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Corresponding Author: Prof. Bruno Fabiano, Prof., PhD

Corresponding Author's Institution: Genoa University

First Author: Tomaso Vairo

Order of Authors: Tomaso Vairo; Mauro Quagliati, Dr.; Tania Del Giudice, Dr.; Antonio Barbucci, PhD; Bruno Fabiano, Prof., PhD

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Abstract: Even if safety in the shipping industry improved significantly over the last decades, by novel design and construction techniques, driven by technological, cultural and regulation improvements, recent passenger ship accidents emphasized that significant safety challenges still remain. The modern trend towards large cruise ships can pose a serious threat in terms of both people evacuation/rescue and potential impact on sensible environmental targets. This paper firstly presents a critical analysis of three passenger ship accidents, identifying main similarities with the process sector and relevant learning points. Secondly, the study approaches risk evaluation, acceptance criteria and sea use planning in connection with cruise activity, referring to the worldwide known sensible area of Portofino (Italy). By utilizing numerical methods, the study develops a consequence-based framework incorporating the effects, the hazardous distance and the reaction time scale, related to fuel spill and fire scenarios with smoke spreading. The results evidence that the approach can be a powerful tool to design optimal ship route and temporary docking points for cruise tourism, balancing economic issues and mitigating physical impact to sensitive biological communities. Additionally, it can provide a technical basis for setting-up emergency planning, with appropriate response equipment and thus minimizing coastal impact from a spill.

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*Highlights (for review)

# Highlights

- We present a critical analysis on three ship accidents identifying key learning points and similarities with the process sector, from a risk perspective.
- A  consequence based approach to water-use planning in connection with cruise ship activity is proposed.
- Anchorage activity can be designed on the basis of the release scale and  the reaction time scale at the environmental vulnerable receptor.
- Based on spill and fire scenarios modelling, emergency planning with appropriate response equipment can reduce environmental risk in a sensitive area.

# From land- to water-use-planning: a consequence based case-study related to cruise ship risk

Tomaso Vairo[a], Mauro Quagliati[a], Tania Del Giudice[a], Antonio Barbucci[b] and Bruno Fabiano[b*]

[a] ARPAL, via Bombrini 8 – 16149 Genoa, Italy

[b] DICCA Civil, Chemical and Environmental Eng. Dept. - Polytechnic School – University of Genoa, via Opera Pia 15 – 16145 Genoa, Italy

*corresponding author

# From land- to water-use-planning: a consequence based case-study related to cruise ship risk

Even if safety in the shipping industry improved significantly over the last decades, by novel design and construction techniques, driven by technological, cultural and regulation improvements, recent passenger ship accidents emphasized that significant safety challenges still remain. The modern trend towards large cruise ships can pose a serious threat in terms of both people evacuation/rescue and potential impact on sensible environmental targets. This paper firstly presents a critical analysis of three passenger ship accidents, identifying main similarities with the process sector and relevant learning points. Secondly, the study approaches risk evaluation, acceptance criteria and sea use planning in connection with cruise activity, referring to the worldwide known sensible area of Portofino (Italy). By utilizing numerical methods, the study develops a consequence-based framework incorporating the effects, the hazardous distance and the reaction time scale, related to fuel spill and fire scenarios with smoke spreading. The results evidence that the approach can be a powerful tool to design optimal ship route and temporary docking points for cruise tourism, balancing economic issues and mitigating physical impact to sensitive biological communities. Additionally, it can provide a technical basis for setting-up emergency planning, with appropriate response equipment and thus minimizing coastal impact from a spill.

Keywords: cruise ship risk; Costa Concordia; Jolly Nero; Norman Atlantic; oil spill; fire scenario

## 1. Introduction

In the aftermath of severe accidents Regulatory Bodies, research companies, healthy organizations and more generally society are forced to re-examine the way things were done, determine immediate and root causes and make appropriate changes possibly applying novel methodologies and solutions. Owing to historical, cultural, administrative, legislative, and other reasons, the risk assessment methods applied in the EU Member States to support land use planning vary significantly (Christou et al., 2011). On one hand, every region and/or country makes its own decision on the use of QRA for gaining insights into individual risks, societal risks, and on the use of QRA for LUP. On the other hand, there seem to be no significant differences noticeable in safety performance levels of industry working under the umbrella of the Seveso Directive (Pasman & Reniers, 2014), which in the latest version, the so-called Seveso III Directive (EU, 2012), came into force on 1st June 2015. Even though the legislation regulates the use of land in many Countries considering the risk from industrial plants and mobile sources, there are still some unexplored possibilities of managing safety for man and the environment, starting from the approaches already well established in the process sector. The focus of this paper, based upon a preliminary work performed on the subject (Vairo et al., 2015), is to present a case-study combining for the first time, at least to our knowledge, use planning from land to sea water. Marine traffic risk is coupled with transport safety, shipping efficiency, distribution reliability and loss prevention, while port risk management assumes high importance, as accidents at industrial ports can result in injuries or fatalities, as well as in severe environmental damages (Fabiano et al., 2010). A correct and careful risk analysis is necessary to design and implement a Safety Management System able to pursue the policy's objectives and allowing an effective revision of the policy itself and assure that those elements and conditions used as reference for the emergency planning (internal and external) are at least preserved in time (Demichela et al., 2004). To these purposes, the methods and the data used should be steadily improved, because the accuracy of calculated risk is currently only within one or two orders of magnitude, due to the variability in scenarios, the assumed failure rates, and human factor influence (De Rademaeker et al., 2014). Port risk assessment is commonly based on its peculiar features: discrete storage of hazardous chemicals, in transportable containers, or as open piles, poses different hazards, as compared to conventional storage installations, requiring ad hoc solutions to reduce environmental impact (Fabiano et al., 2014). The main environmental threat posed by ship accidents is associated with HazMat transportation and possible environmental impact following a loss of containment; in this regard, the most effective mitigation actions are mainly based on the knowledge of the long time fate of the oil spot (Palazzi et al., 2004). However, passenger ships can represent a serious threat too: even though the accident chances in modern cruise liners are very rare (Vanem et al., 2006), a casualty involving a spill, or flammable cloud forming and pool fire can lead to severe consequences in terms of fatalities, property damage and impact on sensible environmental targets. Risk assessment of vulnerable coastlines and near shore waters is also an essential element of oil spill preparedness and can be done by evaluating ship traffic and the accidents likelihood, along with the probability of releases from fixed offshore installations and impact on the surrounding waters (Galt et al., 1999). Fire hazard to a cruise ship due to fuel leak, electrical cables malfunction, engine room troubles or caterings is considered the worst scenario in shipping industry because of life losses and its serious environmental consequences on the surrounding environment and marine life (Wang et al., 2004). This hazard is increased by the current international trend of the ship industry towards ultra-large cruise vessel, posing critical issues in terms of emergency preparedness and evacuation effectiveness. The remainder of this paper is as follows: firstly, we provide a simplified statistical overview on ship accidents and analyze three recent notable ship accidents evidencing aspects that influence major hazard risks and similarities with the process industry. Then we present a quite general approach combining land and water use planning in connection with cruise line risk, discussing its practical application in a sensible target area.

## 2. A survey on sea accident risk

In the maritime sector, despite a several century experience and many catastrophes, there is not a long accident investigation tradition in which the mission of learning lessons is separated from the allocation of blame and disciplinary actions against the officers on board of seagoing vessels (Dechy et al., 2012). The statistics about accident frequency presented in several papers can provide an overall view of the levels of safety involved in the shipping activity, allowing the quantification of the actual safety levels for different ship types, the main failure modes also considering parameters such as ship sizes, ages, flag etc. (Guedes Soares & Teixeira, 2001). A noteworthy analysis performed on 471 accidents occurring in seaports by Darbra and Casal (2004) covering the time span 1941-2002, showed a clear upward trend of the accident frequency in port areas in part attributable to the increase in port activities and in part to the growth in hazardous substances sea transport. In this context, they evidenced as well two main contributing operations, namely collision (44% of events) and transport (57% of the accidents). Darbra et al., (2004) presented a further exhaustive accident analysis covering 1,033 port accidents from MHIDAS database. They evidenced that the main accident types were loss of containment (70% of the cases), fire (30% of events) and explosion (24% of cases), even if with several overlapping scenarios during accident evolution or escalation. Suggestively, following the same order of the process industry, even if with different percentages, this study evidenced that the most frequent accident affecting population is fire (30%) followed by explosion (24%) and gas cloud (5%). An analysis covering the period 1987-1998 and including 6,111 ship accidents, during open sea transport, irrespectively of their severity performed by Fabiano et al., (2002) allowed sorting the three main accident cause as mechanical and electrical failures with engine troubles (30%); collisions (24%) and stranding (12%). By considering only major accidents, from the same study it followed that the immediate causes are human errors and severe atmospheric events (23%), on-board fires and explosion (20%), followed by collision (19%); interestingly in this case, technical troubles or failures were identified as determining cause only in 4% of the events. As observed by Kelman

(2008), the hazards in the marine supply chain involve a complex interaction of natural effects, hardware serviceability and vigilance on the part of the crew: in most circumstances, the degradation of any one of these will not lead to an incident, but a combination of any two raises the risk of an incident significantly. According to Lloyd Register (2011), the cause of high severity accidents over the years 2000-2010 causing total loss and considering all ship types, can be summarized as depicted in Fig. 1, from which the most relevant scenarios can be sorted: foundering (49.1%) stranding (18%) and fire/explosion (14.7%) are the most common causes. From the same source, it resulted that cargo vessels cover 44.5% of total loss record, fishery 26.6 %), tankers and bulk carriers 15.2% and passengers ship, including cruise, cover a percentage of 6.3%. Dealing with passenger vessel accidents causing injuries and fatalities, Talley et al. (2006) identified as main determining causes human mistakes rather than environmental and vessel-related causes. Likewise in the process sector, the contribution played by human errors should be considered alongside all phases of the process, i.e. design, construction, operation and ship management. This item and the determining role of possible safety deficiencies and management shortcomings on sea accidents were drivers for the introduction of the International Safety Management (ISM), also given the major challenge offered by an ad hoc safety management system in reducing the spill frequency due to failure (Milazzo et al., 2010). Dealing with the maritime transport of bulk on containerized products, Kelman (2008) argued that in contrast to what might be expected, frequently the most outwardly hazardous goods have a lower frequency of serious incidents than the more benign cargoes. The items of faulty perceived safety of the ship and the route are well represented by the high-profile accidents occurred over a limited time span (2012-2014) in a rather narrow geographical area.

**2.1 Three recent notable ship accidents**

A preliminary study is here presented aiming at identifying “what did go wrong” starting from available factual data. In fact, the following case studies provide three recent examples of the severe consequences of lapses in concentration, technical errors, failure to ensure that safe practices are followed at all times and emergency procedures be effectively and promptly activated, with causation result of wrong risk estimates, lack of overview, and communication between individuals involved. They seem confirming also in these last years the previously mentioned role of human error (Talley et al., 2006), in determining high severity ship accidents.

**Costa Concordia 13 January 2012**

Costa Concordia, represented a perfect example of a modern cruise ship designed for a total onboard people of 4890 (of which 3780 passengers). It was built in the years 2004-2005 by Fincantieri CNI S.p.A. of Sestri Ponente (Genoa, Italy) and equipped with state-of-the-art electronic aids to navigation, security and resources management systems. The passenger ship with on overall length of 289.59 m was provided with two electric motors of total power 2 · 21,000 kW at 146 rpm, ensuring a nominal speed of 19.6 nodes. The ship capsized in January 2012, causing 32 fatalities, under calm sea and clear visibility conditions, having struck a rock in the Tyrrhenian Sea, near the shore of Giglio Isle, on the West coast of Italy. When Costa Concordia was struck into the sea, its tanks were full of 2,380 t of heavy diesel that could have leaked into the sea causing a worst destruction of the highly vulnerable ecosystem. The vessel drifted back onto shore and grounded; this probably saved many lives. Concordia accident provides an illuminating example of the types of human and organizational failures that can result in major accidents. The immediate cause is connected to the hazardous choice of sailing the ship close to the isle, so as to blow the ship's horn, figuratively bowing, or saluting the port (known as "inchino," Italian word for "bow"). In this respect, as reported in different contexts (Prielipp et al., 2010), it is noteworthy noting how a deviant behaviour occurring over the years without any consequence, induces people within the organization to expect and accept these violations. Key factors associated with the accident and its severity, as resulting from the technical report of the consultant of the Preliminary Investigation Magistrate and from press articles (e.g., Margiocco, 2013) could include:

- direct human error by the captain deviating from the navigation plan, for non-operational reasons and causing the vessel to ground, puncture the hull and lose engine power;
- hazardous navigation route at "severe conditions": excessive speed (up to 16 nodes), coast proximity and night-time (inherently unsafe conditions);
- efficiency of fault and corrective maintenance system;
- poor work and safety-critical communication hampered by poor linguistic ability;
- delay in general emergency alarm activation;
- emergency procedures for responding to accidents and non-adequate emergency training of the staff (risk management).

**Jolly Nero, 7 May 2013**

Jolly Nero was a Ro-Ro cargo ship with an overall length of 229.36 m, a width of 30.5 m, built in 1975 and entered into service in 1976. It was equipped for carriage of containers, vehicles or loads on wheeled beds and intended to operate in any area and any period of the year. A single diesel engine of nominal power 23,389 kW ensured propulsion, with auxiliary electrical air blowers to be activated during the engine starting. Jolly Nero was manoeuvring out of the port of Genoa, in a narrow channel, with a port pilot on board, utilizing its own propulsion and with the help of two tugboats in calm sea conditions. According to the recovered Voyage Data Recorder (VDR), due to mechanical failure of the ship engine, while moving back at a speed of nearly 3.4 nodes, it failed restarting the engine, as required after reversing the movement. Notwithstanding the tug action and a delayed desperate but untimely anchor casting, the vessel violently crashed into the 55 m tall concrete and glass tower (see Fig. 2), at 23 p.m., just when a shift change was taking place in the control tower and 13 people were thought to be inside (Il Secolo XIX, 2013), causing 9 fatalities, four injured people and the whole building collapse. Even though the technical investigation is currently under development, from a critical analysis based on public information some key factors associated with the incident severity could consider:

- fault instrumentation (dashboard tachometer), so that the crew member was not informed, or even mislead;
- efficiency of fault and technical near-miss reporting and corrective maintenance system;
- operating conditions (3.4 nodes speed) not allowing a prompt recovery in case of technical fault (un-resilient system);
- emergency recovery and timely action following a technical deficiency (risk managing);
- learning from previous similar low severity collision of a chemical tanker (organizational memory and learning from experience);
- adequacy of the localization of the control tower from a risk perspective addressing a major impact scenario (land use planning);
- design of the control tower in connection with its localization and major impact scenario (no layer of protection, or inherent high impact resistance).

**Norman Atlantic 28 December 2014**

A striking example of ship accident with fire scenario is provided by the Norman Atlantic ferry, a Ro-Ro vessel designed to carry wheeled cargo, such as cars, trucks, semi-trailer trucks, trailers, and railroad cars that are driven on and off the ship on their own wheels. The blaze is believed to have broken out early morning, in the lower deck garage of the vessel, the fire apparently quickly went out of control notwithstanding modern vessels are equipped with emergency systems which should prevent a local fire from escalating into high severity accidents. The captain sent a distress signal when the Norman Atlantic was 35 nautical miles northwest from the island of Corfu, between Italy and Albania sailing towards the port of Ancona (Italy). A total of 503 passengers and crew members were on board and the long lasting fire resulted in more than 11 fatalities, 18 missing people, an unknown number of stowaways victims and nearly one hundreds injured people. The severity of this accident scenario could be related to the exposure to a very broad range of toxic combustion products originated from truck/car fire in confined environment (Vianello et al., 2012) and to the extent of their duration and bio-persistence. In case of cruise liner fire, compounds such as carbon dioxide, methane, chlorofluorocarbons, aerosols, nitrogen oxides, sulphur oxides, carbon monoxide and particulate matter in the form of propagating smoke potentially affect visibility, human and environmental health. Even though the technical investigation is currently under development, also with regard to the identification of the most probable immediate causes, some key factors associated with the incident severity could include, also as root causes:

- apparent underestimation of potential fire scenario severity and smoke evolution (understanding hazard and risk);
- reliability of the fire detection and fire safety systems including alarm (passive and active engineered safety systems);
- perceived safety of the transport and of the vessel;
- hazard awareness and evaluation (lack of perception of vulnerability);
- emergency plan effectiveness and response for dealing with high profile accident (managing risk).

This last accident evidences as well the need for thorough risk assessment procedure, proper emergency preparedness and crew training in order to maximize the survival chances in case of fire in the car deck.

Summarizing, the accidents previously analysed provide illuminating examples of the types of human and organizational failures that can result in major accidents: while at first sight ship activity seems having little in common with process industry, a deeper cause accident analysis can reveal that many immediate and underlying aspects influencing major hazard risk are similar. In the three cases some of the contributing factors are the same that appear in several process accidents, e.g.: failed/poor instrumentation not allowing the crew member to know the actual state of the system; lack of explicit criteria and operator training to deal with emergency; poor hazard and consequence analysis and resulting under-appreciation of risk; risk habituation. Some underlying items can include: rising productivity and economic requirements that are making plants more complex and increasing people's workload; experience and knowledge drain through retirement and job-hopping while dedication and discipline are stagnant; work communication, which may be hampered by poor linguistic ability, time pressure and fragmentation of the organization (De Rademaeker et al., 2014). The issues raised from the critical analysis of these accidents suggest as well the possibility of a mutual cross-sector organizational learning.

## 3. Cruise liner environmental risk assessment

Based on the ship accidents investigation described above and starting from the land-use-planning perspective, it seems advisable to evaluate the extent of the danger posed by a potential cruise ship accident beyond the immediate water boundaries. In this section, we face risk assessment starting from the approach to the mitigation of the off-site consequences based on the control of the uses of land in the immediate vicinity of a major hazard site. As previously outlined, the release of oil in case of accident to a cruise ship is considered one of the most serious threat to coastal and marine environment exerting immediate and potential long-term consequences. To this end, three central questions must be answered:

1. What might be the short time environmental consequences of an accident to a ship in a sensible area, involving oil spill, possibly followed by a fire considering alternative anchorage locations?
2. What might be the long-term environmental consequences of cruise ship activity in the gulf area?
3. To what extent can a cruise related hazard be considered acceptable in the light of environmental and societal factors?

These issues are well relevant in Europe, where the cruise routes are mainly affecting coastal waters (no obstacles within 2 miles) and narrow waters (no obstacles within 0.5 miles) rather than open waters (no obstacles within 5 miles) and consequently the collision and grounding hazard is more relevant if compared for example with the Caribbean cruise trade taking place mainly in open sea waters. A modeling study was conducted, to assess possible environmental consequences along the coast of Portofino and Santa Margherita Ligure (Italy). To this end, an in-depth approach should consider in detail following objectives as basis of the cruise environmental risk assessment study: to identify the possible causes of damage to the ship leading to loss of containment; to quantify the physical effects through oil spill and fire consequence modeling, due to loss of containment; to evaluate the unwanted event frequency, by using frequency obtained from historical data and, at last, to perform a qualitative risk assessment based on event frequency and consequence results. A similar approach was fully applied considering HazMat transportation in urban areas and thoroughly examining prevention or protection measures suitable to reduce the risk to a significant extent (Milazzo et al., 2002). Numerical risk models are powerful tools for environmental risk assessment of fire scenario representing a proactive approach allowing determining the probability of such a situation to occur and the expected consequence of the incident (Vanem et al., 2006). As amply known, by utilizing a risk matrix and defining a target line of consequence-frequency combinations allows a simplified cost-benefit assessment and helps to answer the question how safe is safe enough, considering both acute risk and chronic risk. Following items were considered: definition of chemical of concern for each scenario; quantification of the release scale at different weather conditions for significant consequence at the receptor; quantification of the reaction time scale for environmental impact minimization. In the following subsections, we assess environmental risk caused by fire from tank rupture, or catastrophic failure of a cruise ship, by utilizing standard numerical methods according to a water use perspective.

### 3.1 Reference pilot area

According to a preliminary study (Vairo et al., 2015), we considered a sensible area represented by Portofino promontory, located about 25 km East of Genoa (Italy) with 13 km of coastline into the Ligurian gulf. The peninsula has a rough coastline, steep seabed and high indices of biodiversity, both in its terrestrial and marine ecosystems. Since 1935, a terrestrial protected area known as Portofino Park was established and since 2001 the seaward area became a marine reserve. The reserve is structured into three different protection levels: Zone A of integral environmental protection, between Punta Torretta and Punta del Buco, where navigation, fishing, scuba diving and human activities are strictly forbidden; Zone B of main environmental protection, from Portofino Punta del Faro to Punta Chiappa, where fishing is allowed to residents, scuba diving is allowed to diving centers, while is free diving and swimming is allowed with limitations. Zone C partial reserve, stretching along both sides of the Portofino promontory where diving and swimming are generally allowed. The natural sensitivity of the area already addressed hydrogeological, geological investigations and monitoring activities aiming at environmental risk minimization and proper land use planning (Brandolini et al., 2007). Fig. 3 shows Portofino promontory and coast, as well as a detail of the considered area for modelling simulations of environmental pollution scenarios, focused on assessing the impact from source points corresponding to cruise ship anchorage points.

### 3.2 Oil spill modelling

The simulation was performed on MIKE, a platform customized by DHI (Hørsholm, Denmark). The 3D hydrodynamic circulation model is achieved utilizing MIKE 3 HD approach (Hørsholm, Denmark), which simulates level and stream variations as a function of all the phenomena influencing the hydrodynamics of coastal and ocean environments: density gradients (temperature / salinity), effect of the tides, wind effect, heat exchange with the atmosphere and the Coriolis force.

We adopted a numerical finite volume discretization method, on the flow and transport equations in the horizontal dimension, with a non-structured triangular mesh having a variable resolution from offshore and towards the coast. We adopted a computational domain wide enough to understand the key dynamics of the Ligurian Sea and including the whole coastline between Livorno and Nice (France). The vertical dimension was discretized using 10 levels of variable thickness (sigma-layers) and 30 levels of constant thickness (z-layers). The platform is currently up and is running on a daily basis, in order to evaluate the Liguria Sea dynamics, receiving the boundary conditions from the circulation model of the Mediterranean Sea MFS (Mediterranean Forecast System). These boundary conditions are available within the European program COPERNICUS, operated by the Consortium MyOcean, by combining weather data from the meteorological model MOLOCH, and hydrological model runs Drift, both developed at the CFMI-PC (ARPAL). The operational chain provides, twice a day, prediction of circulation, sea level, salinity and temperature for the next 48 hours. The hydrodynamic stream fields provide the basis for the calculation of hydrocarbons transport. Oil spill modelling was based on a Lagrangian dispersion of particles in the sea, providing information on the trajectories and the slew rates generated by the stream and the wind surface; the chemical transformations of spilled organic product is considered as a function of the state variables. Modelling was performed simulating a release rate of 100 kg/h of heavy fuel and assuming relevant meteorological conditions in terms of surface current and wind direction and intensity, resulting from local experimental observations.

### 3.3 Fire hazard modelling

The consequence evaluation arising from the development of a fire on board of a cruise ship was performed referring to the source points corresponding to the identified temporary anchoring points of the cruise ships. These points were cautiously selected to protect vulnerable communities of designated marine features, with the aim of meeting both the environmental and safety goals. The fuel is perfectly analogous to the one utilized by Costa Concordia and its chemical-physical characteristics are summarized in Table 1. Based on historical data, hole sizes corresponding to medium size leak was considered and a qualitative estimation of the frequency of each loss of containment event and associated scenarios was calculated using a combination of API 581 standard and event tree technique. Frequency and severity results were utilized as coordinates in a risk matrix to compare the acceptability of different options, rather than obtain by composition an actual risk index. The corresponding fire evolution scenarios at each point were evaluated considering as well the propagation of the combustion fumes resulting from the fire. A multi-method approach to effect evaluation was performed utilizing well-established and validated software models: EFFECTS 5.5 (TNO), for the evaluation of the impact zones of a fire and ALOFT-FT 3.1 (A Large Outdoor Fire plume Trajectory) of NIST, for the propagation of smoke caused by the fire. We utilized wind rose data obtained from meteorological statistical observations over Portofino Mount over the year 2014, to select relevant wind directions and speeds and identify the higher probability occurrence. The 2 F weather stability class was adopted for the consequence modelling, considering worst-case consequence in connection with flammable gas dispersion.

### 3.4 Atmospheric dispersion of smoke due to transit

The atmospheric dispersion of combustion gas in connection with the standard engine activity of the ship was faced accounting for transit and temporary anchorage activities as resulting from statistics covering the yearly time span and frequency commonly dedicated to cruise in the Mediterranean area. To this purpose, we selected ADMS (Atmospheric Dispersion Modelling System) considering that its validation against a wide range of data sets (Riddle et al., 2003) confirmed that the predictions of the model are in reasonable agreement with observation, in particular over flat terrain, likewise the sea surface. The atmospheric boundary layer properties utilized in this quasi-Gaussian dispersion model are characterized in terms of the boundary layer depth and the Monin-Obukhov length, instead of the single parameter Pasquill-Gifford class. According to a previous applicative study on stationary source emissions (Vairo et al., 2014), a meteorological pre-processor is used in the modelling approach to accurately calculate the values of the meteorological parameters in the boundary-layer starting from the input meteorological data acquired on-site.

## 4. Results and discussion

Cruise activity can result in either direct or indirect accidental hazardous scenarios with the potential to cause damage to the environment or local community. Careful site selection for anchorage and route towards the shore in the daily visit to the site can be used to minimize damage to coastal habitats. Results are discussed with the focus on assessing temporary anchorage area eligibility, based on the environmental consequences connected to the extension of the potentially damaged areas and the environmentally vulnerable receptors.

### 4.1 Oil spill

Over the summer and autumn 2014, a series of real-time simulations were carried out, to model the effect of a given fuel flow rate from fixed sources localized within the ships anchorage area. The main purpose was to examine the possible trajectories and the arrival times of the spilled fuel on the coast, as a result of a hypothetical accident. The movement of floating hydrocarbon particles is highly dependent on the hydrodynamic structure of the superficial layer, which is affected by the influence of the local wind fields on the sea surface. The weather exerts a two-fold influence on the motion of particles: from one side it represents an input in the hydrodynamic model as a meteorological driver on the sea surface, on the other side it acts as a driver directly affecting the floating particles motion in the wind direction. Given these characteristics, each simulation results as a space-time dynamic composition of the two transport factors: the hydrodynamic and the weather one. Modelling is based on three components, namely data organization and elaboration, hydrodynamic modeling evidencing the effects of spreading and weathering processes on spill evolution and visualization and analysis of the result. For the sake of brevity, we present three scenarios connected to relevant meteorological and hydrodynamic conditions in the considered area, in form of graphs of immediate readability. The results here summarized are a careful selection of many real-time simulations performed during the year 2014, covering a wide series of the main directions of particles drift. For each run of the modelling study, in the following Figs. 5-7 are evidenced: a screenshot representing the map of the stream vectors of the superficial layer of the hydrodynamic model and the maps of the arrival time of the particles in the computational domain, considering the most critical current and planned anchorage points. Results can be utilized within a decision support system to be implemented in coastal zone management when appropriate measure must be promptly applied after oil spill occurrence.

Fig. 5 corresponds to moderate and uniform superficial current range in the North-West direction, associated with winds from the second quadrant. The trajectory examination reveals a predominant and persistent North-West transport (towards the shore of the nearby town of Rapallo) lasting nearly 32 h, followed by a re-circulation of oil particles. Designed anchorage point A implies a prevalent stranding of the spill on the shores of Santa Margherita, Rapallo and Zoagli with arrival times lower than four hours. The spill evolution considering the currently utilized anchorage point B reveals a similar behaviour with higher residence times (4 h – 8 h), causing a secondary involvement of C area of Portofino reserve. Fig. 5 corresponds to calm conditions and main circulation within the Tigullio Gulf. It is associated with a general stagnation of the weak current towards the West direction around Portofino cape, in connection with weak and variable winds. From trajectories examination, it results that the vortex centered on Punta Portofino, under calm wind condition, causes a clockwise movement of the spilled oil within Tigullio Gulf and subsequent escape out of Portofino bay towards West with the current backflow. The designed anchorage point A is connected to arrival times of the oil spill from 4 to 12 hours at the coast of Portofino area C, Santa Margherita, Rapallo, Zoagli and Chiavari. The hypothetical spill at anchorage point B shows a longer open sea residence time and reaches the coast after a period longer than 12 hours, however involving the zone B of the Protected Area too. At last, Fig. 76 depicts the condition associated with strong of surface current fields in the South West direction, associated with intense and persistent winds from the fourth quadrant. Under these conditions, the oil spill trajectory is mainly directed away from the Promontory towards open sea and the East direction, with re-circulating effect only after 32 hours from the event. The anchorage point A evidences that a hypothetical spill in the early 4 hours is trapped in the re-circulation affecting the coast of Portofino and the area C and Santa Margherita Ligure. In case of anchorage point B, the bulk of the spill is dispersed off for most of the simulated period, unless the recirculation at residence time longer than 28 h. Summarizing, the present simplified approach highlighted, first of all, the complexity of the coastal currents circulation around the Protected area of Portofino, since the establishment of complex phenomena due to the combined effects of the interference both on the dominant hydrodynamic circulation and on the wind field. The anchorage area is located right in the gravity center of the circulatory structure, which develops between Punta Portofino and the Tigullio Gulf. The agreement between the wind and superficial current field measurements and model results are rather fair and appropriate to the purpose of this preliminary work, allowing a comparative estimate of the overall spill risk. Additionally, this knowledge could minimize coastal impact on the sensitive area by staging spill response equipment and adequate local response planning.

### 4.2 Fire and atmospheric dispersion modelling

To the purpose of the present simplified evaluation, we evaluated one event/scenario: the random rupture of ship fuel tank causing the release of a flammable and toxic substance. According to the preliminary study described in Vairo et al. (2015), the qualitative assessment of the acceptability criteria of environmental risk, we considered a simplified ALARP matrix, based on the definition of risk as the relation between frequency and the number of people/environmental targets suffering from a specified level of harm in a given population from the realization of specified hazards. As amply reported, rate and amount of smoke produced during fire scenario depend upon the type and quality of material involved in fire, combustion rate and the rate at which air is entrained into the plume (Palazzi et al., 2012). By means of the numerical methods previously outlined, the scenario corresponding to a medium size loss of containment event of a cruise ship (tank rupture of 10 cm ca.) and subsequent fire was based on a maximum release rate equal to 305 kg/min, a total released mass of 12,654 kg and a calculated maximum pool diameter of 55 m. Analogously to the previous section, Fig. 7 depicts the modelling results in form of immediate readability evidencing the extension of the hazardous area and assuming as point source the most critical MEDA 2 site. The resulting maximum downwind extension of the hazardous area at 10% Lower Flammable Limit (LFL) was calculated equal to 34 m while the downwind extension at 60% LFL corresponds to 86 m. Dealing with fire combustion products, referred to the considered LOC event, the corresponding plume rise and extension potentially affecting the coast are reproduced in Fig. 8. The worst case corresponding to East wind shows carbon dioxide plume raising up at a height of 250 m with an effect distance on Portofino promontory of nearly 1 km. No other accidental fire scenarios affect the coast environment. The scenario corresponding to a catastrophic leakage and subsequent fire assumed a maximum release rate corresponding to 4,000 kg/min, a total released mass of 231,210 kg and a corresponding maximum pool diameter of 200 m ca. Again, the point MEDA 2 represents the most sensitive case: the maximum downwind extension of the hazardous area at 10% LFL corresponds to 477 m while the downwind extension at 60% LFL corresponds to 477 m (as shown in Fig. 9). Analogously, the combustion products environmental impact with the plume rise and extension referred to the worst-case event, with potential impact on Portofino coast are reproduced in Fig. 10. Summarizing, the catastrophic failure of the tank at MEDA 2 is the only accidental fire scenario impacting environmental receptors on the promontory and is characterized by an expected frequency lower than $10^{-7}$ $y^{-1}$, even considering that the limitation of the estimate is within one order of magnitude. Additionally, it should be noted that fire smoke, under wind conditions affecting the cruise ship, implies hazards for ship passengers too, namely toxicity of carbon monoxide, irritant effect of smoke particles as well as reduction of visibility thereby limiting the evacuation possibility. The preparation and deployment of emergency response plan of the cruise ship should consider sound organisational principles, allowing an appropriate response to a wide range of potential emergency response situations, identified by the different scenarios following a loss of containment and hazardous release. Even if this item is out of the purpose of the current study, the assessment of cruise ship risk provides a useful basis for the introduction of detailed emergency response procedures, including effective emergency ship abandonment strategy, with the focus of saving passenger lives and protecting the environment.

As anticipated, likewise normal continuous emissions, well controlled in industrial operations, a further potential of environmental harm was evaluated as resulting from normal ship transit, taking into account the peculiar vulnerability of Portofino promontory. To this purpose, we performed a long-term evaluation of potential environmental damage considering the atmospheric dispersion of combustion gas in connection with the standard engine activity of the ship. Starting traffic statistics from the main cruise companies referred to the yearly time span and frequency dedicated to the activity in the Mediterranean area, we referred to transit and temporary anchorage impact. The effect distance is considered as the distance at which an observable adverse effect occurs to the biophysical environment. The dispersion path of the combustion products was cautiously evaluated making reference as emission source to the already mentioned anchoring point MEDA 2, utilizing as input data for the three-dimensional wind field elaboration were obtained from the statistical wind rose covering the period May-October 2014. Fig. 11 shows the calculation domain covering Portofino promontory and the designed receptor grid suitable to perform the simulation runs accurately. Fig. 12 shows in the form of isopleths curves the results referred to nitrogen oxides. The atmospheric dispersion map expressed in terms of the hourly average over the cruise season, evidenced a maximum NOx corresponding to 10 $\mu g \backslash m^3$. As remarked in the preliminary investigation (Vairo et al., 2015) we limited the simulation runs to the reference pollutant, which is amply known as precursors for photochemical ozone formation mainly in presence of consistent solar radiation, like in the considered area. The critical hazardous level for impact on all vegetation types is currently assumed at a precautionary value of 30 $\mu g/m^3$, while an annual value of 40 $\mu g/m^3$ is recognized as an air quality guideline. (WHO, 2000). The modeling exercise described above, even if limited to a consequence-based approach and developed at a preliminary stage, provided important information for the here defined “water-use- planning”. Namely, an environmentally correct anchorage activity can be designed assessing the “release scale”, based on the quantity and atmospheric/sea weather conditions realizing a relevant impact on the vulnerable area and on the “reaction time scale”, based on the knowledge of the arrival time of the hazardous compound at the vulnerable receptor. The proposed framework considering ALARP as a risk criterion below a tolerable and above an acceptable limit, can be helpful for effective risk-informed decision-making procedures also in different sea contexts.

## 5. Conclusions

Recent high profile accidents involving passenger liners evidenced the need for better preparation by the maritime sector to deal with events possibly triggering an environmental disaster. From one side, ship accidents, even not connected to HazMat transportation, can give rise to high profile fire scenarios with lasting extended to several days and comparable to process accidents. From the other side, land-use planning should be considered as a critical issue in the passenger maritime sector, especially in case of sensible environmental or historical/artistic targets. In this paper, we illustrated an application of risk prevention in sensible areas from a water use planning perspective. To demonstrate the application of the methodology we employed a consequence-based approach, in which the possibilities of both accidental and routine emissions are identified and analyzed accounting for adverse effects. For this purpose, we firstly considered oil spill in connection with different anchorage points and its impact under different atmospheric conditions. Secondly, we assessed environmental risk from ship cruise in connection with fire scenarios by estimating a reasonably conservative effect distance at which an observable effect could occur. The atmospheric dispersion map of the heuristic pollutant connected to ship transit and anchorage evidenced a maximum concentration nitrogen oxide below the most stringent reference value, for all considered anchorage points. The simplified framework to cruise risk can be used to make comparative evaluations through the relative ranking of risk reduction strategies (e.g. anchoring point localization, engine/ship management and operation etc.) addressing water use planning. Additionally, it can build awareness on safety and emergency procedures, both for passengers evacuation and to reduce site vulnerability increasing the overall safety of the given sensible area. Upon proper refinement, the framework can be applied to the evaluation of cruise ship risk in case of transit and temporary anchorage nearby of sites characterized by notable historical and artistic heritage (e.g. Venice, Italy). This item is currently under debate in Italy and requires effective risk information and decision-making procedures. An additional accuracy is clearly necessary including a further theoretical effort to refine the approach, adding a quantitative risk evaluation, mainly in terms of expected frequency, for the different relevant scenarios.

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Table 1. Basic chemico-physical characteristics of cruise ship fuel oil.

| **FUEL OIL** |
|---|
| **Lower Flash Point** 325 K |
| **Lower Flammable Limit (LFL)** 1.3 % |
| **Upper Flammable Limit (UFL)** 6 % |
| **Auto-ignition Temperature** 350 to 625 ° F |
| **Vapor Pressure** 2.17 mm Hg at 70.0 ° F |
| **Specific Gravity** 0.841 at 289 K |
| **Boiling Point** 556-611 K at 1,013.25 hPa |
| **Water Solubility** < 1 mg $mL^{-1}$ at 294 K |

**Figure1**

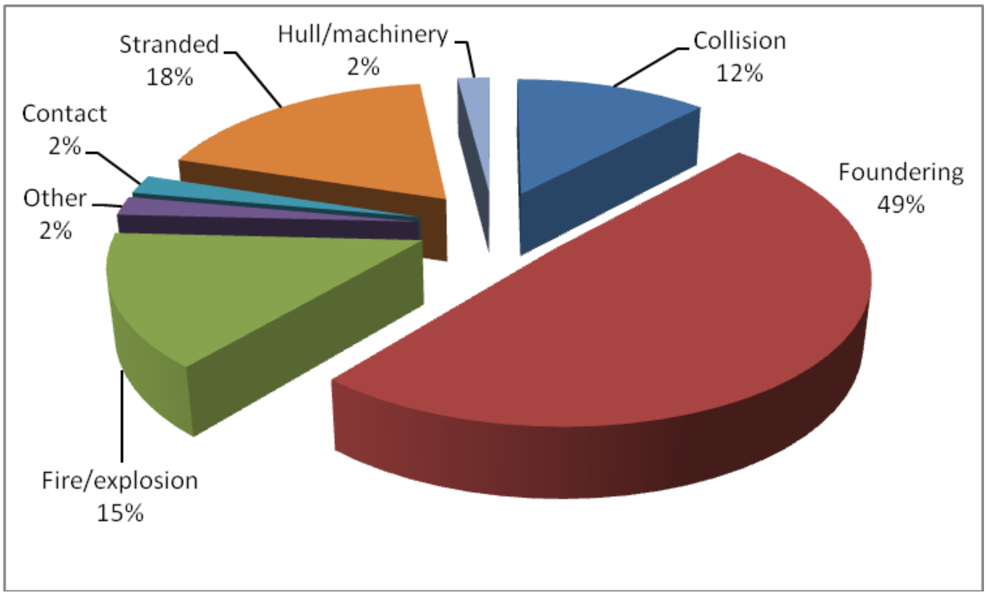


**Figure 1.** Worldwide statistics on main accident scenario distribution, causing total loss, over the time span 2000-2010 for all ship/vessel types (Lloyds Register, 2001).

Figure2

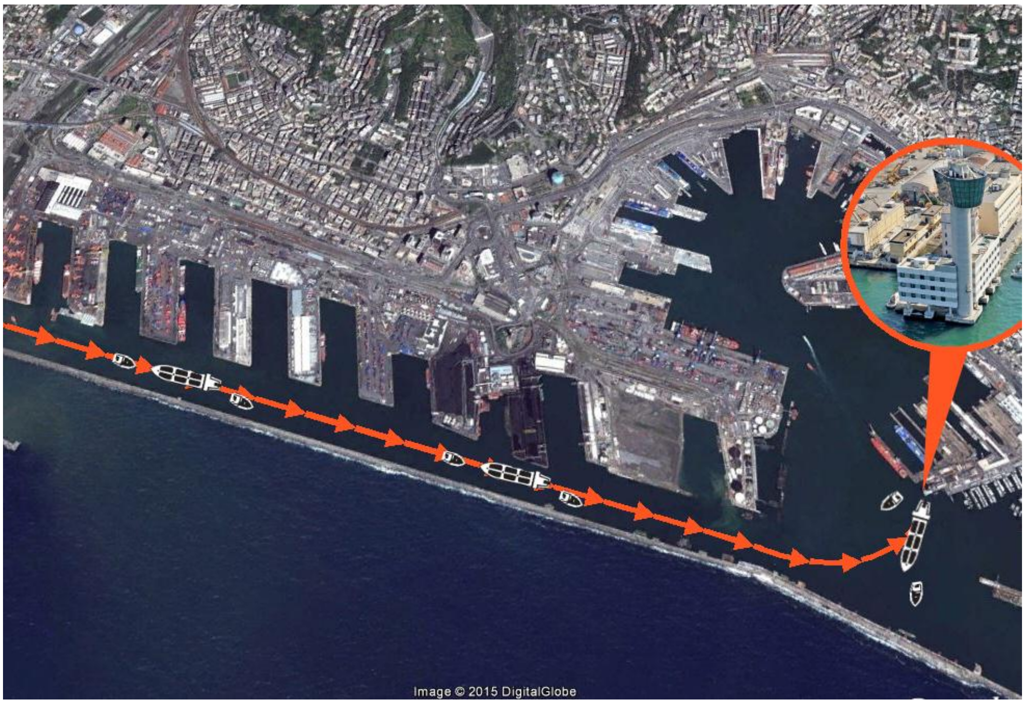


**Figure 2.** Schematic route of Jolly Nero back exit from Genoa port with auxiliary two tug boats and impact point on the control tower (torre Piloti)

**Figure3**


**Figure 3.** Geographical area of investigation and different source points utilized during modelling simulation **A** and **B** anchoring points; **MEDA 1** and **MEDA 2,** correspond as well to real current data acquisition points.

Figure4

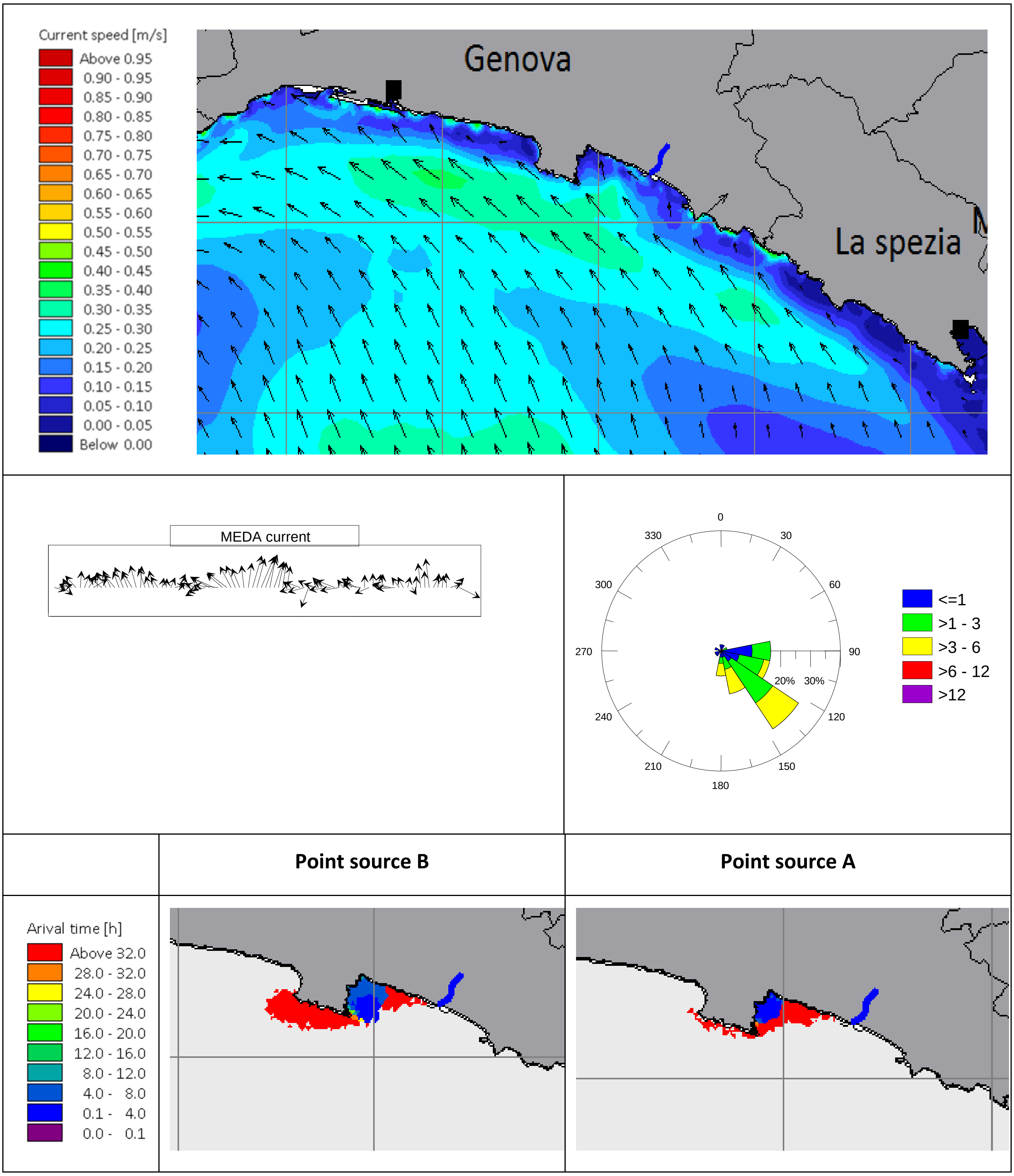


**Figure 4.** North-West scenario: hydrodynamic simulation (speed [m/s] ) with experimental data of sea current field recorded at MEDA 1 point and actual wind rose [m/s] (upper side); oil spill time evolution [h] corresponding to different designed anchorage points for a cruise liner, as point source (lower side).

**Figure5**

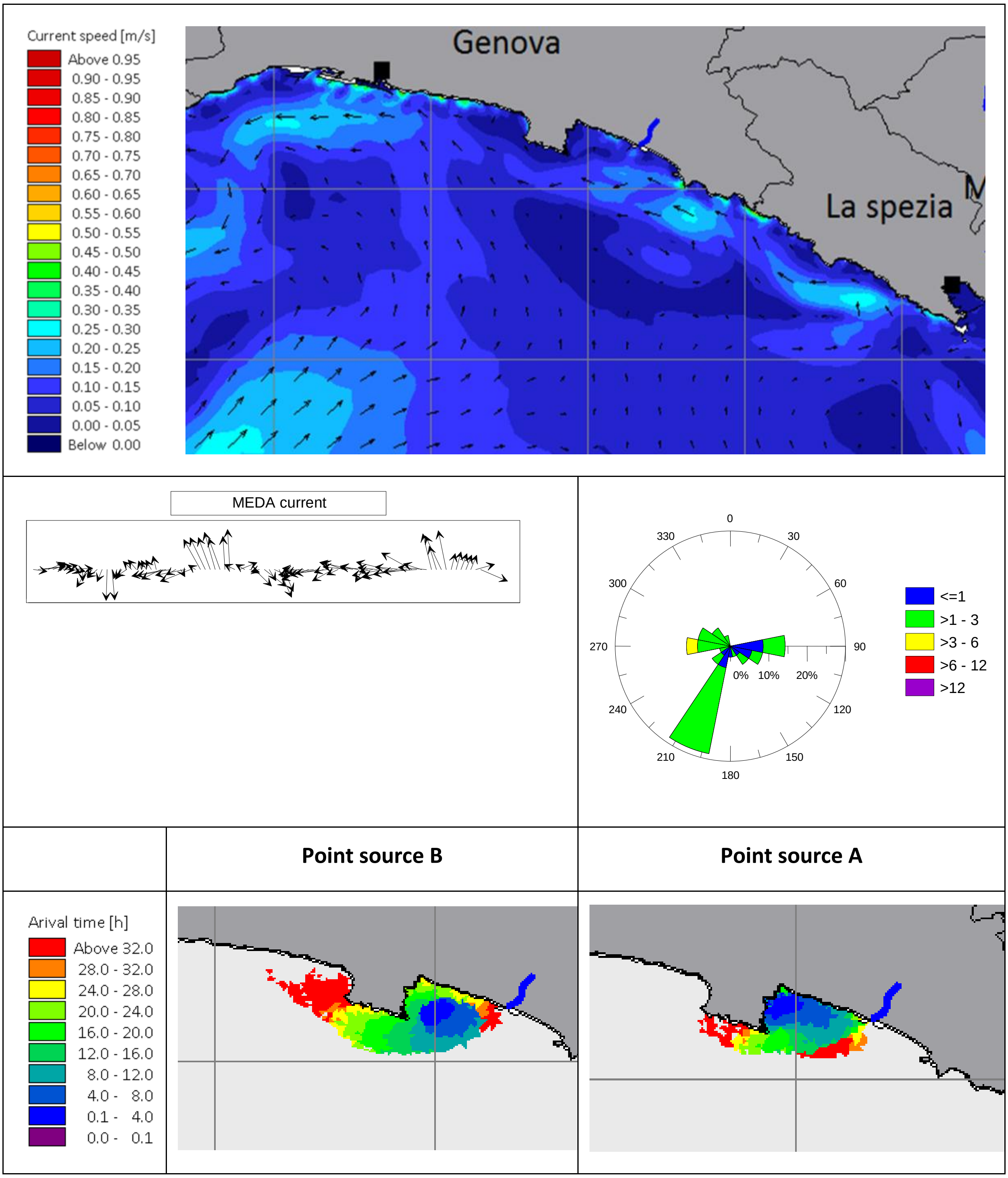


**Figure 5.** Gulf circulation scenario: hydrodynamic simulation (speed [m/s]) with experimental data of sea current field recorded at MEDA 1 point and actual wind rose [m/s] (upper side); oil spill time evolution [h] corresponding to different designed anchorage points for a cruise liner, as point source (lower side).

Figure6

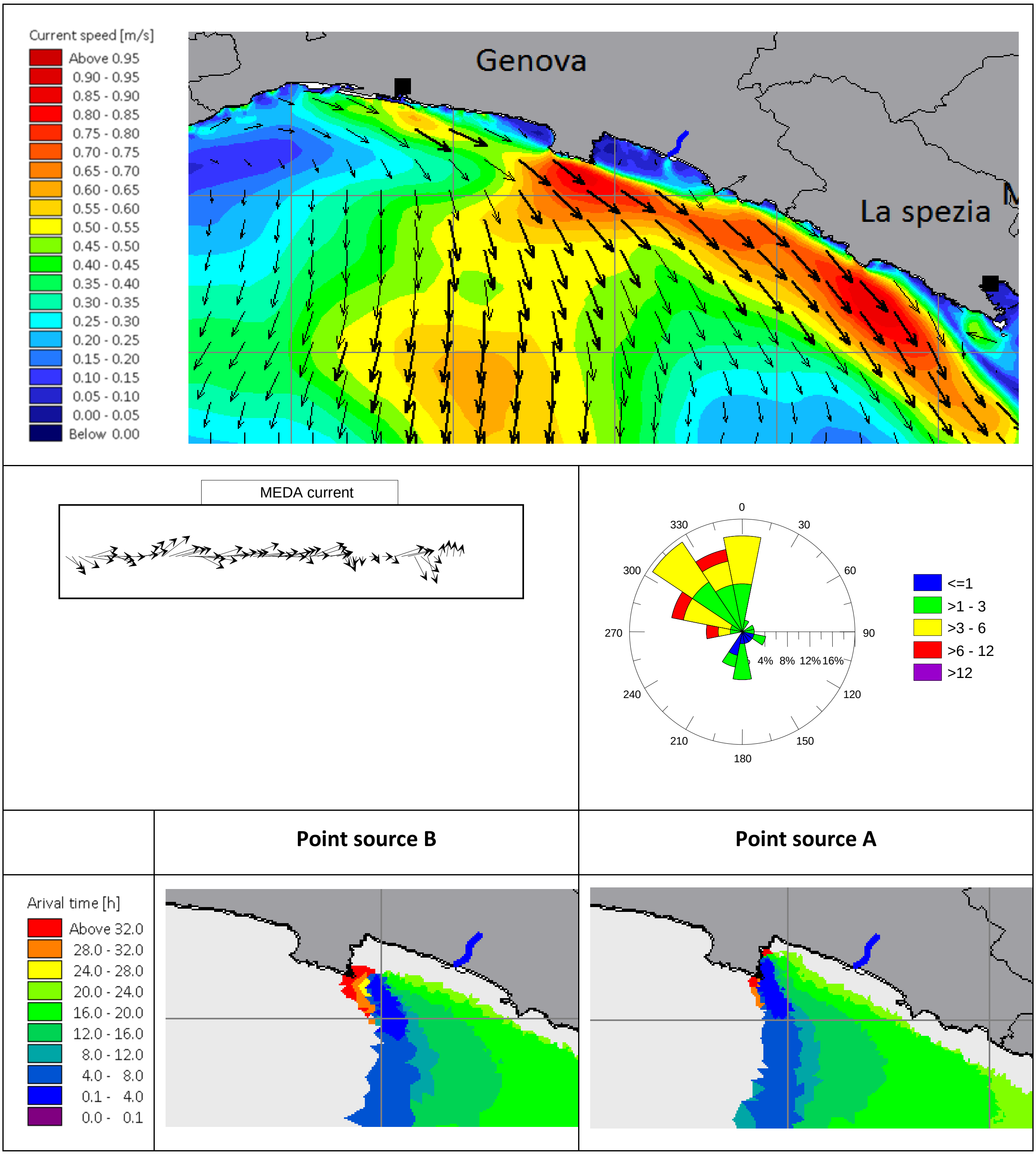


**Figure 6.** South-Eastern scenario: hydrodynamic simulation (speed [m/s]) with experimental data of sea current field recorded at MEDA 1 point and actual wind rose [m/s] (upper side); oil spill time evolution [h] corresponding to different designed anchorage points for a cruise liner, as point source (lower side).

Figure7

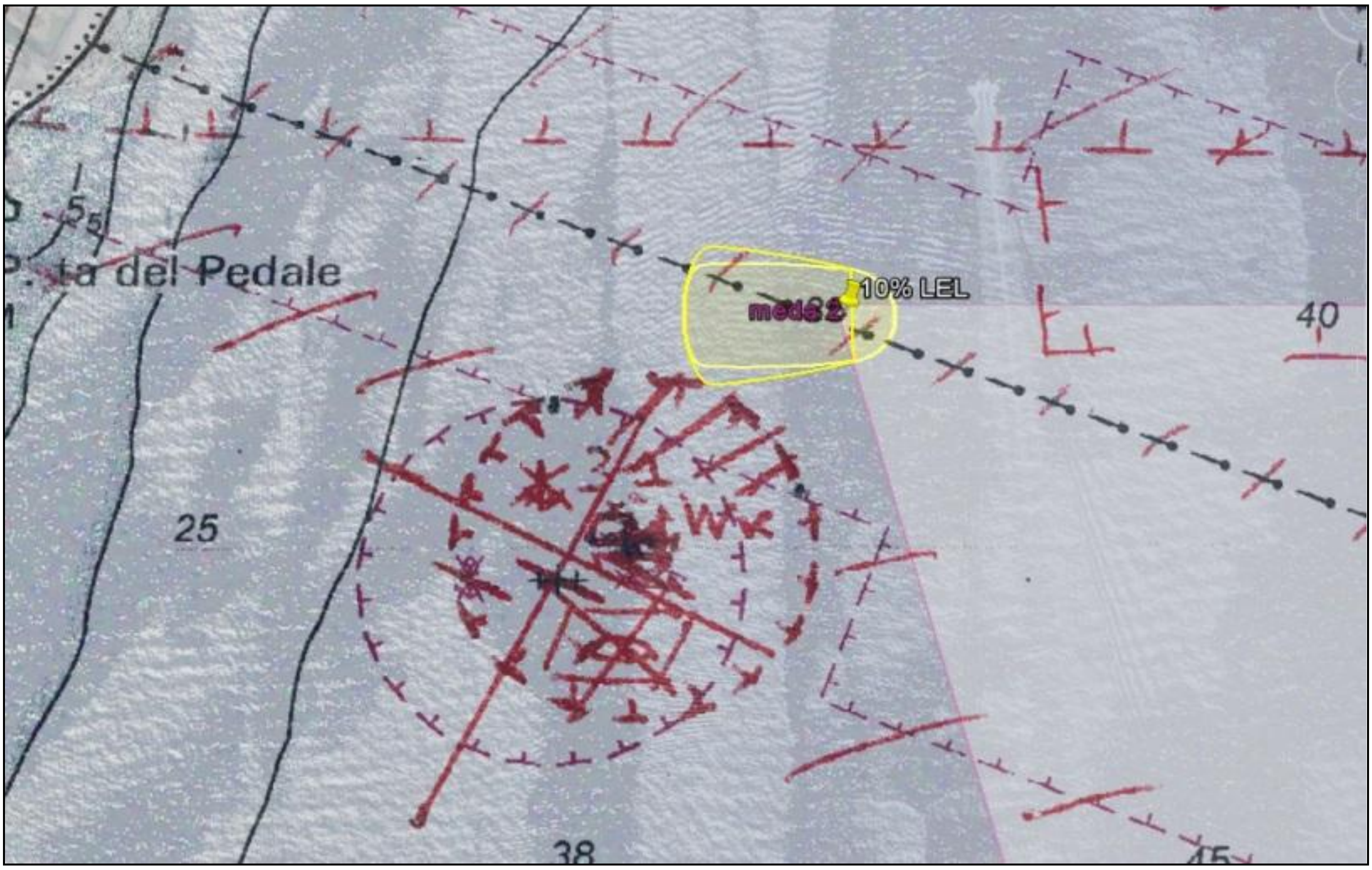


**Figure 7.** Extension of the hazardous area corresponding to 10% LFL East wind with point source localized at Meda 2 point, considering medium size leakage.

Figure8

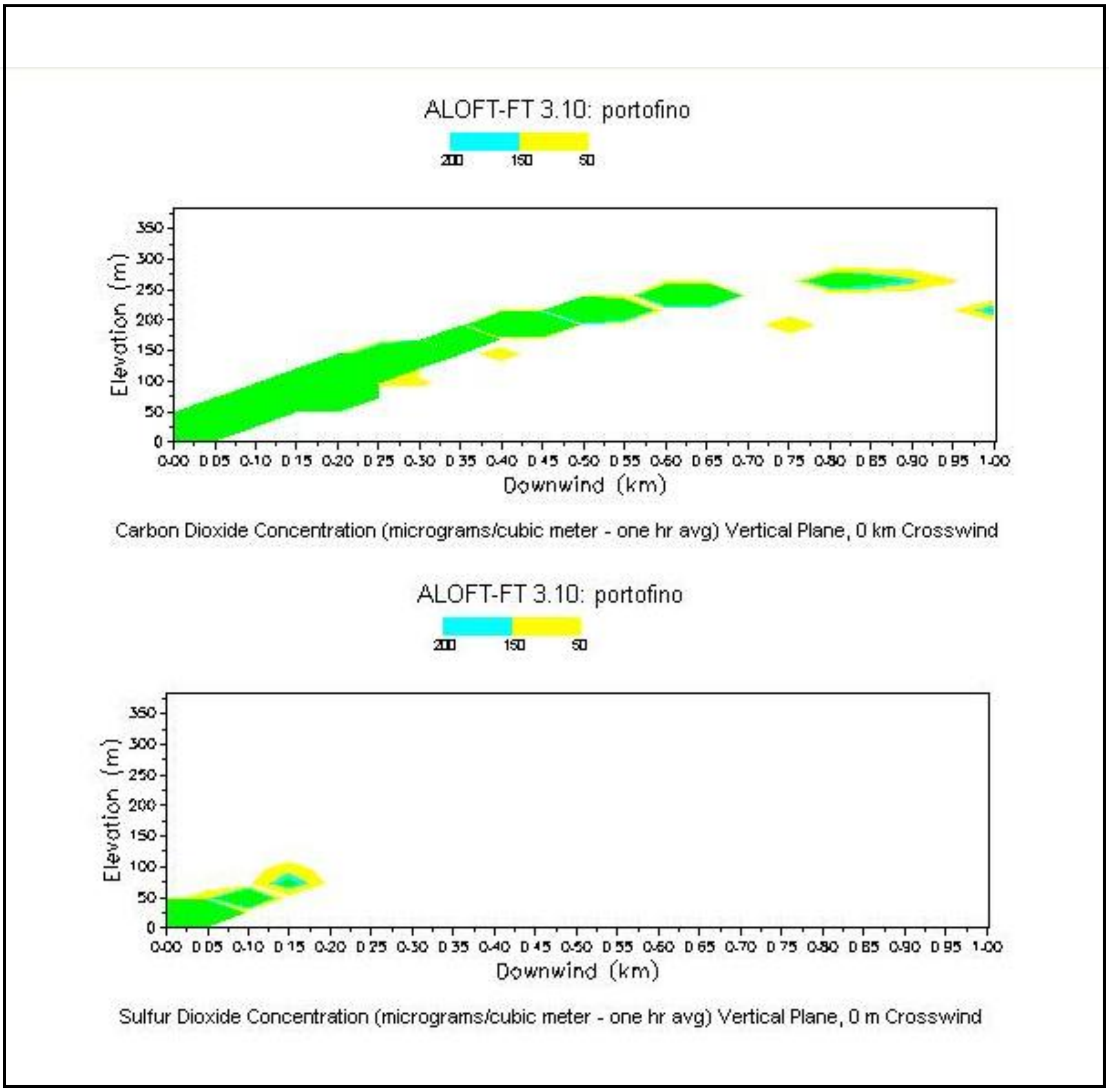


**Figure 8.** Downwind concentration profiles of the main combustion products ($CO_2$ and $SO_2$) considering middle size LOC of the cruise ship tank and consequent pool fire. Other combustion products are PM2.5 (plume rise: elevation 250 m ca., downwind 0.4 km ca.), PM10 (plume rise: elevation 200 m ca., downwind 0.35 km ca.), VOC (plume rise: elevation 100 m ca., downwind 0.2 km ca.), CO (plume rise: elevation 150 m ca., downwind 0.35 km ca.).

Figure9

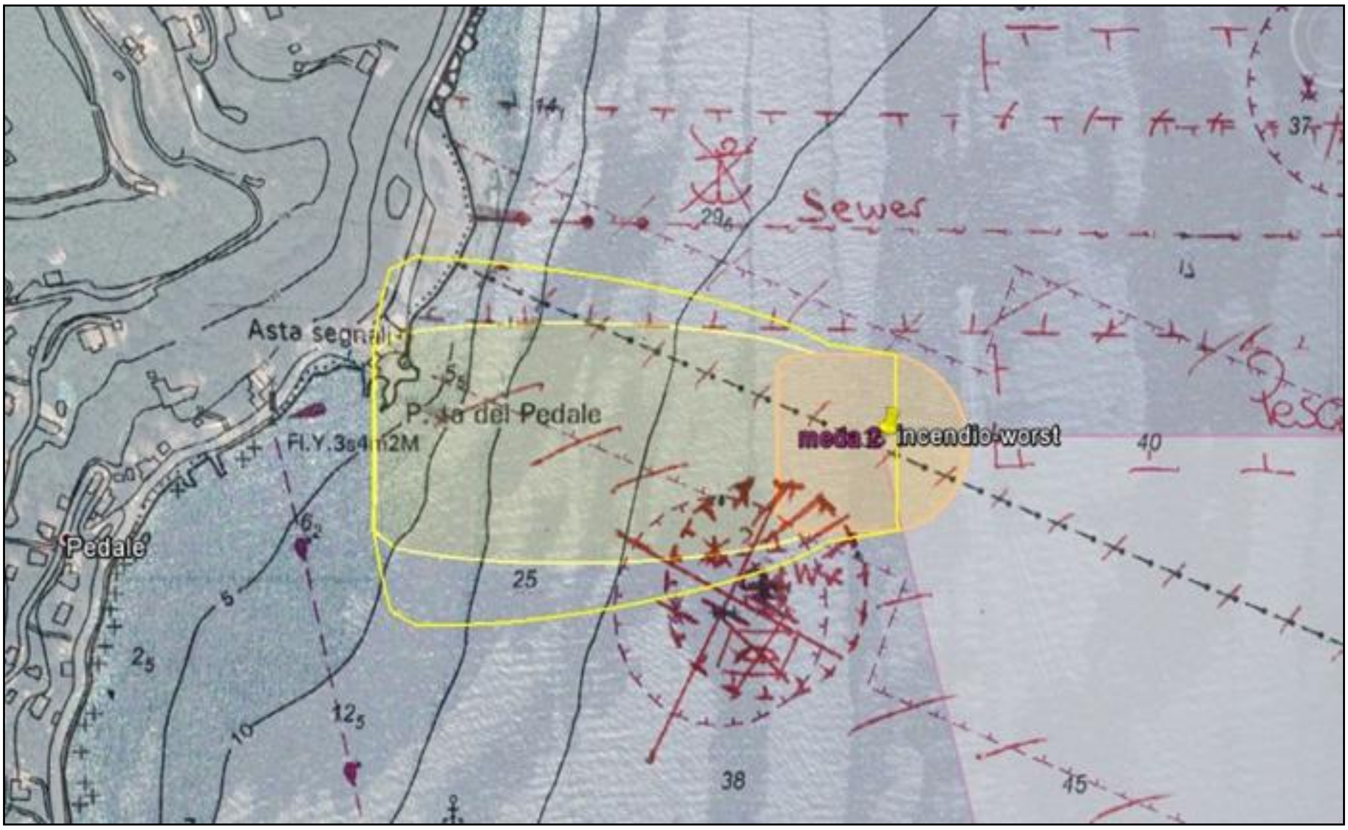


**Figure 9.** Extension of the hazardous area corresponding to 10% LFL East wind source at Meda 2 point, considering a catastrophic tank failure.

Figure10

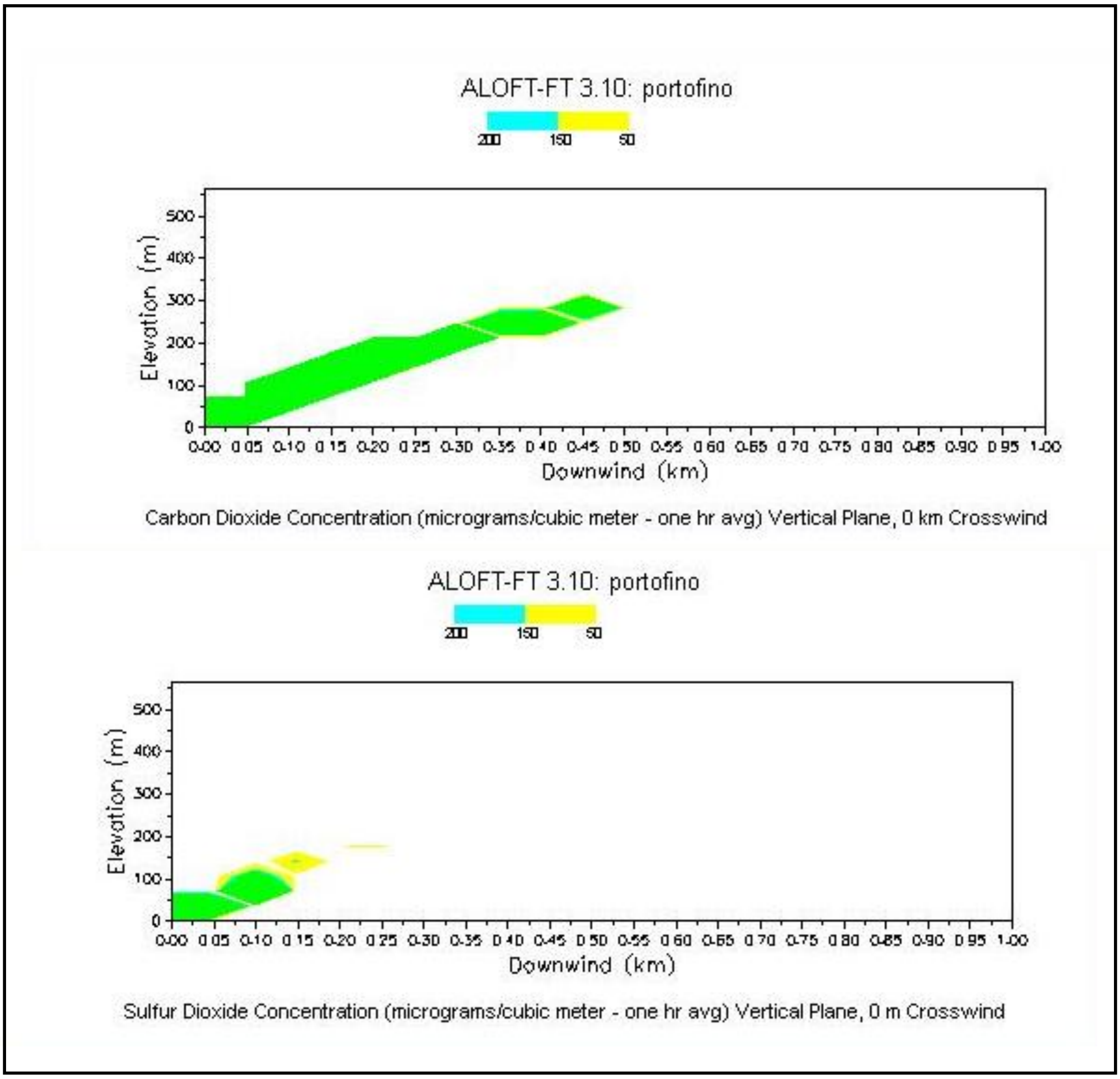


**Figure 10.** Downwind concentration profiles of the main combustion products ($CO_2$ and $SO_2$) for catastrophic cruise ship tank failure and consequent pool fire. Other combustion products are PM2.5 (plume rise: elevation 250 m ca., downwind 0.3 km ca.), PM10 (plume rise: elevation 250 m ca., downwind 0.35 km ca.), VOC (plume rise: elevation 150 m ca., downwind 0.2 km ca.), CO (plume rise: elevation 250 m ca., downwind 0.35 km ca.).

**Figure11**

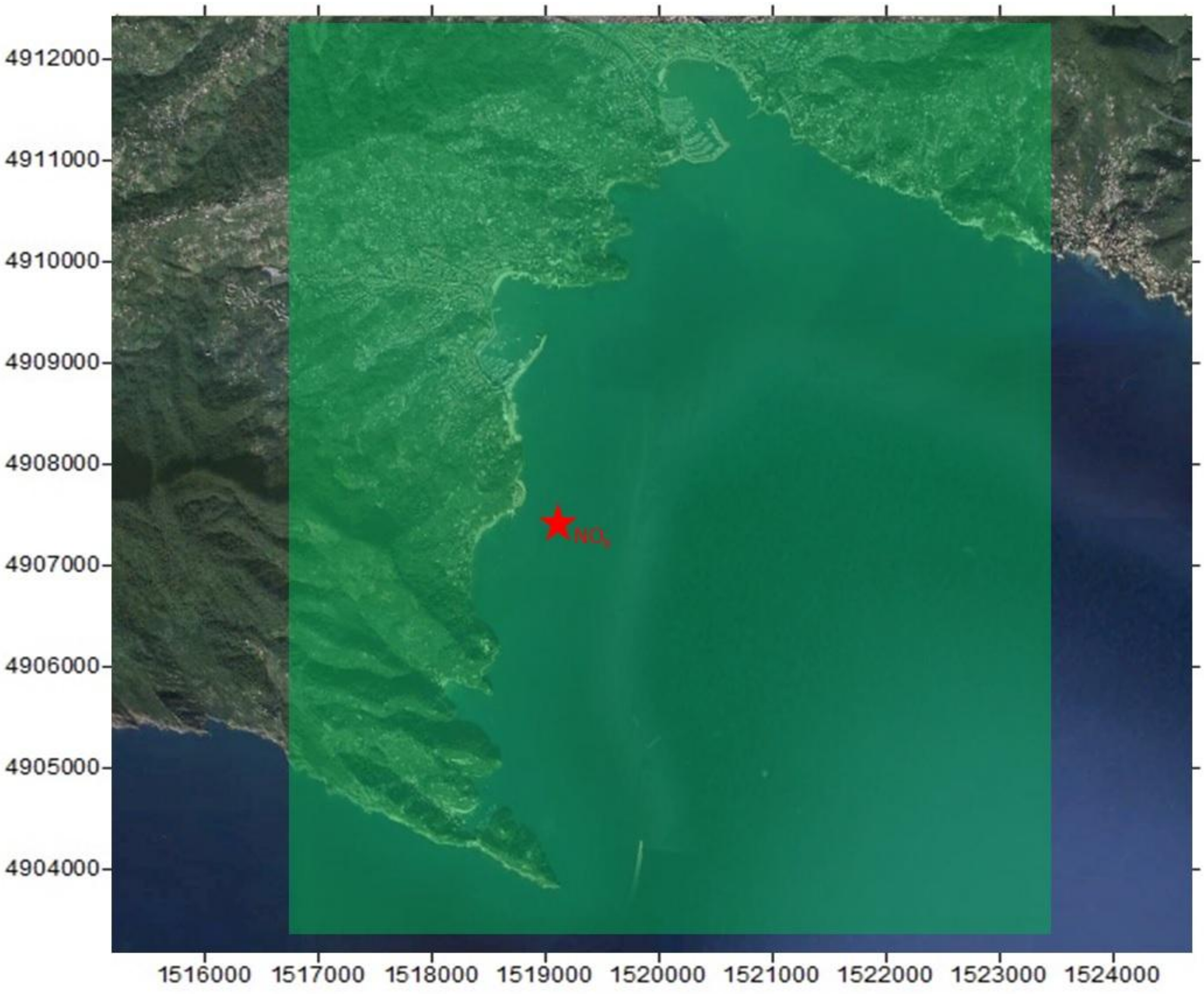


**Figure 11.** ADMS calculation domain, receptor grid and point source location.

Figure12

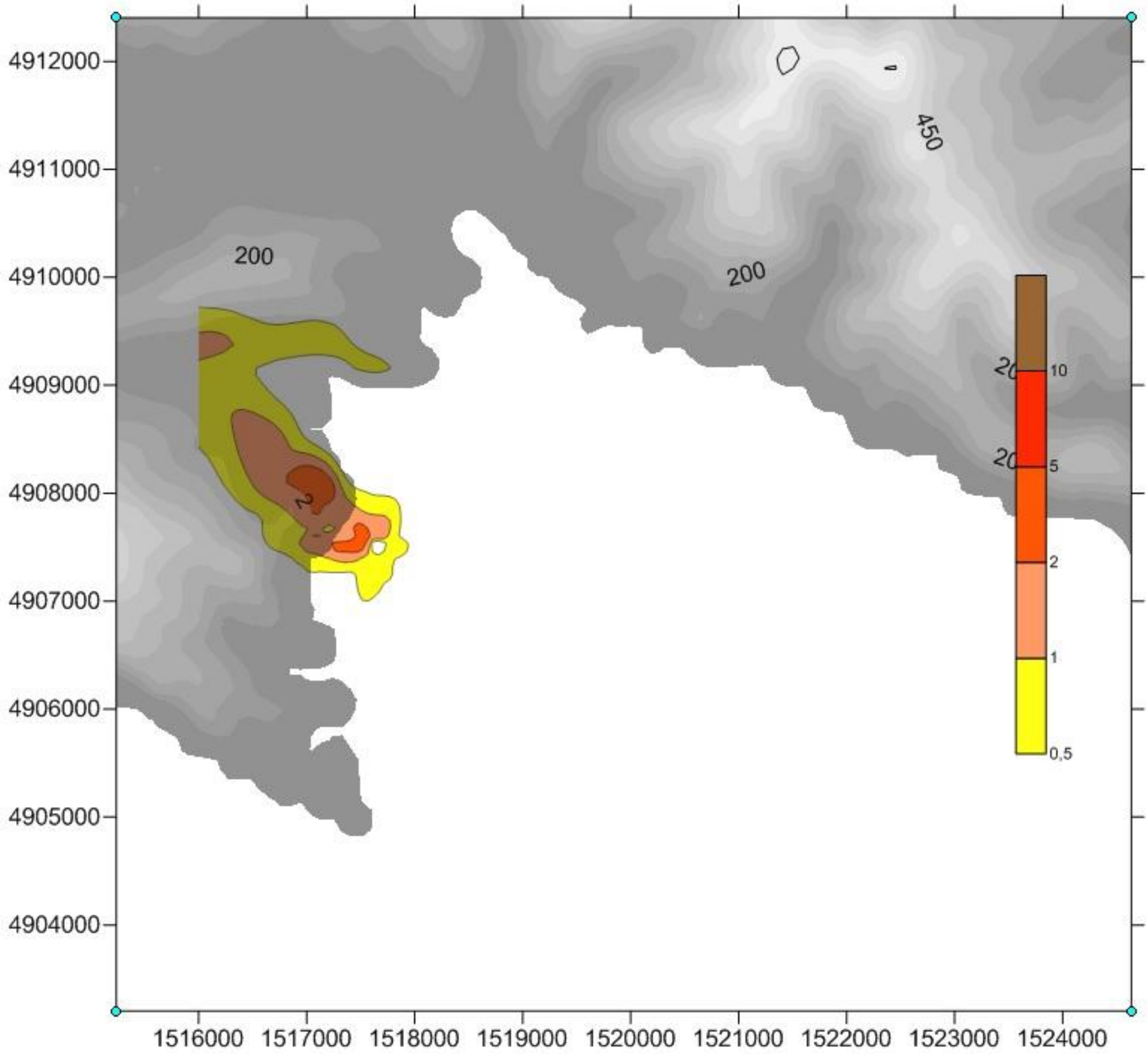


**Figure 12.** Long-term nitrogen oxide fallouts (µg /m$^3$) based on cruise ship emission during the transit and anchorage within the Portofino gulf.