SUMMER SCHOOL WORKSHOP

ACTION 2020-2-21:
COPERNICUS
FOR CULTURAL HERITAGE

APPLICATION OF AIR POLLUTANT DATA FOR CULTURAL HERITAGE PRESERVATION

Raffaela Gaddi

ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale

13-16.06.2023

PARCO REGIONALE DELL'APPIA ANTICA
Ex Cartiera Latina - Via Appia Antica, 42

Summary

- The effects of air pollution on outdoor cultural heritage
  - Pollutants and decay typologies
- Methodologies for the damage assessment
  - Dose-response functions
- Sources and analysis of air pollutants data: *punctual* data
  - Application and case study
- Sources and analysis of air pollutants data: *spatial* data
  - Application and case study
- Final remarks

The effects of air pollution on Cultural Heritage

MATERIALS	MAIN TYPOLOGY OF DETERIORATION
STONE/MASONRY MATERIALS	Surface recession and loss of detail; Soiling and blackening; Biological colonization; Formation of "crust".
METALS	Surface corrosion; Development of a stable patina; Pitting and perforation; Deterioration/loss of coating (paint, galvanising, etc.).
TIMBER	Biological decay; Deterioration/loss of coating (paint).
GLASS	Corrosion of medieval potash glass; Soiling of modern soda glass.

Source: "The Effects of Air Pollution on Cultural Heritage" J. Watt, J. Tidblad, W. Kucera, R. Hamilton (2009)

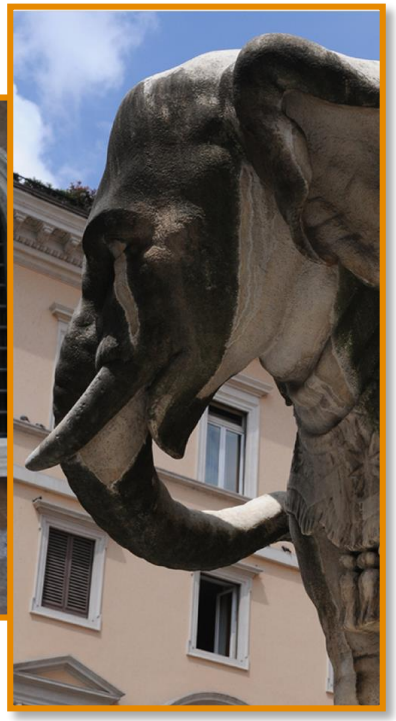
The effects of air pollution on Cultural Heritage

POLLUTANTS	SOURCES
NO_2	Vehicular traffic; civil and industrial heating systems, power plants for the production of energy and a wide range of industrial processes.
O_3	Road transport, civil heating and energy production.
SO_2	Energy production plants, thermal heating plants, some industrial processes and, to a lesser extent, vehicular traffic.
PM_{10}	Natural origin, anthropic origin (mainly use of wood in civil heating, vehicular traffic).
$PM_{2.5}$	Exhaust gases from internal combustion vehicles, from energy production plants and from combustion processes in industry, from domestic heating systems, from fires.

The effects of air pollution on Cultural Heritage

Limestone materials

Material loss;
Blackening;
Biological colonization



NO_2; SO_2;
PM_{10}; $PM_{2.5}$

Methodologies for damage assessment: dose response functions

Surface recession

Lipfert (1989)

$$Rs = 18.8\ Rain + 0.016\ [H^+]\ Rain + 0.18\ (V_{ds}\ [\mathbf{SO_2}] + V_{dN}\ [\mathbf{HNO_3}])$$

Tidblad (ICP Materials 1998)

$$Rs = 2.7\ [\mathbf{SO_2}]^{0.48} \exp(-0.018T)\ t^{0.96} + 0.019\ Rain\ [H^+]\ t^{0.96}$$

Kucera (Multiassess Project 2007)

$$[HNO_3] = 516\ e^{-3400/(T+273)}\ ([\mathbf{NO_2}]\ [\mathbf{O_3}]\ Rh)^{0.5}$$

$$Rs = 4 + 0.0059\ [\mathbf{SO_2}]\ Rh_{60} + 0.054\ [H^+]\ Rain + 0.078\ Rh_{60}\ [\mathbf{HNO_3}] + 0.0258\ \mathbf{PM_{10}}$$

Blackening

Watt (2009)

$$R = R_0 \exp(-\lambda \mathbf{C_{PM}} t)$$

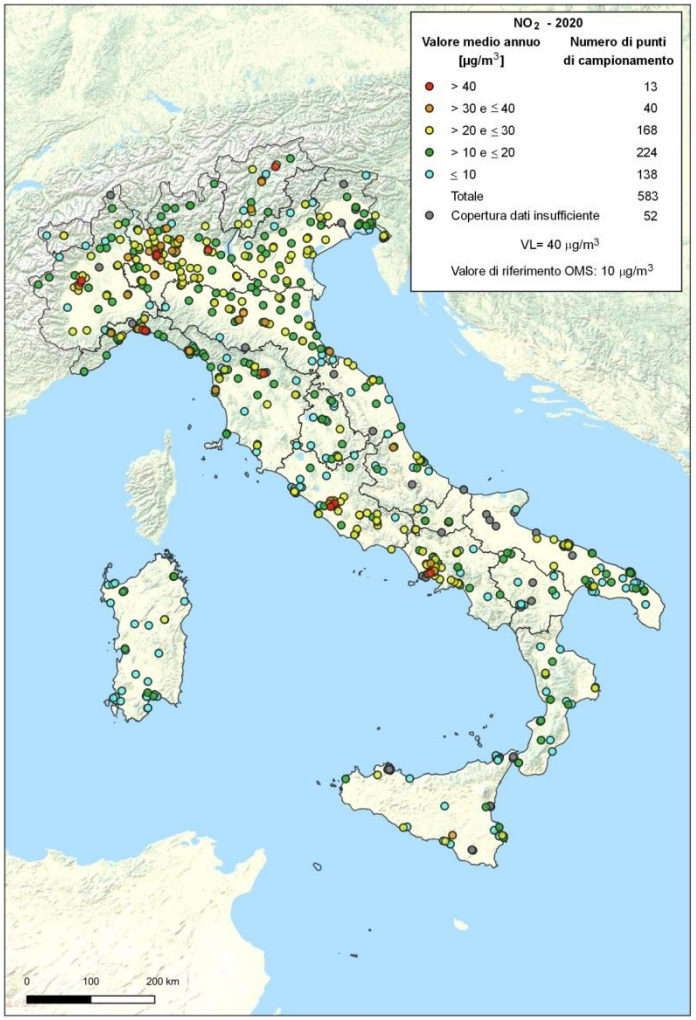
R= surface recession (μm/year); H^+= hydrogen ion; SO_2= sulphur dioxide concentration (μg/m³); HNO_3= nitric acid concentration (μg/m³); O_3= ozone concentration (μg/m³); PM_{10}= particulate matter concentration (μg/m³); Rain= precipitation (mm); T= temperature (°C); t= time (days); Rh_{60}= relative humidity (Rh-60, %); V_{dS}= sulfur deposition rate; V_{dN}= nitrogen deposition rate

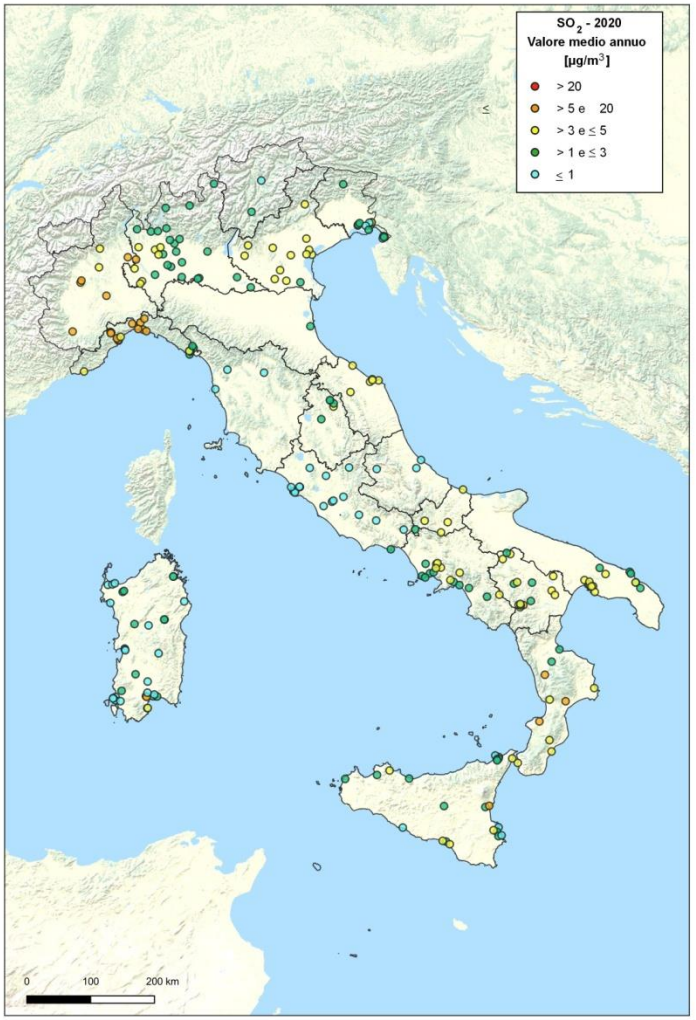
Sources and analysis of air pollutant data: *punctual* data

Air quality monitoring network

- Air quality monitoring, assessment and forecasting through a national network of fixed monitoring stations consistent with the provisions of the European Directive and Legislative Decree 155/2010
- The measurement stations are located throughout the national territory
- The data acquired by the stations are collected, processed and disseminated at national level

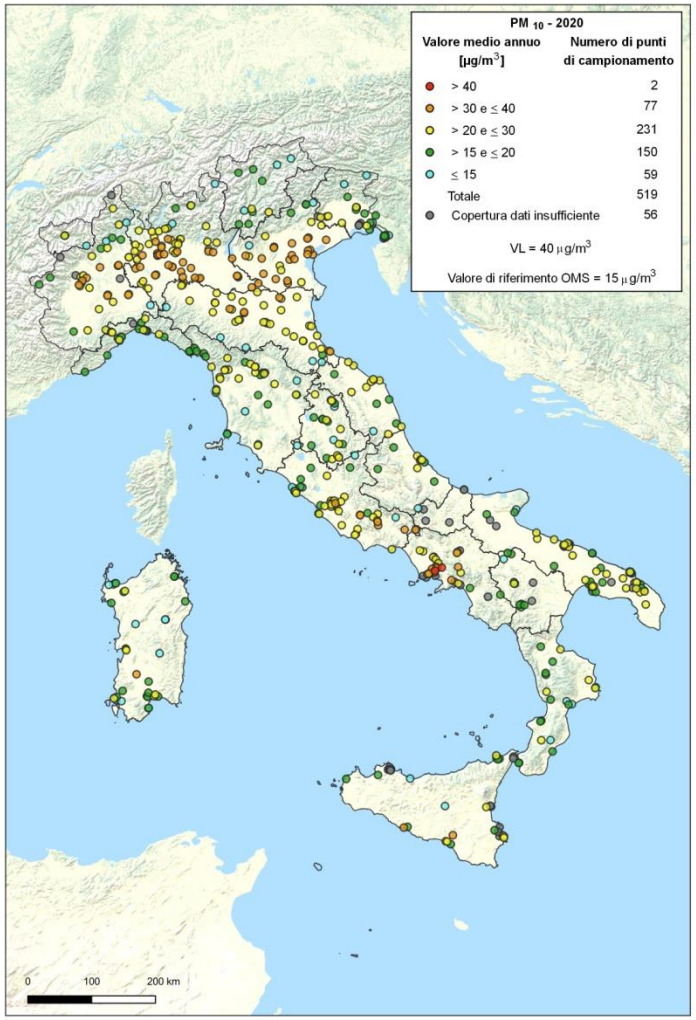
Sources and analysis of air pollutant data: *punctual* data

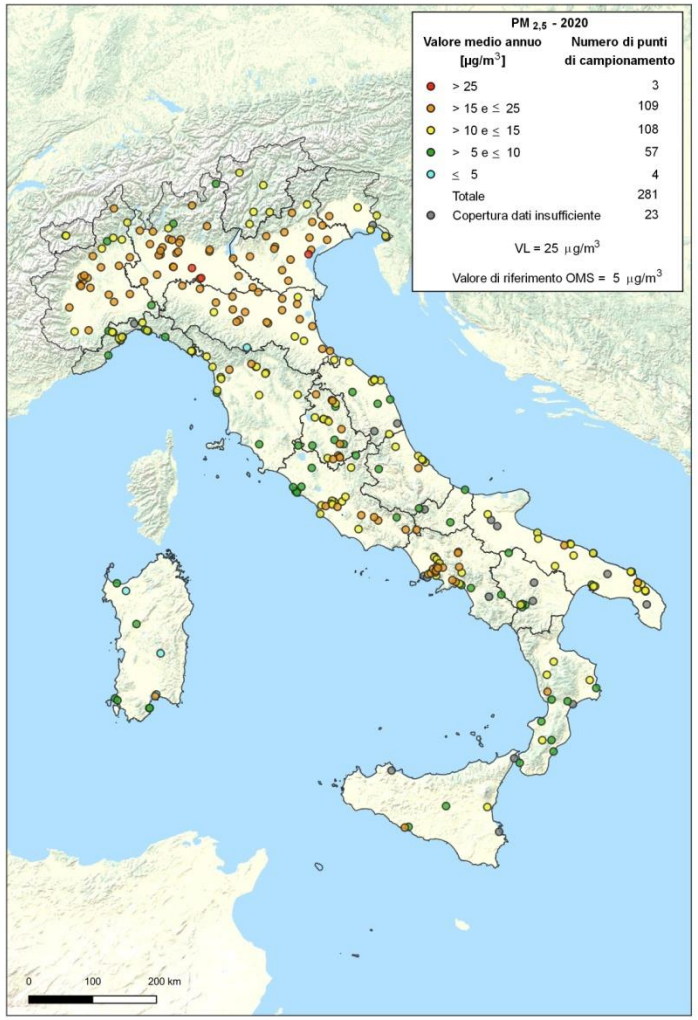




https://indicatoriambientali.isprambiente.it/sys_ind/779

Sources and analysis of air pollutant data: *punctual* data

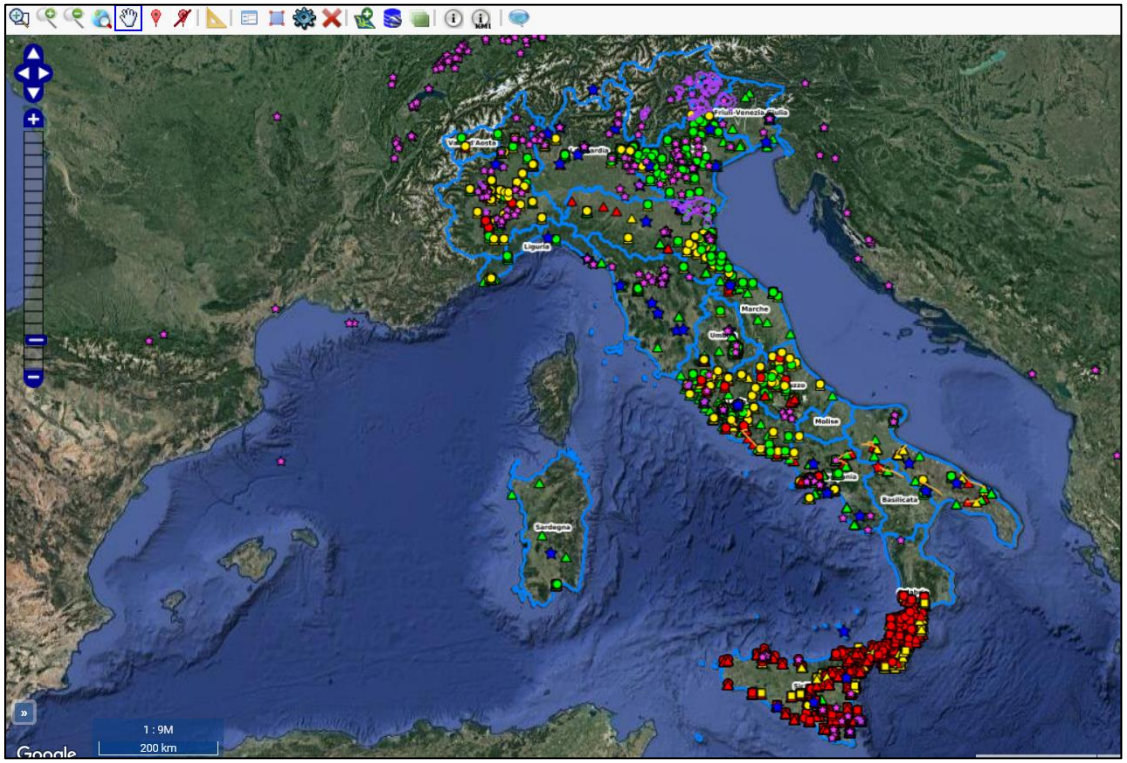




Sources and analysis of air pollutant data: *punctual* data application

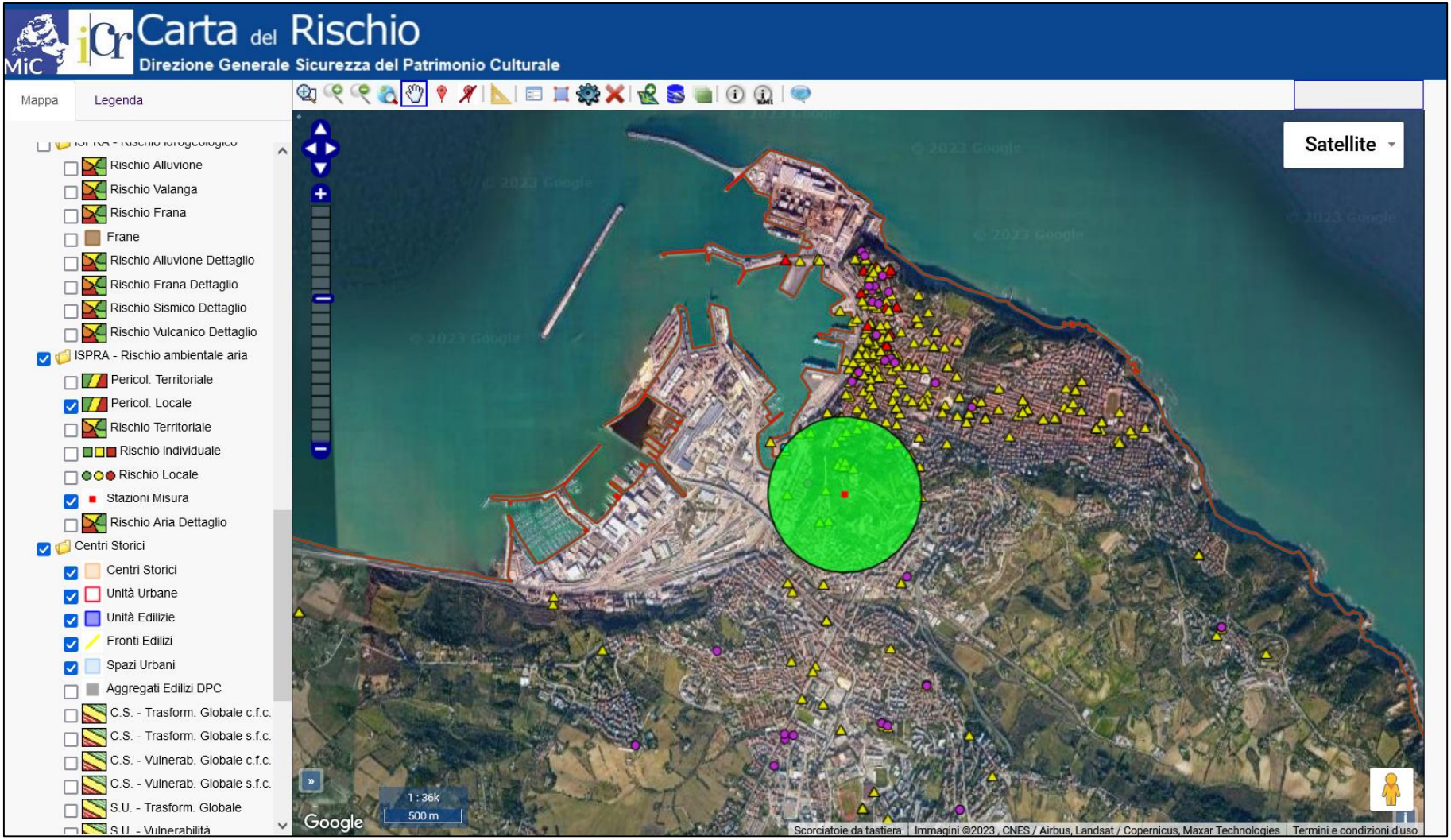
Collaboration: ISPRA - ICR- Direzione Generale Sicurezza (MiC)

- Collection of environmental data
- Overlapping between environmental data and the distribution/vulnerability of the cultural heritage georeferenced in VIR database
- Risk assessment



http://www.cartadelrischio.beniculturali.it/

Sources and analysis of air pollutant data: *punctual* data application

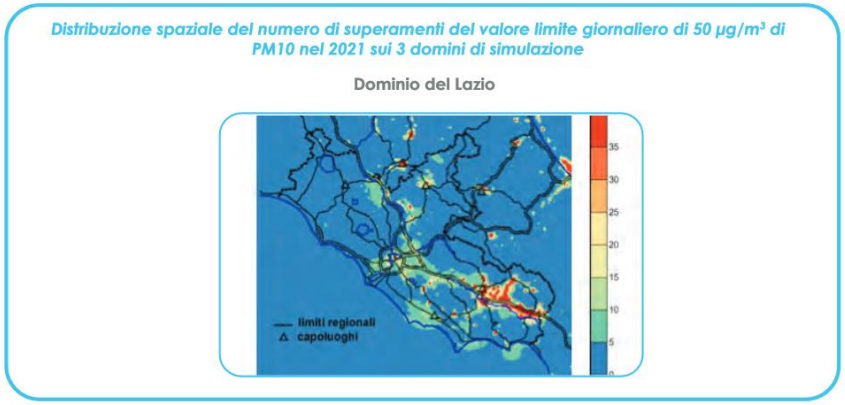


http://www.cartadelrischio.beniculturali.it/webgis/

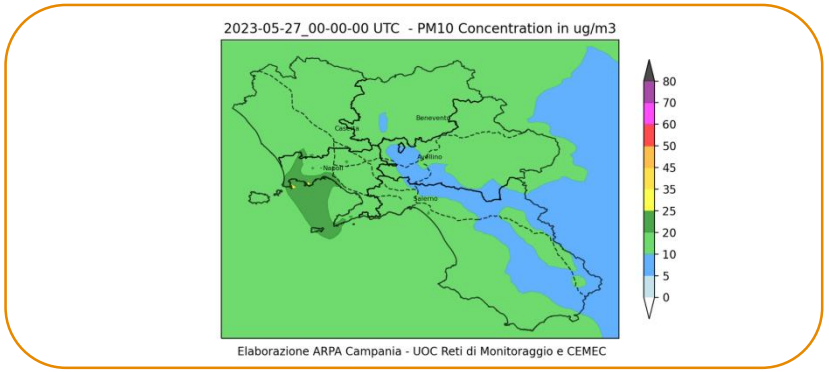
Sources and analysis of air pollutant data: *spatial* data

1. Atmospheric dispersion modeling

- Use of modeling systems for spatializing the pollutant concentrations, starting from the meteorological characteristics, micrometeorological, orographic and emissive data of the territory, to reconstruct the dispersion, tra- chemical changes (both in the gaseous and solid phase) of the substances that are introduced (and of the substances residing) in the atmosphere.
- Sources spatial data: Regional environmental Agency (SNPA)



https://www.arpalazio.it/documents/20124/88ace5e4-f8ca-145d-9b1a-8fcfdaf6790a



https://www.arpacampania.it/chimere

Sources and analysis of air pollutant data: *spatial* data application

Application: Artek Project (2016-2018)

Team:

Nais (prime contractor), ICR, ISPRA, CNR-IMAA, ENAV, Strago, Superelectric, Iptronix

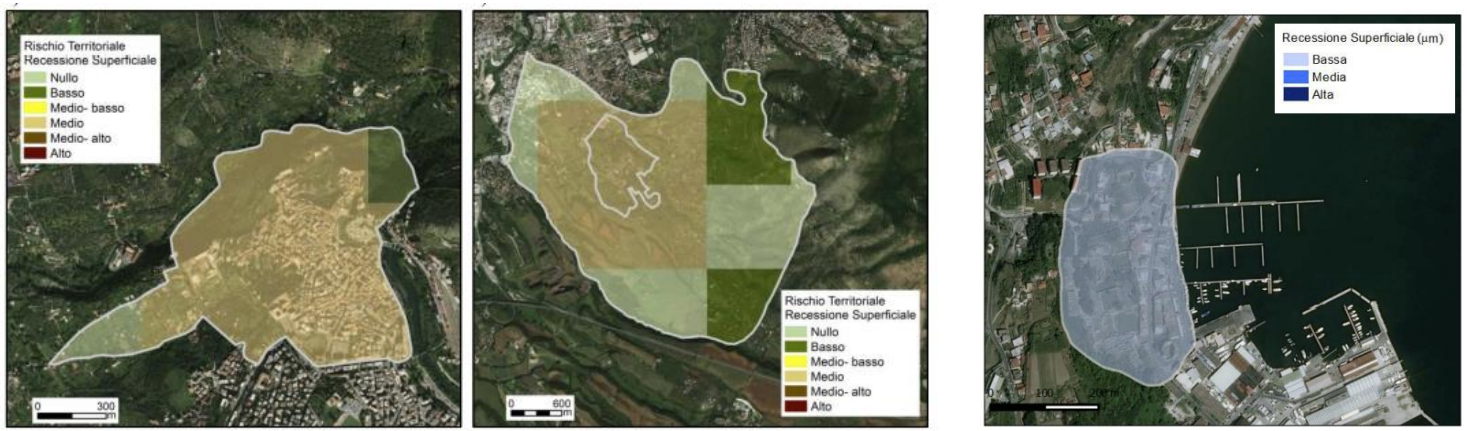
Objective : Calculation of the surface recession damage at the local level.

Input data : concentrations spatialized with atmospheric dispersion models.

Resolution :

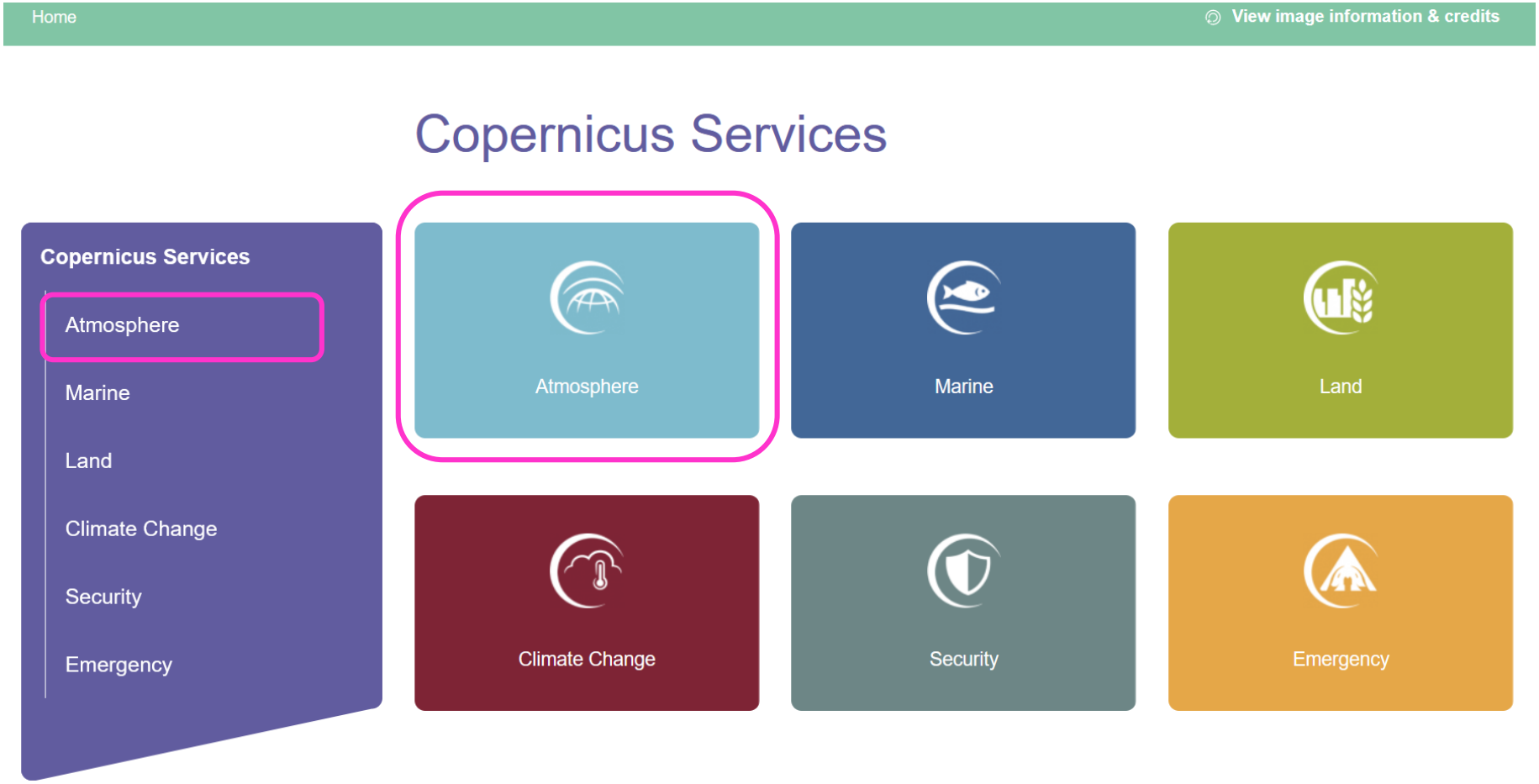
- 1 km (FARM) for Tivoli (ARPA Lazio)
- 5 km (CHIMERE) for Baia (ARPA Campania)

Tivoli ***Villa Adriana*** ***Baia***

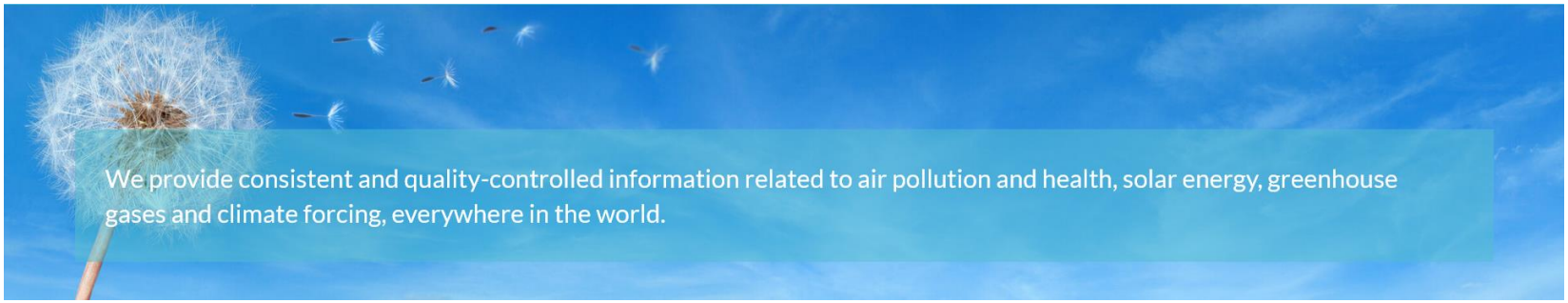


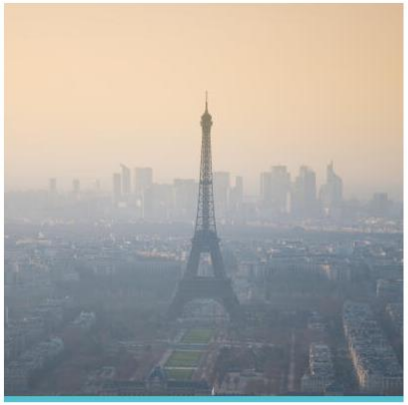
Sources and analysis of air pollutant data: *spatial* data

2. Copernicus Products



Sources and analysis of air pollutant data: *spatial* data





Europe

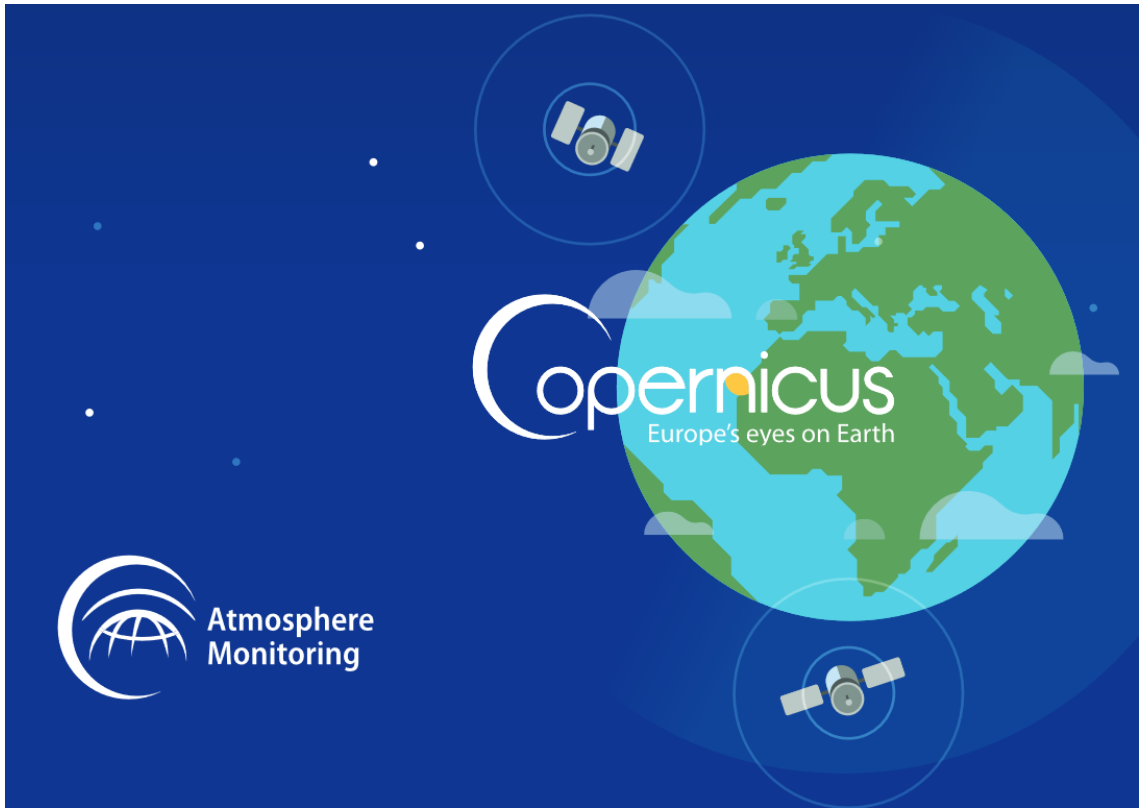
Worldwide

https://atmosphere.copernicus.eu/

Sources and analysis of air pollutant data: *spatial* data

CAMS DATA

- Air quality monitoring, forecast information and maps
- Historic assessments of air quality back to 2003
- Identification of pollutants and their sources
- Forecasts of pollen levels
- Resources for evaluating emission control measures
- Historical data records for solar radiation



Sources and analysis of air pollutant data: *spatial* data

CAMS European air quality reanalyses

This dataset provides annual air quality reanalyses for Europe based on both unvalidated (interim) and validated observations. CAMS produces annual air quality (interim) reanalyses for the European domain at significantly higher spatial resolution (0.1 degrees, approx. 10km) than is available from the global reanalyses. The production is currently based on an ensemble of nine air quality data assi...

CAMS European air quality forecasts

This dataset provides daily air quality analyses and forecasts for Europe. CAMS produces specific daily air quality analyses and forecasts for the European domain at significantly higher spatial resolution (0.1 degrees, approx. 10km) than is available from the global analyses and forecasts. The production is based on an ensemble of eleven air quality forecasting systems across Europe. A median en...

CAMS global emission inventories

This data set contains gridded distributions of global anthropogenic and natural emissions. Natural and anthropogenic emissi are key drivers of the evolution of the composition of the atmosphere, so an accurate representation of them in forecast mod compiles inventories of emission data that serve as...

CAMS global greenhouse gas reanalysis (EGG4)

This dataset is part of the ECMWF Atmospheric Composition Reanalysis focusing on long-lived greenhouse gases: carbon dioxi fluxes at the surface are crucial for the evolution of the long-lived greenhouse gases in the atmosphere. In this dataset the CO order to simulate the variability across a ...

CAMS global greenhouse gas reanalysis (EGG4) monthly averaged fields

This dataset is part of the ECMWF Atmospheric Composition Reanalysis focusing on long-lived greenhouse gases: carbon dioxi fluxes at the surface are crucial for the evolution of the long-lived greenhouse gases in the atmosphere. In this dataset the CO order to simulate the variability across a ...

CAMS global radiative forcings

This dataset provides geographical distributions of the radiative forcing (RF) by key atmospheric constituents. The radiative fo additional model simulations and are provided separately for... carbon dioxide methane tropospheric ozone stratospheric ozc radiation interactions between anthropoge...

CAMS global radiative forcing - auxilliary variables

This dataset provides aerosol optical depths and aerosol-radiation radiative effects for four different aerosol origins: anthropogenic, mineral dust, marine, and land-based fine-mode natural aerosol. The latter mostly consists of biogenic aerosols. The data are a necessary complement to the "CAMS global radiative forcings" dataset (see "Related Data"). The calculation of aerosol radiative forcing...

CAMS global reanalysis (EAC4) monthly averaged fields

EAC4 (ECMWF Atmospheric Composition Reanalysis 4) is the fourth generation ECMWF global reanalysis of atmospheric composition. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using a model of the atmosphere based on the laws of physics and chemistry. This principle, called data assimilation, is based on the method used by numer...

CAMS global reanalysis (EAC4)

EAC4 (ECMWF Atmospheric Composition Reanalysis 4) is the fourth generation ECMWF global reanalysis of atmospheric composition. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using a model of the atmosphere based on the laws of physics and chemistry. This principle, called data assimilation, is based on the method used by numer...

CAMS global inversion-optimised greenhouse gas fluxes and concentrations

This data set contains net fluxes at the surface, atmospheric mixing ratios at model levels, and column-mean atmospheric mixing ratios for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Natural and anthropogenic surface fluxes of greenhouse gases are key drivers of the evolution of Earth's climate, so their monitoring is essential. Such information has been used in particular as par...

CAMS solar radiation time-series

The CAMS solar radiation services provide historical values (2004 to present) of global (GHI), direct (BHI) and diffuse (DHI) solar irradiation, as well as direct normal irradiation (BNI). The aim is to fulfil the needs of European and national policy development and the requirements of both commercial and public downstream services, e.g. for planning, monitoring, efficiency improvements and the i...

CAMS global biomass burning emissions based on fire radiative power (GFAS)

Emissions of atmospheric pollutants from biomass burning and vegetation fires are key drivers of the evolution of atmospheric composition, with a high degree of spatial and temporal variability, and an accurate representation of them in models is essential. The CAMS Global Fire Assimilation System (GFAS) utilises satellite observations of fire radiative power (FRP) to provide near-real-time inform...

CAMS global atmospheric composition forecasts

CAMS produces global forecasts for atmospheric composition twice a day. The forecasts consist of more than 50 chemical species (e.g. ozone, nitrogen dioxide, carbon dioxide) and seven different types of aerosol (desert dust, sea salt, organic matter, black carbon, sulphate, nitrate and ammonium aerosol). In addition, several meteorological variables are available as well. The initial conditions of...

Sources and analysis of air pollutant data: *spatial* data

CAMS European air quality reanalyses

Atmosphere Monitoring Service

CAMS European air quality reanalyses: The dataset provides annual air quality reanalyses for Europe based on both unvalidated (interim) and validated observations.
CAMS produces annual air quality (interim) reanalyses for the European domain at significantly higher spatial resolution (0.1 degrees, approx. **10km)** than is available from the global reanalyses. The reanalysis combines model data with observations provided by the European Environment Agency (EEA) into a complete and consistent dataset using various data assimilation techniques.
The production is currently based on an ensemble of nine air quality data assimilation systems across Europe. A median ensemble is calculated from individual outputs, since ensemble products yield on average better performance than the individual model products.

DATA DESCRIPTION	
Data type	Gridded
Horizontal coverage	Europe (east boundary=25.0° W, west=45.0° E, south=30.0° N, north=72.0°)
Horizontal resolution	0.1°x0.1° (10 km x 10 km)
Vertical coverage	Surface, 50m, 100m, 250m, 500m, 750m, 1000m, 2000m, 3000m, 5000m
Temporal coverage	2018, 2019, 2020, 2021
Temporal resolution	monthly files containing 1-hourly analyses
File format	NetCDF
Update frequency	twice a year

https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-europe-air-quality-reanalyses

Sources and analysis of air pollutant data: *spatial* data

CAMS European air quality forecasts

Atmosphere Monitoring Service

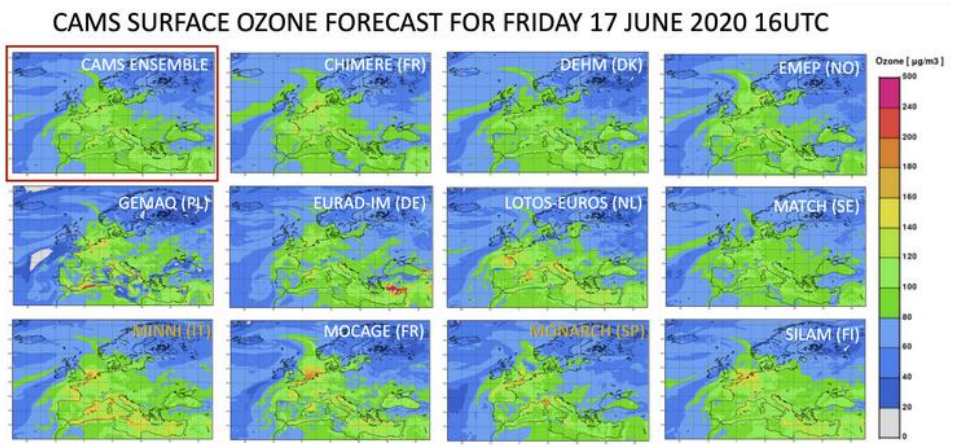
CAMS European air quality forecasts: The dataset provides daily air quality analyses and forecasts for Europe.
CAMS produces specific daily air quality analyses and forecasts for the European domain at significantly higher spatial resolution (0.1 degrees, approx. **10km**) than is available from the global analyses and forecasts. The production is based on an ensemble of eleven air quality forecasting systems across Europe. A median ensemble is calculated from individual outputs, since ensemble products yield on average better performance than the individual model products. The analysis combines model data with observations provided by the European Environment Agency (EEA) into a complete and consistent dataset using various data assimilation techniques. In parallel, air quality forecasts are produced once a day for the next four days.

DATA DESCRIPTION	
Data type	Gridded
Horizontal coverage	Europe (west boundary=25.0° W, east=45.0° E, south=30.0° N, north=70.0°)
Horizontal resolution	0.1°x0.1° (10 km x 10 km)
Vertical coverage	Surface, 50m, 100m, 250m, 500m, 750m, 1000m, 2000m, 3000m, 5000m
Temporal coverage	three-year rolling archive
Temporal resolution	1-hourly
File format	GRIB, NetCDF
Update frequency	daily

https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-europe-air-quality-forecasts?tab=overview

Sources and analysis of air pollutant data: *spatial* data

ENSEMBLE MODELLING

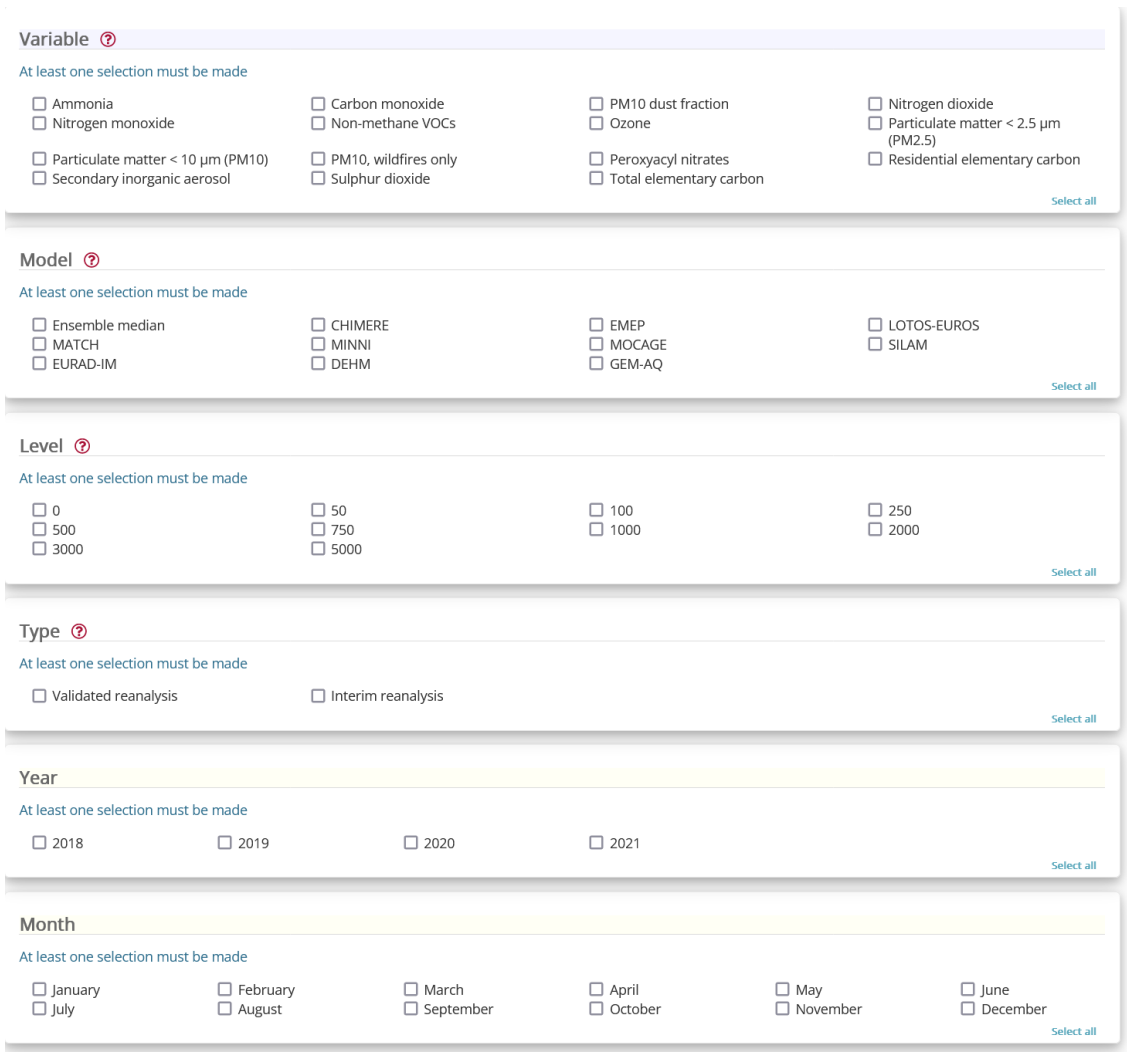


https://atmosphere.copernicus.eu/cams-european-air-quality-ensemble-forecasts-welcomes-two-new-state-art-models

- CHIMERE from INERIS
- EMEP from MET Norway
- EURAD-IM from University of Cologne
- LOTOS-EUROS from KNMI and TNO
- MATCH from SMHI
- MOCAGE from METEO-FRANCE
- SILAM from FMI
- DEHM from AARHUS UNIVERSITY (Denmark)
- GEM-AQ from IEP-NRI (Poland)
- MONARCH from BSC (Spain)
- MINNI from ENEA (Italy).

Sources and analysis of air pollutant data: *spatial* data

CAMS European air quality reanalyses



Variable

At least one selection must be made

- Ammonia
- Carbon monoxide
- PM10 dust fraction
- Nitrogen dioxide
- Nitrogen monoxide
- Non-methane VOCs
- Ozone
- Particulate matter < 2.5 µm (PM2.5)
- Particulate matter < 10 µm (PM10)
- PM10, wildfires only
- Peroxyacyl nitrates
- Residential elementary carbon
- Secondary inorganic aerosol
- Sulphur dioxide
- Total elementary carbon

Select all

Model

At least one selection must be made

- Ensemble median
- CHIMERE
- EMEP
- LOTOS-EUROS
- MATCH
- MINNI
- MOCAGE
- SILAM
- EURAD-IM
- DEHM
- GEM-AQ

Select all

Level

At least one selection must be made

- 0
- 50
- 100
- 250
- 500
- 750
- 1000
- 2000
- 3000
- 5000

Select all

Type

At least one selection must be made

- Validated reanalysis
- Interim reanalysis

Select all

Year

At least one selection must be made

- 2018
- 2019
- 2020
- 2021

Select all

Month

At least one selection must be made

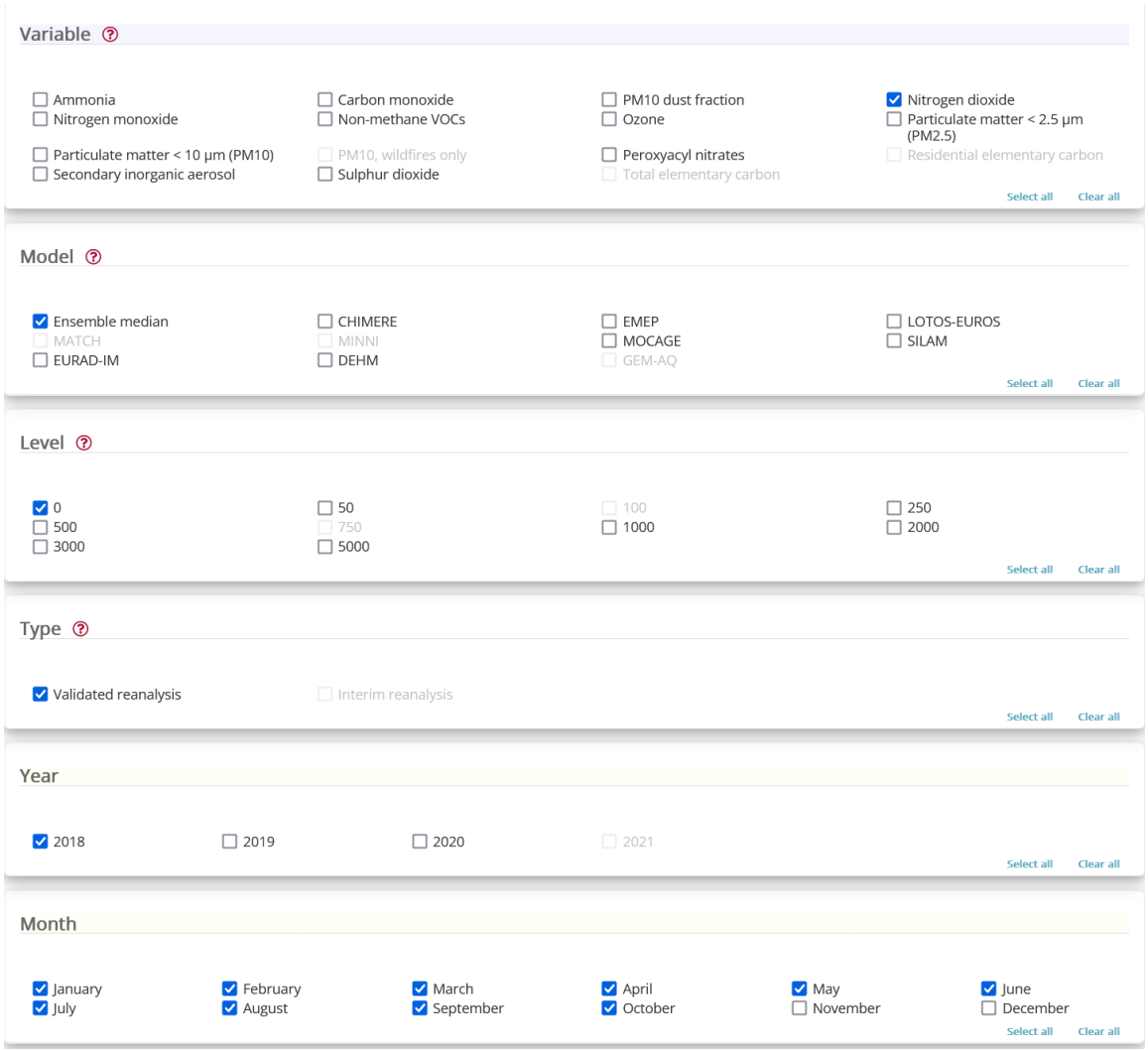
- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December

Select all

https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-europe-air-quality-reanalyses?tab=form

Sources and analysis of air pollutant data: *spatial* data

CAMS European air quality reanalyses

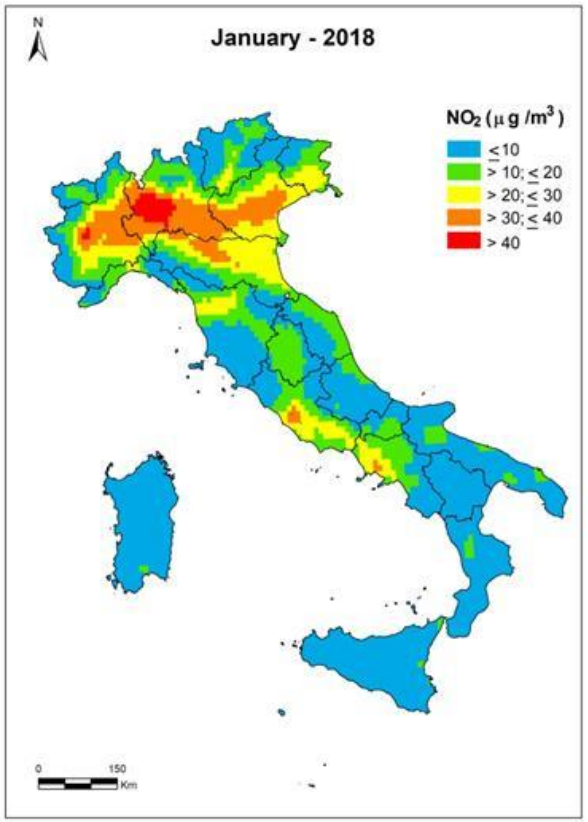


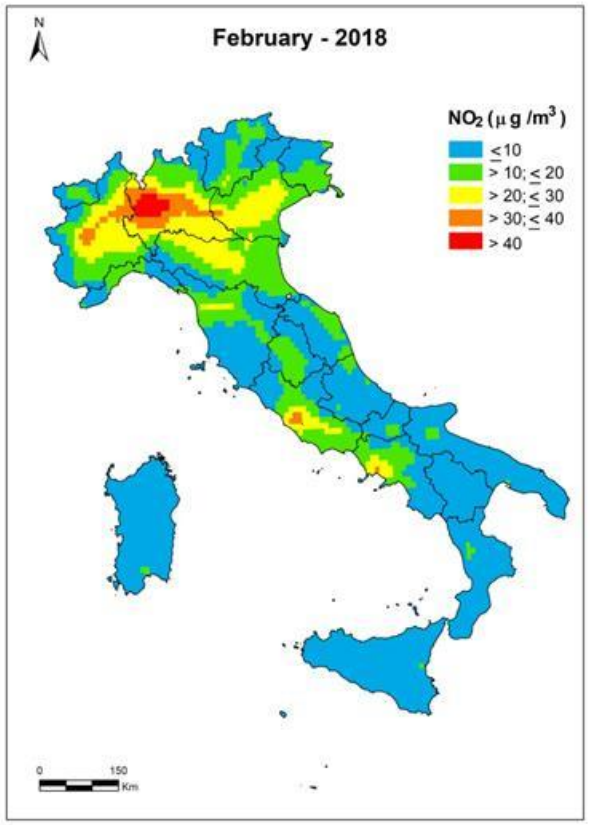
https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-europe-air-quality-reanalyses?tab=form

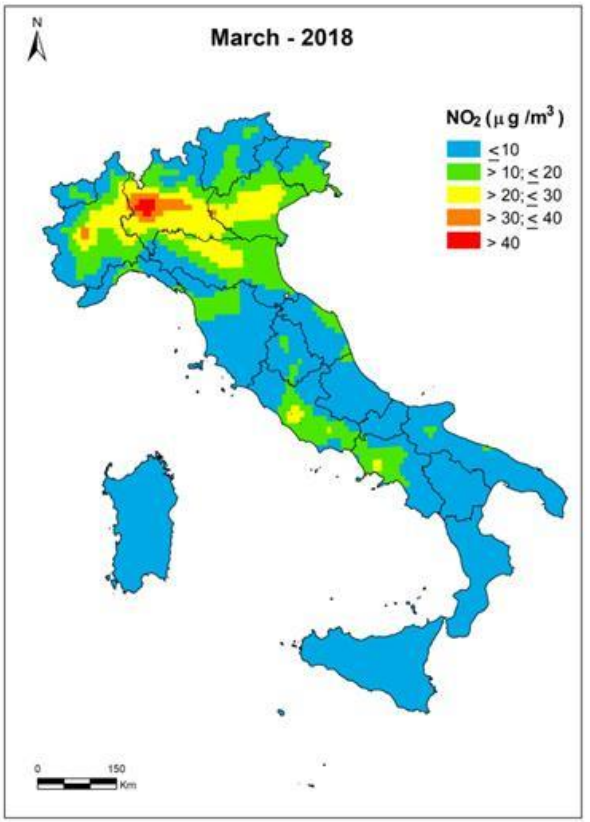
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

NO_2



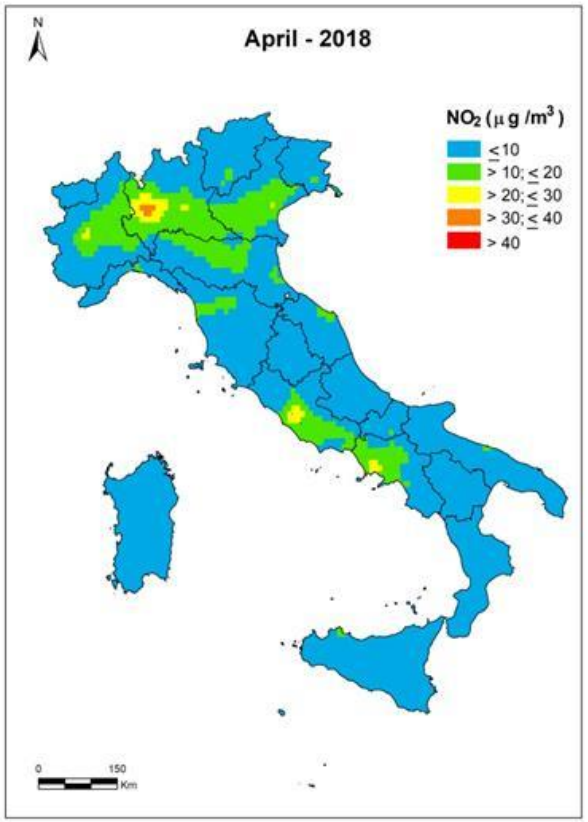


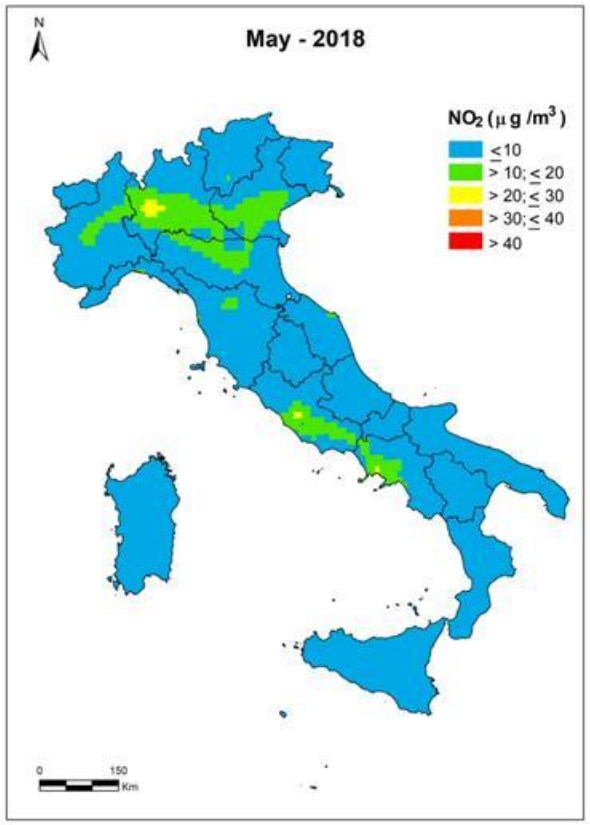


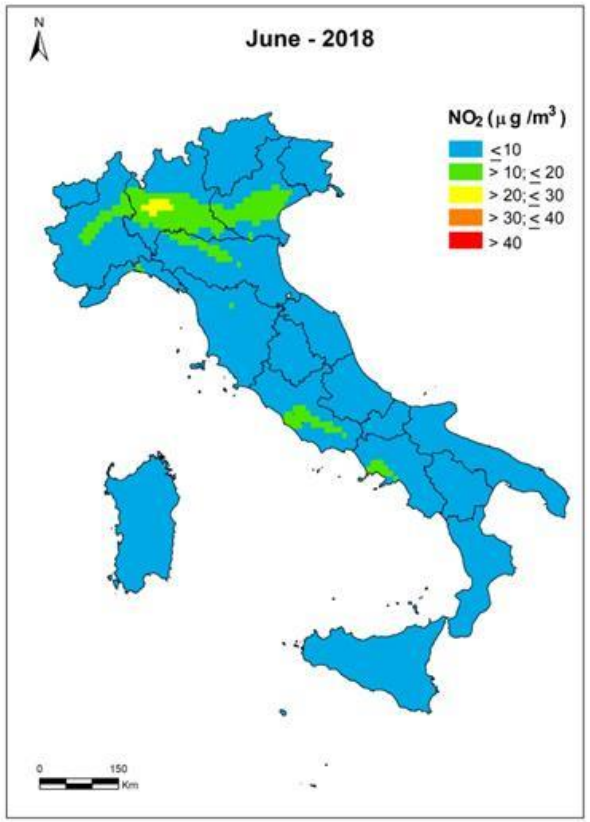
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

NO_2



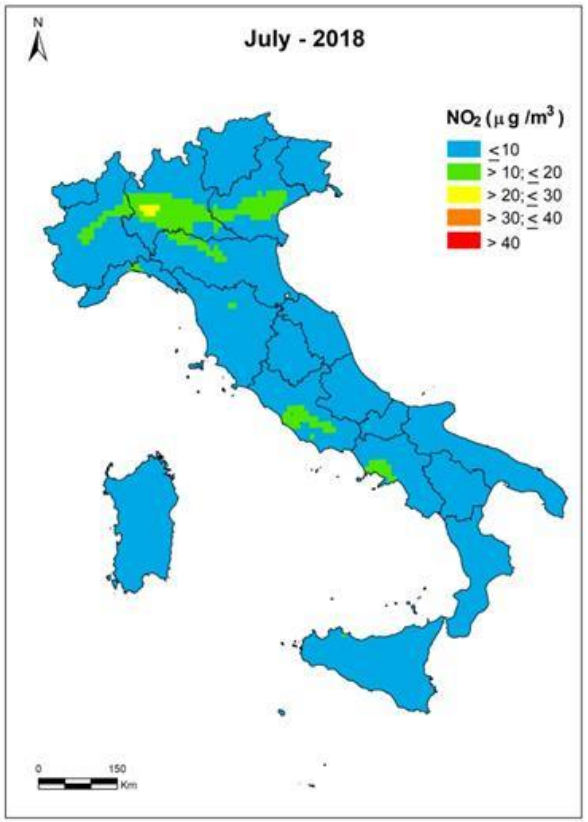


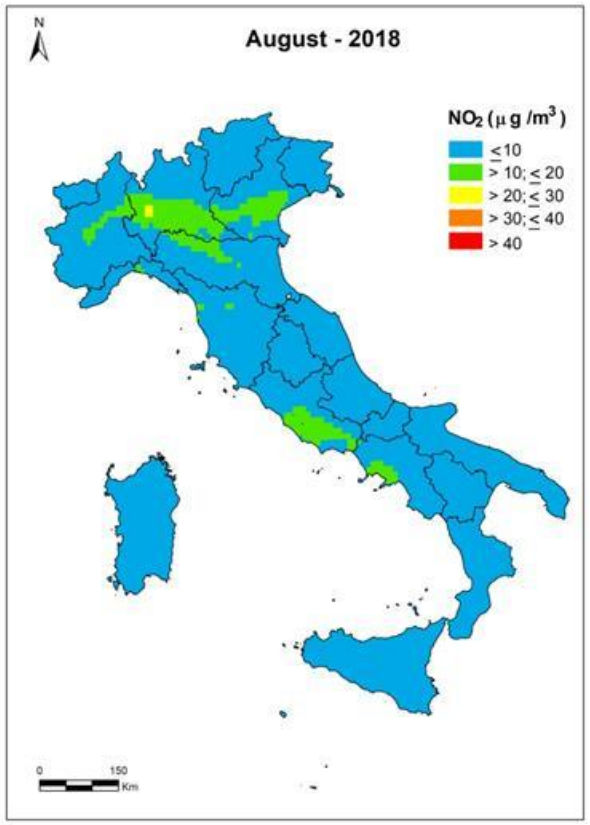


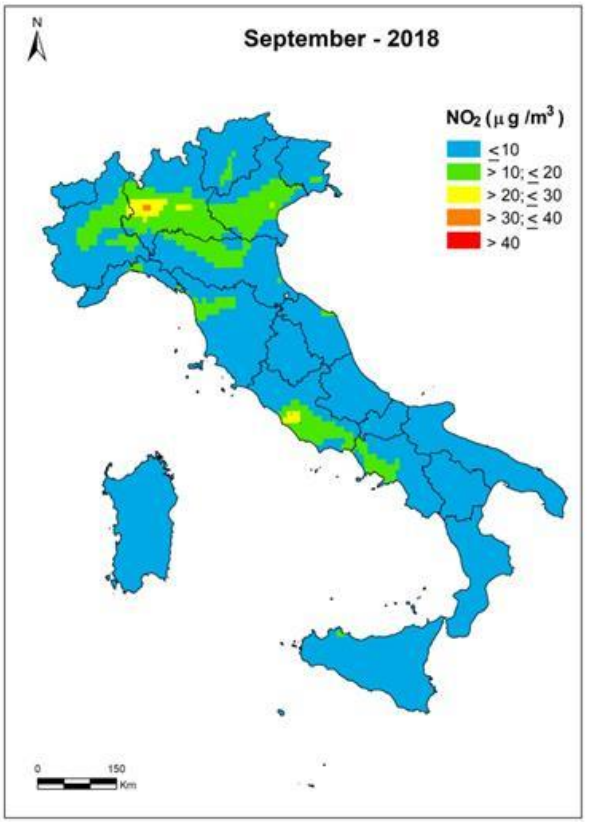
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

NO_2



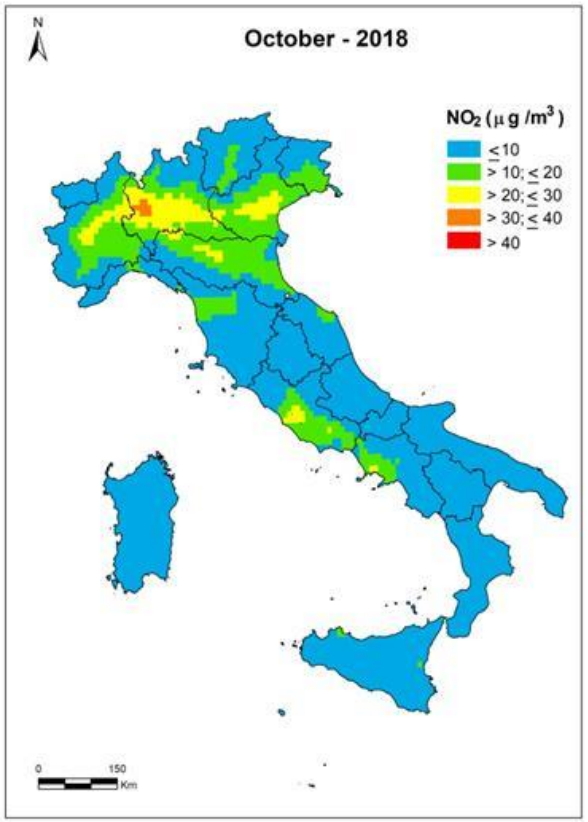


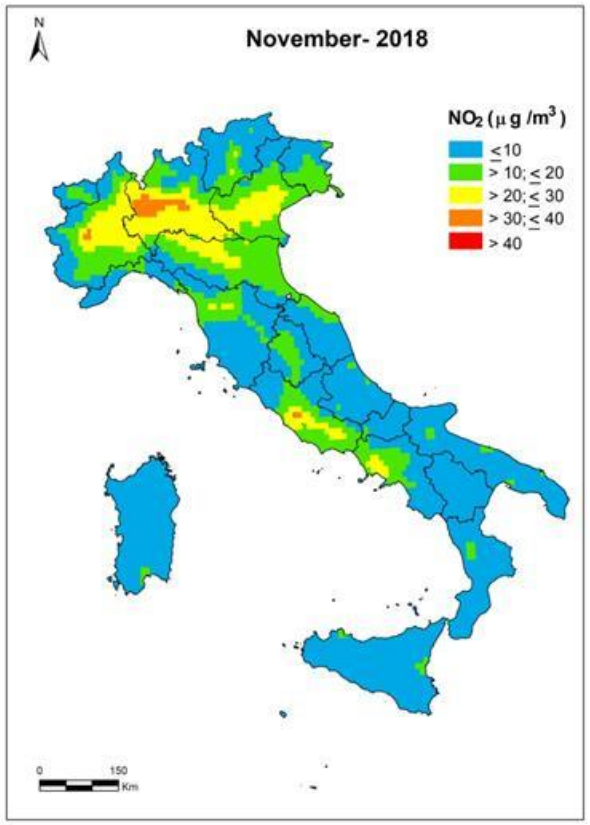


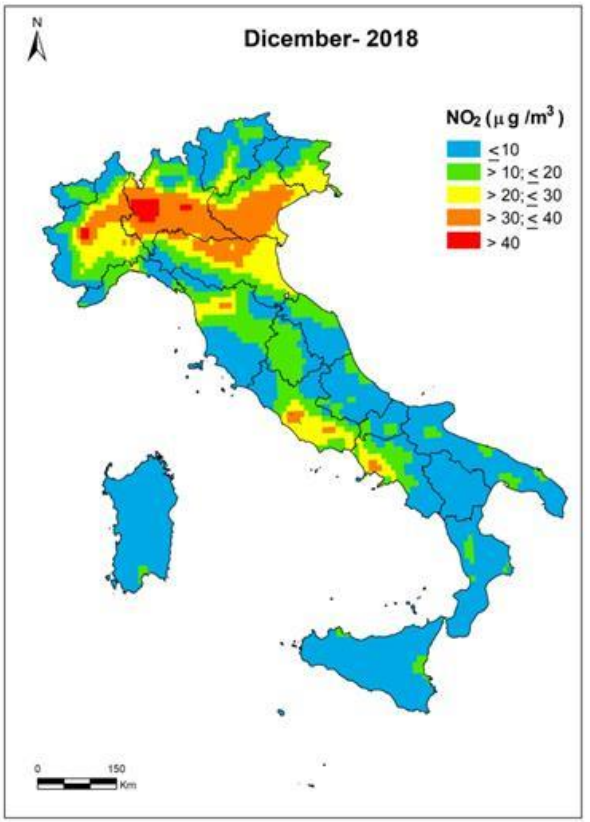
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

NO_2



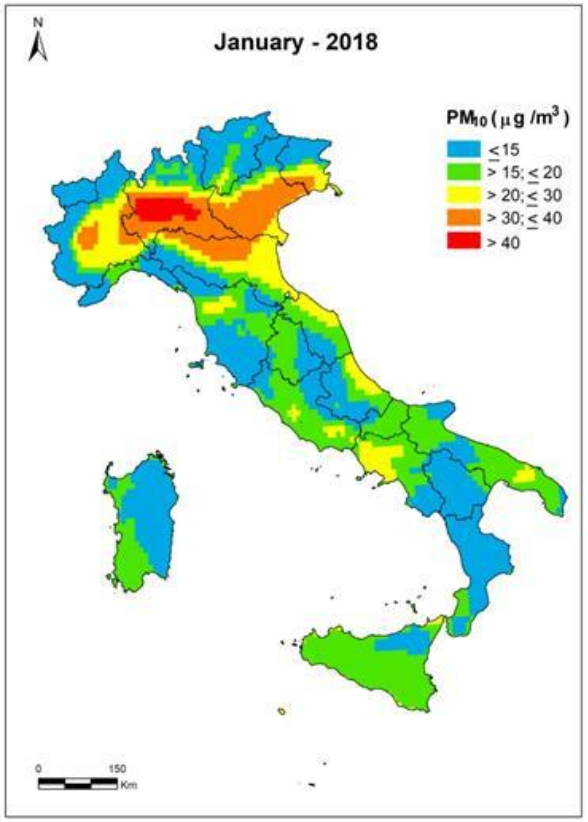


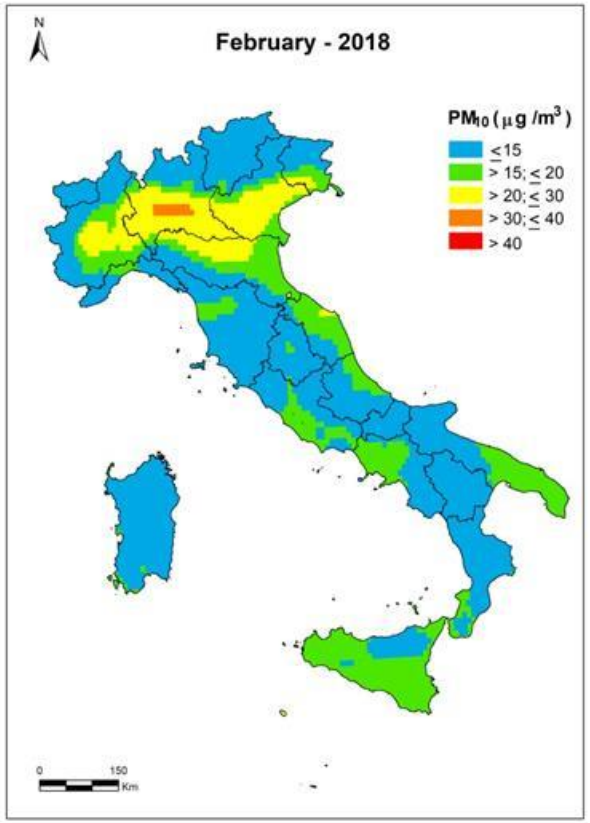


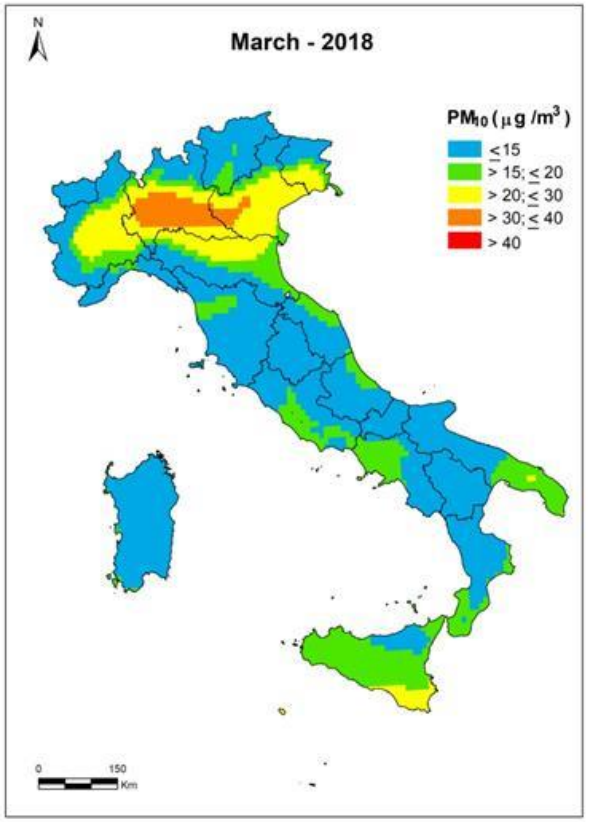
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

PM_{10}



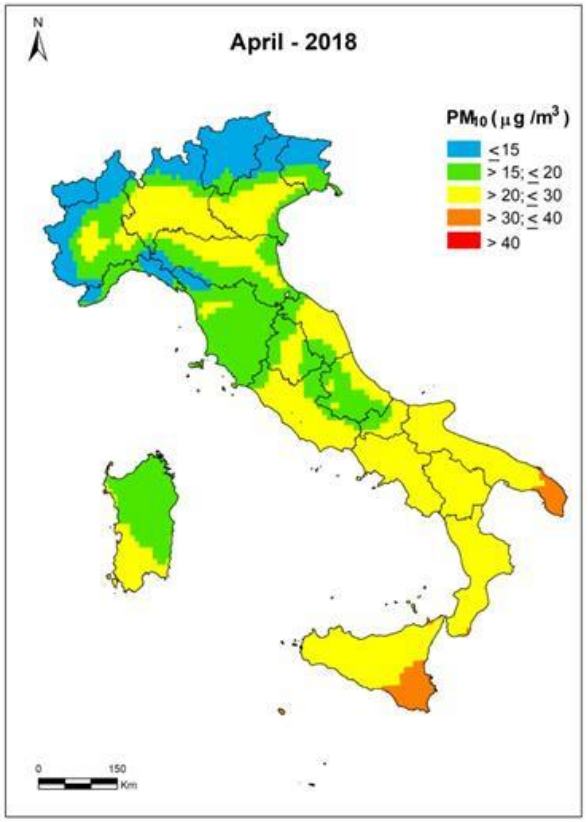


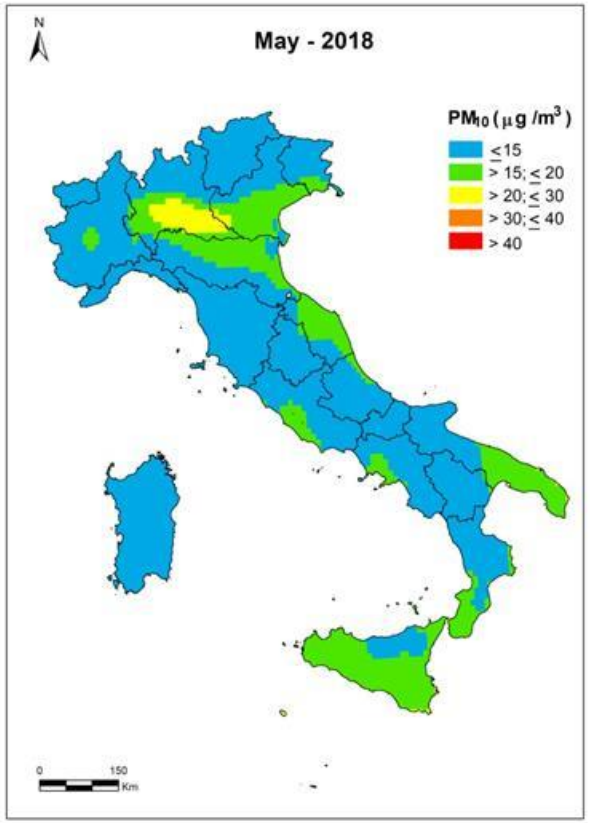


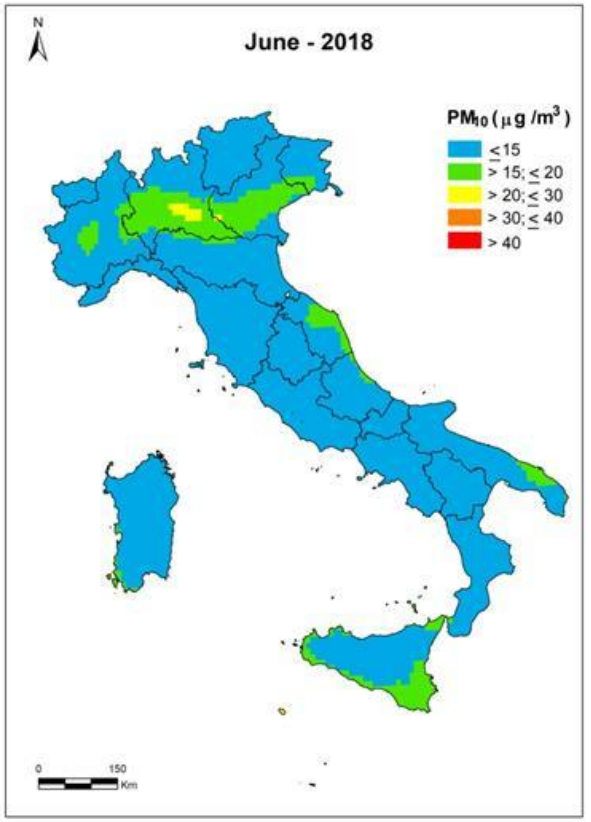
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

PM_{10}



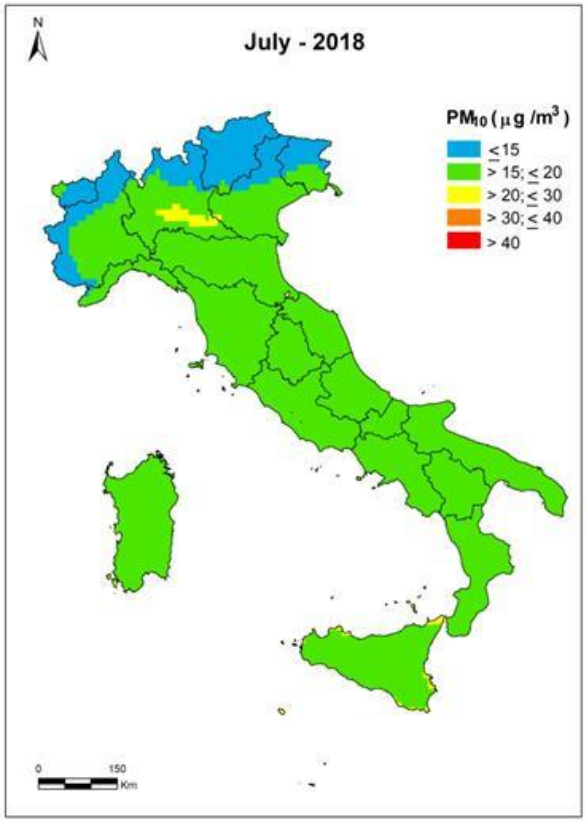


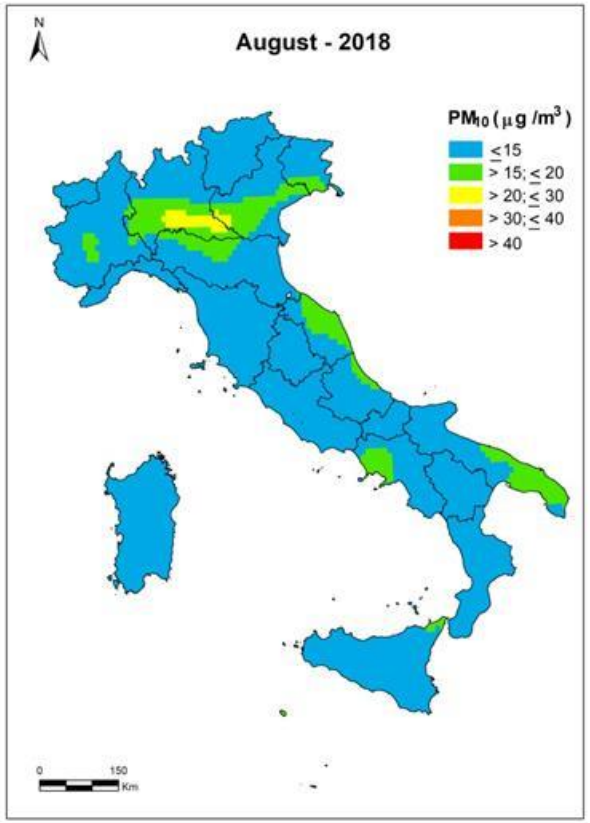


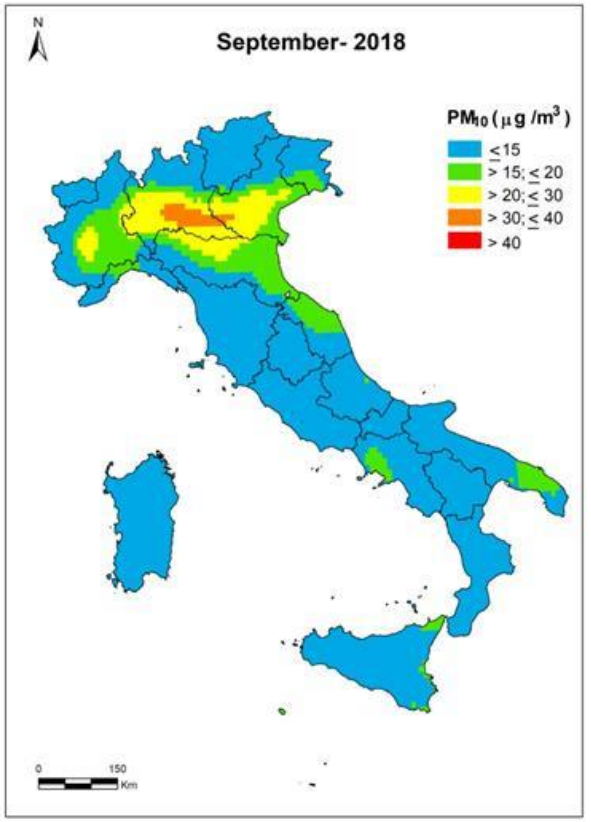
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

PM_{10}



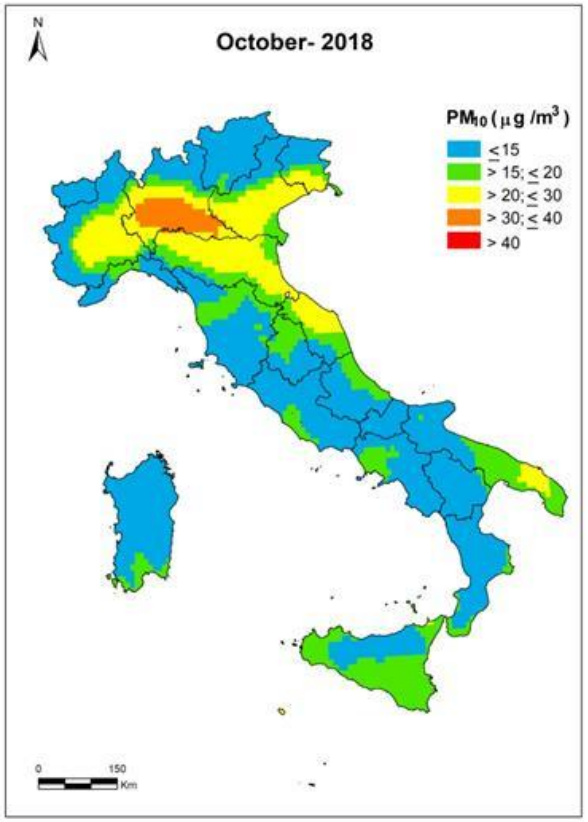


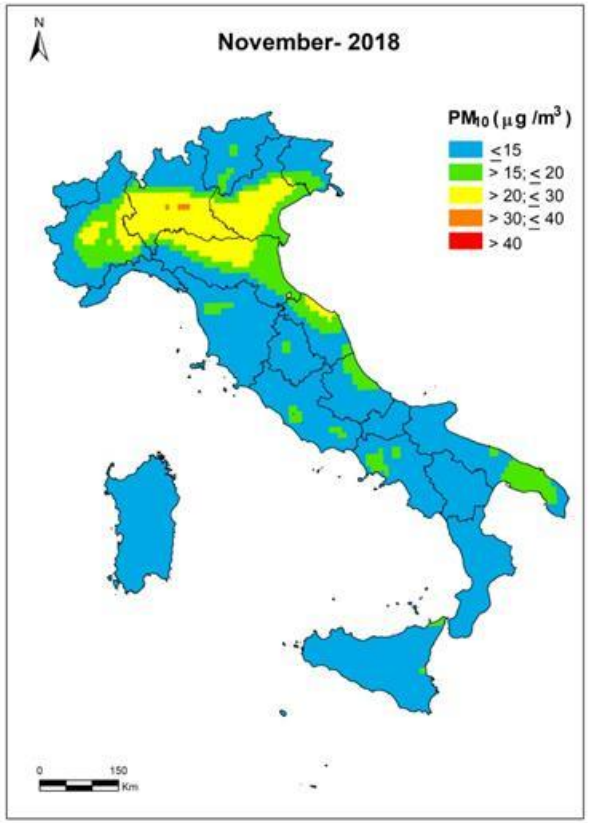


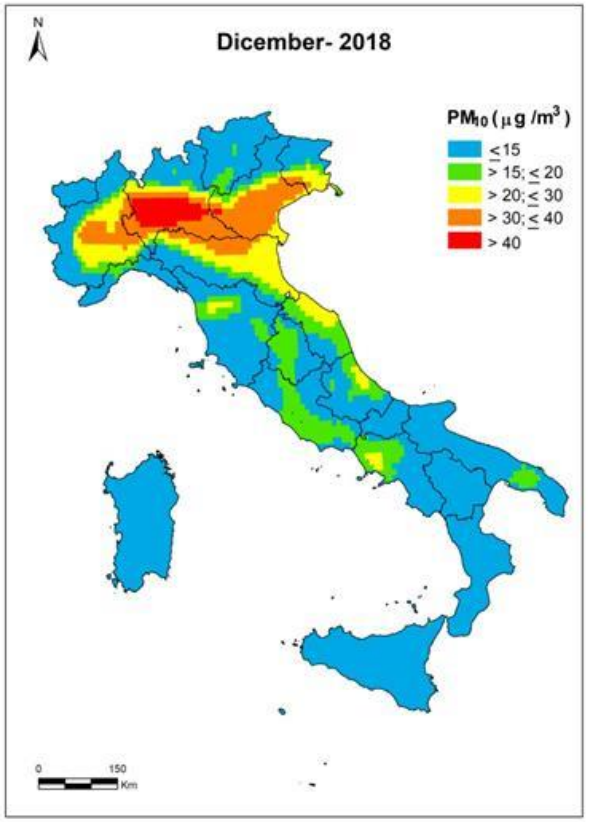
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

PM_{10}



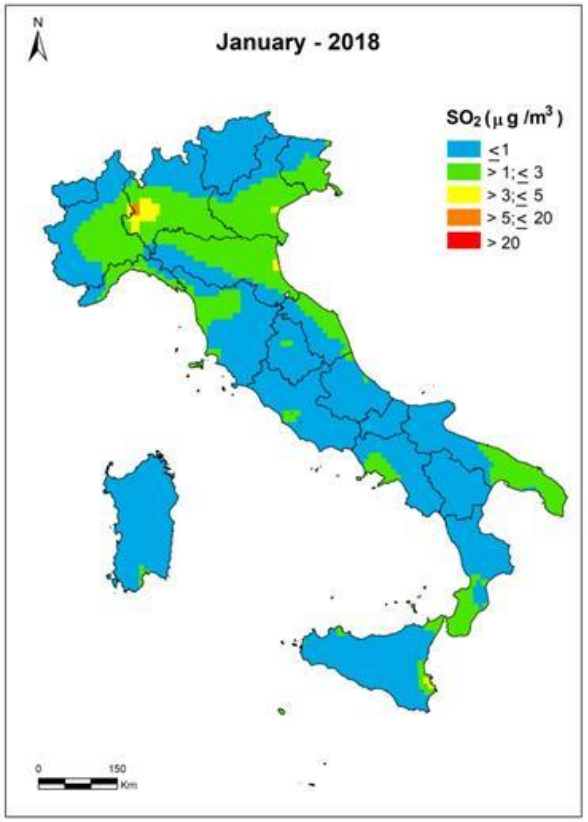


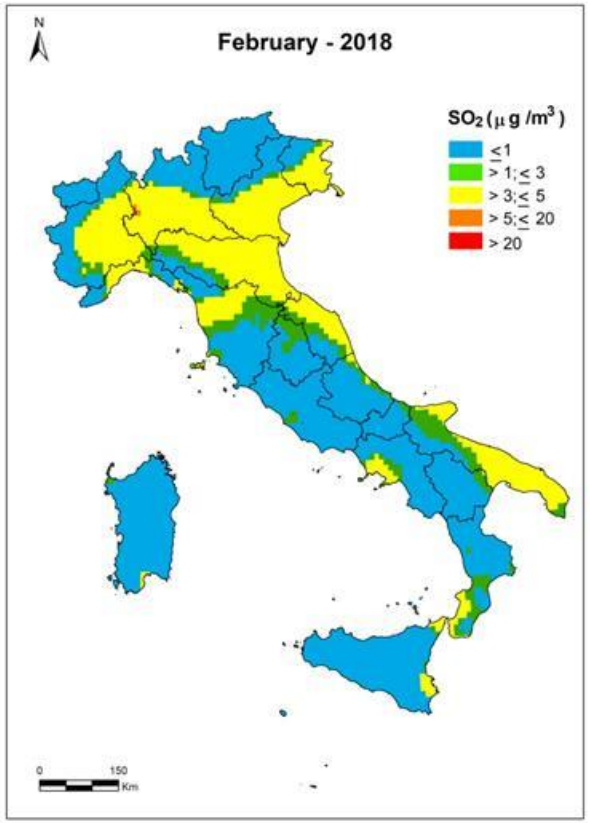


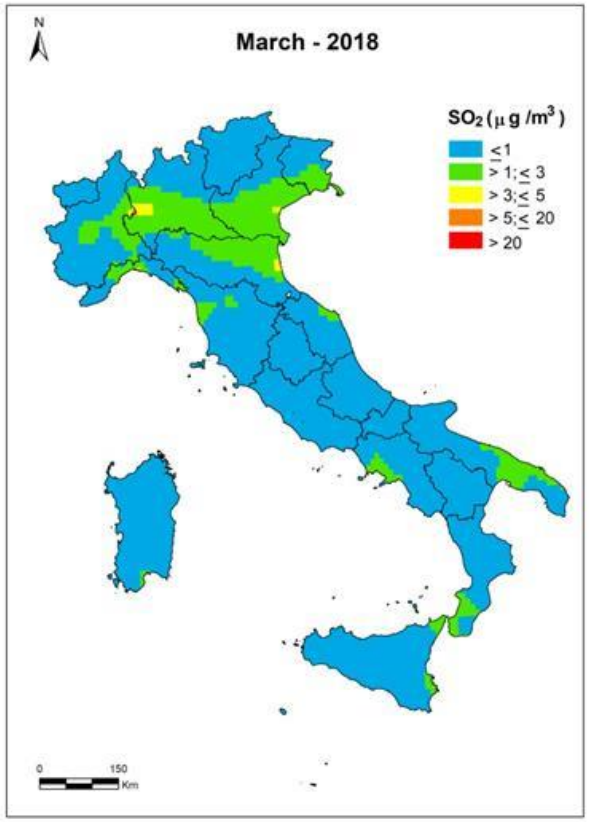
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

SO_2



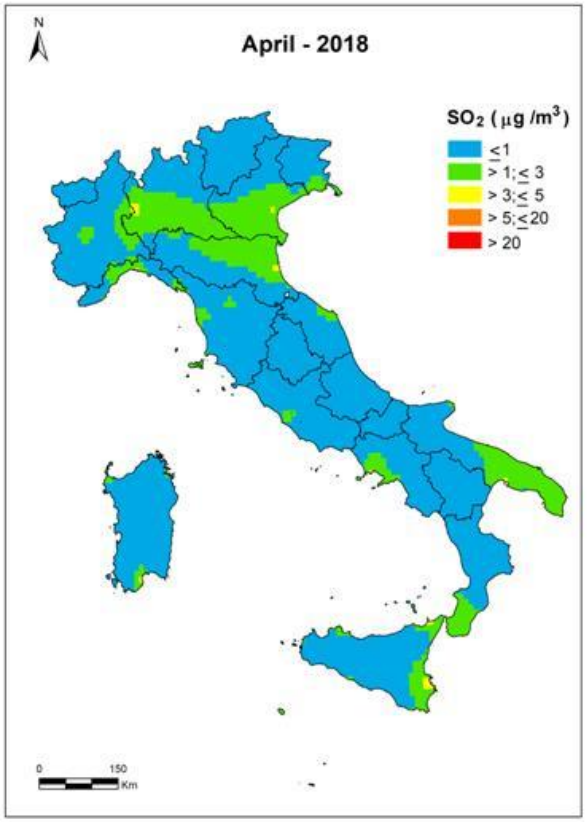


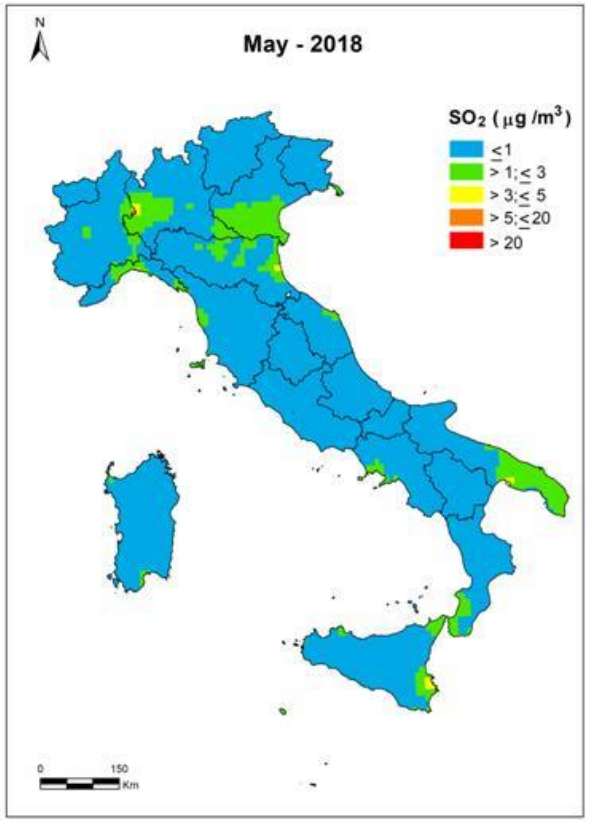


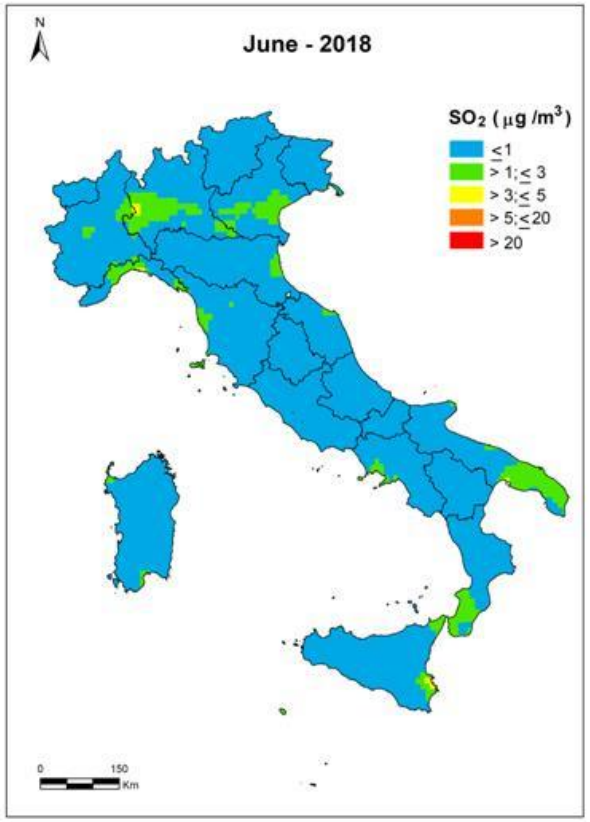
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

SO_2



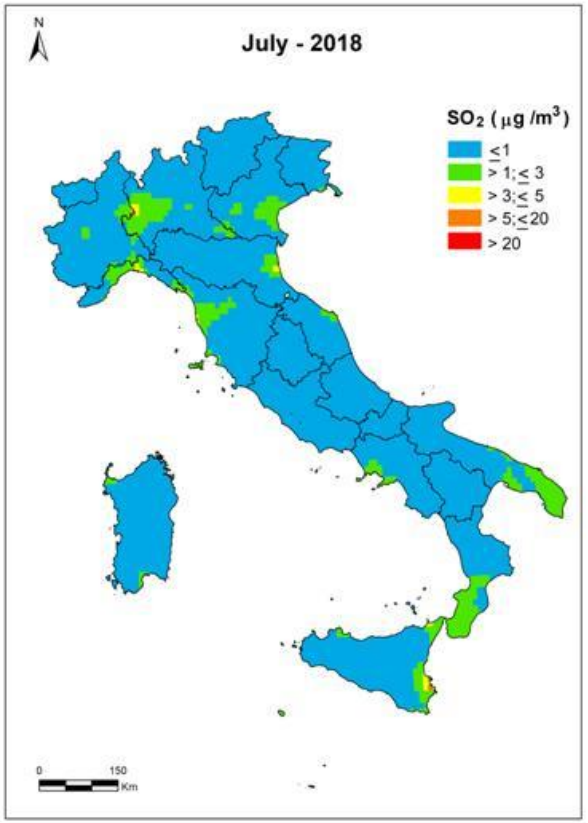


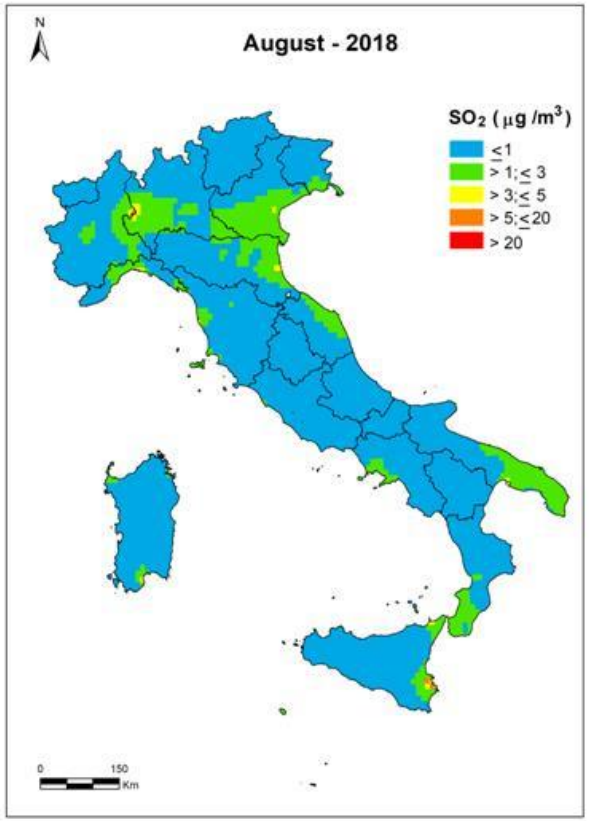


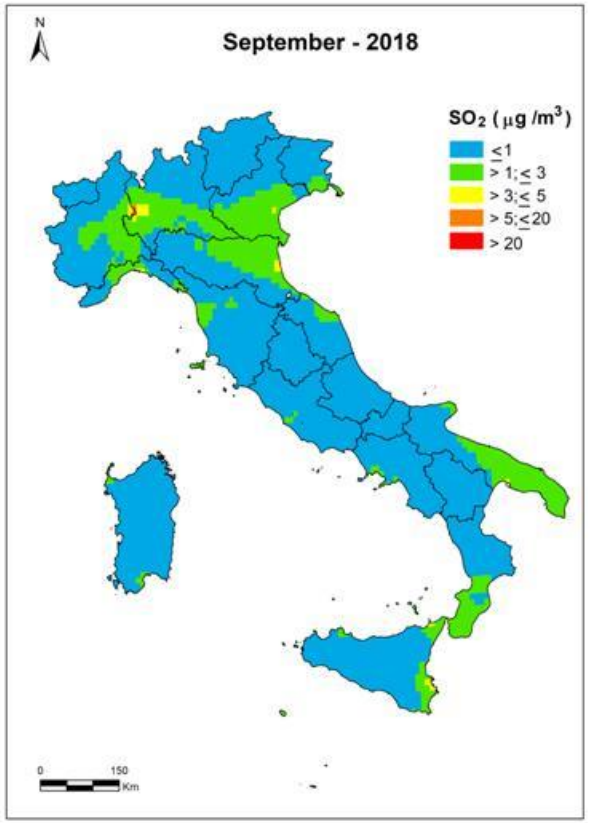
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

SO_2



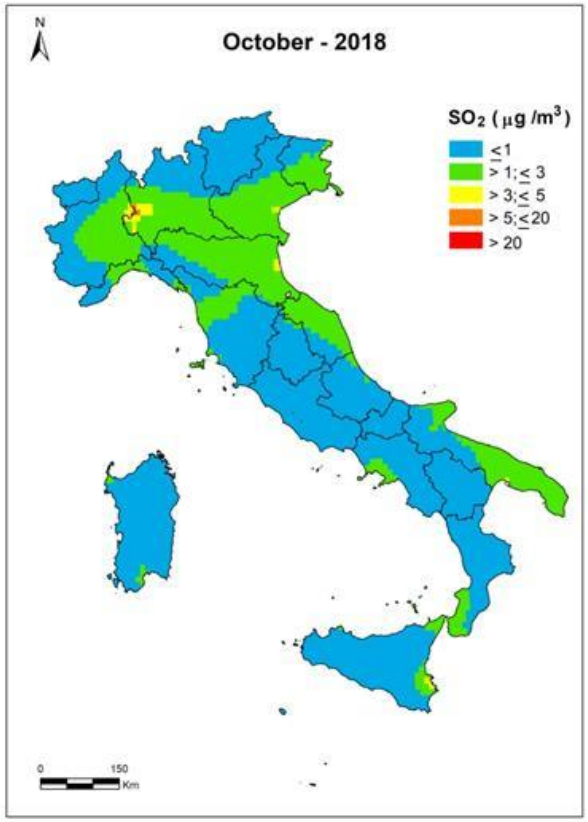


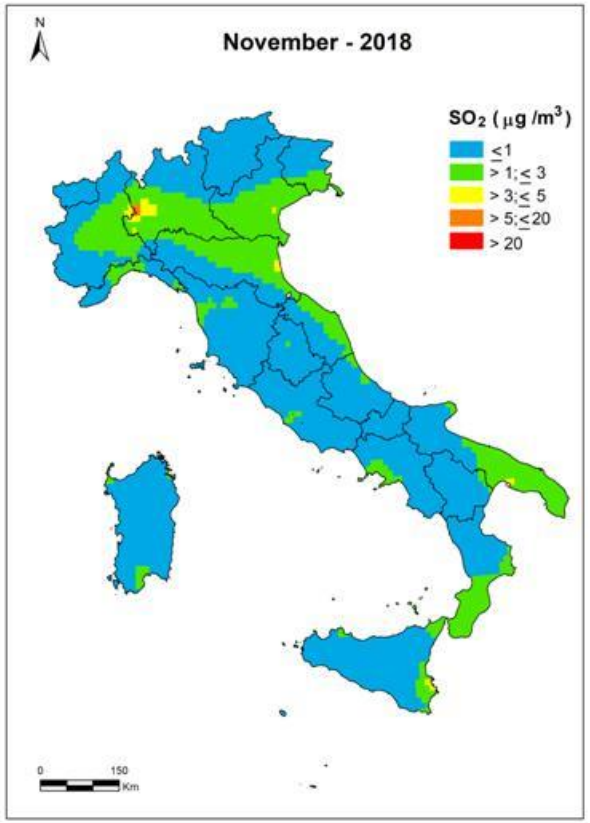


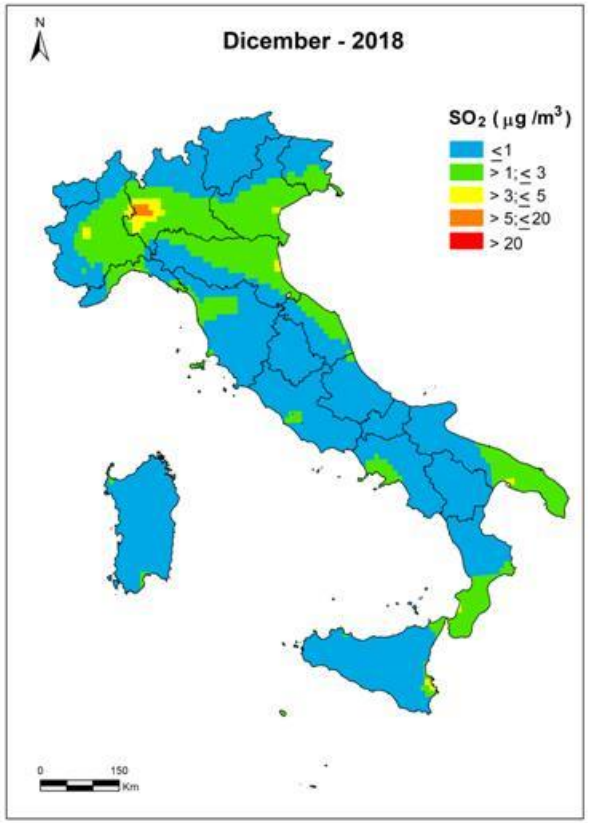
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Monthly- 2018

SO_2



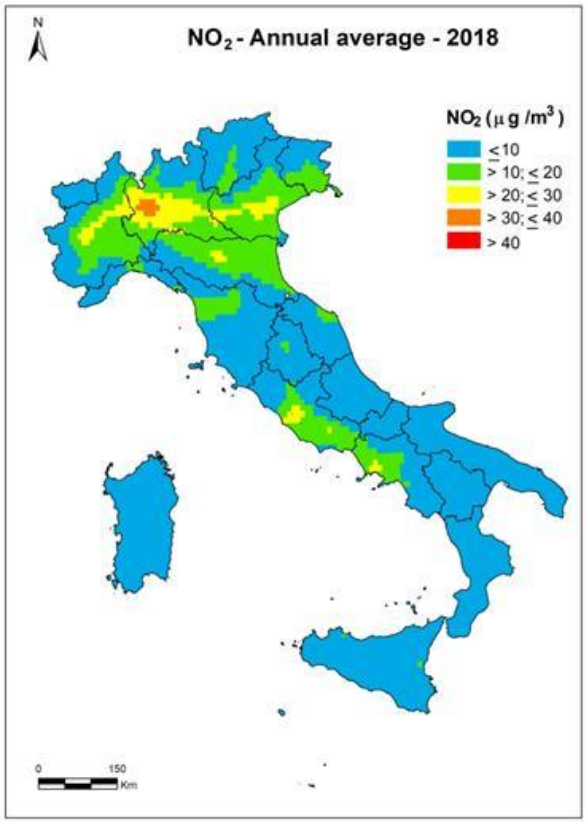




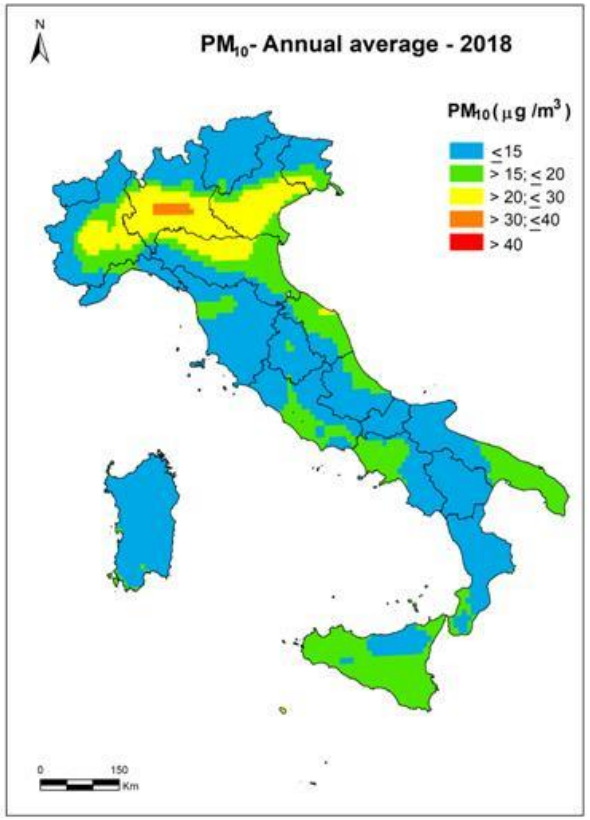
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Annual Average - 2018

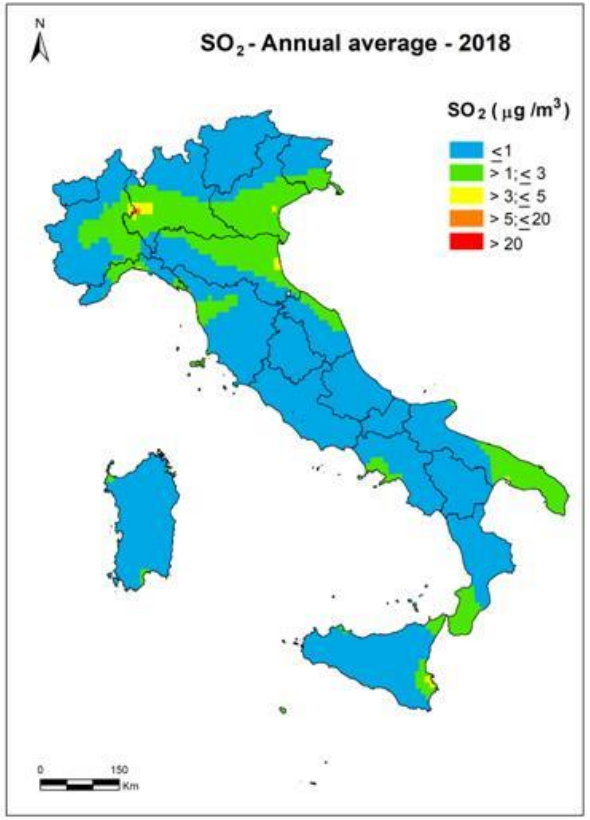
NO_2



PM_{10}



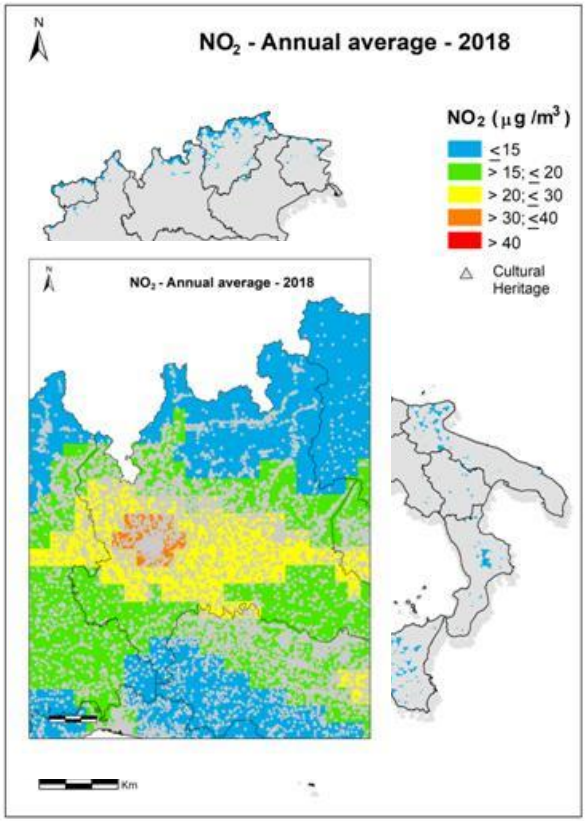
SO_2



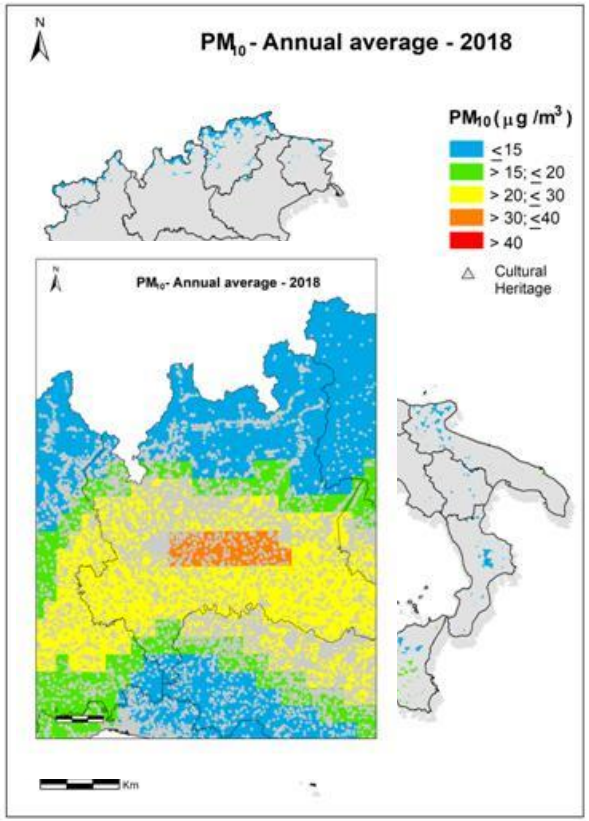
Sources and analysis of air pollutant data: *spatial* data

CAMS- Reanalyses – Annual Average - 2018

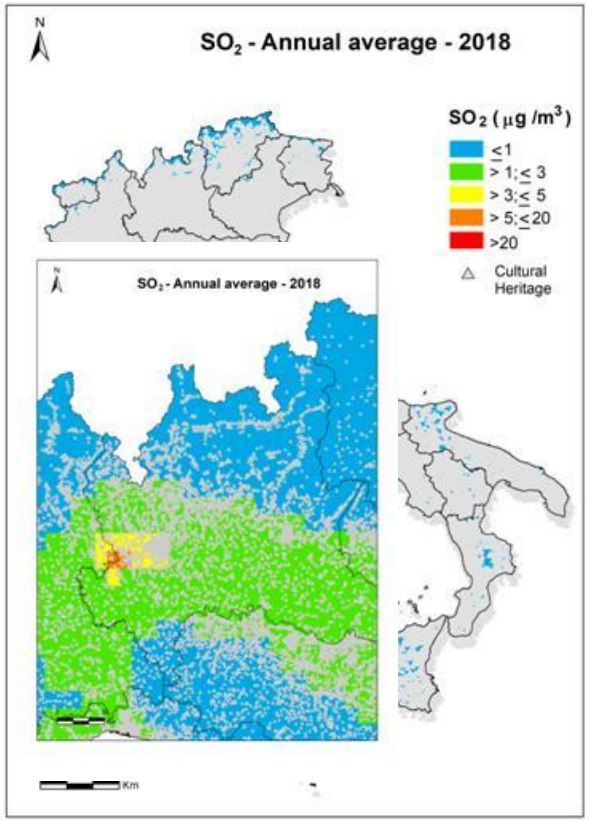
NO_2



PM_{10}



SO_2



Fonte dati Beni Culturali: Carta del Rischio del Patrimonio Culturale (Direzione Generale Sicurezza - MiC)

Sources and analysis of air pollutant data: *spatial* data application

Piano Straordinario di Monitoraggio e Conservazione dei Beni Culturali Immobili

Direzione Generale Sicurezza (MiC)

Goals:

1. Implementation of the ISPRA-ICR methodology for the study of the impacts of air pollution on immovable cultural heritage and the estimation of individual and local anthropic risk on cultural heritage;

2. Analysis of decay typologies for calcareous materials, byspecific studies of degradation carried out in situ;

3. **Processing of Copernicus products (CAMS service);**

4. Support for the identification of priority areas/territorial areas characterized by anthropic hazard.

Sources and analysis of air pollutant data: *spatial* data application

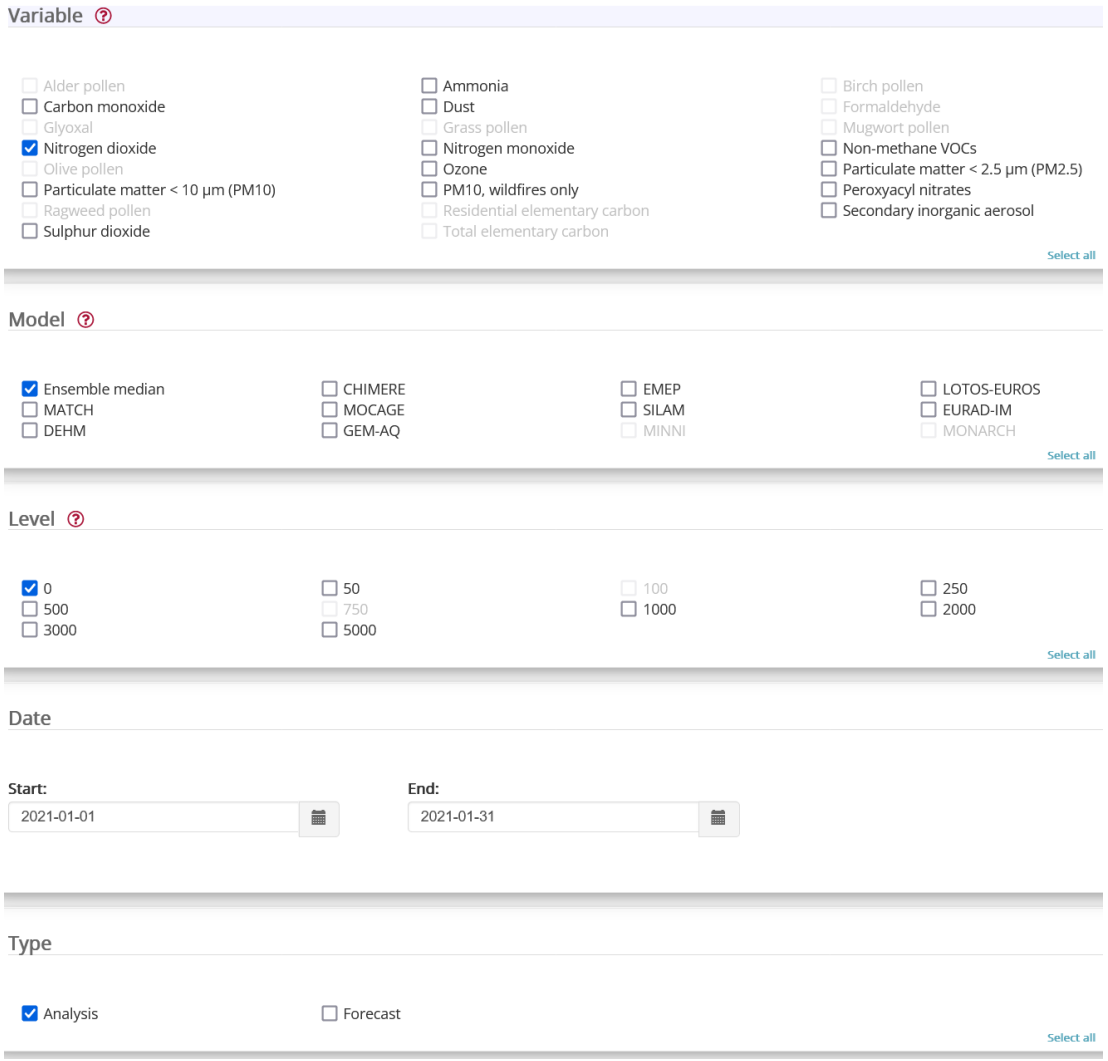
SITES

Ferrara
- **Livorno**
- **Pisa**
- Padova
- Rieti
- ***Roma (Mura Aureliane)***
- **Venezia**
- **Verona**

3. Comparison between local processing (data measured by national air quality monitoring stations), and Copernicus products (CAMS service).

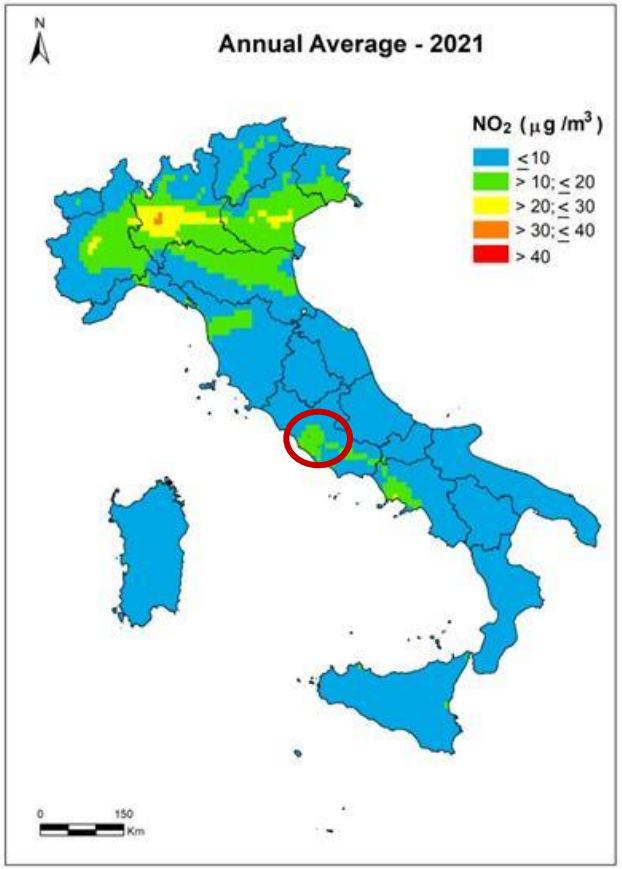
Sources and analysis of air pollutant data: *spatial* data application

CAMS European air quality forecasts

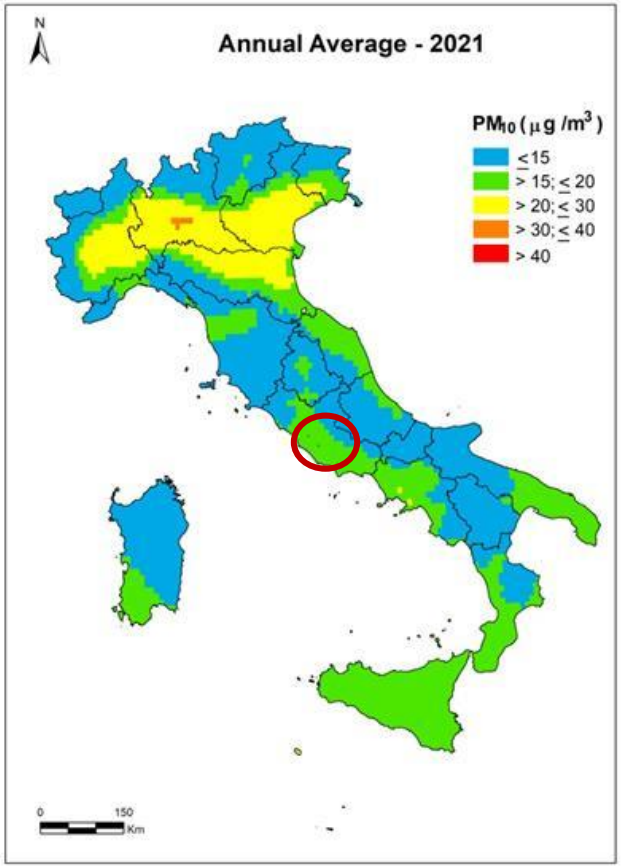


Sources and analysis of air pollutant data: *spatial* data application

NO_2



PM_{10}

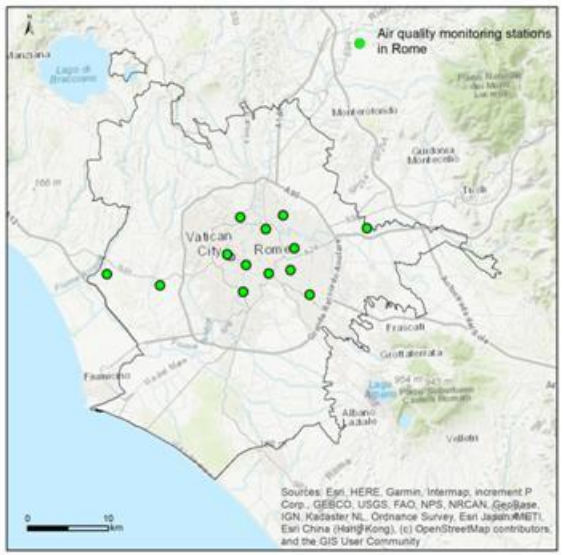


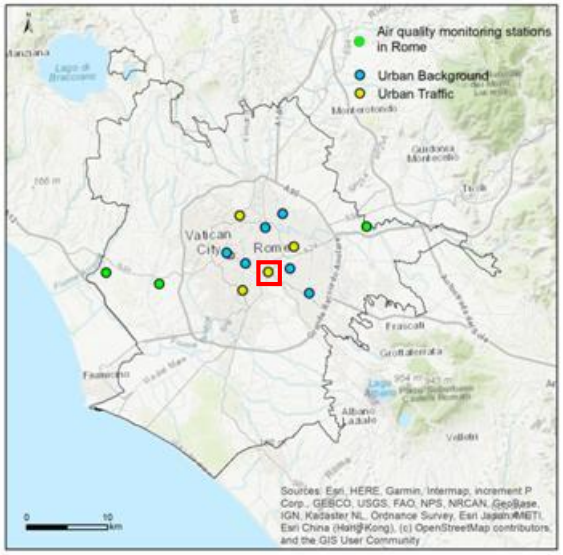
Sources and analysis of air pollutant data: *spatial* data application

Measured data and CAMS products

Case study: ***Rome*** *monitoring air quality stations*

STATION	ZONE TYPE	STATION TYPE
C.SO FRANCIA	URBAN	TRAFFIC
L.GO MAGNA GRECIA	URBAN	TRAFFIC
CASTEL DI GUIDO	RURAL	BACKGROUND
VILLA ADA	URBAN	BACKGROUND
CINECITTA	URBAN	BACKGROUND
TENUTA DEL CAVALIERE	SUBURBAN	BACKGROUND
L.GO PERESTRELLO	URBAN	BACKGROUND
TIBURTINA	URBAN	TRAFFIC
BUFALOTTA	URBAN	BACKGROUND
BUFALOTTA	URBAN	BACKGROUND
CIPRO	URBAN	BACKGROUND
FERMI	URBAN	TRAFFIC
FERMI	URBAN	TRAFFIC
ARENULA	URBAN	BACKGROUND
ARENULA	URBAN	BACKGROUND
MALAGROTTA	SUBURBAN	BACKGROUND

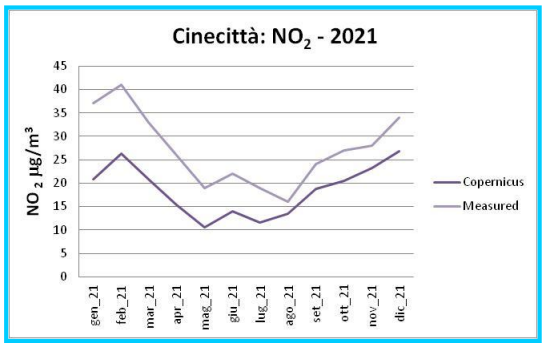


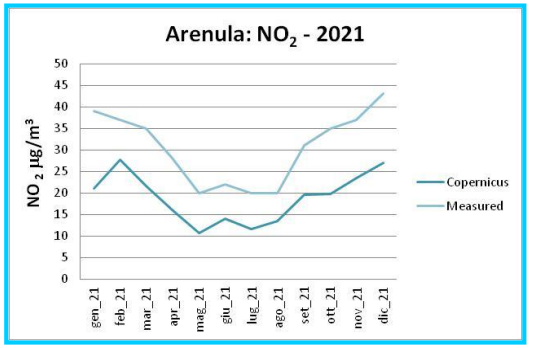


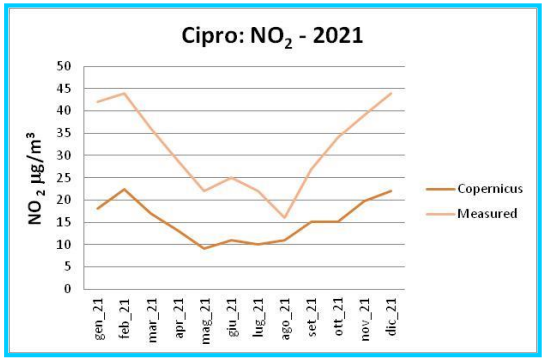
Sources and analysis of air pollutant data: *spatial* data application

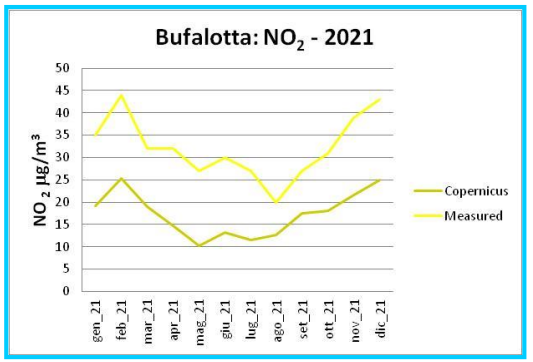
WORK IN PROGRESS

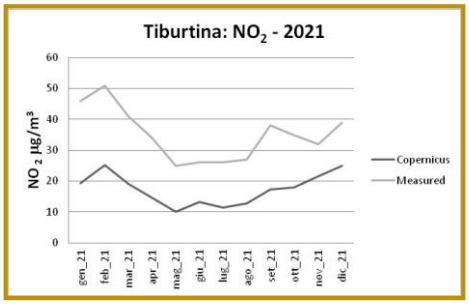
Case study: ***Rome*** *monitoring air quality stations-* ***NO_2***

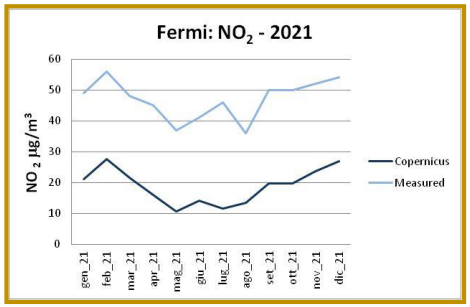


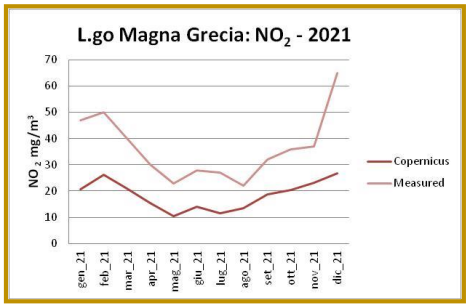


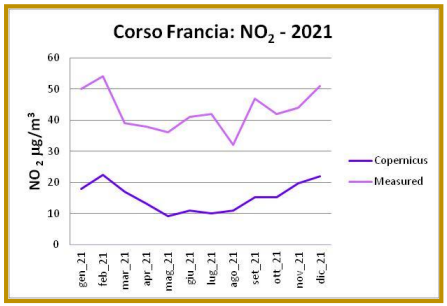








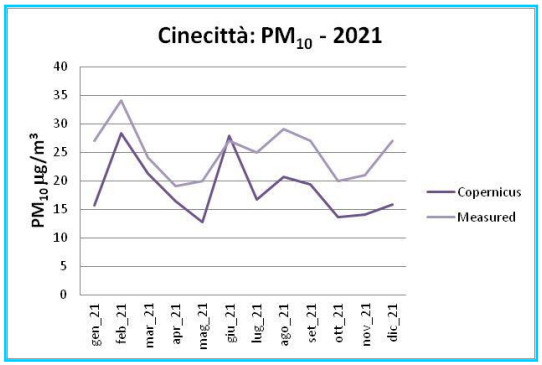


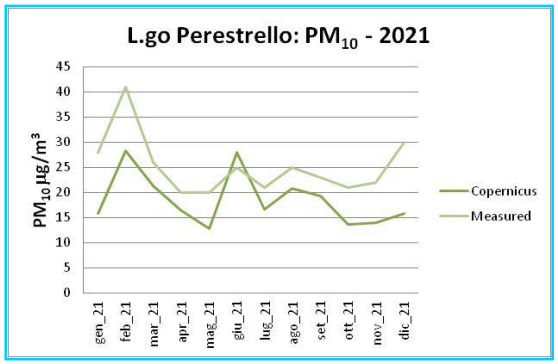


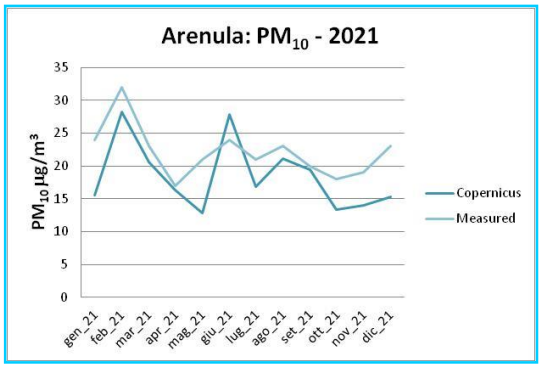
Sources and analysis of air pollutant data: *spatial* data application

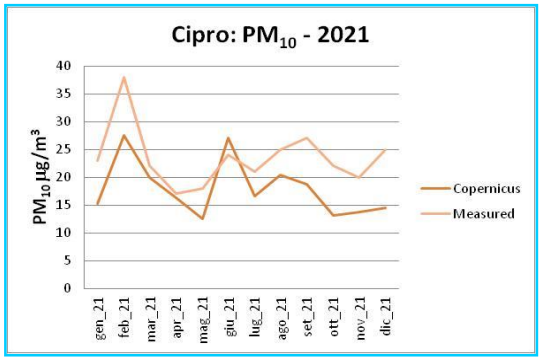
WORK IN PROGRESS

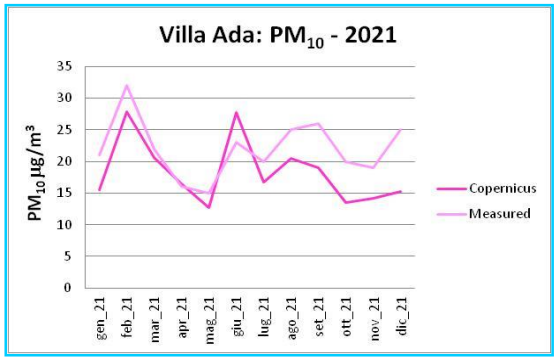
Case study: ***Rome*** *monitoring air quality stations-* ***PM_{10}***

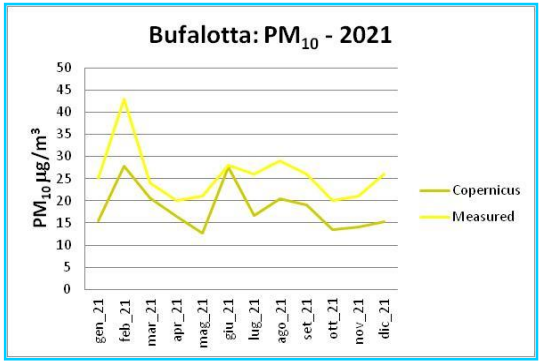


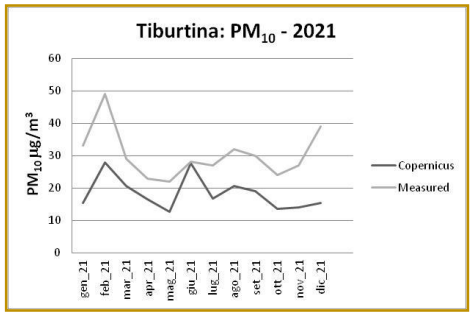


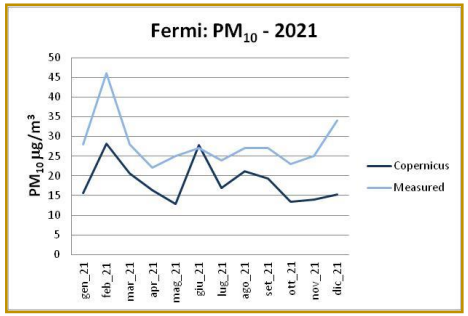


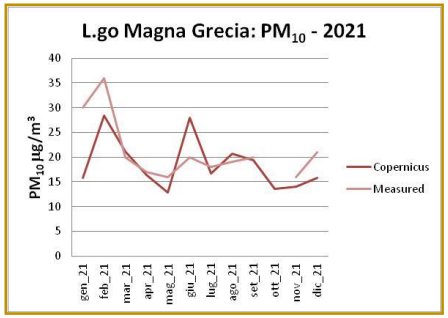


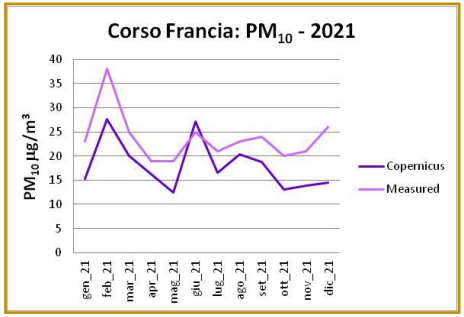












Final remarks

- Pollutant data can be used to define the decay caused by air pollution to cultural heritage;
- Punctual data, recorded by national air quality network, provide standardized measured information at national level;
- Copernicus CAMS products provide a complete spatial cover and they can be used to integrate measured data.

ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

SUMMER SCHOOL WORKSHOP

ACTION 2020-2-21: COPERNICUS FOR CULTURAL HERITAGE

Cyprus University of Technology

DLR

THANK YOU FOR YOUR ATTENTION

raffaela.gaddi@isprambiente.it

13-16.06.2023

PARCO REGIONALE DELL'APPIA ANTICA

Ex Cartiera Latina - Via Appia Antica, 42