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How covid affects global ship trade: a port congestion monitoring based on AIS data and Spatio-Temporal Datacubes from Defined Locations

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Abstract. The research was based on an automatic identification system (AIS) dataset on the daily positions of global containerships for the year 2021. The authors aim to extract value-added information by analyzing changes in the maritime logistics in relation to the Covid19 epidemic. Due to the effects of the epidemic (an increase in the cost of freight and charter rates of containerships and an increase in the delivery time of goods), port congestion (i.e. an increase in the waiting time for containerships to dock in a port) has developed in some major nodal ports of the logistics network due to the large number of ships waiting to load and unload containers. This slowdown and port congestion are mainly due to direct or indirect sanitary causes, i.e. the reduction of manpower due to Covid19 infections and the chain effect due to the closure of some nodal ports for virus containment measures. Considering the daily AIS positions near the most affected ports, it is possible to observe a different spatial arrangement in 2021 and the stationary presence of many containerships for consecutive days. Using this spatial distribution and with the help of satellite radar images (Sentinel 1), the authors outlined reference AOIs on a number of ports that became the basis for data analysis. Lastly, using the "Space-time Cube by Defined Location" tool in ArcGis Pro, it was performed a space-time analysis and monitoring utilizing the polygons of the ports to define the bins for the creation of a data-cube. Using data-cubes the authors investigated three case studies analyzing the port congestion phenomenon through graphs and trend analysis. The three case studies were: the Yantian terminal closure, port congestion at the ports of Shanghai and Ningbo and finally port congestion at the American ports of Los Angeles/Long Beach and Savannah.

Keywords: AIS data , maritime trade, Space-time Cube, vessel's position, satellite.

1. Introduction

The maritime trade represents one of the most significant and used commercial transport methods thanks to the possibility of covering long distances with large international shipments. It accounts, in fact, for around 80% of global import-export trade (Unctad, 2017). There are more than 50,000 merchant ships trading internationally on the sea (Yang et al., 2021). In order to guarantee a safe navigation avoiding collisions, the International Maritime Organization (IMO) has required a real time tracking system, the Automatic Identification Systems (AIS), for ships over 300 tons. These consist of small ship-mounted transponders that use shortwave VHF radio signals and GNNS technology to transmit each vessel's position as well as other relevant information to ground stations located at a maximum distance of about 50 miles from the coast. With space-based AIS (S-AIS) the signals from ships are collected by satellites, strongly enlarging the coverage performance at the expense of a lower data rate (Graziano et al., 2019). AIS has been primarily conceived for collision avoidance, but today's applications range from maritime surveillance and safety to impact's assessment on the environment, to traffic monitoring and forecasting, to evaluation of commercial and trade activities.

In this paper, it was investigated how Covid19 has substantially influenced the whole of maritime logistics. The epidemic had mainly two effects: an increase in the cost of freight and charter rates for containerships and an incremental growth in the delivery time of goods. These two factors are putting a strain on global supply chains negatively affecting production costs, sourcing capabilities and consumer prices of goods globally. One of the main causes of these two phenomena is the port congestion of some of the main nodal ports of the global logistics network, mainly American and Asian ports. Port congestion refers to the increased waiting time for containerships to dock at a port due to the high number of ships waiting to load and unload containers and the slowdown in logistical processes. During the year 2021, there were several events that contributed to the intensification of port congestion. The various anti-Covid19 prevention measures imposed in some countries or in some cities have required temporary closures or major slowdowns for the implementation of security measures. In addition to this other timely events such as the blockade of the Suez Canal in late March and the storms that hit the Chinese coast caused the temporary closure of the ports of Shanghai and Ningbo in late July and mid-September. This situation is part of a period of severe imbalances generated as early as 2020 that led to a dysfunctional distribution of empty containers creating a shortage at the very ports where there was the greatest need and thus further slowing down cargo handling operations (UNCTAD, 2021)(Komaromi et al., 2022). The development of methodologies for analyzing these phenomena is therefore important for understanding, and in part trying to predict, a key component of the global economy. In this paper, the authors focus on the use of space-time data cubes to geospatially analyze previously described phenomena at the point and trend level.

2. Methodology

2.1 Port AOI definition

The definition of AOI is a key step in analyzing the phenomenon of port congestions. In fact, AOIs define the spatial range within which to perform the spatio-temporal analysis. Their variation can considerably affect the results of the analysis. As can be seen from the arrangement of AIS data near the ports there is a distinguishable spatial

distribution of ships related to the phenomenon of port congestion. This delineation was then adjusted on the basis of Sentinel 1 radar satellite images focused on ports, which clearly return the positions of vessels. The ports that were chosen for this analysis are the American and Chinese ports that have suffered most from this problem. These ports are particularly emblematic given also their position in the global ranking of cargo traffic and their top position in the hierarchy of maritime logistics chains. The chosen ports are Los Angeles/Long Beach and Savannah ports on the American side and the terminal of Yantian, in the Shenzhen region, the ports of Shanghai and Ningbo on the Chinese side.
The first two California ports were handled as one because of their geographic proximity and complementary work. In addition, as can be seen in **Fig 1** ships waiting for both ports remain together anchored in the bay adjacent to the city.

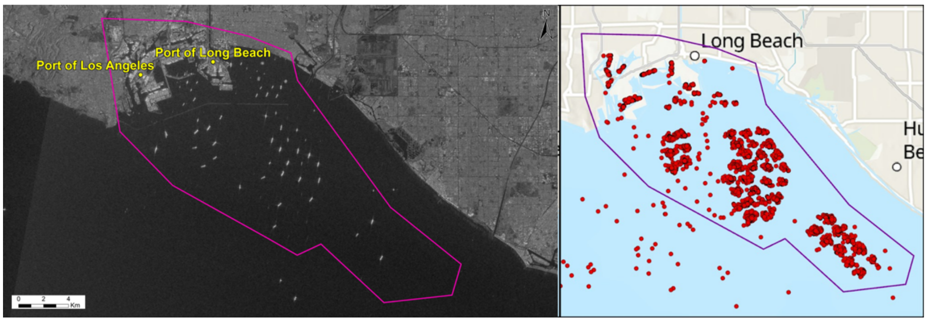

Fig 1. Ships waiting at the port of Los Angeles/Long Beach on Sentinel 1 image (Sentinel-1B (2021) (acquired on 25/03/2021 at 13:52 UTC, GSD 10.0 m) provided under COPERNICUS by the European Union and ESA)(left) and processing on ArcGIS pro (right).

The port of Savannah, on the other hand, is one of the major ports on the Atlantic coast of the USA and has been subject to heavy congestion related to the general slowdown in logistics chains. On the Chinese side, on the other hand, the port of Yantian, was the first Chinese port to close due to a lockdown cause knock-on slowdowns at various other ports. Finally, the port of Shanghai, a central hub of global logistics that, especially in the second part of 2021, has experienced port congestion unprecedented in history. A slowdown capable of severely affecting global trade.

2.2 Space time data cube

Spatial data analysis refers to a set of techniques designed to find patterns, detect anomalies, or test hypotheses and theories, based on spatial data (Goodchild, 2008). Among spatial data analysis techniques, the creation of space-time data cubes has been considered adequate to analyze the AIS dataset. The authors used the ESRI ArcGIS Pro Space Time Pattern Mining toolbox to insert the mentioned AIS records referred to year 2021 into a netCDF data structure, by counting positions and aggregating specified attributes into space-time bins. These bins were defined using AOIs ports via the "defined location" function in the Data Cube creation. Trend analysis was then carried out on a number of Chinese and American ports by looking at the number of ships present, the total sum of TEUs of ships stopped, and the waiting time outside each port. In order to calculate the consecutive dwell days of ships in the AOI of ports and thus the average dwell time related to waiting times for loading and unloading freight, the authors developed a tool for QGIS in the Python language. This tool returned for each AIS data by adding two fields. One containing the daily count of the number of consecutive days the related ship was present in the AOI on the specific day of the data and the other containing the total number of days the ship stopped each time it entered the AOI. Through the first it was possible to calculate the average of the days spent in the AOI in the datacube. The second was instead used to filter the extreme values reasonably unrelated to a loading and unloading waiting time.

3. Spatial analysis

3.1. Annual analysis of the ports

The analyses carried out in this research were based on the annual observation, using data cubes, of certain phenomena within the ports' AOIs, namely the number of ships present in the areas, the number of days the ships stayed in the areas, and the overall carrying capacity of the vessels in the areas. An example of this first analysis can be seen in the graph in Fig 2 showing the ships stopped at the ports of Shanghai, Ningbo, Yantian, Los Angeles and Savannah in 2021. And again in Fig 3, the ships stopped at the aforementioned ports, divided by TEUs. Thanks to this first global analysis, the authors were able to visualize and focus the research on three main case studies that will be illustrated in the following paragraphs.

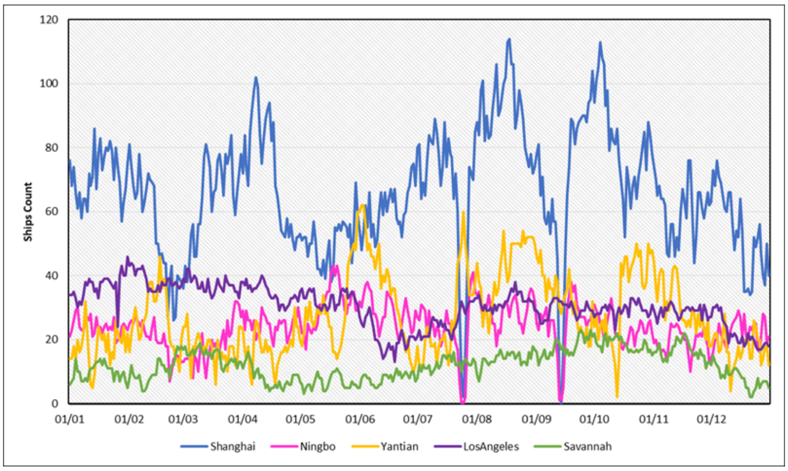

Fig 2. Number of ships in AOI identified in ports of Shanghai, Ningbo, Yantian, Los Angeles and Savannah during 2021.

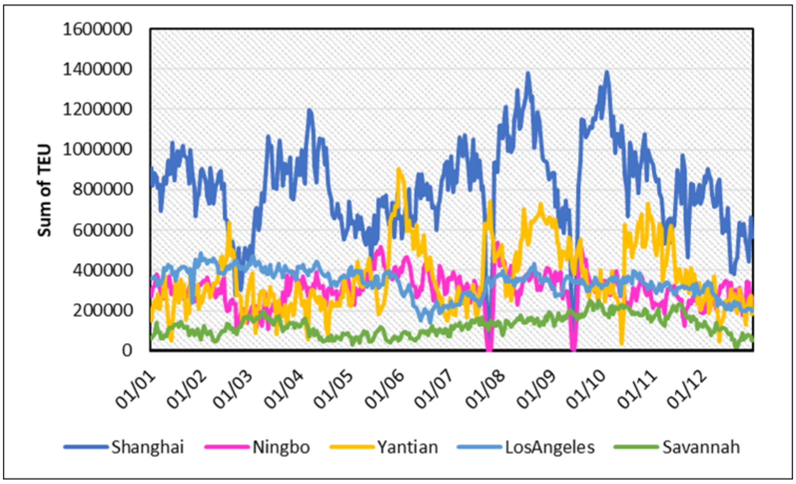

Fig 3. Number of ships stopped at ports of ports of Shanghai, Ningbo, Yantian, Los Angeles and Savannah in 2021 and divided by number of TEU.

3.2 Lockdown and closure of Yantian terminal

The first case study analyzed by the authors is that of the temporary closure of the Yantian terminal. During the month of May 2021, the Chinese government decreed a general lockdown measure on the Shenzhen metropolitan area due to the elevation of Covid-19 cases within the population. Having found several cases of infection among workers at the port, the government has decreed its closure. The Yantian terminal was closed from May 21 to June 10, 2021, blocking dozens of containerships for days and significantly slowing down cargo loading and unloading processes for dozens of days. This closure had a major impact on the region and was considered one of the most significant port congestion in 2021 (UNCTAD, 2021).

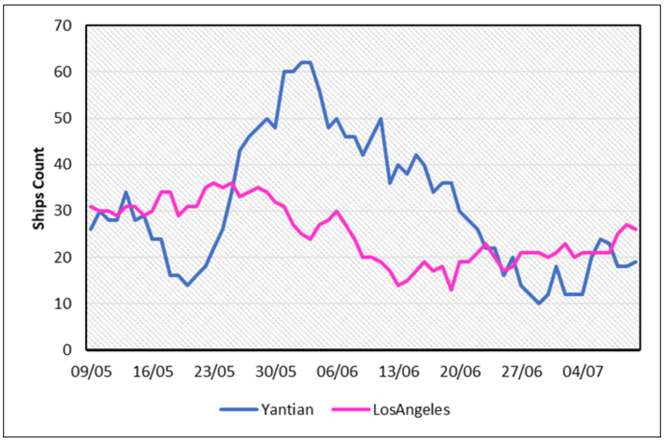

Fig 4. Graph of the number of ships present in the Yantian and Los Angeles port areas during the weeks of the closure period.

As can be seen in the Fig 4 up to 50 ships above 7000 TEU can be counted stopped waiting to enter port. The congestion started on 21 may and lasted until June 25. From the same graph, a likely strong logistical relationship emerges between the Port of Shenzhen (Yantian) and the Port of Los Angeles/Long Beach. The onset of port congestion in the former corresponds almost mirror-image to the easing of congestion in the latter. In our dataset, the peak of the largest contraction of vessels stopped for closure occurred on June 2 and 3 reaching 62 vessels. On the other hand, the peak related to firm cargo capacity in the area was reached on May 31 with 905092 TEUs (Fig 5). This cargo capacity decreased in the following days despite the increase in the number of ships. In fact, in the June 3 there was a decrease of more than 68000 TEUs that were probably redirected to other ports. From Fig 6 it is possible to guess a connection between the blockade at Yantian and the significant decline in the number of ships in the Los Angeles port area.

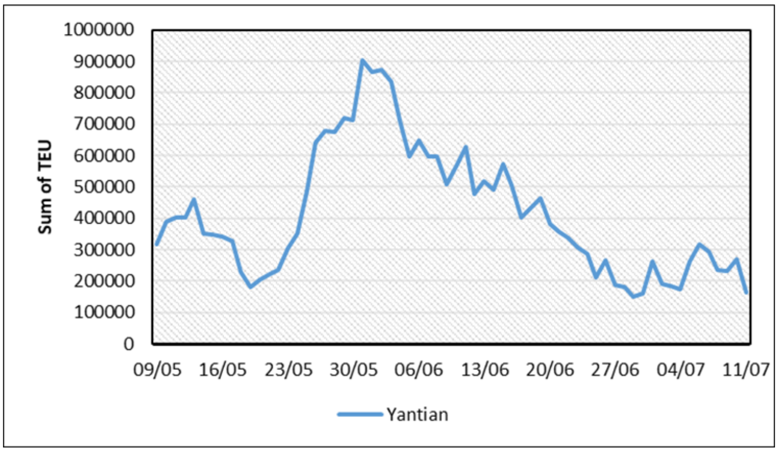

Fig 5. Cargo capacity in port Yantian port area during the weeks of the closure period.

The map in Fig 6 also displays that the average dwell time of ships in our dataset in the Los Angeles port area also has a negative trend, in contrast to those in Yantian and Shanghai ports.

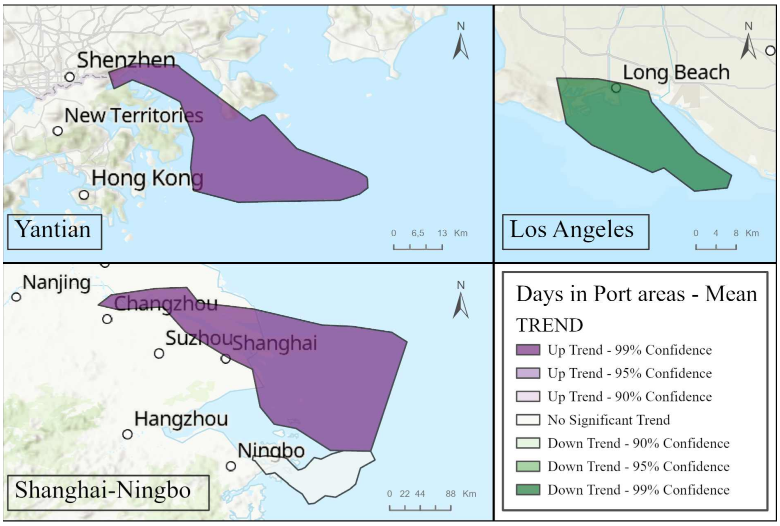

Fig 6. Map of Trends of dwell time of ships in the port areas during the weeks of the closure period.

These trends can also be observed in the graph in Fig 7. It can be seen from the graph values extrapolated from the data cube that the average dwell time of ships in the Yantian port area increased exponentially following the closure and that the return to a more conventional waiting time was achieved only after the return to full operability on June 24.

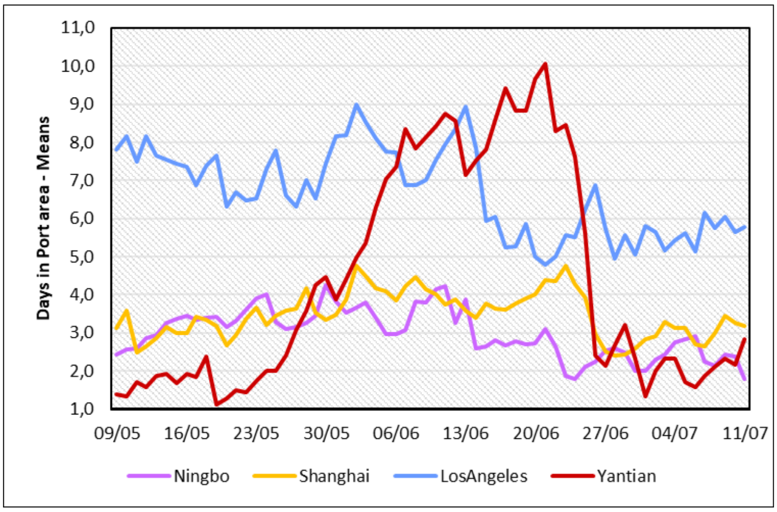

Fig 7. Dwell time of ships in the port areas during the weeks of the closure period.

3.3 Port congestion of Shanghai and Ningbo

The second case study is port congestion on the ports of Shanghai and Ningbo. The two ports from July until October were subject to the phenomenon of port congestion due to various factors of different nature. In fact, in these months, both ports have experienced slowdowns and closures both due to the finding of Covid19 cases among workers and the resulting restrictions, and due to the arrival of two major typhoons that on two occasions forced the interruption of port activities. Fig 8 shows that in the AOIs of the two ports, there were two main periods when there was a significant increase in ships. For both ports, these increases were preceded by two vertical. These declines are probably due to the fact that most ships have moved away from the areas where they usually stay while waiting to enter port. In this way, ships have avoided being in the open sea in bad weather conditions by probably seeking a more protected position. Bad weather coupled with simultaneous Covid19 issues led to two peaks in the concentration of containerships on Shanghai AOI on 18 August, with 114 vessels, and 4 October with 113 vessels. On these two occasions, the concentrated load capacity in the two areas was 1380620 and 1385340 TEUs respectively.

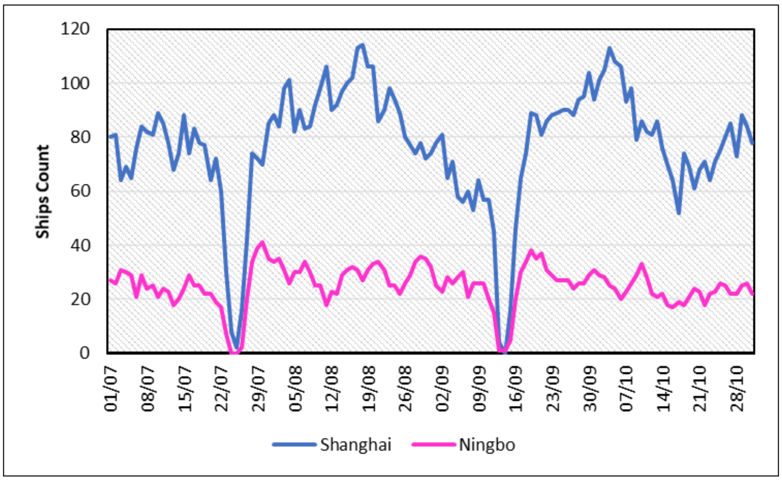

Fig 8. Graph of the number of ships present in the Shanghai and Ningbo port areas during the months of port congestion.

Analysis of the dataset shows that these slowdowns in such a crucial port area with such a high concentration of ships influenced, or were simultaneous with, a general slowdown in logistical operations in all the ports examined. In the map in Fig 9, it can be seen that there is a general upward trend in the average dwell times of containerships within the AOIs of ports.

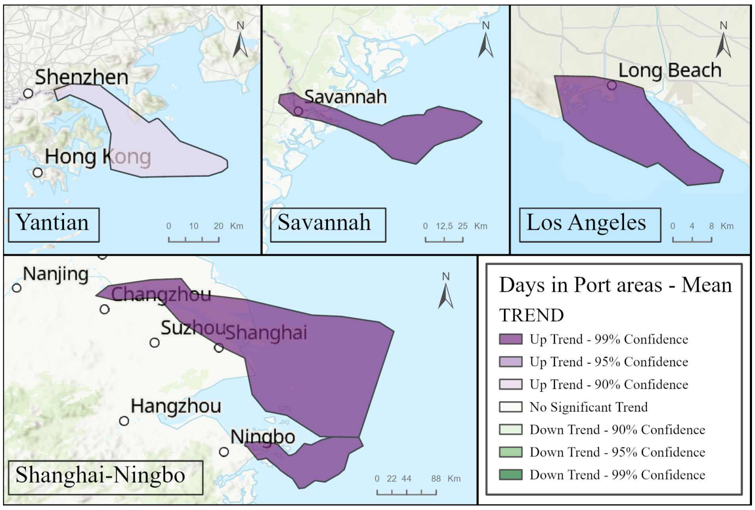

Fig 9. Waiting times from 1July to 30 October in the ports of Yantian, Savannah, Los Angeles and Shanghai-Ningbo.

Looking at the dwell time of ships in Fig 10 however, the strong resilience of Chinese ports is evident. Although there is an increase in waiting days, they remain below 4 days for most of the period under consideration, exceeding it only at peak times, reaching 4.95 on the two days with the highest number of ships in Shanghai port. These waiting times, however, remain much shorter than in the most important American port, Los Angeles, which despite considerably lower traffic numbers maintains significantly higher waiting times.

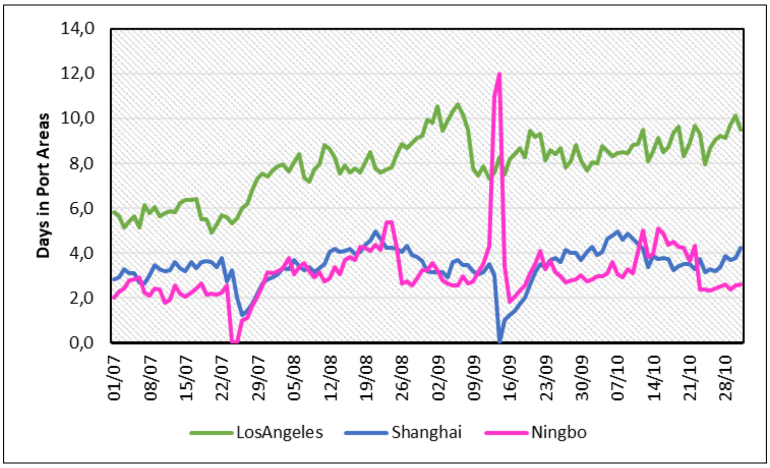

Fig 10. Dwell time of ships in the port of Los Angeles, Shanghai and Ningbo.

3.4 Port congestion in USA

The last case study considered is that of port congestion in the major US ports, namely the ports of Los Angeles/Long Beach and the port of Savannah. Again, this is due to several factors. Both ports, but especially the Port of Los Angeles/Long Beach were slowed down by the Covid19 outbreak that affected many port workers as well as inland logistics workers. In addition, there was a noticeable change in import volumes, also due to an increase in e-commerce during the pandemic, which increased traffic volume in an already stressed sector. **Fig 11** shows a continuous increase from July to early December in the number of ships in the AOIs of US ports. An increase that some even linked to an early Christmas holiday import intensification to compensate for the long delivery times.

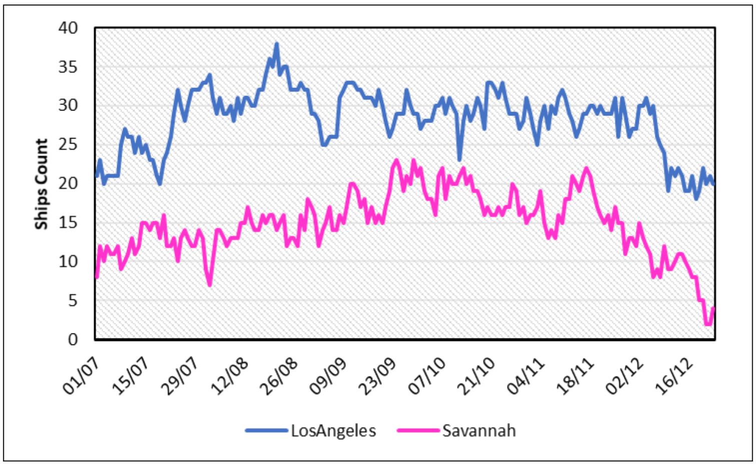

Fig 11. Graph of the number of ships present in the Los Angeles/Long Beach and Savannah port areas.

This general increase in the number of ships, however, has increased the stress on the American logistics system. As can be seen in Fig 12, there has been an upward trend in the number of days ships stay within AOIs, which for the port of Los Angeles/Long Beach remained well above 8 days from September until mid-December.

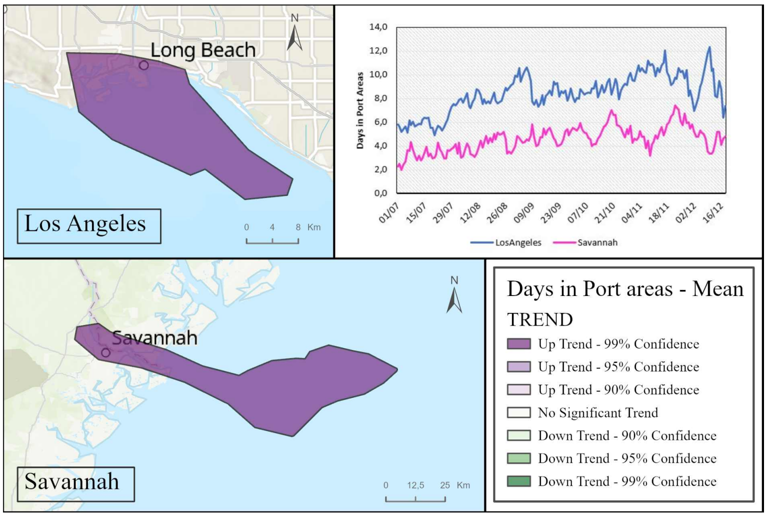

Fig 12. Number of days ships stay in ports of Los Angeles and Savannah

4. Conclusions

In conclusion, the research presented in this paper is open to different considerations of a methodological and substantive nature on the focus topic. From a methodological perspective, it can be said that AIS data prove to be a valuable resource for analyzing complex and global phenomena related to maritime logistics and the world economy. The analysis of these data by means of the spatio-temporal Data Cube tool capable of analyzing and aggregating data in defined locations proves to be an innovative and effective tool for analyzing these phenomena. The possibility of analyzing the data on a temporal level and in a defined area, as well as the visualization of both graphs and trends within map products, proves to be a powerful tool that is able to return both punctual events, such as typhoons on the Chinese coast and the lockdown in Yantian, and trend processes such as the gradual increase in traffic on American ports. Looking at the results of the research into the substance of the topic instead, it can be said that 2021 was definitely a year of great logistical stress. The containment measures of the Covid19 epidemic and the effects on the health of port workers are confirmed as one of the main causes of this stress. However, one can also see how certain slowdowns in port logistics processes, even of a few days as in the case of Shanghai, in some crucial locations of global maritime logistics are able to influence the performance of other ports even significantly.

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