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XXXV Cycle

Real-time monitoring of port dynamics for safety of navigation and mooring manoeuvres within the European Interreg Maritime Project SINAPSI

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Other papers published during the Ph.D.

- Cutroneo L., Cincinelli A., Chelazzi D., Fortunati A., **Reboa A.**, Spadoni S., Vena E., Capello M. (2020). Baseline characterisation of microlitter in the sediment of torrents and the sea bottom in the Gulf of Tigullio (NW Italy). Regional Studies in Marine Science 35, 101119. https://doi.org/10.1016/j.rsma.2020.101119

- Cutroneo L., **Reboa A.**, Besio G., Borgogno F., Canesi L., Canuto S., Dara M., Enrile F., Forioso I., Greco G., Lenoble V., Malatesta A., Mounier S., Petrillo M., Rovetta R., Stocchino A., Tesan J., Vagge G., Capello M. (2020). Microplastics in seawater: sampling strategies, laboratory methodologies, and identification techniques applied to port environment. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-020-07783-8

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I. AIM OF THE THESIS

The present PhD thesis develops within the Project "SINAPSI - Navigation assistance for safe access to ports", which is part of the Interreg Italy-France Maritime 2014-2020 Programme. The Project SINAPSI involved the participation of Italian and French Partners, for the creation and development of instrumentation networks suitable for monitoring marine conditions in the Project ports, aiming to improve the safety of navigation. Thus, the Port of Genoa is one of the entities involved, and this thesis deals specifically with the implementation of a network of Acoustic Doppler current profilers (ADCPs) for monitoring port water dynamics.

To this end, it is necessary to conduct an initial characterization of the Port of Genoa area, both in terms of management and logistics, and of the most frequently occurring weather and sea conditions. This will make it possible to identify the areas that may be most problematic for navigational safety and most interesting for the study of dynamics. In addition, being the safety of navigation one of the main motivations of the Project, research will be conducted regarding the issues and conditions most frequently encountered in maritime accidents, including the role of weather and sea conditions. Furthermore, part of the PhD Project is the involvement of international port realities to obtain useful information with respect to the characteristics that a monitoring network must have in order to be as efficient as possible.

Before the network of current meters can be set up, monitoring campaigns will be carried out, with the aim to collect data on the dynamics of the Port of Genoa under different weather conditions. In addition, data from previous studies in the area will also be analysed. This will provide preliminary information to create a solid base on which to develop the Project, and to be compared with the data that will be obtained from the monitoring network.

The implementation of the monitoring network will consist of several steps. First, it will be necessary to acquire the instruments and the facilities for their installation and for data transmission. Then, suitable sites for the placement of the current meters will have to be identified, working with the Port Authority and the stakeholders. Finally, the instruments can be installed in the selected areas of the Port of Genoa. Part of the Project will also be to conduct data collection campaigns for the purpose of verifying the proper functioning of the current meters. Once the monitoring network is installed, the data obtained will be analysed for the study of water dynamics in the Port of Genoa.

This PhD Project therefore aims to realise a fundamental tool for ensuring safety to navigation in port waters. This type of system had never been present in the Port of Genoa, and its implementation was designed precisely to meet the needs of the Port Authority. Therefore, the ultimate aim of this thesis is both to improve and help the management of safety requirements for maritime traffic and to deepen scientific knowledge regarding the water dynamics of the area Port of Genoa.

II. INTRODUCTION

II.1 ANALYSIS OF MARINE INCIDENTS

Marine traffic accounts for about 80% of world goods transport, and it is affected by an increase in volume and dimensions of ships. The ongoing growth in the size of ships has not been followed by the same expansion in the shape and configuration of ports (Portcrash, 2016), which can lead to difficulties during port entry procedures and docking manoeuvres. Furthermore, the passage of large vessels within the ports produces changes in the conformation of the seabed, creating depressions and sediment accumulations, which must be levelled out and brought back to depths accessible to large ships, through constant dredging activities. Heavy vessel traffic within ports must therefore be carefully monitored, and instruments are needed to facilitate operators, in particular in the event of adverse weather and sea conditions. In these cases, human intervention, especially the ability of operators to handle critical situations, is crucial to the success of port entry and docking procedures. In the event of an accident, the consequences can not only result in damage to ships and docks, but also in environmental emergencies, injuring of persons, and lives loss (EMSA, 2021). For this reasons, safety of navigation of ships in port areas is of main interest to port authorities and operators, as well as citizens.

The total number of marine casualties and incidents reported by the European Maritime Safety Agency (EMSA) over the period 2014-2020 is 22,532 (EMSA, 2021). The 6-year trend remained almost stable, showing a slight increase from 2014 to 2019, and a decrease in the year 2020. The increase, although limited, in the number of incidents over the years is likely to be related to the increase in maritime traffic and the issues mentioned above. Similarly, the numbers observed in 2020 are due to a drop in maritime goods and passenger transport, that occurred in conjunction with the Covid-19 global pandemic. In Italy, the amount of goods embarked and disembarked in ports in 2020 decreased by 7.6% compared to the previous year, while passenger transport decreased by more than a third (-36.3%) (Istat, 2022). Analysing the number of maritime incidents in Italian national waters in the period 2010-2019, an almost stable trend can also be observed in the report published in 2020 by the Ministry of Sustainable Infrastructures and Mobility (MIMS) (ex-Ministry of Infrastructure and Transport – MIT), although in this case the values are slightly decreasing over the years. It is interesting to note that in 2018 there was a peak in the number of accidents, which almost doubled compared to the previous and following year. This increase was due to an abnormal weather event that occurred in October 2018, namely the storm called Vaia, which caused severe storms and enormous damage in several ports, especially on the coasts of northern Italy (**Fig. 1**). If the data on this event are removed from the statistics, the number of maritime incidents in 2018 in Italy is in line with the others of the decade (Fig. 1). In fact, the occurrence of adverse climatic events is highly relevant as a cause of maritime accidents, and it is therefore extremely important that ports be equipped with monitoring instruments suitable for detecting parameters relating to weather and sea conditions.

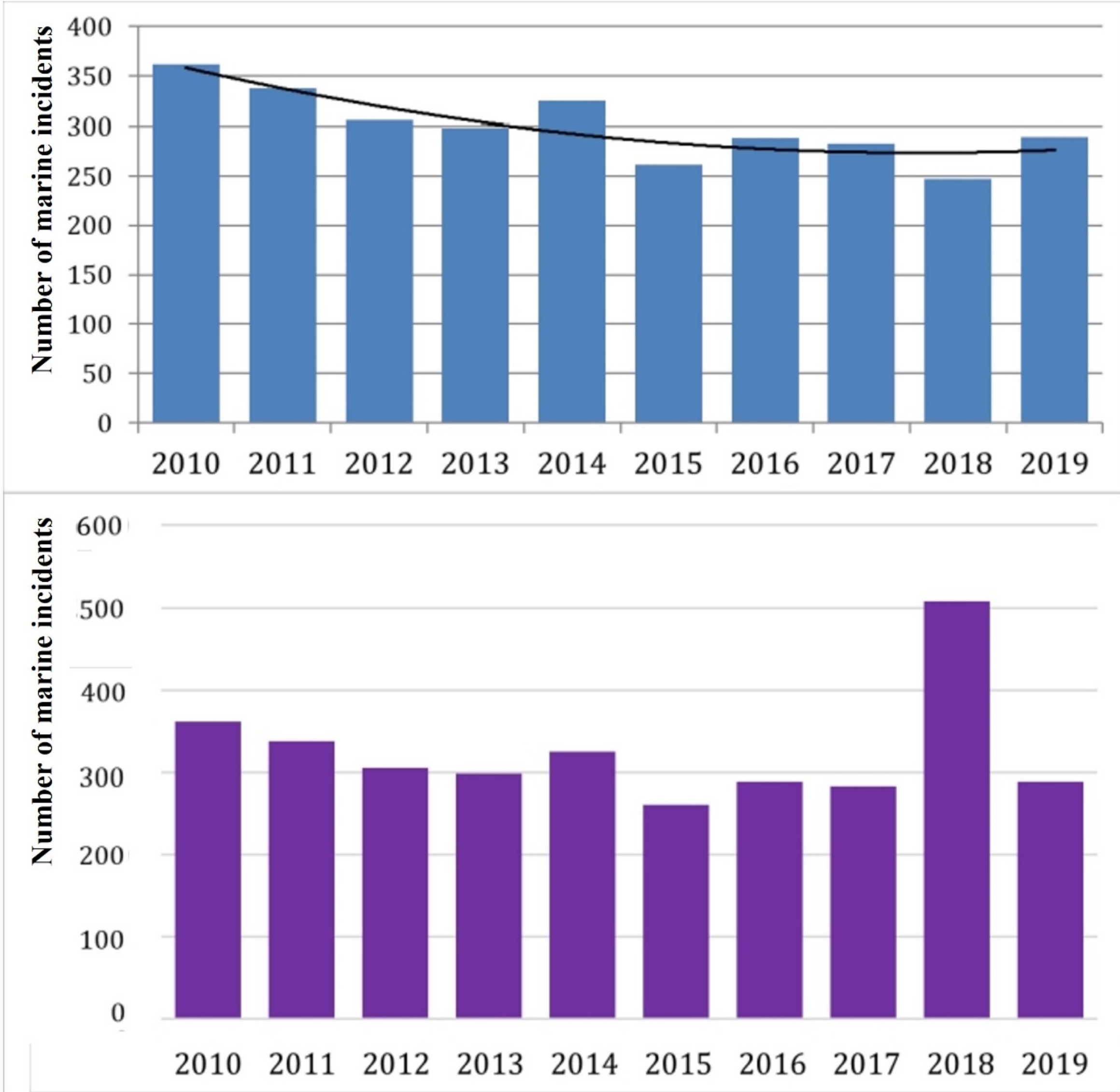

Fig. 1: Incidents to ships of any flag in Italian territorial waters over the period 2010-2019, excluding (above) and including (below) those related to the weather event of 29/10/2018 (MIT, 2020)

The complexity of the port environment determines an added risk factor to navigational safety. The EMSA report (2021) shows the "en route" moment as the most critical for safety, followed by "anchored", then "arrival" and "departure". Internal waters are the location where more than half of the casualties take place, followed by territorial sea, but what it is to be highlighted is that 41.5% of all accidents occur in port areas (**Fig. 2**) (EMSA, 2021). Although the size of ships tends to increase, so does the complexity of port morphology, due to the construction of new quays and specialised terminals, often created by filling in existing stretches of water (Portcrash, 2016). This trend leads to the creation of limited spaces for manoeuvring and docking ships, whereby even a small change in the external environment can affect safety. In addition, many ports have to use auxiliary means, such as tugs, to allow the safe navigation of large cargo ships in particular, while at the same time increasing the number of vessels and operators involved in operations and exposed to a potential risk. Looking at the Italian ports, Genoa ranks second among the Marine Directions involved in maritime incidents, together with Livorno and Brindisi and after the one of Napoli (MIT,2020). The type of vessel whose presence is most critical for port areas are obviously cargo ships, due to their considerable size. Cargo ships tend to increase in size, which is often incompatible with the existing port infrastructure. The future of maritime transport envisages container cargo ships capable of transporting 20,000 teu, over 400 m long and 60 m wide (Portcrash, 2016). In fact, cargo ship is the type mostly involved in marine incidents in Europe, reaching the 44% of the total number of ships involved in accidents in the period 2014-2020 (**Fig. 3**) (EMSA, 2021). At the second place in the ranking of types of ship involved in marine accidents there are passenger ships, and this is due to the increasing dimension of cruises happening in the last years.

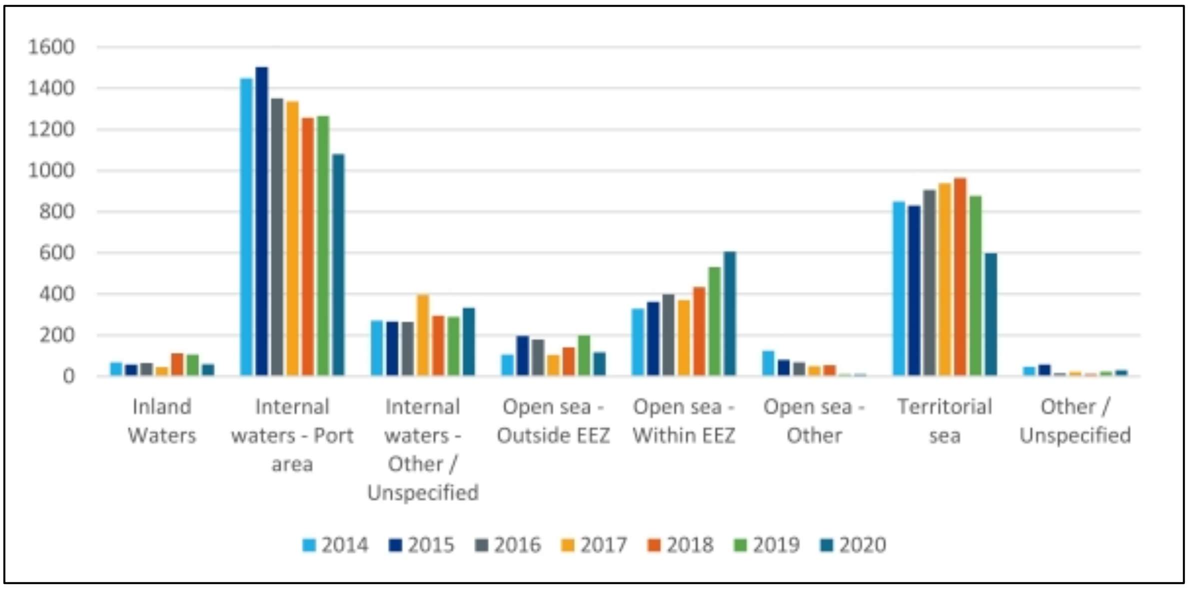

Fig. 2: Distribution by location of marine casualties and incidents in European territory (EMSA, 2021)

	Inland waters	Internal waters	Open Sea	Territorial sea	Other / Unspecified	Total
Cargo ship	457	6076	1935	2392	121	10981
Fishing vessel	11	745	1703	1645	28	4132
Passenger ship	52	3657	650	1530	37	5926
Service ship	50	1683	367	730	26	2856
Other ship	33	583	45	204	12	877
Grand Total	603	12744	4700	6501	224	24772

Fig. 3: Location of marine casualties and incidents per ship type for 2014-2020 in European territory. Highest number of incidents happened for cargo ships in internal waters (EMSA, 2021)

According to EMSA's report (2021), the main type of maritime accidents is loss of control due to loss of propulsion power, with a percentage of 22% over the period 2014-2020; however, when considering collision, contact and grounding events together, marine casualties amount to a total of 43%. A similar situation can be observed when considering accidents occurring on Italian territory, where sinking, collision and contact events accounted for 24%, 19% and 17%, respectively, in the period 2010-2019 (MIT, 2020). Each maritime casualty may be characterised by one or more casualty events that can be divided into the following categories: human action, system or equipment failure, other agent or vessel, hazardous material and/or unknown. At the same time, each casualty event can have one or several contributing factors, according to the following three main categories: external environment, shore management and shipboard operation (EMSA, 2021). EMSA and MIMS agree that the main cause of marine incidents, both on European and Italian territory, is human action; in addition, according to the EMSA (2021), within human action the main contributing factors are related to shipboard operations. The external environment is particularly crucial when focusing on marine incidents which involved "other agent or vessel", where it happens to be the most relevant contributing factor (EMSA, 2021). Within the Italian territory, the external environment is the second biggest cause for marine incidents, being involved in 27% of the total number of accidents over the period 2010-2019 (**Fig. 4**) (MIT, 2020). When considering the external environment, an important contribution is made by the occurrence of adverse marine weather conditions. The concomitance of bad marine weather conditions negatively influences the evolution of the accidental event and aggravates its consequences, in addition to the critical and causal factors that give rise to each specific maritime accident (MIT, 2020).

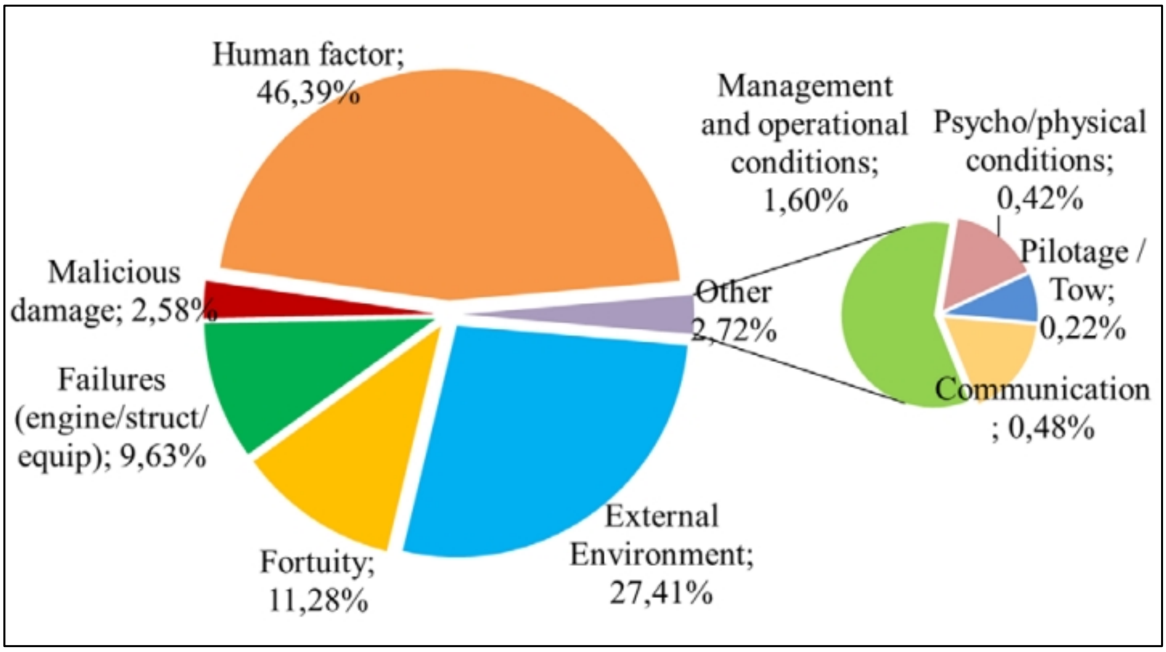

Fig. 4: Causes of maritime incidents occurred to ships in Italian territorial waters (MIT, 2020)

Changes in the intensity and direction of sea and wind currents, the wind gusts and the storm events can lead to unforeseen events during manoeuvres of ships entering port and while anchoring; the lack of information on such data in real time can lead to decision-making errors by operators. Many of the accidents categorised as 'less serious' are mainly caused by marine weather events that can lead to or occur together with manoeuvrability problems, imperfect coordination between ship and tugs, and delayed machinery responses, even in very modern ships (Portcrash, 2016). The MIT (2020), following the 10-year report on maritime accidents, issued several recommendations, eight of which related to the verification of weather and sea conditions prior to the departure of the vessel and the adoption of appropriate precautionary measures. The adaptation of the main Italian ports is therefore essential, as they should be equipped with a network of instruments capable of providing information on weather and sea conditions in real time.

II.2 THE PROJECT SINAPSI

The present PhD study develops in the context of the Project "SINAPSI - Navigation assistance for safe access to ports", which is part of the Interreg Italy-France Maritime 2014-2020 Programme. SINAPSI started on April 2019 and has a duration of three years. The idea of the whole Project comes to actually respond to the needs of the Port System Authority of Genoa, which wanted to implement the safety aspect of navigation in the port area. The Project SINAPSI aimed to develop a network of instruments for monitoring marine weather conditions, in different Italian and French ports. The areas involved in the Project were the ports of Genoa, La Spezia and Livorno-Piombino in Italy, and the port of Toulon in France (**Fig. 5**). Several international Partners participated in the project, as follows: the University of Genoa (UNIGE), the University of Toulon (UTLN), the Chamber of Commerce and Industry of the Var (CCI-VAR), the Institute of Marine Sciences - National Research Council

(ISMAR – CNR), the Consortium LaMMA (LaMMA), the Port System Authority of the North Tyrrhenian Sea (ADSP-MTS), and the European Research Institute (ERI).

Fig. 5: The Maritime Programme area and the ports involved in the Project.

Each port of the Project had different characteristics, and the monitoring network was created and/or implemented on the basis of its features and requirements. The fixed instruments used throughout the Project were current meters, wave meters and HF radars, but the choice of installing one or more type of instruments was decided depending on the actual needs and positioning possibility. Similarly, the installation of the current meters was realised with different types of supports, whether buoys or ground mounted structures. depending on the location site and the type of instrument established. Current meters and wavemeters were exploited for acquiring data in sites usually located at the entrances or inside the ports, recording and/or transmitting information about marine currents direction and intensity, and wave height, respectively. The use of HF radars allowed the monitoring of a wider area at the entrances and outside the ports, providing information on surface sea currents. The near real-time transmission of the collected data, and the possibility to access the information through public web portals, provides an important and useful tool for port Authorities and operators, implementing the safety during navigation and manoeuvres procedures. Furthermore, part of the Project SINAPSI consisted in the implementation of numerical models to realise previsions of the marine circulation inside and outside port areas. Marine circulation forecasts are also available through the web portals.

The Project consisted in different steps, as management, implementation and dissemination of the Project. In order to be able to manage the project effectively, it was first of all necessary for all partners to work closely together, which was made possible through the organisation of Steering Committees (CoPil), through which all representatives were able to keep abreast of each other's progress and to check the progress of the defined programme. These meetings made it possible to coordinate not only the implementation and installation of the monitoring networks, but also administrative and financial matters. In parallel, meetings were also organised with technical and scientific working groups according to project needs. The implementation phase of the Project was differentiated according to the two types of planned outputs, namely the monitoring network and the numerical models. With regard to the monitoring network, the implementation of this phase of the Project involved not only its design and the installation of the instruments, but also the realisation of monitoring campaigns both prior to and contemporaneous with the presence of the fixed instruments. This made it possible to acquire the so-called 'sea truth', i.e. to obtain data directly in the field, which can be compared with forecasts made by modelling. The campaigns were carried out using both two different types of instruments: vertical current meters and drifters. Vertical current meters were mounted on the hulls of boats, allowing the acquisition of data on currents throughout the water column along transects. Drifters, on the other hand, are instruments that are released at sea to be able to passively follow the course of surface currents and acquire data remotely. Finally, the communication phase developed in two different modes: dissemination and capitalisation. Dissemination exploited useful tools and simple concepts to explain the issues of SINAPSI and the problems it aims to solve. To this end, social media platforms and videos were used to inform different age groups about the Project's objectives. Capitalisation, on the other hand, involved the dissemination of oceanographic data measured by installed instrumentation and modelling applied to ports. This involved a more technical audience and stakeholders interested in the Project's outputs, such as Port System Authorities, Port Management Authorities, Maritime Authorities, Pilots, and other port operators.

During my PhD project, I had the opportunity to actively participate in the Project SINAPSI, regarding the development of Project activities, the management of the Project, and the relationship aspects with Partners and stakeholders. I was directly involved in the realisation of the Project Products and took part in the Steering and Technical Committees, thus actually contributing to the realisation of the Project. Furthermore, I was involved in the dissemination of the Project, participating in the production of digital content and interviews that were shared via the SINAPSI's platforms (**Fig. 6**).

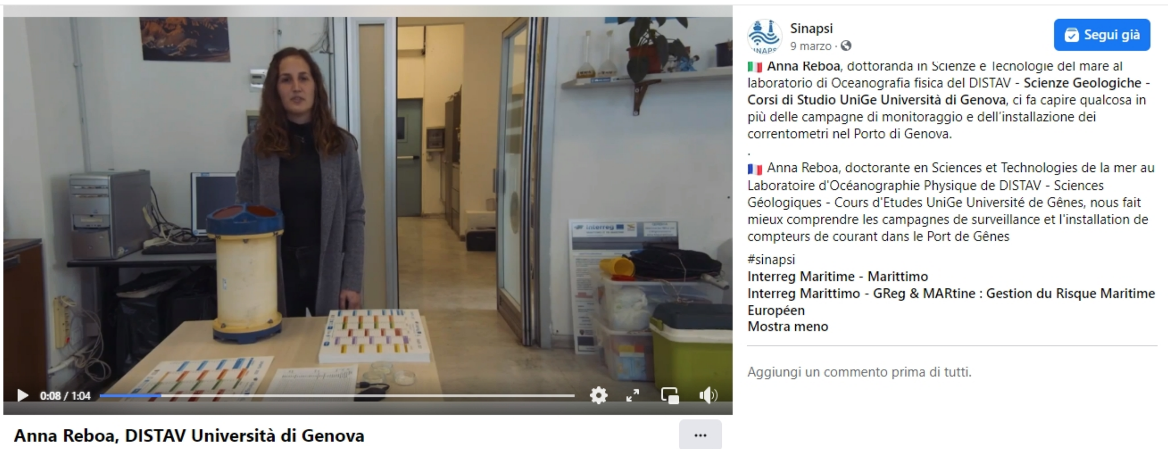

Fig. 6: Interview for the dissemination of the Project SINAPSI activities.

II.3 THE PORT OF GENOA

The Port of Genoa is located in the centre of the Liguria Region, which occupies the northwest coast of Italy. The port stretches along the coast for about 20 km, with a total area of more than 7 million m^2 (**Fig. 7**) (Ruggieri et al., 2011). Within the Port of Genoa there are 25 terminals equipped to accommodate all types of ships and goods: containers, miscellaneous goods, perishable goods, metals, forestry, solid and liquid bulk, petroleum products and passengers, with a full range of complementary services, from ship repairs to ship fitting out, telematics and computerization (Ports of Genoa website, 2022). The most significant functions are distributed as follows: commercial function in the Sampierdarena and Voltri area; industrial function in the area between Calata Gadda and the "Piazzale di Levante", as well as in the Sestri Ponente area; passenger function in the area between Ponte Caracciolo and Ponte dei Mille (Porto Antico Basin); oil function in the Multedo area; and urban function articulated in different territorial contexts (Fig. 7) (Ports of Genoa website, 2022). Regarding the commercial sector, the Port of Genoa is a leader in the traffic of conventional goods, transported by ships with differentiated characteristics (traditional, ro-ro, specialized), but in recent years it has undergone changes aimed at implementing the growing container transport market. In this context, in fact, the Port of Genoa is of great commercial importance internationally, ranking tenth among the top 20 ports in Europe and the Mediterranean in 2020 (Eurostat, 2020), moving a total cargo of 2.4 million TEUs, increasing to 2.6 million TEUs in 2021 (Ports of Genoa website, 2022). In addition, The Port of Genoa is ranked first in 2020 for Ro-Ro cargo transport, among all European and Mediterranean ports (Eurostat, 2020). An increase in maritime traffic has also occurred due to a growing interest in cruise shipping. This growth can be attributed to the lively demand for the "Mediterranean product" that has occurred since the early 1990s, which was followed on the one hand by more intense operations of the major cruise lines and, on the other, by the commissioning of the cruise terminal at Ponte dei Mille. In fact, cruise traffic in the Port of Genoa reached nearly 1.5 million passengers in 2019, then suffered a drastic and inevitable decline due to the Covid-19 pandemic, dropping to 131,000 passengers in 2020, but increasing again in 2021 (Ports of Genoa website, 2022). A similar trend occurred for ferry passenger transport, which had reached over 2 million passengers in 2019 (Ports of Genoa website, 2022). Another very prolific sector in the Port of Genoa is the industrial sector (Fig. 7), which is composed almost exclusively of small and medium-sized private companies. These companies represent a quantitatively and qualitatively significant component of the market and are present in almost every segment into which the sector is divided, with a range of products and recognized quality (Ports of Genoa website, 2022). The Port of Genoa is closely connected with the city of Genoa, which directly overlooks its innermost water basin (Porto Antico Basin), and within the port area two of the most important metropolitan streams flow into the city, namely the Polcevera Torrent (in the western area of the Sampierdarena Channel) and the Bisagno Torrent (just outside the eastern entrance of the port) (Fig. 7). The two streams have a catchment area of 93 km^2 and 140 km^2 for the Bisagno Torrent and Polcevera Torrent, respectively (Cutroneo et al., 2017), and their presence affects the characteristics of the water masses inside the port. In fact, following rainfall, a surface layer of relatively fresh water can be detected close to the mouths, which tends to drift into the port area, from the Polcevera Torrent in the case of north/northwest winds and from the Bisagno Torrent in the case of southeast winds (Capello et al., 2010).

Fig. 7: Satellite picture of the Port of Genoa (Google Earth): the commercial area (in blue); the passengers' area (in orange); the industrial area (in pink). Red dots highlight the mouths of the Polcevera Torrent (left) and the Bisagno Torrent (right)

The Port of Genoa overlooks the Ligurian coast, which is characterized by the presence of a permanent cyclonic current with meanders and eddies developing along its limits (Cutroneo et al., 2017). Currents that develop inside the Port are strongly influenced by the wind which tends to confine water masses within the port area when coming from the south. In contrast, in case of northerly winds, currents tend to flow out of the harbor in a south/southwesterly direction in the western zone, with a velocity that can reach 50 cm·s-1, while in the eastern zone, a movement of water masses can be observed heading toward the inner part of the breakwater and exiting through the eastern mouth of the harbor (Capello et al., 2010). In the case of a southeasterly wind, a double flow occurs at the eastern entrance of the port, where outgoing currents along the breakwater are opposed to incoming currents along the landward side of the entrance (Cutroneo et al., 2017). Analyzing the dynamics within the port area in detail, it is very complex and strongly influenced by the presence of piers and docks that create an intricate geometry of structures jutting into the basin. In addition, the wind forcing is accentuated by the relatively shallow depth of the port area. In particular, the geometry of the harbor is intricate and complex in the innermost part of the port, leading to the occurrence of a series of current vectors going in all directions with varying intensities. In that area, there is a near absence of intense inward current flows, while currents of higher intensity tend to move outward from the port creating a confined area with low oxygen content (Capello et al., 2010).

II.4 THE ACOUSTIC CORRENT DOPPLER PROFILERS (ADCPs)

Acoustic Doppler Current Profilers (ADCPs) are current meters that measure water movements based on acoustic waves. They take advantage of the fact that sound is subject to the Doppler effect, i.e. the increase or decrease in frequency of sound waves that occurs when the source and the point of observation of the sound are approaching or receding from each other (Trembanis et al., 2021). ADCPs therefore emit sound waves that record the current-driven movement of suspended particles in the water column, based on the frequency shift of the sound waves that are reflected by the particles and return to the instrument (Trembanis et al., 2021). The instrument measures the resulting velocity and direction of the currents by dividing the water column into cells (bins). Both the size of the bins and the number of sound inputs (pings) emitted by the instrument can be set as desired, based on the characteristics of the environment to be observed and the resolution to be obtained (Ton et al., 2020). There are vertical ADCPs (V-ADCPs) and horizontal ADCPs (H-ADCPs). V-ADCPs measure the current along the vertical profile of the water column, and can be used in different configurations, i.e. either on the bottom directed towards the surface, or on the surface directed towards the bottom, and, in the latter case, can be mounted on the hull of a vessel in order to take measurements in motion along transects (Parsons et al., 2013). Instead, H-ADCPs measure the current along a horizontal profile and are therefore designed to be installed in a fixed position on a structure at the desired depth (Moore et al., 2012). ADCP current meters can have a different number of transducers (beams) that are positioned at an angle of between 20 and 30°, and this inclination leads to a spatial extent of the measured volume that increases with distance from the instrument (Ton et al., 2020). The length of the measured profile, both vertical and horizontal, depends on the frequency of the instrument: lower frequencies, which requires larger bins, can penetrate further than high frequencies, which in turn need smaller bins size and thus present a better spatiotemporal resolution (Jay et al., 2015). Hence, the choice of the frequency of the instrument should be made depending on the characteristics of the environment and the results needed; however, the most common frequencies used are 300 kHz, 600 kHz and 1200 kHz (Moore et al., 2012). Despite vessel-mounted-V-ADCPs are very useful in monitoring campaigns, they are not particularly suitable in case of fixed stations in port environments, due to the huge maritime traffic and operational activity that happens constantly in those areas. In fact, the presence of a buoy on the surface may disrupt the passage of ships, and an instrument placed on the sea bottom can be damaged for example during dredging activities. For these reasons, the choice of H-ADCPs is preferable when installing a fixed monitoring station in ports, since it can be easily placed along docks or a breakwater without interfering with traffic and port activities.

III. MONITORING NETWORKS FROM INTERNATIONAL PORTS

My doctoral research for the development of a marine current monitoring network in the Port of Genoa, involved the study of marine weather monitoring systems in several international ports. Due to the global Covid-19 pandemic, it was not possible for me to observe most of these systems in person, but I was able to engage with various international Institutions and Port Authorities via web-meetings. The information gathered was very useful to understand the needs of the different port realities according to their conformation, and structural and environmental characteristics. Furthermore, I became aware of the characteristics required for the development of a monitoring network that complies with the standards set by the Italian Port Authorities. This information was crucial for my study and can be used to implement in the future the installed monitoring network.

III.1 PORT OF VENICE

Web meeting, October 28, 2021

With: Paolo Menegazzo - Head of Strategic Transport Planning Area at the Strategic Planning and Development Department (North Adriatic Sea Port System Authority)

Technical additional information:
Stefano Venturino – Head of Environmental Networks and Measures Unit Environment and Territory Area (Thetis S.p.A.)
Massimo Marrazzo - Lieutenant, Chief of TLC systems for monitoring maritime traffic (General Command of the Harbour Office Corps - Coast Guard)

The Port of Venice is located in the inner part of the Lagoon of Venice, which means ships have to transit through narrow channels to access it and the transit lasts about two hours from outside the Lagoon to the port area; thus, a constant dredging activity is required. The canals accessing the Port of Venice present several problems related to navigation safety, especially due to their limited width, which measures approximately 60 m at its narrowest points, which is problematic to manage, especially in adverse wind and current conditions. For this reason, a meteorological-marine data monitoring network has been developed and is supplied in real time to port operators directly through the Automatic Identification System (AIS) installed on ships. The data provided in real time, in addition to those identifying the vessel and its path, concern currents, waves, tide level, wind and visibility. In addition, a public computer application has been developed, where a dedicated map shows real time the characteristics, position, course and speed of the ships present in the coastal area in front of the Venice Lagoon and within it (**Fig. 8**) (VePorto website, 2022). On the same map, it is also possible to view all the monitoring stations and the data recorded in real time by the various instruments, including anemometers, current meters and wave meters (**Fig. 9-10**). Finally, tidal forecasts and data from all instruments in tabular form are available. The application was initially developed for use by pleasure boats, as large ships need to have access to this information already during the approach to port, and therefore outside the coverage of the telephone network. For this reason, a programme agreement was made with the General Command of the Harbour Master's Office, so that real-time data is transmitted via AIS, allowing it to be within the standards of the International Maritime Organisation (IMO).

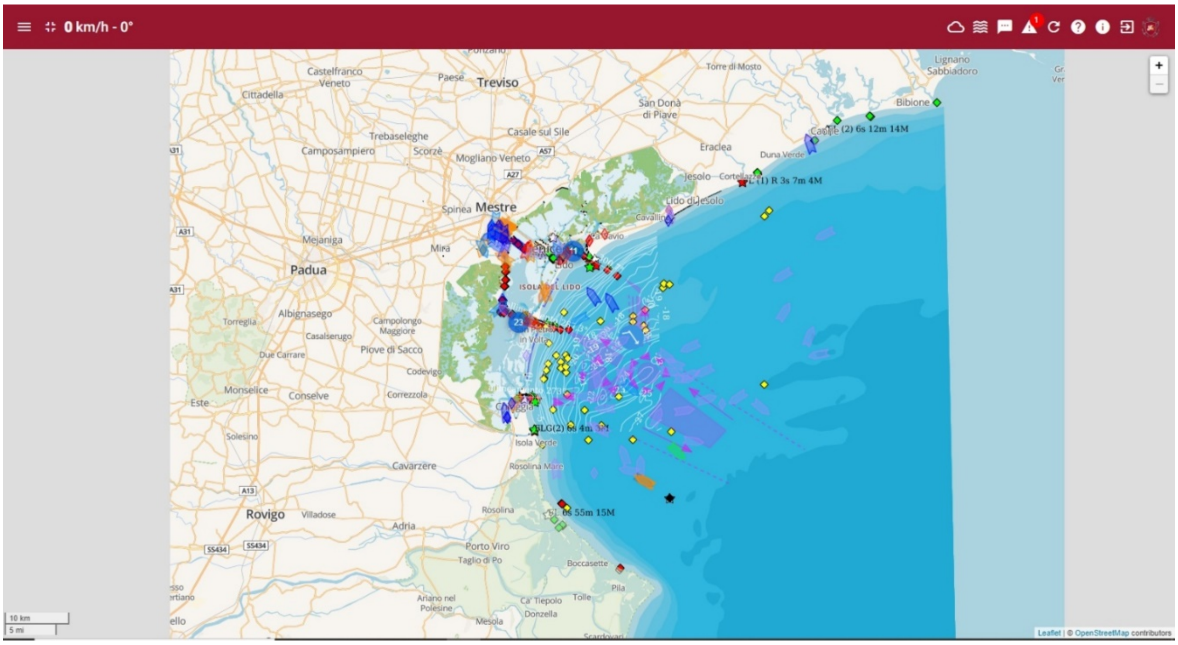

Fig. 8: Application area (VePorto website, 2022)

Fig. 9: Example of visualitation of data (VePorto website, 2022)

Fig. 10: Example of visualization of instrument location (VePorto website, 2022)

Weather and sea data are also transmitted to the Pilots via Pilot portable units (Ppu), which are advanced portable devices that provide real-time precision data to support the Pilots' activities. These instruments are equipped with modelling systems that, starting from the tidal height data received, are able to update bathymetries in real time, and, starting from the speed and direction data of the sea currents at the inlets, report the current speed gradient for the approach; thus, the Pilot can know the ship's position in the following seconds during manoeuvres.

In the Venice lagoon, three Teledyne vertical-ADCP have been positioned at the lagoon inlets, (i.e. the Lido, Malamocco and Chioggia access points) (**Fig.11**), where the Mose system is in place and is managed by the same agency as the current meters. The instruments are positioned on the sea bottom and directed towards the surface, and their frequency characteristics differ depending on the depth of the site. At the Lido site there is a 1200 kHz current meter, as the depth is approximately 6 m, while at the Malamocco and Chioggia sites there are 600 kHz current meters, for depths of approximately 10-12 m. The data is transmitted to the Port Authority server via fibre optic or telephone provider, every five minutes, in text document format (.txt). Both the raw data and the average values of all cells recorded by the instrument, are provided. The Port Authority converts the data received into JSON (JavaScript Object Notation) string format, and exposes it via a web service, so that the Harbour Master's Office can collect it and convert it into a format that can be received by the AIS systems.

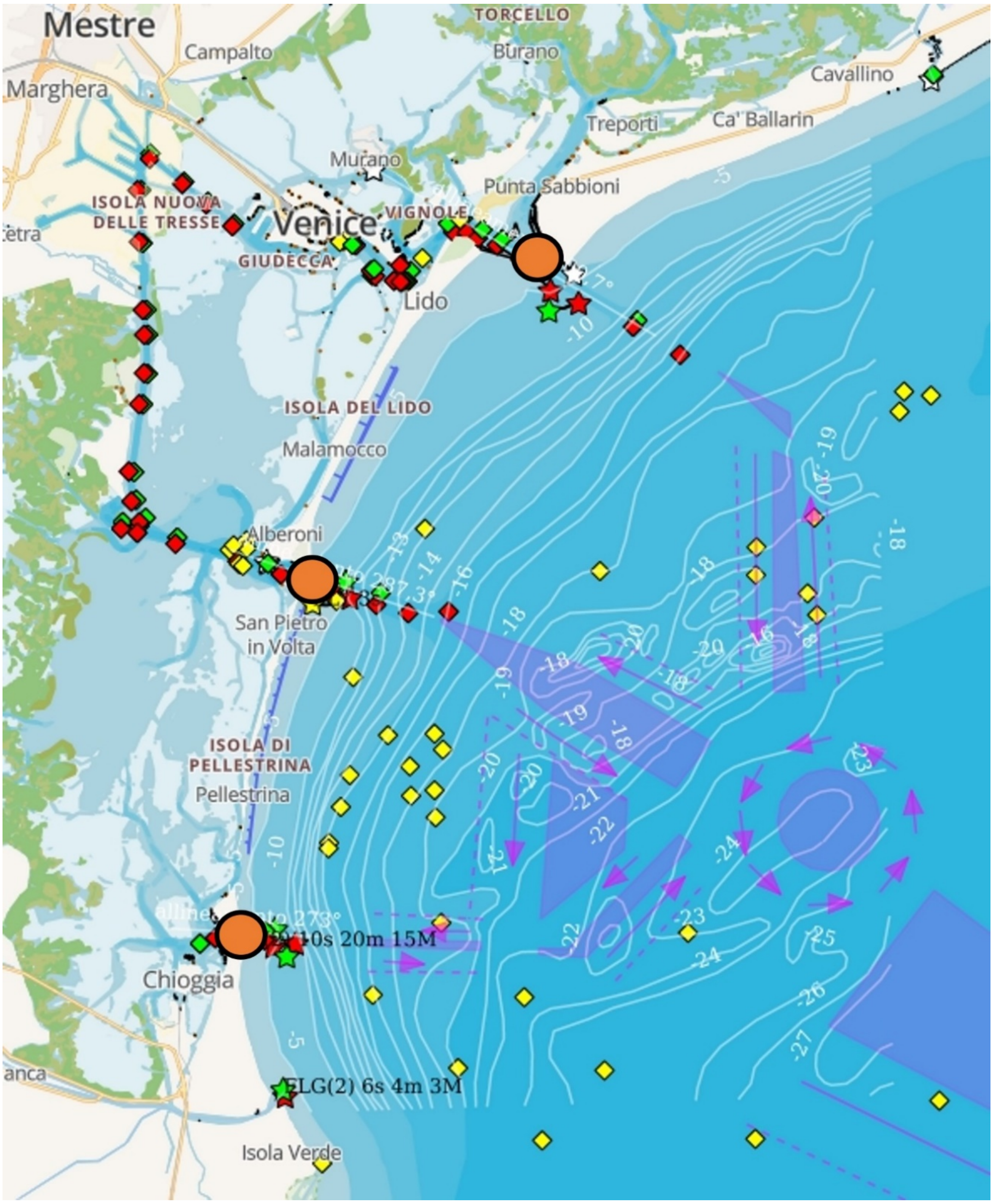

Fig. 11: Current meter locations (orange circles) (VePorto website, 2022)

The main problem related to safety during navigation in the Port of Venice concerns tidal trends, and consequently the closure forecasts of the Mose system. The Mose is a system of 4 barriers consisting of 78 mutually independent movable sluice gates designed to temporarily separate the lagoon from the sea, and to defend Venice from both exceptional and destructive tidal events (up to 3 m) and the more frequent rise in sea level (up to 60 cm) (MOSE website, 2022). Therefore, the marine weather data are used both for the management of ship manoeuvres and for the forecasting of short-term conditions that allows the planning of maritime traffic. In fact, the Mose currently allows the barriers to close in case of high-water events exceeding 130 cm, and its function can result in the complete blockage of traffic for 6-7 hours. These timeframes will increase when the Mose will be at its full capacity, and will already work during high-water events above 110 cm. The tidal height in the Port of Venice is measured against a local reference, which is 23 cm higher than the mean sea level in Genoa; daily variations of approximately 130 cm (-50 and + 80) are recorded.

III.2 PORT OF TOULON

Live Meeting, November 25, 2021

With: Francis Gaborit – Port development at la Chambre de Commerce Territoriale du Var (CCI Var)

The Port of Toulon consists of different areas along the Roadstead of Toulon (**Fig. 12**). Most of the territory is occupied by the Military Harbour, while the remaining areas are dedicated to ferry and cruise passenger transport, commercial traffic, and industrial activities. The Terminal Toulon-Côte d'Azur (TCA), which is in the basin in front of the city centre of Toulon, accommodates ships and activities dedicated to transporting passengers by ferry on routes connecting Toulon with Corsica and Tunisia, as well as several cruise ships. In the westside area of the Roadstead of Toulon at La Seyne-sur-Mer, there is the Port of Bregaillon where there are two terminals dedicated to commercial traffic. This port, specialised in intra-Mediterranean cargo transport, is capable of handling specific traffic, and its strengths are its security, operational reliability and the versatility of its sites, as well as its ability to handle complex materials. The Multimodal North Terminal handles ro-ro and conventional goods, heavy cargo, bulk and new vehicles, and is directly connected to the road and rail networks, constituting a logistics alternative in terms of multimodal transfer. The South Terminal is dedicated to special traffic, as dangerous goods, and consists of one hectare of quay whose access can be closed off for secure and confidential operations. Industrial activities are present at the Port of Bregaillon in La Seyne-sur-Mer, such as the ones dedicated to yacht industry, as well as the Ifremer Institute of Marine Science and Technology. A cruise terminal is in the South-West area of La Seyne-su-Mer and can accommodate larger vessels than the TCA. In addition, within the Toulon harbour there are two marinas dedicated to the mooring of pleasure boats, one located in the area in front of the TCA, and therefore close to the city centre of Toulon, and one located in La Seyne-sur-Mer, between the industrial area and the South Terminal of the Port of Bregaillon.

Fig. 12: The Port of Toulon: passenger area (blue); commercial area (red); industrial area (green). (OpenStreetMap)

Within the Project ALACRES2 "Advanced Laboratory Service for Crises and Emergencies in the Port in the Upper Tyrrhenian Cooperation Space, based on Simulation", which is part together with SINAPSI of the cluster of Interreg Maritime Projects "Greg & Martine", a detailed mapping of the Port of Toulon was developed (**Fig. 13**). The 3D reconstruction was developed based on drone surveys, which took three months. The map is developed interactively, so that it is possible to isolate individual areas, display photographic images and make use of various instruments for measuring. In the future, it will also be possible to include within the reconstruction any current data provided by instruments that are positioned within the Toulon Roadstead.

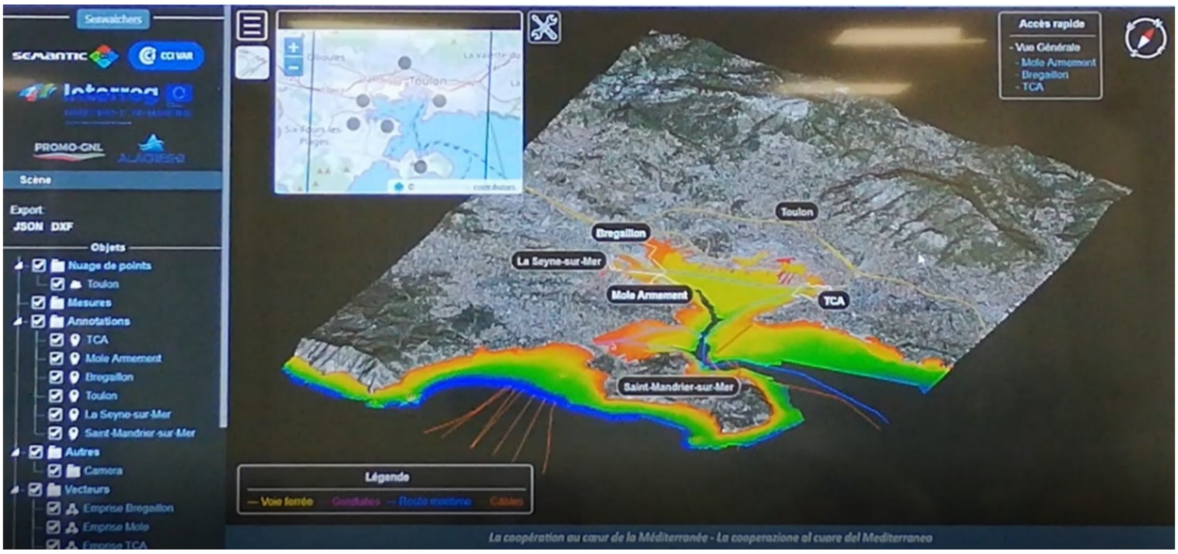

Fig. 13: 3D Reconstruction on the Roadstead of Toulon

In the context of the system for monitoring of marine weather conditions, three WERA 16.15 MHz radar antenna systems are in the area outside and in front of Toulon, and they are operated by the University of Toulon. In particular, the radar antenna system closest to the Toulon Roadstead is on the top of the Peyras Fort, on a promontory 8 km far from Toulon, and consists of 16 antennas; the other two are located on the Island of Porquerolles and on the Cap Bénat Semaphore (**Fig. 14**) (HF Radar website, 2022).

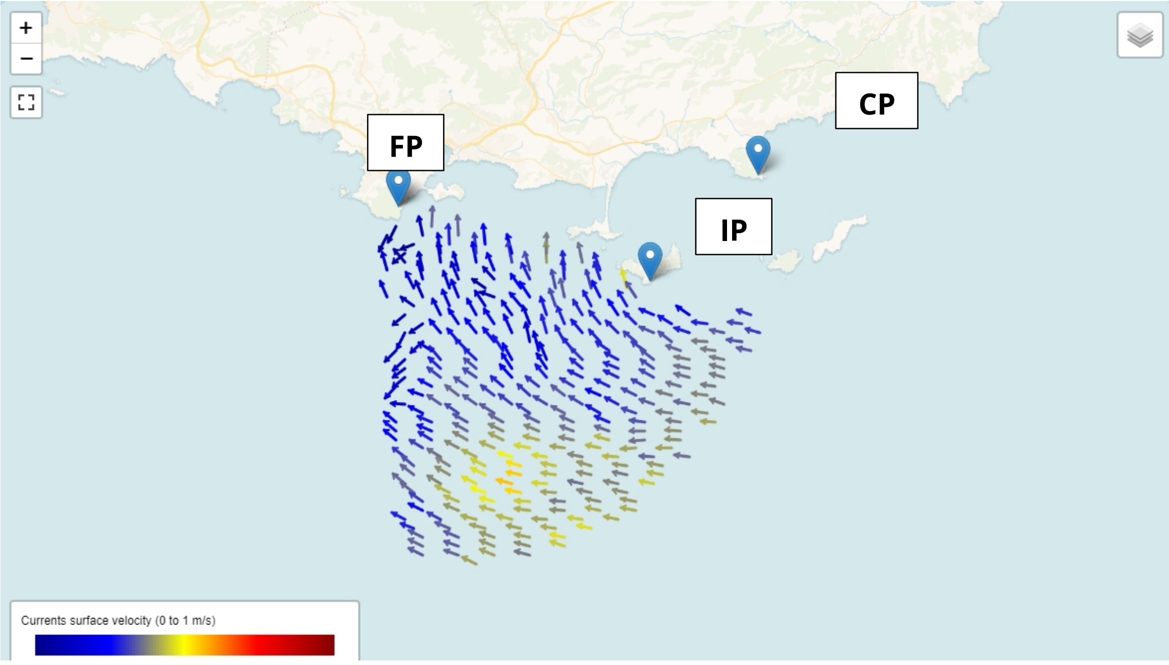

Fig. 14: Positioning of the radars in front of the Toulon Roadstead (FP: Fort de Peyras; IP: on Porquerolles Island; CP: Cap Bénat Traffic Light) and an example of current data collection) (HF Radar website, 2022).

This radar network allows to obtain surface sea current data over an area extending 70 km from the coast, which are provided in near real-time (1 h delay). The radial component of the current vector obtained from each radar system has a resolution of 1.5 km; the interpolation of the data from the different radar systems is performed on a 1km x 1km grid to obtain the current vector. On the website of the Institut Méditerranéen d'Océanologie (MIO) of the University of Toulon, it is possible to access current data on a daily and monthly time scale) (HF Radar website, 2022).

The Project SINAPSI included the positioning of a station for the fixed monitoring of weather and sea conditions in the Toulon Roadstead, carried out by the MIO in collaboration with the company iXblue (ixbuoy-toulon website, 2022). The station is located at the entrance to the Toulon Roadstead and consists of a buoy anchored by an anchor (dead body), placed on the sea bottom at a depth of 40 m, which transmits the data obtained from the connected instruments in near real time (**Fig. 15**). In fact, an anemometer and a wavemeter are installed on the surface buoy above the sea surface, and a CTD (conductivity-temperature-depth) probe and an ADCP current meter are placed close to the bottom (Fig. 15) (ixbuoy-toulon website, 2022). Data on wind intensity and direction, wave height, physical parameters of the surface water (e.g. temperature), and current direction and intensity, are therefore transmitted in near real time. The current meter installed is a Nortek AQP 600kHz, which monitors the vertical profile of the current from the surface to the bottom. In addition, there are three other CTD probes, two along the cable connecting the buoy to the dead body and one on the sea bottom where another ADCP current meter is also located. The latter instruments do not provide real-time data but must instead be downloaded manually.

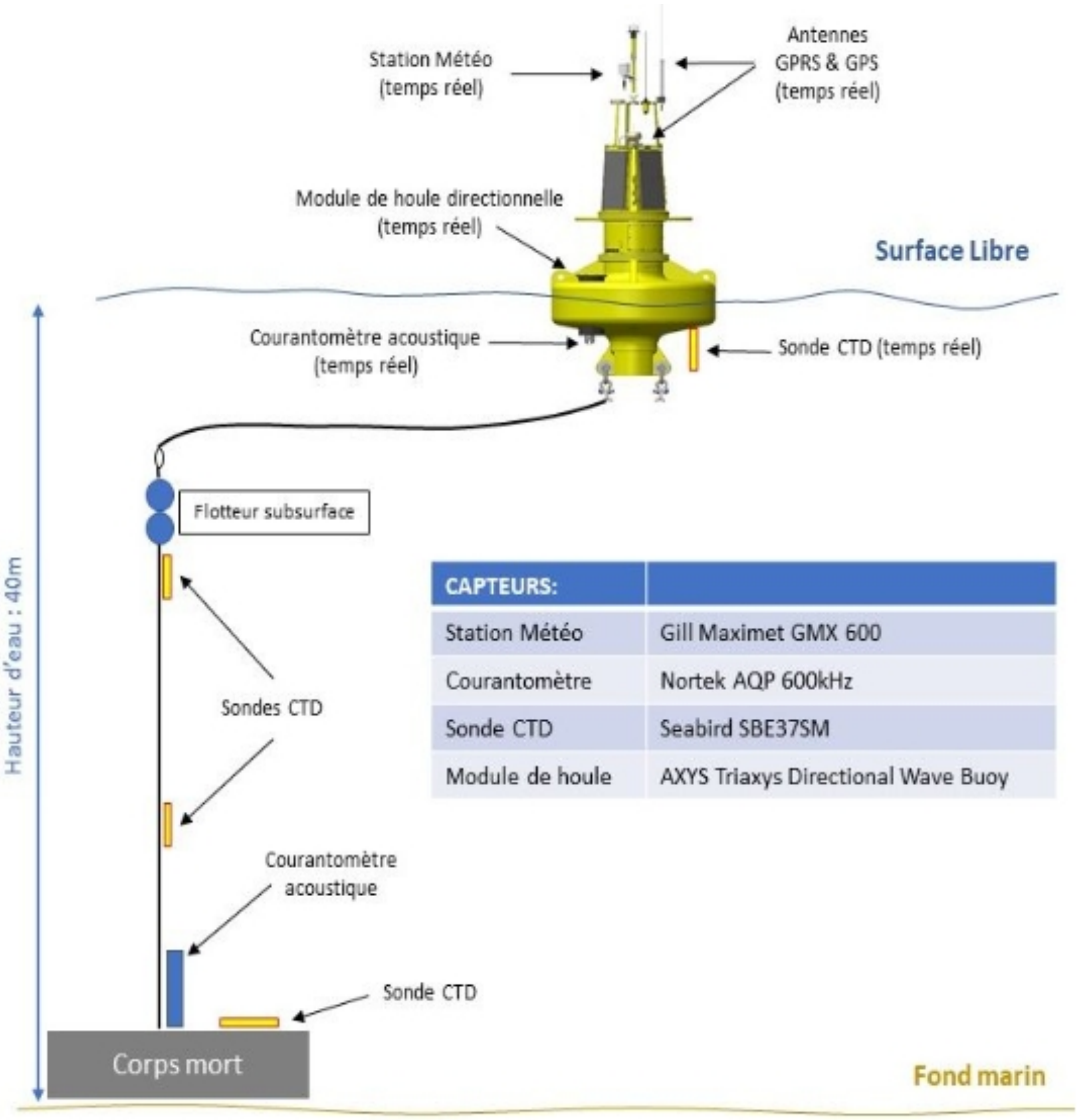

Fig. 15: The monitoring system at the entrance to the Toulon Roadstead
(ixbuoy-toulon website, 2022)

It is also possible to look at the system and the obtained data on a dedicated site, which also provides the evolution of meteorological and marine data in the week preceding the day of consultation (ixbuoy-toulon website, 2022) (**Fig. 16-17**). In particular, information on current direction and intensity is provided at depths of 2 and 10 m, both in the time profile and in real time.

Fig. 16: Real-time visualisation of data obtained from the monitoring system (ixbuoy-toulon website, 2022)

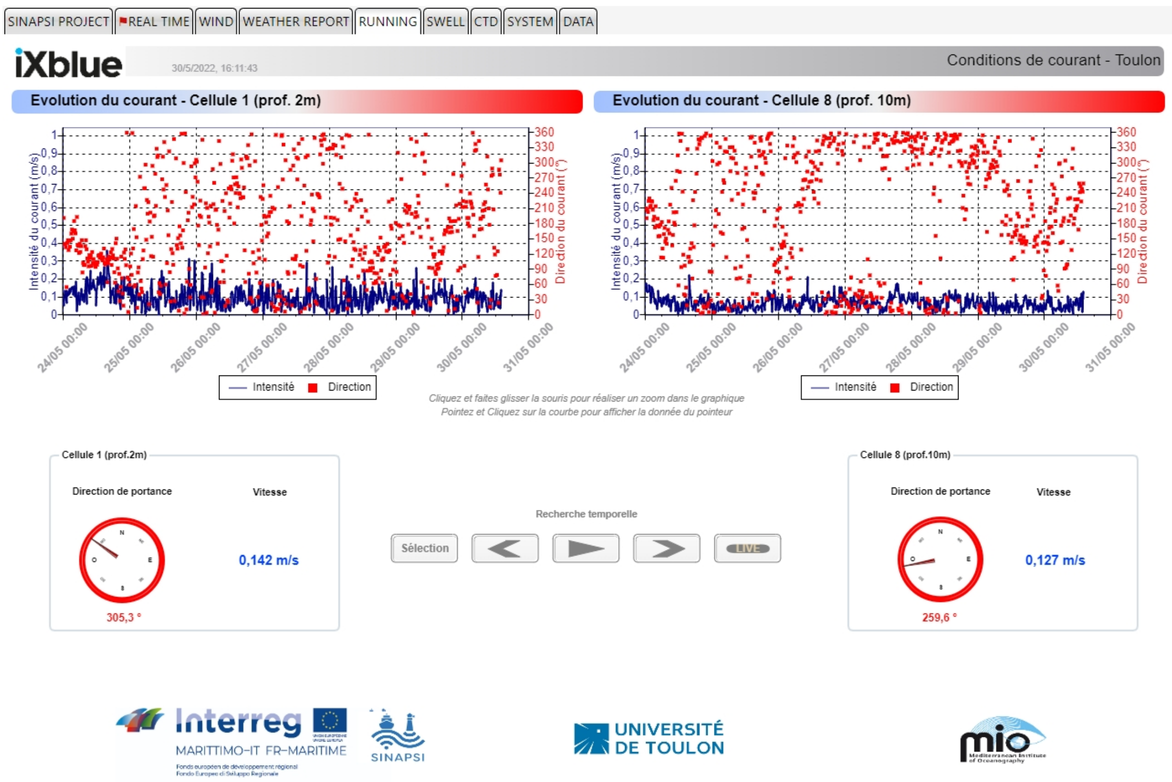

Fig. 17: Temporal profiling of current data obtained from the monitoring system (ixbuoy-toulon website, 2022)

III.3 PORT OF ROTTERDAM

Web Meeting, October 13, 2021

With: Willem Hoebée - Manager Team Nautical and Shipping Affairs (Harbour Master's Division - Port of Rotterdam Authority)

Technical additional information:

Wendy Janssen - Advisor Hydro (and Wind) at Data Management (Port of Rotterdam Authority)
Alex Roozeboom - Assistant Asset manager VTS (Port of Rotterdam Authority)

The Port of Rotterdam is the largest port in Europe, and it is located in the middle of the Rhine-Meuse-Scheldt delta. It covers 105 km^2 along a 40 km long area and includes both commercial and industrial activities. The maximum depth of sea bottom in the port is about 24 m, and it can handle every type and size of vessels, depending on the area of interest. The hearth of the Port of Rotterdam is the Europort, that, together with other areas of the port of Rotterdam, forms one of the largest petrochemical industrial areas in the world (**Fig. 18**). It plays an important role in processing and transporting crude oil, and it is a crucial transit point for transport of bulk between the European continent and other parts of the world1987 (Port of Rotterdam website, 2022). The petrochemical sector of the Port of Rotterdam also includes the Botlek and Vondelingen area, where many companies are based (Fig. 18) (Port of Rotterdam website, 2022). The Waalhaven and Eemhaven area, in the part of the port furthest from the sea, is mainly dedicated to cargo, but other activities and services are present, such as light industries and marine and logistic companies (Fig. 18). Activities related to general cargo also take place in the Merwe-Vierhaven (Fig. 18), which used to be the largest fruits port in the world, and it is now reconverting into a residential and working area. Other commercial activities are present in the Pernis area (Fig. 18), which deals with different products including vegetable oils and fats, oleochemicals, base oils, waxes, biodiesel, and easy chemicals (Port of Rotterdam website, 2022). The part of the Port of Rotterdam which projects into the North Sea is the Maasvlakte area (Fig. 18), where many oil, transhipment and container terminal companies are present. Beside the commercial sector, the Maasvlakte area hosts a power station and different distribution centres, as well as the Slufter area. The Slufter is a 250-hectare depot for contaminated material dredged from port basins and the fairway, which has been in use since 1987 (Port of Rotterdam website, 2022).

The main industrial centre of the Port of Rotterdam is Damen Shiprepair, which has one of Western Europe's largest shipyards, and its services include repairs, refits, and conversions. The types of marine vessels serviced here include offshore, dredgers, tankers, container ships, reefers (refrigerated cargo ships), bulk carriers, heavy crane vessels, renewable energy vessels, and cruise ships. A large cruise terminal is also present in the Port of Rotterdam, built at the Wilhelmina Pier close to the city centre (Cruisemapper website, 2022).

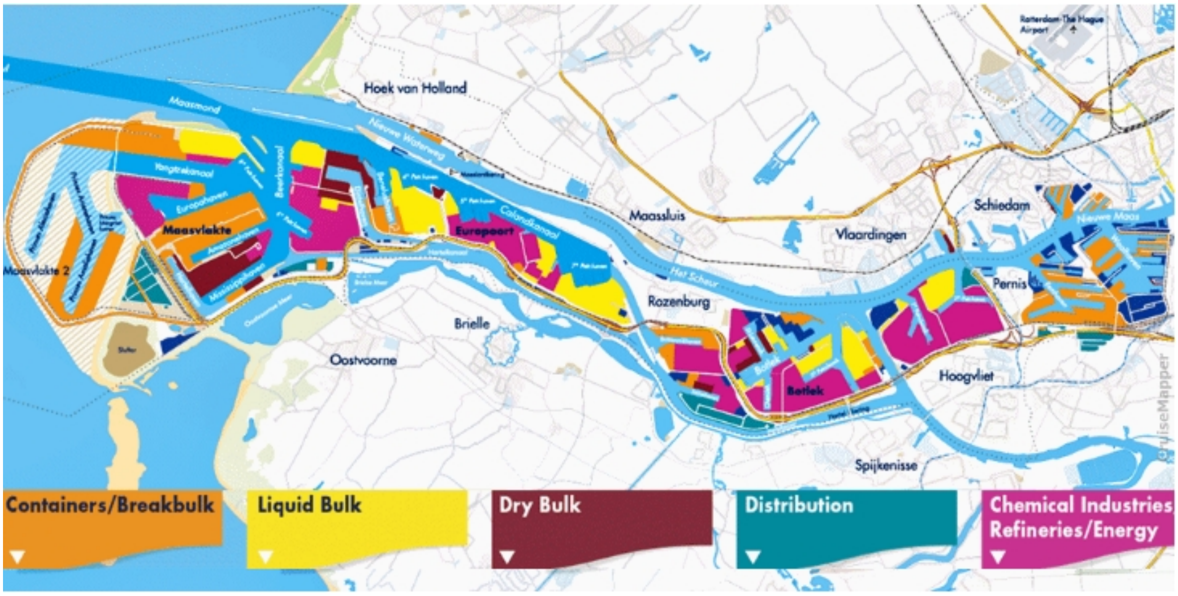

Fig. 18: Map of the Port of Rotterdam (Cruisemapper website, 2022).

The system of canals where the Port of Rotterdam is built, develops along the Nieuwe Waterweg, which is the 40 km long canal that connects the rivers Rhine and Meuse with North Sea, resulting in a complex infrastructure with numerous docks and harbour-basins. Tides and waves are the forcing that mostly affects navigation safety in the Port of Rotterdam, from the approach to the docking manoeuvres, due to the relatively shallow waters that characterised the area. In fact, deep draft ships can enter the port thanks to the presence of a fairway which begins 60 km off the coast, and they make use of high tide, as the tidal difference is 1.7 m. Waves conditions are also to be considered for the entrance of ships in the port, especially when storms from the North-West lead to swell waves of low frequency that raise the sea level and causes the ships to roll. A more serious situation happens with strong wind from the east, which causes extra low tides that are 0.5-1 m lower than normal. Therefore, not only astronomical tides are significative in the area, but also the increase or decrease of the sea level caused by weather conditions. For these reasons, monitoring and prediction of tides and low frequency waves are very important tools for managing safety of navigation in the Port of Rotterdam. There are several tide gauges that acquire data used by a model to predict the tide levels and the consequently tidal stream, with a frequency of 4 hours in the different areas of the port distributed along the Nieuwe Waterweg from the city centre to the open sea. Marine currents can also be critical for navigation safety along the main canal, which is only about 400 m wide In particular, the manoeuvres to enter small basins from the main canal can be dangerous in case of currents of more than about 0.5 kn intensity. Marine currents intensity mainly depends on tidal streams and on the Rhine and Meuse flow rates. Ebb currents are always stronger than flood currents, due to the flow from the rivers which increases the intensity of currents from the inland towards the sea. Visibility and wind are also necessary to be monitored, and wind is particularly important for cargo ship vessels which have a huge windage area. Therefore, admission policy depends on the size of the ship, and the location of the dock. All the marine weather information can be consulted on an open access web site of the Port of Rotterdam (**Fig. 19**) (Weather & Tide website, 2022).

Fig. 19: Weather and tide real-time information and forecast on the Port of Rotterdam website (Weather & Tide website, 2022)

Monitoring of marine current is possible thanks to the presence of four Teledyne RDI workhorse H-ADCP (**Fig. 20**), characterised by 600 kHz frequency and a 3-beam configuration. The instruments are mounted on a galvanized frame that can be raised and lowered using an electric winch, and they are installed on docks up to a depth of 8 meters. All the systems are made in such a way that they can be rotated around their vertical axis for the right angle and that the horizontal angle can be adjusted. To carry out maintenance, the top of the H-beam is made rotatable, allowing the system to be turned inwards for safe working from the platform. Data (RS232) is sent through a Cisco gateway to the cloud. Data are collected every minute and aggregated to 10 minutes values of tidal stream rate and tidal stream direction. The H-ADCPs provide a u- and v-velocity in binary format which can be translated by a software to a resulting velocity and direction. Every minute the gateway installed near the sensor sends data to the cloud using its own SIM-card. Then some checks are done: an extreme check (for instance tidal stream rates above 3 m/s are not realistic for the location and don't pass the check) and a count check. The count check means that data are aggregated to a 10 minutes average only if 9 or 10 valid 1 minute values are available.

Fig. 20: H-ADCP positioning in the Port of Rotterdam (Google Earth)

Additional real-time data on surface currents are provided by the HF Radar WERA system, installed by Helzel Messtechnik GmbH company for the Rijkswaterstaat (**Fig. 21**) (Ministry of Infrastructure and Water Management). Two WERA phased array HF radar stations were installed during 2015, one at Monster on the north side of the port entrance, and the other at Ouddorp on the south side (Heron et al., 2016). The coverage area extends beyond Hoek van Holland to the west and northwest directions occupying an overall area of 60 x 40km² with a resolution of 1 x 1 km² (Hydro International, 2022).

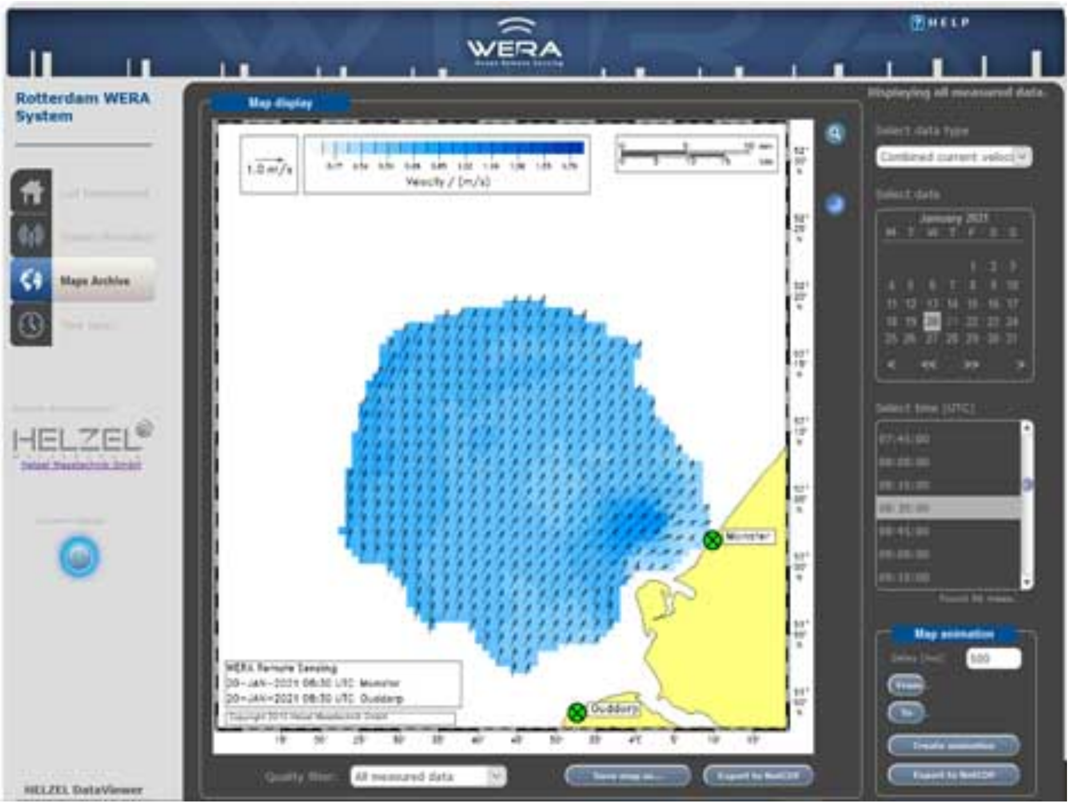

Fig. 21: HF Radar WERA system positioning (green dots) and coverage area (Hydro International, 2022).

Depending on tides and currents, draft can be limiting for navigation of big vessels; thus, continuously dredging is carried out in the Port of Rotterdam. Dredging activities are planned depending on the amount of siltation which differs from year to year; for example, in case of a large amount of north-westerly storms a lot of siltation occurs from the open sea towards the inner harbour. On the other side, siltation also continuously occurs from the rivers; the site where sea and fresh waters meet is in the part of the Nieuwe Waterweg in front of the Botlek area that consequently requires more frequent dredging than others. No fixed barriers are present in the Port of Rotterdam to avoid siltation, but a system of barriers exists to prevent flooding in the event of an atypical rise in sea level (**Fig. 22**) (Ministry of Transport, Public Works and Water Management, 2022). The Maeslantkering flood barrier consists of 2 enormous doors resting in their drydock beds besides Nieuwe Waterweg. When a 3 m above sea level flood is predicted, these gates are floated into position and sunk. When the water level recedes, the gates are floated back to the drydocks. There is a second flood barrier (Hartelkering) in Hartelkanaal and together they form the Europoort Barrier (Fig. 22) (Ministry of Transport, Public Works and Water Management, 2022).

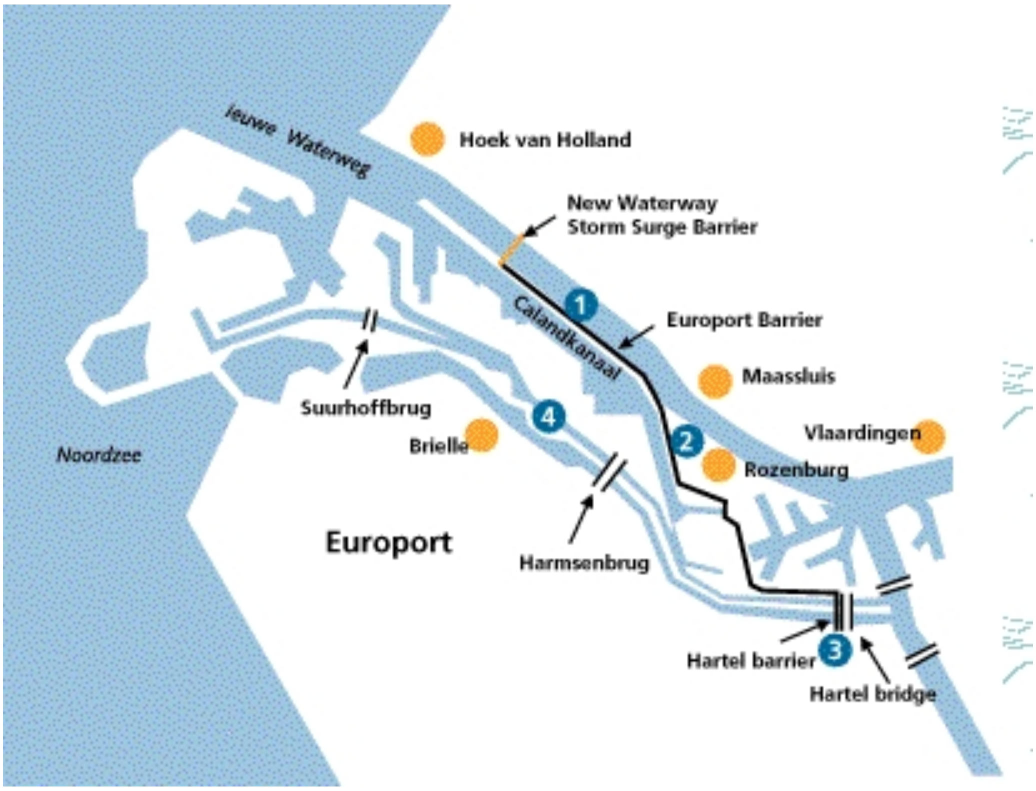

Fig. 22: Flood barriers system of the Eurooport (Ministry of Transport, Public Works and Water Management, 2022).

III.4 PORT OF NEW YORK / NEW JERSEY

Web Meeting, October 12, 2021

With: Robert Miskewitz - Associate Research Professor in Environmental Engineering and Environmental Science at Rutgers University (New Jersey) and Chief Science Officer at Tipping Point Resources Group

The Port of New York and New Jersey is the gateway to one of the most concentrated consumer markets in North America. It is the largest port on the East Coast, and the third largest in the nation. In addition to the Port Authority's port facilities, the Port includes numerous privately owned dry and liquid bulk terminals, general cargo and barging facilities, cruise terminals, ferry landings, and recreational users, as well as vessel support facilities (such as tie-up berths, marine fueling facilities, and tug support) (**Fig. 23**). The commercial area dedicated to container consists of six terminals, which together handled a load of 5,945,718 total TEUs in 2021 (Port Authority Ny/NJ, 2022). The six container terminals are: Port Newark, Maher, APM, GCT New York, GCT Bayonne, and Red Hook. Three cruise terminals are also present in the Port of New York and New Jersey: the Brooklyn Cruise Terminal in the Red Hook section of Brooklyn; the Manhattan Cruise Terminal in Manhattan; the Cape Liberty Cruise Port in Bayonne (New Jersey) (Port Authority Ny/NJ, 2022).

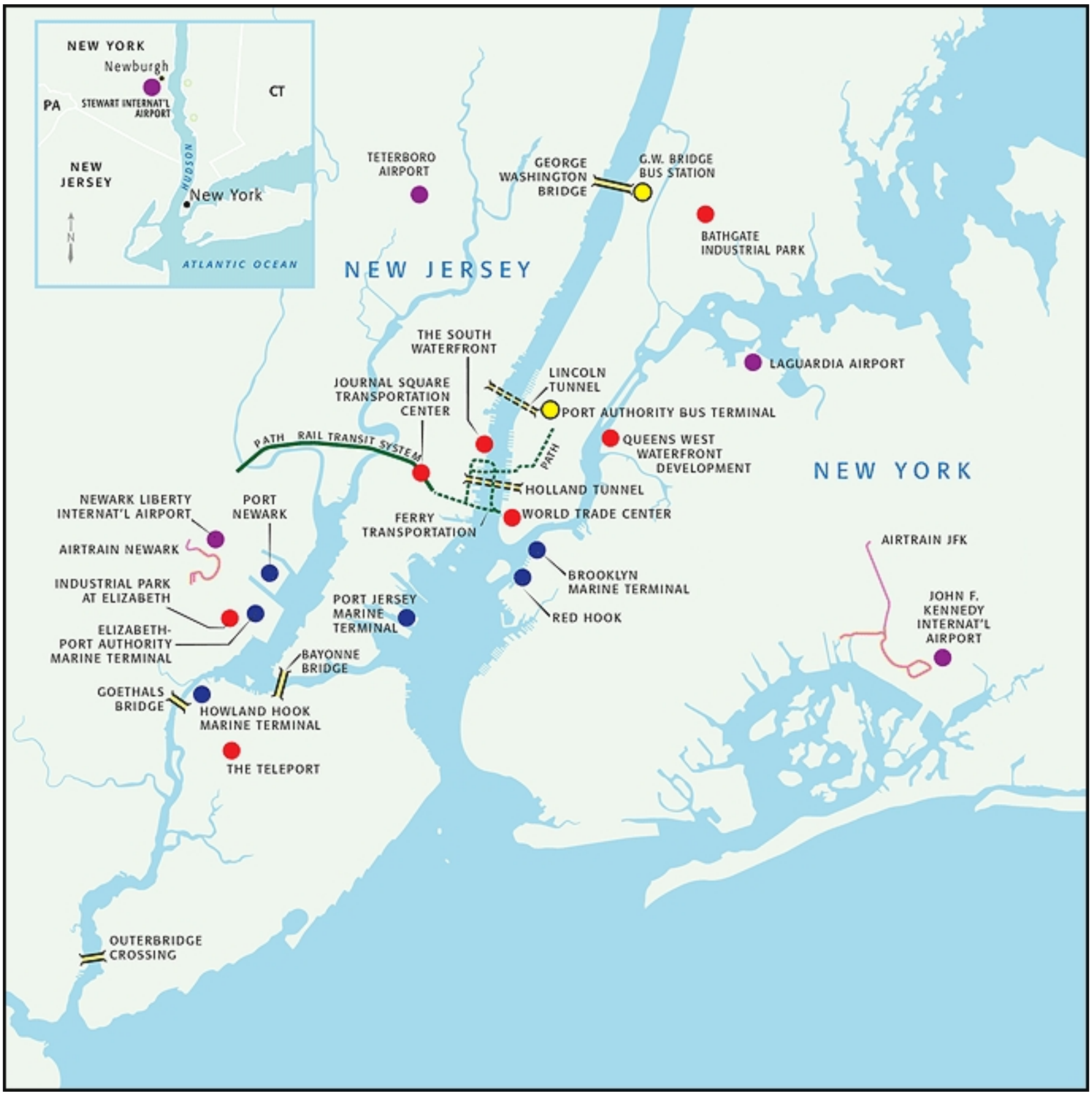

Fig. 23: Map of the Port of New York and New Jersey (Port Authority Ny/NJ, 2022)

The monitoring of marine weather conditions within the Port of New York and New Jersey, as well as other main ports in the United States, is managed by the Government through the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. The Center for Operational Oceanographic Products and Services (CO-OPS) of the NOAA's National Ocean Service has developed several tools to gather oceanographic data along the coasts and provide timely water-level and current measurements that support safe and efficient maritime commerce. Both real-time data and predictions are available on NOAA's website. A particular decision support tool was developed by NOAA, named Physical Oceanographic Real-Time System (PORTS) (**Fig. 24**) (NOAA, 2022).

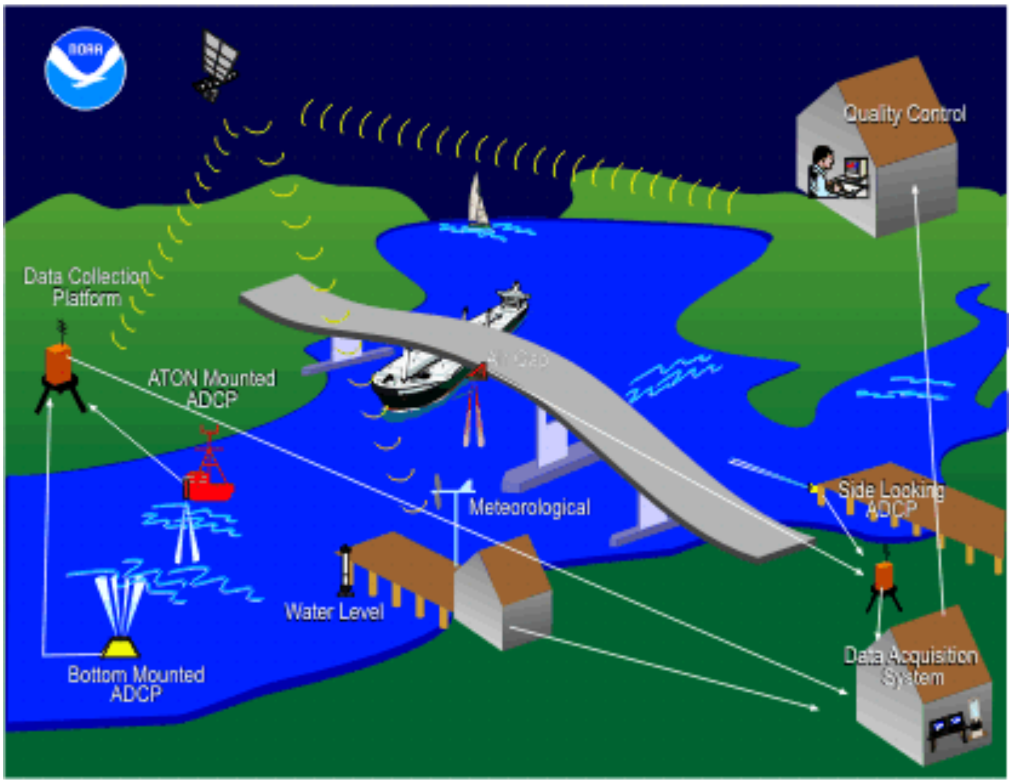

Fig. 24: PORTS graphic including a ship, water level gage, current meter and data collection platform (NOAA, 2022).

PORTS represents one component of NOS's integrated program to promote safe navigation, improving the safety and efficiency of maritime commerce and coastal resource management. This efficient tool collects and disseminates observations of water levels, currents, salinity, bridge air gap and meteorological parameters (e.g., winds, atmospheric pressure, air and water temperatures) that mariners need to navigate safely. PORTS is accessible to maritime users in a variety of user-friendly formats, including telephone voice response and Internet, and it also provides forecasts via numerical circulation models. An application is also available to customise your personal PORTS page by displaying only the needed stations (NOAA, 2022). In the Port of New York and New Jersey, several instruments as part of the PORTS network, including three current-meters' stations (**Fig. 25**). The current meter at the location "The Narrows" is currently offline, while real-time data are available from the two stations at the "Newark Bay Entrance" and "Kill Van Kull" locations. Both observed and predicted data are available, and a composite can be displayed for each monitoring station showing data from all the different instruments located in that particular area (**Fig. 26**) (NOAA, 2022).

Fig. 25: PORTS current meters in the Port of New York and New Jersey (NOAA, 2022).)

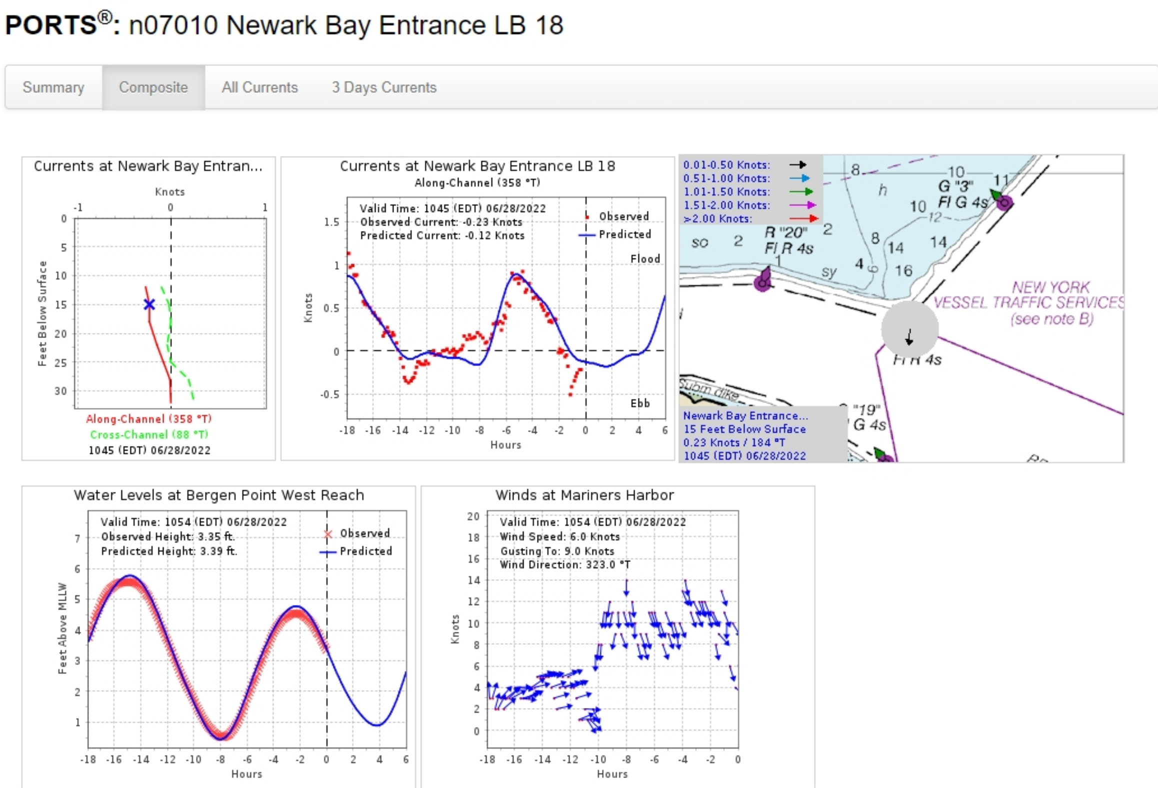

Fig. 26: Example of composite for the "Newark Bay Entrance" location (NOAA, 2022).

Monitoring of marine currents in the Port of New York and New Jersey happen to be necessary when it comes to supporting dredging activities, together with monitoring of turbidity by probes. In these cases, Prof. Miskewitz reported the use of Nortek ADCPs, that are deployed on the bottom of the monitoring area where needed and left for two months recording marine currents data every 10 minutes. Data from monitoring during dredging activities are not available on public platforms, but they are only given to the stakeholders. The data collected from ADCPs are mainly exploited for developing 3D models of circulation; following campaigns are then carried out for validation of the models.

In the area of the Port of New York and New Jersey, marine circulation is mainly driven by tides, which reach up to 2 meters and are easily predictable. Occasionally, weather conditions force the sea circulation, e.g. in the case of strong north-easterly winds or a transition from low to high pressure. The Davidson Laboratory at the Stevens Institute of Technology's in New Jersey has also developed a public consultation web portal for marine currents forecasts, named New York Harbor Observing and Prediction System (NYHOPS) (**Fig. 27**) (NYHOPS, 2022). The system is designed to provide a knowledge of meteorological and oceanographic conditions both in real-time and forecasted out to 72 hours in the Hudson River, the East River, NY/NJ Estuary, Raritan Bay, Long Island Sound and the coastal waters of New Jersey. The web site shows graphic images of: water level; surface and bottom temperature; surface and bottom salinity; surface and bottom currents; NOAA winds; coastal waves - height, period and direction. Water level and flood forecast is continuously updated.

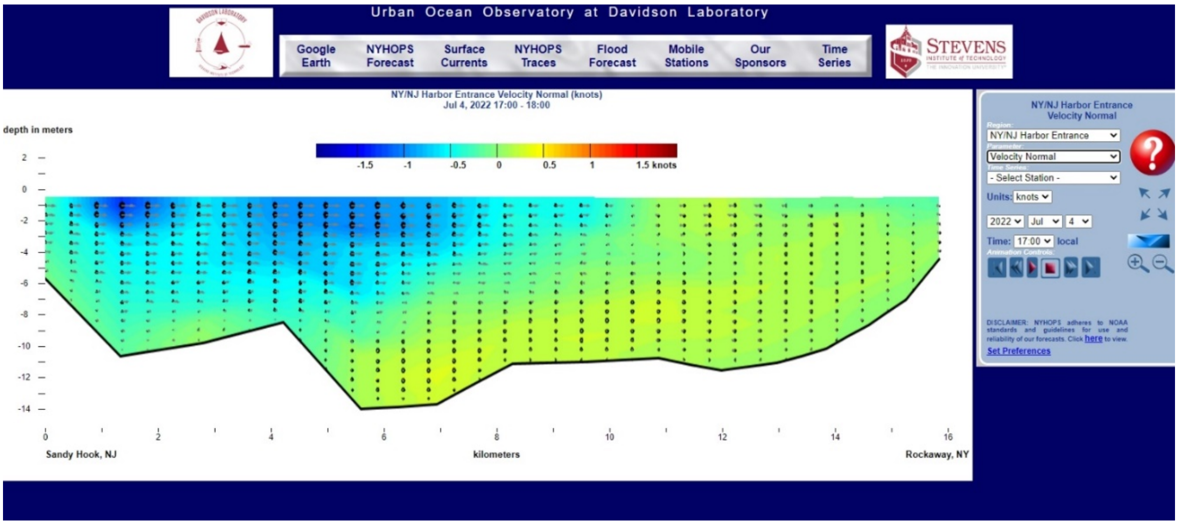

Fig. 27: Predicted currents at the Port entrance (NHYOPS, 2022)

IV. PREVIOUS MONITORING ACTIVITIES IN THE PORT OF GENOA

During the period 2009-2013, major dredging activities were carried out in the Port of Genoa, involving DISTAV's Physical Oceanography Laboratory to monitor dynamics and turbidity during the works. This monitoring activity made it possible to acquire data on the intensity and direction of currents at two sites of particular importance for the transit of ships, i.e. the eastern and western entrances to the port (**Fig. 28**). To this end, two fixed stations were installed to measure currents using Horizontal Acoustic Doppler Current Profiler (H-ADCP) current meters from Teledyne RD Instruments, with a frequency of 300 kHz. Thanks to the analysis of the return signal, the current meters returned the intensity and direction of the currents by dividing the investigated sea stretch into sectors (bins) with a fixed size of 4 m (Cutroneo et al., 2012). The instrument at the east entrance was oriented in the NE direction, while the one at the west entrance was oriented in the SW direction, and both were positioned on the breakwater at a depth of approximately 7 m.

Current data was mapped using a MATLAB application specifically designed for such data (**Fig. 29**) (Konyssova, 2022), to efficiently produce a mapping of the direction and intensity of currents directly onto a satellite image of the instrument's position. The app was developed in a mlapp format, which is the specialized AppDesigner file and opens in any computer platform where the MATLAB is installed. When the program is launched, an interactive interface appears. To start using the App in it firstly necessary to import data exported from WinADCP (RD Instruments, Inc) in mat format. In addition to importing the data file, it is required to enter latitude, longitude and bearing information in decimal degree format on the corresponding fields. When the required data is entered into the fields and file is imported, the program is ready to run. In this step the program performs the procedures starting from pre-processing of the data and ending with plotting current vectors on a base map. A map is produced for each ensemble recorded by the instrument, and saved in a specifically created directory, together with a gif file of all the ensemble of the day loaded. The gif file is not displayed on the app's window but can be accessed from the computer itself.

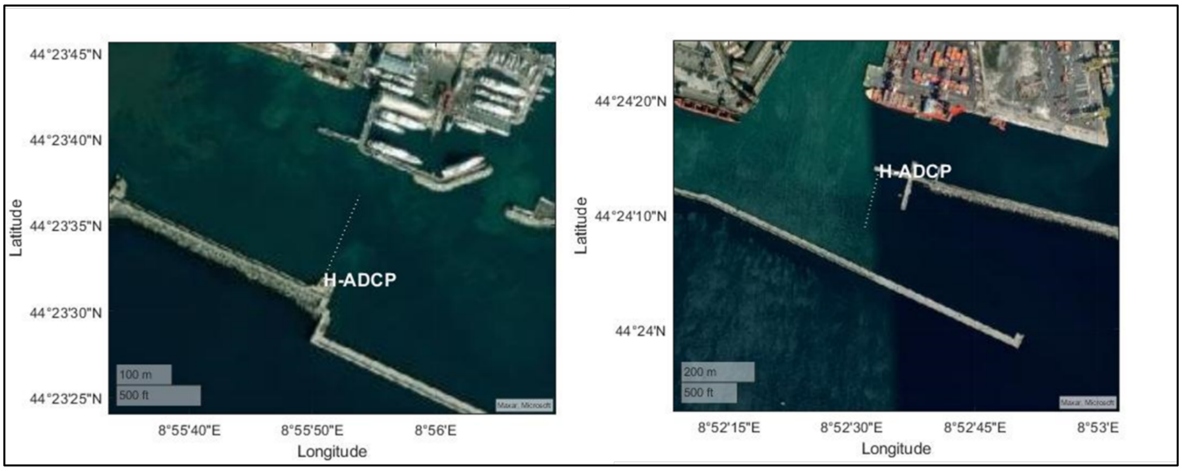

Fig. 28: maps of the H-ADCPs positioning at the eastern (left) and western (right) port entrances (Konyssova, 2022)

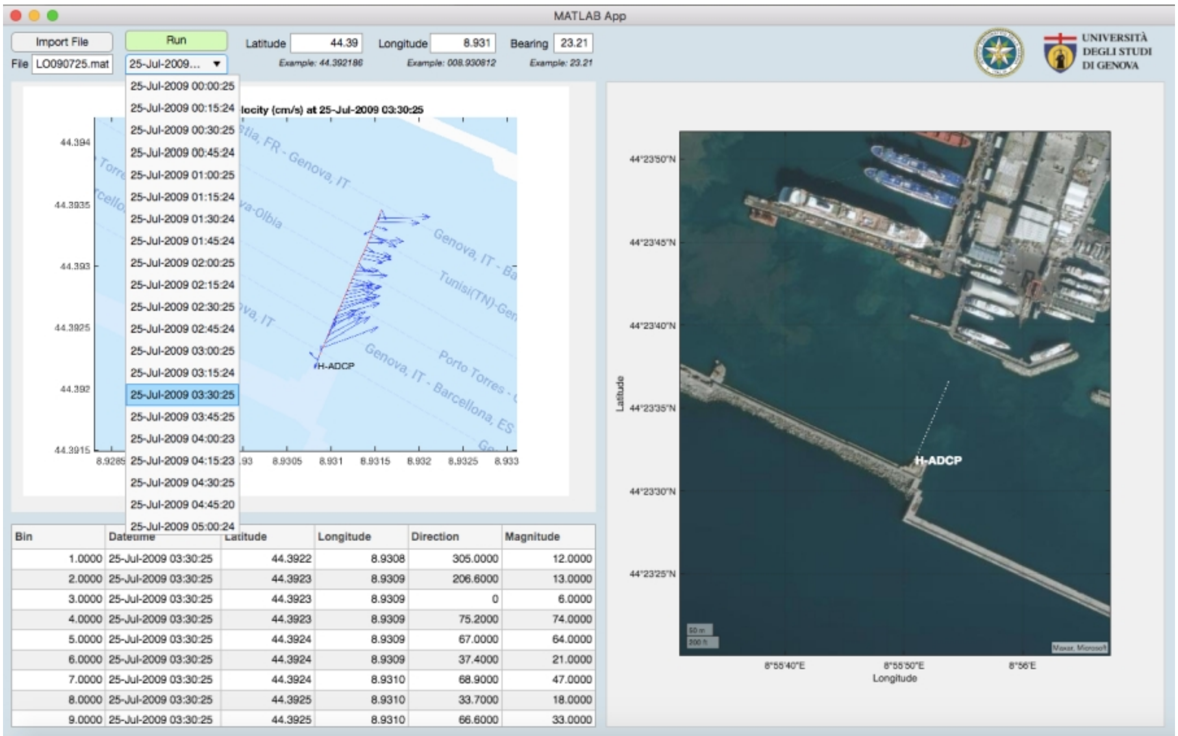

Fig. 29: example of data displayed by MATLAB App (Konyssova, 2022)

Analysing the data from the current meters it was observed that the intensity of the current increased as the distance from the breakwater. This is because the sector closest to the current meters was partially sheltered by the breakwater, and was therefore less influenced by the wind, and the flow of currents was also hindered by the presence of the breakwater itself and its overhangs. The cells around 50 m away from the instrument were more exposed to the action of the wind but were still not affected by any disturbances caused by maritime traffic. Finally, the cells towards the centre of the channel presented the strongest currents, since this is a stretch of sea that is more exposed to the winds and has no obstacles to the free flow of water masses. Here, the currents were also affected by the disturbance caused by the passage of ships.

In the case of the H-ADCP at the eastern entrance, while at the centre of the channel the currents alternated with a SE-NW direction, in the first 50 m away from the breakwater it was possible to notice the clear prevalence of SE-direction currents, even in the case of prevailing southerly winds (**Fig. 30**). This is due to a phenomenon that occurs at the eastern entrance when winds blowing from the SE push the water masses against the northern part of the port entrance and force them to create a vortex, which then causes water to flow out of the port in the southernmost sector towards the breakwater (Cutroneo et al., 2017). The data of the currents recorded at the eastern entrance were compared with those of the winds from the weather station of the ARPAL Functional Centre in Viale Brigate Partigiane (GE) (Liguria Region website, 2022), using the central sector of data provided by the H-ADCP, as it was the most significant because it was not affected by the breakwater and not disturbed by marine traffic. Here, it was observed that the peaks of the currents did not correspond to those of the winds but were always delayed by a variable interval ranging from a few hours to even 20 hours, depending on the speed and persistence of the incident wind (Apigalli, 2014). In addition, it was found that wind and current sometimes showed opposite directions. In particular, the U (west-east) components of both wind and current had higher intensities and were in greater agreement, probably due to the fact that the survey area is more exposed to winds from the east and south-east; on the other hand, the V (south-north) components of wind and currents often showed opposite direction, possibly due to the limited width of the channel whereby the wind cannot develop sufficient strength in the north-south axis (Apigalli, 2014).

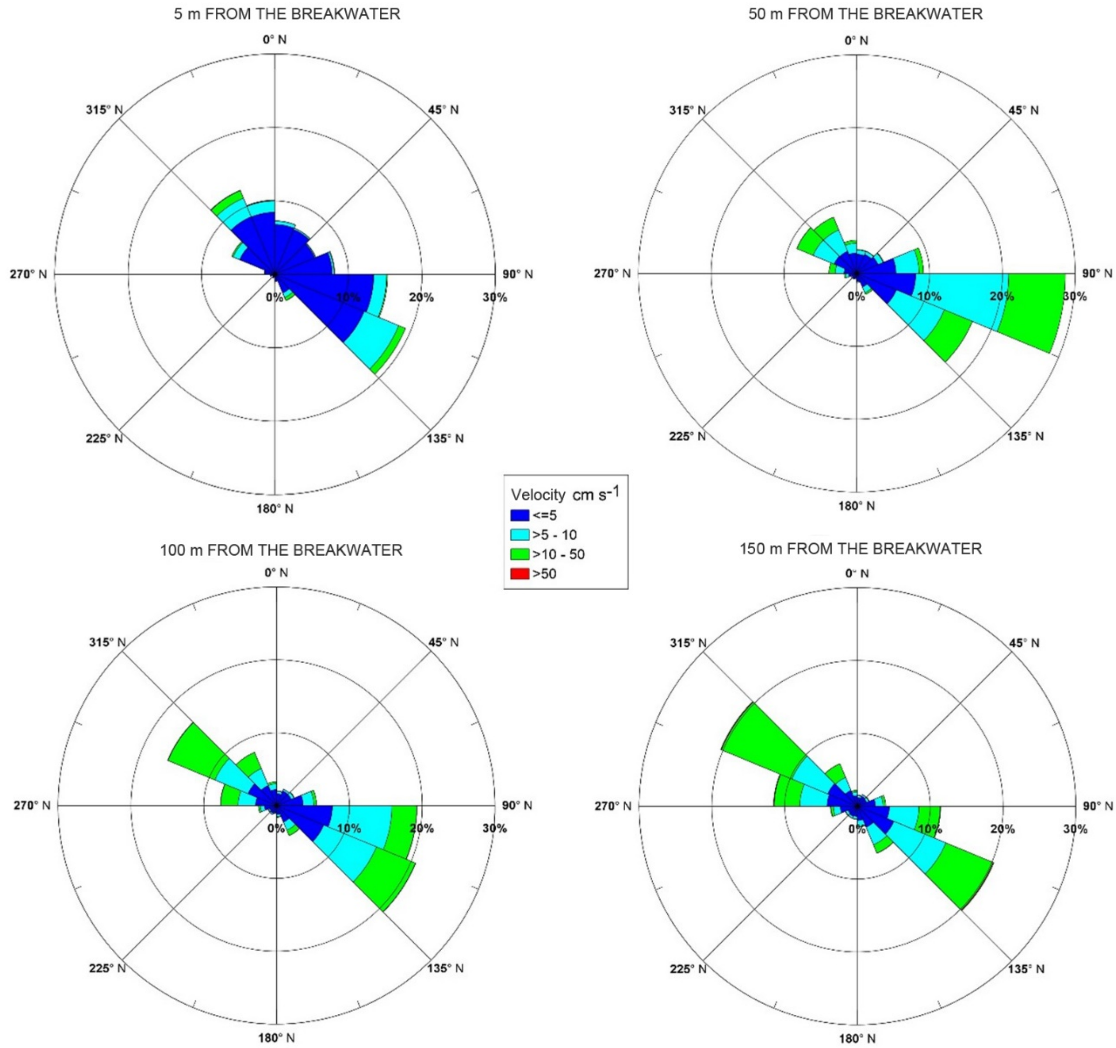

Fig. 30: Intensity and direction of currents recorded by the H-ADCP at the port eastern entrance at the following distances from the breakwater: 5 m (top-left); 50 m (top-right); 100 m (bottom-left) and 150 m (bottom-right)

Observing the current data recorded by the H-ADCP positioned at the western entrance, it was possible to note that the intensity of the current increased as the distance from the breakwater (**Fig. 31**). This was due to the fact that the sector closest to the current meter, in this case, was protected to the north by the breakwater, which obstructs the flow of currents in the SE direction.; in fact, within 5 m from the current meter, the currents showed a prevailing NW direction. In addition, in that site there is a protrusion of the breakwater, where the lantern marking the port entrance is located, which could lead to a disturbance of the main current flow. On the contrary, beyond a distance of 5 m from the breakwater, the directions alternated between NW and SE. At 150 m, there was a prevalence of SE-directed currents flowing out of the port, as well as an increased speed associated with this direction. Since the western entrance is not accessible to big vessels, it can be stated that the higher speeds were due to the effect of the wind and not to maritime traffic.

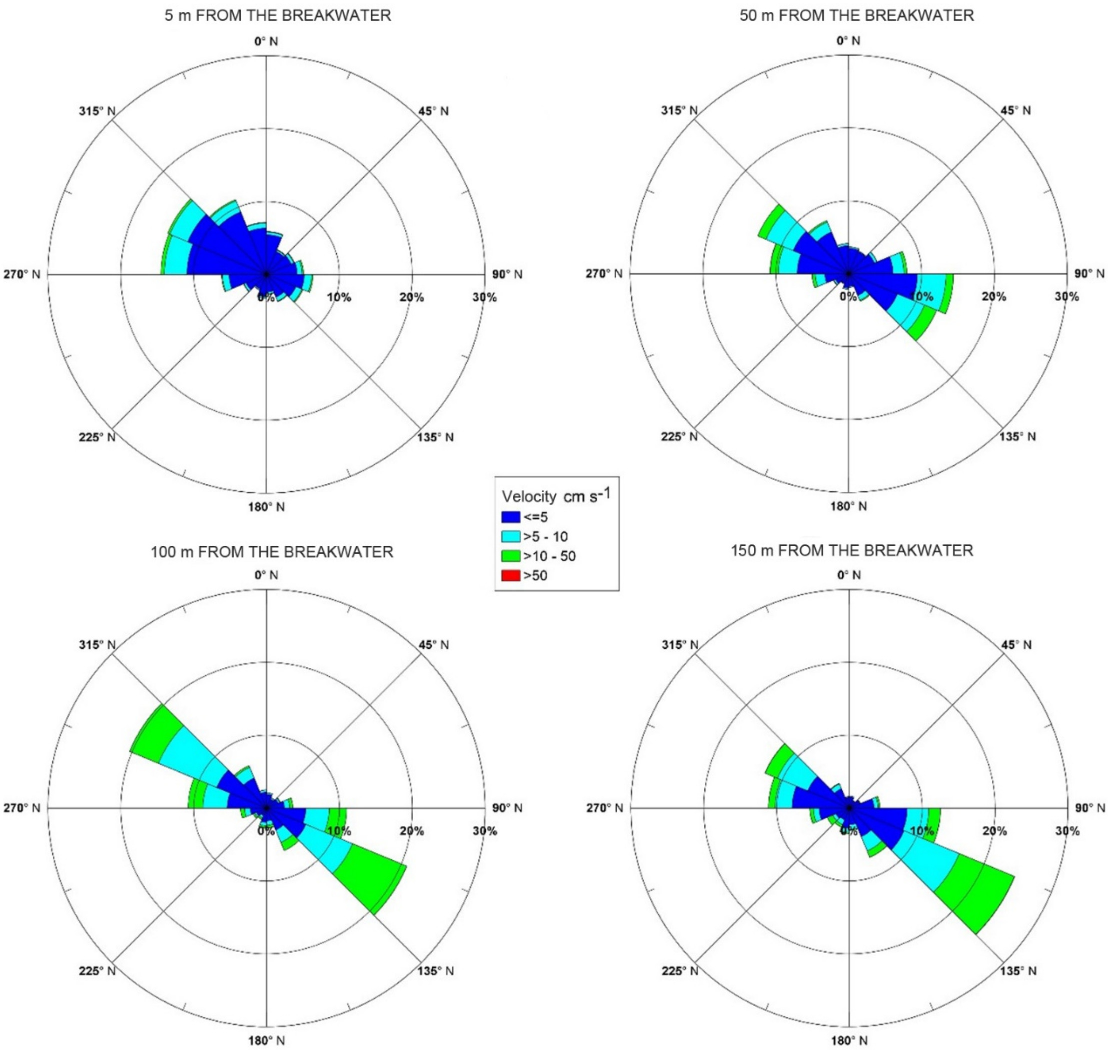

Fig. 31: Intensity and direction of currents recorded by the H-ADCP at the port western entrance at the following distances from the breakwater: 5 m (top-left); 50 m (top-right); 100 m (bottom-left) and 150 m (bottom-right)

V. PRELIMINARY MONITORING CAMPAIGNS

V.1 INTRODUCTION

A preliminary investigation on the marine dynamics of the Port of Genoa was necessary to collect data for a better understanding of circulation in different weather conditions. Data have been exploited to establish the most critical area for navigation and of greatest interest to the Port Authority. In fact, results of the monitoring campaigns were presented to the Port Authority, Pilots and other port operators, during meetings where the positioning of the fixed stations was discussed.

V.2 MATERIALS AND METHODS

Four monitoring campaigns took place between December 2020 and July 2021, on the following days: 15 December 2020, 9 April 2021, 29 April 2021, and 12 July 2021. Surveys were done on board of the "Capo Nord Oceanic" vessel owned by the Barcaioli di Multedo s.c.r.l. and involving students from the University of Genoa.

A downward-looking four-beam Teledyne RDI 600-kHz Workhorse® current meter (Vertical Acoustic Doppler Current Profile - V-ADCP) was mounted on the vessel's side (**Fig. 32)**, fixing the position of the instrument at a 0.5 m depth. The V-ADCP measured current profiles (velocity and direction) and the intensity of the echo (backscatter) along a theoretical vertical line from the instrument's depth to the sea bottom. The size of the V-ADCP bins was set at 1.5 m and covered the entire water column, except for the blanks near the sensor and the bottom, where the instrument does not return a measurement. The instrument measured the velocity (cm s^{-1}) and direction (° N) of the current with a sampling of 10 pings for each ensemble, and using 1 ping for the bottom tracking, thus being able to distinguish the movement of the vessel from the current. Navigational data were received from an external global positioning system (GPS). Several transect were carried out for each campaign, covering as much of the port area as possible considering ships traffic and weather conditions. The software used for the V-ADCP configuration was WinRiverII (RD Instruments, Inc), while the WinADCP (RD Instruments, Inc) and Surfer 13 software were used to process data. Wind data were obtained from the database of the Liguria region website (Liguria Region website, 2022).

During the campaigns held on 9 and 29 July 2021, data on the physical-chemical parameters of the water column were collected by deploying a multi-parameter conductivity-temperature-depth (CTD) probe (IdromarAmbiente). Several deployment stations were randomly selected along the current monitoring transects. Data collected allowed to obtain the vertical profile of the water column in relation to several parameters, including temperature, salinity, and density.

Fig. 32: V-ADCP mounted on side of the vessel during monitoring campaigns

V.3 RESULTS AND DISCUSSION

The monitoring campaign that took place on 15 December 2020 covered the entire area of the Port of Genoa from the eastern entrance to the mouth of the Polcevera Torrent, including the Porto Antico basin (**Fig. 33-34**). The most superficial currents were measured at 3.6 m depth. The mean value of currents intensity was 7.6 cm s^{-1} for superficial currents and 6.6 cm s^{-1} at the bottom; the lower intensity was of 0.1 cm s^{-1} and the maximum intensity did not exceed the value of 50 cm s^{-1}, both at the surface and at the bottom. The average current direction was 167.8 ° N and 162.2 ° N, at the surface and at the bottom respectively. The wind prevalent direction recorded from the Porto Antico station of the Liguria Region was North-East, with an average intensity of 7 km/h (Liguria Region website, 2022).

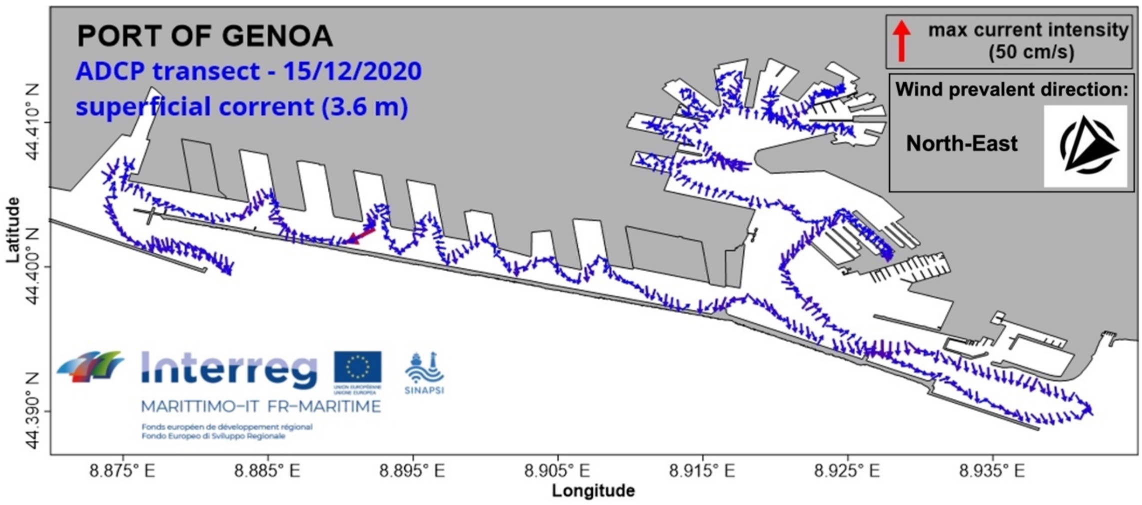

Fig. 33: Intensity and direction of superficial currents in the Port of Genoa for the monitoring campaign on 15 December 2020

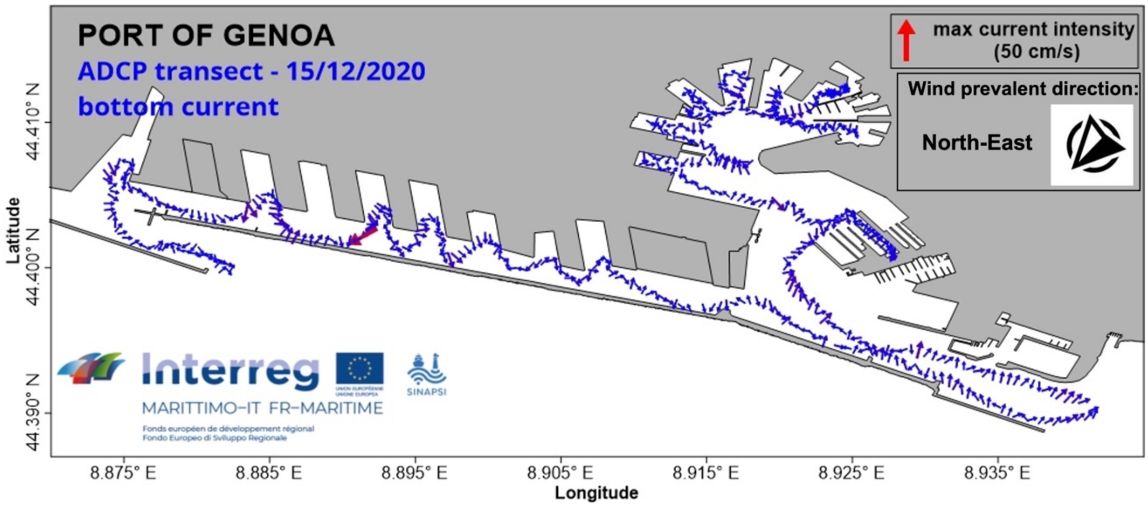

Fig. 34: Intensity and direction of bottom currents in the Port of Genoa for the monitoring campaign on 15 December 2020

Two monitoring campaigns were held in April 2021, of which one from the area of the Porto Antico to the eastern entrance (9 April) and one from the Porto Antico to the Polcevera Torrent mouth along the Sampierdarena Channel (29 April) (**Fig. 35-38**). The mean values for superficial current intensity were 8.1 cm s^{-1} and 9.0 cm s^{-1}, on 9 and 29 April respectively, with maximum values not higher than 50 cm s^{-1} for both campaigns. Analogous conditions of current intensity were also recorded for bottom currents. Marine weather conditions were very similar on both days, with a predominantly southerly/south-easterly wind with an average intensity of 12-13 km/h (Liguria Region website, 2022). The mean values of the direction of the sea currents also fell in the same quadrant during the two campaigns, being 194.3 ° N and 225.8 ° N in the surface layer and 184.4 ° N and 205.0 ° N at the bottom, on 9 and 29 April respectively.

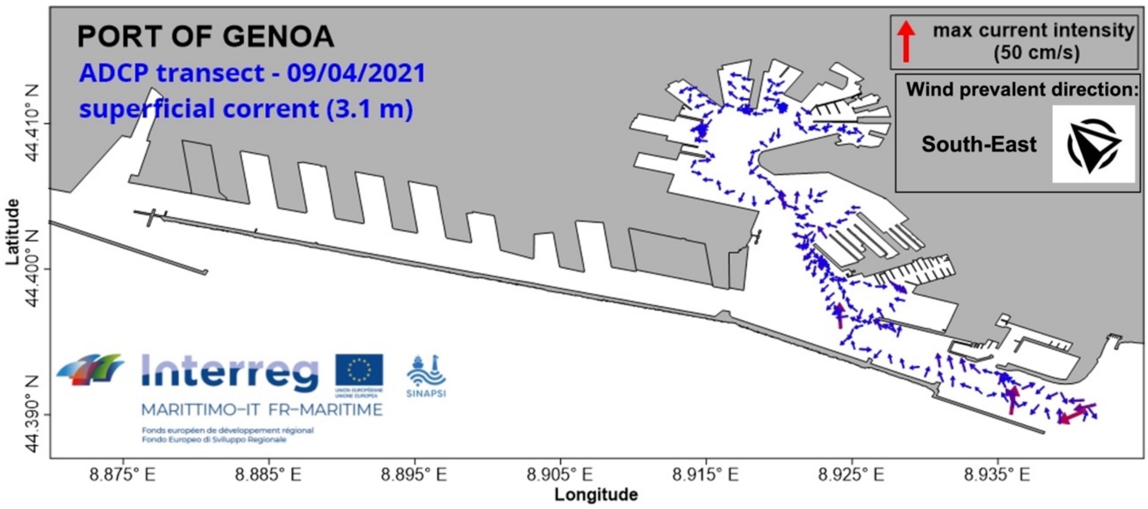

Fig. 35: Intensity and direction of superficial currents in the Port of Genoa for the monitoring campaign on 9 April 2021

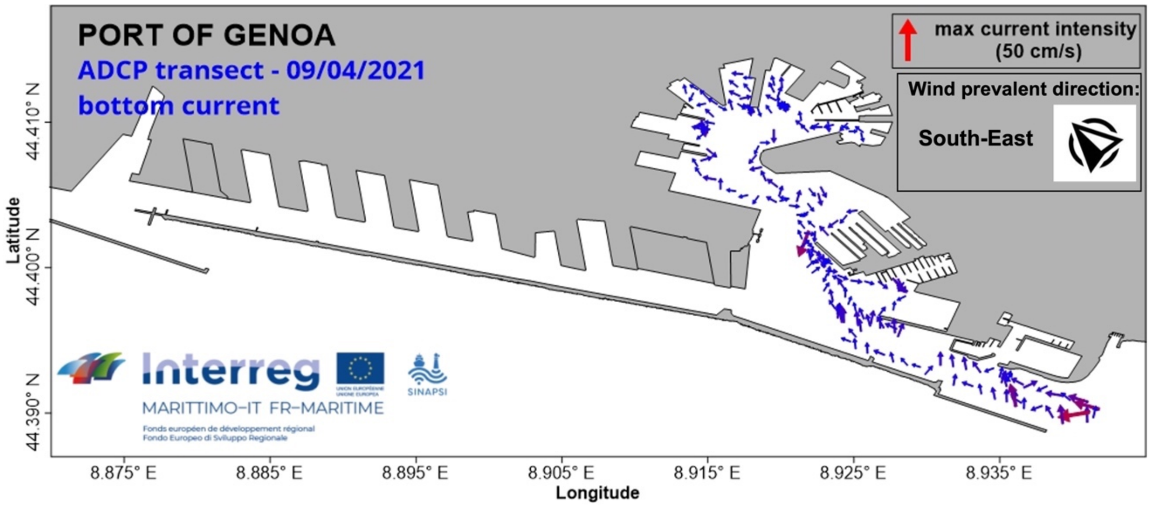

Fig. 36: Intensity and direction of bottom currents in the Port of Genoa for the monitoring campaign on 9 April 2021

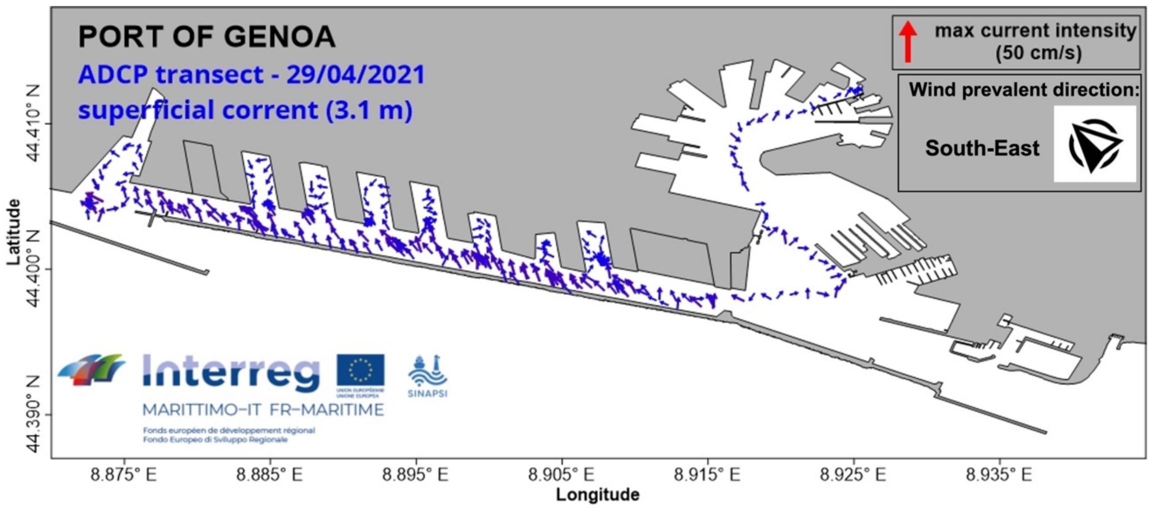

Fig. 37: Intensity and direction of superficial currents in the Port of Genoa for the monitoring campaign on 29 April 2021

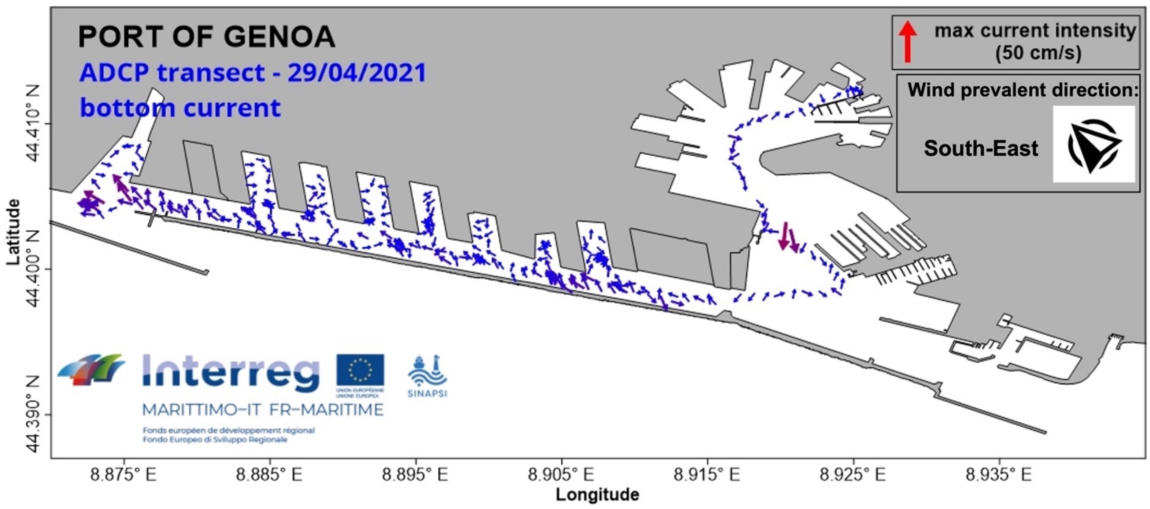

Fig. 38: Intensity and direction of bottom currents in the Port of Genoa for the monitoring campaign on 29 April 2021

The last preliminary monitoring campaign took place on 12 July 2021 and covered the area from the Porto Antico basin to the eastern entrance and the eastern part of the Sampierdarena Channel (**Fig. 39-40**). The maximum values for current intensity were below 60 cm s^{-1} both in the superficial and bottom layers, with an average of 12.5 cm s^{-1} and 12.0 cm s^{-1} intensity for superficial and bottom currents respectively. Mean values of currents direction were 202.2 ° N at the surface and 181.8 ° N at the bottom, with a predominantly southerly wind with an average intensity of 10 Km/h (Liguria Region website, 2022).

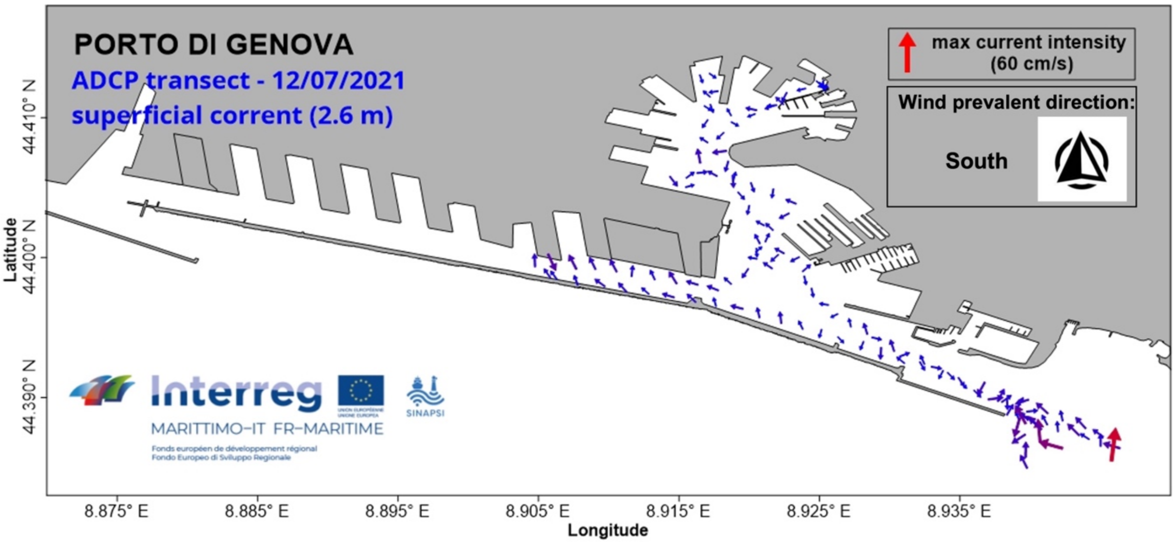

Fig. 39: Intensity and direction of superficial currents in the Port of Genoa for the monitoring campaign on 12 July 2021

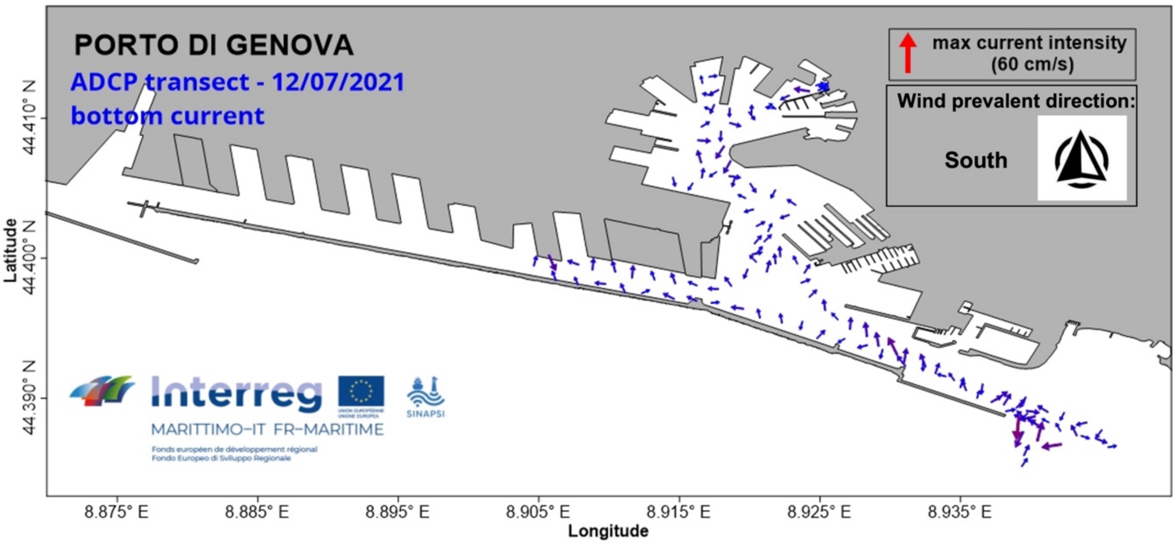

Fig. 40: Intensity and direction of bottom currents in the Port of Genoa for the monitoring campaign on 12 July 2021

Looking at the current data collected during the four campaigns, two main trends can be seen, which occur according to wind conditions. In the case of a northerly wind, outgoing currents, at both the eastern and western entrances of the port, and a general tendency for the water masses to move southwards were observed (Fig. 32-33). On the contrary, in the case of winds from the southerly quadrants, there was a flux of water masses from outside to inside the port area, and a clear current flow along the Sampierdarena Channel can be observed, moving from east to west (Fig. 34-39). These general conditions have also been observed in previous studies on the area (Capello et al., 2010; Cutroneo et al., 2017). However, currents within the port showed more complex patterns than these general trends, especially in the narrow areas between the piers and in the larger areas of the evolution basins, where current vectors with extremely variable directions were recorded. Furthermore, although it can be stated that in the case of a southerly wind, the currents at the easterly entrance move towards the inner side of the harbour, it is possible, as already observed by (Cutroneo et al., 2017), that a contrary flow occurs along the inner side of the breakwater, as shown during the campaign on 12 July 2021 (Fig. 38-39). Moreover, it is interesting to note that, during the April and July 2021 campaigns, in which there was a southerly wind, the main flow of current, from the eastern entrance towards the inner area of the Porto Antico through the evolution basin, was countered by an opposite movement on the west side of the basin, that went from the Porto Antico towards the breakwater and was diverted through the Sampierdarena Channel. The same dynamics can be observed in the campaign carried out by Cutroneo et al. (2017).

During the campaigns carried out on 9 and 29 April 2021, CTD probe measurements were also taken in order to obtain data on the physical characteristics of the water column, in particular temperature and density. The probe was deployed in 9 stations on 9 April and in 14 stations on 29 April, covering the same areas as the current's measurements (**Fig. 41**). Water temperature on 9 April ranged from 14.3 °C to 15.2 °C at the surface and from 14.6 °C to 14.9 °C at the bottom, while on 29 April temperatures fell in the ranges 15.1-15.3 °C and 15.0-15.2 °C, for the superficial and bottom layers respectively. A slight increase in the average temperature of the water column on 29 April compared to 9 April was therefore observed, rising from 14.8 °C to 15.2 °C, following the normal seasonal trend of the Ligurian Sea (Nezlin et al., 2004) (**Fig. 42**).

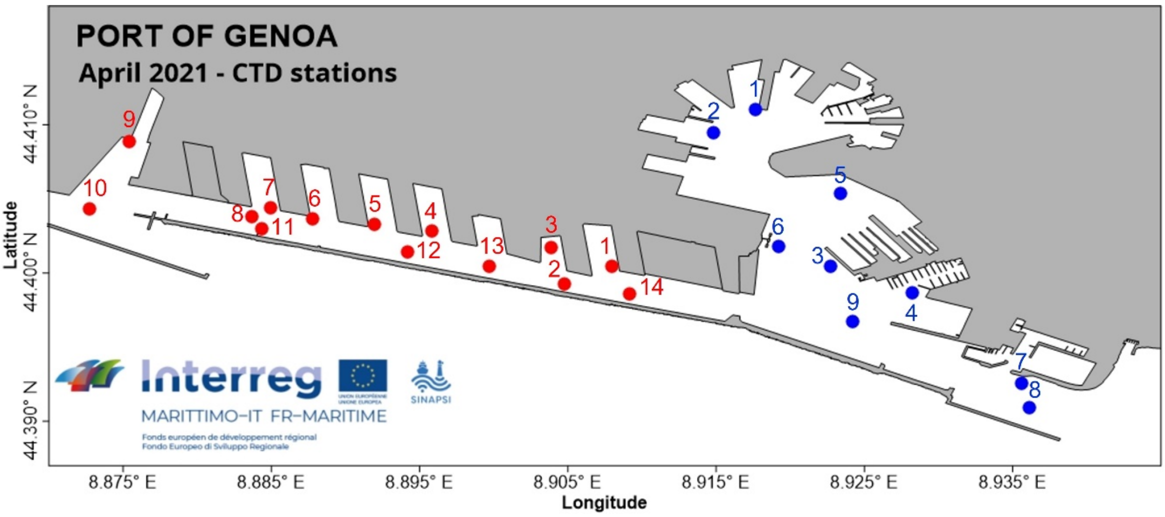

Fig. 41: CTD stations carried out in the Port of Genoa for the monitoring campaigns on 9 April 2021 (blue) and 29 April.2021 (red)

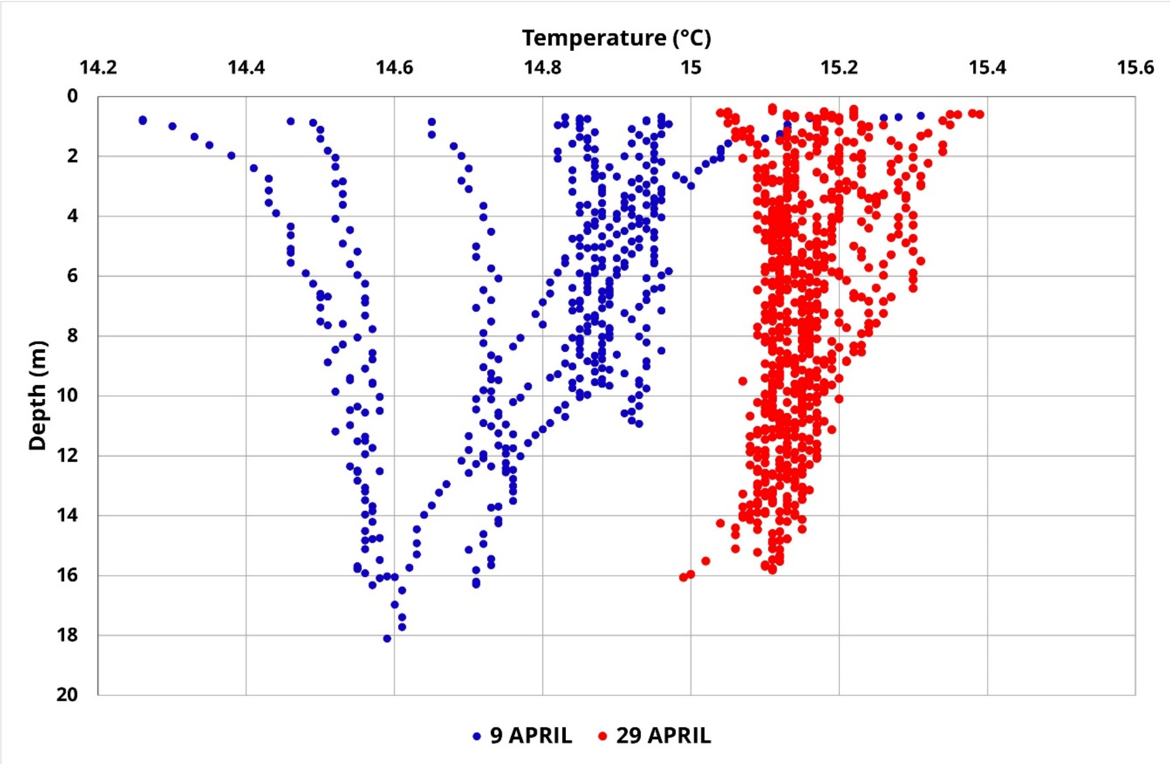

Fig. 42: Vertical temperature distribution on 9 April 2021 (blue) and 29 April 2021 (red)

The temperature values did not vary greatly along the water column, as no thermocline was observed; in fact, it begins to form in spring but becomes evident in May/June, depending on the rising of the atmospheric temperature (Bentaleb et al., 1999). Nevertheless, regarding the horizontal distribution of water temperature on 9 April, it was possible to observe a gradient increasing from the port eastern entrance towards the inner part of the Porto Antico (**Fig. 43-44**). In fact, it has already been highlighted that, during this campaign, the direction of the wind and currents determined a flow of incoming water masses from the easterly entrance, which therefore consisted of a supply of colder water from the outside. This hypothesis of influx of water masses is supported by the horizontal density distribution data, which decreases from outside to inside the investigated port area (**Fig. 45-46**). On the other hand, during the campaign of 29 April, no obvious temperature gradient was observed, but an influx of colder water from outside may have occurred due to the currents moving from east to west along the Sampierdarena Channel; in fact, the temperatures recorded in the more sheltered areas, such as in between docks and the mouth of the Polcevera Torrent, were slightly higher than at the other stations (**Fig. 47-48**). Regarding the data collected during this campaign, it is also interesting to note that there was atmospheric precipitation in the previous days, ranging from 1 to 5.4 mm (Liguria Region website, 2022); in fact, a clear gradient of horizontal density distribution can be observed, which was lower in proximity of the mouth of the Polcevera Torrent (**Fig. 49-50**).

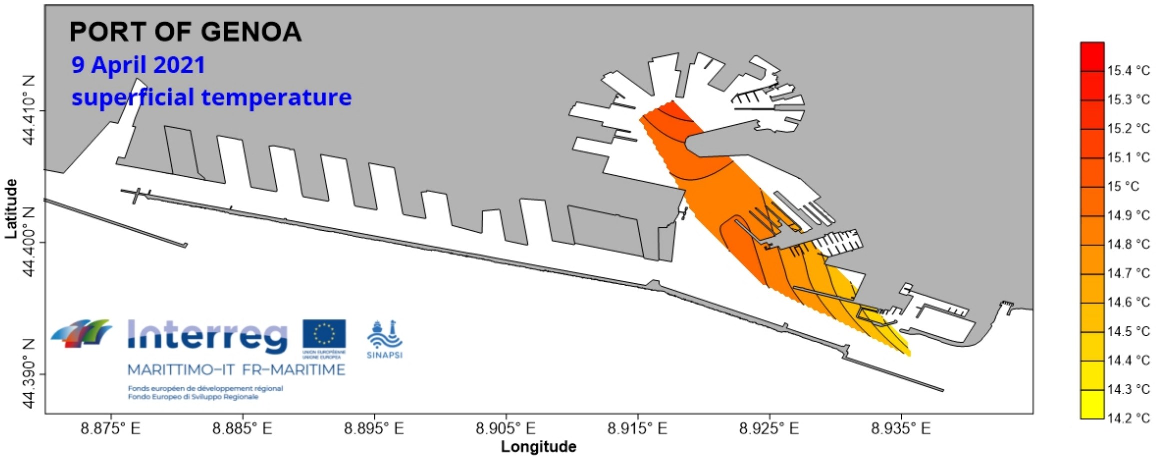

Fig. 43: Horizontal superficial temperature distribution on 9 April 2021

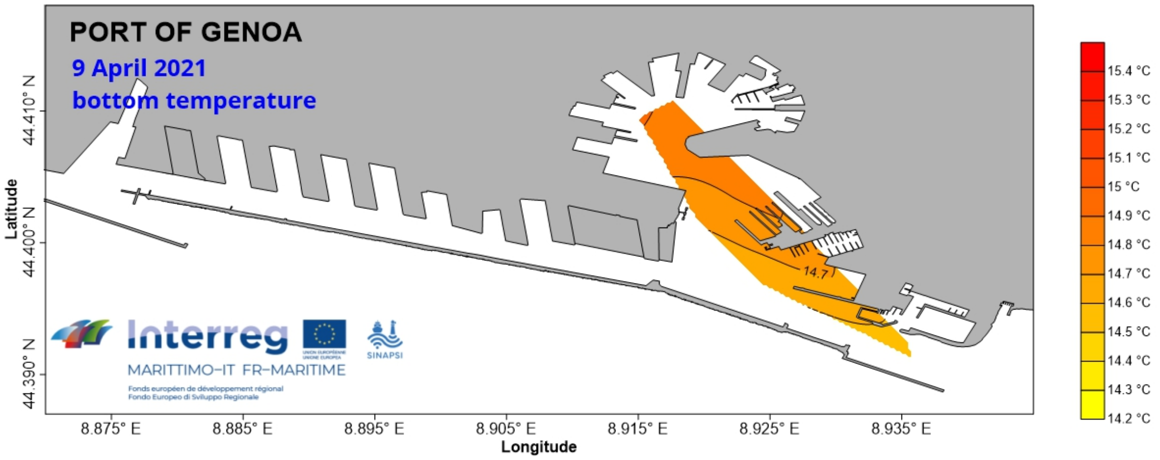

Fig. 44: Horizontal bottom temperature distribution on 9 April 2021

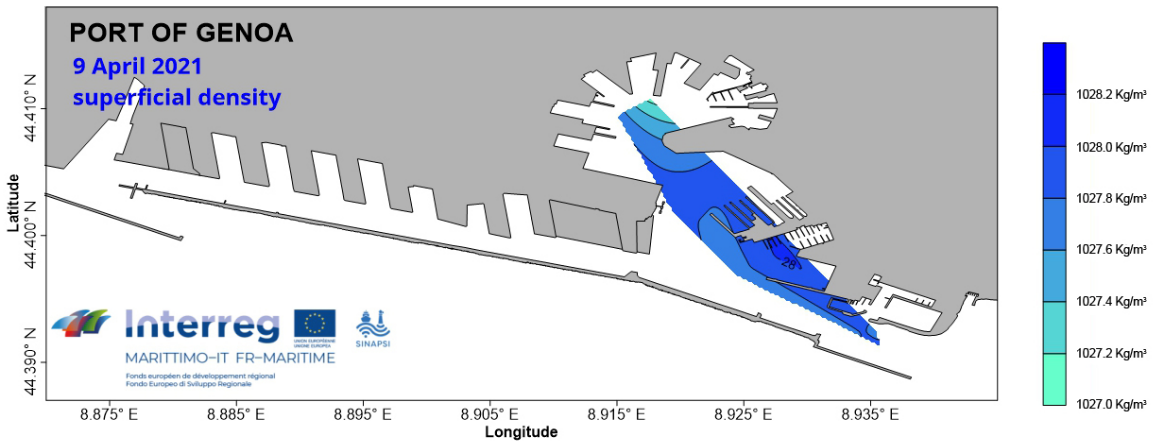

Fig. 45: Horizontal superficial density distribution on 9 April 2021

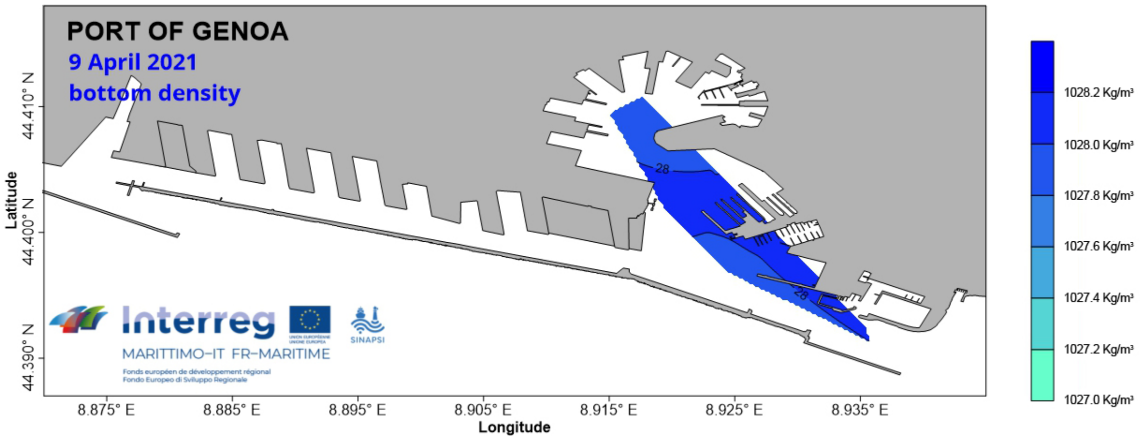

Fig. 46: Horizontal bottom density distribution on 9 April 2021

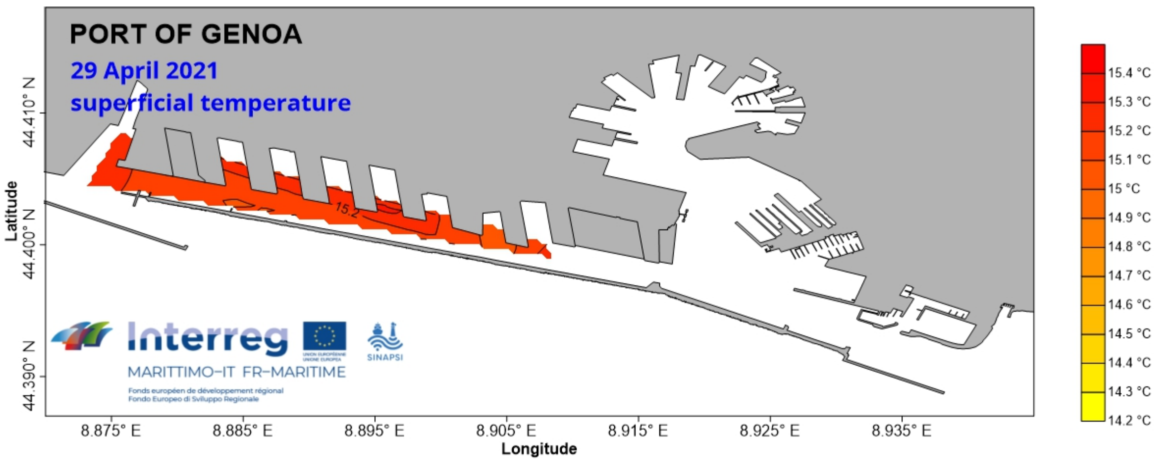

Fig .47: Horizontal superficial temperature distribution on 29 April 2021

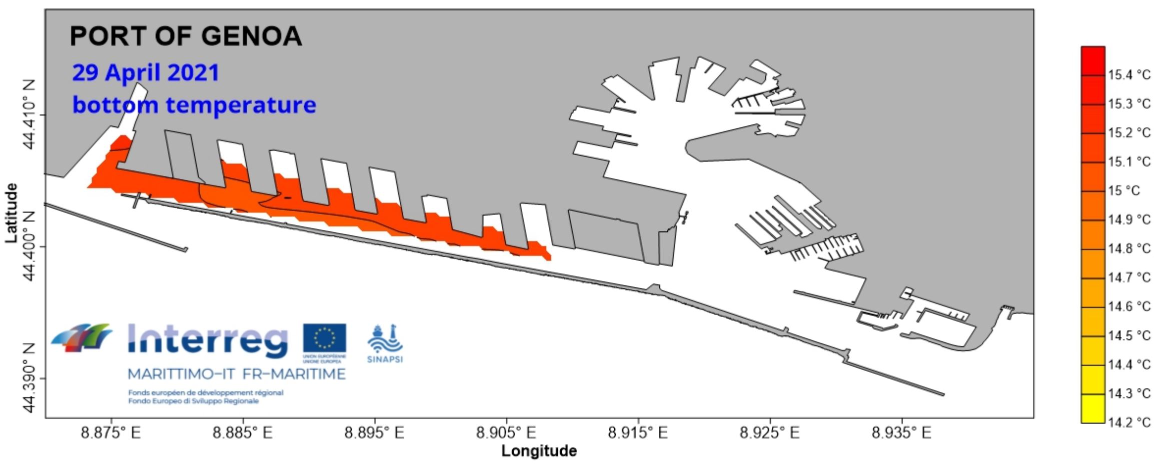

Fig. 48: Horizontal bottom temperature distribution on 29 April 2021

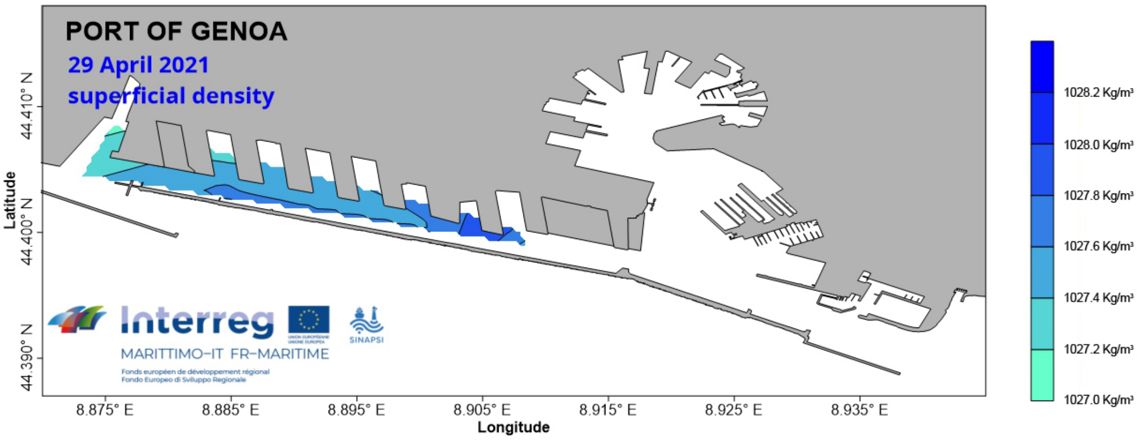

Fig. 49: Horizontal superficial density distribution on 29 April 2021

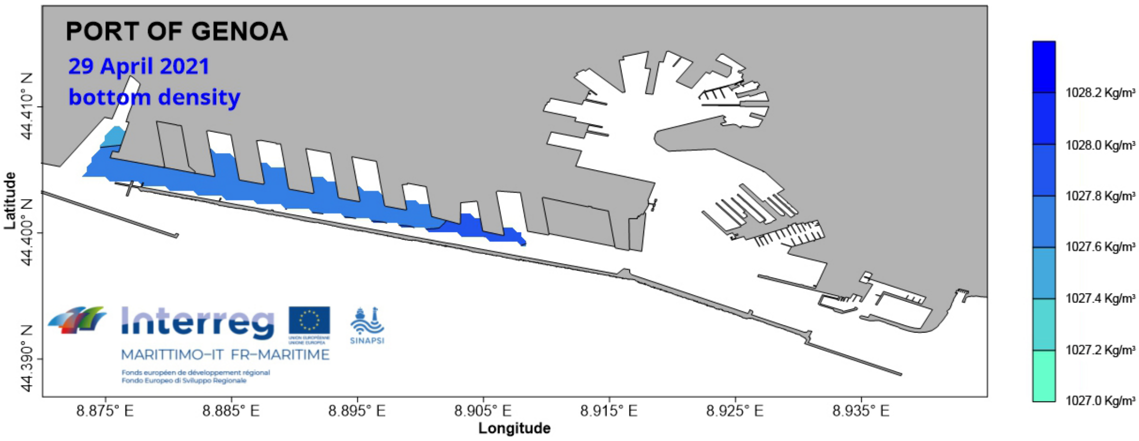

Fig. 50: Horizontal bottom density distribution on 29 April 2021

V.4 CONCLUSIONS

Preliminary monitoring campaigns using the V-ADCP highlighted that the dynamics of the Port of Genoa is influenced by the prevailing wind, but also by the complex morphology of the area. Both the current data and the physical characteristics of the water column showed that it was the areas closest to the port entrances and the Sampierdarena Channel that were most affected by exchanges with external water masses and where the most intense and problematic currents developed. In addition, this is the area of the port where large commercial ships transit and manoeuvre, and therefore the area of greatest interest to the Port Authority with regard to the safety of navigation. The main sites of interest that were identified for the installation of fixed current monitoring stations were therefore the eastern port entrance, the eastern inlet of the Sampierdarena Channel and the western port entrance.