Solar eclipse caused bow waves in Earth's atmosphere

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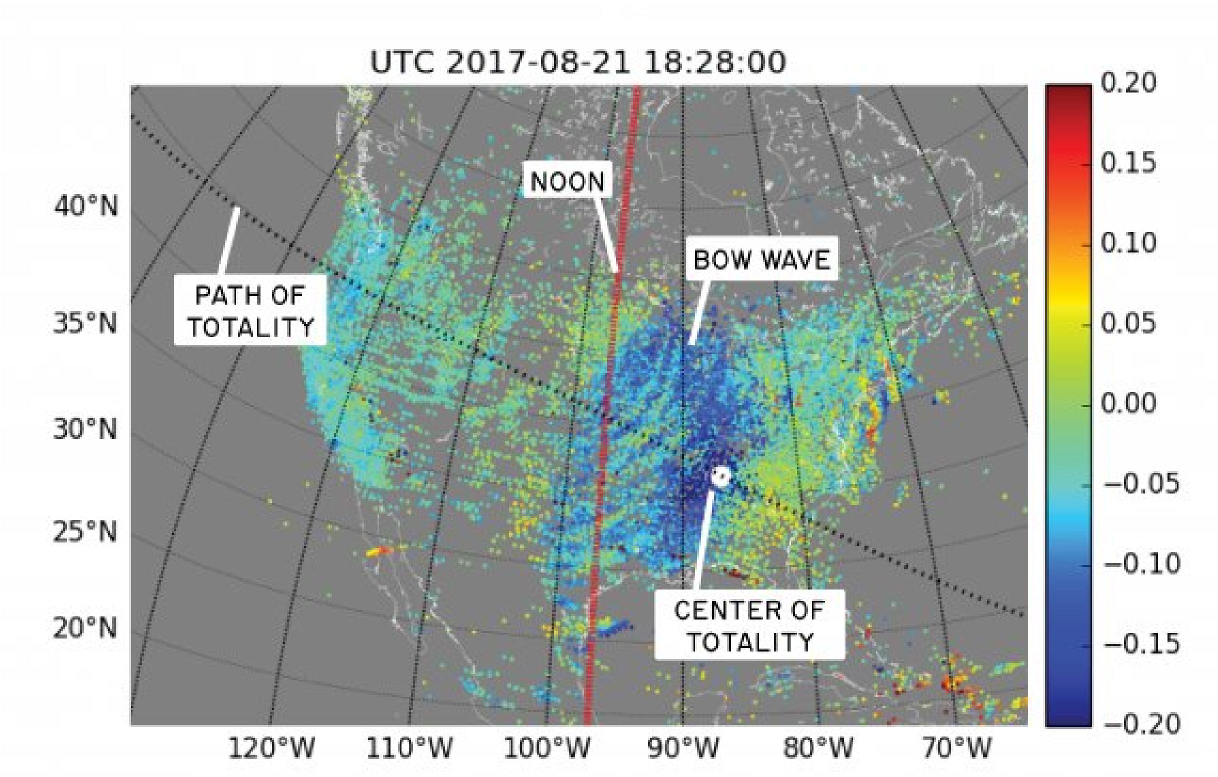

This graphic shows atmospheric bow waves forming during the August 2017 eclipse over the continental United States. Credit: Shunrong Zhang/Haystack Observatory

The celebrated Great American Eclipse of August 2017 crossed the continental U.S. in 90 minutes, and totality lasted no longer than a few minutes at any one location. The event is well in the rear-view mirror now, but scientific investigation into the effects of the moon's shadow on the Earth's atmosphere is still being hotly pursued, and interesting new findings are surfacing at a rapid pace. These include significant observations by scientists at MIT's Haystack Observatory in Westford, Massachusetts.

Eclipses are not particularly rare, but it is unusual for one to cross the entire continental U.S. as happened in August. By studying an eclipse's effects on the electron content of the upper atmosphere, scientists are learning more about how our planet's complex and interlocked atmosphere responds to space weather events, such as solar flares and coronal mass ejections, that can have severe effects on signal information and communication paths, and can impact navigation and positioning services.

The ionosphere is the layer of the atmosphere containing charged particles created primarily by solar radiation. It allows long-distance radio wave propagation and communication over the horizon and affects essential satellite-based transmissions in navigation systems and on-board aircraft. Since the ionosphere is the medium in which radio waves travel and is affected by solar variations, understanding its features is important for our modern technological society. The ionosphere is host to a huge number of naturally occurring waves, from small to large in size and strength, and eclipse shadows in particular can leave behind a large number of newly created waves as they travel across the planet.

One kind of these new waves, known as ionospheric bow waves, has been predicted for more than 40 years to exist in the wake of an eclipse passage. Researchers at MIT's Haystack Observatory and the University of Tromsø in Norway confirmed the existence of ionospheric bow waves definitively for the first time during the August 2017 event. An international team led by Haystack Observatory scientists studied ionospheric electron content data collected by a network of more than 2,000 GNSS (Global Navigation Satellite System) receivers across the nation. Based on this work, Haystack's Shunrong Zhang and colleagues published an article in December in the journal *Geophysical Research Letters* on the results showing the newly detected ionospheric bow waves.

Geospace research scientists at Haystack Observatory were able to observe the eclipse bow wave phenomenon for the first time in the atmosphere with unprecedented detail and accuracy, thanks to the vast network of extremely sensitive GNSS receivers now in place across the U.S. The observed ionospheric bow waves are much like those formed by a ship; the moon's shadow travels so quickly that it causes a sudden temperature change as the atmosphere is rapidly cooled and then reheated as the eclipse passes.

"The eclipse shadow has a supersonic motion which [generates] atmospheric bow waves, similar to a fast-moving river boat, with waves starting in the lower atmosphere and propagating into the ionosphere," the description by Zhang and his colleagues states. "Eclipse passage generated clear ionospheric bow waves in electron content disturbances emanating from totality primarily over central/eastern United States. Study of wave characteristics reveals complex interconnections between the sun, moon, and Earth's neutral atmosphere and ionosphere."

GNSS receivers collect very accurate, high-resolution data on the total electron content (TEC) of the ionosphere. The rich detail provided by this data informed a separate study on eclipse effects in the same issue of *Geophysical Research Letters* by the Haystack research team and international colleagues. Haystack Observatory Associate Director and lead author Anthea Coster and her co-authors describe the continental size and timing of eclipse-triggered TEC depletions observed over the U.S. and observed increased TEC over the Rocky Mountains that is likely related to the generation of mountain waves in the lower atmosphere during the eclipse. The reason for this effect—which was not predicted or anticipated before the eclipse—is being investigated by the geospace science community.

"Since the first days of radio communications more than 100 years ago, eclipses have been known to have large and sometimes unanticipated effects on the ionized part of Earth's atmosphere and the signals that pass through it," says Phil Erickson, assistant director at Haystack and lead for the atmospheric and geospace sciences group. "These new results from Haystack-led studies are an excellent example of how much still remains to be learned about our atmosphere and its complex interactions through observing one of nature's most spectacular sights—a giant active celestial experiment provided by the sun and moon. The power of modern observing methods, including radio remote sensors distributed widely across the United States, was key to revealing these new and fascinating features."

The Haystack eclipse studies, including the bow wave observations, drew the attention of national science media outlets. One of Zhang's readers, an eighth grader from Minnesota, asked some interesting questions:

Q: Was there any prior evidence to show that the waves would be arriving during the eclipse?

A: There were prior studies on the waves based on very limited spatial coverage of the observations. The Great American Eclipse provided unprecedented spatial coverage to view unambiguously the complete wave structures.

Q: Did these waves emit any seismic activity? Did they have a frequency that they could be detected on?

A: No, they didn't. In fact we believe these waves were originated from the middle atmosphere [about 50 kilometers] but we observed them in the upper atmosphere at approximately 300 kilometers. They were very weak-pressure fluctuations if we observe the waves from the ground. This kind of wave was produced by eclipse-related cooling processes; there might be other ways to induce similar waves in the upper atmosphere.

Q: On the path of totality, were the waves stronger? Did they have any different effect anywhere else?

A: Yes, we found that they existed mostly along and within a few hundreds of kilometers from the totality central path. They were first seen in central U.S., then vanished in the central-eastern U.S. They were able to travel for about one hour at a speed of approximately 300 meters per second, slower than the moon shadow's speed.

Haystack scientists will continue to analyze atmospheric data from the eclipse and expect to report other findings shortly. The next major eclipse across North America will occur in April 2024.

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