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Inquinamento da monossido di carbonio
nella regione metropolitana di Milano:
analisi dei dati satellitari nel periodo 2008-2017

Carbon monoxide pollution in Milan metropolitan area:
analysis of satellite data in the time range 2008-2017

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Introduction

The data analysis system of the GIOVANNI NASA has been recognized as a useful tool for accessing and analysing many different types of remote sensing data. The variety of environmental data allows the use of GIOVANNI for different areas of application, like agriculture, hydrology and research on air quality.

This communication also provides a case study on the use of remote sensing data from GIOVANNI in evaluating the associations between seasonal and meteorological influence parameters. Continuous analyses are needed for a better understanding of air pollution, acid deposition and climate change. In recent years, the contribution of satellite remote sensing has played a significant role since it has gradually increased accuracy. In this context, it is possible to retrieve information for a wide range of detectable chemical species including aerosol, carbon monoxide CO, ozone tropospheric ozone, tropospheric nitrogen dioxide NO₂, HCHO formaldehyde and SO₂ sulphur dioxide. This analysis describes the analysis of satellite data recovery of carbon monoxide CO. All this happens thanks to GIOVANNI NASA, in particular the MOPIT program for the measurement of pollutant concentrations.

1 The atmosphere

The atmosphere is of fundamental importance to us since it protects the Earth from harmful radiation from the Sun, regulates the warming of the Earth, contains oxygen, an indispensable element for animal and plant life, contributes to modelling the earth's relief (through chemical processes of rock alteration, disaggregation), allows the continuous exchange of water between the sea and the land emerged (through the processes of evaporation, condensation and precipitation). With the increase of the quotas, above all because of the increase of the solar radiation, a dissociation of the gases is realized that involves a sensitive modification of the percentages of the various components. As the height increases, the lighter gases become increasingly present.

1.1 Atmospheric layers

The atmosphere varies by composition and characteristics and becomes gradually more rarefied until it fades into space. It extends up to 1000 km of altitude and can be divided into 5 layers that, starting from the lower one, are: the troposphere, the stratosphere, the mesosphere, the thermosphere and the exosphere. This division is conventional: one layer does not end abruptly where the other begins, but there are gradual steps.

- The troposphere is the lowest layer of the earth's atmosphere. The troposphere starts at ground level and reaches a height between 7 and 20 kilometres above sea level. Most of the mass (about 75-80%) of the atmosphere is found in the troposphere. Almost all meteorological events occur at this level. The air is warmer at the bottom of the troposphere near the ground level. Above, the air cools. Pressure and air density are also lower at high altitudes. Almost all the particles of water vapour and dust in the atmosphere are found in the troposphere. This is the reason why most clouds are also found in this lower level. The lower part of the troposphere, just above

the surface of the earth, is called the "boundary layer". In places where the surface of the Earth has "relief" (mountains, forests) the winds in the boundary layer are mixed. In places with smooth surfaces (above water or ice) the winds are more fluid. The troposphere is heated from below. Sunlight heats the Earth or the ocean, which in turn radiates heat into the air above it. Hot air tends to rise. This keeps the air in the "mixed" troposphere. The upper part of the troposphere is rather cold. The temperature is around -55 ° C. As it rises, even the air becomes "lighter". The boundary between the upper part of the troposphere and the stratosphere (the layer above it) is called the tropopause. The height of the tropopause depends on the latitude, the station, both day and night. Near the equator, the tropopause is about 20 kilometres above sea level. In the winter, near the poles, the tropopause is much lower. It is about 7 kilometres tall. The air current is below the tropopause. This "air river" travels at almost 400km/h.

- The Stratosphere extends up to 50km in height. The water vapour is almost absent and gases are much more rarefied than those of the troposphere. The temperature increases with increasing height, due to the presence, around 40 km, of an ozone layer. Ozone has the property of absorbing ultraviolet radiation, producing heat and shielding radiation harmful to life on Earth. In the stratosphere there are also clouds formed by ice crystals and dust.
- The Mesosphere reaches up to 80 km of altitude. A fundamental characteristic of the mesosphere is the extreme rarefaction of the elements. In this part of the atmosphere the temperature starts to decrease with the height and reaches the minimum value, between -70°C and -90°C, around 80km; at this altitude you can sometimes see noctilucent clouds made of ice crystals and very small powders; they are visible during the summer, at dusk and appear as thin and brilliant clouds, intensely illuminated by the last rays of the Sun. Observation of these clouds shows that in the high mesosphere there is a complex system of air currents, with variable course, that should reach speeds up to 300km/h.

- The Thermosphere extends beyond 500 km and its temperature grows with height. In the thermosphere there is a zone, called ionosphere, characterized by the presence of charged particles, which are formed by the splitting of the gaseous elements by the cosmic rays coming from the other stars and the Sun. In this layer the polar aurora occurs. In the upper part of the thermosphere there are many artificial satellites and the international space base.
- The Exosphere represents the outermost layer of the atmosphere and has no true upper limit, gradually fading into interplanetary space. The few gaseous elements are light molecules such as hydrogen and helium present in extremely low percentages. The Earth's exosphere is the outer layer of the atmosphere, starting from about 500 km in height. The exosphere is characterized by a temperature of about 700 ° C and varies according to solar activity. The gaseous particles that reach and exceed the escape speed (11.2km/s) no longer participate in the Earth's rotation and are dispersed in space. Generally, the lightest elements (hydrogen and helium) are those that leave our atmosphere more frequently.

1.2 Atmospheric Pollution

Atmospheric pollution can be defined as the presence in the atmosphere of substances that cause a measurable effect on human beings, animals, vegetation or different materials; these substances are usually not present in the normal composition of the air, or they are at a lower level of concentration. Air pollution can arise in various ways. Chemicals are emitted during many different human activities. In the atmosphere, these chemical agents can react with other chemical compounds to form more dangerous substances. Air pollutants often have properties that are harmful to the environment.

Time plays an important role in the formation and disappearance of atmospheric pollution, and it is mainly influenced by wind and temperature. Atmospheric pollutants can be carried by the wind, causing pollution to spread widely. Rain can remove air pollutants, cause water

and soil pollution. Sunlight can help the transformation of atmospheric pollutants into different substances.

The pollutants are usually divided into two main groups: those of anthropogenic origin, which are produced by man, and natural ones.

Pollution in open environments is defined as external, while pollution in confined spaces, such as buildings, is referred to as internal pollution. In fact, the air quality in confined spaces is often referred to as Indoor Air Quality.

So far about 3,000 air contaminants have been catalogued, mostly produced by human activities with various industrial processes, with the use of means of transport or in other circumstances.

The methods of production and release of the various pollutants are extremely varied; in the same way there are many variables that can influence their diffusion into the atmosphere. Regardless of their origin, pollutants are distinguished in primary and secondary.

Primary pollutants are the pollutants that are released directly into the environment following the process that produced them. Secondary pollutants are substances that form from primary pollutants (both anthropogenic and natural) as a result of physical and chemical transformations caused by reactions that often involve atmospheric oxygen and solar radiation.

The main primary pollutants are those emitted in the course of combustion processes of any nature, i.e. carbon monoxide, carbon dioxide, nitrogen oxides (mainly in the form of nitrogen monoxide), particulate matter and unburnt hydrocarbons. In case the fuels contain also sulphur, there are also emissions of sulphur dioxides.

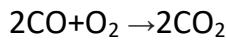
After their emission into the atmosphere, the primary pollutants are subject to diffusion, transport and deposition processes. They can also undergo chemical-physical transformation processes that can lead to the formation of secondary pollutants. These new chemical species can be more toxic and have a wider range of action than the original

compounds. Among the formation processes of secondary pollutants, particular importance is assumed by the series of reactions that occur between nitrogen oxides and hydrocarbons in the presence of sunlight. This chain of reactions leads to the oxidation of nitrogen monoxide (NO) to nitrogen dioxide (NO₂), to the production of ozone (O₃) and to the oxidation of hydrocarbons, there is formation of aldehydes, peroxides, of nitriloperacetic acids (PAN), nitric acid, nitrates and nitro by-products in the particle phase, and hundreds of other minor chemical species. The set of products of these reactions is called photochemical smog, which is one of the most harmful forms of pollution for the ecosystem. The use of the term smog is due to the strong reduction of visibility that is determined during the episodes of photochemical pollution, due to the formation of a large number of particles of considerable size.

The dispersion of contaminants into the atmosphere is determined by the turbulent diffusion and transport of air masses. The removal of pollutants is determined by the various deposition processes. Both the dispersion and the removal are strictly dependent on the various meteorological processes that regulate the behaviour of the air masses in the troposphere (the lowest layer of the atmosphere). For the study of the behaviour of primary pollutants it is therefore necessary not only to know the qualitative, quantitative and temporal profile of the emissions, but also to have information on the meteorological processes affecting the areas subject to the presence of the various pollutants.

Carbon monoxide: one of the main gaseous contaminants is carbon monoxide CO. It is emitted mainly by combustion processes, in particular by the discharge of old vehicles with hydrocarbon engines and stoves, due to incomplete combustion. The highest concentrations are generally found near roads and big cities. Inhalation in large quantities can cause headaches, fatigue and respiratory problems. Above 500 mg / m³ can be lethal. CO is a colorless and odorless gas slightly heavier than air. It is highly toxic and with a low or medium concentration in the air, forms a flammable and explosive mixture. It is classified as one of the main air pollutants. Carbon monoxide above -192 ° C is a colorless and tasteless odorless gas that is practically insoluble in water. Incomplete combustion of C and carbon-containing compounds $2C+O_2 \rightarrow 2CO$.

The CO can be removed by this other reaction if there is enough O₂



If this does not happen, there will be CO release in the lack of O₂ combustion. High temperature reaction between CO₂ and C CO₂ + C → 2CO

It takes place in blast furnaces and the CO produced can escape into the atmosphere. Dissociation equilibrium at high temperatures between CO₂ and CO + O.

Most of the CO emissions, given the reactions described above, occur in internal combustion engines and stoves due to:

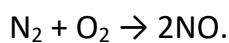
- Incomplete combustion reaction when there is the HIGH fuel-air ratio - that is when we have the richest mixture.
- CO₂ dissociation reaction, when CO₂ is produced at very high temperatures during the blast, it is dissociated into CO + O and, immediately after cooling water is cooled to a low temperature, it no longer returns to CO₂.
- Features of combustion chamber, engine wear, exhaust system
- Driving conditions: less speed and temperature, more CO production

Other sources: 17% waste treatment. Other industrial sources (metallurgical, steel mills, wood and paper refineries) and heating (coal, fuel oil and wood) for the rest. Then there are natural sources that are relatively modest compared to the anthropic ones described above: Volcanoes, gas emissions, electric discharges, biological sources. The pollutant CO, especially in past years, was one of the most critical in urban areas; the introduction of three-way catalytic converters (reduction of CO, -combustion hydrocarbons and NO_x) and the renewal of the car fleet have significantly reduced the levels of this pollutant in Europe.

For CO removal there is an efficient removal by microorganisms present in the soil and by the plants and a removal for chemical processes. The presence of O₂ in the atmosphere would cause the removal from soil microorganisms to be faster. Harmful effects on plants could have, at great concentration, an effect of decreasing the efficiency of nitrogen-fixing

bacteria; however such concentrations are not reached normally. Vice versa on men and animals it has a devastating effect on haemoglobin, in case of acute events. Carbon monoxide is known to poison blood by blocking haemoglobin in a compound the stable carboxyhaemoglobin COHb that no longer allows the efficient exchange of $O_2 \leftrightarrow CO_2$ to the haemoglobin. Carbon monoxide is one of the causes of death of men when it is in high concentrations, but also when it is in concentrations below lethal ones creates negative effects.

The reaction between N_2 and O_2 , normal air components, occurs only above the temperature of $1210^\circ C$. In this case, mainly nitrogen monoxide is formed.



The monoxide, oxidizing itself in turn, forms the $2NO + 2O_2 \rightarrow 2NO_2$ nitrogen dioxide. In non-limiting O_2 conditions, the higher the temperature is, the more nitrogen oxide is formed. NO is present in large quantities in engine emissions. In fact, in these combustions there is always an excess of O_2 in addition to that consumed in the normal combustion reaction by hydrocarbon fuels. This excess could be reduced by making the mixture "poorer", but this would increase CO production. The NO, if the cooling happened slowly, could dissociate in N_2 and O_2 , but this does not happen in a fast flow of gas coming from an internal combustion engine. NO_2 instead forms from NO in cooling conditions and it is proportional to the concentration of O_2 and to the square of NO. So, in the end we get a mixture of the two. From the emissions from vehicles comes an amount of NO_2 estimated at around 10% of the amount of NO. But a part of NO is subsequently transformed by photochemical effect into NO_2 . In addition to combustion, nitrogen oxides are produced by bacteria. But unlike the latter, nitrogen oxides from combustion are produced in heavily populated areas and therefore more significant for urban pollution. The reduction of nitrogen oxides in catalytic converters can often be inefficient; also because of this, nitrogen oxide pollution still represents a serious problem in Italian cities. Other sources besides engine combustion are the combustion from power plants for energy production and non-industrial combustion plants. Furthermore, there are facilities to produce HNO_3 that can enter significant localized quantities of NO_x . For the elimination of nitrogen oxides, they are removed from the

atmosphere mainly by washing away as nitric acid and nitrates. Instead due to the danger on plants and materials it is mainly because of acidifying the rains with consequent acidification of the soil and damage to the roots in the case of plants and corrosive action in the case of materials. On health, NO_2 should have a toxic effect four times greater than NO , but at usual concentrations, the greatest danger appears to be the involvement of oxides in the formation of photochemical smog molecules.

Sulphur oxides present in the atmosphere come from natural sources of about 60% (volcanoes) and 40% from the combustion of sulphur-polluted fuels and foundries that use metals containing minerals in the form of sulphides to produce metals and sulphates. The reference reactions for production by combustion are:



The first reaction is that which produces the greatest amount of oxide; the second reaction decreases the concentration of SO_2 and increases that of SO_3 in the atmosphere. But the concentration of SO_3 is always low because with atmospheric humidity SO_3 produces H_2SO_4



This reaction causes a greater concentration of H_2SO_4 in the atmosphere than SO_3 also because this last reaction is influenced by the humidity of the air, the type and intensity of the light and the presence of catalysts. In principle, during the day and with poor humidity there is a greater presence of oxides in the atmosphere. At night in the absence of light and in the presence of water there is a lower concentration of oxides as droplets are formed with the presence of calcium and ammonium sulphate and sulfuric acid. The aerosol that forms in this way is frequently associated with poor visibility. The effects on plants are considerable. They go from the acidification of the soils due to acid rain and therefore to the suffering of the same from the absorption of the acid by the roots with consequent chronic disease with yellowing (by blocking the chlorophyll function) and falling of the leaves. Furthermore, the concentration of droplets containing oxides on the leaves themselves causes areas of necrosis to form due to the formation of acids. On humans, the SO_2 at 0.3 ppm is already felt by humans due to the pungent smell of gas. The irritating effects are most

felt in the upper part of the respiratory system. At concentrations greater than 1.6 ppm, bronched constriction may occur. Also, eyes and nervous system are affected. The irritating effect of the gas alarms and protects man from further exposure. However, the major consequences are because of the particulate which carries the negative effects of the oxides with it in its deepest points. On materials, damage occurs on paints when these are dried in the presence of sulphur oxides as drying and hardening times are prolonged with consequent brittleness and softness of the paints. Metallic materials deteriorate due to increased corrosion capacity due to acids. Stone materials containing calcium carbonate (marble, slate, and mortars) are affected by the reference reaction is this: $\text{CaCO}_3 + \text{H}_2\text{SO}_4 \Rightarrow \text{CaSO}_4 + \text{CO}_2 + \text{H}_2\text{O}$.

Sulphates are more soluble than carbonates in H_2O and consequently there is a general weakening of the structure. Paper and leather are altered and disintegrate at long exposure.

The study of ozone in the atmosphere must be considered in two respects according to the place where it is intended to be studied. In the stratosphere, ozone is considered a positive substance for humans and the environment as it limits the damage of ultraviolet radiation from the sun. Ozone in the lower layers of the atmosphere is a secondary pollutant, i.e. not produced directly by anthropogenic emissions but by reaction with primary pollutants and the external environment. The increase in its concentration occurs due to the presence of other pollutants (such as Volatile Organic Compounds - VOCs - produced by man or from natural sources, which interfere in the normal cycle of photolytic reactions with nitrogen oxides. Effects on man: the main disorders are related to irritation and inflammation of the eyes and the upper respiratory tract with tearing, coughing, difficulty breathing and wheezing. Ozone, especially in association with other pollutants, may be responsible for the decreased resistance to bacterial lung infections and the aggravation of chronic bronchitis, asthma and cardiac ischemia. Generally, these effects are dependent on short-term exposure and cease quickly with the end of exposure. Prolonged exposure for months and years to high levels of ozone can cause irreversible effects on health, particularly on the structure of the respiratory and cardiovascular system. For example, repeated exposure to

ozone from the lungs during the development of children can lead to a permanent reduction in lung function.

In addition to gases and vapours, different types of solid and liquid particles are present. These particles can be distinguished from each other in various ways, the most significant being according to: physical state (solid or liquid) of the sources of chemical and physical characteristics of the dimensions of the effects on plant health of the effects on human health.

Solid powders are all the particles that are stationed in the atmosphere in a solid form for a certain period. Aerosols are all the particles that stay in the atmosphere in liquid form for a certain period. These particles, regardless of their physical state, sources, chemical and physical characteristics, size, genesis, health effects on animals and plants, are called TSP, i.e. Total Suspended Particulate.

Powder sources can be natural and artificial. Natural springs natural sources of dust and fumes. The natural sources of dust are those due to: the evaporation of sea water droplets which, carried by the wind, in addition to forming very small solid particles of salts, can take them over great distances; the evaporation of mists and aerosols containing dissolved substances which, once the solution has evaporated, produce very small solid particles; the fumes generated by the volcanoes; the dusts raised by wind accidents in particularly producing areas such as deserts or in areas that produce powders such as those subject to erosion; pollens, spores and microorganisms; fires. Other natural sources of aerosol are waves, waterfalls shower heads. Furthermore, the vapours that are in the atmosphere are natural sources of aerosols that, cooling down, condense into liquid particles and generate droplets. In nature, the most important steam that can suffer this phenomenon is water vapour. In addition to water, other chemical substances (including those of artificial origin) that have reached the atmosphere in the form of steam can condense and then coagulate. Coagulation is the phenomenon whereby primary particles (both solid and liquid) condensed by vapours come together to give rise to a new, larger particle which, upon reaching certain dimensions, can precipitate.

In addition to the natural sources, there are sources of particles of anthropic origin. Combustions can serve various purposes and use various types of fuel. PV type motors with solid fuel (coal, wood) liquid (gasoline, gas oil, kerosene) or gas (natural gas or LPG).

The chemical and physical characteristics of the combustion particulates are determined by the fuels used, the combustion conditions and the devices to reduce their impact.

Soot (black smoke), combustion, in addition to gases such as CO₂ and H₂O, produces particulate matter (soot or black smoke) which can be seen by observing any cold point of a drain (chimney or muffler). The black powder is amorphous carbon of a maximum size of about one micron. Within this structure there are structures based on aromatic polycyclic up to 2 nm amorphous in size. In general, the more the combustion is in O₂ deficiency and the more the products are rich in particulate matter, the colder the flame is, the more the products are rich in particulate matter. If you have a premixed flame, the C / O threshold ratio below which you should not have particulate, goes from 0.5 to 1 For a diffusion flame the situation is more complex because in every point of the flame there can be a different value of this report. In general, gaseous fuels such as GN or LPG produce less particulate matter than heavier molecules. For this reason, they are to be preferred for heating and for traction to other fuels, to reduce the amount of particulate matter formed.

About liquid fuels, the formation of particulate matter depends on their physical and chemical properties. The more viscous the liquid is, the larger the diameter of the droplets are, the more volatile it is and the faster the evaporation. The presence of liquid particles increases the probability of finding points with greater presence of carbon and therefore an increase in particulate matter. In the same fuel class the increase in particulate matter depends on the C/H ratio. For premixed flames the presence of soot decreases from aromatics> alkanes> alkenes> alkynes. For diffusion flames from Aromatics> alkynes> alkenes> alkanes, obviously turbulence is also important to vary the production of soot.

Other particulates can be produced during combustion without being part of the actual combustion process. For example, in incinerators, particulates can be formed that contain particles rich in substances present in the waste such as metals or that have formed at high

temperatures such as metal oxides. Other particulate producers are foundries, construction industries, stone and cement industries. Furthermore, other particulates (not from combustion) may be present in accidental or induced collapses due to recovery of the construction area. In these cases, the particulate is formed mainly from particles of inorganic material. Particularly dangerous are the asbestos particles used in the past in construction due to its insulating properties.

The effects of dust on the vegetation are due to its adhesiveness. In case of vegetation located around cement plants, the damage is far more serious. In fact, in this case, a real, untearable crust forms that inhibits the chlorophyll function and makes the plant weaker. Furthermore, there is also a mechanical scraping effect on the leaves that makes them more susceptible to insect and cryptogam attacks. Powders can also act as aggregating nuclei of air humidity where dangerous pollutants are dissolved for plants such as nitrogen and sulphur oxides which tend to acidify the solutions.

On humans the effects of particulate matter depend very much on the chemistry of the particulate, which is on what the particulate matter consists. But they depend even more on the particle size. In fact, these determine the sites reachable by the particles themselves. The most exposed system is obviously the respiratory system. The natural barriers of the respiratory system are the nostril hairs that act as a filter for larger particles. Particles larger than 5 microns are blocked in the nose and throat. The particles up to 0.5 microns reach the bronchioles and are removed from them within a few hours. The smaller particles reach the alveoli, and these are not easily removed and can be released into the bloodstream. Nano particles are particles the size of a few nanometers then of 0.2 microns.

Particulate, once produced, can remain in the atmosphere for a certain period, but even after its precipitation it can be put back into circulation by successive events such as rising winds or passing cars. It should be noted that very fine particulates have the possibility, remaining in the atmosphere for a long time, to be transported from the winds very far from the places of primary production.

1.3 Satellite processing overview

A satellite is an object in space that orbits around a larger object. There are two types of satellites: natural (like the Moon) or artificial (like the International Space Station). There are thousands of natural satellites in the Solar System, almost every planet having at least one moon. Artificial satellites, however, did not become a reality until the mid-20th century. Sputniks and Scouts became the initial shootings of a space race between the United States and the Soviet Union that lasted at least until the end of the 1960s. Attention to satellites as political tools began to give way to people when both countries sent humans into space in 1961. Later in the decade, however, the goals of both countries began to divide. While the United States continued to land people on the moon and set up the space shuttle, the Soviet Union built the world's first space station, Salyut 1, which was launched in 1971. (Other stations followed, such as the United States Skylab and the Soviet Union Mir).

Other countries began sending their satellites into space and the benefits poured into society. Meteorological satellites have improved forecasts, even for remote areas. Earth-watching satellites, such as the Landsat series, have monitored changes in forests, water and other parts of the earth's surface over time. Telecommunications satellites have made long distance calls and live television broadcasts part of normal life. Later generations have helped with Internet connections. With the miniaturization of computers and other hardware, it is now possible to send much smaller satellites in orbit. It is now common for companies and universities to create "CubeSats", or cube-shaped satellites that frequently populate low Earth orbit. These can be placed on a rocket along with a larger payload or sent by a mobile launcher on the International Space Station (ISS).

Satellite remote sensing offers the best opportunity of making global measurements of tropospheric trace gases and aerosols over extended periods of time. It provides an integrating step between observations of emission sources and subsequent in situ measurements taken some distance away, thus allowing the examination of the impact of

intense local pollution sources on continental- and global-scale air quality. Recent developments in aerosol retrieval allow the distinction to be made between coarse and fine mode. Coarse mode aerosols are usually dust or sea-salt particles. These particles are primarily natural, although changing weather patterns and land use practices also play a role in their production. The fine mode particles are formed directly and indirectly from combustion processes, both anthropogenic and wild-fire, and these are the same processes that lead to the emission of carbon monoxide (CO) into the atmosphere. CO is one of the few tropospheric gases that can be successfully monitored from space now. Measurements from the Terra satellite launched in December of 1999 provide a global record of the reengineer annual variability of tropospheric air quality: carbon monoxide (CO) from the Measurement of Pollution in the Troposphere (MOPITT) instrument.

The goal of this work is to compare and contrast these data sets with a view to understanding the general features of the overall pollutant loading of the Milan area. The analyses of the data taken refer to the metropolitan area of Milan from 2008 to 2018 characterized by a strong environmental degradation as the site of numerous industrial plants. The work of the thesis consists in downloading the CO data from the NASA GIOVANNI program. GIOVANNI stands for Geospatial Interactive Online Visualization ANd aNalysis Infrastructure and is a web application developed by the Goddard Earth Sciences Data Center (GES DISC) of NASA. The GIOVANNI application requires you to select the graph, the time interval and the region. Using the drop-down menus, select the "Maps: Temporal Time Map" command. Then provide the time interval (monthly for each year from 2008 to 2018) and the area of interest (in our case the Milan area). The data installed by the MOPITT satellite are then transferred to Panoply is a Java application that allows the user to track raster images of geographic data (geo-referenced) from data sets in netCDF format. The maps and data output of Panoply were then used as a means of comparison with the data processed by remote sensing and direct measurements.

1.4 CO emissions

Carbon monoxide is produced from the partial oxidation of carbon-containing compounds. (https://en.wikipedia.org/wiki/Carbon_monoxide). It is also produced by the combustion of organic compounds in an oxygen-deficient atmosphere. It is used in metallurgy and in organic synthesis of methanol, acetic acid, aldehydes and numerous other compounds (<http://www.thermopedia.com/content/614/>). It is produced by combustion reactions in air defect (ie when the oxygen present in the air is not sufficient to convert all the carbon into carbon dioxide), for example in forest and wood fires, where the main product of combustion remains carbon dioxide. Other natural sources are volcanoes, while most are generated by photochemical reactions that occur in the troposphere. It is also released during combustion in enclosed spaces and old liquid gas stoves, which are responsible for the high frequency of carbon monoxide poisoning. The sources of emission from which the CO is present in the lower layers of the atmosphere are of two distinct types: the natural sources and the anthropic sources, deriving therefore from human activities.

The natural sources are constituted by some geophysical processes and some biological processes. Among the first are the volcanic emissions, natural gas emissions and electrical discharges produced during thunderstorms. Among the biological processes we must remember the metabolism of jellyfish in the seas, the germination of seeds and the development of plants, the emissions from the oceans and marshes and the oxidation of methane and other hydrocarbons. However, the quantities of CO produced in this way are totally negligible in the air of the inhabited centres, compared to the quantities produced in an anthropic way.

In the exhaust fumes of petrol cars, 3.5-10% consists of CO. The highest concentrations occur when the engines run at idle and when their operating regime is quite irregular (continuous accelerations and decelerations typical of traffic inside urban centres). In recent years, interventions to rationalize and regulate traffic in urban centres have contributed to a

general reduction in the levels of CO in the urban atmosphere of large population centres with undisputed environmental advantages.

Industrial emissions are mainly due to iron and steel production processes, which consist in the enrichment of minerals in sintering plants (which improve their chemical and physical properties), in the production of cast iron in blast furnace and in the activity of foundry. In addition to iron and steel processes, the emissions of CO in petrochemicals and in the oil refining industry must also be reported. Emissions from refineries largely derive from the regeneration process of the catalysts used in the oil transformation process. Other CO emissions come from the furnaces used to regenerate lime from calcium carbonate. Then there are CO emissions from combustion in fixed plants that use coal, fuel oil and wood as fuel, while the use of natural gas in these plants produces totally negligible CO emissions. Fortunately, carbon monoxide is present in much smaller concentrations in the atmosphere. There is no doubt that carbon monoxide is a pollutant that can potentially damage all living things. But does CO also influence the Earth's climate? Unlike carbon dioxide, carbon monoxide is not known as a direct contribution to climate change. However, it plays a role in this area. It is different from most pollutants. It can persist in the atmosphere for about a month and can be transported over long distances. However, it is not evenly distributed on Earth. This NASA Science Brief on Carbon Monoxide explains the issue further. Although carbon monoxide is only a weak greenhouse gas, its influence on climate goes beyond its own direct effects. Its presence affects concentrations of other greenhouse gases including methane, tropospheric ozone and carbon dioxide.

Carbon monoxide readily reacts with the hydroxyl radical (OH) forming a much stronger, greenhouse gas: carbon dioxide. This, in turn, increases concentrations of methane, another strong greenhouse gas; because the most common way methane is removed from the atmosphere is when it reacts with OH. So, the formation of carbon dioxide leaves fewer OH for methane to react with, thus increasing methane's concentration. A NASA report indicates that carbon monoxide is responsible for a 13% reduction in hydroxyl concentrations and through other reactions, a 9% drop in sulphate concentrations. Sulphates are credited for offsetting some of the global warming due to greenhouse gases by reflecting incident solar

radiation back to space. Like many pollutants, carbon monoxide has both anthropogenic and natural sources. Natural sources include volcanoes and forest fires while human sources (which make up over half of all carbon monoxide produced) are mainly vehicle emissions and slash and burn agriculture, but also include some industrial activities. As automobile emission controls have improved in recent years, carbon monoxide emissions in western countries have decreased. However, a rapid increase in industrialization and in the number of automobiles in rapidly developing countries like China and India have resulted in increased carbon monoxide emissions in those countries. Your team has been approached by an international foundation concerned about this increase. They are looking forward to your Earth System Science (ESS) analysis.

Biomass burning includes fires started by lightning and fires started by humans. The latter includes fires for the purpose of land clearing to increase agricultural areas or to get rid of the stubble from the previous year's crops. NASA satellites are able to track the huge plumes of carbon monoxide resulting from these fires.

3 Material and methods

3.1 Description of satellite data

Satellite technology has transformed our ability to observe the state of our planet. Our understanding of the Earth and its key systems has improved significantly since the launch of the first observation satellites in the 1960s. Satellites have the unique ability to provide global coverage of the earth's surface and atmospheric composition that cannot be used on land monitoring techniques. The improvements in weather forecasts and natural resource management that have been made possible by Earth observation satellites have had great socio-economic benefits. Atmospheric concentrations of greenhouse gases have risen sharply in recent decades as a result of human activity. Climate changes could have large harmful impacts on human well-being. As a result, there have been international efforts to reduce greenhouse gas emissions, with many countries setting legally binding targets for reductions in the coming decades. Gas emissions are calculated using standardized accounting approaches based on economy and land management data. The emission factors concern the economic and land management data, also known as activity data, to greenhouse gas emissions, for example the amount of CO released per unit of spent fuel. Uncertainties in emissions can derive both from the activity data and from the emission factors used, which can often be difficult to measure or highly variable in different circumstances. Uncertainties about these "bottom-up" calculations of CO emissions generated countries are less than 10%. CO emissions from developing countries and emissions of other greenhouse gases in general have greater uncertainties. Compared to ground-based measurements, the main advantage of satellite measurements is their ability to provide global coverage. Satellite measurements derive from the atmosphere gas concentrations that use the properties of the gases to absorb electromagnetic radiation at specific wavelengths. These instruments mainly use the solar radiation that is reflected from the earth's surface, but some can use the radiation emitted by the Earth or by lasers on board the satellite. An instrument that measures radiation at specific wavelengths is known as a spectrometer.

Satellite-based spectrometers use different wavelengths to measure CO based on their absorption spectra. Satellites that observe the shortest near infrared wavelengths are sensitive to carbon monoxide concentrations near the surface and, therefore, these have proved more useful for investigating surface emissions. Other satellites have been used to detect CO concentrations in the middle of the troposphere of about 6 to 11 km above the earth's surface using thermal infrared plus longer wavelengths (for example, the AIRS and IASI satellites). Detection of column-mediated CO mean concentration of CO inside a vertical column from the earth's surface to the top of the atmosphere is based on the measurement of absorption in three near infrared wavelength bands. These bands are weak and strong.

CO absorption bands about $1.58\mu\text{m}$ and $2.06\mu\text{m}$, respectively, and the band A of molecular oxygen (O_2) in the vicinity of $0.76\mu\text{m}$. Absorption at the weak CO band at $1.58\mu\text{m}$ allows to measure the column-mediated CO because there is very little absorption by other atmospheric gases at this wavelength. However, absorption can also be affected by surface variations pressure due to topography or local weather conditions, or from clouds or aerosols. To take into account the variations in absorption due to surface pressure and to detect clouds, absorption spectra at band A of O_2 a $0.76\mu\text{m}$ are used. Atmospheric O_2 concentrations are constant and, therefore, absorption spectra can be used in the A band of O_2 to derive the surface pressure and the effects of cloud and aerosol dispersion. Observations to the strong absorption band of carbon monoxide at 2.06 microns are used to further limit the impacts of aerosol on full-column CO estimates, as absorption in this the band is very sensitive to the presence of aerosols.

Therefore, regions are frequently obscured as some areas of Italy tend to have poorer coverage. In the lower display mode, the instrument is facing down towards the surface, measuring the absorption of sunlight reflected in the atmospheric column directly below the satellite. Because the measurements rely on reflected sunlight, Nadir measurements are not possible over dark surfaces, such as the ocean. An alternate viewing mode can be used, glint mode, in which the instrument is angled to point at the bright glint spot on the Earth's surface where specular reflection of solar radiation occurs. The use of reflected sunlight also means that observations cannot be made at night-time or at high latitudes during the winter

months. The current satellites that measure CO use the orbits around 600 km of altitude that pass near the earth poles. As the Earth rotates below the satellite, the surface is shifted in longitude from the previous step. The width of the Earth's surface observed by the satellite is known as the swath. The footprint refers to the area of an individual measurement within the swath. Another observational approach uses geostationary satellites, which orbit the Earth at about 36,000 km of altitude. In such a way their orbital period is synchronous with the earth's rotation and remains in constant view of a particular region. Geostationary satellites provide more measurements per day and could be particularly useful for observing urban areas. The emission or removal rate of an atmospheric gas is indicated as a flow. Atmospheric concentrations of CO are governed not only by its flows, but also by the transport and mixing of air. For example, increased CO concentrations from downwind of an area with high CO emissions are likely, but the concentration depends on the rapidity of emissions mixed with the surrounding air. To estimate the space distribution and amount of CO flows using atmospheric concentration measurements, atmospheric transport models including wind speed and other meteorological data must be included. Satellite data is provided free of charge to the public through several access portals. Different types of data can be provided, which are often referred to as data levels. Generally, Level 1 data includes calibrated spectra and radiances for individual satellite observations. Level 2 data contains the calculated physical quantity of interest, for example, column mediated CO concentration for an individual observation. Level 3 data includes grid or interpolated maps. Sometimes higher-level products are also available; for example, estimates of regional CO flows. The monitoring system is developing various projects to be investigated carbon streams that use satellite data and to create data products useful for researchers, policy makers and the private sector. The National Aeronautics and Space Administration (NASA) has acquired a rapidly growing archive of terrestrial remote sensing data, thanks to the Landsat and Nimbus satellite missions in the 1970s and continuing with technologically advanced missions, marked by the recent launches of the Global Precipitation Mission (GPM) and Orbiting Carbon Satellites of the Observatory 2 (OCO-2). The GIOVANNI system provides access to a wide variety of NASA remote sensing data and other datasets related to earth sciences, which allow researchers

to apply selected data to a wide range of research. It is currently hosted by the Goddard Earth Sciences data and information centre (GES DISC, GIOVANNI includes data from many different NASA missions and projects. One of GIOVANNI 's main attributes is its ease of use. GIOVANNI provides remote sensing data along with several basic analytical capabilities, which includes spatial maps of data variable values, difference maps, average area time series, animations and vertical profiles of atmospheric variables. The mapping capacity includes the fast average, then the average values for months, seasons or years can be displayed easily. All maps and graphs generated by GIOVANNI can be downloaded immediately. GIOVANNI allows the execution of operations that required days and weeks for the acquisition of data with procedures to be performed in a few minutes, allowing more detailed analyses with considerably reduced times. The measurements of tropospheric carbon monoxide from space occur with the MOPITT (Measurement of Pollution in the Troposphere) sensor on-board of the NASA Terra spacecraft. The MOPITT measurements allow scientists to analyse the distribution, transport, sources and sinks of CO, a trace gas produced by the oxidation of methane, the consumption of fossil fuels and the combustion of biomass. MOPITT has been operational since March 2000. It has been designed to improve knowledge of the lower atmosphere and to observe how it interacts with terrestrial and oceanic biospheres. The specific focus of MOPITT is on the distribution, transport, sources and sinks of carbon monoxide in the troposphere. The CO hinders the natural ability of the atmosphere to free itself from harmful pollutants. MOPITT is the satellite sensor to use gas correlation spectroscopy (<https://terra.nasa.gov/about/terra-instruments/mopitt>). The sensor measures the radiation emitted and reflected from the Earth in three spectral bands. When this light enters the sensor, it passes through two different paths through the carbon monoxide containers on board. The different paths absorb different amounts of energy, leading to small differences in the resulting signals that are related to the presence of these gases in the atmosphere. MOPITT's spatial resolution is 22km at Nadir and it 'sees' the Earth in swaths that are 640km wide. Moreover, it can measure the concentrations of carbon monoxide in 5km layers down a vertical column of atmosphere, to help scientists track the gas back to its sources. MOPITT Version 8 Level 2 and Level 3 products are now available for the entire MOPITT mission. MOPITT V8 products, for data acquired after March

11 2018, are considered to be provisional ("beta"), subject to recalibration, while data taken before this date are considered archival quality. MOPITT Version 7 Level 2 and Level 3 products are also available for the entire MOPITT mission. Generally, V8 and V7 Level 2 and Level 3 products should become available between three weeks and two months after the actual observations. Version 6 Level 2 and Level 3 products were discontinued as of September 2017.

NASA offers MOPITT products through the following links:

- Earthdata (V7 and V8, Level 2 and Level 3)
- Giovanni (V7 Level 3)
- ASDC data pool via ftp (V7 and V8, level 2 and level 3)
- ASDC data pool of OPeNDAP (V7 and V8, Level 2 and Level 3)
- ASDC MOPITT subserver (Level 2 V7)

The MOPITT project includes three elements: hardware, data production and data analysis. The MOPITT tool was designed by Dr. Jim Drummond and the MOPITT / Canada team at the University of Toronto. The infrared radiation in the absorption bands of CO and methane are measured using the gas-filter correlation radiometry technique. Through the application of the MOPITT recovery algorithm to the calibrated radiations, the vertical profiles of the CO concentration are obtained on a global basis at a moderately high horizontal resolution (~ 22 km). (Methane recoveries so far have not been successful because of problems with excessive "noise" from both instrumental and geophysical sources.) Ultimately, the recovered CO profiles are analysed directly or are assimilated into models for studying chemistry and dynamics of the CO (and other components) in the lower atmosphere. As documented by numerous published articles, the CO recoveries of MOPITT have been accurately validated in a variety of geographical settings. Funding is provided by the Space Science Division of the Canadian Space Agency. Funding for the US effort, including the development of software for the processing of scientific data and scientific data products, is

provided by the NASA Goddard Space Flight Center. Global plots of MOPITT CO products at 1 degree horizontal resolution can be viewed for each day and month of the MOPITT mission.

3.2 Analysis of satellite data

Launched in 1999, the MOPITT instrument on-board NASA's Terra spacecraft makes CO measurements with a thermal and near-IR Nadir-viewing gas-correlation radiometer. MOPITT has a nadir pixel size of 22X22 km and uses a cross-track scan to provide complete global coverage in three days. We use monthly averaged CO mixing ratio profiles reported at a horizontal resolution of 11 on seven vertical levels for cloud-free scenes [Deeter et al., 2003]. Our study uses the 700hPa level because MOPITT has little sensitivity to CO within the boundary layer.

[Deeter et al., 2003; Emmons et al., 2004]. The data have been additionally filtered to use only those profiles where the fraction of the retrieval based on the a priori is less than 50%. A validation study by Emmons [Emmons et al. 2004] showed a good qualitative agreement with in situ profiles, with a 20% high bias at all levels. The measurement precision above 700hPa is ~10%. In these spectral regions, surface temperature dominates as the source of radiance variability. In contrast, the D-signal response is highest very close to the absorption lines. These signals are relatively much more sensitive to atmospheric target gas concentrations than the A-signals. The spectral position of the maximum of the D-signal response function will depend on the particular type and operating parameters of the modulation cell. For example, increasing the absorption for both the minimum and maximum cell absorption states will tend to push the D-signal response function maxima farther into the line wings and away from the line centre. The physical basis of MOPITT's ability to detect tropospheric CO and CH₄ lies in the principles of gas correlation radiometry. Modulation cells containing each of the target gases act as high-spectral resolution optical filters. The filtering characteristics of the cells vary dynamically by modulation of either the cell pressure [Taylor, 1983] (as in a pressure-modulated cell or "PMC") or the optical path length through the absorbing gas [Tolton and Drummond, 1997] (as in a length-modulated cell or "LMC"). In both types of cells, the applied modulation has the effect of varying the

spectral absorption (and emission) only in the vicinity of the absorption lines of the gas contained in the cell. Measurements of the transmitted optical intensity in the modulation cell states of minimum and maximum cell absorption are combined to form two synthetic signals. The average signals (or "A-signals") and difference signals ("D-signals") are calculated, respectively, by taking the mean and the difference of the measured radiances in the cell states of minimum and maximum absorption. The equivalent spectral response functions of these synthesized signals are described by the A- and D-signal response functions [Pan et al., 1995]. Retrievals of CO may involve up to six channels (12 measured signals) in two distinct bands: two channels in a solar reflectance band near 2.3 microns (channels 2 and 6), and four channels in a thermal emission band near 4.7 microns. The thermal band channels include two LMC channels (channels 1 and 5) and two PMC channels (channels 3 and 7). The eight thermal band signals are sensitive to thermal emission from the Earth's surface as well as atmospheric absorption and emission. The solar band signals are sensitive to atmospheric CO through absorption processes only. It is implicitly assumed in the following that only clear-sky radiances (i.e., radiances uncontaminated by clouds) are fed to the retrieval algorithm. A detailed description of the MOPITT cloud detection algorithm has recently been published. The general concepts underlying the MOPITT CO retrieval algorithm have been discussed in detail previously. Recently, however, significant changes have been made to the MOPITT CO retrieval algorithm in order to improve the quality of the retrieval products and make them more useful to potential data users. In addition, after MOPITT became operational, the retrieval algorithm was reconfigured in response to observed noise and bias characteristics of the operational (in-orbit) MOPITT radiances. The purpose of this study is to describe the current operational retrieval algorithm used to process the MOPITT radiance data in detail, describe the MOPITT CO retrieval products (with reference to the retrieval averaging kernels), and finally present some selected actual retrieval results which demonstrate the capabilities of this new tool for global atmospheric chemistry studies. In atmospheric remote sensing, the common problem of inverting a set of measured radiances to determine aspects of the atmospheric state (temperature profile, trace gas mixing ratio profiles, etc.) is often ill-conditioned, meaning that no unique solution exists. Thus additional information of some type is usually

required to constrain the retrieval to fall within physically reasonable limits. The CO retrieval algorithm used for MOPITT exploits the maximum a posteriori ("MAP") solution which is a specific type of optimal estimation technique. The general strategy of such techniques is to seek the solution most statistically consistent with both the measured radiances and the typical observed patterns of CO vertical profiles as represented by the a priori. The equation relating the true atmospheric state and the measured radiances can be written as $S_i^R = S_i^D / S_i^A$

For these reasons, the solar band channels are represented in the measurement vector only through the solar ratio signal S_i^R . The thermal band signals depend not only on the atmospheric CO distribution but also on various other atmospheric quantities (such as the atmospheric temperature and water vapour mixing ratio profiles) and surface parameters (surface temperature T_{sfc} and longwave emissivity E_{sfc}).

Accurate values for all of these geophysical parameters must be obtained to produce accurate retrievals. Atmospheric temperature and water vapour profiles are obtained by spatially and temporally interpolating reanalysis profiles from NCEP to the location and time of each MOPITT pixel. However, sources of geophysical data such as NCEP are unable to provide accurate values of surface temperature and emissivity (both of which are highly variable) at the temporal and spatial resolution demanded by the MOPITT retrievals. Fortunately, information contained in the MOPITT thermal band signals allows retrieval of the surface temperature and emissivity along with the CO profile, and makes external data sources for these quantities necessary only for providing a priori and initial guess values.

Thus, rather than assuming fixed values for T_{sfc} and E_{sfc} , both parameters are included in the retrieval state vector x along with the elements of the CO profile. A detailed inspection of the radiative roles of T_{sfc} and E_{sfc} reveals that their effects on the thermal-band signals are often nearly indistinguishable. Therefore MOPITT radiances do not always contain sufficient information to retrieve both parameters independently. Both parameters are included in the retrieval state vector because they represent physically different sources of radiance variability and assuming fixed values for either parameter would unnecessarily constrain the CO retrieval). For several reasons, operational MOPITT radiances may not be perfectly modelled by the operational forward model (which is perhaps the most critical component of

the retrieval algorithm). Such errors, which may be manifested as either excessive random radiance errors or systematic radiance biases, can produce significant degradation of the retrieval product. For example, early operational MOPITT.

A-signal radiances exhibited a systematic bias which was found to be caused by relative spectral shifts in the initial assumed (pre-launch) and operational (post-launch) optical band-pass filter profiles [Deeter et al., 2002]. This particular source of radiance bias has since been eliminated, though it is possible that other more subtle sources of radiance error still exist. Rather than initially attempting to “force” the CO retrieval algorithm to incorporate all available radiances, we have taken a more conservative approach. Specifically, we have chosen to base the retrievals on the minimum number of radiances necessary for a useful CO profile retrieval. The radiances actually used for the retrievals described throughout the rest of this work include the A signal for channel 7, and the D signals for channels 1, 3, and 7. The channel 5 D signal was excluded because of an apparent radiance bias which greatly degraded the retrievals. A-signal radiances for channels 1, 3, and 5 were excluded because of the high redundancy of the information contained in these signals with the information contained in the 7A signal (signals 1A, 3A, 5A, and 7A are all primarily sensitive to surface temperature and emissivity rather than atmospheric CO).

The solar CO channels 2 and 6 were excluded from the retrievals because of low observed signal-to-noise ratios. (Techniques for reducing the apparent noise in these channels are under development). Although the MOPITT CO retrieval results reported here are based on only four of the available signals, no ‘ad-hoc’ correction factors have been applied either to the radiances or retrieval results. Similarly, the forward model has not been revised to force the retrieval results to behave in any particular way. Signals currently excluded from the retrievals will be incorporated into future versions of the retrieval algorithm after issues of signal-to-noise ratio and radiance bias are resolved.

As defined in equation, the weighting function matrix K defines the sensitivity of the MOPITT CO radiances (contained in the measurement vector y) to the elements of the state vector x (surface temperature Tsfc, surface longwave emissivity _sfc, and discretized CO profile). Numerically, K is calculated by a finite difference algorithm using the operational forward model to calculate the change in each of the MOPITT radiances per unit change in the values

of each of the state vector elements. The sensitivities of the MOPITT radiances to surface temperature and emissivity have been described previously [Pan et al., 1998]. Generally, the thermal-channel “A” radiances (only one of which is used in current operational retrievals) are much less sensitive to changes in the CO profile than are the thermal-channel “D” radiances. Thus the information in the four thermal channel A-signals is highly redundant. The weighting functions shown were calculated for the a priori CO profile. Significant variability of the weighting functions is associated with variability of the atmospheric temperature profile, “true” CO profile, and surface temperature. Thus geographic and seasonal variability of the weighting functions results in significant variability in the vertical sensitivity of the retrievals.

After downloading CO data from the Giovanni web-portal the latter are then visualised by another program called Panoply:

<https://www.giss.nasa.gov/tools/panoply/download/>).

It is a Java application that allows the user to track raster images geo-geographical data (geo-referenced) from data sets in netCDF format:

[\(https://www.unidata.ucar.edu/software/netcdf/\)](https://www.unidata.ucar.edu/software/netcdf/).

Depending on the type of data available, Panoply can be used to create displays in various ways:

- Draw longitude-latitude data as global maps or zonal averages, using one of over 40 projections of global maps
- Overlapping of continental contours or masks on latitude or longitude graphs just trace a particular region.
- View specific latitude-longitude or latitude-vertical arrays from larger multidimensional variables as sections

Panoply also works as a tool for the analysis and reporting of graphical data results by allowing the user to:

- Combine two arrays in a graph by differentiating, adding or average

- Use one of the 30 available colour bars (depending on PAL, ACT or CWC colour tables) or add a custom colour bar.

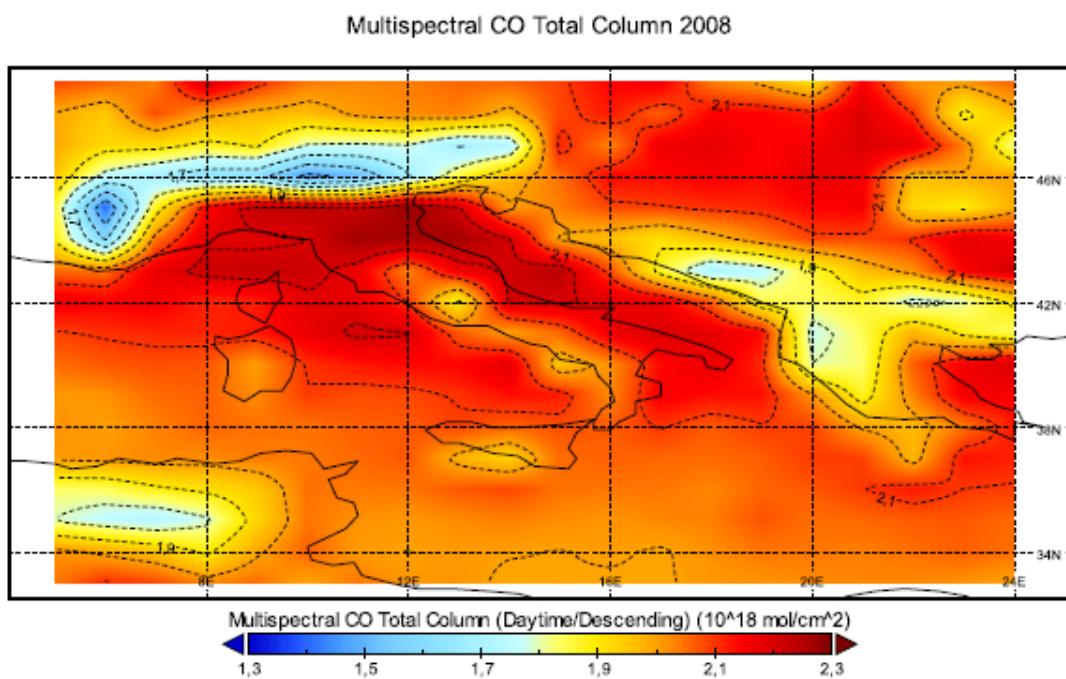
4 RESULTS

After downloading the data from the NASA website, with the PANOPLY application they were trained to track and get a graphical representation. The monthly and annual CO concentrations of the Milan metro area were then developed into a graphical output.

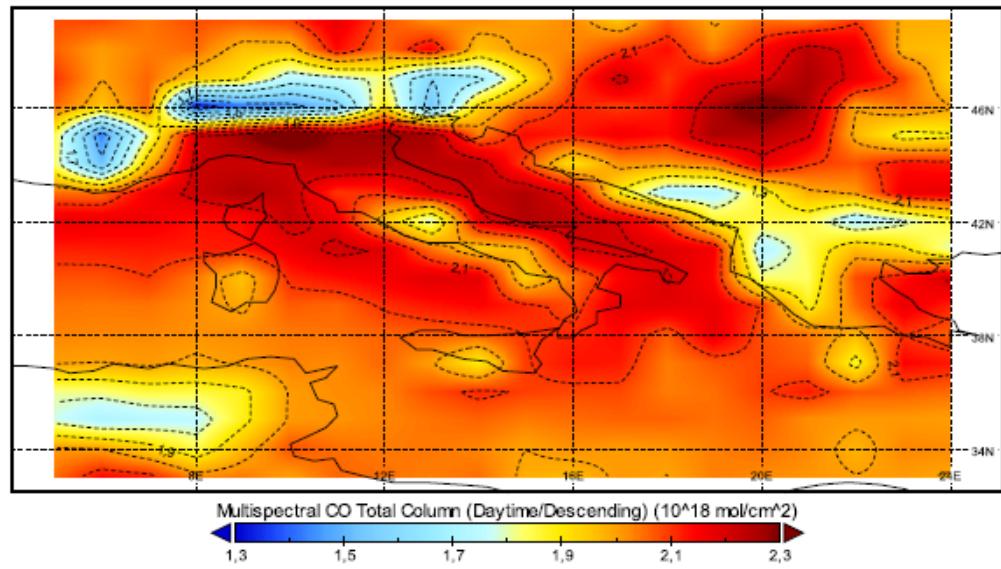
4.1 Carbon monoxide (CO)

4.1.1 Spatial maps

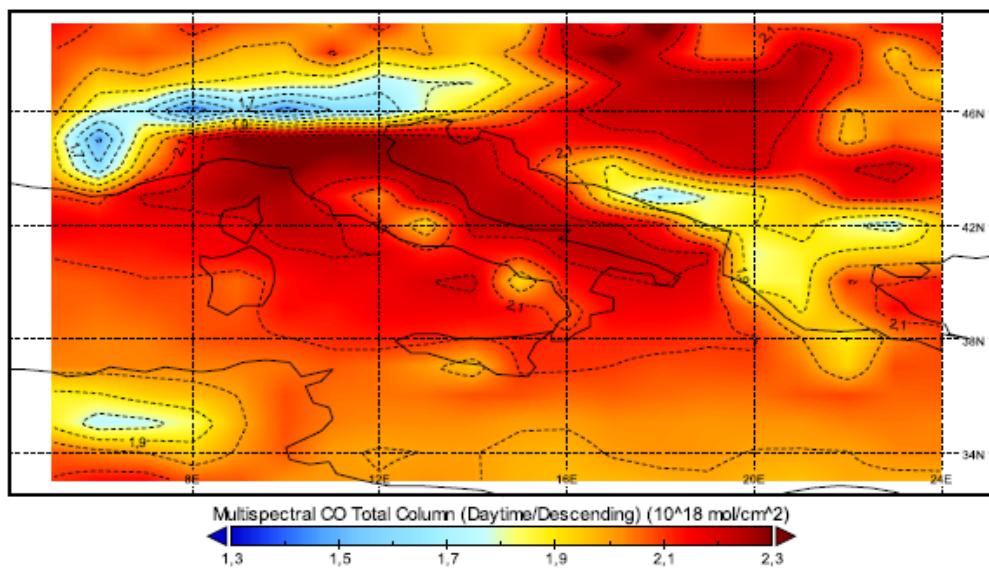
In some years it was not possible to use a single scale of representation because of the variability of the range of concentration values between the different months.



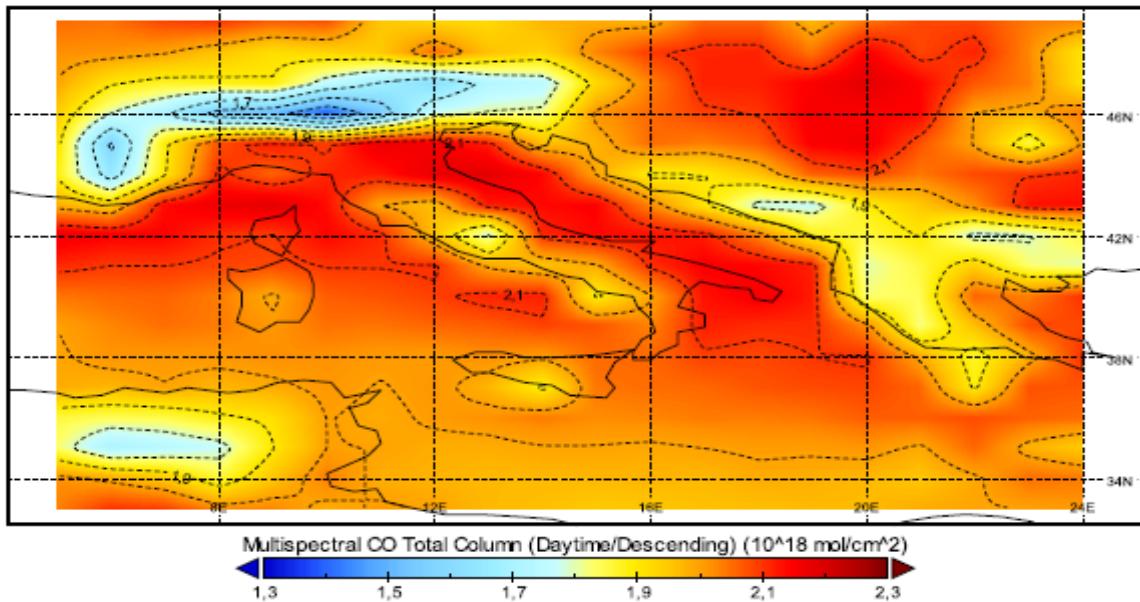
Multispectral CO Total Column 2009



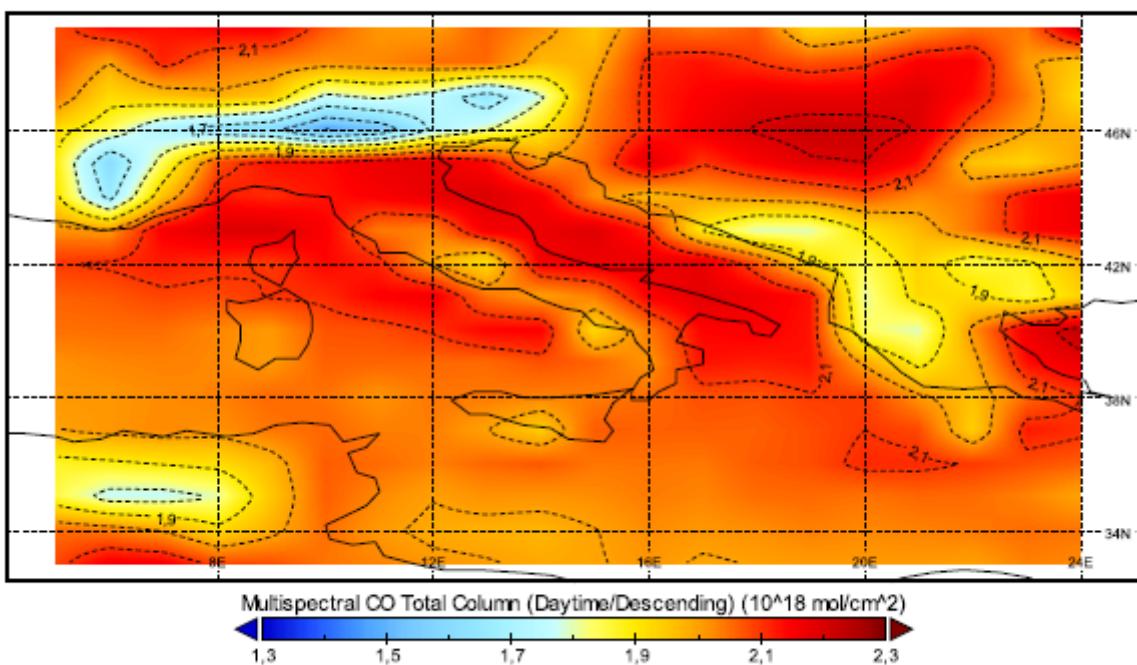
Multispectral CO Total Column 2010



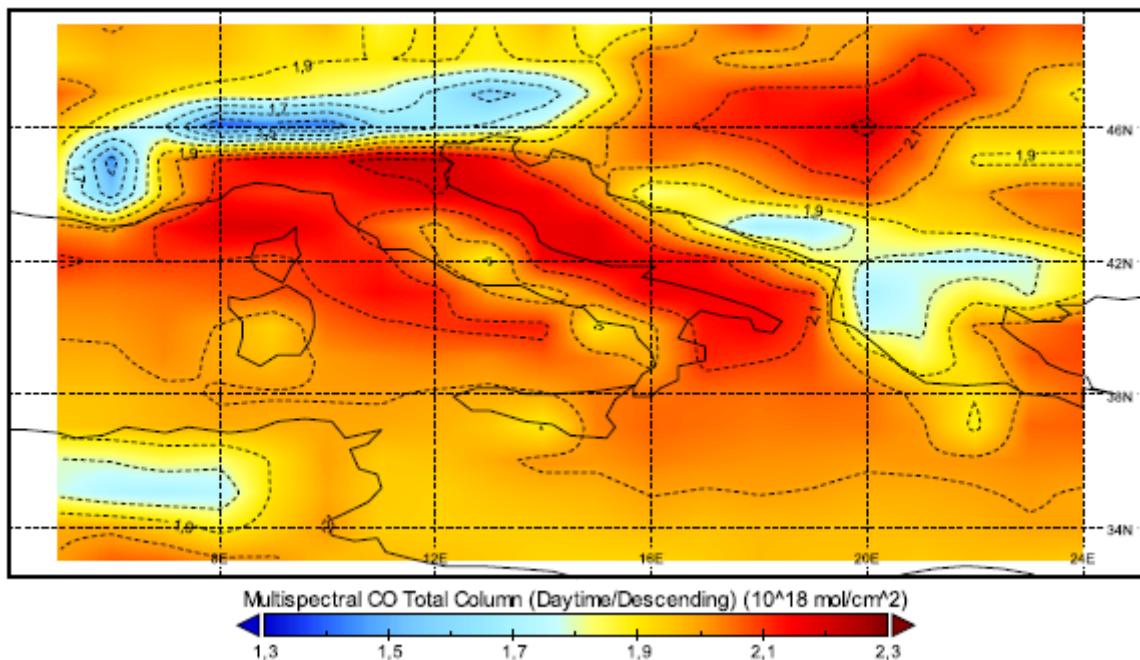
Multispectral CO Total Column 2011



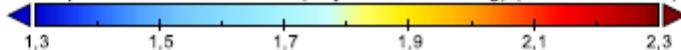
Multispectral CO Total Column 2012



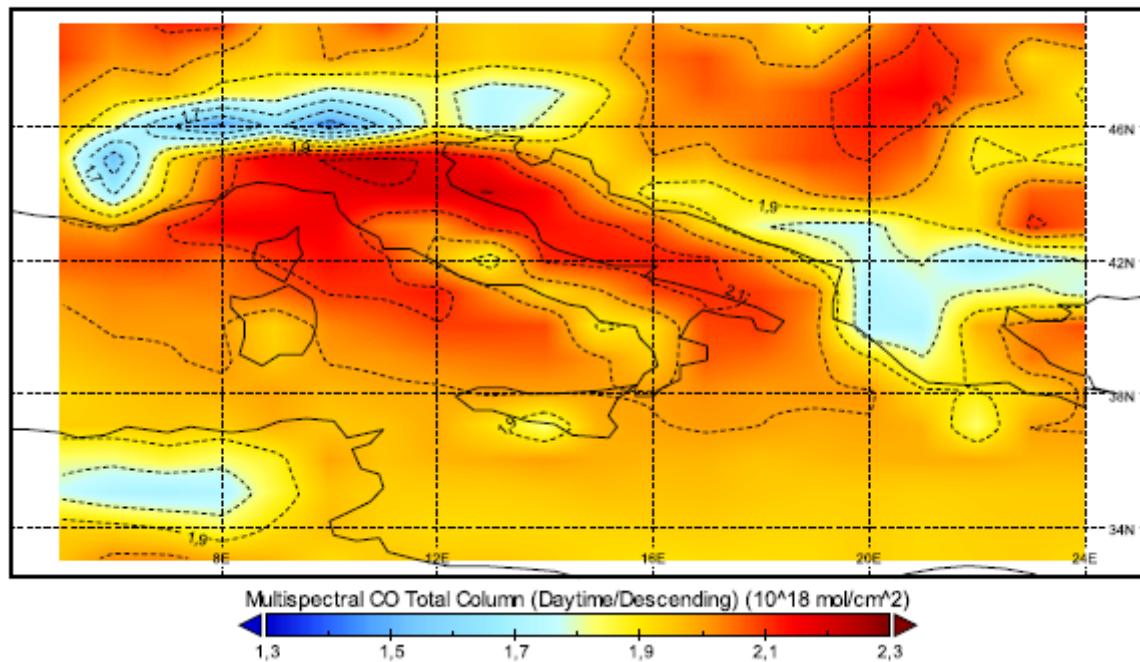
Multispectral CO Total Column 2013



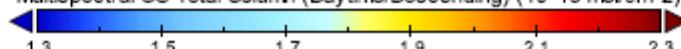
Multispectral CO Total Column (Daytime/Descending) (10^{18} mol/cm^2)



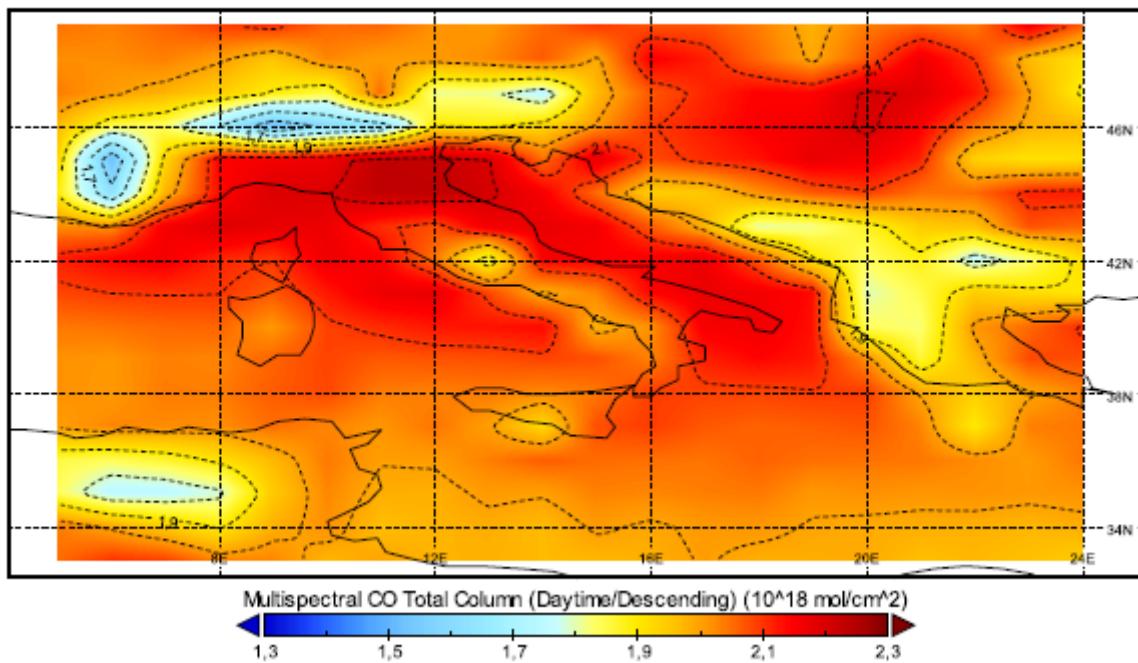
Multispectral CO Total Column 2014



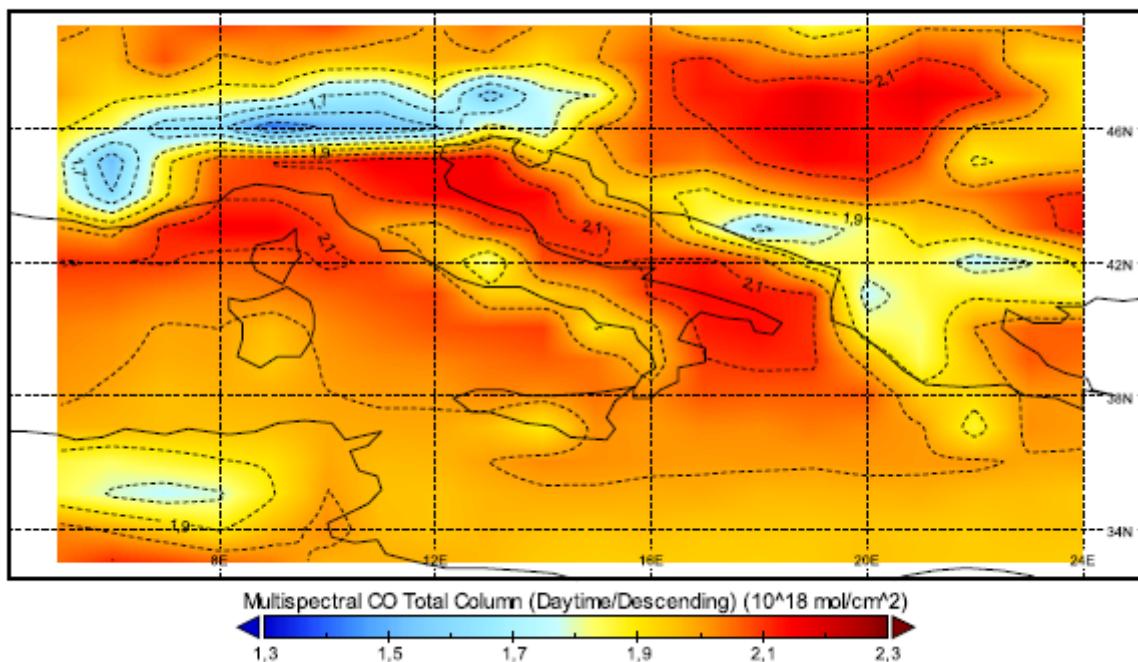
Multispectral CO Total Column (Daytime/Descending) (10^{18} mol/cm^2)



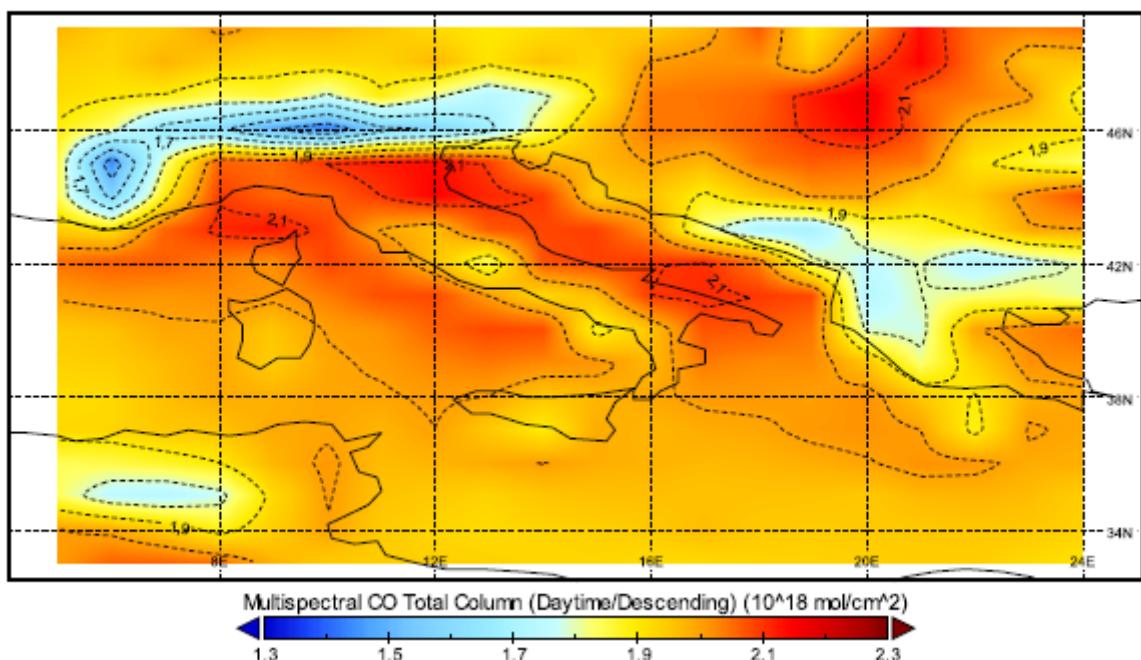
Multispectral CO Total Column 2015



Multispectral CO Total Column 2016



Multispectral CO Total Column 2017



4.1.2 Time series maps

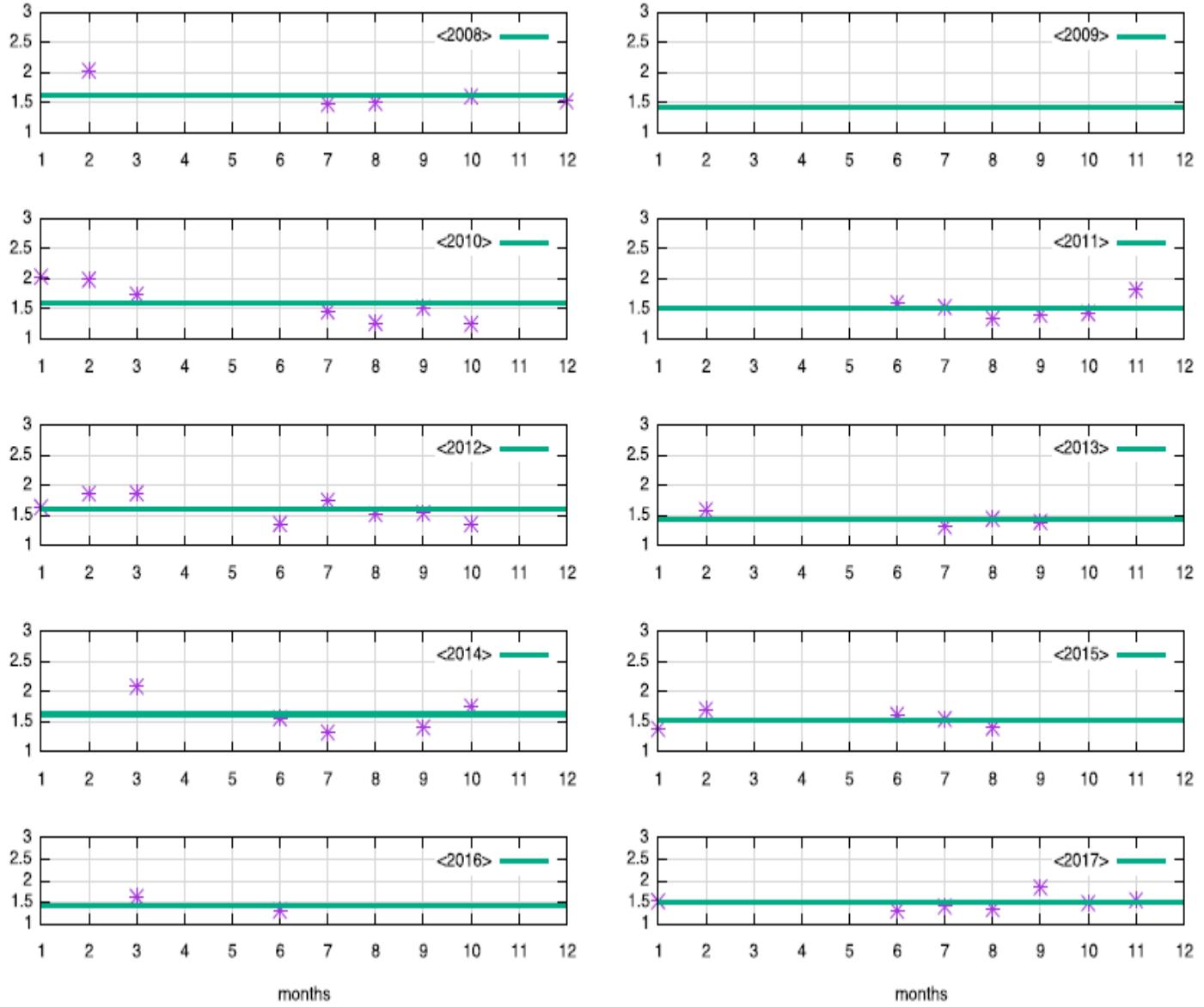


Figure 1: time series evolution of CO concentration over Milan metropolitan region. Unit of Y-axis is 10^{18} mol/cm 2 .

With reference to the Milan area, the annual trend basically confirms the maximum concentration in the winter months but less variability in the other months. It can also be noted that, overall, from 2008 to 2017 there was a general decrease in the average concentration in the interval of time considered. The atmospheric loading of CO shows a

pronounced seasonal variation. The Figures shows the recent interannual variation of the zonally averaged CO total column as measured by MOPITT since January 2008.

Data for both day and night-time measurements are included in this average. Intervals where no data are shown correspond to calibration events, or times when the instrument was experiencing problems. Emissions depend on biomass type, meteorology and combustion stage, with large amounts of CO, CH₄, and other hydrocarbons being emitted in the later smouldering stages of a fire.

Conclusions

The analysis of MOPITT-CO data that are showed above, highlight two important features: highest concentration levels on Pianura Padana; relatively high CO levels in the Adriatic Basin, caused by its transport from Balkan Area. The second aspect deserves further analysis and investigation especially with mesoscale chemical transport models. With reference to the Milan area, the annual time-series basically confirms the maximum concentration in the winter months with less variability in the other months and a general tendency of gradual decreasing of CO levels.

The meteorological conditions, with the same emissions, play a pier based on the levels of concentration of carbon monoxide present in the atmosphere.

The most influential, multi-level parameters on the measured concentrations are the wind speed, the height of the mixing layer (which also depends on the presence of thermal inversions), the passage of atmospheric disturbances, presence of rain, relative humidity, solar radiation.

These parameters control transport, dispersion and the deposition of gas and aerosols on the ground and influencing chemical transformations have direct and indirect effects on the formation of pollutants. Features topographical of the Pianura Padana, as can be seen from the results, strongly influencing the weather conditions, lead to typical weather climate of the region. Specifically, we observe how the Alps restrict often the air currents between northern Italy and the rest of continental Europe. In these conditions the atmospheric pollution has its cause the stagnation of air inside the basin, which needs more days to succeed to disperse the pollutants that have been placed there.

The winds characterize the phenomena of transport. The episodes influential in reducing concentrations of pollutants are characterized by a medium-strong wind.

In the Pianura Padana, due to the weakness of the winds, the most important contribution is given by the thermodynamic component. This explains why the CO concentrations show a marked seasonal cycle, with winter values much higher than the summer ones: as the

thermal turbulence depends on the solar radiation, the usual values of dust and CO, are about double compared in summer and almost all the limits exceeded law occur in winter. Critical conditions for air pollution they occur when the mixing height is low. The concentrations in air of carbon monoxide, measured in traffic stations, where they come from higher values registered, they are progressively reduced, remaining well below the legal limits for a long time. The graphs show the box plots relating to the annual average values of the maximum daily; the graph shows that CO is no longer a significant problem of atmospheric pollution. The combination of measurements from the new tropospheric satellite sensors will play an increasingly important role in explaining chemistry and transport processes in the lower atmosphere. Recent developments in aerosol retrieval techniques allow a distinction between fine and coarse mode particles. The fine mode particles are produced predominantly by anthropogenic combustion processes, which also lead to the emission of CO into the atmosphere. In this work, we have presented the first comparison of the Terra/MOPITT CO column Italian distributions, seasonal cycles, and recent inter-annual variability. This work is important for quantifying the effect of local emissions on the larger-scale pollution distribution, and also for providing a regional or global context to measurements taken at a specific time and location. In general, both the CO columns show highest concentrations in the populated cities. This reflects the greater population and the fact that the primary sources are anthropogenic. In the mountainous areas, large emission events such as biomass burning are the dominant sources and punctuate the seasonal cycle each year. Carbonaceous particles form the principal fine mode aerosol type in smoke from fires. The shifting latitudinal pattern of dry season burning dominates the observed pollutant distributions. The CO seasonal cycles are driven primarily by the atmospheric oxidant loading, which is greatest during the summer months. CO loading usually peaks in April and reaches a minimum in September. Wildfires and biomass burning generally provide the best correlation between CO column and the other pollutants. This is because direct emissions of both CO and aerosol from a common source dominate the measurements. Correlation of CO and sulphate over industrial sources is weaker because the SO₂ must be chemically processed to formulate, and because of transport of the longer-lived CO into the measurement area from other regions. Put another way, a high

degree of correlation between the fine mode, the other pollutants, and CO is indicative of carbonaceous particles composing significant fraction of the fine mode aerosol. This combined with the fact that the average CO lifetime is much longer than the several days lifetime of the predominant aerosol. The MOPITT CO measurement is more useful for tracing long-range transport of fire emissions. This produced an early build-up of the winter CO, and concentrations reached a minimum in 2016. Our model sensitivity studies indicate that such high emissions, late in the year when the OH concentrations are falling, can produce a particularly high CO loading all through the winter months. It is clear the fires can have a significant impact on pollutant loadings. It is also clear that there are large changes, year-to-year, in these emissions. This contrasts with the relatively constant industrial emissions of CO. The work described in this work provides an investigation of the available satellite data and a basis for future modelling studies. The MOPITT CO products could be combined in an inverse modelling scheme to mutually improve emission estimates of each. With the aid of these measurements, the improved model characterization of the CO should pave the way for better estimates of the effect of anthropogenic emissions on photolysis, heterogeneous chemistry, and the regional budget of key tropospheric oxidants.

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