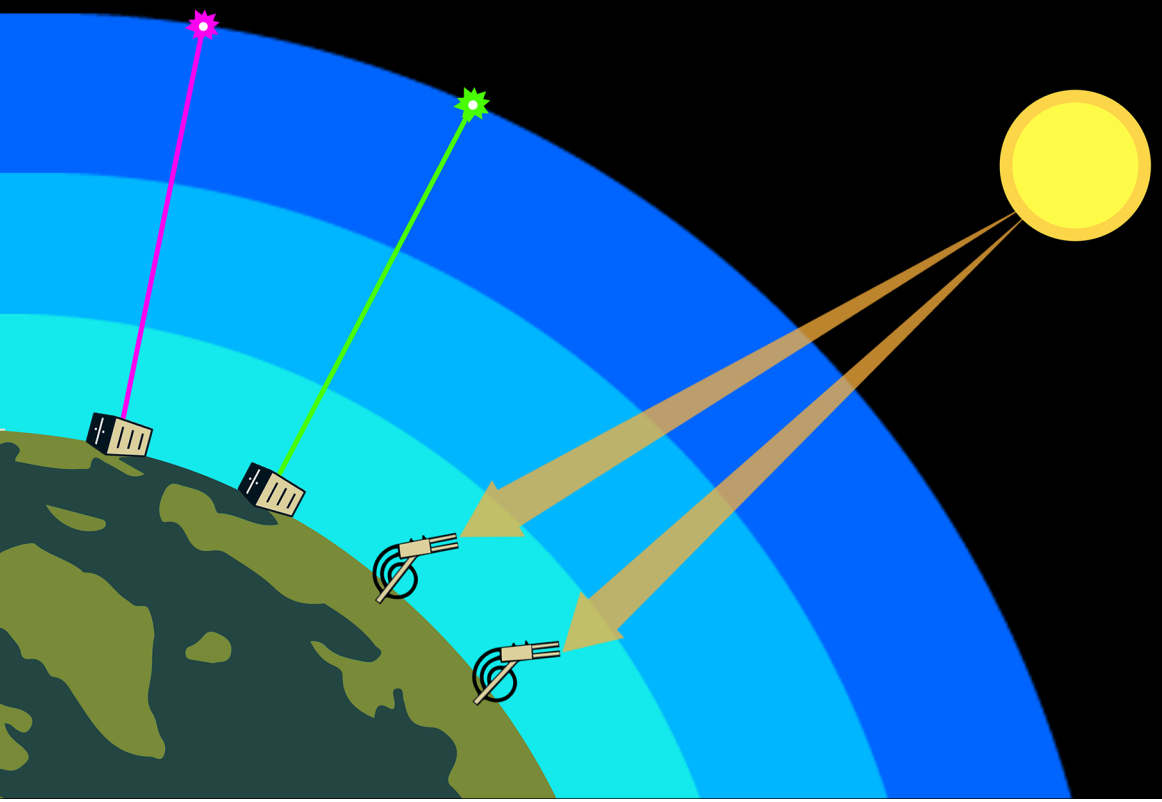
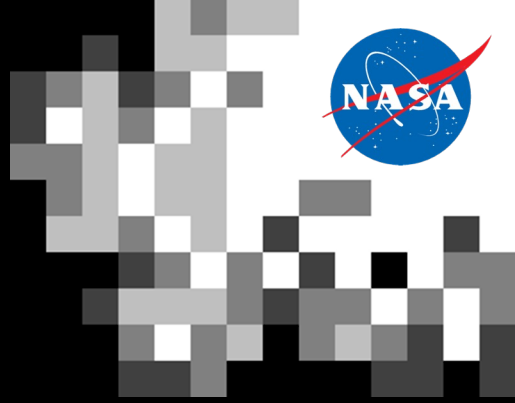
National Aeronautics and Space Administration



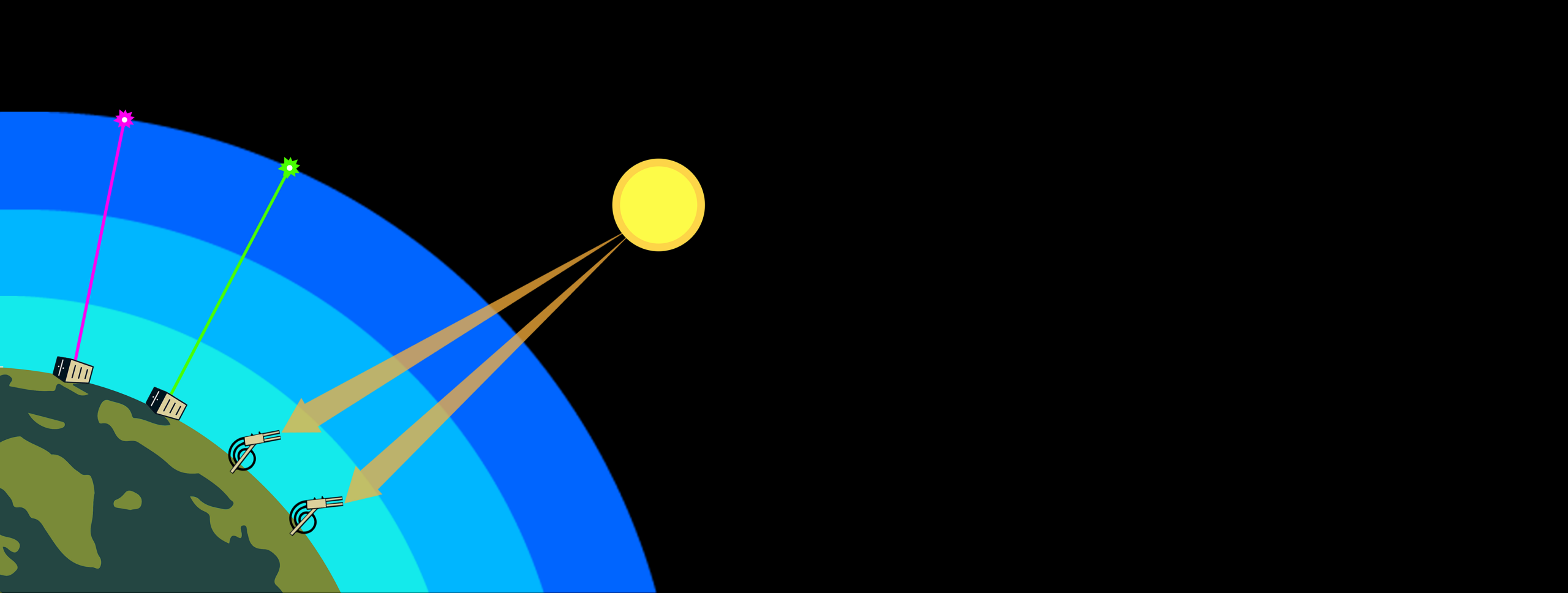


NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications

Part 1: Introduction to the Aerosol Robotic Network (AERONET)

Carl Malings (Morgan State University) & Pawan Gupta (NASA Goddard Space Flight Center)

August 8, 2024



About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.


AGRICULTURE


CLIMATE & RESILIENCE


DISASTERS


ECOLOGICAL CONSERVATION

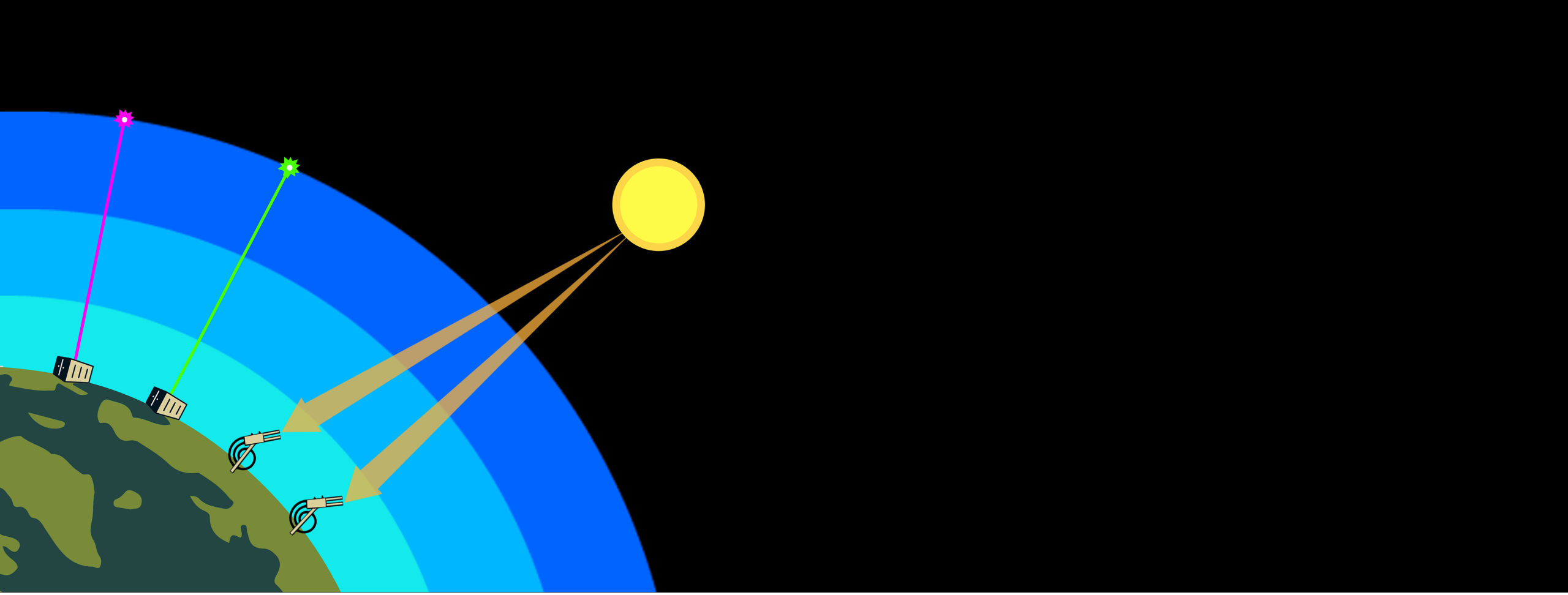

HEALTH & AIR QUALITY


WATER RESOURCES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.

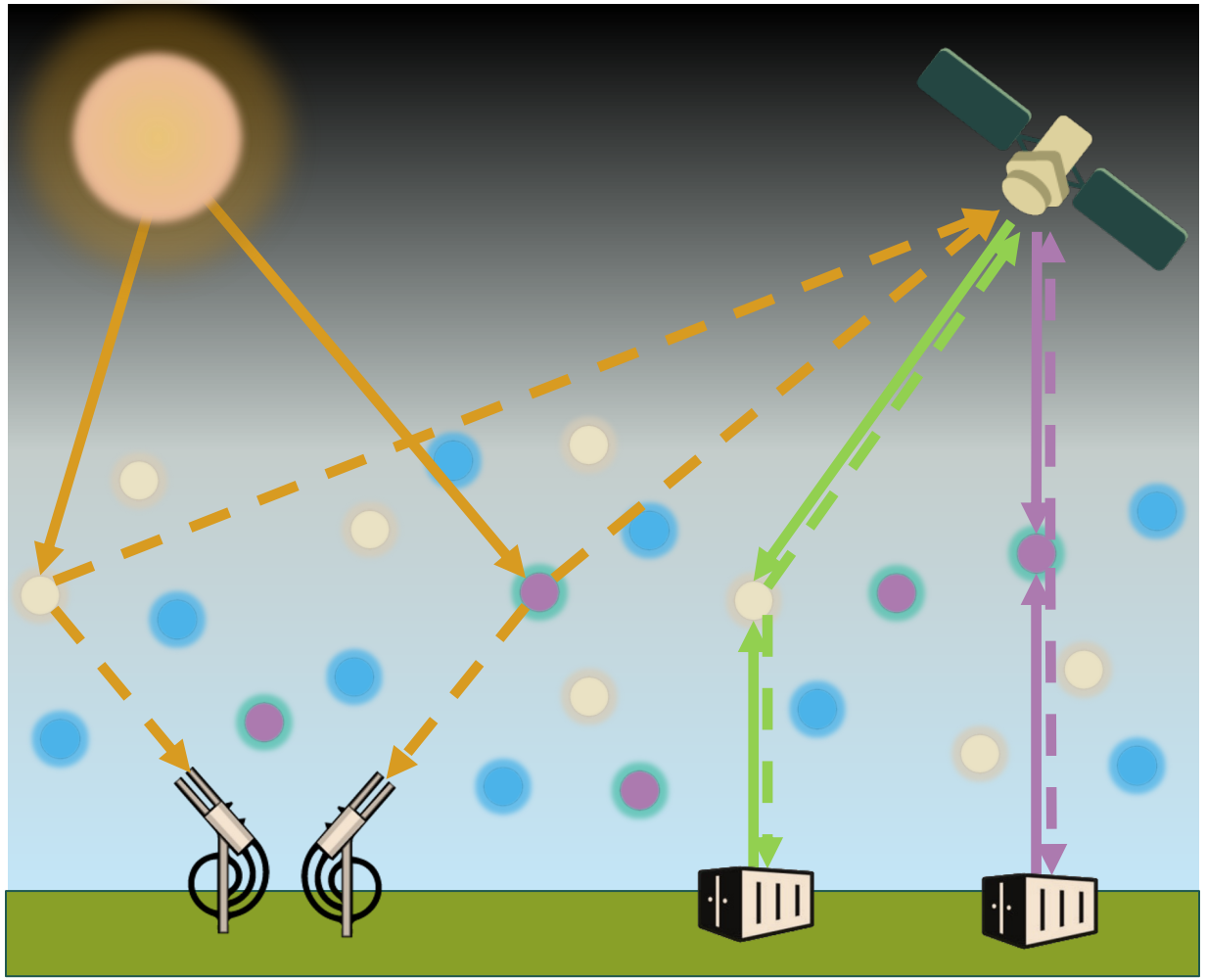


NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications

Overview

NASA's Atmospheric Composition Ground Networks

- NASA supports four atmospheric composition ground-based remote sensing networks:
  - **AERONET**
  - **Pandora**
  - **TOLNet**
  - **MPLNET**
- Ground networks offer a bottom-up view, complementing satellites' top-down view.
- Together, these networks:
  - Provide trace gas and aerosol column concentrations and vertical profiles
  - Support air quality and climate applications
  - Allow for continuity across satellite missions



Training Learning Objectives

By the end of this training, participants will be able to:

- Identify the basic characteristics, capabilities, and limitations of the NASA instruments used for ground-based active and passive remote sensing of aerosols, ozone, and nitrogen dioxide (NO_2).
- Recognize how the ground networks presented in the training sustain global long-term observations, support air quality and climate applications, and complement satellite observations.
- Access relevant atmospheric composition data from appropriate NASA ground networks for given locations and application purposes.
- Compare and jointly analyze specific ground-based atmospheric composition data products with relevant satellite remote sensing data (e.g., satellite aerosol data products) for a given location and time.

Prerequisites

- An Inside Look at How NASA Measures Air Pollution (Introductory Training)

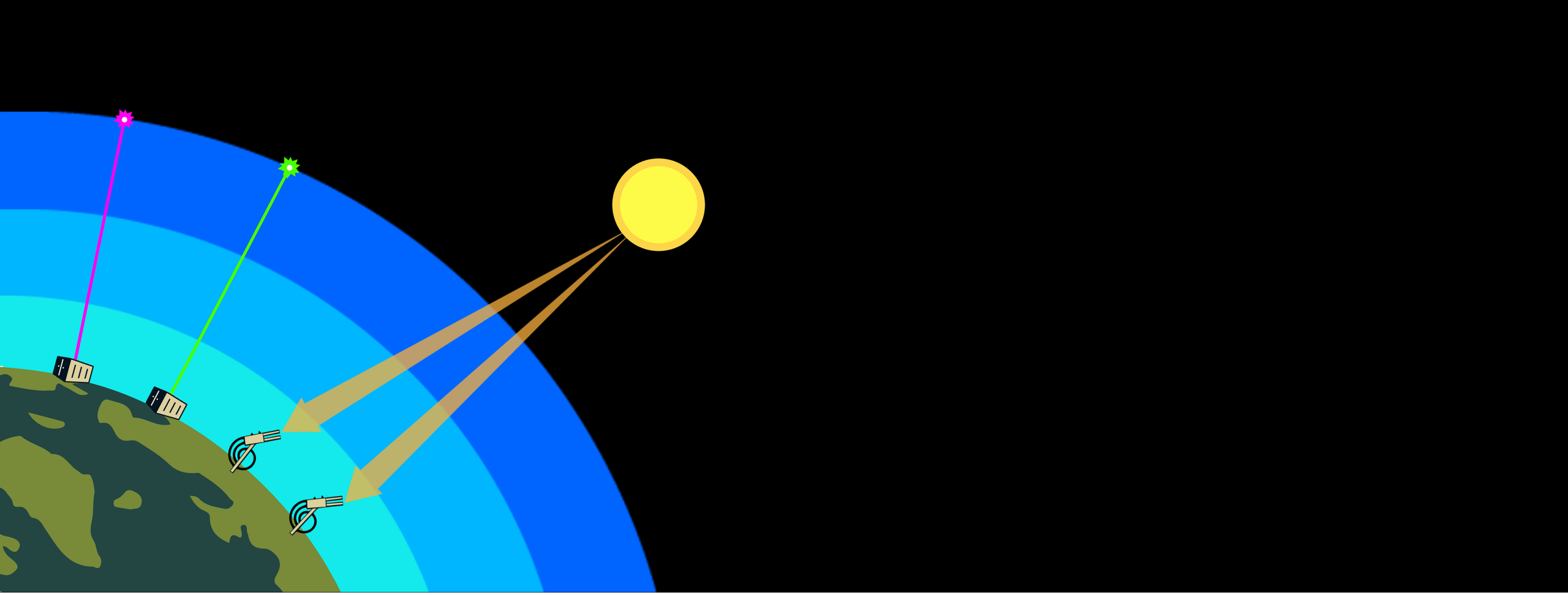
Training Outline

Part 1	Part 2	Part 3	Part 4	Part 5
Introduction to the Aerosol Robotic Network (AERONET)	Hands-on analysis of AERONET data	Introduction to Pandora Instrument and the Pandonia Global Network	Introduction to the Tropospheric Ozone Lidar Network (TOLNet)	Introduction to the Micro-Pulse Lidar Network (MPLNET)
August 8, 2024	August 13, 2024	August 15, 2024	August 20, 2024	August 22, 2024
11:00-12:30 EDT	11:00-12:30 EDT	11:00-12:30 EDT	11:00-12:30 EDT	11:00-12:30 EDT

Homework

Opens August 22 – Due September 05 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.



NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications

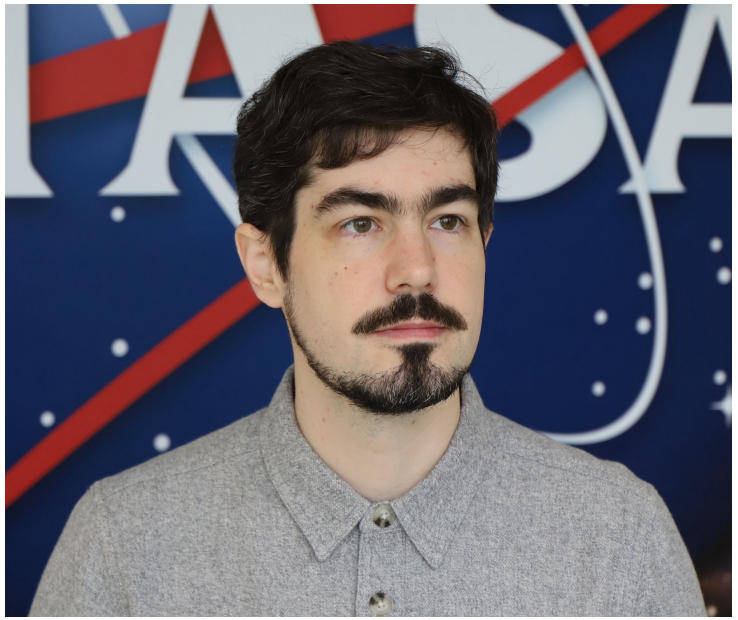
Part 1: Introduction to the Aerosol Robotic Network (AERONET)

Part 1 – Trainers

Dr. Carl Malings

Assistant Research Scientist

Morgan State University, GESTAR-II



Dr. Pawan Gupta

Co-Lead, AERONET

NASA GSFC

Part 1 Objectives

By the end of Part 1, participants will be able to:

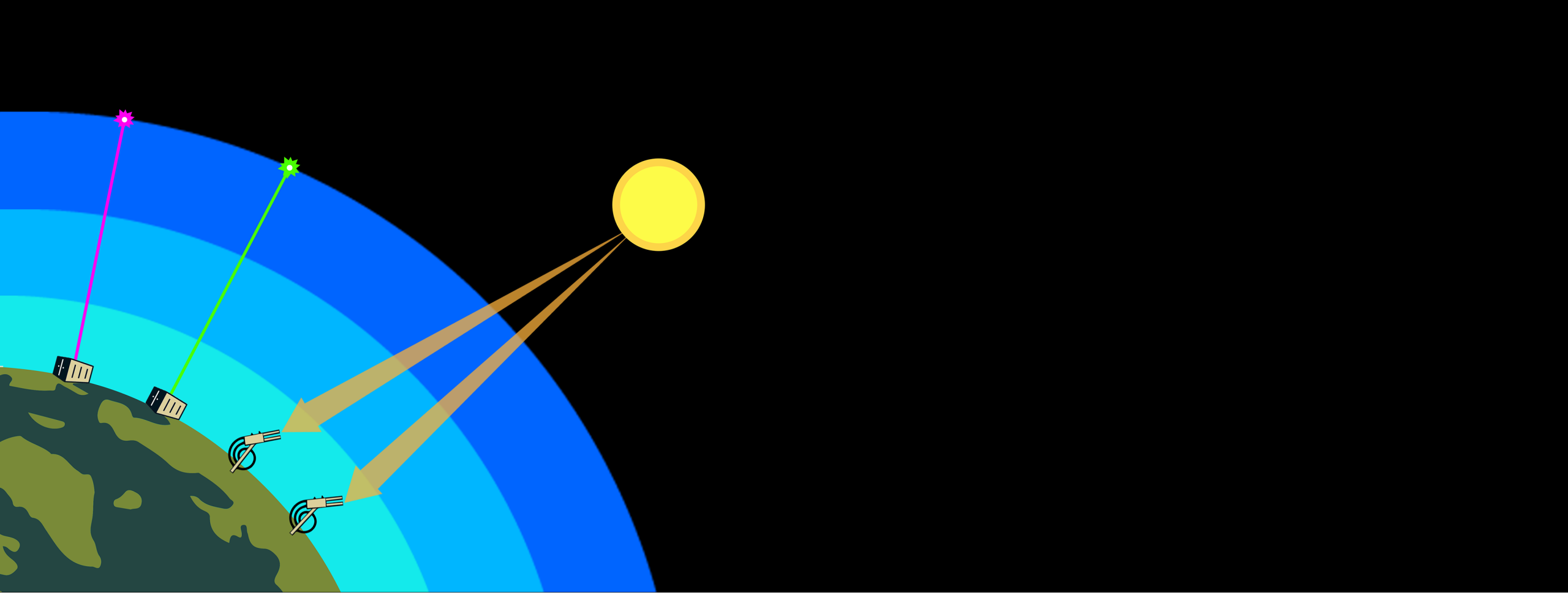
- Identify the basic characteristics of the AERONET instruments used by NASA for ground-based passive remote sensing of aerosols.
- Recognize how the AERONET network sustains global long-term observations, supports air quality and climate applications, and complements satellite observations.

Review of Prior Knowledge

- Aerosols are solid or liquid particles suspended in the atmosphere. They impact air quality, the weather, climate, and the health of humans, animals, plants, and our ecosystem.
- Passive remote sensors rely on direct or reflected sunlight as the source of the electromagnetic radiation they detect.
- Common examples of passive remote sensing instruments on satellites providing aerosol data are:
  - MODIS on the Aqua and Terra satellites
  - VIIRS on the SNPP, NOAA-20, and NOAA-21 satellites
  - ABI on the GOES-East and GOES-West geostationary satellites
  - Several instruments on the newly-launched PACE satellite

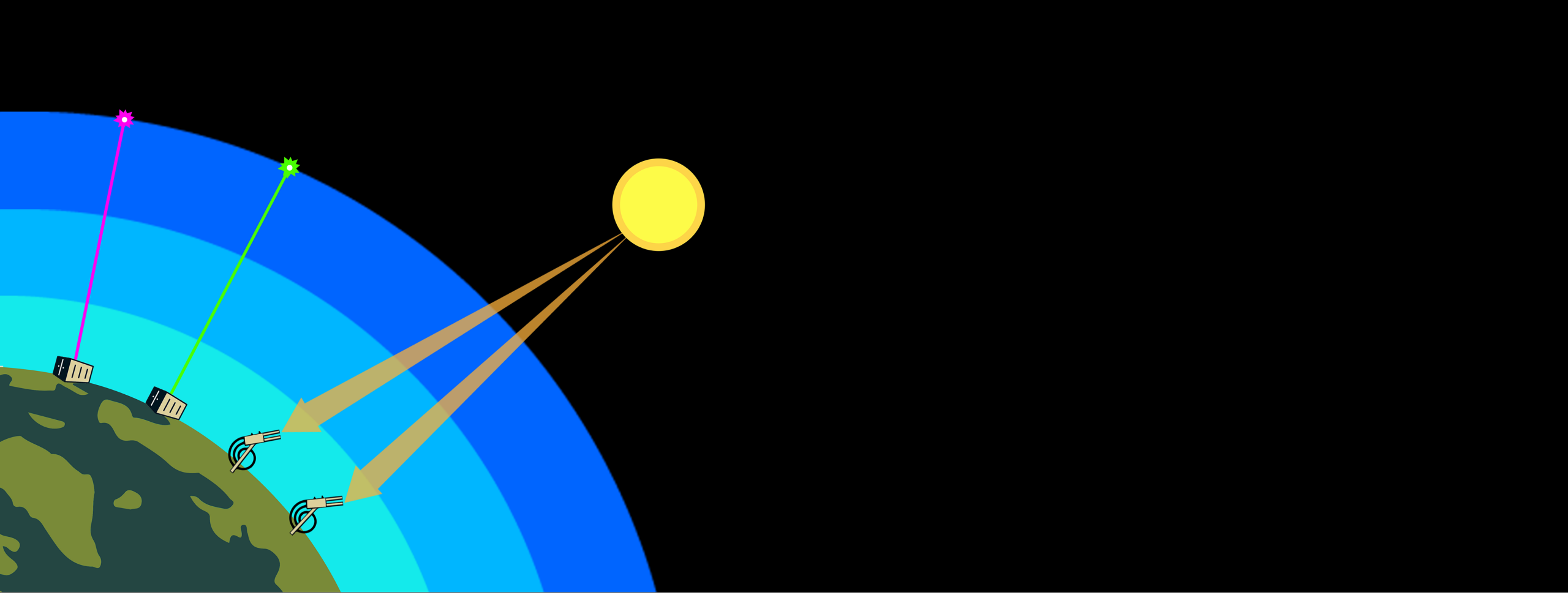
How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



Part 1:

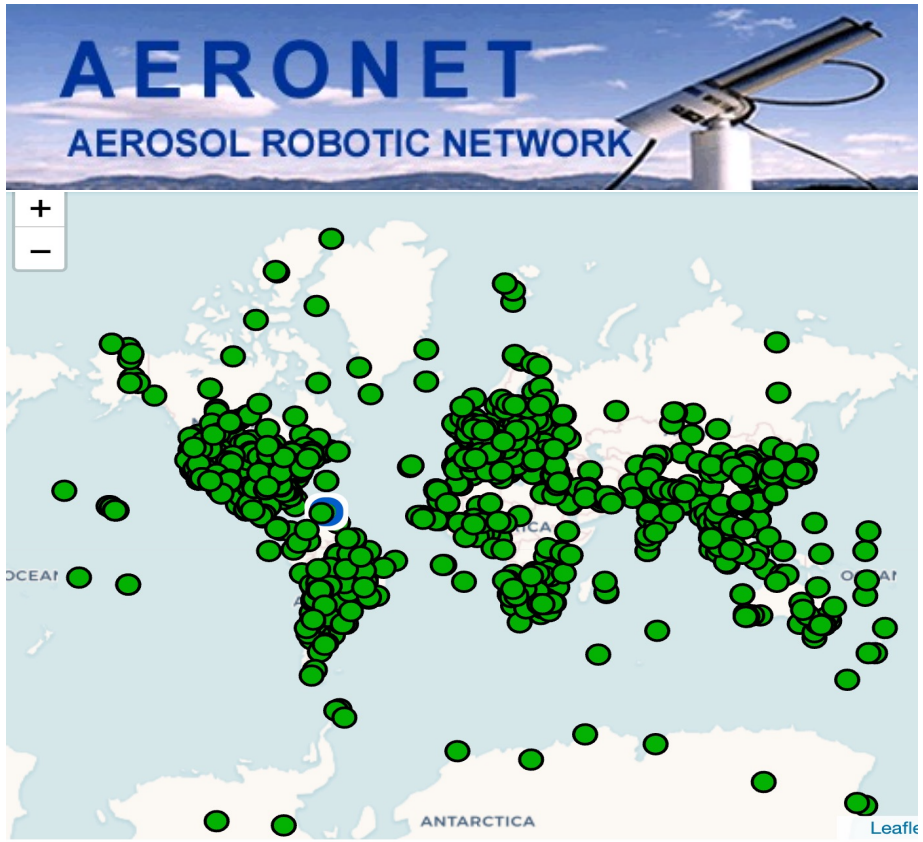
Introduction to the Aerosol Robotic Network (AERONET)



Overview

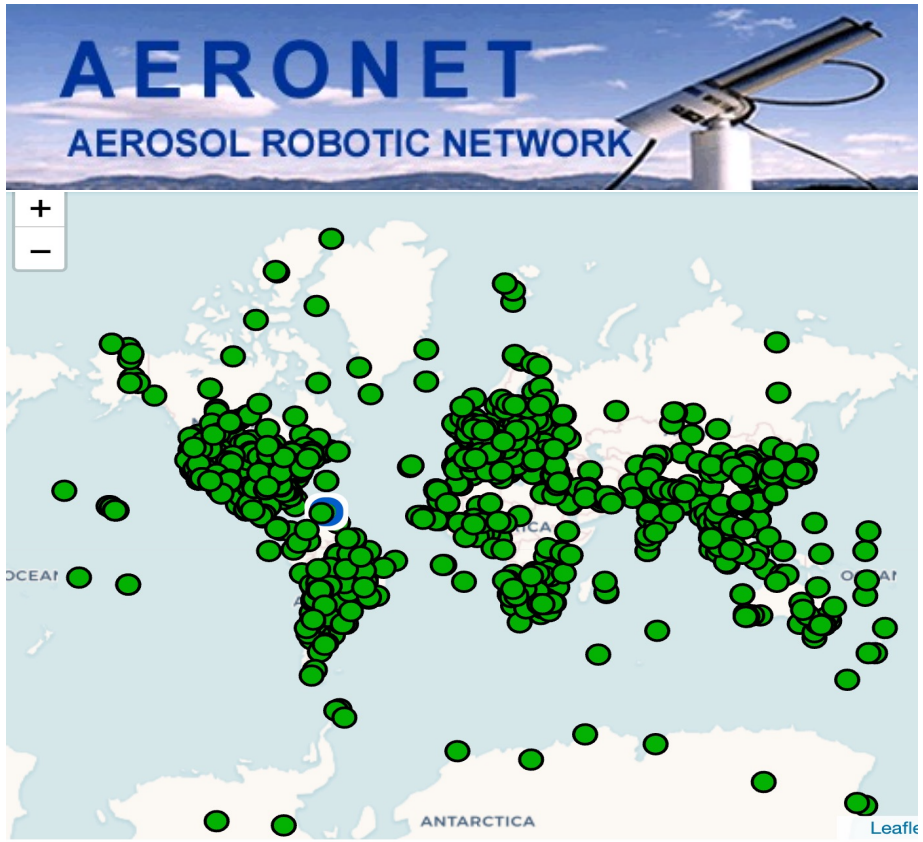
AERONET Overview

- The AERONET program is a federation of ground-based remote sensing aerosol networks.
- It provides Columnar Atmospheric Aerosol Measurements from ground stations.
- It provides a long-term, continuous, and readily accessible public domain database.
- It includes datasets on aerosol optical, microphysical, and radiative properties.
- The network imposes standardization of instruments, calibration, processing, and distribution.
- AERONET datasets are extensively used in aerosol research and characterization, validation of satellite retrievals, climate, and air quality applications.



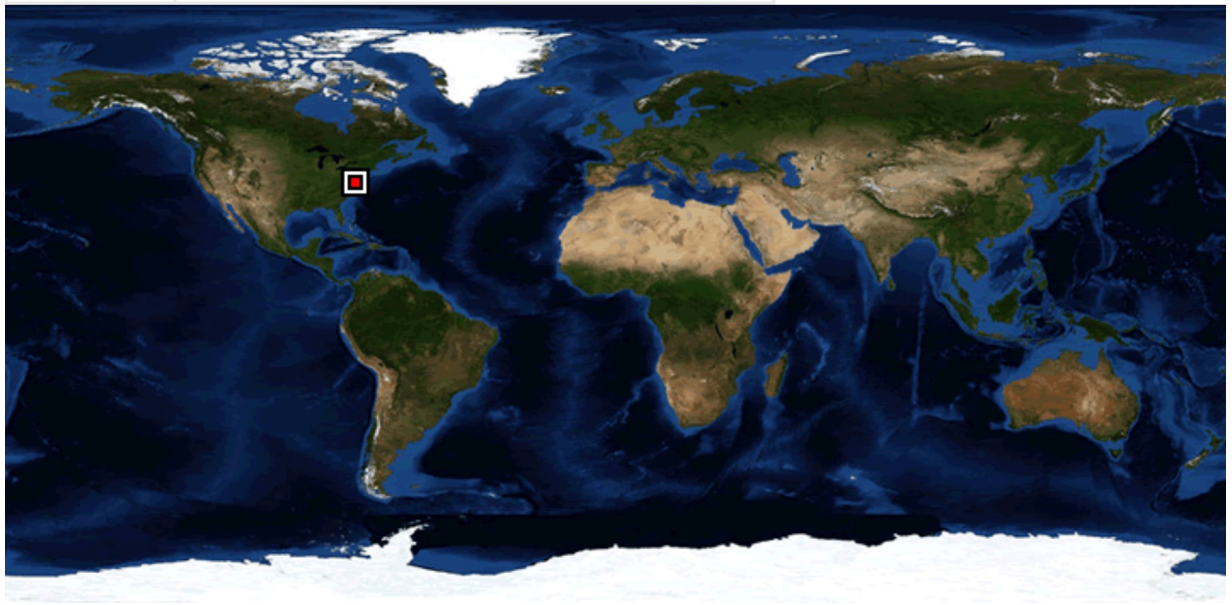
AERONET Background

- Established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire; Univ. of Lille, CNES, and CNRS-INSU)
- Expanded by networks: RIMA, AeroSpan, AEROCAN, AEROSPAIN, NEON, and CARSNET
- Collaborator with national and international agencies, institutes, universities, individual scientists, and partners
- In operation since 1993; **30 years** of data records

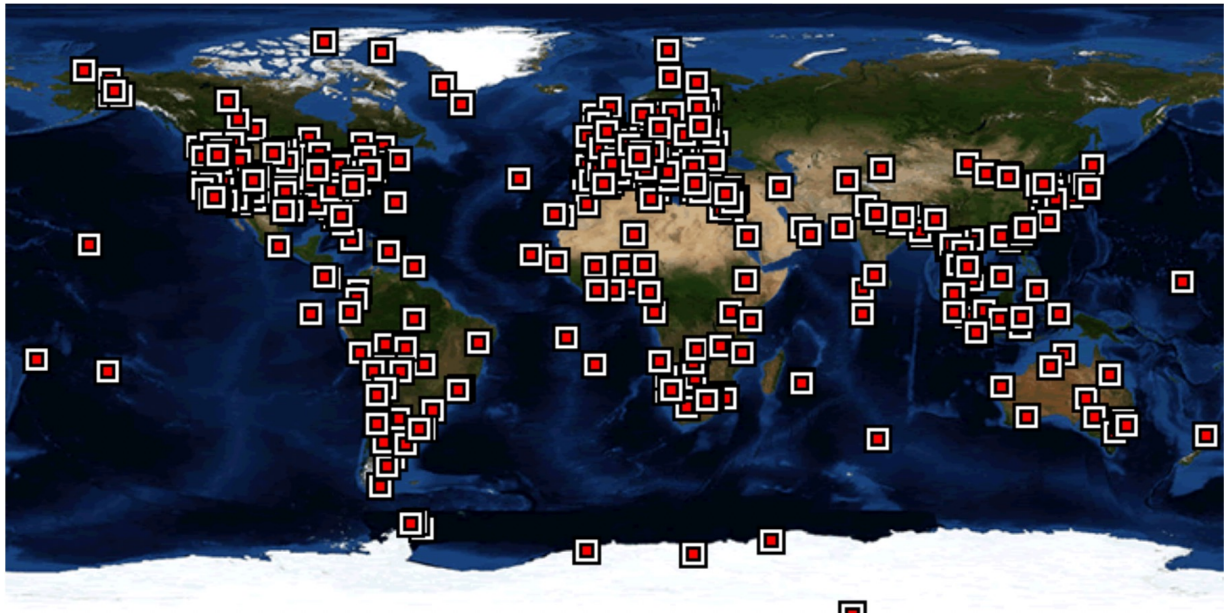


Network of Networks - AERONET Growth

How it Started - May 1993

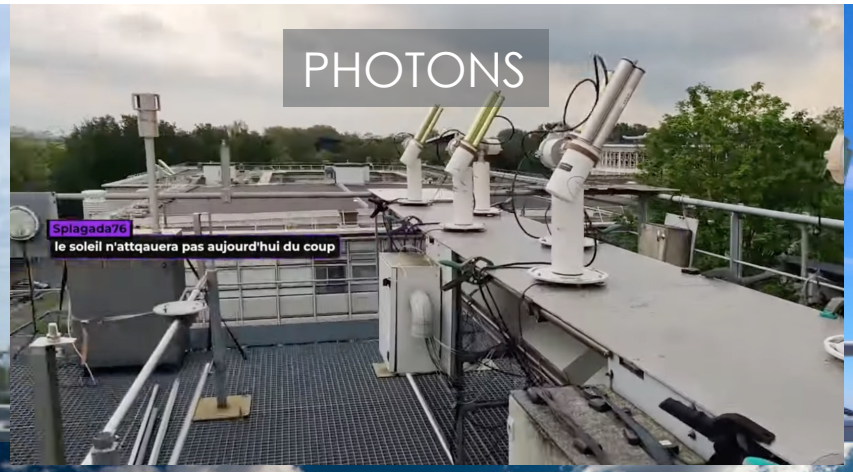


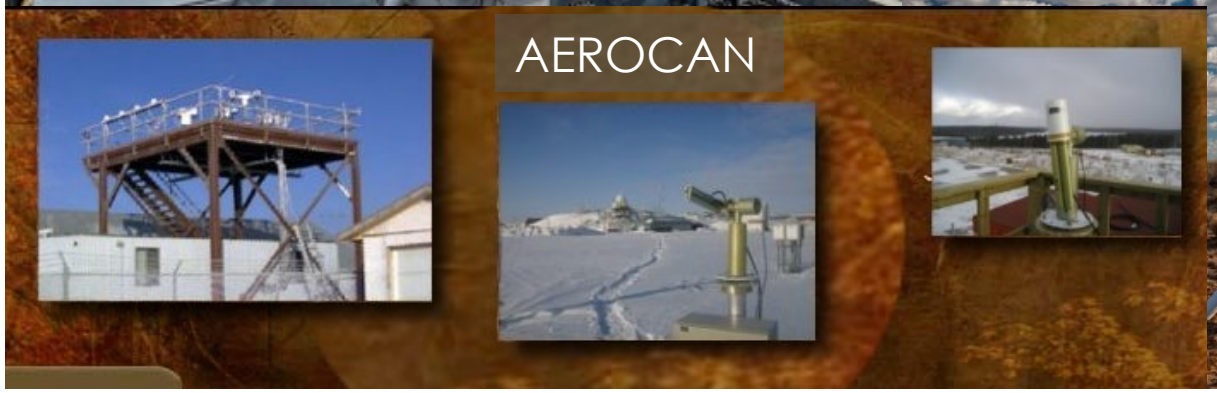
How it's Going - May 2023

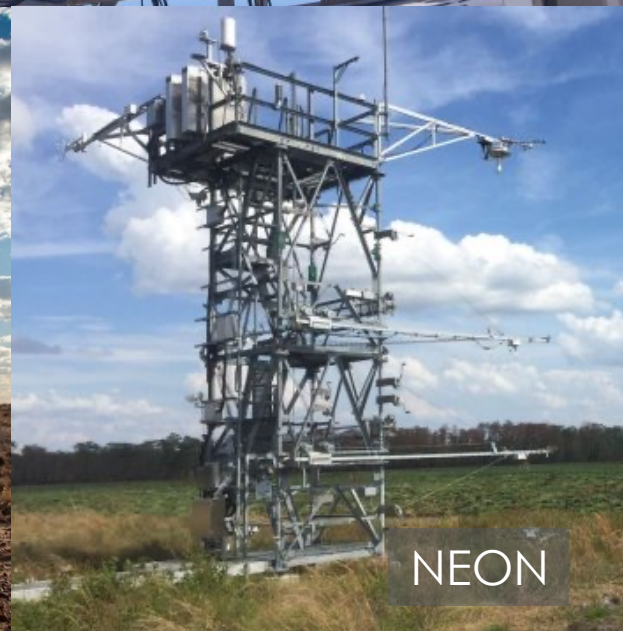


- Currently about 600 Active Stations
- ~1,800 all time deployments with ~2+ million days of data
- 102 countries and territories

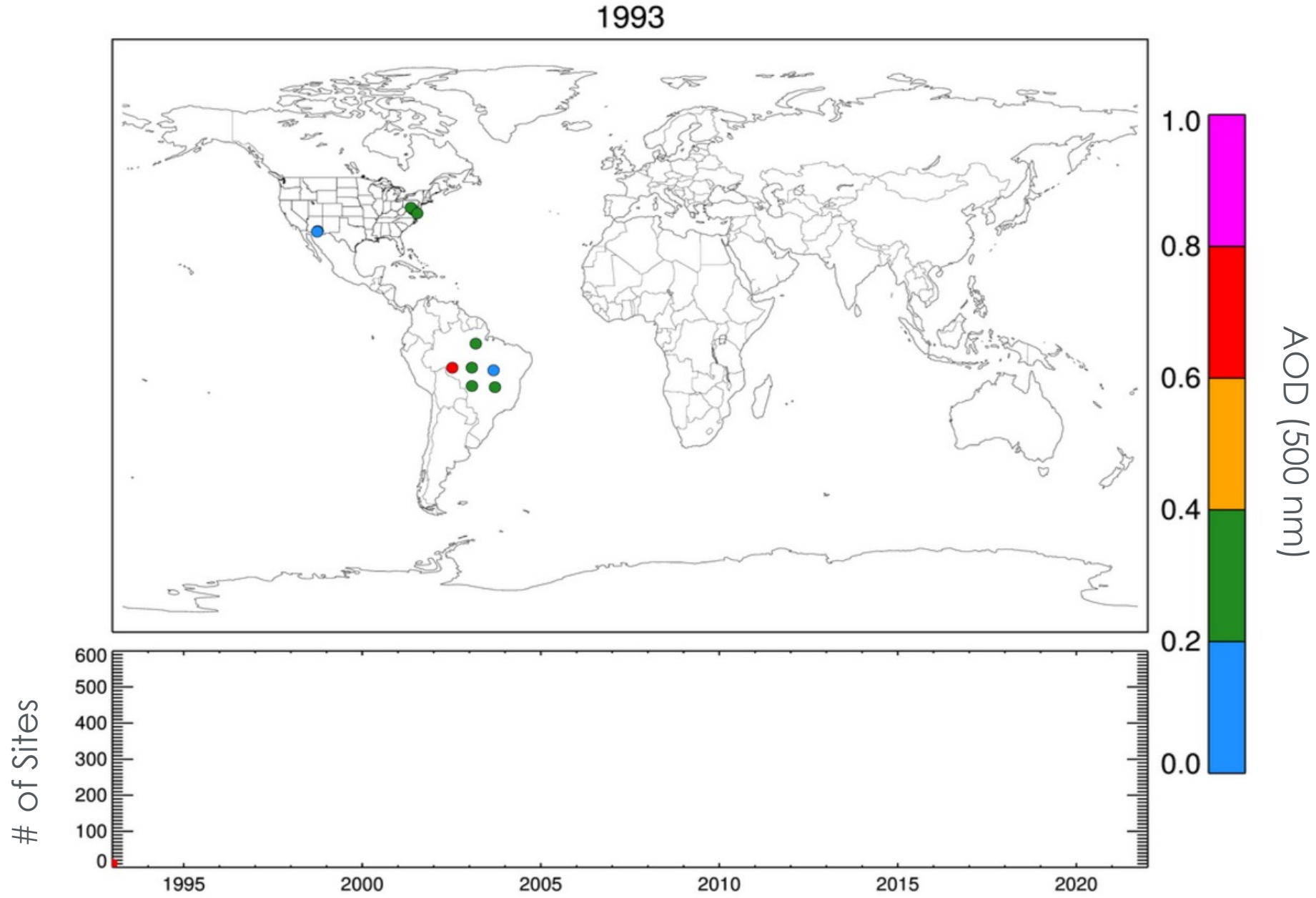
Network of Networks – Calibration Centers/Sites



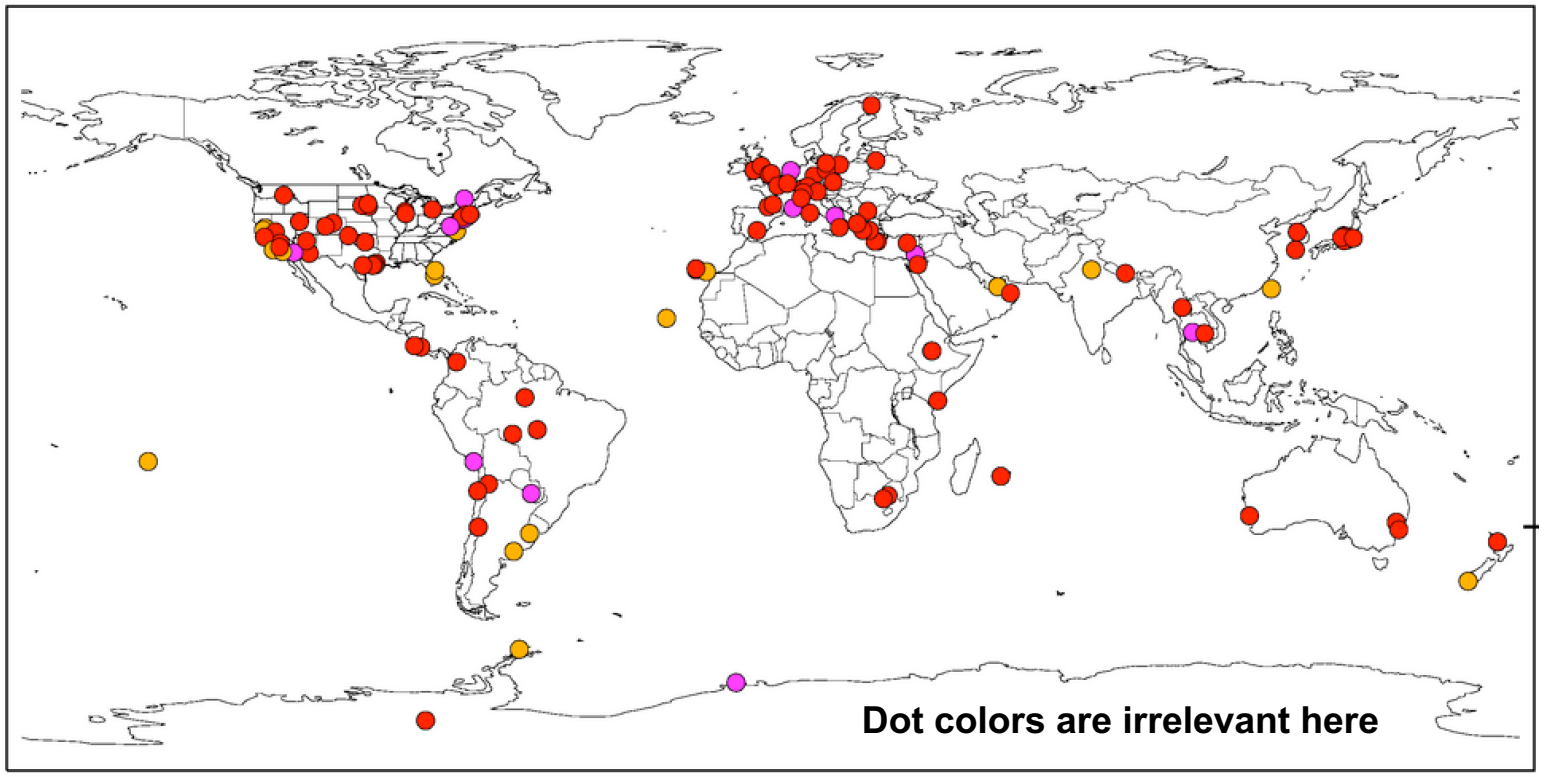




Network Growth



Data Availability and New Sites – (2020-2023)



About 20 upcoming sites in US, Iraq, Saudi Arabia, CA, SA, India, and Africa

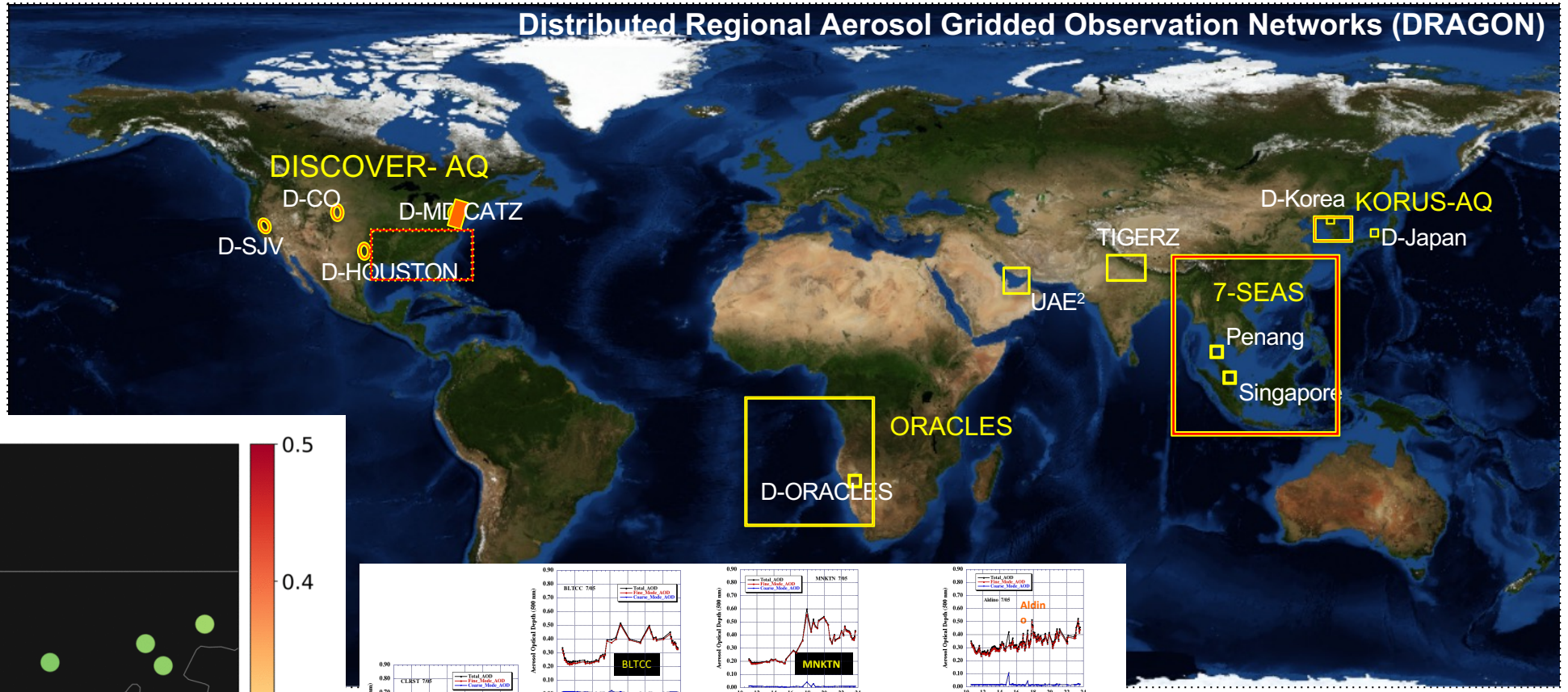
5+ Years – 565 Sites

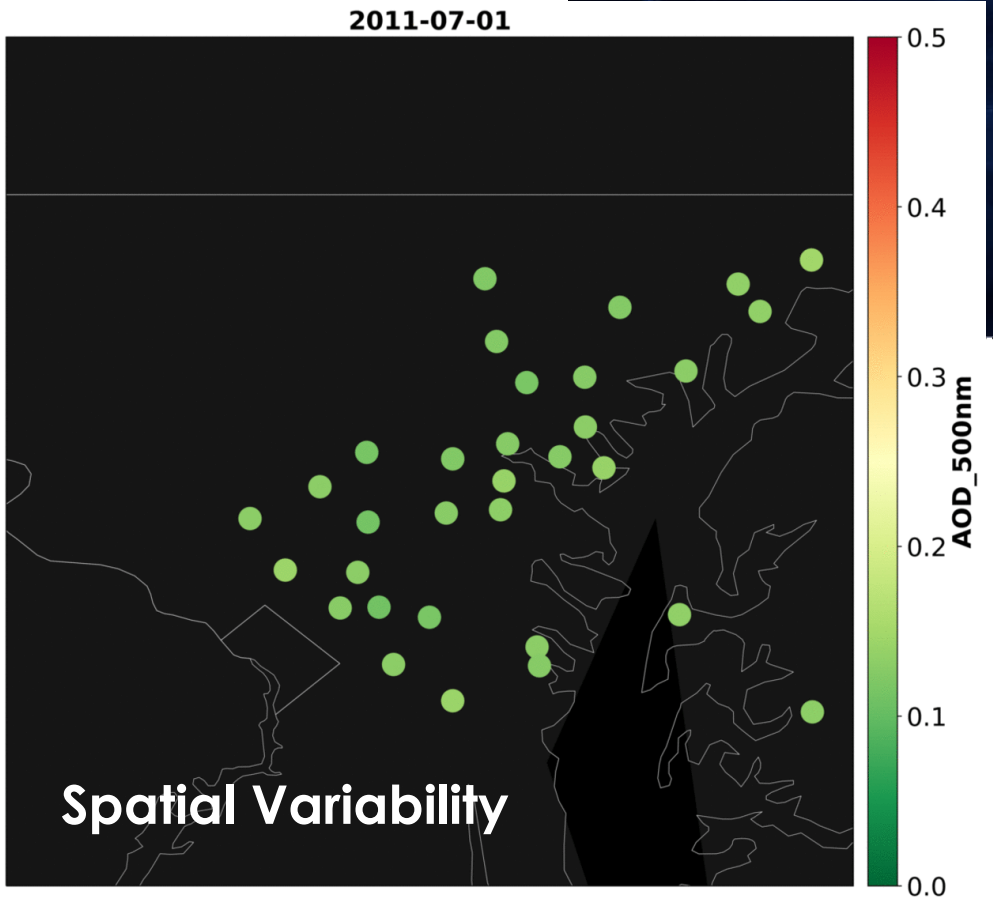
10+ Years – 351 Sites

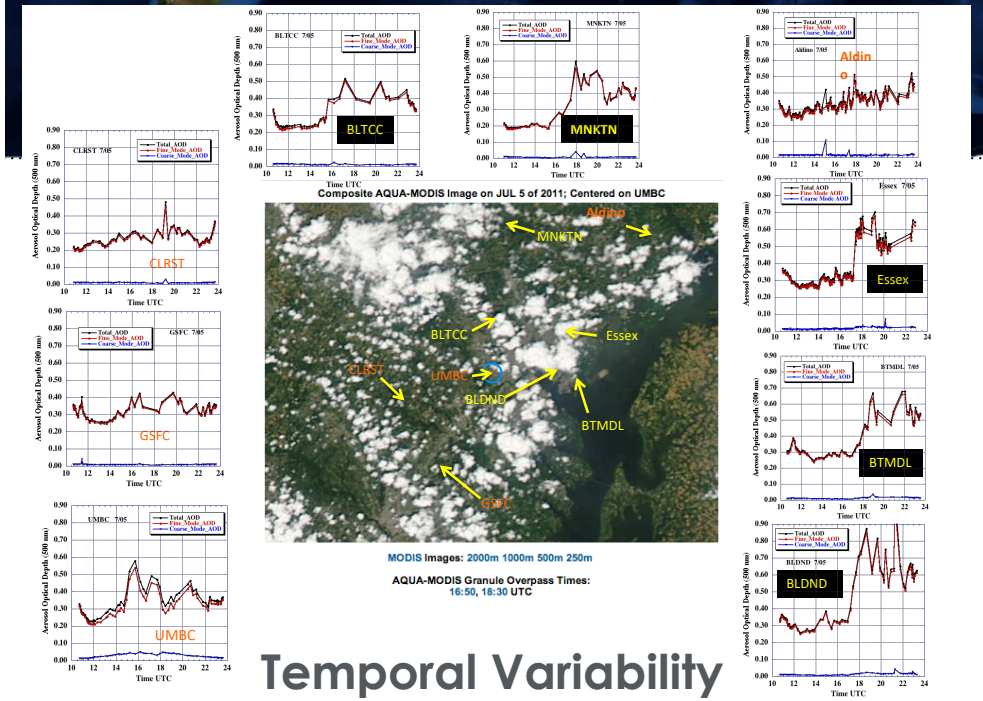
20+ Years – 71 Sites

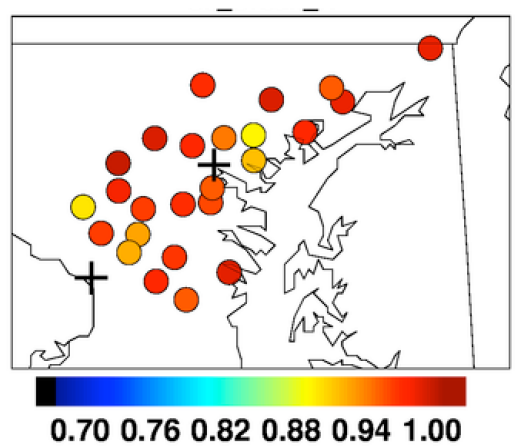
30+ Years – 1 Sites

DRAGON - Field Campaigns

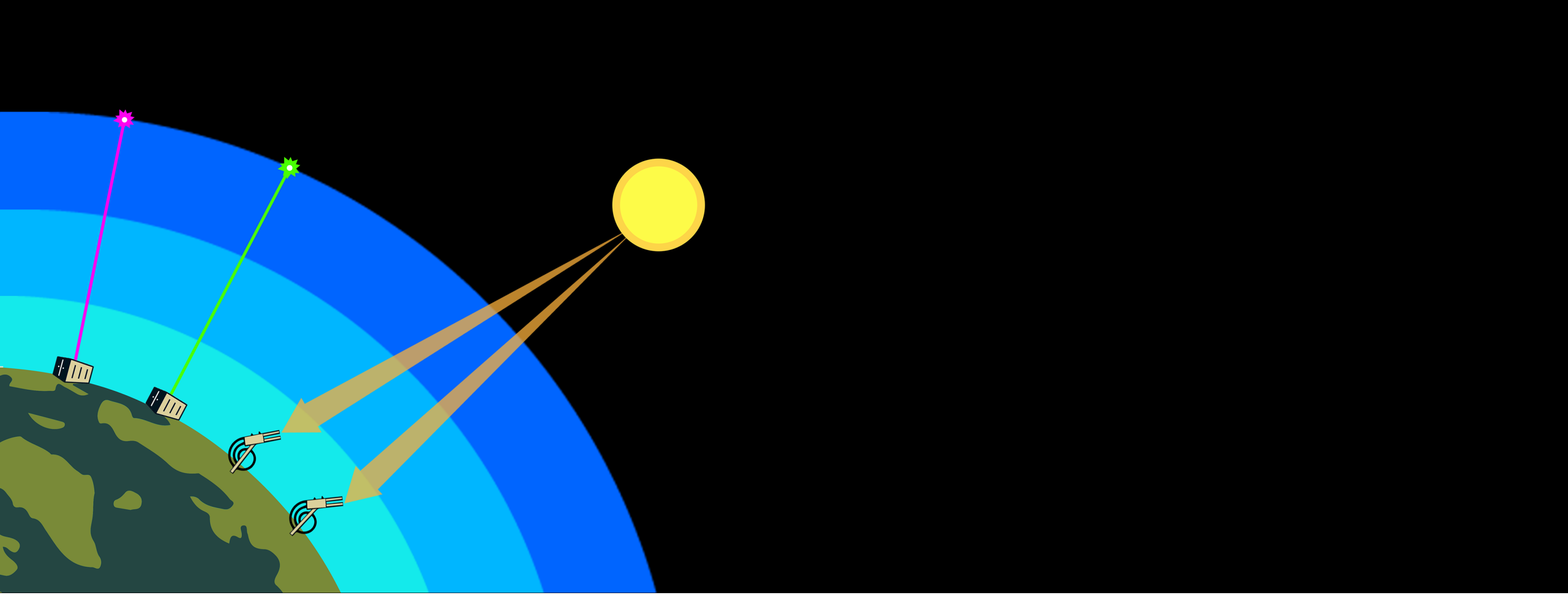






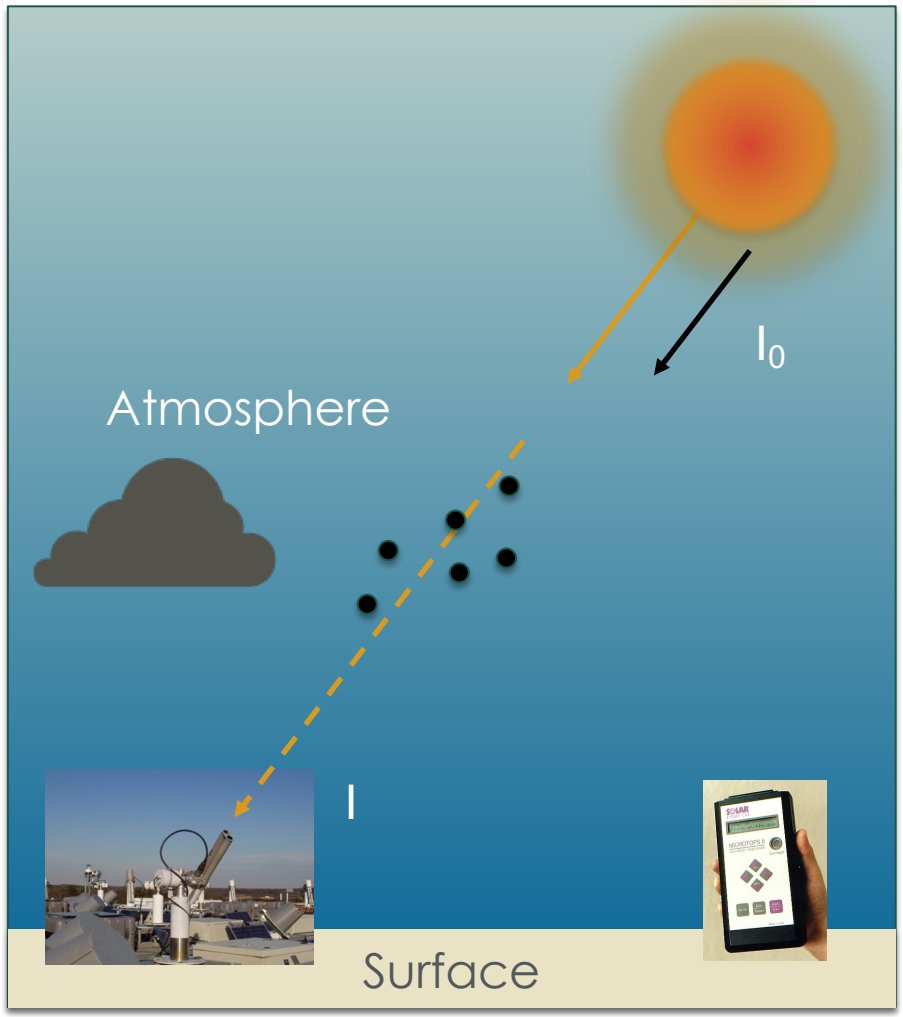


AERONET Deployments



Aerosol Optical Depth and Air Quality

Aerosol Optical Depth/Thickness (AOD or AOT)



- The **optical depth** expresses the quantity of light removed from a beam by scattering and/or absorption during its path through a medium.
- The **aerosol optical depth** represents the loading of particles in the entire column of the atmosphere (from the surface to the top of the atmosphere).
- It is always represented at a certain wavelength (most often at 500 or 550 nm).
- The value depends on particle concentration, shape, size, chemical composition, location in the atmosphere, and wavelength of measurement.
- It can be measured from the ground and from space.

AOD Calculation

Lambert-Beer Law:

$$I(\lambda) = I_0(\lambda)e^{(-m(\theta)*\tau(\lambda))}$$

- I(λ): Solar irradiance at a wavelength of λ at the Earth's surface
- I_0(λ): Extra-terrestrial solar irradiance at a wavelength of λ
- τ(λ): Atmospheric optical depth when the optical air mass is 1
- m(θ): Relative air column length of zenith angle θ at that of zenith direction 1 (optical air mass)

$$\tau = \tau(\text{air}) + \tau(\text{aer}) + \tau(\text{gas})$$

τ(air): Optical Depth of Air Molecules (Rayleigh Optical Depth)
τ(aer): Aerosol Optical Depth (AOD)
τ(gas): Optical depth of the absorbing atmosphere element (e.g., water vapor, CO_2, O_3, NO_2)

https://www.jma-net.go.jp/kousou/obs_third_div/rad/rad_aero-e.html

Angstrom Parameter (Alpha)

- The size distribution of aerosols can be estimated from spectral aerosol optical depth.
- The negative slope (or first derivative) of AOT with wavelength in logarithmic scale is known as the Angstrom Parameter (a).
- This parameter can be calculated from two or more wavelengths using a least squares fit.
- Alpha is typically derived using AODs from 440nm to 870nm.
- Values of greater than 2.0 indicate that fine mode particles (e.g., smoke particles and sulfates) exist, while values near zero (<0.5) indicate the presence of coarse mode particles such as desert dust.

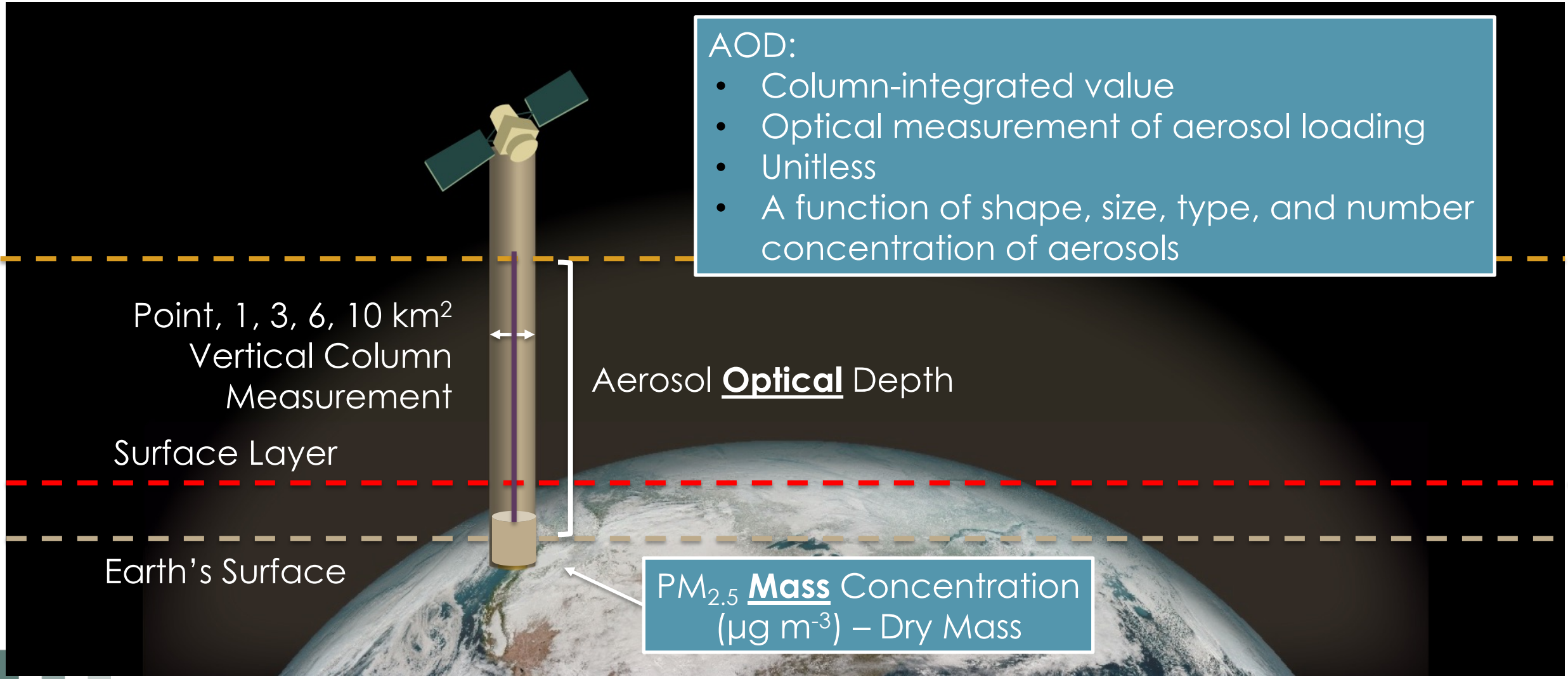
$$\alpha = \frac{\ln(\frac{\tau_1}{\tau_2})}{\ln(\frac{\lambda_1}{\lambda_2})}$$

Where:

- **α is the Angstrom Parameter**
- **τ is Aerosol Optical Depth**
- **λ is Wavelength**

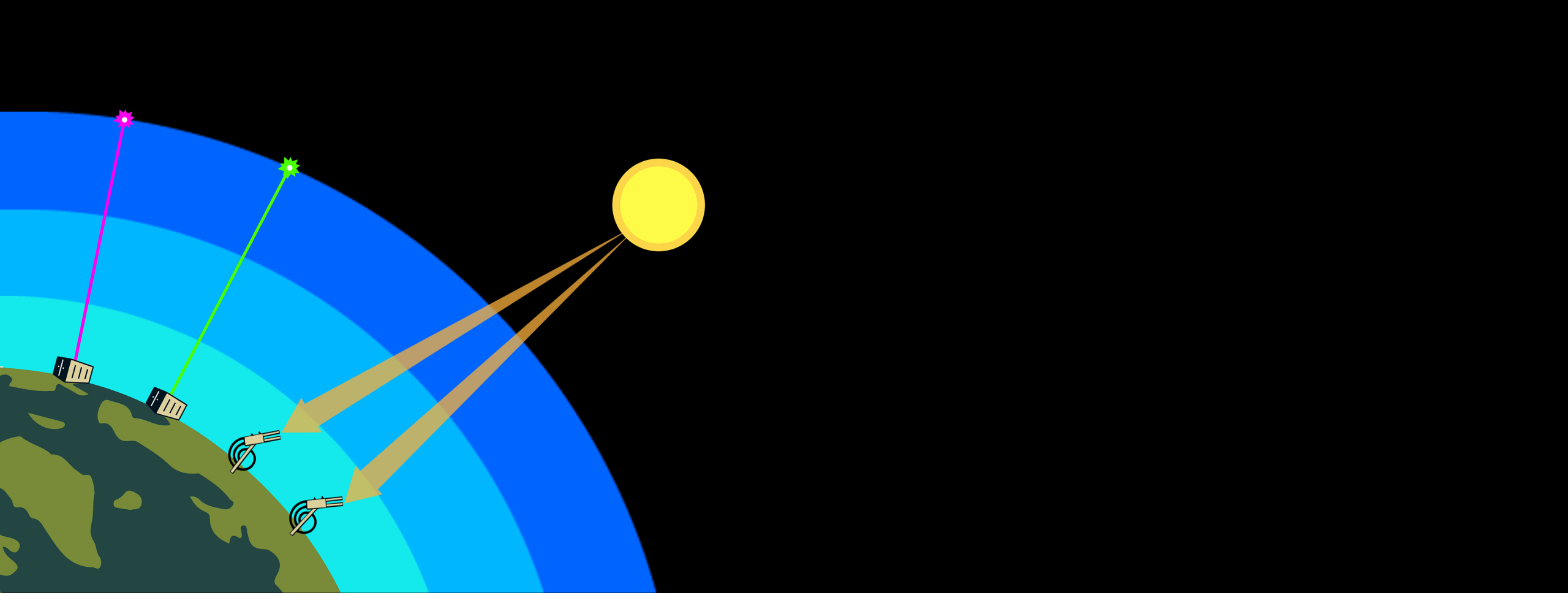
https://aeronet.gsfc.nasa.gov/new_web/Documents/Aerosol_Optical_Depth.pdf

Column vs. Surface (i.e., AOD vs $PM_{2.5}$)



Moving Forward

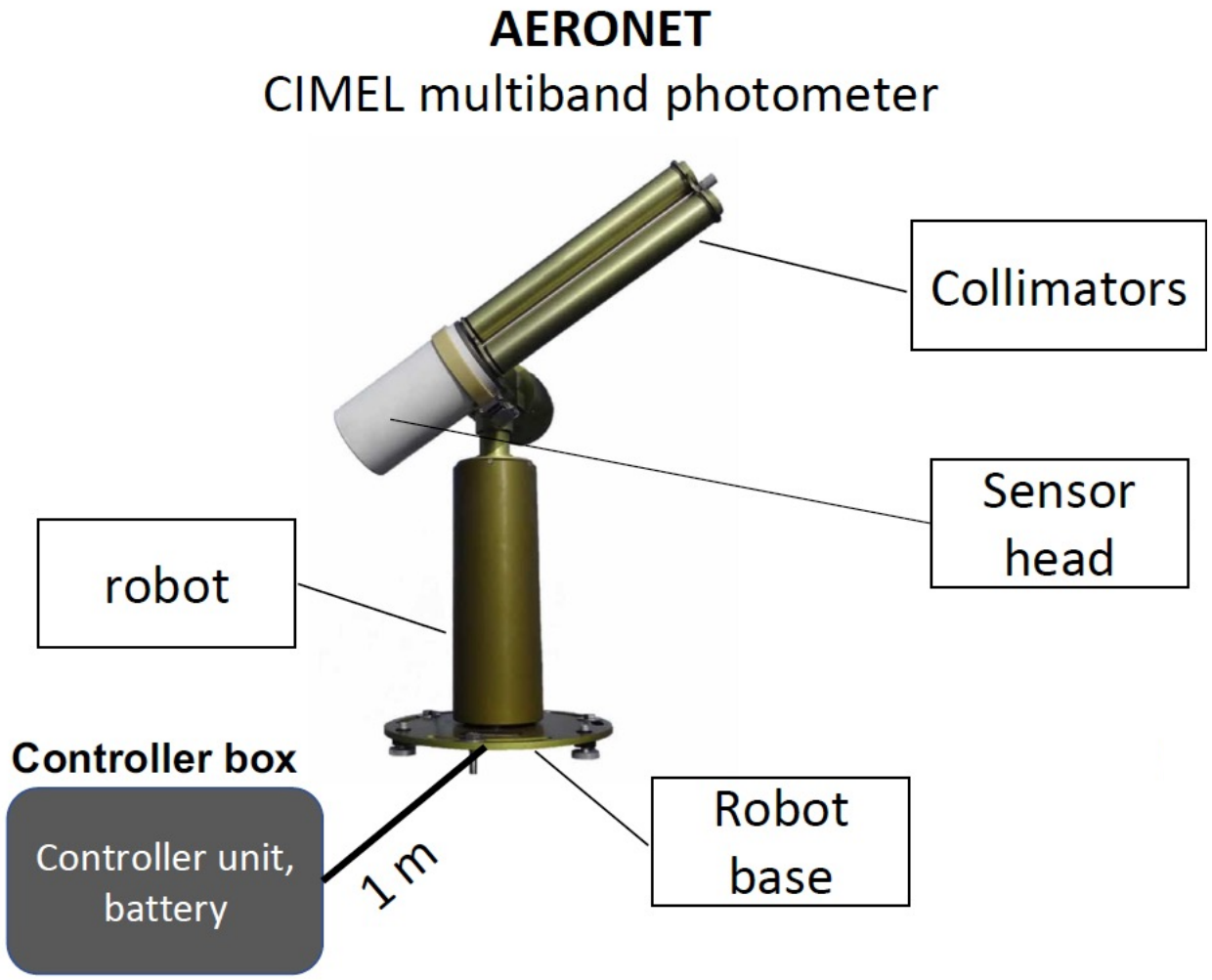
- Instrument
- Calibration
- Datasets



Instrumentation

Sun Photometer

- A sun photometer is a 'light meter' that measures the amount of sunlight within a narrow range of wavelengths or colors.
- The instrument is pointed directly at the sun, and light is collected through a small opening to prevent scattered sunlight from reaching the detector.



CE318-T – Sun Sky Lunar Multispectral Photometer

- Manufactured by Cimel Electronics (https://www.cimel.fr)
- The latest version is CE318-T, adopted by AERONET since 2015
- Capable of sun, sky, and lunar light measurements
- Full autonomy with low power consumption (5W solar panel)
- Day-time (SUN/SKY) & night-time (MOON: from 1st to last quarter) measurements:
  - AOD, PSD, n, water vapor
- Several models according to application:
  - Standard, polarized, BRDF, SeaPRISM, (Ocean & Lake Color)
- High accuracy & long-term stability
- Flexible Communication: RS232, USB, Cellular Modem
- AERONET Compatible: Fully automated & homogeneous data processing
- Secured data storage (on SD card)

CE318-T – Spectral Channels

Photometer models

Reference	Description	Available bands
CE318-TS9	Standard model	340, 380, 440, 500, 675, 870, 937, 1020, 1640 nm
CE318-TP9	Polarized model	340, 380, 440, 500, 675, 870, 937, 1020, 1640 nm / Polarization in three directions
CE318-TU9	BRDF measurements (9 filters)	380, 440, 550, 675, 740, 870, 937, 1020, 1640 nm
CE318-TU12	BRDF measurements (12 filters)	415, 440, 490, 555, 675, 702, 740, 782, 870, 937, 1020, 1640 nm
CE318-TV12-OC (SeaPRISM for Ocean Color)	Measurement of radiances emerging from sea water surface	400, 412.5, 442.5, 490, 510, 560, 620, 665, 779, 865, 937, 1020 nm
CE318-TV12-LC (SeaPRISM for Lake Color)	Measurement of radiances emerging from lake water surface	412.5, 442.5, 490, 510, 560, 620, 665, 681, 709, 865, 937, 1020 nm

User Manual

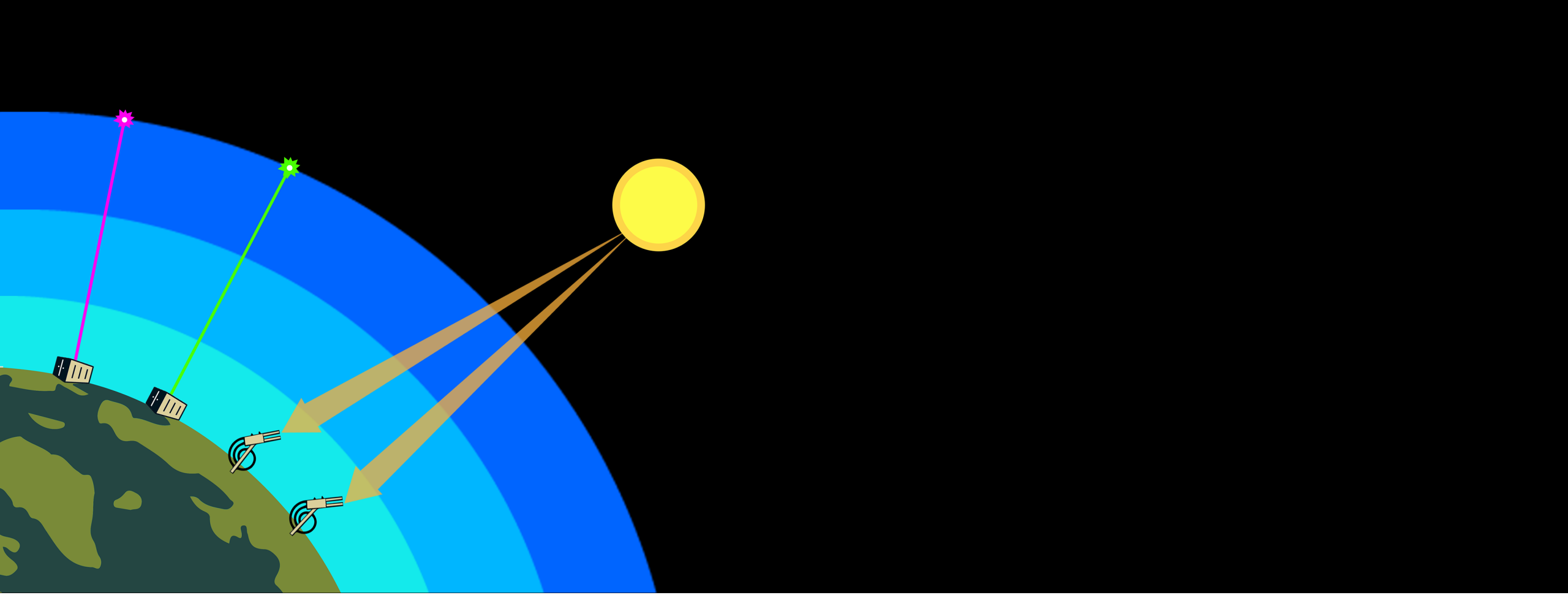
Instrument Operation

- Daytime (Direct Sun/Sky Scanning)
  - 9 (direct sun) and 4 (sky) spectral channels
  - It takes about 10 seconds
  - A series of three measurements are taken to screen the clouds
  - Frequency of measurements varies from 5 to 15 min depending on sun angle
- Nighttime Direct Moon Measurements

Scanning Modes

Principal Plane

Almucantar



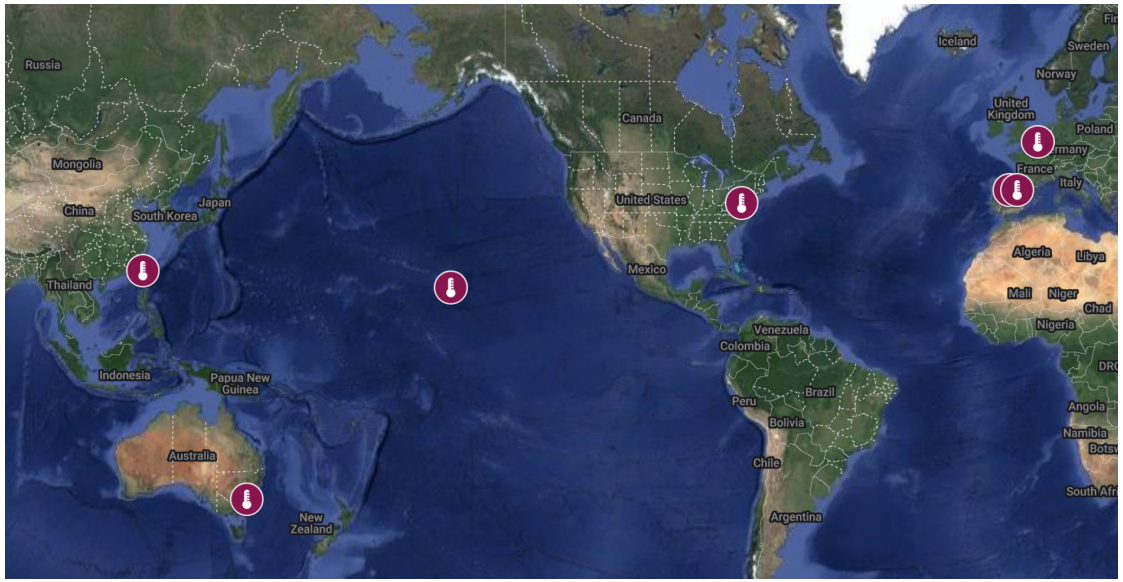
Calibration

Calibration Process Facilities, and Regional Networks

Pre-Deployment Calibration

Field Deployment

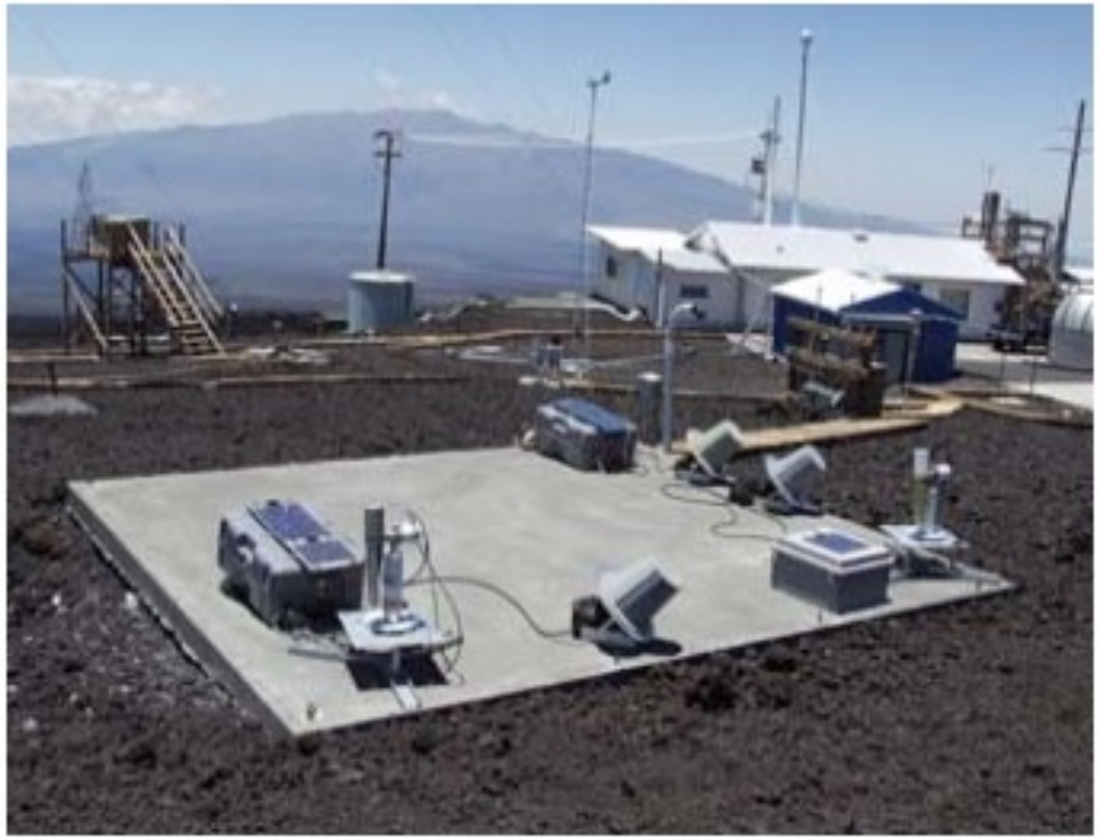
Post-Field Deployment

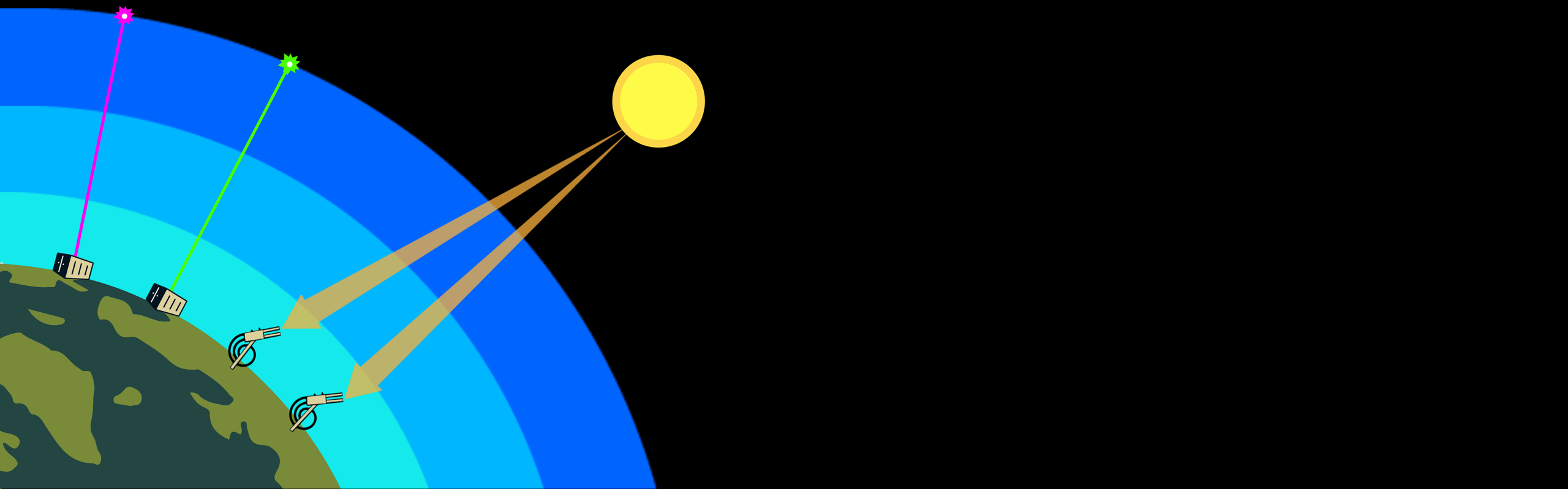


Calibration Sites

- To determine $I_0(\lambda)$: extra-terrestrial solar irradiance at a wavelength of λ, the AERONET reference Cimel (master) is deployed at a high mountain and clean site.
- The Langley Method requires that the atmospheric turbidity or AOD remains low and constant over the time of measurements.
- It consists of measuring the solar signal V(λ) at different solar elevation or optical air masses (m).
- **Mauna Loa Observatory** (altitude 3397 m), Hawaii, is an excellent site.
- **Izana** (altitude 2,367 m) in the Canary Islands, Spain, is another calibration site.
- Master instruments are then used at calibration facilities to calibrate field instruments.

Mauna Loa Observatory

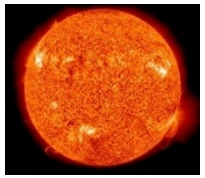




Datasets

Datasets

Sun and Moon Direct Irradiance




3 Sun and 3 Moon Obs. - Triplets

Beer-Lambert Law

Derived Parameters (Columnar)

- ✓**Aerosol Optical Depth (AOD)**
- ✓**Ångström Exponent**
- ✓**Water Vapor**

Sky Radiance (θ,φ)

Almucantar, Principal Plane, and Hybrid

Inversion Procedure

Derived Parameters (Columnar)

- ✓**Microphysical Properties** (e.g., size distribution, sphericity)
- ✓**Radiative Properties** (e.g. single scattering albedo, refractive index)

Data Levels & Parameter List

Version 3 AOD data are computed for three data quality levels:
— Level 1.0 (unscreened),
— Level 1.5 (cloud-screened and quality-controlled), and
— Level 2.0 (quality-assured)

Levels 1.0 and 1.5 data are available in near real-time, but Level 2.0 data can take up to a month to be available after post-field calibration.

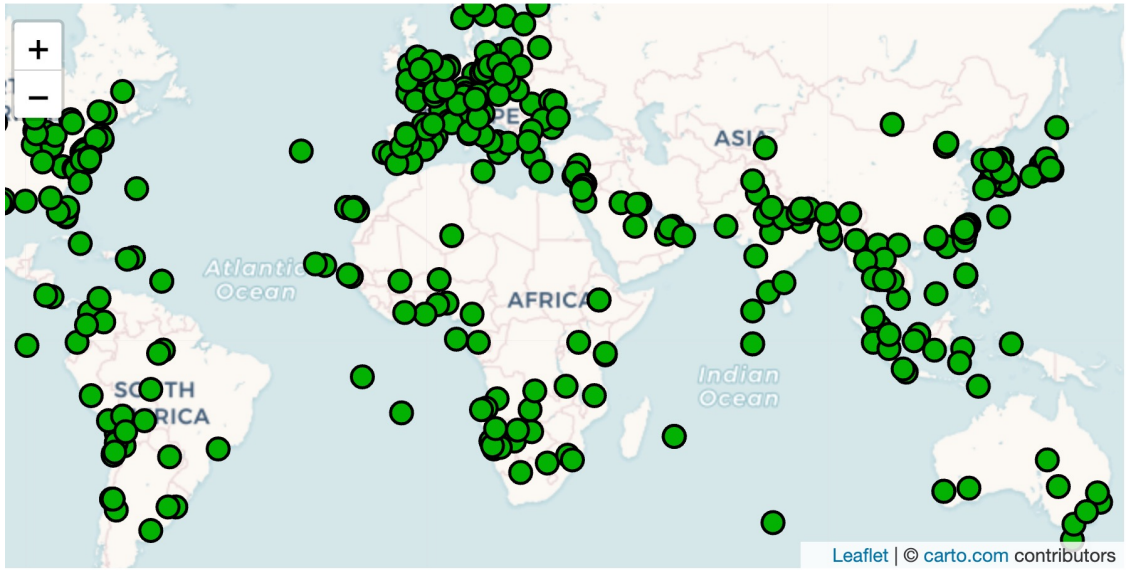
- Spectral Aerosol Optical Depth
- Angstrom Parameters
- Columnar Water Vapor
- Single Scattering Albedo
- Size Distribution
- Refractive Index
- Absorption Optical Depth
- Extinction Optical Depth
- Asymmetry Factor
- Phase Functions
- Fine Mode Fraction

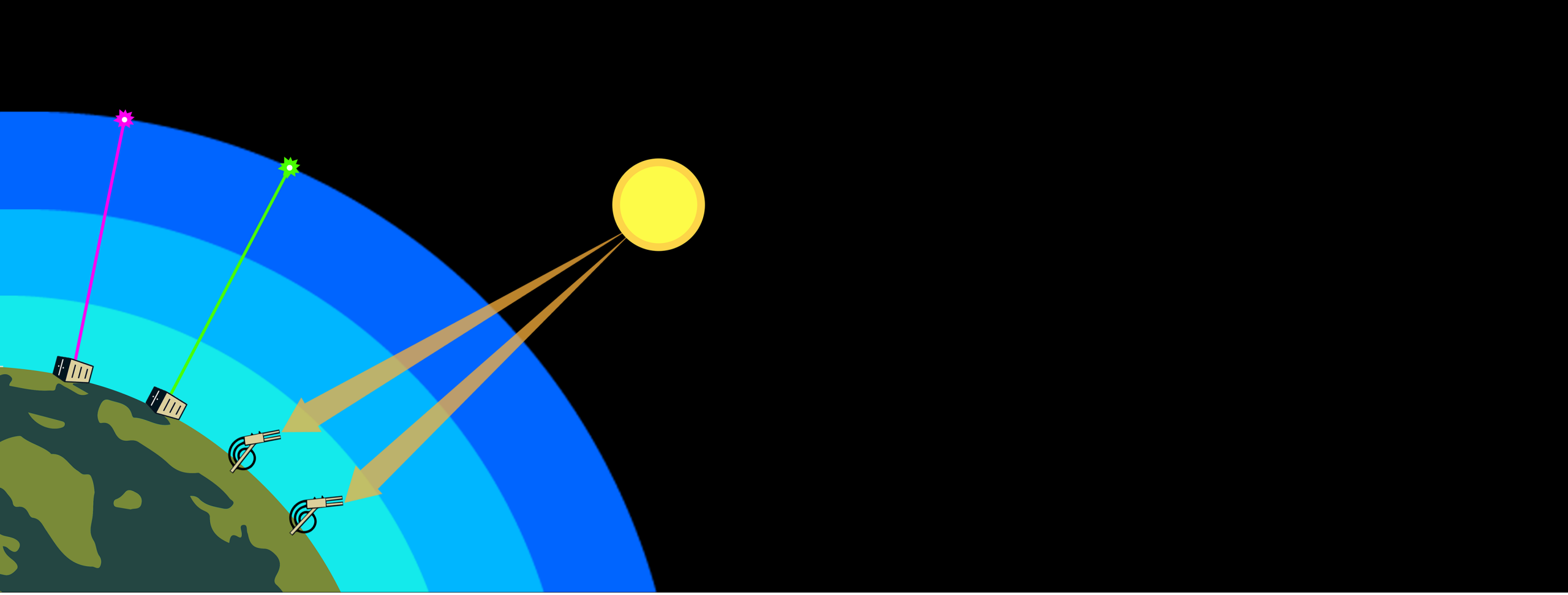
https://aeronet.gsfc.nasa.gov/new_web/data.html

Nighttime Measurements

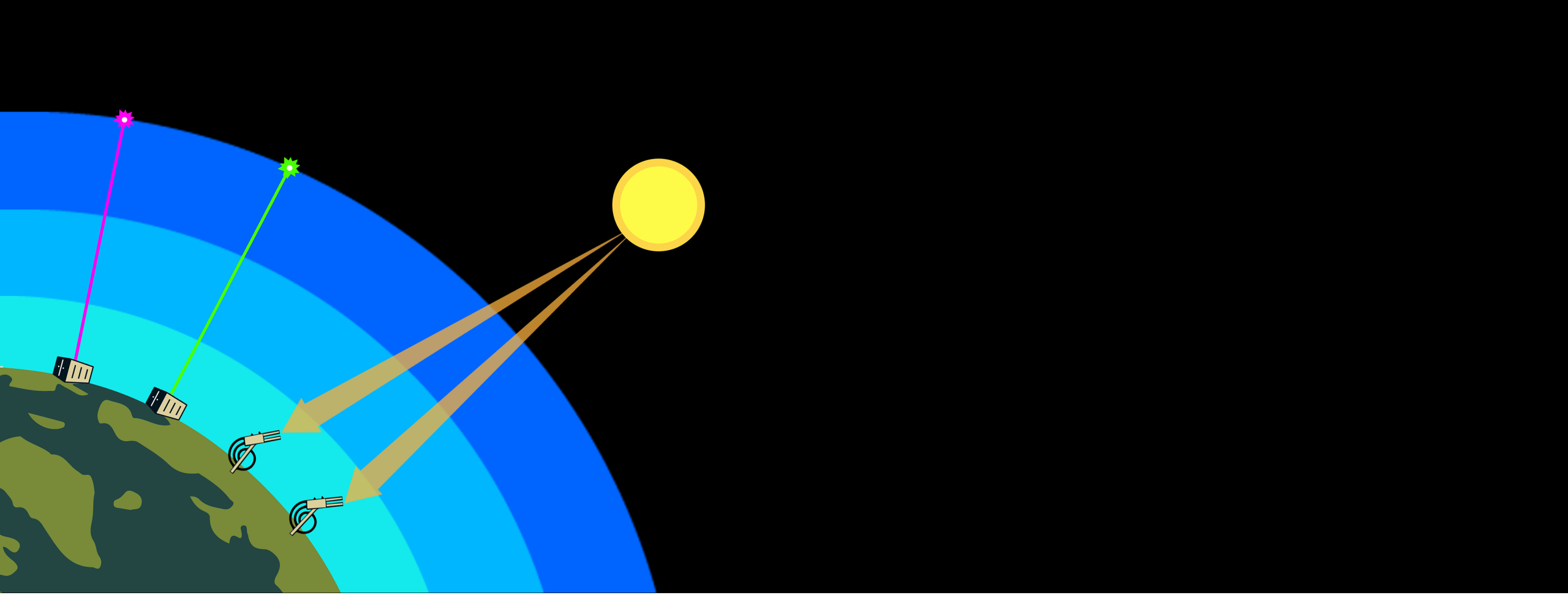
- The new Cimel instrument (CE318-T) is capable of making nighttime AOD measurements by observing the Moon.
- Currently 300+ sites have night measurement capability.
- The datasets are currently provisional and only available at Level 1.5.
- The AERONET team continues to refine and improve this product and a new version will be released soon.

https://aeronet.gsfc.nasa.gov/new_web/Documents/Lunar_Algorithm_Draft_2019.pdf



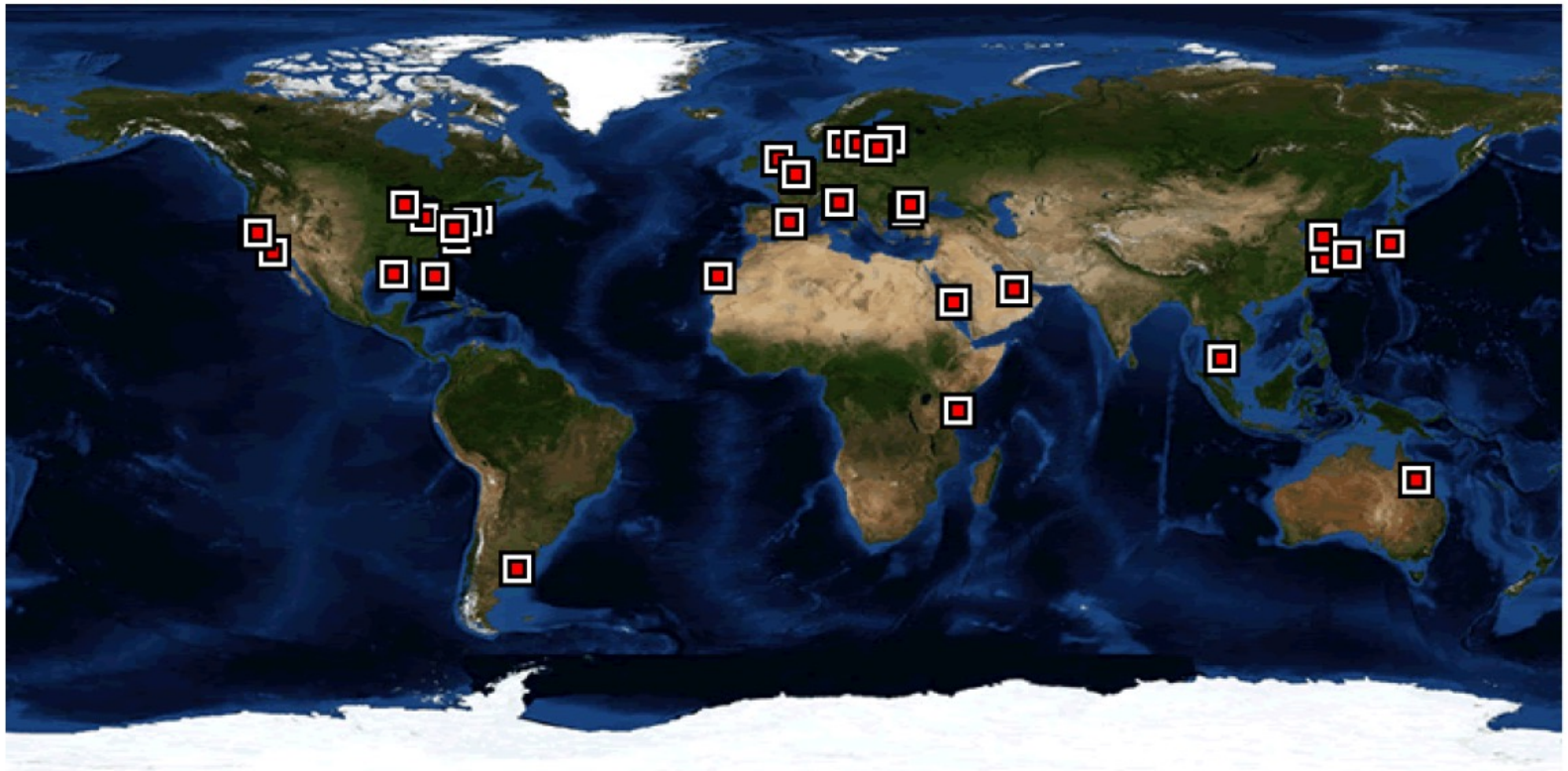


More Networks – Beyond Land Measurements



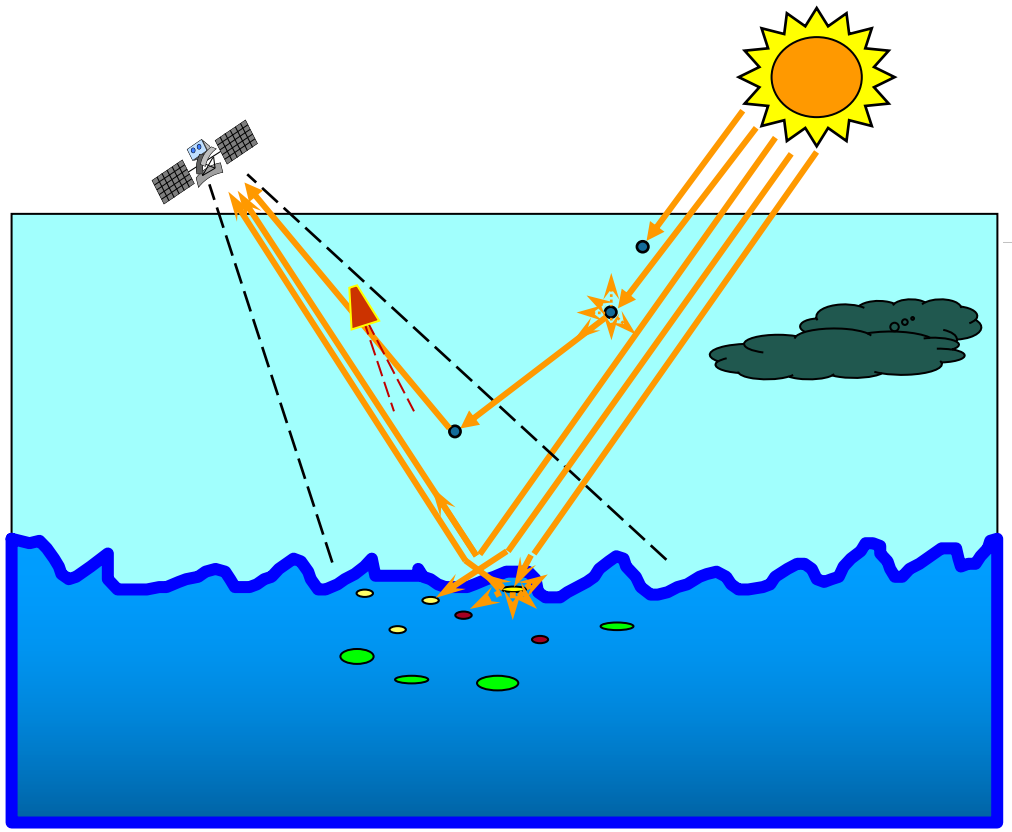
AERONET-OC

AERONET-OC

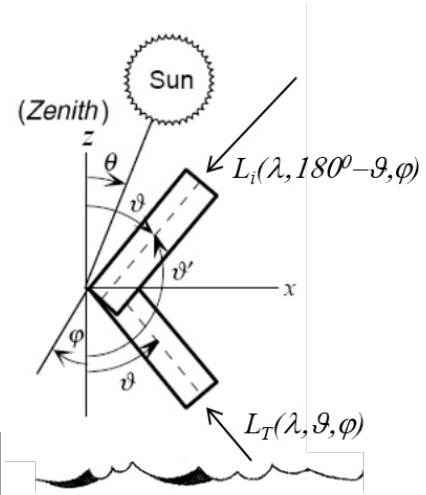


Abu_Al_Bukhoosh (25.495N, 53.146E)	ARIAKE_TOWER (33.104N,130.272E)	Bahia_Blanca (39.148S, 61.722W)
Banana_River (28.367N, 80.633W)	Blyth_NOAH (55.146N, 1.421W)	Casablanca_Platform (40.717N, 1.358E)
Chesapeake_Bay (39.124N, 76.349W)	COVE_SEAPRISM (36.900N, 75.710W)	Gageocho_Station (33.942N,124.593E)
Galata_Platform (43.045N, 28.193E)	Gloria (44.600N, 29.360E)	GOT_Seaprism (9.286N,101.412E)
Grizzly_Bay (38.108N,122.056W)	Gustav_Dalen_Tower (58.594N, 17.467E)	HBOI (27.534N, 80.357W)
Helsinki_Lighthouse (59.949N, 24.926E)	Ieodo_Station (32.123N,125.182E)	Irbe_Lighthouse (57.751N, 21.723E)
KAUST_Campus (22.305N, 39.103E)	Kemigawa_Offshore (35.611N,140.023E)	Lake_Erie (41.826N, 83.194W)
Lake_Okeechobee (26.902N, 80.789W)	Lake_Okeechobee_N (27.139N, 80.789W)	LISCO (40.955N, 73.342W)
Lucinda (18.520S,146.386E)	MVCO (41.325N, 70.567W)	Palgrunden (58.755N, 13.152E)
PLOCAN_Tower (28.041N, 15.385W)	Sacramento_River (38.050N,121.888W)	San_Marco_Platform (2.942S, 40.215E)
Section-7_Platform (44.546N, 29.447E)	Socheongcho (37.423N,124.738E)	South_Greenbay (44.596N, 87.951W)
Thornton_C-power (51.532N, 2.955E)	USC_SEAPRISM (33.564N,118.118W)	USC_SEAPRISM_2 (33.564N,118.118W)
Venise (45.314N, 12.508E)	WaveCIS_Site_CSI_6 (28.867N, 90.483W)	Zeebrugge-MOW1 (51.362N, 3.120E)

AERONET-OC



In Situ Above-Water Radiometry vs. Satellite Ocean Color



Sky-radiance: L_i Sea-radiance: L_T

$$L_W(\varphi,\theta,\lambda) = L_T(\varphi,\theta,\lambda) - \rho(\varphi,\theta,\theta_0,W)L_i(\varphi,\theta',\lambda)$$

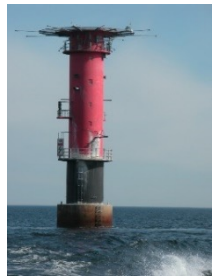
20 Years of Continuous Operation

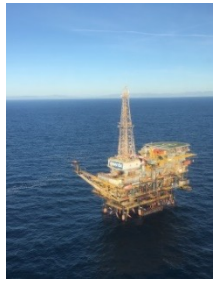
AERONET-OC: History

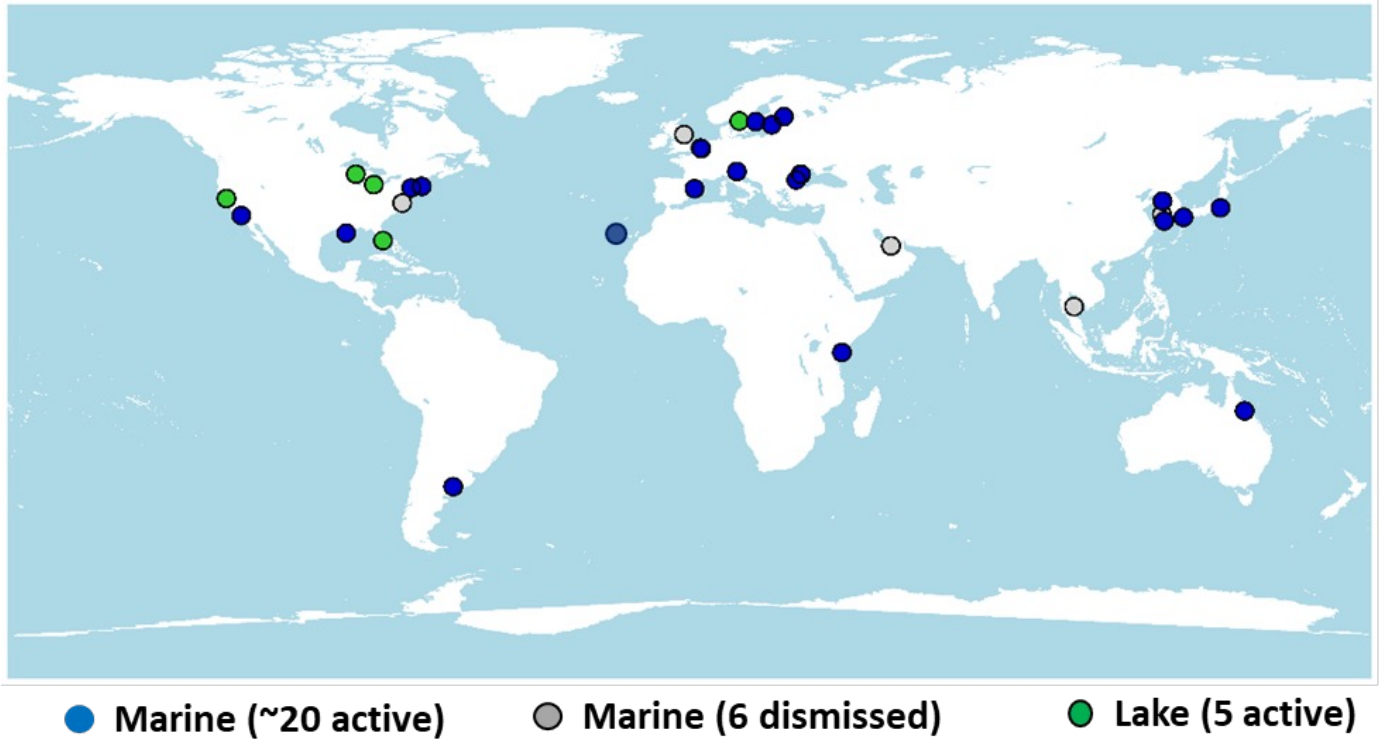
2000: First instrument/protocols prototype
2001: Instrument/protocol consolidation
2002: First measurement site
2003: Processing consolidation
2004: Expansion of measurement sites
2005: Presentation of the network
2009: Presentation of details on network elements
2014: Quantification of site-dependent uncertainties
2017: Deployment of advanced instruments
2019: Presentation of details on network advances
2022: Implementation an automated QC scheme

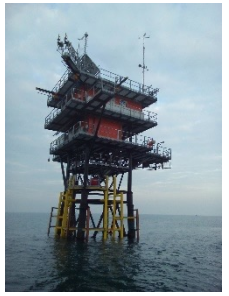
AERONET-OC – An International Automated Measurement Program

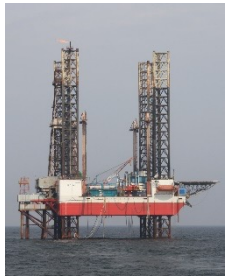
AERONET-OC (the Ocean Color component of the Aerosol Robotic Network) generates a globally distributed time-series of standardized $L_{WN}(\lambda)$ and $t_a(\lambda)$ measurements targeting the validation of satellite ocean color data.





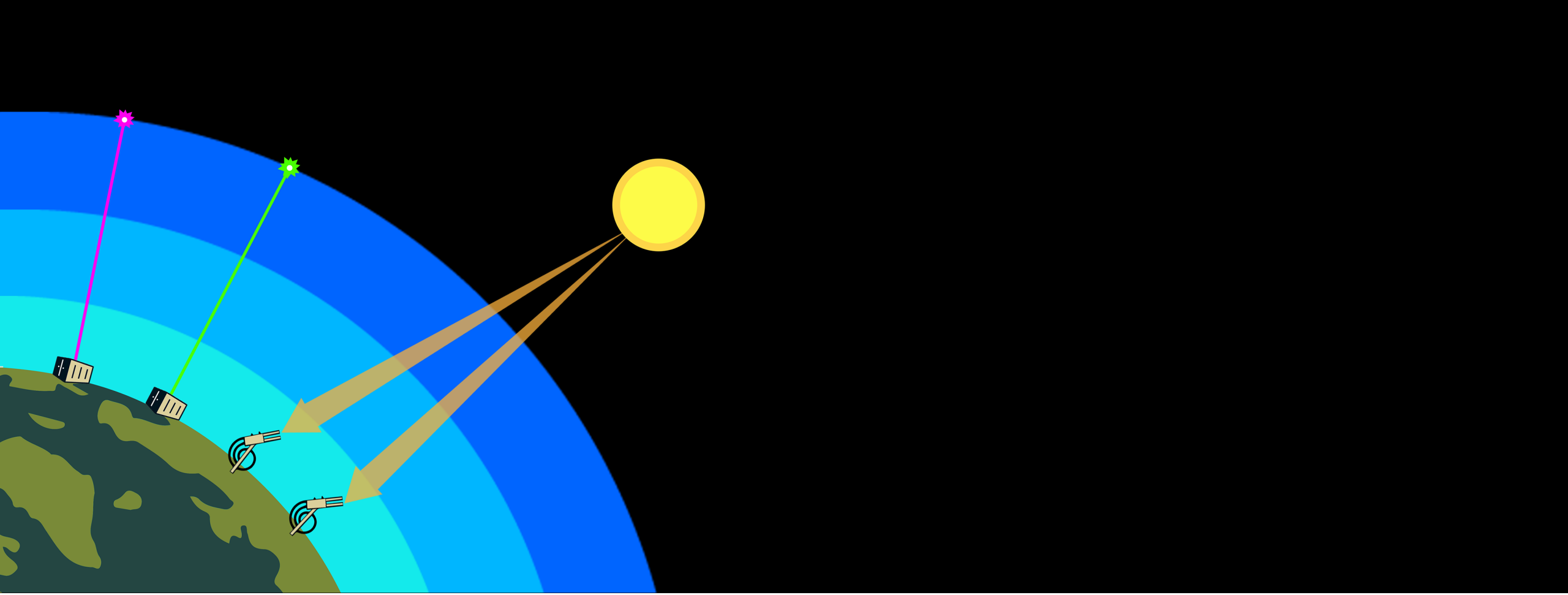






- NASA manages the network by handling the instruments calibration and data collection, processing, quality control, and distribution within AERONET.
- PIs associated with international institutions establish and maintain their sites, benefitting from the network support.

AERONET-OC Deployments



Maritime Aerosol Network (MAN)

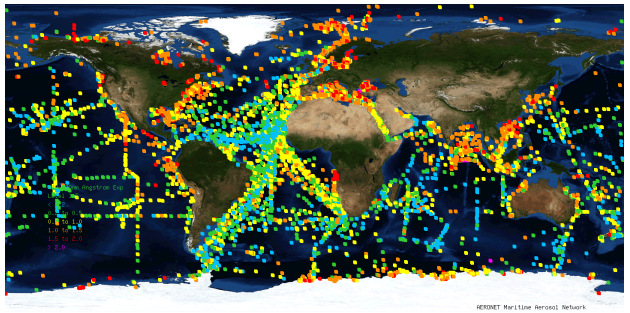
MAN

- The Maritime Aerosol Network (MAN) is a component of AERONET.
- It provides ship-borne aerosol optical depth measurements from the Microtops II sun photometers.
- Microtops II can have either 340, 440, 675, 870, and 936nm or 440, 500, 675, 870, and 936nm.
- In-built temperature and pressure measurement.
- GPS is used for accurate time and location.
- Calibrated at GSFC using master Cimel.
- Since 2004, these instruments have been deployed periodically on ships of opportunity and research vessels to monitor aerosol properties over the world's oceans.
- These data provide an alternative to observations from islands for satellite and model validation.

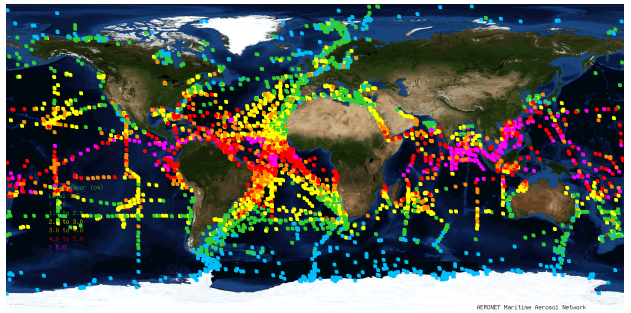
Handheld Sun Photometer – Microtops

MAN Datasets Examples

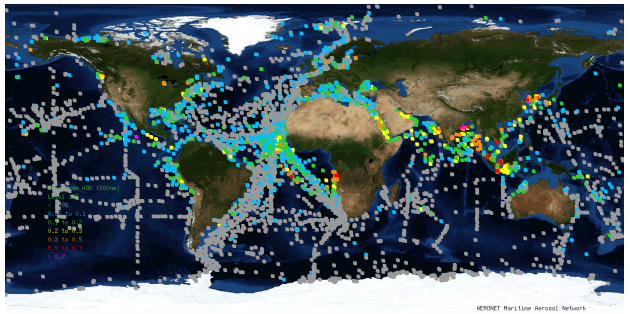
Angstrom Parameter



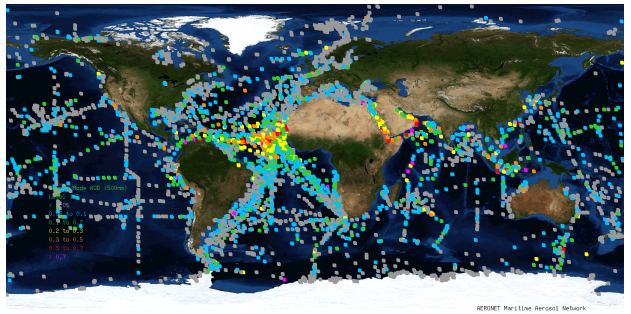
Precipitable Water



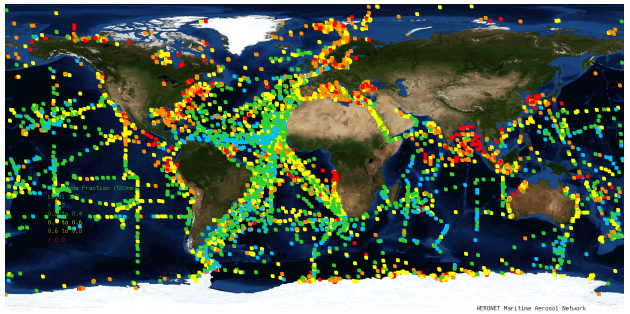
AOD Fine



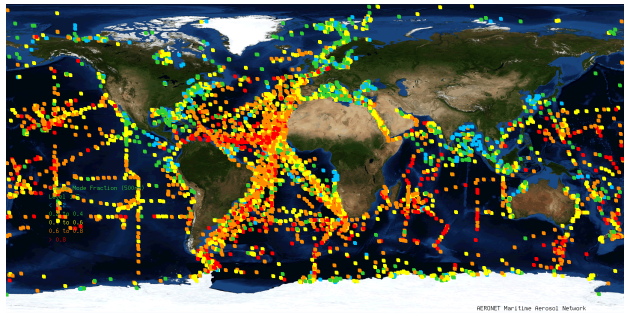
AOD Coarse



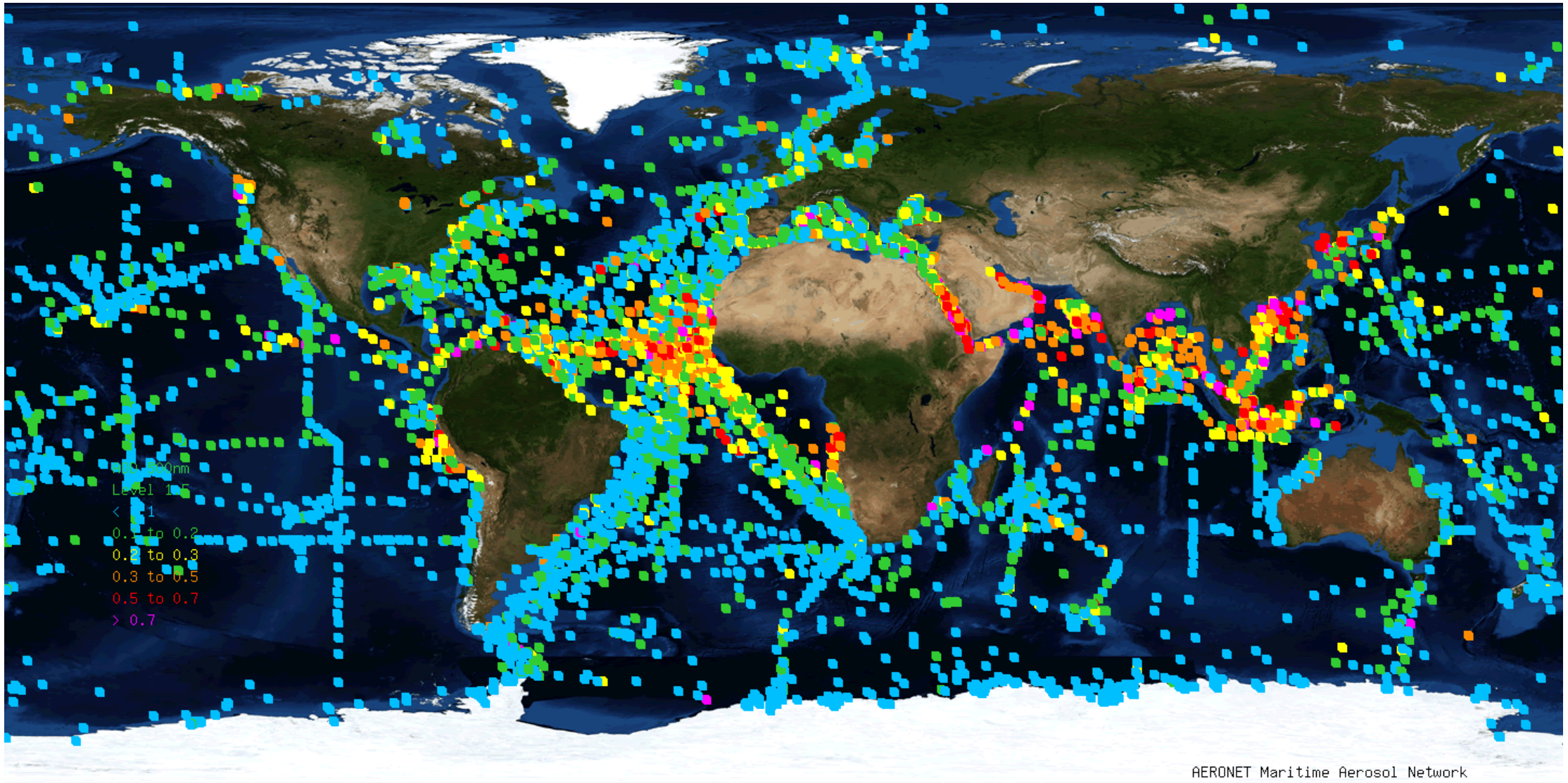
Fine Mode Fraction



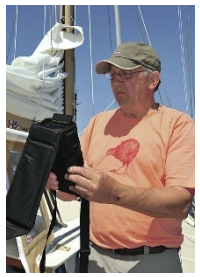
Coarse Mode Fraction

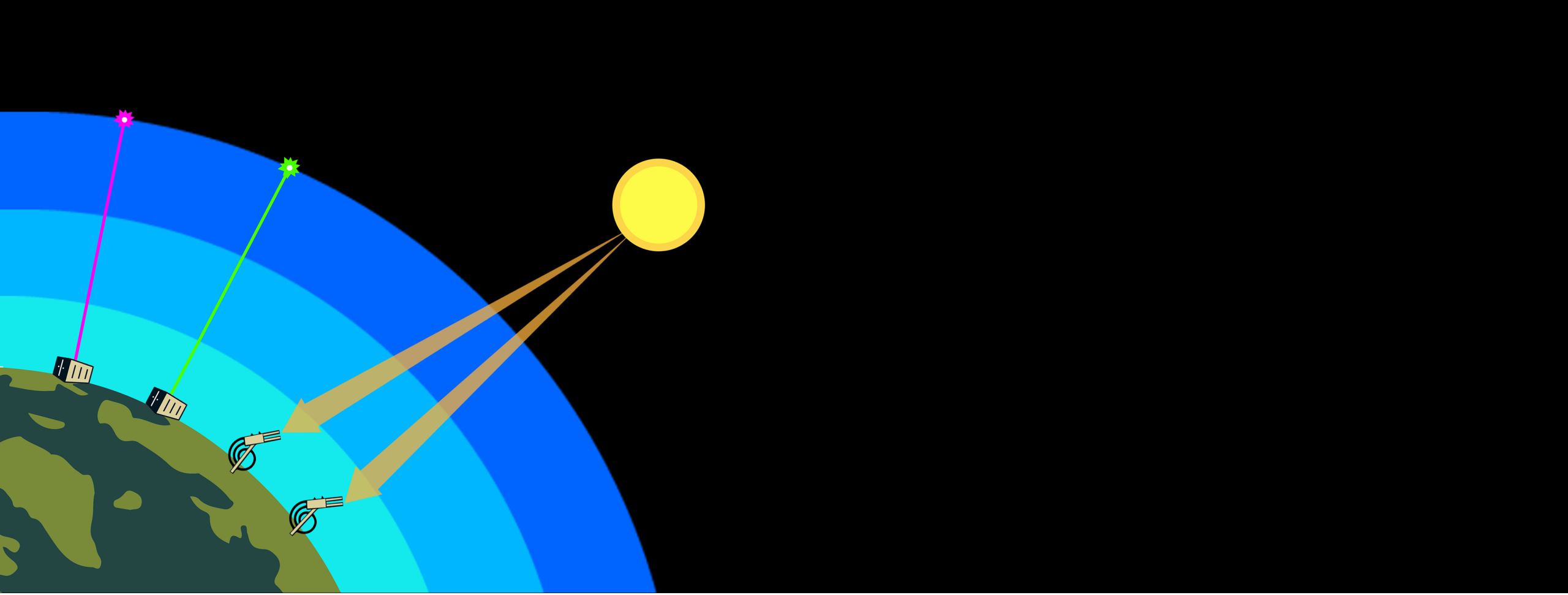


Coverage


AOD 500nm
Level 1.5
< 0.1
0.1 to 0.2
0.2 to 0.3
0.3 to 0.5
0.5 to 0.7
> 0.7
AERONET Maritime Aerosol Network

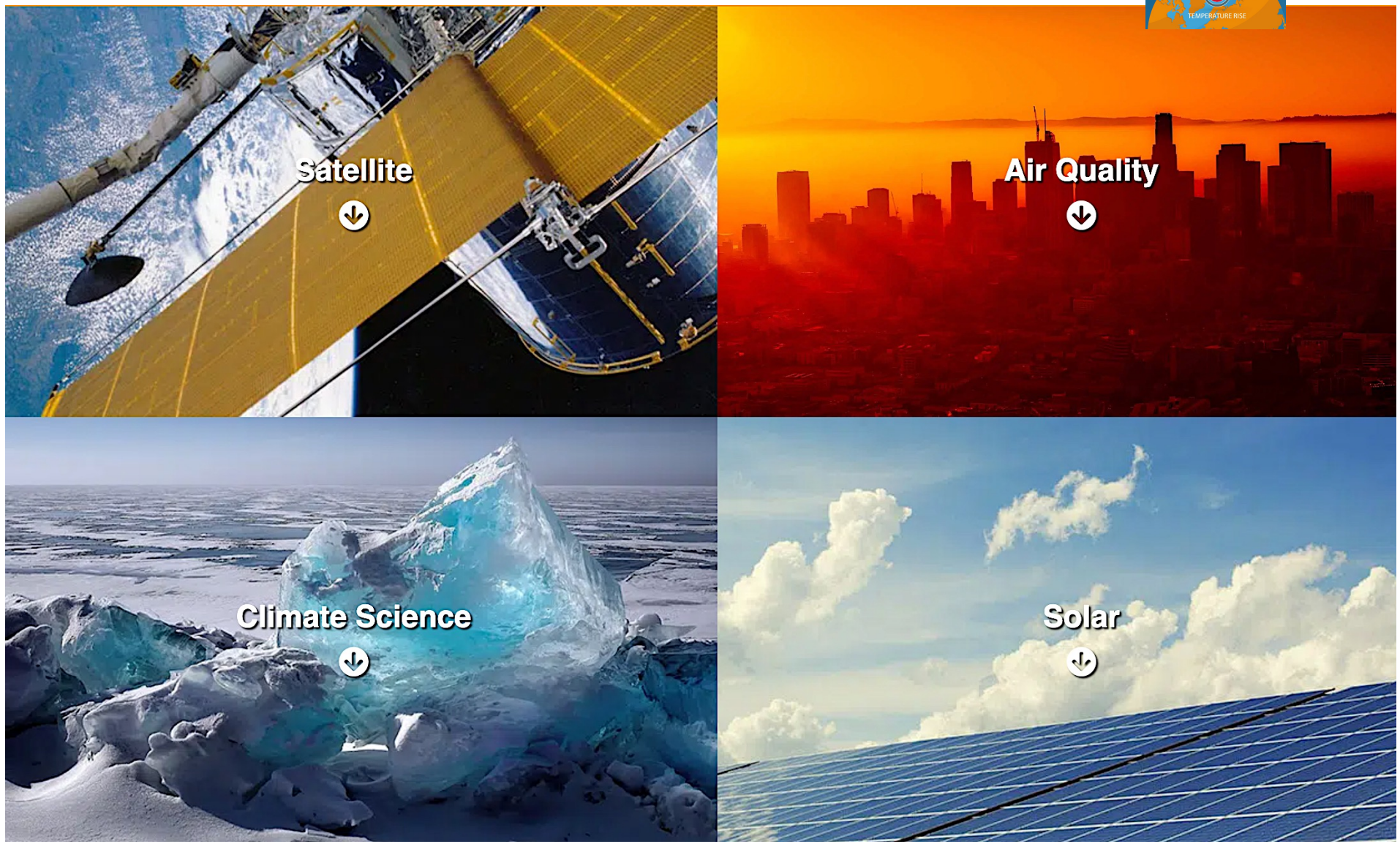
International Collaborative Effort





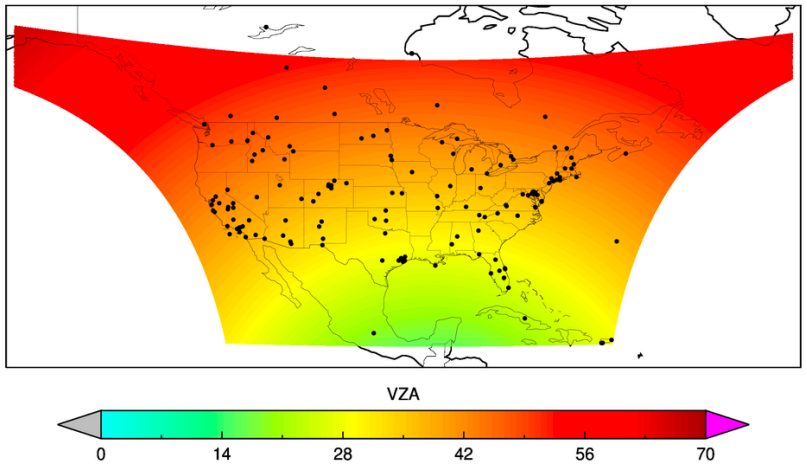
Applications

AERONET Data Applications



Satellite Validation Support

TEMPO – Tropospheric Emissions: Monitoring of Pollution, April 2023



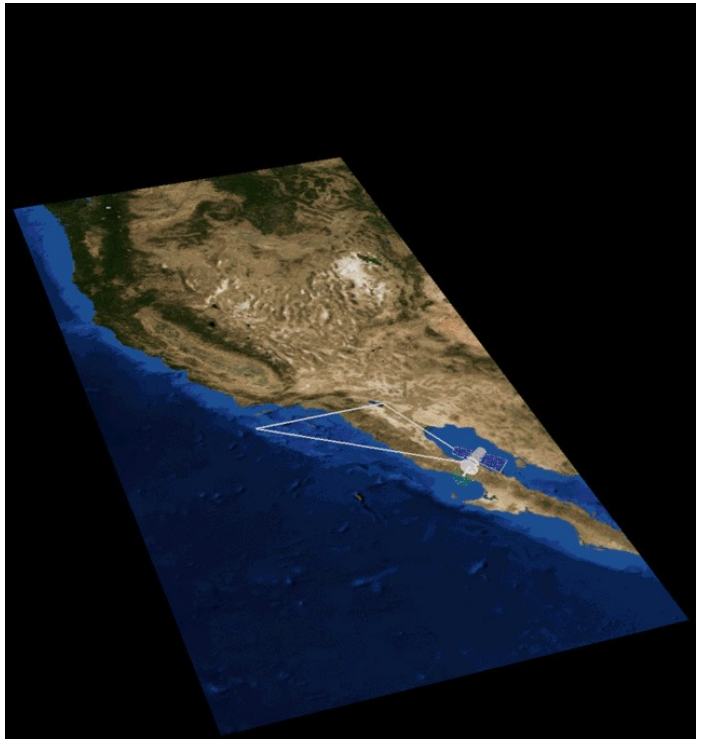
- 160 active sites in 2022
- 140 in US, covering 37 states
- 10 MSI sites coming up

PACE Plankton, Aerosol, Cloud, ocean Ecosystem

February 2024

- Ocean Colors
- Aerosols

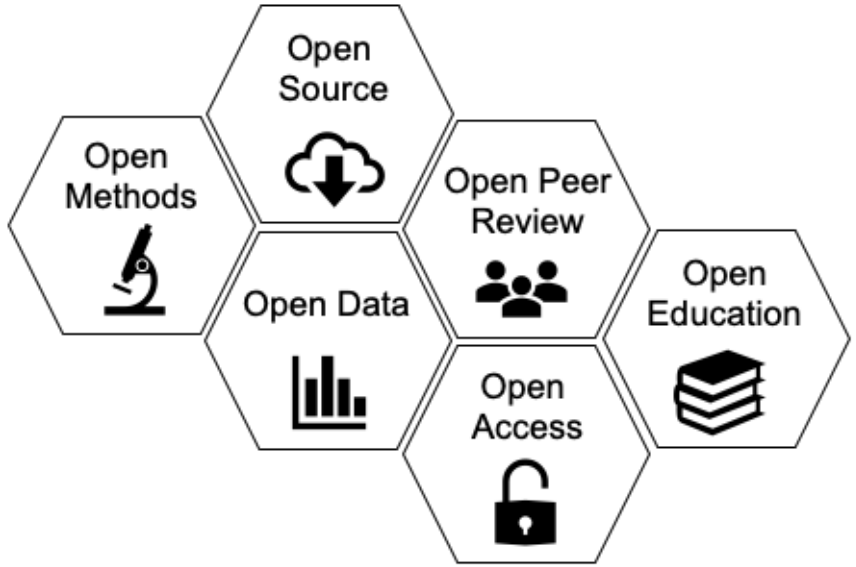
MAIA - Multi-Angle Imager for Aerosols
Anticipated launch 2026

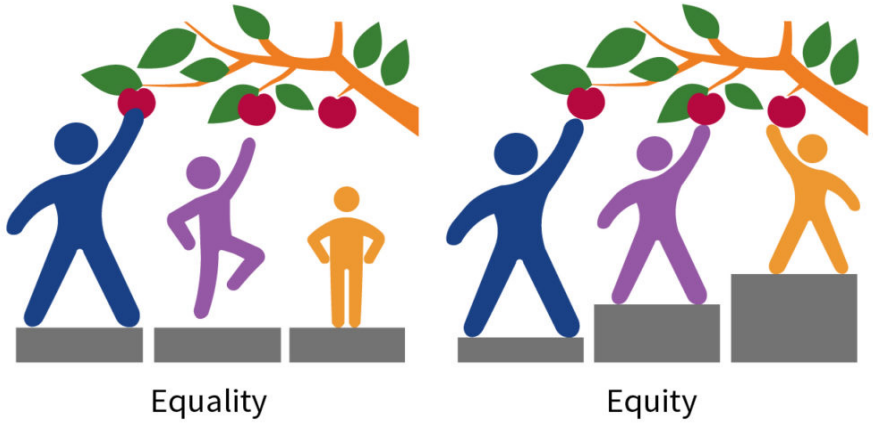


- $PM_{2.5}$ and its health impacts
- Primary target areas

Open-Source Science Initiative (OSSI)

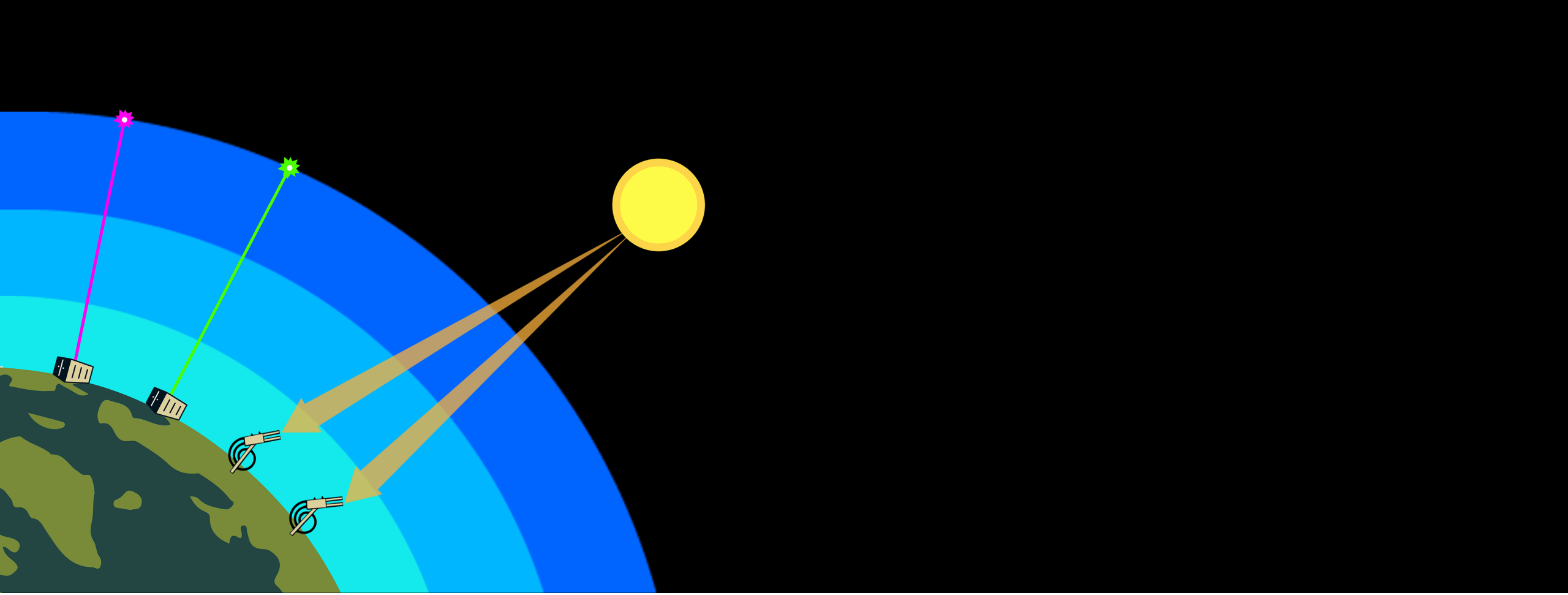
- NASA is building an inclusive open science community.
- To "broaden participation and foster greater collaboration in scientific investigations by lowering the barriers to entry into scientific exploration."





- AERONET stands on a foundation of open data policy.
- The program has done an excellent job in making information available through its web portal ('Equality').
- There is an opportunity to expand its reach and impact to the larger community ('Equity') – data format, training, and relevant data.
- Partnership with ARSET is an attempt to reach out to a larger end-user community.

Ref: https://science.nasa.gov/open-science-overview



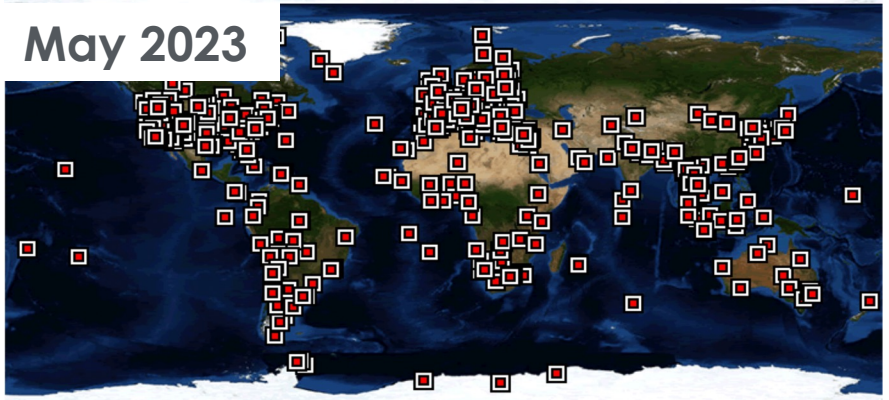
Part 1:
Summary

Summary

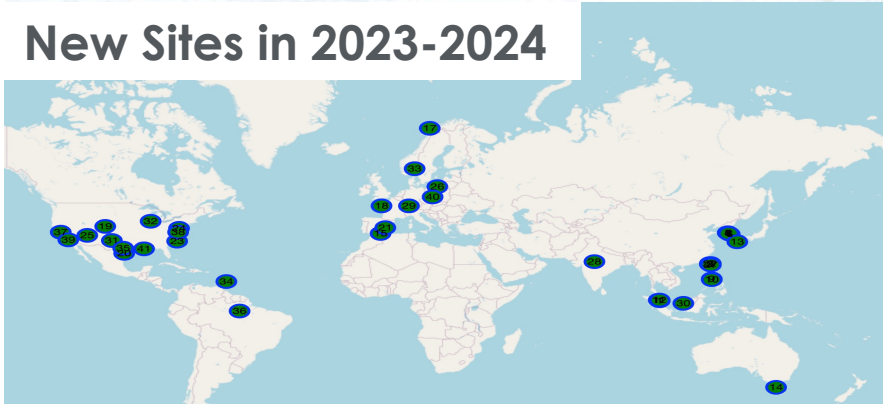
- AERONET has produced 30 years of atmospheric aerosol measurements and continuing
- AERONET continues to grow with currently 600 active sites around the globe
- AERONET continues to provide high quality data for various applications -
  - validation of satellite retrievals (e.g., VIIRS, AOS, PACE, MAIA, TEMPO, MODIS, OMI)
  - model forecasting (e.g., GOCART, ICAP, NAAPS, AEROCOM, NCEP, UKMET, ECMWF)
  - reanalysis assessments (e.g., MERRA, ERA)
  - synergy of surface-based remote sensing (e.g., MPLNET, Pandora, TOLNET, SKYNET, SPARTAN, IMPROVE) to assess air quality
- AERONET DRAGON deployments support NASA field campaigns (e.g., ASIA-AQ) and missions (e.g., TEMPO, PACE, MAIA)
- AERONET-OC released V4 of L_{WN} for PACE validation
- Quarterly Newsletter

May 1993

May 2023



New Sites in 2023-2024



Looking Ahead to Part 2

- Application Examples
- Website Tour
- Data Download
- Data Visualization
- Python Notebooks in Google Colab*
- Satellite Data Validation

* To follow along with these examples, you will need a Google Account

Acknowledgments

- AERONET Team
- AERONET Site PIs
- AERONET Site Managers
- EOS Validation Program
- NASA HQ
- International Partners

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 22/08/2024
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 05/09/2024**

- **Certificate of Completion:**
  - Attend all five live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

Trainers:

- Pawan Gupta
  - pawan.gupta@nasa.gov
- Carl Malings
  - carl.a.malings@nasa.gov

Join the AERONET Mailing List:

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TRAIN - EMPOWER - ADVANCE

Thank You!