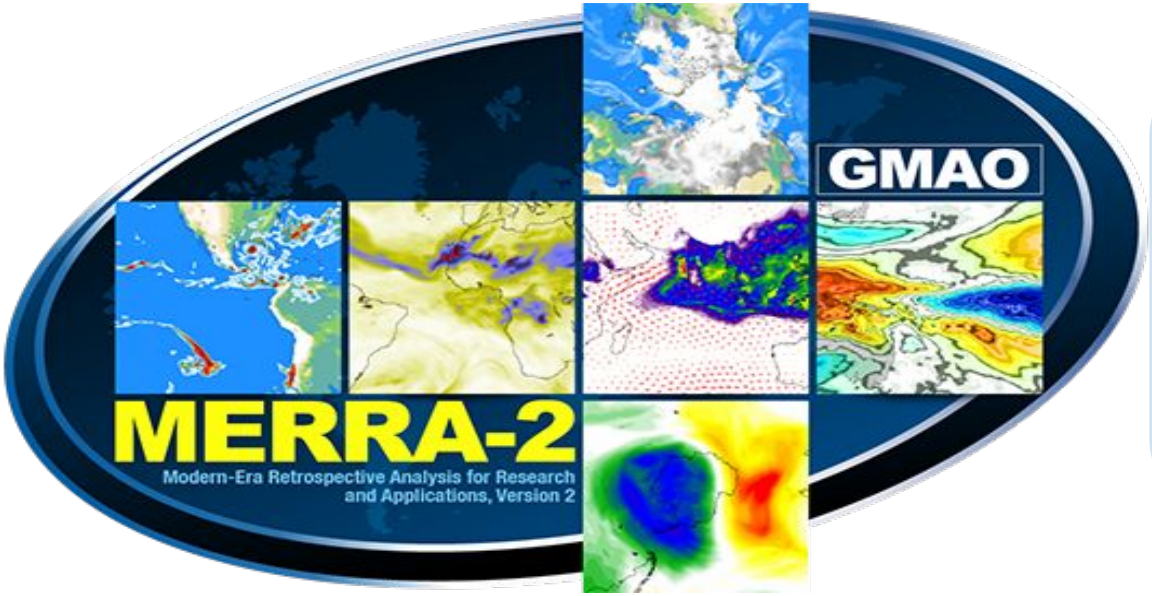
Part 1: Data Assimilation and Reanalysis



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Acknowledgement: The NASA ARSET training and Arlindo da Silva at NASA/GMAO

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GMAO: https://gmao.gsfc.nasa.gov/reanalysis/
GES DISC: https://disc.gsfc.nasa.gov/information/mission-project?title=MERRA-2

Why data assimilation?

Models

Highly spatial and temporal coverage but difficult in specifying emission, microphysical process and transport, leading to large uncertainty

+

Observations

There are a large number of observations, such as aerosol sensors, but with many blind spots

Data assimilation

Integrator of the information from models and observations and conveyor of past observations

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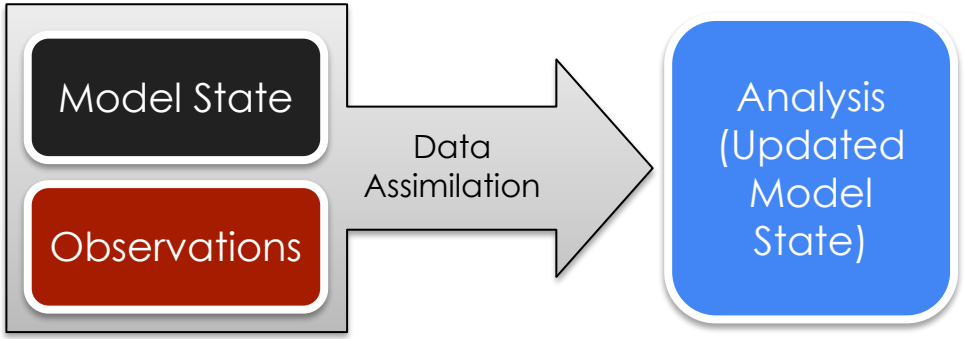
Forecast, Analysis, Reanalysis, Data Assimilation How are they related to each other?

Data assimilation describes the process of assimilating, or incorporating, observations into a model state to produce the best estimate of the atmosphere, land, and ocean conditions.



An **analysis** is the blend of the model and observations.

A **forecast** is a model simulation run forward in time to predict a future state, initialized with the best estimate of current conditions using analysis.

A **reanalysis** is the same as analysis but using a single model version and consistent data assimilation techniques to produce a long-term datasets that can be used for longer term analyses

Reanalysis

What is reanalysis?

- A consistent reprocessing of Earth system observations using a modern, unchanging data assimilation system
- Successful reanalysis ***requires*** a good forecast model combined with bias-corrected and quality-controlled observations
- Relies on models to interpret, relate, and combine different observations from multiple sources

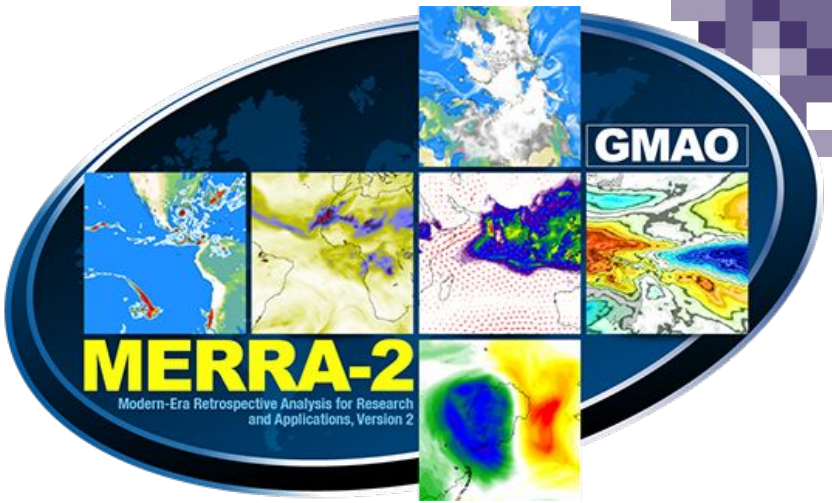
Why do we need it?

- Produces multi-decadal, gridded datasets that estimate a large variety of Earth system variables, including ones that are not directly observed
- Has become fundamental to research and education in the Earth sciences, such as MERRA-2

MERRA-2 Reanalysis

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

- The **M**odern-**E**ra **R**etrospective analysis for **R**esearch and **A**pplications version **2** (MERRA-2) provides data beginning in 1980 and runs a few weeks behind real-time.
- Long-term, model-based reanalyses of multiple datasets using a fixed assimilation system
- Includes meteorology, stratospheric ozone, and aerosols at the spatial resolution of a 0.5° × 0.66° (~50 km) grid

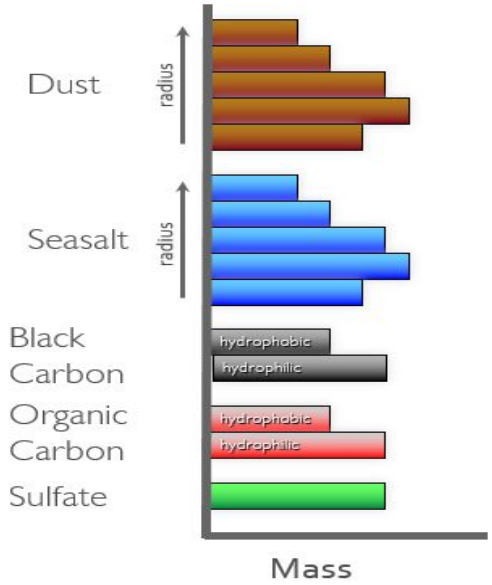


- Three-dimensional variational data analysis (3DVAR) Gridpoint Statistical Interpolation (GSI) meteorological analysis scheme (overviewed in Gelaro et al., 2017)

MERRA-2 Aerosol Model Scheme

Credit: Arlindo da Silva at NASA/GMAO

GOCART in GEOS-5



- Based on the Goddard Chemistry, Aerosol, Radiation, and Transport Model [Chin et al. 2002]
- Sources and sinks for 5 non-interactive species

DUST	wind and topographic source, 5 mass bins
SEASALT	wind driven source, 5 mass bins
BLACK CARBON	anthropogenic and wildfire source, mass hydrophic and hydrophilic
ORGANIC CARBON	anthropogenic, biogenic, and wildfire source, mass hydrophic and hydrophilic
SULFATE	anthropogenic and wildfire source of SO_2, oxidation to SO_4 mass

Nitrate not included

- Convective and large scale wet removal
- Dry deposition (and sedimentation for dust and sea salt)
- Optics based primarily on OPAC

- Aerosols are coupled to the meteorological reanalysis (both radiatively and through emissions/loss processes)

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MERRA-2 Aerosol Observations

- Aerosol assimilation is described in detail in Randles et al. 2017 and https://gmao.gsfc.nasa.gov/pubs/docs/Randles887.pdf.
- The MERRA-2 aerosol analysis uses the Goddard Aerosol Assimilation System (GAAS). Every 3 h, this system assimilates quality-controlled AOD at 550 nm into the GEOS-5/GOCART modeling system.
- Information to keep in mind when using MERRA-2 aerosol output:
  - No information on vertical structure or composition
  - Daylight observations only
  - Subject to meteorological conditions (e.g., clouds) and viewing geometry (e.g., sun glint)
  - When there are no observations, MERRA-2 draws towards the GEOS/GOCART simulation.

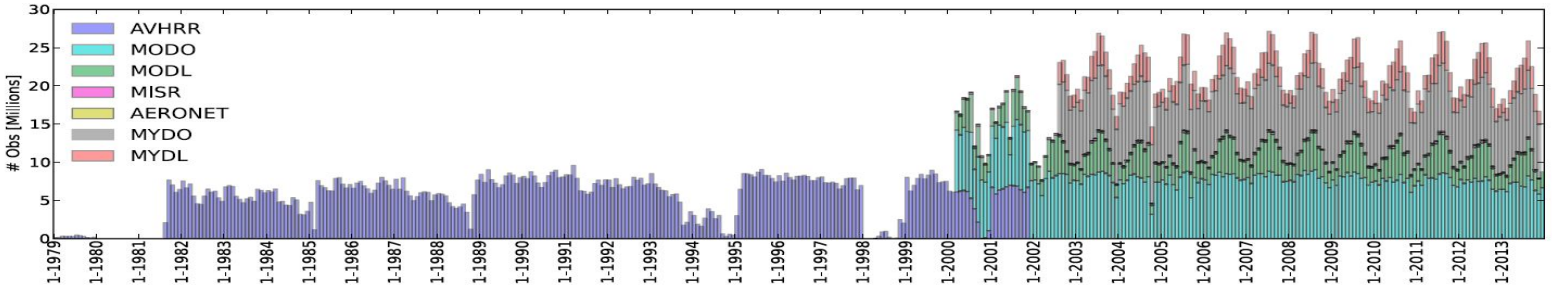


Figure 3 from Randles et al. 2017

MERRA-2 Global Mean AOD Reanalysis

- Aerosol reanalysis for the modern satellite era (1980-onward)
- This is the first multidecadal reanalysis within which meteorological and aerosol observations are jointly assimilated into a global assimilation system

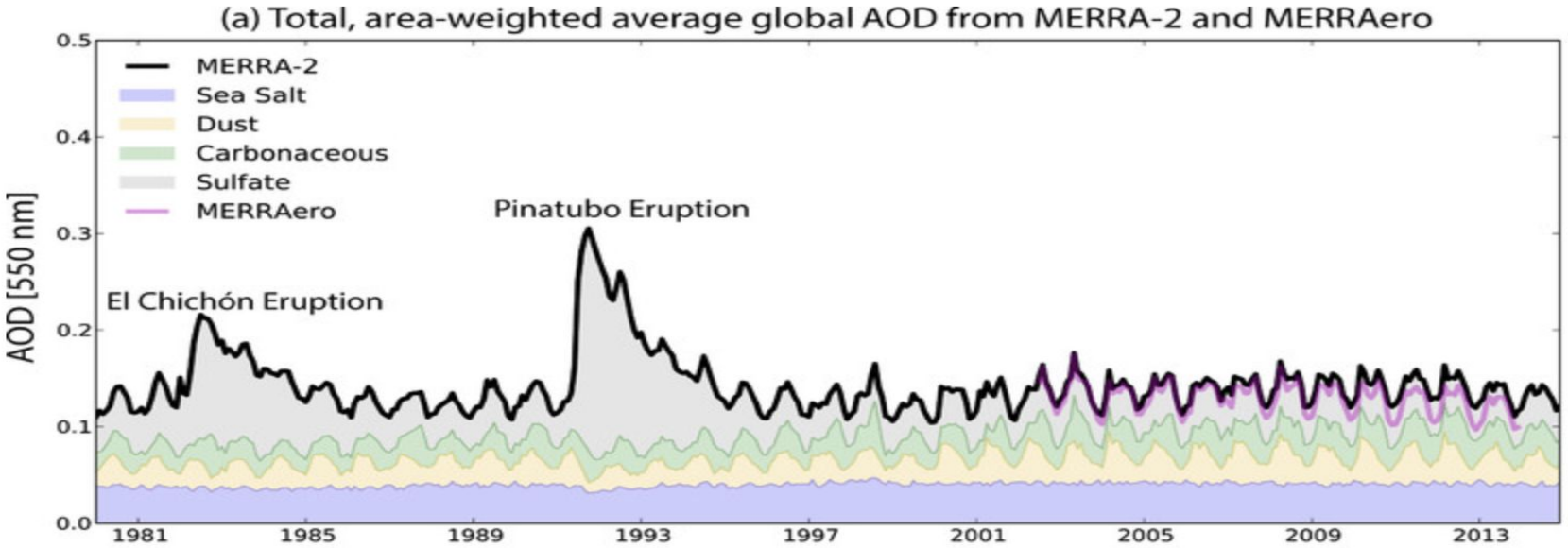


Figure 5a from Randles et al. 2017

Overview of MERRA- 2

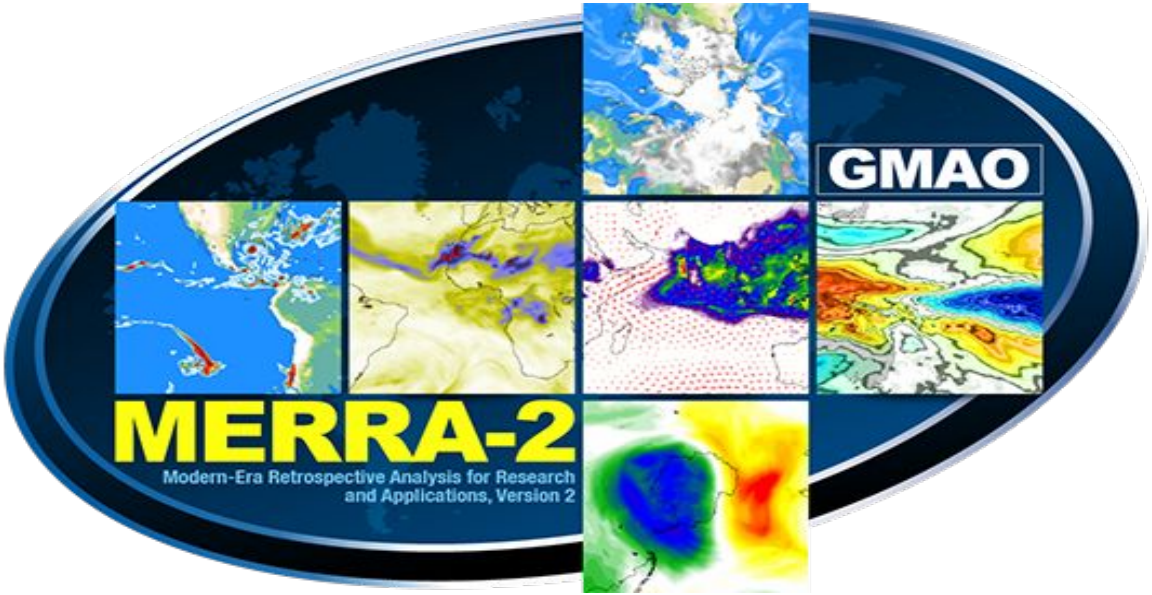
- Generated by NASA Global Modeling and Assimilation Office (GMAO)
- Archived and distributed at NASA GES DISC
- ***Total of 99 collections*** *(95 standard collections, 4 derived climate statistical collections) available in both the on-prem archive and the AWS S3 buckets (list).*
- *One value-added collection monthly $PM_{2.5}$ at country level available in on-prem archive only (link)*

- Model Version: 5.12.4
- Format: NetCDF4
- Temporal Range: 1980-01-01 to Present
- Temporal Resolution: Hourly, 3-Hourly, Daily, Monthly, and Monthly Diurnal
- Spatial Coverage: Global
- Spatial Resolution:
  - 2D: 0.5° × 0.625°
  - 3D: 0.5° × 0.625° × 72 model levels or
  - 0.5° × 0.625° × 42 pressure levels
- **Data Latency: ~ 3 weeks**
- **Users: Over 7000 in 2021**

MERRA-2 project page at the GES DISC

AWS: Amazon Web Services. **S3:** Simple Storage Service.

Part 2: Discover and Access MERRA-2 Air Quality Data



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GES DISC: https://disc.gsfc.nasa.gov/information/mission-project?title=MERRA-2

1. Key MERRA-2 Collections and Variables Useful for Air Quality Studies

Measurements	Data Collection (data DOI hyperlink)	Parameters (variable long-name in the collection)	Temporal Feature
Aerosol Optical Depth (AOD)	M2T1NXAER_5.12.4 (i.e., tavg1_2d_aer_Nx)	total aerosol extinction aot [550 nm]	1 hourly averaged
	M2TMNXAER_5.12.4 (i.e., tavgM_2d_aer_Nx)	total aerosol extinction aot [550 nm]	monthly mean
& $PM_{2.5}$	M2T1NXAER_5.12.4 (i.e., tavg1_2d_aer_Nx)	surface mass concentration of SO_4, BC, OC, dust, and sea salt	1 hourly averaged
	M2TMNXAER_5.12.4 (i.e., tavgM_2d_aer_Nx)	surface mass concentration of SO_4, BC, OC, dust, and sea salt	monthly mean
@ $PM_{1.0}$ & PM_{10}	M2I3NVAER_5.12.4 * (i.e., inst3_3d_aer_Nv)	mixing ratio of SO_4, BC, OC, dust, and sea salt	3 hourly instantaneous
Carbon Monoxide (CO)	M2T1NXCHM_5.12.4 (i.e., tavg1_2d_chm_Nx)	CO surface concentration	1 hourly averaged
	M2TMNXCHM_5.12.4 (i.e., tavgM_2d_chm_Nx)	CO surface concentration	monthly mean
Meteorological Conditions	M2T1NXSLV_5.12.4 (i.e., tavg1_2d_slv_Nx)	wind, specific humidity, air temperature at 2-meter, 10-meter, 850 hPa	1 hourly averaged
	M2TMNXSLV_5.12.4 (i.e., tavgM_2d_slv_Nx)	wind, specific humidity, air temperature at 2-meter, 10-meter, 850 hPa	monthly mean
	M2T1NXFLX_5.12.4 (i.e., tavg1_2d_slv_Nx)	PBL height, precipitation	1 hourly averaged
	M2TMNXFLX_5.12.4 (i.e., tavgM_2d_slv_Nx)	PBL height, precipitation	monthly mean
	M2T3NVASM_5.12.4 * (i.e., tavg3_3d_asm_Nv	wind, relative humidity, air temperature, pressure, height at model levels	3 hourly averaged

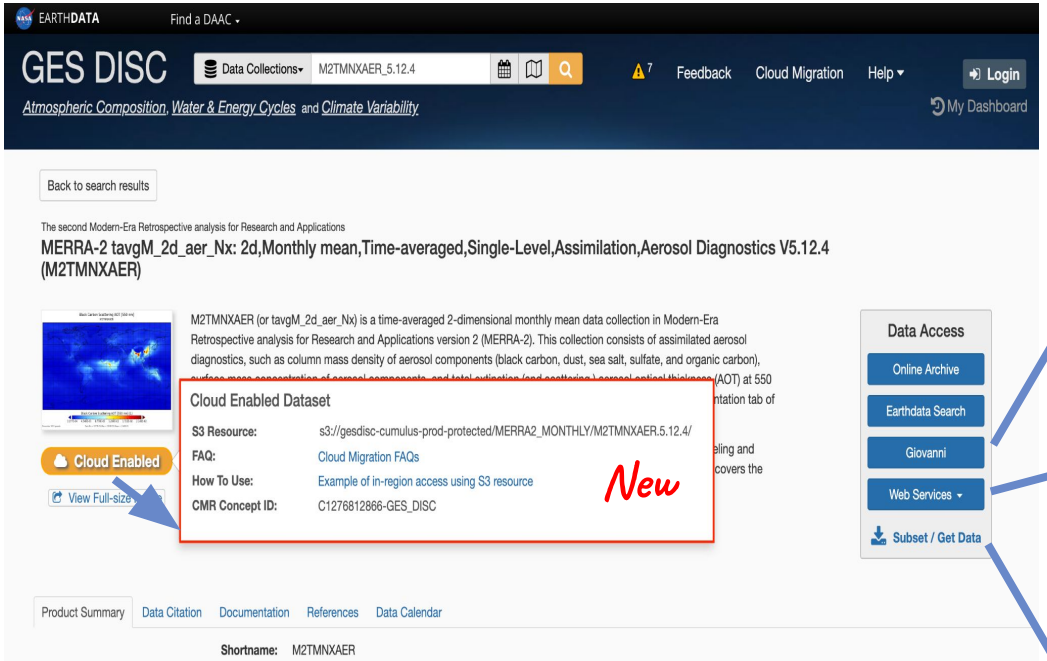
& Surface $PM_{2.5}$ can be derived by variables listed in that collection: TOTSPM25 = OCSMASS+ BCSMASS+ SO4SMASS*1.375+ DUSMASS25 + SSSMASS25

@ $PM_{1.0}$ and PM_{10} the formula can be found at the MERRA-2 project FAQ .

* In 3D (the rest collections in this table are in 2D).

2. Search the MERRA-2 collection and variables

3. Access MERRA-2 Data



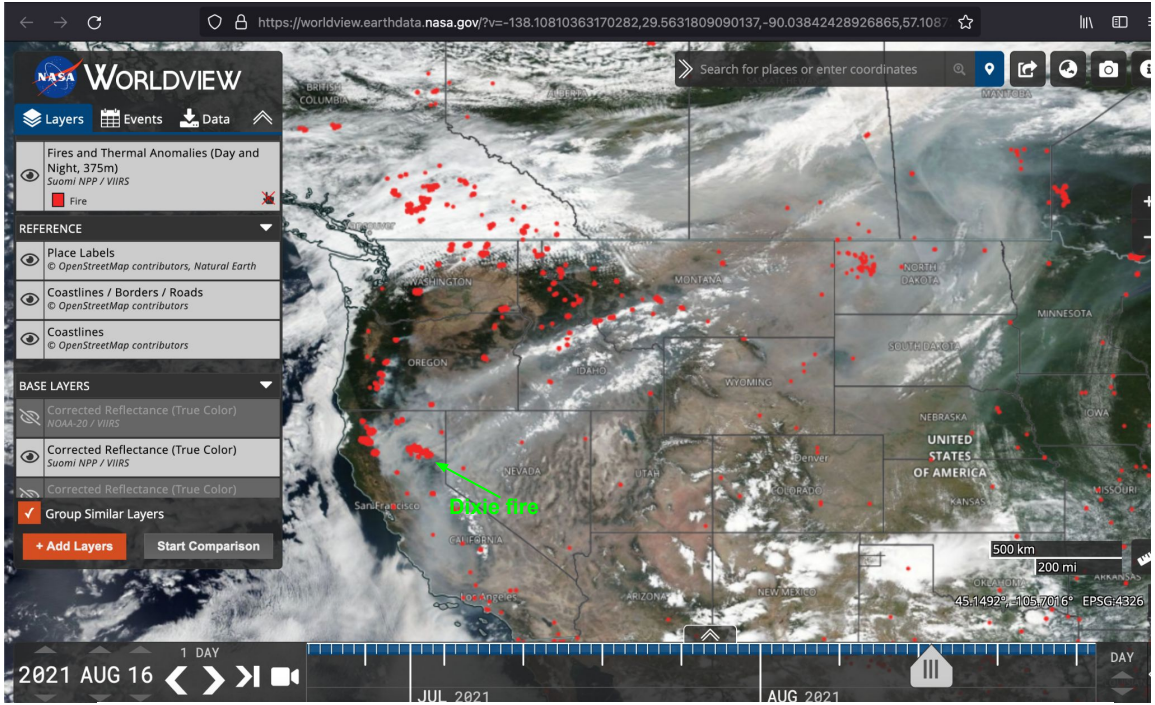
The Dataset Landing Page of the Collection M2TMNXAER

- Giovanni - Interactive visualization webtool (demonstrated later)
- **Web Services**
  - **GDS:** remotely access data with GrADS or other scripts (e.g., Python)
  - **OPENDAP:** subset and download data or remotely access the data via data tools or scripts (e.g., Panoply, IDV, Python, etc.).
  - **THREDDS:** subset, aggregate, and download data, or remotely access time series with data tools or scripts (e.g., Panoply, ArcGIS, Python, etc.).
- **Subset / Get Data** → subset, regrid, and download data, and compute daily statistics (mean, minimum, maximum) on-the-fly

4. Demonstrate data tools

4.1 Demo: How to use Worldview to visualize severe air quality events

Suomi NPP / VIIRS RGB and Hotspots Map on 08/16/2021



Screenshot from NASA Worldview

Science Questions:

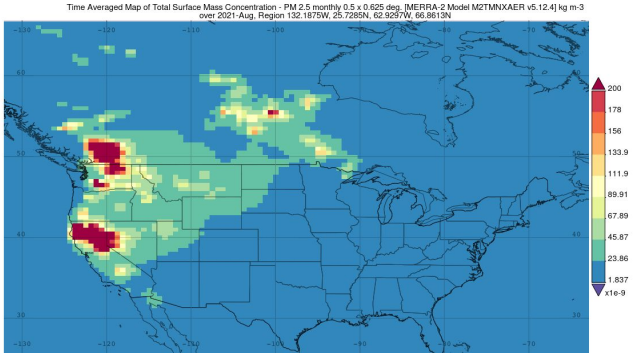
- ❑ How severe were the impacts of 2021 summer California wildfires on air quality?
- ❑ Was it the most severe wildfire season in recent 10 years (2012-2021)?

More Info: What the numbers tells us about a catastrophic year of wildfires (the Guardian)

2021 California wildfires (Wikipedia)

4.2 Demo: How to use Giovanni to visualize MERRA-2 PM2.5

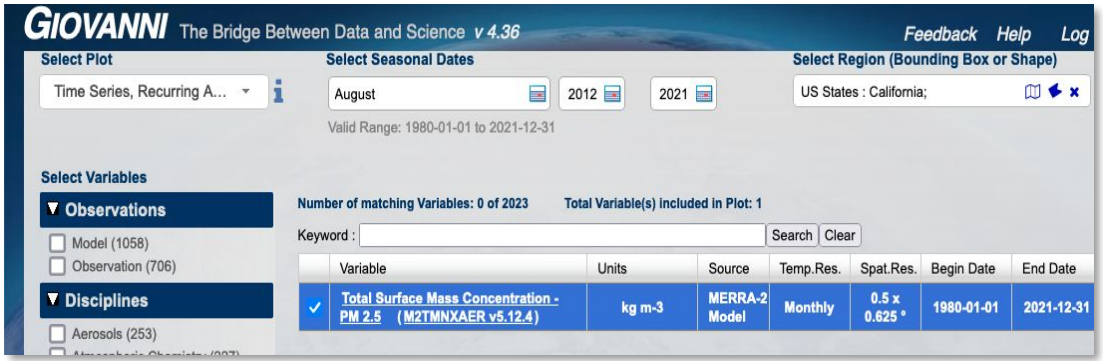
1) $PM_{2.5}$ for August 2021



Dataset: MERRA-2 → monthly $PM_{2.5}$ in collection M2TMNXAER
Visualization Tool: Giovanni
Select Plot: Map, Time averaged Map Average
Select Region: Rectangle

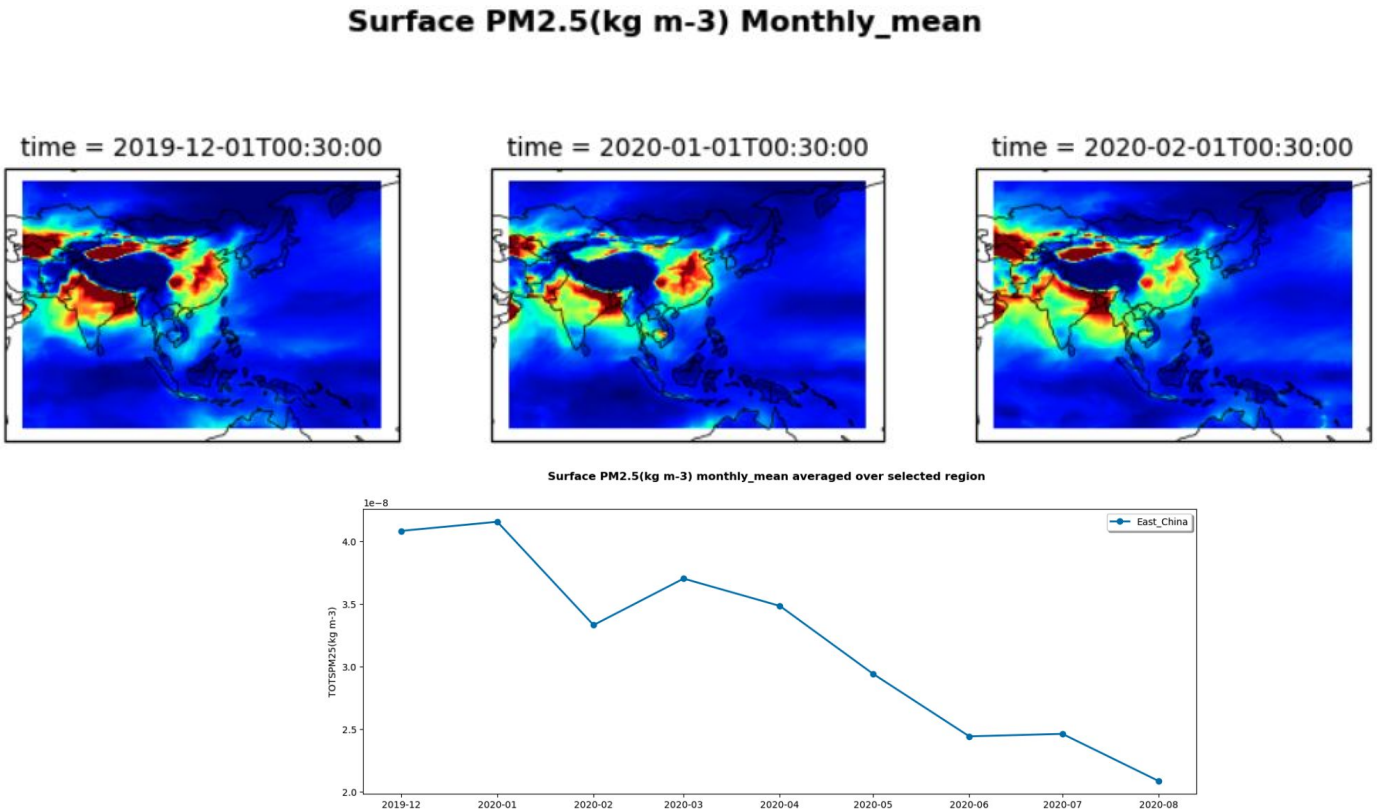
2) Interannual variation of August mean $PM_{2.5}$ over CA for 2012-2021

Dataset: The same
Visualization Tool: Giovanni
Select Plot: Time Series, Recurring Average
Select Region: Shapefile for CA



4. Demonstrate data tools

4.2 Demo: How to use Python notebook to visualize MERRA-2 $PM_{2.5}$



5. Find Assistance for Using the MERRA-2 Data

- Read the MERRA-2 project page at the GES DISC
- Contact Us - GES DISC Help Desk
  - When you need any assistance or to report a data access problem
  - When you want to sign up for the MERRA-2 listserv to receive announcements on the latest data information, tools and services that become available, data announcements from GMAO and more …
- Contact GMAO - merra-questions@lists.nasa.gov
  - When you have questions on science content such as the definition of a variable

References

- GOCART
  - Chin, M., P. Ginoux, S. Kinne, O. Torres, B. Holben, B. Duncan, R. Martin, J. Logan, A. Higurashi, and T. Nakajima (2002), Tropospheric aerosol optical thickness from the GOCART model and comparisons with satellite and Sun photometer measurements, J. Atmos. Sci., 59(3), 461–483. https://doi.org/10.1175/1520-0469(2002)059<0461:TAOTFT>2.0.CO;2
  - Colarco, P., A. Da Silva, M. Chin, and T. Diehl (2010), Online simulations of global aerosol distributions in the NASA GEOS-4 model and comparisons to satellite and ground-based aerosol optical depth, J. Geophys. Res.-Atmos., 115, –, doi:10.1029/2009JD012820. https://doi.org/10.1029/2009JD012820

- MERRA-2
  - https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/docs/
  - File Specification Document - https://gmao.gsfc.nasa.gov/pubs/docs/Bosilovich785.pdf
  - Aerosol Assimilation – Technical Document - https://gmao.gsfc.nasa.gov/pubs/docs/Randles887.pdf
  - Gelaro et al.,. 2017. The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). Journal of Climate. Vol. 30, No. 14, pp. 5419-5454. DOI: 10.1175/JCLI-D-16-0758.1 ISSN: 0894-8755. https://journals.ametsoc.org/view/journals/clim/30/14/jcli-d-16-0758.1.xml
  - Randles et al. (2017) The MERRA-2 Aerosol Reanalysis, 1980 Onward. Part I: System Description and Data Assimilation Evaluation - https://journals.ametsoc.org/view/journals/clim/30/17/jcli-d-16-0609.1.xml
  - Buchard et al. (2017) The MERRA-2 Aerosol Reanalysis, 1980 Onward. Part II: Evaluation and Case Studies - https://journals.ametsoc.org/view/journals/clim/30/17/jcli-d-16-0613.1.xml

Additional slides

MERRA-2 Collection Naming Convention Used by ESDIS

- MERRA-2 outputs are organized into file *collections* that contain related variables.
- The 9-character shortname of a collection has the form, e.g., M2TMNXAER

M2TimeFrequencyDimensionsGroup

Time (1 letter)

Time description
- C = constant
- I = instantaneous
- T = time-average
- S = statistics

Frequency (1 letter or number)

Frequency or averaging interval
- 1 = Hourly
- 3 = 3-Hourly
- 6 = 6-Hourly
- M = Monthly mean
- D = Daily statistics
- U = Monthly-Diurnal mean: consists monthly mean of data at each sub-daily time stamp.
- C = Climatology monthly mean (30 years mean from 1981 to 2010)

Dimensions (two letters)

Dimensions of variables
- NX = 2D (single level)
- NP = 3D at 42 Pressure levels
- NV = 3D at at 72 model layer center

Group (3 letters)

Type of variables
- These are also used in the shortname
  Ex. AER = Aerosol fields
- See documentation for full list

More Info: MERRA-2 Quick Guide - Data Collection

MERRA-2 Collection Naming Convention Used by GMAO

- MERRA-2 outputs are organized into file *collections* that contain related variables.
- The 12 or 13-character shortname of a collection has the form, e.g., tavgM_2d_aer_Nx

Frequency_Dimensions_Group_HV

Frequency

Frequency or averaging interval
- const = time-independent
- inst = instantaneous
- tavg = time-average
- Stat = statistics

Can be 1, 3, 6-hourly, daily (D), monthly (M), or a monthly-diurnal mean (U)

Group

Three letter abbreviation for the type of variables
- These are also used in the shortname
- Ex. aer = Aerosol fields
- See documentation for full list

Dimensions

Dimensions of variables
- 2d = only 2d fields
- 3d = can have 2d and 3d

HV

Horizontal and vertical grid
- H = typically N, for nominal grid
- V = x, horizontal only
- V = p, pressure level
- V = v, model level
- V = e, model layer edges

More info, MERRA-2 Data Collection

MERRA-2 File Naming Conventions

- Each MERRA-2 file has the form, e.g.,
  MERRA2_400.tavgM_2d_aer_Nx.202110.nc4
  MERRA2_SVv.collection.timestamp.nc4

Stream and Version

File version (usually 100, 200, 300, or 400)

Collection

Collection Naming Convention used by GMAO

All MERRA-2 output files are in NetCDF-4 format.

Timestamp

Date and time of data file

- For instantaneous or time-averaged files:
  yyyymmdd
- For monthly files:
  yyyymm

For collections with instantaneous or time-averaging frequency < 1 day, the daily file will contain all of the timesteps

Part 2 from the Series Introduction and Access to Global Air Quality Forecasting Data and Tools

More Info: MERRA-2 Quick Guide - Data filenaming convention