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GODIVA2: interactive visualization of environmental data on the Web

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GODIVA2 is a dynamic website that provides visual access to several terabytes of physically distributed, four-dimensional environmental data. It allows users to explore large datasets interactively without the need to install new software or download and understand complex data. Through the use of open international standards, GODIVA2 maintains a high level of interoperability with third-party systems, allowing diverse datasets to be mutually compared. Scientists can use the system to search for features in large datasets and to diagnose the output from numerical simulations and data processing algorithms. Data providers around Europe have adopted GODIVA2 as an INSPIRE-compliant dynamic quick-view system for providing visual access to their data.

Keywords: interactive; visualization; Web Map Service; four-dimensional; environmental science; INSPIRE

1. Introduction

Visualization is a very important tool for allowing scientists to understand the ever-growing volumes of diverse environmental data and for communicating scientific results within and beyond the scientific community. Many different approaches to visualization are employed in the environmental sciences, including script-based plotting and analysis tools, geographic information systems, 'virtual reality' systems based on three-dimensional graphics and Web portals. Each of these approaches has its own strengths and weaknesses, but typical limitations include a lack of interactivity, a lack of transparency (users have to learn the low-level technical details of the data in question), a lack of mutual compatibility (due to the use of specialist or proprietary data formats), a lack of support for four-dimensional data and a high barrier to entry (due to the need for the user to install and learn how to use a powerful but complex piece of software). This paper describes a new standards-compliant, web-based geospatial visualization system (known as 'GODIVA2') that addresses many of these limitations. GODIVA2 is among the first systems to use dynamic Web mapping technology to explore four-dimensional, terabyte-scale scientific data. This provides users with a highly accessible means to visualize complex information.

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One contribution of 24 to a Discussion Meeting Issue 'The environmental eScience revolution'.

2. The GODIVA2 system

The requirements for the GODIVA2 system were: (i) users need not have to understand any details of file formats or metadata conventions, (ii) users need not have to download large volumes of data, (iii) users need not have to install new software, and (iv) the system should, wherever possible, comply with open, international standards to allow interoperability with third-party systems. GODIVA2 was therefore developed as a client–server system (figure 1), in which the client is as simple as possible and the server handles all the necessary complexity. The client and server communicate through standard, openly published protocols, meaning that the unmodified third-party clients can display imagery from the GODIVA2 server. Conversely, the GODIVA2 client (website) can display imagery from third-party map servers alongside visualizations of the scientific data.

(a) *The server*

The GODIVA2 server (http://ncwms.sf.net) is based on a custom implementation of the Open Geospatial Consortium's Web Map Service (WMS) specification (http://www.opengeospatial.org/standards/wms), which is a widely used international standard for sharing map imagery. The standard WMS interface comprises three operations: *GetCapabilities* for requesting metadata; *GetMap* for requesting a map image; and *GetFeatureInfo* for requesting more information about a specific map pixel. The GODIVA2 server is fully backward compatible with versions 1.3.0 and 1.1.1 of the WMS specification but also provides some custom capabilities that allow for the more efficient provision of metadata to the GODIVA2 website, easier styling of the scientific data and the generation of non-map outputs such as time-series plots. A description of these custom capabilities will be published separately.

The GODIVA2 server is designed specifically to generate imagery from gridded data (e.g. numerical model output and satellite data) stored in NETCDF (http://www.unidata.ucar.edu/software/netcdf/) files that conform to the Climate and Forecast metadata conventions (http://www.cfconventions.org). (Adapters for other file formats can be created.) The server is designed to generate images from the source data quickly and efficiently: on typical modern server hardware, the server is capable of generating a 256×256 pixel image from the source data in less than half a second, which is sufficient to enable interactive visualization. Precise timings vary according to many factors including the source data resolution and the number of simultaneous users. In order to spread the load, a single GODIVA2 client may be backed by several distributed servers. In such a distributed system, each data provider installs their own copy of the GODIVA2 server, which provides imagery and metadata to the website. Any GODIVA2 server can be configured to read the data and metadata from remote archives using the widely used OPENDAP protocol (http://opendap.org). This means that data do not need to be centralized on a single GODIVA2 server. GODIVA2 is therefore a scalable system that provides a portal to many terabytes of the data that are physically distributed around the world.

(*b*) *The client*

The GODIVA2 website (figure 1) is designed to be highly interactive, making use of Ajax (asynchronous JavaScript and XML) technologies to provide a responsive interface. Having selected a dataset and variable from the menu, the data are displayed on a draggable, zoomable map interface, on the top of a background map that gives spatial context (users can select from a number of backgrounds, which are loaded from third-party WMS servers). Users can select the elevation/depth level and the time value, and can also select a range of time values in order to create an animation. By clicking on the map the user can find the precise data value, or create a time-series plot (using the *GetFeatureInfo* operation). The colour palette can be changed, and the contrast range adjusted, in order to highlight features of interest. The current view can be exported to Google Earth to allow the data to be visualized alongside other data that third parties have provided in the newly standardized KML format (http://www.opengeospatial.org/standards/kml; Blower *et al.* 2007). The GODIVA2 website was declared the Open Geospatial Consortium's website of the month in January 2008.

3. Applications and use cases

In the scientific community, GODIVA2 has been used as a tool for searching visually for features in large high-resolution model and satellite datasets, such as the daily 5 km global satellite sea surface temperature product OSTIA (Stark *et al.* 2007), using the ability to rapidly display imagery at a wide range of zoom levels. GODIVA2 has been used in data assimilation research in both physical and biological ocean modelling. It is able to visualize the data interactively on the different curvilinear grids commonly used to avoid polar singularities in models of the global ocean, such as NEMO (Madec 2008). It has been used to detect unexpected results that might indicate problems with new assimilation algorithms, or with the response of any of the numerous biogeochemical tracers. The PlankTOM5 functional type model (Le Quéré *et al.* 2005) has, for example, 29 nutrient and biological ocean tracers that are relevant to modelling of the marine carbon cycle, and these can be quickly explored and compared within GODIVA2.

The UK National Centre for Ocean Forecasting (http://www.ncof.co.uk/) provides a visualize and browse interface to all of its operational oceanography products on a near real-time daily basis through a GODIVA2 system. This technology has also been taken up by European oceanography programmes. The MERSEA (Loubrieu *et al.* submitted) and ECOOP (htttp://www.ecoop.eu/) programmes, which are the forerunners of a new operational European ocean forecasting service, have adopted GODIVA2 to provide interactive browsing of daily ocean forecasting products from multiple European countries. The GODIVA2 software complies with the standards and obligations set by the European INSPIRE directive (http://www.ec-gis.org/inspire/) for access to geospatial data using international, open-standard Web service interfaces.

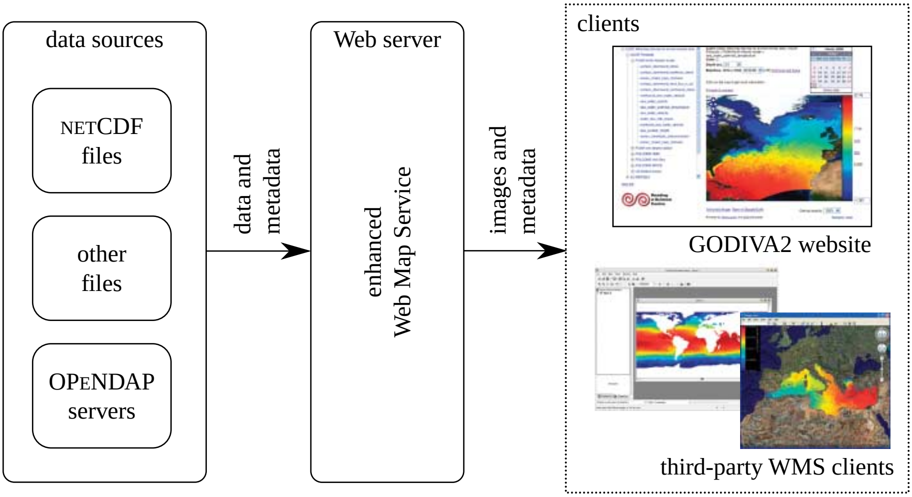

Figure 1. Architecture of the GODIVA2 client–server system. The data are read from files on the server or via the OPeNDAP Internet protocol. The data are converted to imagery using an enhanced Web Map Service (WMS) and displayed on the GODIVA2 website (http://www.reading.ac.uk/godiva2) or any WMS-compatible client.

4. Discussion

The GODIVA2 system highlights the importance of adopting community standards for describing, sharing and visualizing the environmental data (Lowe *et al.* 2006; Lawrence *et al.* 2009). The use of the WMS standard allows interoperability between GODIVA2 and many other data visualization systems, providing the important ability to overlay and compare data from different sources. This interoperability is essential for supporting future interdisciplinary science and for allowing scientific results to be shared with other communities such as industry, government and education. At a lower level, the use of standard data formats and metadata conventions has greatly reduced the overall cost of developing the system.

Future work will be focused on: (i) the ability to combine different datasets in a single view, (ii) the ability to visualize *in situ* observations (e.g. data from Argo floats) overlain upon gridded data, which will have important applications in fields such as data assimilation, (iii) the ability to perform simple processing on single or multiple datasets, such as data differences, anomaly views and model–data comparisons (Gemmell *et al.* submitted), and (iv) the supplementary generation of different kinds of plots such as vertical sections (Lowe *et al.* 2006), to allow the full potential of the four-dimensional data to be explored.

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