GLOBE Observer Data: 2016-2019

Helen Marie Amos[1], Matthew J Starke[2], Tina M Rogerson[3], Marilé Colón Robles[3], Travis Andersen[4], Rebecca Boger[5], Brian Campbell[6], Russanne Low[7], Peder Nelson[8], David Overoye[9], Jessica E Taylor[3], Kristen L Weaver[2], Trena M Ferrell[2], and Holli Kohl[2]

[1]National Aeronautics and Space Administration
[2]NASA Goddard Space Flight Center
[3]NASA Langley Research Center
[4]University Center for Atmospheric Research
[5]Brooklyn College
[6]NASA Wallops Flight Facility
[7]IGES
[8]Oregon State University
[9]Science Systems and Applications, Inc.

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Abstract

This technical report summarizes the GLOBE Observer dataset from 1 April 2016 to 1 December 2019. GLOBE Observer is an ongoing NASA-sponsored international citizen science project that is part of the Global Learning & Observations to Benefit the Environment (GLOBE) Program. GLOBE Observer is the largest citizen science project in the Earth Science Division at NASA. Participants use the GLOBE Observer mobile app (launched in 2016) to collect atmospheric, hydrologic, and terrestrial observations. 38,000 participants have contributed 320,000 observations worldwide, including 1,000,000 geotagged photographs. It would take an individual more than 13 years to replicate this effort. Comparing the same data types between the GLOBE Observer app and the formal GLOBE Program, the app doubled data volume and substantially increased geographic coverage over the study period. GLOBE Observer data are publicly available at observer.globe.gov.

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[1] NASA Goddard Space Flight Center, Greenbelt, Maryland, USA
[2] Science Systems and Applications, Inc., Lanham, Maryland, USA
[3] NASA Summer Internship Program Participant, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA
[4] NASA Langley Research Center, Hampton, Virginia, USA
[5] Science Systems and Applications, Inc., Hampton, Virginia, USA
[6] GLOBE Implementation Office, University Corporation for Atmospheric Research, Boulder, Colorado, USA
[7] Brooklyn College, Earth & Environmental Sciences, New York, New York, USA
[8] NASA Wallops Flight Facility, Wallops Island, Virginia, USA
[9] Global Science & Technology, Inc., Greenbelt, Maryland, USA
[10] Institute for Global Environmental Strategies, Boulder, Colorado, USA
[11] Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, Corvallis, Oregon, USA
[12] Science Systems and Applications, Inc., Pasadena, California, USA

*Corresponding author: Helen Amos (helen.m.amos@nasa.gov). ORCiD: 0000-0002-0297-6643

Key Points

- GLOBE Observer is a mobile app from NASA used worldwide by citizen scientists to collect Earth system observations.
- 38,000 participants have submitted 320,000 observations – including 1,000,000 geotagged photographs – from all seven continents.
- It would take an individual more than 13 years to replicate the same sampling effort.

Plain language summary

GLOBE Observer is a NASA citizen science app that gives anyone with a smartphone or table the opportunity to share what they see in the sky and on the landscape around them. GLOBE Observer is available for free from Google Play and the Apple App Store. Since 2016, tens of thousands of people around the world have taken hundreds of thousands of observations. An individual scientist would have to work non-stop for more than 13 years to make the same number of observations. All of the data sent through GLOBE Observer goes into a worldwide database that's made freely available to everyone at observer.globe.gov. This article describes how the GLOBE Observer app works and shows what three years of data look like.

Abstract

This technical report summarizes the GLOBE Observer dataset from 1 April 2016 to 1 December 2019. GLOBE Observer is an ongoing NASA-sponsored international citizen science project that is part of the Global Learning & Observations to Benefit the Environment (GLOBE) Program. GLOBE Observer is the largest citizen science project in the Earth Science Division at NASA. Participants use the GLOBE Observer mobile app (launched in 2016) to collect atmospheric, hydrologic, and terrestrial observations. 38,000 participants have contributed 320,000 observations worldwide, including 1,000,000 geotagged photographs. It would take an individual more than 13 years to replicate this effort. Comparing the same data types between the GLOBE Observer app and the formal GLOBE Program, the app doubled data volume and substantially increased geographic coverage over the study period. GLOBE Observer data are publicly available at observer.globe.gov.

1. Introduction

The Global Learning and Observations to Benefit the Environment (GLOBE) Program is an international science and education program that launched in 1995 (globe.gov) (Berglund, 1999; Finarelli, 1998; Means, 1998; Muller et al., 2015; Nugent, 2018; Rock et al., 1997) GLOBE Observer is a NASA-funded citizen science project that is part of the GLOBE Program (observer.globe.gov). The NASA GLOBE Observer mobile app was launched in 2016 and was created to broaden the opportunities for the general public to contribute to GLOBE as citizen scientists and increase the spatiotemporal density of observations. Through the GLOBE Observer app, participants in GLOBE countries (globe.gov/globe-community/community-map) can contribute ground-based atmospheric, terrestrial, and hydrologic observations complementing NASA's suite of airborne and spaceborne observing platforms. Previous publications have analyzed subsets of GLOBE Observer data associated with specific sampling events (Aïkpon et al., 2019; Colón Robles et al., 2020; Dodson et al., 2019). This paper presents the first summary and analysis of the 2016-2019 GLOBE Observer citizen science dataset and discusses areas for future improvement.

2. GLOBE Observer mobile app

The GLOBE Observer (GO) app is a NASA-funded citizen science app available free-of-cost in the Apple App Store and Google Play Store (observer.globe.gov/get-the-app). The GO app was designed as a tool for the general public to collect and submit data without extensive training or external equipment. The app is written in Javascript, HTML, and CSS, utilizes the AngularJS framework, and is built using Apache Cordova for deployment to multiple platforms (i.e., iOS and Android). GO observations are publicly available at observer.globe.gov. GLOBE has built free on-line tools to visualize the data on a world map and download as a zipped keyhole markup language (kmz) file (vis.globe.gov), retrieve data as a comma separated value (csv) file (datasearch.globe.gov), and an application programming interface (API) to facilitate automated or command line data queries (api.globe.gov/search/).

The GO app currently accepts observations of clouds, mosquito breeding habitats, land cover, and tree heights. There is also a temporary tool for solar eclipses, which was activated in the app for a limited time for the 2017 North American solar eclipse (Dodson et al., 2019) and again for the 2019 South American solar eclipse (GLOBE Observer, 2019). For every observation, date, time, latitude, and longitude are automatically recorded from the internal clock and GPS receiver of the participant's device. Participants answer a series of six yes/no questions about surface conditions that affect satellite retrievals (e.g., presence of snow or ice on the ground), then photograph and classify what they see (e.g., cloud type). Additional detail about the tools in the app are in GLOBE (2019a). **Figure 1** shows a schematic of the app flow.

Participants can opt-in to notifications on their device when certain cloud-observing satellites (Aqua, Terra, and CALIPSO) are flying over their location. Participants who make a cloud observation within 15 minutes of a satellite overpass, and who have opted-in to receive emails, receive a personalized email with their cloud observation alongside the satellite observation. The satellite matching is performed by a team at NASA Langley Research Center and also includes matching to geostationary satellites: GOES, Meteosat, and Himawari. A description of the satellite matching process is given in Colón Robles et al. (2019). Between 1 January 2017 and 1 December 2019, 203,000 GO cloud observations have been matched to satellite observations. GLOBE clouds data with satellite matches for 2017-2019 is publicly available (observer.globe.gov/get-data/cloud-data).

3. GLOBE Observer data: 2016-2019

Figures 2 and 3 show the geographic coverage of observations made using the app. As of December 2019, 170,000 users have created accounts on the app, and 38,000 users have submitted 320,000 observations from all seven continents. Assuming (1) it takes a participant five minutes to go outside, find a suitable sampling location, and complete an observation with the GLOBE Observer app and (2) an average work year has 2000 hours, it would take an individual person 13 work years and 5 months to collect the same number of observations. That is equivalent to more than $1 million (USD) in salary paid to a PhD-level scientist, assuming a GS-12 step 1 pay grade for fiscal year 2019 (opm.gov), and does not include the cost of sampling equipment or the extensive travel it would require to visit the same locations.

Figure 2 contrasts the spatial distribution of observations submitted through the GLOBE Observer app and through the traditional GLOBE channels. The app has increased the geographic coverage of GLOBE observations. Some geographic gaps in the coverage exist and will persist in countries which are not participating GLOBE countries. Similar to other international citizen science projects, North America and Europe are the most intensely observed regions (e.g., iNaturalist; Chandler et al. (2017)). Notable increases in geographic coverage enabled by the app include India, west Africa, South America, and Australia.

Figure 3 shows locations of observations from each app tool individually. Each tool was introduced to the app at a different time. In total, participants have submitted 290,000 cloud observations (since April 2016), 19,000 mosquito habitat observations (since May 2017), 8,400 land cover observations (since September 2018), and 9,500 tree height observations (since March 2019). For comparison, 350,000 cloud, 1,500 land cover, and 3,000 tree height observations have been collected and submitted to GLOBE over the same time periods through traditional methods that do not use the GLOBE Observer app. GLOBE formerly supported a pen-and-paper version of a mosquito larva observation protocol that is now inactive; 1100 observations were submitted between 4 October 2015 and 9 August 2019.

The geographic variability in data coverage among the different app tools illustrated in **Figure 3** is multi-factorial. The success of a tool in the app is connected in part to the size of the active GLOBE community prior to a tool's launch in the app. For example, GLOBE schools submitted 87,000 cloud observations in the 12 months prior to the launch of the cloud tool in the app, versus only 1,100 land cover observations submitted in the 12 months prior to the launch of land cover in the app. The difference in activity level seen in traditional GLOBE persists with the app; 35x more cloud observations than land cover observations have been submitted through the app. Another factor driving app activity is internal data collection campaigns, such as the three-year (2018-2021) *Trees around the GLOBE* campaign (GLOBE, 2020). To illustrate this point, the tree height tool in the app has been available for half the time of the land cover tool, but tree heights observations are submitted through the app at twice the rate (1400 tree height observations per month versus 650 land cover observations per month, on average). In **Figure 3**, there are also notable examples on the map of externally-driven data collection in Australia (Australian Scouts), the Arctic, and the Southern Ocean (Polar Collective, polarcollective.org; (Colón Robles et al., 2018)). GLOBE trainings are third influential factor. In **Figure 3**, a striking example of the mark of GLOBE trainings are the hotspots of mosquito observations in Thailand (GLOBE, 2019b), Benin (Aïkpon et al., 2019), and Brazil (mosquito.strategies.org), where extensive trainings took place as a result of a US State Department initiative.

The Clouds tool drawing in an order of magnitude more observations merits further discussion here. Cloud observations are more numerous and ubiquitous in part simply because the clouds tool has been in the app longest (2.75 years versus 7 months for the trees tool). Clouds are also a more ubiquitous natural phenomena that change on the order of hours (versus seasonal timescales of change for land cover), providing more opportunities to observe. Other important contributing factors include the well-organized volunteer base and outreach materials GLOBE inherited from the NASA Students' Cloud Observations On-Line (S'COOL) project, which seeded a community of GLOBE teachers collecting clouds data before the app launched (Chambers et al., 2017; Chambers et al., 2003). Within the app, Clouds is currently the only tool participants can opt-in to receive notifications of NASA satellite flyovers to their phone and have their satellite matches emailed to them (Colón Robles et al., 2019).

Figure 4 shows the number of observations submitted per day through the GLOBE Observer app. Large, organized outreach efforts can have a demonstrable impact on data volume and spatiotemporal coverage, such as in the cases of the 2017 North American total solar eclipse (Dodson et al., 2019; Rahman et al., 2019; Weaver et al., 2019) and the 2018 GLOBE Spring Cloud Challenge (Colón Robles et al., 2020; Hayden et al., 2019). Not all outreach efforts produce similar increases in data. A recent example is the 2019 South American solar eclipse (GLOBE Observer, 2019). The absence of a significant effect may be attributable to lack of concurrent NASA promotion (e.g., the 2017 solar eclipse was bolstered by NASA-wide promotion), geographic domain of the eclipse transit, and historically lower user engagement in the region. By most metrics, the 2018 Cloud Challenge has outperformed all other outreach events and is closely examined in Colón Robles et al. (2020). In one month, the 2018 Spring Cloud Challenge brought in 56,000 observations and attracted data submissions from 5800 new, unique app users. The GLOBE Program as a whole has experienced a sustained increase in daily submissions since. App users during the 2018 Spring Cloud Challenge used the app in a unique way and reported wildfire smoke, extreme haze, and dust storms affecting their areas, with photographs of these phenomena. In 2019, a Fall Cloud Challenge was organized (15 October 2019 – 15 November 2019) promoting sky observations like those unique reports of smoke, haze, and dust storms with a guide on how to enter them on the app (Colón Robles, 2019). The 2019 Fall Cloud Challenge, with little media promotion compared to the 2018 Spring Cloud Challenge, still resulted in over 45,000 observations in 93 countries and attracted data submissions from 2100 new, unique app users.

Figure 5 shows the diurnal distribution of submissions coming through the GLOBE Observer app. Cloud observation submissions are the dominant driver. The peak around 11:00UTC is driven by participation in Europe. The peak around 18:00 UTC is driven by North America and coincides with (1) timing of GLOBE Observer social media posts and (2) Aqua flyovers on the East Coast of the United States. In contrast, traditional data submissions from GLOBE peak between 9:00-11:00 UTC and the unimodal distribution is skewed towards the school day in the Middle East. Prior to 2016 and the app, GLOBE suggested cloud observations be done at local solar noon and many traditional GLOBE schools continue this today. The Saudi Kingdom does not currently support use of the GLOBE Observer app, but very actively contributes cloud observations through traditional GLOBE channels.

Photographs, while qualitative, are a valuable asset to the GLOBE database because they provide visual evidence of reported phenomena (e.g., landslides, haboobs, *Aedes aegypti* mosquito larvae) that can be independently verified by data end-users. Here the considerable benefit the GLOBE Observer app brings to the GLOBE Program is the ubiquity of built-in cameras in modern smartphones. Participants have contributed 1,000,000 geotagged photos with the GLOBE Observer app between 1 April 2016 and 1 December 2019, compared to 100,000 photos from traditional GLOBE during the same period. GLOBE Observer photos include

940,000 cloud photos; 45,000 land cover photos; 8200 tree photos; 15,000 photos of aquatic mosquito habitats and 5800 photos of mosquito larvae.

Figure 6 shows the percentage of participants who submit cloud or land cover photos. Cloud and land cover are used for comparison here because they both include the same six standard photos (north, south, east, west, up, down). Taking photographs is optional for participants, but strongly encouraged. The app's design has evolved to encourage a greater percentage of participants to take photos with their observation. In the Clouds tool (released in 2017), participants classify cloud types and then take photographs. For clouds, 41% of cloud observations include all six photos and 77% include at least one photo. In the Land Cover tool (released in 2018), the app's flow was reversed so that participants take photographs first and then classify land cover types. As a result, 80% of land cover observations include all six photos and 95% include at least one. In both cases of clouds and land cover, we find participants are most likely to omit the down photo (i.e., looking straight at the ground). The reason for the systematic omission is not entirely understood. A modification to the app may remedy the issue (e.g., pop-up message when the down photo is omitted).

4. Data quality and limitations

Figure 7 shows the percent of observations submitted through the app flagged by quality checks. The system of quality flags presented here was developed and piloted in summer 2019 and has not yet transitioned to be operational. The flags are an adaptation of Foody et al. (2017), which is an adaptation of ISO 19157 Standard Quality Measures, and of traditional GLOBE range and logic checks (GLOBE, 2019a). The suite of flags check for logical consistency, temporal quality, and geospatial quality. Between April 2016 and December 2019, we find 7.8% of all GLOBE Observer app observations were flagged compared to 13% of observations submitted through traditional GLOBE channels. Of the total flagged observations, more than half are flagged for potentially being over water. In most cases, a participant is recording an observation on a ship (clouds only) or at a coastline.

The set of flags HC, OD, OP, OR, or OX (see **Figure 7** caption for definitions) checks for logical consistency around reports of haze or other obscurations in the sky. These results are consistent with anecdotal participant feedback that it is confusing in the app how to correctly report the presence of haze, smoke, and dust. The flag set MR and NR checks reported mosquito larvae and contrail counts for unexpectedly large values (e.g., mosquito larvae count = 1,000,000). ER checks that the reported elevation is between 6000 m and -300 m (GLOBE, 2019a). Observations flagged ER were measured over the ocean where a negative elevation is returned reflecting the ocean bathymetry. Data consumers are advised to use caution with such flagged data in statistical analyses. For both sets of flags, modest revisions of the app's design could potentially remedy the data quality issue.

The most commonly triggered flag, "LW", checks if an observation might be reported over ocean and is intended to alert data consumers to potentially erroneous locations. Here we use Cartopy's 50-m resolution earth geometry for the land/ocean mask. In the app, a participant's location is automatically displayed on a map using the mobile device's GPS, but a participant may manually re-locate their position marker on the map. Most of the flagged observations are taken along a coastline or are cloud observations reported aboard a ship (see The Polar Collective in Section 3). A small number (<0.05%) of tree, land cover, and mosquito observations over open ocean appear truly erroneous. This may be due to location "spoofing" by a participant to obscure their location (Zhao & Sui, 2017), or reported performance issues with the app's map function when a participant is in offline mode (i.e., without cellular or wifi signal).

A limitation of GO data not captured in **Figure 7** is unclassified observations. Classifying cloud type, land cover type, or mosquito genus is optional in the app. If a participant chooses not to perform classifications, any photos submitted will be missing detailed identifying labels/tags and therefore of limited searchability. Cloud type is classified only 68% of the time, land cover type 43%, and mosquito genus only 14%.

5. Lessons Learned

Several lessons have been learned about participant photos. Outreach messaging coming from GLOBE O a majority of participants will take photos and a much smaller percentage will complete the in-app classification. End-users of the data have expressed a strong preference for observations that include photos. A mechanism for scientists to ask participants to take photos at a particular time, location, phone orientation, or of a particular phenomenon is highly requested. Taken together, this suggests outreach messaging and in-app user experience should pivot and optimize for targeted data collection photo-taking. Photo labeling could be crowdsourced on a platform like Zooniverse to assemble a training dataset for AI-assisted image classification (e.g., (Fortson et al., 2018); Willi et al. (2019)). AI-assisted image classification could facilitate rapid in-app feedback to participants and would increase the information content available for research. Early work using Amazon's Rekognition™ AI software is in progress by the GLOBE Data Information Systems (DIS) team.

Cloud satellite matching is popular with participants and is being leveraged in research to a greater extent than any data product (Ault et al., 2006; Chambers et al., 2017; Colón Robles et al., 2020; Dodson et al., 2019). Satellite matching is performed by a team at NASA Langley Research Center with the goal of combining ground-based and space-borne perspectives to increase the amount of information about a single cloud scene. The analysis here adds to the growing body of evidence supporting the value of satellite matching. Since 2017, 203,000 observations have been matched to Aqua, Terra, CALIPSO, GOES, Himawari, and Meteosat satellite retrievals. We find here that the GLOBE Observer dataset contains two orders of magnitude more cloud observations than any other type of observation. We also find satellite overpasses contribute to peak submission times over the course of a day. This suggests that the expansion of satellite matching to the mosquito (GPM – Global Precipitation Mission), land cover (MODIS/Landsat), and tree height (ICESat-2) tools in the app could be a worthwhile investment for the GLOBE Observer project team. The satellite matching component has been an effective way to engage citizen scientists with larger NASA missions and provides co-located, independent data that can be leveraged in research.

6. Conclusions

GLOBE Observer is a NASA-sponsored international citizen science project (observer.globe.gov) that is part of the Global Learning & Observations to Benefit the Environment (GLOBE) Program founded in 1995 (globe.gov). This article presents the first summary of the GLOBE Observer dataset. GLOBE Observer launched a mobile app in 2016 for Android and iPhone devices that anyone in a participating GLOBE country can use to make observations (including photographs) of cloud cover and cloud type, mosquito breeding sites and mosquito species, land cover type, and tree height.

Between 1 April 2016 and 1 December 2019, 38,000 participants have submitted 290,000 cloud, 19,000 mosquito, 8400 land cover, and 9500 tree observations spanning all seven continents. This represents as 1.91-fold increase in data volume in the GLOBE Program's database for these four protocols over the period of April 2016-December 2019 and a substantial expansion in geographic coverage. The majority of observations are submitted from Europe and North America between the hours of 11:00-18:00 UTC. About half as many GLOBE Observer observations (7.8%) as traditional GLOBE observations (13%) are flagged for quality; in both cases, the most likely reason for an observation to be flagged is for the location potentially being over water. GLOBE Observer data are made publicly available for everyone (observer.globe.gov) and offer a novel ground-based dataset to augment space-borne, air-borne, and *in situ* Earth observations. Analysis of the data here suggest the satellite matching for clouds is a notably successful feature. The data suggest expansion of satellite matching to the land cover, mosquitoes, and tree app tools; and optimization for targeted photo-taking could be productive avenues of development.

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Data availability

GLOBE Observer data are publicly available at observer.globe.gov. The Python code to read, analyze, and visualize GLOBE data for this article is available at https://github.com/helenmamos/Amos2020_GLOBE.

References

Aïkpon, R., Dramane, G., Klotoé, J. R., Brettenny, M., Lawani, Y., Aïkpon, G., & Yadouléton, A. (2019). Assessment of population dynamics and biting trends of Aedes aegypti in northern Benin: Public health implications. *International Journal of Entomology Research, 4*(3), 57-62.

Ault, T. W., Czajkowski, K. P., Benko, T., Coss, J., Struble, J., Spongberg, A., Templin, M., & Gross, C. (2006). Validation of the MODIS snow product and cloud mask using student and NWS cooperative station observations in the Lower Great Lakes Region. *Remote Sensing of Environment, 105*(4), 341-353. https://doi.org/https://doi.org/10.1016/j.rse.2006.07.004

Berglund, K. (1999). World Wide Weather: Involving students in GLOBE's real-life scientific research. *Science & Children*, 5. https://www.nsta.org/store/product_detail.aspx?id=10.2505/4/sc99_037_03_31

Chambers, L. H., McKeown, M. A., McCrea, S. A., Martin, A. M., Rogerson, T. M., & Bedka, K. M. (2017). CERES S'COOL Project Update: The Evolution and Value of a Long-Running Education Project with a Foundation in NASA Earth Science Missions. *Bulletin of the American Meteorological Society, 98*(3), 473-483. https://doi.org/10.1175/bams-d-15-00248.1

Chambers, L. H., Young, D. F., Costulis, P. K., Detweiler, P. T., Fischer, J. D., Sepulveda, R., Stoddard, D. B., & Falcone, A. (2003). The CERES S'COOL Project. *Bulletin of the American Meteorological Society, 84*(6), 759-766. https://doi.org/10.1175/bams-84-6-759

Chandler, M., See, L., Copas, K., Bonde, A. M. Z., López, B. C., Danielsen, F., Legind, J. K., Masinde, S., Miller-Rushing, A. J., Newman, G., Rosemartin, A., & Turak, E. (2017). Contribution of citizen science towards international biodiversity monitoring. *Biological Conservation, 213*, 280-294. https://doi.org/https://doi.org/10.1016/j.biocon.2016.09.004

Colón Robles, M. (2019). See a dust storm? Submit your photos with the GLOBE Observer app. *The GLOBE Program*. 5 July 2019, accessed 25 February 2020, https://www.globe.gov/web/marile.colonrobles/home/blog/-/blogs/58493073

Colón Robles, M., Amos, H. M., Dodson, J. B., Bouwman, J., Rogerson, T. M., Bombosch, A., Farmer, L., & Taylor, J. E. (2020). Clouds around the world: How a simple data challenge became a worldwide success. *Bulletin of the American Meteorological Society*. https://doi.org/https://doi.org/10.1175/BAMS-D-19-0295.1

Colón Robles, M., Farmer, L., Dodson, J. B., Tackett, J. L., Cruickshank DeFontest, C., Ivey, K., Rogerson, T. M., & Taylor, J. E. (2018). Citizen science cloud observations compared to near ground cloud observations from CALIPSO and MODIS satellite data over the Drake Passage. American Geophysical Union Fall Meeting, Washington, DC.

Colón Robles, M., Rogerson, T. M., & Dodson, J. B. (2019). *NASA GLOBE Clouds: Documentation on How Satellite Data is Collocated to Ground Cloud Observations (v1.0)*. https://www.globe.gov/web/s-cool/home/satelitte-comparison

Dodson, J. B., Robles, M. C., Taylor, J. E., DeFontes, C. C., & Weaver, K. L. (2019). Eclipse across America: Citizen Science Observations of the 21 August 2017 Total Solar Eclipse. *Journal of Applied Meteorology and Climatology, 58*(11), 2363-2385. https://doi.org/10.1175/jamc-d-18-0297.1

Finarelli, M. G. (1998). GLOBE: A Worldwide Environmental Science and Education Partnership [journal article]. *Journal of Science Education and Technology, 7*(1), 77-84. https://doi.org/10.1023/a:1022588216843

Foody, G., See, L., Fritz, S., Mooney, P., Olteanu-Ramond, A.-M., Costa-Fronta, O., & Antonou, V. (2017). Mapping and the Citizen Sensor. In G. Foody, L. See, S. Fritz, P. Mooney, A.-M. Olteanu-Ramond, O. Costa-Fronta, & V. Antonou (Eds.), *Mapping and the Citizen Sensor*. Unbiquity Press. https://doi.org/https://doi.org/10.5334/bbf.a

Fortson, L., Wright, D., Lintott, C., & Trouille, L. (2018). Optimizing the Human-Machine Partnership with Zooniverse. *arXiv*. Retrieved 26 February 2020, from https://ui.adsabs.harvard.edu/abs/2018arXiv180909738F

GLOBE. (2019a). GLOBE Data User Guide v1, GLOBE-19-001, NASA Goddard Space Flight Center, https://www.globe.gov/globe-data/globe-data-user-guide.

GLOBE. (2019b). GLOBE Thailand Engages in Series of 2018-2019 Trainings to 'Shut Down Mosquito Population' and Reduce Threat of Mosquito-borne Disease. 29 May 2019, accessed 25 February 2020, https://tinyurl.com/v3enycq

GLOBE. (2020). *Trees around the GLOBE*. accessed 4 February 2020 from https://www.globe.gov/es/web/trees-around-the-globe/overview/community

GLOBE Observer. (2019). Eclipse 2019 in South America. accessed 25 February 2020, https://observer.globe.gov/en/news-events-and-people/events/obseventsdetail/19589576/eclipse-2019

Hayden, L., Taylor, J., & Robles, M. C. (2019). GLOBE: Connecting to Community of Observers Directly to NASA Satellites *IEEE Geoscience and Remote Sensing Magazine, 7*(1), 98-99. https://doi.org/10.1109/MGRS.2019.2891930

Means, B. (1998). Melding Authentic Science, Technology, and Inquiry-Based Teaching: Experiences of the GLOBE Program. *Journal of Science Education and Technology, 7*(1), 97-105. https://doi.org/10.1023/A:1022592317752

Muller, C. L., Chapman, L., Johnston, S., Kidd, C., Illingworth, S., Foody, G., Overeem, A., & Leigh, R. R. (2015). Crowdsourcing for climate and atmospheric sciences: current status and future potential. *International Journal of Climatology, 35*(11), 3185-3203. https://doi.org/10.1002/joc.4210

Nugent, J. (2018). Cloudy with a chance of "cirrus" science: NASA Globe Observer Clouds. *Science Scope, 42*(2), 26-27.

Rahman, I. U., Czajkowski, K., Jiang, Y., & Weaver, K. (2019). Validation of GLOBE Citizen Science Air Temperature Observations Using Data from the Great American Solar Eclipse. In *Celebrating the 2017 Great American Eclipse: Lessons Learned from the Path of Totality* (Vol. 516, pp. 501-509). Astronomical Society of the Pacific.

Rock, B. N., Blackwell, T. R., Miller, D., & Hardison, A. (1997). The GLOBE Program. In K. C. Cohen (Ed.), *Internet Links for Science Education: Student—Scientist Partnerships* (Vol. 4, pp. 17-30). Springer US. https://doi.org/10.1007/978-1-4615-5909-2_3

Weaver, K., Kohl, H., Martin, A., & Burdick, A. (2019). How Cool Was the Eclipse? Collecting Earth Science Data With Citizen Scientists and GLOBE Observer. In *Celebrating the 2017 Great American Eclipse: Lessons Learned from the Path of Totality* (Vol. 516, pp. 511-524). Astronomical Society of the Pacific.

Willi, M., Pitman, R. T., Cardoso, A. W., Locke, C., Swanson, A., Boyer, A., Veldthuis, M., & Fortson, L. (2019). Identifying animal species in camera trap images using deep learning and citizen science. *Methods in Ecology and Evolution, 10*(1), 80-91. https://doi.org/10.1111/2041-210x.13099

Zhao, B., & Sui, D. Z. (2017). True lies in geospatial big data: detecting location spoofing in social media. *Annals of GIS, 23*(1), 1-14. https://doi.org/10.1080/19475683.2017.1280536

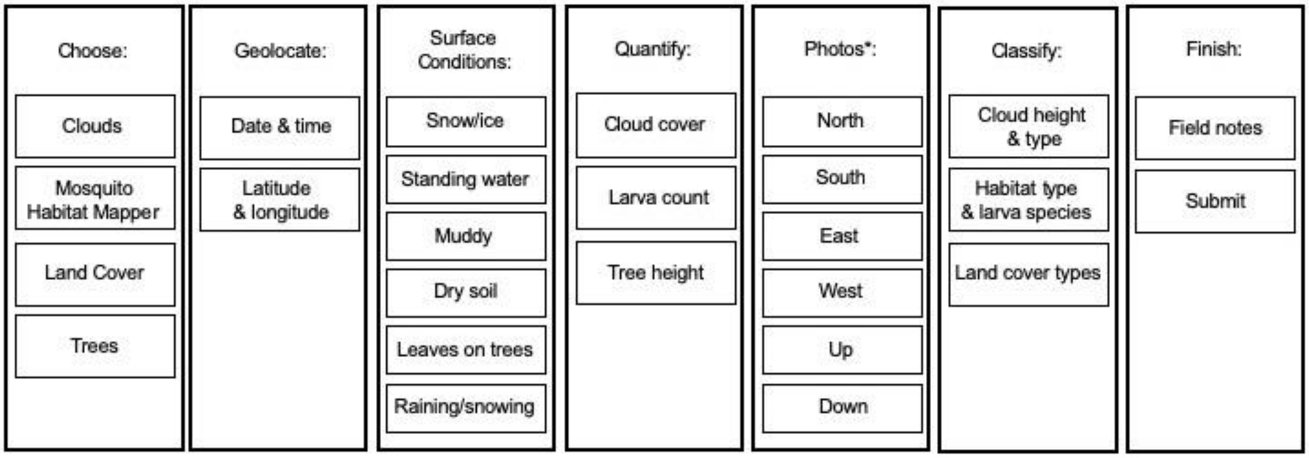

Figure 1. General components of the NASA GLOBE Observer mobile app. The flow of the app is from left to right, beginning with the participant choosing the kind of observation they wish to make. Cloud and land cover photos are taken in four cardinal directions, plus up (sky) and down (ground) as depicted. For tree height, the observation includes a single photograph of the tree. For mosquitoes, the observation can include photographs of the habitat (e.g., discarded tire) and multiple photos of the larva's head, abdomen, and/or full body.

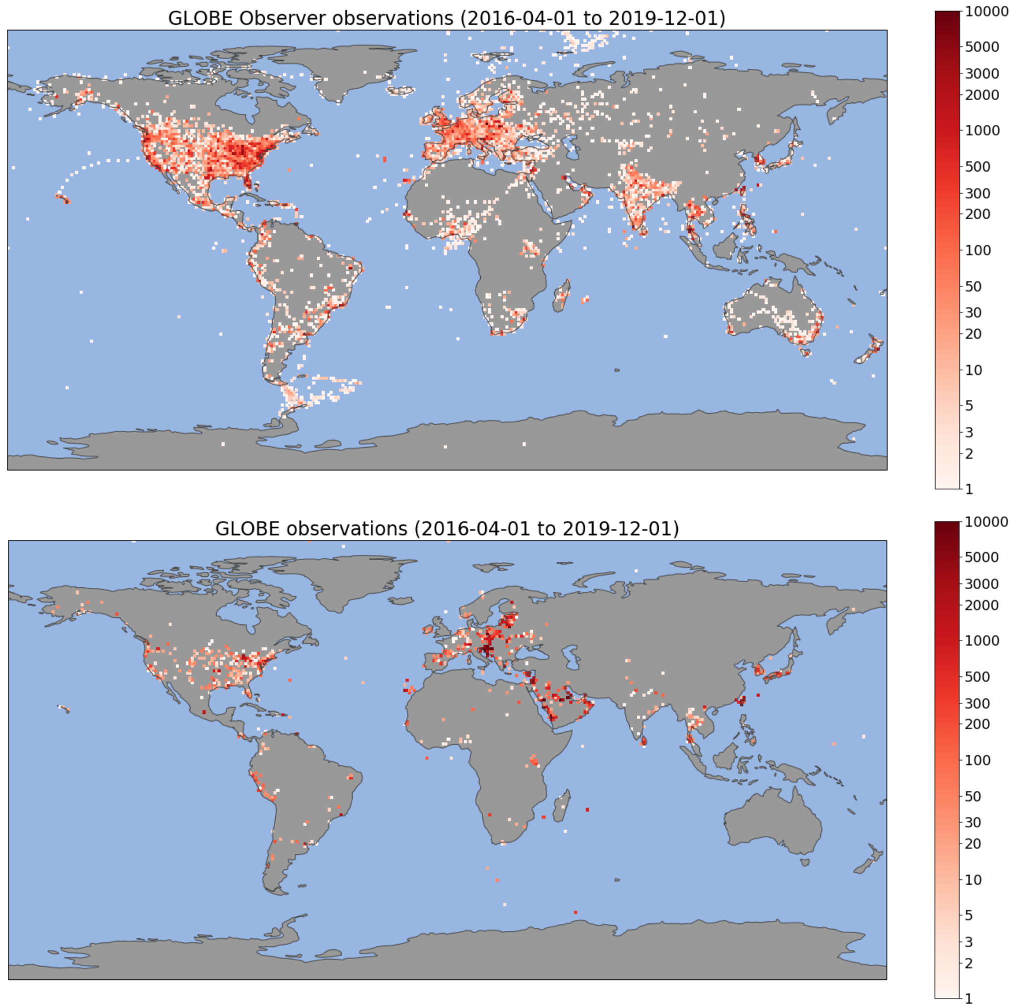

Figure 2. Heatmap of observations submitted via the NASA GLOBE Observer mobile app (top) and traditional channels of GLOBE (bottom) from 1 April 2016 to 1 December 2019. Includes observations from the GLOBE Observer Clouds, Mosquito Habitat Mapper, Land Cover, and Trees tools and equivalent GLOBE protocols.

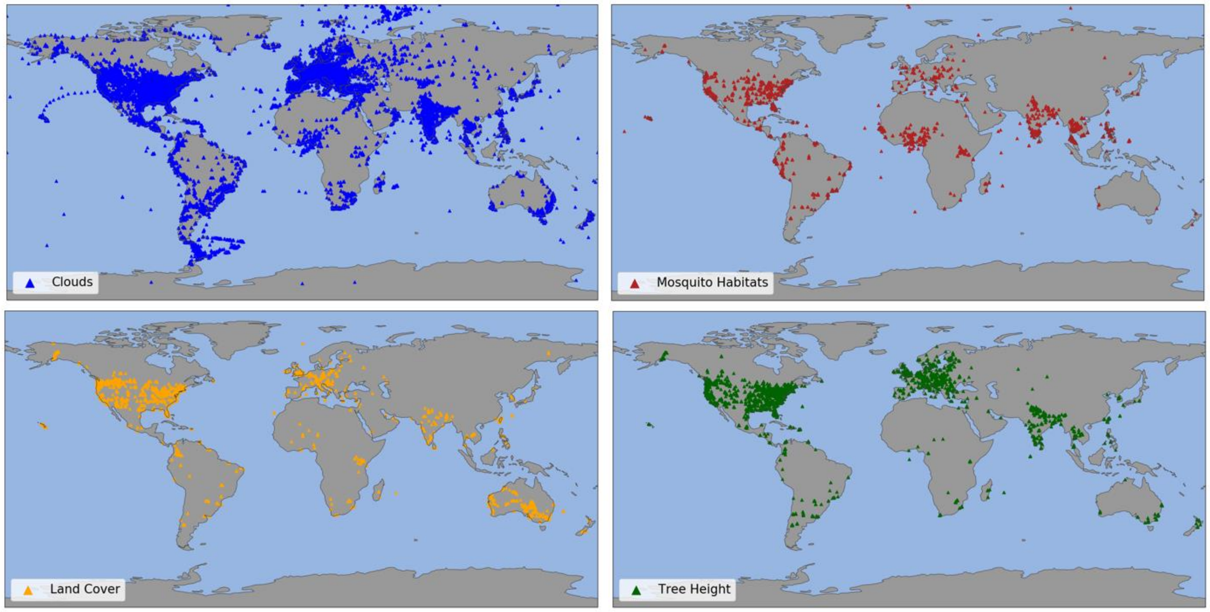

Figure 3. Location of observations made using the NASA GLOBE Observer mobile app from 1 April 2016 to 1 December 2019.

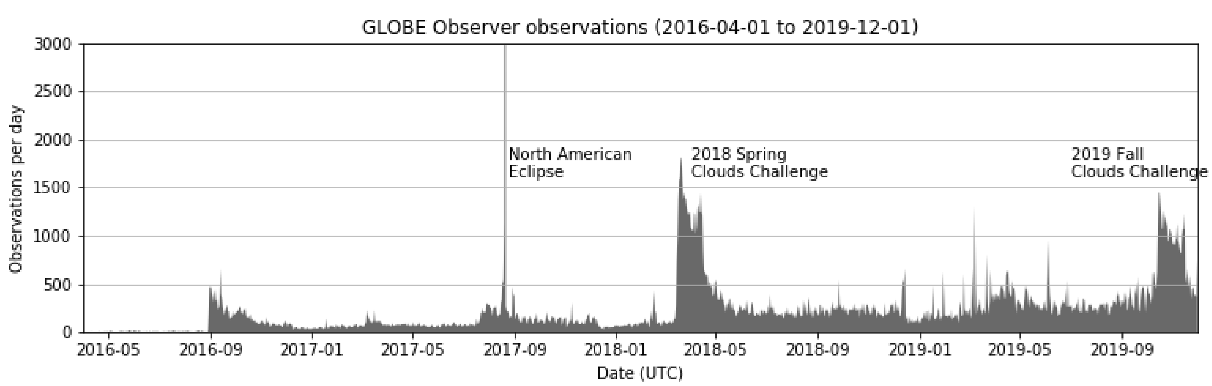

Figure 4. Timeseries of observations made with the NASA GLOBE Observer mobile app from 1 April 2016 to 1 December 2019. Includes observations from the GLOBE Observer Clouds, Mosquito Habitat Mapper, Land Cover, and Trees tools. The y-axis is cut off at 3000 observations per day, but on the day of the 2017 North American Total Solar Eclipse more than 18,000 observations were submitted with the GLOBE Observer app.

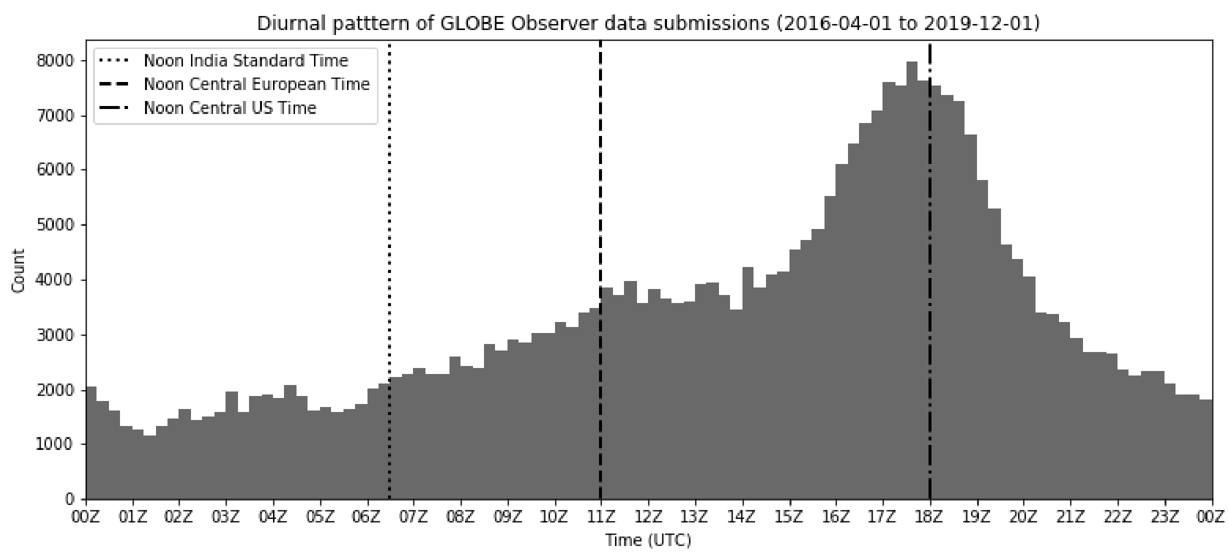

Figure 5. Diurnal frequency of data submissions through the GLOBE Observer mobile app. Includes observations from the GLOBE Observer Clouds, Mosquito Habitat Mapper, Land Cover, and Trees tools during the period 1 April 2016 to 1 December 2019.

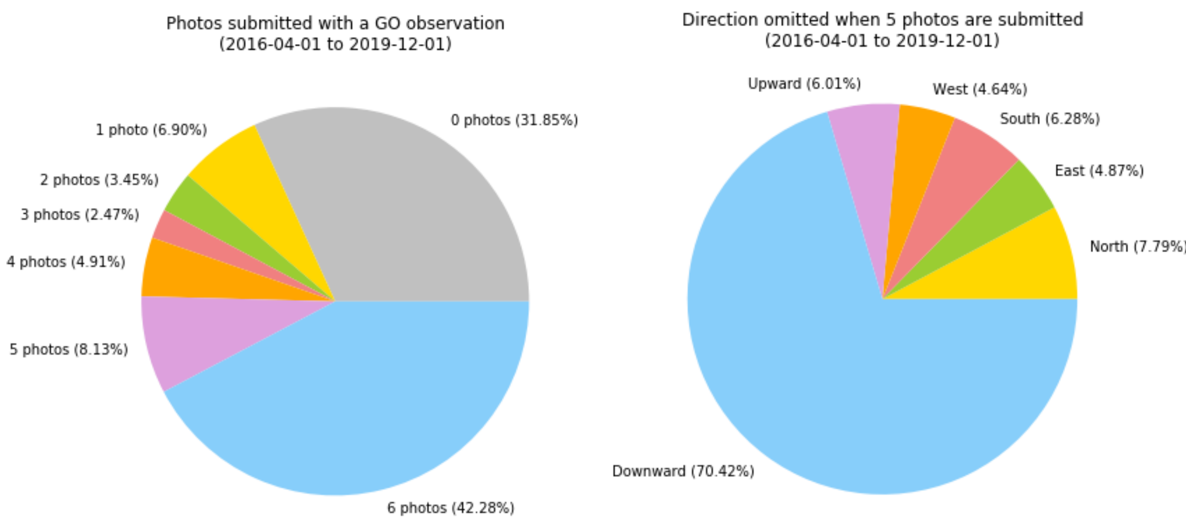

Figure 6. Number and direction of photos submitted with GLOBE Observer clouds and land cover observations between 1 April 2016 and 1 December 2019.

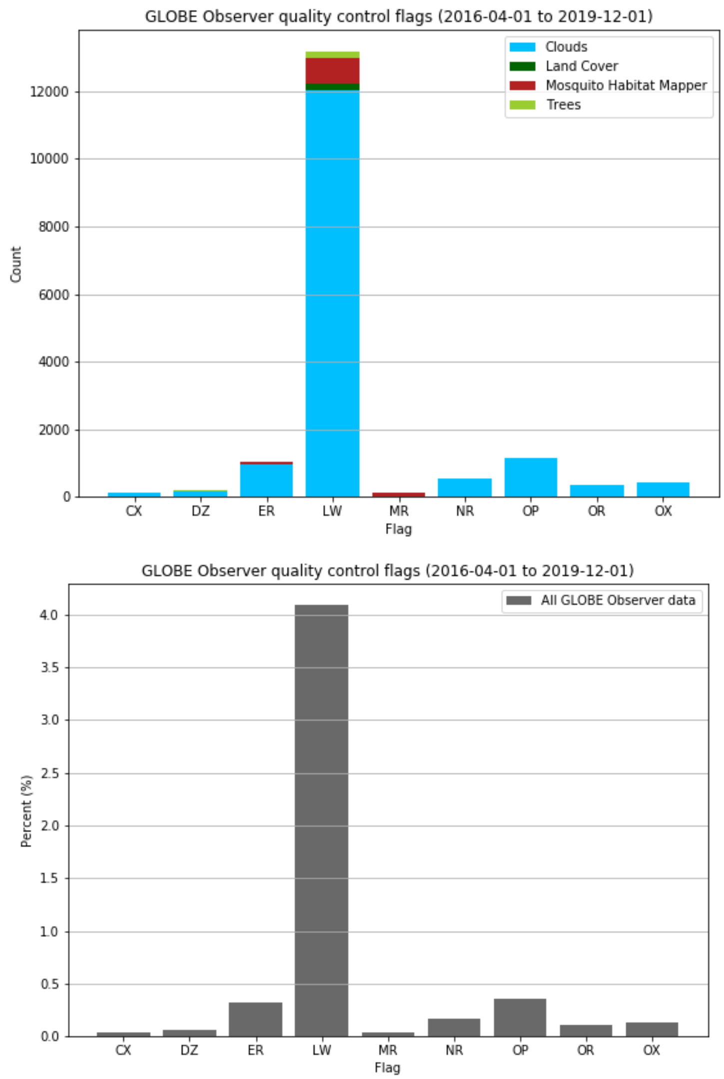

Figure 7. Total number (top) and percent (bottom) of flagged GLOBE Observer observations between 1 April 2016 and 1 December 2019. **CX** = cloud cover is blank (clouds only); **DZ** = datetime is 00:00:00 UTC; **ER** = elevation out of range; **LW** = location may be over water; **MR** = mosquito count is outside expected range [0, 199] (mosquitoes only); **NR** = total number of contrails is outside expected range [0, 19] (clouds only); **OP** = sea spray reported over land (clouds only); **OR** = three or more obscuration types reported; **OX** = sky reported as obscured, but no obscuration type selected (clouds only).