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La terra vista dal cielo: la regione metropolitana di Milano

The earth seen from the sky: Milan’s metropolitan region

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ABSTRACT

The characteristics of atmospheric pollution are constantly changing in relation to the anthropic activity, for example, air over major cities in the world has become overburdened with gases produced by vehicles and domestic heating, together with the technological evolution and its applications. In the last years, people realized that polluted air has serious effects on their health and climate changing. Over the last decade the contribute of satellite remote sensing got a significant role since it has improved its accuracy and precision.

It is possible to retrieve information for a wide range of detectable chemical species including aerosols, tropospheric Ozone O_3, tropospheric nitrogen dioxide NO_2, carbon monoxide CO, formaldehyde HCHO and sulphur dioxide SO_2.

The aim of the work that will be described in this thesis is to give a knowledge about the atmosphere, the air pollution and how the satellites works and how they are used for the remote sensing and then focus on the analysis of the retrieval of satellite data, regarding four main pollutants such as nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3) and carbon monoxide (CO); the US Environmental Protection Agency (EPA) has designed these atmospheric constituents as posing serious threats to human health and agricultural productivity. Satellite data referring to the Ozone Monitoring Instrument (OMI) that can distinguish between aerosol types, such as smoke, dust, and sulphates, and measures cloud pressure and coverage, which provides data to derive tropospheric ozone.

The evolution of the concentration of the main pollutants has been analysed considering a period of ten years, from 2008 to 2017, in relation to the northern Italy area and focusing on the Milan's metropolitan region. Satellite data were processed through a software program and were used to create georeferenced maps and thematic maps in order to compare the situation over the years. Which specific reference to the Milan area, the trend for each year were graphically reproduced for each pollutant.

ASTRATTO

Le caratteristiche dell'inquinamento atmosferico sono in continuo cambiamento a causa dell'evolversi delle attività antropiche, come ad esempio si può constatare nelle grandi città, caratterizzate da un elevato numero di abitanti, dove l'aria è stata sovraccaricata da gas prodotti da veicoli e sistemi di riscaldamento domestici, uniti all'evoluzione tecnologica e alle sue applicazioni nei vari campi dell'industria. Con il passare del tempo la coscienza comune ha realizzato l'importanza degli effetti che l'inquinamento ha sulla nostra salute e sui cambiamenti climatici che sono sempre più evidenti. Negli ultimi anni il telerilevamento ha dato un contributo significativo, grazie allo sviluppo di tecnologie sempre più precise, capaci di fornire dati sempre più accurati.

È possibile ricavare informazioni riguardo una vasta gamma di specie chimiche come: aerosol, ozono troposferico O_3, diossido di azoto troposferico NO_2, monossido di carbonio CO, formaldeide HCHO e diossido di zolfo SO_2.

Lo scopo del lavoro descritto in questa tesi, dopo aver introdotto alcune nozioni sull'atmosfera, gli inquinanti, ed approfondito le dinamiche con cui funzionano e vengono utilizzati i satelliti, è quello di analizzare i dati satellitari raccolti riguardo i principali inquinanti oggetto della ricerca quali: diossido di azoto (NO_2), diossido di zolfo (SO_2), ozono (O_3) e monossido di carbonio (CO); l'EPA (Environmental Protection Agency) degli Stati Uniti ha segnalato questi componenti atmosferici come una minaccia alla salute umana e alla produttività agricola.

I dati satellitari derivano dalla piattaforma di monitoraggio dell'ozono chiama OMI (Ozone Monitoring Instrument) capace di distinguere tra diversi tipi di aerosol come: il fumo, le polveri ed i solfati, ed è inoltre capace di misurare la pressione e la copertura delle nuvole, fornendo dati dai quali possiamo dedurre informazioni sull'ozono troposferico.

L'evoluzione della concentrazione di questi principali inquinanti è stata analizzata prendendo in considerazione un periodo di dieci anni, dal 2008 al 2017, studiando l'area del Nord Italia, concentrando l'attenzione sulla città di Milano, nota appunto per la sua elevata densità abitativa e forte industrializzazione. I dati satellitari raccolti sono stati quindi processati attraverso un software utilizzato per creare mappe georeferenziate e mappe tematica allo scopo di comparare lo sviluppo della situazione nel corso degli anni. Per quanto riguarda l'area di Milano sono stati realizzati dei grafici indicassero l'andamento delle concentrazioni per ogni anno, per ciascuno degli inquinanti.

1. INTRODUCTION

1.1 The atmosphere

Earth's atmosphere contains the air we breathe, the weather we experience and is our natural shield against harsh condition of outer space including everything from meteors and falling satellites to deadly sun ultraviolet radiation. It is also fundamental to regulate the temperature of the planet.

The atmosphere is divided into five distinct layers, each with its own specific characteristics:

- The Troposphere:
  Is the lowest layer, starting at ground level, it extends upwards to about 10 km. Humankind live in the troposphere, and nearly all weather occurs in this lowest layer. Most clouds appear here, mainly because of 99% of the water vapour is found in the troposphere. Air pressure drops, and temperatures get colder, as you climb higher through the troposphere.

- The Stratosphere:
  It extends from the top of the troposphere to about 50 km above the earth surface. Ozone molecules in this layer absorb high-energy ultraviolet radiation from the Sun, converting the UV energy into heat. In this layer the temperature increases with altitude, which means that the air in the stratosphere lacks the turbulence and updrafts of the troposphere beneath. That's the reason why commercial jets fly in the lower stratosphere.

- The Mesosphere:
  Is the third layer of the atmosphere, it extends upward to a height of about 85 km above the ground. Most meteors burn up in the mesosphere. Temperatures once again grow colder as you rise up through this layer, with an average value of about -90 °C (-130 °F). Air pressure at the bottom layer is well below 1% of the pressure at sea level and continues dropping as you go higher.

- The Thermosphere:
  High-energy X-rays and UV radiation from the Sun are absorbed in the thermosphere, raising its temperature to hundreds or at times thousands of degrees. However, the air is so thin that it would feel freezing cold to our skin. In many ways the thermosphere is more like outer space than a part of the atmosphere. Many satellites actually orbit Earth within this layer. Temperatures

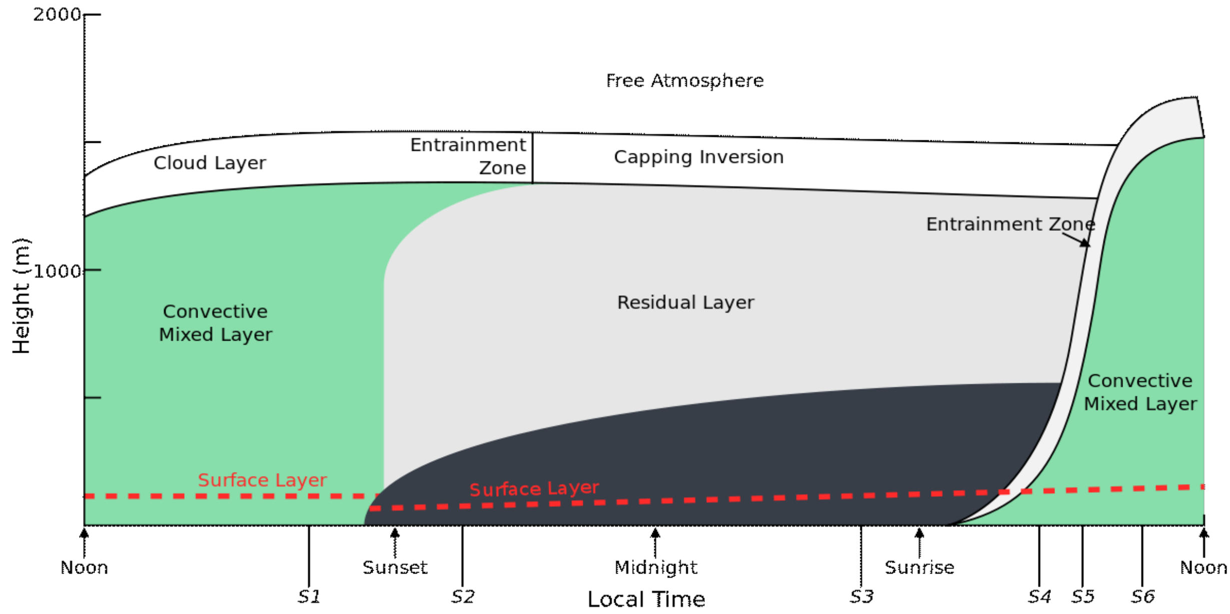
in the upper thermosphere can range from about 500 °C (932 °F) to 2.000 °C (3.632 °F).
The aurora, the Northern Lights and Southern Lights, occur in the thermosphere.

- The Exosphere:
  Is the actual "final frontier" of Earth's gaseous envelope. This layer extends from around 170 km above the Earth to nearly 10.000 km. There is no clear-cut upper boundary where the exosphere finally fades away into space.
  This layer contains a large portion of low-Earth orbiting satellites.

(UCAR – University Corporation for Atmospheric Research, http://scied.ucar.edu/atmosphere-layers)

1.1.1 Atmospheric Boundary Layer

The atmospheric boundary layer (ABL) is defined as the part of the troposphere that directly feels the effect of the Earth's surface. Its depth can range from just few meters to several kilometres depending on the local meteorology. Turbulence is generated in the ABL as the wind blows over the Earth's surface and by thermals (updrafts), such as those rising from land as it is heated by the Sun, but also thermals associated with clouds. All the turbulence redistributes heat, moisture and the drag of the wind within the boundary layer, as well as pollutants and other constituents of the atmosphere. In this context, it plays a crucial role in modulating the weather (temperature, humidity, air quality, etc...) as we experience it, living on the surface. The structure of the ABL changes during the day and it can be divided in the three major components that are the mixed layer, residual layer and the stable boundary layer as it's shown in the figure below.



(Fig. 1.1: Atmospheric Boundary Layer)

The turbulence in the mixed layer is usually convectively driven, although a nearly well-mixed layer can form in regions of strong winds. Convective sources include heat transfer from a warm ground surface, that creates thermals of warm air rising from the ground, and radiative cooling from the top of the cloud layer that create thermals of cool air sinking from cloud top. The mixed layer reaches its maximum depth in late afternoon. Right before the sunset the thermals cease to form, allowing turbulence to decay in the formerly well-mixed layer.
The resulting layer of air is called the residual layer, which is neutrally stratified. Because of these characteristics smoke plumes emitted in this layer tend to disperse at equal rates in the vertical and lateral directions. During the night the low portion of the residual layer is transformed into a stable boundary layer because of its contact with the surface. In this layer the air is statically stable, and the turbulence is weaker, as a result, pollutants emitted disperse relatively little in vertical.

(Met Office; Boundary Layer Meteorology – Stull, 1988)

1.2 Definition and classification of atmospheric pollution

Air pollutants are airborne substances that occur in concentration high enough to threaten the health of people and animals, to harm vegetation and structures, or to toxify a given environment. Air pollutants come from both natural sources and human activities:

Natural sources include wind picking up dust and soot from the Earth's surface and carrying it aloft, volcanoes belching tons of ash and dust into our atmosphere, and forest fires producing vast quantities of drifting smoke.
Anthropogenic sources include sources that encompass industrial complexes, power plants, homes, office buildings, and so forth; mobile sources include motor vehicles, ships, and jet aircraft.

NATURAL SOURCES	Volcanic eruptions, seismic activities, spontaneous fires, geothermal activities, wind storms, marine aerosols, biogenic emissions, etc...
ANTROPOGENIC SOURCES	Vehicular traffic, domestic heating, industries and crafts, off-road vehicles (trains, quarry vehicles, tractors, etc...), agriculture and other activities.

Atmospheric pollutants can also be classified into:

- Primary pollutants, because they enter the atmosphere directly from natural or anthropogenic sources.
- Secondary pollutants, form only when a chemical reaction occurs between a primary pollutant and some other component of the air, such as water vapour.

1.2.1 Carbon monoxide (CO)

A major pollutant of the modern metropolitan region, its colourless, odourless and a poisonous gas that forms during the incomplete combustion of carbon-containing fuels. Is the most plentiful of the primary pollutants. Because carbon monoxide cannot be seen or smelled, it can kill without warning. Here's how: normally, your cells obtain oxygen through a blood pigment called haemoglobin, which picks up oxygen from the lungs, combines with it, and carries it throughout your body. Unfortunately, human haemoglobin prefers CO to oxygen, so if there is too much carbon monoxide in the air, your brain will soon be starved of oxygen, and headache, fatigue, drowsiness may result.

(Essentials of Meteorology – C. Donald Ahrens)

1.2.2 Sulphur dioxide (SO_2)

It is a colourless gas that comes primarily from the burning of sulphur-containing fossil fuels (such as coal and oil). Its primary source includes power plants, heating devices, smelters, petroleum refineries, and paper mills. However, it can enter the atmosphere naturally during volcanic eruptions and as sulphate particles from ocean spray. Sulphur dioxide readily oxides to form the secondary pollutants sulphur trioxide (SO_3) and, in moist air, highly corrosive sulphuric acid (H_2SO_4). Winds can carry these particles at great distance before they can reach the Earth as undesirable contaminants. When inhaled into the lungs, high concentration of sulphuric dioxide aggravates respiratory problems, such as asthma, bronchitis and emphysema. Sulphur dioxide in large quantities can cause injury to certain plants, producing bleached marks on their leaves and reducing their yield.

1.2.3 Nitrogen dioxide (NO_2)

Nitrogen oxides are gases that form when some of the nitrogen in the air reacts with oxygen during the high-temperature combustion of fuel. The two primary nitrogen pollutants are nitrogen dioxide and nitric oxide (NO), which, together, are commonly referred to as NO_x. Although both (NO_2 and NO) are produced by natural bacterial action. In moist air, nitrogen dioxide reacts with vapour to form corrosive nitric acid (HNO_3), a substance that adds to the problem of acid. The primary source of nitrogen oxides are motor vehicles, power plants and waste disposal system. High concentration is believed to contribute to heart and lungs problems, as well as lowering the body's resistance to respiratory infections. Moreover, nitrogen oxides are highly reactive gases that play a key role in producing ozone and other ingredients of photochemical smog.

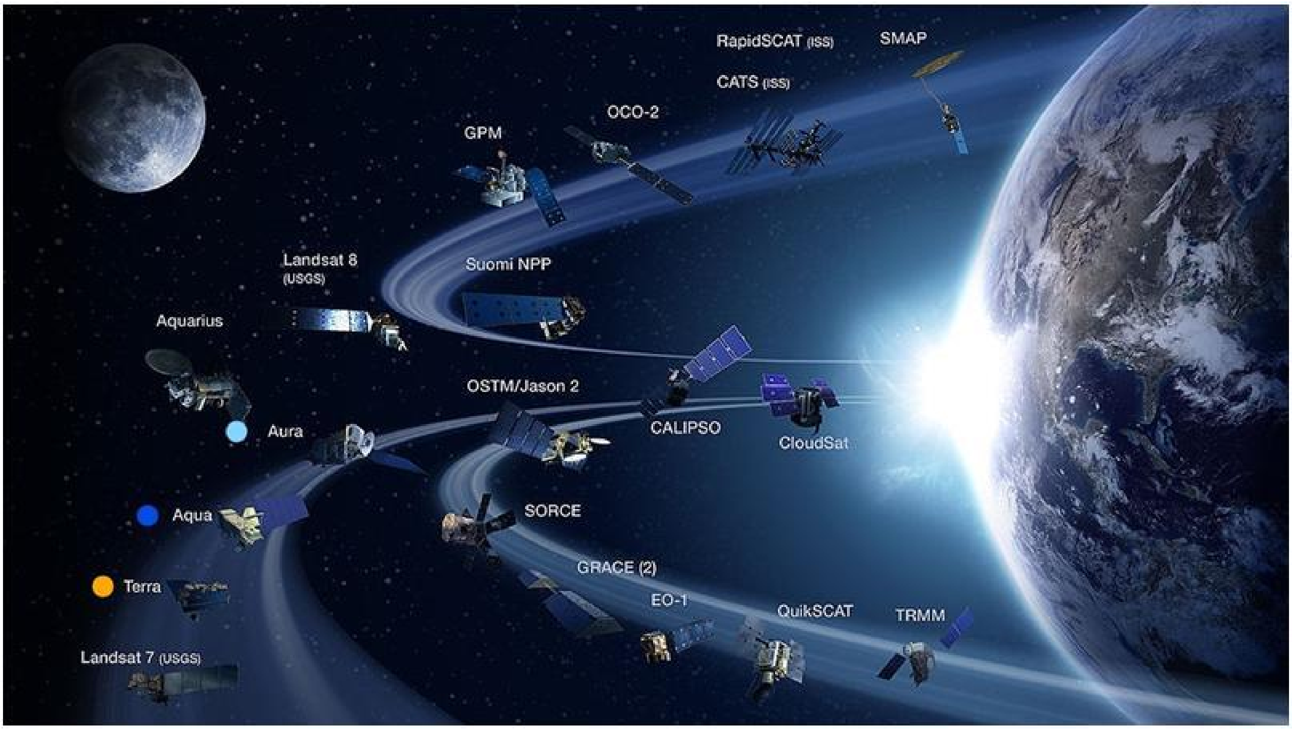
1.2.4 Ozone (O_3)

Ozone is a harmful substance with an unpleasant odour that irritates eyes and the mucous membranes of the respiratory system, aggravating chronic diseases, such as asthma and bronchitis. Ozone also arracks rubber, retards tree growth and damagers corps. Near the surface, in polluted air, ozone is a secondary pollutant that is not emitted directly into the air. Rather, such as nitrogen oxides and volatile organic compounds (VOC, hydrocarbons). Because sunlight is required to produce ozone, concentration is normally higher during the summer months, when sunlight is more intense. This type of smog forms when chemical reactions take place in the presence of sunlight is called photochemical smog.

2 SATELLITE PROCESSING OVERVIEW

2.1 Satellite history

The Earth Observing System (EOS) is a NASA's program comprising a series of satellite missions and scientific instruments in Earth orbit for the global monitoring of the land surface, biosphere, atmosphere and oceans.
(Wikipedia, 2020)



(Fig. 2.1: Earth Observing System satellites)

Each of those satellites carries different sensors used to observe and study specific parameters. Especially three of them: Terra, Aqua and Aura (Fig. 2.1).

- **Terra**: is a multi-national NASA scientific research satellite. It is the flagship of the EOS program, launched on December 18th, 1999. It carries five remote sensors (ASTER, CERES, MISR, MODIS, MOPITT) designed to monitor the state of Earth's environment and climate change. Of particular interest is the MOPITT (Measurement of Pollution in the Troposphere) developed to observe changes in pollution patterns and its effect in the lower atmosphere of the Earth. It uses correlation spectroscopy to calculate total column observation and profiles of carbon monoxide.
- **Aqua**: its designed to study the precipitation, evaporation and cycling of water. It's the second major component of EOS after Terra and it carries six sensors

including AIRS (Atmospheric Infrared Sounder) that measures atmospheric temperature and humidity, land and sea surface temperatures.

- **Aura**: (Latin for Breeze) it's the third major component of the EOS program. It studies the Earth's ozone layer, air quality and climate. It carries four instruments to investigate the atmospheric chemistry including OMI (Ozone Monitoring Instrument) that uses ultraviolet and visible radiation to produce daily high-resolution maps.

The research based on Milan metropolitan region is focused on four main pollutant which are: CO, NO_2, SO_2 and O_3. Remote sensors used to monitor the atmosphere concentration of those pollutant are MOPITT for the CO, and OMI for NO_2, SO_2 and O_3.

2.1.1 MOPITT

The sensor MOPIT, acronym for "Measurement of Pollution in the Troposphere", is an instrument designed to enhance our knowledge of the lower atmosphere and to observe how it interacts with the land and ocean biosphere. MOPITT's specific focus is on the distribution, transport, sources, and sinks of carbon monoxide (CO) in the troposphere. MOPITT is one of the earliest satellite sensors to use gas correlation spectroscopy. The sensors measures emitted and reflected radiance from the Earth in three spectral bands. As this light enter the sensor, it passes along two different paths through onboard containers of carbon monoxide. The different paths absorb different amounts of energy, leading to small differences in the results signals that correlate with the presence of those gases in the atmosphere. MOPITT's special resolution is 22 km at nadir and it "sees" the Earth in swaths that are 640 km wide. Moreover, it can measure the concentration of carbon monoxide in 5 km layers down a vertical column of atmosphere, to help scientists track the gas back to its sources.
(NASA Terra site, 2020, terra.nasa.gov/about/terra-instruments/mopitt)

2.1.2 OMI

The Ozone Monitoring Instrument can distinguish between aerosol types, such as smoke, dust, and sulphates, and measures cloud pressure and coverage, which provides data to derive tropospheric ozone. OMI continues the TOMS (Total Ozone Mapping Spectrometer) retrieval for total ozone and other atmospheric parameters related to ozone chemistry and climate. OMI measurements are highly synergic with the other instruments on the Aura platform. The OMI instrument employs hyper-spectral imaging in a push-broom mode to observe solar backscatter radiation in the visible and ultraviolet. The hyper-spectral capabilities improve the accuracy and precision of the total ozone amounts and also allow for accurate radiometric and wavelength self-calibration over the long term.

The instrument is a contribution of the Netherlands's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI) to the Aura mission.

OMI derives its heritage for NASA's Total Ozone Mapping Spectrometer (TOMS) instrument and the European Space Agency (ESA) Global Ozone Monitoring Experiment (GOME) instrument. It can measure many more atmospheric constituents than TOMS and provides much better ground resolution then GOME. OMI is a key instrument on Aura for monitoring the recovery of the ozone layer in response to the phase out of chemicals, such as CFC's, agreed to by the nations of the world in the Montreal protocol and later modifications to it at Copenhagen and London. OMI measures criteria pollutants such as O_3, NO_2, SO_2, and aerosols. The US Environmental Protection Agency (EPA) has designated these atmospheric constituents as posing serious threats to human health and agricultural productivity. These measurements are made at near urban scale resolution and track industrial pollution and biomass burning. OMI also detects volcanic ash and sulphur dioxide produced in volcanic eruptions.

The instrument observes Earth's backscattered radiation with a wide-field telescope feeding two imaging grating spectrometers. Each spectrometer employs a CCD detector. Onboard calibration includes a white light source, LEDs, and a multi-surface solar-calibration diffuser. A depolarizer removes the polarization from the backscattered radiation.

(NASA Aura site, 2020, aura.gsfc.nasa.gov/omi.html)

2.2 Remote sensing

Remote sensing is the acquiring of information from a distance. NASA observes the Earth and other planetary bodies via remote sensors on satellites and aircraft that detect and record reflected or emitted energy. Remote sensors, which provide a global prospective and wealth of data about Earth system, enable data-informed decision making based on the current and future state of our planet.

2.2.1 Orbits

There are three primary types of orbits in which satellites reside:

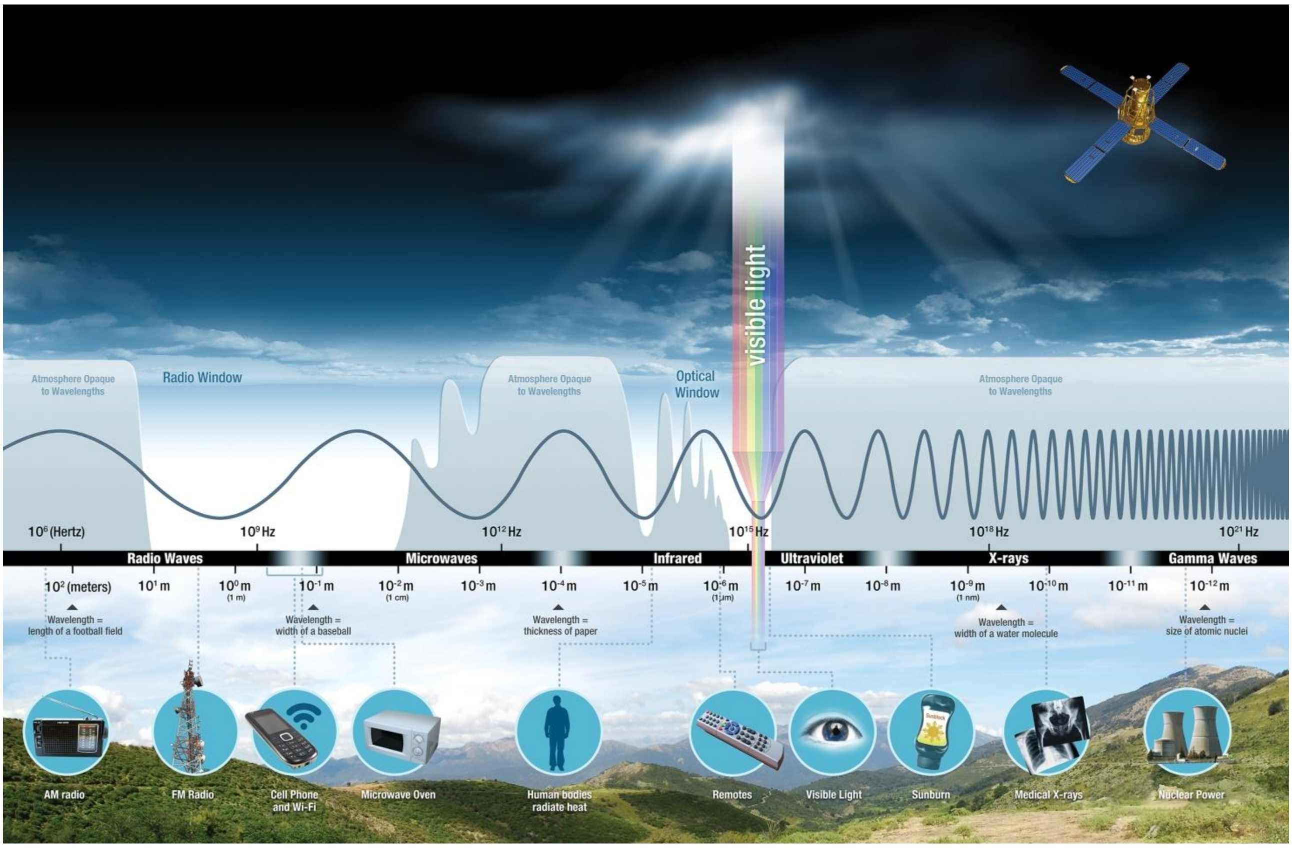
- **Polar:** The orbital plane is inclined at nearly 90 degrees to the equatorial plane. This inclination allows the satellite to sense the entire globe, including the polar regions, providing observations of locations that are difficult to reach. Many of those satellites are considered sun-synchronous, meaning that the satellite passes over the same location at the same solar time each cycle.
- **Non-polar, low-Earth orbits:** are at an altitude of typically less than 2,000 km above the Earth's surface. These orbits do not provide global coverage but instead cover only a partial range of latitudes. The Global Precipitation Mission (GPM) is an example of a non-polar, low-Earth orbit satellite.
- **Geostationary:** satellites in this orbit follow the Earth's rotation and travel at the same rate of the rotation; because of this, the satellites appear to an observer on Earth to be fixed in one location. These satellites capture the same view of Earth with each observation and so provide almost continuous coverage of one area. Weather satellites such as the Geostationary Operational Environmental Satellite (GOES) series are examples of geostationary satellites.

2.2.2 Electromagnetic Spectrum

Electromagnetic energy, produced by the vibration of charged particles, travels in the form of waves through the atmosphere and the vacuum of space. These waves have different wavelengths and frequencies (Fig. 2.2). Some, like radio, microwave, and infrared waves, have a higher frequency, while others, such as ultraviolet, x-rays, and gamma rays, have a much shorter frequency. Visible light sits in the middle of that range of long to shortwave radiation. This small portion of energy is all that the human eye is able to detect. Instrumentation is needed to detect all other forms of electromagnetic energy. NASA instrumentation utilizes the full range of the spectrum to explore and understand processes occurring on Earth.

Some waves are absorbed or reflected by elements in the atmosphere, like water vapour and carbon dioxide (CO_2), while some wavelengths allow for unimpeded movement through the atmosphere; visible light has wavelengths that can be transmitted through the atmosphere. Microwave energy has wavelengths that can pass through clouds; many of our weather and communication satellites take advantage of this.

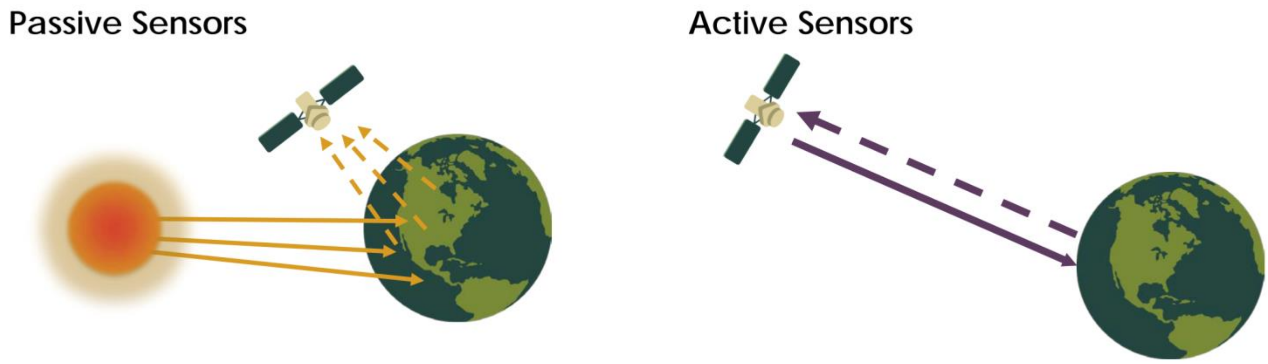
The primary source of the energy observed by satellites, is the sun. The amount of the sun's energy reflected depends on the roughness of the surface and its albedo, which is how well a surface reflects light instead of absorbing it. Often, when energy is absorbed, it is re-emitted, usually at longer wavelengths. For example, the energy absorbed by the ocean gets re-emitted as infrared radiation. All things on Earth reflect, absorb, or transmit energy, the amount of which varies by wavelength. Everything on Earth has a unique spectral "fingerprint" and we can use this information to identify different Earth features.



(Fig. 2.2: Electromagnetic spectrum)

2.2.3 Sensors

Sensors, or instruments, onboard satellites and aircraft use the sun as a source of illumination or provide their own source of illumination, measuring the energy that is reflected back. So, we can distinguish between two type of sensors (Fig. 2.2).



(Fig. 2.3: passive and active sensors)

- **Passive sensors** include different types of radiometers (instruments that quantitatively measure the intensity of electromagnetic radiation in select bands) and spectrometers (devices that are designed to detect, measure, and analyse the spectral content of reflected electromagnetic radiation). Most passive systems used by remote sensing application operate in the visible, infrared, thermal infrared, and microwave portions of the electromagnetic spectrum. These sensors measure land and sea surface temperature, vegetation properties, cloud and aerosol properties, and other physical properties.
- **Active sensors** include different types of radio detection and ranging (radar) sensors, altimeters, and scatterometers (or diffusionmeter). The majority of active sensors operate in the microwave band of the electromagnetic spectrum, which gives them the ability to penetrate the atmosphere under most conditions. These types of sensors are useful for measuring the vertical profiles of aerosols, precipitation and winds, sea surface topography, and ice, among others.

2.2.4 Data processing

Remote sensing data acquired from instruments aboard satellites require processing before the data are usable by researchers and applied science users. Most raw, NASA Earth observation satellite data (Level 0) are processed at Science Investigator-led Processing System (SIPS) facilities. All data are processed to at least a Level 1, but most have associated Level 2 and Level 3

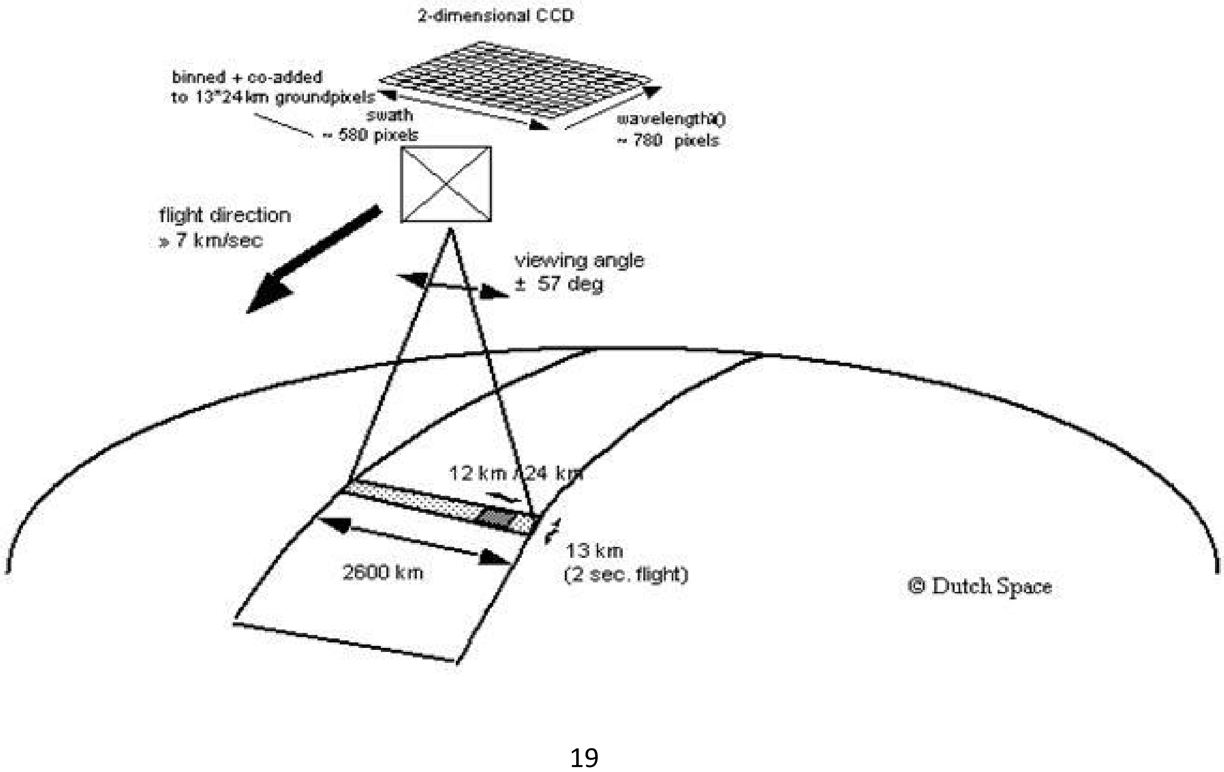
products. Many even have Level 4 products. NASA Earth science data are archived at one of the Distributed Active Archive Centres (DAACs).
Once data are processed, they can be used in a variety of applications, from water resources to health and air quality.
(Earthdata.nasa.gov/learn/remote-sensing)

3 SATELLITE DATA DESCRIPTION

Our purpose is to collect and analyse the concentration data of CO, SO_2, NO_2 and O_3, detected by the OMI sensor fitted on the NASA Aura spacecraft, downloaded from the website (http://giovanni.gsfc.nasa.gov/giovanni/).
GIOVANNI is an acronym for GES-DISC Interactive Online Visualization And aNalysis Infrastructure, and it is an application, developed by GES-DISC (Goddard Earth Sciences Data and Information Service Centre), that we use to visualize, analyse and access vast amount of Earth science remote sensing data about: atmospheric chemistry, atmospheric temperature, water vapour and clouds, atmospheric aerosols, precipitation and ocean surface temperature.

3.1 Ozone Monitoring Instrument (OMI)

The OMI instrument is a nadir viewing imaging spectrograph that measures the solar radiation backscattered by the Earth's atmosphere and surface over the entire wavelength range from 270 to 500 nm, with a spectral resolution of about 0.5 nm. The 114° viewing angle of the telescope corresponds to a 2600 km wide swath on the surface, which enables measurements with a daily global coverage. In the normal global operation mode, the OMI pixel size is 13 km x 24 km at nadir (along x across track). In the zoom mode the spatial resolution can be reduced to 13 km x 12 km. The small pixel size enables OMI to look in between the clouds, which is very important to retrieve information about troposphere (Fig. 3.1).



(Fig. 3.1: OMI Measurement Design)

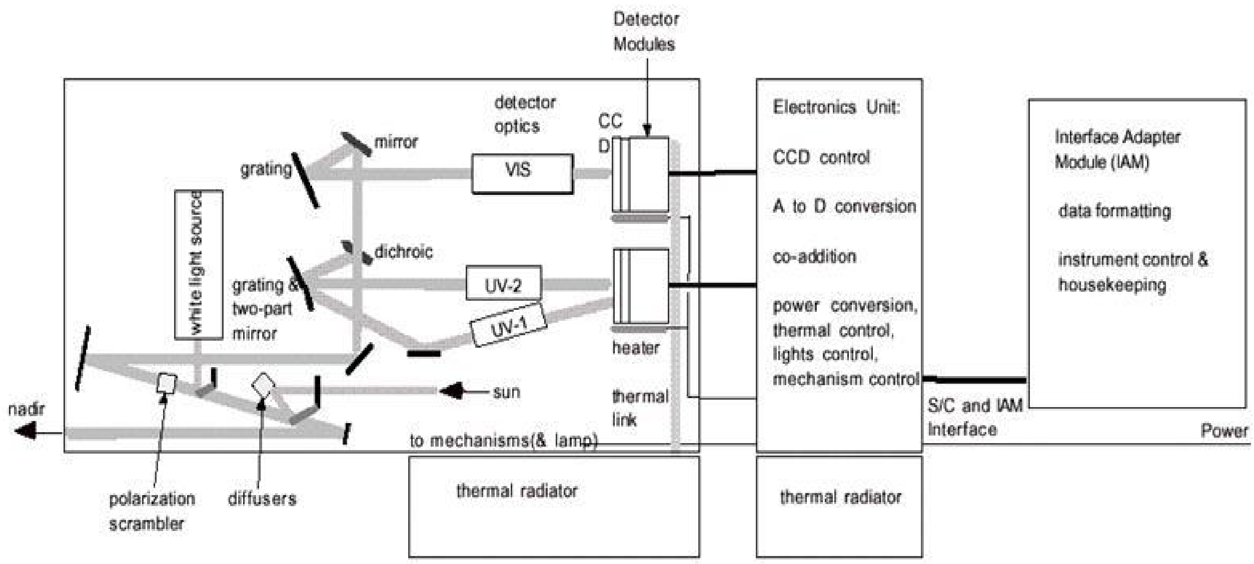
The heritage of OMI is the European ESA instruments GOME and SCIAMACHY, which introduced the concept of measuring the complete spectrum in the ultraviolet/visible/near-infrared wavelength range with a high spectral resolution. This enables one to retrieve several trace gases from the same spectral measurement. The American predecessor of OMI is NASA's TOMS instrument. TOMS has the advantage that it has a fairly small ground-pixel size (50 km x 50 km) in combination with a daily global coverage.
OMI combines the advantages of GOME and SCIAMACHY with the advantages of TOMS, measuring the complete spectrum in the ultraviolet/visible wavelength range with a very high spatial resolution (13 km x 24 km) and a daily global coverage. This is possible by using a two-dimensional detector.

3.1.1 Main elements

The OMI instrument is composed of the following three elements:

1. Optical Assembly (OA), consisting of the Optical Bench (OPB), two Detector Modules (DEM), and Thermal Hardware.
2. Electronics Unit (ELU), performing CCD readout control and analogical-to-digital conversion (ADC)
3. Interface Adaptor Module (IAM), performing Command Buffering as well as the Data Formatting and Satellite Bus Interface functions.

The light entering the telescope is depolarised using a scrambler and then split into two channels: the UV channel (wavelength range 270 – 380 nm) and the VIS channel (wavelength range 350 – 500 nm) (Fig. 3.2).



(Fig. 3.2: scheme of the light path inside OMI instrument)

3.1.2 Data processing level

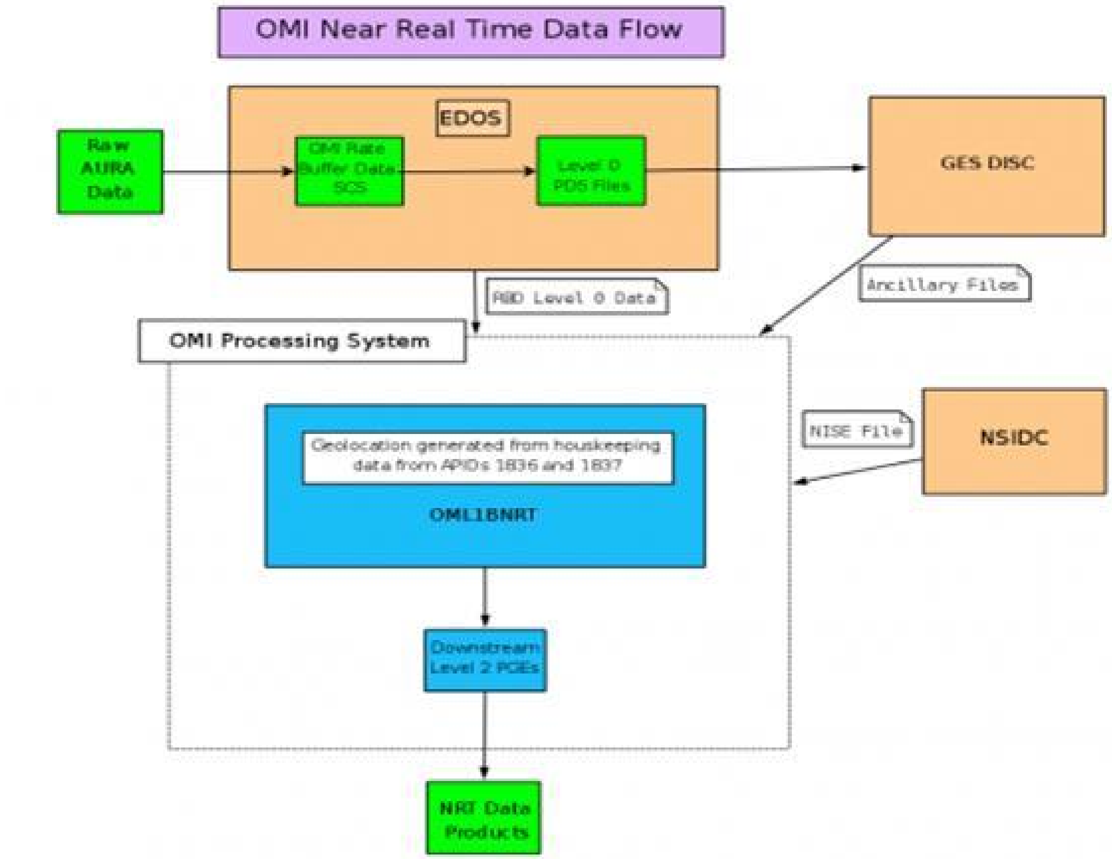
Data products are processed at various levels ranging from level 0 to level 4.

Level 0	Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artefacts (e.g., synchronization frames, communication headers, duplicate data) removed. In most cases, the EOS Data Operation System provides (EDOS) these data to the data centre as production data sets for processing by the Science Data Processing Segment (SDPS) or by a SIPS to produce higher-level products.
Level 1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters computed and appended but not applied to level 0 data.
Level 1B	Level 1A data that have been processed to sensor units.
Level 2	Derived geophysical variables at the same resolution and location as Level 1 source data.
Level 3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
Level 4	Model output or results from analyses of lower-level data.

(Earth Data – NASA, 2019)

3.1.3 Data flows

The data flow is shown in the diagram below (Fig. 3.3). The session-based Level 0 (L0) data for OMI are ingested from NASA's EOS Data Operations System (EDOS). These are pre-processed by OML1BRBD APP which removes duplicate packets and incorrectly time tagged data before processing by the Level 1B (L1B) software. All EDOS data products are sent to the PDR server by EDOS and ingested by LANCE-OMI.



(Fig. 3.3: Diagram of the data flow)

(http://www.projects.knmi.nl/omi)

3.2 Satellite data extraction

Giovanni application require to select the plot, time data range and region. Using the drop-down menus, select the "Maps: Time Averaged Map" command. Then providing the time frame (for each year from 2008 to 2017) and the area of interest (centred around northern Italy). The time-averaged map shows data values for each grid cell within the user-specified area, averaged over the user-specified time range as a map layer. The generated map can be zoomed and panned. Plot options includes setting minimum and maximum values for the colour scale, and in some cases selecting other palettes. In our case, data were downloaded and reprocessed through the panoply software.

3.3 Data processing with Panoply application

Panoply is a Java application developed by Robert Schmunk at NASA GISS (Goddard Institute for Space Studies), that enables the user to plot raster images of geo-referenced data from datasets in network Common Data Form (net CDF) format and also function as a tool for geographical data analysis and reporting.
Panoply can be used to create displays in a variety of ways:

- Plot longitude-latitude data as global maps, using any of over 40 global map projections.
- Overlay continent outlines or mask on longitude-latitude plots, or just plot a particular region.
- Display specific latitude-longitude or latitude-vertical arrays from larger multidimensional variables as slices.
- Use scale colour-bars provided (based on PAL, ACT or CWC colour tables);
- Save plots to disk as PNG or GIF images.

Work focused area display at Latitude 44°N Longitude 11°E with a grid of 8° width and 6° height.

3.4 Milano area concentration analysis

With reference to the “Giovanni-NASA” site downloaded data, for each pollutant the “.log” file has been extracted, related to the average concentration values for every year, relatively to Milan domain. The data have been tabulated through a database in Excel Office to obtain a graphic output for every year.

4 PRESENTATION OF RESULTS

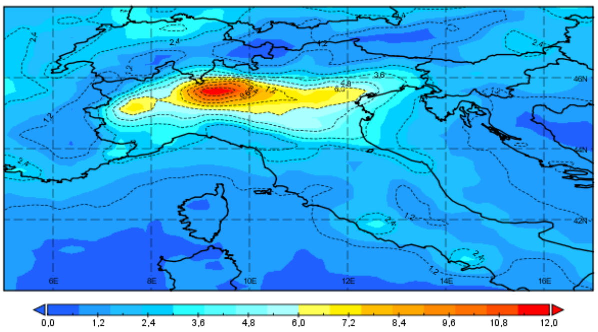
Once data have been downloaded from the NASA website, they have been elaborated with the "PANOPLY" application in order to plot them and obtain the 2D map representation showed below. At the same time, the concentration at Milan metropolitan area (lat=45.3°, lon=9.12°) for each year were elaborated and displayed in a time-series map.

4.1 Nitrogen Dioxide (NO_2)

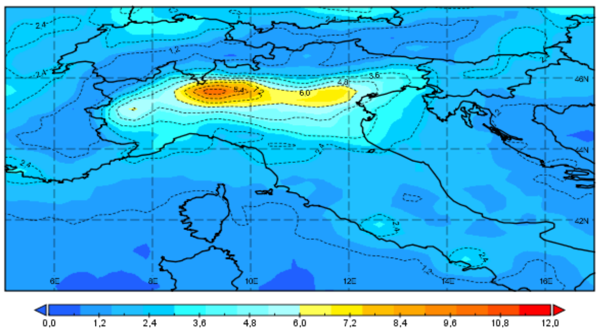
4.1.1 Spatial maps

In the following figures 4.1 (a)-(l) it is reported the NO_2 tropospheric columnar concentration maps expressed in 10^{15} cm^{-2} for each year starting from 2008 and ending in 2017.

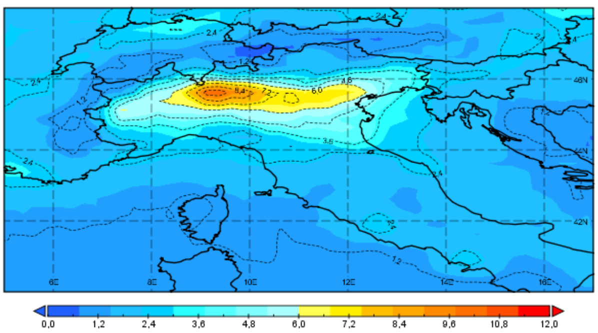
a) NO_2 Tropospheric Colum 2008



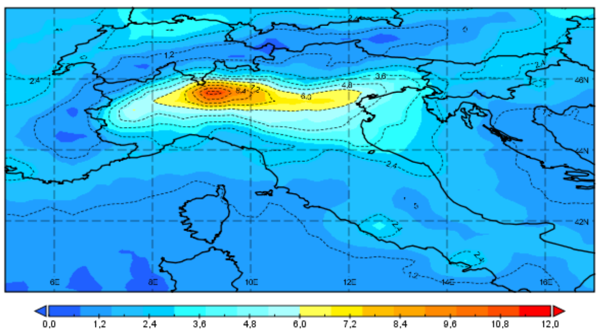
b) NO_2 Tropospheric Colum 2009



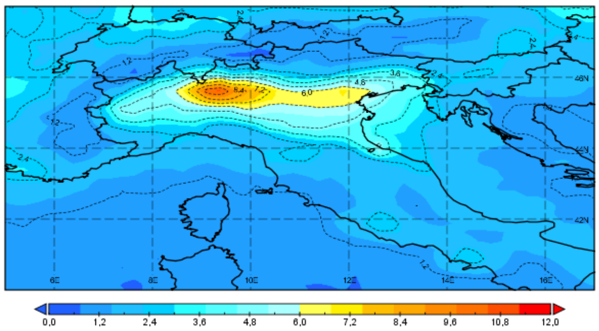
c) NO_2 Tropospheric Colum 2010



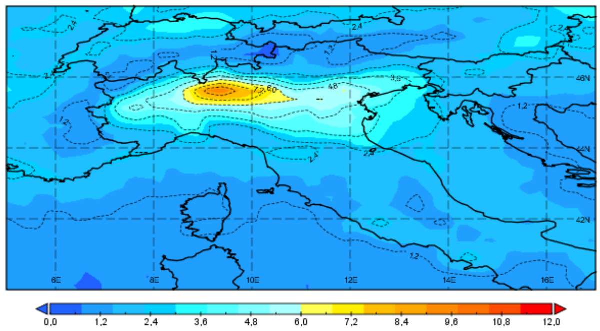
d) NO_2 Tropospheric Colum 2011



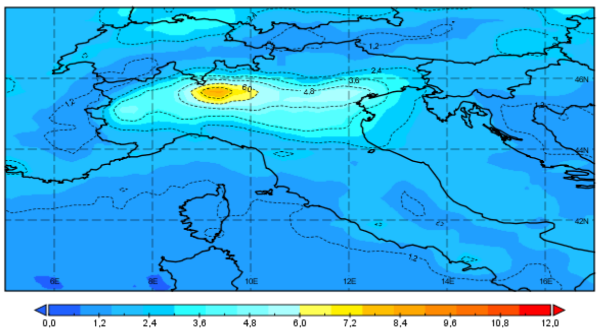
e) NO_2 Tropospheric Colum 2012



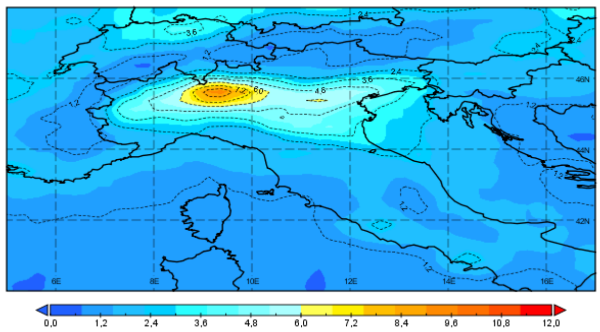
f) NO_2 Tropospheric Colum 2013



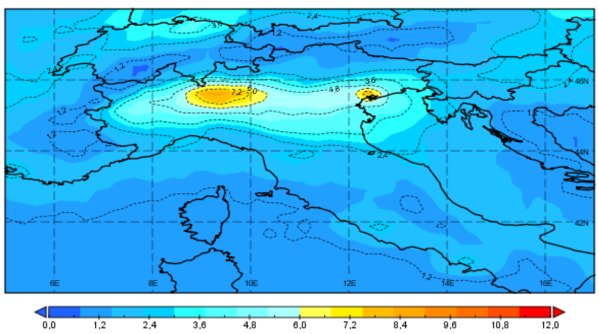
g) NO_2 Tropospheric Colum 2014



h) NO_2 Tropospheric Colum 2015



i) NO_2 Tropospheric Colum 2016



l) NO_2 Tropospheric Colum 2017

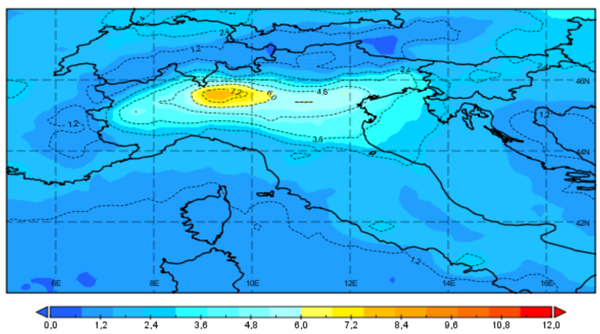


Fig. 4.1 a), b), c), d), e), f), g), h), i), l): NO_2 Tropospheric Column; concentration maps expressed in 10^{15} cm^{-2} for each year from 2008 to 2017.

The analysis of the spatial maps through the years from 2008 to 2017 confirm that anthropogenic sources like: motor vehicles, power plants and waste disposal systems, are the most influencing factors for this pollutant. In fact, the highest concentration is located on the Milan metropolitan area due to the higher population's density.

4.1.2 Time series maps

The following figure 4.1(m) shows the time-series map of NO_2 concentration at Milan metropolitan area.

m)

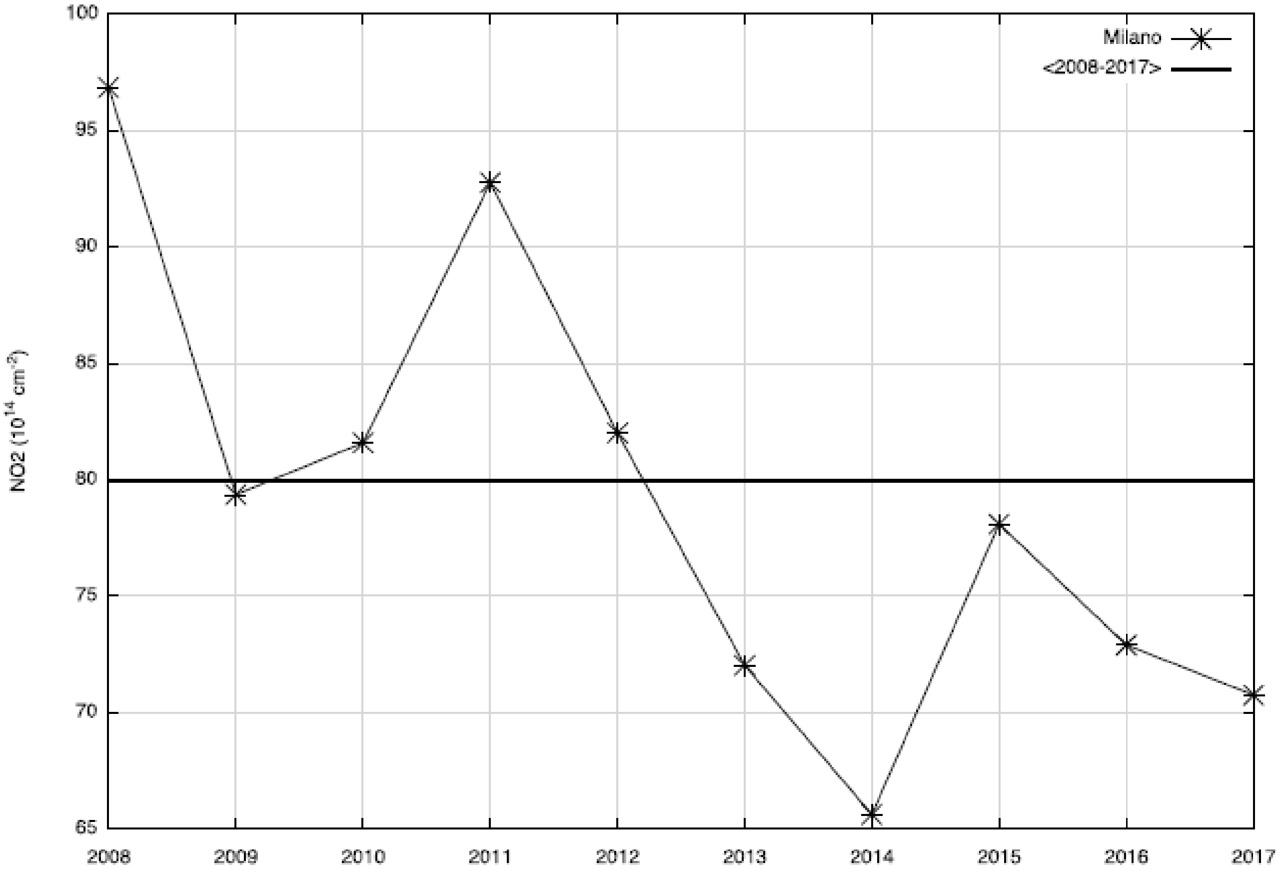


Fig. 4.1(m) : Milan NO_2 time series maps of concentration for each year from 2008 to 2017.

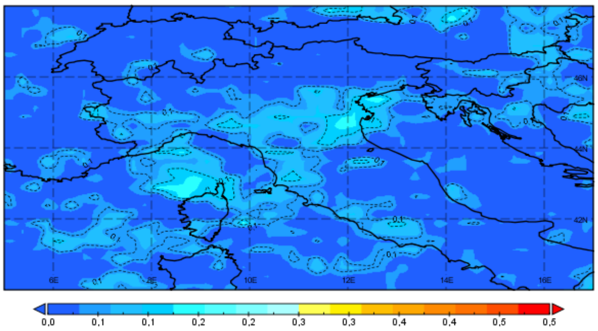
With reference to the Milan area, we can see a mean peak the first year in 2008 and a smaller peak in 2011. It can also be observed that in general from 2011 and 2017 there has been a general decrease in the average concentration.

4.2 Sulphur Dioxide (SO_2)

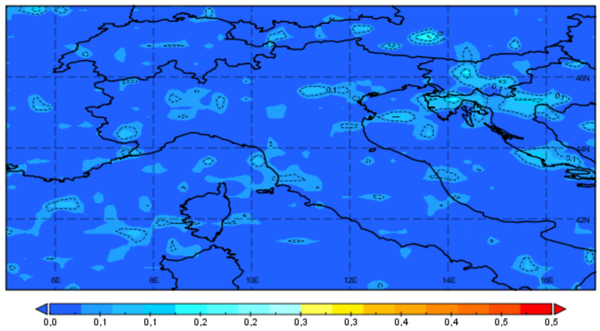
4.2.1 Spatial maps

In the following figures 4.2 (a)-(l) it is reported the SO_2 tropospheric columnar concentration maps expressed in Dobson Units (DU) for each year starting from 2008 and ending in 2017.

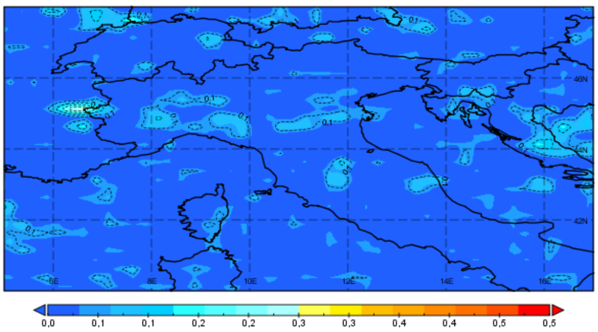
a) SO_2 Column Amount 2008



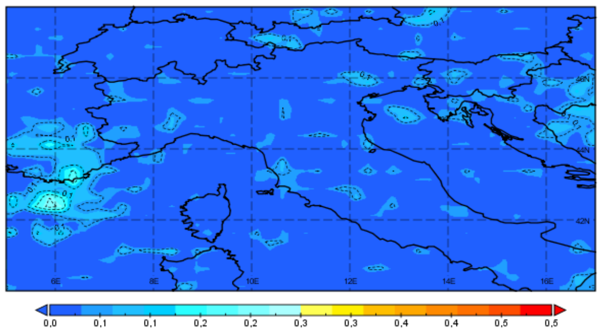
b) SO_2 Column Amount 2009



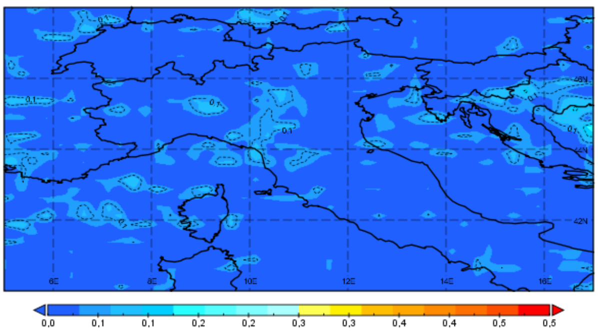
c) SO_2 Column Amount 2010



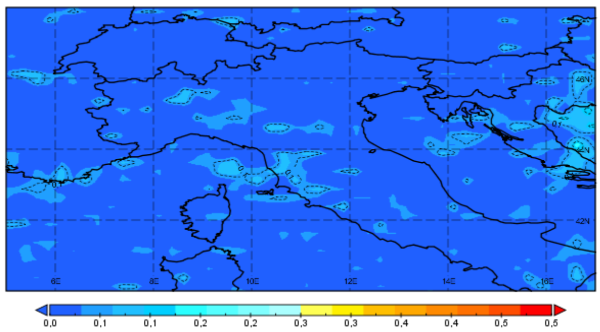
d) SO_2 Column Amount 2011



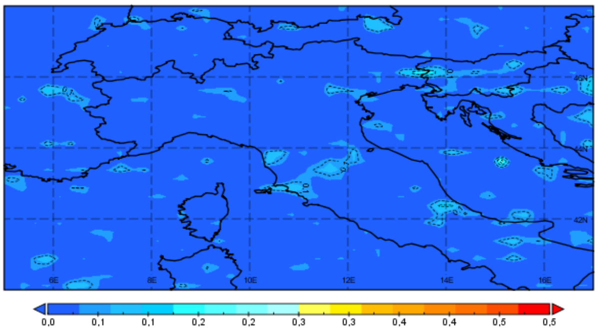
e) SO_2 Column Amount 2012



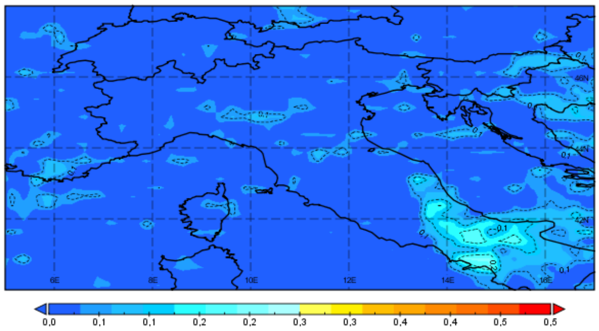
f) SO_2 Column Amount 2013



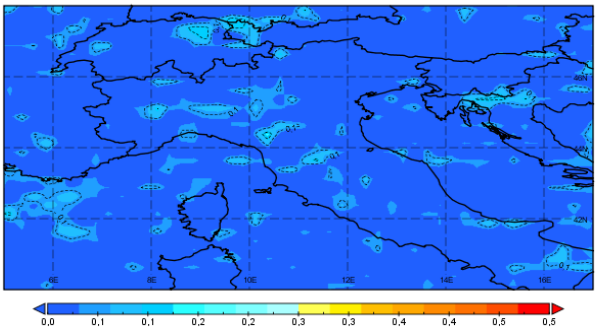
g) SO_2 Column Amount 2014



h) SO_2 Column Amount 2015



i) SO_2 Column Amount 2016



l) SO_2 Column Amount 2017

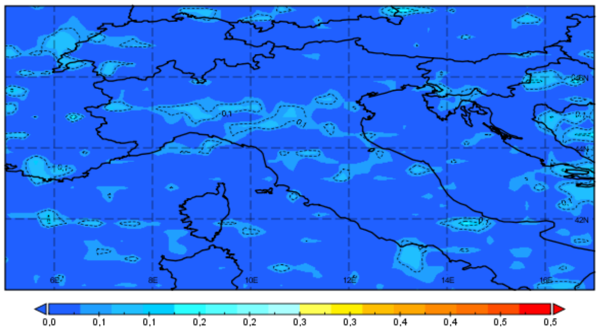


Fig. 4.2 a), b), c), d), e), f), g), h), i), l): SO_2 Column Amount (Planetary Boundary Layer) OMSO2e v003; concentration maps expressed in Dobson Unit (DU) for each year from 2008 to 2017.

The analysis of the spatial maps for each year show that the SO_2 concentration is mainly connected to the Etna volcanic activity, as observed in Fig. 4.1 h) the SO_2 emission of eruptive activity in 2015 was one of the most intense occurred recently, with substantial consequences on the whole southern regions of Italy. We can clearly see on the map the trace of the pollutant rising from the southern regions as a consequence of wind pollution transport.

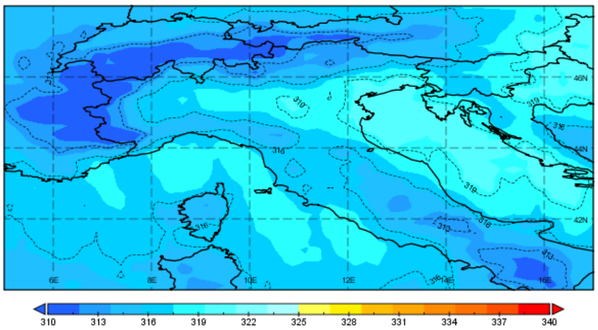
However, it is not possible to appreciate a significant value for this pollutant in the region of our interest, for this reason it has been decided to omit the time series map for the SO_2.

4.3 Ozone (O_3)

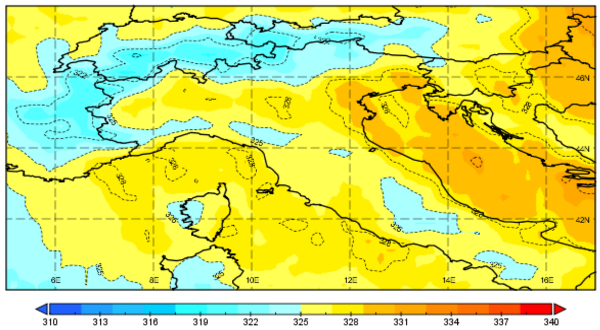
4.3.1 Spatial maps

In the following figures 4.3 (a)-(l) it is reported the Ozone Total Column maps expressed in Dobson Units (DU) for each year starting from 2008 and ending in 2017.

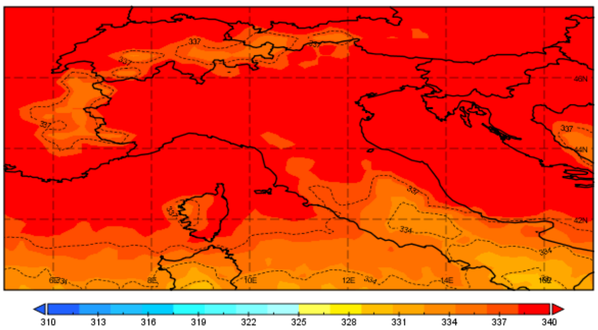
a) Ozone Total Column (DOAS) 2008



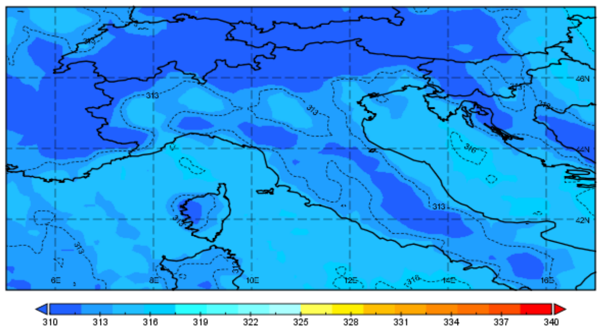
b) Ozone Total Column (DOAS) 2009



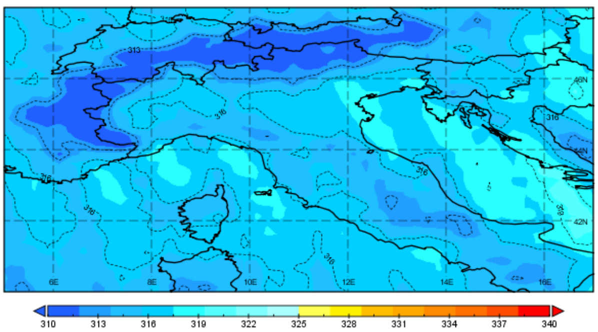
c) Ozone Total Column (DOAS) 2010



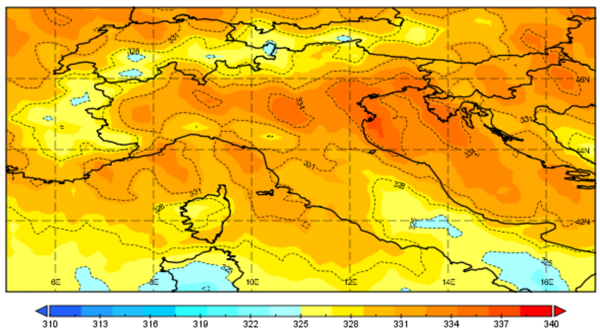
d) Ozone Total Column (DOAS) 2011



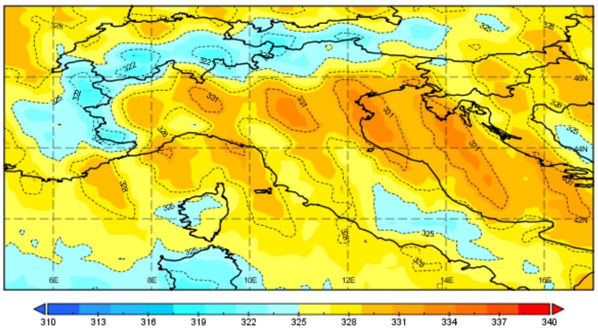
e) Ozone Total Column (DOAS) 2012



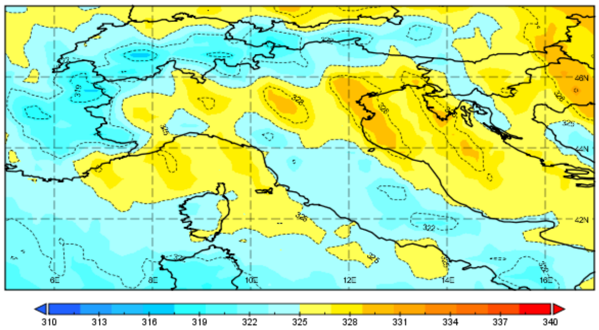
f) Ozone Total Column (DOAS) 2013



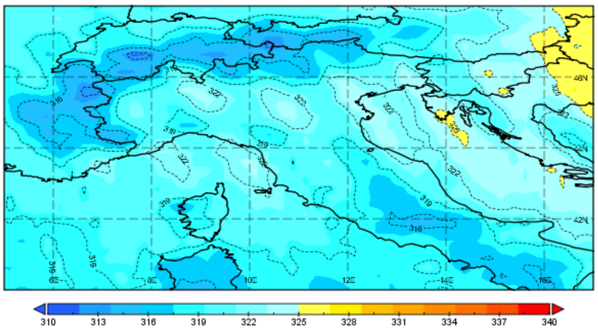
g) Ozone Total Column (DOAS) 2014



h) Ozone Total Column (DOAS) 2015



i) Ozone Total Column (DOAS) 2016



l) Ozone Total Column (DOAS) 2017

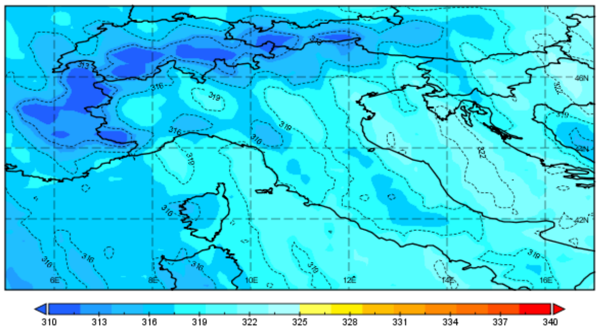


Fig. 4.3 a), b), c), d), e), f), g), h), i), l): O_3 Ozone Total Column (DOAS); concentration maps expressed in Dobson Unit (DU) for each year from 2008 to 2017.

In the analysis of the spatial maps for each year for ozone, a stable trend is not appreciable, but the higher concentration is observed in 2010.

4.3.2 Time series maps

The following figure 4.3(m) shows the time-series map of O3 concentration at Milan metropolitan area.

m)

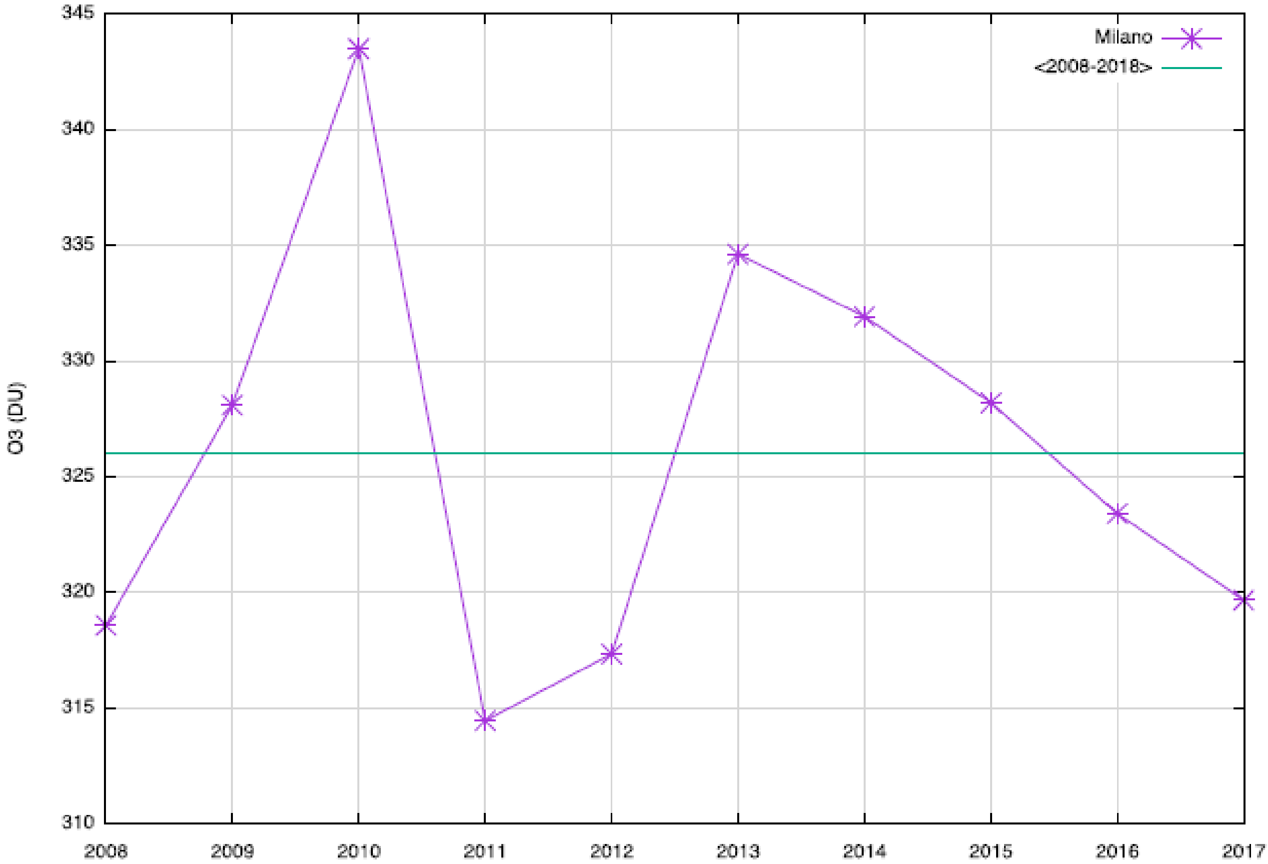


Fig. 4.3 m) : Milan O_3 time series maps concentration for each year from 2008 to 2017.

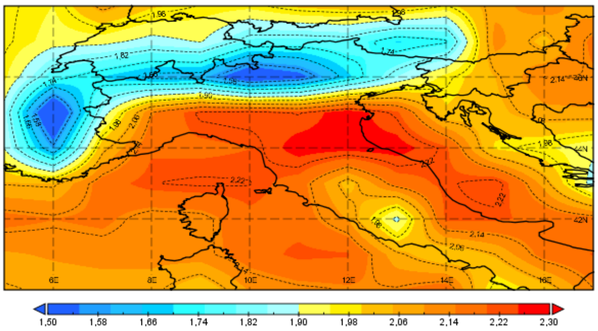
With reference to the Milan area, the graphic show a dangerous isolated peak in 2010, and a high variability along the years.

4.4 Carbon monoxide (CO)

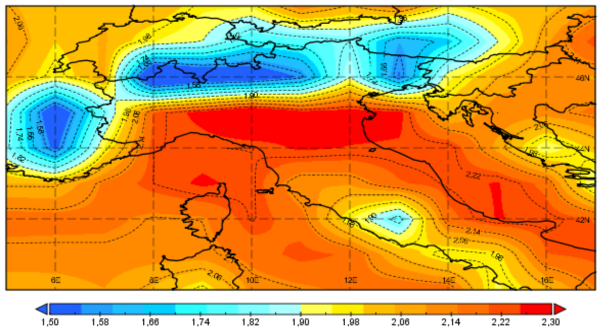
4.4.1 Spatial maps

In the following figures 4.4 (a)-(l) it is reported the Multispectral CO Total Column maps expressed in mol/cm² for each year starting from 2008 and ending in 2017.

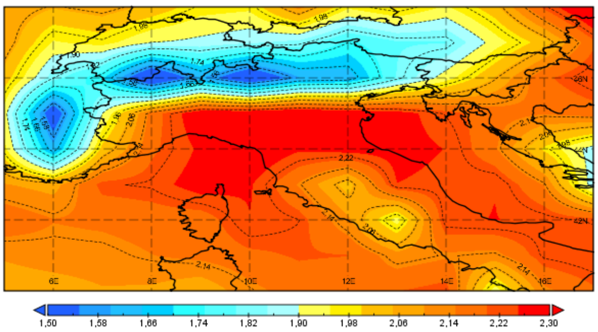
a) Multispectral CO Total Column 2008



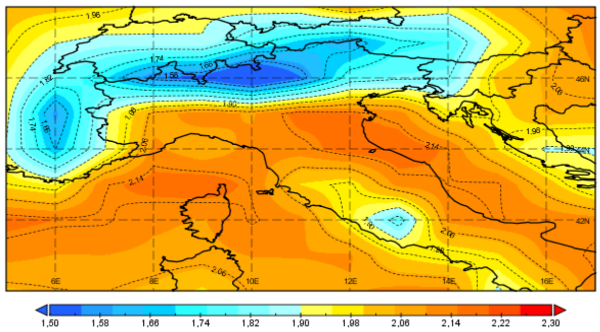
b) Multispectral CO Total Column 2009



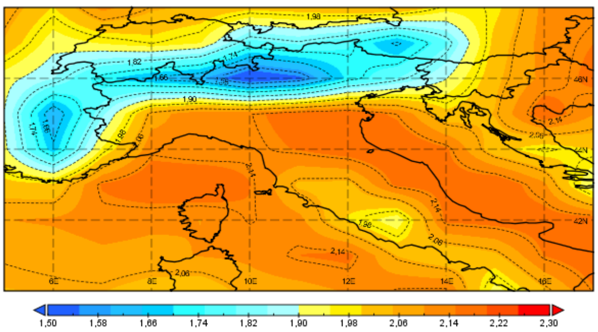
c) Multispectral CO Total Column 2010



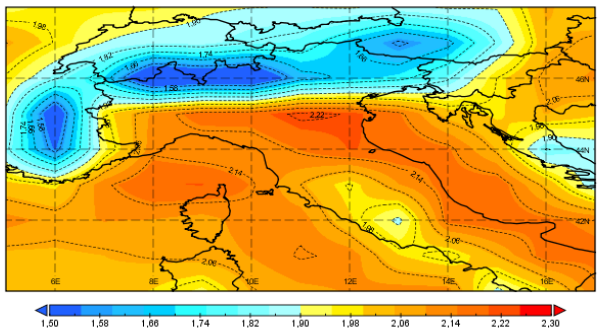
d) Multispectral CO Total Column 2011



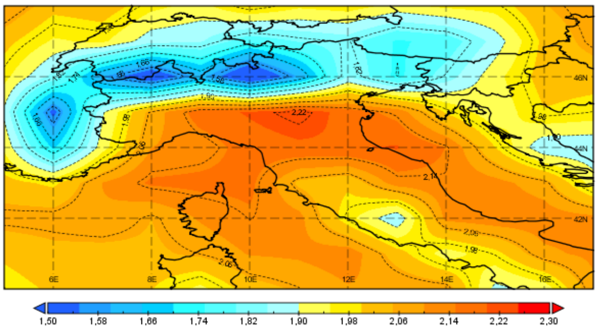
e) Multispectral CO Total Column 2012



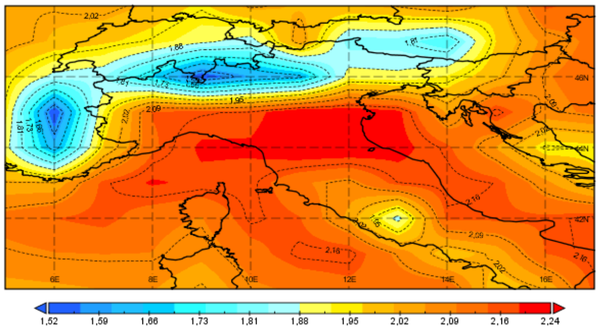
f) Multispectral CO Total Column 2013



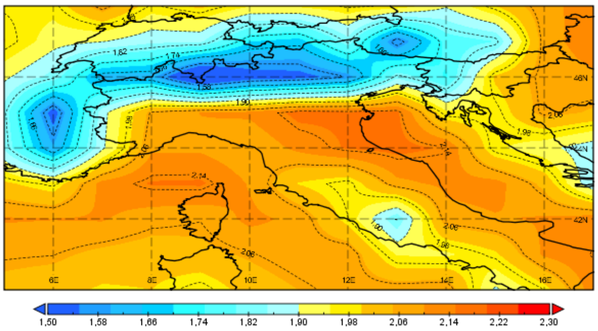
g) Multispectral CO Total Column 2014



h) Multispectral CO Total Column 2015



i) Multispectral CO Total Column 2016



l) Multispectral CO Total Column 2017

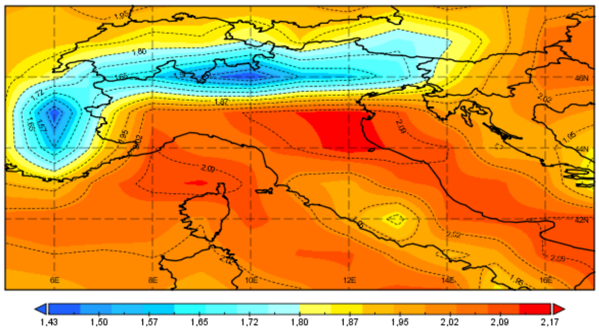


Fig. 4.4 a), b), c), d), e), f), g), h), i), l): Multispectral CO Total Column; concentration maps expressed in mol/cm² for each year from 2008 to 2017.

The analysis of the spatial maps of each year for CO, show that the concentration increases from the first year in 2008 reaching the peak value in 2010. In the other years, the trend is almost stable.

4.4.2 Time series maps

The following figure 4.4(m) shows the time-series map of Multispectral CO Total Column concentration at Milan metropolitan area.

m)

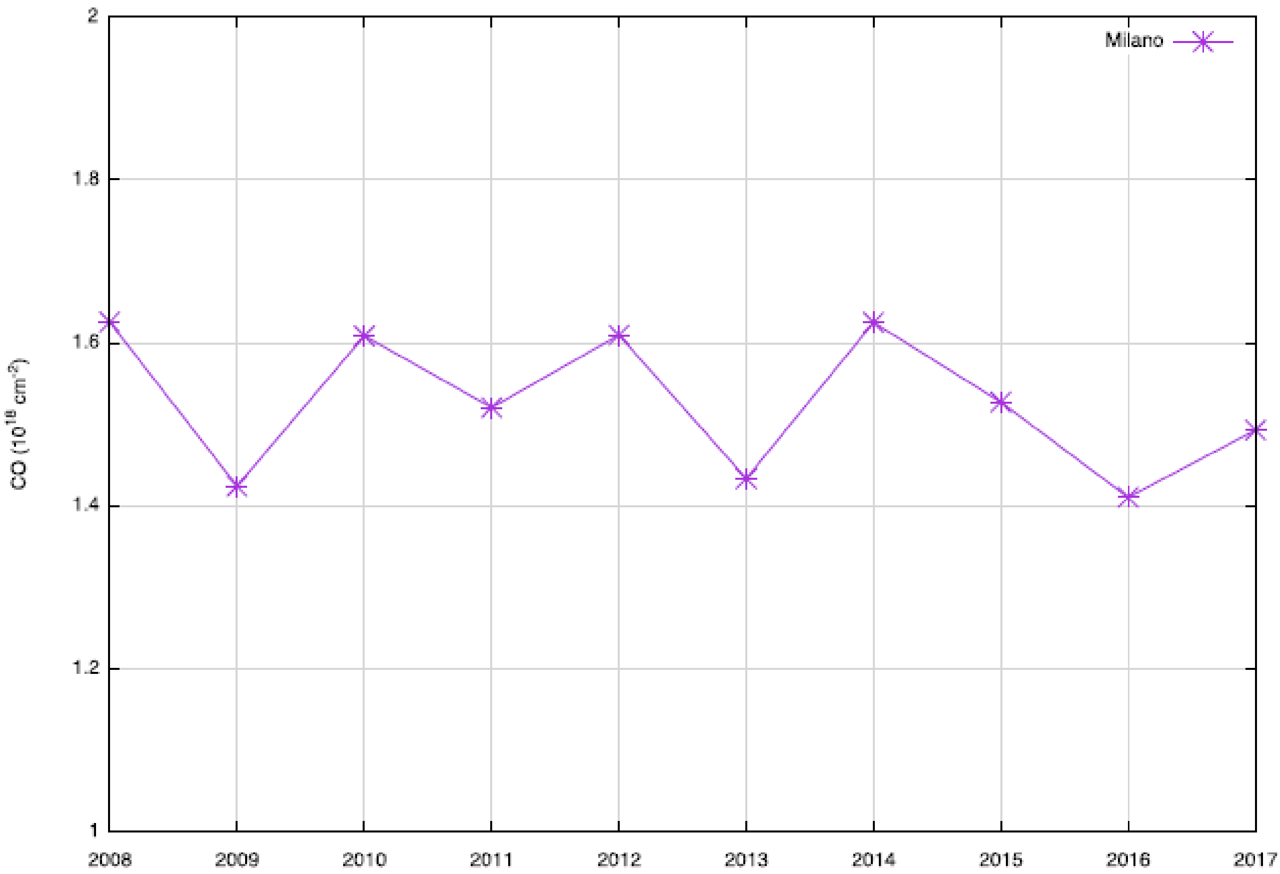


Fig. 4.4 m) : Milan CO time series maps concentration for each year from 2008 to 2017.

With reference to the Milan area, a stable trend is identifiable over the years, without peaks of intensity.

5. CONCLUSIONS

The thesis purpose is to analyse the trend of concentration regarding four main pollutants (Nitrogen dioxide NO_2, Sulphur dioxide SO_2, Ozone O_3 and Carbon monoxide CO) in a time-window of ten years, from 2008 to 2017.

The focus area considers the Milan's metropolitan region, which is marked by high population density, heavy traffic and industrialization.

Data from the OMI sensor on the NASA Aura platform have been downloaded through the GIOVANNI Nasa web-portal. Data were processed with the "Panoply data viewer" application which returned the georeferenced maps, on the average concentration for each year from 2008 to 2017. Milan pollutant concentration were extracted and elaborated through a spreadsheet to obtain linear statics graphics showing the trend along the period of ten years.

Output data observation made possible to recognize for the NO_2 two mean peaks recorded in 2008 and in 2010 that deserve further specific analyses. However, it is possible to appreciate a general decreasing trend in the mean concentration value over the following years analysed. Also for SO_2, influenced by natural emissions as known and specifically by volcanic activities, the trend for the area in question is marginally influenced by the volcano Etna, located in the Southern Italy, and shows concentrations substantially in line with the greater or less eruptive activity. The Ozone interpretation, being a secondary pollutant, is less definable in a general sense, but in both the analysis regions it assumes higher values in the first period, with an important peak in 2010 and then decreases, without a wide range of variability. Finally, as concerns the concentration of CO, the results of the analysis show a stable trend over the years, except for the 2010, where the spatial map put in prominence a higher value that deserve further specific analyses.

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