1556546 Lightning Data, A New Geophysical Data Type

H. R. Nelson, Jr.[1], D. James Siebert[1], and Les R. Denham[1]
(1) Dynamic Measurement LLC (DML), Barker, TX, United States.

Introduction

Lightning data, first documented as an electrical phenomenon by Benjamin Franklin in Pennsylvania, has been collected for decades for insurance, meteorological, and safety reasons. Geophysicists have indirectly used lightning data as part of the electrical source for magnetotellurics (MT) and other electrical telluric measurements since the 1950's. Up to now geophysicists have missed the fact there are databases with the location of billions of lightning strikes available to data mine and to integrate with other exploration data. We recognized these lightning databases as a new geophysical data type.

In the early 1980's new measurement technologies enabled accurate identification of lightning strike locations. This led to defining nearly all cloud-to-ground (CG) lightning strike locations and related lightning physical characteristics across the continental United States starting in 1989. The result was the creation of the National Lightning Detection Network (NLDN), which transitioned from the academic community to the commercial community, funded largely by insurance companies fighting fraudulent claims of loss due to lightning strikes.

A dozen studies over the last five years show 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 controlled only by topography or vegetation or water depth.

Lightning is a meteorological phenomenon. However, lightning strike location and lightning strike attributes appear to be controlled by geology. Telluric currents - which are modified by faults, mineralization, anisotropy, fluids, and geology like kimberlite pipes - control lightning strike locations. When we mapped the various attributes recorded in the lightning databases from Texas, New York, North Dakota, and Michigan we found the same spatial variation and temporal consistency.

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 with seismic data to explore for natural resources.

Initial Insight

Lightning strikes occurred at exactly the same location on two annual duck hunting excursions to the edge of the Hockley Dome in Harris County, TX. Joseph H. Roberts asked the authors if lightning strikes twice at the same place, and if it does, could be because of subsurface geology or fluids. The first step was to identify if lightning strikes locations are recorded, and, if so, to identify whether the data are available. Lightning strike locations in the continental U.S. are recorded by the NLDN and owned by Vaisala, Inc. An opportunity came up to confirm the accuracy of this database when another storm sent dozens of lightning strikes surrounding the same property on 27 September 2011. Figure 1 is a map showing the lightning strikes which occurred on this day, where each strike is colored by its Peak Current in kilo-amps. The Hockley Salt Dome is in the center of the white box at top center, and the property is the yellow outline, right of center of this box.

NLDN (National Lightning Detection Network)

The first lightning Direction Finders in the northeast U.S. were set up by the State University of New York at Albany in March 1982 (Orville, 2008). The technology rapidly spread across the U.S. and by 1988 the entire country was covered with lightning detection sensors. These sensors are about 6 feet, tall and are typically placed at airports. There are 330 sensors covering the continental U.S.A. today. With this number of sensors the NLDN is able to identify basic characteristics of cloud-to-ground lightning strikes with published accuracy less than 1 kilometer (1,600 feet). Overlaying processed data and the resulting mapped faults on a proprietary study, DML has shown accuracy approaching 50 meter 3-D seismic trace and line spacing. For each strike the location, time, rise-time, peak current, peak-to-zero time, number of sensors recording the strike, and some statistical measurements are recorded. Faster sampling and larger disk drives have made it possible to record the full waveform of each lightning strike. However, an economic incentive to store the resulting pedabytes (10^{15} bytes) of data has yet to be demonstrated.

Meteorologists have studied lightning data to understand how storms form and how they move across the country. This information becomes a key component of meteorological forecasting models. Studies include determining the number of flashes, the polarity of the flashes, the peak current and other attributes of the flashes, and mapping these various attributes (Orville, et. al., 2011), Figure 2 shows the density of lightning strikes in the continental U.S.A. from 1997-2007 as recorded by the NLDN. The NLDN is the largest and longest running lightning detection network in the world and has the most data available for data mining. One of the issues DML discovered in data mining these databases is there are noise streams in the data, like feedback between different sensors and circular areas around sensors where data appears to have been filtered. Developing methods to remove this noise has taken time and effort. There are lightning detection networks in many other countries across the world. For the last three years Vaisala has collected data worldwide. In addition, private networks can be set up, which have the potential of providing a way to do electromagnetic time-lapse studies of hydrocarbon fields.

Topography, Vegetation, Infrastructure, and Offshore Impacts on Strike Locations

Common knowledge is lightning strikes the tallest object. The left graph on Figure 3 shows in North Dakota almost all strikes occur where the local relief is less than 80 meters. The elevations used for this analysis were taken from the 3 second DEM (Digital Elevation Map) of North Dakota. The graph to the right breaks this down by replacing the vertical axis with rugosity, or a measure of small-scale variations in the height of a surface. With small elevation differences, there is equal probability of strikes in the low or in the high areas. But for more than 20 meters elevation differences, the high spots are more than twice as likely to be struck. For 40 meter high spots, they are about seven times as likely to be struck. Even though elevation is significant if there is more than about 15 meters of elevation difference from surroundings, there is no concentration of strike locations where there is large relief. North Dakota was selected for this study because it is relatively flat. These small variations in local relief affecting the location of lightning strikes can only be explained by the shortening of the path through the atmosphere by a small amount (between 8 and 40 meters out of 2,000 meter cloud height, or between 0.5 and 2.0% of the atmospheric path). This implies lightning is not as attracted to topographic differences as to electrical differences, since rocks have about 10^{10} times the conductivity of air.

The second study DML did was located in Steuben County, New York, where elevations range from 450 feet to 2,390 feet, as shown on the left half of Figure 4. The red overlay on this map is a basement fault interpretation by S. Parker Gay, Jr. of Applied Geophysics in Salt Lake City, Utah. This fault interpretation is based on NewMag processing of an Aeromagnetic Survey over this area. Note how streams and erosion are tied to the basement fault network. However, note how on the right half of Figure 4, which shows lightning density, there is more correlation between the strike density and the fault interpretation than with the topography. Apparently the basement fault blocks are separate electric cells, and the strikes are associated with some of these cells, and particularly with the basement fault intersections.

The first study DML did was in Colorado County, Texas where there is some correlation between oak trees and positive lightning strikes. Further evaluation of this will require study of the electric potential of trees with different root systems, and more generally the modification of telluric or earth currents by faults and natural resources. Vegetation does not seem to be a general control of lightning strike location.

DML obtained 261 full waveform lightning strikes which occurred in Texas between 12:00 and 1:00 PM on 08 March 2010. Plotting the location of these strikes and overlaying it on a fault map of South Texas from the Bureau of Economic Geology showed most of the lightning strikes occurred along major fault lines. Of particular interest was how none of the strikes which occurred over this 1 hour period hit any infrastructure. In fact, in the Pan Handle part of Texas, there was a storm which had many strikes next to one of the large windmill farms. These windmills are set on top of the Buda Limestone outcrops, which provide several hundred more feet of elevation for the 300 foot tall windmills. Figure 5 shows how all of the strikes in this area were to the south of where the Buda Limestone outcrops. Some of the strikes were closer to the windmills than the height of the windmills, and yet did not hit the windmills. Along a similar line of thought, in North Dakota DML evaluated the density and patterns of lightning strikes across the Beaver Lodge Field, the most densely drilled field in on the Nesson Anticline, and density and patterns of lightning strikes 50 miles to the east and to the west of this field, where there is no infrastructure. The lightning strike density and patterns are similar in all three places. Together these observations imply infrastructure is not a controlling factor in where lightning strikes occur.

In a study in South Texas, shown in Figure 6, DML demonstrated there is some correlation between lightning strike clusters and known oil and gas fields. Of particular interest is the fact the lightning cluster trends continue offshore, out to the shelf break. This fits with the first article we found unwittingly relating lightning strikes with oil and gas fields, where it says:

> "Not expected, however, was the unusually high percentage of Cloud-to-Ground lightning flashes of negative polarity with Imax>75 kA found over the salt waters of the northern Gulf of Mexico, and off the southeastern U.S. coastline. The reason for the large number of intense –Cgs in this region is not clear. While perhaps associated with the high conductivity of the underlying saltwater, the fact this pattern tends to extend more than 100 km inland suggests that surface features are not the only causative factor." (Lyons, et. al., 1998)

The areas described in this article encompasses: (1) most of the large oil and gas fields in Louisiana and North Texas; and (2) the densest gas hydrate deposits offshore the Carolinas. Conrad Schlumberger demonstrated oil and gas deposits are resistive in the subsurface. However, when methane reaches the atmosphere from a seep, it becomes electrostatically charged, and this disruption in the atmospheric dielectric could be driving upward lightning streamers.

While topography, vegetation (especially oak and elm trees), and infrastructure have an impact on lightning strike density, it is not a overall controlling impact. Lightning is a meteorological event, and lightning can gravel for hundreds of kilometers cloud to cloud before going to the ground. Where lightning strikes occur is largely controlled by telluric currents and where these telluric currents are modified by geologic factors like faulting, resistive oil and gas fields, and conductive mineral, geothermal deposits, kimberlite pipes, and methane seeps.

Regional Exploration

Patterns from regional lightning analysis show patterns similar to, and yet different from, patterns found with other potential field data, like maps of gravity, magnetic, and electrical measurements. Figure 7 provides an example with an initial analysis of the state of Michigan, showing topography on the left and lightning density on the right. A regional fault interpretation is overlaid on the lightning density map. Gas wells (red) and oil wells (green) are overlaid on both maps. Interpreters who have worked Michigan have described how hard it is to define a series of strike-slip faults which are known to exist across the state. The interpretation shows a preliminary analysis of where these strike-slip faults could be, based only on lightning data analysis. Note the lightning clustering and lineament trends continue offshore into The Great Lakes.

An important contribution this new geophysical data type provides is the fact the data is already collected and is currently available for data mining. This means any basin in the world can have a preliminary analysis within a couple of months, and costs much less than collecting potential field data or even the commissioning / set up costs for a seismic crew. In addition, there is always more data being added to the database. So once cleaned up derivative data is in house, new algorithms can be applied and new data added to improve the understanding of an area and its sweetspots at any time.

Play Fairway Exploration

Play fairways can cross a basin or be tied to a political boundary like a country or a state or a county. Examples of lightning analysis at the Play Fairway scale are provided below for Mountrail County, ND and for some counties in South Texas.

Figure 8 outlines existing fields in Mountrail County, ND on the left, and, at the same scale and with the same colored outline overlays, shows a lightning analysis for the same area on the right. Correlations are obvious. Interpretation of the correlations is not so obvious. The lightning data were ordered, received, cleaned, and filtered before being mapped. In this case, the filtering involved not just removing noise between and around sensors, filtering also involved only using those lighting strikes which occurred at high lunar tide.

Lunar tides are typically only thought of as affecting the oceans. However, onshore the rocks and sediments also move as the moon circles the earth, although much less than the movement of tides. Old brittle rocks, like are found in the Williston cratonic basin, tend to pull apart, and basement faults, like the ones shown in Figure 4, tend to open up and reactivate. In the Williston Basin these basement faults crack the old brittle rocks above and create vertical faults, which can reach all the way to the surface. These vertical faults are typically not seen on seismic, and are hard to detect with other geophysical data types.

Statistical analysis showed there are 25% more lightning strikes at high lunar tide than at low lunar tide in North Dakota. Assumptions as to why this is so include: (1) high lunar tides open up vertical faults so brines enter the fault scarp and change the telluric currents; or (2) methane enters the vertical faults and there are seeps during high lunar tides. When the map was first shown to an industry group, one of the participants pointed out how the map highlights a fault at the east end of the Red Sky 3-D Seismic Survey (yellow outline), which was not visible on the seismic. When the map was provided, with the yellow seismic survey outline on it, the response was to point out how the lightning analysis highlights the Parshall Field (red), the Beaver Lodge Field (magenta), the Antelope Field (green), and the north part of the Blue Buttes Field (cyan).

Figure 9 shows a similar Play Fairway lightning analysis covering parts of several Texas counties, and centered on Colorado County, Texas. The data are not as filtered as the North Dakota example. There are maps of three key lightning attributes: rise-time (microseconds), average peak current (kilo-amps), and peak-to-zero (microseconds), both for the entire area and for the area covered by a small 3-D seismic survey, where seismic fault interpretation has been posted over each map. The key point is the lightning data trends are not random, and the more the data is worked with the more geological information has been derived. Based on the projects to date, DML anticipates similar new insights will occur with each new lightning analysis undertaken.

Lead and Prospect Exploration

The above examples show lighting strikes cluster. Lightning strike clusters are also somewhat consistent over time. Figure 10 shows lightning strike density over the eastern flank of the Hockley Dome, in northwest Harris County, Texas. There are 11 maps in this figure. The map on the left shows the depth to the top of the caprock. The yellow outline defines Joseph H. Roberts and his associates land. The top left small box is the lightning density for 2000, then 2001, 2002, and 2003 stepping to the right. The middle row of lightning density maps are for 2004, 2005, 2006, and 2007 from left to right. The bottom row of lighting density maps are for 2008, 2009, 2010, and 2011 from left to right. Other than an initial cleaning of the data, there was no filtering done before contouring these maps in a Landmark SeisWorks project. The red and orange probably fault lines were derived from Lidar data covering this same area.

The lightning density clusters do not exactly stack, and yet each year shows the largest number of strikes occur between the two faults and next to the edge of the salt dome on the west property line. This is where the initial two lightning strikes, separated from each other by a year, which started DML's analysis occurred. Based on these maps, DML claims lightning strike clusters are somewhat consistent over time.

The final example goes back to the first project DML did in Colorado County, Texas. Figure 11 shows the first lightning density map overlaid on GeoMap definition of oil and gas fields in Colorado County. GeoMap has contours of the depth to the fields in maroon over their field outlines, and to overlay the data, a background with the same color as these contours was used to hide these contours. Then contours from a Landmark SeisWorks project were captured, overlaid, and registered. Since the details of the lightning density contours do not show up at this scale, a close-up of the southern part of the county is shown in Figure 12. Note there are lightning anomalies at a lead and prospect scale which are over existing fields (white circles), and which are exploration leads (yellow circles). Again, DML anticipates as lightning analysis is done for new projects at this scale, there will new patterns and new insights which will help better explain what this new data type is identifying.

Conclusions

Lightning strikes cluster. Lightning clusters appear to be controlled by telluric currents and geology, and to not by topography, vegetation, infrastructure, nor water depths less than 400 feet. These lightning strike clusters are somewhat consistent over time. Data mining of lightning databases provides a new geophysical data type. This data type is unique in that it is already collected, ready for licensing and evaluation, and is evergreen, in that new data is constantly being added to the database.

New geophysical data types have been identified about once a decade since the 1920's. Each time a geophysical data type is identified, it takes several years to determine how to optimally use the results. Often the results are oversold, and companies using the new geophysical data type are disappointed. Each new geophysical data type eventually develops a sweet spot, where it meets an exploration need.

Data mining lightning data bases has enabled the mapping of faults and anisotropy, has showed a relationship to sediment thickness, possibly predicting seeps. The ability to map faults and predict anisotropy means there is the potential to differentiating between ductile and brittle shales in resource plays. These insights enable high-grading of lease positions. Knowing the tectonic framework for an area of study, whether in a new basin or a new exploration area for an exploration company, enables the company to optimize orientation of new seismic acquisition or spec seismic purchases to be across faults and across the tectonic framework. This minimizes issues of side-wipe, which can be carried into interpretations even after migration and pre-stack depth migration.

Acknowledgements

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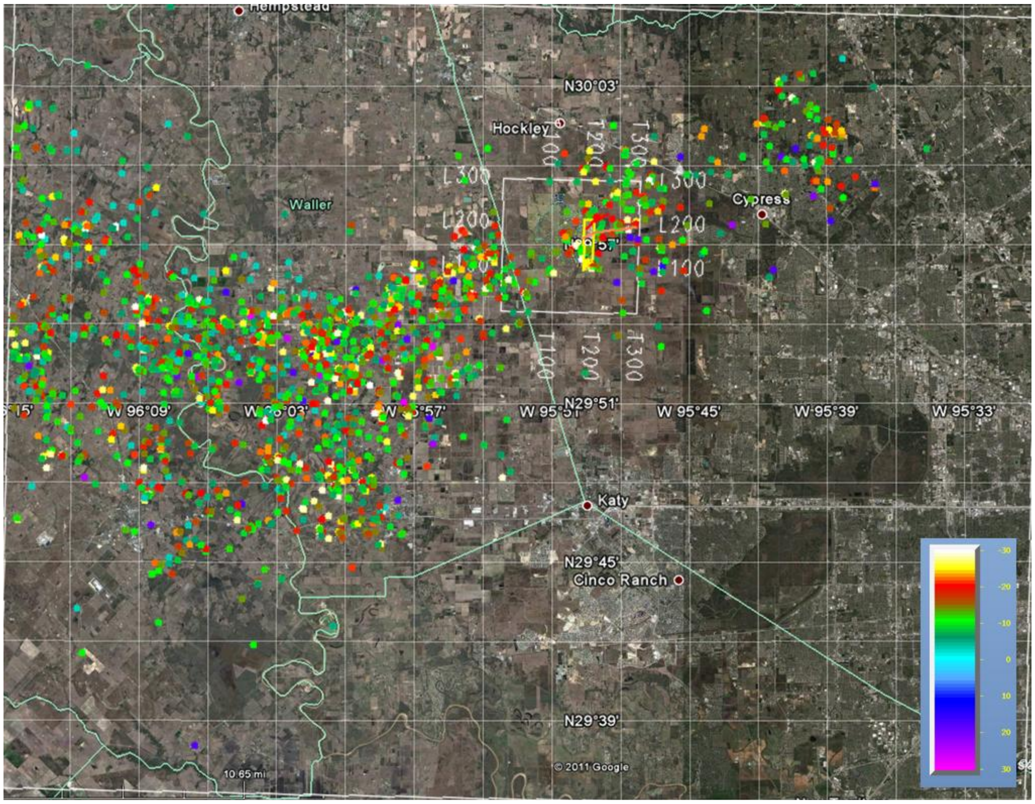

Figure1. Lightning strikes near Hockley Dome, 27 September 2011

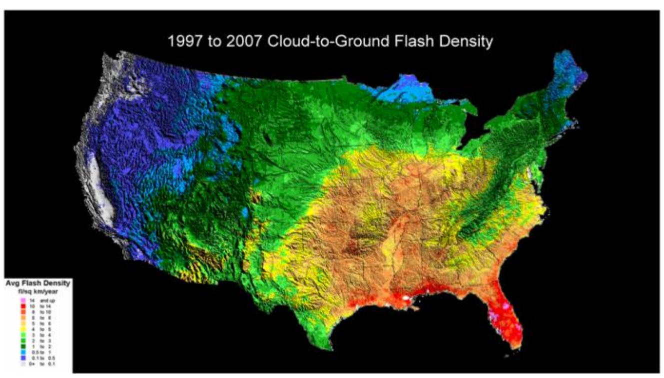

Figure 2. NLDN Cloud-to-Ground Flash Density

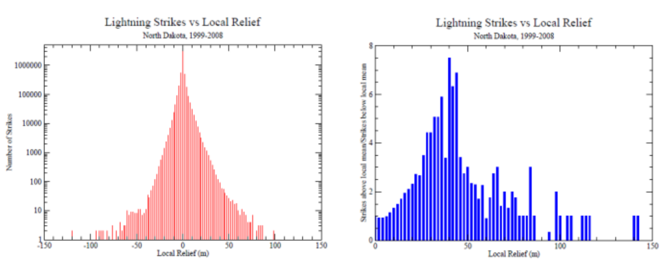

Figure 3. Topography, Rugosity, and Lightning Strike Locations.

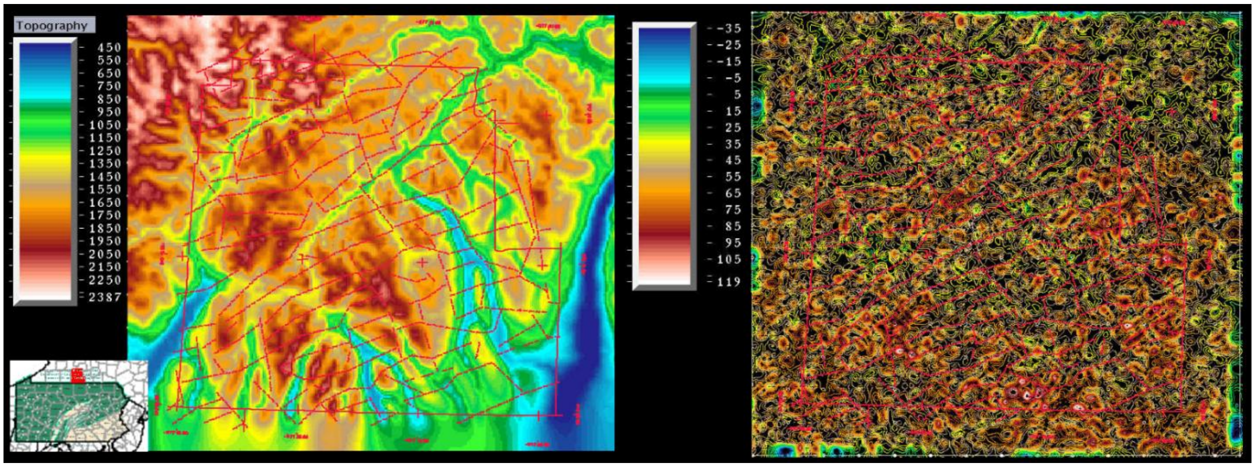

Figure 4. Topography (right), and lightning density (right) in the Marcellus of Steuben County, New York.

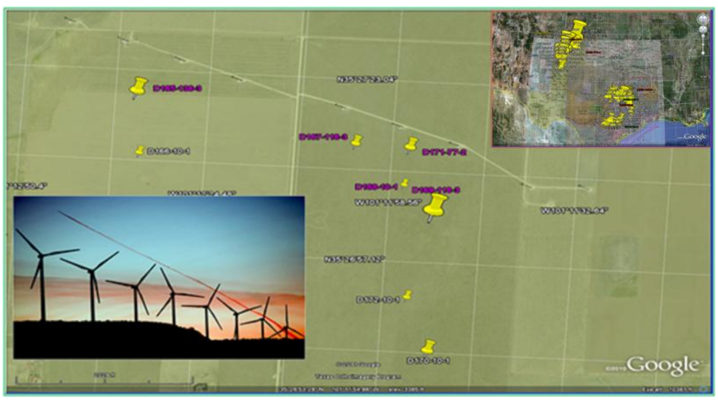

Figure 5. Lightning strikes from 12:00 - 1:00 PM on 08 March 2010 were all on the exposed Buda Outcrop

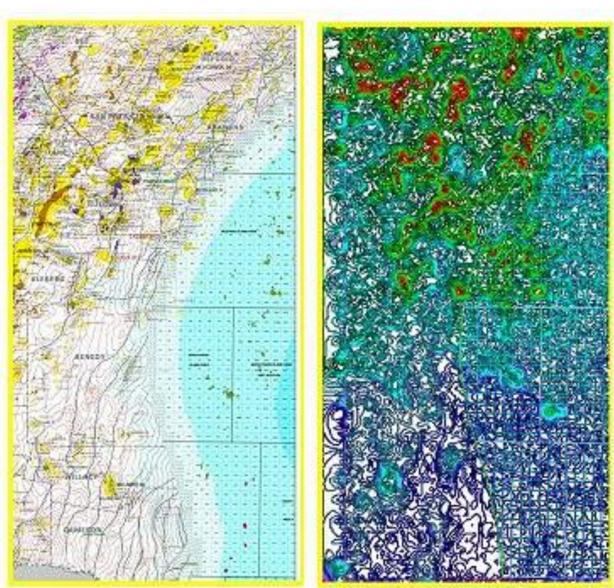

Figure 6. Oil fields (left) and lightning density (right) show clustering continues offshore to the shelf edge.

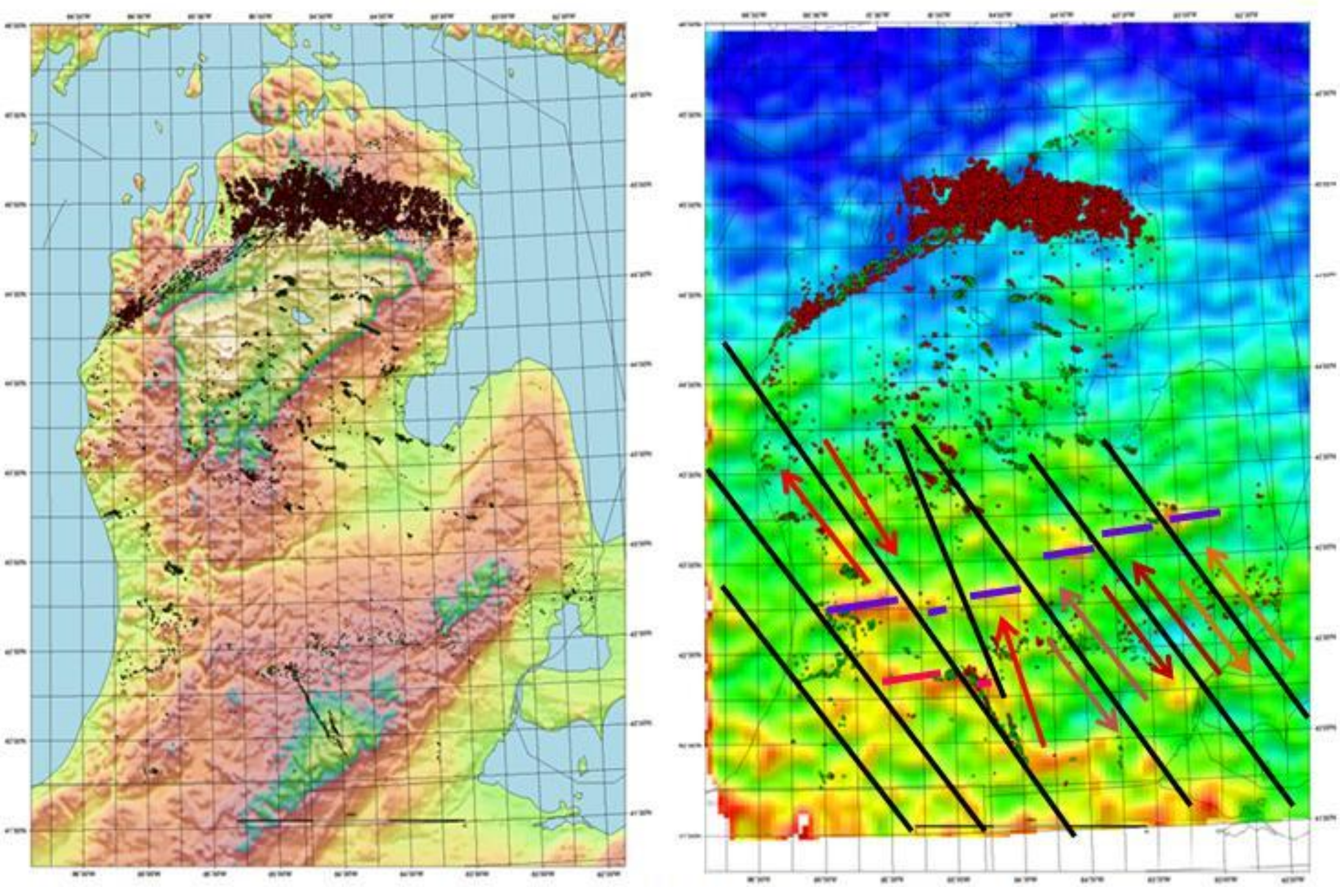

Figure 7. Michigan topography (left) and Lightning Density Interpretation (right): red gas and green oil.

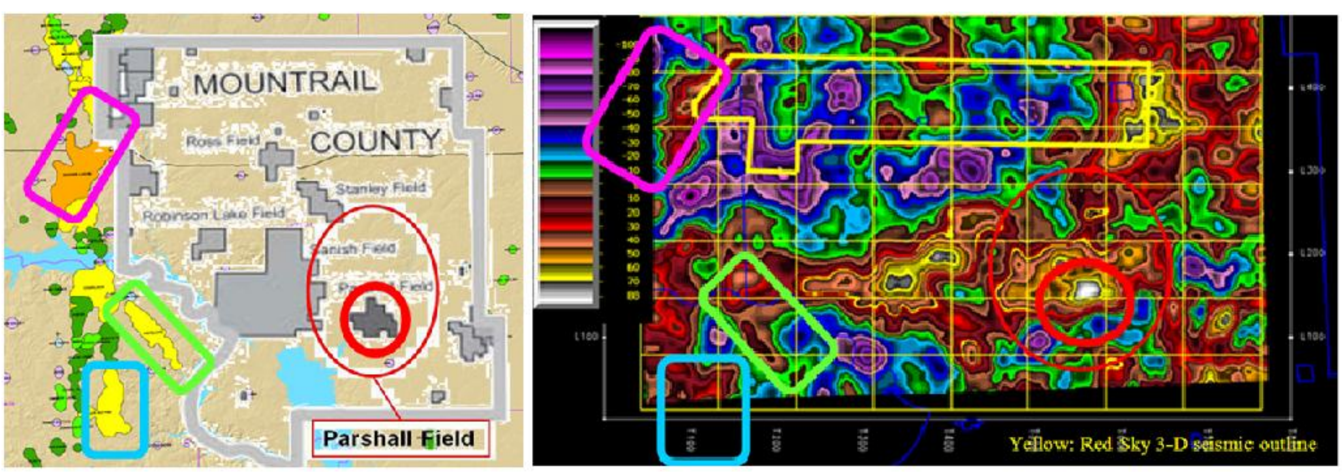

Figure 8. Mountrail County, ND major fields (left) and Lightning Density and Fields (right).

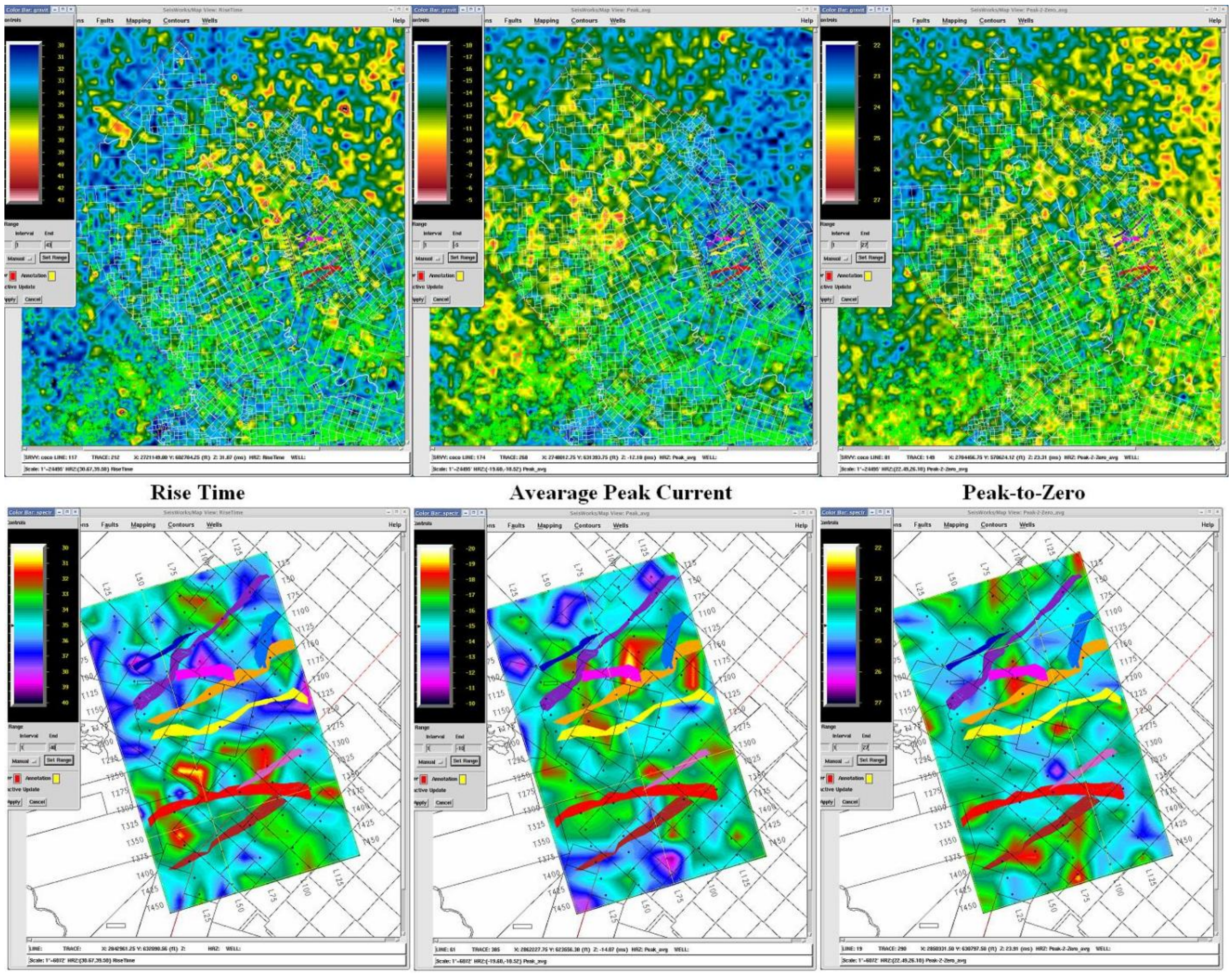

Figure 9. Texas County and 3-D Seismic Lightning Measurements Rise Time (microseconds), Average Peak Current (kilo-amps), and Peak-to-Zero (microseconds) at a county and 3-D seismic scale.

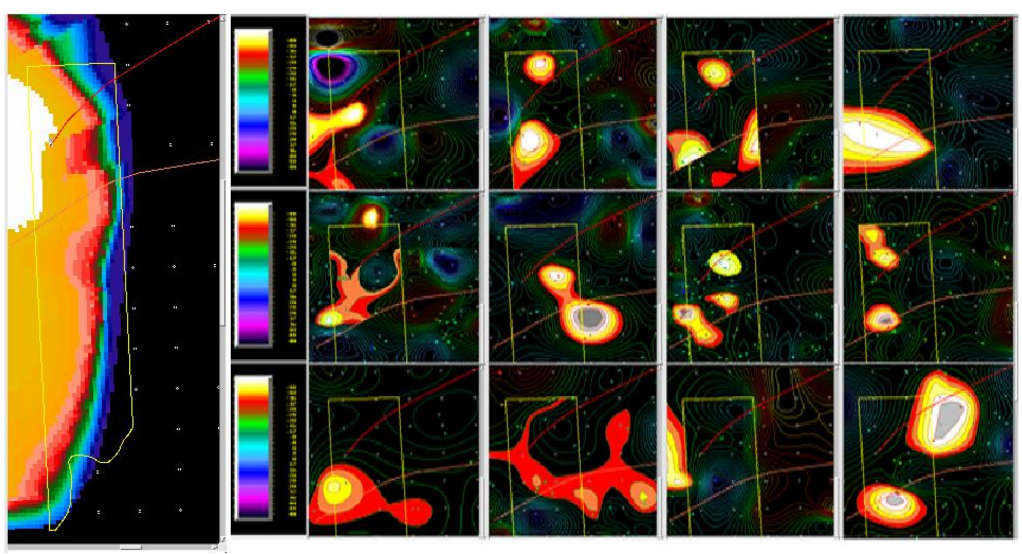

Figure 10. Yearly lightning strike density, Hockley Dome, TX (right): 2000 upper left to 2011 lower right.

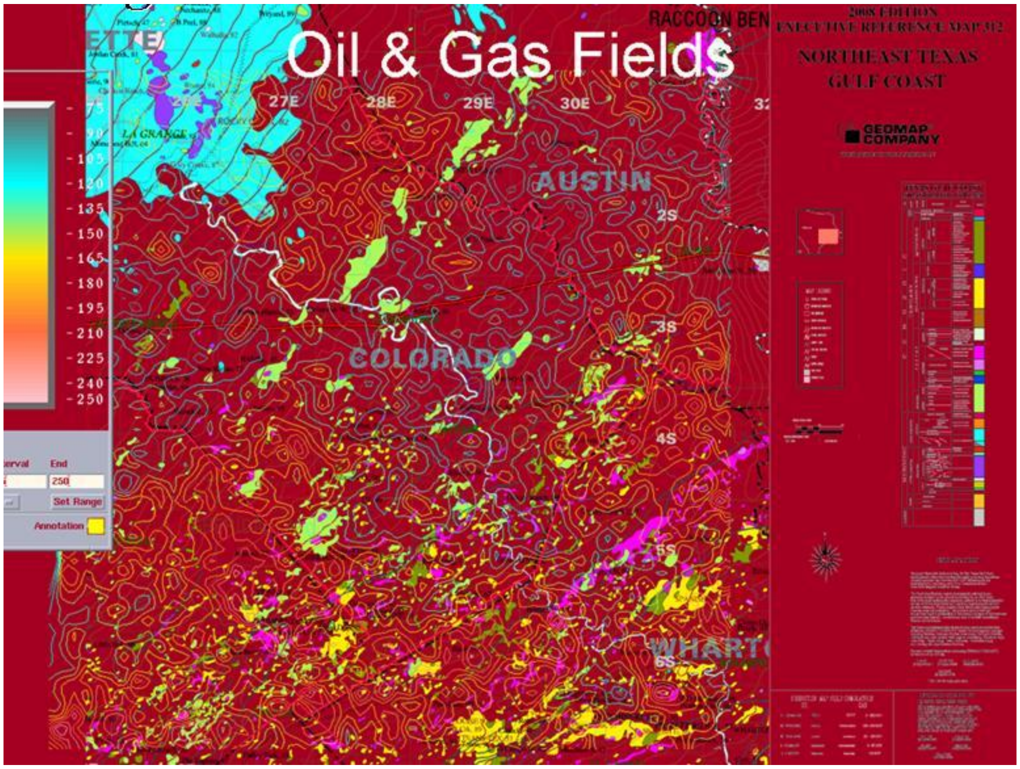

Figure 11. Colorado County, TX Lightning Density Map.

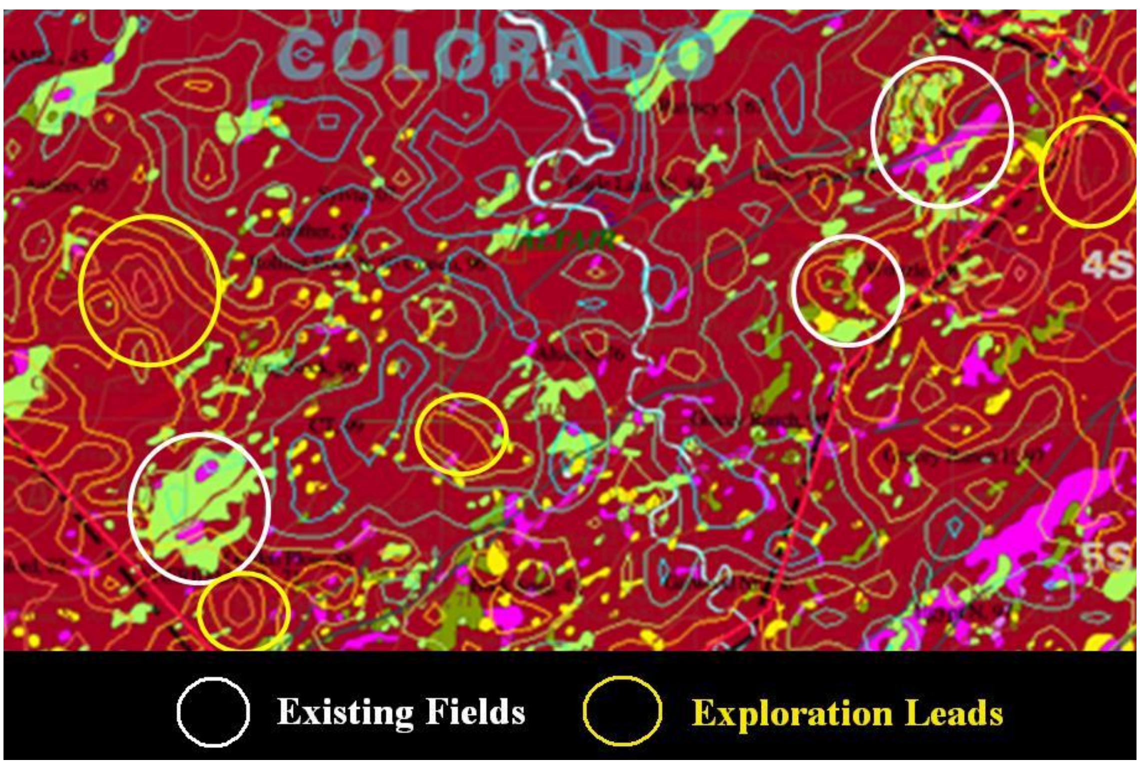

Figure 12. Close-up of lightning density mapping of Fields and Leads in Southern Colorado County, TX