Aerosol sun photometry state of the art and progress and the COST action Harmonia

Stelios Kazadzis

Physics and Meteorology Obs. Davos, World Radiation Center, Switzerland

N. Kouremeti, A. Masoom, J. Gröbner, C. Toledano, L. Doppler, M. Campanelli, V. Estelles, R. Roman, I. Fountoulakis, S. Solomos, S. Vandenbussche , A. Nemuc, P. Raptis, P. Dagsson-Waldhauserova, M. J. Costa, K. Papachristopoulou

Deutscher Wetterdienst (DWD), Meteorologisches Observatorium Lindenberg, Germany
University of Valladolid (UVa), Group of Atmospheric Optics, Spain
National Research Council (CNR), Institute of Atmospheric Sciences and Climate, Italy
Univ. of Valencia, Dep. Of Earth Physics and Thermodynamics, Spain
Academy of Athens, Research Centre for Atmospheric Physics and Climatology, Greece
National Institute for Research and Development for Optoelectronics, Romania
National Observatory Of Athens, Greece
Agricultural University of Iceland, Iceland
Univ. Of Evora, Dep. Of Physics, Portugal
Royal Belgian Institute for Space Aeronomy, Belgium

HARMONIA
International network for harmonization of atmospheric aerosol retrievals from ground based photometers

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the Horizon 2020 Framework Programme of the European Union

pmod wrc

Outline

State of the art on basic principles of direct sun and sky radiance measurements and retrieval methods used worldwide

Calibration procedures for aerosol sun photometry

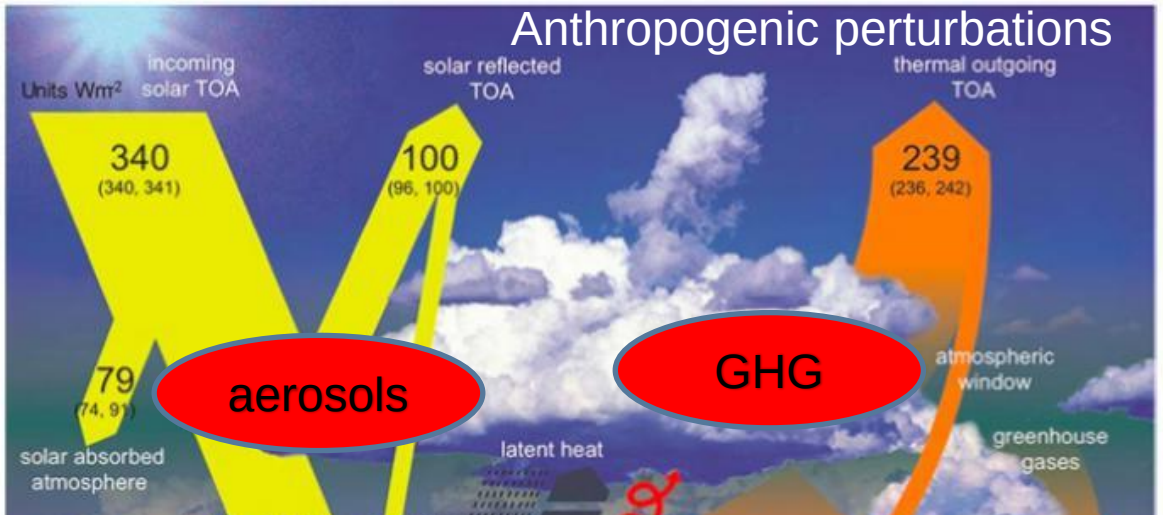
Global efforts for aerosol optical properties homogenization

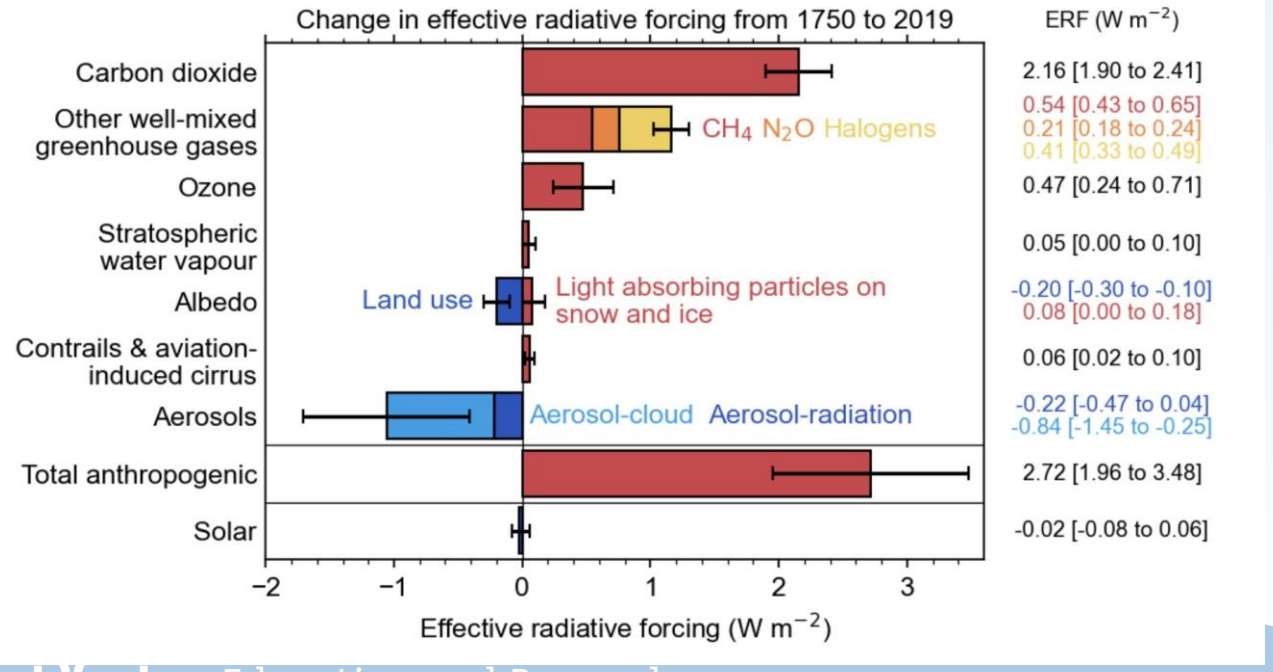
Estimation of the aerosol optical depth uncertainty and the factors affecting it

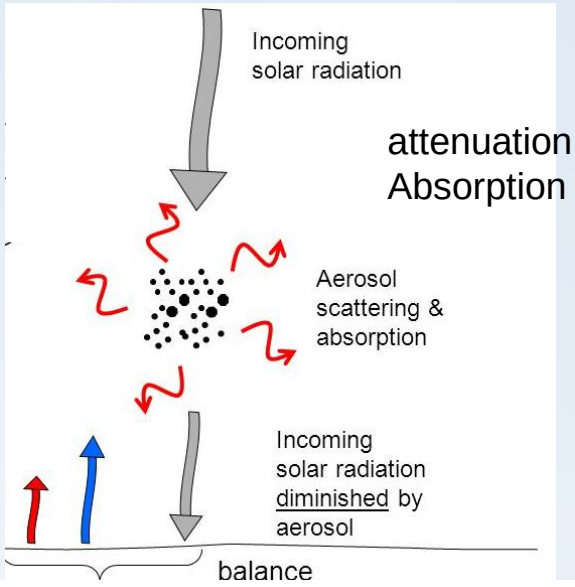
Examples of aerosol retrievals, trends and spatiotemporal variability on a global scale

The HARMONIA COST action

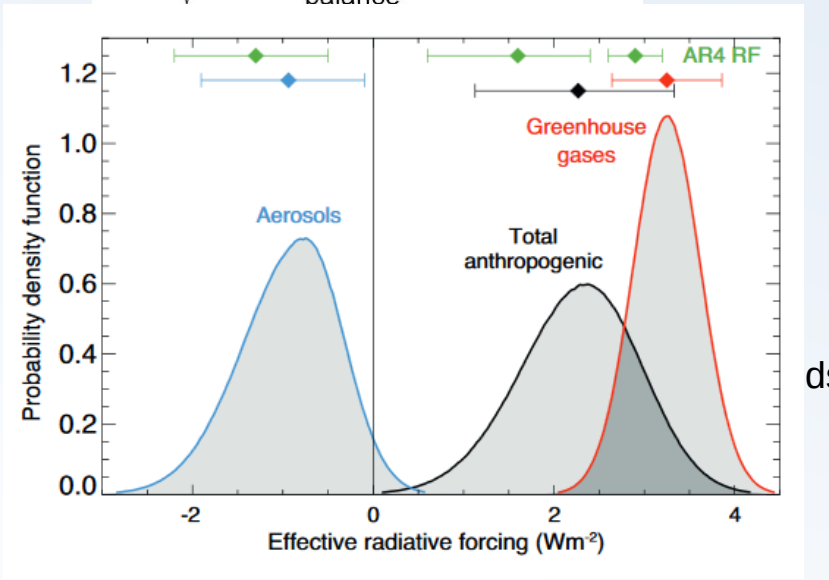
Motivation: Aerosols and Climate





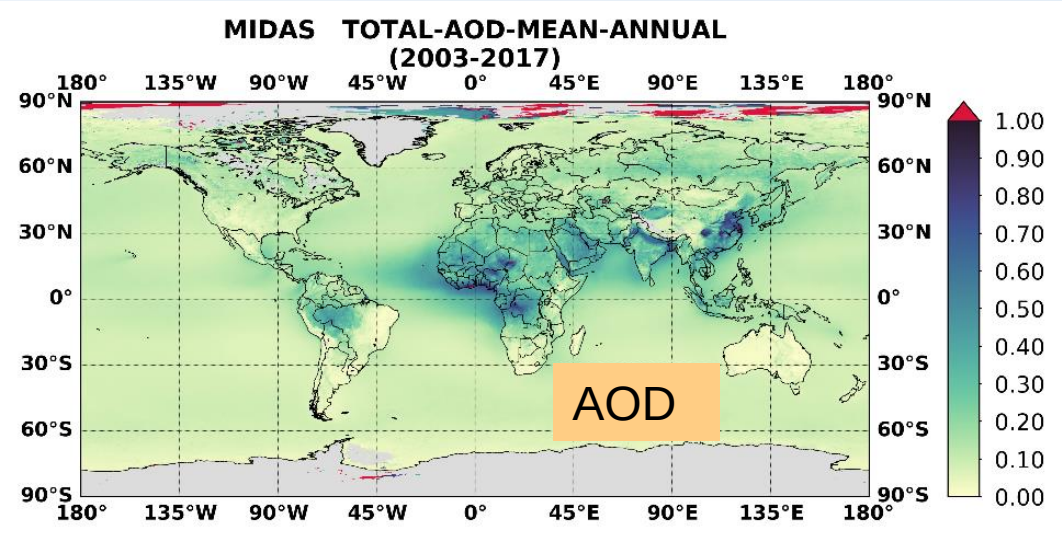


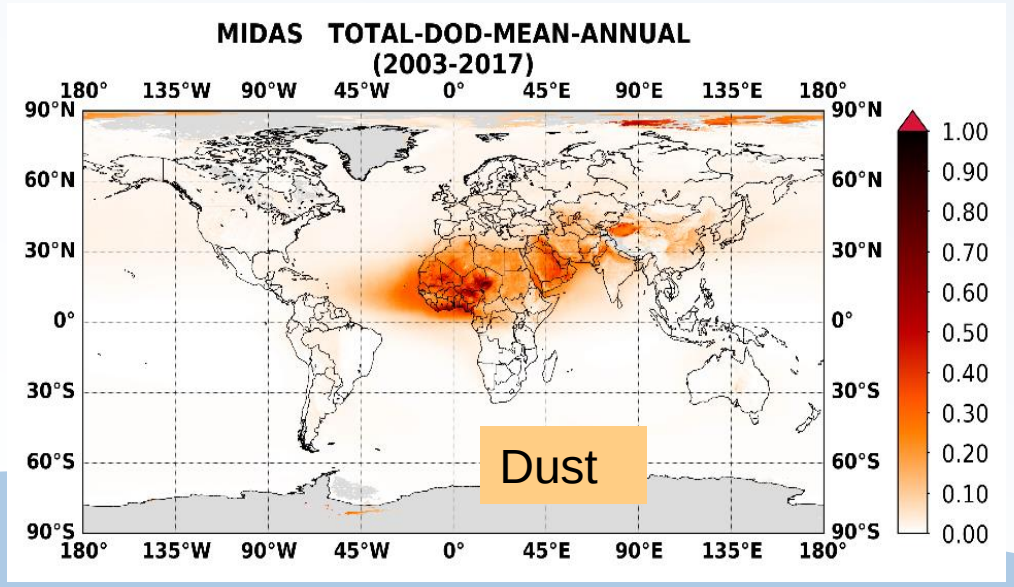
attenuation
Absorption and scattering



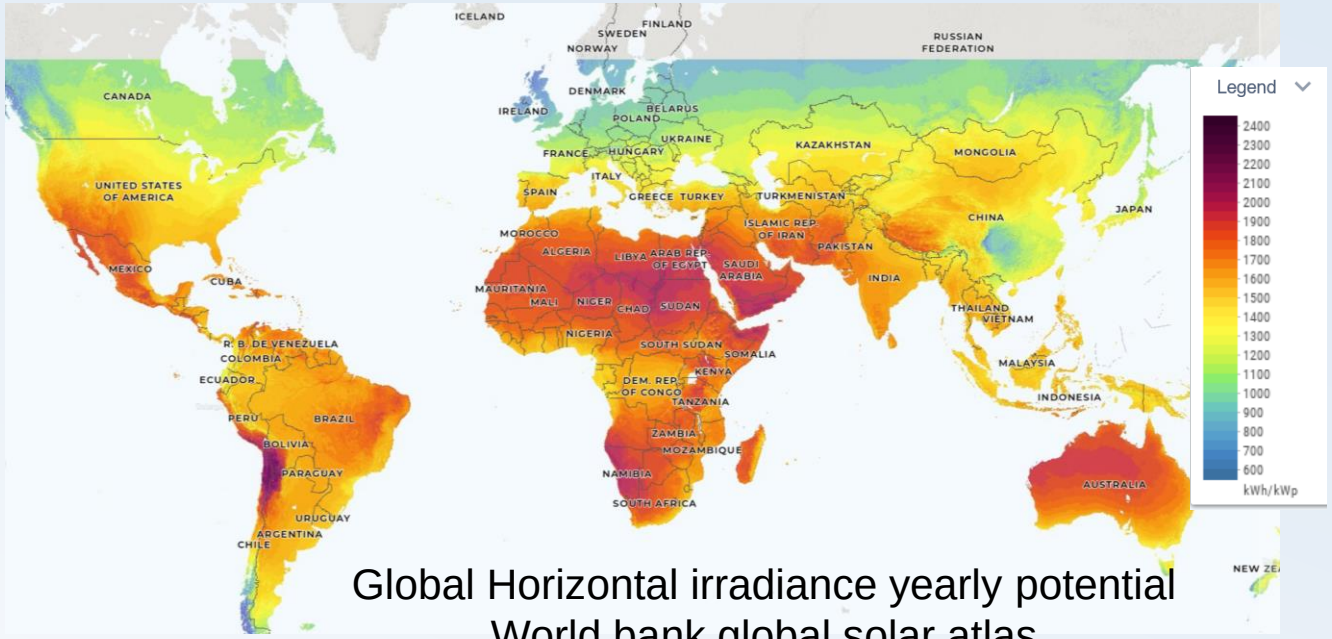
ds

Solar radiation attenuation





Global solar potential aerosols areas



Global Horizontal irradiance yearly potential
World bank global solar atlas

Average dust optical depth from Gkikas et al., 2021

Sun-photometers: Retrieval of aerosol optical properties

Aerosol products:

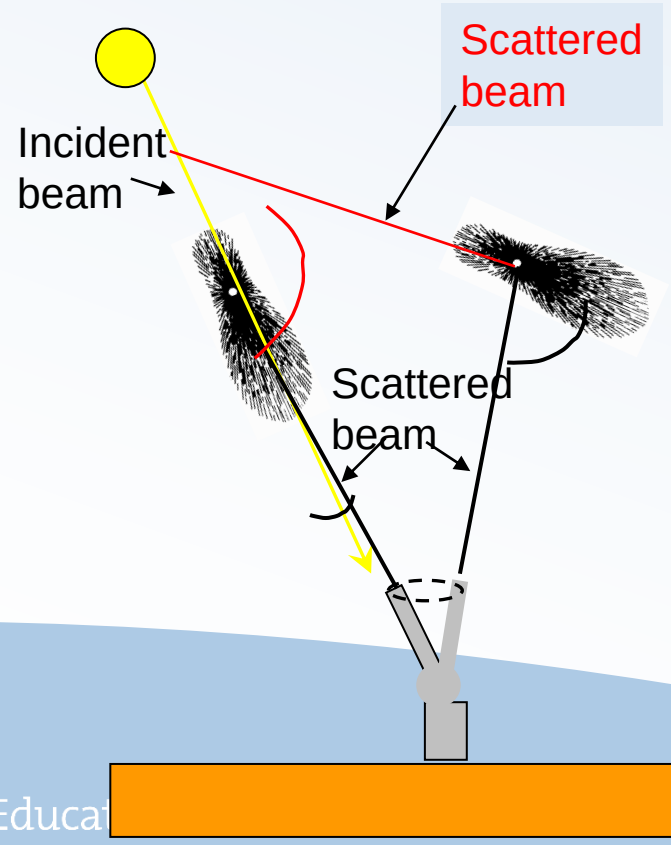
- Aerosol optical depth retrieved from direct solar/lunar irradiance

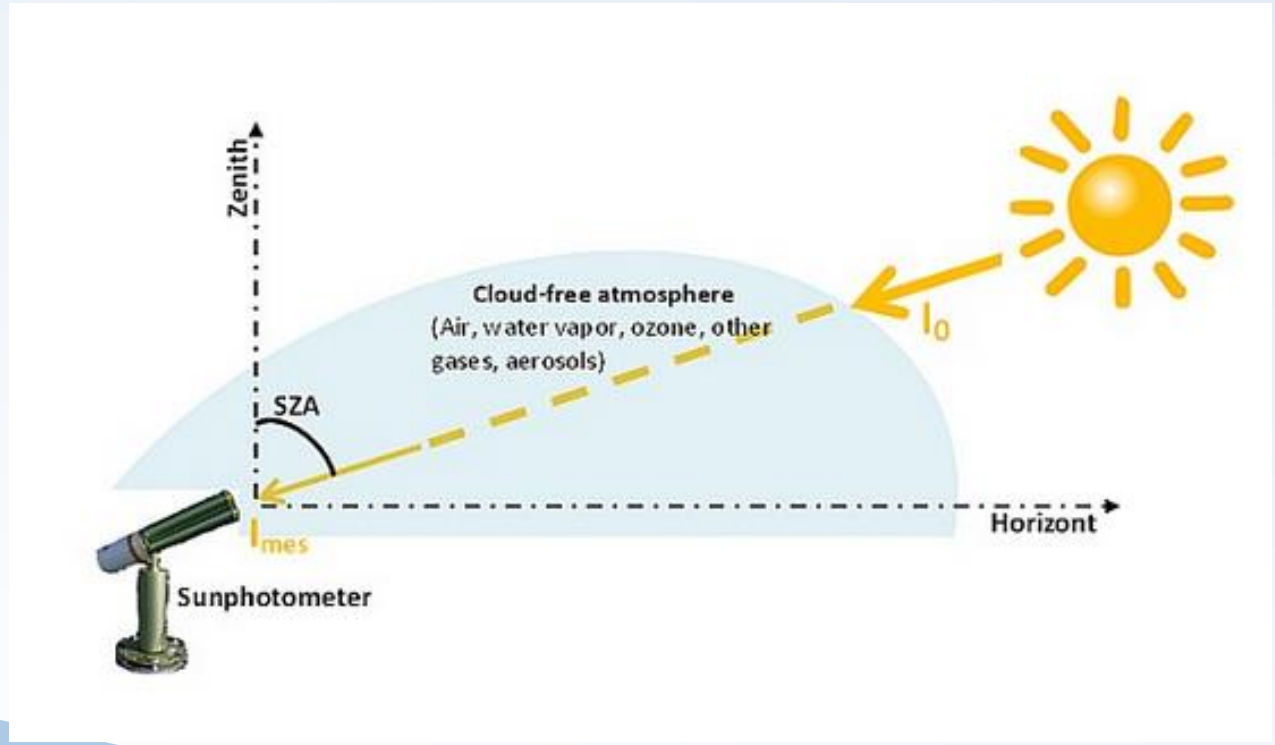
- Size distribution,
- Single scattering albedo,
- Scattering phase function,
- Refractive indices.

} solar radiance

Aerosol optical depth (AOD) is obtained from transmission measurements of the atmosphere:

Other aerosol properties are obtained from inversion modelling combining direct and scattered solar irradiance.

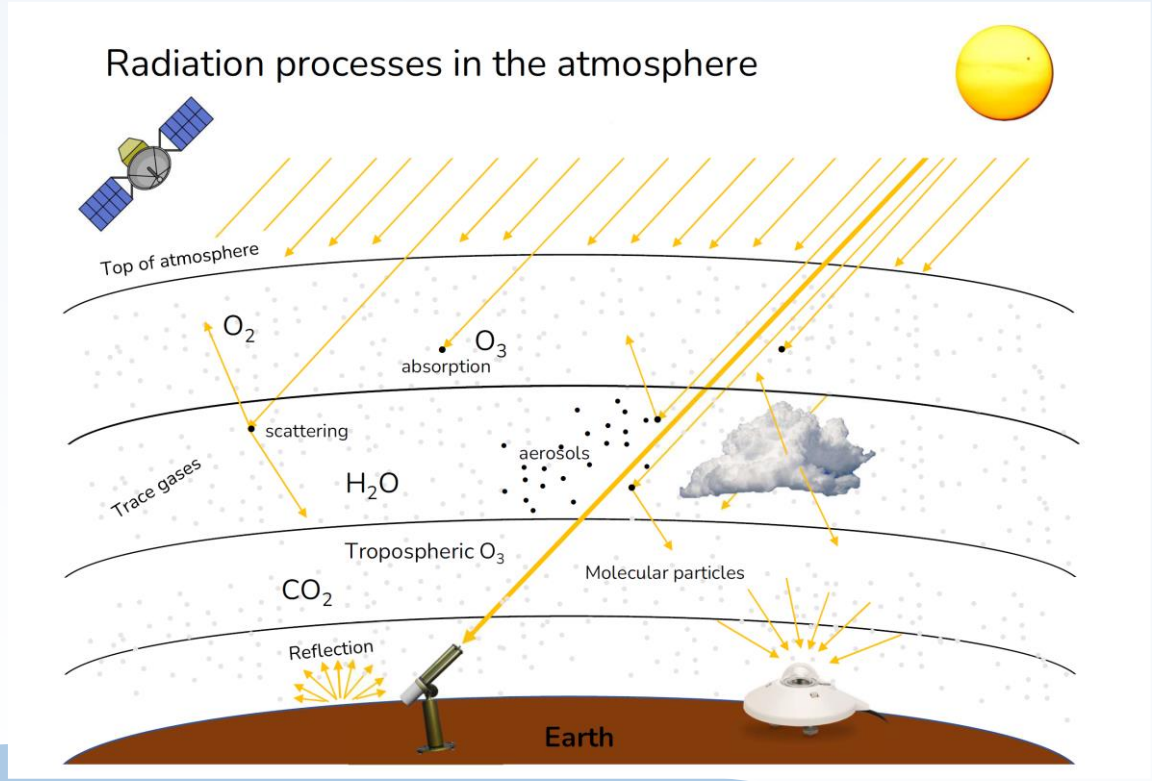




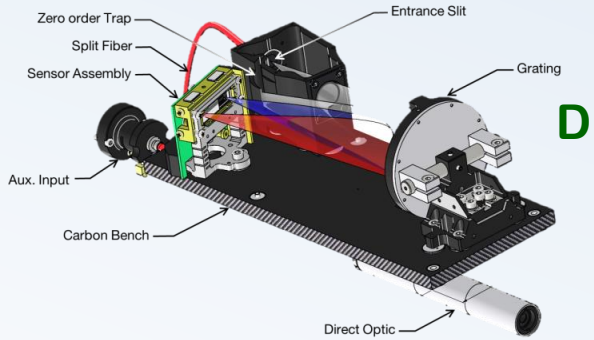
What columnar aerosol properties are retrieved / used for studying their radiative effects ?

Aerosol Optical Depth *(AOD) is a quantitative estimate of the amount of aerosol present in the atmosphere it is a measure of the extinction of a ray of light as it passes through the atmosphere. (main aerosol radiative impacts variable)*

Aerosol Optical Depth (AOD) ~ aerosol amount



Direct sun filter radiometers



Direct sun spectroradiometers

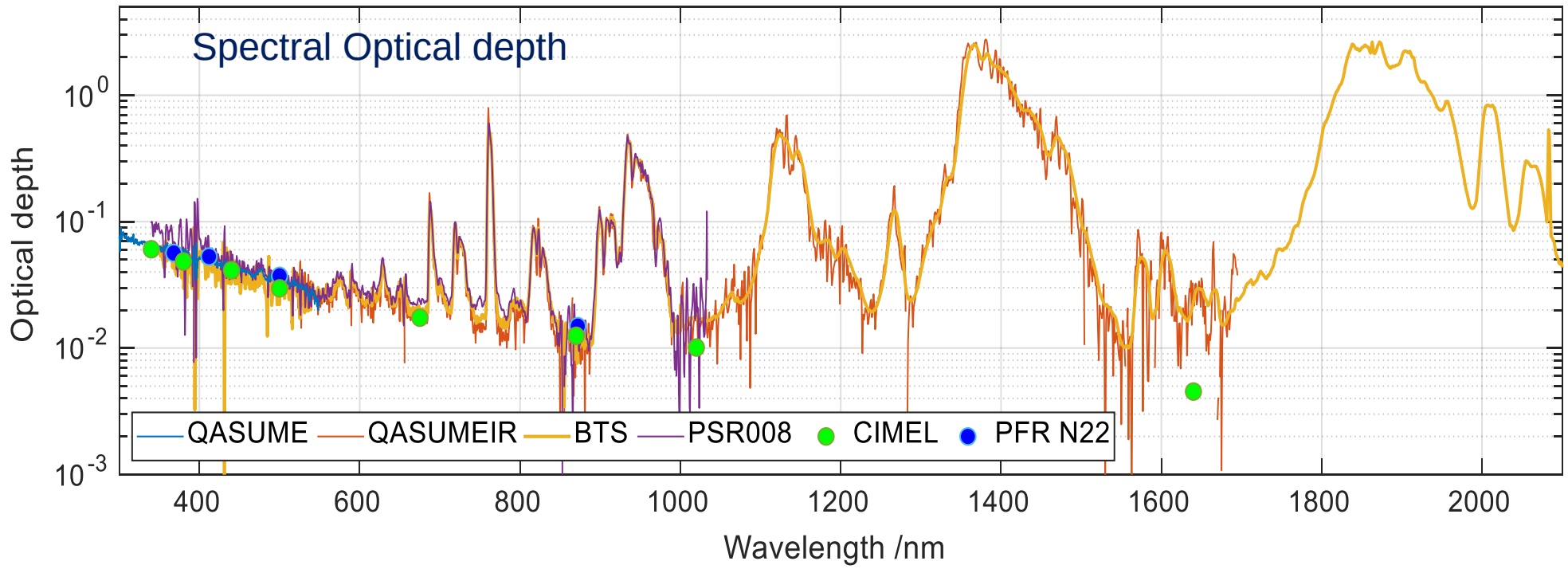
Global (total) and diffuse filter

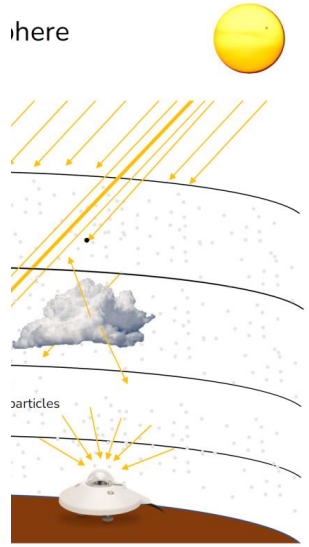
What columnar aerosol properties are retrieved / used for studying their radiative effects ?

Aerosol Optical Depth *(AOD) is a quantitative estimate of the amount of aerosol present in the atmosphere it is a measure of the extinction of a ray of light as it passes through the atmosphere. (main aerosol radiative impacts variable)*

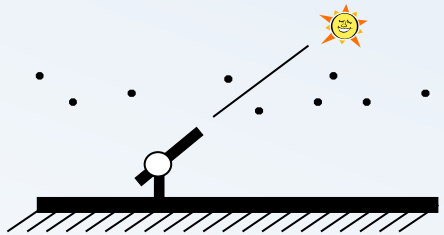
Aerosol Optical Depth (AOD) ~ aerosol amount
Beer – Lambert law

$$I = I_0 * e^{-m\tau}$$





Aerosol optical depth sun photometer measurement principles



Signal Volts (λ)

Calibration
Post processing (Atm. inputs)
Cloud "flagging"

AOD (λ)

unitless

$$I_\lambda = I_\lambda^0 * e^{-\tau_\lambda m}$$

Calibration

Atmospheric inputs

$$AOD = \delta_\tau(\lambda) = \frac{\ln\left(\frac{I_0(\lambda)}{I * r^2}\right) - \frac{p}{p_0} m_R(\theta)\delta_R(\lambda) - m_{O3}(\theta)\delta_{O3}(\lambda) - m_{NO2}(\theta)\delta_{NO2}(\lambda)}{m_\tau(\theta)}$$

measurement

Differences
- Calibration
- Algorithms
- NO_2, O_3, Rayleigh inputs
- Measurements
- Cloud flagging

PMODWRC – The World Radiation Center

Bureau International des Poids et Mesures

International Bureau of Weights and Measures

MR Agreement

WORLD METEOROLOGICAL ORGANIZATION
Weather · Climate · Water

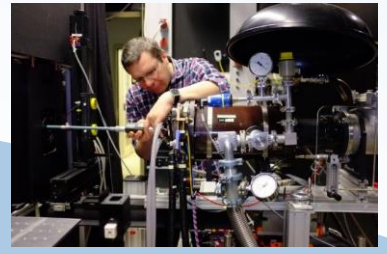
Standing Committee on Measurements, Instrumentation and Traceability

World Radiation Center (WRC)
Designated Institute for "Solar Irradiance"
4 sections

Solar Radiometry Section (WRC-SRS)

Infrared Radiometry Section (WRC-IRS)

World Calibration Center for UV (WCC-UV)



World Optical Depth Research and Calibration Center (WORCC)

Instruments: possible problems !!

Quality control and assurance procedures

Recalibration* (When ?)

Solar Pointing tolerance and link with the initial calibration (0.05 deg)

AOD retrieval inputs: e.g. Ozone, pressure, e.t.c.

Cloud flagging algorithm

Temperature

Wavelength crossing checks (negative AEs ?)

Ångström paremeter threasholds

Visual inspections

Uncertainty estimation

$$\tau_{aod} = \left[\log\left(\frac{Ic}{Io}\right) + \left(\tau_{ray} m_{ray} + \sum_i \tau_i m_i \right) \right] / m$$

direct solar irradiance I (signal or calibrated)
straylight in the FOV of the instrument
attenuation due to clouds .
I_0 solar irradiance at the top of the atmosphere
τ_{ray} optical depth of Rayleigh scattering
m_{ray} airmass for Rayleigh scattering
τ_{NO2} optical depth of nitrogen dioxide
m_{NO2} airmass for nitrogen dioxide
τ_{O3} ozone optical depth
m_{O3} ozone airmass
m aerosol airmass
P pressure at the site
trace gas absorption cross-section at wavelength λ

Calibration

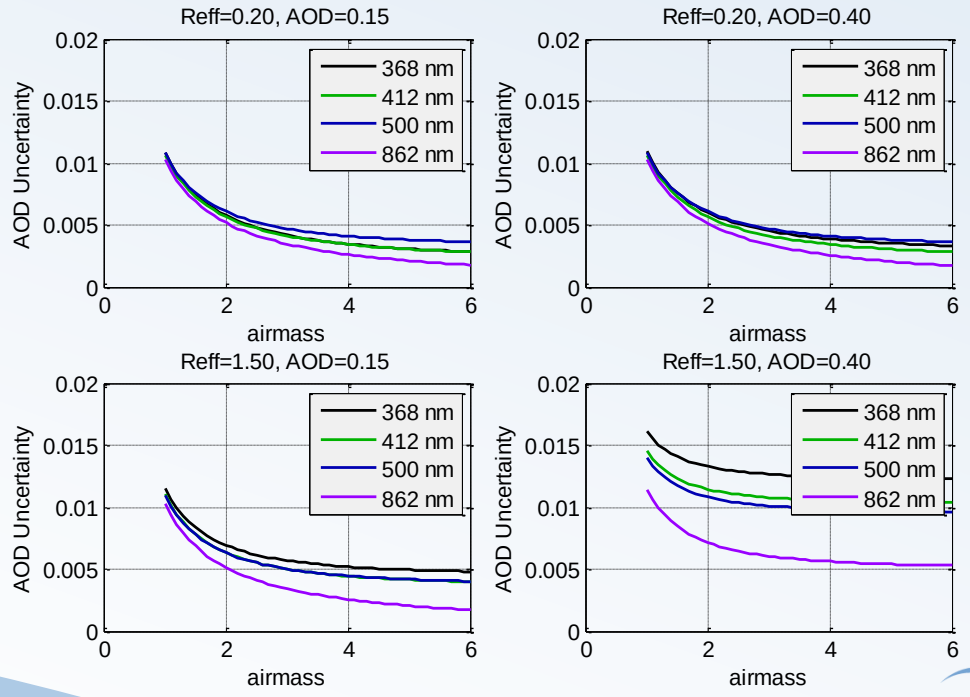
$$\frac{\vartheta \tau_{aod}}{\vartheta I_0} = \frac{1}{I_0} \cdot \frac{1}{m}$$

Ozone TC

$$\frac{\vartheta \tau_{aod}}{\vartheta \tau_{O3}} = \frac{m_{O3}}{m}$$

$$u = \sqrt{\sum_i \left(\left(\frac{\partial f}{\partial x_i} \right) \cdot u_{xi} \right)^2}$$

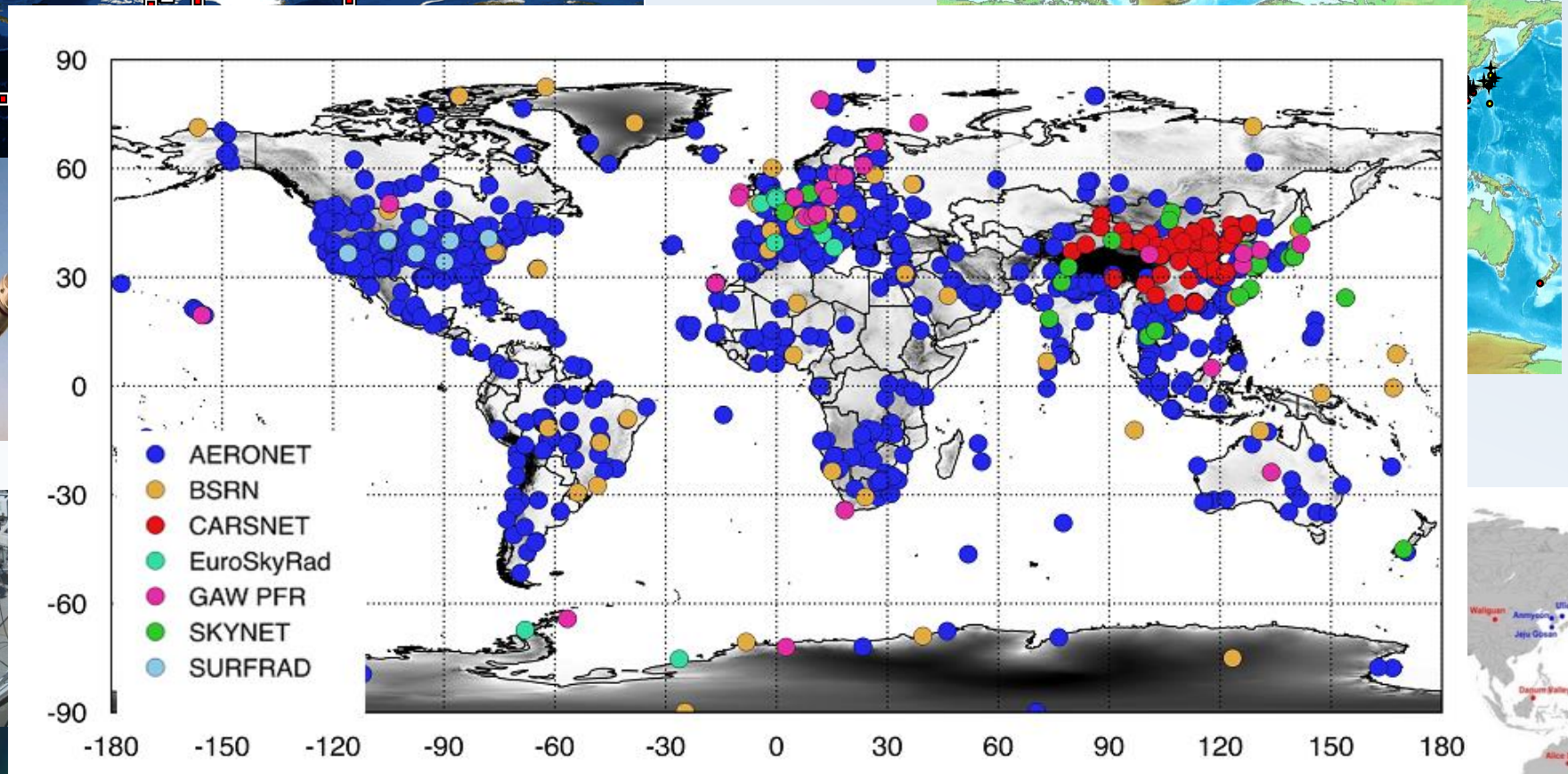
	aod		%	
PFR wavelength (nm)	**Coefficient of variation**	Standard Error (norm. distribution)	**Coefficient of variation**	Standard Error (norm. distribution)
368	**0.0013**	0.00015	**0.13**	0.015
412	**0.0015**	0.00015	**0.15**	0.015
500	**0.0014**	0.00014	**0.14**	0.014
863	**0.0017**	0.00009	**0.17**	0.009



AOD Networks and calibration and post processing hierarchy

AERONET Europe

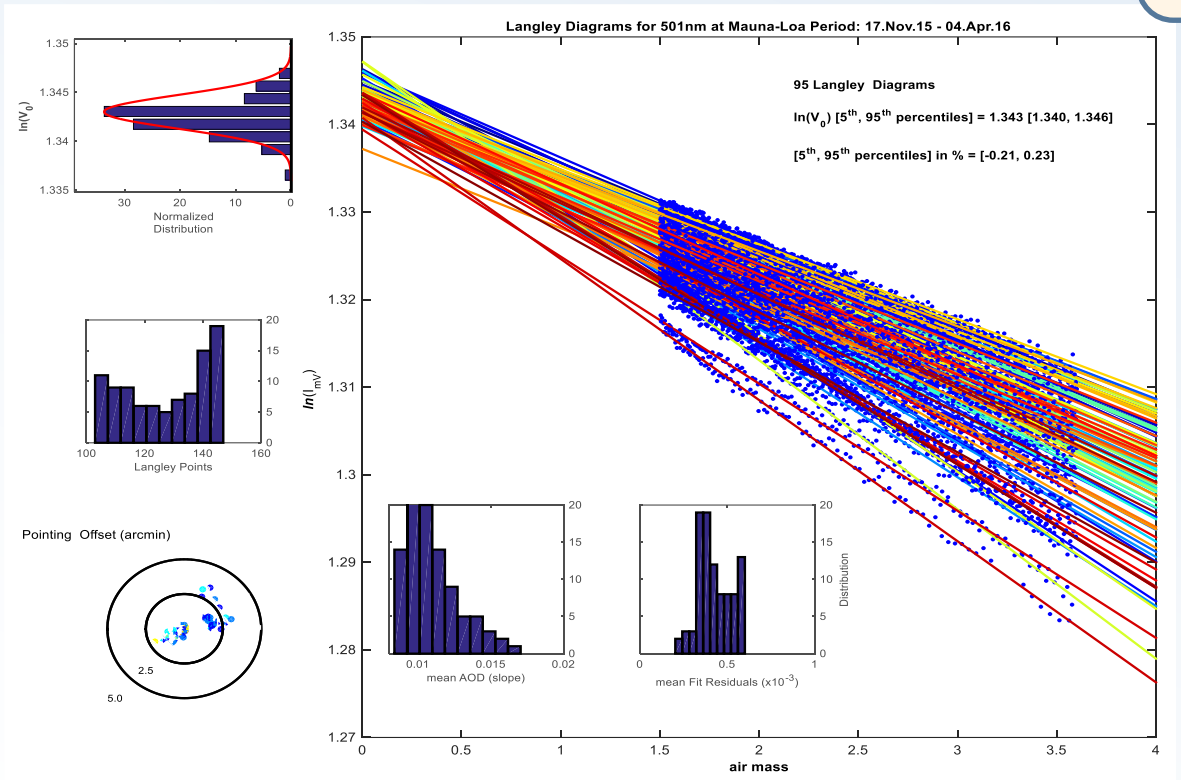
Skynet



GAW - PFR

Calibration of AOD measurements

Langley Technique



Langley plots and statistics to determine the calibration factor

Comparison with references

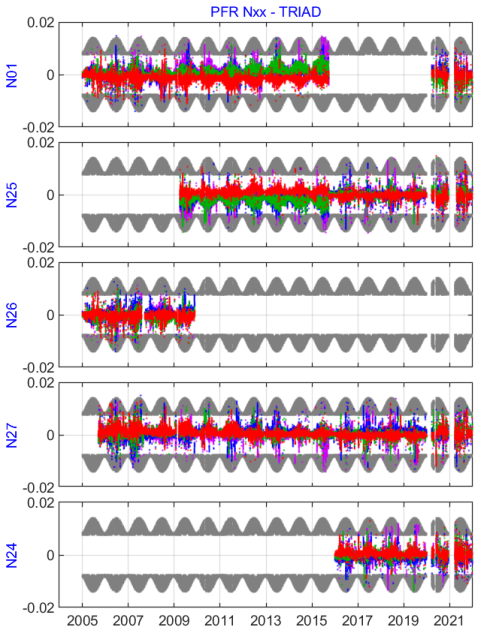
Bureau International des Poids et Mesures

International Bureau of Weights and Measures

MR Agreement

WORLD METEOROLOGICAL ORGANIZATION
Weather · Climate · Water

World Optical Depth Research and Calibration Center (WORCC)



ACTRIS (Calibration of Aerosol Remote sensing)

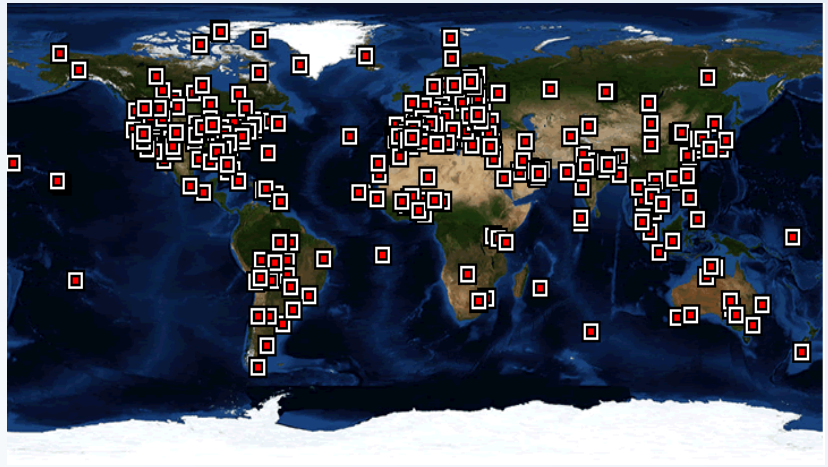
graubünden Education and Research.

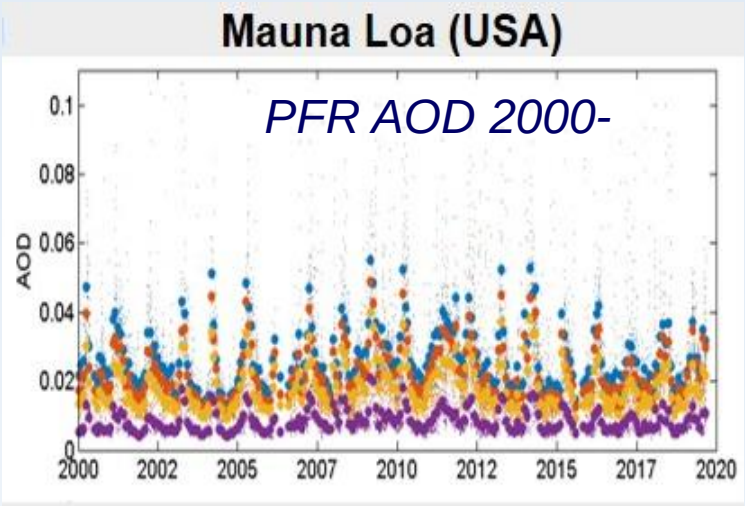
pmod wrc

Link with networks homogenization: Aeronet/NASA

Uncertainty 0.01 for >400nm, ~0.02 for UV

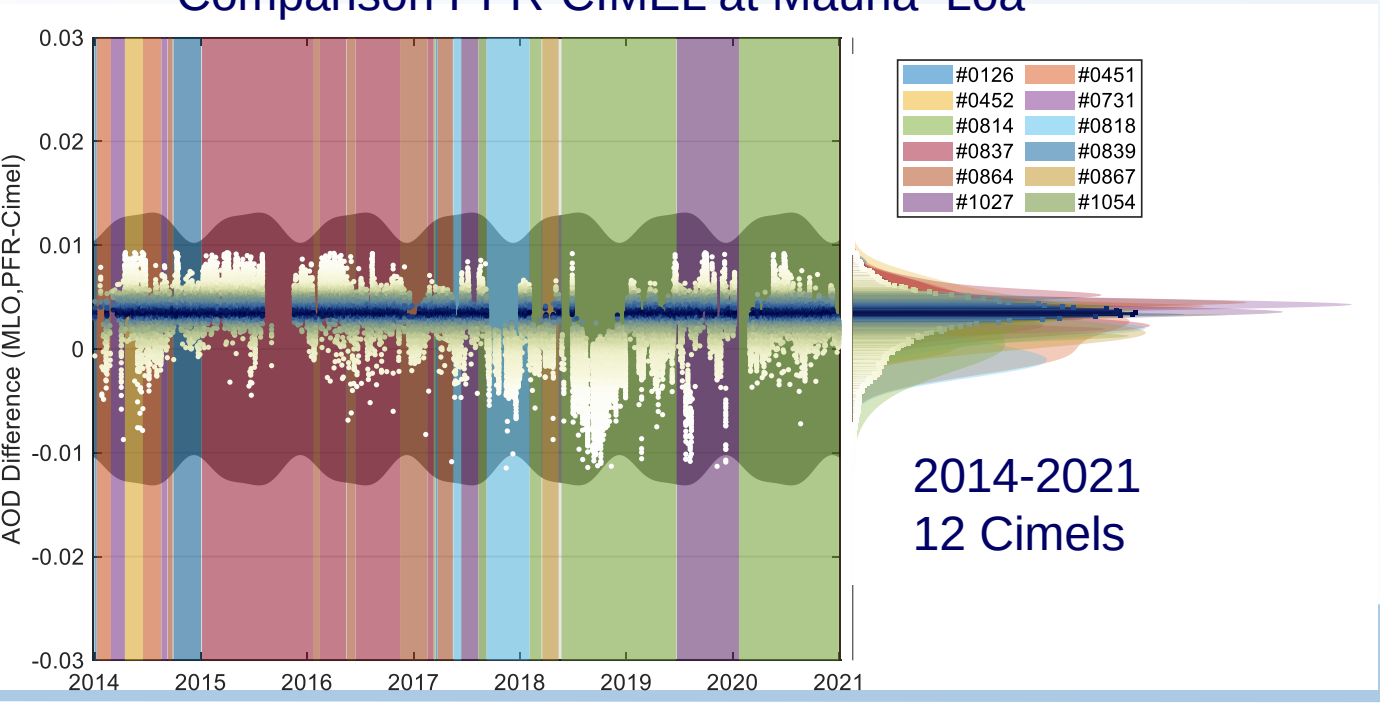
Aeronet



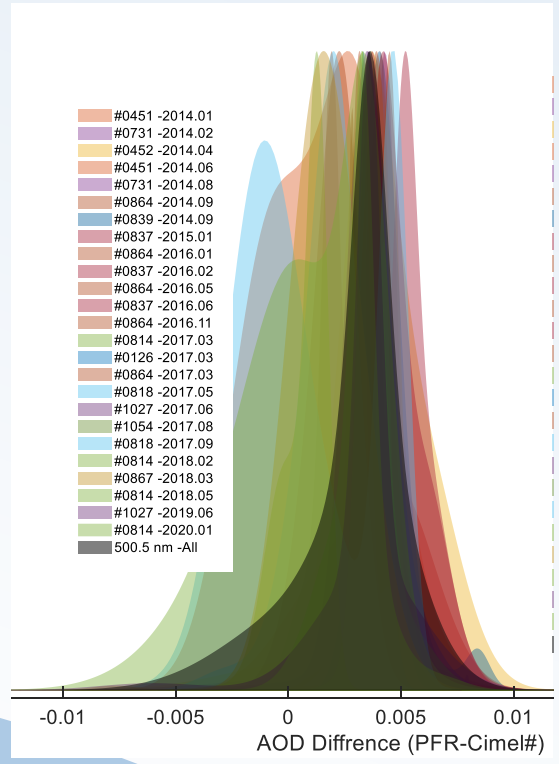


Aeronet reference site at Mauna Loa

Comparison PFR-CIMEL at Mauna Loa



2014-2021
12 Cimels

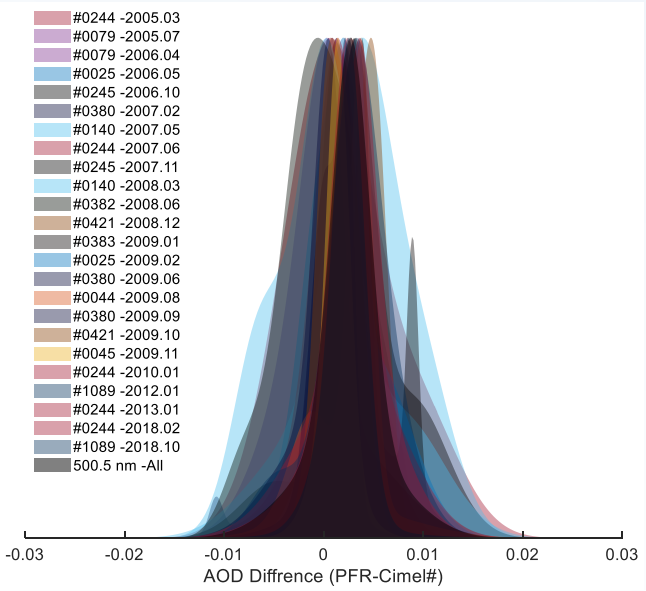


2000-2021
>95% of data
Within ±0.01

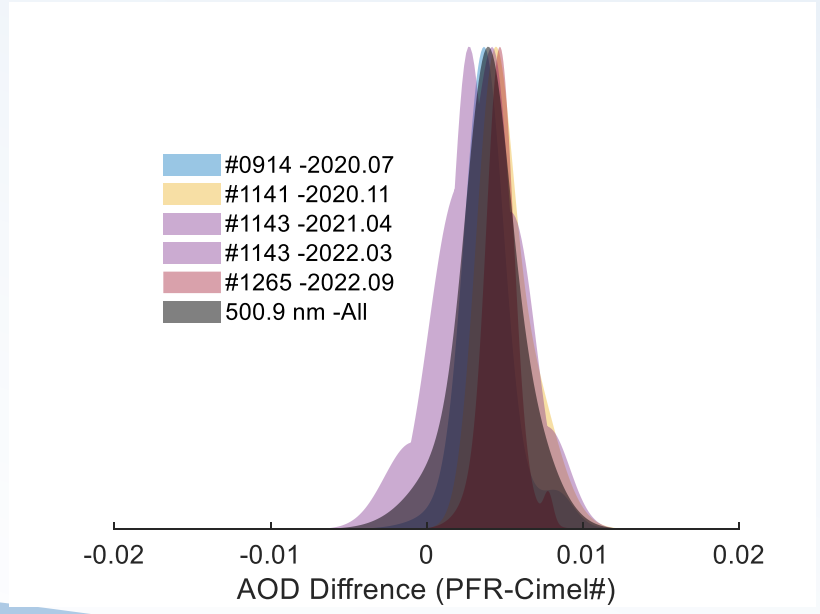
pmod wrc

ACTRIS - CARS and actris CH overview

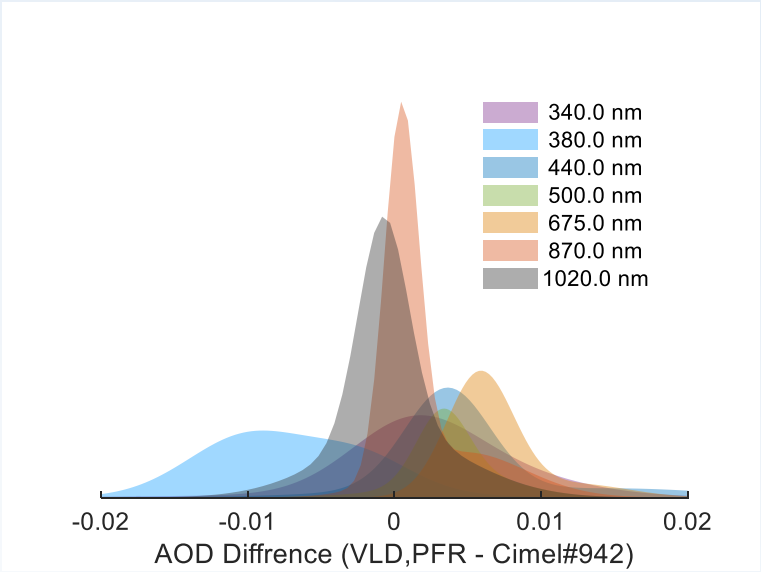
Izaña, Spain



Ohp, France



Valladolid, Spain



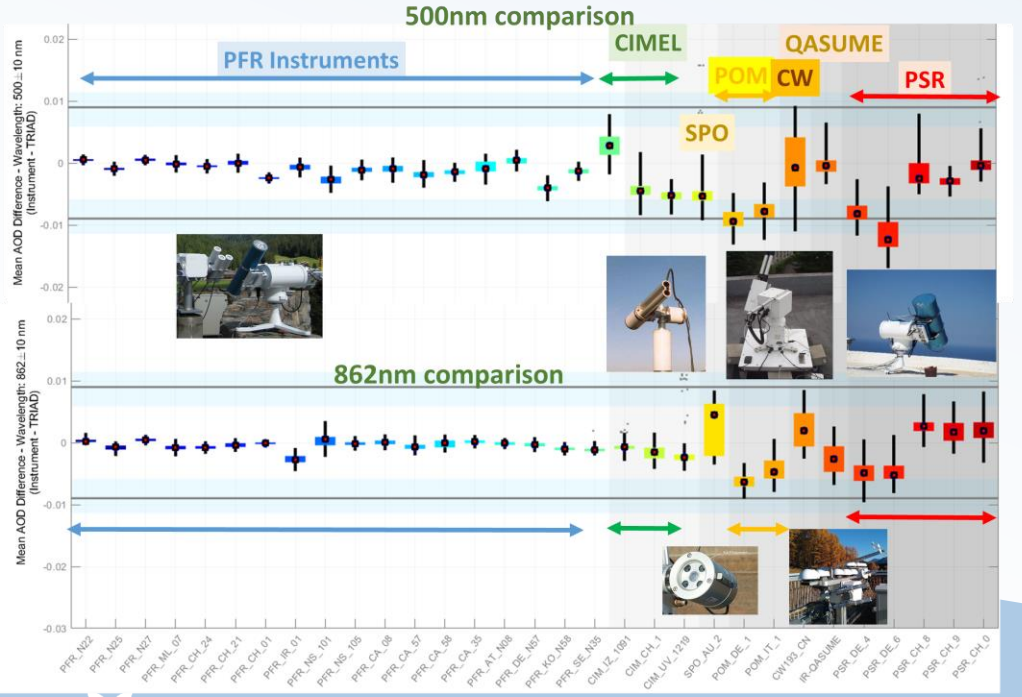
380 nm	440 nm	500 nm	865 nm
92.7%	95.7%	95.8 %	98.0%

Global AOD homogenization – Filter radiometer comparisons (2000 - 2021)

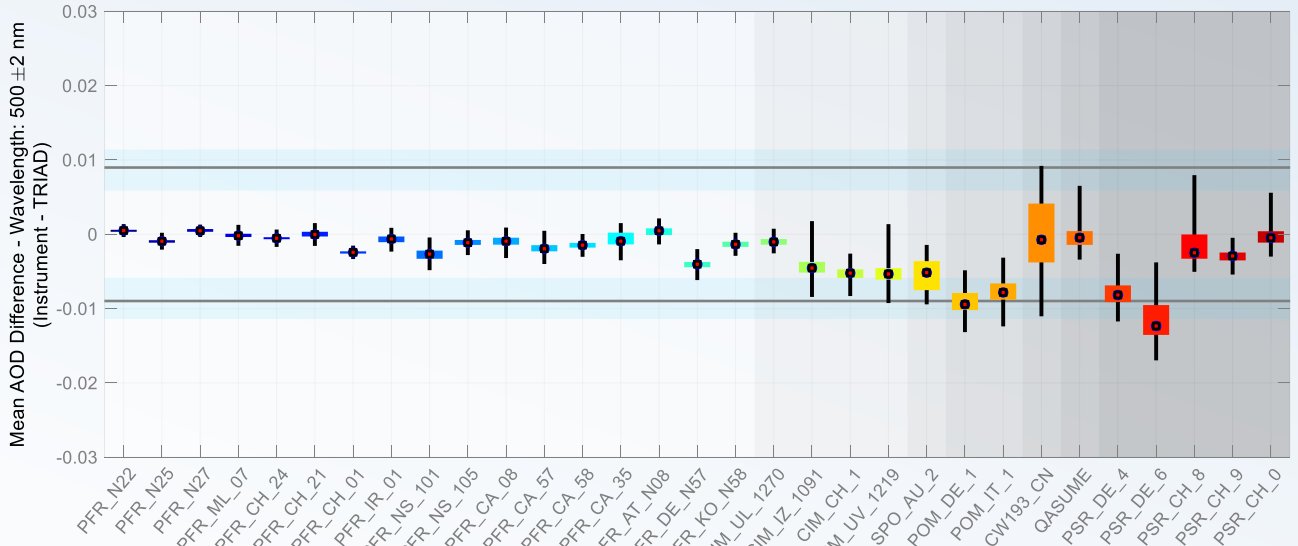
Davos, October 2021

Aerosol Optical Depth at 500nm

2015



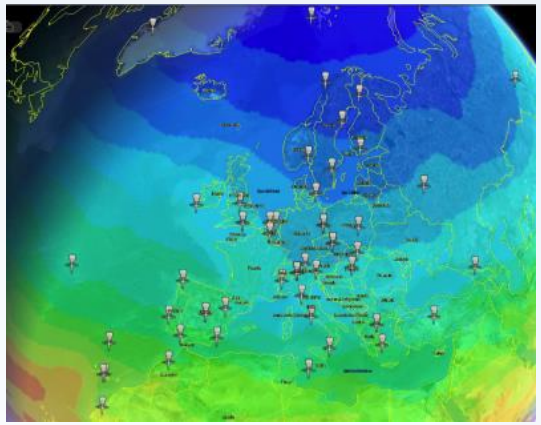
2021

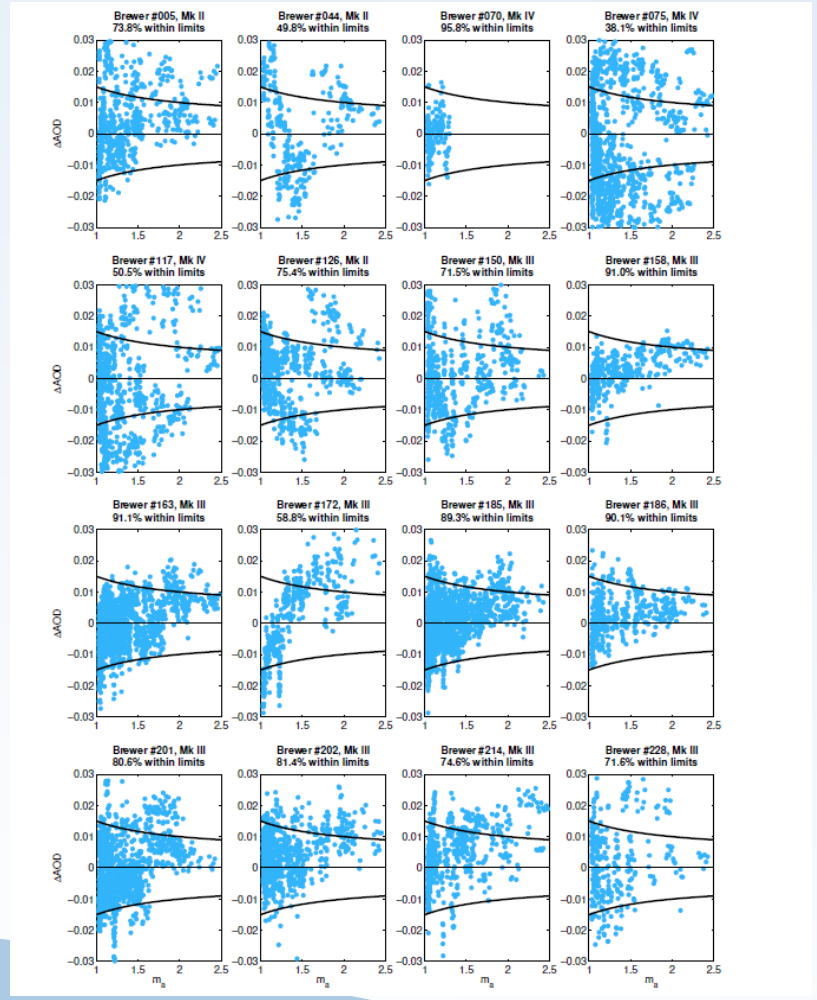


European brewer Network

Development of a traveling UV-PFR reference for calibrating Brewer instruments

Participation in 10th Regional Brewer Calibration Campaign, Huelva, Spain, 2015





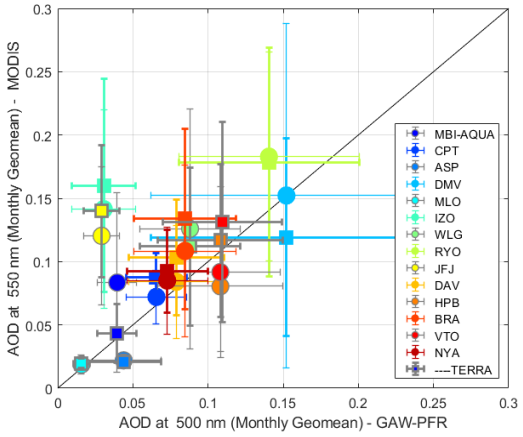
16 Brewers vs UV-PFR, AOD comparison at 313.5 nm,

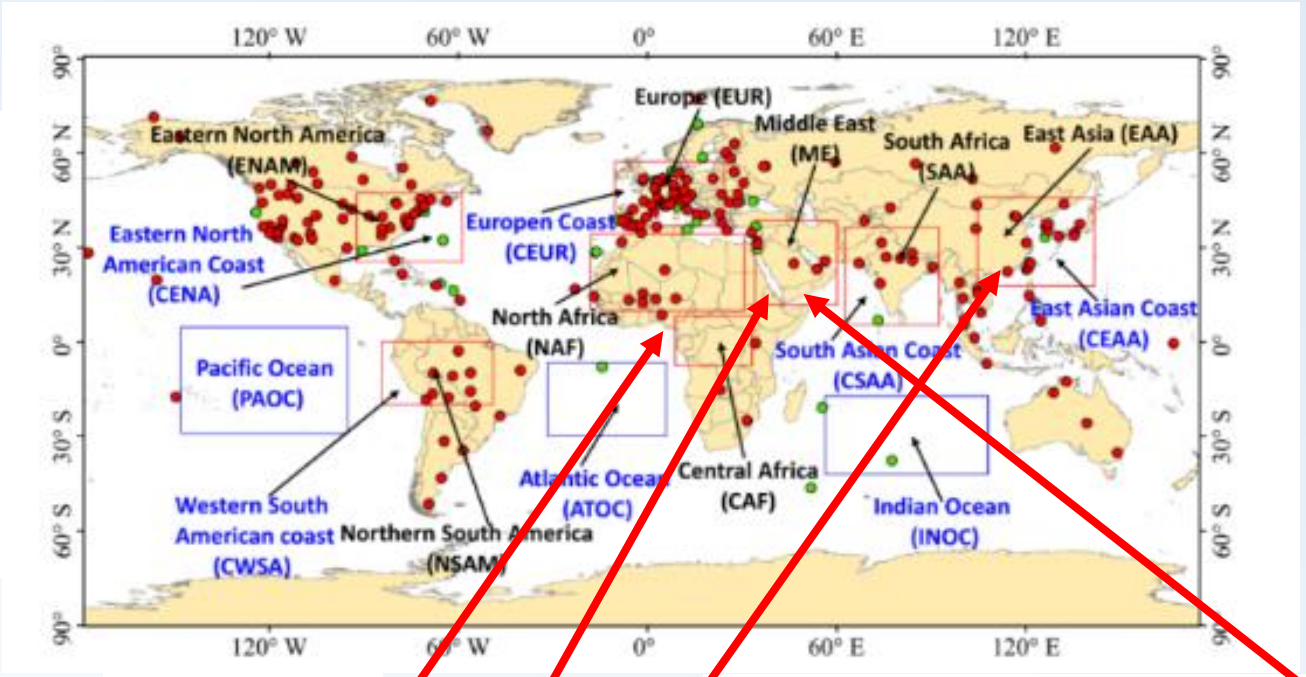
Ozone !!

Solano et al., 2018
Carlund et al., 2017

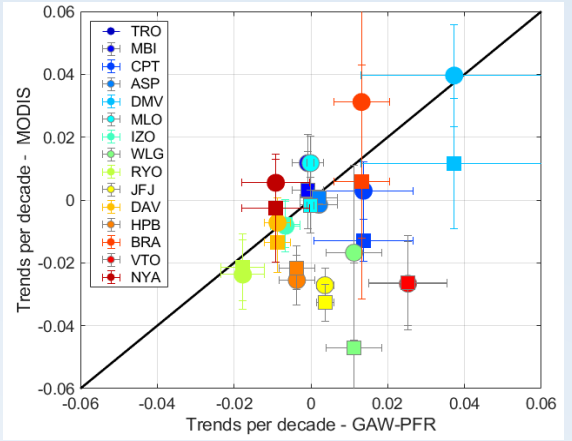
Why do we need homogenized surface based measurements of AOD ?

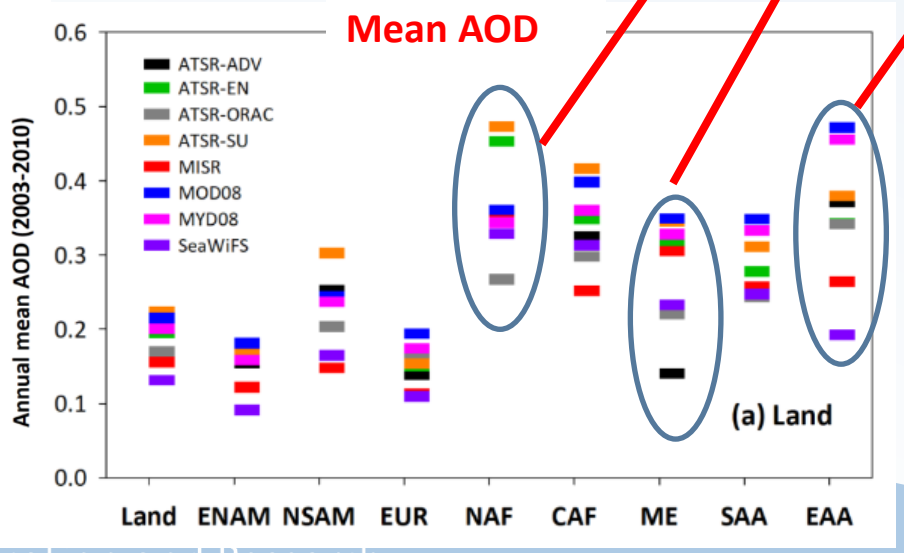
comparison

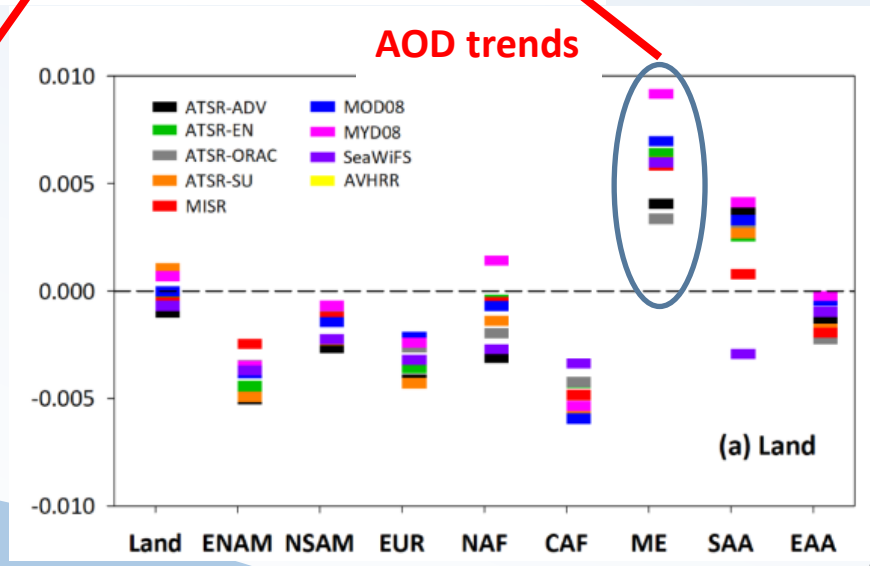




trends



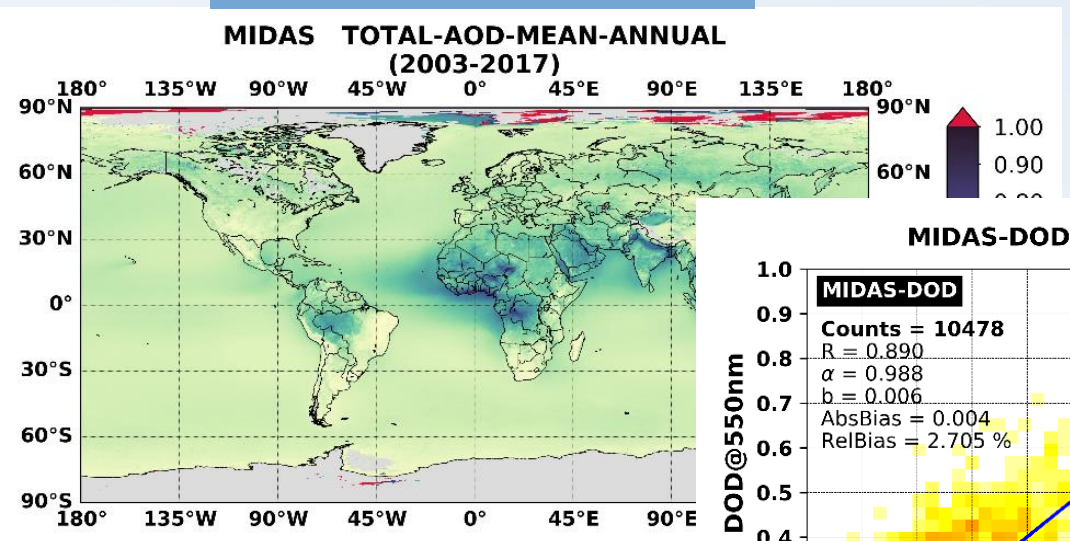




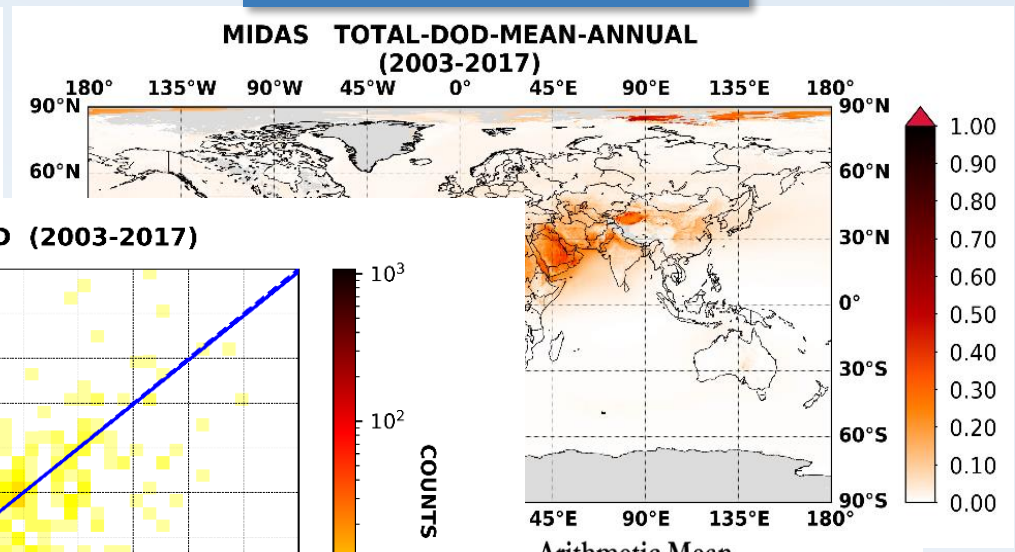
Wei et al., 2018

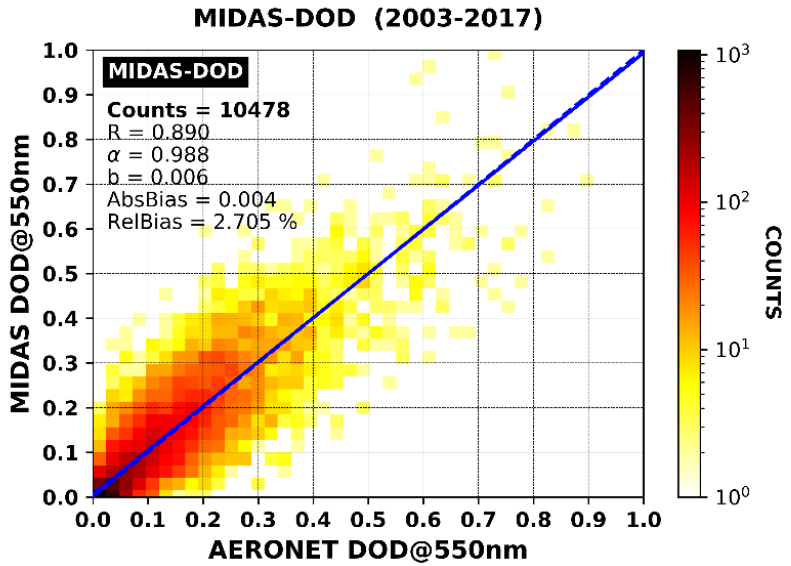
Satellite AOD

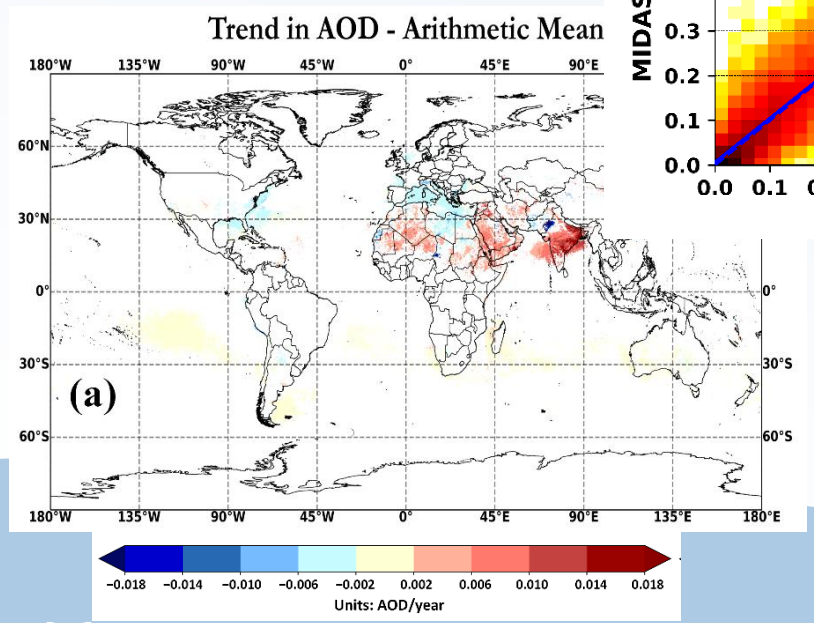
MODIS-Aqua AOD_{550nm}

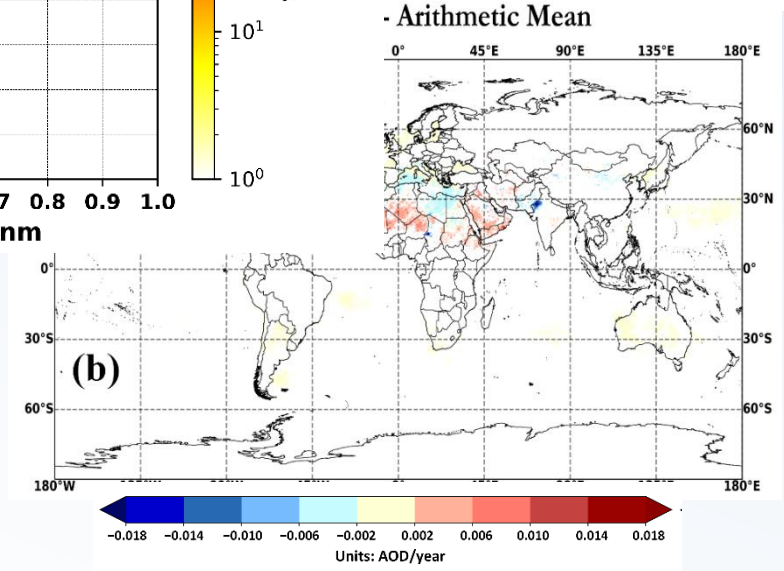


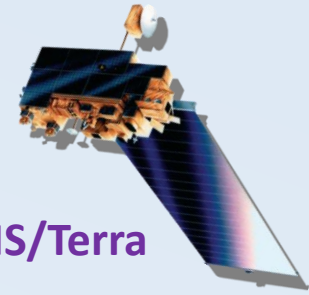
MIDAS DOD_{550nm}





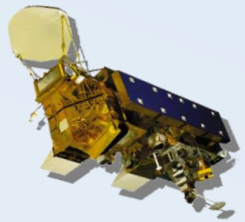




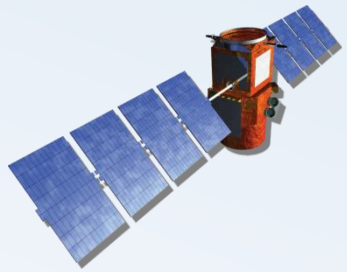


MODIS/Terra

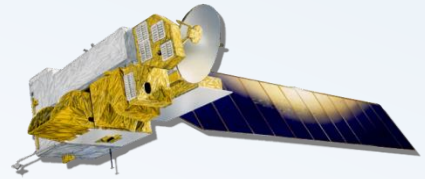
MODIS/Aqua



Calipso/Caliop



Aura/OMI



Gkikas et al., AMT 2020,
Logothetis et al., 2021

Temporal variation of global and hemispherical averages

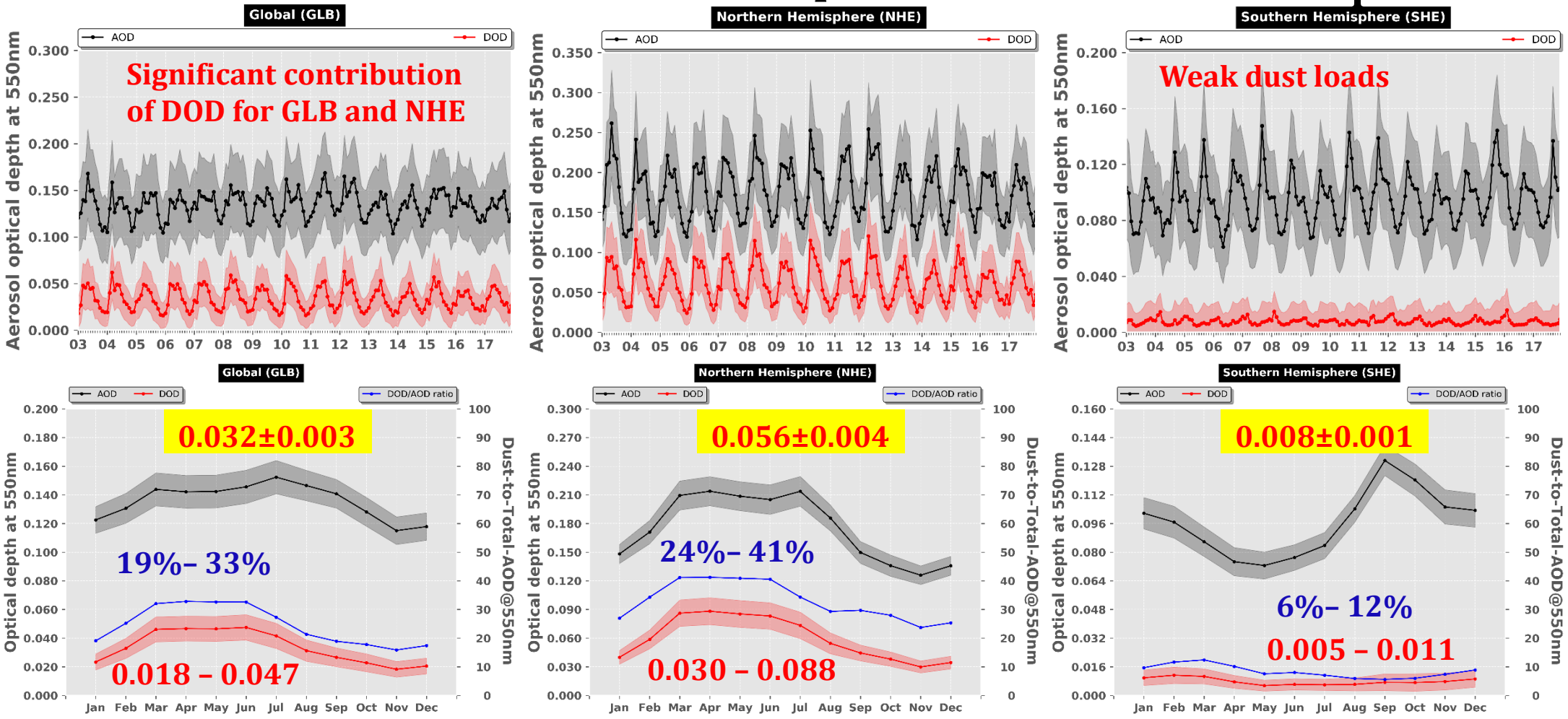
Global

N. Hemisphere

S. Hemisphere

Interannual

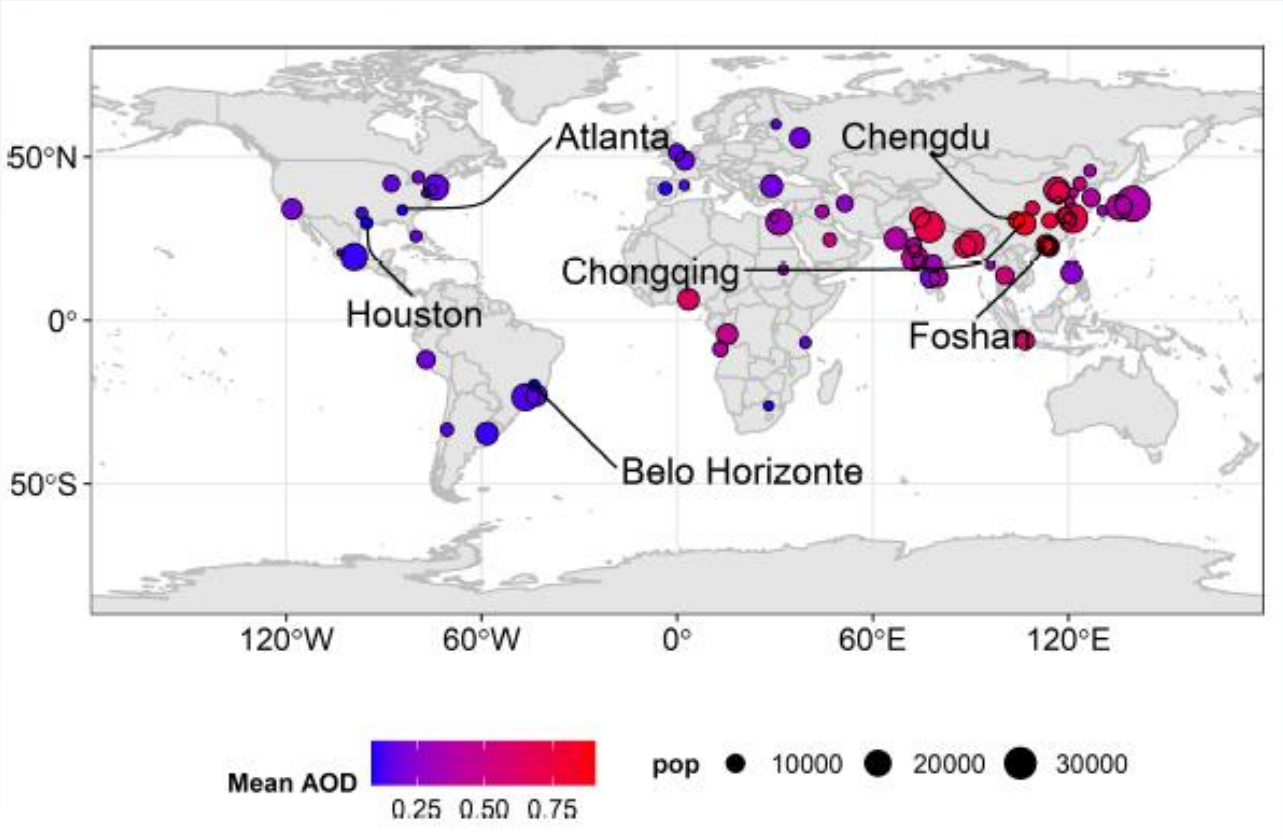
Intra-annual



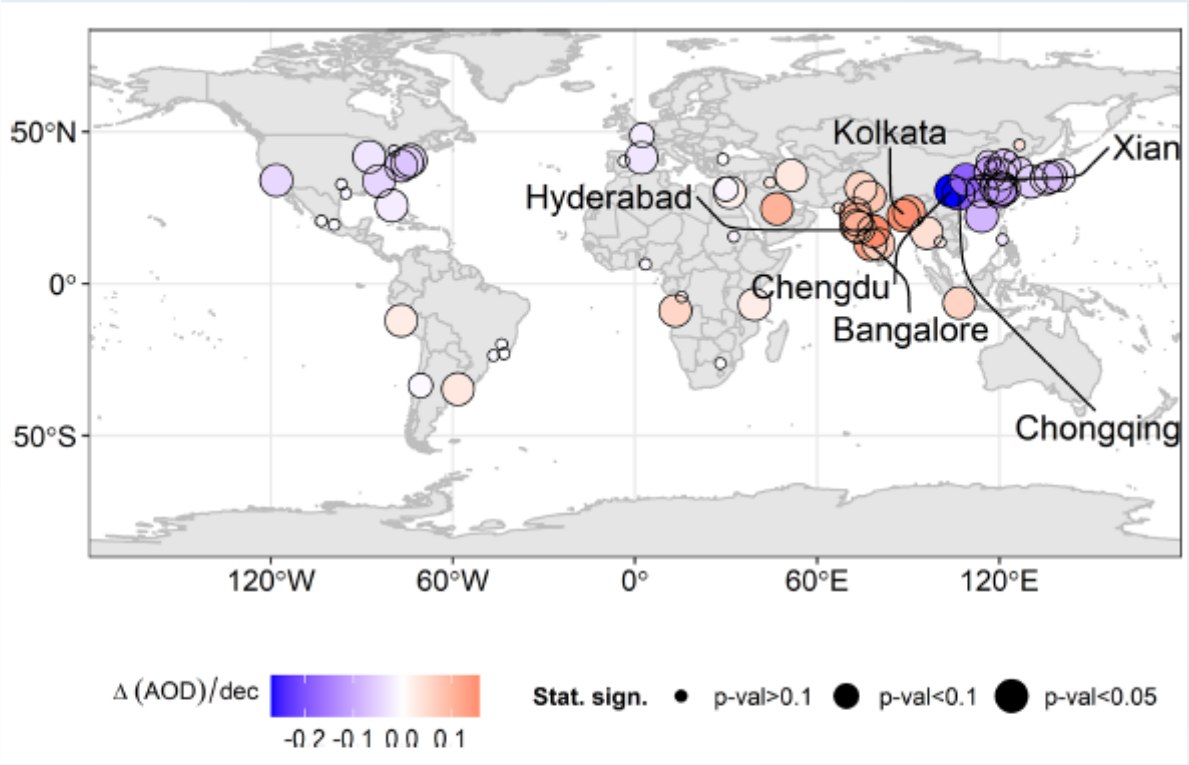
AOD | DOD | DOD-AOD ratio

Megacities – AOD and population

AOD



AOD change per decade



Papachristopoulou et al., ACP 2023

HARMONIA
International network for harmonization of atmospheric aerosol retrievals from ground based photometers

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the Horizon 2020 Framework Programme of the European Union

Harmonia: International network for harmonization of atmospheric aerosol retrievals from ground-based photometers

https://harmonia-cost.eu/

Action Chair
Stelios Kazadzis – PMOD World Radiation Center – Switzerland

graubünden Education and Research.

pmod wrc

What is COST ?

European Cooperation in Science & Technology

MISSION

COST provides networking opportunities for researchers and innovators in order to strengthen Europe's capacity to address scientific, technological and societal challenges

Networking Action

STRATEGIC PRIORITIES

- **Promoting and spreading excellence**
- **Fostering interdisciplinary research for breakthrough science**
- **Empowering and retaining young researchers**

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

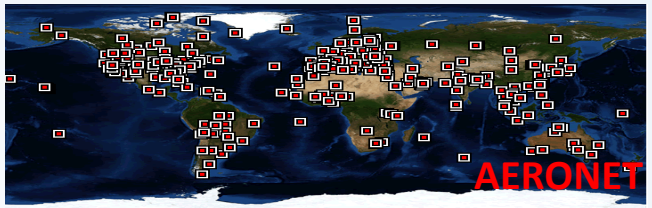
Funded by the Horizon 2020 Framework Programme of the European Union

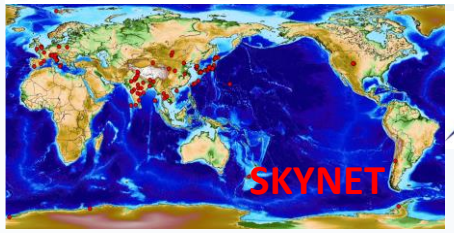
pmod wrc

Harmonia - Challenges / Questions

How European and global sun-photometer users can use common standards?

WG1
Aerosol measurement homogenization





ACTRiS

Calibration
Post processing
(Atm. inputs)
Clouds

→ *Direct sun or inversion based Aerosol optical properties*

- *Langley Calibrations*
- *Comparison with reference instruments*
- *In situ calibrations*
- *SI traceable calibrations*

Different reference standards

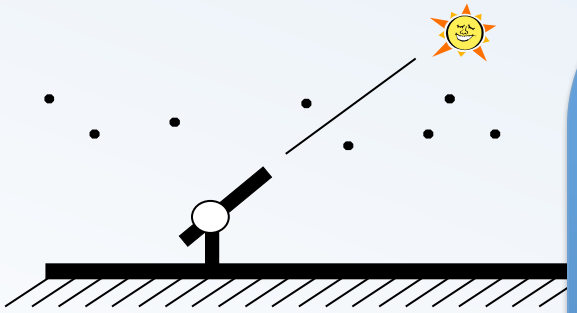
- *Post processing models and inputs*

pmod wrc

Harmonia - Challenges / Questions

How can scientists improve the measurement quality of aerosol optical properties?

WG2
Aerosol measurement improvement



Uncertainty sources

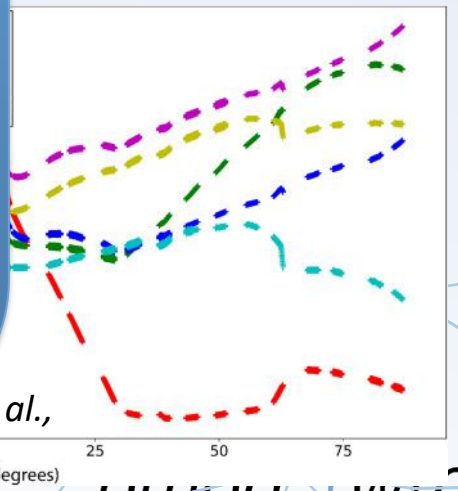
- ✓ Direct solar irradiance measureme
- ✓ Top of atmosphere solar irradiance
- ✓ Radiance calibration
- ✓ Inversion modeling
- ✓ Rayleigh optical depth
- ✓ Ambient pressure
- ✓ Ozone and NO_2 optical depth
- ✓ Airmass
- ✓ Temperature correction
- ✓ Water vapor and CO2-CH4 correct
- ✓ Field of view - stray light
- ✓ Window cleaning
- ✓ Cloud contamination

Davos Oct, 2015-2021
WMO – FRC campaign

Izaña, Lunar campaign 2018
Lindenberg, Scilla, campaign 2020

AEMET SeAtember 2022
MAPP campaign

Rome, 2018-2021
Quatram campaigns

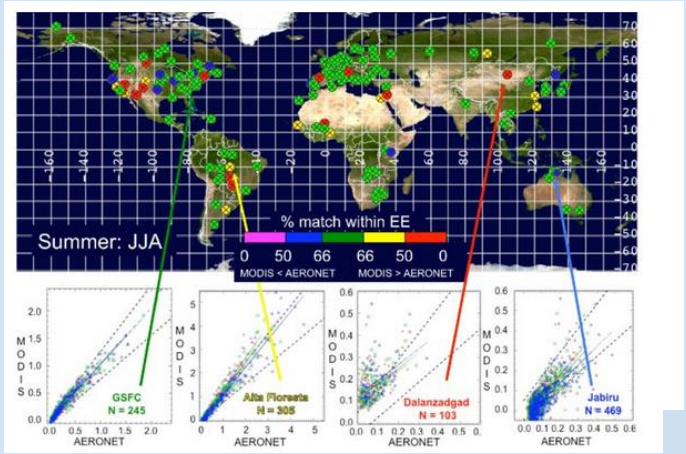


et al.,

Harmonia - Challenges / Questions

How can the aerosol community increase the applicability of the aerosol products?

Satellite validation



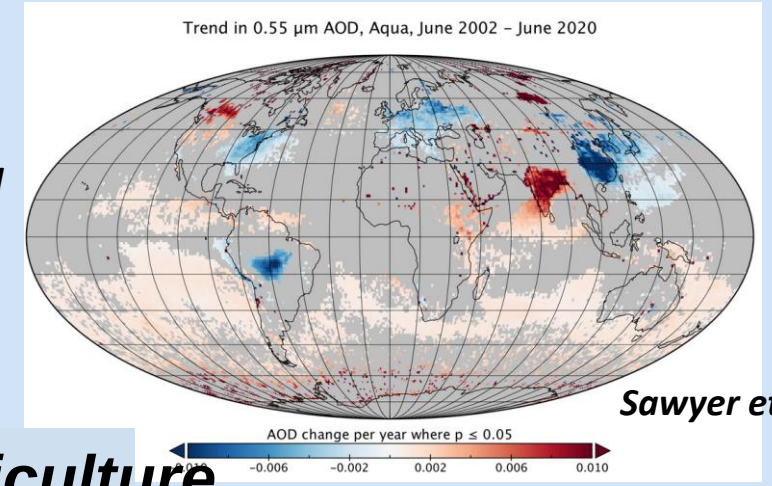
Satellite based sensors are constantly validated with surface based sun photometers

Spatiotemporal changes

R. Kahn et al.,

Aerosol climatology and trends

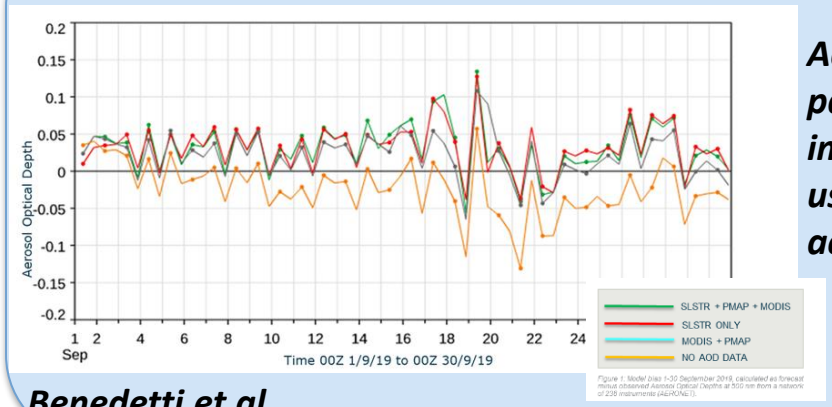
Aerosol trends and uncertainty



Sawyer et al.,

+ Climate, Solar energy , agriculture..

Model improvement



Aerosol and other parameter forecasting improvement with the use/assimilation of aerosol data

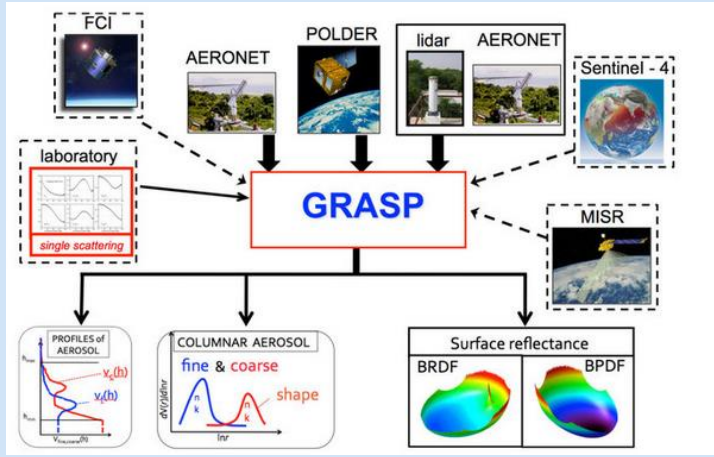
Benedetti et al.,

Synergies

Model products including sun photometric aerosols

e.g. lidars, satellites

Dubovik et al.,



Harmonia - Challenges / Questions

WG4

Industry engagement towards innovative hardware, software products

How can scientists improve aerosol measurement quality through hardware/software innovation, including low-cost sensors?

Hardware developments to improve retrievals
Collaboration with Metrological institutes
New spectroradiometers for aerosol retrievals
Software improvements for post processing
Low cost sensors

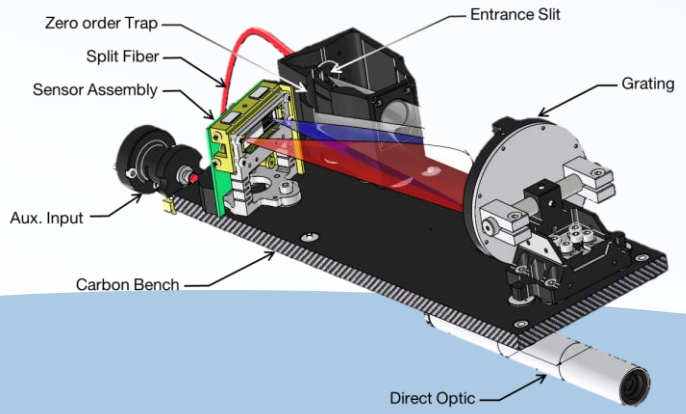
CIMEL EXPLORE THE CLIMATE

Gigahertz-Optik Member of the BERGHOF GROUP

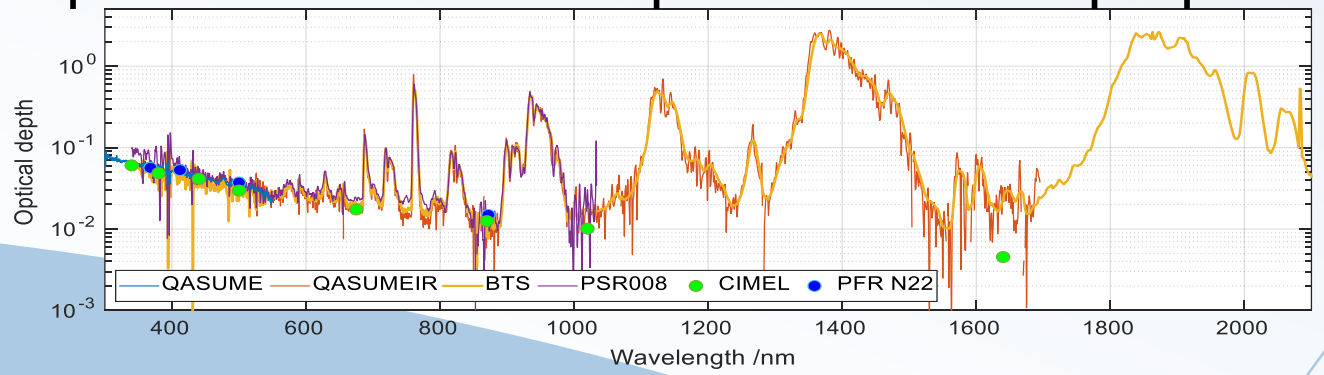
EKO Beyond Accuracy.

GRASP

raymetrics



Spectroradiometers/ spectral aerosol properties



graubünden Education and Research.

pmod wrc

- Memberships

Nov. 2022 – Oct. 2026
MC members: 54
MC Countries: 36
ITC: 22

WG members: **110 approved, from 41 countries**

Cost Harmonia Tools

- ***Short term scientific missions***
- ***Virtual Mobility***
- ***IT Coutries conference Grants***

Harmonia tools

Short-term scientific missions (STSM)

WHERE:
To a host organization located in a **different** country than the country of affiliation

Grant AMOUNT:
Up to 4000 EUR
Paid after report approval (after the STSM)

Based on the Harmonia objectives
Who: everyone from a COST country

ITC Conference Grants

WHERE:
To high-level conference **not organised by the Action itself**

Grant AMOUNT:
Up to 2000 EUR or 500 EUR (virtual) Paid after report approval (after the conference)

Based on the Harmonia objectives
Who: ITC or NNC countries and less than 40 years old

Virtual mobility grant

WHAT:
A collaboration in a virtual setting among Action researchers or innovators to exchange knowledge, learn new techniques, etc.

Grant AMOUNT:
Up to 1500 EUR
Paid after report approval from Core group

Based on the Harmonia objectives
Who: everyone

ITC: Albania, Bulgaria, Cyprus, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, North Macedonia, Poland, Portugal, Romania, Serbia, Slovakia, Turkey, Ukraine*

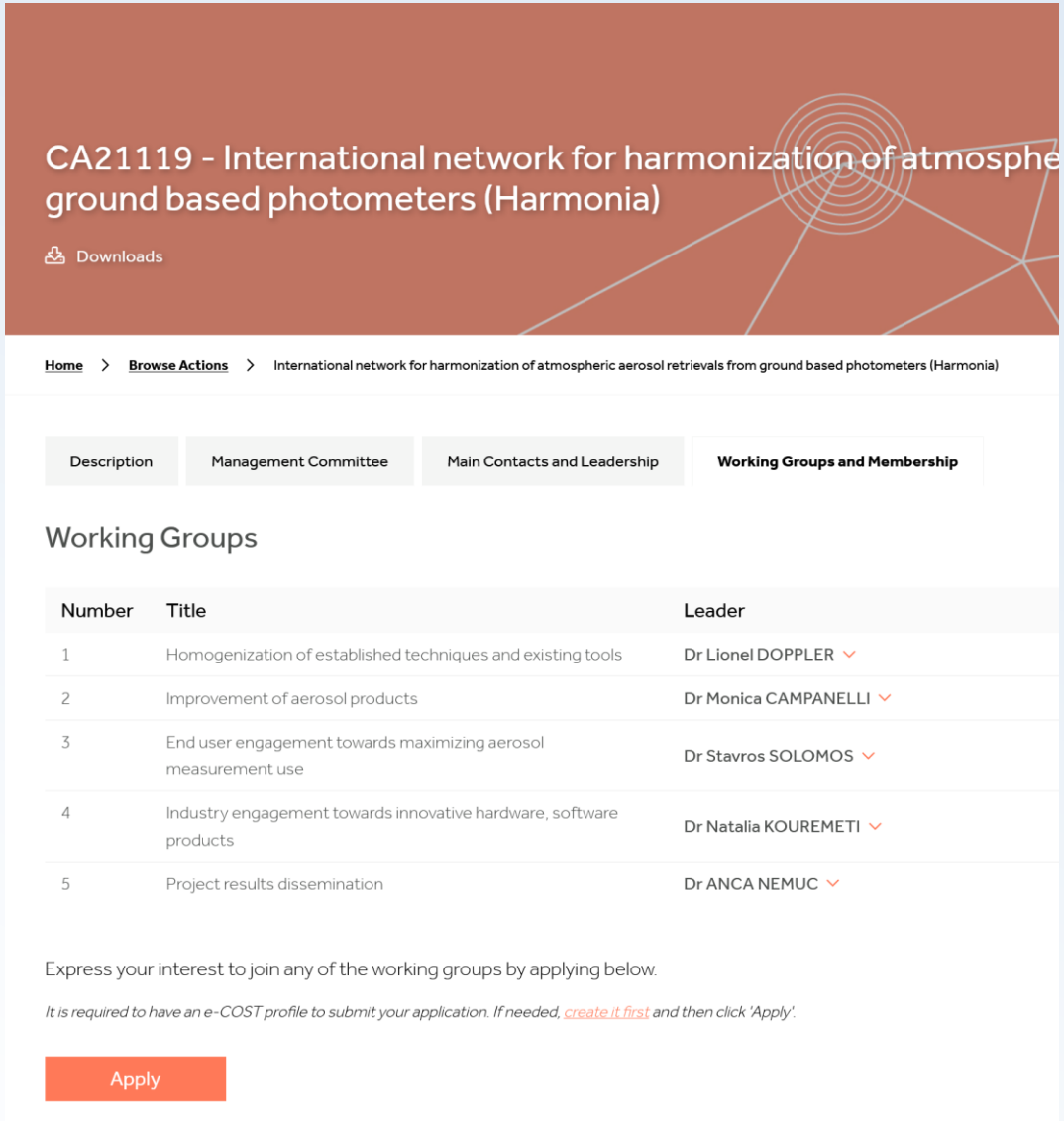
NNC: Algeria, Armenia, Azerbaijan, Egypt, Georgia, Jordan, Kosovo, Lebanon, Libya, Morocco, the Palestinian Authority, Syria, Tunisia and Ukraine*

Joining Harmonia

https://www.cost.eu/actions/CA21119/

https://harmonia-cost.eu/

@HARMONIA_COST
Stelios.Kazadzis@pmodwrc.ch



CA21119 - International network for harmonization of atmosphe
ground based photometers (Harmonia)

Downloads

Home > Browse Actions > International network for harmonization of atmospheric aerosol retrievals from ground based photometers (Harmonia)

Description | Management Committee | Main Contacts and Leadership | **Working Groups and Membership**

Working Groups

Number	Title	Leader
1	Homogenization of established techniques and existing tools	Dr Lionel DOPPLER
2	Improvement of aerosol products	Dr Monica CAMPANELLI
3	End user engagement towards maximizing aerosol measurement use	Dr Stavros SOLOMOS
4	Industry engagement towards innovative hardware, software products	Dr Natalia KOUREMETI
5	Project results dissemination	Dr ANCA NEMUC

Express your interest to join any of the working groups by applying below.

It is required to have an e-COST profile to submit your application. If needed, create it first and then click 'Apply'.

Apply

https://harmonia-cost.eu/

Thank you for your attention

@HARMONIA_COST
Stelios.Kazadzis@pmodwrc.ch

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the Horizon 2020 Framework Programme of the European Union