May 14, 2026

Cloud-based Approach to Atmospheric Model Evaluation: Introducing AMET-Web

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CMAS Center, UNC Institute for the Environment

Recognition for the EPA developers of AMET; (AQ) Wyat Appel and (MET) Robert Gilliam, and AMET tools; Christian Hogrefe at U.S. EPA

Disclaimer: The information and views shared in this presentation are the speaker's and any mistakes or omissions are the speaker's responsibility and does not necessarily reflect the knowledge, views or policies of the U.S. EPA

The University of North Carolina at Chapel Hill

Webinar Objectives

- Describe resources supported by the CMAS Center and EPA
- Introduce the Atmospheric Model Evaluation Tool
- Demonstrate AMET Website on AWS Cloud VM
  - AMET database on AWS Cloud VM pre-loaded with model-obs paired data for:
    - July 2018 (aqExample for CMAQ 12US1)
    - July 2016 (metExamples for WRF (CONUS), MCIP (CONUS) and MPAS(Global))
    - **2002-2019 EQUATES: EPA's Air QUAlity TimE Series Project (CMAQ 12US1)**
- Create and visualize air quality (AQ) and meteorology (MET) model-observation evaluation plots using the AMET AQ and MET Websites

CMAS Center Resources

CMAS Center Supported - EPA Open-Source Software (available on github – developed over past 25 years)

AMET	VERDI	SMOKE	CMAQ
1.3 (2017)	2.1.5 (2024)	5.0 (2023)	5.32 (2020)
1.4 (2019)	2.1.6 (2025)	5.1 (2024)	5.4 (2022)
1.5 (2022)	2.2 (2025)	5.2 (2025)	5.5 (2024)
1.6 (2026*)	2.3 (2026*)	5.3 (2026*)	6.0 (2026*)

10+ additional CMAS Center Supported Tools and Models including WRF-CMAQ and MPAS-CMAQ

Release Calendar: https://www.cmascenter.org/download/release_calendar.cfm

*Planned Releases

Cloud-based AMET-Web available on AWS

- The **A**tmospheric **M**odel **E**valuation **T**ool (AMET) is a publicly available and open-source software developed by the U.S. EPA to facilitate the evaluation of meteorological and air quality models
  - https://www.epa.gov/cmaq/atmospheric-model-evaluation-tool
  - Appel et al, 2011 https://www.sciencedirect.com/science/article/abs/pii/S1364815210002653
- AMET itself is built using several open-source software packages including R and is dependent on MariaDB database software that is leveraged to store and query the paired observation and model outputs
- AMET (v1.6) contains the PHP code that uses an Apache Server for web-based model evaluation
- CMAS Center created an AWS AMI pre-installed with AMETv1.6 to facilitate the use of AMET-Web for the CMAS user community

CMAS Center Resources supporting AMET

CMAS Data Warehouse

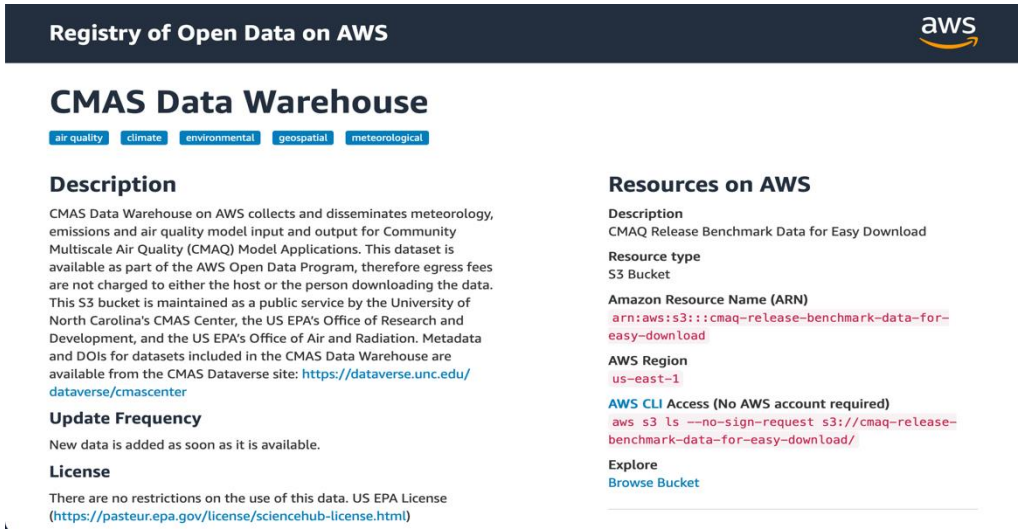
- AWS Open Data Program hosts AMET, CMAQ and Model-ready Emissions Datasets
  - https://registry.opendata.aws/cmas-data-warehouse/
  - AMET S3 Bucket: https://cmas-amet.s3.amazonaws.com/index.html
- Metadata for AMET model/obs datasets available on UNC Dataverse
  - https://dataverse.unc.edu/dataset.xhtml?persistentId=doi:10.15139/S3/XT8V2I

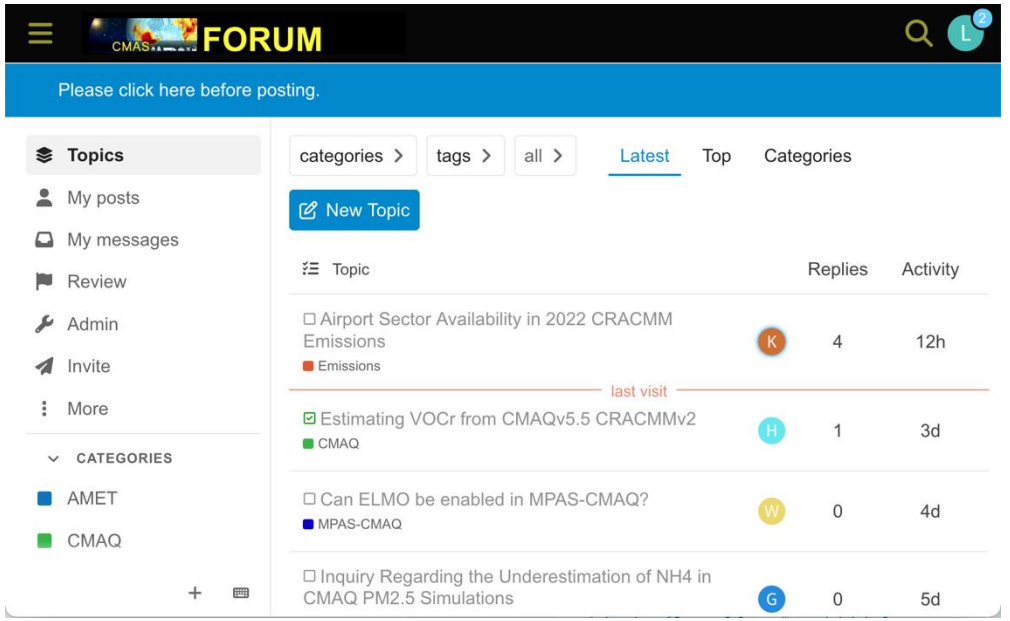
CMAS User Forum

- Discourse forum link for AMET Category
  - https://forum.cmascenter.org/c/amet/16

CMAS Center Website

- Conference
  - AMET-Web users are invited to submit abtract for Cloud Computing Session, due July 17, 2026
  - 2026 CMAS Conference Website
- Webinars
  - https://www.cmascenter.org/resources/webinars.cfm
  - AMETv1.4 Webinar
- Cloud Tutorials
  - CMAQ and AMET on AWS
- Cloud Help Desk via Zoom
  - 1st Thursday of Month, 3-4pm
  - https://unc.zoom.us/meeting/register/tJMscumurzMvHtFJ32koXFqT5PAbJdlrceHR





Introduction to AMET

General Overview of AMET

- Model evaluation tool for both MET and AQ models
  - MET: WRF, MCIP, MPAS
  - AQ: CMAQ, CAMx
  - Coupled Models: WRF-CMAQ, MPAS-CMAQ
- Utilizes open-source software
  - MariaDB database
  - AMET Tools (CMAQ Post-processing): Fortran https://github.com/USEPA/CMAQ/tree/main/POST#post-processing-tools
  - R statistical software (MySQL queries and analysis)
- Advantages of AMET
  - capable of managing large datasets efficiently
  - partially automated system
  - relational database allows for unique querying of data
  - pre-defined analysis scripts and R programs
  - users can develop own custom analysis or leverage output files to do their own analysis

Air Quality Model Evaluation

Help identify and confirm:

- Hourly, daily, seasonal pollution patterns
- Pollutants with a short atmospheric lifetime help provide information on local and regional air quality
  - Use AMET spatial plots help determine if there is a spatial pattern to the model bias
- Pollutants with a long atmospheric lifetime help provide information on long distance transport at synoptic scales
- Behavior of secondary pollutants
  - $PM_{2.5}$ is made up of both primary (directly emitted) as well as secondary (through chemical conversion of gas-phase species) components
- Are models capturing both the minimum and maximum values of Ozone, PM and other pollutants compared to observations?

AMET contributes to CMAQ Model Evaluations:

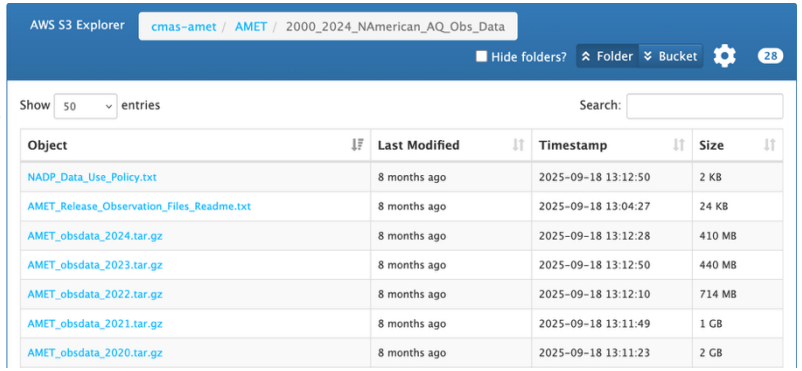
- Evaluate the impact of
  - new deposition schemes
  - boundary and initial conditions
  - model resolution
  - new chemical mechanism
  - improvements in emission inventories
  - Improvements in emission inventory resolution (1km NEMO)
  - improved wildfire emissions
- Evaluate long-term trends
  - Observe decrease in pollution due to effective emissions controls
- Evaluate meteorology model improvements
  - Improvements in timing and extent of cold fronts that transport pollutants from the boundary layer to the troposphere help reduce model bias.
- Model evaluations:

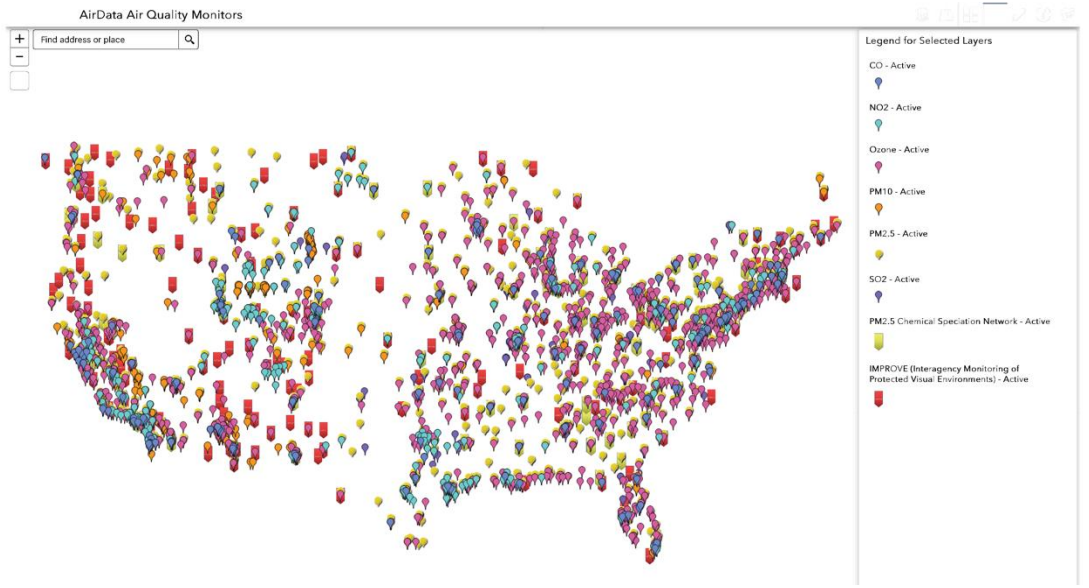
- Appel, K. W., Pouliot, G. A., Simon, H., Sarwar, G., Pye, H. O. T., Napelenok, S. L., Akhtar, F., and Roselle, S. J.: Evaluation of dust and trace metal estimates from the Community Multiscale Air Quality (CMAQ) model version 5.0, Geosci. Model Dev., 6, 883–899, https://doi.org/10.5194/gmd-6-883-2013, 2013.
- Campbell, P. C., Tang, Y., Lee, P., Baker, B., Tong, D., Saylor, R., Stein, A., Huang, J., Huang, H.-C., Strobach, E., McQueen, J., Pan, L., Stajner, I., Sims, J., Tirado-Delgado, J., Jung, Y., Yang, F., Spero, T. L., and Gilliam, R. C.: Development and evaluation of an advanced National Air Quality Forecasting Capability using the NOAA Global Forecast System version 16, Geosci. Model Dev., 15, 3281–3313, https://doi.org/10.5194/gmd-15-3281-2022, 2022.
- Farzad, K., Zhang, Y., Tong, D., Ma, S., Tang, Y., Huang, J., et al. (2026). Application and evaluation of a NOAA GFS-driven air quality model using CMAQv5.4 and high-resolution emissions: FIREX-AQ 2019. Journal of Geophysical Research: Atmospheres, 131, e2025JD045668. https://doi.org/10.1029/

Understanding AQ Observational Data

AMET AQ Observational Data for 2000-2024 (available in North America)

- **Prepared by EPA AMET Developer**
- Metadata on UNC Dataverse CMAS Center: https://dataverse.unc.edu/dataset.xhtml?persistentId=doi:10.15139/S3/XT8V2I
- **Download from CMAS Center Data Warehouse on AWS**: https://cmas-amet.s3.amazonaws.com/index.html#AMET/2000_2024_NAmerican_AQ_Obs_Data/
  - Understand what species are available from each observation network to avoid plot errors (no data available).

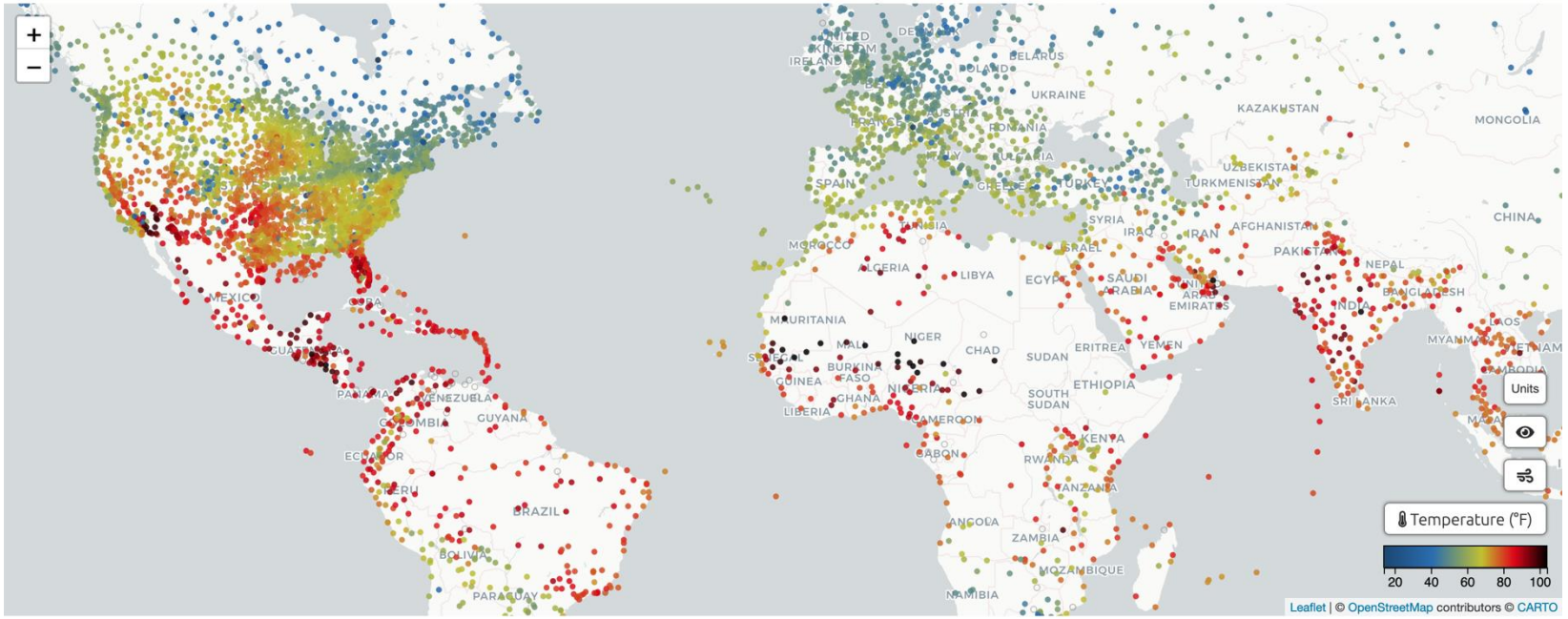




https://www.epa.gov/outdoor-air-quality-data/interactive-map-air-quality-monitors

Understanding MET Observational Data

AMET MET Observational Data is automatically downloaded from MADIS GTS METAR Data (available from World-wide sites) as model-obs pairs are loaded into MySQL



Understanding Model Output Data

- The model species available are much more extensive than what is measured at observation networks
- Plots may be generated only for paired model-observation data.
  - 6 MET variables in metExample projects (mcip, wrf, and mpas)
  - 40 AQ species in EQUATES (cmaq)
  - 126 AQ species in aqExample (cmaq)
- Number of paired model-obs data are dependent on the horizontal resolution and geographic area (regional, continental, or global scale model) and time range (month, annual, decades) available in the model output. Are there multiple observation sites within a single grid cell? Are these observation values averaged or interpolated prior to comparison to model data?
- Understand the model scenario: month, year, duration, model version, model options (chemical mechanism, physics options, boundary conditions, initial conditions)

WRF, MCIP, MPAS Simulation Domains VERDI Plots of Temperature

AMET loads model/obs paired data, obtaining domain, grid resolution, time period, species, units from model and matches to obs data. Resolves names from various models (T2, TA, t2m) to correct observational species name (2 meter Temperature), and does require unit conversions

Domain information from model output

WRF:

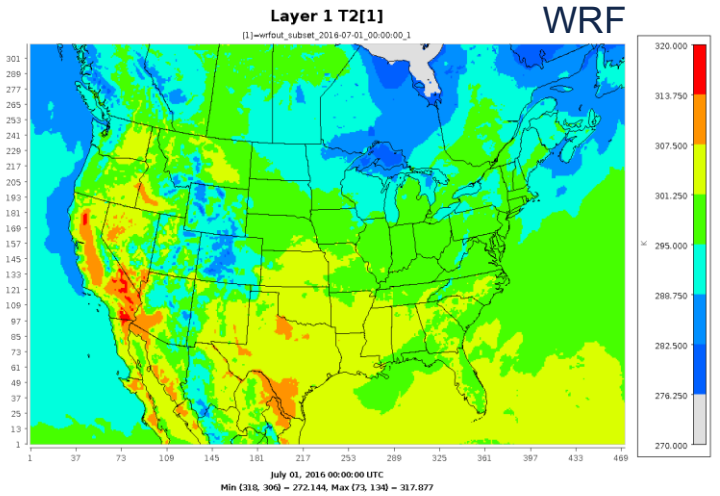
- `WEST-EAST_GRID_DIMENSION = 472 ;`
- `:SOUTH-NORTH_GRID_DIMENSION = 312 ;`
- `:BOTTOM-TOP_GRID_DIMENSION = 36 ;`

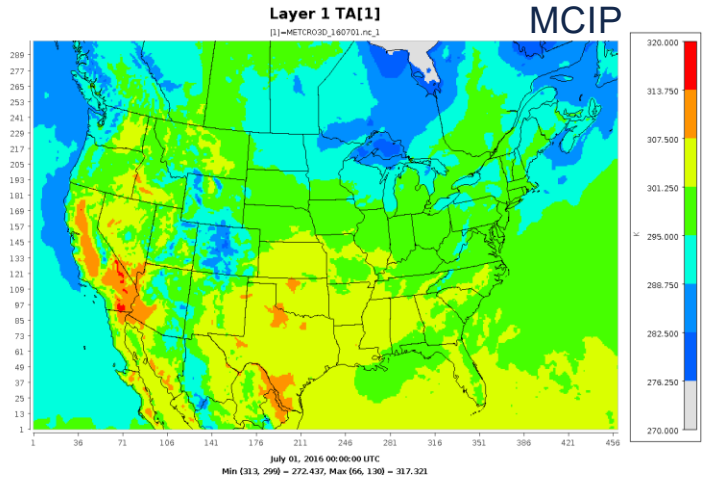
MCIP

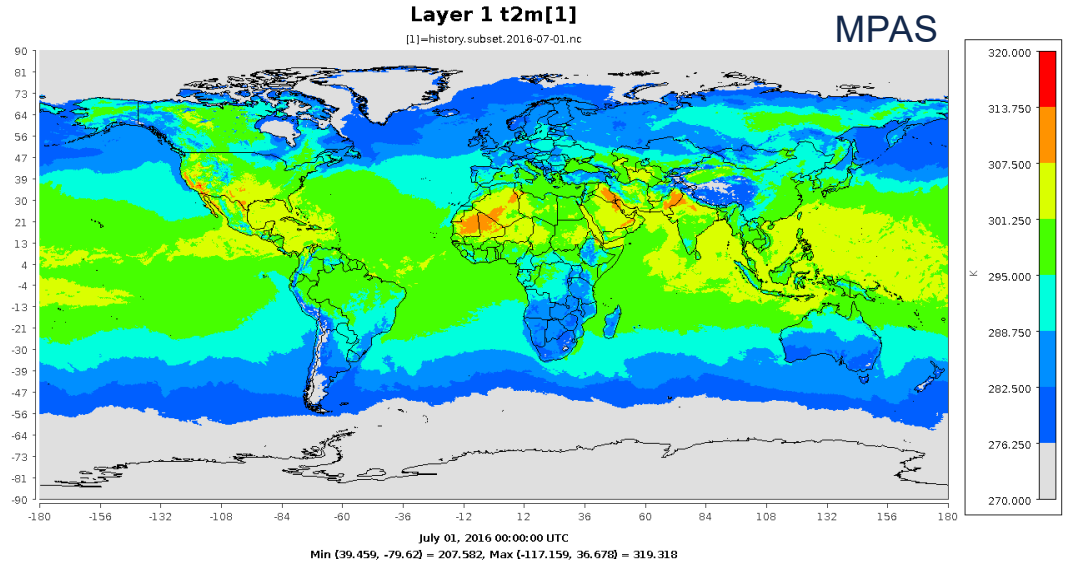
- `NCOLS = 459 ;`
- `NROWS = 299`

MPAS:

- `dimensions: nVertLevels = 50 ; nCells = 40962 ; nEdges = 122880 ; nVertices = 81920 ;`

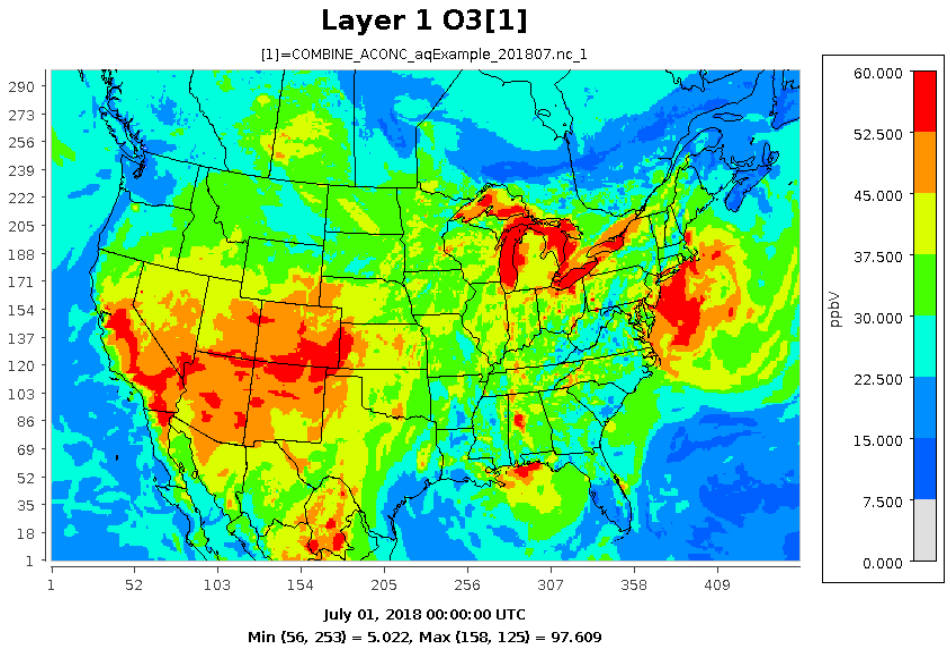




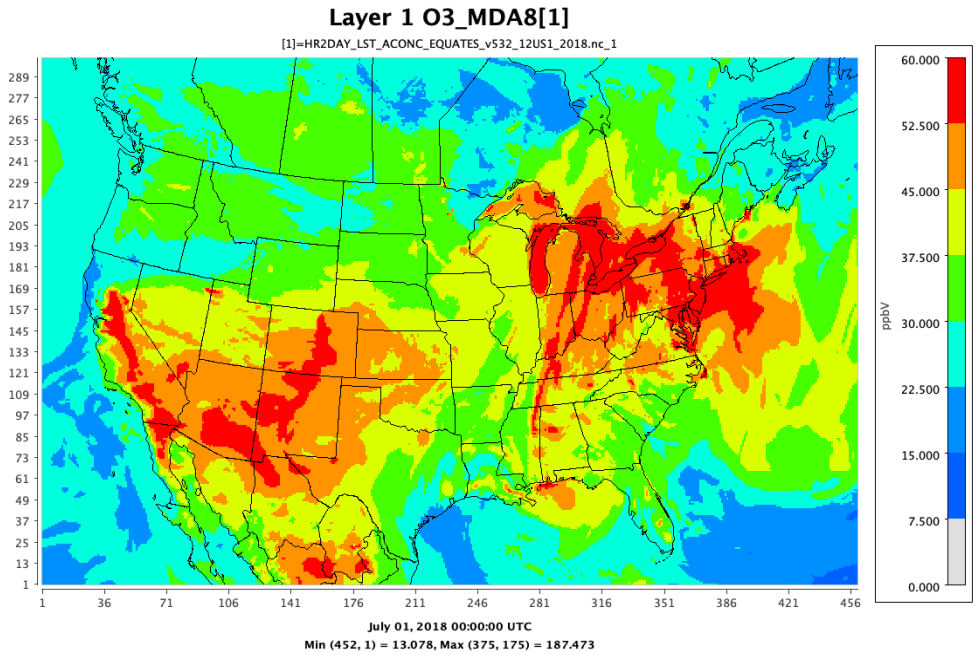


aqExample and EQUATES Simulation Domains VERDI plots of Ozone

aqExample_CMAQv532 July 1, 2018



EQUATES_CMAQv532 July 1, 2018



Pairing Model and Observational Data

https://registry.opendata.aws/cmas-data-warehouse/

CMAQ post processing tools:

- combine – combine model variables to create species (e.g. particulate matter less than 2.5 um (PM2.5) comparable to species measured at observational sites and create hourly post processed output for the entire time period of simulation to be used by AMET)
  - Model output obtained from CMAS Data Warehouse
  - file sizes for model data prior to running sitecmp and loading data into MariaDB
    - 1 month of CMAQ 12US1 ACONC data – 51 GB
    - 1 month of CMAQ 12US1 DEPOSITION data – 39 GB
    - 1 month of MET (WRF, MCIP, MPAS) - 787.4 GB
- sitecmp - used to match model species output for particular locations for corresponding observed values of species from one or more networks of monitors
  - Size of MariaDB table files under /var/lib/mysql
    - EQUATES (2002-2019) – 220 GB
    - AMET (metExample and aqExample) - 3.8 GB

Description
AMET Data

Resource type
S3 Bucket

Amazon Resource Name (ARN)
`arn:aws:s3:::cmas-amet`

AWS Region
`us-east-1`

AWS CLI Access (No AWS account required)
`aws s3 ls --no-sign-request s3://cmas-amet/`

Explore
Browse Bucket

AWS S3 Explorer | cmas-amet / AMET / v1.6_example / AQ / aqExample

Hide folders? Folder Bucket 3

Show 50 entries Search:

Object	Last Modified	Timestamp	Size
output/			
COMBINE_ACONC_aqExample_201807.nc	8 months ago	2025-08-25 15:07:15	51 GB
COMBINE_DEP_aqExample_201807.nc	8 months ago	2025-08-25 15:12:16	39 GB

Showing 1 to 3 of 3 entries Previous 1 Next

AMET Tools Model-Observation Data Harmonization

Synchronizing data across networking sites and model data is handled by AMET Tools (combine and sitecmp)

including:

- Format data files and types
- Align time zones and time standards
- Ensure model and observed variables match
- Uses quality control flags for observed data
- Ensure units are uniform
- Harmonize parameter data with metadata
- Ensure site locations (latitude, longitude) match with gridded model data
- Ensure consistent averaging periods

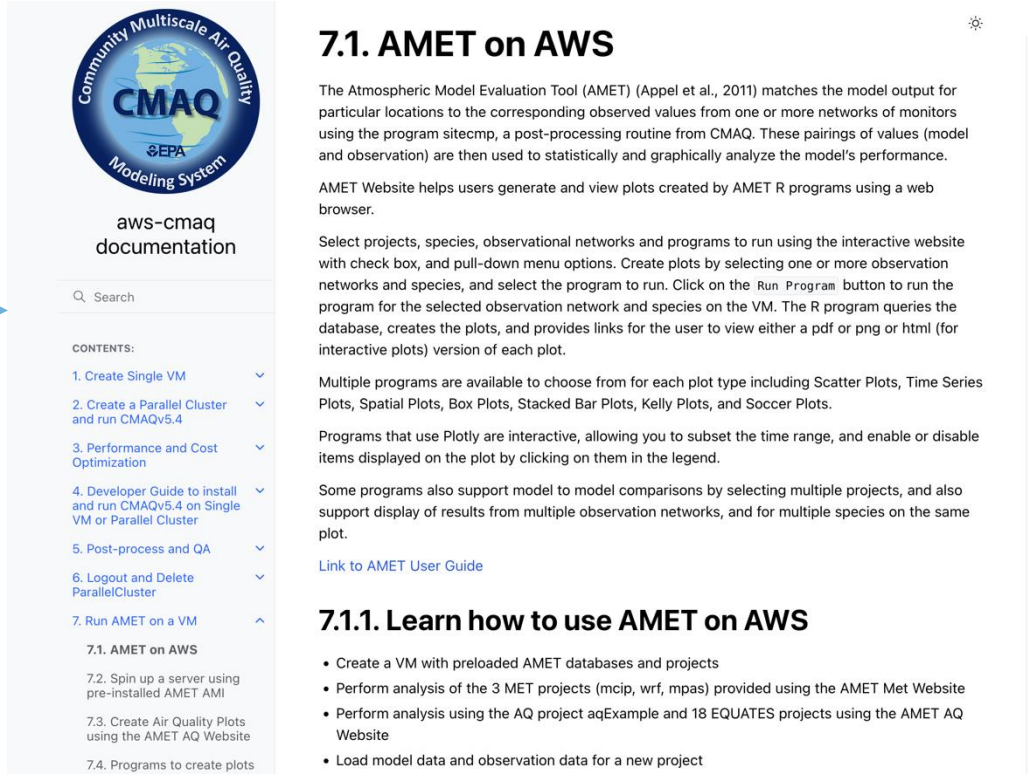
AMET Plot Programs (#)
use different R packages: leaflet, plotly, ggplot2

- **Scatter plots** (14) - correlation between model and observational values
  - Binned, Density, Model to Model, Percentiles, Single Network, Forecast Skill, Soil
- **Time series plots** (12) - trends over time, pattern over time (diurnal, weekly, seasonal), random fluctuations (error), missing data
  - Model to Model, Multi-Network
- **Spatial plots** (14) - spatial patterns of model-observation data across a region, identify neighborhoods or regions impacted by pollution
  - Difference, Model to Model, Ratio
- **Box plots** (7) - visualize the distribution, concentration, and variability of pollutants (such as PM2.5, NO2, or O3) over time or across different locations. Horizontal lines represent the median concentration, shading represents the interquartile range (IQR, 25th–75th percentile), and vertical lines identify extreme values or outliers
  - Hourly, Day of Week, MDA8, Roselle
- **Stacked bar plots** (9) - variation in species that make up PM2.5 for each season for CMAQ Model versus Observational Neworks (CSN, IMPROVE) and for seasons (Winter, Spring, Summer and Fall)
  - AERO6, Panel, AERO6 Panel, Soil
- **Miscellaneous scripts** (Kelly plot (regional statistical evaluation), soccer plot, bugle plot, histogram) (14), **Experimental scripts** (4)
- **Statistics**
  - Correlation coefficient, Normalized Mean Bias (NMB), Normalized Mean Error (NME), Root-mean-square error (RMSE), Index of Agreement (IA)

AMET Website on AWS

Advantages of Cloud-based AMET

- Pre-release of AMET 1.6
  - new features in develop branch https://github.com/USEPA/AMET/tree/develop#atmospheric-model-evaluation-tool
  - pre-installed libraries and software (AMETv1.6, MariaDB, netCDF, I/O API, R packages, Apache Web Server, PHP)
- **AMET on AWS Tutorial**
  - **user instructions – how to launch AMET Website and do analysis**
  - **developer instructions - how AMETv1.6 was installed and saved to AWS AMI**
- Matching Model with Observations and loading into MariaDB
  - Pre-loaded using **aq_pre_and_post.csh (turn off plots to save time**)
    - aqExample – CMAQ, 12US1, July 2018
    - metExample – WRF, MCIP, MPAS July 2016
    - EQUATES - **E**PA**'s Air QUAlity TimE Series Project for** 2002-2019, exported from EPA MariaDB
  - Load new projects using scripts under `$AMETBASE/scripts_db`
    - Requires uploading model data and editing db load scripts
- Web-based (PHP) GUI for Analysis
  - Create interactive plots from Web Browser using PHP and Apache Web Server



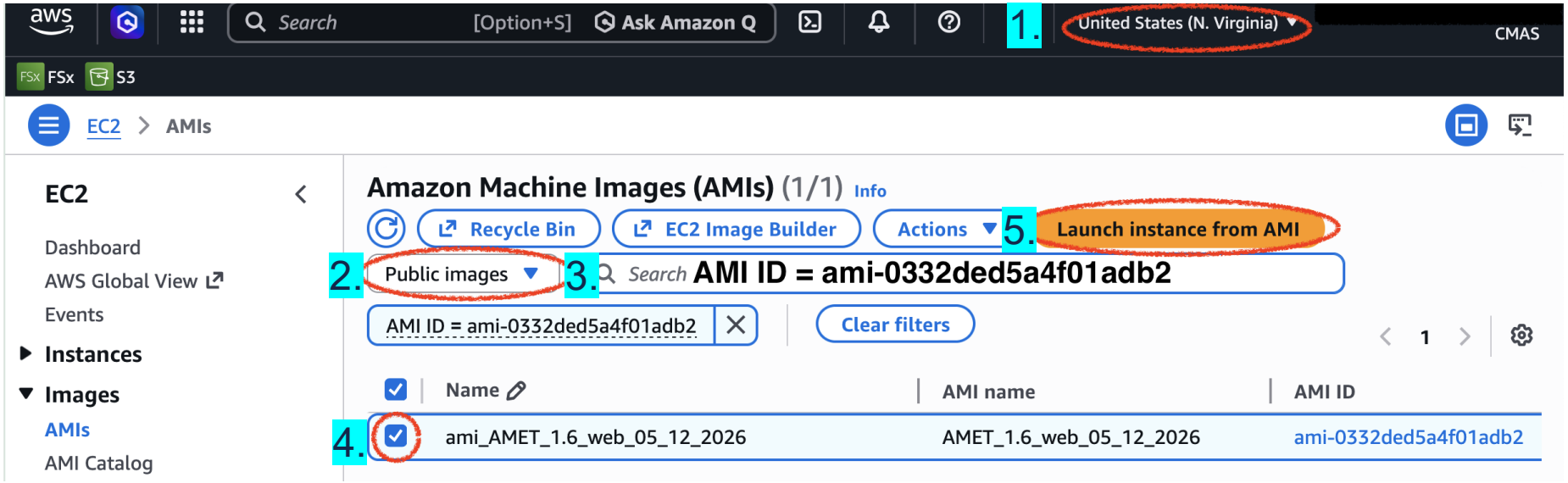
https://pcluster-cmaq.readthedocs.io/en/latest/user_guide_pcluster/amet/ami_website.html

AWS is Scalable

- allows users to increase computing power, storage, and network bandwidth and memory on demand to meet changing needs
  - note: expand or reduce additional storage volumes (avoid expanding root volume)
- EC2 instance (VM) can be stopped/started/terminated when not in use to reduce or save cost

Create AWS EC2 Instance (VM) from AMI

- Sign in to Console after creating AWS account
- Search for AMIs on AWS Management Console
  1. Select N. Virginia Region (us-east-1)
  2. Select Public Images Tab
  3. Search query: AMI ID = ami-0332ded5a4f01adb2
  4. Select ami, then click
  5. Launch Instance from AMI

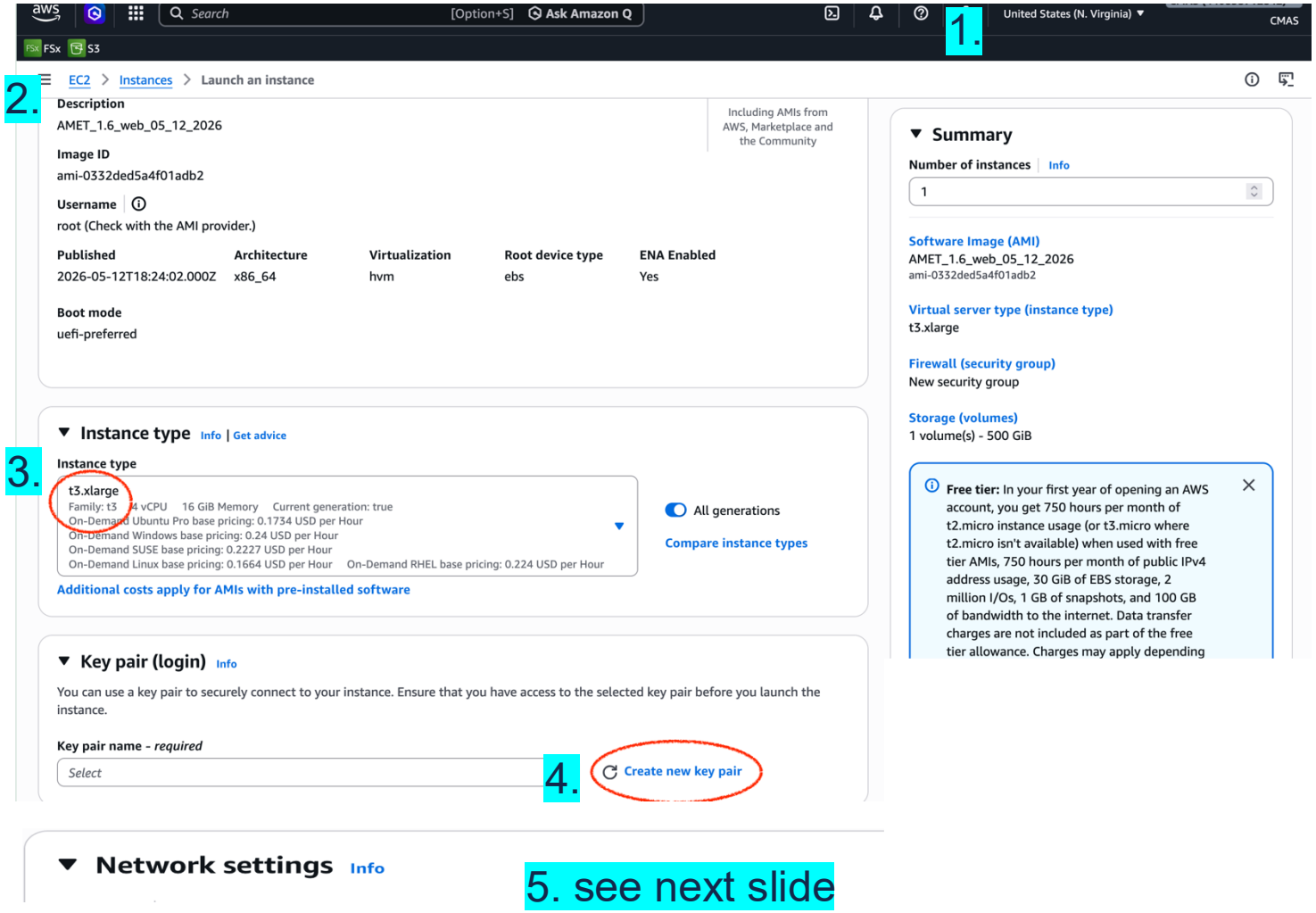


Select size and launch Instance (VM)

1. **From Virginia (us-east-1) Region**
2. Verify selected ami ID
3. Select Instance Type: t3.xlarge
4. Create new key pair (login key)
5. Use default storage but modify network settings (see next slide)

For different region, AMI will need to be copied to that region before launching instance

* costs vary by instance type, amount of storage, region



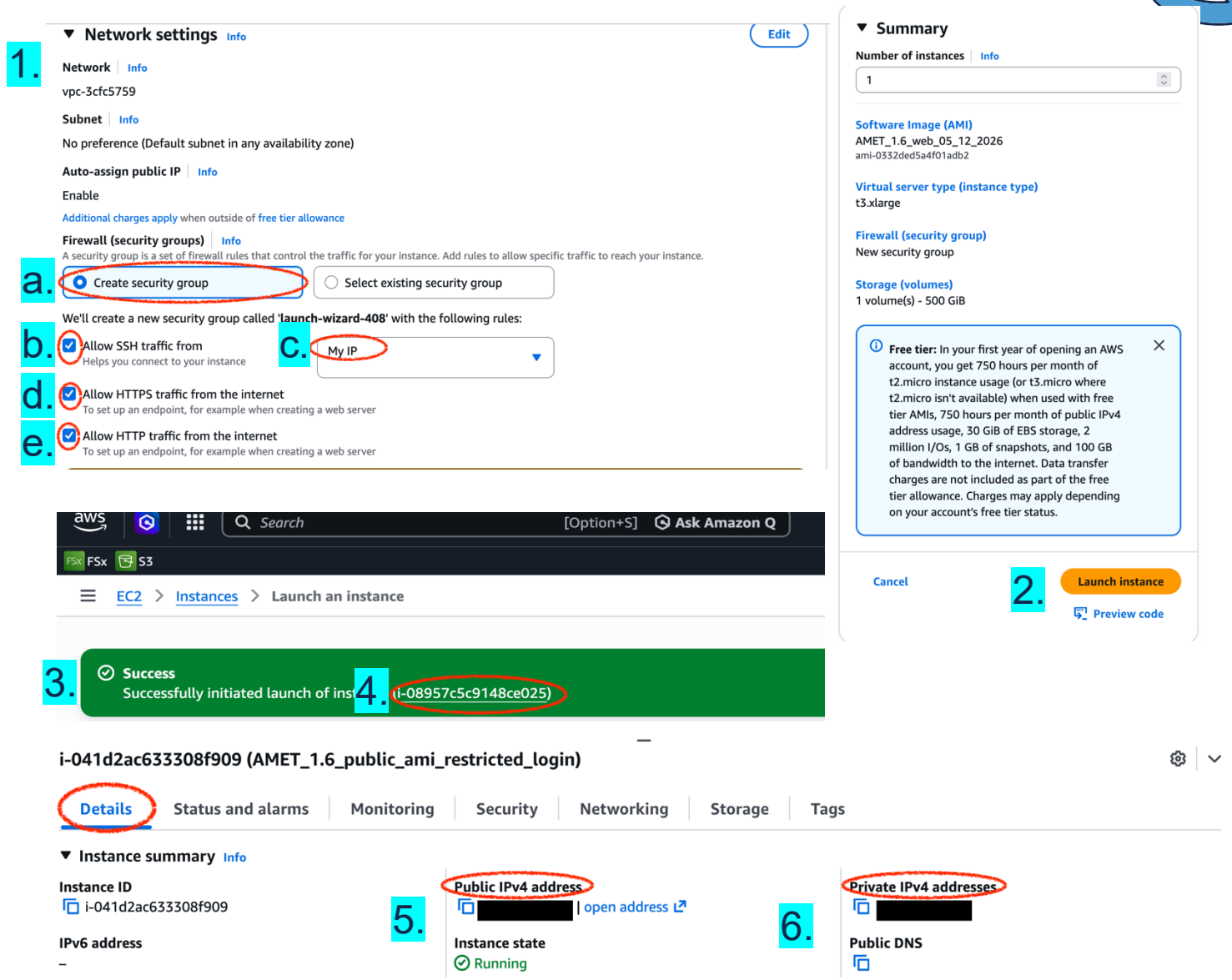
Modify network settings and launch Instance (VM)

1. Configure network settings
   a. create new security group
   b. allow ssh traffic
   c. restrict ssh traffic to your IP address
   d. allow https traffic from the internet*
   e. allow http traffic from the internet*
2. Launch Instance (VM)**
3. View Success window
4. Click on Instance ID to view instance details
5. Copy public IP address to use to for login
6. Copy private IP address for apache ports.conf

*Please consult with Cloud IT Support for advice on need for more restrictive organizational access policies

**For different region, AMI will need to be copied to that region before launching instance

**costs vary by instance type, amount of storage, region (see next slide)



Cost of EC2 Instance (virtual machine) and storage

EC2 cost For Virginia (us-east-1) Region

T3 instance type, physical processor: Intel Skylake E5, CPU Architecture: x86_64

EC2 Instance Type	# vCPUs	Memory	Cost/hour	Cost/day
t3.2xlarge	8	32GB	$.33	$7.92
t3.xlarge	4	16GB	$.166	$3.98
t3.large	2	8GB	$.083	$1.99

Storage cost For Virginia (us-east-1) Region https://aws.amazon.com/ebs/pricing/

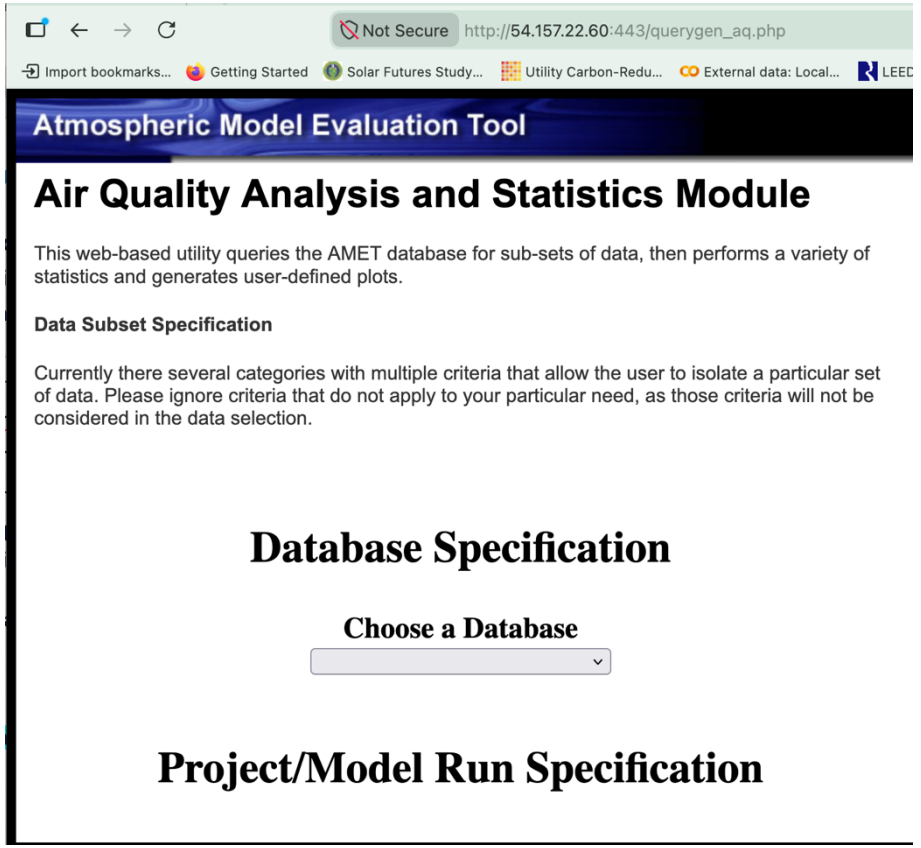
- A 500 GiB AWS gp3 EBS volume typically costs $40.00 per month for storage alone ($0.08 per GiB-month) 3,000 IOPS & 125 MB/s throughput free
- The Amazon Machine Image (AMI) with 500 GB of storage, which relies on EBS snapshots, typically costs $25.00 per month ($0.05 per GB-month) in the US East region. If using the AMI in the us-east-1 region it does not need to be copied to your AWS account, saving the cost of the ami ~ $.83/day.
- Total cost of running AMET Website for EQUATES+aqExample+metExample: (VM + storage (volume + ami))= $6/day
- Note, if you stop the instance, the storage costs still accrue, but no charges for the VM. Storage costs alone: $1.33 (gp3) + .83 (ami) = $2.16/day
- Reduce cost for AMI without EQUATES database (requires deleting EQUATES database and resizing root volume; not yet available)
  - Use smaller VM (t3.large) with small root volume (~ 30 GB, gp3 volume: cost $.08 per day, snapshot cost: $.05/day,
  - Total cost of running AMET Website for aqExample + metExample: VM + storage (volume + ami))= $2.12/day
  - Storage cost alone = $.13/day
- MariaDB table sizes under /var/lib/mysql (paired values loaded into database)
  - 3.8G ./amet (aqExample, metExample_wrf, metExample_mcip, metExample_mpas)
  - 220G ./amad_EQUATES (2002-2018)

Deploy AMET Website

Login to AMET_1.6_web from the AWS EC2 console

- obtain the IP address
- open an ssh client
- Locate your private key file
- Run this command, if necessary, to ensure your key is not publicly viewable.

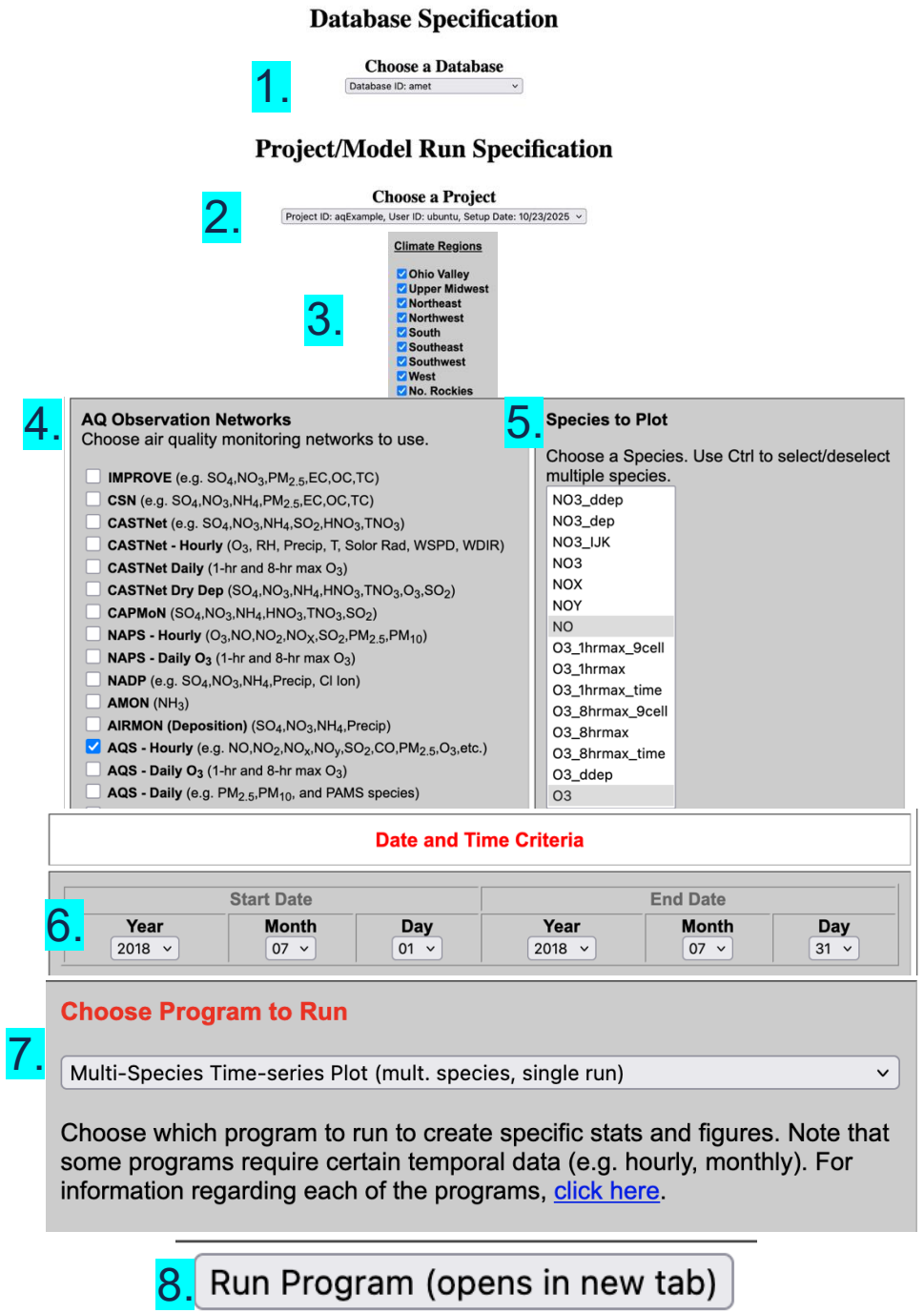
  chmod 400 ”key_pair_name.pem”
- Connect to your instance
- `ssh -Y -I “key_pair_name” ubuntu@public_IP_address`
- Edit the apache2 ports.conf file to specify the private IP address for the EC2 instance that is being used to run AMETv1.6
  - `sudo su`
  - `vi /etc/apache2/ports.conf`
- Restart apache server
  - `systemctl restart apache2`
- Start MariaDB Server
  - `systemctl start mariadb`
  - `exit ! Out of sudo su`
- **Create Air Quality Plots using the AMET AQ Website**
  - `http://public-ip-address:443/querygen_aq.php`



AMET Website Navigation

Choose a

1. Database
2. Project(s)
3. Region(s)
4. Observation Network(s)
5. Species(s) to Plot
6. Start and End Date
7. Choose Program to Run
   a. some support multiple species, multiple networks, multiple model runs
8. Run Program



AMET Website Actions and Results

querygen_aq.php is located under $cache_amet which is set to /var/www/html

When user submits “Run Program” on AMET Website

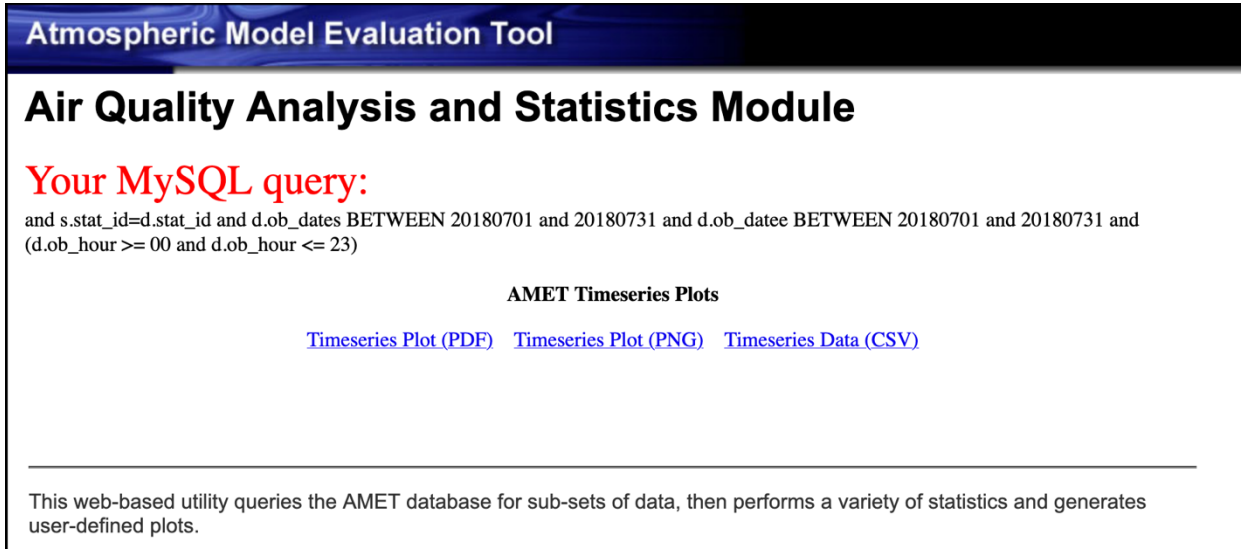
- settings are saved to `${cache_amet}/run_info.r`
- the R program name and environment variables are saved to `${cache_amet}/run_script.csh`

Each R program saved within `run_info.r` wrapper

e.g.
`AMET_v16/R_analysis_code/AQ_Timeseries_multi_species.R`

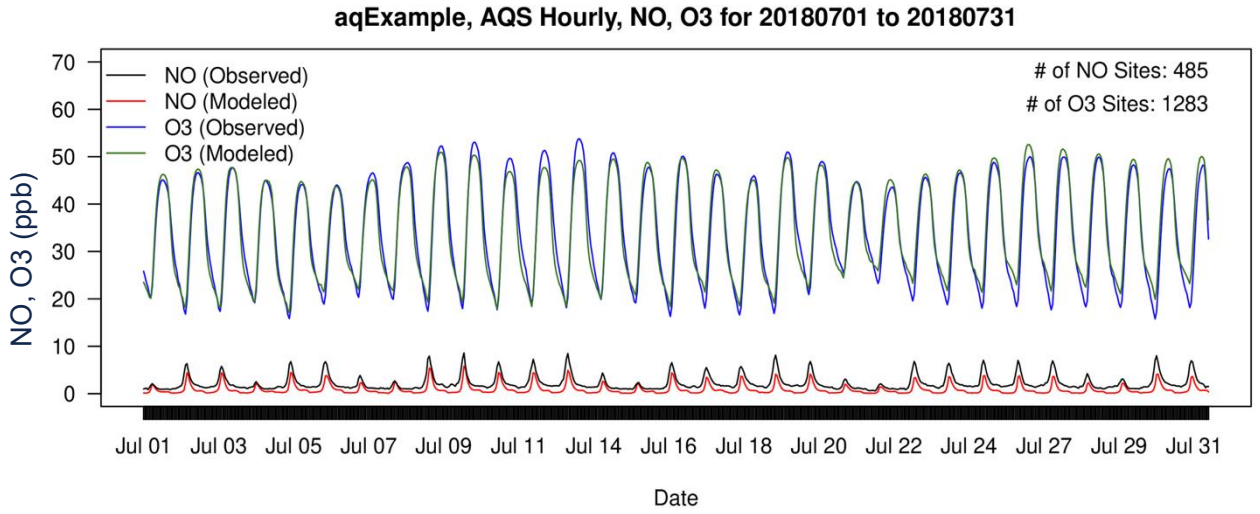
- has a description at the top
- queries the MariaDB or reads the sitex file (if database is not used)
- saves the data to a data.frame
- Calculate Obs and Model Means and bias
  - using selected averaging (daily, hourly, monthly)
- Write data to be plotted to a csv file
- Calculate some values for plot formatting
- runs the statistical analysis (correlation, rmse)
- creates the plots and saves the output

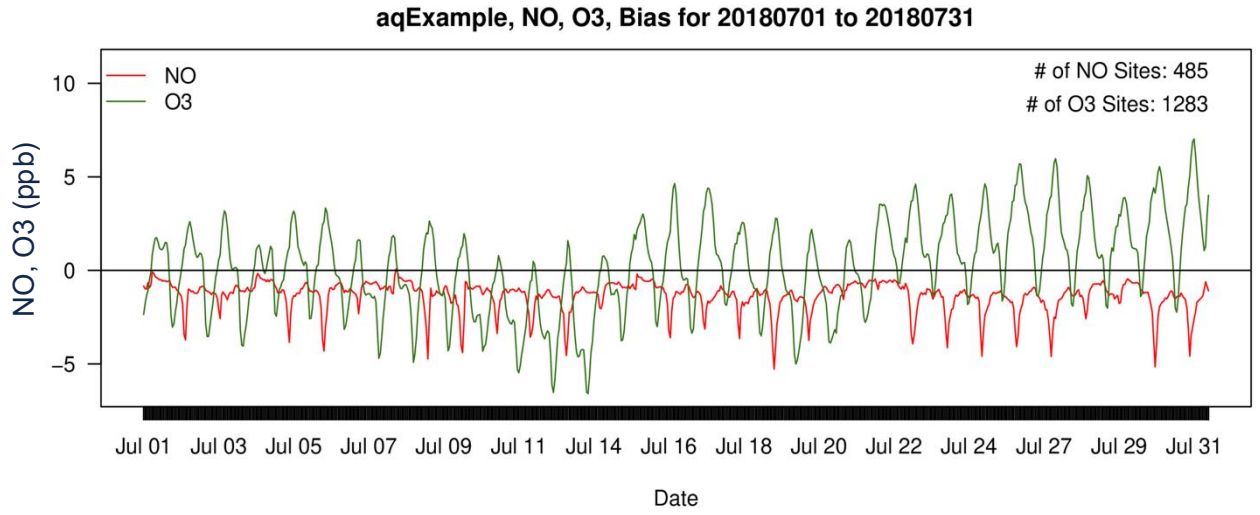
- after program completes, the plots are saved to the cache directory and displayed to the website or an error message is saved to web_query.txt and displayed to the user

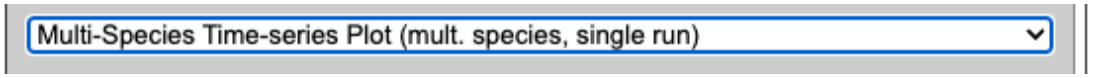


AMET Multi-species Timeseries Plot

- Ozone Observed and Modeled (aqExample database) values in July increase during day, and decrease at night, with Modeled values slightly underestimating the observed maximum values and underestimating the minimum values.





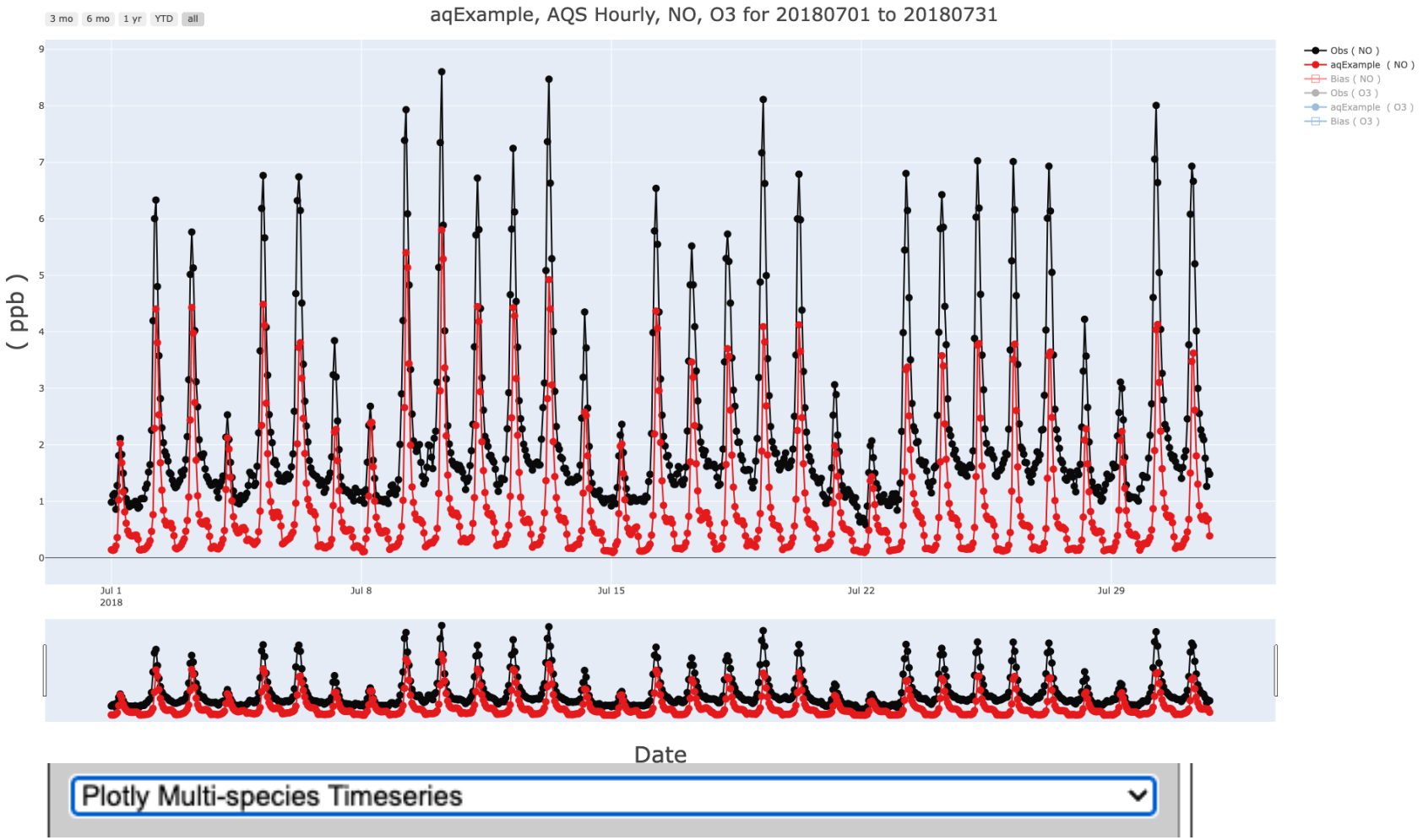


Plot takes 1 minute to create, query is for 2 species for 1 month

AMET Plotly Multi-species Timeseries Plot

AqExample database model and observed NO values increase at night; with the model NO values being underestimated compared to the observed values

With interactive plots, the user can click on the legend to enable/disable the timeseries plot for that item. O3 obs and model values and bias values are greyed out and disabled in this plot to allow us to focus on **Observed NO (obs)** and Model NO (aqExample).



Interactive Plot takes 2 minutes to create, query is for 2 species for 1 month
http://34.235.138.0:443/cache/aqExample_multispec_995235_timeseries.html

AMET Plotly Multi-simulation Timeseries Plot
MDA8 Ozone 12US1 EQUATES (CMAQv532)

Trends Analysis

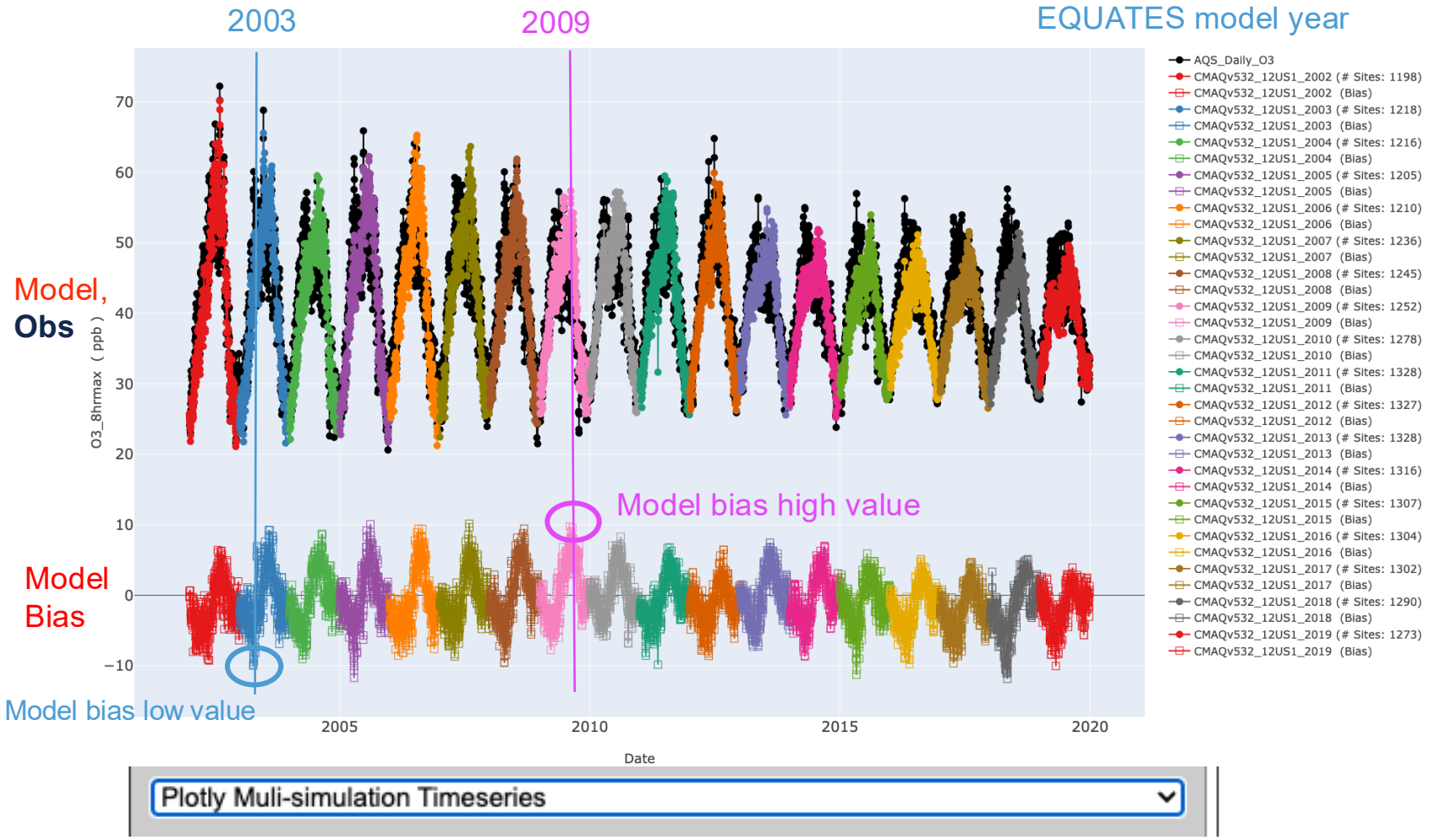
Observation and model both show a wavy pattern with a decrease of the higher values of daily maximum 8-hour average Ozone (MDA8) and AQS Daily O3 observations over time (2002-2019) due to emission controls in the U.S., with higher values in the summer, and lower values in the winter

Model Bias is also a wavy pattern.

Model bias is lowest just before the peak of the 2003 MDA8 O3 values where the model is underestimating the concentrations compared to the observations.

Model bias is highest just after the peak of the 2009 MDA8 O3 values where the model is overestimating the concentrations compared to the observations.

OBS – black
Model - Color for each EQUATES model year



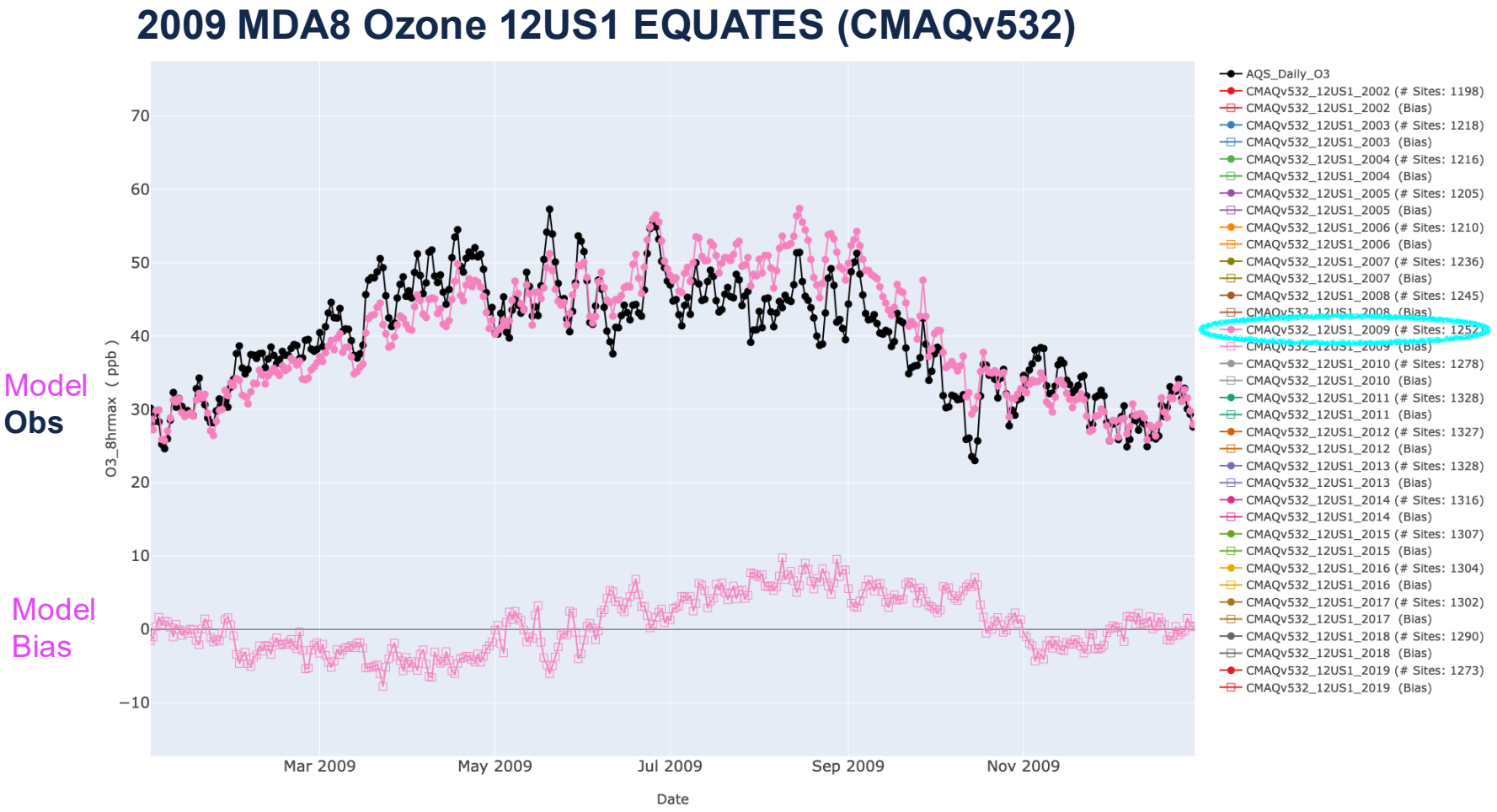
This Plotly multi-simulation timeseries plot takes 5 minutes to create, query is for 1 species for 18 years
http://34.235.138.0:443/cache/CMAQv532_12US1_2002_O3_8hrmax_203698_timeseries.html

AMET Plotly Multi-simulation Timeseries Plot Zoomed into year 2009

Trends Analysis

EQUATES model/obs paired data is for a long enough time period to see increase in ozone over the summer, and decrease in the winter over the 12US1 domain.

AqExample dataset has only one month of data.



AMET Plotly Multi-simulation Timeseries Plot PM25_TOT 12US1 EQUATES (CMAQv532)

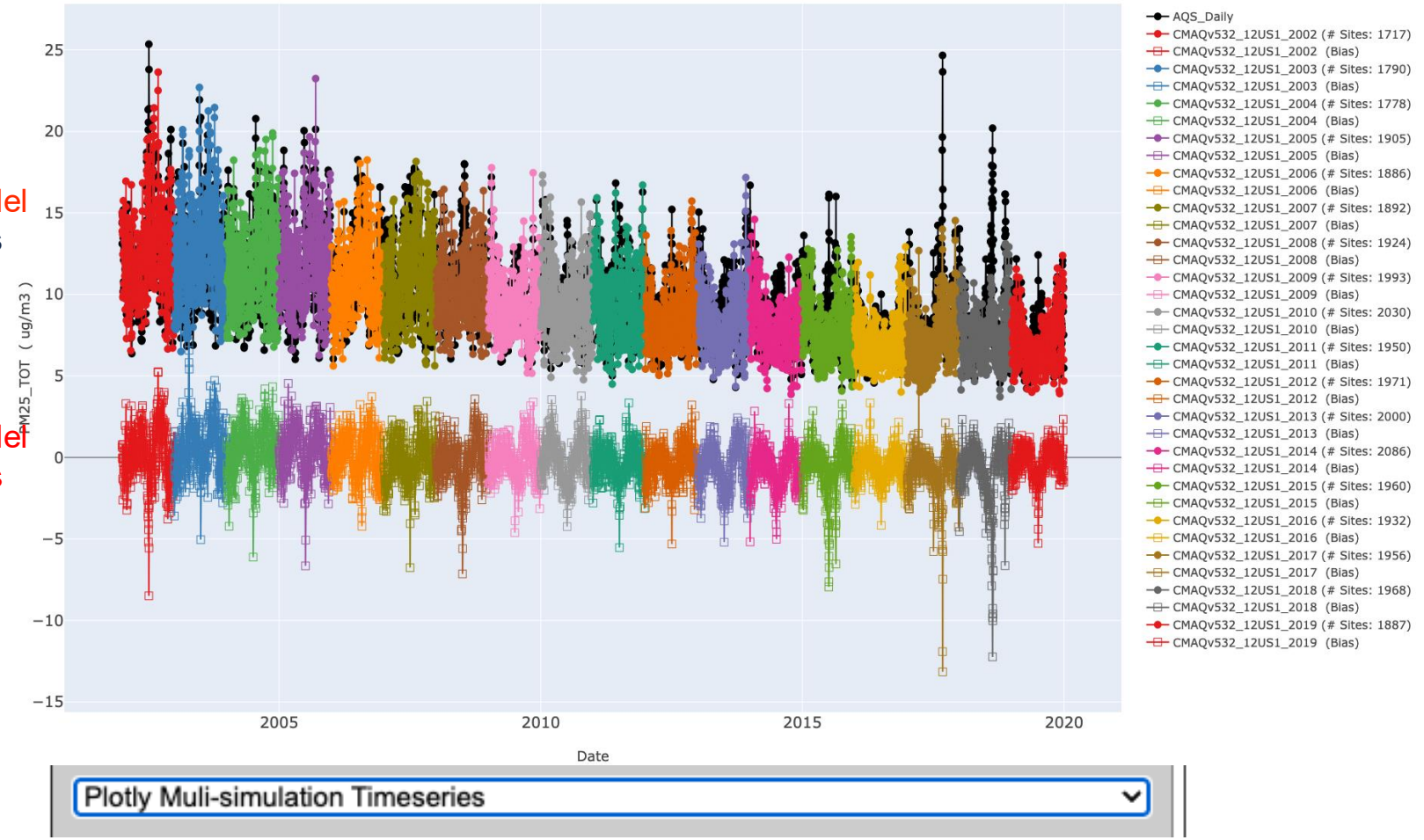
Trends Analysis

Observation and model show a decrease in PM25_TOT over time (2002-2019) due to emission controls in the U.S., with lower values in the Spring and Fall, and higher values in both the summer and winter

(interactive AMET plotly plot allows user to explore data)

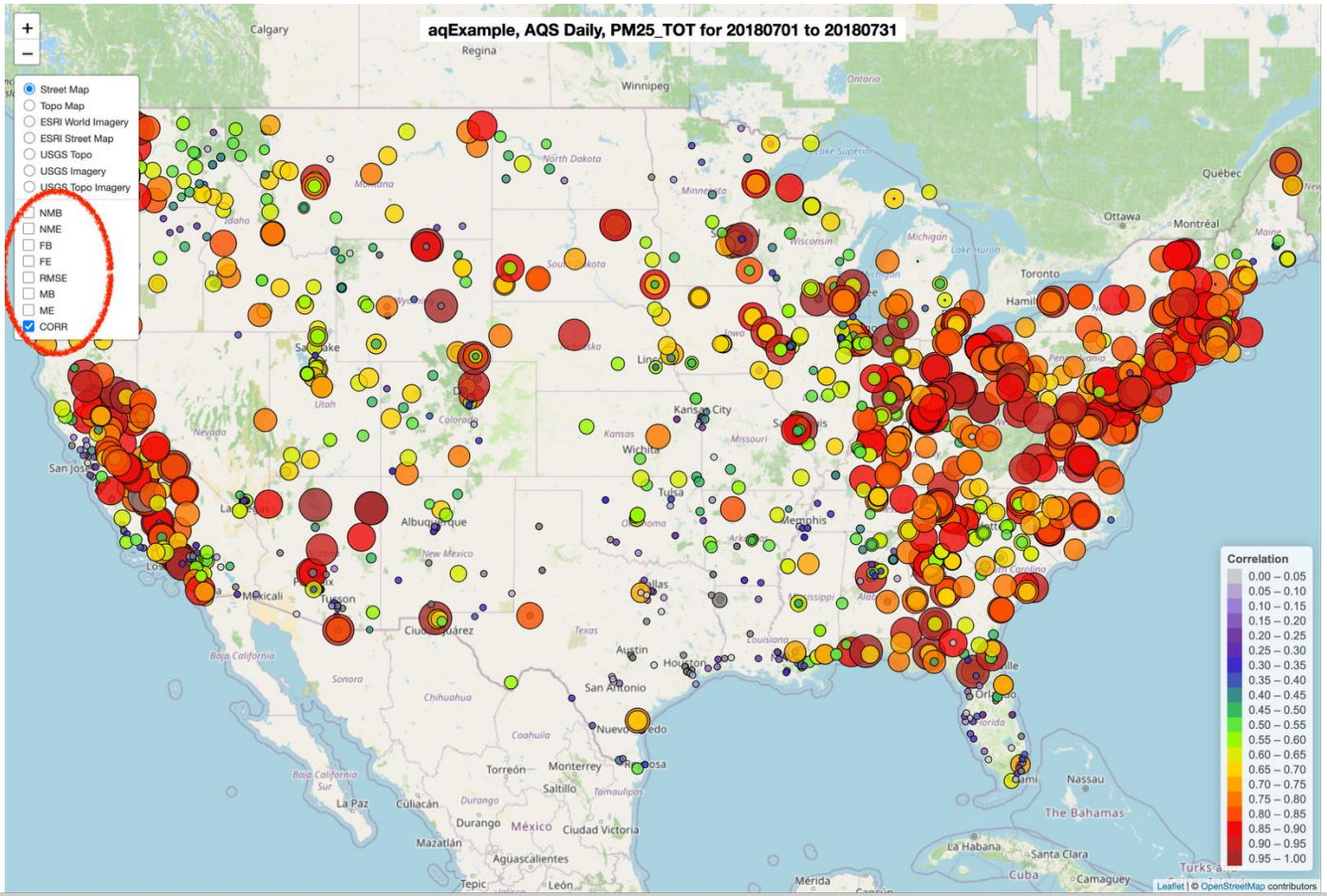
Model
Obs

Model
Bias



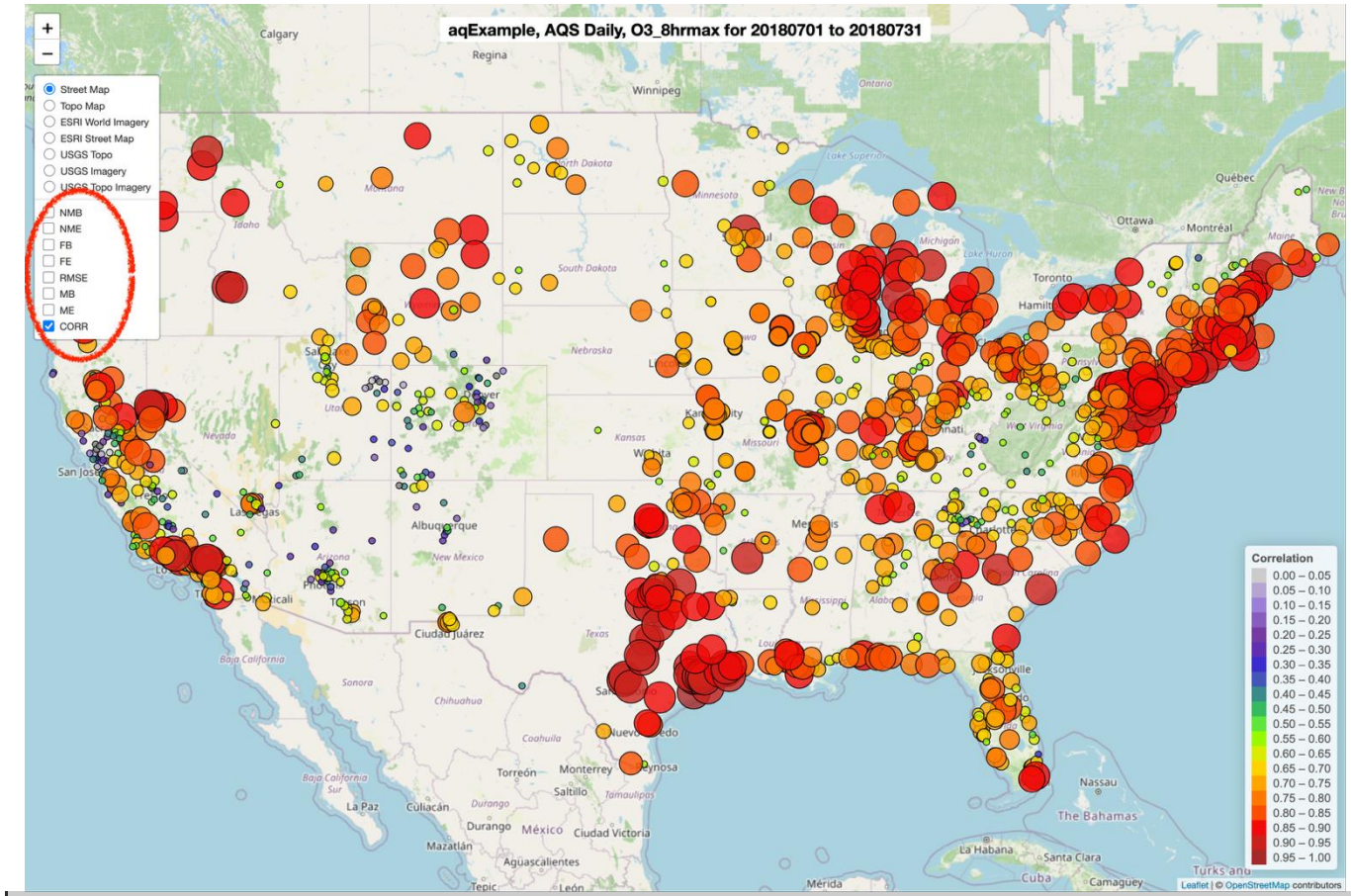
This Plotly multi-simulation timeseries plot takes 43 minutes to create. (compared time stamp on the run_script.csh to the time stamp on the AQ_Timeseries_plotly.Rout)
http://34.235.138.0:443/cache/CMAQv532_12US1_2002_PM25_TOT_83985_timeseries.html

AMET Leaflet Spatial Plot of Model/Observation Correlation for PM25_TOT



http://34.235.138.0:443/cache/aqExample_PM25_TOT_276110_stats_plot.html

AMET Leaflet Spatial Plot of Model/Observation Correlation for O3_8hrmax

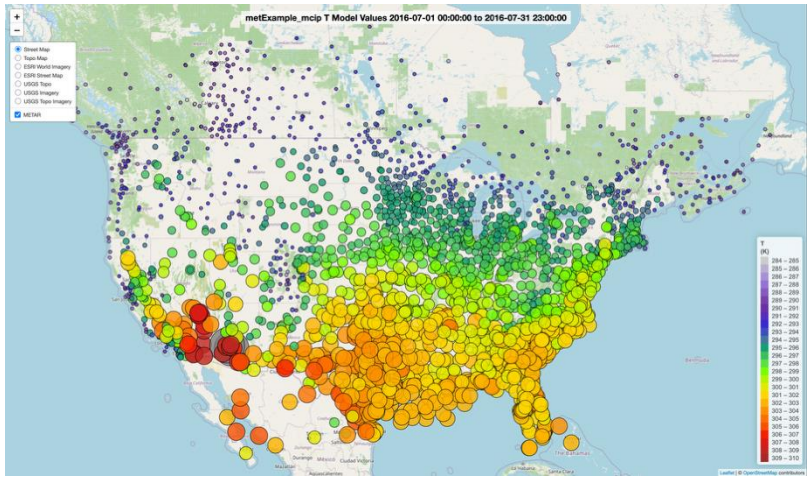


http://34.235.138.0:443/cache/aqExample_O3_8hrmax_838443_stats_plot.html

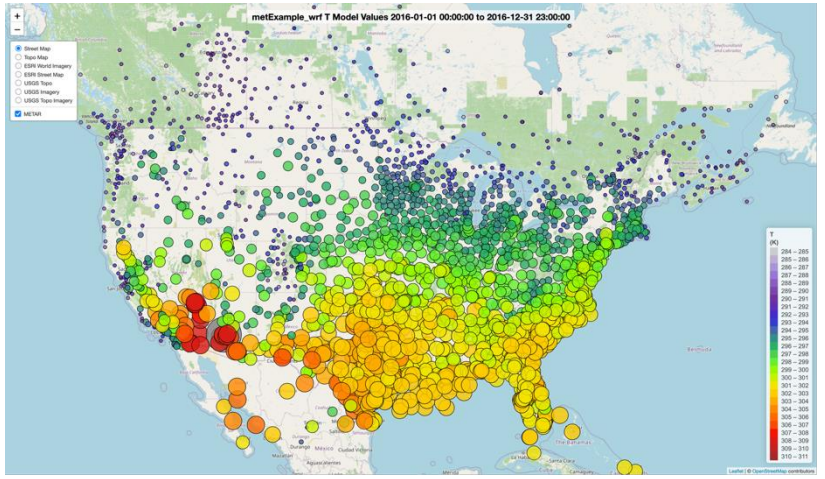
AMET Model Temperature Plots for 3 Domains

http://34.235.138.0:443/querygen_met.php

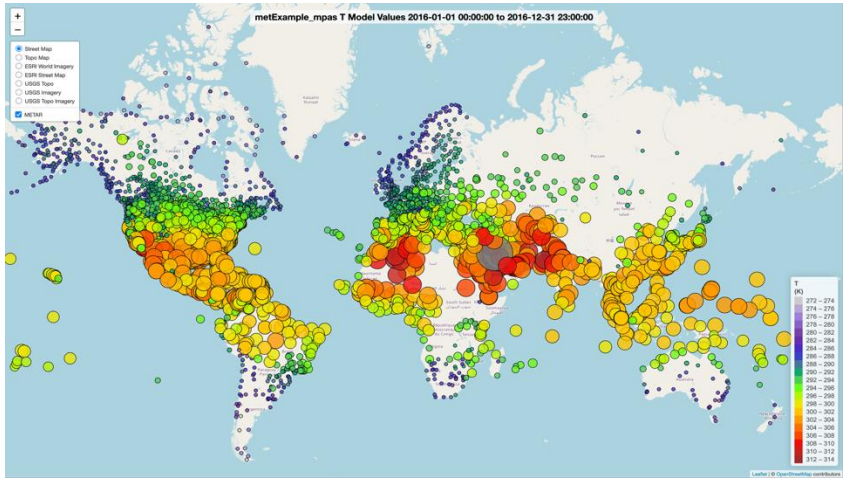
MCIP (subdomain of wrf)



WRF



MPAS (global)



Interactive Spatial Plot (multiple plots)

For looking at a comparison of Temperature timeseries for these model and observations, need to specify the lat-lon values to limit model/obs region to same area (CONUS)

http://34.235.138.0:443/cache/metExample_mcip_T_921392_spatialplot_mod.html
http://34.235.138.0:443/cache/metExample_wrf_T_976831_spatialplot_mod.html
http://34.235.138.0:443/cache/metExample_mpas_T_311801_spatialplot_obs.html

Geography Criteria

Latitude-Longitude

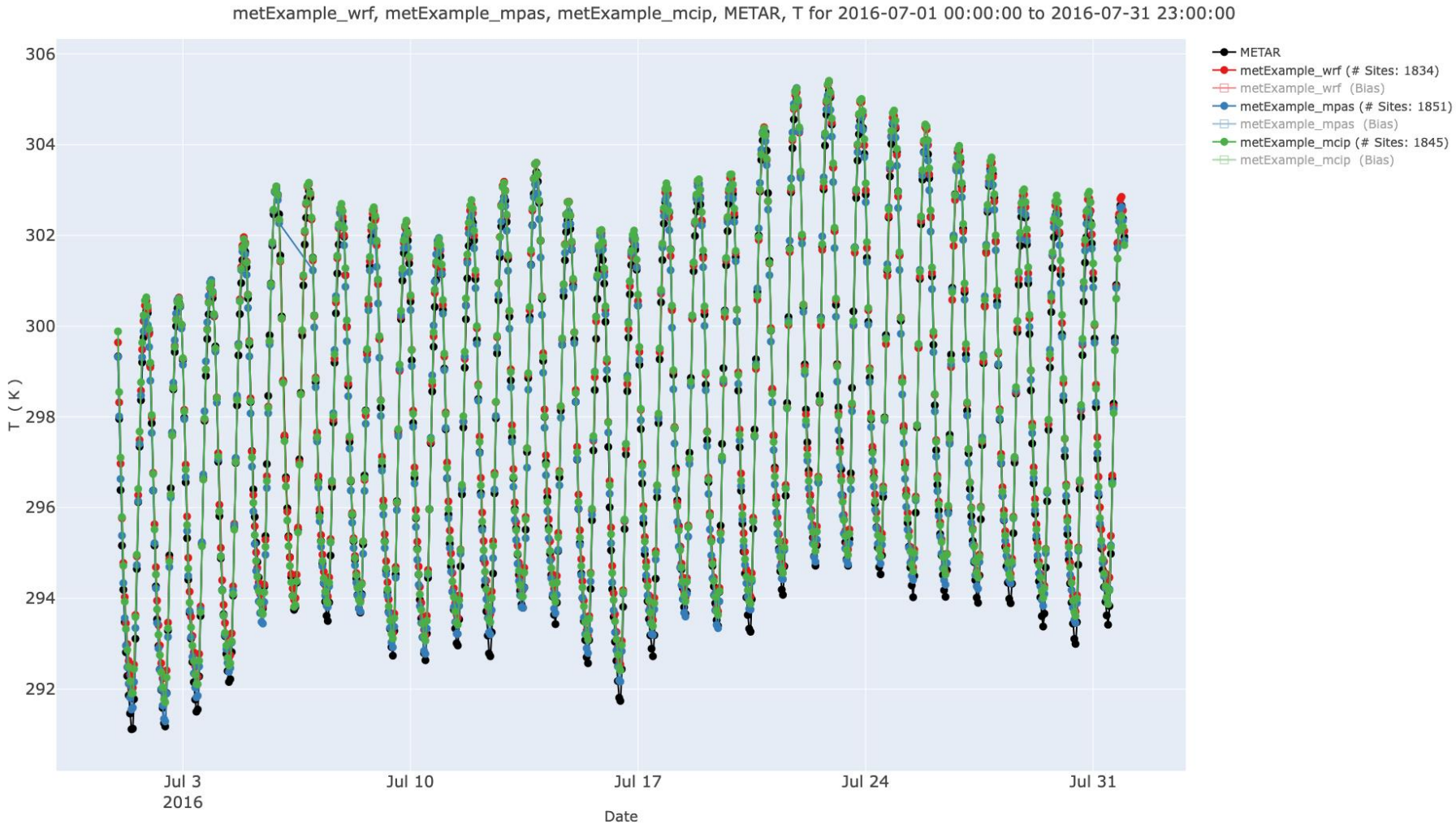
Lat between 24.52 & 49.38 deg

Lon between -124.77 & -66.95 deg

Specify bounds on the evaluation data to examine. Latitudes must be given south to north, and Longitudes must be given west to east.

AMET Model Temperature Plots for 3 Models (WRF, MPAS, MCIP) vs OBS (METAR)

http://34.235.138.0:443/querygen_met.php

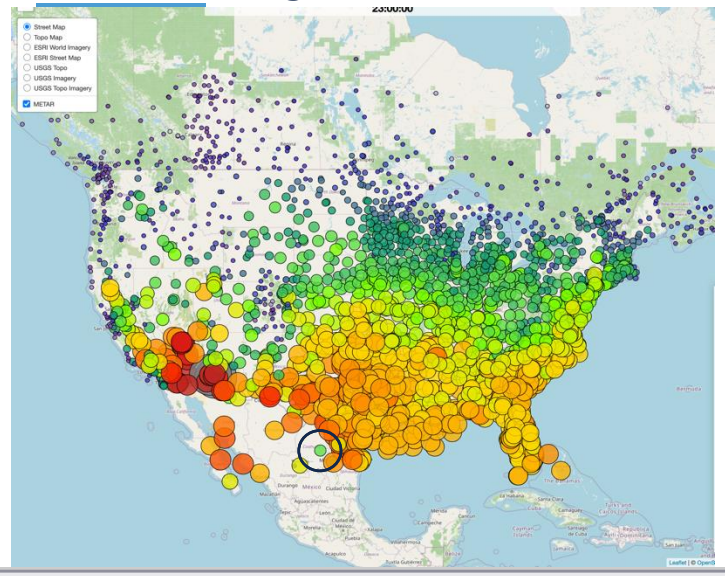


http://34.235.138.0:443/cache/metExample_wrf_T_849283_timeseries.html

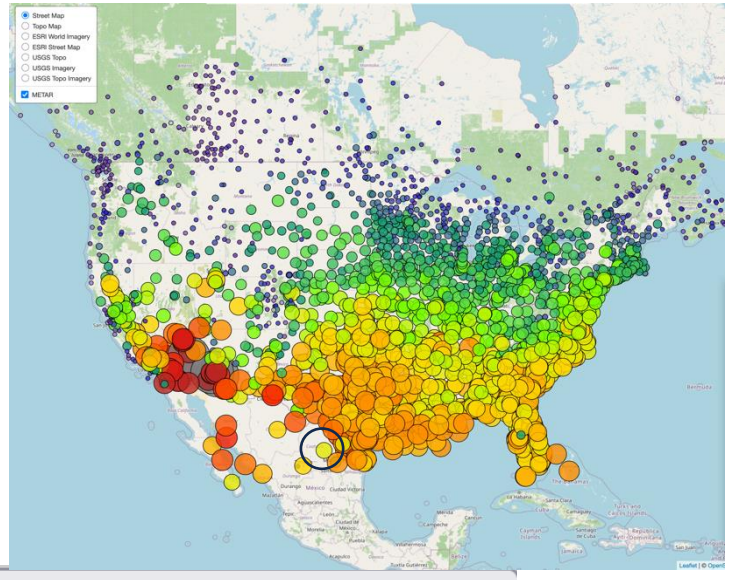
AMET Temperature (Monthly Avg, July 2016) Plots (MCIP vs METAR)

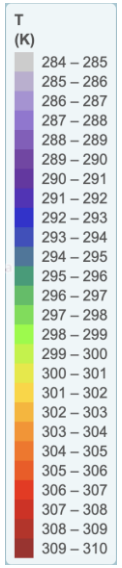
http://34.235.138.0:443/querygen_met.php

MCIP Model



METAR





Circled Site In Mexico
Information displayed in pop-up window after clicking on site:

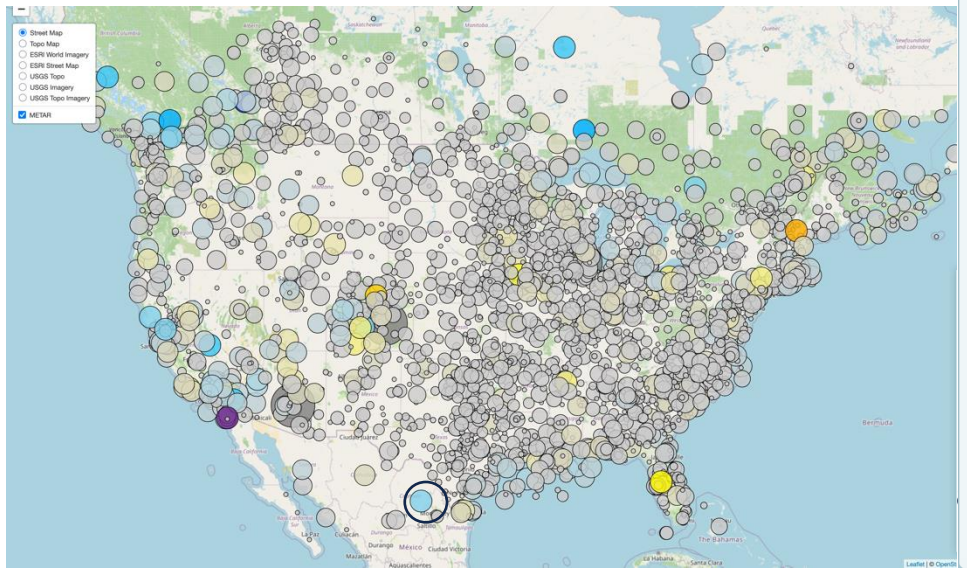
Site: MMMV
Network: METAR
Latitude: 26.8799991607666
Longitude: -101.419998168945
State: CH
Obs: 300.68 K
Mod: 297.59 K
Diff: -3.09 K

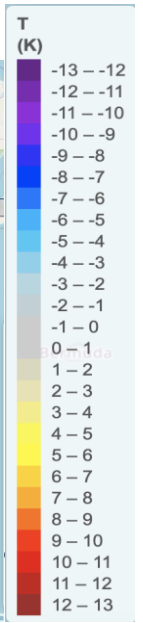
Interactive Spatial Plot (multiple plots)

Size of the circle in the difference plot is determined by the magnitude of the difference between values
It helps to interactively click on a few sites, and verify that the Model-Obs difference values are correctly calculated.

http://34.235.138.0:443/cache/metExample_mcip_T_921392_spatialplot_mod.html
http://34.235.138.0:443/cache/metExample_mcip_T_921392_spatialplot_obs.html
http://34.235.138.0:443/cache/metExample_mcip_T_921392_spatialplot_diff.html

Model-Obs Difference





Offline AMET vs AMET Website on AWS

AMET v1.6 Offline

- Requires
  - Clone of AMETv1.6 using github along with installation of:
    - CMAQ Libraries ,R packages ,MariaDB
  - Obtaining data from CMAS Data Warehouse (model and obs)
  - Run database loading script
  - Run analysis scripts
  - View scripts from command line or install website (apache, php)
- Customization
  - Analysis scripts can be modified to use additional MariaDB queries
- Model/Obs Paired Data Cshell scripts
  - AQ scripts

    `$AMETBASE/scripts_analysis/aqExample`
  - MET scripts

    `$AMETBASE/scripts_analysis/metExample_*`
- Plots saved to $AMETBASE/output
- View plots using display (png), ocular (pdf) or firefox (html)
- The AMET C-shell scripts create plots for projects included in AMET release. Analysis scripts can be modified for your own projects by copying the scripts to a new project directory, and editing the scripts to use

```
setenv AMET_PROJECT    new_project_name
```

AMET v1.6 Website on AWS

- Ease of use
  - AMETv1.6 pre-installed
  - Model/Observation Paired data pre-loaded into MariaDB
  - create and view plots using web browser
  - Interactive Plotting
- AWS is scalable, use smaller VM to reduce costs or larger VM to handle memory requirements of higher resolution/larger domain modeling projects
- Limits
  - query options
  - how plots are annotated
  - Loading data for new projects requires logging into VM
- Customization
  - Underlying php code and R programs can be modified
- Allows users to try to make selections that may fail to create plots, or create plots that are unclear
  - missing data (no observation data for selected network)
  - incompatible settings such as time ranges used for Model to Model comparisons.
  - Comparing one year of observations to model output for multiple years

Interactive Demo of AMET-AQ

Link to AMET-AQ aqExample section of Tutorial
Link to AMET-AQ EQUATES section of Tutorial

Practice Examples AMET-AQ

Link to AMET-AQ aqExample section of Tutorial
Link to AMET-AQ EQUATES section of Tutorial

Plotly Multi-species Timeseries

View and interact with the plot for O3 and NO and AQS Hourly for aqExample, zoom in on a single day

Spatial Plots w/ Animations (plotly version)

View and interact with plot for PM25_TOT and AQS – Daily for aqExample, zoom in, use pan to focus on a region, and animate over time.
Spatial Animation PM25_TOT_aqExample Model Concentrations Plot
Spatial Animation PM25_TOT Observed AQS Daily Concentrations Plot
Spatial Animation PM25_TOT aqExample Model - Obs Difference Plot
View animated diff plot for O3-1hrMax and CastNet Daily for EQUATES for 2019
Spatial Animation O3-1hrMax EQUATES Model Concentration Plot
Spatial Animation O3-1hrMax Observed AQS Daily Concentration Plot
Spatial Animation O3-1hrMax EQUATES Model-Observed Difference Plot
Is there a difference in difference plots for urban (AQS Daily) vs rural (CastNet Daily) Sites? Find an example of negative bias in March/April, and positive bias in Aug. TS plots are averaging over entire domain, spatial plots display the bias patterns geographically.

Plotly Muli-simulation Timeseries

View and interact with the EQUATES 2002-2019 data for Ozone MDA8 vs. **AQS - Daily O_3** (8-hr max O_3), zoom in on a single year
AQS Daily Obs vs O3_8hrmax CMAQ (Urban Sites) Timeseries Plot
CastNet Obs vs O3_8hrmax CMAQ (Rural sites) Timeseries Plot
EQUATES 2002-2019 PM25_TOT vs AQS - Daily (PM2.5 species) Timeseries Plot

No IMPROVE network sites in EQUATES dataset, can't create Multi-Simulation Timeseries plot with rural PM25_TOT sites

Practice Examples AMET-MET

Link to the AMET-MET section of the Tutorial

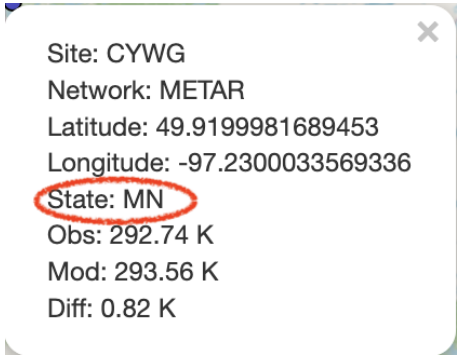
Plotly Muli-simulation Timeseries

Select three projects: metExample_wrf, metExample_mpas, and metExample_mcip and plot T versus METAR Temperature for all of the Climate Regions, turn off the bias traces, zoom in on a single day and examine the traces for each model run compared to the METAR observations

WRF, MCIP, MPAS Interactive Temperature Plot

Interactive Spatial Plot (multiple plots)

Select metExample_wrf and plot T for all Climate Regions (notice this failed to limit sites to CONUS) - see sites including Winnipeg in Manitoba, clicking on a site shows Province of Manitoba (MN) given a state label of MN, which matches state of Minnesota (MN) in the Climate Regions query. This likely influenced the bias reported in timeseries plot above for MPAS.



METAR Temperature (Obs) Interactive Spatial Plot
WRF Temperature (Model) Interactive Spatial Plot
WRF vs METAR Temperature Difference (Model-obs) Interactive Spatial Plot

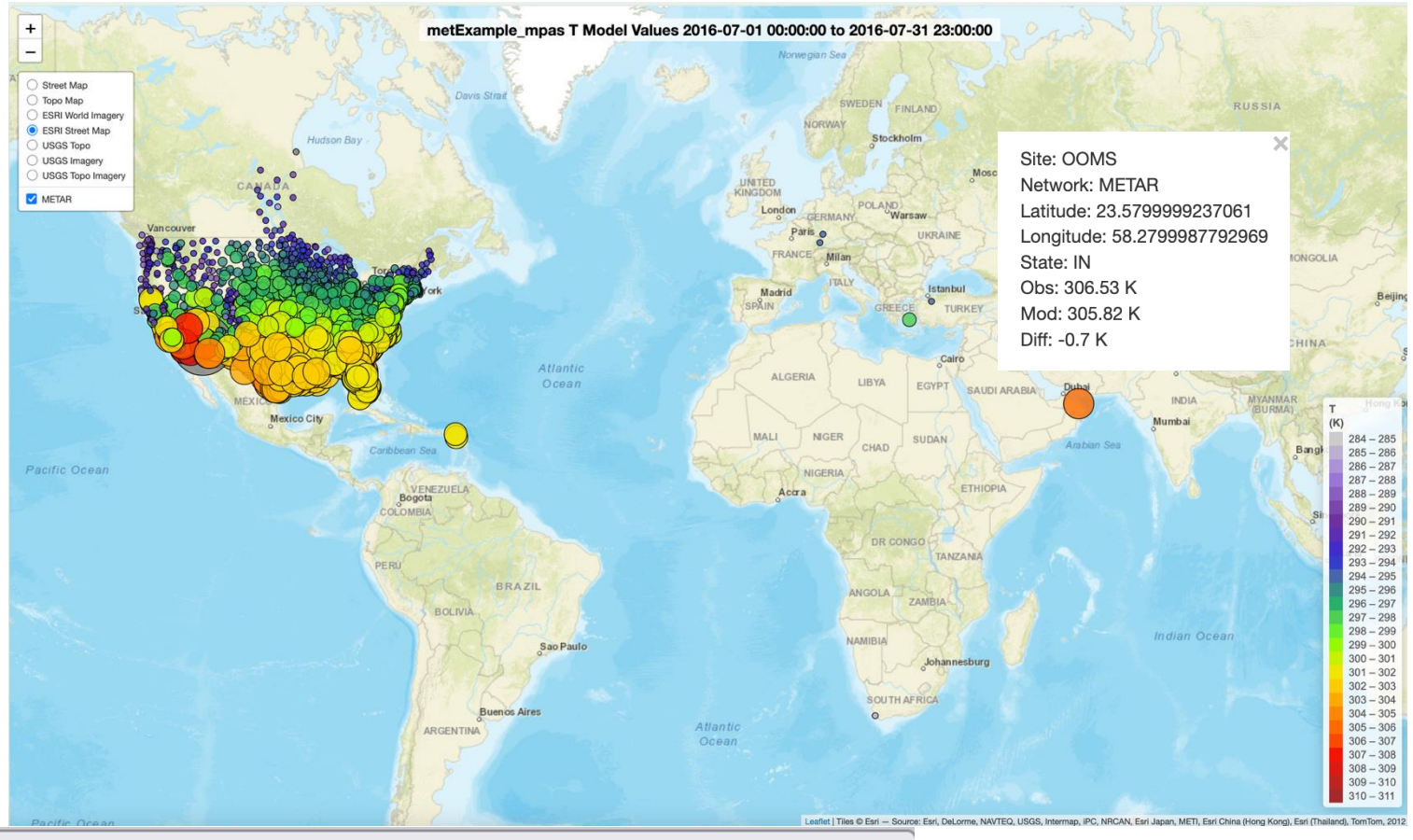
Select metExample_mpas and plot T using min, max lat and lon values for CONUS (this works). Screening by State does not, as some of the stations outside of the use have State ID's that are identical to CONUS State IDs.

METAR Temperature (Obs) Interactive Spatial Plot Geographic Limited by Lat/Lon
MPAS Temperature (Model) Interactive Spatial Plot Geographically Limited by Lat/Lon
MPAS vs METAR (Model-Obs) Interactive Spatial Difference Plot Limited by Lat/Lon

AMET Model Temperature Spatial Plot for MPAS

http://34.235.138.0:443/querygen_met.php

MPAS Query filtered by States or Climate Regions included sites from Canada, Europe and Middle East. (site in Oman mistakenly labeled with state=IN label). Recommend using lat/lon values to filter to CONUS.



Interactive Spatial Plot (multiple plots)

Additional resources

AMET Website Documentation in AWS on Cloud Tutorial:
https://pcluster-cmaq.readthedocs.io/en/latest/user_guide_pcluster/amet/ami_website.html#amet-on-aws

Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM2.5, and Regional Haze, - Evaluating Performance starting on page 69
https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf

Sections related to AMET:

3.2.1 Metrics – definition of statistical metrics
3.2.3 Ozone Model Performance - It is recommended that, at a minimum, statistical performance metrics be calculated for hourly ozone and 8-hour ozone maxima for each day of the model simulation used to support the attainment demonstration
Ozone precursors and related gas-phase oxidants (partial list) are listed below
• Total Volatile Organic Compounds (VOCs), Speciated VOC, Nitric acid (HNO3), Nitric oxide (NO), Nitrogen dioxide (NO2), Peroxyacetyl nitrate (PAN), NOy (NOx=NO+NO2 and other oxidized nitrogen compounds), Carbon monoxide (CO)
3.2.4 PM2.5 Model Performance - Performance metrics for PM and regional haze are similar to those calculated for ozone
Metrics should be estimated for components of PM2.5 and PM precursors
3.3 Ambient Measurement Networks - Overview of some of the ambient air monitoring networks

Model Evaluation papers:

- Boylan and Russell, 2006 https://www.sciencedirect.com/science/article/abs/pii/S1352231006000690
- Emery et al, 2016 https://www.tandfonline.com/doi/full/10.1080/10962247.2016.1265027
- Simon et al, 2012 https://www.sciencedirect.com/science/article/abs/pii/S135223101200684X

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AMET Website Installation on UNC VM and feedback on AMET Cloud Tutorial: Jiacheng Yang and Manish Soni

UNC-EPA Operations team for CMAQ and AMET support:

EPA; Kristen Foley, Christian Hogrefe, Fahim Sidi, Daiwen Kang, David Wong, Sergey Napelenok, Sara Farrell, Rohit Mathur, Jeff Willison, Havala Pye, Chris Misenis, Wyat Appel, Rob Gilliam

UNC; Elizabeth Adams, Manish Soni, Sedona Ryan, Sarav Arunachalam

AWS Technical assistance - Timothy Brown (Amazon Web Services)

AWS Open Data Program - hosting CMAS Data Warehouse

CMAS Community Participation – using AMET and providing feedback on CMAS User Forum helps improve our air quality models and tools

Thank you & Q/A