# Operational considerations of AERONET to global aerosol forecasting

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And the entire international Cooperative for Aerosol Prediction (ICAP) community

AERONET Technical Exchange
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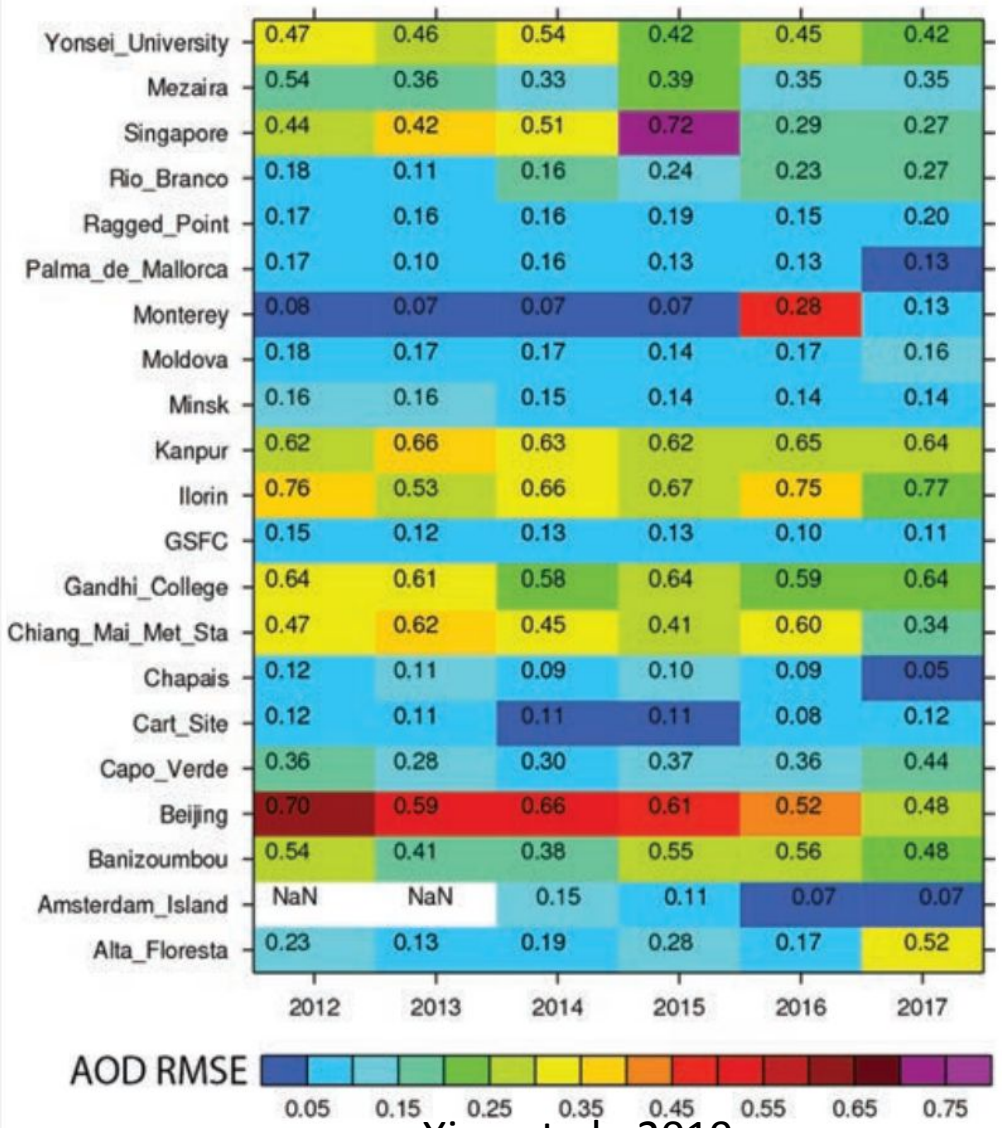
# AERONET: Where would the global aerosol community be without you?

This technical exchange is a testament to the importance of the federated AERONET program to the global aerosol community.

Operational Global Numerical Aerosol Prediction (NAP) is one cohort of that community, and likewise AERONET is the bedrock for verification and now even assimilation.

AERONET was originally not designed for us, or even most of you for that matter. But by being accessible, fast, and well characterized, AERONET is a model of how to have an impact.

Here are just a few thoughts on how AERONET helps us and what we do to promote this symbiotic relationship.

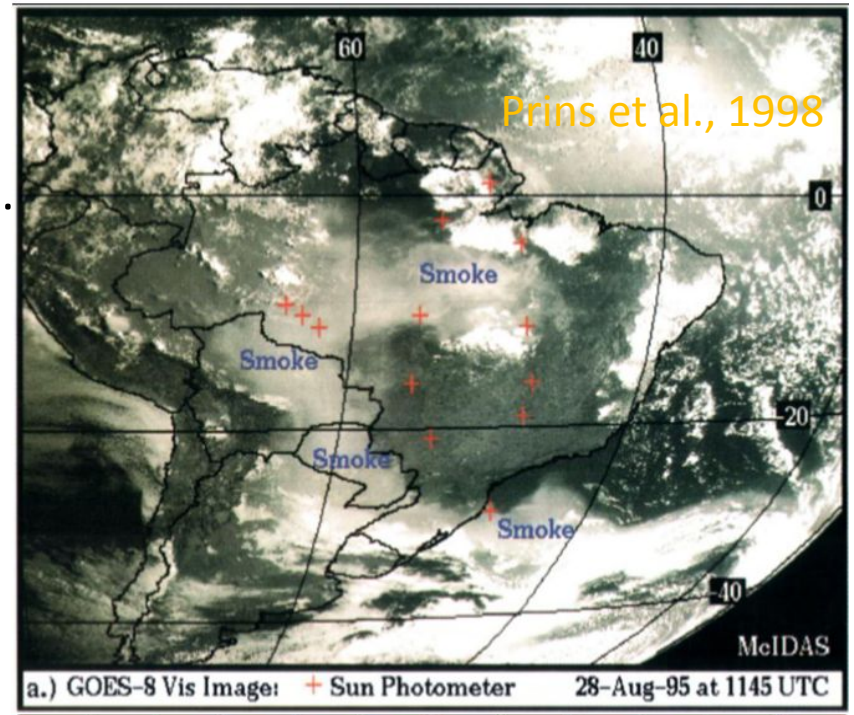


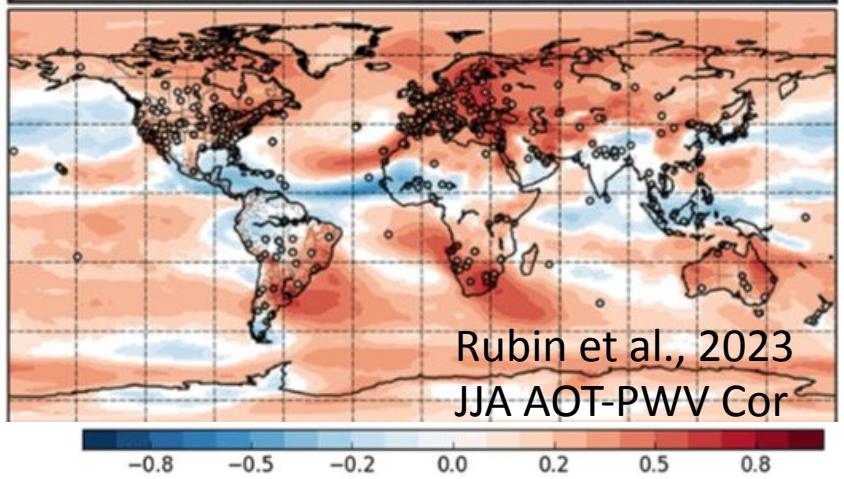

Xian et al., 2019

**FIGURE 12** Evolution of ICAP-MME performance in terms of RMSE of total AOD at 550 nm of the 6 h forecasts for the 21 AERONET sites shown in Table 1, over 2012–2017. The number inside of each grid represents yearly mean AERONET V3 L1.5 total AOD at 550 nm for the site and year. RMSE is shown in colour. "NaN" means not enough data points (at least 100) for evaluation [Colour figure can be viewed at wileyonlinelibrary.com].

# AERONET and Numerical Aerosol Prediction do in fact have a symbiotic relationship

- The relationship between AERONET and aerosol operations goes back to SCAR-B in Brazil in the mid 90s: GOES-8 aerosol retrievals and INPE aerosol forecasts. And each needed the others.
- Now, the NAP community is one of the biggest consumers of AERONET data. We take all of it all of the time.
  - Global model verification
  - Secondary satellite product assessment, debiasing, and error modeling
  - Machine learning basis set, eg., MODIS/VIIRS NN product by da Silva.
  - Assimilation
- Granted NAP asks
  - Level 1.5 data processing (e.g., NRT cloud screening, SS Rtrievals, SDA)
  - NRT data delivery
  - Corrections to cloud clearing (Version 3).
- Thanks to the assimilation process, we see things that climate community, or even the satellite developers often don't see.
- What we also do *<u>with</u>* AERONET
  - Model context
  - Our own regridding of observations and satellite data with error models.
  - Information content studies and SDA with Norm
  - Spatial characterization
  - Product development



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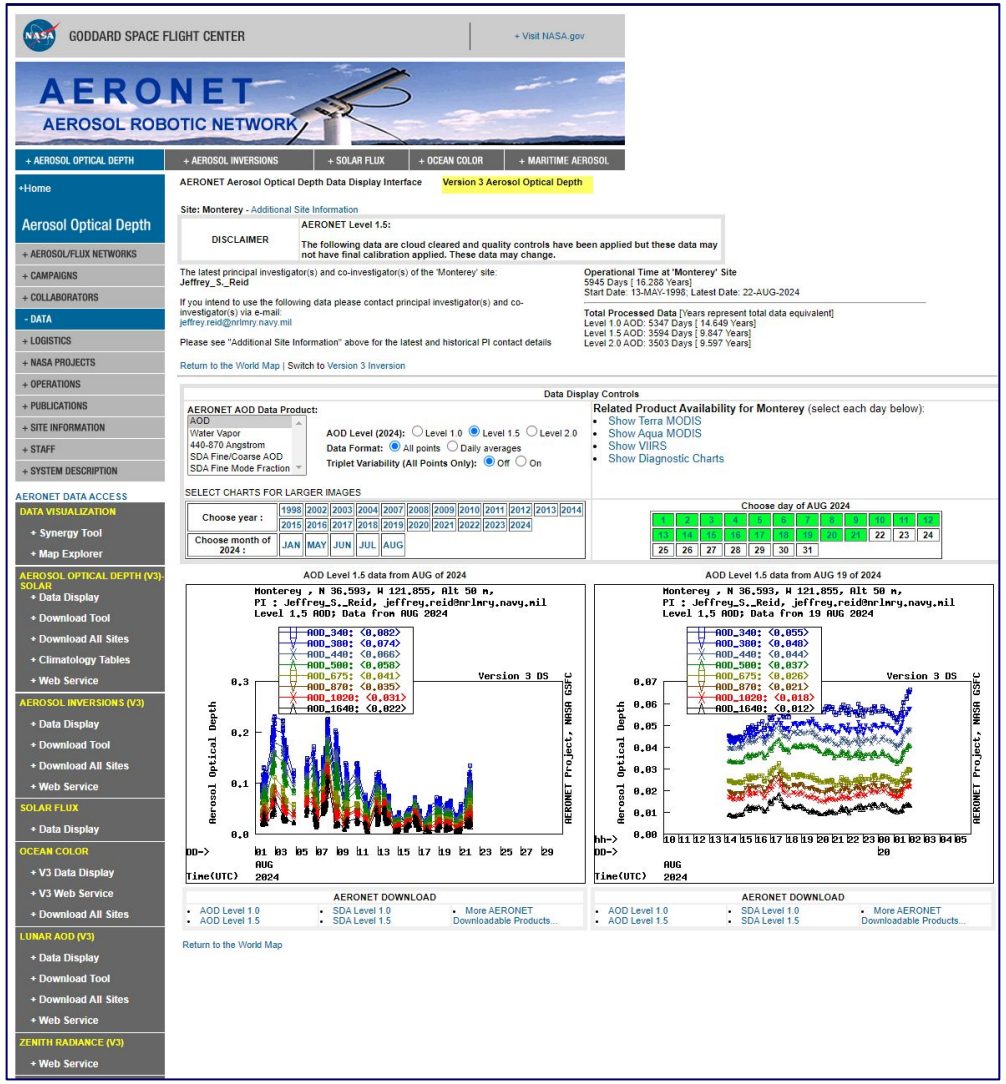
# CURRENT ICAP OPERATIONS: Highlighted are those with reanalyses

| Organization | BSC | Copernicus/ ECMWF | JMA | Meteo France | NASA | US Navy | NOAA | FMI | UKMO |
|---|---|---|---|---|---|---|---|---|---|
| Model | MONARCH | CAMS | MASINGAR | MOCAGE | GEOS-5 | NAAPS | NGAC/FV3GFS-Chem | SILAM | MetUM |
| Status | QO | O-24 hrs | QO | O | QO | O | O | O | O |
| Meteorology | Inline NMMB | Inline IFS | Inline AGCM | Offline ARPEGE | Inline GEOS-5 | Offline NAVGEM | Inline GFS/FV3GFS | Offline IFS | Inline UM |
| Resolution | 0.7x0.5 | 0.4x0.4 | 0.375x0.375 | 0.5x0.5 | 0.25x0.31 | 0.33x0.33 | 1x1/0.25 | 0.2x0.2 | 0.35x0.23 |
| levels | 48 | 137 | 40 | 60 | 72 | 60 | 64 | 28 | 70 |
| DA | LETKF$^{p}$ | 4DVar | 2DVar LETKF$^{p}$ | 3DVar | 2DVar +LDE | 2DVar, 3DVar, EnKF$^{p}$ | NA | 3Dvar$^{p}$, 4Dvar$^{p}$, EnKF$^{p}$ | 4DVar |
| Assimilated Obs | NA | DAQ MODIS DT+DB PMAp VIIRS/NOAA20 | MODIS, AHI$^{p}$, CALIOP$^{p}$ | MODIS, VIIRS | Neural Net MODIS, AERONET | DAQ MODIS, VIIRS$^{p}$, EPIC$^{p}$ CALIOP$^{p}$, AERONET$^{p}$ | | NA | MODIS Dust AOT |
| Species | Dust, Sea Salt BC, OC (POA,SOA) Sulfate, Nitrate, Ammonium | BC, OC Dust, Sea Salt Sufate, Nitrate, Ammonium, SOA | BC, OC Dust Sea Salt Sulfate | BC, OC Dust Sea Salt Sulfate, Nitrate, Ammonium | BC, OC Dust Sea Salt Sulfate Nitrate | Anthro+bio B. B. Smoke Dust Sea Salt | Dust BC, OC Sea Salt Sulfate | BC, Dust, OC, Sea Salt, Sulfate, Nitrate, B.B. Smoke | Dust |
| Size Bins | 8 (dust, salt), 6 (OM), 2(BC), 3(NI), bulk sulfate and ammonium | 3 (dust, salt), bulk for others | 10 (dust, salt), bulk for others | 6 | 5 (dust, SS), 2(BC, OC), 3(NI*), bulk sulfate | bulk | 5 (dust, SS), 2(BC, OC), bulk sulfate | 4 (dust), 5 (SS), 3 (B.B. Smoke), 2 (sulfate), bulk for others | 2 |
| Antho. & Biogenic Emission | CAMS-GLOB v4.2 (anthro), MEGANv2.04 (biogenic) | CAMS_GLOB_ANT (anthro), MEGAN (biogenic) | MACCity | MACCity (anthro.) MEGAN-MACC (biogenic) | EDGAR V4.1/4.2, AeroCom Phase II, GEIA | MACCity, BOND, POET | EDGAR V4.1+CEDS AeroCom Phase II, GEIA | CAMS_GLOB_ANT v2_1 (v6_2$^{p}$), MEGANE, HTAP(Coarse PM) | NA |
| Bio. Burn. Emissions | GFAS | GFAS | GFAS | GFAS | QFED | FLAMBE | GBBEPxV2 | IS4FIRES | NA |

# AERONET as a model of data distribution

- AERONET is *prevalent*, because it is easy
  - Simple downloads *on easily navigable websites* of files *consistent in format over time*.
  - Straightforward to join and persist *the Federation.*
  - Good tech support.
  - Responsive to community needs.
  - Provides online discover and interpretation tools

- AERONET is *impactful* because it is accurate, well documented, & fast
  - Excellent quality control
  - Team members are integrated with the community
  - Are willing to try out new things in a well constrained system.
  - For ***O****perations*, consisntent NRT production

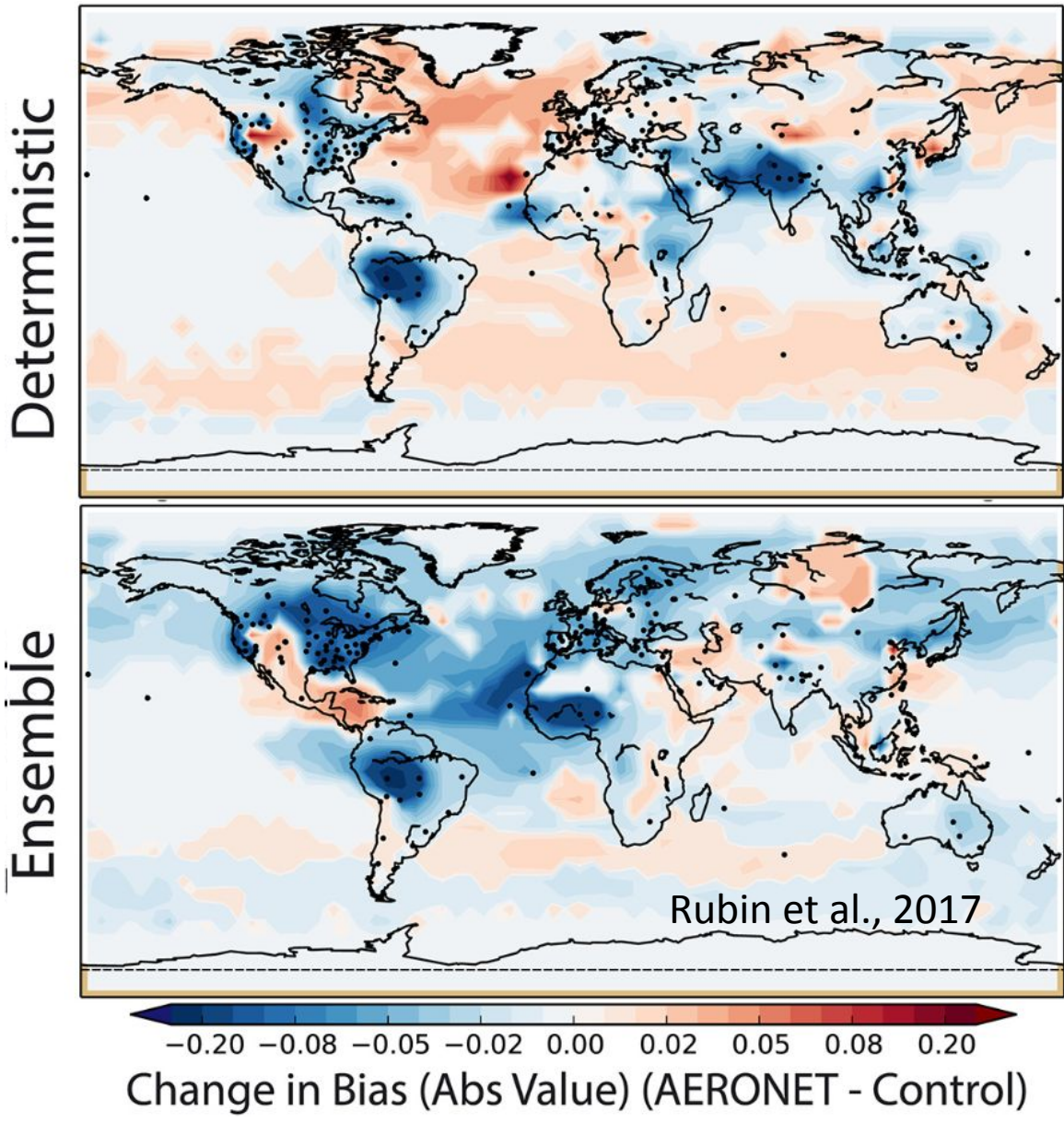


# A few words on AERONET in data assimilation

1) Current variational methods are mostly effectively an error weighted mean with an area of influence around each ob. Even for 4Dvar, **none of the centers have an adjoint for aerosol microphysics or optical properties; n**ot even really a forward operator. Plus there comparatively few AERONET sites. Nevertheless, GEOS/MERRA assimilates AERONET. But hey, you look great verifying against your assimilated observation

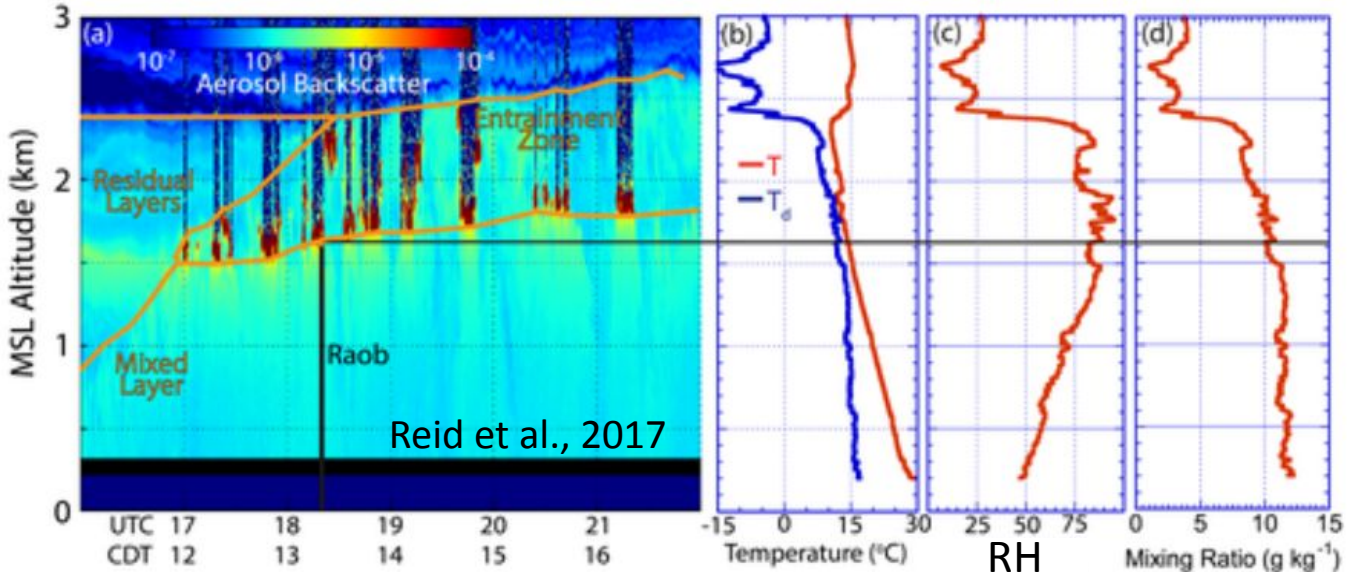
2) By running the model dozens of times, **ensemble methods are conceptually easier, account for flow dependence and don't need an adjoint**; everything is driven by covariances in the ensemble. Thus a little bit of AERONET data goes a long way in ENAAPS. But, it is a lot of data to work with, you are at the mercy of confounders, and if there is no ensemble spread then there is no impact of observations. This can become tricky with the assimilation of aerosol microphysical parameters that doesn't have appropriate dispersion.

3) There is general agreement that **coupled and hybrid systems are the way to go**, which will make even better use of AERONET, but we still have away to go…. JEDI is almost there for basic 3D/4D HybridVar infrastructure.

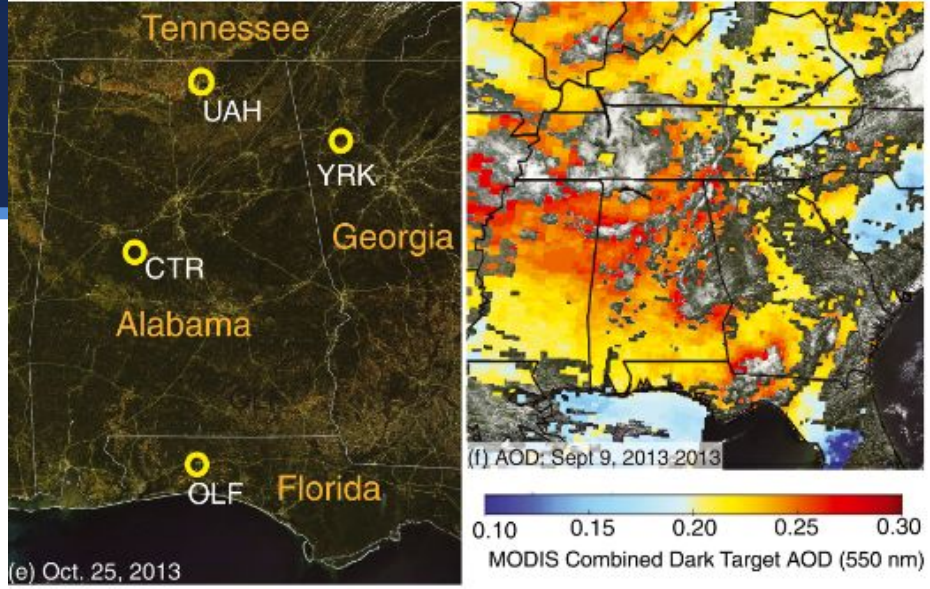


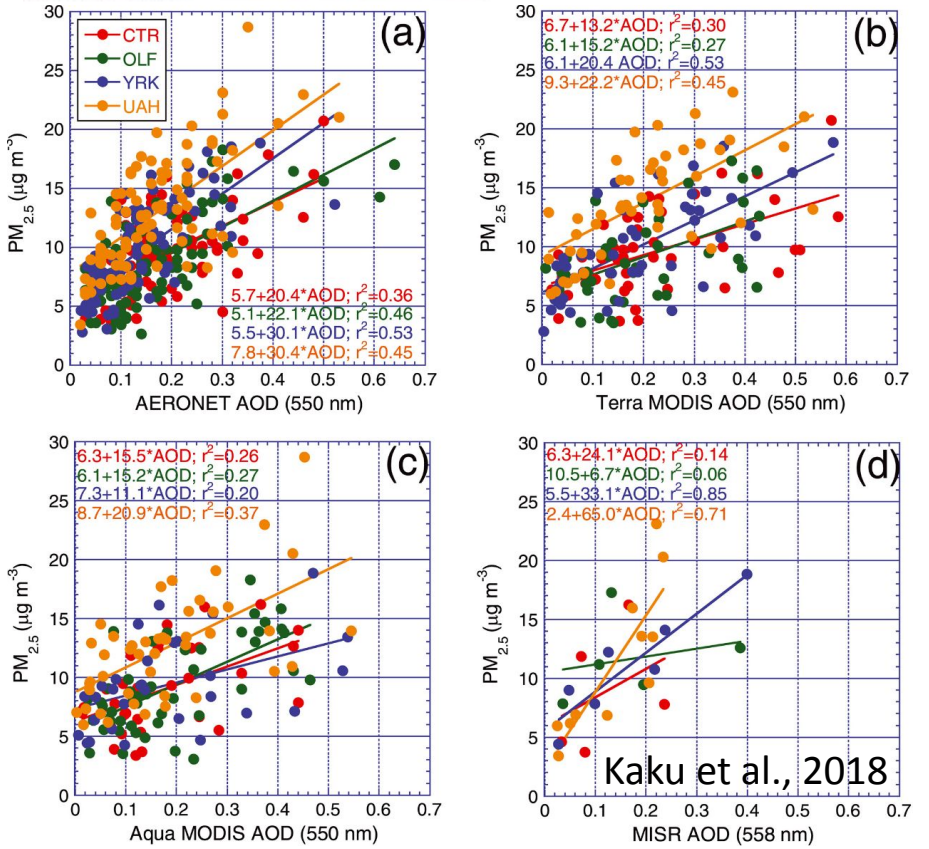
# Everybody verifies & assimilates AOT, because it is easily available from MODIS and AERONET

- AERONET verification, and its downstream impacts are critical in improving operational aerosol AOT products…and now assimilation. This makes models better right?
- Well yes, for AOT, but for other parameters it all depends on your model and DA system.
- Generally, AOT and $PM_{2.5}$ are only moderately related, and even then only if you have a perfect measurement.
- While AOT is often dominated by the boundary layer, *AOT variability* is dominated by the entrainment zone and lower free troposphere.
- So "fixing" AOT, you may break something else, like surface concentrations.



Reid et al., 2017

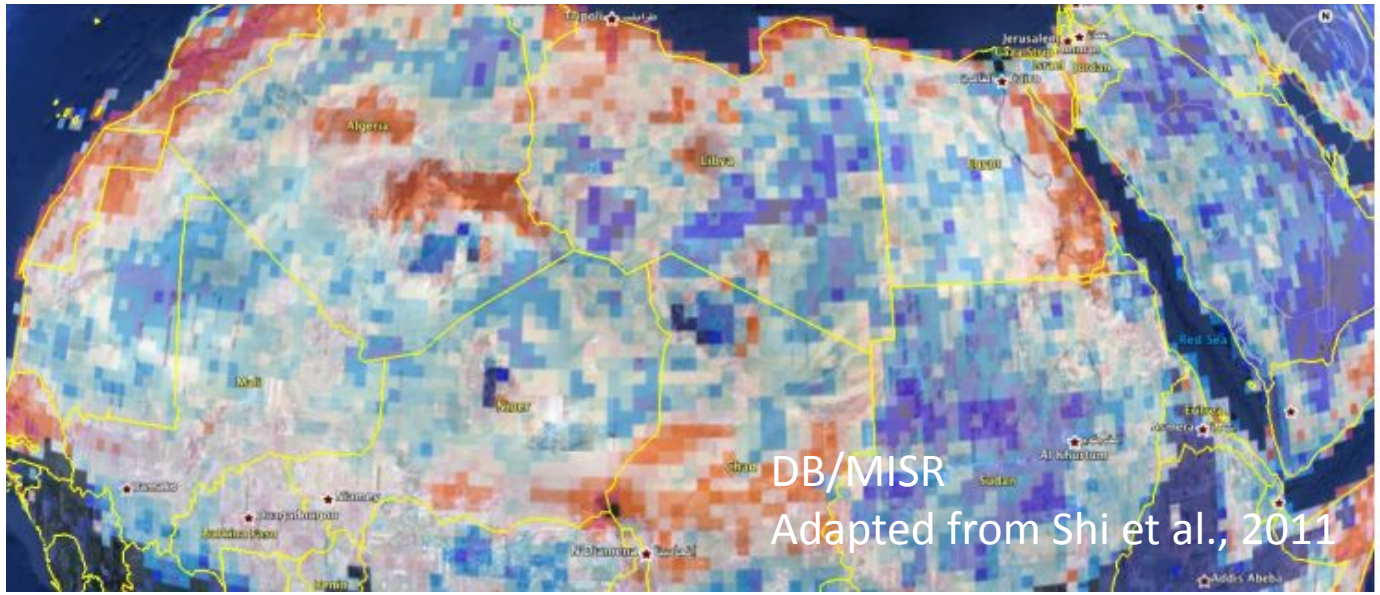


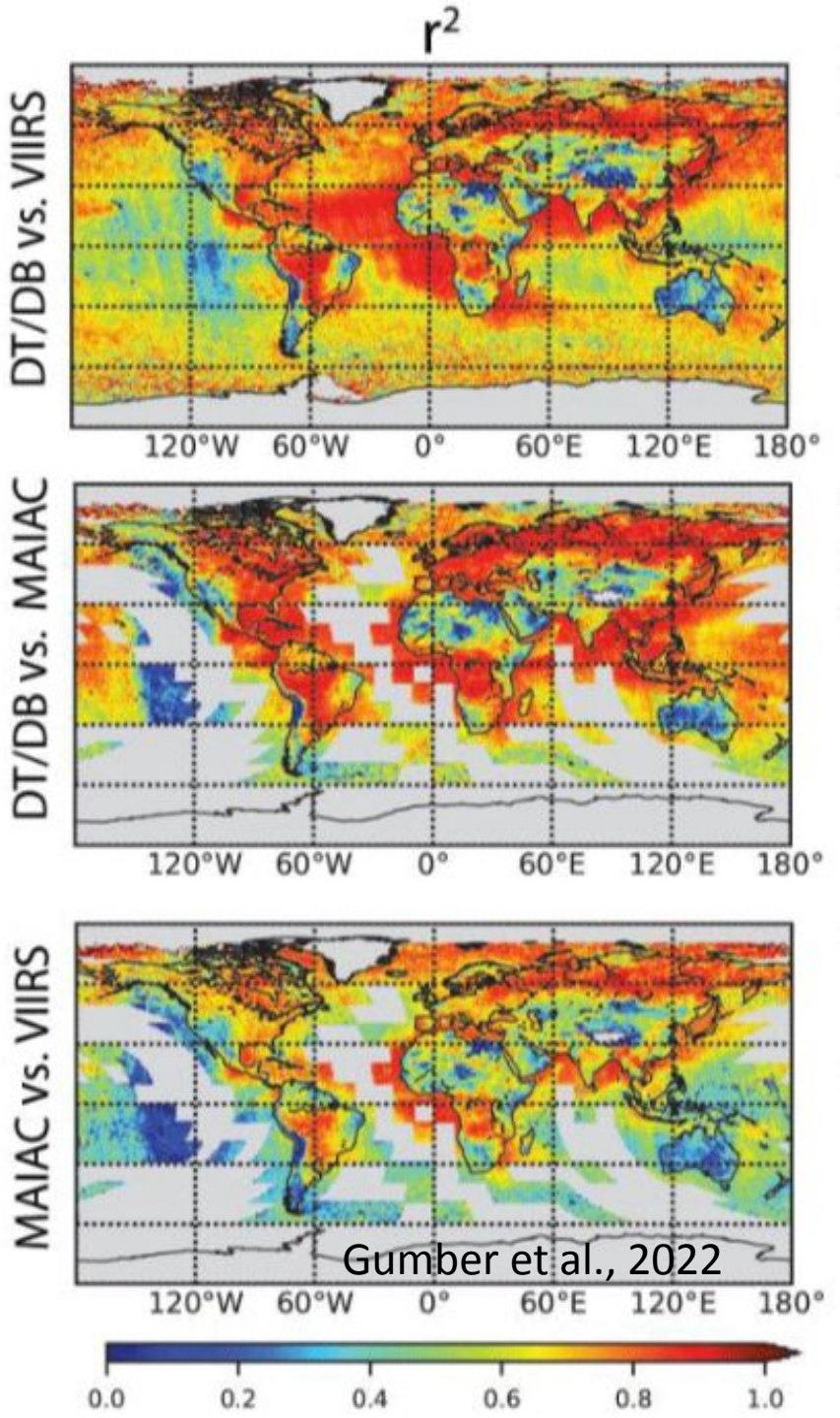



Kaku et al., 2018

# Yes, we always want more data, but where?

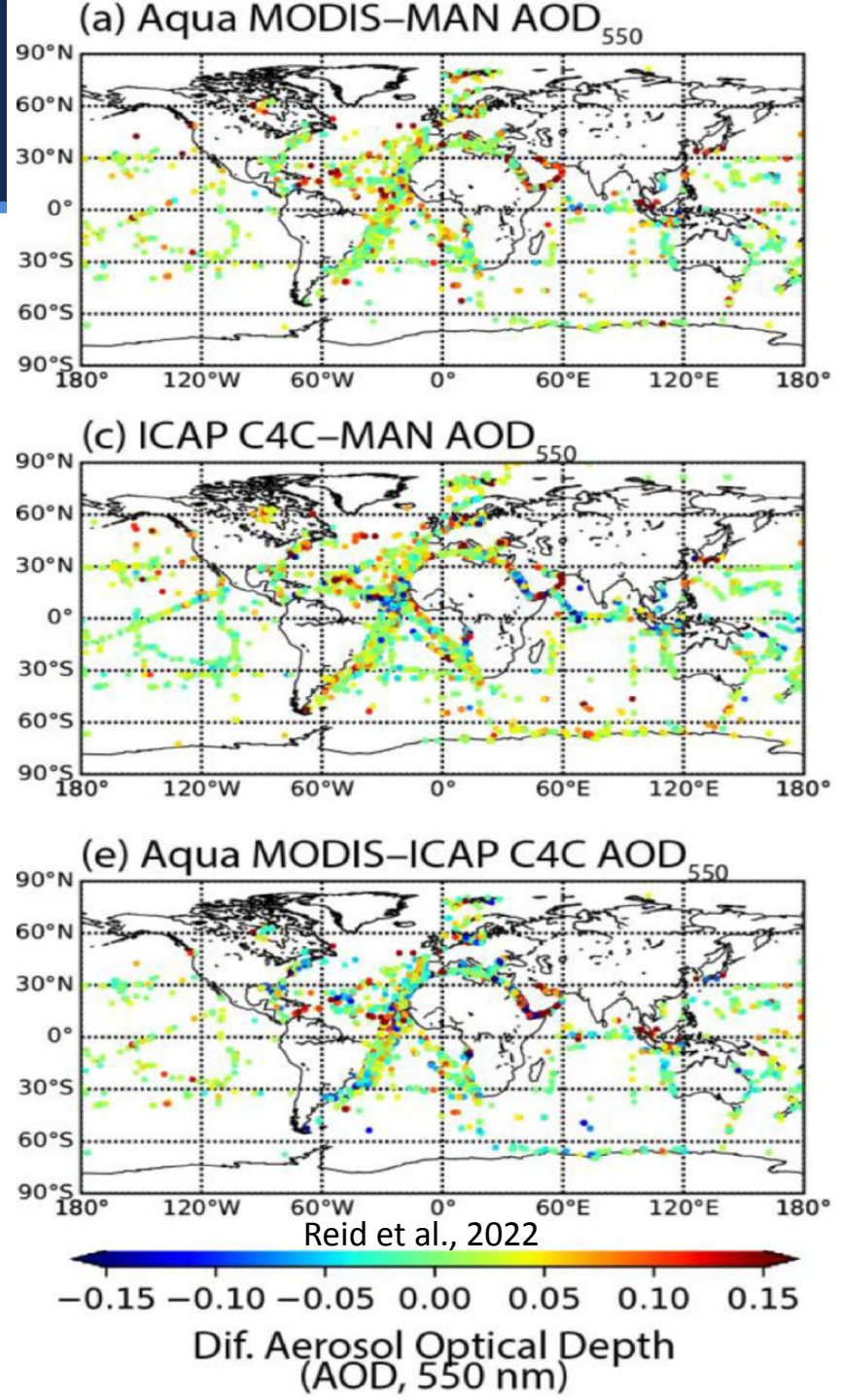
- Of course we will take what we can get, and more is better-especially if our community is not paying for it…. 8^)
- This said, we do start to run into $\sqrt{N}$ sorts of issues in certain places.
- The nice thing about the US and Europe is there are lots of opportunities for coupled measurements (e.g., PM and AOD, lidar sites, NEON & ACTRIS). Although these are the places where satellite retrievals do well.
- The lower boundary condition is still a problem, so site along the edges of surface types are needed.



# Speaking of numbers, AERONET is great, but lets not forget the MAN component

- Spatially we are pretty rich over land, but there is a lot of ocean out there.
- Good news is lower boundary condition for ocean is comparatively easy.
- We can't get data in NRT from MAN, but it is nevertheless a critical dataset for satellite verification that in turn impacts operations.
- As far as we can tell, quality assurance is excellent.
- We do worry about sample bias for more sever weather and remote locations, and hope there can be more automated solutions.


Reid et al., 2022

# "What does Numerical Aerosol Prediction need?" Probably mostly what the rest of you need

- ICAP's tenants are in Benedetti et al., 2020, our data stream has to be accessible, timely &, *well characterized. AERONET hits all of these things well.*
- Thus, by far the most important thing for AERONET is to keep up the tradition of simple, fast and open data exchange with rigorous quality assurance.
- Lunar observations are becoming a big-big-big deal to help improve nighttime aerosol event monitoring and the assimilation cycle. Further investigations on the cloud mask please.
- Speaking of cloud masks Ed Hyer would like a file that includes everything, and flag, good, cloud and precip masks. Knowing fails is a help too.
- Have you considered LANCE delivery too?
- May want to consider additional packaging for ML/AI basis set. Things can be done to make it even easier.
- We do have ideas on new products, but it could be an AERONET production thing or GitHub code exchange.