Urban traffic and air pollutant emissions: a complex relationship

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Integreen Workshop

Ing. Gianluca Antonacci, Ph.D.,
Ing. Gianluca Vignoli, Ph.D.
CISMA srl, Bolzano / Bozen - Italy
Email: gianluca.antonacci@cisma.bz.it
gianluca.vignoli@cisma.bz.it

Summary

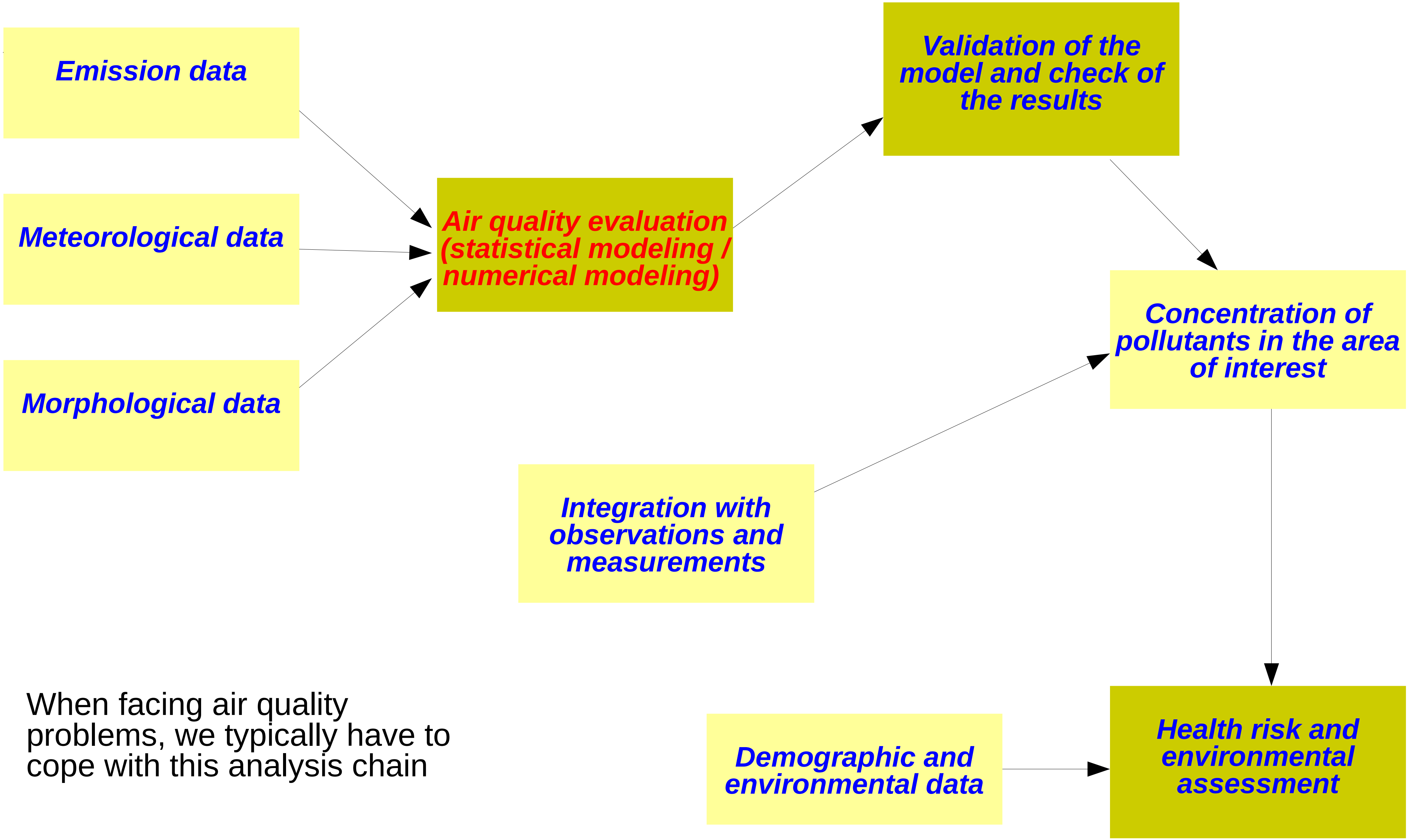
1. General aspects on air pollution analysis

2. Urban area analysis of traffic induced pollution: a case study facing the methodological aspects

3. Performing mobile measurements to get an enhanced overview of street-level emissions: our experience

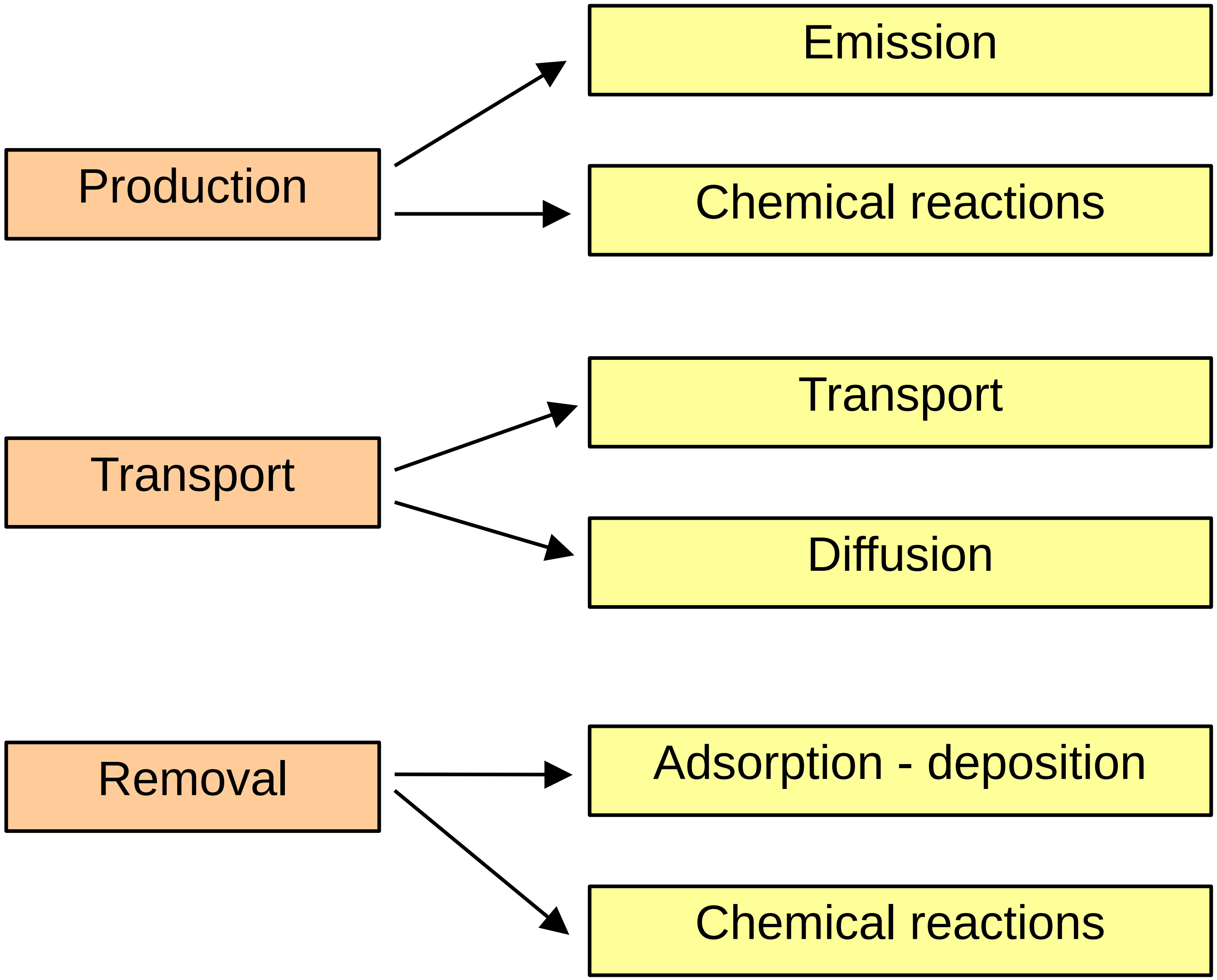
General aspects on air pollution analysis

Air quality analysis chain



When facing air quality problems, we typically have to cope with this analysis chain

Role of the chemical-physical processes



These pollutants are normally taken in air quality assessment in urban areas:

- Carbon monoxide (CO)
- Nitrogen oxides (NO_x)
- Hydrocarbon (HC)
- Ozone (O_3)
- Sulfur oxide (SO_x)
- Heavy metals (Pb, Cd, Hg, ...)
- Dioxins and furans (PCDD/F)
- Particulate matter (PM)

- Carbon dioxide (CO_2) -> greenhouse gas

How to chose the suitable approach

The optimal approach should be chosen according to:

1) **aim of the study**

   a) short term estimate for rapid response

   b) long term study to determine the environmental effects and planning

2) **characteristics of the study**

   a) spatial scale: micro-scale, local scale, regional scale, large scale

   b) temporal scale: short term (hours-->days), long term (months-->years), estimate

   c) ground characteristics: flat uniform terrain, complex orography

   d) source type: point, line, area

   e) pollutant type: non-reactive, reactive (i.e. secondary pollutants)

Input/Output data in air quality studies

Input data

Site characteristics:
- Digital elevation model
- land use (-> roughness, water content)

Meteorology:
- wind speed and direction
- temperature
- pressure
- relative humidity
- solar gloabal and net radiation
- heat fluxes

Emissions:
- flow rate
- concentration
- temperature
- exit velocity (where needed)

Output data

Pollution:
- concentrations of air pollutants
- deposion rates
- time series

Meteorological data

- Wind speed and direction near ground level are needed to reconstruct the wind field (for example needed by air quality numerical models) or for statistical analyses

- Temperature, humidity, pressure, solar radiation are used to determine the parameter of atmospheric stability in an indirect manner, at least if no sophisticated measures of atmospheric turbulence are available

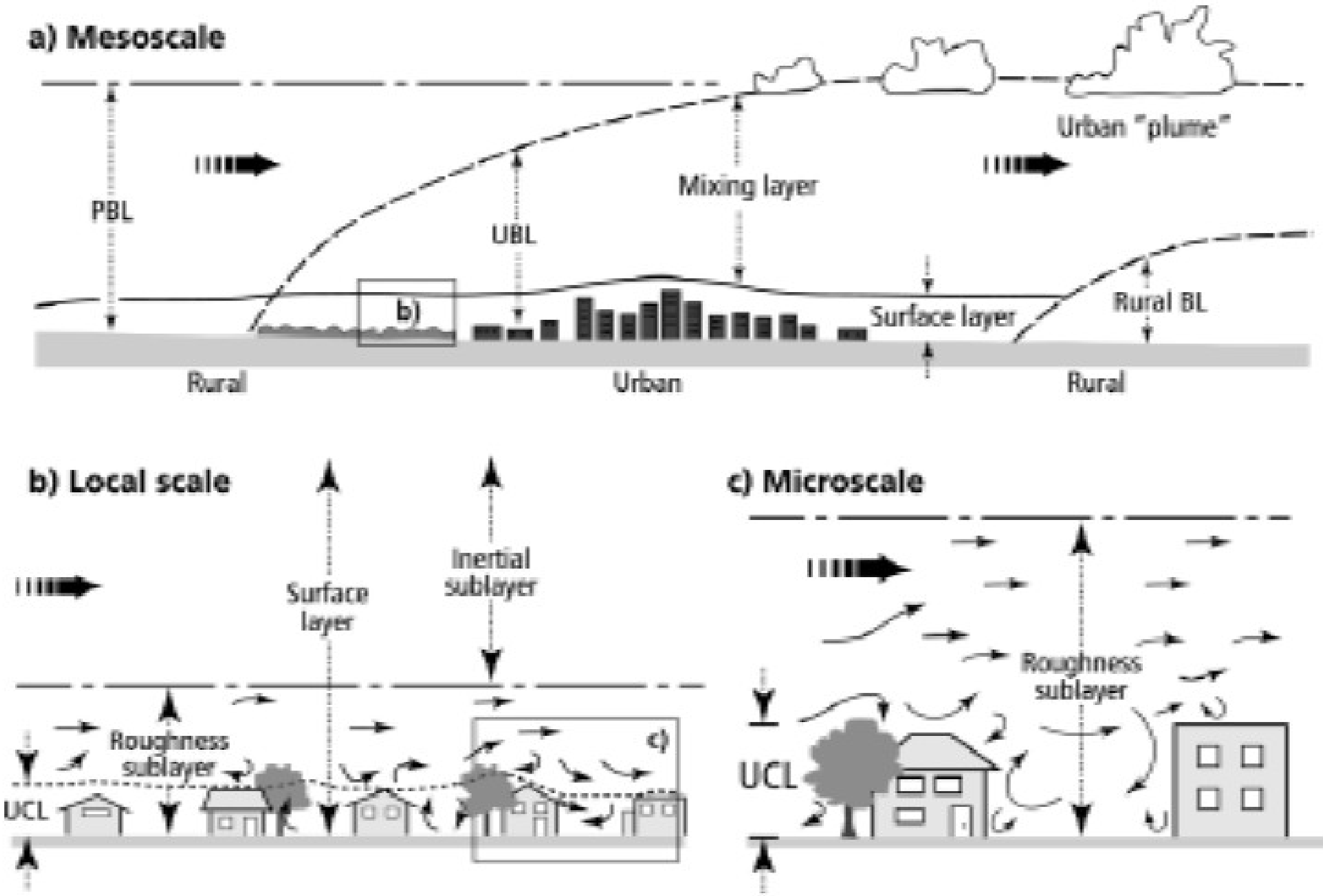
Atmospheric turbulence (also indicated through the parameter "stability") indicates the degree of turbulent kinetic energy of an air mass due to solar forcing; in other words represents the diluition capability of the air volume. Atmospheric turbulence vary of more than one order of magnitude at ground level, so its effects are not negligible in evaluating pollutant dispersion. When adressing street-level dispersion processes (inside the urban canopy), mechanical turbulence can rise to the same order of magnitude of heat induced turbulence and even more.

↓

Meteorological data cannot be neglected when assessing air pollution

Spatial scales (1)

Data analyses should emphasize the distinction between those values induced by local characteristics (e.g. urban canopy) and those influenced by large spatial scale meteorological conditions.

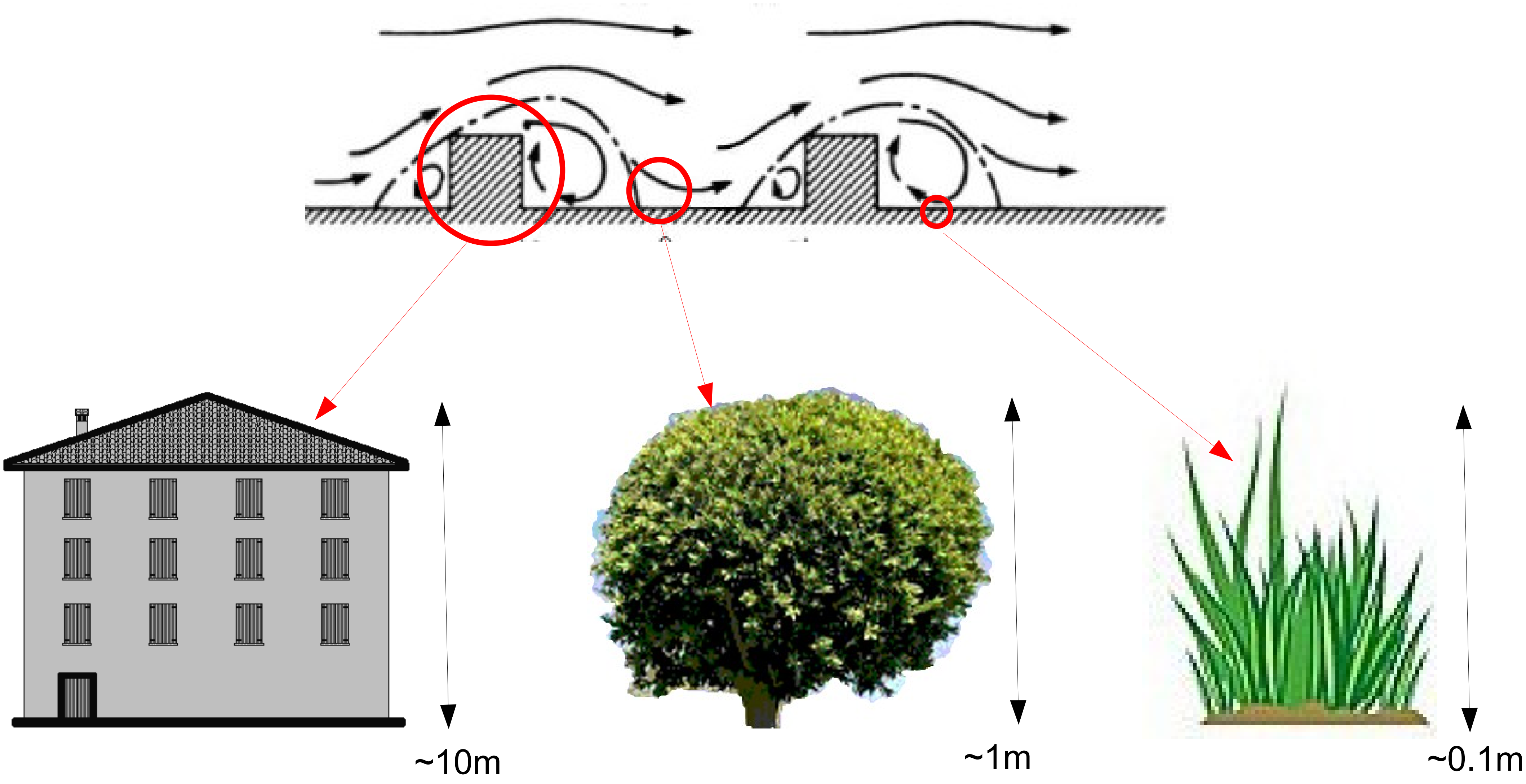


Topographical complexity influences air pollution at different scales

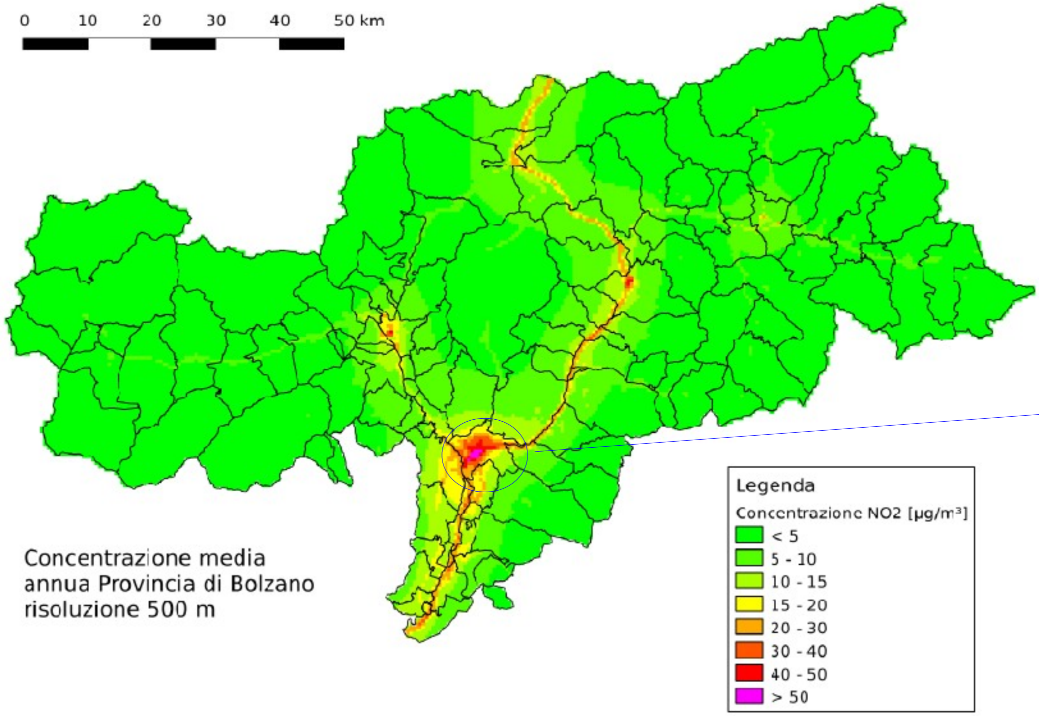
Choice of the correct scale and of the correct tool (the analysis should be projected correctly)

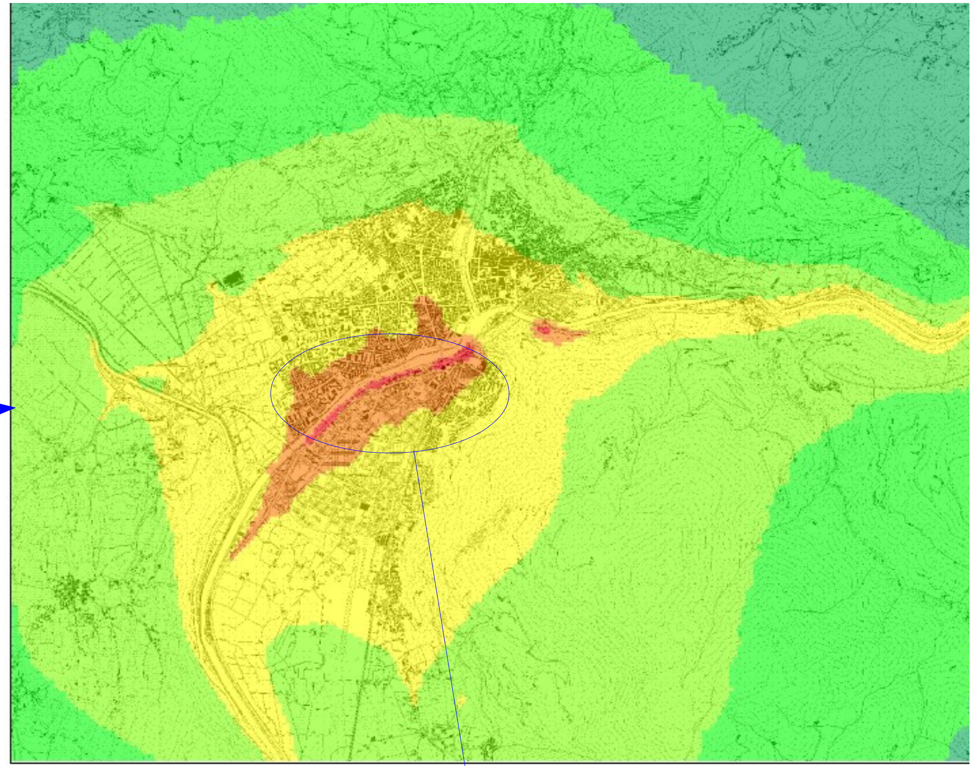
Spatial scales (2)

Pollutants dispersion is a multiscale problem; after choosing the right scale we are interested in, the suitable schematizations can be done. In the case of urban air pollution the smaller (nowadays practically feasible) suitable scale is of the order of the street width.

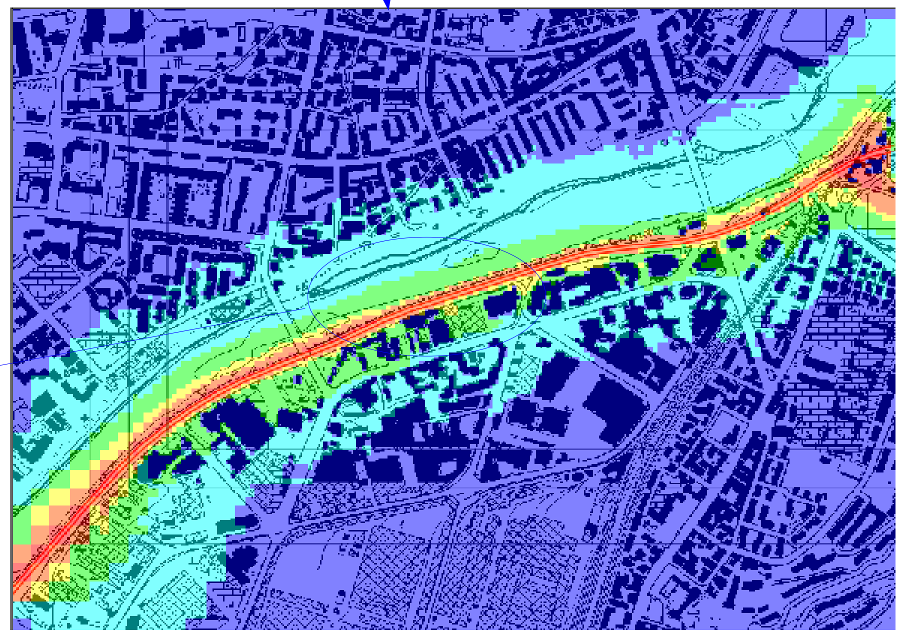


Spatial scales (3)

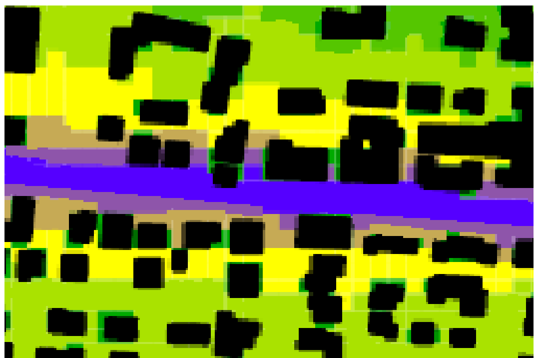




NO2 annual average concentration at different scales: Southtyrol province → town of Bolzano → highway → street-level detail



Beware: <u>*different models, evaluation models, input data, algorithm implementations, details*</u>, are needed when downscaling the problem



Direct air quality measurements and mathematical models

Direct measurements can be coupled with mathematical modelling in order to spatially enhance results.

Best results are achievable through merging of these two techniques. Generally measurements are done in fixed points.

Doing mobile measurements can also enhance results, but additional problems arise:

- instrumentation problems, which should be adressed from the hardware point of view

- post-processing, because cross-correlation of emission and immission has to be calculated both in space and time; doing a "lagrangian" measurement as in mobile sampling introduces a further variable with respect to fixed “eulerian” measurement

Measurements meaningfulness

- When thinking in terms of fixed air quality monitoring points (AQ stations), their density, or the spatial resolution of the observed data, are linked to both the space-time scale of the phenomenon under examination

- An observation of emission (e.g. traffic, industrial, domestic heating), weather and air quality should be accompanied by the assessment of its spatial representativeness (a certain area according to the needed application).

- The “exposure” of a certain monitoring station to pollution sources is a valuable information for get correct interpretation of data. For example a monitory station near a busy junction is mostly influenced by local traffic and is meaningful of a smaller area, than a background station with no dominant source nearby.

- That's why standards are important to identify traffic AQ stations, urban background AQ stations, rural background AQ stations, industrial area AQ stations...

Urban area analysis of traffic induced pollution: a case study facing the methodological aspects

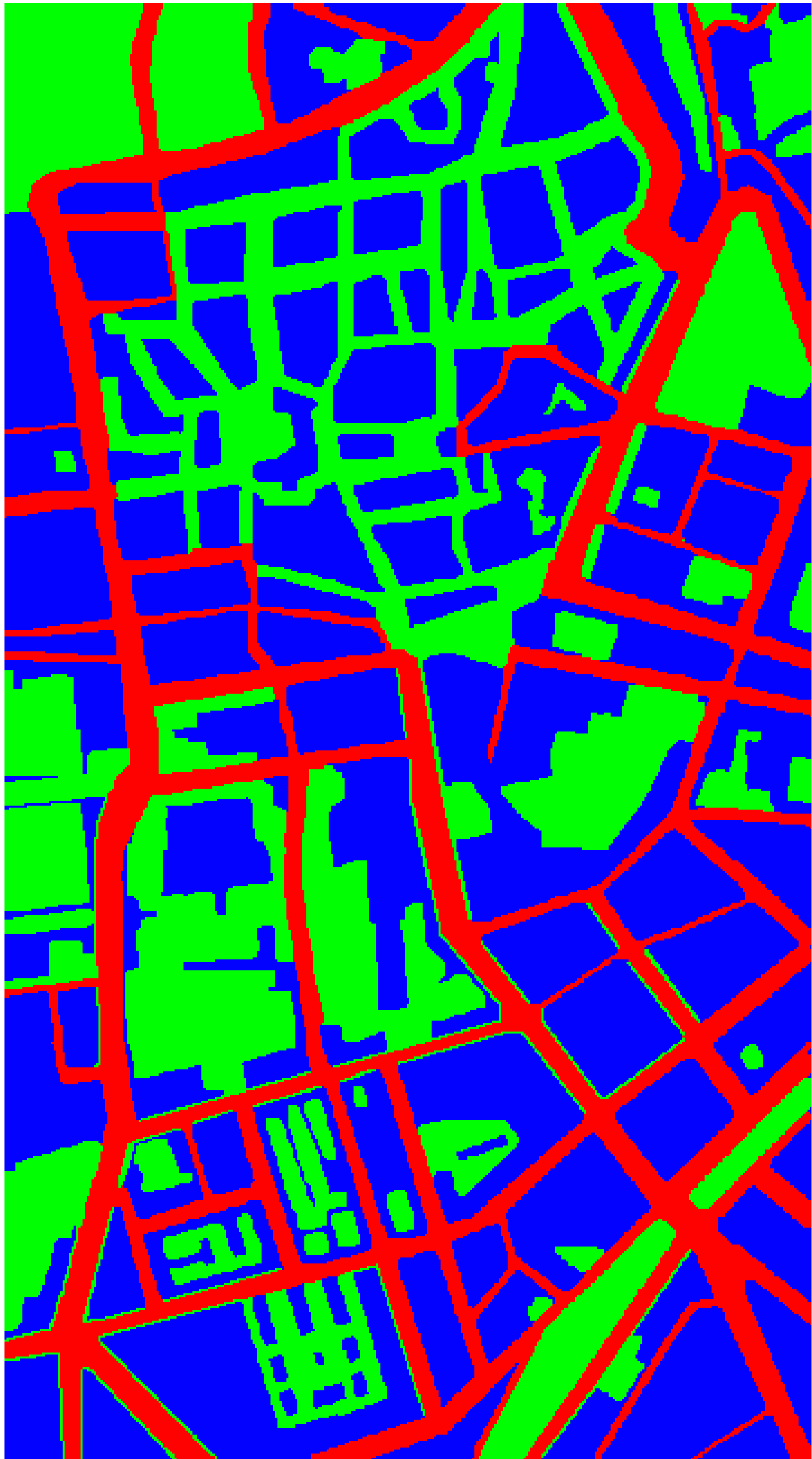
Urban scale modeling: application to the town of Trento

Buildings

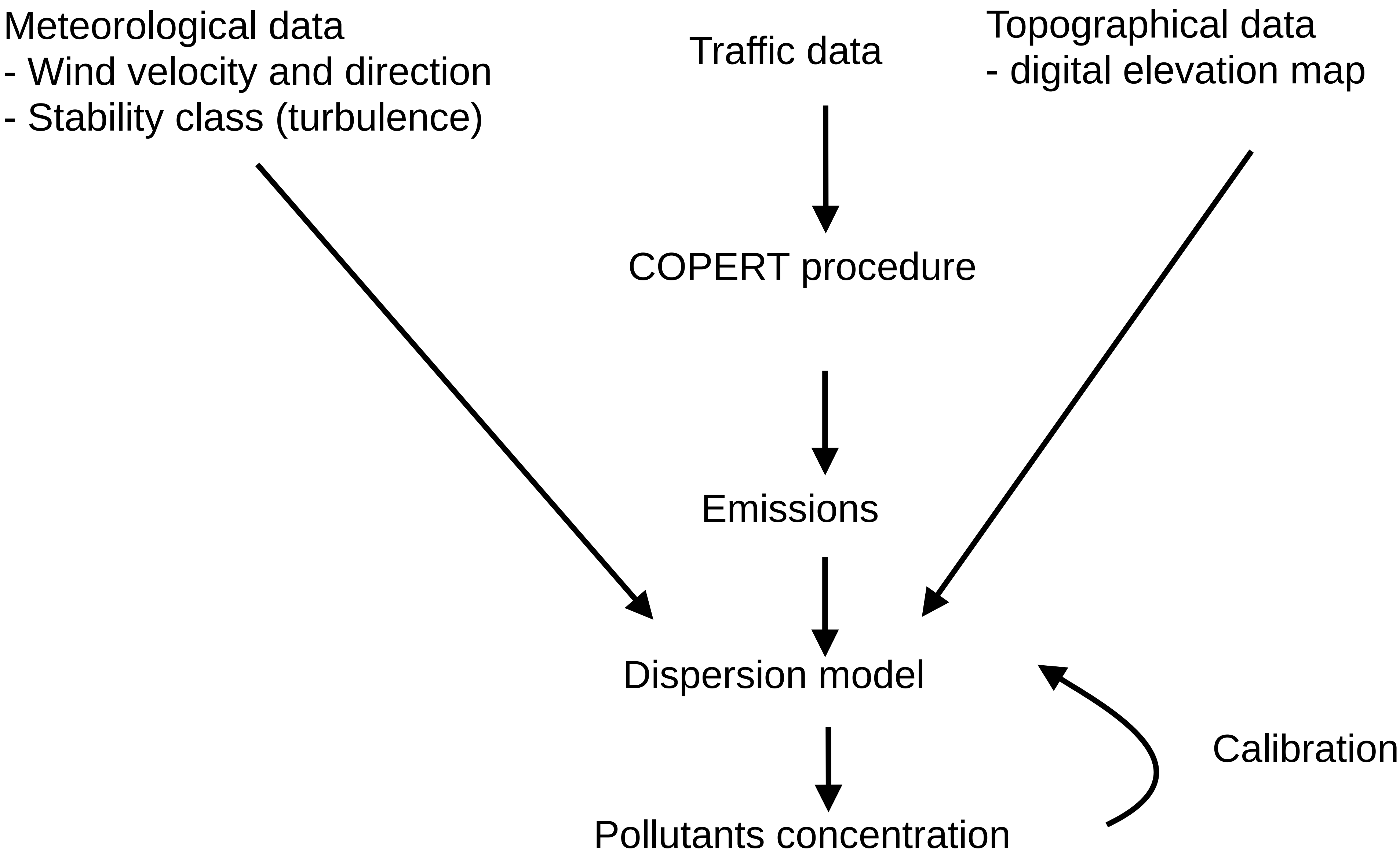
Roads

Open areas or roads without traffic

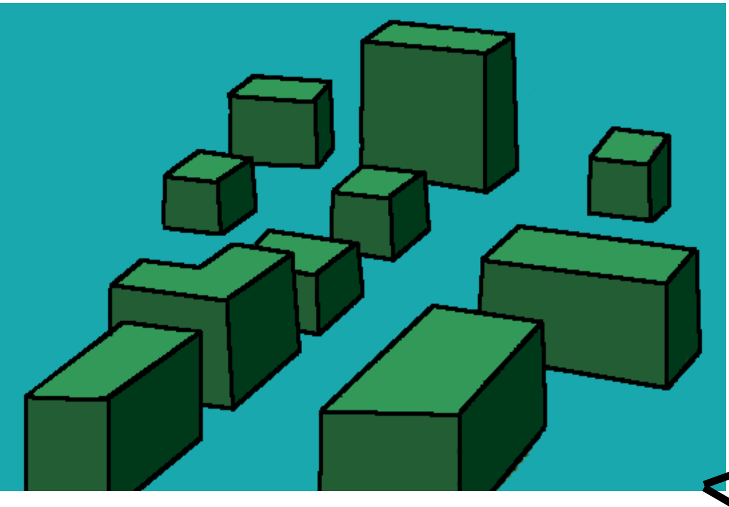
A methodological local scale case study performed in 2004, aimed at investigating data prerequisites

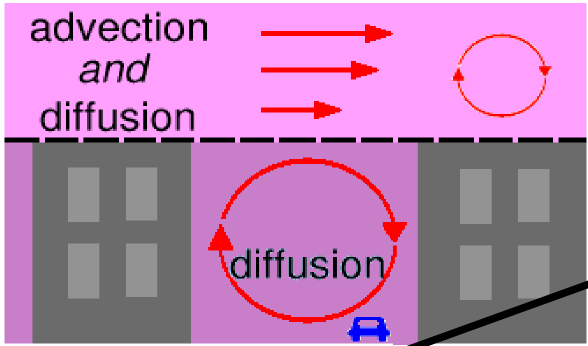


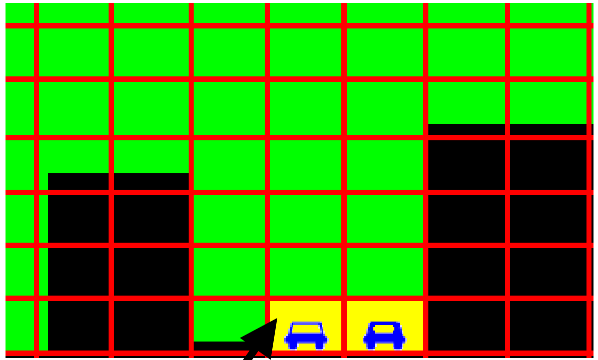
Dispersion in urban area: procedure



Urban scale modelling

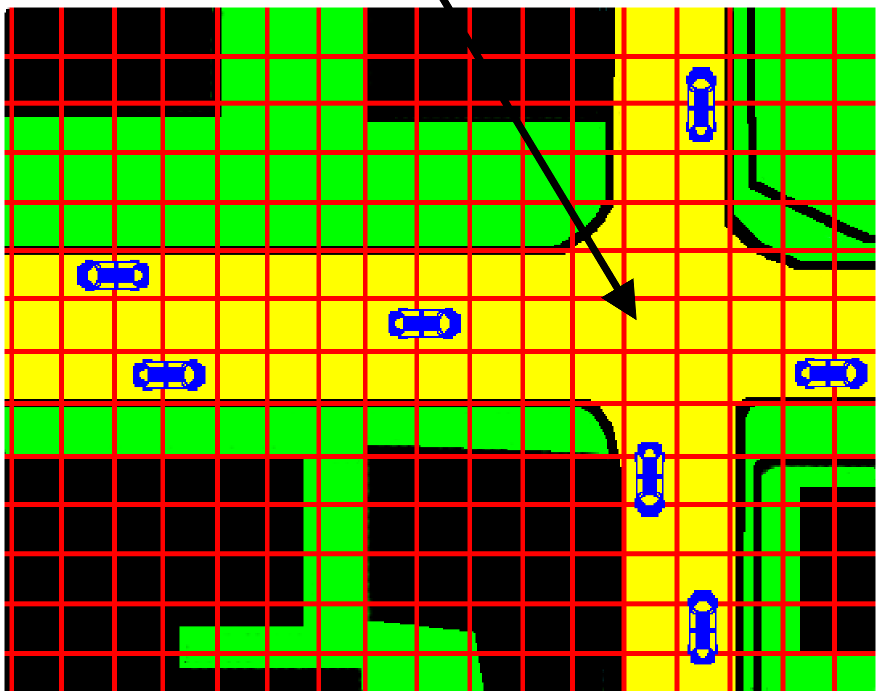






Analysis of the **dispersion processes** is essential to obtain concentration from emission data

Emission cells



Computational grid derived from DEM; there are 3 different cell types:

- Cells with a positive source term (roads)
- Cells that belong to the domain but do not have emissions (parks, parking areas, pavements, areas without traffic)
- Cells that do not belong to domain (buildings)

- Source type influences ground level impact: linear sources as street-level traffic induce spatially limited area significant impact (order of magnitude of significant level: tenths to hundreds of meters, depending on source strength)

Emission estimates

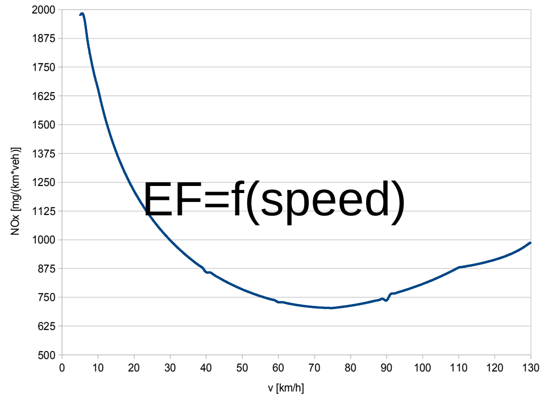
Fuel Variables
- consumption
- specifications per fuel type

Activity Data
- number of vehicles per vehicle category
- distribution of vehicles into different exhaust emission legislation classes
- mileage per vehicle class

Driving Conditions
- average speed per vehicle type

Other Variables
- climatic conditions
- mean trip distance
- evaporation distribution

COPERT procedure, as Adopted by European Environmental Agency

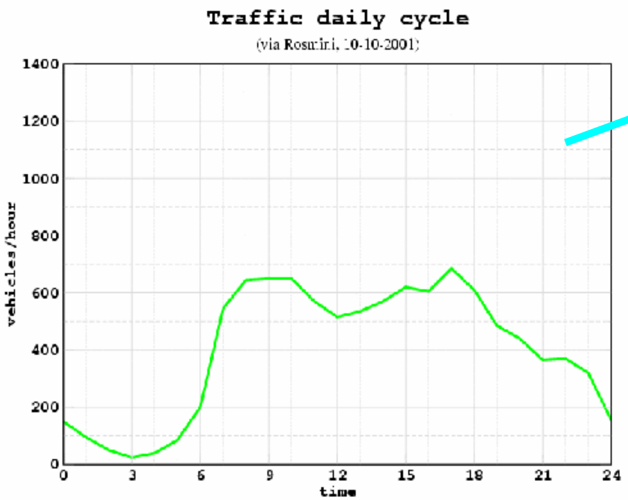


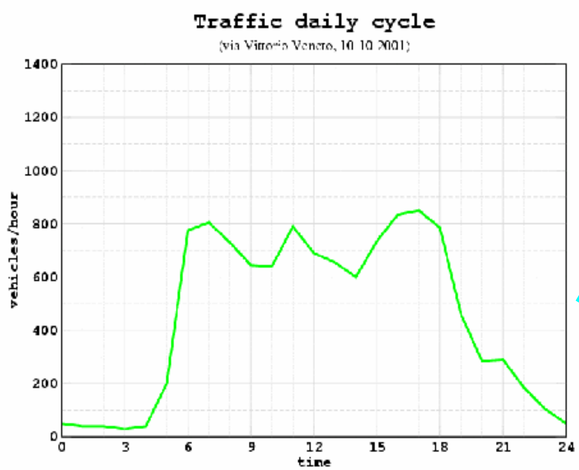
Emission Factors
- per type of emission (hot, cold, evaporation)
- per vehicle class
- per road class

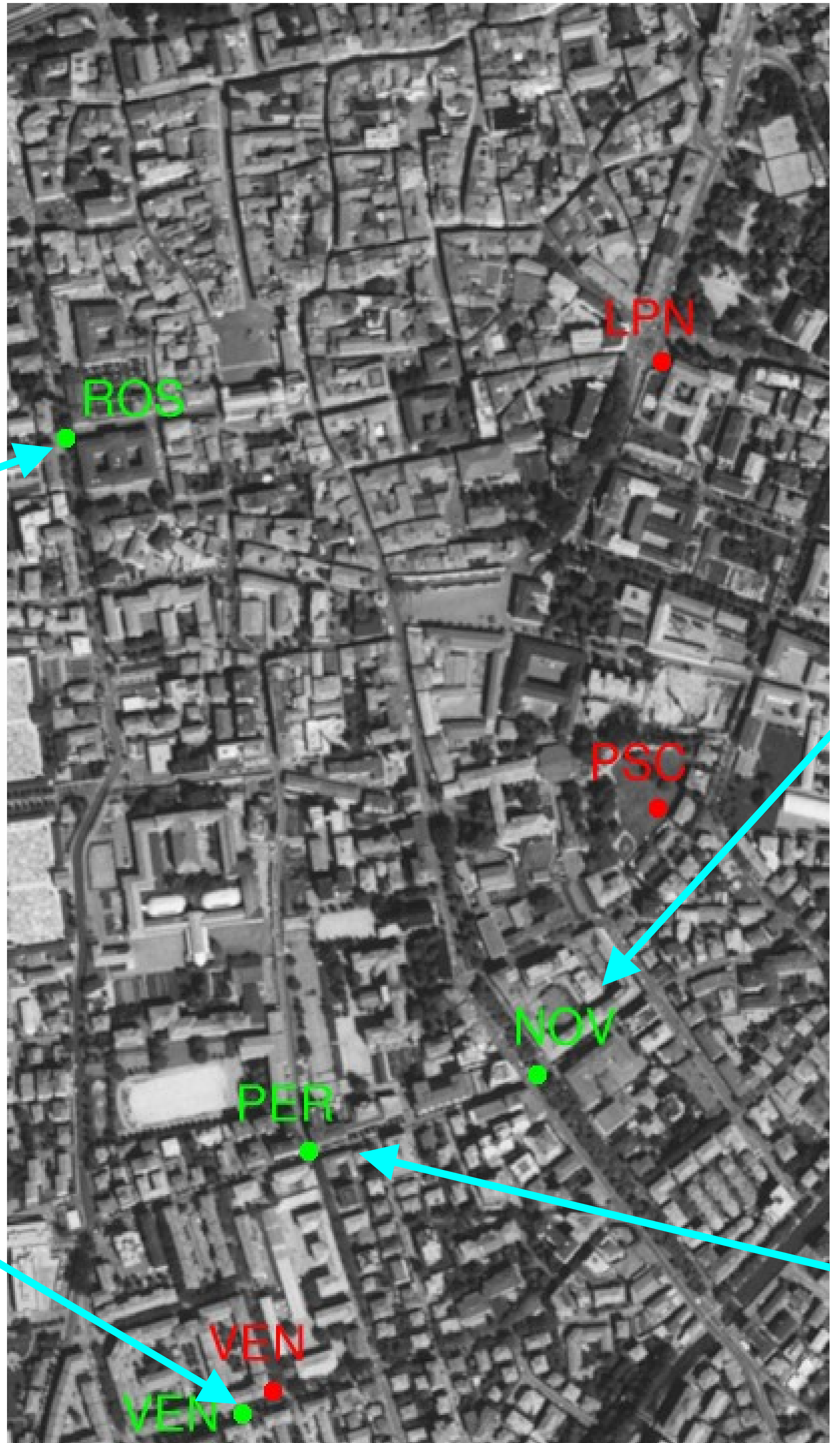
Traffic & air quality monitoring data

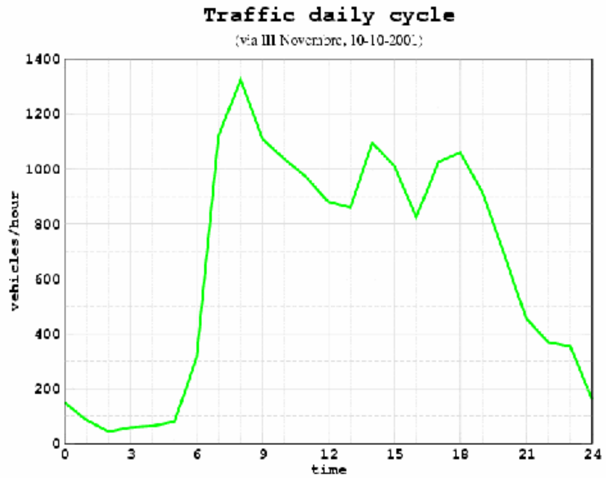
o = AQ monitoring

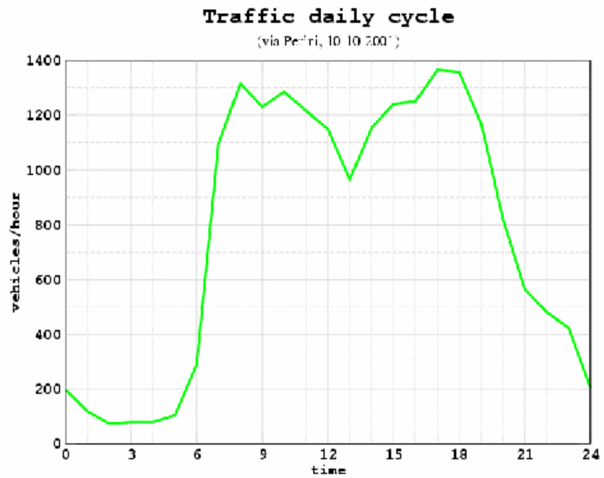
o = Traffic monitoring





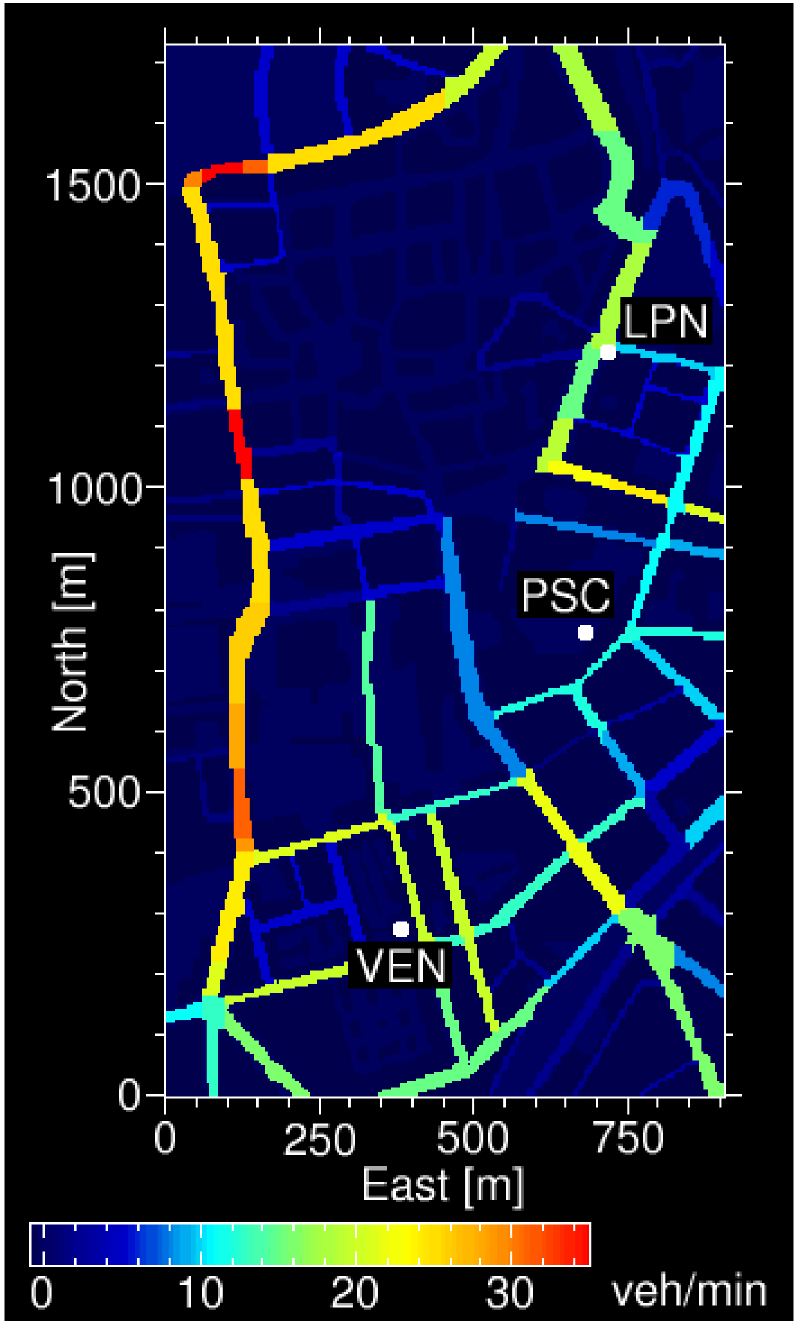






Traffic monitoring

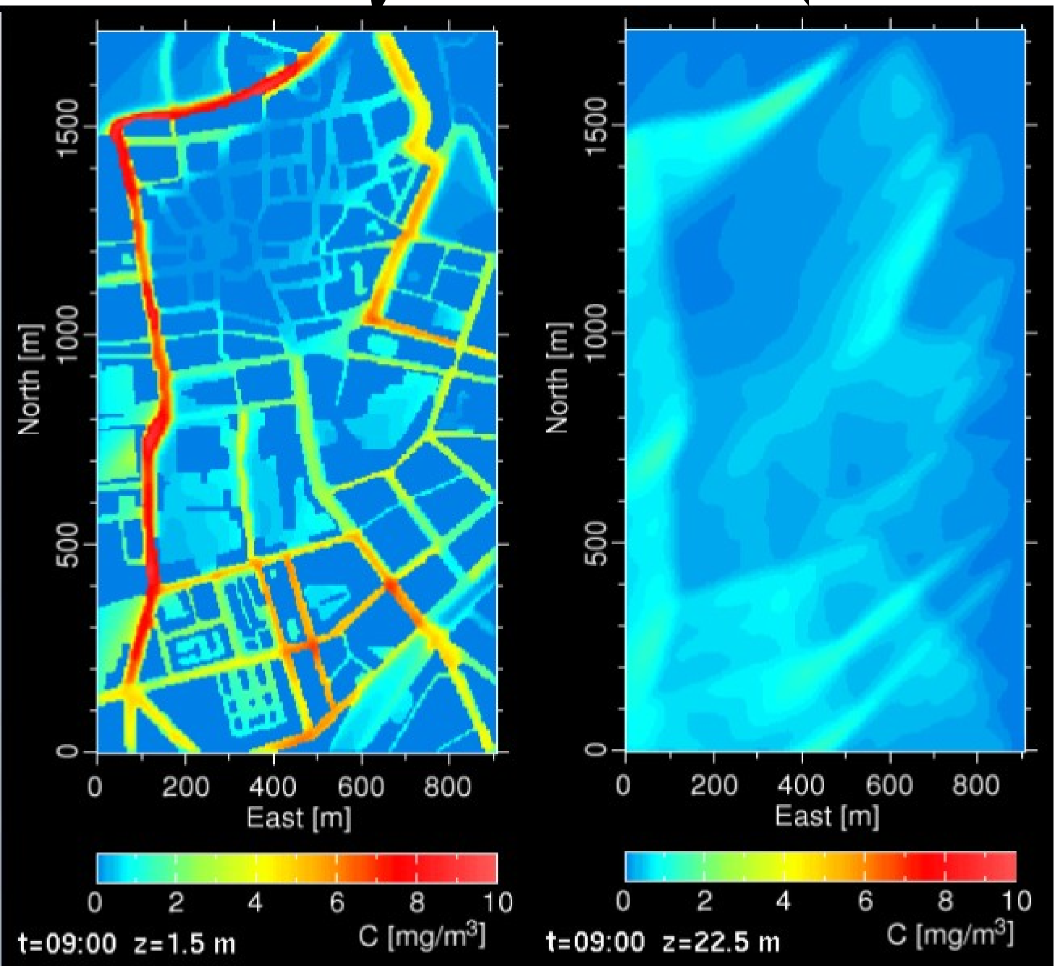
Traffic data with 5' temporal resolution in about 100 road segments; by means of COPERT methodology it was possible to estimate emission (attention: emission is an estimate, the direct measurement consists of traffic data)



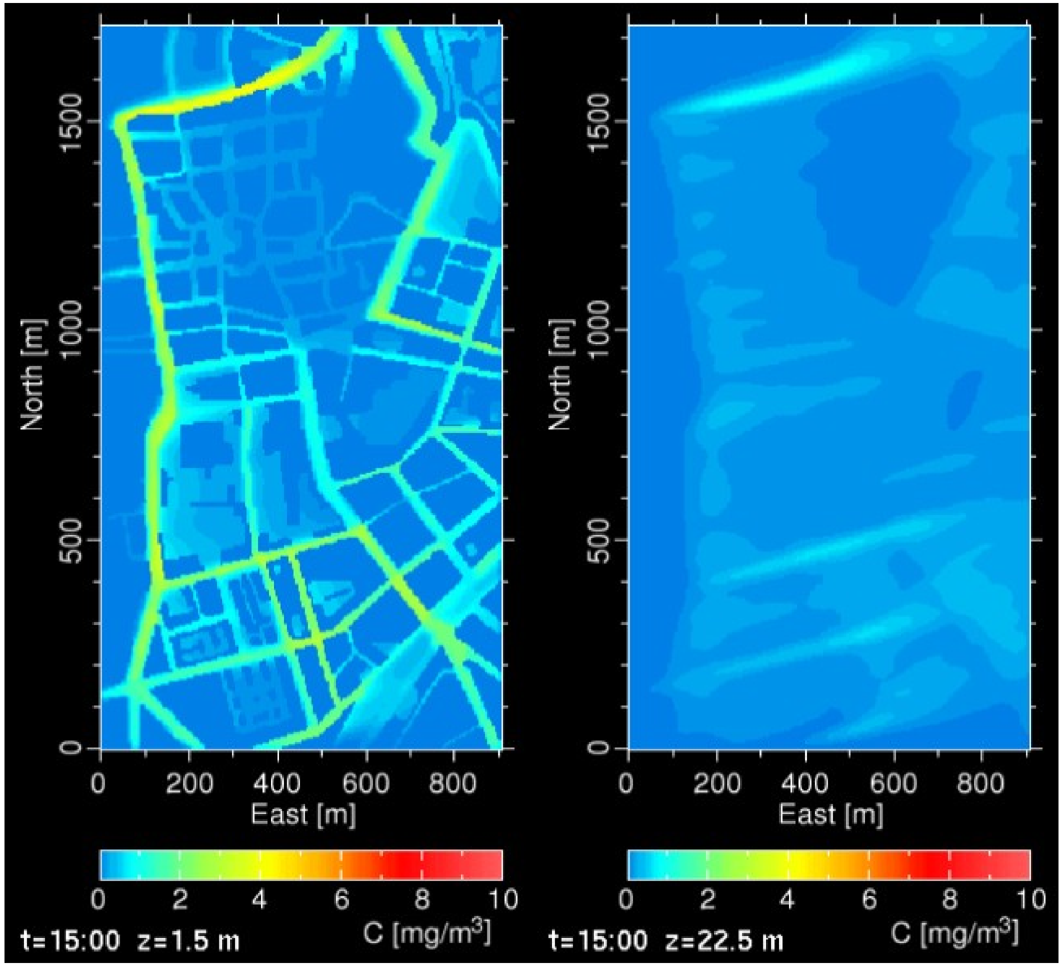
Urban area simulations

What happens when the atmospheric stability conditions vary and the traffic conditions remain the same?

Street level – Above urban canopy



Low wind, stable atmosphere -> lower diffusion



High wind, unstable atmosphere -> stronger diffusion

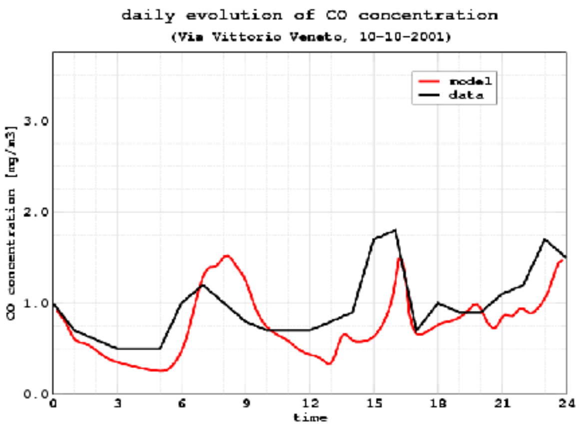
CO has been chosen as pollution tracer because can be considered almost chemically passive in the time-scale we're interested in

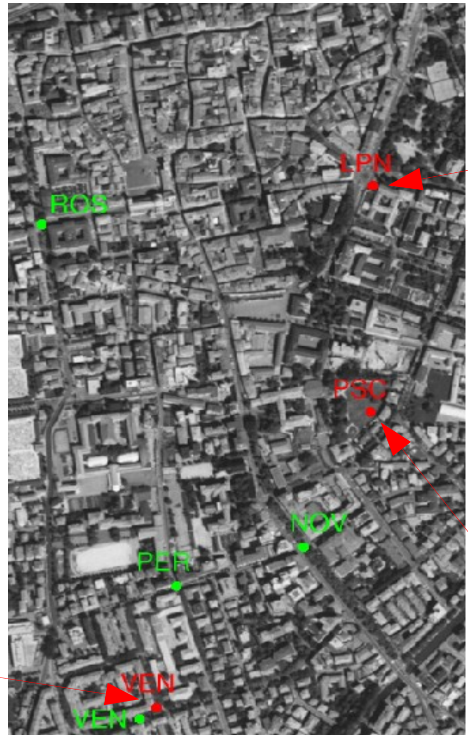
Calibration

Measured (black line) and estimated (red line) concentration values

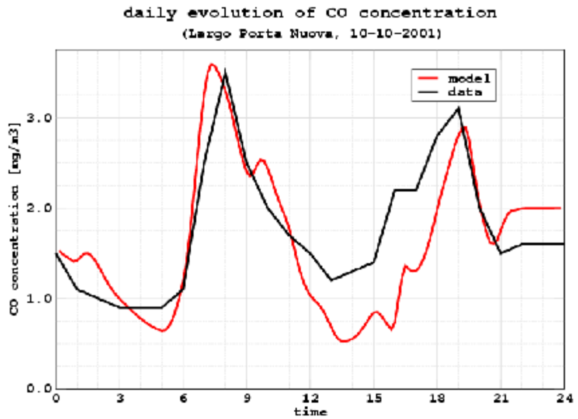
CO concentration values are lower at station n°3 Parco Santa Chiara (because it's inside a park)

CO concentration
Station n° 1 (Via Veneto)

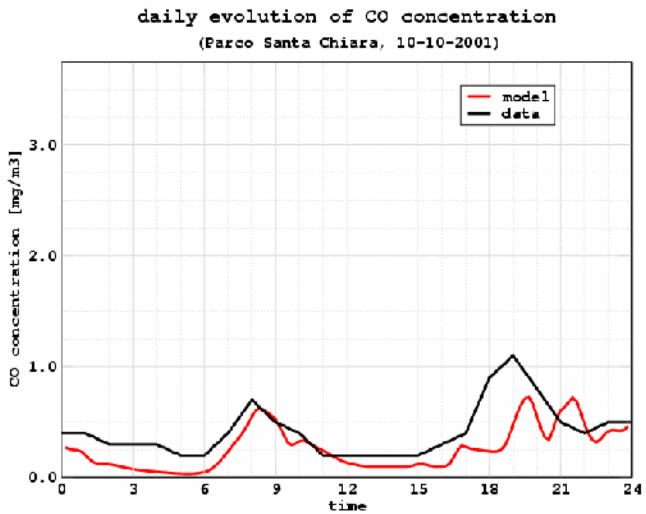




CO concentration
Station n°2 (Largo Porta Nuova)

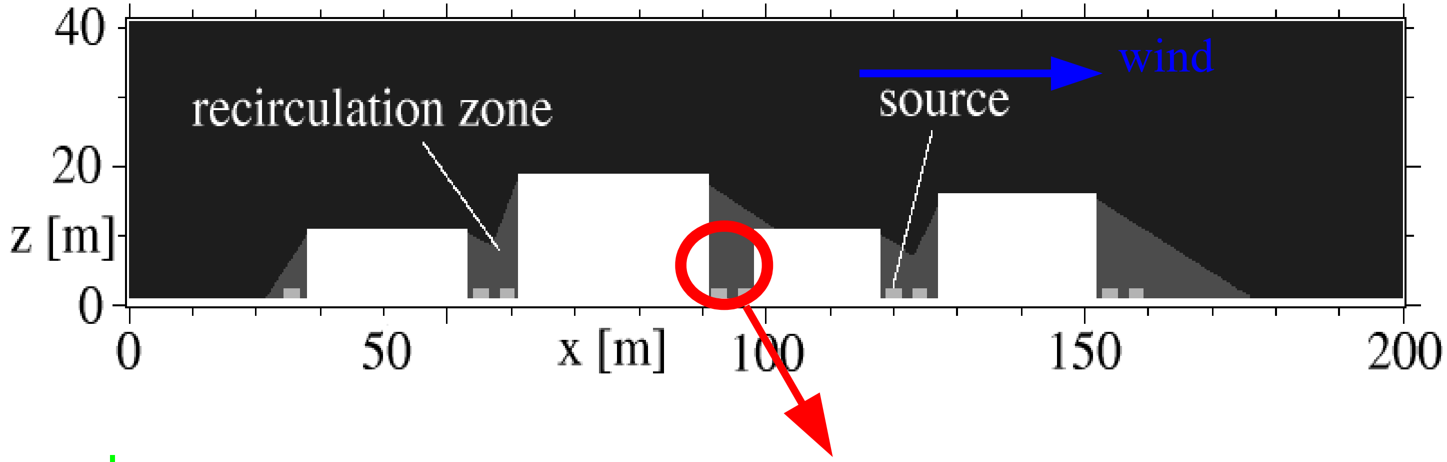


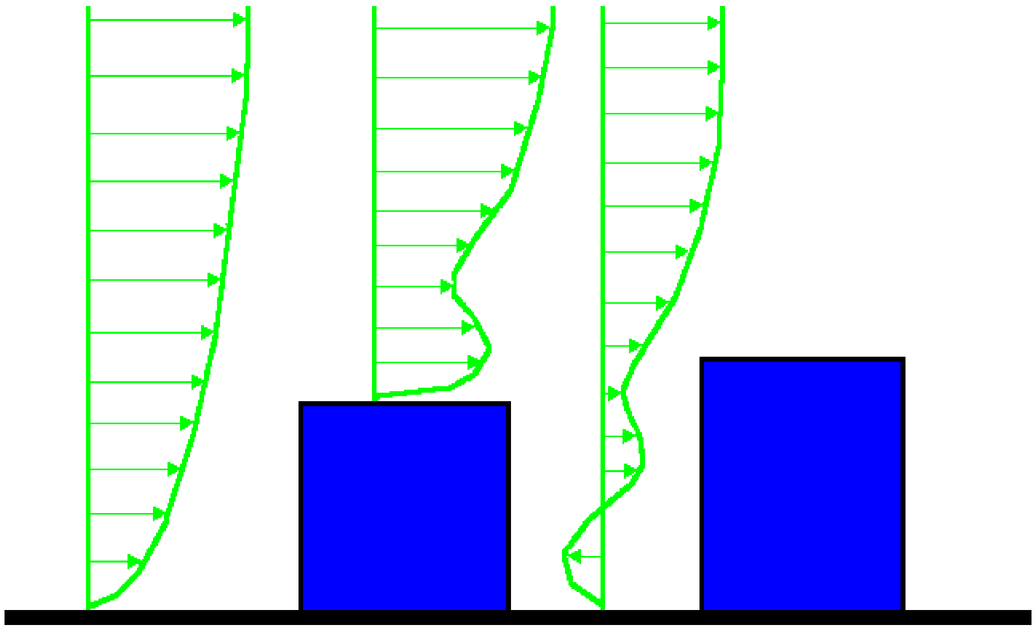
CO Concentration
Station n°3 (Parco Santa Chiara)

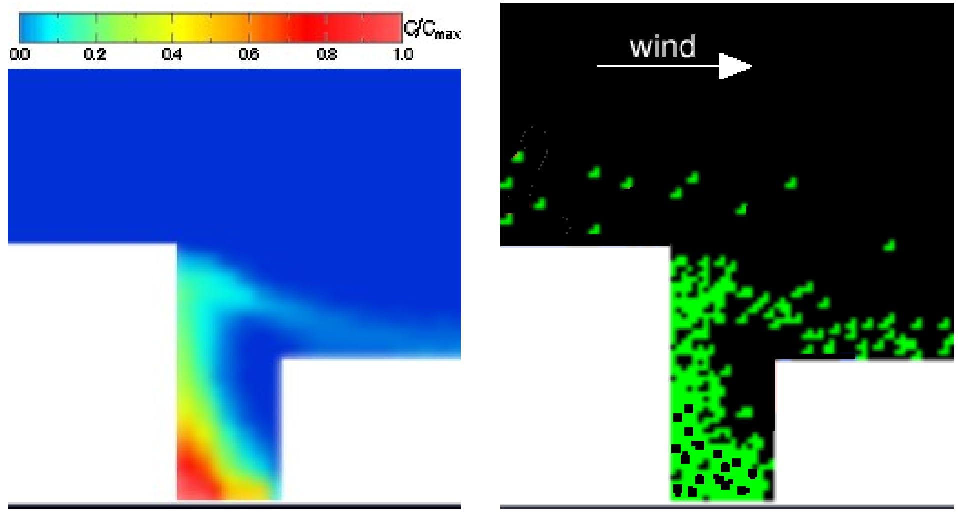


- Pollution at ground level within urban canopy is strongly related to traffic cycles; outside the urban canopy other effects arise and can eventually dominate the dispersion process
- Only by using detailed emission geometry data it is possible to obtain high spatial resolution results (but they are not always necessary: it depends on the aim of the study)
- In case of high winds and/or strong turbulence, the small scale approach becomes meaningless because of the high mass transport effect (and in any case concentration tends to diminish)

Wind perpendicular to street axis: heavier situation because of the canyoning effects, recirculation zones and pollutants stagnation







Sheltering effects of a building with respect to a lower one and entrapment effects (particularly particulate matter) at the street level

Performing mobile measurements to acquire an enhanced overview of street-level emissions: our experience

Mobile Air Sampling System (1)

MASS = Mobile Air Sampling System, developed by CISMA in 2006, aimed at PM monitoring at street level.

To be mounted on a car, customizable

Mobile Air Sampling System (2)

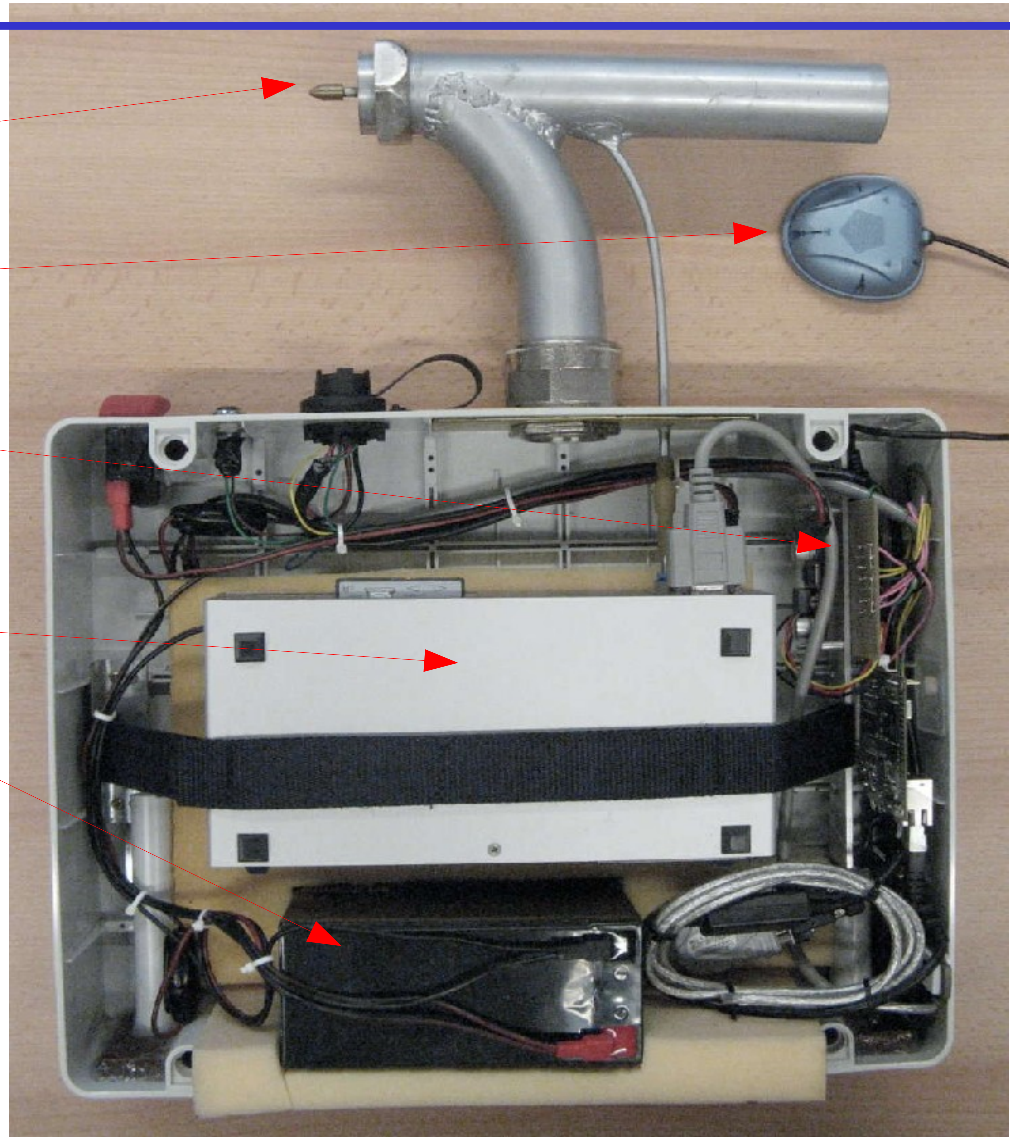
The MASS development was based on a detailed analysis of previous analogous experiences:

- University of Trieste (I) – 2002/2003: mobile measurement
- Paul Scherrer Institute (CH) – 2001/2003: development and construction of a mobile van, acting as a mobile laboratory capable of measuring all parameters in motion (project “Mosquita”)
- University of Innsbruck (A) – 2005/2006: PM mobile measurements within the European Interreg Project IIIb “ALPNAP”
- Desert Research Institute (USA) – 2002/2004: Mobile measurement of road dust PM with equipped vehicle within the “TRAKER experiment”

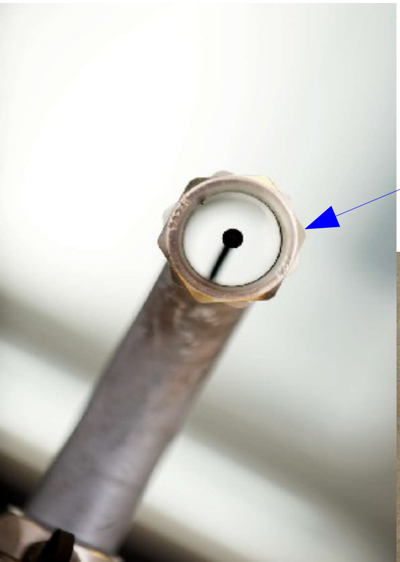
Mobile Air Sampling System (3)

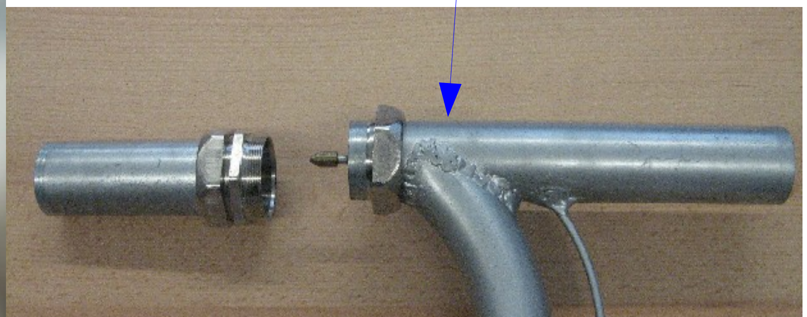
How is the MASS built up?

- Iso-kinetic Inlet probe
- GPS antenna
- Control and acquisition board (linux embedded system)
- GRIMM 1.108 particle counter
- Battery (can also be alimented through car 12V power source)

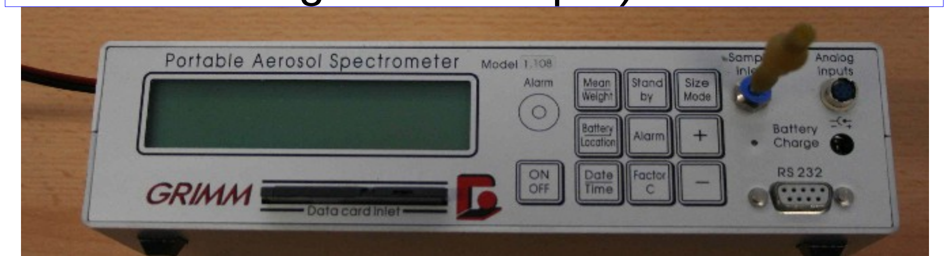


Inlet: front view & side view



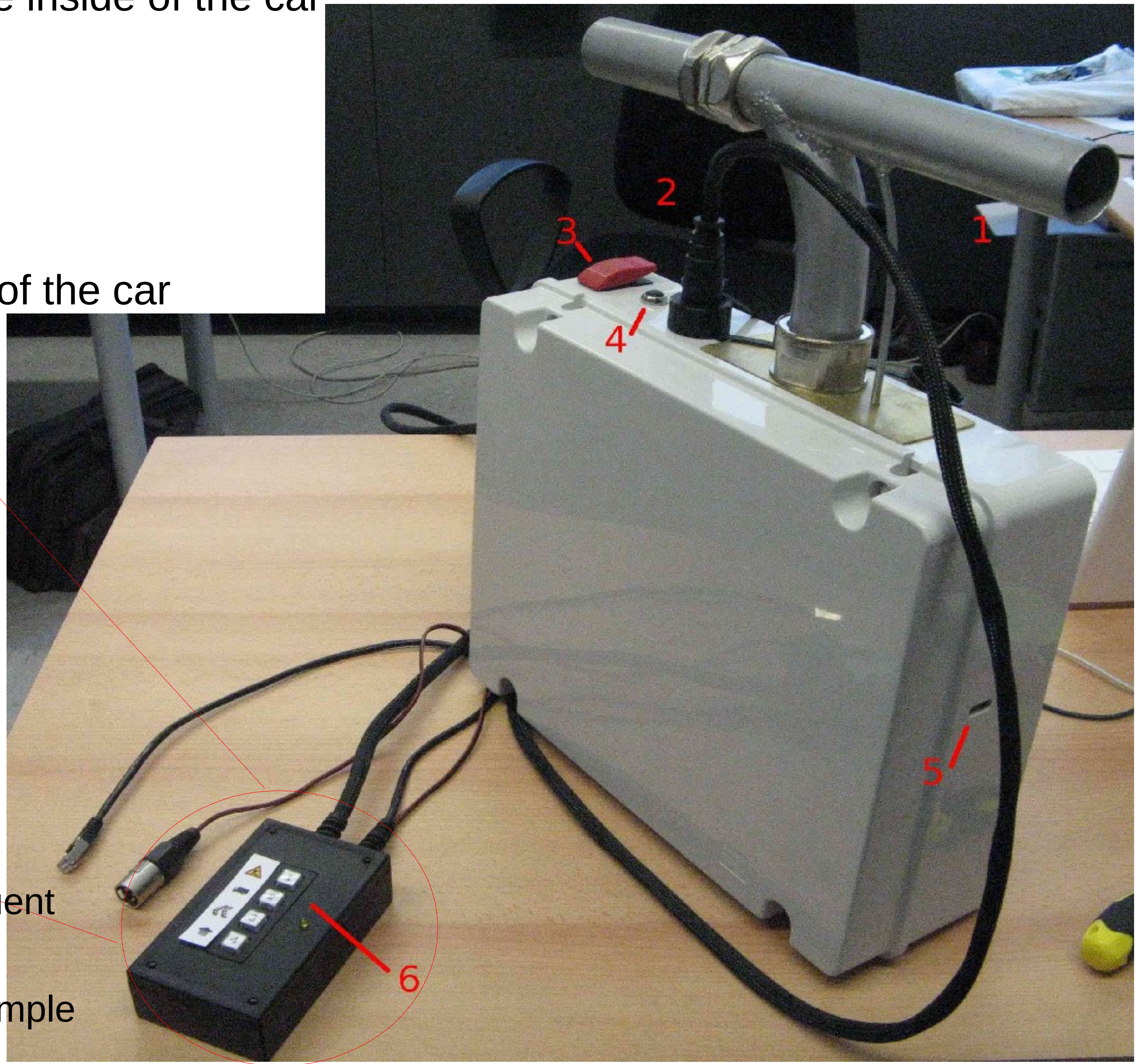


PM optical particle counter (15 dimension classes in range 0.3 – 20 µm)



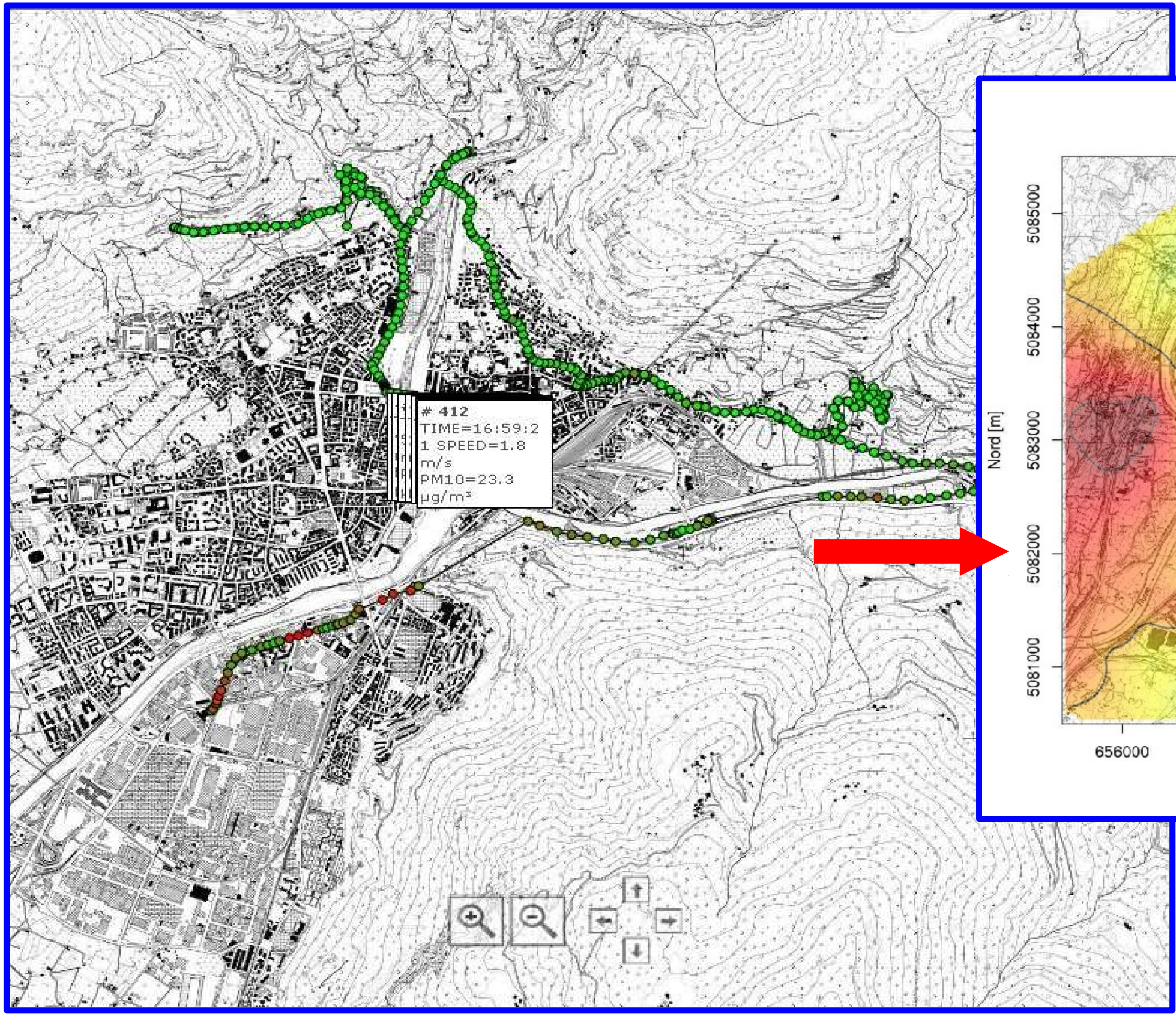
Mobile Air Sampling System (4)

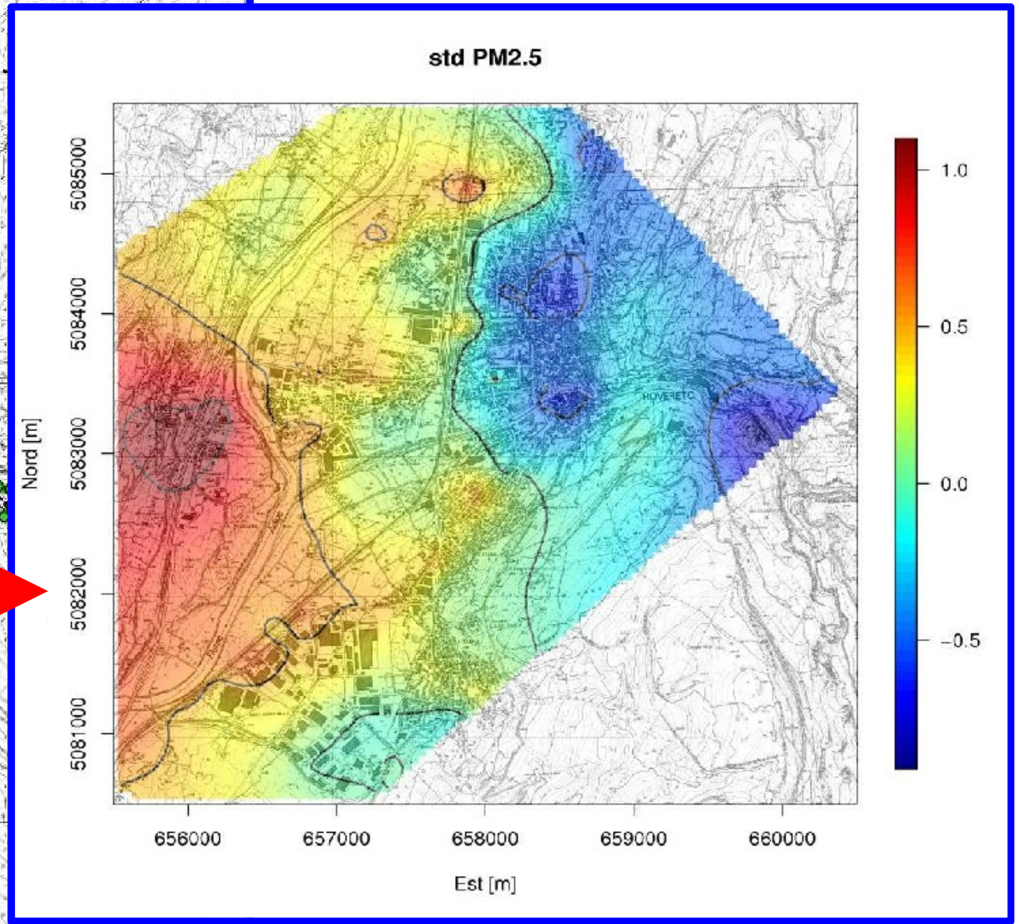
1. Isokinetic sample
2. Control and power cable → to the inside of the car
3. On/off switch (acquisition board)
4. Control switch (particle counter)
5. Control LEDs
6. Numeric keypad → to the inside of the car



User selected events: essential for subsequent data post-processing:
1) construction
2) heavily polluting vehicle in front of the sample
3) traffic jam
4) fog (humidity changes dramatically results)

Mobile Air Sampling System (5)





An example of mobile sampled PM data directly on a web system + offline maps elaboration

Mobile Air Sampling System (6)

Post-development control tests, performed thanks to the essential and useful collaboration of the Environmental Protection Agency of Bolzano/Bozen:

- **two days of inter-comparison measurements in a fixed air quality station in Bolzano (results compared with those from gravimetric system, TEOM and other optical particle counters)**

- **one day test with mobile measurement in the vicinity of an urban air quality station (Bolzano) and a background AQ station (Merano)**

- **six days of continuous drive & measurement (8h/day) in the town of Merano, in Jan/Feb 2007**

Mobile Air Sampling System (7)

On the basis of previous experiences (our & others) some considerations on advantages and disadvantages of mobile measurements in urban areas can be drawn:

- mobile measurements of concentrations are indeed indirect measure of emission (we are collecting data directly on the source line)

- a mobile measurement instrument is suitable for evaluating emissions within the traffic flux. It cannot capture the actual air quality in the nearby target.

- complex (in terms of algorithms) post-processing is needed for deriving useful information

- complete post-processing would also need meteorological and traffic data

- currently mobile measurements are valuable tool for calibrating dispersion models, not yet for direct feeding of dispersion models (too few data in space and time)

- the calibration of other proxies (e.g. fixed traffic monitoring station) would be a smart use of mobile measurements

Thank you for your attention!

...and: any questions?