Visualizing hydrologic drought information on the web using state-of-the-art geospatial mapping technology

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ABSTRACT

Recent advances in web technologies, such as those used by Google Maps (http://maps.google.com), have facilitated the development of more interactive geospatial mapping technologies. The technology behind these mapping tools is known as Asynchronous JavaScript and XML (AJAX), which is aimed at more stable functionality, fast interactivity between servers and clients, and cost-effective data exchanges between the servers behind the scenes. Although Google Maps takes full advantage of this recent technology, there are still many restrictions in terms of customization, source modification, and licensing issues. We propose to use ka-Map (http://ka-map.maptools.org/), which is a very powerful tool for customizing user components such as graphical user interfaces (GUI). Ka-Map can be coupled with MapServer (http://mapserver.gis.umn.edu/), which was developed at the University of Minnesota. Since both ka-Map and MapServer are open source web-mapping technologies that are compliant with Open Geospatial Consortium (OGC) standards, application of these tools for water resources management is of great interest.

INTRODUCTION

A geographic information system (GIS) provides a spatial framework to support decisions for the intelligent use of water resources. These days, applications of GIS are crucial in the sense that many water-related issues and man-made environmental problems can be analyzed and resolved through geospatial data analysis. For instance, many wise environmental decisions, such as how best to manage water resources in regional watersheds, involves geography and advanced geospatial web mapping to better disseminate information, manage resources, and respond to emergencies caused by extreme hydrologic events (e.g. flood and drought) and other cases (e.g. water-borne disease).

Many studies have been done to better manage water resources using GIS technologies from spatial analysis in modeling framework to web-based visualization over the internet (ESRI 2009). Web-based GIS applications, in particular, have grown substantially over the past few decades. Thanks to advanced computer technologies and enriched GIS datasets, the field of geographic information continues to grow.

Web application platforms such as Google Maps/Earth are showing seamless performance by providing interactive maps to communicate our everyday activities around the world. These tools and technologies help us to improve our understanding of the environment, natural disasters, geopolitical complications, human activities and changes in natural resources. For hydrologic database management applications, the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CAUAHSI- http://www.cuahsi.org/) Hydrologic Information System (HIS) project has been initiated to facilitate data accessibility and visualize geographically distributed hydrologic data sources through the universities' alliances. The goal of CAUAHSI-HIS is to bring all water resource data, including precipitation, streamflow, water quality, and ground water levels together into a service-oriented architecture through "web services", known as specialized machine-to-machine communications via internet protocols (Maidment 2008). Such efforts are extremely important in providing seamless service for the widest variety of water data available to the research community and public domains. Hydrologic ontology defined in geospatial databases can be utilized to translate water observations data from various formats (e.g. text, excel, binary) into a single format compatible with an internet friendly hierarchical data structure (e.g. eXtensible Markup Language (XML)) that can be stored effectively (Maidment 2008). The water data discovery and acquisition system, called HydroSeek (http://www.hydroseek.org), is a good example of a geospatial database available on the internet.

In this paper, we propose to use ka-Map to visualize hydrologic drought information across the country. One major advantage of this tool is that all analysis output and dynamic maps of hydrologic information through data processing can be displayed efficiently on the web through an OpenGIS framework. Additionally, many different image formats of the maps (as users create them on their web browsers) are made available, including png, gif, tiff, and pdf formats Such visualization and customized maps are very useful for integrating and assimilating environmental datasets into digital watersheds along with other real-time data collections, including satellite-based remote sensing and/or automated wireless data networks. Additionally, local decision makers responsible for hydrologic event response plans and management can easily identify the spatial extent of areas vulnerable to upcoming hydrologic events, especially drought.

DATA ASSIMILATION

The United States Geological Survey (USGS) maintains 1,659 unregulated gauge stations, known as the Hydro-Climatic Data Network (HCDN) across the country to provide naturalized streamflow data for research activities related to climate change and other subjects (http://pubs.usgs.gov/wri/wri934076/1st_page.html). Records of unregulated streamflow (i.e., natural streamflow, as opposed to streams with upstream diversions or dam operations) are important in understanding the effects of hydrologic drought on regional water resources. A total of 1,009 unregulated gauge stations, a subset of 1,659 stations, were utilized for this study to visualize hydrologic drought information across the country. Selection criteria for streamflow gauge stations and data assimilation processes were determined based on a data quality assurance test. First, daily streamflow data was downloaded from the USGS website (http://waterdata.usgs.gov/nwis/sw). Time horizons of the daily streamflow data was taken from as early as 1845 to the year 2005 and saved in text format, and then additional test was conducted to maintain data integrity. For instance, some stations that had duplicate records of streamflow within several unnecessary columns and whole segments of data missing were eliminated.

VISUALIZATION TECHNOLOGY

Open source based web-mapping platforms such as MapServer are commonly used by many water scientists wanting to publish maps online. Although MapServer is well suited for interactive web-mapping, MapServer alone is not able to accomplish a set of advanced actions such as enhancing robust and stable interactions between servers and clients. AJAX supports the functions of MapServer and is based on open standards, which means this technology is less dependent on any established or specific operating system and/or commercial software. The main advantage of AJAX is that it is very fast and reduces the time spent in (processing time) redrawing dynamic maps requested by the client within a web browser. AJAX accomplishes faster data processing by manipulating data via specific requests (e.g., event handling) rather than reading the entire page on the web. This high-speed mapping technology drives developers to integrate AJAX applications into web services. Figure 1 represents an integrated system of dynamic mapping technology within an open-source platform, including MapServer, geospatial database, and ka-map utilizing AJAX technology.

MapServer

Mapserver, an open source development environment, is widely used to implement web-based GIS solutions around the world since it was originally developed at the University of Minnesota (UMN) in collaboration with the National Aeronautics and Space Administration (NASA) and the Minnesota Department of Natural Resources (MNDNR). Although MapServer is not a full-featured GIS system, MapServer can visualize various formats of GIS data (e.g., images, raster, and vector data) through an internet gateway. Additionally, MapServer allows users to create and manage map files, which characterize individual map layers including data source, legend, scale, and metadata. In this project, MapServer will be enhanced to produce integrated maps along with drought prediction outputs as follows. First, all metadata will be customized to help the end users. A customization of metadata will help reduce the time required for map caching as it predefines analysis settings such as the queryable field, hyperlink information, color setting, and layer description. Second, the system should be able to operate conjunctively with the geospatial database to provide reliable web services in terms of time and quality. These components will enhance the dynamic mapping system through GIS technology, and help local decision makers identify the spatial extents of potential droughts via customized views.

Geospatial Database, PostGIS

A reliable geospatial database is another important key element in accomplishing the goals of this project. PostGIS (http://postgis.refractions.net/) is a tool used to support geographic objects within PostgreSQL (http://www.postgresql.org/), a powerful open-source relational database system. PostGIS enables the PostgreSQL server to be used as a backend spatial database for geographic information systems (GIS), such as ESRI's ArcSDE and Oracle's spatial extension. PostGIS is also developed in an open-source environment so that it complies with Open-Source Geospatial Consortium (OGC) standards. Currently, PostGIS supports various geospatial data formats as well as data validations associated with geological coordinate systems. PostGIS can be used by implementing SQL routines to visualize the results via MapServer so that the interactive dynamic maps will be made available much faster over high-speed broadband internet connections.

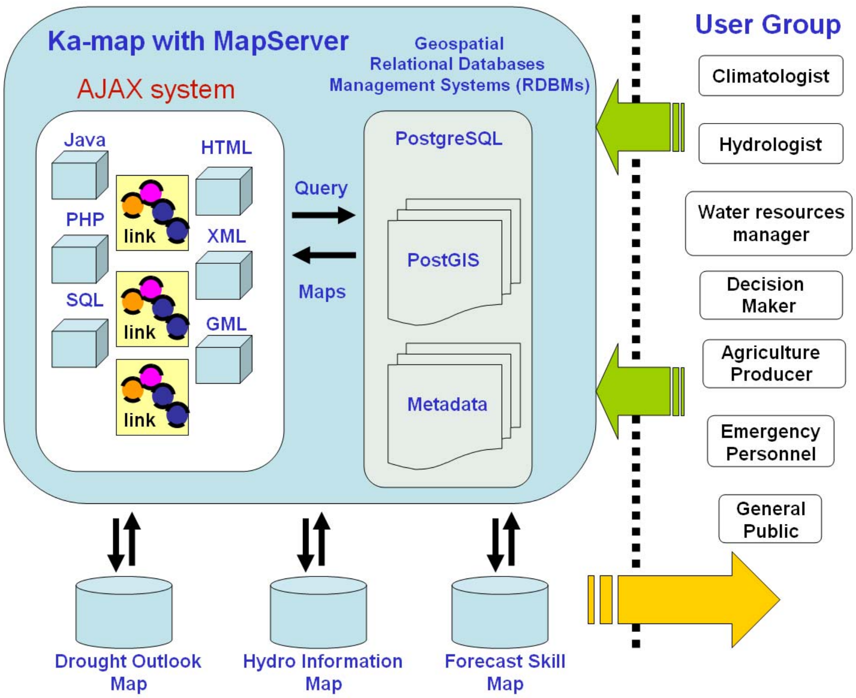

Figure 1. Integrating MapServer into ka-map utilizing AJAX technology

Ka-Map with AJAX technology

As an open source package, ka-Map will also be integrated with MapServer. Normally, a map is created by MapServer through map files (e.g., mymapfile.map) and then is made available on the web in cached form through ka-Map. Basic processing of these integrations is conducted through a simple cycle. MapServer is in charge of creating maps, and it waits for requests from users via a graphic user interface (GUI) in ka-Map. When a request is initiated by the user, both MapServer and ka-Map work together to generate and present new maps on the web. But when many duplicate requests are presented, only ka-Map is working on caching and redrawing the maps; MapServer sits idle and waits for the next batch of new calls. Traditionally, this process is done by a series of subsequent protocols including mouse clicks and/or zooming in, and then waiting for the entire map image, and waiting again for the web browser to publish maps, whereas the integration with ka-Map splits maps into several pieces when first requested and stores them on the server, then retrieves the map later for the user. This simplified cycle leverages system enhancements by improving the performance of the web browsers. Moreover, AJAX technologies facilitate the level of interactivity between servers and clients, pre-rendering by caching the tile images stored in the server, and saving time by accelerating smooth panning and zooming.

DEMONSTRATION

For testing and demonstration purposes, we developed a mock-up to visualize raw geographic data (e.g. vector, raster, and coverage) on web-based GIS services (Web Service). Advantages of this service provide interactive communication tools between Web Service and end-users that require customizing geophysics applications. Figure 2 and Figure 3 show the main page of the mock-up and a sample of client's web service request, respectively. For instance, users can request the map for the area of interest to identify USGS gauge stations for further information. The graphical user interface (GUI) main page shown in Figure 2 allows the user to change the map sizes from the drop-down lists or enables them to zoom in or zoom out by clicking zooming tools built in ka-Map.

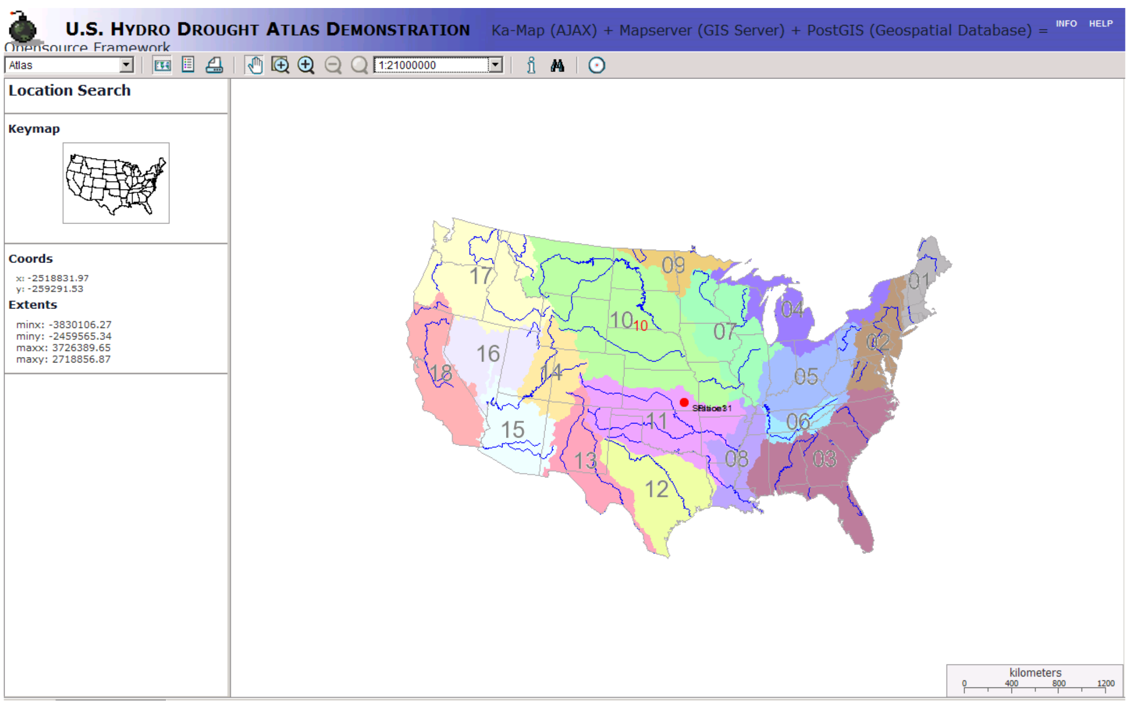

Figure 2: Main page with web-based GIS services. The color ramp in the main frame represents a total of 18 watersheds in the conterminous U.S.

The red circle on the left panel in Figure 3 indicates that the user has identified two USGS streamflow gage stations for further investigation.

Future Work

We created a mock-up of a web-based GIS service for data visualization to end-users using state-of-the-art geospatial mapping technologies, including AJAX and PostGIS. All these services comply with OGC standards so that many potential deployments to multi-disciplinary research activities are expected. The initial development activity is part of the first stage of an ongoing U.S. Drought Atlas project underway at the National Drought Mitigation Center (NDMC). A number of improvements and enhancements are needed to pursue seamless Web Services for NDMC clientele. These activities may include: 1) stabilizing robust web service architecture in combination with geospatial database, PostGIS, to manage high volumes of geospatial datasets (e.g. raster, satellite images); 2) integrating current Web Services with other services, such as Web Map Service (WMS 2009) and Web Feature Service (WFS 2009); and 3) improving the GUI to better communicate and understand service availability and accessibility for advanced users, and seeking further information (e.g. metadata) for their research interests.

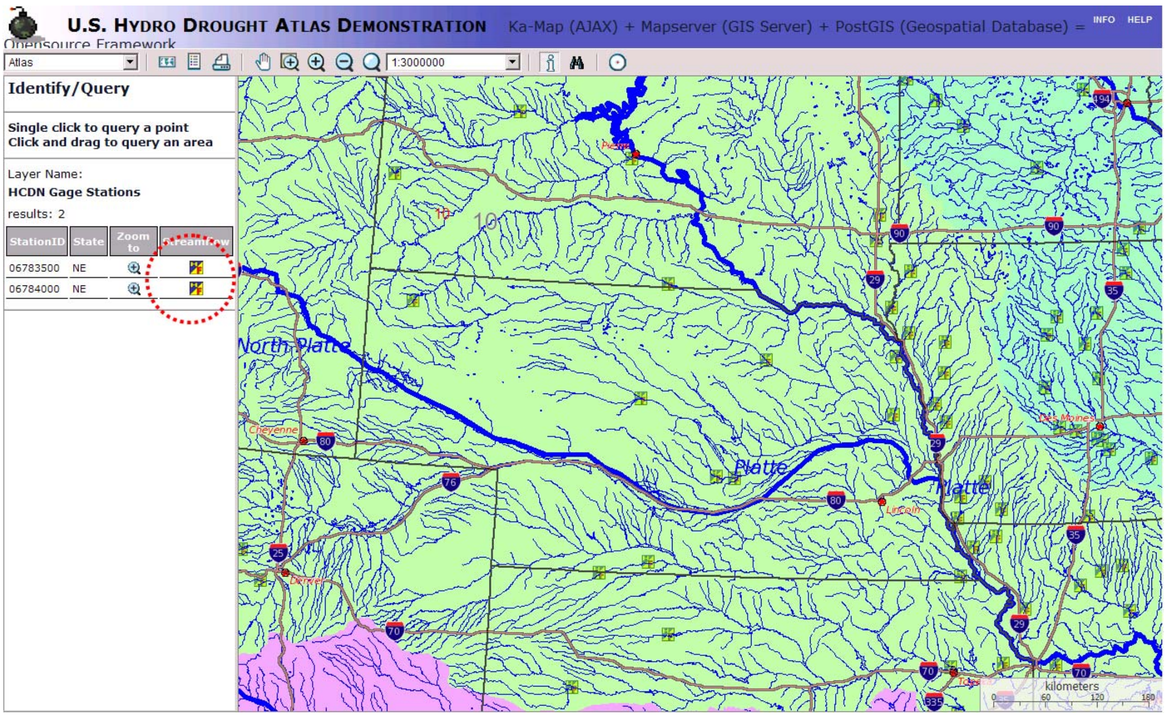

Figure 3: Web Services are customized for the client's view.

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