Clouds around the World
How a Simple Citizen Science Data Challenge Became a Worldwide Success

Marilé Colón Robles, Helen M. Amos, J. Brant Dodson, Jeffrey Bouwman, Tina Rogerson, Annette Bombosch, Lauren Farmer, Autumn Burdick, Jessica Taylor, and Lin H. Chambers

ABSTRACT: Citizen science is often recognized for its potential to directly engage the public in science, and is uniquely positioned to support and extend participants' learning in science. In March 2018, the Global Learning and Observations to Benefit the Environment (GLOBE) Program, NASA's largest and longest-lasting citizen science program about Earth, organized a month-long event that asked people around the world to contribute daily cloud observations and photographs of the sky (15 March–15 April 2018). What was considered a simple engagement activity turned into an unprecedented worldwide event that garnered major public interest and media recognition, collecting over 55,000 observations from 99 different countries, in more than 15,000 locations, on every continent including Antarctica. The event was called the “Spring Cloud Challenge” and was created to 1) engage the general public in the scientific process and promote the use of the GLOBE Observer app, 2) collect ground-based visual observations of varying cloud types during boreal spring, and 3) increase the number and locations of ground-based visual cloud observations collocated with cloud-observing satellites. The event resulted in roughly 3 times more observations than during the historic and highly publicized 2017 North American total solar eclipse. The dataset also includes observations over the Drake Passage in Antarctica and reports from intense Saharan dust events. This article describes how the challenge was crafted, outreach to volunteer scientists around the world, details of the data collected, and impact of the data.

https://doi.org/10.1175/BAMS-D-19-0295.1
Corresponding author: Marilé Colón Robles, marile.colonrobles@nasa.gov
In final form 10 February 2020
©2020 American Meteorological Society
For information regarding reuse of this content and general copyright information, consult the AMS Copyright Policy.
The 2018 NASA Global Learning and Observations to Benefit the Environment (GLOBE) Clouds Spring Data Challenge (or Spring Cloud Challenge) was a citizen science event that collected a total of 55,639 ground-based visual cloud observations by engaging participants from more than 15,000 locations in 99 countries, on every continent, including Antarctica (Fig. 1). The event asked citizen scientists (including students, teachers, and the general public) from all around the world to take up to 10 ground-based visual cloud observations per day from 15 March through 15 April 2018 using with an assurance that the top observers per geographical regions would receive a shout-out from a NASA scientist. Observations for the Spring Cloud Challenge were collected through the GLOBE Program; a science and education program that promotes community investigation of their local environment to inform global understanding (Finarelli 1998; Berglund 1999; Muller et al. 2015). The GLOBE Program is sponsored by NASA and is supported by the U.S. Department of State, the National Science Foundation, and the National Oceanic and Atmospheric Administration (NOAA). The University Corporation for Atmospheric Research (UCAR) manages the GLOBE Program’s Implementation Office. The GLOBE Program’s vision is a worldwide community of students, teachers, scientists, and citizens working together to better understand, sustain, and improve Earth’s environment at local, regional, and global scales. Over 120 countries have formal agreements to participate in the GLOBE Program, and since its inception, it has leveraged the professional expertise of both scientists and educators in developing the program. Data collection protocols were developed by scientists and teachers and create the foundation of the GLOBE Program’s data collection so that everyone collecting data follows the same scientific procedure and instrument specification, as necessary. The GLOBE Program also provides robust learning activities aligned to each protocol and made available in different languages.

The GLOBE Program began on Earth Day 1995 and for nearly 25 years has invited students in countries around the world to

---

1 The National Academies of Science, Engineering, and Medicine defines citizen scientist as nonscientists or people who are not professionally trained in the methods and standards of research of the selected citizen science project (National Academies of Sciences, Engineering, and Medicine 2019).
collect environmental data. In 2016, the program debuted the GLOBE Observer mobile app (GLOBE Observer 2019; Nugent 2018), a citizen science mobile app created to engage the wider public, including the GLOBE Program’s alumni (adults who previously participated in the GLOBE Program as students), in the collection of data using a mobile device. Special consideration has been made to determine which GLOBE Program’s protocols should be made available on the GLOBE Observer citizen science mobile app. For example, only data collection that requires no- or low-cost instrumentation is in the app so as to ensure accessibility. In the case of the existing GLOBE Observer tools (clouds, mosquito habitat mapper, land cover, and tree height), the phone or electronic device becomes part of the instrumentation to assist in consistent photographic evidence or, as in the case with trees, the phone becomes a clinometer. The GLOBE Program’s cloud protocol is historically the most popular protocol as your eyes are all the only instruments you need to collect observations of the sky. Ground-based visual cloud observations, when possible, are collocated to the nearest overpass times of geostationary satellites (GOES-15, GOES-16, Meteosat-8, Meteosat-11, or Himawari-8), or to Clouds and the Earth’s Radiant Energy System (CERES) instruments onboard Aqua and Terra, or the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite. If a citizen scientist makes an observation at the same time and location as the satellite’s measurements, a personalized e-mail from NASA is then sent to the participant. The satellite overpasses and personalized emails are part of the successful Students’ Cloud Observations Online (S’COOL) Project (Chambers et al. 2003; Chambers et al. 2017) that merged with The GLOBE Program in 2016, creating NASA GLOBE Clouds (www.globe.gov/web/s-cool). The GLOBE Clouds team at NASA Langley Research Center produces the satellite overpass schedules and sends roughly 4,000 emails per month to participants. The e-mail contains a link to a satellite match table displaying the person’s observations alongside the satellite collocation results, which include the actual satellite images of the collocation results (GLOBE 2019c; Hayden et al. 2019). Students and the general public can engage and learn about how satellites study Earth’s atmosphere by reading the results on the table and also through the visual analysis of the satellite images, available at the bottom of the table (GLOBE 2019d). These collocations of ground-based visual cloud observations and satellite derived observations, as well as data documentation guides, are freely available for each latitude and longitude on the GLOBE Observer website (https://observer.globe.gov/get-data/cloud-data). All data collected through the GLOBE Program are freely accessible through multiple data accessing tools (https://observer.globe.gov/get-data). The GLOBE Program has received over 550,000 citizen science ground-based visual cloud observations since 2017 from 34,000 schools and over 140,000 citizen scientists across 121 countries. Periods of intense observations, like the Spring Cloud Challenge, increase the amount of data received during the challenge; this is followed by an increase in the baseline of data received throughout the rest of the year (Fig. 2).

The Spring Cloud Challenge dataset contains a collection of ground-based visual cloud observations collocated to satellite data, with accompanying sky photographs that can be used for satellite validation, contrail investigations, or comparisons of cloud types in different parts of the world. Each cloud observation includes information on cloud fraction, obscuration (sand, fire, haze, dust, volcanic ash, sea spray, fog, and heavy rain or snow) and surface conditions (e.g., snow or ice on the ground). Reports may also include the following optional observations: sky color; sky visibility; cloud type(s); number and type(s) of contrail (short lived, persistent, persistent spreading); and the observed opacity of cloud layers reported at low, mid-, and high altitudes (Table 1).

This event aligns with recent call from Moss et al. (2019) for broader use of citizen science projects in climate science and assessment. In addition to building community awareness and public engagement, the GLOBE Clouds data are being used to study contrails and
Table 1. GLOBE Clouds required and optional fields for participating citizen scientists with examples of photographs that can accompany the observations.

<table>
<thead>
<tr>
<th>Observation</th>
<th>Detailed options</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cloud cover</td>
<td>No clouds, few (&lt;10%), isolated (10%–25%), scattered (25%–50%), broken (50%–90%), overcast (90%–100%)</td>
<td>Yes</td>
</tr>
<tr>
<td>Obscuration (if &gt;25% sky cover)</td>
<td>Sand, spray, smoke, dust, haze, blowing snow, heavy rain, fog, volcanic ash</td>
<td>Yes</td>
</tr>
<tr>
<td>Sky color (if &lt;50% cloud cover)</td>
<td>Deep blue, blue, pale blue, light blue, milky</td>
<td>No</td>
</tr>
<tr>
<td>Sky visibility (if &lt;50% cloud cover)</td>
<td>Unusually clear, clear, somewhat hazy, very hazy, extremely hazy</td>
<td>No</td>
</tr>
<tr>
<td>Cloud types by height</td>
<td>High: short-lived contrails, persistent contrails, persistent spreading contrails, cirrus, cirrostratus, cirrocumulus Middle: altostratus, altocumulus Low: fog/stratus, nimbostratus, stratocumulus, cumulus, cumulonimbus</td>
<td>No</td>
</tr>
<tr>
<td>Opacity by height</td>
<td>Opaque, transparent, translucent</td>
<td>No</td>
</tr>
<tr>
<td>Cloud cover by height</td>
<td>No clouds, few (&lt;10%), isolated (10%–25%), scattered (25%–50%), broken (50%–90%), overcast (90%–100%)</td>
<td>No</td>
</tr>
<tr>
<td>Surface condition</td>
<td>Yes/no: snow/ice, standing water, muddy, dry ground, leaves on tress, raining/snowing</td>
<td>Yes</td>
</tr>
<tr>
<td>Photographs</td>
<td>App assists in directional photos: north, south, east, west, up, and down</td>
<td>No</td>
</tr>
</tbody>
</table>

Fig. 2. Total number of ground-based visual cloud observations received through the GLOBE program per day from January 2017 to December 2019. Three big intensive observation periods are evident within the number of observations received per day, the North American total solar eclipse on 21 Aug 2017 (labeled A), the Spring Cloud Challenge (15 Mar–15 Apr 2018; labeled B), and the Fall Cloud Challenge (15 Oct–15 Nov 2019; labeled C).
contrail types (Duda et al. 2009; Colón Robles et al. 2019a), evaluate the NASA Goddard Earth Observing System (GEOS) model (Starke et al. 2019), investigate marine haze over the Southern Ocean (Colón Robles et al. 2018), and augment sparse ground-based monitoring data on dust events (see “Unanticipated scientific observations: Drake Passage and intense Saharan dust event” section). Dodson et al. (2019) tested the robustness of these ground-based visual cloud observations collected through the GLOBE Program during the total solar eclipse over North America in 2017. Through the use of a Monte Carlo–style sampling test, demonstrated the utility of an analysis methodology that takes advantage of the large volume of observations to compensate for variability in reporting among volunteer citizen scientists.

**Data collection.** There are two modes within the GLOBE Program's data collection. The first mode applies the GLOBE Observer mobile app available for iPhone and Android devices ([https://observer.globe.gov/about/get-the-app](https://observer.globe.gov/about/get-the-app)). The app contains tutorials, data collection, and data submission. The second mode of data collection is a pen-and-paper mode of data collection done by schools around the world. A printable data sheet with steps on how to make ground-based visual cloud observations (GLOBE 2019e) is available for teachers to use with students. The information collected is then entered using one of the various GLOBE program’s data entry options ([www.globe.gov/globe-data/data-entry](http://www.globe.gov/globe-data/data-entry)). This pen-and-paper mode of data collection contributed 27.7% of the Spring Cloud Challenge observations, while 72.3% of the observations came from the GLOBE Observer app. Classroom teachers must complete the GLOBE Program’s training for the protocol either online or in-person before becoming certified to collect and contribute observations through the pen-and-paper data collection mode. Teachers then train their students and supervise student data collection. Even though the GLOBE Observer app was designed for the general public, teachers have been integrating the app into the classroom (Colón Robles et al. 2019c) to collect and submit ground-based visual cloud observations. Traditionally, teachers use other modes of data collection and entry (e.g., pen-and-paper data collection, desktop data entry to an online web form; see details at [www.globe.gov/globe-data/data-entry](http://www.globe.gov/globe-data/data-entry)). The clouds tool inside the GLOBE Observer app mirrors the pen-and-paper version of the GLOBE Clouds protocol. GLOBE Observer app users can choose to receive notifications on their phones about upcoming NASA *Terra/Aqua* or *CALIPSO* satellite overpasses at their location and can opt to receive a “satellite match” e-mail if their observation coincides with the overpass. The GLOBE Observer app is also used by formally GLOBE-trained classroom teachers and students, but the bulk of the app users are anonymous volunteer citizen scientists. Through the GLOBE Observer app, citizen scientists step through a series of questions, following the GLOBE Clouds protocol ([www.globe.gov/do -globe/globe-teachers-guide/atmosphere](http://www.globe.gov/do-globe/globe-teachers-guide/atmosphere)). Embedded in the app are tutorials, help guidance and image representations. Data contributors are encouraged to take observations outdoors with a relatively unobstructed view of the sky; they can also take photographs of the sky (north, south, east, west, up) and a straight down or downward photograph that documents the surface conditions reported ([www.globe.gov/web/s-cool/home/observation-and-reporting/surface-conditions](http://www.globe.gov/web/s-cool/home/observation-and-reporting/surface-conditions)). The GLOBE Observer mobile app guides users to orient their smartphone cameras horizontally, aligned in the cardinal directions, and tilted to a 14° angle to mimic a conventional sky camera; the app is then programmed to automatically take photographs (GLOBE 2019f). This produces a consistent image set across users. The total time spent making a cloud observation averages to about 5 min. Considering over 55,000 observations were contributed to the Spring Cloud Challenge, this event alone represents roughly 4,500 h of volunteer data collection. Studies have found a systematic misreporting of obscured versus overcast skies by the volunteer citizen scientists (Starke et al. 2019). Educational products discussing the difference between overcast and obscured skies were developed to better educate the GLOBE Program participants (GLOBE 2019g).
**Ground-based visual cloud observations and satellite collocations.** Ground-based visual cloud observations, when possible, are collocated to the nearest overpass times of multiple satellites, including geostationary satellites. For satellites in low-Earth orbit (Terra, Aqua, or CALIPSO), citizen scientists are asked to make observations within 15 min before or after an overpass time for their latitude and longitude (Colón Robles et al. 2019c). Participants can get satellite overpass notifications from the GLOBE Observer app or print-out times using the satellite overpass tool ([https://scool.larc.nasa.gov/GLOBE/globe_overpass-en.html](https://scool.larc.nasa.gov/GLOBE/globe_overpass-en.html)). Matches to geostationary satellites occur if observations are within 15 min from half-hourly to hourly data within the GOES field, and 15 min within every hour in locations within the Meteosat and Himawari fields of view (Colón Robles et al. 2019c). Spatially, the match includes all geostationary data within a 40 km radius circle around the ground observation and includes both an infrared and visible image. Observations are comparable to CERES instruments onboard Terra and Aqua satellites if the CERES swath includes measurements within a 0.4° latitude-longitude radius around the ground observation within 15 min before or after the satellite passes over the observing site. This means the physical area included in the match varies with latitude (~45-km-radius circle at equator; ~45 km × 40 km radius oval at 45°N latitude). Now that observations are regularly coming from polar regions, this latitude-longitude match criterion may need to be reassessed. Observations are collocated to CALIPSO if they are within a 10-km strip on either side of CALIPSO’s path and within 15 min before and after CALIPSO’s overpass near the observation site (Colón Robles et al. 2019c). In addition to the public engagement aspect of these satellite overpasses and match emails, the GLOBE Clouds team develops a value-added science data product that includes the citizen science ground observations and the matched satellite measurements ([https://observer.globe.gov/get-data/cloud-data](https://observer.globe.gov/get-data/cloud-data)). During the Spring Cloud Challenge, a total of 33,974 observations (61%) were collocated to satellite overpasses (Fig. 3). Because of the field of view of geostationary satellites, in combination with the satellite collocation criteria selected by the GLOBE Clouds team, no collocations with geostationary satellites were obtained in the Drake Passage region.

**Over-the-ocean ground observations of clouds in the Drake Passage region**

A special region where data were reported during the data challenge was over the Drake Passage, a body of water between the southern tip of South America and the Antarctic Peninsula. From October through March, the Drake Passage is frequently traversed as tourists explore the Antarctic and sub-Antarctic islands on board expedition vessels. Several expedition cruise operators, who are members of the International Association of Antarctica Tour Operators (IAATO), use the GLOBE Observer app to contribute to scientific efforts by involving their passengers in observing cloud cover over the ocean during their cruises in this area. These efforts are strongly supported by The Polar Citizen Science Collective (PCSC; [www.polarcollective.org](http://www.polarcollective.org)), a nonprofit organization that facilitates citizen science projects on board tour vessels. PCSC helps to drive the collaboration between the polar tourism industry and the scientific community. Ship operators do presentations and training onboard the vessels to interested passengers on different citizen science opportunities available. PCSC, in coordination with NASA scientists, organizes pertinent material for ship operators (including presentation slides, training resources, and satellite overpass times pertinent for their traveling routes) to ensure a successful implementation of the citizen science project. This unique, over-the-ocean perspective of cloud and visibility observations can supply unique information about clouds and haze layers near the ocean surface.

Since 2017, this coordination has led to over 570 cloud and visibility observations (Fig. 4) within the Drake Passage region. Preliminary investigations explore low-lying haze layers observed and photographed by the citizen scientists compared to CALIPSO and the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument (Colón Robles et al. 2018).
Intense Saharan dust event hits Canary Islands, then Greece, and GLOBE Observers catch it all

While the goal of the Spring Cloud Challenge was to collect ground-based visual cloud observations, we discovered participants were using the GLOBE Observer app in novel ways to also report and photograph wildfire smoke, extreme haze, and dust events affecting their local areas. A notable example of this type of unanticipated science was an intense Saharan dust event that swept over Europe, then swung southwest depositing dust over the Atlantic Ocean during the Spring Cloud Challenge (Carlowicz 2019a,b). Observers were submitting photographs throughout the duration of the event, capturing images of skies obscured by thick reddish dust (Fig. 5). Since the Challenge, the World Meteorological Organization Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) dust research community has taken interest in GLOBE observations as a source of data to augment extremely sparse in situ dust monitoring data (Amos and Colón Robles 2019). Researchers are interested in the GLOBE Program’s geotagged photographs of dust events to compare to satellite data and models. To support this, GLOBE has issued a call to its community of over 940,000 students, teachers, and citizen scientists to report dust events with the GLOBE Observer app (GLOBE 2019h);
compiled a library of resources for their community (GLOBE 2019d); released Python code and instructions for retrieving raw dust data (GLOBE 2019b); and released a 2012–19 analysis-ready dust dataset (Amos et al. 2020).

**The power of social media and the success of the event**

To begin advertising the Spring Cloud Challenge citizen science data call, the following news article was released: “Calling All Cloud Gazers: NASA Needs Your Help!” March 2018. The article requested observers for a collection of cloud-type observations as the Northern Hemisphere transitioned from winter to spring and promised a congratulatory video from a NASA scientist to the top observers (www.nasa.gov/feature/langley/calling-all-cloud-gazers-nasa-needs-your-help).

Within 5 days, more than 120 news articles in multiple countries and languages were published, including English, French, Romanian, Polish, Spanish, Indonesian, Chinese, Italian, Japanese, and Serbo-Croatian. That led to a surge of observations and broadcast news stories about the Spring Cloud Challenge. Also of note was a special broadcast on French network television station, TF1, during their news show *Le Journal de 20H*. The challenge was also highlighted during the World Meteorological Organization’s (WMO) World Met Day (23 March), with a Facebook Live event (https://youtu.be/Qp8sGyKVIQw) featuring WMO Secretary-General Dr. Petteri Taalas, as well as a NASA Snapchat/Instagram/Facebook story that ran 23–24 March 2018. These two World Met Day/Cloud Challenge products reached over 2.1 million people. In addition to the World

---

**Fig. 4.** Ground-based visual cloud observations reported by tourists since 2017 on expeditions vessels through the IAATO exploring the Antarctic and sub-Antarctic islands. Expedition vessels travel from the tip of South America to the Falkland Islands and to South Georgia, before continuing southward to the Antarctic Peninsula.

**Fig. 5.** Intense, multiday Saharan dust event in spring 2018 observed (bottom) from space by NASA satellites and (top) from the ground by citizen scientists with the NASA GLOBE Observer mobile app. Image credits: NASA Worldview MODIS/Aqua and Terra, Suomi NPP, and NASA GLOBE Observer.
Met Day collaboration and products, the Spring Cloud Challenge was further communicated as part of the NASA Citizen Science Day (14/15 April) through a Snapchat/Instagram/Facebook story. This product reached over 1.5 million people on these platforms. The themes described by the news reporters of “simple” and “even I can do this” were consistently talked about in news reports, social broadcasts, and social media (e.g., https://abc7news.com/weather/how-to-help-nasa-observe-the-clouds/3280986/).

Frequent communication and outreach was also key in motivating participants to collect and submit multiple observations to the GLOBE Program throughout the challenge. The communications team developed multiple image-based social media posts that are cross-promoted on multiple NASA social media streams concerning the challenge, along with “tips and tricks” on how to collect ground-based visual cloud observations. These posts were then released weekly through multiple platforms (Fig. 6). Communication in various modes has been found to be important for maintaining interest of different types of participants in the program, in addition to serving as updates, training, and showing how their data are being used by the research community (National Academies of Sciences, Engineering, and Medicine 2019, p. 37).

More than 27,000 new users registered for the GLOBE Observer mobile app during the challenge period, representing a 15-fold increase in app users. The data volume submitted was 10 times larger than what the GLOBE Program has received, requiring a doubling of the program’s server capacity. Figure 7 shows the cumulative number of observations by day, each color representing a different region of the world, as shown in Fig. 1. The trend in Fig. 7 clearly shows that interest and participation were maintained throughout the challenge period, as the rate of data collection did not noticeably decline toward the end of the challenge. Figure 8 shows the direct correlation between communication products and spikes in the increase of new app users (downloads per day). To reward the top observers from both GLOBE and GLOBE Observer, a congratulatory video from a NASA scientist highlighting the top observer per geographical region was published. The regional winners each received a downloadable and personalized certificate. A second video was also made due to the unprecedented amount of data received. We thanked the worldwide community in a second video featuring multiple NASA scientists and educators congratulating all the observers in multiple languages (www.youtube.com/watch?v=Qzr9vx9dDgg).

**Ground-based visual cloud observations beyond the data challenge: Benefits of classroom involvement**

The Spring Cloud Challenge was a catalyst to gather ground-based visual cloud observations around the world during a month-long period. The GLOBE Program allows for a continuous flow of citizen observations that have the potential to improve our understanding of the Earth's atmosphere and climate. These observations can be used to support educational activities in classrooms, providing students with real-time data that they can analyze and use to make informed decisions. This not only enhances scientific literacy but also fosters a sense of engagement and responsibility among the participants, encouraging them to become active citizens in the scientific community.

**Fig. 6. Social media posts highlighting the GLOBE Observer mobile app with a tip on how to use the app and make a correct cloud observation for a particular scenario.**

**Fig. 7. Number of ground-based visual cloud observations per day per geographical region during the Spring Cloud Challenge (15 Mar–15 Apr 2018).**
science data collected year round. Teachers use events like the Spring Cloud Challenge as a catapult to encourage students and, in turn, to create their schoolwide events that go beyond the school year.

Shumate Middle School (Gibraltar School District, Michigan) is an example of an active GLOBE school where students regularly use the GLOBE Observer app daily to measure cloud and contrail formations, mosquito populations, land cover, and tree height during the school year. Over the past three years, Shumate Middle School has organized the Shumate GLOBE Observer Challenge to engage Shumate students in citizen science during summer vacation (June–August) because students were disappointed they could not continue once school was no longer in session.

Participating students of the Shumate GLOBE Observer Challenge receive a GLOBE student account (login and password), help downloading the GLOBE Observer app onto their mobile devices, and learn from teachers how to correctly utilize the app and the importance of accurate measurements. Various challenges are issued by the teacher to get students excited throughout the summer.

At the conclusion of the 2018/19 school year, the students were challenged to collect a minimum of 50 cloud measurements during their summer vacation. During summer 2019, Shumate students submitted 226 cloud measurements from all over the state of Michigan (in both the lower and upper peninsulas) and from multiple states where students traveled during their summer vacation (including Pennsylvania, Virginia, Alabama, South Dakota, Wyoming, Utah, Arizona, and Hawaii). According to Shumate Middle School student, Drew Sikora (Fig. 9), “I really enjoyed going to different places to pin cloud measurements. I loved using the GLOBE app to observe and record different types of cloud formations.” Students who participate in the Shumate GLOBE Observer Challenge receive a special certificate and recognition at the conclusion of each challenge.

Data collected during the Shumate GLOBE Observer Challenge are often utilized by students conducting environmental research and participating in either the GLOBE International

**Summary**

Citizen science data collected within the GLOBE Program present unique opportunities to engage the public by contributing scientific data that help to fill data gaps, track key climate change indicators, inform and improve model development, and document changes in areas with preexisting environmental challenges.

The Spring Cloud Challenge was successful in collecting over 55,000 observations of varying cloud types during boreal spring in more than 15,000 locations in 99 countries and on every continent including Antarctica. The event was also successful in engaging the general public with ground-based visual cloud observations through the use of the GLOBE Observer mobile app as over 27,000 new users downloaded the app during the challenge. The event also showed how a period of intense observations can increase the number and locations of ground observations collocated with cloud-observing satellites and raise the baseline of year-round observations received by citizen scientists.

A simple call for a data challenge resulted in a dataset with worldwide ground-based visual cloud observations, increasing the number and reach of observations to areas that are difficult to study or may be cost prohibitive. Unanticipated observations over the Drake Passage, as well as ground observations of dust events worldwide, are just some examples of the unique observations within this dataset and how it can lead to new scientific discoveries and better understanding our the atmosphere.

A second citizen science challenge, the Fall Cloud Challenge: What’s Up in Your Sky? (www.nasa.gov/feature/langley/nasa-wants-your-help-identifying-clouds-fall-cloud-challenge), took place in late 2019 (15 October–15 November). The Fall Cloud Challenge had a strong social media component but it did not lead to multiple stories in news media outlets like the Spring Cloud Challenge. The Fall Cloud Challenge still resulted in a success with over 45,300 ground-based visual cloud observations in more than 17,000 locations in 93 countries on every continent, including Antarctica (www.nasa.gov/feature/langley/globe-fall-cloud-challenge-rakes-in-the-observations). First glimpses through the observations and photographs submitted by participants the team found reports of haboobs and other types of dust events, as well as and bushfires in Australia occurring in November 2019 (Carlowicz 2019c). This second success shows that the general public is excited to participate in these challenges and are motivated by a recognition from a scientist. The GLOBE Clouds team will launch regional calls for photographs of dust events during peak seasons (e.g., Ginoux et al. 2012) with emphasis on observations from the southwestern United States and from high-latitude locations.

The GLOBE Clouds data, including both the Spring and Fall Cloud Challenge datasets, are free and available to the public and includes information on cloud fraction, cloud types, contrails and aviation, dust events, wildfires, and solar eclipses. Satellite data from collocated ground-based visual cloud observations are also available (https://observer.globe.gov/get-data/cloud-data).

**Acknowledgments.** The authors want to thank the GLOBE Program, NASA Earth Communications team, the CERES and CALIPSO satellite missions, and the NASA Langley Cloud and Radiation Research team, in particular Mr. Kris Bedka, Dr. William Smith, and Mr. Douglas Spangenberg, for their hard work and contributions to the collection and satellite colocation of ground-based visual cloud observations. The authors are in debt to all the citizen scientists that contributed their observations during the Spring Cloud Challenge, in particular to the top observers per geographical region: Sydney Fryer from South Africa, Harikrishnan P U from India, Arkadiusz Bielecki and the students at Boleslaw
Prus Primary School in Poland, Antonija Kojundžić and students at OŠ Ivana Filipovića in Croatia, Tibot Tóth and students from Kossuth Lajos Gimnázium in Hungary, Helio Cabral from Brazil, Homan Hatan from Saudi Arabia, Zaifah Bahry and students at Al-Matan Intermediate and Secondary Girls School at Sabya in Saudi Arabia, and Peter Tlusty and the students at Saint Mary’s Catholic School in Richmond, Virginia. A special thank you as well to Mr. John Schimmels, Mr. David Overoye, and Mr. Travis Andersen for their hard work maintaining the data system during the challenge. This event was made possible by the work supported by NASA under Award NNX6AE28A. Thank you to NASA Goddard Space Flight Center Summer Intern, Mr. Matthew Starke, for providing an early version of the Python code that was adapted to produce Fig. 2.
References


