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Navy Global Aerosol Ensembles and Data Assimilation

ICAP 12th Technical Working Group Meeting

Monterey, CA

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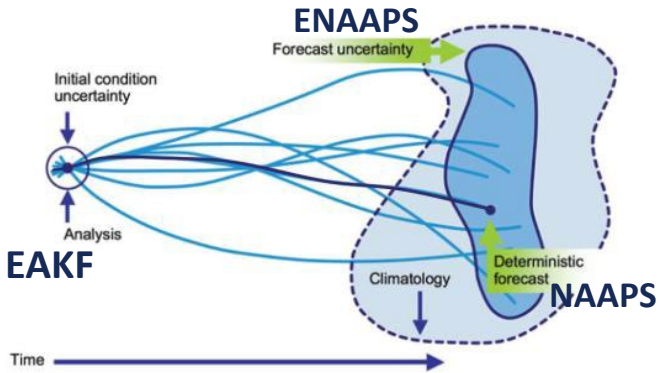
Ensemble Navy Aerosol Analysis Prediction System (ENAAPS) Overview

- **NAAPS** is used to generate operational global aerosol forecasts (**deterministic**).
- **Current operational gap:** Aerosol forecast uncertainty. Need to assess questions like:

  What is the range of potential aerosol outcomes? What is the probability of being impacted by an optically thick aerosol event?
- **ENAAPS** is an ensemble version of the NAAPS system that was developed to fill this gap.
- It has also been used to implement **ensemble data assimilation** for generating aerosol analyses using more efficient use of data (Ensemble Adjustment Kalman Filter, **EAKF**).



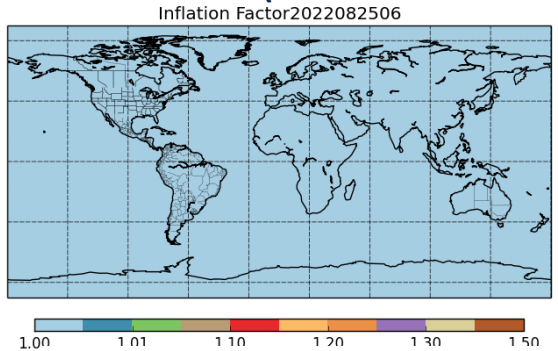
ENAAPS Configuration:

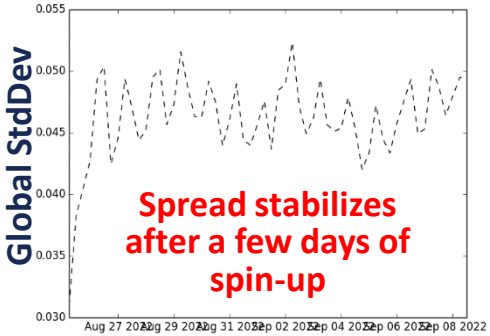
- 80 NAAPS ensemble members for 6hr data assimilation cycling.
- 20 NAAPS ensemble subset for long-range forecast (5 days).
- Ensembles account for meteorology (runs with NAVGEM ensemble) and aerosol emissions uncertainty (perturbed emissions).
- Analyses generated with the EAKF, including MODIS and AERONET AOD assimilation.
- 1 degree horizontal resolution, 40 vertical levels.
- Output: 3d mass concentration fields, AOD Netcdf files with ensemble mean, standard deviation, percentiles (10,25,50,75,90), probabilities (AOD > 0.2,0.3, 0.5, 0.8).

ENAAPS Data Assimilation Overview

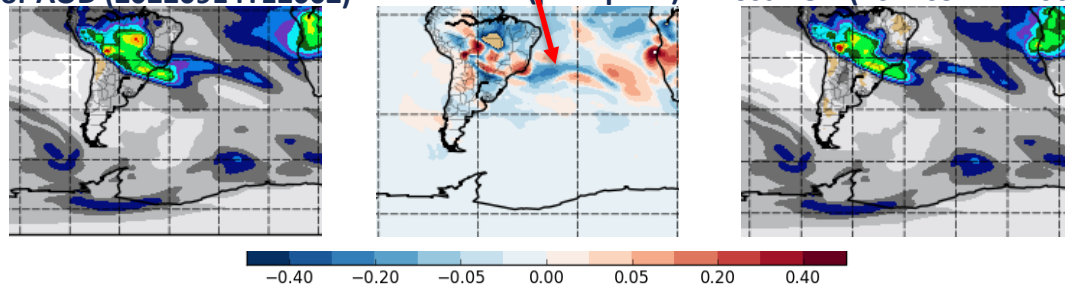
- **ENAAPS** uses ensemble data assimilation with the DART Ensemble Adjustment Kalman Filter (EAKF).
- MODIS + AERONET obs assimilated every 6 hours.
- The EAKF setup was tested to ensure:
  1. Sufficient and stable ensemble spread (adaptive, state-space inflation in prior).
  2. Reduced impacts of spurious correlations (Gaspari-Cohn localization, 1000km lengthscale).
- ENAAPS accounts for met uncertainty with the use of the NAVGEM ensemble: flow-dependent corrections.

Inflation Factor: CPEX (20220825-20220920)



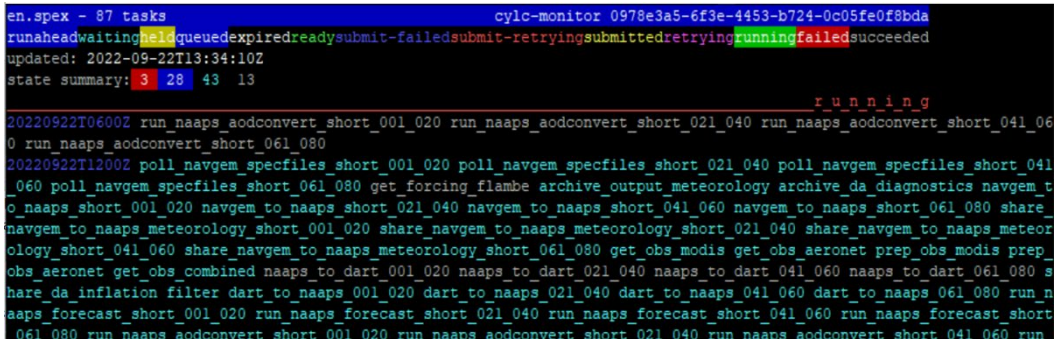


Prior AOD (20220914T1200Z) | **Correction (post-prior)** | **Post AOD (20220914T1200Z)**



ENAAPS Operational Status

- **ENAAPS** is scheduled for operational transition to Fleet Numerical Meteorology and Oceanography Center (FNMOC) this year. Several delays due to resource limitations.
- ENAAPS will run operationally at the Navy DoD Supercomputing Resource Center (DSRC). This is where current NRT runs are being conducted, however, we are in the process of moving it to a new machine.
- ENAAPS is fully implemented with Cylc:
- Ops ENAAPS Products:
    1. NRL Map Room
    2. ICAP Page
- The validation test report (VTR) has been completed and submitted to FNMOC. Outlines system performance and is an important step in the transition process.

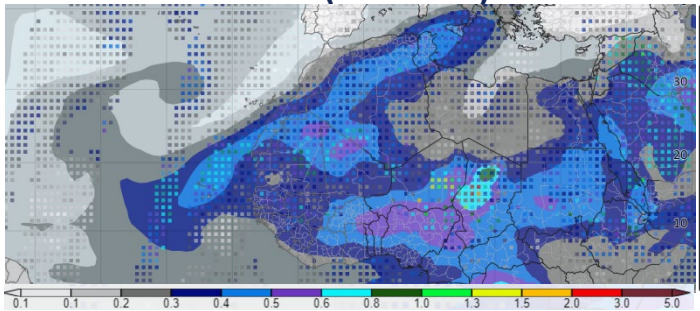


Snapshot of NRT running ENAAPS Cylc Suite.

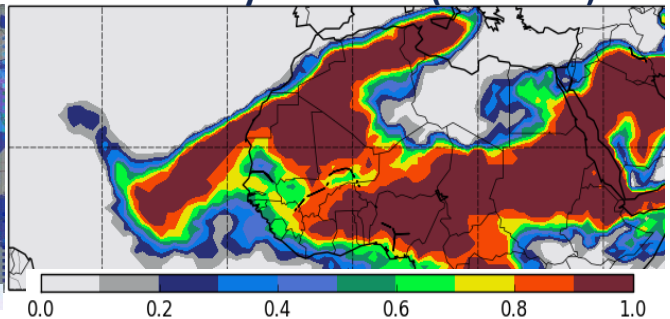
ENAAPS Aerosol Products: CPEX-AW Example 2022

Dust Event, September 9, 2022 on NRL Map Room:

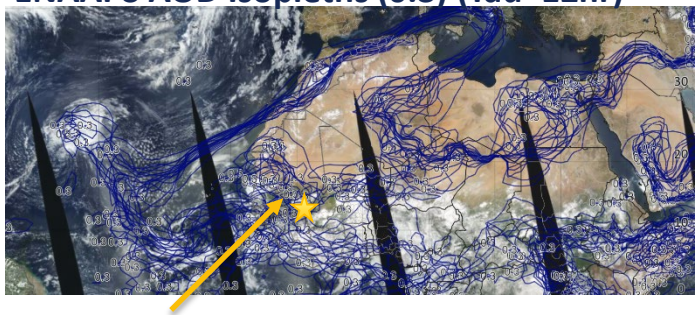
ENAAPS Mean AOD (Tau=12hr)+ MODIS Obs



Probability AOD > 0.3 (Tau=12hr)

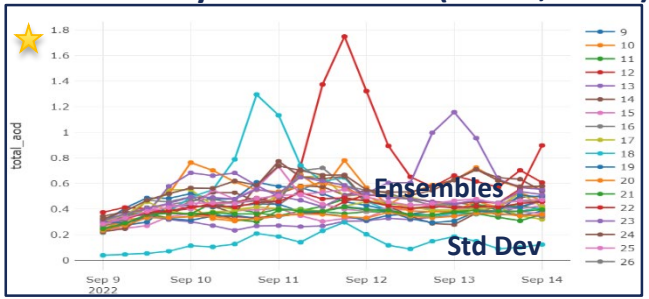


ENAAPS AOD Isopleths (0.3) (Tau=12hr)



Regions of disagreement indicate uncertainty

ENAAPS 5-Day AOD Forecast (16.5N, 7.5W)



- ENAAPS near-real-time aerosol products are posted to NRL Map Room (J. Reid, J. Roetman).
- Ensemble mean/std dev AOD, ensemble member AOD fields, AOD percentiles, time series are available.
- Working on adding probability plots, vertical information (boundary layer, lower/upper/mid free troposphere AOD) and ensemble met info (TPW).

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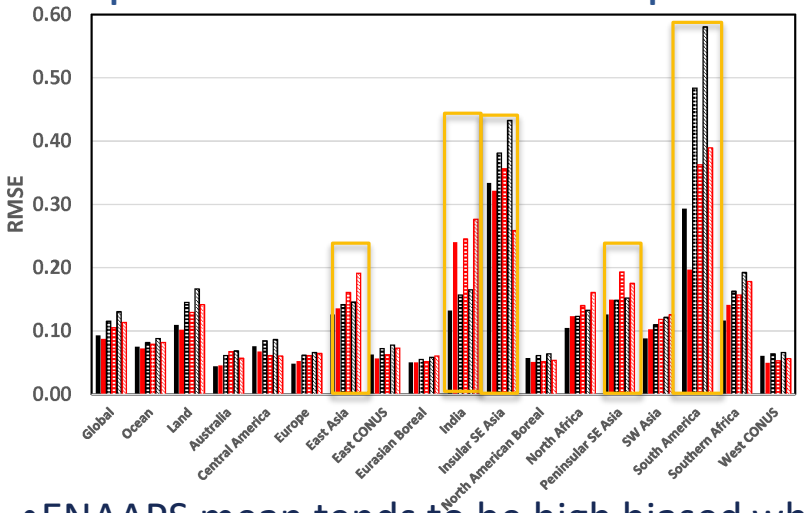
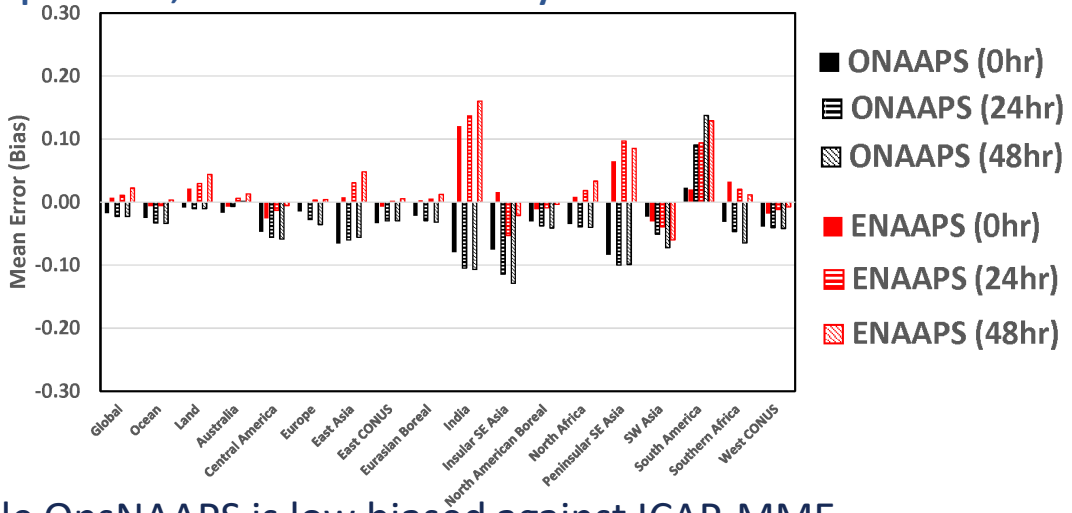
ENAAPS Verification Overview

ENAAPS verification work conducted with NCAR's verification software, MET v10.0.1:

September 2019: ENAAPS Mean Comparison to Ops NAAPS, OBS = ICAP-MME Analysis





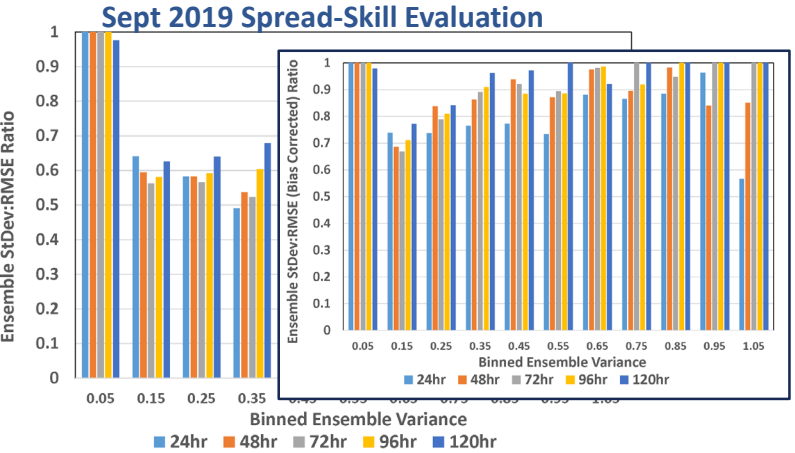
- ENAAPS mean tends to be high biased while OpsNAAPS is low biased against ICAP-MME.
- **Positive bias issues** mainly associated with background aerosol levels, particularly in pollution dominated conditions (India, East/Southeast Asia). Bias correction to address this.
- ENAAPS mean has **advantage in biomass burning regions**, attributed to AERONET assimilation.
- Some speciation differences due to DA. Ops NAAPS has more sea salt and ENAAPS mean has higher smoke/pollution. Dust varies by location.

ENAAPS Verification Overview

How well does the ensemble spread represent forecast uncertainty?

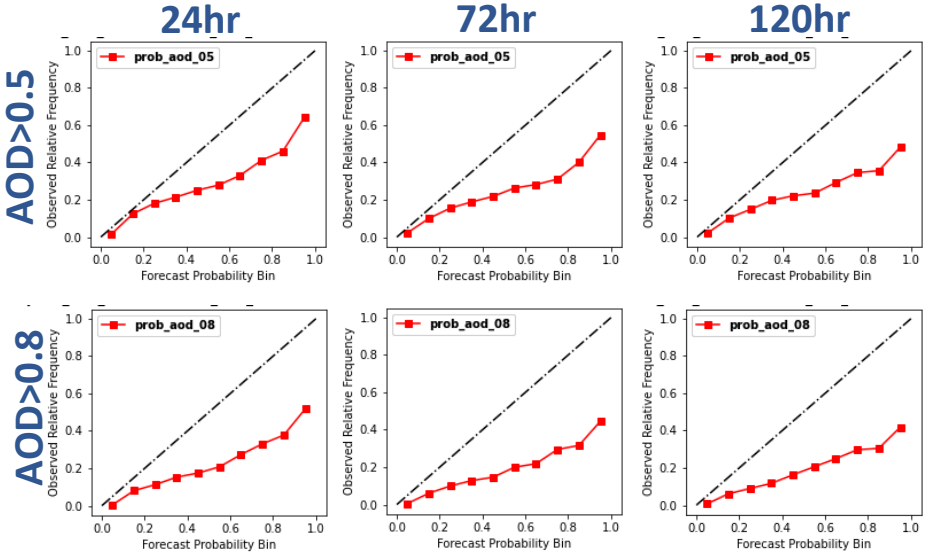
Spread-Skill Evaluation:

- Evaluated by lead time/region, data binned by ensemble variance.
- The Sept 2019 period (below) had Spread:RMSE ratio at ~ 0.5, increasing with lead time, especially for high AOD events.
- If the forecast error is corrected for bias, the ensemble spread is much more representative of the random error (~0.8-0.9).
- Shows bias correction will be very helpful.



How do forecasted probabilities compare to obs for high AOD events?

Reliability Diagrams for the Raw Ensemble:

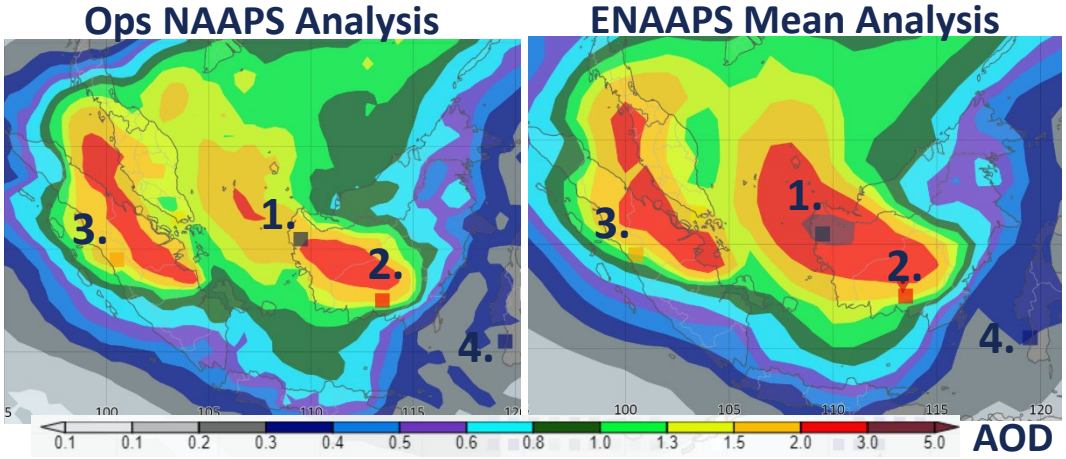


- Results were consistent across the seasonal evaluation time periods.
- Forecast probabilities found to increase with observed probability (good trait).
- Compared well for low probability events (<0.2) and an increasing over-forecasting for higher probabilities.
- Consistency of the reliability diagrams indicates that post-processing can easily correct forecast probabilities.

ENAAPS AERONET Assimilation in Near-Real-Time

- ENAAPS includes near-real-time AERONET observations for assimilation from the U of Wisc SSEC (B. Holz, A. Gumber).
- Showed previously that AERONET DA is beneficial for ENAAPS in biomass burning regions.
- These observations have been found to be quite effective at improving AOD values in peak source regions, including for biomass burning.

Example: CAMP²ex, September 22, 2019



1. AERONET = 3.57
   ENAAPS = 3.35
   NAAPS = 2.0
   ICAP = 3.7

2. AERONET = 1.94
   ENAAPS = 1.89
   NAAPS = 1.7
   ICAP = 3.1

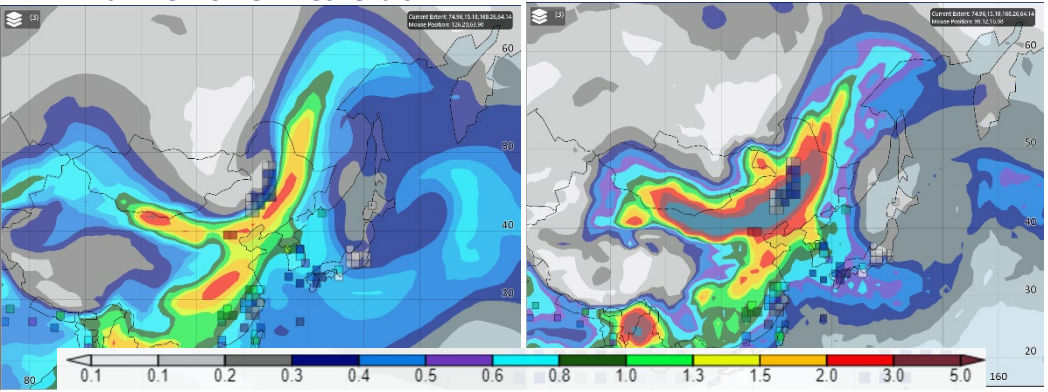
3. AERONET = 1.56
   ENAAPS = 1.61
   NAAPS = 1.63
   ICAP = 3.5

4. AERONET = 0.28
   ENAAPS = 0.31
   NAAPS = 0.29
   ICAP = 0.31

ENAAPS AERONET Assimilation in Near-Real-Time

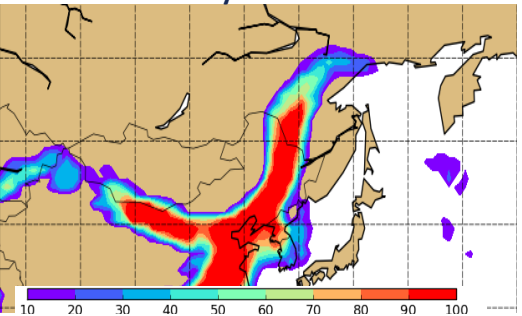
Record Dust Storm over China 3/15/21:

ENAAPS Mean 24hr Forecast with MODIS AOD Retrievals

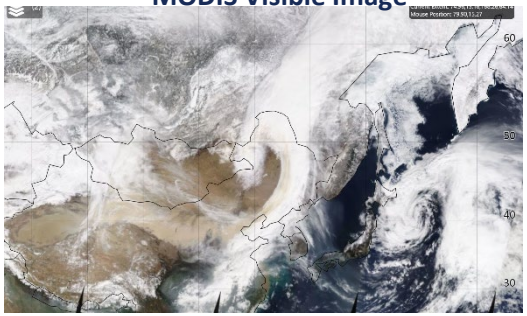


Ops NAAPS 24hr Forecast with MODIS AOD Retrievals

Probability of AOD>0.8



MODIS Visible Image



- Example when NRT ENAAPS assimilation uses AERONET obs only (MODIS obs were not available).
- ENAAPS better captures the dust front compared to operational NAAPS.
- The ensembles generally agree on the front position (indicating confidence).
- In peak regions, Ops NAAPS overpredicts AOD (AOD>5).
- In peak regions, ENAAPS ensemble range is consistent with obs (ENAAPS range = 1.25 to 3.07, obs = 2.60).
- Demonstrates the ability of ENAAPS to perform in NRT, despite not running optimally.
- AERONET found to be good back-up obs in certain parts of the world (consistent with Rubin et al. 2017)

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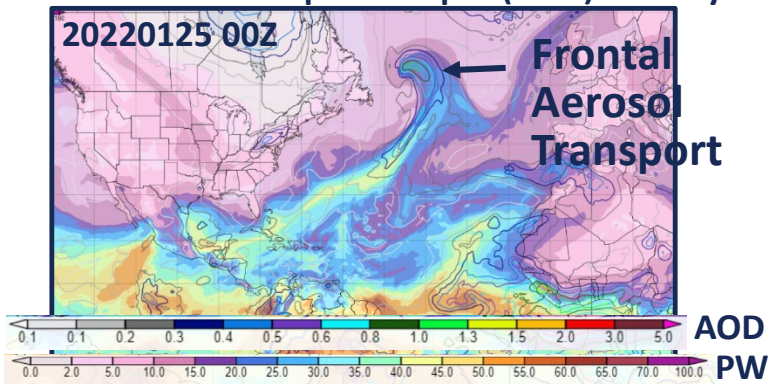
Preparing for Future Coupled Met/Aerosol Data Assimilation

Aerosol and water vapor co-transport events are regularly observed in model and satellite data. This has also been shown for many case studies in the literature.

The goal of this work has been to quantify the aerosol and water vapor relationship such that we can:

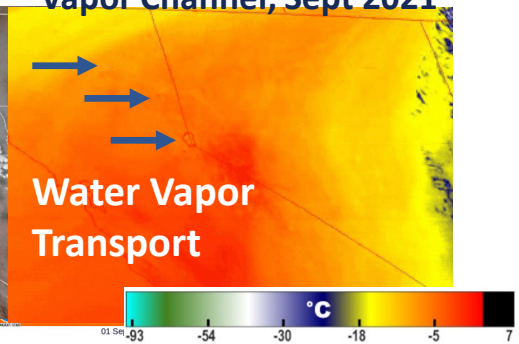
1) Use water vapor as a tracer for evaluating FT aerosol life cycle.
2) **Understand how to exploit ubiquitous water vapor obs for coupled aerosol-meteorology data assimilation.**

NAVGEM Total Precipitable Water (PW) with NAAPS Aerosol Optical Depth (AOD) Overlay



GOES-West RGB, Sept 1 2021

GOES-West Lower Level Water Vapor Channel, Sept 2021



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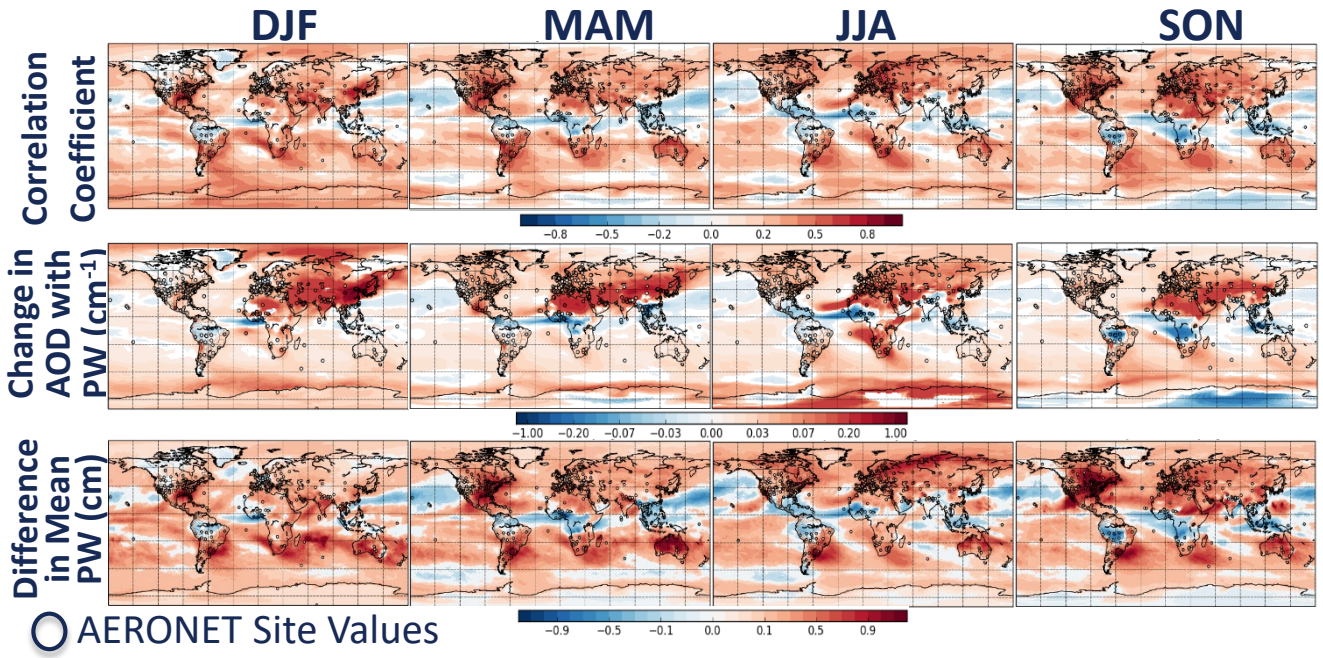
Quantifying Aerosol and Water Vapor Relationships with AERONET and the NAAPS Reanalysis

Seasonal AOD/PW relationships quantified with correlations, Thiel-Sen Slopes, and probability distribution evaluations:



- **Positive** and statistically significant relationships generally found.
- Biomass burning (BB) and Sahel regions are **negative**.
- Negative relationships in BB regions are a reflection of dry conditions leading to higher AOD. Case studies showed positive relationships.
- Sahel negative relationships associated with ITCZ scavenging. Creates strong dipole over North Africa.

Rubin et al. 2022, ACPD

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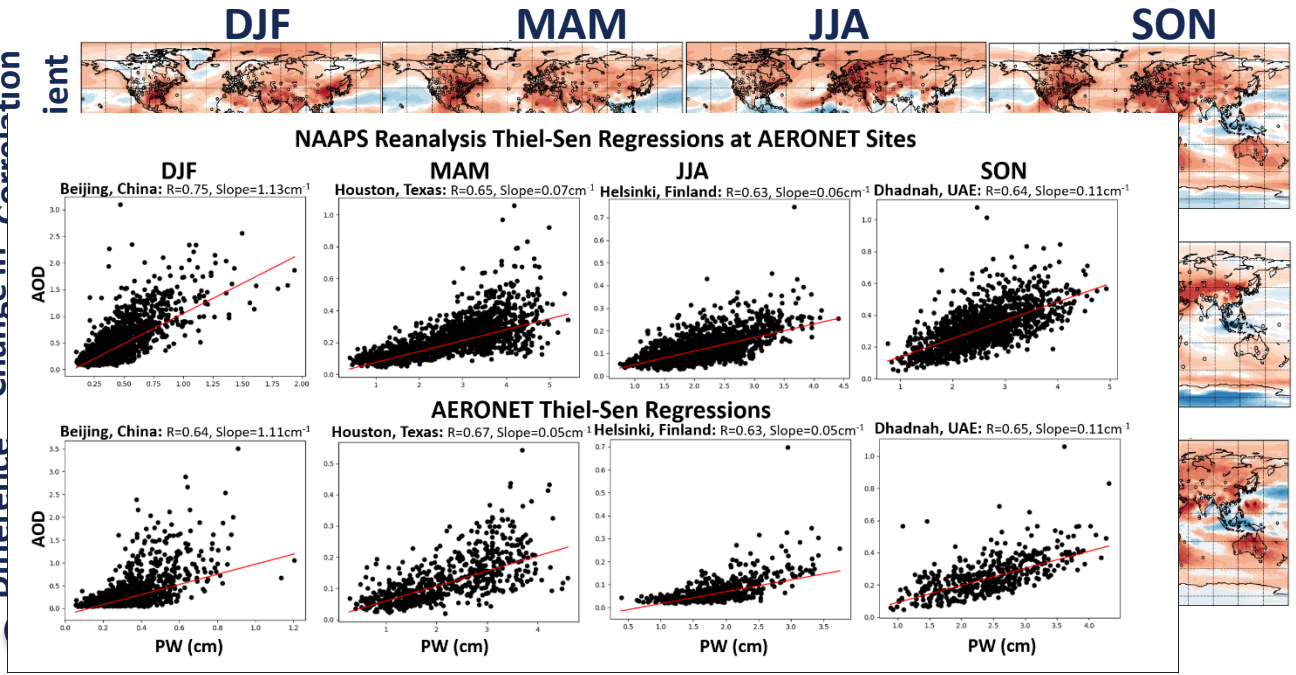

NAAPS and AERONET found to be in good agreement on sign of relationships, strongest agreement in slope.

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ENAAPS Overview and Future Work

- ENAAPS v1.0 fills the current operational gap of aerosol uncertainty info with anticipated 2023 transition.
- We are using NRL Map Room as a means for distributing probabilistic aerosol products and getting customer feedback. An important focus is how to use the ensemble information effectively.
- ENAAPS verification is also an area of focus. Extensive verification work indicates regional biases and the importance of statistical post-processing of the ensemble to improve performance. This is a focus in FY23, including post-processing in the NRT cycling system for the mean and probabilistic forecasts.
- Currently working on ENAAPS vertical verification.
- NRT AERONET assimilation in the ENAAPS EAKF has been successful and demonstrates the ability of the EAKF to use sparse observations. We hope to include other sparse datasets in ENAAPS DA.
- Uncertainty in what the future of global aerosol ensemble looks like. It is dependent upon the next generation Navy meteorological forecasting system (NEPTUNE) and its ensemble.
- In the new modeling framework, we hope to make use of meteorological obs for aerosol data assimilation. Water vapor/aerosol work is in preparation of this. Need further work to understand aerosol/meteorology covariances beyond water vapor.