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The Contribution of Port-Related Emissions and Meteorology in the Air Quality of Igoumenitsa Port †

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Abstract: Among the most important trade bridges for Western Europe and the Balkans is the Port of Igoumenitsa in Western Greece that experiences heavy traffic of goods and passengers. This study primarily aimed to investigate the effect of shipping and port activity on air quality in the Port of Igoumenitsa comparing two representative seasons of air quality measurement campaigns. The first, high activity season, ranges from 25/8/2018 to 31/08/2018, and the second, the low activity season, ranges from 17/5/2018 to 25/5/2018. A mobile air quality monitoring system was used to perform the analysis. To investigate the air quality differences between the two seasons, the wind speed rose diagrams, the correlation analysis as well as the hourly variations in concentrations of pollutants and meteorological parameters, were studied. In addition, the impact of meteorology and atmospheric circulation on local air quality were investigated. For study implementation, various types of data, obtained from NASA Worldview application, Barcelona Supercomputing Center (BSC) and Giovanni online system (NASA-GES-DISC) were included. The results indicate that port operations affect the air quality in the Port of Igoumenitsa, as the high season showed higher concentrations of air pollutants compared to the low season. A notable exception was the concentration of PMs which was affected by an African dust transfer event during the low season. Finally, the analysis shows that meteorology affects air quality, and emphasizes the importance of developing a green and sustainable management system within the port.

Keywords: air quality; shipping; port activity; climate; meteorology; synoptic atmospheric circulation; African dust transfer; eastern Mediterranean; green and sustainable port management

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1. Introduction

The port activities and shipping are a major source of pollutants for the coastal areas affecting not only air quality and its degradation [1,2] but also human health [3,4].Although the port-related emissions represent a small fraction of global marine emissions, are related to health problems and have an impact on mortality levels [5,6]. In particular, it turns out that human health problems are associated with exposure to $PM_{2.5}$ emitted by shipping [1,7]. Emissions from shipping obviously contribute significantly to the NO_x, SO_2, and PM concentrations over port and coastal regions, while between 2007 and 2012, shipping accounted for about 1 billion tonnes of GHGs [8]. The IMO's 4th Greenhouse Gas Study [9] projected that the GHGs shipping emissions by 2050 will increase up to 50% compared to 2018 levels. Consequently, increasing shipping and port activities contribute to climate change [10]. In particular, the increased concentration of pollutants in the atmosphere affects the weather and climate [11] producing positive climate forcing and enhancing the climate risk.

The port of Igoumenitsa is an important trade hub between Western and Eastern Europe that connects the main Italian ports with Western Greece. About 2.5 million passengers and 250,000 trucks move through the port each year. As there are no previous studies that investigate the impact of shipping and atmospheric features (meteorology and synoptic atmospheric circulation) on the air quality of Igoumenitsa port, this work aims to fill the gap and study the impact of shipping and port activity on the air quality. The comparison of two representative seasons is characterized by high and low port activity, respectively. Thus, the air measurements campaigns conducted in 2018 investigate the effect of port activity on the air quality, as well as the impact of meteorology on the air quality of the port of Igoumenitsa.

2. Methods and Data

The Igoumenitsa city (39.50615° N, 20.265534° E) is located in Western Greece (Figure 1a) and it is a major trade route for southeastern Europe. The port of the city has high commercial activity as a large number of passengers, cars, and trucks use it on an annual basis. A mobile air quality monitoring station, equipped with ambient air pollution sensors (HORIBA sensors) and in accordance with the EN regulations for certified measurements, was employed at the port of Igoumenitsa. The sensor recordings include gases (NO_x; ppb, NO; ppb, NO_2; ppb, O_3; ppb, CO; ppm, SO_2; ppb), particle matters (PM_1, $PM_{2.5}$, PM_4, PM_{10}, $PM_{\_tot}$; $\mu g/m^3$) and meteorological parameters (wind speed—WS; m/s, wind direction—WDir; °, temperature—T; °C, pressure—P; hPa and relative humidity; RH—%).

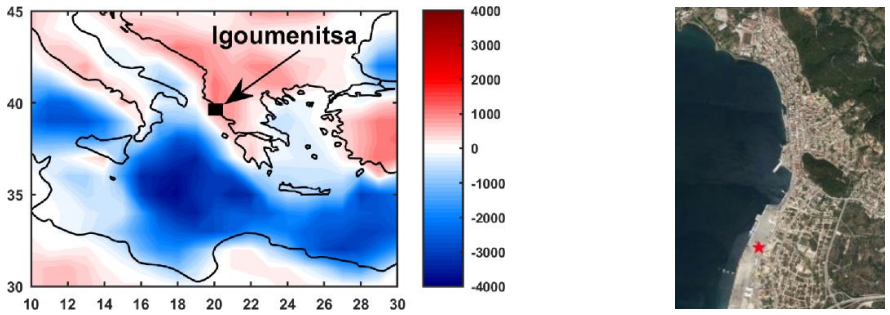


Figure 1. (**a**) Location of Igoumenitsa in Western Greece over the eastern Mediterranean (topography map). (**b**) Location of the mobile air quality monitoring station (red star).

To study the impact of port activity in the port of Igoumenitsa two representative seasons of 2018 were studied. The first season, with high port activity, is considered the period from 25/8/2018 to 31/8/2018, and the second, with low port activity, is from 17/5/2018 to 25/5/2018. In order to investigate the relation between meteorology and concentration of pollutants, the Spearman correlation is employed for both studied seasons. Moreover, the hourly variation of meteorology parameters and concentration of pollutants are calculated to study the effect of hourly port activity during the two seasons. To investigate the impact of synoptic atmospheric circulation on concentrations of PMs in the port, satellite image provided by the National Aeronautics and Space Administration (NASA) Worldview application (https://worldview.earthdata.nasa.gov), part of NASA's Earth Observing System Data and Information System (EOSDIS) is also used. Additionally, figure provided by the DREAM8b model, operated by the Barcelona Supercomputing Center (http://www.bsc.es/ess/bsc-dust-daily-forecast/ (accessed on)) is shown. Results from MERRA-2 model (Modern-Era Retrospective analysis for Research and Applications, Version 2; M2T1NXAER v5.12.4) available from the Giovanni online data system (https://giovanni.gsfc.nasa.gov/giovanni/ (accessed on)), developed and maintained by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC) [12], are also used for the analysis. Finally, the $PM_{2.5}/PM_{10}$ ratio is calculated to study the

impact of shipping traffic and port operations in the port of Igoumenitsa for both seasons studied [2].

3. Results

Figure 2 shows the wind roses plots for the two studied periods where the wind speeds are stronger during the low port activity season compared to the high season and blow mainly from the western sector and western as well as eastern directions for the high and the low season respectively.

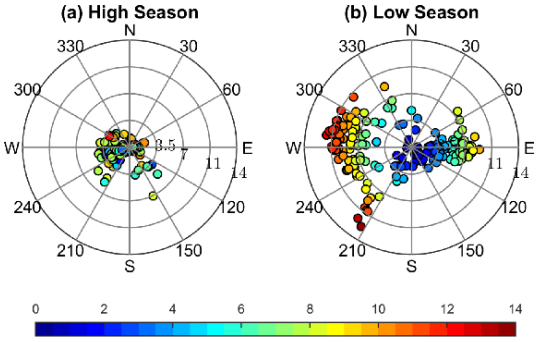


Figure 2. Wind-rose plot for (**a**) high port activity season and (**b**) low port activity season.

The correlation analysis between wind speed and the concentration of pollutants, for the high season, shows that the wind speed is negatively associated with PM_{10}, CO, NO_2, and NO_x, and not correlated with PM_1, $PM_{2.5}$, and PM_4.The negative correlation of the wind speed with the concentration of pollutants indicates that higher winds tend to improve the air quality. On the other hand, the analysis, for both seasons studied, shows that the wind speed is positively correlated with the concentration of O_3 that is a secondary pollutant formed by NO_x and volatile organic compounds whose concentration is affected by photochemical reactions during the sunlight hours [11]. This explains the higher concentration of O_3 during the daytime (from 9:00 to 19:00 LT). Moreover, the concentration of O_3 is significantly negatively correlated (about −0.65) with NO_2 and NO_x. For the low port activity season, wind speeds are negatively correlated with pollutant concentration other than O_3 (which indicates a positive correlation coefficient) and PM_1 (not correlated). To conclude, the analysis shows that meteorological conditions significantly affect the air quality [13,14].

Figure 3 shows the hourly variation of meteorology parameters (Figure 3a–e) and the concentration of pollutants (Figure 3f–p) for both high and low port activity seasons. The analysis shows that the concentration of pollutants is maximized during the hours with high ship traffic (7:00–11:00 LT and 19:00–24:00 LT) indicating the impact of port operations on the air quality degradation in the port of Igoumenitsa. Comparing the two seasons studied, the O_3 and NO_x concentration increased by about 10 ppb for the high port activity season. Additionally, the concentrations of NO_2 and SO_2 are increased by about 2.5 ppb for the high season compared to the low port activity season. For the high season, the concentration of PM_1 is also increased by about 2.5 μg/m³ while in contrast the concentration of PM_4, as well as PM_{10}, is reduced by about 5.5 μg/m³. The positive difference of PM_4 and PM_{10}, between high and low port activity season, is explained by the synoptic atmospheric circulation. In particular, it must be stated that the Saharan dust is a major component for PM_{10} over the Mediterranean basin [15]. During the low port activity season, African dust transferred from the Sahara desert affects the eastern Mediterranean region and the Western Greece and peaks on 23.5.2018 (Figure 4a,b). Moreover, the results of the analysis of MERRA-2 model (available from the Giovanni data system) indicate that during the low port activity season, the difference of mean dust column mass density (gr/m²) increases compared to the high season, affecting the PM concentration (mainly PM_{10} and PM_4) over Western Greece and the port of Igoumenitsa (Figure 5).

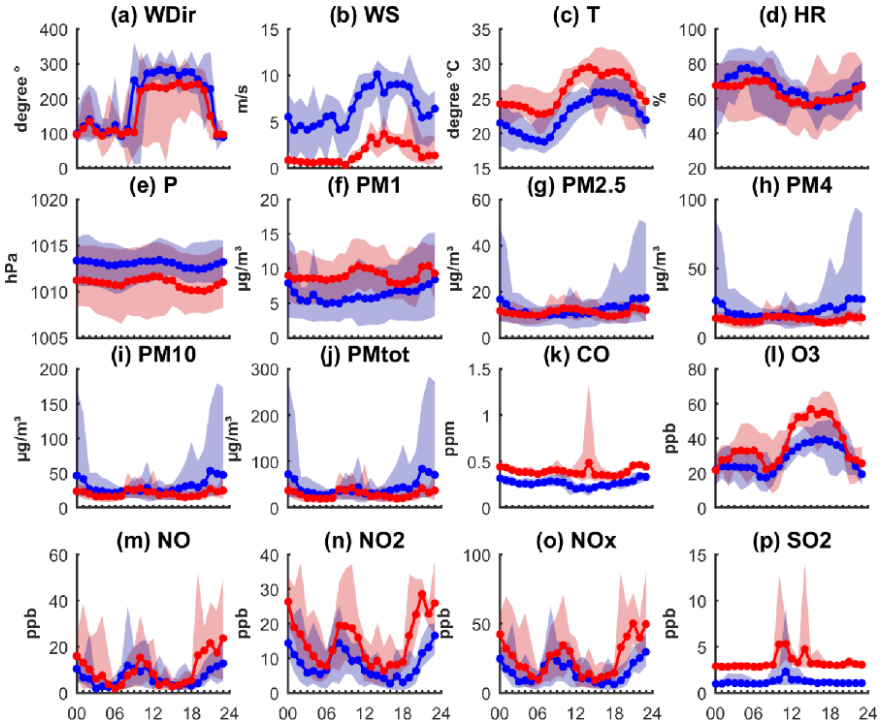
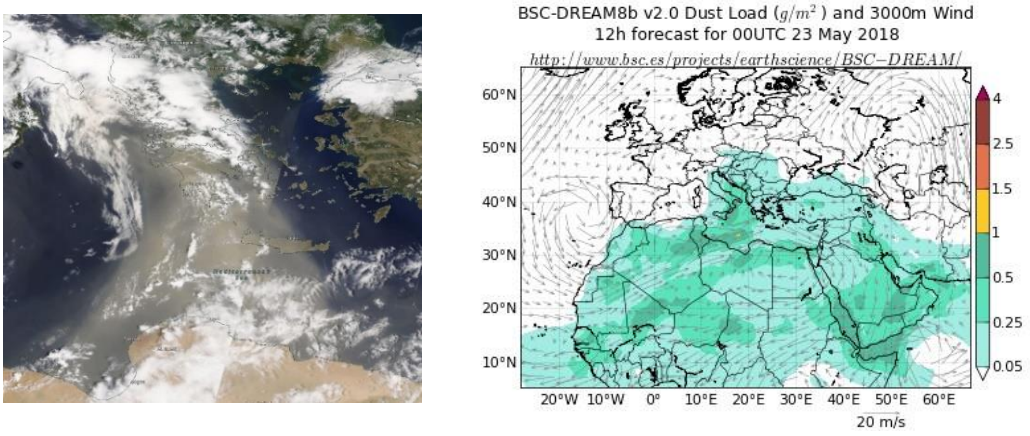


Figure 3. Hourly evolution of meteorology (**a**–**e**) and air quality parameters (**f**–**p**). The red/blue lines indicate the high/low port activity season. The shaded area indicates the range between lower and higher hourly variability during the two studied seasons (red for the high and blue for the low port activity season).



(**a**) (**b**)

Figure 4. (**a**) Image of African dust transport in Greece on May 23, 2018 (MODIS visible imagery). (**b**) Dust load and 3000 m wind speed for May 23 0000UTC, 2018 (BSC-DREAM8b).

In order to investigate the impact of shipping and port activity on Igoumenitsa port the ratio between $PM_{2.5}$ and PM_{10} that is associated with the primary pollution of anthropogenic activity [2,16], is calculated. Figure 6 shows the variability of $PM_{2.5}/PM_{10}$ ratio for the two studied seasons. During the high port activity season, the $PM_{2.5}/PM_{10}$ ratio is about 0.13 higher compared to the low port activity season (Figure 6c), consequently during the high season the shipping has a more significant effect on the air quality in the port of Igoumenitsa compared to the other season.

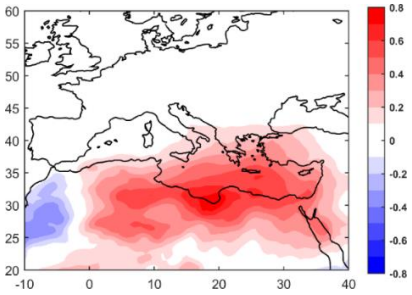


Figure 5. Composite difference of mean dust column mass density (gr/m^2) between low port activity and high port activity season. Red/ blue colors indicate an increase/decrease of the mean dust column mass density (gr/m^2).

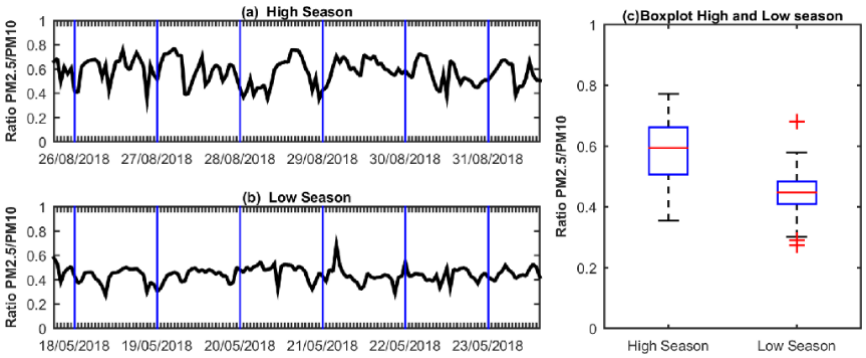


Figure 6. Timeseries of $PM_{2.5}/PM_{10}$ ratio for the (**a**) high port activity season and (**b**) low port activity season. (c) boxplot of $PM_{2.5}/PM_{10}$ ratio for high and low port activity season.

4. Conclusions

This study examines the impact of shipping and port activity on the air quality of the port of Igoumenitsa in Western Greece. The analysis is carried out by comparing a high and a low port activity season during 2018 and the obtained results point to that meteorology affects the concentration of pollutants. In particular, wind speed is associated with lower levels of pollution. For both seasons, elevated concentrations of pollutants occur during hours of high shipping traffic. It should be noted that the concentration of pollutants generally increases during the high port activity season compared to the low one PM_4 and PM_{10} concentrations excluded due to the effect of an African dust transfer event. The aforementioned dust episode occurs during the low port activity season affecting the PM concentrations over Western Greece. The higher ratio of $PM_{2.5}/PM_{10}$ during the high season compared to the low season clearly shows the impact of shipping on air quality degradation of Igoumenitsa port. Finally, this study emphasizes the importance of further investigation regarding the impact of shipping and port activities on coastal air quality, and underlines that the competent authorities need to adopt energy saving practices that reduce air pollution footprint in ports.

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Data Availability Statement: Publicly available datasets were analyzed in this study. This data can be found here: http://www.bsc.es/ess/bsc-dust-daily-forecast/, https://worldview.earthdata.nasa.gov (accessed on) and https://giovanni.gsfc.nasa.gov/giovanni/ (accessed on).

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tang, L.; Ramacher, M.O.P.; Moldanová, J.; Matthias, V.; Karl, M.; Johansson, L.; Jalkanen, J.-P.; Yaramenka, K.; Aulinger, A.; Gustafsson, M. The impact of ship emissions on air quality and human health in the Gothenburg area—Part 1: 2012 emissions. *Atmos. Chem. Phys.* **2020**, *20*, 7509–7530, doi:10.5194/acp-20-7509-2020.
2. Logothetis, I.; Antonopoulou, C.; Sfetsioris, K.; Mitsotakis, A.; Grammelis, P. Comparison analysis of the effect of high and low port-activity season on air quality in the port of Heraklion. In Proceedings of the 4th International Electronic Conference on Atmospheric Sciences, Online, 16–31 July 2021; MDPI: Basel, Switzerland, doi:10.3390/ecas2021-10329.
3. Gobbi, G.P.; Liberto, L.; Barnaba, F. Impact of port emissions on EU-regulated and non-regulated air quality indicators: The case 29 of Civitavecchia (Italy). *Sci. Total Environ.* **2020**, *719*, 134984; doi:10.1016/j.sci- 30totenv.2019.134984; ISSN 0048-9697.
4. Prussi, M.; Scarlat, N.; Acciaro, M.; Kosmas, V. Potential and limiting factors in the use of alternative fuels in the European 18 maritime sector. *J. Clean. Prod.* **2021**, 291, doi:10.1016/j.jclepro.2021.125849.
5. Viana, M.; Fann, N.; Tobías, A.; Querol, X.; Rojas-Rueda, D.; Plaza, A.; Aynos, G.; Conde, J.A.; Fernández, L.; Fernández, C. Environ- 36 mental and health benefits from designating the Marmara Sea and the Turkish Straits as an emission control area (ECA). *Environ. Sci. Technol.* **2015**, *49*, 3304–3313, doi:10.1021/es5049946.
6. Sofiev, M.; Winebrake, J.J.; Johansson, L.; Carr, E.W.; Prank, M.; Soares, J.; Vira, J.; Kouznetsov, R.; Jalkanen, J.-P.; Corbett, J.J. Cleaner fuels for ships provide public health benefits with climate tradeoffs. *Nat. Commun.* **2018**, *9*, 406, doi:10.1038/s41467- 40 017-02774-9.
7. World Health Organization (WHO). *Health Risks of Particulate Matter from Long-Range Transboundary Air Pollution*; Joint WHO/Convention Task Force on the Health Aspects of Air Pollution, European Centre for Environment and Health Bonn Office, Eds.; WHO: Copenhagen, Denmark, 2006.
8. Smith, T.W.P.; Jalkanen, J.P.; Anderson, B.A.; Corbett, J.J.; Faber, J.; Hanayama, S.; O'Keeffe, E.; Parker, S.; Johansson, L.; Aldous, L.; et al. *Third IMO Greenhouse Gas Study 2014*; International Maritime Organization: London, UK, 2015; 327p.
9. International Marina Organization. *Fourth IMO GHG Study 2020 Executive Summary*; International Maritime Organization: London, UK, 2021. Available online: www.imo.org (accessed date).
10. Wang, X.; Shen, Y.; Lin, Y.; Pan, J.; Zhang, Y.; Louie, P.K.K.; Li, M.; Fu, Q. Atmospheric pollution from ships and its impact on local air quality at a port site in Shanghai. *Atmos. Chem. Phys.* **2019**, *19*, 6315–6330, doi:10.5194/acp-19-6315-2019.
11. Shilenje, Z.W. Observed surface ozone trend in the year 2012 over Nairobi, Kenya. *Atmosfera* **2014**, *27*, 377–384, doi:10.1016/S0187-6236(14)70036-0.
12. Acker, J.G.; Leptoukh, G. Online Analysis Enhances Use of NASA Earth Science Data. *Eos Trans. AGU* **2007**, *88*, 14–17.
13. Merico, E.; Gambaro, A.; Argiriou, A.; Alebic-Juretic, A.; Barbaro, E.; Cesari, D.; Chasapidis, L.; Dimopoulos, S.; Dinoi, A.; Donateo, A.; et al. Atmospheric impact of ship traffic in four Adriatic-Ionian port-cities: Comparison and harmonization of different approaches. *Transp. Res. Part D Transp. Environ*. **2017**, *50*, 431–445.
14. Karagiannidis, A.; Poupkou, A.; Giannaros, T.; Giannaros, C.; Melas, D.; Argiriou, A. The air quality of a Mediterranean urban environment area and its relation to major meteorological parameters. *Water Air Soil Pollut.* **2015**, *226*, 2239.
15. Pey, J.; Querol, X.; Alastuey, A.; Forastiere, F.; Stafoggia, M. African dust outbreaks over the Mediterranean Basin during 2001–2011: PM10 concentrations, phenomenology and trends, and its relation with synoptic and mesoscale meteorology. *Atmospher. Chem. Phys.* **2013**, *13*, 1395–1410, doi:10.5194/acp-13-1395-2013.
16. Zhao, C.; Li, Y.N.; Zhang, F.; Sun, Y.L.; Wang, P.C. Growth rates of fine aerosol particles at a site near Beijing in June 2013. *Adv. 40 Atmos. Sci.* **2018**, *35*, 209–217, doi:10.1007/s00376-017-7069-3.