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An open source Java web application to build self-contained web GIS sites



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ABSTRACT

This work describes OWGIS, an open source Java web application that creates Web GIS sites by automatically writing HTML and JavaScript code. OWGIS is configured by XML files that define which layers (geographic datasets) will be displayed on the websites. This project uses several Open Geospatial Consortium standards to request data from typical map servers, such as GeoServer, and is also able to request data from ncWMS servers. The latter allows for the displaying of 4D data stored using the NetCDF file format (widely used for storing environmental model datasets). Some of the features available on the sites built with OWGIS are: multiple languages, animations, vertical profiles and vertical transects, color palettes, color ranges, and the ability to download data. OWGIS main users are scientists, such as oceanographers or climate scientists, who store their data in NetCDF files and want to analyze, visualize, share, or compare their data using a website.

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Software availability

OWGIS is free and it can be downloaded as a Web application Archive (WAR file) from <http://owgis.org/>. This WAR file contains the stable version of OWGIS and can be deployed in any servlet container, like Apache Tomcat. The source code of OWGIS is maintained at GitHub and it can be downloaded by enthusiastic users and developers from <https://github.com/olmozavala/OWGIS.git>.

1. Introduction

Over the last decades the amount of geospatial data has grown rapidly as a result of the number of satellites and the use of Global Positioning Systems (GPS). To assist in the analysis and visualization of all this data, several geographic information systems (GISs)

and Web GIS sites have been developed (Steiniger and Hunter, 2012). Some of the Web GIS sites share common functionalities, such as access to raw data or the ability to overlap different layers (Kulawiak et al., 2010; Karnatak et al., 2012; Nair and Katiyar, 2011). Web GIS sites that display environmental data, like the Pacific Islands Ocean Observing System (Voyager) or the Web GIS sites developed by the European Environment Agency, have an even larger set of common features, such as the ability to identify layer data at any coordinate, and the capability to plot data in real time. However, there is not, to the best of our knowledge, any open source program that automatically generates Web GIS sites with a minimum set of features that allow efficient publication of 4D geospatial data.

A common procedure for publishing georeferenced data on a Web GIS site includes the following steps. First, generate the data to be published. Then, upload the data into a map server such as MapServer (Kropka, 2005), GeoServer (Deoliveira, 2008), ArcMap Server, ncWMS (Blower et al., 2013), etc. Finally, with a group of programmers and web designers, build the web interface (the Web GIS site) to display the data for the user. This interface provides several ways to visualize and serve data, and, even when most Web GIS sites do not have direct access to the data, they normally obtain

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the data through map servers. The software described in this paper greatly simplifies the final step, building Web GIS sites, thus reducing the time and costs for publishing geospatial data on the web.

Free and Open Source Software (FOSS) that helps building Web GIS sites already exists. Fig. 1, adapted from Steiniger and Hunter (2013), shows the FOSS GIS software that is available to aid publishing geographic data on the web at any of the previously discussed steps. The software in the *Desktop GIS* category are programs that run on personal computers and are able to display, query, update, and analyze geographic data. Quantum GIS (Shekhar and Xiong, 2007) and GRASS (Neteler et al., 2012) are two of the most mature FOSS desktop GIS programs. These two programs can accomplish a multitude of tasks and have been used to prepare and analyze environmental data for several projects (Gkatzoflias et al., 2013; Grinand et al., 2013).

The *Web Map Servers* category accommodates software that provides several options to access and visualize georeferenced data through standards of the Open Geospatial Consortium (Web Mapping Services (WMS) (de la Beaujardiere, 2006), Web Feature Services (WFS) (Vretanos, 2005), and Web Coverage Services (WCS) (Baumann, 2010)). The two best-known web map servers are MapServer and GeoServer, both of them offer vector and raster support and have comparable functionality to similar proprietary software (Steiniger and Hunter, 2013).

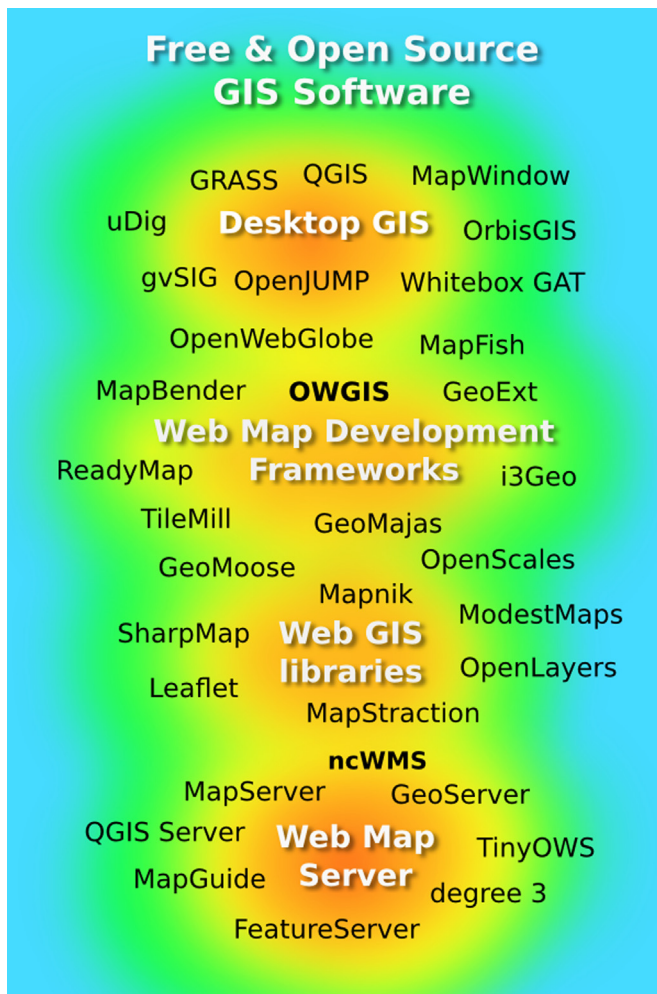


Fig. 1. Simplified scheme of the free and open source geographic information software for the web. Adapted from Steiniger and Hunter (2013).

Another web map server, that is worth mentioning for the environmental modeling community, is the ncWMS which has the particular feature of being able to serve 4D data stored as NetCDF files, a widely used file format for storing environmental model datasets (Rew and Davis, 1990). The DEFENSE (Tiranti et al., 2014), and the interactive visualization system by Kulawiak et al. (2010) are some examples of environmental decision support systems that use FOSS web map servers.

The *Web GIS libraries* and the *Web Map Development Frameworks* are two categories that encompass GIS software used to build the final interface to display geographic data as dynamic maps on the web. The web GIS libraries are application programming interfaces (APIs) for the visualization and manipulation of spatial data that implement the WMS, WFS, etc. OpenLayers (Hazzard, 2011) is one of the most extensive libraries in this category, it is implemented in JavaScript. Finally, the software in the *Web Map Development Frameworks* category, contribute with tools for creating advanced web applications. These frameworks use the web GIS libraries and contain tools for the management of layers, menus, and themes of the Web GIS sites. Some well known programs in this category are Mapbender3 (<http://mapbender3.org/>), GeoMajas (<http://www.geomajas.org/>), MapFish (<http://www.mapfish.org/>) and GeoMOOSE (<http://www.geomoose.org/>). OWGIS belongs to this last category as it gives an easy way to develop Web GIS sites through the configuration of XML files. The main feature that differentiates OWGIS from the rest of the development frameworks is the set of tools that OWGIS provides to visualize 4D data through the web.

OWGIS (<http://owgis.org/>), originally *Open Web GIS*, is an open source software that creates self-contained Web GIS sites with common features used by the scientific community. OWGIS is a Java web application that generates websites by automatically writing HTML and JavaScript code. The websites built with OWGIS are configured by XML files and can accommodate maps with layers served through any map server, such as GeoServer, that complies with the WMS standard. OWGIS is also capable of constructing Web GIS sites that display 3D data served by the THREDDS servers (Domenico et al., 2006) or the ncWMS servers, using the WMS extension proposed by Blower et al. (2013).

The current features that OWGIS provides on the generated Web GIS sites are: multiple languages, animations, mobile interface, Contextual Query Language (CQL) filtering (http://en.wikipedia.org/wiki/Contextual_Query_Language), identify features, the ability to download data as KML, GeoTIFF or shape files, and the capacity to plot vertical profiles and vertical transects at different locations. Though some of these features are already available in many Web GIS sites, regardless of whether or not they display scientific data or other types of geographic data, OWGIS allows building and maintaining new sites with all these features by simply editing XML files.

OWGIS is being developed at the Center for Ocean-Atmospheric Prediction Studies (COAPS), Florida State University (FSU), in collaboration with the Universidad Nacional Autónoma de México (UNAM). OWGIS is currently used as the interactive visualization map of the Digital Climatic Atlas of Mexico (Zavala-Hidalgo et al., 2010), which has been available since 2009 and provides access to more than 2000 layers of oceanic climate, climate change scenarios, bioclimatic parameters, and socioeconomic indicators, among other variables. OWGIS is also used by the Deep-C Consortium (<http://deep-c.org/>) to display oceanographic data from the Gulf of Mexico.

The paper is organized as follows. Section 2 describes the architecture of OWGIS and the design principles that it follows when creating websites. Section 3 explains how to configure OWGIS for new applications. Section 4 illustrates the current features provided by OWGIS. Section 5 describes a specific case study where OWGIS is

successfully used to display ocean data from the Gulf of Mexico. Section 6 ends with a discussion on the presented software and outlines some future functionality of OWGIS.

2. Architecture

Like other Java web applications, OWGIS can be contained in a web archive (WAR) file that can be deployed in any servlet container, such as Apache Tomcat. Similar to a common web application, OWGIS creates web content, JavaScript, and HTML; however with OWGIS, the final websites are self-contained Web GIS sites. The JavaScript code generated by OWGIS uses OpenLayers (<http://openlayers.org/>), an open source library for creating dynamic maps. OWGIS also creates custom JavaScript code for requesting data from servers that comply with the WMS and WFS standards.

OWGIS-created websites display layers that are served through map servers. The information about each layer, such as the name of the layer, is configured using XML files. These files are used to modify the look and content of the OWGIS sites and are described in Section 3. OWGIS monitors any changes to these files, made by the administrators, and is able to update websites without reloading the web application on the server. This feature is very useful when the data being displayed on the map is modified often. Fig. 2 shows a simple diagram of the process used by OWGIS to generate web content for the user.

When a user makes a new HTML request, OWGIS verifies that have been no modifications to the XML configuration files. If there have been any changes, OWGIS parses all the information in the XML files and rebuilds internal data structures for the sites. Once the information is stored internally, OWGIS uses it to build the desired interface, taking into account the specific user request.

The OWGIS source code is divided in four general modules: **model**, **business**, **servlets**, and **tools**. The **model** module stores all the layers obtained from the XML files as well as the menus in a set of data structures. The **servlets** module contains all the servlets, which are in charge of receiving new requests from the user and redirecting each request to the proper method in the **business** module. The servlets module also sends customized JavaScript code to the user. The **business** module is in charge of reading the current user's configuration and the data of the model module to build the proper JavaScript code for the user. The **tools** module contains a number of static functions used to create web content.

2.1. Design principles

There are infinite ways to build Web GIS sites and OWGIS can not create all of them. The websites that are created by OWGIS follow a set of design principles that we believe can be applied in

a large number of circumstances. These design principles were defined by analyzing a few of the currently available Web GIS sites.

Sites that display scientific data have, in many cases, a large set of layers that can be overlaid all at the same time. Having many layers available at the same time makes it difficult, for a normal user, to find the specific data to visualize. Moreover, there are several Web GIS sites where the majority of the data are raster (pixel based) layers, which occlude themselves when super-imposed with each other, and overlaying raster layers makes a map incomprehensible.

With this in mind OWGIS separates layers into three different categories:

- **Background.** Layers in this category are used as the spatial reference of the map and normally cover the whole domain. This category is designed to have just a few layers that are visible bellow layers in other categories. The Blue Marble dataset (Stekli et al., 2005) is widely used as a *background* layer on scientific Web GIS sites.
- **Main.** This category should contain the majority of the data being displayed by OWGIS sites. There can be thousands of *main* layers on each OWGIS site. Main layers are hierarchically organized and can be grouped easily. Layers in the main category are displayed one at the time and are positioned above background layers and below optional layers. This category is expected to contain raster data but is not restricted to do so.
- **Optional.** Layers in this category can be overlaid with any other optional layer and are located above the main layers. This category is designed to contain just a couple of tens of layers, to avoid overwhelming the user, but there is no limit on the total number of optional layers. Optional layers are hierarchically organized and, even though they are not restricted to do so, optional layers are designed to accommodate vector data.

One last design principle that OWGIS sites follow is to show only the most important features to the user, rather than all the features available. More advanced tools, like the manipulation of the color ranges, color palettes, and the CQL filtering are encapsulated in submenus that an experienced user can access within the main site. Section 4 describes the features available on OWGIS sites.

In summary, the design principles that OWGIS follows when creating WebGIS sites are: the layers displayed on the maps are grouped into three categories: background layers, main layers, and optional layers; the main layers can only be visualized one at the time; the 4D layers retrieved from ncWMS servers have to be configured as main layers; the available features are divided by categories that can be accessed through the main web site but are not displayed in the default view of the maps.

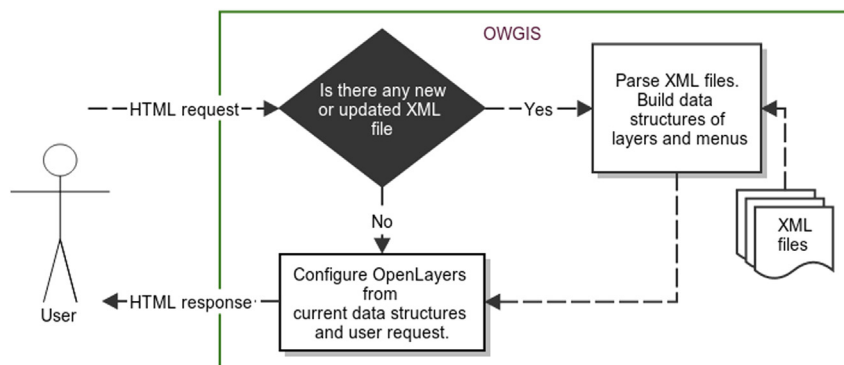


Fig. 2. Simplified scheme of OWGIS sites generation from XML files.

3. Configuration

OWGIS sites are configured by two types of files: Java properties file and XML files. There is only one Java properties file for each OWGIS site and it is used to define general display options of the Web GIS interface, such as setting the default center of the map. The Java properties file is normally modified just once for each OWGIS site. The XML files are used to configure the layers that will be displayed on the map as well as the texts of the menus to be used in the interface. XML files are expected to be constantly modified to add new data into the OWGIS sites.

3.1. Configuration files

Java properties files contain a set of parameters which are simply defined using the syntax *var = value*. Table 1 shows the options that are configured by OWGIS using this file. For every modification in the Java properties file it is necessary to reload the OWGIS site on the web server. The variables in Table 1 are used to define the initial view of the map and should be configured once for each Web GIS site.

The XML files are mainly divided into four element tags: **Menus**, **BackgroundLayers**, **MainLayers**, and **OptionalLayers**. The purpose of the **Menus** tag is to allow the creation of independent menus to which multiple layers can point to. For example, layers that hold temperature data from the month of January for different years can all point to the same menu *January*. Each menu is defined using the **Menu** tag which has two required attributes: *ID*, to identify the menu, and *EN*, to specify the menu text in English. OWGIS allows additional menu languages by using two character attributes, such as *ES* for Spanish. OWGIS compares the browser language with the two character strings defined on the menu tag and selects the text that is displayed on the Web GIS site.

As mentioned in Section 2, layers are grouped in three categories: background, main and optional. The **BackgroundLayers**, **MainLayers** and **OptionalLayers** XML elements relate directly to this division. There are many configurable attributes for each layer type but for most Web GIS sites, the default values will generate the expected behavior. Nevertheless, each layer type requires some attributes to be specified. For **BackgroundLayers** the required attributes are: *server*, which contains the URL of the WMS server that stores the layer, and *name*, which denotes the name of the layer on the server. **MainLayers** have *server* and *name* as required attributes plus *EN*, which defines the title of the main layer in English and

MenuIds, which is a set of menu ids separated by colons that define the menu hierarchy of the layer. The title of the main layers can be defined for other languages but only English is mandatory. Another attribute for **MainLayers** that is not required but is worth mentioning is *ncWMS*, this attribute needs to be set to true if a layer is been retrieved from a ncWMS server, otherwise the layer may still be displayed on the map but the 4D tools provided by OWGIS will not be available. **OptionalLayers** have *server*, *name* and *MenuIds* as required attributes. The complete set of attributes that can be configured with **BackgroundLayers**, **MainLayers** and **OptionalLayers** element tags are described in detail at the website <http://owgis.org/>.

The code in Listing 1 is an example of an XML configuration file with three layers: the BlueMarble as a background layer, the average precipitation of the month of January for the U.S. in 2004 as a main layer, and the U.S. States boundary as an optional layer.

```
<MenuConf xmlns:xsi="..." xsi:noNamespace="...">
  <Menus>
    <Menu ID="Id1" EN="Menu ENG txt" />
    <Menu ID="Id2" EN="Precipitation"/>
    <Menu ID="Id3" EN="US States" />
  </Menus>

  <BackgroundLayers server="http...">
    <layer name="bluemarble" />
  </BackgroundLayers>

  <MainLayers server="http..." >
    <layer MenuIds="Id1,Id2" name="prec" EN="Title: Prec"/>
  </MainLayers>

  <OptionalLayers server="http..." >
    <layer MenuIds="Id3" name="states" selected="true" />
  </OptionalLayers>
</MenuConf>
```

Fig. 3 shows the self contained Web GIS site built by OWGIS using the example XML file shown in Listing 1. OWGIS creates a black window that contains the optional layers and a transparent window with drop-down menus for the main layers. The example in Fig. 3 also shows a set of features built by OWGIS (Google Earth, Transparency, Download Data, and Help). Section 4 describes all the features that can be generated by OWGIS.

If the user wants to add new layers into the Web GIS site, it is necessary to modify the XML file by adding new menus and new layers. The configuration made through the XML files can be divided into multiple files or it can be automatically created using a scripting language. Using scripting languages it is possible to build Web GIS sites with hundreds of layers quickly. OWGIS will monitor any change in the XML files and update the generated Web GIS site automatically.

3.2. Languages

The texts used for the menus can be modified for different languages as described in the previous Section, but the Web GIS sites built by OWGIS contain many more texts, for example texts on buttons, headers, help texts, etc. These texts can also be modified for different languages using the standard internationalization approach for JSP/Servlets web applications. This approach uses a *resource bundle* (properties file) for each language. The resource bundles in OWGIS are stored in the *messages* package. Current version 1.0.0 contains the English and Spanish resource bundle. To add another language, it is necessary to create a new bundle, which can be done easily by copying one of the available bundles,

Table 1
Software parameters.

Variable	Description
<i>basepath</i>	Indicates the name of the website. Its default value is OWGISTemplate.
<i>tilesOrigin</i>	The location that OpenLayers uses to generate tiles. Default value is [−180, −90] which will work for most cases.
<i>numZoomLevels</i>	Defines the number of levels available on the sites. Level 0 corresponds to <i>maxResolution</i> , and <i>numZoomLevels</i> corresponds to <i>minResolution</i> .
<i>zoom</i>	Initial zoom level to use on the website. Ranges from 0 to <i>numZoomLevels</i> , and the default value is 4.
<i>mapcenter</i>	Defines the initial center of the map. Its default value is "lat = 0, lon = 0."
<i>maxResolution</i>	Defines the maximum resolution of the map. Larger numbers allow the map to be seen from farther away.
<i>minResolution</i>	Sets the minimum resolution of the map. Smaller numbers allow closer views of the map.
<i>restrictedExtent</i>	Restricts the domain where the user can move on the map. The default value is [−180, −90, 180, 90] (no restriction).
<i>defaultLanguage</i>	Defines the default language to be used on the website. The default language is EN.

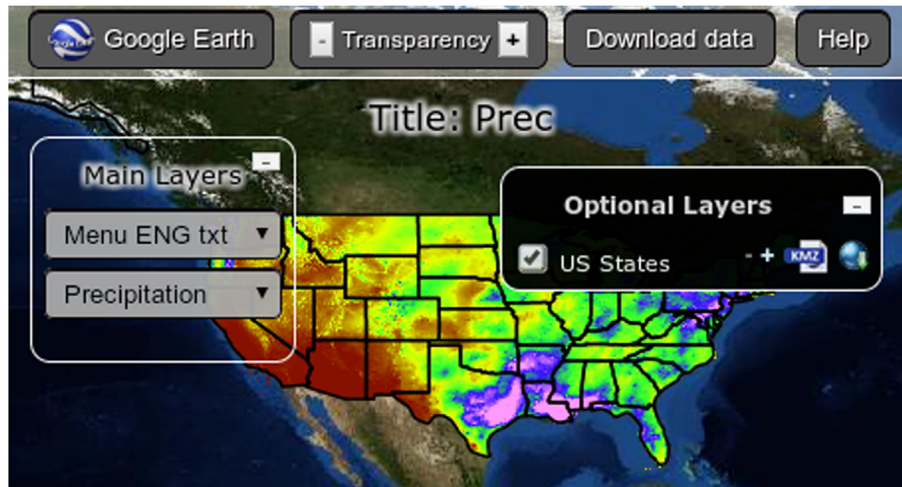


Fig. 3. Example interface built by OWGIS with three layers: the Blue Marble as a background image, precipitation data as a main layer and states boundaries as an optional layer.

translating each text inside it to the desired language, and saving it with the rest of the bundles. Because this software is open source, any new translation made by an individual can be shared with the rest of the world, expanding in this way the available languages of OWGIS.

4. Features

The features available through OWGIS depend on the type of layer. In this case, the division of layers is different from the categories explained in Section 2. Here, the types of layers are divided into: *vector layers*, raster layers from GeoTIFF files (*GeoTIFF layers*), and raster layers served through ncWMS servers (*ncWMS layers*). This division is necessary because each type of layer has its own characteristics. For example, it is not possible to create vertical profiles from vector layers only from ncWMS layers. *Vector layers* and *GeoTIFF layers* can be used in any of the categories explained in Section 2, but *ncWMS layers* can only be used as **main layers**. This restriction is to avoid overwhelming the users with too many options.

The features that are available independently of the layer type are: *mobile interface*, *multiple languages*, *identify features*, *download*

as KML, and *transparency*. The *mobile interface* is a specifically designed interface that displays on Web GIS sites when they are accessed by a mobile phone or Tablet. Fig. 4 shows the mobile interface when is visualized through an iPad 2 tablet in portrait mode.

The mobile interface displays the menu options in a separate page, allowing a better visualization of the menus and, at the same time, giving more space to visualize the maps. This interface is not a mobile app, it is a web interface that has been designed for mobile devices and can be accessed through any mobile browser. The mobile interface allows accessing the Web GIS sites from any mobile device, independently of the platform, but it does not take advantage of native input controls that each mobile platform provides.

The *identify features* tool uses the WMS and the WFS standards to request data at specific locations in the map. OWGIS uses AJAX to identify layer features asynchronously, allowing multiple requests to run simultaneously without having to queue each request. Fig. 5 shows an example of the *identify features* capability used on a map with three visible layers: topography, average precipitation for the month of January, and state boundaries for the United States.

OWGIS builds the proper requests to generate KML files from map servers such as GeoServer or ncWMS. This feature, *download*

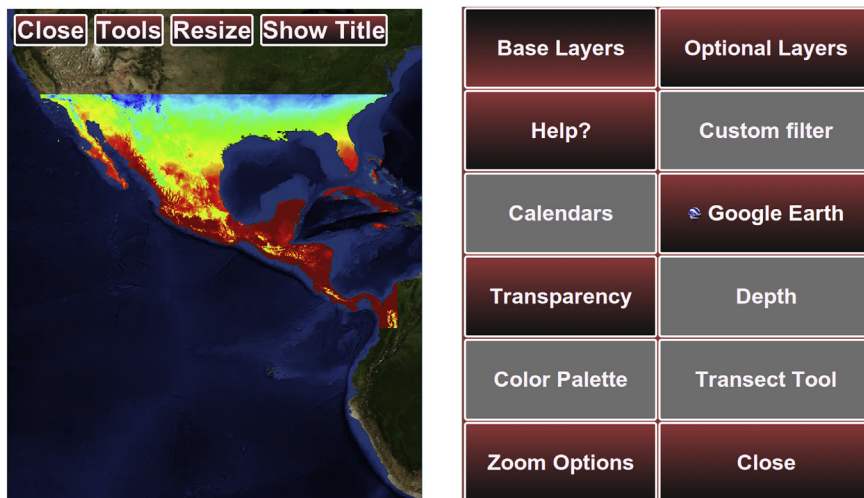


Fig. 4. Example of the user interface generated by OWGIS for mobile devices.

data as KML, allows visualizing layers in clients that display KML data, such as Google Earth. People have been using this feature to compare data from OWGIS's servers with different data available in the KML clients. Fig. 6 shows sea surface temperature of the Gulf of Mexico displayed using Google Earth.

The *transparency* feature allows users to change the opacity of any main layer or optional layer. Being able to modify the opacity of the layers has become a core functionality in many Web GIS sites and is used for comparison between layers, mainly when the layers contain raster data.

The *CQL filter* feature is exclusively available for vector layers and allows, as the name implies, filtering vector data using CQL. The scientific community uses this feature regularly to analyze data by filtering vector data. CQL filters modify data being displayed by the main layer and update the KML and *download data* URL requests by applying the filter into the requests. Fig. 7 shows an example of the generated interface for filtering vector data using CQL.

Some features are only available for ncWMS layers. Those features are *animations*, *vertical profile*, *vertical transect*, *time series*, *color palettes*, and *depth selection*. Animations and time series are available for temporal data. These two features are very important for scientists, especially oceanographers and climate scientists, because these features allow them to visualize and analyze changes in data across time. Version 1.0.0 of OWGIS can generate animations where the smallest time step is one day; future versions will be able to generate animations using smaller time steps. OWGIS is capable of requesting animations with three different resolutions 128×128 , 256×256 , and 512×512 pixels.

Depth selection is available for ncWMS layers that contain a z-axis coordinate, normally depth, but the z-axis can refer to a different variable, such as height or pressure. OWGIS builds a nicely paginated window where users can select from the available z-axis values. The *depth selection* feature is one of the tools that OWGIS provides for visualizing 3D data. Fig. 8 shows an example of the interface built by OWGIS that shows sea temperature from the Gulf of Mexico at different depths.

Vertical profiles and *vertical transects* are also available for ncWMS layers with z-axis information. Vertical profiles and vertical transects can be requested at any location on the map and are obtained in real time by the ncWMS servers. These two features are

also very important for the scientific community and used regularly. An example of a vertical transect of Gulf of Mexico temperature's is shown in Fig. 9.

Color palettes is another feature available for ncWMS layers. OWGIS queries ncWMS servers, asking for available color palettes, and generates the proper web interface that allows the user to switch between these palettes. Fig. 10 shows an example of the web interface generated by OWGIS to select color palettes.

The features presented in this Section are currently available for version 1.0.0 of OWGIS, and it is worth mentioning that these features have yet to be tested when layers are stored in different map servers. The CQL filter feature has only been tested with GeoServer, and the color palette, vertical profile, vertical transect, and time series features are only feasible for layers served by ncWMS servers.

5. Environmental modeling case study

This Section describes a successful example where OWGIS was used to build a self-contained Web GIS site that displays environmental data from an operational ocean model system. The Web GIS site, available at <http://viewer.coaps.fsu.edu/DeepCProject/mapviewer>, was built for the Deep-C Consortium at the Center for Ocean-Atmospheric Prediction Studies (COAPS), Florida State University (FSU). The Deep-C Consortium is a long-term, interdisciplinary study of deep sea to coast connectivity in the northeastern Gulf of Mexico. The Consortium is investigating the environmental consequences of petroleum hydrocarbon release in the deep Gulf on living marine resources and ecosystem health. Deep-C examines the geomorphologic, hydrologic, and biogeochemical settings that influence the distribution and fate of the oil and dispersants released during the Deepwater Horizon (DWH) accident, and use the resulting data for model studies that support improved responses to possible future incidents. More than 100 scientists and students at 10 academic and research institutions in the United States and Norway are participating in Deep-C.

This case study, referred to as the *Deep-C MapViewer*, displays temperature, salinity, sea surface elevation, and ocean currents for the Gulf of Mexico. The oceanographic variables are generated daily, using outputs from the HYbrid Coordinate Ocean Model (HYCOM) ocean prediction system (Chassignet et al., 2009). The end

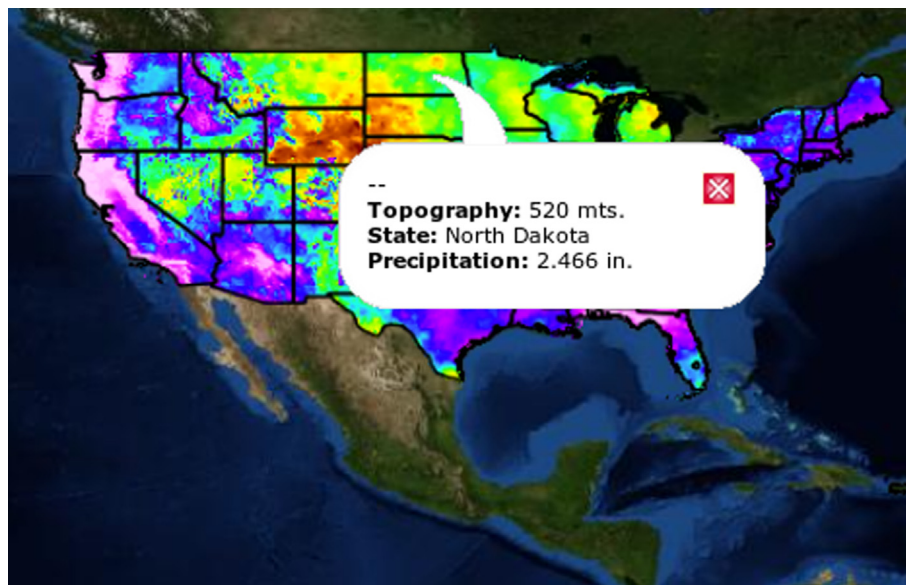


Fig. 5. Data obtained with OWGIS by the *identify features* capability for three layers: topography, average precipitation for the month of January, and states boundaries for the U.S.

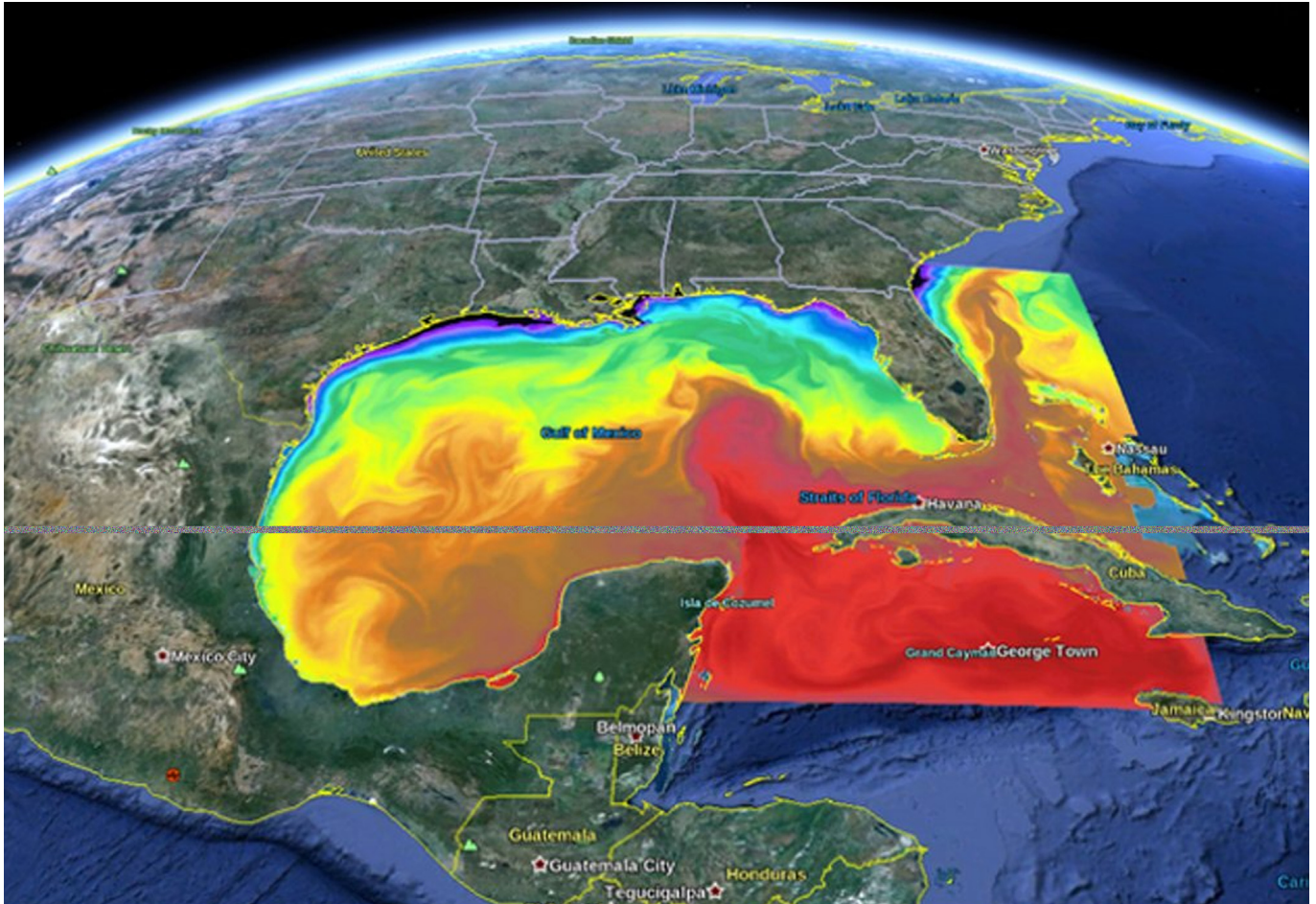


Fig. 6. Example of the download as KML feature of OWGIS. Sea surface temperature of the Gulf of Mexico visualized using Google Earth.

product is a Web GIS site that shows daily data of four oceanographic variables from 2010 to the time of access and forecasts for the next 15 days. This project has been available since January 2013.

The main benefit that OWGIS provides to this project is the ability to display 4D data generated by the HYCOM model and

served through an ncWMS server. Most environmental models, such as the Weather Research and Forecasting (WRF) Model and the WAVEWATCH III wave model, use the NetCDF output format and could benefit from OWGIS following the same architecture as this project. A wide variety of variables, such as wind, sea ice,

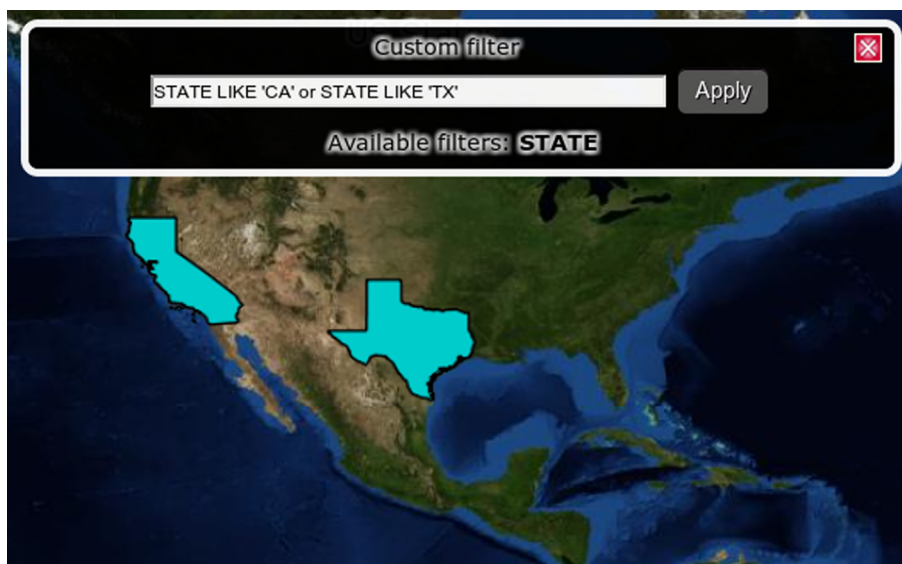


Fig. 7. CQL filtering example. In this example, the layer that displays the state boundaries for the U.S. is filtered to show only those states whose initials are 'CA' or 'TX'.

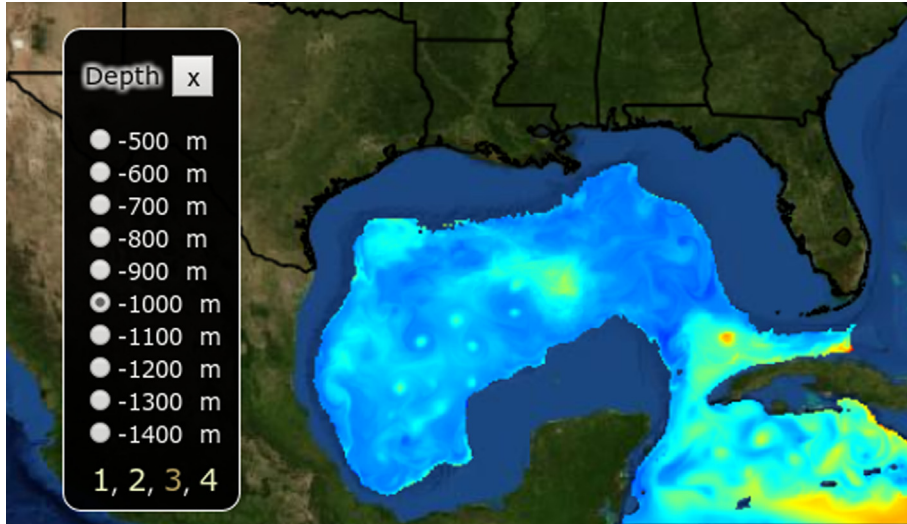


Fig. 8. Multiple depth selection example. Paginated window displays different elevations available for layers served by ncWMS servers.

relative humidity, surface temperature, etc., could also be displayed by OWGIS.

The architecture used on the *Deep-C MapViewer* project has four modules: a configuration of HYCOM as an operational system; an instance of the ncWMS server to provide WMSs of the environmental model; an instance of GeoServer to provide 2D geospatial layers through the WMS and WFS standards; and an instance of OWGIS to generate a self-contained Web GIS user interface. These four modules interact with each other as shown in Fig. 11.

Whichever environmental model the project uses, the architecture shown in Fig. 11 can be applied. If the environmental data is already available through an ncWMS server or other WMS compliant map server, the only module that is required to build a Web GIS site is the OWGIS module. The rest of the Section explains

in detail how each of these four modules were implemented for the *Deep-C MapViewer* project.

5.1. Environmental model (HYCOM)

A detailed description of the HYCOM ocean prediction system is available at <http://hycom.org/dataserver/goml0pt04/expt-31pt0>. The HYCOM configuration used for the *Deep-C MapViewer* has a $1/25^\circ$ equatorial resolution, a latitudinal resolution of $1/25^\circ \cos(\text{lat})$, and 20 coordinate surfaces in the vertical. This system uses the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005) to assimilate ocean variables obtained through satellites and in-situ measurements. The system runs at the Naval Oceanographic Office (NAVOCEANO) Major Shared Resource Center, and the output of each run is saved to CF-compliant NetCDF.

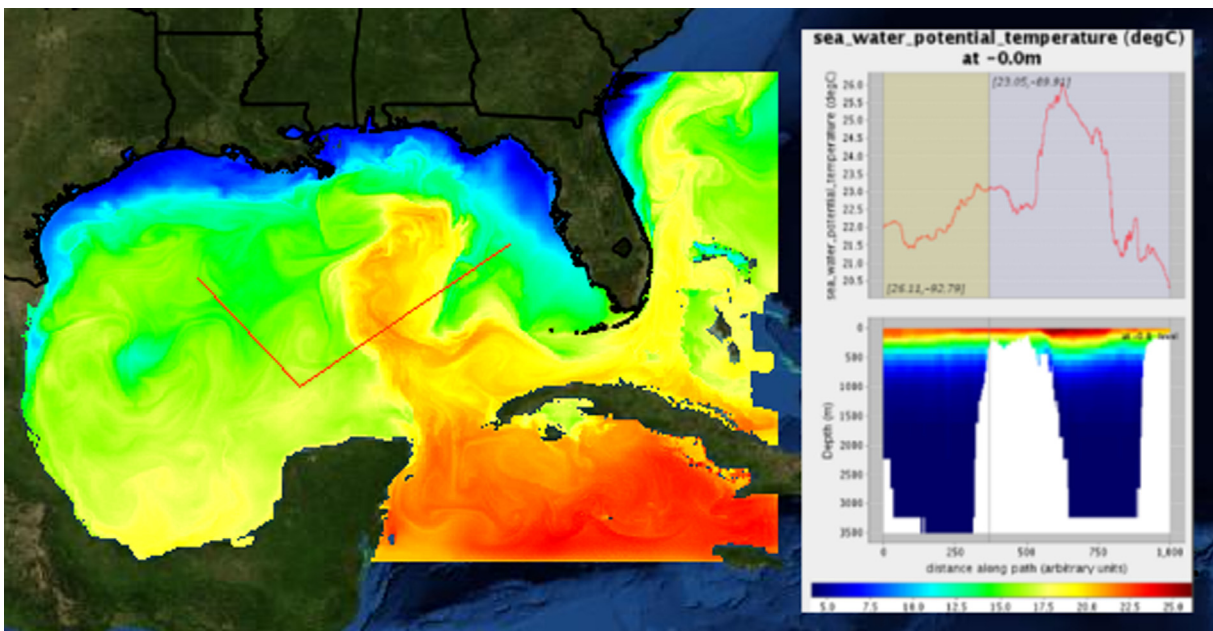


Fig. 9. Vertical transects obtained through the OWGIS software using temperature data for the Gulf of Mexico.

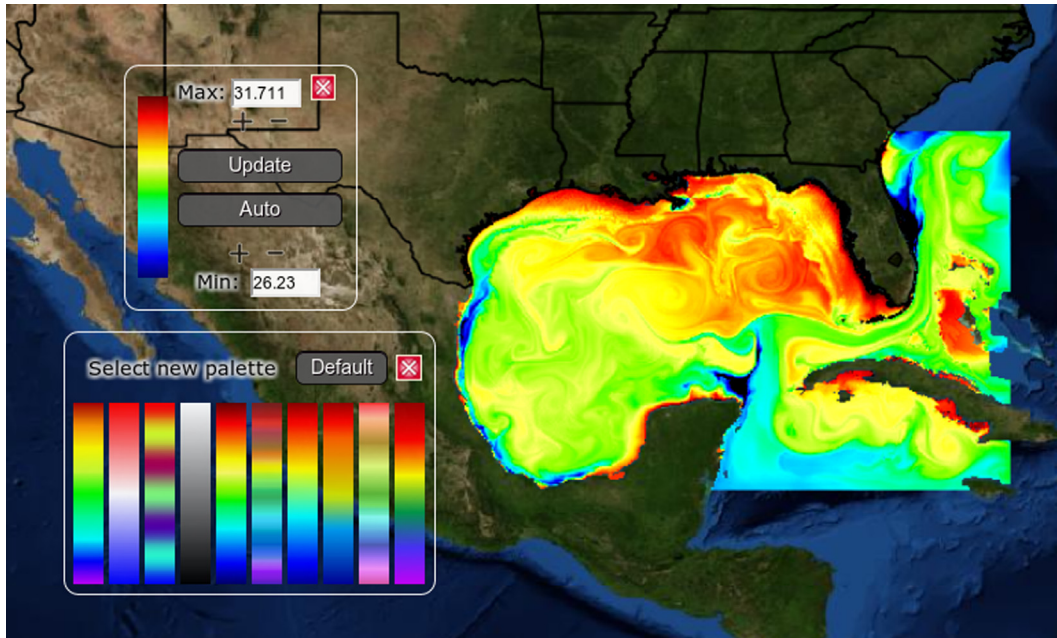


Fig. 10. Example of the windows generated by OWGIS that allow users to select color palettes and to modify color ranges.

5.2. ncWMS

The ncWMS (Blower et al., 2013) is a web application used to visualize multidimensional environmental data stored as NetCDF files. ncWMS can be easily deployed in an application server such as WebSphere, JBoss, Jetty, or, as in this project, Apache Tomcat. ncWMS is configured through a web interface where the administrator defines each of the datasets being published. For The *Deep-C MapViewer*, ncWMS is used to serve the output of HYCOM with five datasets configured, one for every year from 2010 to 2014. Each dataset points to a folder where NetCDF files with all the

oceanographic variables generated by HYCOM are stored. The only folder that is being refreshed daily is 2014.

5.3. GeoServer

GeoServer (Deoliveira, 2008) is an open source web application that is used to view and edit geospatial data using standards from the Open Geospatial Consortium (OGC). GeoServer is a more mature server than ncWMS, it has better documentation, the users can easily modify the output format of the web feature service (used by the identify feature), and it provides additional features for vector layers, like CQL filtering or been able to request data in JSON format. For those reasons we believe it is better suited for serving geospatial data that is not stored as NetCDF files. For the *Deep-C MapViewer* project, GeoServer is configured to serve the Blue Marble dataset (the background layer) and several vector layers, such as the state boundaries of the U.S. and the bathymetry contours of the Gulf of Mexico. There is extensive documentation on the GeoServer website (<http://geoserver.org/>) on how to configure vector and raster layers on the server.

5.4. OWGIS

OWGIS is used to build the interface with the user. Once all the data is available through the map servers, OWGIS provides an easy way to build Web GIS sites to visualize, analyze and share that data. In this case study, OWGIS is configured with the Blue Marble layer as a background, 20 main layers that store each of the four oceanographic variables for each year from 2010 to 2014, and two optional layers that display U.S. state boundaries and bathymetry contours of the Gulf of Mexico.

The Java properties 3.1 is configured with *DeepCProject* as the basepath and $lon = -87.81606$, $lat = 28.45786$ as the center of the map. The rest of the parameters retain their default values from the OWGIS template. For the *Deep-C MapViewer* project, four XML files define the menu titles, background layers, main layers and optional layers. As an example, the XML code on listing 2 shows how to

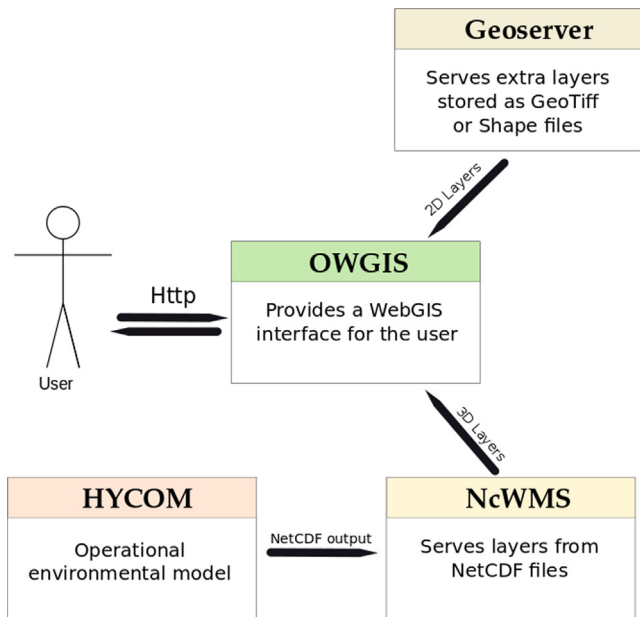


Fig. 11. Architecture used to build the *Deep-C MapViewer*. Its four modules are: an instance of GeoServer and ncWMS servers; HYCOM model as an operational ocean model; and OWGIS to generate the web interface for the user.

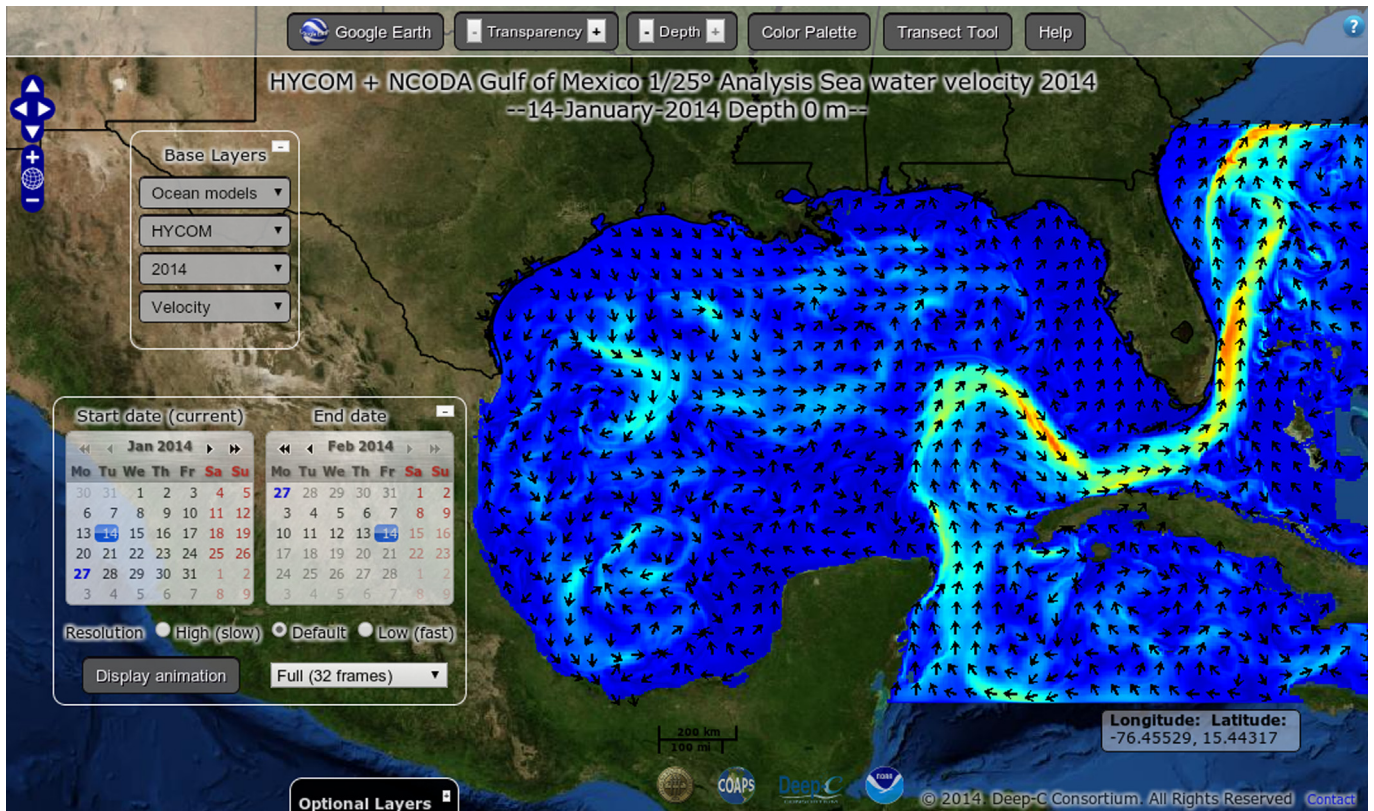


Fig. 12. Ocean currents of the Gulf of Mexico displayed from the *Deep-C MapViewer* for the 14th of January, 2014.

configure all the oceanographic variables for the year 2013 as main layers in OWGIS.

```
<MenuConf xmlns:xsi="..." xsi:noNamespaceSchemaLocation="schema.xsd">
  <MenuEntries>
    <MenuEntry ID="2013" EN="2013" ES="2013"/>
    <MenuEntry ID="omodel" EN="Ocean models" ES="Modelos oceano"/>
    <MenuEntry ID="hycom" EN="HYCOM" ES="HYCOM"/>
    <MenuEntry ID="Temp" EN="Temperature" ES="Temperatura"/>
    <MenuEntry ID="Salinity" EN="Salinity" ES="Salinidad"/>
    <MenuEntry ID="SeaElev" EN="Elevation" ES="Elevacion"/>
    <MenuEntry ID="SeaVel" EN="Velocity" ES="Velocidad"/>
  </MenuEntries>

  <MainLayers BBOX="-98.0,18.091,-76.40,31.960"
    format="image/gif" server=".../ncWMS/wms"
    ncWMS="true" mincolor="13" maxcolor="34">
    <layer Menu="omodel,hycom,2013,Temp"
      name="hycom2013/temperature"
      EN="... Temperature 2013"
      ES="... Temperatura 2013">
    <layer Menu="omodel,hycom,2013,SeaVel" style="vector"
      name="hycom2013/sea_water_velocity"
      EN="... Sea water velocity 2013"
      ES="... Velocidad 2013"/>
    <layer Menu="omodel,hycom,2013,SeaElev"
      name="hycom2013/ssh"
      EN="... Sea Surface Elevation 2013"
      ES="... Elevacion superficial del mar 2013"/>
    <layer Menu="omodel,hycom,2013,Salinity"
      name="hycom2013/salinity"
      EN="... Salinity 2013"
      ES="... Salinidad 2013"/>
  </MainLayers>
</MenuConf>
```

By creating these two simple configuration files, OWGIS builds a Web GIS site with all the required functionality to visualize the oceanographic variables: color palettes, depth selection,

animations, multiple language menus, etc. Fig. 12 shows the interface of the *Deep-C MapViewer* project when ocean velocity for the 14th of January, 2014 is selected.

The amount of data displayed on the *Deep-C MapViewer* website is growing rapidly thanks to the ease of configuration of OWGIS.

6. Discussion and conclusion

OWGIS is the first open source software that can build Web GIS sites that display 2D, 3D, and 4D data served from distinct map servers that can be located anywhere. The main features OWGIS provides in the interfaces it builds are: multiple languages; animations; vertical profiles and vertical transects; color palettes; and the ability to download data. All these features are created automatically depending on the type of data and without any additional web programming.

In the introduction, OWGIS was placed inside the vast family of open source programs where OWGIS's tools for visualizing 4D data stand out. Within the commercial GIS software, where esri is the international leading enterprise, the overview is similar. Some examples of environmental Web GIS sites created with esri's system ArcGIS are: PRAGIS (McCool, 2014), Virtual Fire (Kalabokidis et al., 2013), and River run (Halls, 2003). ArcGIS online (<http://arcgis.com/>) is the key component of the ArcGIS system that provides similar features than OWGIS to build Web GIS sites. ArcGIS online has a web interface that allows the user to choose from different base maps, and it has a searching tool where the users can find content that has been made public by the community. It also has the capability of displaying 4D layers on the maps it creates, as well as the option to download layers in GIS format or as KML files. OWGIS lacks an administration interface as well as a searching engine for geographical data on the web. Nevertheless, OWGIS

exceeds ArcGIS online in its features provided to display and style 4D data acquired from ncWMS servers. The only ArcGIS online example, that we know of, that has the ability to retrieve data from ncWMS servers (<http://dte-sci01.esri.com/MultiDimWMSViewer/>) do not has the possibility to modify color palettes or the color ranges of layers. This example also lacks the option to create vertical profiles, vertical transects, and time series. These extra features, plus the fact that ArcGIS online license costs thousands of dollars per year, makes OWGIS a good alternative to build WebGIS interfaces, specially for environmental scientists that store their geospatial data as NetCDF files.

Configuring new instances of OWGIS is made easy through XML files. In these files, the layers and texts of the websites are defined, providing an easy way to add and edit new layers that expand the content of each project. At the same time it allows sharing content between institutions and eases the maintenance of the websites. OWGIS conveniently stores all the texts in separate files to allow multiple languages on the Web GIS sites, thus increasing the potential number of users who can access the data.

The current version of OWGIS uses Java 7 and OpenLayers 2 to build maps. This version has been used by scientists who store their data in NetCDF files, but it has also been used to display other types of geospatial data. It is used to visualize ocean variables of the Gulf of Mexico in the *Deep-C MapViewer* project (<http://viewer.coaps.fsu.edu/DeepCProject/mapviewer>); it is used to display forecast data for the ocean and the atmosphere using the Weather Research and Forecasting Model (WRF) and the Regional Ocean Modeling System (ROMS), also in the Gulf of Mexico area, (<http://viewer.coaps.fsu.edu/GoM-FS/mapviewer>); is the main component of the Digital Climatic Atlas of Mexico, which displays more than 300 layers of climate data (<http://uniatmos.atmosfera.unam.mx/ACDM/servmapas>); and it has also been used to display public transportation data (<http://viajandodf.com>) and useful information for immigrants (<http://www.americas.datafest.net>).

The current development of OWGIS is focused on incorporating new web technologies that allow visualizing data faster. OWGIS 2.0 will use OpenLayers 3, taking advantage of WebGL and HTML5 to build new and faster responsive Web GIS sites, placing emphasis in the user experience for mobile devices. We hope that OWGIS becomes a popular open source software and the standard tool for building Web GIS sites in scientific fields where netCDF files are the default file format for storing data.

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