A GEOSPATIAL WEB SERVICE APPROACH FOR CREATING ON-DEMAND CROPLAND DATA LAYER THEMATIC MAPS

W. Han, Z. Yang, L. Di, P. Yue

ABSTRACT. *A thematic map displays the spatial patterns of one or more data themes for a specified geographic area. Thematic maps are used, for example, in geospatial data distribution and exchange, multi-source geospatial data aggregation, visual communication, and decision support. The latest web technologies and open geospatial standards make it feasible to produce on-demand thematic maps in an internet environment. This article describes a geospatial web service approach for creating customized thematic maps of cropland data layer (CDL) data. The design and implementation of the geospatial web service using open-source software are described in detail. The service meets the requirements of producing, sharing, and printing CDL thematic maps for the areas of interest without requiring additional mapping software. Examples of service invocation are given to demonstrate the applicability of the proposed approach. This service offers a new dissemination channel to distribute CDL data to the general public. Feedback from users in the agricultural community shows that the implemented web service has greatly improved the availability, customization, and timeliness of CDL thematic maps, reduced operational resource requirements and cost, facilitated geospatial data distribution and usability, and broadened the reach of geospatial cropland data products. In the first 20 months of availability, users have produced over 10,000 thematic maps.*

Keywords. *Geospatial web service, Service-oriented architecture, Thematic map, Cropland data layer, CropScape.*

A map presents qualitative or quantitative attribute values within a geospatial context, while a thematic map shows the spatial distribution of one or more specific data themes for the geographic area of interest (Slocum et al., 2005). In the past decade, web (or internet) mapping has become a major channel of geospatial data dissemination and publication because of its advantages of openness, timeliness, and accessibility over traditional media such as paper maps and CD/DVD copies. The functionality of online and on-demand thematic map creation is needed in web mapping applications to address the needs of users for real-time customized mapping, especially users who have no GIS skills or experience. In addition, open web services are highly needed that can provide an interoperable thematic map for mash-ups (Balley and Regnauld, 2011). Regnauld (2007) indicated that meeting these demands presents big challenges for research.

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The latest web service technologies and open standards from the World Wide Web Consortium (W3C) and Open Geospatial Consortium (OGC) make it feasible to construct web geospatial applications and generate online thematic maps (Iosifescu-Enescu et al., 2010). Geospatial web services enable users to leverage distributed geospatial data and computing resources over the network and from third-party geospatial applications, and to automate geospatial data integration and analysis (Zhao and Di, 2010). OGC has developed numerous specifications and standards for geospatial data and processing for sharing and interoperability. These standards have been widely adopted in many web applications that distribute geospatial data and processing services.

Among the popular geospatial data and processing standards from OGC, including Web Map Service (WMS), Styled Layer Descriptor (SLD), Web Coverage Service (WCS), Web Feature Service (WFS), Web Map Context (WMC), and Web Processing Service (WPS), the combination of WMS and SLD is widely adopted to provide map publication services in online geospatial applications (Rautenbach et al., 2013). WMS serves the map images over the web. It portrays raster or vector data in the styles defined in the SLD language (de la Beaujardière, 2006). Iosifescu-Enescu et al. (2007) attempted to extend WMS and SLD to produce a composite thematic map with the combined visualization of geospatial data. Foerster et al. (2011) combined WMS, SLD, and WMC with user profile technology to create on-demand base maps. However, detailed knowledge of OGC specifications is required to organize the cartographic elements (e.g., map layers, legend, scale bar, title, caption, and logo) together in a geographic context. In addition, requested data layers with non-rectangular boundaries must be processed using additional mapping software to generate the thematic map since OGC WMS supports retrieving only georeferenced data layers with a bounding box.

Web geoprocessing offers an alternative approach for generating thematic maps with the necessary elements in a self-contained geoprocessing unit (Granell et al., 2010). Web geoprocessing services can be constructed by wrapping existing geospatial tools or functions, or they can be developed from scratch (Han et al., 2012a). Dominkovics et al. (2011) developed a geoprocessing service that used ArcGIS toolboxes to generate dot density maps of an epidemic. However, this kind of geoprocessing service is software dependent and has to be deployed, for example, on a commercial ArcGIS server. The W3C web service using Web Services Description Language (WSDL) and Simple Object Access Protocol (SOAP) provides another option to implement a web geoprocessing service for creating thematic maps. This type of service is adopted in our implementation because its machine-to-machine interaction and simpler interface allow for easy use (Friis-Christensen et al., 2009).

The cropland data layer (CDL) data produced annually by the USDA National Agricultural Statistics Service (NASS) provide specific crop and non-crop land cover information encompassing the contiguous U.S. (CONUS) (Boryan et al., 2011). CDL users can visualize, customize, download, and analyze CDL data within a specified area of interest (AOI) through CropScape, a web-service based online geospatial application (Han et al., 2012b). On-demand CDL data and images can be retrieved easily via CropScape's WMS and WCS, or through a geospatial web service named CDLService. Request examples are listed in table 1.

However, to create a CDL thematic map, a user has to first download the CDL data from CropScape and then load the CDL data or images, select map styles, and add map components using traditional desktop GIS software, such as ArcGIS. This process is laborious, time consuming, and dependent on commercial mapping software. Therefore, many CropScape users, especially those with little or no GIS experience or no access to GIS software, have strongly requested that a function for generating on-demand, high-quality CDL thematic maps be developed and implemented in CropScape so that high-quality CDL thematic maps could be viewed, printed, and shared in a commonly used file format with or without the CropScape application.

To address the above-mentioned issues, this article proposes a geospatial web service approach to create on-demand CDL thematic maps with customized settings. The remainder of this article is organized as follows. The second section introduces related materials and methods, and describes the users' requirements. The third section describes the design and implementation of this geospatial web service within the Service Oriented Architecture (SOA), including service construction, processing workflow, service integration and deployment, and service invocation. The next section discusses implementation results and some applications of the new geospatial web service. Finally, the concluding section summarizes contribution of this article and future enhancements.

Materials and Methods

CDL and CropScape

NASS has produced the CDL data annually since 1997 using mid-resolution satellite data and high-quality ground truth data. The annual CDL data provide the specific crop and non-crop land cover classifications encompassing CONUS in georeferenced raster files (Boryan et al., 2011). The valuable CDL data were previously distributed only at the state level through traditional channels, such as paper maps, CD/DVD copies, or HTTP/FTP bulk download files. For users with limited or no GIS skills, it is not easy to extract the CDL data within a specified AOI, such as a county or Agricultural Statistical District (ASD), directly from the original data files, nor is it easy to analyze the requested data to produce statistics reports or charts using desktop GIS software.

CropScape (http://nassgeodata.gmu.edu/CropScape) was built to meet the needs for navigating, visualizing, retrieving, analyzing, and disseminating CDL data interactively through a common web browser (e.g., Internet Explorer, Firefox, or Chrome) on any internet-connected computer (Han et al., 2012b). CropScape has greatly reduced NASS's operational expenses and resource needs for creating and shipping traditional media for CDL data, and improved the efficiency and effectiveness of CDL data access, dissemination, application, and cropland-related agricultural decision support. It has been used extensively in various applications and research studies, including pesticide deposition (Belden et al., 2012), food security (Hartz at al., 2012), agricultural characterization (Kutz et al., 2012), biomass assessment (Chandola and Vatsavai, 2011), and biofuel crop evaluation (Wang et al., 2011), by users from government agencies, non-profit organizations, educational institutions, and commercial businesses. Moreover, CropScape,

Table 1. Web service request examples.

Service Name	Operation	Request Example
CDL WMS	*GetMap*	http://gis.csiss.gmu.edu/cgi-bin/wms_cdlall?service=wms&version=1.1.1&request=getmap&layers=cdl_2010&srs=epsg:4326&bbox=-96,40,-90,43&width=800&height=400&format=image/png
CDL WCS	*GetCoverage*	http://gis.csiss.gmu.edu/cgi-bin/wms_cdlall?service=wcs&version=1.0.0&request=getcoverage&coverage=cdl_2009&crs=epsg:102004&bbox=130783,2203171,153923,2217961&resx=30&resy=30&format=gtiff
CDLService	*GetCDLImage*	http://nassgeodata.gmu.edu:8080/axis2/services/CDLService/GetCDLImage?files=http://nassgeodata.gmu.edu/nass_data_cache/byfips/CDL_2010_19169.tif&format=png
CDLService	*GetCDLFile*	http://nassgeodata.gmu.edu:8080/axis2/services/CDLService/GetCDLFile?year=2011&fips=19

combined with other modern technologies in agriculture, helps farmers manage their land better than ever before (Mason, 2012). Site visit statistics at the end of September 2012 showed that more than 50,000 users from over 100 countries and territories had visited CropScape since it was officially launched in January 2011. About 200 GB of CDL data, images, and reports are downloaded from this web geospatial application every month.

Software Packages for Development

As a popular open-source web service/SOAP/WSDL engine, Apache Axis2 is built in an efficient, modular, configurable, reliable, and secured framework (Apache, 2009). It not only handles SOAP messages but also supports the Representational State Transfer (REST) style of web service. The comprehensive API functions of Axis2 in Java or C language can be called to interact with web services. Geospatial web services for CDL data are deployed in the Apache Axis2 runtime environment, which also serves as a standalone web application in Apache Tomcat.

The Geospatial Data Abstraction Library (GDAL) is an open-source geospatial library (OSGeo, 2011). GDAL provides a set of API functions to read and write raster files. As a part of GDAL, the OGR library handles vector data. Common geospatial data formats, such as GeoTIFF, Arc/Info ASCII Grid, ESRI Shapefile, and GML, can be translated and processed using the command line utilities of GDAL or applications developed from GDAL functions. GDAL has been extensively adopted in free and commercial GIS and remote sensing software. In the implementation of web geospatial services for CDL data, GDAL API functions are used to implement the executable programs of pixel value retrieval, format transformation, subsetting and rasterization, statistics calculation, and change analysis. These programs are wrapped as the corresponding geospatial web services in CropScape.

Cairo Graphics is an open-source 2D vector graphic library written in C language (Cairo, 2011). It offers powerful drawing APIs, such as Graphics Device Interface (GDI) APIs on windows, to draw geometries, images, and texts with various styles and to perform affine transformations in a graphic device. The output formats include PNG, PDF, Postscript, SVG, as well as contexts of Win32 GDI, OpenGL, etc. Its API functions can be utilized to draw all elements of a thematic map in a specified surface, which depends on the output format.

Users' Requirements

CropScape had no capability to create an on-demand presentation-quality CDL thematic map automatically. To create a CDL thematic map within a geographical context, users previously utilized traditional desktop mapping software after obtaining CDL data. However, this process is neither easy nor convenient for users in the agricultural community who have limited or no GIS skills, or who have no access to GIS software. Therefore, it is highly desired by users to provide a capability in CropScape of creating on-demand thematic maps for specified AOI in printable quality and in a commonly used file format.

PDF format can be an ideal choice for on-demand CDL thematic maps because this format allows users to easily access, display, print, and share CDL thematic maps in all computer systems, and therefore helps broaden the reach of this geospatial cropland product. For example, a CDL thematic map in PDF format can be inserted directly into a user's research report or printed as a poster to present crop patterns. The next section will present the design and implementation details of the extended functionality of CropScape, i.e., a new geospatial web service for creating on-demand CDL thematic maps.

System Design and Implementation

CropScape was built in an SOA environment, which allows system scalability for future augmentation (Han et al., 2012b), so it is easy to add a new functional component by assimilating new services in the extensible framework of CropScape. The API functions of Apache Axis2, GDAL, and Cairo Graphics library are used to develop this new web service.

Architecture

The general architecture of CropScape is shown in figure 1. For a detailed description of the overall architecture of CropScape, refer to Han et al. (2012b). Within this architecture, CDLService is deployed in the Apache Axis2 web service runtime environment to support CDL data exploration, customization, visualization, statistical and change analysis, and thematic map creation. Its WSDL can be accessed at: http://nassgeodata.gmu.edu:8080/axis2/services/CDLService?wsdl.

GDAL API functions are called in the executable programs to generate images and statistical information from CDL data within a given AOI. Cairo API functions are utilized in the executable programs to render the CDL image and other map elements in a drawing context, which is exported as the CDL thematic map in PDF format. These executable programs with multiple parameters are invoked in the geospatial web service for creating the CDL thematic map.

WSDL Design

The Axis2 plug-ins and Web Services Tools (WST) of the Eclipse Java Integrated Development Environment (IDE) are utilized to design, develop, and deploy web services. In our implementation, a top-down approach is adopted. The web service description (i.e., WSDL) is first updated using the WSDL Editor Tool to add new operation: *GetCDLPDF*. The skeleton code of CDLService is generated from the updated WSDL in Eclipse IDE. As shown in figure 2, the classes *GetCDLPDFRequest* (including crop year, FIPS code/bounding box/multiple points/vector file link, paper size, title, and boundary flag) and *GetCDLPDFResponse* (URL of the PDF file) are used in the *GetCDLPDF* operation of the existing skeleton class of CDLService. The executables derived from C APIs of GDAL and Cairo are called using Java Process and Runtime class in this operation to avoid redundant programming and memory limit of the Java Virtual Machine (JVM).

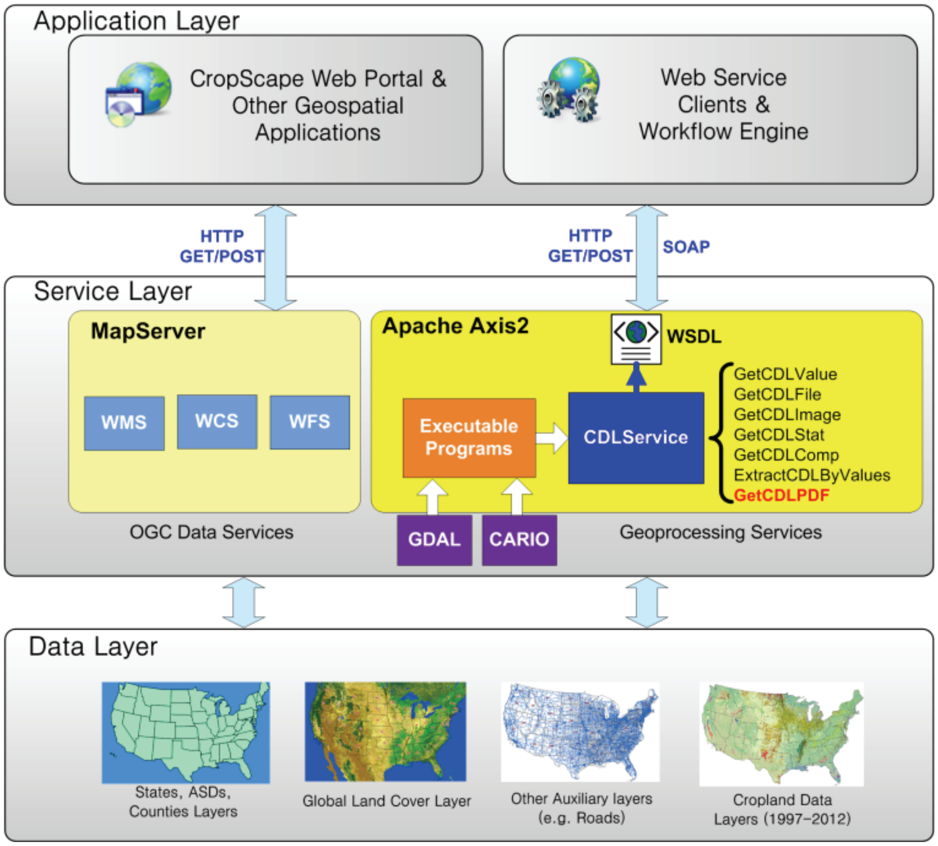

Figure 1. Overall CropScape architecture (modified from Han et al., 2012b).

SERVICE IMPLEMENTATION

In the service implementation, the whole process for creating the on-demand thematic map in PDF format is streamlined and automated, as illustrated in figure 3. All necessary map elements and information are created, retrieved, and rendered in the process.

The parameter that provides the AOI information is processed first. The *GetCDLPDF* operation supports four different options for AOI definition: (1) by specified Federal Information Processing Standards (FIPS) codes for the state or county, or ASD codes, (2) by bounding box, (3) by polygon, and (4) by the uploaded vector file. For option 1, a GML file of the AOI boundary is retrieved using the FIPS or ASD code as filename by sending a *GetFeature* request with property filter to the WFS server and obtaining the boundary information from the response. The retrieved GML file is kept if this GML file does not already exist in the cache directory. For options 2 and 3, the coordinates in the projection of the USA Contiguous Albers Equal Area Conic USGS Version retrieved from the request are stored as geometry features in a GML file with a unique name. For option 4, a vector file is obtained from the specified URL and transformed into a GML file in the above-mentioned projection using GDAL/OGR's *ogr2ogr* utility.

Next, the obtained AOI GML files are used as a mask to subset and rasterize the CDL file within the AOI for the given year. GDAL's *gdalwarp* utility is invoked to generate the required CDL file in GeoTIFF format. The CDL image in PNG format is then generated from this CDL file using GDAL's *gdal_translate* utility, and the agricultural and non-agricultural category information within the AOI is counted using *cdlstat*. The *cdlstat* program is built from GDAL API functions for opening/closing the raster file, fetching the raster band, reading raster data, and counting pixels, and its output information, including value, pixel count, land cover category name, and red, green, and blue (RGB) color value, is sorted by decreasing count and stored in a comma-separated values (CSV) file, as shown in table 2. If these files for CDL, image, and CSV with filenames of FIPS or ASD code already exist, then the corresponding operations are skipped.

Finally, the map elements, including the CDL image, the sorted category information, the title, USDA and NASS logos, and a scale bar, are drawn on the thematic map surface with the *createpdf* program, which utilizes Cairo Graphics API functions. A set of map templates for various paper sizes (letter, A4, A3, A2, A1, and A0) are created with the above-mentioned elements in their predefined positions.

SERVICE INVOCATION

The geospatial web service for creating on-demand CDL thematic maps has been integrated in CropScape to provide interactive and on-demand thematic map generation. Users can also utilize this service along with other existing web CDL services using standard HTTP GET, HTTP POST, or SOAP requests in their applications, or in their service chains to accomplish some particular task.

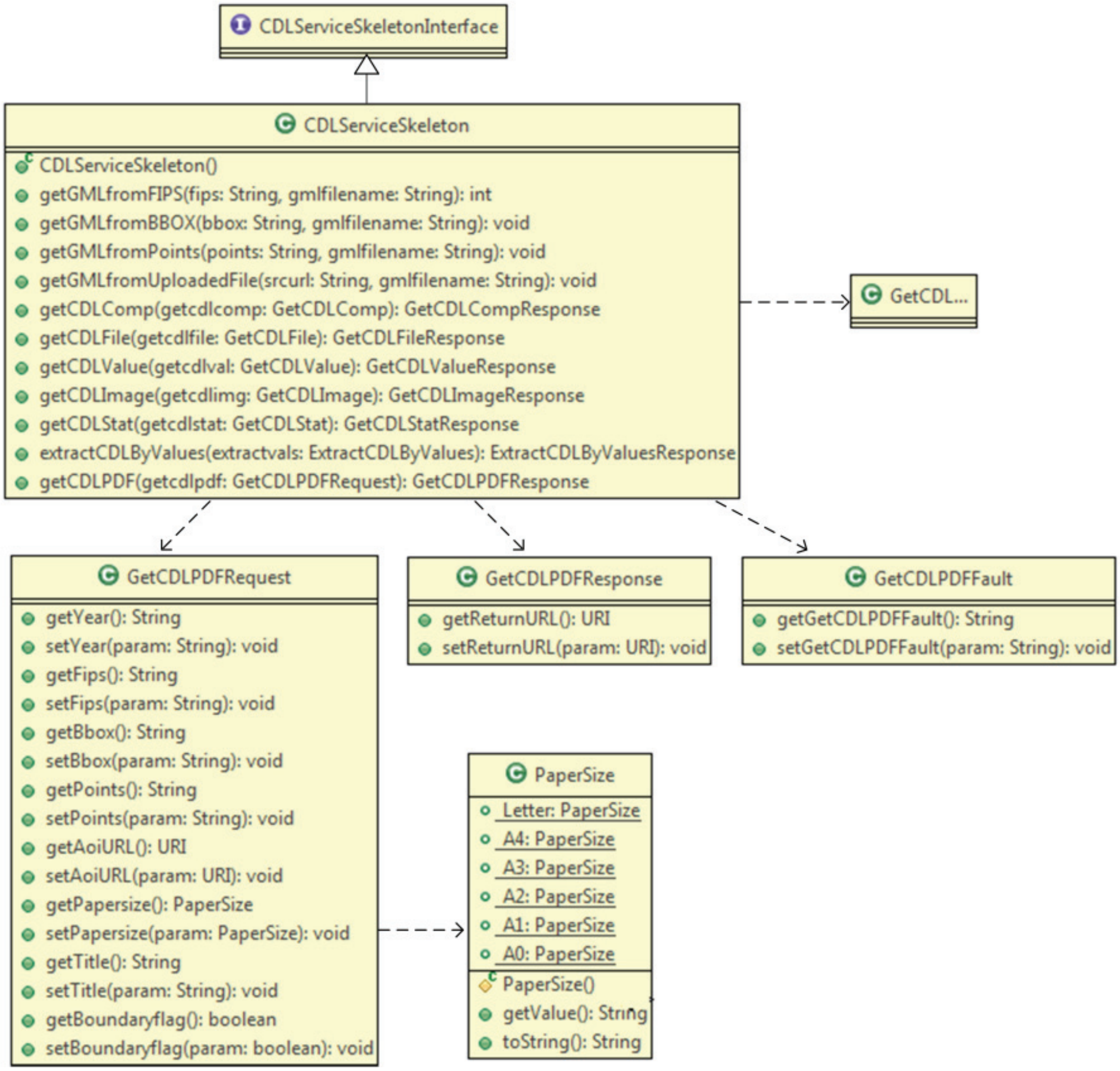

Figure 2. WSDL of the *GetCDLPDF* operation.

To invoke the proposed thematic map generating service in CropScape, an AOI such as administrative district, rectangle, circle, or polygon is first defined. The state, ASD, and county lists of CONUS are preloaded in the browser client for selection. After the administrative district of interest has been selected, the GML file for this selected district is returned and highlighted in the map view. The AOI for a rectangle, circle, or polygon can be drawn directly. The AOI can also be defined by an uploaded vector file in GML or ESRI Shapefile format. Next, the title and paper size of the CDL thematic map are specified in a popup window. These input parameter values are sent to CDLService in a SOAP request. When the browser client receives the response from the web service, the returned PDF file (as shown in fig. 4) is loaded in a popup window for display and downloading.

Users can incorporate this web service in their geospatial applications to obtain and display CDL thematic maps in PDF format by sending standard HTTP GET, HTTP POST, or SOAP requests. Detailed request examples are provided in the CropScape Developer Guide (http://nassgeodata.gmu.edu/CropScape/devhelp/help.html . Figure 5 provides an example of a SOAP request and response for obtaining a 2011 CDL thematic map of Chickasaw County, Iowa (FIPS code: 19037) in letter paper size and PDF format.

Discussions

In implementation, the new web service was assimilated in the extensible framework of CropScape. The existing API functions of Apache Axis2, GDAL, and Cairo Graphics library were utilized. The predefined map layout templates facilitate the automation of CDL thematic map generation. The implementation proved that this web service approach is effective and robust. It provides a new method to automatically and efficiently generate on-demand thematic maps.

The geospatial web service for creating on-demand CDL thematic maps not only enriches the functionality of Crop-

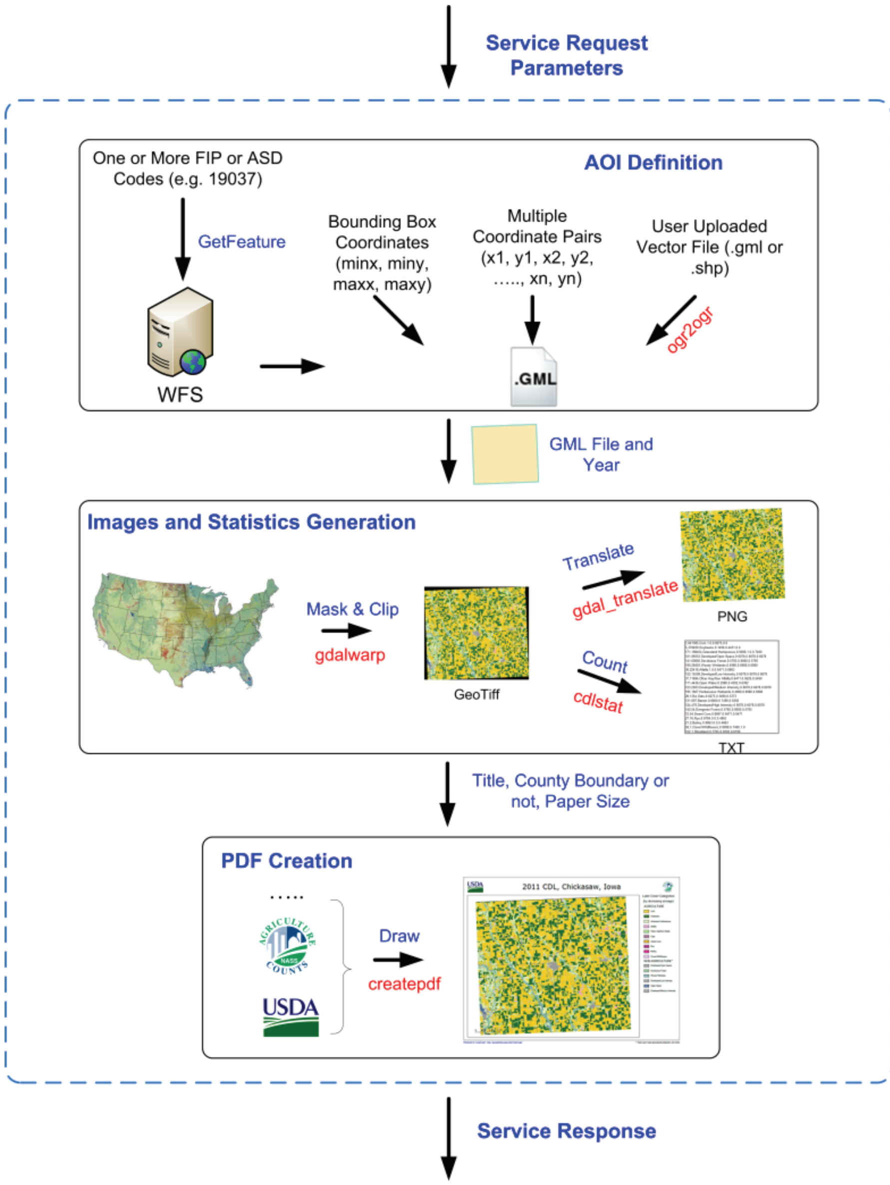

Figure 3. Data processing flow in the web service.

Table 2. Output of *cdlstat* program.

Pixel Value	Pixel Count	Category Name	Color (R, G, B)
1	2777321	Corn	255, 211, 0
5	2404300	Soybeans	38, 113, 0
195	1195780	Herbaceous wetlands	127, 178, 178
171	491624	Grassland herbaceous	232, 255, 191
121	372704	Developed/open space	155, 155, 155
...	...	...	...
6	2582	Sunflower	255, 255, 0

Scape but also offers a convenient and practical method to present land cover information. CDL thematic maps in PDF format also help promote applications of this geospatial cropland product because the maps can be easily displayed, printed, and transmitted. As evidenced by the monthly statistics for PDF map generation and downloading (table 3), this service has been popular among users in the agricultural community since it was released with the 2011 CDL data on 31 January 2012. The operational results of the new service show that the open-source software based implementation is robust and meets the operational requirements of NASS.

USDA-NASS field offices in Idaho, Iowa, and Nebraska have utilized this new web service to create CDL thematic maps for the 2011 crop year in PDF format at county level from CropScape, and their websites provide links to PDF files for all counties for public downloading:

Idaho CDL maps:
www.nass.usda.gov/Statistics_by_State/Idaho/Publications/Special_Reports.

Iowa CDL maps:
www.nass.usda.gov/Statistics_by_State/Iowa/Publications/Cropland_Data_Layer/2011/index.asp.

Nebraska CDL maps:
www.nass.usda.gov/Statistics_by_State/Nebraska/Cropland_Datalayer/2011_Counties/index.asp.

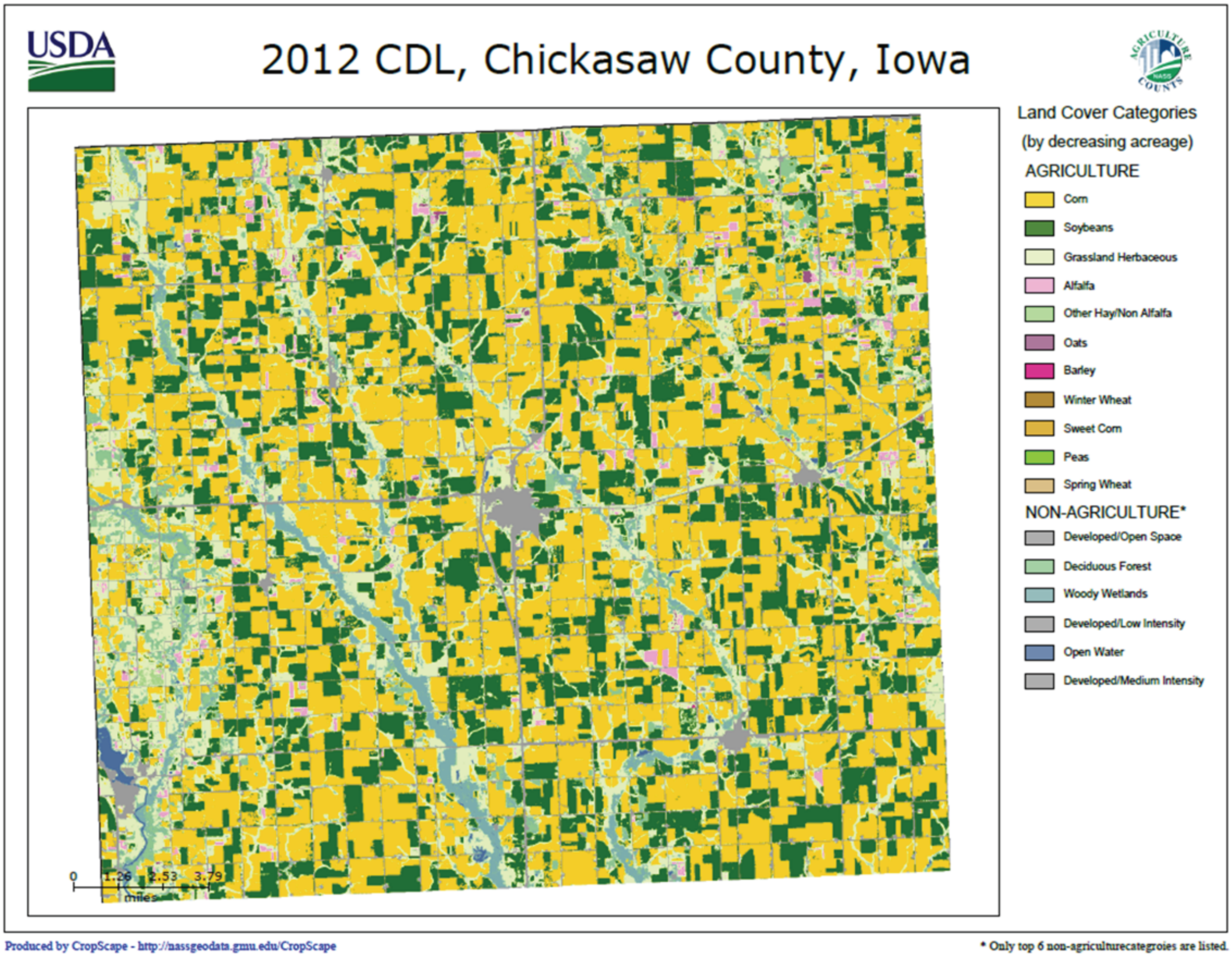

Figure 4. Sample CDL thematic map in PDF format.

```
<?xml version='1.0' encoding='utf-8'?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/">
    <soapenv:Body>
        <ns1:GetCDLPDF xmlns:ns1="http://cropscape.csiss.gmu.edu/CDLService/">
            <year>2011</year>
            <fips>19037</fips>
            <papersize>Letter</papersize>
            <title>2011 Chickasaw County, Iowa</title>
            <boundaryflag>true</boundaryflag>
        </ns1:GetCDLPDF>
    </soapenv:Body>
</soapenv:Envelope>
```

(a)

```
<?xml version='1.0' encoding='utf-8'?>
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/">
    <soapenv:Body>
        <ns1:GetCDLPDFResponse xmlns:ns1="http://cropscape.csiss.gmu.edu/CDLService/">
            <returnURL>
                http://nassgeodata.gmu.edu/nass_data_cache/CDL_2011_19037.pdf
            </returnURL>
        </ns1:GetCDLPDFResponse>
    </soapenv:Body>
</soapenv:Envelope>
```

(b)

Figure 5. SOAP (a) request and (b) response example.

Table 3. Monthly statistics of GetCDLPDF invocation.

Month	State	ASD	County	Self-Defined
Feb. 2012	158	1	400	250
Mar. 2012	44	4	115	147
Apr. 2012	32	2	60	158
May 2012	37	2	3	10
June 2012	15	1	55	71
July 2012	29	6	43	41
Aug. 2012	49	7	28	33
Sept. 2012	25	1	34	52
Oct. 2012	53	3	41	140
Nov. 2012	42	2	125	188
Dec. 2012	19	0	24	158
Jan. 2013	95	23	59	207
Feb. 2013	194	6	279	252
Mar. 2013	75	0	126	340
Apr. 2013	190	1	413	707
May 2013	71	9	175	421
June 2013	172	0	279	568
July 2013	106	133	488	572
Aug. 2013	272	3	323	617
Sept. 2013	380	9	156	441
Oct. 2013	89	0	160	804

Previously, staff at NASS headquarters loaded the CDL data on desktop computers and then used the ArcGIS Desktop tool to subset the CDL data using county boundaries and create a CDL thematic map for each county. That process was laborious, inefficient, and dependent on commercial mapping software. With this new web service, users can obtain on-demand CDL thematic maps for individual counties directly from CropScape without needing to process the geospatial data in traditional mapping software. The custom legend obtained is map-specific based on land cover abundances. Advanced users can specify the CDL data using county FIPS codes for batch tasks in their own programs to produce on-demand CDL thematic maps. This geospatial web service is very helpful for reducing the operational resource requirements and cost for these users.

The CDL thematic maps produced by CropScape have been used in white papers, business plans, technical reports, and other documents for multiple purposes. In their guide to measuring, monitoring, and enforcing temporary water transfers from agriculture, Jones and Colby (2012) highly recommended CropScape as an example of a local real-time tool for agricultural monitoring. A thematic map of the 2011 CDL data for Alamosa County, Colorado, was created in PDF format and included in the guide to display the major crop distribution in the study area. Jones and Colby (2012) used the discovered cropping patterns to estimate fallowed water savings in their research. Farmers also use CDL thematic maps to document their land use. The Save Our Crops Coalition (SOCC) submitted an electronic comment to the U.S. Environmental Protections Agency (EPA) to prevent injury to non-target crops from exposure to 2,4-D and dicamba (SOCC, 2012). In SOCC's submission, a CDL thematic map of a portion of Monroe County, Michigan, produced from CropScape, was used as a supporting example of a typical crop pattern (in this case, a tomato field surrounded by corn and soybean fields) in the Midwest to discuss the potential non-target plant damage caused by drift of dicamba.

Although this new functionality for creating presentation-quality CDL thematic maps has received high praise from the agricultural community, further enhancements suggested by users should be considered in future CropScape improvements, such as allowing more map layers in the thematic map, allowing for more flexibility with the fixed predefined map template (e.g., landscape layout only), and a study of the feasibility of publishing thematic maps in GeoPDF format.

Conclusions

The ability to create online, on-demand CDL thematic maps for a specified AOI, such as an administrative or statistical region, is highly important to many users. However, no open-platform online geospatial application was available with such a functional service. This article describes a geospatial web service approach to address this issue. It presents the design and implementation of this new web service for on-demand CDL thematic map generation in CropScape. This new geospatial web service extends the reach of CDL data and promotes sharing and utilization of geospatial cropland information in agriculture-related decision making. The new web service has proven to be very useful in NASS operations and has been utilized by many members of the agricultural community. It significantly reduces operational resource requirements and cost, and it greatly improves the efficiency of CDL data presentation. The technical aspects of the web service design and implementation described in this article can be adopted in other applications to create thematic maps for other geospatial data (e.g., soil classification data, land capability classification).

This article demonstrates the ability to add capabilities to CropScape based on user input and technological advances. Future plans for the thematic map capability include a WYSIWYG (what you see is what you get) user interface to improve the user experience (Jenny et al., 2010) by directly rendering vector files, and increasing the resolution of the thematic map PDF files to more than 300 dpi (the Cairo Graphics library limit).

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