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Lightning data and resource exploration

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Dynamic Measurement LLC

Lightning data is a new, inexpensive, and useful tool for resource exploration. Slide 1

I'll be talking briefly about how lightning is recorded and what we know about its physics, then going over what we might expect to see from the lightning data before going on to a more detailed discussion of the data and its interpretation. Finally, I'll summarize where we are and what lies ahead. Slide 2

Scientists first realized they could locate and measure cloud-to-ground lightning strikes about thirty years ago. This realization led to installation of the infrastructure needed to record strikes, first in the United States (where we now have continuous records for about fifteen years) and eventually worldwide. Slide 3

We can now generate maps of lightning strikes anywhere in the world. Television meteorologists do this daily in weather reports, showing viewers where lightning has struck in the last few minutes. For exploration, we can use lightning record for up to fifteen years. Slide 4

Lightning originates when collisions between water droplets in turbulent conditions inside a cumulonimbus cloud ionize the droplets, typically at altitudes of 4500 to 7500 meters above ground level. Positive ions collect at the top of the cloud, negative at the bottom. The ions at the bottom of the cloud make their way towards the ground, forming a low resistance path. The return stroke from the ground then builds to a peak current from thousands of amps to hundreds of thousands of amps within microseconds. The current then decays over tens of microseconds. Slide 5

A ground-based network such as the National Lightning Detection Network in the United States determines the location and character of each strike by measuring at several stations the electromagnetic pulse produced by the lightning. Slide 6

The shape of the pulse is typically like this. Most lightning strikes are negative, like this one. Slide 7

What determines the location of a lightning strike? It originates several thousand meters above the surface, and comes towards the surface in a series of steps. The actual point struck seems to be determined only when the stoke is within fifty meters of the ground. Slide 8

Most meteorologists consider the subsurface irrelevant. But we have seen real correlation between geology and lightning strikes.

The theory of lightning behavior within the atmosphere comes from electrical field theory, presented here as the obligatory equations needed in any geophysical presentation. Slide 9

Two points are important when we look at where lightning strikes: if a conductor has no internal electrical currents, all excess electrical charge is on its surface; and when that conductor is the earth, it is approximately a sphere with a radius of 6378.1 km. Slide 10

So, what effect can we expect geology to have on lightning?

Lightning is a breakdown of the capacitor formed by the conducting ionosphere and the conducting earth, separated by the non-conducting lower atmosphere. Such breakdowns Slide 11 will occur where the electrical intensity is larger, or the thickness of the non-conducting layer is smaller. The force between two charged points is inversely proportional to the square of the distance between them. So more lightning is expected where elevations are higher. But the earth's resistivity is not uniform, so the electrical intensity on the surface is not uniformly distributed.

What causes changes in resistivity within the earth? Most geological phenomena. Chemical reactions, mechanical stresses, for example. A recent paper by Chinese researchers has shown a convincing relationship between lightning density and earthquakes. Movement of fluids in pore space and movement of the rocks themselves change resistivity, variations in pore fluids, variations in mineral composition, and so on. Slide 12

Concentrations of excess charge might occur in several specific situations: at faults, adjoining salt domes, and at the edges of large hydrocarbon accumulations. Slide 13

How do we record the data?

Each lightning strike produces an electromagnetic pulse. Multiple stations detect pulses and the direction from the detector. Pulses are correlated, and positions determined within a few tens of meters, using both the direction of reception and the time delays between stations. Slide 14

Electromagnetic pulses from several stations synthesize a composite waveform for the strike, shown here for fourteen strikes. Slide 15

Recording the composite waveform for every strike is beyond the bandwidth and storage capabilities of current hardware. Ground networks record time of a strike, location, peak current, chi-squared for the location, the shape of the error ellipse, rise time in microseconds, peak-to-zero time, and the number of network sensors used for the solution. Slide 16

Satellite networks record time, location and peak current. Locations are less accurate, and the waveform is not recorded at all. Slide 17

Now we'll look at some of the things besides geology that do affect lightning.

Lightning does strike more often at higher elevations, but only at locally higher elevations. Houston, Texas gets many more lightning strikes than Denver, Colorado, even though Denver is more than 1500 m higher. If we smooth the measured elevations, on the left in red, to get a local average in blue, and then subtract this from the measured elevations, we have local relative elevations shown on the right in red. Slide 18

Now we look at the number of strikes as a function of local relative elevations, shown on the left. There are more strikes to the right of zero – locally higher elevations – than to the left – locally lower elevations. Note that the vertical axis is logarithmic: about 99% of lightning strikes were within 15 m of the local average variation. The dataset for this plot is all cloud-to-ground lightning strikes in the western half of North Dakota in a ten year period. Slide 19

Now we look at the ratio of the number of strikes at elevations above the local average divided by the number of strikes the same amount below the local average, shown on the right. The red line means equal numbers above and below. For elevation differences up to nine meters, there is no difference. A point nine meters below local average is just as likely to be struck as a point nine meters above. But beyond that, local elevation variation is important. A point 25 m above the local average is four times as likely to be struck by lightning as a point 25 m below. The total number of strikes at points with more than 40 m local elevation difference is so small that the results are unreliable.

Next we'll look at tidal variations, specifically the rate of change of tidal gravity. This slide shows the frequency of occurrence of tidal gravity gradient over a lunar month. If lightning strikes are independent of the tides, we would expect this distribution when the gravity gradient is plotted against strike frequency. We will normalize strike frequency by dividing the observed frequency by these values. Slide 20

The results are surprising. Instead of getting values close to 1.0, which would indicate lightning is independent of tidal gravity, we get many more strikes at times when the tidal gravity gradient is close to a maximum, either positive or negative. At least, this is the case in the middle of the U.S., from North Texas to North Dakota. Slide 21

For one project in a coastal southern state, the tidal gravity effect is very different. Slide 22

This difference surely depends on geology, not meteorology. Slide 23

Some phenomena which might have an effect on lightning apparently do not affect it.

This is the average number of lightning strikes per day in North Dakota as a function of visible sunspots. Points beyond 160 sunspots are doubtful because very few days occurred with more than 160 sunspots. Slide 24

Solar wind values appear to have no correlation with peak current of lightning strikes. Slide 25

How do we interpret the lightning data?

Here is a regional example. The Yellowstone hot spot has moved across southern Idaho over the last 16 million years, leaving behind the Snake River Volcanics, a broad plain cutting through the mountains. This path has visibly lower lightning density than its surroundings. The lower lightning density may be partly meteorological in origin, but the scale of the lightning density feature seems too big to be explained solely from meteorology. Slide 26

Lightning density over the Michigan peninsula and surrounding waters, right, shows little influence from variations in surface elevations (shown on the left), but allows interpretation of strike-slip faulting in basement. Slide 27

This is a map of lightning strike density at high lunar tide over part of North Dakota, showing anomalies associated with some existing oil fields. Slide 28

On the left is a map of lightning peak current over an area west and northwest of Houston. This is the average peak current of lightning strikes from 2000-2011, scaled to give red for Slide 29 the maximum density and magenta for the minimum density, as shown by the scale bar. The same normalized scaling is used in the following slides.

On the right is a map of strike density over the same area for the same period. We have superimposes a contour map of the top Wilcox, showing the position of two salt domes which penetrate this level, and a third dome immediately west of Katy. Each of these geological features is marked by arcuate features in the lightning strike density map following the structure contours.

While each of the strike density maps for a single year is different, they all show the bands of higher and lower strike density wrapping around the geological domes. Slides 30-35

Now we'll look at what remains to be done.

We need more projects over known geology, and more study of full-waveform lightning recordings. Slide 36

In summary, lightning data is recorded worldwide, and is a useful exploration tool. Geology definitely affects lightning, in both obvious and subtle ways. Projects have already been completed in North Dakota, New York, Michigan, Texas and Florida. This is a low cost exploration tool which will develop rapidly with more interpretation experience. Slide 37

Here are some references for further reading. Slide 38