

“Capacity Building and Strengthening Institutional Arrangement”

Workshop: “Environmental Impact Assessment (EIA)  
(for Assessors)”

## **Environmental Impact Assessment Models: Atmosphere**

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Air quality mathematical models use numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere.

Based on inputs of meteorological data and source information like pollutant emission rates and stack height, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and, in some cases, secondary pollutants that are formed as a result of complex chemical and physical reactions within the atmosphere.

Atmospheric dispersion modelling is the mathematical simulation of pollutant dispersion in the ambient atmosphere. It is performed using computer programs that solve the mathematical equations and algorithms which describe dispersion of air pollutants.

The dispersion models are used to estimate or to predict the downwind concentration of air pollutants emitted from sources such as industrial plants and vehicular traffic. Such models are important for governmental agencies asked for protecting and managing ambient air quality.

The dispersion models require data input including:

- Meteorological conditions such as wind speed and direction, the amount of atmospheric turbulence (as characterized by what is called “atmospheric stability”), ambient air temperature and inversion layer height that characterize the so called “mixing height”.
- Emissions parameters such as source location and height, stack diameter and exit velocity, exit temperature and mass flow rate.
- Terrain elevations at the source location and at the receptor location.
- The location, height and width of any obstructions (such as buildings or other structures) along the path of the emitted gaseous plume.
- Many of the modern, advanced dispersion modelling programs include a pre-processor module for meteorological and other data, and also a post-processor module for graphing the output data and/or plotting the area impacted by the air pollutants with isopleth of the pollutant air concentration.

## Planetary Boundary Layer (PBL)

The lowest part of the troposphere is called atmospheric boundary layer (ABL) or planetary boundary layer (PBL) and extends from the Earth's surface to about 1.5 to 2.0 km in height.

The air temperature of the atmospheric boundary layer decreases with increasing altitude until it reaches what is called the inversion layer (where the temperature increases with increasing altitude) that caps the atmospheric boundary layer.

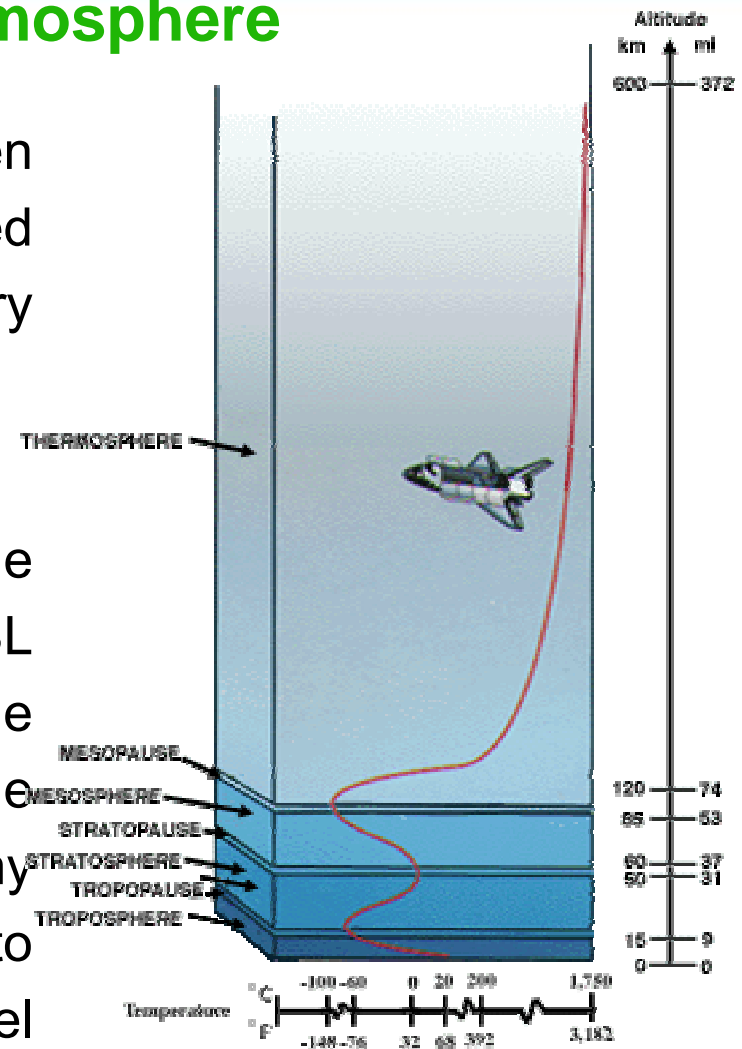
The upper part of the troposphere (i.e., above the inversion layer) is called the free troposphere and it extends up to the 80 km height of the troposphere.

The ABL is of the most importance with respect to the emission, transport and dispersion of airborne pollutants.

## Current state Characterization: Atmosphere

The atmospheric pollution phenomena happen in the lower portion of the atmosphere called “Planetary Boundary layer” (Planetary Boundary layer), or PBL.

The layers of the Earth's atmosphere from the surface of the ground upwards are: the ABL made up of the mixing layer capped by the inversion layer; the free troposphere; the stratosphere; the mesosphere and others. Many atmospheric dispersion models are referred to as boundary layer models because they model air pollutant dispersion within ABL.



Source: <http://liftoff.msfc.nasa.gov/>

## Meteorological conditions

The turbulence in the ambient atmosphere affect the dispersion of air pollution plumes because turbulence increases the entrainment and mixing of unpolluted air into the plume and thereby acts to reduce the concentration of pollutants in the plume (i.e, enhances the plume dispersion). It is therefore important to categorize the amount of atmospheric turbulence present at any given time.

A commonly used method for categorizing the atmospheric turbulence was the one developed by Pasquill in 1961. He categorized the atmospheric turbulence into six stability classes named A, B, C, D, E and F with class A being the most unstable or most turbulent class, and class F the most stable or least turbulent one.

## The Pasquill stability classes

Stability class	Definition	Stability class	Definition
A	very unstable	D	neutral
B	unstable	E	slightly stable
C	slightly unstable	F	stable



## Meteorological conditions that define the Pasquill stability classes

Surface windspeed		Daytime incoming solar radiation			Nighttime cloud cover	
m/s	mi/h	Strong	Moderate	Slight	> 50%	< 50%
< 2	< 5	A	A – B	B	E	F
2 – 3	5 – 7	A – B	B	C	E	F
3 – 5	7 – 11	B	B – C	C	D	E
5 – 6	11 – 13	C	C – D	D	D	D
> 6	> 13	C	D	D	D	D

**Note: Class D applies to heavily overcast skies, at any windspeed day or night**

■ Building effects or downwash: When a plume flows over nearby buildings or other structures, turbulent eddies are formed in the downwind side of the building.

The effect can greatly increase the resulting near-by ground-level pollutant concentrations downstream of the building or structure.

If the pollutants in the plume are subject to depletion by contact with the ground (particulates, for example), the concentration will increase just downstream of the building or structure and then further downstream will decrease.

Deposition of the pollution plume components to the underlying surface can be defined as either dry or wet deposition:

✓ Dry deposition is the removal of gaseous or particulate material from the pollution plume by contact with the ground surface or vegetation (or even water surfaces) through transfer processes such as absorption and gravitational sedimentation. This may be calculated by means of a deposition velocity, which is related to the resistance of the underlying surface to the transfer.

✓ Wet deposition is the removal of pollution plume components by the action of rain. The wet deposition of radionuclides in a pollution plume by a burst of rain often forms so called hot spots of radioactivity on the underlying surface.

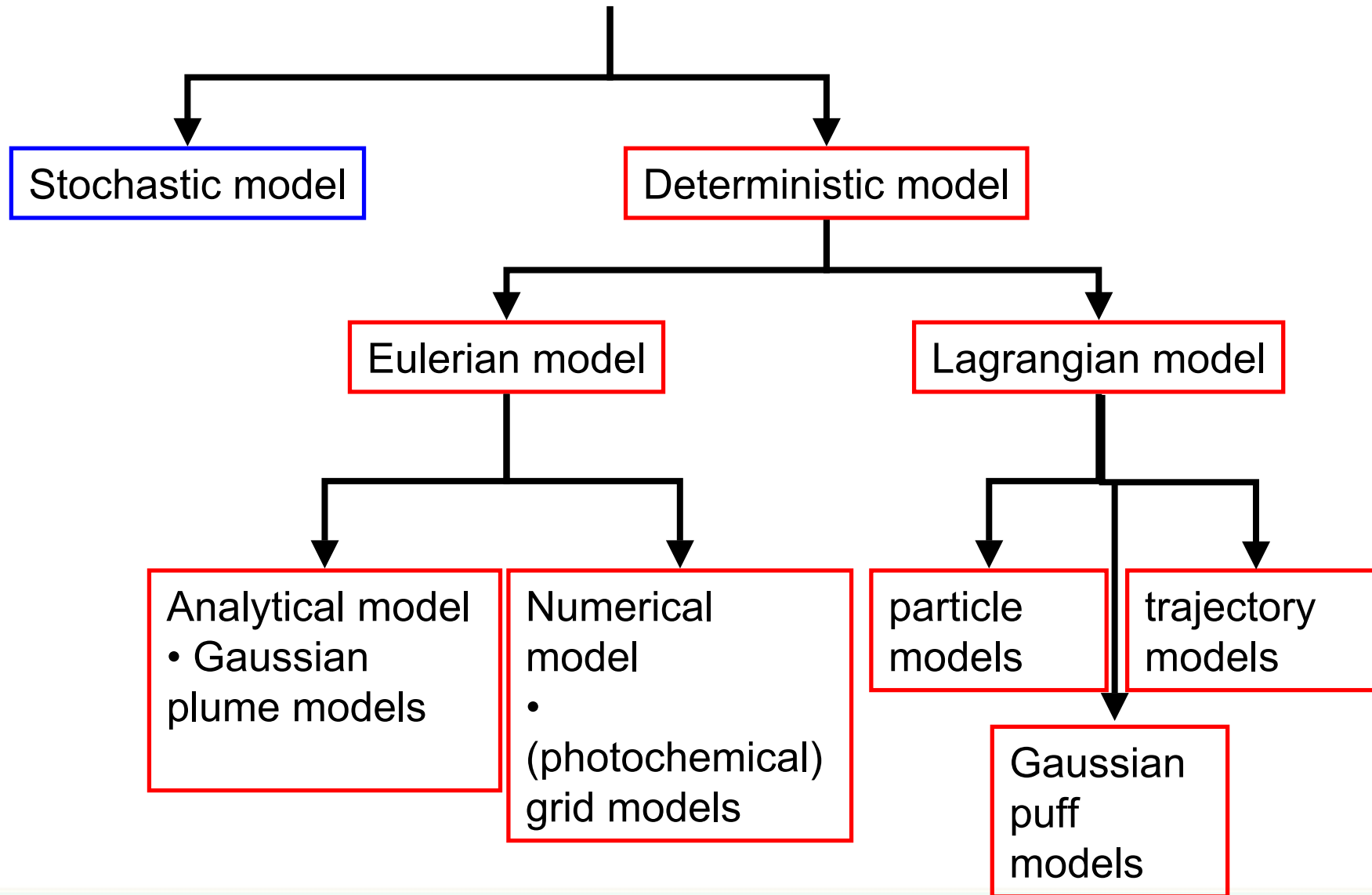
■ Inversion layers: Normally, the air near the Earth's surface is warmer than the air above it because the atmosphere is heated from below as solar radiation warms the earth's surface, which in turn then warms the layer of the atmosphere directly above it. Thus, the atmospheric temperature normally decreases with increasing altitude.

However, under certain meteorological conditions, atmospheric layers may form in which the temperature increases with increasing altitude. Such layers are called inversion layers. When such a layer forms at the earth's surface, it is called a surface inversion. When an inversion layer forms at some distance above the ground, it is called an inversion aloft.

■ Mixing height: When an inversion aloft is formed, the atmospheric layer between the earth's surface and the bottom of the inversion aloft is known as the mixing layer and the distance between the earth's surface and the bottom of inversion aloft is known as the mixing height. Any air pollution plume dispersing beneath an inversion aloft will be limited in vertical mixing between ground and the bottom of the inversion aloft.

A pollution plume may partially or totally penetrate the inversion layer. In this case the part of the plume that penetrates the layer does not affect the air at ground level in terms of pollutants concentration.

## Air Quality Models



There are various types of air pollution dispersion models:

■ Box model: The box model is the simplest of the model types. It assumes the airshed (i.e., a given volume of atmospheric air in a geographical region) is in the shape of a box. It also assumes that the air pollutants inside the box are homogeneously distributed and uses that assumption to estimate the average pollutant concentrations anywhere within the airshed. Although useful, this model is very limited in its ability to accurately predict dispersion of air pollutants over an airshed because the assumption of homogeneous pollutant distribution is very often unrealistic.

■ Gaussian model: The Gaussian model is perhaps the oldest (about 1936) and the most commonly used model type. It assumes that the air pollutant dispersion has a Gaussian distribution, meaning that the pollutant distribution has a normal probability distribution. Gaussian models are most often used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources. Gaussian models may also be used for predicting the dispersion of non-continuous air pollution plumes (called puff models). The primary algorithm used in Gaussian modelling is the *Generalized Dispersion Equation For A Continuous Point-Source Plume*.



The Gaussian models, calculate the concentration of the pollutants by using the equation of the Gaussian dispersion

$$\langle c_i(x, y, z) \rangle = \frac{Q_p}{2 \cdot \pi \cdot v \cdot \sigma_y \cdot \sigma_z} \exp\left[-\left(\frac{y}{\sqrt{2}\sigma_y}\right)^2\right] \cdot \exp\left[-\left(\frac{z-H}{\sqrt{2}\sigma_z}\right)^2\right]$$

The value of concentration in output is directly proportional to flow of pollutants ( $Q_p$ ), to height of emission sources ( $H$ ) but inversely proportional to the wind speed ( $v$ ) and to the deviation line standards values ( $\sigma_y$  and  $\sigma_z$ ) which depend on the transport time ( $t = x/v$ ).

The simplificative hypotheses initially mentioned are following:

- atmosphere stationarity and homogeneity;
- flat surface of the ground;
- absence of vertical flows;
- Axis  $x$  directed as the average of the wind speed;
- it is considered that the emission happens in a point to height  $H = h_s + \Delta h$  (plume elevation).

■ Lagrangian model: a Lagrangian dispersion model mathematically follows pollution parcels (also called particles) as the parcels move in the atmosphere and they model the motion of the parcels as a random walk process. The Lagrangian model then calculates the air pollution dispersion by computing the statistics of the trajectories of a large number of the pollution plume parcels. A Lagrangian model uses a moving frame of reference as the parcels move from their initial location.

The gaussian puff model is also a lagrangian model.

■ Eulerian model: The most important difference between the Lagrangian and Eulerian models is that the Eulerian model uses a fixed three-dimensional Cartesian grid as a frame of reference rather than a moving frame of reference.

## Meteorological data for modelling

When using a conventional model, we will need to obtain at least one (preferably two or more) year's data on the meteorology of the area, with high data recovery and verifiable data accuracy. In the simplest situations, the data may be limited to that necessary to provide reliable hourly average estimates, at a representative site, of:

- wind speed
- wind direction
- air temperature
- mixing height
- atmospheric stability

## Air pollutant emission sources

The basic technology for analyzing air pollution is through the use of a variety of mathematical models for predicting the transport of air pollutants in the lower atmosphere. The principal methodologies are:

- Point source dispersion, used for simple industrial sources.
- Line source dispersion, used for roadway air dispersion modelling
- Area source dispersion, used for urban zones, airports, dumping, forest fires etc.
- Volume source A volume source is a three-dimensional source of diffuse air pollutant emissions.
- Photochemical models, used to analyze reactive pollutants such as ozone

## Air pollutant emission sources

Other air pollutant emission source characterizations are:

- Sources may be characterized as either **stationary** or **mobile**. Flue gas stacks are examples of stationary sources and buses are examples of mobile sources.
- Sources may be characterized as either **urban** or **rural** because urban areas constitute a so-called *heat island* and the heat rising from an urban area causes the atmosphere above an urban area to be more turbulent than the atmosphere above a rural area.
- Sources may be characterized by their elevation relative to the ground as either **surface** or **ground-level, near surface** or **elevated** sources.
- Sources may also be characterized by their time duration:
  - **puff** or **intermittent**: short term sources (for example, many accidental emission releases are short term puffs)
  - **continuous**: a long term source (for example, most flue gas stack emissions are continuous)

The following list may not be exhaustive but is provided for checking purposes:

- trapping of plumes in mixed layers of limited height or, alternatively, penetration of plumes through elevated temperature inversions
- vertical plume dispersion in convective conditions
- fumigation of plumes into an encroaching mixed layer or thermal internal boundary layer near a coastline. Investigations of this phenomenon may require estimates of wind direction shear in stable layers
- sea breeze trapping, recirculation of pollutants
- near-surface dispersion under very stable calm conditions
- topographic influences - impact of plumes on elevated terrain, effect on spatially varying wind fields, valley winds (anabatic and katabatic winds), ponding of air in stable conditions
- surface roughness
- building wake effects, stack tip downwash (avoided by good engineering stack design)
- deposition, chemical transformation

## Modelling cumulative impacts

For each modelled pollutant, the assessment must account for existing concentrations caused by other sources plus (if significant) the background concentration (whether natural or manmade) in order to estimate the cumulative concentration.

Consequently, in order for the contribution to be properly assessed, the required modelling results should be presented for:

- the existing emissions plus background concentration (pre-proposal)
- the contribution by the proposed project (excluding existing emissions)
- the combined (existing plus proposed plus background) emissions

## Where air quality models are used in Italy?

- In predisposition of Environmental Impact Studies (EIS) of works subject to EIA (Environmental Impact Assessment) (DPCM 27 dic. 1988)
- In air quality evaluation and management (D. Lgs. 351/99 e DM 2 aprile 2002 n. 60)
- In air quality monitoring in addition to measurements (D. Lgs. 351/99 e DM 2 aprile 2002 n. 60)
- In the predisposition of protection plans and programs and air quality healing (D. Lgs. 351/99 e DM 1 ott 2002 n. 261)
- In the Strategic Environmental Assessment (SEA) (Direttiva 2001/42/CE)



A summary of data input for mathematical air quality models

## **input data related to the territory characterization**

➤ Orography and cartography

➤ **input data related to the meteorology**

▪ wind speed and direction; temperature; humidity; pressure and solar radiation at ground level.

➤ **input data related to the emtyissions**

▪ source localization; geometric characteristics, capacity and chemical nature of the pollutant emitted in atmosphere.

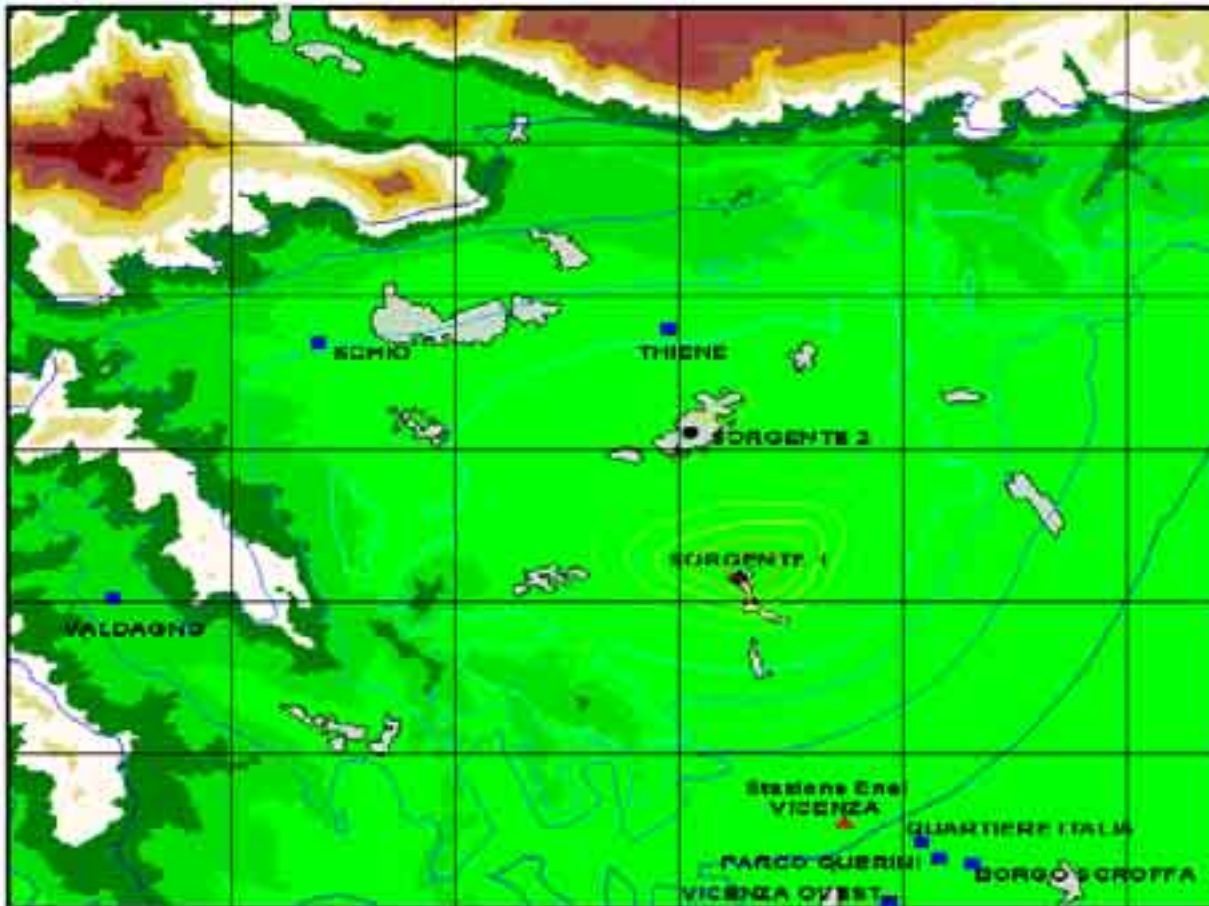
## **Data Output**

The data output of an air quality dispersion model consist in:

- Concentration maps at ground level
- Overlapping or comparison maps of the pollutant concentration

# Average annual concentration at ground level of NO<sub>x</sub> for industrial source ( $\mu\text{g}/\text{m}^3$ )

Velocità medio del livello totale di concentrazione



# Average daily concentration at ground level of particulate for linear source ( $\mu\text{g}/\text{m}^3$ )

