MISSIONE 4
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ITINERIS

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1 INTRODUCTION

The ITINERIS project is designed to significantly strengthen Italy's capability to understand atmospheric processes by promoting the state-of-the-art of observations through measurements and instrumentation. To characterize the components that play crucial roles in atmospheric chemistry, air quality, climate forcing, and the Earth's radiative balance, the operative unit of ISAC-CNR in Bologna (ISAC-CNR-BO) has prioritized the enhancement of atmospheric monitoring infrastructure to better characterize key components such as trace gases, reactive species, aerosols, and clouds.

This deliverable presents a thorough account of the newly acquired instrumentation within the ITINERIS framework, focusing on their technical specifications, operational readiness, and the scientific goals they support over both short and long timescales. Each atmospheric constituent is addressed in dedicated sections, detailing the instruments' functions, deployment sites, and the anticipated contributions to ongoing research and monitoring activities. The installations are strategically located in regions of atmospheric interest, such as the highly polluted Po Valley and the mountain background site of Monte Cimone (2165 m asl, GAW-WMO global station) that overlooks it, the Mediterranean marine site of Capo Granitola and the alpine site of Plateau Rosa. In addition, the AROLAB mobile platform will extend the spatial coverage of ISAC observation in other environment also supporting the activity at the permanent observatories. These measurement sites provide integrated and complementary environments for observing the interactions between aerosols, clouds, and trace gases under varying atmospheric conditions. The instruments included in this deliverable range from ground-based Fourier Transform Spectrometers for vertical profiling of trace gases to advanced cloud microphysics sensors, aerosol optical property analysers, and remote sensing devices like Doppler cloud radars and Raman lidars.

This document thus provides an updated and detailed overview of the instrumentation portfolio developed under ITINERIS by the ISAC-CNR-BO operative unit, enabling to develop a robust scientific agenda on medium long term.

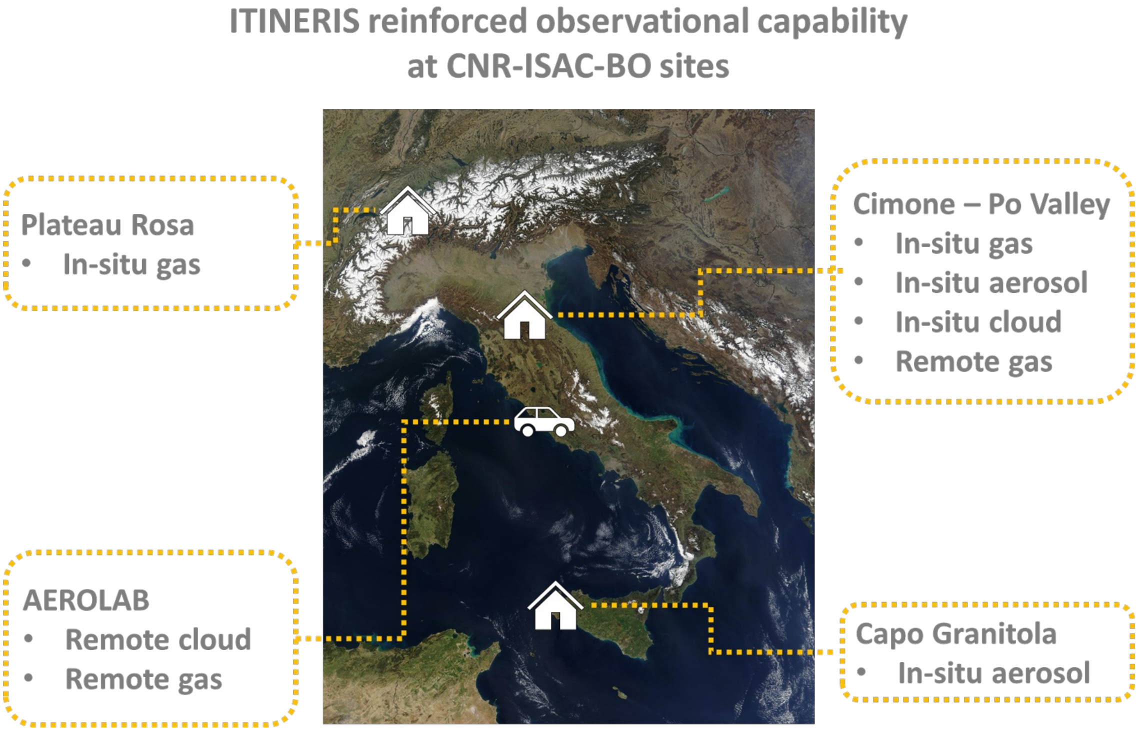

Figure 1 Distribution of remote and in-situ measurement, managed by CNR-ISAC across the Italia observational network

2 TRACE GASES

2.1 Vertical profiling of trace gases

LOTTO 4 of GARA 1 a Fourier Transform Spectrometer (FTIR) IFS 125HR, produced by Bruker. The FTIR will perform ground-based atmospheric measurements in the infrared spectral range (850–9000 cm^{-1}) with a resolution of 0.0036 cm^{-1}. This instrument will enable the retrieval of trace gas concentrations such as O_3, HCl, HF, $ClONO_2$, HNO_3, N_2O, CH_4, CO, C_2H_6, HCN, CO_2, H_2O, O_2, and HDO . The system includes gold-coated optics optimized for the mid-infrared and a dual-channel spectral acquisition setup with CaF_2 and KBr windows.. It will support the use of three detectors: MCT (cooled with liquid nitrogen), InSb (also LN_2-cooled), and InGaAs (room temperature). The instrument will have a collimated solar input, an internal automatic source switch, two IR sources (NIR and MIR), a mobile dual-position sample holder, and optical configuration for simultaneous dual-detector measurements using a dichroic filter or beamsplitter. The FTIR complies with both NDACC and TCCON network standards, ensuring compatibility and comparability with international datasets.

2.1.1 Vertical distribution of trace gases: status

The procedure is in development phase, with the contract signed and delivery to ISAC-CNR-BO planned in September

Table 1 vertical distribution of trace gases: instruments status

Instrument	Type	Status	Measurement site
FTIR	Remote	Acquired	CMN-PV -Bologna

2.1.2 Vertical distribution of trace gases: application

It will be installed at the CNR site in Bologna, a strategic location in the highly polluted Po Valley, offering optimal conditions for atmospheric observations. The measured spectra will be mainly used to retrieve information on the atmospheric composition in order to perform air quality studies, useful for human health, and to monitor the green-house gases concentrations, useful for the climate models. Its very precise measurements will also represent an important opportunity to validate data acquired by both ground-based instruments (several ground-based instruments are present at the CNR site in Bologna) and satellites.

2.2 Volatile organic compounds

A Liquid Calibration System was purchased for volatile organic compounds (VOCs) to be used with a proton transfer reaction mass spectrometer (PTR-MS). The PTR-MS requires two main calibration steps: the first calibrates the mass measurement to ensure the accuracy of the m/z value and to correctly identify the spectral signal corresponding to one or more reference molecules or molecular fragments; the second calibrates the instrument's sensitivity to quantify the exact concentration of a given measured m/z, establishing the relationship between ions per second and concentration. This relationship is specific to each measured mass, each instrument used, acquisition parameters, and can vary over time. Beyond these reasons, a system that allows the introduction of known concentrations of individual compounds or simple compound mixtures also enables the evaluation of the presence and amount of fragments and clusters generated within the instrument that may interfere with the analysis. For these reasons, it is important to equip the PTR-MS with a calibration unit to correctly identify and quantify the measured compounds. The Liquid Calibration System is designed for seamless use with all Vocus CI-TOF models, providing the option for calibration of instrument response with liquid standards.

2.2.1 Volatile organic compounds: status

Table 2 VOC instruments status

Instrument	Type	Status	Measurement site

Liquid Calibration System	In-situ	Delivered	CMN-PV

2.2.2 Volatile organic compounds: application of a calibration system

The PTR-MS was purchased to complement measurements of aerosol concentration, gaseous tracers, halogenated organic compounds, and volatile organic compounds in the light hydrocarbon fraction (C2-C6), as well as the physical properties of aerosols, within the ACTRIS Research Infrastructure. Its use is planned in ITINERIS measurement campaigns to study the processes influencing the variability of ground-level concentrations, which are affected by emissions, chemical reactivity, and dilution. The PTR-MS analyzes VOCs at their protonated mass by ionizing molecules through a proton transfer reaction, producing a mass spectrum where protonated molecules appear as signals with intensities measured in ions per second according to their mass-to-charge ratio (m/z). The use of the calibration system will guarantee the determination of the instrument sensitivity and detection limit.

2.3 Near-surface greenhouse gas measurements

ISAC-CNR-BO acquired two CRDS systems for the simultaneous measurements of CO_2, CH_4, CO and one CRDS system for the measurements of isotopic composition (C13 and C12) in CO_2 and CH_4. The two systems for the simultaneous measurements of CO_2, CH_4 and CO (Picarro G2401) are compliant with the technical requirements defined by ICOS RI (2020) and allow atmospheric sites to meet the minimum requirements for class-2 labelling for ICOS atmospheric sites. The systems are based on the Cavity Ring Down Spectroscopy (CRDS) at wavelengths around 1.6 µm and by the implementation of the calibration routines defined by ICOS can meet the WMO goals for laboratory intercomparability (± 0.1 ppm for CO_2 and ± 2 ppb for CH_4 and CO). The system for the measurement of isotopic composition ($^{12}CO_2$, $^{12}CH_4$, $^{13C}O_2$, $^{13}CH_4$). It provides the isotopic abundance of ^{13}C in CO_2 and CH_4 expressed as delta (δ) per mil, by allowing an interpretation of the potential sources of CO_2 and CH_4 variability and integrating the information provided by WMO-compliant instrument G2401.

2.3.1 Near-surface greenhouse gas measurements: status

Table 3 Near-surface greenhouse gas measurements: instruments status

Instrument	**Type**	**Status**	**Measurement site**
CRDS Picarro G2401	In-situ	Delivered	CMN-PV
CRDS Picarro G2401	In-situ	In-acquisition	Plateu Rosa
CRDS Picarro G2201-i	In-situ	In-acquisition	CMN-PV

2.3.2 Near-surface greenhouse gas measurements: application

The availability of the Picarro G2401, allows the Monte Cimone (CMN) class-2 atmospheric sites to maintain the ICOS data quality objective for the upcoming years. Thanks to the applications of the strict quality assurance adopted within ICOS-RI, these measurements can be used not only for trend detection of greenhouse gas in the atmosphere but also for investigation of natural/anthropogenic sources (including wildfires) and sinks that affect their interannual and seasonal variability. Moreover, such high-quality data can be ingested in atmospheric inversion systems for providing "top-down" estimates of CO_2 and CH_4 emissions (e.g. Bergamaschi et al., 2022) The redundance of this type of analyzer at CMN, allow to support the ICOS national network,

The use of the atmospheric signals of $\delta^{13}CO_2$ and $\delta^{13}CH_4$ to determine methane sources and sinks is an important area of research. The "isotopic" CRDS G2201-i installed at CMN since December 2024, can provide valuable information to partition regional emissions of both CO_2 and CH_4. In particular, the stable isotopes of methane have been shown to be valuable in partitioning methane emissions between various source like biogenic, thermogenic and pyrogenic (see Röckmann et al., 2016). A characterization phase is currently ongoing at CMN for the instrument CRDS G2201-i to investigate potential intereferences on the measurements as well as to define the best calibration strategy and the fitness for purposes of these observartions.

3 CLOUDS

3.1 Liquid water content and effective radius

The ACTRIS Cloud in-situ central facility supports high-quality measurements of cloud microphysical properties, essential for understanding cloud–aerosol interactions (Wagner et al., 2020). Mandatory variables to become national facility include liquid water content (LWC) and effective radius (re), which influence cloud reflectivity, lifetime, and precipitation formation. With GARA 3 Lotto 1, ISAC-CNR-BO is acquiring two custom made spectrometer for the quantification and sizing cloud droplets. This spectrometer is a modified version of the Cloud Droplet Analyzer (Palas GmbH, Karlsruhe, Germany) allowing a droplet detection on a wider number concentration and diameter range. The Welas optical droplet detectors is designed for in-situ measurement of cloud and fog microphysics. Each system provides real-time data (<10 s resolution) on the number concentration and size distribution of water droplets in the 0.2 µm to ≥100 µm range, with a detection range from 0 to ≥15,000 #/cm³. From these measurements, the instruments derive effective radius and liquid water content (LWC). The detectors are optically calibrated to the refractive index of water (1.33) and are equipped for continuous outdoor operation, suitable for deployment at both Monte Cimone (-20°C to +25°C) and San Pietro Capofiume (0°C to +40°C). Each unit includes a weatherproof enclosure, vertical sampling lines to minimize droplet loss, integrated sonic anemometers (for vertical wind).

3.1.1 Liquid water content and effective radius: status

The contract for the two customized Welas systems is signed, and the delivery and testing are expected for July-August.

Table 4 Liquid water content and effective radius: instruments status

Instrument	Type	Status	Measurement site
Welas#1	In-situ	Acquired	CMN-PV -Cimone
Welas#2	In-situ	Acquired	CMN-PV - S.Pietro Capofiume

3.1.2 Liquid water content and effective radius: application

The acquisition of the two system will give continuity to the cloud and fog observations conducted at ISAC-CNR-BO (Giulianelli et al., 2014). The first application of the sensors will be the participation to the intercomparison, and calibration campaign planned for 2026 at the Sonnblick Observatory and organized by the European Center for Cloud Ambient Intercomparison (ECCINT). Deployment in the Po Valley interaction of local aerosol with fog, in polluted condition mostly in winter. At Cimone, we will focus on the background aerosol and the typical interaction with clouds in the free troposphere. Integrating other aerosol-in situ and cloud-in-situ observations, one of the first scientific objectives is to identify anomalies in the first indirect aerosol effect caused by changes in the aerosol concentration which may alter the LWC and r_e (Zanatta et al., 2023), thus cloud and fog optical properties.

3.2 Cloud liquid chemical composition

A cloud water droplet sampler is acquired as a direct procedure within ITINERIS. The instrument is custom built by 4S System (Brussels, Belgium). The system is designed for the selective collection of cloud water droplets with an aerodynamic diameter of at least 7 µm, based on a single-stage impactor. The sampler operates at an aspiration flow rate of 80 m^3/h (±10 m^3/h) with "wind-stop" system, ensure sampling at sub-zero temperatures by heating critical components such as the impaction plate and the wind-stop. The sampler guarantees the collection of liquid samples representative of the droplets selected by the impactor into a collection volume located downstream of the impactor. The collected liquid is driven by a peristaltic pump that transfers the liquid from the collection volume to storage containers. The systems allow for continuous sampling up to 6 liquid samples.

3.2.1 Cloud liquid chemical composition: status

Table 5 Cloud liquid chemical composition: instruments status

Instrument	Type	Status	Measurement site
Cloud sampler	In-situ	Acquired	CMN-PV -Cimone

3.2.2 Cloud liquid chemical composition: application

part of the ITINERIS project, ISAC-CNR aims to enhance aerosol and cloud monitoring at the "Monte Cimone – Bologna – San Pietro Capofiume" supersite, a candidate ACTRIS National Facility. The new sampler will enable chemical characterization of the cloud liquid phase, including inorganic ions via ion chromatography (IC), dissolved organic carbon (DOC) through total organic carbon (TOC) analyzers, and—working alongside the ECAC OGTAC unit—organic marker compounds using liquid chromatography mass spectrometry (LC-MS) or related techniques. Sampling and chemical analysis procedures are harmonized by the Centre for Cloud Water Chemistry (CCWaC). Cloud sampling at Cimone will complement historical fog composition data from the Po Valley (Decesari et al., 2017; Giulianelli et al., 2014), aiding in tracing anthropogenic impacts on the hydrometeorological cycle in one of Europe's most polluted regions(Fuzzi et al., 2002).

3.3 Ice nucleating particles.

Ice nucleating particles (INP) are the source for primary ice formation in clouds, hence their concentration has a critical impact on the temporal and spatial distribution of precipitation as well as a major impact on climate. The INP number concentration is one of the specializing variables of the cloud in-situ central facility. With GARA 3 Lotto 4, ISAC-CNR-BO is acquiring a Portable Ice Nucleation Experiment chamber (PINE; Bilfinger Nuclear & Energy Transition GmbH, Germany). PINE operates in cycles with three modes: flush (aerosol intake), expansion (activation into droplets and ice crystals), and refill (reset to ambient pressure). Ice crystals are detected with a specialized optical counter, and INP (ice-nucleating particle) concentration is calculated based on crystal count and air volume. Measurements can be done at constant temperature for high time resolution or by scanning temperature to observe INP variation with temperature (e.g., -17°C to -31°C over 2 hours). INP concentrations are quantified between -10°C and -65°C with a temporal resolution of minutes.

3.3.1 Ice nucleating particles: status

The contract as to be signed by the company, delivery and testing are expected for July-August.

Table 6 Ice nucleating particles: instruments status

Instrument	Type	Status	Measurement site
PINE	In-situ	In-acquisition	CMN-PV

3.3.2 Ice nucleating particles: application

The PINE will allow understand the impact of aerosol particle on the formation of ice in clouds. By deploying it at the Cimone observatory, ISAC-CNR-BO will be capable to improve the characterization of INP particles initiated with off-line technique (Rinaldi et al., 2017), increasing the temporal resolution and extending the temporal coverage the objective is to provide the first complete climatology of INPs in Italy. With the integration of PINE with other in-situ observations at Cimone it will be possible to identify the aerosol types of contribution more to the ice formation. This will include mostly Saharan dust events which systematically influence the Mediterranean atmosphere (Vogel et al., 2025) and are considered among the most efficient INP in the atmosphere

(Vogel, 2022). The combination of INP and INP observations will initiate an innovative line of research directed to differentiate the main ice formation mechanisms such as deposition and immersion freezing.

3.4 Vertical profiling of cloud particles

ISAC-CNR-BO will acquire a Doppler Cloud Radar system (model Mira 35C, METEK, Meteorologische Messtechnik GmbH, 25337 Elmshorn, Germany) for vertical profiling of cloud as well as precipitation properties. The radar will operate in the Ka-band (35 GHz) and will provide vertical profiles of radar reflectivity and Doppler spectra, including both co- and cross-polarized signals for the calculation of the Linear Depolarization Ratio (LDR). The Mira35 system will yield measurements of radar reflectivity, sensitive to clouds and precipitation particles, and Doppler velocity, which characterizes vertical air motions. The radar also captures Doppler spectral width, related to turbulence and particle variability, and, the linear depolarization ratio, revealing particle shapes so useful for identifying particle microphysics phase (i.e., solid or liquid particles). These observations will support the monitoring of cloud and precipitation evolution and vertical layering, offering insights into microphysical processes. In particular, the analysis of Doppler spectra and their moments enables the characterization of particle sedimentation, turbulence, and size distribution. The system is fully automated, remotely controllable, and compliant with ACTRIS-CCRES (Centre for Cloud Remote Sensing) technical requirements for Doppler Cloud Radars.

3.4.1 Vertical profiling of cloud particles: status

Table 7 vertical profiling of cloud particles: instruments status

Instrument	Type	Status	Measurement site
Mira35C	Remote	In acquisition	Mobile platform AEROLAB

3.4.2 Vertical profiling of cloud particles: application

The instrument will be integrated into the mobile platform “AEROLAB,” part of ACTRIS-Italy, and will support remote sensing observations that are required by ACTRIS National Facilities in the Cloud Remote Sensing domain. A Doppler Cloud Radar provides continuous, vertically resolved observations of cloud structure and dynamics. Within intense observation periods, the integration of the MIRA-35 Doppler Cloud Radar with in-situ measurements at Monte Cimone will enables a detailed study of aerosol-cloud interactions. Radar profiles of cloud structure and dynamics will be combined with local data on droplet size, CCN, INP, and chemical composition, allowing investigation of how aerosol properties influence cloud formation, phase, and microphysics under real atmospheric conditions. This instrument could support the calibration and validation (Cal/Val) of satellite missions such as EarthCARE, through potential comparisons with ATLID and CPR observations. Although CPR and Mira35 operate at different frequencies (W-band and Ka-band, respectively), frequency conversion method (e.g. Bracci et al., 2023) could enable a consistent translation of Ka-band reflectivity into the W-band domain, allowing for direct comparison.

4 AEROSOL PARTICLES

4.1 Absorption coefficient

The spectral measurement of the atmospheric aerosol absorption coefficient is a mandatory requirement for the ACTRIS National Facility in the area of in situ aerosol observations. Within GARA 1 LOTTO 1, ISAC-CNR-BO acquired a multi-wavelength absorption photometer (7 wavelength aethalomoeter, AE33; Aerosol d.o.o., Kamniška 39A SI-1000, Ljubljana, Slovenia). These analyzers operate based on the transmittance measurement of a filter onto which atmospheric aerosol is continuously collected (Drinovec et al., 2015). Absorption coefficient measurements cover at seven wavelengths, allows for continuous, high temporal resolution measurements of the in-situ aerosol absorption coefficient, in full compliance with international guidelines and protocols, including those defined by ACTRIS and GAW. The measurement data will provide detailed information on the optical properties of atmospheric aerosols and their variability due to physical and chemical transformation processes. Additionally, absorption data at specific wavelengths, particularly at 880 nm, will be used to estimate equivalent black carbon concentration via a dedicated algorithm. A second analyzer, the Aerosol Magee Scientific Carbonaceous Aerosol Speciation System (CASS), is a combined unit of a Total Carbon Analyzer TCA08 and an Aethalometer AE33 providing a revolutionary scientific OC/EC analyzer that measures the Total Carbon Content(TC), the Elemental Carbon content(EC), the Organic Carbon content (OC) and the Black Carbon content (BC) of suspended aerosol particles in near-real Time (Ivančič et al., 2022).

4.1.1 Absorption coefficient: status

The AE33 and CASS instrumentation is acquired and in delivery phase, will be tested in July.

Table 8 absorption coefficient: instruments status

Instrument	Type	Status	Measurement site
AE33	In-situ	Acquired	CMN-PV
CASS	In-situ	Acquired	Capo Granitola

4.1.2 Absorption coefficient: application

The AE33 of the CMN-PV facility will complement the existing observations at three sites of the CMN-PV facility. The instrument will be deployed during intense observation periods to complement the capability of black carbon source apportionment including emission form anthropogenic and natural events (Zotter et al., 2017). The CASS of the Capo Granitola observatory will give continuity to the in-situ observations, integrating more classic techniques (Dinoi et al., 2017).

4.2 Scattering coefficient

The spectral measurement of aerosol light scattering is a requirement for ACTRIS National Facilities involved in in situ aerosol observations. Within GARA 2 LOTTO 1, ISAC-CNR-BO acquired 2 state-of-the-art integrating nephelometer (Aurora NE300;ACOEM), designed to measure the aerosol light scattering coefficient at multiple wavelengths with high temporal resolution. The Aurora NE300 operates by measuring the intensity of light scattered by aerosol particles suspended in an air sample within an integrating sphere, providing real-time data on total, hemispheric backscatter, and angular scattering at three wavelengths (450 nm, 525 nm, and 635 nm). The system ensures accurate quantification of the scattering properties of aerosols across a wide dynamic range, with temperature and humidity control options to ensure data quality and comparability under varying ambient conditions.

4.2.1 Scattering coefficient: status

Table 9 scattering coefficient: instruments status

Instrument	Type	Status	Measurement site
2 x Nephelometer	In-situ	Acquired	CMN-PV

4.2.2 Scattering coefficient: application

The two nephelometer Aurora NE300 will be installed in the CMN-PV facility and together with the AE33 aethalometer will support the derivation of key aerosol properties such as the scattering Ångström exponent and single scattering albedo. The Aurora NE300 complies with ACTRIS and GAW technical standards and protocols, ensuring harmonized data acquisition, quality assurance, and long-term data usability within the ACTRIS in situ aerosol observation network.

4.3 Refractory black carbon

Within GARA 1 LOTTO 2, the operative unit aimed to acquire an instrument for the selective quantification of refractory black carbon. The single particle soot photometer with extended range (SP2-XR, Droplet Measurement Technologies, USA) is a specialized instrument designed to measure the mass, size, and optical properties of individual refractory black carbon-containing particles in real time. The SP2-XR is based on the Laser-induced incandescence technique and a novel design compared to its predecessor (SP2; Stephens et al., 2003). This allows quantifying scattering particles in the 100-500 nm diameter range and rBC particles in the 50-800 nm diameter range.

4.3.1 Refractory black carbon: status

Table 10 refractory black carbon: instruments status

Instrument	Type	Status	Measurement site

SP2-XR	In-situ	Acquired	CMN-PV

4.3.2 Refractory black carbon: application

On the short term, the SP2-XR will be installed at the Cimone observatory to complete the existing optical observations (Aethalometer/MAAP/nephelometer). This unique setup will allow investigate the variability of BC optical properties such as the mass absorption cross-section (MAC), asses the microphysical properties of BC emitted by different sources, allowing an optical closure using optical modelling (Zanatta et al., 2018). The instruments will serve as a comparison base to address potential instrumental biases in filter-based absorption photometers such a s the MAAP and aethalometer (Renzi, 2024). Within one-year we expect a full characterization of the Po-Valley "breath" into the free troposphere. On longer term, the SP2 could be eventually deployed in other Italian stations to address the impact of forest fires in the Mediterranean region.

4.4 Aerosol size distribution

Within GARA 1 LOTTO 3, the operative unit aimed to acquire an instrument for measure of the number-based aerosol size distribution. The Scanning Mobility Particle Sizer Spectrometer (SMPS, TSI, USA) measures particle size distribution and number concentration, from 2 nm to 1 µm, using differential mobility analysis (Wiedensohler et al., 2012). This method relates a particle's electrical mobility to its size. The SMPS provides direct numerical concentrations without assuming particle shape, independent of refractive index, with high sizing accuracy and repeatability. This instrument is compliant with CEN/TS 17434:2020 for size distribution measurement from 10 nm to 800 nm.

4.4.1 Aerosol size distribution: status

The contract was signed, and the instruments is in delivery phase

Table 11 aerosol size distribution: instruments status

Instrument	Type	Status	Measurement site
SMPS	In-situ	In delivery	CMN-PV

4.4.2 Aerosol size distribution: application

The SMPS will complement the existing observations at three sites of the CMN-PV facility. The instrument will be deployed during intense observation periods for simultaneous observations in the free troposphere (Cimone) and boundary layer (Bologna/San Pietro Capofiume) or coupled with other instruments for size selective measurements of, for example, cloud condensation nuclei.

4.5 Aerosol concentration

Within a sub-threshold procurement procedure the operative unit of CNR-ISAC-BO acquired two Condensation Particle Counter (Model CPC 3750;TSI) developed for long term atmospheric monitoring particle number concentration larger than 10 nm. The TSI 3750 CPCs operate on the principle of condensing vapor on aerosol particles to grow them to optically detectable sizes. The instruments have been configured and validated for operation with a 50% cut-off diameter (D_p50) of 10 nm in accordance with ACTRIS data quality requirements. These CPCs provide continuous, real-time measurements of total particle number concentration, with high temporal resolution e low detection limits.

4.5.1 Aerosol concentration: status

Table 12 aerosol concentration; instruments status

Instrument	Type	Status	Measurement site
2 x CPC	In situ	Acquired	CMN-PV

4.5.2 Aerosol concentration: application

Two TSI CPC 3750 have been installed at the CMN-PV facility, where they perform continuous measurements of total particle number concentration for particles larger than 10Nm. This variable represents an integral measurement across a broad size range, encompassing nucleation, Aitken, and accumulation modes. It supports multiple scientific purposes, including the analysis of atmospheric trends and validation of size distribution measurements. The CPC 3750 instruments comply with ACTRIS and GAW technical standards and protocols, ensuring harmonized data acquisition and quality assurance. Vertical profiling of aerosol particles

To continue the integration of in-situ with remote sensing observations, an advanced Raman Lidar system (Model LR221-D300; Raymetrics;) was acquired through GARA 1 LOTTO 5, while a Ceilometer (Model CHM15K; Lufft) and a sun photometer (model CE318-T; Cimel) were acquired through sub-threshold procurement procedures for the vertical profiling of atmospheric aerosols. The Raman Lidar will provide vertical profiles of aerosol backscatter and extinction at 355 and 532 nm, depolarization ratios at 532 and/or 355 nm, and vibrational Raman returns at 607 and 387 nm, both in the planetary boundary layer (PBL) and the free troposphere (Ansmann and Müller, 2005). Technically, the system uses a Nd:YAG laser emitting at 355 and 532 nm, with beam diameter between 0.5–5 mm, divergence <1.2 mrad, and pulse duration under 12 ns. Polarization purity must be at least 98.5%. The primary telescope mirror must have a diameter ≥200 mm, with a secondary mirror ≤80 mm, and a full-overlap region ≤300 m. The system is fully remote-controlled, ACTRIS-compliant (per D5.1 – ACTRIS PPP), and operable by a single operator.

The CHM15K Ceilometer (Lufft) is a single-wavelength lidar operating at 1064 nm, designed for continuous unattended operation and optimized for cloud base height detection and aerosol layer identification up to 15 km altitude. The system features a laser pulse energy of up to 8 µJ, a pulse repetition rate of 5–7 kHz, and a full overlap typically reached within 150–250 m. The system includes automatic window contamination detection and correction algorithms and operates within a temperature range of -40 °C to +60 °C, making it suitable for harsh environmental conditions.

The CE318-T sun photometer (Cimel) provides high-precision spectral measurements of direct solar irradiance and sky radiance at multiple wavelengths (typically 340, 380, 440, 500, 675, 870, 940, and 1020 nm). The instrument supports automatic sun tracking and performs almucantar and principal plane scans for aerosol optical depth (AOD) retrieval and aerosol inversion products (e.g., particle size distribution, refractive index, and single scattering albedo). The CE318-T includes temperature stabilization, GPS-based time synchronization, and robotic motorization to ensure precise pointing and data acquisition under varying illumination conditions.

4.5.3 Vertical profiling of aerosol particles: status

The contract was signed, and the instruments will be delivered in September

Table 13 vertical profiling of aerosol particle: instruments status

Instrument	**Type**	**Status**	**Measurement site**
Raman Lidar	Remote	In delivery	Mobile platform AEROLAB
Ceilometer	Remote	Acquired	Mobile platform AEROLAB
Sun Photometer	Remote	Acquired	Mobile platform AEROLAB

4.5.4 Vertical profiling of aerosol particles: application

hese instruments will be integrated into “AEROLAB” (AERosol mOnitoring LABoratory), a mobile platform component of ACTRIS-Italy, designed to enable the detailed characterization of aerosol properties across a wide range of environments (Alas et al., 2019; Gobbi et al., 2020).

The combined operation of the Raman lidar (model LR221-D300; Raymetrics), ceilometer (model CHM15K; Lufft), and sun-lunar photometer (model CE318-T; Cimel) enables a synergistic retrieval of both vertically resolved and column-integrated aerosol properties. This integrated observational setup allows for a comprehensive characterization of aerosol optical and microphysical parameters including extinction and backscatter profiles, mass concentrations, aerosol optical depth (AOD), and size distribution supporting long-term monitoring and data assimilation. The approach follows ACTRIS standards and methodologies, ensuring compliance and facilitating the production of high-quality aerosol products. Recent studies (Bellini et al., 2025; Bellini et al., 2024) have demonstrated the effectiveness of combining lidar, ceilometer, and photometer measurements for advanced aerosol profiling and for the evaluation of numerical models such as ERA5 and CAMS.

5 SUPPORT TO MEASUREMENTS

With the upgrade of the instrumentation and implementation of new measurements techniques, a renovation of support apparel was needed. This action was needed to ensure the safe operation of the instrumentation and the efficient transfer, analysis and storage of the high flow of data produced at the observational platforms. These include: i) Uninterruptible Power Supply (UPS) battery system at the CMN-PV observatory (Cimone); ii) platform for data analysis; iii) multi-terabyte system for data storage; iv) webcam for visual monitoring of sky conditions and station; v) a mobile container for the FTIR system.

6 PERSPECTIVES

The acquisition of these instruments has already made it possible to expand observational activities, allowing to provide a solid foundation for continuous, high-quality atmospheric observations across multiple sites in the future.

From a scientific standpoint, having these instruments operational over the medium to long term will generate extensive datasets on atmospheric composition, aerosols, trace gases, and cloud properties which, inserted in the EBAS and ITINERISHUB databases, will guarantee the study of their trends. These datasets will improve the understanding of local and regional atmospheric processes, such as pollutant sources, aerosol-cloud interactions, and chemical transformations. The data will support validation of satellite products and atmospheric models, contributing to more accurate air quality forecasts and climate assessments.

Long-term measurements will also enable the detection of trends and episodic extreme events which occurs more and more frequently in the Mediterranean climate hotspot in the form of Saharan dust outbreaks, Medicanes, heatwaves and precipitation downburst. Moreover, it will allow to study the impact of pollution mitigation policies on the aerosol-cloud-radiation interactions and human heath in one of the most polluted regions of Europe. The heterogeneity of the instrumentation will ensure the multidisciplinary the ISAC-CNR-BO scientific agenda, allowing the opening towards new scientific questions and international cooperation.

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