Università Politecnica delle Marche

Master Degree in Environmental Engineering

Master Thesis

Aerosol Speciation analysis

during emergency period of Covid-19

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Sommario

ABSTRACT

In this study we performed a speciation analysis of the atmospheric aerosol, during the lockdown period related to the emergence of Covid-19.

Taking advantage of Aerosol Optical Depth measurements, carried out with the aid of remote sensing, we have investigated, in terms of concentration, the average levels of aerosol subfractions such as:

- black carbon
- organic carbon
- SO_4
- dust
- sea salt

over a period of three months between January and March.

Through this research, we have been capable to detect and highlight the scattering time evolution of abovementioned compounds and, therefore, make assessments on the different scenarios.

It means, hence, evaluating the significant differences between the period antecedent to lockdown and during that. Since is evident how strong would have been the impact of restrictive measures on human activities.

Later we made some hypothesis about possible scenarios trying also to draw connections between recorded values and possible variation of anthropogenic activities.

Eventually, through the use of environmental agencies reports, ground-base data, and spatial agencies records, we have assessed if there could be any interrelationship between our surveys and their detections (e.c. relevant atmospheric events) acquired in different ways.

The reason why we conduct this survey is to prove, cause-effect relationship, between relevant scatter divergences and manufacturing activities suspension due to lockdown.

1. INTRODUCTION

Air pollution is a global issue with a huge impact on natural ecosystems and on human health.

Especially in some specific areas of our planet, emissions have tragically increased in the recent years.

Nowadays air pollution represents the major risk to human health since bad air quality is responsible for respiratory and cardiovascular diseases. (European Commission, 2017)

Real action aimed at reducing of air pollution and its harmful impacts, requires firstly a good knowledge and a deep understanding of it sources. It means where pollutants are originated and their mechanisms of transformation and spread in the atmosphere.

Moreover, it needs a specific knowledge about the chemical composition of specific compounds existing in the atmosphere and how they react over time, if subjected to particular conditions. (European Commission, 2017).

In the last couple of years, aided by increasingly evident environmental effects, there has been ever-growing social interest around air pollution issue.

Consequently, daily growing interests from media and public interest, about air quality and related issues, forced also the establishments and the politic to move in a certain direction trying to act effectively.

1.1 Aerosol

In the last 20 years, the interest in aerosols has been increased since it was well established that they have significant environmental and health impacts (Burrows, 2011).

For these reasons, today, there is a growing interest about air quality and monitoring mechanisms. This interest has prompted an important increase in atmospheric pollution research, which is a complex task requiring knowledge of all the factors and processes involved.

Atmospheric aerosol can be defined as an ensemble of airborne solid or liquid particles in a gas, with their diameters in the size range of 0.1 – 1.0 μm. Aerosol consists of several small unit structures of various chemical composition, merged by interparticle attractive forces, in such a manner that aerosol particles behaves as a single unit in suspension (Seinfeld, 1998).

Aerosols are originated by wide variety of sources, both natural and anthropogenic. They can be the results of man's activity, photochemical processes, plant life, chemical reactions and erosion by wind. Furthermore, the wind is also responsible for the so-called sea spray originates on the sea surface. (Hänel, G. 1976).

The solid and liquid airborne particles, ranging from nano and micro-meters, play a major role in the earth's balance, residing mainly in the two lowest layers of the atmosphere: the troposphere, and the stratosphere.

Moreover, aerosol exhibits a wide variation in term of size and chemical composition as well.

They influence not only the energy budget of the planet, but also the hydrological cycle, the atmospheric circulation and the amount of reactive trace gases as the greenhouse one. (Pöschl, U. 2005).

Eventually they play crucial roles in the reproduction of biological organisms and can cause or enhance diseases. (Pöschl, U. 2005).

Generally most of the aerosols are characterized by their sizes and, in order to be classified as an aerosol, the particles have to be small enough not to sediment down from the atmosphere immediately. This can only be achieved by extremely small particles that are affected by such a weak gravitational pull from the Earth that it can be balanced by winds and turbulent flow, forcing the aerosol to follow the movement of the air. An exact size range for aerosols is not set, but particles with a diameter from a few nano-meters (nm) to hundreds of micro-meters (μm) are generally considered to be aerosols. (Wallace and Hobbs, 2006).

The size, number and chemical composition of the particles may vary due to different processes. After their release and evolution, the particles can be removed from the atmosphere by dry, wet deposition and heterogenous chemistry (Delmas et al., 2005).

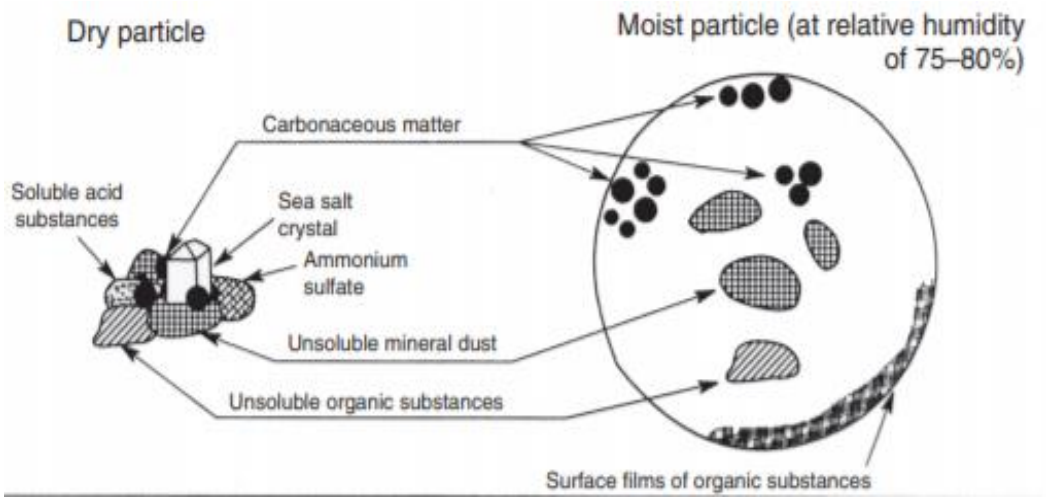

FIGURE 1: AEROSOL PARTICLE DESCRIPTION (UNIVERSALCHEMISTRY)

To give an idea of the shape of an aerosol particle suspended in dry air, a schematic representation of a particle originating from the aggregation of various kinds of particulate matter fragments is shown in Figure 1.

The aerosol particles production can take place in multiple ways:

1) Primary production which occurs in the close proximity of the source. It is mechanically generated from the action of the wind to the sea surface, creating particles in a range of nm (accumulation mode) to several μm (coarse mode).
2) Primary production which takes place by condensation, creating particles with size about 10 nm or around 40-100nm of diameter. This happen within few

seconds after the combustion which can be vehicles, wood combustion, chimneys, etc.

3) Secondary production which happen from nucleation of gases during the gas-to-particle phenomena, forming particles below of 10 nm (nucleation mode).
4) Secondary production through the cloud droplet evaporation, reducing the droplet particles to aerosol particles of diameter between 0.1 and 1 μm (accumulation mode). The average lifetime of an accumulation aerosol particle is about one week due to wet deposition (Birmili et al., 2001),

1.1.2 Sources

According to their source, aerosols may have natural or anthropogenic nature:

Natural aerosols

Soil dust, sea salt, botanical debris, volcanic dust, forest fires are some common sources of natural aerosols. The natural sources of aerosols can be divided into two groups: stratosphere aerosols and troposphere aerosols.

The stratosphere ranges 11 to 50 km from the earth surface. There are some relevant important volcanic eruptions which injected SO_2 into the stratosphere and chemical reaction form sulphuric acid droplets from SO_2. These droplets are the main precipitation nuclei in the formation of atmospheric cloud.

In the troposphere, the region just below the stratosphere (below 11km of altitude), the natural aerosol depends on the direct release of gas to particle formation from natural sources. Direct emission of salt from oceans, dust from the deserts, products from vegetation, constitute the emission in the troposphere.
The concentration of particles in this region, varies inversely with altitude: the higher is the altitude, the lower is the concentration of aerosols and vice versa. (Jacobson, M. Z. 2001).

Volcanic eruptions are capable of ejecting enormous amount of primary particles and gases (e.g., gaseous sulphur) very high into the atmosphere. Most of the particles ejected from volcanoes (dust and ash) are water insoluble mineral particles, silicates, metallic oxides such as SiO_2, Al_2O_3 and Fe_2O_3, which may remain in the atmosphere for a long time.
Volcanic aerosols in the troposphere have important effects on the Earth's climate, both directly through absorption and backscattering of solar radiation, and indirectly through modification of clouds and cloud radiative properties

Anthropogenic aerosols

In the urban areas and above all in industrial areas, the generation of aerosol is characterized almost entirely by anthropogenic sources. Their concentrations in these areas are very high.

In heavily polluted cities, industrial, mining areas, their mass varies from a few tens of μg/m3 to one mg/m3. Particles with size less than 0.1 micro-meters, are mainly formed in the atmosphere by gas-to-particle conversion and they are usually findable near highways, industrial places and source of combustions. They have relatively short lifetime in the atmosphere since they coagulate quickly.

Smog particles, combustion particles and coagulated nuclei-mode particles have a size in the range of 0.1 micro-meters to 2.5 micro-meters. They are tiny but on the other hand they coagulate too slowly to reach the coarse-particle mode. Therefore, they have a relatively long lifetime to reach the atmosphere, and they are the reason for most of the visibility effects of the atmospheric aerosols. (Institute of Technology Rourkela).

Eventually there are the coarse particles (particle size greater than 2.5 micro-meters) which include wind-driven dust, large salt particles from the sea, and mechanically generated anthropogenic particles such as those from agriculture and surface mining. Because of their large size, they are very heavy in mass. Therefore, the coarse particles readily settle out or impact on the surface. The lifetime of these particles in the atmosphere is only a few hours.

1.1.3 Aerosol classification

The increasing importance of thematic concerning the environmental effects, lead to a greater interest for understanding of aerosols details and therefore their characterization.

Essentially the aerosol characterization can occur into a physical and a chemical part.
The physical part includes the determination of particle size and distribution.

The chemical characterization includes the analysis of the gas phase, the definition of chemical composition of collective and single particles

Physical characterization

Evidence about concentration and dimensional diffusion of aerosol are crucial to understand the behaviour of the particles, their transport and deposition but also the residence time into the atmosphere.

These parameters play in fact a key role for the study of atmospheric aerosol and its related effect on the climatic system. (Seinfeld and Pandis, 2006).

The dimension of the particles it is an essential parameter which allows to determine the interaction with the solar radiation and hence to estimate the magnitude of the impact on the climate.

In fact, we register a higher solar radiations diffusion whereas the diameter of the particles is larger. The dimensional spectre of aerosol become an instrument of primary importance to describe a complex system like that. Moreover, particles with same shape but different chemical composition will have a different density and consequently distinct dynamic behaviour (Dickerson et al., 1997).

Atmospheric particulate matter ranges in size from a few nano-meters (nm) to tens of micro-meters (μm) in diameter (Seinfeld and Pandis, 2006).

There are three different ways to classify the atmospheric particles, and between them we recognise:

- Dimensional distribution
- Grain size cut
- dosimetry

The dimensional distribution of particles is characterized by tri-modal distribution corresponding to:

- Nucleation mode: particles smaller than 0,1 micron deriving from combustion and gas-particle mutation.
- Accumulation mode particles ranging from 0,1 a 1 μ m belonging to coagulation of smaller particles.
- Coarse mode particles with aerodynamic diameter between 1 and 100 μ m

There is also a rigorous characterization which identify only two classes: fine fraction with diameter between 1 and 3 micron and coarse fraction with diameter between 3 and 10μ m.

All the three distinct size classes have different chemical composition, optical properties and deposition pattern. Moreover, their origin, transformation and removal mechanisms are also different.

In the picture 2 we can see the different types of particles in relation to their dimension. From the left to the right, they increase up to “coarse” particles like dust, volcano etc.

Furthermore, dimension constitutes the main distinction between single aerosol particles and so it is the principle parameter used to characterize the atmospheric aerosol. As we will see below aerosol’s properties depends on the size of constituent particles (Hoppel et al., 1994).

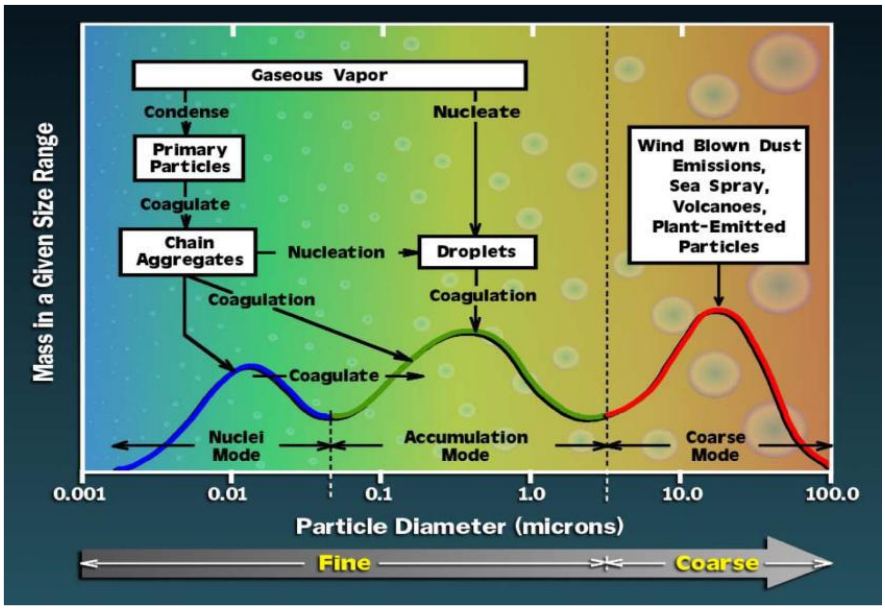

FIGURE 2: SIZE CHARACTERIZATION (SCIENCE.CO)

According to the classification proposed by Whitby and Cantrell (1976), coarse particles generally have a diameter greater than 2.5 μm, below this limit they are referred to as fine aerosols.

Large size particles, because of the dimension, do not remain suspended for long before falling out of the atmosphere by dry deposition.
Coarse mode aerosols consist of mechanically produced natural and anthropogenic aerosols.

The fine is usually secondary aerosol which are formed by nucleation or condensation of atmospheric gas compounds, but also primary sea salt.

Moreover, we also know that particles with the same shape but different chemical composition will have a different density and consequently, distinct dynamic behaviour (Dickerson et al., 1997).

Chemical characterization

Aerosols play a leading role in the field of air quality, of public health, of climate change but also in atmospheric chemistry. Many of the effects of atmospheric aerosols (e.g. radiative effect) depend on their chemical composition, which rarely consists exclusively of a single component. (Jacobson, 2001).

Since aerosols are generated from multiples natural and anthropogenic sources, they are generally composed of a mixture of species and it is obvious that they will have an extraordinary chemical multiplicity and variety. (Jacobson, M. Z. 2001).
It is difficult so to imagine that change on chemical composition does not play a key role.

The chemical description of microstructures therefore assumes a significance of primary interest. (Niessner, R. 1990).

Microstructures are characterized by a not homogeneous distribution of internal constituents, over the whole cross-section of the particle.

The chemical complexity of the small particles constituting the atmospheric aerosols, represent in fact a new issue for the categorization, since it contains several different compounds with many molecular properties. (Goldstein and Galbally; Jimenez).

Atmospheric aerosols is composed of a variety of organic and inorganic compounds, which range from neutral and high soluble substances such as ammonium sulphate, ammonium nitrate and sodium chloride passing through sorry particles mainly composed of elemental carbon covered of inorganic compounds and essentially not soluble minerals such as clay and sand. We can find also trace elements, polycyclic aromatic hydrocarbon, n-alkanes, dicarboxilic acids, water soluble compounds etc. (Alves, 2008).

Organic substances, and not soluble carbonaceous chemicals, generally consist of gas and particulate matters from not complete combustion, which contain for the most carbon and other post combustion residuals.

When the surrounding humidity of relative air, grow reaching levels higher than 70%, the same particle (containing soluble substances) grows gradually by condensation of water vapor to become a water droplet in which pieces of insoluble matter are suspended.

We constantly need to investigate the function and the aim of the size-dependent chemical composition of aerosol particles and their number size distribution in order to create a general approaches for the description of the interaction aerosol-cloud in various climate or air quality applications. (Dusek et al., 2006).

According to their chemical composition, aerosols can be divided in five major categories: soil dust, sea salt, sulphate, nitrate, and carbonaceous aerosols.

Carbonaceous compounds are an important fraction of atmospheric aerosols, because it has great influences on global radiation budget, cloud microphysics (Seinfeld and Pandis, 1998), (Lyamani et al.,2006), global climate change and human health. (Hitzenberger et al., 1999).

1.1.4 Compounds

As shown in figure 3 there are different fractions of aerosols that we will go to treat and analyse using remote sensing.

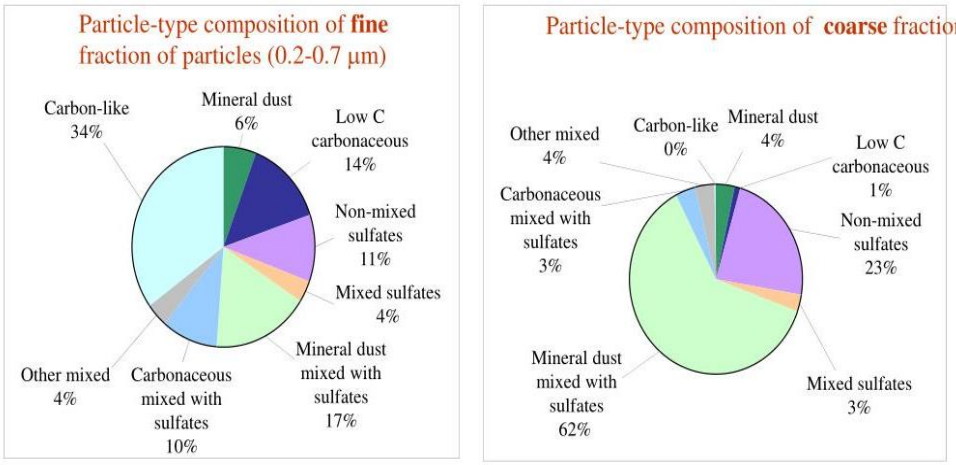

FIGURE 3: PARTICLE-TYPE COMPOSITION

Dust

Particles originating from the soil are usually mineral aerosols and are produced by weathering of soil (Tengen and Fung, 1994; Alfaro et al., 1997).

The wind's action over a rough terrain or over a soil, can produce a huge amount of dust and sand from the Earth surface and then deposit them into the atmosphere.

Especially in arid regions with high temperature gradient, the wind tends to form ultra-fine salt particles (D'Almedia et al., 1991).

These particles are generated close to earth's surface and usually they remain confined to troposphere.

Also, the rock withering and agriculture farming contribute to increase the presence of dust in the atmosphere. They and can transport them over a long distance, far away from the original place. (S.K. Sathneesh, K.K. Moothy and J. Srinivasan, 2004).

Sea salt: The oceans and the seas represent the main source of production and injection of this material into the atmosphere. When strong winds blow over the sea, they give rise to waves and therefore a great spray of droplets is originated at the crest of these waves (W.A. Hoppel et al., 1990).

When slow wind blows over the sea, the air trapped into the waves produces bubbles which reaching the air surface creating a shower of small jet droplets into the atmosphere. What happens upon is that these sprays immediately evaporate, and the crystalline compound (NaCl) is spread into the atmosphere (S.K. Sathneesh, K.K. Moothy and B.V. Krishna Murthy, 1997).

Another process related to the ocean is the emission of dimethyl sulphide into the atmosphere by a natural process that features the phytoplankton which with the action of sunlight is converted into SO2 and sulphate aerosols through gas to particle conversion.
These are also other chemicals which naturally occur in marine atmosphere. However, Sea-salt particles is without a doubt the main one. (R.J. Chalson et al., 1987).

Sulphate

Is one of the main contributors for what concerns the mass of atmospheric aerosol.

Atmospheric aerosols are generally composed of variable amounts of sulphate, ammonium, nitrate, sodium, chloride, trace metals, crustal elements, water and carbonaceous material.

The sulphate component is derived predominantly from the atmospheric oxidation of anthropogenic and natural sulphur-containing compounds such as sulphur dioxide (SO2) and dimethyl sulphide (DMS), respectively. Nitrate is formed mainly from the oxidation of atmospheric nitrogen dioxide (NO_2). Sulphate and nitrate are initially formed as sulphuric (H_2SO_4) and nitric acids (HNO_3) but are progressively neutralised by atmospheric ammonia forming the corresponding ammonium salts.

SO_2 in the atmosphere, reacts in the presence of oxidizing species with the droplets of humidity leading to the formation of $H2SO_4$. It gives rise to Sulphate, $(SO_2)^{2-}$, which is then neutralized by ammonium (NH_4), becoming ammonium sulphate $(SO_4)2NH_4$. (Forster et al., 2007). The process is shown in figure 4.

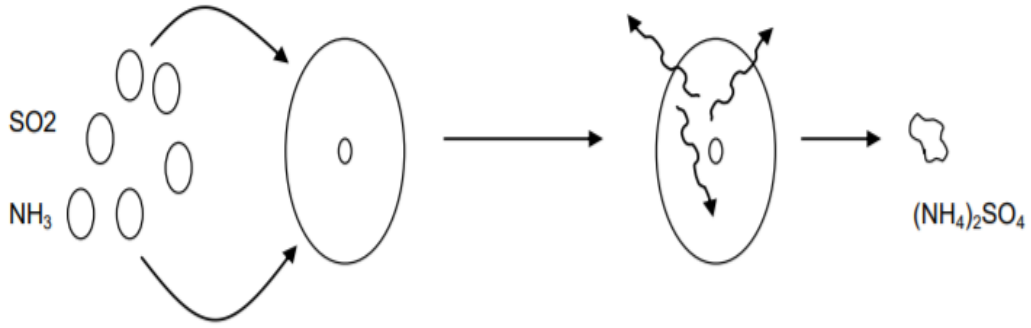

FIGURE 4: PROCESS OF SULPHATE COMBINATION [RESERCHEGATE.NET]

Carbonaceous particles

Carbon is typically the largest elemental fraction of atmospheric aerosol particles, present in many different chemical and physical forms.

Carbonaceous aerosols are a kind of aerosol, which contain at least one atom of carbon. Carbonaceous particles present in the atmosphere, have recently gained importance due to their role on the climate change and all that implies. (Frazer, 2002.).

In fact, they are the major dominant component of the mass of suspended particles in polluted atmosphere. The carbonaceous fraction is generally between 20% and 50% of the total aerosol mass (Kanakidou et al., 2005).

The source of those aerosols may be either primary or secondary. (Kanakidou et al., 2005). Total carbonaceous aerosol (TCA) is a complex mixture of different particles: it includes an organic fraction of carbon call organic carbon (OC) and another one composed of elemental carbon (EC) or black carbon (BC).

The total amount of carbon (TC) that can be found in particulate matter can be readily determined by elemental analysis (Gelencsér, A.2004).

EC and BC are referred to the same fraction of carbon but assume different name according to their property quantification (thermal and optical): EC when quantified using thermal methods, while BC when quantified using optical methods. (Contini, D., Vecchi, R., & Viana, M. 2018). However, they refer to the same carbonaceous fraction: particles of carbon with microstructure is similar to the graphite and aggregated in spheres with diameter in the range of 10 and 50 nm.

EC-BC and OC in suspended particulate matter play important roles in health, visibility, and climate effects (Cao et al., 2005) and Both groups have a primary importance for what concern health and climate effects. (Satsangi A).

Elemental carbon is a primary pollutant, directly emitted during processes of not complete combustion of fossils fuels or biomass fuels.

Organic carbon is OC is a mixture of several particulate organic compounds, containing polycyclic aromatic hydrocarbon and other hazardous components which can harm human health and increase morbidity and mortality (Vedal, 1997; Pope and Dockery, 2006; Mauderly and Chow, 2008).

Human activities are the main source of carbonaceous aerosols and these emissions can be strongly reduced by improving the combustion efficiency and the treatment of exhausts.

Black carbon

Black carbon (BC) is mainly composed of particles which are the result of incomplete combustion.

It is the dominant form of particulate matter present in the atmosphere able to absorb light with characteristic in range of visible spectre wavelengths (380÷760 nm) and infrared radiation (Arpa Lombardia).

Suspended in the air, black carbon particles absorb the sunlight and, as a result, heat the atmosphere and darken surfaces, specifically the snow and ice. Incorporated into cloud droplets, (CB) particles reduce the cloud albedo. This phenomenon, is called reflectivity.

Furthermore, when these particles settle on snow or ice, the solar radiation are absorbed rather than being reflected. Unavoidably, this phenomenon, leads to an increase of temperature and as a result the loss of artic ice. (magee scientific).

This warming effect is in contrast with the cooling effect of other fractions of aerosols that are primarily scattering. (Haywood and Boucher et al., 2000).

Therefore, BC exert a positive radiative forcing, increasing the warm effect due to anthropogenic increases in CO_2 and other greenhouse gases. However, it is still not clear how the climate sensitivity to black carbon aerosol forcing compares with the sensitivity to greenhouse gas forcing. (Roberts, D. L., & Jones, A. 2004).

BC aerosols can also affect the climate system by altering the clouds through local heating (semi-direct effect) or by acting as cloud condensation nuclei (indirect effect).

So Black carbon (BC) as we saw, it is also an important issue, both at local and global scales; it has a primary origin and other than forest fires, it is emitted mainly from anthropogenic combustion sources, including industrial emissions, road transport, and domestic heating.

Lastly black carbon has adverse effects on human health, deteriorating the quality of air. It is relevant to say that, despite BC does not represent one of the greater directly toxic component of fine aerosol, it can facilitate the spread of a wide variety of toxic compounds (combustion-derived chemical constituents), by acting as vector. (Janssen et all).

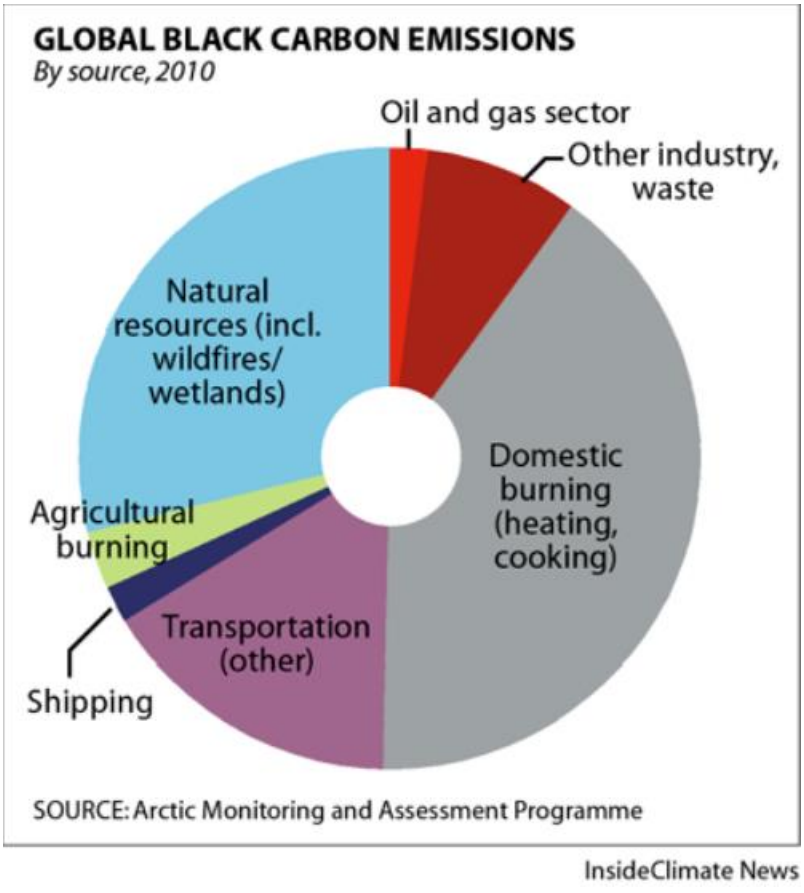

FIGURE 5: GLOBAL BLACK CARBON COMPOUNDS

Organic carbon

The organic carbon (OC) is the not absorptive fraction of the carbonaceous aerosol characterized by lower molecular weight than EC. It can contain reactive compounds, which are involved into atmospheric-chemical (Tsigaridis et al., 2006).

OC includes a wide group of compounds in which tetravalent carbon is chemically linked to other atoms of carbon, with hydrogen and other elements such as oxygen, sulphates, phosfates and chlorine. In operation term it is the carbonaceous fraction which evolve in atmosphere at temperature lower than 1000 °C.

Organic carbon (OC) is a major component of aerosol in the atmosphere and it originates from various sources which can be anthropogenic (combustion processes) and natural (sea-spray and biogenic emissions). (Cooke et al., 1999).

While as we saw before, BC has a primary origin, the source of Organic carbon can be primary source and secondary source as well; primary sources can be anthropogenic or biogenic while secondary sources are atmospheric processes of oxidation. In fact, OC can also be formed directly in the atmosphere.

The natural sources of organic carbon aerosols can be different and are estimated as follows: Smoke aerosols from wild fires were estimated from estimates of the amount of fuel burned in forest wild fires using the emission factor of 16 g per kg fuel noted above for forest burning. (Logan et al., 1981).

On the other hand, concerning anthropogenic sources, OC is formed primarily by incomplete combustion of coal, fossil fuels, biomass, and industrial activities or the oxidation of gas-phase precursors. (Cooke et al., 1999).

It is estimated that almost 50% of global emissions of EC arise from the fossil fuel combustion. Organic carbon represents a mixture of more than hundreds of organic compounds. (A. Satsangi et al.,2012).

While as we saw before, BC has a primary origin, the source of Organic carbon can be primary source and secondary source as well; primary sources can be anthropogenic or

biogenic while secondary sources are atmospheric processes of oxidation. In fact, OC can also be formed directly in the atmosphere (Lewandowska et al., 2010).

Secondary organic carbons are in fact originated from oxidation of gas-to particle conversion of volatile organic compounds (VOC).

They are also formed when reactive volatile hydrocarbons, including aromatic hydrocarbons from automobile exhaust and biogenic hydrocarbons released by vegetation, undergo atmospheric transformations and subsequently form oxidation products (Rengarajan, R et al.).

1.2 How aerosols affect the climate

Aerosols influence climate in different ways:

- by changing the amount of heat that penetrate and leave the atmosphere
- by acting on the mechanism of clouds formation
- by altering the reflectivity, or albedo, of the planet.

Different types of aerosol have significant direct radiative impact through absorption and scattering of incoming radiation, according to their physical properties. These peculiar properties, of scattering and absorbing, are defined by scientists as the "direct effect" of aerosols on Earth's radiation field.

However, since the aerosol include a huge amount of different type of particles with, in turn, present many different properties, it is very hard to forecast the overall real impact.

Although most aerosols reflect sunlight, some also absorb it. An aerosol's effect on light depends primarily on the composition and colour of the particles. Broadly speaking, bright-coloured or translucent particles tend to reflect radiation in all directions and back towards space. Darker aerosols can absorb significant amounts of light.
Some kinds of aerosol, especially particular types of dust from ground-up rocks, present a light colouration and so have a reflective property. Pure sulphates and nitrates for

example, reflect nearly all radiation they encounter, cooling the atmosphere. When the sun rays beam them down, they bounce the rays back out of the atmosphere, preventing that heat from ever reaching Earth's surface (figure 7). In same case, the effects can be dramatic. (Hänel,1976).

The properties of atmospheric aerosol particles as functions of the relative humidity at thermodynamic equilibrium with the surrounding moist air. (Elsevier).

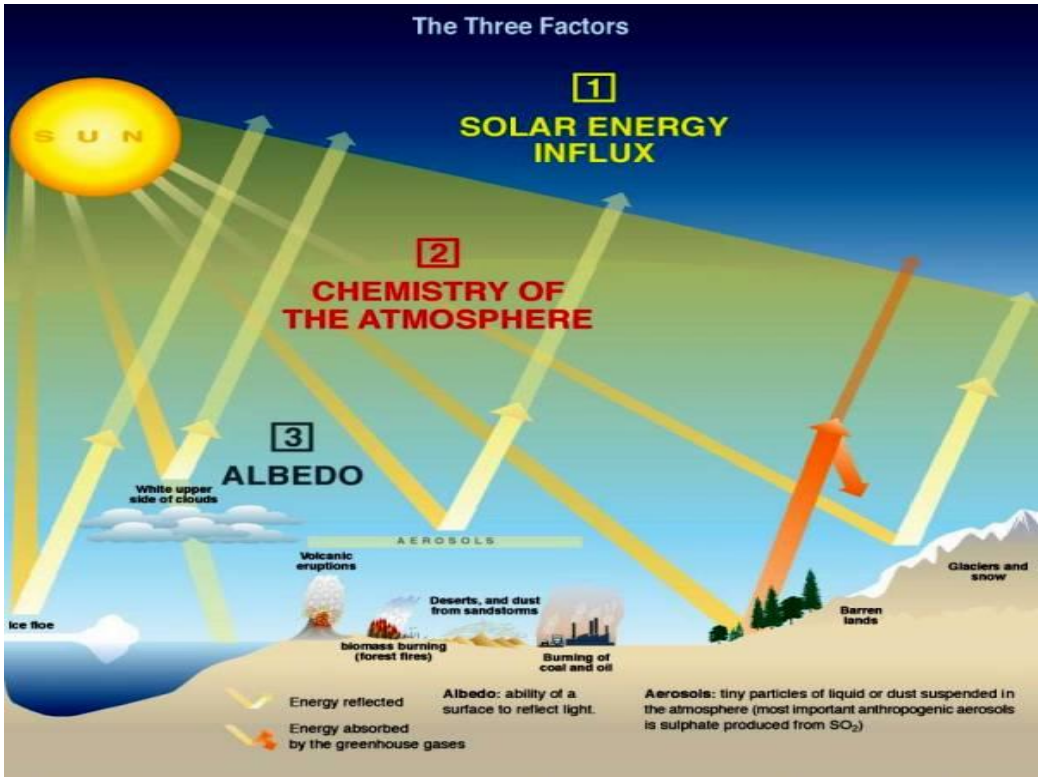

FIGURE 6: THE 3 FACTORS WHICH AFFECT THE CLIMATE

On the other hand, Black carbon absorbs radiation readily, warming the atmosphere but also shading the surface. Organic carbon, sometimes called brown carbon or organic matter, has a warming influence on the atmosphere depending on the brightness of the underlying ground. Dust impacts radiation to varying degrees, depending on the composition of the minerals that comprise the dust grains, and whether they are coated with black or brown carbon. Salt particles tend to reflect all the sunlight they encounter.

Moreover, aerosol also influence the formation process and growth process of the clouds. Water droplets merges quickly around the particle, promoting the cloud formation. In

turn white clouds reflect incoming sun, preventing it from getting to the surface and warming land or water, but they also absorb the heat that the planet is constantly emitting back outward, trapping it in the lower atmosphere. Depending on the cloud type and location, they can either warm their surroundings or cool them. (NASA)
Furthermore, besides to scattering and absorbing radiations, aerosols also have another peculiarity called reflectivity or albedo.

A purely scattering aerosol raises the albedo of the atmosphere, causing the decrease in the quantity of radiation which reaches the Earth's surface. In the presence of aerosol absorption, a direct "energy-feeding" of the atmosphere takes place. Thus the anti-greenhouse effect appears when the atmosphere is excessively heated and the surface is cooled. (Kondratyev. 1986).

If we said before that bright surfaces reflect radiation and cool the climate while, darker surfaces absorb radiation and produce a warming effect, the White surface of sea ice, for instance, reflect a great deal of radiation, whereas darker surfaces, such as the ocean, tend to absorb solar radiation and have a net warming effect.

Aerosols, in particularly black carbon, can affect this equilibrium by distorting the reflectivity of the ice, covering this bright surface with a layer of dark residue .In the Arctic especially, aerosols from wildfires and industrial pollution are likely hastening the melting of ice.

1.3 Radiative properties

Atmospheric radiative transfer is the science essential to understand, how electromagnetic radiation emitted by both the Sun and Earth, interacts with the gases, clouds and particles making up our atmosphere. It basically attempts to describe the propagation of electromagnetic radiations through the atmosphere.

Atmospheric aerosol particles affect the earth's radiative balance in several ways. They can scatter and absorb radiation, directly changing the amount of solar rays reaching a specific

location. Furthermore, aerosol particles indirectly influence the earth's radiative balance by acting as cloud nuclei.

The magnitude and sign of the aerosol forcing effect are determined, in part, by both the horizontal and vertical distribution of the aerosol particles. (Haywood and Ramaswamy, 1998).

When the solar radiation propagates through the atmosphere it will interact with the atmospheric particles by scattering and absorption with the consequence of mitigation of the radiation.

In the scattering and absorbing process, a photon hits one particle and the kinetic energy of the photon-particle system is conserved. The radiation that has been scattered maintain the same wavelength as the incident beam, while the trajectory of the scattered photon is altered. Scattering and absorption properties of particles are determined by their chemical composition, their size and wavelength of the incident ray. (Hobbs 2000).

Scattering is a process where incoming solar radiation photons are extracted and scattered into one or several other directions and therefore changing the propagation path of the radiation bean.

Absorption on the other hand usually takes place in conjunction with scattering and it is the phenomena in which photons are absorbed rather than redirected and converted in other forms of energy, (figure 7). (Mishchenko et al., 2002).

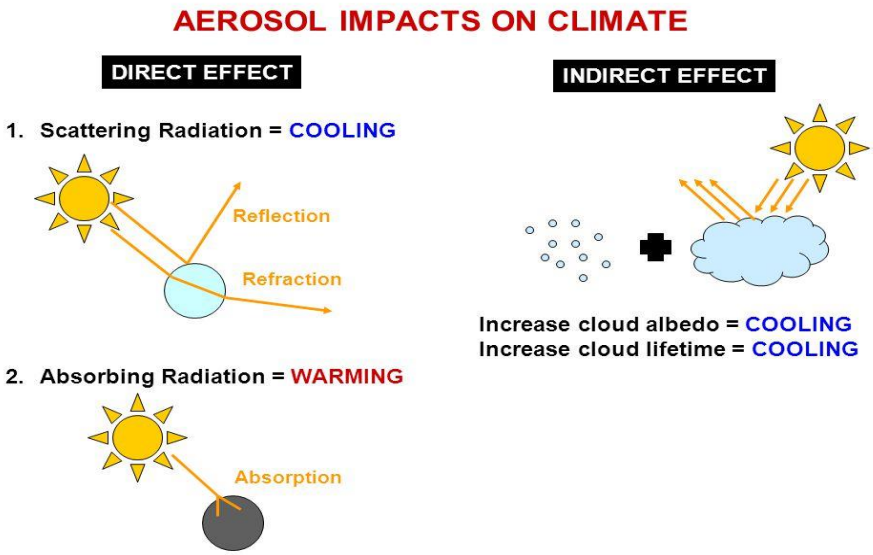

FIGURE 7: SCATTERING AND ABSORPTION RADIATIONS

Moreover, the mechanisms by which the aerosol particles act by modifying the radiation balance can be summarized in a direct and an indirect effect (figure 7).

1.3.1 Direct radiative effects of aerosol

The aerosol has become an actual important universal issue since of its direct and indirect effects on the environment and as consequence on the human health. (Poschl, 2005).

The direct effect represents the processes of absorption and diffusion of electromagnetic radiation of solar and terrestrial origin.

Aerosol particles modify the radiation balance of the atmosphere, by absorbing and scattering the solar radiations and UV bands, by interacting with infrared radiation, affecting de facto the earth's radiation field. (Dickenrson et al., 1997; Lau et al. 2006).

Large dimensions mineral aerosol particles (Dp > 3 μm) have also a primary role on the radiative impact due to the aerosol (Otto, 2011). The radiative forcing attributable to the

direct effect of aerosols, depends on the vertical distribution, chemical composition and size distribution of the aerosol. (Quajano 2000). For instance, pure sulphates and nitrates almost reflect every radiation they encounter rendering the atmosphere cool whereas black and organic carbon absorb radiations warming the atmosphere. The behaviour of the dust grain to radiation depends on the composition of the minerals that comprise (Voiland, 201).

Usually the infrared radiations do not have a strong absorption for two reasons: firstly, because the opacity of aerosol decrease with the increase of wavelength. Secondly because the aerosol is concentrated mainly in the lower troposphere, where the temperature of the atmosphere, which determines the emission, is about the same as that of the earth's surface. (Hobbs 2000).

1.3.2 Indirect radiative effects of aerosol

Aerosol particles indirectly affect the climate both globally and regionally by modifying the presence of clouds, their lifespan and the amount of precipitation (Rosenfeld et al., 2001). The indirect effect represents two different mechanisms. The aerosol particles, serving as a ground in heterogeneous chemical reactions, can alter the concentrations of substances which have a direct impact on the climate.

Moreover, as already mentioned above, the mineral aerosol particles influence the formation of clouds operating as condensation nuclei and glaciation nuclei in the formation of cloud systems increasing the planetary albedo and indirectly contributing to cooling the planet. (Huang, et al, 2014).

The clouds with their brighter nature, reflect the sunrays before they can reach the earth, protecting the ground with shadow and producing net cooling.

This bright effect of the clouds takes the name of cloud albedo. Cloud systems, in turn, interact with solar and terrestrial radiation, in ways that depend on factors related to the structure of the system: concentration and size of droplets, cloud thickness, altitude, presence within clouds of CCN or particularly absorbent particles such as carbonaceous aerosols (figure 8). (Huang, et al, 2014).

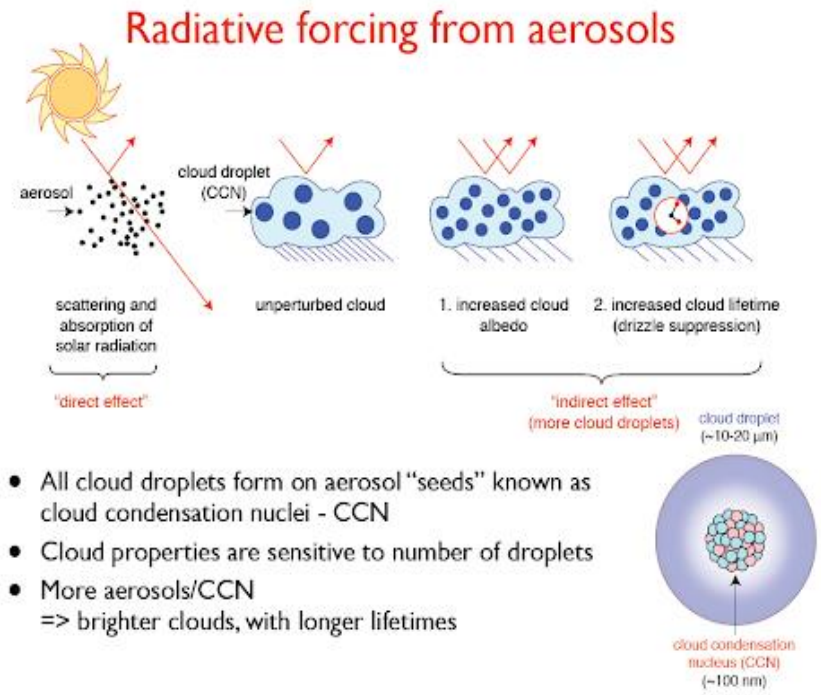

FIGURE 8: RADIATIVE PROCESS

1.3.3 Influence on tropospheric gases

The presence of mineral aerosol in the atmosphere, in addition to directly impact the climatic system, influence also, the behaviour of some tropospheric gases, modifying the capacity of oxidation of the atmosphere. (Arimoto, R. 2001).

The particles which spread the UV radiation in the boundary layer, in fact, they accelerate the photochemical reactions producing photochemical smog. On the contrary the aerosol particles which have a large external surface, as mineral dust, absorb the UV radiation, decreasing the rate of photochemical reactions and the formation of pollutants.

Moreover, in the particle surfaces, occur reactions like the decomposition of ozone. This is very important since ozone is a greenhouse gas (IPPC, 2007).

1.4 Effects on the environment

The environment is also affected due to direct and indirect effects of the aerosol. The vegetation, specifically leaves for instance, use to perform a filtration process, but only when the coarser particles have a certain size. Otherwise they fail when the particles are too small.

Vegetation is also affected due to aerosols through direct and indirect pathways. The leaf usually filters the coarser particles at much higher rates, but it fails when the particles are lesser in size.

The amounts of particles deposited on plants and their composition change significatively, affecting the physiology. Moreover, the deposition of pollutant changes the soil conditions and hence leads to an indirect effect of air pollutants on vegetation and plants. (Jimoda, L. A. 2012).

1.5 Effects on human health

Aerosols exist in different forms and size. Airborne dust, mists, smokes, fumes are some of them. In the occupational places, each one of these forms may be substantial because they are related to many activities. The finer the particles the more dangerous they are. The fine particles with a dimension smaller than 10 micro-meters or even than 2.5 micro-meters have a very strong influence on human health. They contribute to a variety of diseases. There is a significant relation between the exposure to fine particulate matter and its health impact. Most of them, fine and ultrafine materials are generated from combustion sources.

They are the mixture of elemental and organic carbon, metals, and inorganic compounds such as sulphates. In the process of respiration, the particles enter in our body through the nose. Due to their small size, they cannot be checked by nose hairs and thus enter in the lungs. They also penetrate in the circulatory system and lodge in organs such as liver and heart. The symptoms of health impacts are of both acute and chronic. The acute diseases

are asthma and bronchitis. Chronic diseases are irritation and inflammation of respiratory tract, which can potentially lead to cancer (Bickis, et al., 1998).

According to the estimation from the World Health Organization (WHO), particle pollution contributes to approximately 7 million premature deaths each year, making it one of the leading causes of worldwide mortality (Media centre, 2014).

1.6 Aerosol Optical Depth

Aerosol optical depth is a quantitative estimation of the amount of aerosol present in the atmosphere. It is a measure of the extinction of the solar beam by dust and haze. Aerosol Optical Depth (AOD) measures aerosol distributed within a column of air from the earth's surface to the top of the atmosphere. Basically, the particles suspended in the atmosphere like sand, dust, smoke, salt, pollution can block the sun lights by absorbing or by scattering light.

AOD is a key parameter which suggest us how the amount of direct sunlight avoided from reaching the ground, by these aerosol particles.
It is a dimensionless number that is related to the amount of aerosol in the vertical column of atmosphere over the observation location.

Aerosol Optical depth (AOD) is fully established as a crucial indicator in understanding process of atmospheric physics and regional air quality since it allows us to quantifying aerosol loading in the atmosphere.

As we mentioned before, according to their typology, size and position, aerosol can both cool or warm the surface. Aerosol can also boosts the clouds to form or at the same time it can avoid their formation.

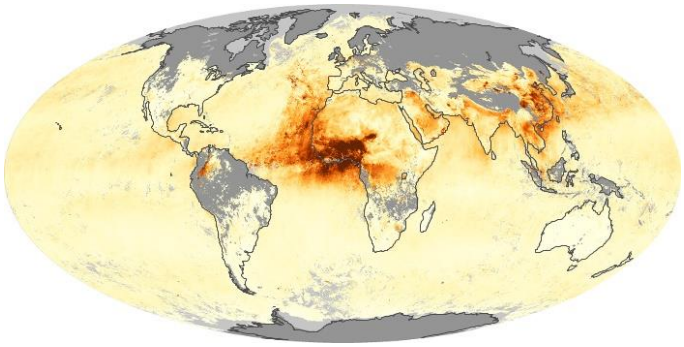

FIGURE 9: MONTHLY AEROSOL

These maps (figure 9) show average monthly aerosol amounts around the world based on observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. Satellite aerosols measurements, called aerosol optical thickness (AOT), are based on the fact that the particles change the way the atmosphere reflects and absorbs visible and infrared light.

1.6.1. Typical AOD Values and the AOD Distribution

According to their typology, size and position, we saw that aerosol can both cool or warm the surface. Aerosol can also boosts clouds to form or at the same time it can avoid their formation.

AOD values range from zero and upwards (table 10). A higher AOD means higher attenuation and hence more aerosols in the atmosphere. In particular an optical thickness of less than 0.1 (palest yellow) indicates a clear sky with maximum visibility, whereas a value of 1 (reddish brown) indicates very hazy conditions.

AOD	Corresponding Condition
0	Clear sky, free from aerosols
0.02	Very clean, usually over isolated areas
0.2	Fairly clean air
0.6	Polluted air
1.5	Heavy smoke/dust event (e.g. volcanic eruption)
> 3	The solar disk is obscured

Table 10: AOD levels and the corresponding atmospheric conditions (Levy et al. 2014)

1.7 Monitoring methods of aerosols

Although there are different other techniques, measuring aerosols through AOD is one of the most convenient and efficient process.

Satellite based AOD measurement is, without any doubt, far better compared to ground level monitoring. In fact, satellite data covers the full earth surface while the application of ground level monitoring is limited to particular sites. Aerosol Optical Depth (AOD) measures aerosol distributed within a column of air from the earth's surface to the top of the atmosphere.

1.7.1. Techniques

Monitoring of aerosols is crucial for keeping track of air quality. Having a better knowledge of aerosol particles, allows us firstly to understand and evaluate the situation, then to be ready and act in the direction of improving the conditions.
Every characteristic such the concentration of aerosols in the air, the source of their generation, their properties and effects can be discovered by monitoring them.
Aerosol properties are typically acquired in 2 distinct ways with different techniques (figure 11):

-In situ measurements,

-Column integrated optical depth measurement.

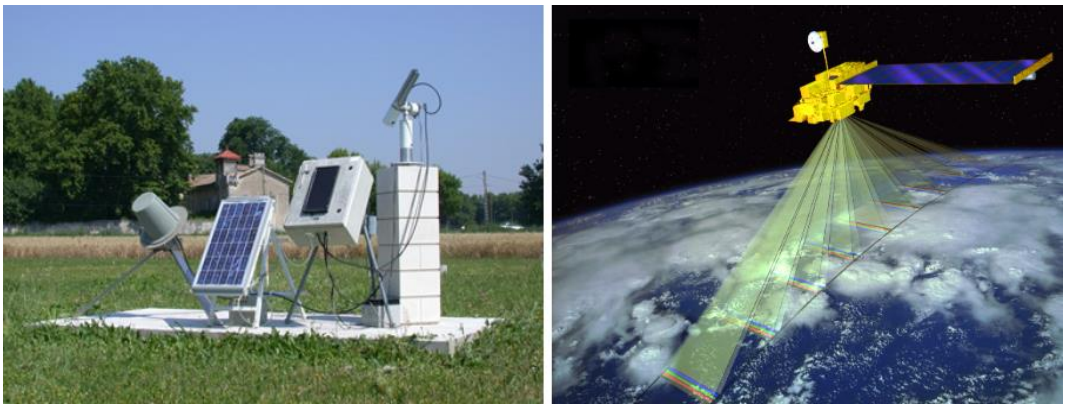

FIGURE 11: TYPES OF ACQUISITION

Aerosols optical depth (AOD) is a column integrated optical depth measurement of aerosols. To perform the measure of the aerosol optical depth, there are several ground-based networks working in concert with satellite-based sensors

Ground-based instruments

The ground-based measurements were taken with well calibrated multichannel filter instruments. These types of measurements require very accurate instrument and detailed calibration to guarantee high quality data compulsory to validate of satellite data. Several kinds of instruments are used for such purposes and they include, spectroradiometers, multichannel radiometers, and broadband radiometers.

The most known ground-based AOD retrieval systems are sun-photometry and lidar.

The first one is a passive optical system that is able to measure the extinction of direct-beam radiation in distinct wavelengths and retrieves the aerosol contribution to the total extinction. Ground-based sun-photometry radiometer uses the down-welling radiances of solar radiation to recover total columnar AOD in a specific area (image 12).

The second one is an active optical system which transmits light into the atmosphere and then collects the backscatter light signals to retrieve the aerosol attenuation in total columnar atmosphere (image 13).

FIGURE 12 AND 13: SUN-PHOTOMETER [AIR DISTRICT] AND LIDAR

Satellite Remote Sensing

There are many satellite instruments into space, (image 14), sent by different space agencies, for instance NASA, ESA, the Japanese Aerospace Exploration Agency, KNMI, and many others.

Remote sensing data are very important in the oceanography, but above all, they are crucial in atmospheric studies (like in our case) since their elevated spatial and temporal resolution.

Satellites are equipped with exclusive sensors able to detect emitted, back scattered or reflected solar radiation in the visible region but also in infra-red part of the spectrum.

Satellite remote sensing gives us the opportunity to illustrate and articulate precisely, the pollution and its compounds such as dust, smoke, and volcanic events since atmospheric aerosols are well appropriate for satellite remote sensing (P. Kulkarni, 2011).

There are different types of algorithms which have been developed according to the different characteristics of satellite sensors. Satellite-based instruments designed for aerosols retrieval (Kokhanovsky, et al., 2007) are as follows:

- "Moderate Resolution Imaging Spectro-radiometer (MODIS)"
- "Multi-angle Imaging Spectro-Radiometer (MISR)"
- "Polarization and Directionality of the Earth's Reflectance (POLDER)"
- "Polarization and Anisotropy of Reflectance for Atmospheric Sciences Coupled with Observations from LIDAR (PARASOL)"
- "Advanced Very High Resolution Radiometer (AVHRR)"
- "Along Track Scanning Radiometer (ATSR)"
- "Advanced Along Track Scanning Radiometer (AATSR)"
- Satellite remote sensing allows us to carefully illustrate the scattering of single atmospheric aerosol compound such sea salt, smoke, dust and organic/inorganic compounds, since they lend themselves well for satellite remote sensing. (P. Kulkarni, 2011).

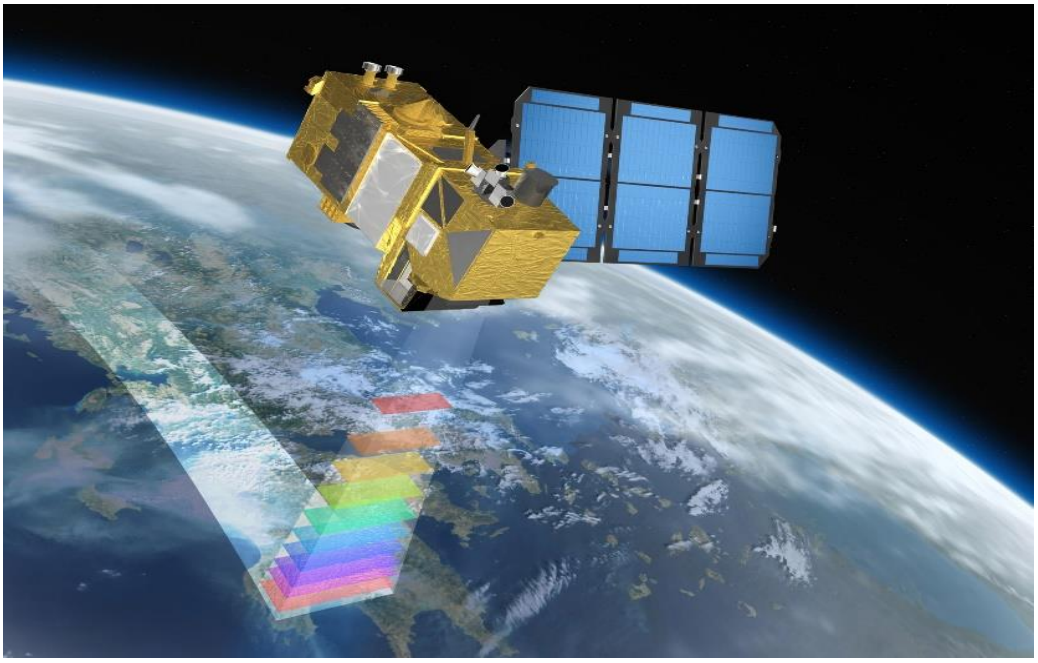

FIGURE 14: SATELLITE REMOTE SENSING

The current satellites orbiting the Earth are either in geostationary or polar orbits, so it means they orbit around the earth in the equatorial plane approximatively 36 kilometres far from surface.

It is possible to monitoring of dynamic meteorological phenomena because the rotation's velocity of the satellite is the same of the Heart. In this way they can supervise events such as major dust clouds, volcanic eruptions, smoke plumes or regional pollution events as they evolve throughout the day.
AOD retrievals from MODIS sensors show higher time-aggregated values respect to MERRA-2 reanalysis. This is probably due to the fact that MERRA-2 uses additional sources of data in its aerosol data assimilation system. (MISR, AERONET) (Rizza, et al., 2019).

2. AIM OF THE THESIS

The aim of this thesis is to perform an analysis of the scattering, and it is variation over time, of chemical compounds which make up the atmospheric aerosol, through AOD measurements, before and during the period of Lockdown.

This analysis is further finalized to investigate possible correlations, to assume potential interrelationship and to establish, whereas possible, cause and effect relations, between AOD levels variations and anthropogenic activities.

This analysis is further finalized to investigate and assuming possible correlations, with major events occurred in the same period of our study and then, whereas possible, to establish cause and effect relations with AOD variations levels.

We need a focus about the variations of AOD measures, which can be traced back to special measures, and limitations due to lockdown, which have de facto completely interrupted almost the whole industrial production and any other sort of anthropic process.

2.1. Assumptions

We expect to encounter valuable variations in term of compounds scattering, between the three periods that we have taken into account:

- 1-31 of January normal period without any limitation,
- 1-29 of February with some restrictions up to 23/02,
- 1-31 of March full lockdown period.

Moreover starting from the data provided by ground control units, (in our case supplied by ARPA) we incorporated also reports of not ordinary natural events as fires, eruptions, sandstorms, occurred in a certain period.
Then we focused our attention on few specific days of March (28-29/03), since uncommon concentrations of particles were registered through ground base instruments.

2. MATERIALS AND METHODS

3.1. Materials

3.1.1. Field of study

The present study has been performed on a particular region which includes parts of Europe and Asia Minor (image 15a). More specifically, the investigated area covers the following regions: central-southern Europe, east Europe, Balkans, Caspian Sea, Black Sea and a small portion of middle east. (image 15a).

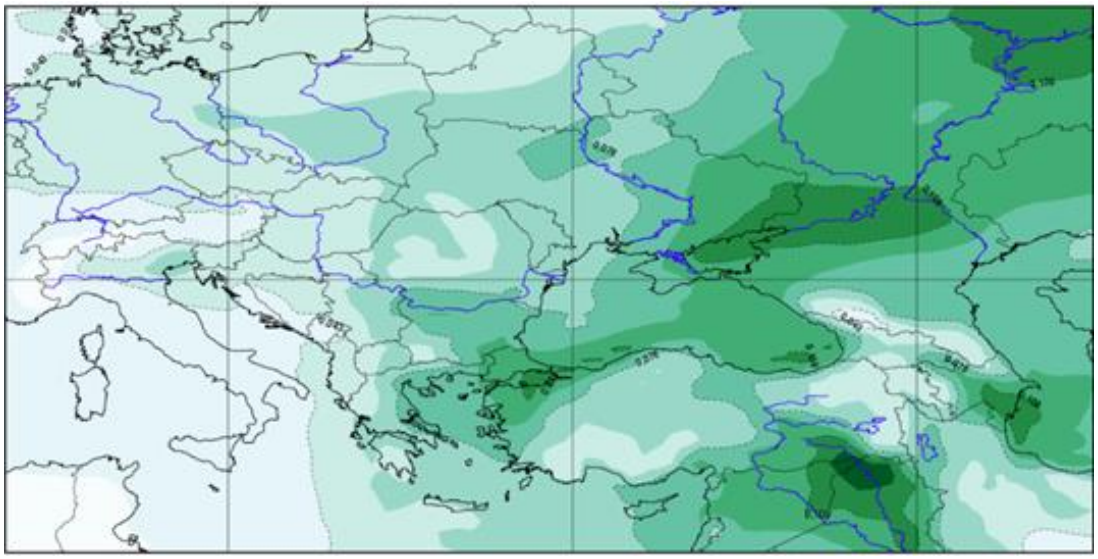

FIGURE 15(A): FIELD OF STUDY OF THE RESEARCH

Furthermore, our research has focused in particular on the northern part of Italy, where, one of the highest rates of air pollution, are registered in the Europe.
The area concerned, known as Padan plain, it is a densely populated and intensively industrialized area, and experiences the highest AOD value in Europe (Rizza, et al., 2019).

The Po Valley is very unhappily situated for atmospheric pollution in terms of climate and geography. The wind is weak and uncommon and there are many and extended events of climatic inversion. It means that the air is colder in the plains compared to the mountains.

On a European scale, the air pollution levels that registers over the Padan plain (image 15b), is assimilable only to southern Poland, where there are many coal factories and frightening sources of pollution.

FIGURE 15(B): PADAN PLAIN

1.1.2 Period of the study

We have examined composite AODs scattering covering a period of three months from 01 January until 31 March.

Further we assess the values of each single period (January-February-March) comparing the recorded values of each different phase, to figure out and highlight the variations.

The choice of the period to be examined is not random, rather is based on a valid assumption that we are going to demonstrate. There could be a great evidence between values of dispersion gathered during the lockdown and values collected before, as consequence of cessation of mostly of human activities.

It should be noted that for a detailed analysis and quantification of the impact of COVID-19 over this region, other details should be taken into consideration in addition to columnar AOD data.

Climatological and meteorological factors are necessary, as well as the effect of the extensive biomass burning in this season, that are independent from the restriction measures and the general lockdown.

In the present study, in order to achieve information about the AOD for the examined area, several different data sets have been used, provided by different organizations.

It is important to say that almost the totality of the AOD observations, assimilated in MERRA-2, belong to Moderate Resolution Imaging Spectroradiometer (MODIS), sensors on-board the Terra and Aqua satellites, which provide data.

3.1.3 Reanalyses

Reanalyses bring together model fields with observations distributed irregularly in space and time into a spatially complete gridded meteorological dataset, with a constant model and analysis system that cover the historical data record. The earlier generations of reanalyses from the National Oceanic and Atmospheric Administration/ National Centers for Environmental Prediction (NOAA/ NCEP), the European Centre for Medium-Range Weather Forecasts (ECMWF), and the Japan Meteorological Agency (JMA) have proven to be extremely valuable scientific tools, enabling climate and weather research not otherwise possible.

They continue to be used, even with their known limitations, because of the basic utility afforded by such datasets for scientific analysis.

3.1.4 Satellite Aerosol data

Two AOD data which have been used in this study from both data sets, originated from the MODIS sensor flying onboard the satellite Aqua (Figure 16).

Aqua was launched in 2002 as one of the Earth observing satellites and is a member A-train, the group of six Earth observation satellites that fly in formation (Figure 18).

Aqua is currently flying in a low Earth orbit, with an altitude of 705 km. The inclination of the orbit is 98 degrees which makes the satellite to orbit close to the north and south polar allowing a global coverage (NASA, 2014a).

Due to this characteristics, the angle formed with the sun is the same angle formed with each location every time the satellite passes over it. It is advantageous for remote sensing where the solar radiation is used for data retrieval (NASA, 2014a).

FIGURE 16: AQUA SATELLITE

Terra satellite's orbit around the earth is adjusted in such a way that it passes from north to south across the equator in the morning time, while Aqua passes south to north over the equator in the afternoon (image 17). The satellites are viewing the entire earth's surface every 1 to 2 days. They acquired the data in 36 spectral bands or groups of wavelengths.

These information help in the comprehension of worldwide progression and process happening in the area, in the seas, and in the lower atmosphere.
MODIS is conveying a significant role in the building of validated, global, interactive Earth system models which can predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of the environment.

On polar satellites different types of sensors are mounted and they provide a wide footage of AOD at multiple spectral wavelengths that cover the Earth in great measure.

However, satellite-derived AOD have few weaknesses. They only provide low temporal resolution and relatively low pixel resolution, moreover in presence of clouds in the atmosphere, data won't be available (Gueymard, C.A mentioned by Midyan Aldabash).

The AOD images are available as gridded reanalysis as well, like modern-era retrospective analysis for research and application (MERRA-2). Here satellite and ground-based measurements of AOD have been assimilated into Earth system modelling.

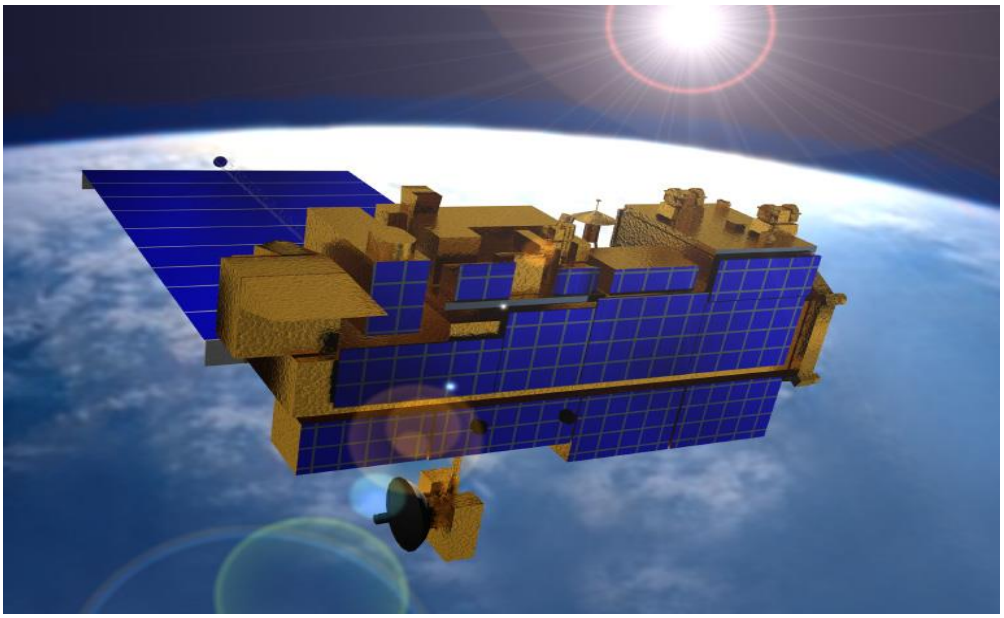

FIGURE 17: TERRA SATELLITE

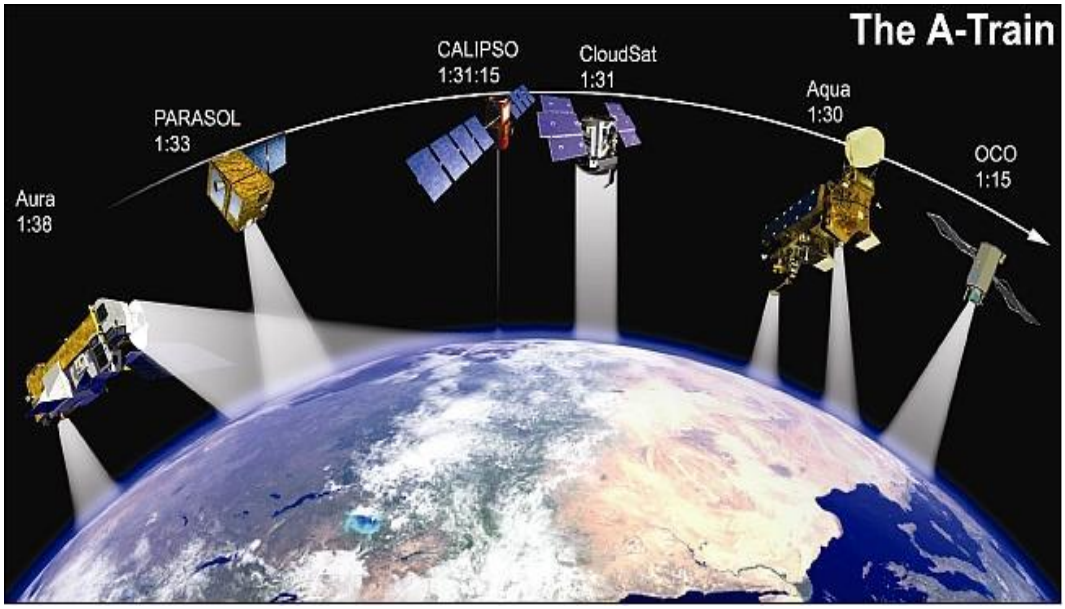

FIGURE 18: A-TRAIN, THE CONSTELLATION OF SATELLITES

Modis

MODIS (Moderate Resolution Imaging Spectro-radiometer) is an extensive program using special sensors mounted on two satellites namely Terra and Aqua, which provide complete daily coverage of the earth.

MODIS is an across track scanner (also called whisk broom scanner), which is a type of scanner used for passive satellite remote sensing. The scanner consists of a rotating mirror that reflects light from below to a receiving detector. The mirror rotates in such a way that the scan direction is across the satellites flight direction. A simplified model of the scanning principle of an across track scanner can be seen in picture 19.

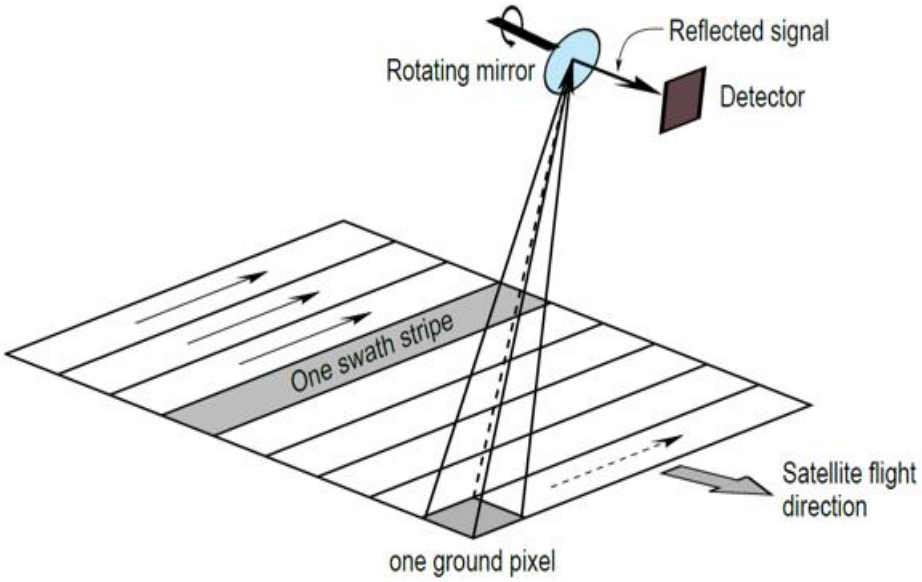

FIGURE 19: THE SCANNING PRINCIPLE OF AN ACROSS TRACK SCANNER.

For each revolution of the mirror a stripe extending 10 km (at nadir) along the satellite flight direction and 2330 km across the satellite track is scanned.
With such a large swath width, the MODIS instrument can deliver a near global coverage in less than two days (NASA, 2014).
The data have a variety of resolutions: spectral, spatial and temporal. MODIS products are available at different processing levels which are categorised as level 1, 2, 3:

- Level 1 is geolocated and calibrated brightness temperatures and radiances.
- Level 2 is derived geophysical data products.
- Level 3 is gridded time average products.

MODIS, (image 20), plays a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment (Nasa).

The MODIS instrument provides high radiometric sensitivity (12 bit) in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm. The responses are custom tailored to the individual needs of the user community and provide exceptionally low out-of-band response. Two bands are imaged at a nominal resolution of 250 m at nadir, with five bands at 500 m, and the remaining 29 bands at 1 km. A ±55-degree scanning pattern at the EOS

orbit of 705 km achieves a 2,330-km swath and provides global coverage every one to two days.

The Scan Mirror Assembly uses a continuously rotating double-sided scan mirror to scan ±55-degrees and is driven by a motor encoder built to operate at 100 percent duty cycle throughout the 6-year instrument design life. The optical system consists of a two-mirror off-axis afocal telescope, which directs energy to four refractive objective assemblies; one for each of the VIS, NIR, SWIR/MWIR and LWIR spectral regions to cover a total spectral range of 0.4 to 14.4 µm.

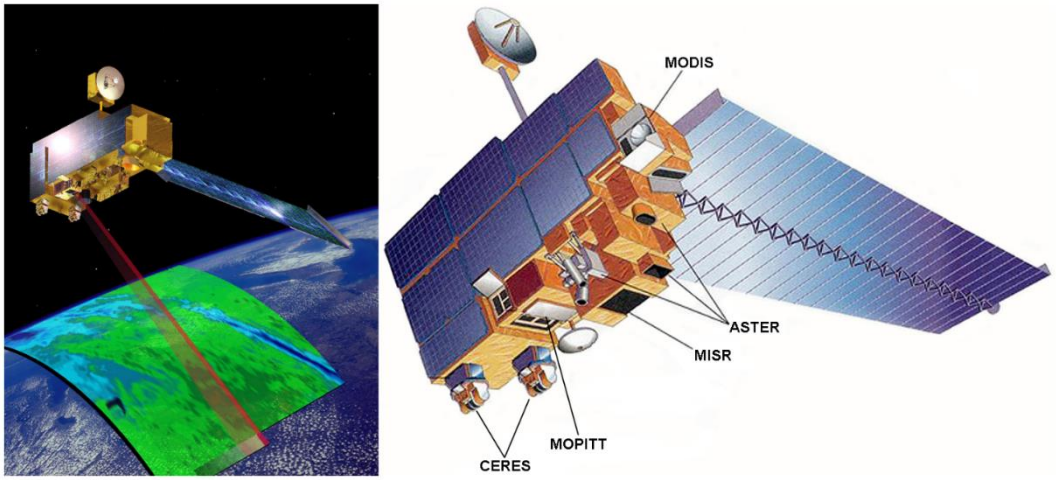

FIGURE 20: TERRA SATELLITE WITH MODIS SENSOR AND OTHER SPECIFICATIONS (NASA)

Merra-2

The Modern-Era Retrospective Analysis for Research and Application (MERRA) was stimulated by the recognition that various aspects of the hydrologic cycle, represented in previous generations of reanalyses, were not adequate for climate and weather studies.

MERRA proposed to improve upon the water cycle as a contribution to the science community and to reanalysis research.
The Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) provides data beginning in 1980 (scheme 21).

It was introduced to replace the original MERRA dataset because of the advances made in the assimilation system that enable assimilation of modern hyperspectral radiance and microwave observations, along with GPS-Radio Occultation datasets. It also uses NASA's Ozone profile observations that began in late 2004. Additional advances in both the GEOS model and the GSI assimilation system are included in MERRA-2. Spatial resolution remains about the same (about 50 km in the latitudinal direction) as in MERRA.

Natural and anthropogenic aerosols are simulated in MERRA-2, considering the Goddard chemistry, aerosol, radiation, and transport model.
This model simulates the sources, sinks, and chemistry of mixed aerosol tracers: dust, sea salt, hydrophobic and hydrophilic black carbon and organic carbon, and sulphate.
This may be considered particularly helpful for the evaluation of urban air pollution at a regional/global level, since different cities may have the tendency to exhibit a mixed aerosol composition.

MERRA-2 aerosol reanalysis, thanks to the capability to make a differentiation of aerosol speciation, is an advanced and effective tool. Through the use of MERRA-2 we are able to estimate the AOD of individual aerosol species with a global coverage.
It can be considered particularly helpful to evaluate the urban air pollution at a regional/global scale, since many of these areas, may display a mixed aerosol composition. (Rizza, et al., 2019).

Feature	Description
Model	GEOS-5 Earth Modeling System with GOCART aerosols coupled to radiation parameterization
Fire Emissions	RETRO, GFED, and QFED: Daily, NRT, MODIS FRP based
Met. Data	MERRA-2 (run simultaneously with met. reanalysis)
Aerosol Observing System	MODIS: Aqua & Terra Neural Net Retrievals (NNR) of 550 nm AOD, AERONET, MISR (surface albedo > 0.15), AVHRR.
Resolution	~50 km (0.5° × 0.625° latitude × longitude), 72 layers, top ~85 km
Aerosol Species	Dust (DU), sea-salt (SS), sulfates (SO_4), organic and black carbon

FIGURE 21: SYSTEMS CHARACTERISTICS SCHEME

Panoply Data Viewer

Panoply is a cross-platform application which plots geo-gridded arrays from net CDF, HDF and GRIB datasets.

It supports the following operations:

- Slice and plot specific latitude-longitude, latitude-vertical, longitude-vertical, or time-latitude arrays from larger multidimensional variables.
- Combine two arrays in one plot by differencing, summing or averaging.
- Plot lon-lat data on a global or regional map (using any of over 75 map projections) or make a zonal average line plot.
- Overlay continent outlines or masks on lon-lat plots.
- Use any ACT, CPT, GGR, or PAL colour table for scale colour bar.
- Save plots to disk GIF, JPEG, PNG or TIFF bitmap images or as PDF or PostScript graphics files.
- Export lon-lat map plots in KMZ format.
- Export animations as AVI or MOV video or as a collection of individual frame images.
- Explore remote THREDDS and OpenDAP catalogue and open datasets served there.

To be plotted by Panoply, dataset variables must be tagged with metadata information using a convention such as CF.

3.2. Methods

The monthly averaged AOD images and daily averaged AOD images have been acquired through the aid of Modern-Era Retrospective Analysis for Research and Applications.

We analysed the MERRA-2 reanalysis to evaluate the trend of urban air pollution by elaborating the AOD over a period of three months.

They were further plotted using Panoply. The first were used for analysing monthly AOD variation whereas the seconds for daily AOD variation.

The steps for monthly AOD variations were:

- Step 1: the desired plot of month averaged map was selected
- Step 2: The required area was selected by entering the longitude and latitude of the edges of our desired box as West, South, East, North or through the use of zoom plot in – zoom plot out
- Step 3: The scale has been arranged in order to be common to every map of each compound
- Step 5: The scaling and the thick format have been arranged in order to be functional with our values
- Step 4: The desired colour table was set to have a better visual feedback
- Step 5: The overlays have been modified getting a better definition
- Step 7: The selection of contour lines in order to have a direct view of the values thanks also to the labels.

Regarding to creation of daily averaged AOD images, firstly we selected the days we were interested in studying. (27-28-29 of March).

Secondly, we decided to create 3-4 plots for each day, dividing the day in regular fractions, in order to have a logical framework of the whole day (6:00 am, 12:00 am, 20:00 pm). At this point, we have replicated exactly the same steps used for the analysis of monthly AOD.

Later, once we plotted all the needed maps, we proceeded to studying them, examining their scattering levels and their peaks.
Eventually, once the maps have been sufficiently described and deeply analysed, we began to compare those related to same pollutant, but different periods.
Through this we release an assessment of the variation of dispersion trends, before and during the lockdown. This step has been crucial to figure the magnitude of the effects on the atmosphere, due to limitations, just processing the aerosol scattering variations.

4. ANALISYS AND DISCUSSION

In the following chapter the results of this thesis will be presented. The results are separated in two major parts.

In the first part are displayed the results of monthly AOD data while in the second part are presented the results obtained using daily AOD data.

In the first part will be processed the AOD data which refer to three different periods covering from 01 of January to 31 of March and related to the main chemical compounds present in the aerosol. In the second part will be treated average daily AOT data relating to the total aerosol extinction over a period of 2 days (28-29 of March).

The results are presented using scatter plots which show maps with different colours according to different level of concentrations. Below every map, the caption shows the range of values.

Further we compared the values of each different phase to reveal the variations in term of scattering from one period examined to another highlighting the relevant variations.

It should be noted that for a detailed analysis and quantification of the impact of COVID-19 over this region, climatological and meteorological factors should be taken into account. Moreover it is necessary to consider also the extensive biomass burning in this season, that are independent from the restriction measures and the general lockdown.

The first group of compounds on which we focused our attention are those compounds which have mainly anthropogenic sources, since they take a particular meaning and relevance for our research.

4.1 Analysis of total averaged Monthly AOD

The map, figure 22 shows the total averaged aerosol extinction over January.

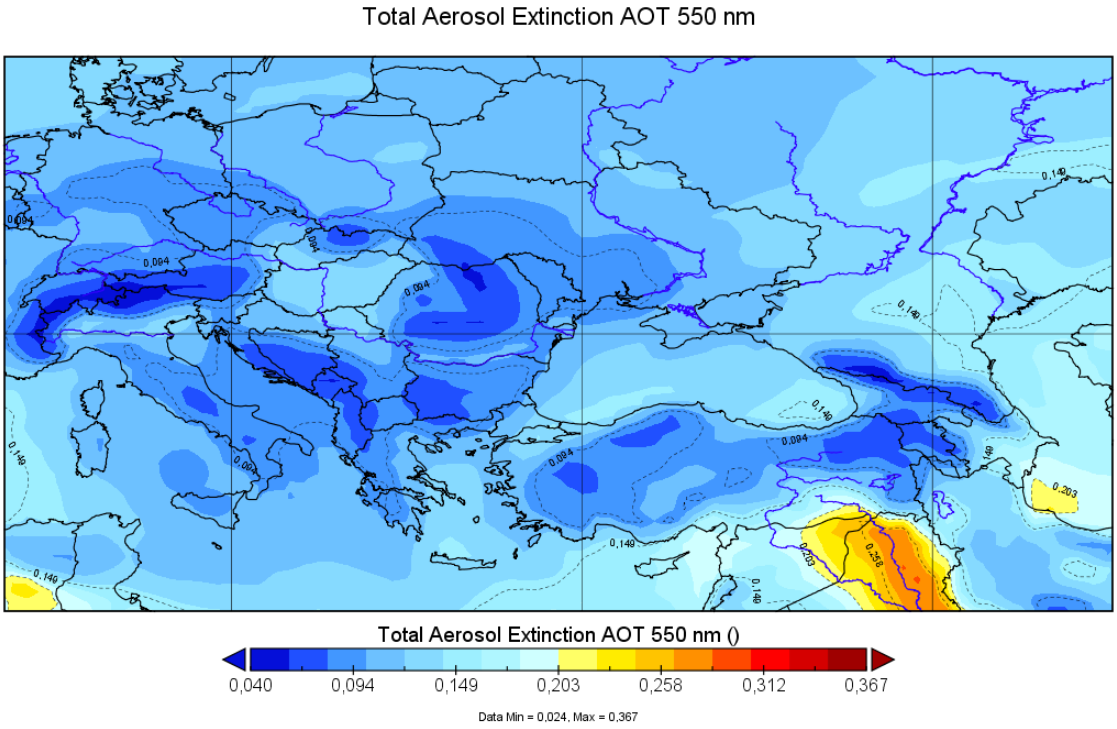

Figure 22: Total aerosol extinction, 01-31 of January

During this period we have encountered quite homogenous values over the whole Europe and on Mediterranean area, with values in the range of 0.06 and 0.160.

In some areas such as Alps, Balcans Romania and east part of Turkey, values are even lower than the avarage, around 0.040-0.050

On the other hand, In the Asia Minor, values are measurably higher between 0.203 and 0.258.

The map of figure 23 shows the situation related to February.

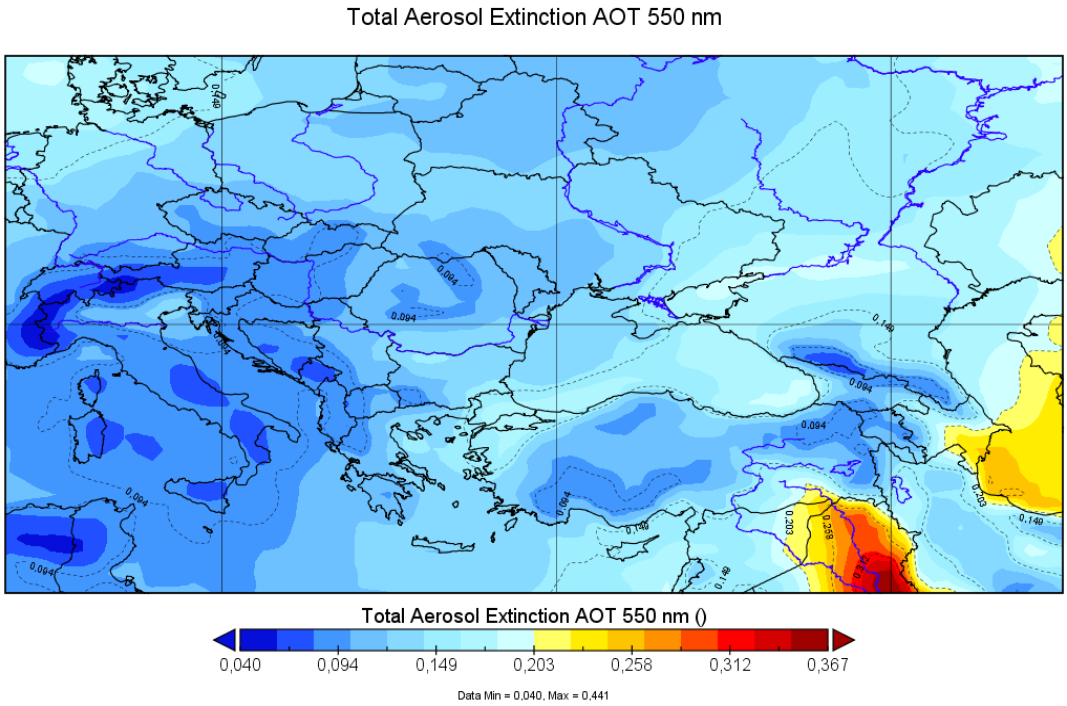

Figure 23: Total aerosol extinction, 01-29 of February

We have found a substantial reduction of levels in almost all the examined area, especially in the Centre-South Europe and over all the Mediterranean area, Italy and Northern Africa. The values oscillate between 0.060 up to 0.150, with some areas like Alps, southern Italy and North Africa which seems to benefit of good health with values below 0.050.

In the middle east, again, we register the highest values, around 0.203, with peaks from 0.250 up to 0.320. The Caspian Sea area is also interested showing values between 0.200 and 0.258.

So, we can say that from January to February, there is a downtrend of total aerosol extinction values that affect the whole centre-west Europe. Rather the trend remains constant, (around 0.150) in the northern-west Europe.

In March, on the contrary, values sharply increase in the whole Mediterranean area and Balkans reaching 0.250 with peaks up to 0.312 in some regions such as Romania, Bulgaria and Black sea. (figure 24)

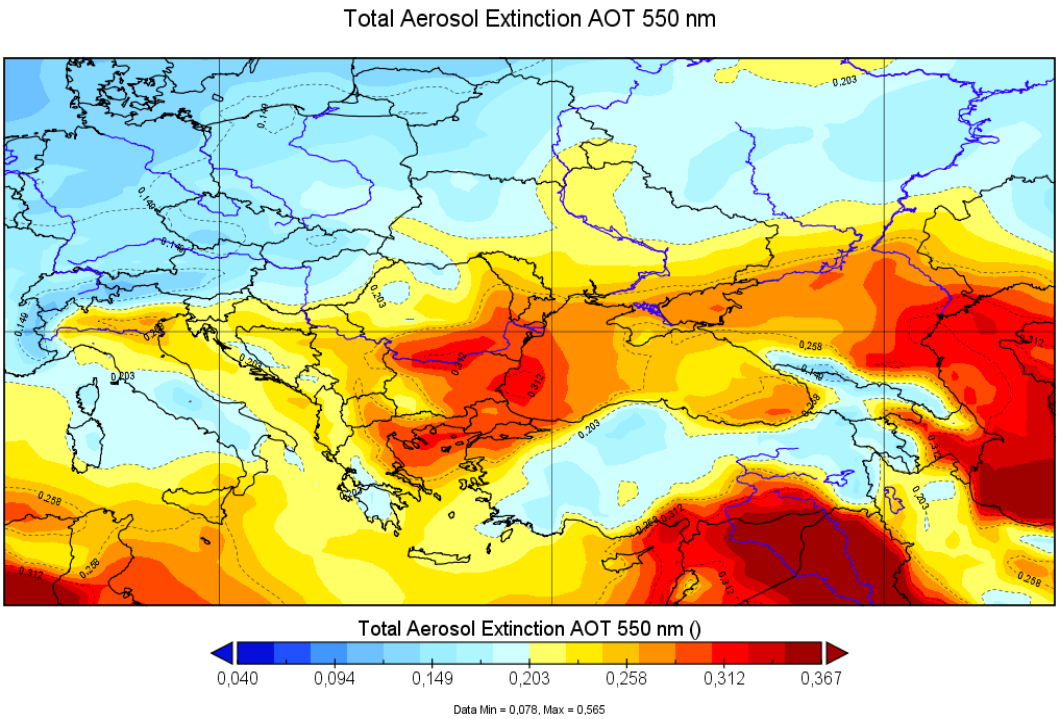

Figure 24: Total aerosol extinction, 01-31 of March

In the Northern Africa also, values remarkable increase, especially on the north-west, hitting 0.312

The Minor Asia is still the most hit zone, showing large values close to 0.350. The highest ones are recorded over the Caspian Sea, Syria and Jordan with peaks of 0.367.

Through the analysis the total aerosol extinction over this period, we can start making a general assessment about the variation of aerosol extinction during and before the lockdown.

We have seen that from January to February there were minor changes occurred. We have to take in mind that, except for Italy, almost all of the other European countries did not take any restrictive measures in February. Focusing now on March, the situation appears radically evolved, in fact satellites registered a huge increase of AOD values.

It is important to underline that this event does not concern all the map, but in particular the south-eastern part of Europe and the Middle Asia.

The total AOD analysis offers us a worthwhile instrument to have a general framework about AOD. On the other hand it does not provide any relevant detail about the chemical composition and which compounds are predominant. For this reason, we performed a deeper and a more specific investigation.

Black Carbon

Starting from the scattering analysis of Black carbon, (figure 24), in January we notice homogeneous situation in almost in all the area we are focused on. Unsurprisingly, as we have seen in the previous part, the highest values are detectable in the northern Italy (Padan plain) where levels are between 0.07-0.009 with peaks on Piemonte region and Lombardy region.

We have a similar situation in the areas of Poland and Hungary between 0.07 and 0.08. The middle east proves to be once again the most hit zone with values beyond 0.10.

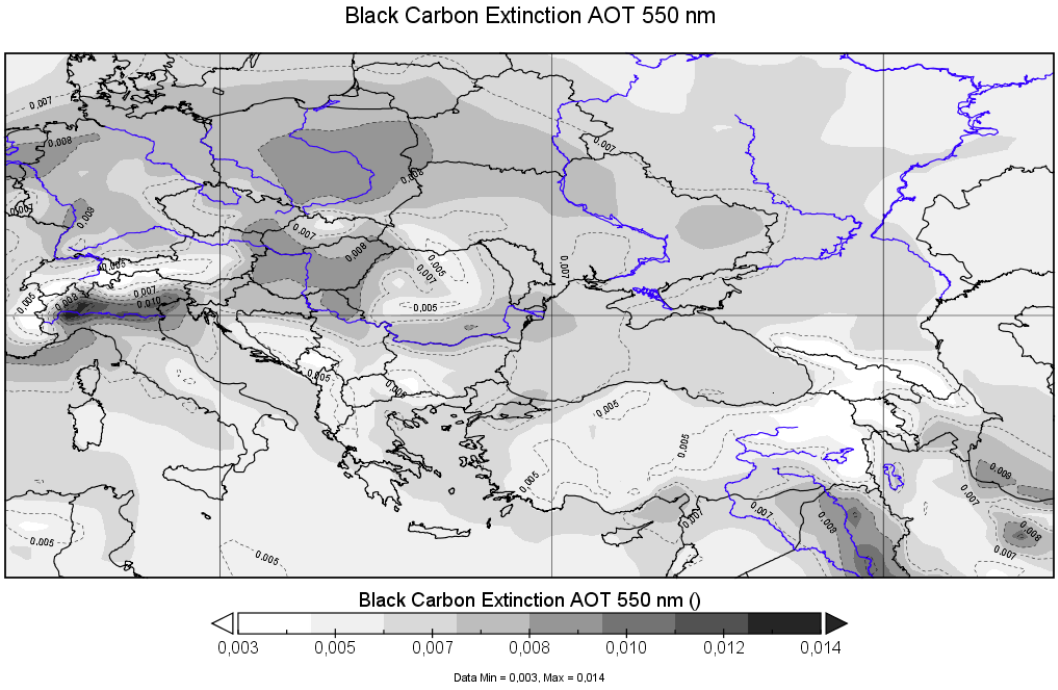

FIGURE 25: BLACK CARBON EXTINCTION, 01-31 OF JANUARY

From January to February we assist a reduction of the values especially for what concern the northern Italy ranching a range between (0.07-0.08) as it shown in figures figure 25-26

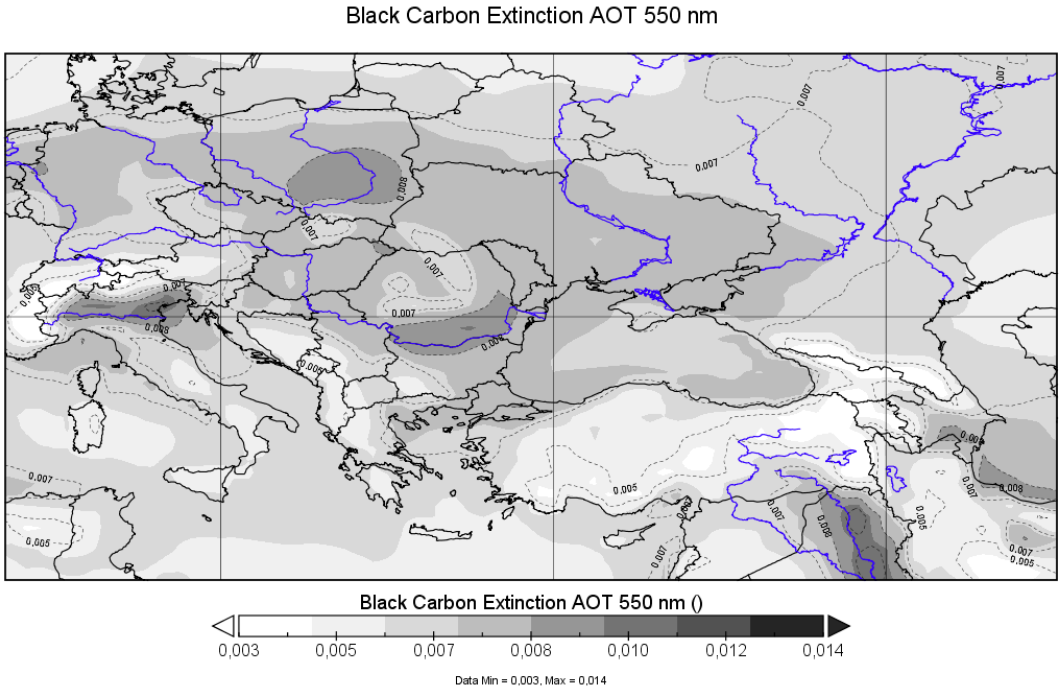

FIGURE 26: BLACK CARBON EXTINCTION, 01-29 OF FEBRUARY

In March there is an explosive increase of the scattering of black carbon. In fact, we register a peak of the concentrations in almost the entirely map. The most affected area is the south-east of Europe, and in particular the Caspian sea and Romania, (figure 27).

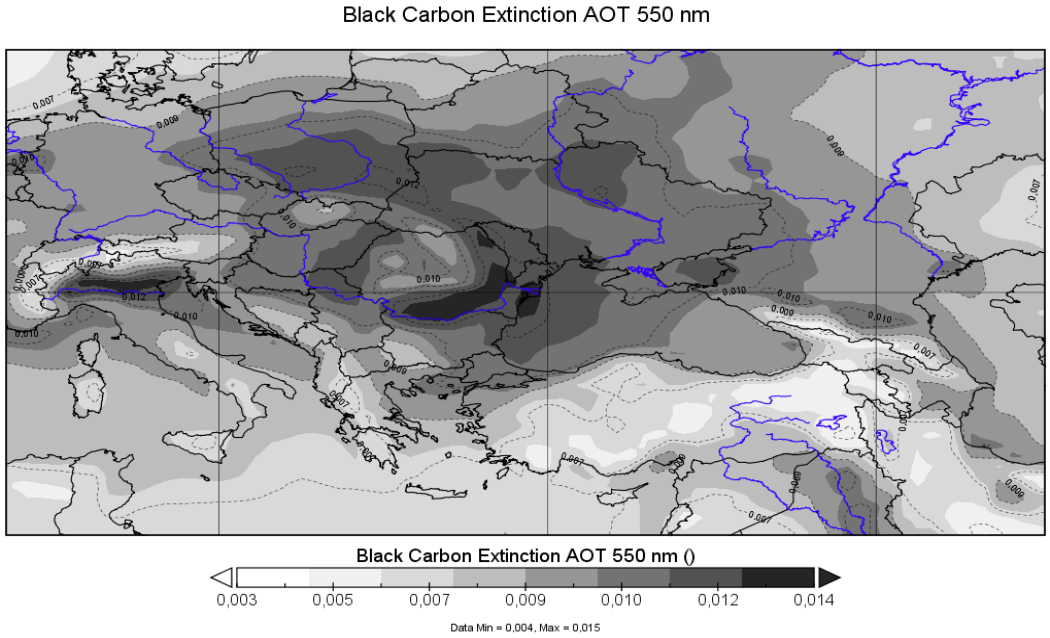

FIGURE 27: BLACK CARBON EXTINCTION, 01-31 OF MARCH

In Padan plain, we recorded again peaks of levels close to 0.014.

Oganic Carbon

Now we move toward the assessment of another Carbonaceous compound, Organic Carbon.

In January, in figure 28, the values are attested around 0.014 in almost the whole map, with the exception parts of east Europe, where we register higher values around 0.018 with occasional peaks of 0.024.

In the middle east we encounter higher values in especially over Syria, with peaks of 0.018.

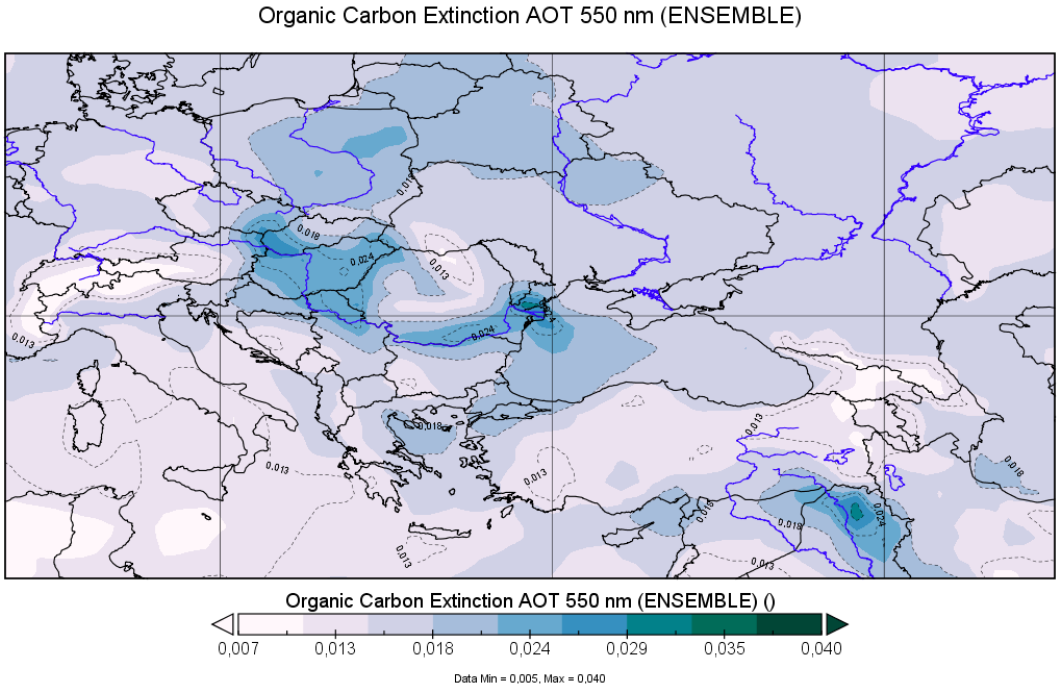

FIGURE 28: ORGANIC CARBON EXTINCTION, 01-31 OF JANUARY

In February, (shown below in figure 29) we notice small changes compared to January. Values are mostly similar in all the areas. The main differences consist in some reductions in Hungary and, more in general in the centre-easter Europe. At the same time, in Russia, we asses a light increase from 0.015 to 0.018.

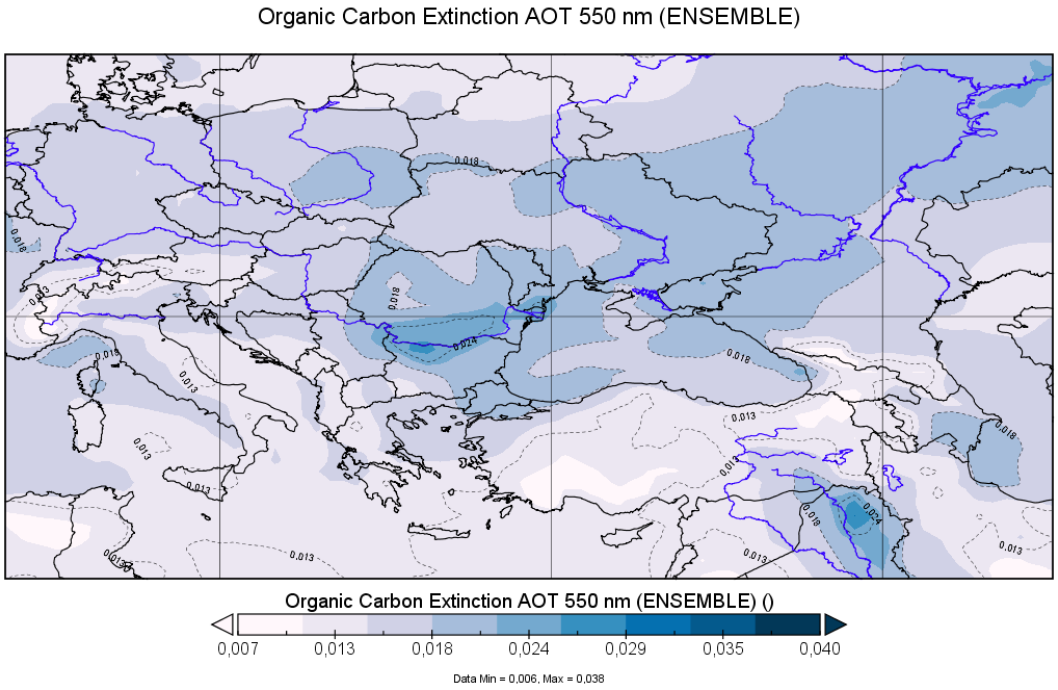

Figure 29: Organic Carbon Extinction, 01-29 of February

Moving from February to March (figure 30) we cannot fail to notice the enormous increase of organic carbon in the whole area with some regions particularly affected.

In the western part of Europe, primarily in the Mediterranean region, (Italy and Balkans), are the most affected with levels between 0.18-0.24.

Moving toward the east Europe, we notice a huge outbreak of pollution especially in Romania, Ukraine and Russia areas. There the values are assessed over 0.040, almost twice respect to February.

Black sea and Caspian Sea are also very hit fluctuating between 0.32 with peaks of 0.040.

This time, the middle east looks far better registering almost the lower values of the area, even lower than 0.020.

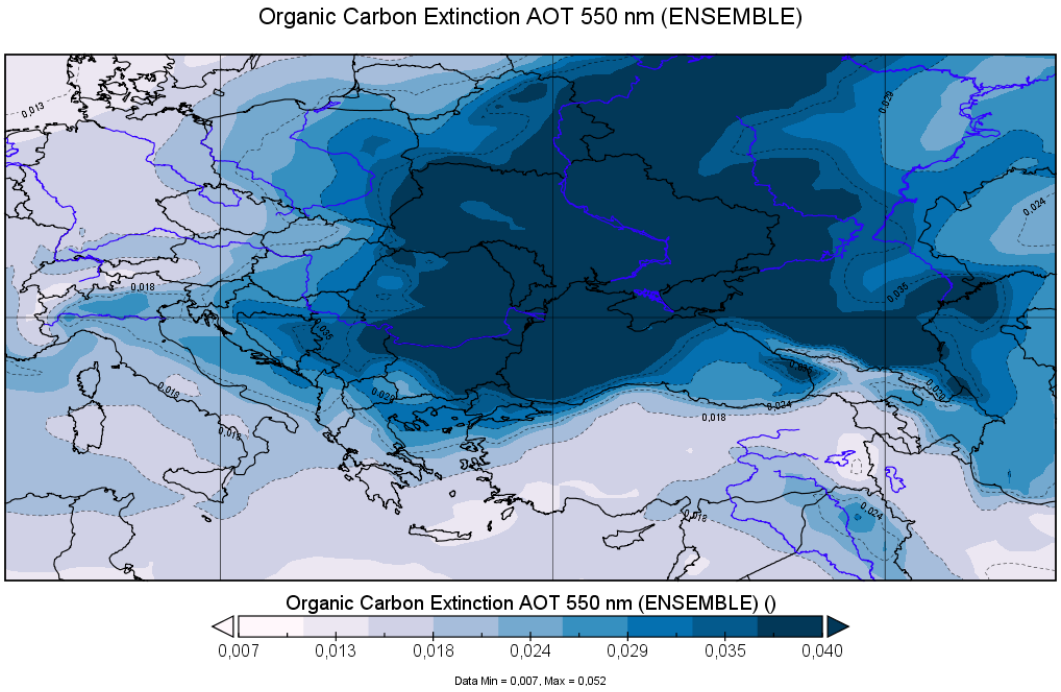

FIGURE 30: ORGANIC CARBON EXTINCTION, 01-31 OF MARCH

Sulphate

To corroborate and to reinforce the initial hypothesis of our study, which is to find a connection between AOD values and anthropogenic activities during lockdown, we go to ass also the AOD levels of SO_4.

In January we register high values especially in the east, while the centre west Europe proves to affected by low values around 0.041. Padan Plain, Croatia and Hungary register higher values in the range of 0.053.

In the eastern Europe and in Russia we register at most values between 0.60 and 0.80 with regions where values increase up to 0.105.

However, the region with the highest SO_4 extinction is the Middle East in particular Syria, where the oscillations goes between 0.093 and 0.117.

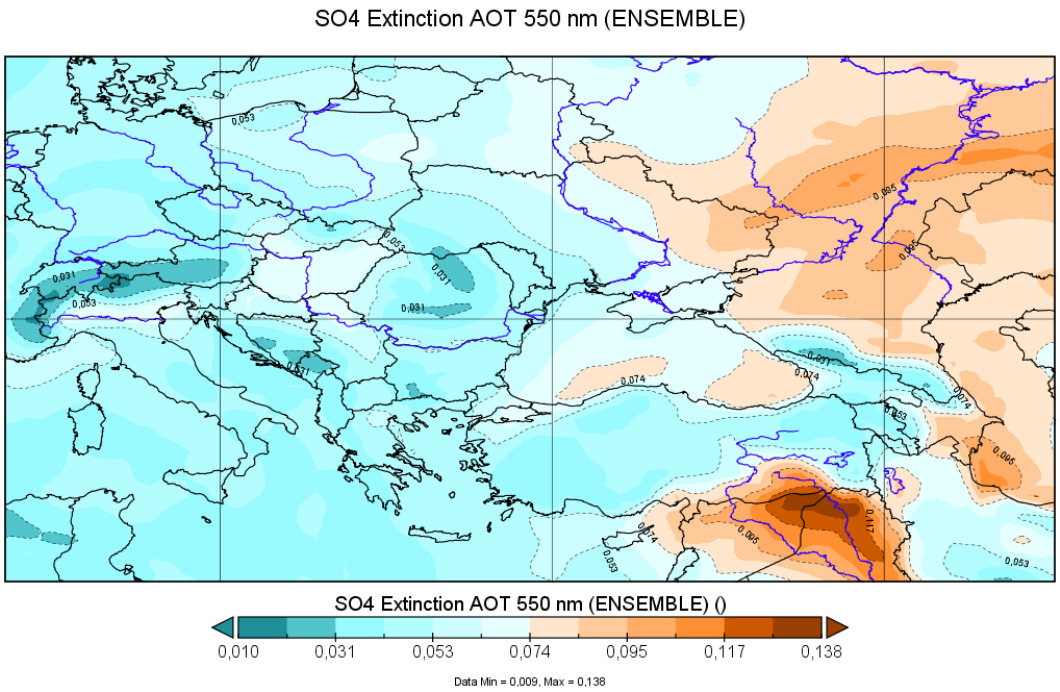

FIGURE 31: SO_4 EXTINCTION 01-31 OF MARCH

From January to February it occurs a reduction of values on the south-west part of Europe (especially Italy, Swiss and Austria) where values drop from 0.041 to 0.010.
There is also a decrease in Hungary and Croatia where levels go from 0.053 to 0.031.

An unaltered situation is observed in centre-north of Europe where almost nothing changed, while moving forward to East, there is an evident increase in Russian area with values around 0.08-0.095 with few peaks up to 0.117.

Stationary the condition of south east, while values increase in the Black Sea area, Greece and turkey where it reaches 0.117. Moreover, is registers a partial reduction in middle East (figure 31-32).

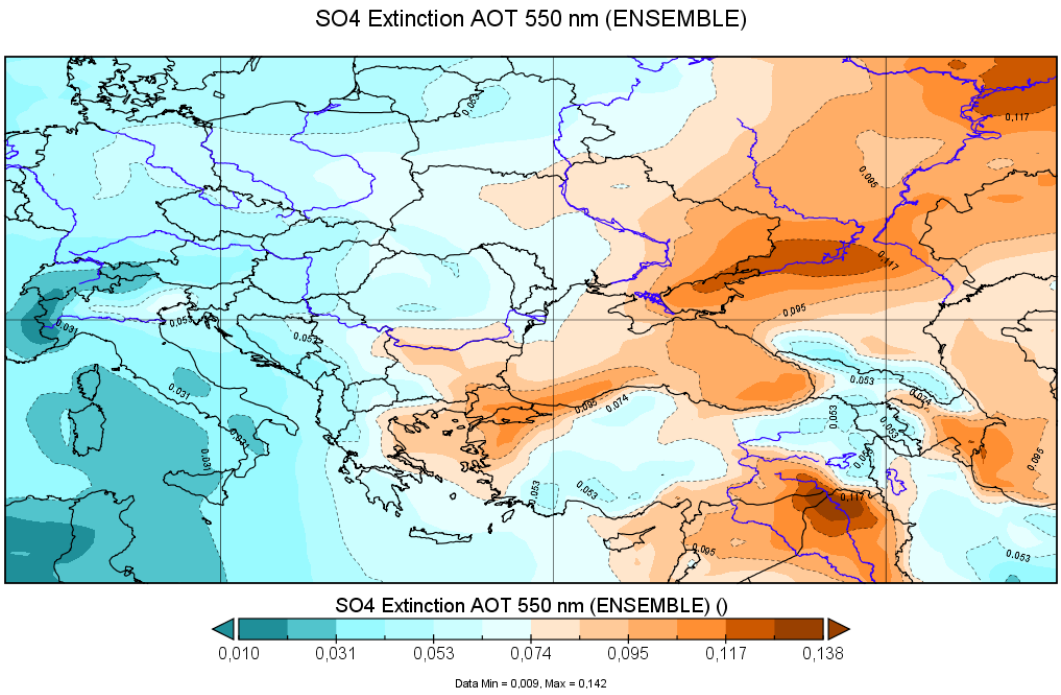

FIGURE 32: SO_4 EXTINCTION 01-28, OF FEBRUARY

From February to March (figure 32-33) we see a huge increase of values mainly in three distinct areas:

- Italy with average values of 0.095 with important peaks up to 0.138 in all the northern region of Padan Plain

- The second and largest area is the southern part of Balkans with involvement of Greece, Bulgaria and Black Sea. Here the level is in around 0.138. Surrounding regions are certainly interested even with lower values around 0.117-0.110.

- The third area is the Middle East where values are in the range of 0.130.

Examining the results belonging from the SO4 analysis, in March the results that we have obtained are consistent with the trend of Black carbon and Organic carbon. Moreover, even in this scenario, the main affected regions seem the same where peaks of BC and OC have been reported.

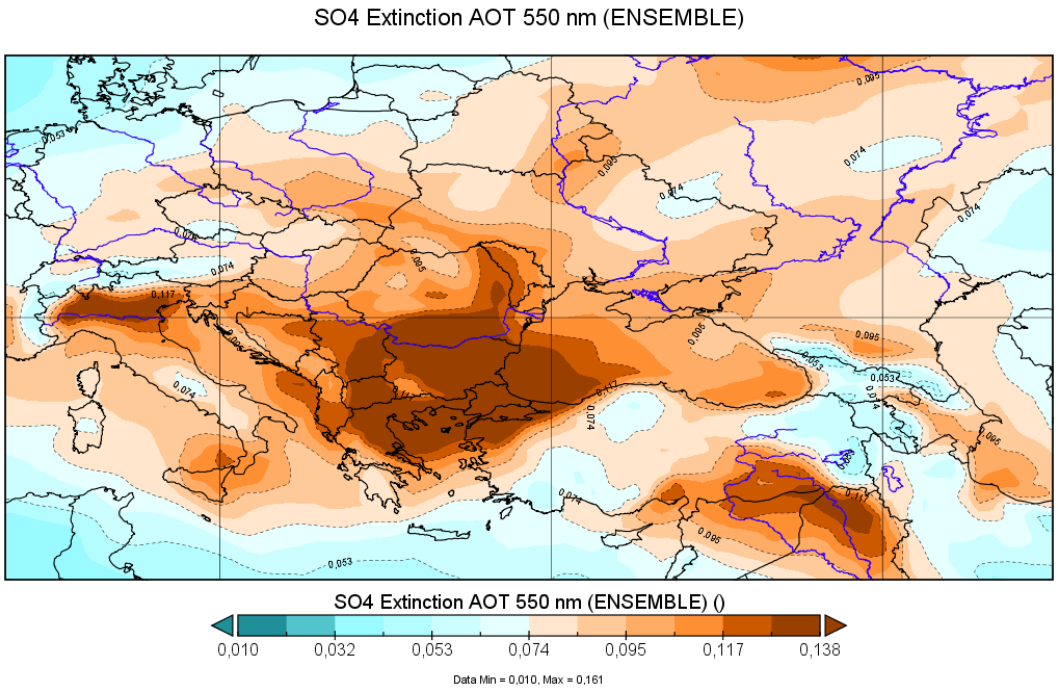

FIGURE 33: SO_4 EXTINCTION, 01-31 OF MARCH

Dust

On the contrary, as we saw from the literature, dust and sea salt have biogenic nature, since are generated almost entirely by wind's action. It means that no autotrophic actions are involved in the variation or alteration of these specific values in the atmosphere.

The AOD analysis of dust particles in January can be resumed quickly. All over Europe, values stay in the range of 0.012-0.040 and the situation appears to be fairly homogenous in the whole examined area, except for higher values detecteble in the middle east and over the Caspian sea. (figure 34).

In February we can asses a general small decrease of values all over the mapp with exception of middle east where they increase up to 0.166.On the caspian see also we witness an increase of dust extinction up to 0.063 (figure 35).

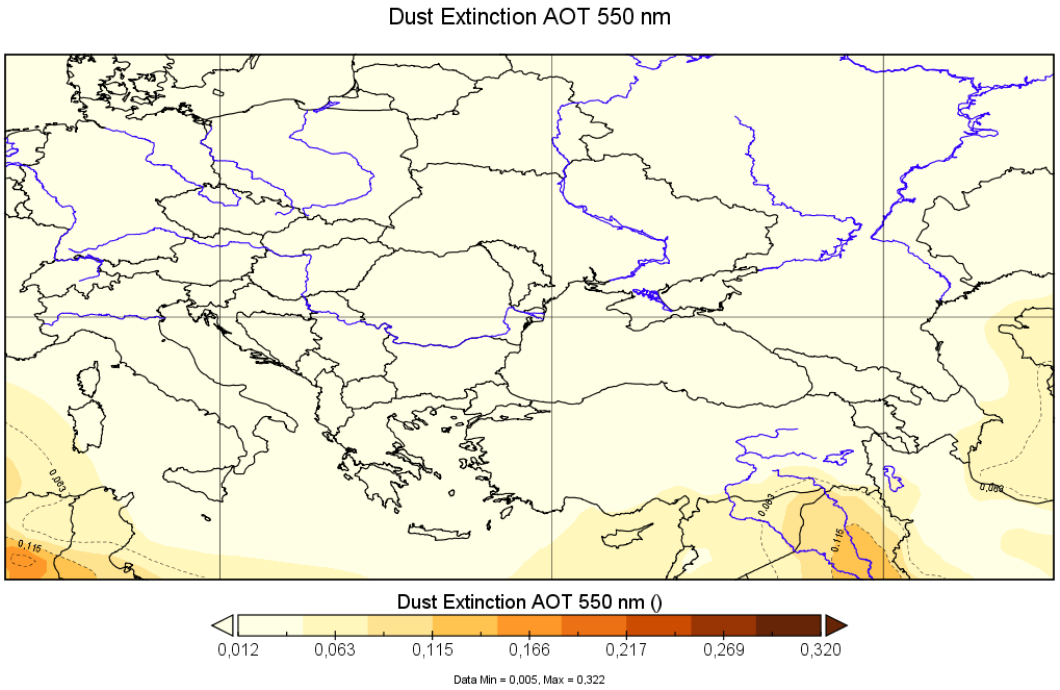

FIGURE 34: DUST EXCTINCTION, 01-31 OF JANUARY

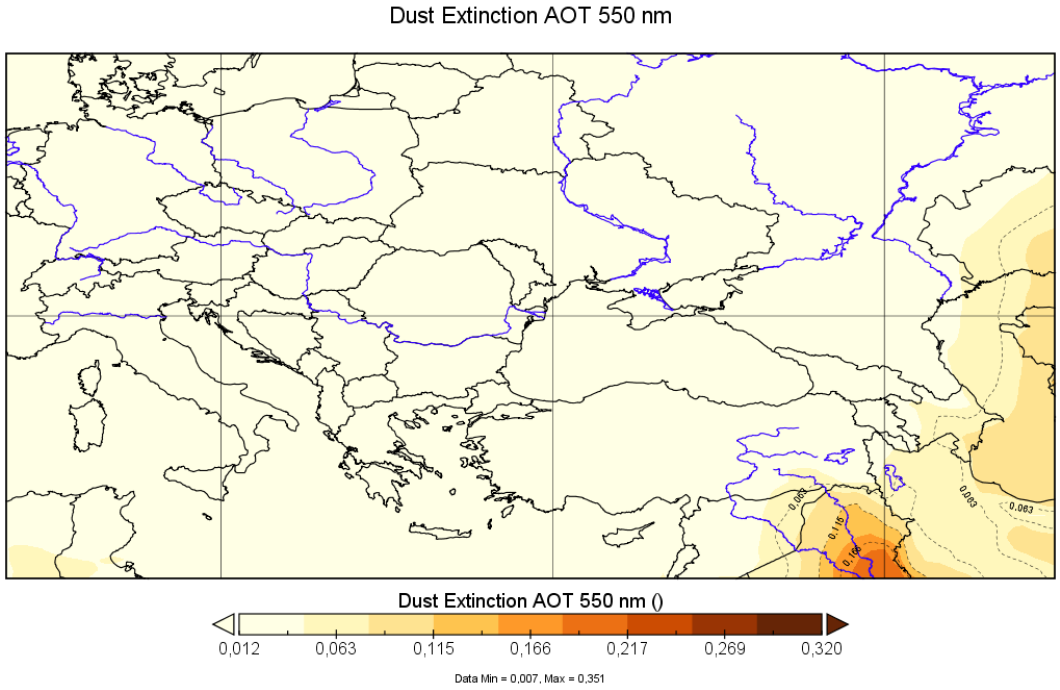

FIGURE 35: DUST EXTINCTION, 01-28 OF FEBRUARY

From february to March we observe an important increase of values especially in the southern part and into the Mediterranean area.

The most affected areas are with no doubts the northern Africa and the Caspian Sea where values are in the range of 217 reaching peaks of 320.

The surrounding area is clearly very affected, just like the Mediterranean area, especially Italy and Balkans where values here oscillate between 0.063-0.115.

The situation improves progressively getting closer to the central-northern part of Europe where the values are below 0.063 (figure 36).

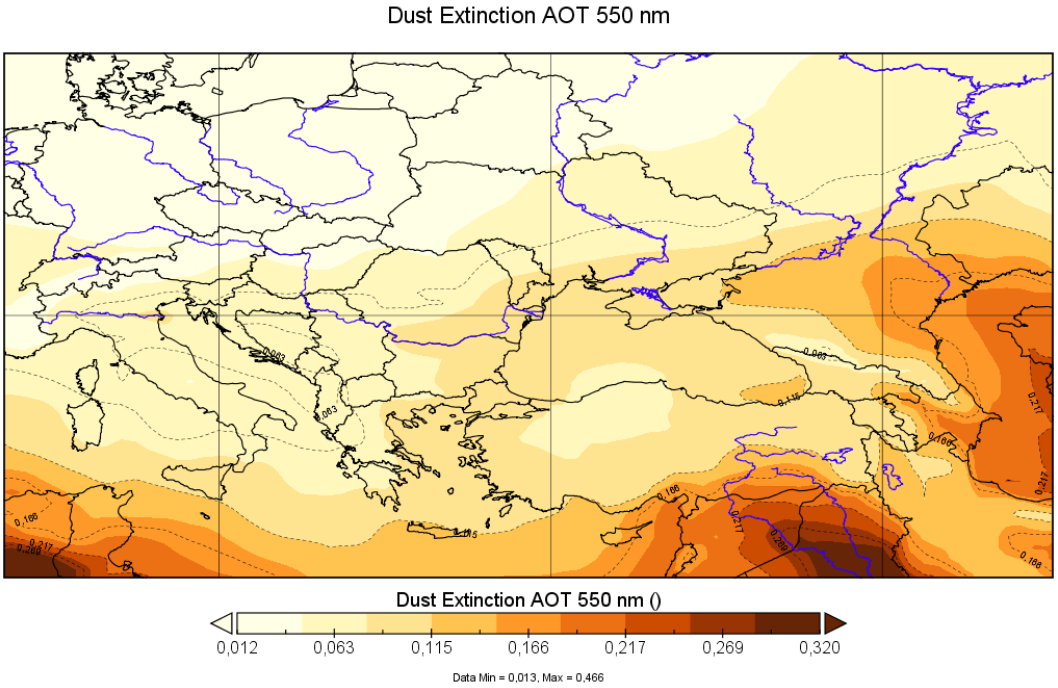

FIGURE 36: DUST EXTINCTION, 01-31 OF MARCH

Sea Salt

For what concern Sea salt extinction, in the whole continental Europe values are very low and at the same time extremely homogenous amounting to 0.001.

Higher levels of sea salt can be detected over the Mediterranean area and in the close proximity of Black sea, where values are higher of 0.021. In the northern part of the Europe, closing to the Northern sea, values grew till 0.61 (figure 37).

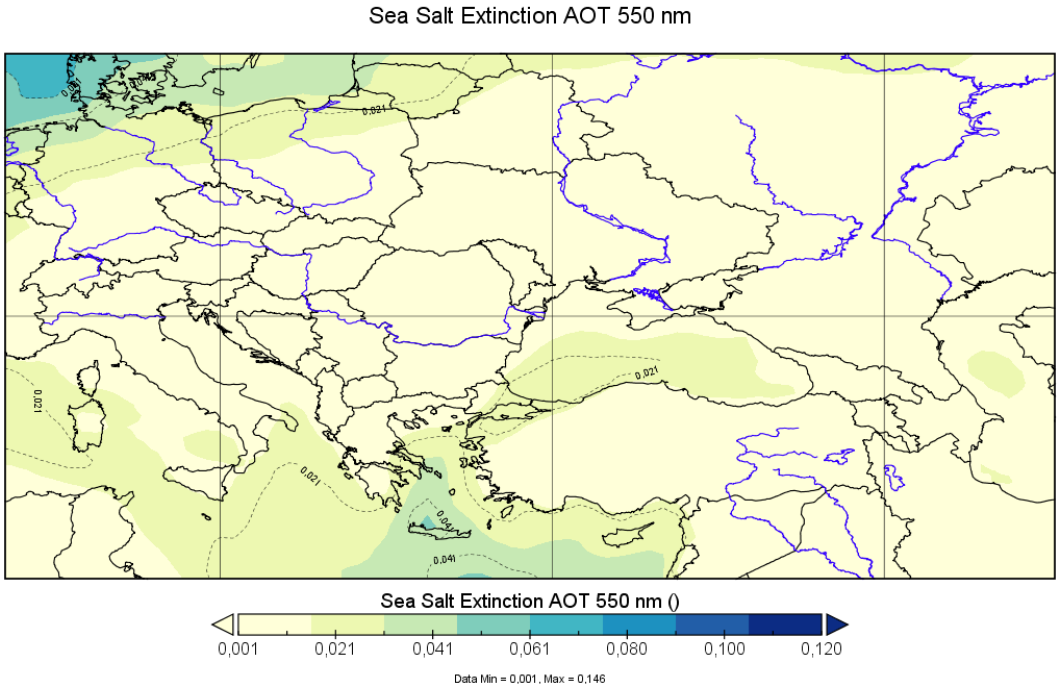

FIGURE 37: SEA SALT EXTINCTION, 01-31 OF JANUARY

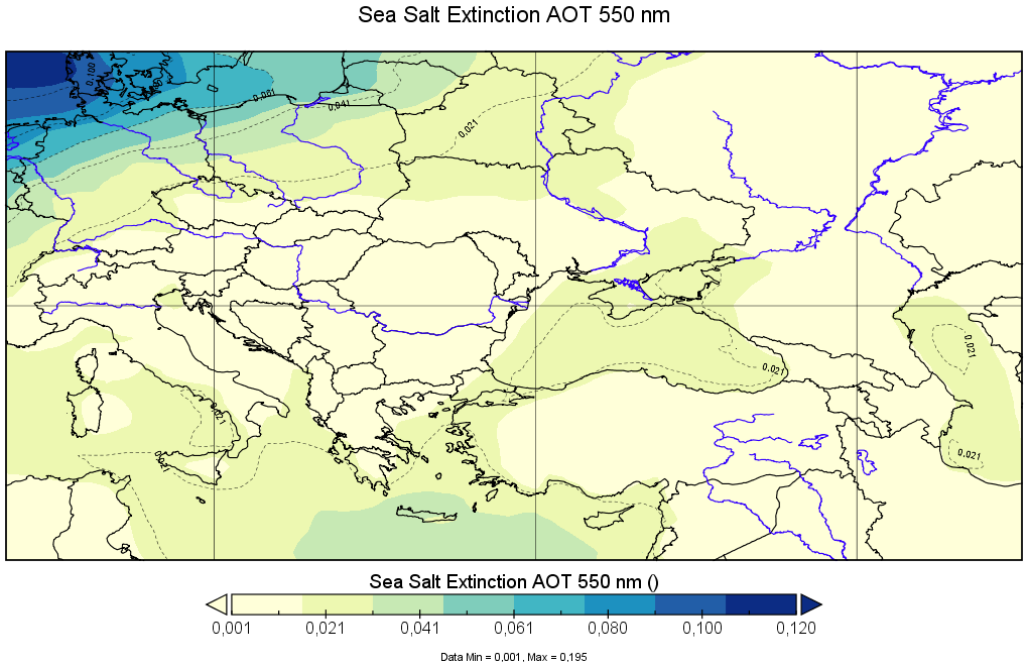

FIGURE 38: SEA SALT EXTINCTION, 01-28 OF FEBRUARY

In February (figure 38) values are almost constant over the Mediterranean area with a small increase in northern Africa reaching 0.05. On the other hand, we reach high levels on the northern Europe in the Northern sea regions, with peaks of 0.100-0.120.

In March (figure 39) values generally decrease everywhere except in the Mediterranean area and Caspian sea, where we assist at a small increment.

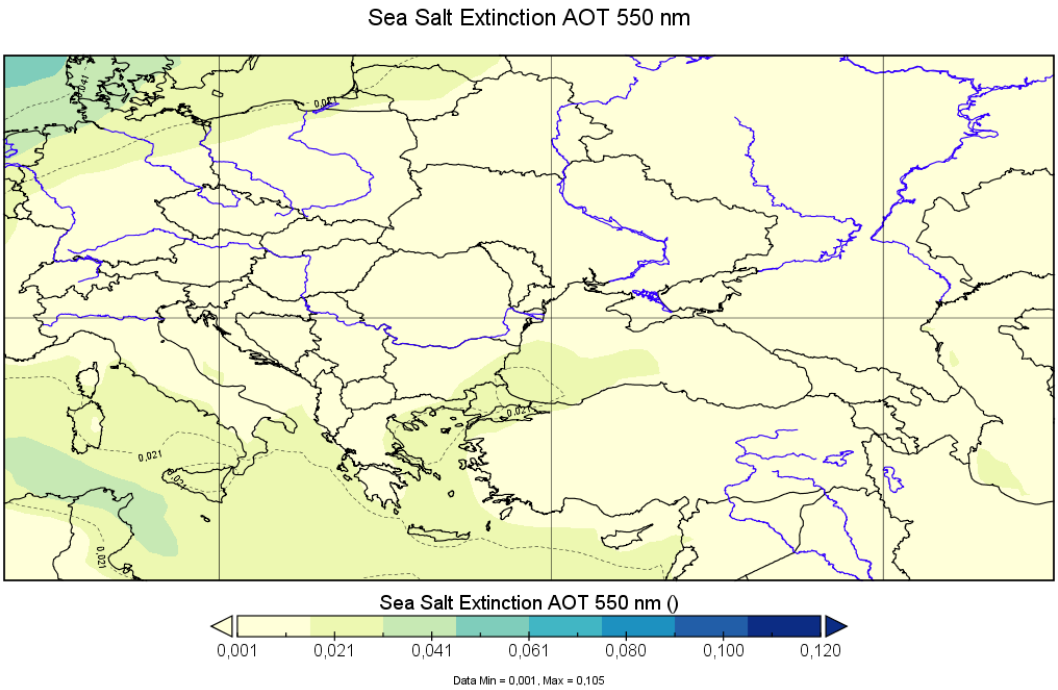

FIGURE 39: SEA SALT EXTINCTION, 01-31 OF MARCH

4.2. Discussions of total average AOD data

Taking stock overall about the obtained AOD measurements, we can do some summative statement. Great similarities have been found between the AOD scattering of black carbon, organic carbon and SO_4. For the three we are witnessing an explosive growth of levels in correspondence of the lockdown period. From literature we know that SO_4, BC and OC, are compound originated mainly by human sources.

So now, we take into account few fundamental assumptions:

1. these kinds of emissions are almost entirely produced by anthropogenic sources, except for major fires or volcanic eruptions and no one of these events has been register at this time.

2. Due to restrictive measures people were forced to stay home, so emissions linked to traffic and industrial production decreased drastically.

3. Eventually, according to meteorological data, in March the temperature remained low. This factor played a crucial role in this situation.

It is therefore reasonable to affirm that the huge increase in terms of BC, OC and SO_4 emissions, during the lockdown period, it is a direct consequence of the incomplete combustion to heat purpose. Moreover, it would be also interesting to understand why the most affected areas are always the same in all the three maps.
The answer can be identified in the structural backwardness and energy shortness which has always characterized these areas.
It is known how lack of appropriate energetic facilities and underdevelopment of energy distribution lead a massive use of combustion of low-quality solid fuels, in particular coal and wood with the consequences of a huge increase of heating emissions, especially domestic ones from chimneys which are substantial contributor to black carbon. Eventually the low efficiency of domestic heating it is only getting worst the situation.
So, we can assert that in all probability the residential heating emissions are the main responsible of rise in AOD values.

For what concern the high values of AOD related to the dust extinction, it is clear that there is no connection with restrictions related to lockdown.

It is reasonable to assume, given also the most affected areas, that the growth of dust extinction during March, might arise from the sand storm originated in deserts of middle east.

4.3. Analysis of total daily AOD data

Following the analysis of averaged monthly AOD values, in the southern-east European area, we detected worrying and dangerous values also in our country, particularly in the northern part of the Italian peninsula. Here, the Padan Plain seems very affected, having reached important peaks of pollution.

We therefore decided to carry out a more specific and detailed analysis on the variation of total AOD over the whole day, in order to have a detailed picture of the variation of AOD day by day.

The purpose is monitoring the trend of the total AOD, highlighting anomalies in the dispersions levels and therefore going to look for possible correlations with macro-events that occurred precisely in conjunction with these anomalies (fires, relevant biogenic events, dispersion of substances, sand storms etc.).

These analysis were supported by data collected with ground base measure instruments. We examined air quality bulletins from monitoring systems belonging to “ARPA Lombardia” and “ARPA Veneto”. It was crucial to have a feedback on our collected data for mainly two reasons:

1. Before proceeding to a daily analysis, it was necessary to have board or an idea of what going to study and above all when. This because it would been impossible to plot every hour of every single day.
2. To receive a confirmation on our collected data, in order to give a sense to our results.

So, this analysis has been supported by data collected with ground base measure instruments. We examined air quality bulletins from monitoring systems belonging to ARPA Lombardia and ARPA Veneto. It was crucial for mainly 2 reasons: to have a feedback on our collected data.

From the study of the data related to the control units located in the Po Valley region, anomalies were found in some days. We therefore went to focus our attention on those.

The analysis covered a period of 2 days: 28/03 and 29/03; this time, although, using daily data instead of average monthly data. We divided the whole day into 2 different parts: early morning and evening. In this way we are sure to cover the entire day and therefore detect even minor variations.

For each day we performed 2 measurements, one in the early morning, and the second one on the evening, in order to have, a complete overview of the evolution of total aerosol diffusion during the day.

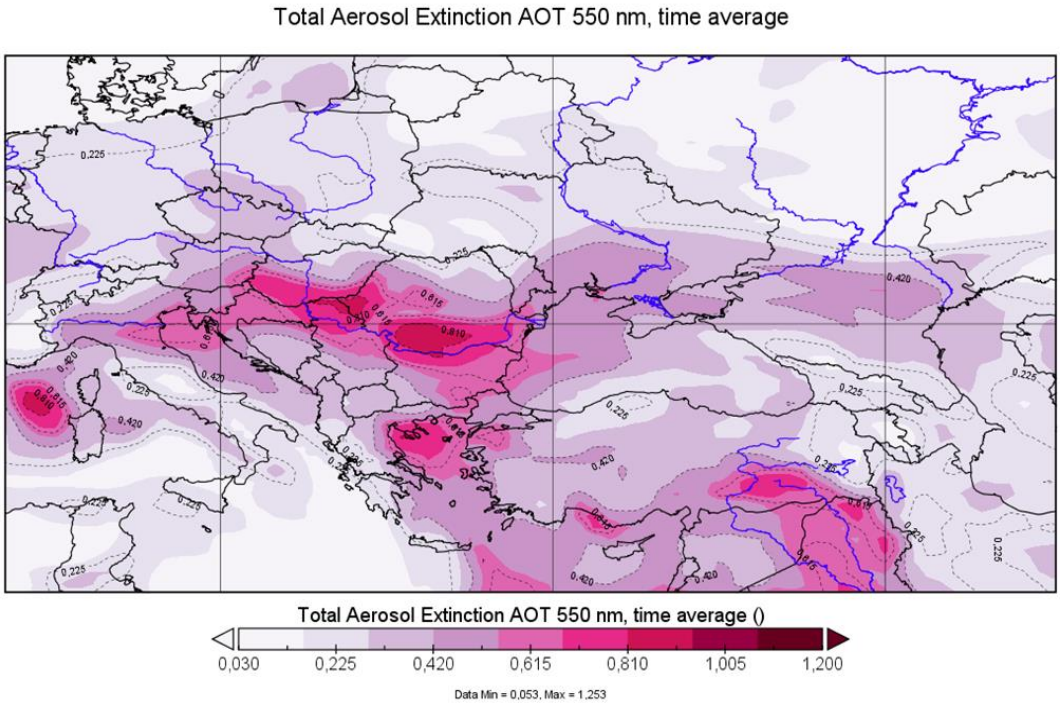

Figure 40: Total daily aerosol extinction of 28/03 at 06:00

Starting from our daily analysis related to 28/03/2020 (figure 40) we can see the variation of the total aerosol extinction focusing on a period of 2 days, from 27 March until 29 March (lockdown).

Focusing on Po valley, we can see how effectively the entire area is subjected to a peak of scattering probably originating from the middle east. The values in Padan Plain are between 0.420 and 0.600 with peaks on the lagoon od 0.620. The affected area reached also part of central east Italy.

By analysing the second plot, we cannot fail to detect how worst the situation became in Padan Plain.

If, as we saw before, during the early morning, levels were around 0.4-0.6, now there is a remarkable peak of the values over the entire area between ranging from 1.05-1.2. It means that in 14 hours, the levels of AOD have more than doubled (figure 41).

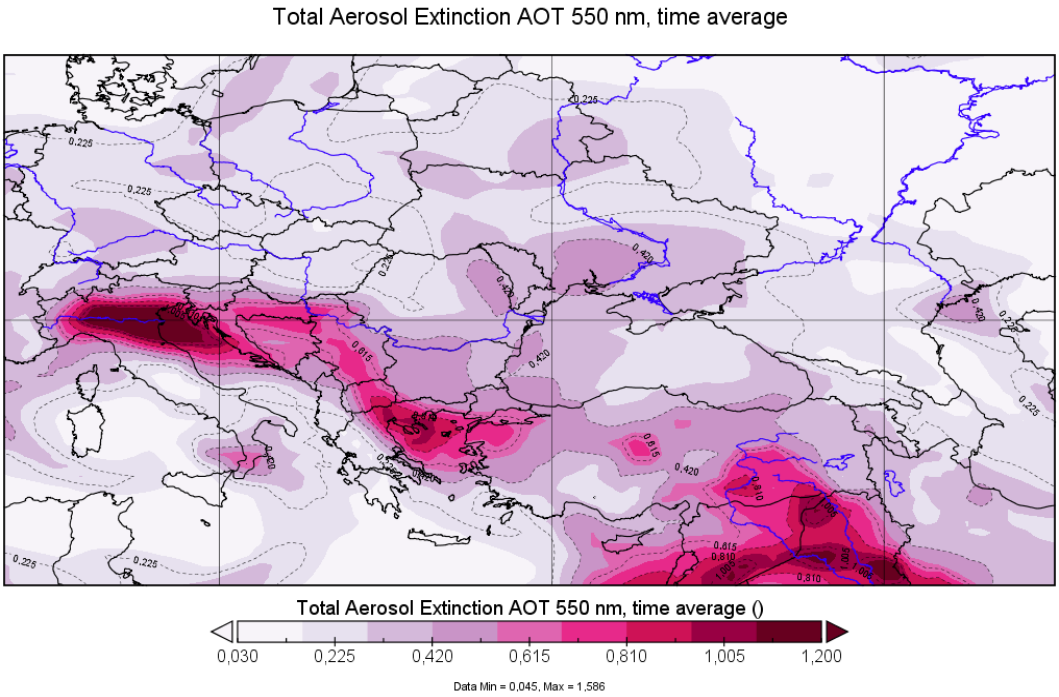

Figure 41: Total daily aerosol extinction of 28/03 at, 20:00

From the second plot, if we shift the gaze over the surrounding areas, we see a connection to the current situation occurring in Middle East.

So, it is reasonable to assume that the huge scattering we saw over Padan plan is a direct consequence of a sand-storm originated in the Arabian desert.

Moving on analyzing the next day 29/03 at 06:00 in the morning, we see that the general situation seems to get better, even if high values are still present (figure 42).

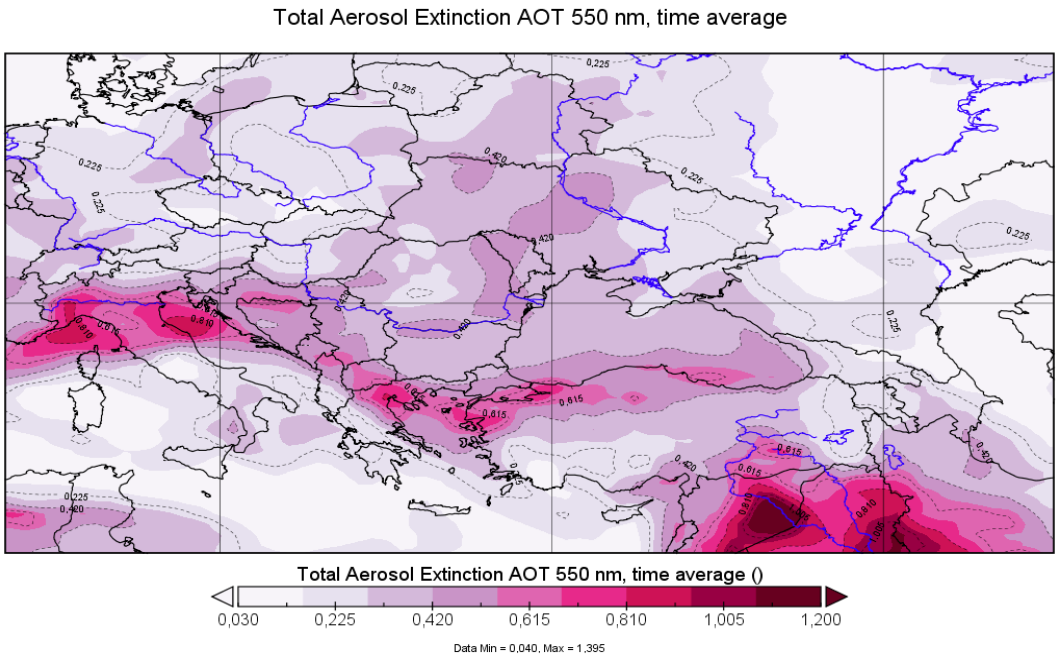

Figure 42: Total daily aerosol extinction of 29/03 at 06:00

Over the Padan plain, values decreased from 1.200 to an average of 600-700, despite the fact that peaks of 810 still remain, especially on the lagoon of Veneto and over the lagoon of Genova. Center and south of Italy appears clean.

Now we go analyzing now the situation of the same day but at 20:00 (figure 43).
At first sight is evident how the general situation continued to get better and better, in all the area, but most importantly over the Padan plain.

The values have crashed up to 0.300 with only a small peak of 0.500 over Tuscany.
Generally in the northern Italy the levels are around 300-350 almost 4 times lower than what registered just one day before.

Even Europe looks far better and the only affect area seems to be the middle east.

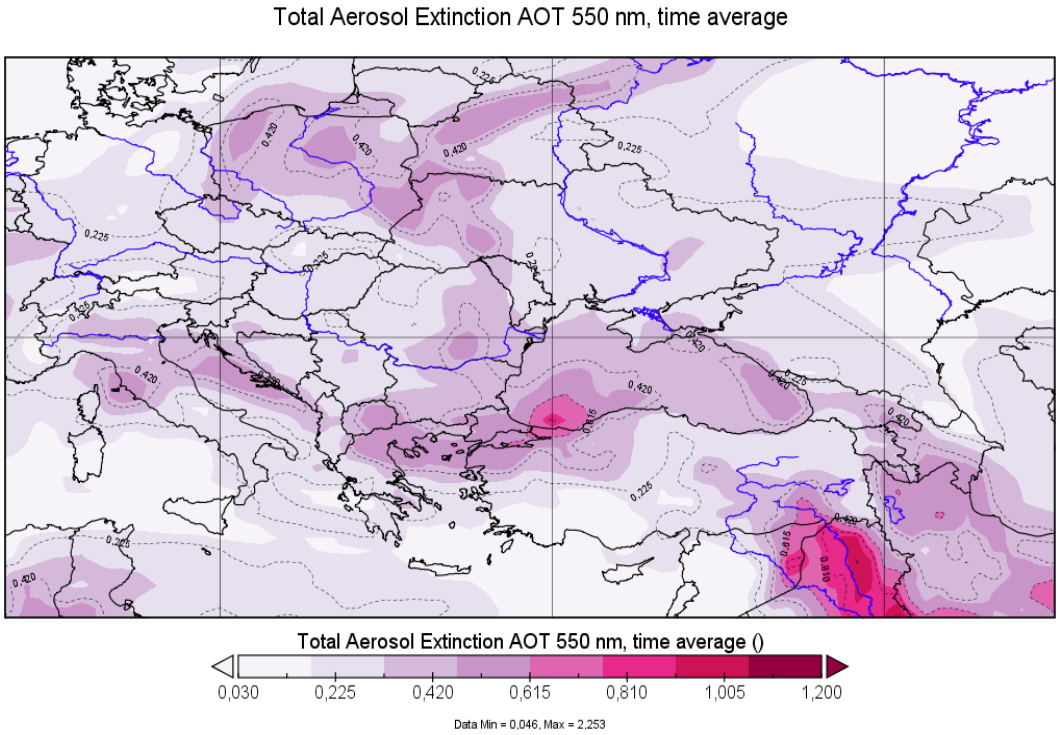

Figure 43: Total daily aerosol extinction of 29/03 at 20:00

4.4. Discussion of total daily AOD data

Now that our AOD studies have been carried out, it is interesting to compare our results, obtained by satellite remote sensing, with local analysis performed on the ground such as air quality bulletins.

Starting from the first one from report from ARPA of Lombardia:
Over the period of 28 and 29 March - when due to the transport of particulate matter of desert origin from Asian regions (as confirmed by the global model "Copernicus Atmosphere Monitoring Service"), the concentrations of PM10 were found to be very high compared to a lower increase in PM2.5 concentrations - clearly shows the complexity of phenomena related to the formation, transport and accumulation of atmospheric particulate.

By relaying also on report from Arpa Veneto, they recorded a peak of concentrations during the 28-29 of February, in occasion of a transport phenomena of desertic sands from Caspian sea area, as a result of strong oriental winds.

We can assume with certainty that both of these reports fully match with our results.In particular during these 2 days ground based instruments and remote sensing such as Copernicus satellite recorded a large quantity of particles.

All of these produce supporting documents to our AOD results. Moreover as we assumed before, the large scattering values recorded have biogenic source, belonging from the Arabian desert.

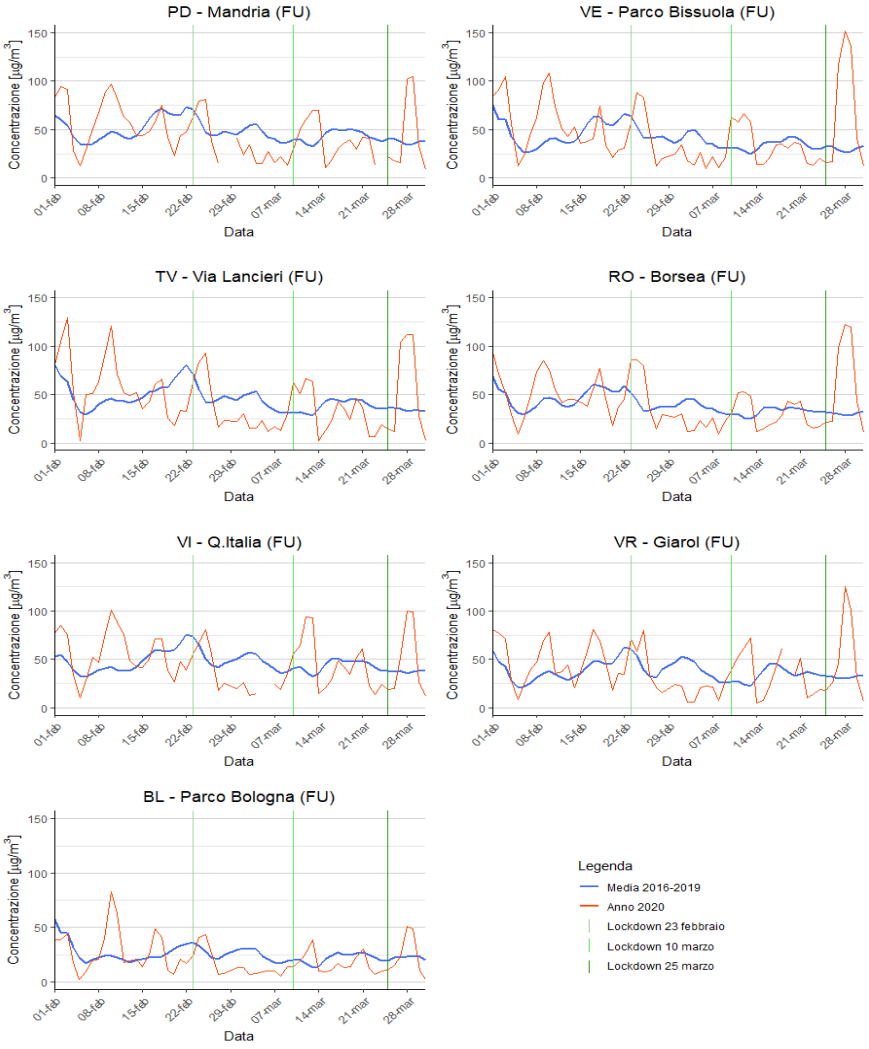

FIGURE 44: CONCENTRATIONS OF PARTICLES REGISTER IN DIFFERENT AREAS IN DIFFERENT PERIODS

The graph in Figure 44 shows the daily trend of the concentrations of particulate matter over a period including February and March 2020, compared with the same daily average of PM10 concentrations of the previous 4 years.

Through the graphs it can be easily seen the beginning of the lockdown since the concentrations of PM10 are generally lower but above all we can see how values strongly increased, on 28-29 of March, validating our results.

5. CONCLUSIONS

This thesis project is focused on the analysis of MERRA-2 reanalysis, through the elaboration of AOD of specific aerosol species, over a specific period of 3 months (January 2020 – March 2020), in order to evaluate the impact of lockdown restrictions on the quality of the air.

The period under review was characterized by the Covid-19 pandemic crisis, which had enormous health, social and environmental repercussions.

This study had as primary purpose the identification and then the assessment of any implications, between the results obtained through the analysis of aerosol speciation and certain anthropogenic activities. Furthermore, with the aid of analytical air monitoring reports, determine if possible, plausible correlations with relevant atmospheric events.

The aerosol analysis was carried out through the use of remote sensing satellites. The monthly averaged AOD images and daily averaged AOD images have been acquired through the aid of MERRA-2 and subsequently plotted and investigated by using Panoply. We also took into consideration the bulletins of various environmental and territorial agencies, using them as a support to our work.

In the first part of the study, analyzing the total aerosol extinction, we found homogeneous values during January and February. In the west part of Europe we found a finest situation with values in the range of 0.150-0.200 with Alps and part of Balkans between 0.40 and 0.94. No peaks of particular relevance have been found.

On the other hand, in March, the situation evolved dramatically and values strongly raise, ranging from 0.210 to 310 with peaks up to 0.367 in many parts of Asia Minor.

Then we performed a detailed analysis of the levels of the individual constituents of the AOD, in order to identify which one of aerosol's compounds can be the main responsible.

The black and organic carbon have been the first to be analyzed. Both showed a similar trend of values during the period of January and February, albeit with some difference.

On January a significant presence of BC (between 0.10-0.12) has been registered in Padan Plain while, in the same period., there is a low presence of OC in the Po Valley.
In March, values of both rise exponentially, in line with total AOD analysis. The affected regions almost coincide for both the species, with the BC showing peaks of 0.14 in the Po valley and in southeastern Europe. The OC is less present in the Po Valley, while it shows very high values over the whole area of Ukraine, Romania and the Caspian Sea, reaching peaks of 0.040.

Similar situation regarding SO_4. We assist to an exponential growth in March, with averaged values of 0.95 in almost the entire map, with two mainly affected areas, namely the Po Valley and the Balkans and the Black Sea with peaks up to 0.138

The responses have been meaningful, since for all these species, which have in common a primary anthropogenic origin, we recorded exponential growths in the same period and almost in the same areas.

The values emerged from this study, related to the organic and carbonaceous compounds, highlight clear correlations between them and relevant variations into certain human activities.
In the most backward areas, we registered double or even triple scattering values of these specie, respect to other regions more developed. Ass well known, the uncontrolled increase in combustion processes, related to an incorrect use of fossil fuels, give rise to an enormous dispersion of BC and OC within the atmosphere.

The results achieved so far, prove the existence of a very close cause-and-effect relationship, between anthropogenic activities and their impact on the health of the environment

Moving towards other kind of compounds, we performed a detailed analysis about other species of AOD which have biogenic sources and so no correlations with the lockdown.
Despite this, their analysis was also extremely significant for some reasons.
By examining their dispersion, we were able to assess the extent of the impact they have on air quality
For what concern the dust, in January and February no anomalies were recorded and the dust values remained in the average range (0.10-0.30). In March, on the other hand, a peak

has been recorded especially in the North African and Middle East area (0.166-0.217) which therefore affected the Mediterranean and Eastern Europe later on.
In this research we have ascertained, through the AOD analysis and through the ground based surveys, that the mass of sand and dust came from the Middle East, reasonably originated in a desert.

Eventually, in this research, we relied also on surveys and reports obtained through instruments and remote sensing such as Copernicus satellite, which is able to record the movement of a large quantity of particles.
Thanks to the integration of these reports and our data, we have been able to ascertain the provenience of the dust.
So, we can reasonably state that, the mass of sand and dust registered in Padan plain on 28-29 of March, is originated from a desert in the middle east.

Future developments in this area could concern the correlation between AOD values before and during lockdown and the incidence rates of SARS-CoV-2 infection.
Starting from these data, an epidemiological study could be carried out comparing areas with different AOD values. In this way it could be possible to see if there is a correlation between AOD values and infection values.

6. References

- Abril, G., Guérin, F., Richard, S., Delmas, R., Galy-Lacaux, C., Gosse, P., ... & Matvienko, B. (2005). Carbon dioxide and methane emissions and the carbon budget of a 10-year old tropical reservoir (Petit Saut, French Guiana). *Global biogeochemical cycles*, *19*(4).Kristensson, A. (2005). *Aerosol particle sources affecting the Swedish air quality at urban and rural level*. Univ., Institute of Technology.
- Burrows, M. T., Schoeman, D. S., Buckley, L. B., Moore, P., Poloczanska, E. S., Brander, K. M., ... & Holding, J. (2011). The pace of shifting climate in marine and terrestrial ecosystems. *Science*, *334*(6056), 652-655.
- Cao, J.J., Wu, F., Chow, J.C., Lee, S.C., Li, Y., Chen, S.W., An, Z.S., Fung, K., Watson, J.G., Zhu, C.S., Liu, S.X., 2005. Characterization and source apportionment of atmospheric organic and elemental carbon during fall and win
- Contini, D., Vecchi, R., & Viana, M. (2018). Carbonaceous aerosols in the atmosphere
- Dickerson, R. R., Kondragunta, S., Stenchikov, G., Civerolo, K. L., Doddridge, B. G., & Holben, B. N. (1997). The impact of aerosols on solar ultraviolet radiation and photochemical smog. *science*, *278*(5339), 827-830.
- Cachorro, V. E., & de Frutos, A. M. (1994). Retrieval of atmospheric aerosol characteristics from visible extinction data at Valladolid (Spain). *Atmospheric Environment*, *28*(5), 963-971.
- Charlson, R. J., Lovelock, J. E., Andreae, M. O., & Warren, S. G. (1987). Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. *Nature*, *326*(6114), 655-661.Forster et al., 2007, sect. 2.4.4.1). Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D. W., ... & Nganga, J. (2007). Changes in atmospheric constituents and in radiative forcing. Chapter 2. In *Climate Change 2007. The Physical Science Basis*.

- Dusek, U., Frank, G. P., Massling, A., Zeromskiene, K., Iinuma, Y., Schmid, O., ... & Andreae, M. O. (2011). Water uptake by biomass burning aerosol at sub-and supersaturated conditions: closure studies and implications for the role of organics.
- Goldstein, A. H., & Galbally, I. E. (2007). Known and unexplored organic constituents in the earth's atmosphere. (Alves, 2008) Alves, C., Vicente, A., Pio, C., Kiss, G., Hoffer, A., Decesari, S., ... & Spindler, G. (2012). Organic compounds in aerosols from selected European sites–Biogenic versus anthropogenic sources. *Atmospheric Environment*, *59*, 243-255.
- Hänel, G. (1976). The properties of atmospheric aerosol particles as functions of the relative humidity at thermodynamic equilibrium with the surrounding moist air. In *Advances in geophysics* (Vol. 19, pp. 73-188). Elsevier
- Hitzenberger, C. K., Baumgartner, A., Drexler, W., & Fercher, A. F. (1999). Dispersion effects in partial coherence interferometry: implications for intraocular ranging. *Journal of Biomedical Optics*, *4*(1), 144-152.
- Hoppel, W. A., Frick, G. M., Fitzgerald, J. W., & Larson, R. E. (1994). Marine boundary layer measurements of new particle formation and the effects nonprecipitating clouds have on aerosol size distribution. *Journal of Geophysical Research: Atmospheres*, *99*(D7), 14443-14459.
- https://earthobservatory.nasa.gov/
- https://mageesci.com/our-story/measuring-carbonaceous-aerosols/
- https://nasa.github.io/data-nasa-gov-frontpage/
- https://www.arpalombardia.it/Pages/Aria/Inquinanti/Carbonio.aspx?firstlevel=Inquinanti
- https://www.thelocal.it/20190228/po-valley-air-pollution-italy
- Jacobson, M. Z. (2001). Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. *Nature*, *409*(6821), 695-697
- Jacobson, M. Z. (2001). Global direct radiative forcing due to multicomponent anthropogenic and natural aerosols. *Journal of Geophysical Research: Atmospheres*, *106*(D2), 1551-1568.

- Janssen, N.A.H.; Hoek, G.; Simic-Lawson, M.; Fischer, P.; van Bree, L.; ten Brink, H.; Keuken, M.; Atkinson, R.W.; Anderson, H.R.; Brunekreef, B.; et al. Black carbon as an additional indicator of the adverse health effects of airborne particles compared with PM10 and PM2.5. Environ. Health Perspect. 2011, 119, 1691–1699. [CrossRef] [PubMed]
- *Journal of Geophysical Research: Atmospheres*, *109*(D16). Climate sensitivity to black carbon aerosol from fossil fuel combustion
- Kanakidou, M., Seinfeld, J. H., Pandis, S. N., Barnes, I., Dentener, F. J., Facchini, M. C., ... & Swietlicki, E. (2005). Organic aerosol and global climate modelling: a review. *Atmospheric Chemistry and Physics*, *5*(4), 1053-1123
- **Kondratyev. (1986)** Kondratyev, K. Y., Ivanov, V. A., Pozdnyakov, D. V., & Prokofyev, M. A. (1986). Natural and anthropogenic aerosols: A comparative analysis. *Studies in Environmental Science, vol*, *26*, 281-303
- Lewandowska, A., Falkowska, L., Murawiec, D., Pryputniewicz, D., Burska, D., Bełdowska, M., 2010. Elemental and organic carbon in aerosols over urbanized coastal region (southern Baltic Sea, Gdynia). Sci. Total Environ. 408, 4761–4769
- Logan, J. A., Prather, M. J., Wofsy, S. C., & McElroy, M. B. (1981). Tropospheric chemistry: A global perspective. *Journal of Geophysical Research: Oceans*, *86*(C8), 7210-7254.
- Lyamani, H., Olmo, F. J., Alcántara, A., & Alados-Arboledas, L. (2006). Atmospheric aerosols during the 2003 heat wave in southeastern Spain II: Microphysical columnar properties and radiative forcing. *Atmospheric Environment*, *40*(33), 6465-6476.
- mass Kanakidou, M.; Seinfeld, J.H.; Pandis, S.N.; Barnes, I.; Dentener, F.J.; Facchini, M.C.; Van Dingenen, R.; Ervens, B.; Nenes, A.; Nielsen, C.J.; et al. Organic aerosol and global climate modelling: A review. Atmos. Chem. Phys. 2005, 5, 1053–1123. [CrossRef].
- Mauderly, J. L., & Chow, J. C. (2008). Health effects of organic aerosols. *Inhalation toxicology*, *20*(3), 257-288.

- Niessner, R. (1990). Chemical characterization of aerosols. *Fresenius' Journal of Analytical Chemistry*, *337*(5), 565-576.
- Pope III, C. A., & Dockery, D. W. (2006). Health effects of fine particulate air pollution: lines that connect. *Journal of the air & waste management association*, *56*(6), 709-742.
- Pöschl, U. (2005). Atmospheric aerosols: composition, transformation, climate and health effects. *Angewandte Chemie International Edition*, *44*(46), 7520-7540
- Putaud, J.P.; Van Dingenen, R.; Alastuey, A.; Bauer, H.; Birmili, W.; Cyrys, J.; Flentje, H.; Fuzzi, S.; Gehrig, R.; Hansson, H.C.; et al. A European aerosol phenomenology3: Physical and chemical characteristics of particulate matter from 60 rural, urban, and kerbside sites across Europe. Atmos. Environ. 2010, 44, 1308–1320. [CrossRef]
- Rengarajan, R., Sarin, M.M., Sudheer, A.K., 2007. Carbonaceous and inorganic species in atmospheric aerosols during wintertime over urban and highaltitude sites in North India. J. Geophy. Res. 112, D21307.
- Rizza, U., Mancinelli, E., Morichetti, M., Passerini, G., & Virgili, S. (2019). Aerosol Optical Depth of the Main Aerosol Species over Italian Cities Based on the NASA/MERRA-2 Model Reanalysis. *Atmosphere*, *10*(11), 709.
- Seinfeld, J. H., & Pandis, S. N. (1998). From air pollution to climate change. *Atmospheric Chemistry and Physics*, *1326*.
- S.K. Sathneesh, K.K. Moothy and J. Srinivasan, 2004. Patel, M. P. *Study of Aerosol Optical Depth and Black Carbon concentration over Dehradun and surroundings* (Doctoral dissertation, ISRO).
- Tsigaridis, K., Krol, M., Dentener, F. J., Balkanski, Y., Lathiere, J., Metzger, S., ... & Kanakidou, M. (2006). Change in global aerosol composition since preindustrial times. *Atmospheric Chemistry and Physics*, *6*(12), 5143-5162.
- Vedal, S. (1997). Ambient particles and health: lines that divide. *Journal of the Air & Waste Management Association*, *47*(5), 551-581.

- Wallace, J. M., & Hobbs, P. V. (2006). *Atmospheric science: an introductory survey* (Vol. 92). Elsevier.
- W.A. Hoppel et al., 1990. Hoppel, W. A., Fitzgerald, J. W., Frick, G. M., Larson, R. E., & Mack, E. J. (1990). Aerosol size distributions and optical properties found in the marine boundary layer over the Atlantic Ocean. *Journal of Geophysical Research: Atmospheres*, *95*(D4), 3659-3686.