Data Collection During the Great American Eclipse

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I am lucky enough (and old enough) to have seen three total eclipses. About a year ago, I became aware of the total eclipse that was coming to the United States on August 21, 2017. Because I knew how exciting a total eclipse can be, I spent a lot of time encouraging people to travel to the zone of totality if they possibly could. I also encouraged teachers to turn this event into a STEM lesson by taking data. We asked teachers to join us in collecting data during the eclipse and to share it. The people collecting these data were either teachers or former teachers (like me). Many times, the sensors were mounted with duct tape and rubber bands, but we got some great data!

The most frequently monitored parameters were illuminance (a measure of light brightness as perceived by human eyes, in lux) and irradiance (total solar radiation, in W/m^2). UV levels, temperature, and other parameters were also measured. People from all over the United States sent data to me. Figures 1–8 are some typical results from people in the zone of totality. They aimed their light sensors in the direction of the Sun and placed their temperature sensors in the shade in a well-ventilated area (the conventional way to measure air temperature).

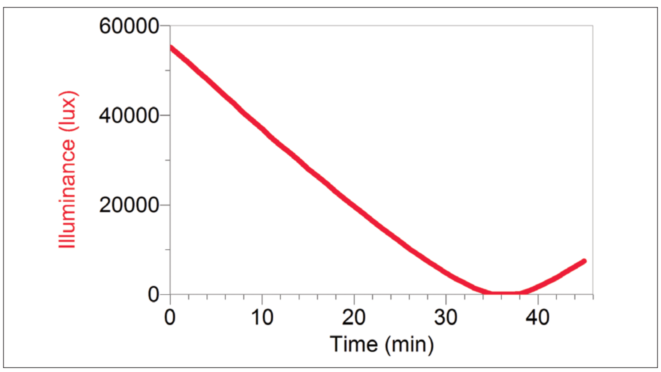

Fig. 1. Illuminance vs. time in totality in Gaston, SC, with clear skies. Data collected by Sonia Faletti, Bishop Ireton High School, Alexandria, VA.

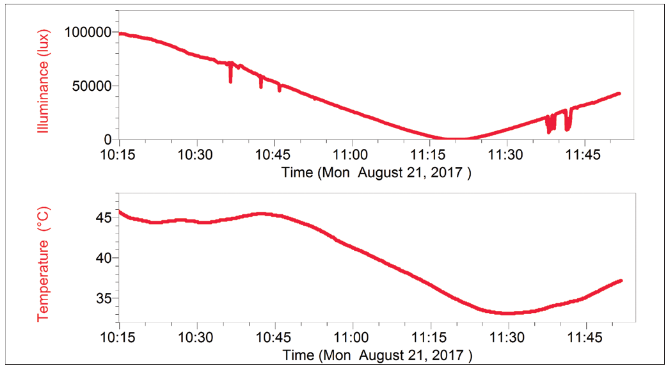

Fig. 2. Eric Sullenberger, of Russia High School in Ohio, traveled to the path of totality in Perryville, MO, to take these data. Note that the temperature minimum occurs a little after totality. This may partly be due to the fact that Eric was using a temperature sensor contained inside a stainless-steel tube, making it a little slow to respond to changes in air temperature.

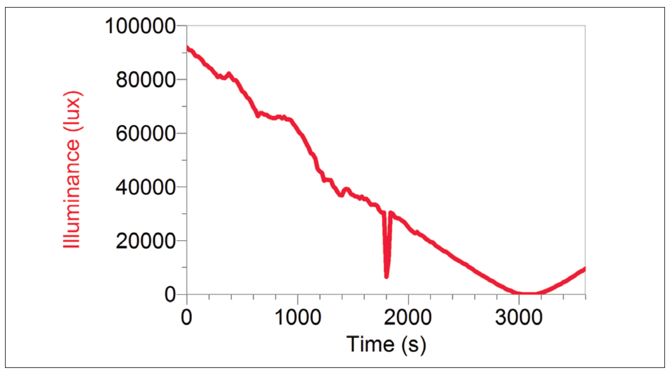

Fig. 3. Illuminance vs. time near Mitchell, OR, in totality, with some high, thin clouds early in the data collection. Data taken by Tom Smith, a Vernier technical support staff member and a former physics teacher.

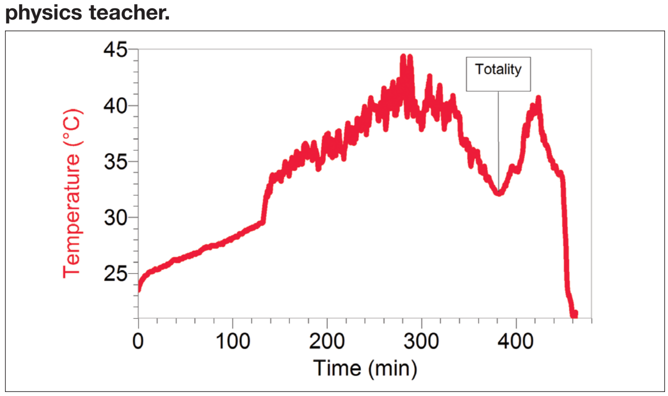

Fig. 4. Lisa Tiedemann, Waterloo High School, took these temperature data in Waterloo, IL (in totality). A cold front and rain came in after the eclipse, which shows up on the graph near the end.

I have looked at temperature graphs from more than a dozen different sites in totality. Typically, temperature change as the eclipse proceeds is between 4 and 12 °C, probably depending a lot on wind and terrain. Every measurement I have seen, even when the temperature sensor was in the sunlight, shows noticeable cooling as the eclipse becomes more complete.

The graphs in Figs. 1–4 show visible light levels and air temperature. There are lots of other types of solar radiation coming from the Sun and many people graphed those.

Figures 5–8 show graphs of UVA and UVB levels and illuminance data, in some cases.

Many eclipse monitors had to deal with clouds, smoke, and even rain during the eclipse. Compare the graphs in Fig. 5 (with clear skies) with the two sets of graphs below, Figs. 6 and 7, also showing data taken in totality.

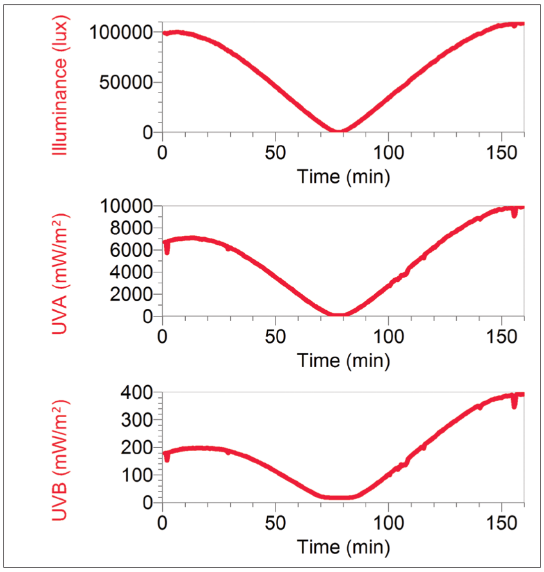

Fig. 5. Illuminance, UVA, and UVB readings in totality in Turner, OR. I took these data, and I was lucky to have an absolutely clear day. I manually rotated the sensors to keep them aimed at the Sun. There are some interesting details that show up in these light level graphs. Compare the levels before and after the eclipse. Note that in all cases, light levels are higher after the eclipse. Why? Since the eclipse here was total at 10:18 a.m. PDST, the Sun was rising in the sky. It was at 41 degrees at totality, and higher after totality. So all of the readings are higher, especially the UV readings. This is, of course, why we are warned about UV damage to the skin, especially when the Sun is high.

The Detroit, OR, group used some other sensors that are great for this kind of study. They used a pyranometer, which measures irradiance (the sum of all solar radiation: IR, visible, and UV). They also used a PAR (photosynthetically active radiation) sensor, which measures the part of the spectrum that is most useful for photosynthesis in plants. One great thing about both of these sensors is that they are designed to be mounted vertically, and they can measure radiation coming from all directions.

So, you might wonder how math can be brought into the analysis of eclipse data. One thing I noticed in looking at dozens of graphs of various types of solar radiation from the Sun plotted vs. time during the eclipse is that they mostly have the same shape. I started thinking about the geometry of what is going on during a total eclipse. To a fair approximation, a luminous disk in the sky (the Sun) is being gradually blocked by an opaque object of approximately the same size (the Moon) moving at a constant velocity, with the centers perfectly aligned. The geometry to calculate the fraction of the Sun visible as a function of position (and time) involves the classic overlapping circles geometry problem.

If the circles are of the same size, the equation for the area overlapping as a function of the distance between the centers

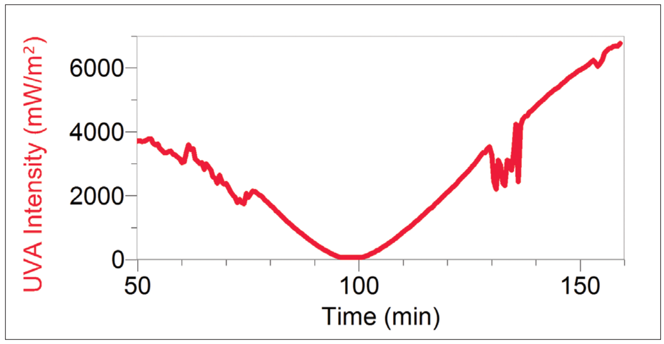

Fig. 6. Data taken by Karen Jo Matsler, from Arlington, TX, in Knob Noster, MO. Karen Jo had some cloudy skies both before and after totality but nice clear sky around totality.

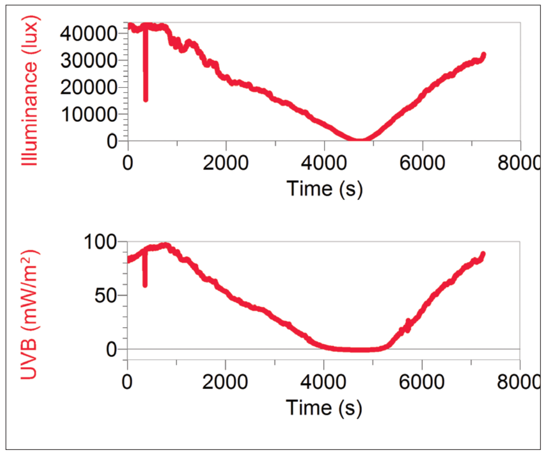

Fig. 7. Data taken by Fran Poodry and Colleen McDaniel, Vernier technical support staff and former teachers, in Detroit, OR. They had to deal with smoke from forest fires, especially before totality. Note that their peak readings were less than half of the comparable readings in Fig. 5, also in Oregon, but with clear skies.

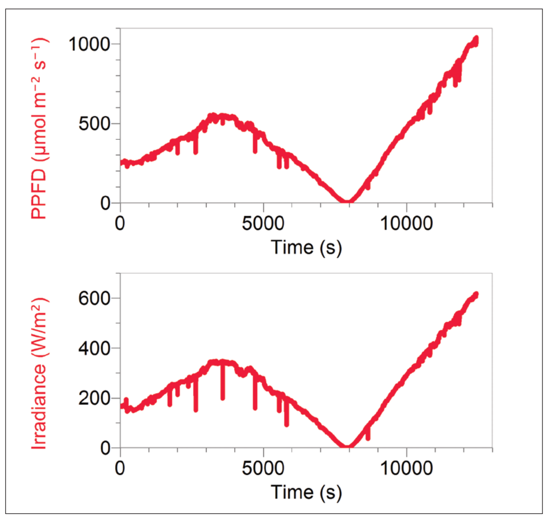

Fig. 8. Data from Detroit, OR, in totality, using a photosynthetically active radiation (PAR) sensor and a pyranometer. There was smoke in the air in the morning, and it shows up on these graphs as well as on Fig. 7.

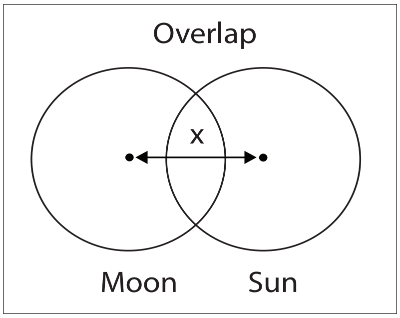

Fig. 9. The eclipse modeled as two circles of the same size, with one passing over the other, aligned at the centers. The area of Sun still visible is the Sun's area minus the overlap as the eclipse proceeds.

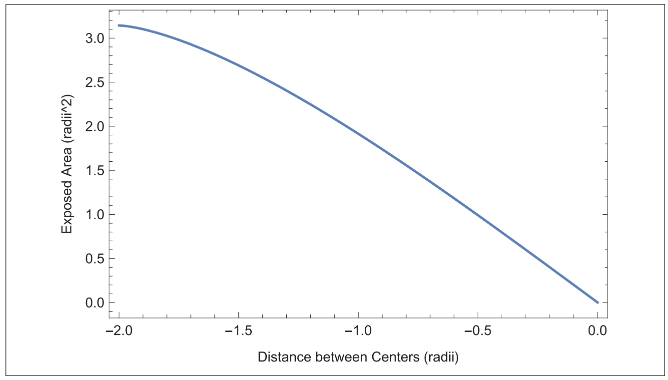

Fig. 10. Area of a circle exposed, as a second circle of the same size moves across it, as a function of distance between the centers of the circles.

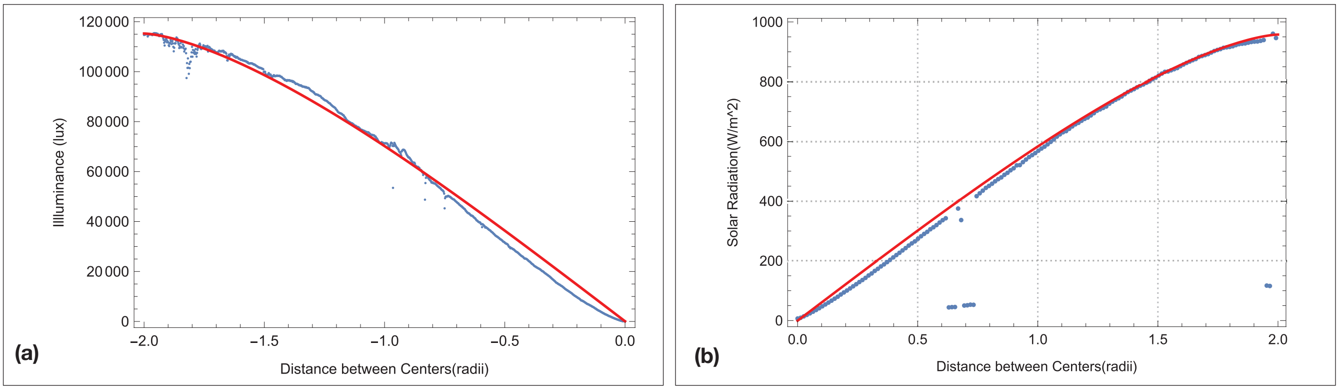

Fig. 11. Comparing the intersecting circles model with data collected during the eclipse. Both sets of data are taken from locations in totality, with relatively clear skies. The overlapping circles model is fit to the data and shown in red. The graph on the left shows illuminance data taken from first contact to second contact (the beginning of totality) using data taken by Eric Sullenberger, in Perryville, MO. The horizontal axis was scaled based on the known times of the first and second contact. The graph on the left shows total solar radiation, taken by the author in Turner, OR, from third contact (the end of totality) until fourth contact. Again, the horizontal axis was adjusted to match the known times of the eclipse.

is:

$$\text{Overlap} = 2\cos^{-1}(x/2) - (x/2)\sqrt{(4-x^2)}, \qquad (1)$$

where x is the distance between the centers of the circles (in units of circle radii).[1,2] Consider the stages of the eclipse: At first contact, when the Moon first starts to block the Sun, $x = 2$ and the overlap is 0. The exposed area of the Sun is $\pi r^2 = \pi * 1^2 = \pi$. As the eclipse proceeds, more and more of the Sun and Moon overlap. The exposed area of the Sun is the area of the Sun surface minus the overlap. At second contact, when totality begins, $x = 0$ and overlap $= \pi$. The exposed area of the Sun is 0. The equation for the exposed area of the Sun is:

Area = Area of Sun – Overlap

$$\text{Area} = \pi - 2\cos^{-1}\left(\frac{x}{2}\right) - \frac{x}{2}\sqrt{(4-x^2)}. \qquad (2)$$

Once you have this equation, it is interesting to see how various light levels varied compared to the fraction of the Sun visible in some of the data from the total eclipse.

Granted, this is an oversimplified approximation (in fact, if it were the real situation, totality would be instantaneous), but the general shape of the graph matches nicely. This is the shape we see on most of the light sensor and UV graphs made from total eclipse data.

All the graphs displayed above are from locations in the zone of totality. People who had only a partial eclipse still sent us some interesting data.

Compare Figs. 12 and 13 with Fig. 5, which shows data collected with the same type of sensors but in the zone of totality. The illuminance (a measure of the light level, as perceived by human eyes) has a minimum of about 5200 lux in 93% totality. On graphs made in the zone of totality, the minimum illuminance readings are typically below 200 lux. These graphs document one of the arguments I made many times in trying to encourage people to travel to the zone of totality, if they possibly could: "The difference between a total eclipse and a partial eclipse is literally night and day." The light intensity, even at a location with a 99% total eclipse, is many times higher than during totality. It is simply not the same experience.

One easy way to collect some interesting solar eclipse data is to use a local weather station. One issue with weather station data is that it typically is not recorded very frequently, so it would be easy to miss the peak of the eclipse. Many weather stations, like one graphed in Fig. 14, log data only every 15 minutes, which is normally plenty often enough, but not fast

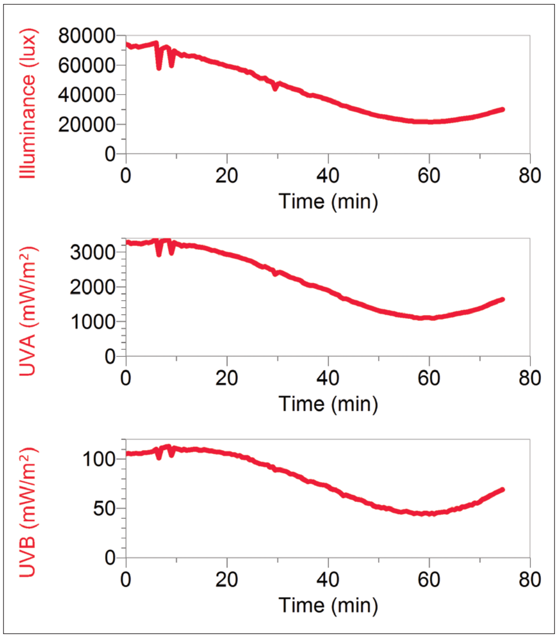

Fig. 12. Data collected by Clarence Bakken in Sunnyvale, CA, where the eclipse peaked at about 74% total.

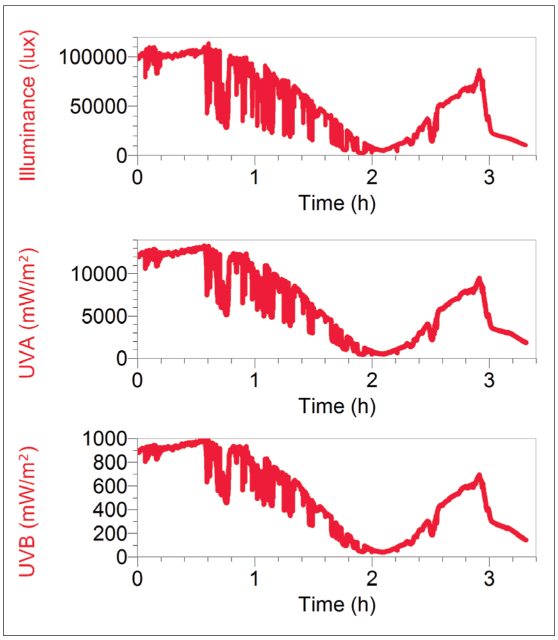

Fig. 13. Data collected by Benjamin Grimes at his school, Roncalli High School, in Indianapolis, IN, where the eclipse peaked at about 93%. There were quite a few clouds, especially early.

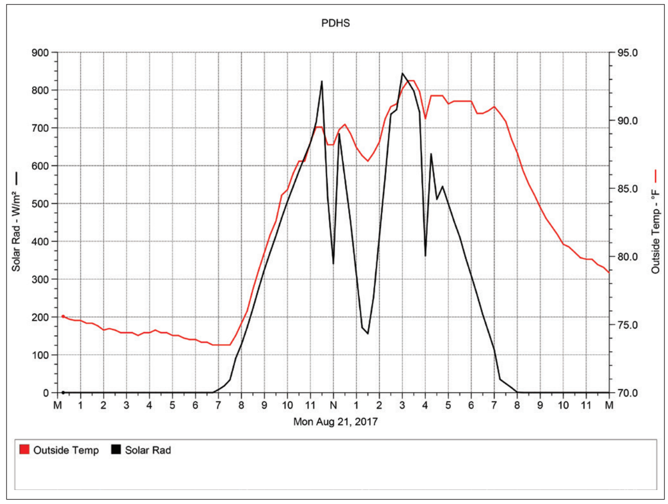

Fig. 14. Glenn Sullivan of Plain Dealing High School, located in northern Louisiana at about 80% of totality, took some interesting data using a Davis Instruments weather station. The red line is outside temperature and the black line is irradiance (total solar radiation). Irradiance dropped from around 800 W/m^2 down to around 200 W/m^2, and then it returned to around 850 W/m^2.

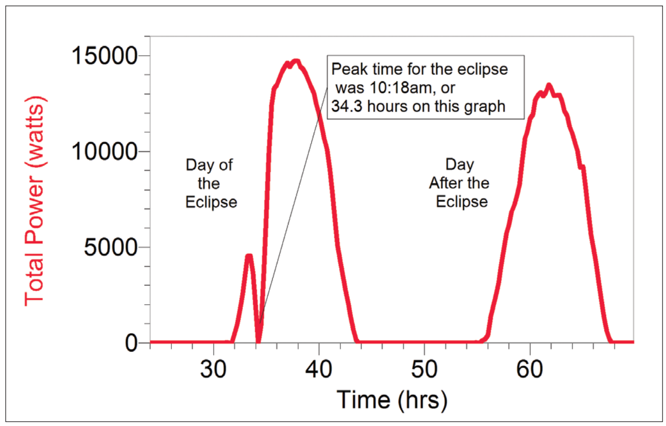

Fig. 15. Solar panel power production vs. time at the Vernier building in Beaverton, OR, at 99% totality, on eclipse day and the day after. Note the major drop in production on the morning of eclipse day. Both days were mostly clear, with slightly more high clouds on the day after the eclipse.

enough to catch all the interesting things that happen during a solar eclipse.

There was a lot of discussion before the eclipse about the impact of the eclipse on solar power production. Most solar panel inverter systems provide a way to log their power output. At our office building, in Beaverton, OR, we have 17 kW of solar panels. Figure 15 shows their power output, which is reported every 15 minutes.

Even though it was 38 years since the last total solar eclipse in the continental United States before the Great American Eclipse, there will be five total eclipses visible in the next 35 years in the continental United States. On April 8, 2024, there will be a total eclipse sweeping from Texas, through the Midwest, and up into Maine. In 2044, 2045, and 2052 there will be three additional total eclipses in the United States. So, what lessons did we learn that can help teachers and students get ready for the next eclipse?

- ***Having students get involved in the data collection*** can be a great experience for them. Note the next major eclipse, in 2024, is during the normal school year, and on a Monday in the early afternoon. The Sun will be high in the sky, which leads to the best eclipse viewing and data collection.

- ***Keep your temperature sensors in the shade.*** This is the conventional way to measure air temperature. Of course, the sensors should also be in a well-ventilated area, away from equipment, people, and animals. Also, many temperature sensors have stainless-steel cases to make them very durable. That is great, but it means that the sensor takes some time to respond to a change in air temperature. A sensor that is more exposed, and made for measuring air temperature, is best.
- ***It is important to think about how you are going to aim sensors,*** such as light sensors and UV sensors. You have a lot of choices: You can try to "track" the Sun by manually moving the sensors every few minutes. Alternately, you can simply aim the sensor in a general direction toward the Sun and leave it fixed. For light sensor measurements, you can also aim the light sensor downward, pointed at a piece of white cardboard (measuring the reflected light).
- ***Sensors like pyranometers and PAR (photosynthetically active radiation) sensors are really great*** for this kind of experimentation since they are designed to measure all solar radiation coming from all directions. You do not have to worry about adjusting their position during the eclipse.
- ***Consider bringing a portable weather station along for your eclipse data collection***. It will gather and log lots of data, including wind speed and direction. Some weather stations also measure UV levels and irradiance. If it is possible, speed up the station's rate of data collection on eclipse day. You do not want to miss the interesting things that happen quickly near totality. If you cannot do that, consider manually recording important weather data at more frequent intervals than the station logs them near the most interesting time, near totality.
- ***Consider how you are going to handle measuring wind speed. There are a lot of options:***
  - Manually point the anemometer into the wind each time you take a reading.
  - Mount the anemometer so that it swings around to be always pointed into the wind by making a homemade wind vane (or just use a weather station's anemometer).
- ***A general tip is to remember that you can do a "dry run" almost anytime.*** Set up your equipment as you plan to use it during the eclipse, at roughly the time of day of the upcoming eclipse, and take data. You will probably quickly discover some things you had not planned for, such as battery issues, getting sensors oriented properly, and how to retrieve the data.

Who knows what sensor and data-logging technology will be available when the next eclipse happens? We did not get very interesting data on the solar radiation spectrum, wind speed, or pressure change when we collected data during this eclipse, but those may be worth trying again.

I would like to thank all of the teachers who sent data to me that they carefully collected during the Great American Eclipse. I could not use all of it in this article. More sample graphs and, in most cases, the data and background information are at http://www.vernier.com/eclipse. Mark your calendars for April 8, 2024, and collect some data. Also, if you can possibly make it to the zone of totality, do it. A total solar eclipse is something you will never forget.

References

1. Angel M. Carreras Jusino, "Area of Overlapping Circles," The University of Georgia, http://jwilson.coe.uga.edu/EMAT-6680Su12/Carreras/EMAT6690/Essay2/essay2.html or "Circle-Circle Intersection," Wolfram MathWorld, http://mathworld.wolfram.com/Circle-CircleIntersection.html.
2. For a good simulation and calculator to determine the overlap area see: http://demonstrations.wolfram.com/MakingTheThreeAreasDefinedByCongruentOverlappingCirclesEqual/.

Dave Vernier *was the founder and is now co-president of Vernier Software & Technology. He was a high school physics teacher in Cleveland, OH, and Hillsboro, OR. He started the company based on his experience using early microcomputers to assist his physics teaching.*
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