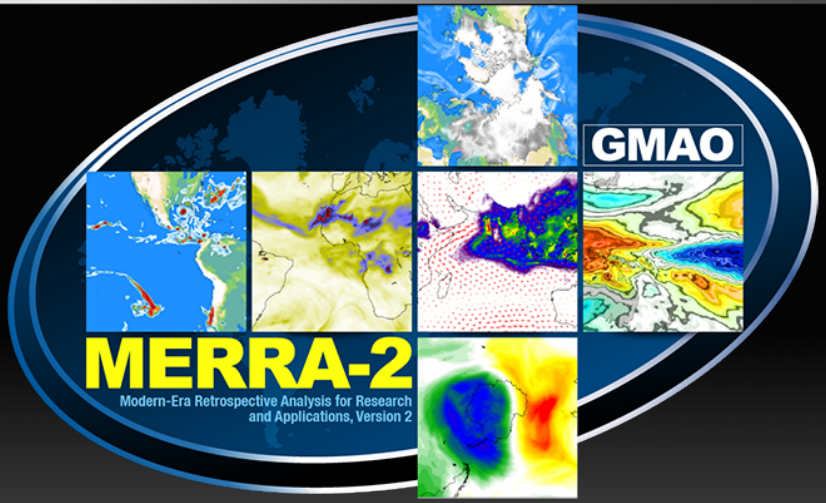


Overview of MERRA-2 for Applications, Decision-making, and Climate Assessment

Michael Bosilovich, Allison Collow, Paul Stackhouse, Natalie Thomas, Kanan Patel, Helen Amos, Ana Prados, Stephanie Schollaert Uz

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)

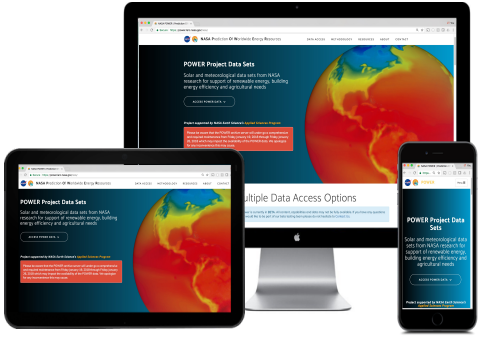
- Climate Research Uses: Extreme events (Precipitation and Drought), River Flow, Air Quality, Fire Weather and even Highway Deterioration

- 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

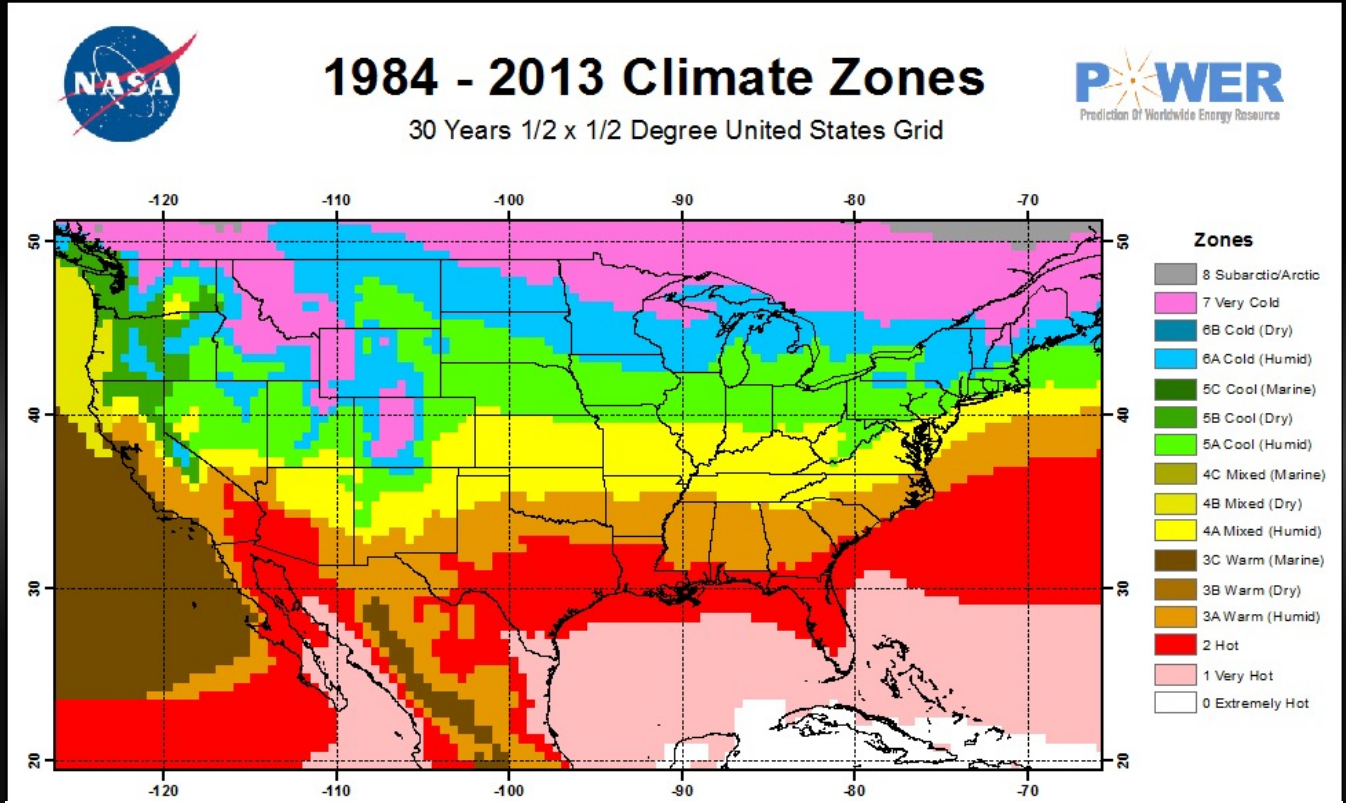
Courtesy P. Stackhouse, LaRC

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 Infared 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

Courtesy P. Stackhouse, LaRC

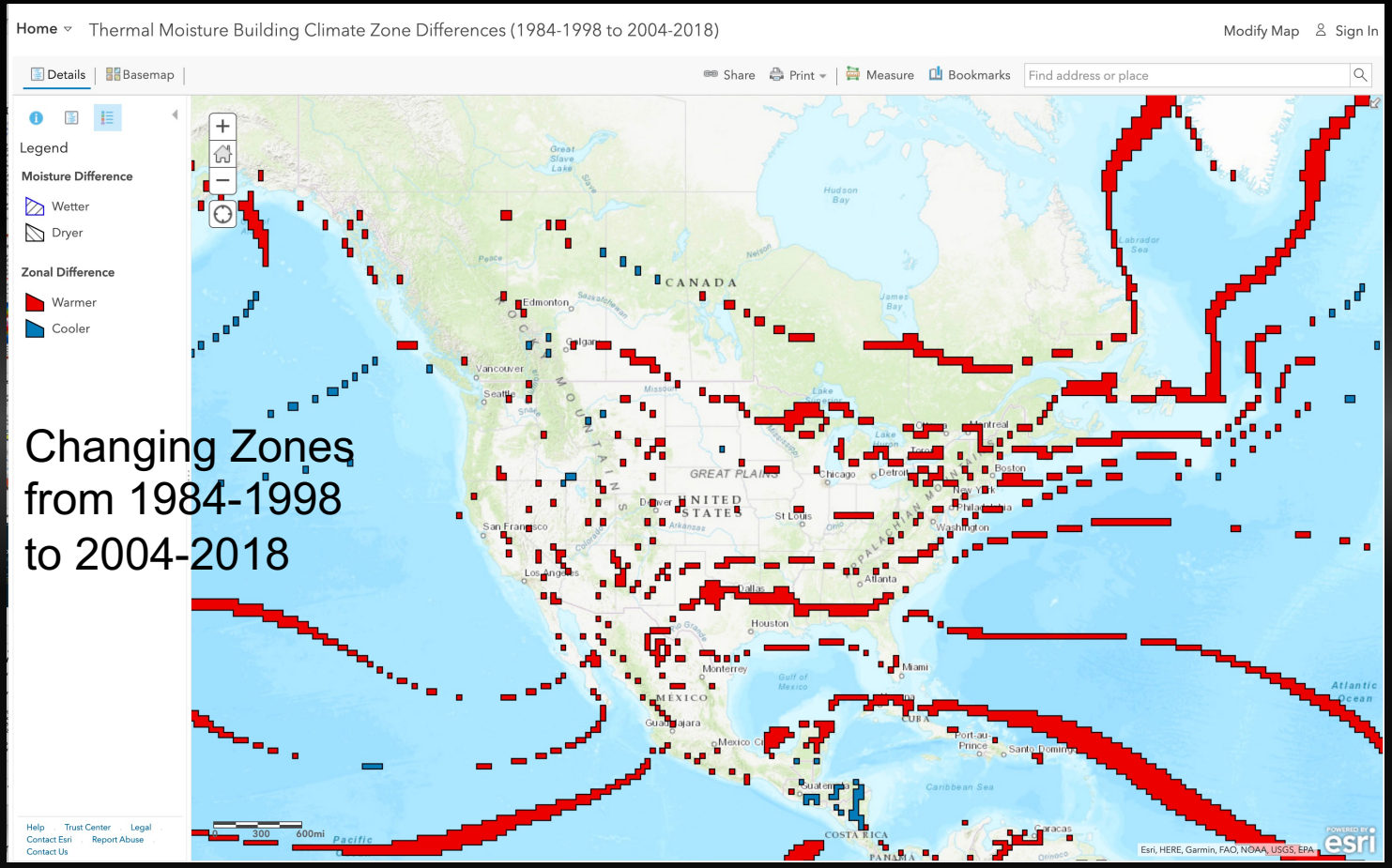
Example of MERRA-2 Applied use: ASHRAE



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

Courtesy P. Stackhouse, LaRC

U.S. ASHRAE Building Climate Zones from MERRA-2 Differences

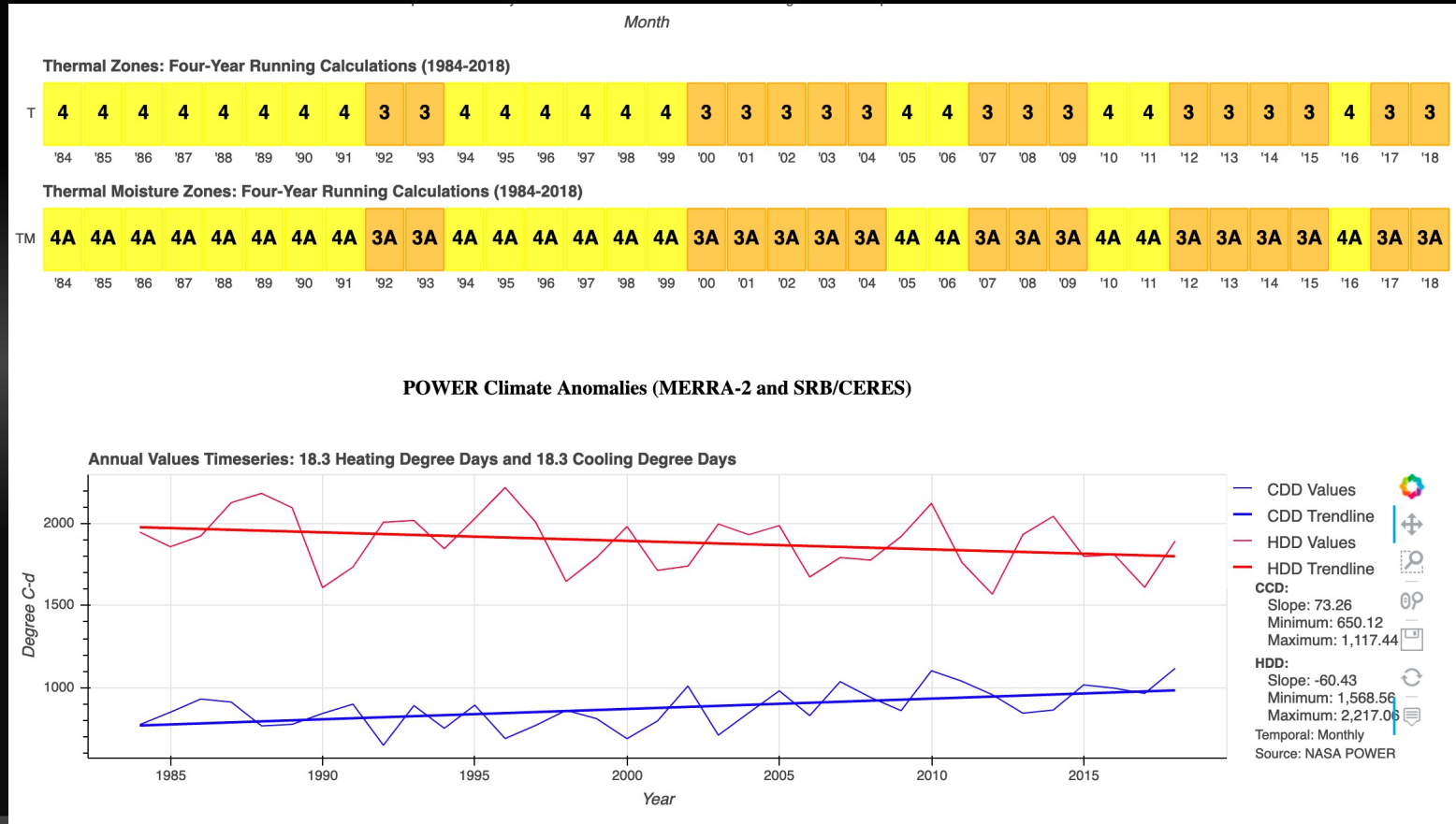


Courtesy P. Stackhouse, LaRC

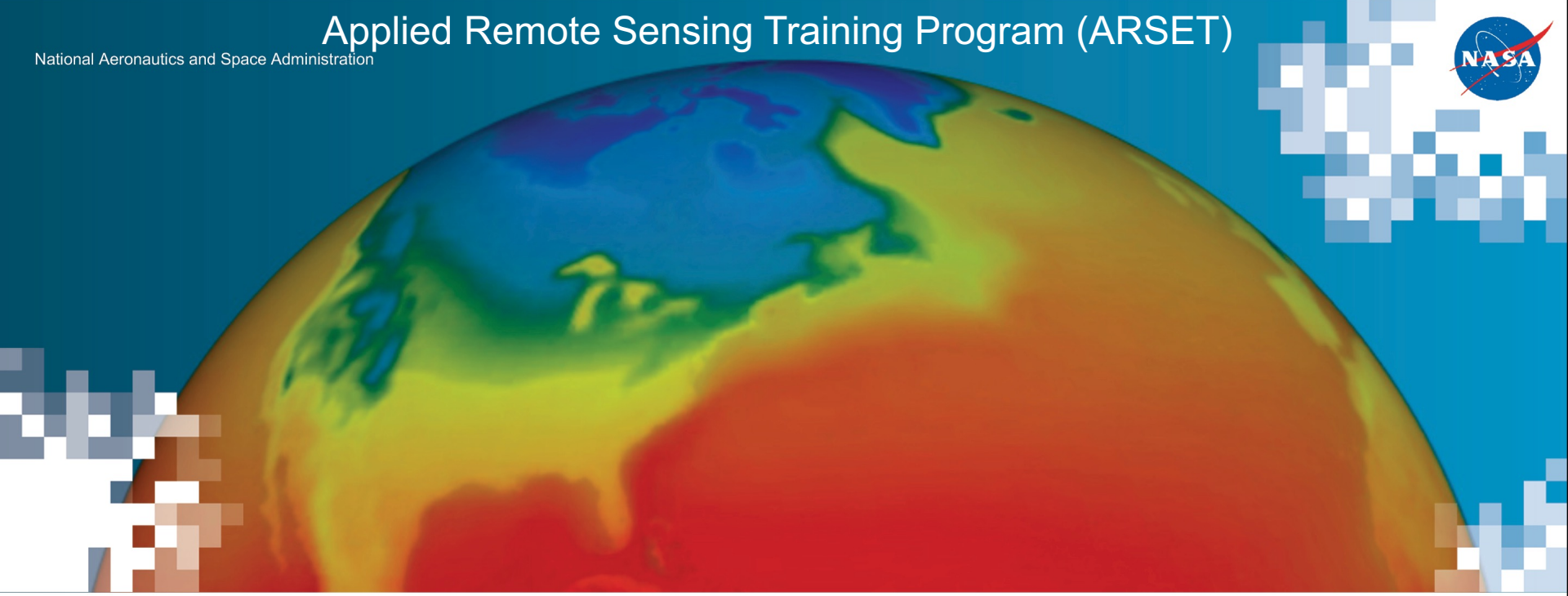
Climate Variability and Anomaly Reports for NASA Langley Research Center

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

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



Courtesy P. Stackhouse, LaRC



Understanding and Obtaining NASA Data Products Through POWER

Collaboration between NASA POWER and NASA ARSET

June 15, 2021

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

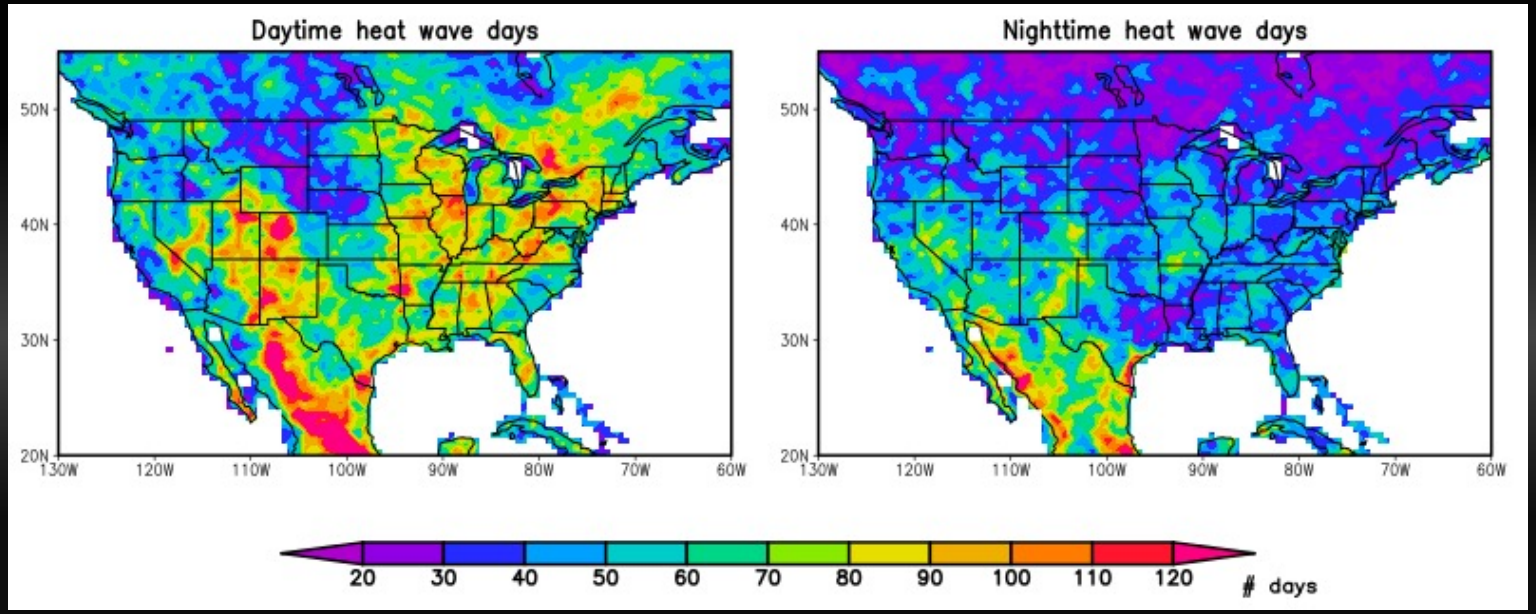
MERRA-2 as a Climate Assessment Enabling Tool

- 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 (>=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 >= 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

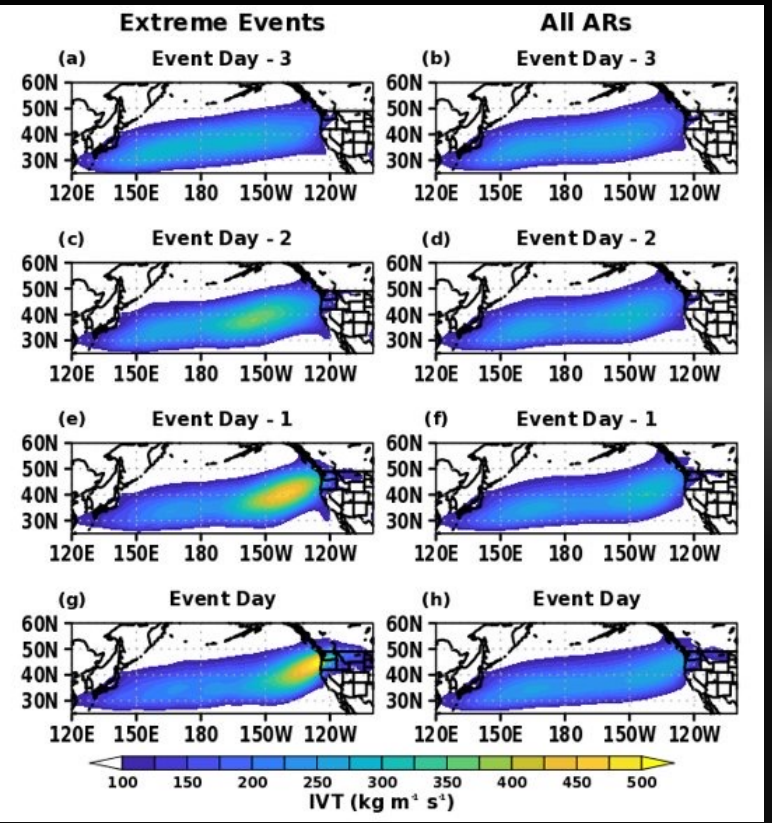
Mechanisms associated with daytime and nighttime heat waves

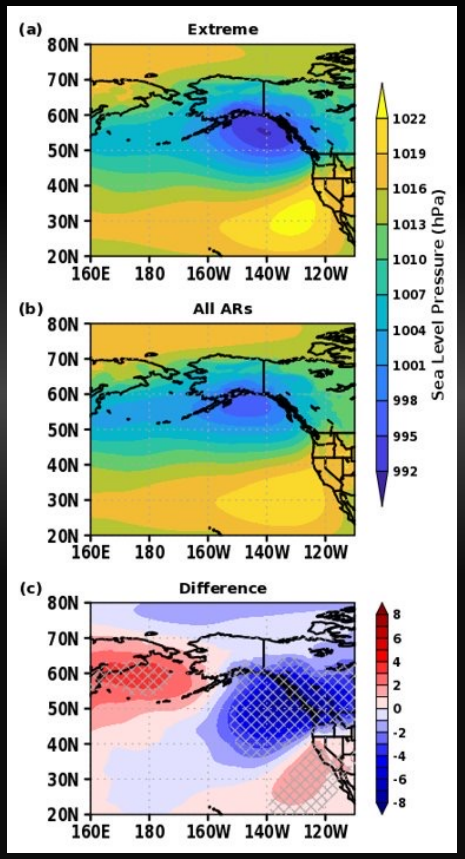


Number of daytime and nighttime heat wave days at each grid point in MERRA-2 over JJA 1980-2018

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 > 95th 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

Collow et al. (2020, J Hydrometeorology)

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/

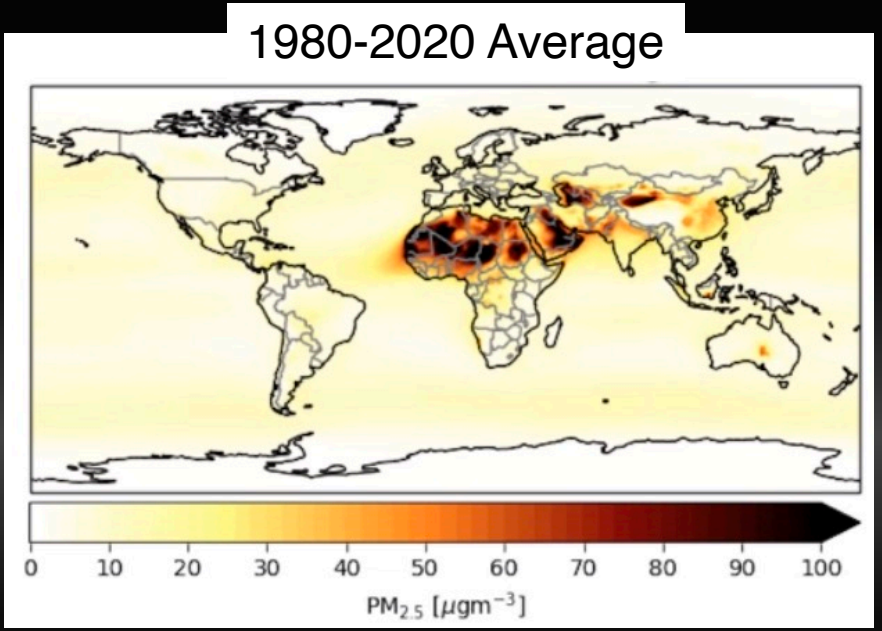


Figure credit: Christoph Keller (NASA GMAO)

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/

Slide Courtesy of Helen Amos

Developing Collaboration: CDC

US Centers for Disease Control (CDC)

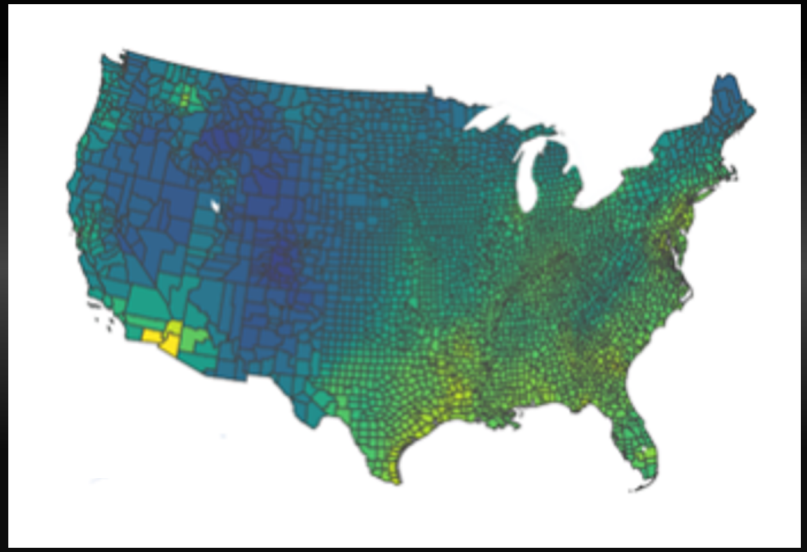
- Climate & Health Program
- Tracking Program

ENVIRONMENTAL PUBLIC HEALTH TRACKING

CDC

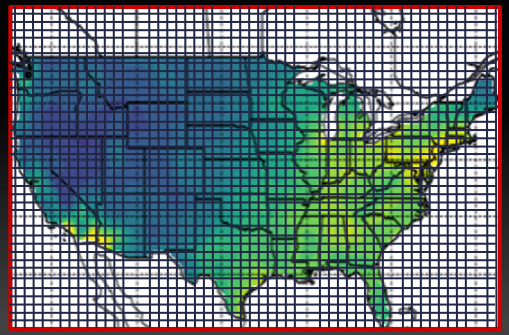
CDC's requirements

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

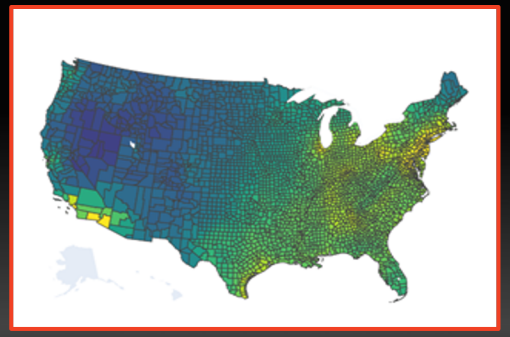


Goal of the internship was to make it easier for public health professionals to use NASA data

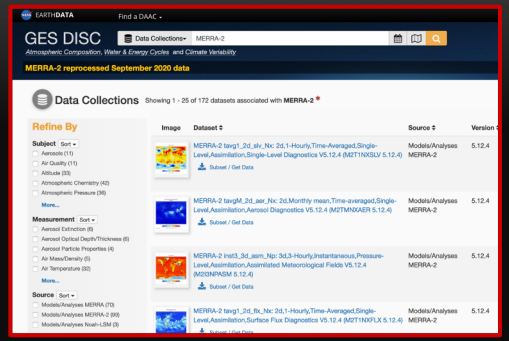
On a climate model grid



County level



In an unfamiliar location



In a central clearinghouse for environ. health data

GMAO Development: Reanalysis of the 21st 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
- GMAO Reanalysis:
  - https://gmao.gsfc.nasa.gov/reanalysis/
  - https://fluid.nccs.nasa.gov/reanalysis/
- POWER: http://power.larc.nasa.gov/