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ACTRIS Aerosol Remote Sensing Data Acquisition, Processing, and Submission

Training Course
11-13 November 2024
CNR-IMAA

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 "Education and Research" - Component 2: "From research to business" - Investment 3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures"

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
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ACTRIS Aerosol Remote Sensing Data Acquisition, Processing, and Submission

11-13 November 2024

Consiglio Nazionale delle Ricerche – Istituto di Metodologie per l'Analisi Ambientale (CNR-IMAA)

C.da S. Loja 85050 – Tito (Pz) – Italy

11 November		
09:00 – 09:30	**Arrival, registration, Coffee**	
09:30 – 09:40	• Welcome and logistics	Gianluca Di Fiore (CNR-IMAA)
09:40 – 10:00	• Aerosol Remote Sensing data standardization: ACTRIS approach	Giuseppe D'Amico (CNR-IMAA)
10:00 – 11:30	• ACTRIS Aerosol Remote Sensing data processing: SCC overview	Giuseppe D'Amico (CNR-IMAA)
11:30 – 12:30	• ACTRIS Aerosol Remote Sensing instrumental quality assurance	Nikolaos Siomos (LMU)
	Lunch	
14:00 – 14:30	• Lidar data pre-processing	Giuseppe D'Amico (CNR-IMAA)
14:30 – 15:30	• SCC web interface/API	Claudio Dema (CNR-IMAA)
15:30 – 16:00	• Raw data conversion/submission tools	Pilar Gumà Claramunt (CNR-IMAA)
	Coffee break	
16:30 – 17:30	**Hands on**: setup of simple system, submission of raw data file, basic processing	Giuseppe D'Amico (CNR-IMAA) Claudio Dema (CNR-IMAA) Ina Mattis (DWD) Pilar Gumà Claramunt (CNR-IMAA)

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12 November		
09:00 – 10:00 10:00 – 11:00	• Depolarization calibration: instrumental correction • Depolarization calibration: SCC implementation	Nikolaos Siomos (LMU) Giuseppe D'Amico (CNR-IMAA)
	Coffee break	
11:30 – 12:30	• Optical processing of lidar data	Ina Mattis (DWD)
	Lunch	
14:00 – 16:00	**Hands on:** optimized processing settings, submission depolarization calibration data	Giuseppe D'Amico (CNR-IMAA) Claudio Dema (CNR-IMAA) Ina Mattis (DWD) Pilar Gumà Claramunt (CNR-IMAA) Nikolaos Siomos (LMU)
	Coffee break	
16:30 – 17:30	**Hands on:** optimized processing settings, submission depolarization calibration data	Giuseppe D'Amico (CNR-IMAA) Claudio Dema (CNR-IMAA)
		Ina Mattis (DWD) Pilar Gumà Claramunt (CNR-IMAA) Nikolaos Siomos (LMU)

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13 November		
09:00 – 09:20	• ACTRIS Aerosol Remote Sending data processing: Future Developments	Giuseppe D'Amico (CNR-IMAA)
09:20 – 10:30	• ACTRIS Aerosol Remote Sensing datacenter: ARES overview	Lucia Mona (CNR-IMAA)
	Coffee break	
11:00 – 11:30	• Automatic Quality control on ARES products	Pilar Gumà Claramunt (CNR-IMAA)
11:30 – 12:00	• ARES submission data portal	Pilar Gumà Claramunt (CNR-IMAA)
12:00 – 12:30	• ARES data portal/API	Claudio Dema (CNR-IMAA)
	Lunch	
14:00 – 14:30	• ARES data portal: new products	Lucia Mona (CNR-IMAA)
14:30 – 16:00	**Hands on**: exploring and getting products from ARES data portal/API	Claudio Dema (CNR-IMAA) Pilar Gumà Claramunt (CNR-IMAA)
	Coffee break	
16:30 – 17:15	**Hands on**: exploring and getting products from ARES data portal/API	Claudio Dema (CNR-IMAA) Pilar Gumà Claramunt (CNR-IMAA)
17:15 – 18:00	**Visit to CIAO**	

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Aerosol Remote Sensing Data Standardization: ACTRIS approach

Giuseppe D'Amico

giuseppe.damico@cnr.it

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Outline

- Crucial role of the atmospheric aerosols in Earth climate system
- Importance of Lidars observations
- A further step forward: Coordinated lidar networks/ Atmospheric RI
- Importance of products standardization in a RI
- ACTRIS/EARLINET challenges: inhomogeneous network

Atmospheric Aerosols Radiative Impact

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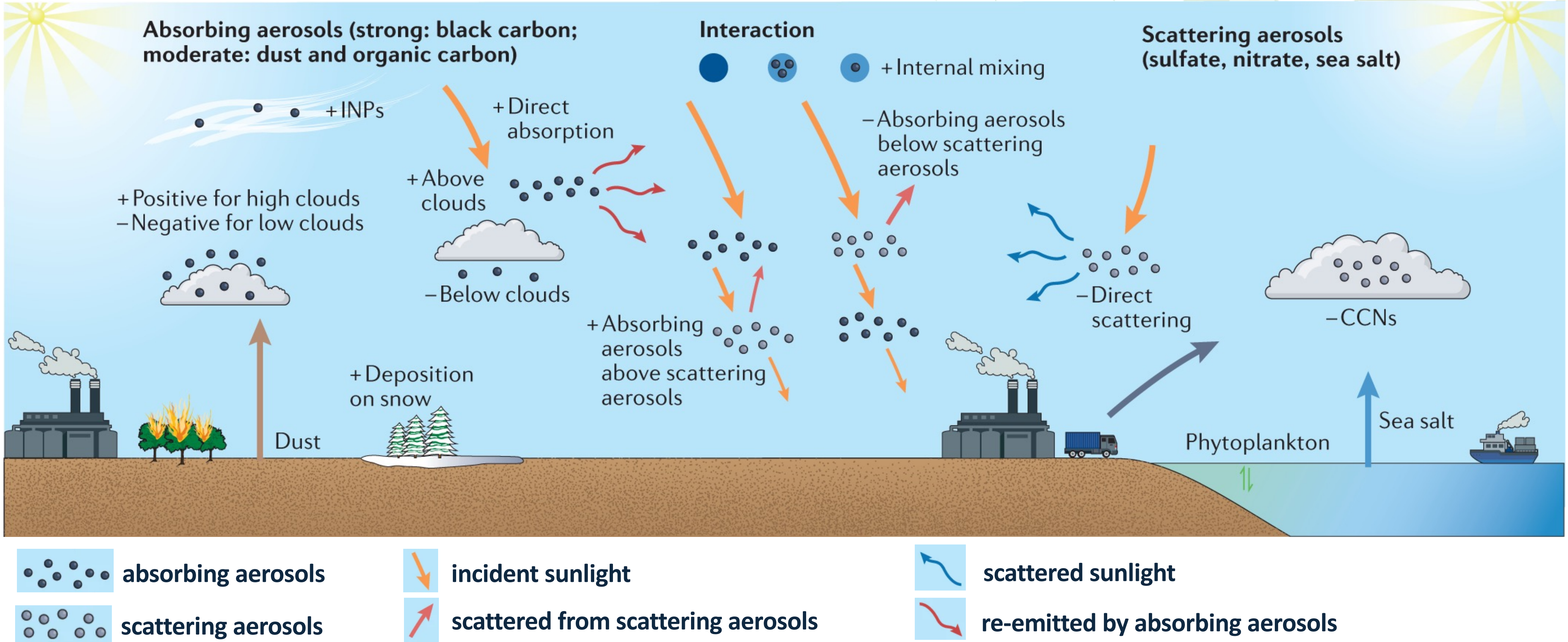

Li, J. et al. Scattering and absorbing aerosols in the climate system. Nat Rev Earth Environ 3(2022). https://doi.org/10.1038/s43017-022-00296-7

Atmospheric Aerosols Radiative Impact

High complexity scenario

- Many different aerosol sources
  - dust
  - volcanic
  - biomass burning
  - pollution
  - marine…
- Each aerosol type has different optical properties and interacts with other atmospheric components differently
- Even for the same aerosol type, the optical properties may change over long path transportation
- Aerosol interaction with other particles or clouds may depend on vertical position and concentration

For example,

scattering aerosols above absorbing aerosols → Negative forcing (cooling)

scattering aerosols below absorbing aerosols → Positive forcing (warming)

Atmospheric Aerosols Radiative Impact

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High complexity scenario →

Large uncertainties in quantify the aerosol role in relevant atmospheric processes like:

- **Earth radiative budget**
- **Climate change**
- **Forecast models**
- **…**

- Many different aerosol sources
  - dust
  - volcanic
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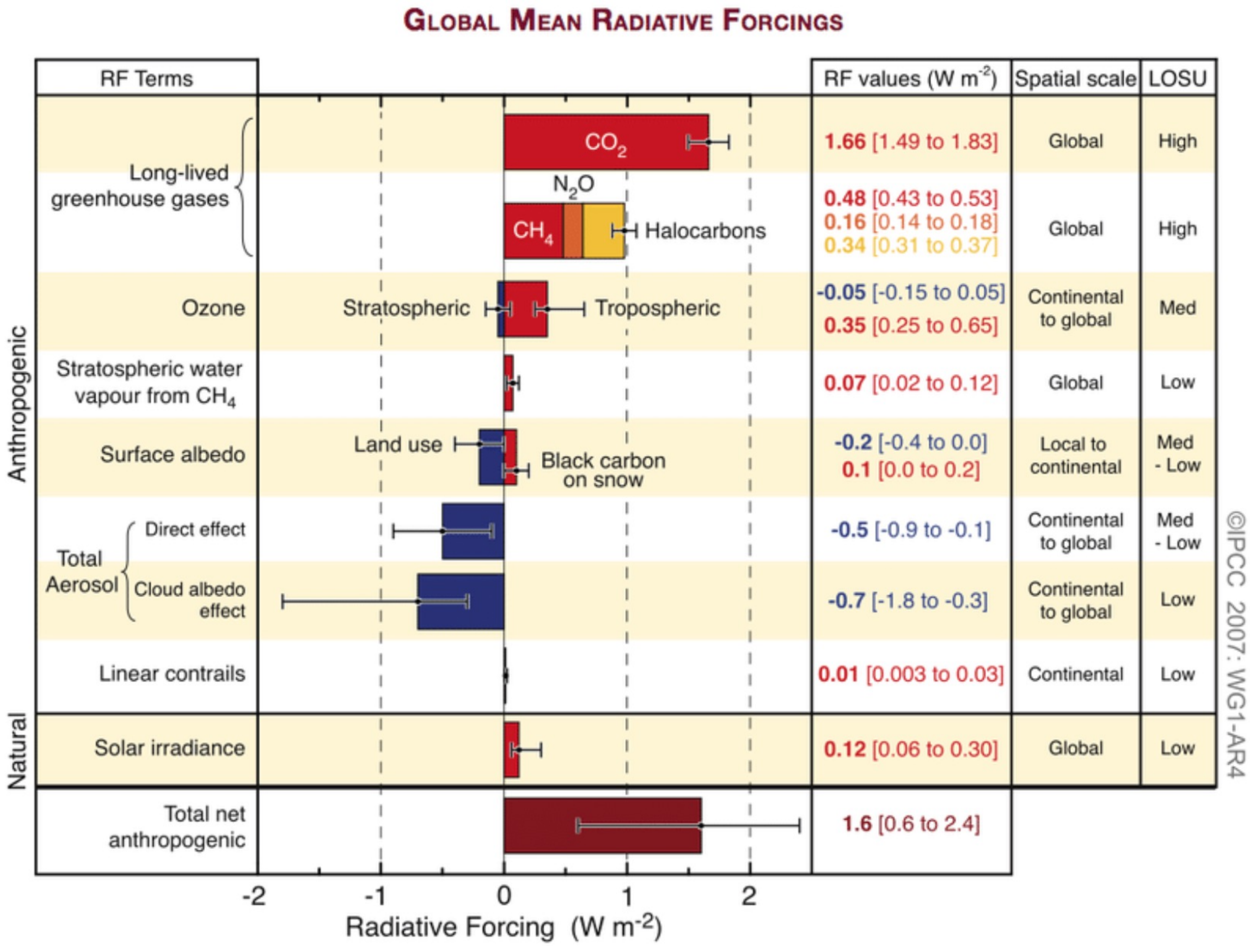
Atmospheric Aerosols Radiative Impact



Atmospheric Aerosols Radiative Impact

High complexity scenario

Large uncertainties in quantify the aerosol role in relevant atmospheric processes like:

- **Earth radiative budget**
- **Climate change**
- **Forecast models**
- **…**

Critical need to get vertically-resolved information on aerosol optical properties

Currently Multi-wavelength Raman Lidars (and HSRL) are the only instruments capable to provide such measurements.

Aerosol Lidar Measurements

Lidar equation

- **Elastic backscattered power**

$$P(z,\lambda_L) = P_0 \frac{C(\lambda_L)}{z^2}\left[\beta^{(p)}(z,\lambda_L) + \beta^{(m)}(z,\lambda_L)\right]T^2(z,\lambda_L)$$

Particle backscatter coefficient — Molecular backscatter coefficient

- **Atmospheric transmissivity**

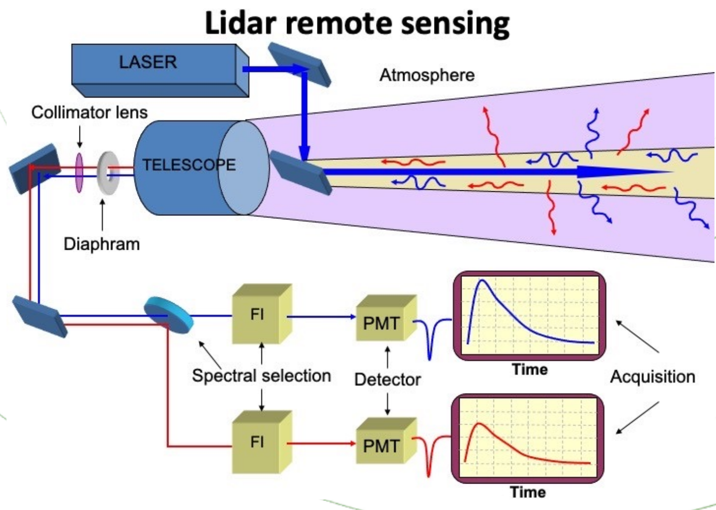
$$T(z,\lambda) = exp\left\{-\int_0^z\left[\alpha^{(p)}(\xi,\lambda) + \alpha^{(m)}(\xi,\lambda)\right]d\xi\right\}$$

Particle extinction coefficient — Molecular extinction coefficient

- **Anelastic (Raman) backscattered power**

$$P(z,\lambda_L,\lambda_i) = P_0 \frac{C(\lambda_R)}{z^2}\beta_i^{(Ram)}(z,\lambda_L,\lambda_i)T(z,\lambda_L)\,T(z,\lambda_i)$$

Raman backscatter coefficient for molecular species “I”



Aerosol Lidar Measurements

Lidar equation

- **Elastic backscattered power**

$$P(z,\lambda_L) = P_0 \frac{C(\lambda_L)}{z^2}\left[\beta^{(p)}(z,\lambda_L) + \beta^{(m)}(z,\lambda_L)\right]T^2(z,\lambda_L)$$

→ **2 unknowns**

unknown

- **Atmospheric transmissivity**

$$T(z,\lambda) = exp\left\{-\int_0^z\left[\alpha^{(p)}(\xi,\lambda) + \alpha^{(m)}(\xi,\lambda)\right]d\xi\right\}$$

- **Anelastic (Raman) backscattered power**

$$P(z,\lambda_L,\lambda_i) = P_0 \frac{C(\lambda_R)}{z^2}\beta_i^{(Ram)}(z,\lambda_L,\lambda_i)T(z,\lambda_L)\,T(z,\lambda_i)$$

→ **1 unknown**

Aerosol Lidar Measurements

A typical Multi-wavelength Raman Lidar can provide vertical profile of

- Particle backscatter coefficient at 3 wavelengths (1064nm, 532nm, 355nm) **EXTENSIVE**

$$\beta^{(p)}(z,\lambda) = \sum_i \beta_i(z,\lambda) = \sum_i N_i(z)\sigma_i^{(bck)}(\lambda)$$

from elastic (and anelastic) signals

Numerical density of aerosol "i" — Backscatter cross section of aerosol "i"

- Particle extinction coefficient at 2 wavelengths (532nm, 355nm) **EXTENSIVE**

$$\alpha^{(p)}(z,\lambda) = \sum_i \alpha_i(z,\lambda) = \sum_i N_i(z)\sigma_i^{(ext)}(\lambda)$$

from anelastic (Raman) signals

Numerical density of aerosol "i" — Extinction cross section of aerosol "i"

- Total volume depolarization ratio at 3 wavelengths (1064nm, 532nm, 355nm) **EXTENSIVE**

$$\delta_V(z,\lambda) = \frac{\beta_\perp^{(p)}(z,\lambda)+\beta_\perp^{(m)}(z,\lambda)}{\beta_\parallel^{(p)}(z,\lambda)+\beta_\parallel^{(m)}(z,\lambda)}$$

← Cross polarized total (particles+molecules) backscatter

← Co-polarized total (particles+molecules) backscatter

Aerosol Lidar Measurements

A typical Multi-wavelength Raman Lidar can provide vertical profile of

- Particle extinction-to-backscatter-ratio (Lidar ratio) at 2 wavelengths (532nm, 355nm) **INTENSIVE**

$$S_i\,(z,\lambda) = \frac{\alpha_i(z,\lambda)}{\beta_i(z,\lambda)}$$

→ **Sensitive to aerosol type**

- Angstrom exponents **INTENSIVE**

$$k_\alpha(\lambda_1,\lambda_2) = \frac{ln\left[\frac{\alpha_i(z,\lambda_1)}{\alpha_i(z,\lambda_2)}\right]}{ln\left[\frac{\lambda_2}{\lambda_1}\right]} \qquad k_\beta(\lambda_1,\lambda_2) = \frac{ln\left[\frac{\beta_i(z,\lambda_1)}{\beta_i(z,\lambda_2)}\right]}{ln\left[\frac{\lambda_2}{\lambda_1}\right]}$$

→ **Sensitive to aerosol size**

- Particle depolarization ratio at 3 wavelengths (1064nm, 532nm, 355nm) **INTENSIVE**

$$\delta_i(z,\lambda) = \frac{\beta_{i,\perp}(z,\lambda)}{\beta_{i,\parallel}(z,\lambda)}$$

→ **Sensitive to aerosol shape**

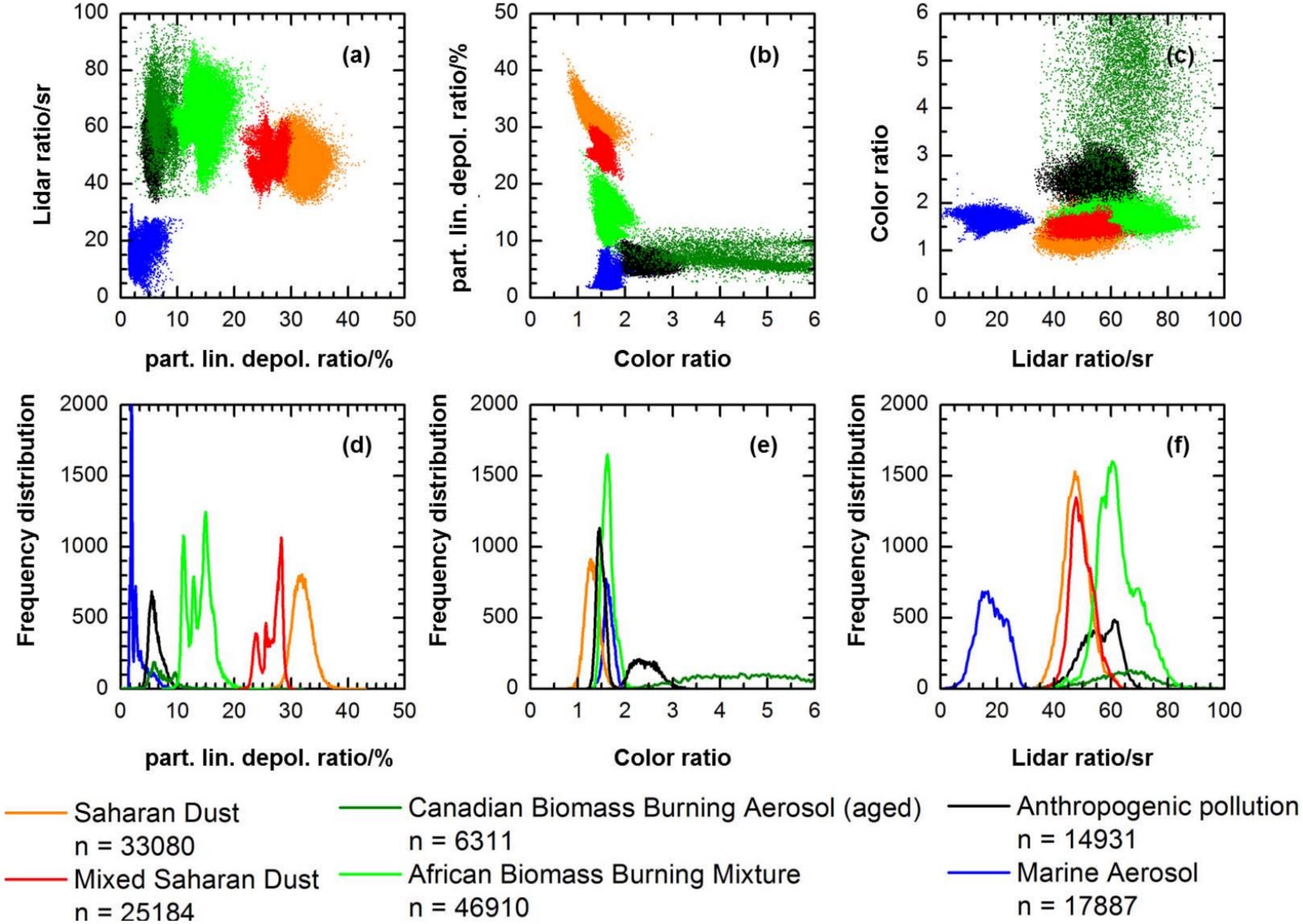
Aerosol Lidar Measurements

Table 2. Mean value ± standard deviation of aerosol lidar ratio, particle linear depolarization ratio and color ratio of backscatter for the examined aerosol types, as well as value of maximum frequency, range, and median. The data in brackets give the counts per bin.

Aerosol Type	mean ± stdv	value of maximum frequency	range	median
aerosol lidar ratio [sr] at 532 nm				
Saharan dust	48 ± 5	47 (1538)	33–68	48
mixed Saharan dust	50 ± 4	48 (1348)	32–71	49
biomass burning mixture (Africa)	63 ± 7	60 (1601)	36–91	62
biomass burning aerosol (Canada)	69 ± 17	61 (485)	42–93	65
marine aerosol (North Atlantic)	18 ± 5	18 (687)	0–33	18
anthropogenic pollution aerosol (Europe)	56 ± 6	61 (485)	33–72	56
particle linear depolarization ratio [%] at 532 nm				
Saharan dust	32 ± 2	32 (806)	25–43	32
mixed Saharan dust	27 ± 2	28 (1034)	21–31	27
biomass burning mixture (Africa)	14 ± 2	15 (1245)	8–26	14
biomass burning aerosol (Canada)	7 ± 2	6 (188)	4–12	7
marine aerosol (North Atlantic)	3 ± 1	2 (2596)	1–11	2
anthropogenic pollution aerosol (Europe)	6 ± 1	6 (686)	3–11	6
color ratio of backscatter				
Saharan dust	1.30 ± 0.15	1.29 (913)	0.7–2.56	1.3
mixed Saharan dust	1.48 ± 0.09	1.46 (1134)	1.16–1.96	1.48
biomass burning mixture (Africa)	1.63 ± 0.13	1.62 (1651)	1.04–2.41	1.63
biomass burning aerosol (Canada)	4.70 ± 1.30	4.43 (108)	2.60–7.21	4.62
marine aerosol (North Atlantic)	1.64 ± 0.10	1.6 (773)	1.17–2.62	1.64
anthropogenic pollution aerosol (Europe)	2.43 ± 0.27	2.3 (209)	1.72–3.45	2.41

Groß, S. et al.: Aerosol classification by airborne high spectral resolution lidar observations, AC, https://doi.org/10.5194/acp-13-2487-2013

Aerosol Lidar Measurements



Groß, S. et al.: Aerosol classification by airborne high spectral resolution lidar observations, AC, https://doi.org/10.5194/acp-13-2487-2013

Aerosol Lidar Measurements: Lidar Networks

A single lidar provides **punctual** observations (2D) for the complete characterization of atmospheric aerosols

- ideal for:
  - climatological studies of specific sites
  - study the dynamic (in time) of the aerosol contents of specific locations
- but inappropriate for:
  - climatological studies on continental scale
  - study of long-range aerosol transport mechanism
  - monitor extreme events on large scale

Coordinate lidar networks → add horizontal dimensions opening for a 4D aerosol studies

Aerosol Lidar Measurements: Lidar Network (Europe)

2000

EARLINET

European **A**erosol **R**esearch **LI**dar **NET**work

- Research lidar network
- First standardization attempt
- First continental vertical aerosol properties db

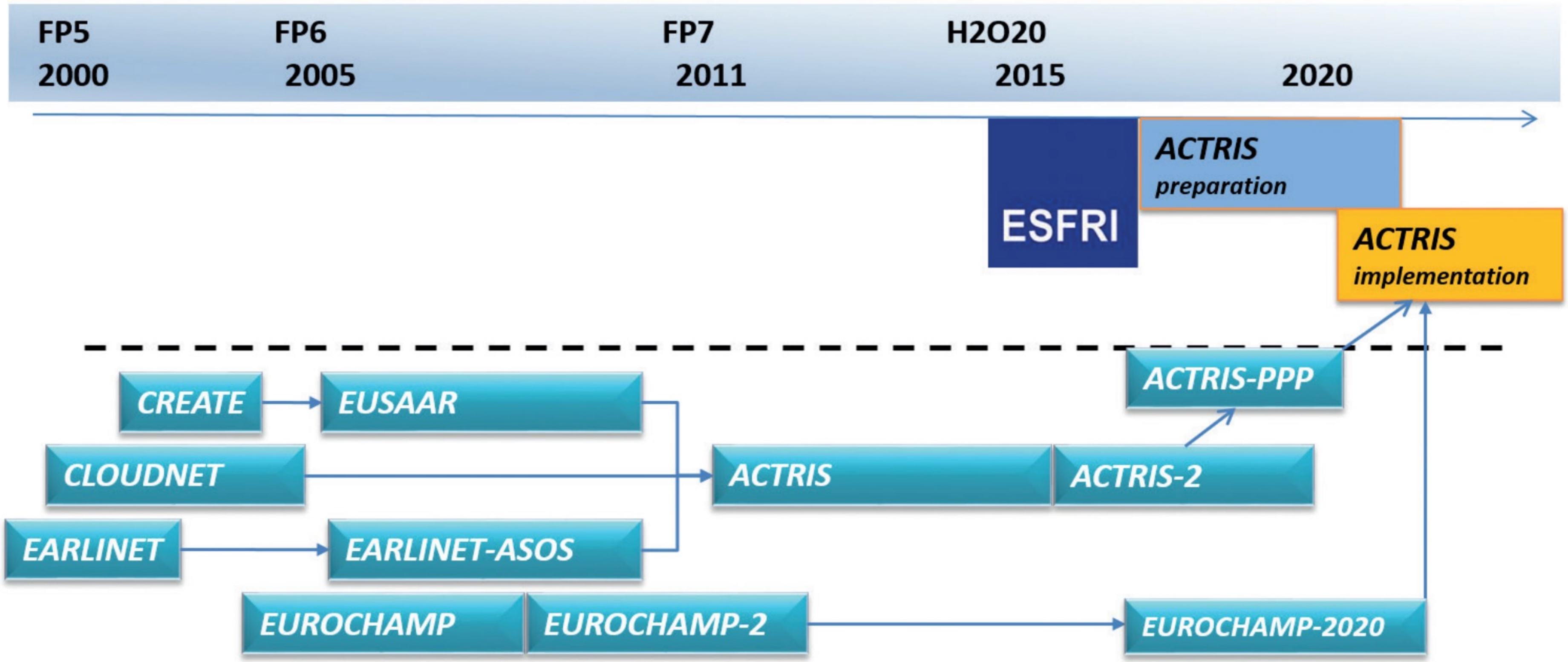
2011

ACTRIS
Exploring the Atmosphere

Aerosols, **C**louds and **TR**ace gases **R**esearch **I**nfra**S**tructure

- EARLINET community joined ACTRIS
- Research Infrastructure
- Standardization of products extended to different communities

Aerosol Lidar Measurements: Lidar Network (Europe)



Aerosol Lidar Measurements: Lidar Network (Global)

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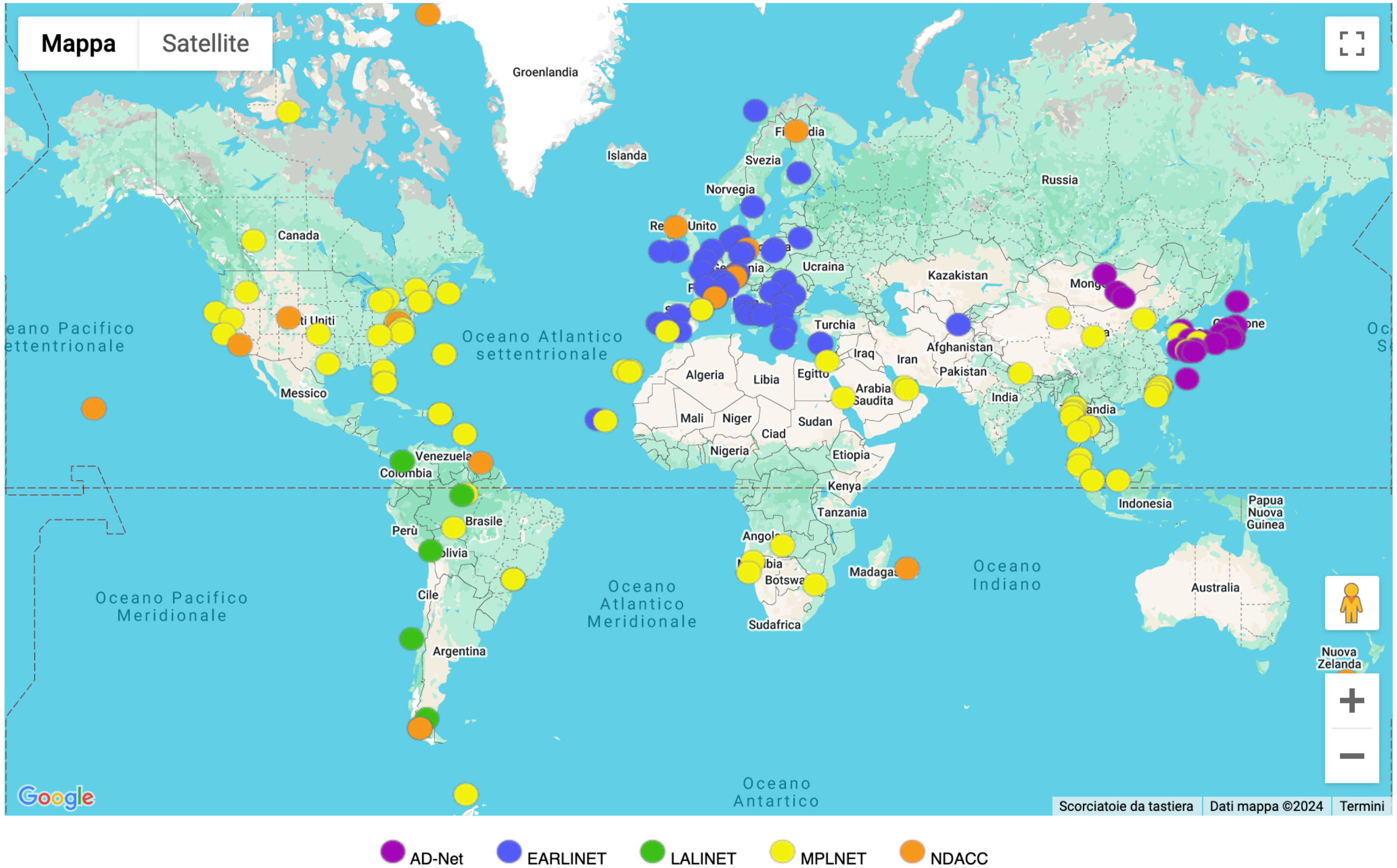
GALION

The GAW Aerosol Lidar Observation Network

https://galion.world



Main requests for a modern and efficient RI

ITINERIS

- Standardization
- Full traceability
- Quality control
- Unique data access point
- NRT data provision
- FAIR compliance

    https://www.force11.org/group/fairgroup/fairprinciples

Main requests for a modern and efficient RI

To be Findable:

F1. (meta)data are assigned a globally unique and eternally persistent identifier.
F2. data are described with rich metadata.
F3. (meta)data are registered or indexed in a searchable resource.
F4. metadata specify the data identifier.

To be Accessible:

A1 (meta)data are retrievable by their identifier using a standardized communications protocol.
A1.1 the protocol is open, free, and universally implementable.
A1.2 the protocol allows for an authentication and authorization procedure, where necessary.
A2 metadata are accessible, even when the data are no longer available.

To be Interoperable:

I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
I2. (meta)data use vocabularies that follow FAIR principles.
I3. (meta)data include qualified references to other (meta)data.

To be Re-usable:

R1. (meta)data have a plurality of accurate and relevant attributes.
R1.1. (meta)data are released with a clear and accessible data usage license.
R1.2. (meta)data are associated with their provenance.
R1.3. (meta)data meet domain-relevant community standards.

From: https://www.force11.org/group/fairgroup/fairprinciples

Main requests for a modern and efficient RI

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- Standardization
- Full traceability
- Quality control
- Unique data access point
- NRT data provision
- FAIR compliance

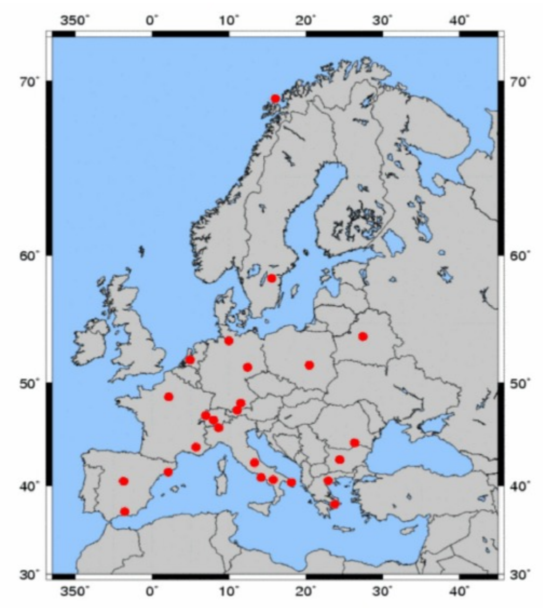
https://www.force11.org/group/fairgroup/fairprinciples

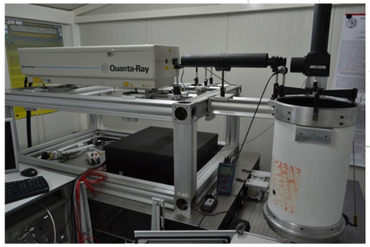
These are mandatory requirements to provide operative monitor services like for example CAMS or to participate in satellite validation plans.

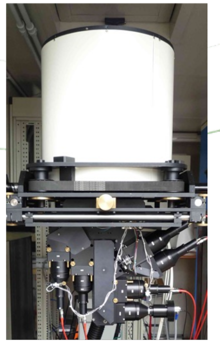
→ Submission of raw data to centralized processing chain

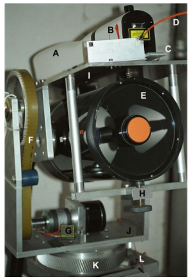
ACTRIS ARS Products Standardization

- Standardization of ACTRIS/EARLINET products is difficult
- EARLINET was born as Research Lidar Network
- lidar systems as often highly customized or fully home made
- differences in laser sources, telescopes, detection and acquisition systems









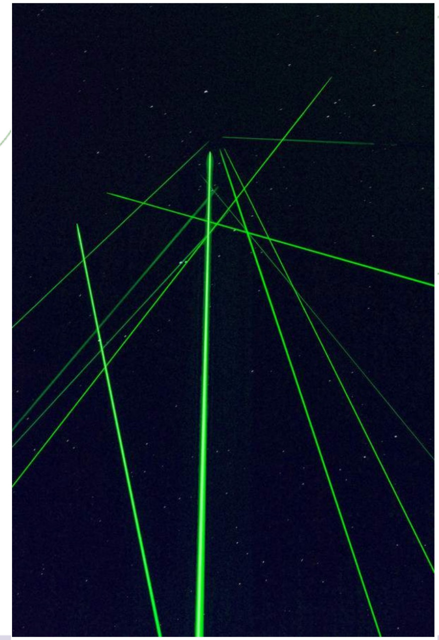
ACTRIS ARS Standardization Approach

- Define quality control procedures to be applied on both hardware and software levels
  - Telecover measurements (check signals in near range)
  - Rayleigh fit (check signals in far range)
  - Dark measurements (check electronic distortions)
  - Polarization calibration
  - Algorithm intercomparison (check quality assured data processing algorithms)

ACTRIS ARS Standardization Approach

- Define quality control procedures to be applied on both hardware and software levels
- Several inter-comparison campaigns
  - mobile reference systems performing co-located measurements with systems to "validate"
  - EARLI09
  - SPALI10
  - NALI10
  - …

EARLI09



Wandinger, U., et al: EARLINET instrument intercomparison campaigns: overview on strategy and results, AMT, https://doi.org/10.5194/amt-9-1001-2016, 2016

ACTRIS ARS Standardization Approach

- Define quality control procedures to be applied on both hardware and software levels
- Several inter-comparison campaigns
- Definition of a standard format for all the data products including raw data (NetCDF, CF compliance)
- Development of an automatic and centralized processing chain (Single Calculus Chain - SCC)
- Storage of all the processing parameters in persistent way

- Long process: started on 2006 (EARLINET-ASOS) and still in progress in the framework of ACTRIS

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THANKS!

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