NATIONAL WEATHER SERVICE

Progress Towards Global Aerosol Analysis Capabilities at NCEP

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Outline

- Background / Motivation
- Adding Global Analysis Capabilities
- Initial Results
- Future Work

Background / Motivation

Current Operational Capabilities

- The NEMS GFS Aerosol Component (NGAC) version 2 provides global 1° forecasts out to 5 days of dust, sea salt, sulfate, and carbon aerosols.
  - This was an upgrade implemented in 2017 over NGACv1 which only provided dust forecasts
- Xian et al., 2019 notes that unlike aerosol modeling systems from ECMWF, JMA, UKMet, the US Navy, and others, NCEP's aerosol modeling system does not currently assimilate any observations of aerosol optical depth (AOD)

Xian, P, Reid, JS, Hyer, EJ et al. Current state of the global operational aerosol multi-model ensemble: An update from the International Cooperative for Aerosol Prediction (ICAP). *Q J R Meteorol Soc* 2019; 145 (Suppl. 1): 176– 209. doi:10.1002/qj.3497

Short-Term Improvements

The next version of the NCEP Global Ensemble Forecast System (GEFS) is set to be implemented later in 2020

- GEFSv12 will utilize the Finite-Volume Cubed Sphere (FV3) dynamical core that was included in the GFSv15
- C384 (approximately 0.25°) resolution with 64 levels
- One ensemble member will be coupled with the Goddard Chemistry Aerosol Radiation and Transport (GOCART) scheme
  - This member will replace the current NGACv2 for NCEP's global aerosol prediction product
  - Still no assimilation of AOD observations, however

Adding Global Analysis Capabilities

Aerosol DA with GSI

Gridpoint Statistical Interpolation (GSI) has previously been used for regional aerosol DA (e.g. Pagowski et al., 2014)

Additional capabilities added to GSI include:

- I/O of global aerosol fields for both NGACv2 and GEFSv12
- Support for VIIRS AOD observations in addition to MODIS
- External utilities to:
  - Compute increments for input to model
  - Produce background error estimates using NMC method

Pagowski, M., Liu, Z., Grell, G. A., Hu, M., Lin, H.-C., and Schwartz, C. S.: Implementation of aerosol assimilation in Gridpoint Statistical Interpolation (v. 3.2) and WRF-Chem (v. 3.4.1), Geosci. Model Dev., 7, 1621–1627, https://doi.org/10.5194/gmd-7-1621-2014, 2014.

3D Aerosol Analysis

GSI has the capability to produce a 3D aerosol mass variational analysis using the GOCART scheme

- Community Radiative Transfer Model (CRTM) is used as the observation operator to convert 3D aerosol mass to 2D AOD
- 14 3D control variables for one 2D observation leads to an under constrained solution
- Compromises/assumptions must be made:
  - How to handle 4 vs 5 sea salt size bins (CRTM vs GOCART)
    - Background ratio used when available, otherwise 50/50 for seas1,2
  - Vertical distribution
    - Dependant on background as well as static background error

Initial Results

Model Spin-Up

- C96L64 model resolution (approximately 1°) initialized from downscaled operational GFS initial conditions at 2019-06-10 00Z
- Model was cycled 4 times a day with the downscaled operational GDAS analysis increment added for updating the meteorology
  - Aerosol fields were merely copied from the 6-hour forecast to the analysis without any zeroing or assimilation
- The model spin-up period ran until the 2019-06-17 00Z cycle, providing one week, enough time for emissions of aerosols from anthropogenic and natural sources to accumulate in the model atmosphere

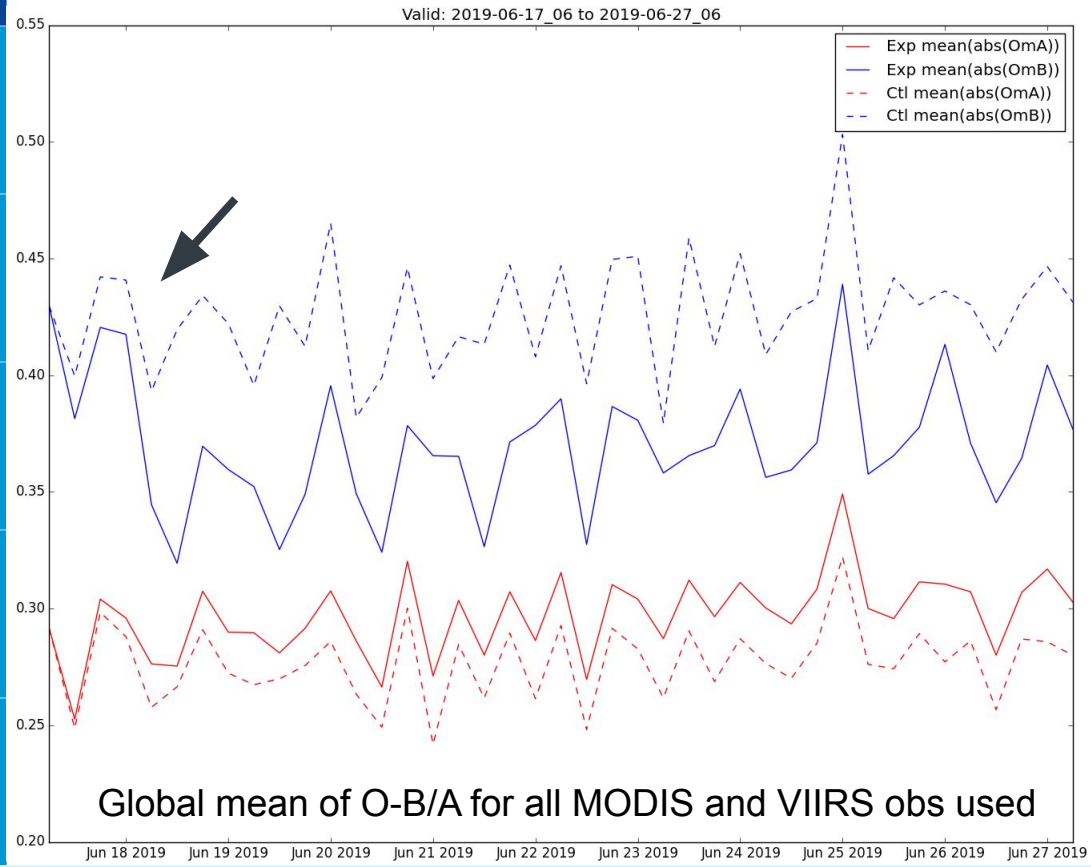
List of Experiments

- No DA (control)
- Initial Experiment (DA1)
  - MODIS, VIIRS, low observation error (1.5 gross; 0.05 obs error)
- Just VIIRS (DA3)
  - VIIRS, low observation error (1.5 gross; 0.05 obs error)
- Just MODIS (DA2)
  - MODIS, low observation error (1.5 gross; 0.05 obs error)

All cycled every 6 hours

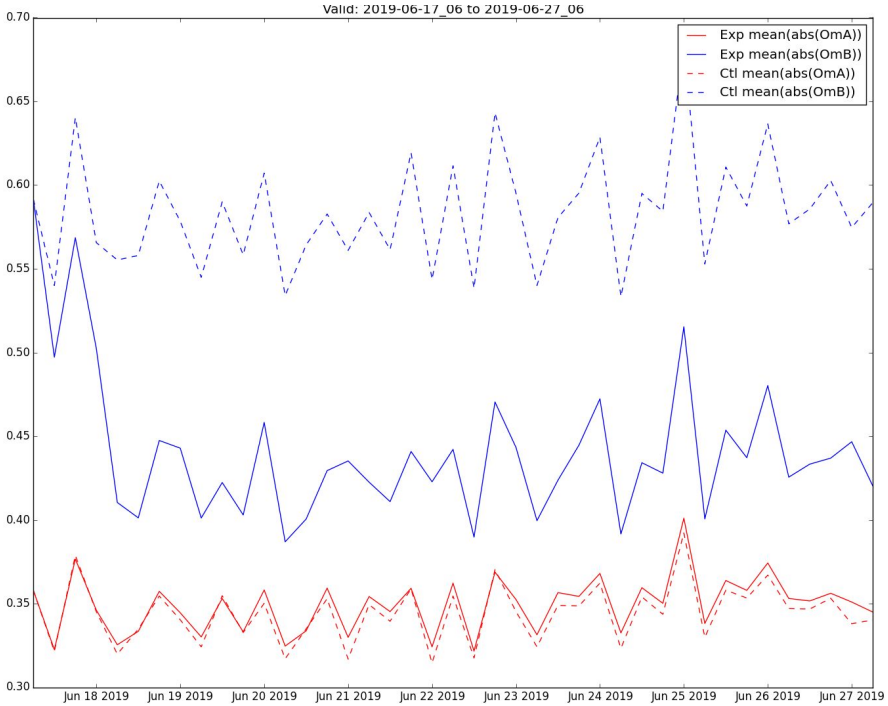
# of obs used: ~3000 per cycle for MODIS; ~6000 per cycle for VIIRS

Initial Experiment

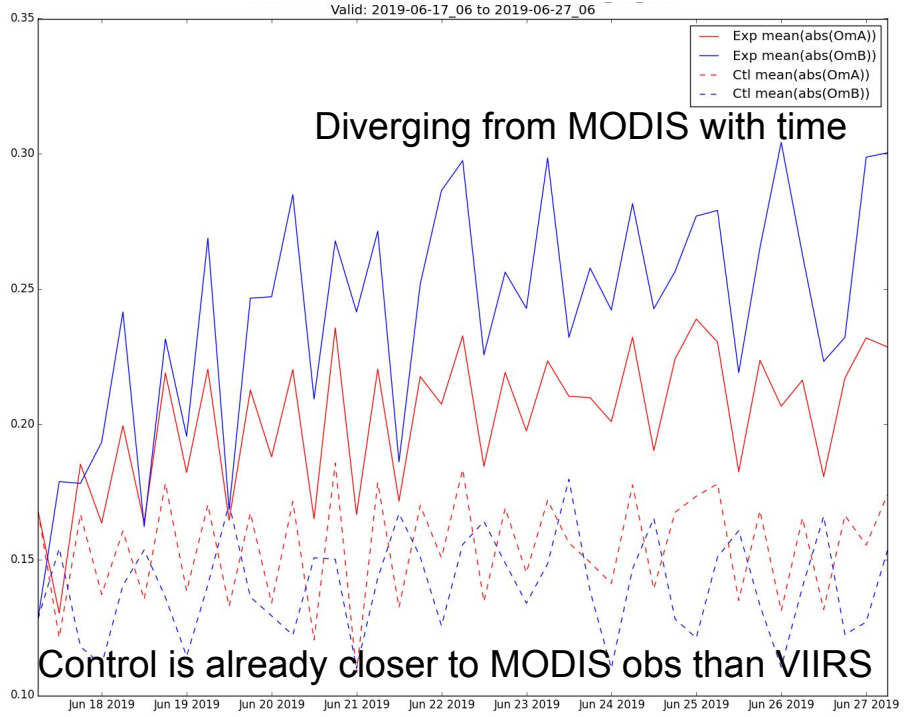


- Decrease in mean absolute difference between obs and forecast after ~ 4 cycles
  - Because of polar orbiters and requiring daylight each cycle only has ~1/3 global coverage
- Forecast skill not improving much (and analysis actually getting worse)

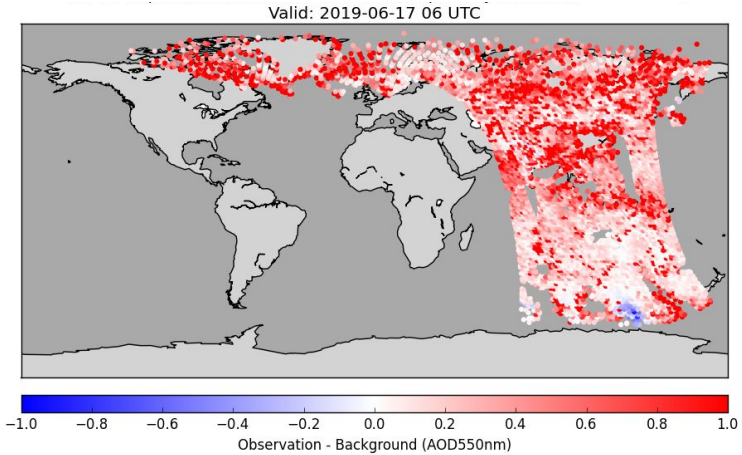
Initial Experiment

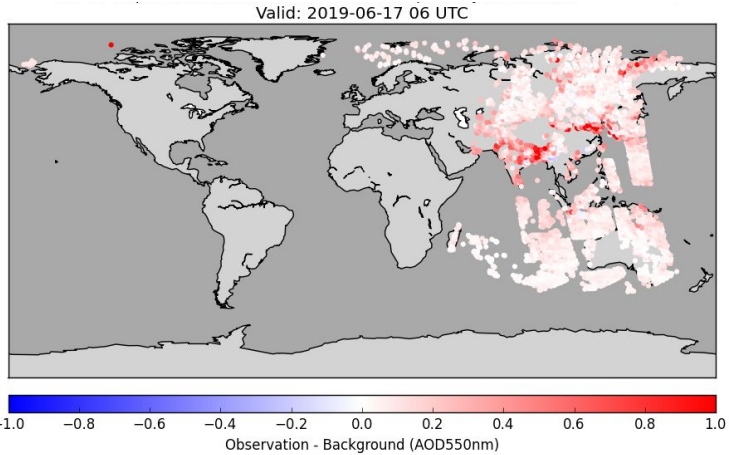


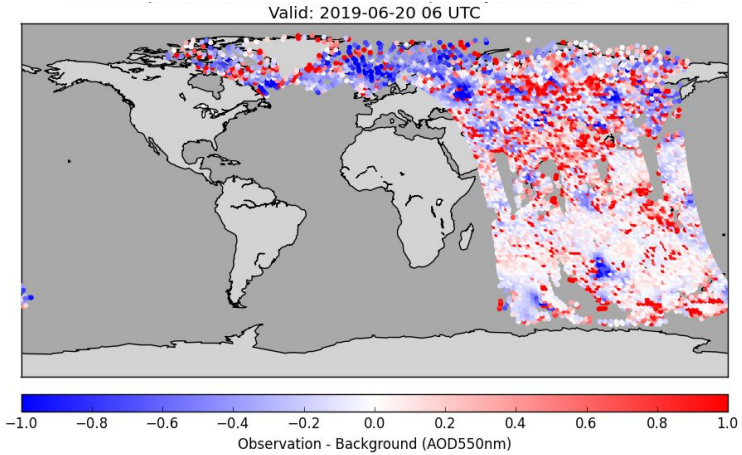
Mean O-B/A for VIIRS obs

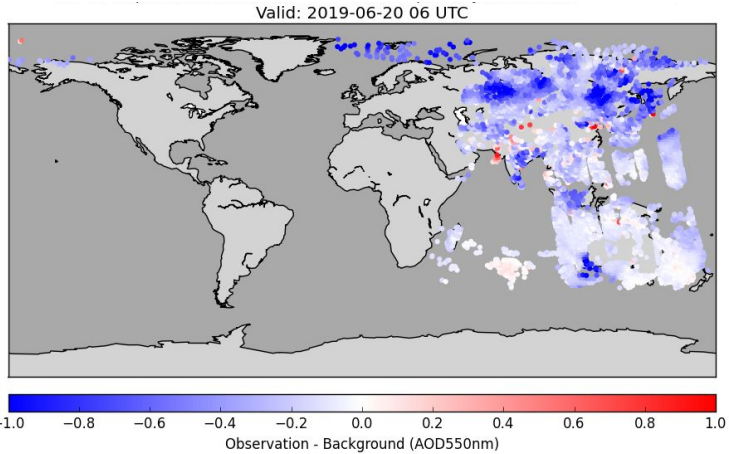


Mean O-B/A for MODIS obs





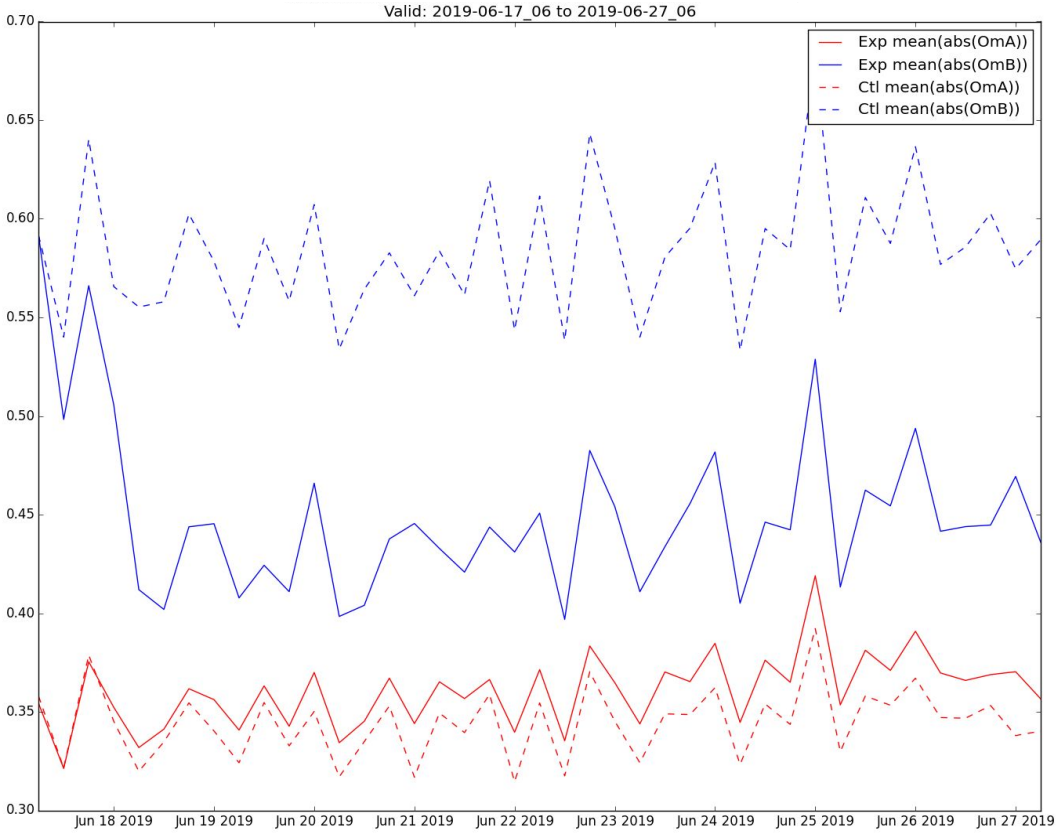




VIIRS obs

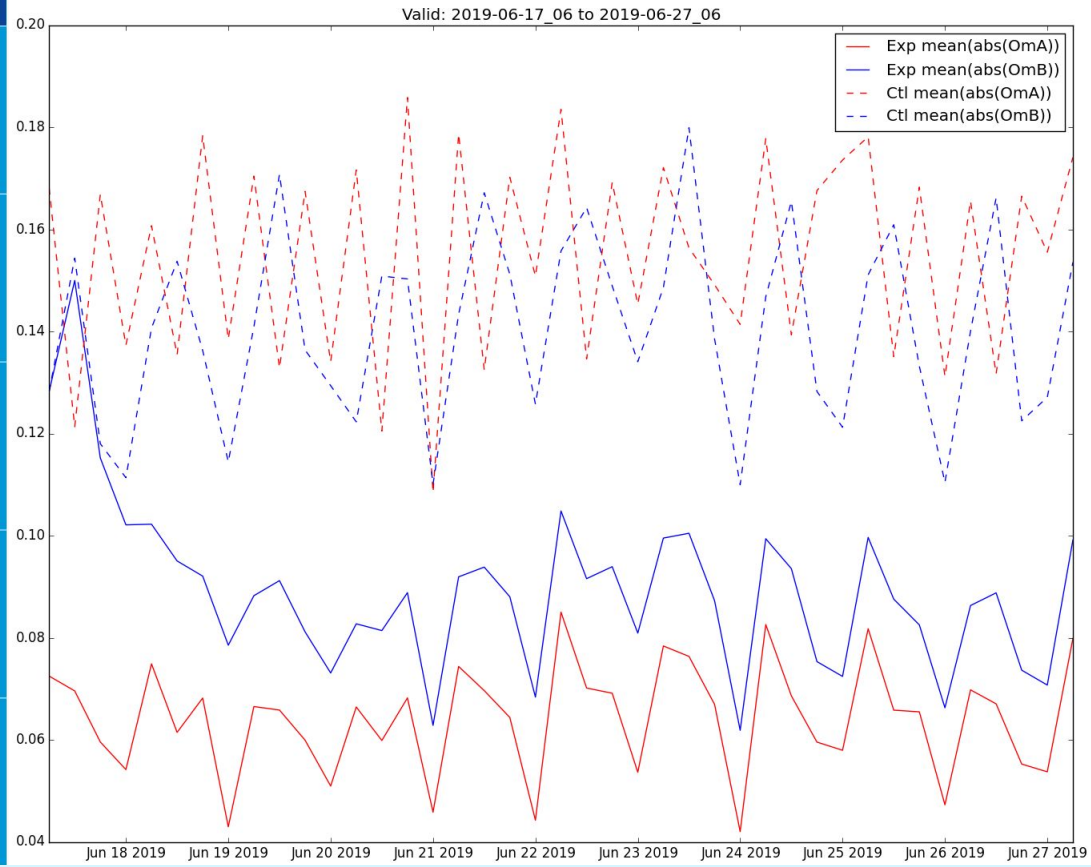
MODIS obs

Only Assimilate VIIRS AOD

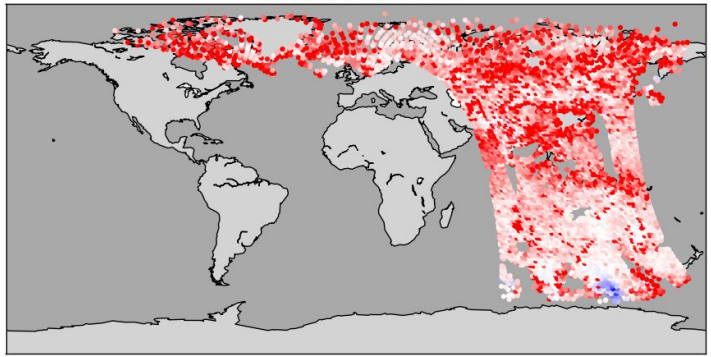


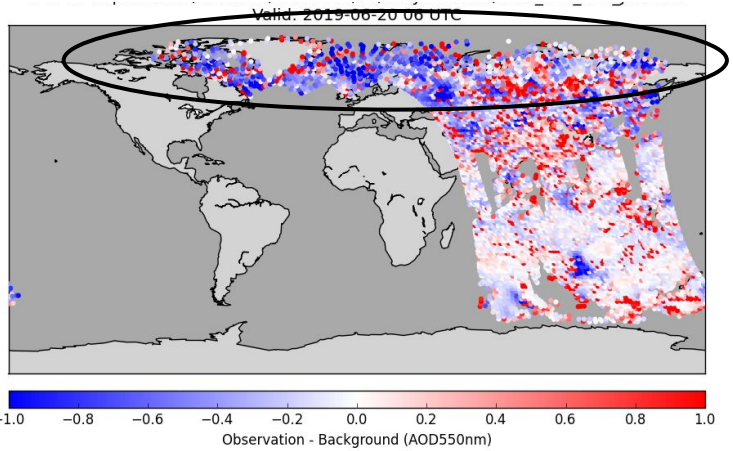
- Very similar to the results when assimilating both MODIS and VIIRS but only looking at VIIRS statistics
  - Improved forecast skill slightly
  - Analysis get slightly worse with time
  - O-B and O-A still relatively large AOD values

Only Assimilate MODIS AOD



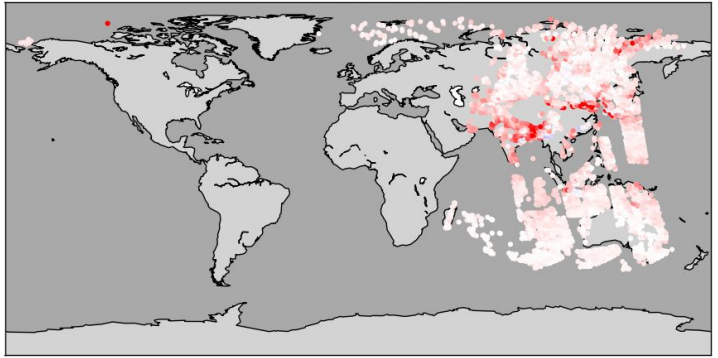
- Control experiment is already close to MODIS obs
- Assimilation of just MODIS brings O-F average to within 0.1 AOD
- Analysis and forecast values converge and difference becomes ~0.02

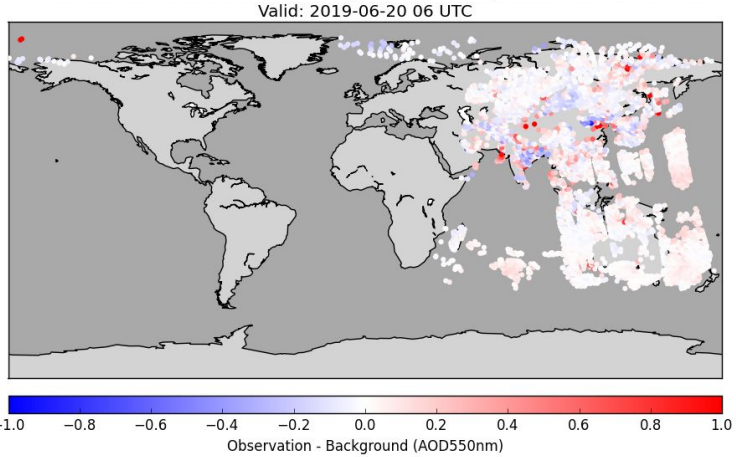




VIIRS obs only

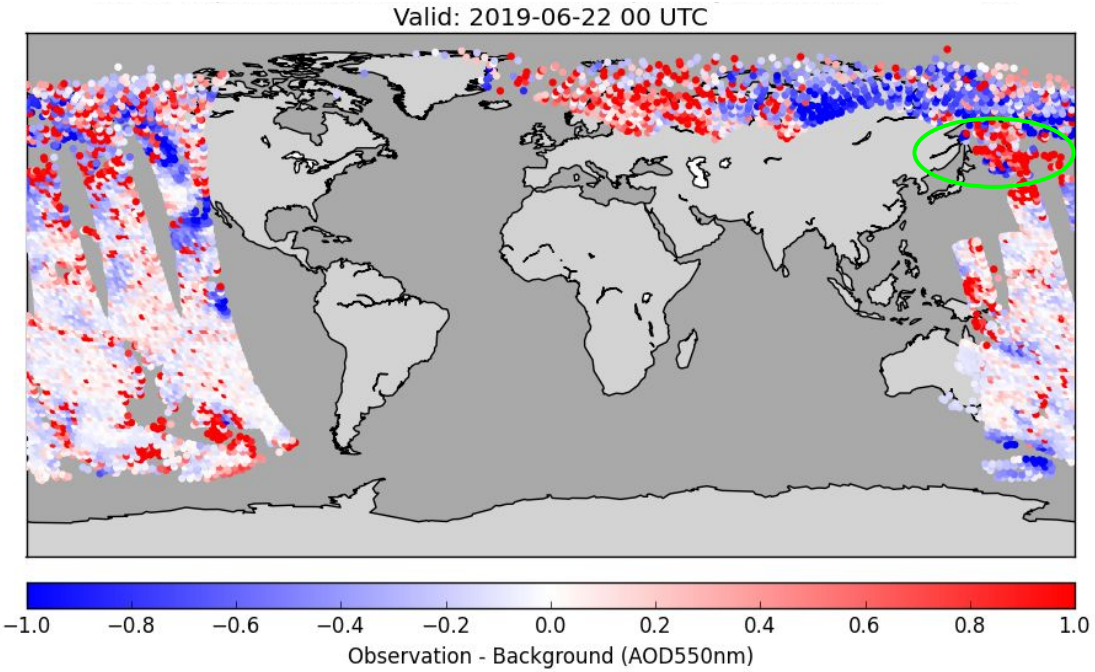
VIIRS stats improve by ~0.05 when excluding from calculation; need to test excluding from assimilation

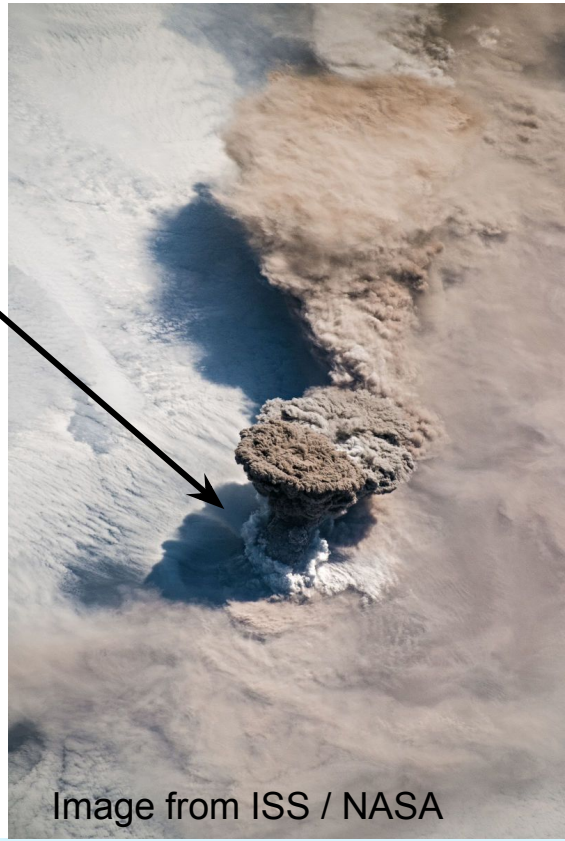




MODIS obs only

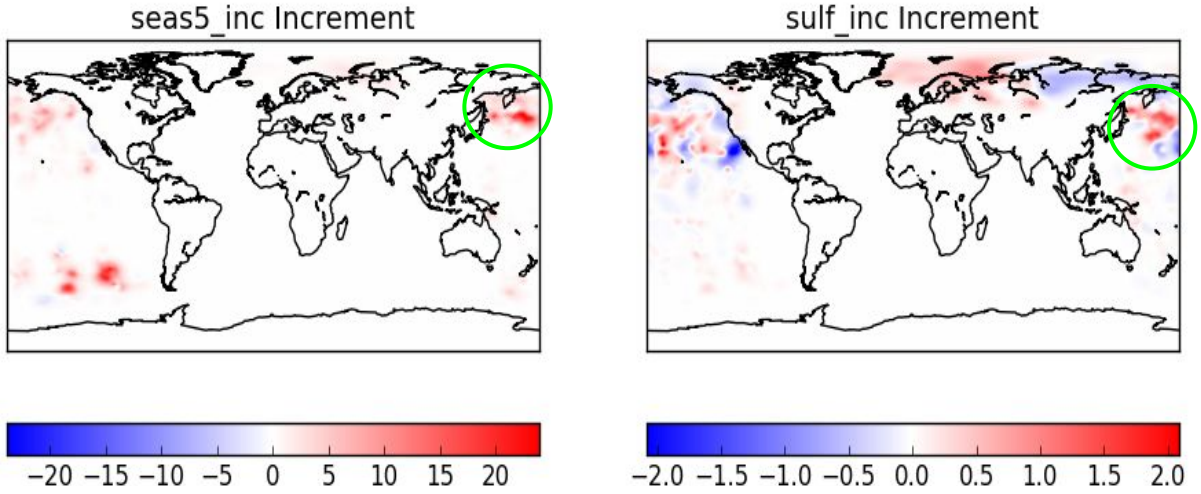
Raikoke Erupts





Volcanic eruption on June 22, 2019 captured in large AOD observations not predicted by the model

Current Limitations and Future Work



Volcanic eruption positive increment for sulfate (good) and sea salt (bad). 2D AOD to 3D speciation depends heavily on 3D background error

Limitations/caveats of these initial results:

- No bias correction applied to the satellite AOD observations
- Results are not great using VIIRS AOD
  - Is this because of high latitude data? Bias/errors? Quality control of VIIRS obs used? Something wrong with the VIIRS observation operator? Need to diagnose

3DVar vs Ensemble DA

- 3DVar system is relatively simple and cheap to run, but is very dependent on background error covariance
  - This will be problematic for anomalous events
  - Limits ability to improve vertical distribution of analyzed aerosol mass fields
- Future work will include exploration of using ensembles to improve background error estimation with both hybrid-variational and full ensemble Kalman filter approaches
  - Computational cost will be a concern but there are options to explore to mitigate the added expense of aerosol ensemble members

Additional Future Work

- Variational Quality Control (VQC) may be something that proves useful for this application
  - Large plumes in observations not shown in the forecast may cause AOD obs to be rejected rather than assimilated
- GEFSv12 (later in 2020) will not have aerosol data assimilation but GEFSv13, the next implementation, is expected to assimilate satellite-based AOD observations
  - Exact details are still TBD
- Transitioning towards using a JEDI-based infrastructure rather than GSI for experiments and potential implementation
  - See M. Pagowski's talk in ~15 mins for progress on JEDI-based 3DEnsVar aerosol DA

Thank You for Your Attention!

Questions?

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