Mapping Faults and Natural Resources with Lightning Data Bases

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Summary

Lightning data, first documented as an electrical phenomenon by Benjamin Franklin, has been collected for decades for insurance, meteorological, and safety reasons (Orville, 2008). There are about three years of data available worldwide and 15 years of data available covering the continental United States. Geophysicists have indirectly used lightning data as an electrical source for magnetotellurics (MT) since the 1950's (Cagniard, 1953). There are databases with the location of billions of lightning strikes, along with the basic data defining the waveform of lightning strikes. These data are available to data mine and to integrate with other exploration data.

We recognize these lightning databases as a new geophysical data type. Lightning data is similar to gravity and magnetic and electromagnetic data, in that it is potential field data. As with the other potential field data, it is different in acquisition, processing, interpretation, and integration, The recorded response is indicative of more conductive subsurface strata, including fluid filled fault zones. Lightning data has been used to predict faulting (Xiaobing Jin, 2013), and this paper demonstrates how it can be used to map faulting from an exploration standpoint.

Based on limited case histories (Nelson, 2012; Denham, 2013; and Nelson, 2013), we also anticipate broad use of lighting data to explore for hydrocarbons, minerals, kimberlite pipes, geothermal energy, water, and other natural resources. Knowing the impact of telluric currents on where lightning strikes will influence civil engineering projects, like the location of pipelines, golf courses and subdivisions, important for engineering geophysics.

Introduction

In the early 1980's new measurement technologies enabled accurate identification of lightning strike locations. Funding by the Electric Power Research Institute and the National Science Foundation to the State University of New York at Albany started lightning detection networks. This led to defining nearly all cloud-to-ground (CG) lightning strike locations and related lightning physical characteristics across the entire continental United States starting in 1989 (Orville, 2008). At this time, almost 60% of claims of home fires being caused by lightning strikes were inaccurate or fraudulent, and insurance companies wanted this data to minimize their exposure (Orville, 2012). The result was the creation of the National Lightning Detection Network (NLDN), which was transitioned from the academic community to the commercial community and is now privately owned. Canada has a similar lightning detection network, the Canadian Lightning Detection Network (CLDN), and the data is owned and distributed by the Canadian government. There are also lightning detection networks in Australia, China, Europe, and many other places around the globe. In 2010 the Global Lightning Detection Network GLD360 (Hembury and Holle, 2011) was introduced, and there are other commercial and government lightning detection networks. To our knowledge none of the lightning detection network data has been used to explore for natural resources prior to our work. Meteorologists pursue applications above the ground. Geophysicists tend to pursue applications beneath the surface of the earth. The closest relationship to lightning data is MT. MT is based on measuring telluric currents in the earth, which currents are internal to the crust of the earth, and charged by the ionosphere and by billions of historical and on-going CG lightning strikes. Magnetotelluric data is integrated with reflection seismic data in hydrocarbon exploration in order to detect resistivity variations in subsurface structures, allowing a better interpretation of which structures are hydrocarbon filled and which are not. MT is also used to explore for base metals, for mapping kimberlite pipes, for geothermal exploration, for groundwater exploration and mapping, for hydrocarbon reservoir monitoring, for studying deep bedrock electrical properties, etc. Lightning data can be similarly used as a new tool for geophysical exploration.

Controlled source electromagnetics (CSEM) has been used as an electrical exploration approach since the 1960's, both offshore (Chessman, et.al., 1987) and onshore (Keller and Frischknecht, 1967; Nabighian, 1991; Wilt, et.al., 1989). Since then CSEM has been tied to deep water exploration. Lightning data is a noise train to be removed from a CSEM study. The use of lightning data as a new geophysical data type is usually called audio magnetotellurics (AMT or AFMAG, Sheriff 2002) sourced electromagnetics. The obvious comparison in the seismic world is passive microseismic recordings, which have proven to be very useful over the last decade (Duncan and Eisner, 2010).

A dozen preliminary studies over the last six years confirm lightning strike locations are not random. We mapped faults, showed relationship to sediment thickness, possibly predicted seeps, and mapped anisotropy, which has the potential to differentiate between ductile and brittle shales in resource plays. We demonstrated lightning strike location are not dominantly tied to infrastructure (wells and pipelines), nor are locations primarily controlled by either topography or vegetation.

Mapping faults and natural resources with lightning databases

History

The idea lightning describes the subsurface evolved from several conversations which occurred about the same time. Joseph Roberts was hunting ducks on the Hockley Dome in northwest Harris County, TX. He was aware of the location of the edge of the Hockley Dome caprock. He saw a large cloud form and it seemed to wrap around the edge of the dome with a large lightning strike hitting the edge of the dome. The next year he saw a similar event, and inquired about it. Several years later, on the 27th of September 2011, he observed the phenomena a third time, and we confirmed these strikes with data from the NLDN database. Obviously, lightning strike location is related to higher subsurface conductivity and can occur at the same location.

Theory and method

Lightning is a meteorological phenomenon (Rakov, 2003). However, lightning strike location and lightning strike attributes appear to be controlled by geology. Figure 1 summarizes our working theory: telluric currents, which are modified by faults, mineralization, and fluids, control lightning strike locations, shown with an example of Kimberlite pipes. Similar modifications of telluric currents occur at faults, or where there are fluids or anisotropy. This fits the fact Cloud-to Cloud lightning has been shown to travel 50 to 120 miles before determining where to become a CG strike.

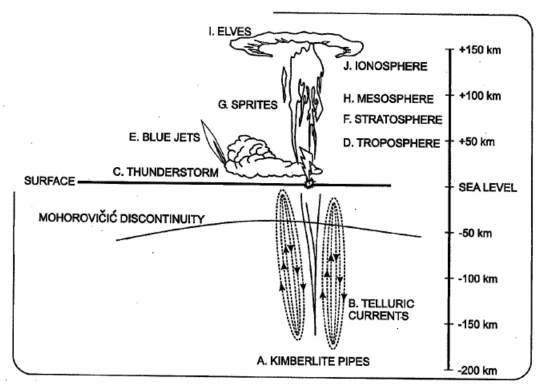

Figure 1: Relationships between lightning and telluric currents (Nelson, et. al., 2011)

Lightning data collection and processing procedures are described in meteorological literature (Murphy, et. al., 2008, and Baba, 2008). Figure 2 shows typical lightning waveform. Key attributes of the waveform are the rise time (RT in microseconds), Peak Current (PC in kiloampres), and Peak-to-Zero (P2Z in microseconds). Because of the large volume of data the full waveform is typically not recorded except for scientific studies. We anticipate there is significant useful information in these data.

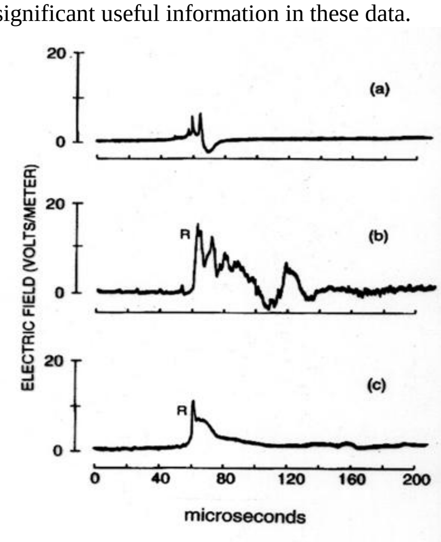

Figure 2: Lightning waveform: (a) cloud discharge; (b) cloud-to-ground first return stroke; (c) cloud-to-ground subsequent stroke (Krider, 1986)

Our first evaluations were to map the density of lightning strikes across time by year, for specific seasons, and for specific times of the day. The resulting maps from Texas, New York, North Dakota, Florida, and Michigan demonstrated lightning strike density varies spatially, and there is some consistency as to where the densest lightning strike locations occur over time. When we mapped the various attributes recorded in the lightning databases, we found the same spatial variation and temporal consistency. We also found the lightning databases have noise. Some of the noise is related to feedback between sensors. Some is related to the distance from the sensors. Some noise is tied to upgrades in the sensors. We have found, as we come to recognize the source of the bias, we are able to come up with ways to remove it from the data. We expect significant improvements in this area over the next few years.

Examples

The first example shows spatial variation lightning density in Mountrail County, North Dakota. Lightning data were retrieved from the NLDN database and mapped using Landmark Graphic's SeisWork software package. Figure 3 shows a map of the Peak Current for each lightning strike occurring from 2008 through 2010 within this area. Similar spatial density variations occur for the count of the number of strikes over various time intervals, the RT, positive PC, negative PC, absolute PC, P2Z, and other mapped attributes.

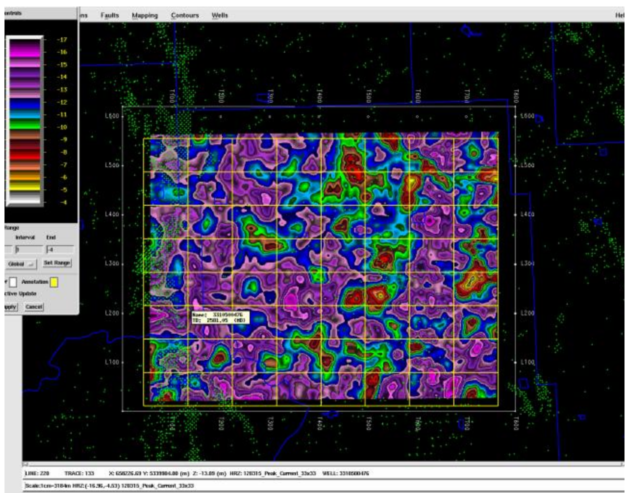

Figure 3: Peak Current Mountrail County, ND

One of the surprises of these initial studies was the impact of lunar tides on lightning strike density. We found 25% more lightning strikes during high lunar tide than during low lunar tides. This variation is possibly related to hydrocarbon seepage (hydrocarbons are resistive in reservoirs and highly electrostatically charged as a gas). Seeps could explain the high density of lightning strikes offshore the Carolinas where there are significant known gas hydrate deposits and on and offshore Louisiana where many of the largest Gulf Coast fields are located. Figure 4 shows PC spatial variations for lightning strikes occurring during high lunar tides in Montrail County, ND.

Our second example is from the Hockley Dome, in South Texas. Figures 5 a - 5 f show lightning strike peak current and lightning strike density maps from 2000 through 2011. Again, the data were retrieved from the NLDN database, cleaned, normalized, and contoured. These maps show the absolute value of the PC for each year after normalizing against the strongest strikes for each year. There are overlays on Figure 5b of the Hockley and Sealy salt domes and a legacy map to Top Wilcox. Figures 5c-5f have the overlay of the legacy map to Top Wilcox. Zooming in on an electronic version allows study of the somewhat consistency in lightning strike density over time.

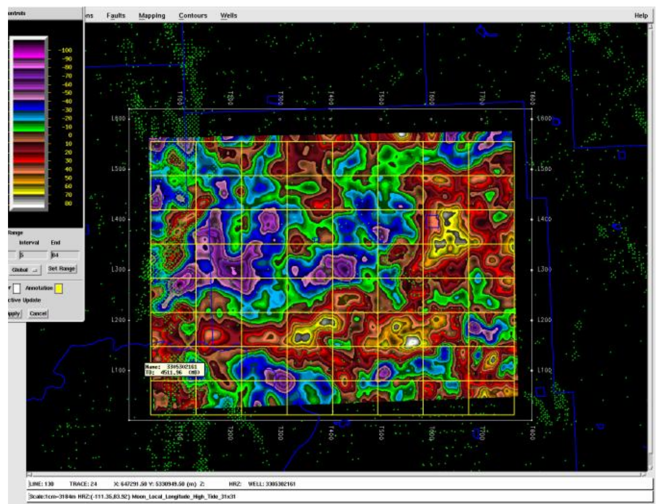

Figure 4: Peak current from lightning strikes occurring during high earth tide, Mountrail County, ND

Conclusions

Lightning strike density varies spatially, and these variations are somewhat consistent over time. Data mining databases of lightning strikes provides a new geophysical data type, which can be integrated with other potential field data types and seismic data to explore for natural resources. Initial studies show correlation with geologic features like fault zones, fracture systems, sediment thickness, etc. all based on the fact lightning strikes seek conductive zones.

Acknowledgements

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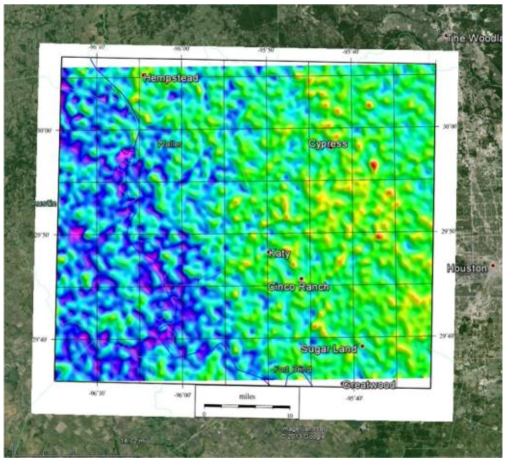

Figure 5a: Peak Current 2000-2011 Hockley Dome area.

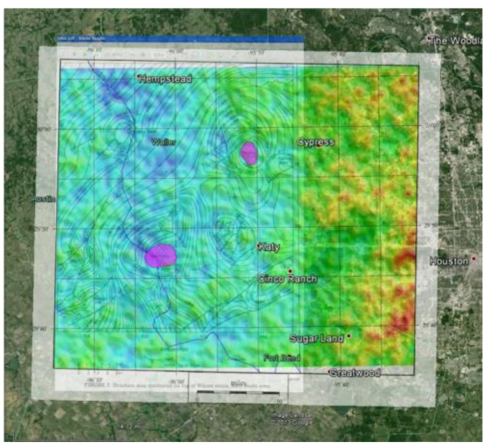

Figure 5b: Lightning Strike Density 2000-2011.

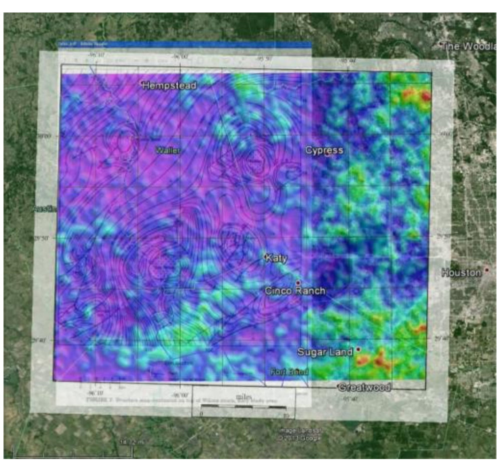

Figure 5c: Lightning Strike Density 2003.

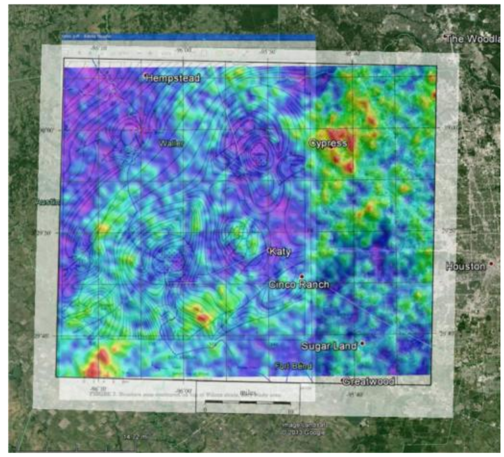

Figure 5d: Lightning Strike Density 2005

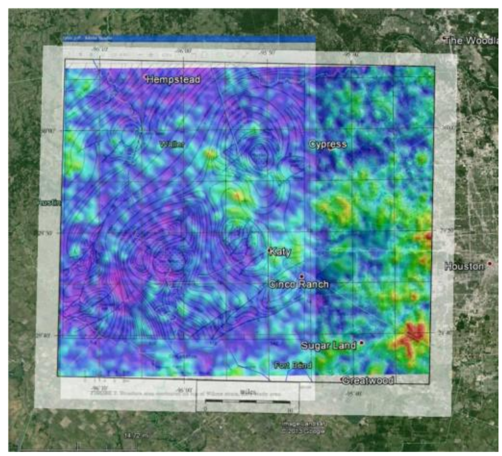

Figure 5e: Lightning Strike Density 2007

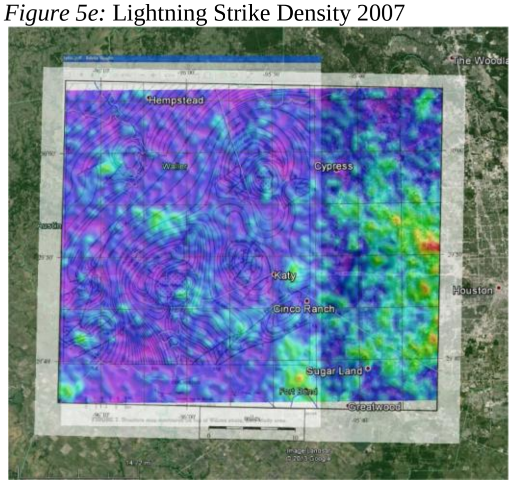

Figure 5f: Lightning Strike Density 2009

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