave And SHortwave Radiative Fluxes (FLASHFlux)
- Modern Era Retro-analysis for Research and Applications (MERRA-2)
- Forward Processing – Instrument Team FP-IT (GEOS 5.12.4)