UNIVERSITA' POLITECNICA DELLE MARCHE

Master degree in Environmental Engineering

Department of Industrial Engineering and Mathematical Sciences

DISPERSION OF PRIMARY AEREAL POLLUTANTS IN VALLEY-COASTAL ENVIRONMENTS

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Summary

INTRODUCTION

This study was born as a collaboration between the Department of Industrial Engineering and Mathematical Sciences (Dipartimento di Ingegneria Industriale e Scienze Matematiche, DIISM) of Università Politecnica delle Marche (UNIVPM) and the Marche Region, with the aim of analysing in depth a portion of the Marche territory and study the impacts of the Ascoli Piceno macro-area on it from the point of view of atmospheric pollution, in order to also represent a tool to support statistical and epidemiological studies and the effects of exposure to fine particles on human health.
The domain analysed involved parts of the provinces of Ascoli Piceno and Fermo for a total of 43 municipalities and the data analysed refer to the year 2016.
The term 'atmospheric dust', or 'suspended particulate material' (PM), refers to a mixture of solid and liquid particles suspended in the air, variable in composition, mass and size, in relation to their different origin and the different meteorological conditions; in the present case the pollutant analysed was the PM_{10}, micro-particle with a diameter $\leq 10\mu m$.
It mainly derives from uncontrolled combustion (e.g. forest fires), marine aerosol, soil erosion processes (e.g. volcanic eruptions and wind transport), tire erosion from friction with road and rock erosion.
The work carried out in this thesis is based on the implementation of the input data relating to the chosen domain within the AERMOD software, i.e. a model for the simulation of the dispersion of pollutants over a short range in that part of the earth's atmosphere just above the earth and which is directly influenced by the heterogeneous presence of the earth's surface; this model has already been used for several years by public administrations, research bodies and universities.
The input data consist in an accurate definition of the domain that has been manually entered municipality by municipality within the software and the definition of the Source Pathway, for which all sources of the pollutant have been entered, dividing them into areal, linear and punctual; data relating to the site's meteorological and topographical characteristics were also entered.
The output data of the model consist of X-Y coordinates (UTM) of the 403 receptors distributed in the domain with the relative concentrations in $\mu g / m^3$ of PM_{10} calculated by the software that associates a concentration value to each receptor.

Of these 402 receptors, 2 are discrete receptors represented by the coordinates of the physical detection stations for atmospheric pollution of San Benedetto del Tronto (urban traffic) and Ascoli Piceno (urban area); once obtained from the software and sorted the PM_{10} concentration values, a statistical analysis was made to catalogue and study the data and compare them with the values recorded by the monitoring stations. The main objective of these analyses is to adapt and validate a computer modelling tool in order to carry out retrospective environmental and epidemiological

investigations, i.e. by inserting numerous and detailed input data in order to obtain reliable results at the same time.
The complexity of this study lies in the fact that the concentration of a pollutant in the atmosphere depends on many factors, first of all on the degree of mixing and therefore of dilution which begins at the instant of emission into the atmosphere and ends when the molecule of pollutant arrives at the receptor point, and secondly from the difficulty of representing in a realistic way the complex reality of the various activities that lead to the production of the particulate matter; for these reasons, this study is to be considered a preliminary result, although realistic, which requires validation and future investigations.

1. Physics and dynamics of the Earth's atmosphere

"Come è più difficile a 'ntendere l'opere di natura che un libro d'un poeta." (Leonardo da Vinci)

"How much more difficult it is to understand the works of nature than a book of a poet", with this sentence, the great inventor and artist Leonardo da Vinci well describes the human condition when we talk about nature and its laws and mysteries; little do we know about the origin of our Earth and its atmosphere as well.

The atmosphere is the gaseous cover that runs all around our planet and, according to scientists, it has no physical upper limit, as it gradually merges with the interplanetary space; however there is a lot of uncertainty about how far from the surface of the Earth this happens, just to confirm the difficulties we have at addressing certainty to such a complex reality. (Saha, 2008)

In any case scientists have been able to reconstruct a layered structure of the atmosphere considering the upper limit approximatively at 100 kilometers above the surface of the planet (UCAR, 2015); this structure is subdivided as follows moving from the Earth's surface from the upper limit:

- Troposphere,
- Stratosphere,
- Mesosphere,
- Thermosphere,
- Exosphere. (The exosphere gradually fades away into the interplanetary space).

The troposphere is the lowest layer of the Earth's atmosphere since its lower limit is the Earth's surface. The troposphere extends upwards up to an average value of about 10 km above sea level, this value is considered an average because the height of the troposphere varies with latitude (it is lower at the poles and higher at the equator) and according to the season (it is lower in winter and higher in summer): it can reach up to 20 km near the equator and up to 7 km at the poles in winter.

In the troposphere is concentrated most of the mass (about 75-80%) of the atmosphere and it is by far the wettest layer of the atmosphere; all of the layers above contain very little moisture; its composition is characterized by a 99% of molecular nitrogen and oxygen and by a 1% of a great series of gasses among which argon. (CSI, 2016)

The presence of the Earth's surface affects the temperature: the air is warmer in the lower part of the troposphere near the ground level and becomes colder as it rises through the troposphere; air pressure and density also decrease with altitude.

The boundary between the troposphere and its upper layer, the stratosphere, is called the "tropopause" while the fraction of the layer in contact with the Earth's soil is called the Planetary Boundary Layer (PBL).

The processes occurring in the troposphere are mainly responsible for weather disturbances and climate variability.

The stratosphere is the second layer of the atmosphere as you go upward and since this layer is right above the troposphere, which is 10 km high, the bottom of the stratosphere is located about 10 km above the ground in mid-latitudes and also varies according to troposphere variations, the top of the stratosphere is located at an altitude of 50 km. The upper boundary is called the stratopause.

The ozonosphere is located between 15-35 km of altitude and corresponds to the lower part of the stratosphere. In this area, some of the solar UV radiation is filtered by ozone, an unusual type of oxygen molecule that is relatively abundant in the stratosphere, causing the temperature to rise as you move upward through the stratosphere. This is exactly the opposite of the behavior in the troposphere, where temperatures drop with increasing altitude. Due to this temperature stratification, there is little convection and mixing between stratosphere and troposphere, so the air layers are quite stable.

Ozone is produced by the following reaction:

$$O_2 + \text{UV radiation} \rightarrow O + O$$
$$O + O_2 \rightarrow O_3$$

Then the solar radiation dissociates one molecule of ozone in one of diatomic oxygen and one of monoatomic oxygen:

$$O_3 + \text{UV radiation} \rightarrow O_2 + O$$

During the night, monoatomic oxygen, being highly reactive, combines with ozone to form two diatomic oxygen molecules:

$$O_3 + O \rightarrow 2\ O_2$$

To keep the amount of ozone in the stratosphere constant, these photochemical reactions must be in perfect balance with each other, but they are easily disturbed by molecules that may interfere in this balance, such as chlorinated compounds and others. (Wikipedia, 2021)

The composition of the air in the Stratosphere is similar to that of the Troposphere; the peculiarity consists in the fact that the gases of which it is composed appear more rarefied, moreover, the stratosphere is very dry; the air contains little water vapor; for this reason, few clouds are found in this layer.

The mesosphere is difficult to study, so very little is known about this layer of the atmosphere, it extends approximately from 50 to 85 km above our planet; the temperature decreases with height throughout the mesosphere and the coldest temperatures in the Earth's atmosphere, around -90 °, are found near the top of this layer.

The boundary between the mesosphere and the thermosphere is called mesopause.

Most meteors vaporize in the mesosphere and some materials persist in this layer so that it has a relatively high concentration of iron and other metal atoms.

The stratosphere and mesosphere together are sometimes referred to as the intermediate atmosphere. The thermosphere extends from about 90 km to between 500 and 1,000 km upward; this variation is due to the fact that a large part of the Sun's X-rays and UV radiation is absorbed in the thermosphere; when there is high-energy radiation, the thermosphere becomes warmer and expands.
Solar activity strongly affects the temperature in the thermosphere; temperatures in the upper thermosphere can range from approximately 500 ° C to 2,000 ° C or more. These high temperatures are due to the absorption of solar radiation by the atomic oxygen present in the mesosphere which ionizes; it is for this reason that the upper part of the thermosphere is called the ionosphere.
The boundary between the thermosphere and the exosphere is called the thermopause.
The most common definition says that space begins at an altitude of 100 km, at the bottom of the thermosphere because, even though the thermosphere is considered part of the Earth's atmosphere, the density of the air is so low in this layer that most part of the thermosphere is what we normally think of as outer space. In the upper thermosphere, atomic oxygen (O), atomic nitrogen (N) and helium (He) are the main components of air.
The exosphere is the highest region of the Earth's atmosphere as it gradually vanishes into the vacuum of space. The air in the exosphere is extremely thin, in many ways almost equal to the airless void of outer space. It is interesting knowing that not all scientists agree that the exosphere is really part of the atmosphere; some consider the thermosphere to be the highest part of the Earth's atmosphere and the exosphere is actually just a part of space, others consider the exosphere to be part of our planet's atmosphere; once again this enormous field of study has to deal with uncertainty.
The gaseous particles that reach and exceed the escape velocity no longer participate in the Earth's rotation and are dispersed in space, generally they are the lightest elements (hydrogen and helium), this phenomenon attributing to this layer a high degree of rarefaction and a particularly low density. (UCAR, 2015). (Holton, 2004)

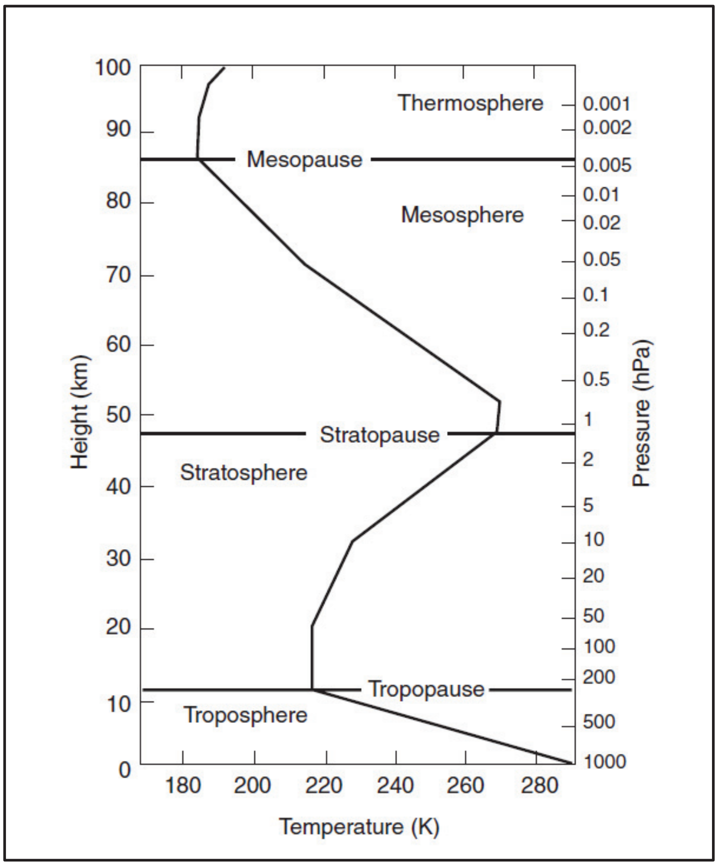


Figure 1.1 - Stratification of the atmosphere and midlatitude mean temperature profile. Based on the U.S. Standard Atmosphere (1976). (Holton, 2004)

1.1. Atmospheric phenomena

Atmospheric phenomena, on any scale, represent a manifestation of energy and the enormous amount of energy contained in the form of heat (manifest and latent) and mechanical energy in the atmosphere, comes from solar radiation.

The intensity of incoming solar radiation at the top of the atmosphere is called the solar irradiance; it was formerly known as the solar constant even if it is not since it varies from about -1360 to -1380 $W \cdot m^2$.

Some of this radiation is attenuated by scattering, absorption, and reflection from clouds on the way down to the surface. (Stull, 1988) (Twomey, 1974)

Solar radiation affects both the Earth's surface and the overlying gas phase.

The gas phase has the following irradiation modes:

• Convection: it is the main process of heat transfer within an aeriform fluid such as the atmosphere; the resulting heat flux is used in the definition of turbulence in the atmospheric boundary layer (PBL);

• Evaporation: a substantial part of the heat is spent in the passage of the state of water from the liquid state to the vapor, the heat necessary for this process is called "latent heat of evaporation"; a typical example of the release of energy retained in the form of vapor is represented by precipitation, the greater the heat contained in the atmospheric system, the greater the energy released during precipitation.

The solid surface, instead, radiated, undergoes the phenomena of reflection, storage and conduction; ‘the planetary albedo is simply the fraction of incident light from the sun which is reflected back into space by the earth. The light not reflected is absorbed by the atmosphere and by the surface and provides the energy input for driving the motions of atmosphere and ocean, maintaining the climate, and, in short, making the earth habitable.’ (Twomey, 1974)
The albedo varies from about 0.95 over fresh snow, 0.4 over light-coloured dry soils, 0.2 over grass and many agriculture crops, 0.05 over dark wet soils. The albedo of water is a strong function of sun angle; when the sun is directly overhead over a smooth water surface, the albedo is about 0.05, while it increases almost up to 1.0 at low elevation angles. (Stull, 1988)
The angle of incidence of solar radiation is greater in the equatorial regions than in the polar ones, therefore there is an imbalance, considering the first law of thermodynamics, between incoming and outgoing energy; this energetic imbalance is rebalanced by the atmospheric and oceanic circulation on a planetary scale.

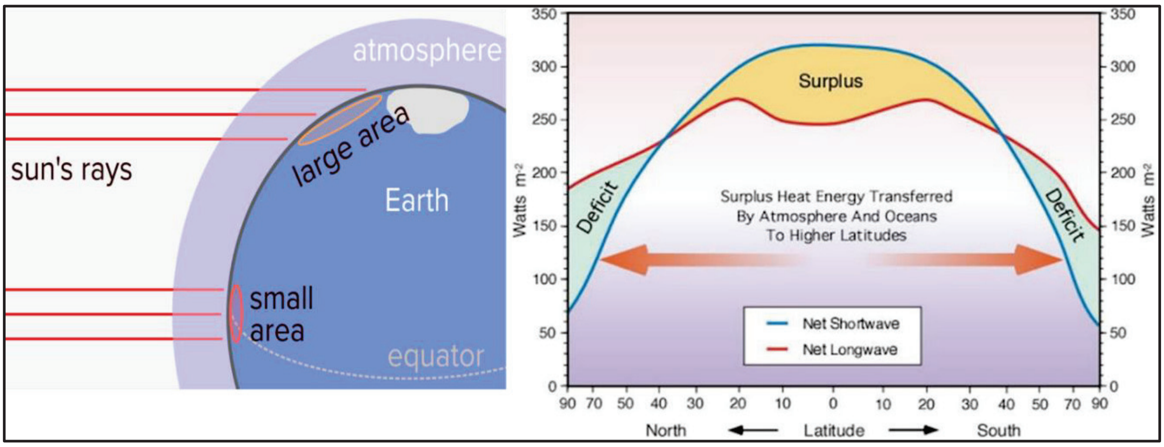


Figure 1.2 - Solar radiation incidence (right) and solar radiation imbalance (left)

So far the influence of solar radiation on atmospheric phenomena has been analysed, but it is important to consider the scale of the phenomenon to be analysed because, on a planetary and global scale, atmospheric circulation is influenced not only by solar radiation, but also by the forces due the rotation of the Earth and the breezes; for this reason, the scale analysis of the phenomenon is now shown in-depth.

1.2. Scale Analysis

The scale analysis of a phenomenon is the definition of the most appropriate scale to study it, in order to develop valid approximations in its physical-mathematical study, which translate into a simplification of some terms of the fundamental equations that regulate the motion of geophysical fluids.

The motions of the ocean and the atmosphere, can be analysed on different spatial and temporal scales, ranging from the size of the Earth over the years, up to the average free path of individual molecules.

The scales are: the planetary scale, the synoptic scale, the mesoscale and the small scale, also called microscale; an important property of all scales, (except the small scale), is that in them the motions are almost horizontal, i.e. the vertical component of the motion is more than an order of magnitude smaller than the horizontal component. (Wikipedia, 2021)

Since the type of atmospheric motion is so strongly dependent on the horizontal scale, this scale provides a convenient method for classifying motion systems: synoptic and planetary scale circulations which are large scale motions, are strongly influenced by the rotation of the earth so that outside the equatorial zone the Coriolis force dominates over inertia; while motions with horizontal scales of a few kilometres or less tend to have short time scales so the terms that imply the rotation of the earth are negligible.

The planetary scale covers distances greater than 1000 km, the mesoscale dynamics is generally defined to include the study of motion systems that have horizontal scales in the range from about 10 to 1000 km; the complexity is due to the fact that the systems are not superimposed on each other but are wedged together.

Below is the table with the different types of phenomena classified according to their horizontal scale. (Holton, 2004)

Type of motion	Horizontal scale (m)
Molecular mean free path	10^{-7}
Minute turbulent eddies	$10^{-2} - 10^{-1}$
Small eddies	$10^{-1} - 1$
Dust devils	$1 - 10$
Gusts	$10 - 10^{2}$
Tornadoes	10^{2}
Cumulonimbus clouds	10^{3}
Fronts, squall lines	$10^{4} - 10^{5}$
Hurricanes	10^{5}
Synoptic cyclones	10^{6}
Planetary waves	10^{7}

Figure 1.3 - Scales of atmospheric motion (Holton)

The time scale of atmospheric phenomena is proportional to the horizontal scale, this is shown below in a table extracted from "Hyerarchy of mesoscale flow assumptions and equations" by Thunis e Bornstein (1995). (P.Thunis, 1995)

L_H	Lifetime	Atmospheric phenomena
	1 month	General circulation, long waves
10 000 km		
		Synoptic cyclones
2000 km	1 week	
		Fronts, hurricanes
200 km	1 day	
		Low-level jets, thunderstorm groups, mountain winds and waves, sea breeze, urban circulations
20 km		
	1 h	Thunderstorm, clear-air turbulence
2 km		
		Cumulus, tornadoes, katabatic jumps
200 m	30 min	
		Plumes, wakes, waterspouts, dust devils
20 m	1 min	
2 m	1 s	Turbulence, sound waves

Figure 1.4 - Spatial and temporal scales of atmospheric phenomena

In the present case small-scale phenomena are of particular interest, so that the phenomenon of breezes is now being defined.

'The local diurnal winds induced by temperature difference between land and sea are defined as land and sea breezes; the wind that blows from land to sea by night is the land breeze; the wind that blows from sea to land by day is the sea breeze.' (Wexler, 1946)

Solar radiation is able to penetrate the water body several meters deep while in the ground it is able to penetrate only a few centimetres, so the heating occurs more slowly in the water than for the soil. Therefore, especially on summer days with good weather, the ground heats up quickly with the effect of also heating the layer of air in contact and decreasing its density.

For this reason the air above the ground tends to rise; the lifting of the air increases the pressure in height from the ground relative to that above the surface of the sea. The air rising above the mainland is replaced by cooler sea air (sea breeze), while the air from the high pressure zone above the mainland is moved towards the sea, completing the circulation of the cell.

At night the dispersion of heat by radiation is faster on land and the circulatory trend is reversed compared to that which occurs during the day, so that the warmer air tends to rise from the surface of the sea, it is replaced by cooler air from the mainland (land breeze) and in the altitude there is a flow in the opposite direction. Usually the temperature difference between the mainland and the sea surface at night is less than the one during the day, so the land breezes at night are weaker than the sea breezes during the day.

The rotation motion of the direction of the breezes is obviously not immediate as the phenomenon is linked to solar radiation during the hours of the day-time, then it progresses with the hours of the day and has a cyclical characterization in the event that the conditions of general meteorological stability are conserved. (Wexler, 1946)

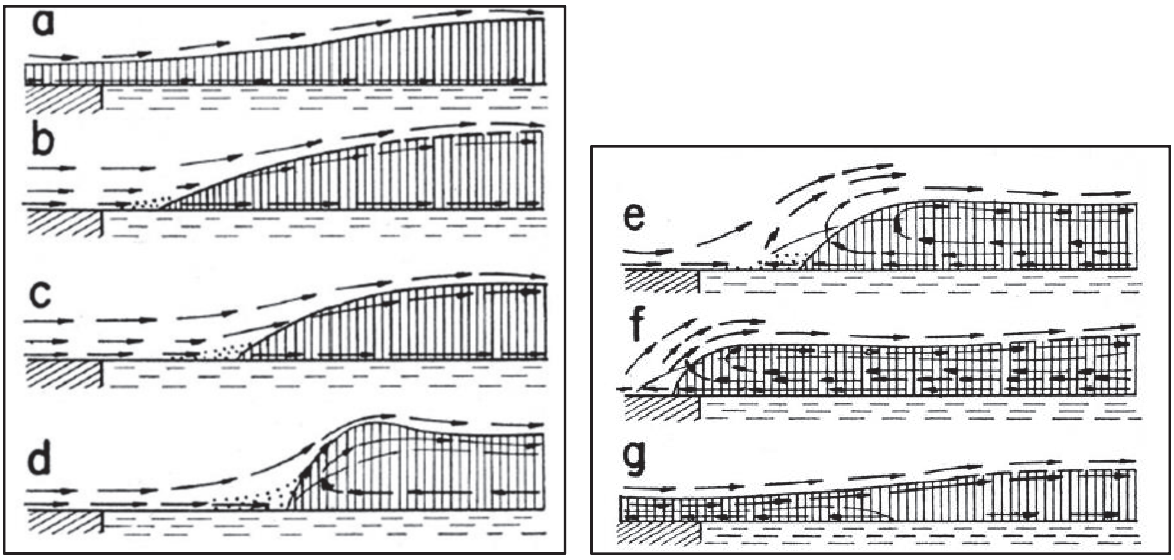


Figure 1.5 - Representation of the theory of the sea breeze (Wexler), the land is represented on the right; going from image a to g, it can be noticed the motion of the warmer air from the land to the sea in form of arrows, and the cold air from the see, represented with vertical stripes, that moves from the sea toward the land. The motion of the land breeze is the exact opposite.

1.3. Atmospheric stability

Stability is an important concept in relation to the atmosphere since, thinking about atmosphere, everyone would imagine something instable that tends to change in continuous, such as thunderstorms, clouds and cumulus which change just in few seconds.

On the contrary, something which is stable is defined as something that is in balance and unlikely to change; anyway, the formation of clouds and in general the vertical motion of the air is strictly related to the stability and, in turn, the instability of the atmosphere.

To address to this topic, it is usually referred to a parcel of air that can expand and contract but remains consistent in itself without mixing with the ambient air in the surroundings.

'Given some initial change in the elevation of an air parcel, if the air is in stable equilibrium, the parcel will tend to return back to its original position after it is forced to rise or sink; in an unstable equilibrium an air parcel will accelerate away after being pushed; the motion could be upward or downward, but generally unstable atmosphere favours vertical motions; finally, in a neutral equilibrium, an initial change in the elevation will not result in any additional movement'. (Alison Nugent, 2019)

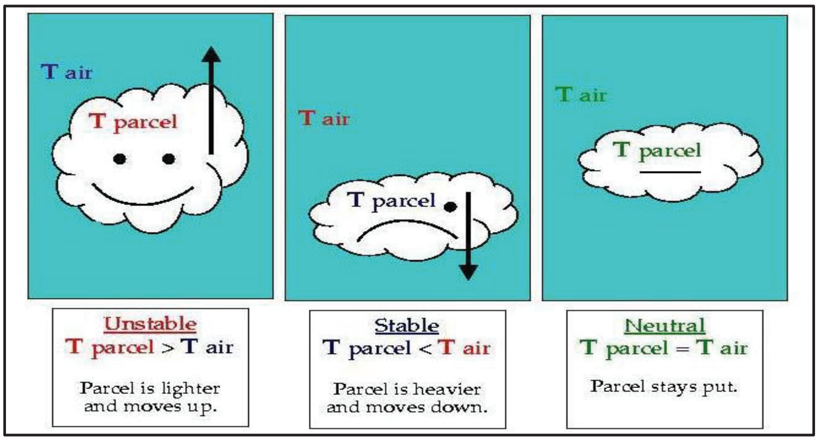


Figure 1.6 - Diagram describing stable, unstable and neutral air. (Image from Columbia University)

As shown in the image above, the vertical motion of the defined air parcel is imposed by a temperature gradient, imagine of having an air parcel at the ground level, if this parcel heats up, the particles increase their energy and tend to move fast and away so that the air parcel expands and decreases its density rising in the vertical direction; on the contrary, if it is colder than the surrounding in its new position, it will have less energy and higher density and it will tend to go down in a motion toward the bottom that is called 'sinking'. (Alison Nugent, 2019)

"Adiabatic" is called a process where the parcel temperature changes due to an expansion or compression, no heat is added or taken away from the parcel. The rate of temperature change with height is called "lapse rate", the unit of lapse rate is °C/km.

The changing behaviour of the atmosphere with temperature and altitude is shown in the following graph; in dry adiabatic conditions unsaturated parcels cool at a rate of 9,8 (~10)°C/km, in moist adiabatic conditions a saturated parcel of air cools at the moist adiabatic lapse rate of 5,9 (~6)°C/km. The moist adiabatic lapse rate is less than the dry rate because, as vapor condenses into water (in general when water changes status) for a saturated parcel, latent heat is released into the parcel, mitigating the adiabatic cooling. (Ackerman S.A., 2007).

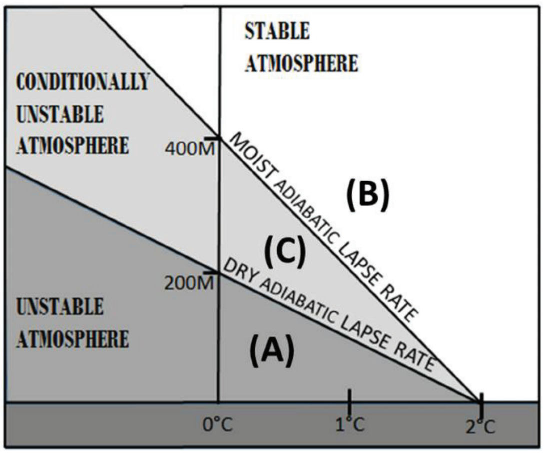


Figure 1.7 - Dry (9.8 °C/km) and moist (5.9 °C/km) adiabatic lapse rates (James Feiccabrino, Lund University | LU · Division of Water Resources Engineering)

In the case of unstable atmosphere, the slope of the real T gradient, called 'state curve', is less than or equal, in absolute value, to that of the adiabatic gradient, this means that the actual temperature decrease is equal or higher the dry adiabatic lapse rate (9.8 °C/km). (Feiccabrino J. et al. 2015).
Comparing the real vertical temperature profile with the dry adiabatic lapse rate for unsaturated parcels of air and with the moist adiabatic lapse rate for saturated air particles, air stability is determined. (Joseph M. Moran, 1991)

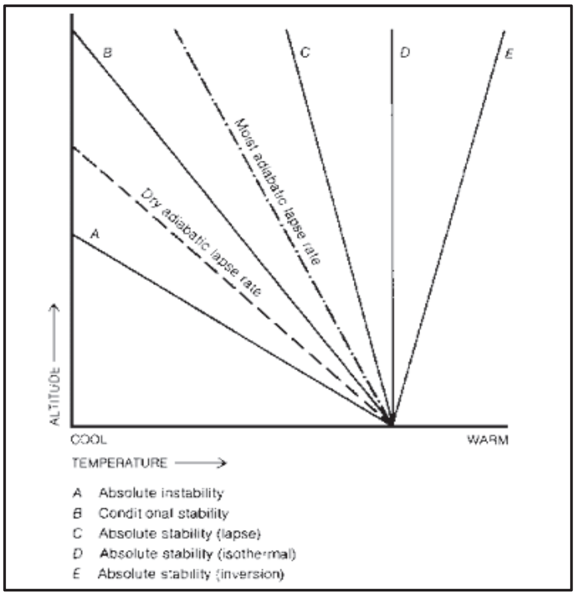


Figure 1.8 - Air stability (Joseph M. Moran, 1991)

Curve (A) represents the "superadiabatic" condition, it is in an unstable condition so the temperature of the state curve decreases faster than the adiabatic curve. The T of the rising bubble is always warmer than the surrounding one, so it always tends to rise. The atmosphere is very unstable in this condition and pollutants spread rapidly.
Curve (B) represents "neutral" conditions, the state curve is equal to the adiabatic gradient, an air bubble that starts rising will have colder and denser air, this will promote both ascending and descending vertical movement . There will be convection movements.
Curve (C) is the "subadiabatic" condition, the air T decreases with height but more slowly than the adiabatic curve. The air bubble will cool at a speed of 10 ° C km^{-1} while the surrounding air will do so more slowly, in this way the air in the bubble will be colder and denser and it will tend to go down.
Curve (D) "isothermal" condition, the T of the air is constant in height, the slope of the state curve is zero, air movement is not favoured.
Curve (E) represents the “inversion condition” generally found in winter and autumn in the Northern Hemisphere, air T increases with height instead of decreasing, a mass of hot air wins over a mass of cold air in so that the cold air layer does not have a possibility to rise and the pollutants released are stagnant, that is why inversions are thought as big covers.

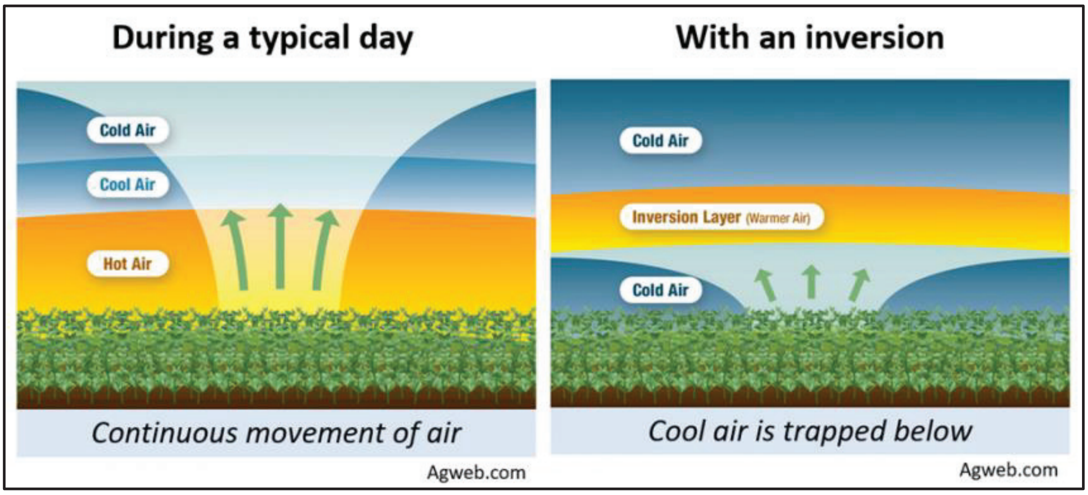


Figure 1.9 - Development of a Temperature Inversion. Iowa State University (Basol T., 2020).

As seen from Figure 1.8, the curves analysed divide the area into six slices, these represent the six atmospheric stability classes individuated by Frank Pasquill in 1961.
He assigned each class a letter from A to F going from the more unstable to the more stable plus the fog (which represents a class on its own); these classes are defined by the temperature of the atmosphere as already explained but not only, indeed relevant importance have the solar radiation, the direction and velocity of the wind and the cloud coverage. The six classes with their characteristic values for the listed parameters are presented below.

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

Figure 1.10 - Atmospheric stability classes by Pasquill

Wind velocity at surface	Solar radiation intensity			Night cloud coverage	
[m/s]	*strong*	*medium*	*weak*	*coverage > 4/8*	*coverage < 3/8*
< 2	A	A/B	B		
2 – 3	A/B	B	C	E	F
3 – 5	B	B/C	C	D	F
5 – 6	C	C/D	D	D	D
> 6	C	D	D	D	D

Figure 1.11 - Weather conditions defining Pasquill atmospheric stability classes (Wikipedia, 2017)

1.4. Planetary Boundary Layer (PBL)

The PBL can be defined as the lowest part of the troposphere, it is in strict contact with the planetary surface so that it is directly and profoundly influenced by it, the height of the PBL is largely driven by convection together with the changing surface temperature of the Earth (e.g. rising during the day and sinking at night), so that, as already described for the breezes, in this layer it is fundamental the influence of the solar radiation and, also, the dynamics of the winds. There are four main external factors which determine the PBL depth and its mean vertical configuration:

- the wind speed of the free atmosphere;
- the surface heat balance (i.e. buoyancy);
- the free atmosphere density stratification;
- the free atmosphere vertical wind shear (or baroclinicity).

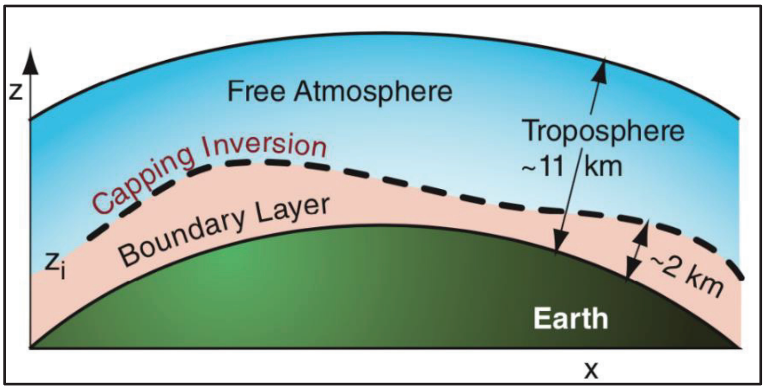


Figure 1.12 - Location of the boundary layer

The temporal scale in this layer is very small since meteorological phenomena can change very rapidly in the order of hours or less.
As said at the very beginning of this section, the solar radiation is the most important mechanism driving the motions in the PBL; when the radiation reaches the atmosphere, three things can happen:

- a part of the available energy is transmitted by conduction to the ground (Heat Flux in the ground);
- a part is used to evaporate the water present in the soil and vegetation (Turbulent Flow of Latent Heat);
- the rest is emitted from the ground and transmitted to the first millimetres of air and is transformed into irregular movements of the air masses of the PBL (Turbulent Flow of Sensible Heat).

The air that passes over the earth's surface exchanges energy and alters its physical characteristics since it receives sensible heat and latent heat from the ground and these are the sources of convective energy; moreover, due to the roughness of the soil, it loses energy due to friction (loss of mechanical energy). As with all turbulent fluids moving on a rough surface, a mechanical turbulence is therefore generated.
The reduction in speed near the surface is a function of the roughness of the surface, so the wind speed profiles change with different types of terrain; uneven terrain, rough and artificial obstacles on the ground can reduce the speed of the geostrophic wind (it is the balance of the pressure gradient and the Coriolis force) by 40% to 50%. The reduction may be only 20% to 30% on open water or ice. (Wikipedia, 2021)
The air flow, i.e. the wind, can be divided into three components: mean wind, waves and turbulence; each of these can exist separately or in partial presence of each of the others even if, in reality, waves and turbulence are commonly superimposed on the mean wind.
In the PBL, the propagation of phenomena such as heat, momentum, humidity and pollutants is dominated horizontally by the mean wind and vertically by turbulence.
The mean wind is obviously responsible for the rapid horizontal transport: advection; the horizontal speed values that characterize the advection process are commonly in the range of $2 \div 10\ ms^{-1}$; however, it should be noted that friction with the ground causes a decrease in the horizontal speed of the average wind near the ground itself. The vertical speed of the average wind is rather modest, generally in the order of millimetres or centimetres per second (on flat ground and in conditions of weak solar radiation).
The flow in the PBL is generally turbulent; turbulence is generated by non-linear effects that overlap the mean flow and can be visualized as a set of vortices of different sizes interacting with each other and with the mean flow; the energy associated with each vortex scale defines the turbulence

spectrum. It is useful considering that most of the turbulence in the PBL is caused by forcing related to the presence of the ground. (Ferrero, 2009)

During the day, when the net radiation (RN)> 0, the energy lost by friction is mostly less than the one acquired by convection (Convective situations); while at night (Rn <0), there is only a global loss of energy (Stable Situations).

Obviously, the way in which pollutants are dispersed is also different in the two cases. (Roberto Sozzi, 2002)

1.4.1. Convective PBL

During the day, the heat absorbed by the soil is reintroduced to the soil-atmosphere interface by means of various mechanisms and two completely different sources of turbulence are established: the first is mechanical, common to all viscous fluids moving on a rigid and rough surface and which gives rise to vortices of relatively limited size, the second is of the convective type and therefore of thermal origin, which produces vortices (thermals) of much larger size on which the Archimedes force acts due to the difference in air density of the vortices with respect to the surrounding air. Their driving force is therefore buoyancy and their dimensions are much greater than those of mechanical origin, reaching many hundreds of meters.

The generation of hot bubbles or thermals and their rise in the PBL causes the vertical profile of the mean potential temperature in convective situations to have a very precise shape, like the one reported below. (APAT, 2003)

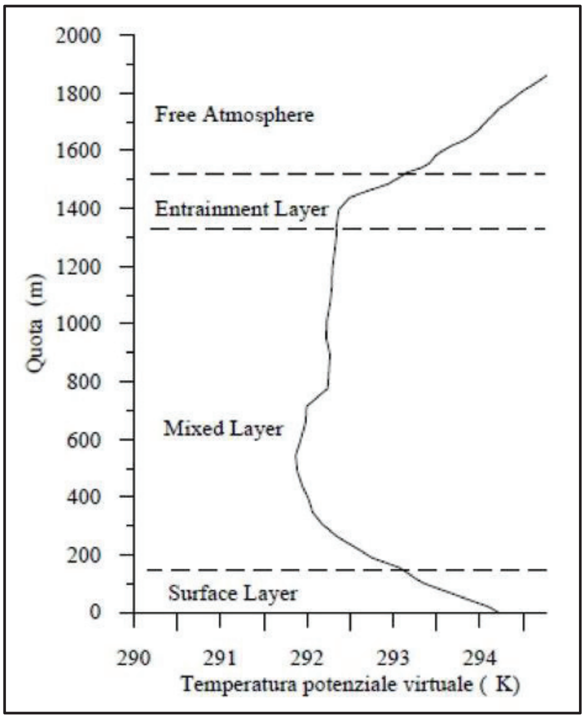


Figure 1.13 - Vertical profile of the mean potential temperature

Surface layer (SL), 0-100m, the potential temperature decreases with height (instability) is a kind of upward catapult for the flow of particles (pollutants).
Mixed layer (ML), the potential temperature is almost constant (static adiabatic) a particle that reaches the ML from the SL encounters no obstacles to its upward movement, with the exception of aerodynamic resistance.
Entrainment layer (EL), there is a strong positive potential temperature gradient, there is air infiltration from the upper layers.
A particle arriving here from SL and ML will be in stable conditions and will tend to stop its motion, at this point the particle will be enclosed in a descending vortex and will arrive on the earth's surface where it will be thrown upwards again in a cycle that will end only when solar radiation ceases; this is why pollution is actually trapped in the PBL.
Free atmosphere layer, the potential temperature constantly increases.

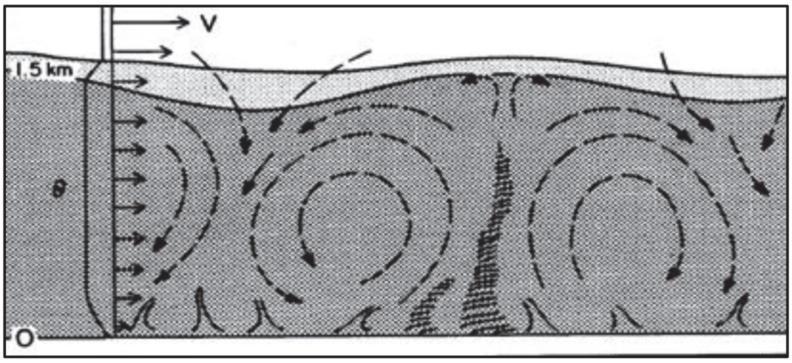


Figure 1.14 - Structure of turbulent vortices (Wyngaard, 1990)

Therefore, in the PBL we can identify:

- an ascending flow (updraft) which consists of large vortices that originate near the ground, rise in the SL and in the ML reaching the entrainment layer where they mix with a part of the free atmosphere;
- a descending flow(downdraft) that slowly descends towards the ground.

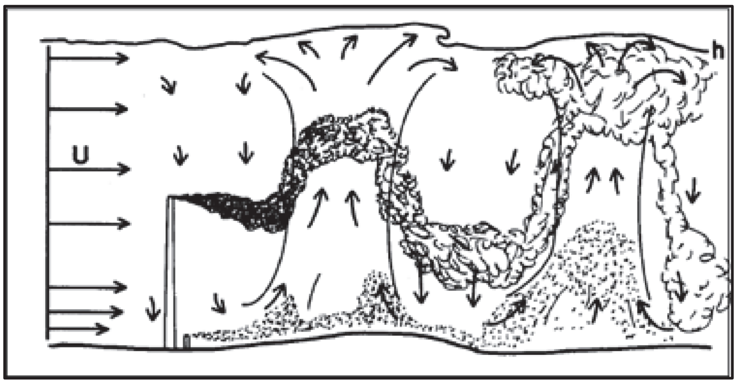


Figure 1.15 - Behaviour of updraft and downdraft flux in the convective PBL (Briggs, 1998)

As regards the vertical profile of the wind speed, the no-slip condition determines a zero speed near the ground (not exactly on the ground, but in correspondence with a small but variable altitude, depending on the vertical dimensions of the elements present on the ground that determine its roughness). As the altitude increases, the wind speed increases approximately logarithmically within the SL in which the presence of shear is a clear indication of the mechanical turbulence always present in a viscous fluid such as the atmosphere. Within the ML the wind speed remains approximately constant and the shear is reduced, indication that here the production of mechanical turbulence is reduced. Vice versa, in entrainment layer the wind speed changes, rapidly adapting, with increasing altitude, to the situation dictated by large-scale pressure gradients (geostrophic wind). Both the evaporation from water bodies (oceans, lakes and rivers) and the transpiration of vegetation makes the Earth's surface as the main source of the humidity of the PBL

Humidity tends to decrease with the altitude with a relatively high rate within the SL, remaining almost constant in the ML. In correspondence with the Entrainment Layer, there is a rapid decrease in it until it virtually disappears in the Free Atmosphere (this is not generally true, especially when there are synoptic clouds). The physical structure of the PBL constitutes a trap also for the humidity of the air. (APAT, 2003)

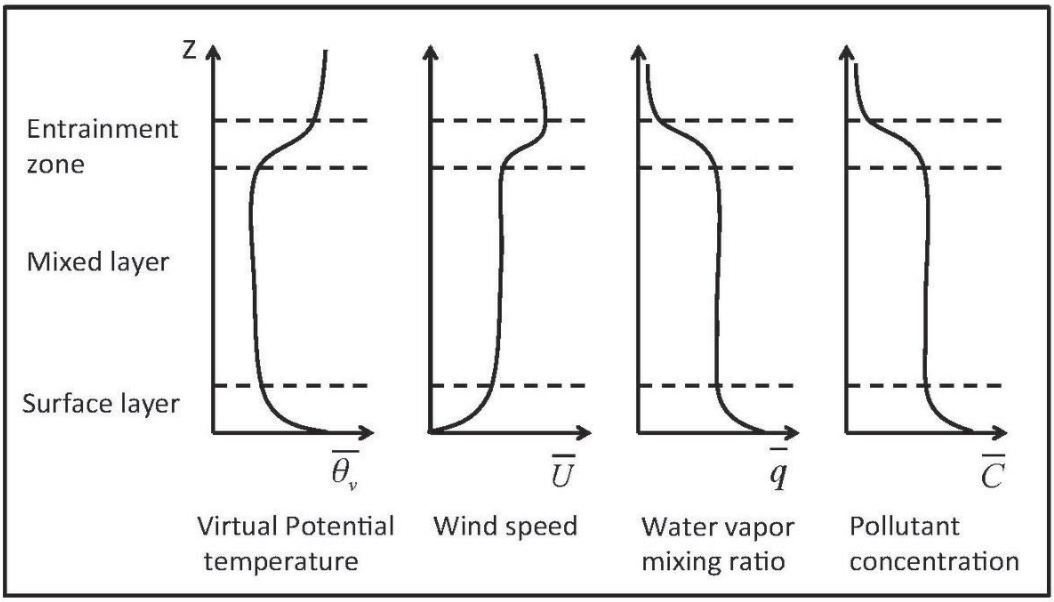


Figure 1.16 - vertical profiles of the main physical quantities

Above the earth's surface, the PBL assumes a well-defined structure, with different components:

- mixed layer;
- residual layer;
- stable boundary layer.

If there are clouds in the BL, there is the affirmation of an additional layer called the cloud layer with its substrate, the sub-cloud layer.
The vertical extension of the PBL presents a characteristic diurnal evolution:

⇒ it is minimal in the early morning (only due to mechanical turbulence);
⇒ it increases with the arrival of solar energy until sunset and in particular in a proportional way to the integral over time of the sensible heat turbulent flow;
⇒ it decays very quickly at sunset with the loss of solar energy.

It is worth describing the characteristics of the residual layer as it represents the moment of connection between one day and the next and justifies the choice of simulating the behaviour of pollutants through the use of models that are able to maintain their environmental conditions and concentration even during the night between one day and the next.
The residual layer generates at sunset, when the solar energy supply ceases and the thermal winds that characterize the mixed layer disappear. The daytime conditions of temperature, humidity and pressure, however, cannot suddenly dissolve, passing from the highly energetic mixed layer to a state of absolute calm: hence the formation of the residual layer.

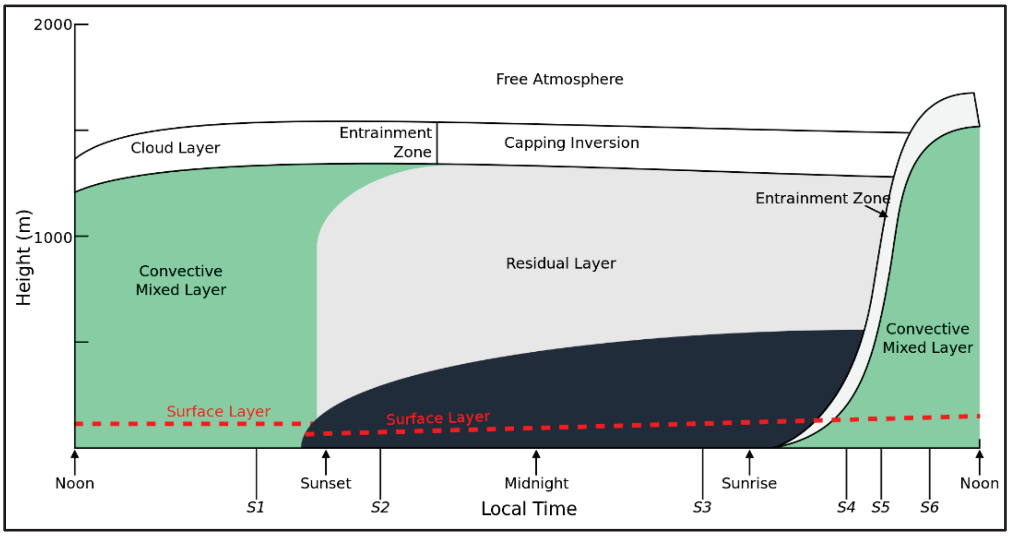


Figure 1.17 - Different zones of the PBL in its daily evolution

The pollutants dispersed during the day obviously remain in the BL's night setting; turbulence assumes a constant trend with height, and the result is observable in the shape of the plumes.
In fact, it is in this region of the atmosphere that is in closer contact with the ground, that the dispersive processes take place; here is where the release of pollutants happens, which are diffused and transported by atmospheric movements.
The release of pollutants generally involves a chimney, concerning industrial activities or even the domestic heating, so it is possible to study the way in which the pollutant spreads into the ambient air through the analysis of the plumes generated from the top of a chimney. (C.R. Mechoso, 2015)
There are five classic plume types that relate to the stability of the atmosphere and two of them are related to the convective case:

- looping profile,
- coning profile.

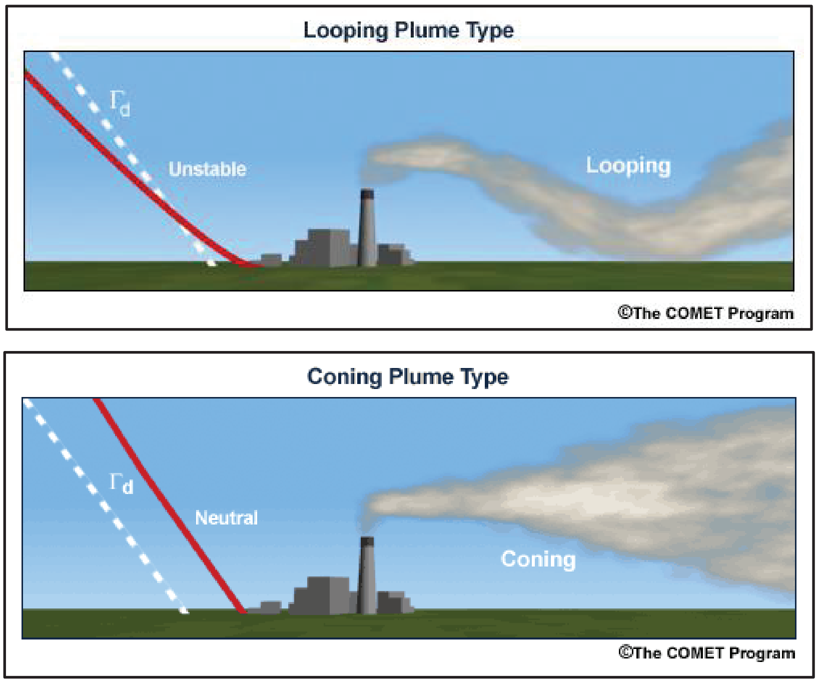


Figure 1.18 - Profile of the plume for different atmospheric conditions (COMET)

Looping profile, unstable situation; turbulence causes a good dispersion of pollutants which are mixed and the plume reaches the ground in a point very close to the emitting spot.

Coning profile, it is a neutral situation in the nocturnal asset, the state curve is similar to the adiabatic so that the plume has a neutral behaviour itself and has a conical shape.

1.4.2. Stable PBL

An SBL is typical at night time in all locations and also during the day in places where the earth's surface is colder than the air above.
During the night the lower part of the residual layer, the one that would come into contact with the ground, evolves into a condition of extreme stability, presenting new characteristics:

• Statically stable air
• Weak and sporadic turbulence.

The wind on the ground becomes calm or weak, as opposed to the wind at altitude which assumes supergeostrophic speeds, taking the name of ‘low-level nocturnal jet’; the result is that the resulting energy is released through sudden and circumstantiated phenomena of mixing in the SBL.
Winds have a very complex character during the night: just above the ground the speed is small or zero, around 200 meters in height the winds have more important components following the shear induced by the jets above; there is also the possibility of katabatic winds of descent due to gravity and colder air density from the slopes. (APAT, 2003)

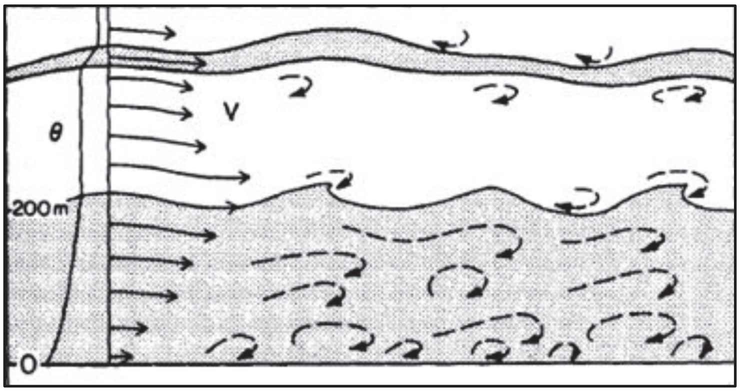


Figure 1.19 - Pictorial representation of the stable PBL (Wyngaard, 1990)

A typical potential temperature profile in a night situation is that of Figure 1.20, during the night a Stable Layer (SBL) with weak and sporadic turbulence forms near the ground.

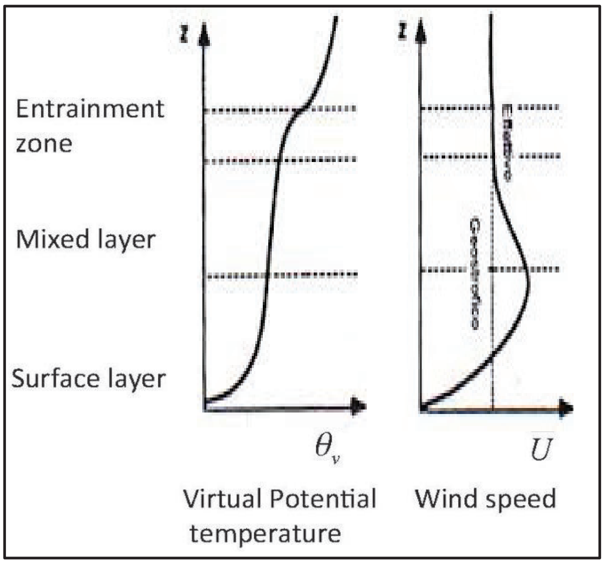


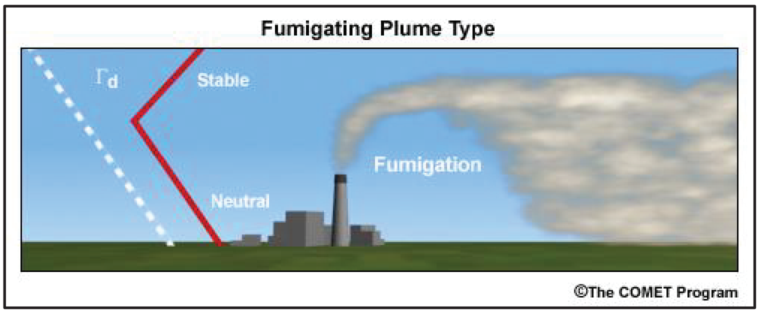
Figure 1.20 - Vertical profiles of the mean potential temperature and mean wind modulus, in the SBL (in a high pressure region); (Stull, 1988)

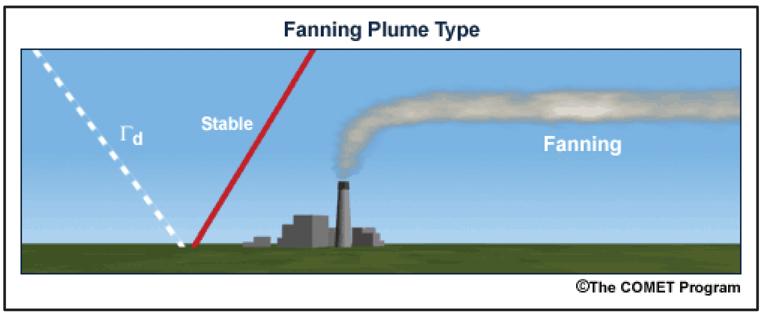
The temperature trend during the night, obviously in close connection with the turbulence, has a decisive influence on the positioning of the plumes, these have different characteristics from those of the two plumes already seen in the case of the convective PBL, and are identified as follows:

• fanning profile;

• fumigation profile;

• lofting profile.





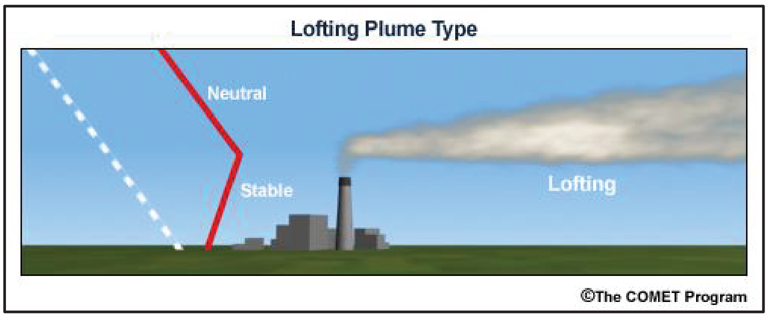


Figure 1.21 - Profile of the plume for different atmospheric conditions (COMET)

Fanning profile, it is a stable condition, the dispersion of the plume is minimal and it is called a 'fan-shaped' plume, it tends to spread in the horizontal while staying confined in the vertical direction.

Fumigating profile, again a stable situation, the thermal inversion occurs above the stuck height and superadiabatic conditions are found below the inversion layer, this is the most dangerous profile since pollutants are dispersed directly to ground level.

Lofting profile, stable situation, there is a thermal inversion below the stuck height; subadiabatic conditions above the stuck height enhance limited vertical movements and the shape of the plume is conical; it is favourable in terms of impact at ground level.
Looping profile, unstable situation; turbulence causes a good dispersion of pollutants which are mixed and the plume reaches the ground in a point very close to the emitting spot.

1.5. Atmosphere chemical structure

Our planet is the only one in the entire solar system with an atmosphere capable of supporting life. (Sharp, 2017)
The three main constituents of the earth's atmosphere are nitrogen, oxygen and argon, but there are many other compounds that characterize the composition of the atmosphere, for example water vapor even though it represents about 0.25% of the atmosphere by mass.
Here a list of the components of the atmosphere:

- Nitrogen (N_2) 78.084 %
- Oxygen (O_2) 20.946 %
- Argon (Ar) 0.9340 %
- Carbon dioxide (CO_2) 0.041361 %
- Neon (Ne) 0.001818 %
- Helium (He) 0.000524 %
- Methane (CH_4) 0.000187 %
- Krypton (Kr) 0.000114 %
- Water vapour (H_2O) 0–3%

Atmospheric gas concentrations are typically indicated in terms of dry air (no water vapor).

The concentration of water vapor (a greenhouse gas) varies significantly from about 10 ppm by volume in the parts of the atmosphere which are cooler, to 5% by volume in warm and humid air masses.

Other gases are often referred to as trace gases, greenhouse gases are listed in this category, but also carbon dioxide, methane, nitrous oxide and ozone.

In addition to argon, already mentioned, there are also other noble gases, neon, helium, krypton and xenon. In any case, the composition of the atmosphere is a complex issue since unfiltered air includes traces of many other chemical compounds; many substances of natural origin can be present in small quantities which vary locally and seasonally as aerosols, including powders of mineral and organic composition, pollen and spores, sea spray and volcanic ash; various industrial pollutants can also be present as gases or aerosols, such as chlorine (elemental or in compounds), fluorine compounds and elemental mercury vapours.

Sulphur compounds such as hydrogen sulphide and sulphur dioxide (SO_2) can be derived from natural sources or from industrial air pollution. (Wikipedia, 2021)

However, the composition just described is taken as a reference and with respect to it the presence of pollutants is measured, i.e. solid, liquid particles, vapours and gases introduced into the reference gaseous mixture both by natural phenomena and by human activities.

The analysis is made more complex by the fact that pollutants interact with each other and with the other gases present in the atmosphere, so the quality of the air is determined by the nature and quantity of the pollutant emitted and the extent of atmospheric interactions. (dispersion and chemical reaction).

It is important to talk in this section about the percentage of pollutants present in the atmosphere because the presence of some of them is altering the structure of the atmosphere itself, changing its behaviour and triggering mechanisms that are harmful to the planet and to the life of the species that they live there.

Specifically, the presence of the so-called GHG (GreenHouse Gasses) pollutants, such as: water vapor, carbon dioxide, methane, nitrous oxide, ozone, chlorofluorocarbons (CFCs).

These pollutants have the ability to absorb a lot of energy that comes from the sun, the ability to absorb this energy is evaluated with the Global Warming Potential (GWP) in relation to the GWP of CO_2 which is 1.

The absorption of energy by these compounds will lead to an increase in the global mean temperature over the years.

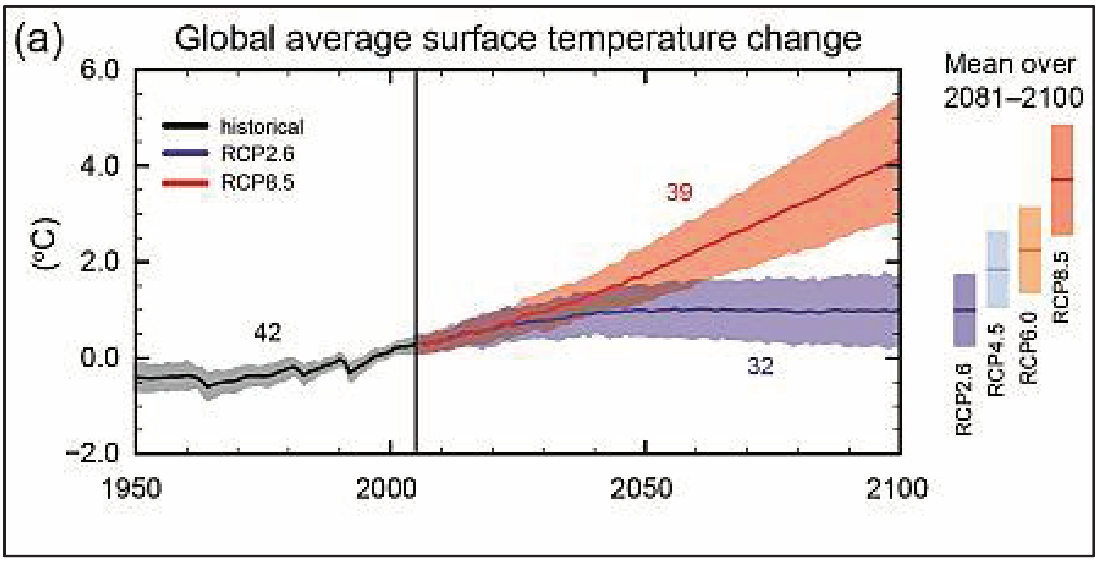


Figure 1.22 - Multi-model simulated time series from 1950 to 2100 for change in global annual mean surface temperature relative to 1986–2005. (IPCC 2013)

The figure above represents the IPCC (Intergovernmental Panel on Climate Change) simulated scenario for the change in the global annual mean surface temperature, the blue line represents the scenario with an higher reduction of pollutants which includes the reduction in production of GHG; the red line on the other hand, represents the scenario with a lower reduction of emissions (only aerosol reduction).

The IPCC stated that Global-mean surface warming by the end of the 21st century is likely to exceed 1.5 °C relative to 1850–1900 for all RCPs (Representative Concentration Pathways) except RCP2.6 (blue line); and it is likely to exceed 2°C for RCP6.0 and RCP8.5 (red line).

In any case, warming will continue beyond 2100 for all the RCPs (except RCP2.6). The global mean surface warming for 2081–2100 relative to 1986–2005 is projected to be around 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5); and it will continue to show variability. (Collins M. et al., 2013)

Another change in the structure of the atmosphere is the stratospheric ozone depletion, it is the significant diminution of the ozone content of the stratosphere, it is important to have an ozone layer in the upper atmosphere since it protects the biological activity from the damaging solar radiations. This significant reduction is due to the growing emissions of synthetic CFCs.

Finally another important and well known consequence of pollution is the smog; there are two different types: industrial or grey smog that is caused by the activity of industries and its composition is mainly a mixture of sulphur dioxide, droplets of sulphuring acid and a great variety of solid particles in suspension; and photochemical smog that is a mixture of pollutants of primary origin (NOx) with other secondary (ozone) that are formed by reactions caused by the sunlight.

In places with dry, warm and sunny weather it represents an important phenomenon, for this same reason summer is the worst season; moreover, thermal inversion can aggravate this problem.

2. Atmospheric pollution

Air pollution is defined in art. 268 of 'Codice dell'Ambiente' (Dlgs 152/2006) as "any modification of the atmospheric air, due to the introduction into it of one or more substances in quantities and with characteristics such as to harm or constitute a danger to the human health or the quality of the environment or such as to harm material goods or compromise the legitimate uses of the environment".

It is therefore the set of all physical, chemical and biological agents that modify the natural characteristics of the earth's atmosphere.

Air pollution causes the deaths of approximately 7 million people worldwide each year and is the largest single environmental health risk in the world. (Wikipedia, 2021)

2.1. Main air pollutants

Pollutants are the product of the human activities carried out in the area of interest; therefore, for a correct nomenclature of airborne atmospheric pollutants, the characteristics of the area from the industrial and settlement point of view must first be studied. Therefore, regarding our domain as well as all areas with similar characteristics, the fundamental pollutants that can be found are: Carbon Monoxide (CO) produced essentially by combustion in internal combustion engines, Nitrogen Oxides (NOx) produced by diesel engines and steel industries, Sulphur oxides (SOx) generated by the extinction processes of fossil fuels and by the heavy chemical industry, Volatile Organic Compounds (VOCs) whose formation can derive from different chemical-physical and industrial processes, Polycyclic Aromatic Hydrocarbons (PAHs) abundantly contained in coal and oil and produced in incomplete combustion (petrol engines, diesel and thermal power plants), Ozone (O3) a secondary pollutant produced by photoreaction between sunlight and NOx or VOCs and the Total Suspended Particles (TSP) whose compositions and origins are very varied and therefore widely discussed later. (E. Taurino, 2015)

In recent decades in Italy the state of atmospheric emissions has profoundly changed: results have been achieved in the reduction of pollutants mainly due to the use of petroleum and coal derivatives, characterized by high quantities of sulphur dioxide (SO_2), as well as that of particulate matter, NOx, carbon monoxide CO and benzene (C_6H_6); these pollutants are called 'primary pollutants', because they are found in the air in the same form in which they are emitted, and the control of their concentration levels in the atmosphere is direct: you just have to act on the emission sources, and the concentrations in the atmosphere of these substances are reduced by the same amount; for this reason, for primary pollutants there is in fact a direct proportionality between emissions and concentrations in the air. (ISPRA I. S., 2016)

In the case of sulphur dioxide, the result was achieved by using fuels with very low content, or even sulphur-free such as natural gas, in fact, on the other hand, there has been an increase in emissions of particulate matter and nitrogen oxides due to the combustion of natural gas and carbon monoxide emissions from road traffic.

Particulate Matter (PM) is, in a certain sense, in an intermediate situation between primary and secondary pollutants: its presence in the air is in fact due to a primary component, which is the one that derives from the release into the atmosphere of PM directly from the emission sources, plus a secondary component, which is formed in the atmosphere as a result of chemical and physical processes starting from the precursors of PM: nitrogen oxides, sulphur dioxide, ammonia, volatile organic compounds. (Giavazzi)

For PM, which is currently the most critical pollutant due to the high levels of concentration and the magnitude of the negative effects on health, it is possible to state that the mass concentrations in the air have decreased significantly since the end of the 80s and during the 90s thanks to the reduction of primary PM emissions. Starting from the second half of the 2001-2010 decade, there was an increasing use of biomass, encouraged by legislation aimed at encouraging the use of renewable energy sources, which however, to take into account the climate policies, did not take into account the air quality policies. It has led to a significant increase in primary PM emissions, with the result of raising the weight of the primary component of PM concentrations in the air in the cold season. (ISPRA I. S., 2016)

Consequently, today air pollution mainly affects urban areas, large road infrastructures and industrial centres; in particular, in urban areas vehicular traffic is the factor that pollutes the most, it is the origin of high concentrations of pollutants, the accumulation of which can be aggravated by adverse weather conditions. To date, also due to the introduction of new gasolines, the most critical pollutants for urban centres are particulate matter, O_3 and photochemical smog and there are still critical issues with regard to nitrogen dioxide.

The term ‘atmospheric dust’, or ‘suspended particulate material’, refers to a mixture of solid and liquid particles suspended in the air, which varies in size, chemistry and origin. (ARPAV, 2016).

Inhalable airborne particles (PM_{10}) are a complex mixture of solid and / or liquid corpuscles, variable in composition, mass and size, in relation to their different origin and the different meteorological conditions. The PM_{10} particles are divided into two particle size fractions for the purpose of their measurement and on the basis of their diameter: the coarse fraction and the fine one.

The coarse fraction is mainly composed of mineral particles with a diameter between 2.5 and 10 µm; it has a variable composition depending on the geology of the place in fact it mainly derives from uncontrolled combustion (e.g. forest fires), marine aerosol, soil erosion processes (e.g. volcanic eruptions and wind transport), tire erosion from friction with road and rock erosion.

The fine fraction is composed of a mixture of carbonaceous particles deriving from combustion processes (diesel engine emissions, industrial production activities, thermoelectric power plants, etc.) and salts generated by photochemical reactions in the atmosphere (sulphates and nitrates partially neutralized) having diameter less than 2.5 µm.
This carbonaceous fraction consists of elemental and organic carbon aggregates on which metals (Pb, Cd, V, Ni, Cu, Zn, Mn, Fe), biological contaminants and organic compounds are adsorbed. Moreover, the fine fraction includes an ultrafine one, composed of carbonaceous particles with a diameter of about 0.01-0.1 µm and derived mainly from diesel emissions (Diesel Exhaust Particles, DEP), these ultrafine particles constitute the numerically most significant fraction of PM_{10} and can aggregate contributing in part in the formation of fine particles.
Figure 2.1 below, shows the coarse part of PM10 (particles with dimensions between 2.5 and 10 µm), specifically, particles with a diameter > 9 µm are visible. (M.Ballabeni, 2004)

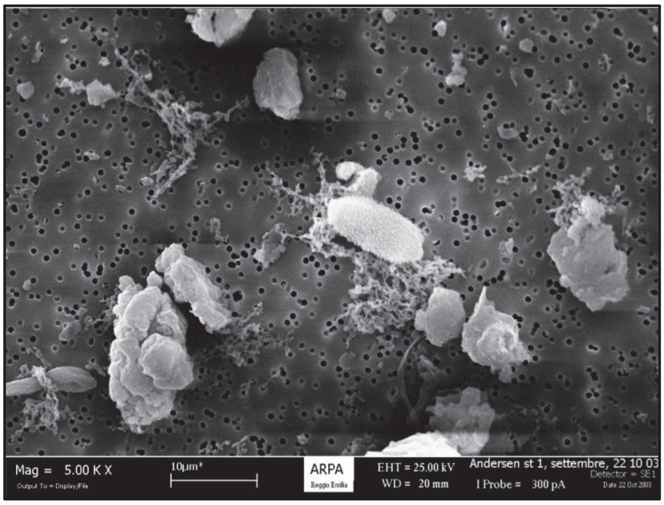


Figure 2.1 - PM_{10}, seen under the microscope

Figure 2.2 shows, instead, the fine fraction of PM.

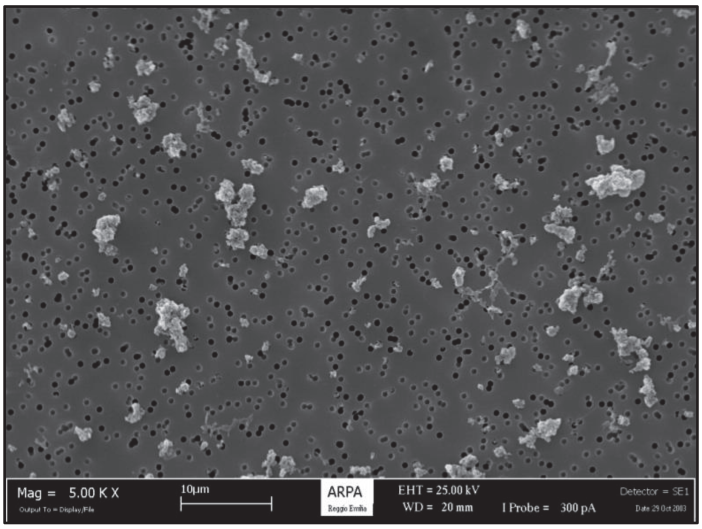


Figure 2.2 - $PM_{2,5}$, seen under the microscope

In Figure 2.3a, one of the strange behaviours of $PM_{2.5}$ can be seen; submicronic particles tend to group into colonies.
Figure 2.3b is a detail of the previous photo and shows a detail of a $PM_{2.5}$ colony; the individual particles, which are about 0.09 microns (90 billionths of a meter) in size, come together in clusters.

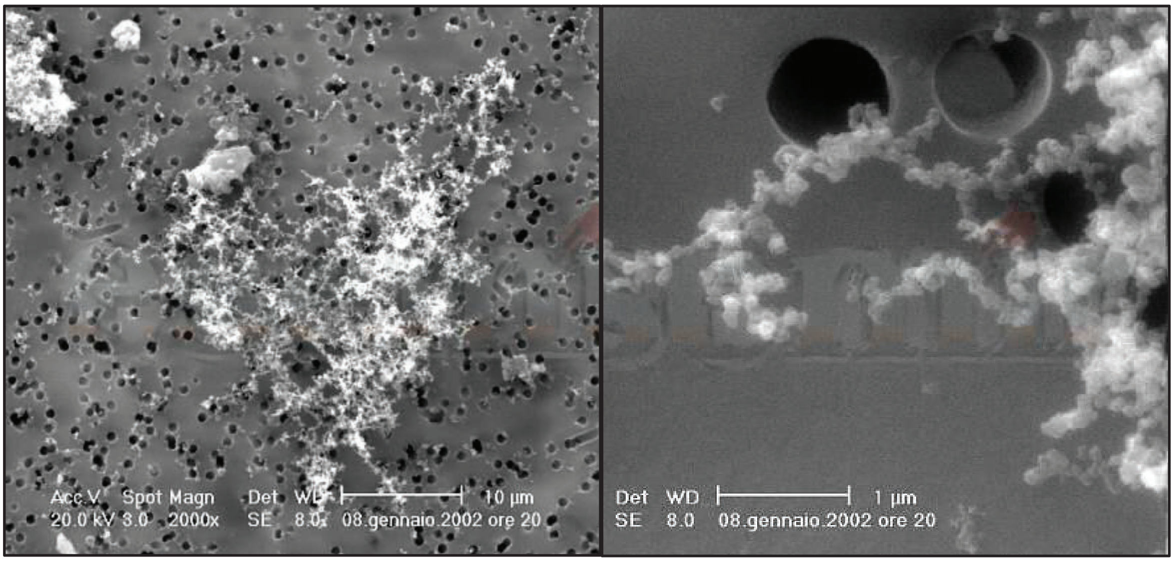


Figure 2.3 - a-$PM_{2,5}$, 2000 enlargements; b-detail of a $PM_{2.5}$ colony

Generally, in routine environmental investigations, the contribution of the ultrafine fraction to the total mass of PM_{10} is not determined, although knowledge of this data could be important because a modest increase in the mass of PM_{10} in the atmosphere could correspond to a considerable increase in the mass of ultrafine particles and therefore in the total number of particles. The contribution of the three fractions to the total mixture is variable, but the concentrations of $PM_{2.5}$ and PM_{10} are generally closely related(PM_{10} is made of about 60% by $PM_{2.5}$).
The levels of PM in the atmosphere can be expressed according to three different parameters: the mass, the surface and the number of particles per unit of volume. Each of these gains a different relative importance depending on the particle size fraction in question since the coarse and fine fractions are predominant by mass, the fine by surface and the ultra-fine by number.
Furthermore, fundamental to study is the toxicological relevance of these parameters since a different particle size and chemical composition could correspond to different effects, in relation to the different reactivity and interaction with the human body. (Balduzzi, 2003)

2.2. Inventories and emission sources

Emissions inventory means a collection of data relating to atmospheric emissions which has to be coherent and organized, these data are distinguished by activity (electricity production, transport, livestock), time interval (year, month, hour), territorial unit (region, province, municipality), fuel used (petrol, diesel, methane ..), type of emission (punctual, widespread…) type of pollutant.
The purpose of this "tool" is to fulfil the objectives of Legislative Decree 155/2010:

- Support to modelling for the air quality assessment;
- Verification of the effectiveness of air quality remediation plans, and support in the drafting of Urban Traffic Plans, Environmental Impact Assessment;
- Preparation of energy and emission scenarios for territorial planning both as regards the identification of "at risk" areas, and to plan the distribution of new sources;
- Harmonization of emissions between national and local data;
- Evaluation, through the support of appropriate and specific mathematical models, of the cost / benefit ratio of the control and intervention policies.

(DOC N.78/CF, Inventari Regionali delle Emissioni in Atmosfera e Loro Articolazione a Livello Locale, 2016)
In accordance with the APAT guidelines (CTN_ ACE, 2001) and extending its contents, the preparation of an inventory involves the following activities:

- Planning;
- Data collection;
- Data processing and emission calculation;
- Critical analysis of the results and implementation of quality controls;
- Preparation of the documents aimed at publishing and using the results.

The most complex and burdensome part is the set of collection activities of the data relating to the amount of pollutants introduced into the atmosphere from each emission source. The goal is to identify the different polluting sources present in a given area.
Once the sources of pollution have been surveyed and an inventory compiled, the actual emissions are estimated.
A basic inventory should provide at least the total annual emissions of the main pollutants divided by the main macro-sectors of activity to pursue the primary purpose of verifying the achievement of the emission reduction targets of each individual region, province, municipality (depending on the area under consideration).
A more complex inventory, on the other hand, must consider a large number of pollutants, different emission activities at multiple levels of spatial and temporal disaggregation, in order to provide more

detailed information and input data to the models of dispersion and transformation of pollutants in the atmosphere.

As already explained, the use of modelling techniques for the assessment and management of ambient air quality and the elaboration of the respective emission scenarios are some of the various competences entrusted to Legislative Decree 155/2010 which establishes that the administrative functions relating to the assessment and management of ambient air quality are the responsibility of the State, the regions, the autonomous provinces and local authorities, in the ways and within the limits provided by the same decree.

In Italy, therefore, it is possible to obtain information on emissions on the basis of the national inventory and / or local inventories: the national inventory of atmospheric emissions falls within the institutional tasks of the National Agency for Environmental Protection (ANPA, Agenzia Nazionale per la Protezione dell'Ambiente) and is an integral part of the National Environmental Information System (SINA, Sistema Informativo Nazionale Ambientale); the “local” ones, on the other hand, refer to territories that are less than or equal to the Region.

The availability of local inventories in Italy is still uneven in terms of coverage of the territory, methodologies used, year of reference, chemical species and emission activities taken into consideration; therefore currently, in the most frequent situation, the existing inventory does not fully meet the needs of the modelist and numerous resources are still needed to make up for the missing information, however the situation is gradually improving. (Marco Deserti, 2001)

In the Code of the Environment, in addition to the definition of "air pollution", already mentioned, the concept of *emission* is enunciated, which corresponds to any solid, liquid or gaseous substance introduced into the atmosphere that may cause air pollution.

An emission is defined as "conveyed" if the gaseous effluent is released through one or more specific points, otherwise we speak of "diffuse" emission; the sum of diffuse and conveyed emissions corresponds to the total emissions.

The attention paid to air pollution obviously derives from the health risks it entails, mainly associated with the inhalation of gas and particulate matter, (health risks have been observed in both short- and long-term); as well as from the damage observed to ecosystems and materials, with particular regard to monuments.

The emission sources can be classified in different ways according to the Ministerial Decree 261/02: according to the operating mode, according to the spatial dislocation and according to the spatial configuration.

Based on the operating mode they can be:

- *Continuous sources*: those that emit regularly or according to a certain periodicity (e.g. domestic heating);
- *Discontinuous sources*: those that emit intermittently and not regularly.

According to the spatial dislocation, they can be:

- *Fixed sources* their position is constant over time;
- *Mobile sources* their position varies over time.

According to the spatial configuration:

- *Point sources;*
- *Line sources;*
- *Area sources.*

The *point sources* are those characterized by the emission into the atmosphere of pollutants located in a geographically well-located point. Typical examples are factories, or individual plants that emit quantities of pollutants above certain thresholds; the emission values together with other technical data (section and height of the chimneys, speed, temperature, flow rate, humidity of the fumes) and related to the production, are obtained from the compilation of questionnaires that are sent to the plants by the bodies in charge. Furthermore, large companies are subjected to the AIA (Autorizzazione Integrata Ambientale), the Italian version of the IPPC (Integrated Pollution Prevention and Control) procedure for which punctual data is available, there are geometric data, emission and production hours related to the chimneys.

The *line sources* consist of both land (roads, motorways) and sea communication routes.

The *area sources* correspond, on the other hand, to industrialized and / or residential areas, to cultivated lands, within which we can find both point and line sources, which in any case emit less than the thresholds established for the definition of point source; small and medium-sized companies are subject to AUA (Autorizzazione Unica Ambientale) certification; they have diffuse emissions and therefore spread over an areal surface. (DM_261_01/10/2002)
The classification just proposed is the most used in practice, as it involves the identification of appropriate threshold values, i.e. emission values on the basis of which to differentiate between sources that must be considered in their own right (if the emissions exceed the established threshold) or that can be grouped with others, similar by type of pollutant and process. The threshold values are set based on the degree of detail of the information to be obtained and also based on the available resources and the purpose of the inventory (inventory of emissions on a national or local scale, etc).
Furthermore, the sources can also be divided into:

- *localized sources*, (systems above a certain threshold of emission, important road arteries), which must be characterized individually;
- *diffuse sources*, (domestic heating, set of small streets in an urban centre), whose emissions are estimated using a statistical analysis.

It is good to specify that a source can be localized or diffused according to the geographical reference taken into consideration; for example, given a small industrial plant, this can be considered as a localized source if it refers to the urban area in which it is located, while it will be a diffuse source on a regional or national scale.
From the experience gained in the field of regional emission inventories, it may emerge the need to deepen the level of detail of the three main types of emission sources (point, area and line) through a more detailed classification, expanding the definition contained in Ministerial Decree 261/02.
Point sources can be defined as falling into two types:

- Point strict sense, which can be represented through a point with known coordinates (e.g: industrial chimney, etc);
- Punctual understood as localized areas, representative of portions of territory identifiable through a specific area or layer (e.g: quarries, airports, etc).

An area source can instead be defined as:

- Area strict sense, in the event that the area where the emission activity is carried out is assigned to a single type of source (e.g: cultivated areas, forest extension, etc);
- Complex area, that can be characterized within a municipality by a set of polygons not exclusively from a single type of source (e.g: port area, urban heating, etc).

(DOC N.78/CF, Inventari Regionali delle Emissioni in Atmosfera e Loro Articolazione a Livello Locale, 2016)

2.2.1. Particulate emission sources and definition of activities for inventory

The sources that produce PM_{10} and $PM_{2.5}$ are many; as already mentioned, the 2 different types of particulate emissions have different matrices: the first mechanical-erosive and the second chemical-energetic.
The sources that contribute most significantly are:

- emissions produced by vehicular traffic;
- emissions produced by other machinery and vehicles (construction / agricultural equipment, airplanes, trains, etc);
- combustion processes of coal and oils (thermoelectric power plants, civil heating), wood, waste, etc;
- industrial processes (cement factories, foundries, mines, etc).

Once emitted, PM_{10} can remain suspended in the air for about 12 hours, while particles with a diameter of 1 mm remain in circulation for about a month. This is one of the characteristics that makes inhalable and breathable powders particularly insidious for human health.

PM_{10} is also made up of a mixture of substances that include elements such as carbon, lead, nickel, compounds such as nitrates, sulphates or organic compounds and complex mixtures such as soil particles or diesel vehicle exhausts.
While in $PM_{2.5}$ a certain number of substances are present such as: the sulphates produced by sulphur dioxide emissions, they are acidic in nature and can react directly with the lungs; the carbon produced during the combustion of gasoline that can capture carcinogenic chemicals such as benzo-pyrene and allow it free access to the lungs; finally, several studies have shown the presence of toxic metals such as lead, cadmium and nickel in higher concentrations in the $PM_{2.5}$ fraction than in larger particles. (ARPAV, 2005)
The main microclimate within which aerial particulate develops is undoubtedly the urban-industrial one, that is, an environment where there are significant civil and industrial heating systems and with a considerable use of road transport.
The emission sources included in the Regional Inventory of Atmospheric Emission Sources (IRSE, nell'Inventario Regionale delle Sorgenti di Emissioni in atmosfera) are classified within the Corinair project (EEA, EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013, 2013), according to the European standard nomenclature called SNAP '97 (Selected Nomenclature for Air Pollution). This classification is based on the partition of anthropogenic and natural activities responsible for emissions of monitored pollutants into the atmosphere, in 11 macro-sectors which are:

01 - Energy production and fuel transformation
02 - Non-industrial combustion
03 - Combustion in industry
04 - Production processes
05 - Extraction and distribution of fossil fuels and geothermal
06 - Use of solvents
07 - Road transport
08 - Other moving sources and machinery
09 - Waste treatment and disposal
10 - Agriculture and livestock
11 - Other sources and absorptions

Macro-sector 1: Energy production and fuel transformation
This macro-sector brings together the emissions of boilers, gas turbines and stationary engines and focuses on the combustion processes necessary for large-scale energy production. The criteria to be adopted in choosing the sources to be considered in this group are the following:

- qualitative: public and cogeneration plants, district heating plants, industrial boilers
- technological: boilers with thermal power falling into one of the following ranges:

- not less than 300 MW;
- between 50 and 300 MW;
- less than 50 MW.

The emissions to be included in this macro-sector are those released during a controlled combustion process and the primary abatement processes (during the production phase) and secondary abatement processes (downstream of the production process) must be taken into account. The fuels can be solid (biomass or waste must be included if these are used as fuel), liquid and gaseous.

Macro-sector 2: Non-industrial combustion

It includes combustion processes similar to those of the previous macro sector, but not industrial. Therefore, commercial and institutional systems, residential ones (heating and domestic combustion processes such as fireplaces, stoves, etc.) and stationary agricultural ones (heating, gas turbines, stationary engines and more) are considered.

Macro-sector 3: Combustion in industry

As before, it includes plants similar to those in Macro-sector 1 but closely related to industrial activity; therefore it encloses all the processes that require energy produced on site by combustion (boilers, furnaces, first metal casting, production of gypsum, asphalt, cement, etc.).
It is important to remember that emissions due to combustion processes and not those due to the production of goods or materials should be estimated.

Macro-sector 4: Production processes

Compared to the previous macro-sector, here the specific emissions of a given process must be considered, i.e. not those related to combustion, but to the production of a given good or material. Here are collected the estimates regarding the emissions due to the refining processes in the oil industry, to the processing in the steel, mechanical, chemical (organic and inorganic), wood industries, food production, etc.

Macro-sector 5: Extraction and distribution of fossil fuels and geothermal

This macro-sector groups together the emissions due to the production, distribution and storage processes of solid, liquid and gaseous fuels and concerns both local and off-shore activities. It also includes emissions due to geothermal energy extraction processes.

Macro-sector 6: Use of solvents

It includes all activities that involve the use of solvent-based products; therefore, production such as manufacturing of pharmaceutical products, paints, glues, blowing of plastics and asphalt, printing and photography industries, and also the emissions due to the use of these products.

Macro-sector 7: Road Transport

This macro-sector includes the following sectors: cars, light vehicles, heavy vehicles, motorcycles (all further subdivided, according to the type of route, into highways, extra-urban roads, urban roads), mopeds, gasoline evaporation, tires and brake wear.

Macro-sector 8: Other moving sources and machinery

It includes rail transport, inland navigation, military vehicles, maritime traffic, air traffic and non-road internal combustion mobile sources, such as agricultural, forestry vehicles, those related to gardening activities and industrial vehicles (bulldozers, caterpillars, etc.).

Macro-sector 9: Waste treatment and disposal

It includes the activities of incineration, spreading, landfill of waste, but also related aspects such as wastewater treatment, composting, biogas production, sludge spreading, etc; in addition, the incineration of agricultural waste (but not of brushwood on the fields, which are considered in the subsequent macro-sector) and the cremation of corpses.

Macro-sector 10: Agriculture and livestock

It includes emissions due to agricultural activities (with and without fertilizers and / or pesticides, herbicides) and the incineration of residues carried out on site; breeding activities (enteric fermentation, production of organic compounds) and nursery production are also part of the macro-sector.

Macro-sector 11: Other sources and absorptions

Often referred to with the name "Nature", this macro-sector includes all those non-anthropogenic activities that generate emissions (phytological activity of plants, shrubs and grass, lightning, spontaneous gas emissions, emissions from the soil, volcanoes, natural combustion, etc.) and those activities managed by man that are linked to them (managed forests, planting, repopulation, malicious burning of woods). (ANPA, 2001) (ARPALAZIO, 2015)

There is a SNAP code that identifies the activities and consists of three digits: macro sector, the sector and the activity to which the estimate of emissions refers.

Below is the table with the codes for all the emissive activities of each Macro-sector:

MACRO-SECTOR 1	Energy production and fuel transformation
010100	Public energy plants (Thermoelectric Power Plants)
010200	District heating plants
010300	Oil refineries
010400	Transformation plants for solid fuels
010500	Coal mines - oil / gas extraction - pipe compressors
MACRO-SECTOR 2	**Non-industrial combustion**

020100	Commercial and institutional installations
020200	Residential installations
020300	Installations in agriculture, forestry and aquaculture
MACRO-SECTOR 3	**Combustion in industry**
030100	Combustion in boilers, turbines and internal combustion engines
030200	Contactless process furnaces
030300	Combustion processes with contact
MACRO-SECTOR 4	**Production processes**
040100	Processes in the oil industry
040200	Processes in the iron and steel industries and in coal mines
040300	Processes in non-ferrous metal industries
040400	Processes in inorganic chemical industries
040500	Processes in organic chemical industries
040600	Processes in the wood, pulp, food, beverage and other industries
040800	Production of halogenated hydrocarbons and sulfur hexafluoride
MACRO-SECTOR 5	**Extraction and distribution of fossil fuels and geothermal**
050100	Extraction and first treatment of solid fossil fuels
050200	Extraction, first treatment and loading of liquid fuels
050300	Extraction, first treatment and loading of gaseous fuels
050400	Distribution of liquid fuels (except gasoline)
050500	Distribution of gasoline
050600	Gas distribution networks
050700	Geothermal energy extraction
MACRO-SECTOR 6	**Use of solvents**
060100	Painting
060200	Degreasing, dry cleaning and electronic components
060300	Production or processing of chemicals
060400	Other use of solvents and related activities
060500	Use of HFC, N20, NH3, PFC and SF6
MACRO-SECTOR 7	**Road transport**
070100	Automobiles
070200	Light vehicles <3.5
070300	Heavy vehicles> 3.5 t and buses
070400	Mopeds (<50 cm3)
070500	Motorcycles> 50 cm3
070600	Petrol vehicles - Evaporative emissions
MACRO-SECTOR 8	**Other moving sources and machinery**
080100	Military transport
080200	Railways
080300	Inland waterways
080400	Maritime activities
080500	Air traffic
080600	Agriculture
080700	Forestry
080800	Industry
080900	Gardening and other household activities

081000	Other off-road transport
MACRO-SECTOR 9	**Waste treatment and disposal**
090200	Waste incineration
090400	Burial of solid waste
090700	Incineration of agricultural waste (except 100300)
090900	Cremation
091000	Other waste treatments
MACRO-SECTOR 10	**Agriculture and livestock**
100100	Crops with fertilizers
100200	Crops without fertilizers
100300	Stubble combustion
100400	Enteric fermentation
100500	Waste management referred to organic compounds
100600	Use of pesticides
100900	Waste management referred to nitrogen compounds
1001000	Particulate emissions from farms
MACRO-SECTOR 11	**Other sources and absorptions**
110100	Unmanaged deciduous forests
110200	Unmanaged coniferous forests
110300	Forest fires and other vegetation
110400	Grasslands and other types of low vegetation
110500	Wetlands (swamps, marshes)
110600	Waters
110700	Animals
110800	Volcanoes
110900	Gas infiltrations (geysers)
111000	Lightnings
111100	Managed deciduous forests (SNAP94 cod 100700)
111200	Managed coniferous forests
112100	Changes in forest carbon stocks and other woody biomasses
112200	Transformation of forests and grasslands
112300	Abandonment of cultivated land
112400	Soil CO2 emissions and absorptions
112500	Other

Figure 2.4 - SNAP codes for all the emissive activities of each Macro-sector.

(ARPAPUGLIA, 2014)

2.2.2. Definition of territorial and temporal units

The inventory is therefore an organized series of data that define the amount of pollutants introduced into the atmosphere from natural and anthropogenic sources, but this definition must be completed by integrating references to a certain period of time and to a territorial area.

In general, the territorial scales can range from sub-municipal to national scales; as already mentioned, those referring to territories less than or equal to the region are defined as "local". (Marco Deserti, 2001)

Considering that almost all the regions make estimates with municipal detail, care must be taken to take into good consideration any administrative variation following the institution, suppression, change of name and change of belonging to the province and any territorial variation due to the acquisition or sale of the territory, in order to correctly develop, update or compare inventories.

The Italian Institute for Environmental Protection and Research (ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale) carries out the provincial disaggregation of the national inventory every five years in order to produce a uniform representation of the main emission sources in the Italian provinces, obtaining comparable results, as they are generated using the same methodology. As regards individual and particular local realities it is preferable to refer to local inventories, more detailed even if difficult to compare with each other as they are often made with different methodologies. (ISPRA)

With regard to the temporal aspect, generally the estimates of regional emissions are carried out on an annual basis but more in-depth analyses can be made for specific cases or for specific sectors for which detailed information is available that allows to increase the temporal resolution. (DOC N.78/CF, Inventari Regionali delle Emissioni in Atmosfera e Loro Articolazione a Livello Locale, 2016)

2.3. Emissions estimation

To estimate the emissions of the point sources of individual plants or chimneys characterized by significant emissions of pollutants, the starting point are the declarations of the individual companies for authorization purposes or the measurements made. In case of lack of data in reference to a specific pollutant, it is possible to make estimates on the basis of an appropriate emission factor and specific parameters of the source.

Emissions from line and area sources are generally estimated using the following product:

$$Ei = A * FEi$$

where:

- Ei represents the emission of pollutant i (in g of pollutant / year);
- A is an appropriate indicator of the activity correlated with the quantities emitted (eg. Fuel consumption for heating systems) whose sources of information can be: ISTAT censuses, trade associations, various public and private entities;
- FEi is the emission factor for the pollutant i and the activity expressed by A, i.e. the mass of the pollutant emitted for a unit quantity of the indicator (g of pollutant / kg of product).

(ANPA, 2001)

The reliability of this estimate depends on the precision of the emission factors, the greater the more detailed the individual production processes are, using specific emission factors which are characteristic of the plant type.

In the case of emissions from motor vehicle traffic, specific calculation methods are applied which consider the dependence of the emissions on numerous parameters (type of vehicle, displacement, type of fuel, type of route, travel speed, etc.). (Ahlvik, 1997)

The main source for finding the 'FEi' emission factors is the "the EMEP / CORINAIR Atmospheric Emission Inventory Guidebook" (EEA, 2019) created and updated by a Task Force made up of experts from all over Europe operating in the context of working groups (Expert panel) on some main issues such as combustion and industrial activities, transport, agriculture and livestock, nature etc.

This Task Force periodically emits the reference manual, the Guidebook, which, for most of the activities envisaged by the SNAP97 nomenclature, provides two possible calculation methodologies (simplified and detailed methodology) in relation to the degree of detail of the information available on the activity and consequently, different values of the emission factors. The guide also integrates other contributions developed in the context of related projects and international working groups, for example from the IPCC (Intergovernmental Panel on Climate Change), the United States Environmental Protection Agency (US EPA) etc. (EEA, 2019) (Marco Deserti, 2001) (ISPRA)

The methods that can be used to estimate and validate emissions are mainly two and they are quite different; one is the "bottom-up" method, it estimates emissions from statistical analyses of activity data together with country-specific emission factors; the other is the “top-down” method, which estimates emissions on the basis of observations and dividing the national annual values at different spatial levels such as regional or by provinces or municipalities and at different time levels, from annual to hourly resolution. (Penwadee Cheewaphongphan, 2019)

2.4. Measurement and monitoring of particulate matter

In order to monitor PM emissions into the atmosphere, it is essential that each air quality detection unit in the area in question is equipped with suitable instrumentation for reporting and analysing the particulate matter. The network of automatic instruments used for monitoring now makes it possible to measure the concentrations of the main pollutants on a daily basis.

Technologies generally used for measuring particulate matter concentration include (Wikipedia, 2021):

- gravimetric methods;
- optical methods;
- microbalances.

Gravimetric method

The measurement of the concentration of atmospheric pollutants, if carried out in accordance with European legislation, must be conducted with the use of instruments and methods defined by the legislation itself; in the case of particulate material, the standard establishes that the reference method is the "manual" one, i.e. a suction pump must be used that allows the flow of atmospheric air to pass through a filter for 24 consecutive hours. The amount of dust that is collected on the filter is determined by the difference between the mass of the "clean" filter and that of the "dirty" filter. The masses of the filters are determined by weighing on a gravimetric balance (a traditional balance with adequate sensitivity), after conditioning at controlled temperature and humidity. The particulate concentration is given by the ratio between the quantity of particles and the volume of air sucked in. To determine the particulate with a particle size lower than 10 microns (PM_{10}) or 2.5 microns ($PM_{2.5}$), a special selector is placed at the head of the suction line that eliminates (with approximation) particles larger than 10 or 2.5 microns.

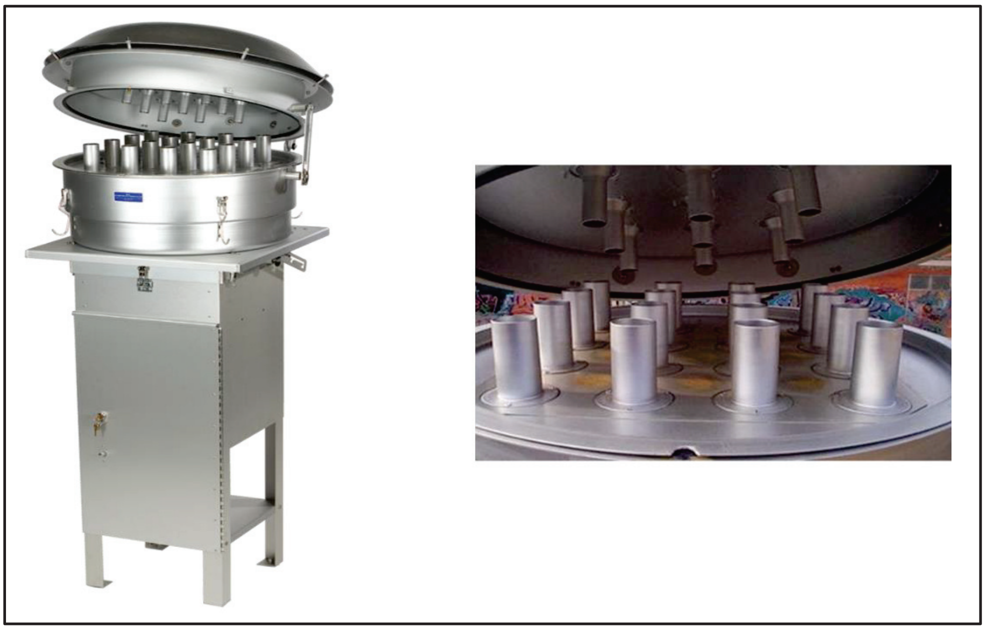


Figure 2.5 - Instrument for measuring the mass concentration of PM_{10} based on the gravimetric principle (left) and detail of the air collection head (right)

Figure 2.6 - Dirty filter after 24 hours of sampling (left) and clean filter before sampling (right)

The standard establishes the various parameters involved such as suction flow rate and sampling duration, filter dimensions, macro and micro-scale characteristics of the detection site. (Grechi)
The reference method requires, as it is evident, a large use of specialized personnel and, for this reason, the bodies in charge (e.g. the ARPAs) now universally use automatic instrumentation "certified equivalent" to the reference method or devices that have been tested by subjects in charge of verifying their performance and who provide, under equal conditions, analytical values equal to those provided by the reference method.
The two mainly used are described below.

Beta attenuation
The instrument uses glass fiber filters (1 filter / 24h) to collect the airborne particulate. The white filter, before collecting the particulate, is placed between a radioactive source inside the instrument that emits electrons (beta radiation) and a detector (Geiger-Muller counter) that measures the radiation that passes through the "clean" filter (white measurement); subsequently a constant flow of air for 24 hours passes through the filter on which the suspended particulate is deposited; at the end of the sampling period the filter is repositioned under the radioactive source and the Geiger counter measures again the radiation that passes through the sampled filter. Since the particulate has deposited on the surface of the filter, the intensity of the beta radiation will be attenuated compared to the white measurement. The difference between the 2 measurements is proportional to the concentration of particulate in ambient air in the 24 hours. The selection with respect to the size (aerodynamic diameter) of the particles (PM_{10} or $PM_{2.5}$) is obtained by means of special sampling heads which, thanks to a specific geometric construction, are able to sample only the desired particle size. (UNIUPO)

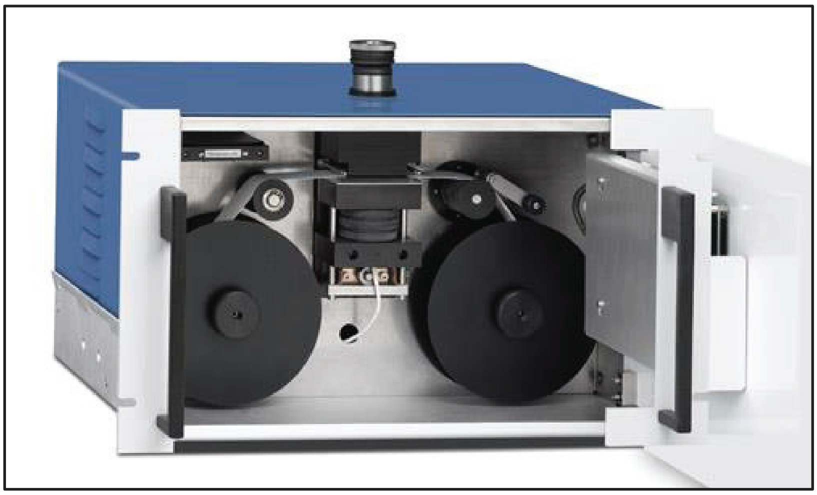


Figure 2.7 – Beta-ray system

Oscillating inertial microbalance

Tapered Element Oscillation Microbalance (TEOM) directly measures the mass collected on a filter by measuring the corresponding frequency changes of a tapered element on which the filter is placed. This element vibrates at a frequency dependent on its geometric and mechanical properties and on the mass of the filter. As the particles are collected by the filter the natural oscillation frequency of the element decreases in a directly proportional way and a microprocessor directly converts the vibration frequency into a measure of mass concentrations.

The instrument causes a heating of the incoming air (which reaches a temperature about 50 °C), minimizing the interference of evaporation and condensation of water on the filter and providing a stable and reproducible measurement. The increase in temperature, however, determines the evaporation of volatile substances (e.g. ammonium salts, organic species, etc.), a factor that leads to an underestimation of the concentration measurements of the particulate matter carried out by the TEOM, which is why in some places the measurements have been corrected by a multiplication factor, determined by the comparison of data obtained from TEOM and gravimetric instruments.

(UNIUPO)

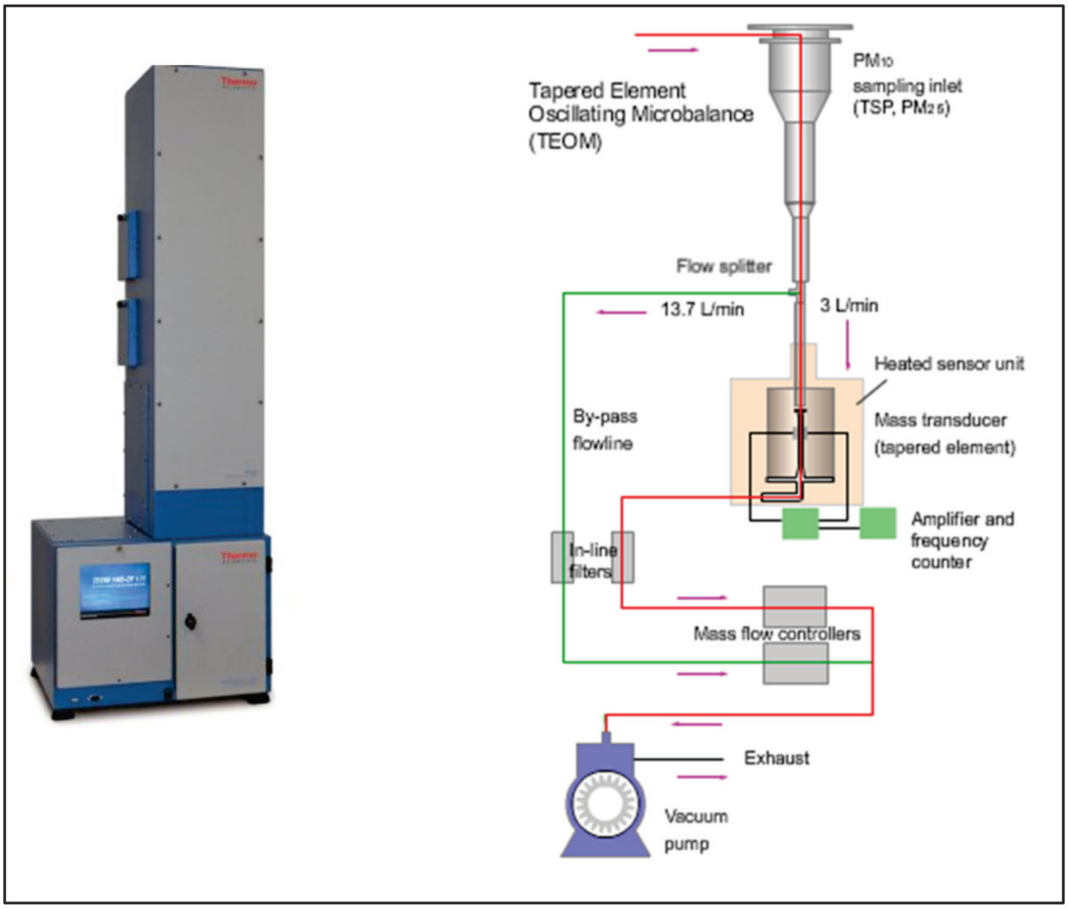


Figure 2.8 - TEOM tool operation diagram (Queensland Department of Environment and Heritage Protection, "Tapered element oscillating miscrobalance, 2017)

(Università degli Studi di Napoli Federico II)

3. The epidemiological study and the biological effects of PM on human health

This chapter introduces some essential concepts and explanations on epidemiology and how air pollutants, in particular PM_{10}, are harmful to human health.
This brief exposition attempts only to raise awareness on increasingly topical problems which are very broad, specific in the medical field and therefore not treated in detail here.

3.1. Introduction to epidemiology

The word epidemiology comes from the Greek words 'epi'= on or upon, 'demos'= people and 'logos'= study of; in other words, it has its roots in the study of what befalls a population.
Many definitions have been proposed, but one which is clear and complete is the one given by the Oxford University Press: 'Epidemiology is the study (scientific, systematic, and data-driven) of the distribution (frequency, pattern) and determinants (causes, risk factors) of health-related states and events (not just diseases) in specified populations (neighborhood, school, city, state, country, global). It is also the application of this study to the control of health problems.' (Last, 2001)
Two important terms concerning epidemiology are 'frequency' and 'pattern', referring to health events in a population:

- Frequency refers to the number of health events and also the ratio of that number to population size. The resulting rate allows epidemiologists to compare the onset of the studied disease in relation to different populations.
- Pattern refers to the occurrence of health-related events based on: temporal pattern (annual, seasonal, weekly, daily, hourly or any other that may influence the onset of the disease), location pattern (geographic variation, urban location / rural, work sites or schools) and personal characteristics that consider demographic factors (age, sex, marital status, socioeconomic status, environmental behaviour and exposure).

Other fundamental factors are the determinants, which are the causes that influence the occurrence of diseases and health-related events.
The planning of an epidemiological study generally starts from a local or national public authority in charge of health and / or the environment, it can take place before or after the occurrence of a harmful (or potentially harmful) event for the health of the exposed population.
As with all scientific studies, the practice of epidemiology is based on a systematic approach. In very simple terms, there are three main steps; the epidemiologist:

- Count cases or health events and describe them in terms of time, place and person;
- Divide the number of cases by an appropriate denominator to calculate rates;

- Compare these rates over time or for different groups of people.

(CDC, 2011)

Particular attention is now paid to the definition of environmental epidemiology, it aims to evaluate and quantify the effect of exposure to environmental agents on the frequency and distribution of diseases in populations. (ARPAM)

To summarize, the traditional structure of epidemiology is in three sectors (although cases of interaction between sectors are common):

- Descriptive epidemiology;
- Analytical epidemiology;
- Experimental epidemiology.

Descriptive epidemiology studies the frequency and distribution of diseases and health parameters in populations and describes health events such as diseases, causes of death and the presence of risk factors such as, for example, air pollution.

This branch uses statistical tools called frequency measurements and demographic information. It aims at discovering information such as who got sick, where and when; to do this, the investigative tools used are:

- ecological studies;
- cross-sectional studies (they are observational, descriptive studies).

Analytical epidemiology studies the cause-effect relationships between risk factors and diseases. Taking up the previous example, analytical epidemiology seeks the link between the risk factor e.g. "air pollution" and the onset of possible pathologies related to it (lung cancer, emphysema, mortality, etc.). The main objective is to answer two questions:

1. which specific diseases can that type of "exposure" or "risk factor" produce?
2. from what possible "exposures" can those specific illnesses / deaths be caused by?

The investigative tools used by analytical epidemiology are:

1. cohort studies: compare the rates of mortality and / or incidence of specific diseases in different exposed (and non-exposed) populations;
2. the case-control studies: they compare the frequencies of possible exposures and / or risk factors in the group of "cases" (specific patients) and "controls", i.e. subjects not sick (of the disease under examination).

Finally, experimental epidemiology evaluates the effectiveness of the health interventions adopted following epidemiological investigations. It can be both preventive (e.g. evaluation of the effective success of awareness campaigns) and therapeutic (e.g. drug trials and surgical techniques). Studies in experimental epidemiology can be performed single-blind (only the volunteers do not know they are in the control or experimental group), double-blind (even the researcher does not know who belongs to one group and who to another, only the supervisor knows); or triple-blind (rely on an external researcher). (Wikipedia, 2021)

ARPAM has an Environmental Epidemiology Service (SEA, Aervizio di Epidemiologia Ambientale) which was formally established in 2001; its activity concerns the disciplines of environmental epidemiology, risk assessment (e.g. support to the ASUR for risk analysis) and risk perception and communication.

It also operates as the central nucleus of the interdepartmental structure, called the Environmental Epidemiological Observatory (OEA, Osservatorio Epidemiologico Ambientale) of Marche Region, established by resolution of the Regional Council no. 1500 of 28/09/2009 with the aim of the functional integration of the specific provincial / supranational teams operators of Regional Health System (SSR, Servizio Sanitario Regionale) dedicated to research and advice on environmental epidemiology in the area. (ARPAM)

3.1.1. Epidemiological case study for Marche Region

Using a model of the fallout of atmospheric pollutants developed by National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA, Ente per le Nuove tecnologie, l'Energia e l'Ambiente) and the health risk functions obtained from international scientific literature, they were calculated for the years 2007, 2010 and 2020 hospitalizations and deaths attributable to air pollution for $PM_{2.5}$ concentrations exceeding the proposed WHO quality criteria.

The study provides further confirmation of the utility and convenience of implementing effective environmental policies to mitigate air pollution.

The $PM_{2.5}$ concentrations used were provided by ENEA; specifically, the concentrations of pollutants produced by the simulation of chemical and physical processes in the atmosphere were used through the national integrated atmospheric modelling system MINNI (Modello Integrato Nazionale a supporto della Negoziazione internazionale sui temi dell’Inquinamento atmosferico) with a spatial resolution of 4 x 4 km.

The data on mortality were obtained from the ARPAM Environmental Epidemiological Atlas ‘v. 9/2014’, elaborated on the basis of ISTAT data provided as part of the National Statistical Program "Processing of mortality, hospitalization and outcomes of conception data for purposes of supporting regional and local planning" (PSN MAR0006) by the P.F. Statistical and management control systems of the Council of the Marche Region (updated October 2014).

The calculation of attributable deaths was carried out using the method used in recent international publications. (WHO W. H., 2006)

For the assessment of attributable health events, the average annual concentrations of the atmospheric pollutants were used.

Below are the tables extrapolated from the reference document showing the deaths and hospitalizations in 2010 and 2020 attributable to exposure to $PM_{2.5}$.

	PM 2,5				
	Mortalità				Ricoveri ospedalieri
COMUNE	TUTTE LE CAUSE	MALATTIE CARDIOVASCOLARI	MALATTIE RESPIRATORIE	TUMORE AI POLMONI	EVENTI CORONARICI
Pesaro	16,53	9,73	1,77	1,35	23,41
	(9,82 – 20,72)	(5,19 – 13,72)	(0,00 – 5,36)	(0,64 – 1,97)	(0,00 – 38,32)
Urbino	0,66	0,41	0,10	0,06	1,03
	(0,39 – 0,83)	(0,22 – 0,59)	(0,00 – 0,46)	(0,03 – 0,09)	(0,00 – 1,79)
Ancona	16,58	9,29	1,39	1,09	20,66
	(9,83 – 20,81)	(4,93 – 13,14)	(0,00 – 3,73)	(0,51 – 1,60)	(0,00 – 34,42)
Macerata	10,17	5,61	0,89	0,57	14,85
	(6,06 – 12,71)	(3,00 – 7,87)	(0,00 – 2,66)	(0,27 – 0,83)	(0,00 – 23,64)
Ascoli Piceno	1,53	0,85	0,15	0,14	2,39
	(0,90 – 1,93)	(0,45 – 1,21)	(0,00 – 0,38)	(0,07 – 0,21)	(0,00 – 4,11)
Fermo	6,03	3,46	0,44	0,30	8,15
	(3,57 – 7,58)	(1,83 – 4,91)	(0,00 – 2,27)	(0,14 – 0,44)	(0,00 – 13,81)
	PM 2,5				
REGIONE MARCHE	TUTTE LE CAUSE	MALATTIE CARDIOVASCOLARI	MALATTIE RESPIRATORIE	TUMORE AI POLMONI	EVENTI CORONARICI
Totali regionali	216,99	123,07	19,52	13,89	277,97
(i.c.95%)	(128,93 – 271,96)	(65,60 – 173,59)	(0,00 – 112,54)	(6,58 – 20,32)	(0,00 – 455,59)

Figure 3.1 - Deaths and hospitalizations attributable in 2010 to exposure to $PM_{2.5}$ (95% CI) in provincial capitals and regional totals

	PM 2,5				
	Mortalità				Ricoveri ospedalieri
COMUNE	TUTTE LE CAUSE	MALATTIE CARDIOVASCOLARI	MALATTIE RESPIRATORIE	TUMORE AI POLMONI	EVENTI CORONARICI
Pesaro	23,47	13,74	2,51	1,90	32,33
	(14,02 – 29,32)	(7,38 – 19,23)	(0,00 – 6,98)	(0,91 – 2,76)	(0,00 – 50,88)
Urbino	0,07	0,04	0,01	0,01	0,12
	(0,04 – 0,09)	(0,02 – 0,06)	(0,00 – 0,06)	(0,00 – 0,01)	(0,00 – 0,21)
Ancona	35,59	19,76	2,95	2,32	42,02
	(21,30 – 44,40)	(10,66 – 27,56)	(0,00 – 7,50)	(1,11 – 3,35)	(0,00 – 64,80)
Macerata	4,10	2,27	0,36	0,23	6,29
	(2,42 – 5,15)	(1,20 – 3,22)	(0,00 – 1,17)	(0,11 – 0,34)	(0,00 – 10,75)
Ascoli Piceno	0,96	0,54	0,09	0,08	1,49
	(0,57 -1,21)	(0,29 – 0,77)	(0,00 – 0,30)	(0,04 – 0,12)	(0,00 – 2.58)
Fermo	5,86	3,32	0,45	0,30	7,95
	(3,47 – 7,37)	(1,76 – 4,71)	(0,00 – 2,15)	(0,14 – 0,44)	(0,00 – 13,41)
	PM 2,5				
REGIONE MARCHE	TUTTE LE CAUSE	MALATTIE CARDIOVASCOLARI	MALATTIE RESPIRATORIE	TUMORE AI POLMONI	EVENTI CORONARICI
Totali regionali	248,24	138,97	21,96	16,95	308,63
(i.c.95%)	(147,96 – 310,51)	(74,45 – 195,07)	(0,00 – 111,59)	(8,08 – 24,65)	(0,00 – 493,82)

Figure 3.2 - Deaths and hospitalizations attributable in 2020 to exposure to $PM_{2.5}$ (95% CI) in provincial capitals and regional totals

(ARPAM, 2016)

3.2. Short and long term effects of main air pollutants

The fact that atmospheric pollution represents a risk to human health no longer raises any doubts; numerous epidemiological studies in recent decades have highlighted an association between the levels of atmospheric pollutants typically present in our cities and a very broad spectrum of negative health effects, even if the effects of the individual components are not yet fully known.

The pollutants which have been found having the most convincing evidence of association with health effects are: suspended particles, nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO), ozone, benzene and PAHs (Polycyclic Aromatic Hydrocarbons), for each of which the air quality regulations provide for continuous monitoring.

However, airborne particles and especially smaller fractions such as PM_{10} and $PM_{2.5}$ were found to be the air quality indicator most associated with a number of adverse health effects.

It remains largely unknown which of its chemical components and characteristics (e.g. size, shape) are most responsible for the health effects even for particulate matter for which, as just mentioned, the strongest association evidence exists.

Although studies and investigations are still ongoing, it can be said that the health effects of pollution are very significant, these can be both short and long-term and affect a very wide range of pathologies. (Zanasi, 2017)

Going more in depth with the sanitary analysis, air pollution does not only affect the respiratory system; in fact, bacteria, viruses and allergens such as pollen, or substances contained in tobacco smoke can also cause other ailments at a more general level as well as pollutants in the air.

For example, volatile hydrocarbons and carbon monoxide penetrate the lungs and reach the brain and other organs via the blood, and tiny metal particles can reach the blood and can be deposited in bones, teeth and kidneys.

Finally, the particulate also causes effects on the cardiovascular system.

A brief description of the human respiratory system is now introduced in order to have a clearer understanding of the mechanics of the absorption of harmful substances from the atmosphere.

The upper airways are lined with a mucous membrane, consisting mainly of hair cells (that is, with very small hairs) and goblet cells (which secrete mucus).

The cilia of the cells move in a wave, in a coordinated way; so they carry the thin layer of mucus and the foreign substances that remain attached to the oral cavity, where they are swallowed.

Furthermore, between the cells of the mucosa there are the endings of very fine nerve fibers which can be irritated by harmful substances in the air, and can cause a contraction of the bronchial muscles, an increase in mucus secretion and cause coughing.

In the alveoli, i.e. the deepest parts of the lungs, the cleaning function is no longer carried out by these cells, but by other cells called macrophages (or scavenger cells) that eat and dispose of the bacteria that have entered the body, as well as the remains of destroyed cells.

The harmful substances that enter the respiratory tract, both as a result of acute (i.e. short-term) and chronic exposures, damage all these defence mechanisms in various ways. (Zanasi, 2017)

In the figure below, the representation of the respiratory tract with the detail of the dimension of the particles and the places in the tract in which they settle down; particles whose aerodynamic diameter is >10 μm are usually deposited in the nares and posterior pharynx, the ones with sizes ranging from 2 to 10 μm are deposited along the conducting airways, then particles 0.5-3 μm sediment in the terminal airways and alveoli. Therefore, physical defence mechanisms are essential for clearance of particles and gases in the upper airways and conducting respiratory tract, while cellular defence mechanisms are essential for clearance and protection of the terminal airways and alveoli.

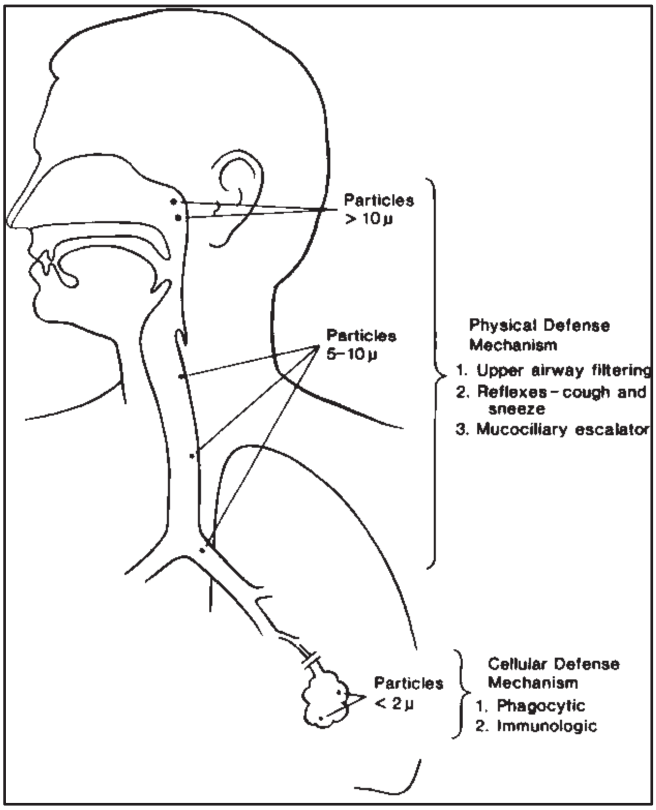


Figure 3.3 - Particle deposition in the respiratory tract. (R. N. Harada, 1985)

Going into the specifics of the effects of each individual air pollutant; as regards Nitrogen Oxide, it has a rather mild action on humans compared to Nitrogen Dioxide which is much more toxic as it is an irritating gas for the mucous membranes and can contribute to the onset of various alterations in lung functions, chronic bronchitis, asthma and pulmonary emphysema. The long-term effects and therefore those caused by a continued exposure, even at low concentrations, causes a drastic decrease in lung defences and consequent increase in the risk of respiratory tract diseases.

Sulphur Dioxide is very soluble in water and therefore it is easily absorbed by the mucous membranes of the nose and respiratory tract, for this reason only very small quantities are able to reach the pulmonary alveoli, it is a very irritating compound since it is very reactive; at low concentrations it causes respiratory system diseases such as bronchitis, asthma and tracheitis, and can also cause irritation to the skin and eyes.

Ozone is an extremely reactive oxidizing molecule, it is capable of oxidizing amino acids, proteins and lipids which are some of the main cellular components. At low concentrations it causes irritation of the eyes and throat, also attacking the mucous membranes, in sensitive individuals asthma attacks can occur; high concentrations, on the other hand, cause irritation of the respiratory system, cough and tightness in the chest which makes breathing difficult. (L. Simonato, 2006)

Inhaled Carbon Monoxide (CO) binds with haemoglobin, the protein present in red blood cells that carries oxygen, forming carboxyhaemoglobin, this bond is much more stable (about 200-300 times) than that formed between haemoglobin and oxygen, in this way the CO prevents the normal transport of oxygen to the peripheral tissues, causing toxicological effects of different magnitudes.

The severity of the clinical manifestations of CO intoxication depends on its concentration in the inhaled air, the duration of exposure and the health conditions of the people involved.

For environmental concentrations of CO below 5 mg / m^3 there are no appreciable effects on health in healthy individuals, while in patients with heart disease, even low concentrations can cause an anginal crisis. In some subjects, a long-term exposure to the absorption of small quantities of the pollutant has carried symptoms characterized by headache, dizziness, parkinsonian and epileptic syndromes and arrhythmias.

At higher concentrations, headache, confusion, disorientation, dizziness, impaired vision and nausea occur. Particularly high concentrations at short-term can cause coma and death from asphyxiation. Particularly susceptible are the elderly, people with cardiovascular and respiratory diseases, pregnant women, babies and children in general. (Ministero della Salute, 2015).

Regarding Benzene, short exposures of 5-10 minutes to very high levels in the air (10,000-20000 ppm) can lead to death. Lower concentration levels (700-3000 ppm) can cause dizziness, drowsiness, increased heart rate, tremors, confusion and loss of consciousness. Minor but more prolonged concentrations over time can alter memory and certain psychic abilities. Benzene is also responsible for an irritating effect on the skin and mucous membranes (ocular and respiratory in particular). It is well known for its great toxicity to blood cells and the organs that produce these cells (especially bone marrow). The effects can range from simple anaemia to a simultaneous decrease in red blood cells, white blood cells and platelets; the long-term consequence that worries the most is the appearance of blood cancer due to repeated exposure to Benzene concentrations of a few ppm for several tens of years.

Finally, PAHs can cause skin cancers by contact and lung cancers due to their high carcinogenic / mutagenic activity. (Ministero della Salute, 2015).

The WHO has estimated that air pollution causes approximately 2 million premature deaths worldwide each year and more than half of these deaths occur in developing countries. By reducing the levels of pollution, there would be a decrease in the incidence of diseases due to respiratory infections, heart diseases and lung cancers. Furthermore, actions aimed at reducing air pollution would contribute to a decrease in gas emissions that affect climate change, thus generating additional benefits in terms of health protection.

Below is a more detailed analysis of the health effects and toxicology of the main air pollutant studied in this elaboration: PM_{10}. (Zanasi, 2017)

3.3. PM_{10} toxicology

The proportion of particulate in the air that is inhaled depends on the speed and direction of movement of the air in the vicinity of the individual, on his / her respiratory frequency and if this is nasal or oral.

If the particles deposited in some part of the respiratory system are liquid or soluble, they can be absorbed by the tissues and cause damage around the point of absorption if they are corrosive or radioactive; insoluble particles can be transported, depending on their size, to other parts of the respiratory tract or body, where they can be absorbed or cause biological damage.

Furthermore, the airborne particulate is able to adsorb toxic gases and vapours on the surface of the particles; this phenomenon contributes at increasing the concentrations of gaseous pollutants that reach the deepest areas of the lungs, transported by the PM_{10} and $PM_{2.5}$ particles.

Numerous studies have shown a correlation between acute exposure to airborne particulate and alterations in respiratory function, bronchial asthma crisis, hospitalization and mortality from respiratory diseases; but also cardiac pathologies in predisposed subjects, circulatory and ischemic disorders. (Zanasi, 2017)

Prolonged exposure over time to particulate matter, even starting from low doses, is associated with an increase in mortality from respiratory diseases and diseases such as chronic bronchitis, asthma and reduced respiratory function. Furthermore, chronic exposure is likely associated with an increased risk of respiratory tract cancer. Cancer has been particularly associated with exposure to combustion particulate matter (finer particulate matter); in fact, soot has carcinogenic properties and numerous polycyclic aromatic hydrocarbons, some of which are carcinogenic, are absorbed on the fine particulate which is deeply inhaled into the lungs. (Ministero della Salute, 2015).

Studies on the long-term effects are few in number because they require monitoring the health status, exposure to pollutants and other co-risk factors (diet, lifestyles, etc.) of a large number of people. Studies conducted so far, mainly in the United States and Europe, have shown increases of 22% in the incidence of lung cancer (Raaschou-Nielsen, 2013), and 12% (1–25%) increased risk of fatal coronary heart disease for each increase of 10 micrograms per cubic meter in the annual mean of PM_{10}. (G. Cesaroni, 2014)

In many cities, the average annual levels of PM_{10} exceed 70 $\mu g/m^3$. In the European Union, the finest particulate matter alone ($PM_{2.5}$) causes a loss of life expectancy of about 8.6 months.

The table summarizes the health consequences of atmospheric pollution, in the short and long term, estimated for an increase of 10 $\mu g/m^3$ in the concentration of PM_{10}; these data are based on the epidemiological literature currently available.

EFFETTI SULLA SALUTE	Incremento % della frequenza degli effetti sulla salute per un aumento di 10 µg/m3 di PM10	Intervalli di confidenza
Effetti a breve termine (acuti)		
Uso di bronco dilatatori	3	2 - 4
Tosse	3	3 - 5
Sintomi delle basse vie respiratorie	3	1,8 - 4,6
Diminuzione della funzione polmonare negli adulti rispetto alla media (picco espiratorio)	- 13	- 0,17 a 0,09
Aumento dei ricoveri ospedalieri per malattie respiratorie	0,8	0,5 - 1,1
Aumento della mortalità giornaliera totale (escluse morti accidentali)	0,7	0,6 - 0,9
Effetti a lungo termine (cronici)		
Aumento complessivo della mortalità (escluse morti accidentali)	10	3 - 18
Bronchiti	29	1 - 83
Diminuzione della funzione polmonare nei bambini rispetto alla media (picco espiratorio)	- 1,2	-2,3 a 0,1
Diminuzione della funzione polmonare negli adulti rispetto alla media (picco espiratorio)	- 1	non valutabile

Figure 3.4 - Percentage increase in the frequency of sanitary phenomena in a city due to an increase of 10 µg / m3 of PM_{10} (WHO, 2000)

3.4. Law limits for PM_{10}

Epidemiological studies have shown a linear relationship between exposure to particles and health effects; that is to say, the higher the concentration of particles in the air, the greater the effect on the health of the population.

However, there is broad consensus in recognizing the absence of thresholds below which pollution levels are harmless to health; this was found for both short and long term effects.

In the current state of knowledge, according to the World Health Organization (WHO) it is not possible to set an exposure threshold below which no adverse health effects occur in the population for sure.

In this regard, the WHO proposes much stricter air quality objectives than the national standards in force in many parts of the world, and in some cities the adoption of these references would mean a reduction of more than three times of current pollution levels.

Specifically, the WHO indicates "risk functions" for different health effects; these functions quantify the excess adverse health effect that is to be expected for each unit increase in PM_{10} or $PM_{2.5}$ concentrations.

The Legislative Decree 13 August 2010, n. 155, in transposition of the Ambient Air Quality and Cleaner Air for Europe Directive no. 50/2008 of 21 May 2008, sets the limit values and quality objectives for the concentrations in ambient air of Sulphur Dioxide, Nitrogen Dioxide, Benzene, Carbon Monoxide, Lead, PM_{10}, $PM_{2.5}$ and Ozone.

For PM_{10}, the limit concentration values are shown in Annex XI; a distinction is made between the limit value averaged over a day (i.e. a 24-hour mean) which is equal to 50 $\mu g / m^3$ which must not be exceeded more than 35 times for a calendar year and the limit value averaged over a calendar year which is equal to 40 $\mu g / m^3$. (Ministero della Salute, 2015).

WHO Air quality guidelines Global Update 2005 states that the lower range of concentrations at which adverse health effects has been demonstrated is not greatly above the background concentration, the standard-setting process needs to achieve the lowest concentrations possible in the context of local constraints, capabilities and public health priorities.

In the following table, extrapolated from the WHO guidelines, the different targets for PM_{10} and $PM_{2.5}$ on an annual mean and a 24-hour mean level are shown, linked with the consequences they showed on human health.

Annual mean level	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	Basis for the selected level
WHO interim target 1 (IT-1)	70	35	These levels are estimated to be associated with about 15% higher long-term mortality than at AQG levels.
WHO interim target 2 (IT-2)	50	25	In addition to other health benefits, these levels lower risk of premature mortality by approximately 6% (2–11%) compared to IT-1.
WHO interim target 3 (IT-3)	30	15	In addition to other health benefits, these levels reduce mortality risk by approximately another 6% (2–11%) compared to IT-2 levels.
WHO air quality guidelines (AQG)	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to $PM_{2.5}$ in the ACS study *(323)*. The use of the $PM_{2.5}$ guideline is preferred.

Figure 3.5 - Air quality guideline and interim targets for PM: annual mean (WHO, 2005)

24-hour mean level [a]	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	Basis for the selected level
WHO interim target 1 (IT-1)	150	75	Based on published risk coefficients from multicentre studies and meta-analyses (about 5% increase in short-term mortality over AQG)
WHO interim target 2 (IT-2)	100	50	Based on published risk coefficients from multicentre studies and meta-analyses (about 2.5% increase in short-term mortality over AQG)
WHO interim target 3 (IT-3) [b]	75	37.5	About 1.2% increase in short-term mortality over AQG
WHO air quality guidelines (AQG)	50	25	Based on relation between 24-hour and annual PM levels

[a] 99th percentile (3 days/year).
[b] For management purposes, based on annual average guideline values, the precise number to be determined on the basis of local frequency distribution of daily means.

Figure 3.6 - Air quality guideline and interim targets for PM: 24-hour mean (WHO, 2005)

On the basis of these information, it is correct to consider 20 µg / m^3 as the limit for the PM_{10} on an annual mean and 50 µg / m^3 as the limit on a 24-hour mean according to WHO.

4. AERMOD

4.1. General introduction

The goal of simulation models is to predict the evolution over time of the concentration of a substance with an adequate degree of approximation; to do this it is necessary to take into consideration a large number of phenomena: physical, chemical-atomic, physicochemical.
The types of models are divided into:

- statistical models, determine the relationships between pollutants and meteorological variables through statistics;
- deterministic models, are able to predict the concentration of pollutants in the atmosphere on the basis of physical transport processes, exploiting the knowledge of the data on emissions and those on meteorological events. They can be further divided into:
    - Eulerian models, the reference system position remains fixed in time and space, based on the integration of the differential equation of diffusion, there are analytical models (puff and Gaussian), box and grid models, depending on how the differential equation is solved;
    - Lagrangian models, the reference system moves with the mean atmospheric motion, among them they can be distinguished trajectory and particle models. (Michela Sinesi, 2004)

  and:

    - stationary, the temporal evolution of a pollution phenomenon is treated as a sequence of quasi-stationary states, which considerably simplifies the model, even though decreasing its generality and applicability;
    - non-stationary, they deal with the evolution of the phenomenon in a dynamic way. (APAT, 2003)

In the early 90s, the AERMIC (AMS / EPA Regulatory Model Improvement Committee) a committee founded by two of the main American public environmental bodies (AMS, American Meteorological Society and EPA, Environmental Protection Agency) developed a new model of dispersion of pollutants in the PBL (Planetary Boundary Layer).
AERMIC will was to find a replacement model for the ISC3 dispersion model (Industrial Source Complex), the previous model created by the US-EPA, maintaining the same structure as regards inputs and outputs, but updating it with new algorithms that reflect the current state of environmental modelling.
The ISC3 model is the reference stationary deterministic Gaussian model, the use of which is limited to determining the first approximation of the impact of various polluting sources on a territory of

limited extension and with extremely regular characteristics; it has been used for many years to simulate the impact of industrial sources on the ground or in elevated position, in simple or moderately complex orography. (Enviroware)

The assumptions underlying the model are four:

1. slowly variable meteorological situations, therefore represented as a sequence of stationary states;
2. wind field and other meteorological variables are horizontally homogeneous;
3. for all meteorological variables a known vertical profile is assumed.
4. atmospheric turbulence must be described in the simplest and most compact way possible. (APAT, 2003)

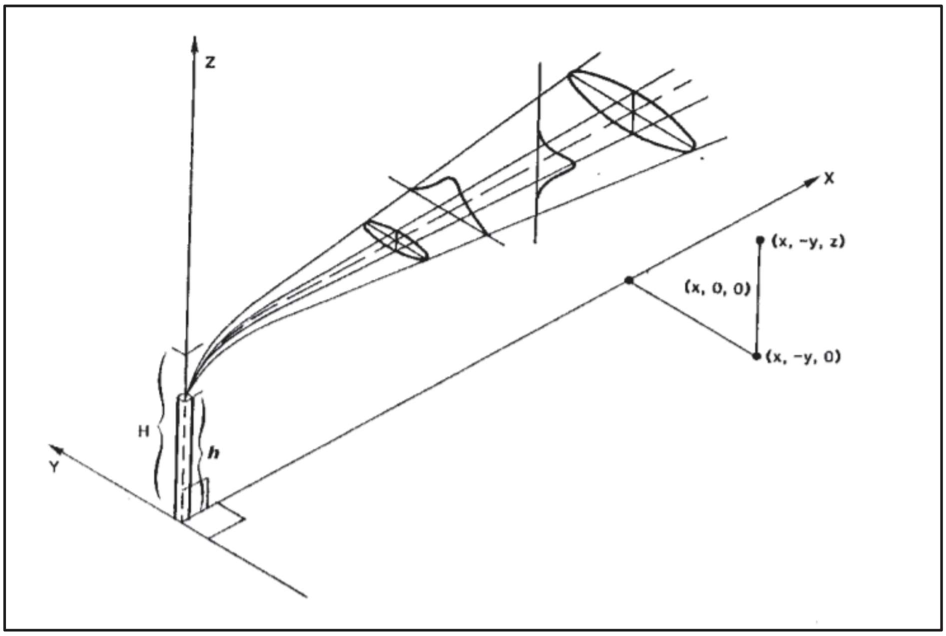


Figure 4.4.1 - Cartesian coordinate system for a Gaussian Model Plume (Dobbins, 1979)

Compared to ISC3, an attempt was made to improve the approach to the processes that characterize the dispersion in the ML and SL, AERMOD was thus created.

After the initial formulation, a first evaluation was carried out by performing a developmental evaluation that provided a basis for selecting formulation options.

This developmental evaluation was conducted using five data bases that cover elevated and surface releases, complex and simple terrain, and rural and urban boundary layers. (U.S.EPA, 2016)

After various reviews carried out by external committees, the model itself is subjected to a careful study by the EPA's OAQPS (Office of Air Quality Planning and Standards) to become part of the officially recognized modelling. (Tecsa SRL per IES di Mantova, 2005)

4.2. Description of AERMOD

The US EPA established AERMOD as a regulatory model in 2005, replacing ISC3.

AERMOD is a Gaussian analytical diffusive model that calculates the concentration of pollutants in an established area and studies their dispersion in the atmosphere incorporating updated treatments of turbulence and dispersion in the PBL; it is applicable in both urban and rural areas with complex orography and it considers many types of sources (volume, area and point) and, as with ISCST3 (Short-Term), the AERMOD is considered accurate for dispersion modelling at distances not exceeding 50 km from the source of emission (US EPA, 2005). (Kanyanee Seangkiatiyuth, 2011) (Leonor Maria Turtos Carbonell, 2010)

The model uses the AERMOD dispersion model and two pre-processors to process the input data: the AERMET meteorological processor, and the AERMAP orographic processor necessary to enter the characteristics of the territory and generate a grid of receptors.

AERMOD is a steady-state plume model, i.e. a model that considers emissions as if they were stationary over a time interval of one hour.

In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both the vertical and horizontal; in the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function (pdf). (U.S.EPA, 2016)

Additionally, in the CBL, AERMOD treats “plume lofting” whereby a portion of plume mass, released from a buoyant source, rises to and remains near the top of the boundary layer before becoming mixed into the CBL.

Where appropriate, the plume is modelled as either impacting and/or following the terrain. This approach has been designed to be physically realistic and simple to implement avoiding the need to distinguish among simple, intermediate and complex terrain, as required by other regulatory models.

One of the major improvements is that AERMOD is able to constructs vertical profiles of required meteorological variables basing on measurements and extrapolations of those measurements using similarity (scaling) relationships. Vertical profiles of wind speed, wind direction, turbulence, temperature, and temperature gradient are estimated using all available meteorological observations. (U.S.EPA, 2016)

The surface data refer to measurements made at a height of about 10 meters for the wind (direction and speed), temperature and cloud cover which represent the essential data. In addition to these, parameters concerning land use are introduced in the area of interest: albedo, bowen ratio, surface roughness.

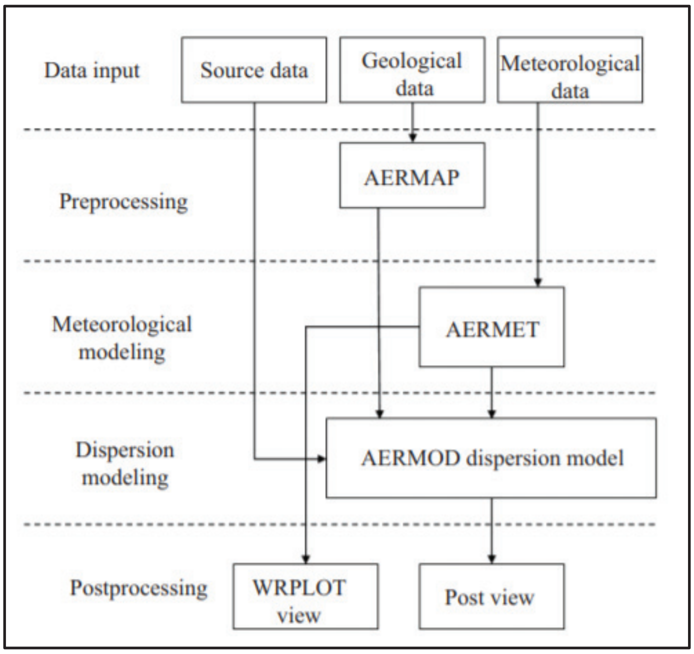


Figure 4.4.2 - Data flow in AERMOD modelling (Kanyanee Seangkiatiyuth, 2011)

Figure 4.2 shows how AERMOD is organized with its two pre-processors.

The previously listed meteorological data represent input data for AERMET that then calculates the PBL parameters: friction velocity, Monin-Obukhov length, convective velocity scale, temperature scale, mixing height, and surface heat flux. These parameters are then passed to the 'interface' (which is within AERMOD) where similarity expressions (in conjunction with measurements) are used to calculate vertical profiles of wind speed, lateral and vertical turbulent fluctuations, potential temperature gradient and potential temperature. (U.S.EPA, 2016)

The AERMAP pre-processor, through the use of a grid from Digital Elevation Model (DEM) data, subdivides the territory and calculates a Hc (terrain height scale) defined for each receptor. The information that will then be provided to AERMOD will be the position of each receptor, its height with respect to sea level and the height scale Hc. Basically, an initial morphology is inserted which will then be transformed into an effective one depending on the altitude and the distance from the receptor. (Regione Marche, 2009)

4.3. Pre-processor AERMAP

AERMAP is the pre-processor used by AERMOD to provide inputs relating to the orography of the territory. This program allows to enter the morphology of the area studied, thus making AERMOD a model capable of analysing situations with both complex and flat terrain.
The input data necessary for AERMAP are:

- DEM formatted terrain data;
- Design of receptor grid (AERMAP accepts either polar, Cartesian or discrete receptors).

The maps to be encoded by AERMAP, as just seen, have a very particular format: USGS DEM file (Digital Elevation Map), they are formed by a grid in which the orographic elevation of each node is known; unfortunately, digitized maps in this format are not very widespread in Italy or in Europe, while there is a large collection for the United States of America.
The operations carried out by AERMAP in the preprocessing of data on the territory make it necessary to use the digitized format, in fact the concept of "dividing streamline" is used, that is a characteristic height Hc that divides the flow of pollutant into two parts (Regione Marche, 2009); assuming that the wind speed increases with height, Hc can be thought of as the altitude in the stable atmosphere where the flow has sufficient kinetic energy to overcome the stratification and rise; the height scale quantifies the influence that the surrounding orography has on the receptor. (U.S.EPA, 2016)
This data is fundamental since the concentration estimate will be carried out as a weighted sum of the two different contributions of the plume identified by Hc.

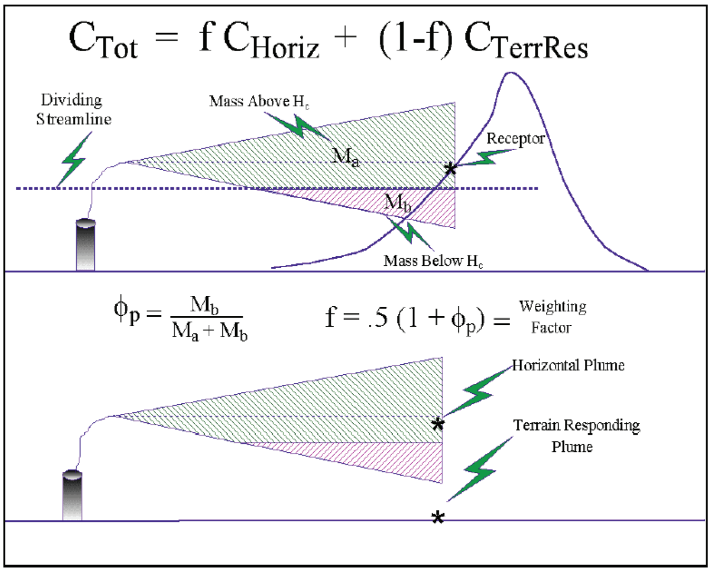


Figure 4.4.3 - Construction of the weighting factor used in calculating total concentration (U.S.EPA, 2016)

Once this height is known, the territory will be characterized for each receptor in a different way by reworking the data from the point of view of the single receptor: a different morphology will be associated with each receptor. The digital format helps us because for each point of the considered area it provides a vector that will be filled from time to time with the heights referred to all the receptors. (Regione Marche, 2009)
For each receptor, AERMAP passes the following information to AERMOD:

- the receptor's location (xr , yr);
- its height above mean sea level (zr);
- the receptor specific terrain height scale (hc).

4.4. Pre-processor AERMET

The purpose of this pre-processor is to collect the meteorological data representative of the area in order to calculate the parameters that characterize the PBL and allow AERMOD to obtain the vertical profiles of the variables. The input data are collected and stored in files with particular formats to allow easy extrapolation by models of mainly American origin.
The NWS (National Weather Service) has collected these data for many representative locations in the United States of America in three main categories:

- hourly surface data (wind, temperature, cloud cover plus additional optional data), these refer to measurements made at a height of about 10 meters from the physical detection units;

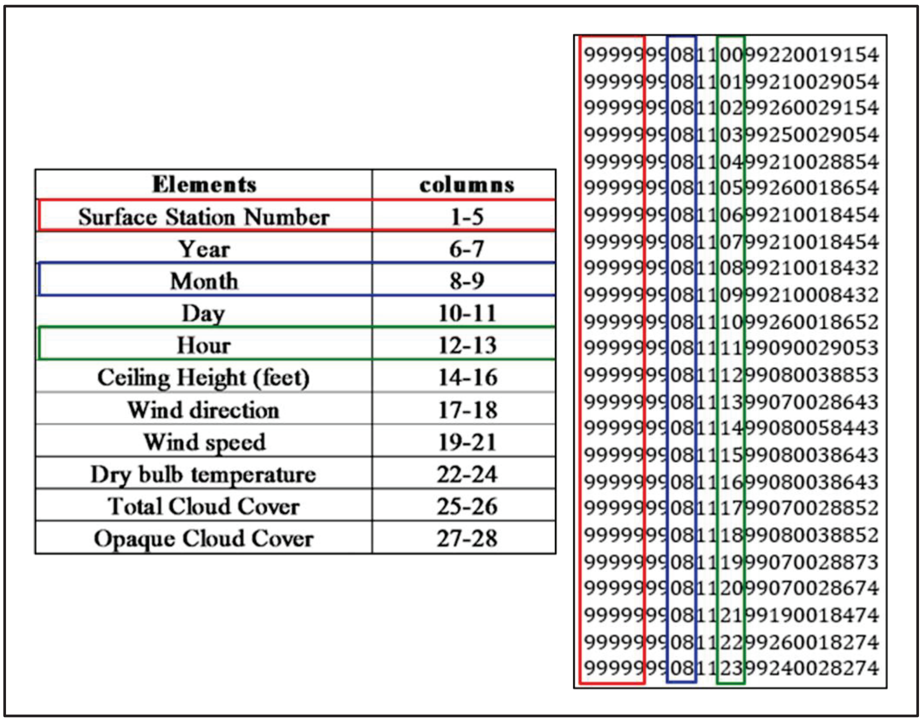
- altitude measurements (upper air) with measurements of temperature, wind, relative humidity, pressure and geopotential height; the required frequency is two measurements per day (at 12 and 24) but in many countries these data are not available so an estimator is used;

- optional on-site data with information on turbulence, atmospheric pressure and measurement of solar radiation, obtained from the control units.

  (Regione Marche, 2009)

With all these input data, AERMET calculates the parameters necessary for AERMOD to extrapolate the vertical profiles of the most important meteorological variables.
Input file format for AERMET:

- CD-144: uses alphanumeric characters to represent the various meteorological data which are then stored, for each hour, on the various records;
- SCRAM: it is a reduced format of the CD-144 as it contains less data which however include: maximum height of the clouds, wind direction, wind speed, dry bulb temperature and total and opaque cloud cover;
- SAMSON: The '.sam' files consist of two records: the first contains information regarding the data of the survey station, while in the second a reference position identified by a number is associated with each meteorological variable. (US EPA)



Elements	columns
Surface Station Number	1-5
Year	6-7
Month	8-9
Day	10-11
Hour	12-13
Ceiling Height (feet)	14-16
Wind direction	17-18
Wind speed	19-21
Dry bulb temperature	22-24
Total Cloud Cover	25-26
Opaque Cloud Cover	27-28

Figure 4.4.4 - SAMSON file format, the table on the left indicates which position of the numerical code on the right is occupied by each information

4.4.1. AERMOD meteorological interface

In the AERMOD structure there is a series of procedures used for the treatment of meteorological variables elaborated by AERMET. The purpose of this part of the program is to extrapolate the vertical profiles of the most important meteorological variables:

- wind speed;
- wind direction;
- temperature;
- vertical gradient of potential temperature;
- vertical turbulence;
- horizontal turbulence.

For each of these six profiles, the height at which the meteorological variable must be calculated will be compared with the heights at which the measurements were made, and whether this altitude is below the lowest measurement or above the highest one then an appropriate similarity function will be used, i.e. an operation will be carried out which tends to interpolate the measured data with the numerical results.

If data are available both above and below a certain height, a linear interpolation will be carried out between the measured data, while trying to maintain the shape of the profile obtained from the interpolation operations. This methodology therefore takes advantage of the use of both direct measurements and parameterization of the variables through appropriate algorithms.

It is important to underline the necessity to have at least one level of measurement to estimate the profile of wind speed and direction and temperature, while for turbulence it is possible to do it without direct surveys. (U.S.EPA, 2016)

The next step is the determination of the concentration values, considering the transport and dispersion of the plume in areas with complex orography. If there is a stable flow, a structure formed by two layers develops, the lower one remaining almost horizontal while the upper one tends to rise. As already mentioned above, conceptually the two layers are divided by Hc (Dividing Streamline).

In neutral or unstable conditions the lower layer disappears and the whole flow tends to rise. A plume below Hc remains horizontal and if it encounters an obstacle (e.g. a hill) it can stop at the point of impact or bypass it, and will also tend to sink towards the surface. The flow located above Hc, on the other hand, will tend to rise and increase the vertical turbulence.

AERMOD, to maintain a certain simplicity in the formulation, considers the effects of vertical turbulence on the plume but neglects those due to the flow that deviates laterally. The concentration of a receptor placed at a certain height (z_t: height above sea level, z_p: height of the receptor from the ground) is calculated as the sum of two weighted combinations of limit cases:

- the plume is horizontal due to atmospheric stability conditions so that the flow bypasses the obstacle;
- the plume follows the morphology of the territory vertically so that the height from the ground of the central line of the plume remains constant. (Regione Marche, 2009)

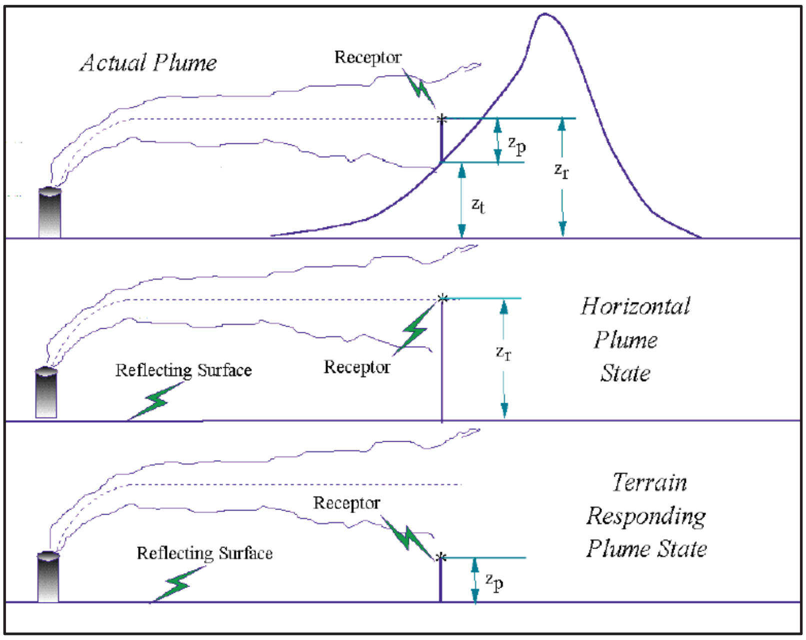


Figure 4.4.5 - AERMOD two state approach. The total concentration predicted by AERMOD is the weighted sum of the two extreme possible plume states (U.S.EPA, 2016)

The real situation will oscillate between these two extremes depending on these characteristics:

- atmospheric stability;
- wind speed;
- relative height of the plume from the ground.

In stable conditions the situation will be closer to the case of the horizontal plume while in neutral or unstable conditions the plume tends to follow the surface. (Regione Marche, 2009)

AERMOD simulates five different plume types depending on the atmospheric stability and the position inside and above the boundary layer: 1) direct, 2) indirect, 3) penetrated, 4) injected and 5) stable. All of these plumes will be discussed in detail in the rest of this paper.
Under stable conditions, the plumes are modelled with the horizontal and vertical Gaussian formulations; under convective conditions the horizontal distribution is still approximately Gaussian while the vertical concentration distribution is assumed to be a random variable and characterized by its probability density function (pdf) and results from a combination of three types of plume: 1) the material of the direct plume within the mixed layer that initially does not interact with its lid; 2) the indirect plume material inside the mixed layer which rises and initially tends to rise near the top of the mixed layer; and 3) the penetrated plume material which is released into the mixed layer but, due to its buoyancy, penetrates the elevated stable layer.
In convective conditions, AERMOD also manages a special case called injected source where the top of the stack (or release height) is greater than the mixing height. The injected sources are modelled as plumes under stable conditions. (U.S.EPA, 2016)

4.5. Receptors

In this step AERMOD requires the definition of the receptors position, i.e. the points where, during the processing phase, the concentrations of the particulate will be evaluated.
The receptors are reference points scattered within the screened domain, they represent points sensitive to atmospheric pollution and are generally areas of a territory considered particularly important from an environmental point of view, for example schools, hospitals, green areas and goods of historical and artistic interest.
It is essential to have receptors since the program makes use of the two previously described pre-processors which associate meteorological (AERMET) and plano-altimetric (AERMAP) data to each receptor.
The processor offers the possibility of calculating concentrations both according to a geometric arrangement and according to arbitrary points entered manually.

In the first case, a GRID of receptors will be inserted whose geometric characteristics can be defined by selecting one of the options proposed by the program:

• uniform Cartesian grid;
• non-uniform Cartesian grid;
• uniform grid around one pole;
• uneven grid around one pole;
• grids with different densification built around a pole.

In the second case, the receptors are defined as DISCRETE receptors; their position is defined either by inserting their geographic coordinates (discrete cartesian receptors) or by specifying their linear and angular distance from a specific source (discrete polar receptors).
Here, they have been inserted, among the discrete receptors, the coordinates of two RRQA (Regional Air Quality Detection Network) particulate detection units managed by the ARPAM which fall within the area, i.e. the monitoring stations of San Benedetto del Tronto (urban traffic) and Ascoli Piceno (urban area).
In the figures below the coordinates of the three control units that have been entered in the software and their locations on the map.

San Benedetto del Tronto	Lat	42.943038
	Long	13.882635
Ascoli Piceno	Lat	42.849014
	Long	13.621014

Figure 4.4.6 - coordinates of the ARPAM control units entered

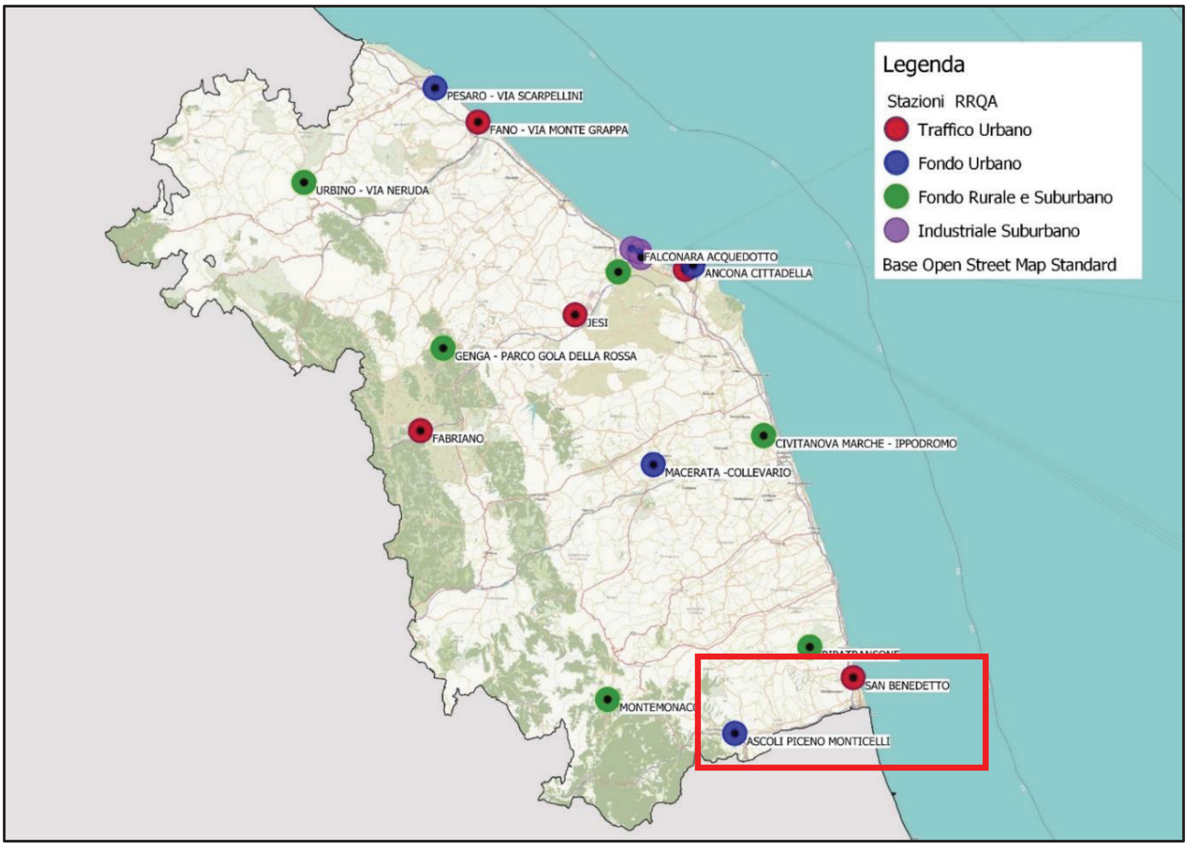


Figure 4.4.7 - Location of the discrete receptors (ARPAM)

The discrete receptors, i.e. the control units, are inserted in the simulation because in this way, by setting the post processing setup, it is possible to extract the data as hourly averages and perform comparisons between the simulation results and the measurements made by the control unit for the same days in order to verify the reliability of the simulation itself.

To evaluate the impact of the particulate more in detail, a grid of receptors was placed side by side with the discrete receptors, for this simulation a uniform Cartesian Grid Receptor Network centred in Offida was chosen with a number of points equal to 20 with spacing of 2136.11 meters among one another, for a length of 40586.09 meters and a total of 400 nodes.

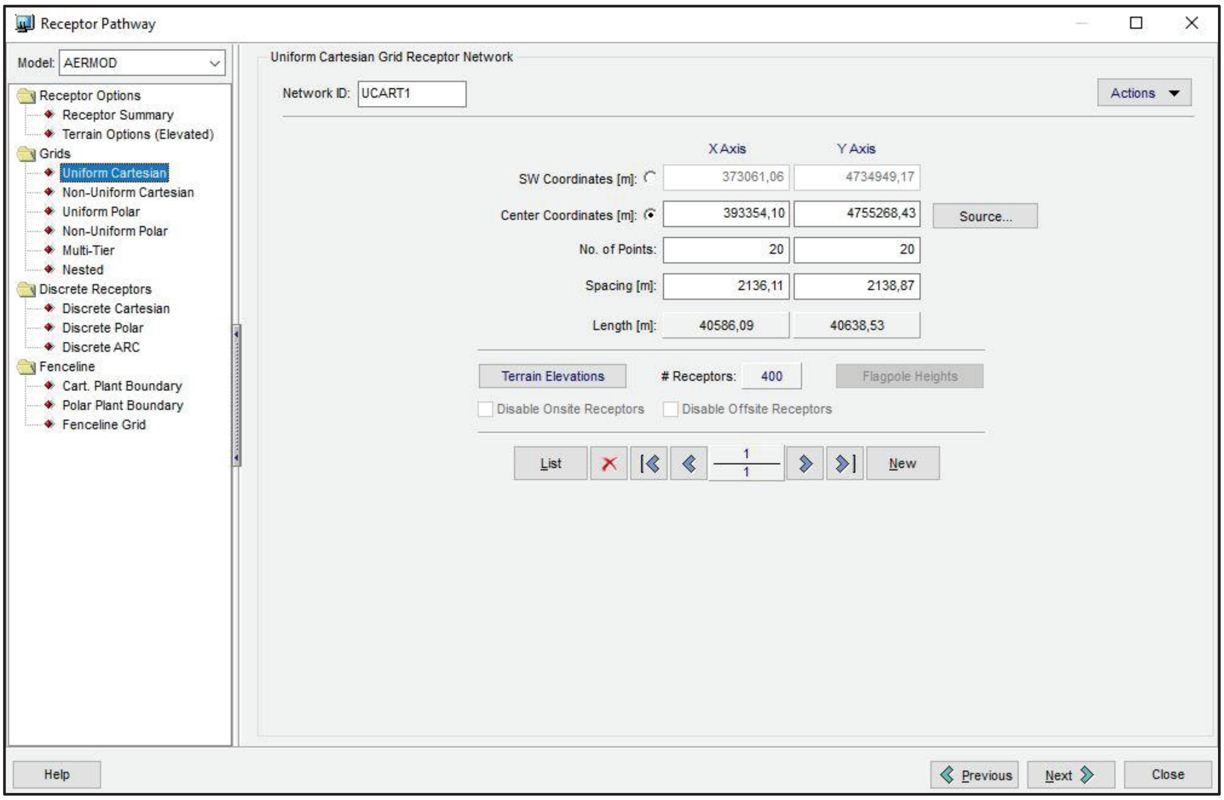


Fig.4.8 - Uniform grid of receptors characteristics

Fig.4.8 - Uniform grid of receptors

Overall, therefore, the concentrations of particulate were calculated in 402 receptors.

Each receptor corresponds to a triple coordinate in space: 2 UTM coordinates in the plane and the height from the ground.

5. Input data for AERMOD simulation

This statistical analysis stems from the need for medical-epidemiological research to study the causes of the occurrence of certain diseases and their possible correlation with the prolonged exposure to certain factors.

New and ever more perfected simulations are continuously requested by ARPAM in order to obtain the well-known dose-effect curve that can better interpolate the data of sick or deceased people due to a precise disease with exposure. This type of diffusive analysis is the basis of environmental epidemiology studies, which are increasingly useful for understanding what effect a specific factor has had on our health and on our life.

5.1. Domain description and analysis

Geographical framework of the area: For the creation of the domain, it was necessary to use Google Earth, software that generates virtual images of the Earth using satellite images obtained by terrestrial remote sensing, aerial photographs and topographical data stored in a GIS platform.

The geographical coordinates in the software have been set on UTM and a municipality has been chosen which will act as a reference point, i.e. as the centre, of the circumference that will serve to draw the domain.

The chosen municipality is the already mentioned Offida, a small municipality which is about 30 km from Ascoli Piceno and about 16 km from San Benedetto del Tronto; this will act as the centre of the domain; then a radius of 20 km was chosen in order to reach the coast in the direction of San Benedetto del Tronto, trespassing for a short distance into the sea.

Thanks to the software, Offida coordinates were found and entered in AERMOD in the appropriate work window.

Offida	393803.87 EAST
	4755092.17 NORTH

Figure 5.1 - Coordinates of the municipality of Offida

In 'reference point' it is necessary to select 'center' since in this way the domain is centered in a point with the aforementioned east and north coordinates which must be entered respectively in 'x' and 'y', then the chosen radius of 20 km must be entered, and checked out to verify that the domain is actually the one of interest and the definition of the domain is completed.

The domain thus created is larger than the actual receptor grid that we will insert.

It is an area of 990 km2 with an involved coastal strip of about 27 km, from San Benedetto del Tronto to Altidona and an internment in the territory up to the height of Ascoli Piceno.

The domain includes the following municipalities belonging to the province of Ascoli Piceno: Acquaviva Picena, Appignano del Tronto, Ascoli Piceno, Carassai, Castel di Lama, Castignano, Castorano, Colli del Tronto, Cossignano, Cupra Marittima, Folignano, Force, Grottammare, Maltignano, Massignano, Monsampolo del Tronto, Montalto delle Marche, Montedinove, Montefiore dell'Aso, Monteprandone, Offida, Ripatransone, Rotella, San Benedetto del Tronto, Spinetoli, Venarotta; and the following municipalities in the province of Fermo: Altidona, Belmonte Piceno, Campofilone, Monsampietro Morico, Monte Giberto, Monte Rinaldo, Monte Vidon Combatte, Monteleone di Fermo, Montelparo, Monterubbiano, Montottone, Moresco, Ortezzano, Pedaso, Petritoli, Santa Vittoria in Matenano , Servigliano; for a total of 43 municipalities.
Municipalities cut by the limits of the domain were not considered for simulation purposes.

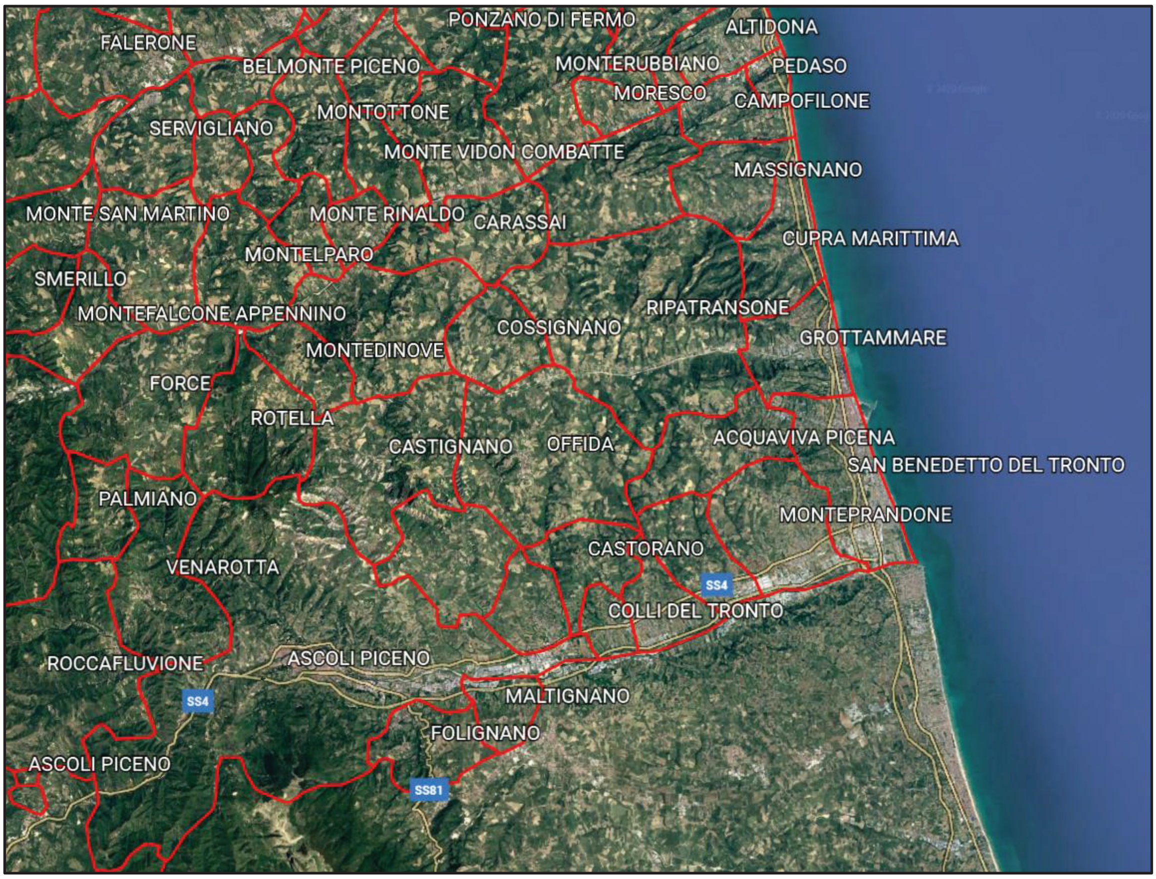


Figure 5.2 - The domain (in Google Earth)

In the figure above it is shown the domain generated by the software and in red are highlighted the contours of the municipalities considered for this simulation; it appears evident that in the domain generated, municipalities of the Abruzzo region are also included but they will not be considered for simulation purposes; however it seems necessary to make the following consideration: obviously, in reality, there will be a contribution from the municipalities of Abruzzo; however, the program's approximations allow not to consider them.

The geomorphological trend of the area is mainly valley-hilly as shown in the following satellite photo.

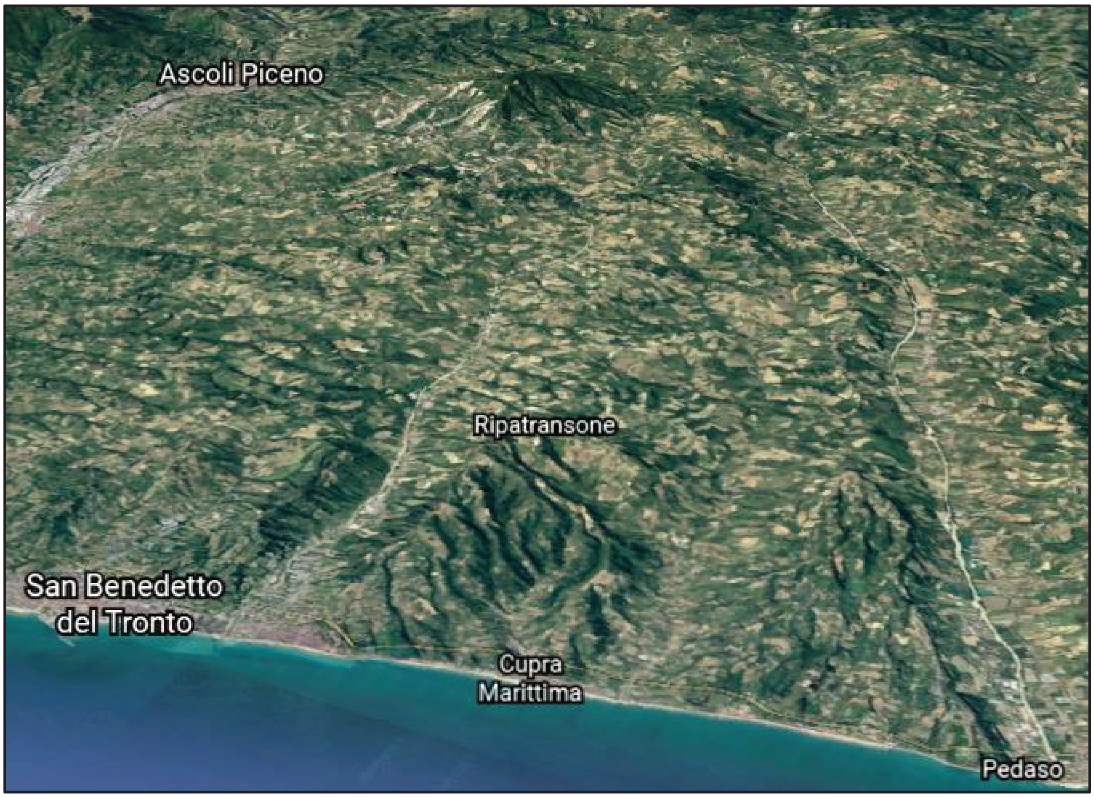


Figure 5.3 - Satellite image of the domain area

<u>Infrastructural framework:</u> the relevant public works created for traffic and transport falling within the domain are the following: A14 motorway, State road 16, motorway junction 11.

<u>Environmental risk classification:</u> the environmental criticalities found in the area in question are of two different matrices, one of natural origin and one anthropic. The first alludes to areas subject to risk of flooding and landslides in the Tronto river basin, to the significant erosive activity of the sea along the coast, as well as to other areas of hydrogeological instability present mainly in the hinterland where the territory mainly takes on a hilly morphology.

The anthropic environmental emergencies, on the other hand, are associated with the industrial activities identified by the Territorial Coordination Plan (PTC, Piano Territoriale di Coordinamento) of the provinces of Ascoli Piceno and Fermo even if these are not subject to urbanization control. (ISPRA I. S., 2018)

<u>Demographic classification:</u> according to ISTAT data 01/01/2019, the total resident population in the 43 municipalities of the domain is approximately 1,523,497.00 inhabitants; with a highly variable density throughout the area and particularly high along the entire coastal strip.

The following table shows the population density and the number of resident population in the areas of interest, the municipalities are reported in alphabetical order:

COMUNIVERSO: Municipalities of Marche Region *[Ancitel elaboration 2020]*					
	Province	**Municipality**	**Area(kmq)**	**Resident population(01/01/2019)**	**Popul. Density(ab/kmq)**
1	Ascoli Piceno	Acquaviva Picena	21,06	3747,00	180,36
2	Fermo	Altidona	12,97	3501,00	266,09
3	Ascoli Piceno	Appignano del Tronto	23,19	1728,00	76,18
4	Ascoli Piceno	Ascoli Piceno	158,02	48169,00	308,65
5	Fermo	Belmonte Piceno	10,53	626,00	59,25
6	Fermo	Campofilone	12,21	1912,00	157,07
7	Ascoli Piceno	Carassai	22,24	1018,00	47,44
8	Ascoli Piceno	Castel di Lama	10,98	8589,00	784,66
9	Ascoli Piceno	Castignano	38,80	2709,00	70,55
10	Ascoli Piceno	Castorano	14,08	2315,00	166,43
11	Ascoli Piceno	Colli del Tronto	5,94	3717,00	622,22
12	Ascoli Piceno	Cossignano	14,95	922,00	63,67
13	Ascoli Piceno	Cupra Marittima	17,34	5361,00	309,05
14	Ascoli Piceno	Folignano	14,86	9138,00	617,94
15	Ascoli Piceno	Force	34,31	1249,00	37,25
16	Ascoli Piceno	Grottammare	18,00	16073,00	898,36
17	Ascoli Piceno	Maltignano	8,17	2337,00	288,91
18	Ascoli Piceno	Massignano	16,30	1651,00	100,59
19	Fermo	Monsampietro Morico	9,76	634,00	65,25
20	Ascoli Piceno	Monsampolo del Tronto	15,43	4591,00	294,61
21	Ascoli Piceno	Montalto delle Marche	33,94	2037,00	61,22
22	Fermo	Monte Giberto	12,53	775,00	62,63
23	Fermo	Monte Rinaldo	7,92	352,00	45,32
24	Fermo	Monte Vidon Combatte	11,17	426,00	38,86
25	Ascoli Piceno	Montedinove	11,93	510,00	41,73
26	Ascoli Piceno	Montefiore dell'Aso	28,21	2033,00	72,78
27	Fermo	Monteleone di Fermo	8,21	370,00	46,38
28	Fermo	Montelparo	21,63	749,00	35,05
29	Ascoli Piceno	Monteprandone	26,38	12708,00	480,66
30	Fermo	Monterubbiano	32,24	2167,00	67,13
31	Fermo	Montottone	16,38	930,00	58,00
32	Fermo	Moresco	6,35	559,00	90,69
33	Ascoli Piceno	Offida	49,60	4927,00	100,03
34	Fermo	Ortezzano	7,07	758,00	108,13
35	Fermo	Pedaso	3,85	2854	732,26
36	Fermo	Petritoli	24,00	2280,00	95,70
37	Ascoli Piceno	Ripatransone	74,28	4202,00	56,97
38	Ascoli Piceno	Rotella	27,44	849,00	31,71
39	Ascoli Piceno	San Benedetto del Tronto	25,41	47330,00	1863,70
40	Fermo	Santa Vittoria in Matenano	26,18	1310,00	50,50
41	Fermo	Servigliano	18,49	2270,00	122,59
42	Ascoli Piceno	Spinetoli	12,58	7254,00	566,75
43	Ascoli Piceno	Venarotta	30,21	1997,00	67,20

Figure 5.4 - List of municipalities in the domain with resident population and population density

5.2. Preparation of the Source Pathway

Before proceeding with any other action, it is necessary to insert the sources that emit the considered pollutant (in our case the fine particulate), distinguishing them in *area, line, point,* and *volume*.

5.2.1 Area Sources

AREA SOURCES represent areas in which the contaminant can be considered as uniformly emitted. In this study, as area sources are considered those that fall within Macro-sectors 2 (non-industrial heating), 4 (production activities), 7 (road transport).

All 43 municipal territories included in the domain have been enclosed in polygons and, within each municipality, urban and industrial areas have been enclosed in other polygons as shown in the figure below.

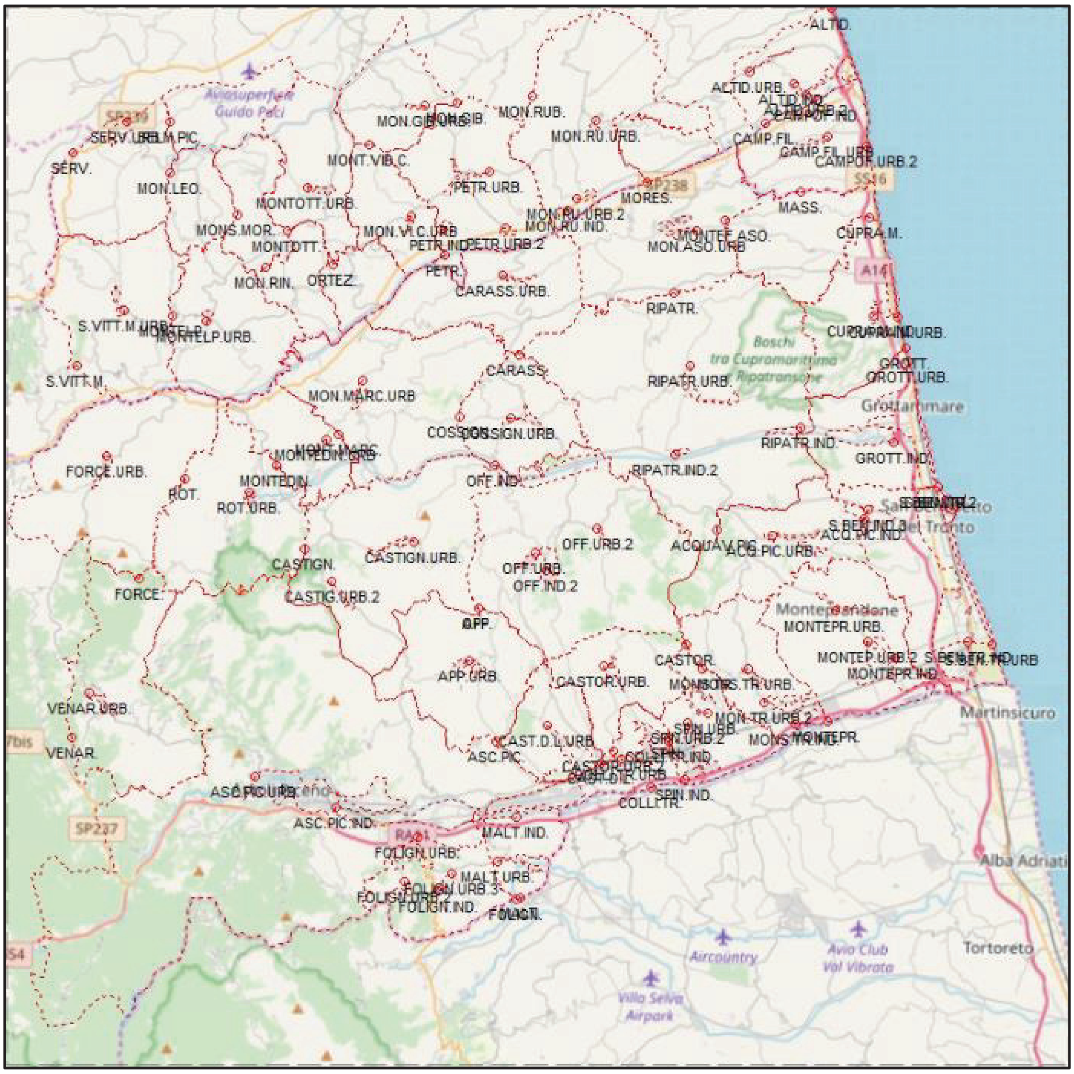


Figure 5.5 - Aspect of the domain after the insertion of all the Area Sources

This phase has been implemented in the AERMOD software manually; on the left menu, the 'polygon area source' tool was used; this allows to trace the boundaries of each municipality within the domain. The boundaries are created by means of a broken line with a minimum approximation of the angles and curves, taking into account the presence of errors due to manual insertion; however the resolution of the program is such that the boundaries can be considered not in detail.
Once the polygon is closed, the area description box opens automatically and data can be entered.
In order to correctly and, above all, clearly enter the data of the municipalities within the respective boxes, there was the need to create a nomenclature to rename each source so that they could be easily recognized and classified; since with the 'polygon area source' tool with the use of broken lines the municipal areas were selected, it was decided to type 'Area' in the 'description' box and to rename all the highlighted municipalities with this technique with an abbreviation able to recall the name of the highlighted municipality (e.g. Asc.Pic. For Ascoli Piceno).
This being done for each municipality within the area of interest.
The same procedure was used to highlight the industrial areas of each municipality, the municipalities can have one, two or more industrial areas which, where possible, must be identified and reported among the list of sources, this because it would be a too strong approximation inserting an industrial source and spread it over the whole municipal area when in reality it is emitted, precisely, from the industrial area; this because increasing the emission surface would reduce the local effect; in this way instead we have more refined approximations at the local level.
The nomenclature for industrial areas will be, for each municipality, its abbreviation to which is added the abbreviation 'ind.' (e.g. Asc. Pic. ind.); same thing for the 'description' to be added, which will be for all industrial areas: 'Area ind.'
Now, it has also been considered the real urban centre of the city where there is the greatest concentration of population and, therefore, the residential areas; it is important to include this sub-group because PM_{10} emissions from domestic heating have exceeded those from traffic. The nomenclature in this case will be the abbreviation of the municipality plus the abbreviation 'urb.' (e.g. Asc.Pic.urb.).
In the case of small municipalities, if the houses are distributed homogeneously over the entire surface of the municipality, the urban polygon is not created and the emissions from domestic heating will therefore be distributed throughout the generic municipal area; in the case, however, the urban agglomeration is clearly distinguishable from the rest of the areas of the municipality, it will be enclosed in an urban polygon since it could be an agricultural context with few scattered houses.
On the contrary, in the case of municipalities with a high resident population, it was decided to refer to the General Regulatory Plan (PRG, Piano Regolatore Generale) of these municipalities, in order to identify in detail and obtain a better correspondence between the real urban and industrial areas and those represented in the software.
Below are the municipalities of the domain with the respective abbreviations used within AERMOD.

Province	Municipality	Acronym
ASCOLI PICENO	Acquaviva Picena	ACQ.PIC.
ASCOLI PICENO	Appignano del Tronto	APP.
ASCOLI PICENO	Ascoli Piceno	ASC.PIC.
ASCOLI PICENO	Carassai	CARASS.
ASCOLI PICENO	Castel di Lama	CAST.D.L.
ASCOLI PICENO	Castignano	CASTIG.
ASCOLI PICENO	Castorano	CASTOR.
ASCOLI PICENO	Colli del Tronto	COLLI.TR.
ASCOLI PICENO	Cossignano	COSSIGN.
ASCOLI PICENO	Cupra Marittima	CUPRA.M.
ASCOLI PICENO	Folignano	FOLIGN.
ASCOLI PICENO	Force	FORCE.
ASCOLI PICENO	Grottammare	GROTT.
ASCOLI PICENO	Maltignano	MALT.
ASCOLI PICENO	Massignano	MASS.
ASCOLI PICENO	Monsampolo del Tronto	MON.TR.
ASCOLI PICENO	Montalto delle Marche	MON.MARC.
ASCOLI PICENO	Montedinove	MONTEDIN.
ASCOLI PICENO	Montefiore dell'Aso	MON.ASO.
ASCOLI PICENO	Monteprandone	MONTEP.
ASCOLI PICENO	Offida	OFF.
ASCOLI PICENO	Ripatransone	RIPATR.
ASCOLI PICENO	Rotella	ROT.
ASCOLI PICENO	San Benedetto del Tronto	S.BEN.
ASCOLI PICENO	Spinetoli	SPIN.
ASCOLI PICENO	Venarotta	VENAR.
FERMO	Altidona	ALTID.
FERMO	Belmonte Piceno	BELM.PIC.
FERMO	Campofilone	CAMPOF.
FERMO	Monsampietro Morico	MONS.MOR.
FERMO	Monte Giberto	MON.GIB.
FERMO	Monteleone di Fermo	MON.LEO.
FERMO	Montelparo	MONTELP.
FERMO	Monte Rinaldo	MON.RIN.
FERMO	Monterubbiano	MON.RU.
FERMO	Monte Vidon Combatte	MON.VI.C.
FERMO	Montottone	MONTOTT.
FERMO	Moresco	MORES.
FERMO	Ortezzano	ORTEZ.
FERMO	Pedaso	PED.
FERMO	Petritoli	PETR.
FERMO	Santa Vittoria in Matenano	S.VITT.M.
FERMO	Servigliano	SERV.

Figure 5.6 - List of municipalities in the domain with their respective abbreviations

In order to create the source, it is necessary to fill in all the fields of the box, which are mandatory, however the program will take all the real values from the orography model that will be loaded at a later stage so the first step has been to insert the default value 1 for all fields; this is both for the areas of the entire municipality and for the areas relating to industrial and urban areas.

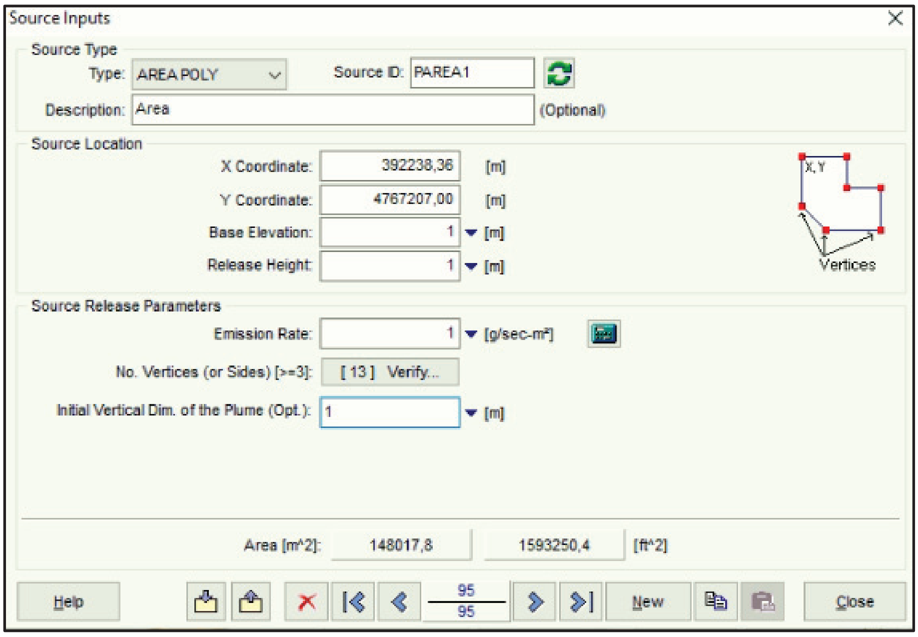


Figure 5.7 - Entering data relating to an area source in AERMOD

These polygons are used to have a clear view of the territory in AERMOD operational interface, i.e. the exact location of the municipalities, while the polygons that enclose the urban and industrial areas are used to have the surface of the areas actually producing fine particulate, therefore having an idea of their extension over the entire municipal area.

The next step is the description of the process of entering the emission values into the area sources, where the surfaces that AERMOD has calculated starting from the areas drawn manually, were used to calculate the emissions in g / s * m^2, unit of measure required for input data to be entered in AERMOD.

From the inventory of the Marche Region the data in tons / year of the emissions were taken, divided by Macro-sectors. The Macro-sectors of interest, as already mentioned above, are respectively: 2 (non-industrial heating), 4 (production activities), 7 (road transport).

First of all, the emission values provided have been converted into g / s and subsequently inserted in the box for the creation of the sources, using the specific conversion tool that distributes the g / s on the m^2 calculated by the software mentioned previously.

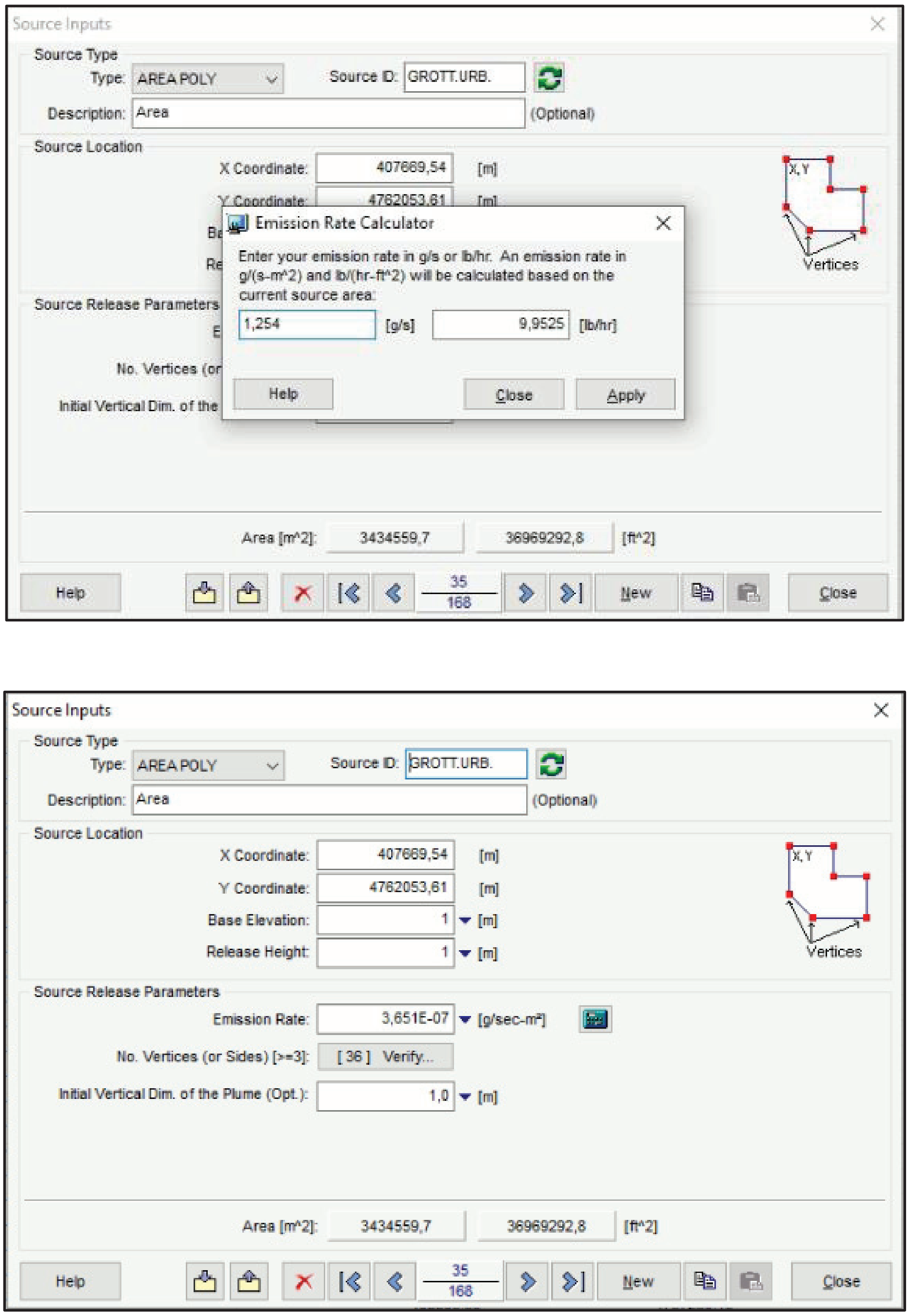


*Figure 5.8 - Entering the emission value in g / s in AERMOD (above), returning the value in g / s * m2 (below)*

These emission values have been converted into g / s * m^2 for the entire municipal area or differentiating between urban and industrial areas.

It is now described the different approach adopted to the various sectors, due to their heterogeneity and the heterogeneity of the areas considered:

- <u>Macro-sector 2 (non-industrial heating)</u>; as already mentioned, it was considered important to give meaning to the relationship between the area that actually produces pollution in a municipality (i.e. the urban and industrial area) and the total area of the municipality itself, so the emissions due to

macro-sector 2 have been attributed only to the areas designated by the suffix 'urb.', i.e. the purely urban and residential areas of the municipality.
However, there are 7 exceptions because for the municipalities of Massignano, Belmonte Piceno, Monsampietro Morico, Monteleone di Fermo, Monte Rinaldo, Moresco and Ortezzano, it was not possible to identify a real urban area due to a dispersed distribution of houses and therefore, the emission relating to this macro-sector has been included in the area of the entire municipality.
On the contrary, in some municipalities it was necessary to identify two or more urban areas, in this case the total emission value of those municipalities was simply divided by the number of their urban areas.
The table below shows the emission values for all the municipalities (urban area) of the domain, in tonnes / year, g / s and reporting the values divided by 2 urban areas (/ 2) or 3 urban areas (/ 3) in municipalities with these characteristics.

Province	Municipality	PM10			
		ton/year	g/s		
				/ 2	/ 3
ASCOLI PICENO	Acquaviva Picena	9,190	0,291		
ASCOLI PICENO	Appignano del Tronto	4,525	0,143		
ASCOLI PICENO	Ascoli Piceno	66,386	2,105		
ASCOLI PICENO	Carassai	3,062	0,097		
ASCOLI PICENO	Castel di Lama	19,614	0,622		
ASCOLI PICENO	Castignano	7,432	0,236	0,117834	
ASCOLI PICENO	Castorano	5,706	0,181	0,09047	
ASCOLI PICENO	Colli del Tronto	8,575	0,272		
ASCOLI PICENO	Cossignano	2,553	0,081		
ASCOLI PICENO	Cupra Marittima	13,699	0,434		
ASCOLI PICENO	Folignano	21,333	0,676		0,225491
ASCOLI PICENO	Force	3,552	0,113		
ASCOLI PICENO	Grottammare	39,556	1,254		
ASCOLI PICENO	Maltignano	5,952	0,189		
ASCOLI PICENO	Massignano	3,859	0,122		
ASCOLI PICENO	Monsampolo del Tronto	10,398	0,330	0,164865	
ASCOLI PICENO	Montalto delle Marche	5,816	0,184		
ASCOLI PICENO	Montedinove	1,591	0,050		
ASCOLI PICENO	Montefiore dell'Aso	5,472	0,174		
ASCOLI PICENO	Monteprandone	25,022	0,793	0,396717	
ASCOLI PICENO	Offida	13,428	0,426	0,212893	
ASCOLI PICENO	Ripatransone	10,556	0,335		
ASCOLI PICENO	Rotella	2,441	0,077		
ASCOLI PICENO	San Benedetto del Tronto	126,515	4,012		
ASCOLI PICENO	Spinetoli	17,175	0,545	0,272302	
ASCOLI PICENO	Venarotta	5,555	0,176		
FERMO	Altidona	8,296	0,263	0,131526	
FERMO	Belmonte Piceno	1,619	0,051		
FERMO	Campofilone	4,665	0,148	0,073956	
FERMO	Monsampietro Morico	1,808	0,057		
FERMO	Monte Giberto	2,051	0,065		
FERMO	Monteleone di Fermo	1,227	0,039		
FERMO	Montelparo	2,314	0,073		
FERMO	Monte Rinaldo	0,955	0,030		
FERMO	Monterubbiano	5,788	0,184	0,091774	
FERMO	Monte Vidon Combatte	1,249	0,040		
FERMO	Montottone	2,508	0,080		
FERMO	Moresco	1,611	0,051		
FERMO	Ortezzano	2,230	0,071		
FERMO	Pedaso	6,745	0,214		
FERMO	Petritoli	6,297	0,200	0,099843	
FERMO	Santa Vittoria in Matenano	3,839	0,122		
FERMO	Servigliano	5,854	0,186		

Figure 5.9 - List of municipalities in the domain with emission values in urban areas for macro-sector 2

- Macro-sector 4 (production activities); contrary to what was done previously with macro-sector 2, for the macro-sector 4 relating to production activities it was necessary to make considerations and hypotheses.

First of all, a distinction must be made between AIA and AUA authorizations.

The Integrated Environmental Authorization AIA, "Autorizzazione Integrata Ambientale", is the integrated authorization necessary for the operation of some types of production installations that can produce significant environmental damage; it is integrated because the various damages to the environment caused by the activity to be authorized are taken into consideration in the relative technical assessments, as well as all the operating conditions of the installation, thus pursuing an optimal environmental performance.

The categories of activities subject to this authorization are indicated in detail in the regulation (Annex VIII to the second part of Legislative Decree 152/06), and in summary they are:

- energy activities;
- metal production and processing;
- mineral products industry activities;
- chemical industry activities;
- waste management activities;
- some other activities such as paper mills, tanneries, slaughterhouses, intensive farms.

The "AUA" "Autorizzazione Unica Ambientale", is a specific form of authorization introduced by Presidential Decree no. 59 (in force since 13 June 2013) to simplify the environmental administrative requirements, the AUA regulation applies to small-medium enterprises (SMEs), as well as to plants not subject to the provisions on Integrated Environmental Authorization (AIA).

(Guagnini G.)

Each individual emission value provided contained both the emission value of the companies subject to AUA and of those subject to AIA; however, the companies subject to AIA authorization will also be inserted subsequently in the form of point emissions (considering the chimneys as a point emission source); therefore in the first analysis, it was necessary to dissociate these two contributions for the municipalities that present AIA companies with point emissions, in order not to twice consider the contributions due to these companies; to do this, the step has been to subtract from the total values already converted into g / s, the emission values of the chimneys, in order to obtain only the emission value relating to AUA production activities.

In total, 6 companies subject to AIA certification were identified, located between the municipalities of Ascoli Piceno, Monterubbiano, Monteprandone and Campofilone, the total emissions of their chimneys was calculated and subtracted from the total value as described above.

Companies	Mass flow (g/s)		
TOT EMISSION BARILLA G. E R.	0,0125	0,0163	Ascoli Piceno
TOT EMISSION ELANTAS	0,0038		
TOT EMISSION FIB SRL	0,0752		Monterubbiano
TOT EMISSION PICENA ZINC	0,0088		Monteprandone
TOT EMISSION GENERALZINCO	0,0057	0,0087	Campofilone
TOT EMISSION VALZINCO	0,0031		

Figure 5.10 - Total values of the emissions of the chimneys and location of the companies

At this point it was necessary to make some considerations; the complexity is given by the fact that even small production companies such as small bakeries for example which do not fall within the identified industrial area, are subject to AUA certification (therefore subject to widespread emissions) and their emissions are included in the values to be entered, it appears clear, therefore, how in reality the attribution of emissions is an estimate; the challenge lies in making this estimate as reliable as possible.

For the municipalities in which the industrial area was identified, it was considered reliable to divide the total emissions and assign 70% of the total value of each municipality to the industrial range and insert the remaining 30% throughout the total municipal polygon, to take these small realities into account.

Province	Municipality	PM10						
		ton/year	g/s					
			TOT=AUA+AIA	TOT- AIA (where present)	70% (in IND)	/ 2	/ 3	30% (in tot municipality)
ASCOLI PICENO	Acquaviva Picena	0,921	0,029	0,029	0,02043			0,00876
ASCOLI PICENO	Appignano del Tronto	0,130	0,004	0,004				
ASCOLI PICENO	Ascoli Piceno	8,944	0,284	0,267	0,18710			0,08019
ASCOLI PICENO	Carassai	0,101	0,003	0,003				
ASCOLI PICENO	Castel di Lama	0,484	0,015	0,015				
ASCOLI PICENO	Castignano	0,718	0,023	0,023				
ASCOLI PICENO	Castorano	0,380	0,012	0,012				
ASCOLI PICENO	Colli del Tronto	0,546	0,017	0,017	0,01212			0,00520
ASCOLI PICENO	Cossignano	0,083	0,003	0,003				
ASCOLI PICENO	Cupra Marittima	0,268	0,008	0,008	0,00595			0,00255
ASCOLI PICENO	Folignano	0,294	0,009	0,009	0,00652			0,00280
ASCOLI PICENO	Force	0,468	0,015	0,015				
ASCOLI PICENO	Grottammare	1,852	0,059	0,059	0,04110			0,01761
ASCOLI PICENO	Maltignano	0,624	0,020	0,020	0,01385			0,00594
ASCOLI PICENO	Massignano	0,140	0,004	0,004				
ASCOLI PICENO	Monsampolo del Tronto	0,715	0,023	0,023	0,01587			0,00680
ASCOLI PICENO	Montalto delle Marche	0,075	0,002	0,002				
ASCOLI PICENO	Montedinove	0,023	0,001	0,001				
ASCOLI PICENO	Montefiore dell'Aso	2,002	0,063	0,063				
ASCOLI PICENO	Monteprandone	3,520	0,112	0,103	0,07195			0,03084
ASCOLI PICENO	Offida	1,779	0,056	0,056	0,03948	0,01974101		0,01692
ASCOLI PICENO	Ripatransone	1,818	0,058	0,058	0,04035	0,02017392		0,01729
ASCOLI PICENO	Rotella	0,070	0,002	0,002				
ASCOLI PICENO	San Benedetto del Tronto	5,045	0,160	0,160	0,11198		0,03732705	0,04799
ASCOLI PICENO	Spinetoli	1,326	0,042	0,042	0,02944			0,01262
ASCOLI PICENO	Venarotta	0,252	0,008	0,008				
FERMO	Altidona	1,451	0,046	0,046	0,03221			0,01380
FERMO	Belmonte Piceno	0,247	0,008	0,008				
FERMO	Campofilone	0,613	0,019	0,011	0,00747			0,00320
FERMO	Monsampietro Morico	0,205	0,007	0,007				
FERMO	Monte Giberto	0,533	0,017	0,017				
FERMO	Monteleone di Fermo	0,000	0,000	0,000				
FERMO	Montelparo	0,010	0,000	0,000				
FERMO	Monte Rinaldo	0,029	0,001	0,001				
FERMO	Monterubbiano	2,129	0,068	-0,008	0,04727			0,02026
FERMO	Monte Vidon Combatte	0,026	0,001	0,001				
FERMO	Montottone	0,120	0,004	0,004				
FERMO	Moresco	0,081	0,003	0,003				
FERMO	Ortezzano	0,484	0,015	0,015				
FERMO	Pedaso	0,339	0,011	0,011				
FERMO	Petritoli	0,424	0,013	0,013	0,00941			0,00403
FERMO	Santa Vittoria in Matenano	0,325	0,010	0,010				
FERMO	Servigliano	0,655	0,021	0,021				

Figure 5.11 - List of municipalities in the domain with emission values for macro-sector 4

In the table, the municipalities that have values in the 70% and 30% columns are the municipalities with an ‘ind’ polygon, for these, as already mentioned, the total value was divided between the industrial and municipal area as indicated in the table; the municipalities that do not have values in the aforementioned columns, on the other hand, are municipalities in which it was not possible to identify a well-defined industrial area and in this case the total of the emissions was included in the polygon relating to the entire municipality.

Columns "/ 2" and "/ 3" refer to municipalities with 2 or 3 industrial areas in which the value to be entered has been divided by 2 or 3 respectively and entered in the software, once for each industrial area.

An important consideration has been done regarding the insertion of the values in the polygons relating to the entire municipal area since a total of 7 municipalities already had values entered in the previous step, that is relating to the macro-sector 2 of domestic heating, since these were devoid of urban area.

In this case, since all of these 7 municipalities are also devoid of ‘ind.’polygons, the new value, i.e. the total of emissions (column TOT-AIA in the tab) was also entered, in the insertion box, in the polygon relative to the entire municipality and added to that already present.

Municipalities	M02	M04	M02+M04
Massignano	0,122	0,004	0,127
Belmonte Piceno	0,051	0,008	0,059
Monsampietro Morico	0,057	0,007	0,064
Monteleone di Fermo	0,039	0,000	0,039
Monte Rinaldo	0,030	0,001	0,031
Moresco	0,051	0,003	0,054
Ortezzano	0,071	0,015	0,086

Figure 5.12 - Values entered in municipal polygons

- Macro-sector 7 (road transport), the contribution of the roads present within the municipal area is now considered, differentiating the main road infrastructures from the secondary and inter-estate roads; starting from the total emission value in tons / year provided for each municipality by the inventory of the Marche Region.

This value refers to the municipal roads net of the main road structures which will be inserted later in the software in the form of linear sources (these are the A14, the SS16 and the RA11), therefore only the emissions attributable to the area source of the municipality were entered in this phase.

To differentiate the total municipal value from that of the urban area alone, reasoning was made based on the typology of the different roads; the values were calculated on the basis of some emission factors deriving from the COPERT database (it is a statistical model for estimating emissions at regional and urban level provided by the European Environment Agency, EEA); "The model, thanks to an appropriate subdivision of the vehicles into particular emission categories and a further subdivision of these categories into a certain number of "legislative "emission classes, is able to provide the emission factors for a large number of polluting substances. " (Maria La Gennusa, 2015) COPERT suggests dividing the roads within each municipality by vehicle category and driving cycle (urban, rural, highway) using as discriminant the average speeds on which these emission factors are calculated (Salvatore Saija, 2001):

- *rural*, inter-country roads or in any case peripheral roads where the average travel speed is estimated to be less than 50 km / h;
- *urban*, city streets with an estimated travel speed between 50 and 100 km / h;

- *highways,* roads with travel speeds higher than 100 Km / h.

As already mentioned, in this phase only the emissions within the municipalities given by secondary and inter-estate roads were considered and therefore the emission factors relating to urban and rural were used.
The experimental hypothesis was to divide the total emission value of each municipality into the two categories and each half was assigned its respective emission factor.
The values found for both urban and rural in each municipality were therefore reported in g / s and added to the others already included in the municipal polygons as shown in the following table.

Province	Municipality	PM_{10}					
		M02	M04	M04	M07 RURAL	M07 URBAN	TOT to enter
		g/s	30% g/s	(no area ind, all municipality)	g/s	g/s	g/s aermod
AP	Acquaviva Picena		0,008757289		0,015592276	0,016033713	0,040
AP	Appignano del Tronto			0,004123017	0,007910148	0,008134095	0,020
AP	Ascoli Piceno		0,080185138		0,195554932	0,201091349	0,477
AP	Carassai			0,003215953	0,005222761	0,005370624	0,014
AP	Castel di Lama			0,015337624	0,034067385	0,035031877	0,084
AP	Castignano			0,022759055	0,012481421	0,012834787	0,048
AP	Castorano			0,01203921	0,010233788	0,01052352	0,033
AP	Colli del Tronto		0,005195002		0,014962504	0,015386112	0,036
AP	Cossignano			0,002638731	0,004430117	0,00455554	0,012
AP	Cupra Marittima		0,002548025		0,021037628	0,021633231	0,045
AP	Folignano		0,002795406		0,037341111	0,038398287	0,079
AP	Force			0,014842862	0,006601743	0,006788647	0,028
AP	Grottammare		0,01761353		0,062407106	0,064173933	0,144
AP	Maltignano		0,005937145		0,010250075	0,010540268	0,027
AP	Massignano	0,122		0,004452859	0,006829764	0,007023124	0,141
AP	Monsampolo del Tronto		0,006802978		0,018333953	0,018853012	0,044
AP	Montalto delle Marche			0,00239135	0,010201214	0,010490023	0,023
AP	Montedinove			0,000742143	0,002329069	0,002395008	0,005
AP	Montefiore dell'Aso			0,063494466	0,009750601	0,010026654	0,083
AP	Monteprandone		0,030837554		0,048296965	0,049664315	0,129
AP	Offida		0,016920863		0,022791216	0,023436465	0,063
AP	Ripatransone		0,017291934		0,018800853	0,01933313	0,055
AP	Rotella			0,002226429	0,004728716	0,004862592	0,012
AP	San Benedetto del Tronto		0,047991921		0,18215057	0,187307491	0,417
AP	Spinetoli		0,012616433		0,028649178	0,029460273	0,071
AP	Venarotta			0,007998653	0,008746224	0,008993841	0,026
FM	Altidona		0,013803862		0,006680534	0,006890002	0,027
FM	Belmonte Piceno	0,051		0,007833733	0,001329343	0,001371025	0,062
FM	Campofilone		0,00319984		0,004175334	0,004306251	0,012
FM	Monsampietro Morico	0,057		0,006514367	0,001519249	0,001566885	0,067
FM	Monte Giberto			0,016904371	0,001805409	0,001862018	0,021
FM	Monteleone di Fermo	0,039			0,000980748	0,0010115	0,041
FM	Montelparo			0,000329841	0,00189646	0,001955923	0,004
FM	Monte Rinaldo	0,030		0,000907064	0,000827262	0,000853201	0,033
FM	Monterubbiano		0,020257716		0,000941726	0,000971254	0,022
FM	Monte Vidon Combatte			0,000824603	0,00479448	0,004944811	0,011
FM	Montottone			0,003793176	0,002078562	0,002143735	0,008
FM	Moresco	0,051		0,002556271	0,001259104	0,001298583	0,056
FM	Ortezzano	0,071		0,015337624	0,001797605	0,001853969	0,090
FM	Pedaso			0,010764075	0,00466961	0,004816026	0,020
FM	Petritoli		0,004032311		0,005140473	0,005301653	0,014
FM	Santa Vittoria in Matenano			0,010307543	0,002983868	0,003077427	0,016
FM	Servigliano			0,020780007	0,00454474	0,004687241	0,030

Figure 5.13 - List of municipalities in the domain with emission values for macro-sector 7 and total for all macro-sectors

5.2.2. Line Sources

LINE SOURCES concern road and railway infrastructures. The model converts the linear sources into corresponding volume sources by associating to the infrastructure layout (which must be drawn in the considered domain) a cross section whose dimensions are required as input data. The data required by the processor for each linear source are the *Source ID*, the *Emission rate* expressed in grams / second and the dimensions of the cross section, i.e. the width of the carriageway (*Length of Side*) and the height of the hypothetical rectangle (*Vertical Dimension*), both expressed in meters.
It is then necessary to specify whether the infrastructure adheres to the ground (*Release Height* ~ 0) or it is raised above it (*Release Height* > 0).
Also for these sources, reference is made to the Macro-sectors, and in particular to number 7 (road transport).
In this study, the impact of emissions from only road traffic was assessed and only the main road infrastructures of the domain were included: the A14 motorway, the SS16 Adriatica and the motorway junction 11.
The layout of these roads has been reported section by section in the domain, using, as done also for the area sources, the Google Earth program. This measure proved to be very useful for a more real view of the road situation, minimizing the errors due to the non-total territorial correspondence.

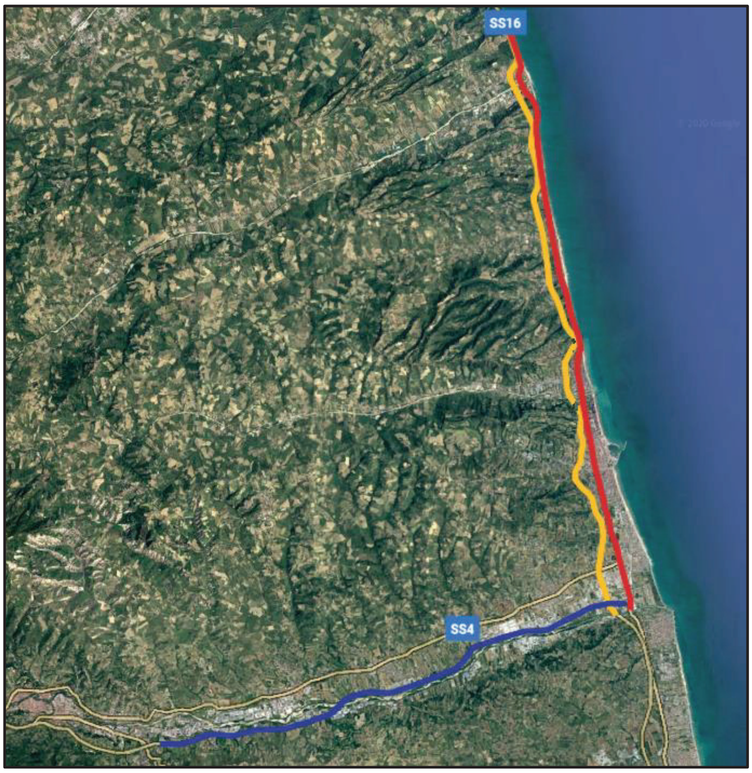


Figure 5.14 - Main roads in the domain: in yellow-highway A14, in red-SS16, in blue the junction 11

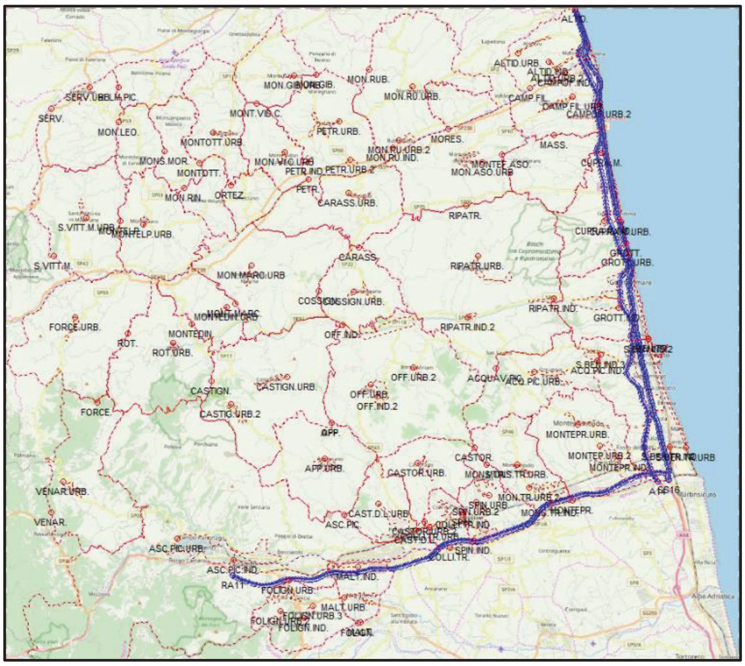


Figure 5.15 - Roads of the domain reported in AERMOD

In AERMOD this time, to design the linear sources, the "*Line Area Source*" tool was used (so in any case it is an emission per m^2) and, also in this case, as done for the municipalities, in "*Source ID*" abbreviations have been inserted to indicate the roads taken into consideration, which are respectively: A14 (Highway A14), SS16 (State Road 16), RA11 (Motorway Junction 11). Regarding the cross sections, bearing in mind that both lanes of the opposite directions of travel are enclosed in the single segment traced manually, the width of the road surface was set equal to 24m for the A14, 15m for the SS16 and 22m for the RA11.

Figure 5.16 shows an example of a linear source, in particular the RA11:

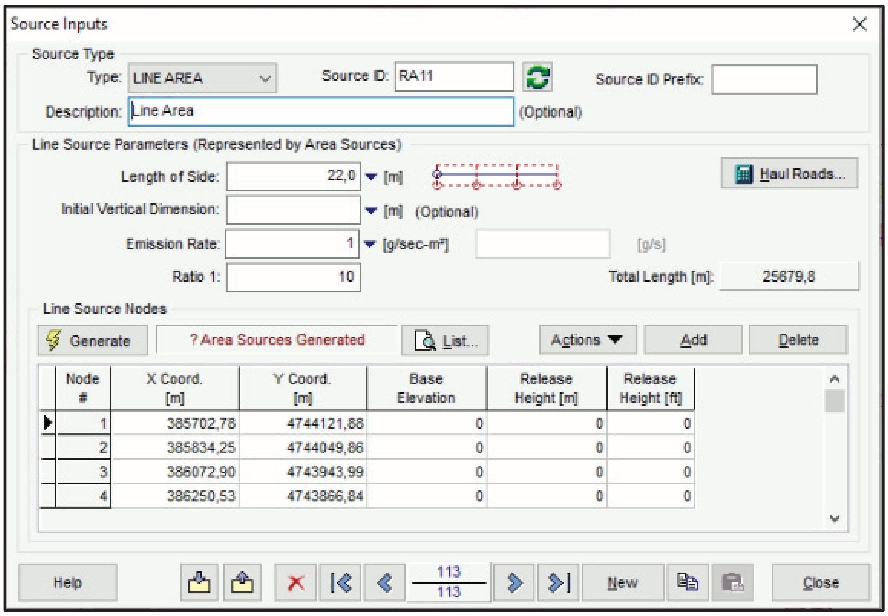


Figure 5.16 - Entering data relating to the RA11 line source into AERMOD

As it can be seen from the figure, in the box for inserting the linear source, there is the item "*Vertical Dimension*", this refers to the height of the vehicle exhaust pipe and is optional as the data to be entered should be an average of all heights of the exhaust pipes, weighted for the different types of vehicles (classified by the Environmental Protection Agency, EPA, in: Passenger Vehicles, Light-duty Trucks (LDT), and Heavy-duty Vehicles (HDT)) (TransportPolicy.net.); however, in the present case, this step would be too laborious since we would need the total traffic data and the number of each type of vehicle mentioned, for the chosen volume which is very high and at the limit of the software capabilities (the maximum of the domain is indicated at 50 km to the side due to the equations underlying the Gaussian model).

However, it can be said that, precisely because of the size of the domain in question, the fact of not entering the vertical dimension has a negligible impact and in no way affects the results of the simulation.

For the calculation of the emissions of the linear sources, reference was made to the data provided by the inventory of the Marche region which correspond to the total of the emission of the whole road.

Considering these values for each of the roads taken into consideration (A14, SS16, RA11), and the lengths of the sections of these roads falling within our area, we can easily obtain the total emissivity values of the single section of road falling within the domain, which in the AERMOD interface are displayed in the "*Emission Rate*" item.

In the software the roads are represented as broken lines, the end of a section corresponds to the beginning of the next section. In order to avoid calculation errors, due to the distribution of emissions on each m^2, the total emission data attributed to the entire road section is entered in g / sec, the model divides the emission value attributed to the road for all the various segments by which that road is constituted, i.e. for m^2, and for continuity associates a contribution to each segment.

5.2.3. Point Sources

POINT SOURCES refer to the stacks of industries and power plants from which the fumes containing the contaminant of interest come out.

For each chimney AERMOD asks to specify the name (*Source ID*), the description, the position (*Source Location*) and the emission parameters (*Source Release Parameters*).

The *Source Location* is defined by entering the geographic coordinates (X for the longitude and Y for the latitude), the altitude at which the base of the chimney is located (*Base Elevation*) and the release height of the plume (*Release Height above Ground*).

The *Source Release Parameters* include the emission factor (*Emission Rate*) expressed in grams / second, the smoke release temperature (*Stack Gas Exit Temperature*) expressed in Kelvin degrees, the release speed (*Stack Gas Exit Velocity*) expressed in meters / second and the internal diameter of the chimney at the release point (*Stack inside Diameter at Release Point*) expressed in meters.

The activities that can be considered point sources according to the SNAP nomenclature are classified in Macro-sectors: 1 (power plants), 4 (production activities), 5 (fossil fuel extraction), 6 (use of solvents) and 9 (waste treatment).

In the present study, of the five Macro-sectors mentioned, only the fourth is considered, as the others do not produce particulates; and the former is, in this case, negligible. Macro-sector 4 includes all the various companies falling within the area, both those subject to AIA authorization and those subject to AUA, as already explained in the paragraph concerning the area sources.

The names of the various industrial plants and the chimney data to be included as inputs were obtained from the Integrated Environmental Authorizations (AIA) presented by the companies and referred to 2016; the data on the internal diameter of the chimney and the release speed were absent for some of the companies considered and were assumed to be equal to the average value among all the other available values; for the ELANTAS company, the release height for the only E1 chimney was present and this was also maintained for the remaining 17 chimneys.

In the data obtained from the authorizations, the coordinates of the companies Generalzinco Srl, Indesit Company SpA, Picena Zinc Srl and Valzinco Srl, were incorrect, this may be due to the fact that very often the administrative offices are reported in the authorization documents instead of the production sites. Following a careful verification carried out with the help of Google Earth, the coordinates have been corrected and the company 'Indesit Company SpA' has been eliminated from the data since the new coordinates position it outside the domain of interest.

Although the data contained all the chimneys of the companies of interest, the chimneys considered are only those that release the pollutant PM_{10} (the data indicated the pollutant PTS, that is a set of PM_{10} particles and particles of larger diameter, however when PM_{10} is not specified in the AIA documents, it is reasonable to assume the PTS as an indicative value of this pollutant since it is in this way in favour of safety).

A total of 6 companies have been included, for a total of 53 chimneys representing as many emission points (point sources).

Company	Municipality	N° of stacks for PM10
Barilla G. e R. Fratelli SpA	Ascoli Piceno	29
ELANTAS	Ascoli Piceno	5
FIB Srl	Monterubbiano	15
Generalzinco Srl	Campofilone	1
Picena Zinc Srl	Monteprandone	1
Valzinco Srl	Campofilone	2

Figure 5.17 – Companies considered for this survey with their municipality of belonging and the number of stacks for PM10

In reality, the point sources considered in our study could be 73, as they may include the 10 tunnels in the area, which are a part of the linear sources (roads and highways), but which could be considered to be point sources taking the entering and exit points of such tunnels and attributing to each of these points half of the emission value corresponding to the section of the tunnel itself.
However, it has been chosen not to implement this solution since the domain in this specific study is too wide and the approximation allows the results not to be influenced by it.

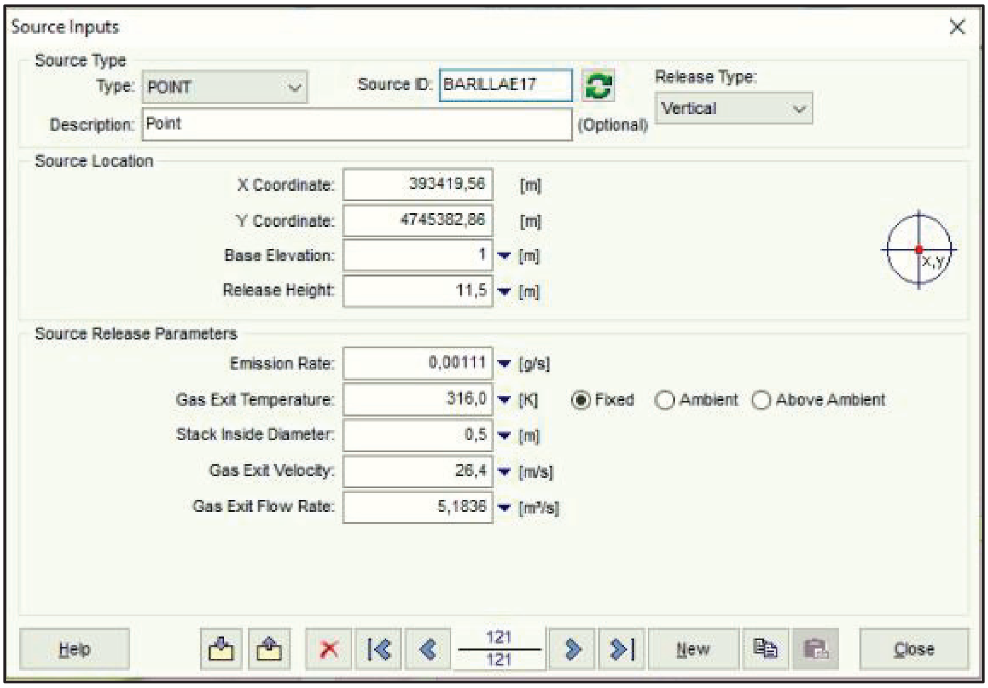


Figure 5.18 - Entering the data relating to a point source into AERMOD

5.2.4. Temporal Profiling

In reality, it should be borne in mind that each emission contribution analysed has a different impact on the day, week or month; for example, considering domestic heating it is reasonable to weigh that the emission contribution is greater during the winter months or considering the streets, the contribution even varies throughout the day according to the opening or closing hours of the workplaces that cause the movement of workers to reach their workplace or home.

It is therefore needed a section that takes into account these different time profiles to further refine the quality of the simulation.

In AERMOD it is possible to insert the profiling and in order to make the analysis more organic and rapid, the different types of emission sources have been gathered into groups.

By clicking on 'sources' and then on 'source pathway' it is possible in the left column to select the item 'source groups' and create new groups, specifically the following groups have been created: STRADE, URBANO, INDUSTRIALE; in which all the previously created data, grouped according to their type, were then entered.

By selecting the 'Variable Emissions' item, it is possible to change the profiling by choosing from various types of proposals.

For the URBANO group a 'By Month' profiling was chosen since the contribution given by domestic heating is the one which dominates, the model does not need a very defined detail when working on large domains, it therefore makes no sense to make a temporal disaggregation on an hourly basis, the monthly is adequate and so the colder months will have a higher value while the warmer ones will have a lower value.

The following figure shows the software screen with the values critically chosen for the profiling, the values have been chosen considering that the value ‘1’ would mean attributing all the emission only to that month or hour.

In the urban case, the total of emissions corresponds to 12, that is, as if the maximum value of 1 were attributed to all the months (12 months), therefore disaggregating means distributing this total among the various months in a critical way so as to best represent the real distribution; the total of the values attributed to the various months must therefore give 12.

For disaggregation on an hourly basis the same principle applies with a total value of 24.

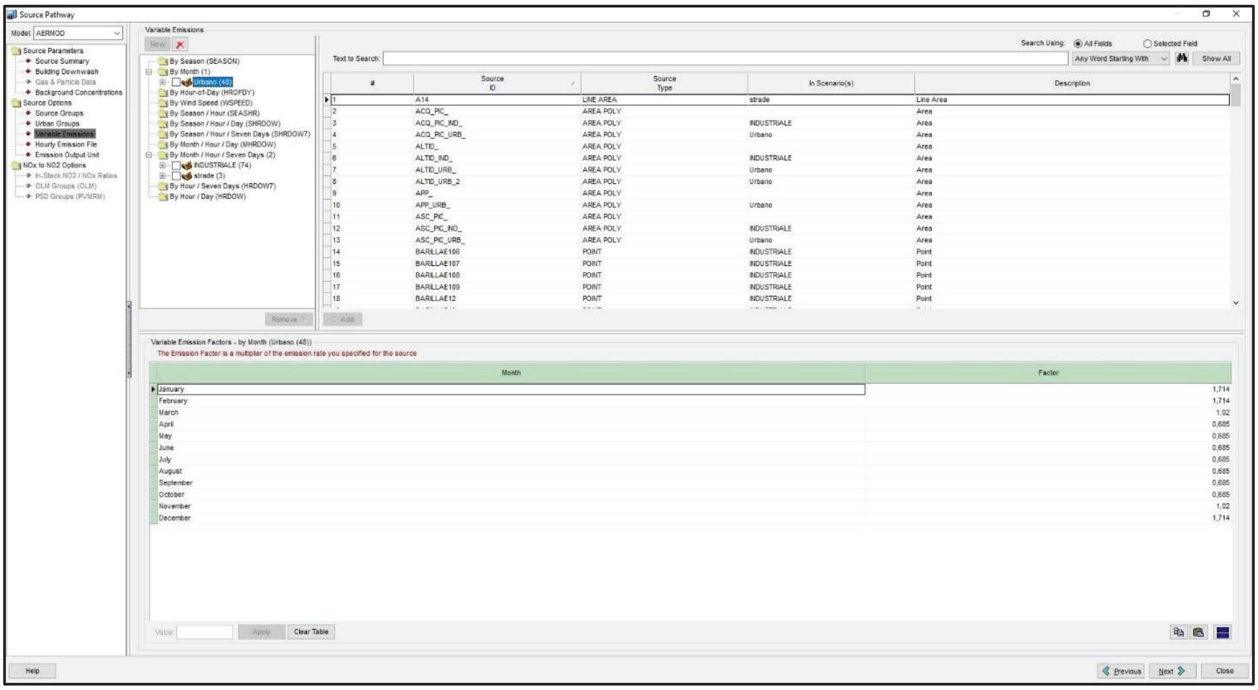


Figure 5.19 - Urbano group entry time profiling screen

For the INDUSTRIALE group, a more advanced profiling was chosen, 'By Month / Hours / Seven Days', this type of profiling is in some terms too advanced for the type of qualitative analysis conducted but it is still usable since we are analysing a set of small and medium-sized enterprises and a single profile would represent a great imprecision; the most appropriate generalization consists in choosing the profiling with a dominant trend and therefore, it is assumed that companies work from Monday to Sunday at standard hours, i.e. from 6:00 to 22:00, considering these values as an average of the Region.

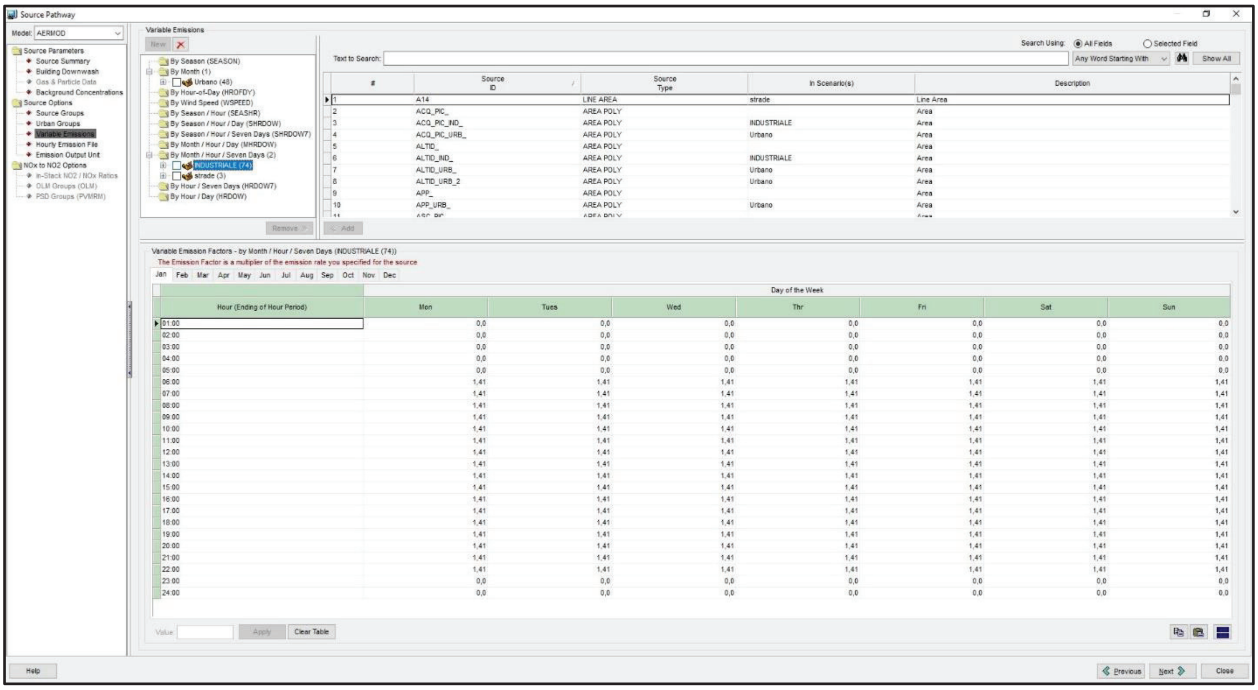


Figure 5.20 - Industriale group entry time profiling screen

Finally, for the STRADE group, the predominant profiles are those of urban centres, so the previously described profiling can be used, the hypothesis of urban reality implies a trend with 3 peaks, i.e. an emission peak during the morning hours in which people go to work, one in the evening when they come back home and one during the hours of the lunch break.

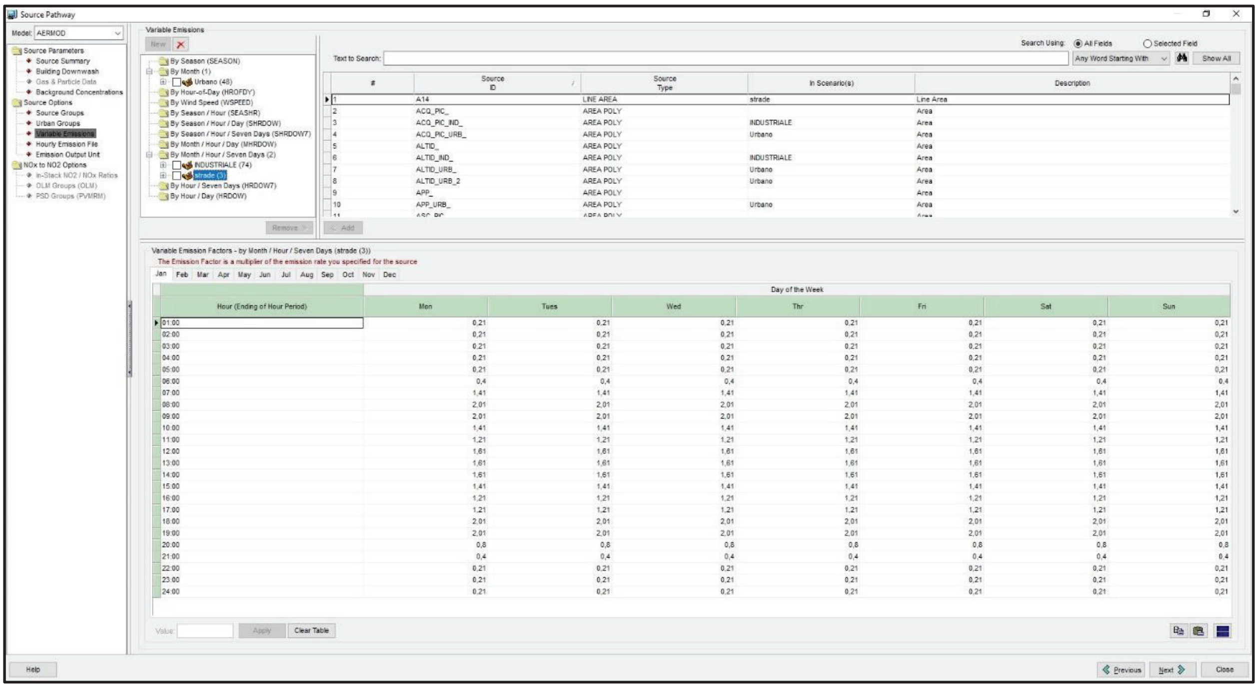


Figure 5.21 - Strade group entry time profiling screen

Time profiling represents the coarsest part of a simulation as it is mainly based on assumptions and decisions which, although made in a critical way, represent an approximation of reality; therefore, further investigation is needed in order to take better account of all the variables involved.

5.2.5. Background

As already seen in the previous sections, the emissions for industrial areas, urban areas, chimneys and roads were defined in order to have a detailed picture of the different contributions of the different sectors; the next step is to define an overall vision, identified in the new 'All' group in which the background value has to be preloaded.

The background represents the base concentration found on a territory that is considered not affected by various kinds of emissions released by production activity (obviously currently in highly productive countries it is difficult to find areas that are not affected by emissions due to production since an area is not only influenced by what is produced on site but migration paths make it difficult to quantify the effective influence of anthropogenic activities present even at considerable distances) however, theoretically, it can be estimated that the control unit that measures the lower values of emissions on the area in question, is the one that measures the background values.

In the specific case, the values of the Montemonaco control unit were chosen, it is a rural background type and located in an area outside urban and industrial contexts, so it is reasonable to consider these values as minimum concentrations of PM_{10} for the Marche Region. For the type of simulation performed, it is correct to use as temporal profiling for the background the monthly one, then the monthly average concentration values for the reference year are entered so that the program considers this base concentration as fixed and constant and sum it up to the concentrations that the model assigned to each source, and it does this for each hour of each month, in order to consider as the starting concentration not zero but the calculated background value.

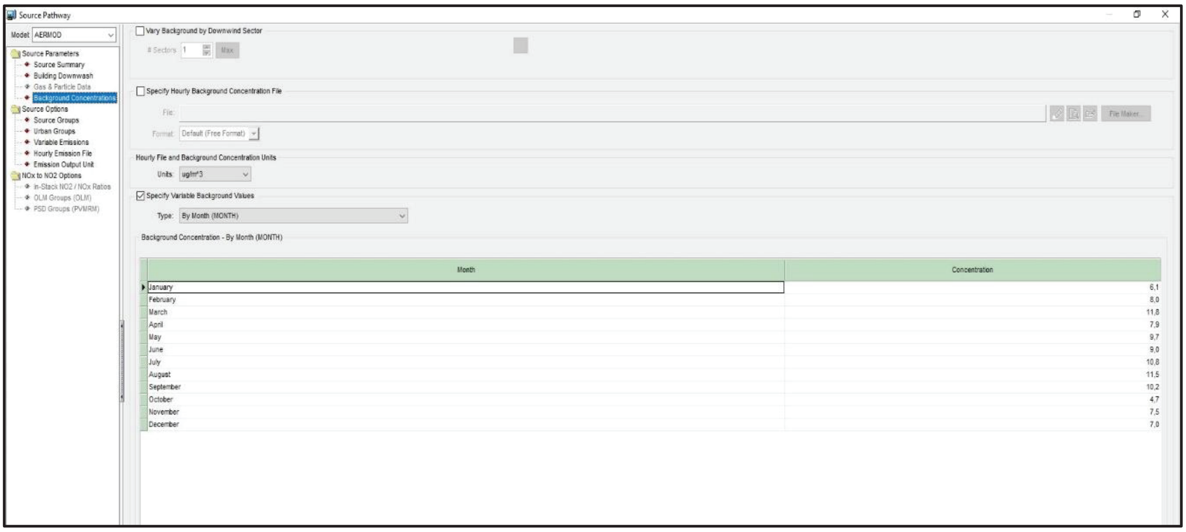


Figure 5.22 - Background monthly average values entry screen

5.3. AERMET and AERMAP setting

The files to be used in this phase, for the setting of AERMET, are the surface files that are measured with the weather stations; in the case in question, the control unit considered is that of Offida provided by Marche Agro-Food Sector Services Agency (ASSAM, Agenzia Servizi Settore Agro-Alimentare Marche).

The hourly surface data files provided range from 2015 to 2016 , these files, measured precisely by physical control units, are raw data with their own specific format and provide information such as: wind direction, global radiation, net radiation, average temperature, relative humidity, average velocity, precipitation, cloud cover.

The pre-processor, however, works according to its own data order so the excel worksheet to be imported must be reorganized according to this format: year, month, day, hour, average speed, wind direction, average temperature, humidity, pressure, precipitation and cloud cover.

Once all the data are organized in the right format, the step is to proceed to insert them into the software: from the AERMOD work screen can be accessed the AERMET pre-processor by clicking on 'tool' and 'Aermet' and once opened, it can be imported the reorganized excel file by clicking on 'import surface data from excel'; the characteristics of the control unit also need to be included, i.e. lat, lon and height.

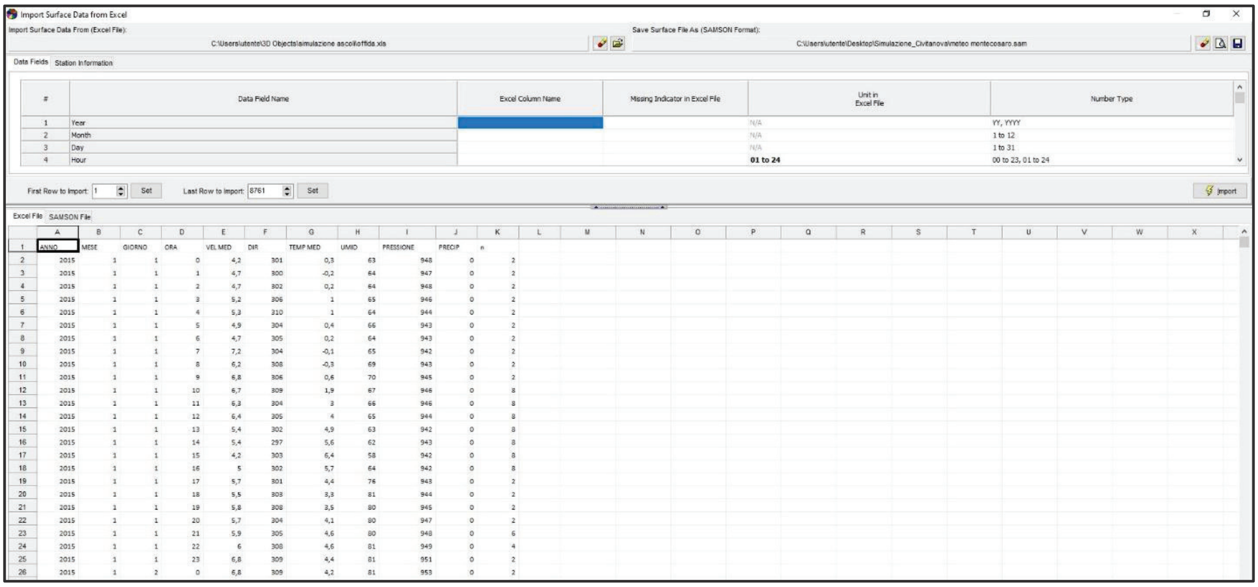


Figure 5.23 - AERMET screen with insertion of the excel file

Proceeding, there is the step of the 'onsite data' i.e. ground data; the software, specifically, asks if you want to include such data, in the present case the ground data are not provided because the domain is very large and therefore the onsite data should refer not to a single point but to the entire area, which is obviously not possible.

Only the data provided by the city of Offida were considered, since this town is contained within the domain and also represents a strategic position as it is located exactly within the most productive areas of the domain (it is located halfway between Ascoli Piceno and San Benedetto del Tronto which are the cities with the highest production activity) moreover it is located in a hilly area therefore, again, an intermediate quality between the characteristics of the whole area concerned.

Taking the data of a location on the coast or in the mountains would mean having a representation of the extremes with unrealistic values of wind speed and direction.

Now, the model has to pre-process the surface data just entered and needs to build vertical profiles i.e. 'Upper Air Data' because the simulation obviously does not refer only to the ground level but the mixing also takes place at higher levels in altitude; to simulate this condition an 'Upper Air Estimator' was used which is contained in AERMOD, this utility is the simplest one and estimates convective mixing heights based on surface meteorological data, but it is in any case good in this case since the present simulation is qualitative and is interested in the big picture. (Leonor Maria Turtos Carbonell, 2010)

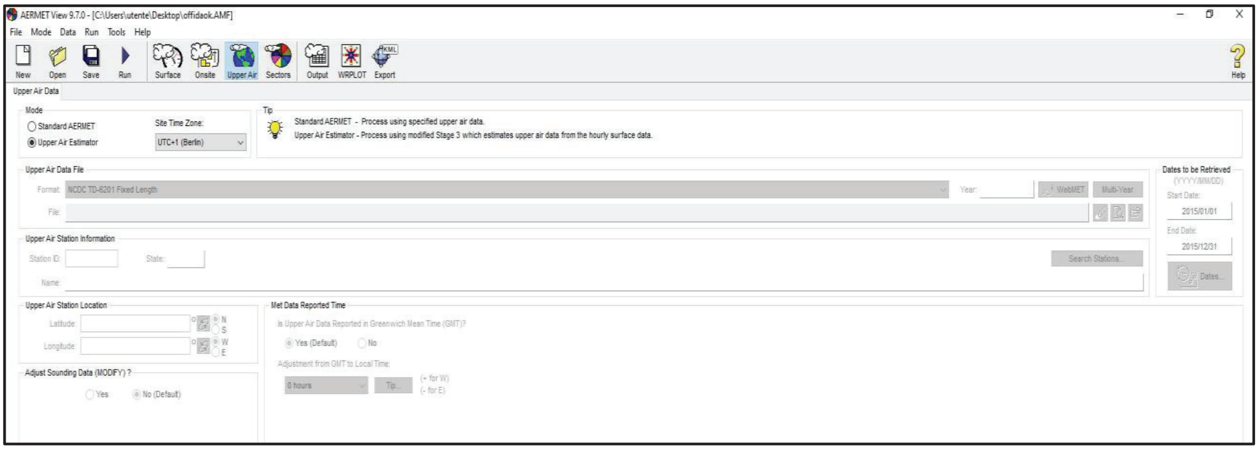


Figure 5.24 - AERMET screen relating to the 'Upper Air' section

The next step is the definition of 'land use', i.e. the characteristics of the soil under consideration; the software divides the survey area into a series of sectors represented as segments of a circumference and for each of these pieces it indicates the value of some characteristic parameters of the soil such as:

- albedo, it is the fraction of light or, more generally, of incident solar radiation that is reflected in all directions, thus it indicates the reflecting power of a surface (Wikipedia, 2021);
- bowen ratio, it is used to describe the type of heat transfer for a surface that has moisture (Wikipedia, 2021);
- surface roughness, it is a component of surface texture, the values considered for modelling purposes consider different roughness if a city or cultivated land is considered, the city has

maximum roughness that is 1, considering the presence of buildings and other structures with a certain height and volume, the roughness of cultivated land will obviously be less.

In this way, the simulation will be able to evaluate each of these zones differently.

When the situation in the area is not known in depth, the 'average' condition in the software is chosen and then a critical consideration must be made to define the type of soil that best describes the analysis area; in this case it was considered that about 70-80% of the domain area is to be considered as 'cultivated land', at this point the software returns typical values of the soils with the selected characteristics.

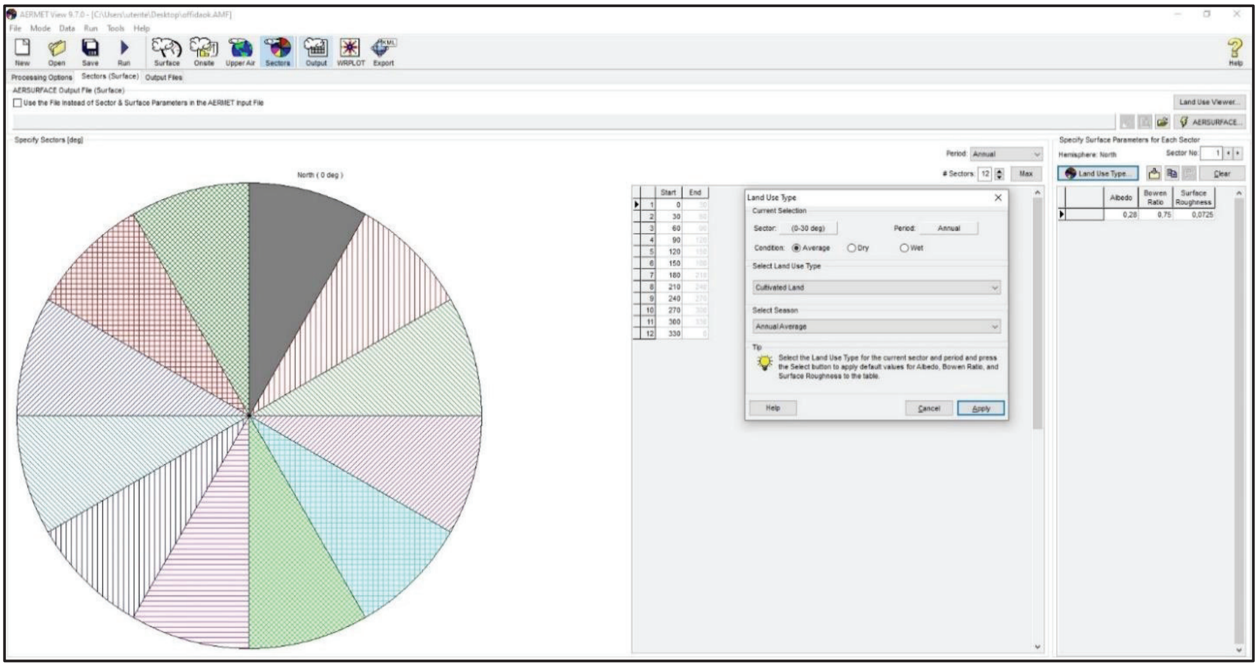


Figure 5.25 - AERMET screen for the 'Land Use Type'

The next step is to launch the 'run' so that the software generates two files: a surface file (.sfc) which represents the processing of the previously described and imported data, and a profile file (.pfl) which represents the vertical profiles processed through the estimator.

The last step is the generation of the 'wrplot' surface files.

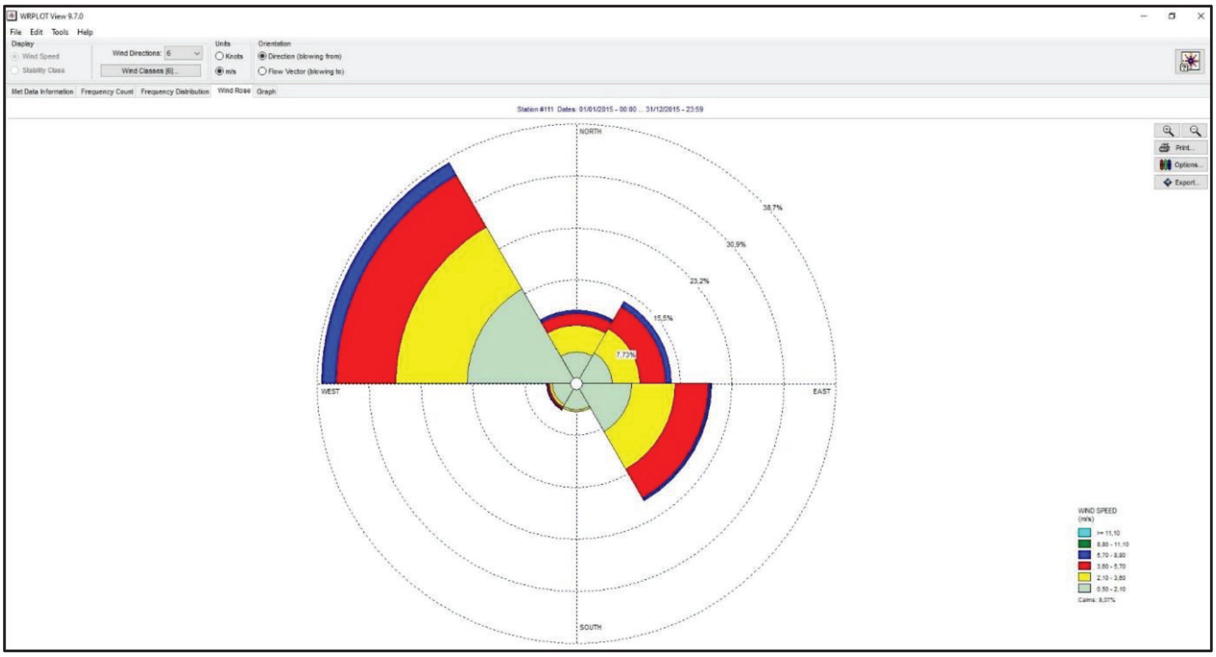


Figure 5.26 - Surface file representing the wind rose

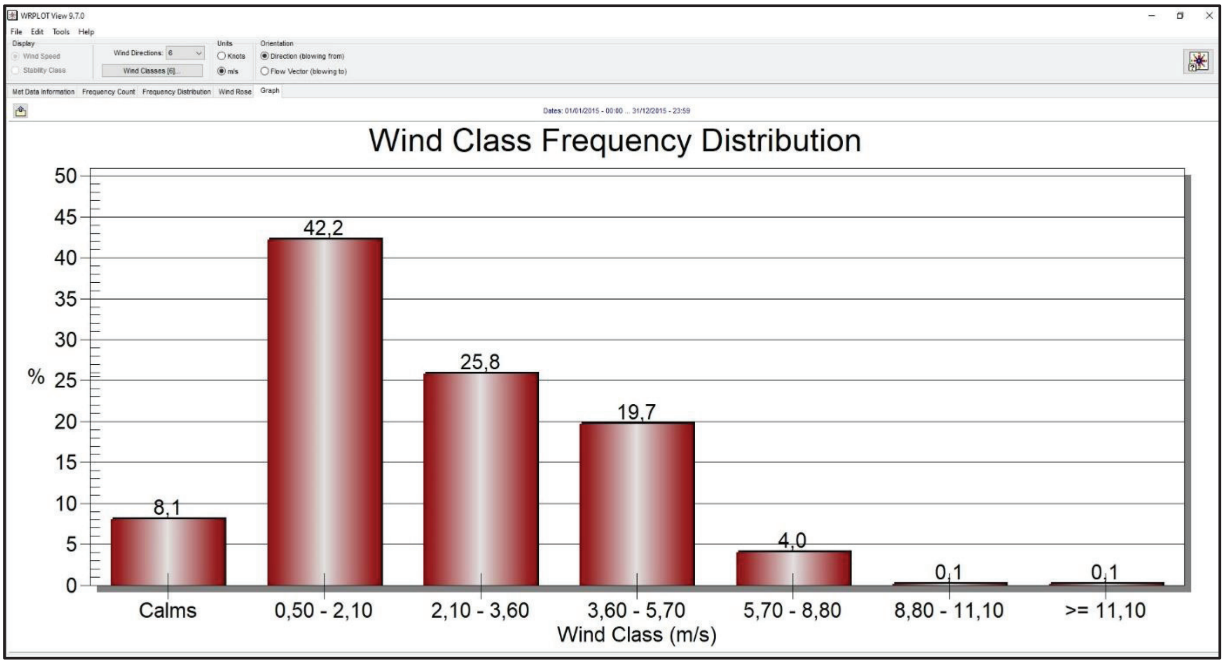


Figure 5.27 - Surface file representing a graph depicting the wind classes

Particular values can be noted:

- 'calms', indicates the hours of calm wind that is when the wind speed is lower than 0.5 m / s, in these hours the model can show malfunction so it has been chosen the option for which the software does not consider these values in order to avoid problems for the distribution on the territory, this is in any case appropriate in this case since the model has a big domain and it supports this approximation;

- 'missing data'; they are physiological missing data, when a data is measured in a wrong way due to malfunctions of the control unit or technical errors or in the case the data are not validated.

The Italian legislation says that there must be more than 90% of quality data for a certain number of years or in any case on the analysed year but in the case of qualitative simulation such as this one, the data available are more than acceptable.

Concerning the setting of AERMAP, the software automatically extracts the elevation of the grid points and of the discrete receptors from the digitalized file that has been imported in this phase.
This file is a SRTM file with a resolution of 90 meters.
The Shuttle Radar Topography Mission (SRTM) is an international research that has managed to obtain a digital elevation model on an almost global scale from 56°S to 60°N, to generate the most complete high-resolution digital topographic database possible. The SRTM consisted of a system of two radar antennas that flew aboard the Space Shuttle Endeavor during the STS-99 mission in February 2000. The technique employed is known as Interferometric Synthetic Aperture Radar.
The elevation models are distributed in tiles, each representing one degree of latitude and one of longitude named according to their south western corners, so it follows that "n42e013" stretches from 42°00′N 13°00′E to 43°00′N 14°00′E. The resolution of the raw data is one arcsecond (30 meters along the equator) and coverage includes Africa, Asia, Australia, Europe, North America, and South America but the raw data are restricted for government use; for other purposes, only three arcsecond (90 m along the equator) data are available.
It is used as Horizontal Datum the WGS84 and as Vertical Datum the EGM96 (Earth Gravitational Model 1996).
Elevation models derived from SRTM data are used in Geographic information systems (GIS); they can be freely downloaded and their file format is supported by several software programs. (USGS)

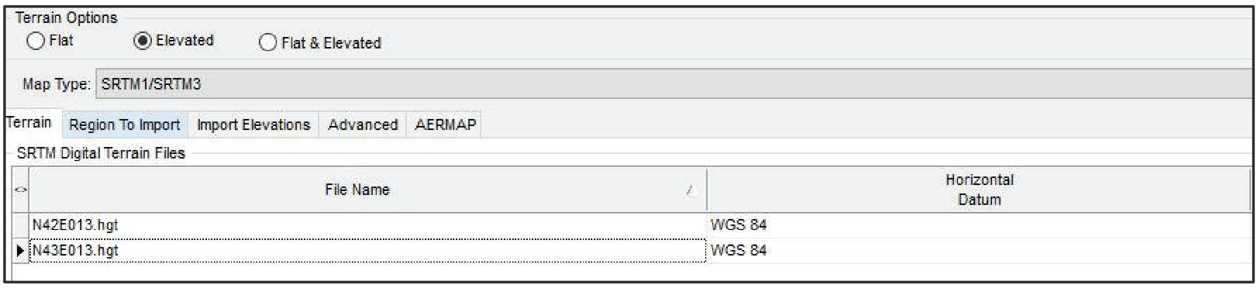


Figure 5.28 – insertion of the SRTM file in the software

Below, a map of the domain showing the terrain contours; here is again noticeable the strategic choice of Offida as centre of analysis from a visual point of view since it is located between the gray and bluish area of the coast representing a lower elevation and the yellowish and orange area of the hinterland characterized by an higher elevation.

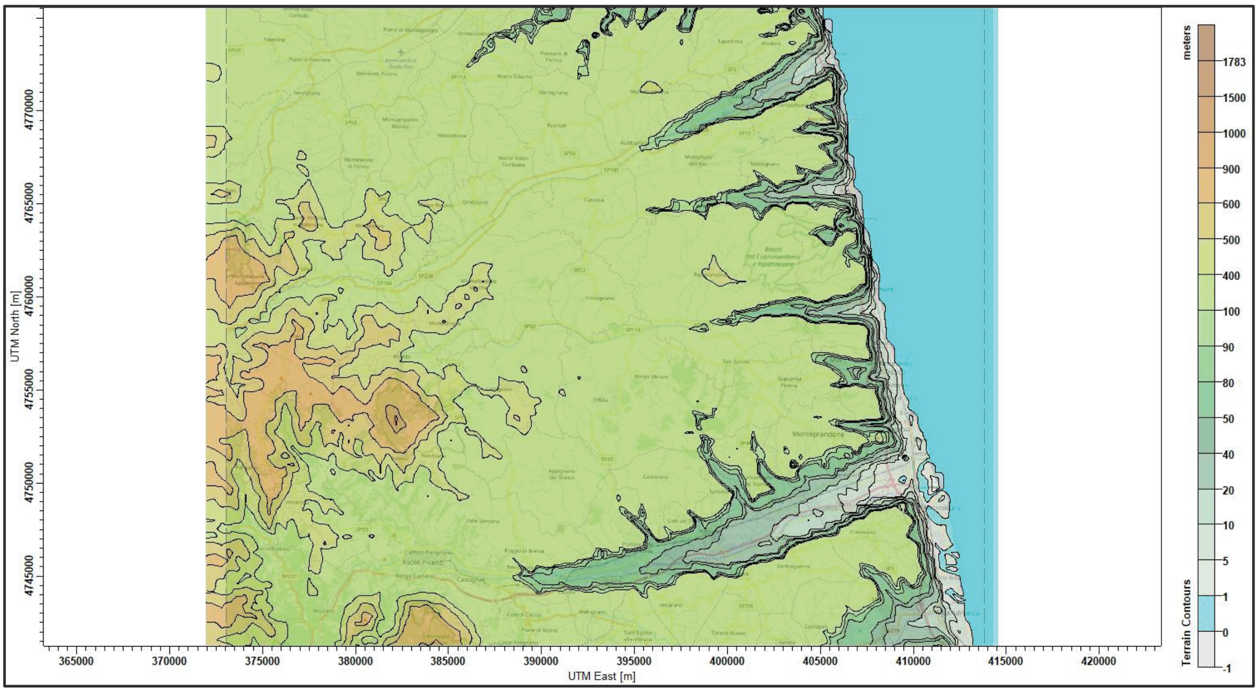


Figure 5.29 – Terrain contours of the domain

6. Output from AERMOD

AERMOD gives us a large results file that describes in detail all the hourly values processed for each receptor and for each source group inserted in the Source Pathway.

The difficulty of an immediate reading of the results, due to the large amount of data provided, is overcome thanks to the possibility of viewing the concentrations distribution maps of the desired pollutant, in the domain of receptors entered, called iso-concentration maps.

These graphic outputs are practically physical maps of the domain in which it is possible to view the dispersion of PM_{10} on the territory thanks to colours representative of the numerical value of concentration, the legend, in fact, indicates the conversion scale: the maximum value is shown at the top and it decreases downwards.

In the iso-concentration maps it is possible to see the graphic outputs by discriminating the single types of sources; therefore there are interfaces of the ALL group, i.e. the sum of all the emission sources, but also the maps of the single contribution of industrial areas, urban areas and roads.

The iso-concentration output maps are now shown. It is possible to choose the colour for a more immediate reading of the results; in this case it has been chosen to use a scale of colours from purple, through blue, green, yellow, orange and up to red; the legend that is automatically created will therefore go from a purple shade for areas with very low PM_{10} values to red for the most contaminated areas.

The map relating to the "strade" source is shown below.

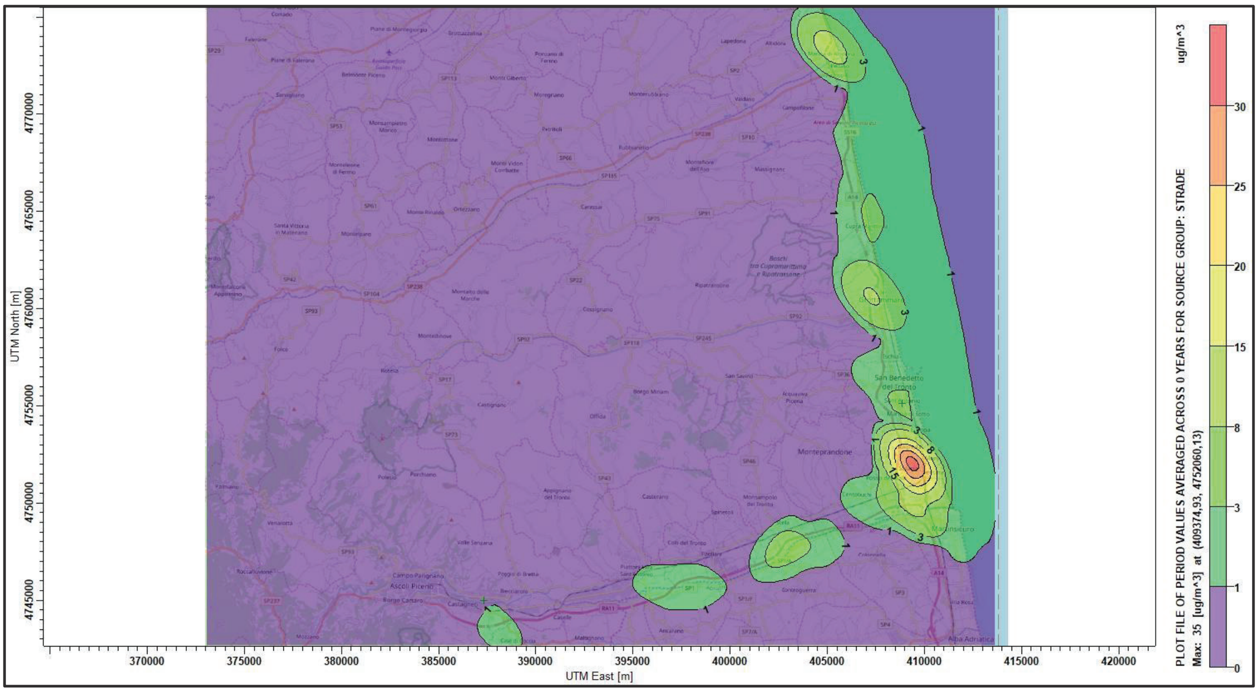


Figure 6.1 - Iso-concentration map for PM_{10} for source group "strade"

In this specific case, the model only shows the outputs due to the emissions deriving from the roads; in fact, the presence of green and yellow "spots" is evident along the motorway junction 11 and along the coast, where the state road 16 and the A14 are located.
The lighter coloured circles that are interspersed along the coast are due to the fact that the model sees higher concentration values at the points where the SS16 and A14 meet.
An area with greater concentration is clearly visible at the height of San Benedetto del Tronto with values that increase concentrically passing from 3 to 8 to 15 up to a peak of 35 µg / m^3; this may be due to the fact that that is a strongly anthropized area in which all the roads analysed convey, and also with minimum heights almost at sea level; this information is important as a function of the channelling phenomenon that causes the transport of pollutants on the coast.
However, this concentration peak in such a localized area is to be handled carefully as it could be a singularity of the model; in this case it is reasonable to consider an average of 20 µg / m^3 on the affected area.

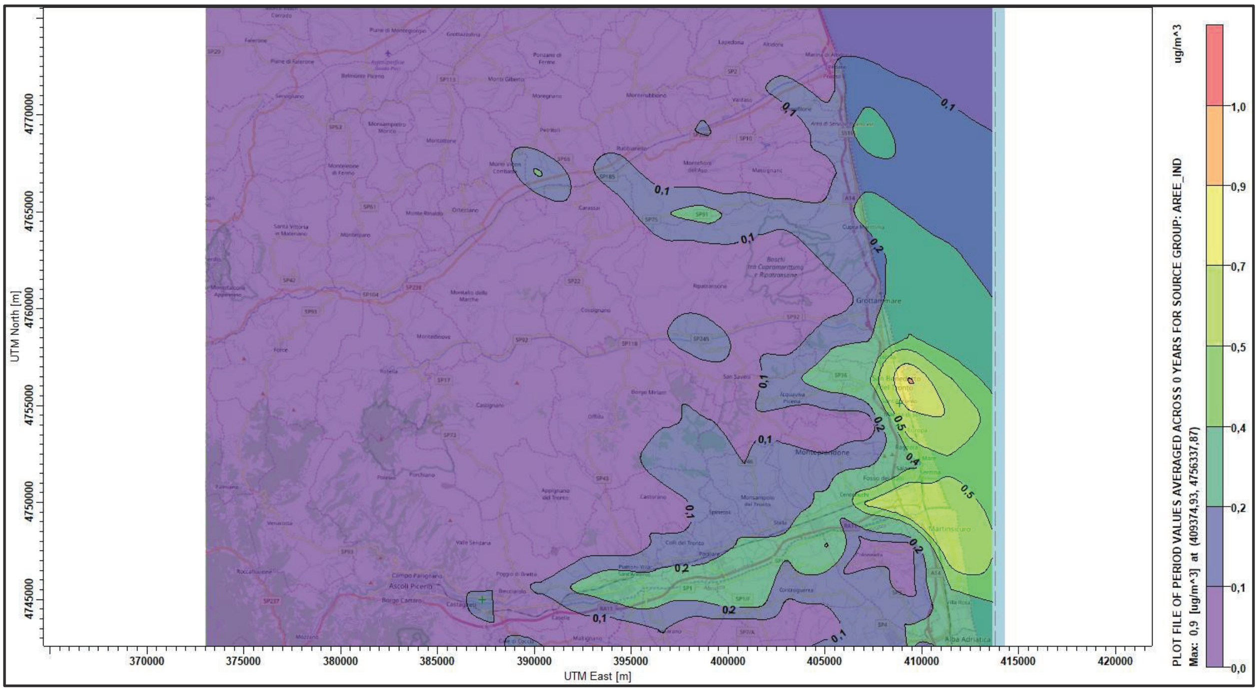


Figure 6.2 - Iso-concentration map for PM_{10} for source group "industriale"

The map above refers to the outputs generated by the only sources related to the industrial area.
The maximum concentration detected is 0.9 µg / m^3; these values represented, which are the minimum values detected among all the outputs, are due to the rigorous regulations that regulate and control the emissions of companies that also use emission abatement systems. There are therefore no critical issues.
It is now shown the map related to the urban area sources.

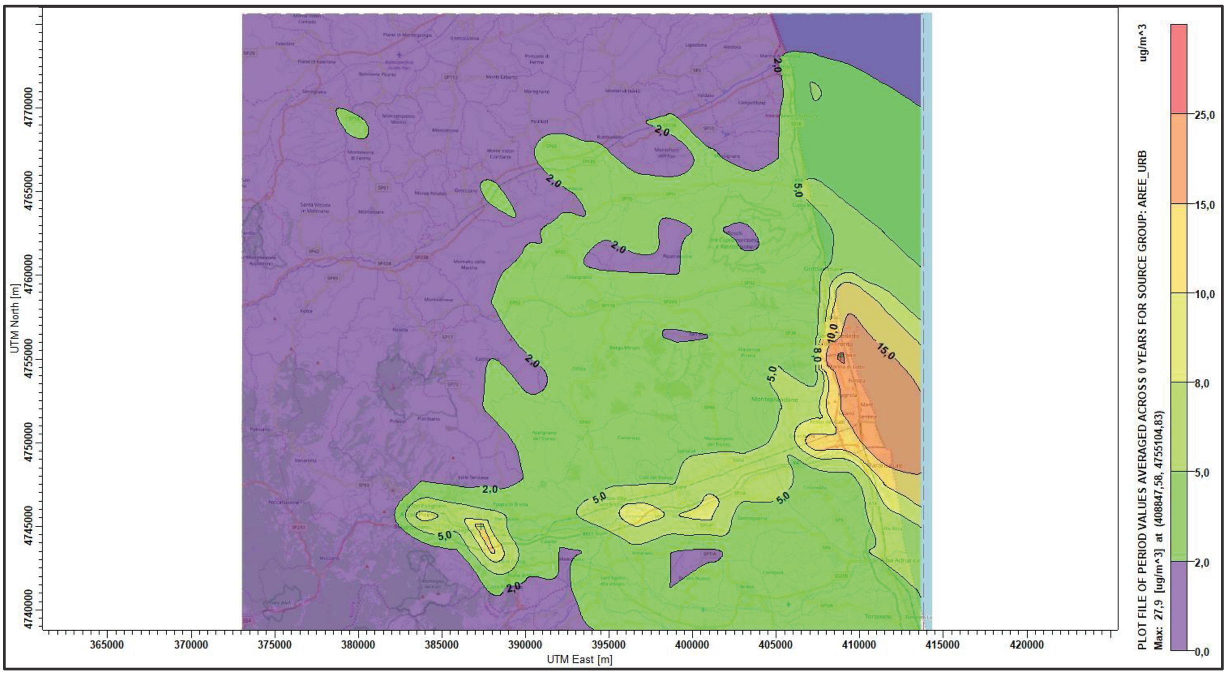


Figure 6.3 - Iso-concentration map for PM_{10} for source group "urbano"

The city of Ascoli is visible on the left and the large red area above San Benedetto del Tronto stands out on the right.

Concerning the area of San Benedetto, the reasons for these concentration values and the large area involved in this case are mainly two; the classic channelling phenomenon that transports pollutants from the highest elevation areas to the valleys and on the coast; and secondly the high population density of San Benedetto.

Below is a three-dimensional view of the domain that allows a better understanding of the distribution of pollutants based also on the topography of the land.

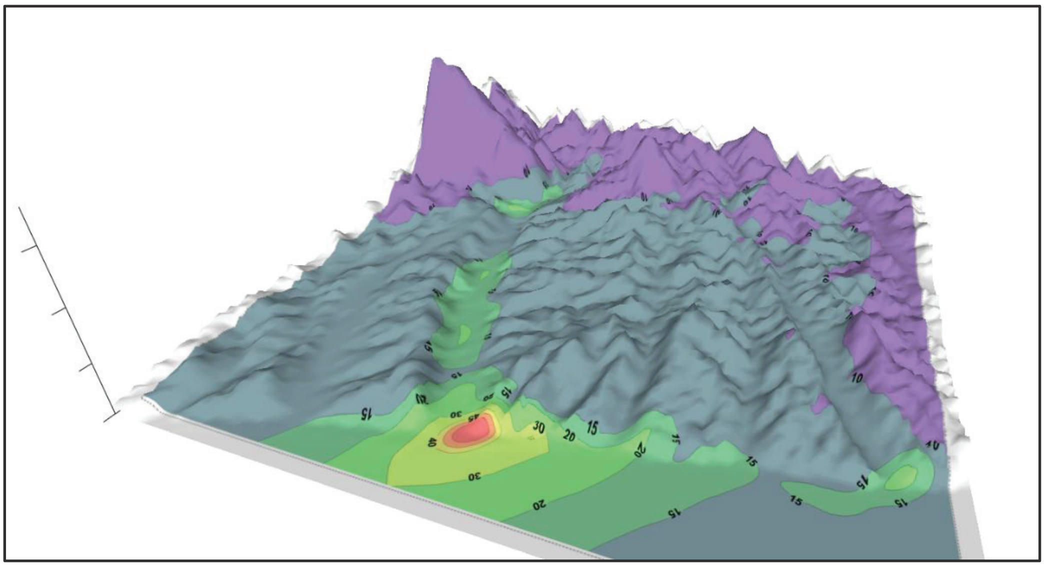


Figure 6.4 - Three-dimensional representation of the domain depicting the outputs generated by all emissive sources

Finally, among the interfaces that can be displayed, the most statistically important is that relating to the ALL group, that is the contribution of all the sources, shown below.

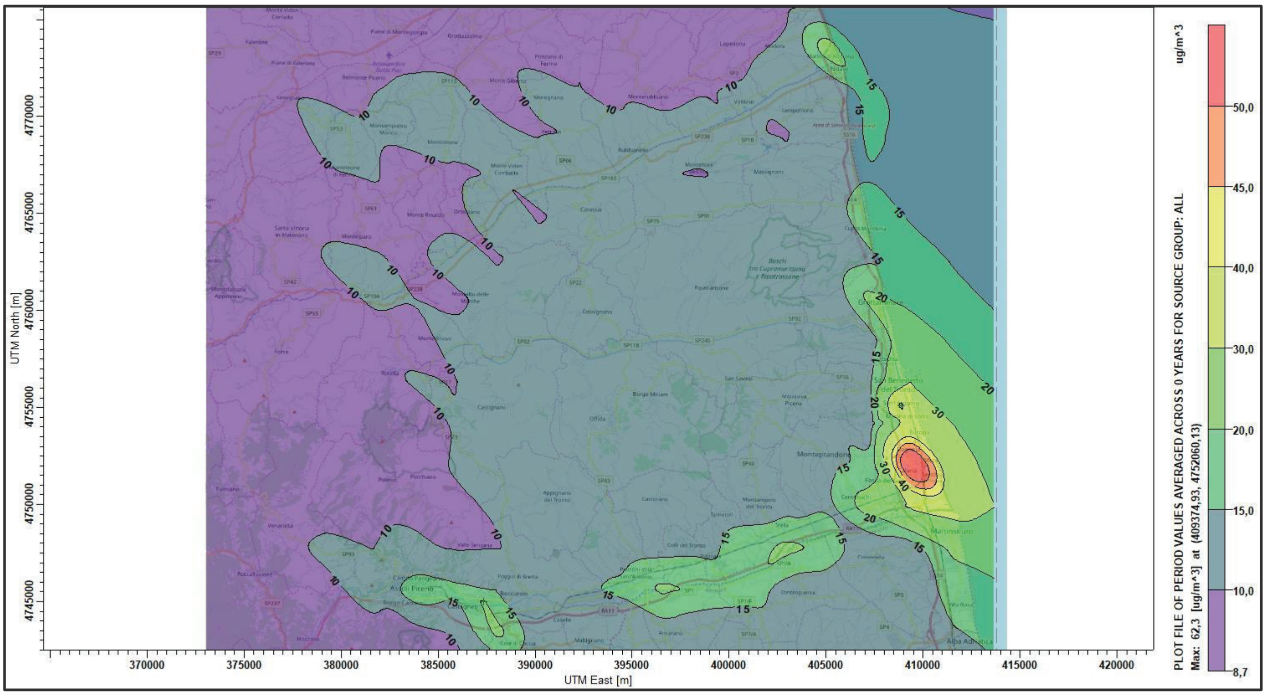


Figure 6.5 - Iso-concentration map for PM_{10} for all sources

This map represents the average of the period that is the average over the year.

As shown by the almost total presence of blue and purple colours, it is around 10 µg / m^3 per year which represent a reasonable value; analysing the map from left to right, a first green and yellow "spot" can be seen which represents the residential and industrial area of Ascoli Piceno where concentrations obviously tend to rise as seen in the previous maps; then, again in green and yellow, it can be seen the motorway junction 11 which connects to the other roads on the coast for values that are around 20 µg / m^3.

Concentrations tend to rise in the residential and industrial area of San Benedetto, showing a peak at the intersection between the road infrastructures analysed.

As mentioned earlier, the higher concentration values along the coast are entirely reasonable and in this case it is correct to assume that the spot of greater concentration in San Benedetto is not a singularity since values of around 50 µg / m^3 over the entire city are reasonable considering the high population density.

7. Comparison between simulation and observed data

The text-format files accompanying the maps contain the daily averages of PM_{10} concentrations expressed in µg\m^3 for the period; as already mentioned, these outputs contain a large number of information, therefore there is a need to filter them, specifically because they also contain the coordinates of the meshes, i.e. the nodes of the Cartesian grid used by the simulator as a spatial reference, while in this phase it is only necessary the outputs related to the discrete receptors, that are the physical control units.

The sources considered in the simulation, as known, are: STRADE, INDUSTRIALE, URBANO and ALL; for the purpose of comparison with the real data recorded by the control units, the outputs corresponding to the ALL values of concentrations of the 402 receptors during the year were considered averaged over twenty-four hours, since the physical control units are not able to distinguish the various sources of the particles they sample, so the data they detect correspond to the so-called 'ALL' group.

The AERMOD output file is reorganized into a .csv file executable in Excel.

The data relating to PM_{10} values for the year 2015 were then collected for the Ascoli Piceno and San Benedetto del Tronto control units, respectively urban background and traffic stations, previously mentioned in the section relating to the receptors; the data are available to anyone who wants to consult them and can be found on the ARPAM website.

The distinction between the background station and the traffic station is important for the correct interpretation of the results and will therefore be explored further on.

In Excel, therefore, the simulation results were graphically compared with the values measured by the control units, generating a graph with two time series.

This comparison is useful above all to verify how the parameters set during the launch phase of a simulation affect the simulator making it more and more correct and reliable.

It is performed now the analysis of the comparisons, starting from the data of the background control unit located in Ascoli Piceno in Monticelli area.

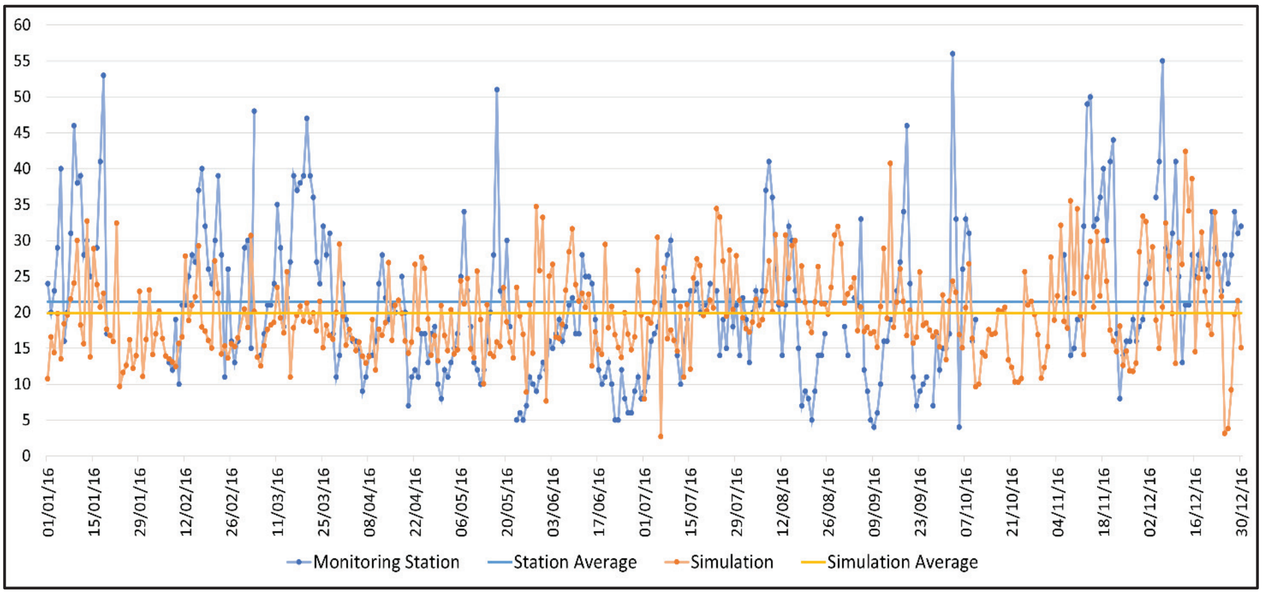


Figure 7.1 – Graphical comparison of real data and simulated data relative to Ascoli monitoring station

The blue trend represents the real data recorded by the monitoring station, the orange one, on the other hand, represents the output values generated by the software for the discrete receptor corresponding with the same station.

As it is possible to appreciate from the graphical comparison, there is a fair correspondence in the two trends even if it is evident that those simulated are still concentration values not yet perfectly coinciding with those of the real world and specifically they are underestimated, this is due to the fact that the software has limits in detecting the peaks and, moreover, in reality a monitoring station also detects dust from lifting, biogenic emissions and any other aliquot of fine dust of any origin, which now a software cannot simulate.

It is shown now the comparison between the data simulated by the software for the discrete receptor located in San Benedetto del Tronto and the real data recorded by the same control unit. At this point it is good to highlight the difference between the background station and the traffic station, the core of the difference lies in the location of the two stations, the first is such as to record without being predominantly influenced by one or the other source, but by the contribution of all types of sources, therefore attributable to the 'ALL' group of this study; the traffic station, on the other hand, is located close to a specific road or groups of roads and mainly detects emissions from the so-called 'STRADE' source group; this type of control unit is not adequate for the type of domain of the present study which is very large and more correctly comparable with the background stations, however a comparison is still useful, taking into account all these factors.

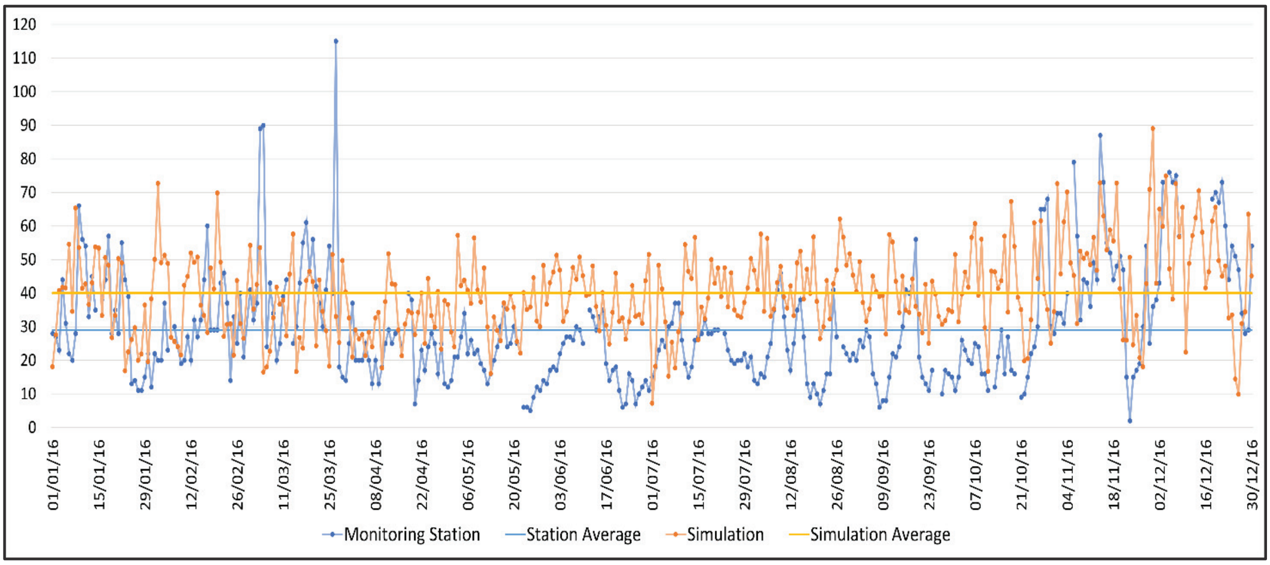


Figure 7.2 - Graphical comparison of real data and simulated data relative to San Benedetto monitoring station

Also in this case the orange trend, relative to the simulated data, is similar to the blue one of the real data from the control unit; however it is evident that the gap between the average values of the two trends in this case is increased and inverted, with the simulation values this time overestimated with respect to the real case.

This result is not surprising since, as previously explained, the traffic station of San Benedetto is not adequate for this kind of analysis and the data studied but it is in any case possible to give an explanation of the behaviour of these trends.

As seen in the section of iso-concentration maps, the 'STRADE' source group showed a maximum concentration of 35 $\mu g/m^3$, the 'ALL' group reached a maximum of 63 $\mu g/m^3$; it is therefore evident, taking as good the orders of magnitude of the emissions of the different sources even in reality, that since the simulation refers to all the sources, therefore to the 'ALL' group, while the San Benedetto control unit only to the roads in the area, in the comparison graph it is justified that the trend relating to the control unit is positioned lower than that of the simulation and that the gap between the average values is, in this case, greater.

It is presented now a more in-depth statistical analysis of the simulated data as in this way it is possible to analyse the annual averages and other values extrapolated through a descriptive statistic generated in Excel.

Below are the tables with the values extrapolated from the statistical analysis in Excel for the two discrete receptors of Ascoli and San Benedetto (S.B.T.) and for the respective monitoring stations.

Monitoring Station Ascoli	
Average	21,47
Standard error	0,59
Median	20,00
Standard deviation	10,31
Sample variance	106,31
Minimum	4,00
Maximum	56,00
Sum	6591,00
Count	307,00

Simulation Ascoli	
Average	19,84
Standard error	0,33
Median	18,91
Standard deviation	6,21
Sample variance	38,57
Minimum	2,68
Maximum	42,40
Sum	7243,30
Count	365,00

Monitoring Station S.B.T.	
Average	29,02
Standard error	0,90
Median	25,00
Standard deviation	16,71
Sample variance	279,08
Minimum	2,00
Maximum	115,00
Sum	9895,00
Count	341,00

Simulation S.B.T.	
Average	40,01
Standard error	0,68
Median	39,69
Standard deviation	12,88
Sample variance	165,88
Minimum	7,19
Maximum	89,04
Sum	14564,42
Count	364,00

Figure 7.3 – Descriptive statistics generated by Excel

The tables present a different count of the number of data present since the physical control units may have problems in measuring the pollutant due to device malfunctions or a failure in the validation of the data, for which the missing data were not included in the count.

The data extracted from the statistical analysis are useful for verifying that the law limits are respected, the Legislative Decree 155/2010 imposes a limit of 50 µg / m^3 of PM_{10} per day and, since the tables also contain the minimum and maximum concentration values in the annual data series, it is already possible to note that only in the Ascoli simulation there are no values that exceed this limit, while in the remaining three cases the value is exceeded, it is therefore possible to deepen the analysis by counting among the values of the Ascoli monitoring unit (which is the background one and therefore the most suitable for the analysis), how many times the limit value is exceeded in a year in order to verify that this does not occur more than 35 times as specified by the Legislative Decree, and that it is in any case in line with the result of the simulation; in fact, the exceeding occurs only 4 times and is therefore acceptable both by law and for comparison purposes.

As regards, instead, the values of San Benedetto control unit (which is a traffic station) and the results of the simulation of the relative receptor, the limit value is exceeded respectively 38 and 73 times; this result is however in line with what has been described up to now, in fact, also in this case, it can be noted that the station relating to the road arteries, i.e. that of San Benedetto, is affected by the highest concentration values.

Finally, it is performed the analysis of the annual averages which are useful for verifying the respect of the law limits present in the Legislative Decree 155/2010 which imposes a limit of 40 µg / m^3 of PM_{10} in a calendar year.
As can be seen, both for the simulations and for the real cases of both localities, this limit is respected, therefore also in the San Benedetto area.

CONCLUSIONS

From the results obtained from the graphic outputs it is evident that the majority of the domain is not particularly affected by large emissions of particulate matter as the annual average from the simulation is in line with the legal limits even if the area of San Benedetto del Tronto shows noteworthy values.

The AERMOD model is created to simulate the dispersion of pollutants emitted by fixed sources and on short range (no more than 50 km), despite the great potential of the software and its ability to simulate complex situations, it should be emphasized that, in any case, it is a diffusive model affected by limitations; for example it does not respond well to wind speeds lower than 0.5 m/s while, as has been shown, the stagnation of pollutants in the valley areas and complex orography are considered.

It has been demonstrated, however, that with valid approximations and considerations, the model is able to correctly simulate a trend of emission of particulate so that it adapts to the real trend recorded by the physical control units present on site; even if presenting differences in the real emission values due to the inability of the control units to distinguish contributions such as the raising of dust or dust intrusions from biogenic emissions from the strict PM_{10} value.

In order to reduce the impact of this problem, the contribution of a background emission source has been included in this work, which takes into account the base concentration present on site.

It must be specified that the one in question is a very extensive domain and therefore required adequate approximations which in some cases may have influenced the accuracy of the model's outputs; however, despite these considerations, the result remains in line with the potential of the model itself.

Ultimately, in the light of what has been said, it is evident that he models must be further improved and perfected, always bearing in mind, however, their limits that do not allow us to approximate reality to perfection due to the countless variables involved.

This work, therefore, can be framed as a preliminary phase that refers to future developments based on the deepening of the approximations chosen, such as the choice of more circumscribed domains, the use of weather data over three or more years and temporal profiling more specific for the realities analysed.

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