Update on the NOAA FV3GFS-Chem Global Aerosol Model

Rick Saylor
NOAA Air Resources Laboratory
rick.saylor@noaa.gov

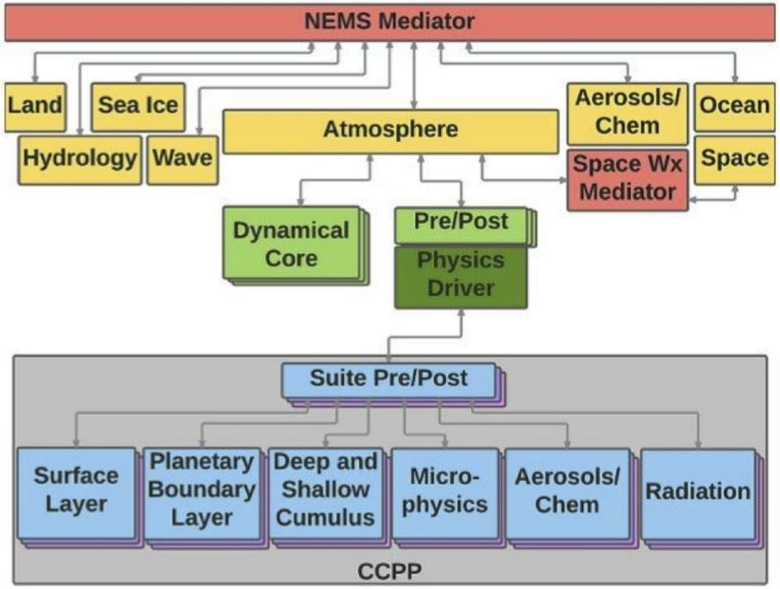
Jeff McQueen, Li Pan, Partha S. Bhattacharjee, Jack Kain,
Ivanka Stajner (NWS/NCEP)
Georg Grell, Li Zhang, Raffaele Montuoro (ESRL/GSD)
Greg Frost, Stu McKeen (ESRL/CSD)
Barry Baker, Daniel Tong (ARL)

ICAP 11th WG Meeting, Tsukuba City, Japan, July 22-24, 2019

Unified Forecast System for Operational Earth System Prediction (2018)

ESMF/NUOPC/NEMS architecture enables unified global and regional coupled modeling and DA

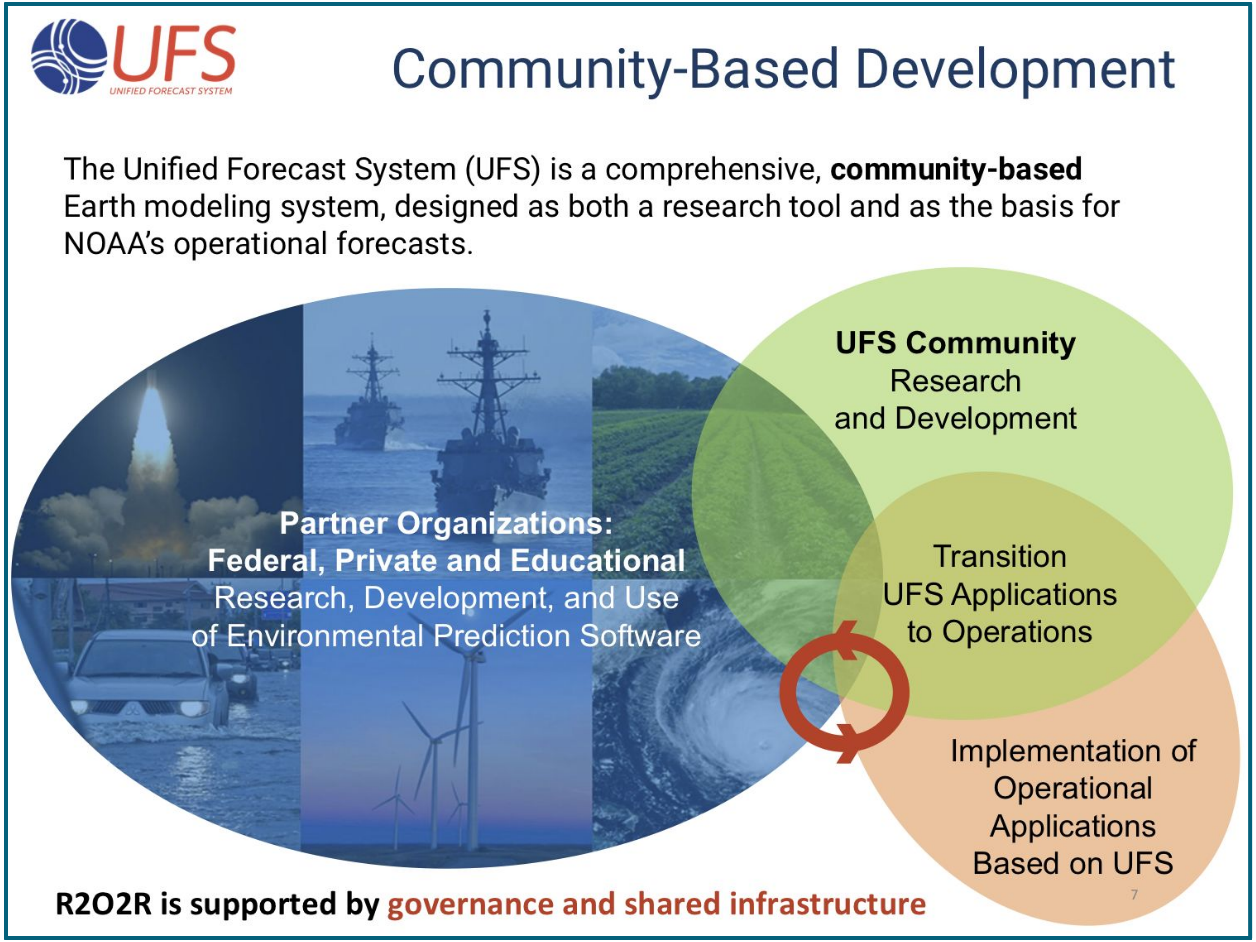
Consistent with broader community (CESM) and US National ESPC



Courtesy Developmental Testbed Center

From Dorothy Koch's presentation to the NOAA Coordination Meeting for UFS SIP Annual Update May 14, 2019

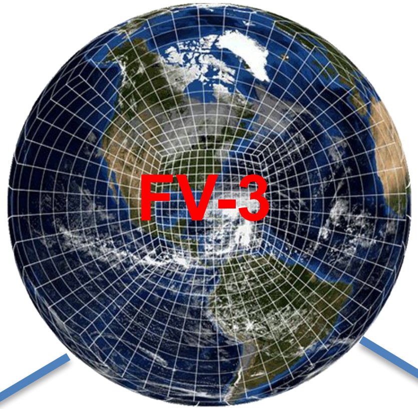
GEFS-Aerosols (FV3GFS-Chem) slated to replace NGAC as a control member of the Global Ensemble Forecast System (GEFS) v12 in <u>late summer 2020</u>



From Dorothy Koch's presentation to the NOAA Coordination Meeting for UFS SIP Annual Update May 14, 2019

Earth Prediction Innovation Center (EPIC) Community Workshop
Aug 6-8 in Boulder

GFS physics, including sub-grid scale tracer transport



Other more advanced physics options are available through Common Community Physics Package (CCPP)

GEFS-Aerosols initially only GOCART

Coupled chemistry suites

NUOPC coupled WRF-Chem-based suite for global model

Simplified sulfur chemistry.	More sophisticated aerosol modules including secondary organic aerosols (SOA)	
GOCART	GOCART RACM	RACM SOA

NUOPC coupled CMAQ suite for **NAQFC**

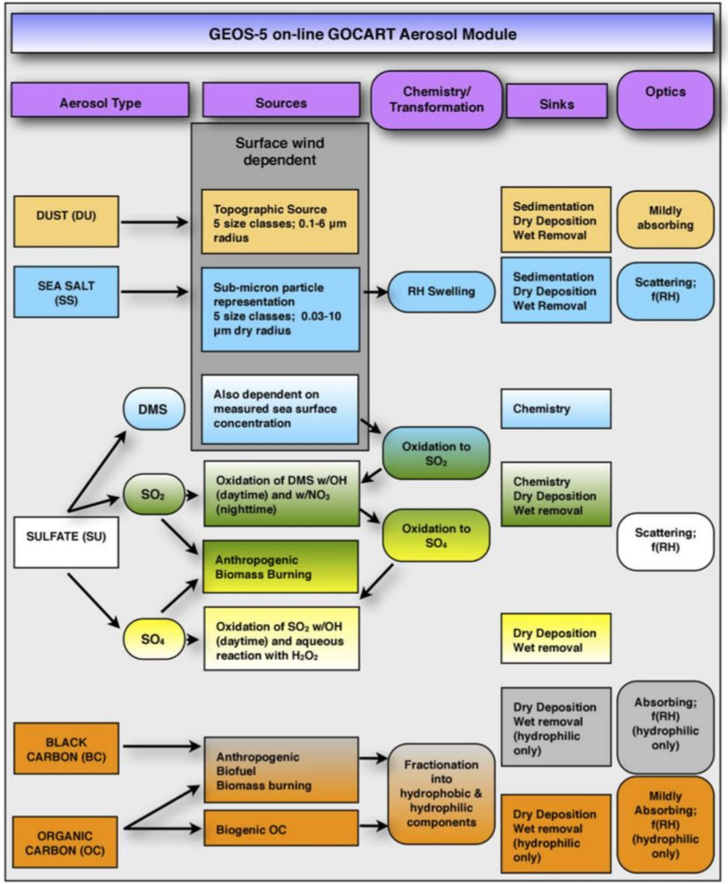
Operational CMAQ EPA modules in progress (CB06, AERO)

GOCART Module

In-line chemistry advantage

- Consistency: no spatial-temporal interpolation, same physics parameterization
- Efficiency: lower overall CPU costs and easier data management
- Interaction: Allows for feedback to meteorology

GOCART diagram provided by Peter Colarco (GSFC)



From Vijay Tallapragada's presentation to the Coordination Meeting for UFS SIP Annual Update May 14, 2019

Configuration for GEFS-Aerosols in GEFS v12

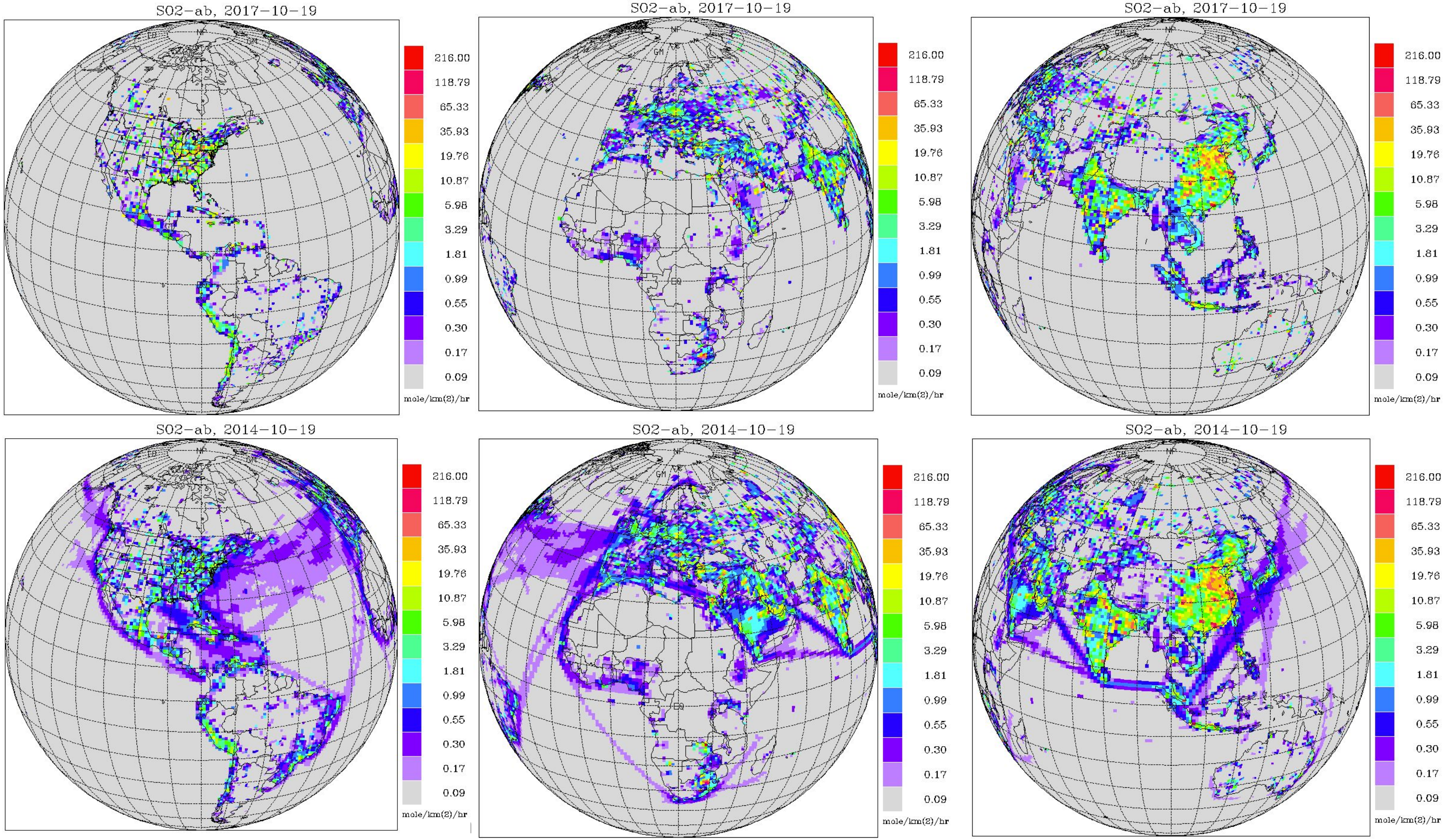
- **Resolution:** C384, L64 to 120 hrs 4x/day
- **Transport:**
  - Grid-scale transport provided by FV3
  - Sub-grid transport by PBL and convection in chemistry component or GFS physics
- **Deposition:**
  - Wet deposition (for aerosols and sulfate) and dry deposition (all species)
- **Anthropogenic Emissions:** CEDS-2014 (SO_2, PSO_4, POC, PEC)
- **Biomass burning:** NESDIS Global Biomass Burning Emission Product (GBBEPx) used for fire size and location; 1d shear-dependent cloud model used to calculate injection heights and emission rates online
- **Dust:** 2 options available; 5 size bins
  - AFWA dust scheme : Marticorena and Bergametti scheme provides bulk vertical dust flux; size distribution from Kok 2010 (PNAS)
  - FENGSHA dust scheme: scheme used in current NAQFC (Tong et al; Baker et al.)
- **Sea-salt:** NASA GEOS-5 GOCART
- **Marine Dimethyl Sulfide:** GOCART w/ monthly values as in Lana et al. (2011)
- Chemistry cycled for initial conditions
- Meteorological initial conditions from FV3GFS analysis

Emissions Upgraded to CEDS-2014 (CEDS-2016 as soon as available)

Anthropogenic SO_2 Emissions on FV3 grid (C96)

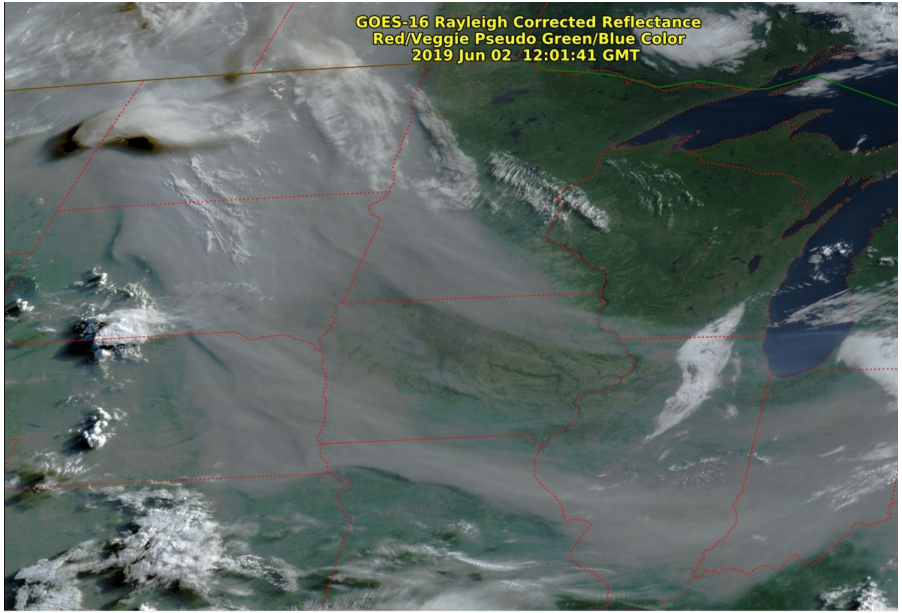
HTAP-2010

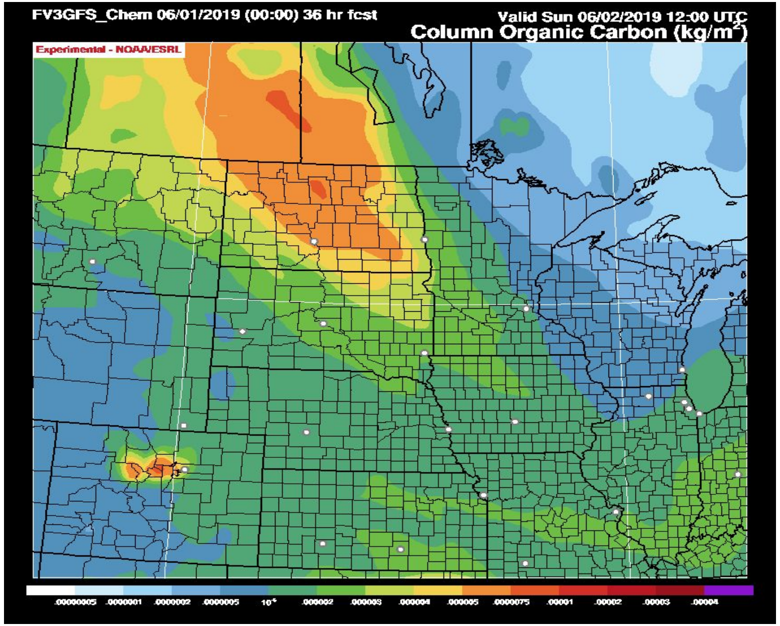
CEDS-2014



Real-Time Forecasts of North American Wildfires: Prelude to FIREX-AQ

June 2, 2019 – 12:00 UTC



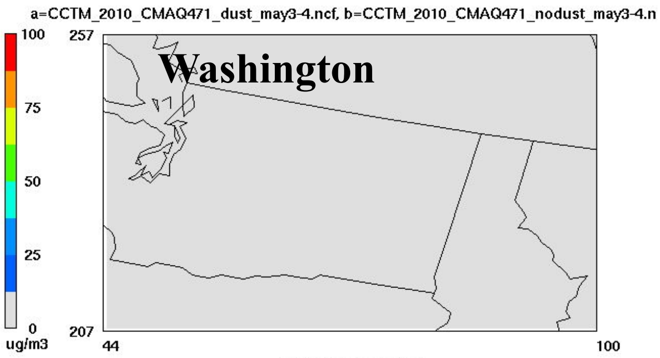


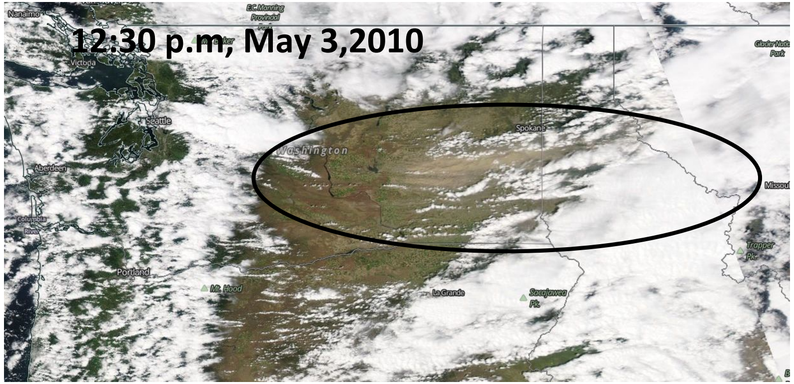
- Transport of Northern Alberta smoke reproduced well.
- 5 to 7.5 mg/m^2 column Organic Carbon over central ND.
- Compared to HRRR-Smoke: 50 to 80 mg/m^2 .
- Compared to RAP-Smoke: 30 to 60 mg/m^2 .

https://fim.noaa.gov/FV3chem

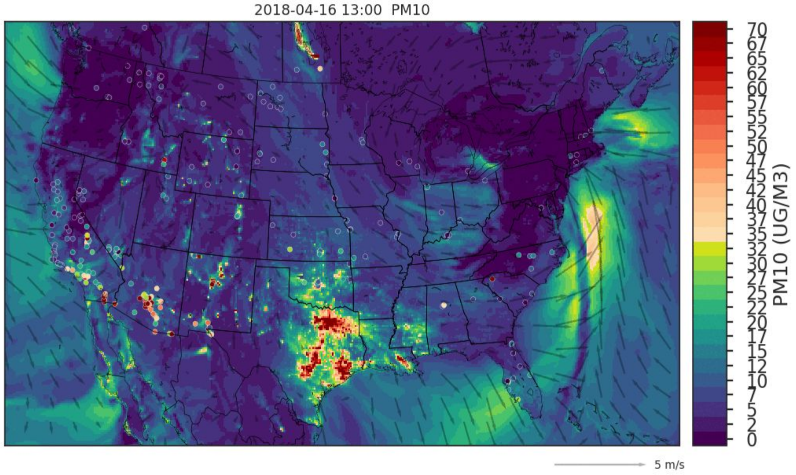
FENGSHA - National Air Quality Forecast Capability (NAQFC)

Dust PM2.5 on May 3,2010





MODIS-AQUA True Color NASA Worldview



FENGSHA used in NAQFC to forecast dust emissions from cropland, rangeland, and deserts.

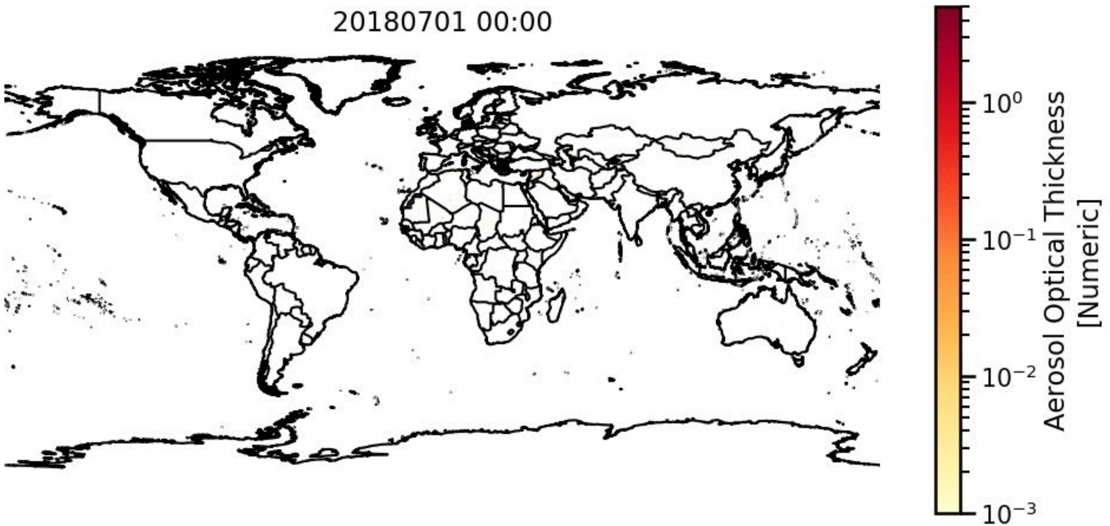
FENGSHA dust scheme (Tong et al., Baker et al. in prep.)

Vertical Dust Flux

Surface Friction Velocity

Surface Threshold Velocity

$$F = \alpha \times A \times S \times \frac{\rho}{g} u_{*T}^{3} \left(1 - \left(\frac{u_{*t}}{u_{*T}}\right)^{2}\right)$$



FENGSHA Parameterization Options

1a — Threshold Friction Velocity over smooth dry surface

Size Independent, based on soil texture classification measurements, field and wind tunnel studies done by Dale Gillette

1b — Drag partition Correction $R(z_0, z_{0s})$

Option 1: MB95

$$R(z_0, z_{0s}) = 1 - \frac{\ln\left(\frac{z_0}{z_{0s}}\right)}{\ln\left[0.7\left(\frac{10cm}{z_{0s}}\right)^{0.8}\right]}$$

Option 2: MacKinnon et al 2004

$$R(z_0, z_{0s}) = 1 - \frac{\ln\left(\frac{z_0}{z_{0s}}\right)}{\ln\left[0.7\left(\frac{12255cm}{z_{0s}}\right)^{0.8}\right]}$$

Required Parameters:

- Smooth Roughness Length
- Aeolian Roughness length
  - Constant = 1e-4

1c — Moisture Correction

if $w \geq w'$

$$H(w) = \left[1 + 1.21(w - w')^{0.68}\right]^{1/2}$$

$$w'(\%) = 0.0014(\%clay)^2 + 0.17(\%clay)$$

Required Parameters:

Gravimetric Soil Moisture (w)

Saturated Soil Moisture Content
Option 1a: Clay content parameterized based on soil texture
Option 1b: Clay Content from ISRIC database
Option 2: ISRIC Saturated Soil Moisture database

1 — Threshold Friction Velocity

$$u_t(z_0, w) = \frac{u_{*ts}}{R(z_0, z_{0s})} H(w)$$

2 — Soil Erodibility Potential

$$S = (\%clay)\varepsilon_1 + (\%silt)\varepsilon_2 + (\%sand)\varepsilon_3$$

Required Parameters:

Option 1) Clay, Sand and Silt Content
Option 2) Parajuli and Zender Sediment Supply Map

3 — Horizontal (saltation) flux

$$Q_h = cS\frac{\rho_a}{g}u_*^3\left(1 - \frac{u_{*t}^2}{u_*^2}\right)$$

Required Parameters:

Friction Velocity
Air Density
Soil Potential

4a — Vertical Flux
Marticorena and Bergametti (1995)

$$\alpha = \frac{F}{Q} = 10^{0.134(\%clay)-6}$$

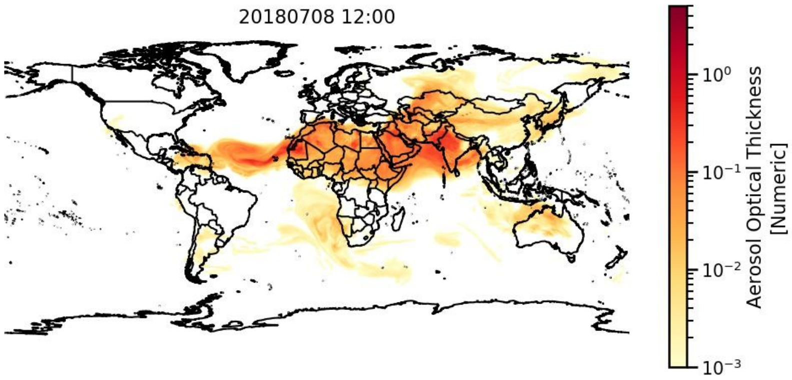
Required Parameters:
Clay Content
Option 1) soil texture parameterization
Option 2) ISRIC Soil Database

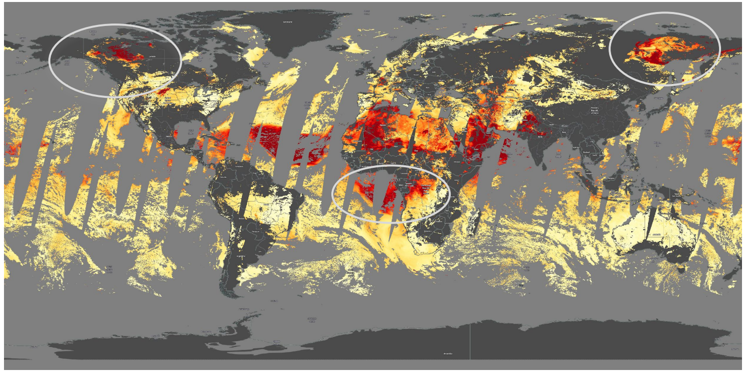
4b — Vertical Flux
Lu and Shao 1999

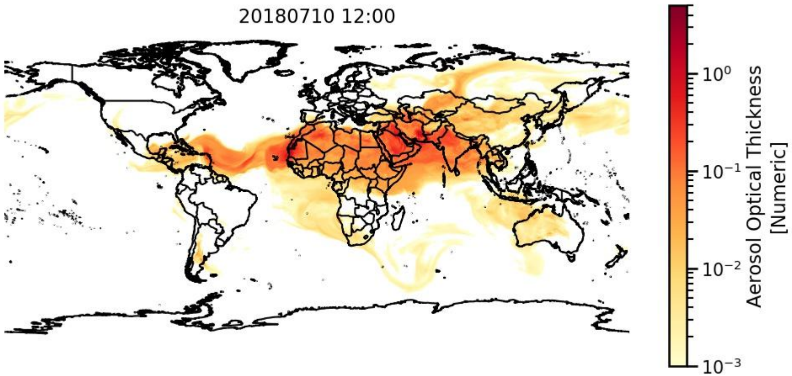
$$\alpha = \frac{C_\alpha g f \rho_b}{2p}\left(0.24 + C_\beta u_* \sqrt{\frac{\rho_b}{p}}\right)$$

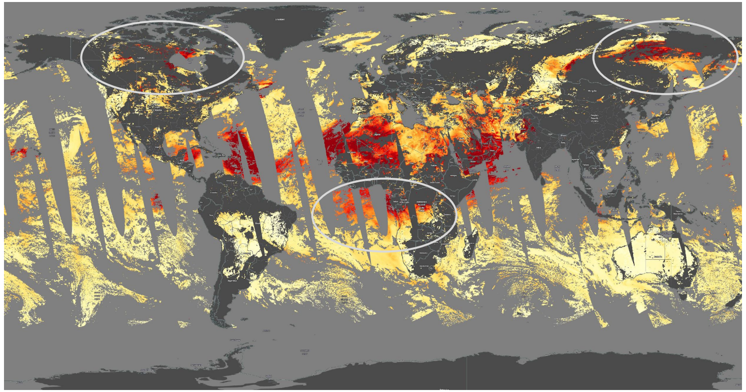
Required Parameters:
Fine fraction
Plastic pressure (constant)
Soil density
Option 1) constant
Option 2) ISRIC Soil Database

FENGSHA - FV3GFS-Chem



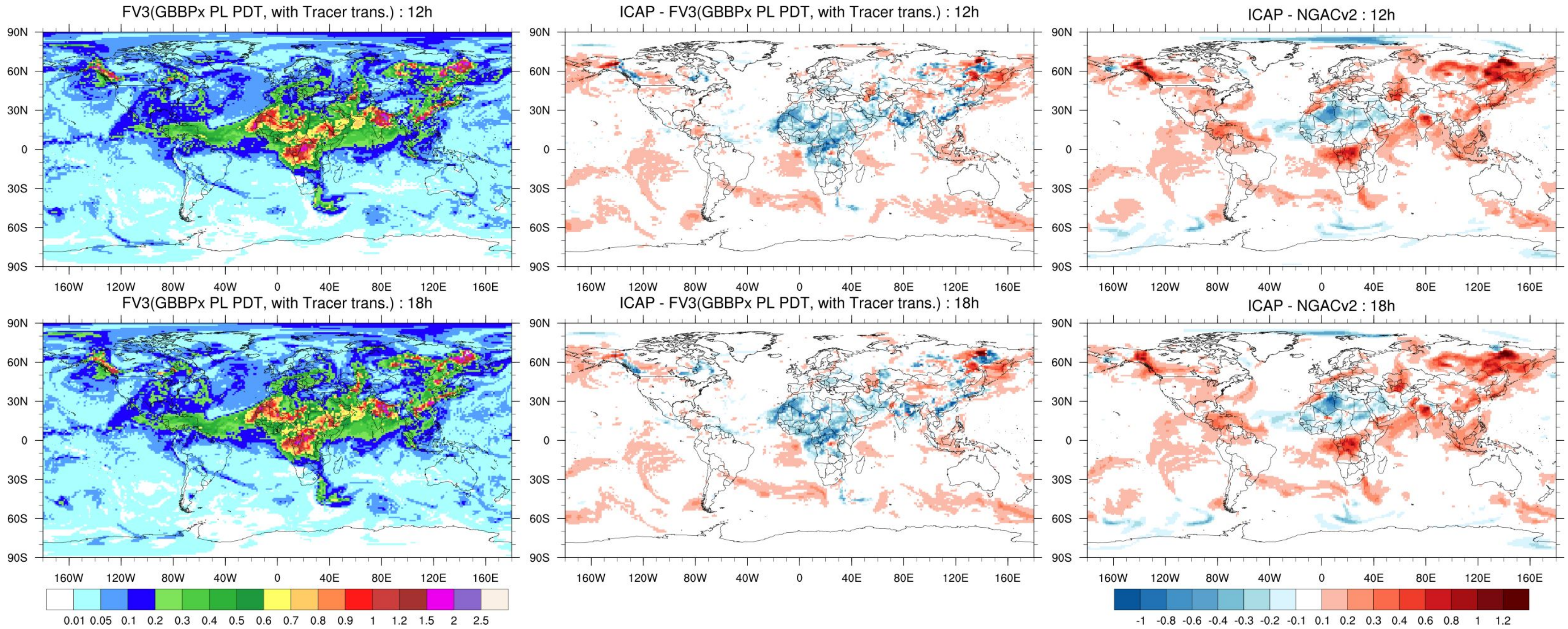






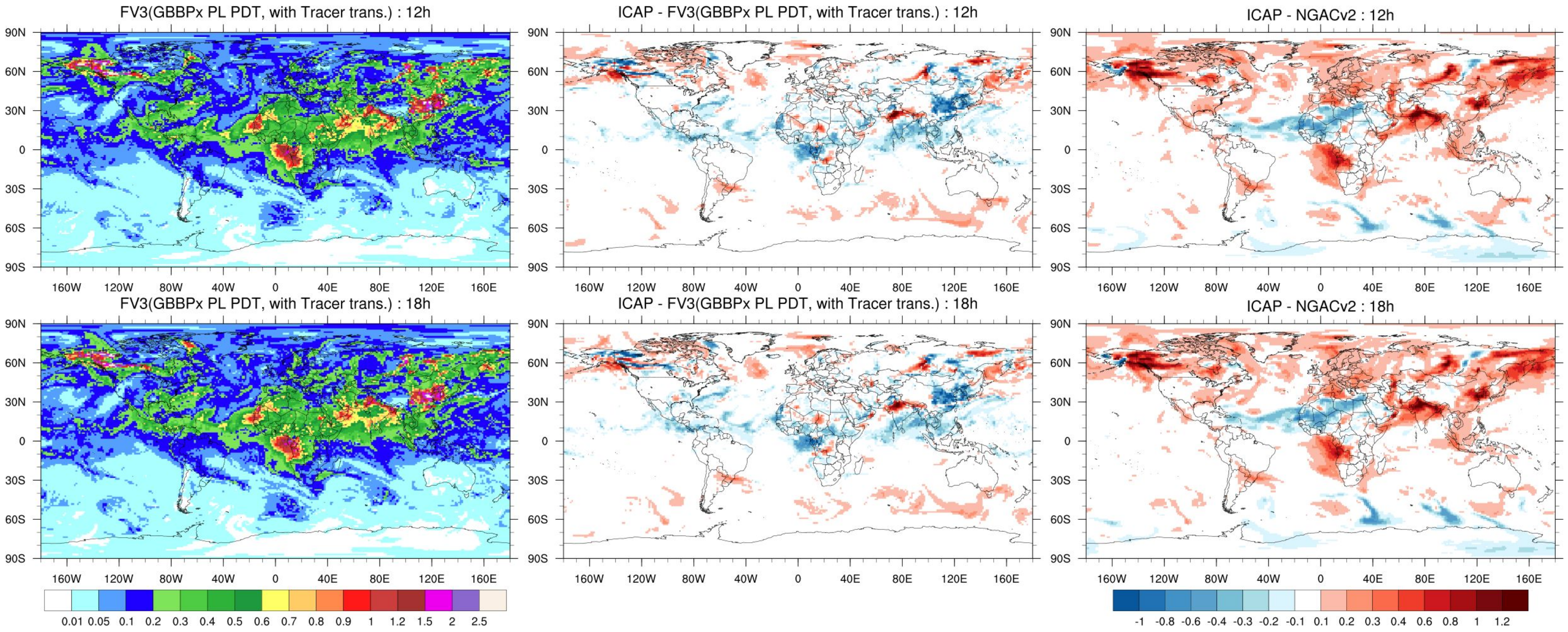
Likely fire locations circled

Total AOD at 550 nm - July 1, 2019

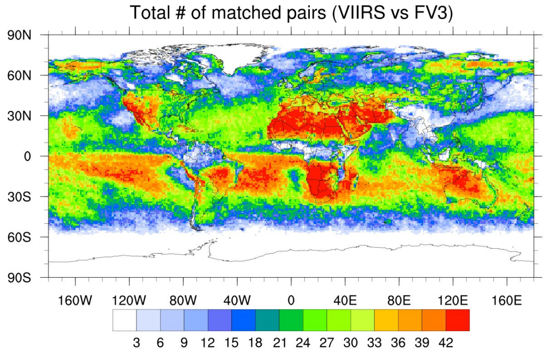


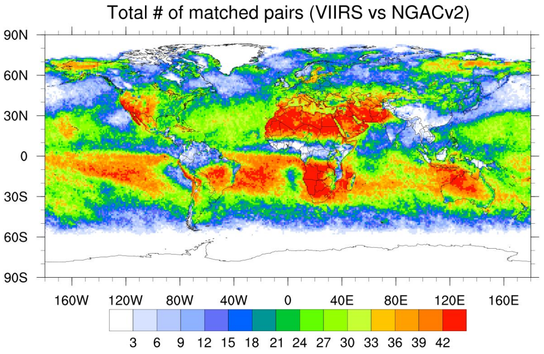
Clear improvement over NGACv2

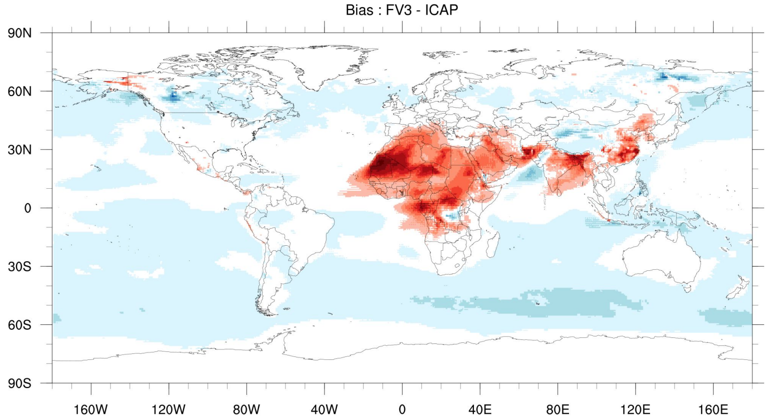
Total AOD at 550 nm - July 14, 2019

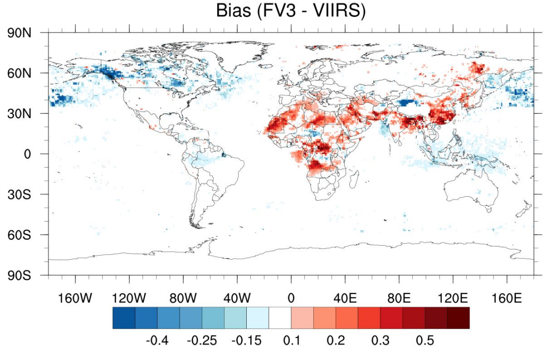


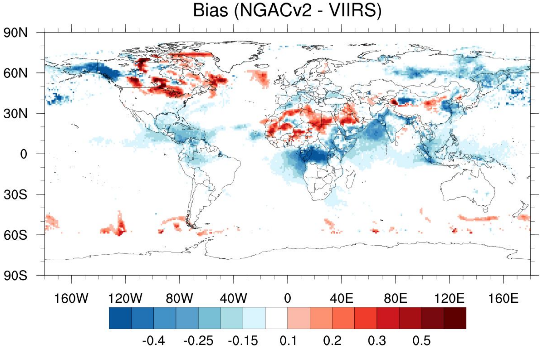
Clear improvement over NGACv2

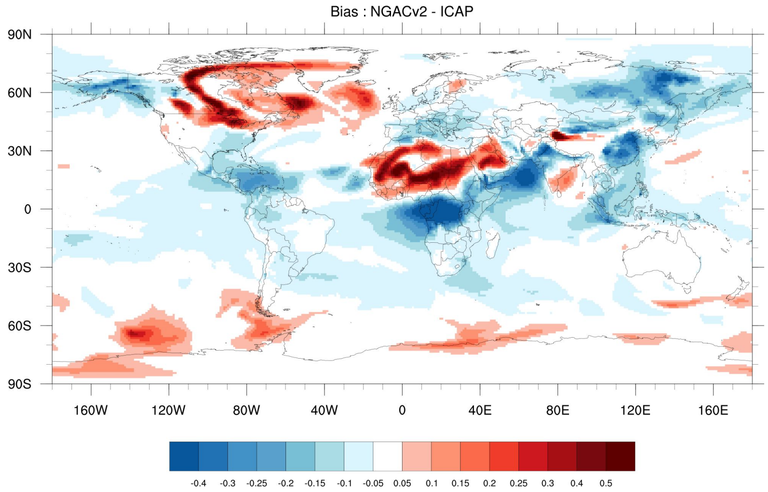




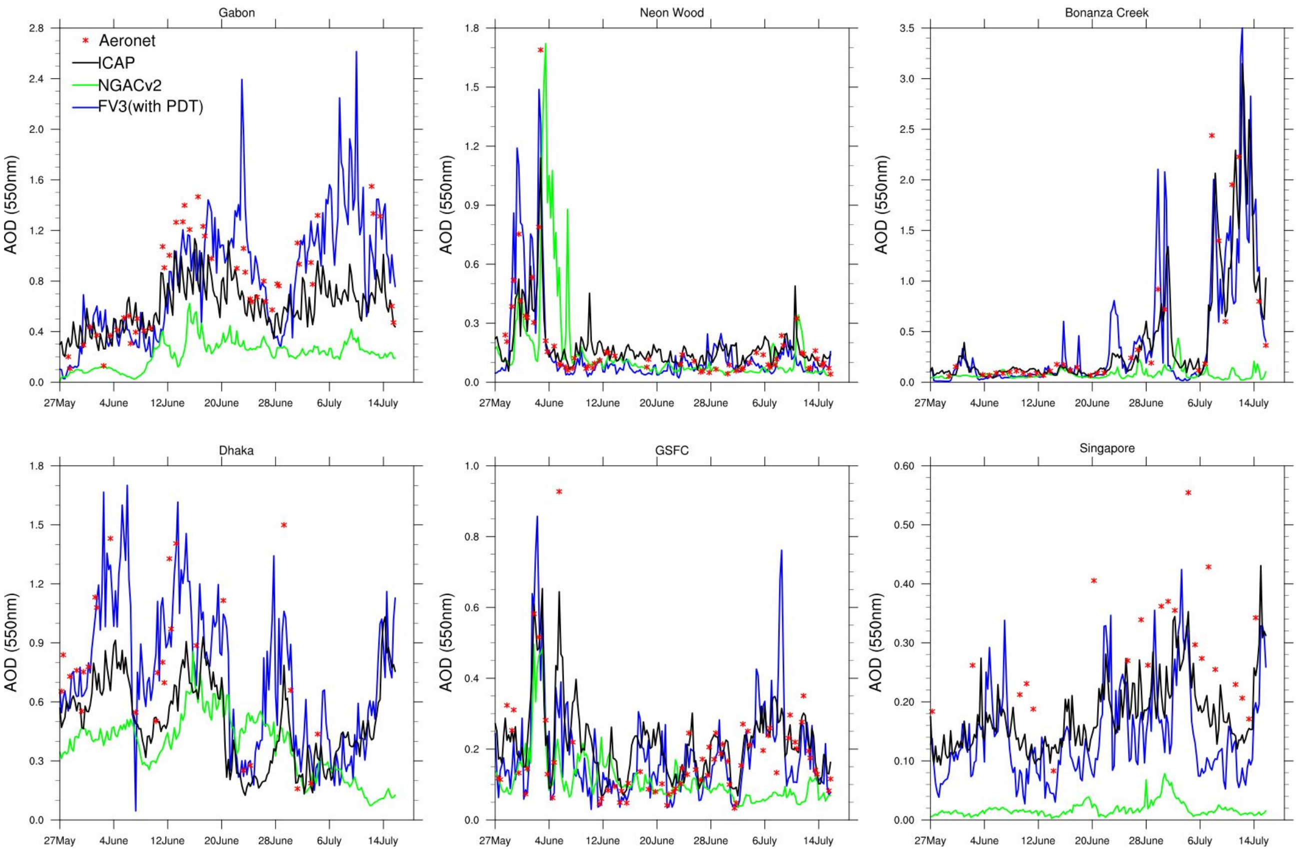




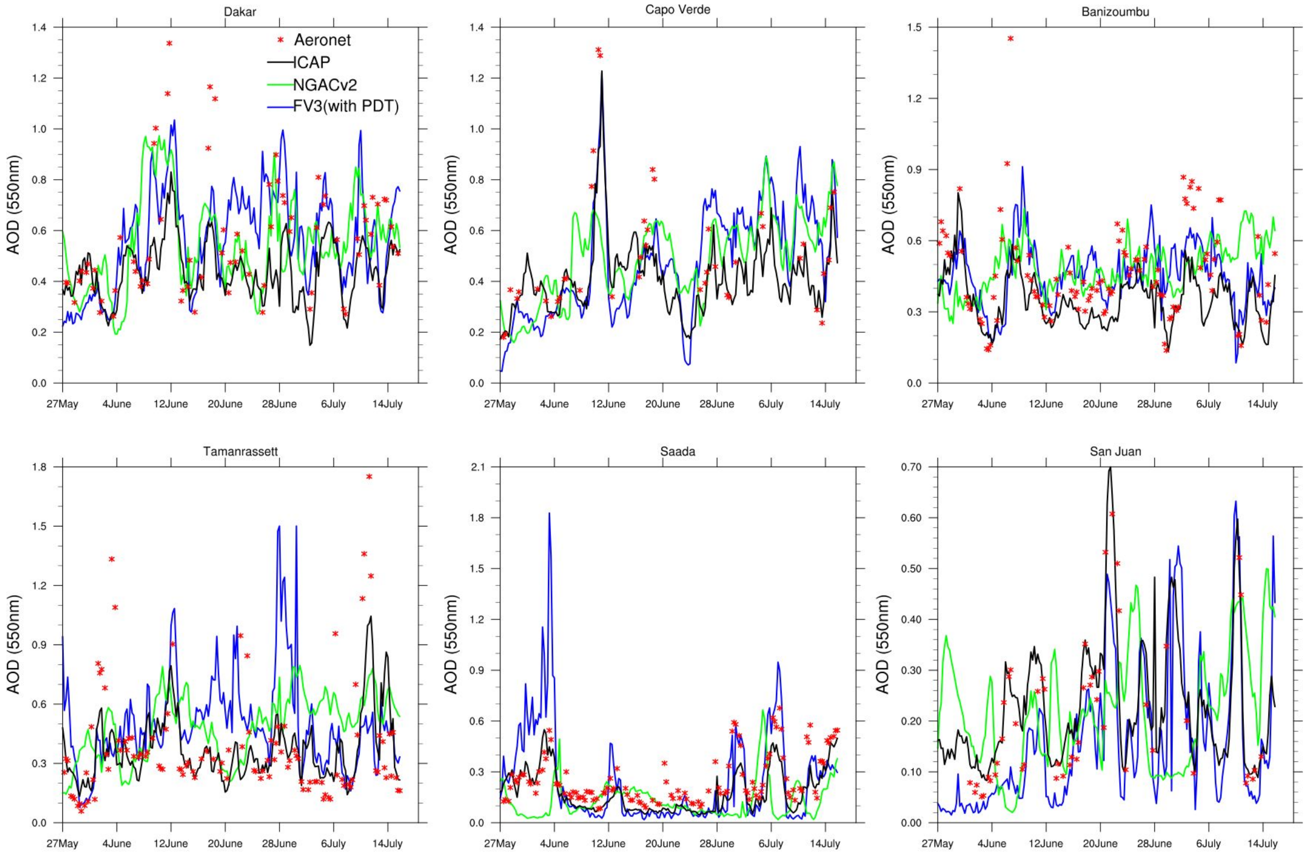




Comparison against ICAP forecasts and independent satellite (VIIRS Deep blue) indicate improvement with FV3



BB dominated AERONET locations (top row) and over urban areas w/ mixed aerosols (bottom row) illustrate improvement over NGACv2

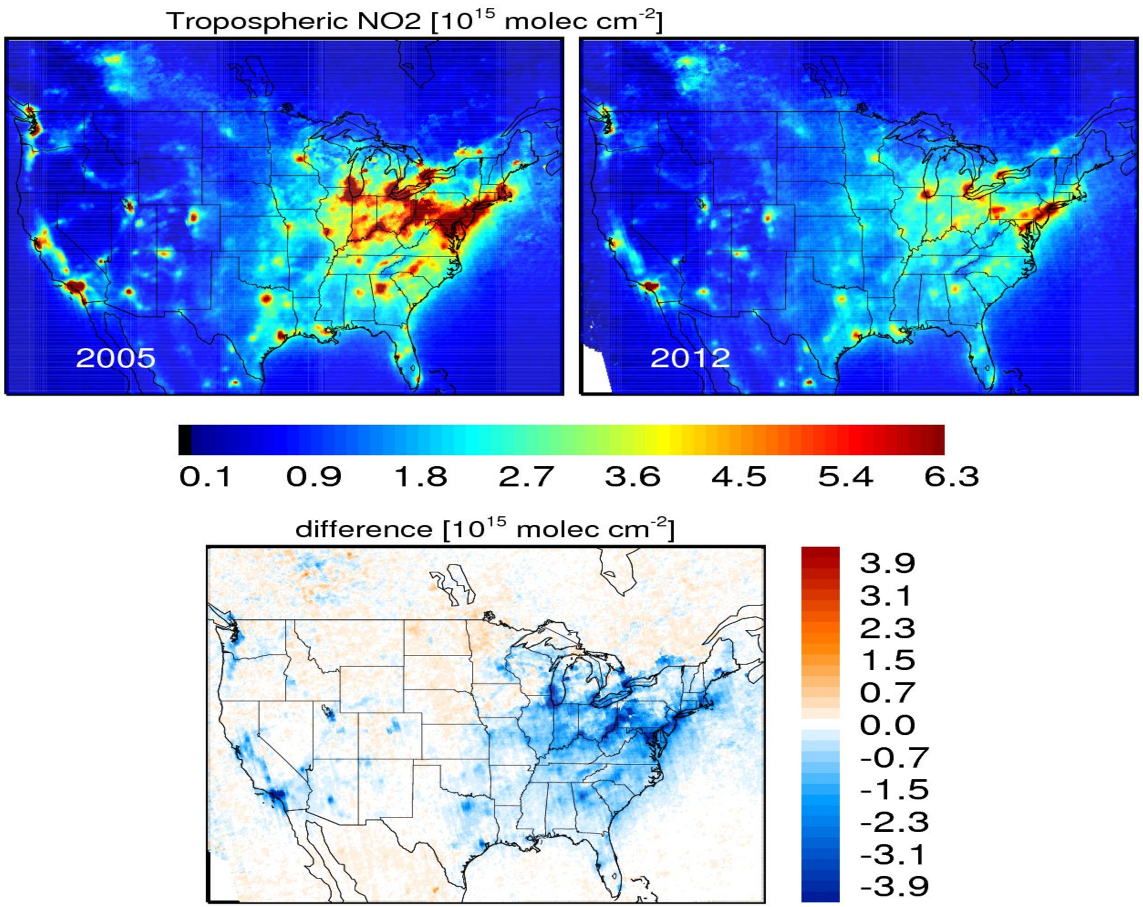


Dust dominated AERONET locations both near source and downwind sites, FV3 matches more closely with ICAP and should improve further with FENGSHA

Future Developments: Emissions Data Assimilation

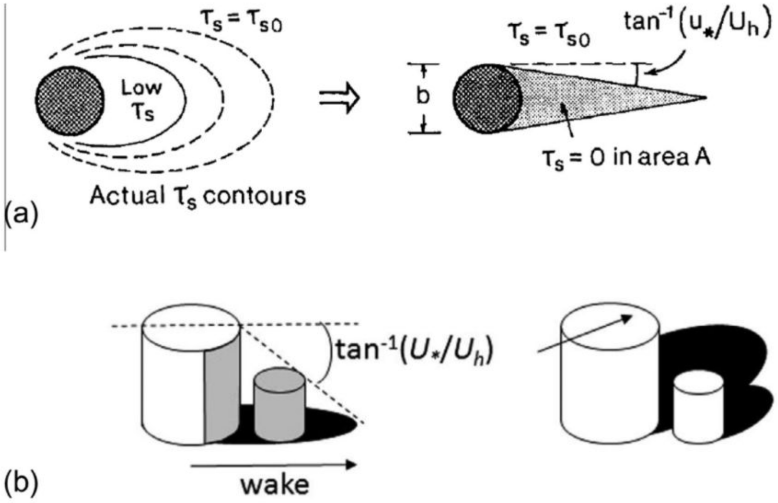
Satellite data (OMI/OMPS) used to adjust base year emissions of SO_2 to near real time.

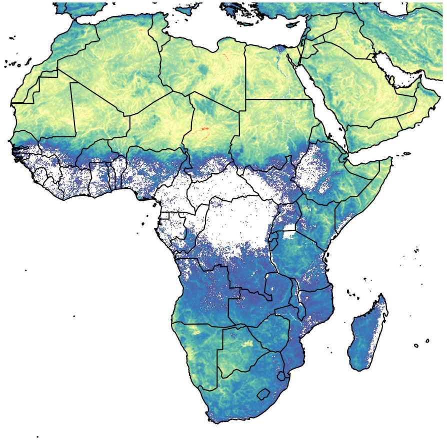
Emissions Data Assimilation (EDA) techniques developed at NOAA Air Resources Laboratory and used in NAQFC.



Future Developments: FENGSHA albedo

Use an albedo-based approximation of aerodynamic sheltering (Lw) to adjust surface roughness and dust emissions (Chappell et al., 2016).





Parajuli & Zender (2017) sediment supply map

Low contrast between high dust sources and low dust sources

Static (no seasonality)

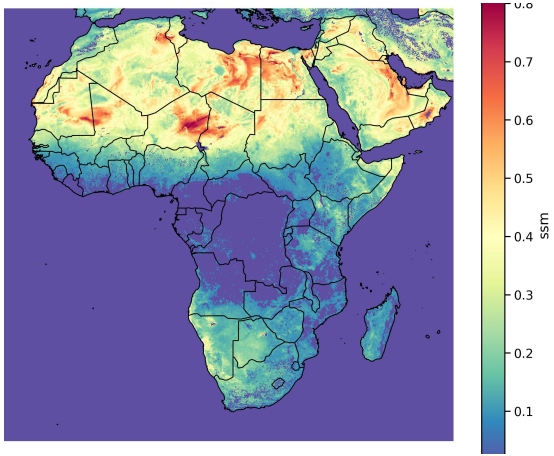
Coastal values biased low

Baker & Schepanski sediment supply map

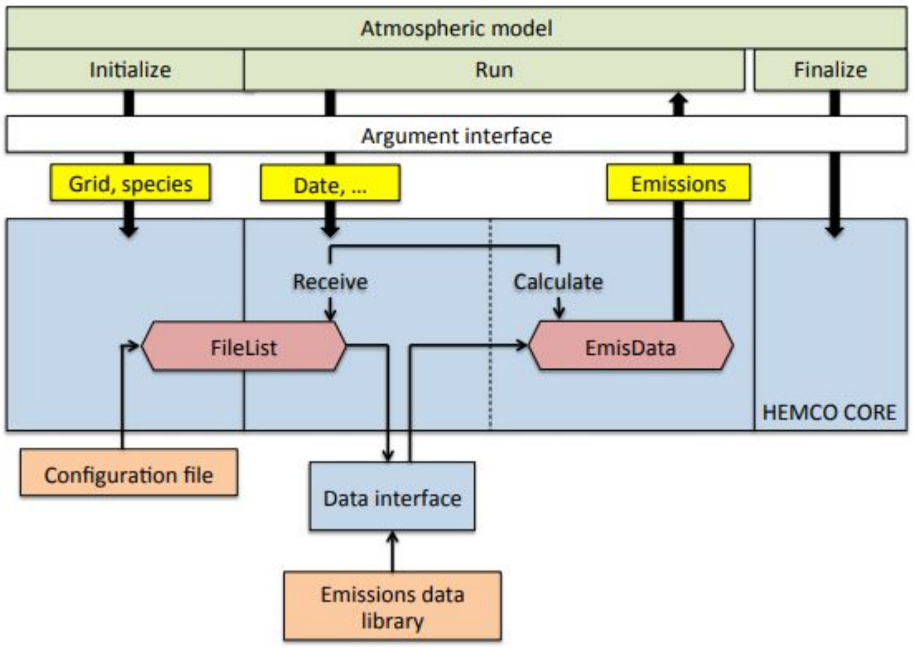
Higher contrast between high and low dust sources

Seasonal (satellite albedo)

Better representation of coastal source regions



Future Developments: NOAA Emissions and eXchange Unified System (NEXUS)

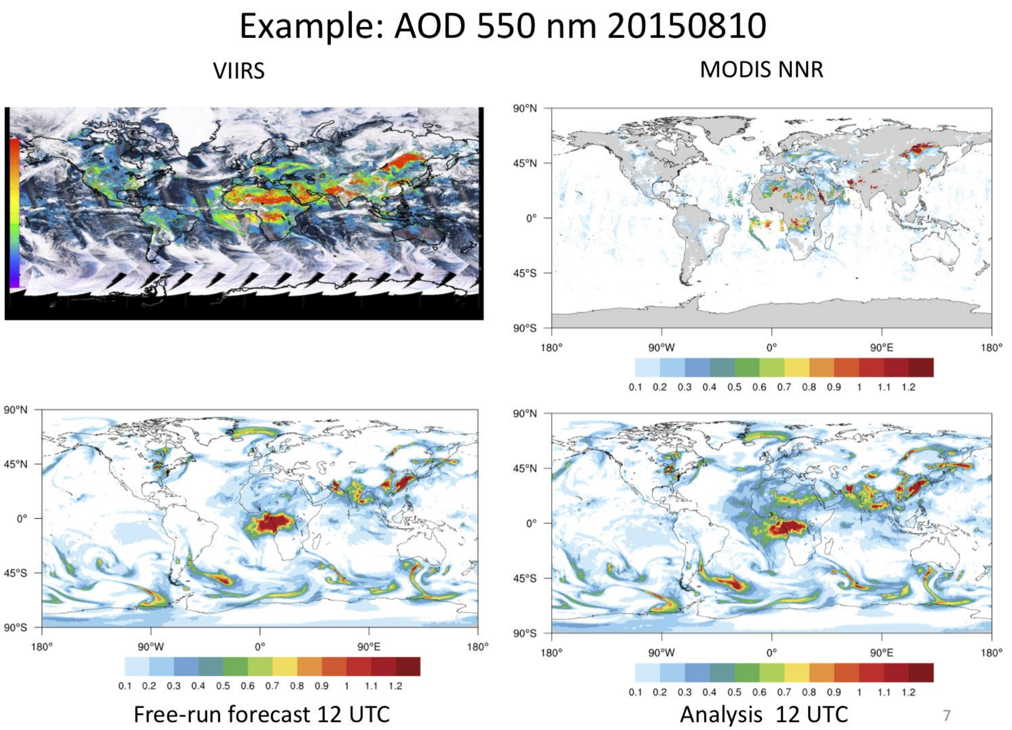


Keller, C. A., et al.: HEMCO v1.0: a versatile, ESMF-compliant component for calculating emissions in atmospheric models, Geosci. Model Dev., 7, 1409-1417, 2014.

Features

- Derived from NASA/Harvard HEMCO
- ESMF compliant for use inline with NUOPC and NGGPS.
- Self described input and output files (netCDF)
- Able to handle many different datasets (HTAP, CEDS, NEI, etc.).
- Update rapidly with new inventories or satellite/ground observations.
- Apply temporal, speciation, and spatial/mask profiles.
- Run online or offline driven by different datasets and models.
- Provide consistent interface to other Earth system components (land, ocean, etc).
- Include deposition in gas phase and aerosol phase.
- Include bi-directional processes for NH_3 and more.
- Include inline emissions, dust, fire, marine, biogenics, etc.

Future Developments: Aerosol Data Assimilation

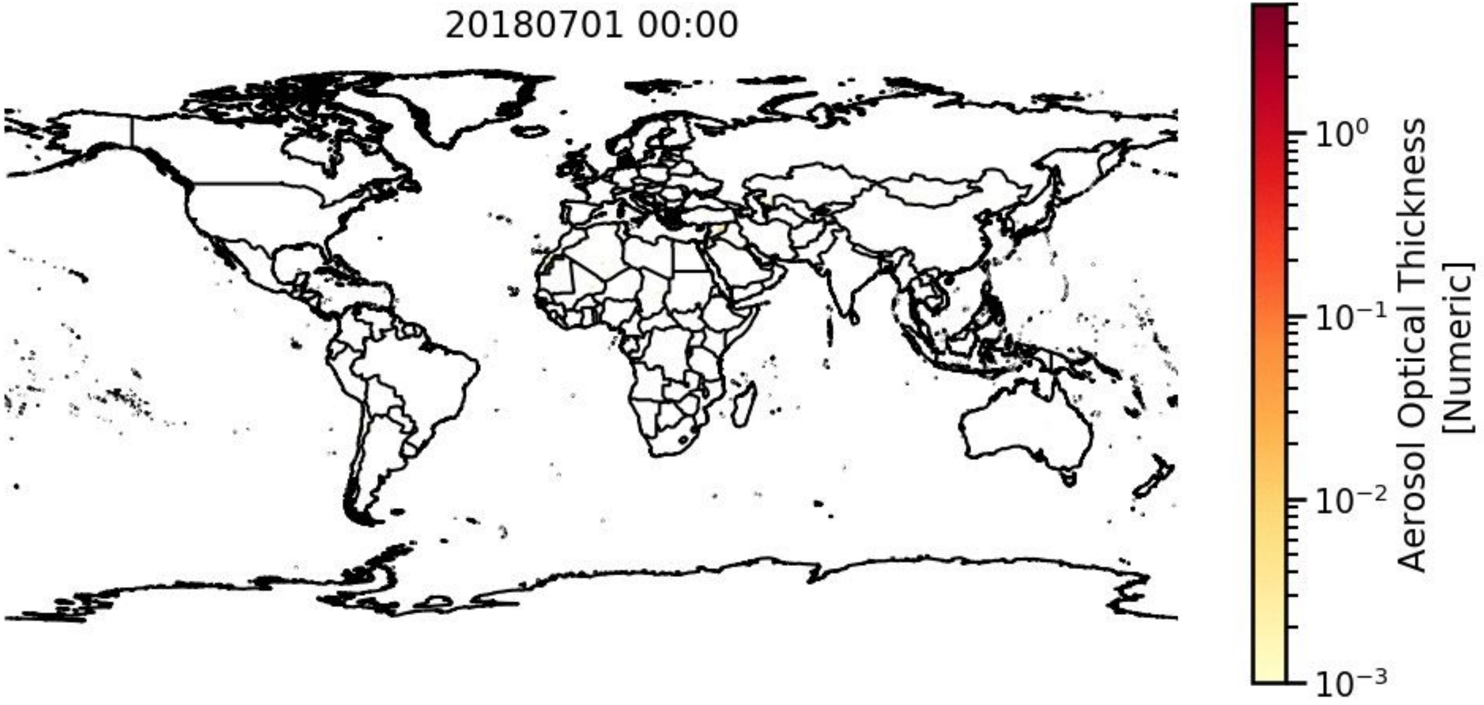


USWRP Project led by Mariusz Pagowski, NOAA Boulder

- Calculate “climatological” background error statistics from operational GEFS-Aerosols and deploy near real-time 3D-Var (GSI) based assimilation of MODIS and VIIRS AOD retrievals at 550 nm
- Develop ensemble perturbation strategies specific for aerosols and evaluate the quality of the ensemble and 3D-VarEns in comparison with 3D-Var
- Verify forecasts against MERRA-2 and CAMSIRA, multi-channel NNR and VIIRS AOD retrievals and surface observations
- Implement AOD assimilation within the JEDI framework
- Deploy a cycled aerosol data assimilation system for the national real-time aerosol forecasting.

Challenges

- Operational constraints on model complexity (computational efficiency) vs. best representation of known science
- Consistency and continual improvement of emissions inputs
- Two-way coupling of aerosols and composition with meteorology
- Aerosol data assimilation and post-processing of model products
- Consistency of atmospheric composition simulations between global and regional domains
- Evaluation of model results beyond standard large-scale or long-term metrics
- Consistency in land surface-atmosphere interactions for both physical (surface energy, momentum and moisture fluxes) and chemical (emissions and deposition) processes
- Limited resources for model improvements, transition to operations and model maintenance
- Limited HPC resources



Thanks!

rick.saylor@noaa.gov