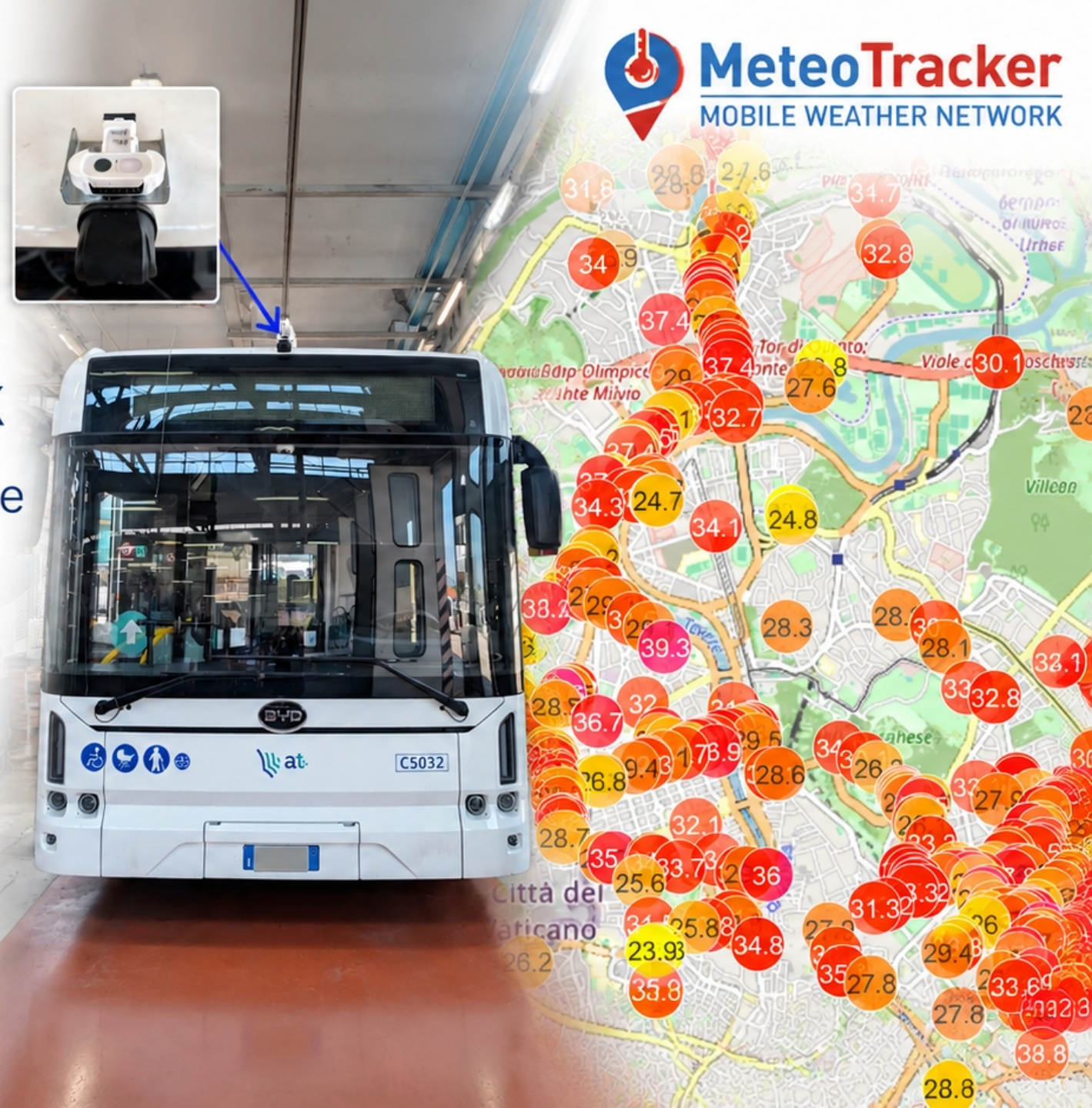
**SISC2026**
14th Annual Conference

Bolzano, Italy
2–4 November 2026

# City buses as a Mobile Weather Network

## Measuring urban climate at meter scale with MeteoTracker across urban environments

**Juri Iurato, Timoteo Galia**
IoTopon S.r.l. — MeteoTracker, Italy



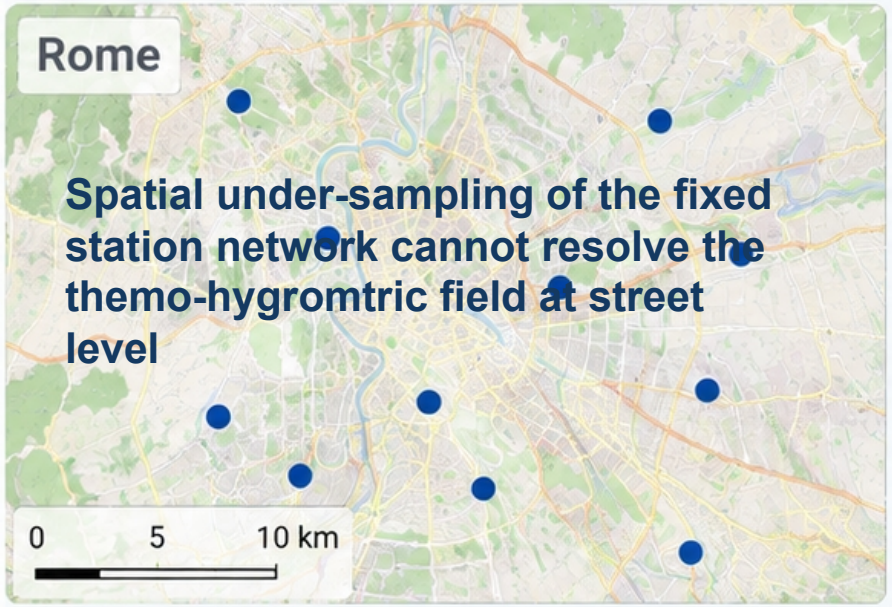
MeteoTracker
MOBILE WEATHER NETWORK

# The Urban Climate Observation Gap

Urban climate shows strong spatial variability at the scale of hundreds of meters, but traditional fixed networks provide only sparse measurements.

## Fixed meteorological stations

Sparse coverage at the urban scale




- Low spatial density (kilometer scale)
- Limited representation of intra-urban variability
- Often located in non-representative sites
- Not sufficient to capture local climate conditions

## The Observation Gap

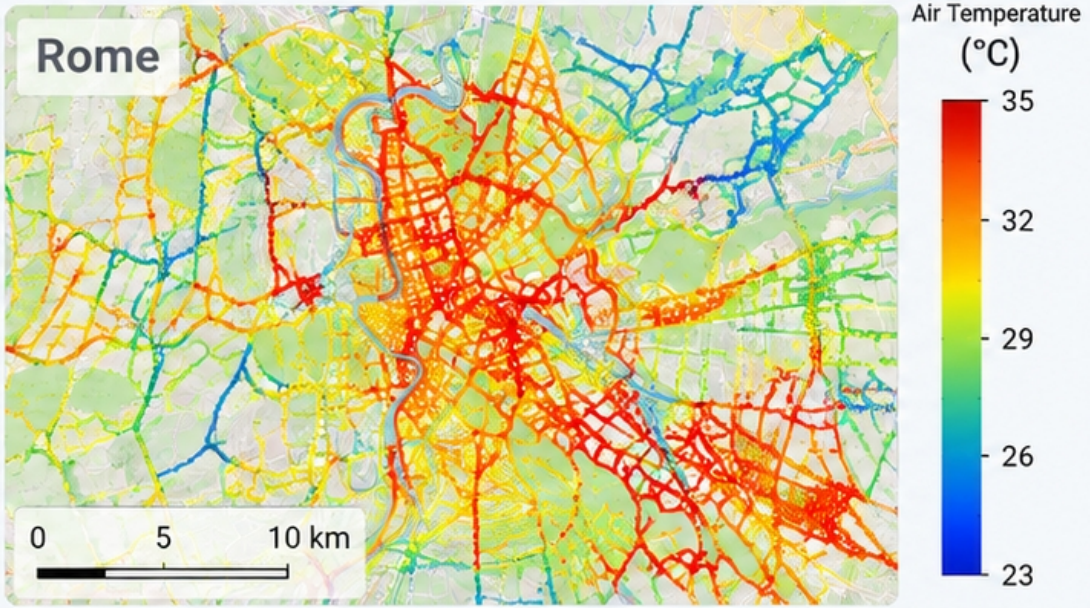
**High spatial variability**
(meters – hundreds of meters)

**vs.**

**Low observation density**
(kilometers)

## Urban temperature at meter scale

High spatial variability revealed by mobile observations




- Strong spatial variability at the neighborhood and street level
- Temperature differences of several degrees within short distances
- Influence of land use, morphology and urban infrastructure
- Revealed by high-resolution mobile observations with MeteoTracker

MeteoTracker
MOBILE WEATHER NETWORK

# City buses as a mobile weather network

## Turning existing public transport fleets into a high-density urban climate observation infrastructure.




Mobile sensing on an existing urban bus route

### Existing public transport fleet

Sensors installed on regular public transport buses.
No dedicated monitoring vehicles.

### Fully automated and complete HW and SW integration

Continuous data acquisition during normal service.
No driver involvement.
API and other data service

### Street-level observations

Georeferenced air temperature observations along bus routes at meter-scale spatial resolution.

**From public transport infrastructure to (opportunistic) urban climate infrastructure.**

MeteoTracker
MOBILE WEATHER NETWORK

# Measuring air temperature and humidity on moving vehicles

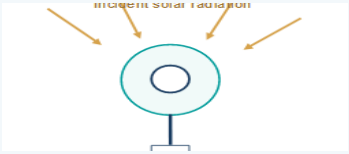
## High quality data collection is a complex matter: 4 key challenges

### 01 Fast Response



Resolving **sharp temperature changes** over short distances.

### 02 Solar Radiation Error correction



Accurate measurements **without** bulky radiation shields.

### 03 Speed Dependence removal




Preventing **airflow-induced bias** as vehicle speed changes (radiation vs convection dynamic equilibrium).

### 04 Easy & Safe Installation



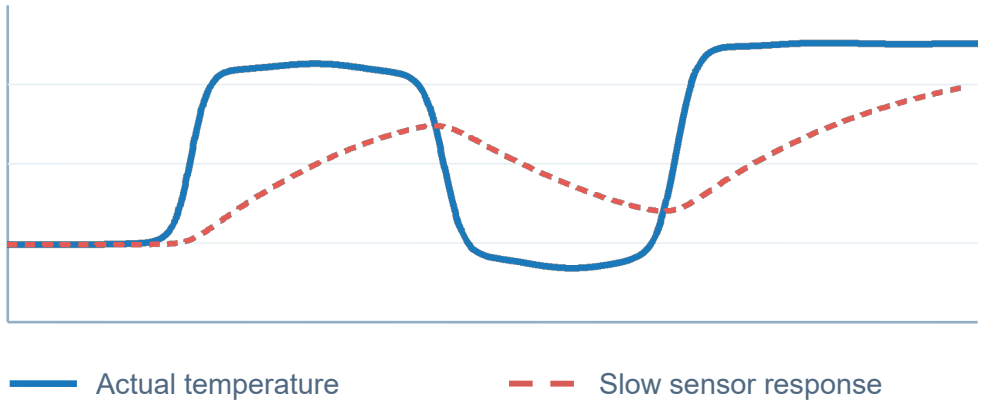
**Compact, lightweight device**; quick, secure mounting without invasive modifications.

**Reliable mobile measurements require accuracy under strong solar radiation exposure and changing conditions with compact, safe, easily deployable instrumentation.**

# Fast response and radiation error removal

## Fast thermal response

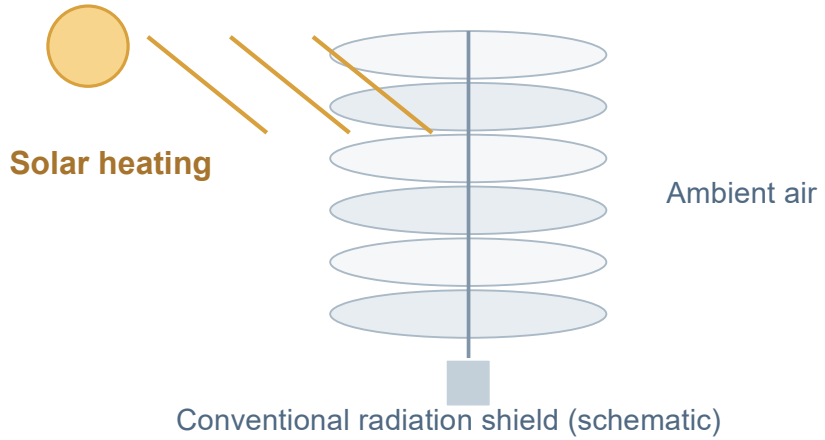
Air temperature may present strong spatial variation ratio along a moving transect




**Slow response introduces spatial smoothing and displacement of temperature features.**

## Solar radiation bias

Strong exposture to solar radiation




**Direct and diffuse solar radiation can heat the sensor above ambient air temperature. Conventional shielding not feasible for large-scale installations**

**Mobile measurements require both rapid thermal response and effective radiation-error correction in a compact device.**

MeteoTracker
MOBILE WEATHER NETWORK

# RECS: Radiation error correction, speed independence and compactness

How we addressed the 4 key point: the patented **Radiation Error Correction System** — compensating solar heating and airflow-dependent measurement bias while keeping high-speed measurement and compactness.

**Solar radiation**

Sensor heating

**Vehicle speed**

Convective action

**Raw measurement**

Radiation vs. convective equilibrium point Potential huge thermal bias

**RECS**
Radiation Error Correction System

**Radiation-error compensation and negative feedback**

against speed-dependent thermal bias




**Corrected air temperature**

**Effective correction of solar radiation errors and vehicle speed–induced measurement biases.**

RECS patents | US 11,525,745 B2 · EP 3645989 · JP 7198510

MeteoTracker
MOBILE WEATHER NETWORK

# MeteoTracker Standalone: fully automated data acquisition

Existing vehicles become autonomous, georeferenced meteorological sensing nodes.

## AUTOMATED ACQUISITION CHAIN

**MeteoTracker sensor**



Urban bus installation





**4G / GNSS**
Connectivity + position

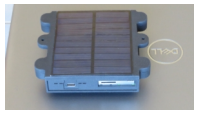
**Cloud platform**
Georeferenced data

**Movement-triggered · No driver interaction**

## OPERATIONAL CHARACTERISTICS

1. Compact temperature, RH and pressure sensor installed on the vehicle rooftop.
2. 4G/GNSS communication and geolocation unit.
3. Fully automatic acquisition triggered by vehicle movement.
4. Georeferenced measurements transmitted to the cloud.
5. No driver interaction or dedicated monitoring vehicles.
6. Software quality control: guard time after stops and autopause during stationary thermal transients.
7. Humidex index and other derived parameter automically computed and visualized on map
8. Additional optional IR (road temperature) and air quality sensors



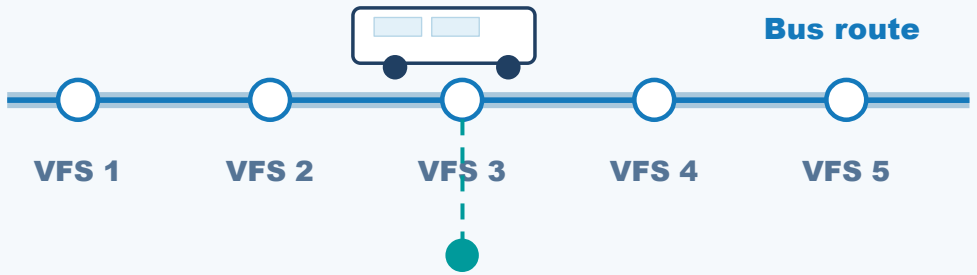


**Existing bus fleets become operational meteorological observation networks without changing their normal service.**

# Virtual Fixed Stations: turning mobile observations into fixed monitoring points

**A Virtual Fixed Station is a predefined georeferenced location along a bus route. Whenever an equipped vehicle passes sufficiently close to that location, its meteorological observation is associated with the corresponding virtual station.**

## FROM MOBILE TRANSECTS TO FIXED-LOCATION TIME SERIES




**EXAMPLE: VFS 3 Repeated observations at one location**




## HARDWARE AND SOFTWARE FULLY INTEGRATED

1. **API and Virtual Fixed Stations** (VFS): geo-fencing feature → predefined georeferenced locations along bus routes.
2. Meteorological observations associated with each VFS whenever an equipped bus passes nearby (one or more radius, user definde).
3. Repeated passages generate time series at each VFS → **spatial to time domain transformation**.
4. Enables **direct comparison** (time-serie) with conventional reference stations.
5. Combines mobile spatial coverage with fixed-point temporal observations.

**Repeated mobile measurements can provide time series at predefined locations, functioning as a distributed network of virtual stations.**

# The multiplication effect: spatial density and temporal continuity

Example scenario: 5 km segment · 30 km/h · 5-second sampling · 10-minute bus service headway.

| | |
|---|---|
| **10 min** | **Bus headway** |
| **~40 m** | **Sampling distance** |
| **120** | **Virtual Fixed Stations** |

## SPATIAL MULTIPLICATION

1. One equipped bus traversing the route produces approximately 120 observations in 10 minutes.
2. A fleet operating at 10-minute intervals can revisit the same VFS approximately every 10 minutes.
3. Over 14 hours of service, this corresponds to approximately 84 observations per VFS per day.
4. With 120 VFS distributed along the 5 km section, this corresponds to 84 × 120 = 10,080 observations per day within those 5 km.

## TEMPORAL CONTINUITY & NETWORK SCALE

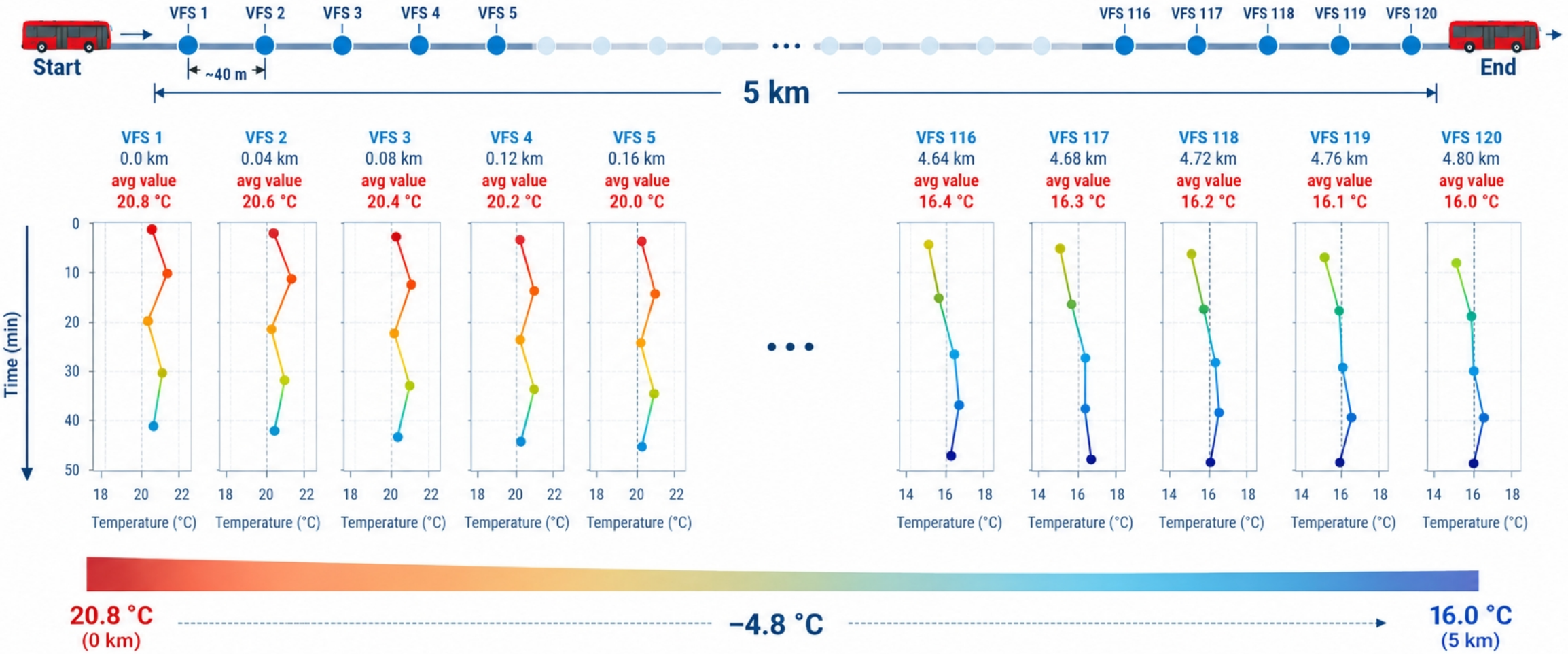
5. Considering the entire bus route, assuming a distance of 15 km between the two termini, this corresponds to 360 VFS, each collecting approximately 84 observations per day, for a total of 360 × 84 = 30,240 observations per day along the 15 km route.
6. Only 6–7 MeteoTracker-equipped buses are needed to ensure a 10-minute service headway along this 15 km route.
7. Considering also the return journey, the observation frequency at each VFS can increase significantly, further enhancing the temporal density of the monitoring network.

**A limited number of mobile sensors can generate both a dense spatial observation network and repeated temporal measurements across the urban environment.**

MeteoTracker
MOBILE WEATHER NETWORK

# SPATIAL MULTIPLICATION & TEMPORAL CONTINUITY

One bus traverse generates ~120 observations in 10 minutes (one every ~40 m) along a 5 km route.



# The multiplication effect: economic efficiency

A mobile observation network can achieve exceptionally high spatial density with a fraction of the hardware investment required by a conventional fixed-station network.

## METEOBUS NETWORK

**6 buses** — Equipped with MeteoTracker Standalone

**360 Virtual Fixed Stations · 15 km route**

~30,240 observations/day, one direction

**Installation & power** MeteoTracker on bus roof; 4G/GNSS modem inside. Rechargeable battery >1 year; accessory solar panel can extend autonomy.

## CONVENTIONAL FIXED NETWORK

**360 stations** — Shielded temperature and humidity sensors

**360 physical installation sites**

Continuous observations, including outside bus service hours

**Installation & power** Dedicated mounts and sites; theft/vandalism protection; mains or solar power.

## PRELIMINARY COST COMPARISON — ILLUSTRATIVE ASSUMPTIONS

| Parameter | MeteoBus network | Fixed network |
|---|---|---|
| Number of units | 6 | 360 |
| Assumed hardware cost per unit | €800 | €500 |
| **Total hardware investment** | **€4,800** | **€180,000** |
| Investment ratio | 1× | 37.5× |

Hardware-only comparison. Unit costs are illustrative and require validation. Installation, power supply, connectivity, maintenance and operating costs are not included.

# Operational MeteoBus networks in Bolzano, Rome, Genoa and Florence

## Operational deployments across distinct Italian urban environments

### BOLZANO (Eurac)

**25** MeteoBus

**Operational since 2022**

**Alpine valley-floor urban environment**

### ROME (ISAC-CNR | ATAC)

**20** MeteoBus

**27** Million observations

Operational since 2024

Scientific study published in Urban Climate (2026)

- https://app.meteotracker.com/html/teamMap/trams_roma?lat=41.851&lon=12.516&zoom=11&id=T0&idTimeMap=24

### GENOA (CIMA)

**6** MeteoBus

**24** Million observations

**Operational since 2024**

**Coastal urban environment**

### FLORENCE + other Tuscany cities (Uni Firenze – Autolinee Toscane)

**30** MeteoBus

**8** Million observations

**Operational since July 2026**

**River valley and urban interactions**

- https://app.meteotracker.com/html/teamMap/Genova_LIV_LAB_ICHANGE_PRJ?lat=44.450&lon=8.950&zoom=11&id=T0&idTimeMap=24
- https://app.meteotracker.com/html/myTeam/at?lat=43.558&lon=11.672&zoom=9&id=m10&idTimeMap=24

**81** METEOBUSES — **Across four Italian cities**

**MeteoTracker has been already deployed in operational public transport networks across many cities, enabling repeated, high-resolution meteorological observations under real urban conditions.**

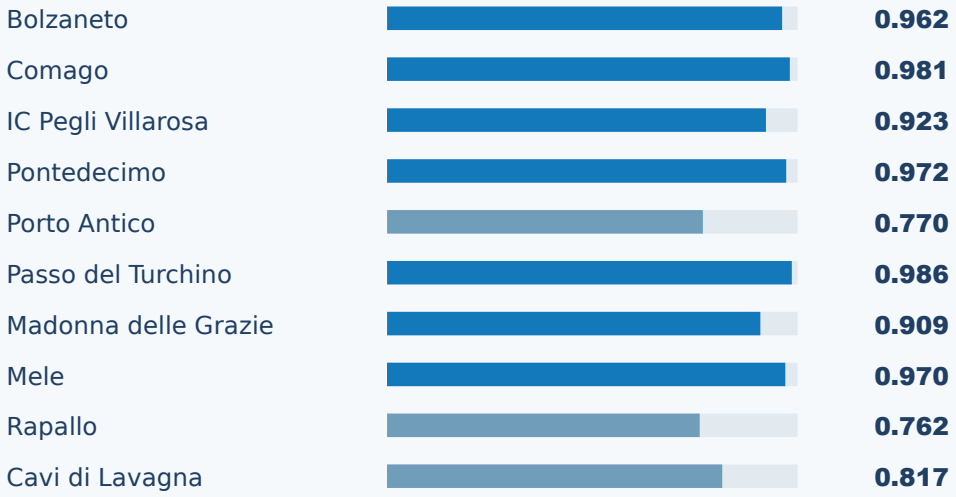
MeteoTracker
MOBILE WEATHER NETWORK

# Scientific validation through Virtual Fixed Stations

Scientific reliability of MeteoTracker mobile observations

## PUBLISHED VALIDATION RESULTS

MeteoTracker vs. official weather stations · Genoa




$R^2$ (coefficient of determination)

*Measured data · Loglisci et al. (2024), Table 1*

**1 Independent scientific validation**

Measurements compared with conventional meteorological reference stations.

**2 Excellent agreement**

Official ARPA station comparisons show strong correlations (Loglisci et al., 2024; Cecilia et al., 2026).

**3 Virtual Fixed Stations (VFS)**

Repeated observations at predefined locations enable local temperature time series and comparisons with fixed stations.

**4 Operational scientific application**

Rome MeteoBus observations underpin peer-reviewed urban climate research.

**5 Interpreting observed differences**

Spatial mismatch may contribute: fixed reference stations are not located exactly along the bus routes.

**SENSOR TYPICAL ACCURACY** Air T: ±0.1 °C | RH: ±1% RH

**High spatial observation density can be combined with scientifically validated temperature measurements.**

Loglisci et al. (2024), Sensors, 24(14), 4598; Cecilia et al. (2026), Urban Climate, 66, 102832.

# MeteoTracker in scientific literature

## Liang et al. (2026)

From Citizens to Satellites to Aircraft: Emerging Urban Climate Data Source s

*Climatic Change*

## Cecilia et al. (2026)

The Impact of Tree Canopy Cover and Imperviousness on Air Temperature i n Rome

*Urban Climate*

## Esbrí et al. (2025)

Implementing Citizen Science Activities for Climate Action: The I-CHANGE D ay

*Frontiers in Environmental Science*

## Koedel et al. (2024)

Enhancing Citizen Science Impact in Environmental Monitoring

*Frontiers in Environmental Science*

## Zanetti et al. (2024)

Bridging the Gap: Matching Mobile Sensors and Satellite Data for UHI Rese arch

*ISPRS Archives*

## Loglisci et al. (2024)

Validation of Citizen Science Meteorological Data

*Sensors*

## Barbano et al. (2024)

Performance Evaluation of MeteoTracker Mobile Sensor for Outdoor Applica tions

*Atmospheric Measurement Techniques*

## Zanetti et al. (2023)

Volunteered Geographic Information for Mapping Urban Climate and Air Qua lity

*ISPRS Archives*

## Cecilia & Peng (2022)

Validating a Cycle-Based IoT Sensor for Mapping Intra-Urban Air Temperatur e and Humidity

*PLEA 2022*

MeteoTracker
MOBILE WEATHER NETWORK

# Urban thermal variability at meter scale: Rome MeteoBus network

The impact of tree canopy cover and imperviousness on air temperature during summer using low cost sensors on public transportation in Rome, Italy
Cecilia et al. (2026), Urban Climate 66, 102832

**MOBILE OBSERVATIONS**

## 1.8 million

Collected over 60 summer days
from instrumented public buses

**NIGHTTIME UHI**

## 3–4 °C

Urban–nonurban contrast
associated with imperviousness

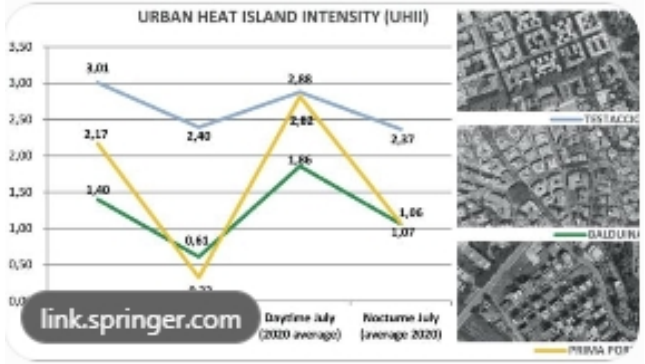
**MORNING TREE-CANOPY EFFECT**

## up to 0.7 °C

Observed cooling at 40% canopy cover
Potential: 1.6 °C at 100% (extrapolated)

### WHAT HIGH-DENSITY MOBILE OBSERVATIONS REVEAL

- Localized hot and cool spots across heterogeneous urban environments
- Sharp spatial transitions linked to vegetation, built surfaces and street morphology
- Day–night differences in the drivers of urban thermal variability



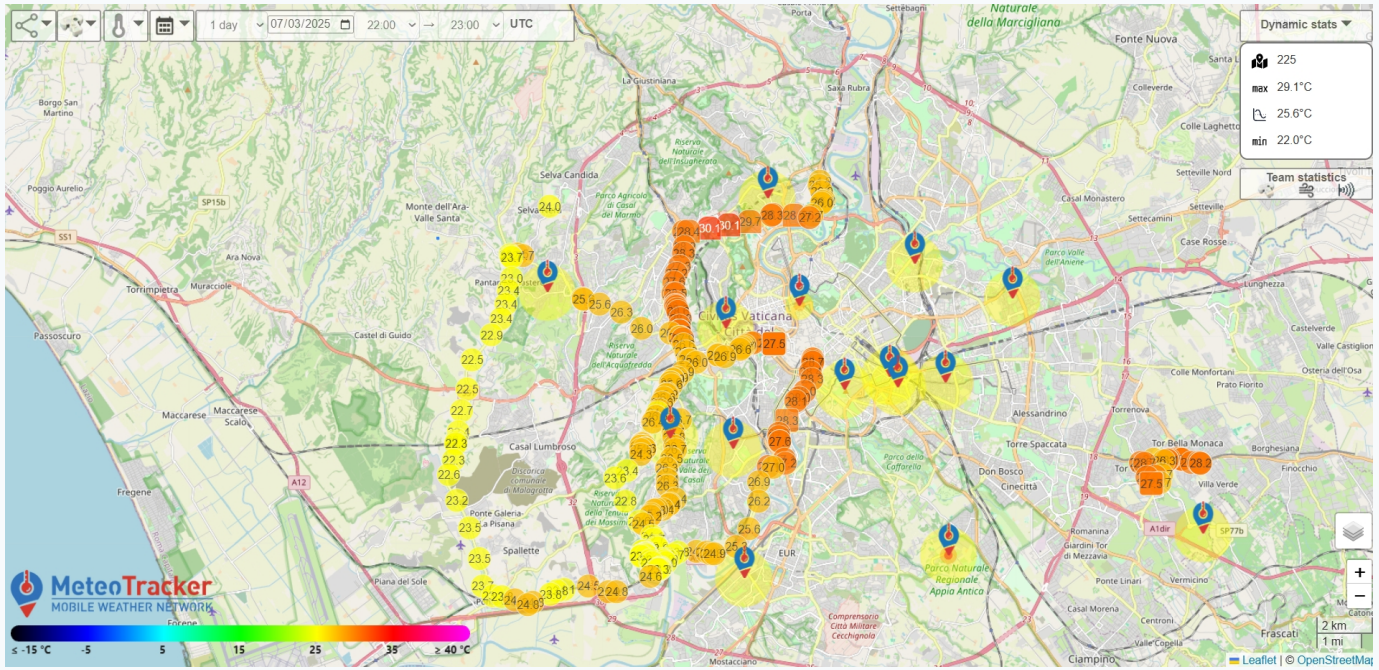

**OBSERVATION SPACING: METERS | PUBLISHED SPATIAL ANALYSIS: 500 m GRID**

**Mobile observations reveal fine-scale variability beyond conventional fixed-station coverage.**

# Rome: example of urban heat island quantification by the MeteoBus network

## MeteoTracker mobile observations | July 3rd 2025, 22-23 PM

### MOBILE OBSERVATIONS ACROSS ROME




### TEMPERATURE ALONG A MOBILE TRANSECT




### OBSERVED TEMPERATURE DIFFERENCE DUE TO UHI

**7.1 °C** 22.0–29.1 °C in a few km

## Strong temperature contrasts emerge across different urban areas during evening mobile monitoring

https://app.meteotracker.com/html/teamMap/trams_roma?lat=41.891&lon=12.465&zoom=12&id=T0&date=2025-07-03&timeFrom=22&timeTo=23

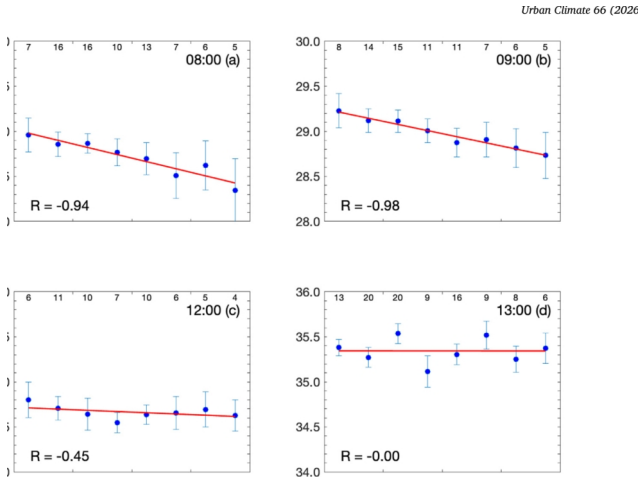
# Vegetation, impervious surfaces and urban morphology

Rome MeteoBus network | Observed effects of urban surface characteristics

## TREE CANOPY COVER · FIG. 7



Tree-lined urban streets

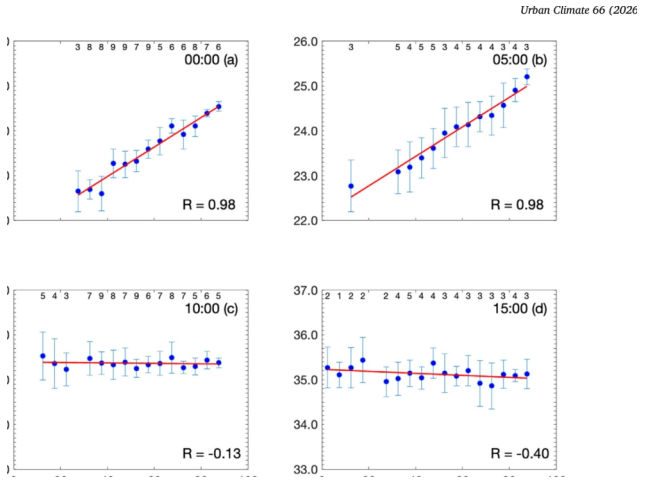



Early morning (08:00–09:00): significant cooling associated with tree cover; the signal weakens after sea-breeze onset.

## IMPERVIOUS SURFACES · FIG. 8



Asphalt, concrete and buildings




Night (00:00–05:00): strong positive association with imperviousness (R = 0.98), corresponding to 3.3–3.6 °C.

**LOCAL SURFACE EFFECTS ARE TIME-DEPENDENT AND MODULATED BY MESOSCALE CIRCULATION**

The impact of tree canopy cover and imperviousness on air temperature during summer using low cost sensors on public transportation in Rome, Italy — Cecilia et al. (2026), Urban Climate 66, 102832

MeteoTracker
MOBILE WEATHER NETWORK

# Scaling up: From individual routes to city-wide monitoring

From individual bus routes to a distributed urban observation infrastructure

01

## FLEET-WIDE DEPLOYMENT

Equip buses across multiple lines with fully automated MeteoTracker Standalone sensors.

BUS ROUTES

02

## SPACE–TIME COVERAGE

Select complementary routes and overlapping services to maximize spatial coverage and ensure temporal continuity through repeated vehicle passages.

MOBILE OBSERVATIONS

03

## INTEGRATED NETWORK

Combine dense mobile measurements with continuous observations from fixed stations.

CITY-WIDE NETWORK

**SCALABLE BY DESIGN** **More equipped vehicles → broader coverage, with no dedicated routes or driver involvement.**

**An existing public transport fleet can become a scalable, city-wide meteorological observation infrastructure.**

MeteoTracker
MOBILE WEATHER NETWORK

# From high-resolution observations to urban climate services

Turning dense observations into actionable climate information

### URBAN ATMOSPHERIC MODELLING

Model validation, data assimilation and improved representation of fine-scale urban thermal variability.

SCIENTIFIC MODELLING

### REAL-TIME MONITORING & ALERTS

Detection of localized thermal anomalies and development of high-resolution heat-risk monitoring and warning services.

OPERATIONAL MONITORING

### URBAN PLANNING & ADAPTATION

Identifying priority areas, supporting adaptation strategies and evaluating the effects of urban interventions.

CLIMATE ADAPTATION

**FROM DATA TO VALUE** **High-density mobile observations complement fixed stations and support new urban climate applications.**

**The same MeteoBus network can support scientific research and enable operational urban climate services.**

MeteoTracker
MOBILE WEATHER NETWORK

# Conclusions & key takeaways

MeteoBus: transforming existing transport infrastructure into a high-density urban climate observation network

### 01 RELIABLE MOBILE MEASUREMENTS

Purpose-built, scientifically validated sensing technology addresses key challenges of measuring air temperature on moving vehicles.

### 02 HIGH-DENSITY OBSERVATIONS

Existing bus fleets enable widespread, systematic observations with meter-scale spatial sampling.

### 03 MULTIPLICATION EFFECT

Mobile sensors provide repeated observations at hundreds of Virtual Fixed Stations, reducing fixed-sensor hardware needs.

### 04 SCIENTIFIC EVIDENCE

Operational deployments and peer-reviewed research demonstrate the scientific value of fine-scale urban climate observations.

### 05 CLIMATE ADAPTATION

A dense observational foundation for urban modelling, real-time monitoring, planning and adaptation services.

**THE TAKE-HOME MESSAGE**

**MeteoBus networks enable an unprecedented volume and spatial density of meteorological observations, opening a new dimension in measuring and understanding urban micrometeorology at street level**

# Collaborations, partners & contacts

MeteoTracker urban monitoring networks and scientific applications are developed and deployed in collaboration with:

- **EURAC Research**
- **CIMA Foundation — Ing. Antonio Parodi**
- **CNR-ISAC — Prof. Stefania Argentini**
- **ATAC — Roma Capitale**
- **GeoLab — University of Florence — Prof. Gherardo Chirici**
- **Autolinee Toscane**

## CONTACTS

**IoTopon srl | MeteoTracker** **www.meteotracker.com** **info@meteotracker.com**