



Developing an integrated cloud-based spatial-temporal system for monitoring phenology



M. Cope^a, E. Mikhailova^{a,*}, C. Post^a, M. Schlautman^b, P. McMillan^a

^a Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC, USA

^b Environmental Engineering and Earth Sciences, Clemson University, Anderson, SC, USA

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ABSTRACT

Geospatial cloud computing offers computing infrastructure, software and data services that enable rapid integration of ecological data from various resources. The objectives of this study were to utilize readily-available and low-cost technology (e.g., GPS-enabled cameras, Cloud photo storage, Google Drive) to create a cloud-based spatial-temporal inventory of plant (including flowering phenology) and other relevant information. An interactive ArcGIS Online Map of Lake Issaqueena, SC with sampling locations of flowering plants allows users to obtain additional information (plant, soil, weather data) by selecting sampling locations or soil polygons. The contents of the map can be filtered using any of the attributes (e.g., growth form) in the data tables by selecting specific information. Plant information can be viewed at custom time intervals using the settings in ArcGIS Online. Spatial patterns (e.g., clustering) in the plant data can be viewed using the ArcGIS Online heat map view. The map can be easily queried and viewed on both computers and hand-held devices. Services from multiple cloud infrastructures can be integrated for use by various species monitoring programs, improving workflow and assessment capabilities.

1. Introduction

The evolution of informatics and cyberinfrastructures is rapidly transforming how professionals and researchers approach ecological questions and applications (Chaowei et al., 2010). For example, a wealth of geographic data and open source web-mapping services are increasingly being used to support scientific research, decision-making and education in numerous disciplines (Hamilton et al., 2016). Current research indicates a transition to geospatial cloud computing, which offers computing infrastructure, software and data as services that are accessible over an internet connection without needing to purchase or maintain in-house servers (Buyya et al., 2009; Chaowei et al., 2011). These services are now widely available, allowing for rapid integration of data from various resources in interactive map interfaces for use on a range of computing devices (Zastrow, 2015). Additionally, these technologies are being used to create virtual learning environments that are being implemented in various science education curriculums (Muñoz-Cristóbal et al., 2015).

Several studies have described and demonstrated the potential of web-based geographic information systems (GIS) to share and explore ecological data using a client-server approach where the application and data are hosted on a central server. For example, Janicki et al.

(2016) demonstrated the use of large-volume data to create Antmaps.org, an open-source, interactive web-map made from the Global Ant Biodiversity Informatics database. Based on the larger MOL: Map of Life (2016) application, the site hosts a global map of ant species distributions with toggle views for species diversity, species ranges and regional comparisons. Auer et al. (2011) similarly developed a client-server interface designed for exploring distribution ranges of plant species throughout California. Bricker et al. (2016) used the Aquaculture Mapping Atlas (<http://seagrant.uconn.edu/whatwedo/aquaculture/shellmap.php>) to integrate a resource management model that informs site selection for marine aquaculture in Connecticut. Additionally, several plant species monitoring programs, such as Project Budburst (<http://budburst.org/>) and the USA National Phenology Network (<https://www.usanpn.org/>), and plant informational databases such as the USDA Plants Database (USDA, NRCS, 2013), offer basic interactive mapping interfaces online for exploring or retrieving data. Although these are examples of web-based mapping and applications, the primary disadvantages of the client-server approach are the long-term expenses of purchasing and maintaining central servers and the information technology experience needed to make the applications.

Cloud services that offer geospatial computing are making the customized use of web-based GIS capabilities instantly and widely

* Corresponding author.

E-mail address: elianam@clemson.edu (E. Mikhailova).

available by providing cyberinfrastructures for storing, managing and sharing user-generated spatial data. For example, Green et al. (2015) employed novel methods in Google Drive to map an urban tree and soil inventory for the city of Clemson, SC. The U.S. Forest Service developed interactive Story Maps in the cloud-based ArcGIS Online, with one example being a virtual tour of fall tree phenology in the mainland U.S. (USFS, 2017). Similar Story Maps have been published for exploring old growth forests in southwest Oregon (ILCP, 2017), the Adirondack Mountains (The Nature Conservancy, 2017) and sensitive wetland areas in Florida (FDEP, 2017). With the collaborative abilities and instant availability of geospatial cloud computing applications, similar cloud-based techniques will be increasingly used for applications in ecological monitoring, inventorying and information sharing.

Geospatial cloud computing can be utilized for ecological monitoring, inventory and assessment efforts, and studies of flowering phenology have identified the need for new methods of collecting and transmitting large amounts of phenological data with spatial and temporal referencing (Ide and Oguma, 2010; Primack and Miller-Rushing, 2009). One of the challenges is the capture and management of numerous field observations. Pamplin et al. (2016) and Hart et al. (2017) demonstrated the use of cloud-based methods for capturing large numbers of in situ flowering observations at Lake Issaqueena, SC using a GPS-enabled camera and a cloud-based photo service (Google Picasa) for photo storage, annotation and transformation of spatial metadata. However, these studies only demonstrated an organization method but not a system that could be used for web-based visualization and analysis.

Current geospatial cloud computing services are somewhat limited for ecological applications because it is often necessary to link multiple services. For example, Qing et al. (2013) described concepts of “multi-clouds integration” for leveraging services distributed among multiple cloud infrastructures for the creation of new, efficient business process workflows. With the current, publically available services, it is often necessary to manually integrate, or simply migrate and link data between, multiple infrastructures to leverage available services.

The present study develops an integrated, cloud-based spatial-temporal system and demonstrates the use of multiple cloud services for the collection and assessment of the spring flowering plant locations at Lake Issaqueena, SC, using a subset (2014) of the original georeferenced photos collected by Pamplin et al. (2016) and Hart et al. (2017). Specifically, the objectives of this study were to: 1) demonstrate the applicability of low-cost technology, such as GPS-enabled cameras and cloud photo storage, to create a photographic, spatially and temporally referenced inventory of plants; 2) use open source cloud data management platforms to integrate field level location data and photographs with links and information from the PLANTS Database (USDA, NRCS, 2013) and SSURGO databases (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, 2016a, 2016b); and 3) use ArcGIS Online (ESRI, 2013: Redlands, CA version 5.1) to create an interactive, cloud-based map that can be shared and explored on any computer or smart device connected to the internet.

2. Materials and methods

2.1. Study area and phenological monitoring

The Clemson Experimental Forest was established in 1934, and there are currently 17,500 acres dedicated to long-term conservation and research. The forest is located in the foothill region between the Blue Ridge Mountains and the South Carolina Piedmont. Monthly phenological surveys were conducted in 2012, 2013, and 2014 by Pamplin et al. (2016) and Hart et al. (2017). A GPS-enabled Casio EXH20G digital camera was used to photograph plants along the Issaqueena trail which generally follows the edge of the lake. All actively flowering plants that could be sighted and reasonably accessed

Table 1
Data sources and tools.

Data/Tools	Source
Soil maps and data	Web Soil Survey (http://websoilsurvey.sc.egov.usda.gov/)
Soil series descriptions	USDA (https://soilseries.sc.egov.usda.gov/osdname.asp)
Weather data	NOAA (https://www.ncdc.noaa.gov/cdo-web/)
Plant Information	USDA PLANTS Database (http://plants.usda.gov/java/)
Cloud photo storage	Flickr (http://www.flickr.com)
Google Drive	(https://support.google.com/drive/answer/2424384?hl=en)
Floral survey	GPS-enabled photo camera
Web mapping	ArcGIS Online (http://www.arcgis.com/features/)

from the trail were photographed, and GPS coordinates recorded by the camera in Exchangeable Image File (Exif) format with a geographic coordinate system using the World Geodetic System 1984 Datum. This GPS-enabled camera is expected to have a location accuracy of ± 10 m (Kamada et al., 2013). The present study uses selected data from the March, April and May surveys of 2014 (from a three-year study) as an example to demonstrate the approach for a cloud-based spatial-temporal inventory for phenological monitoring and visualization. Data sources and tools are listed in Table 1. Original attribute data headings from the sources listed (Table 1) were used to create the database and web map.

2.2. Cloud photo storage and annotation

A conceptual diagram of the steps used in this study is shown in Fig. 1. Photographs of plants were uploaded to Flickr.com. For the present study, all account privacy settings, including geo-privacy, were set to “public” which allows the pictures and their location to be viewable by anyone. Each plant was identified using the USDA PLANTS Database, previously identified data, and expert knowledge. This identification was recorded in the title of each picture after the original picture ID. The syntax of the picture and species identification in the title was arranged as follows: PhotoID Family Genus Species Common name. It should be noted that spaces may not be ideal delimiters in all situations, but the commands used in later steps of the present study are easily configured to use spaces as delimiters.

2.3. Geodatabase construction and formatting

After photo annotation, the spatial, temporal and identification metadata are first converted from Exif to Keyhole Markup Language (KML) (Google Inc., 2017). The metadata include photo date, time and location as latitude/longitude coordinate pairs. The conversion to KML enables picture viewing in a map interface via a uniform resource locator link (URL) to the picture's webpage, but KML is not always functional across different mapping platforms. Therefore, several steps were taken to simplify the data's structure while maintaining each picture's unique URL. A free online conversion tool (<http://www2.adamfranco.com/photosetToKML.php>) was used to convert photo Exif information to KML. The KML files were individually uploaded to Google Drive, opened in Fusion Tables, and then converted to comma separated value file (CSV) and opened in Google Sheets (Fig. 2). Each picture's URL (in KML format) was transformed to a unique link to the picture's source web page.

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