Celebrating the 2017 Great American Eclipse: Lessons Learned from the Path of Totality
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How Cool Was the Eclipse? Collecting Earth Science Data With Citizen Scientists and GLOBE Observer

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Abstract. During the total solar eclipse of August 21, 2017, the Global Learning and Observations to Benefit the Environment (GLOBE) Program, through the GLOBE Observer app and other means, sought to engage citizen scientists in the shadow of the eclipse by asking them to collect Earth science data, especially about clouds and air temperature, to answer the question, "How Cool is the Eclipse?" The team utilized infrastructure that was already in place, such as existing GLOBE data collection protocols and database, as well as creating new systems and supports using the app and GLOBE Observer website. By leveraging social media (including large NASA accounts), as well as more traditional television, radio and print venues and in-person and virtual outreach events, millions of people potentially heard about the opportunity to help NASA collect data, and tens of thousands downloaded the app. The result was over 20,000 clouds observations and over 80,000 air temperature measurements on the day of the eclipse, from observers in the United States both on and off the path of totality, as well as other nearby countries that only experienced a partial eclipse. Besides exceeding expectations in terms of data collection, the 2017 eclipse provides a test case with valuable lessons learned to apply to future citizen science campaigns during upcoming eclipses in South America in 2019 and 2020, and again in North American in 2024.

1. Background

The solar eclipse of 2017 presented an extraordinary opportunity to engage the public in shared science activity across the entire United States. The 60-mile-wide swath of the Moon's shadow from Oregon to South Carolina put millions of people within a day's drive of the path of totality on August 21st, 2017, and everyone in the United States (including Alaska and Hawaii) was able to see at least a partial eclipse. While a natural focus of the eclipse is on astronomy and heliophysics, there was also an opening for excellent Earth science connections, which the Global Learning and Observations to Benefit the Environment (GLOBE) Program sought to take advantage of. Indeed, since time of totality ranged from only two minutes to two minutes 40 seconds, depending on location, and many people would be gathering for much longer periods before and after totality, Earth science observations and data collection were seen to be an excellent, substantive addition to occupy observers while they waited for the main event.

During the eclipse, the goal of the GLOBE Observer team was to have thousands of citizen scientists across the country and beyond, in the path of totality or outside it, observing not just the amazing astronomical spectacle, but also the effect that even temporarily blocking the Sun's light has on the atmosphere. The Earth is a solar-powered planet, and we rely on the Sun's energy as the driving force for many Earth processes, such as the water cycle, weather and climate, and ocean circulation. Making scientific observations during the relatively rare opportunity of a sudden drop in sunlight has the potential to advance our understanding of Earth's energy budget, but certainly helps increase the awareness of the citizen science observers about the complexities of the Earth system. By crowd-sourcing data on and off the path of totality, the hope was to be able to see patterns that wouldn't be apparent with fewer data points.

1.1. What is the GLOBE Program?

The GLOBE Program[1] is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process and contribute meaningfully to our understanding of the Earth system and global environment. Since 1995, GLOBE has been training teachers to collect data with their students through grade-level appropriate, interdisciplinary activities and investigations about the atmosphere, biosphere, hydrosphere, and pedosphere.

In 2016, the GLOBE Observer app was created, expanding that audience to citizen scientists who might not be connected to a school, but are still interested in collecting data. GLOBE Observer uses the technology of the app to walk people through making the observations, so they don't need extensive training ahead of time. The app initially launched in August of 2016 with the Clouds protocol, asking observers to report about percentage cloud cover and cloud type, and to take pictures in all four cardinal directions, as well as up and down (for surface conditions). In early 2017, an update was made to the GLOBE Clouds protocol to merge it with the NASA Students' Clouds Observations On-Line Project,[2] adding additional data collection about cloud opacity, sky color and sky visibility, as well as the ability to match ground observations to NASA satellite overpasses. In May 2017, the Mosquito Habitat Mapper was added as a second protocol, followed by Land Cover in July 2018.

GLOBE is sponsored by the U.S. National Aeronautics and Space Administration (NASA) with support from the National Science Foundation, National Oceanic and Atmospheric Administration (NOAA), and Department of State. Internationally, GLOBE is implemented through government-to-government agreements, with each country partner responsible for in-country activities. As the lead agency for GLOBE in the U.S., NASA has the primary responsibility for administering the government-to-government agreements, and for the management of the GLOBE Implementation Office and the data and information system that support the worldwide implementation. The GLOBE Observer program is primarily run out of NASA's Goddard Space Flight Center in Greenbelt, Maryland with funding from the Science Activation Collective of NASA's Science Mission Directorate under a cooperative agreement called the NASA Earth Science Education Collaborative, managed by the Institute for Global Environmental Strategies. Other members of the GLOBE Observer team are based at NASA's

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[1] `https://www.globe.gov/`

[2] `https://scool.larc.nasa.gov/`

Langley Research Center and the Jet Propulsion Lab, as well as other locations around the country.

2. Citizen Science Data Collection

2.1. What to Measure

While any number of atmospheric measurements made during the eclipse might result in interesting science, GLOBE Observer chose to focus on clouds and air temperature because they are comparatively simple to measure and require only inexpensive equipment in addition to the app on a smartphone or tablet. Also, both measurements were existing GLOBE protocols, so the infrastructure to collect and maintain the data was already in place. Cloudiness and air temperature were two of the variables collected by the National Eclipse Weather Experiment (NEWEx), a citizen science project conducted during a partial solar eclipse in the United Kingdom in March of 2015 (Barnard, et. al, 2016). That project also collected information about wind speed and direction, something GLOBE Observer choose not to do since they are not currently stand-alone GLOBE protocols. It's worth noting that NEWEx only collected cloudiness on a four-category scale (clear sky, some cloud, much cloud and totally overcast), providing less detail than we were able to achieve through the platform of the existing cloud protocol.

Since the Clouds protocol already existed in the app, little work was needed to prepare for cloud observations during the eclipse. Air temperature, on the other hand, was not a variable citizen scientists could report through the GLOBE Observer app. Also, the GLOBE system was set up to normally accept one temperature measurement per day, while the eclipse data collection required multiple submissions. Therefore, a special temporary mini-protocol was created to allow everyone to submit current air temperature. Once downloaded and set up, the GLOBE Observer app is designed to function without an internet connection, facilitating use of the app for data collection in remote areas. An internet connection is required to ultimately send in the data to the GLOBE database.

2.2. Measurement Frequency

The next question was timing, both in terms of how long before and after the maximum eclipse to ask participants to collect data, and how frequently the data should be collected. Since the data collection was all being done by citizen science volunteers, it was also necessary to balance scientific best practices and what can reasonably expected of a volunteer. The temperature could start dropping when the partial eclipse began, up to an hour and a half before maximum eclipse. Aplin et. al. (2016) also noted several examples of the lag between totality and the temperature minimum which could be up to 30 minutes, although is more often 10-12 minutes.

GLOBE Observer eventually determined to ask for temperature measurements for two hours before and after maximum eclipse, to completely cover the period of partial eclipse starting at first contact of the moon with the Sun, but vary the frequency expectation during that time to reduce the burden on observers. Therefore, participants were asked to make observations every ten minutes initially, then increase the frequency to every five minutes for the half hour before and after maximum eclipse. Cloud observations could be less frequent, every 15–30 minutes or about every third temperature measurement, or if the observer noted something changing. Although those were the

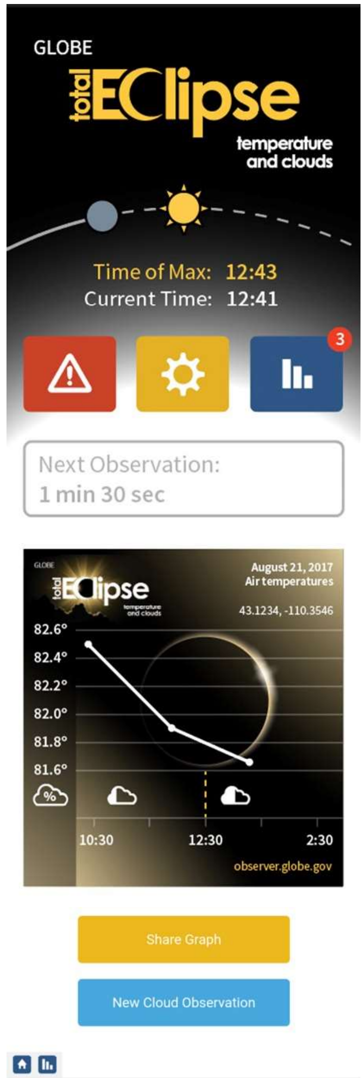

Figure 1. Example of the interface for the temporary Eclipse Protocol within the GLOBE Observer app.

ideal data collection conditions, it was expected that some observers would not collect data for the full period, or as frequently as requested.

The eclipse protocol section of the app was designed to pull up the time for maximum eclipse based on the user's location and give appropriate pop-up reminders when it was time for the next measurement. Keeping in mind that a total solar eclipse is an amazing experience, apart from the interesting science involved, the GLOBE Observer team recommended that first-time eclipse observers put down their phone or camera during the precious few minutes of totality itself and just enjoy the event. Taking that into account, the reminders in the app prompted participants to make observations and measurements before and after totality, but not during totality itself.

The instructions on the website suggested that observers try to take observations on August 20th at the same time as maximum eclipse would occur the next day, both as a potential comparison and to practice the data collection protocol. This was suggested by a point made by Aplin, et. al. (2016), commenting on the difficulty of separating out the effect of the eclipse from the effect of a front or other atmospheric changes. Comparing the data on the day of an eclipse to the days before and after is one approach to this problem, although that only works if the weather conditions are similar across the days in question, as Harrison and Gray (2017) point out.

Finally, while collecting data in the path of totality was a primary focus, one of the advantages of this type of data collection is that people could also participate in areas that were only going to experience a partial eclipse. In fact, having comparison data from locations off of totality could be important for some scientific investigations.

2.3. Equipment

A goal of the project was to make participation easy and accessible to as many people as possible, so the equipment required was limited. Anyone who wanted to download the free GLOBE Observer app (available for Android and iPhone) could contribute by submitting cloud observations during the period of the eclipse. For air temperature, a separate thermometer was required, but this could be anything from a simple liquid-filled type to a more complex digital model. The GLOBE Program generally has very strict requirements in terms of the equipment used to collect data, to ensure it is of high scientific quality. In the case of such a large event as the eclipse was expected to be, and with so many untrained citizen scientists participating, the determination was made to relax those expectations and allow any sort of weather thermometer to be used. To help ensure that participants had indeed acquired a thermometer, and weren't going to rely on a weather app on their phone, the first time a user opened the eclipse portion of the GLOBE Observer app to collect data, they were asked in a broad sense what type of thermometer they were using.

Another concern about the variety of potential thermometers was whether they would be responsive enough to relatively quick changes in temperature. The "Citizen Explorers" section of the NASA Eclipse 2017 webpage[3] had some useful guidance in their "Temperature Change during Totality" activity regarding this, which led the team to test a number of thermometers by moving them in and out of an air-conditioned space on a hot day and comparing the results to control thermometers left in each location. In general, given that measurements would only be asked for every five minutes, all the thermometers tested proved to respond quickly enough for the desired purpose.

Ensuring that air temperature measurements were being taken appropriately was also an issue. Normally, GLOBE air temperature measurements are expected to be taken by a thermometer in a ventilated instrument box. However, it was clear that wouldn't be available for most eclipse observers. Instructions were given to take measurements in the shade, but there would be no way to confirm that these instructions were followed. In general, for this unique event, it was determined that making some quality compromises would be outweighed by the data quantity collected, especially since the project had outreach and education goal in addition to scientific goals. This

[3] `https://eclipse2017.nasa.gov/citizen-explorers`

Figure 2. Sample thermometers tested by the GLOBE Observer team for use during the eclipse.

proved to be a good assumption, since most citizen observations clustered around temperatures reported by trained observers in the same location.

2.4. Other Optional Observations

While the focus of data collection with GLOBE Observer was on clouds and air temperature, the GLOBE Program encouraged trained educators and others who were willing to take training to collect additional related data during the eclipse, including surface temperature, humidity, and barometric pressure. Wind speed and direction are not stand-alone GLOBE protocols, but could be entered as notes on other observations. A website was created outlining eclipse observing options utilizing the full GLOBE Program, rather than just the subset that is GLOBE Observer.[4] In addition, the GLOBE Mission Earth Program,[5] another NASA Science Activation Collective partner, did a great deal of specific outreach to teachers, especially relating to surface temperature.

3. Spreading the Word

The GLOBE Observer team drew on a wide range of partnerships as well as direct outreach to spread the word about eclipse activities. Although the basic instructions were embedded in the app, a website was created providing detailed instructions about how to observe.[6] Additional activities and resources, including printable handouts, were also available for interested individuals or event organizers. In addition, information

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[4] `https://www.globe.gov/web/eclipse`

[5] `https://www.globe.gov/web/mission-earth`

[6] `https://observer.globe.gov/science-connections/eclipse2017`

about GLOBE and GLOBE Observer was included on the main NASA eclipse website,[7] coordinated by the Heliophysics Education Consortium (now the NASA Space Science Education Consortium), based out of NASA's Goddard Space Flight Center in Greenbelt, Maryland. The citizen science page subsite of the NASA eclipse page, where GLOBE Observer was mentioned, on its own received 119,961 hits between May 31st and August 29th. (stats from S. Odenwald, personal communication, August 31st, 2017).

Team members from NASA's Langley Research Center led outreach to formal educators, including GLOBE teachers, in collaboration with the GLOBE Implementation Office and the Mission Earth Program, as mentioned in the previous section. This included hosting webinars as well as presenting information at in-person teacher development workshops and distributing over 15,000 solar viewing glasses to 84 different GLOBE partners and teachers hosting eclipse events and viewing parties, as well as to 34 other organizations or sites (for example libraries or Boys & Girls Clubs).

Personnel staffed large-scale public events before and during the eclipse to increase awareness and facilitate participation of citizen scientists within GLOBE Observer. Overall, the team documented 91 instances of staff supporting the GLOBE Observer Eclipse app and eclipse events across the nation. Team members from Langley Research Center, Goddard Space Flight Center, the Jet Propulsion Laboratory, and the Institute for Global Environmental Strategies gave presentations about the eclipse and how to participate at as varied events as webinars with the Night Sky Network (amateur astronomers), the Earth to Sky Program (park interpreters) and in person to the general public at AwesomeCon (the Washington, D.C. area's version of Comic-Con), the Idaho Falls Zoo, and libraries, community colleges, and community centers in Maryland, Virginia, Oregon and Nebraska. On the day of the eclipse itself, the team had significant on-site presence across the country including in North Carolina, South Carolina, Tennessee, Illinois, Idaho, Nebraska, Oregon, South Dakota, Virginia, Maryland, and Washington, D.C. The reach of public events before the day of the eclipse is estimated at 28,000, and on the day of the eclipse at more than 85,000.

Social media in the month leading up to the eclipse highlighted awareness of the eclipse itself and options for participating in an international citizen science effort via GLOBE Observer. The team leveraged the NASA and NASA Earth social media accounts, as well as other organizations including NOAA Education and Outreach, the Oregon Museum of Science and Industry, the National Earth Science Teachers Association, and Apple Education. Eleven social media events or campaigns with large-scale reach were promoted, reaching more than 3.5 million members of the public. Reach metrics varied across platforms, with very large numbers viewing Facebook Live events and the multiple Snaps/Snapchat Stories. Reach numbers are an approximation based on available data.

In terms of traditional media coverage, the team contributed to 36 stories or posts. The project evaluator was able to establish reach to more than 7.5 million, with much greater reach that cannot be estimated through media in a number of local, regional, and national markets. National coverage included Fox News, CBS News, the Hallmark Channel and PBS New Hour, and on the NASA TV and NASA Edge broadcasts. GLOBE Observer was promoted as part of the NASA Earth Science Communication plan for the eclipse, focused on Earth's energy budget and with the theme that

[7] `https://eclipse2017.nasa.gov/`

Figure 3. GLOBE Observer project coordinator Holli Kohl staffing a table at an event in Idaho.

Figure 4. Examples of social media activities. Left, a snap from a Snapchat story featuring GLOBE Observer team member Tassia Owen; right, a shareable used for Facebook and Twitter.

Earth is a solar-powered planet. This included being mentioned in many of the 72 “live shots” media interviews conducted from NASA’s Goddard Space Flight Center on July 21st, 2017, reaching numerous TV and radio stations around the country. Broad virtual/online coverage included Popular Science, Space.com, and United Press International. In addition, GLOBE Observer received local coverage via television news, print, and radio in 13 states and the District of Columbia, including places such as Virginia, Nebraska, Colorado, California, and Georgia. One interview was even given to a science website for kids in the Republic of Korea, well off the path of totality.

4. Outcomes

On August 21st, 2017, GLOBE received 20,378 clouds observations and 86,671 air temperature measurements from around the world (as retrieved from the GLOBE Data Visualization system as of June 15, 2018). Those measurements came from at least 10,000 different users and included over 60,000 photographs of clouds. Almost all of the observations (20,143 or 98.8% of clouds observations and 82,689 or 95.4% of the air temperature measurements) were from areas experiencing at least a partial eclipse that day. In contrast, on a more typical observation day, for example one week previous, on August 14th, 2017, only 322 cloud observations and 7460 air temperature measurements were received by the GLOBE system. These numbers show just how powerful an exciting event such as an eclipse can be in terms of generating interest in citizen science data collection.

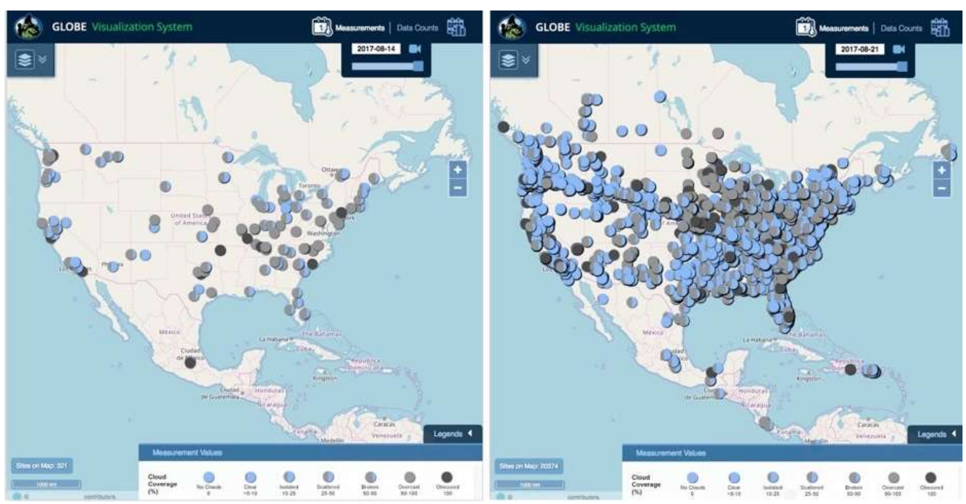

Figure 5. Comparison of the number of clouds observations submitted to the GLOBE database on the day of the eclipse and one week previous, retrieved from the GLOBE Visualization System, vis.globe.gov.

In contrast, the National Eclipse Weather Experiment conducted during the partial eclipse of March 2015 in the United Kingdom, collected 15,606 observations from 309 locations. (Barnard et. al., 2016) The higher numbers from GLOBE Observer during Eclipse 2017 can be attributed to many causes, not least of which is the much larger population in the path of the eclipse. The utilization of technology, such as using an app to submit the data, also likely played a role.

In addition, the GLOBE Clouds team at NASA's Langley Research Center processed and analyzed GLOBE Observer cloud measurements and provided cloud retrieval matches to a suite of satellites (including CERES, CALIPSO, and geostationary

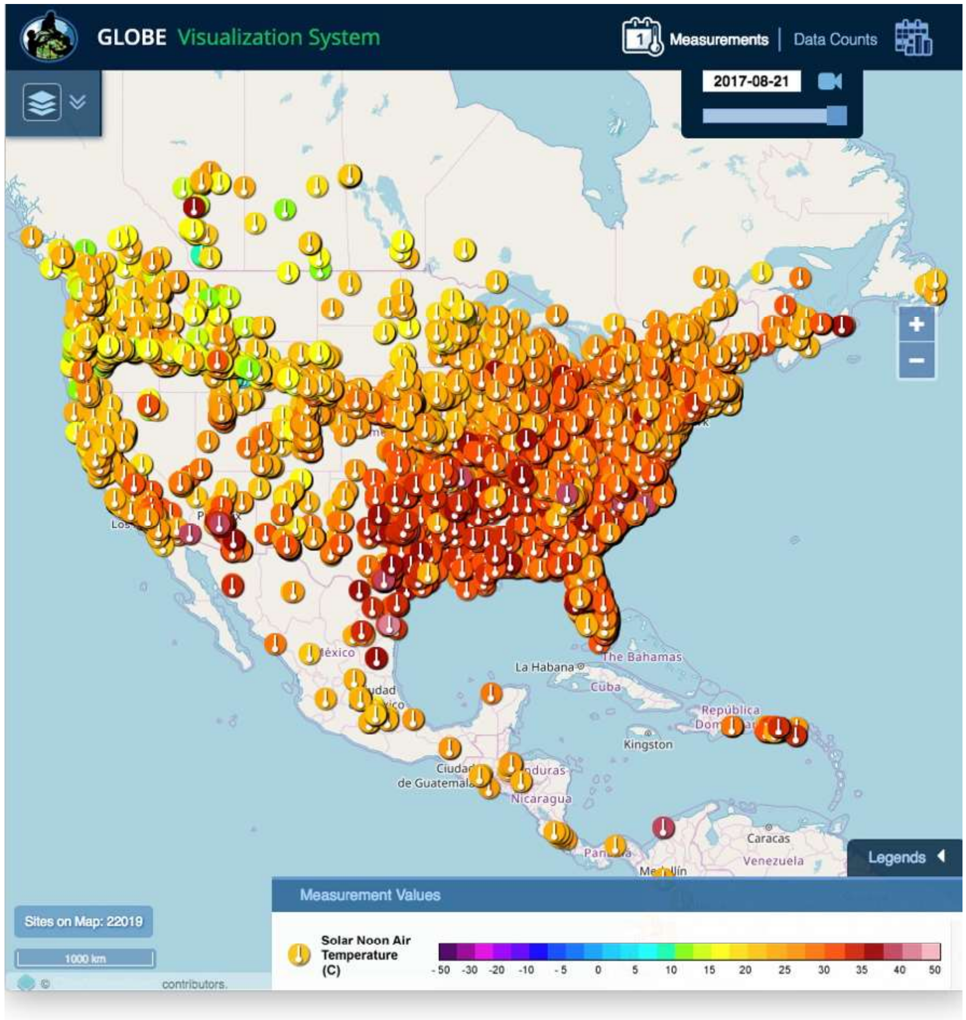

Figure 6. Air temperature observations submitted to the GLOBE database on August 21st, 2017, retrieved from the GLOBE Visualization System, vis.globe.gov.

satellites). They processed more than 19,000 measurements from 4,450 users, with more than 18,000 of those measurements close enough to a satellite overpass to receive a match.

Beyond pure data collection, one of the goals for GLOBE Observer is to encourage use of citizen science data for research, both by students and by professional scientists. A resource page was created on the GLOBE Observer website (observer.globe.gov/eclipse-data-analysis) with information about how to access the eclipse data, as well as some data files for easy download. The GLOBE Observer team also offered recognition in the form of digital badges for students who submitted projects based on eclipse data, either through the GLOBE International Virtual Science Symposium or the in-person U.S. Regional Student Research Symposia. At least one student group, from Crestwood High School in Dearborn Heights, Michigan (Rae Johns et. al., 2018) submitted

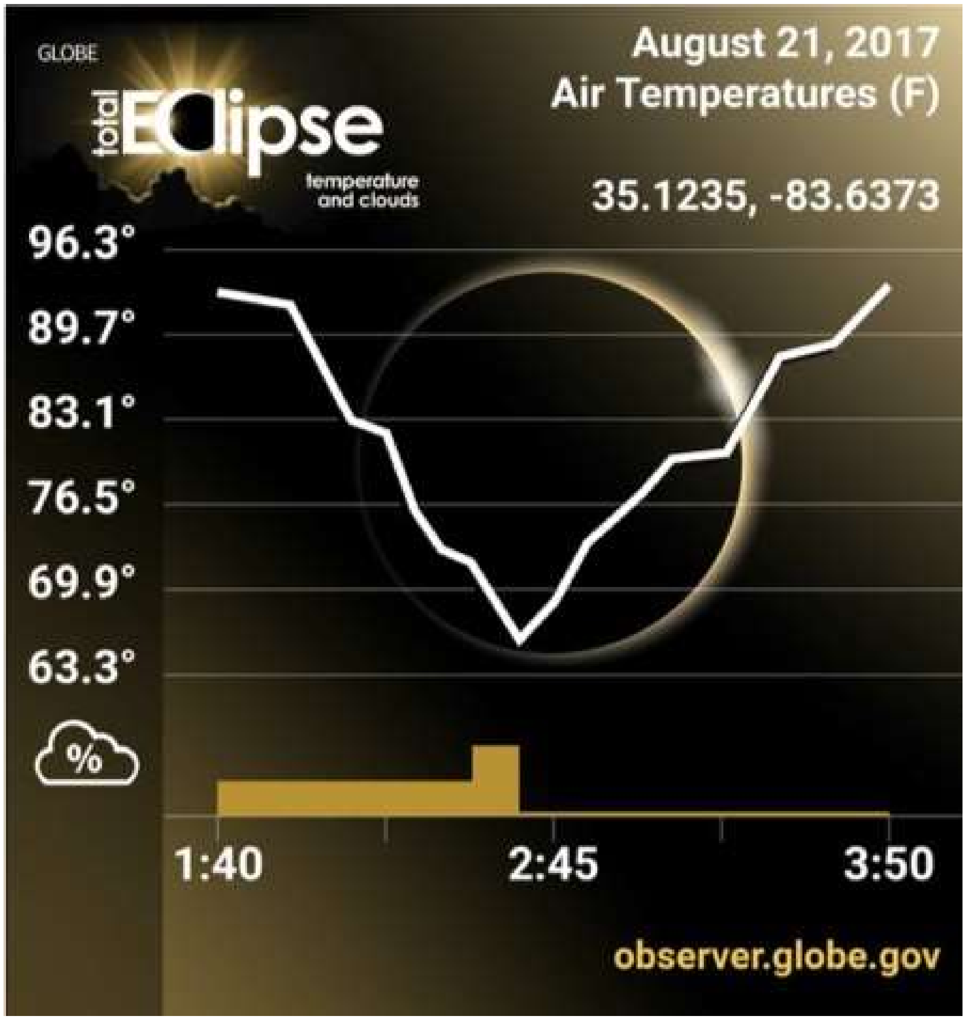

Figure 7. Example of an air temperature graph from the app, in this case from data collected in Natahala National Forest, North Carolina.

a paper through the 2018 IVSS. It is still being determined how many students in the regional symposia may have used eclipse data, as those events were ongoing throughout the spring of 2018. An example of work by professional scientists using GLOBE Observer eclipse data appears on p. 501 in this volume (Rahman et al. 2019) The hope is to build on these initial successes for additional research, including through a potential data hack-a-thon in the fall, discussed more in the future plans and lessons learned section.

The eclipse also increased the GLOBE user base, especially with the promotion and support of the larger NASA eclipse effort, including traditional and social media outreach. In the period between launch of the app in August 2016 until July 2017, the total number of users who had downloaded the GLOBE Observer app and created new accounts was about 18,000. After the media push beginning with the "live shots" media event on July 21st from NASA Goddard, that number skyrocketed, reaching nearly 70,000 cumulative accounts created by the time of the eclipse. While many of those users joined specifically for the eclipse and have not necessarily continued to submit data after that, they still represent a user base that has downloaded the app and who might begin collecting data again in the future with the right motivation.

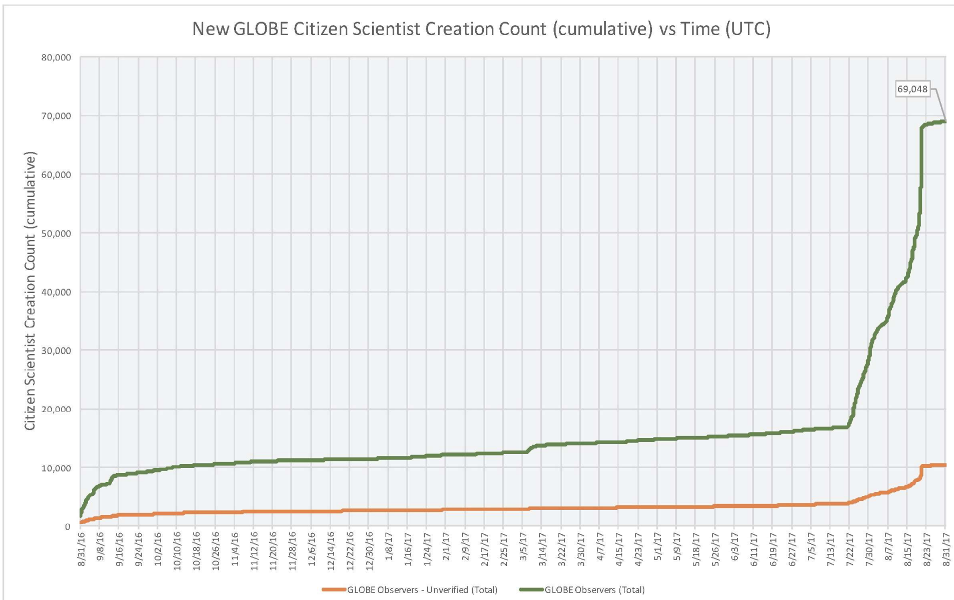

Figure 8. Graph of cumulative GLOBE Observer accounts created during the first year of the app's release. "Unverified" means the user requested an account but never verified their email address.

5. Future plans and Lessons Learned

While we consider the overall GLOBE Observer eclipse project a success for 2017, and the quantity of data collected vastly exceeded expectations, there is always room for improvement. The eclipse portion of app was designed to be able to easily be activated within the larger GLOBE Observer app for future eclipses. We are especially looking forward to applying our lessons learned to upcoming solar eclipses in South America when on July 2nd, 2019 and December 14th, 2020 the paths of totality will intersect with Chile and Argentina, both of which are GLOBE countries. And of course, in April of 2024, the United States, Canada and Mexico will again have the opportunity for another total solar eclipse.

In terms of the logistics of data collection, the app seemed to work well as a platform. Several potential gaps arose, however, which may especially come in to play for the next two eclipses in South America. A number of people asked if there was a web interface to enter data, either because they did not have the correct type of smartphone, or because they had collected appropriate data during the eclipse but only found out about the app after the fact. Both of these options are available for trained GLOBE members, but not for untrained GLOBE Observer users, so having a more concrete plan ahead of time for how to respond to such requests would be helpful, either directing interested parties to training, or also making a web form available temporarily to untrained users in a similar way to the eclipse protocol appearing the app only in the days immediately before and after an eclipse.

An area of uncertainly came up when trying to verify whether users were in fact using an appropriate thermometer for their temperature measurements. While the app asked at the very beginning what type of thermometer will be used, a better strategy may be to have participants actually take a picture of their thermometer as part of the process. That way it can be ensured that they are indeed using a physical thermometer, rather than a weather app, and perhaps also determine if they have set up the thermometer appropriately in a shaded area rather than in direct sunlight, for example. Also, the timer and reminder for the next data collection point had an unexpected and unintended consequence—the timer countdown didn't allow data entry before the next reminder, so those enthusiastic observers who wished to enter date more frequently than the expected timeline were not able to do so.

In planning, we were unsure how much time we could expect citizen scientists to devote to data collection. An ideal sequence would have data collected for several hours before and after the eclipse. While many observers did start data collection appropriately early, it often dropped off shortly after the eclipse. The team would like to investigate incentives we might be able to develop to encourage people to stick around and collect data longer, even after the main show of the eclipse itself is completed.

Having this past experience and information about the data collection, including examples of both student and professional science papers published, the GLOBE Observer team expects to be able to generate more initial interest before upcoming eclipses, and have more interaction ahead of time with researchers who might be interested in using the data for their work, and commitment from them to do so. In the meantime, we are also exploring the idea of a data hack-a-thon in the fall, focused on analyzing GLOBE Observer data, both from the eclipse and from other protocols. The self-contained eclipse data set is especially well suited for such a short-term analysis period. The targeted audience is expected to be undergraduates looking for an opportunity to work with an interesting data set, but may be extended to middle or high school students if a compatible format can be worked out.

GLOBE Observer, and the broader GLOBE Program, are long-term projects, not just about large-scale events such as solar eclipses, but the team appreciated the opportunity to be part of a such a massive effort that engaged so many people around the United States and in other countries in a spectacular science experience. Millions of people gathered together to watch an astronomical event, and while only a small portion of them participated by collecting data as citizen scientists, it can still be deemed a success for GLOBE as well as for the science community more broadly.

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