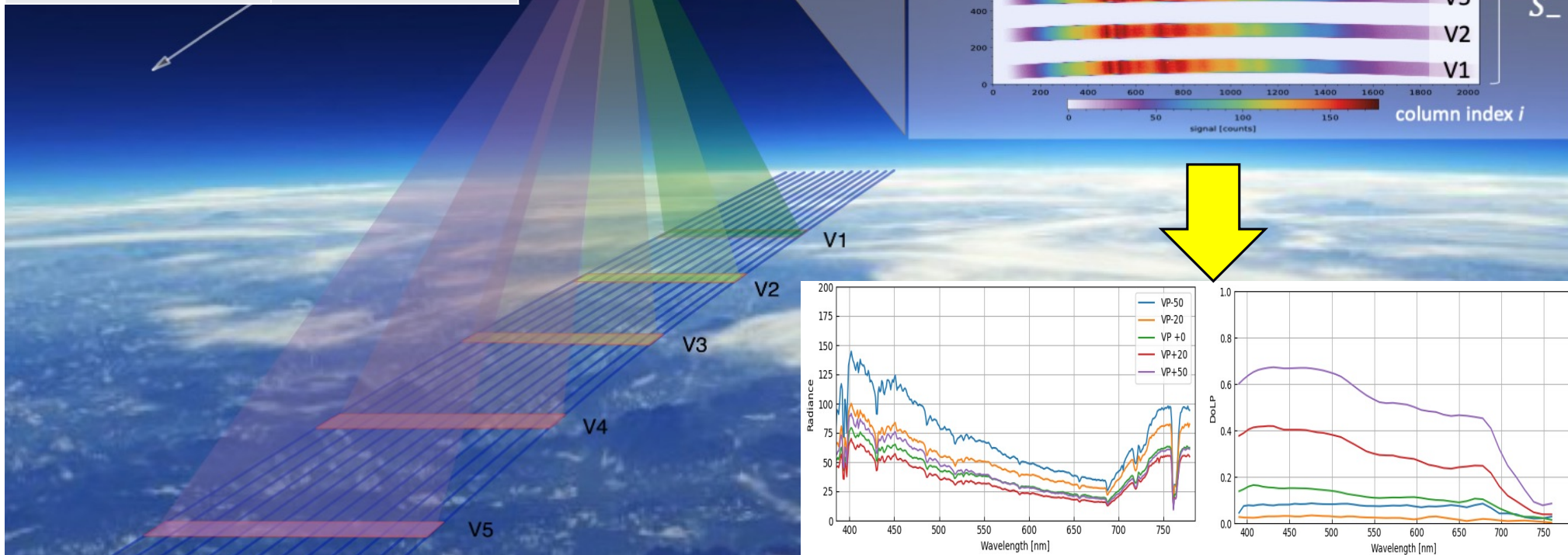
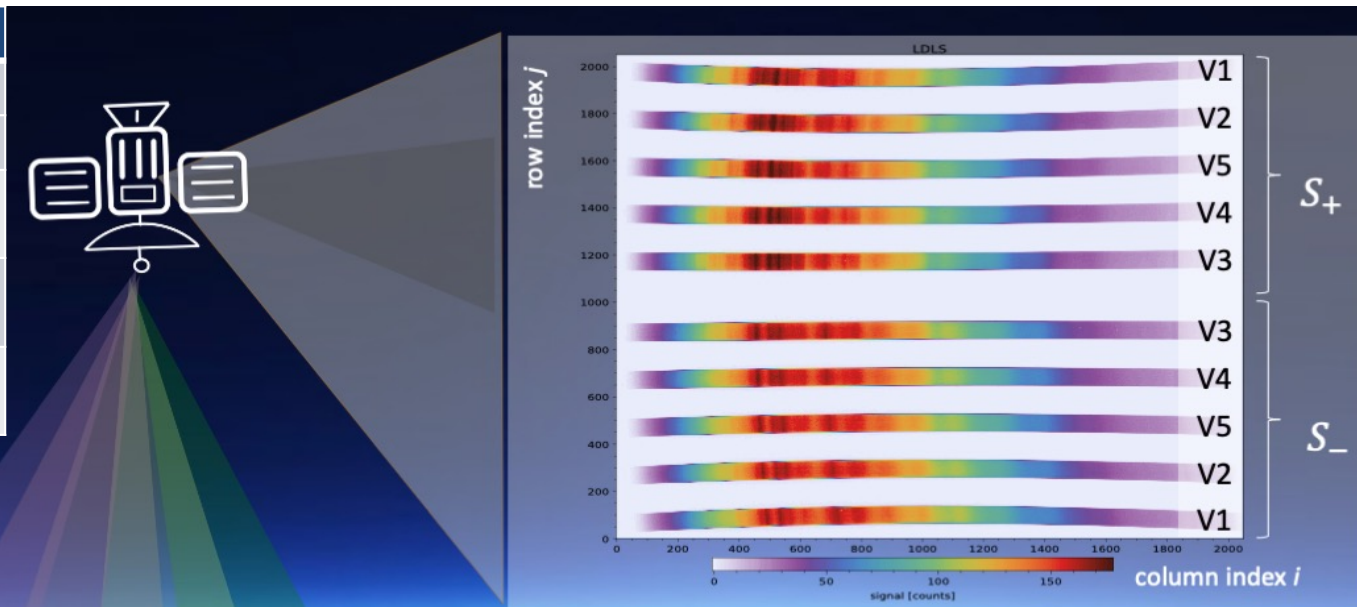


# Atmospheric Aerosol Characterization with SPEXone: Data Products and Applications

Otto Hasekamp & Guangliang Fu, on behalf of the SPEXone Team



Parameter	Specification
Spatial resolution	5X5 km <sup>2</sup>
Swath	100 km
Spectral resolution (radiance)	400 bands, 2nm FWHM
Spectral resolution (polarization)	50 bands 10-30 nm FWHM
Accuracy	2% (radiometric), 0.003 (polarimetric)



# Geophysical Research Letters\*

Research Letter |  Open Access | 

## Aerosol Retrievals From SPEXone on the NASA PACE Mission: First Results and Validation


Guangliang Fu , Jeroen Rietjens, Raul Laasner, Laura van der Schaaf, Richard van Hees, Zihao Yuan, Bastiaan van Diedenhoven, Neranga Hannadige, Jochen Landgraf, Martijn Smit, Kirk Knobelspiesse, Brian Cairns, Meng Gao, Bryan Franz, Jeremy Werdell, Otto Hasekamp  
... See fewer authors 

First published: 17 February 2025 | <https://doi.org/10.1029/2024GL113525>

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 64, 2026

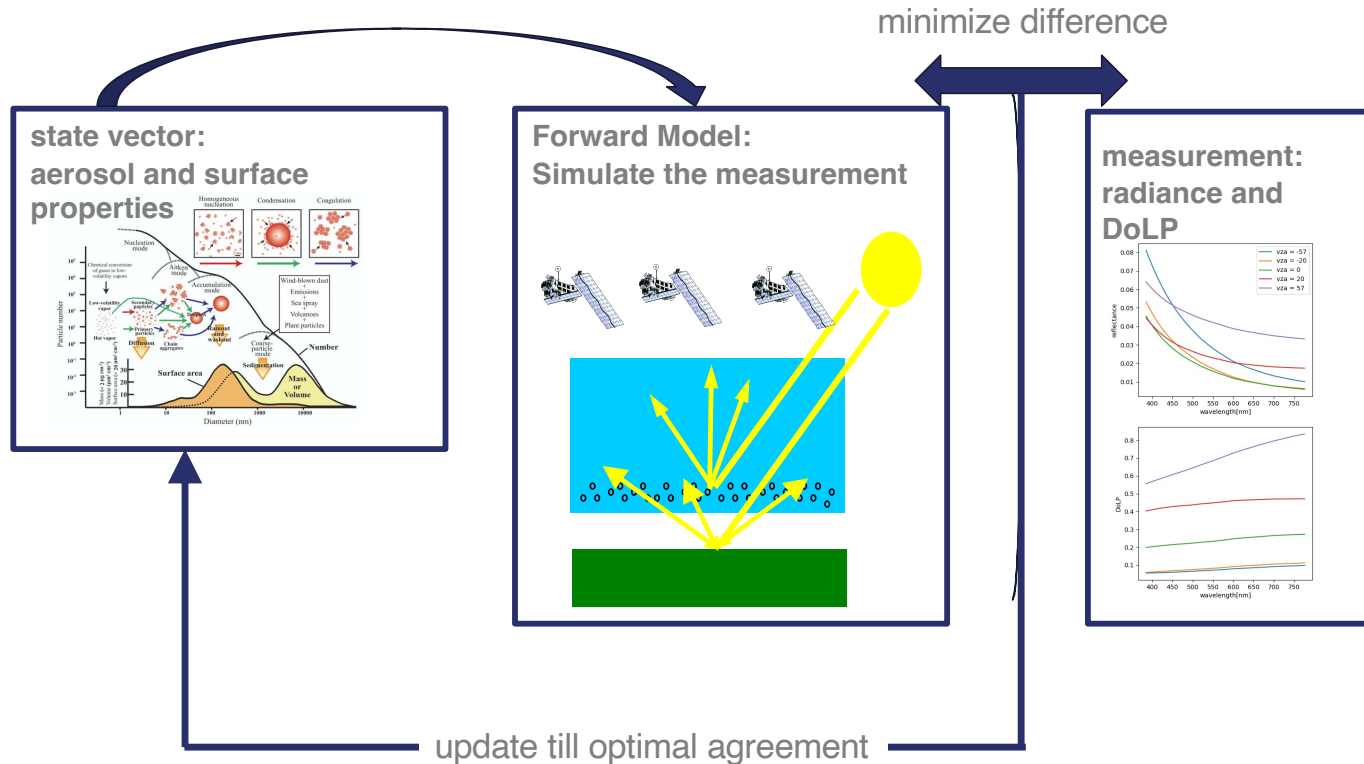
4107019

## Collaborative Neural Networks Significantly Improve Global Aerosol Retrievals From Multiangle Polarimeters

Guangliang Fu , Sha Lu, Meng Gao , Jeroen Rietjens, and Otto Hasekamp

SRON

# Retrieving Aerosol Properties: The RemoTAP algorithm

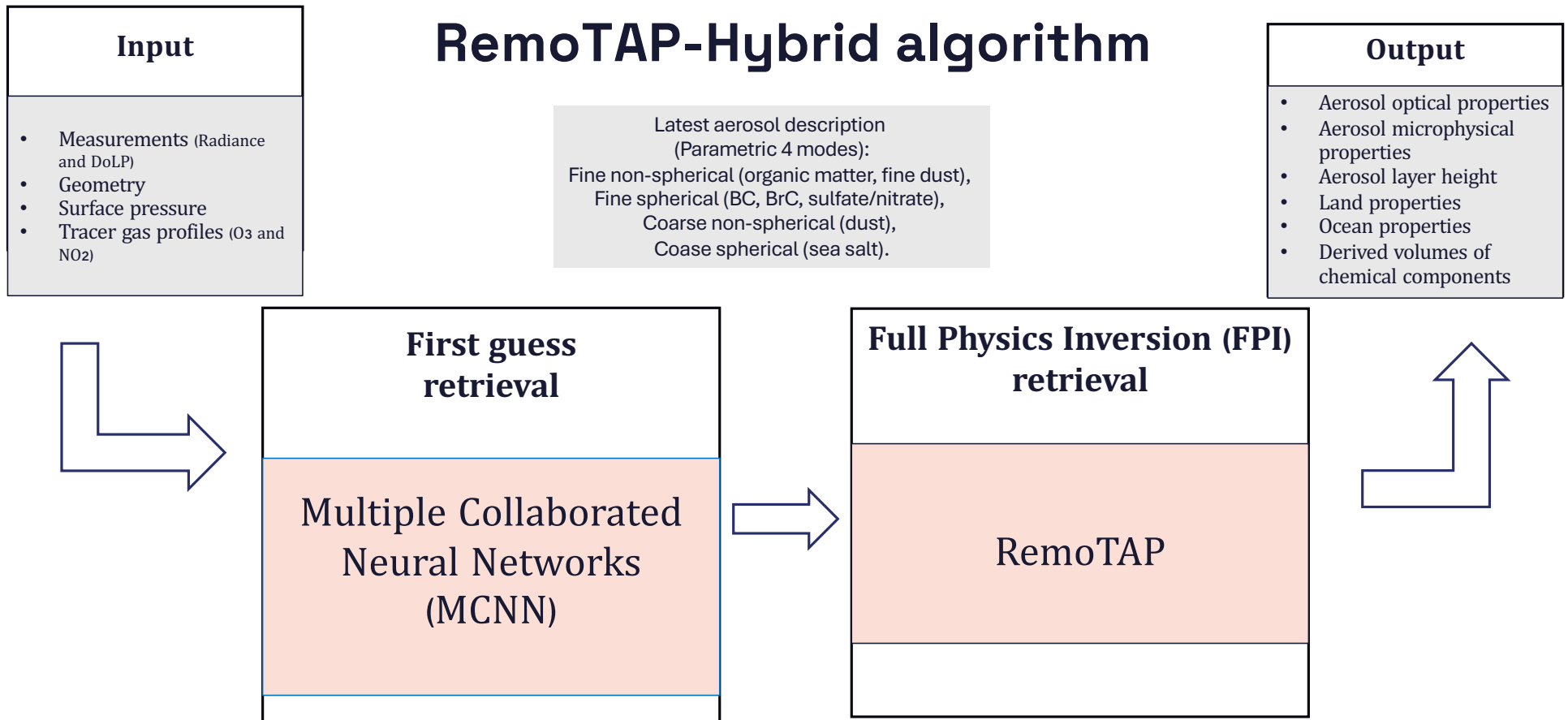


References:  
 Fu et al, GRL, 2025  
 Hasekamp et al., AMT, 2024  
 Lu et al., Frontiers Rem. Sens., 2022  
 Fu et al., AMT, 2018; 2022  
 Fan et al., Rem. Sens., 2019  
 Hasekamp et al., JGR, 2011

RemoTAP: REMOte sensing of Trace gas and Aerosol Products

**Products:** optical properties, size distribution, chemical composition

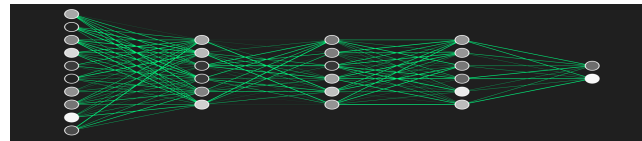
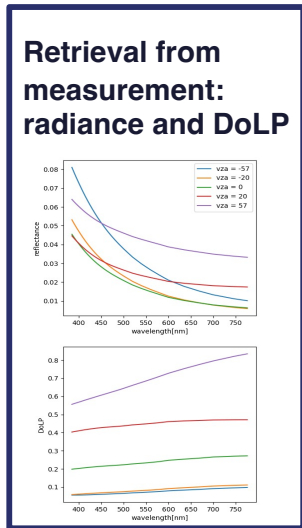
# RemoTAP-Hybrid algorithm



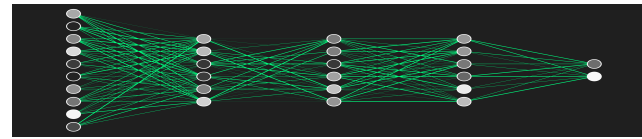
- *RemoTAP-Hybrid combines MCNN and RemoTAP, where MCNN provides a first guess and RemoTAP provides a final FPI retrieval.*
- *In this concept, RemoTAP-Hybrid is expected to combine and make use of the capability of both MCNN and RemoTAP.*

# Multiple Collaborated Neural Networks (MCNN)

MCNN combines 3 retrieval networks (one master NN, one small AOT NN, and one large AOT NN) together with a forward model neural network. It has been well tested to achieve comparable performance as RemoTAP from both synthetic and real measurements.



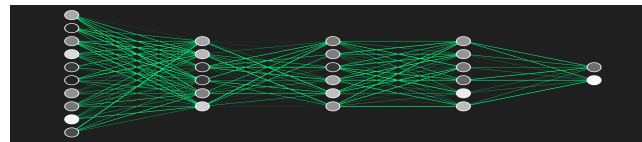
Small AOT NN



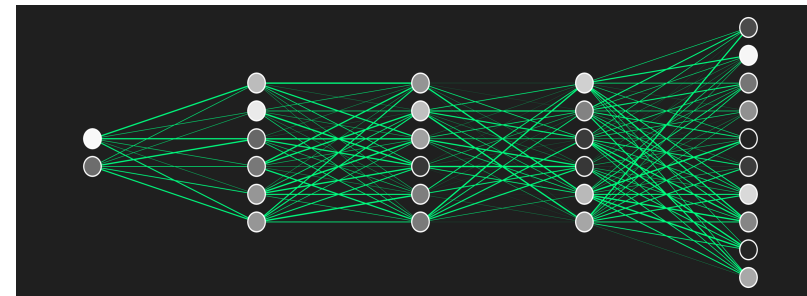
Master NN



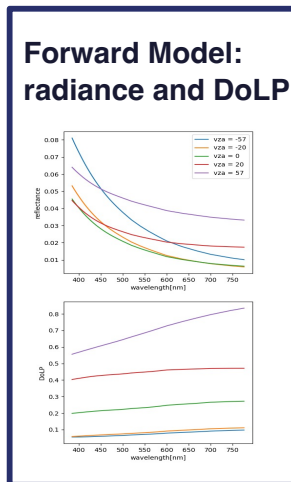
Retrieved state vector



Large AOT NN



Forward model NN



Goodness-of-fit (chi2)  
Select the smallest chi2 from the three retrieval NNs as the best retrieval

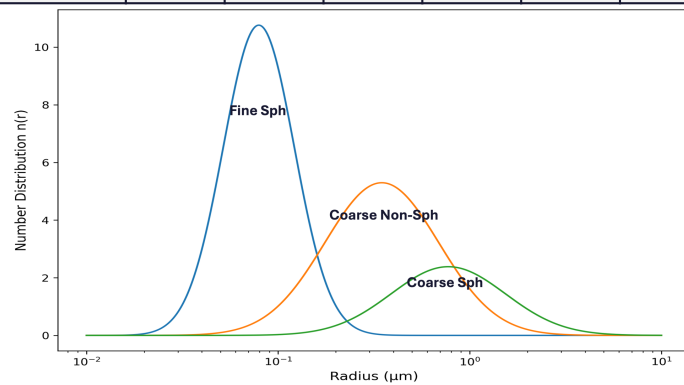
# Extending aerosol description

Based on a one-year AERONET data analysis

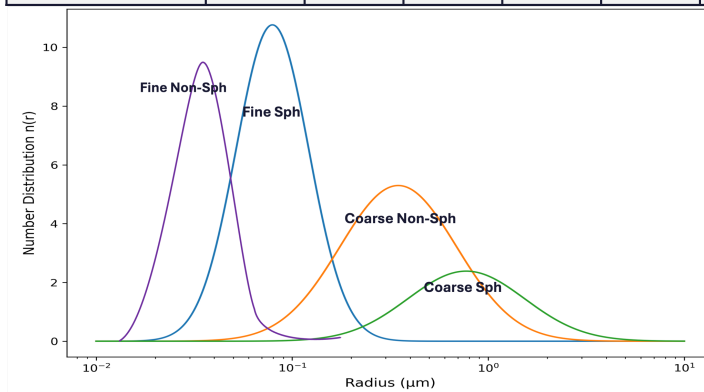
AERONET Analysis	Fine Mode Fraction (FMF)	Spherical Fraction (SF)	Percentage
Fine Non-Sph	> 0.9	< 0.1	21 %
Fine Sph	> 0.9	> 0.9	79 %
Coarse Non-Sph	< 0.1	< 0.1	42 %
Coarse Sph	< 0.1	> 0.9	58 %

The Fine Non-Spherical particles takes 21% of AERONET scenes, which indicates a need to explicitly consider a fine non-spherical mode in the state vector

Parametric 3-mode	r_eff	v_eff	RRI	IRI	N	f_sph	ALH
Fine Sph	✓	✓	✓	✓	✓	✓	✓
Coarse Non-Sph	✓	✓	X	✓	✓	X	
Coarse Sph	✓	✓	✓	X	✓	X	

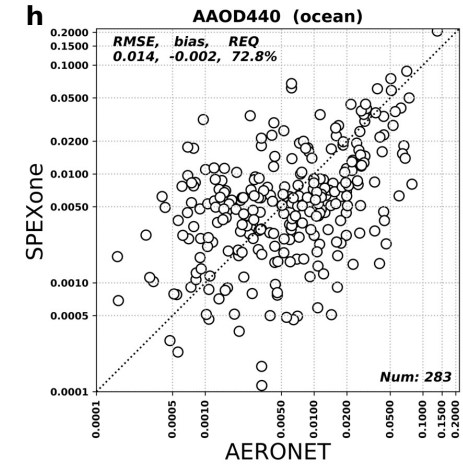
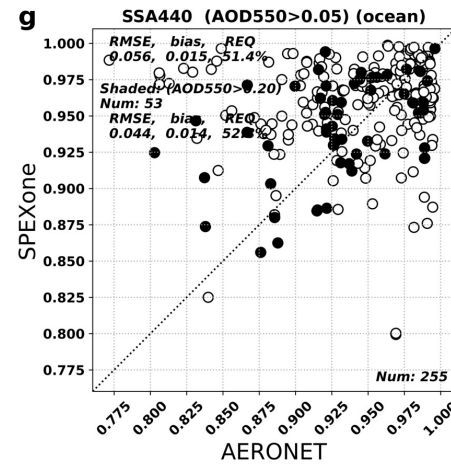
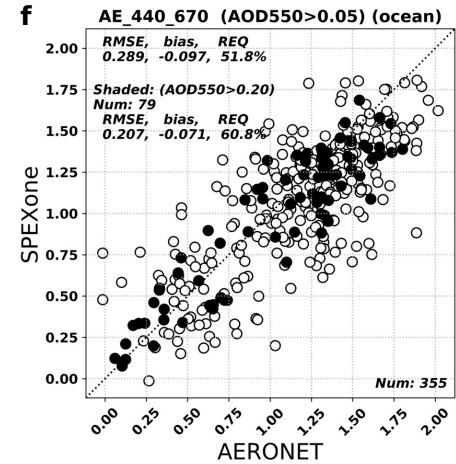
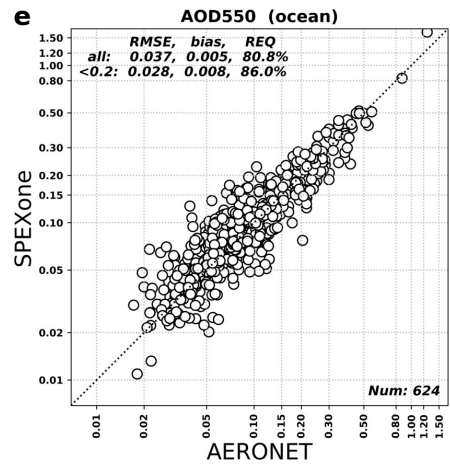
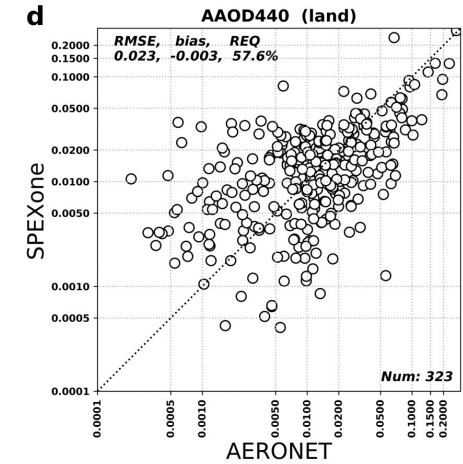
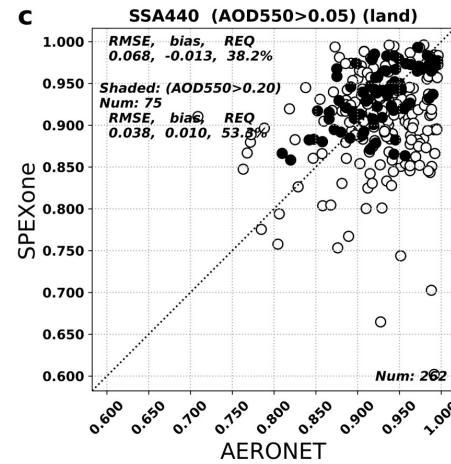
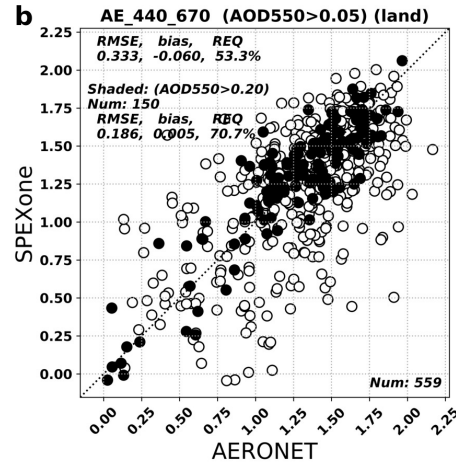
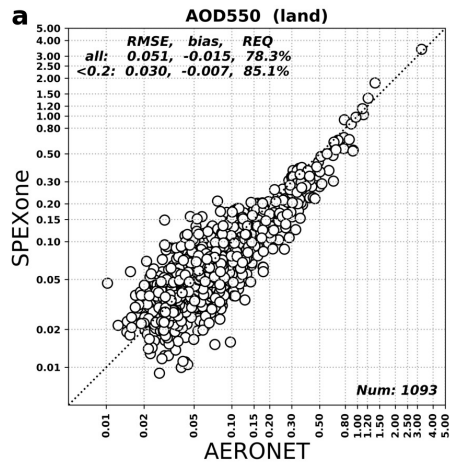


Parametric 4-mode	r_eff	v_eff	RRI	IRI	N	f_sph	ALH
Fine Non-Sph	✓	✓	✓	✓	✓	X	✓
Fine Sph	✓	✓	✓	✓	✓	X	
Coarse Non-Sph	✓	✓	X	✓	✓	X	
Coarse Sph	✓	✓	✓	X	✓	X	



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# RemoTAP-Hybrid performance (one-year)



# Validation Statistics

RemoTAP (Land / ocean)	RMSE	bias	REQ
<b>AOD</b>	0.051 / 0.037	-0.015 / 0.005	78.3% / 80.8%
<b>AE (AOD&gt;0.2)</b>	0.186 / 0.207	0.005/-0.071	70.7% / 60.8%
<b>AE(AOD&gt;0.05)</b>	0.333 / 0.289	-0.060 / -0.097	53.3% / 51.8%
<b>SSA (AOD&gt;0.2)</b>	0.038 / 0.044	-0.013 / 0.014	53.3% / 51.4%
<b>AAOD</b>	0.023 / 0.012	-0.003 / -0.002	57.6% / 72.8%

- Unprecedented agreement with AERONET.
- Very similar performance over both land and ocean.
- Small but opposite bias between land and ocean

### Requirements

Property	Real
AOD <sup>1</sup>	max(0.04, 10%)
AE <sup>2</sup>	0.2
SSA <sup>2</sup>	0.03
AAOD <sup>2</sup>	max(0.01, 10%)
FAOD <sup>1</sup>	max(0.04, 10%)
CAOD <sup>1</sup>	max(0.04, 10%)
reff_fine <sup>2</sup>	10%

# Performance towards low AOD

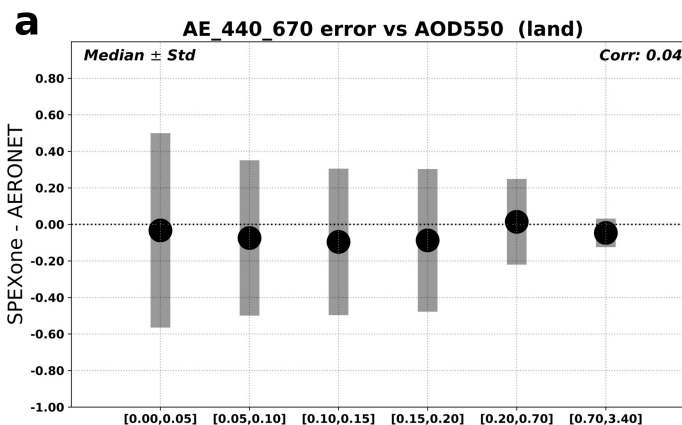
Land →

Mostly increase in spread but not in bias (low correlation of error with AOD)

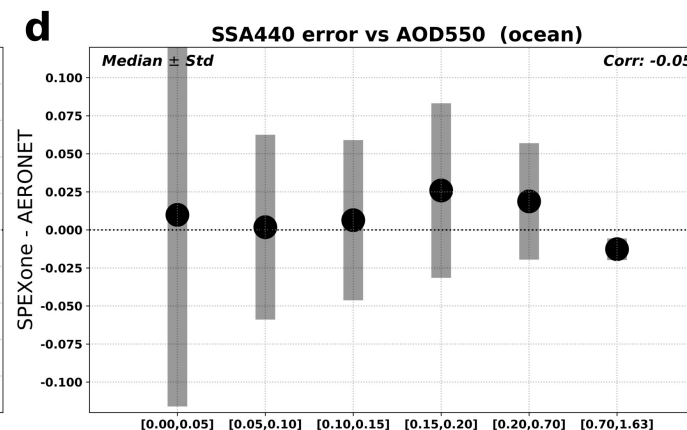
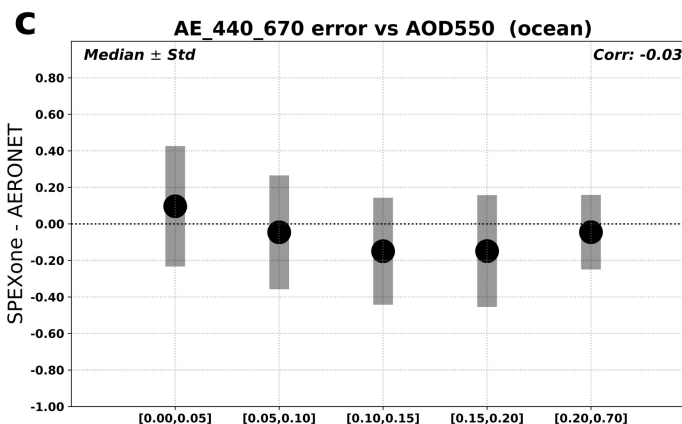
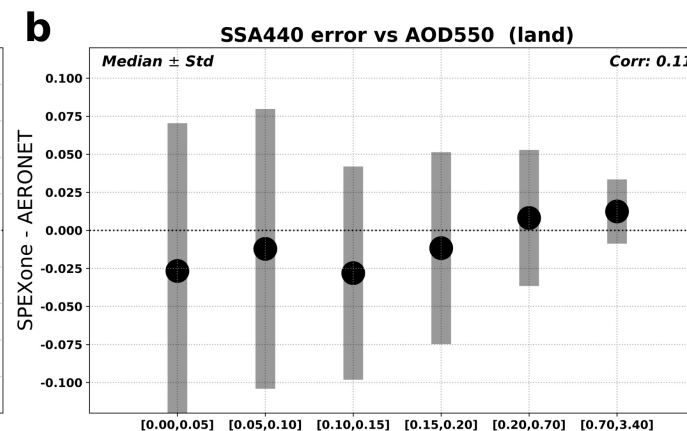
This indicates for low AOD cases, the AE and SSA from SPEXone also contain useful information.

Ocean →

Angstrom Exponent

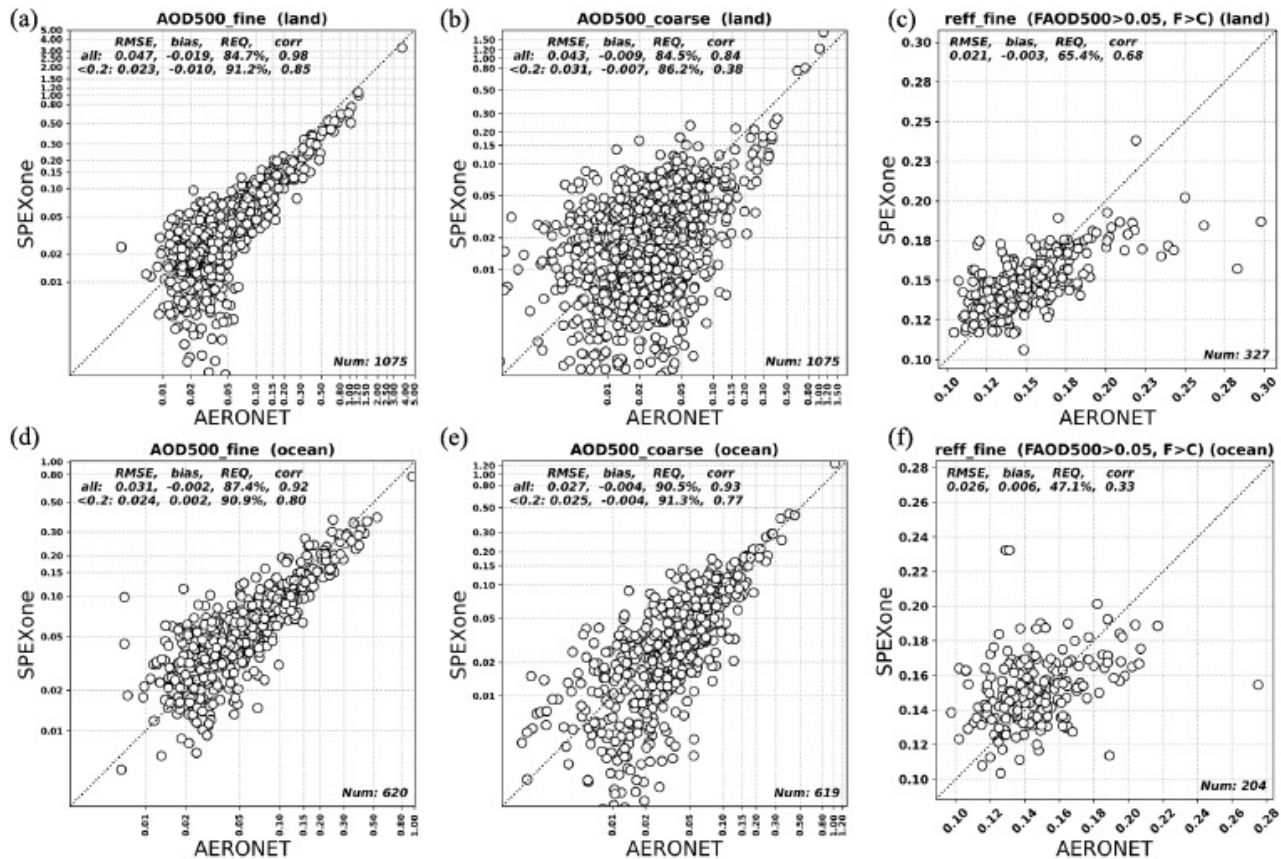


Single Scattering Albedo

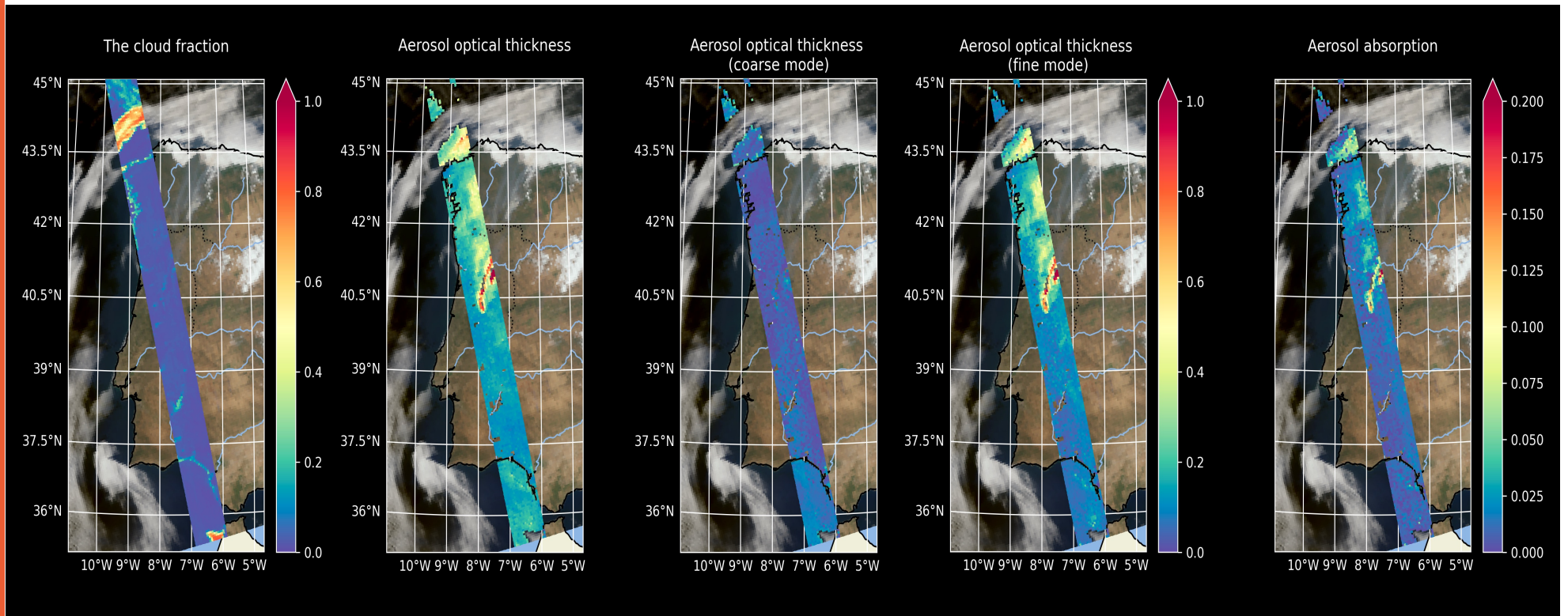


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# Fine- and Coarse AOD and Effective Radius

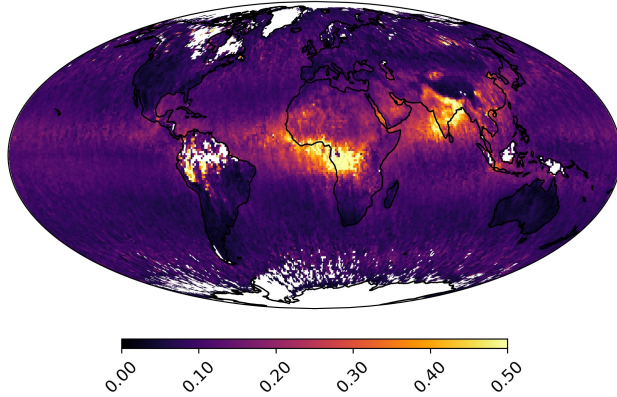


# Fires over Portugal (August 2025)

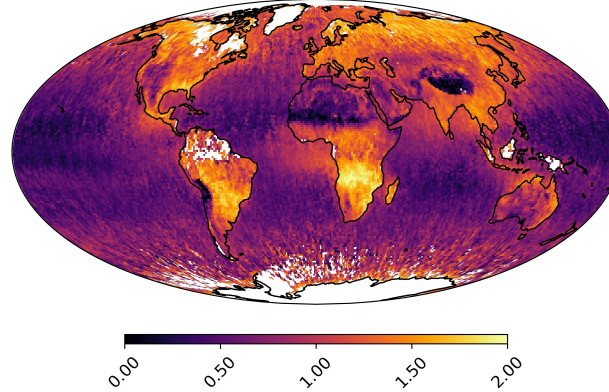


# Global SPEXone Data: AOD and Angstrom Exponent

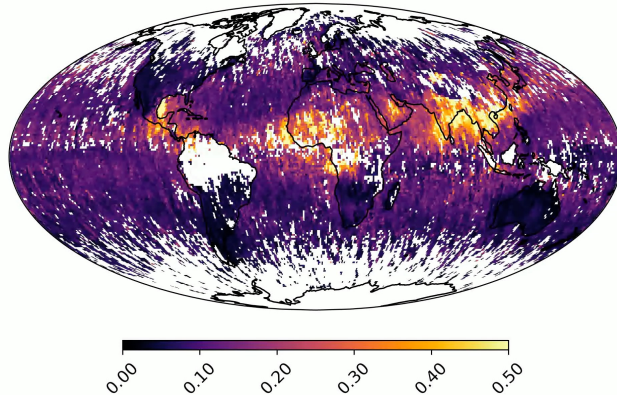
aot\_two-year\_march2024\_feb2026



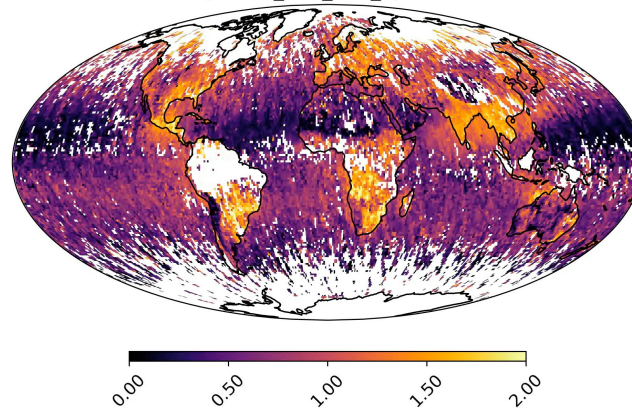
angstrom\_440\_670\_two-year\_march2024\_feb2026



aot\_april2024



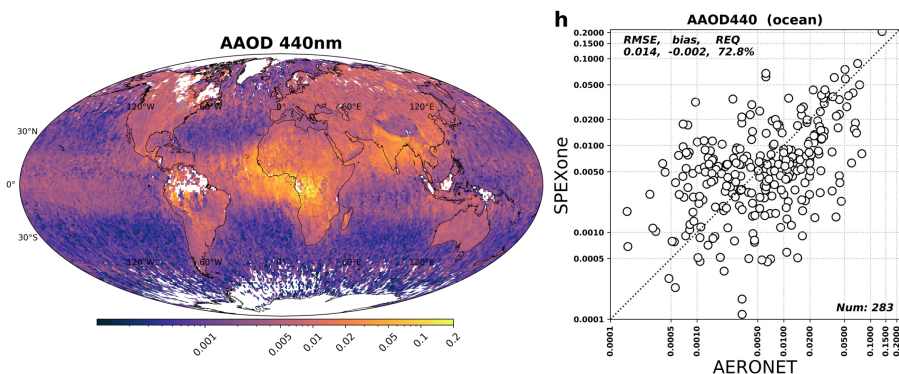
angstrom\_440\_670\_april2024



- Largest overall AOD for biomass burning and Ganges valley, followed by Dust and industrial pollution.
- Much stronger Amazon fire in 2024 than 2025
- Smallest particles (large Angstrom Exp) for smoke – with clear seasonal pattern on each hemisphere. Outflow affect oceans globally
- Small particles over southern ocean in Austral Spring and Summer.

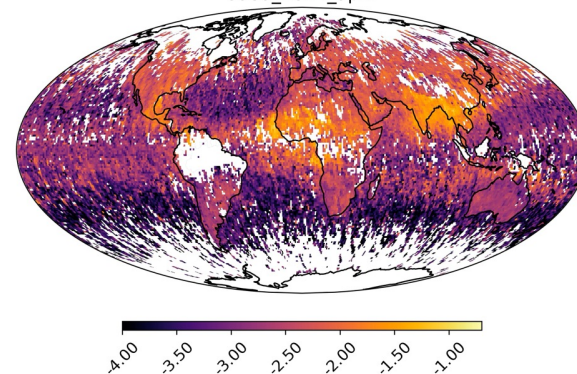
# Absorbing AOD (AAOD)

## New Version (RemoTAP-Hybrid)

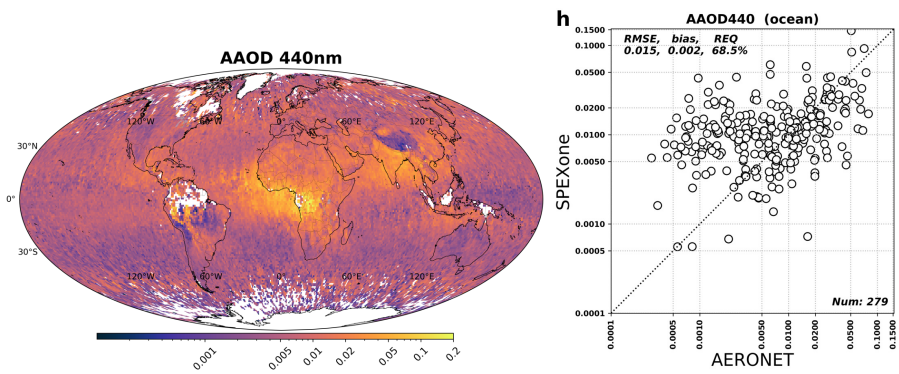


## log(AAOD)

aaod\_2024\_april

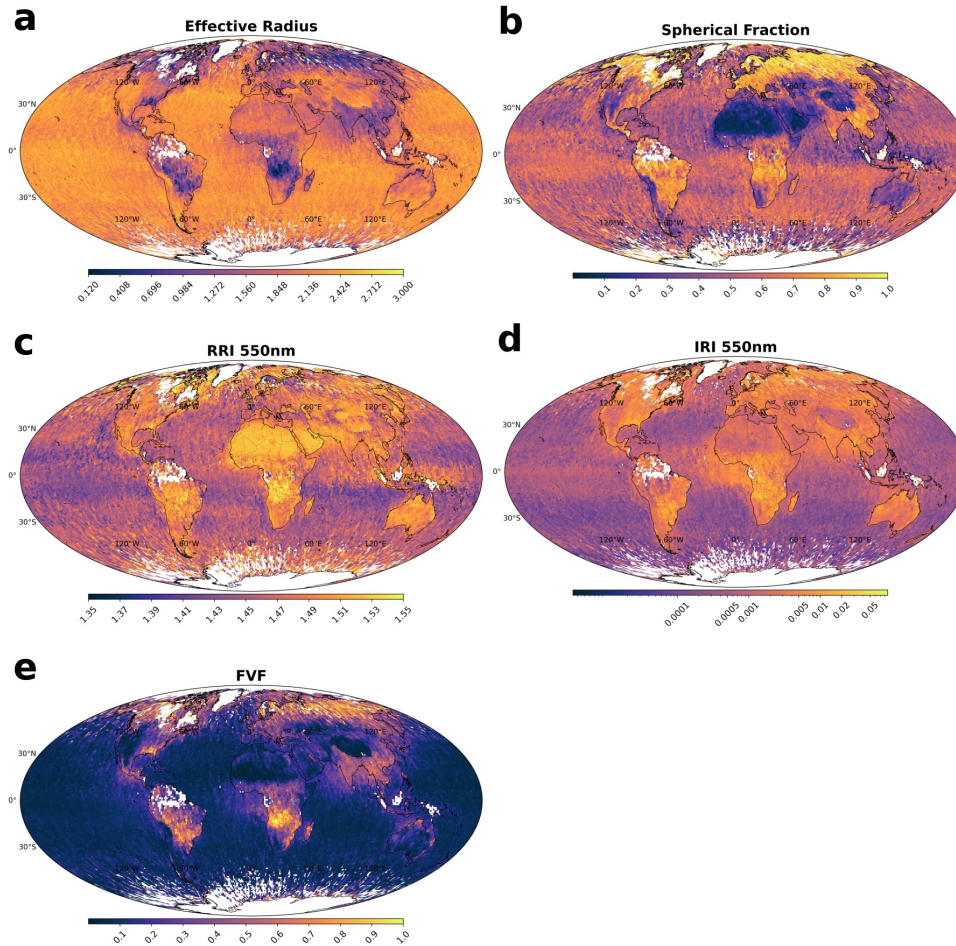


## Old Version



- RemoTAP Hybrid (new version) removes positive bias at low values over ocean.
- Remote ocean more realistic in new data
- Strongest absorption for African smoke. Amazon smoke less absorbing
- Outflow affects absorption over ocean globally

# Aerosol microphysical properties



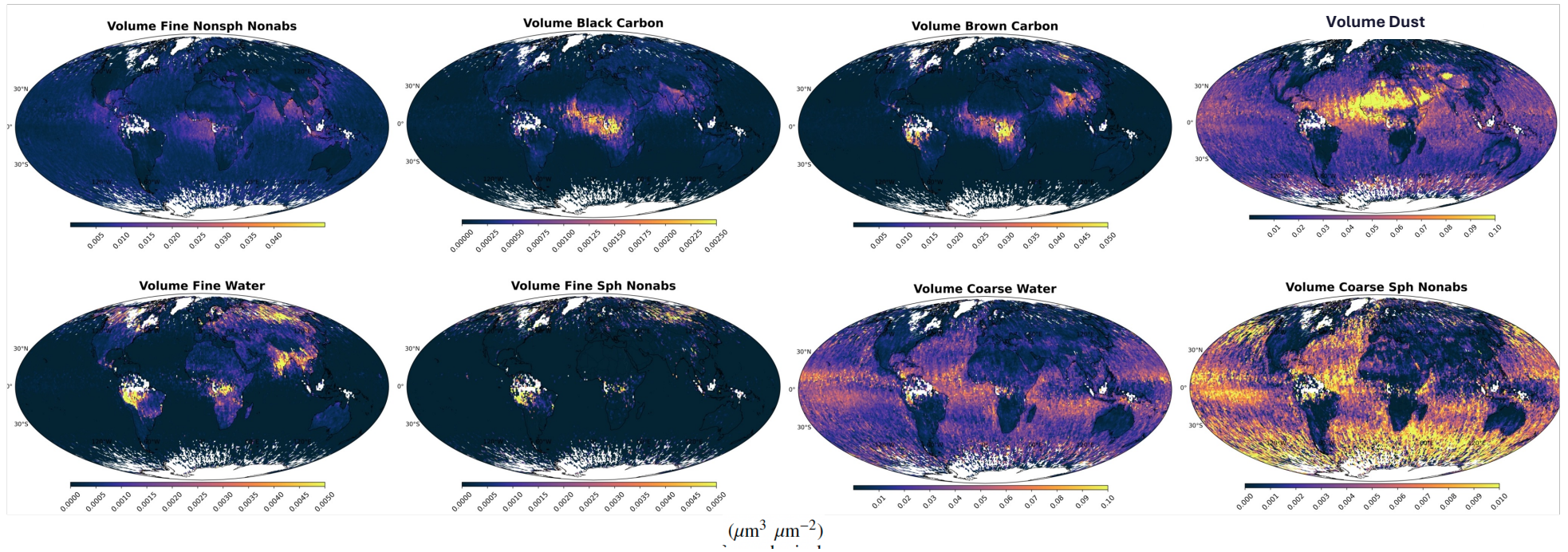
Characteristic and realistic properties can be recognized, e.g.,

- Biomass burning regions (fine spherical smoke) are with low ER (small particle), high SF (sphere), moderate-high RRI, high IRI (absorbing), high FVF (high volume of fine mode).
- Desert dust (coarse non-spherical) are with high ER, low SF, RRI~1.53, IRI~0.01, low FVF.
- Ocean (mixed hydrated sea salt + dust outflow) are with high ER, moderate-high SF, low RRI, low IRI, low FVF.

# Deriving Chemical Composition

- Coarse non-spherical mode → Mineral Dust
- Coarse spherical mode → Hydrated Sea Salt
  
- Fine mode consists of secondary aerosol(non-absorbing), black carbon, brown carbon, dust, and water:
  - $m(\lambda) = f_{dust}m_{dust}(\lambda) + f_{nonabs}m_{nonabs}(\lambda) + f_{bc}m_{bc}(\lambda) + f_{brc}m_{brc}(\lambda) + f_{h2o}m_{h2o}(\lambda)$
  - Volume fractions of BC, BrC, and Dust can be derived from spectral dependence of imaginary refractive index:  $m_i(\lambda) = f_{dust}m_{dust}(\lambda) + f_{bc}m_{bc}(\lambda) + f_{oc}m_{oc}(\lambda)$
  - Then fraction of non-absorbing aerosol (secondary aerosol) and water can be derived from real part.
  
- The total volume of each mode can be computed from the retrieved size distribution. With the fractions above, we can retrieve total volume for each component (and the volume fraction)

# Volume of Chemical Components

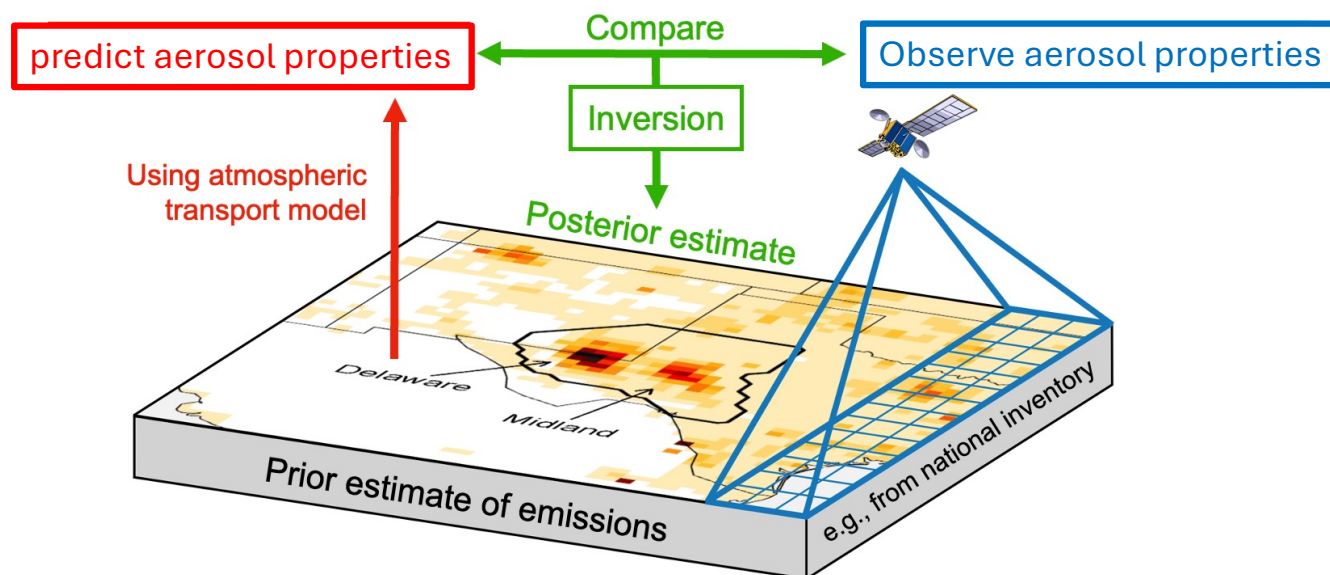


$(\mu\text{m}^3 \mu\text{m}^{-2})$

# Considerations for Data – Model Combinations

- We should make sure to compare apples-to-apples!
- Fine-/coarse AOD, Angstrom Exponent, SSA, AAOD most straightforward
- Effective radius (fine/coarse): handle correctly vertical dependence (total volume, total number → column average effective radius)
- Chemical components:
  - Satellite values for BC, OC and secondary aerosol (fine mode) are based on retrieved total refractive indices and assumed component refractive indices and critically depend on the latter assumptions. Can we assume BC and OC refractive indices are constant over space and time?
  - Aerosol water fraction is based on real refractive index and more robust against assumptions
  - Coarse dust and Sea Salt (SS) depends on the assumption that SS is spherical and Dust non-spherical. This should be mostly fine.
- Beyond ground-based validation, global comparison between satellite products (e.g. SPEXone – 3MI) is essential to understand and quantify the effect of different instrument characteristics and retrieval assumptions.

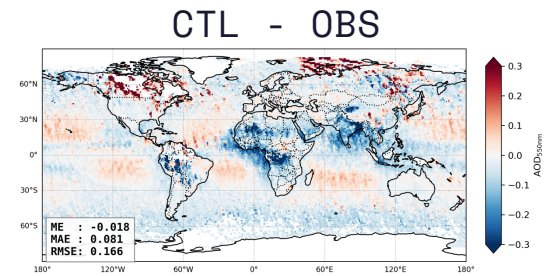
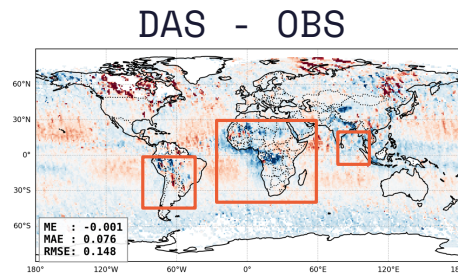
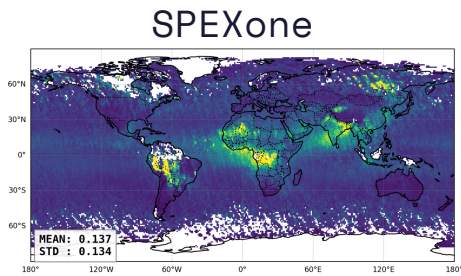
# Data Assimilation of SPEXone Aerosol Data



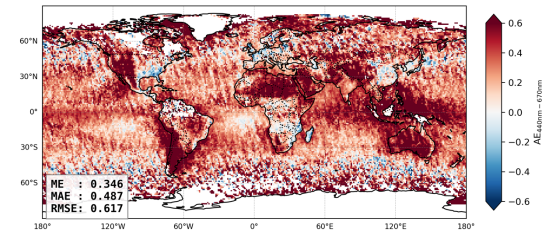
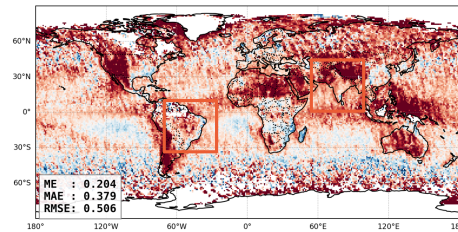
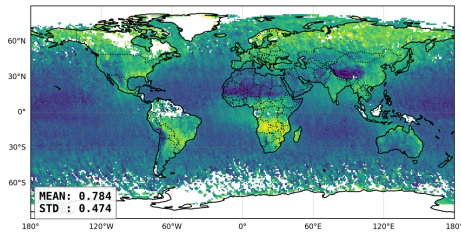
Assimilate aerosol amount (AOD), size (Angstrom Exponent), absorption (SSA) observations in ECHAM-HAM model to estimate aerosol emissions

# Data Assimilation of SPEXone data in ECHAM-HAM

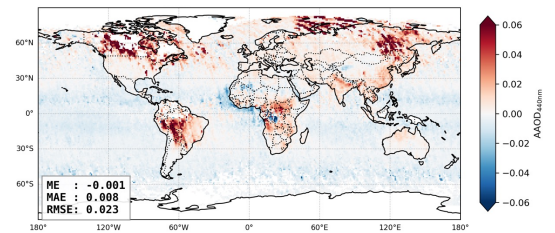
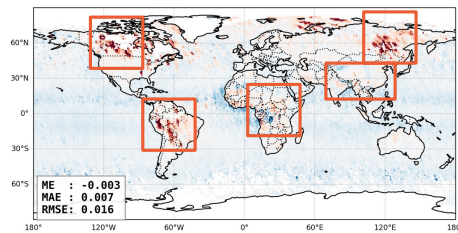
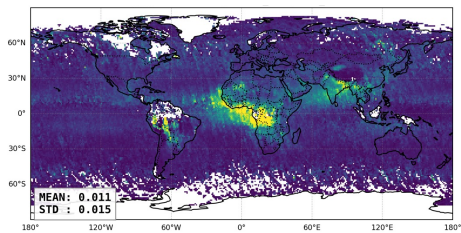
Quantity:  
AOD<sub>550nm</sub>



Size:  
AE<sub>440nm-670nm</sub>



Absorption:  
AAOD<sub>440nm</sub>



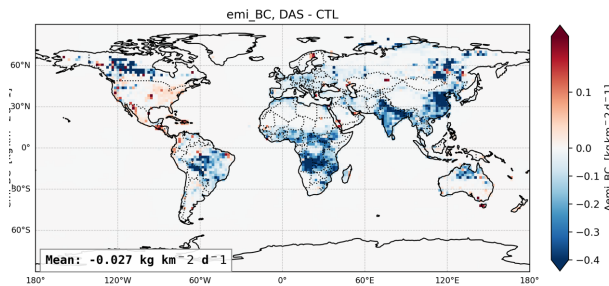
Assimilated field also show better agreement with AERONET.

Arifi et al., in prep.

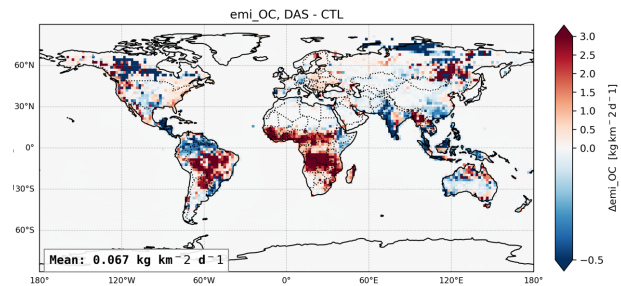
# SPEXone data suggest strong change in emissions

## Change in Emissions

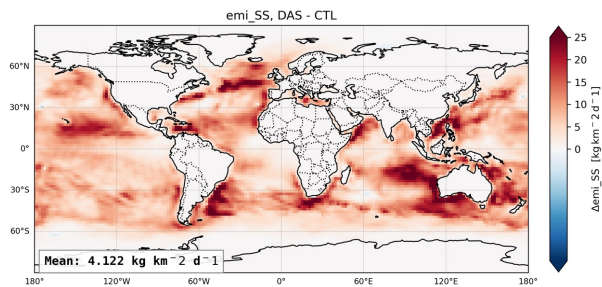
Black carbon



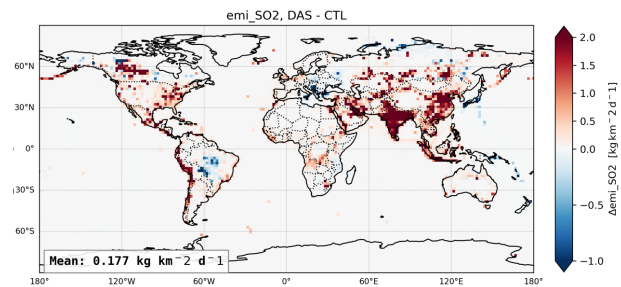
Organic carbon



Sea salt



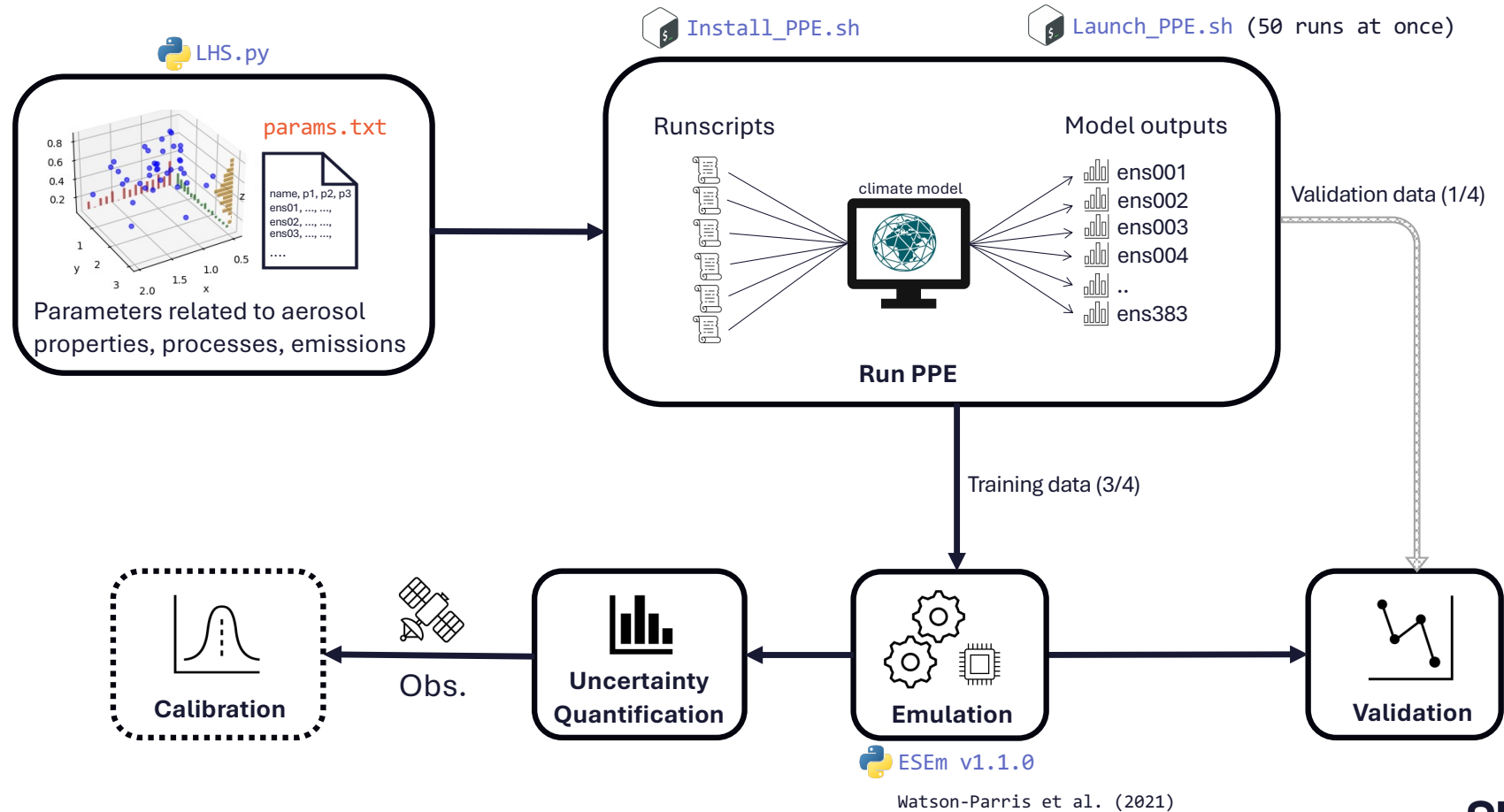
SO2



Arifi et al, in prep.

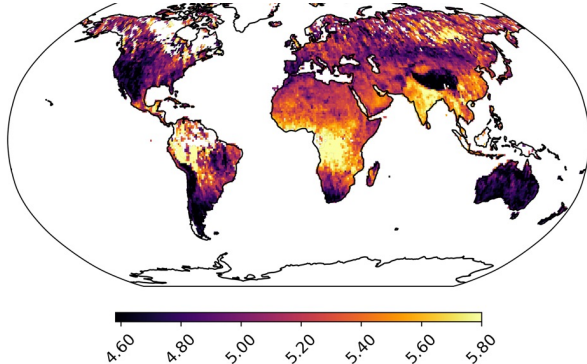
SRON

# Reducing Climate Model Uncertainty with Perturbed Parameter Ensembles (PPEs)

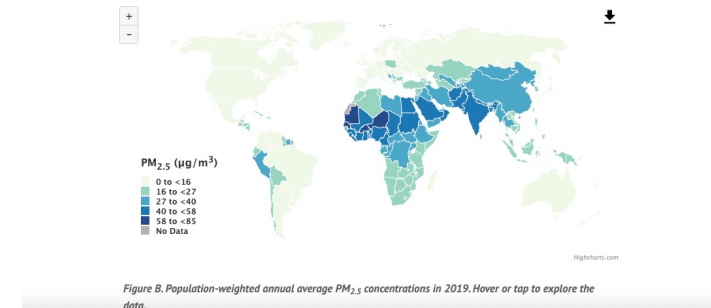
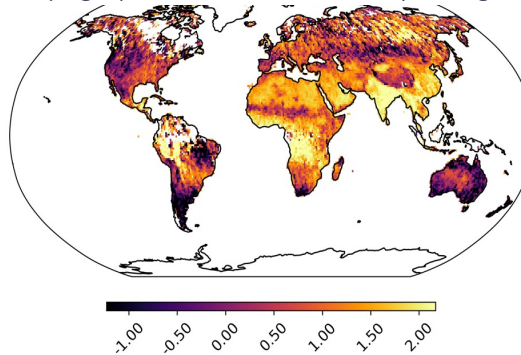


# Preliminary maps of PM2.5 from space (SPEXone)

(Log of) PM2.5 Column (micro-gram /m2)



(Log of) PM2.5 BL concentration (micro-gram /m3)



- PM2.5 Mass concentration aerosols with a dry diameter < 2.5 micron. For AQ purpose, concentration in planetary boundary layer (PBL is relevant).
- Can be computed from size distribution, component fractions (including water), and aerosol layer height (ALH).
- There are many caveats (ALH uncertainty, assumptions on components, etc) but there is clear potential (much more information than from previous satellites)

STATE OF GLOBAL AIR

Pollution and Its Sources ▾ Health Impacts of Air Pollution ▾ Explore the Data ▾ Reports and Resources ▾

## PM<sub>2.5</sub> Exposure

Fine-particle outdoor air pollution remains high across much of the world.

**Typical ranges PM2.5 surface concentration:**

- **Clean background / remote regions:**  
~1–5 µg/m<sup>3</sup>
- **Rural / suburban areas:**  
~5–15 µg/m<sup>3</sup>
- **Urban background in developed countries:**  
~10–30 µg/m<sup>3</sup>
- **Highly polluted urban/industrial regions:**  
50–200+ µg/m<sup>3</sup>
- **Extreme episodes (wildfires, dust storms):**  
can exceed 500 µg/m<sup>3</sup> locally.

## Take-Home Messages

- SPEXone provides novel and/or improved information about aerosol: **Amount** (Aerosol Optical Depth), **Size** (angstrom Exponent, fine mode fraction, effective radius), **absorption** (Single Scattering Albedo) and **composition** (Brown/black Carbon, Secondary aerosol, Dust, Sea Salt).
- Data have shown important value for data assimilation (emissions), climate model calibration, process studies and have potential for air quality applications (PM2.5)

### Data Links

#### SPEXone L2:

NASA: <https://search.earthdata.nasa.gov/search?q=10.5067/PACE/SPEXone/L2>

SRON: <https://public.spider.surfsara.nl/project/spexone/RemoTAP-SPEXone/> (includes 'soft' radiometric calibration)

#### SPEXone L3 (GRIDDED):

NASA: <https://search.earthdata.nasa.gov/search?q=10.5067/PACE/SPEXone/L3>

SRON: <https://public.spider.surfsara.nl/project/spexone/RemoTAP-SPEXone-GRIDDED/>

**SRON**