Carbon dioxide concentrations over Italy by using OCO-2 time series acquisitions

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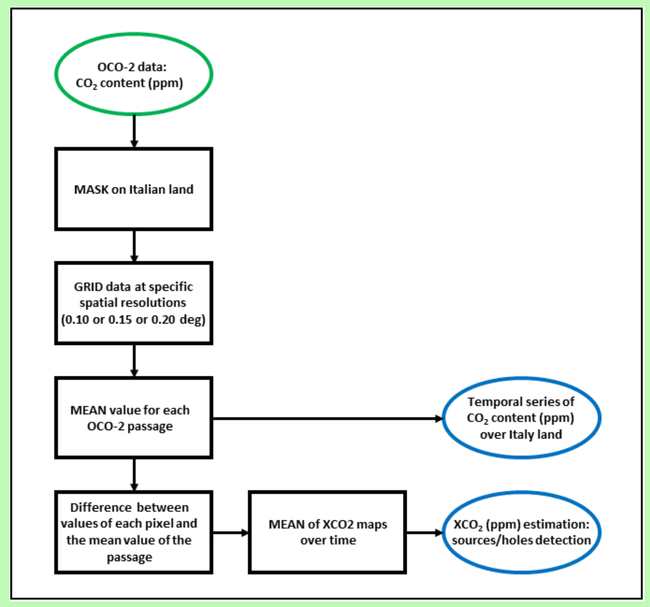
Carbon dioxide is a greenhouse gas with sinks and sources related to natural cycles and anthropic activities. OCO-2 (Orbiting Carbon Observatory-2) is a NASA space mission, launched in 2014, for measuring the CO2 concentrations in the atmosphere by recording sunlight reflected off the Earth and provides, at the state of the art, the highest spatial resolution for mapping CO2 at global scale. In this work, we analyse 8 years of OCO-2 acquisitions over the Italian territory, obtaining the main temporal trend and the seasonal behaviour of CO2 over land. Specifically, an increment of 21 ppm has been found in the period from 2015 to 2022, meaning an average rate of about 3 ppm/year. Such trends are in agreement with those achieved by the ECMWF (European Centre for Medium range Weather Forecasts) model. The data time series was also used to perform a spatial analysis of areas characterized by lower/higher CO2 concentrations to detect sinks/sources in Italy related to the land use. The analysis reveals that the northern Italian regions, with more population and industries, are the principal source of CO2. Local sources are along the coast corresponding to the Civitavecchia harbour area (north east of Rome), the city of Naples, the Olbia harbour and the north part of the Adriatic coast were many cities and industrial areas are present. Moreover, the fundamental role of vegetation as a sink of CO2 is confirmed. CO2 sinks mainly correspond to mountain regions covered by dense vegetation and sparsely populated as eastern and western Alps, Liguria, central Italy, Calabria and north of Sicily.

OCO-2 data and methodology

The OCO-2 instrument utilises a push broom scanning technique with a swath width of about 10 km and a spatial resolution of 1.29 km (cross-track) and 2.25 km (along-track), with a revisit time of 16 days.

The dataset is composed of 875 OCO-2 images acquired over Italian territory in the period September 8, 2014 – December 29, 2022 ("OCO2_L2_Standard" products).

An algorithm has been developed and implemented to perform temporal and spatial analyses over Italian territory at different spatial scales. The processing chain provides, as output, the temporal trend of CO2 concentrations and the land distribution map of XCO2 sinks and sources at several spatial resolutions (0.10, 0.15 and 0.20 deg).



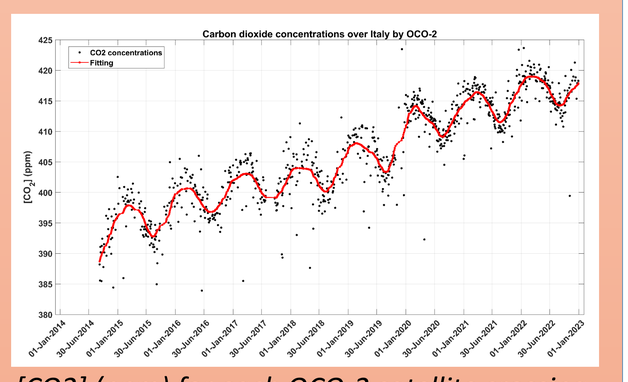
Scheme of the processing algorithm to analyse OCO-2 data

Temporal analysis

The temporal analysis is performed calculating the average value of OCO-2 soundings for each satellite crossing over Italy.

The estimated increasing trend is of about 3 ppm/year during the 8 years analysed.

The seasonal variability is characterized by maximum and minimum values in the periods March-April and August-September of each year, respectively.



[CO2] (ppm) for each OCO-2 satellite crossing (black points) and fitting trend (red line)

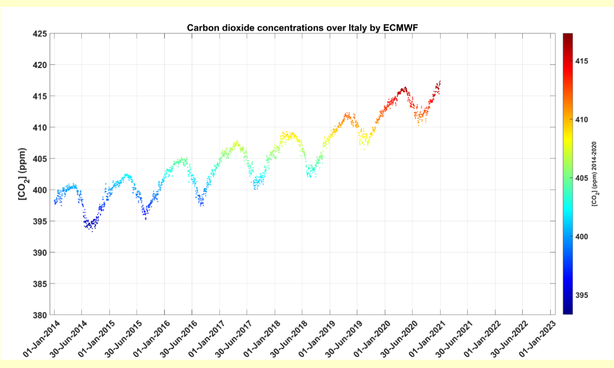
Year	Mean value (ppm)	Error (ppm)
2015	395.86	± 0.38
2016	399.05	± 0.36
2017	401.55	± 0.40
2018	402.55	± 0.39
2019	406.15	± 0.40
2020	411.98	± 0.25
2021	414.28	± 0.26
2022	416.94	± 0.25

Yearly mean values of [CO2] (ppm)

ECMWF model

CO2 concentrations by the European Centre for Medium Range Weather Forecasts (ECMWF) database have been considered for the Italian territory. The dataset is the latest global Atmospheric Composition (AC) reanalysis by the Copernicus Atmosphere Monitoring Service (CAMS) with a regular spatial grid of 0.75°x0.75° lat/lon.

The CO2 time series were extracted from 2015 to 2020 over Italy; a land/sea mask has been applied to consider only the land pixels. The average growth rate results of about 2.9 ppm/year.



[CO2] (ppm) over Italy by the CAMS

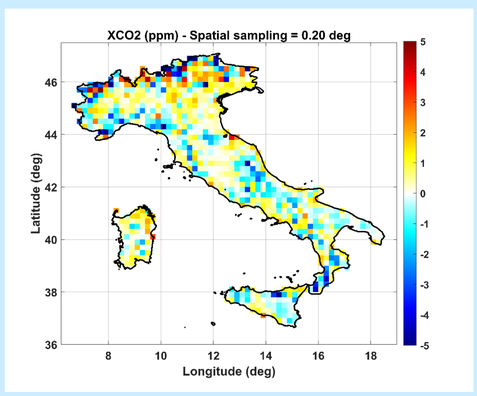
Year	Max value (ppm)	Min value (ppm)
2015	402.5	395.3
2016	405.2	397.4
2017	407.9	400.1
2018	409.2	402.0
2019	412.3	407.0
2020	416.3	410.7

ECMWF maximum and minimum derived values of [CO2] (ppm) for each year

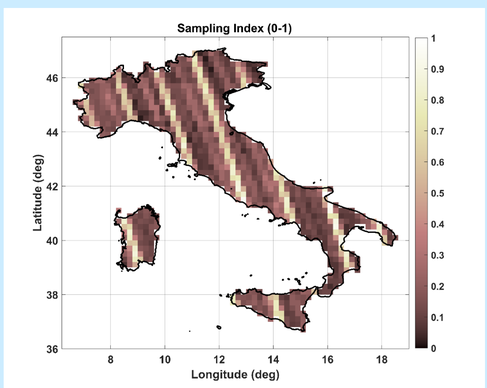
Spatial analysis

The spatial analysis reported here was performed on a regular grid of 0.20 deg. Colour bars indicate the average over the time (8 years) of differences in the CO2 concentration (XCO2).

An index representing the sampling rate of satellite data, for each pixel of the grid, was introduced. The Sampling Index, ranging from 0 to 1, is calculated as the ratio between the number of acquisitions for each pixel and the maximum number of acquisitions in the entire time period (2015-2022). Such index provides information on the quality of the XCO2 spatial estimations.



XCO2 (ppm) map at 0.20 deg

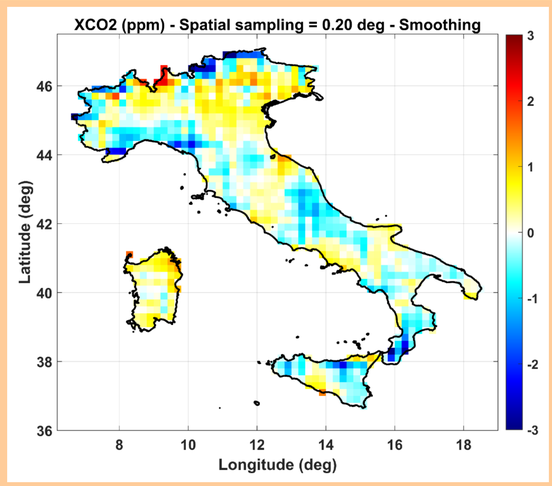


Sampling Index map at 0.20 deg

Map of CO2 sinks/sources

The spatial analysis reveals sinks and sources of CO2 that well correspond to vegetated areas and densely inhabited areas, respectively.

The analysis reveals a source area of CO2 that mainly corresponds to the north Italian regions with more population and industries, in particular Lombardia, Piemonte and Veneto regions. Local sources are along the coast corresponding to: the city of Civitavecchia harbour area; the city of Naples with an overlapping of high density populated, industrial and active volcanic degassing areas; the Olbia harbour in Sardinia and along the north part of the Adriatic coast were many cities and industrial areas are present. CO2 sinks areas mainly correspond to mountain massifs covered by dense vegetation and sparsely populated (eastern and western Alps, Liguria, central Italy, Calabria and north of Sicily).



Smoothed XCO2 (ppm) map at 0.20 deg

CORINE land cover map

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