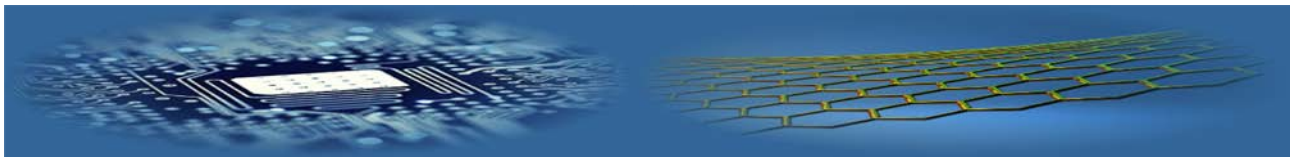

# The Development of Risk Assessment System for Accidental Oil Spill in the Northern Caspian Sea

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**Abstract**

This article describes the development of a multifunctional geoinformation system RANDOM (Risk Assessment of Nature Detriment due to Oil spill Migration), realizing a multiprocessor calculation of probabilistic risk models to assess the negative impact of the oil spill on the biota of the North Caspian. The urgency of the problems associated with the development of oil fields in a very vulnerable shallow part of the Caspian Sea, where a major accident could have disastrous consequences. This article describes the development process from design to implementation to testing. The system is designed on the basis of service-oriented architecture (SOA), which allows for easy, flexible integration of services, and access them via the Internet. Through the use of SOA, the system can be expanded and upgraded. In this approach, the services may be located on physically different servers. Described in detail the process of parallel processing of large data set, shows the comparative tests on performance calculations. Tests have shown the benefit of using a supercomputer, it enables us to obtain a risk assessment for an adequate time. This system is designed for professionals in the field of ecology and mathematical modeling and subsoil oil fields on the continental shelf of the seas and oceans. RANDOM system as the final result of the decision of risk assessment tasks includes a series of calculation modules based on the methods of probability theory, computational mathematics, hydrodynamics, oil chemistry, marine biology, mathematical modeling and geoinformatics.

*Keywords:*

GIS
RANDOM
Risk
Oil Spill
Caspian Sea

## 1 Introduction

The rapid growth of the activity of oil and gas operations in the Kazakhstan sector of the Caspian Sea in recent years increases the urgency of the environmental safety of the Caspian Sea. The uniqueness and isolation of the Caspian Sea may result in the event of a major oil accident to a large-scale ecological catastrophe of the whole region, and the damage could exceed the damage from a similar accident in the Gulf of Mexico. The most dangerous for the coastal zone of anthropogenic impact is the accidental spill of oil, particularly high risk of such accidents in areas where fish oil or its transportation is conducted. Multiple oil spill could lead to a deterioration of the environmental situation not only at the spill site but in the surrounding areas. In this type of coast and local climatic conditions determine the behavior of the oil spill and the extent of its impact on the surrounding area. Therefore, risk of oil contamination zone maps are an information system allowing operatively to determine priorities for spill response, to model and predict the process related to oil spills, as well as to evaluate possible damage on the coast as a result of oil spills. Emergency oil spill in the North Caspian Sea can cause catastrophic damage to flora and fauna of the sea. As a result, the intensification of oil operations on the shelf of the Northern Caspian Sea brings to the task of risk assessment plan for the defeat of biota with accidental oil spills [1-4].

To automate the process of calculating the subsequent spills and environmental risk assessment was designed and implemented a 4-tier service-oriented computer-aided calculation of risk mapping with GIS elements. Simulation of a large number of oil spills with different parameters is performed using a high-performance cluster. The developed system is used as a management tool for resource assessment, oil spill response, planning and damage assessment.

## 2 Systems development

### 2.1 ENGINEERING DESIGN

The main functions of the system RANDOM are interaction procedures with a risk assessment system and produce presentable results in a spatial and temporal map for the following services:

1. Service Meteo - provides the user with the processed data ECMWF weather forecast maps as a predictive meteorological elements in vector format for 120 hours.
2. Service Hydro - allows to perform the calculation of the forecast of the Caspian marine currents, formed under the influence of wind, temperature and other weather forecast data for 120 hours.

3. Service Oil Migration – allows to calculate the forecast for the next 120 hours spread detected oil spill taking into account the physico-chemical transformations of oil.
4. Service Risk Oil - provides the possibility of building an oil pollution risk maps of the sea above the maximum permissible concentration (MPC) for the given parameters of the accident (place, length, power, oil properties, and others.)
5. Service Risk Biota - provides an opportunity to build risk maps damage to flora and fauna of the sea with oil spills.

On an abstract level logical view of the system architecture can be viewed as a set of interacting components, grouped into layers. Design involves charting series. Among them occupies an important place component diagram (Figure 1). As physical components can serve files, libraries, modules, executables, packages, etc. The components are linked through dependencies, when connected to the required interface of one component with another available component interface. Thus is illustrated the relationship of client-source between all pairs of components.

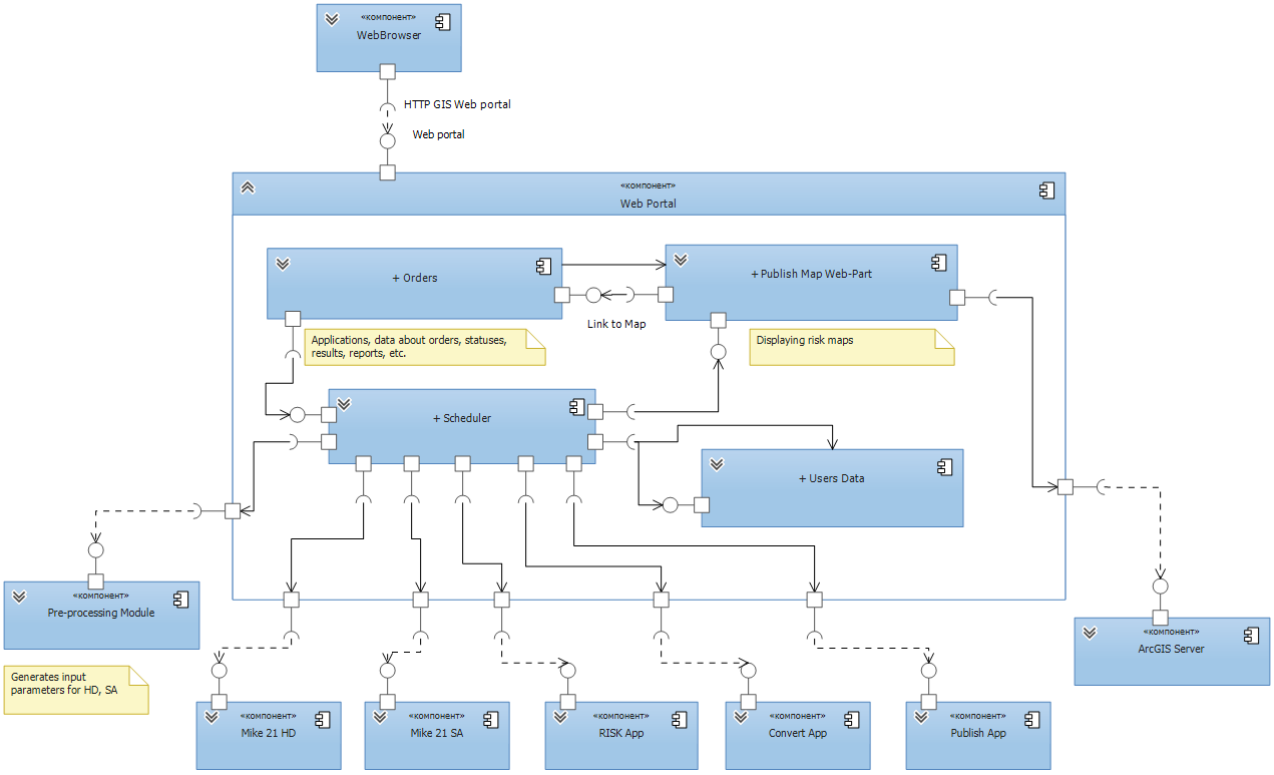


FIGURE 1 Component diagram

Web Portal component is a web server that will be deployed RANDOM system developed on the Microsoft ASP.NET platform. Users access to the system through a web browser. When accessing to the system, the user will need to authenticate to the web server. The web server is responsible for processing all user queries.

Orders component provides storage and the structural representation of users' requests.

Component Publish Map Web-Part provides display bands on the map, also provides tools for processing geospatial data.

Component Users Data storage provides risk maps and accompanying reports.

Scheduler component is responsible for the order of startup applications for payment. Produces the coordination of the calculations, depending on the type of service selected, parameter passing, and creating subtasks.

ArcGIS Server component provides storage cards as a service to display in the Publish Map Web-Part.

Pre-processing Module Component allows the generation of configuration files required for the calculation of wind, hydrodynamics and oil spill.

Component Mike 21 HD [5] provides the calculation of hydrodynamics.

Component Mike 21 SA [6] calculates an oil spill.

RiskApp component calculates the probability risk of oil pollution of the sea and the destruction of biota in the Northern Caspian.

ConvertApp component converts the digital data received from Mike 21 and RiskApp classified in the respecttive colors of the map layers.

PublishApp component is responsible for the automated collection of converted data in the map service, and further publication to ArcGIS Server by using ArcMap services.

At the final stage of design to integrate RANDOM with applications MIKE 21 HD, MIKE 21 OS, Risk App, Convert App, Publish App, were designed web services Preprocessing, Proxy HD, Proxy SA, HPCRiskModel, MapConverter and Task Scheduler.

1. Task Scheduler - an application that is responsible for the procedure call web services depending on the requested service and control and monitoring of running tasks.
2. Web Service Preprocessing, provides a configuretion file for the module and Proxy SA Proxy HD

(calculate spill and hydrodynamics).

3. On the Web Service Proxy HD provides interaction with the scheduler functional part of the automated calculation of hydrodynamics at the predetermined period. The functional part is implemented using MIKE 21 HD applications.
4. On the Web Service Proxy SA provides interaction with the scheduler functional part of the automated calculation of the spill in the given period. The functional part of the application is implemented MIKE 21 SA.
5. The Web service HPCRiskModel provides interaction scheduler module for calculating the risk of marine pollution and the risk of biota. The functional part of the application module is implemented Risk App.
6. The Web service MapConverter provides interaction scheduler with automated conversion of files obtained from the risk unit in vector layers and publishing them to ArcGIS Server. The functional part of the converter implemented application Convert App, and the publication module using the Publish App application [7].

## 2.2 THE ARCHITECTURE

Selecting a Service Oriented Architecture (SOA) is connected with the fact that the technology in the construction of corporate automation and information systems specifically designed for the integration of differently-platform applications that provide business processes as required in connection with inclusion in the set of independent software.

In this section detailed structure of the system in the form RANDOM 4-level service-oriented architecture based on the W3C Web Services standard. The choice of this approach is based on the need to integrate differently-platform applications, as well as the need for their reuse. The modular approach to software development provides for the expansion of software processes into separate services, where each service has the functionality. This achieves flexibility.

Figure 2 is a service-oriented system architecture. This figure shows the 4-level system: the client, the interface, the level of applications and the level of data storage.

Client layer provides access to the system. Accessing the system can execute both from PC and mobile devices.

Presentation layer consists of a web server on which the platform is Microsoft SharePoint Server 2013 is deployed for the demo version of the portal and portal RANDOM working on Microsoft ASP.NET, published on the Web server IIS. Selecting the Microsoft ASP.NET platform was due to the fact that it provides tools to automate business processes and supports the principle of service-oriented architecture.

The application layer is a set of web services that represent management services over the software installed on the computer cluster and performing calculations and spill risk analysis. This level is the functional core of the system. At this level will be used computing cluster, which provides fast parallel processing of data it. In computing cluster installed the following software: Mike 21 SA, Mike 21 HD, Risk Biota, Meteo. This level closed to the user and the interaction with the system and management of software packages is done via web services: Task Controller, Preprocessing, HPCRiskModel and MapConverter.

Storage layer comprises a database for storing information [8].

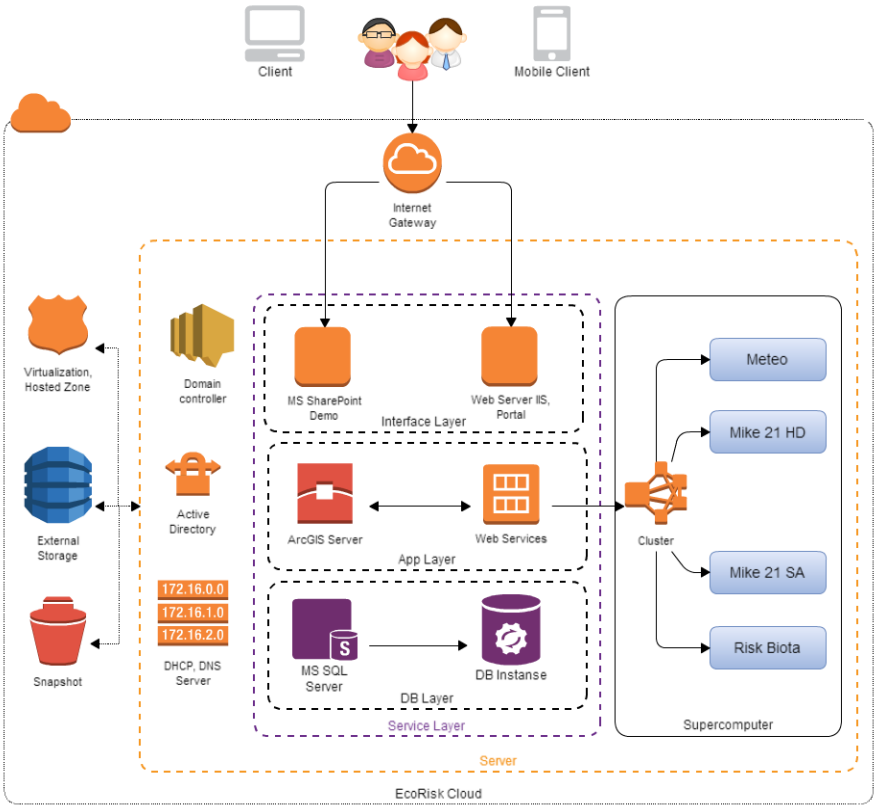


FIGURE 2 General scheme of the system architecture random

### 2.3 THE SCHEME CALCULATIONS

The system RANDOM implements two computational branches: one is related to the generation of short-term forecast, the second - with the statistics and risk. The first branch is implemented through a series of phases: forecast, marine forecast hydrodynamics and marine pollution forecast with the oil spill. Those the latest forecast is an eventual result of the first leg, so it runs at the same time testing the calculations of all kinds of short-term forecast based on data from the European Centre for Medium Range Weather Forecasts (ECMWF). The nett result of the settlement of the second branch are risk maps, using the statistics in the form of wind fields, pressure, water temperature and air for 36 years from the database ERA Interim (Figure 3).

To implement the risk measurement system required the development of software for automated calculation of fluid flow and the oil spill. Thus, the system allowed the maximum eliminate the human factor for the duration of the complete cycle of calculations. Before calculations of hydrodynamics and oil spill is required to produce the preliminary operations on the input data of the wind. For this purpose the package pre- and post- processing programs, which interpolates each wind forecast file to calculate the Caspian hydrodynamics. Also, the subsequent processing and saving the file to calculate the wind oil spill. For these operations, spent considerable time for a set of statistics are needed repeatedly calculated oil spills, so the task parallelization and automation of these processes.

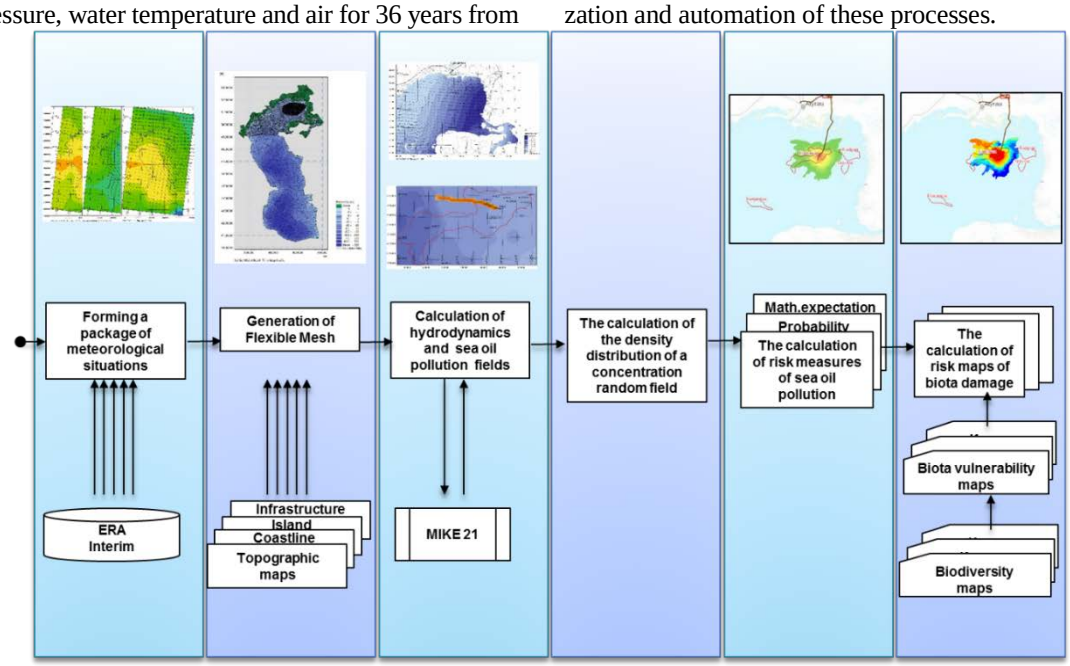


FIGURE 3 Scheme of the calculation of risk maps

## 3 Computation

### 3.1 SINGLE COMPUTATION

Service "Prediction of Oil Spill" is a service for the calculation of the spread of the oil spill, working in real time and provides the user on the sea surface maps the spread of the oil slick from the sources specified by the user, taking into account the physico-chemical properties of oil entered them. The calculations are carried out on the model MIKE 21 Oil Spill, which takes into account the basic processes of transfer and physical-chemical transformations of oil (emulsification, precipitation, evaporation, dispersion, dissolution, biodegradation, etc.). Results are available in vector format and would be used in planning for oil spill response, placing booms, protection of coastal infrastructure and others.

For the development of the service modeling the spread of the oil spill following the procedures have been implemented:

1) Pre-processing of the necessary meteorological data;
2) Calculation of the sea hydrodynamics model MIKE-21 HD for the selected date;
3) The calculation of the spread of oil pollution on the model MIKE-21 OS;
4) Post-processing results and publication RANDOM system;

Figure 4 illustrates an example of imaging oil spill modeling results RANDOM system. There were performed more than 40 runs with bug fixes.

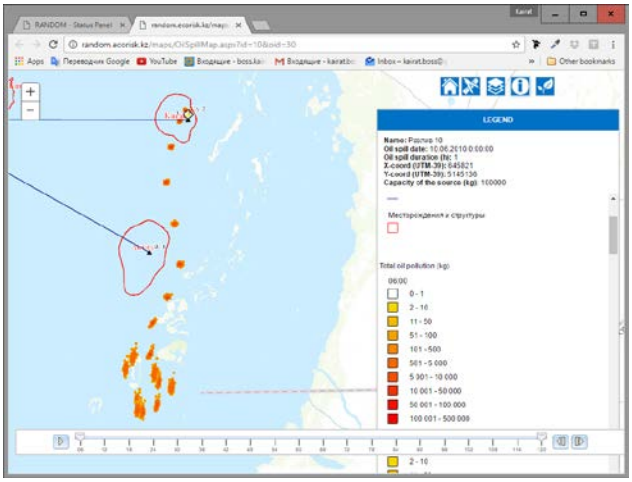


FIGURE 4 Vizualization of an oil spill simulation results on the field in Kayran 10.06.2010 RANDOM system

### 3.2 PARALLEL COMPUTATION

This service is carried out construction of sea oil pollution risk maps. Map zoned on the degree of probability of oil pollution. The user can set the parameters of the accident (the coordinates of the source, the accident time, power spill, oil properties) or choose from the attached background information.

Technology risk mapping of oil contamination includes the following steps:

1) Pre-treatment package of historical meteorological data, including the user selected each day of the month for the period from 1979 to the present;
2) Sea hydrodynamic simulation model for the MIKE-21 HD for each day of the selected month;
3) The calculation of the spread of oil pollution on the model MIKE-21 OS for each day of the selected month;
4) The calculation of the risk of oil pollution;
5) Post-processing results and publication RANDOM system;

The results are an execute in the form of a card containning a legend and the visualization of the scale necessary signatures. Then, map the results with the use of ArcGIS Server is published in RANDOM system (see Figure 5).

This service provides mapping risky damage to marine biological communities in the propagation of oil spills. As part of the service performed the most complex calculations. This takes into account the probability of sea pollution in the vicinity of the accident, and the sensitivity of the population living there to this contamination and especially seasonal migration of species.

Technology risk mapping destruction of marine biota includes the following steps:

1. Pre-treatment package of historical meteorological data, including the user selected each day of the month for the period from 1979 till the present;
2. Simulation of the sea hydrodynamics on the model MIKE-21 HD for each day of the selected month;
3. There is a growing spread of oil pollution on the model MIKE-21 OS for each day of the selected month;
4. Building biodiversity maps and sensitivity of biota [9];
5. The calculation of risk destruction of biota;
6. Post-processing results and publication RANDOM system;

Figure 6 illustrates the results of risk mapping destruction of biota, rendered in RANDOM system.

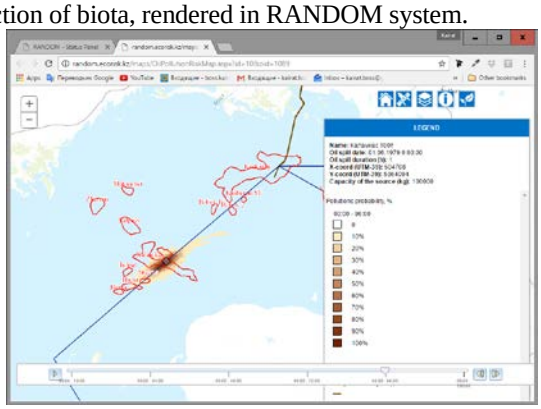

FIGURE 5 Visualization an oil marine pollution risk maps at a point in time 96 hours

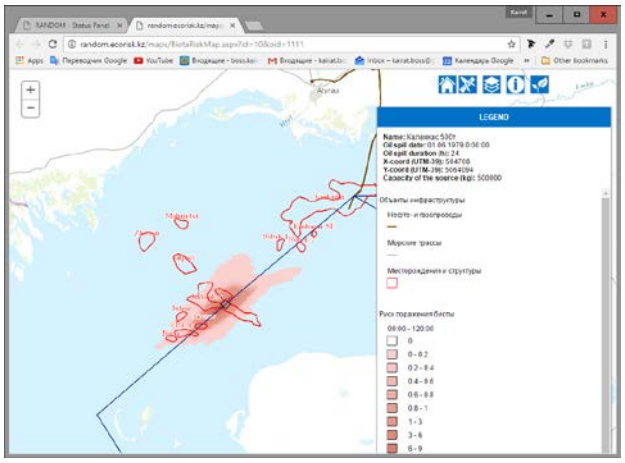

FIGURE 6 Risk map destruction of biota in the accident from the source to Kalamkas-sea after 240 hours

### 3.3 COMPARISON

To calculate the risk maps of marine pollution and the destruction of biota is necessary to calculate crowd an oil spills to obtain representative placement of the sample at various meteorological situation. It was implemented an automated system for multiple calculations of hydrodynamics and oil spill without the intermediate participation specialist. Below is a comparative analysis of travel time for the calculation of risk maps using a supercomputer and without it. In Figure 7 we can see that for the calculation of the oil spill took about 7 minutes considering the use of Fujitsu BX920S1 calculation server with 2 Intel Xeon 5550 processors and 16 gigabytes of RAM.

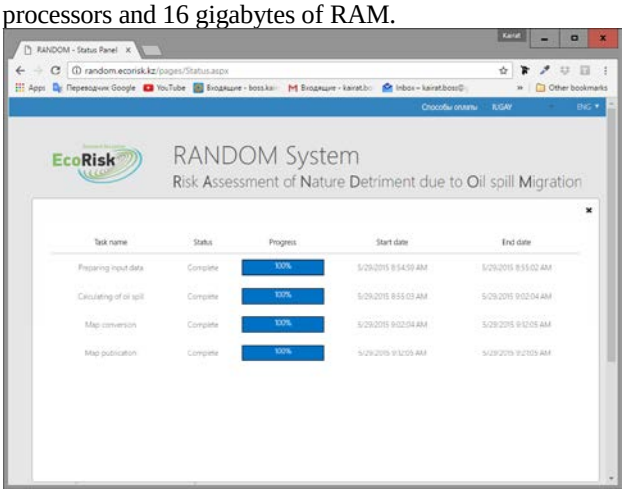


FIGURE 7 Time expended to calculate in a single case of oil spill

To obtain the necessary sample meteorological situation various meteorological parameters were downloaded for the period from 1979 to 2014. For the calculation of risk maps for the selected month is necessary to calculate the oil spill for each day of the month for 36 years. Thus it is necessary to count 36 years x 30 days = 1080 different cases of oil spill. Total estimated amount required to obtain the result T = 1080 x 7 minutes = 7560 minutes = 126 hours = 5 days 6 hours. So we decided to use the power of a supercomputer and parallelized calculation 4 compute node. How we see in Figure 8 for the calculation of the oil spill took 27 hours 6 min or 1686 min. It is 4.48 times faster than the calculation

would be on the same node (see Figure 9). You could use even more components, but we are limited by the terms of the license software MIKE 21, which enables the parallel run only on 32 cores.

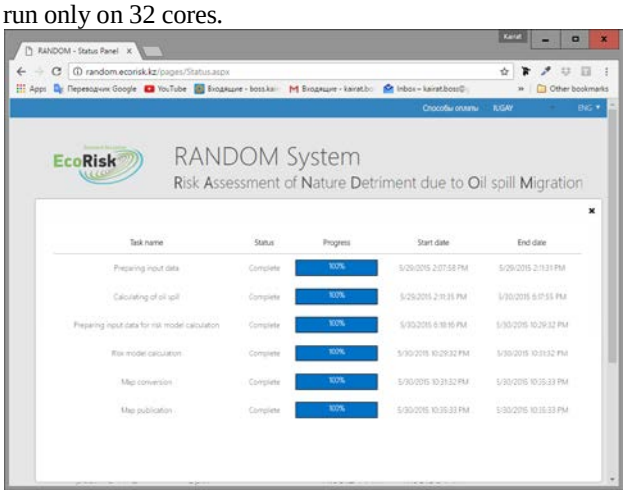


FIGURE 8 Time spent for calculation of marine pollution risk maps

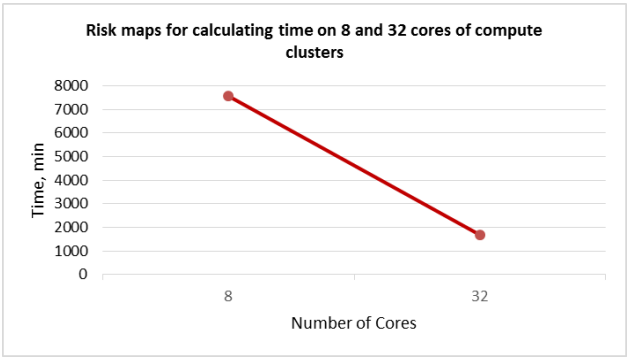


FIGURE 9 Schedule time spent before and after parallelization

To calculate the required oil spill previously calculated hydrodynamics file the time of receipt of which is how we see the figure 10 of about 25 minutes. Hydrodynamics is used to calculate the oil spill, so we decided to pre-calculate it for the entire set meteosituation that we have. Total turn out to count all the hydrodynamics need T = 25 min x 365 days x 36 years = 328,500 minutes = 5475 hours = 228 days for 3 hours. = More than 7 months of continuous calculation. Using 4 node we considered it for 2 months. In all it took 14.5 Tbyte of disk storage.


FIGURE 10 Time expended to calculate the hydrodynamic

## 4 Conclusions

We have presented in the paper the service-oriented GIS system RANDOM for risk mapping of oil spills integrated with high performance cluster. The design and integration methodology of the system are based on service-oriented architecture that allows provide an easy, flexible integration of any service into any desktop or mobile client. We have designed and build 4-tier SOA on the basis of W3C Web service standard. The process of multiple modeling of oil spills has been automated on the high performance cluster. The Risk model for risk assessment is implemented as an application. We have developed the portal with user-friendly interface and sequence of user order processing. The following results were obtained within the framework of this work:

- a risk model of destruction of biota at the man-made accidents. A mathematical model for the description of the biota in the form of map algorithms biodiversity and vulnerability and performed it for the implementation of the Northern Caspian. The developed method has been used for risk analysis in accidental oil spills in the Caspian Sea oil fields.
- a service-oriented web portal to evaluate the environmental risk of biota at the oil spill in the North Caspian Sea. The system is automated and integrated with high-performance computing cluster for the calculation of high-tech research problems. Fully implemented and integrated into all blocks RANDOM project a single system, including the portal, interfaces, geodatabase design models, and others.
- as a result on the basis of the developed technique based series of maps showing the risk of exposure to the accident at the fauna of the North Caspian Sea. Skill testing RANDOM logical structure of the system for two main branches, one of which is associated with the development of short-term forecast, the second - with the statistics and risk. At the same time identified and corrected software errors and interface errors.
- carry out a test the test model of the transport and transformation of the oil spill on the sea MIKE 21 OS, which is the main design module for modeling of oil marine pollution forecasts and risks.
- a comparative analysis of the runtime calculations using computational cluster, which confirms the need to use for this type of research.

## Acknowledgment

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