

# Overview of MERRA-2 for Applications, Decision-making, and Climate Assessment

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Acknowledgements: Amal El-Akkraoui, Will McCarty, Ron Gelaro, Amin Dezfuli



## Atmospheric Reanalyses

- A **retrospective analysis** of historical meteorological observations (some systems include land, ocean, aerosol, biology analysis)
- 3 Critical Components
  - Observations, provides reality, but the data is irregularly available in space and time, and many different types
  - Model, provides a complete and consistent background estimate and forecast (most reanalysis data derived here)
  - Data assimilation, considers the uncertainty of the model and obs data, merge for a forecast initial condition
- A **global continuous** representation of the **weather and climate**



# Applications Users of MERRA-2

- AWEA – American Wind Energy Association
- IRENA – International Renewable Energy Agency
- RETScreen – Clean Energy Management Software developed by Natural Resources Canada
- Famine Early Warning Systems Network (FEWSNET, Interagency)
- National Solar Radiation Database
- Prediction of Worldwide Energy Resources (POWER, LaRC)
- Agriculture Model Intercomparison Project (AgMIP, GISS)
  
- Climate Research Uses: Extreme events (Precipitation and Drought), River Flow, Air Quality, Fire Weather and even Highway Deterioration
  
- NASA Research Proposals on National Climate Indicators Research Projects

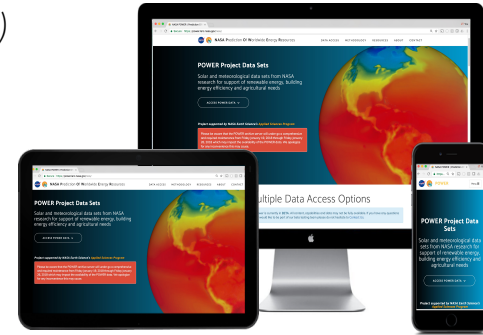


# NASA's POWER Project

Prediction Of Worldwide Energy Resources (POWER)

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

*Integrate Earth Science mission observational data, analysis and modeling from NASA Earth Science and provide customized accessibility solutions for energy related and agricultural applications.*



## Geospatially Enabling NASA ES Data For:

- **Renewable Energy Applications** (ie., solar and wind technologies): Users such as Nokia Solar, Customer First Renewables, RETScreen Users worldwide, Friesen Energy, ...
- **Energy-Efficient Building Design** (i.e., building climate zones): **ASHRAE society**, 3M, Johnson Controls, Lockheed Martin, Universities (U. of MI, Auburn, MIT), State Govt. (PA for solar hot water heating), Local Govt. (Public Schools in Hawaii), ...
- **Agricultural Crop Modeling Applications**: USDA, Ferrero (Nutella), World Agroforestry, AfricaRice, Global Yield Cap Atlas, Lumigrow, ...



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

### POWER-GIS v1 Usage

2018/05/01 – 2020/12/31	
Requests	> 144 Million
Unique Users	294,342
Data Volume	13.8 TB

Courtesy P. Stackhouse, LaRC

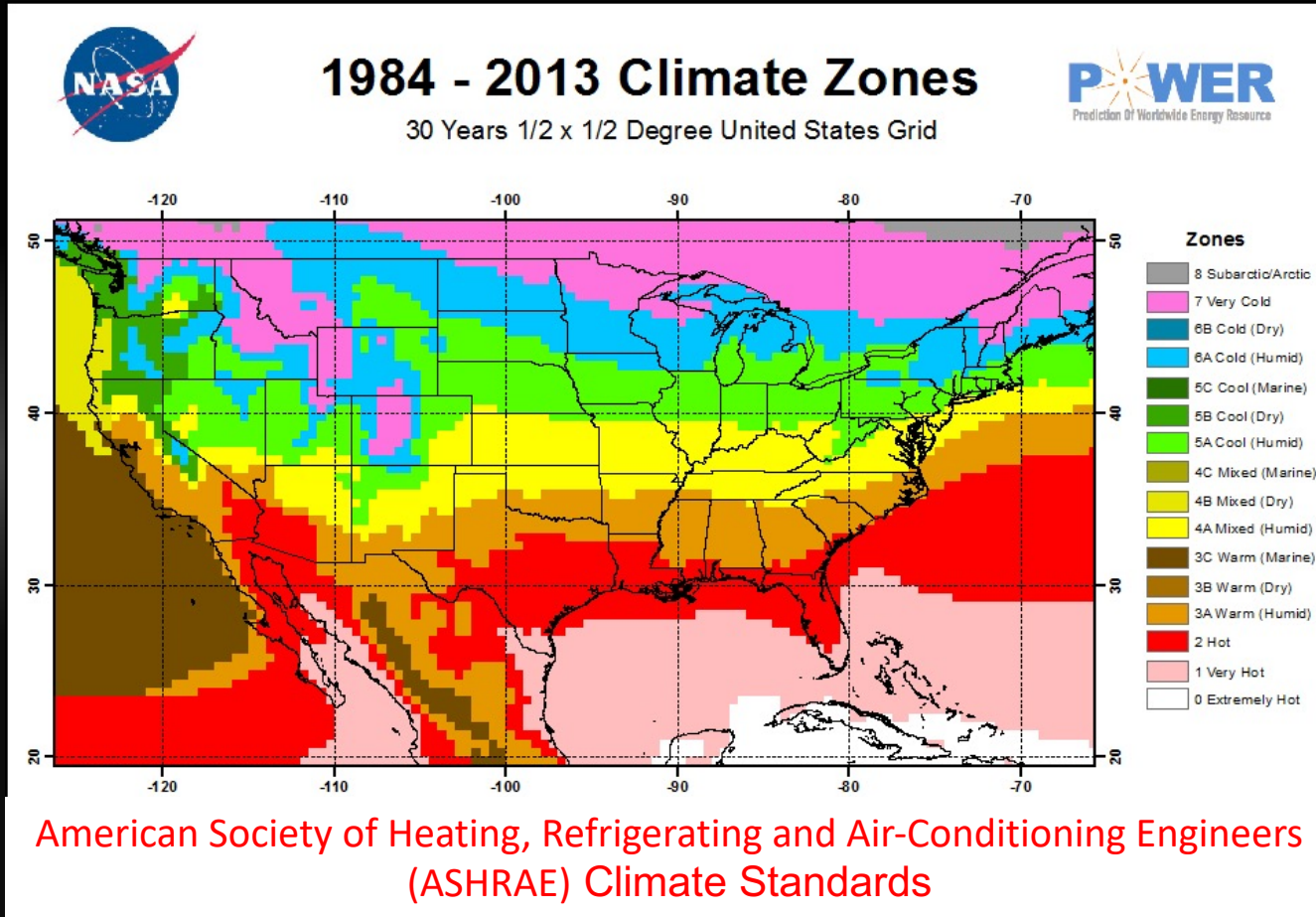




# Hourly Parameters

Category	Parameters	Source
Solar Parameters	Top-Of-Atmosphere Shortwave Downward Irradiance	CERES (SORCE, TSIS)
	Top-Of-Atmosphere Shortwave Direct Normal Radiation	CERES (SORCE, TSIS)
	All Sky Surface Shortwave Downward Irradiance (horizontal), Diffuse Horizontal, Direct horizontal, Direct Normal Irradiances	CERES SYN1Deg Ed4
	Clear Sky Surface Shortwave Downward Irradiance (horizontal), Diffuse Horizontal, Direct horizontal, Direct Normal Irradiances	CERES SYN1Deg Ed4
	Insolation Clearness Index, Clear-sky clearness index, and normalized clearness index	CERES SYN1Deg Ed4
	Surface Albedo	CERES SYN1Deg Ed4
	Solar Zenith Angle	CERES SYN1Deg Ed4
Thermal Infrared Irradiance	All Sky and Clear-sky Surface Longwave Downward Irradiance	CERES SYN1Deg Ed4
Cloud	Cloud fraction, optical depth, cloud top and base heights	CERES SYN1Deg Ed4
Aerosol	Aerosol optical depth at 0.55 and 0.85 micrometers	CERES SYN1Deg Ed4
Surface Meteorology	Surface pressure, temperature (2, 10 m), surface air density (2m), specific humidity (2, 10m), relative humidity (2, 10m), dew/frost point temperatures (2m), wet bulb temperature (2, 10m)	MERRA-2
	Earth Skin temperature	MERRA-2
	Wind Components (at 2, 10, 50 Meters)	MERRA-2
	Precipitation, Precipitation Corrected	MERRA-2
Meteorology	Total Column Precipitable Water, Total Column Ozone, Planetary Boundary Layer Top Pressure	MERRA-2
Surface Properties	Ice Covered Fraction, Land Snowcover Fraction, Snow Depth, Zero Plane Displacement Height, Surface Roughness	MERRA-2
	Surface Soil Wetness, Soil Temperatures (5 Layers)	MERRA-2

# Example of MERRA-2 Applied use: ASHRAE



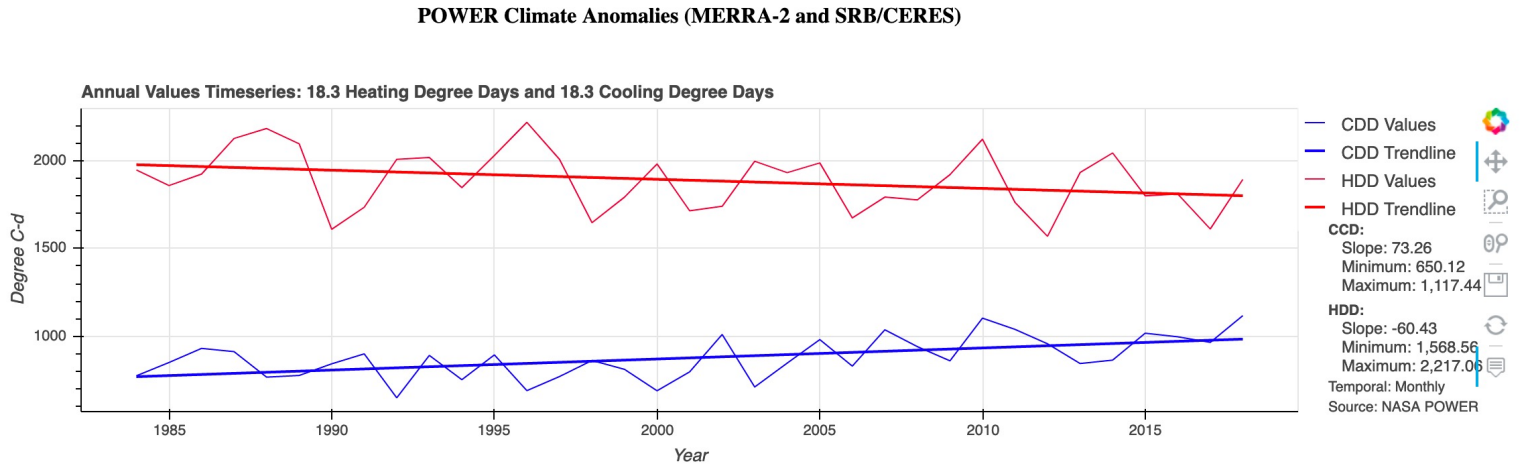
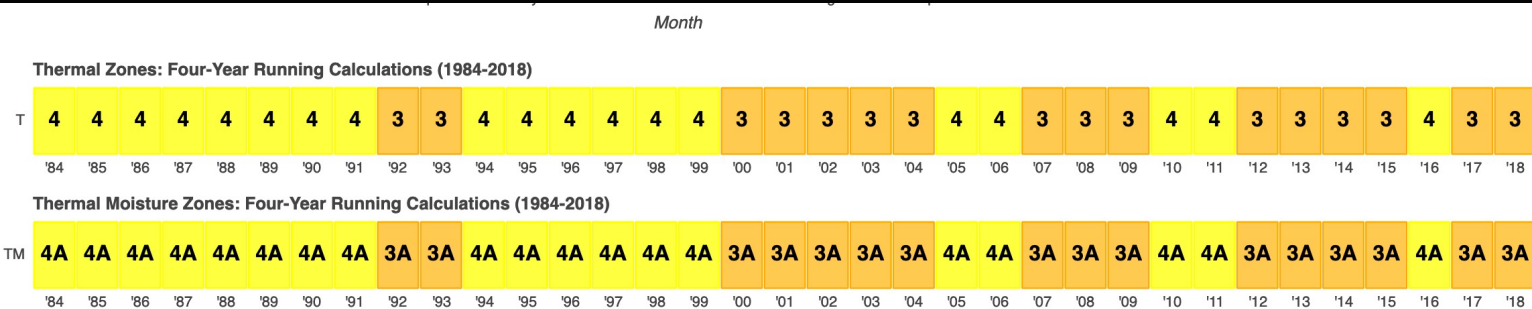




# Climate Variability and Anomaly Reports for NASA Langley Research Center

Note change to warmer ASHRAE climate zone using 4-year running zones

Note decrease of Heating Deg Days; increase of Cooling Deg Days





# Applied Remote Sensing Training Program (ARSET)

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

<https://appliedsciences.nasa.gov/join-mission/training/english/arset->

[nasa-earth-observations-energy-management](https://appliedsciences.nasa.gov/join-mission/training/english/arset-nasa-earth-observations-energy-management)



**GMAO**

gmao.gsfc.nasa.gov



## MERRA-2 as a Climate Assessment Enabling Tool

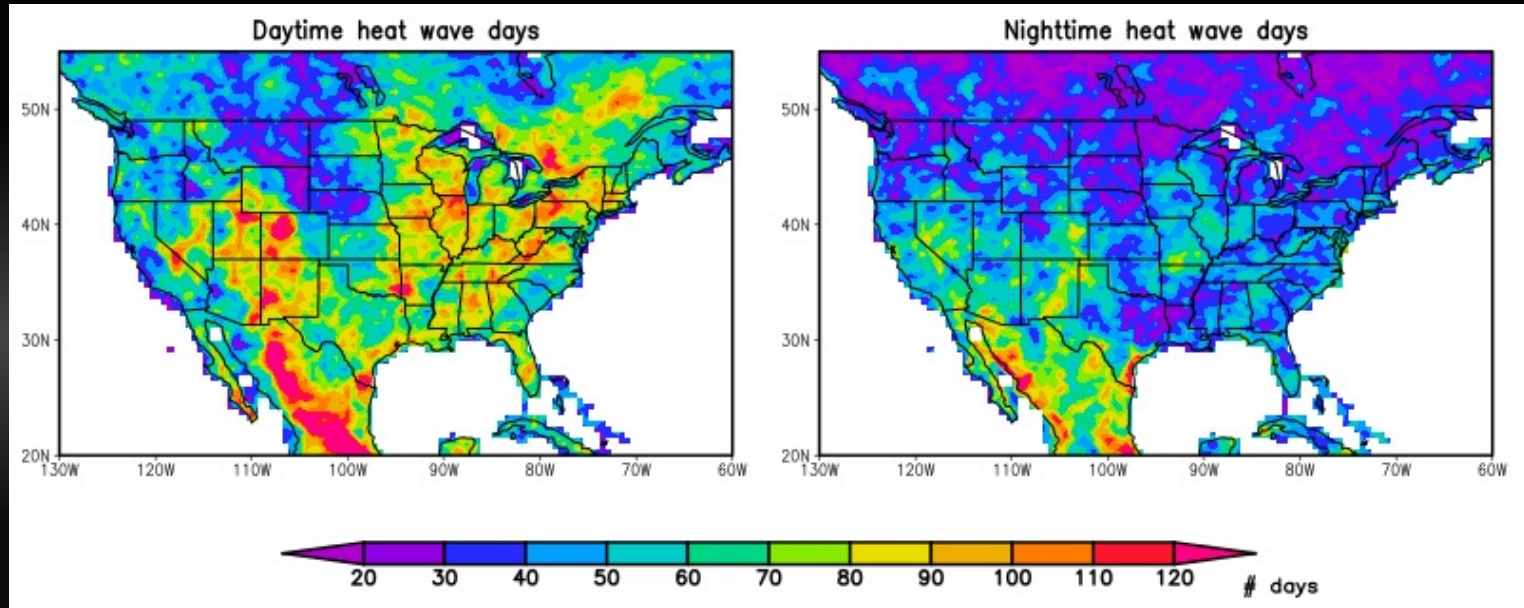
- Utilize MERRA-2 to address National Climate Assessment questions
  - The modeled precipitation can be more uncertain than observations
  - The large-scale meteorology is well represented
- Test and Understand the limits of reanalyses in the US
- Foster connections with applied users and developers of climate indicators, to improve their understanding of limitations and needs for data
- Weather and Climate Diagnostics/Indices
  - <https://fluid.nccs.nasa.gov/reanalysis/>

## Extreme and Weather Indices

- **TN10p** percentage of time daily min 2-m Temp < 10th pctl
- **TX10p** percentage of time daily max 2-m Temp < 10th pctl
- **TN90p** percentage of time daily min 2-m Temp > 90th pctl
- **TX90p** percentage of time daily max 2-m Temp > 90th pctl
- **DTR** diurnal 2-m temperature range
- **T2M** 2-m temperature
- **R90p** total precipitation from days > 90th percentile
- **R95p** total precipitation from days > 95th percentile
- **R99p** total precipitation from days > 99th percentile
- **R90d** count of days with precipitation > 90th pct
- **R95d** count of days with precipitation > 95th pct
- **R99d** count of days with precipitation > 99th pct
- **PRCPTOT** total precipitation on days > 1 mm
- **CDD** maximum number of consecutive days when Pr < 1 mm
- **CWD** maximum number of consecutive days when Pr > 1 mm
- **SDII** ratio of annual total Pr to the No. of wet days ( $\geq 1$  mm)
- **WSDI** count when at least 6 consecutive days of max temperature > 90th percentile
- **CSDI** count when at least 6 consecutive days of min temperature < 10th percentile
- **LWS** length of longest warm spell
- **LCS** length of longest cold spell
- **HWN** Number of Heat Wave Events
- **HWD** Longest Heat Wave
- **HWF** Number of Heat Wave Days
- **HWA** Temperature on Hottest Day of Hottest Event
- **HWM** Avg Temp anomaly over all Heat Wave Days
- **DRYDAYS** count of days with precipitation < 1 mm
- **WETDAYS** count of days with precipitation  $\geq 1$  mm
- **RX1Day** Highest one day precipitation is the maximum of one day precipitation amount in a given time period
- **R10mm** Heavy precipitation days is the number of days per time period with daily precipitation sum exceeding 10 mm
- **R20mm** Very heavy precipitation days is the number of days per time period with daily precipitation sum exceeding 20 mm
- **RX5Day** Highest precipitation amount for a five day interval, including the calendar day as the last day
- **RX5Daycount** number of 5day heavy Pr periods per time period



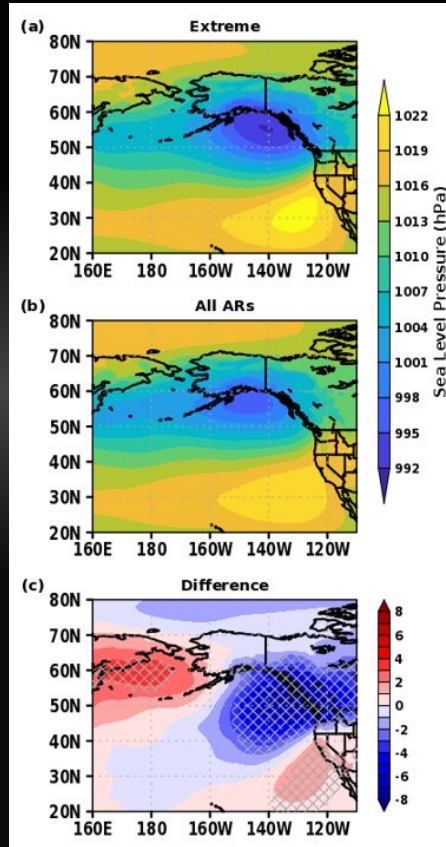
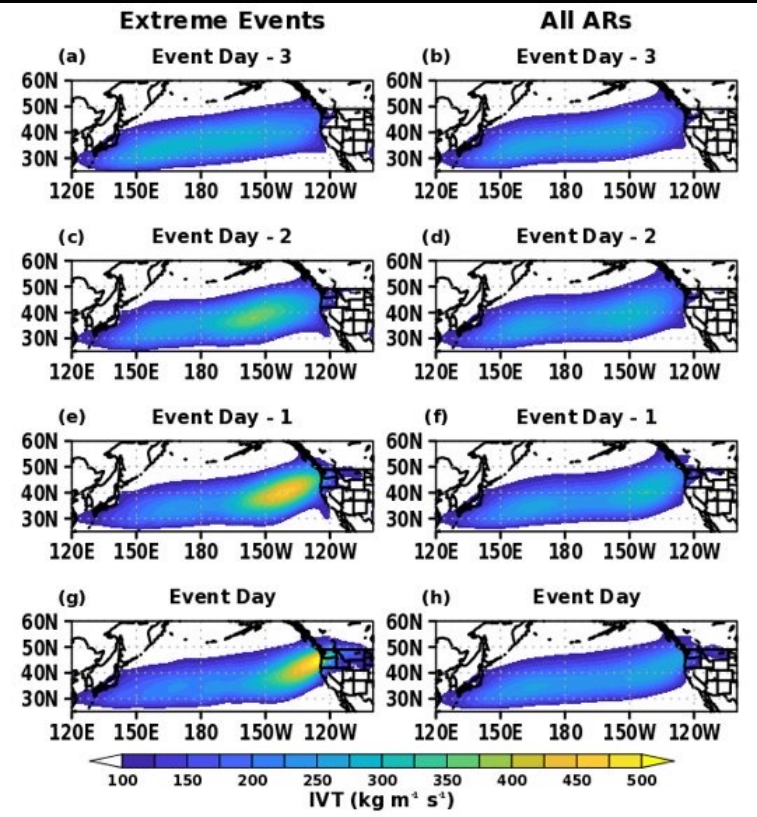
# Mechanisms associated with daytime and nighttime heat waves



Number of daytime and nighttime heat wave days at each grid point in MERRA-2 over JJA 1980-2018

Thomas et al. (2020, JAMC)

# How Does the Large-scale Circulation Differ when Atmospheric Rivers Result in Extreme Precipitation in Washington State?



- Used 40 seasons worth of data from MERRA-2 for a large enough sample size
- Extreme events > 95<sup>th</sup> percentile of observed precipitation
- Notable differences in transport of water vapor is present days before an extreme event occurs
- On the day of an extreme event, the subtropical high is stronger and the low pressure system is deeper, positioned eastward, and negatively tilted

# MERRA-2 Post Processed PM2.5

- **Global**
- 1980 – 2020
- Monthly averages
- Country-level
- Available as csv
- Companion python tutorial
- To be archived at <https://disc.gsfc.nasa.gov/>

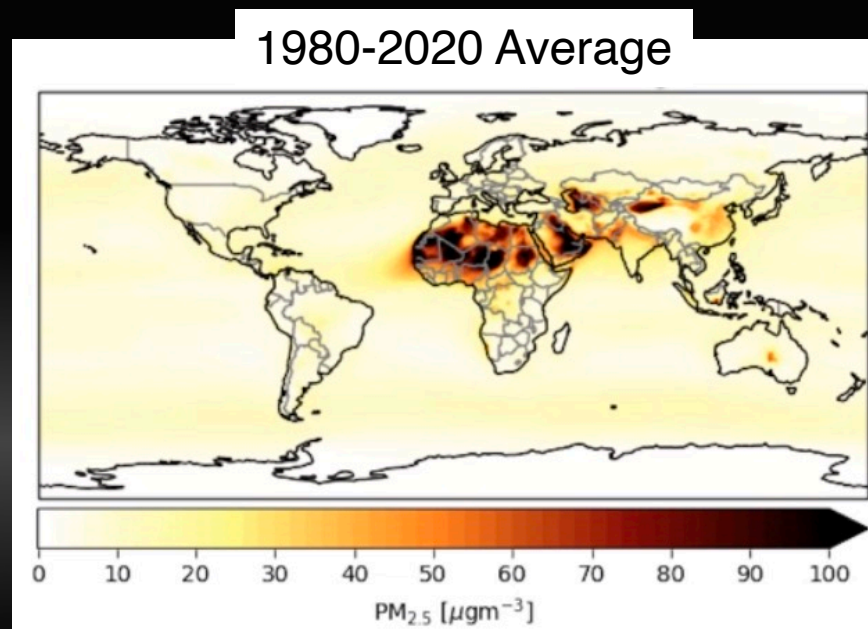


Figure credit: Christoph Keller (NASA GMAO)

**Daily county-level PM2.5 over the US** coming soon on [CDC's Environmental Public Health Tracker](#)

**Visualize** maps of MERRA-2 PM2.5  
[https://fluid.nccs.nasa.gov/reanalysis/chem2d\\_merra2/](https://fluid.nccs.nasa.gov/reanalysis/chem2d_merra2/)

Slide Courtesy of Helen Amos

# Developing Collaboration: CDC

## US Centers for Disease Control (CDC)

- Climate & Health Program
- Tracking Program

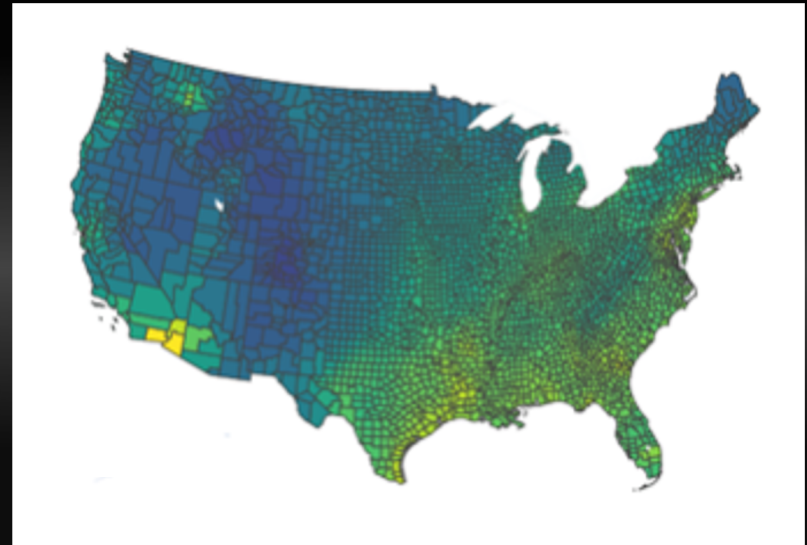


The screenshot shows the CDC website interface. At the top left is the CDC logo and the text 'Centers for Disease Control and Prevention CDC 24/7: Saving Lives. Protecting People.™'. A search bar is on the top right. Below the navigation bar is a green header for 'National Environmental Public Health Tracking Network'. Social media icons for Facebook, Twitter, and a plus sign are visible. The main content area includes a section titled 'Better information for better health' with a paragraph explaining the Tracking Network's purpose and a list of user capabilities: 'Use the Data Explorer to view interactive maps, tables, and charts', 'View Info by Location for county level data snapshots', and 'Visit state & local tracking websites'. Below this is a link to 'Learn more about Tracking'. A featured banner for the 'Heat & Health Tracker' shows a person using a laptop and includes the text 'View local, timely data and info to help communities prepare for and respond to extreme heat events.' At the bottom, three call-to-action buttons are present: 'ACCESS THE NEW DATA EXPLORER' (View & download all data, Maps - Charts - Tables), 'INFO BY LOCATION' (Data for you! View data by county or zip code), and 'STATE & LOCAL TRACKING PROGRAMS' (Websites, Grantee Profiles, Data Highlights).



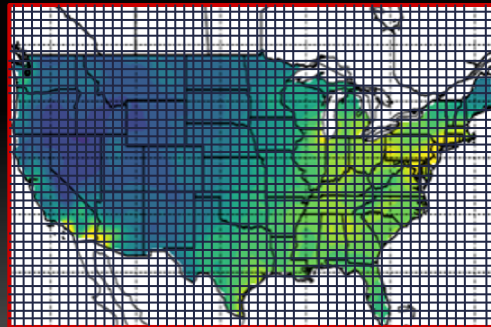
# CDC's requirements

- Contiguous US
- County-level
- Local date & time
- Surface
- Daily mean, min, max, std dev
- Saved as CSV files

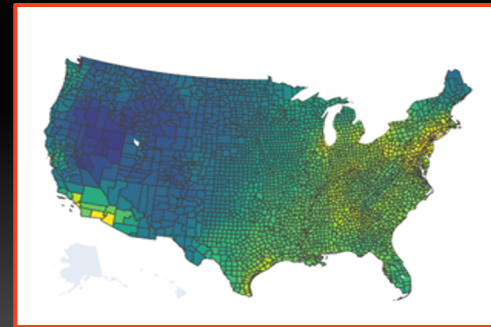


# Goal of the internship was to make it easier for public health professionals to use NASA data

On a climate model grid



County level



In an unfamiliar location

**EARTHDATA** Find a DAC -

**GES DISC** Data Collections - MERRA-2  
Atmospheric Composition, Water & Energy Cycles, and Climate Variability

**MERRA-2 reprocessed September 2020 data**

**Data Collections** Showing 1 - 25 of 172 datasets associated with **MERRA-2**

**Refine By**

**Subject** Sort -

- Aerosols (11)
- Air Quality (17)
- Altitude (23)
- Atmospheric Chemistry (2)
- Atmospheric Pressure (2)
- More...

**Measurement** Sort -

- Aerosol Extinction (8)
- Aerosol Optical Depth/Thickness (8)
- Aerosol Particle Properties (6)
- Air Mass/Fraction (2)
- Air Temperature (2)
- More...

**Source** Sort -

- Models/Analyses MERRA-2 (2)
- Models/Analyses MERRA-2 (2)
- Models/Analyses Reanalysis (2)

Image	Dataset	Source	Version
	MERRA-2 tarq1_2d_ah_Nc_3d.1-Hourly,Time-Averaged,Single-Level,Assimilation,Single-Level-Diagnostics V5.12.4 (MGT1N0SLV.5.12.4)	Models/Analyses MERRA-2	5.12.4
	MERRA-2 tarq1_2d_ah_Nc_3d.Monthly,mean,Time-averaged,Single-Level,Assimilation,Aerosol-Diagnostics V5.12.4 (MGT1N0SLV.5.12.4)	Models/Analyses MERRA-2	5.12.4
	MERRA-2 tarq1_2d_ah_Nc_3d.3-Hourly,Instantaneous,Pressure-Level,Assimilation,Assimilated Meteorological Fields V5.12.4 (MGT1N0SLV.5.12.4)	Models/Analyses MERRA-2	5.12.4
	MERRA-2 tarq1_2d_ah_Nc_3d.1-Hourly,Time-Averaged,Single-Level,Assimilation,Surface Flux-Diagnostics V5.12.4 (MGT1N0SLV.5.12.4)	Models/Analyses MERRA-2	5.12.4

**CDC** Centers for Disease Control and Prevention  
CDC 24/7 Saving Lives. Preventing Hazards.

**National Environmental Public Health Tracking Network**

Better information for better health  
The National Environmental Public Health Tracking Network (Tracking Network) brings together health data and environmental data from national, state, and city agencies and provides supporting information to make the data easier to understand. The Tracking Network has data and information on environmental health, health effects, and surveillance data.

On the Tracking Network, you can:

- Use the Data Explorer to view interactive maps, tables, and charts
- View data by location for county-level data requests
- Visit state & local tracking websites

CDC's National Environmental Public Health Tracking Program created and maintains the Tracking Network. Learn more about Tracking.

**Heat & Health Tracker**

View local, state data and links to help communities prepare for and respond to extreme heat events.

**ACCESS THE NEW DATA EXPLORER**  
View & download all data  
Browse - Choose - Filter

**INFO BY LOCATION**  
Data for you!  
From ZIP to County or ZIP code

**STATE & LOCAL TRACKING PROGRAMS**  
View state & local tracking programs

In a central clearinghouse for environ. health data

# GMAO Development: Reanalysis of the 21<sup>st</sup> Century (R21C)

## GEOS MERRA-2 (1980-present)

- ~50 Km Horizontal Resolution
- 72 Vertical Layers
- 3D Variational Data Assimilation
- Clear-sky Radiance Assimilation
- First reanalysis to include Interactive and Assimilated Aerosols

## GEOS R21C (2000-present)

- ~25 Km Horizontal Resolution
- 91 Vertical Layers (?)
- 4D Ensemble Variational Data Assimilation
- All-sky Radiance Assimilation
- ❖ Add focus on atmospheric composition
- ❖ Add 3-D Boundary Layer Constant Height Data Collection





## Thanks and Stay Safe!

- Questions: [Michael.Bosilovich@nasa.gov](mailto:Michael.Bosilovich@nasa.gov)
- GMAO Reanalysis:
  - <https://gmao.gsfc.nasa.gov/reanalysis/>
  - <https://fluid.nccs.nasa.gov/reanalysis/>
- POWER: <http://power.larc.nasa.gov/>