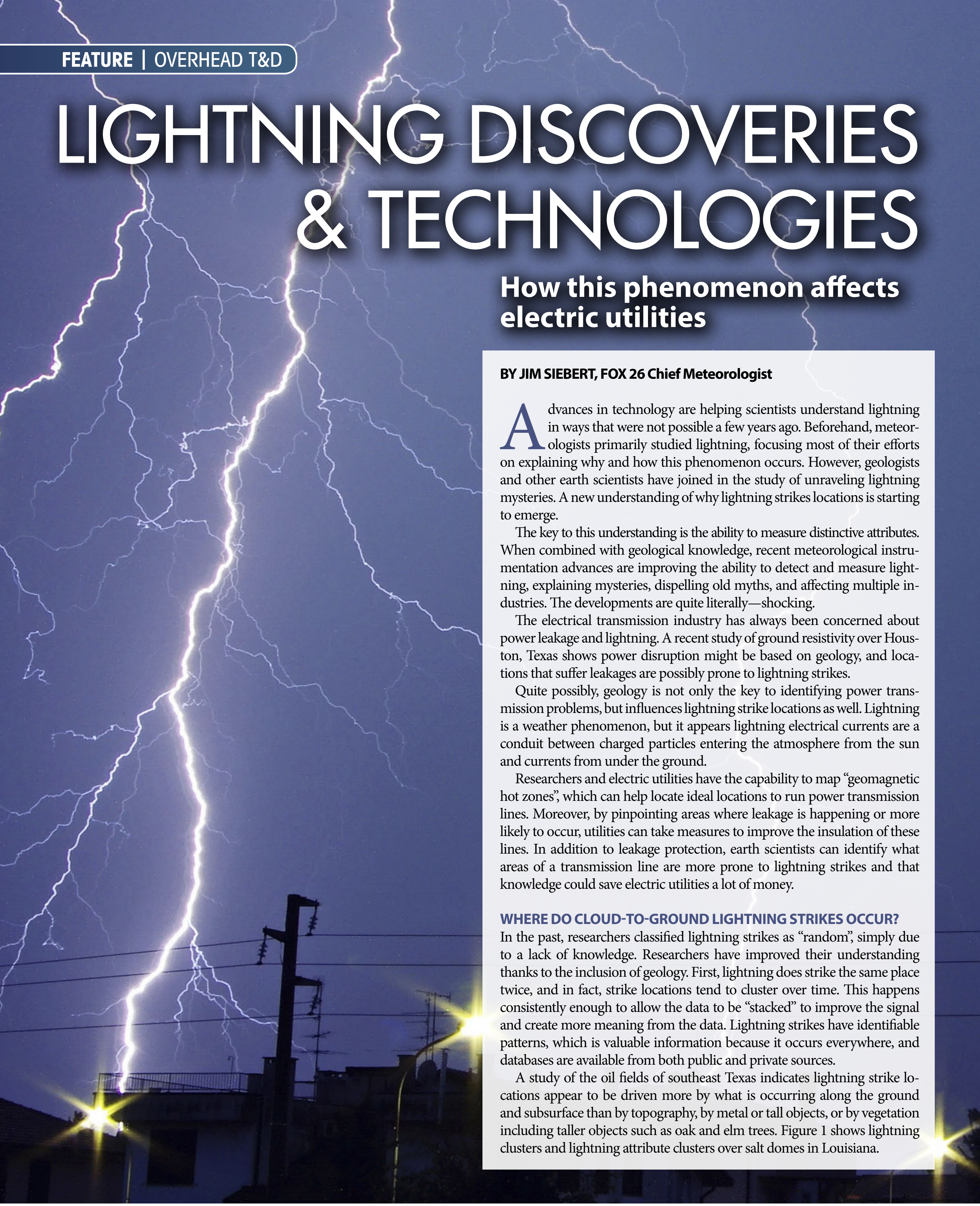


LIGHTNING DISCOVERIES & TECHNOLOGIES

How this phenomenon affects electric utilities

BY JIM SIEBERT, FOX 26 Chief Meteorologist

Advances in technology are helping scientists understand lightning in ways that were not possible a few years ago. Beforehand, meteorologists primarily studied lightning, focusing most of their efforts on explaining why and how this phenomenon occurs. However, geologists and other earth scientists have joined in the study of unraveling lightning mysteries. A new understanding of why lightning strikes locations is starting to emerge.

The key to this understanding is the ability to measure distinctive attributes. When combined with geological knowledge, recent meteorological instrumentation advances are improving the ability to detect and measure lightning, explaining mysteries, dispelling old myths, and affecting multiple industries. The developments are quite literally—shocking.

The electrical transmission industry has always been concerned about power leakage and lightning. A recent study of ground resistivity over Houston, Texas shows power disruption might be based on geology, and locations that suffer leakages are possibly prone to lightning strikes.

Quite possibly, geology is not only the key to identifying power transmission problems, but influences lightning strike locations as well. Lightning is a weather phenomenon, but it appears lightning electrical currents are a conduit between charged particles entering the atmosphere from the sun and currents from under the ground.

Researchers and electric utilities have the capability to map "geomagnetic hot zones", which can help locate ideal locations to run power transmission lines. Moreover, by pinpointing areas where leakage is happening or more likely to occur, utilities can take measures to improve the insulation of these lines. In addition to leakage protection, earth scientists can identify what areas of a transmission line are more prone to lightning strikes and that knowledge could save electric utilities a lot of money.

WHERE DO CLOUD-TO-GROUND LIGHTNING STRIKES OCCUR?

In the past, researchers classified lightning strikes as "random", simply due to a lack of knowledge. Researchers have improved their understanding thanks to the inclusion of geology. First, lightning does strike the same place twice, and in fact, strike locations tend to cluster over time. This happens consistently enough to allow the data to be "stacked" to improve the signal and create more meaning from the data. Lightning strikes have identifiable patterns, which is valuable information because it occurs everywhere, and databases are available from both public and private sources.

A study of the oil fields of southeast Texas indicates lightning strike locations appear to be driven more by what is occurring along the ground and subsurface than by topography, by metal or tall objects, or by vegetation including taller objects such as oak and elm trees. Figure 1 shows lightning clusters and lightning attribute clusters over salt domes in Louisiana.

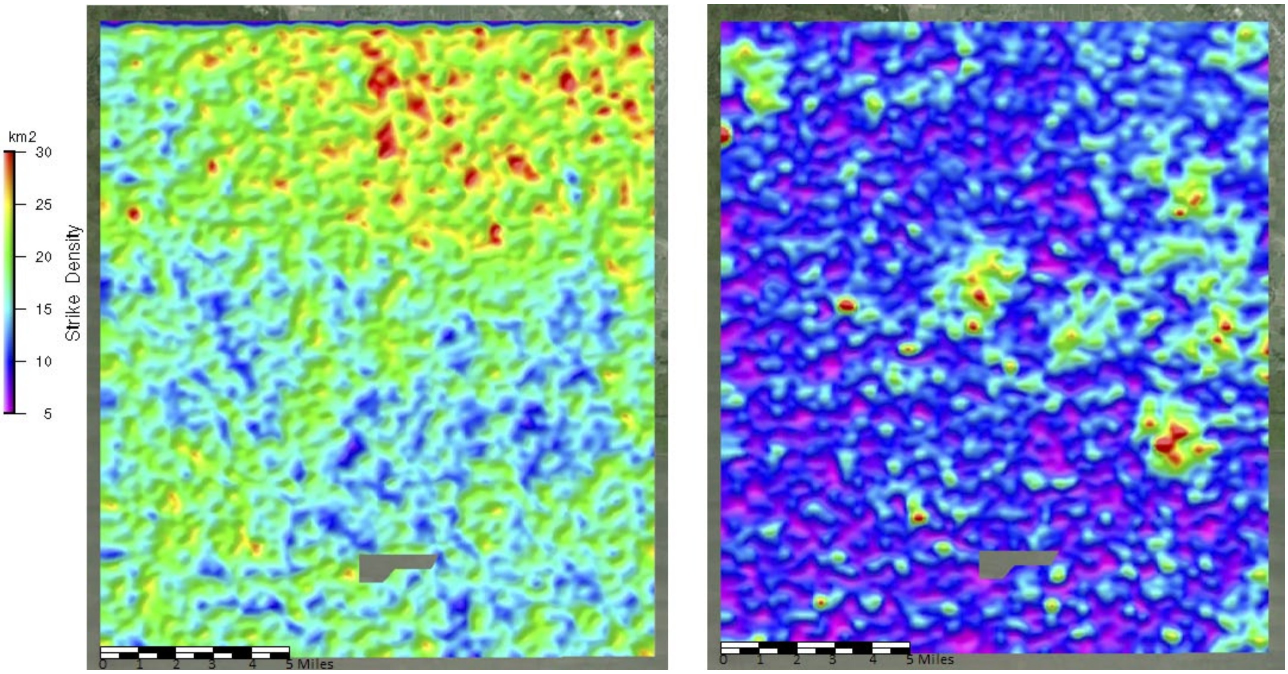


Figure 1: The 15-year lightning strike density map on the left illustrates lightning clusters. The map on the right is created with attributes of the lightning strike recordings, and highlights the location of three major salt domes in the same area, illustrating how lightning strikes are controlled by geology.

More lightning strikes occur on the tops of some mountains, and less on the tops of others. A friend, who has a cabin in the Hill Country of Texas, described how his family enjoys watching lightning storms from the top of their mountain down in the valley, and how very few lightning strikes occur above the limestone outcrop their house is built on. Figure 2 provides a visual illustration of a time-lapse of thunderstorms over a wind farm where multiple cloud-to-ground discharges are controlled more by geology as they bypass the high profile turbines to strike the ground.

Figure 2: A time-lapse of thunderstorms over a wind farm where multiple cloud-to-ground discharges are controlled more by geology as they bypass the high profile turbines to strike the ground.

Logically, drill pipes, which are 18,000-foot lightning rods, should attract lightning strikes. However, a recent study shows that no more lightning strikes occur in the most densely drilled oil field in western North Dakota than 50 miles to the east and 50 miles to the west, where no oil and gas infrastructure exists.

The study concluded electrical currents in the rock matrix, or structural layers of subsurface rocks, have much more impact than a drill pipe that is only a few inches in diameter. In fact, the fingers of lightning strikes are more inclined to hit a power line, but not the main lightning bolt. The main shaft is more inclined to follow the geology and hit the ground, as is shown in Figure 3. This new understanding may alter how transmission lines are constructed and insulated.

Figure 3: One of thousands of images available which show the main lightning bolt hitting the ground, and lightning fingers either being attracted to or hitting transmission lines.

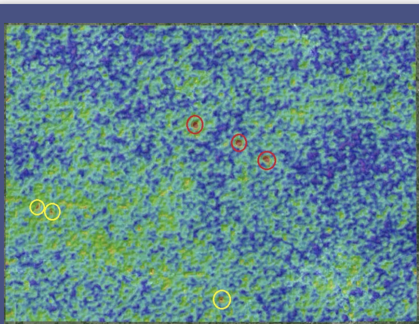


Figure 4a: Red circles show lightning clusters tied to radio towers. Yellow circles highlight areas with anomalies that have no discernable surface infrastructure.

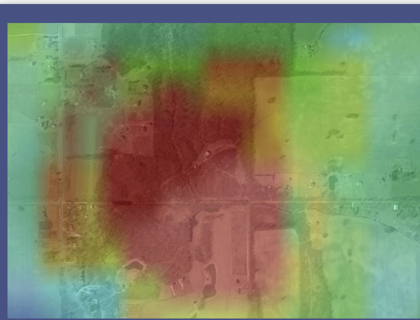


Figure 4b: Close-up upper right anomaly within a red circle where it appears a radio transmission tower is causing the anomaly.

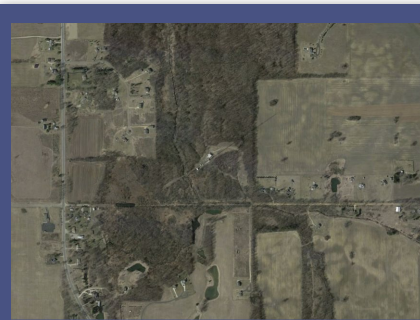


Figure 4c: Close-up of upper left yellow-circled area where there is no visible infrastructure creating the anomaly.

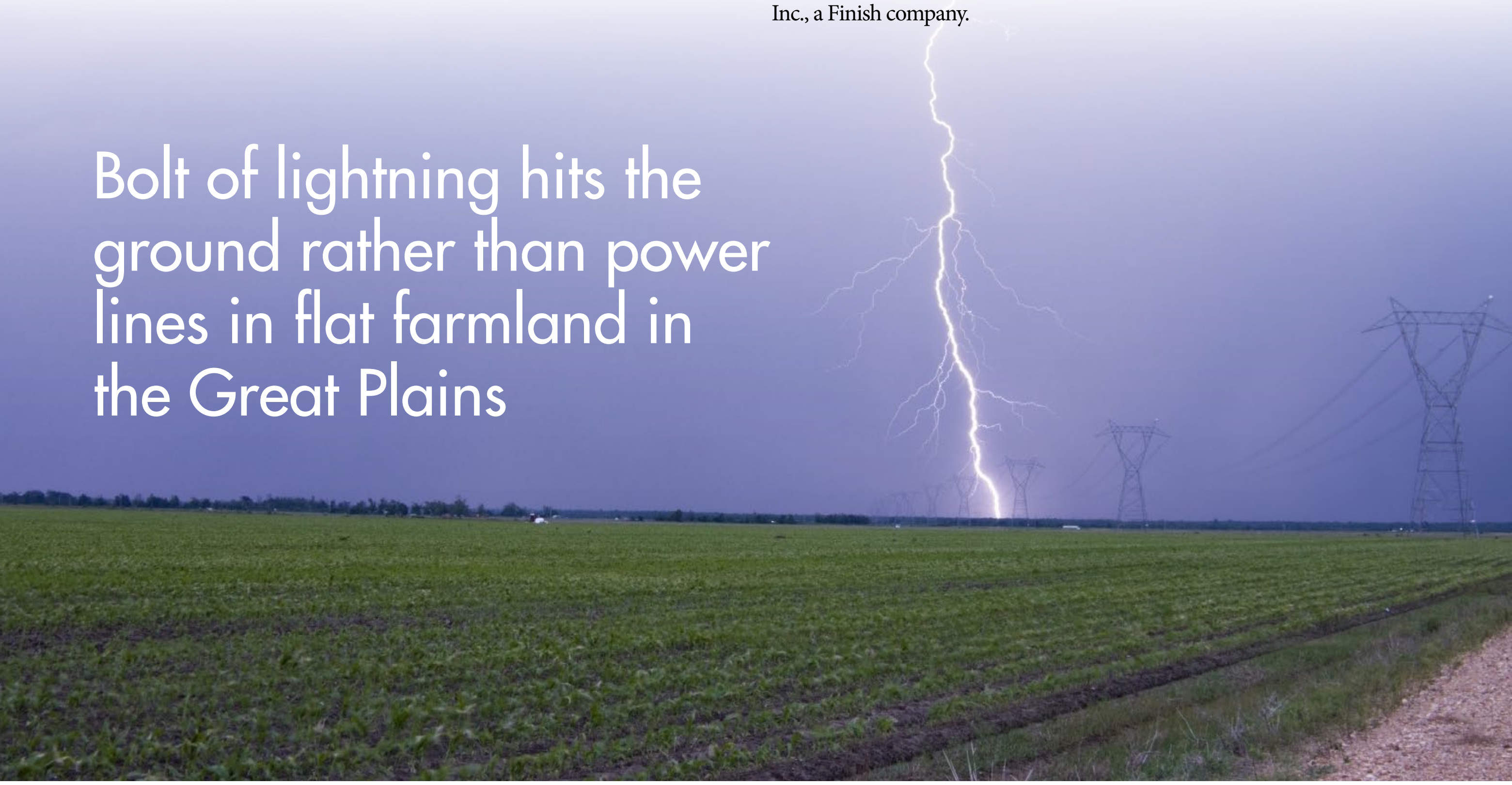
Lightning strikes some radio transmission towers more than others. Figure 4a to 4c, taken from a recent study in Michigan, shows three radio transmission towers have had an anomalous number of lightning strikes hitting them, while other areas with lightning clusters have no visible infrastructure creating the lightning density clusters. Figure 4 shows unique characteristics separating transmission towers and geologic clusters. Additionally, Figure 4 illustrates how scientists have measured and accounted for infrastructure changes in their studies.

In fact, other recent studies have shown lightning often travels 250 kilometers (155 miles) cloud-to-cloud before going to ground. What grounded object, if any, attracts lightning to strike that certain location? Is it because of a 50-foot tall oak or elm tree? Most likely, lightning strikes the ground at a certain location because of the soils where oak and elm trees tend to grow, or because a fault exists in the subsurface near the tree that is disrupting the flow of shallow earth (terralevis) currents.

HOW ARE LIGHTNING STRIKE LOCATIONS AND ATTRIBUTES MEASURED?

In the early 1980s, new measurement technologies enabled accurate identification of lightning strike locations. The early technology was closely related to measuring static on an AM radio. Whenever a thunderstorm moves into an area, static charges can be heard as cracks over the radio with each lightning strike. Advances in computer technology and the sensitivity of the equipment has led to defining nearly all cloud-to-ground (CG) lightning strikes and related lightning physical characteristics across the continental U.S. starting in 1989.

Roughly, 330 six-foot-tall sensors now record lightning strikes and their attributes. They are similar to radio antennas, only with sophisticated weather sensors. These sensors have been upgraded with new technologies at least twice over the past decade. The result was the creation of the National Lightning Detection Network (NLDN), a private database owned by Vaisala, Inc., a Finish company.



Bolt of lightning hits the ground rather than power lines in flat farmland in the Great Plains

The sensitivity of the measuring instruments used to detect and record every lightning bolt has greatly increased over the past decade and that has opened the door for lightning to become a new geophysical data type.

Meteorologists created the NLDN and the insurance industry funded the initial projects to identify fraudulent insurance claims, but this also lead to an unintended isolation of the technology. Nobody was looking at the larger picture of how lightning fit within the earth's electrical system and how it might relate to other geosciences, which, consequently, lead to the natural resource industries not recognizing the relationship between lightning strike locations and geology.

Richard Orville, PhD, a professor at Texas A&M University, who founded the NLDN, told me that in the early 1980s, when the first lightning measurements were taken, up to 60 percent of the reports of houses burned down by lightning were fraudulent or misrepresented. The NLDN has 16 years of consistent lightning data in the continental United States.

A satellite-based network, called the GLD-360 (Global Lightning Database), has four years of data worldwide, with less horizontal resolution, and without all of the lightning attributes found in the National Lightning Detection Network. The satellite data includes the peak current or electricity of a strike, but not the rise time, which is the speed in microseconds of the time to go from background electrical noise to the peak current.

Attributes measured by the NLDN include polarity, rise-time, peak current, the peak-to-zero, or the microseconds from the peak current down to below background electrical noise. By far, most lightning strikes have negative polarity that means negative electrons are discharged toward the earth and tend to originate from the lower end of a cloud. Positive polarity is a positive electric discharge that originates from the higher part of the storm and tends to arrive from cloud toward ground. Positive discharges tend to occur at the later stages of a storm and have a much higher peak current.

Additionally, positive strikes tend to have the loudest thunder. When a storm is off in the distance, an individual may hear rumble, rumble, rumble—and then *boom*. Chances are the boom came from a positive strike and these types of strikes tend to give researchers more insight into the relationship between atmospheric electricity and earth currents.

With all of the advances in our ability to record and store detailed information about lightning strikes, scientists have learned that, in a way, each bolt has an individual signature, similar to how each snowflake is unique. Significant differences exist between each strike from the level of electricity to the duration of a strike; the comparison of these—and other—differences is making new research possible. Researchers have identified that geology and fault lines are more prone to being struck by lightning with particular attributes. Consequently, scientists can use this lightning data to identify sweet spots for natural resources.

The earth's electrical system is a large capacitor

In January 2013, the U.S. government granted a methodology patent (US 8344721 B2) to Dynamic Measurement, LLC, to use lightning data for natural resource exploration including oil, natural gas, and other resources.

HOW DO LIGHTNING STRIKE LOCATION CLUSTERS RELATE TO GEOLOGY?

Geophysicists have known, since the 1950s, about telluric currents or deep earth currents, caused by differences in heat, pressure, and rock structure. Lightning strikes, often occurring on the other side of the globe, are influencing the electrical currents.

The earth's electrical system is a large capacitor. Solar radiation comes into the atmosphere as charged particles, and this charges the ionosphere, which is located in the upper atmosphere. It turns out the ionosphere is acting as part of that capacitor.

The Mohorovičić discontinuity side (boundary between the Earth's crust and the mantle) of the capacitor is kept in balance by lightning strikes, and the bright light displays of the Aurora Borealis (the Northern Lights), and the

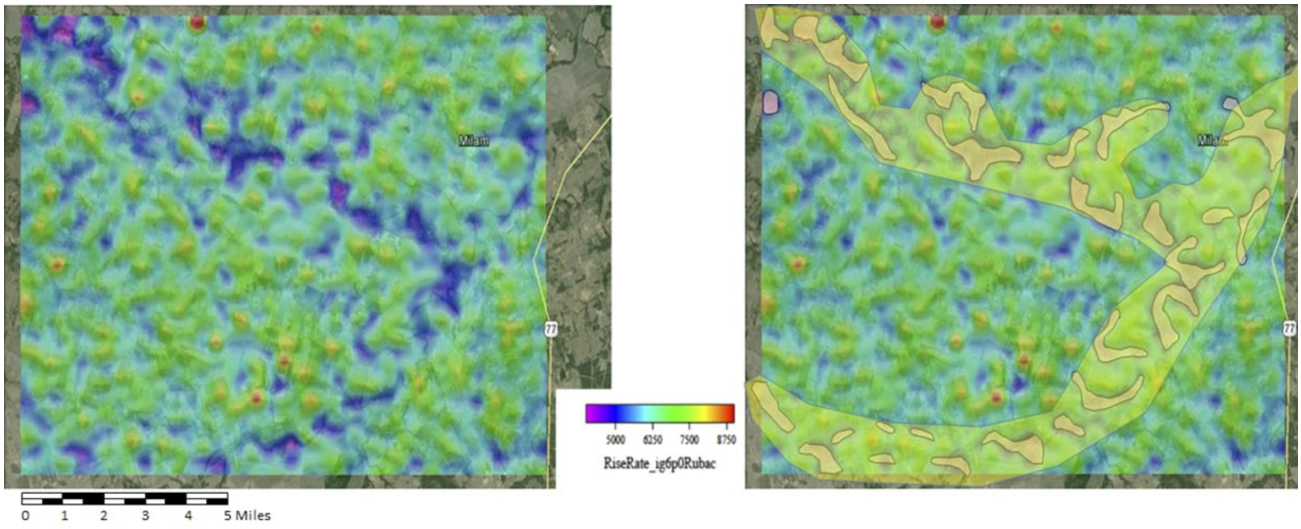


Figure 5: A lightning attribute, rate of rise-time, on the left shows shallow stratigraphy, which is interpreted as point bar sand channels on the right hand slide

Aurora Australis (the Southern Lights). The collision between electrically charged particles from the sun and the earth's atmosphere causes both auroras to display a brilliant light show above the north and south poles. The poles have more activity because the particles travel through more atmosphere due to the angle with the sun.

Telluric currents are earth currents moving through the rock matrix, or structural layers of subsurface rocks. Terralevis currents are the shallow extensions of telluric currents.

Magnetotellurics is the science developed in Russia and France in the 1950s that measures natural variations of magnetic and electrical fields at the surface of the earth.

Geophysicists use Magnetotellurics as an exploration tool to investigate depth ranges between 1,000 and 30,000 feet depths for groundwater monitoring and other resources including hydrocarbon, geothermal, and mining exploration.

Compared to Magnetotellurics, researchers have only collected lightning data and strike characteristics for a few years. Working with earth scientists, geophysicists recognized rather quickly that the lineaments between these clusters are related to faults or planes where geologic layers have been broken by tectonic and gravitational forces. Tectonic refers to the conditions within the earth that causes movements of the crust and continental plates.

Lightning tends to strike some fault lines more often than other lines. Faults are fractures where rocks slip past each other and fault blocks are areas that have numerous faults. Additionally, some fault blocks seem to have more lightning strikes than other blocks.

Research shows that earth currents, which flow in clay layers and are disrupted by faults and resistive hydrocarbon or salt deposits, are stronger in certain areas than others. Meteorologists name the areas with stronger terralevis currents "geomagnetic hot zones". Fault gouge, a rock formed by tectonic forces, are largely comprised of conductive clays.

When the fault comes close to the earth's surface, it becomes a conductor for lightning. Dart leaders (tips of lightning located closest to the earth's surface) extend downward from below a thunderstorm searching for a connection. Research shows that dart leaders have a strong attraction to fault lines.

Disruptions in terralevis currents build up energy in the ground and start moving positive charges upward (also known as streaks or upward leaders), as a response to the discharge of negative charges coming from the clouds. Once the positive (upward current) and negative (downward current) charges meet, lightning strikes occur.

Additionally, mineralization can increase the number of lightning strikes per square kilometer. Mineralization often occurs due to the cooling of hydrothermal fluids injected from deep in the earth along fault lines. In addition, stratigraphy (a branch of geology that studies rock layers) can affect lightning attributes.

Figure 5 is a lightning analysis from north-central Texas, where shallow point bar sand channels, also known as sandbars that highlight the riverbank, are interpreted along the confluence of two existing river channels, also known as a conflux where a tributary joins a larger river. These point bar channels are not geomagnetic hot zones in this particular geologic environment, and the example is included to show how geology can affect these geomagnetic hot zones. Collectively, these analyses were completed using lightning data alone.

The point is, geology does not change over thousands of years, and certainly not over the 16 years the NLDN has been collecting lightning data. Meteorology changes every time a storm forms. Since the storms are sweeping across the same geology and the same terralevis currents, the patterns are similar and consistent enough that millions of lightning strikes can be added together to create a picture of subsurface geology. This same process occurs in deserts, where only 0.1 to 0.5 lightning strikes occur per square kilometer, per year.

Stacking 16 years of lightning data results in a database with 1.6 to eight lightning strikes per square kilometer, which is sufficient to map these patterns. Additionally, measurement equipment can map strikes and geomagnetic hot zones offshore, out to about 300-foot water depths, which is where the shelf break typically starts to occur.

WHO BENEFITS KNOWING HOW DISRUPTIONS IN TERRALEVIS CURRENTS AFFECT ELECTRICAL TRANSMISSION LINES?

The logical extension to these insights is these geomagnetic hot zones are related to power leakage on electrical transmission lines. Figure 6 is another example showing how the main lightning bolt hits the ground. Notice how the lightning's fingers hit the power lines or towers. In an ideal world, technology that can create a CAT-scan of the earth underneath a proposed or existing power transmission line to search for areas of probable leakage would work wonders.

A new patent is pending for calculations created from the electrical measurements in the NLDN database that create resistivity volumes of the subsurface. The first of these resistivity volumes has been compared to a three-

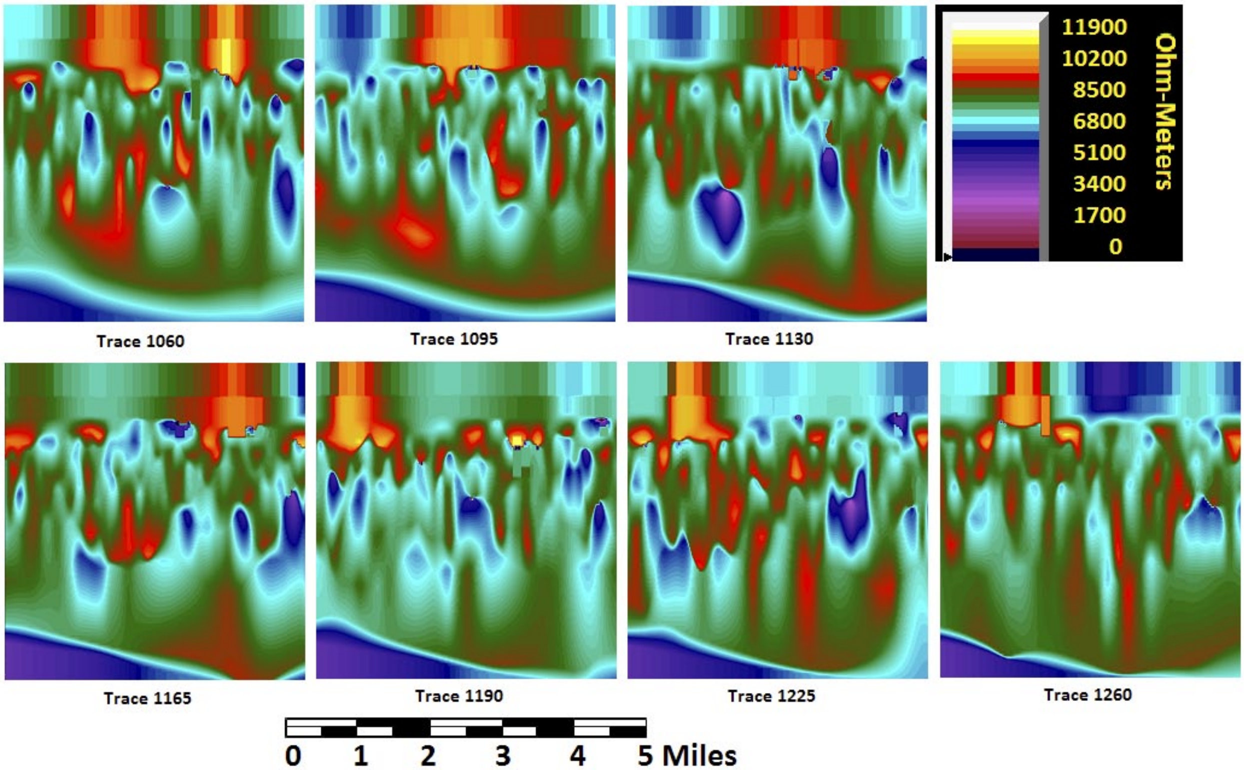


Figure 7: Seven vertical cross-sections from a "CAT-scan" of the earth created from NLDN lightning data

Figure 6: A time lapse of a thunderstorm in west Texas and several cloud-to-ground strikes

dimensional (3-D) seismic survey in Louisiana, and the results are a phenomenal match. According to Park Seismic, a seismic survey is a geophysical survey that measures the earth's (geo-) properties by using physical (-physics) values such as electric, magnetic, and thermal theories.

A movie of resistivity slices is similar to a CAT-scan of the earth. Figure 7 shows seven slices across the area in Louisiana. Red areas are high resistance, and blue areas are high conductivity. The horizontal and vertical axes are approximately the same.

FAMOUS LAST WORDS

Electric utilities can expect the recent discoveries about strike tendencies to have a large impact on the power industry because researchers have identified that towers, substations and other assets are more susceptible to lightning strikes and power leakage if located over a geomagnetic hot zone.

Scientists are just beginning to understand the magnitude of impacts from these zones. Most of the currently identified faults and fault blocks using the lightning data technique were previously unknown. None of these discoveries was considered during the construction of the identified towers and substations, which explains why some these assets are constantly under repair due to electrical issues.

To be sure, most of us will never look at lightning the same way again. It was not that long ago when strike locations were considered random or just the tallest object, but now we have more knowledge. The recent influx of new lightning data is just the beginning of developing this new data type, and according to the experts, we are just scratching the surface with this technology. The future may not only be bright, it may be quite literally illuminating similar to a flash of lighting across the sky. ET