CO2 and NO2 distributions over Greece as seen by OCO-2 and TROPOMI

GIALESAKIS N.[1], DASKALAKIS N.[2] and KANAKIDOU M.[1,2,3,*]

[1] Environmental Chemical Processes Laboratory, Department of Chemistry, University of Crete, Heraklion, Crete, Greece
[2] Institute of Environmental Physics, University of Bremen, Bremen, Germany
[3] CSTACC, ICE-HT, FORTH, Patras, Greece

*corresponding author:
e-mail: mariak@uoc.gr

Abstract

Greenhouse gases are the driving force behind human-induced global warming. Carbon dioxide (CO_2) is the greenhouse gas (GHG) with the longer lifetime in the atmosphere, in the order of hundreds of years, and the largest contribution to the radiative forcing of the atmosphere due to its increasing levels since the pre-industrial era. Therefore, monitoring and restraining CO_2 anthropogenic sources is an urgent matter. Nitrogen dioxide (NO_2) is co-emitted with CO_2 and due to its short atmospheric lifetime (of the order of a day) it can be used to pinpoint CO_2 emission sources. Satellite observations of CO_2 levels provide invaluable information in order to understand its levels, and sources and sinks. In this study we investigate the distribution of CO_2 and NO_2 over Greece for 2019 using data from the Orbiting Carbon Observatory-2 (OCO-2) satellite for CO_2 and from the Sentinel-5 Precursor TROPOMI satellite instrument for NO_2 in order to identify hot spots for CO_2 emissions.

Keywords: carbon dioxide, nitrogen dioxide, remote sensing, TROPOMI, OCO-2

1. Introduction

Carbon dioxide (CO_2) has a lifetime in the atmosphere between 300 to 1000 years, emitted mainly by fossil fuels combustion, cement production and land-use activities (Friedlingstein et al., 2019). Carbon dioxide is responsible for the largest share of radiative forcing due to human activities since 1750 (IPCC, 2013). Anthropogenic activities have increased the CO_2 levels by 50% since the beginning of the Industrial Era in 1750 (Joos and Spahni, 2008). In 2014, CO_2 levels reached for the first time the 400 ppm barrier since the Pliocene epoch (de la Vega et al., 2020).

Nitrogen dioxide (NO_2) is produced mostly by combustion processes, either from naturally ignited forest fires and lightning or by anthropogenic activities such as fossil fuel combustion which are the dominating emission sources. Due to its short atmospheric lifetime, NO_2 is not transported very far from its source regions and can thus be used as an indicator of anthropogenic activities involving combustion, like energy production and transportation. Nitrogen dioxide is a major contributor to urban air pollution, affecting human health directly in high concentrations (Latza et al., 2009) and indirectly as a precursor of tropospheric ozone.

To limit climate change below 2°C compared to pre-industrial levels, the participating countries of the 2015 Paris Agreement committed to reduce their greenhouse gas (GHG) emissions by 40% compared to the 1990 levels by the year 2030 (UNFCCC, 2015). However, the establishment of climate change mitigation policies is hindered by the large uncertainties in the sources and sinks of GHG and the interaction of the carbon cycle processes with climate change. Therefore, monitoring of GHG emissions is needed, which can be achieved by remote sensing observations using satellite instruments that provide better spatial coverage but complementary to ground-based measurements.

During the last decades fast progress has been made in remote sensing, with satellites that are now observing the atmosphere with high spatial and temporal resolution. In particular, the TROPOspheric Monitoring Instrument (TROPOMI) onboard the Sentinel-5 Precursor satellite launched in October 2017 enables for high quality, wide-region and great temporal coverage with remarkable spatial resolution of nitrogen dioxide (Veefkind et al., 2012). Therefore, TROPOMI is able to detect hot spot NO_2 large emission sources, like power plants, urban agglomerations, fires etc. in a sole overpass (Schneising et al., 2020). In parallel, the NASA's Orbiting Carbon Observatory-2 (OCO-2) launched in July 2014 is part of the A-train satellite constellation and provides extremely high spatial resolution observations of CO_2.

In the present study, we investigate the OCO-2 derived distribution of CO_2 over Greece together with that of NO_2 from TROPOMI in order to identify potential covariations. The aim is to better constraint the CO_2 emission sources in Greece, which is located in a climate sensitive region at the interception of three continents (Europe, Asia, Africa) and is therefore affected by air masses containing anthropogenic emissions, mainly from Europe and the Black Sea, mixed with biomass burning for the Balkans and Ukraine (Sciare et al., 2008), biogenic (Liakakou et al., 2009) and other natural emissions (Gerasopoulos et al., 2011).

2. Data and Method

Carbon dioxide column concentrations are obtained from the Orbiting Carbon Observatory-2 (OCO-2) that has a sun-synchronous orbit at 705 km, crossing the Equator at 13:30 local time with a 16-day cycle. It is equipped with an instrument using diffraction grating to measure the solar backscattered radiance in three independent wavelength bands in the spectral regions of the near infrared (NIR) and shortwave infrared (SWIR). The swath width of OCO-2 is approximately 10 km with a spatial resolution of 3 km^2 (Crisp et al., 2017). Due to the small swath of the instrument, the geographic coverage over Greece is very limited. Here, we use the NASA's operational bias-corrected OCO-2 L2 Lite product v10, downloaded from https://daac.gsfc.nasa.gov (last access: May 2021). The analyzed data correspond to the period between 1/1/2019 and 31/12/2019.

Nitrogen dioxide tropospheric column concentrations are obtained from the TROPOMI instrument that has a sun-synchronous orbit at approximately 824 km, crossing the Equator at 13:30 local time with a 16-day orbital cycle. TROPOMI is a nadir-viewing spectrometer for the ultraviolet spectral region with additional channels in the NIR and SWIR. It has a swath width of about 2600 km and a spatial resolution near nadir of 7x3.5 km^2 for all spectral bands, with the exception of the UV1 band (7x28 km^2) and SWIR bands (7x7 km^2) (Veefkind et al., 2012). We use here Level 2-NO_2 TROPOMI data available from ESA's website https://s5phub.copernicus.eu/dhus/#/home (last access: May 2021), for the period between 1/1/2019 and 31/12/2019. The data were gridded into a 0.2° x0.2° grid for the calculation of the average distribution of NO_2 over Greece.

OCO-2 and TROPOMI have the same crossing the Equator time, therefore the relatively few CO_2 column observations can be compared to those of NO_2. Note however that the short lifetime of NO_2 will lead to fast reduction in its concentrations with distance from the sources, while CO_2 lifetime is long enough to allow transport far from sources, thus hampering the identification of its source's location.

3. Results and Discussion

Figure 1 depicts the near-surface monthly mean concentrations of CO_2 derived from continuous measurements at the Finokalia Lasithiou background station in Crete (35°20N, 25°40E, 250 m asl) for the year 2019 (Gialesakis et al., 2021). A clear seasonal variation can be seen, with maximum monthly mean values about 417 ppm during winter and early spring and minimum values around 405 ppm during the summer months, reflecting CO_2 sink during photosynthesis.

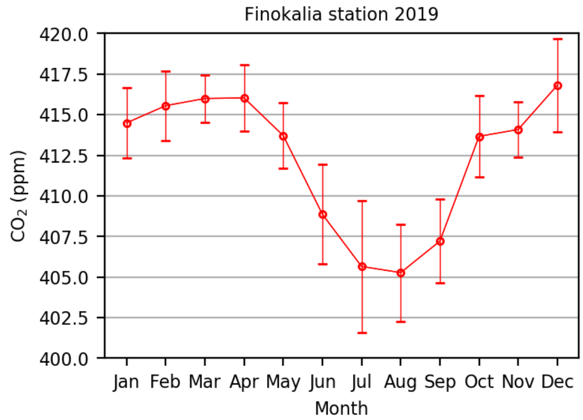

Figure 1. Monthly mean CO_2 near-surface concentrations as observed at Finokalia in 2019

Figures 2-5 depict the gridded average tropospheric NO_2 columns from TROPOMI for one month per season (February, April, August, October) together with the CO_2 column observations as seen by OCO-2 for the same months (all data).

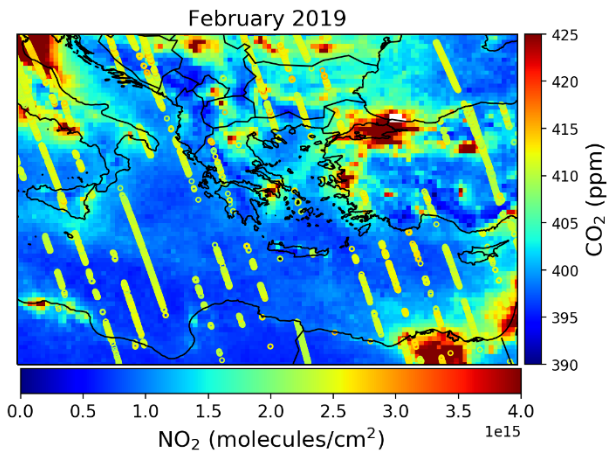

Figure 2. Monthly mean tropospheric NO_2 column from TROPOMI (map) and CO_2 column concentrations from OCO-2 (circles) for February 2019

The tropospheric columns of NO_2 clearly show hot spots over urban agglomerations like Istanbul and Athens but also the pollution by the lignite-fired power plant at Ptolemaida, specially during winter and fall. In April and August, shipping emissions can also be seen clearly at the southern part of Mediterranean. Similar seasonal behavior can be seen for the period 2018-2019 at Po Valley in northern Italy (Cersosimo et al., 2020) and over China for the same period (Zheng et al., 2019).

Carbon dioxide observations from OCO-2 are in general agreement with the ground-based measurements from Finokalia. Highest values were recorded in April, when photosynthesis in not yet strong. In August the plants absorb part of the CO_2 and therefore the minimum columns of CO_2 are observed. Good agreement of OCO-2 columns of CO_2 with ground-based measurements has been also reported for the Zugspitze region of Germany for the period 2017-2018 (Yuan et al., 2019).

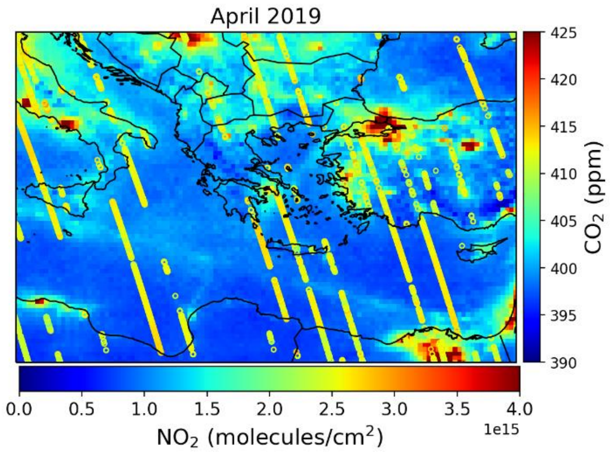

Figure 3. Monthly mean tropospheric NO_2 column from TROPOMI (map) and CO_2 column concentrations from OCO-2 (circles) for April 2019

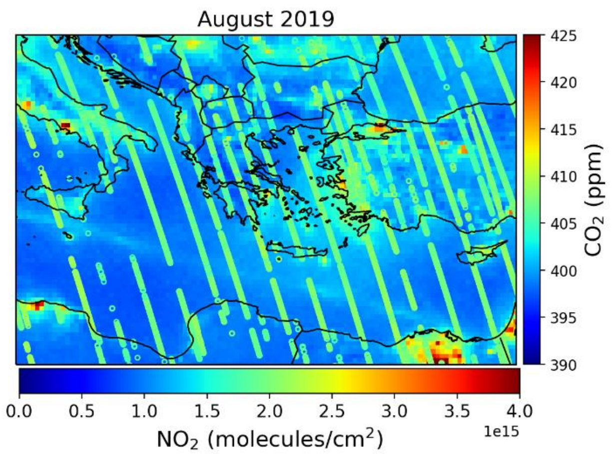

Figure 4. Monthly mean tropospheric NO_2 column from TROPOMI (map) and CO_2 column concentrations from OCO-2 (circles) for August 2019

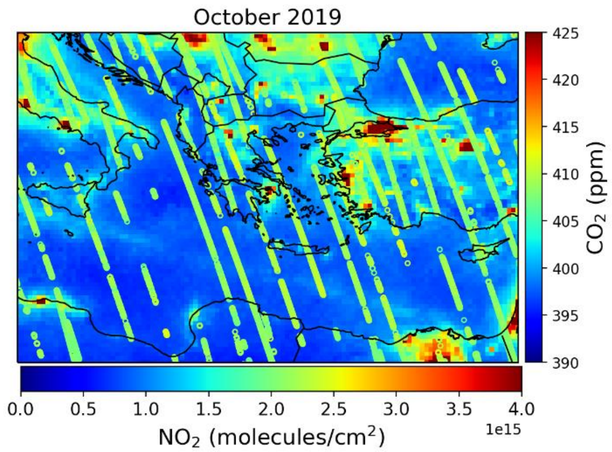

Figure 5. Monthly mean tropospheric NO_2 column from TROPOMI (map) and CO_2 column concentrations from OCO-2 (circles) for October 2019

4. Conclusions

In this study we have presented the distribution of CO_2 retrieved over Greece from OCO-2 satellite observations and compared it to the tropospheric NO_2 column from S5P-TROPOMI observations that was regridded in a 0.2°x0.2° grid.

Carbon dioxide column observations of OCO-2 agree with CO_2 near-surface measurements at Finokalia station, capturing the seasonal variability and the existing levels of CO_2. Tropospheric NO_2 column from TROPOMI clearly depicts the pollution produced from megacities, large agglomerations and ships. Despite the scarcity of OCO-2 observations, compared to TROPOMI NO_2 columns, the combination of the two satellite products together with the ground-based measurements and numerical modeling can be a powerful tool to geolocate, monitor and confine the emission sources of CO_2.

Acknowledgments. This work is funded by the Action “National Network on Climate Change and its Impacts (CLIMPACT)” implemented under the project “Infrastructure of national research networks in the fields of Precision Medicine, Quantum Technology and Climate Change”, funded by the Public Investment Program of Greece, General Secretary of Research and Technology/Ministry of Development and Investments; and by the Deutsche Forschungs-gemeinschaft (DFG, German Research Foundation) under Germany´s Excellence Strategy (University Allowance, EXC 2077, University of Bremen).

References

Cersosimo, A., Serio, C. & Masiello, G. (2020), TROPOMI NO_2 Tropospheric Column Data: Regridding to 1 km Grid-Resolution and Assessment of their Consistency with In Situ Surface Observations. *Remote Sensing*. **12**, 2212.

Crisp, D., Pollock, H., Rosenberg, R., Chapsky, L., Lee, R., Oyafuso, F., Frankenberg, C., Dell, C., Bruegge, C., Doran, G., Eldering, A., Fisher, B., Fu, D., Gunson, M., Mandrake, L., Osterman, G., Schwandner, F., Sun, K., Taylor, T., Wennberg, P., Wunch, D., (2017). The on-orbit performance of the Orbiting Carbon Observatory-2 (OCO-2) instrument and its radiometrically calibrated products. Atmos. Meas. Tech. 10, 59–81. https://doi.org/10.5194/amt-10-59-2017

Friedlingstein, P., Jones, M.W., O'Sullivan, M., Andrew, R.M., et al., (2019). Global carbon budget 2019. Earth Syst. Sci. Data 11, 1783–1838. https://doi.org/10.5194/essd-11-1783-2019

Gerasopoulos, E., Amiridis, V., Kazadzis, S., Kokkalis, P., Eleftheratos, K., Andreae, M.O., Andreae, T.W., El-Askary, H., Zerefos, C.S., (2011). Three-year ground based measurements of aerosol optical depth over the Eastern Mediterranean: The urban environment of Athens. Atmos. Chem. Phys. 11, 2145–2159. https://doi.org/10.5194/acp-11-2145-2011

Gialesakis, N., Kouvarakis, G., Kalivitis, N., Ramonet, M., Mihalopoulos, N., Delmotte, M., Lett, C., Legendre, V., Kanakidou, M., (2021). Interannual and seasonal variability of greenhouse gases at Finokalia station in the East Mediterranean, to be presented at COMECAP 2021.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., et al. (eds.)]. Cambridge University Press, Cambridge, U.K. and New York, NY, USA, 1535 pp.

Joos, F., Spahni, R., (2008). Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years. Proc. Natl. Acad. Sci. U. S. A. 105, 1425–1430. https://doi.org/10.1073/pnas.0707386105

Latza, U., Gerdes, S., Baur, X., (2009). Effects of nitrogen dioxide on human health: Systematic review of experimental and epidemiological studies conducted between 2002 and 2006. Int. J. Hyg. Environ. Health 212, 271–287. https://doi.org/10.1016/j.ijheh.2008.06.003

Liakakou, E., Bonsang, B., Williams, J., Kalivitis, N., Kanakidou, M., Mihalopoulos, N., (2009). C2-C8 NMHCs over the Eastern Mediterranean: Seasonal variation and impact on regional oxidation chemistry. Atmos. Environ. 43, 5611–5621. https://doi.org/10.1016/j.atmosenv.2009.07.067

Schneising, O., Buchwitz, M.,Reuter, M., Vanselow, S., Bovensmann, H. and Burrows, J. P. (2020), Remote sensing of methane leakage from natural gas and petroleum systems revisited, *Atmospheric Chemistry and Physics*, **20**, 9169–9182.

Sciare, J., Oikonomou, K., Favez, O., Liakakou, E., Markaki, Z., Cachier, H., and Mihalopoulos, N. (2008). Long-term measurements of carbonaceous aerosols in the Eastern Mediterranean: Evidence of long-range transport of biomass burning. Atmos. Chem. Phys. 8, 5551–5563. https://doi.org/10.5194/acp-8-5551-2008

UNFCCC: United Nations Framework Convention on Climate Change Paris Agreement, available at: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, 2015

Veefkind, J.P., Aben, I., McMullan, K., Förster, H., de Vries, J., Otter, G., Claas, J., Eskes, H.J., de Haan, J.F., Kleipool, Q., van Weele, M., Hasekamp, O., Hoogeveen, R., Landgraf, J., Snel, R., Tol, P., Ingmann, P., Voors, R., Kruizinga, B., Vink, R., Visser, H., Levelt, P.F., (2012). TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications. Remote Sens. Environ. 120, 70–83. https://doi.org/10.1016/j.rse.2011.09.027

Vega, E., Chalk, T., Wilson, P.A., Bysani, R.P., Foster, G.L., (2020). Atmospheric CO_2 during the Mid-Piacenzian Warm Period and the M2 glaciation. Sci. Rep. 10, 14–21. https://doi.org/10.1038/s41598-020-67154-8

Yuan, Y., Sussmann, R., Rettinger, M., Ries, L., Petermeier, H., Menzel, A., (2019). Comparison of Continuous In-Situ CO_2 Measurements with Co-Located Column-Averaged XCO2 TCCON/Satellite Observations and CarbonTracker Model Over the Zugspitze Region. *Remote Sens.* 11, 2981. https://doi.org/10.3390/rs11242981

Zheng, Z., Yang, Z., Wu, Z., Marinello, F., (2019). Spatial Variation of NO2 and Its Impact Factors in China: An Application of Sentinel-5P Products. *Remote Sens.* 11, 1939. https://doi.org/10.3390/rs11161939