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# Interoperable web GIS services for marine pollution monitoring and forecasting

Torill Hamre[1], Hajo Krasemann[2], Steve Groom[3], Declan Dunne[4], Gisbert Breitbach[2], Bruce Hackett[5], Kai Sørensen[6] and Stein Sandven[1]
[1]Nansen Environmental and Remote Sensing Center, Norway.
[2]GKSS Forschungszentrum Geesthacht GmbH, Germany
[3]Plymouth Marine Laboratory, United Kingdom
[4]Coastal and Marine Resources Centre, University College Cork, Ireland
[5]Norwegian Meteorological Institute, Norway
[6]Norwegian Institute for Water Research, Norway

## *Abstract*

This paper presents services and systems developed in the FP6 InterRisk (Interoperable GMES Services for Environmental Risk Management in Marine and Coastal Areas of Europe) project, which addresses the need for better access to information for risk management in Europe, both in cases of natural hazards and industrial accidents. The overall objective of the project is to develop a pilot system for interoperable GMES monitoring and forecasting services for environmental management in marine and coastal areas. This pilot system is based on established and widely adopted web-GIS standards, in line with INSPIRE recommendations. The pilot is comprised of, among other things, a portal and a web-GIS map viewer, both developed using open source tools. Providers using commercial tools adhering to the adopted standards, however, can also deliver products to the InterRisk pilot. The InterRisk services and system are based on a combination of free and commercial software, and have been demonstrated to end-users in three European areas: Norwegian, UK and Irish waters, and German and Polish waters. Products and services offered in these areas are presented, along with an outline of the technical development of web-GIS clients and portals.

**Keywords:** web-GIS, WMS, GMES, INSPIRE, marine pollution, interoperable services

## *Introduction*

Marine pollution in European coastal areas has become an increasing problem in recent years. The pollution can stem both directly from man-made activities such as ship traffic, and offshore oil and gas exploitation, as well as from natural phenomena such as blooms of toxic algae, and seepage of oil from the sea bottom. Regardless of origin, marine pollution can cause severe and long-lasting damage to the marine environment. This was illustrated by the Prestige tanker accident in November 2002, where hundreds of kilometres of coastline were polluted in France, Spain and Portugal with heavy oil, which resulted in the killing of vast amounts of sea birds and fish. In addition to the massive impact on the marine environment, economic losses can also be substantial after a major marine pollution event, affecting sectors such as fishing, fish farming, and aquaculture industries, as well as tourism connected to coastal zone areas.

A number of different sensors and numerical models can be used to monitor and predict the progression of marine pollution events. Many such systems are already in place across Europe, which cater for needs at a national level. However, marine and coastal environmental risk and crisis events, such as oil spills and harmful algal blooms, usually have an international dimension. Thus, users in several countries and organisations need access to the same data, including observations, derived parameters, and predictions of future conditions. While many national monitoring and forecasting services are well developed, they are customised to their country's territorial waters, and are often based on proprietary or non-standard solutions that hinder data exchange. Despite the efforts at national scales, there is a lack of a pan-European infrastructure for uniform access and distribution of environmental data, which is a severe problem in all types of risk and crisis management.

The need for coordination and development of a pan-European system for monitoring and forecasting of pollution events, both on land and at sea, led to the establishment of the GMES (Global Monitoring for Environment and Security) initiative in 2000. During the initial phase (2001-2003), the focus was on assessing the strengths and the weaknesses of the then available national environmental services while preparing for the establishment of European GMES services. This resulted in a list of prioritised thematic areas, for which identified products and services could form the basis for operational systems. In the following 4-year period, 2004-2008, a set of fast-track services were developed for selected applications in land, marine, and emergency response domains. GMES is now in its pre-operational phase, where fast-track services have evolved into mature services, which are run in pre-operational mode (COM(2008)748, 2008). The GMES fast track service concerning the marine domain is called Marine Core Service (MCS). The MCS, together with data delivery services from Earth Observation (EO) and in situ sensor networks, as well as atmospheric forcing data from national weather services and the ECMWF (European Centre for Medium-Range Weather Forecasts), constitute what is termed *upstream* GMES services (Ryder, 2007). Upstream services thus deliver generic, quality controlled products of standard met-ocean parameters, such as sea surface temperature and salinity, which are applicable in a wide range of marine application areas. Products from upstream services are then delivered to services termed *downstream* services that downscale the upstream products, optionally ingest higher-resolution local data, and combine these different data layers into a customised product for specific end-users. The services developed in the InterRisk project falls in both categories. Some services deliver fundamental met-ocean parameters like forecasted surface wind speed, while others produce higher-level information such as potential oil spills in German and Polish waters.

Sustainable GMES service development requires that the system components and data products to be integrated are *interoperable*. From the end-users point of view, this means GMES services must enable them to work effectively, i.e. view, process and analyse data obtained from different providers, without relying on custom-built or proprietary software to reformat, read and extract relevant parts of the provided products. From the system development point of view, two of the key issues in achieving interoperability, include harmonisation and infrastructure. Data and metadata harmonisation is needed for efficient data exchange, and service integration and chaining necessitates harmonisation of system communication protocols. A Spatial Data Infrastructure (SDI) is required to manage the vast amounts of geo-spatial data in order to realise the objectives of GMES.

In the global geographic data user community, the Open Geospatial Consortium[1] (OGC) has been a driving force in defining specifications for GIS data and metadata models, platform independent representations and system protocols. Among OGC's many de facto standards are Web Map Service (WMS) (de la Beaujardiere, 2006), Web Features Service (WFS) (Vretanos, 2005) and Web Coverage Service (WCS) (Whiteside and Evans, 2008). These standards define interfaces for querying and accessing maps (raster), vector and gridded data, respectively. They are currently supported by a number of software tools, both public domain and commercial tools, which can be used to build interoperable services for environmental data. Adhering to OCC standards are therefore seen as a sound basis for developing sustainable GMES services. Other relevant standards in this respect include ISO 19115 Geographic information – Metadata (ISO, 2003) and ISO 19139 Geographic information – Metadata – XML schema implementation (ISO, 2007).

[1] www.opengeospatial.org/

Together with other European initiatives such as INSPIRE[2], GEO/GEOSS[3] and SEIS[4], GMES are in the process of building a pan-European SDI. While their combined effort has resulted in many of the required components for this infrastructure and pre-operational environmental services and systems are emerging, there is still a real need to test and demonstrate their deployment in large, integrated systems to increase their use and appreciation in the user communities (O'Flaherty, 2008). Several EC FP6 and FP7 projects have achieved noteworthy results that can be used to establish an operational GMES system, including ORCHESTRA[5], WIN[6] and SANY[7], which have developed open service-oriented architectures for production and distribution of information for risk management and crises handling, as well as pilot services for several terrestrial and marine application domains. Another IST project, DISMAR[8] (Data Integration System for Marine Pollution and Water Quality), developed a marine GMES web-GIS prototype using the OGC Web Map Service (WMS), as shown by Ó Tuama and Hamre (2007) and Hamre et al. (2005).

Other OGC services such as Web Features Service (WFS) and Web Coverage Service (WCS), offer significant challenges beyond the relatively coarse-grained nature of the web map services. The FP6 project InterRisk[9] (Interoperable GMES Services for Environmental Risk Management in Marine and Coastal Areas of Europe), builds on the achievements of DISMAR, ORCHESTRA, MASS[10] and other RTD projects to develop data harmonisation and interoperability between marine GMES services for marine pollution monitoring and forecasting. The services and systems presented in this paper have been developed in the InterRisk project.

## *Web-GIS systems*

### Data and metadata distribution services protocols

The OGC (Open Geospatial Consortium) has specified a number of standards that enables the dissemination of geographic data and metadata through web interfaces. These standards include Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS). Another well established standard for data dissemination is OPeNDAP[11] (Open-source Project for a Network Data Access Protocol). OPeNDAP, which has been developed independently of OGC, is commonly used for data exchange within the environmental science community. Finally, the OGC Catalogue Service for Web (CSW) (Nebert et al., 2007) standard is used to enable dissemination and searching of distributed metadata catalogues.

The OGC WMS standard supports the electronic retrieval of static maps that portrays geographic data. The map returned is typically in an image format such as PNG, GIF or JPEG. The standard enables WMS clients to visualise portions of a server's geographic data holdings based on spatial constraints and other criteria (de la Beaujardiere, 2006). As WMS retrieves and portrays spatial data as static maps, it does not retrieve data with its original data semantics. ISO has approved WMS as an international standard: ISO 19128 (ISO 19128:2005 - Geographic information -- Web map server interface).

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2 http://inspire.jrc.ec.europa.eu/
3 http://www.earthobservations.org/
4 http://ec.europa.eu/environment/seis/
5 www.eu-orchestra.org/
6 http://www.win-eu.org/
7 http://sany-ip.eu/
8 http://www.nersc.no/dismar/
9 http://interrisk.nersc.no/
10 http://earth.esa.int/rtd/Projects/MASS/Index.html
11 http://opendap.org/

The OGC WFS standard supports the electronic retrieval of geographic data as discrete “features”. Examples of features include a point feature (e.g. buoy), a line feature (a ship’s track), and a region feature (e.g. an oil slick). The standard enables WFS clients to choose portions of a server's geographic data holdings based on spatial constraints and other criteria. Unlike WMS, which returns static maps, WFS returns original geographic data semantics in an XML notation called GML (Geography Markup Language) (Portele, 2007). In essence, GML is a data format used to transport and store geographic information (Evans, 2003). GML can be used to develop domain specific (or application specific) GML application schemas. While still in its infancy, domain specific GML application schemas are recognised as important and starting to be developed by various user communities (e.g. MarineXML (Millard et al., 2005). Community driven GML application schemas improves data semantic interoperability between WFS servers, and makes the development of the domain specific WFS client applications more successful.

The OGC WCS standard supports the electronic retrieval of geographic data as discrete "coverages" (i.e. geo-spatial information representing space-varying phenomena) (Vretanos, 2002). A common example of a coverage are points on a regular grid (i.e. a raster dataset). The WCS standard enables WCS clients to choose portions of a server's geographic data holdings based on spatial constraints and other criteria. Similar to WFS, WCS returns original geographic data semantics. The format of the geographic coverage data returned includes, among others, GML, GeoTIFF[12] and CF-NetCDF[13]. Also, community schemas and conventions for retrieved data are important to improve data semantic interoperability between WCS servers (e.g. application schemas for GML format, CF convention for netCDF format, etc.).

The OPeNDAP Data Access Protocol (DAP) protocol supports the electronic retrieval of scientific data across the web. OPeNDAP was originally designed and developed by the oceanographic and computer science communities. However, it is not constrained to use within just oceanography. For instance, the meteorological and space science communities use the OPeNDAP protocol.

A number of tools support the standard OGC protocols described above, both public domain and commercial tools. Two commonly used web map/feature/coverage compliant open source tools are the University of Minnesota (UMN) MapServer[14] and GeoServer[15], while MapInfo[16] and ESRI ArcIMS[17] (Internet Map Service) are among the many commercial tools that support these standards. There are also several tools that support the OPeNDAP protocol, e.g. HYRAX[18], THREDDS[19] and LAS[20] (Live Access Server). Different providers can use various tools, as long as they support the underlying OGC and OPeNDAP standards. The benefit of such standardisation enables subsystems and their services to integrate and interoperate effectively.

## DISPRO concept

The FP5 DISMAR project developed an OGC WMS compliant web-GIS prototype named DISPRO. Figure 1 illustrates the main steps and subsystems in the production of products for

[12] http://www.remotesensing.org/geotiff/geotiff.html
[13] http://cf-pcmdi.llnl.gov/
[14] http://mapserver.gis.umn.edu/
[15] http://geoserver.org/display/GEOS/Welcome
[16] http://www.mapinfo.com/
[17] http://www.esri.com/software/arcgis/arcims/index.html
[18] http://opendap.org/download/hyrax.html
[19] http://www.unidata.ucar.edu/projects/THREDDS/
[20] http://ferret.wrc.noaa.gov/Ferret/LAS

distribution to users via this prototype. Initial data acquisition from remote or in situ sensors, as well as model forecasts of future met-ocean or pollution situations, are done by dedicated systems, often operated by multiple organisations. A possible set-up of subsystem 1 (Product Processing Chain) is that the initial acquisition is done by a commercial company, e.g. for downloading and pre-processing remote sensing data from one or more satellites. This company then makes the first level of processed data available for research institutions, governmental agencies and value-adding companies. Further processing is then done at these organisations, yielding a higher-level product suitable for distribution to end-users. Thus, the Product Generator System is really comprised of multiple systems running in different locations that exchange data via the Internet or (in rarer cases) offline media.

Many Product Generator Systems are already established. To “DISPRO enable” them, the only functionality that may need to be added is the transformation of their final product into a standard format supported by OGC, together with the generation of ISO compliant metadata. If the product generators store intermediate products in legacy formats, whether it is an internal, proprietary, or a standard format, and which may or may not include a variable amount of metadata, then these intermediate products can be left unchanged. The standardisation of data and metadata only needs to be applied to the last step of the processing chain. This results in a cost-effective solution for making products accessible through the DISPRO system.

The second subsystem of DISPRO, a Data Server, makes the products available to any web-GIS portal that follows the OGC WMS standard. Each provider must implement an OGC WMS interface on top of their data repository, converting legacy formats, as required, to the data formats supported by the WMS implementation. Each WMS server instance, called a DISPRO Node, runs on a standard HTTP server.

The third subsystem, the DISPRO portal is responsible for keeping track of all data servers that may offer products of interest to its users. The portal will contact each data server to get a list of products and delivery options for each of these (format, resolution, geographical coverage, etc.). Then, when users are connecting to the portal through the DISPRO client (subsystem 4), the portal will obtain the user-chosen products from the DISPRO nodes and prepare an integrated map display within the web browser.

The last two DISPRO subsystems, the DISPRO Portal and the DISPRO Client, are also based on Open GIS compliant software, including the UMN MapServer, various XML processing tools and a native XML database. The DISPRO portal and WMS client also run on a standard HTTP server, while each end-user accesses the services through a standard web browser on his local computer.

The processing chain illustrated in Figure 1 provides a high degree of flexibility for the producers, as they do not need to alter any of their internal systems, but just add on conversion tools to make products interoperable with the DISMAR prototype. In addition, a WMS server needs to be installed to set up a DISPRO node.

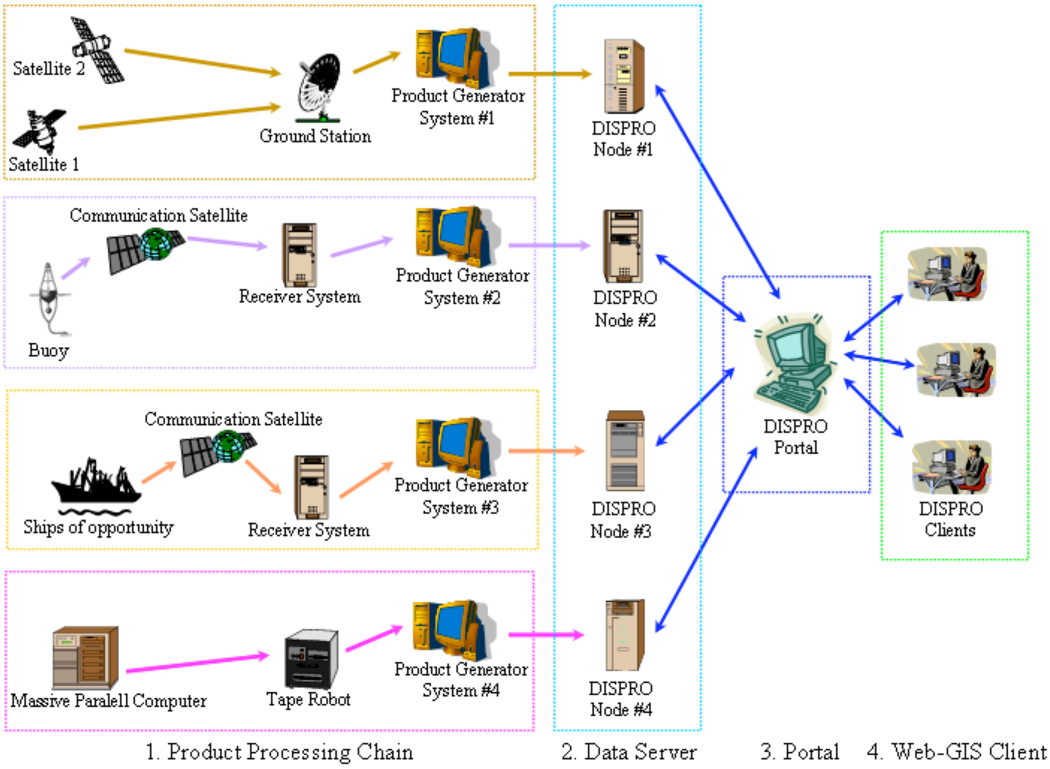


**Figure 1 The DISPRO system concept.**

## Portal development

The DISPRO portal is implemented using the Cocoon content management system (Ziegeler and Langham, 2002) and an XML native database called eXist (Mimaroglu, 2005). The portal is comprised of several subsystems, notably an aggregator that collects layer descriptions from a network of DISPRO nodes, a catalogue browser that facilities interactive searching of metadata for all available layers, a news browser displaying information on new and updated data, pollution events and service notices in the system, and a GIS viewer component through which the user interacts with the GIS to select which layers to display (Ó Tuama and Hamre, 2007). Providers can be added and removed from the system dynamically, and the aggregator updates the metadata catalogue with new layers every 15 minutes (configurable).

## Web-GIS client development

The FP6 InterRisk project has built upon the success of the DISPRO system. For example, InterRisk has further investigated additional open source libraries including msCross[21], Mapbender[22] and Mapfish[23]. Each of these has features that make them attractive as client GUI tools. The msCross library is very compact, comprised of only one JavaScript file of 68 kilobytes, which enables overlay of multiple layers and the traditional GIS operations like pan, zoom in and out, select area of interest by drawing a rectangle on the screen, and reset area to the original map extent. It also offers a reference map that displays the location of the currently selected area in the main map windows.

Mapbender is implemented in PHP, but also uses JavaScript for displaying WMS maps. Besides the traditional GIS operations of pan, zoom and selecting area of interest, it

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[21] http://datacrossing.crs4.it/en_Documentation_mscross.html
[22] http://www.mapbender.org/Main_Page
[23] http://trac.mapfish.org/trac/mapfish

also offers a richer feature set including MapServer and GUI configuration. It requires a database (PostgreSQL is recommended) for storage of data and configuration parameters.

Mapfish[24] is a web mapping application framework. Mapfish is implemented in Python and JavaScript (and utilises the free OpenLayers[25] library), and consists of two parts: MapFish Client and MapFish Server. MapFish Client is a JavaScript framework based on OpenLayers for the mapping part and on ExtJs[26] for the GUI (widgets) part. MapFish Server is Python framework based on Pylons. MapFish is intended to be easy to use either as a standalone application or as an add-on to an existing web application, and has a similar rich feature set as Mapbender.

### *Regional demonstrations*

Upon completion of the first version of the InterRisk pilot system, largely based on the DISMAR system concepts, the InterRisk system has been demonstrated to end-users in targeted regions of Europe. Three of these demonstrations are:

- The HAB monitoring and forecasting service for Norwegian Waters
- The potential oil spill observation service for German and Polish Waters
- The UK and Ireland Water Quality and HAB Services

### The HAB monitoring and forecasting service for Norwegian Waters

The objective of the Norwegian Harmful Algal Bloom (NORHAB) Service[27] is to deliver daily information regarding all relevant parameters for monitoring algal bloom situations along the Norwegian coast. This facilitates early warning of potentially harmful algal blooms.

The flagellate family *Chattonella* appears to have established itself in the Skagerrak after the initial toxic bloom in March 1998. Blooms have occurred in successive springs with varying toxic impact on fish, depending mainly on the circulation pattern. Use of satellite data to monitor ocean colour and water quality parameters such as sea surface temperature and chlorophyll-a concentration allows for early detection and warning of potential HAB situations for the aquaculture industry.

HAB detection and monitoring depends on regular access to near real-time observations, both from space and in the ocean. Remote sensing data provides coverage of large areas, typically with a coarse resolution of about one kilometre (Figure 2(a)), while in situ data provides much higher spatial resolution but limited to single points (Figure 2(b)). As ocean colour remote sensing data are affected by cloud conditions, combining such data with in situ data can improve data coverage (Figure 3).

Operational ecosystem models can aid in forecasting HAB events, but must be constrained by assimilation of routine observations, and complemented by in situ measurements to determine species and toxicity. Standard meteorological and ocean forecasts (wind, currents, waves, etc.) for the coming 3-10 days are provided on a daily basis. These data are used as forcing fields for an ocean-ecosystem model predicting nutrients and algae bloom development from for the coming 10 days, also run on a daily basis.

The DISPRO system can easily overlay remote sensing and meteorological forecasts of key sea state parameters like wind and waves, to aid the operator in interpreting the current situation during a potential HAB event (Figure 4). Whether the different types of data (remote sensing, in situ, weather predictions) are delivered by a single or multiple providers makes no difference to the end-users, as DISPRO provides seamless access to all data provided by any of the associated DISPRO nodes. In the NORHAB service, there are currently three

[24] http://trac.mapfish.org/trac/mapfish/wiki
[25] http://openlayers.org/
[26] http://extjs.com/
[27] http://wms.nersc.no/norway/

providers: NERSC providing satellite images and derived products, the Norwegian Institute for Water Research providing Ferrybox data, and the Norwegian Meteorological Institute providing numerical model forecasts of weather and ecosystem parameters.

The NORHAB portal is based on DISPRO, but has reengineered the web-GIS client GUI using the msCross library. This has given a more flexible and easy to use organisation of the layer list (to the left of Figure 4), a new map with intuitive controls for zooming, panning, etc., while retaining the other components of the DISMAR-DISPRO system (e.g. the news viewer shown to the right of Figure 4). The DISPRO nodes serving data to the NORHAB portal are realised by UMN MapServer, ESRI ArcIMS, and a custom-made WMS server tailored for time dependant data like weather forecasts.

(a)

(b)

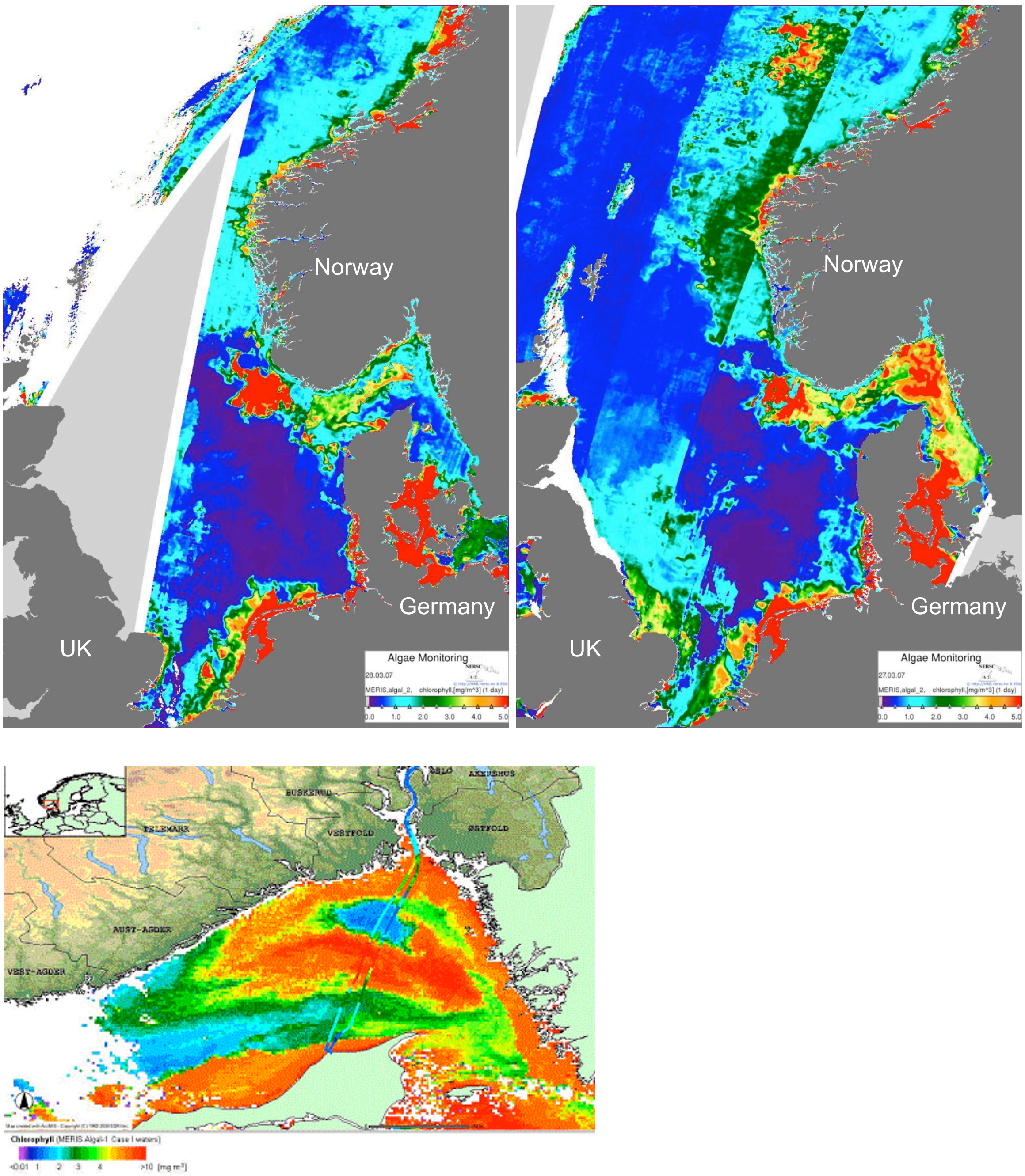


**Figure 2 (a) Chlorophyll-a concentrations from Envisat MERIS data on 27 and 28 March 2007, and (b) chlorophyll-a concentration measured by Ferrybox sensors onboard passenger ferries.**

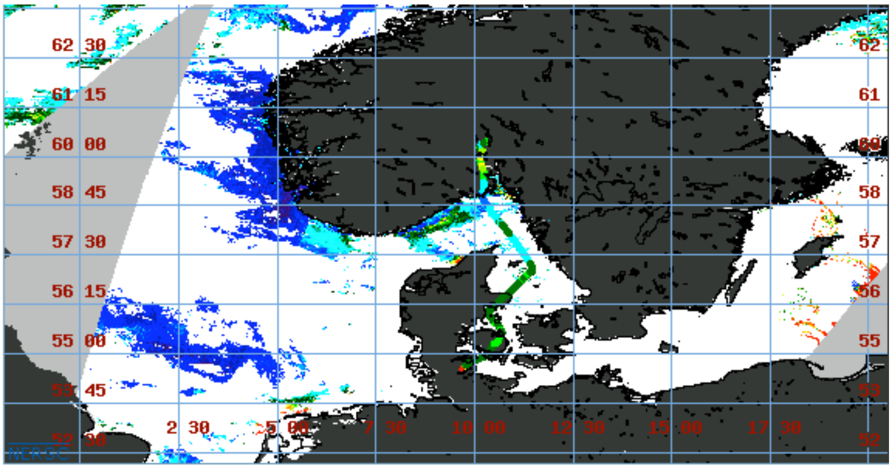

Figure 3 DISPRO overlaying in situ measurements of chlorophyll-a to complement remote sensed data.

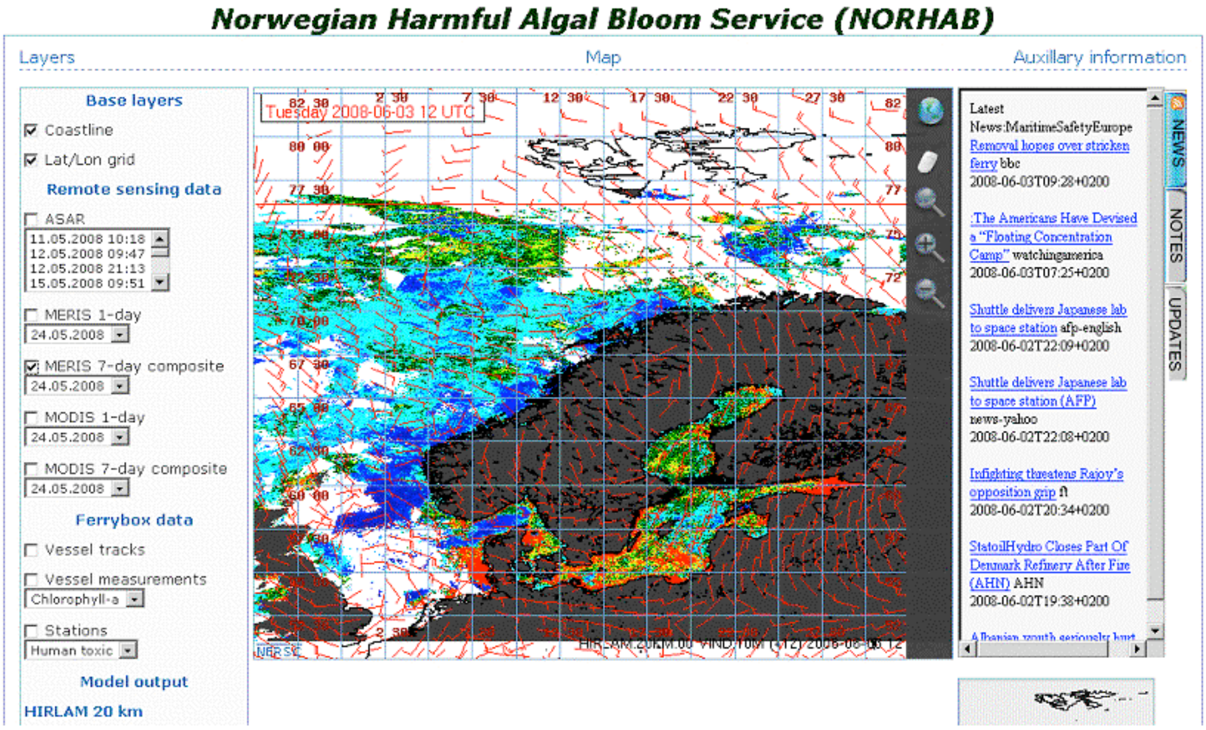


Figure 4 Overlaying a weekly composite of MERIS-derived chlorophyll-a and wind forecast in DISPRO.

## The potential oil spill observation service for German and Polish Waters

The potential oil spill observation service for German and Polish Waters[28] aims to give a near real-time overview of the situation in German and surrounding waters. The service provides key sea state parameters such as surface roughness and wind, as well as information about potential oil spills detected in satellite radar or aircraft multisensory imagery. Areas of interest for German users extend national waters, and include the southern and western Baltic and the southern and central North Sea with a special focus on the German Bight.

For German waters, the users include operators and decision-makers from authorities responsible for hazard management, authorities responsible for maritime affairs in general and those responsible for management and conservation of national parks and environment in general. This includes, among others, the Central Command for Maritime Emergencies

[28] http://kofserver2.gkss.de/mapbender/frames/login.php?name=interrisk&password=interrisk

Germany (Havariekommando), Germany's National Meteorological Service – Department Marine Meteorological Services (Deutscher Wetterdienst, Abteilung Seeschifffahrt) and the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie).

The service for the detection of potential oil spills uses satellite radar imagery from the Envisat ASAR sensor, and is based on algorithms that calculate the difference between the expected sea surface roughness from surrounding regions and the seen roughness in oil slicks (Figure 5). The service is complemented by aircraft radar observations (Figure 6), which provides confirmation of whether suspicious slicks are oil spills. The aircraft SLAR (Side Looking Airborne Radar) data have a resolution of approx. 75 meters.

Based on Envisat ASAR imagery, wind direction is derived using FFT (Fast Fourier Transform) or the least gradient algorithm, and wind speed from the CMOD4 algorithm with extensions for HH-polarised data (Figure 7). Estimating the instantaneous wind from the satellite radar image helps in analysing the situation and determining whether suspicious slicks are likely to be caused by oil spills.

The German and Polish Waters portal is also based on the DISPRO system concept, but realised through the Mapbender framework. The Mapbender client offers a flexible organisation of layer lists into groups and subgroups, the option to display meta-information for each layer, and a rich map viewer component (see middle of Figure 6) which can customised to suit the user's needs. The Mapbender portal connects to a number of DISPRO nodes, which are implemented through tools such as GeoServer, HYRAX and UMN MapServer.

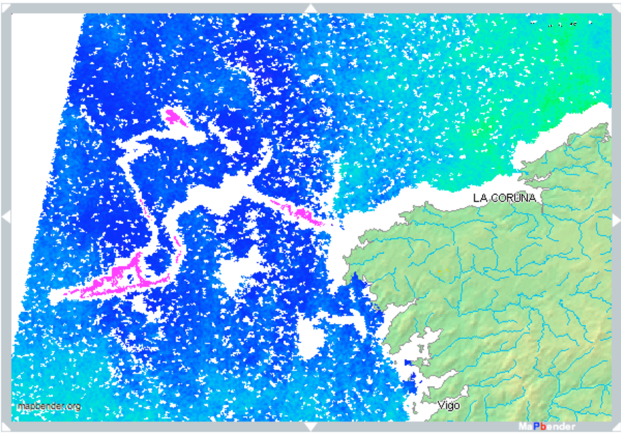


**Figure 5 The Prestige oil spill, as seen by ASAR. Oil is presented in magenta.**


**Figure 6 Aircraft SLAR image of an oil spill in German Waters. The spill is marked by the red rectangle.**

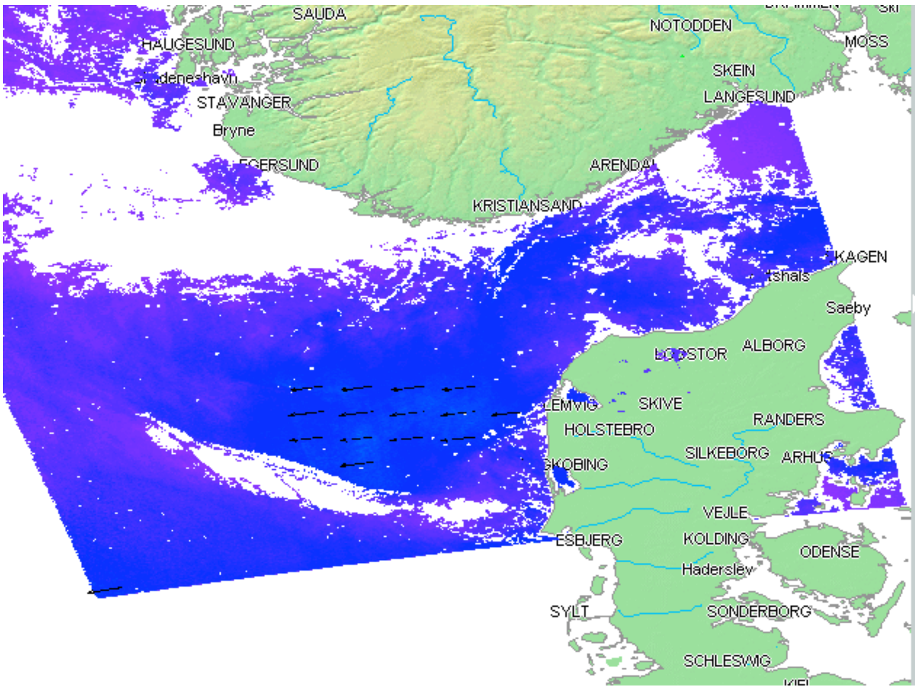


**Figure 7 Envisat ASAR derived wind using the WiSAR tool [Koch et al., 2006].**

## The UK and Ireland Water Quality and HAB Services

The objective of the UK and Ireland Water Quality and HAB services[29] is to undertake continuous near real-time monitoring of marine biological conditions around the UK and Irish coasts to provide forewarning of HAB or eutrophication (high chlorophyll) events. In the UK, there are a wide range of target users who could be split into three "camps": HAB and fisheries, water quality, and scientific or observatory users. HAB, fisheries and water quality users include the UK Environment Agency, as well as other governmental organisations such as the Fisheries Research Services Marine Lab, Aberdeen and the Scottish Association for Marine Sciences. In Ireland, potential HAB end-users include the Irish Shellfish Aquaculture sector, Food Safety Authority of Ireland (FSAI), Department of Communications Marine and

[29] http://www.npm.ac.uk/rsg/projects/interrisk/

Natural Resources (DCMNR), Environmental Protection Agency (EPA), Marine Institute and Irish Navy.

One of the products offered by this service is MODIS NRT (near real-time) chlorophyll-a data delivered by the UK and Irish Waters regional portal (Figure 8). This allows early warning of potential harmful algal bloom situation, within a few hours of satellite overpass. In cases of potential toxic events, an ecosystem model can then be run to forecast the likely evolution and spread of the bloom.

Figure 9 shows how a WMS based solution can be used to overlay data products from a number of different providers. Accessible and visible in the portal is reference data, such as coastline and bathymetry, meteorological forecasts and ecosystem model results, satellite data, and in situ data. These data are provided by both InterRisk partners and external organisations, each offering their data through a WMS compliant DISPRO node.

The UK and Irish waters InterRisk portal is based on the DISPRO system concept, but realised through the MapFish web mapping application framework. The MapFish client (see e.g. Figure 8) offers a highly customisable and powerful GUI where layer lists can be readily organised, and a date/time component can be used to select a single date/time or a date/time range. An easy to use map viewer is also included, allowing users to quickly zoom in/out, pan, etc. The MapFish server is responsible for aggregating layers from the DISPRO nodes. In InterRisk, the UK and Irish waters portal is pulling data from a number of different nodes, among others, UMN MapServer, GeoServer, ESRI ArcIMS, HYRAX and a custom-made WMS server for time dependant data. The portal is also extracting WFS data, which is displayed as clickable symbols on the map (see red "pin" in south-western England near the lower edge of Figure 8). Upon clicking the symbol, information about the available data at this point is shown, and a plotting component (also developed in InterRisk) is launched.

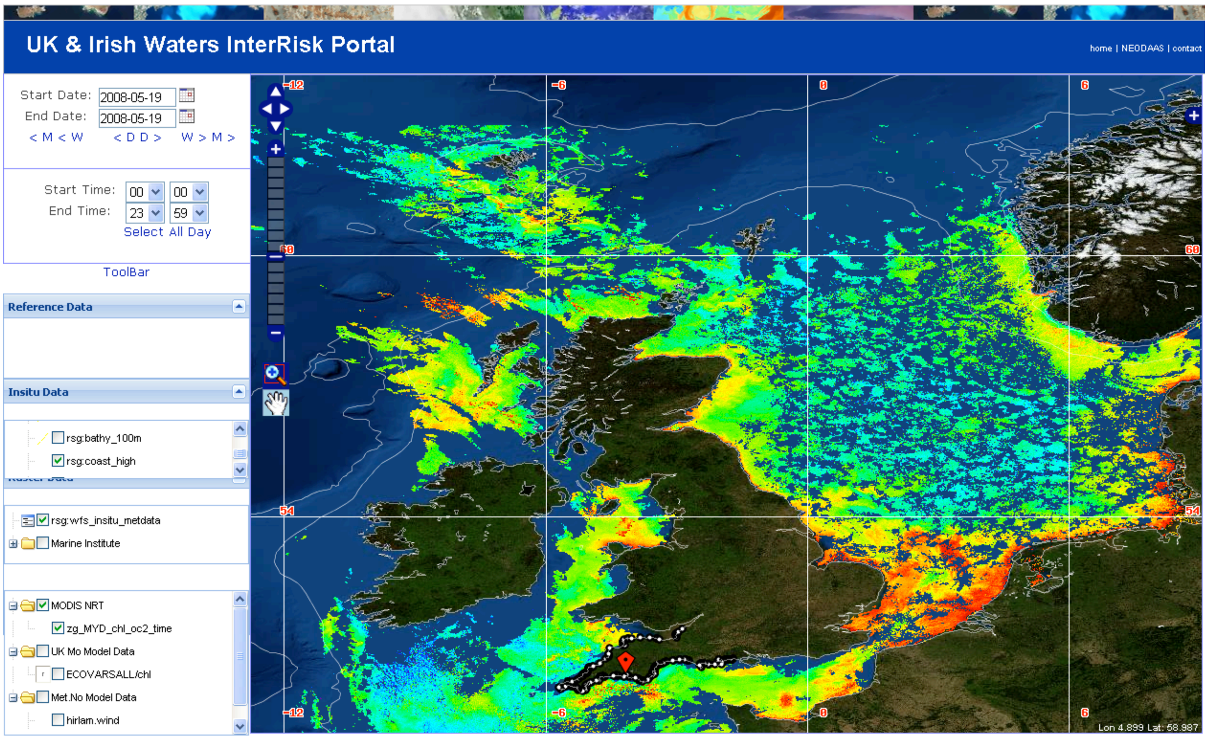


**Figure 8 MODIS NRT chlorophyll-a concentrations for UK and Irish Waters.**

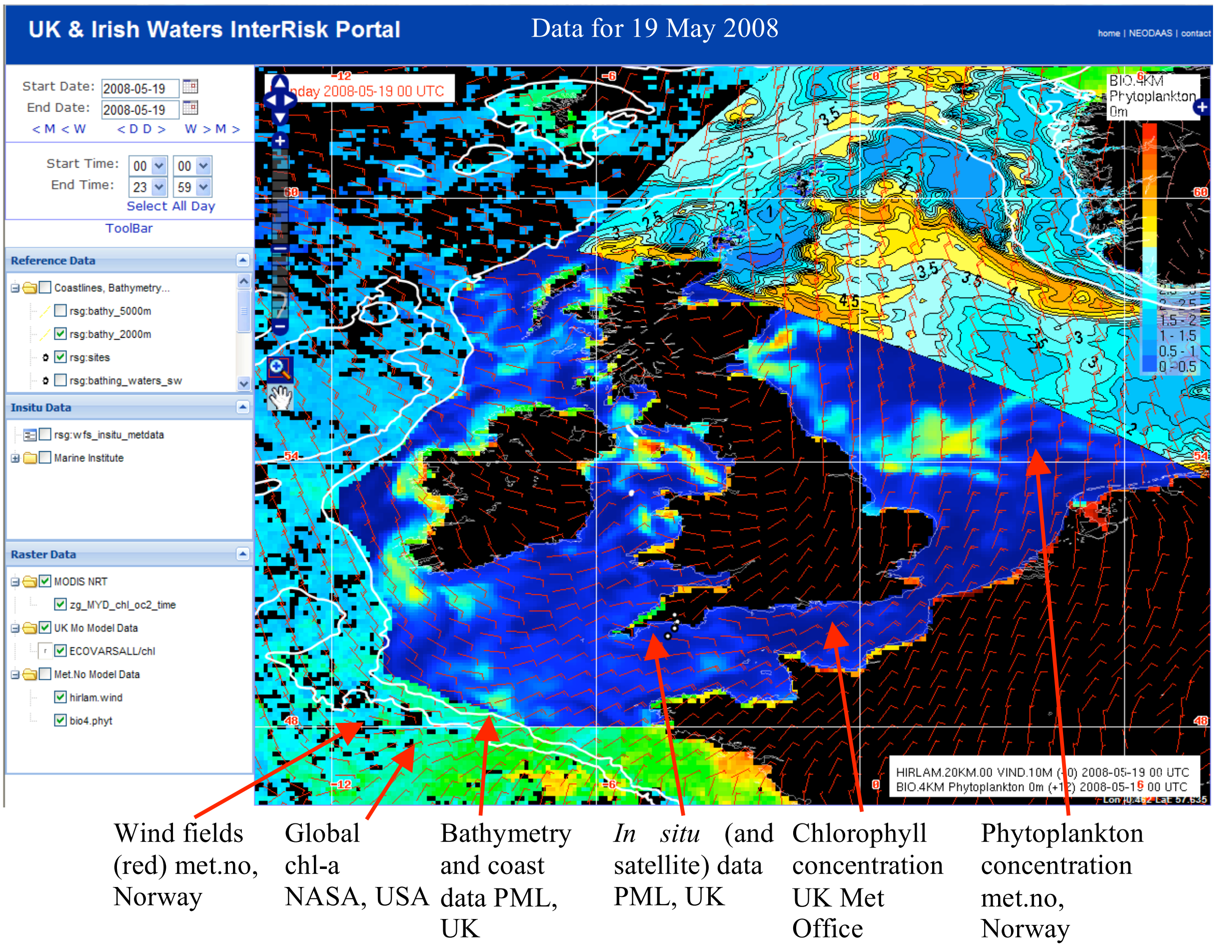


**Figure 9 Overlay of products from numerous providers in the UK and Irish Waters regional portal.**

## *Results and discussion*

During the InterRisk project, existing processing chains for satellite, aircraft and in situ data, as well as model forecasts, have been enhanced and enabled for delivery through standard web-GIS protocols to the InterRisk system. The processing chains now all deliver products in one or more of the standard data formats supported by the OGC or OPeNDAP standards, and are accompanied with metadata according to a profile of the ISO 19139 standard.

All service providers have established DISPRO nodes, i.e. an OGC or OPeNDAP compliant data server, which are providing products to the service network for one or more InterRisk portals. Different software tools, both free and commercial, have been used for this purpose, but because they all adhere to the same standard protocols, they can be integrated in the portals without special treatment of different tools. This means the data delivery is transparent for the portals, and a provider can make his products available to multiple portals through the same data server, without making modifications. Thus, a multiple provider – multiple portal service network is realised.

Three InterRisk portals have been developed, all based on the same DISPRO system concept developed in the DISMAR project. The first portal, for the NORHAB service, is also based on the DISMAR-DISPRO system, but with significant enhancements of the web-GIS view component by utilising a new JavaScript library allowing for more flexible organisation of layers and easy-to-use GIS operations for zoom, pan, etc. The second portal, for the potential oil spill detection service in German and Polish Waters, was also developed using a new web mapping framework, Mapbender. Mapbender also offers a powerful and customisable web-map client, with extensive GIS functionality, and like MapFish, a server component where the portal provider can dynamically configure. The third portal, for the UK and Ireland Water Quality and HAB services, is constructed by means of the new web mapping application framework, MapFish, which provides a highly flexible and customisable front-end. This also includes functions for selecting date and time ranges. This third portal also included a new plotting component, allowing time series of oceanographic parameters served by WFS, to be plotted instantly when clicking on the layer symbol in the map, as well as a profiling mechanism allowing users to customise which layers they want to include, which data nodes to retrieve layers from, and which layer(s) to include.

The use of new libraries for the web-map viewers has allowed for more flexible and customisable front-ends in the InterRisk portals. As the user interface is the system's window to the outside, the end-users, having an easy-to-use and appealing GUI is a crucial issue for systems to be accepted and being well received by the target audience. All investigated web-GIS libraries have provided valuable improvements in that respect, yielding better user interfaces in the developed portals.

## Conclusion

This paper has presented the development of services and a distributed web-GIS system for marine pollution monitoring and forecasting in the framework of GMES. A first version of the system has been installed by several service providers and has been demonstrated to selected end-users in coastal zone areas of Europe.

First feedback from end-users is generally positive to the web-GIS solution, enabling them to access data from multiple providers via the same integrated system. This integration makes it simple to select data of interest from a wide range of offerings, and easy-to-use functionality for customised display. Some additional features were also requested, such as improved handling of time dependent data, products from new data sources (e.g. higher resolution satellites) and better temporal and spatial coverage of the offered products. The latter will depend on better availability of, for example, satellite data, which is beyond the scope of the InterRisk project.

The service providers in the InterRisk consortium have built a working knowledge of using web-GIS servers and clients for setting up a service network that can supply products to one or more regional portals. The chosen tools, a combination of open source and commercial, all support one or more of the de facto OGC and OPeNDAP standards for web-based delivery of geographic data and metadata. Once an OGC (or OPeNDAP) compliant data server has been set up for delivery to a specific InterRisk portal, no additional work is needed for the provider to deliver his products to other portals as well. Through the developed services, we have successfully demonstrated that the same product can be delivered seamlessly to several regional portals. Investigation of new client side libraries, have allowed us to develop more flexible and powerful GUIs in the InterRisk portals, enabling the user to find relevant data easier and incorporating new plotting facilities for time series of point observations.

Future work on the InterRisk services and system will include addition of new and improved products, increased frequency of updates (when data sources permit this) and further streamlining of the production chains preparing products for dissemination within the InterRisk systems. Together with additional enhancements within the portals and web-GIS clients, these services and systems can form the basis for sustainable GMES services that can be run in operational mode.

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