Air quality and aerosol predictions at NOAA/National Weather Service

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NATIONAL WEATHER SERVICE

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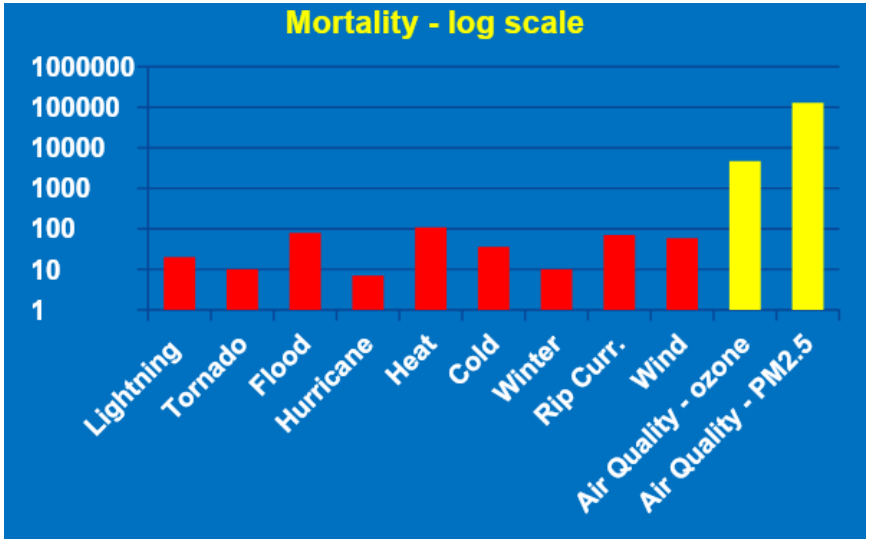
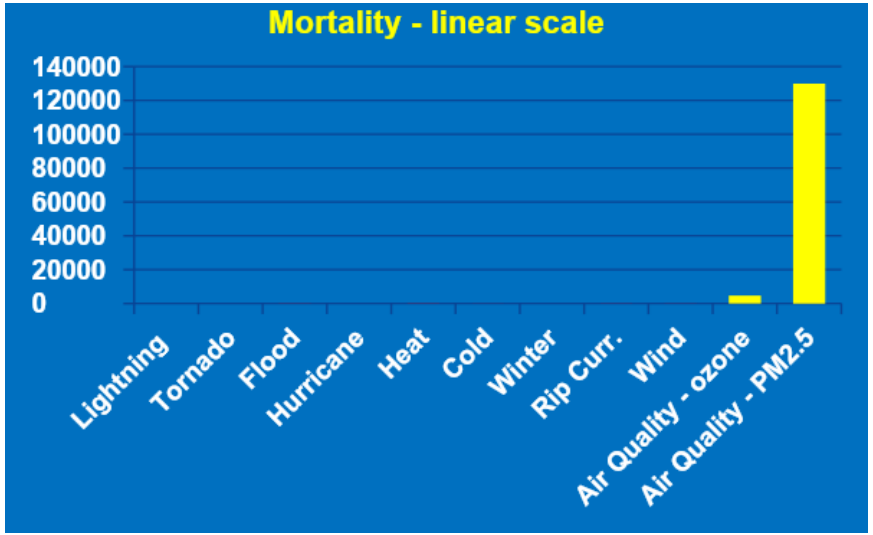
with
NOAA's Regional Air Quality and Global Aerosol Prediction Team

Outline

- Why does air quality prediction matter?
- Regional air quality prediction
- Global aerosol prediction
- Assimilation of satellite data
- Summary, needs and challenges

Societal Impacts of Weather and Air Quality





Red: Weather fatalities for 2018 (source: https://www.weather.gov/hazstat/)

Yellow: Air Quality mortality for 2005 (source: Fann et al., Risk Analysis, 2012 https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1539-6924.2011.01630.x)

same data - linear scale

In the United States, annual mortality from poor air quality (over 100,000) substantially exceeds mortality from all other weather phenomena (530).

Customers

The main customers for NWS air quality (AQ) forecast guidance are **state and local environmental agencies** who issue official AQ forecasts for their respective areas.

These official AQ forecasts are disseminated to the public through various outside channels including AirNow.gov web site, media, mobile applications and through NWS Weather Forecast Offices (WFOs).

Additionally, NWS AQ forecast guidance is distributed directly to the **general public** on maps at https://airquality.weather.gov/,

in grib files, and as a web service at

https://idpgis.ncep.noaa.gov/arcgis/rest/services/NWS_Forecasts_Guidance_Warnings

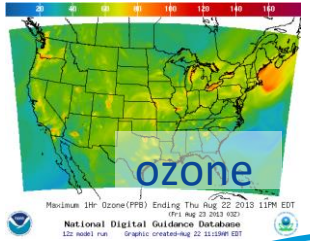
The web service is used by **partner agencies**:

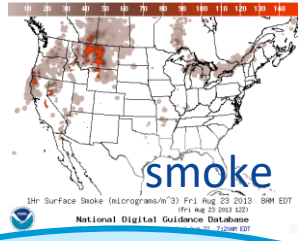
- the Centers for Disease Control (**CDC**) for vulnerability assessment
- the Environmental Protection Agency (**EPA**) in their Smoke Sense mobile application.

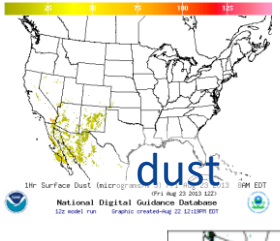
Air Quality Forecasting Partnership

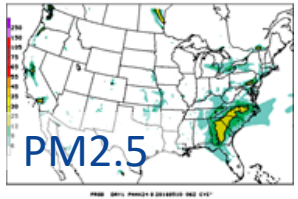
- Exposure to fine particulate matter and ozone pollution leads to premature deaths of over 100,000 annually in the US *(Fann, 2011, Risk Analysis)*
- Air quality forecasting in the US relies on a partnership among NOAA, EPA, state and local agencies. **NOAA-EPA MOU renewed in January 2021.**
- NOAA air quality forecasting team includes NWS, OAR and NESDIS

http://airquality.weather.gov/



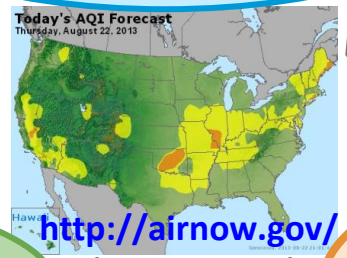






NOAA

integrate, evaluate and improve models; provide operational AQ predictions



EPA

maintain national emissions, monitoring data, develop AQ models; disseminate/interpret AQ forecasts

State and local agencies

provide monitoring data & emissions; provide AQI forecasts

National Air Quality Forecast Capability

Operational predictions at http://airquality.weather.gov

over expanding domains since 2004

Ozone and PM2.5

Linked numerical prediction system

Operationally integrated on NCEP's supercomputer

- **NOAA/EPA Community Multiscale Air Quality (CMAQ) model**
- **NOAA/NCEP North American Mesoscale Forecast System (NAM) weather prediction. Development and testing: → GFS → online with RRFS**

Observational Input:

- **EPA emissions inventory, AirNow for bias correction**
- **NESDIS fire locations**

Gridded forecast guidance products 2x daily nationwide

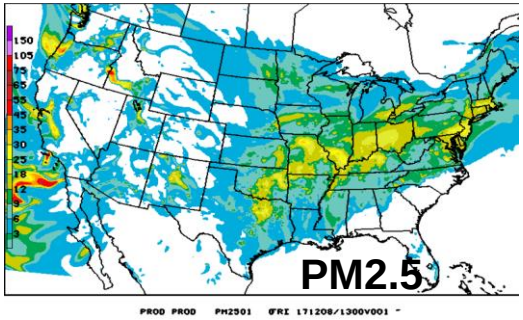
- **At airquality.weather.gov and ftp-servers (12km resolution, hourly for 48 hours).**
- **On EPA servers**

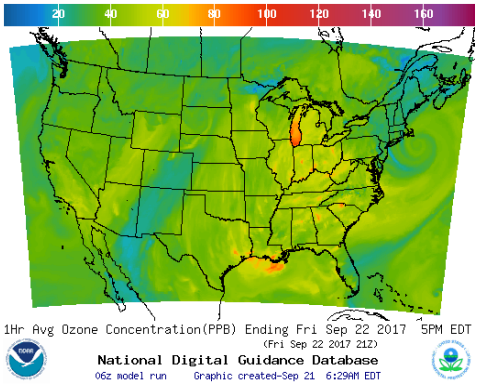
Verification, near-real time:

- **Ground-level AirNow observations of surface ozone and PM2.5**

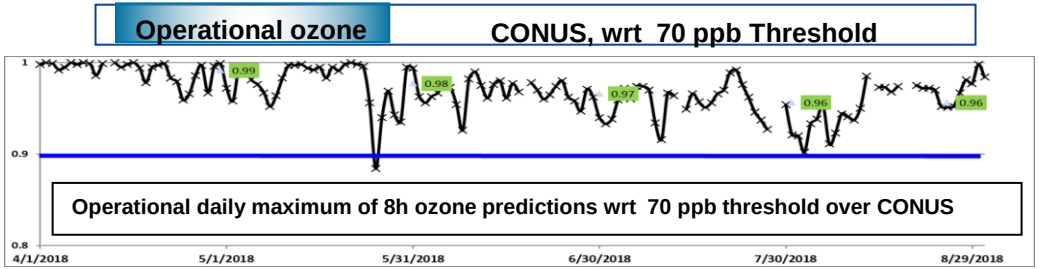
Customer outreach/feedback

- **State & Local AQ forecasters coordinated with EPA**
- **Public and Private Sector AQ constituents**



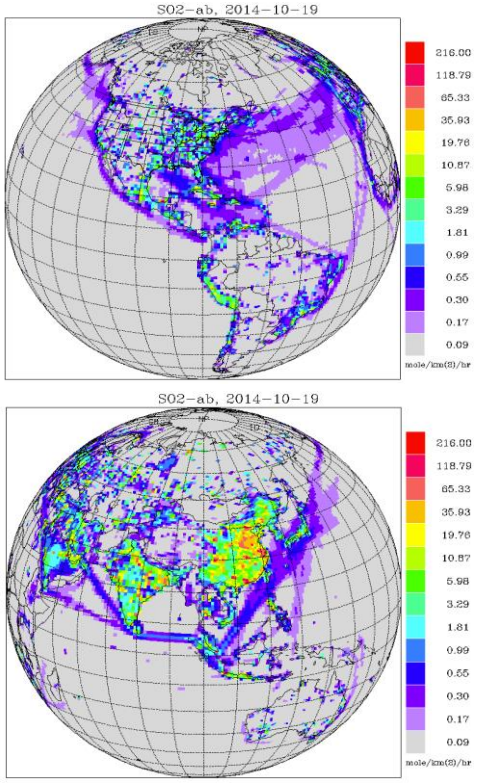


Ozone



Maintaining prediction accuracy for lowered warning threshold and under changing pollutant emissions

GEFS-Aerosol member



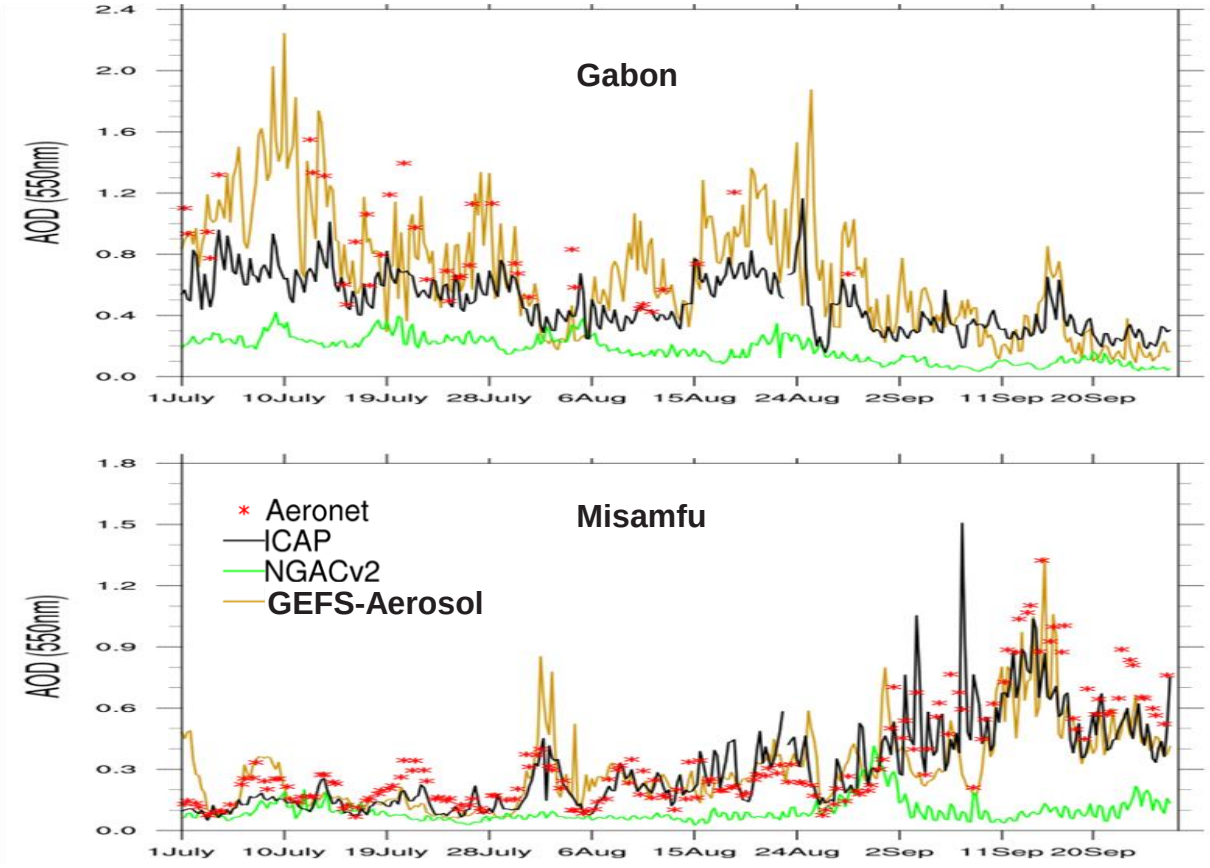
CEDS-2014 SO2 emissions

- Online aerosol representation based on NASA's GOCART
- Implemented into operations in September 2020 in the first UFS coupled model: GEFS with Aerosols and Waves.

GEFS-Aerosol member:

- GFSv15 meteorology at ~25 km, 64 levels, to 120 hrs, 4x/day
- GOCART: Sulfate, Organic Carbon, Black Carbon, Dust, Sea Salt
- **Emissions**: CEDS-2014 (SO2, PSO4, POC, PEC), GBBEPx biomass burning, FENGSHA dust, GEOS-5 sea salt, marine DMS
- Initial conditions: cycled for aerosols (no data assimilation) and GFSv15 analysis for meteorology
- Smoke plume rise: Wind shear dependent 1-d cloud model to simulate tilt of plume. Fire Radiative Power is used to calculate convective heat flux and determine injection height
- Tracer transport and wet scavenging are included in Simplified Arakawa-Schubert (SAS) scheme. Fluxes are calculated positive definite. Scavenging coefficient is α=0.2 for all aerosol species.

AERONET comparisons



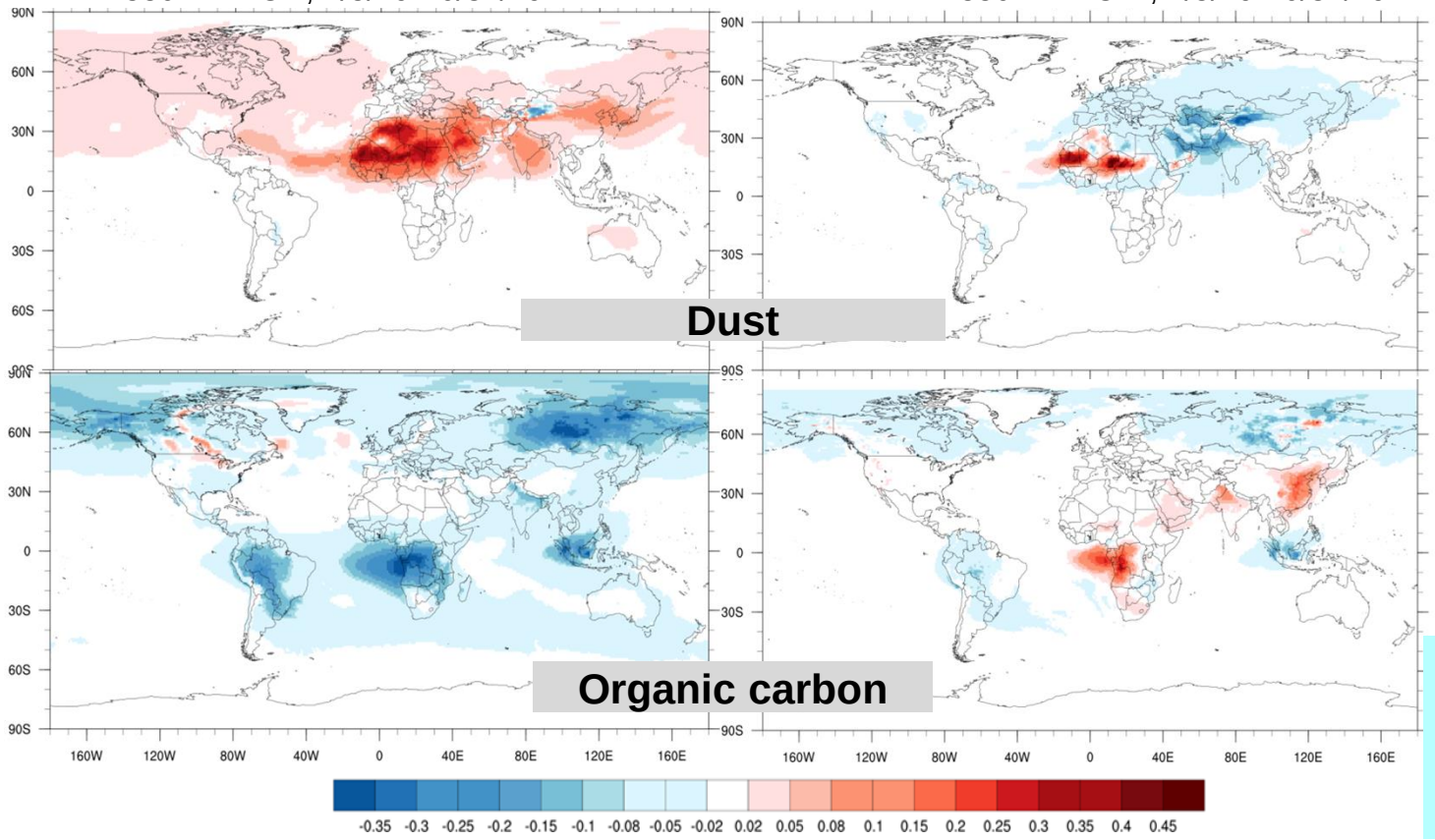
Comparison against AERONET AOD in Africa. GEFS-Aerosol tracks observed total AOD magnitude and variability much better than NGAC in western (Gabon) and eastern (Misamfu) Africa.

NGAC day 1 prediction – GEOS-5 analysis

550 nm AOD, 7/5/19-10/31/19

GEFS-Aerosol day 1 prediction – GEOS-5 analysis

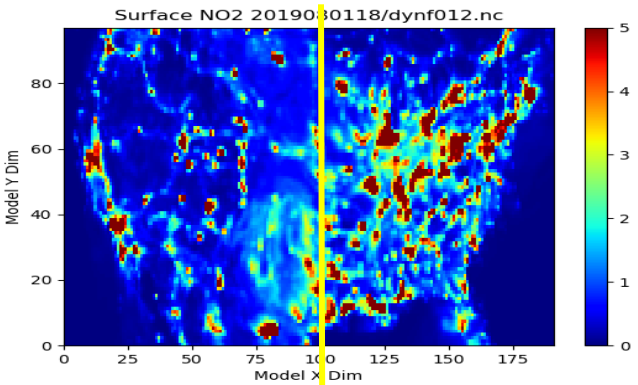
550 nm AOD , 7/5/19-10/31/19



Biases with respect to GEOS-5 analyses (which assimilate satellite AOD) are smaller for GEFS-Aerosols (right) than those for NGAC (left) for dust, organic carbon and sulfate aerosols (not shown).

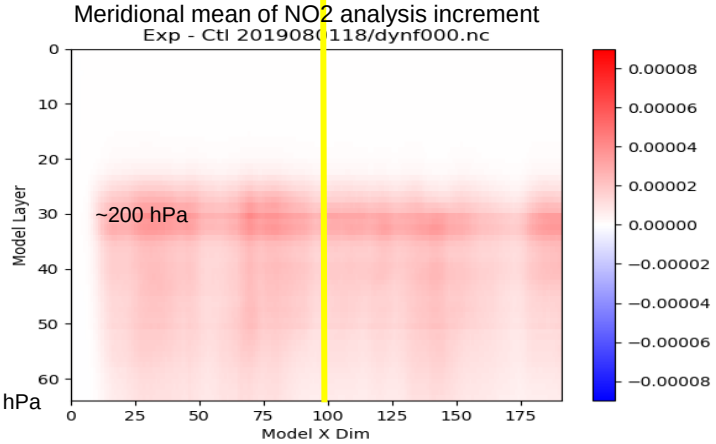
Satellite AOD data are also used for verification

NO2 Data Assimilation (DA)

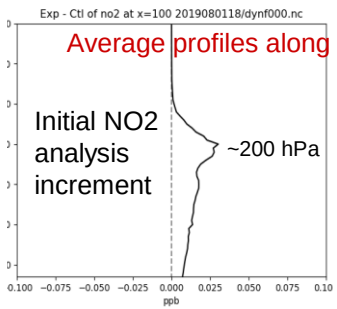


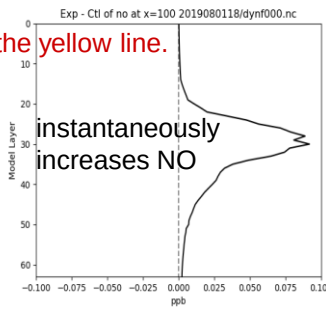
Development and testing of **tropospheric column TROPOMI NO2** Data Assimilation in the regional coupled system RRFS-CMAQ:

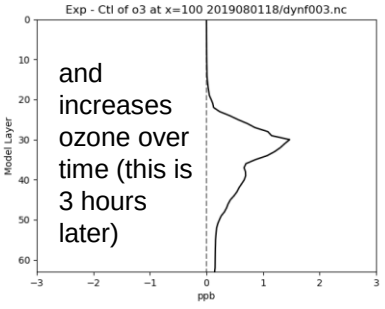
- Cycled DA consistently increases atmospheric NO2. This increases NO quickly, and later increases ozone
- Consistent increments indicate the need to improve emissions (through coupled DA) and/or model processes



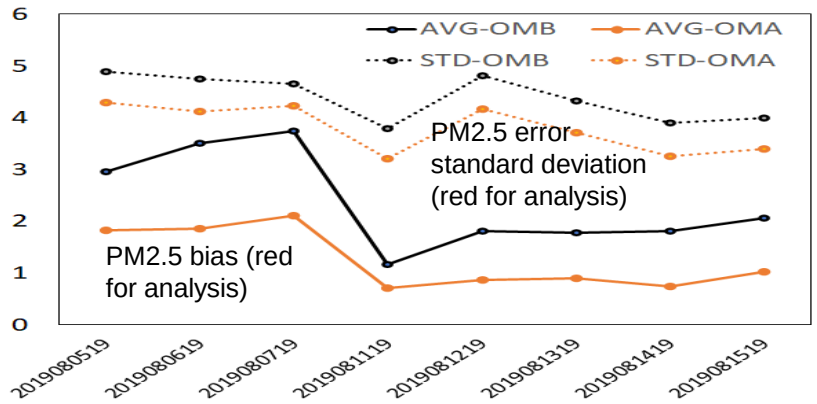
~200 hPa

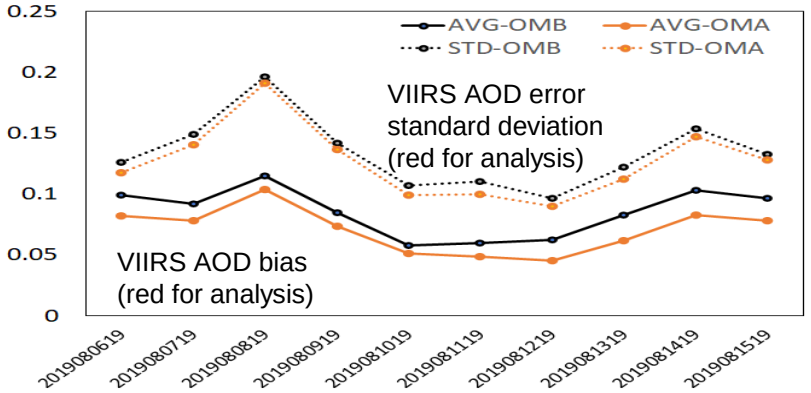




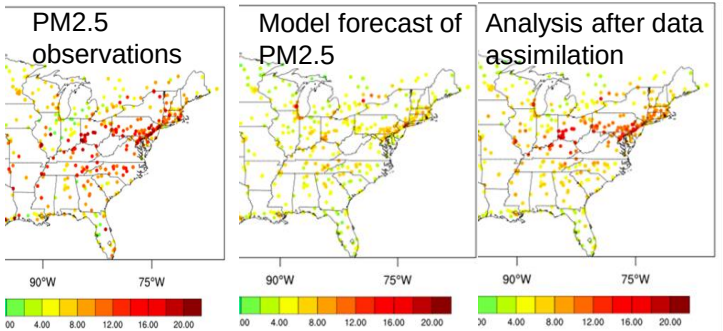


Regional aerosol Data Assimilation (DA)



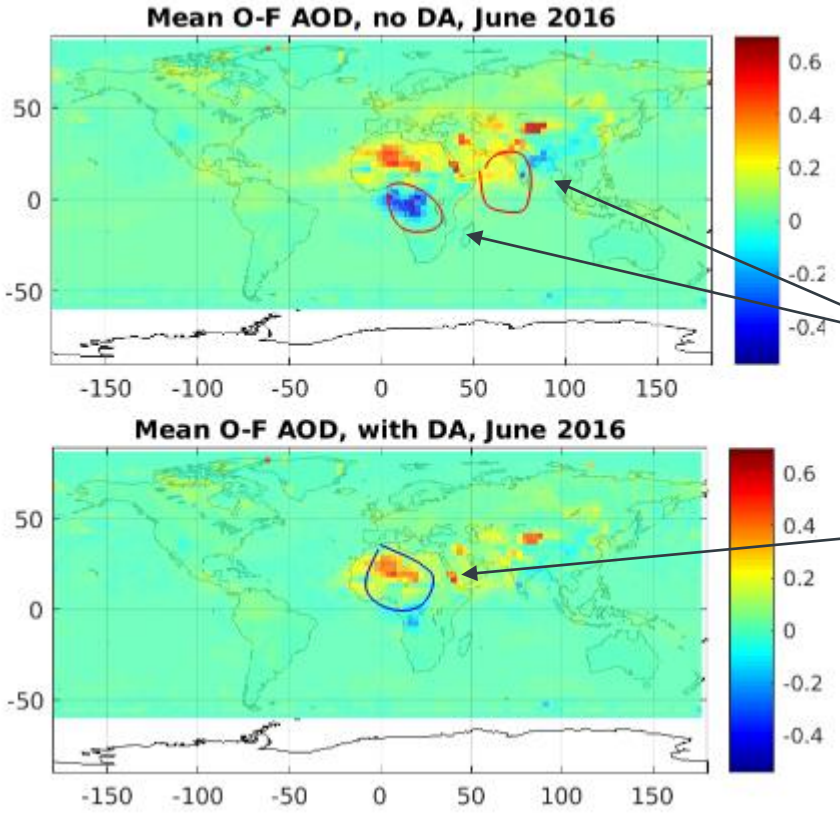


Development: Single cycle assimilation provides analyses that are closer to observations than the model forecast (bias and error standard deviation are reduced). VIIRS AOD data were bias corrected.



- Severely under constrained problem, especially for AOD
- How to best update distribution of species, sizes and where in the vertical profile?
- How to best update input emissions and model processes?

Global AOD Data Assimilation



Development and testing for June 2016

MODIS AOD:

Data assimilation (DA) cycling experiment is compared to control model run (without DA). DA reduces biases in the system.

Assimilation of MODIS AOD observations reduces forecast overestimates in Western Africa and underestimates in the Arabian Sea (red circled regions in upper plot).

AOD underestimation in Northern Africa shows a smaller reduction (blue circle), likely due to higher observation errors over high albedo desert regions. This is an area of current research focus.

VIIRS AOD:

Reanalysis with VIIRS AOD DA has smaller bias than the free-running model with respect to NASA's MERRA-2 (not shown)

Summary

National AQ predictions:

- NWS provides national ozone, PM2.5, smoke, dust predictions.
- Partnership among NOAA, EPA, state and local agencies to provide AQ forecasts
- Mortality for poor AQ far exceeds that from all other weather phenomena combined

Global aerosol predictions:

- GEFS-Aerosol model was implemented operationally in September 2020. It shows great improvements over the previous model

Satellite data use:

- Emissions inputs (fire emissions, NOx trends, dust sources) and verification of predictions
- **Developing assimilation of satellite AOD** into GEFS-Aerosol
- **Developing assimilation of satellite AOD and NO2 data** into CMAQ coupled with a high resolution weather model

Needs and challenges

Build the base DA capability to effectively use satellite data, including GEO-XO data

Emissions:

- Specification & prediction of biomass burning & dust emissions
- Timely updates of anthropogenic emissions

Data Assimilation:

- Integral quantities observed – AOD is integral over all aerosol species, sizes and the column
- Loss of satellite instrument sensitivity for gaseous composition in PBL
- Quality Control and correction of observation biases
- Better coordination with product developers from retrieval to data assimilation

Synergies:

- Coupled data assimilation for real-time updates of atmospheric concentrations and emissions
- Use information from observation-model comparisons in DA to improve process representation in the model

Thank you

National Air Quality Forecast Capability

Smoke and dust

Emission sources

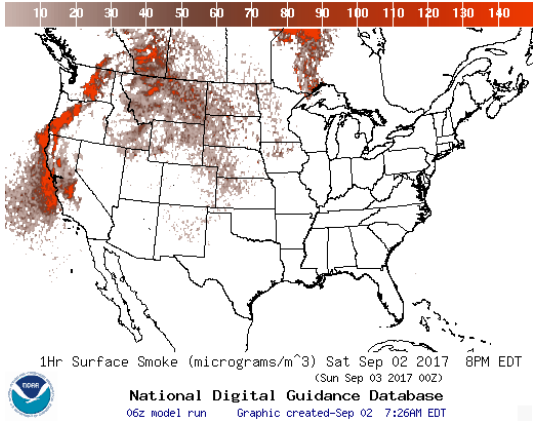
- **Smoke: NESDIS detects wildfire locations from satellite imagery. Emissions estimated by USFS BlueSky system.**
- **Dust: Source regions with emission potential are from MODIS deep blue climatology for 2003-2006. Emissions are modulated by wind and soil moisture.**

HYSPLIT model with NAM meteorology for transport, dispersion and deposition

- **Smoke: daily, nationwide**
- **Dust: 2x per day, CONUS**

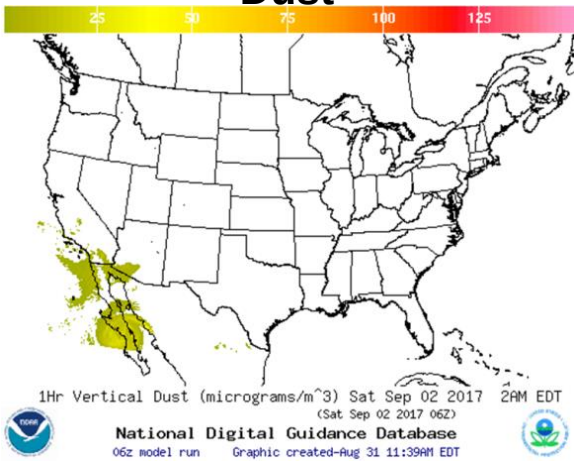
Satellite products developed for verification

Operational predictions at http://airquality.weather.gov



Smoke

Dust

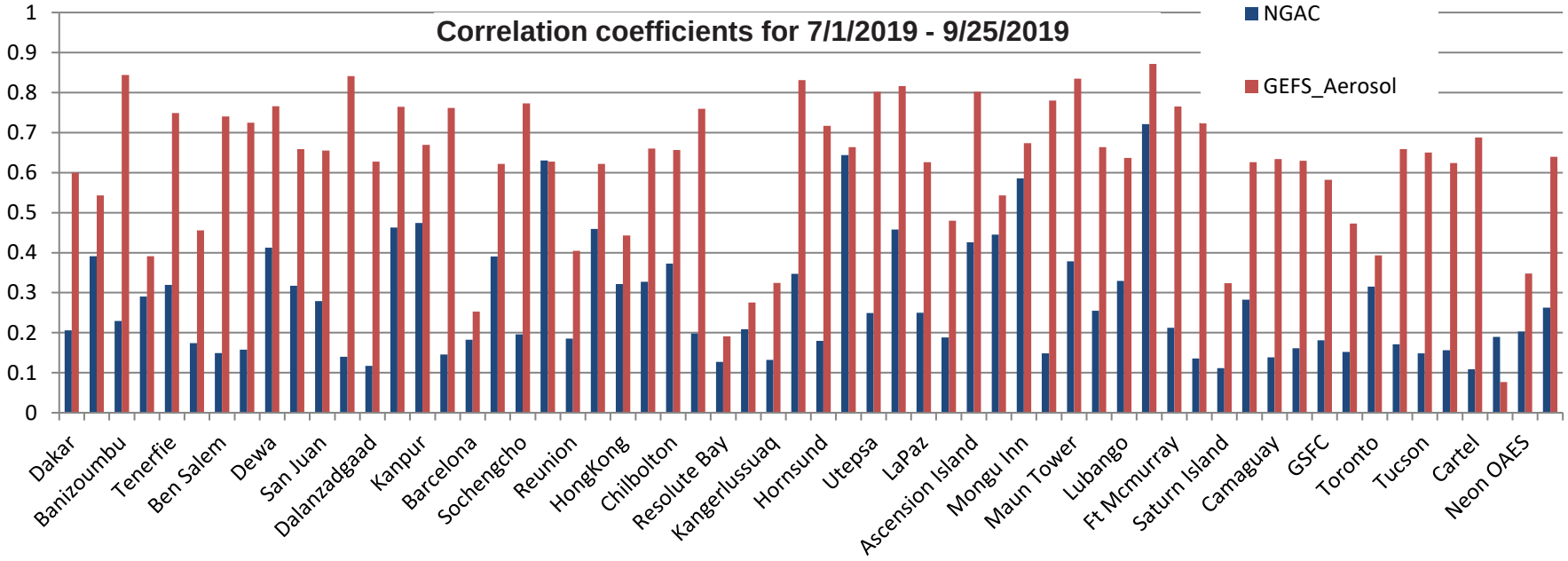


Satellite data use:

- Emissions
- Verification

HRRR smoke wan implemented in the operations.

Correlations with AERONET



Correlations with AERONET AOD are higher for GEFS-Aerosols (red) than for NGAC (blue): 0.61 vs 0.27 on average.