ARCOPOL

Updating Risk Maps & Decision Support Tools:

Technical Report on Dynamic Risk Analysis Tool, Future Implementations and Guidelines for Transferability in the Atlantic Regions

(Technical and User Manual of *DynamicRiskTool* software)

Activity 4

Tasks 4.3.3 and 4.5

ARCOPOL

The Atlantic Regions' Coastal Pollution Response

Version:	Version 1
Last updated on:	30/12/2011
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Summary

This document describes the technical aspects of one of the deliverables of ARCOPOL project, in Activity 4: the development of a software application providing real-time and historic shoreline risk maps and levels, and also risk of accidents for each vessel. The software tool is called DynamicRiskTool – software is available to download in http://arcopol.maretec.org (direct link: http://arcopol.maretec.org/Tools/RiskTool/Installer.zip). This report has also the purpose of work as technical & user manual of DynamicRiskTool.

An innovative system to dynamically produce quantified risks in real time, integrating best available information from numerical forecasts and the existing monitoring tools, has been developed.

This system provides coastal pollution risk levels associated to potential (or real) oil spill incidents, taking into account regional statistic information on vessel accidents and coastal vulnerability indexes (Environmental Sensitivity Index and Socio-Economic Index, determined in EROCIPS project), real time vessel information (positioning, cargo type, speed and vessel type) obtained from AIS, best-available metocean numerical forecasts (hydrodynamics, meteorology - including visibility, wave conditions) and simulated scenarios by the oil spill fate and behaviour component of MOHID Water Modelling System.

Different spill fate and behaviour simulations are continuously generated and processed in background (assuming hypothetical spills from vessels), based on variable vessel information, and metocean conditions, and results from these simulations are used in the quantification the consequences of potential spills.

This system was initially implemented in Portugal. The implementation at different regions in the Atlantic and the adaptation to chemical spills will be executed in the scope of ARCOPOL+ project. DynamicRiskTool was not designed to replace conventional mapping tools, but to complement and that type of information with an innovative approach to risk mapping, providing decision-makers with an improved decision support model and also an intelligent risk-based traffic monitoring.

After an introduction explaining the context and motivation behind the development of this tool, a chapter is dedicated to explain the system architecture. In Chapter 3, detailed information in relation to the computation of risk levels will be explained. Then, following 4 chapters describe the main software components used by this system (database, console application, graphic user interface and oil spill model). Chapters 8 and 9 provide more specific information about additional information layers used (AIS data, and metocean forecasting systems).

Chapter 10 provides guidelines on the transferability of this tool to other regions, and finally, Chapter 11 describes the known bugs, limitations and future implementations and improvements expected.

1. Introduction

The increasing ship traffic and maritime transport of dangerous substances make it more difficult to significantly reduce the environmental, economic and social risks posed by potential spills, although the security rules are becoming more restrictive (ships with double hull, etc.) and the surveillance systems are becoming more developed (VTS, AIS).

In fact, the problematic associated to spills is and will always be a main topic: spill events are continuously happening, most of them unknown for the general public because of their small scale impact, but with some of them (in a much smaller number) becoming authentic media phenomena in this information era, due to their large dimensions and environmental and social-economic impacts on ecosystems and local communities, and also due to some spectacular or shocking pictures generated.

The planning and prevention in the management of accidents with spills at sea is extremely important in the reduction and minimization of potential impacts on the coastline.

The increasing predictive capacity of metocean conditions and fate and behaviour of pollutants spilt at sea or costal zones, and the presence of monitoring tools like vessel traffic control systems, can both provide a safer support for decision-making in emergency or planning issues associated to pollution risks.

Understanding and mapping the major risk zones gives decision-makers a good support to a better definition and distribution of pollution response resources and equipments, to implement mitigation measures (like a better monitorization in specific sites) and can also be helpful when prioritizing actions in case of an accident.

Previously, pollution risks in coastal and marine environments were only quantified in a static mode, considering historical data, reference situations, and typical or extreme scenarios, in a planning stage. The increasing predictive capacity of metocean conditions and fate and behaviour of pollutants spilt at sea or costal zones, and the presence of monitoring tools like vessel traffic control systems, can both provide a safer support for decision-making in emergency or planning issues associated to pollution risks.

An innovative system to dynamically produce quantified risks in real time, integrating best available information from numerical forecasts and the existing monitoring tools, has been developed. This system provides coastal pollution risk levels associated to potential (or real) oil spill incidents, taking into account regional statistic information on vessel accidents and coastal sensitivity indexes (determined in EROCIPS project), real time vessel information (positioning, cargo type, speed and vessel type) obtained from AIS, best-available metocean numerical forecasts (hydrodynamics, meteorology - including visibility, wave conditions) and simulated scenarios by the oil spill fate and behaviour component of MOHID Water Modelling System. Different spill fate and behaviour simulations are continuously generated and processed in background (assuming hypothetical spills from vessels), based on variable vessel information, and metocean conditions, and results from these simulations are used in the quantification the consequences of potential spills.

As referred, the risk levels are generated in real-time, and the historic results are kept in a database, allowing later risk analysis or compilations for specific seasons or regions, in order to obtain typical risk maps, etc.

A dynamic system like this can improve the decision-support model, allowing a better prioritisation of individual ships and geographical areas, facilitating strategic and dynamic tug positioning, and providing an intelligent risk-based traffic monitoring.

The integration with metocean modelling results (instead of using typical static scenarios), as well as continuous background oil spill modelling, provide a more realistic approach to the estimation of risk levels – the metocean conditions and oil spill behaviour are always different and specific, and it’s virtually impossible to previously define those conditions even if several thousands of static scenarios were previously considered.

Taking advantage of interoperability between forecasting models, oil spill simulations, AIS monitoring systems, statistical data and coastal vulnerability, this software can provide to end-users real-time risk levels, allowing an innovative approach to risk mapping, providing decision-makers with an improved decision support model and also an intelligent risk-based traffic monitoring. For instance, this tool allows the prioritisation of individual ships and geographical areas, and facilitates strategic and dynamic tug positioning. The integration with up-to-date outputs from metocean numerical forecasts improves the quantification of spill probabilities, and this feature together with the continuous background oil spill modelling, improves quantification of consequences to the shoreline.

2. Software Architecture and Data flow

The entire software tool was developed in Microsoft Visual Studio .NET 2011 environment, with C#.NET language, although is also using SQL Server components and MOHID model.

The data flow diagram is illustrated in next figure:

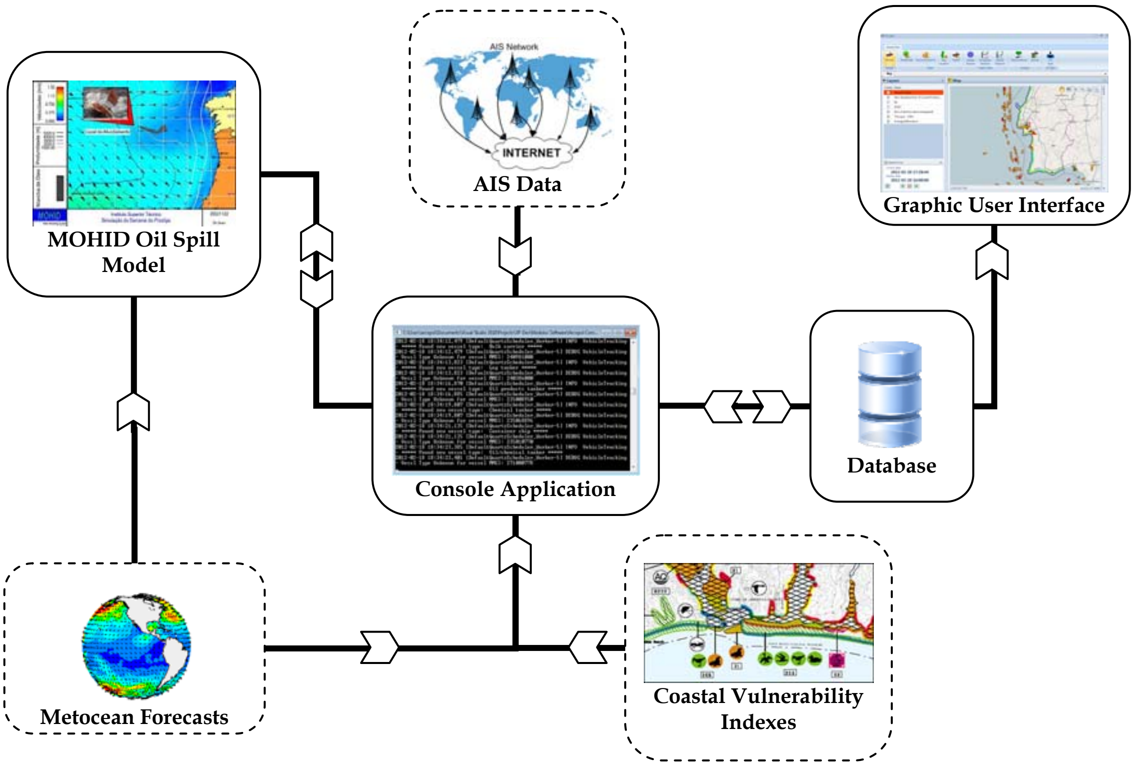


Figure 2.1 – Data Flow Diagram of DynamicRiskTool

The main philosophy of the software architecture was to create separate layers, allowing distributed tasks in different processes or computers, and a lighter GUI.

The main software framework is composed by 4 main components, exchanging information between them:

- an SQL Server database, where all the data and meta-data is stored;

- a console application, which is continuously loading / downloading updated data from different data sources, managing MOHID oil spill model, processing all information (and computing risk levels) and storing data on database;
- MOHID oil spill project / executable file, which is continuously generating and running virtual oil spill simulations based on ship positions, based on instructions managed by the console application.
- A Graphic User Interface (GUI), directly connected to the database, and showing requested data to end-user (the only extra-processing activity here is, when requested by the end-user, to compute on-the-fly risk levels of coastal contamination posed by user-selected vessels; or ships contributing to the risk of coastal contamination in user-selected geo-locations. These are done on-demand, because if it was done continuously, huge amount of information would be generated after just a small time, increasing exponentially the size of the database)

GUI and console application must be running on the same computer. Database and MOHID model can be redirected to a different machine.

Some information layers are collected from different data sources:

- AIS data
- MetOcean forecasting systems
- Coastal Vulnerability

Other parameters are directly provided by the end-user in ASCII configuration or input data files:

- parameters related to accidents frequency, based on statistical data from previous accidents

- distance correction factors, used to compute non-modelled contamination risk levels

End-User can also configure several different aspects in these ASCII configuration files:

- AIS vessel traffic information
    - o Geographical region to download AIS information
    - o Details about file (Google Earth file) with AIS information
- MOHID files configuration
- Definition of time frequency to import model outputs (metocean forecasting systems and oil spill model)
- KML file with coastal vulnerability indexes
- Time frequency for computing risk levels

The details about metocean forecasting systems are configured through the GUI. Here user will define files and parameters to be imported by the system. This is done for meteorological, wave, and hydrodynamic models.

3. Risk Methodology

The main purpose of this tool is to determine risk indexes due to maritime traffic.

Conceptually, the quantification of risk is based on the typical approach of probability and severity, where risk is the product of the probability (or frequency) of oil spill accidents from maritime traffic, times the severity of the events:

Risk = Probability x Severity

The methodology and some of the statistic data is based on the risk assessment produced for Portugal and Galicia in the scope of EROCIPS project.

In order to facilitate the development of scale of risk and its values, logarithmic scales are used, defined by indexes, where I_P is the index of probability, I_S is the index of severity, and I_R is the index of risk:

Log(Risk) = Log (Probability) x Log(Severity)

Or

$$I_R = I_P \times I_S$$

3.1 Risk Indexes

Two different risk indexes are determined:

- Risk of spill accident (associated to the vessels) (I_{RSA})
- Risk of shoreline contamination (associated to shoreline stretch) (I_{RSC})

The risk of spill accident takes in account the possibility of an eventual spill accident from vessel(s).

The risk of shoreline contamination includes not only the possibility of an eventual spill accident from vessel(s), but also the shoreline impact due to that given spill accident. Thus, this risk index can include additional parameters - coastal vulnerability index (I_V), and a correction factor based on spill site (which represents the possibility of spill accident reach to shoreline) (F_{SS}).

This risk type can be determined by two different methods:

- Non-modelled risk of shoreline contamination : $I_{RSC} = f(I_{RSA} - F_{SS} + I_V)$
- modelled risk of shoreline contamination: $I_{RSC^*} = f(I_{RSA^*} + I_V)$

The function f(…) present in this risk type means that the risk obtained for each shoreline stretch is a user-defined percentile of the list of significant shoreline contamination risks from each vessel. By default, the percentile is 98. Significant shoreline contamination risk from each vessel is considered as 6, but it is also configurable.

The non-modelled risk assumes that the correction factor based on spill site risk is dependent of the distance to the shoreline; the modelled risk takes a more complex approach, and the quantification of consequences / severity (I_{RSA^*}) is determined by the amount of virtual spilled oil reaching the shoreline, using MOHID lagrangian & oil spill numerical model.

Further explaining is presented in this document.

3.2 Detailed Information and Approximations

3.2.1 Vessels included

The risk calculus is only applied to vessels corresponding to specific characteristics and positions:

- Position: DynamicRiskTool only collects information from vessels inside a user-specific window. The defined window is equal to PCOMS domain.
- Weight: Only vessels with a Dead Weight Tonnage equal or bigger than 100 t are considered.
- Vessel Type: tankers, cargo, dry cargo and fishing vessels (only fishing vessels in restricted waters) are considered

It is assumed that a vessel is navigating in restricted waters if distance to shoreline is not higher than 3 nautical miles, or if water depth is not deeper than 20 meters.

3.2.2 Types of Accidents Considered

In this version of the software, the types of accidents considered to the estimation of risk were:

- Grounding (no differentiation is made for ships in restricted waters):
    - Grounding during navigation
    - Drift grounding
- Foundering and structural failures (only if ship is not in restricted waters)
- Collision:
    - Collision ship to ship
    - Collision to port facilities (only if ship is in restricted waters)

Fire and Explosion will be included in a future version of the software.

3.3 Risk of Spill Accident

The risk of occurrence of a spill accident from a ship is obtained by the product of the probability of happening a spill accident times the consequences of the given spill.

Since there is a differentiation on risk indexes based on types of accidents, and ships navigating (or not) in restricted waters, several different specific risk indexes can be determined:

Table 3.1 – Different types of risk indexes

Navigation	Type of accident	Risk index
Ship navigating in restricted waters	Ship-to-ship collision	Restricted Waters - Risk of Spill Accident (Ship to Ship Collision) = $I_{RSA\_CS2S\_restricted}$
	Collision with port facilities	Restricted Waters - Risk of Spill Accident (Collision with Port Facilities) = $I_{RSA\_CPF\_restricted}$
	Grounding	Restricted Waters - Risk of Spill Accident (Grounding) = $I_{RSA\_Gr\_restricted}$
Ship navigating in unrestricted waters	Ship-to-ship collision	Unrestricted Waters – Risk of Spill Accident (Ship to Ship Collision) = $I_{RSA\_CS2S\_unrestricted}$
	Foundering and structural failures	Unrestricted Waters –Risk of Spill Accident (Foundering) = $I_{RSA\_Fo\_unrestricted}$
	Grounding during navigation	Unrestricted Waters –Risk of Spill Accident (Grounding

		during navigation) = $I_{RSA\_GDN\_unrestricted}$
	Drift grounding	Unrestricted Waters –Risk of Spill Accident (Drift Grounding) = $I_{RSA\_DG\_unrestricted}$

In the determination of these risk indexes, previously mentioned generic risk formula (risk indexes are a sum of probability and severity indexes) applies. Per example, for ships navigating in restricted waters, next formula represents the risk of spill accident from a ship-to-ship collision:

$$I_{RSA\_CS2S\_restricted} = I_{P_{CS2S\_restricted}} + I_{S_{CS2S\_restricted}}$$

Statistical frequencies, correction factors and other parameters used in the determination of probabilities and severities can be different for the same type of accident, depending on ship position (restricted / unrestricted waters), and ship type.

Thus, information about ship type and position is essential to correctly determine probabilities and severities, as can be seen in the next chapters.

Integrated risk index is also determined (I_{RSA_I}), which means that we can also have the risk of accident of a specific ship, independently of type of accident. This is called the Risk of Spill Accident (integrated). This integrated risk is not simply just a sum of all the risk indexes obtained for each type of accident.

Thus, if a ship is navigating in restricted waters:

$$I_{IRSA\_I} = I_{\Sigma P\_restricted} + \overline{I_{S\_restricted}}$$

$$I_{\Sigma P\_restricted} = f(P_{CS2S\_restricted} + P_{CPF\_restricted} + P_{Gr\_restricted})$$

$$\overline{I_{S_{restricted}}} = \frac{P_{CS2S\_restricted} \times I_{S_{CS2S\_restricted}} + P_{CPF\_restricted} \times I_{S_{CPF\_restricted}} + P_{Gr\_restricted} \times I_{S_{Gr\_restricted}}}{\Sigma P_{restricted}}$$

Alternatively, if a ship is navigating in unrestricted waters:

$$I_{IRSA\_I} = I_{\Sigma P\_unrestricted} + \overline{I_{S\_unrestricted}}$$

$$I_{\Sigma P\_unrestricted} = f(P_{CS2S\_unrestricted} + P_{Fo\_unrestricted} + P_{GDN\_unrestricted} + P_{DG\_unrestricted})$$

$$\overline{I_{S_{unrestricted}}} = \frac{P_{CS2S\_unrestricted} \times I_{S_{CS2S\_unrestricted}} + P_{Fo\_unrestricted} \times I_{S_{Fo\_unrestricted}} + P_{GDN\_unrestricted} \times I_{S_{GDN\_unrestricted}} + P_{DG\_unrestricted} \times I_{S_{DG\_unrestricted}}}{\Sigma P_{unrestricted}}$$

Probability and severity indexes are obtained from specific formulas, described in the following chapters.

3.3.1 Probability

The probability / frequency of occurrence of a specific type of accident in a ship, which may lead to oil spills is obtained from statistical constants (annual frequency of accidents per nautical mile) corrected with a combination of a different factors that were identified as relevant in the generation of those accidents (like visibility, currents, proximity to coast, etc.).

Thus, generically, the probability of accident in a specific time period is computed like this:

$$P = C \times (dS) \times I$$

Where C is the frequency constant (accidents /nautical mile), dS is the distance navigated by the ship (in miles), and I is the multiplying correction factors.

3.3.1.1 Distance navigated

The distance navigated by the ship is obtained directly by ship velocity (from AIS data) and time period for risk analysis (defined by the end-user).

3.3.1.2 Frequency constants

Frequency constants of accidents per nautical mile are obtained from http://www-pub.iaea.org/MTCD/publications/PDF/te_1231_prn.pdf (Severity, probability and risk of accidents during maritime transport of radioactive material), and missing constants are obtained from the combination of previous report with Lloyd's Register accidents database (relation between annual frequency constants was used to extrapolate frequency constants per nautical mile). Next table illustrates the frequency constants used.

Table 3.2 – Frequency constants of accidents used

Restricted Waters		Unrestricted Waters	
Type of Accident	Accident Frequency	Type of Accident	Accident Frequency

	per nautical mile		per nautical mile
Ship to Ship Collision	1.90 x 10^{-7} (1)	Ship to Ship Collision	6.8 x 10^{-9} (1)
Collision with Port Facilities	2.28 x 10^{-7} (2)	Foundering	4.95 x 10^{-8} (1)
Grounding	1.53 x 10^{-7} (2)	Grounding During Navigation	6.65 x 10^{-8} (2)
		Drift Grounding	1.02 x 10^{-8} (2)

3.3.1.3 Multiplying correction factors

Multiplying correction factors were obtained from Risk Assessment Report for the Portuguese and Galician Coast – EROCIPS. They are used to modify the probabilities based on metocean conditions (wind, currents, waves, and visibility), proximity to coast and ship type.

Currents (I_{curr})

The currents velocity is obtained from the user-defined hydrodynamic forecasting model. The system uses the velocity corresponding to the location of the ship, in the same time instant. Higher currents velocities mean higher correction factor, and consequently higher probability of accident. Next table shows the variation of the correction factor due to currents velocity:

Table 3.3 – Correction factor associated to currents velocity

currents velocity (knots)	Multiplying correction factor (I_{curr})
>= 3	2.0
>= 2 AND < 3	1.6
>= 1 AND < 2	1.2
>= 0.7 AND < 1	0.8
< 0.7	0.4

Wind (I_{wind})

Wind velocity is obtained from the user-defined meteorological forecasting model. The system uses the velocity corresponding to the location of the ship, in the same

1 Value from www-pub.iaea.org/MTCD/publications/PDF/te_1231_prn.pdf (Severity, probability and risk of accidents during maritime transport of radioactive material); July 2001

2 Value extrapolated based on (1) and relations between annual frequencies from Risk Assessment Report for the Portuguese and Galician Coast – EROCIPS

time instant. Higher wind velocities mean higher correction factor, and consequently higher probability of accident. Next table shows the variation of the correction factor due to wind velocity:

Table 3.4 - Correction factor associated to wind velocity

Wind velocity (km/h)	Multiplying correction factor (I_{wind})
>= 90	2.0
>= 50 AND < 90	1.6
>= 30 AND < 50	1.2
< 30	0.8
>= 90	2.0

Visibility (I_{visib})

This property is obtained from the user-defined meteorological forecasting model. The system uses the visibility corresponding to the location of the ship, in the same time instant. The correction factor related to visibility is only used by ships navigating in unrestricted waters, and for two types of accidents (ship to ship collision and foundering). It is assumed that less than 1 nautical mile is good visibility. Next table shows the different correction factors used:

Table 3.5 - Correction factor associated to type of accident analysed

	Multiplying correction factor (I_{visib})	
Type of Accident	Good visibility (> 1 nautical mile)	Bad visibility (<= 1 nautical mile)
Ship to ship collision	0.24	1.76
Foundering	0.6	1.4

Waves (I_{wav})

Wave height is obtained from the user-defined wave forecasting model. The system uses the significant wave height corresponding to the location of the ship, in the same time instant. Higher wave height means higher correction factor, and consequently higher probability of accident. It is assumed that less than 2.5m of significant wave height is calm sea. Next table shows the different correction factors used:

Table 3.6 - Correction factor associated to wave height

	Multiplying correction factor (I_{wav})

Type of Accident	Turbulent sea (significant wave height >=2.5m)	Calm sea (significant wave height <2.5m)
Foundering	1	0.1
Grounding during navigation	1.4	0.6
Drift Grounding	1.78	0.22

Proximity (I_{prox})

Distance to shoreline is also a factor that is considered to affect the probability of an accident, but only for ships in unrestricted waters. Longer distances tend to decrease the probability of an accident, as can be shown in the following table:

Table 3.7 - Correction factor associated to proximity to shoreline

Proximity to shoreline (in nautical miles)	Multiplying correction factor (I_{prox})
<= 6	2.0
> 6 AND < =8	1.0
> 8	0.8

Ship Type (I_{ship})

Correction factors were found, in order to differentiate probabilities of certain types of accidents, based on ship types, and depending on the position of ships in restricted / unrestricted waters.

Next table describes these correction factors for ships in restricted waters:

Table 3.8 - Correction factor associated to type of accident in restricted waters

Type of Accident	Multiplying correction factor (I_{ship})		
	tankers	cargo	Fishing
Ship to Ship Collision	1.7	2.0	0.3
Grounding	1.6	1.6	0.2
Collision with Port Facilities	1.0	1.0	0.7

Next table describes this correction factors for ships in unrestricted waters:

Table 3.9 - Correction factor associated to type of accident in unrestricted waters

Type of Accident	Multiplying correction factor (I_{ship})	
	tankers	cargo

Ship to Ship Collision	1.629	3.343
Foundering	0.113	3.606
Grounding during navigation	0.612	4.286
Drift grounding	1.6	2.133

The multiplying correction factors can be summarized in the following table:

Table 3.10 – Summary of multiple correction factors used

<table>
<tr><th colspan="2">Restricted Waters</th><th colspan="2">Unrestricted Waters</th></tr>
<tr><th>Type of Accident</th><th>Correction Factors (I)</th><th>Type of Accident</th><th>Correction Factors (I)</th></tr>
<tr><td>Ship to Ship Collision</td><td rowspan="4">I_{curr} x I_{wind} x I_{prox} x I_{ship}</td><td>Ship to Ship Collision</td><td>I_{curr} x I_{wind} x I_{visib} x I_{wave}</td></tr>
<tr><td>Collision with Port Facilities</td><td>Foundering</td><td>I_{wave} x I_{prox}</td></tr>
<tr><td rowspan="2">Grounding</td><td>Grounding During Navigation</td><td>I_{curr} x I_{wind} x I_{visib} x I_{wave} x I_{prox}</td></tr>
<tr><td>Drift Grounding</td><td>I_{curr} x I_{wind} x I_{wave} x I_{prox}</td></tr>
</table>

3.3.1.4 Probability Indexes

To obtain a probability index, a US Coast Guard table (which finds correspondence between annual probability and index of probability) is used:

Table 3.11 – Determination of Index of Probability

Probability / Frequency	Annual Probability / Frequency (P)	Index of Probability (I_P)
Very High	10 to 100 or more	> 7 - 8
High	1 to 10	> 6 – 7
Medium	10^{-2} to 1	> 4 – 6
Low	10^{-4} to 10^{-2}	> 2 – 4
Very low	10^{-5} to 10^{-4}	0 - 2

Dynamic Risk Software Tool computes the annual probability based on the next equation:

$$Annual\_Probability = 1\_year \times \frac{P}{time\_period}$$

P is the probability obtained by the previous method explained in this chapter, for a specific time period.

A function to represent the previous table was implemented in the software tool:

$$I_P = \log(P) + 6 \ (I_{Pmin} = 0; I_{Pmax} = 8)$$

3.3.2 Severity / Severity Index

The severity of hydrocarbon and other hazardous substances spills, whether in open sea or in restricted waters due to the various types of accidents, may be classified following the IMO recommendations as presented in the following table (obtained from Report for Risk Assessment in the Portuguese and Galician Coast – EROCIPS):

Table 3.12 – Description of Severity Index

Severity Degree	Impacts			Severity Index
	Human Health	Environment	Socio-Economic Activities	
Catastrophic	Catastrophic number of injuries and physical disabilities to people in the region affected by the spill	Catastrophic and permanent damage to the marine flora and fauna.	Affecting in a catastrophic scale and for long periods of time: (i) the use of water and commercial activities along the coast, (ii) leisure and recreational activities, and (iii) other inherent use of the sea. Losses are estimated as more than €400 millions	>7 to 8
Extreme	Extremely high number of injuries, fatalities, and physical disabilities to people in the region affected by the spill.	Extreme and permanent damage to the marine flora and fauna.	Affecting at extreme scale and for long periods of time: (i) the use of water and commercial activities along the coast, (ii) leisure and recreational activities, and (iii) other inherent use of the sea. Losses are estimated between €200 millions and €400 millions.	>6 to 7
Very High or Very Serious	Very high number of injuries, fatalities, and physical disabilities to people in the region affected by the spill.	Very serious and almost permanent damage to the marine flora and fauna.	Affecting at very high scale and for long periods of time: (i) the use of water and commercial activities along the coast, (ii) leisure and recreational activities, and (iii) other inherent use of the sea. Losses are estimated between €20 millions and €200 millions.	>5 to 6

High or Serious	High number of injuries or physical disabilities to people in the region affected by the spill.	Long term damage to the marine flora and fauna. High cost of measures needed to restore the resources affected by the spill.	Affecting at high scale and for long periods of time: (i) the use of water and commercial activities along the coast, (ii) leisure and recreational activities, and (iii) other inherent use of the sea. Losses are estimated between €2 millions and €20 millions.	>4 to 5
Medium or Moderate	Medium number of injuries (unlikely to result in physical disabilities) to people in the region affected by the spill.	Medium term damage to the marine flora and fauna. Moderate cost of measures needed to restore the resources affected by the spill.	Affecting at medium scale and for long periods of time: (i) the use of water and commercial activities along the coast, (ii) leisure and recreational activities, and (iii) other inherent use of the sea. Losses are estimated between €200,000 and €2 millions.	>3 to 4
Little or Slight	Little number of injuries to people in the region affected by the spill. Little first aid assistance.	Short term damage to the marine flora and fauna. Low cost of measures needed to restore the resources affected by the spill.	Affecting at little scale and for long periods of time: (i) the use of water and commercial activities along the coast, (ii) leisure and recreational activities, and (iii) other inherent use of the sea. Losses are estimated between €10,000 and €200,000.	>2 to 3
Very Little or Very Slight	Very little number of injuries to people in the region affected by the spill. Very little first aid assistance.	Very short term damage to the marine flora and fauna. Very low cost of measures needed to restore the resources affected by the spill.	Affecting at little scale and for long periods of time: (i) the use of water and commercial activities along the coast, (ii) leisure and recreational activities, and (iii) quality of water. Estimated losses may be less than €10,000.	>1 to 2
Insignificant	No reported harm to human health.	No damage to the marine flora and fauna. No restoration measures needed.	Not affecting (i) the use of water and commercial activities along the coast, (ii) leisure and recreational activities, and (iii) quality of water. Estimated losses may be less than €1,000.	0 to 1

The severity index in the risk of spill accident varies with the ship position (restricted / unrestricted waters), and with the amount of spilt product. The estimation of this parameter is based on the ship weight and in the type of accident being calculated. Next table illustrates how to determine the amount of oil (Q) based on dead weight (DW) and ship type. Equations were obtained from Report for Risk Assessment in the Portuguese and Galician Coast – EROCIPS, based on ITOPF:

Table 3.13 – Average amount of oil per accident type and ship type

Type of Accident	Equation Q = oil amount (ton); DW = DeadWeight (DWT)		
	Tanker (crude)	Fishing Vessels (diesel)	Cargo (bunker)
Ship to ship collision	$Q = 1E\text{-}07DW^2 + 0.0327DW$	Q = 6	Q = 60
Collision with port facilities	$Q = 5E\text{-}08DW^2 + 0.0134DW$	Q = 3	Q = 25
Foundering	Q = DW	Q = 12	Q = 1300
Grounding	$Q = 5E\text{-}07DW^2 + 0.1362DW$	Q = 2	Q = 130

Based on the oil amount, the determination of severity indexes can be obtained following the next table (Equations were obtained from Report for Risk Assessment in the Portuguese and Galician Coast – EROCIPS):

Table 3.14 – Quantification of severity index

	Unrestricted waters	Restricted waters
Crude (tanker)	$I_{s\_unsrestricted} = 0.4037\ln(Q) + 1.9534$ $I_{s\_unrestricted\ min} = 0$; $I_{s\ max} = 8$	$I_{s\_restricted} = 0.4693\ln(Q) + 1.9903$ $I_{s\_restricted\ min} = 0$; $I_{s\ max} = 8$
Diesel (fishing)	$I_s = 0.4343\ln(Q) + 1.301$ $I_{s\_unrestricted\ min} = 0$; $I_{s\ max} = 7$	$I_s = 0.4689\ln(Q) + 1.666$ $I_{s\_restricted\ min} = 0$; $I_{s\ max} = 8$
Bunker (cargo)	$I_s = 0.3996\ln(Q) + 1.9285$ $I_{s\_unrestricted\ min} = 0$; $I_{s\ max} = 8$	$I_s = 0.4517\ln(Q) + 2.1643$ $I_{s\_restricted\ min} = 0$; $I_{s\ max} = 8$

3.4 Risk of Shoreline Contamination

As mentioned previously, the risk of shoreline contamination relates to the shoreline impact due to a potential spill accident from any ship.

The determination of this risk is made in this tool by two different methods:

- Non-modelled risk of shoreline contamination:
- Modelled risk of shoreline contamination

In relation to the risk of spill accident, non-modelled risk (I_{RSC}) includes additional parameters - coastal vulnerability index (I_V), and a correction factor based on spill site (which represents the possibility of spill accident reach to shoreline) (F_{SS}), as it can be seen in the next equation:

$$I_{RSC} = f(I_{RSA} + I_V - F_{SS})$$

Alternatively, other way can be used to compute the risk of shoreline contamination, which is called in this software tool as the modelled risk of shoreline contamination (I_{RSC^*}). The main difference here is the methodology used to quantify the severity / consequences to the shoreline. In the non-modelled approach the specificities of fate & behaviour of the substance spilled is not taken into account; however they can be extremely important. As an example, it is possible to have a potential oil spill from a ship near a specific coastline (meaning a high non-modelled risk of shoreline contamination), but currents and winds can transport the substance offshore, reducing significantly the risk for the shoreline (meaning a low modelled risk of shoreline contamination). In this alternate method, the risk of spill accident is modified (I_{RSA^*}), with severity corresponding to the amount of potential oil spilled reaching the shoreline (in the standard risk of spill accident, severity corresponds only to the amount of oil potentially spilled). Thus, since in this case the possibility of spill accident reaching to shoreline is already included in I_{RSA^*}, spill site correction factor (F_{SS}) is not included in the equation:

$I_{RSC^*} = f(I_{RSA^*} + I_V)$

The shoreline contamination risks provided are in fact a percentile (by default, percentile 98) of the shoreline contamination risks determined from each vessel. Shoreline contamination risks below a user-defined value (by default, the value is 6) are not considered.

3.4.1 Correction Factor Based on Spill Site

This correction factor (F_{SS}) is only used in the non-modelled risk of shoreline contamination (I_{RSC}) for the correction on the consequences to shoreline, based on the site of the potential spill.

The determination of this factor depends on distance between spill site and shoreline (D_{SS}), and on ship type (see following table).

Table 3.15 – Correction factor based on spill site used, in function of ship type

Ship Type	Equation for Correction Factor (F_{SS})
Fishing	$F_{SS} = 0.3 \times D_{SS}$
Tanker	$F_{SS} = 0.2 \times D_{SS}$

Cargo	$F_{SS} = 0.1 \times D_{SS}$

3.4.2 Modified Risk of Spill Accident

This risk index is only used on the quantification of modelled risk of shoreline contamination, and as explained before, is a more complex and realistic approach to determine the impact risk of oil spills on the shoreline, since fate and behaviour of oil spilled is taken into account.

The whole approach used in Risk of Spill Accident (chapter 3.3) is kept, with modifications on Table 3.14. In this case, a modified amount of oil (Q*) will be used (see next table) and there is no differentiation in the severity indexes between restricted and unrestricted waters:

Table 3.16 - Quantification of modified severity index to be used in modelled risk of shoreline contamination

	Restricted and unrestricted waters
Crude (tanker)	$I_{s*} = 0.4693\ln(Q^*) + 1.9903$ $I_{s*\,min} = 0; I_{s\,max} = 8$
Diesel (fishing)	$I_{s*} = 0.4689\ln(Q^*) + 1.666$ $I_{s*\,min} = 0; I_{s\,max} = 8$
Bunker (cargo)	$I_{s*} = 0.4517\ln(Q^*) + 2.1643$ $I_{s*\,min} = 0; I_{s\,max} = 8$

Where:

$$Q^* = \frac{Q \times M}{L_{stretch}} \times L_{unit}$$

M is the modelled ratio of oil reaching near the shoreline stretch in a user-specified time period, $L_{stretch}$ is the shoreline stretch extension (m) , and L_{unit} is the shoreline distance unit used (by default is 1000m, but end-user can change this value). Thus, Q* is the amount of oil spilled reaching near the shoreline stretch per shoreline extension unit. An increase in L_{unit} will generate higher severity indexes, so this value needs to be properly calibrated.

The quantification of modelled oil contaminating a specific shoreline stretch is based on the amount of oil present inside an area near the referred shoreline stretch. The definition of this "nearshore" area for each shoreline stretch is based on the distance to the shoreline stretch; thus, if the modelled oil reaches this nearshore area, is assumed as relevant to the quantification of shoreline contamination risk. The nearshore distance is user-defined, and by default it is assumed that the nearshore area corresponds to the definition used for restricted waters (definition in 3.2.1). The time period used in the quantification of oil spilled reaching near the shoreline stretch has a default value of 24 hours. Updates and new oil spill simulations are made every 6 hours (this value is also configurable). More information about the oil spill modelling system is described in chapter 7.

3.4.3 Coastal Vulnerability

A place vulnerable to spill accidents is defined as a location of environmental and social-economic importance, which can be affected with a certain degree of severity if affected by the spills. Obviously the identification and quantification of these zones is closely linked to a correct determination of the risk of shoreline contamination. As showed before, the coastal vulnerability index (I_V) is used in both methods (modelled and non-modelled) to determine the risk of shoreline contamination. Next equation describes how to determine the coastal vulnerability index in this tool:

$$I_V = CSI + SESI \text{ if } ECSI = 0$$

Or

$$I_V = ECSI \text{ if } ECSI > 0$$ [3]

I_V represents the quantification, in logarithmic scale, of the vulnerability of the areas of maritime coast and/or of surrounding waters, that presumably will be reached, and, in a general way, it is equal to the sum of the of coastal sensitivity index (CSI), socio-economical index (SESI), and ecological index (ECSI) of the place affected for the spill.

The characterization of the Coastal Vulnerability in the Portuguese coast was made in the scope of EROCIPS project. Along with desk work, based on Aerial photos and on Google Earth, field surveys were conducted to the whole Portuguese shoreline. This

[3] This method is not used, since ecological index is not included in this software version

information is available on the web through Google Earth, on: http://arcopol.maretec.org/CoastalAtlas/AtlasCosteiro_PORTUGALCONTINENTAL_Netlink.kmz

3.4.3.1 Coastal Sensitivity Index

This index (CSI) represents the quantification, in logarithmic scale, of the valuation of the environmental sensitivity (ecological, landscape) of the areas of the maritime coast and/or the surrounding waters that can be reached by sea pollution from hydrocarbons and/or other dangerous substances spills.

For the general group of areas of the maritime coast, NOAA's ESI (Environmental Sensitivity Index) was adapted for the Portuguese Continental Coast (modifications were related to the specificities of the Portuguese shoreline). The value of this index, that varies of 1 the 10, coincides with the scale of the NOAA's ESI, defined to characterize zones of the shoreline in function of the following parameters:

- Exposure to wave and tidal energy
- Slope of the coast (intertidal zone)
- Type of substrate (size, permeability and mobility)
- Biological productivity and sensitivity
- Ease cleanup

Next table provides the categorization of the Portuguese shoreline's sensitivity to oil discharges used in this tool, based on NOAA's Environmental Sensitivity Index approach. Colours used to visualize the CSI are the same as used in NOAA's ESI. More details can be found in Portuguese Coastal Atlas Report available from EROCIPS project.

Table 3.17 – Detailed description of classes used for Environmental Sensitivity Index

Colour	Coastal Sensitiviy Index (CSI)	Color code (RGB)			Environmental Sensitivity Index and type of shoreline
		R	G	B	
	1	119	38	105	1A exposed rocky shores 1B Exposed, solid man-made structures
	2	174	153	191	2 Exposed Wave-cut Platform in Bedrock, Mud, or Clay. Medium slope
	3	0	151	212	3 Exposed fine to medium-grained sand dissipative beaches
	4	146	209	241	4 Exposed beaches with coarse grained or fine to medium-grained sand; sheltered beaches with fine grained sand
	5	152	206	201	5 Mixed sand and gravel beaches
	6	0	149	32	6A Gravel beaches 6 B Riprap
	7	214	186	0	7 Exposed tidal flats
	8	225	232	0	8A Sheltered scarps in bedrock, mud or clay 8B Sheltered, solid man-made structures
	9	248	163	0	9A Sheltered tidal flats 9B Sheltered low banks
	10	214	0	24	10 salt and brackwish waters marsh, freshwater marshes, swamps, mangroves or scrub wetlands

In regions like coastal shoreline (restricted) waters, commercial ports, and all purpose terminals, fishing ports, marinas or yacht harbours, and unrestricted waters, costal vulnerability index (I_V) is invariable and considered to be 6. However, as this tool is only estimating risks of shoreline contamination (thus, the tool is not estimating the risk at sea; only in shoreline), coastal vulnerability indexes of restricted waters or unrestricted waters / open sea are not considered by the DynamicRiskTool.

3.4.3.2 Socio-Economical Index

This index (SESI) intends to reflect the social-economic importance to the populations of the exploitation of the costal zone under analysis. For example, a beach not often used, or used but without significant infrastructures, and/or a beach with important economic value (restaurants, etc.). While the coastal sensitivity index CSI already considers the normal habitats for that shoreline, it does not consider other improvements that can exist in the zone and that are not specific of the characterization of index CSI, as for example fisheries or aquiculture, that has to be considered through the social-economic index SESI.

Next table provides the Socio-economical Index values.

Table 3.18 Description and classes used in Socio-Economical index

Socio-Economical Index (SESI)	Description
5	Area of extreme importance in terms of environmental resources, leisure and other sea-related activities; Area of very high regional and national interest. There is very high investment and economy of the area that may be affected by the spill. Human population lives directly or indirectly from the resources provided by sea-related activities.
4	Area of high importance in terms of environmental resources, leisure and other sea-related activities; Area of high regional and national interest. Human population lives directly or indirectly from the resources provided by sea-related activities. The economy of the area and neighbouring areas can be affected by the spill; or there is high investment that may be affected by the spill.
3	Area of medium importance in terms of environmental resources, leisure and other sea-related activities; Area of medium regional and national interest. There is medium investment that may be affected by the spill. The spill affects the economy of the area and few economical aspects of neighbouring areas.
2	Area of low importance in terms of environmental resources, leisure and other sea-related activities; Area of local interest. There is low investment that may be affected by the spill; Some interests of the area are affected by the spill.
1	Area of none or very low importance in terms of environmental resources, leisure and other sea-related activities. Specific interests of the area are affected by the spill. Human population doesn't live directly or indirectly from the resources provided by sea-related activities.

3.4.3.3 Ecological Index

Some areas must present ecological aspects that can make them the most important areas in the zone that needs priority in protection and cleanness activities.

As previously mentioned, there are special maritime shoreline zones, where its environmental sensitivity cannot be defined exclusively by the coastal sensitivity index CSI. Other situations may exist in which socio-economical relevance of certain zones can be truly exceptional and require a treatment not contemplated by its maximum value, as Table 3.18. Some areas must present ecological aspects that can make them the most important areas in the zone that needs priority in protection and cleanness activities. The ecological aspects superimpose the Coastal Sensitivity Index, and Socio economic Index, and ecological index (ECSI) is calculated by a formula to guarantee that it has a bigger value than the Vulnerability Index in surroundings areas.

It's more a relative index taking in account all aspects of the area related with sensibility, socio economic aspects and the special ecological characteristics of the zone than an absolute index. The shorter the area covered by an Ecological Index the more efficient will be its use.

Ecological Index is not used in this version of DynamicRiskTool.

4. Console Application

The console application is the “brain” of the system: it is the application responsible to continuously download and compute all the information layers needed and to store it all this in the database. This application should be always running in the background, in order to keep all the information obtained (vessel characteristics, numerical model results, and risk levels) in a continuous way.

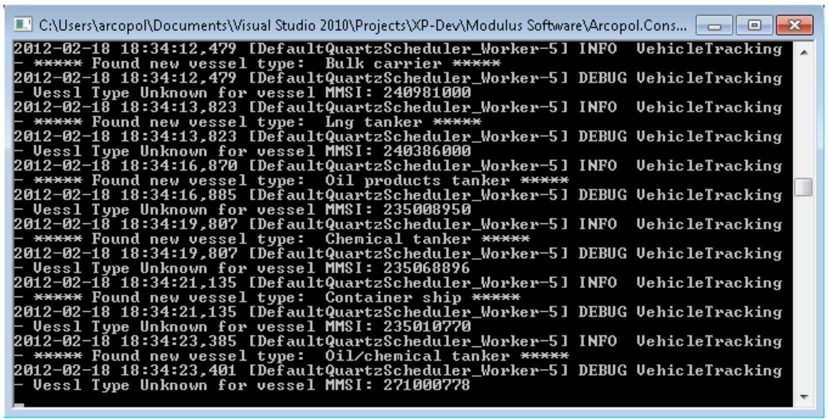


Figure 4.1 – Console application running

After the installation of the DynamicRiskTool, the console application running at first time will generate the ARCOPOL database, where all information is stored.

4.1 Console Application Configuration files

The frequencies, time periods, spatial windows, and risk levels used for downloading or processing information in this console application can be configured by the end-user.

The configuration files are kept in C:\ProgramData\Action Modulers

4.1.1 Arcopol.config

This file is saved in C:\ProgramData\Action Modulers\Arcopol\, and keeps the information related with risk parameterizations, probability indexes, correction factors, etc.

Percentile is also defined in this file, as well as the minimum significant shoreline contamination risk value from each vessel.

The time frequency used for the computation of risk levels is also configured in this file, and by default, risk levels are computed every 30 minutes (keyword for this is <RiskCalculationCronExpression>). The process of risk level calculation is automatically preceded by the downloading of vessel characteristics. For the determination of risk, end-user is able to expand the time window used for searching for updated information from vessels in the database. This is useful because sometimes ships fail to supply their information. To configure this, <VesselBackWindowMinutes> keyword is used. By default, the spatial window used by the risk algorithm is 30 minutes.

With this default options, we are downloading vessels and computing risk every 30 minutes, and taking precautions of searching for vessel updates in the last 30 minutes.

Keyword <ShapesDirectory> represents the folder path to search for specific data layers, including the shapefile with the definition of restricted areas, and also the kml file with coastal vulnerability indexes (and also the geographical definition of the shoreline stretches / geolocations). The file name of the kml with coastal vulnerability indexes is configured in keyword <KMLfilename>. By default, the folder with the layers associated is defined as C:\Program Data\Action Modulers\Arcopol\Storage, kml file name is defined as "atlascosteiro.kml", and the shapefile name used for the definition of restricted waters is set up in Vesseltracking.config file (see chapter 4.1.4)

4.1.2 Arcopol.UI.config

This configuration file is also saved in C:\ProgramData\Action Modulers\Arcopol\, and keeps information regarding the Graphic User Interface. User can configure here the visualization of risk levels. Several properties can be configured for shoreline contamination risk levels – inside "<RiskLineStyle>" block. These properties include minimum and maximum values, normal or logarithmic scale, colours below and above minimum and maximum values, etc. By default, these risk values are defined between 0 and 18.

Relation tables for the specification of classes for visualization of risk of spill accidents are also defined in this file. By default, visualization classes for risk of spill accidents are defined as follows:

4.1.3 Operational.config

This file is saved in C:\ProgramData\Action Modulers\Arcopol.ConsoleApplication\Configurations\, and keeps the definition of the time frequency for downloading metocean forecasting results. This time frequency is defined as cron expressions, and by default, results are downloaded every 6 hours, starting at 00:00. The folder related with MOHID Water, needed to run oil spill simulations, is also saved here. More information is presented in chapter 9.

4.1.4 VesselTracking.config

This configuration file has the configurations related to the process of downloading vessel characteristics from the web. Spatial window to be considered for download is defined in this file, as well as the shapefile with the boundary of the restricted waters and other advanced configurations – keyword is <ShallowWaterLayerFileName>, and default name is "Portugal3MilesZone.shp". Note that time frequency for download vessels characteristics is not defined here (it's defined in arcopol.config, together with the time frequency for risk levels computation); the cron expression present in this file is not being used.

5. Database

All the downloaded data and information generated by the tool is stored in a database system. Metocean forecasts are also indexed in the database, in order to be used by the risk algorithms. The application is configured to work under Microsoft SQL Server 2008 or Microsoft SQL Server Express 2008 (which is free), or any earlier version. The database is automatically generated at the first time that console application runs, without any need of configuration, unless access to database is made through specific user or password (by default SQL Server Express is installed with Integrated Security / Windows Authentication Mode, without any specific user access). In that case, user account must be provided in a configuration file with the same name as Console Application exe file (included in the application folder).

Thus, prior to DynamicRiskTool installation, one of the SQL Server 2008 mentioned versions must be installed.

Although the existence of a database increments the complexity of the application in terms of installation, it is very useful to keep all the historic information, and allowing posterior data analysis.

In some machines, there are some problems in the automatic generation of the database due to user permissions. This is more usual after delete the original database (then the application fails to create the new one, invoking user permissions issues). In order to work-around this issue, an additional script file (CreateDatabase.sql) is included in the installer package – this script file must be executed inside SQL Server Management Studio. After running it, database is created, and console application and/or Graphic user Interface can be launched.

6. Graphic User Interface (GUI)

The graphic user interface has been developed in c#.NET language, in VisualStudio.NET 2010 Environment. It has been fully tested in Windows Vista, Windows 2008 Server and Windows 7.

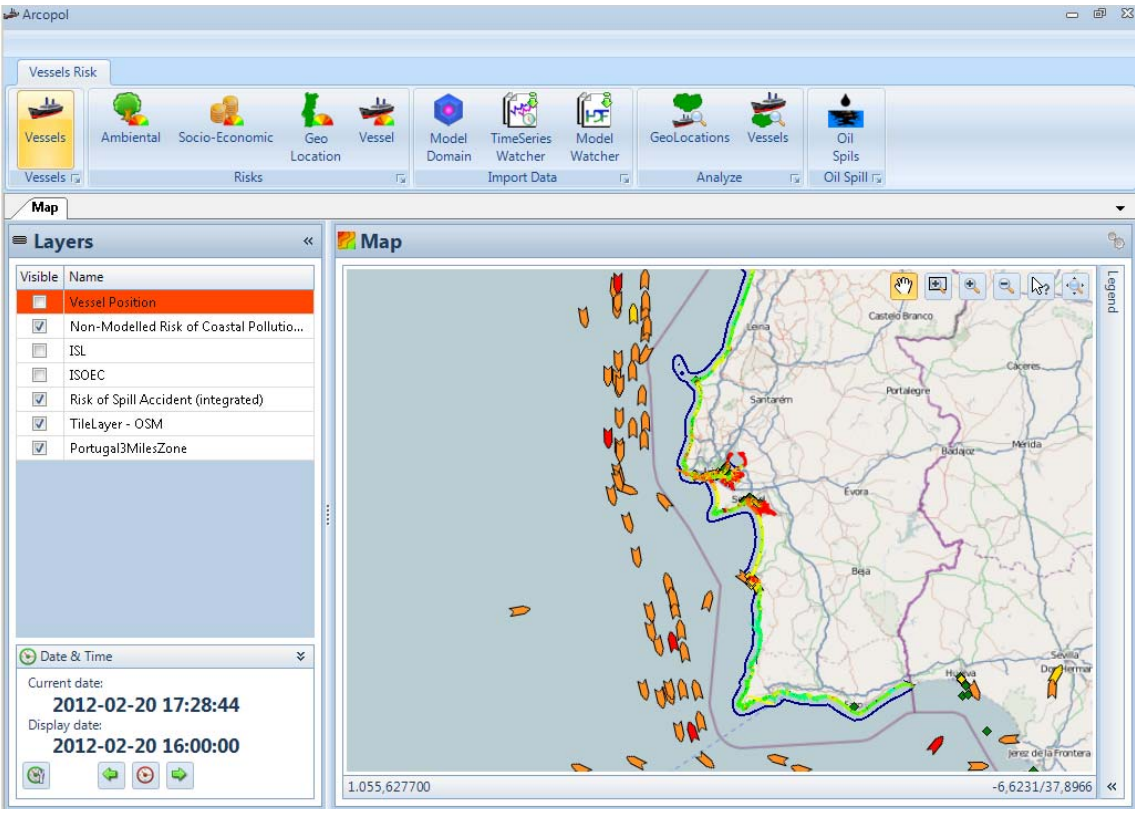


Figure 6.1 – Graphic User Interface

6.1 Map Layers

This application allows the user to interact with the database. Different map layers are available to be visualized in real-time, namely:

- Vessel Position – AIS Information about ships
- Non-Modelled Risk of Coastal Pollution
- Modelled Risk of Coastal Pollution
- ISL – NOAA's Environmental Sensitivity index / ESI
- ISOEC – Socio-Economic Sensitivity Index

- Risk Of Spill Accident (integrated)
- Tile Layer ("TileLayer – OSM") – Representation of The Land Map, from OpenStreetMap
- Delimitation of Restricted Waters ("Portugal3MilesZone")

If a information layer is selected as active layer (clicking with the right button on one layer), user is able to select one (or more) specific object(s) and view object's detailed information related to that active layer. The selection is made using the selection info button seen in the map: . The active selected layer appears in orange, as shown in the next picture:

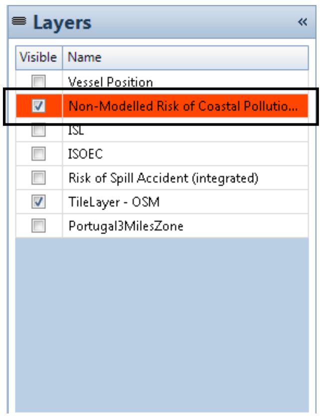


Figure 6.2 – Layers included; active layer in orange

6.1.1 Vessel Position layer

The continuously downloaded AIS information is included in this map layer. The real-time (or historic) positions of the vessels are shown on the map, using different colours and shapes for the ships, based on ship types and ship status, respectively:

Green colour – cargo ships

Red Colour – tanker ships

Pink colour – fishing ships

Vessel shape – ship underway

Square shape – ship anchored / moored

User can also find more detailed information about one specific vessel, or a group of vessels:

1- Selecting vessel position as active layer;

2 – selecting an area including the vessel chosen. After this selection, a form like this is shown:

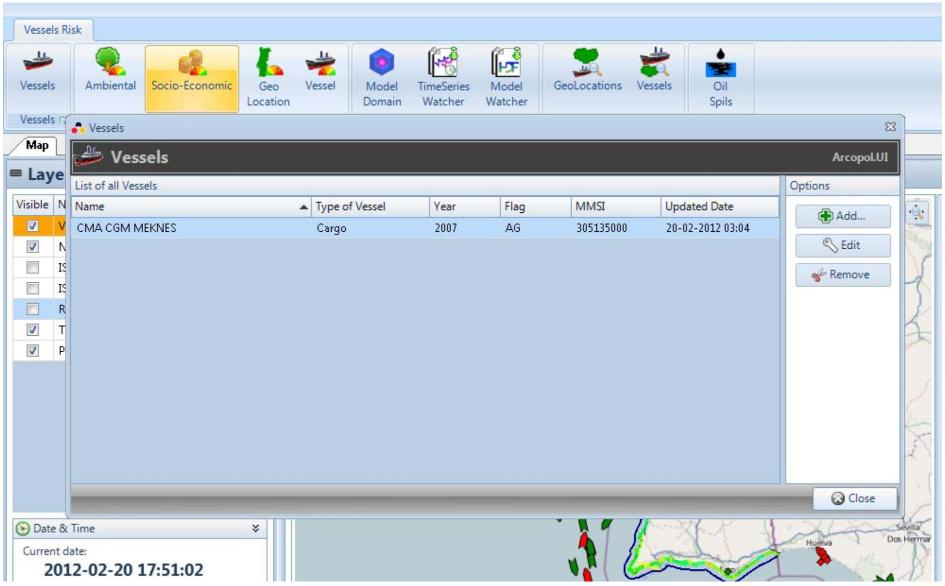


Figure 6.3 – Vessel Details I

Even more specific details can be shown about this vessel, clicking on Edit button. Next picture illustrates that:

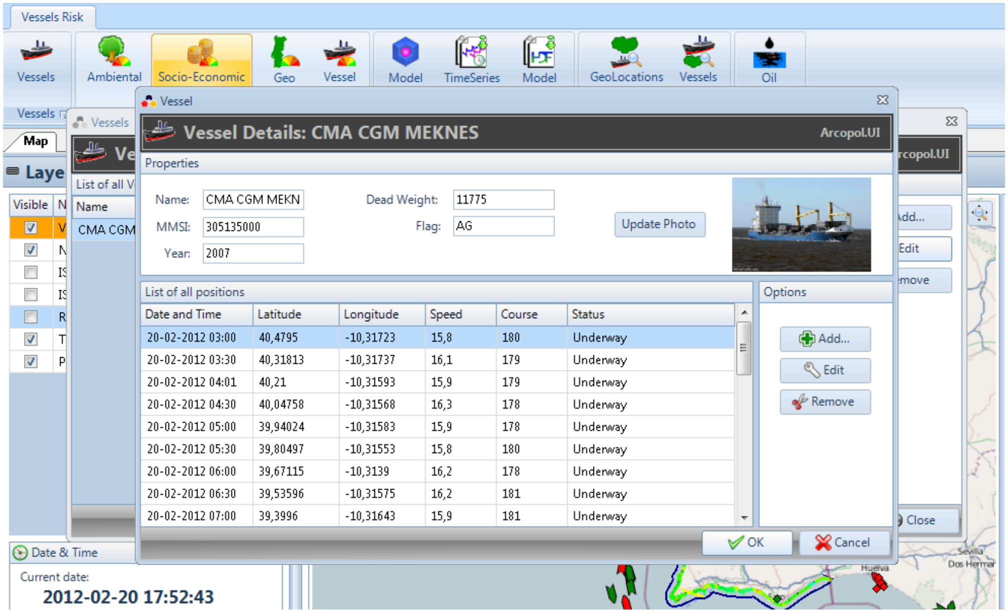


Figure 6.4 – Vessel Details II

The button "Update Photo" will search for any new photo about a ship, since vessel pictures are uploaded to database at first time, and this information is not automatically updated.

Changing information in the database through Add, Edit and Remove buttons is not tested, thus this is not recommended.

6.1.2 ISL (Environmental Sensitivity Index)

The information visualized in the map is based on a colour scheme defined by NOAA in Table 3.17, which is based on index values, and where "cooler" colours mean lower values, and warmer colours mean higher values (more sensitive areas).

Value indexes and description of the shoreline stretches for a specific area can also be seen, if layer is defined as active, and a specific area is selected using the selection info button.

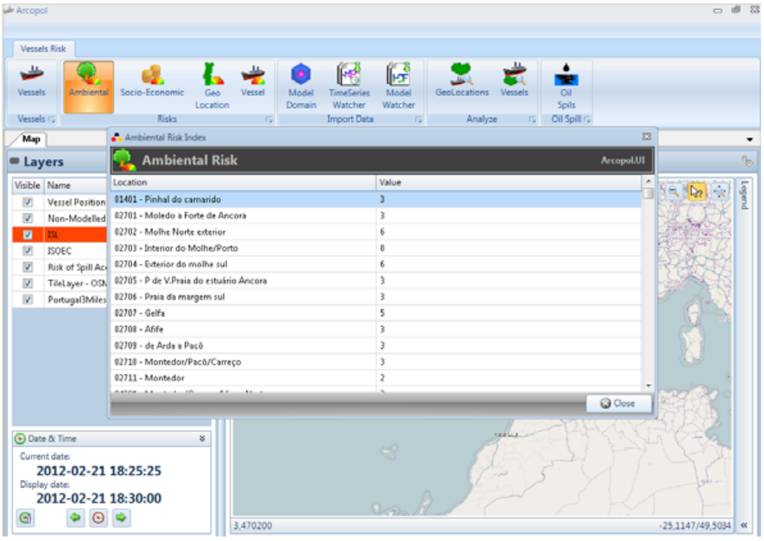


Figure 6.5 – Details on Environmental Sensitivity Index layer

6.1.3 ISOEC (Socio-Economic Sensitivity Index)

The 5 different categories visualized in the map (see Table 3.18) is based on a colour scheme where "cooler" colours mean lower values, and warmer colours mean higher values (more sensitive areas).

Table 6.1 – Colours used in the classification of Socio-Economical index

Colour	ISOEC value
	1
	2
	3
	4
	5

Value indexes and description of the shoreline stretches for a specific area can also be seen, if layer is defined as active, and a specific area is selected using the selection info button:

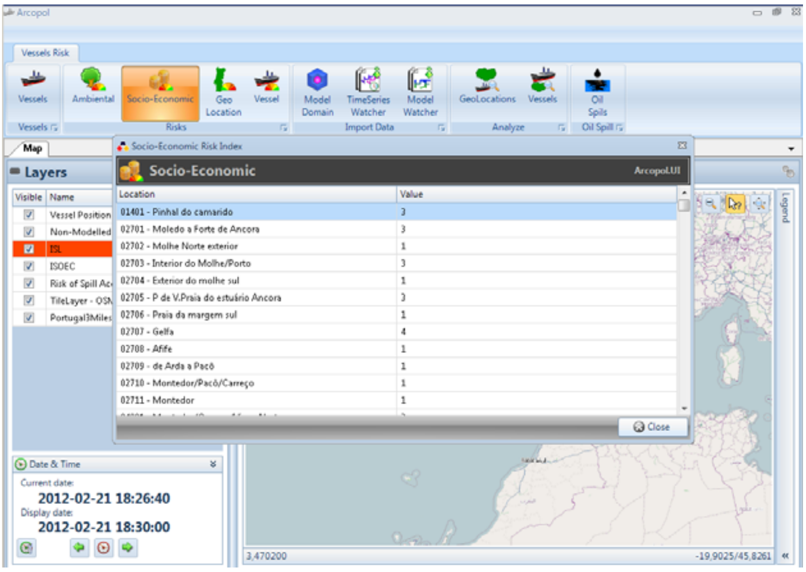


Figure 6.6 – Details on Socio-Economical Index layer

6.1.4 Tile Layer

This layer represents visually the land map and the coastline. Data source is OpenStreetMap. Information usually seems to refresh a bit slow; improvements are expected in a future version.

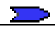
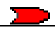
6.1.5 Delimitation of Restricted Waters ("Portugal3MilesZone")

A line is shown representing the delimitation of the restricted waters, which in this work is characterized as the zones where distance to shoreline is not higher than 3 nautical miles, or if water depth is not deeper than 20 meters. This information is used to define the risk algorithms to be computed from each vessel, based on their navigation waters (see more information on chapter 3.2 and chapter 3.3).

6.1.6 Risk of Spill Accident (integrated)

This layer represents visually the ship's integrated risks of spill accident (it's called integrated because includes all accident types determined in the application). The shape of the ship is determined by the ship status (as explained in chapter 6.1.1), and the colour scheme is pre-defined as follows:

Table 6.2 – Ship representation of the different risks of spill accident

Ship colour		Risk of spill accident (integrated)
(ship anchored or moored)	(Ship underway)	0 – 6
		0 – 6
		6 – 8
		8 – 9
		9 – 10
		10 - 11
		11 – 12
		12 - 16

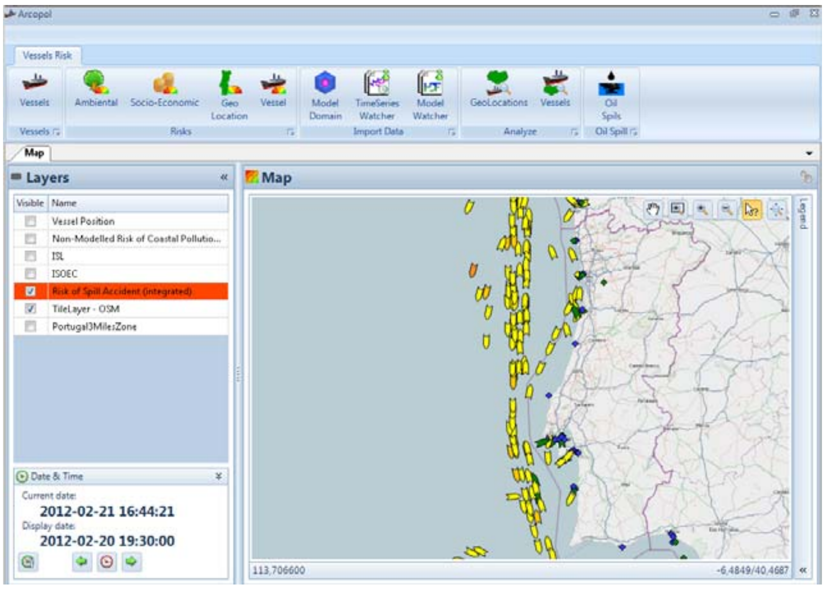


Figure 6.7 – Visualization of map layer with ship's risk of spill accident (integrated)

Detailed information in the application time instant, about a ship or a group of ship risk levels is also provided to the user, through the same methodology used in the other layers: layer must be defined as the active layer, then a specific area is selected using the selection info button.

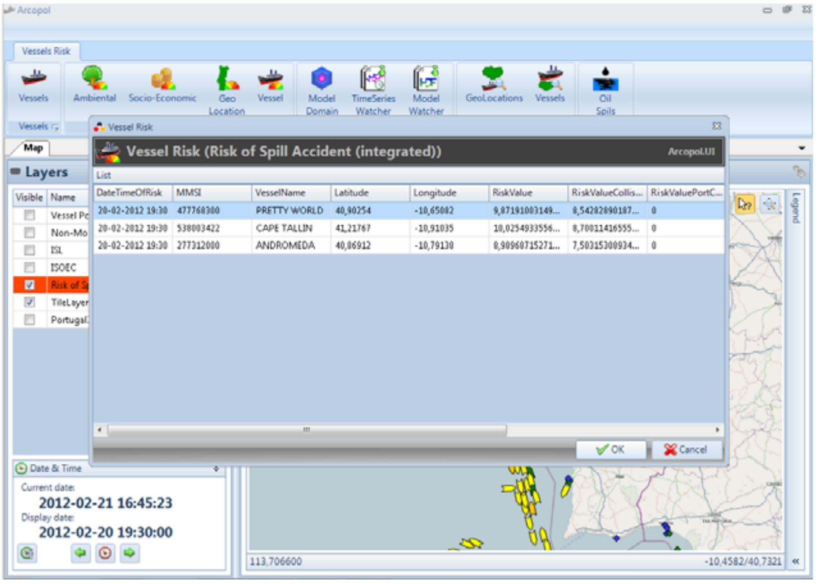


Figure 6.8 – Details on Vessel Risk

The detailed information comprises all the partial risks of spill accidents determined for each ship.

As already mentioned, by default these risk levels are computed every 30 minutes, immediately after the downloading of vessel information (see 4.1.1 and 4.1.3).

6.1.7 Non-Modelled Risk of Costal Pollution

This layer is the visual representation of a user defined percentile (by default, percentile 98) of the shoreline contamination risks from each vessel, without using the lagrangian spill modelling approach, as explained on chapter 3.4.

Information is displayed in the coastline, overlapped with the other coastline layers, ISL and ISOEC. Thus, these layers must be disabled to allow the visualization of shoreline contamination risk levels. As referred in chapter 4.1.2, the default colour scale used for visualization of this layer is defined between 0 and 18, using a continuous colour scale. Risk values above 18 are represented in the same colour as 18.

Once again, this layer also allows detailed information for a selected area including different shoreline stretches (called in the application as "geolocations"), using selection info button. However, for this layer, detailed information included here is only the description name of the shoreline stretch (geolocation) and the risk value (see next picture) in the time instant.

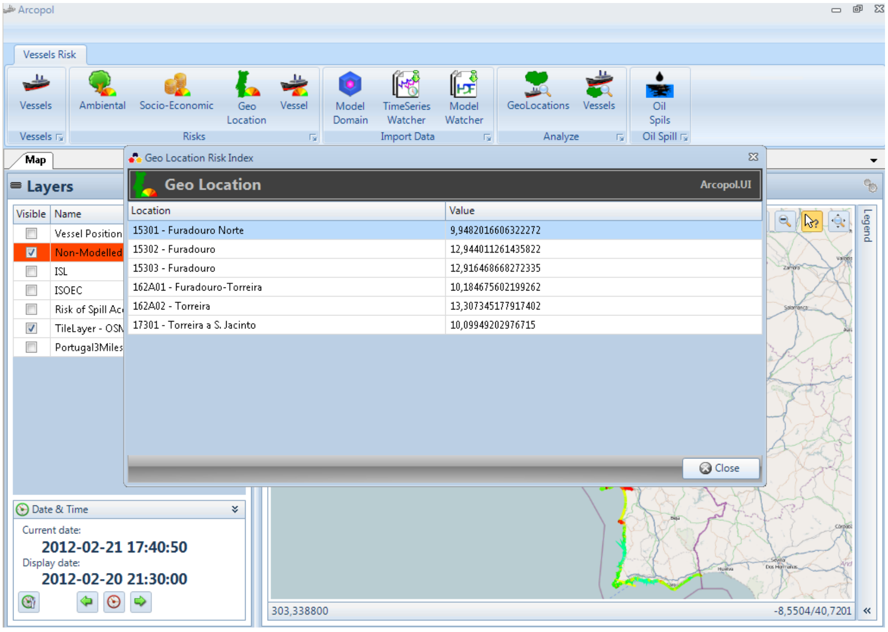


Figure 6.9 – Details on non-modelled risk of coastal pollution

6.2 Buttons

In the upper part of the graphical user interface different buttons are included, as can be seen in the following picture:

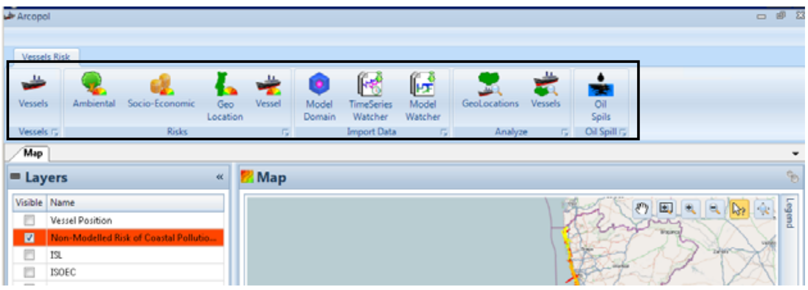


Figure 6.10 – Buttons included in the main form of GUI

In this chapter, the function of these buttons is described.

6.2.1 Vessels | Vessels

This button allows the visualization of details of all vessels in the area, in the same format as explained in chapter 6.1.1 for the detailed information.

6.2.2 Risks | "Ambiental"

The complete list of environmental sensitivity indexes for the shoreline stretches (or "geolocations") is shown after pressing this button. The visualization format is the same as the detailed view described in chapter 6.1.2.

6.2.3 Risks | Socio-Economic

The complete list of socio-economic indexes for the shoreline stretches (or "geolocations") is shown after pressing this button. The visualization format is the same as the detailed view described in chapter 6.1.3.

6.2.4 Risks | Geo Location

This button allows the visualization of the evolution in time of the non-modelled shoreline contamination risk levels, for a specified shoreline stretch / geolocation.

Pressing this button, a window pops up, showing all the shoreline stretches included:

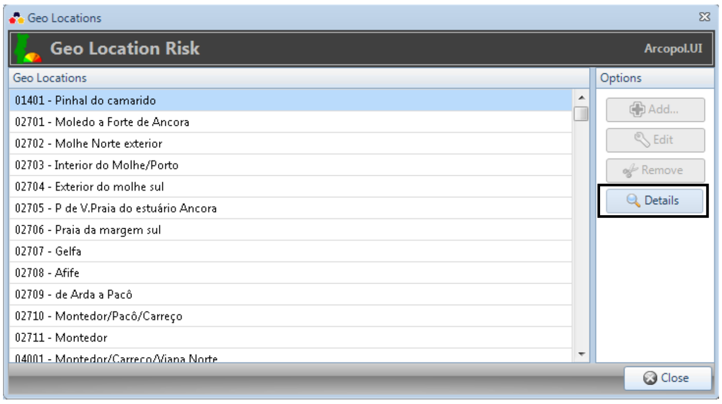


Figure 6.11- List of geo-locations, and button to visualize details on the time evolution of the selected geo-location risk

User must then select one shoreline stretch and click on Details button, where a new window opens, showing the risk evolution on time for the chosen shoreline stretch:

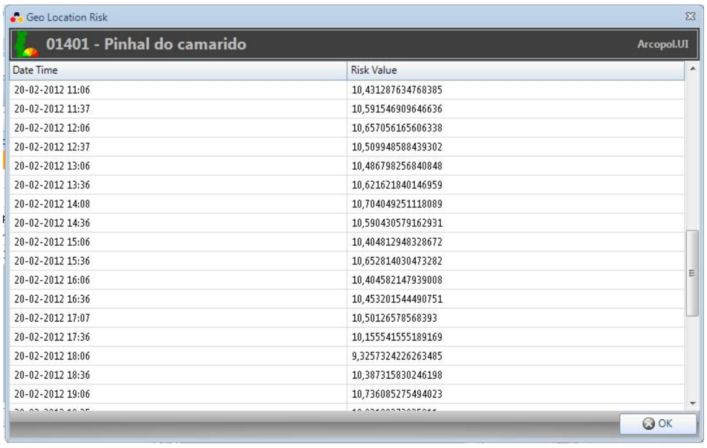


Figure 6.12 – Details on the time evolution of the selected geo-location risk

6.2.5 Risks | Vessel

This button allows the visualization of the evolution in time of all vessel's risks of spill accidents. Pressing this button, a new window appears, showing different vessel properties, status, integrated and partial risk levels, as shown in Figure 6.8. The only difference is the vessel status, shown here.

6.2.6 Import Data | Model Domain

This button allows the configuration of the name of the metocean model types to be imported by the application. The addition of "model domains" is saved in database, thus this process needs to be done after database creation (which is done after a short first run of console application, cancelling it after message of successful database creation), and before the configuration of "Model Watcher" (chapter 6.2.8).

For simplicity, the added names for model domains should correspond to model types included. Presently, the application is configured to import data from IST's meteorological model in MM5, IST's wave model in WW3, and IST's Portuguese Coastal Operational System (PCOMS) in MOHID. A storage directory must also be defined (even if imported data to be configured in chapter 6.2.8 – is not stored).

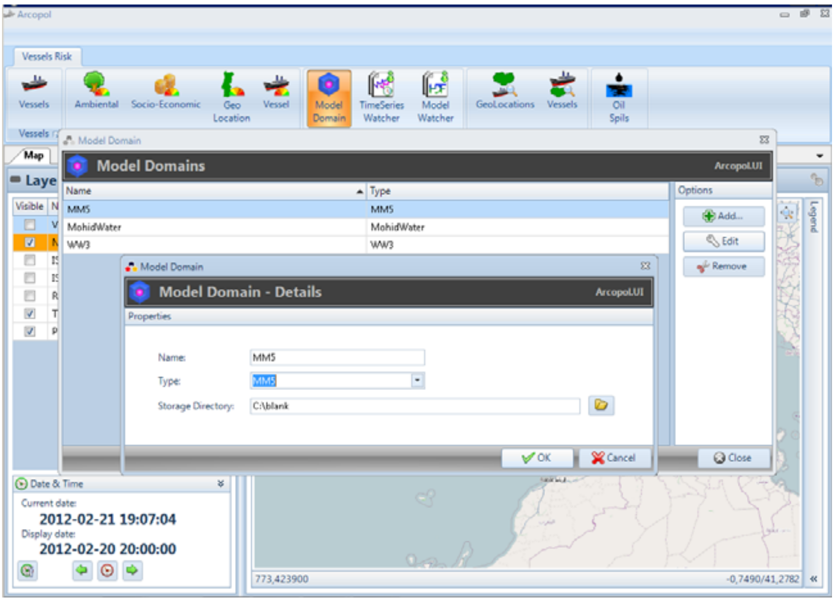


Figure 6.13 – Model Domain configuration

6.2.7 Import Data | TimeSeries Watcher

TimeSeries Watcher allows importing timeserie data files (per example model outputs) to database. This must be used to import oil spill model outputs, in order to be used in modelled shoreline contamination risks.

6.2.8 Import Data | Model Watcher

Model Watcher is the form used to configure how to import numerical model output files to the database. File data is not effectively included in database (only metadata is included), but all the information is properly indexed, in order to be used by the DynamicRiskTool.

Without the inclusion of a list of metocean files (meteorological, currents, and wave model outputs) to be "watched" through this "Model Watcher", risk levels are not able to be properly computed. Prior to the configuration of a list of files to be "watched", a list of model domains must be defined (chapter 6.2.6). These configurations are saved in the database, thus this procedure must be done after database creation (after a first short run of console application, and cancelling it after message of successful database creation). After a proper configuration of metocean files to import / "watch", risk levels can be computed – console application can now be run effectively.

Next picture illustrates the menu forms for the configuration of Model Watcher:

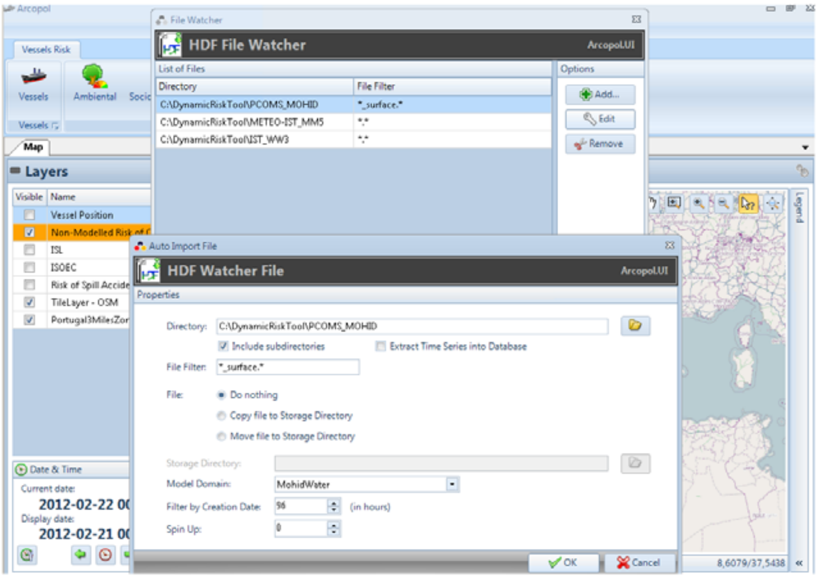


Figure 6.14 – Model Watcher configuration

The file filter must include the output files of the metocean forecast model results.

Files can be copied or moved to a storage directory, or can simply be directly indexed in database (choosing the option "do nothing").

The files can also be filtered by their creation date (in hours); per example, if 24 hours (the default value) is defined in this option, this means that the console application will only import files that were created in the last day. A safe option would be at least 72 hours, in order to prevent possible network problems downloading data.

Spin Up option is not valid in this application, and should be neglected.

6.2.9 Analyze | GeoLocations

Sometimes there is a specific interest to a certain geographical area, and try to understand what are the main potential sources / vessels contributing with higher shoreline contamination risks in the area analysed. To answer to this need, a user (after pressing this feature button to analyse geolocations) has the possibility of choosing one area with shoreline stretches / geolocations with the selection info button. Then, detailed information about vessels contributing with relevant shoreline contamination risks to the area being analysed, as illustrated in the following picture:

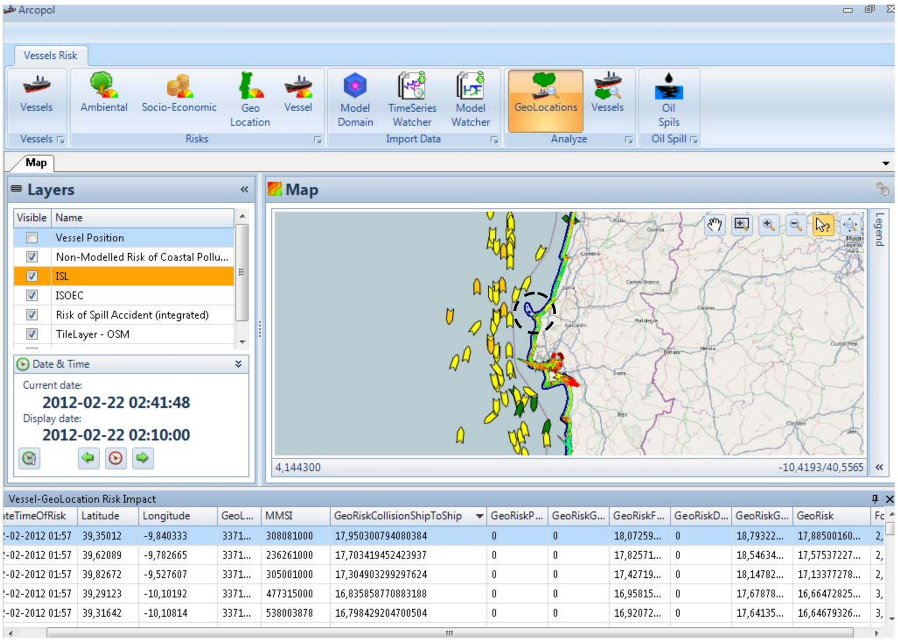


Figure 6.15 – Analysing ships generating geo-location risks in a specific area

The user can sort the vessels by any column selected, pressing in the column header (per example, sorting by the vessels with higher shoreline integrated contamination risk levels coming from ship to ship collision accident type, in the area being analyzed).

The identification of the vessels is made with the MMSI number.

6.2.10 Analyze | Vessels

A specific vessel (or a group of vessels) can pose several risks to a specific area, and can be irrelevant to other regions. Pressing this button to analyze de vessels, user must select a geographical area including one or more vessels (using the selection info button). Then a table is provided with the list of geolocations / shoreline stretches affected by the vessels chosen, as well as corresponding shoreline contamination risks coming from vessels being analysed, as can be seen in the following picture:

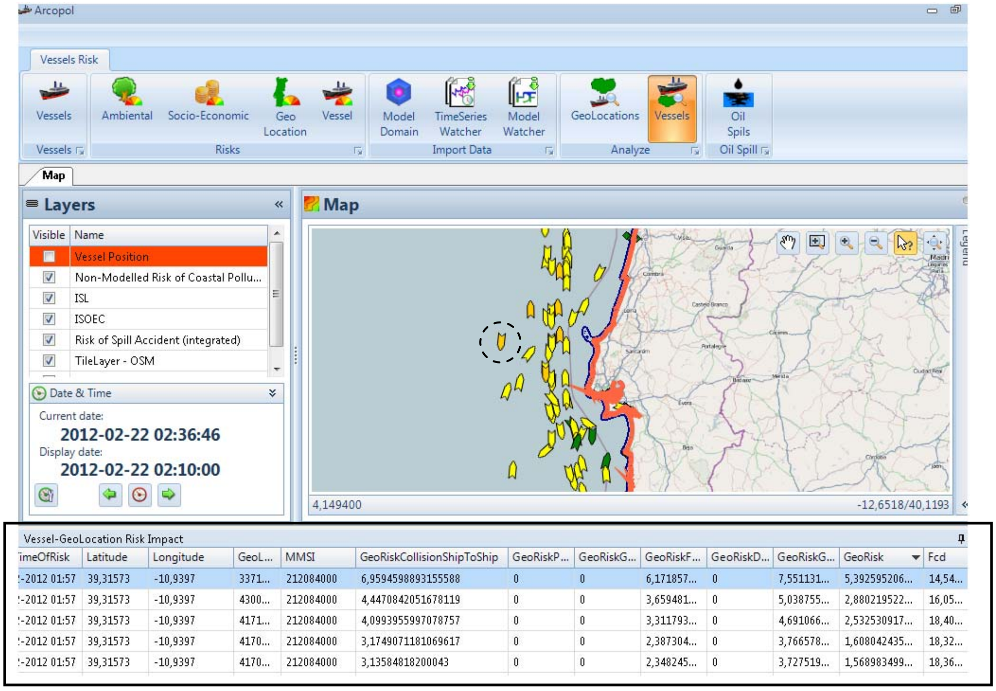


Figure 6.16 – Analysing the contribution of one ship to the geo-location risks in the coast

Once again all the tables can be sorted by the user (per example, sorting by the geolocations with higher shoreline contamination risk levels from vessels analysed).

6.2.11 Oil Spills | Oils Spill

This button allows the visualization of hypothetic oil spills from the different vessels affecting the shoreline.

6.3 Date & Time

In the lower left part of the application (see next figure), there is the date & time panel, which allow user to configure how information is displayed in terms of evolution in time.

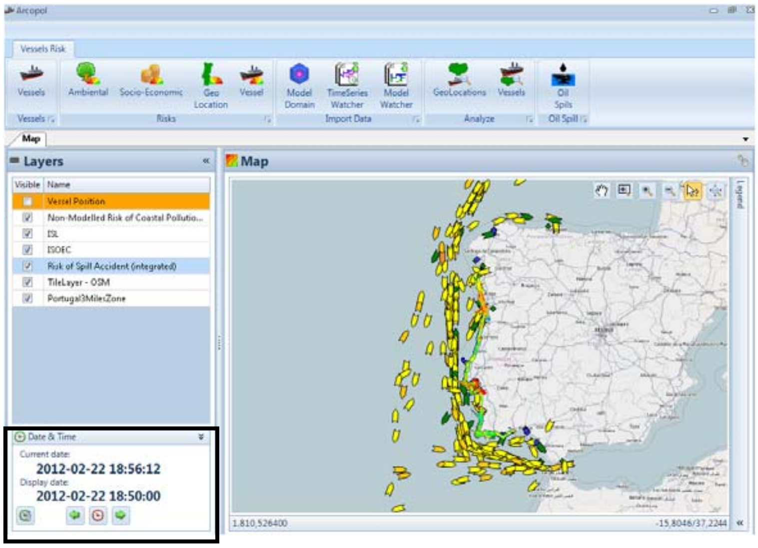


Figure 6.17 – Date & Time panel

By default, the current instant is obtained from the system clock, and the display instant is relative to the current instant, with a time step of 30 minutes. This means that the layers to be visualised are updated on the screen every 30 minutes. Per example, for the position of vessels, DynamicRiskTool will display the last positions obtained in the interval between the half time step (15 minutes) before display instant, and half time step after display instant.

The display date can be changed using the green arrows, and between them there is the clock button – pressing it, will adjust the display date to a rounded instant, the nearest around current time.

Date & Time current and time step for display instants can both be customized, using the lower left button of the application (see next figure).

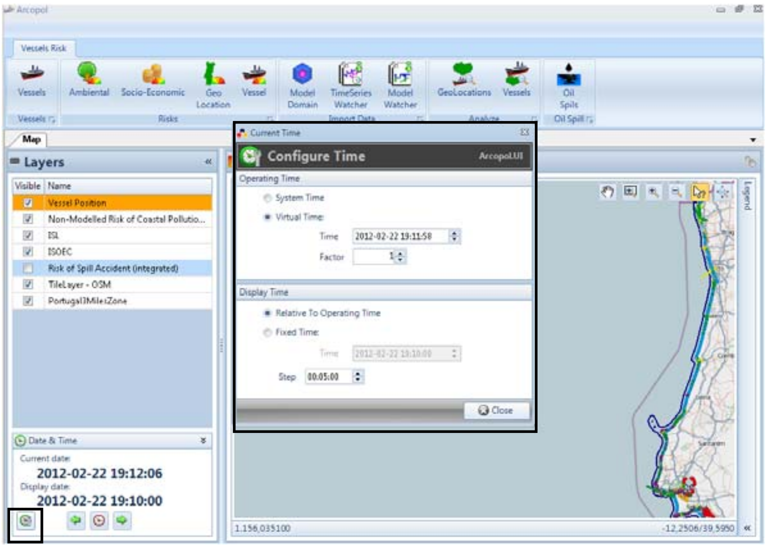


Figure 6.18 – Configuration of date & time panel

After pressing the referred button, a new menu ("Configure Time") is displayed, with several different options. The current time / operating time used by DynamicRiskTool interface can be based on system clock, or in a user-defined virtual time. Using the factor, it is possible to "accelerate" or "decelerate" the time cadence of the virtual time.

Display time is also configurable, since this information can be automatically updated based in the operating time (explained above), or simply fixed in time relative to a reference time defined by the user.

Time step is also defined in this menu.

7. MOHID Oil Spill model

Based on ship positions being continuously recorded, virtual spills are assumed from their position, and an oil spill modelling system (with a lagrangian particle approach) predicts (and quantifies) the possibility of those virtual spills reaching the nearshore. Model results are outputted to ASCII files, with all the required information to be used in the risk calculation (the information generated by the model includes the geographical position of oil particles, as well as mass, volume, density, viscosity, water content (emulsification), etc.). Model launches every 6 hours, producing oil spill simulations from the ships for the next 24 hours. These time definitions can be user-defined. More details about the integration of oil spill model in the risk determination can be consulted in chapter 3.4.2.

In order to produce adequate oil spill simulations, reliable metocean data (currents, wind velocity, water and air temperature, wave height and period) must be used. This metocean data is provided as described in chapter 9.

The oil spill fate & behaviour numerical model used in this application is the lagrangian component of MOHID water modelling system (www.mohid.com).

MOHID framework has been built to comprise great flexibility and versatility, developed in such a way that can be used to study different types of applications at different environments.

MOHID lagrangian module has been widely used in different types of studies and applications, not only in oil spills, but also in sediments transport, harmful algal blooms (HAB's), fish larvae, residence time in estuaries, faecal contamination in bathing waters and plume diffusion and dispersion (near and far field) in water column from submarine outfalls and / or rivers. A list of MOHID / MARETEC references is attached at the end of this proposal.

Oil spill simulations have been used since Prestige Oil Spill (2002), with generation of oil spill trajectory forecasts. Forecasts were generated in the early stages of the oil spill, and predictions were initially validated in-situ by the response team, then, by remote sensing, and at last, by aerial observations. Since then, MOHID has been used operationally in other real accidents and in spill exercises performed by Portugal and Spain, always generating satisfactory results. The oil spill module is a trajectory and weathering model, with the ability to run integrated with hydrodynamic solution, or independently (coupled offline to metocean models), being this last one the option for the operational tools developed (to reduce computation time, taking advantage of metocean models previously run).

The numerical model was also subject of several adaptations and updates, in order to increase its adaptability to the ARCOPOL modelling tools – horizontal velocity due to Stokes Drift, vertical movement of oil substances (3D), modelling of floating containers, backtracking modelling and a multi-solution approach (generating computational grid on-the-fly, and using the available information from the multiple metocean forecasting solutions available) are some of the main features recently implemented.

8. AIS

The dynamic information about vessels is crucial on this tool, since all the risk levels are related on the ship traffic.

Several ship information parameters are used by the DynamicRiskTool in the risk determination (see chapter 3), namely:

- Geographical position
- Ship type (tanker, cargo, etc.)
- Ship weight (deadweight tonnage)
- Speed
- Status (anchored / moored; underway)
- Course (in degrees)

These properties are usually provided by AIS (Automatic Identification Systems). Different web services are available on the web providing this type of information.

DynamicRiskTool downloads AIS information immediately before risk calculation through Console Application (see chapter 4), which can then be visualized in the Graphic User Interface (see chapters 6.1.1 and 6.2.1).

9. Metocean Forecasting Systems used

Different parameters generated by metocean numerical models, including currents, waves and meteorological model outputs, are used in the determination of probability of spill accidents from the ships, converting those model outputs in correction factors, as described in chapter 3.3.1.3.

Additionally, these metocean models are also used by the oil spill model (chapter 7), helping in the quantification of modelled risk of shoreline contamination (see more details in chapter 3.4).

The incorporation of metocean forecasting systems in the DynamicRiskTool allows the utilization of this tool as a predictive tool, forecasting risk levels.

Presently, the forecasting systems tested and imported by the tool in the pilot area of Portuguese Continental coast are managed by MARETEC – IST. These models are downloaded from an ftp server, where new results are continuously uploaded.

9.1 Hydrodynamic & Water Properties: *PCOMS* (MOHID, IST)

The forecasting system imported – PCOMS - is a regional operational forecasting system for the Portuguese Coast. The system provides on a daily basis a 72 hours forecast of ocean currents, sea surface height, temperature and salinity. Results are disseminated to the internet, where data is made freely available at http://opendap.mohid.com:8080/thredds/catalog.html and in http://forecast.maretec.org.

The core of the system is based on the MOHID Water Modelling System (Leitão et al. 2005, http://www.mohid.com). It solves the three-dimensional primitive equations assuming hydrostatic equilibrium and Boussinesq approximations. Model variables are arranged following an Arakawa C-grid formulation with a generic vertical coordinate (Martins et al, 2001). Vertical turbulent mixing is computed using the k-epsilon model (Canuto et al, 2001) included in GOTM (Burchard et al, 1998), MOHID's 1D vertical turbulent models library. Horizontal mixing is parameterised for momentum with a biharmonic operator and for tracers with variable viscosities/diffusivities. At the bottom, a quadratic shear stress is used. Density is computed using the non-linear equation of state of UNESCO (1981).

The model grid, shown on Figure 9.1Figure 6.8, includes the entire Portuguese Continental coast (34.8°N to 45°N) and also the Galician coast, the Gulf of Cadiz and the Gibraltar strait. The domain has a fixed horizontal resolution of 0.06° (5-6 km). The vertical resolution comprises 50 vertical layers, where the 43 at bottom are in Cartesian coordinates and the top 10m are 7 sigma coordinate layers. The bathymetry is calculated by interpolation of the SRTM30 data set. At the open boundary the model downscales the solution of the General Circulation Model MERCATOR-Ocean PSY2V4. A 2-D tidal reference solution (to the supplied at boundary by a 2-D barotropic model domain with 0.06º of resolution forced only with the FES2004 tidal atlas solution, using a Blumberg and Kantha (1985) radiation scheme) is superposed linearly to the Mercator solution according to the methodology described by Leitão el al. (2005). Tidal solution is applied with a Flather (1976) radiation scheme to the 3D model, which is also submitted to a flow relaxation scheme (FRS) to the Mercator solution, following the methodology described in Martinsen and Engedahl (1987).

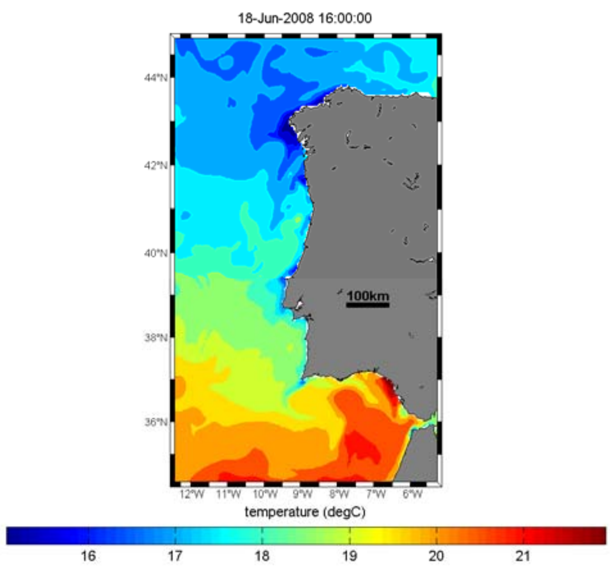


Figure 9.1 – Geographical area modelled in PCOMS | surface temperature

At the ocean-atmosphere interface, the model is forced by hourly forecasts updated every 6 hours from the MM5 operated at IST (http://meteo.ist.utl.pt). The variables used are air temperature, relative humidity, wind velocity at 10, solar radiation and downward long wave radiation. Bulk formulas are used to compute heat transfer from/to the atmosphere to the ocean.

9.2 Waves: Wave Forecast for the Portuguese Coast (WW3, IST)

The Wave Forecasting System used is based in WaveWatch III numerical model, developed at NOAA / NCEP.

The model is set up for 3 domains: North Atlantic Ocean, Iberian Peninsula and Portuguese Coast. These 3 domains are nested, meaning the larger domains provide boundary conditions to the smaller domains. All the domains are forced with the GFS wind forecasts with 0.5º resolution.

The model then runs everyday at 1h00, at IST and publishes the results everyday (around 6h30 in the morning) with a 7 days forecast, in: http://maretec.mohid.com/ww3/

9.3 Meteorology: *MM5-IST* (WW3, IST)

The meteorological forecasting system used in this application is based on MM5 model (Meteorological Model). This is a regional, non hydrostatic, sensitive to topography (sigma coordinates), allowing to simulate and predict the evolution in time of three-dimensional fields of all the atmospheric variables (e.g. atmospheric pressure, wind fields, temperature, relative humidity, precipitation), solving numerically the Navier-Stokes equations, as well as the Energy equations for compressible fluids (energy and mass conservation, linear moment, etc.), coupled to a soil model. The MM5-IST system imported is applied operationally since February 2001 (http://meteo.ist.utl.pt), generating 3-days forecasts, updated every 6 hours. The configuration, initiated after an optimization study (Sousa, 2001) uses 2 nested models (27 and 9 km) (see next Figure) and boundary and initial conditions supplied by global circulation model GFS (Global Forecast System), with 0.5º of spatial resolution.

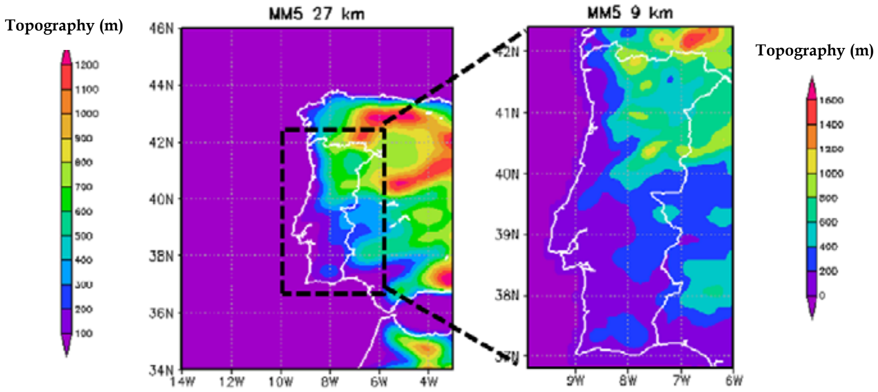


Figure 9.2 – Nested model domains simulated in the meteorological forecasting system at IST

10.Transferability to Other Regions

As already mentioned, this application was firstly implemented in the Portuguese Coast, with the aim to test it initially, and then proceed with some minor adaptations in the tool and with some compilation of different data layers from the regions interested in implementing the DynamicRiskTool, in order to make a smooth transfer of the tool. A description of this requirements and adaptations is presented below.

10.1 Vessel Information / AIS data

As already mentioned, this type of information can be obtained from several different web services. One data provider must be chosen, and then a parser needs to be built in the console application, in order to allow the download of the information and the subsequent storage in the database. The programming of the parser becomes easier if data is provided in a structured format, like xml or kml (Google Earth) files.

The data provider must be able to supply information related with what is described in chapter 8. Any missing parameter will compromise the risk determination.

10.2 Metocean Forecasting Systems

To apply the DynamicRiskTool to a specific region, metocean forecasting numerical model results should be available to download, for the determination of probability of accidents, and also to feed oil spill modelling system.

Parameters needed are: currents velocity fields and water temperature (hydrodynamic and water properties model in the water column); 10m wind velocity fields, surface air temperature, visibility (meteorological model); significant wave height, and wave period (wave model).

The less common property provided is visibility. If it's not available, the effect of this factor in the probability of an accident will be neglected. If the hydrodynamic and water properties results only provide surface fields, oil spill model will be simulated with the surface velocity only, reducing the liability of the oil spill model results for substances with tendency to entrain in the water column and transport in subsurface layers.

Although the DynamicRiskTool in this version doesn't allow downloading remote files through the web, there is an application – ModelDownloadManager[4] – that was developed with this specific purpose. This software is able to deal with some of the operational models available in the Atlantic Regions, and can be adapted to include even more data sources. ModelDownloadManager can also be used to run conversion tools (like ConvertToHDF5) after download.

The DynamicRiskTool imports files in HDF5 format. If model results are to be provided in NetCDF format, a pre-processing conversion prior to DynamicRiskTool importing operation must be pursued. This conversion can be made per example with ConvertToHDF5 tool developed by MOHID community, which is already used to convert the most common forecasting models outputs in the Atlantic Region.

10.3 Coastal Vulnerability

The shoreline contamination risk needs an environmental sensitivity index and a socio-economic sensitivity index, in order to adequately quantify the shoreline impacts of potential spills from vessels. Ecological index is also advisable, but it was not integrated in the DynamicRiskTool, since there was no information on this item for the Portuguese coast.

These indexes were obtained for some partners in previous European projects (EROCIPS), and without any quantification of the coastal vulnerability, there is no possibility to understand how serious a potential oil spill can affect the shoreline.

Although the same methodology of quantification of the coastal vulnerability / sensitivity indexes is recommendable, this is not mandatory to make

[4] ModelDownloadManager is a software developed in the scope of EASYCO, and also tested and updated with ARCOPOL collaboration, since it was adaptable to "feed" MOHID Desktop Spill Simulator (task 4.3.2). This software product can be downloaded in http://www.project-easy.info/, under Members Area (registration is required)

DynamicRiskTool work – however, if a different scale is defined for any index, the risk levels will have a different scale, and the end-user should have that into account. Changes in the coastal vulnerability scale will result in a change on relative weight on this parameter in the shoreline contamination risk. Additionally, these changes will also reduce the possibility of comparing risk levels between different regions.

The methodology used to generate the coastal vulnerability indexes is described in chapter 3.4.3.

Since the coastal vulnerability indexes obtained for the Portuguese coastline are compiled in a kml (Google Earth) file, a parser to import those data was programmed in the DynamicRiskTool. Different parsers can be developed for different data formats, but if the coastal vulnerability indexes applied in other regions keep the same structure already used in the Portuguese coastline, the process of importing this information will be straightforward. The structure used for the coastal vulnerability in the Portuguese coastline can be seen here: http://arcopol.maretec.org/CoastalAtlas/AtlasCosteiro_PORTUGALCONTINENTAL_Netlink.kmz

10.4 Probability of Accidents: Frequency Constants and Multiplying Correction Factors

The quantification of the probability of an accident determined by DynamicRiskTool is based on statistical values and correction factors that derived from previous studies and analysis of ship traffic accidents (most of the values and methodology used was built in EROCIPS project). All the information used is described in chapter 3.3.1.

These values used can be changed, to reflect regional statistical background of accidents with ships. As already referred, these values are configurable in configuration file "Arcopol.config" (see chapter 4.1.1).

11. Known Bugs, Limitations, and Future Implementations

In some machines, there are some problems in the automatic generation of the database due to user permissions. This is more usual after delete the original database (then the application fails to create the new one, invoking user permissions issues). In order to work-around this issue, an additional script file (CreateDatabase.sql) is included in the installer package – this script file must be executed inside SQL Server Management Studio. After running it, database is created, and console application and/or Graphic user Interface can be launched.

Performance of the graphic user interface can become slow when loading some information layers, or trying to display details about risk levels, vessel information, etc. Progress bar or waiting cursor are not included in the application, and should be included in the future. Some performance problems must also be corrected in the future, including the loading of the Tile layer.

The lines corresponding to some layers (e.g. shoreline contamination risk) are not configurable in the graphic user interface; only on the configuration files. In the future, this limitation will be solved.

At the conclusion of this report, it was not possible to obtain the visibility parameter from the meteorological model. A constant value of 1 is assumed for the correction factor related to this parameter. Efforts are being done to obtain a fully tested stable version of the software including visibility parameter from the meteorological model, which is expected to be released during the first trimester of 2012.

The navigation between different time instants in the visualization of risk of spill accident (integrated) usually fails to refresh. Checking and unchecking the vessel positions seem to solve the problem in some cases. Also sometimes the ship positions displayed in vessel position layer and risk of spill accident happen to be different, for the same instant. These issues will be corrected in the near future.

In relation to the metocean forecasts imported by the DynamicRiskTool, presently there is no possibility to visualize them in the application, which should be implemented in the future. Additionally, the process of downloading metocean models through the web is not directly managed by the DynamicRiskTool (needs to be managed by third-party software). Integration with ModelDownloadManager will be considered.

In the implementation of this pilot project, the ecological index (chapter 3.4.3.3) was not included in the determination of shoreline contamination risk index, because this information is not available for the Portuguese coastline. DynamicRiskTool must be adapted to allow the possibility of integration of this index.

Fire and Explosion is a type of accident that was not included in DynamicRiskTool, since this type of accident was not included in the risk assessment study developed for the Portuguese Coast, under the scope of ARCOPOL. Since this is one of the most important types of accidents at sea, it should also be considered for future integration in this tool.

Beyond the corrections, improvements, updates and new features mentioned above, more complex implementations are expected to be developed in the DynamicRiskTool:

- A web GIS interface is planned to be developed. Risk levels, ship information, and coastal vulnerability indexes will be displayed.
- Results should be published in OGC WFS or WMS standards, allowing requests for geographical features (using WFS) or georeferenced map images (using WMS) across the web using platform-independent calls. This means that results provided by DynamicRiskTool will be able to be loaded by different applications.
- If possible, more detailed information about ship type will be displayed and taken into account for risk calculation.
- The incorporation of more individual ship information for increase the quantification of probability of spill accident is a main purpose for the future. The methodology adopted is to include the Individual Ship Risk Profile, as determined by EMSA's THETIS[5] system (https://portal.emsa.europa.eu/web/thetis/ship-

[5] THETIS is a new information system developed by EMSA in cooperation with Member States and the European Commission, which will support the New Inspection Regime for Port State Control

risk-profile-calculator; according according article 10 and Annexes I and II of the new Port State Control Directive 2009/16/EC), and making use of the ship information available through this system.

- A new risk calculation tool is being considered for development: the aim of this tool is to be able to compute risk levels based on past information available on the database (vessel information and metocean model results), for a user-defined time period (instead of computing risk levels in real-time). A tool like this would be very useful for sensitive analysis and in-depth studies for specific regions.

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Main references from IST / MARETEC directly associated to work with MOHID lagrangian model (including oil spills, faecal contamination, sediments transport and fish larvae), which is the model used in the proposed work.

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