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Collect Earth: An online tool for systematic reference data collection in land cover and use applications

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ABSTRACT

Land cover monitoring efforts are important for resource planning and ecosystem services in many countries. Collect Earth Online (CEO) is a new, free open source and user-friendly software tool for land monitoring. It is the product of a collaborative effort between NASA, Food and Agriculture Organization of the United Nations (FAO), US Forest Service and Google. This paper provides a full overview of CEO's structure and functionality. Based on the cloud, CEO's structure supports simultaneous data entry by multiple users. No desktop installation is required and only an internet connection is required setting minimal requirements for using the software. Google Earth Engine widgets can be created for assisted plot interpretation such as image collection, time series graphs featuring indices such as Normalized Difference Vegetation Index (NDVI) and related statistics. We also provide a case study and related findings from a CEO workshop held in Myanmar.

1. Introduction

Land cover data plays an indispensable role in policy development, planning, management and other data driven decisions in most sectors (Turner et al., 1995; Lambin et al., 2001; Poortinga et al., 2018). Examples of sectors that use land cover information include, but are not limited to food security (Verburg et al., 2013; Bastiaanssen and Ali, 2003), hydrology modeling (Poortinga et al., 2017; Simons et al., 2016), ecosystem services (Sturck et al., 2014; Troy and Wilson, 2006; Simons et al., 2017) and natural resource management planning. However, consistent and timely information on land cover remains an outstanding issue. Maps are updated infrequently while classification systems do not always meet needs of the user while data is not widely shared among different institutes. Traditional methods to create land cover maps required extensive field research however latest methods use satellite remote sensing (Anderson, 1976; Chen et al., 2012; Margono et al., 2012; Rogan and Chen, 2004). Methods based on this technology still require large amounts of field data, expertise, and can be considered as fairly expensive when high resolution satellite imagery or expensive infrastructure to store and process the data is required. Recent advances in cloud based remote sensing technologies have overcome most technological challenges regarding storage capacity and computing power [e.g. Gorelick et al., 2017, Markert et al., 2018a, Markert et al., 2018b]. Software from FAO such as Collect Earth (Bey

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et al., 2016) enables experts with a minimal background in remote sensing to conduct robust land assessments via interpretation of Very High Resolution satellite imagery (VHR) of any area using free and open source tools. While Collect Earth offers exciting new functionality for land cover mapping, it requires the users to share and regularly update the software and backup the data, which can potentially become bottlenecks especially in the context of resource constrained environments and developing countries.

To address the various concerns in the use cases above, Collect Earth Online (CEO) is a custom built, open-source, high resolution satellite image viewing and interpretation system developed by SERVIR, a joint venture between National Aeronautics and Space Agency (NASA) and the U.S. Agency for International Development (USAID). In this context, CEO was developed for use in projects that require land cover and/or land use reference data. CEO promotes consistency in locating, interpreting, and labeling reference data plots for use in classifying and monitoring land cover/land use change. The full functionality of Collect Earth Online, including collaborative compilation of reference point databases, is implemented online so there is no need for localized desktop installations. The CEO codebase has also been shared with the Open Foris Initiative of the Food And Agriculture Organization of the United Nations. It can be accessed at: http://collect.earth.

This paper presents a detailed overview of Collect Earth's online architecture and data collection features in the following sections. Moreover, an example of data collection in Myanmar is presented with a list of practical guidelines for robust sampling strategies using CEO.

2. User interface

CEO (Fig. 1), is a free and open-source image viewing and interpretation tool. CEO enables simultaneous visual interpretations of various sources of satellite imagery based on cloud computing. The full functionality is implemented online, no desktop installation is required.

2.1. Institutions

After registration on the website, users can create an institution or be added to an existing institution. Within an institution, data collection projects and imagery sources are defined and user roles assigned. The institution page offers space for institution description and for logo upload.

2.2. Users

Users can register as members or institution managers. Institution manager can create projects and collect data, while users can only collect data. The different available user roles are “member” or “admin”. An admin can add users via email invitation. Membership requests to the institution can be changed by admins from pending to a specified user role. Statistics are available for each user for the following categories: speed score, completed plot number, accuracy score for both a project-basis and total, as well as the overall ranking of the user within an institution.

2.3. Imagery

CEO provides global coverage from Digital Globe and Bing Maps, and a variety of data sets from Google Earth Engine. The imagery year can be selected for Digital Globe imagery on the fly, enabling convenient comparison of different years. A variety stacking profiles are available for Digital Globe, focusing on either resolution, minimized cloud cover content, chronology or best color. CEO offers the ability to connect to your own Web Map Service (WMS) or Web Map Tile Service (WMTS), and hence use own imagery for data collection.

2.4. Projects

Projects are created under an institution. Project visibility and accessibility can be set to public, to institution level or to group admins only. These security levels are pre-determined for each project by the project manager. Several publicly available crowd-sourced mapathon projects are featured in the map window on the home screen. Anyone with an internet connection can log into CEO and begin collecting data for public projects. The area of interest for the data collection is either specified in the project setup by drawing a bounding box or by uploading the sample plot locations as csv-file. Plot locations are automatically generated based on the assigned number of plots and plot spacing according to a random or gridded design. Alternatively, predefined plot locations can be uploaded. Each plot contains the actual sample points which are used for data collection. Sample design options are random or gridded distribution, using a user specified number of samples per plot and sample resolution in meters. Analysis in CEO is assisted by the GeoDash, which uses information from Google Earth Engine based on Landsat imagery. The GeoDash can be set up to show time series or an image collection for Normalized Difference Vegetation

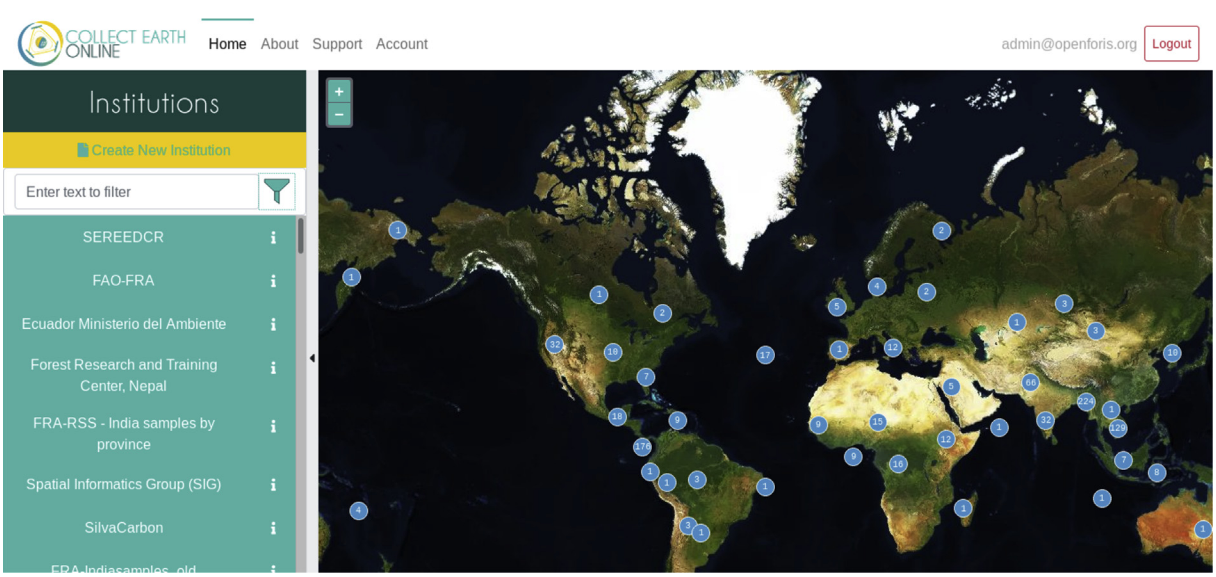

Fig. 1. The interface of Collect Earth Online.

Index, Enhanced Vegetation Index, Enhanced Vegetation Index 2, Normalized Difference Moisture Index, Normalized Difference Water Index or a customized band combination. Project statistics are available in the Project Dashboard page and list members, contributors, the number of total, flagged, unanalyzed and analyzed plots as well as dates. The user specified sampling scheme allows for multi-attribute and hierarchical data collection. Each sample value group consists of a user specified number of sample values and color labels. (In a simple example, a first attribute is “land cover” with options for “tree”, “water” and “other”. A second attribute is “landscape change” containing options for “tree loss”, “tree gain” and “no change”.) Projects can also be set up by copying another project's template.

2.5. Issue reporting

The website contains a link to the Github issues page, which found in the “Support” section and located under https://github.com/openforis/collect-earth-online/issues. Users can get in direct contact with the developer team and report issues or suggest additional features or functionalities. The “Support” section contains also a user manual for CEO.

2.6. Data collection features

The data collection page displays one sample plot, which may contain one or many sample points. The user can choose under Imagery Options from the available imagery datasets, for Digital Globe specific years can be selected as well as the stacking profiles. The Geo-Dash opens in a new browser tab displaying time series, such as NDVI, or an image collection to assist with the interpretation. The user assigns all sample points to the appropriate Sample Values. A plot can be skipped for later analysis, or flagged as bad if the imagery quality is not sufficient for analysis. When all sample points of a plot are interpreted, the points are saved by the user and the next plot appears. Project stats listing the number of assigned, flagged, completed and total number of plots are visible.

3. System architecture

Collect Earth Online's system architecture provides a single uniform web interface that may be linked with multiple database back-ends depending on user needs and technical skill. The web server component of CEO is written in Java 10+, using the Spark library[1] for request routing and Freemarker[2] for HTML templating. The web client component of CEO is written in Javascript/ECMAScript version 6 using React JS[3] for the interactive user interface and OpenLayers[4] for embedded web maps. All front-end and back-end code is written in a functional programming style to keep the code base simple and easy to reason about.

For data persistence, CEO may be run with one of three database back-ends:

- Embedded JSON Database: This option is the simplest to use as it requires no additional software to be installed by the system administrator. It is best suited for small to medium-sized instances.
- PostgreSQL: For greater scalability, performance, and security, CEO may store all of its information in the open source PostgreSQL[5] Object Relational Database Management System. This option is of moderate complexity as it requires the system administrator to install and configure the PostgreSQL database server on the same machine that runs CEO.
- Collect & OF Users Gateways: For direct communication and data sharing with OpenForis' Collect and Calc software tools,[6] CEO may be configured to persist projects and imagery through OpenForis' Collect Gateway and users and institutions through OpenForis' OFUsers Gateway. The two gateways run as independent web applications that should be co-hosted within a Tomcat[7] application server alongside CEO.

3.1. Geodash

The Geo-Dash gives the user a collection of widgets to help identify features and aid in the classification process. These widgets are preconfigured by one of the institution administrators while setting up the project for collection. The administrator can configure the widgets as Image collections, Time series graphs, Statistics, Dual Image collections, or pre-processed image assets. With exception of the basemap imagery, all of the data for the Geo-Dash widgets come from Google Earth Engine which is accessed through the gee-gateway originally developed by the Open Foris team and now jointly maintained.

3.2. Database

Collect Earth Online can use three different back ends to get the data. These are Collect, JSON and PostgreSQL databases. JSON database can be used for medium sized instances and does not need installation and configuration.

For better performance with larger data, PostgreSQL, an Object-Relational Database Management System (ORDBMS) can be used. This database server needs to be installed and configured in the machine that runs Collect Earth Online.

The schema of the PostgreSQL database is shown in the figure Fig. 2. Each table has multiple columns and the tables are related by primary key and foreign key columns. There are database functions that update tables or retrieve data from the tables according to the user's interaction with the interface.

4. Case study

4.1. Overview and study region

Myanmar is a Lower Mekong Region country and is presently in the mandate of both SERVIR-Mekong and SERVIR-HKH hubs. SERVIR is a collaborative project between the USAID and NASA, covering and providing services in themes, namely, “Agriculture and Food Security",“Climate and Weather”, “Landscape and Ecosystems” and “Water and Disasters."

Myanmar's climate is classified as tropical monsoon climate and is characterized by strong monsoon influence. Hence, it has intense rainy periods and high humidity with the annual average temperature ranging from 22 °C to 27 °C. It has over 80 species across the greatest expanse of tropical forest in mainland Southeast Asia, and a biodiversity greater than temperate forests. As such, Myanmar faces deforestation and environmental degradation due to increasing urbanization and development in the country. According to FAO, there was a loss of 19 of forest cover between 1990 and 2010 (FAO and Global forest resources assessment, 2010). In this regard, effective measures are being taken to avert such losses with the development of a land cover monitoring system as a key strategy.

Towards developing a reliable national land cover monitoring system to address rising issues, the Forest Department of Myanmar was

[1] http://sparkjava.com/.
[2] https://freemarker.apache.org/.
[3] https://reactjs.org/.
[4] http://openlayers.org/.
[5] https://www.postgresql.org/.
[6] http://openforis.org.
[7] http://tomcat.apache.org/.

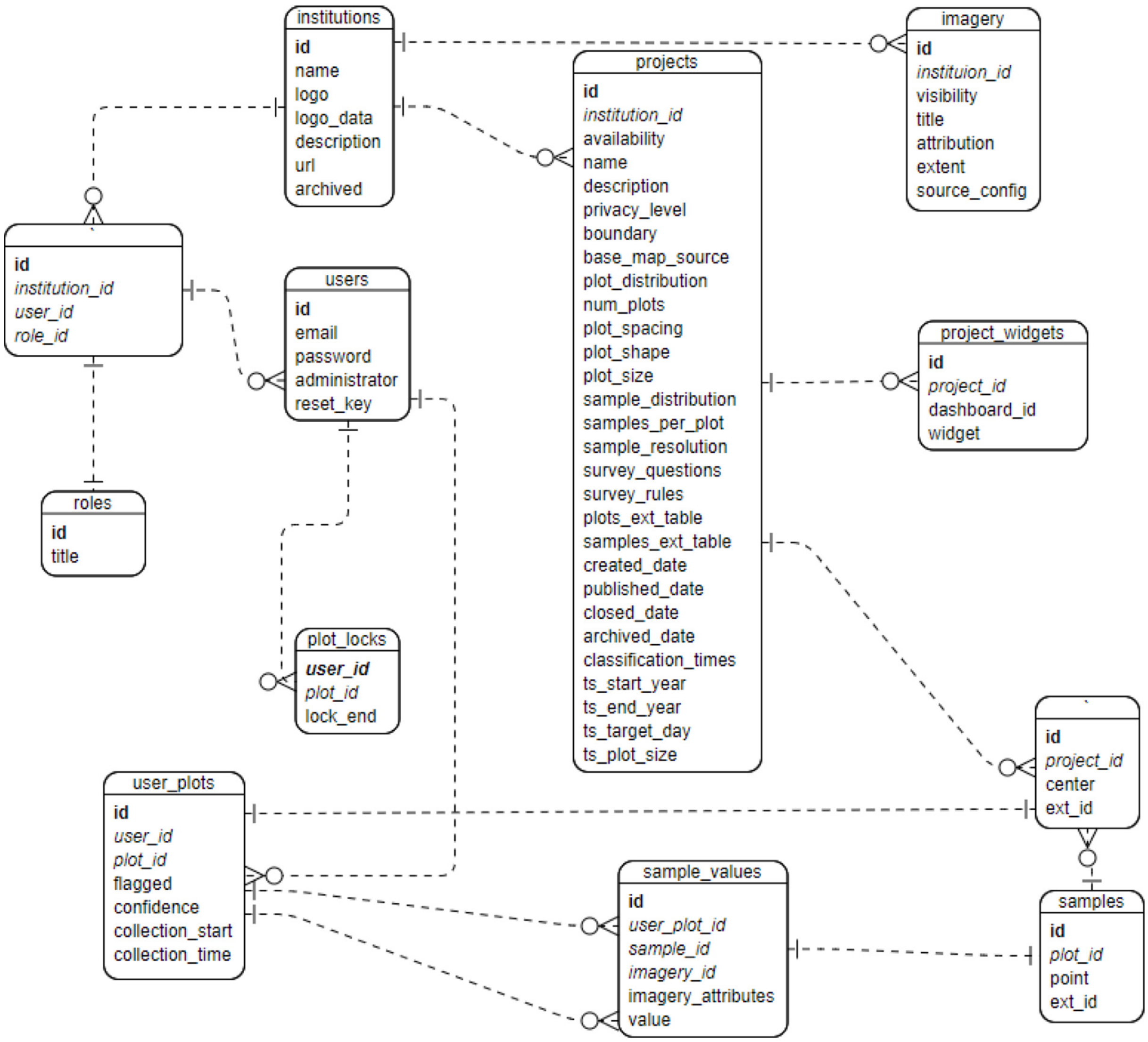

Fig. 2. The Collect Earth Online database design.

involved in a series of stakeholder consultation meetings on land cover mapping with SERVIR-Mekong and -HKH teams. As an outcome of these events, on 17 January 2018, in Nay Pyi Taw, clear needs were indicated for SERVIR-Mekong and -HKH representatives for a national land cover system which will support reporting for Forest Resource Assessment (FRA) to FAO and Intergovernmental Panel for Climate Change (IPCC) reporting to United Nations Framework for Climate Change (UNFCCC) as top priorities.

In order to develop the national land cover monitoring system (NLCMS) which provides high accuracy annual land cover map in the region, SERVIR partnered with multiple stakeholders, including the Forest Department of Myanmar and agreed to work on the following:

- a national land cover monitoring system for Myanmar which can produce accurate LULC baseline datasets, and be updated annually to contribute to UNFCCC reporting
- a high quality national forest type and change map to fulfill the FRA reporting to FAO
- capacity building of technical staff of Forest department and other partners to be able to operate the above systems

In order to start implementing these objectives, a workshop and capacity building training on Land Cover Classification System (LCCS) and Sample data collection using High Resolution images in the Collect Earth Online (CEO) was conducted from June 18–22, 2018 in Nai Pyi Taw, Myanmar. In the first three days, introduction to the LCCS and CEO were provided, while for the rest of the workshop data collection was conducted using CEO. As such, a main objective of the training workshop was training on CEO to collect land cover training sample for national land cover mapping for Myanmar.

4.1.1. *Analysis*

The first (and all subsequent) day's training data were exported from CEO, compiled, and then analyzed to assess concordance or inter-rater agreement. The data tables were imported into R 3.5.0 (R Core Team, 2018) and processed using the tidyr package (v0.8.1) Wickham and Henry (2018), and analyzed using the irr package (v0.84) (Gamer and Jim Lemon, 2012). Plots flagged as unusable were removed from the data. For the small training data sets we calculated iota (ι), a multivariate measure of agreement between raters or interpreters, essentially a generalized form of kappa (Conger, 1980; Janson and Olsson, 2001). In the first two days of data collection, the session started with 20 points which were focused upon with the attendees and their performance was shared with emphasis on difficulties faced in particular classes. At the end of the day, 300 points were further analyzed and ι was determined.

Table 1
Changes in ι, a multivariate metric of agreement between raters.

Day 1 Training Set	Day 1	Day 2 Training Set	Day 2
Points = 20	Points = 300	Points = 20	Points = 300
Raters = 6	Raters = 5	Raters = 4	Raters = 3
ι = 0.519	ι = 0.445	ι = 0.576	ι = 0.581

Table 2
Changes in intraclass correlation coefficient (ICC) between training sessions. Dashes indicate classes with too few non-zero values to calculate.

Class Names	ICC Session 1	ICC Session 2	Change
Forest Tree	0.4195	0.5983	0.1788
Mangrove	0.4336	0.7651	0.3314
Grass	0.142	0.146	0.004
Shrub	0.2966	0.4724	0.1758
Plantation Orchard	0.3171	0.4143	0.0973
Crop	0.4988	0.5075	0.0087
Paddy Rice	0.1377	0.4757	0.338
Impervious	0.4015	0.8628	0.4613
Built Tree	0.3049	0.5733	0.2684
Built Vegetation	−0.005	−0.0014	0.0035
Barren	0.2997	0.3163	0.0166
Rocky Mountain	0.4063	0.7049	0.2986
Mining	0	–	–
Water	0.8775	0.9511	0.0736
Wetlands	0.2403	−0.0039	−0.2442
Aquaculture Pond	0.4987	−0.0022	−0.5009
Aquatic Vegetation	0.0824	0.2748	0.1924
Snow	0.6809	0.6507	−0.0301
Other	0	–	–
Unknown	−0.0052	−0.0022	0.003

After each session's data was processed and metrics were calculated, the data was reviewed to find plots that showed the most disagreement. A slide was created for each plot, showing an image of the plot and how it had been interpreted by each group, along with a set of brief discussion points and tips on how to improve interpretation of similar plots. A brief internal document detailing the overall performance of the workshop participants, what types of errors seemed to be most common, and how those errors might be addressed was also produced. The presentation and internal report were used to provide feedback to the participants at the beginning of the following day over the course of the workshop.

As indicated by findings shown in Table 1, the additional trainings on particularly challenging classes helped. For the overall data set collected each day, interclass correlation coefficients (ICC) for each land cover class were calculated for each of the 20 classes in addition and shown in Table 2 (Bartko, 1966). Here too, improvement in the ICC for most classes are indicated as the training and data collection were conducted in tandem. The overall number of plots collected in the workshop was 2669 across 20 classes.

5. Discussion

Providing specific feedback tailored directly to the previous day's performance appears to have generated improvement in agreement between image interpreters. After the initial training, groups worked with a larger set of plots, and agreement suffered considerably, with many classes having poor agreement (<0.4), as shown in Table 2. After reviewing their previous work and receiving tips on how to improve performance, the score associated with both the training and subsequent larger data sets also improved. Many classes saw their ICC improve by 0.2 or more. Several of the very rare classes saw negative changes in their ICC scores, likely due to a majority of, but not all, groups changing how they assigned plots to those groups. Two classes, "Mining" and "Other" had no plots assigned to them during the second cross validation set, and as such no ICC could be calculated.

Some amount of improvement over the course of the workshop may also have been due to easier communication among the smaller number of participants, as some participants left and the number of groups decreased.

A notable issue in the training was the lack of reliable internet connectivity. The participants relayed that interruptions of this service hampered their learning and work flow during the sessions. In contrast to Collect Earth Desktop, this limitation requires careful consideration, especially in the context of applicability of CEO in resource constrained environments.

Overall, the findings indicate that preparatory sessions help in facilitating CEO data collection, especially for users who are unfamiliar with the interface and do not have appropriate background in remote sensing.

6. Conclusion

CEO is a new, free, open source and user-friendly software tool for land monitoring, which is important for resource planning and ecosystem services across the globe. This paper provides a full overview of CEO's structure and functionality, where We have summarized software features and present user case studies to illustrate the application of the tool. It is the product of a collaborative effort between NASA, Food and Agriculture Organization of the United Nations (FAO), US Forest Service and Google. CEO enables crowd-sourced visual interpretation with satellite imagery such as DigitalGlobe and Bing Maps and the ability to connect to user WMS/WMTS feeds. CEO is based on the cloud which supports simultaneous data entry by multiple users, requiring minimal requirement of an internet connection.

One of CEO's functionalities include Google Earth Engine widgets. These can be calculated for plot interpretation such as image collection, time series graphs featuring indices such as NDVI and compute related statistics. Non-expert users can analyze over 100 sites/day using a fairly simple classification scheme. In this work, the data collection process is described, comprising sample point classification, multi-attribute options, toggling between imagery years as well as data export and analysis options.

To showcase a recent application, We present information and user experiences from a crowd sourced CEO mapathon hosted in collaboration with Forest Department, Myanmar as part of service delivery by SERVIR-Mekong and SERVIR-HKH hubs. We present salient findings including increased performance of CEO in land cover typology classification for improving reference data collection after delivery of key training procedures.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envsoft.2019.05.004.

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