The Abdus Salam International Centre for Theoretical Physics

Air quality measurements and modelling

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SISTEMA SANITARIO REGIONALE
ASL ROMA 1

REGIONE LAZIO

Air pollution

The presence of toxic chemicals or compounds (including those of biological origin) in the air, at levels that pose a health risk.

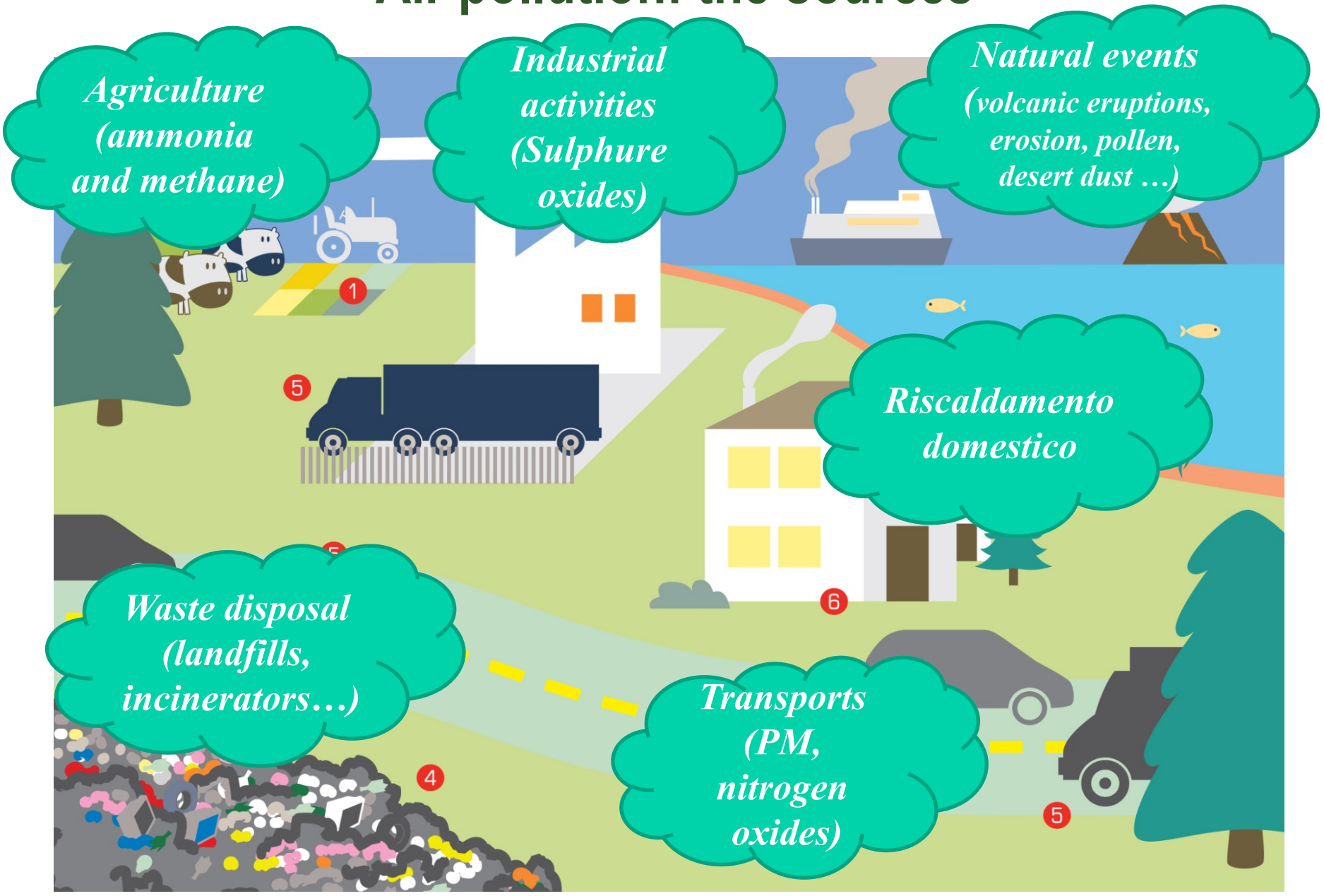
In a broader sense, air pollution means the presence of chemicals or compounds in the air which are usually not present and which lower the quality of the air or cause detrimental changes to the quality of life (such as the damaging of the ozone layer or causing global warming).

⇒ **pollutants**: **any substance being present in the ambient air which might cause adverse effects on human health or on the environment in general.**

The ones included in the EU legislation are:

- **Sulphur dioxide (SO_2)**
- **Nitrogen dioxide (NO_2) / Nitrogen oxides (NO_x)**
- **Particulate matter (PM), inhalable (PM_{10}) and fine ($PM_{2.5}$)**
- **Lead (Pb)**
- **Ozone (O_3)**
- **Benzene (C6H6)**
- **Carbon monoxide (CO)**
- **Polycyclic aromatic hydrocarbons (PAH)**
- **Cadmium (Cd)**
- **Arsenic (As)**
- **Nichel (Ni)**
- **Mercury (Hg)**
- **Benzo(α)pyrene (B[α]p)**

Air pollution: the sources



Primary pollutants

Substances emitted directly near the ground:

SO_2
NO, NO_2
CO
Benzene
PAH
Lead, heavy metals
PM

Secondary pollutants

Organic and inorganic substances:

- Not directly emitted by the sources near the ground
- Derive from chemical reactions which occur in the low atmosphere (in both gaseous and liquid phases) of pollutant substances otherwise not present in the air:

  ⇒ Ozone

  ⇒ NO_2

  ⇒ PM

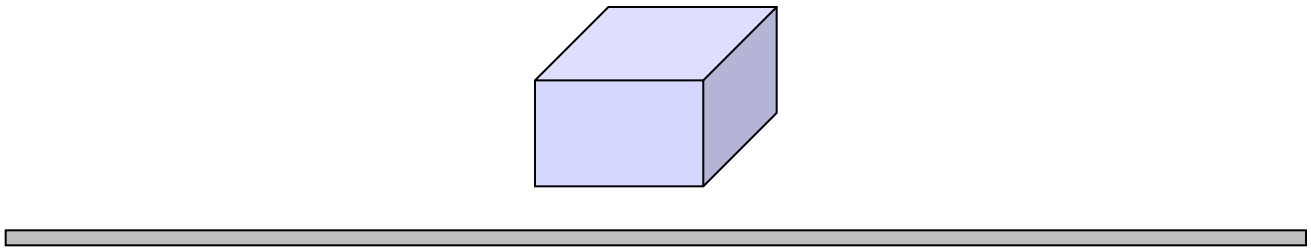
  ⇒ ……..

Technical Box 1

Level: concentration of a substance in the ambient air in a given time unit

Concept of level (concentration) of a pollutant

Es. let's consider NO_2 on the ground level



1) Isolate a volume V of air near the ground on a specific time unit t_i and consider the mass M of NO_2 present there. The instantaneous concentration at t_i is:

$$C_i = (M/V)_i \quad (\mu g/m^3)$$

2) Repeat the instantaneous measure in following time units (ex. every minute for one hour), getting 60 measurements. If I am interested in the average hourly NO_2 concentrations, such level will be the hourly mean concentration of NO_2, i.e.:

Hourly value = Hourly mean concentration =
Sum (C_i) / N

When we study the health effects of air pollutants, we are never interested in instantaneous values, but rather in average values, where the averaging time depends on the pollutant and the objective of the study (hourly, daily, annual, etc.)

Measurement methods

Referent methods are defined, for each pollutant, by law

⇒ For gaseous pollutants (SO_2, NO_2, O_3, CO, benzene) there are automated methods.

⇒ For PM, the reference method would entail the weighting of a filter, therefore it would not be automated. However, law foresees *equivalent methods* which provide automatic measurements

⇒ For other pollutants (PAH, Pb, ecc.) there are methods based on laboratory testing

PARTICULATE MATTER

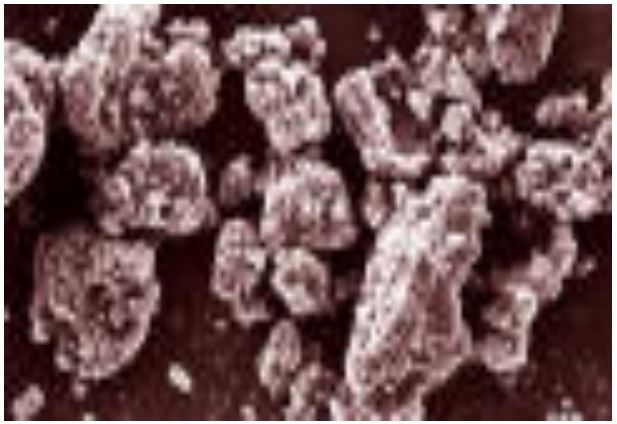
- Complex heterogeneous mixture of solid and liquid components

- Sources:
  - Power plants and industry
  - Motor vehicles
  - Domestic coal burning
  - Natural sources (volcanoes, dust storms)
  - Secondary small particles from gases (nitrates and sulfates)

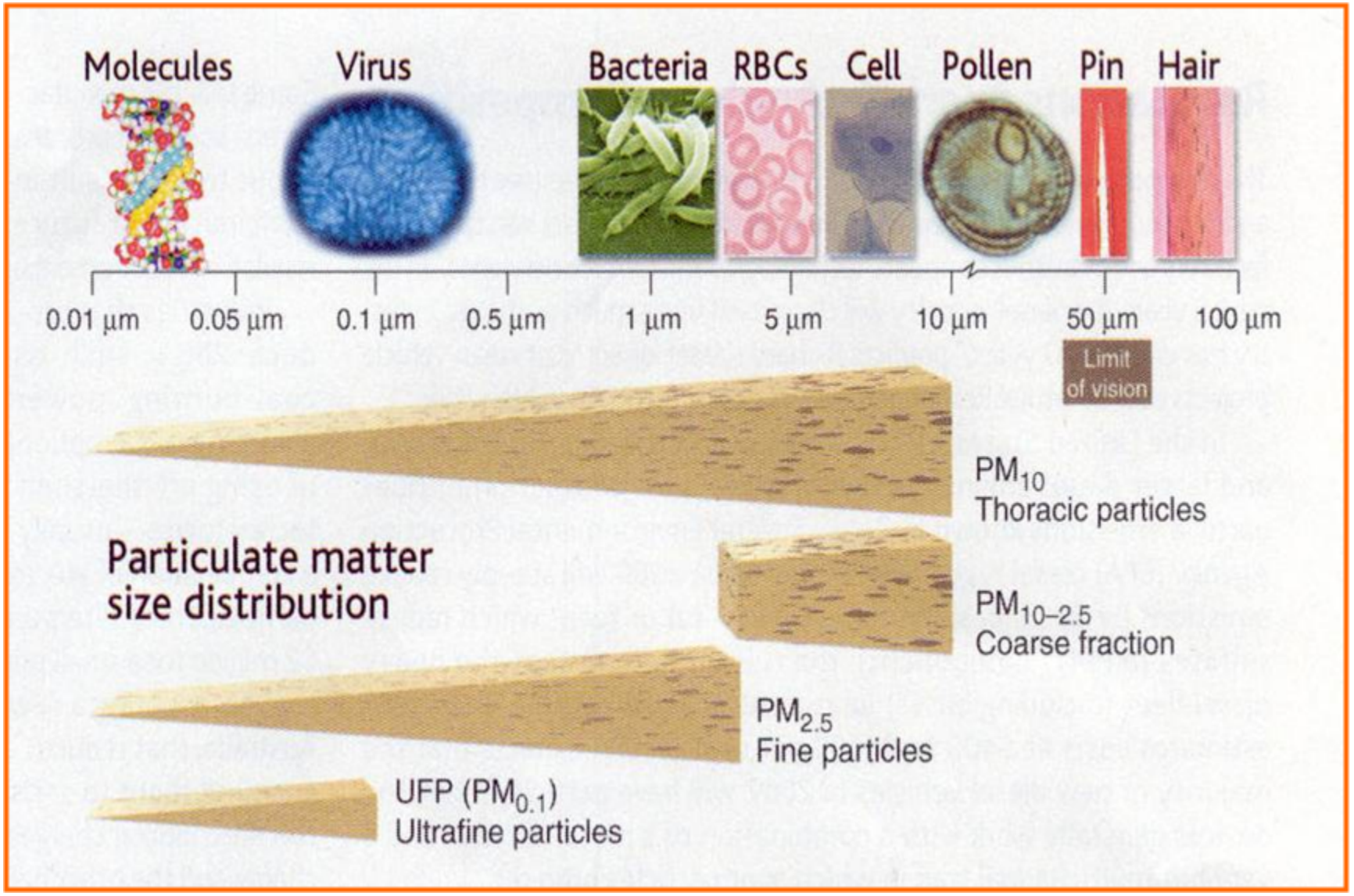
PARTICULATE MATTER: definitions

A complex mixture of airborne solid and liquid particles, including soot, organic material, sulfates, nitrates, other salts, metals, biological materials.

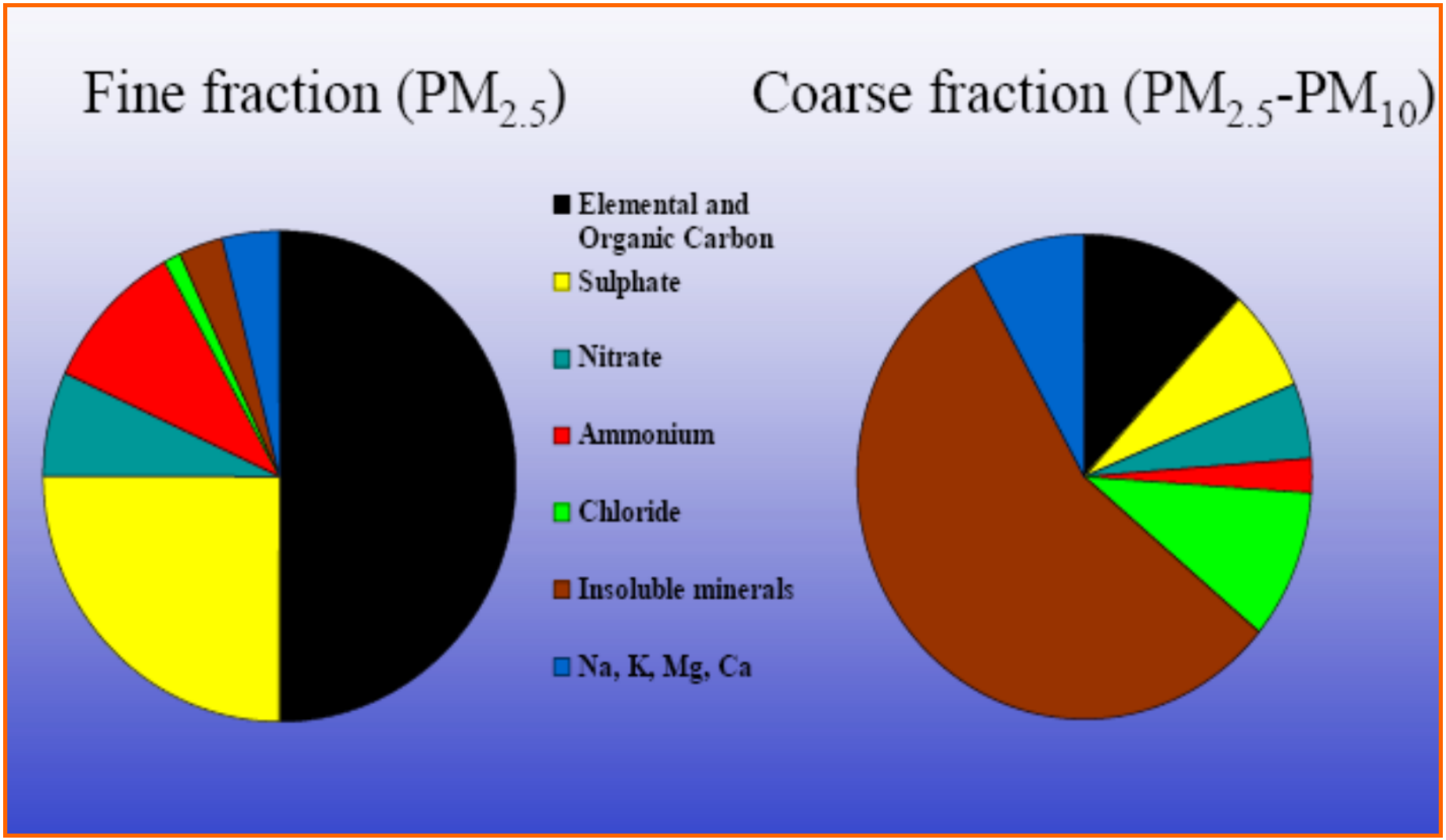
- PM_{10} -- inhalable particles
- $PM_{2.5}$ -- fine particles
- PM_{10}-$PM_{2.5}$ -- coarse particles
- $PM_{0.1}$ -- ultrafine particles



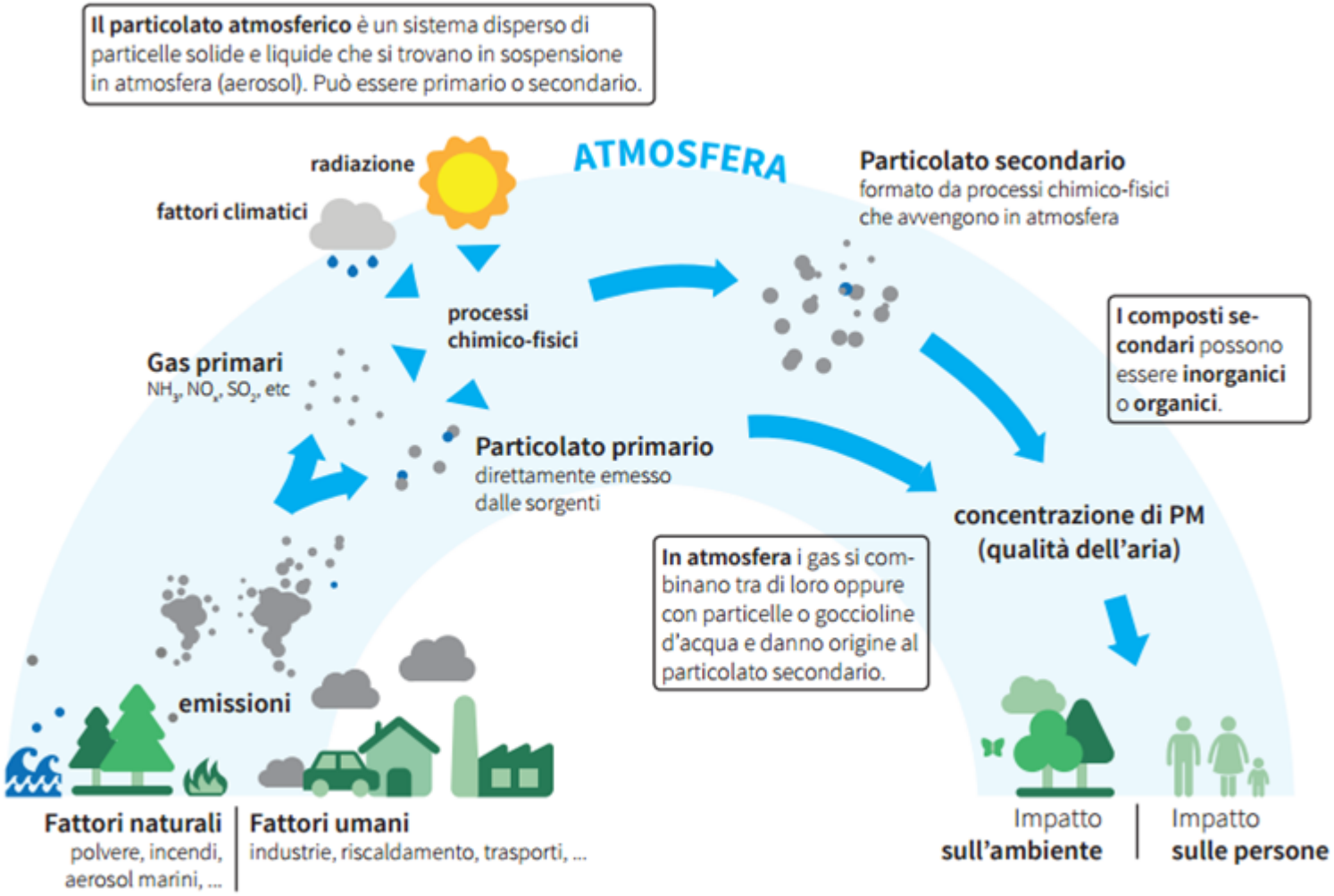
Particulate matter



PARTICULATE MATTER: composition



Primary and secondary PM



Fonte: Dati ambientali 2015 - La qualità dell'ambiente in Emilia-Romagna

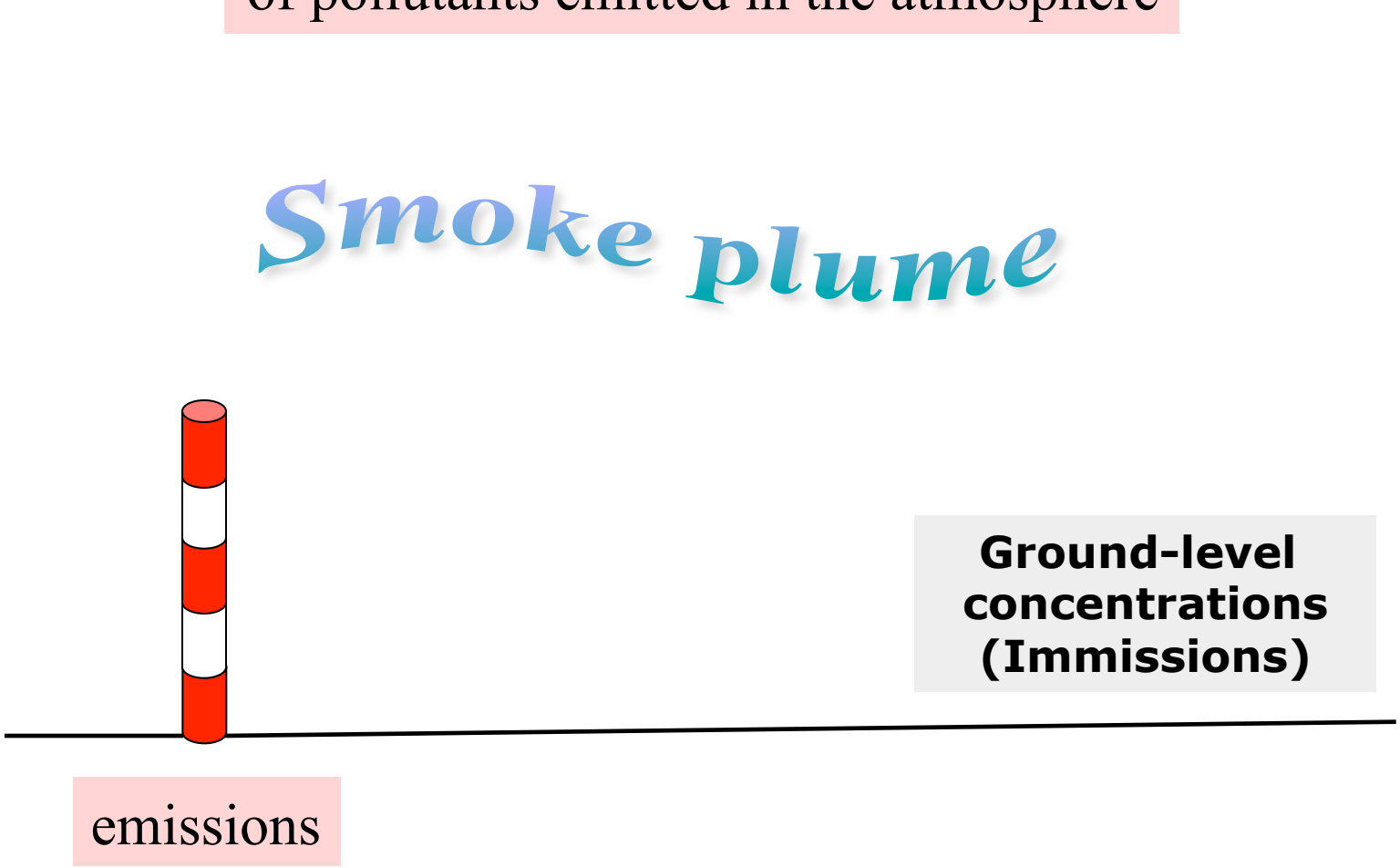
Technical Box 2

Main cause for the presence of air pollutants in the air

Emissions = any substance (solid, liquid or gaseous) introduced in the atmosphere which might cause air pollution

Therefore, by definition, emissions are made solely by primary pollutants (ex. ozone is NOT emitted)

Transport and diffusion
of pollutants emitted in the atmosphere



Law limits (D. UE 2008/50/CE)

Biossido di azoto (NO2)

Limite orario

Inferiore a 200 microgr/m3 per non più di 1 ora

Limiti annuali

Sforamento del limite orario per non più di 18 volte l'anno

Concentrazione media annua entro i 40 microgrammi/m3

PM10

Limite giornaliero

Inferiore a 50 microgrammi/m3

Limiti annuali

Sforamento del limite giornaliero per non più di 35 giorni l'anno

Concentrazione media annua entro i 40microgrammi/m3

PM2,5

Limiti annuali

Concentrazione media annua entro i 25 microgrammi/m3

Ozono (O3)

Definizione delle soglie

120

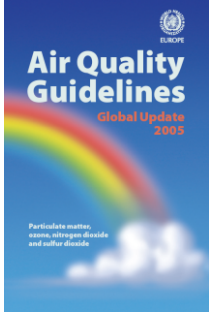
soglia obiettivo a lungo termine: esposizione fino a 120 microgrammi/m3, calcolato come massimo giornaliero della media mobile su 8 ore (media calcolata sui dati orari scegliendo un intervallo di 8 ore)

180

soglia informazione (rischi per la salute per soggetti sensibili): esposizione a 180 microgrammi/m3 per più di 1 ora

PM_{10} monitoring network in Italy

WHO AQG Summary (2005)



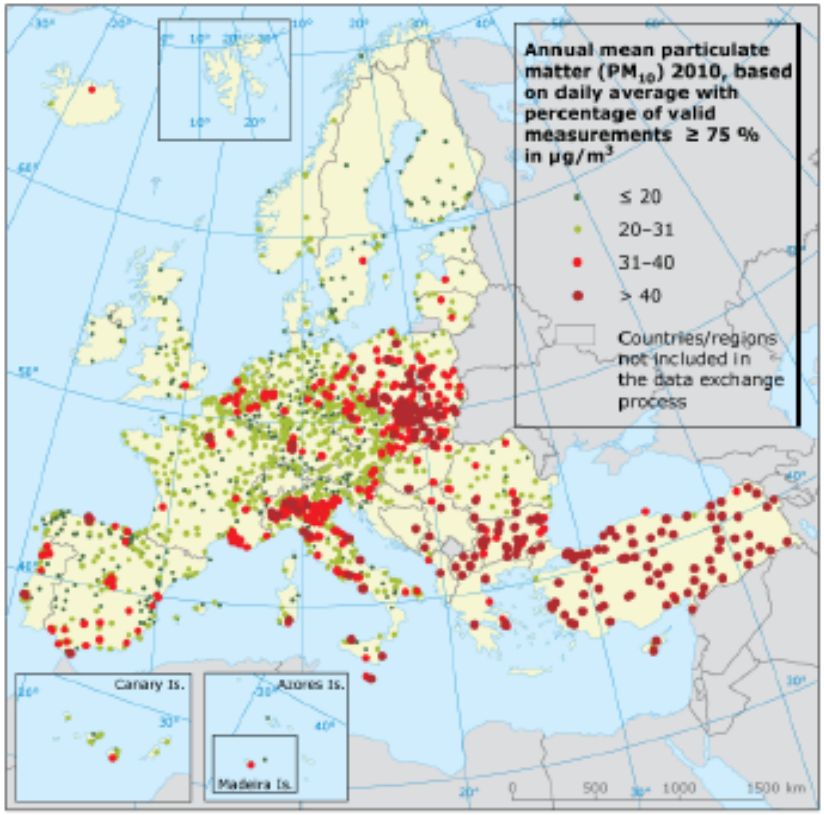
Pollutant	Averaging time	AQG value	*EU standard (target or limit value)*
Particulate matter			
$PM_{2.5}$	1 year	10 µg/m^3	*25 µg/m^3*
	24 hour (99th percentile)	25 µg/m^3	*--*
PM_{10}	1 year	20 µg/m^3	*40 µg/m^3*
	24 hour (99th percentile)	50 µg/m^3	*50 µg/m^3****
Ozone, O_3	8 hour, daily maximum	100 µg/m^3	*120 µg/m^3****
Nitrogen dioxide, NO_2	1 year	40 µg/m^3	*40 µg/m^3*
	1 hour	200 µg/m^3	*200 µg/m^3****
Sulfur dioxide, SO_2	24 hour	20 µg/m^3	*125 µg/m^3****
	10 minute	500 µg/m^3	*350 µg/m^3*** (1 hr)*

WHO levels are recommended to be achieved everywhere in order to significantly reduce the adverse health effects of pollution

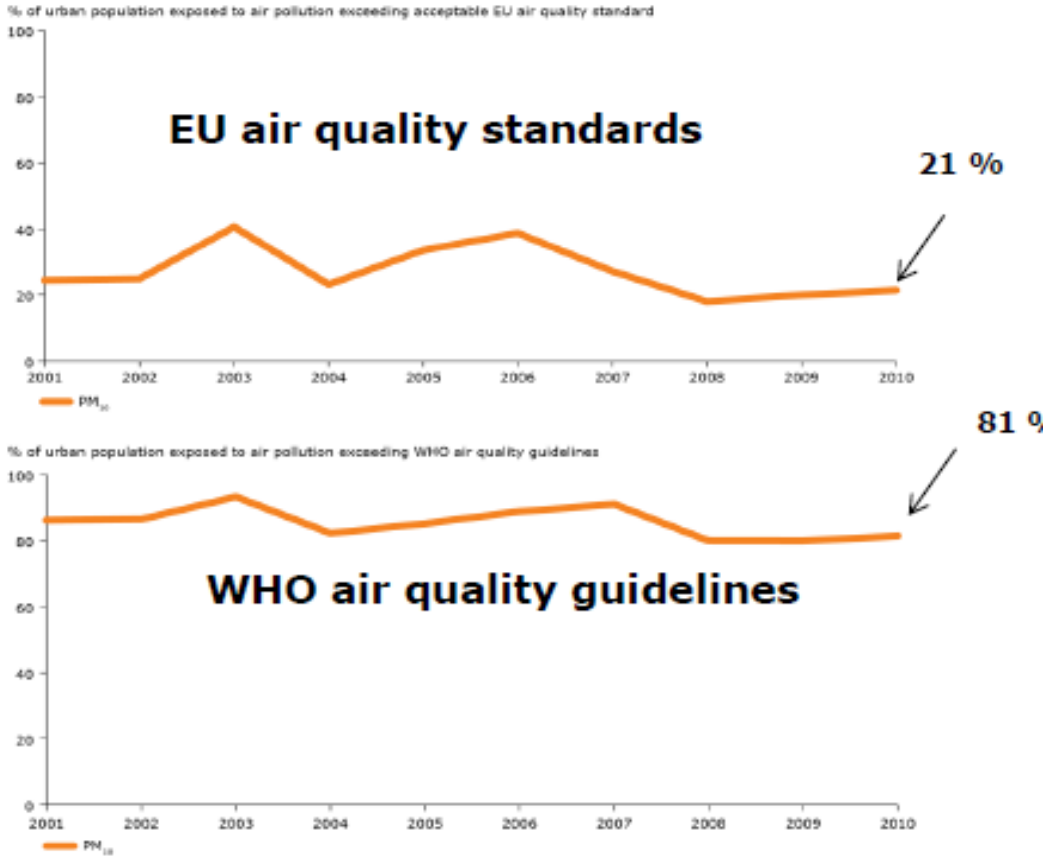
Ambient Air Quality Directives

PM10 concentration

In red: above EU limit values



Percentage of the EU's urban population exposed to exceeding PM10 limits



Source: EEA Air Quality report 2012

European Commission

Dispersion models

Simulate, using fluidodynamic laws, emission, transport, dispersion and deposition of airborne pollutants, and also their chemical reactions

They can be of different degrees of complexity depending on the sources they include, characteristics of the territory, source types and meteorological conditions.

In general, they need as input:

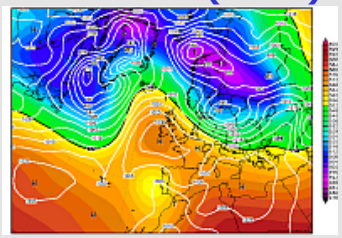
⇒ Quantities of emitted pollutants, their localization and how they are emitted

⇒ The structure (often 3D) of relevant meteorological parameters

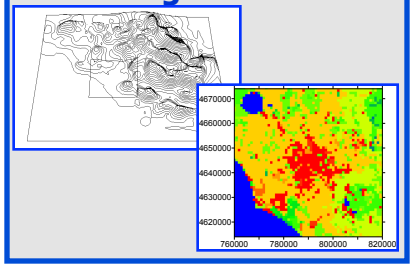
⇒ Characteristics of the territory (orografy, presence of sea/ lakes, *land use*, ecc.)

Example. The modelling chain in Lazio Region

Previsioni Meteorologiche Sinottiche (NCEP)



Dati Geografici



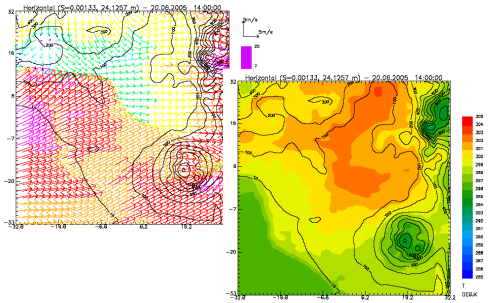
DATI EMISSIVI

RAMS

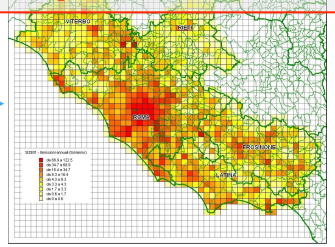
Gap SurfPRO

EMMA

Input Meteorologico

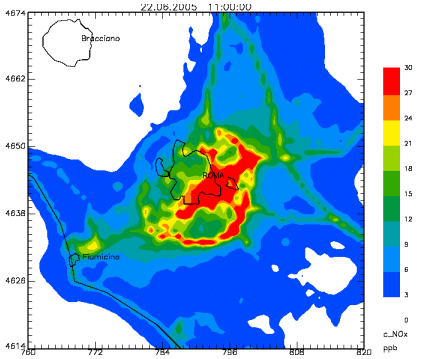


Input Emissivo

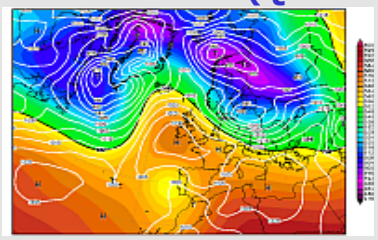


FARM

Campi di concentrazione



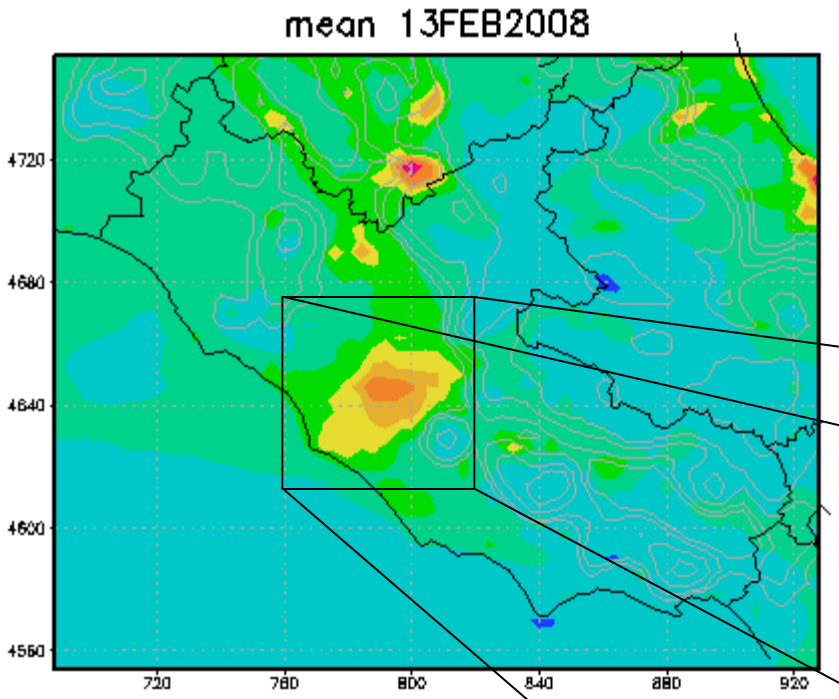
Previsioni Inquinamento a scala nazionale (QualeAria)



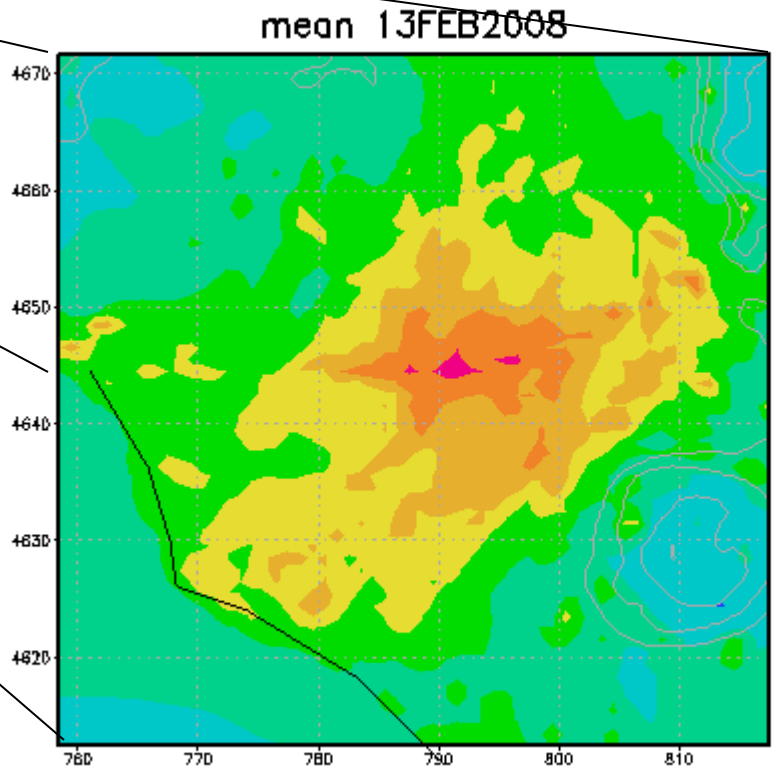
Source:
ARPA lazio

Air pollutants concentration maps

Regional domain



Metropolitan area of Rome



Land-use regression models

They are aimed to predict pollutant concentrations in different spatial location by taking advantage of the spatial relationship between observations and land use characteristics

They can be of different degrees of complexity depending on the data they include: road/traffic networks, population density, land cover, orography, etc.

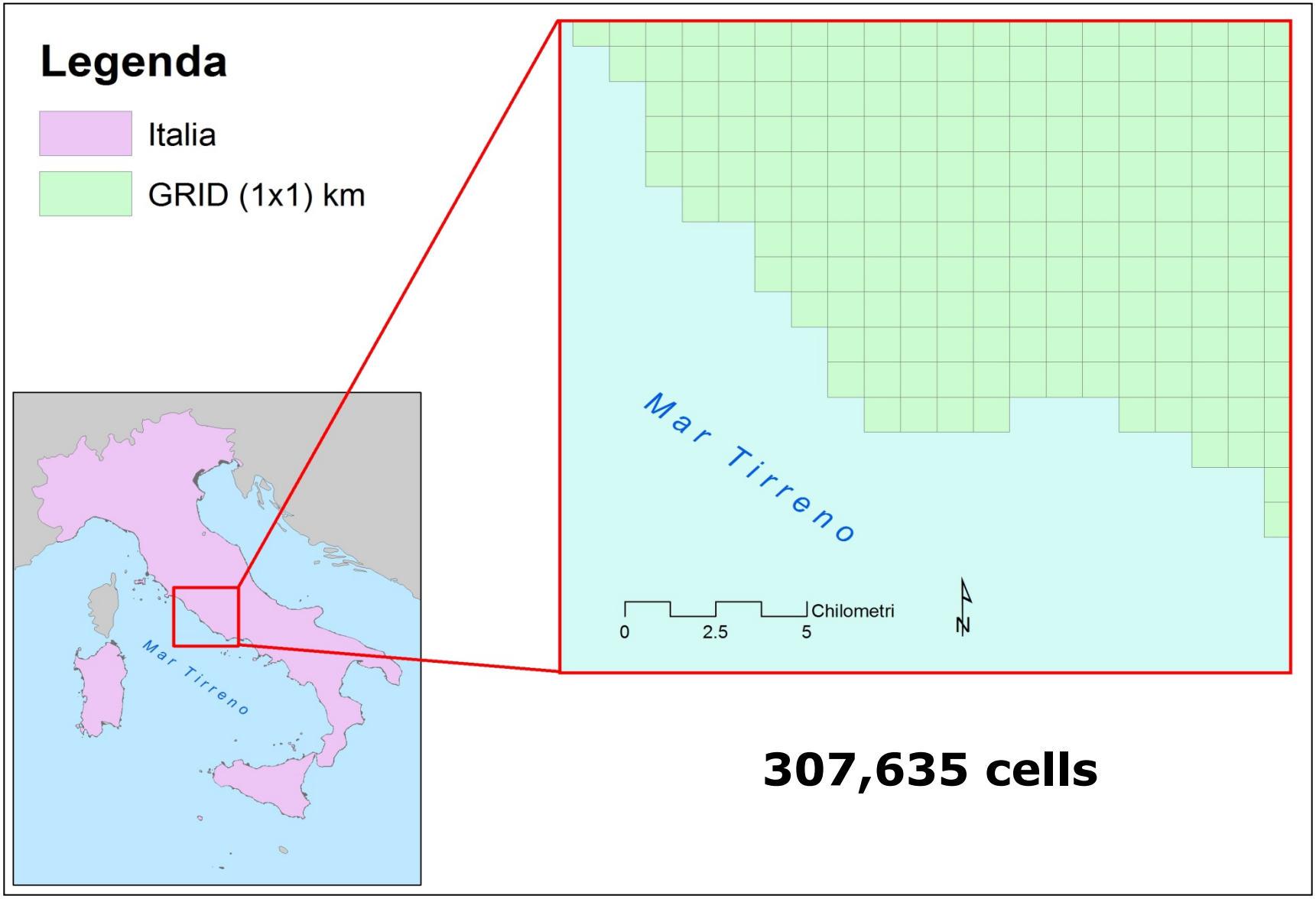
In general, they need as input:

⇒ Observed measurements of the pollutant from one or more monitoring campaigns, with coordinates of the sites

⇒ Data on land use characteristics (and GIS expertise)

⇒ Statistical expertise to develop a flexible model which relates land use data to the monitored pollutant(s)

1x1-KM FIXED GRID



307,635 cells

DATA OVERVIEW

Daily **PM concentrations**

Daily Aerosol Optical Depth (**AOD**) at 1x1-km

Spatial parameters

- **Population density**
- **Emissions** from main inustrial plants
- **Land-use characteristics**
- **Road network** (distance from/meters of highways/main/minor roads)
- Others (**elevation, impervious surfaces, geoclimatic zones, administrative layers,** etc.)

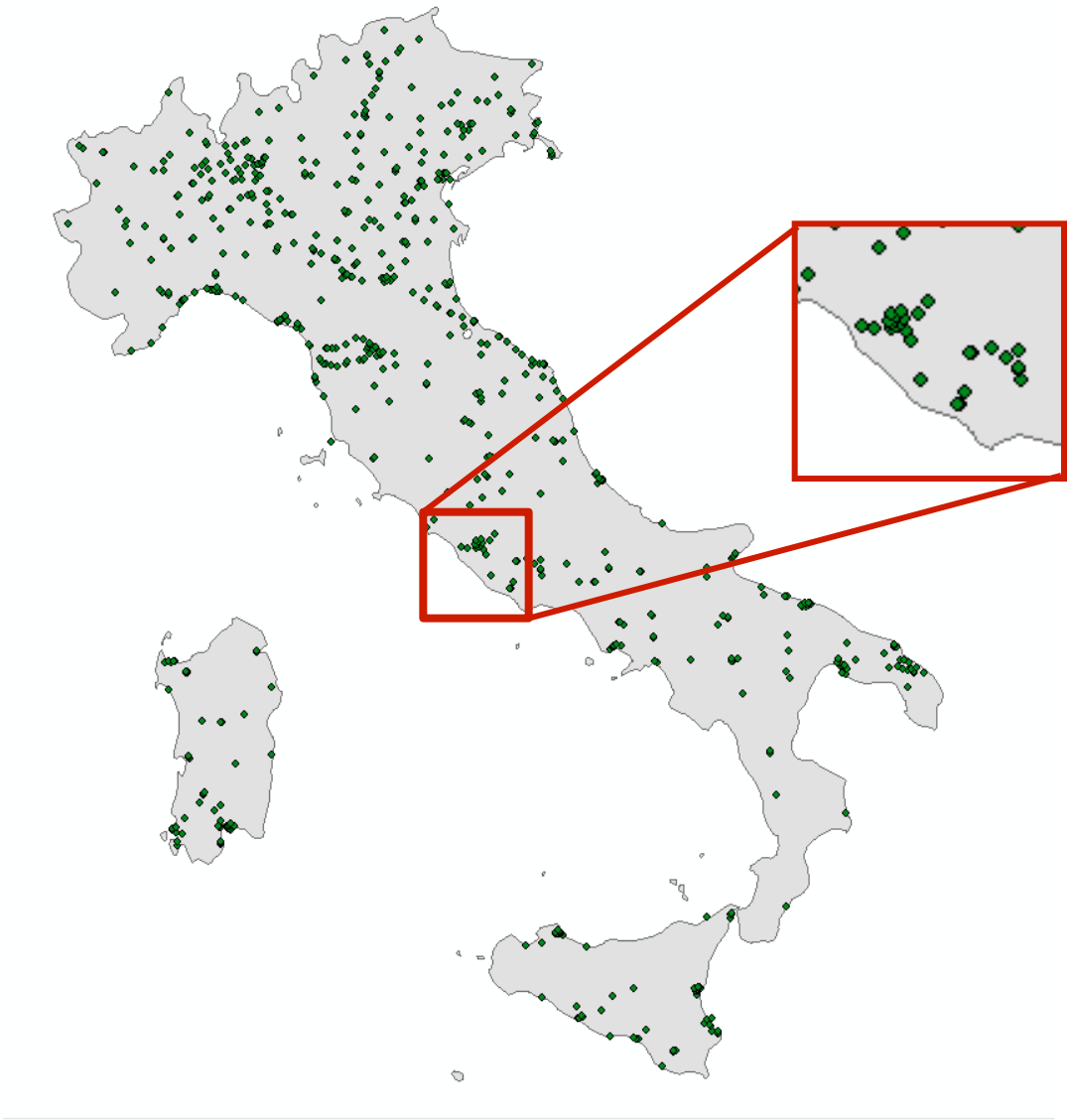
Spatiotemporal parameters

- Daily **meteorology**
- Monthly Normalized Difference Vegetaion Index **(NDVI)** at 1x1-km resolution
- Daily Planetary Boundary Layer (**PBL**) estimates at 10x10-km resolution
- **Saharan dust**

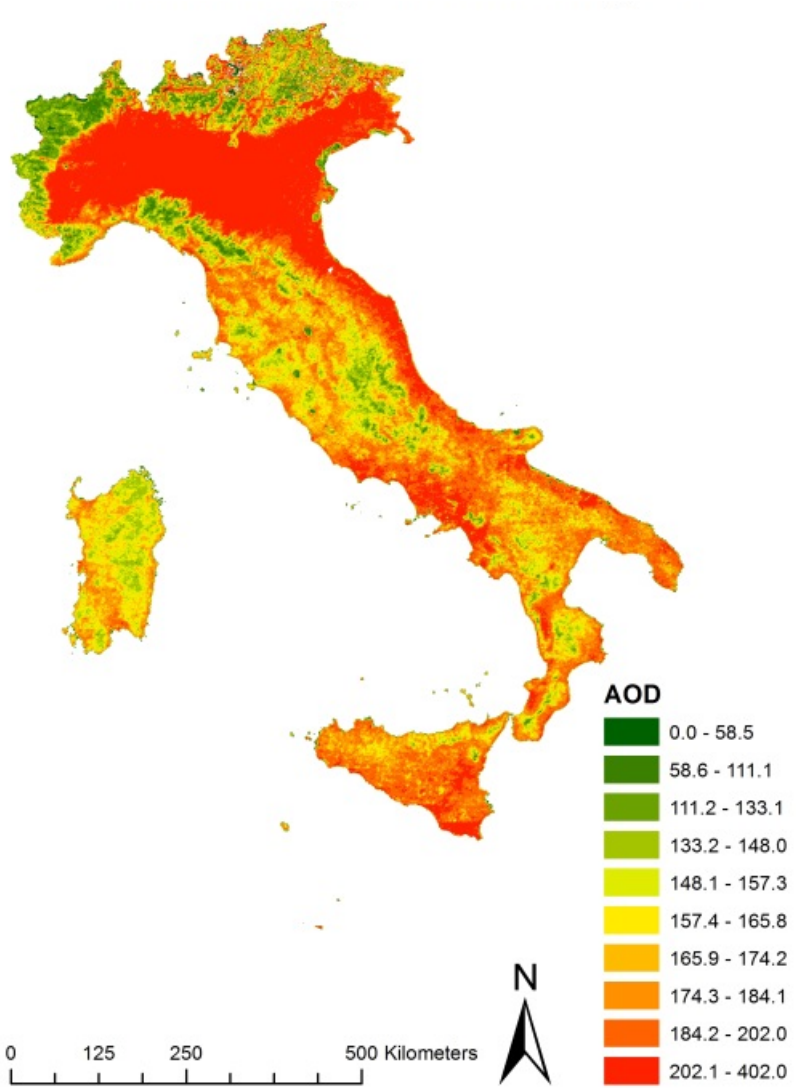
PM MONITORS

686 monitors

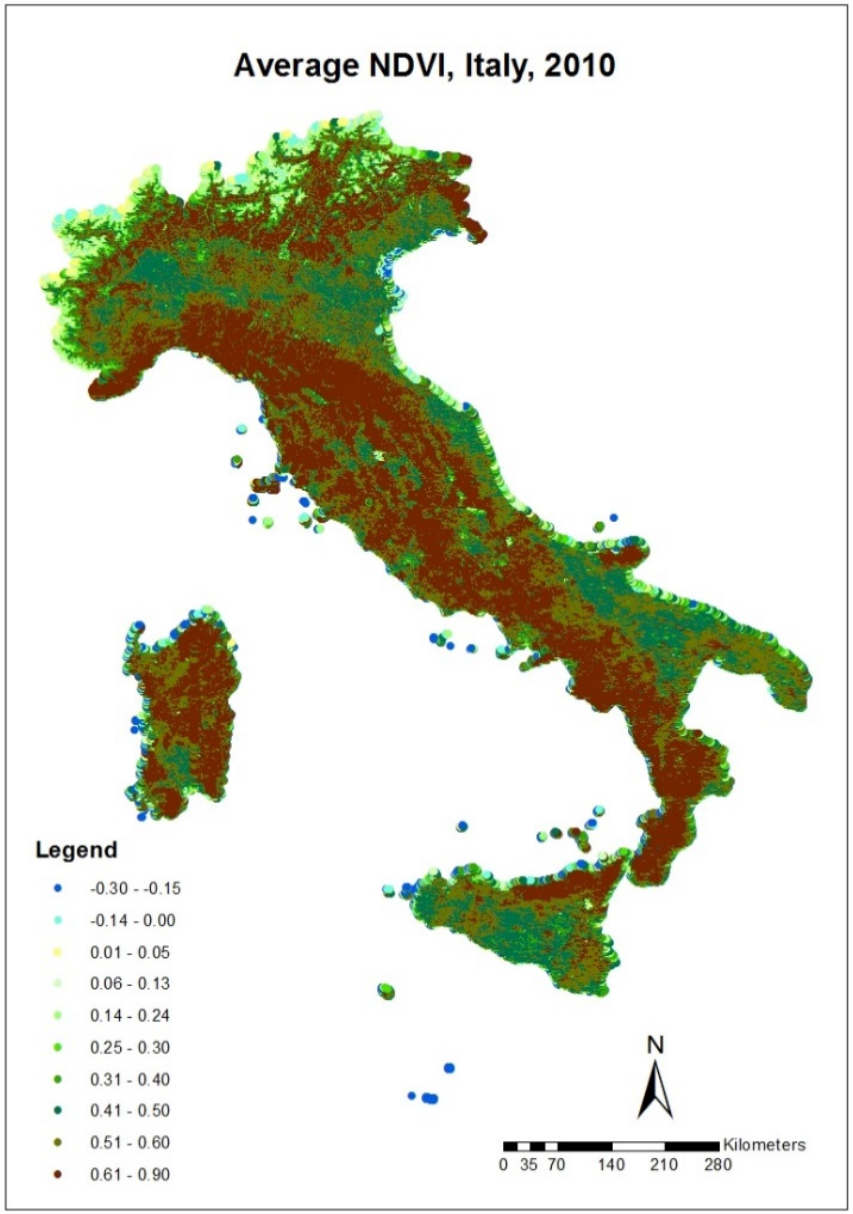
PM_{10} and $PM_{2.5}$



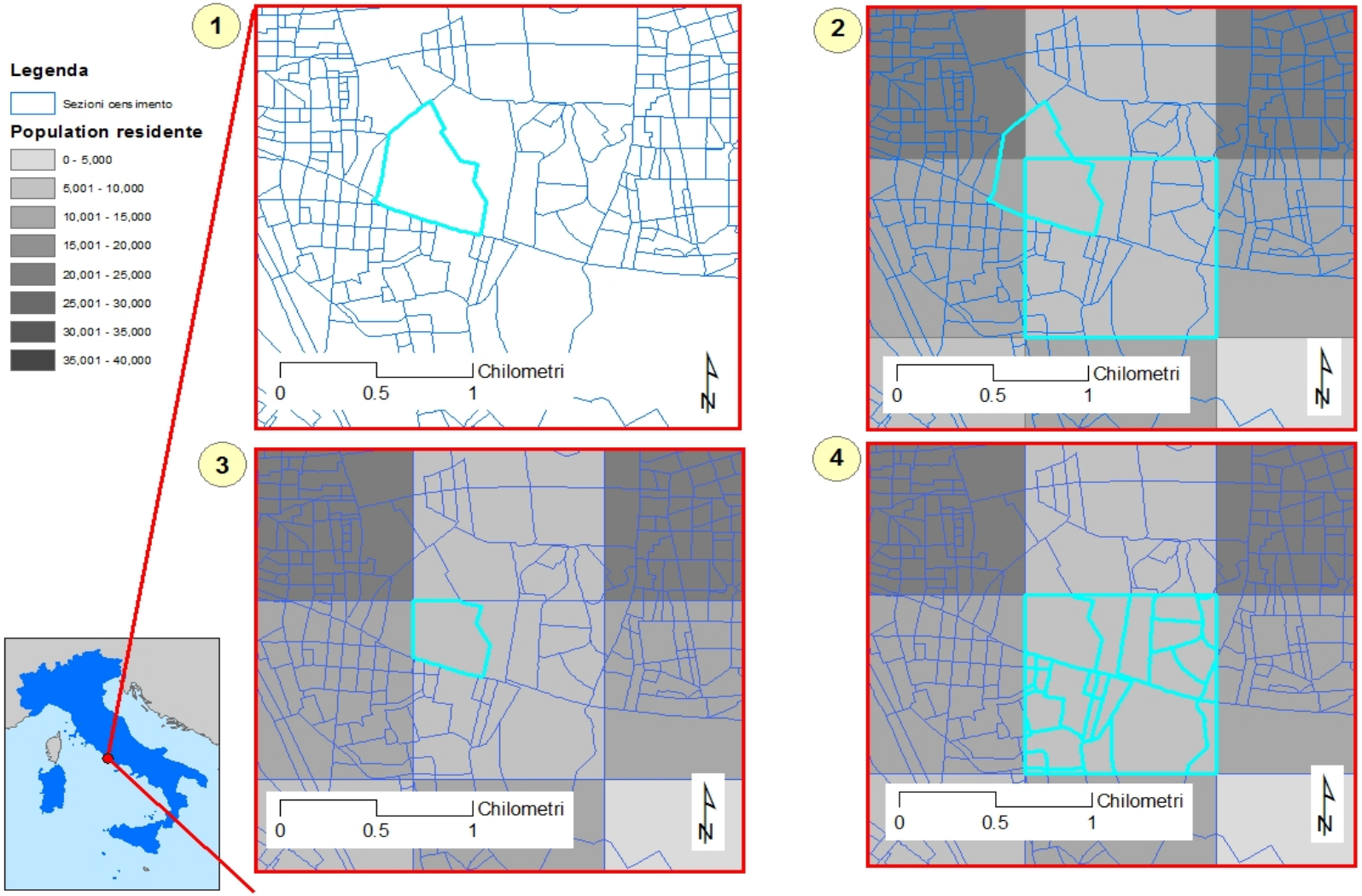
SATELLITE DATA: AOD and NDVI



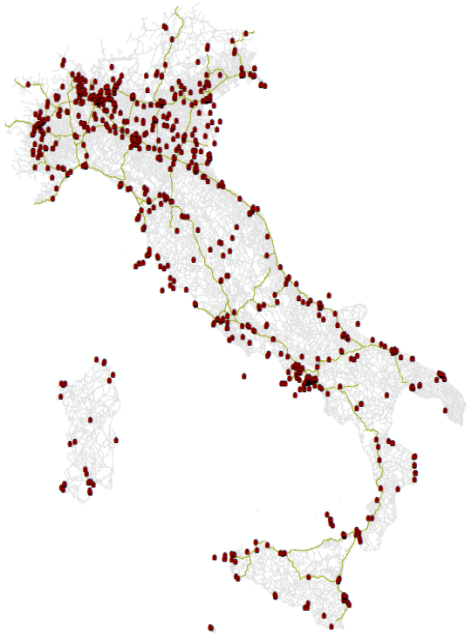
Annual average AOD, Italy 2010



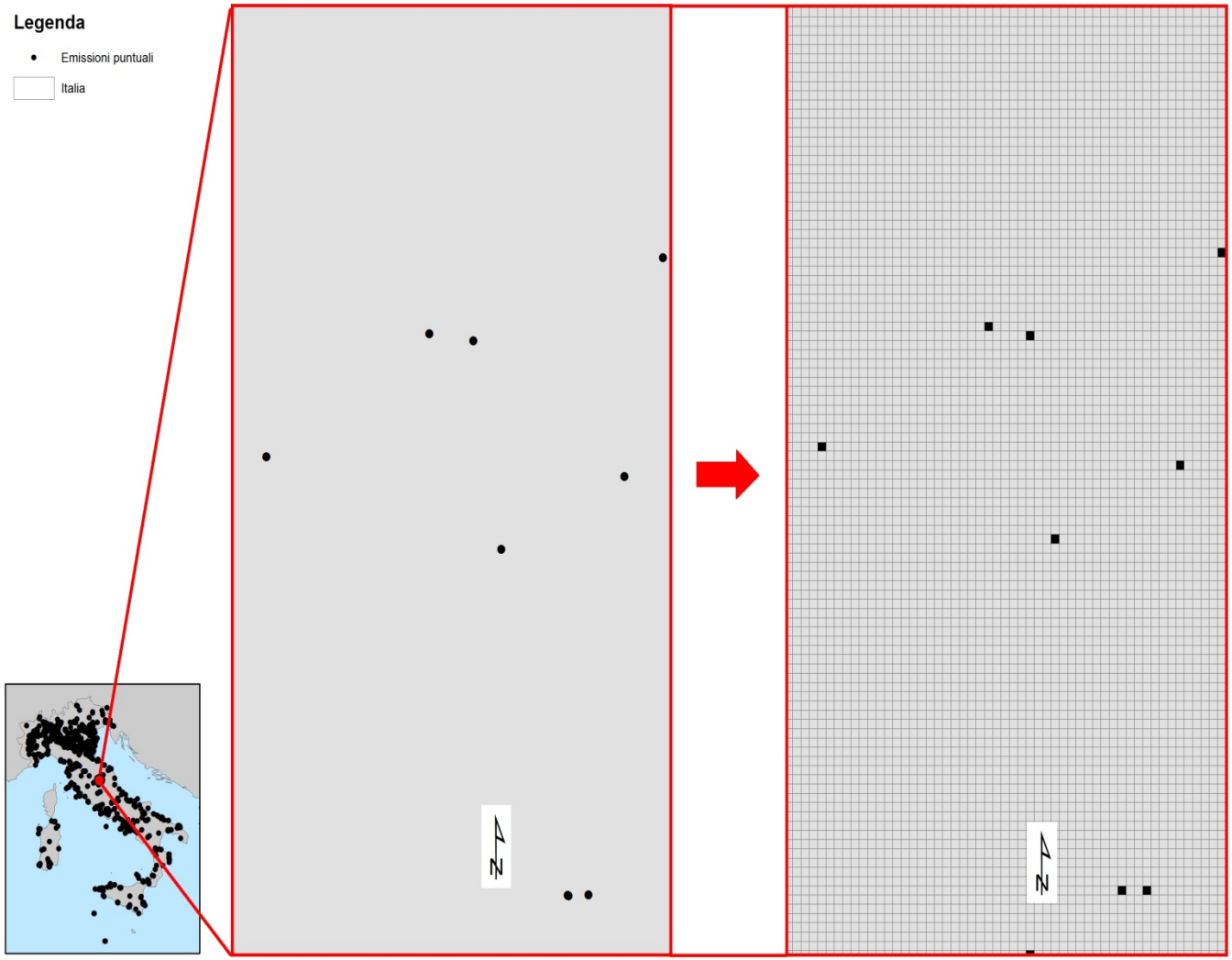
POPULATION DENSITY



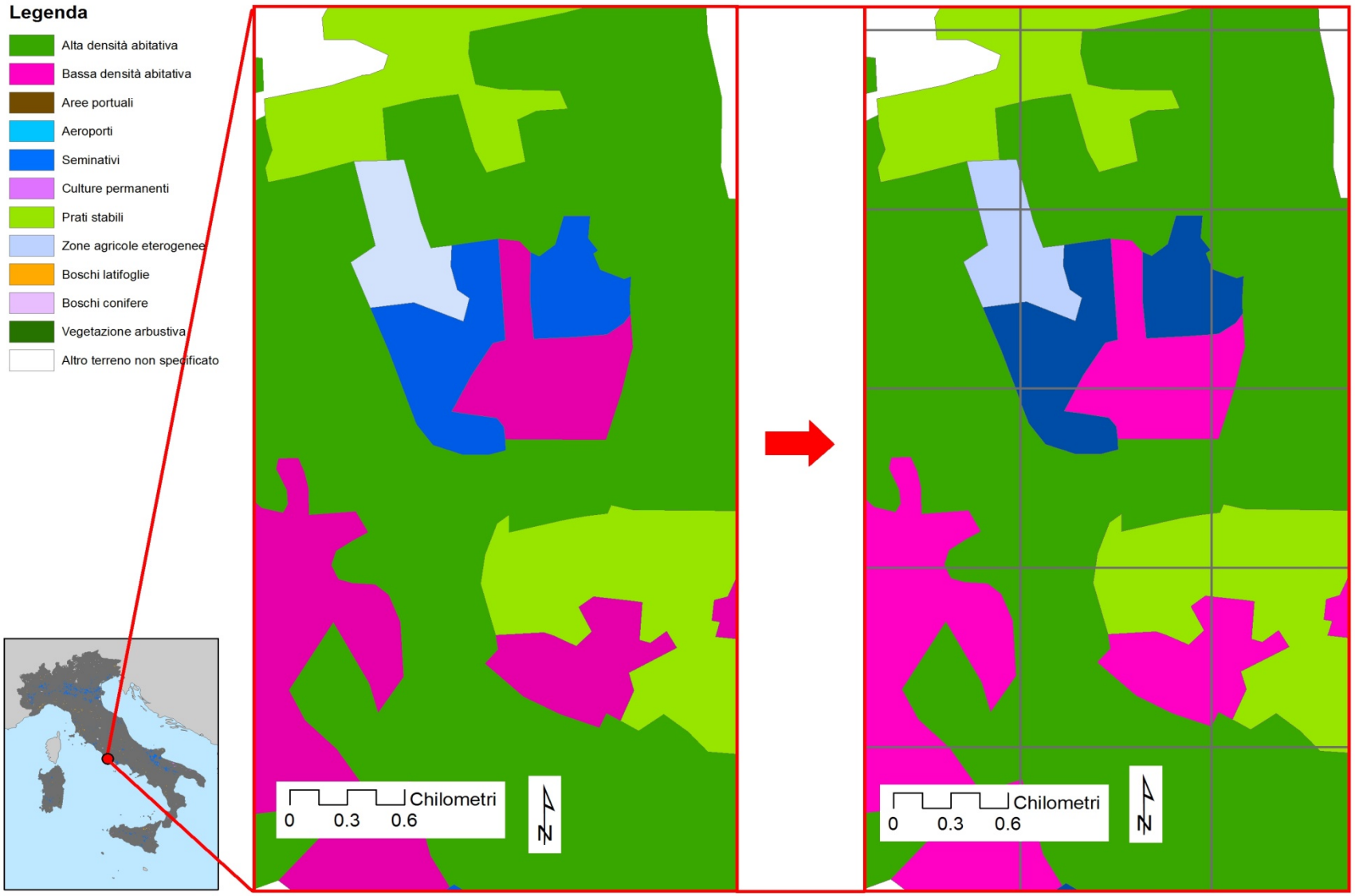
INDUSTRIAL EMISSION POINTS



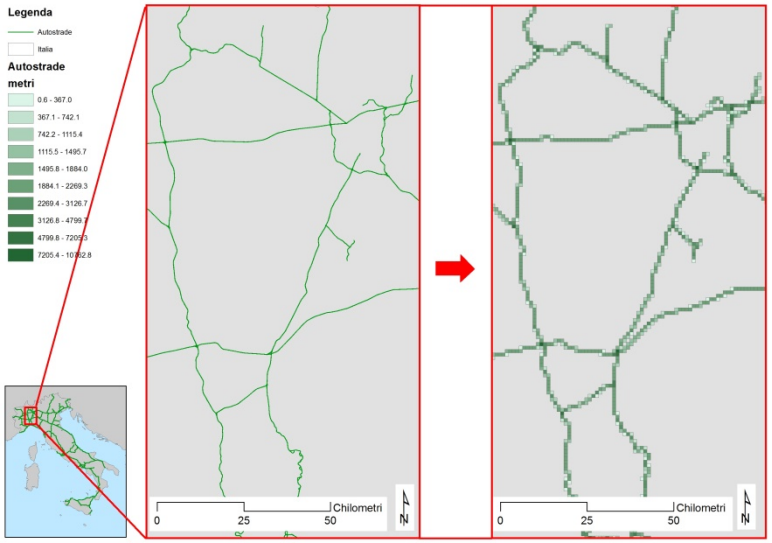
~ 700 industrial sites

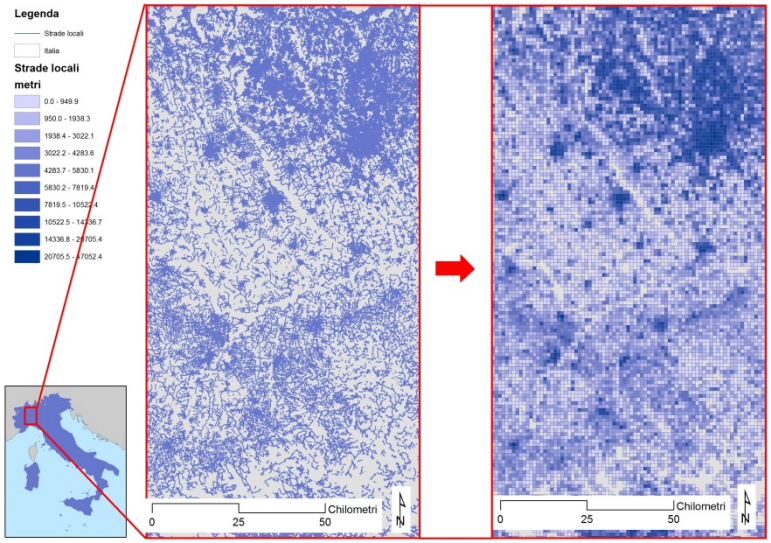


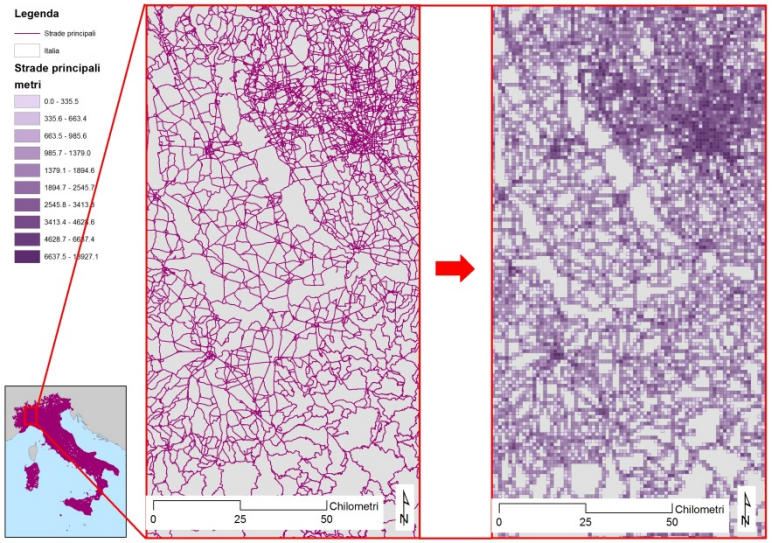
LAND-USE CHARACTERISTICS



ROAD NETWORK



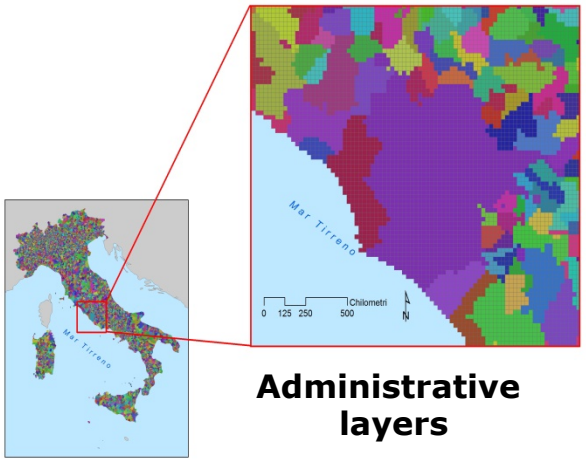




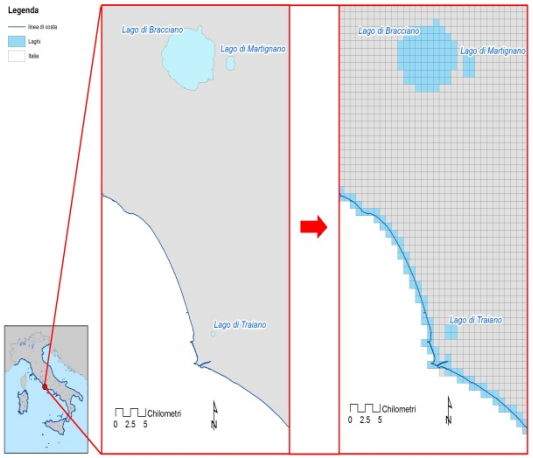
For each grid cell, and each of the three types of roads, two indicators:

- **DISTANCE** of the cell centroid from the closest road
- **DENSITY**, as number of meters of roads in the cell

OTHER SPATIAL PARAMETERS

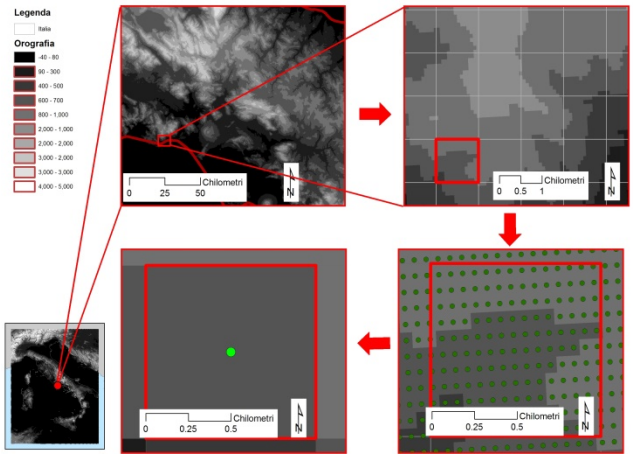


Administrative layers

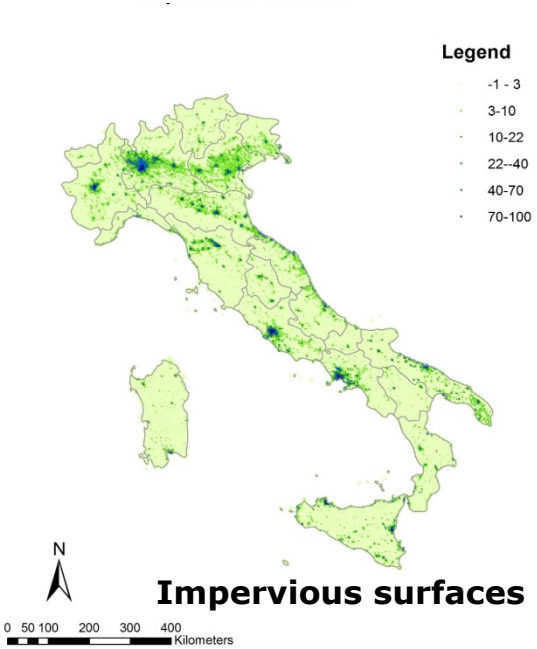


Water bodies

Geoclimatic zones

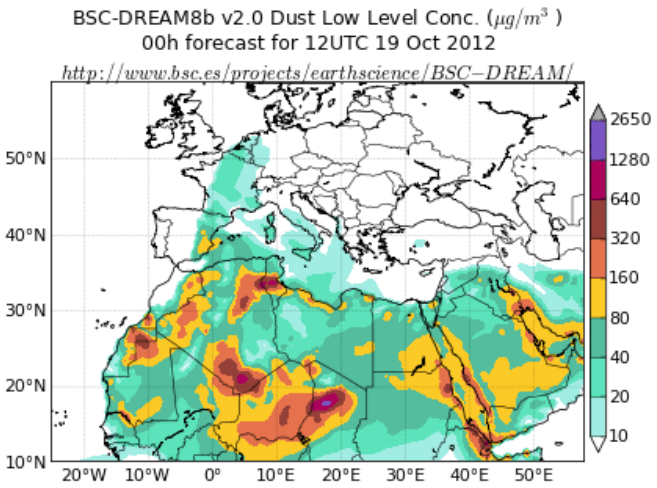


Elevation

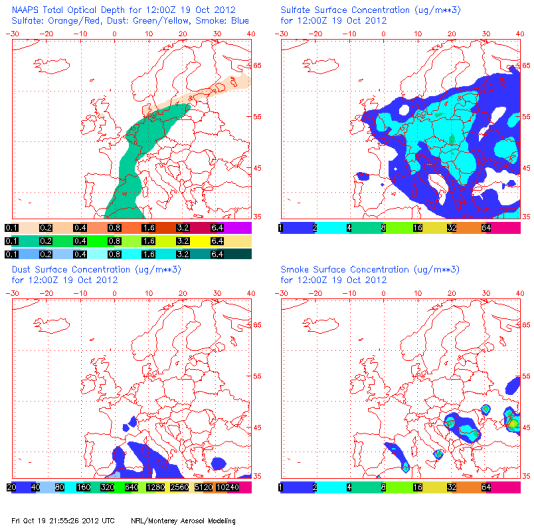


Impervious surfaces

SAHARAN DUST

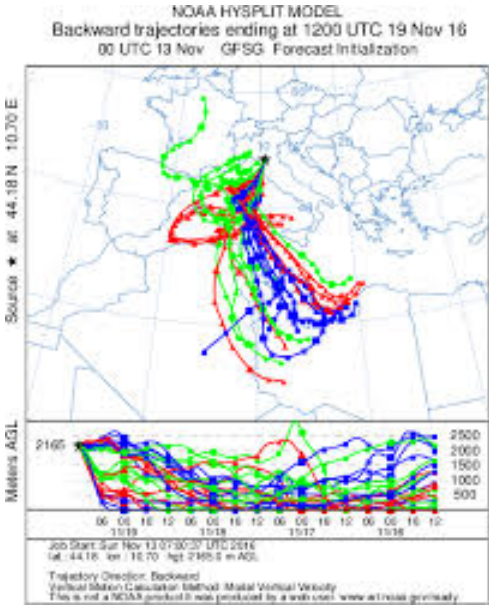


Surface dust concentration maps - **DREAM-BSC**

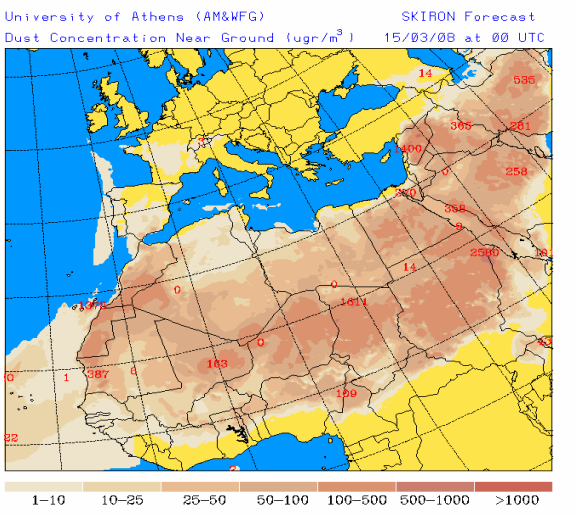


Surface dust, sulfate and smoke concentration maps

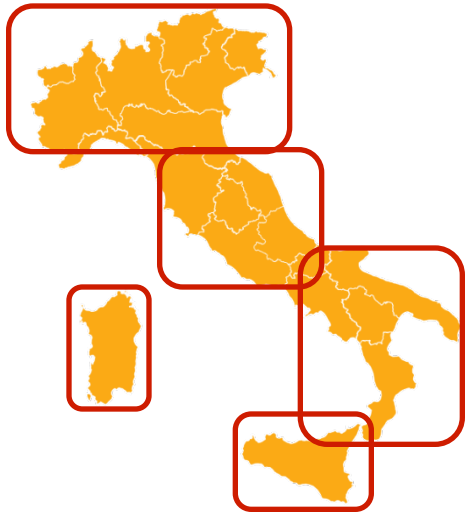
NAAPS-NRL



Back-trajectories - **HYSPLIT**

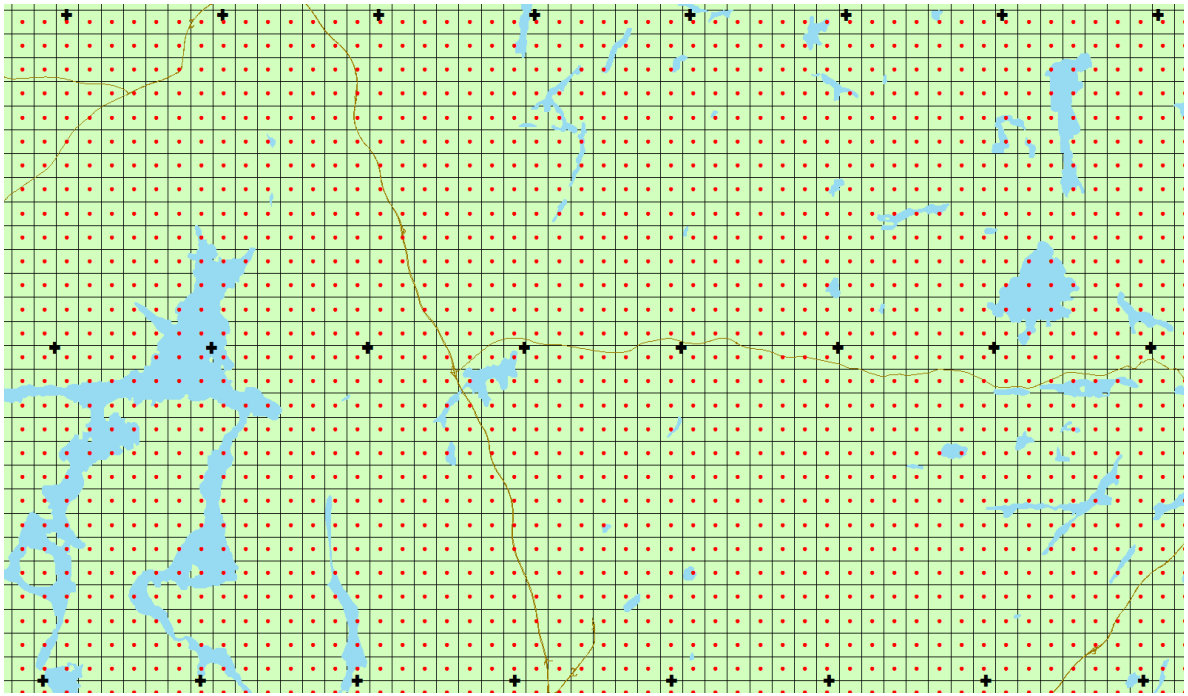


Integrated dust load maps **SKIRON** simulations



PLANETARY BOUNDARY LAYER (PBL)

- Planetary boundary layer (PBL) is the lowest part of the atmosphere, extending from ground to the bottom of where cumulus clouds form.
- ECMWF provides hourly estimates of the PBL height at different times of the day (0.00, 6.00, 12.00, 18.00) and different spatial scales (0.125°x0.125°, ~ 10x10-km for the purposes of this project).
- PBL data are provided at ~ 10km resolution. We attributed to each cell daily values at 0.00 and 12.00, based on proximity



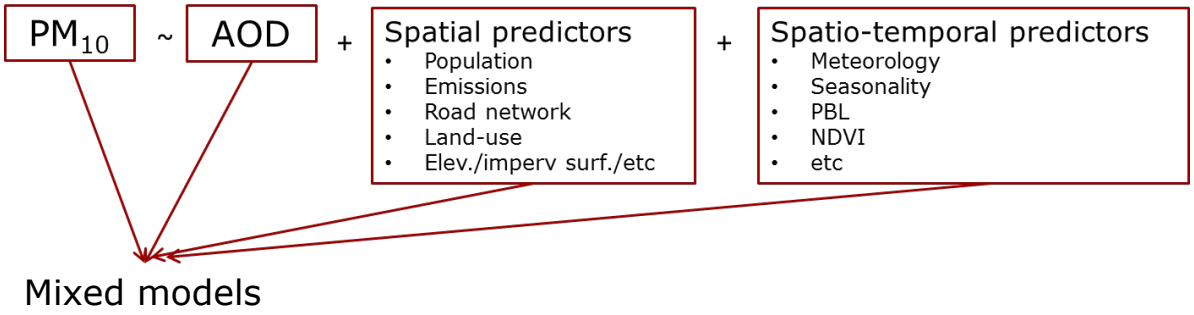
METEOROLOGICAL DATA

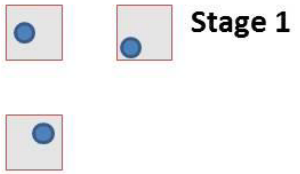
630 stations:

140 airport stations
200 ARPA Lombardia,
200 ARPA-E,
33 ARPA Lazio,
24 Toscana,
33 Wunderground (2006 -)

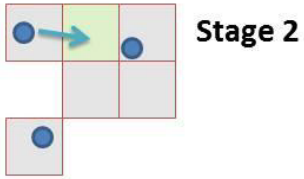
METHODS

4-stage approach

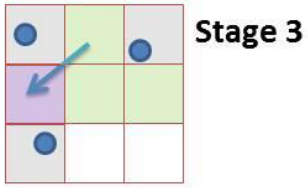




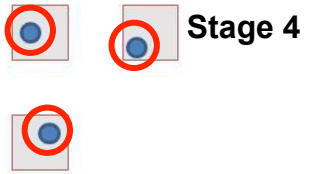
Fit daily calibrations using data from pixels with co-located PM and AOD
PM_{10} ~ AOD + other spatio-temporal pars. (with mixed models)



Use the calibration model fit to predict PM_{10} in grid cells and days with AOD but without monitors

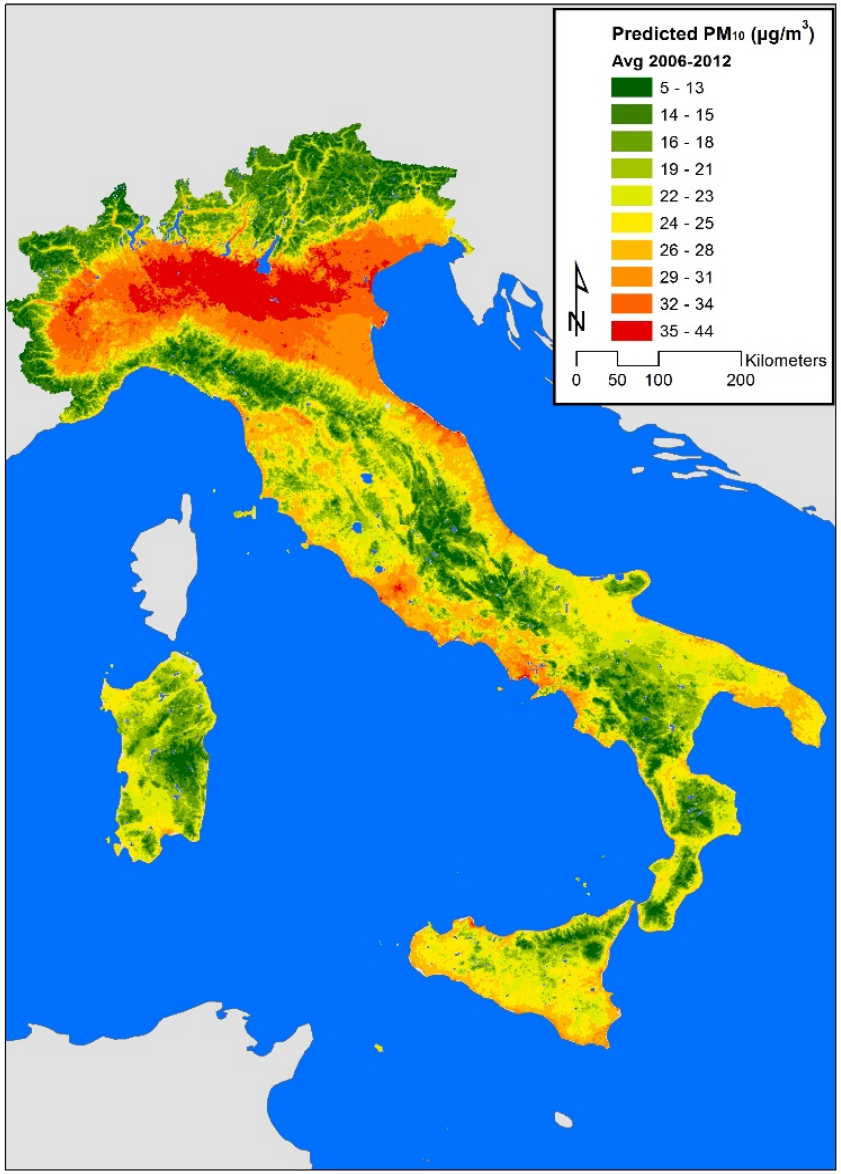


Estimate PM_{10} in cells with no available AOD data using spatial smoothing of nearby AOD and bimonthly regional patterns



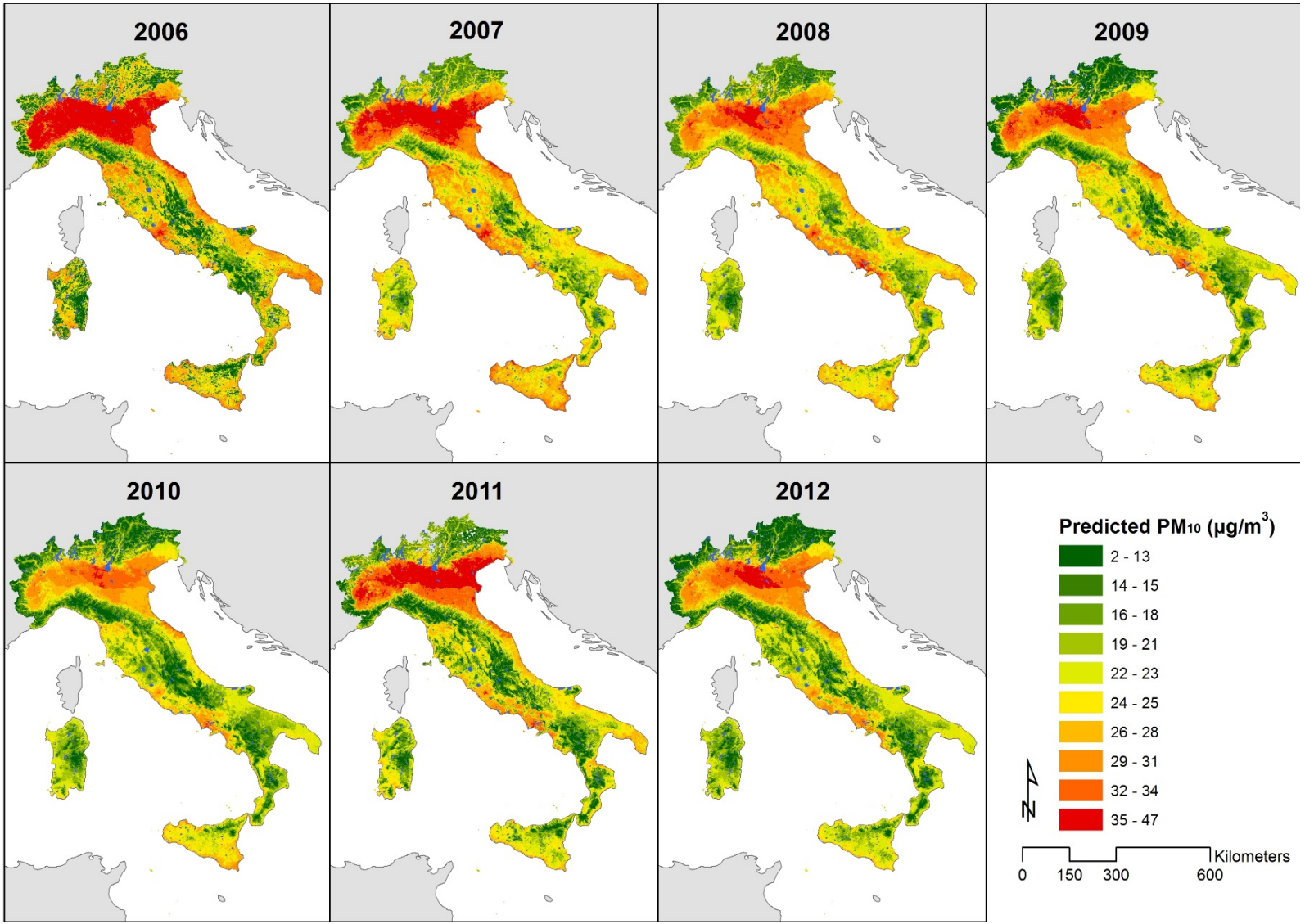
Improve Stage 1 PM_{10} predictions by capturing additional sources of PM variation within grid cell due to very local sources. We collected data on small-scale spatial predictors defined around each monitoring station, and regressing them on the residuals of the CV stage 1 model

RESULTS: Italy map



- Fine spatial detail
- Mean predicted PM_{10} from 5 µg/m^3 to 44 µg/m^3
- Predicted PM_{10} concentrations higher in the Po river valley, in major urban areas such as Rome and Naples, and close to the main industrial sites
- Lower on the Alpine and Apennine ridges

RESULTS: annual time trends



RESULTS: day-to-day variability