Satellite-Assisted Particulate Matter (SAPM) for the Models, In situ, and Remote sensing of Aerosols (MIRA) Working Group

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1. What is MIRA?

- A forum that fosters international collaborations amongst the aerosol Modeling, In situ, and Remote sensing specialties
- A collection of interdisciplinary and independently funded projects/topics with clear goals
- Projects/topics are generally characterized by requests for additional scientific data (both observational and modeled)

- Purpose: to contextualize both observations and model results through encouragement of holistic projects and collaborations

MIRA webpage: https://science.larc.nasa.gov/mira-wg/

Sign up for MIRA emails at: https://espo.nasa.gov/lists/listinfo/mira/

2. The SAPM Topic Group

- Fine particulate matter ($PM_{2.5}$) is a major contributor to air pollution and negatively impacts human health
- SAPM aims to provide intercomparisons of various methods and techniques for retrieving surface $PM_{2.5}$ assisted by satellite remote sensors, global aerosol models, and in situ aerosol measurements

- Benefits of space-based/model-assisted $PM_{2.5}$ estimates:
  - Approximate $PM_{2.5}$ concentrations over areas lacking in situ ground station coverage
  - Assess spatial & temporal variations of PM2.5 pollution on both regional & global scales

- Benefits of spaceborne lidar/model-assisted $PM_{2.5}$ estimates:
  - Provide nighttime space-based $PM_{2.5}$ estimates
  - Characterize vertical structure of near-surface aerosols

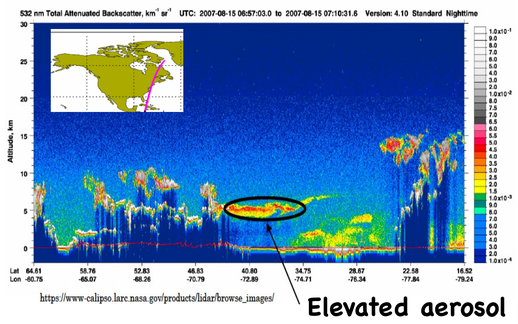
SAPM webpage: https://science.larc.nasa.gov/mira-wg/projects/sapm/

Request for international datasets

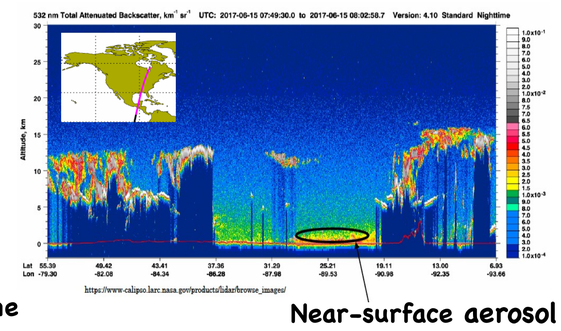
- To improve/validate the $PM_{2.5}$ estimates, the SAPM Topic Group seeks international in situ datasets of:
  - **Mass scattering/absorption coefficient and aerosol hygroscopic properties for various aerosol species**
  - **Ground-based $PM_{2.5}$ concentrations**

3. Estimating $PM_{2.5}$ using CALIOP (space-based lidar)

CALIOP curtain plots (https://www-calipso.larc.nasa.gov/products/lidar/browse_images/production/)



Elevated aerosol plume



Near-surface aerosol

Unlike column-integrated aerosol optical thickness (AOT) from passive sensors, lidars provide aerosol vertical distribution, including aerosol extinction near the ground (a more realistic representation of near-surface aerosol properties)

$PM_{2.5}$ derivation algorithm (using CALIOP aerosol extinction & assumed mass extinction efficiency):

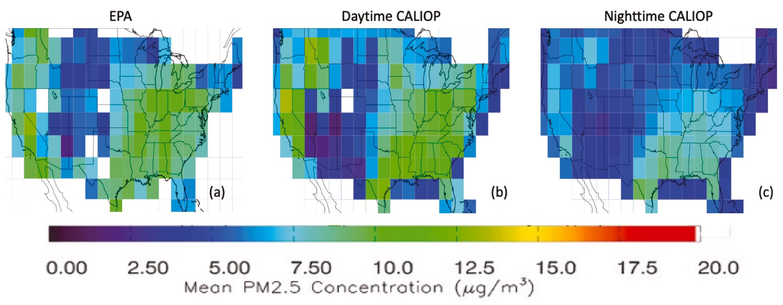
$$PM_{2.5} = \frac{\sigma \times \varphi \times 1000}{(\alpha_{scat} \times f_{rh} + \alpha_{abs})}$$

- ***$PM_{2.5}$*** → $PM_{2.5}$ mass concentration ($\mu g\ m^{-3}$)
- α_{scat} → mass scattering efficiency (**3.40** $m^2\ g^{-1}$)
- α_{abs} → mass absorption efficiency (**0.37** $m^2\ g^{-1}$)
- φ → $PM_{2.5}$ to PM_{10} ratio (**0.6**)
- σ → extinction coefficient (m^{-1})
- ***1000*** → unit conversion factor

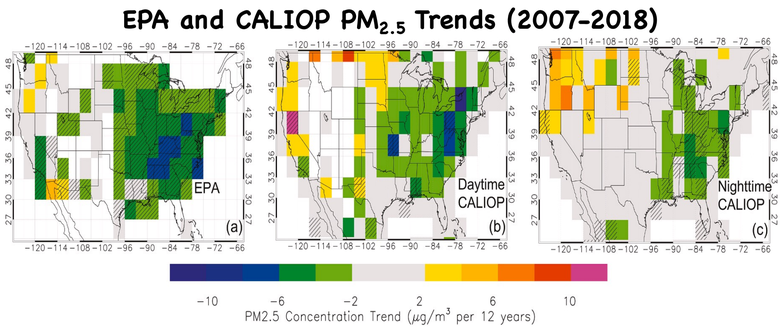
Hygroscopic growth factor

$$f_{rh} = \left(\frac{1-RH}{1-RHref}\right)^{-\Gamma}$$

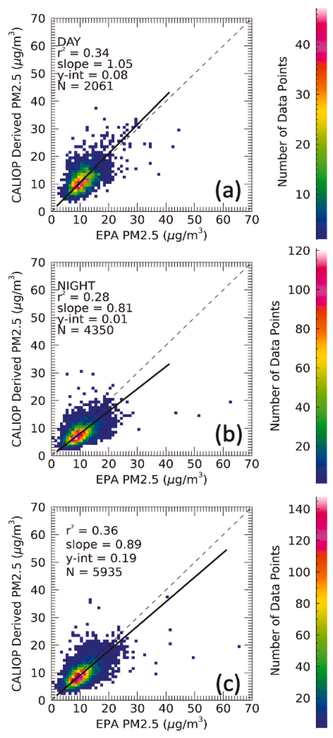
Spatial Mean $PM_{2.5}$ from EPA and CALIPSO (2007-2018)



EPA and CALIOP $PM_{2.5}$ Trends (2007-2018)



Initial Validation Efforts

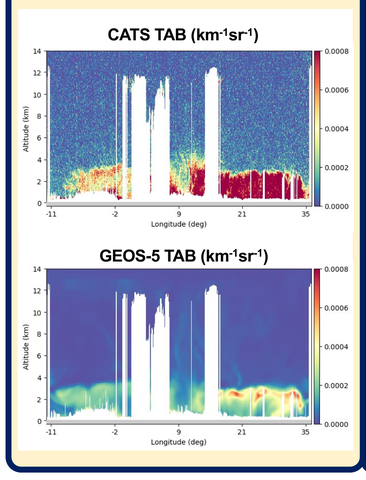


(Toth et al., 2022, Atmos. Env., https://doi.org/10.1016/j.atmosenv.2022.118979)

4. Estimating $PM_{2.5}$ using CATS (space-based lidar)

Methodology

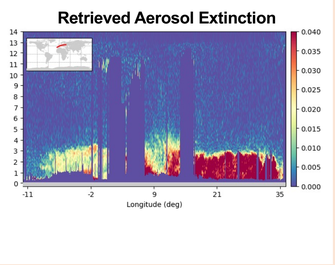
① Mask cloudy profiles and re-grid to the same resolution.



② Perform 1-D EnsVar assimilation to retrieve aerosol extinction.

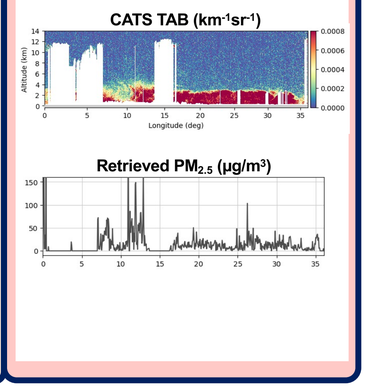
$$x = x_0 + \left(\frac{PH^T}{HPH^T + R}\right)(y - Hx_0)$$

x = Predicted extinction
x_0 = GEOS 1064nm extinction
H = Linear operator
P = GEOS error covariance
R = CATS error covariance
y = CATS 1064nm TAB



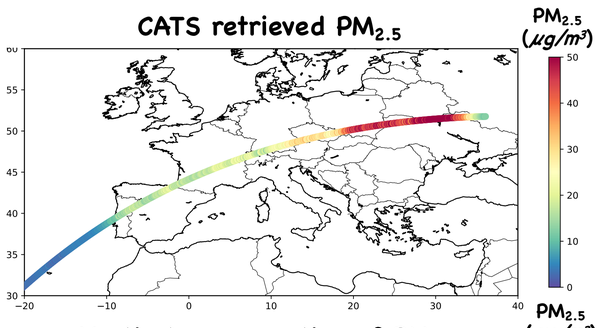
③ Convert speciated mass concentrations to total $PM_{2.5}$.

$$PM_{2.5} = [DU_{2.5}] + [SS_{2.5}] + [BC] + 1.4 \times [OC] + 1.375 \times [SO_4]$$

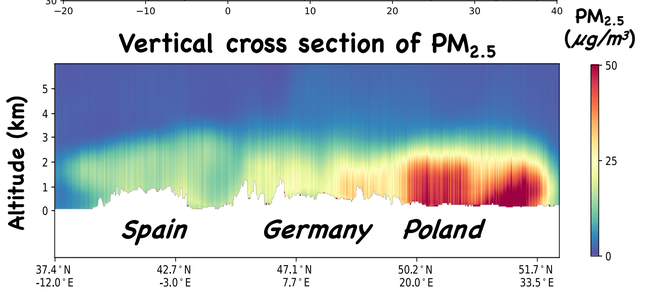


---Case study over Europe on 12 Sep 2016---

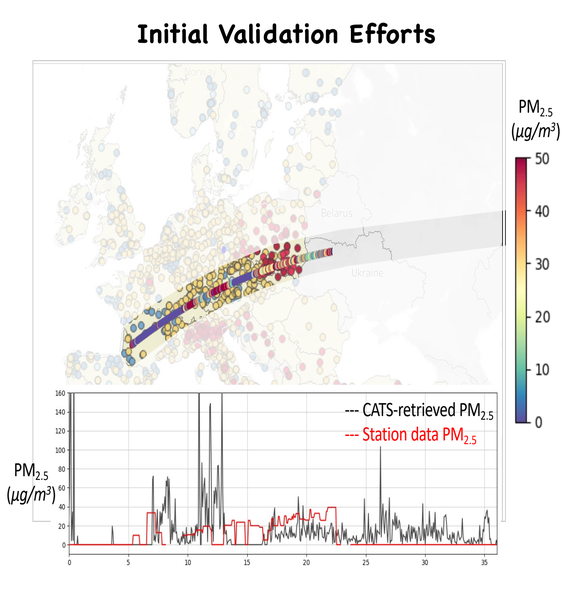
CATS retrieved $PM_{2.5}$



Vertical cross section of $PM_{2.5}$



Initial Validation Efforts



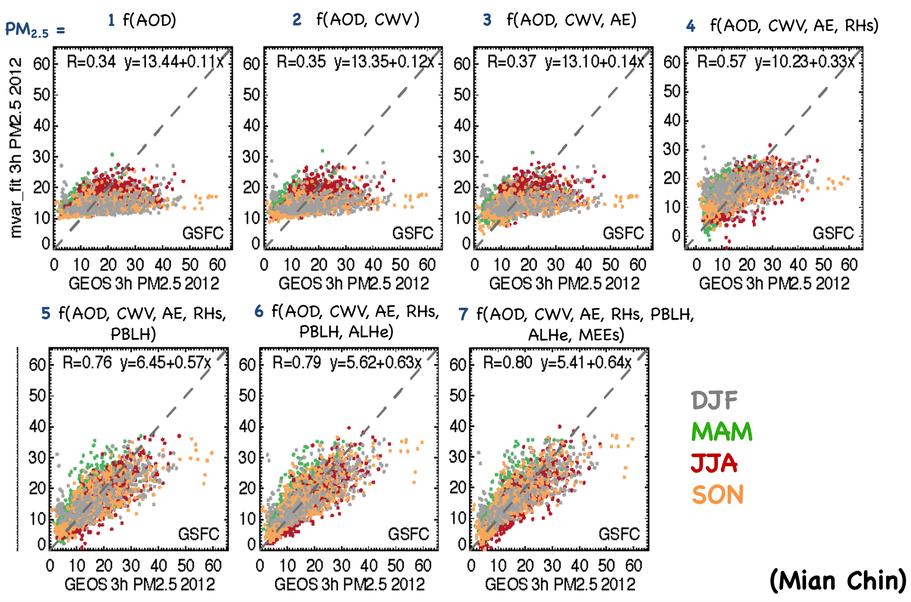
("New approach for $PM_{2.5}$ air quality retrievals using the NASA CATS spaceborne lidar and GEOS-5 model", Matus et al., in prep.)

5. Studying $PM_{2.5}$ using GEOS (global aerosol model)

Estimated $PM_{2.5}$ from multivariate regression vs. "true" GEOS-calculated $PM_{2.5}$ at a US site (2012; GSFC, MD)

We select several key "observable" variables from the GEOS model for multi-variable regression to estimate the 3-hourly $PM_{2.5}$ concentrations from model simulated AOD and compare them to the "true" model calculated $PM_{2.5}$ values:

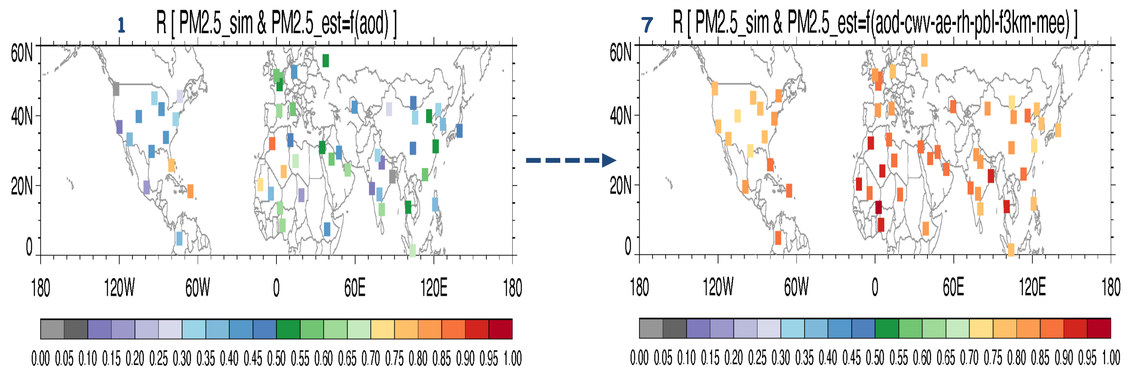
1 - Aerosol optical depth (AOD)
2 - Column water vapor (CWV)
3 - Angstrom Exponent (AE)
4 - Surface RH (RHs)
5 - PBL Height (PBLH)
6 - Aerosol effective layer height (ALHe)
7 - Surface mass extinction efficiency (MEEs)



(Mian Chin)

Correlation Coefficients between simulated ("true") and estimated $PM_{2.5}$ at 56 NH sites

2 R [$PM_{2.5\_sim}$ & $PM_{2.5\_est}$ = *f* (AOD, CWV)]
3 R [$PM_{2.5\_sim}$ & $PM_{2.5\_est}$ = *f* (AOD, CWV, AE)]
4 R [$PM_{2.5\_sim}$ & $PM_{2.5\_est}$ = *f* (AOD, CWV, AE, RHs)]
5 R [$PM_{2.5\_sim}$ & $PM_{2.5\_est}$ = *f* (AOD, CWV, AE, RHs, PBLH)
6 R [$PM_{2.5\_sim}$ & $PM_{2.5\_est}$ = *f* (AOD, CWV, AE, RHs, PBLH, f3km)



Including the 6 additional parameters in estimating surface $PM_{2.5}$ from AOD can deliver much improved results