



Navy Ensemble Aerosol Prediction and Data Assimilation: Updates and Verification

ICAP 13th Working Group Meeting

Darmstadt, Germany

November 8, 2023

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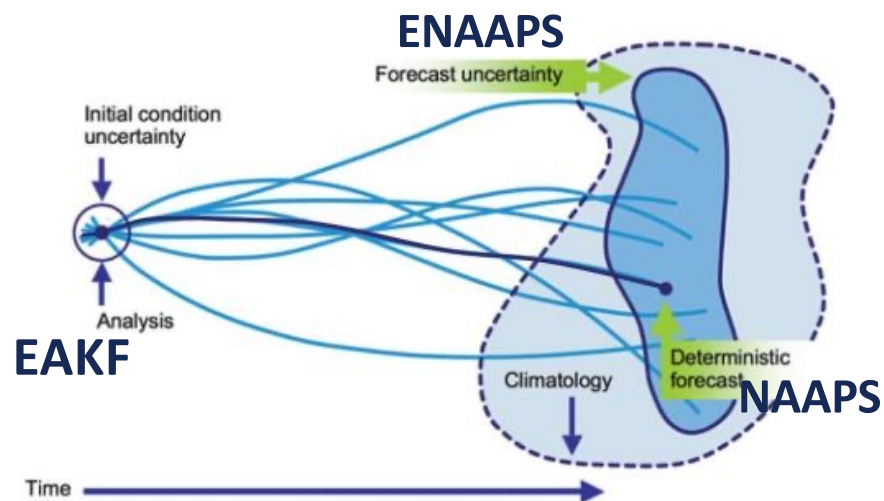
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³ Devine Consulting, Naval Research Laboratory, Monterey, CA

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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**).



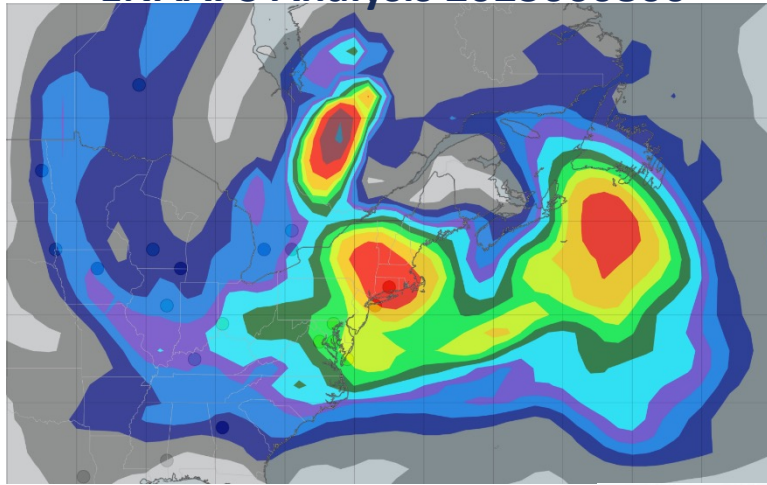
ENAAPS Configuration:

- 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).

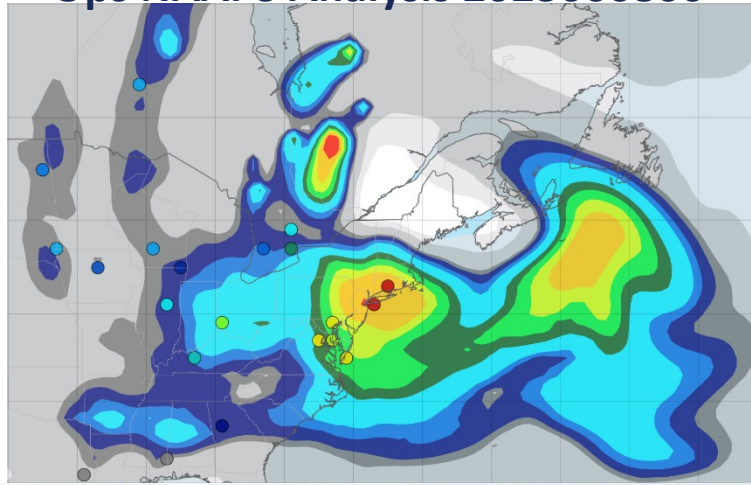
ENAAPS Data Assimilation Overview

- **ENAAPS** uses ensemble data assimilation with DART Ensemble Adjustment Kalman Filter (EAKF).
- MODIS + AERONET observations assimilated every 6 hours. AERONET found to be particularly beneficial for improving prediction of high AOD events (ex. Canadian wildfires 6/8/23) :

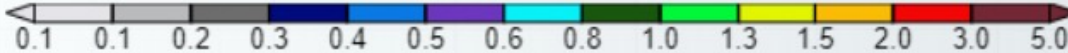
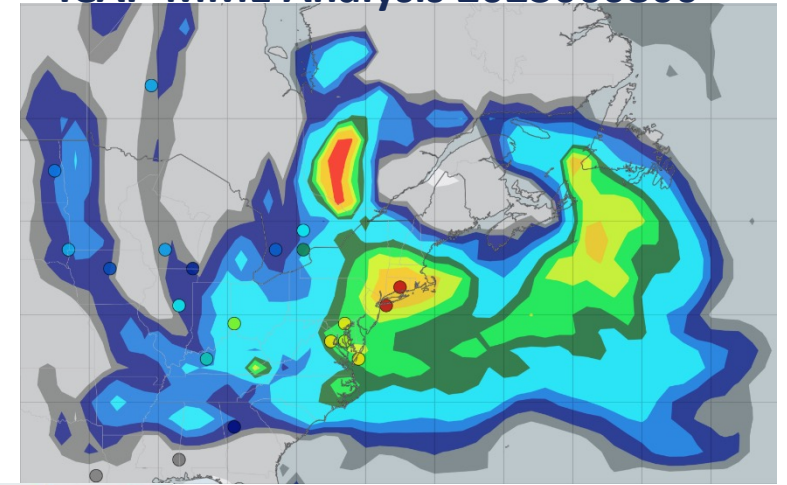
ENAAPS Analysis 2023060800



Ops NAAPS Analysis 2023060800

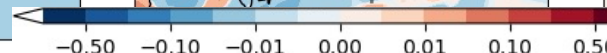
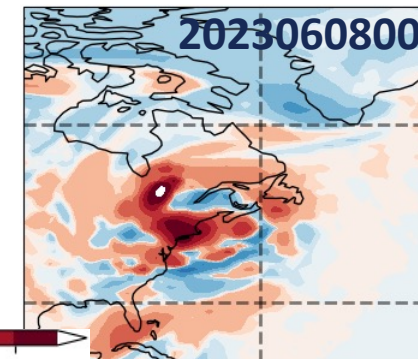
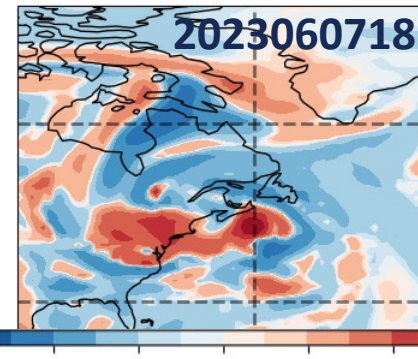
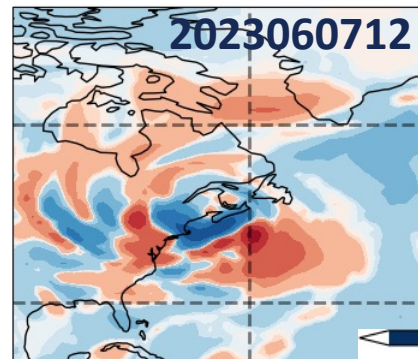


ICAP-MME Analysis 2023060800



○ = AERONET AOD

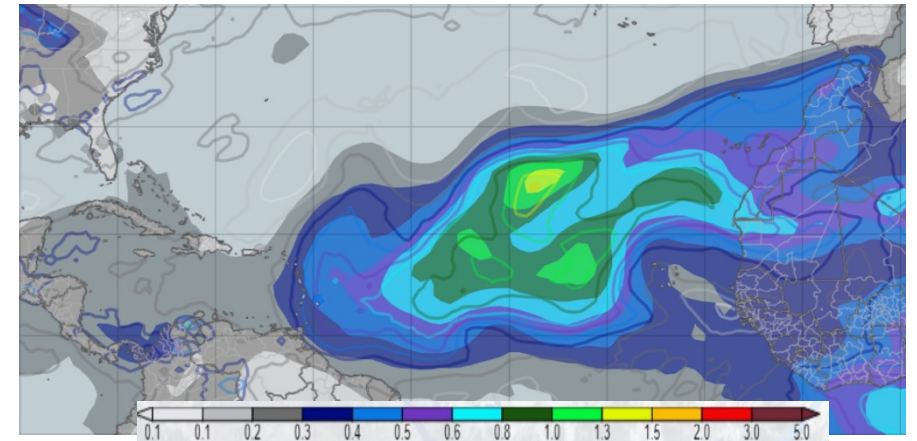
- ENAAPS accounts for met uncertainty with the use of the NAVGEM ensemble: flow-dependent corrections.



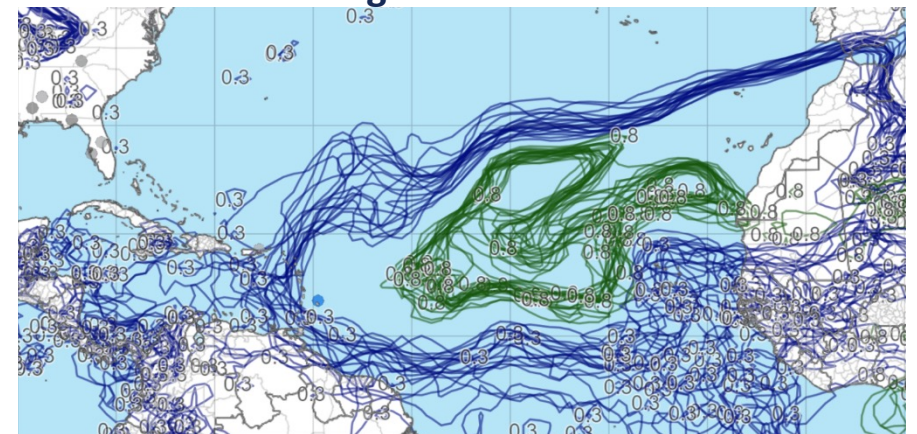
ENAAPS
AOD
Analysis
Increments

ENAAPS Operational Status

- **ENAAPS v1.0** code was delivered to Fleet Numerical Meteorology and Oceanography Center in FY23. Operational testing planned in FY24.
- ENAAPS will run operationally at the Navy DoD Supercomputing Resource Center (DSRC). Some example near-real-time output from the DSRC shown.
- System runs via Cylc scripts.
- Next major system upgrade is replacing NAAPS code with NAAPS 2.0, currently working on this (E. Hyer, C. Camacho). Scheduled to be delivered in FY24.
- Currently focusing on developing new ensemble products, including new vertical output and aerosol warning products.



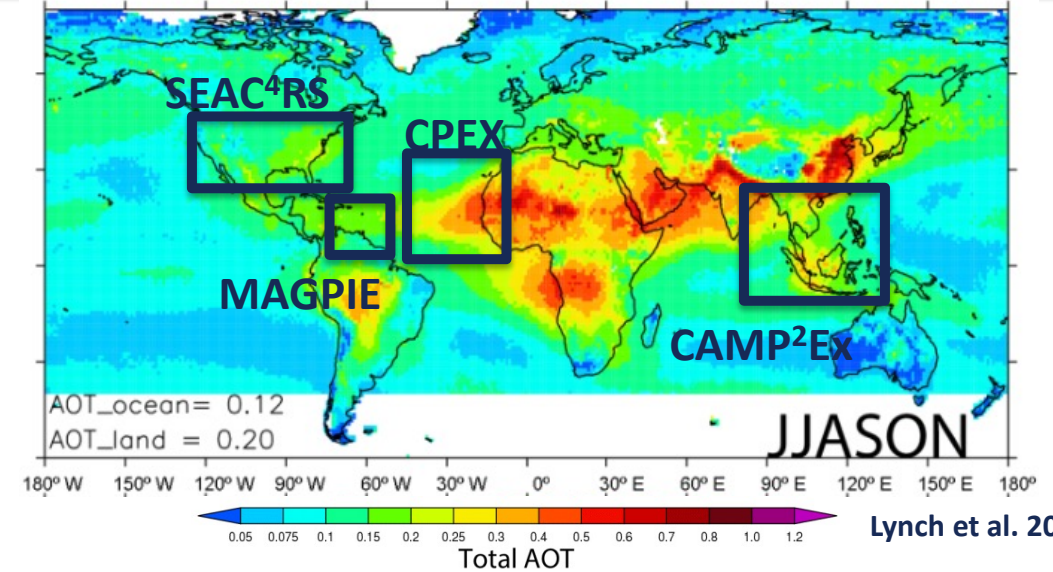
ENAAPS Mean (filled contours) and Operational NAAPS (unfilled contours) AOD on 8/14/23 at 00Z, both showing dust coming across the Atlantic.



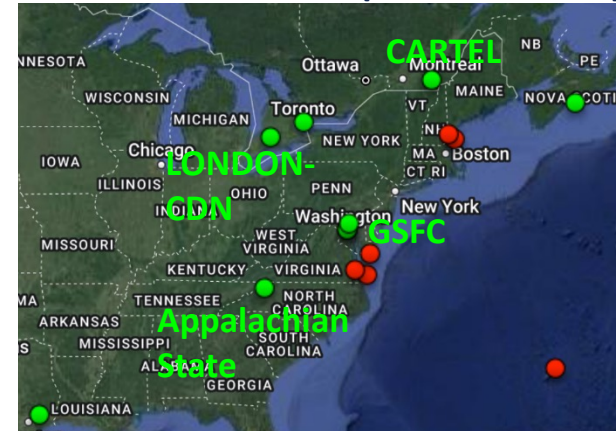
ENAAPS ensemble AOD isopleths for 0.3 (blue) and 0.8 (green) for 8/14/23 at 00Z

Ongoing Vertical Verification Work

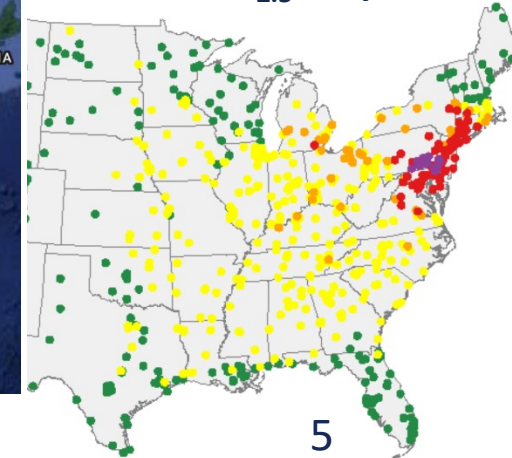
- As AOD is assimilated and used for verification, models generally predict AOD well.
- Surface and PBL mass and spectral extinction are much more difficult to monitor and predict. Lots of spread between models.
- We are currently conducting an evaluation of Navy model performance in aerosol vertical distribution for downstream applications.
- This includes:
 - **Operational NAAPS** ($0.3^\circ \times 0.3^\circ \rightarrow 0.25^\circ \times 0.25^\circ$), 35 levels. NAVDAS-AOD MODIS assimilation.
 - **NAAPS reanalysis** ($1^\circ \times 1^\circ$), 25 levels. NAVDAS-AOD MODIS assimilation
 - **ENAAPS** ($1^\circ \times 1^\circ$), same vertical levels as Ops NAAPS. EAKF MODIS+AERONET assimilation.
- Using field campaign data, MPLNET, AirNow data, new ICAP PM products and eventually surface extinction.



NASA MPLNET Sites (Green=Active)



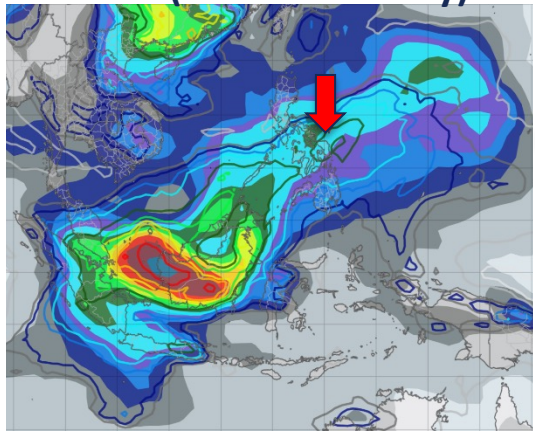
AirNOW PM_{2.5} Map 6/8/23



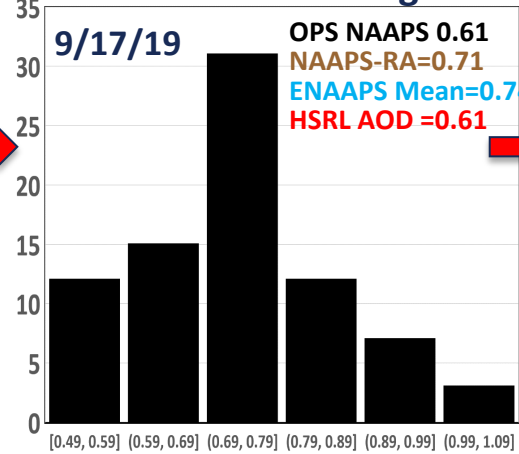
Aerosol Vertical Evaluation Southeast Asia

Overall findings so far: Model performance varies with the overall complexity of the aerosol vertical structure. For synoptic scale aerosol events where the extinction is predominantly in the boundary layer, the models did the best (i.e. CAMP²Ex below).

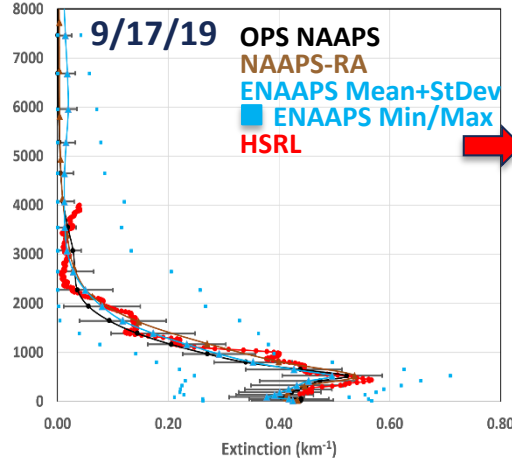
ENAAPS Mean (filled contour), Ops NAAPS (unfilled overlay) AOD



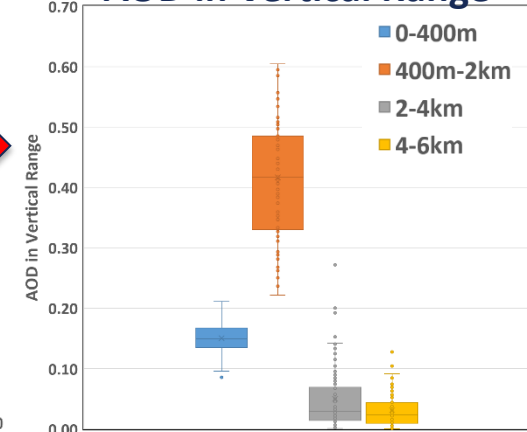
ENAAPS AOD Histogram



Extinction Profiles



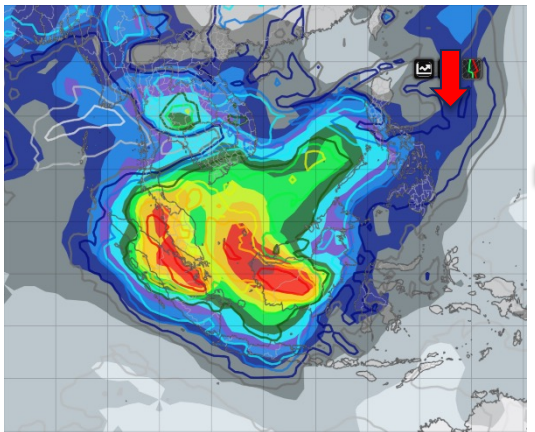
ENAAPS Fraction of AOD in Vertical Range



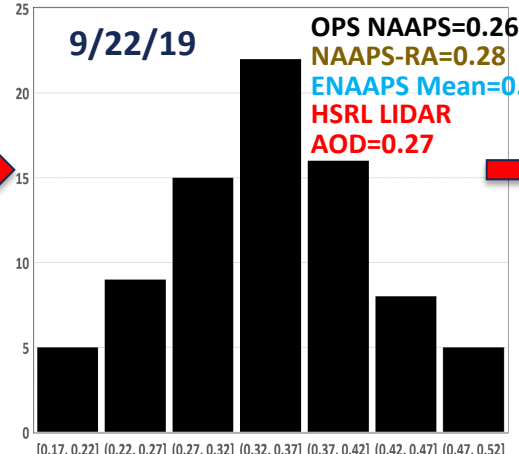
-Models are generally consistent in AOD and extinction.

- Ensemble distribution encompasses observed extinction.

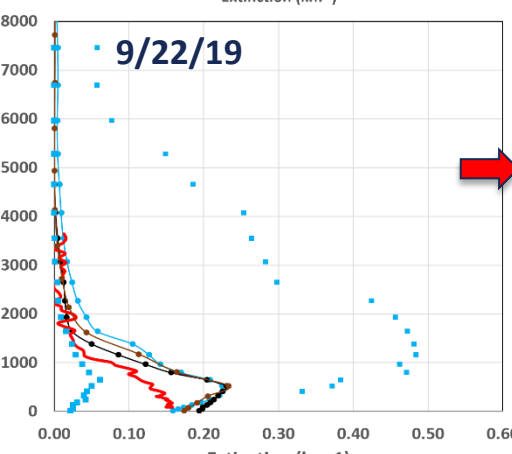
-Most ensembles put the extinction in the correct vertical range.



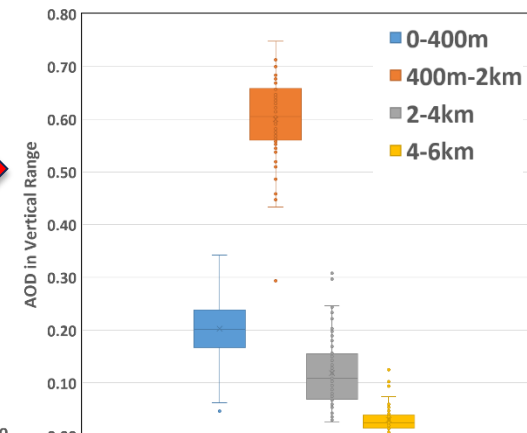
ENAAPS AOD Histogram



Extinction Profiles



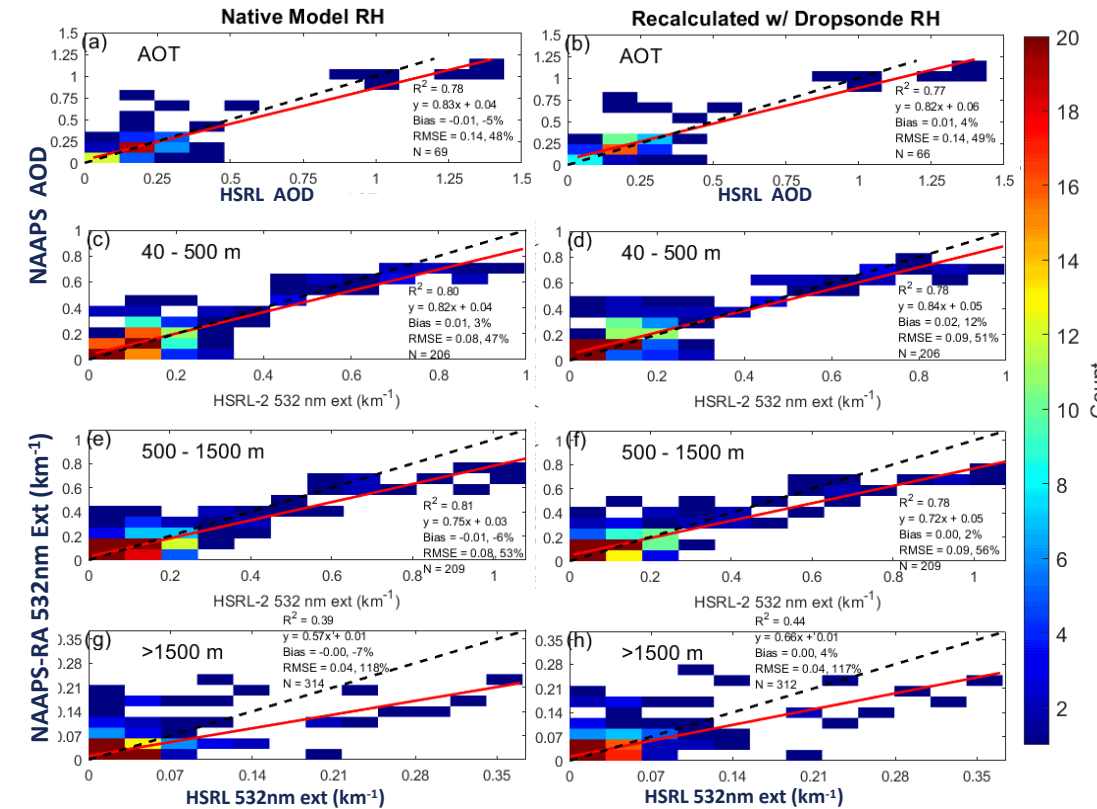
ENAAPS Fraction of AOD in Vertical Range



Aerosol Vertical Evaluation: CAMP²Ex

- A thorough evaluation was conducted on the NAAPS-RA during CAMP²Ex with comparisons to all HSRL data.
- Results are consistent with what we've seen in individual profile comparisons across models.
- NAAPS-RA extinction compared well to HSRL in the MBL mixed layer with $R^2=0.80$ (40-500m) and 0.81 (500-1500m) during CAMP²Ex.
- Performance decreased >1500 m ($R^2=0.39$).
- Model RH had poor correlation with dropsondes and exhibited dry bias at all altitudes.
- The impact of replacing model RH with dropsonde RH on AOD/extinction output was evaluated. Limited impact with extinction bias becoming more positive.
- NAAPS-RA overestimates the hygroscopicity of Maritime Continent biomass burning aerosol.

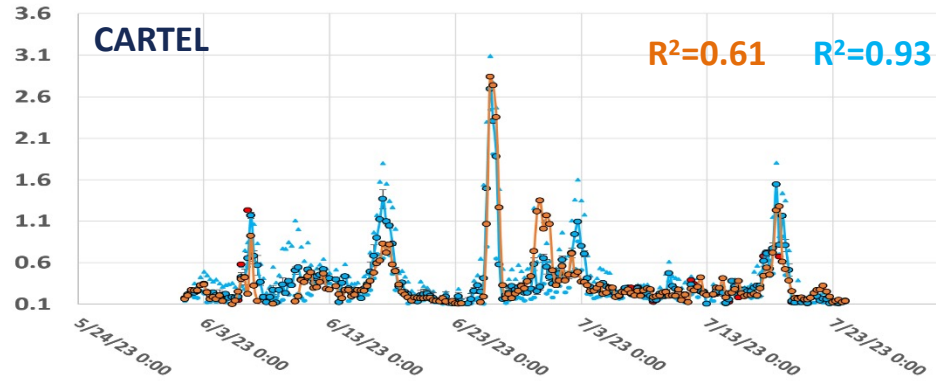
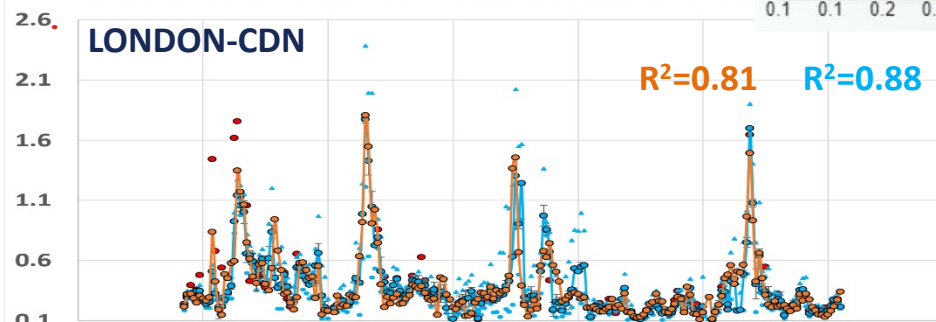
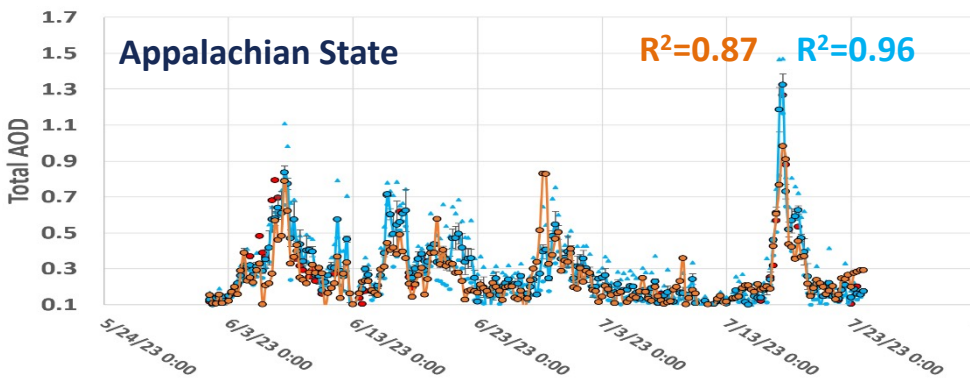
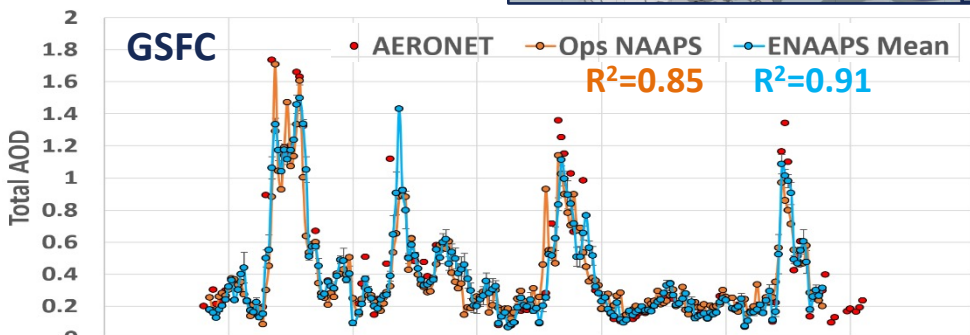
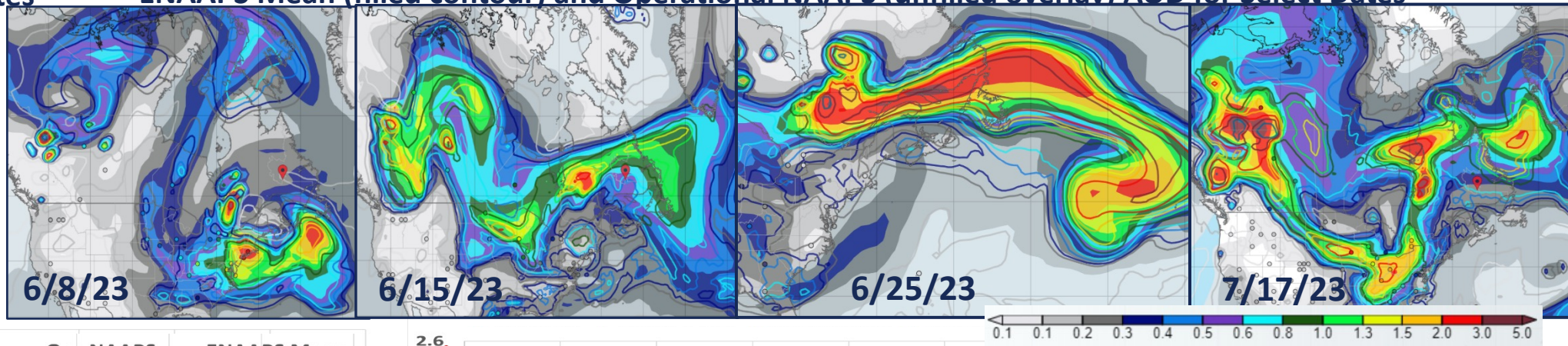
Comparison of NAAPS-RA to CAMP²ex HSRL AOD/extinction (532nm).



Edwards et al. 2022

Aerosol Evaluation: Transported Smoke 2023 Canadian Wildfires

NASA MPLNET/AERONET Sites ENAAPS Mean (filled contour) and Operational NAAPS (unfilled overlay) AOD for Select Dates

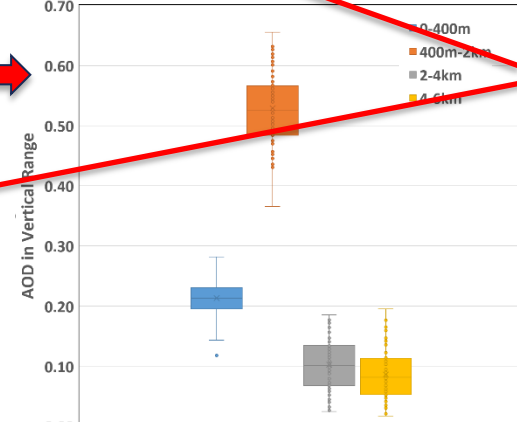
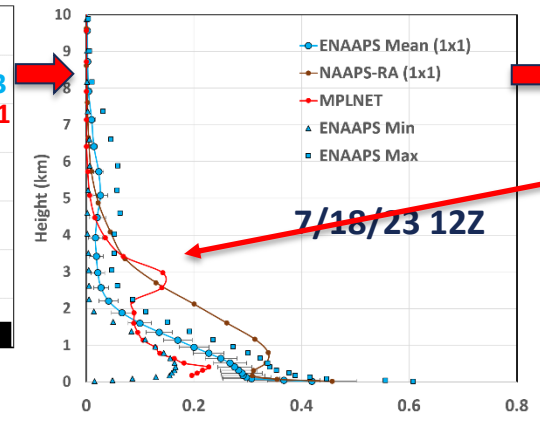
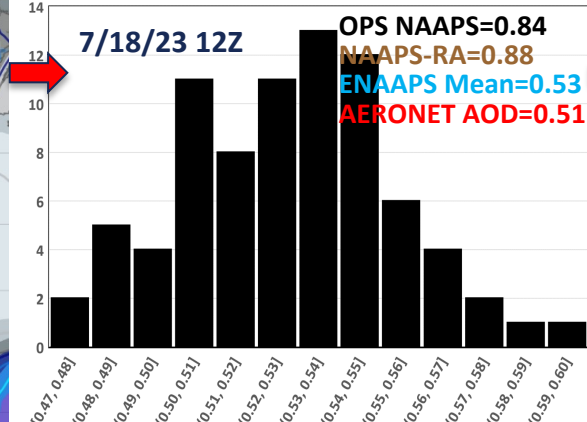
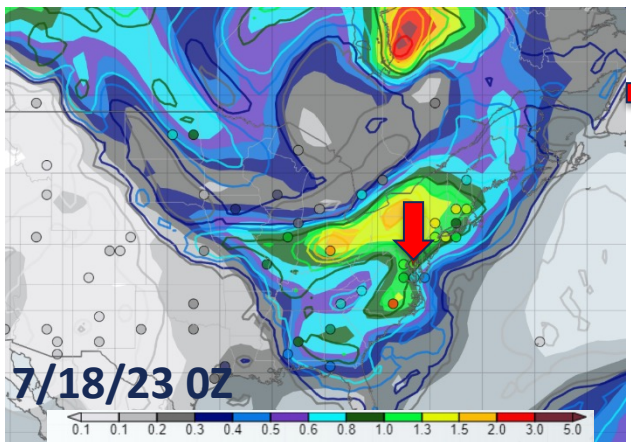
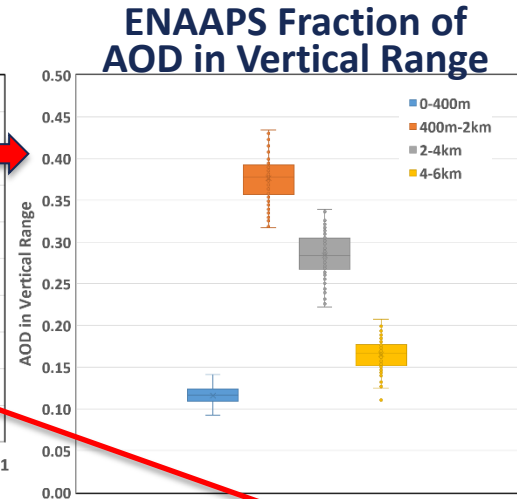
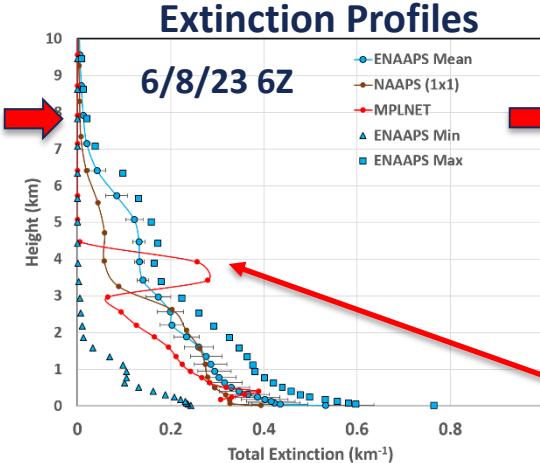
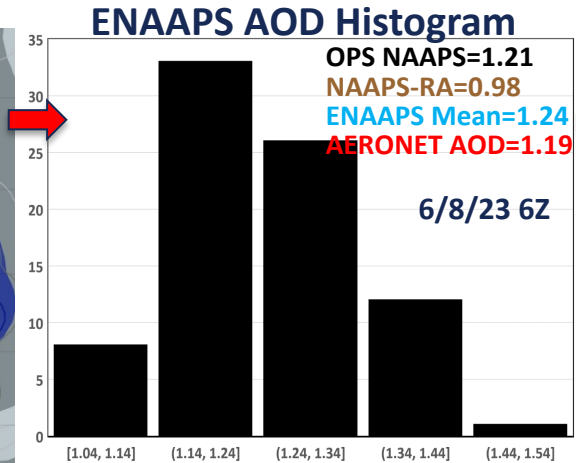
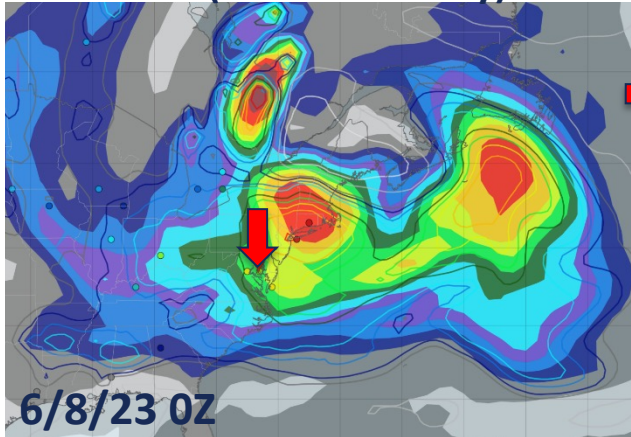


- AOD timeseries at AERONET sites with active MPLNET are shown.
- Models are well correlated with AERONET.
- Correlations stronger in ENAAPS because it assimilates the data.

Aerosol Vertical Evaluation: Transported Smoke 2023 Canadian Wildfires

Evaluations of transported smoke events during recent extreme Canadian fires and observed during SEAC⁴RS provide a little bit different picture.

ENAAPS Mean (filled contour), Ops
NAAPS (unfilled overlay) AOD



- Some diff in AOD due to AERONET assimilation
- Ensemble distribution encompasses observed extinction near surface.
- Models consistently miss elevated smoke layers.
- At least for 6/8 ensemble does indicate some extinction in 2-4km range

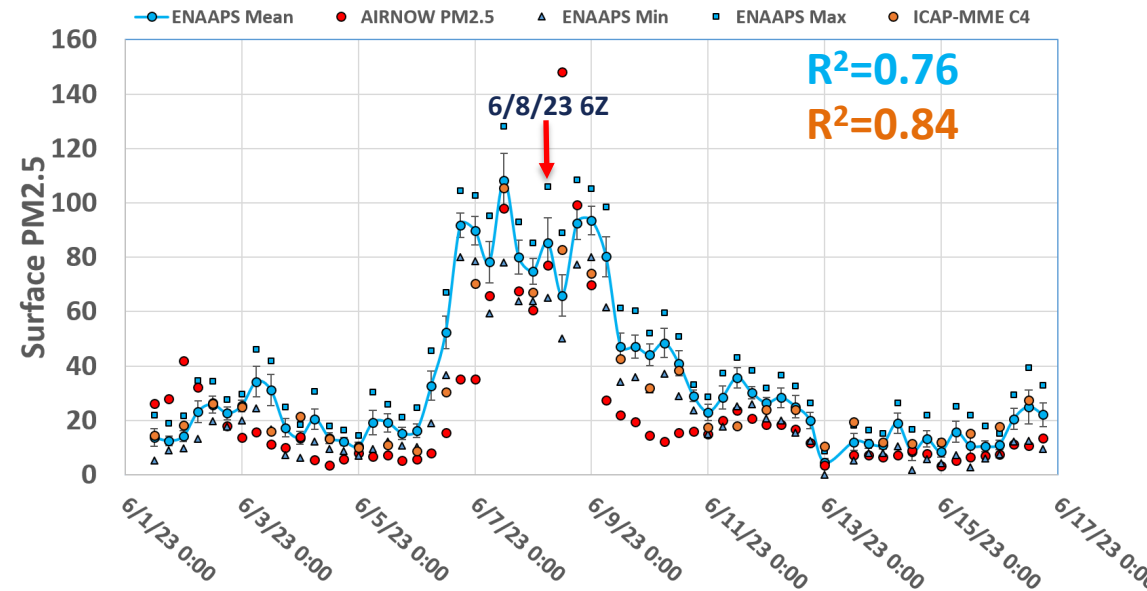
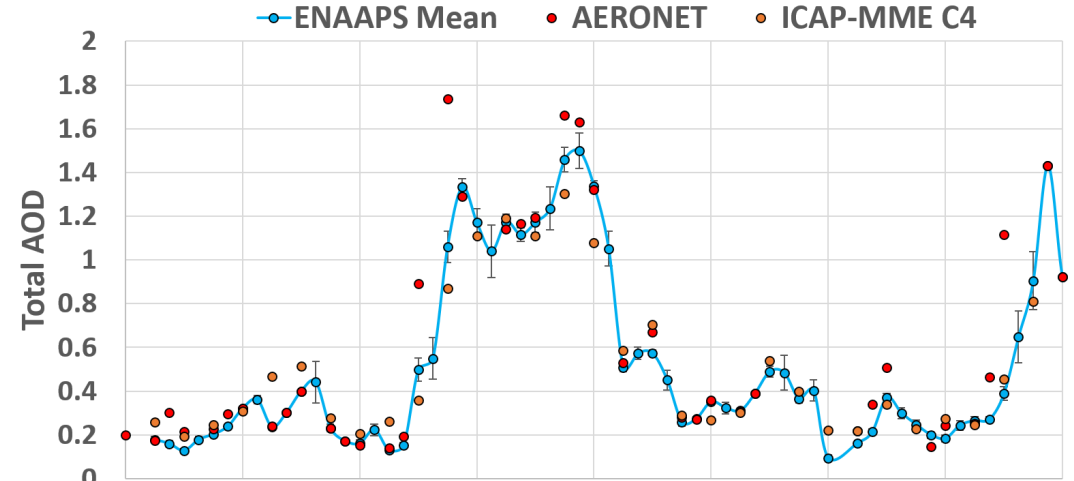
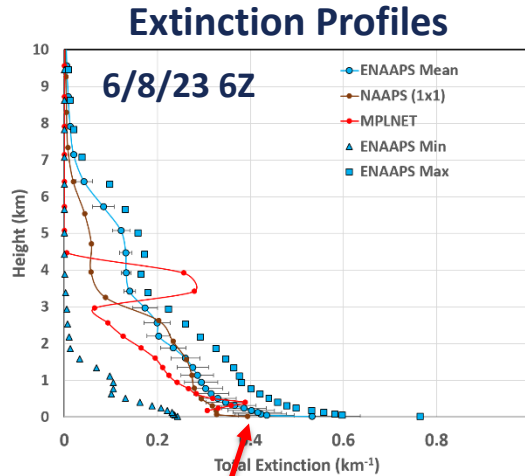
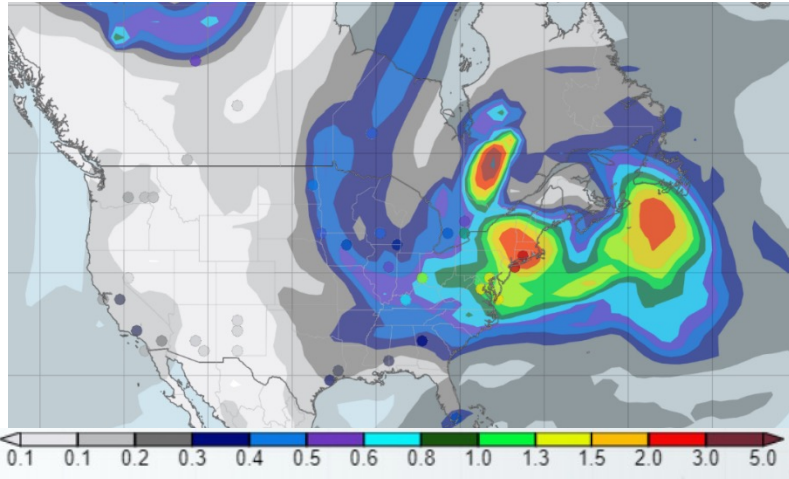
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Aerosol Vertical Evaluation: Transported Smoke 2023 Canadian Wildfires

In addition to MPLNET, surface PM evaluations are ongoing using AirNOW and new ICAP products:

ENAAPS AOD Analysis 6/8/23 00Z, Canadian Smoke

○ = SSEC AERONET Total AOD

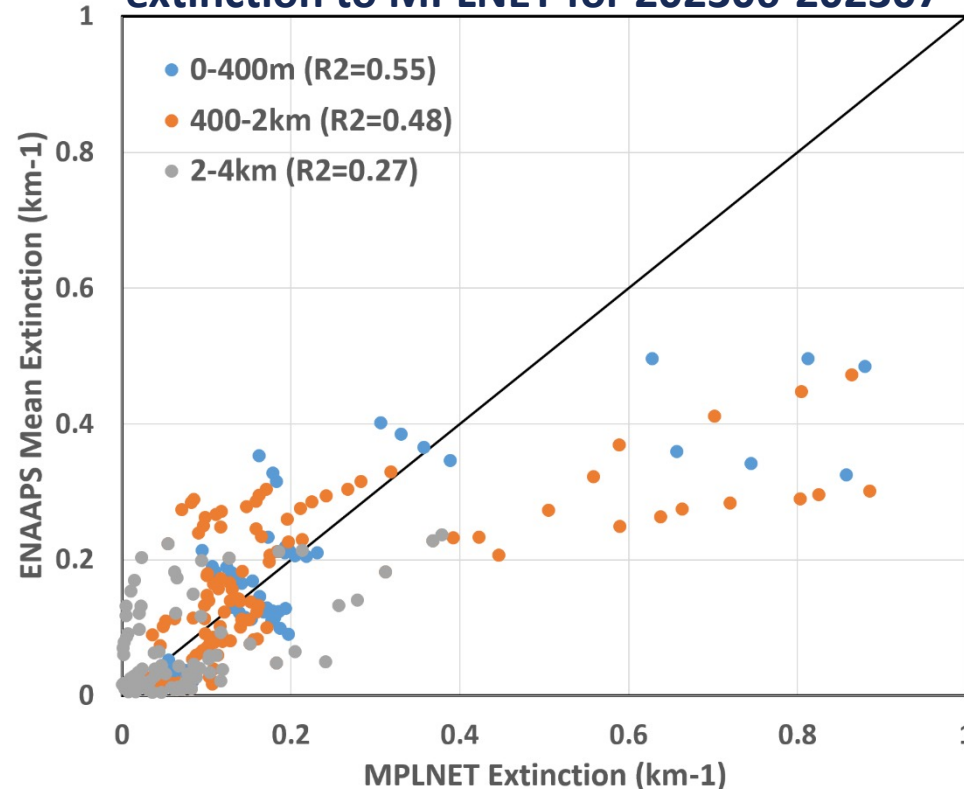


- University of Wisconsin now generates AirNow PM products for use in surface verification.
- Shown are timeseries evaluations at GSFC using AERONET and nearby PM2.5 data.
- ENAAPS/ICAP are well correlated in both AOD and surface PM, however, there is a tendency to overestimate surface PM.
- Sign of surface PM bias in ENAAPS mean is consistent with surface extinction evaluations in the MPLNET data for large-scale smoke with ensemble distribution encompassing the observed value.

Aerosol Vertical Evaluation: Transported Smoke 2023 Canadian Wildfires

- ENAAPS mean was compared against all available MPLNET data for June-July 2023 time period (GSFC comparison shown).
- Results shown over height ranges that are consistent with previously presented vertically-integrated AOD ranges.
- Scatter at all levels, but surface is better than free troposphere.
- For very high extinction values, the mean is consistently low biased. This is Also the case in extinction evaluations from other field campaign data (CPEX).

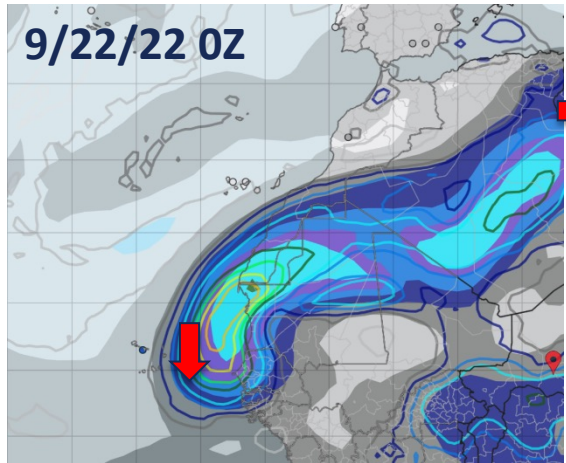
Scatterplot Comparison of ENAAPS mean extinction to MPLNET for 202306-202307



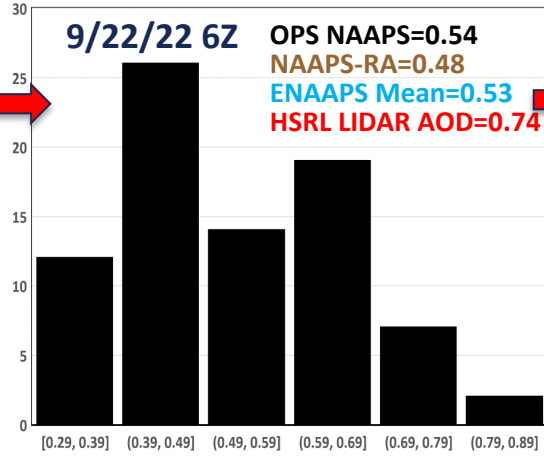
Aerosol Vertical Evaluation: CPEX-CV

Dust observed during CPEX had the most complex vertical structures that we looked at. This was very challenging for all of the models.

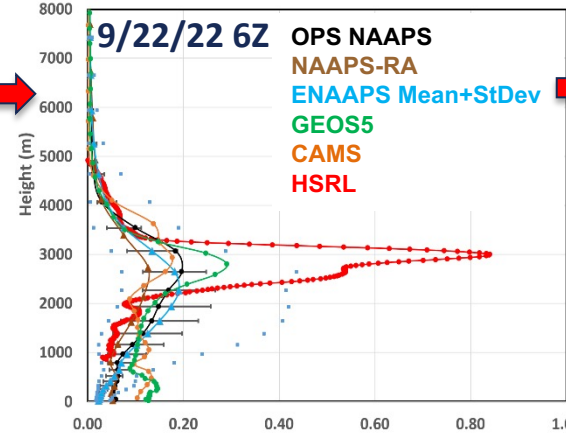
ENAAPS Mean (filled contour), Ops NAAPS (unfilled overlay) AOD



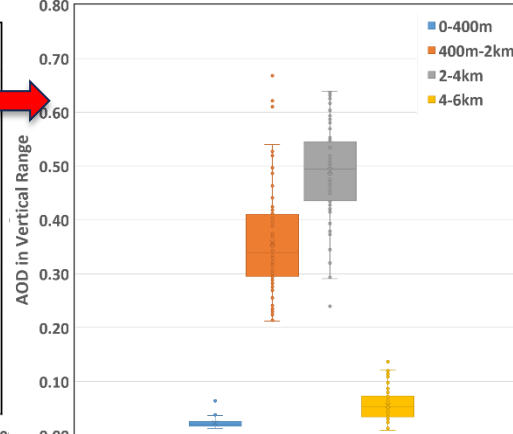
ENAAPS AOD Histogram



Extinction Profiles



ENAAPS Fraction of AOD in Vertical Range

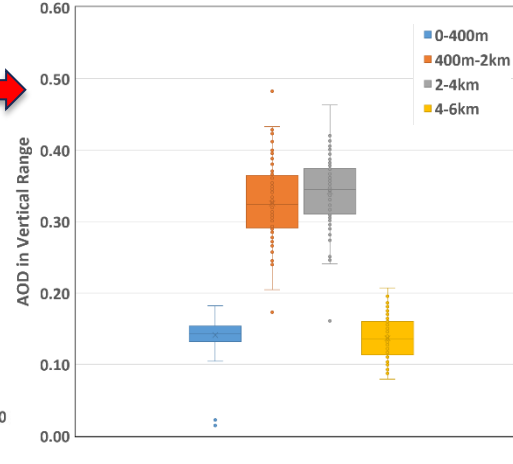
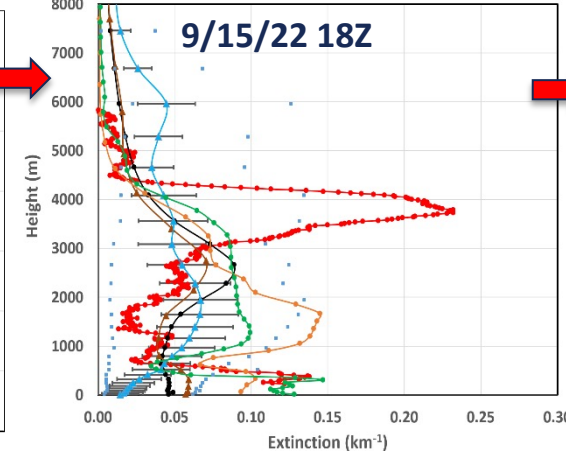
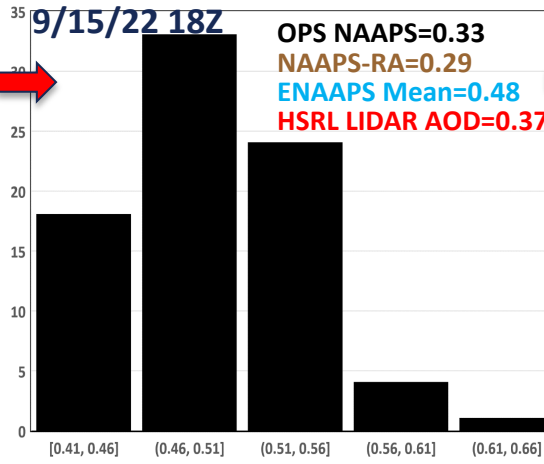
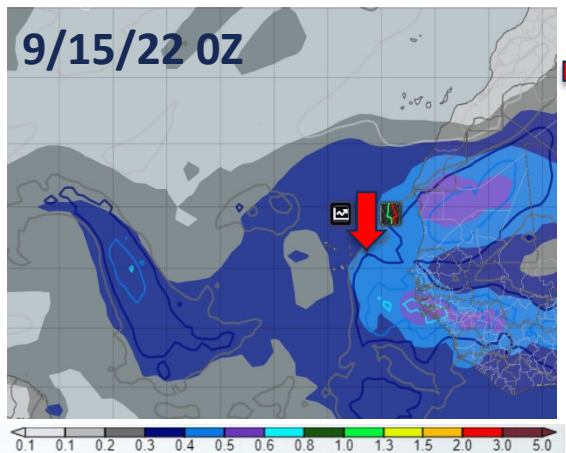


-General agreement in AOD for 9/22 case which is low biased.

- More discrepancy for 9/15 case.

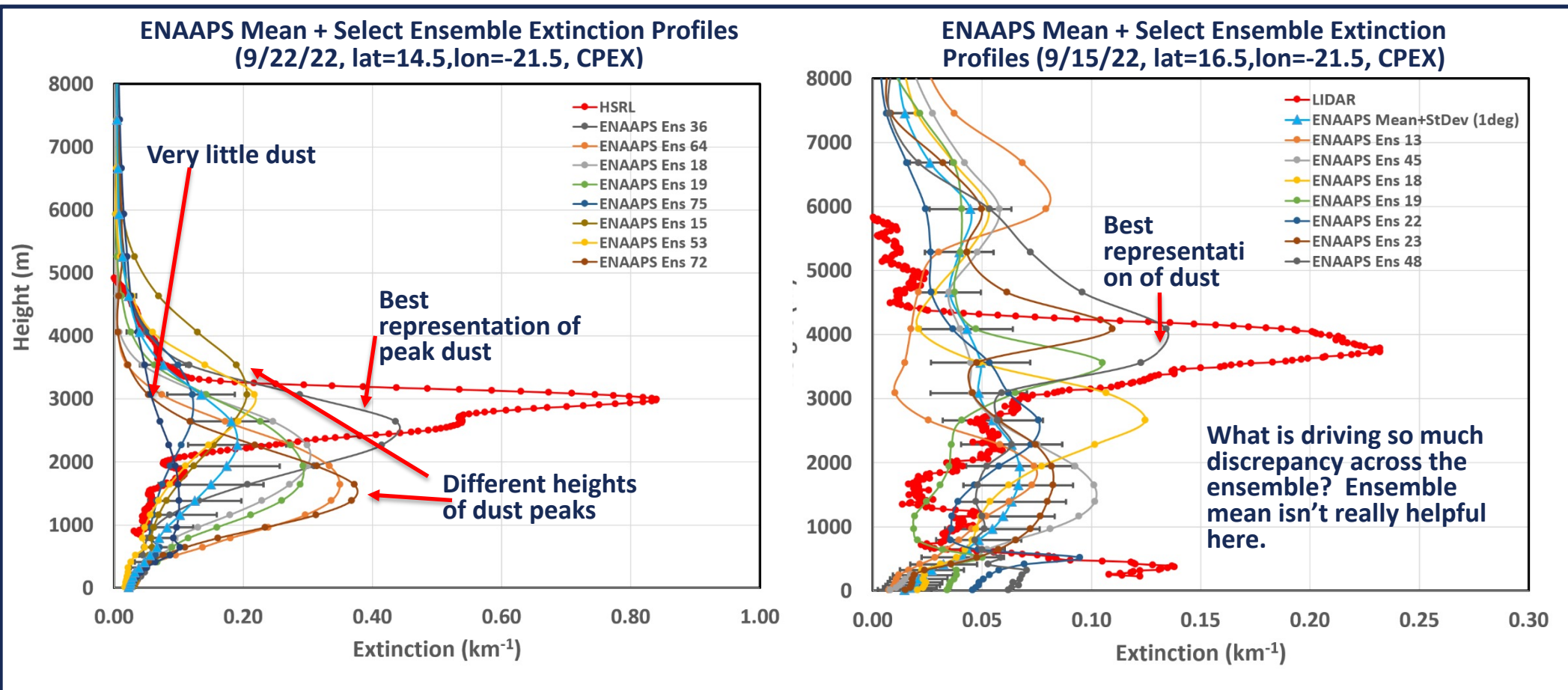
- Greater diff in ENAAPS/NAAPS near-surface and at high altitudes attributed to DA.

-A lot of vertical variability in the ensemble, especially for 9/15.



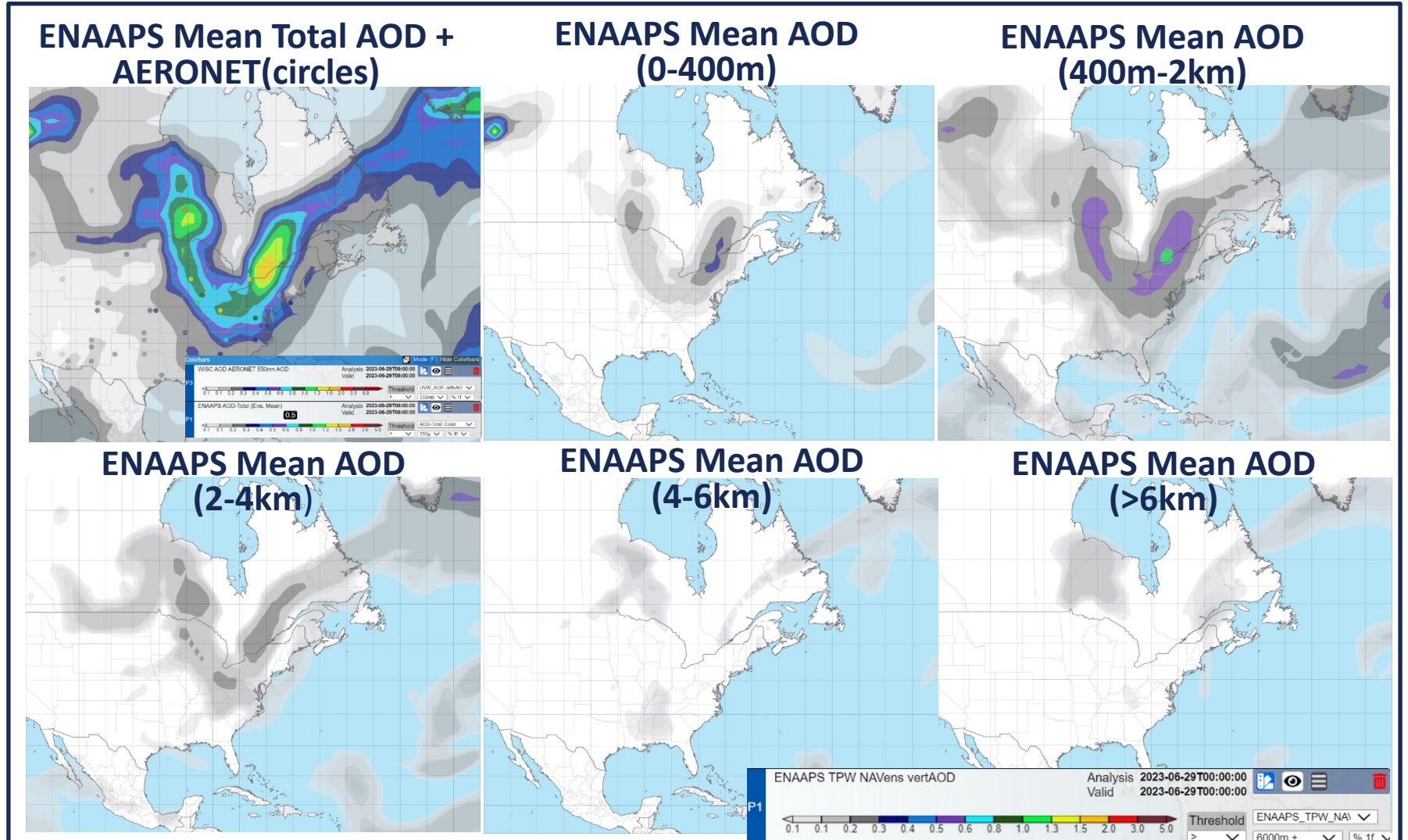
Aerosol Vertical Evaluation: CPEX Ensemble Variability

Significant vertical variability in the ensemble for these dust cases (height/strength of elevated dust) with select ensemble members shown below. For 9/15, the ensemble was all over the place. Currently investigating individual members to understand driving differences.



Near-Real-Time Vertical AOD ENAAPS Products

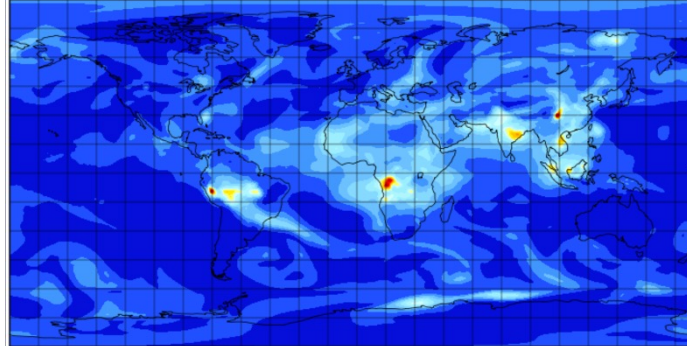
- Extinction performance varies with complexity of the aerosol event.
- To provide vertical information with improved skill, we now also generate vertically-integrated ENAAPS AOD products which will be the basis for aerosol warning products in development.
- Provides a quick-look at where an aerosol event is expected vertically.
- This output is now posted to NRL Map Room.



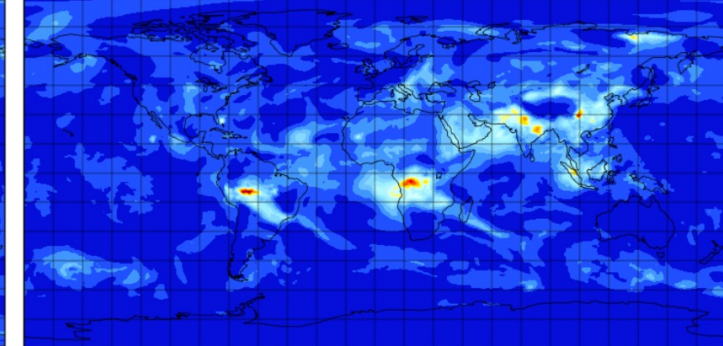
ENAAPS Statistical Post Processing

- Based on completed ENAAPS Validation Test Report, we know that positive bias is an issue in the ensemble as well as over-forecasting of probabilities.
- Statistical post-processing has been a focus to improve ensemble products.
- An aerosol capability was implemented within an operational code base (J. McLay, D. Hodyss).
- Ensemble mean bias correction has been implemented, tuning as a f(lead time).
 - Tested different methods.
 - Radius size for obs inclusion.
 - Archive length.
- Example shown for a 24 hour forecast, valid at 9/3/19 (CAMP²ex).
- Binned Mean works better than regression (generates negative values).
- Larger radius (10 vs 5) for obs smooths out fields, reduces peak AOD values.

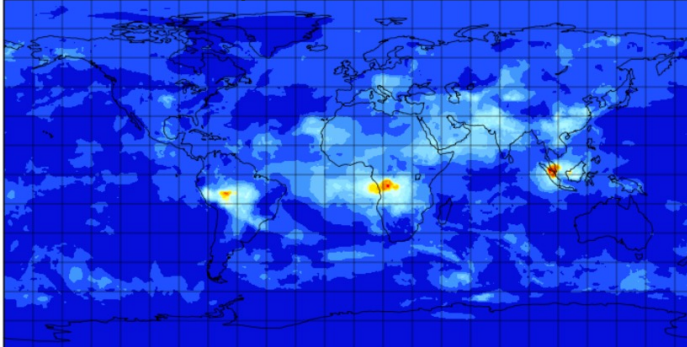
ENAAPS Mean 24hr Fcst (raw) (Valid 9/3/19)



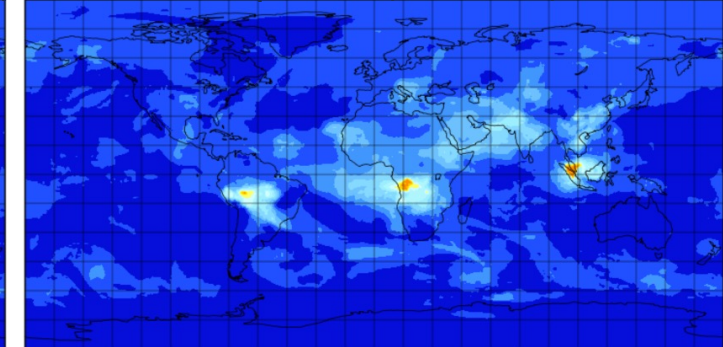
Reanalysis "Obs" (Valid 9/3/19)



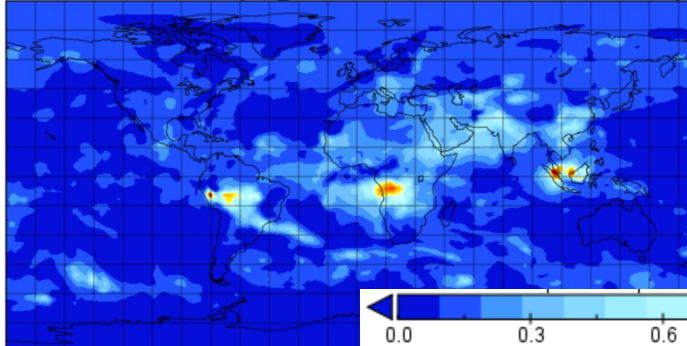
Mean 24hr Fcst (binmean, 5° radius, 10d archive)



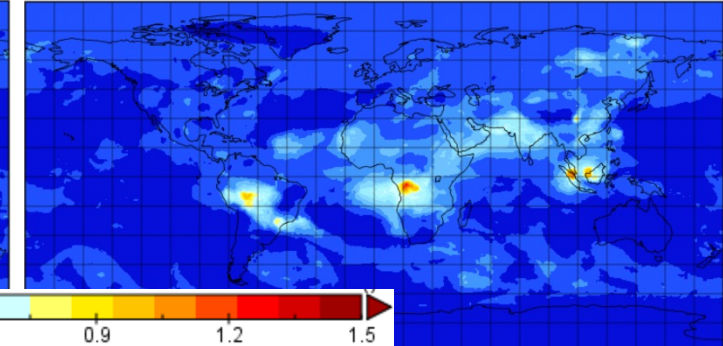
Mean 24hr Fcst (binmean, 10° radius, 10d archive)



Mean 24hr Fcst (regress, 5° radius, 10d archive)

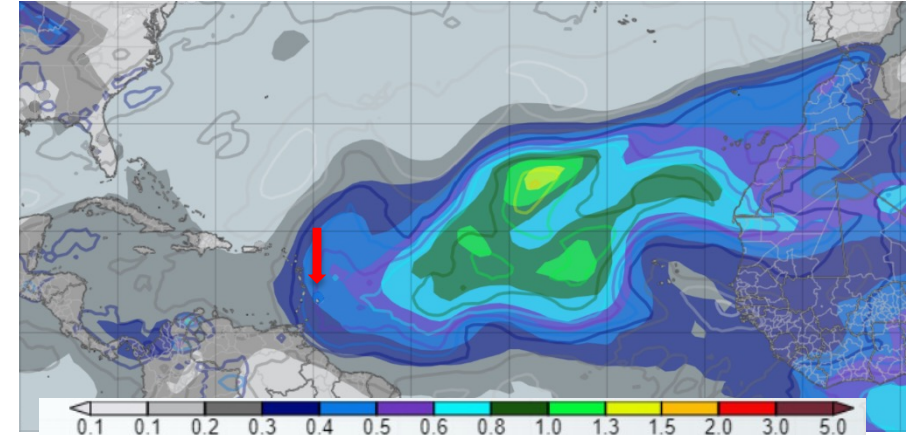


Mean 24hr Fcst (binmean, 5° radius, 30d archive)



ENAAPS Overview and Future Work

- A main focus of this coming year is ENAAPS operational testing and the next system upgrade to NAAPS 2.0.
- Statistical post-processing of ENAAPS ensemble mean bias has been implemented. Next steps are post-processing of probability forecasts. Pathway to operations.
- Vertical evaluations indicate performance depends on complexity of the vertical profile, emissions improvements are needed.
- Vertically-integrated AOD products are now available in near-real-time from ENAAPS through NRL Map Room to provide quick look vertical information.



ENAAPS Mean (filled contours) and Operational NAAPS (unfilled contours) AOD on 8/14/23 at 00Z, both showing dust coming across the Atlantic.

