Cosmic charges

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>
> Themis Chronis
> Hellenic Centre for Marine Research

by Laura Naranjo

Plug in your cell phone or even something as mundane as your toaster, and currents pulse obediently through cables and wing through wires. We have tamed electricity and put it to good use. Or so we think. Earth's entire atmosphere is bristling with electricity, but we are only aware of it when we see lightning—electricity made visible—sizzle across the sky.

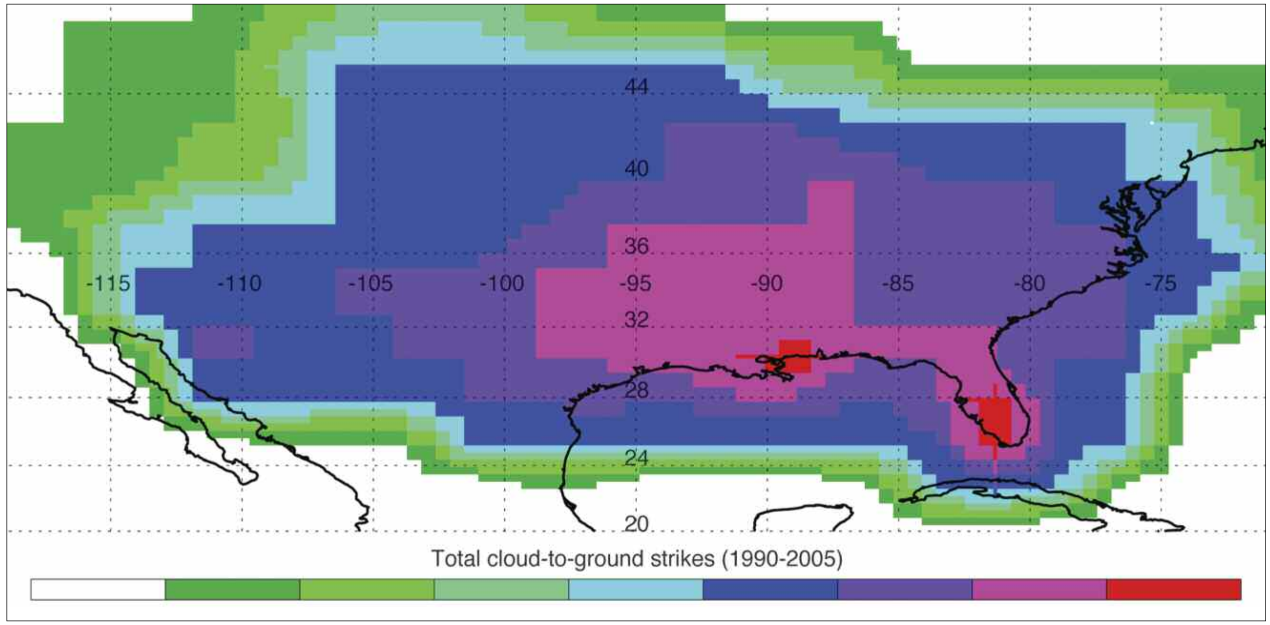
Scientists have discovered that lightning is more than just nature's light show: it can create dangerous weather, disable electrical utilities, and even contribute to air pollution. Earth's electrical environment, however, is not a closed

Thunderstorms discharge electricity as both cloud flashes and ground flashes, as shown in this photograph. Each type of lightning may have different effects on air quality and atmospheric electricity. (Courtesy K. Arnett) circuit. It may be receiving jolts from an unusual, extraterrestrial source: galactic cosmic rays. "Our atmosphere is bombarded with cosmic rays every single second," said Themis Chronis, at the Hellenic Centre for Marine Research. Galactic cosmic rays may seem the stuff of video games, but Chronis found that these rays might be fueling the ebb and flow of Earth's lightning strikes.

A giant battery

Despite their name, cosmic rays are not rays at all. When these were first discovered, scientists assumed they were rays beaming through space, similar to sunlight, and the misnomer stuck. In fact, they are tiny atomic particles released by distant and ancient interstellar events, such as supernova explosions. As these particles ricochet across the galaxy like billiard balls, the force and speed of their travels strips electrons away, often turning them into positively-charged protons by the time they reach Earth.

When cosmic rays enter the atmosphere, they can be one factor in the formation of lightning. "You can consider the atmosphere around the Earth a giant battery," Chronis said. Cosmic rays charge and electrify Earth's atmosphere, and lightning discharges some of that energy. Chronis was intrigued at how much of a role cosmic rays played in triggering lightning all over Earth. At the time, he was completing post-doctoral research at the NASA Global Hydrology and Climate Center, co-located with the Global Hydrology Resource Center (GHRC), which houses data from the National Lightning Detection Network (NLDN). "I had this entire data set that no one else has looked at in this way," he said. "It is the most sophisticated lightning detection system in the world, and the data go back to 1988."



This map of the United States shows the total number of cloud-to-ground lightning strikes from 1990 to 2005 over the United States. Green indicates the fewest strikes, and red indicates the most strikes. Lightning strikes occur most frequently in the southeastern part of the country, in states like Florida and Texas. Data are from the National Lightning Detection Network (NLDN). (Courtesy T. Chronis)

Forbush decreases

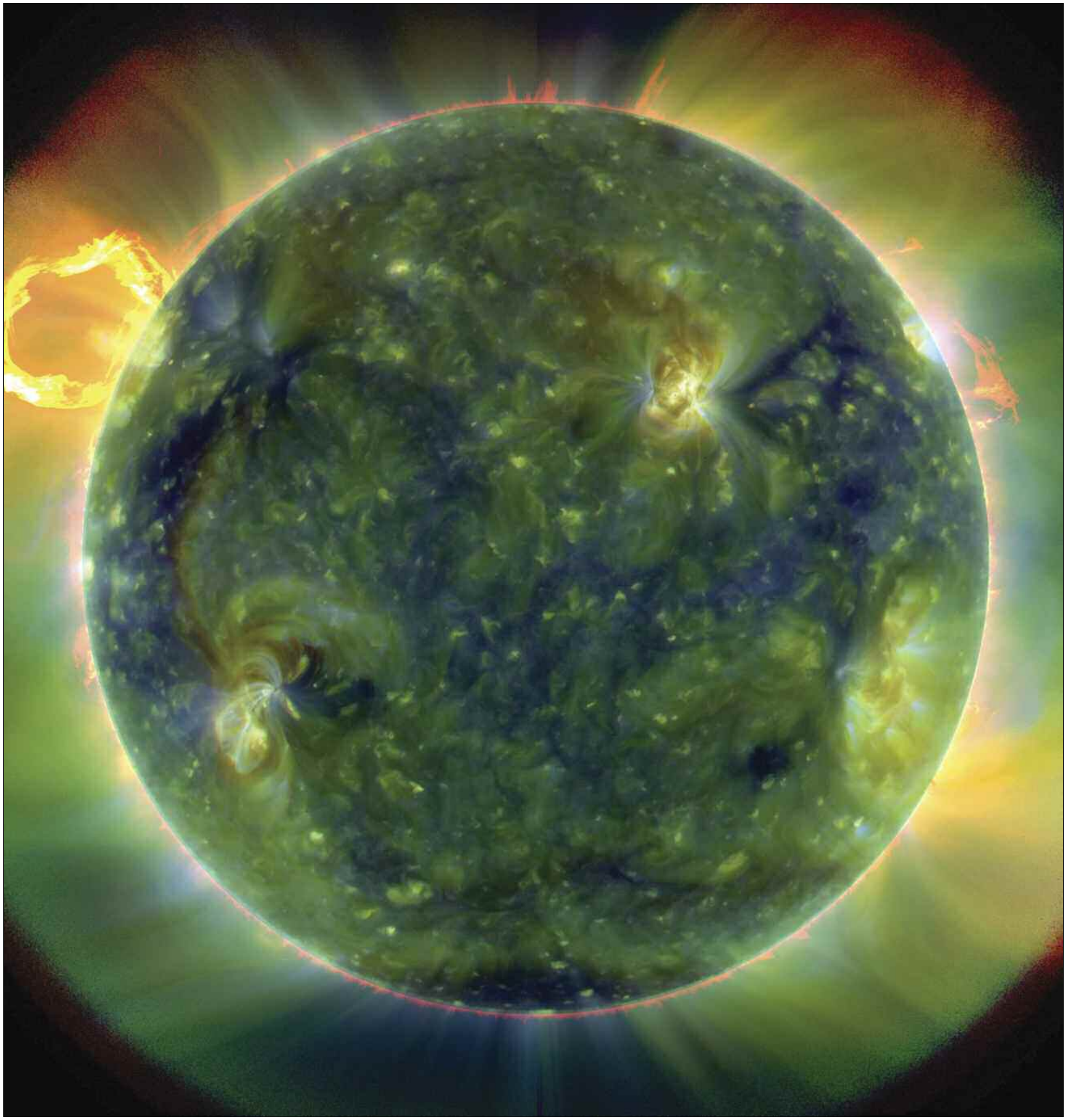
Using the NLDN data, Chronis compared daily cloud-to-ground lightning strikes to data on cosmic ray activity over the continental United States. He found that lightning frequency was indeed linked to the flow of cosmic rays, which in turn are governed by other galactic processes, such as solar flares.

"A solar flare may reduce the cosmic rays that are coming into Earth's atmosphere," Chronis said. During solar flares, the sun ejects massive amounts of plasma gas that diverts cosmic rays, temporarily sweeping them away from the Earth. Chronis discovered that these sudden decreases, called Forbush decreases, also reduced lightning for about four to five days afterwards: Forbush events temporarily made Earth's atmosphere less conductive, resulting in less lightning.

Chemistry in a flash

Although Chronis's findings are preliminary, such a large-scale connection between cosmic rays and lightning holds deeper implications for researchers. Scientists still do not completely understand Earth's electrical environment. But understanding lightning might help reveal how atmospheric electricity influences our everyday life, including the quality of the air we breathe.

William Koshak, a researcher at the Marshall Space Flight Center, studies how lightning affects air chemistry. He said, "Lightning is one of the most important sources of nitrogen oxides in the upper troposphere, and is coupled into the whole



This image of the sun captured a massive solar flare eruption. Intense solar flares can temporarily interrupt the galactic cosmic rays that normally stream into Earth's atmosphere. Scientists have found that these decreases in cosmic rays also reduce lightning frequency on Earth. (Courtesy NASA)

issue of air quality and global warming." Lightning produces the nitrogen oxide gases nitric oxide and nitrogen dioxide, which are toxic air pollutants. Through a chemical chain reaction in the atmosphere, these pollutants can form ozone, which mixes with man-made ozone generated by vehicle exhaust and power plants. In the upper atmosphere, ozone shields us from excessive solar radiation. In lower levels of the atmosphere, however, ozone is harmful to human beings, and has been linked to heart attacks, asthma, and other health problems.

Researchers who assess air pollution and help determine bad air days are equally interested, because current computer models do not adequately account for nitrogen oxides produced by lightning. In addition, scientists do not know enough about Earth's electrical environment to determine which type of lightning contributes more nitrogen oxides to the atmosphere: ground flashes or cloud flashes.

"If you have a better understanding of how many ground and cloud flashes you're dealing with, and better information on lightning channel lengths, currents, and altitudes, then you can do a better job estimating the amount of nitrogen oxides from lightning, which in turn helps you better estimate ozone. It is a complex problem," Koshak said.

Future needs

Scientists do not yet have all the tools needed to unravel this problem on a global basis. Most lightning networks, such as the NLDN, are data-rich. However, these networks are ground-based, which limits them to specific areas. Lightning sensors on satellites can record lightning strikes around the world, but they lack the ability to discern between ground and cloud flashes. "When you're viewing lightning from space, the cloud obscures your view," Koshak said. So Koshak is developing an algorithm that will enable space-based sensors to estimate what fraction of lightning strikes the ground.

Koshak, Chronis, and other lightning researchers hope that future sensors will uncover some of the mysteries about lightning and Earth's electrical environment. Currently, there is only one space-based lightning sensor and a few ground-based networks that observe lightning activity on a global scale. NASA and the National Oceanic and Atmospheric Administration are collaborating to launch a new Geostationary Operational Environmental Satellite-R series (GOES-R) mission, which will include a lightning mapping instrument. This sensor will continuously monitor lightning in the Western Hemisphere, helping to improve severe weather warnings and provide a better understanding of lightning nitrogen oxide production, crucial for improving regional air quality modeling.

Chronis's research revealed that galactic cosmic rays influence the number of lightning strikes over the United States. He still ponders larger questions about lightning, such as what happens to the electrical quality of clouds, and the water and ice within, after lightning discharges. Chronis plans to take advantage of the global view of lightning that the new sensor will provide. He said, "We'll have to wait for a few years to develop a time series, but we will have lightning observations every couple of milliseconds over an entire hemisphere."

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About the data used

Network	National Lightning Detection Network (NLDN), operated by Vaisala, Incorporated
Sensor	Vaisala IMPACT ESP Lightning Sensors
Data sets	GAI Lightning Ground Strikes and Vaisala U.S. NLDN Flash Data
Resolution	Continental United States
Parameter	Lightning
Data center	NASA Global Hydrology Resource Center (GHRC)

About the scientists

Themis Chronis is a researcher at the Hellenic Centre for Marine Research in Greece. He studies climatological aspects of regional and global lightning activity, hydrology, and remote sensing of extreme weather. The Oak Ridge Associate Universities and the NASA Postdoctoral Fellowship Program supported his research. (Photograph courtesy T. Chronis)

William Koshak is an atmospheric physicist and lightning expert at the NASA Marshall Space Flight Center. His research has included a broad range of activities including mathematical inversion studies, remote sensing of lightning, lightning radiative transfer, lightning chemistry studies, and space sensor calibration and validation. NASA supported his research. (Photograph courtesy E. L. Given)

References

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Koshak, W. J. 2010. Optical characteristics of OTD flashes and the implications for flash type discrimination. *Journal of Atmospheric and Oceanic Technology*, doi:10.1175/2010JTECHA1405.1.

For more information

NASA Global Hydrology Resource Center (GHRC)
http://ghrc.nsstc.nasa.gov

National Lightning Detection Network
http://ghrc.nsstc.nasa.gov/uso/ds_docs/vaiconus/vaiconus_dataset.html

NASA Marshall Space Flight Center
http://www.nasa.gov/centers/marshall/home

Hellenic Centre for Marine Research
http://www.hcmr.gr