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Mapping Lightning Strikes from Space

If lightning strikes anywhere in the Western Hemisphere, odds are it has already been detected and mapped by satellite-bound cameras orbiting some 35,000 kilometers above Earth.

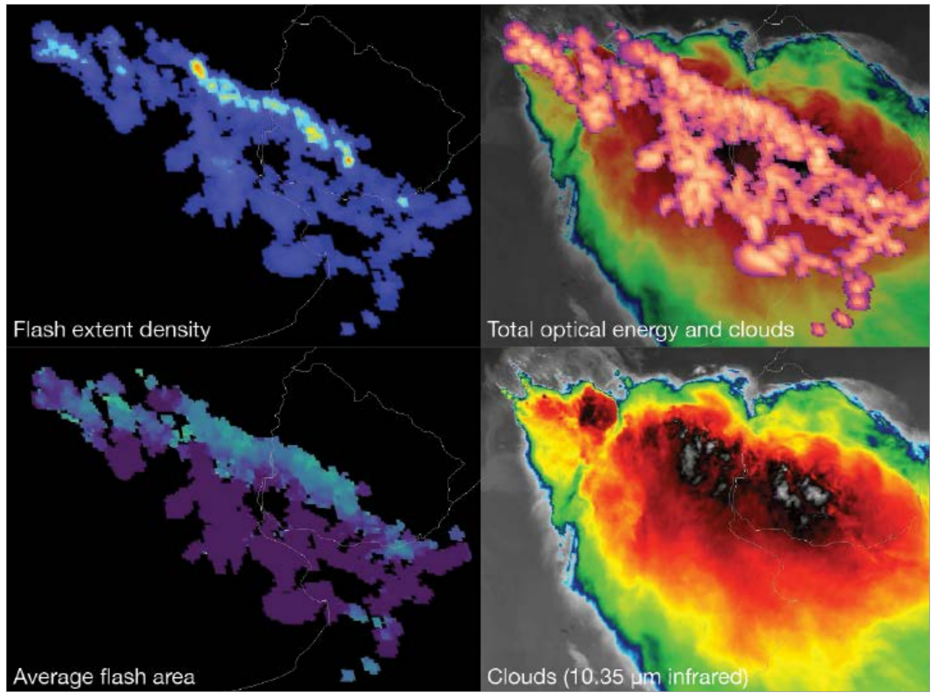
Lightning flashes are more typically mapped from ground-based networks using radio frequencies to generate precise data on the order of meters (see "Lightning Research Flashes Forward," p. 28). However, ground-based systems have a limited line of sight. The view from a satellite does not, for example, need to "account for things like tree lines or city skylines or even just general dissipation over distance," said Michael Peterson, an atmospheric scientist at Los Alamos National Laboratory in New Mexico.

The idea of using a satellite to detect lightning has been around since at least the 1980s, but with the launch of the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite–R Series (GOES-R) weather satellites starting in 2016, researchers and forecasters have attained unprecedented amounts of lightning data from the Geostationary Lightning Mapper (GLM) instruments attached to the satellites.

An interdisciplinary team of researchers now has developed a technique that can map out the lightning flashes GLM detects across the entire Western Hemisphere in real time.

"It's not only a matter of being able to see more, but being able to see things completely," said Peterson, who was not involved in the study.

The new technique was reported in the *Journal of Geophysical Research: Atmospheres* (bit.ly/GLM-images) and has been adapted for use by the U.S. National Weather Service (NWS).



Five minutes of lightning from the Geostationary Lightning Mapper show small areas of high lightning flash rates (maximum of about 100 per minute) and a few very large flashes that cover thousands of square kilometers. Credit: NOAA/NESDIS/Scott Rudlosky

Seeing Lightning More Completely

The GLM is essentially a video camera in space that captures lightning flashes across the Western Hemisphere at 500 frames per second. "There's very little dead time. No matter how rare the lightning flash is, you're probably going to see it," Peterson said.

But that deluge of data comes with a downside. "You can't send all that video data down to the ground," said Eric Bruning, an atmospheric scientist at Texas Tech University in Lubbock and lead author on the study. Instead, the data are sent as pixels attached to geolocation information that clustered into lightning flashes. "For a lot of users, it's just really challenging to even know what to do with those data," he said.

The new technique reconstructs and spatially maps the lightning flashes while retaining the quantitative physical measurements made by the GLM. "In a way, it's just restoring the video nature of the camera," Bruning said.

Adapting the technique to work with the NWS systems required getting the product to work with NWS operational display systems, matching data formats, making it timely, and not allowing it to fail.

The researchers demonstrated that this space-based lightning mapping technique can distinguish the many tiny flashes of lightning within thunderstorm cores and the large lightning flashes that are part of mesoscale storm systems.

Myriad Applications

The technique's application for weather forecasters was readily apparent and rapidly developed over the course of a year to be used by NWS. The process required getting the product to work with NWS operational display systems, matching data formats, making it timely, and not allowing it to fail, Bruning said. In adapting the tool for practical applications, "you find all the bugs that you just ignore as a researcher in your code."

Using this technique, it would be possible to track the origin of so-called bolts from the blue that occur without rain, said Chris Schultz, a research meteorologist at NASA's Short-term Prediction Research and Transition Center in Huntsville, Ala., and coauthor on the study. Seeing the origin of the flash is important to anticipate future lightning and is not possible with traditional ground-based lightning data. This capability is important for public safety because "the majority of injuries and fatalities occur just before the rain has started or just after the rain has ended," Schultz said.

"Right now the main users are [at] the National Weather Service, and that's mainly because the instrument is brand-new to the public," said Schultz. He expects that as the technology evolves and gets into the public's hands, it will become more widely used, like radar is now.

"It is certainly useful to be used in real time, but it's not as useful as it could be," Peterson said. One major caveat with the technique is that it relies on the data provided by NOAA and assumes their veracity. "Unfortunately, the algorithm is not perfect."

Because of the complexity of the data, large flashes of lightning are automatically split into multiple flashes, explained Peterson. He recently published a new processing system to stitch these smaller flashes back together. "Now, this isn't a huge deal in terms of overall statistics. We're talking 4% to 8% of all lightning depending on what storm you're looking at."

Still, the latest study adds a powerful new tool for scientists and forecasters studying lightning. The technique, which is available as open-source software, also grants "the ability to use lightning to monitor the climate and also to even study storm processes in places where we don't have the rich radar network that we have in the U.S.," Bruning said.

"I think it's important to keep that global perspective in mind," he added.

By **Richard J. Sima** (@richardsima), Science Writer

Earth's Skies Transmitted Signs of Life During Lunar Eclipse

During a total lunar eclipse, the Moon travels first through the umbral (orange) and then the penumbral (red) shadow of the Earth, becoming progressively darker and redder before returning to normal. This is a composite of a sequence of images of the 21 January 2019 total lunar eclipse as seen in Austria. Credit: H. Raab, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

Last year's so-called super blood wolf moon gave astronomers the chance to measure the spectrum of Earth's atmosphere as if it were a transiting exoplanet, a feat that is possible only during a total lunar eclipse.

"It's a very fascinating thought to imagine that the spectrum of Earth is always broadcast to the outside," said Matthias Mallonn, a postdoctoral researcher at Leibniz Institute for Astrophysics Potsdam in Germany. Mallonn and other researchers on the project typically hunt for faint spectral signals from the atmospheres of distant worlds, but the lunar eclipse let them look at Earth instead.

During the 21 January 2019 total lunar eclipse, the researchers used one of the largest visible-light telescopes on Earth to measure the spectrum of sunlight that had passed through the top of Earth's atmosphere. That light bore signals from molecular oxygen and water vapor and also sodium, potassium, and calcium. This is the first time this method has been used to spot those three elements in Earth's atmosphere.

"Exoplanets are truly alien worlds and typically have very different properties from the solar system planets," said Eliza Kempton, an assistant professor of astronomy at the University of Maryland in College Park who was not involved with this research. "We must first establish what the Earth and other solar system planets look like 'as exoplanets' to benchmark our understanding of the far more exotic extrasolar planets."

Lunar Eclipse Mimics a Transit

One way that astronomers can measure the chemical composition of exoplanet atmospheres is called transmission spectroscopy, which captures starlight that has passed through a planet's atmosphere. The atmosphere imprints a chemical signature on the starlight that can reveal major components like water, methane, or even metal oxides. So far, most of these measurements have been done for large, gaseous planets that orbit close to their stars.

Future telescopes will allow similar measurements of Earth-sized planets in the hab-

We must first establish what the Earth and other solar system planets look like 'as exoplanets' to benchmark our understanding of the far more exotic extrasolar planets.

itable zones of their host stars, and the researchers wanted first to test this out on Earth. Fortunately, the positions of the Sun, Earth, and Moon during a total lunar eclipse mirror the geometric setup needed for this: the Sun as the distant star, the Earth as the exoplanet, and the Moon as the far-off observer, Mallonn explained.

However, there is no telescope on the Moon waiting to capture the transmitted light. Instead, the team measured that light after it reflected from Tycho Crater. That light then entered our atmosphere and was observed by the Large Binocular Telescope (LBT) over a roughly 4-hour period. After accounting for the spectra of sunlight, the lunar surface, and contamination from traveling to the telescope on the ground, the team was left with the signal as it appeared when the light passed through Earth's atmosphere.

Earth's transmission spectrum showed strong signals from molecular oxygen and from water, both important biosignatures. Sodium, calcium, and potassium also appeared in Earth's transmission spectrum, and all three elements have been detected in the atmospheres of hot Jupiter exoplanets. These results were published in *Astronomy and Astrophysics* (bit.ly/eclipse-Earth-transit).

"The entire exercise was not to learn something new about the Earth's atmosphere," Mallonn said, "but to prove the technique and check out how well we can actually get to the biosignature features, the molecules that might be indicative of life."

"Studies such as this one, which observe solar system planets as if they were exoplanets—i.e., using the same types of observational techniques and/or observing geometry—are vital for our understanding of exoplanet atmospheres," Kempton said.

Awaiting Future Telescopes

Mallonn acknowledged that a lunar eclipse isn't a perfect analogue to what astronomers could expect to see from a transiting exoplanet. During a total lunar eclipse, an observer on the Moon would see the entire Sun blocked by the Earth, but a transiting exoplanet blocks only a small fraction of its host star. The atmospheric signal from such an exoplanet would be much weaker than what the team observed for Earth, he said.

At the moment, "if we were in the situation where we found an Earth-sized planet around a Sun-like star, the LBT could hardly do anything about it," he said. "We would have to wait another 10 years for the next generation of ground-based telescopes with much larger mirror sizes and much larger apertures." Some of those telescopes, such as the European Extremely Large Telescope and the Thirty Meter Telescope, are currently in development and are expected to play a crucial role in detecting signs of life on exoplanets, Mallonn said.

Moreover, molecular oxygen and water aren't the most convincing of biosignatures. Methane, ozone, and a host of gases are more suggestive of life. However, the most persuasive biosignatures produce signals at longer infrared wavelengths that are difficult to measure beneath Earth's atmosphere. The atmosphere absorbs much of that light in what's called a telluric spectrum.

"In the infrared, the space telescopes have the strong advantage of not being affected by the telluric component of the spectrum," Mallonn said. The James Webb Space Telescope is expected to fill that role.

"It's rather simple to see that there's life on Earth," he said. "If another civilization living out there takes a spectrum of the Earth, then [it'll] actually see by our own biosignature molecules that there is life…and I just hope that in another 30 years or whenever, we might be able to do a similar observation of another planet."

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

Opposite: Josep Castells/Unsplash