RESEARCH

The Impact of Crises on Maritime Traffic: A Case Study of the COVID-19 Pandemic and the War in Ukraine

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Abstract

Maritime transport plays a key role in the global and local economy, accounting for 80% of global trade by volume. This makes smooth operation of the maritime transport essential. However, the sector faces the constant risk of various crises and their potential consequences that may significantly impact and disrupt the movement of goods on local, regional, and global levels. In recent years, two notable crises, namely the COVID-19 pandemic and the war in Ukraine, have been observed. This paper aims to analyse how international crises, such as armed conflicts and pandemics, influence maritime traffic and assess their impact on both global and local economies. A comparison is drawn between the periods before and during the COVID-19 pandemic and before and during the war in Ukraine to exemplify the effects of crises. The findings are then extrapolated to apply to potential future crises. Vessel movements are studied using data collected from Automatic Identification Systems (AIS). In our quantitative approach, we analyse big data using dedicated tools and visualisation techniques to gain insights into specific phenomena. The paper identifies economically significant regions for maritime traffic and examines the impact of crises on their performance. Its unique value lies in its flow-based analysis of changes in maritime traffic. The main conclusion is that China's importance for worldwide maritime traffic is increasing. This makes the global economy heavily reliant on China to a substantially greater extent than it is, for example, on Russia. Consequently, any crisis in the China region could exert a dramatic impact on the global economy. The paper also discusses observations of changes in maritime traffic following the outbreak of the war in Ukraine.

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1 Introduction

An estimated 80% of global trade by volume and 70% of such trade by value is transported by sea. Today's maritime transport plays a key role in both the global (UNCTAD 2022) and local economies. The efficiency of the maritime sector is a factor in enhancing the competitive advantage and political standing of certain countries. This is because the performance of such countries is linked to international cooperation, their ability to attract foreign investment, their membership and status in international organisations and other key factors (Agbaba 2020). Therefore, ensuring the efficiency of maritime operations and the uninterrupted flow of goods is paramount in today's world. Against this background, it is vital to recognise that maritime transport is vulnerable to various crises and their aftermath, which have the potential to disrupt the smooth movement of goods on the local, regional, and global scales.

A crisis is a sudden and rapid anomaly that may be exacerbated by other interconnected crises and their consequences. Crises may not be restricted to a single area within a common border (Mikušová and Horváthová 2019). In other words, a crisis can manifest as a disaster, business interruption, catastrophe, or emergency. Its causes may range from organisational failures and disfunctions, crisis mismanagement to external threats such as natural disasters, wars, and epidemics that undermine an organisation. Some crises involve only one of these causes, while others are due to two or more of them (Kovoor-Misra 2019). Irrespective of its origin, a crisis necessitates a swift and timely response to mitigate damage and impact, particularly adverse effects, economic fallout and disruptions to business, trade and supply chains, as well as to protect lives and assets (Xue et al. 2022). Therefore, crisis management is of utmost importance for most organisations worldwide, including those in the maritime sector. The three primary phases of crisis management are pre-crisis (prevention and preparation), crisis response, and post-crisis (learning and revision) (Coombs 2020).

With regard to crisis management in the maritime domain, security assurance is a critical factor in facilitating international business and trade (Barnes and Oloruntoba 2005). Therefore, various security measures and practices have been adopted over the years to ensure the smooth operation of maritime transport. A major role here is played by the International Maritime Organisation (IMO) and International Maritime Bureau (IMB), which establish standards and publish reports on safety and security issues within the world trading system, such as the Safety of Life at Sea (SOLAS) (International Maritime Organisation 1974), or the International Ship and Port Facility Security (ISPS) Code (International Maritime Organisation 2003). The importance of adhering to rules in practice and integrating operational processes and security regimes in ports and port infrastructure, and between ports and maritime trading routes, has been emphasised for years, e.g., (Barnes and Oloruntoba 2005). Such integration requires the incorporation of security and safety practices into the risk and crisis management systems of maritime and port-related organisations.

Despite the deployment of measures designed to ensure the seamless operation of maritime transport, the sector continues to be vulnerable to various crises

and their consequences. As emphasised by the authors of the Review of Maritime Transport 2022 (UNCTAD 2022), such vulnerabilities are tied to the complexity of the environment in which maritime transport operates. Over the past four years, the related risks have been laid bare by such events as: 1) the COVID-19 pandemic, which caused a 3.8% decline in maritime trade in 2020; 2) the war in Ukraine, Ukraine being one of the largest global exporters of food; and 3) extreme weather events such as hurricanes, floods, and heatwaves affecting Australia, Brazil, Pakistan, East Africa, and the USA. All of these factors have heavily influenced maritime transport due to their global reach and/or the involvement of multinationals. According to (Coombs and Laufer 2018), the number of such crises will only increase in the future as organisations build longer supply chains and expand into new, foreign markets.

This paper delves into the possible impacts of crises on maritime transport. The analysis is based on a case study of the COVID-19 pandemic and another of the war in Ukraine in 2022. Its focus is limited to international crises (that emerge in more than one country and that impact multinationals) and crises caused by external threats (two of which are selected). Moreover, the study centres on the second phase of the crisis management process, which is an analysis of crisis response on the part of maritime transport networks and the effects of such crises on international maritime trade.

In order to identify changes in maritime traffic caused by the two afore-mentioned crises, vessel movements are studied. To this end, maritime traffic before and after the occurrence of an event that leads to a crisis is compared. In the case of the COVID-19 pandemic, comparisons are made of traffic before (2018–2019) and after (2020–2021) the outbreak of the COVID pandemic. Similarly, for the Ukraine war, comparisons are performed of vessel movements on the Black Sea in 2021 and in spring and summer of 2022. In doing so, we seek to establish the extent to which these two crises impacted sea traffic between major maritime ports and maritime traffic hot spots depending on vessel type, and identify any changes therein. The findings are then generalised and discussed in view of other potential crises.

The remainder of the paper features a section on crisis management in maritime industry followed by an outline of the two case studies. A short review of literature on maritime traffic analysis is provided. Section 3 discusses the methodology and characterises the Automatic Identification System (AIS), which forms a basis of our analyses. Section 4 summarises our findings from the two case studies. The paper ends with a discussion of the results, a summary, and a preview of future work.

2 Related Work

2.1 Crisis Phase Management in Maritime Transport

Certain factors known to occur in the maritime industry may pose security risks and, as a consequence, precipitate crises. These include the lack of transparency in ship registration and ownership, tolerance of 'flag-of-convenience' mechanisms and open registries, the use of cargo vessels to smuggle people and weapons, modern

and sophisticated piracy, and armed robberies. These security threats, as well as other sources of active threats, result in high levels of uncertainty to businesses and the world economy at large. Maritime transport is also vulnerable to external factors arising in the realms of international trade, politics, finance, technology, and legislation (Agbaba 2020). Given that demand for maritime transport stems primarily from the needs of the industry, many crises in the shipping sector are driven by industrial cycles and the performance of the global economy.

The three key characteristics of a crisis are the existence of a threat, the surprise factor, and short decision time. Every crisis leads to change as previously existing systems can no longer be retained. Many crises are difficult to predict and may never repeat again. As a result, a solution developed during one crisis may not be directly applicable to another. As a consequence, crisis management requires dealing with a disruptive unexpected event that threatens to harm an organisation, its stakeholders, or the general public (Mikušová and Horváthová 2019). However, as demonstrated in the literature (Coombs 2020), many organisations lack the crisis management capabilities that are needed to tackle industrial disasters and business and organisational deficiencies.

The literature takes two views of crises and crisis management (Bundy et al. 2017). These are internal (focused on crisis management within organisations) and external (focused on interactions across organisations and with external stakeholders). In the latter perspective, crisis management involves coordination with stakeholders to prevent, solve, and grow from a crisis. As mentioned earlier, the crisis phase represents a response to a crisis, including that by multinationals and their stakeholders.

In their crisis management, organisations may adopt a number of response strategies ranging from defensive to accommodating (Bundy et al. 2017). A defensive strategy is to assume less responsibility and attempt to reduce an organisation's perceived association with a crisis (by way of denial, defiance, or scapegoating). The accommodative strategy is to accept more responsibility and acknowledge an organisation's causal role in a crisis (by promising to take corrective measures or offering apologies). According to (Mikušová and Horváthová 2019), an organisation can refuse to respond to a crisis (hoping to avoid its impact and to continue its business as usual) or may respond either positively (aiming to maintain the organisation in its original condition or even achieve improvement) or by terminating its business.

Crisis management is also needed in the maritime industry. Since international trade is heavily reliant on safe and open waterways, any disruption to maritime supply chains will have significant implications for economic activities and world trade, such as increased inventories, lead and travel times, and transport costs (Barnes and Oloruntoba 2005). With this regard, ports play a critical role since their operations significantly influence economic performance at the national and international level. This is particularly true for the so-called 'hub ports', which have become essential for the functioning of the global supply network.

The literature provides numerous examples of crises in the shipping industry. These include the global economic crisis that began in 2007 and the piracy attacks that for many years have been a major issue in some regions of the world (such as East Africa or South China Sea). According to the International Maritime Organisation, 4785 incidents of piracy and robbery took place worldwide between 2005

and 2020, 22% of which occurred in East Africa and 26% on the South China Sea (Stróżyna et al. 2022). Maritime piracy comes in many shapes and forms including hijacking, arms smuggling, 'bunkering', illegal wiretapping, and the theft and sale of crude oil in large quantities (Agbaba 2020).

Another critical maritime-transport-related factor is the sector's potential to destabilise energy markets by transporting liquefied natural gas (LNG) and oil (Fei et al. 2020). When the Ukraine-Russia crisis emerged in 2014, Europe engaged in talks with the United States on diversifying LNG and oil imports from Russia (Goldthau and Boersma 2014). In 2014, the Visegrad Group asked the US to help fast-track LNG maritime exports from its country. The Group justified its request by stating that this would enhance European gas supply security and lower gas prices in Visegrad countries (Lopatka 2014). Unfortunately, they failed to build stable and diversified LNG and oil supply in Europe before the Russian invasion of Ukraine in 2022 (Santora 2022). Thus, oil and energy prices peaked to their highest level since 2008 (Jones 2022).

2.1.1 The COVID-19 Pandemic

Another crisis in which maritime transport significantly affected the global economy was the COVID-19 pandemic. According to recent research (Kumar and Jolly 2021; Yazır et al. 2020; Zhu et al. 2020), the pandemic has led to significant changes in global supply and demand and global trade. Recent statistics from the World Trade Organisation show that the year 2020 saw the volume of world exports decrease by 5%, and world imports drop by 5.6% on 2019 (World Trade Organisation 2021).

The maritime sector was affected by the pandemic in many ways. The problems faced by this sector encompassed reduced demand for freight and passenger transport, port shutdowns, prolonged waiting times for port-related services (such as berthing, transhipment) due to security checks, and rising rates of freight and charter in container shipping. Additionally, a fall in both crude oil demand and price resulted in a decline in crude oil shipments coinciding with a significant increase in floating oil storage in oil tankers. These led to a growing number of vessel defaults and maritime bankruptcies, as well as problems finding vessel crew replacements (Kumar and Jolly 2021; Notteboom and Pallis 2020; Oyenuga 2021; Yazır et al. 2020).

The IAHP survey (Notteboom and Pallis 2020) found that between April and September 2020, approximately 43% of the surveyed ports experienced a decrease in the number of port calls made by container vessels. Such calls were also down for passenger vessels (by 73%) and other cargo vessels (down by 41%) compared to usual levels.

Port occupancy with respect to cargo throughput, passenger numbers, and other port operations is considered an important barometer of the world economy (Zhu et al. 2020). Thus, analysis of changes in maritime traffic across time and space can prove to be a reliable indicator of changes in international trade.

The impact of the COVID-19 pandemic on the maritime industry, and specifically on maritime traffic, has already been investigated with specific conclusions. Some recent publications tackle this issue by generally observing trends and behaviours before and during the pandemic. (Oyenuga 2021) looked at how

the coronavirus impacted the maritime transport sector globally and specifically in Africa. They present short-term impacts (such as a drop in the volume of trade transported by maritime shipping, disruptions caused by de-routed shipments, maritime bankruptcies) and estimates long-term impacts by analysing how the pandemic may affect five trends observed in the industry over the last few years. The indication of COVID-19 factors that have led to a decline and disruption of the maritime industry was also provided by (Kumar and Jolly 2021). (Yazır et al. 2020), in their turn, offer a literature review focused on the effects of COVID-19 on the maritime industry and discuss new challenges to its operation and management. Their analysis reviews four shipping industries, i.e. the dry bulk, tanker, container, and cruiser sector. (Notteboom et al. 2021) investigate the temporal and spatial consequences for container ports and the container shipping industry and discusses the contribution of COVID-19 to supply chain disruptions. (Stannard 2020), in turn, studies how the pandemic influenced the work of crews on board ships. (van Tatenhove 2021) discusses longer-term consequences of the pandemic and proposes four potential maritime scenarios that give insights into the enabling and constraining factors for dealing with the aftermath of COVID-19.

Other related publications take a quantitative approach to examine the impact of COVID-19. (Narasimha et al. 2021; Xu et al. 2021) focus on the effects on port performance. (Xu et al. 2021) analyse the impact on major ports in China, while (Narasimha et al. 2021) offer an analogous study for India. The majority of data-driven analyses rely on AIS data. Other studies take either a global (Verschuur et al. 2021a, 2021b) or a regional perspective (Depellegrin et al. 2020; Shi and Weng 2021; Zhu et al. 2020) while a number of them combine the global, regional, and point approaches (March et al. 2021; Millefiori et al. 2020). The application of AIS data to estimating the volume of imports and exports in the first six months of the pandemic is performed by (Verschuur et al. 2021b). In their research, the authors calculate the weighted index of imports and exports by sea for selected countries, and explore shock propagation, differences in exports between countries that have adopted similarly stringent lockdown strategies, and exports recovery dynamics following the easing of lockdowns. They compare the result obtained with an adaptive economic input–output model to estimate the direct and indirect harm to the economy inflicted by large-scale natural disasters proposed by (Guan et al. 2020). In their second research (Verschuur et al. 2021a) estimate the global losses experienced in maritime trade during the first eight months of the pandemic. The estimate focuses on individual ports (changes in the number of port calls and daily imports and exports) and entire sectors (for specific vessel types). It identifies ports with the largest absolute trade losses. (Millefiori et al. 2020) use AIS data to calculate maritime mobility indexes: cumulative navigable miles of all ships, the number of active and average idle ships, and average fleet speed. They compare mobility between 2020 and 2019 for different ship types and analyse changes in shipping route patterns based on vessel density maps. The analysis is conducted both on a global scale and in selected hot spots in the Mediterranean Sea and the Suez Canal. A similar analysis comparing AIS data in the first half of 2020 with the corresponding period of 2019 is performed by (March et al. 2021). They also analyse global changes in maritime traffic by using ship density maps to calculate the number of

monthly vessel transits per square kilometre for different ship types, and by counting the absolute difference in traffic density in comparison to the reference year 2019. Regional and local changes in vessel traffic density are also provided for selected areas. A change in the daily number of vessels underway within the coastal zone in the western Mediterranean in comparison with the Stringency Index (an indicator of confinement measures adopted in EU countries) is also presented and discussed.

Finally, a number of articles offer AIS-based research on the effects of COVID-19 in selected regions. (Depellegrin et al. 2020) focused on the Veneto region in Italy. They analyse vessel trajectories for four vessel types in March and April of 2020 and compare them to data from 2017. They use AIS data to calculate five measures related to vessel movements: location, timestamp, travel distance, vessel performance in the area (in hours), and the rate of speed change (in knots). As a result, they arrive at the value of vessel trajectory intensity and analyse its changes in the successive lockdown stages between March and April 2020 for the region in question. Even more focused analyses have been conducted by (Zhu et al. 2020) and (Shi and Weng 2021), who study the impact of the pandemic on ship activities in China's ports using AIS. The former calculates the number of berthing ships per month and berthing time between January and April 2020 for the port of Shanghai, Ningbo-Zhoushan, and Tianjin. The latter evaluates the impacts of the pandemic on merchant ship activities and corresponding atmospheric pollutant emissions in the port of Shanghai in February 2020.

As presented in this section, AIS-data-based research has been attempted on changes in maritime traffic due to the COVID-19 pandemic. However, the main drawback of all studies is the relatively short period of analysis. Almost all of them were performed in the first months of the pandemic (January – June 2020). Only the analysis of (March et al. 2021) partially relies on data through November 2020. Moreover, the reference period used to compare the effects of COVID-19 to the pre-COVID-19 status is relatively short and only covers the corresponding months of 2019. In our research, we significantly extend both the COVID-19 period (into mid-2021) and the reference period (by reaching as far back as 2018). We believe that this will allow us to observe and identify revealing patterns not only in the most severe early months of the pandemic, but also in the later months of 2020 and 2021 when case spikes and additional confinement measures were observed. Moreover, we propose to analyse traffic routes in hot spots instead of merely examining traffic density. To compare our results with those presented in previous studies, we also rely on AIS data for our research.

2.1.2 War in Ukraine in 2022

Another crisis we plan to analyse for influence on maritime traffic is the war in Ukraine started by Russia on 24 February 2022. Shortly after the Russian invasion of Ukraine and the imposition of sanctions on Russia by Western states, various changes in vessel movements were observed.

Firstly, the sanctions prevented merchant ships belonging to Russia and those flying the Russian flag from entering US, EU and UK ports (with some exceptions,

such as vessels carrying energy, pharmaceutical, or agricultural products) (European Commision 2022).

Secondly, the Russian invasion resulted in a blockade of Ukrainian ports on the Black Sea and Sea of Azov. Given that Ukraine is one of the world's top agricultural exporters (particularly of sunflower oil, corn and wheat) and that the majority of its exports is moved by sea, there was a high risk that the blockade would put global food supply at risk sparking a global food crisis (France 24, 2022). For comparison, in 2019 Russia's Black Sea ports handled more than a half of the region's cargo traffic with Ukraine controlling almost a quarter of the total cargo volume (Statista Research Department 2021). As of 2021, the Russian seaport of Novorossiysk in the Azov-Black Sea basin was Russia's largest port in terms of cargo throughput.

Thirdly, the European sanctions reduced Russian oil exports to Europe. This prompted Russia to ship its oil to new markets. India and China, both of which were previously irregular buyers of Ural crude, took advantage of cheaper oil from Russia. According to Refinitiv (Aizhu and Tan 2022), in April 2022, 5 million barrels of Ural oil, which makes it the highest volume since June 2020, were destined for China, while ca. 19 million barrels headed to India, up from none in January 2022. The volume of Russian oil supplied to Asia by tankers is estimated to have increased by 50% since the beginning of 2022.

However, sanctions forced European refineries to ramp up their imports from West Africa, mainly from Nigeria, Angola, and Cameroon, bringing its current average to 17% above the 2018–2021 levels. Meanwhile, deliveries from West Africa to India almost halved (Verma 2022).

Unconventional methods of shipping Russian oil from the Baltic and the Black Sea ports to Asia (particularly China and India) have been observed. Firstly, this involved changes of vessel type from large crude carriers (VLCC) to smaller, costlier vessels. This manner of transport used to be rare due to small ships being ill-suited for long voyages and far more expensive per barrel. Moreover, a significant proportion of trade with Asia relies on ship-to-ship transhipment at sea (a larger number of such transhipments are observed in the Mediterranean). This expensive procedure entails a significant risk of leakages.

Finally, according to Rod Schoonover, the former head of the Environment and Natural Resources Section of the US National Intelligence Council (Fant 2022), the invasion of Ukraine may have additionally been motivated by its mineral deposits and agriculture production. The deposits include lithium, which is crucial for the production of batteries for electric vehicles and, as such, plays a major role in the green energy transition. According to geologists, eastern Ukraine holds significant deposits of lithium. Ukraine is also home to 10% of the world's iron reserves, 6% of titanium, and 20% of graphite.

The above demonstrates the sheer breadth of the consequences the Ukraine crisis has had. Our further analysis delves into a single aspect of such consequences, namely shifts in maritime traffic patterns seen on the Black and Azov Seas. Section 4 compares ship movements in the region before and after the outbreak of the war and offers some conclusions.

2.2 Analysis of Maritime Traffic

The literature offers numerous methods and algorithms for identifying maritime traffic patterns, which are then used to chart optimal shipping routes or analyse and visualise ship travels between ports and regions (Ducruet 2020; Wang et al. 2019). Early studies of vessel distribution around the globe employed methods derived from cartography (Ducruet 2020). However, such methods fail to take advantage of network analysis. Later approaches assessed vessel movement density on a square grid superimposed on a world map. The most common approach has been to measure and visualise ship traffic densities using a grayscale based on either radar or satellite data (Ducruet 2020). Other approaches focus on creating a density map rendering the sea routes most commonly travelled by vessels. To generate a density map, a combination of a big dataset of historical locations and an actual digital map is used. This can be accomplished in a variety of ways. Models that use historical AIS data to extract and render maritime traffic patterns have been gaining popularity for years (Azariadis 2017; Silveira et al. 2013; Troupiotis-Kapeliaris et al. 2022; Xiao et al. 2015; Yan et al. 2016). As per classifications by (Riveiro et al. 2018; Yan et al. 2020), the existing research can be divided into grid-based, vector-based, graph-based, and statistical-based approaches.

Grid-based approaches apply to a grid in the sea area in question. To represent traffic patterns, typical vessel behaviour is modelled in each cell by considering such parameters as speed, course, and position (Ristic 2014; Xiao et al. 2017). Given that a grid is superimposed on the sea area in question, the grid-based approach is poorly suited for a wide range of waters (Liu et al. 2023). In contrast, the vector-based method seeks to extrapolate ship trajectories from associated AIS datapoints and identify significant points along these trajectories at which ships manoeuvre, stop or enter a given sea area (Riveiro et al. 2018). Such points are then used to construct a maritime traffic network and mine maritime traffic patterns in regions larger than those used in the grid-based methods (Yan et al. 2020). Graph-based methods, in turn, focus on identifying waypoints and edges between waypoints to produce a shipping network (Liu et al. 2023). The waypoints refer to nodes that could represent ports, anchorage areas, capes, or any areas in which vessels perform their manoeuvres (Filipiak et al. 2020). Finally, statistics-based methods are used primarily for analysing ship traffic flow. They focus on statistical modelling of ship traffic flow characteristics to mine maritime traffic patterns (Yan et al. 2020). They assume statistical modelling of the original data, or model pre-training based on machine learning methods. A commonly-used statistic-based method is clustering.

As indicated by (Yan et al. 2020), irrespective of the approach type, the existing methods for extracting and analysing maritime traffic flows come with a range of drawbacks having to do chiefly with adaptability to large sea areas, their complexity, and compliance with actual maritime routes. All this creates demand for a simple, effective, and accurate method of extracting regional or even global maritime traffic routes.

3 Methodology

In keeping with the latest research trends in modelling and analysing maritime traffic flows on the basis of historical data on actual vessel movements, as discussed in the previous section, our study relies on historical sets of AIS data. Automatic Identification Systems (AIS) currently support real-time vessel tracking on a global scale. While AIS has been designed for collision avoidance on water, AIS data can currently be collected by satellite and applied to new analytical scenarios. The International Maritime Organisation requires that AIS be used by international voyaging ships with 300 or more GT and all passenger ships regardless of size. In AIS, a vessel needs to broadcast, in specified time intervals, information about its current location, speed, and course, as well as its unique identification, type of cargo, destination port, and estimated time of arrival, and more. The frequency of such reports depends on vessel speed. The faster a ship moves, the more frequently it is required to transmit AIS messages. Such time intervals range between a few seconds for dynamic data to a few minutes for static data.
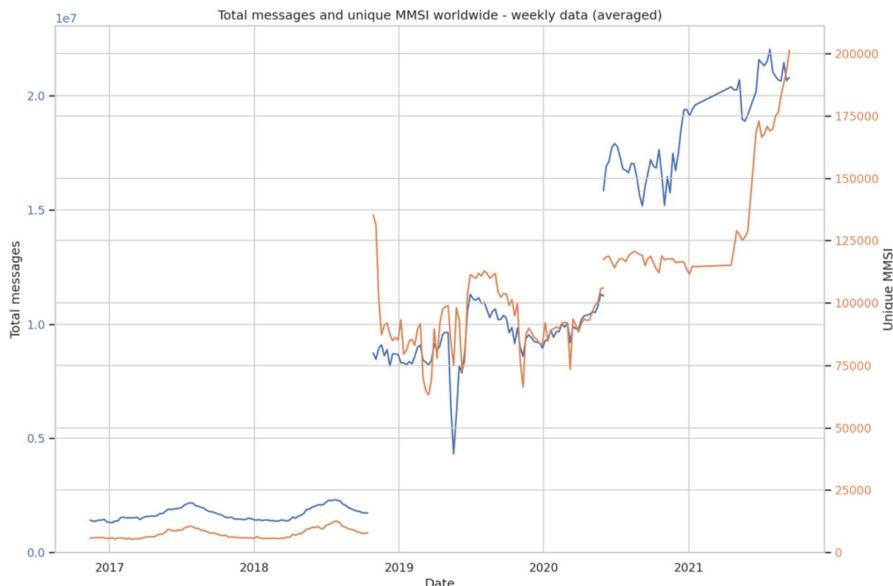
AIS allows one not only to monitor current sea traffic and the movements of every AIS-equipped ship but also to perform a host of analyses based on the data collected. Such analyses can be carried out on either current or historical data. The former may concern the assessment of current traffic density, while the latter allows one to identify traffic patterns over the long term, among others.

Due to its global coverage and the fact that an estimated 200,000 plus ships are equipped with it today, AIS seems to be the best source of data for measuring actual historic ship movements. Moreover, thanks to a relatively broad set of data available from AIS, the system supports analyses of traffic changes over time, e.g. those due to a crisis (war or pandemic) and breaking down traffic data by ship type.

Before one conducts such analyses, it is advisable to consider AIS data processing challenges. Due to the high frequency of AIS data transmissions and the system's popularity with ships, a huge volume of data (millions of AIS messages) is available daily. Thus, a longer time-frame analysis will require the use of big data technologies to accelerate computation and ensure processing efficiency. In our research, the big data approach relies on Apache Spark technology for its analytics and on an efficient data format for long-term AIS data storage.

Our study analyses worldwide AIS data collected over 4.5 years (from mid-2018 to mid-2022). The data was collected from a variety of sources, primarily commercial organisations and public authorities.[1] Even within a single source, improvements were adopted that modified the volume of data we collected. Figure 1 shows the number of AIS messages sent daily (averaged weekly) along with the number of unique vessels as identified by MMSI number. Note that no data is provided for the period from February to March 2021, as shown in the figures presented in the following sections. As can be seen in Fig. 1, we began data collection in 2016 at the rate of 1.2 GB per week (solely from

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[1] The authors gained access to the data through their involvement in various R&D projects with industrial partners. Such data was not available to the general public.
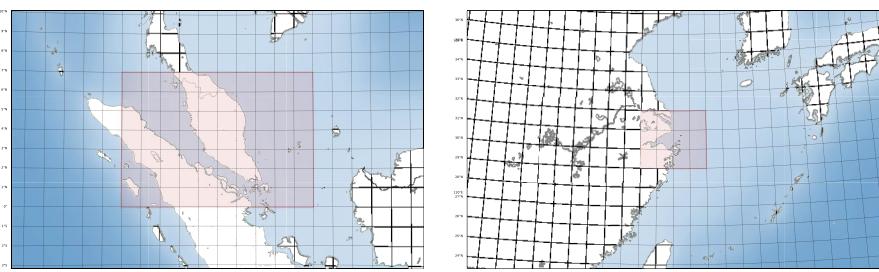
Fig. 1 Number of AIS messages and unique vessels weekly from 2017 to 2021. Source: Own work

terrestrial AIS systems) and reached 7 GB per week in 2019 (with datasets that additionally included satellite-gathered AIS data). By 2020, the volume went up to roughly 2.5 GB daily. The total amount of data processed for the purposes of this article amounted to 1.2 TB (after compression).

Maintaining the required quality of analysis with accelerated data streams and increased data coverage proved to pose an additional challenge. We first needed to ensure that the data would be comparable. To that end, considerable effort went into correlating various sources to obtain consistent statistics. Moreover, as satellite transmissions are more error-prone, we saw higher fluctuations in the number of messages received (as in the case of the drop in the AIS message count in March 2019). Finally, in April 2021, the number of vessels using AIS grew significantly from around 120,000 to over 200,000, on the heels of new laws having been enacted by China (for details, see Sect. 4).

Big data tools cannot be effective unless proper measures are taken to reduce the data burden. In order to gain an understanding of maritime transport, data don't need to be analysed globally. Therefore, for the purposes of our study, we applied a statistical (qualitative) approach focused exclusively on ports and straits, the so-called choke-points, where the majority of international transport takes place. In the case of the COVID-19 analysis, we selected the world's biggest ports, most of which are in China (Shanghai and Shenzen specifically). Only one European port, Rotterdam, made the list of the biggest ports. We additionally included Antwerp, Hamburg, and Piraeus (dubbed China's gateway to Europe). Furthermore, we analysed data on important transit areas such as the Strait of Hormuz, the Strait of Malacca (also encompassing the port of Singapore), the Suez Canal, and the Cape of Good Hope.

Fig. 2 Boundary boxes for the Strait of Malacca (left) and Shanghai also covering Ningbo (right). Source: own work

A total of 10 regions have been selected. Figure 2 presents two of them. For the Ukraine-Russia war, our analysis focused on the Black and Azov Seas.

The boundaries of the areas were defined as follows: Asian ports—Shanghai 32°N 120°E and 29°N 124°E, Shenzen 22.6°N 113.8°E and 22.4°N 114°E; European ports—Rotterdam 52°N 3.5°E and 51.2°N 4.5°E, Antwerp 51.6°N 3.3°E and 51.2°N 4.5°E, Hamburg 54.1°N 8.6°E and 53.5°N 10.2°E, Piraeus 38°N 23.5°E and 37.8°N 23.7°E; straits—Hormuz 27.5°N 54°E and 24°N 58.5°E, Malacca 7°N 97°E and 0°N 107°E, Suez 30°N 32°E and 28°N 34°E; Cape of Good Hope 33.4°S 17.1°E and 41.5°S 27°E; Black and Azov Sea 39.5°N 24.5°E and 48.5°N 42.5°E.

All calculations were conducted on a 32 core 256 GB RAM memory server. The data was stored on a 62 TB matrix linked with the server via a 10Gbit network. Analytics scripts were written in Python in the JupyterLab environment. The calculations were handled by the Apache Spark in-memory cluster computing framework.

4 Results

4.1 The COVID-19 Crisis

4.1.1 Vessels Movements Based on Declared Destinations

Using the approach discussed in the Methodology section, we have conducted analyses in several regions. To identify the impact of the COVID-19 pandemic on maritime traffic and to spot volume and destinations changes (e.g., changes in exports and imports from/to a given region and entries into new markets), we analysed vessel flows between the selected regions and calculated monthly rates, i.e., the average monthly number of vessel transits between such regions before (since mid-2018) and during the pandemic (2020–2021).

One of the fields that a ship captain is required to fill in an AIS message is destination. This field should provide a natural place to learn where the ship is heading. By simple aggregation, it should then be possible to identify potential changes over time. Unfortunately, the data accessible to us was not suited for such analysis. In the dataset covering the period through May 2020, the destination field was left blank in

Table 1 Most popular destinations (not normalised) stated in Shanghai region AIS messages prior to June 2020

Code in AIS message	Number of messages	Explanation
CJK	3398 (0.4%)	Chang Jiang Ko, nearby port
SHANGHAI	3357 (0.4%)	
SINGAPORE	3174 (0.4%)	
CNSHA	3145 (0.4%)	LOCODE for Shanghai
ZHOUSHAN	2867 (0.4%)	Zhoushan, nearby port

Source: own calculations

most cases. For example, in the data subset from the port of Shanghai, 636,254 out of 787,427 (80.9%) messages failed to specify the destination (Table 1).

The post-May-2020 dataset was slightly better (see Table 2) with 21.2% blank destination fields. Most of the mentions of destination referred to Shanghai. But again, we failed to find many declared ultimate destinations, such as ports in Europe. For example, Rotterdam was only mentioned 244 times (0.0001%). This was also the case for other regions as the majority of the stated destinations were local rather than distant. For example, for vessels ultimately bound for Rotterdam, the messages pointed to Rotterdam in 8.4% of cases, Antwerp in 3.1% cases, Vlissingen in 3.0% cases, and Terneuzen in 2.0%). This phenomenon deserves a separate study.

4.1.2 Vessels Movements Based on AIS Data
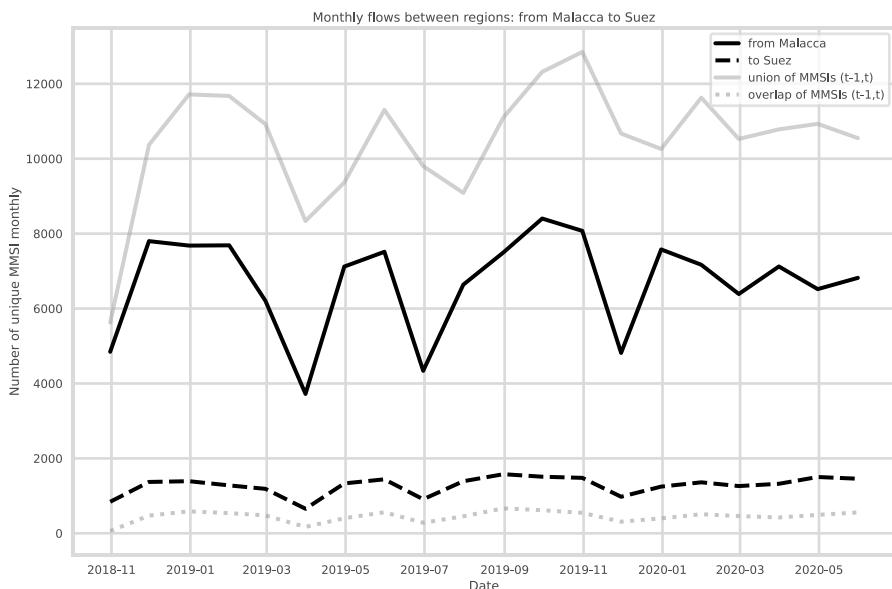
Rather than relying on declared destinations, we chose to calculate vessel flows based on the locations provided in AIS. The general idea was to take all unique vessel identifiers (MMSI numbers) from one area and a given month and check if they appear in another area in the same or the following month.

Let us explain this idea using the charts that show vessel flows between the Strait of Malacca and the Suez Canal. The charts are based on monthly aggregations. One of the charts, in Fig. 3, presents the unique number of vessels monthly. The solid black line specifies the number of unique vessels found in the Strait of Malacca (start), possibly leaving this region, while the dashed black line represents the number of unique vessels found in the Suez Canal (destination), possibly incoming into this region. The grey line is the total number of unique vessels in both regions, also encompassing the previous month (usually greater than the sum of lines for

Table 2 Most popular destinations (not normalised) stated in AIS messages in the Shanghai region after May 2020

Code in AIS message	Number of messages
SHANGHAI	17,415,275 (10.4%)
ZHOUSHAN	12,707,729 (7.6%)
NINGBO	5,321,728 (3.2%)
JIANGYIN	4,119,528 (2.5%)
NANTONG	3,129,105 (1.9%)

Source: own calculations
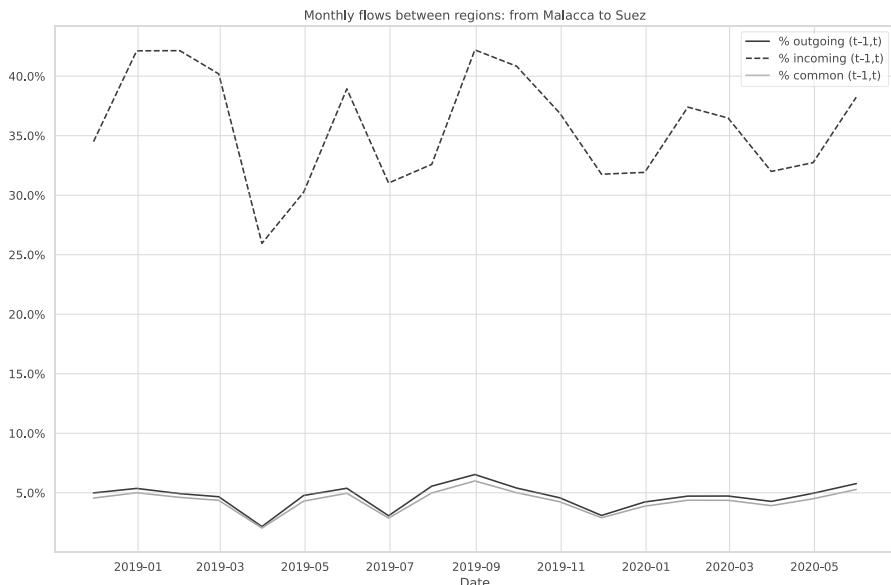
Fig. 3 Absolute monthly vessel flows from the Strait of Malacca to the Suez Canal. Source: own work

locations). The most interesting line is the grey dotted line which represents inter-sections of vessels found in both regions. This line shows changes in the number of vessels that travelled from the Strait of Malacca to the Suez Canal during specific months. We calculated overlaps over two consecutive months, and thus included cases in which a vessel left its point of origin in a given month and reached its des-tination in the same or the following month. The method is more appropriate for regions located far apart. As shown in the chart, the grey dotted line never touches the axis, which means that there is always a ship bound from Malacca to Suez.

Absolute numbers do not always tell the whole story. Figure 4 shows relative numbers. As stated in the legend, the labels should be interpreted as follows: the black solid line, labelled '% outgoing (t-1,t)', is the number of vessels that trav-elled from the Strait of Malacca to the Suez Canal (equivalent to the overlap of the MMSIs in Fig. 3) divided by the number of unique vessels at the point of origin (the Strait of Malacca). In other words, the line represents the percentage of vessels that left the Strait of Malacca in a given or previous month and reached the Suez Canal in that given month. As can be seen, this value amounted to 2–6% before the COVID-19 pandemic and did not change significantly since the pandemic broke out.

The black dashed line, marked '% incoming (t-1,t)', is the percentage of vessels found in the Suez Canal that began their journey in the Strait of Malacca in a given or previous month. These values range from 26% in April 2019 to 42% in September 2019. Shortly after the pandemic broke out (February 2020), the number of ves-sels that left the Malacca Strait and reached the Suez Canal declined. However, this decline only lasted for two consecutive months.
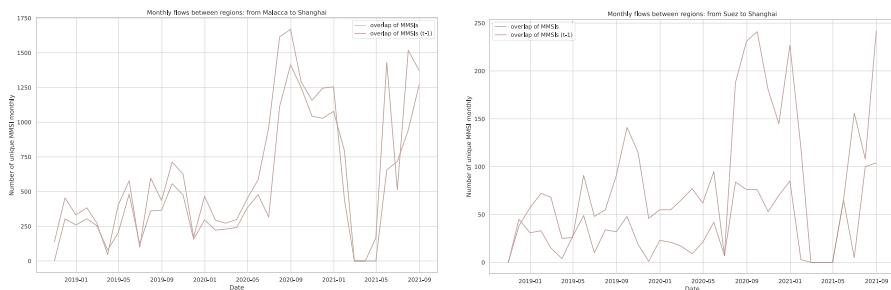
Fig. 4 Relative monthly vessel flows from the Strait of Malacca to the Suez Canal. Source: own work

When the number of unique vessels at the point of origin and destination differs significantly (as in the case in question), it is reasonable to consider the union of sets of vessels found in both regions as the denominator. The grey solid line, labelled '% common (t-1,t)', is calculated by dividing the number of overlapping vessels by the number of vessel set unions (vessels from both origin and destination). This formula is in fact the Jaccard similarity coefficient between two sets: when its value is close to 1, the two sets are very similar (we observe the same ships over two consecutive months in both regions). When the coefficient is close to 0, the two sets differ (different ships are observed in the two regions). In the case in question, this similarity is rather low (3–6%), which suggests that up to 6% of all ships observed in either the Strait of Malacca or the Suez Canal actually travelled the Malacca – Suez route (the remaining 94% of the ships took other routes). No significant change in this parameter was observed since the COVID-19 outbreak.

4.1.3 Absolute Values of Vessel Movements

Having selected ten regions for analysis, we ended up with 90 combinations to study (90 journeys from each given region to each other region). Needless to say, some of the routes share segments so that longer 'flows' contribute to shorter ones. For example, to get from Rotterdam to Shanghai, one needs to cross the Suez Canal and the Strait of Malacca. Nevertheless, such flows are not correlated. The charts for each of the above indicators allow us to distinguish between a range of phenomena.
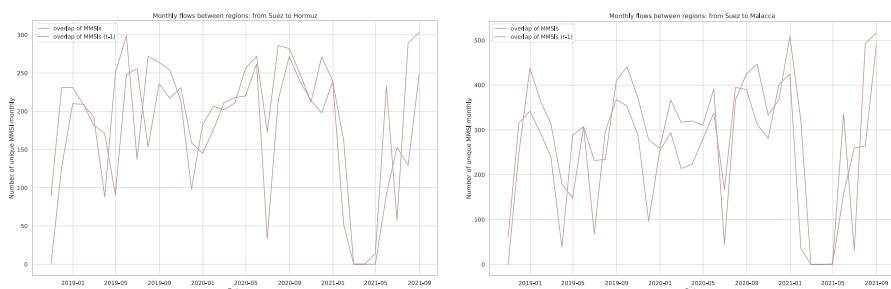
Firstly, in the temporal dimension pertaining to the change of the above-mentioned indicators over time, three periods emerge: pre-COVID-19-outbreak,
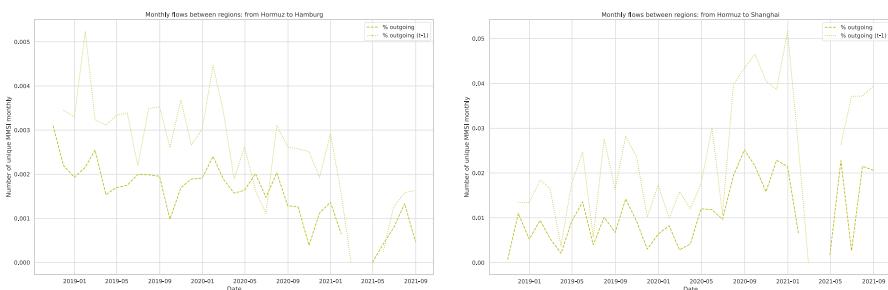
Fig. 5 Number of vessels travelling from the Strait of Malacca (left figure) and the Suez Canal (right figure) to Shanghai, monthly data. Source: own work

COVID-19 peak and COVID-19 recovery. Interestingly, the peak period did not begin until March 2020 and, according to our charts, was delayed until July/August 2020 (see, e.g., Figs. 5 and 6). Maritime transport appears to be relatively slow to respond to global crises. The third period (recovery) starts in May 2021.

A number of interesting observations can be gleaned from the charts. The most evident of them is the increase in trade with Shanghai seen shortly after the outbreak of the pandemic on nearly all routes. The most significant post-pandemic trade volume rise took place between the Malacca Strait and Shanghai. Figure 5 additionally shows changes in trade between the Suez Canal and Shanghai where a significant increase was observed after July 2020. This may suggest that more vessels travelled from Europe to China at the time and that these values remained high in the following months. However, this increase was not observed on all routes. For example, the average number of vessels going from the Suez Canal to the Strait of Hormuz and to the Strait of Malacca remained unaffected by COVID-19 (Fig. 6). The drop observed in all charts in early 2021 was caused by missing data for February and March 2021 rather than a traffic change.

Fig. 6 Number of vessels travelling from the Suez Canal to the Strait of Hormuz (left figure) and the Strait of Malacca (right figure), monthly data. Source: own work
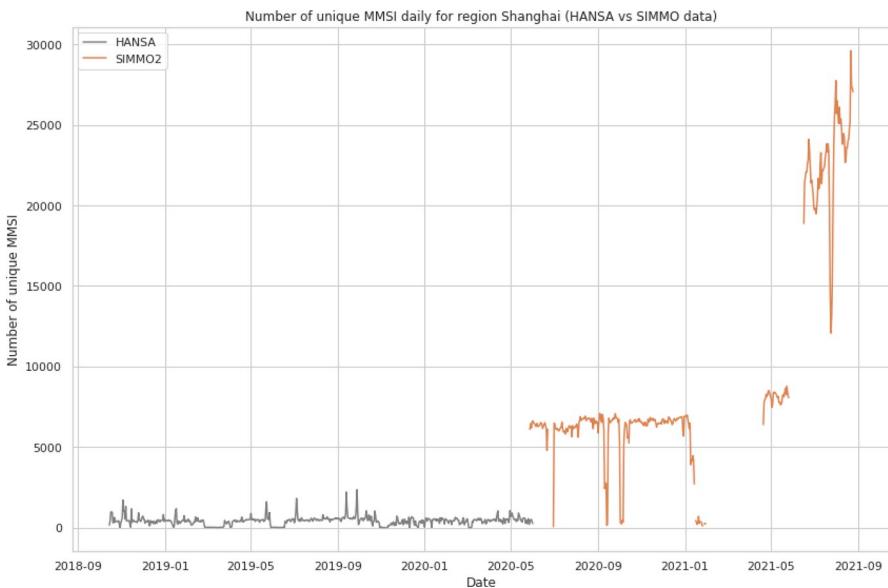
Fig. 7 Change in the proportion of vessels going from the Strait of Hormuz to Hamburg (left) and Shanghai (right). Source: own work

4.1.4 Relative Measures

The following analyses aim to focus on the relative measures which better characterise changes in maritime traffic and afford multiple perspectives on such changes. The so-called 'outgoing' charts characterise changes in outflows from a given region over time (interpreted as exports), while the so-called 'incoming' charts show changes in inflows to a given region and its origin (interpreted as imports). Finally, to observe the overall flows between two regions without referring to origin or destination, the so-called 'overlap' charts are presented.

Starting with the 'outgoing' flow analysis (changes in exports), primary focus is placed on the Hormuz Strait (entry into the Persian Gulf), a region of strategic importance for oil exports. Figure 7 (left-hand side) shows the decreasing significance of Hamburg as a destination port for oil transport. This decrease actually began long before the pandemic struck and is apparently unrelated. However, China has been observed to gain in significance. Figure 7 (right-hand side) indicates growth in imports from the Strait of Hormuz to Shanghai, with a significant spike coinciding with the COVID-19 outbreak and elevated volumes persisting in the recovery period.

An interesting phenomenon was observed in the Chinese ports. Throughout 2021, the number of vessels found daily in and around the ports rose significantly (see Fig. 8). Shenzen recorded 350 to 900 additional vessels per day, while the average increase at Shanghai (and Ningbo, Shanghai and Ningbo being the world's two biggest ports) ranged from 6,000 to 27,000. Two distinct factors might have contributed to these increases. Firstly, in April 2021, China revised its Maritime Traffic Safety Law and adopted new reporting requirements for seagoing vessels. Foreign vessels entering China's territorial waters are now required to declare their ship name, call sign, position, and any hazardous cargo. As a consequence, many vessels for which AIS had not been mandatory ended up acquiring the system. The second reason for the increase might have been the congestion in the Chinese ports due to COVID-19 lockdowns, the China-Australia trade war and extreme weather events (including the In-Fa typhoon that struck East China) (Cook 2021) resulting in queues of vessels waiting to enter the ports. A
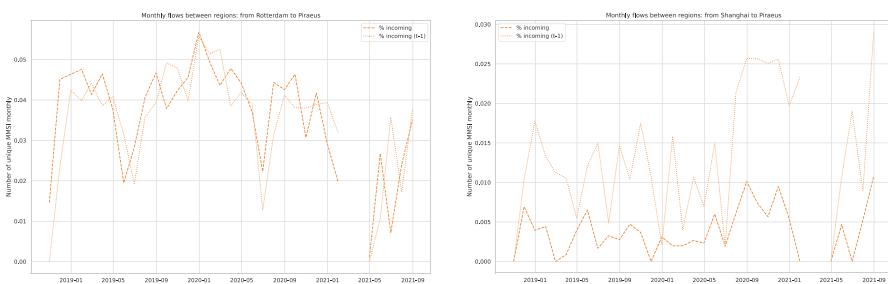
Fig. 8 Number of unique vessels in the ports of Shanghai and Ningbo. Source: own work
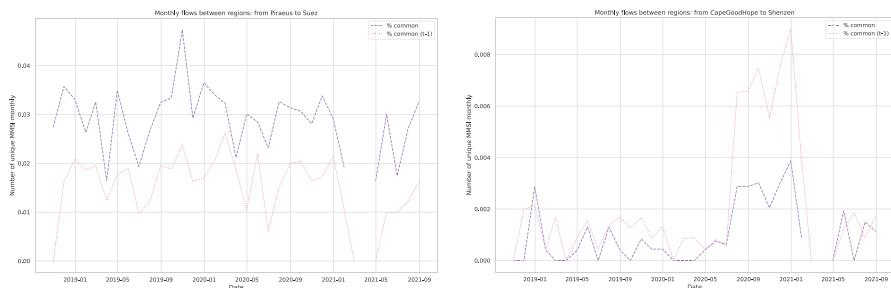
similar situation repeated in the spring of 2022 in the wake of the lockdown of Shanghai (Koh and Varley 2022).

A number of other graphs explore 'incoming' traffic. An interesting case here is that of the port of Piraeus. China has been heavily investing in Piraeus, the port being located along the New Silk Road and considered China's gateway to Europe. Figure 9 does indeed show a change in trade patterns with lower volumes coming from Europe (e.g., imports from Rotterdam dropping after the COVID-19 outbreak) and increased volumes originating in China (e.g., a rise in imports from Shanghai shortly after the COVID-19 outbreak).

Finally, the charts presenting the 'overlapping' flows (e.g., Figs. 10 and 11) allow us to identify patterns observed during the three COVID-19 pandemic periods (pre-pandemic, COVID-19 outbreak, and recovery):

Fig. 9 Changed proportions of incoming vessels at Piraeus originating in Rotterdam (left) and Shanghai (right). Source: own work

Fig. 10 Proportion of overlap between vessels going from Piraeus to the Suez Canal (left) and from the Cape of Good Hope to Shenzen (right). Source: own work
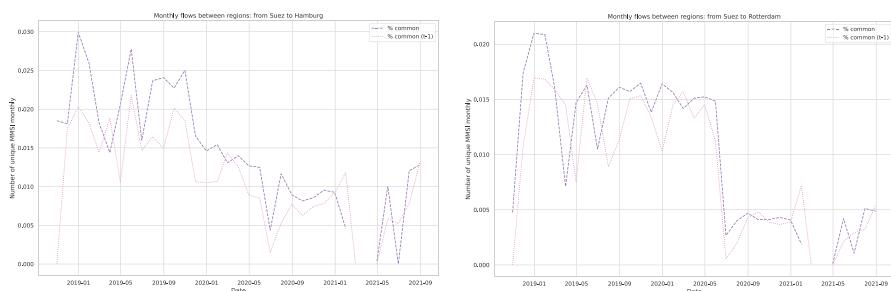
- *Increasing* flow, in which the proportion of ships going from one region to another increased after the pandemic outbreak and remained high in the following months;
- *Decreasing* flow, in which the opposite is true, i.e. the proportion of ships peaked during the pre-pandemic period only to decrease afterwards;
- *Peak* flow, signifying an increase in the wake of the COVID-19 outbreak and a return to pre-pandemic levels during recovery;
- No changes are observed in connection with the COVID-19 pandemic.

Examples of the above patterns are provided in Table 3.

Figure 10 (left) shows an example of a flow unchanged from the COVID-19 outbreak on a route from Piraeus to the Suez Canal. In contrast, the right part of Fig. 10 shows a peak pattern. Interestingly, this pattern was more likely to occur where Shenzen was the destination port. Traffic to Shenzen was at its busiest immediately after the COVID-19 outbreak, and sagged to pre-pandemic levels during recovery. This trend might have resulted from the closure of the port of Yantian, which is home to a critical international container terminal belonging to Shenzen. The trend can be attributed to the fact that a substantial number of vessels lingered in the Shenzen region for Yantian to reopen. It is worth mentioning that in 2020, demand for maritime import into China rose by 9% (UNCTAD 2021), which also explains the increasing and peak patterns at the Chinese ports.

Even where flows decrease, the rate of decrease can still be measured. An interesting example is a flow from the Suez Canal to the two European ports of Hamburg and Rotterdam (Fig. 11). In both cases, the proportion of vessels fell roughly threefold, but with different distributions in time. In the case of Hamburg, the decrease remained roughly unchanged over the analysed period and stabilised since the beginning of the pandemic. Rotterdam's proportion, which was stable before the pandemic, displayed a sudden drop after the COVID-19 outbreak and subsequently levelled out.

The increasing and peak flow patterns show that the negative impact of the COVID-19 pandemic on maritime transport proved to be less damaging than initially feared. As indicated by (UNCTAD 2021), maritime trade performed better

Fig. 11 Proportion of shared vessels going from the Suez Canal to Hamburg (left) and Rotterdam (right). Source: own work

than expected because the pandemic unfolded in phases and at different speeds, with diverging paths across regions and markets. The recovery of trade was also the result of large stimulus packages provided by different countries and increased consumer spending on goods (particularly a growth in e-commerce) and cars. A number of companies also decided to restock and build their inventories. This, in turn, may be one of the reasons for the growing importance of Chinese container ports. Moreover, the fact that demand for iron ore and grain in China remained strong throughout the pandemic mitigated the impact of the pandemic in dry bulk commodity trade (UNCTAD 2021).

Interestingly, although a significant drop in traffic was observed along some routes, such routes were primarily those going to or between European ports. The percentage fall of the world container port traffic between 2019 and 2020 to and from Europe was -4.2%, compared to a mere -0.4% for Asia (UNCTAD 2021). This is consistent with the pre-pandemic trend of strengthening Asia's dominance in international trade (in both imports and exports, which in 2020 amounted to 84.9% and 66.5% respectively) and the diminishing importance of developed countries (particularly in imports).

4.2 The Ukraine-Russia War Crisis
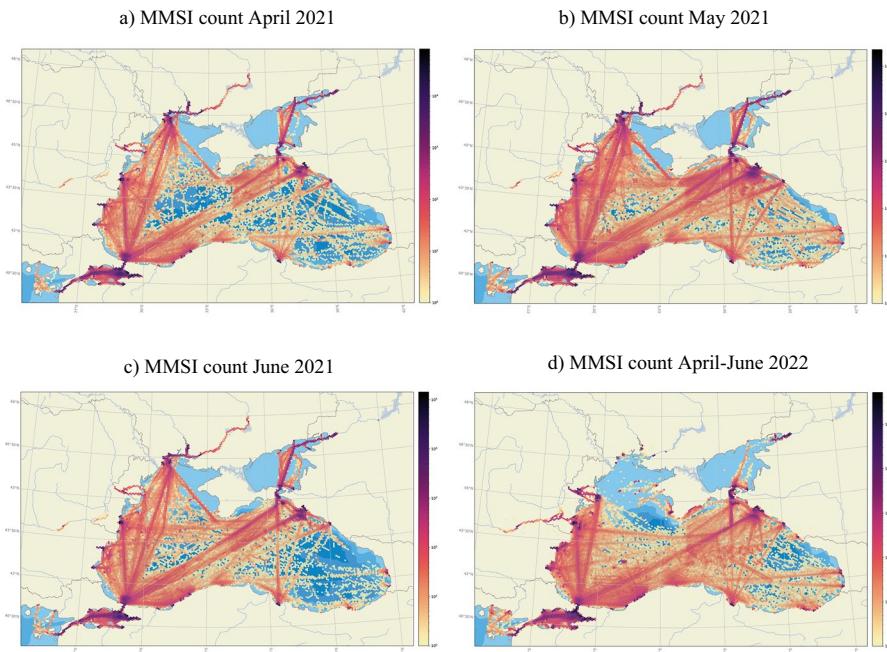
To identify the impacts of the Ukraine-Russia crisis on the region's maritime traffic, we compared the number, movements, and types of vessels that travelled in the Black and Azov Seas. In the comparison, we took a snapshot of the situation before (April-June 2021) and after (April-June 2022) the outbreak of the war. The results, presented in Figs. 12 and 13, offer interesting insights into maritime traffic in the region.

Several Ukrainian and Russian ports played a crucial role in maritime traffic and reported peak volumes of such traffic in 2021. In Ukraine, such ports were Odessa, Yuzhnyy and Mykolaiv on the Black Sea and Mariupol and Berdyansk on the Azov Sea. Kherson served as an important river terminal whereas Dnipro played a vital role in inland transport. These Ukrainian ports proved to be crucial for grain exports. In 2021, five sea ports (three terminals in the Odessa region: Chernomorsk, Odessa,

Table 3 Flow patterns observed along selected maritime routes associated with the COVID-19 pandemic

Increasing flow	Decreasing flow	Peak flow	No change
Strait of Hormuz to Shanghai	Antwerp to Hamburg	Cape of Good Hope to Shenzen	Strait of Malacca to Suez Canal
Strait of Malacca to Shanghai	Strait of Hormuz to Hamburg	Strait of Hormuz to Shenzen	Piraeus to Suez Canal
Strait of Malacca to Shenzen	Strait of Malacca to Hamburg	Suez Canal to Shanghai	Rotterdam to Suez Canal
Strait of Hormuz to Cape of Good Hope	Rotterdam to Hamburg	Suez Canal to Shenzen	Suez Canal to Strait of Hormuz
Shanghai to Cape of Good Hope	Strait of Hormuz to Rotterdam		Suez Canal to Strait of Malacca
Shanghai to Strait of Hormuz	Strait of Malacca to Rotterdam		
Shanghai to Strait of Malacca	Suez Canal to Rotterdam		
Shanghai to Piraeus	Suez Canal to Shanghai		
	Strait of Malacca to Shanghai		
	Cape of Good Hope to Rotterdam		
	Antwerp to Piraeus		
	Rotterdam to Shanghai		

Source: Own work

a) MMSI count April 2021

b) MMSI count May 2021

c) MMSI count June 2021

d) MMSI count April-June 2022
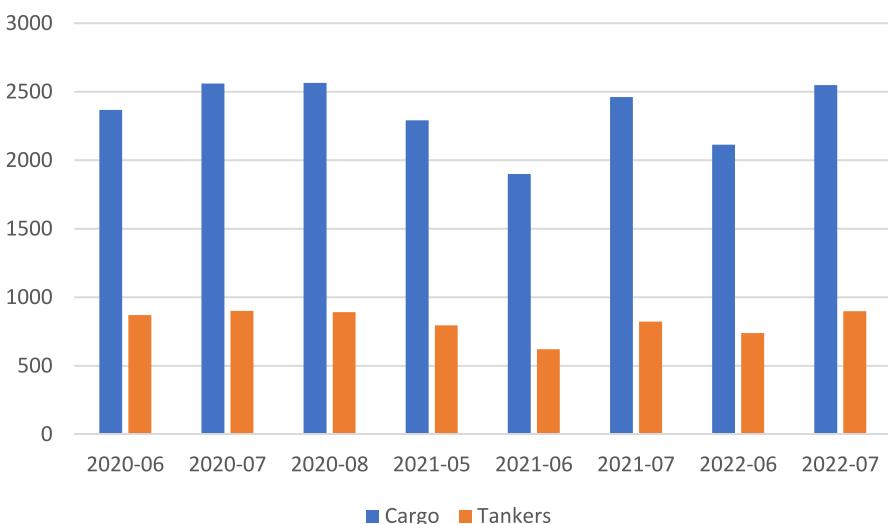
Fig. 12 Maritime traffic (number of vessels) on the Black and Azov Sea in 2021 and 2022. Source: Own work

Olvia, and the ports of Mykolaiv and Pivdenny) shipped 92.9% (or 43.915 mln t) of Ukraine's total grain exports during that year (Latifundist Medi 2022).

The Russian ports experiencing the busiest vessel traffic in 2021 were Novorossiysk, Tuapse and Sochi on the Black Sea and Rostov-on-don and Azov on the Azov Sea.

Regarding maritime traffic in Ukrainian and Russian ports in 2021 (Fig. 12a-c), the prevailing routes led from Ukrainian ports on the Black Sea toward the Bosporus Strait (and on to the Mediterranean Sea and other world regions), from Ukrainian ports on the Black Sea in the south-easternly direction and on to the Azov Sea and back (both directions), between the Azov Sea and the Bosporus Strait (both directions), between Russian ports on the Black Sea and the Bosporus Strait (both directions), and between the Azov Sea and Russian ports on the Black Sea to the Port of Samsun in Turkey (both directions).

The above changed significantly after the outbreak of the war (Fig. 12d). Traffic from and to the Ukrainian ports on the Black and Azov Sea and inland transport through the Dnipro river disappeared entirely, due specifically to the Russian blockade of Ukrainian ports. On the other hand, no change was observed in traffic volumes between ports in Russia and the Bosporus Strait. This, in turn, might be due to the increased exports of Ural oil to Asia. However, traffic between the Azov Sea and the port of Samsun declined, triggered possibly by sanctions against Russia. Interestingly, increased traffic is also observed in ports in the north of Romania (such as Sulina and Tulcea) and across the Danube Delta (south canals), suggesting

Fig. 13 A comparison of the numbers of cargo vessels and tankers on the Black Sea in 2020, 2021, and 2022. Source: Own work

that the previous exports from the Ukrainian ports (of e.g. Kiliya and Izmail) were taken over by Romania after the outbreak of the war.
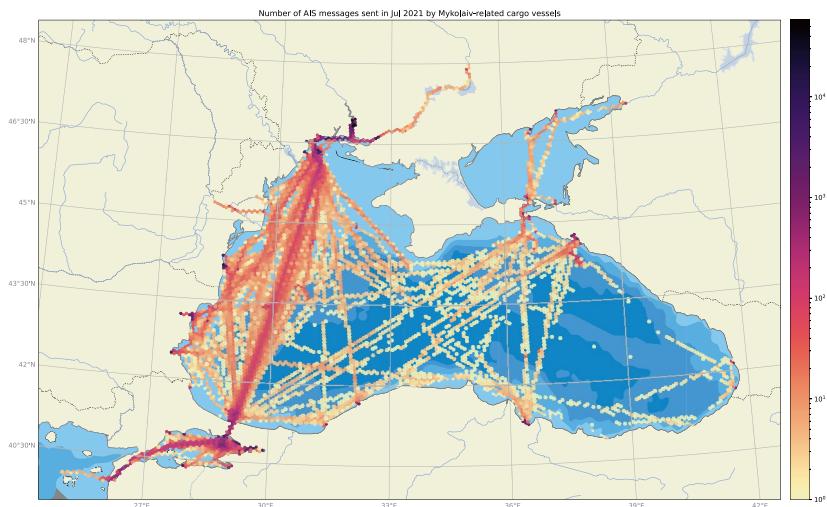
We also looked into changes in the number of cargo vessels and tankers on the Black Sea between 2020 and 2022 (Fig. 13). A comparison for the same times of the year shows that the number of unique vessels observed on the Black Sea did not change significantly over these years. In fact, for both vessel types, the vessel count in 2022 was slightly above that in 2021.

We have also taken a more detailed look at maritime traffic at two selected ports of Mykolaiv, Ukraine and Rostov-on-Don, Russia. The results are elaborated in the following paragraphs.

4.2.1 Maritime Traffic Flows at Ukraine's Largest Grain Port of Mykolaiv
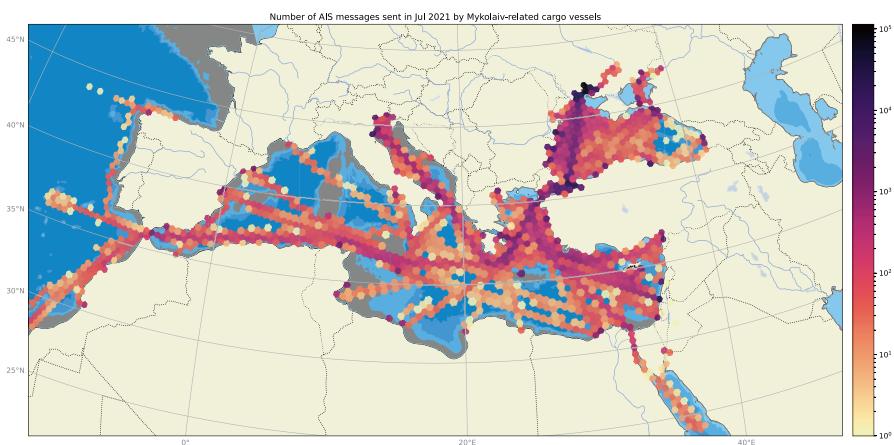
Mykolaiv used to be Ukraine's second largest grain-exporting port (Bobylov and Bland 2022). In October and November 2021, it exceeded other Ukrainian ports in terms of the total volume of grain exports (Latifundist Medi 2022).

Our analysis shows that 122 cargo vessels sent 129,240 AIS messages from the port of Mykolaiv (Nika-Tera) in July 2021. To find which destinations these exports were going to from Mykolaiv, we traced the movements of the 122 vessels in July 2021. To this end, we collected 735,940 AIS messages sent during that month. The distributions of these vessels are presented in consecutive figures on different scales for the Black Sea (Fig. 14), Europe/Africa (Fig. 15), and global (Fig. 16). The charts show that the majority of traffic on the Black Sea headed toward the Bosporus Strait and on to ports in Greece, Italy, France, Spain, Egypt, Libya, Tunisia, and Morocco. Some of the traffic headed even further, via the Suez Canal to India, and via the Gibraltar Strait to the United States, Mexico, and Brazil.
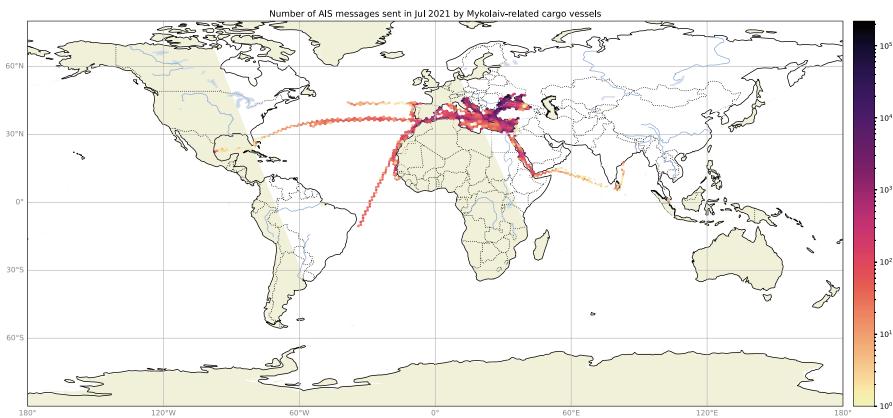
**Fig. 14** Maritime traffic from the port of Mykolaiv in July 2021 – the Black Sea perspective. Source: Own work

For the sake of comparison, note that 56,387 AIS messages were sent out in July 2022. While the total number of messages does not constitute a substantial drop, all of them were transmitted from as few as four vessels stranded in the port of Mykolaiv that were unable to sail and move cargo. These four vessels were bulk Carrier PANDA, general cargo carrier MALLARD S, bulk carrier BOLTEN ITHAKI, and bulk carrier MARYLAND.

Fig. 15 Maritime traffic from the port of Mykolaiv in July 2021 – the Europe/Africa perspective. Source: Own work
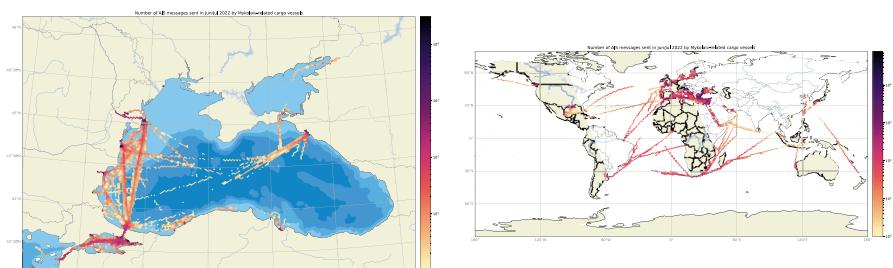
Fig. 16 Maritime traffic from the port of Mykolaiv in July 2021 – the global perspective. Source: Own work
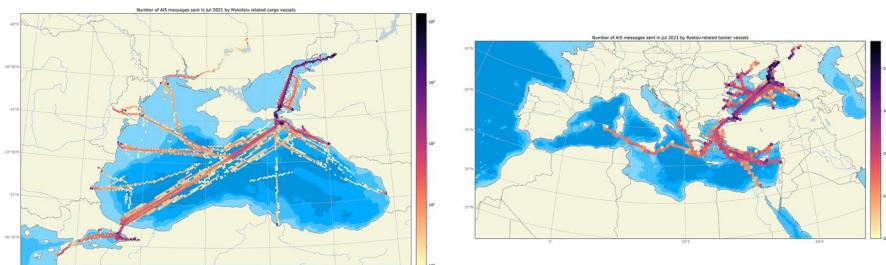
As a point of interest, we visualised the present distribution of the same 122 vessels that transported cargo from the port of Mykolaiv in July 2021 to ascertain their locations in July 2022 (Fig. 17). The vessels sent out a total of 713,720 AIS messages, which, needless to say, originated from other locations around the world. Interestingly, some of them called into the Port of Constanta-Agigea and ports in northern Romania and entered the Danube River. This, again, suggests that the Russian seaport blockade prompted Ukraine to export its grain through Romania, which in fact was confirmed by the news media at the time (Associated Press 2022; Radu 2022).

4.2.2 Flow of Maritime Traffic in the Port of Rostov-on-Don, Russia

Similarly, we compared tanker traffic originated in the port of Rostov-on-Don, Russia. In July 2021, we identified 59,394 AIS messages sent out by 145 tankers located in the port of Rostov-on-Don. Similarly to the port in Ukraine, we studied the routes of these 145 vessels in the same month (Fig. 18). As can be seen, tankers sailing

Fig. 17 Maritime traffic in June/July 2022 made up of vessels that called into the port of Mykolaiv in July 2021 – the Black Sea (left) and global (right) perspective. Source: Own work
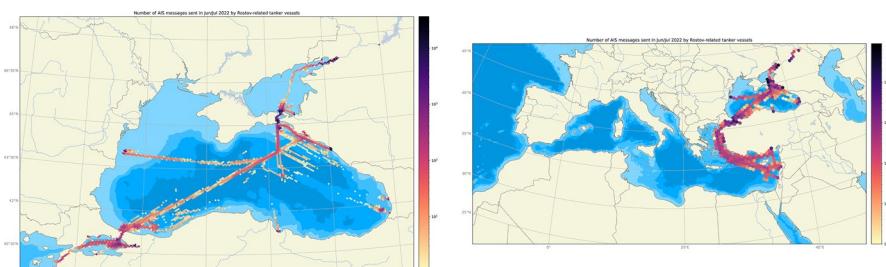
Fig. 18 Maritime traffic from the port of Rostov-on-Don in July 2021 – the Black Sea (left) and Europe/Africa (right) perspective. Source: Own work

from Rostov-on-Don tend to appear in the eastern part of the Mediterranean Sea (Turkey, Lebanon, Albania).

An analogous analysis for July 2022 revealed almost twice as many AIS messages (106,561) sent from a similar number of tankers (122). Again, we tracked the routes of the 122 vessels in July 2022 in search for changes (Fig. 19). Interestingly, the operating area of the vessels was significantly reduced to only a handful of ports in Turkey, Lebanon, and Israel. A more detailed analysis showed that a single Russian tanker visited the ports of Haifa, Israel, Beirut and Kada Tripoli, Lebanon. Fewer vessels reached Rostov via the Azov Sea. These results again confirm that despite the sanctions, Russia remained an active oil exporter, although it changed its destinations by focusing increasingly on the Middle East. Moreover, to escape sanctions, a number of Russian-flagged vessels switched theirs flags to those of other countries (Ha 2022). Along with the flag changes, the vessels also changed their MMSIs (AIS identification numbers), making it impossible to track their history.

Other unusual activities of Russian vessels, namely the switching off of the AIS system and faking the AIS signal, were also observed (MI News Network 2022; Peters 2023). Our analysis additionally revealed that some of the tankers we tracked simultaneously displayed the same MMSI number from two different locations, which may indicate AIS spoofing.

Fig. 19 Maritime traffic from the port of Rostov-on-Don in July 2022 – the Black Sea (left) and Europe/Africa (right) perspective. Source: Own work

5 Discussion and Summary

This paper explores the two crises of the COVID-19 pandemic and the Ukraine-Russia war to examine their effects on maritime logistics. The impact of the pandemic appeared to extend beyond single regions affecting entire global supply chains. In the paper, we attempt to verify this hypothesis and find what changes actually occurred in maritime trade due to the pandemic by examining vessel movements on the basis of AIS data. To this end, we analyse vessel traffic (flows) between the ten regions in which the majority of maritime transport takes place, and compare them before, during and after the pandemic. In our analysis, we assess monthly proportions to ascertain total vessel flows between selected two regions as well as the volumes of imports and exports to and from a given region. These proportions are then tracked over 2019–2021 to establish trends over time. The innovative part of our research as compared to other previously published studies is that we significantly extend the timeframe of our analysis for the case of the COVID-19 crisis. In effect, our research covers the reference period of 2018 and 2019 and the COVID-19 period ending in mid-2021. This allows us to observe and identify interesting patterns not only in the most severe early months of the pandemic, but also in the successive months of 2020 and 2021. Moreover, we analyse the destinations of traffic in the hot spots instead of exclusively examining traffic density.
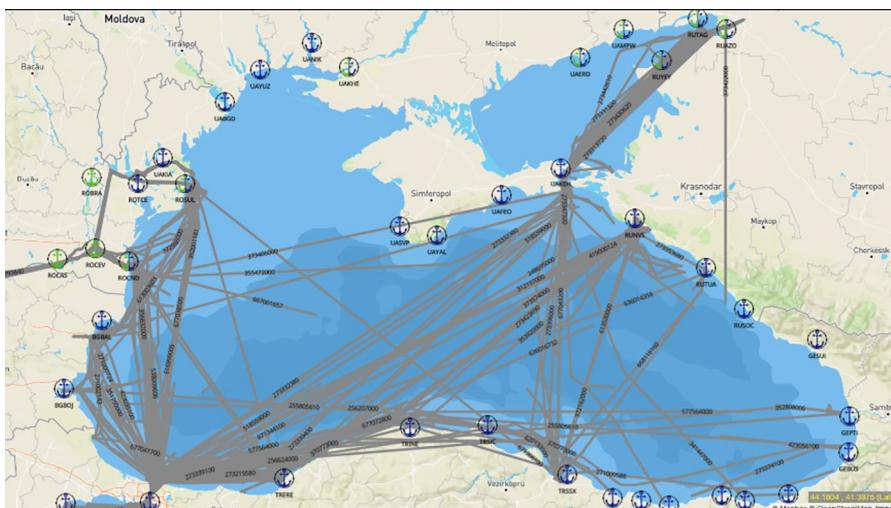
The findings, as presented above, show an evolution of global supply chains. The most conspicuous change was the rise in significance of Shanghai during and after the pandemic. The other Chinese port we looked at, i.e. Shenzen, also reported a vessel flow increase, which in its case was limited to a time shortly following the outbreak of the pandemic (until the end of 2020). In 2021, the proportions returned to pre-pandemic levels. Interesting observations have also been gleaned for the selected European ports. These showed a diminishing importance of Hamburg in favour of Piraeus. Concerning the movements of energy carriers from the Persian Gulf, emphasis has been shifting from Europe to China. A slight increase in maritime traffic over the pandemic period was also observed around the Cape of Good Hope. In this case, the main destination might have been South America, but we were unable to confirm this as no South American ports were included in our analysis. The change may also have been prompted by the Suez Canal obstruction of March 2021 which forced a number of vessels to take the longer route around the Cape of Good Hope. Nevertheless, a future extension of our research to include routes to South America could be interesting, particularly in view of the fact that countries in South America were heavily affected by COVID-19. Traffic in the Suez Canal, the Strait of Hormuz, and the Strait of Malacca was relatively unaffected by COVID-19 despite these traffic diversions.

As for the Russia-Ukraine crisis, rather than focusing on traffic before the beginning of the war (e.g., December 2021-February 2022), our analysis compares the two respective periods before and after its outbreak (the spring of 2021 and 2022). This is a deliberate attempt to avoid conclusions that are biased (at least in part) by natural seasonal fluctuations in maritime traffic (i.e., winter vs. spring/summer). Moreover, since early 2022, ample publicised reports suggesting that Russia might be planning to attack Ukraine had the potential to disrupt regular maritime traffic on the Black Sea at

that time. Therefore, we believe that our findings, as provided above, accurately portray the effect of the Russia-Ukraine crisis on maritime traffic in the region.

Our findings confirm a complete cessation of traffic from and to Ukraine ports following the outbreak of the war. This coincided with increased vessel traffic in the north of Romania and the port of Constanta-Agigea, which suggests that some of the previous traffic from Ukraine was taken over by these Romanian ports. This might be further confirmed by the fact that the number of unique tankers and cargo vessels observed on the Black Sea in June and July 2022 did not change significantly from 2021 and even rose slightly on 2021. On the other hand, hardly any change was seen in the volumes of traffic going from the Russian ports on the Black Sea to the Bosporus Strait. This was also confirmed by tanker movements from the Rostov-on-Don ports. This suggests that, despite the various sanctions imposed on Russia, the country remained an active oil exporter to the eastern Mediterranean region (Turkey and Lebanon). All in all, our findings show that, despite the war, vessels continued to be active on the Black Sea, but with changes in the specific ports they visited.

Regarding the Russia-Ukraine conflict, as of the time of this analysis, the news media (Dikmen and Nichols 2022; Reuters 2022) reported that Ukraine began to move its grain exports down the Danube river despite Russia's port blockade, and that there is a grain export deal with Russia may be signed allowing some Ukrainian ports on the Black Sea to re-open. This change was already reflected in vessel movements on the Black Sea and in increased traffic around the Kiliya and Izmail ports in Ukraine and then from these ports toward the Bosporus Strait in the first half of July 2022 (Fig. 20). The Black Sea Grain Initiative of July 2022 has now allowed exports of grain, other foodstuffs, and fertilizers from three key Ukraine ports of Chornomorsk, Odessa, and Yuzhny/Pivdennyi to resume through a safe maritime humanitarian corridor (UNCTAD 2022). This might provide an interesting area of research into the exact routes of grain exports and the exporting parties.

Fig. 20 Vessel movements on the Black Sea on 10–15 July 2022. Source: Own work

As mentioned earlier, in addition to grain, Ukraine is an important supplier of iron, titanium, graphite and potentially lithium. An interesting case for future research might be to observe changes in shipments of these crudes in the Black Sea ports as a result of the war.

As shown above, global or regional crises may heavily influence maritime transport ultimately affecting global supply chains. Any potential future crisis, such as political conflicts between China and the United States or Europe, China's involvement in the Russia-Ukraine war or further pandemic outbreaks, can heavily impact maritime transport and thus the global economy. Last but not least, crises of other types, as observed in the past (e.g., the 2021 Suez Canal obstruction, incidents in ports, extreme weather events, economic cycles) may precipitate changes in maritime traffic.

Declarations

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