COVID-19 Impact on Global Maritime Mobility

Leonardo M. Millefiori
NATO STO Centre for Maritime Research and Experimentation
Paolo Braca (paolo.braca@cmre.nato.int)
NATO STO Centre for Maritime Research and Experimentation
Dimitris Zissis
University of the Aegean
Giannis Spiliopoulos
MarineTraffic
Stefano Marano
University of Salerno
Peter K. Willett
University of Connecticut
Sandro Carniel
NATO STO Centre for Maritime Research and Experimentation

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Leonardo M. Millefiori[1,+], Paolo Braca[1,+,*], Dimitris Zissis[2,3], Giannis Spiliopoulos[3], Stefano Marano[4], Peter K. Willett[5], and Sandro Carniel[1]

[1]NATO STO Centre for Maritime Research and Experimentation, Research Department, La Spezia, 19126, Italy
[2]University of the Aegean, Department of Product and Systems Design Engineering, Syros, 84100, Greece
[3]MarineTraffic, Athens, 115 25, Greece
[4]University of Salerno, Dipartimento di Ingegneria dell'Informazione ed Elettrica e Matematica Applicata (DIEM), Fisciano (SA), 84084, Italy
[4]University of Connecticut, Department of Electrical and Computer Engineering, Storrs, 06269, USA
[*]paolo.braca@cmre.nato.int
[+]these authors contributed equally to this work

ABSTRACT

To prevent the outbreak of the Coronavirus disease (COVID-19), numerous countries around the world went into lockdown and imposed unprecedented containment measures. These restrictions progressively produced changes to social behavior and global mobility patterns, evidently disrupting social and economic activities. Here, using maritime traffic data, collected via a global network of Automatic Identification System (AIS) receivers, we analyze the effects that the COVID-19 pandemic and the containment measures had on the shipping industry, which accounts alone for more than $80\,\%$ of the world trade. We introduce the notion of a "maritime mobility index", a synthetic composite index, to quantitatively assess ship mobility in a given unit of time. The mobility index calculation used in this study, has a worldwide extent and is based on the computation of Cumulative Navigated Miles (CNM) of all ships reporting their position and navigational status via AIS. We compare 2020 mobility levels to those of previous years assuming that an unchanged growth rate would have been achieved, if not for COVID-19. Following the outbreak, we find an unprecedented drop in maritime mobility, across all categories of commercial shipping. The reduced activity is observable from March to June, when the most severe restrictions were in force, producing a variation of mobility quantified between $-5.62\,\%$ and $-13.77\,\%$ for container ships, between $2.28\,\%$ and $-3.32\,\%$ for dry bulk, between $-0.22\,\%$ and $-9.27\,\%$ for wet bulk, and between $-19.57\,\%$ and $-42.77\,\%$ for passenger shipping. The presented study is unprecedented for the uniqueness and completeness of the employed AIS dataset, which comprises a trillion AIS messages broadcast worldwide by $50\,000$ ships, a figure that closely parallels the documented size of the world merchant fleet.

Introduction

The coronavirus (COVID-19) pandemic has recently produced one of the worst global crises since World War II. As of August 27, 2020, more than 24 million people have been infected worldwide, and over 826 thousand have passed away due to the disease. Consequences of the outbreak are impacting broadly all aspects of our society. In February 2020, the World Health Organization (WHO) recommended containment and suppression measures to slow down the spread of the virus.[1,2]. Towards this direction and aimed at "flattening the curve" of infections so as to avoid overwhelming healthcare systems, many countries implemented unprecedented confinement measures, ranging from bans to travel and social gatherings, to the closure of many commercial activities. Evidence that the lockdown measures achieved a reduction of the rate of new infections are gradually appearing in the scientific literature.[3,4]

Many of the aforementioned restrictions are in contradistinction to "normal" routines. At a time when we are asked to come together and support one another in society, we must learn to do so from a distance. But the behavior changes have been deemed necessary, and some may provide useful insights regarding how we can facilitate transformations toward more sustainable supply and production.[7] The hope is that the macroeconomic system, global supply chains, and international trade relations will not revert back to "normal" and "business-as-usual," and will allow the emergence and successful adoption of new types of economic development and governance models.[7]

On the other hand, both the outbreak and the restrictions are revealing the fragility of the global economy, sparking fears of impending economic crisis and recession.[8] Social distancing, self-isolation and travel restrictions have led to workforce reductions across all economic sectors. Schools have closed down, and the demand for commodities and manufactured products has generally decreased. In contrast, the need for medical supplies has significantly risen. The food industry is also facing increased demand due to panic-buying and stockpiling.[8]

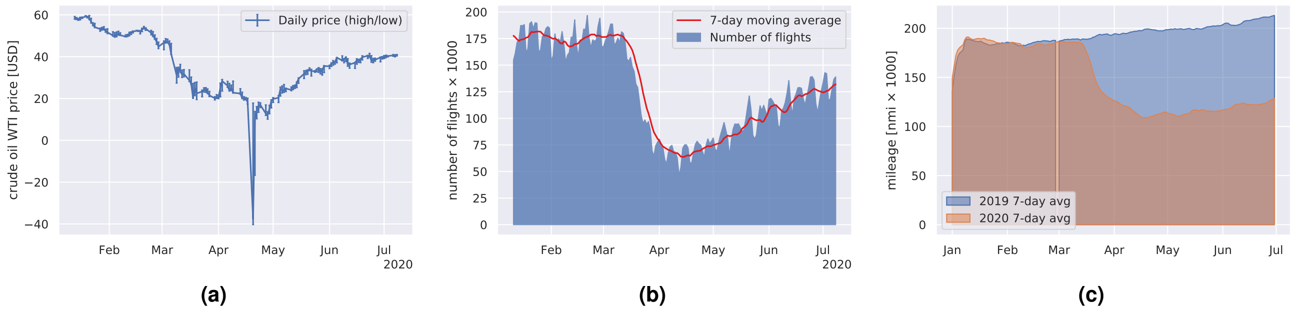


Figure 1. (a) Crude oil WTI price from January to July 2020. [5] Note the sudden and unprecedented negative price in April 2020. (b) Total number of flights tracked by *FlightRadar24* from January to July 2020.[6] At the end of March there was an abrupt decrease of the number of flights (∼ 100 000 units) because of the lockdown restrictions. (c) Daily navigated miles by passenger ships in 2020 compared with 2019.

Overall, world trade is expected to fall by between 13 % and 32 % in 2020 as the COVID-19 pandemic disrupts normal economic activity and life around the world.[11] Business activity across the eurozone collapsed to a record low in March 2020, and US industrial production showed the biggest monthly decline since the end of World War II.[12] An example of the unprecedented financial changes is the price of oil dropping below zero due to expiry of delivery contracts and limited storage capacity to receive them, for the first time in history in April 2020,[5,13] as reported in Fig. 1a. The connection between the recent spread of COVID-19, oil price volatility, the stock market, geopolitical risk and economic policy uncertainty in the US is studied by Sharif *et al.*[14] Guan *et al.*[15] analyzed the supply-chain effects of a set of idealized lockdown scenarios, using the latest global trade modeling framework. Given that lockdowns be necessary, the authors demonstrate that they best occur early, strict and short in order to minimize overall losses.

Useful insights related to the global supply chain can be gained by observing the impact of lockdowns on the mobility of goods. Indeed, in today's increasingly globalized economy, transport plays a central and critical role as the primary enabler of the flow of freight within and across borders. In late March 2020, several sources reported a dramatic decline in air traffic: as governments put travel restrictions in place, airlines halted flights and commercial air traffic quickly dropped significantly below 2019 levels, see Fig. 1b. However, as it accounts only for a small part of the global freight transport, a decline in air traffic, as significant as it may be, would not necessarily imply reduced goods mobility.

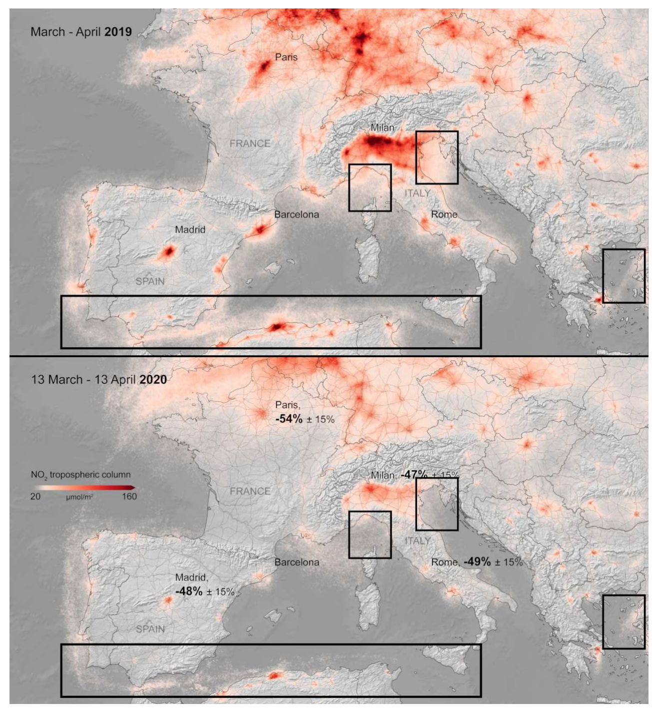


Figure 2. Average nitrogen dioxide (NO_2) concentrations from 13 March to 13 April 2020, compared to the same period in 2019. The decrease of emission is evident, around −50 % in large European cities (Rome, Paris, Madrid and Milan). Highlighted with boxes there are regions of sea where it is evident a decrease of nitrogen dioxide concentrations, probably due to the reduced shipping activity. WHO air quality guideline values quantify in 40 µg m^{-3} (annual mean) the NO_2 limit level for human health.[9] Reproduced with permission. © Contains modified Copernicus Sentinel data (2019-20), processed by KNMI/ESA.[10]

With over 80 % of global trade by volume and more than 70 % of its value being carried on board ships and handled through seaports worldwide, maritime transport for trade and development is of paramount importance.[16–18]. Shipping can be viewed as a barometer for the global economic climate. Total volumes are estimated to have reached 11 billion tons, an all-time high, according to the United Nations Conference on Trade and Development (UNCTAD) records.

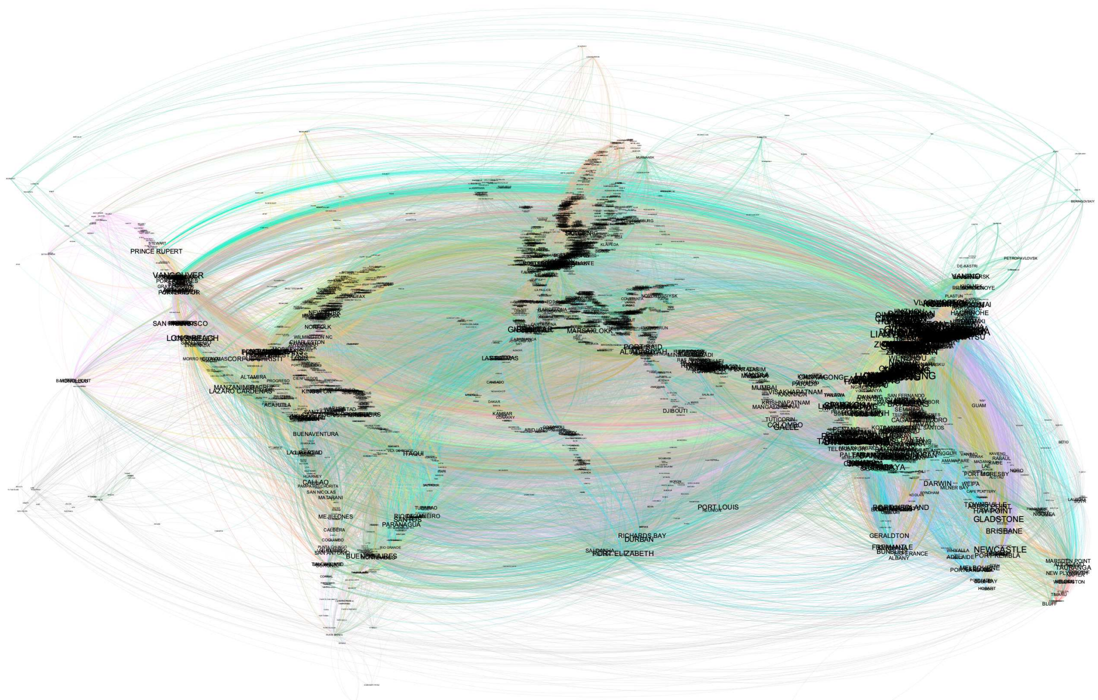


Figure 3. Representation of Shanghai's ego network and its 3-step neighborhood: each port in the picture is reachable from Shanghai with at most three hops. An ego network[24] consists of a focal node (the *ego*) and the nodes (the *alters*) that are connected to it, either directly or within a fixed number of steps.

UNCTAD originally projected an annual average growth rate of 3.4 % for the period 2019—2024.[19] However, this estimated growth will possibly need to be revised,[11] as the coronavirus pandemic led to a 3 % drop in global trade values in the first quarter of 2020. The downturn is expected to accelerate in the second quarter, according to UNCTAD forecasts,[20] which project a quarter-on-quarter decline of 27 %.

Similar to commercial aviation, the maritime tourism industry was the first and most affected traffic segment, with cases of COVID-19 among cruise ships passengers and crew members reported all around the world, from Yokohama (Japan), to Corfu (Greece) and Sydney (Australia).[21,22] The effects on this market segment might also be more enduring than in other sectors, as psychological effects might come into play in addition to restrictive measures, with passengers being less inclined to travel on large crowded ships. In the second half of March 2020, most European cruise terminals partially or in some cases completely, suspended operations[22] (e.g., 19 March in Italy, 20 March in Croatia, 25 March in Spain). In order to limit and slow the spread of the infection, many seaports closed down, limiting—and sometimes banning—cruise traffic at their terminals. National and local restrictions concerning ship operations were enforced, often leading to delayed port clearance. Limitations included crew embarking and disembarking, cargo discharge and loading, imposition of quarantine, and eventually refusal of port entry and refueling. Other measures followed in other maritime sectors and port activities with the aim to ensure safety at terminals and associated logistic facilities of stevedores and other personnel.[23]. The fishing and aquaculture sectors were also affected by containment measures, leading to, e.g., voluntary fishing cessation and suspension or reduction of fish farming, with evident effects on the supply chain of fish food products.[23]

Global maritime mobility reductions not only affect global trade and the economy, but also the environment: especially sea pollution[25,26] and incursions by invasive species[27] are heavily influenced by ship activities; in a recent International Maritime Organization (IMO) report[28] that has been submitted to the Marine Environment Protection Committee (MEPC), greenhouse gas (GHG) emissions from shipping—expressed in carbon dioxide equivalent (CO_2e)—increased increased 9.6 % in 2018 with respect to 2012, and accounted for the 2.89 % of global anthropogenic emissions, with container and bulk shipping being accountable for most of the total emissions. The nexus between COVID-19 and the environment already attracted enormous attention within the scientific community, and several works are already available that analyze the effects of the pandemic in four main areas:[29] (1) environmental degradation, (2) air pollution, (3) climate/metrological factors and (4) temperature. An exemplary environmental consequence of lockdowns is that pollution levels dropped significantly; for instance, greenhouse gas emissions, nitrogen dioxide, black carbon and water pollution decreased drastically[29]. In Fig. 2 we report, using data from the

Copernicus Sentinel-5P satellite,[10] the average nitrogen dioxide concentrations in Europe from 13 March to 13 April 2020, compared with the same period in 2019. The decrease of pollutants is evident, around −50 % in large European cities (Rome, Paris, Madrid and Milan). In the same figure, we have also highlighted with boxes sea regions where the decrease of nitrogen dioxide concentrations is noticeable and could be also due (even if only partially) by a decreased shipping activity. Indeed, it is interesting to observe that just along the first part of one of the main sea lanes in the Mediterranean Sea (Gibraltar-Suez), pollution in 2020 reduced with respect to 2019 levels. Recent work by Faber *et al.*[30] suggests how emissions from ships could be reduced if they reduced their speed; our analysis of AIS data shows that in all highlighted areas, on average, ships reduced their speed in March-April 2020 with respect to the same months in 2019. Specifically, in the highlighted regions of the Gibraltar-Suez route, Ligurian Sea, Northern Adriatic Sea, and Aegean Sea, we report average fleet speed variations of −5.1 %, −15.3 %, −6.0 % and −9.5 %, respectively.

The aim of this study is to analyze the short-term effects that the COVID-19 pandemic and containment measures had on the global shipping industry. As an early reaction to this uncertainty, shipbuilders have reduced capacity and new ship building orders are about 75 % down.[31]. The analysis reported in this paper shows the combined effects the the coronavirus disease and the containment measures, in addition to the reported trade contraction[11,20], had on the global maritime traffic. Maritime traffic reflects these effects and as such shows, for the first time and in specific sectors more than others, signs of slowing down, with possible negative future consequences on the entire global supply chain.

We propose the spatio-temporal analysis of positional AIS messages to compute synthetic indicators capable of quantifying ship activities and highlighting changes in mobility patterns. The indicators are the Cumulative Navigated Miles (CNM), computed for each ship journey per category and the number of *active* and *idle* ships. In other words, we assess, with a data-driven approach, the global ship mobility for the traffic categories that account for the most traffic worldwide.

Maritime trade statistics are usually focused on volume units rather than mobility.[19] However, it is intuitive to acknowledge that there is a close relationship between mobility (e.g. the number of active or idle ships) and trade volumes. Yet, even today most statistics and economic forecasting indices focus only on the starting and finish lines of the supply chain, with little consideration of how goods arrive at their final destination. A more detailed look reveals a complex and dynamic network of ships and their cargo in constant motion across the world's oceans. In this sense, maritime traffic can provide insights into the global supply and demand trends; thus considered as an indicator of future economic growth.

The results reported in this paper are based on a global dataset containing approximately a trillion AIS messages collected between 2016 and 2020 indicating the movement of more than 50 000 commercial ships across the globe, stored in a big data infrastructure of 55 TB. To give an idea of both the worldwide coverage of AIS data and the capillarity of sea routes network, we proffer in Fig. 3 the port of Shanghai's ego network[24] constructed based on AIS data from September 2018–2019.

The global CNM that we have computed from AIS data indicates the scale of ship mobility. From January to June ships cumulatively travelled something around around 530 000 000 nautical miles (nmi) in 2016, 580 000 000 nmi in 2019, and 575 000 000 nmi in 2020. To aid understanding, the distance commercial shipping travelled in the first half of 2016, is comparable to travelling 6.5 times the mean distance between the Earth and sun, and in 2019 almost 7.2 times that.

Instead of increasing, as it has happened in all past years since 2016, the global ship mobility in terms of CNM, in 2020 and for the first time, slightly decreased. The decrease in the first half of 2020, compared to the first half of 2019, amounted to a modest 0.9 % and to over 5 % in the period April-June 2020, compared to April-June 2019. The decline in the first half of 2020 is almost 4 %, compared to the forecast values in 2020, and is over 8 % in the period April-June. Moreover, there is great variation of this figure among traffic categories and different months; for instance, in June container ships decreased 12 % compared to 2019, wet bulk ships of 5 %, and passenger ships of 42 %, while dry bulk ships slightly increased (1.7 %).

Results

The COVID-19 pandemic has lead to vast economic disruption across the world, with a collapse in customer demand and industrial activity. Overall, the shipping industry and seaborne trade followed this negative trend. In this paper we compare global vessel mobility during the first half of 2020 to that of previous years, from 2016 to 2019, and the analysis confirms that shipping mobility has been negatively affected, but to different degrees in each market and depending on the size of vessels. Our results suggest that there is a substantial increase in idle ships across all types of ships/markets globally in the first six months of 2020, and a substantial decline in the vessel mobility measured in CNM per unit of time.

Given that prior to the pandemic mobility, similar to global trade, was on an increasing trend, we compare the 2020 mobility with its forecast based on the analysis of previous years. Specifically, we assume an expected growth in 2020 given by the average growth observed in the same month of a few past consecutive years.

The main result of the analysis is represented in Figure 4, which reports global vessel mobility indicators for four main types of ship traffic: container (a)–(c), dry bulk (d)–(f), wet bulk (g)–(i), and passenger (j)–(l). For each traffic category we report the daily navigated miles from January to June in 2019 and 2020, the monthly navigated miles from 2016 to 2020 (with

Table 1. Monthly Cumulative Navigated Miles (CNM) [nmi $\times 10^6$].

	Year	January	February	March	April	May	June
Container	2016	23.68	23.45	26.01	25.51	26.42	25.35
	2017	26.10	23.28	26.82	25.84	26.76	25.16
	2018	26.17	24.32	26.12	26.10	27.61	26.85
	2019	24.96	22.92	25.91	26.08	27.82	27.24
	2020†	25.39	22.74	25.88	26.27	28.29	27.88
	2020‡	26.20	23.11	24.43	23.98	24.15	24.04
Dry bulk	2016	32.67	31.99	37.08	36.94	37.65	35.38
	2017	38.33	34.43	39.13	38.79	40.25	37.83
	2018	37.76	36.27	39.90	39.36	41.60	39.29
	2019	37.38	35.69	39.45	39.77	42.82	41.93
	2020†	38.95	36.92	40.25	40.72	44.55	44.11
	2020‡	40.32	37.33	41.17	41.17	43.44	42.65
Wet bulk	2016	21.28	20.92	23.24	22.69	23.26	22.48
	2017	24.50	21.69	24.99	24.34	25.18	23.84
	2018	24.55	23.22	25.40	24.84	26.02	24.84
	2019	24.88	23.21	25.94	25.22	27.04	26.28
	2020†	26.07	23.98	26.84	26.06	28.30	27.55
	2020‡	26.92	25.22	26.78	25.92	26.18	24.99
Passenger	2016	4.78	4.73	5.32	5.31	5.51	5.57
	2017	5.33	4.87	5.62	5.67	5.88	5.96
	2018	5.46	5.06	5.74	5.75	6.00	6.08
	2019	5.70	5.19	5.91	5.92	6.23	6.25
	2020†	6.00	5.35	6.11	6.12	6.47	6.48
	2020‡	5.78	5.32	4.92	3.44	3.54	3.71
Total	2016	82.42	81.09	91.64	90.46	92.85	88.78
	2017	94.26	84.26	96.56	94.64	98.07	92.79
	2018	93.94	88.88	97.16	96.05	101.22	97.06
	2019	92.91	87.01	97.22	96.99	103.92	101.70
	2020†	96.41	88.99	99.08	99.17	107.61	106.01
	2020‡	99.22	90.98	97.29	94.51	97.32	95.39

† Forecast mobility levels considering the average growth in past years 2016–2019.
‡ Actual mobility levels recorded in 2020.

2020 forecasts), and the monthly percentage of active/idle ships from 2016 to 2020. The global CNM values in Figure 4 are also reported in Table 1 for each category, where we provide all the total aggregate values.

Interestingly, the mobility forecasts in January and February 2020 (before lockdowns) underestimate the growth of some markets, such as container (Fig. 4b), dry bulk (Fig. 4e), and wet bulk (Fig. 4h) markets, in the sense that the actual 2020 levels are between $+1.11\,\%$ (dry bulk in February) and $+5.17\,\%$ (wet bulk in February) with respect to the forecast level. Conversely, the forecast severely overestimates the mobility growth of passenger ships since January, $-3.69\,\%$ w.r.t. the expected level, up to a dramatic -45.3% in May, as depicted in Fig. 4k. In general, the analysis reveals an overall decrease of mobility levels in 2020 compared both with their expected value (considering the growth observed in past years) and to 2019 levels, with only a few exceptions.

We must note that there is a possible regional effect in the measured mobility levels; the mobility in specific regions might be impacted more than others. Specific sectors of the shipping industry were more resilient and continued delivering goods, while others have been much more vulnerable to such measures (e.g., cruise ships). Indeed, the essential supply chain, e.g., hospital and food, was guaranteed when the restriction measures were in place across the world.

Figures 4a–4c show an evident slowdown in the mobility of container ships with respect to previous years, with an increase of idle ships and a correspondent decrease of navigated miles. The slowdown becomes apparent in March, in comparison to both 2019 and 2020 forecast. Global navigated miles of container ships in June 2020 was on average 10 % below the level in

June 2019, and 13.77 % below the 2020 forecast. Figures 4d–4f informs on the effects of lockdowns on dry bulk shipping. Overall, there is a small increase in idle ships from January to April, and a decline of the navigated miles in May and June. This market appears to be less sensitive to the implemented containment measures in the short term. Dry bulks transport a wide range of cargo, including goods whose demand increased due to the pandemic, such as paper pulp, with several ports reporting record quantities. However, still there is a noticeable decrease, 2.5 % and 3.3 % in May and June, respectively, if compared to the forecast levels. Figures 4g–4i show the mobility of wet bulk shipping. An evident rise of idle ships from the beginning of the year is apparent in this category, with a corresponding decrease of navigated miles from February to June. The reduced mobility of this shipping category is already observable in May and June, if compared with 2019 values, and being this a growing market, the loss is even more pronounced if compared with the expected mobility levels in 2020, with a loss that can be assessed around 7.5 % in May and 9.3 % in June. Finally, Figures 4j–4l report on the global mobility of passenger ships, the traffic category that was most affected by lockdown measures, with a dramatic collapse of monthly mileage recorded since March (more than 40 % less than what expected by 2020 forecasts) and a corresponding increase of idle vessels.

For a closer look into each market, we report the daily navigated miles broken down by ship size. In Figure 5, we compare the daily navigated miles for container ships according to their capacity. Specific segments show a stronger decline compared to others. Across all vessel sizes, with the exception of Ultra Large Container Vessels (ULCVs), from late February or early March, there is a strong decrease of the navigated miles. As before, we must note that, since specific segments and types of ships operate on specific trade routes and regions, there could be regional effects that, in the global indicators, are "averaged out"; in other words, local trends could be different than the global one. However, if considered globally, the ULCV market declined; ship operators cancelled their services, with a consequent rise of idle ships and decrease of navigated miles. In Figures 6 and 7, a similar analysis is available for dry bulk shipping and wet bulk shipping. Dry bulk shipping refers to the movement of commodities carried in bulk: iron ore, coal, grain, steel products, lumber and other commodities classified as the minor bulks. For this category, only a small decrease of mileage across all vessel sizes is observed. In Figure 7, we report the daily navigated miles for wet bulk shipping broken down by ship capacity. Wet bulk cargoes include petroleum products, crude oil, vegetable oils, chemicals and similar products. The slowing demand in goods' production and oil consumption had an effect on the mobility of all vessel sizes. The most significantly affected have been the larger tankers, specifically Panamax, Aframax and Suezmax sizes being affected the most; comprehensive information on ship classification by their size is available to the interested reader in the open literature.[32,33] Due to circumstances unrelated to COVID-19 (i.e., the breakdown of the OPEC alliance—which triggered a 30 % fall in oil prices in March 2020), the mobility reduction is evident only after April 2020. Finally, Figure 8 reports the daily navigated miles of passenger vessels, the most affected segment by lockdown measures. The loss in terms of navigated miles in 2020 compared to 2019 is apparent, with larger vessel sizes affected by stronger losses than smaller ones. With respect to 2019, passenger ships larger than 60K GT, which includes large cruise ships, registered a sharp decrease of navigated miles of more than 80 % since March 2020, when several cruise lines, including Carnival cruises, which alone owns more than 100 cruise ships, suspended the operations. The effects are evident from Fig. 8, with a sharp drop of navigated miles apparent since March.

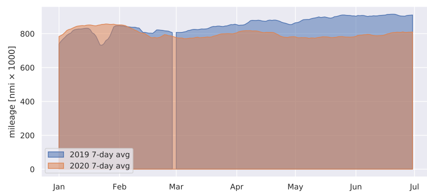
Discussion

The COVID-19 pandemic and containment measures have lead to vast economic disruptions across the world, with near evaporation of both customer demand and industrial activity. Focusing on the first half of 2020 compared with previous years (2016–2019), and based on a global dataset of approximately 1 trillion ship positions received via AIS from more than 50 000 ships, the analysis presented in this paper shows that shipping mobility has also been affected negatively.

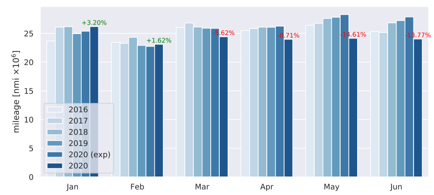
We report an unprecedented slowdown in global shipping mobility, which was steadily increasing since 2016, and a noticeable activity decrease for all ship categories in 2020, when compared with projections (assuming the average growth rate of past years). The most affected traffic segment is that of passenger ships, followed by container ships. Effects of the pandemics on global ship mobility are observable since March until the end of June 2020, with variations ranging between -5.62 % and -13.77 % for container ships, between $+2.28$ % to -3.32 % for dry bulks, between -0.22 % and -9.27 % for wet bulks, and between -19.57 % and -42.77 % for passenger ships.

On the basis of the indicators presented in this paper, we can also conclude that, despite the crisis, shipping was resilient, and in specific markets it was possible to continue operations; in this sense, the analysis highlights the strategic importance of shipping at a global scale.

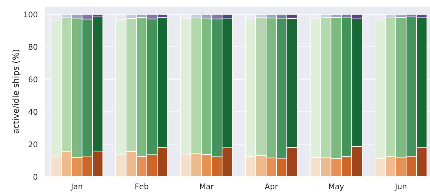
Qualitatively, we have highlighted the nexus between shipping mobility and trade volume, as well as between shipping mobility and environmental emissions. While such connections are intuitive and logical, it is unknown the analytical relationships among such quantities. Future works could be aimed at validating such connections, and explore quantitatively the relation among mobility, trade, and emissions. Additionally as more data becomes available our analysis will focus on longer term impacts while attempting to identify signs of a recovery.



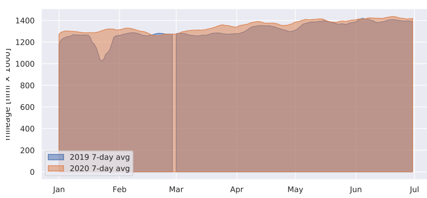
(a) Container: daily mileage



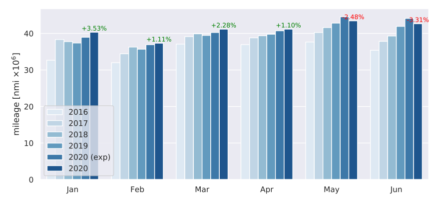
(b) Container: monthly mileage



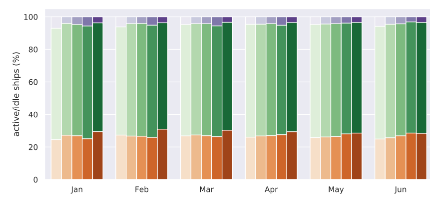
(c) Container: active/idle ships



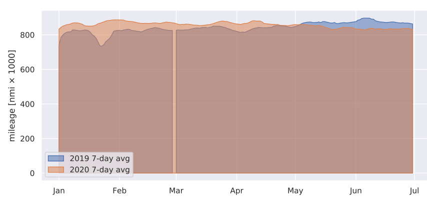
(d) Dry bulk: daily mileage



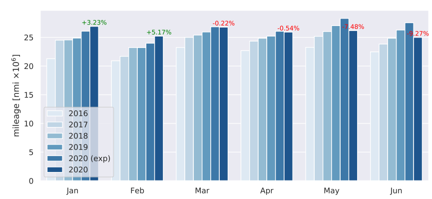
(e) Dry bulk: monthly mileage



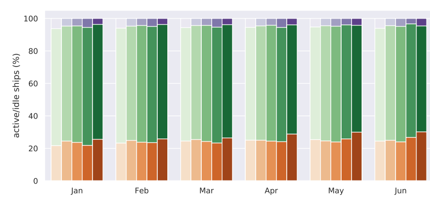
(f) Dry bulk: active/idle ships



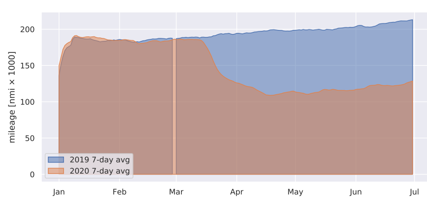
(g) Wet bulk: daily mileage



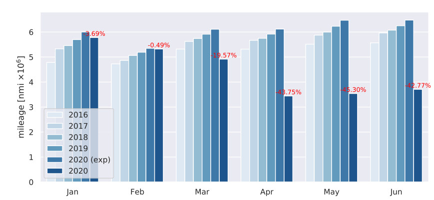
(h) Wet bulk: monthly mileage



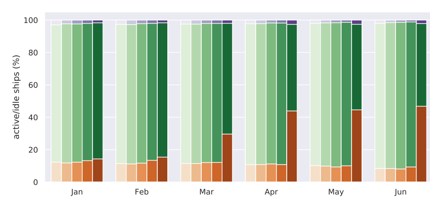
(i) Wet bulk: active/idle ships



(j) Passenger: daily mileage



(k) Passenger: monthly mileage



(l) Passenger: active/idle ships

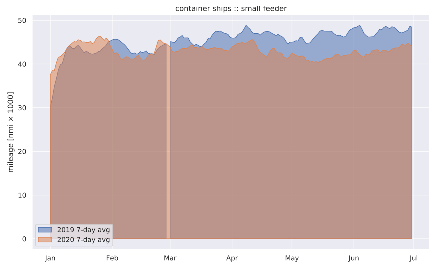
Figure 4. Comparison of traffic indicators for several ship categories: container (a)–(c), dry bulk (d)–(f), wet bulk (g)–(i), and passenger (j)–(l). The left column shows daily navigated miles in 2019 (in blue) compared with 2020 (in orange); the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019. The mid column shows monthly navigated since 2016 up to 2020; the second last bar in each group represents an estimation of navigated miles in 2020 given the growth rate observed in the previous years; the label on the 2020 bar quantifies the percentage increase or decrease w.r.t. the expected 2020 traffic volume. The last column shows the distribution of active (green) and idle (orange) ships over time, compared with past years, arranged by month with bars from left (2016) to right (2020); purple bars represent the (negligible) part of ships that could be labeled neither as active nor idle.

Methods

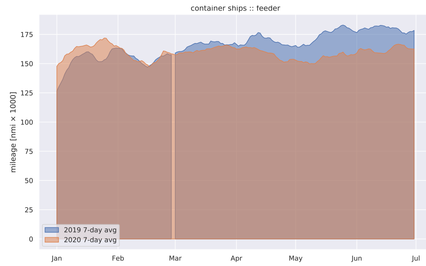
Automatic Identification System (AIS)

Originally designed only for collision avoidance and information exchange between ships, nowadays the AIS is extensively used by operators as the primary means for ship traffic monitoring on a much larger scale than that achievable with conventional coastal surveillance systems. With the AIS, ships voluntarily broadcast their position, velocity, along with other identification and voyage-related information. The AIS communication protocol is asynchronous and prescribes that different types of messages be transmitted with different frequencies. There are two types of AIS transponders. Class A, for large ships, and class B, for smaller vessels. The International Maritime Organization (IMO) mandates that every ship of more than 300 gross tonnage, all passenger ships and all fishing vessels with a length above 15 meters be equipped with class A transponders. Conversely, class B transponders are designed to bring the benefits of AIS on smaller vessels; indeed, they are smaller and less expensive than class A type transceivers. As such, they can be installed on small ships such as recreational vessels that want to have the benefits of having the AIS even if, for their size, they are not required to fit a transponder onboard.

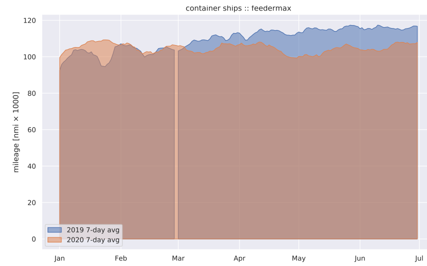
Over the last few years, AIS data have been largely used in research for validation purposes as "ground-truth" information,



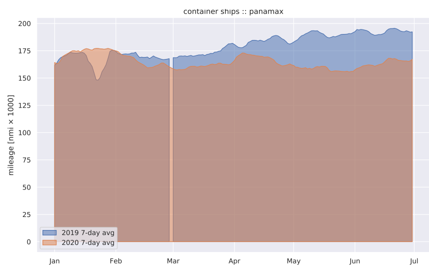
(a) Container ships: Small feeder



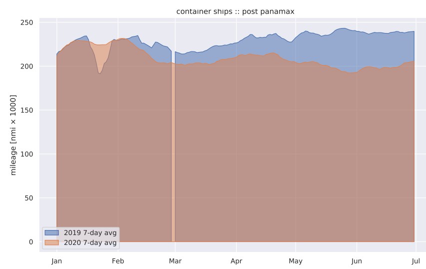
(b) Container ships: Feeder



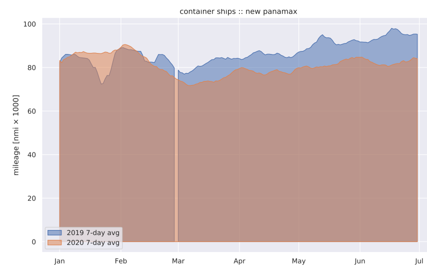
(c) Container ships: Feedermax



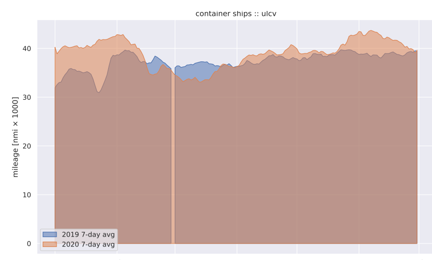
(d) Container ships: Panamax



(e) Container ships: Post-Panamax

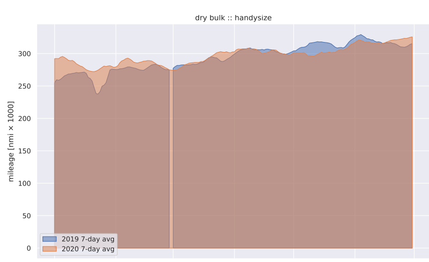


(f) Container ships: New Panamax

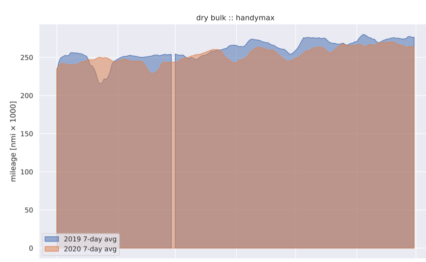


(g) Container ships: ULCV

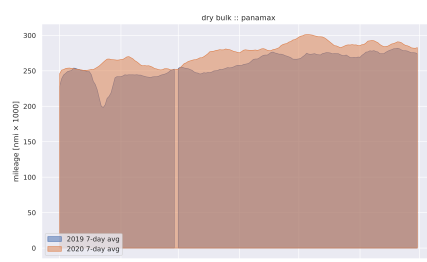
Figure 5. Comparison of daily miles navigated by container ships in the first six months of 2020 (orange) versus 2019 (blue) for different ship size categories, ordered by increasing capacity measured in Twenty-foot Equivalent Units (TEUs); the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019.



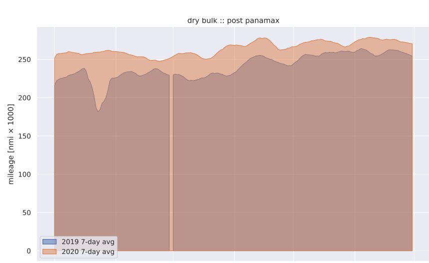
(a) Dry bulk: Handy size



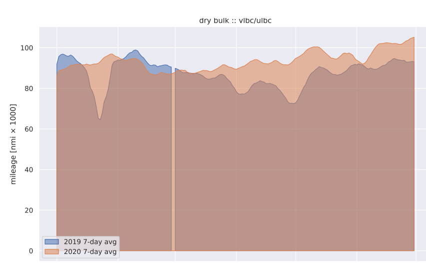
(b) Dry bulk: Handymax



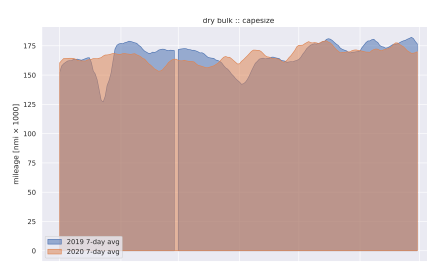
(c) Dry bulk: Panamax



(d) Dry bulk: Post-Panamax

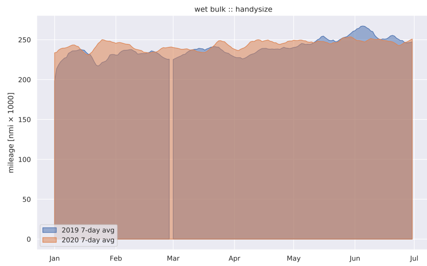


(e) Dry bulk: VLBC

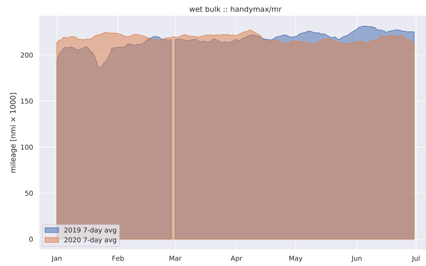


(f) Dry bulk: Capesize

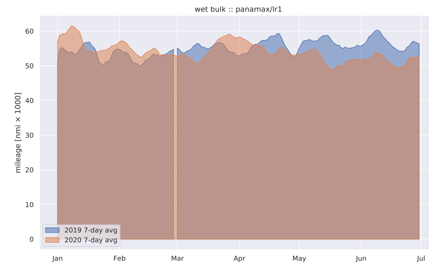
Figure 6. Comparison of daily miles navigated by dry bulk ships in the first six months of 2020 (orange) versus 2019 (blue) for different ship size categories, ordered by increasing deadweight tonnage (DWT); the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019.



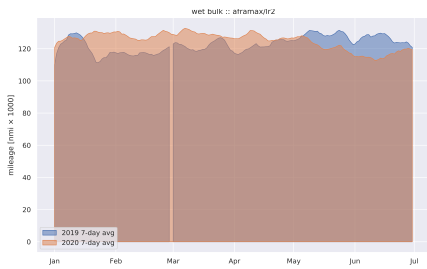
(a) Wet bulk: Handy size



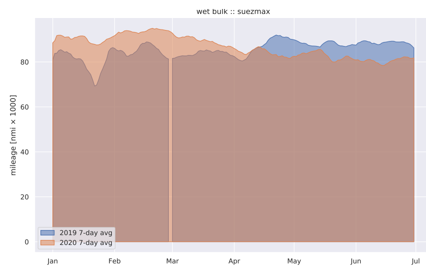
(b) Wet bulk: Handymax



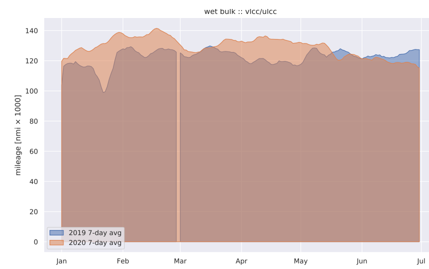
(c) Wet bulk: Panamax



(d) Wet bulk: Aframax

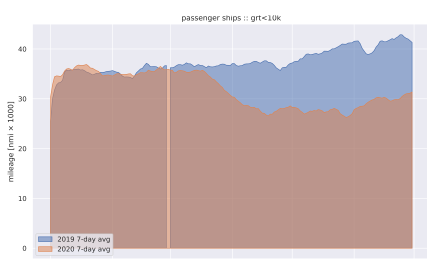


(e) Wet bulk: Suezmax

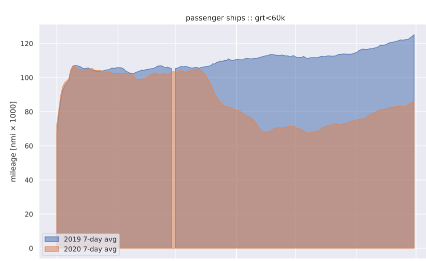


(f) Wet bulk: VLCC

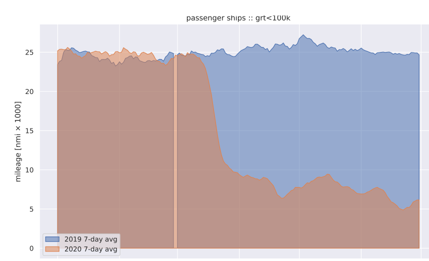
Figure 7. Comparison of daily miles navigated by wet bulk ships in the first six months of 2020 (orange) versus 2019 (blue) for different ship size categories, ordered by increasing DWT; the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019.



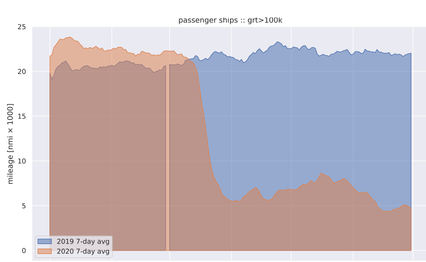
(a) Passenger ships: GT $\leq$ 10K



(b) Passenger ships: 10K $<$ GT $\leq$ 60K



(c) Passenger ships: 60K $<$ GT $\leq$ 100K



(d) Passenger ships: GT $>$ 100K

Figure 8. Comparison of daily miles navigated by passenger ships in the first six months of 2020 (orange) versus 2019 (blue) for different ship size categories, ordered by increasing gross tonnage (GT); the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019.

e.g., in maritime surveillance with coastal radars[34–36] as confirmation tracks for radar detections, or for the validation of a target motion model for long-term ship prediction.[18] AIS has also been used to show how the data association can be sensibly improved using the long-term prediction and combining AIS with HF Surface Wave radar (HFSWR) data, or Synthetic Aperture Radar (SAR) data.[37] But in any case there is a significant literature that considers AIS the sole source of information for maritime surveillance,[18,37–41] port traffic analysis,[42,43] and anomaly detection;[44–48] a common application for historical AIS data is also the training of machine learning, including neural networks, algorithms.[40,49,50] The interested reader can find in the scientific literature an excellent survey[41] of AIS data exploitation for safety, anomaly detection, route estimation, collision prediction, and path planning.

Ship mobility indicators

In this paper, we analyze AIS data to compute mobility indicators. Besides AIS, we made use of information regarding ship characteristics; such as their class, size and type of cargo (i.e., dry or wet bulk), as well as their weight measured in tons and referred to as DWT. The input of the processing chain is represented by positional AIS messages, specifically message types 1, 2, and 3, which are 168 bit long and are used by vessels to broadcast their position via class A transceivers. Then, positional information is augmented with information from type 5 AIS messages (424 bit), which ships use to broadcast their identification, voyage and other static information, such as their size and draught.

The AIS dataset we used has a worldwide extent and contains approximately 1 trillion messages, which were broadcast by more than 50 000 ships, a figure that closely resembles the total number of ships in the world merchant fleet as of January 1, 2019 reported by Statista.[51] The ships considered were equipped with class A transceivers and were employed for the transfer dry and wet cargo, containers and passengers. For the purposes of this study, vessels included in the calculations are above 10 000 DWT for dry bulk, wet bulk and container shipping, and above 1000 DWT for passenger vessels. The total size of the dataset is approximately 55 TB and it is stored in a big data architecture. The processing is based on a distributed cluster of 40 virtual cores and 128 GB of RAM. The overall processing time was less than 4 hours.

The mobility indicator calculation requires a number of processing steps, detailed as follows. The first step fuses data different AIS receivers and converts them into a common format for processing; in this step, positional AIS messages are augmented with information on the ship class and type of cargo. Since data may suffer from errors and coverage gaps, erroneous and redundant data are removed during the second stage. For example, all messages that are found to exceed a 24-hour interval, messages that correspond to infeasible speeds for large vessels (faster than 50 knots), or are not transmitted from the four types of carriers, or are accompanied by invalid identification numbers are discarded. In the third step, *active* and *idle* indicators are computed from the reported navigational status and the ship speed. The ship is assumed to be *idle* if her navigational status is “at anchor,” “not under command,” “moored,” or “aground,” or if the ship speed remains below 2 knots. Otherwise, it is considered *active*. In the fourth step we finally compute the CNM by first aggregating positional data by identification number and than by taking the sum of the great-circle distance between all consecutive positional messages broadcast by active ships. This eventually brings to the computation of the navigated distance per category and unit of time.

References

1. Anderson, R. M., Heesterbeek, H., Klinkenberg, D. & Hollingsworth, T. D. How will country-based mitigation measures influence the course of the COVID-19 epidemic? *The Lancet* **395**, 931–934, DOI: 10.1016/S0140-6736(20)30567-5 (2020).

2. Hellewell, J. *et al.* Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts. *The Lancet Glob. Heal.* **8**, e488–e496, DOI: 10.1016/S2214-109X(20)30074-7 (2020).

3. Dehning, J. *et al.* Inferring change points in the spread of COVID-19 reveals the effectiveness of interventions. *Science* DOI: 10.1126/science.abb9789 (2020).

4. Gaglione, D. *et al.* Adaptive Bayesian learning and forecasting of epidemic evolution - Data analysis of the COVID-19 outbreak. *IEEE Access* (2020, in press).

5. Crude oil WTI price data (Investing.com). https://www.investing.com/commodities/crude-oil. Accessed: 2020-07-09.

6. Total number of flights tracked by Flighradar24. https://www.flightradar24.com/data/statistics. Accessed: 2020-07-09.

7. Sarkis, J., Cohen, M. J., Dewick, P. & Schroder, P. A brave new world: Lessons from the COVID-19 pandemic for transitioning to sustainable supply and production. *Resour. Conserv. Recycl.* DOI: 10.1016/j.resconrec.2020.104894 (2020).

8. Nicola, M. *et al.* The socio-economic implications of the coronavirus pandemic (COVID-19): A review. *Int. J. Surg.* **78**, 185–193, DOI: 10.1016/j.ijsu.2020.04.018 (2020).

9. World Health Organization (WHO). Ambient (outdoor) air pollution. https://web.archive.org/web/20200829124448/https://www.who.int/news-room/fact-sheets/detail/ambient-%28outdoor%29-air-quality-and-health.

10. European Space Agency (ESA). Nitrogen dioxide concentrations over Europe. https://www.esa.int/ESA_Multimedia/Images/2020/04/Nitrogen_dioxide_concentrations_over_Europe. Accessed: 2020-08-26.

11. World Trade Organization (WTO). Trade set to plunge as COVID-19 pandemic upends global economy. https://www.wto.org/english/news_e/pres20_e/pr855_e.htm (2020).

12. Rapaccini, M., Saccani, N., Kowalkowski, C., Paiola, M. & Adrodegari, F. Navigating disruptive crises through service-led growth: The impact of COVID-19 on Italian manufacturing firms. *Ind. Mark. Manag.* **88**, 225 – 237, DOI: 10.1016/j.indmarman.2020.05.017 (2020).

13. Kelly, S. Oil price crashes into negative territory for the first time in history amid pandemic. https://www.reuters.com/article/us-global-oil/u-s-crude-futures-turn-negative-for-first-time-on-scant-storage-weak-demand-idUSKBN2210V9 (2020).

14. Sharif, A., Aloui, C. & Yarovaya, L. COVID-19 pandemic, oil prices, stock market, geopolitical risk and policy uncertainty nexus in the US economy: Fresh evidence from the wavelet-based approach. *Int. Rev. Financial Analysis* **70**, 101496, DOI: 10.1016/j.irfa.2020.101496 (2020).

15. Guan, D. *et al.* Global supply-chain effects of COVID-19 control measures. *Nat. Hum. Behav.* **4**, 577–587, DOI: 10.1038/s41562-020-0896-8 (2020).

16. United Nations Conference on Trade and Development (UNCTAD). Review of maritime transport. https://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1890 (2017).

17. North Atlantic Treaty Organization (NATO). Alliance Maritime Strategy. Official texts (2011).

18. Millefiori, L. M., Braca, P., Bryan, K. & Willett, P. Modeling vessel kinematics using a stochastic mean-reverting process for long-term prediction. *IEEE Transactions on Aerosp. Electron. Syst.* **52**, 1224–1245, DOI: 10.1109/TAES.2016.150596 (2016).

19. United Nations Conference on Trade and Development (UNCTAD). Review of maritime transport. https://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=2563 (2019).

20. United Nations Conference on Trade and Development (UNCTAD). COVID-19 triggers marked decline in global trade. https://unctad.org/en/pages/newsdetails.aspx?OriginalVersionID=2369 (2020).

21. Moriarty, L. Public health responses to COVID-19 outbreaks on cruise ships —– Worldwide, February-March 2020. *Morb. Mortal. Wkly. Rep. (MMWR)* **69**, 347–352, DOI: 10.15585/mmwr.mm6912e3 (2020).

22. Depellegrin, D., Bastianini, M., Fadini, A. & Menegon, S. The effects of COVID-19 induced lockdown measures on maritime settings of a coastal region. *Sci. The Total. Environ.* **740**, 140123, DOI: 10.1016/j.scitotenv.2020.140123 (2020).

23. Coronavirus response: support to the fishery and aquaculture sectors. https://web.archive.org/web/20200515234751/https://ec.europa.eu/fisheries/sites/fisheries/files/2020-factsheet-coronavirus-fishing-aquaculture-sectors_en.pdf.

24. Hanneman, R. A. & Riddle, M. *Introduction to social network methods* (University of California Riverside, 2005).

25. Viatte, C. *et al.* Air pollution and sea pollution seen from space. *Surv. Geophys.* DOI: 10.1007/s10712-020-09599-0 (2020).

26. Melet, A. *et al.* Earth observations for monitoring marine coastal hazards and their drivers. *Surv. Geophys.* DOI: 10.1007/s10712-020-09594-5 (2020).

27. Sardain, A., Sardain, E. & Leung, B. Global forecasts of shipping traffic and biological invasions to 2050. *Nat. Sustain.* **2**, 274–282, DOI: 10.1038/s41893-019-0245-y (2019).

28. International Maritime Organization (IMO). Fourth IMO GHG Study 2020 – Final report. https://docs.imo.org/Shared/Download.aspx?did=125134 (2020).

29. Shakil, M. H., Munim, Z. H., Tasnia, M. & Sarowar, S. COVID-19 and the environment: A critical review and research agenda. *Sci. The Total. Environ.* **745**, 141022, DOI: 10.1016/j.scitotenv.2020.141022 (2020).

30. Faber, J., Huigen, T. & Nelissen, D. Regulating speed: a short-term measure to reduce maritime GHG emissions. Tech. Rep., CE Delft (2017).

31. Stopford, M. Coronavirus, climate change & smart shipping – Three maritime scenarios 2020–2050. Tech. Rep., Seatrade Maritime, part of Informa Markets (2020).

32. MAN Diesel & Turbo. Propulsion trends in container vessels. https://web.archive.org/web/20120507192232/http://www.mandieselturbo.eu/files/news/filesof4672/5510-0040-01ppr_low.pdf (2009).

33. MAN Diesel & Turbo. Propulsion trends in bulk carriers. https://web.archive.org/web/20200902103322/https://marine.man-es.com/docs/librariesprovider6/test/propulsion-trends-in-bulk-carriers.pdf (2019).

34. Braca, P., Maresca, S., Grasso, R., Bryan, K. & Horstmann, J. Maritime surveillance with multiple over-the-horizon HFSW radars: An overview of recent experimentation. *IEEE Aerosp. Electron. Syst. Mag.* **30**, 4 – 18, DOI: 10.1109/MAES.2015.150004 (2015).

35. Granstrom, K., Natale, A., Braca, P., Ludeno, G. & Serafino, F. Gamma gaussian inverse wishart probability hypothesis density for extended target tracking using X-band marine radar data. *IEEE Transactions on Geosci. Remote. Sens.* **53**, 6617 – 6631, DOI: 10.1109/TGRS.2015.2444794 (2015).

36. Papa, G. *et al.* Multisensor adaptive Bayesian tracking under time-varying target detection probability. *IEEE Transactions on Aerosp. Electron. Syst.* **52**, 2193 – 2209, DOI: 10.1109/TAES.2016.150522 (2016).

37. Vivone, G., Millefiori, L. M., Braca, P. & Willett, P. Performance assessment of vessel dynamic models for long-term prediction using heterogeneous data. *IEEE Transactions on Geosci. Remote. Sens.* **55**, 6533–6546, DOI: 10.1109/TGRS.2017.2729622 (2017).

38. Gaglione, D. *et al.* Bayesian information fusion and multitarget tracking for maritime situational awareness. *IET Radar, Sonar & Navig.* (2020, in press).

39. Millefiori, L. M., Braca, P. & Arcieri, G. Scalable distributed change detection and its application to maritime traffic. In *2017 IEEE International Conference on Big Data (Big Data)*, 1650–1657, DOI: 10.1109/BigData.2017.8258101 (2017).

40. Coscia, P., Braca, P., Millefiori, L. M., Palmieri, F. & Willett, P. Multiple Ornstein–Uhlenbeck processes for maritime traffic graph representation. *IEEE Transactions on Aerosp. Electron. Syst.* 2158–2170, DOI: 10.1109/TAES.2018.2808098 (2018).

41. Tu, E., Zhang, G., Rachmawati, L., Rajabally, E. & Huang, G. Exploiting AIS data for intelligent maritime navigation: A comprehensive survey from data to methodology. *IEEE Transactions on Intell. Transp. Syst.* **19**, 1559–1582, DOI: 10.1109/TITS.2017.2724551 (2018).

42. Millefiori, L., Zissis, D., Cazzanti, L. & Arcieri, G. A distributed approach to estimating sea port operational regions from lots of AIS data. In *2016 IEEE International Conference on Big Data (Big Data)*, 1627–1632, DOI: 10.1109/BigData.2016.7840774 (2016).

43. Zhang, L., Meng, Q. & Fwa, T. F. Big AIS data based spatial-temporal analyses of ship traffic in Singapore port waters. *Transp. Res. Part E: Logist. Transp. Rev.* **129**, 287–304, DOI: 10.1016/j.tre.2017.07.011 (2019).

44. Vespe, M., Visentini, I., Bryan, K. & Braca, P. Unsupervised learning of maritime traffic patterns for anomaly detection. In *9th IET Data Fusion Target Tracking Conference (DF TT 2012): Algorithms Applications*, 1–5, DOI: 10.1049/cp.2012.0414 (2012).

45. Katsilieris, F., Braca, P. & Coraluppi, S. Detection of malicious AIS position spoofing by exploiting radar information. In *Proceedings of the 16th International Conference on Information Fusion*, 1196–1203 (2013).

46. d'Afflisio, E., Braca, P., Millefiori, L. & Willett, P. Detecting anomalous deviations from standard maritime routes using the Ornstein-Uhlenbeck process. *IEEE Transactions on Signal Process.* **66**, 6474–6487, DOI: 10.1109/TSP.2018.2875887 (2018).

47. Kontopoulos, I., Chatzikokolakis, K., Tserpes, K. & Zissis, D. Real-time maritime anomaly detection: detecting intentional AIS switch-off. *Int. J. Big Data Intell.* **7**, DOI: 10.1504/IJBDI.2020.107375 (2020).

48. Ristic, B., La Scala, B., Morelande, M. & Gordon, N. Statistical analysis of motion patterns in AIS data: Anomaly detection and motion prediction. In *11th International Conference on Information Fusion* (2008).

49. Forti, N., Millefiori, L., Braca, P. & Willett, P. Prediction of vessel trajectories from AIS data via sequence-to-sequence recurrent neural networks. In *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 8936–8940, DOI: 10.1109/ICASSP40776.2020.9054421 (2020).

50. Zissis, D., Chatzikokolakis, K., Spiliopoulos, G. & Vodas, M. A distributed spatial method for modeling maritime routes. *IEEE Access* **8**, 47556–47568, DOI: 10.1109/ACCESS.2020.2979612 (2020).

51. Statista. Global merchant fleet – Number of ships by type. https://www.statista.com/statistics/264024/number-of-merchant-ships-worldwide-by-type/ (2019).

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Author contributions statement

L.M.M., P.B. and D.Z. conceptualized the methodology and all the investigations and wrote large sections of the paper. L.M.M., P.B., D.Z. and G.S. were involved in the interpretation of the results. L.M.M. was responsible for the visualization and presentation of the mobility indicators and handled the editing of the manuscript. P.B. was responsible for the literature review and general setting of the manuscript. G.S. was responsible for data curation and the computation of mobility indicators. S.M., P.K.W. and S.C. contributed to the writing of the manuscript. All authors discussed and commented on the methods, results and content of the manuscript; all authors also reviewed the manuscript.

Competing interest

The authors declare no competing interests.

Figures

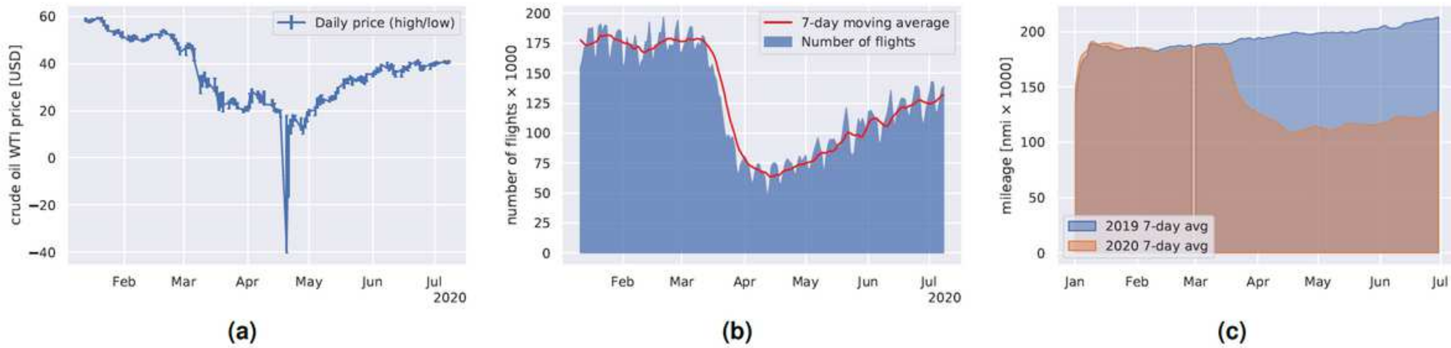


Figure 1

(a) Crude oil WTI price from January to July 2020. 5 Note the sudden and unprecedented negative price in April 2020. (b) Total number of flights tracked by FlightRadar24 from January to July 2020.6 At the end of March there was an abrupt decrease of the number of flights (~100000 units) because of the lockdown restrictions. (c) Daily navigated miles by passenger ships in 2020 compared with 2019.

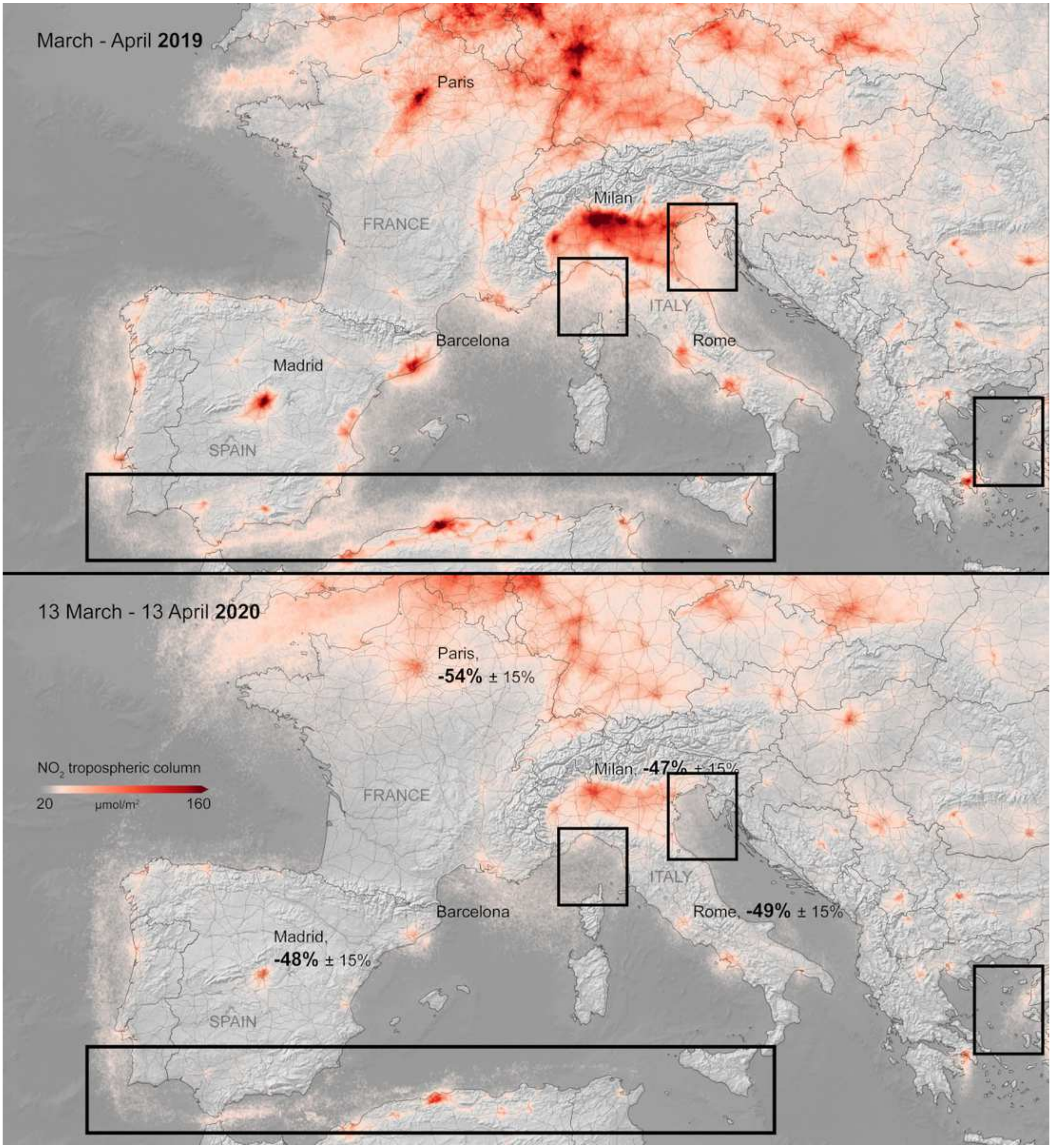
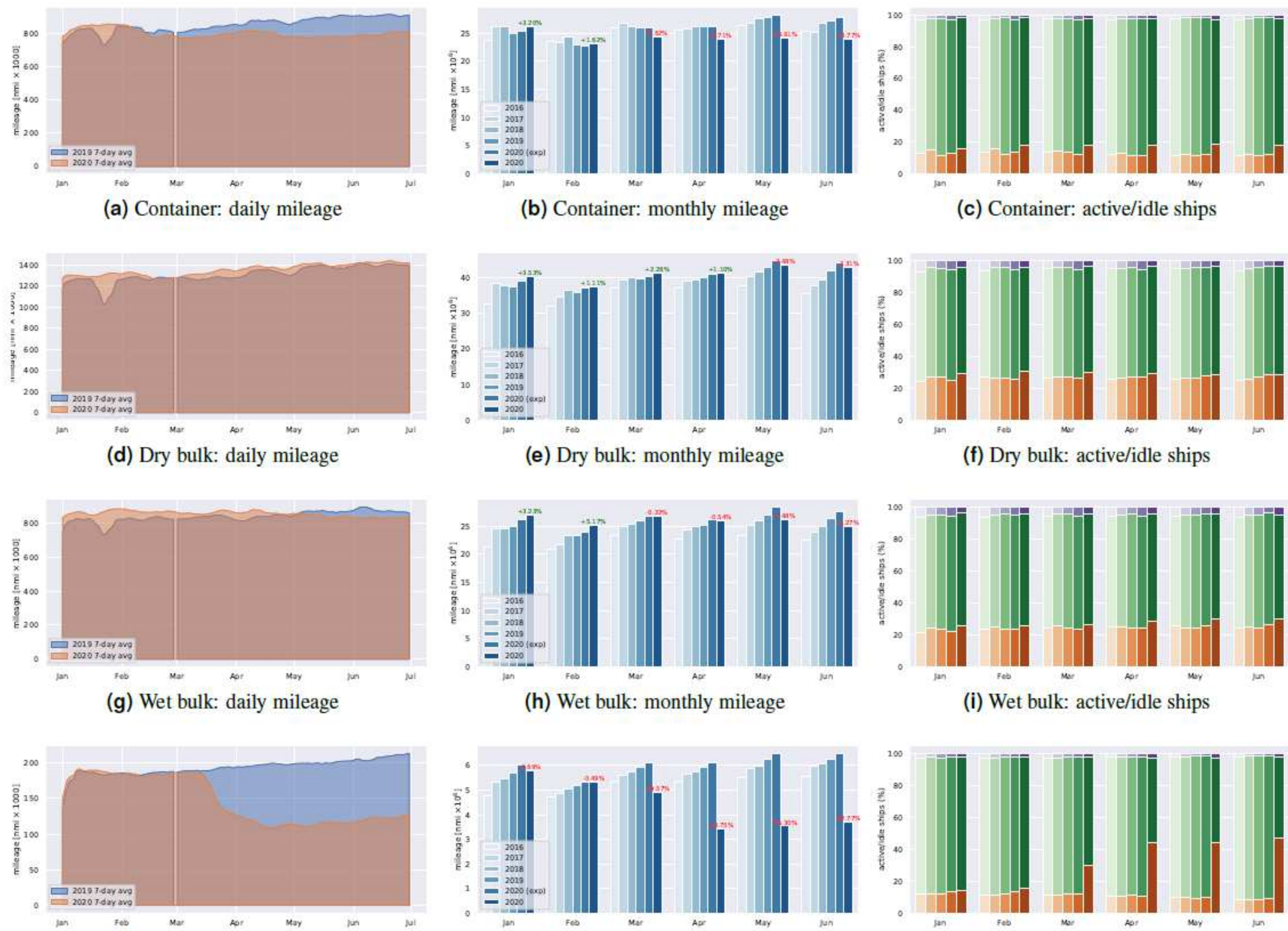


Figure 2

Average nitrogen dioxide (NO2) concentrations from 13 March to 13 April 2020, compared to the same period in 2019. The decrease of emission is evident, around -50% in large European cities (Rome, Paris, Madrid and Milan). Highlighted with boxes there are regions of sea where it is evident a decrease of nitrogen dioxide concentrations, probably due to the reduced shipping activity. WHO air quality guideline values quantify in 40 µgm-3 (annual mean) the NO2 limit level for human health. Reproduced with permission. Contains modified Copernicus Sentinel data (2019-20), processed by KNMI/ESA. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

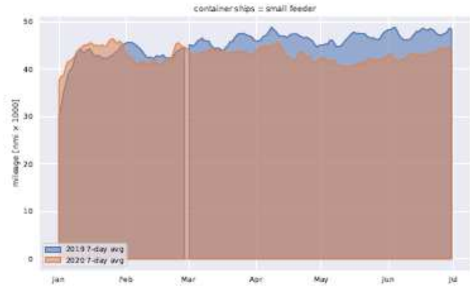
Representation of Shanghai’s ego network and its 3-step neighborhood: each port in the picture is reachable from Shanghai with at most three hops. An ego network consists of a focal node (the ego) and the nodes (the alters) that are connected to it, either directly or within a fixed number of steps. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



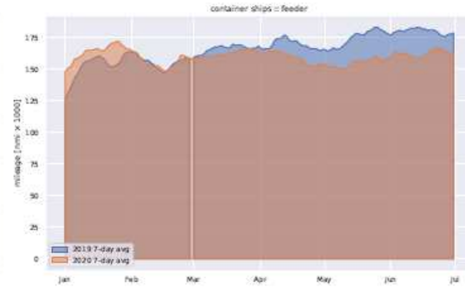
(a) Container: daily mileage
(b) Container: monthly mileage
(c) Container: active/idle ships
(d) Dry bulk: daily mileage
(e) Dry bulk: monthly mileage
(f) Dry bulk: active/idle ships
(g) Wet bulk: daily mileage
(h) Wet bulk: monthly mileage
(i) Wet bulk: active/idle ships
(j) Passenger: daily mileage
(k) Passenger: monthly mileage
(l) Passenger: active/idle ships

Figure 4

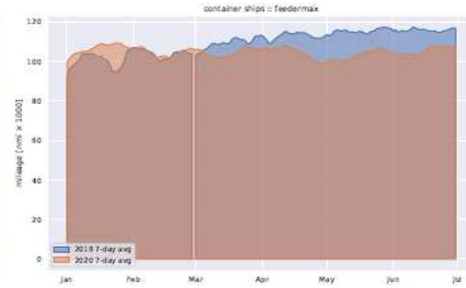
Comparison of traffic indicators for several ship categories: container (a)–(c), dry bulk (d)–(f), wet bulk (g)–(i), and passenger (j)–(l). The left column shows daily navigated miles in 2019 (in blue) compared with 2020 (in orange); the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019. The mid column shows monthly navigated since 2016 up to 2020; the second last bar in each group represents an estimation of navigated miles in 2020 given the growth rate observed in the previous years; the label on the 2020 bar quantifies the percentage increase or decrease w.r.t. the expected 2020 traffic volume. The last column shows the distribution of active (green) and idle (orange) ships over time, compared with past years, arranged by month with bars from left (2016) to right (2020); purple bars represent the (negligible) part of ships that could be labeled neither as active nor idle.



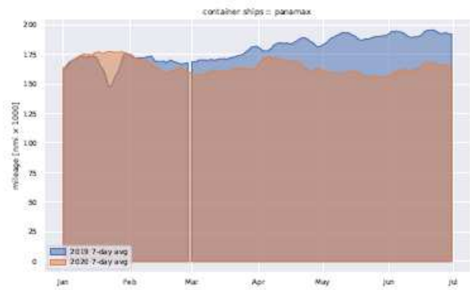
(a) Container ships: Small feeder



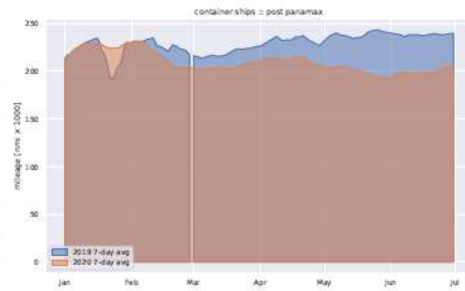
(b) Container ships: Feeder



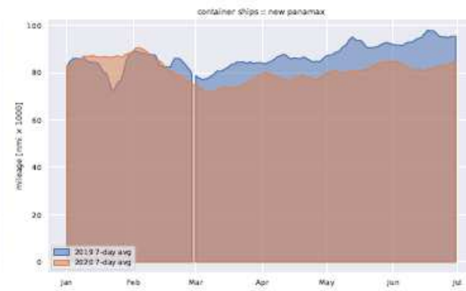
(c) Container ships: Feedermax



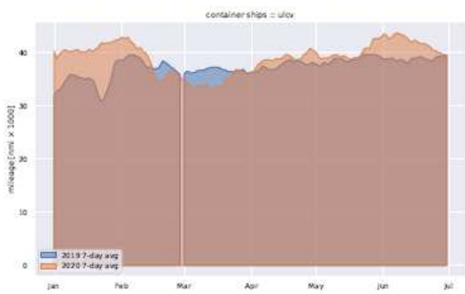
(d) Container ships: Panamax



(e) Container ships: Post-Panamax



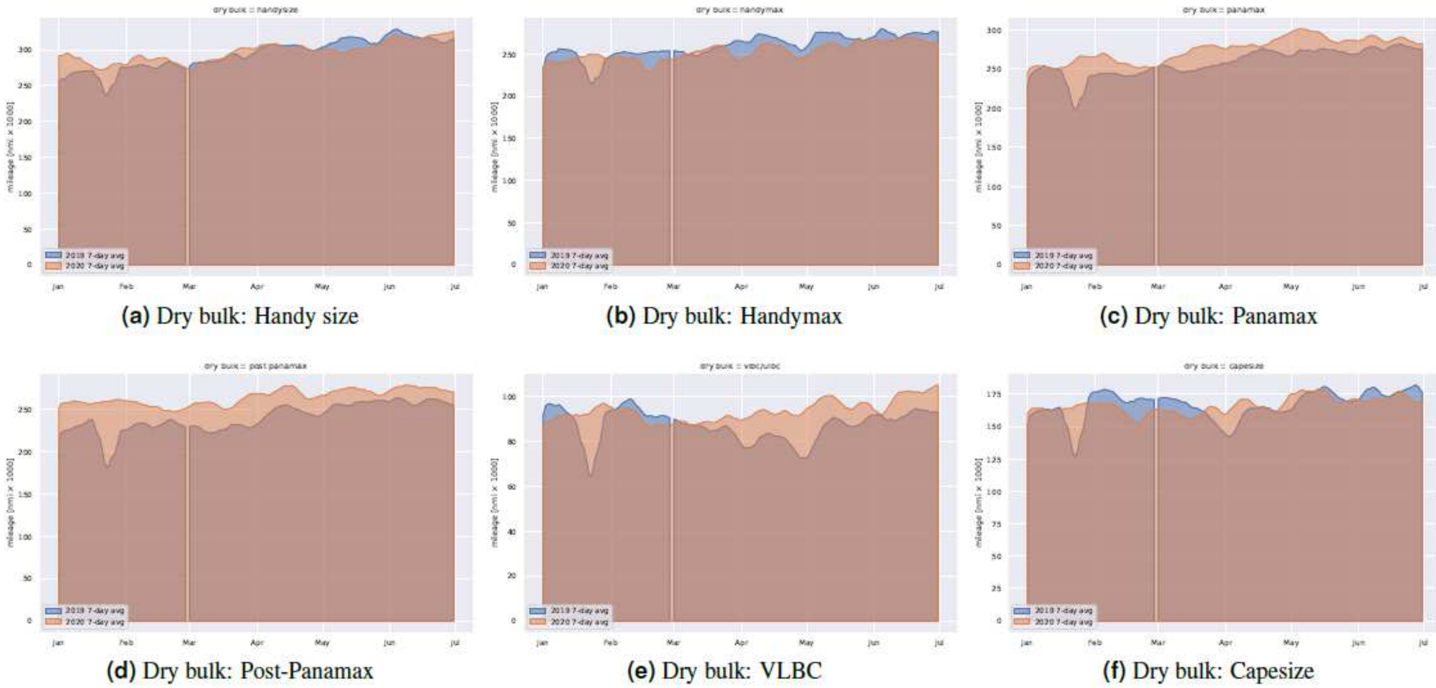
(f) Container ships: New Panamax



(g) Container ships: ULCV

Figure 5

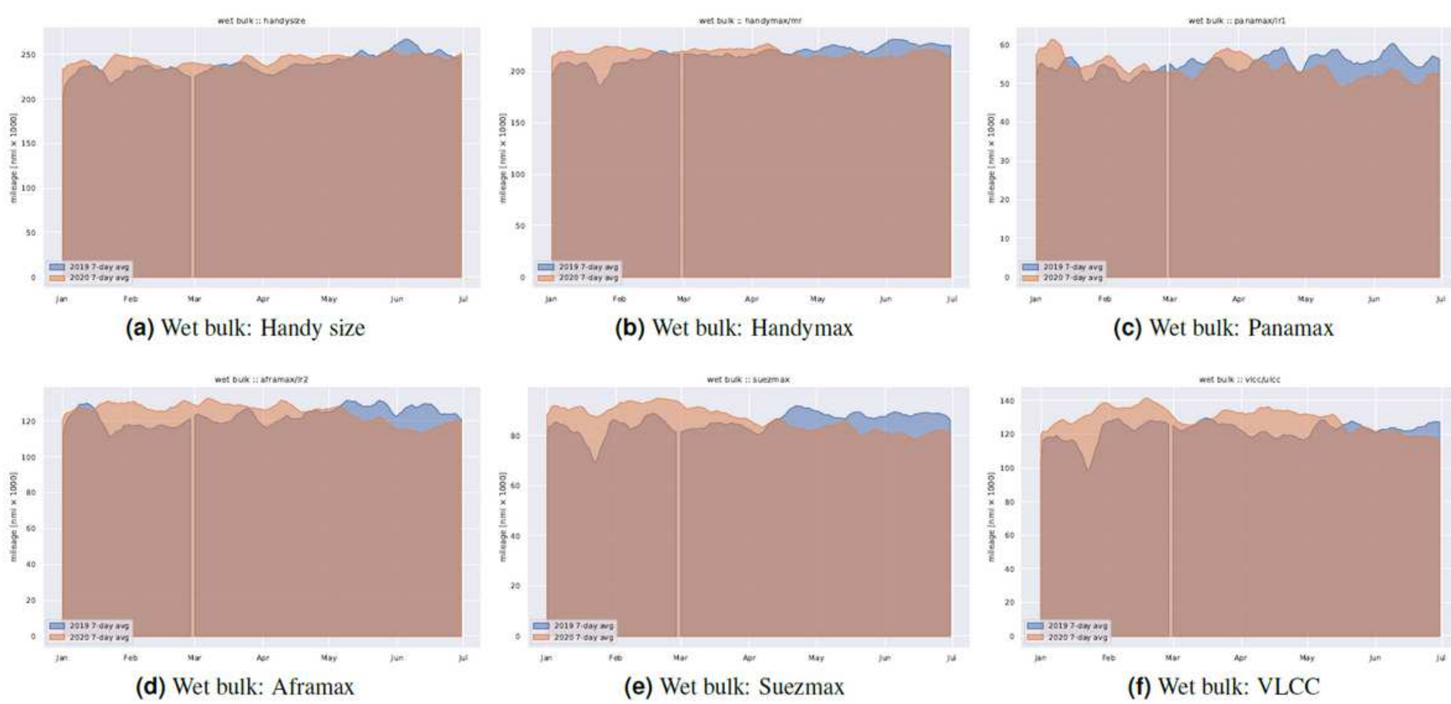
Comparison of daily miles navigated by container ships in the first six months of 2020 (orange) versus 2019 (blue) for different ship size categories, ordered by increasing capacity measured in Twenty-foot Equivalent Units (TEUs); the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019.



(a) Dry bulk: Handy size
(b) Dry bulk: Handymax
(c) Dry bulk: Panamax
(d) Dry bulk: Post-Panamax
(e) Dry bulk: VLBC
(f) Dry bulk: Capesize

Figure 6

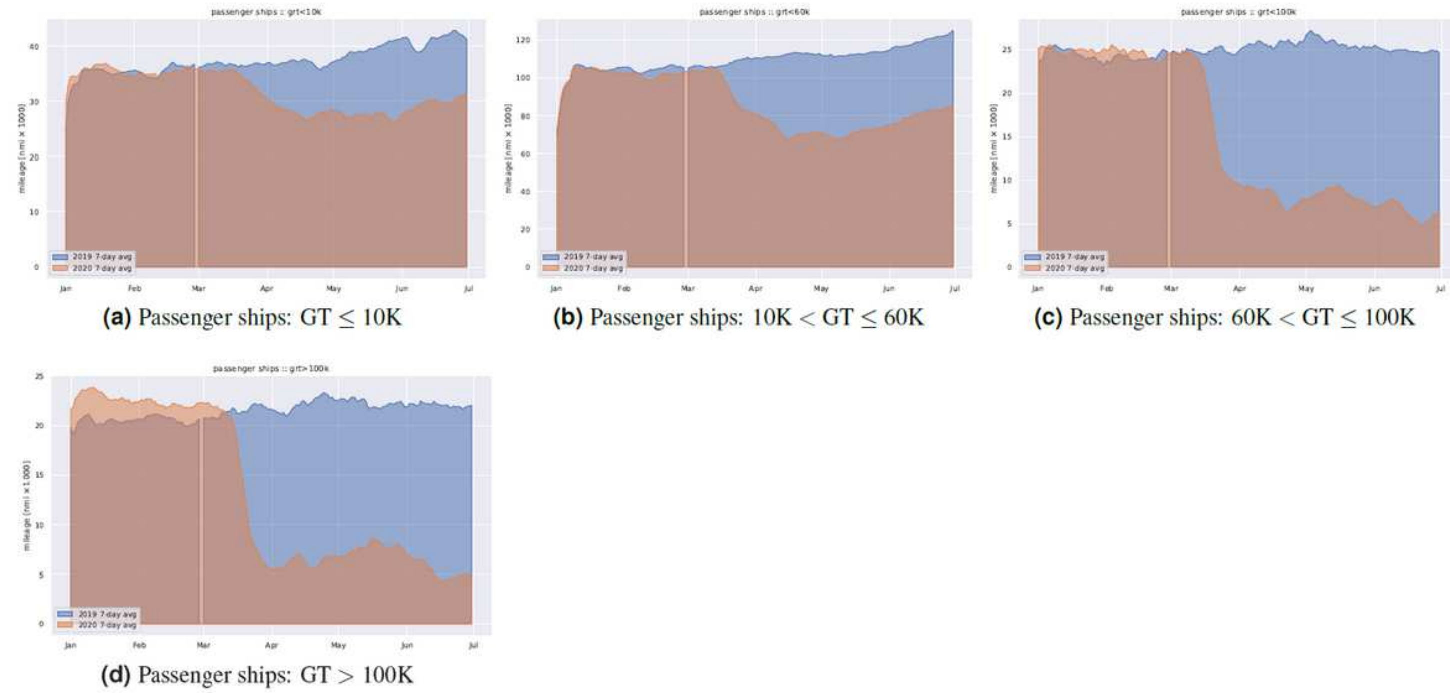
Comparison of daily miles navigated by dry bulk ships in the first six months of 2020 (orange) versus 2019 (blue) for different ship size categories, ordered by increasing deadweight tonnage (DWT); the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019.



(a) Wet bulk: Handy size
(b) Wet bulk: Handymax
(c) Wet bulk: Panamax
(d) Wet bulk: Aframax
(e) Wet bulk: Suezmax
(f) Wet bulk: VLCC

Figure 7

Comparison of daily miles navigated by wet bulk ships in the first six months of 2020 (orange) versus 2019 (blue) for different ship size categories, ordered by increasing DWT; the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019.



(a) Passenger ships: GT $\leq$ 10K

(b) Passenger ships: 10K $<$ GT $\leq$ 60K

(c) Passenger ships: 60K $<$ GT $\leq$ 100K

(d) Passenger ships: GT $>$ 100K

Figure 8

Comparison of daily miles navigated by passenger ships in the first six months of 2020 (orange) versus 2019 (blue) for different ship size categories, ordered by increasing gross tonnage (GT); the two area charts are overlaid in transparency to highlight trend differences; the discontinuity in the blue data series corresponds to the leap day absence in 2019.