Polarimetric Remote Sensing of atmospheric aerosols: First results from the SPEXone instrument on the PACE mission

Otto Hasekamp, Guangliang Fu, Bastiaan van Diedenhoven, Neranga Hannadige, Zihao, Yuan, Raul Laasner, Laura van der Schaaf, Mario Vretenar, Richard van Hees, Jochen Landgraf, Martijn Smit, Jeroen Rietjens



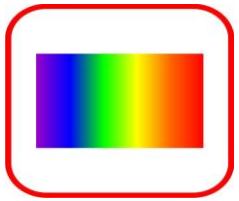




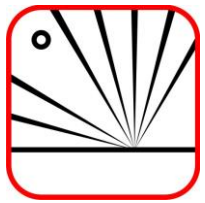
Aerosol: An air Pollutant that cools the Earth

- ✓ **Aerosols vary in their optical properties**:
  Total Extinction (AOD), Absorption vs Scattering (SSA)
- ✓ **Microphysical properties**:
  Number concentration, size, shape, refractive index
- ✓ **Composition** :
  Volume fractions of Dust, Sea Salt, Water, Sulphate, Nitrate, Black Carbon, Organic Carbon

Aerosol properties can be derived from measurements of scattered light

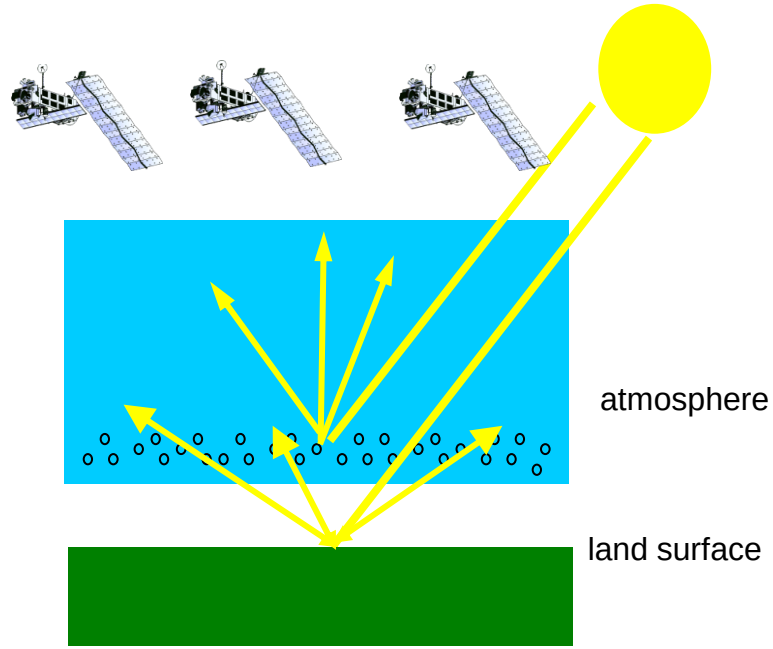


radiance spectrum



Multiple viewing angles

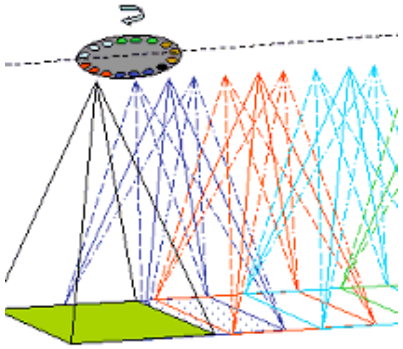
polarization



Polarimeters in Space

2005 2013 2024 2025 2026

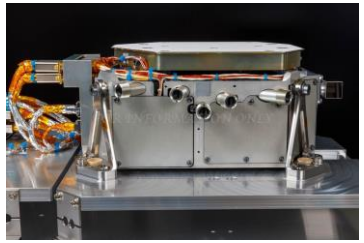
PARASOL



>10 year GAP!

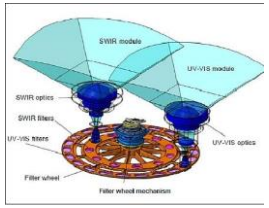
PACE

SPEXone – PACE



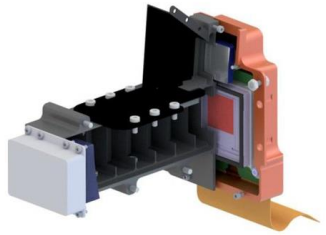
HARP2 – PACE

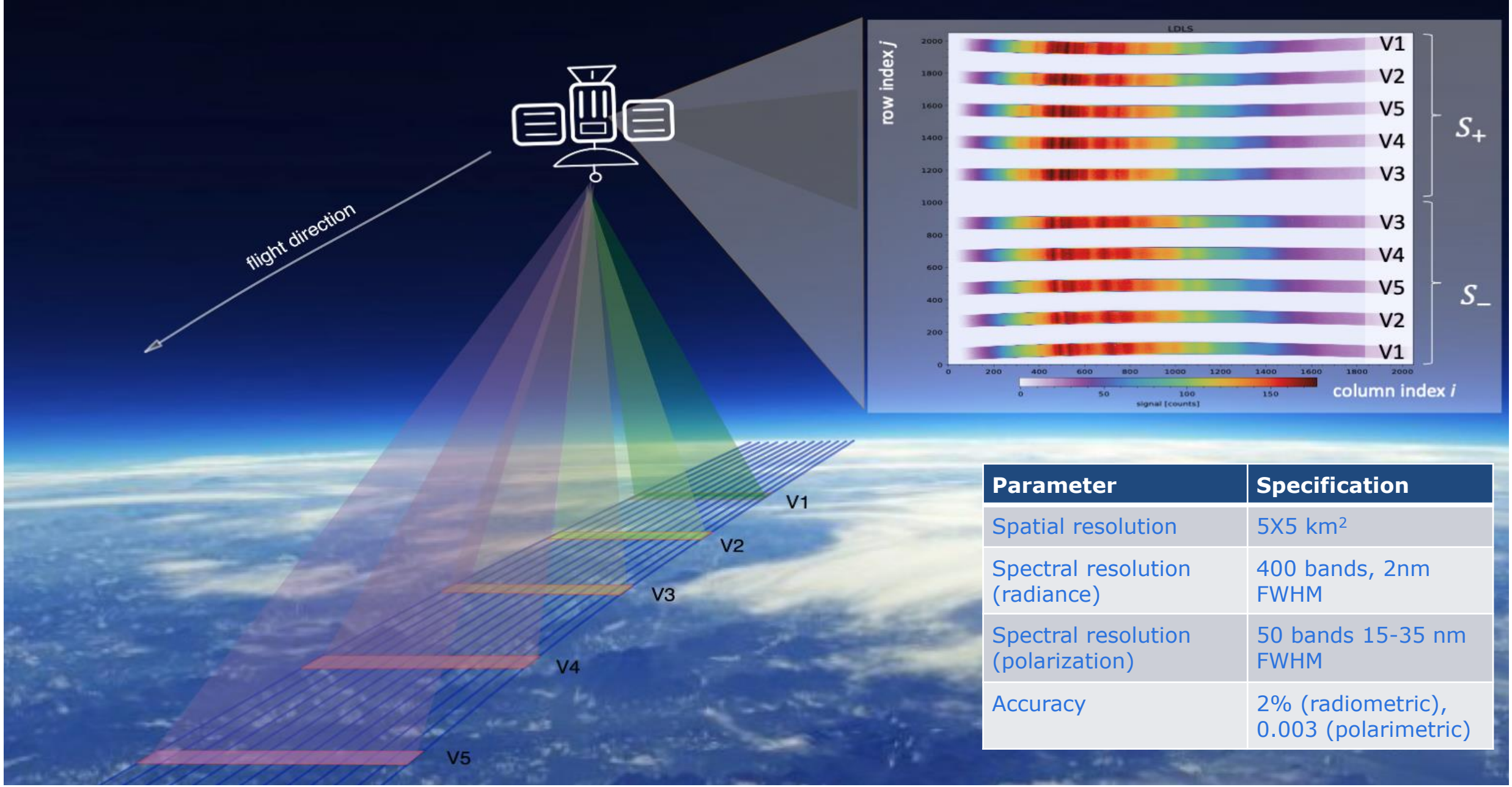
3MI



CO2M

MAP

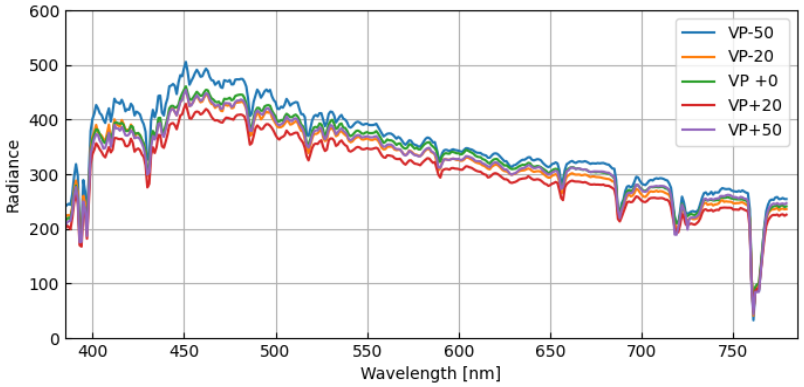


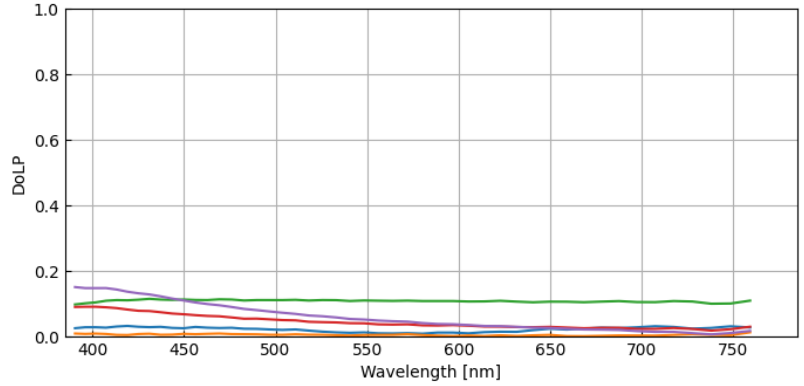


Parameter	Specification
Spatial resolution	5X5 km^2
Spectral resolution (radiance)	400 bands, 2nm FWHM
Spectral resolution (polarization)	50 bands 15-35 nm FWHM
Accuracy	2% (radiometric), 0.003 (polarimetric)

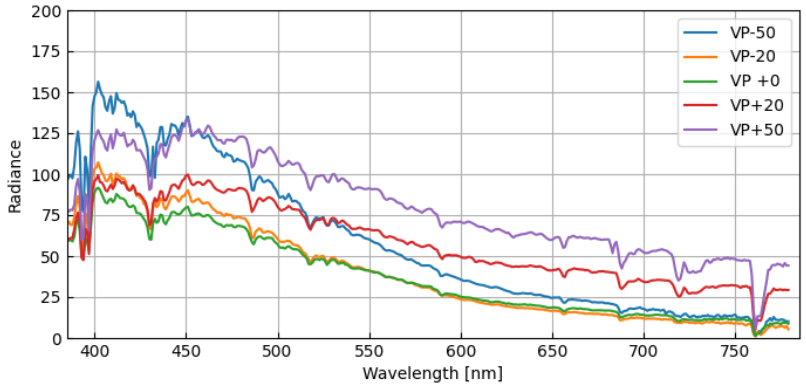
Scene Examples

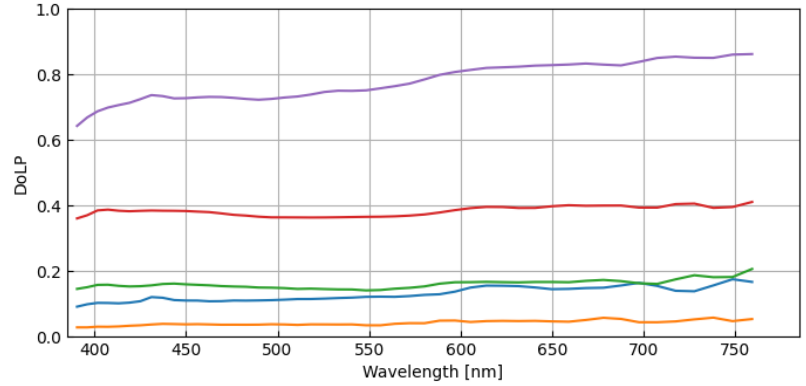
Cloud



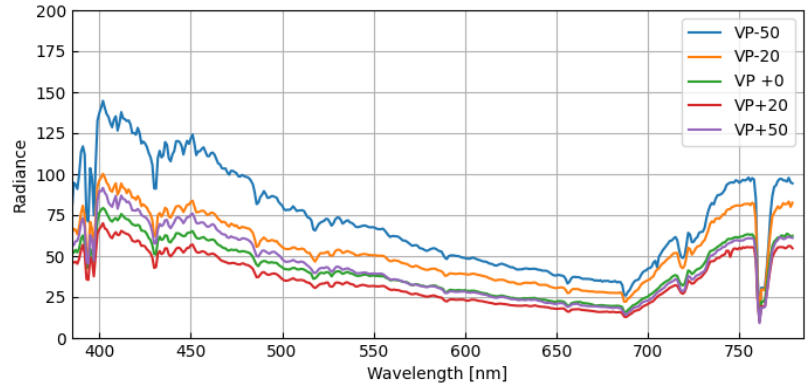


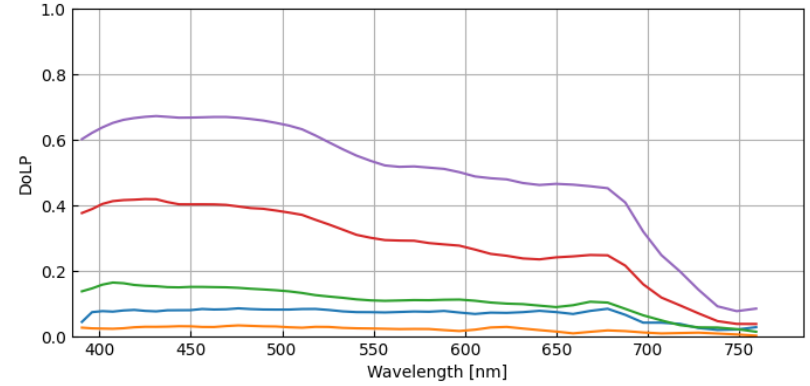
Ocean





Vegetation

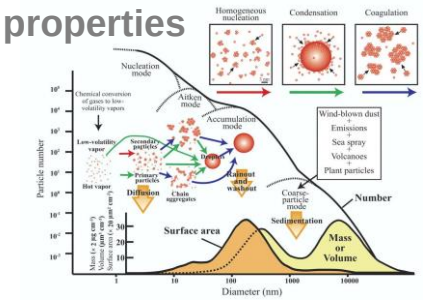




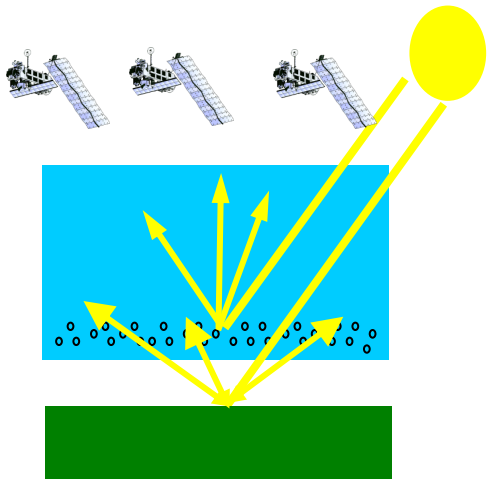
Retrieving Aerosol Properties: The RemoTAP algorithm

minimize difference

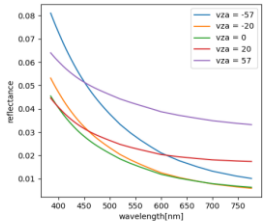
state vector:
aerosol and surface properties

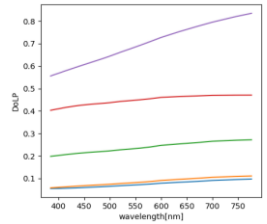


Forward Model:
Simulate the measurement



measurement:
radiance and DoLP





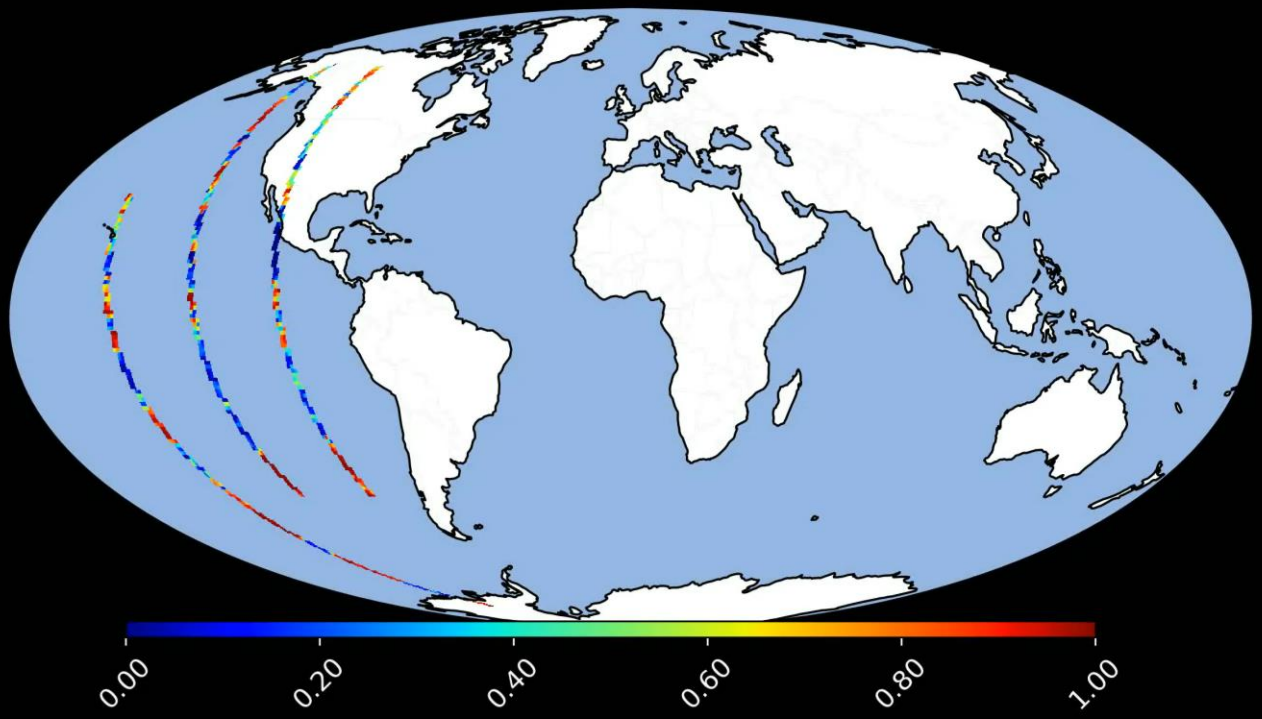
update till optimal agreement

RemoTAP: REMOte sensing of Trace gas and Aerosol Products

References:

Lu et al., Frontiers Rem. Sens., 2022
Fu et al., AMT, 2018; 2022
Fan et al., Rem. Sens., 2019
Hasekamp et al., JGR, 2011

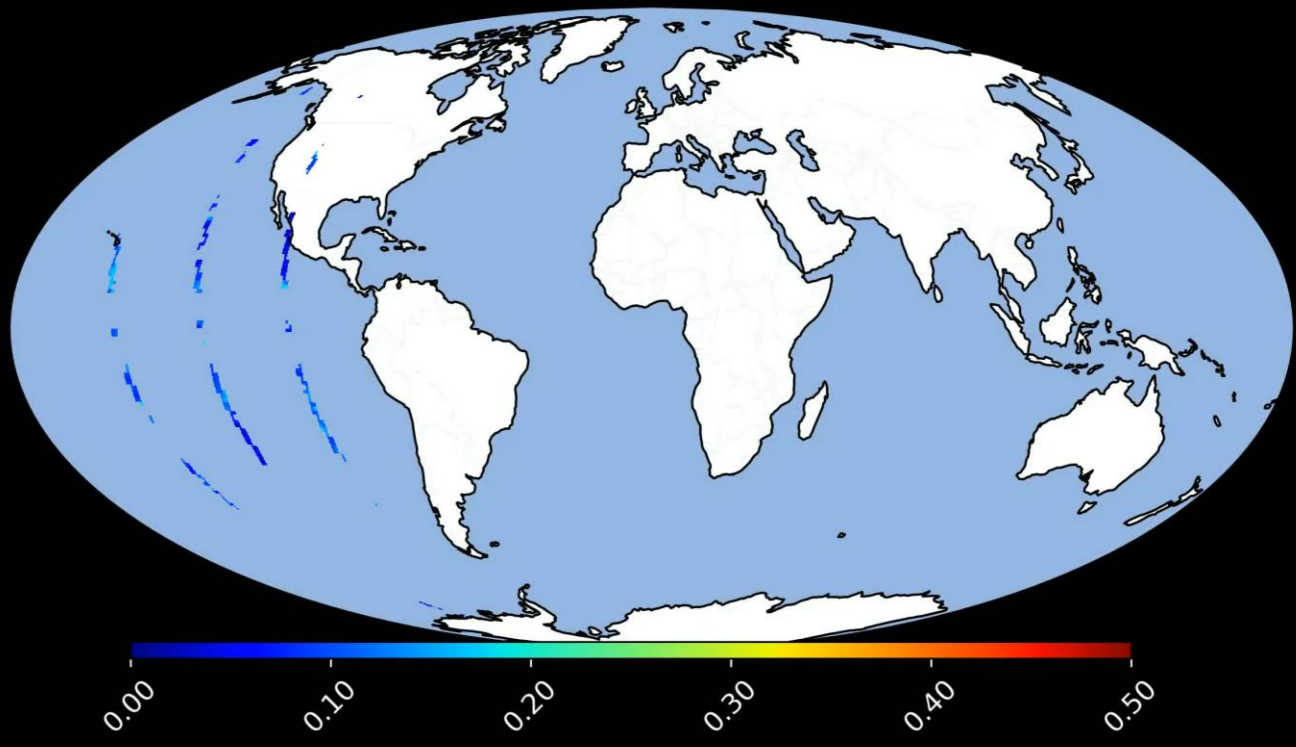
Cloud Fraction



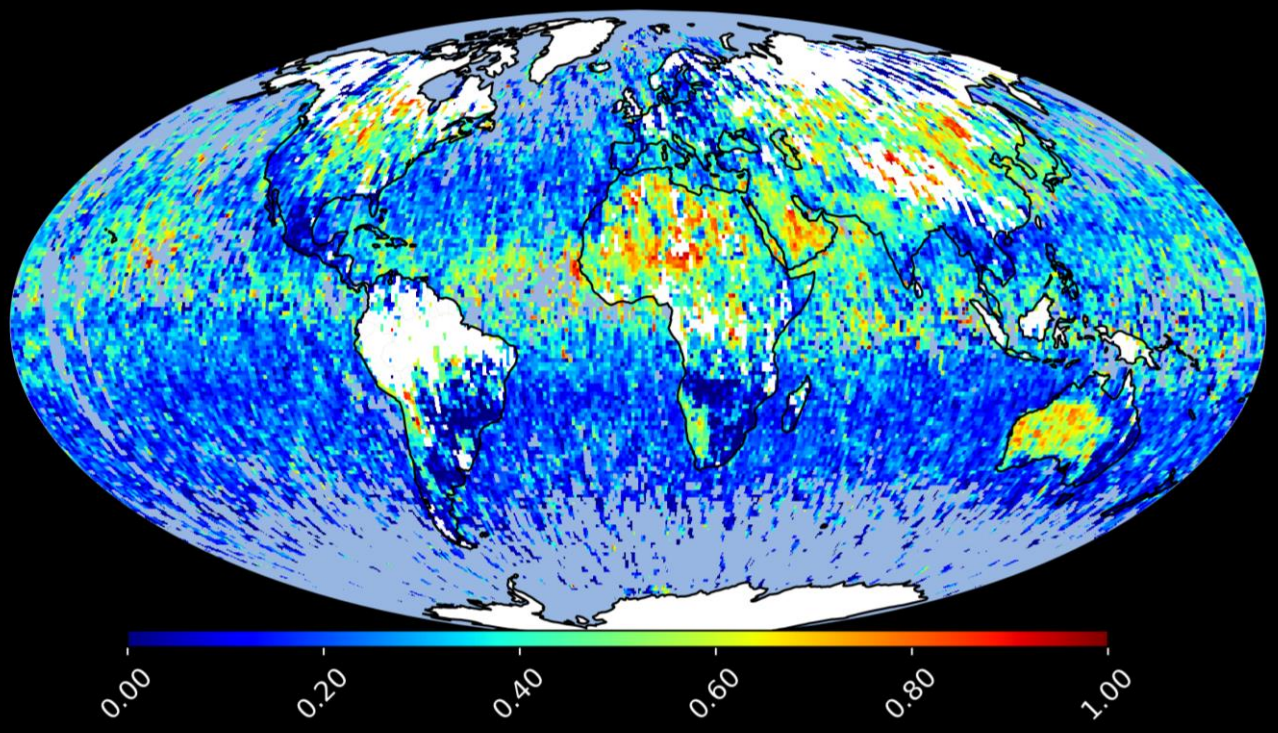
NASA GSFC SRON Airbus DS NL

SPEX one

AOD

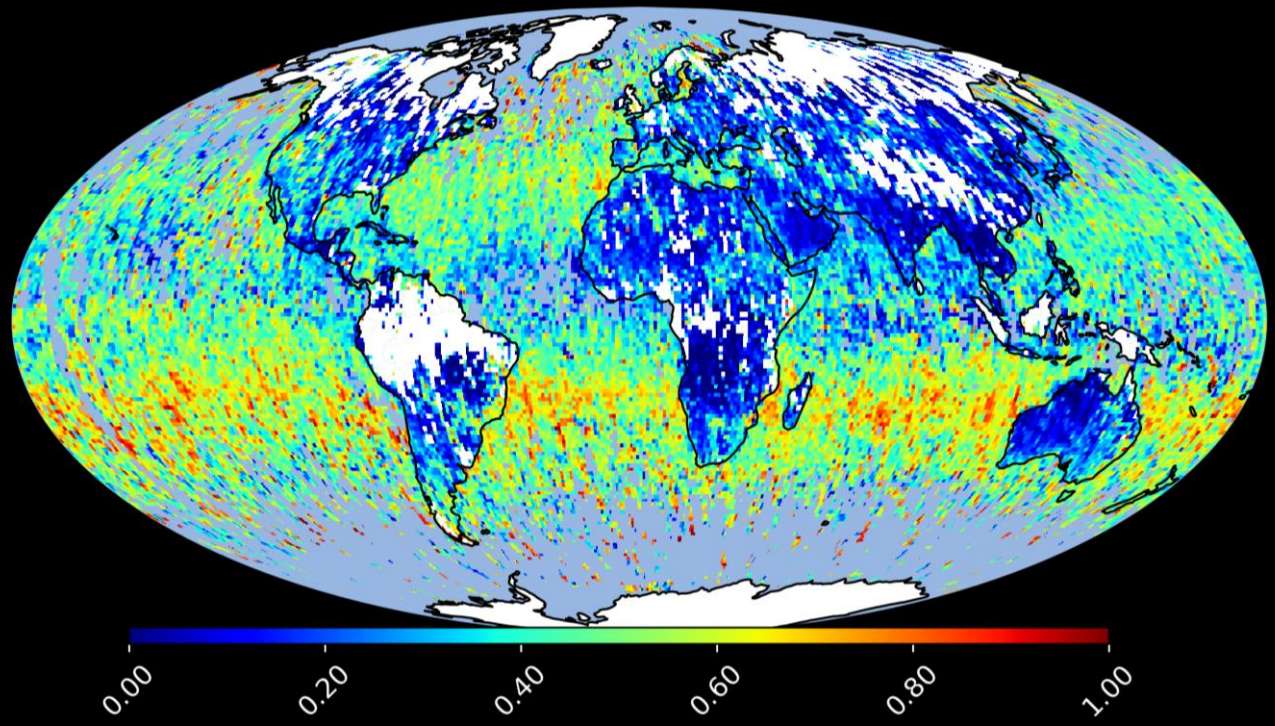


Dust

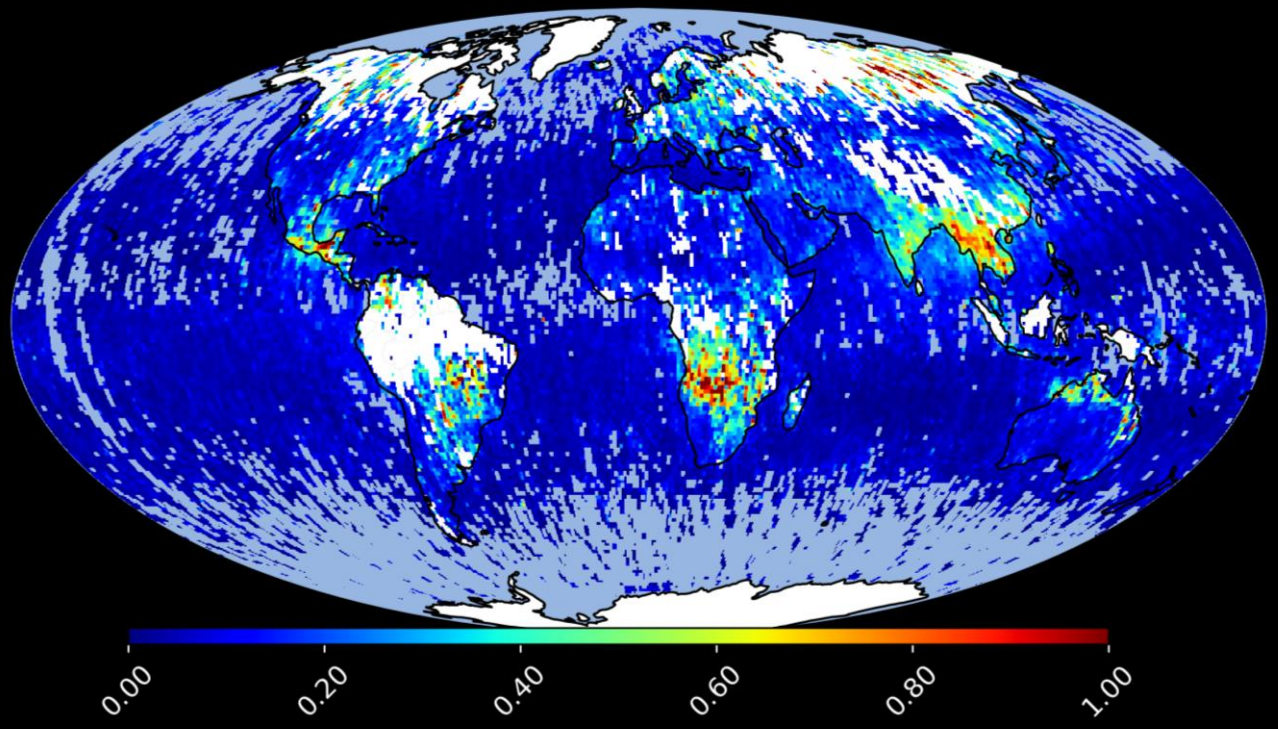


- Dust over deserts (Sahara, Australia, Southern Africa).
- At places with Dust, little water → Dust is hydrophobic
- High fraction of aerosol water over open ocean → Hydrated sea salt

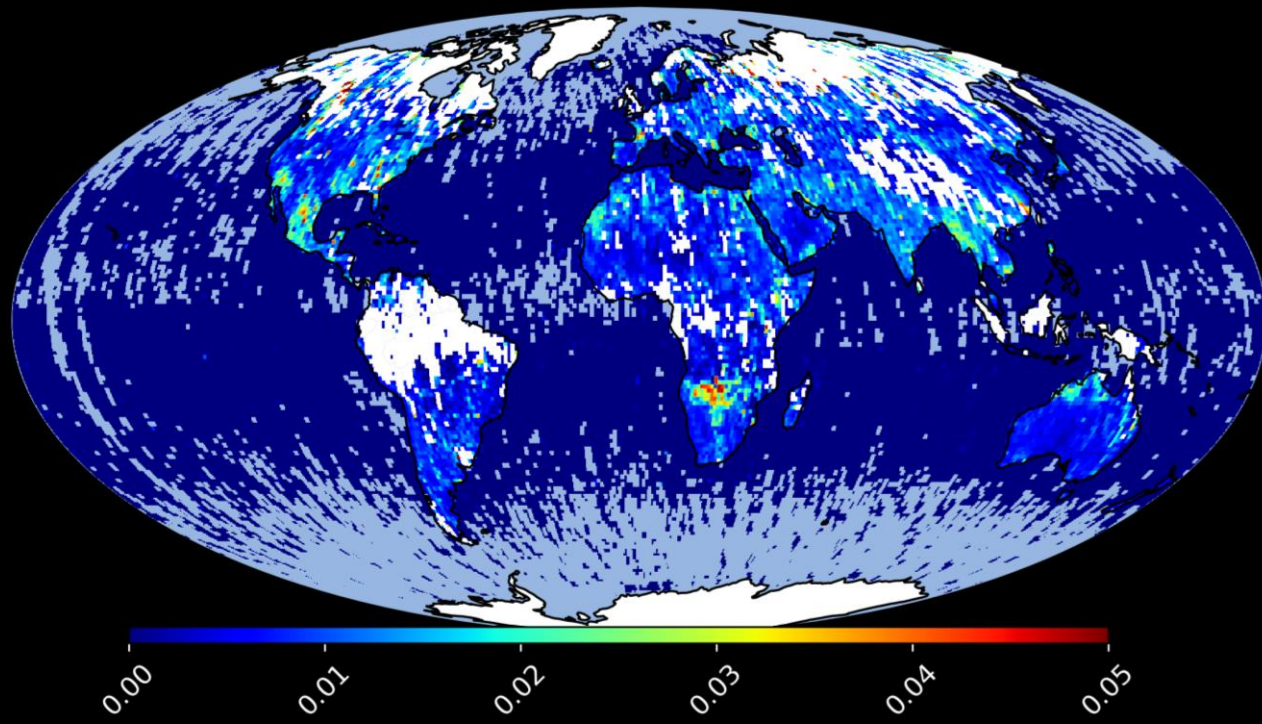
Aerosol Water



Sulphates+Nitrates



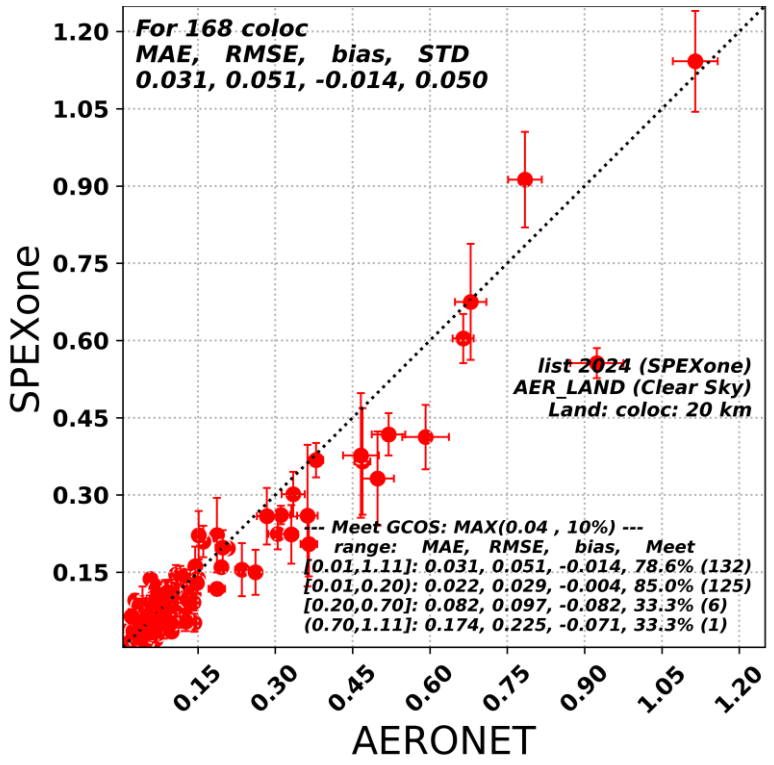
Black Carbon



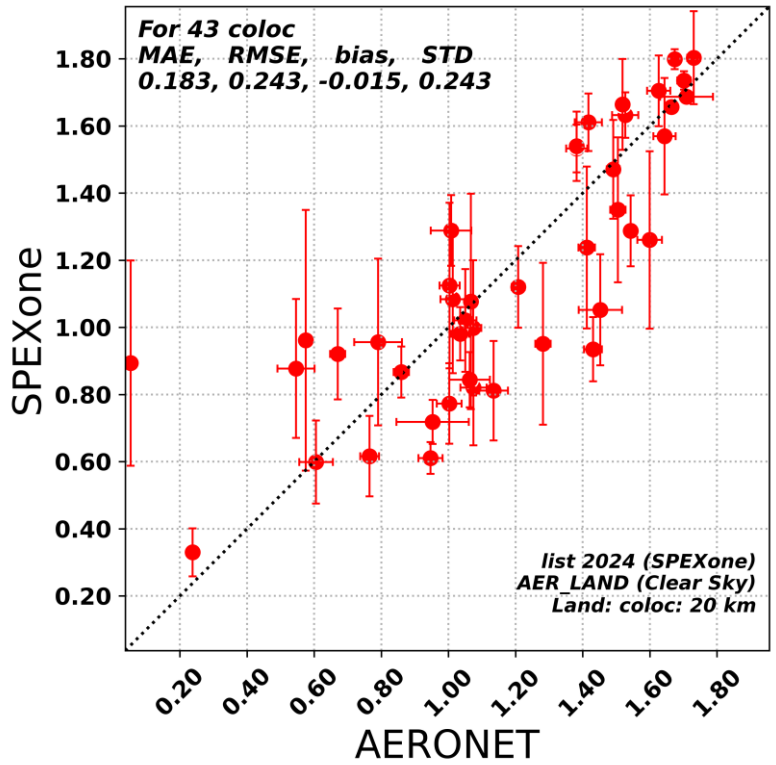
- High Concentration of Sulphates/Nitrates over industrial regions (SE Asia, India, some individual cities like New Orleans)
- Black Carbon over SE Asia, Namibia (biomass burning), and Canada (Forest Fire)

AERONET validations over land (Feb 23 to May 31) (L1C-V3.8)

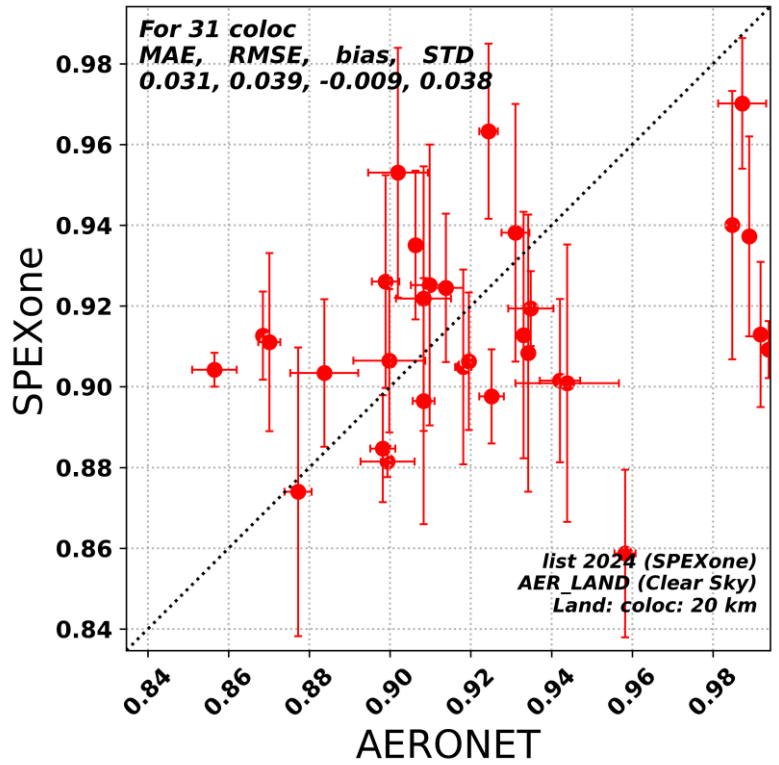
Aerosol Optical Depth (AOD)



Angstrom Exponent (size)



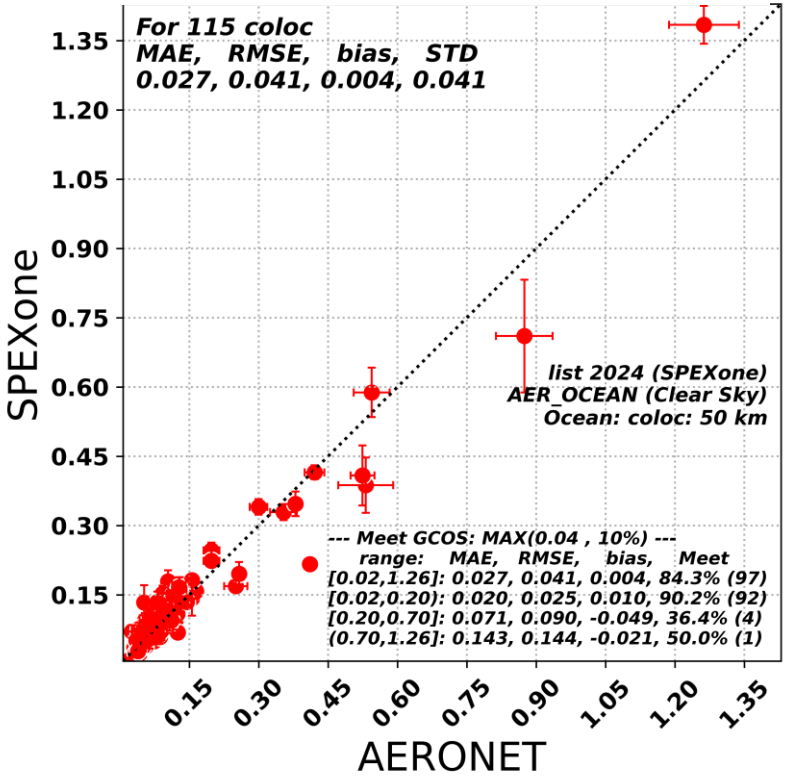
Single Scattering Albedo (SSA)



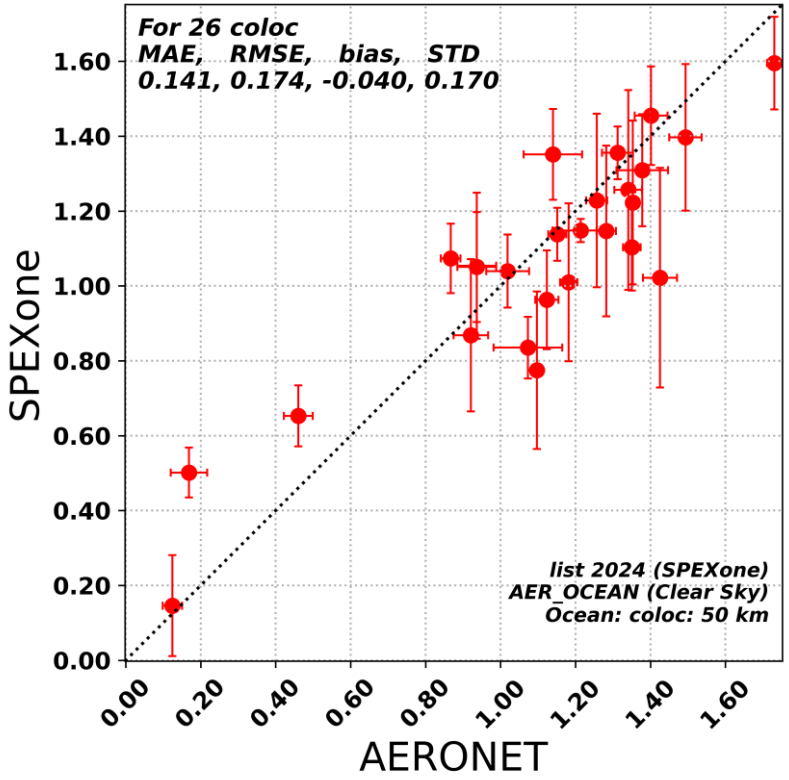
SPEXone	MAE	RMSE	bias	GCOS
AOT	0.031	0.051	-0.014	78.6%
AOT<0.2	0.022	0.029	-0.004	85.0%
AE	0.183	0.243	-0.015	
SSA	0.031	0.039	-0.009	

AERONET validations over ocean (Feb 23 to May 31) (L1C-V3.8)

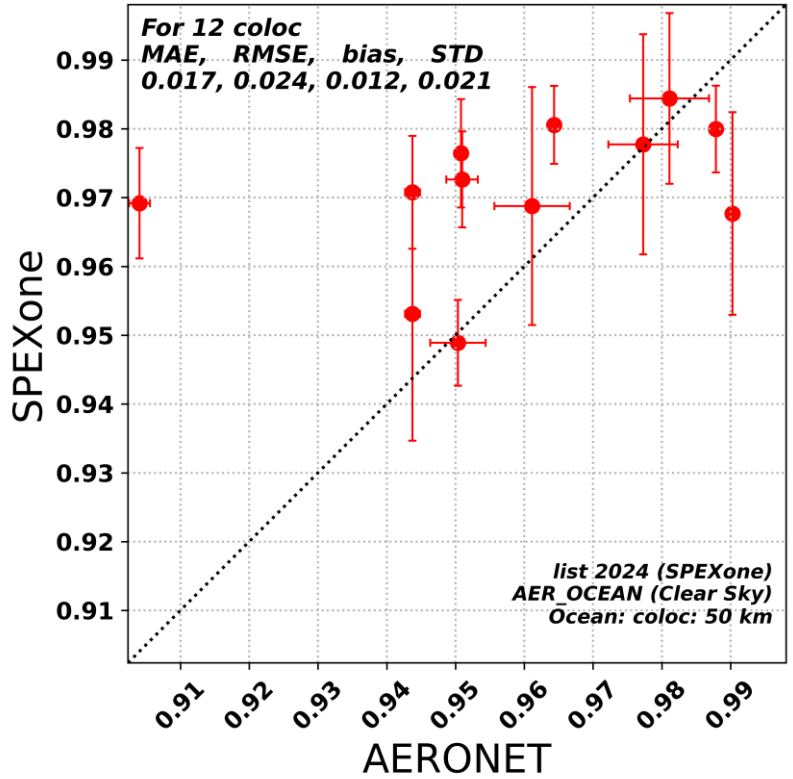
Aerosol Optical Depth (AOD)



Angstrom Exponent (size)



Single Scattering Albedo (SSA)



SPEXone	MAE	RMSE	bias	GCOS
AOT	0.027	0.041	0.004	84.3%
AOT<0.2	0.020	0.025	0.010	90.2%
AE	0.141	0.174	-0.040	
SSA	0.017	0.024	0.012	

Outlook & Synergy

- Evaluation (2 ways) of Earthcare aerosol typing with SPEXone microphysical properties and composition (AIRSENSE).
- Evaluate aerosol cloud relationships (AIRSENSE).
- Constrain climate models using SPEXone and Earthcare simultaneously (CleanCloud)

SRON

Recommendations to ESA for Future Research

- Development of advanced aerosol products (composition, CCN, absorption) including validation strategies.
- Improving the interface between (climate) models and satellite observations of aerosols.
- Exploit synergy between different satellites (Earthcare, PACE, METOP-SG, Sentinel-3)
- Use of Machine Learning to improve accuracy and speed of aerosol retrievals

SRON