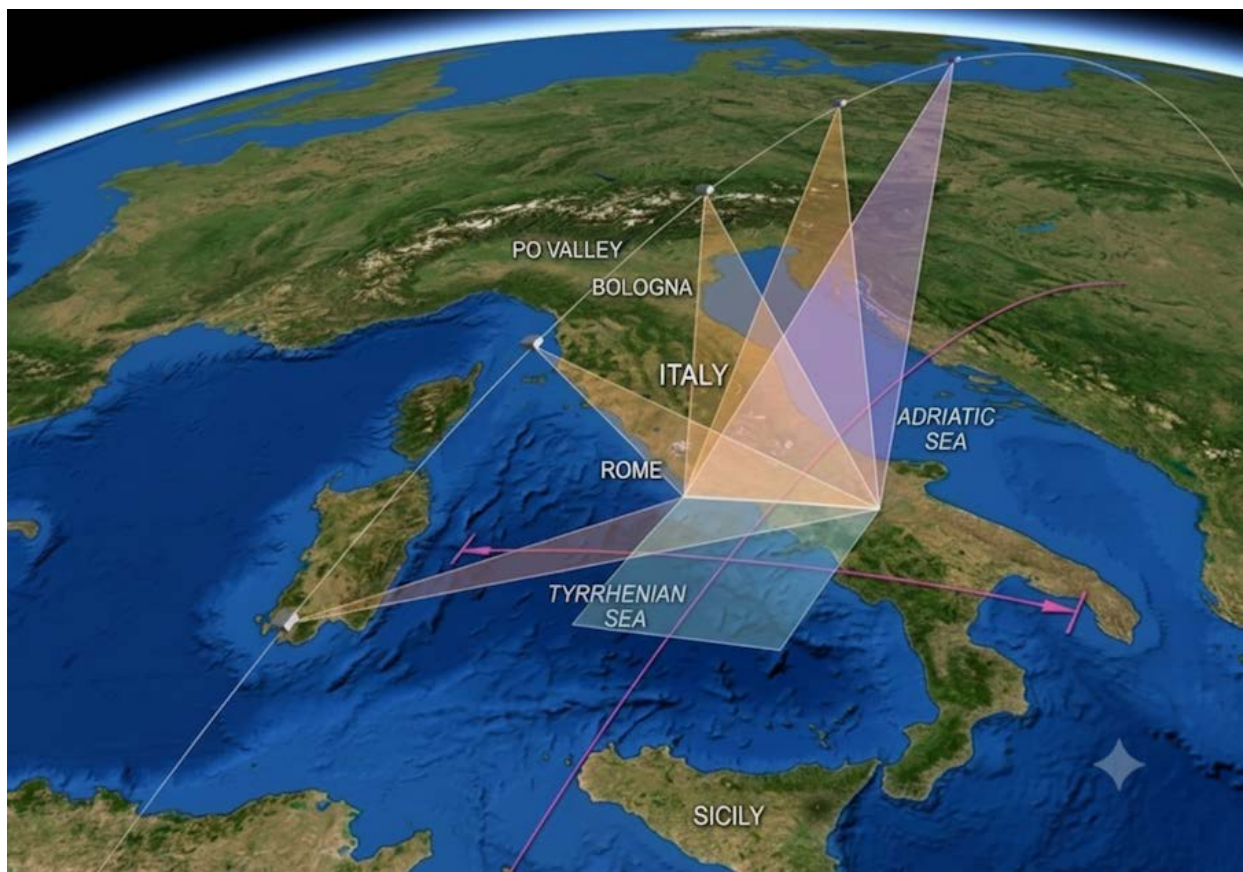




## Workshop “MAIA: Air Quality, Aerosols and Human Health from Space”



**Organised by Agenzia Spaziale Italiana / Italian Space Agency (ASI)**

ASI Headquarters in Via del Politecnico snc, Rome, Italy

14-15 October 2026



## **ASI Scientific and Organising Committee**

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| <b>Assessing Acute and Chronic Illness Risks with ASI-NASA MAIA Mission” .....</b>                                                                                                                                                            | <b>30</b> |
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## SCIENTIFIC-TECHNICAL PROGRAMME

### SCIENTIFIC – TECHNICAL PROGRAMME

**Day 1: 14 October 2026**

| <b>Title</b>                                                                                                                                                                                   | <b>Speaker</b>                                                                             | <b>CEST</b>   | <b>PST</b>    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|---------------|---------------|
| Participants registration                                                                                                                                                                      |                                                                                            | 09:00 – 09:30 | 00:00 – 00:30 |
| Welcome and Workshop objectives                                                                                                                                                                | Francesco Longo and Simona Zoffoli<br>Italian Space Agency (ASI)                           | 09:30 – 09:45 | 00:30 – 00:45 |
| <b>Session #1 “The joint ASI-NASA MAIA Mission”</b><br>Chair: Simona Zoffoli & Sara Venafra<br>ASI                                                                                             |                                                                                            |               |               |
| Multi-Angle Imager for Aerosols (MAIA) Prelaunch Activities and Preparations for the Flight Mission                                                                                            | David Diner<br>Jet Propulsion Laboratory,<br>California Institute of Technology            | 09:45 – 10:10 | 00:45 – 01:10 |
| Programmatic overview of MAIA Mission                                                                                                                                                          | Vincenzo Pulcino<br>Italian Space Agency (ASI)                                             | 10:10 – 10:25 | 01:10 – 01:25 |
| <b>Session #2 “Advanced Aerosol Monitoring from Space: Leveraging Multispectral Data in the Framework of the joint ASI-NASA MAIA Mission”</b><br>Chair: Matteo Picchiani & Sara Venafra<br>ASI |                                                                                            |               |               |
| Status Update and Results from the First Four Years of MAIA’s Ground-Based Particulate Matter Monitoring Network                                                                               | Sina Hasheminassab,<br>Jet Propulsion Laboratory,<br>California Institute of Technology    | 10:25 – 10:45 | 01:25 – 01:45 |
| Overview of MAIA Italian science projects                                                                                                                                                      | Matteo Picchiani<br>Italian Space Agency (ASI)                                             | 10:45 – 11:00 | 01:45 – 02:00 |
| APEMAIA: A Multi-Source AI-Based Approach for Intra-Urban PM Concentration and Population Exposure                                                                                             | Maria Adamo<br>CNR-Institute of Technologies and Environmental Intelligence (CNR-ITIAm)    | 11:00 – 11:15 | 02:00 – 02:15 |
| Coffee Break                                                                                                                                                                                   |                                                                                            | 11:15 – 11:45 | 02:15 – 02:45 |
| The EIRENE Research Infrastructure: recent progress and future developments in bridging environmental science, human exposome studies and effectiveness policy evaluation                      | Nicola Pirrone<br>CNR-Institute of Technologies and Environmental Intelligence (CNR-ITIAm) | 11:45 – 12:00 | 02:45 – 03:00 |
| High-Resolution PM10 and PM2.5 Mapping in Apulia: From APE-MAIA Results to Physics-Informed Modelling                                                                                          | Alessandro Fania<br>University of Bari Aldo Moro (UNIBA)                                   | 12:00 – 12:15 | 03:00 – 03:15 |

|                                                                                                   |                                                                                                                              |               |               |
|---------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|---------------|---------------|
| High-resolution spatio-temporal modelling of daily PM2.5 concentrations across Europe (2005–2022) | Federica Nobile<br>Department of Epidemiology, Lazio Region Health Service/ASL Roma 1                                        | 12:15 – 12:30 | 03:15 – 03:30 |
| Deep Learning Approach for PM2.5 Surface Estimation Using Sentinel-5P Radiance Data               | Antonio Mazza<br>National Research Council of Italy, Institute of Integrated Methodologies for Earth Observation (CNR-IMIOT) | 12:30 – 12:45 | 03:30 – 03:45 |
| High-Resolution PM2.5 Estimation from CAMS Forecasts using Machine Learning                       | Luigi Celona<br>University Of Milan-Bicocca (UNIMIB)                                                                         | 12:45 – 13:00 | 03:45 – 04:00 |
| From Earth Observation to Operations: IRIDE's Air Quality and Hydro-Meteo-Climate Services        | Matteo Picchiani<br>Italian Space Agency (ASI)                                                                               | 13:00 – 13:15 | 04:00 – 04:15 |

| Lunch | CEST          | PST           |
|-------|---------------|---------------|
|       | 13:30 – 14:30 | 04:30 – 05:30 |

|                                                                                                                          |                                                                                             |               |               |
|--------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|---------------|---------------|
| Site-Specific vs. Multi-City Machine Learning for Intra-Urban PM Mapping: the APEMAIA Approach in Southern Italy         | Marica De Lucia<br>CNR-Institute of Technologies and Environmental Intelligence (CNR-ITIAm) | 14:30 – 14:45 | 05:30 – 05:45 |
| A Physically Based Framework for Generating PRISMA-Like Hyperspectral Datasets for Atmospheric and Aerosol Applications  | Marco Di Giacomo<br>Tor Vergata University of Rome                                          | 14:45 – 15:00 | 05:45 – 06:00 |
| Fine-scale estimation of air temperatures using spatiotemporal machine learning models in Italy for the period 2003-2024 | Alessio Felici<br>Department of Epidemiology, Lazio Region Health Service/ASL Roma 1        | 15:00 – 15:15 | 06:00 – 06:15 |
| Remote Sensing of Volcanic Aerosols: State of the Art and Future Strategies for Air Quality Monitoring                   | Claudia Spinetti<br>National Institute of Geophysics and Volcanology (INGV)                 | 15:15 – 15:30 | 06:15 – 06:30 |
| Coffee Break                                                                                                             |                                                                                             | 15:30 – 16:00 | 06:30 – 07:00 |
| Interactive session                                                                                                      |                                                                                             | 16:00 – 16:45 | 07:00 – 07:45 |

**Day 2: 15 October 2026**

| <b>Session #3 “Bridging Satellite and Ground information:<br/>networks and methodologies to measure near surface PM and air quality in support of the joint ASI-NASA<br/>MAIA Mission”</b><br>Chairs: Giovanni Rum & Matteo Picchiani<br>ASI |                                                                                                                                                    |               |               |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|---------------|---------------|
| <b>Title</b>                                                                                                                                                                                                                                 | <b>Speaker</b>                                                                                                                                     | <b>CEST</b>   | <b>PST</b>    |
| Welcome and session introduction                                                                                                                                                                                                             | Simona Zoffoli<br>Italian Space Agency (ASI)                                                                                                       | 09:30 – 09:45 | 00:30 – 00:45 |
| Deeping on air quality topics in Emilia-Romagna region                                                                                                                                                                                       | Vanes Poluzzi<br>Environmental Protection Agency of Emilia Romagna Region (ARPAE)                                                                  | 09:45 – 10:00 | 00:45 – 01:00 |
| ARPA Lombardia Activities in Air Quality Field                                                                                                                                                                                               | Eleonora Cuccia<br>Environmental Protection Agency of Lombardia Region (ARPA Lombardia)                                                            | 10:00 – 10:15 | 01:00 – 01:15 |
| Physics-based source apportionment of near-surface PM: a ground-based approach to support satellite aerosol characterization and health-impact assessment                                                                                    | Caterina Mapelli<br>Regional Environmental Protection Agency of Lazio Region (ARPA LAZIO)                                                          | 10:15 – 10:30 | 01:15 – 01:30 |
| Past Milestones and Future Challenges Supporting MAIA Mission: Bridging Air Quality Ground Networks, High-Altitude Sentinel, and Earth Observation Data                                                                                      | Mariantonia Bencardino<br>CNR-Institute of Technologies and Environmental Intelligence (CNR-ITIAM)                                                 | 10:30 – 10:45 | 01:30 – 01:45 |
| Contributions of ACTRIS and ASCENT networks to ASI-NASA MAIA mission                                                                                                                                                                         | Rosa Maria Petracca Altieri<br>Consiglio Nazionale delle Ricerche (CNR)                                                                            | 10:45 – 11:00 | 01:45 – 02:00 |
| Coffee Break                                                                                                                                                                                                                                 |                                                                                                                                                    | 11:00 – 11:30 | 02:00 – 02:30 |
| Support to in situ and satellite air quality monitoring through operational ground-based measurements of aerosol profiles across Italy within the national cooperative Automated Lldar-CEilometer network ALICENET                           | Francesca Barnaba<br>National Research Council of Italy, Institute of Atmospheric Science and Climate (CNR-ISAC)<br>on behalf of the Alicenet team | 11:30 – 11:45 | 02:30 – 02:45 |
| CIAO (CNR-IMIOT Atmospheric Observatory): an Italian Supersite for the Validation and                                                                                                                                                        | Ilaria Gandolfi<br>National Research Council of Italy, Institute of Integrated                                                                     | 11:45 – 12:00 | 02:45 – 03:00 |

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| Exploitation of MAIA Aerosol Products                                                                                                                                                                                             | Methodologies for Earth Observation<br>(CNR-IMIOT)                                                                    |               |               |
| The Lampedusa Station for Climate Observation: A Mediterranean Site for Aerosol Research and Satellite Validation                                                                                                                 | Giandomenico Pace<br>Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) | 12:00 – 12:15 | 03:00 – 03:15 |
| Validation and characterization of the 3D aerosol fields over the Italian peninsula using relevant ESA-JAXA EarthCARE products from the first two years of satellite operations in the framework of the ASI - ECVALMED.it project | Francesca Barnaba<br>National Research Council of Italy, Institute of Atmospheric Science and Climate (CNR-ISAC)      | 12:15 – 12:30 | 03:15 – 03:30 |
| Airborne Innovative Lightweight Sondes for MAIA In-Situ Validation                                                                                                                                                                | Riccardo Biondi<br>ER S.r.l.s.                                                                                        | 12:30 – 12:45 | 03:30 – 03:45 |
| Interactive session                                                                                                                                                                                                               |                                                                                                                       | 12:45 – 13:30 | 03:45 – 04:30 |

|       |               |               |
|-------|---------------|---------------|
| Lunch | CEST          | PST           |
|       | 13:30 – 14:30 | 04:30 – 05:30 |

| <b>Session #4 “Earth Observation data and Societal Health:<br/>Assessing Acute and Chronic Illness Risks with ASI-NASA MAIA Mission”</b><br>Chairs: Matteo Picchiani & Massimo Stafoggia<br>ASI & Lazio Region Health Service / ASL Roma 1 |                                                                                                 |               |               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|---------------|---------------|
| Title                                                                                                                                                                                                                                      | Speaker                                                                                         | CEST          | PST           |
| Spatiotemporal modelling of air pollution using satellite data for epidemiological applications, an overview                                                                                                                               | Massimo Stafoggia<br>Lazio Region Health Service / ASL Roma 1                                   | 14:30 – 14:45 | 05:30 – 05:45 |
| Assessment of population exposure risk to PM at intra-urban scale in Bari (Italy) using PWEL and GIS Approaches                                                                                                                            | Delia Evelina Bruno<br>CNR-Institute of Technologies and Environmental Intelligence (CNR-ITIAM) | 14:45 – 15:00 | 05:45 – 06:00 |
| Bayesian spatio-temporal exposure modelling of air pollution in Rome, Italy, and short-term effects on cause-specific mortality                                                                                                            | Edoardo Rosci<br>Lazio Region Health Service / ASL Roma 1                                       | 15:00 – 15:15 | 06:00 – 06:15 |
| Coffee Break                                                                                                                                                                                                                               |                                                                                                 | 15:15 – 15:45 | 06:15 – 06:45 |

|                     |               |               |
|---------------------|---------------|---------------|
| Interactive session | 15:45 – 16:30 | 06:45 – 07:30 |
|---------------------|---------------|---------------|

|                                 |               |               |
|---------------------------------|---------------|---------------|
| Conclusive discussion & remarks | <b>CEST</b>   | <b>PST</b>    |
|                                 | 16:30 – 17:00 | 07:30 – 08:00 |

## ABSTRACT BOOK

### Oral presentations

#### **“MAIA: Air Quality, Aerosols and Human Health from Space” (Day 1, 13 May 2026)**

##### *Session #1 “The joint ASI-NASA MAIA Mission”*

Session chaired by Simona Zoffoli, Head of EO downstream sector, and Sara Venafrà, Technologist in the “Earth Observation” Office at the Italian Space Agency (ASI).

The session is jointly organised with NASA-JPL (NASA Jet Propulsion Laboratory, California Institute of Technology).

The session aims to introduce the overarching architecture, programmatic framework, and core scientific goals of the Multi-Angle Imager for Aerosols (MAIA) mission, a pioneering international partnership between the Italian Space Agency (ASI) and NASA. The primary scientific objective of MAIA is to investigate the links between exposure to specific chemical types of airborne particulate matter ( $PM_{10}$ , total  $PM_{2.5}$ , and its constituent species such as sulfates, nitrates, organic and elemental carbon, and trace metals) and human health outcomes, including acute and chronic cardiovascular and respiratory illnesses. This session provides an executive overview of prelaunch activities, flight preparation milestones, and instrument readiness. It details ASI’s critical contributions, including the provision of the high-performance PLATiNO-2 satellite platform, launch management, and mission operations through the ASI Mission Operation Center (MOC). Together, these programmatic and scientific foundations set the stage for advanced aerosol characterization and health-impact mapping from Low Earth Orbit.

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#### ***Multi-Angle Imager for Aerosols (MAIA) Prelaunch Activities and Preparations for the Flight Mission***

David Diner <sup>(1)</sup>, Sina Hasheminassab <sup>(1)</sup>

<sup>(1)</sup> Jet Propulsion Laboratory, California Institute of Technology

While many studies have linked serious human health outcomes with exposure to airborne particulate matter (PM), the relative toxicity of different PM constituents remains uncertain. The MAIA investigation will map near-surface  $PM_{10}$ ,  $PM_{2.5}$ , and chemically speciated  $PM_{2.5}$  (sulfate, nitrate, organic carbon, elemental carbon, dust) at 1 km resolution in 12 globally distributed Primary Target Areas (PTAs), including one PTA in Italy covering Rome, Florence, and Bologna, as well as 2 Secondary Target Areas (STAs) in the vicinity of Milan and Taranto (each target area encompasses 360 km east-west x 480 km north-south). These concentration maps – in conjunction with birth,

death, and hospital records – will enable quantifying health risks associated with acute, subchronic, and chronic exposure to total and speciated PM.

MAIA's PM mapping approach integrates satellite-derived aerosol properties, meteorological variables, land use information, and modeled pollution levels to train geostatistical regression models (GRMs), using surface PM measurements to transform these predictors into near-surface PM concentrations. Cloud-screened aerosol properties will be retrieved from MAIA's pointable UV SWIR polarimetric pushbroom camera, to be launched into polar orbit in 2027–2028 aboard ASI's PLATiNO 2 spacecraft. In the Italian target areas, the project plans to use measurements from surface monitors operated by EEA and various ARPAs to provide ground truth for calibrating the GRMs. Other data sources, such as from ACTRIS, can provide valuable independent validation.

Prelaunch testing of the MAIA ground data processing chain uses Terra MISR and MODIS imagery as partial proxies to exercise and evaluate MAIA retrieval algorithms. The project aims to release these products publicly for early scientific use and community engagement. Surface monitor data and land use maps are already available through NASA Earthdata, with additional products forthcoming. The prelaunch GRMs will be replaced with improved models once MAIA satellite data become available.

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### ***Programmatic overview of MAIA Mission***

Vincenzo Pulcino <sup>(1)</sup>

<sup>(1)</sup> Italian Space Agency (ASI), Rome, Italy

The Multi-Angle Imager for Aerosols (MAIA) mission represents a major benchmark in space-borne Earth observation, combining multi-angle, multispectral, and polarimetric satellite imaging with health-data analytics to characterize particulate matter (PM) composition and assess its impacts on human health. Developed through a formal international partnership between the Italian Space Agency (ASI) and NASA, the mission relies on a joint programmatic architecture to ensure end-to-end operational and scientific success.

This contribution provides a comprehensive programmatic overview of ASI's key responsibilities and contributions within the MAIA mission framework. ASI is responsible for providing the small satellite host platform, PLATiNO-2, managing payload integration, and coordinating launch campaign activities into Low Earth Orbit (LEO). Furthermore, flight and ground operations are managed via the ASI Mission Operation Center (MOC), ensuring seamless mission control, data downlink, and integration with ground processing pipelines. Beyond hardware and operations, ASI coordinates the Italian scientific contribution, managing ground-based validation networks across national Primary and Secondary Target Areas (PTAs/STAs) in close collaboration with regional environmental protection agencies (ARPAs). This programmatic overview highlights the milestone schedule, international governance, and operational readiness driving the mission toward flight operations and downstream scientific exploitation.

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***Session #2 “Advanced Aerosol Monitoring from Space: Leveraging Multispectral Data in the Framework of the joint ASI-NASA MAIA Mission”***

Session chaired by Matteo Picchiani and Sara Venafrà, Technologists in the “Earth Observation” Office at the Italian Space Agency (ASI).

The session aims to highlight the scientific methodologies and advanced data-driven approaches developed to map and model particulate matter ( $PM_{10}$  and  $PM_{2.5}$ ), aerosol optical depth (AOD) and other air quality parameters by using Earth Observation data and at unprecedented spatial resolutions. Key topics include results from MAIA’s ground-based PM monitoring network, the integration of multi-source satellite observations (such as MAIA, PRISMA, Sentinel, and CAMS forecasts), and the application of cutting-edge Artificial Intelligence, Machine Learning, and physics-informed models. Presentations demonstrate downscaling techniques capable of reaching intra-urban resolutions (<500 m), mapping volcanic aerosols, and establishing operational downstream services within national programs such as APEMAIA and IRIDE to enhance exposure assessment and environmental monitoring.

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***Impact of Green Space Decline on Land Surface Temperature in Hanoi using MODIS data***

Sina Hasheminassab <sup>(1)</sup>, David Diner <sup>(1)</sup>, Jeffrey Blair <sup>(2)</sup>, Sabrina Chow <sup>(3)</sup>, Ann M. Dillner <sup>(4)</sup>, Yang Liu <sup>(3)</sup>, Christian L'Orange <sup>(5)</sup>, Randall V. Martin <sup>(6)</sup>, Christopher Oxford <sup>(6)</sup>, Matteo Picchiani <sup>(7)</sup>, Jeremy A. Sarnat <sup>(3)</sup>, and the MAIA Team

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<sup>(2)</sup> AethLabs, San Francisco, CA 94110

<sup>(3)</sup> University of California–Davis, Davis, CA 95616

<sup>(4)</sup> Emory University, Atlanta, GA 30322

<sup>(5)</sup> Colorado State University, Fort Collins, CO 80523

<sup>(6)</sup> Washington University, St. Louis, MO 63130

<sup>(7)</sup> Agenzia Spaziale Italiana (Italian Space Agency), Via del Politecnico snc, 00133 Rome, Italy

NASA and the Italian Space Agency (ASI) are implementing the Multi-Angle Imager for Aerosols (MAIA) mission to investigate how different types of airborne particulate matter (PM) affect human health. The MAIA satellite instrument, a multi-angle imaging spectropolarimeter, will launch into Earth Orbit in the 2027-2028 timeframe and will be used to retrieve aerosol optical and microphysical properties over 12 Primary Target Areas (PTAs) in North America, South America, Europe, the Middle East, Africa, and Asia. The resulting aerosol products will be combined with ground-based PM measurements and WRF-Chem outputs to produce daily, 1-km-resolution maps of near-surface PM<sub>10</sub>, PM<sub>2.5</sub>, and speciated PM<sub>2.5</sub> (sulfate, nitrate, organic carbon, elemental carbon, and dust).

MAIA's surface-based PM measurement network is currently operational. It builds on existing monitoring infrastructures and expands coverage in under-monitored regions. The project leverages the SPARTAN network for PM<sub>2.5</sub> speciation and incorporated additional AirPhoton samplers, deployed supplementary samplers provided by Colorado State University, and installed AethLabs microAeth MA350 black carbon monitors. In Ethiopia, where PM<sub>2.5</sub> monitoring has been historically limited, PurpleAir sensors were deployed to improve ground-based spatial coverage.

This presentation provides an update on MAIA's PM monitoring network and highlights findings from its first four years of operation. Results show elevated PM concentrations at PTAs in low- and middle-income countries (LMICs). IND-Delhi and ETH-AddisAbaba are the most polluted PTAs, with annual average PM<sub>2.5</sub> concentrations approaching  $\sim 100 \mu\text{g}/\text{m}^3$  and  $\sim 30 \mu\text{g}/\text{m}^3$ , respectively. PM<sub>2.5</sub> chemical composition also varies substantially across PTAs, reflecting regional differences in emission sources, aerosol formation, atmospheric processing, and meteorology. Organic carbon contributes strongly to PM<sub>2.5</sub> in several regions (e.g., USA-Atlanta and CHL-Santiago), nitrate fractions are highest in the USA-LosAngeles and KOR-Seoul, elemental carbon is most prominent in Africa (ETH-AddisAbaba and ZAF-Johannesburg), and dust contributes more strongly in arid or dust-influenced regions, including ISR-TelAviv and ESP-Barcelona.

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### ***Overview of MAIA Italian science projects***

Matteo Picchiani <sup>(1)</sup>, Simona Zoffoli <sup>(1)</sup>, Giovanni Rum <sup>(1)</sup>

<sup>(1)</sup> Italian Space Agency (ASI), Rome, Italy

The Multi-Angle Imager for Aerosols (MAIA) mission, jointly developed by the Italian Space Agency (ASI) and NASA, aims to monitor particulate matter (PM) concentrations and chemical composition to evaluate human health impacts. Within this framework, ASI provides the PLATiNO-2 satellite platform, manages launch and mission operations, and coordinates ground monitoring across Italian Target Areas, including major urban regions such as Rome, Bologna, Milan, Turin, Bari, and Taranto. To support retrieval algorithms and validation activities, ASI collaborates with regional environmental agencies (ARPAs), which provide high-precision ground measurements of total and speciated PM<sub>2.5</sub> as part of their institutional monitoring mandate. Furthermore, ASI leads national scientific initiatives, including the MAIA Italy project (in collaboration with CNR-ITIAM and ARPA Puglia) to support speciated PM<sub>2.5</sub> monitoring in Southern Italy, and the APEMAIA project (with CNR-ITIAM). The latter integrates multi-sensor satellite observations (such as MAIA, PRISMA, and Sentinel) with AI-driven downscaling models to map Aerosol Optical Depth and PM concentrations at high intra-urban resolution ( $< 500 \text{ m}$ ). Together, these coordinated efforts establish a robust observational and analytical framework for air quality management and environmental health risk assessment in Europe.

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## ***APEMAIA: A Multi-Source AI-Based Approach for Intra-Urban PM Concentration and Population Exposure***

Maria Adamo <sup>(1)</sup>, Mariella Aquilino <sup>(1)</sup>, Marica De Lucia <sup>(1)</sup>, Cristina Tarantino <sup>(1)</sup>, Silvana Fuina <sup>(1)</sup>, Saverio Vicario <sup>(1)</sup>, Delia Evelina Bruno <sup>(1)</sup>, Francesco De Simone <sup>(1)</sup>, Nicola Pirrone <sup>(1)</sup>, Alessandro Fania <sup>(2, 3)</sup>, Alfonso Monaco <sup>(2, 3)</sup>, Roberto Bellotti <sup>(2)</sup>, Tommaso Maggipinto <sup>(2, 3)</sup>, Angela Morabito <sup>(4)</sup>, Francesca Intini <sup>(4)</sup>, Annalisa Tanzarella <sup>(4)</sup>, Ilenia Schipa <sup>(4)</sup>, Matteo Picchiani <sup>(5)</sup>

<sup>(1)</sup> Institute of Environmental Technologies and Intelligence, National Research Council of Italy (CNR-ITIAM)

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Urban air pollution is one of the major environmental and public health concerns, with human exposure to particulate matter (PM) being among the most relevant. The assessment of intra-urban air quality remains challenging because conventional monitoring networks provide limited spatial coverage, while satellite observations require integration with ground-based and ancillary information to support high-spatial and temporal resolution PM estimates. The APEMAIA project was developed in support of the MAIA mission to develop innovative approaches for estimating PM concentrations and population exposure at the intra-urban scale through the integration of Earth Observation (EO) data, numerical atmospheric and Artificial Intelligence (AI) modelling, and land use information. The project focuses on the urban areas of Bari and Taranto, characterised by different environmental pressure factors (i.e., transportation systems, industrial and commercial activities) and urban landscape.

The APEMAIA approach integrates multi-source EO data with meteorological, environmental and urban information. Satellite observations, including aerosol-related, optical and thermal products, are combined with meteorological fields from the WRF model and spatial predictors describing land use and land cover, vegetation, urban morphology, road networks and population distribution. Machine Learning techniques are investigated to exploit these complementary sources and derive spatially continuous estimates of PM<sub>2.5</sub> and PM<sub>10</sub> concentrations at the intra-urban scale. The developed approaches also provide methodological elements to support the future exploitation of MAIA observations and data products.

Population exposure is addressed by using two different approaches integrating PM concentration fields with high-resolution population distribution. These complementary approaches allow population exposure to be investigated at different temporal scales and provide information that are relevant to environmental assessment, urban planning and epidemiological studies.

Overall, APEMAIA explores the potential of combining satellite observations, atmospheric modelling data, urban geospatial information and AI to improve the geospatial and temporal distribution of intra-urban PM concentrations and population exposure assessments.

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***The EIRENE RI - Environmental Exposure Assessment Research Infrastructure: recent progress and future developments in bridging environmental science, human exposome studies and effectiveness policy evaluation***

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Environmental determinants — such as air quality, chemical pollutants, and food systems — critically shape human health across the lifespan, a reality further amplified by climate change and industrial practices. Although the EU's One Health framework addresses these planetary risks through initiatives like the Green Deal, progress is still hindered by disciplinary silos. Consequently, a lack of harmonized data has caused environmental health research to lag behind genomics, leaving gaps in chronic disease research.

EIRENE (European Infrastructure for Human Exposome) closes this gap. By providing open access to advanced infrastructures, integrated services, and harmonized data, EIRENE drives innovation in human exposome research. Moving beyond Europe, the EIRENE Implementation Phase Project aims to integrate functional exposomics into global biomedical and clinical research, transforming public health by uncovering hidden links between environmental exposure and health outcomes.

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***High-Resolution PM10 and PM2.5 Mapping in Apulia: From APE-MAIA Results to Physics-Informed Modelling***

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Within the APE-MAIA project, a regional modelling framework was developed to estimate near-surface particulate matter concentrations across Apulia, Southern Italy, with the aim of supporting high-resolution exposure assessment in preparation for the MAIA mission. The approach integrates ground-based observations from the ARPA Puglia monitoring network with Earth Observation products, meteorological fields, land-use information, road and building density, population distribution, and temporal descriptors on a common 300 m grid. In particular, satellite-derived aerosol information was combined with WRF meteorology and territorial predictors within an XGBoost framework to estimate daily PM<sub>10</sub> and PM<sub>2.5</sub> concentrations over the entire region. The resulting models achieved  $(R^2)$  values of 0.64 for PM<sub>10</sub> and 0.67 for PM<sub>2.5</sub>, demonstrating the capability of heterogeneous data fusion to reconstruct spatially continuous particulate matter fields at intra-urban scale. Explainable Artificial Intelligence methods were also used to investigate the contribution of aerosol, meteorological, and territorial drivers to the predicted concentrations.

Building on the regional APE-MAIA framework, current work is exploring a new generation of physics-informed approaches aimed at improving temporal resolution, physical consistency, and forecasting capability. In this ongoing development, advection-diffusion-based atmospheric representations are combined with neural architectures, including Physics-Informed Neural Networks and graph-based recurrent models, to exploit meteorological forcing, emission-related information, road and land-use characteristics, and ground observations. The methodology is currently being developed for PM<sub>10</sub> and extended to PM<sub>2.5</sub>, with the objective of producing hourly concentration fields at 300 m resolution and reducing the dependence on purely data-driven spatial interpolation.

This transition from regional Earth Observation-based machine learning to hybrid physics-informed modelling represents a natural evolution of APE-MAIA activities and provides a framework for the future integration of MAIA aerosol products with ground monitoring and atmospheric dynamics for high-resolution exposure and human-health applications.

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### ***High-resolution spatio-temporal modelling of daily PM<sub>2.5</sub> concentrations across Europe (2005–2022)***

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**Objective** To develop spatio-temporal machine-learning models to predict daily fine particulate matter (PM<sub>2.5</sub>) concentrations across Europe at high spatial resolution for the period 2005–2022.

**Material and Methods** Daily PM<sub>2.5</sub> monitoring data were obtained from national networks and centrally compiled by the European Environment Agency (EEA). Each monitoring site was characterized using spatial predictors related to land use, traffic, and population, together with spatio-temporal predictors, including aerosol optical depth, meteorological variables, dispersion-model outputs, and vegetation indices. Random Forest (RF) and Extreme Gradient Boosting (XGB) models were implemented for each year (2005-2022), with hyperparameters optimized to balance performance and computational efficiency. Predictions from both learners were then combined in a geographically weighted generalized additive model (GAM) to obtain a final ensemble model. Model performance was assessed using spatially-blocked nested 10-fold cross-validation scheme. Models were applied to predict daily PM<sub>2.5</sub> concentrations on a high-resolution European grid (combining 100m<sup>2</sup>, 1km<sup>2</sup>, and 5km<sup>2</sup> cells), with finer resolution in populated areas.

**Results** The results for 2019 are presented as an example. Data from more than 3,100 monitoring stations were analysed, with PM<sub>2.5</sub> annual mean values ranging from 5 µg/m<sup>3</sup> in Finland to 33 µg/m<sup>3</sup> in Bosnia and Herzegovina. In both RF and XGB models, dispersion-model PM<sub>2.5</sub> values, monitor coordinates, and boundary layer height (a meteorological variable) were the most influential predictors. All models showed great cross-validated performance; the ensemble achieved the highest overall R<sup>2</sup> (0.78), ranging from 0.31 in Estonia to 0.91 in Belgium, with low variability across regions, climate zones, monitor types, and seasons.

**Conclusion** High-resolution daily PM<sub>2.5</sub> maps, generated through advanced machine-learning methods, provide a valuable tool for investigating air pollution and health effects across Europe, supporting both short- and long-term studies and enabling standardized analyses across diverse cohorts. Furthermore, they might lay the ground for collaborations in less investigated areas.

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### ***Deep Learning Approach for PM<sub>2.5</sub> Surface Estimation Using Sentinel-5P Radiance Data***

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Anthropogenic emissions, such as particulate matter (PM), can have significant adverse effects on human health, making their continuous monitoring of critical importance. Ground-based monitoring stations provide highly accurate measurements of several atmospheric pollutants, but their spatial coverage is inherently limited. Satellite observations represent a powerful tool to overcome this limitation, although atmospheric effects must be properly accounted for when estimating pollutant concentrations, particularly near the Earth's surface. Thanks to its rich spectral information, Sentinel-5P represents a valuable source of information for atmospheric characterization.

Three CNN-based Deep Learning models with different levels of complexity have been developed to estimate surface PM<sub>2.5</sub> concentrations using exclusively Sentinel-5P radiance data. The first employs a lightweight convolutional architecture, while the other two are based on ResNet and U-Net, with the latter being extensively adopted in state-of-the-art remote sensing applications. The spectral richness of the input observations provides the models with information on atmospheric

properties, enabling the generation of spatially continuous PM<sub>2.5</sub> maps over the European domain. CAMS reanalysis PM<sub>2.5</sub> fields, at approximately 10 km spatial resolution, were used as reference data for model training and evaluation. The resulting estimates were also independently validated against ground-based measurements, with the best-performing model achieving an  $R^2$  of 0.86.

The proposed models do not require meteorological or other auxiliary information as input. Moreover, while validated CAMS reanalysis products become available with a substantial temporal delay, currently approaching two years, the proposed approach requires only Sentinel-5P radiance observations at inference time, enabling near-real-time estimation of surface PM<sub>2.5</sub> over Europe. The forthcoming MAIA mission, providing multispectral radiance observations at substantially finer spatial resolution, could offer an opportunity to investigate the extension of the proposed radiance-to-PM<sub>2.5</sub> framework toward finer-scale surface PM<sub>2.5</sub> mapping, potentially supporting more detailed air-quality and human-exposure assessments.

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### ***High-Resolution PM<sub>2.5</sub> Estimation from CAMS Forecasts using Machine Learning***

Andrea Corsico <sup>(1)</sup>, Simone Zini <sup>(1)</sup>, Mirko Paolo Barbato <sup>(1)</sup>, Luigi Celona <sup>(1)</sup>, Paolo Napoletano <sup>(1)</sup>

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Fine particulate matter (PM<sub>2.5</sub>) represents one of the main threats to global public health. While regional chemical transport models offer continuous forecasting, their limited accuracy and coarse spatial resolution often restrict their ability to resolve localized variations in urban environments. In this work, we present an artificial intelligence-based method for downscaling and correcting daily ground-level PM<sub>2.5</sub> forecasts, improving the spatial resolution from 10 km to 1 km on a European scale. The model adopts a machine-learning architecture that integrates regional forecasts from the Copernicus program (CAMS) with high-resolution satellite observations. In particular, data from the Sentinel-5P TROPOMI sensor (for the UV Aerosol Index, UAI) and the VIIRS radiometer (Aerosol Optical Depth, AOD, and nighttime light radiance) are exploited, combined with ERA5 meteorological reanalyses (temperature, wind speed, planetary boundary layer height), vegetation indices (NDVI), topographic data, and population density. Validation against stations of the European Environment Agency (EEA) air quality monitoring network shows a 0.26 reduction in RMSE compared with CAMS forecasts, with an  $R^2$  of 0.44. These results highlight the potential of integrating multispectral data to improve the continuous estimation of PM<sub>2.5</sub> exposure and support air quality and public health applications.

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### ***From Earth Observation to Operations: IRIDE's Air Quality and Hydro-Meteo-Climate Services***

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To empower public stakeholders in decision-making processes regarding air quality and public health, the IRIDE flagship program, led by the Italian Space Agency (ASI) and the Italian Government with the support of the European Space Agency (ESA), introduces a paradigm shift in how public institutions integrate Earth Observation into their daily operational workflows.

As one of the most prominent European space initiatives for Earth Observation, IRIDE is an end-to-end, multi-sensor system comprising upstream satellite constellations, midstream data processing pipelines, and downstream operational user services. The spatial infrastructure encompasses diverse constellation assets—including Synthetic Aperture Radar (SAR), optical high- and medium-resolution sensors and hyperspectral payloads—working in synergy to ensure unprecedented revisit times and multi-spectral capability over the Italian territory. Beyond traditional data access, IRIDE delivers fully operational, end-to-end downstream services—including dedicated modules for air quality monitoring, atmospheric composition, and meteorological and climate observations—tailored for direct ingestion into institutional decision-support systems. All operational services and satellite constellation data are provided free of charge to public entities, accessible through a single, streamlined entry point: the IRIDE System Marketplace, which centralizes service discovery, data access, and user onboarding.

During the conference, the pioneering scientific approaches of the MAIA mission and the operational paradigm shift introduced by the comprehensive IRIDE system will be highlighted, demonstrating how space-based solutions effectively empower public decision-making in air quality management and environmental protection.

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### ***Site-Specific vs. Multi-City Machine Learning for Intra-Urban PM Mapping: the APEMAIA Approach in Southern Italy***

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Urban-scale air quality mapping is critical for assessing population exposure to particulate matter, and sparse ground networks make satellite remote sensing essential. Within the APEMAIA project, we compare site-specific and generalizable multi-city models for Bari (coastal, residential-urban) and Taranto (significant industrial activity), in Apulia, southern Italy.

XGBoost models were developed for PM10 and PM2.5 from WRF fields, satellite data (AOD from a MAIAC-MODIS/Sentinel-3 ensemble, LST from MODIS), urban morphology, demographic and land-cover data, and ARPA ground observations (2019–2022, 300×300 m grid). Validation combined 5-fold cross-validation (CV) and Leave-One-Station-Out (LOSO), with predictor optimization via Recursive Feature Elimination based on permutation importance.

For both PM10 and PM2.5, the two configurations reproduced the observed variability well under 5-fold CV ( $R^2$  0.67–0.78; RMSE 3.3–5.1  $\mu\text{g}/\text{m}^3$ ) and performed comparably, pooled LOSO RMSE differing by less than 0.3  $\mu\text{g}/\text{m}^3$  for both species. Under LOSO,  $R^2$  at held-out stations dropped, moderately for PM10 and more variably for PM2.5, and both compressed the spatial contrast, overestimating the cleanest sites and underestimating the most polluted ones: local calibration therefore remains important, since it captures these peculiarities and preserves more of the spatial variance. In both configurations, PM2.5 at Tamburi, a residential district adjacent to large steelworks, was not reproduced at all, confirming the peculiarity of a site whose levels cannot be inferred from the rest of the network.

Permutation importance and SHAP identified the same dominant variables, and the same response patterns, in both cities and in the multi-city model for PM10 dust concentration, temperature, boundary-layer height and AOD whereas for PM2.5 the leading predictor followed the local emission regime: seasonality in Bari, road proximity in Taranto. This similarity of feature importance across cities suggests that a hybrid approach with locally calibrated parameters is feasible, and preferable where local detail matters.

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### ***A Physically Based Framework for Generating PRISMA-Like Hyperspectral Datasets for Atmospheric and Aerosol Applications***

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Physically based synthetic hyperspectral datasets are essential to support the development and testing of atmospheric and aerosol-related methodologies, especially when cloud-free hyperspectral observations are limited. In this study, we present a physically consistent framework for generating PRISMA-like hyperspectral spectra by integrating atmospheric composition fields from the Copernicus Atmosphere Monitoring Service, spectrally resolved aerosol optical properties derived with FlexAOD, broadband surface reflectance prototypes from the Harmonized Landsat–Sentinel dataset, and full radiative-transfer simulations performed with libRadtran under realistic PRISMA acquisition geometries. The framework is evaluated using six PRISMA acquisitions over the Rome metropolitan area, covering different surface types, atmospheric conditions, and viewing geometries. A two-stage spectral consistency assessment is adopted to compare simulated and observed spectra. First, a spectral distance metric based on PRISMA Level 2C surface reflectance is used to derive scene-independent radiometric partitions of the observations. Second, empirical constraints based on NDVI, NDBI, and VgNIR-BI, computed from PRISMA Level 1 radiance data, are used to verify the physical consistency of the simulated spectra across vegetation, soil, and urban surface classes. Results show a satisfactory radiometric agreement between simulated and observed PRISMA spectra, with most synthetic curves falling within the observed mean spectral envelopes for the main land-cover classes. The spectral distance metric exhibits stable behaviour across the analysed scenes, while the empirical spectral indices remain consistent among acquisitions, supporting the robustness of the proposed approach. The framework enables the integration of real PRISMA observations with physically based synthetic spectra, supporting the construction of large, internally consistent hyperspectral datasets for future studies focused on aerosol optical properties, aerosol speciation, and hyperspectral sensitivity analyses. The approach is readily extendable to other imaging spectroscopy missions, including EnMAP and the upcoming Copernicus CHIME mission.

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### ***Fine-scale estimation of air temperatures using spatiotemporal machine learning models in Italy for the period 2003-2024***

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**Objective:** Estimate daily minimum (Tmin) and maximum (Tmax) air temperature at fine scale (1x1 km) across Italy from satellite and reanalysis data using spatiotemporal machine learning models between 2003 and 2024.

**Methods:** The spatial unit of analysis was a regular grid of 307,635 1x1 km cells covering Italy. A three-stage modelling approach was implemented. In stage one, missing land surface temperature (LST, 1x1 km) data from satellites was imputed using skin temperature from the ERA5-Land reanalysis model. In stage two, XGBoost models were trained to estimate daily Tmin and Tmax by integrating observations from 2,762 weather stations, LST, and spatiotemporal predictors (land cover, NDVI, elevation, population, climatic zones, roads). For each year, 10-fold cross-validation

was conducted to assess, overall and spatiotemporal performance, by season and climate zone. In stage three, daily Tmin and Tmax were estimated for the entire national grid using the stage 2 model.

Results: Stage one models had an average  $R^2$  of 0.979 and a root mean square error (RMSE) of 0.919 °C for daytime LST and 0.988 (0.296 °C) for night-time LST. In stage two, both Tmin and Tmax temporal and spatial validation remained consistent with stage one. Model performance varied slightly across seasons, with autumn and spring showing higher skills. Performance was higher in temperate climate zones, with a Tmax  $R^2$  of 0.975 and RMSE of 1.381 °C. From the final model, an average Tmax of 18.2 °C and Tmin of 8.7 °C were estimated for Italy. Over the 22-year period, an increasing trend in both Tmax and Tmin was observed (Tmax = 1.57 °C; Tmin=0.96°C).

Conclusions: Results show an increase in temperatures across Italy and identify hotspot areas most affected by climate change. Data will be used to estimate the health effects of extreme temperatures in urban and rural areas.

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### ***Remote Sensing of Volcanic Aerosols: State of the Art and Future Strategies for Air Quality Monitoring***

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Explosive eruptions represent a major natural source of fine and coarse aerosol particles, injected directly into the troposphere and stratosphere. Upon reaching the neutral buoyancy level, volcanic plumes form can spread over hundreds of kilometres. The transport and deposition of volcanic ash—ranging from sub-micron to millimetric particles, pose substantial environmental risks and long-term hazards to human health, particularly for the over 500 million people living in proximity to active volcanoes. Accurate, real-time characterization of volcanic plumes is thus critical not only for aviation safety, but also for evaluating local and regional ambient air quality degradation. This work presents a comprehensive review of advanced remote sensing technologies dedicated to the continuous monitoring of volcanic plumes and their dispersion. We evaluate the synergies between spaceborne observations, ground-based radar networks, lidars, and high-resolution visible and thermal camera systems. While satellite platforms provide essential large-scale synoptic coverage, integrated networks, such as the multi-instrument framework operational at Mt. Etna in specific field campaign, demonstrate how multi-angle and multi-sensor approaches overcome spaceborne spatial and temporal limitations. Emphasis is placed on the retrieval of key physical parameters, including plume height, mass eruption rates, and particle size distributions. Finally, we discuss current technological gaps in aerosol speciation and concentrations near the ground, outlining future perspectives for integrating spaceborne imaging with surface monitoring networks to improve health-impact assessments and environmental policy response during severe eruptive

crises. The present work was also funded by ASI SPACE-IT-UP(Cup Master I53D 24000060005), SPOKE 5.

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***Session #3 “Bridging Satellite and Ground information:  
networks and methodologies to measure near surface PM and air quality in support of the joint  
ASI-NASA MAIA Mission”***

Session chaired by Giovanni Rum and Matteo Picchiani, Technologist, in the “Earth Observation” Office at the Italian Space Agency (ASI).

The session aims to address the crucial link between spaceborne observations and in-situ surface measurements needed for algorithm calibration, retrieval validation, and source apportionment. Featuring contributions from regional environmental protection agencies (ARPAs), research infrastructures (such as ACTRIS, EIRENE, and ASCENT), and observational supersites (ALICENET, CIAO, Lampedusa Station), this session explores ground network strategies, aerosol vertical profiling (lidar/ceilometer), airborne sondes, and multi-mission satellite validation (e.g., ESA-JAXA EarthCARE). The discussions focus on harmonizing surface measurements of total and speciated  $PM_{2.5}$  with space-based datasets to ensure seamless data integration across local, regional, and global scales.

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***Deeping on air quality topics in Emilia-Romagna region***

Vanes Poluzzi <sup>(1)</sup>

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Situated on the southern bank of the Po River and being densely populated—with a consequent abundance of residential areas, road infrastructure, industries, and agricultural activities—the Emilia-Romagna region experiences the unique conditions of the Po Valley. This area is characterized by particularly adverse weather patterns in both summer and winter, driven by factors such as low wind speeds, frequent thermal inversions, consistently high relative humidity, and generally poor air mass mixing; these conditions often lead to the accumulation of emitted pollutants and foster the formation of secondary pollutants, such as ozone and atmospheric aerosols of various sizes. Given these conditions and the resulting critical issues (PM<sub>x</sub>, O<sub>3</sub>, NO<sub>x</sub>), Arpae ER has long focused on gaining a detailed, in-depth understanding of atmospheric pollution and its impact on air quality—going well beyond mere regulatory requirements. While the monitoring network comprising 47 fixed stations distributed across the region—provides the baseline data needed to determine pollutant concentrations and assess them against limit values and targets, the additional analyses undertaken (involving observations, simulations, estimates, and environmental and health impact assessments) offer a much broader perspective. This enables more targeted, precise interventions addressing the specific sources of these critical issues. With this in mind, since 2010, Arpae ER has operated two "Supersites"—one in the Bologna urban area and another in the rural area between Bologna and Ferrara. These sites systematically measure sub-micrometer aerosol particles and their size distribution, black carbon, NH<sub>3</sub>, and the chemical composition of PM<sub>2.5</sub> (the latter also being used for the Maia project). Furthermore, various measurement campaigns have been conducted throughout the year using Aerosol Mass

Spectrometers to better characterize atmospheric aerosol in terms of both organic and inorganic components.

Arpae also employs a modeling suite featuring the Ninfa-Chimere photochemical model. This enables both scenario analysis for long-term intervention planning (such as the Emilia-Romagna Region Air Quality Plan) and daily forecasts of critical pollutant levels—the latter being used to guide emergency response measures.

In addition, Arpae produces a biennial emissions inventory to estimate mass flows from various sources (the most recent being from 2023).

Finally, health impact assessments—conducted using epidemiological models at both regional and national scales—round out the comprehensive analysis of air quality issues.

Some results obtained show that the air quality in Emilia-Romagna region in the recent years is slowly improving.

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### ***Local Climate Zone Mapping by Integrating Hyperspectral and Multispectral Data with a Spectral–Spatial Fusion Network***

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Keywords: air quality, atmospheric monitoring, particulate matter, chemical speciation, source apportionment, emission inventory, air quality modelling

Lombardy is the most populous and industrialized region in Italy, located in the Po Valley, an area characterized by high population density, intense industrial and agricultural activities.

Regional Environmental Protection Agency of Lombardy (ARPA Lombardia) contributes to environmental protection through a wide range of environmental monitoring, assessment, and control activities, including the management of environmental monitoring networks, inspection and surveillance activities, support for environmental permitting procedures, natural risk prevention, radiological protection services, and the production of environmental data and knowledge.

ARPA Lombardia's activities in the field of air quality include the operation of the regional air quality monitoring network, the development of emission inventories, the application of simulation models for air quality forecasting and the evaluation of emission scenarios.

In addition to routine monitoring activities, ARPA Lombardia supports air quality research through specialized studies, intensive measurement campaigns, and projects focused on the analysis of emission sources, the processes involved in the formation of secondary pollutants and emerging atmospheric contaminants, as well as the monitoring of particle number concentration, particle size distribution, and volatile organic compounds (VOCs).

Emission assessment activities are supported by the development and continuous updating of the regional emission inventory (INEMAR), which provides a detailed representation of emissions from

both anthropogenic and natural sources. Modelling systems are routinely employed both for operational air quality forecasting and for the evaluation of emission reduction scenarios, supporting the analysis of mitigation measures and future policy options through dedicated studies and scenario-based assessments.

This contribution will present the main activities carried out by ARPA Lombardia in the field of air quality.

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***Physics-based source apportionment of near-surface PM: a ground-based approach to support satellite aerosol characterization and health-impact assessment***

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The health effects of particulate matter (PM) depend on both concentration and aerosol composition and source. The ability of satellite observations to identify and characterize aerosol types and sources is therefore highly relevant for assessing population exposure and health impacts. Ground-based observations are essential to validate and complement these space-based estimates, by providing high-temporal-resolution information on near-surface aerosol variability and source contributions.

We present RASPBERRY (Real-time Aerosol Source apportionment using Physics-Based Experimental data and multivariate factor analysis), a novel source-apportionment methodology based on aerosol physical properties – particle size distributions and spectrally resolved light absorption – measured at high temporal resolution. RASPBERRY provides source-resolved PM estimates from real time to multi-year timescales, complementing chemical source-apportionment approaches. Compared with chemical methods, it can be fully automated, without sample collection and laboratory analysis, and provides hourly rather than typically daily source-resolved information. These features could facilitate integration into monitoring networks and expand the spatial coverage.

The methodology was applied to a five-year (2020–2024) dataset collected at an urban background site in Aosta, in the north-western Italian Alps. Despite its alpine setting, Aosta is influenced by air masses from the Po Valley, one of Europe's major anthropogenic pollution regions, and long-range transport from the Mediterranean basin, including mineral dust. This

makes it a useful testing environment for distinguishing aerosol types and sources under contrasting conditions.

RASPBERRY identified six PM<sub>10</sub> factors, including traffic, biomass burning, secondary aerosol, desert dust, and local dust resuspension. Hourly source-resolved estimates captured rapid pollution and long-range transport events and showed good agreement with chemical source-apportionment results, while comparisons with lidar-ceilometers, sun photometers, and atmospheric modelling provided further support.

The results demonstrate how physics-based ground observations can provide source information for interpreting and validating satellite-derived aerosol characteristics, supporting the MAIA framework linking near-surface PM, population exposure, and health effects.

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***Past Milestones and Future Challenges Supporting MAIA Mission: Bridging Air Quality Ground Networks, High-Altitude Sentinel, and Earth Observation Data***

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Addressing current and emerging environmental priorities, this contribution illustrates a multi-scale strategy integrating a historical national-based air quality network with dedicated mountain observations and targeted satellite-ground synergy.

Compliant with Directive 2008/50/EC, the Special Networks Agreement, coordinated by the Italian Ministry of the Environment alongside CNR-ITIAM, ENEA, and ISS, delivered a consistent national database on PM<sub>10</sub> and PM<sub>2.5</sub> mass concentrations and their chemical composition (ions, EC/OC, and metals) throughout the 2017–2019 period. Sampling sites were strategically chosen to ensure geographic representativeness and nationwide coverage, including dedicated ground-based stations across urban areas, such as Milan, Udine, Padua, Florence, Rome, Taranto, and Cosenza, and rural background sites, like Mantova, Ascoli Piceno, and Lecce. Filters were uniformly collected at stations by regional environmental agencies and all analyzed using standardized methods by ARPA Veneto, ensuring data comparability. The obtained comprehensive dataset served as a national benchmark for advanced knowledge on air quality.

Building upon this national baseline, the Monte Curcio Atmospheric Observatory provides a strategic high-elevation rural background site in the Sila National Park, acting as a sentinel for climate dynamics and atmospheric composition. Complementing its GAW-WMO monitoring, it conducted preliminary aerosol characterization in 2016–2017, followed by continuous sampling and carbonaceous determination (EC/OC) from 2021 onwards for PM<sub>10</sub> and PM<sub>2.5</sub>.

Looking ahead, this observational capacity expands to support human health and exposome research under European frameworks like the EIRENE Infrastructure. A further contribution is the ongoing MAIA-Italy Agreement (2026–2028), conducted in close collaboration with ARPA Puglia, combining ARPA Puglia PM<sub>10</sub>/PM<sub>2.5</sub> mass concentration data with daily PM<sub>2.5</sub> sampling at four stations in Bari and Taranto for chemical analysis of selected filters at CNR-ITIAM laboratories. These high-quality ground-based measurements will support MAIA mission by characterizing particulate matter, validating satellite products, and assessing health impacts over the secondary target area covering Southern Italy.

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### ***Contributions of ACTRIS and ASCENT networks to ASI-NASA MAIA mission***

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ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure) in Europe and ASCENT (Atmospheric Science and Chemistry mEasurement NeTwork) in the United States provide highly complementary capabilities for this purpose. ACTRIS delivers harmonized, quality-controlled long-term observations of aerosol physical, optical and chemical properties through coordinated in situ and remote-sensing platforms. These include particle number and size distributions, light scattering and absorption, black carbon, chemical composition, aerosol optical depth, vertical aerosol profiles and planetary boundary-layer information. ASCENT provides comprehensive, high-time-resolution measurements of aerosol composition and physical properties across the United States, including non-refractory chemical species, trace metals, black and brown carbon, and particle number-size distributions. Within EU-project ATMO-SERV, ACTRIS and ASCENT observation sites provide also physical access to the observation sites allowing targeted new instruments relevant for MAIA data interpretation.

Together, these two networks can provide a powerful observational framework for MAIA calibration/validation and product evaluation. Co-located and temporally matched measurements

can be used to assess satellite-retrieved aerosol properties, investigate relationships between aerosol optical characteristics and surface PM<sub>2.5</sub>, evaluate chemically speciated PM products, and characterize variability associated with boundary-layer dynamics, aerosol sources and atmospheric processing. Their standardized measurement protocols, quality assurance procedures, long-term records and open data infrastructures also enable robust intercomparison across sites and regions.

This contribution will present the measurement capabilities of ACTRIS and ASCENT relevant to MAIA, identify opportunities for coordinated satellite–surface observations. Such cooperation can strengthen the bridge between satellite aerosol retrievals and near-surface air-quality information and expand the scientific value of MAIA for atmospheric and health research in both continents.

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***Support to in situ and satellite air quality monitoring through operational ground-based measurements of aerosol profiles across Italy within the national cooperative Automated Lidar-Ceilometer network ALICENET***

Francesca Barnaba <sup>(1)</sup> on behalf of the Alicenet team

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Air Quality (AQ) is the result of an intricate link between emissions, atmospheric physical and chemical processing and dynamics, each acting over a range of spatial and temporal scales. These aspects are all taken into account for example within chemical transport models (CTM) but model simulations need to be verified, or even driven, by observations. For particulate matter (PM), even dense AQ monitoring networks generally lack information along the vertical dimension. The 3D perspective is conversely essential for a comprehensive understanding of surface-level pollution and driving mechanisms, and this is particularly true over complex terrain, which characterises most of the Italian territory.

Ground-based remote sensing by Automated Lidar-Ceilometers (ALC) can support the operational monitoring of 3D-PM fields providing aerosol profiles from the surface up to the mid troposphere and operating continuously (24/7) and unattended. The capability to disclose the vertical PM distribution is important for both verification of models and synergy with in situ and satellite AQ data.

In Italy, CNR-ISAC set up a cooperative ALC network (ALICENET, [www.alice-net.eu](http://www.alice-net.eu)) in 2015. In the last 3 years, the network grew up and currently includes over 20 systems from Northern to Southern Italy, covering, among others, several main urban areas (e.g., Rome, Milan, Turin) as well as the Etna region. ALICENET is the result of a collaborative effort of research institutions and several regional EPAs (ARPAs). As a main strength, ALICENET makes use of its original data-processing tools, which are co-designed and co-developed with users (e.g., co-authored CNR-ARPAs publications). At the same time, ALICENET data processing is kept centralized at CNR-ISAC to allow homogeneous quantitative retrievals of aerosol products across the network. These include AQ-relevant aerosol properties such as PM mass concentration profiles and automatic identification of aerosol layers and type. The network capability to detect the arrival and displacement of advected layers is also of

particular interest, as Italy is frequently affected by long range transport of Saharan dust, local and transboundary smoke as well as volcanic plumes (e.g., in the Etna region) impacting AQ.

This presentation will describe current and potential capabilities of ALICENET in support to AQ monitoring at national level, including synergy with in situ and satellite components as well as with modelling.

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***CIAO (CNR-IMIOT Atmospheric Observatory): an Italian Supersite for the Validation and Exploitation of MAIA Aerosol Products***

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The CIAO (CNR-IMIOT Atmospheric Observatory – <https://ciao.imiot.cnr.it>), located in Southern Italy, represents one of Europe's most advanced atmospheric supersites and offers a unique opportunity to support the validation and scientific exploitation of data products from the MAIA mission.

CIAO provides a comprehensive observational environment ideally suited for calibration, validation, and algorithm development activities related to MAIA. The observatory hosts a broad suite of continuously operating remote sensing and in-situ instrumentation capable of characterizing atmospheric aerosols from the surface to the upper troposphere. These include advanced multi-wavelength Raman and polarization lidars, sun-photometers, and surface aerosol sampling and characterization systems operating in the framework of ACTRIS (Aerosol Clouds Trace Gases Research InfraStructure). As key station of international research infrastructures and global observing networks, including EARLINET, AERONET, GALION, CIAO delivers high-quality, traceable, and quality-assured observations that are particularly valuable for satellite validation.

CIAO observatory can provide independent information on aerosol air quality parameters (like PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, BC, aerosol size distribution, source apportionment) measured at the ground but also aerosol optical depth, aerosol vertical distribution, particle typing, boundary layer structure, aerosol extinction profiles, and selected aerosol microphysical properties. These measurements are essential for evaluating the accuracy of MAIA aerosol retrievals and for assessing the conversion of column-integrated satellite observations into near-surface particulate matter concentrations, which constitute a critical element of the mission's health-related objectives.

The long-term observational records available at the site enable investigations of seasonal and interannual variability of aerosol properties, support algorithm refinement, and provide benchmark datasets for uncertainty analysis. Being the observatory is also strategically located in the central Mediterranean region, this diversity of aerosol types creates an ideal natural laboratory for

evaluating MAIA's capability to discriminate among different particle populations and estimate their contributions to air quality.

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***The Lampedusa Station for Climate Observation: A Mediterranean Site for Aerosol Research and Satellite Validation***

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Starting from 1997, ENEA has operated the Station for Climate Observation of Lampedusa, a long-term monitoring facility located in the central Mediterranean and dedicated to the continuous observation of key climate variables. The Station comprises three complementary observatories focused on atmospheric, marine, and land-atmosphere exchange processes.

Lampedusa's geographical characteristics make it an ideal site for aerosol satellite-validation activities. The island's small size, low topography, limited population, distance from major continental anthropogenic sources, and homogeneous surrounding marine environment minimize local influences and provide atmospheric conditions representative of the Mediterranean background.

The region experiences a high frequency of cloud-free conditions and is frequently affected by aerosol transport events, including Saharan dust outbreaks, biomass-burning emissions from Mediterranean wildfires, ship emissions, marine aerosols, and, occasionally, volcanic particles. Combined with the availability of long-term observations, these features make Lampedusa particularly suitable for the validation of satellite aerosol products, including those from EarthCARE, and for integrated studies combining satellite observations, ground-based measurements, and atmospheric modelling.

The station contributes to several international monitoring networks and European research infrastructures, including ACTRIS, ICOS, EMSO, and EMEP. Aerosol characterization relies on a comprehensive suite of active and passive remote-sensing instruments, complemented by in situ measurements such as gravimetric aerosol sampling, chemical speciation analyses, and continuous monitoring of aerosol optical properties. The observatory is also equipped with advanced meteorological and atmospheric profiling systems, as well as continuous greenhouse-gas observations.

Measurements are supported by ENEA's FORAIR-IT air-quality modelling system, which provides forecasts and interpretation of aerosol properties at both surface and column scales with a 4 km resolution over Italy.

This contribution highlights the potential role of the Lampedusa Station in supporting the MAIA mission by providing high-quality ground-truth observations for aerosol product validation and fostering the integration of satellite, ground-based, and modelling data in a representative Mediterranean background environment.

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***Validation and characterization of the 3D aerosol fields over the Italian peninsula using relevant ESA-JAXA EarthCARE products from the first two years of satellite operations in the framework of the ASI - ECVALMED.it project***

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The ESA-JAXA Earth Cloud Aerosol and Radiation Explorer (EarthCARE, EC) satellite launched in mid-2024 was designed to make a range of different measurements targeting cloud, aerosol, radiation and their interactions. Among others, the EC payload includes an Atmospheric Lidar (ATLID) and a Multi-Spectral Imager (MSI). This study presents results of a validation activity of EC ATLID and MSI Level-2 aerosol products over Italy performed in the framework of the ECVALMED.it project funded by the Italian Space Agency. In parallel to validation, aerosol measurements from the EarthCARE instruments were also used to provide an overview of the aerosol temporal and spatial (both horizontal and vertical) variability across the country based on the first two-year (July 2024-July 2026) of operations. Validation activities included comparisons of satellite-derived aerosol optical thickness (AOT) with ground-based measurements from Italian AERONET and SKYNET sun-sky photometers using variable spatio-temporal matching configurations (i.e., varying the satellite data spatial aggregation domains and the temporal integration windows of ground-based measurements). In general, MSI-AOT showed overestimated values, particularly at low aerosol load, although the performances improved at coastal AERONET/SKYNET sites, with respect to continental ones. At the same time, MSI-AOT was capable of reproducing AOT seasonal variability over both surface types. To investigate the vertical dimension, ATLID aerosol backscatter ( $\beta$ ) and particle depolarization ( $\delta$ ) profiles (ATL-EBD product) were aggregated onto pre-defined along-track 'curtains' covering the whole Italian territory. Analyzed over the whole 2-year period (2024-2026), these ATLID median profiles allowed to disclose some complex three-dimensional aerosol features across the country and the central Mediterranean, as for example the boundary-layer pollution in the Po Valley, the aerosol vertical distribution in the Etna area or the pattern of the desert dust transport from North Africa. The EC-derived aerosol characterization could be usefully employed for comparison, and possibly in synergy, with MAIA derived data over the country.

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***Airborne Innovative Lightweight Sondes for MAIA In-Situ Validation***

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ER and Aurelia, both SMEs with a strong academic background, operate in the environmental monitoring sector, bringing together expertise from atmospheric science, volcanology, earth observation and space technology. The two teams have jointly developed, manufactured and deployed an innovative generation of airborne multi-gas sondes within the frameworks of VOLANDO (VOLcanic pLume chAracterization using souNDing ballOons), a INGV/University Pisa PRIN 2022 project, and AIREMIT (Aviation In situ measuReMENTS of non-CO2 EMIssion Traces), a project funded by the EU SESAR 3 Joint Undertaking.

Engineered to be lightweight and cost-effective, these devices integrate advanced gas sensors, Optical Particle Counters, and dedicated particle samplers specifically configured to carry out in-situ measurements in volcanic plumes (VOLANDO heritage) and of aircraft emissions at cruise altitudes (AIREMIT). The system relies on customized sounding balloons to deploy the instruments directly into volcanic clouds and aircraft contrails. Conducting these high-altitude in-situ measurements allows researchers to characterize critical physical and chemical emission parameters with high accuracy, significantly reducing the uncertainties traditionally associated with remote sensing retrievals. All onboard sensors undergo strict laboratory calibration prior to deployment and have been validated through cross-comparison experiments with co-located, high-performance fixed instruments.

This presentation will show how this operational framework may provide specific datasets to support and validate observations from MAIA. Specific applications cases include:

- volcanic emissions, addressed with targeted balloon campaigns deployed during active volcanic eruptions to enable the direct validation of MAIA plume detection and parameter estimations;
- aviation emissions, with the validation of MAIA aerosol estimation at ground level providing the impact of the aircraft emissions in the target areas.

Combining affordability with ease of deployment, these lightweight sondes offer a highly scalable solution for atmospheric research. Ultimately, this approach bridges the gap between direct sampling and remote observations, with significant potential for enhancement of MAIA mission capabilities.

**Session #4 “Earth Observation data and Societal Health:  
Assessing Acute and Chronic Illness Risks with ASI-NASA MAIA Mission”**

Session chaired by Massimo Stafoggia, Head Statistician at Dipartimento di Epidemiologia, SSR Lazio / ASL Roma 1 and Matteo Picchiani, Technologist in the “Earth Observation” Office at the Italian Space Agency (ASI).

This Session focuses on the epidemiological and public health applications of Earth Observation data, bridging space technology with health risk assessment. The contributions highlight advanced Bayesian spatiotemporal modeling, high-resolution population exposure assessment at the intra-urban scale, and GIS-based vulnerability mapping. By linking fine-scale satellite-derived particulate estimates with cause-specific mortality, air temperature variations, and acute or chronic health outcomes, this session demonstrates how satellite-driven environmental metrics empower public health decision-makers, epidemiological research, and urban policy implementation.

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***Assessment of population exposure risk to PM at intra-urban scale in Bari (Italy) using PWEL and GIS Approaches***

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This study presents a spatial assessment of population exposure risk to particulate matter (PM<sub>10</sub>, PM<sub>2.5</sub>) in the intra-urban area of Bari, Southern Italy, covering the period 2019-2022. Two complementary approaches were applied: the calculation of Population-Weighted Exposure Levels (PWEL) and a GIS-based risk assessment integrating population vulnerability and PM concentrations.

PWEL was calculated as the population-weighted average of PM concentrations, combining pollutant levels and resident population within each grid cell. High-resolution PM concentration maps were integrated with spatially distributed population data to characterize population exposure. The analysis considered both the total population and specific age groups, including children, adults and the elderly, allowing areas characterized by the co-occurrence of elevated PM concentrations and high population densities to be identified, providing a more realistic

representation of exposure and supporting targeted environmental health assessments and urban planning strategies.

In the GIS approach the methodology follows initially the ISPRA framework to define intrinsic vulnerability estimated for the same population groups, using contact rate, exposure frequency, exposure duration, body weight, and averaging time. Land use has been considered to evaluate also environmental vulnerability. PM concentrations were subsequently incorporated as the hazard component, and the combination of hazard, population vulnerability and land-use characteristics was used to derive spatially explicit exposure-risk indices for the different population groups. The resulting maps highlighted spatial and temporal variability in PM exposure risk. The highest risk values were generally associated with densely populated sectors characterized by higher PM concentrations. The lowest risk values were observed in 2020, coinciding with the period of COVID-19-related restrictions and the associated reduction in anthropogenic activities. Overall, the results demonstrate the value of combining population-weighted exposure indicators with GIS-based vulnerability and hazard assessment to characterize PM exposure and identify areas and population groups potentially requiring greater attention in environmental health assessment and urban air-quality management.

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***Bayesian spatio-temporal exposure modelling of air pollution in Rome, Italy, and short-term effects on cause-specific mortality***

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Assessing fine-scale spatio-temporal air pollution contrasts in urban contexts is a major challenge for environmental epidemiology. We present a Bayesian spatio-temporal model to predict daily concentrations of NO<sub>2</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> in Rome (Italy), over 2011-2022, on a fine grid scale (1 km), using data from 8 to 13 monitoring stations, depending on pollutant. The model specification includes meteorological (ERA5, ERA5-Land) and temporal (working day/weekend) fixed effects, together with a lag-1 autoregressive spatio-temporal random effect aimed at capturing spatial and daily dependence. Predictive accuracy was assessed by leave-one-site-out cross-validation: results showed good overall predictive performance, with larger errors at high-traffic sites. Estimated exposures were then linked to geolocated cause-specific mortality data for Rome (2012-2019), and a case-crossover time-stratified approach was adopted to investigate short-term effects. Results (mean lag 0-5) showed positive association with natural-cause mortality, percent increase in risk of 1.3 (95% CI: 0.6-2.0) for PM<sub>10</sub>, 2.1 for NO<sub>2</sub> (1.4-2.9), and 2.4 for PM<sub>2.5</sub> (1.4-3.3) per 10  $\mu\text{g}/\text{m}^3$  increase. To provide a comparison, corresponding estimates obtained using city-specific daily average exposure and an already validated RF model (Stafoggia et al., 2019) were of comparable magnitude. The proposed Bayesian spatio-temporal framework provides reliable fine-scale exposure estimates for epidemiological use, with results consistent across independent exposure estimates, supporting its application in urban air-pollution health studies.