Plan, Build, and Protect
Remotely Mapping Geology
with Naturally Sourced Electromagnetic Analysis (NSEM)

a presentation by Dynamic Measurement LLC for

NOD/US Army Corps of Engineers

19 December 2014

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Presentation Topic Areas

1. NSEM - A new technology to identify geologic hazards
   - Questions & Answers & Discussion
2. The meteorology behind lightning databases
   - Questions & Answers & Discussion
3. Calculating resistivity volumes from lightning databases
   - Questions & Answers & Discussion
4. Examples of using lightning databases to map geology
   - Questions & Answers & Discussion
5. Goose Point – tectonic driven subsidence lightning case history
   - Questions & Answers & Discussion

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1. NSEM –
A new technology to identify geologic hazards

DML will help the nation's engineers!

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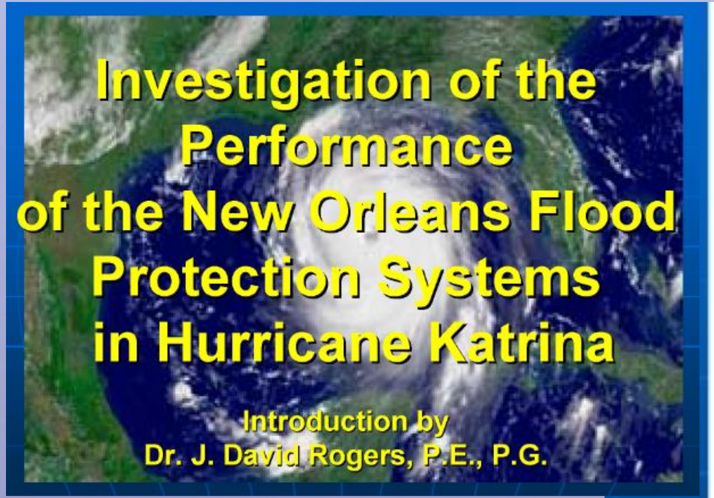
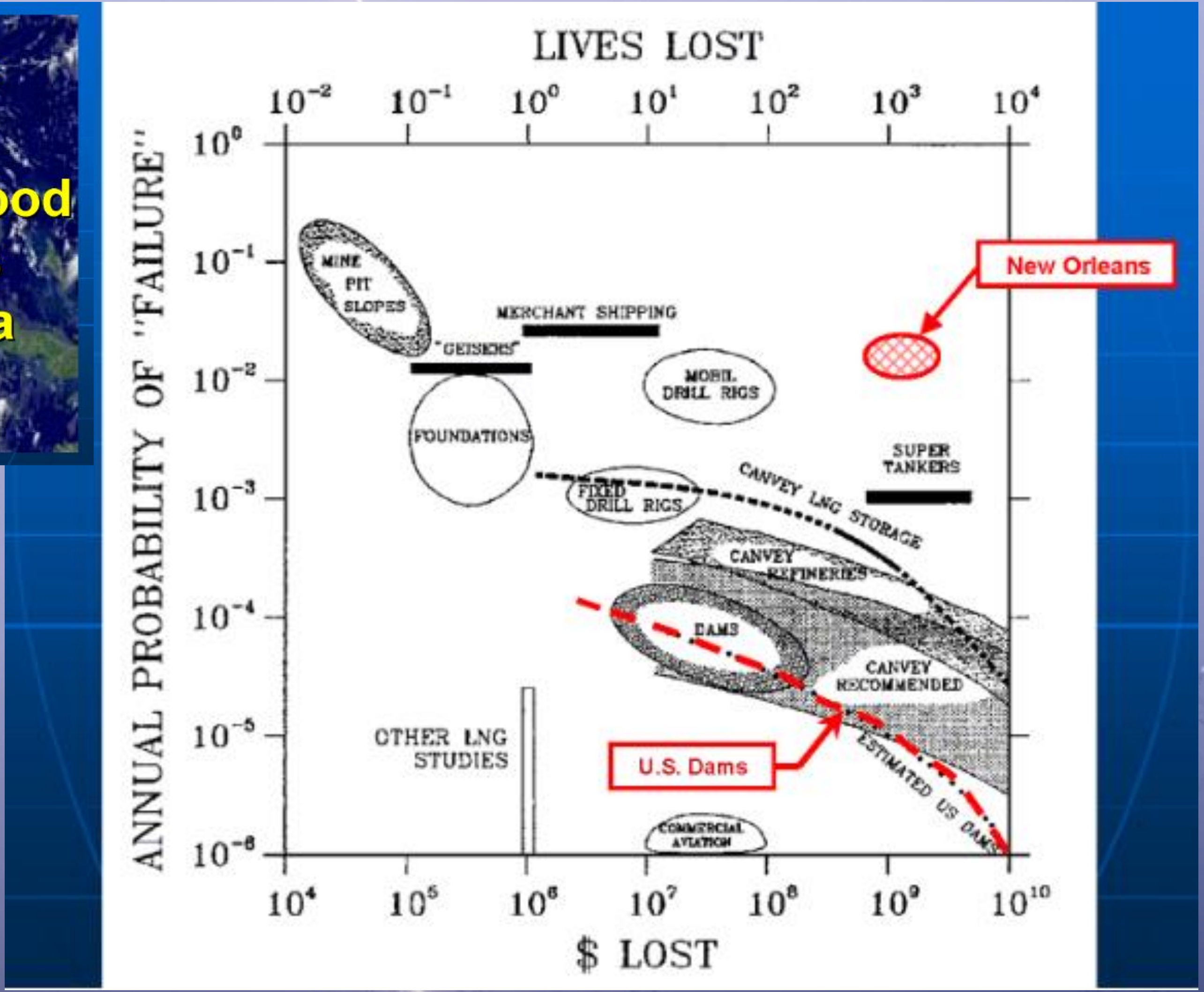




"... individual projects are at high risk."

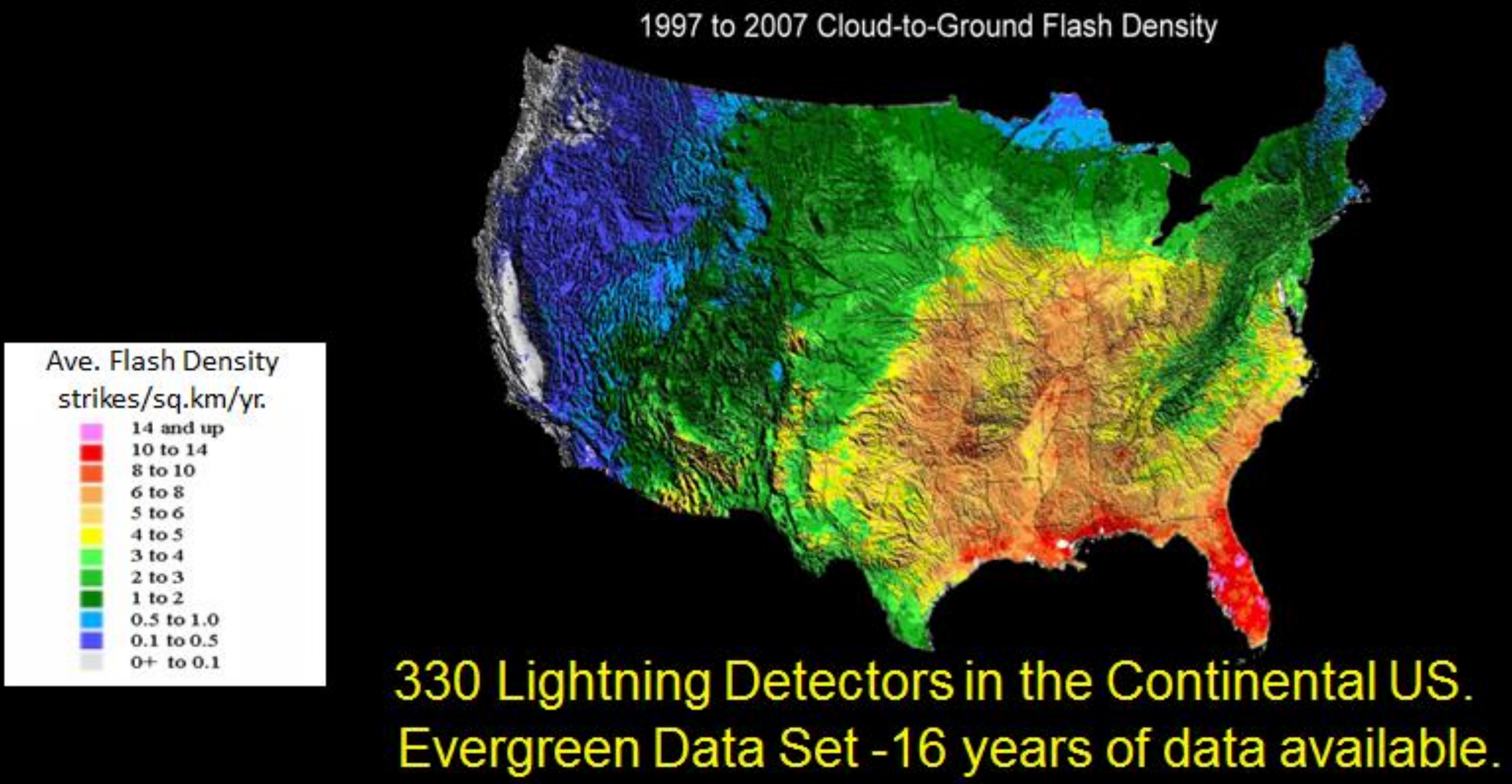
Lt. Gen. Thomas Bostick,
commander of the U.S.A.C.E.

10 Dec 2014

Lightning Theories and Facts

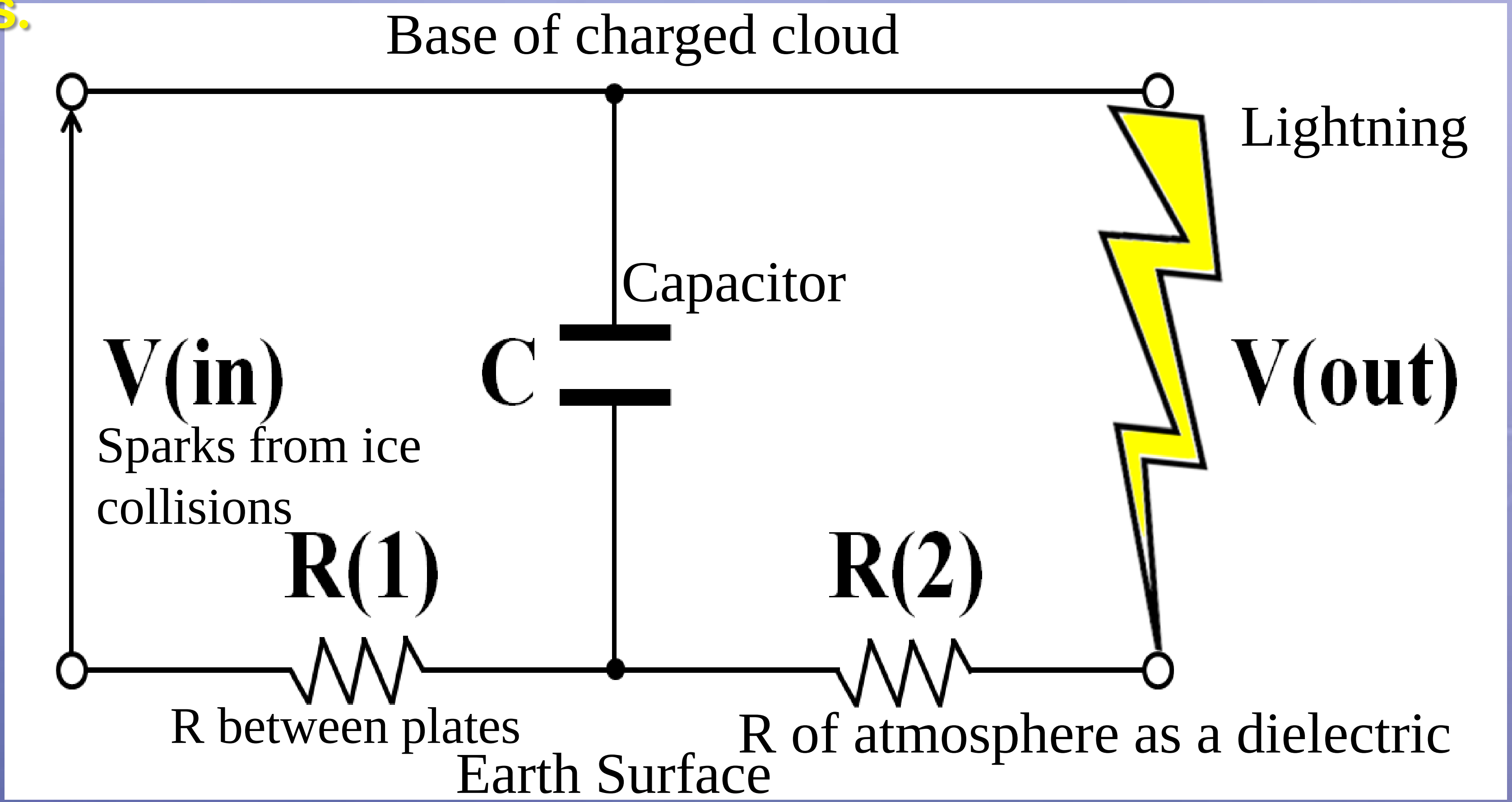
- Lightning occurs everywhere.
- Cloud to cloud lightning travels up to about 150 miles (250 km).
- Cloud to ground lightning follows terralevis/shallow earth currents which reflect geology. Some strikes do hit topography, vegetation, and infrastructure, but can be edited out from location and attribute data.
- Lightning Attributes contain data from various depths and image subsurface features and lineaments such as transforms, faults, drainage basins, and paleo channels.

Strike Density (NLDN) and Topography



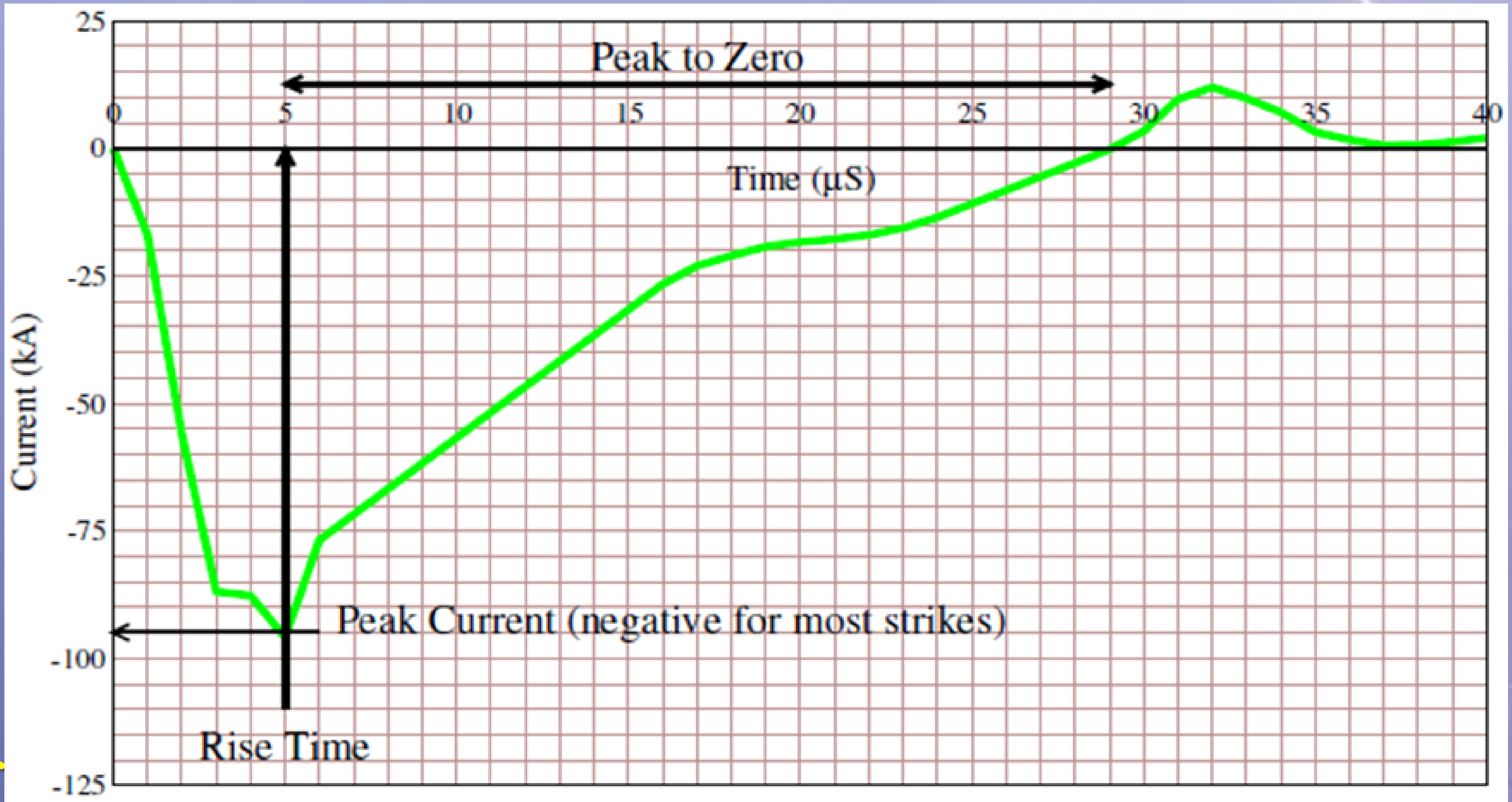
Lightning

Two conducting plates, the storm cloud and the earth, are separated by an insulating dielectric, the atmosphere. Voltage is created by collision of ice within the cloud and lightning bolts rebalance the charge between the plates.

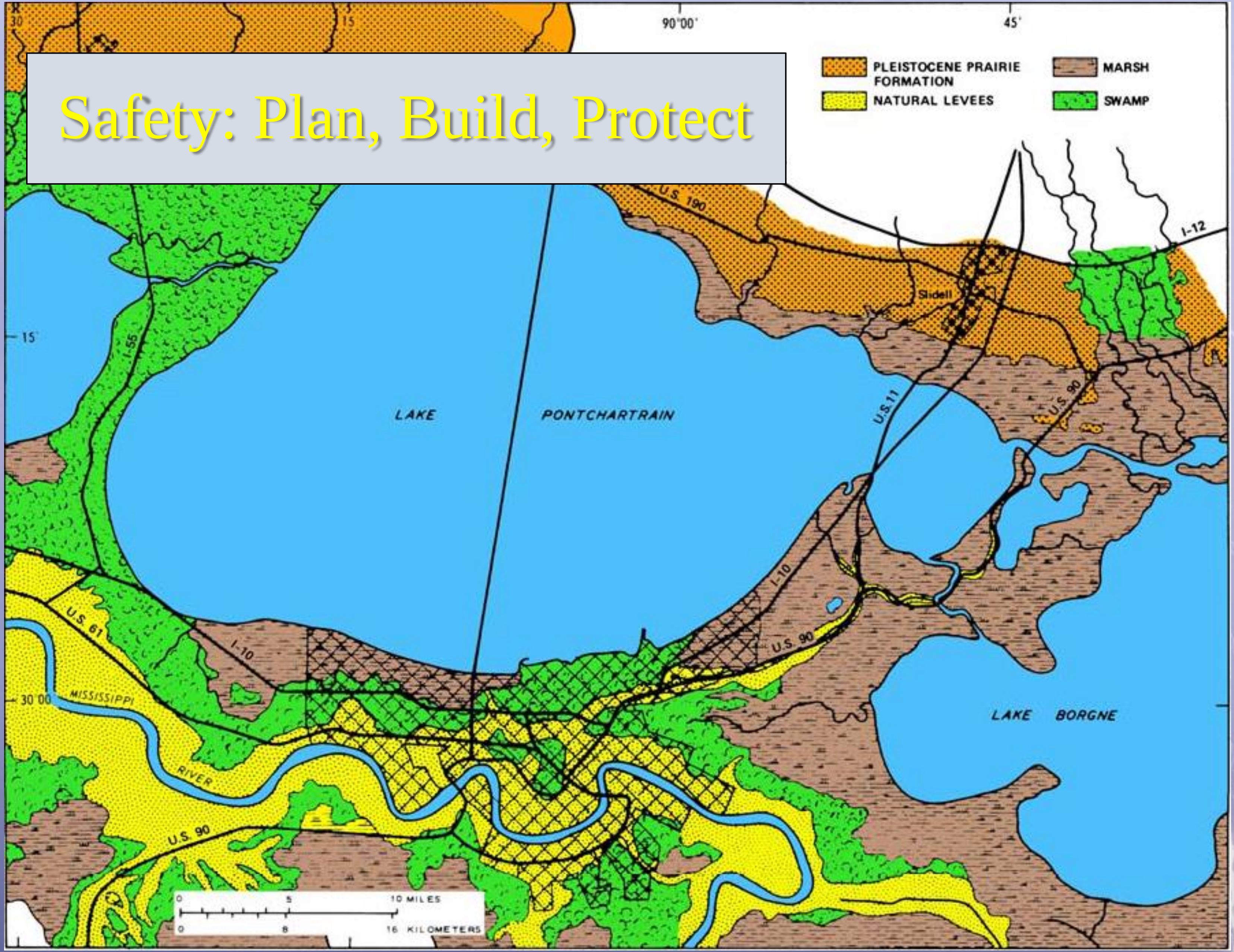


Lightning Measurements/Attributes, & Wave Form

- Location / Time and Duration / # of Sensors
- Rise Time
- Peak Current
- Peak to Zero
- Polarity
- Chi Squared
- Number of Sensors



Safety: Plan, Build, Protect



- Picture shows geology and its associated sedimentary geo-hazards
- Distributary and inter-distributary linear events

Geology is the Foundation of Human Activity

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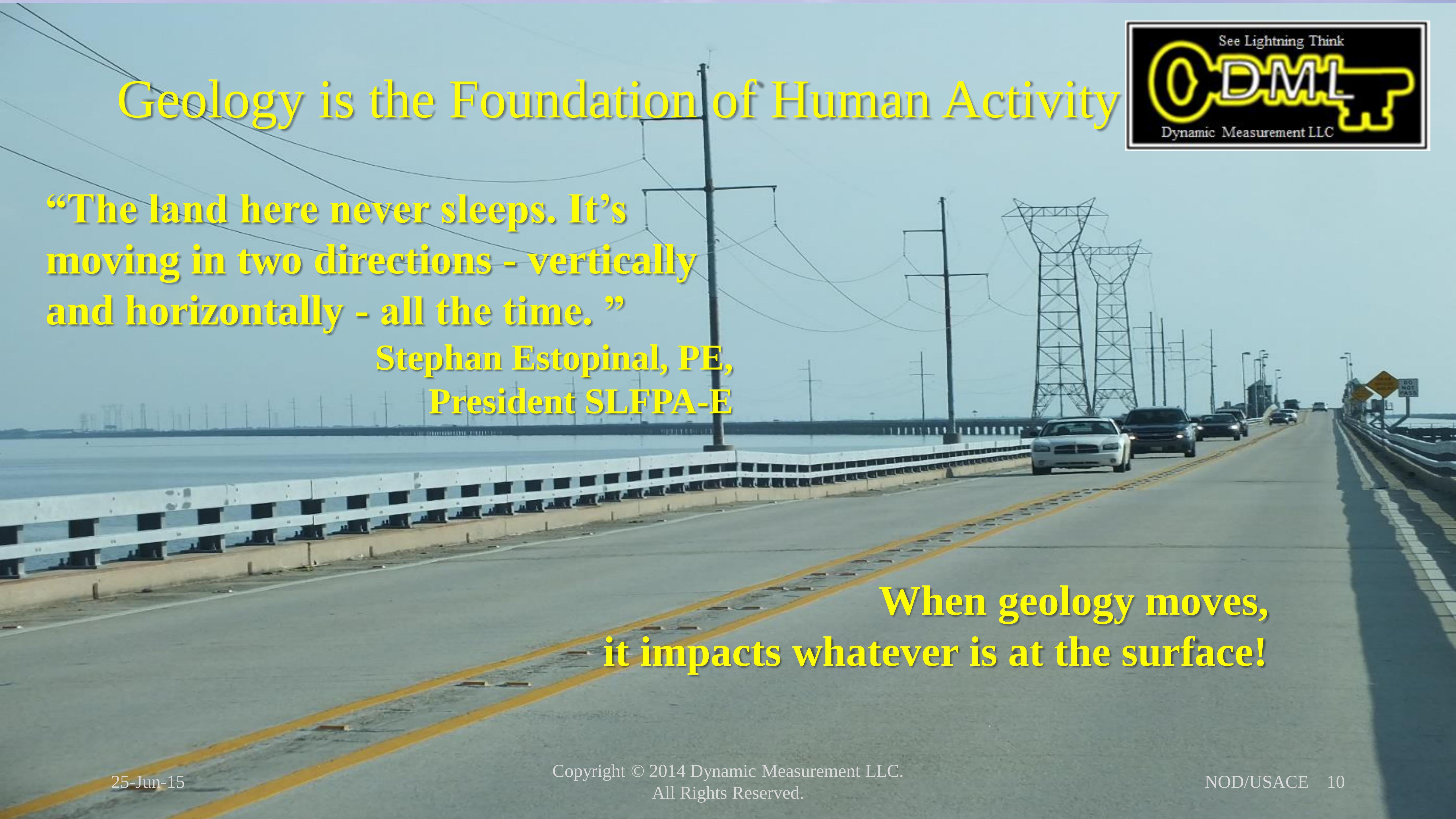
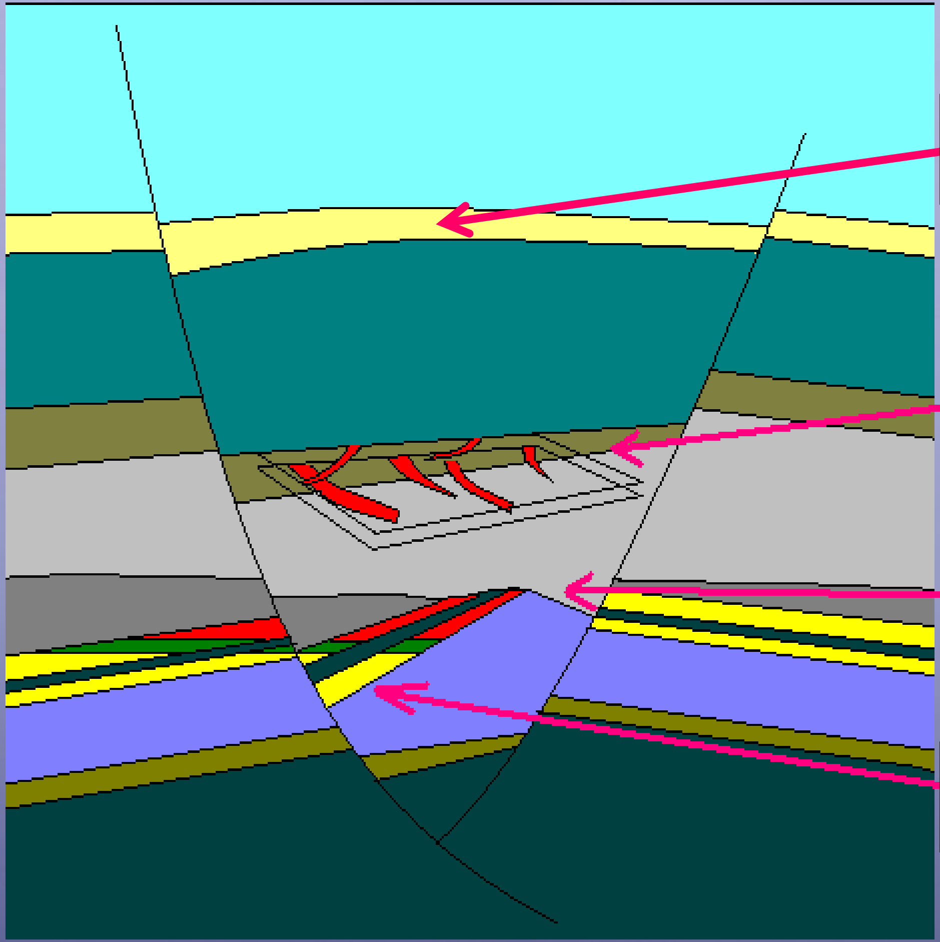


"The land here never sleeps. It's moving in two directions - vertically and horizontally - all the time. "

Stephan Estopinal, PE,
President SLFPA-E

When geology moves,
it impacts whatever is at the surface!

Measurement & Monitoring of Geologic Movement



Peat Deposits

- LIDAR

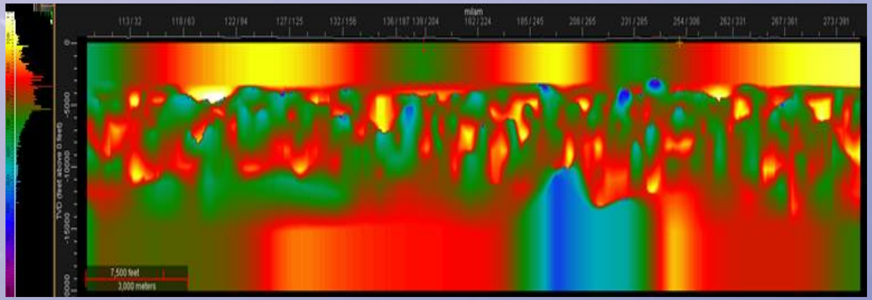
Channels

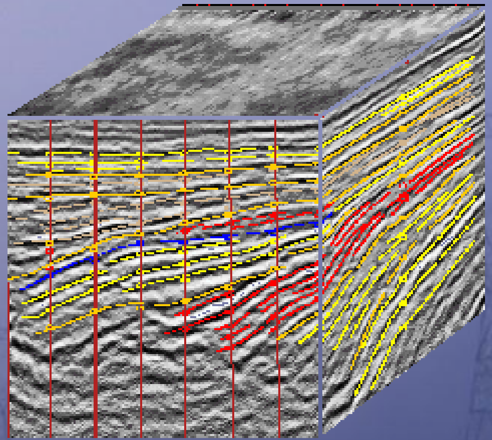
- NSEM (Natural Sourced Electro-Magnetics)

Unconformities

- 2-D and 3-D Seismic

Growth Faults





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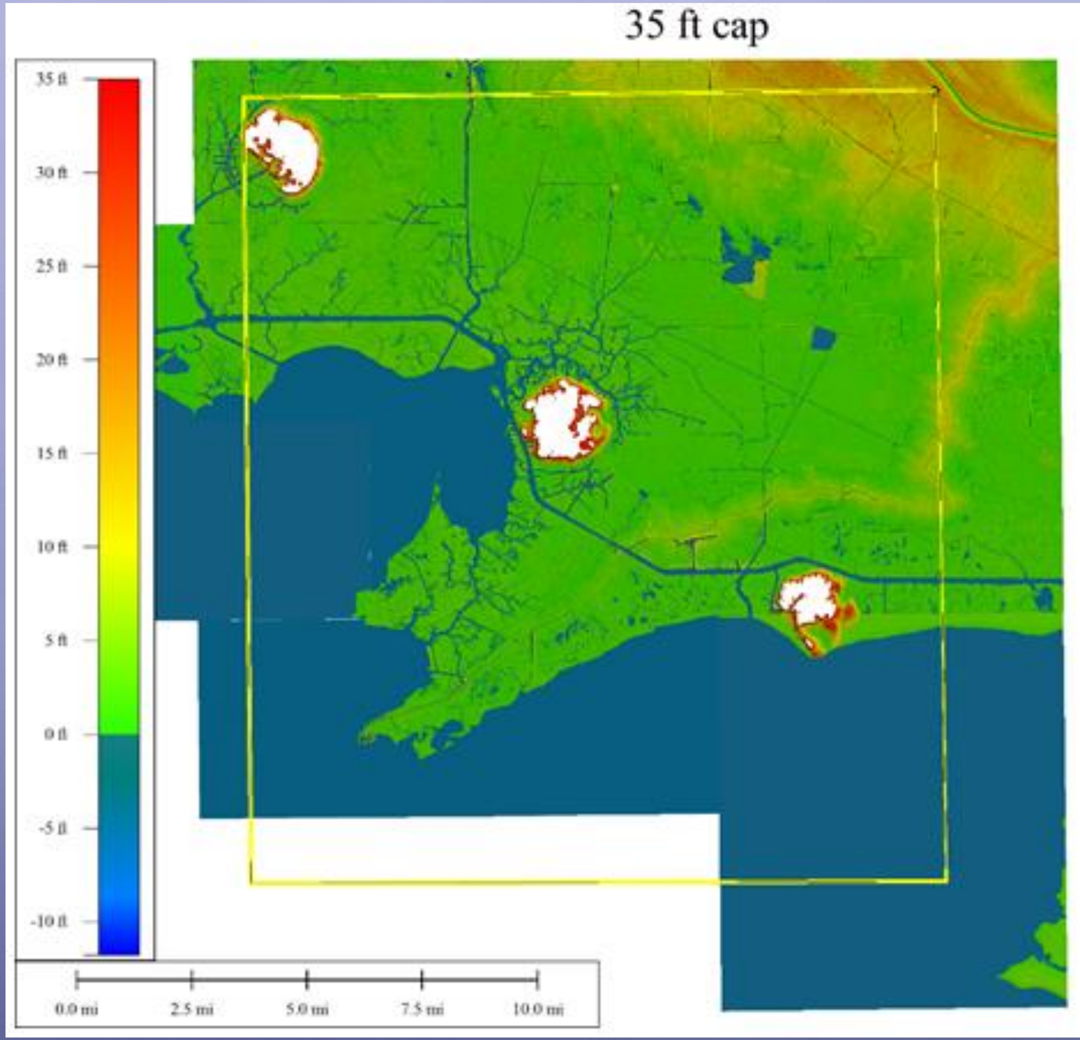
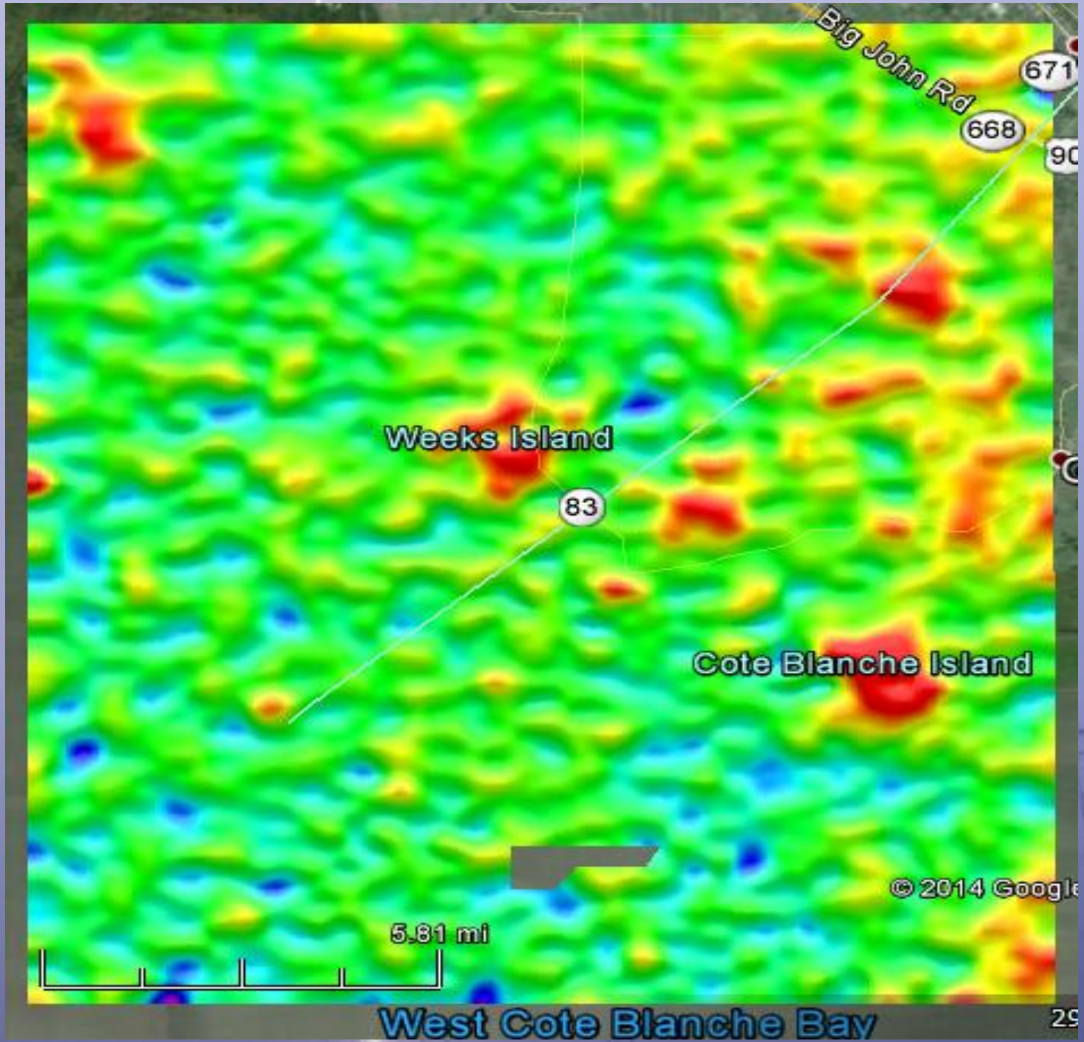
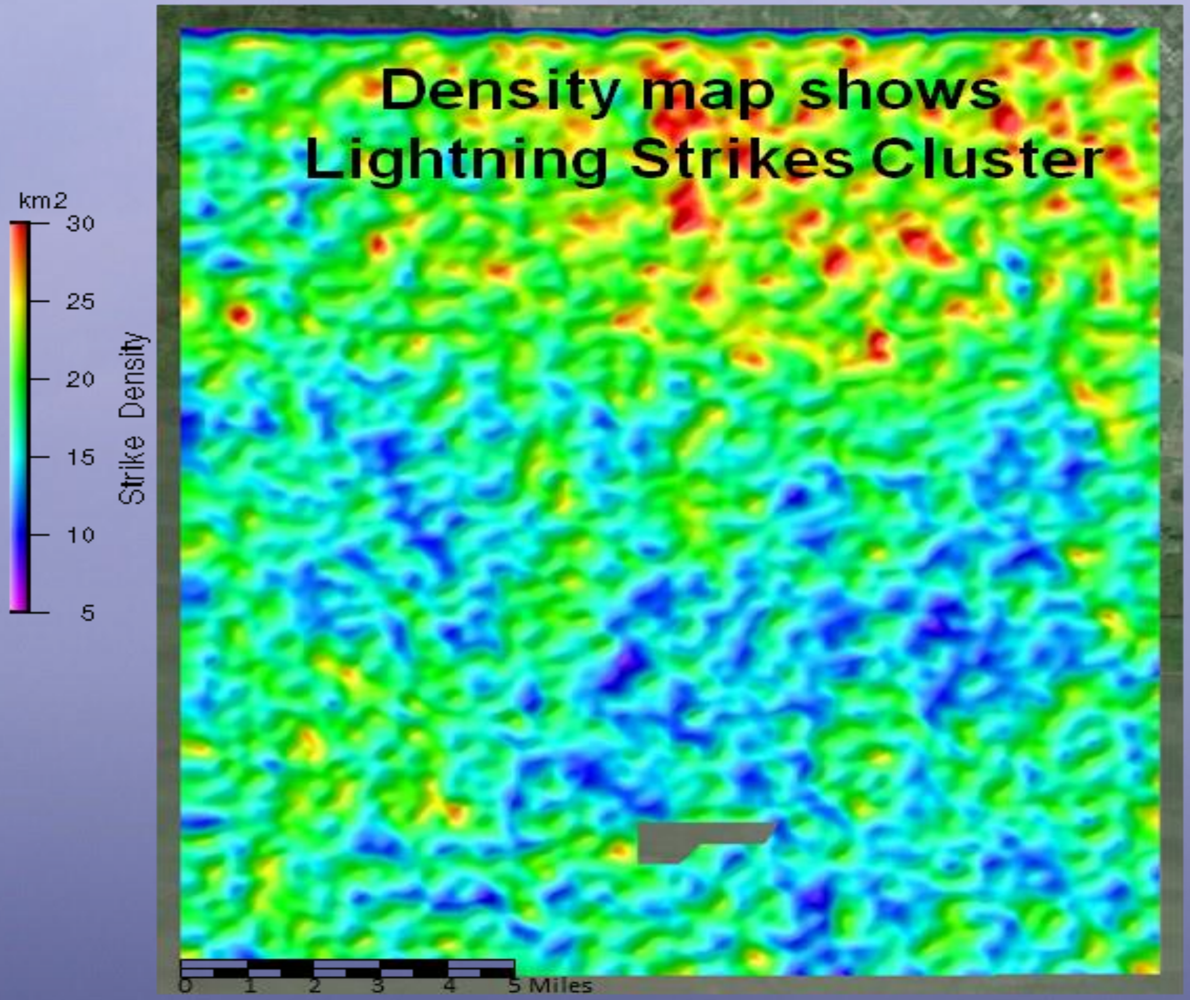
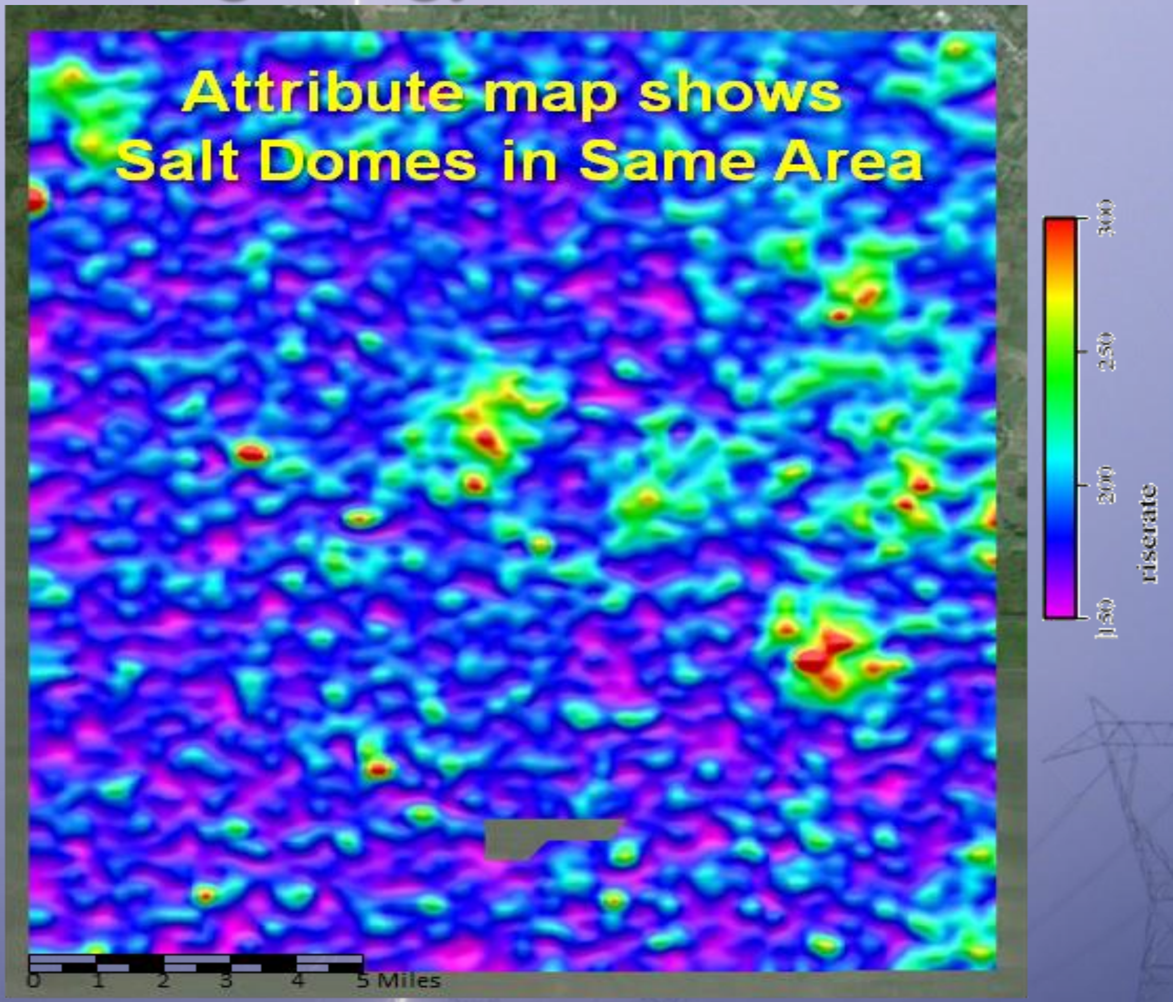
LIDAR Extended with NSEM Analysis





Lightning Data Analysis
demonstrates strikes are tied to geology

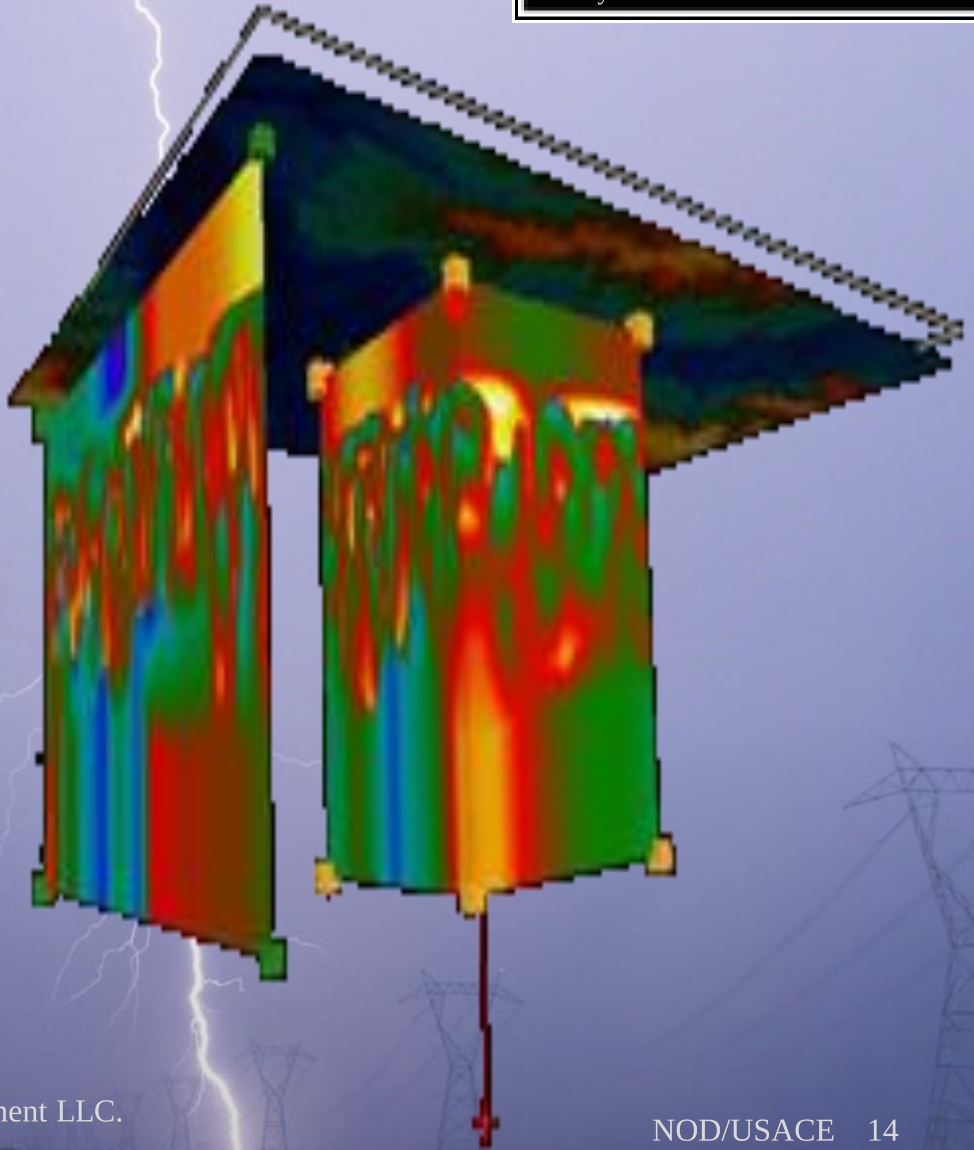




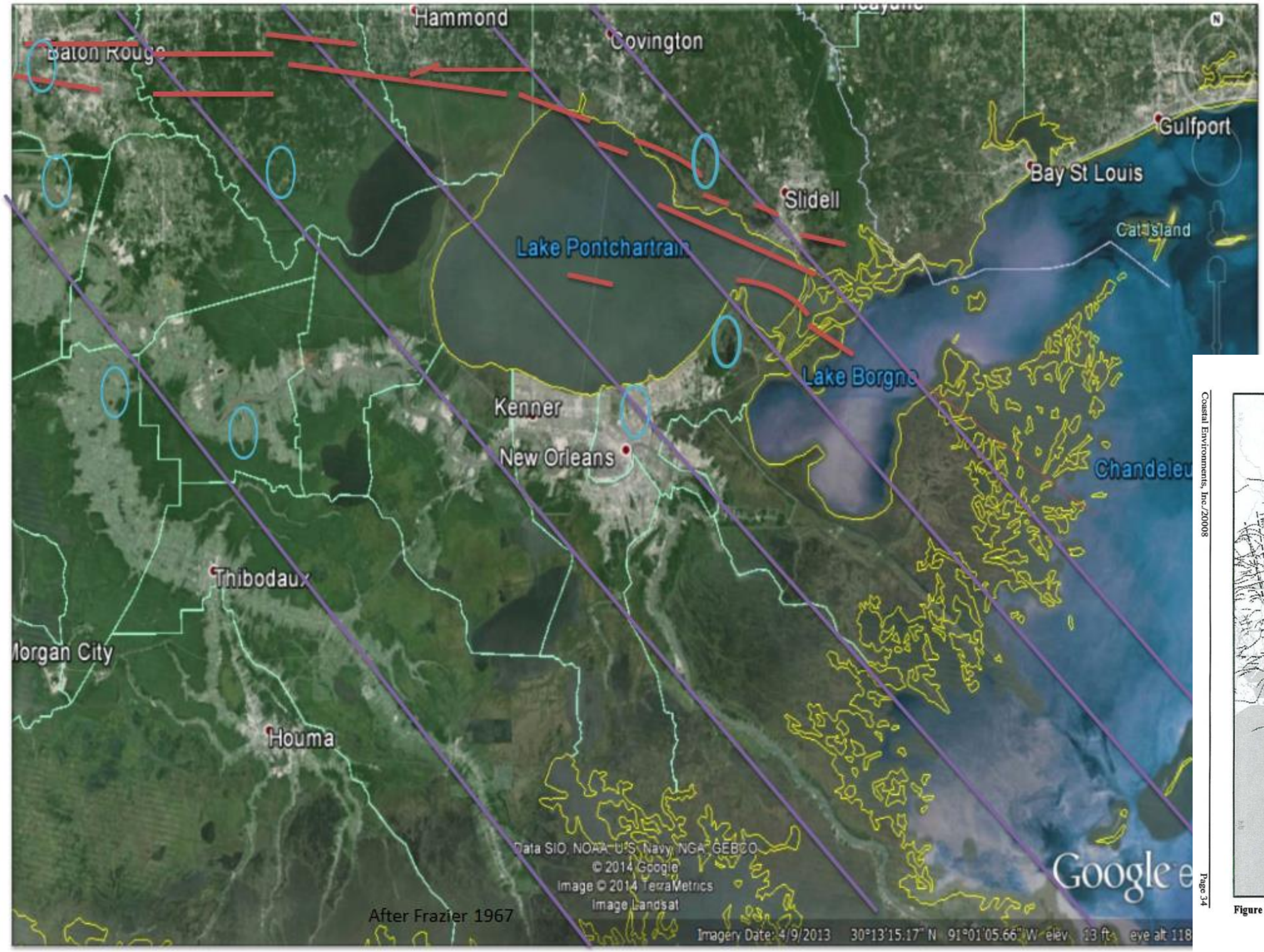
Technical Merit & Economic Benefits

- Sections and Volumes
- Evergreen Data
- 16 year database
- Integrates with other data
- Simple Solution
- Patented, & Patent Pending

- 2 month project turnaround
- Larger Area – Less Expense



Regional Tectonic Setting – Geo-hazards



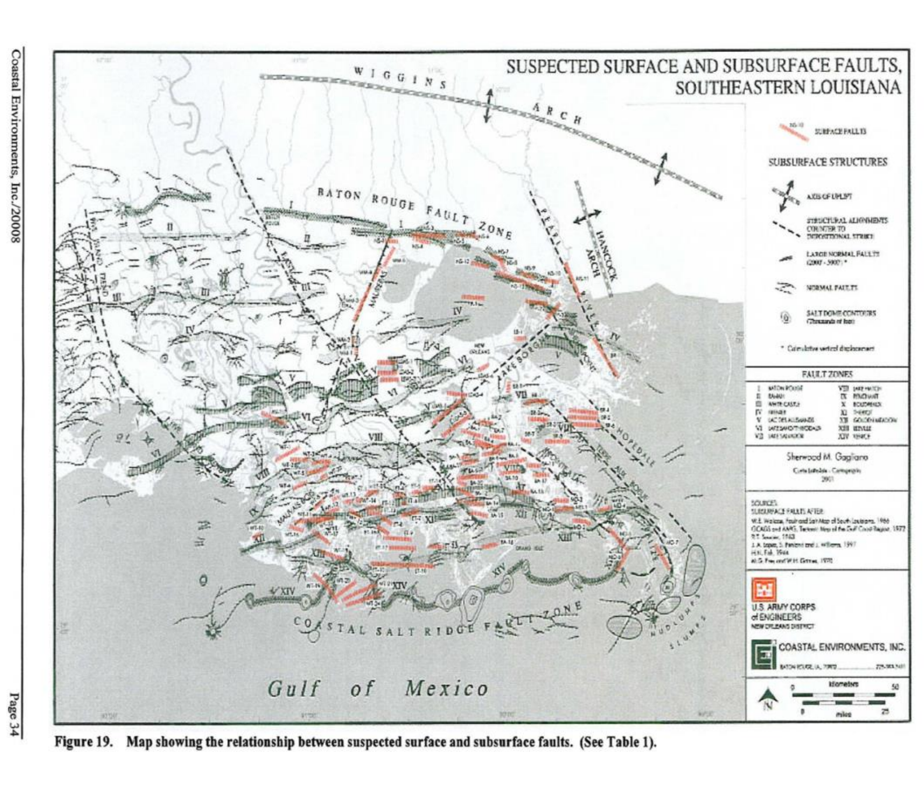
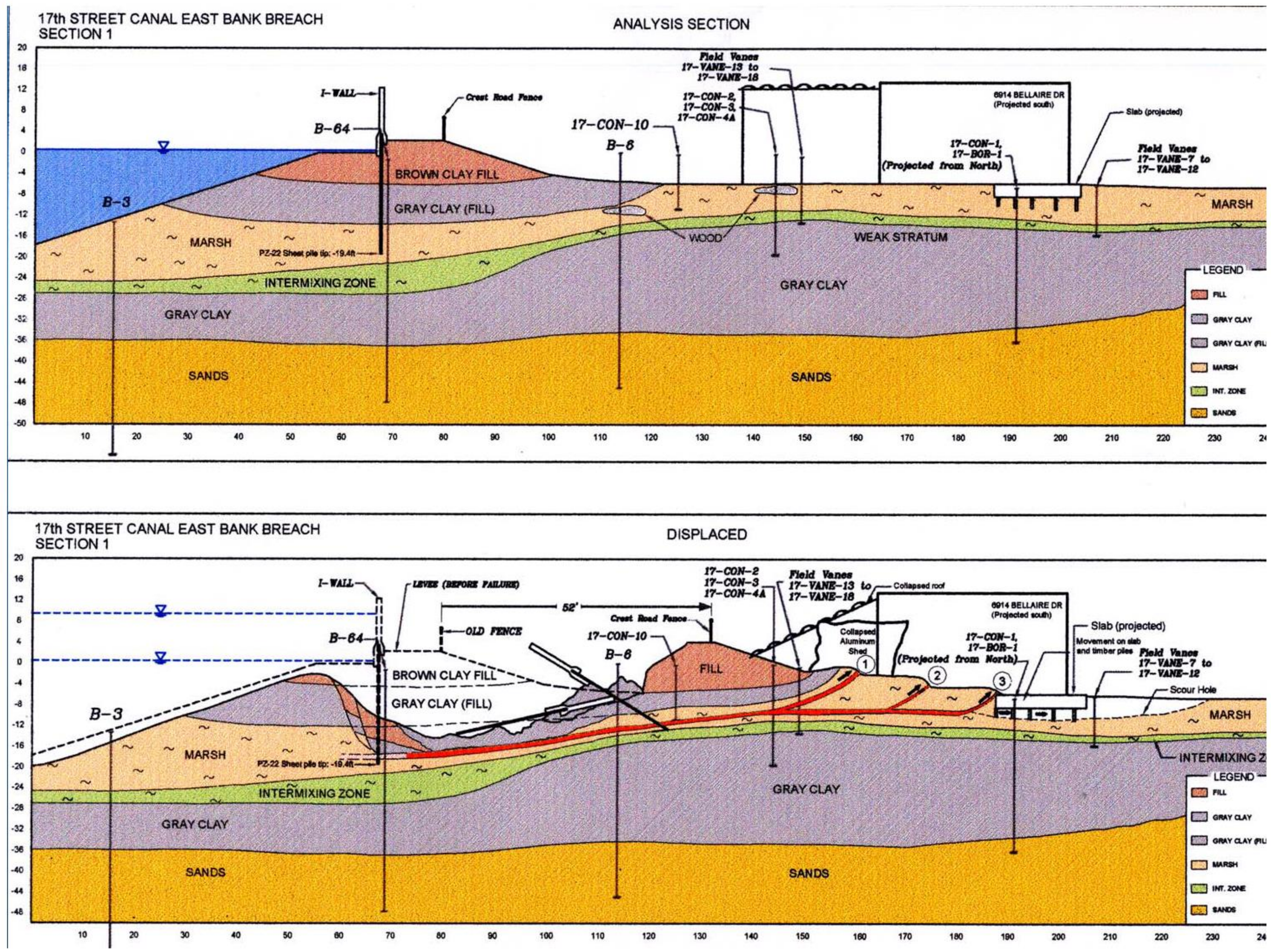
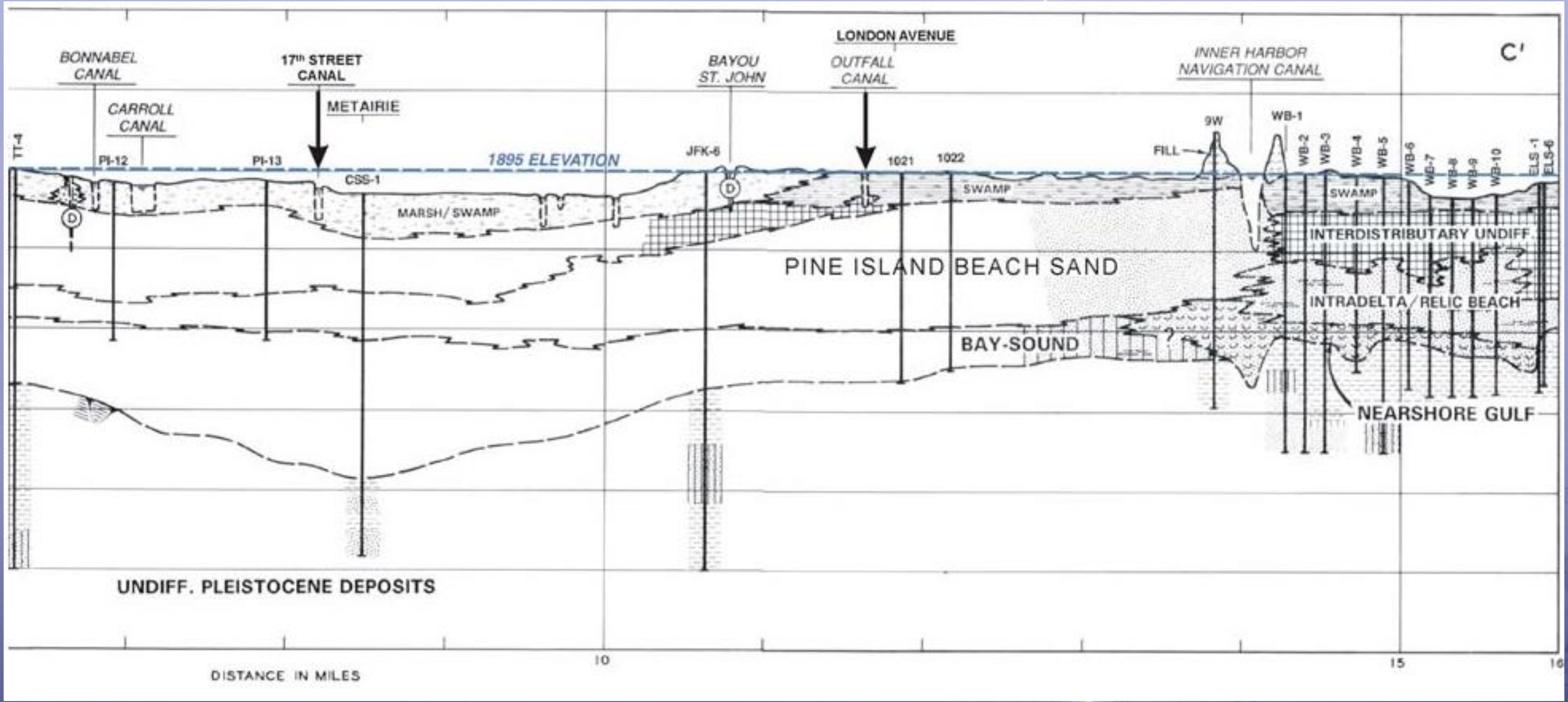


Figure 19. Map showing the relationship between suspected surface and subsurface faults. (See Table 1).

Cross-Section across Flood Wall Failure



Subsidence Happens in Louisiana



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Questions & Answers & Discussion

2. The meteorology behind lightning databases

Lightning Maps and Natural Resources

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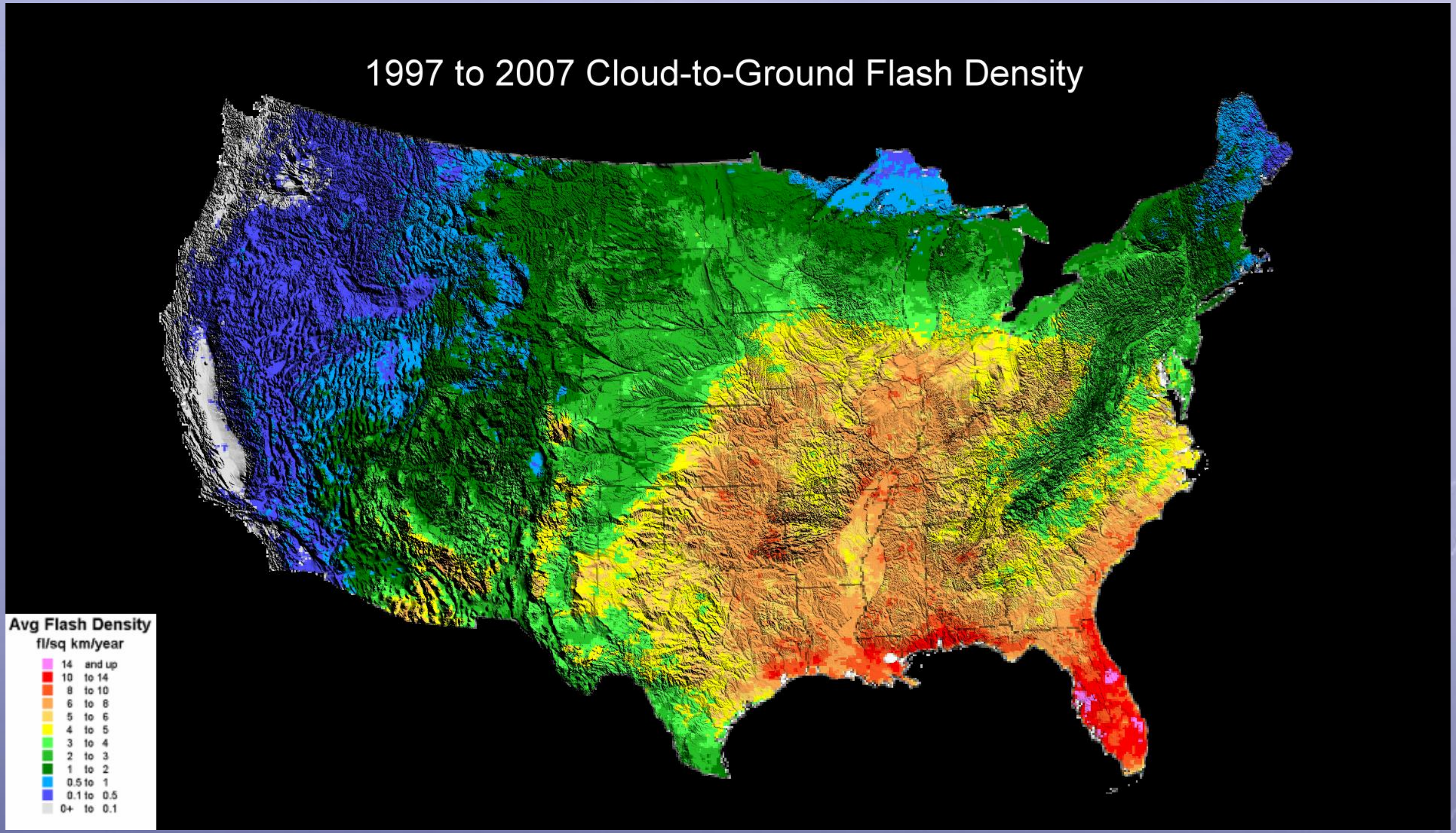
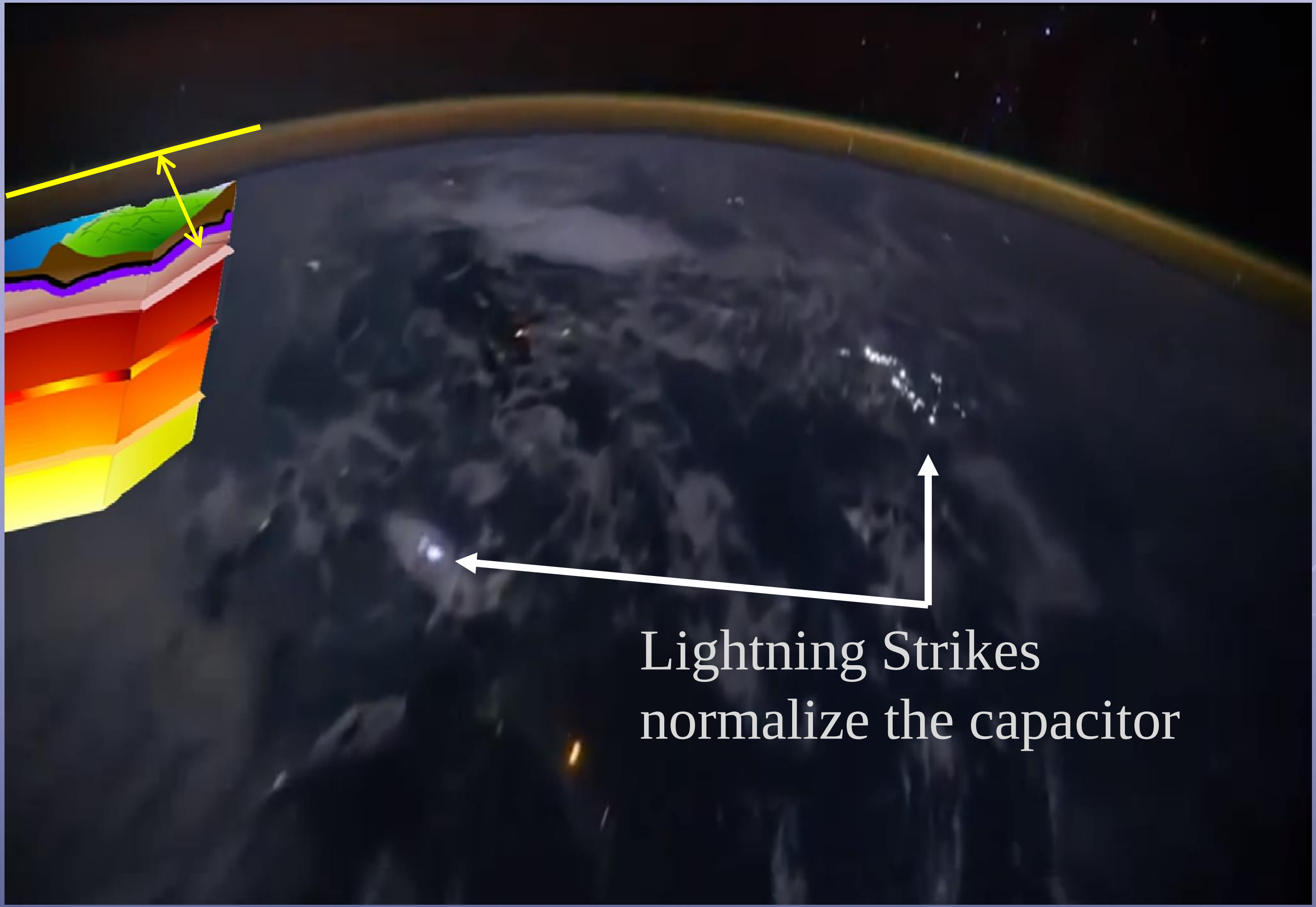
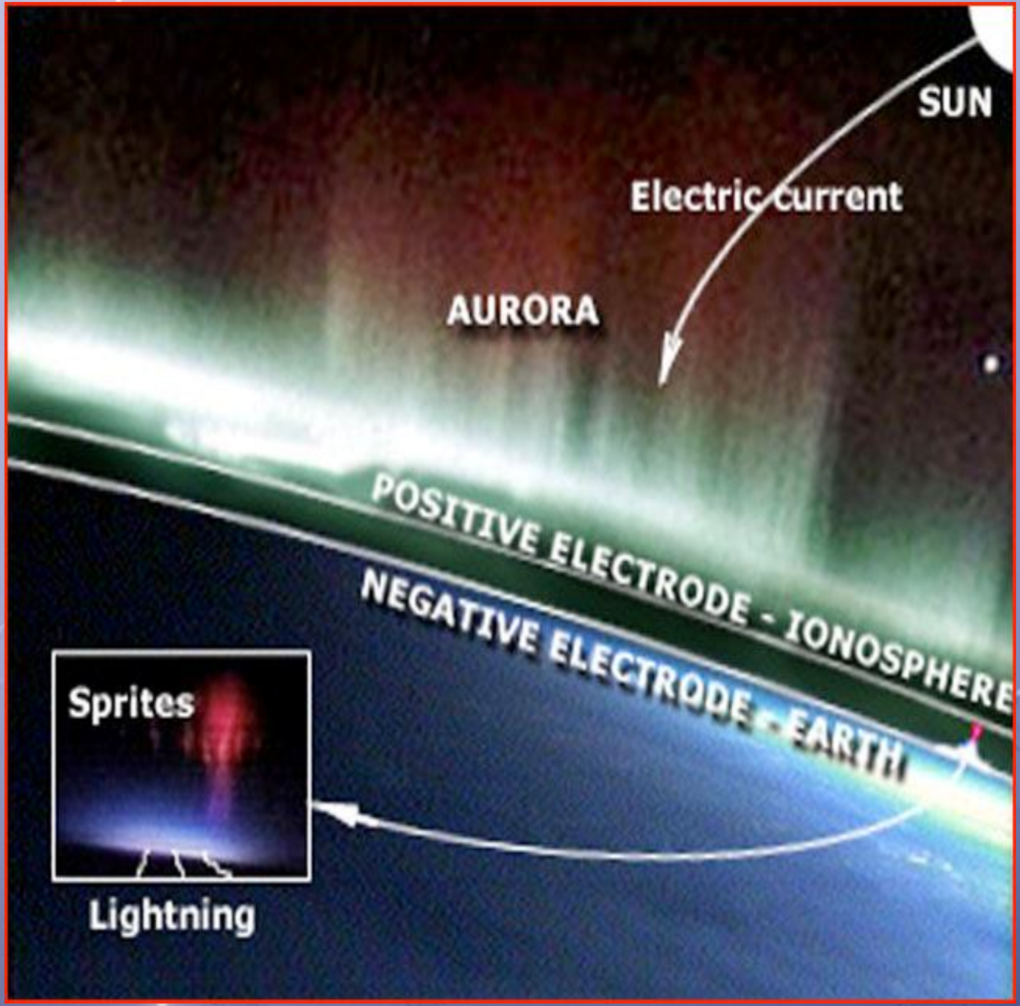


Lightning density regionally controlled by meteorology, and locally controlled by terralevis (shallow earth) currents.

Earth: A Self-Repairing Capacitor





350 million annual Lightning Strikes - a rich database to mine

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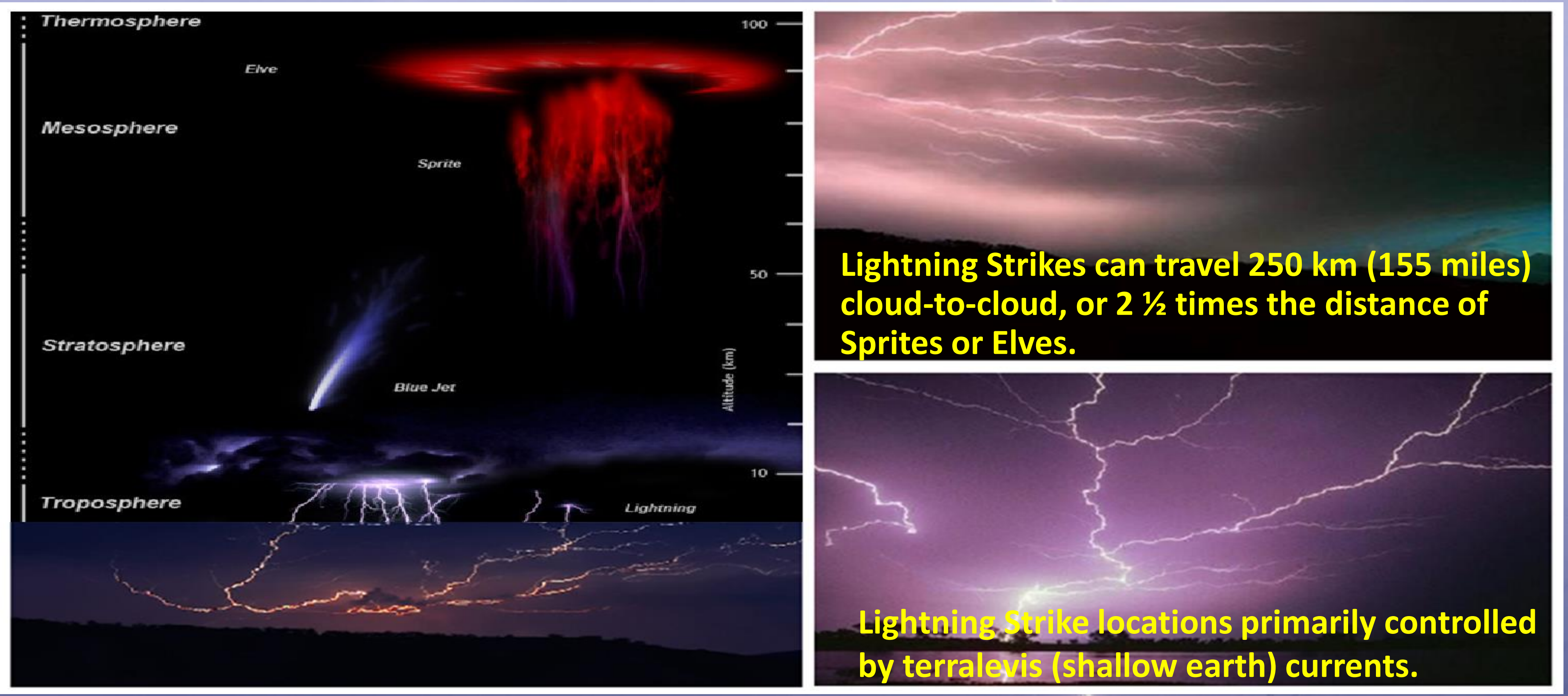

Lightning recorded for early storm warning, safety, **insurance**, and meteorological purposes

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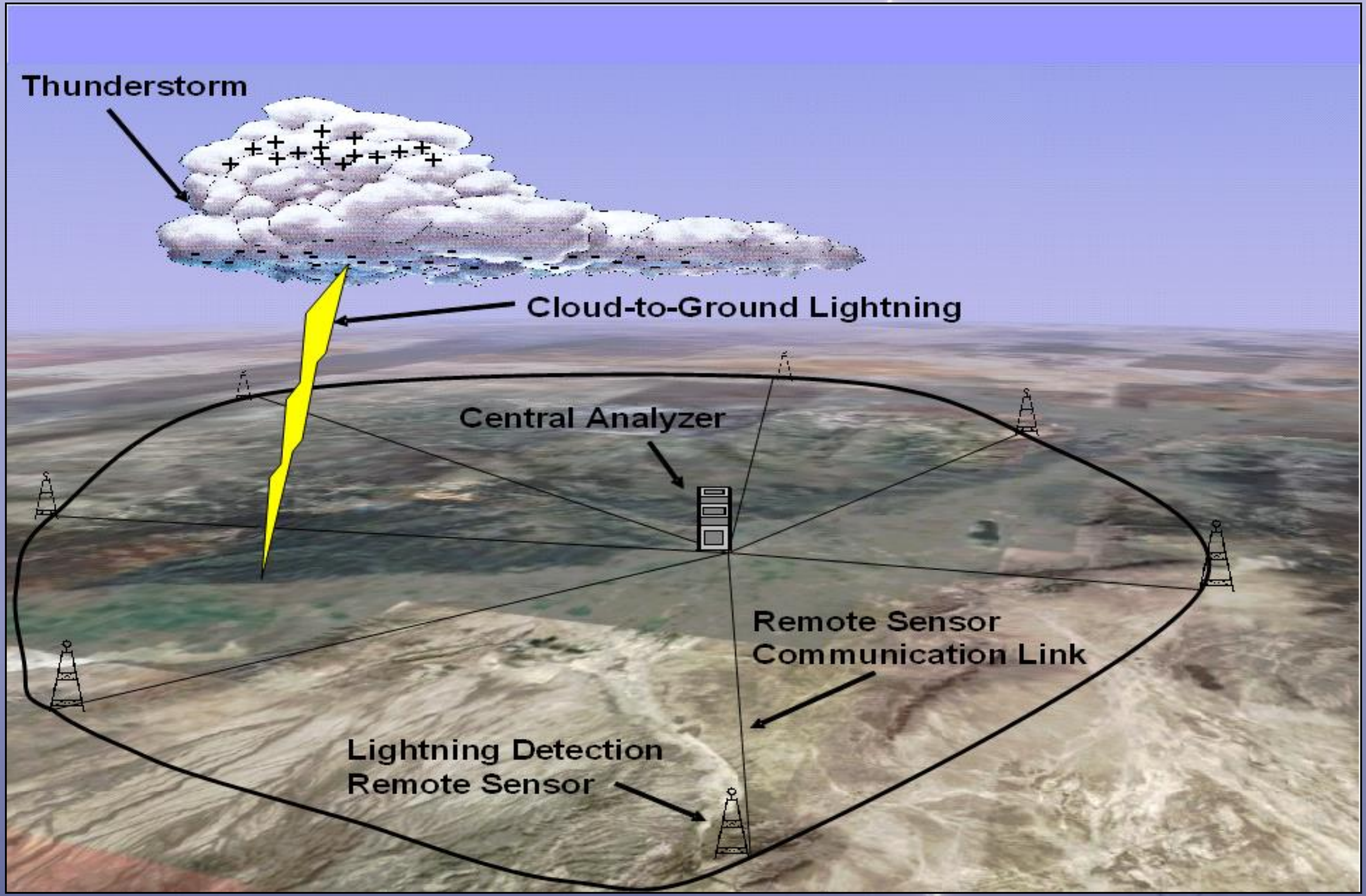
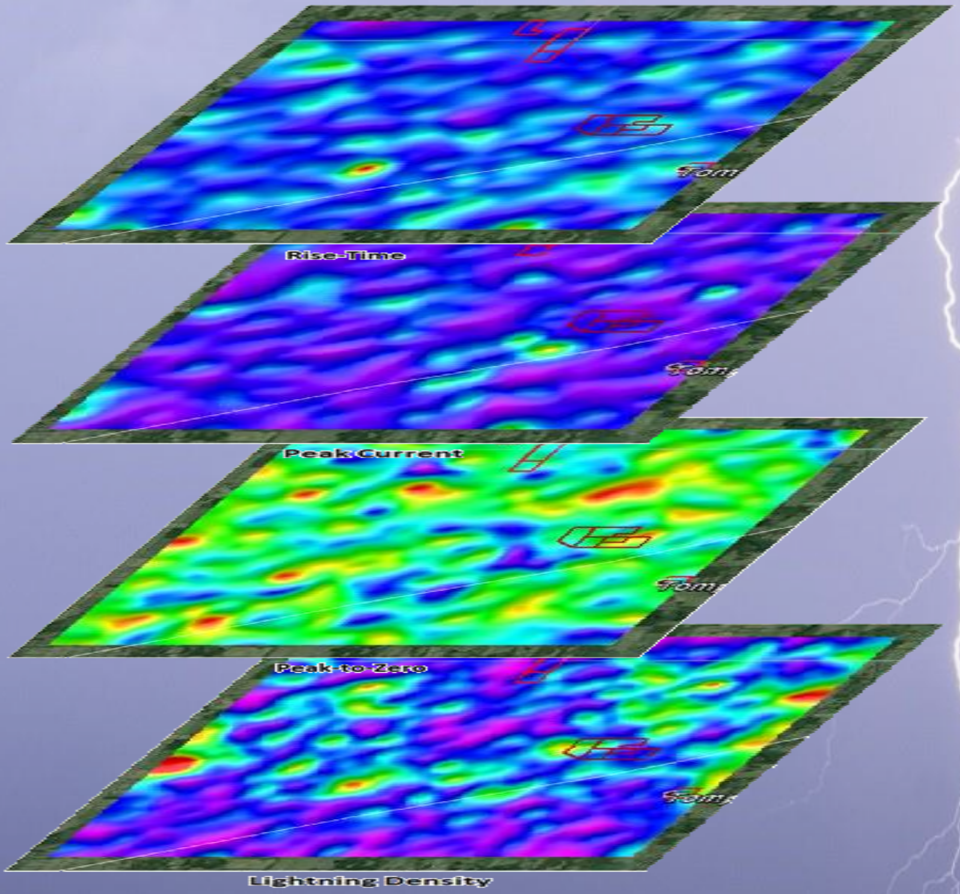
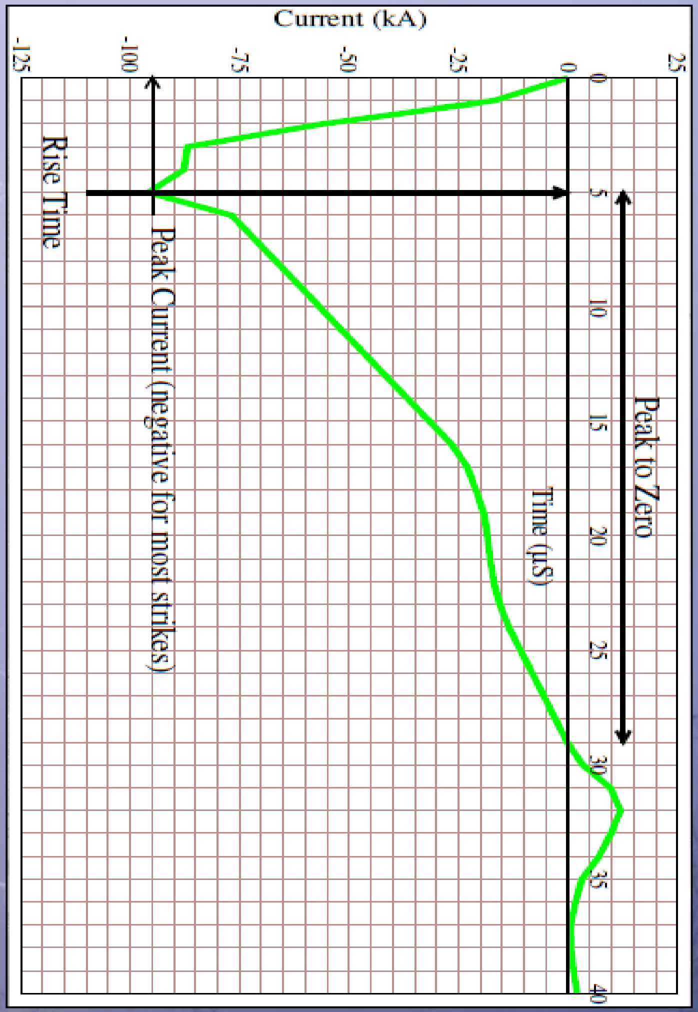
330 Sensors record U.S. lightning strike locations with 100-500 feet (30-150 meter) horizontal resolution



Lightning Strike Measurements

- Location
- Time and Duration
- Rise Time
- Peak Current
- Polarity
- Peak-to-Zero
- Density





Main lightning bolt tied to geology

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Proven and Patented Technology

US008344721B2

(12) **United States Patent**
Nelson, Jr. et al.

(10) **Patent No.:** **US 8,344,721 B2**
(45) **Date of Patent:** **Jan. 1, 2013**

(54) **METHOD FOR LOCATING SUB-SURFACE NATURAL RESOURCES**

(75) Inventors: **H. Roice Nelson, Jr.**, Houston, TX (US); **Joseph H. Roberts**, Houston, TX (US); **D. James Siebert**, Katy, TX (US); **Wulf F. Massell**, Conroe, TX (US); **Samuel D. LeRoy**, Houston, TX (US); **Leslie R. Denham**, Houston, TX (US); **Robert Ehrlich**, Salt Lake City, UT (US); **Richard L. Coons**, Katy, TX (US)

(51) **Int. Cl.**
G01R 31/02 (2006.01)
G01N 27/00 (2006.01)
G01W 1/00 (2006.01)

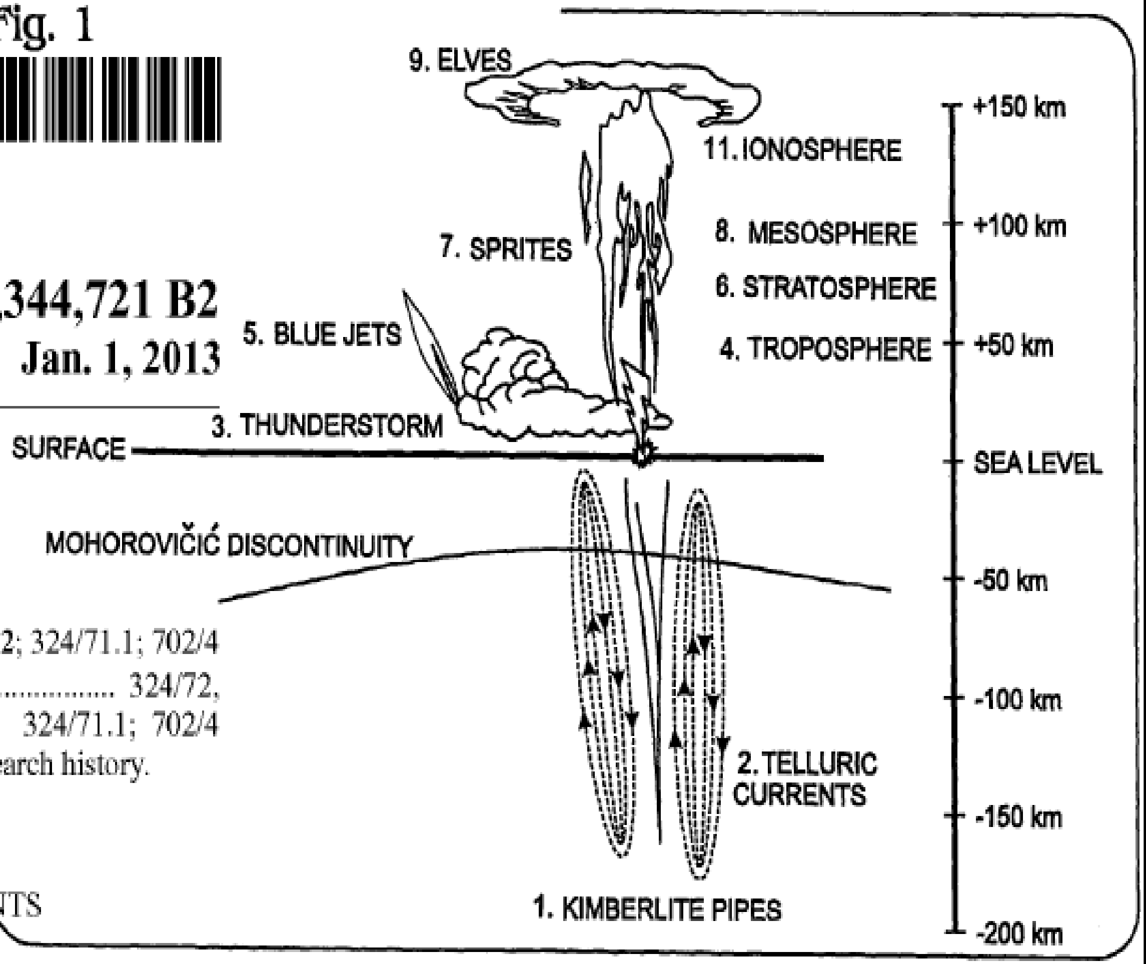
(52) **U.S. Cl.** **324/72**; 324/71.1; 702/4

(58) **Field of Classification Search** 324/72, 324/71.1; 702/4
See application file for complete search history.

(56) **References Cited**

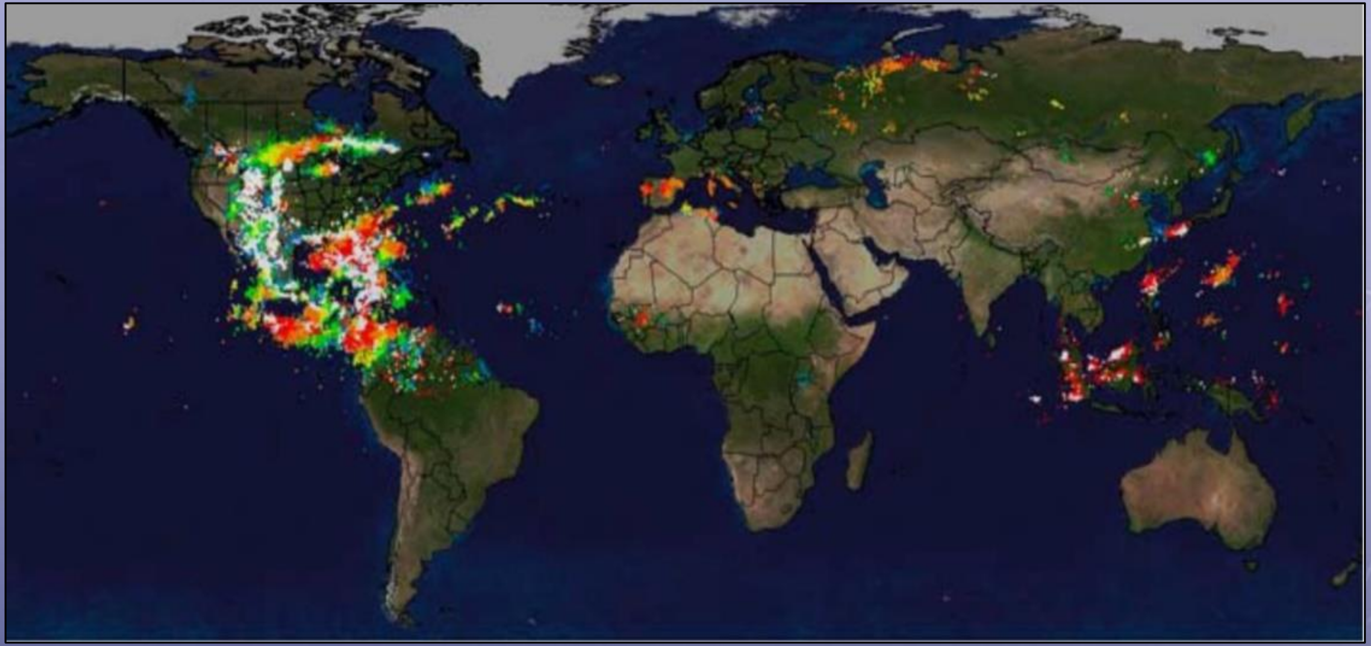
U.S. PATENT DOCUMENTS

Fig. 1



Vaisala Partnership

Exclusive worldwide license with Vaisala of Finland to use their data in the NLDN and GLD-360 for natural resource exploration.



Questions & Answers & Discussion

3. Calculating resistivity volumes from lightning databases

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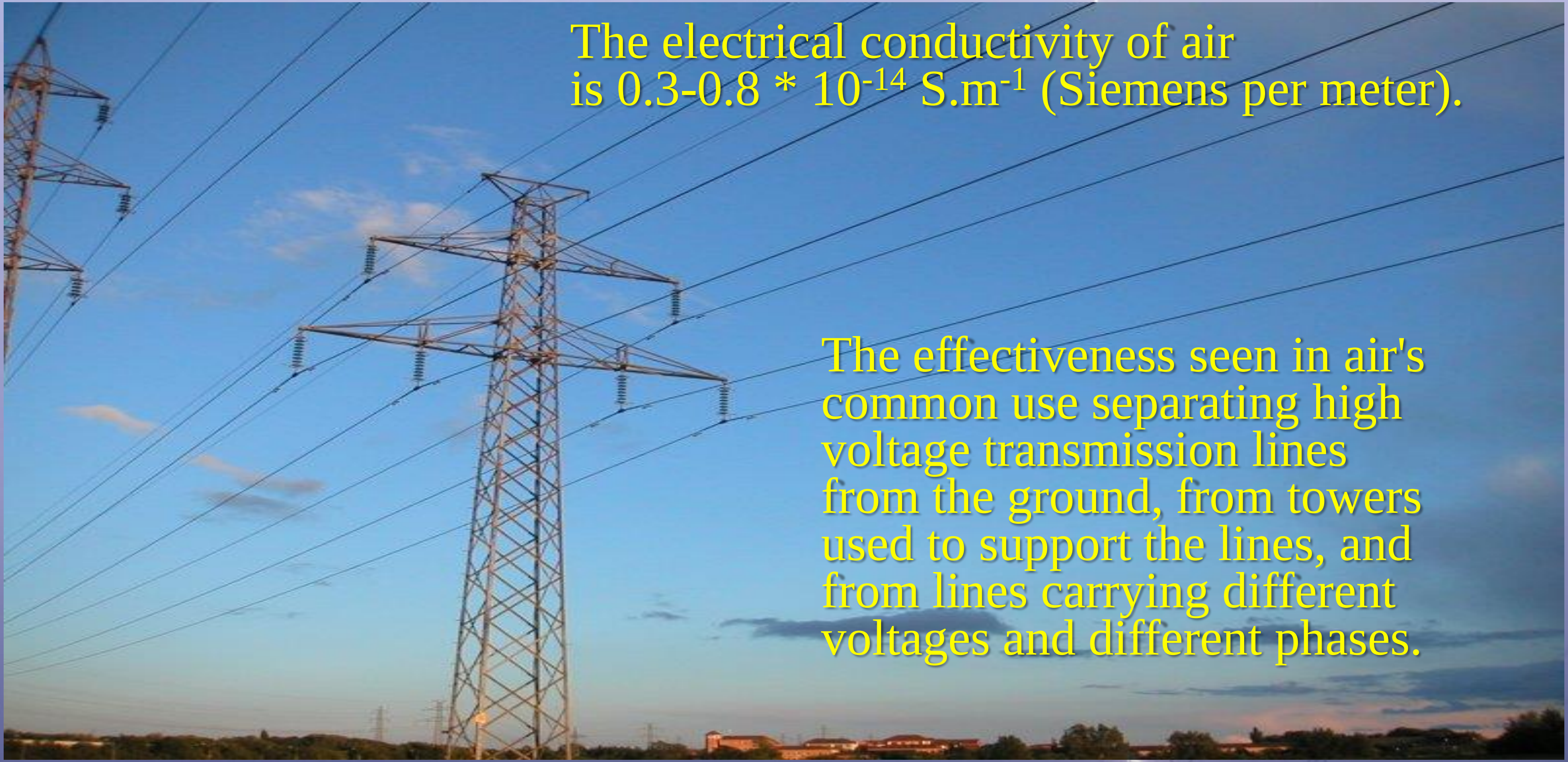
Recorded Lightning Data

- Lightning measurements – 30+ years
- Continuous record in U.S.A. and Canada – 16+ years
- Continuous record worldwide – 4+ years

The atmosphere is an effective insulator

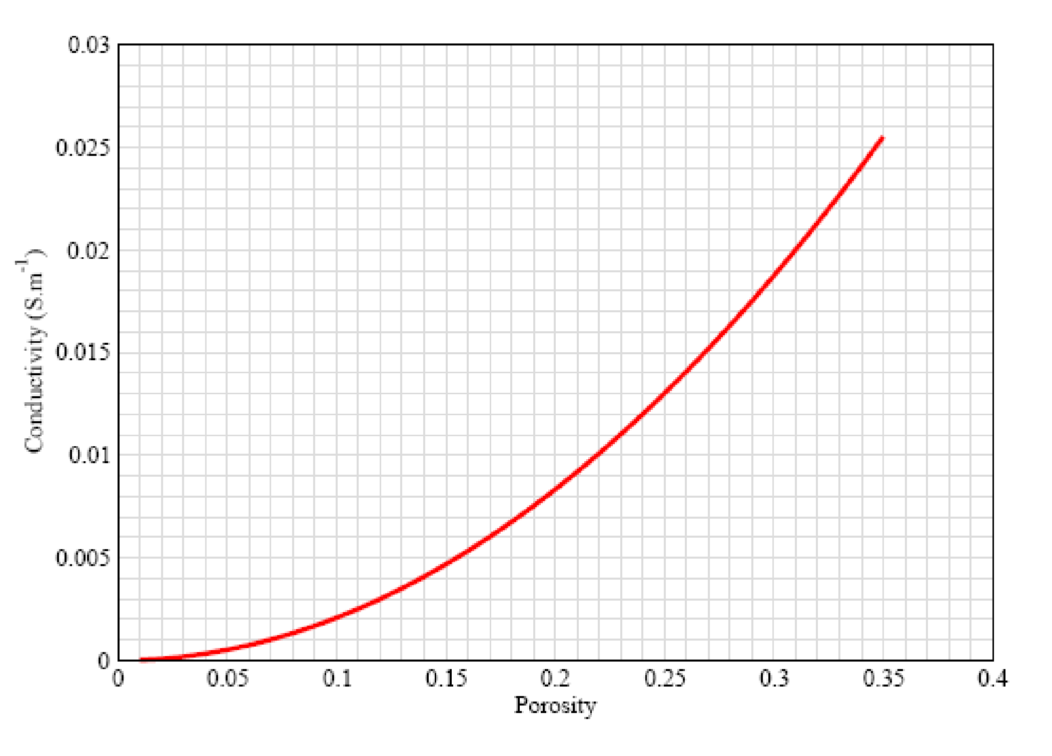


The electrical conductivity of air is 0.3-0.8 * 10^{-14} $S.m^{-1}$ (Siemens per meter).

The effectiveness seen in air's common use separating high voltage transmission lines from the ground, from towers used to support the lines, and from lines carrying different voltages and different phases.

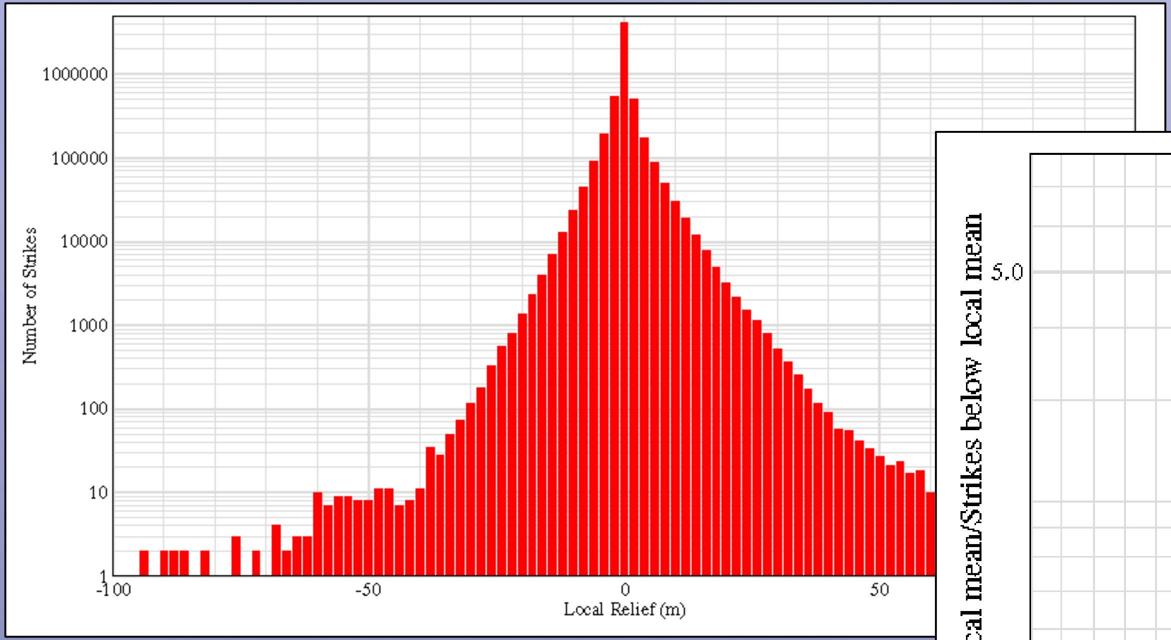
The earth is much more conductive than air

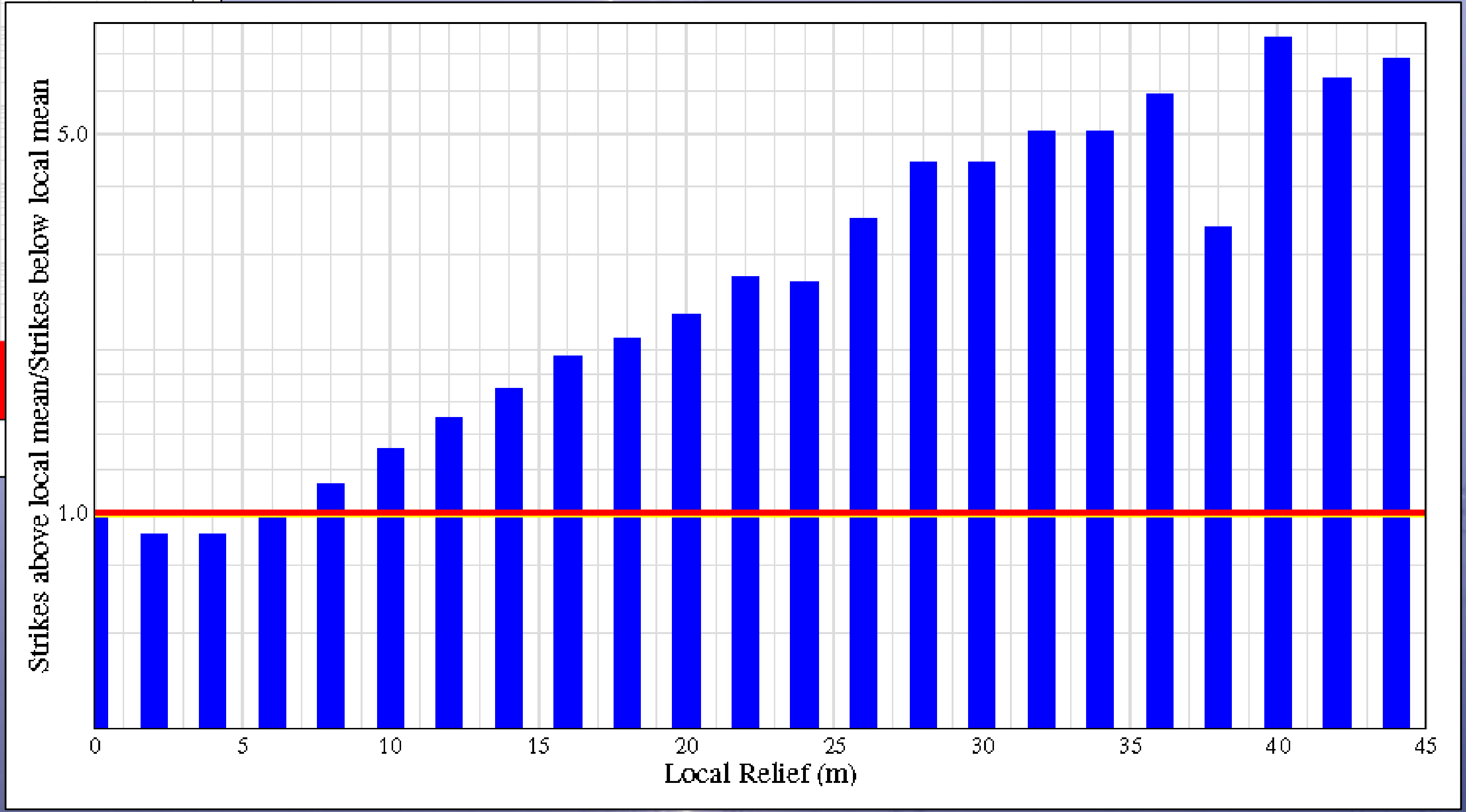
Assuming a typical sedimentary rock has 5% porosity, the electrical conductivity of rocks is $5.0 * 10^{-4}$ $S.m^{-1}$, or about 10^{10} times the conductivity of air.



Rock Conductivity Graph computed for a porous rock with 100% brine saturation using Archie's equation

Linear increase in number of lightning strikes with local relief, shows atmosphere's insulating limits





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The Atmospheric Capacitor

Plate 1

- The charged thundercloud is one plate of a capacitor
- The other plate of the capacitor is the earth underlying the charged cloud
- The dielectric is the air
- Energy from a lightning strike is converted to heat, partly in the air, but largely in the subsurface

Dielectric

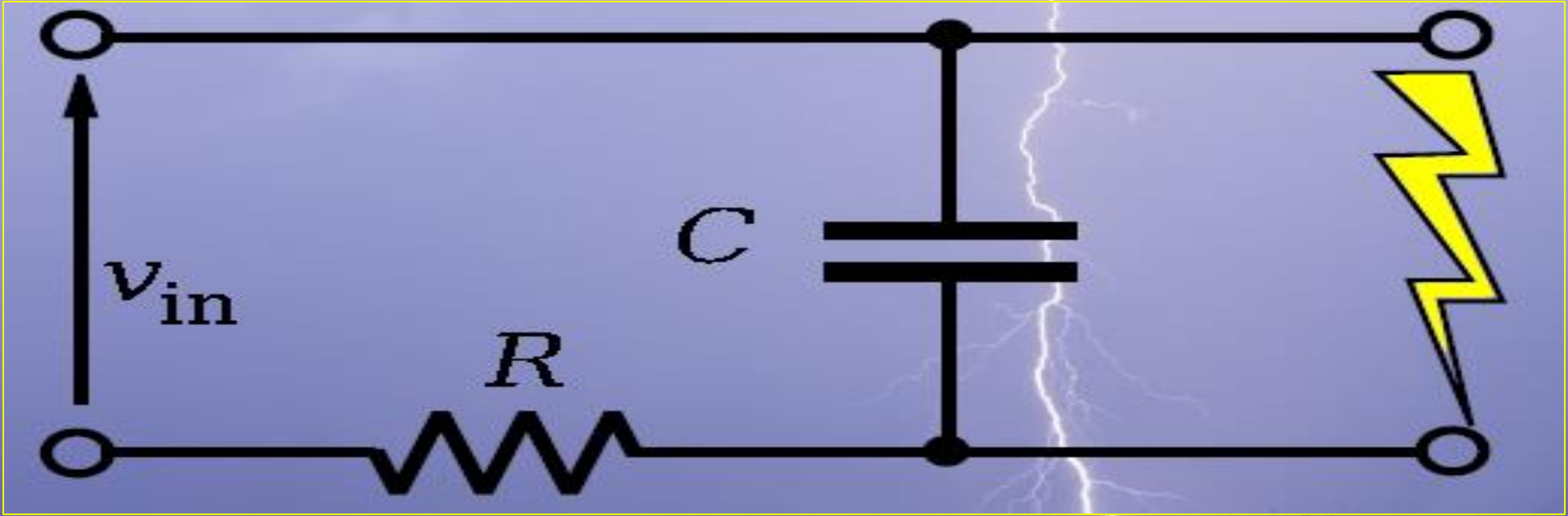
Plate 2

Lightning a Dielectric Breakdown

- Lightning occurs when the voltage across the atmospheric capacitor exceeds the dielectric strength of the air.
- Resistance in the atmosphere is very low once the path is ionized.
- Resistance in the subsurface is approximately constant over long periods of time.
- Atmospheric factors vary with each stroke.

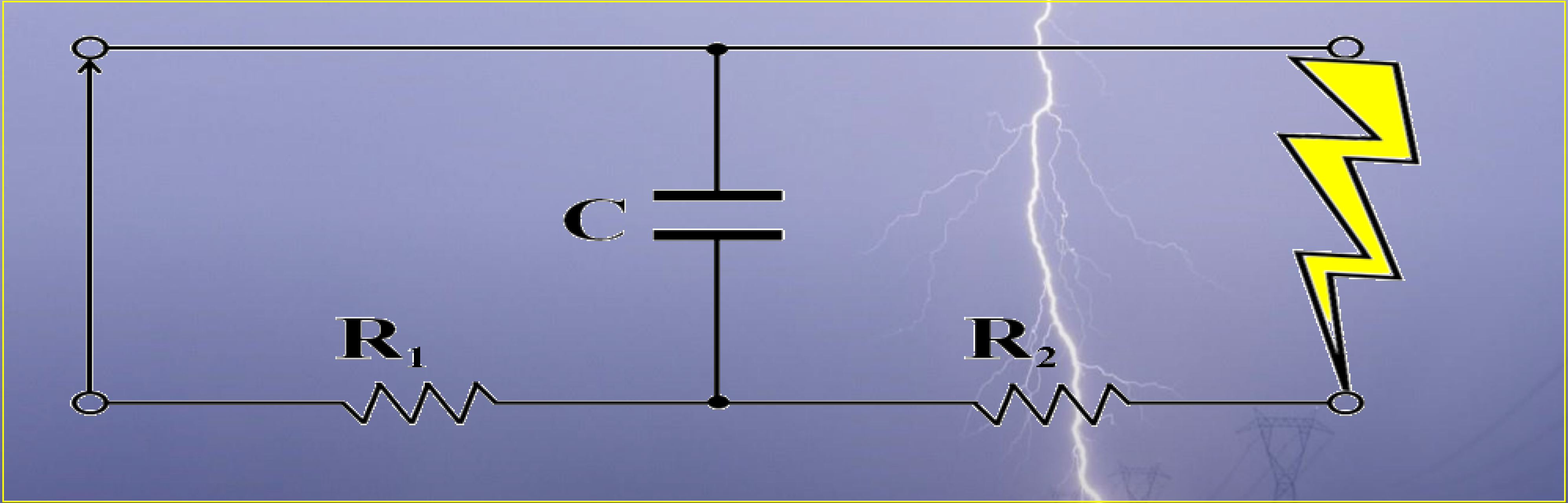
Relaxation Oscillator

- The physics of lightning discharge are similar to the physics of a neon-tube relaxation oscillator.
- In each case, voltage builds across a capacitor until an insulating gas ionizes and becomes a conductor



Lightning Physics

- The atmospheric capacitor is nearly the same
- Just an additional resistance R_2 limiting the current
- R_2 is the resistance between the lightning strike point and the bottom plate of the capacitor

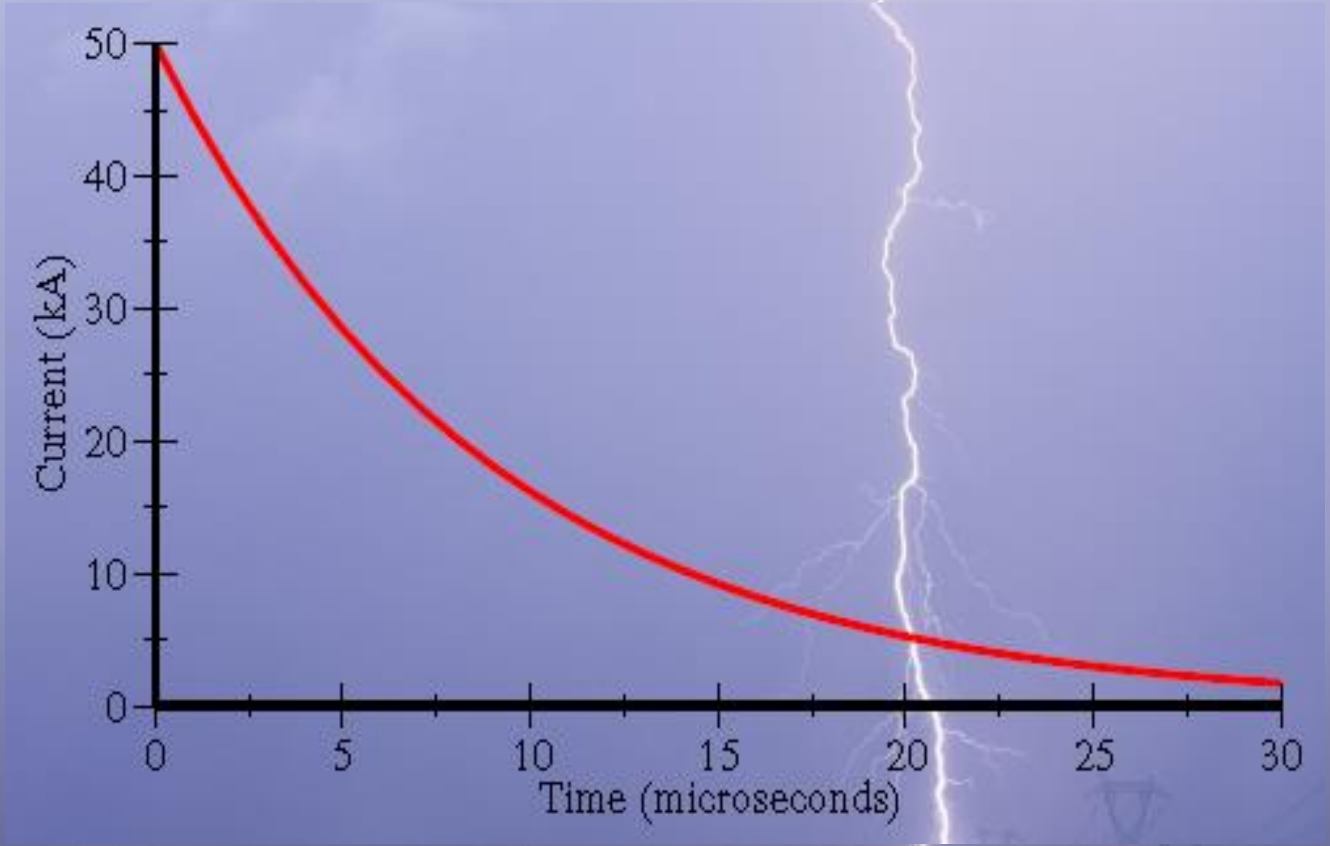


Relaxation Oscillator Physics

- When a relaxation oscillator triggers, the discharge current decays exponentially
- The rate of decay is given by $I_t = I_0 e^{-t/RC}$
- If lightning is similar, can we use the decay to measure resistance?
  - This equation can be rearranged to $ln(\frac{I_t}{I_0}) = -\frac{t}{RC}$ or $R = -\frac{t}{ln(\frac{I_t}{I_0})C}$
  - All we need is the current at two times (I_0 and I_t), and the capacitance (C) to get the resistance R

How do we measure Decay

- Lightning measurements do not give this kind of continuous decay.
- We have two values:
  - Peak current
  - Peak to zero time



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The Available Measurements

- Two points on an exponential curve will define the curve

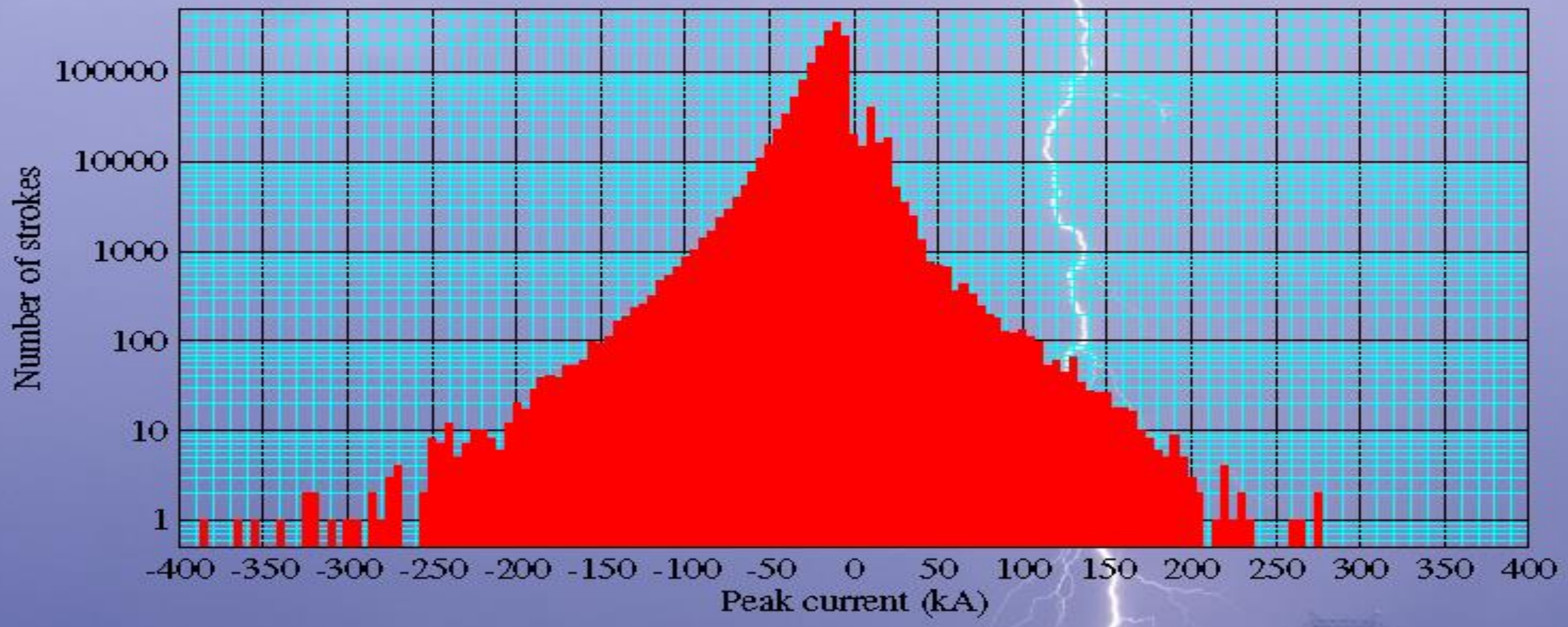
Peak Current:

- The maximum recorded current, when decay starts (I_0)

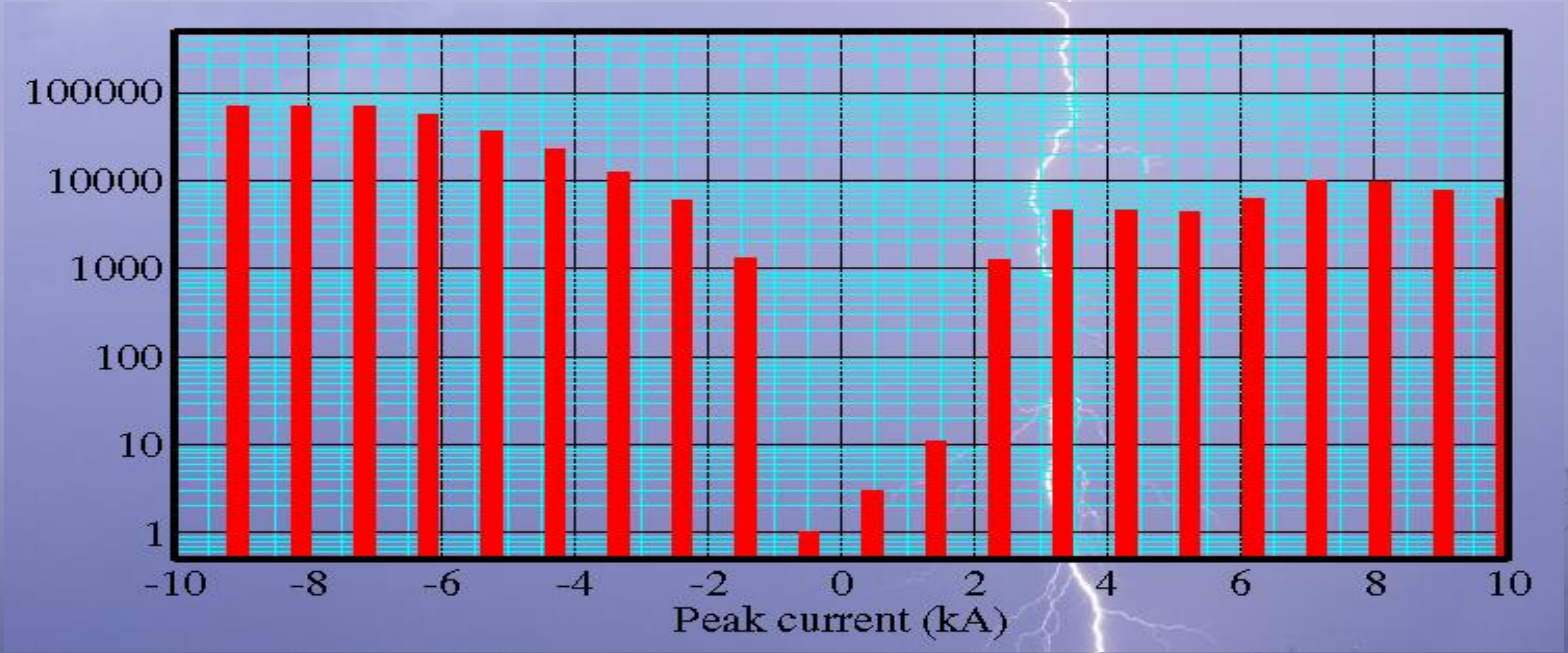
Peak-to-Zero time:

- The elapsed time from the instant of Peak Current until the recorded signal disappears into the background noise.
- This gives us the time *t*.
- But what is the current (I_t)?
- The time for current to decay to a real zero is infinite.
- We need an estimate of the magnitude of the “zero” current (at time *t*) in order to compute resistance.

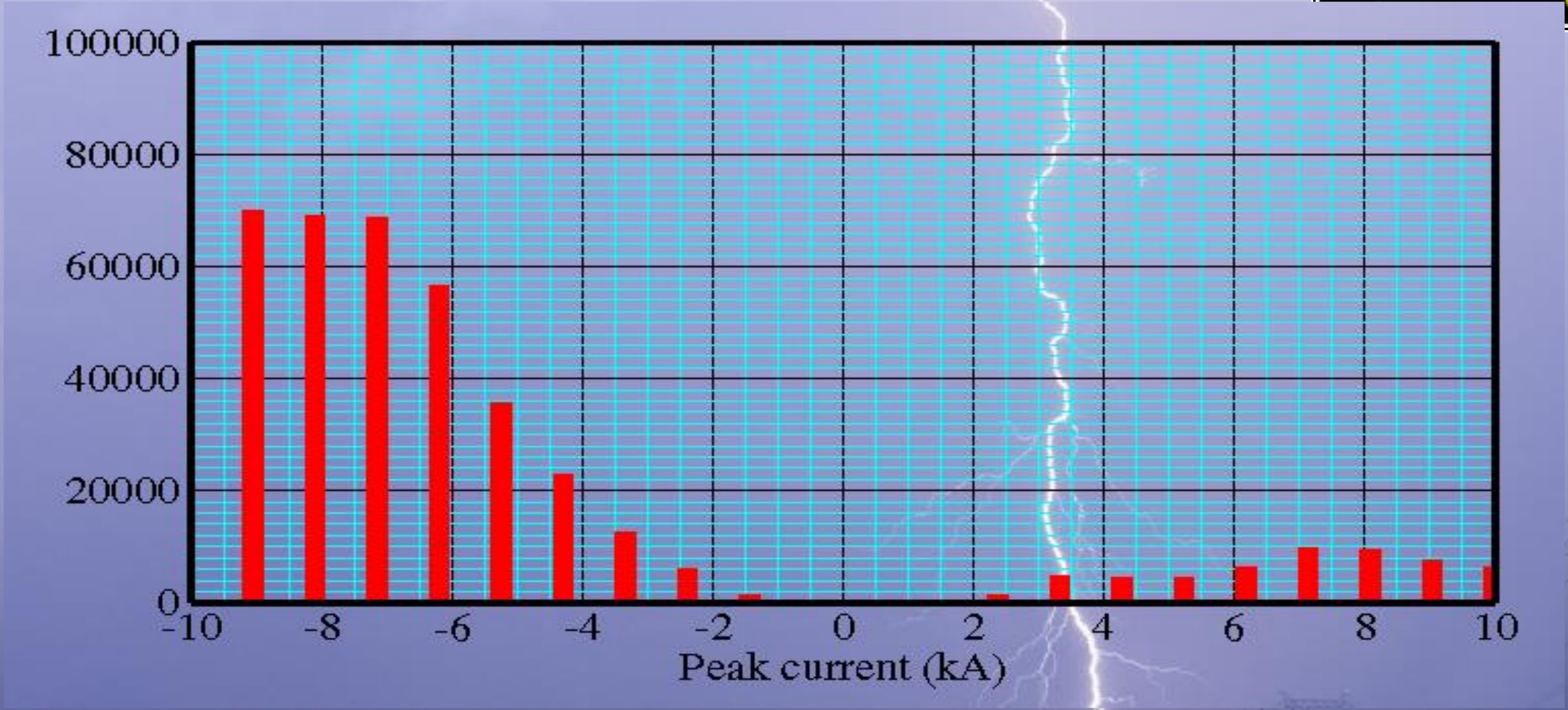
What is “Zero” Current?
Histogram of peak current for 1.6 million strikes



What is Zero Current?



What is Zero Current?



What is Zero Current?

- Total strikes 1.6 million
- 320,000 less than 10 kA absolute peak current
- 30,400 less than 5 kA absolute peak current
- 13,260 less than 4 kA absolute peak current
- 2,579 less than 3 kA absolute peak current
- 15 less than 2 kA absolute peak current
- “Zero” current assumed to be 1 kA

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What About Voltage?

- Resistance is equal to voltage/current.
- Our measurements are of current only.
- But the equation gives a solution with capacitance rather than voltage.
- However, how do we find capacitance?
- Capacitance depends on permittivity, plate area, and plate separation.
- While permittivity is approximately constant and known for air, assumptions for area and separation are needed to solve for resistance.

The Assumptions

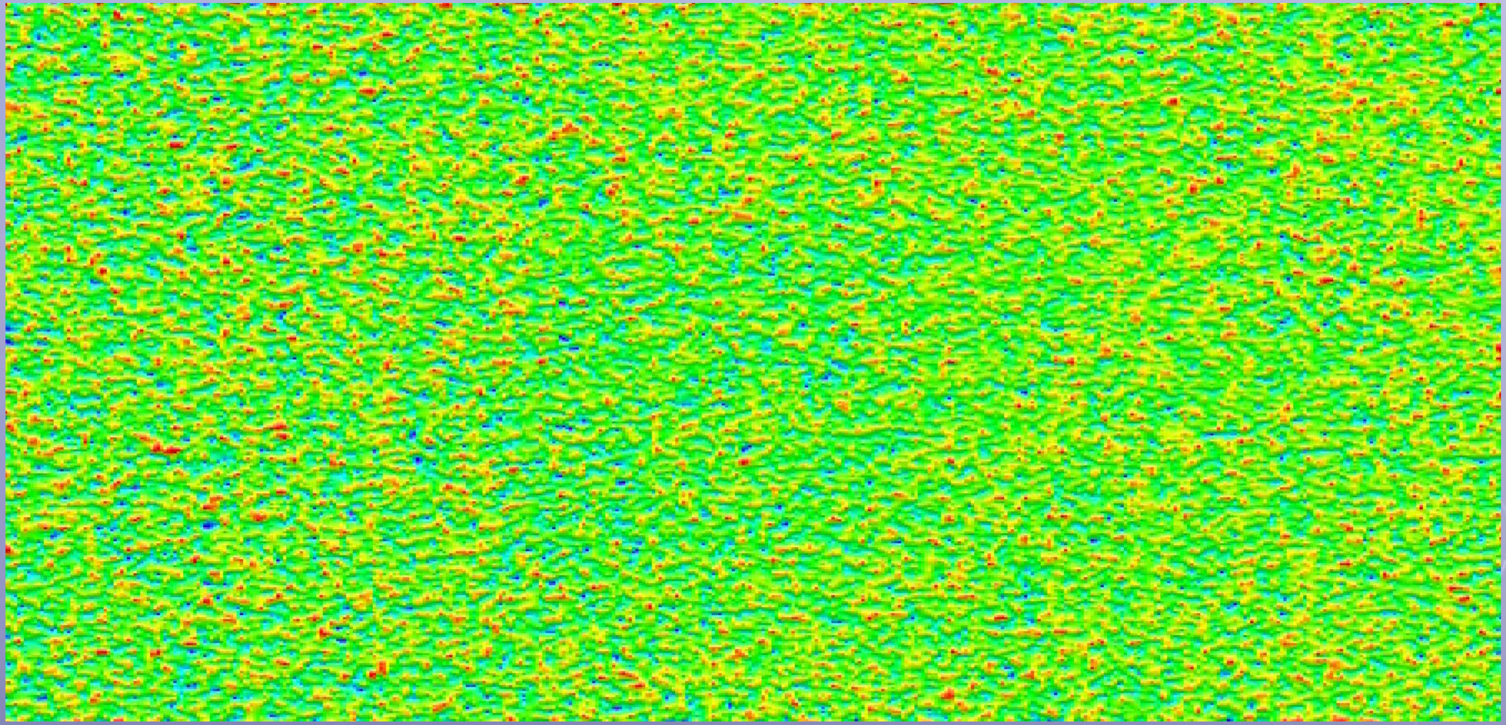
1. Voltage is proportional to peak current (within a local area).
2. Cloud height is proportional to voltage because the dielectric strength of air is more or less constant.
   - This gives plate separation for the atmospheric capacitor
3. The effective capacitor is circular, with a radius proportional to cloud height.
   - This gives plate area for the capacitor
4. With over 100 lightning strikes per square kilometer in the database in many areas, we can stack results to improve signal-to-noise ratio

What is Resistivity?

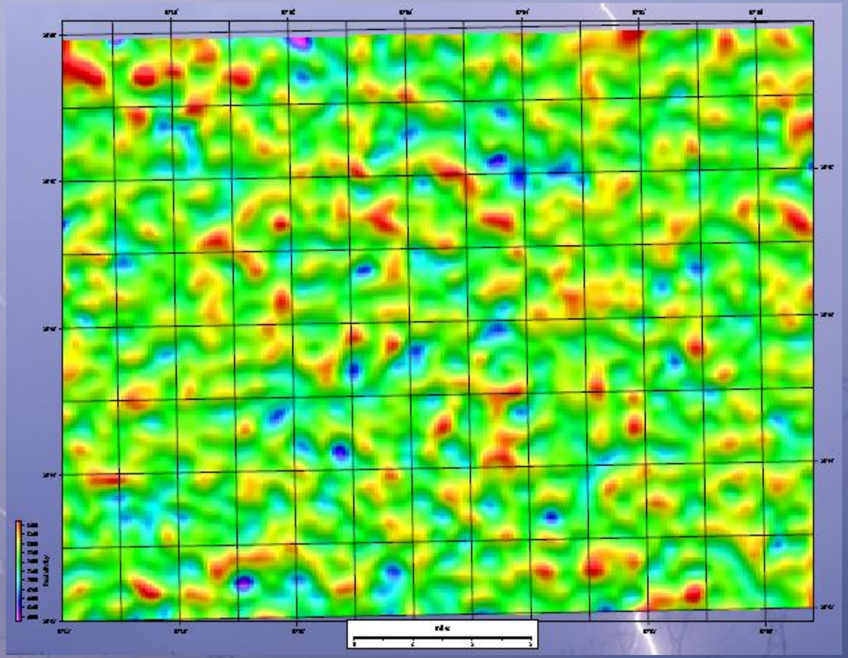
- Resistivity is resistance times cross-sectional area of a conductor, divided by its length; or $\rho = \frac{R \times A}{l}$
- For the lightning energy dissipating in the ground:
    - The area is very small at the strike point, but increases rapidly
    - The length is very short for discharging the charge close to the strike point, but for points near the edge of the effective capacitor, the length is much greater
- For low energy lightning, the resistivity measured is that of rocks close to the surface
- For higher energy lightning, the resistivity measured is an average of resistivities to greater depths.

Resistivity Maps

Houston Area



Milam County



Resistivity and Depth

- As mentioned above, electrical energy from more powerful strikes is partially dissipated at greater depths.

- So grouping strikes by peak current will give resistivities grouped by depth.

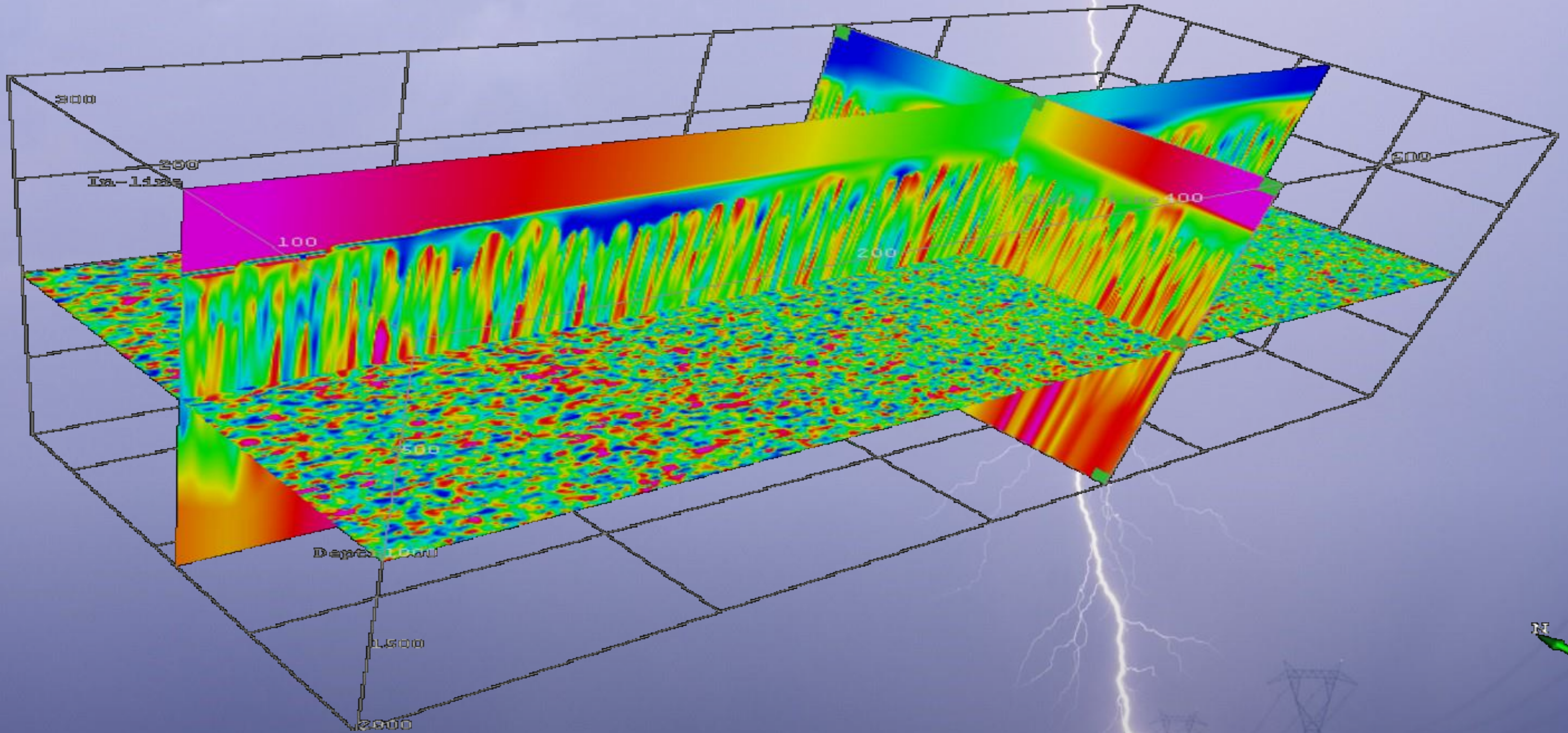
Determining Resistivity and Depth

1. Lightning data is divided into several groups (typically 10) by absolute peak current.
2. Each peak current group is divided into small (typically 0.03-0.04 km^2) cells by latitude and longitude.
   - Not all cells will contain a lightning strike, but some cells will contain more than one lightning strike.
3. For each cell in each group, resistivity and depth values are computed from the lightning data.
4. For each group a smooth surface is fitted to the depth values and to the resistivity values.
   - At any point in the project area, a number of depth/resistivity pairs equal to the number of groups in 1 can be produced by extracting grid values at that point.

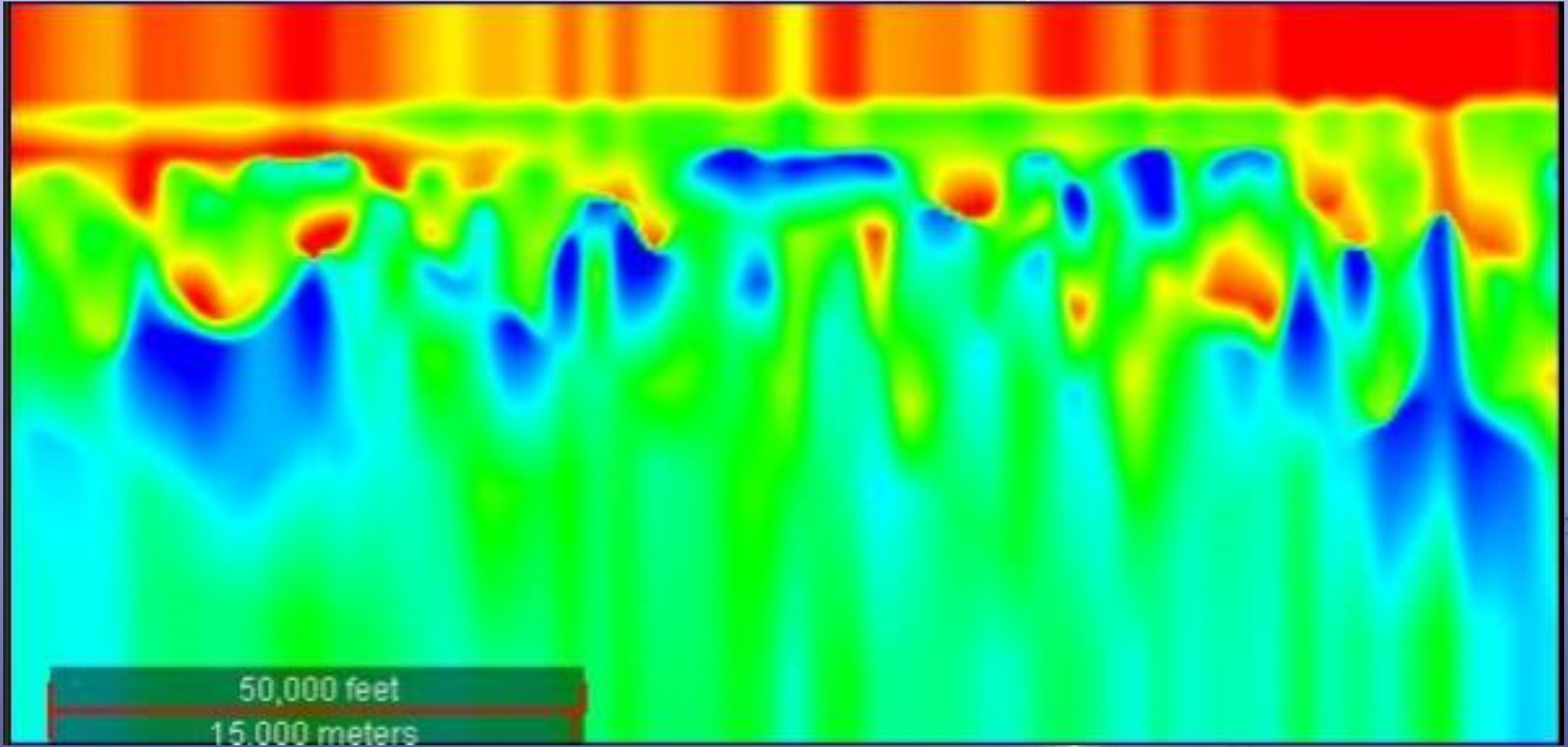
A Resistivity Trace

- For standard seismic interpretation software, data traces need to be uniformly sampled in time or depth, with the same number of samples in each trace
  - At latitude and longitude for the trace, each depth grid is sampled and each resistivity grid is sampled.
  - Resistivity values are interpolated with depth between these points to give samples at uniform intervals.
- Typical sample interval is 48 meters.
- Typical trace length is 125 samples.
- There is no restriction in sample interval or length beyond those imposed by the SEG-Y format.

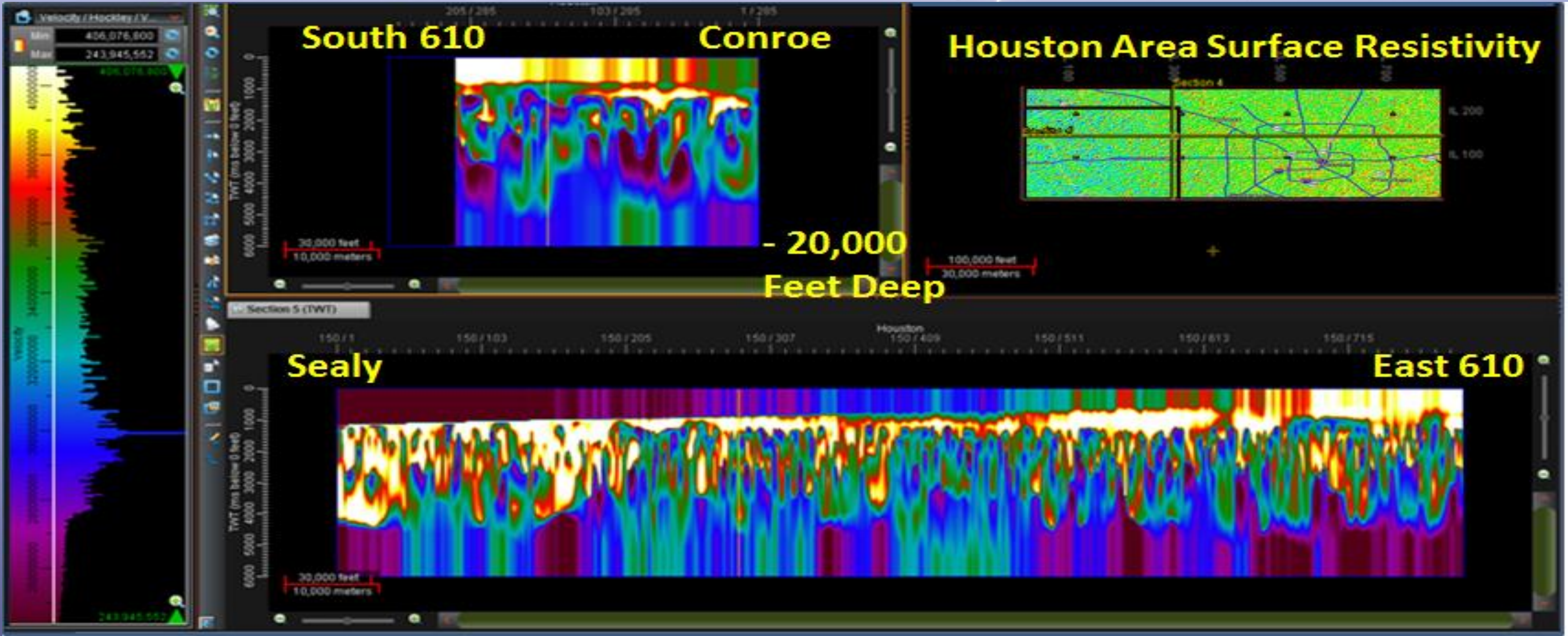
A Resistivity Volume



Resistivity Volume Cross-Section



Resistivity Volumes
Define Subsurface Resistivity



Questions & Answers & Discussion

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4. Examples of using lightning databases to map geology

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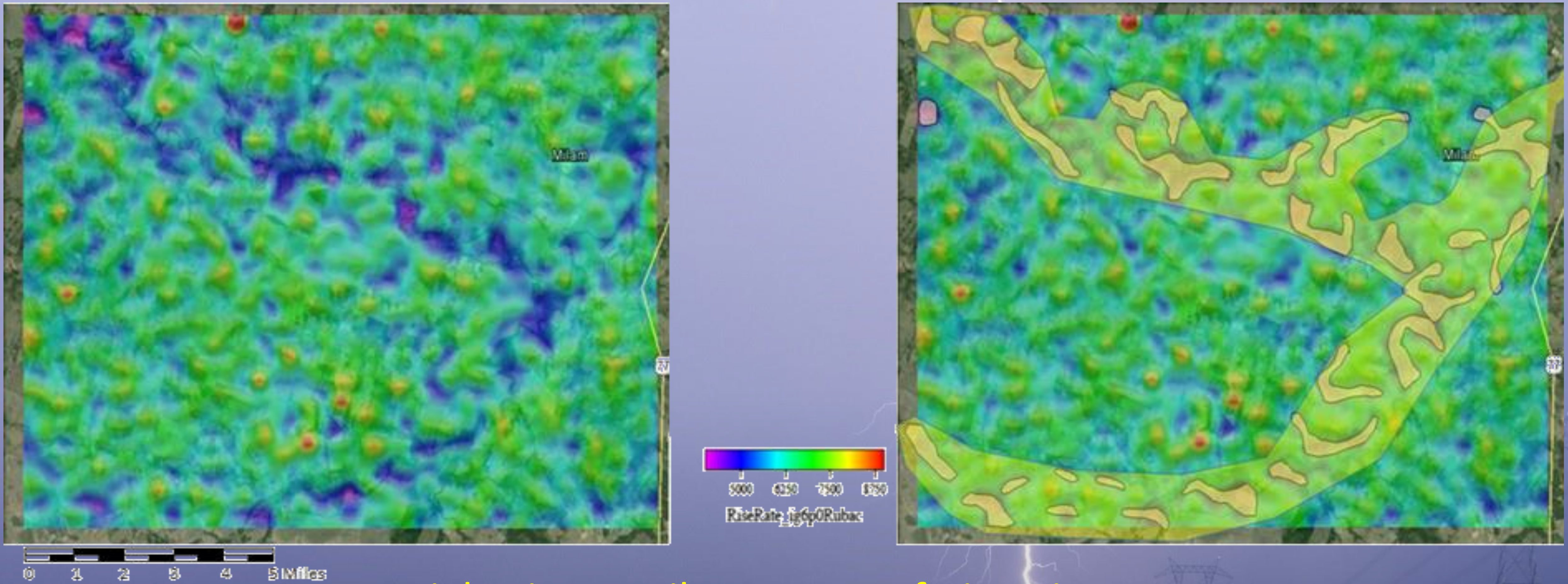
Lightning Analysis
Defines Stratigraphy



Lightning Attribute: Rate of Rise-Time

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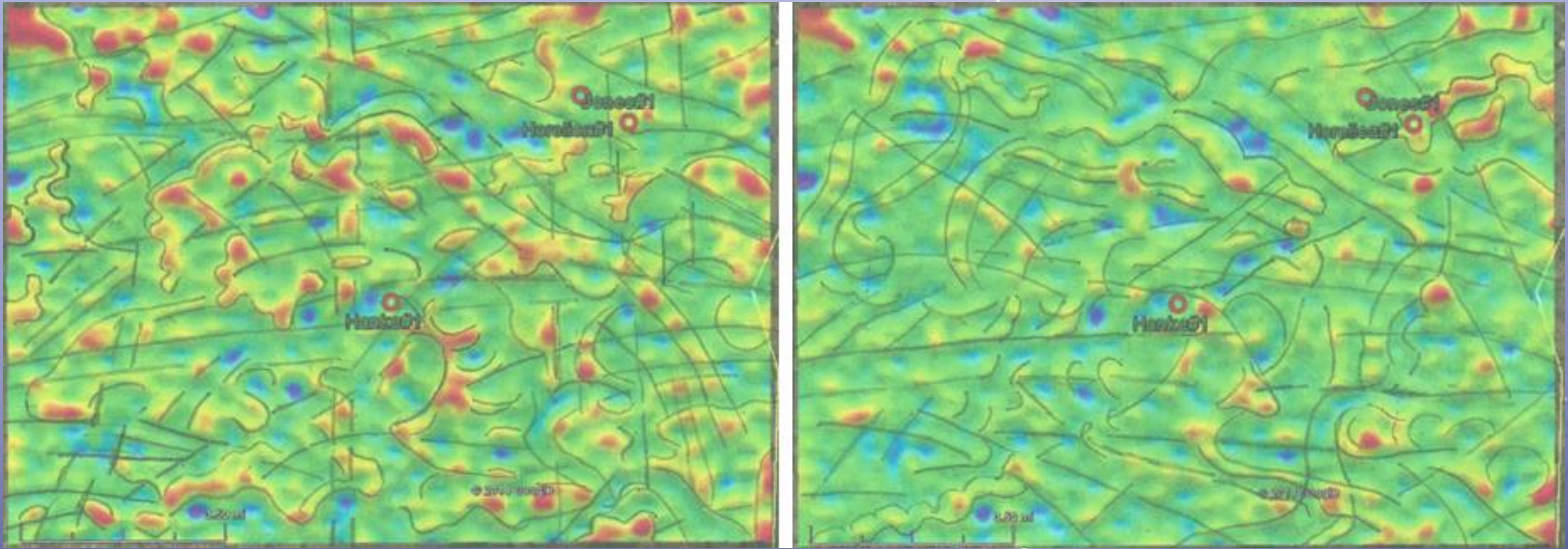
Lightning Analysis
Interprets Paleochannels and Meander Schrolls



Lightning Attributes: Surface Resistivity (left) Peak-to-Zero (right)

Lightning Analysis
Correlates with Fields

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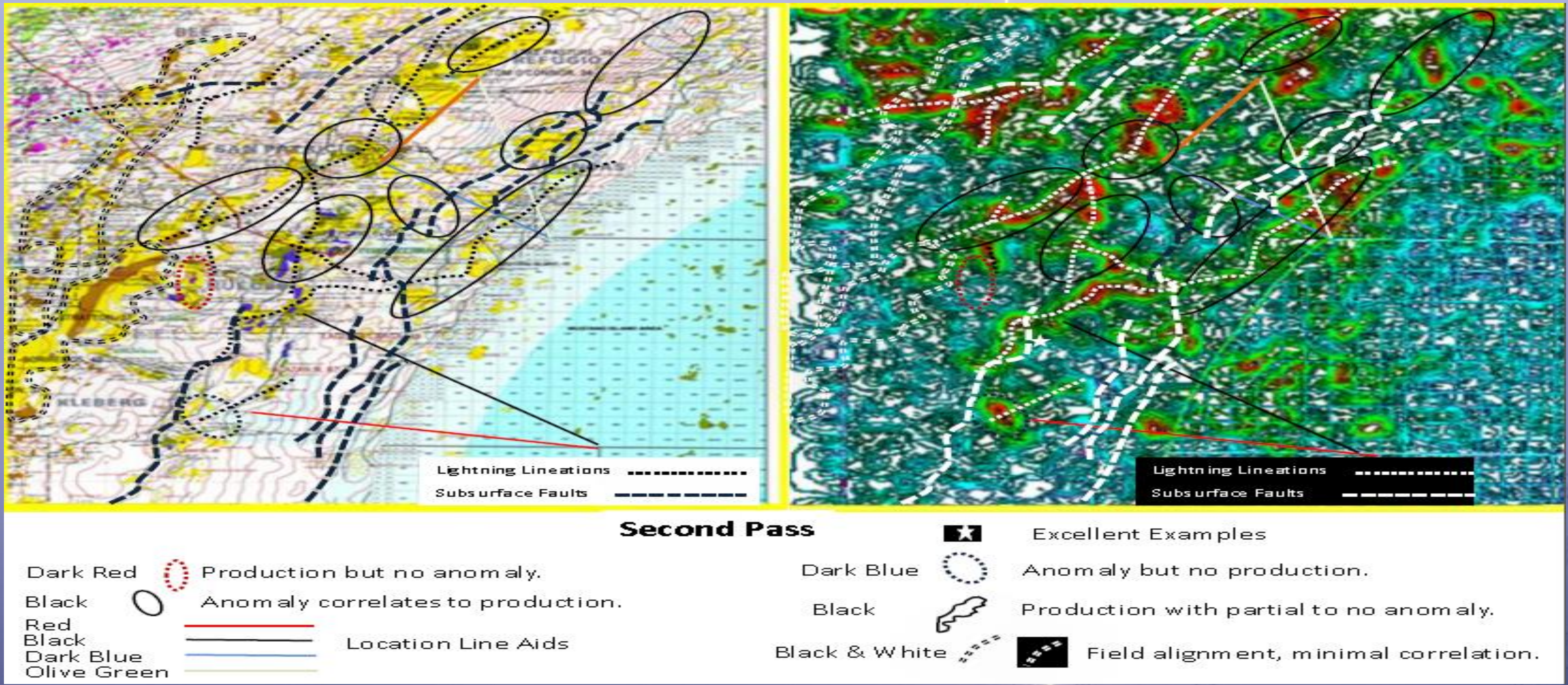
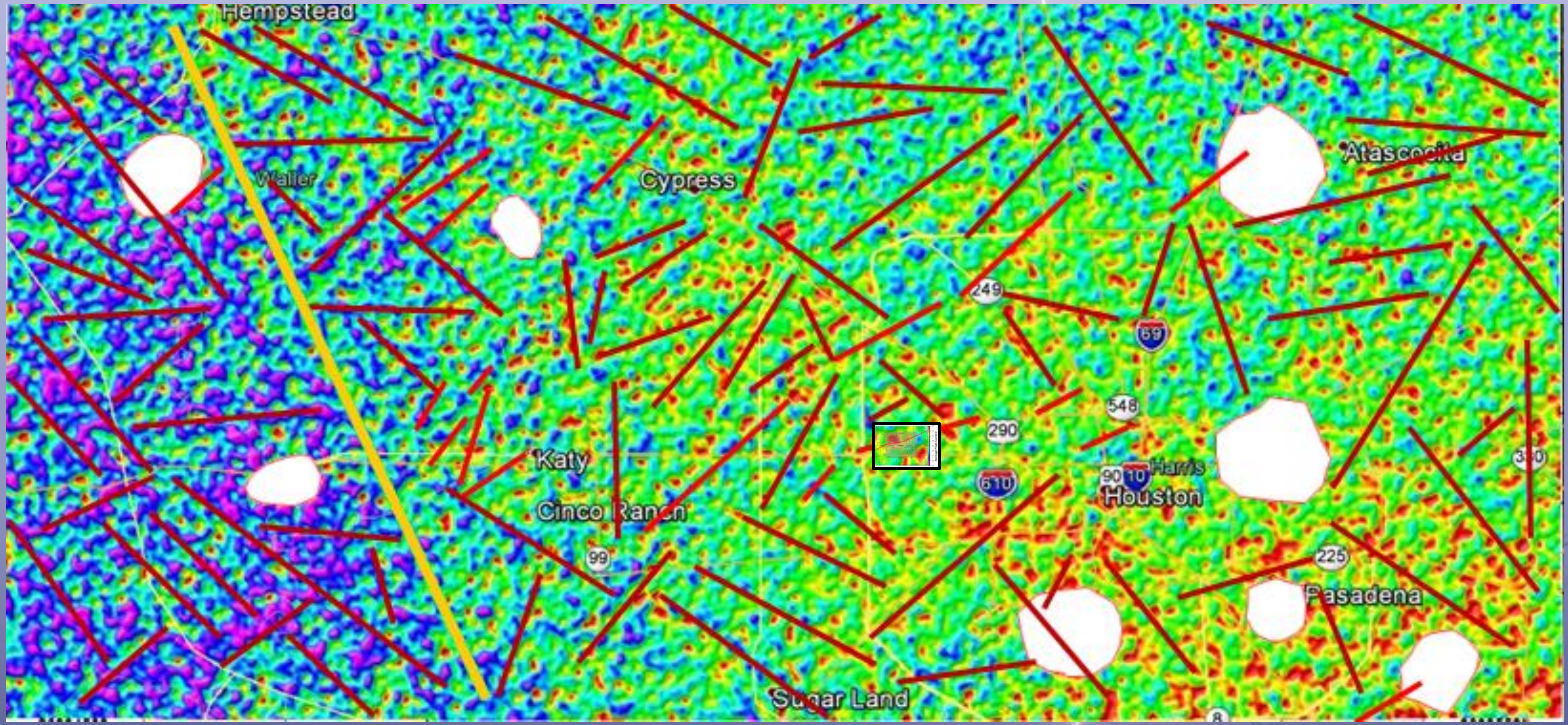
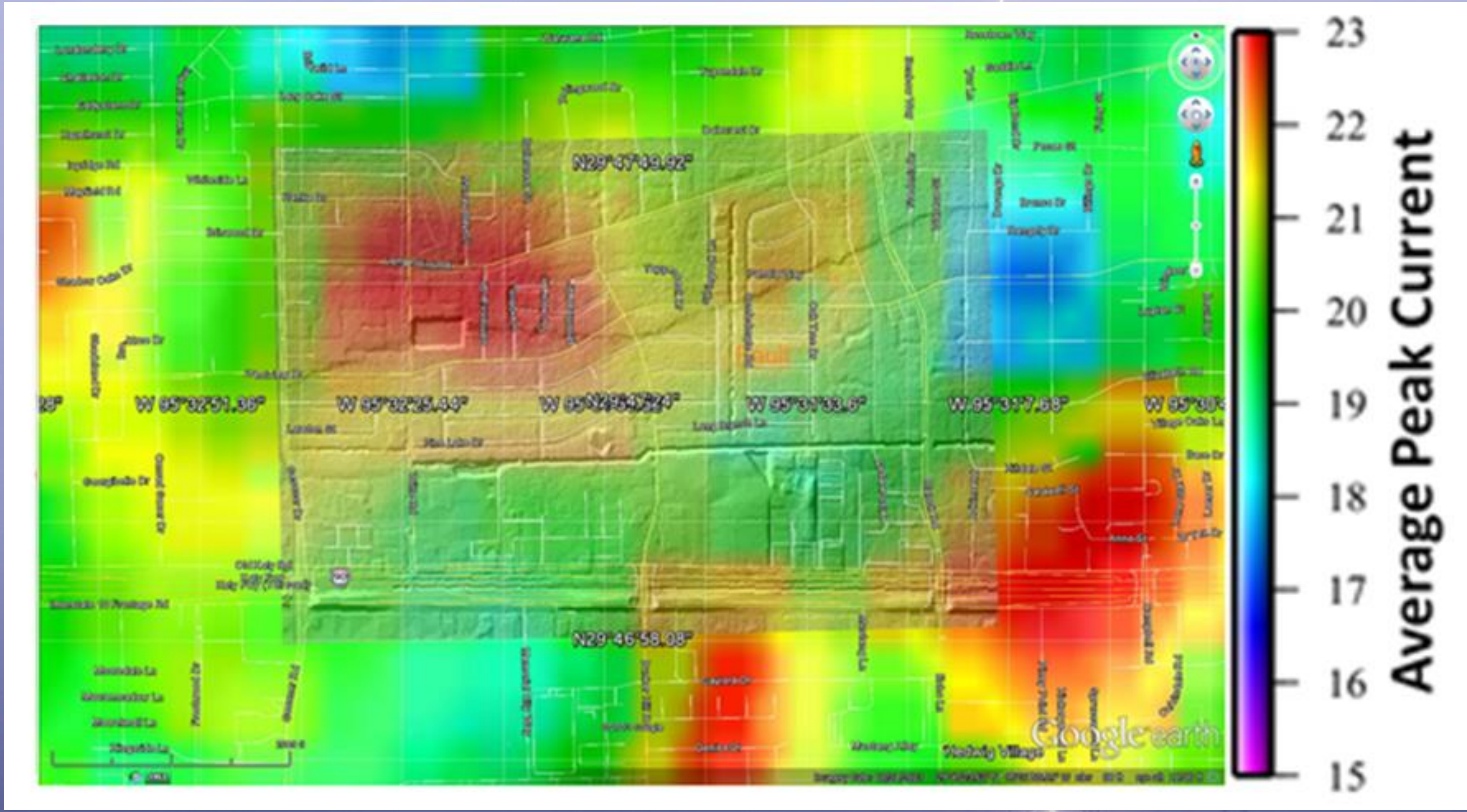


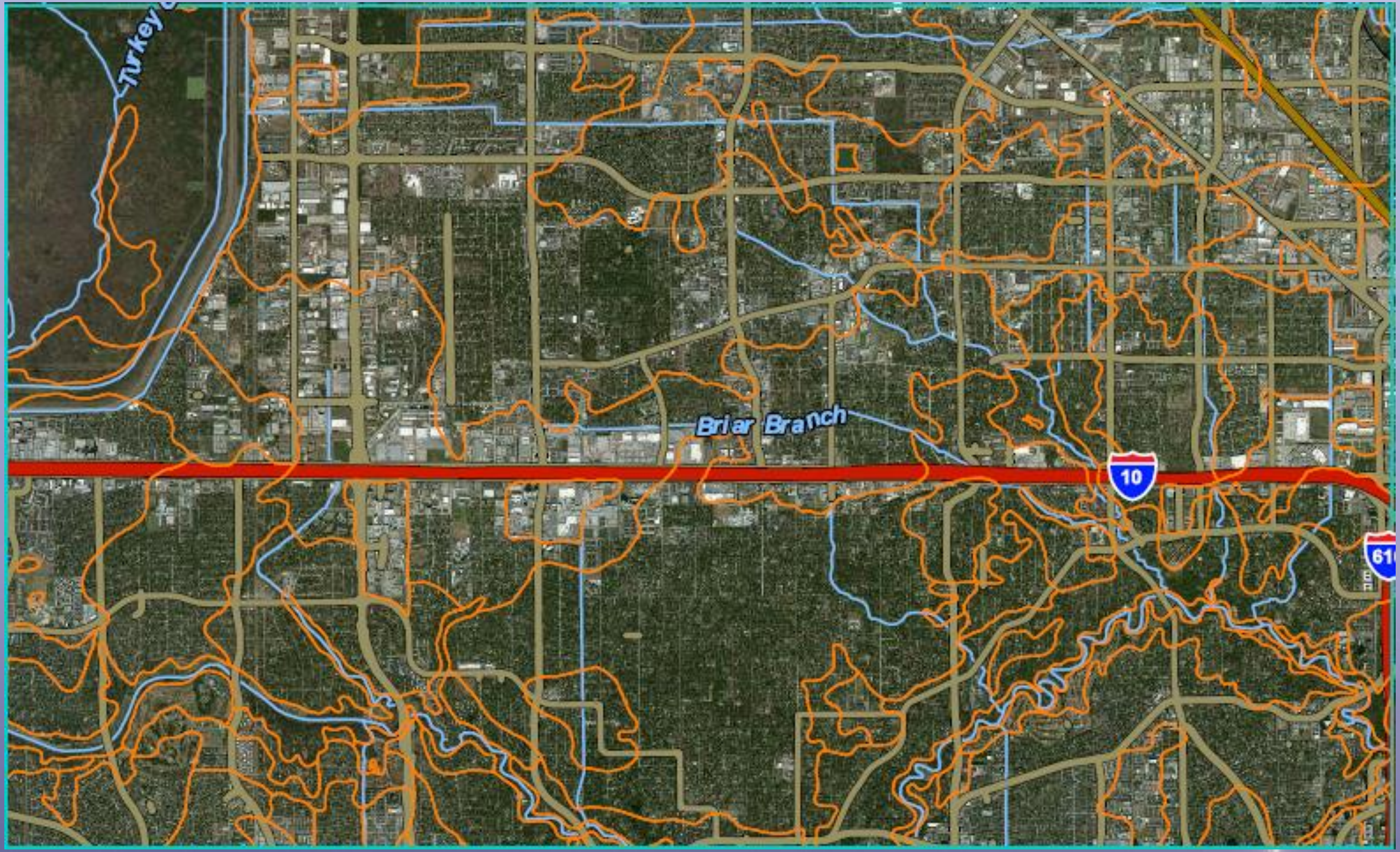
Peak Current from Sealy to East Houston



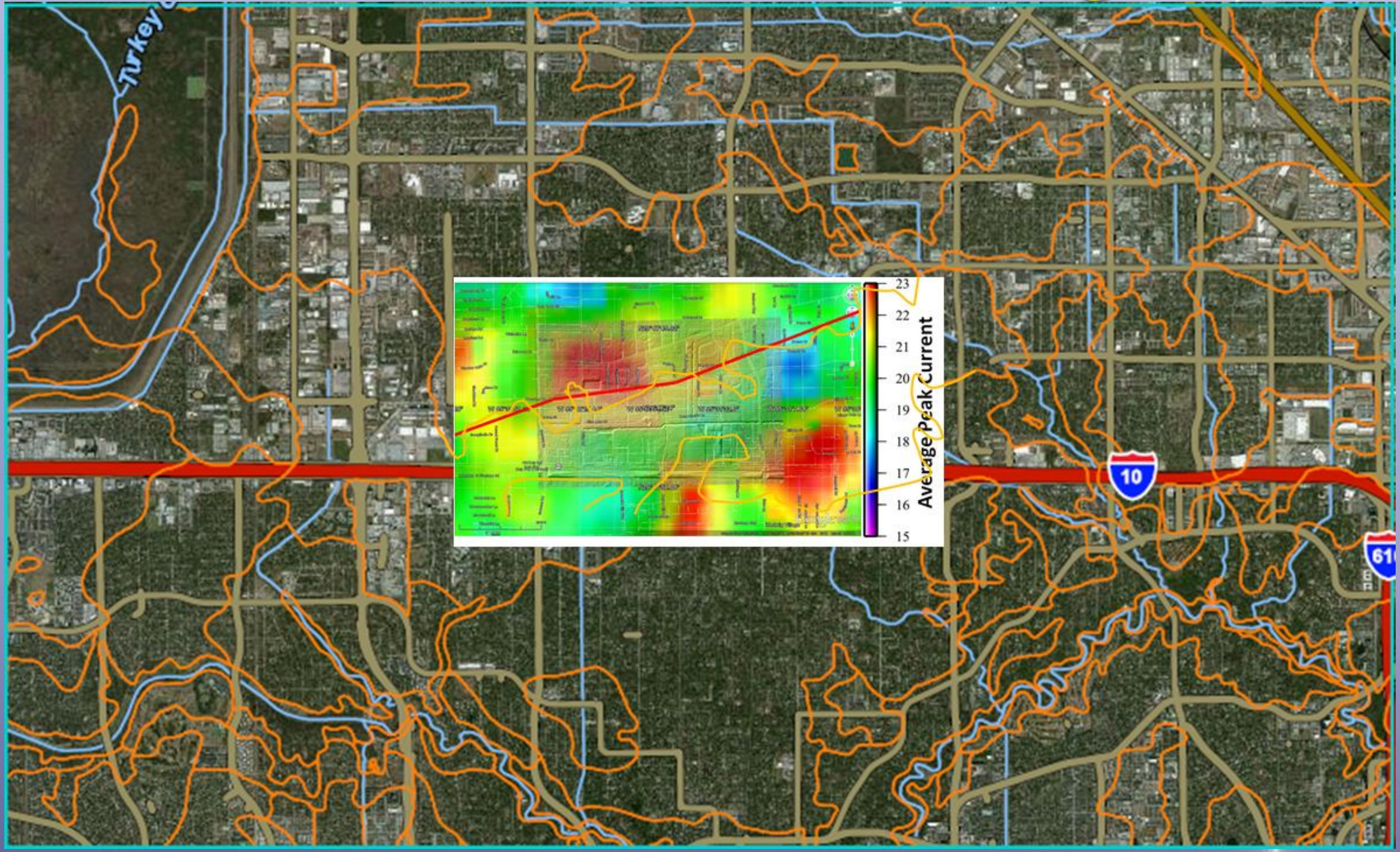
Peak Current Zoom with LIDAR & Long Point Fault



Soils Map over GoogleEarth™ Map



Integration with Long Point Fault over Soils over LIDAR over Peak Current over GoogleEarth™



A New Potential Fields Method, Supplementing Gravity & Magnetics

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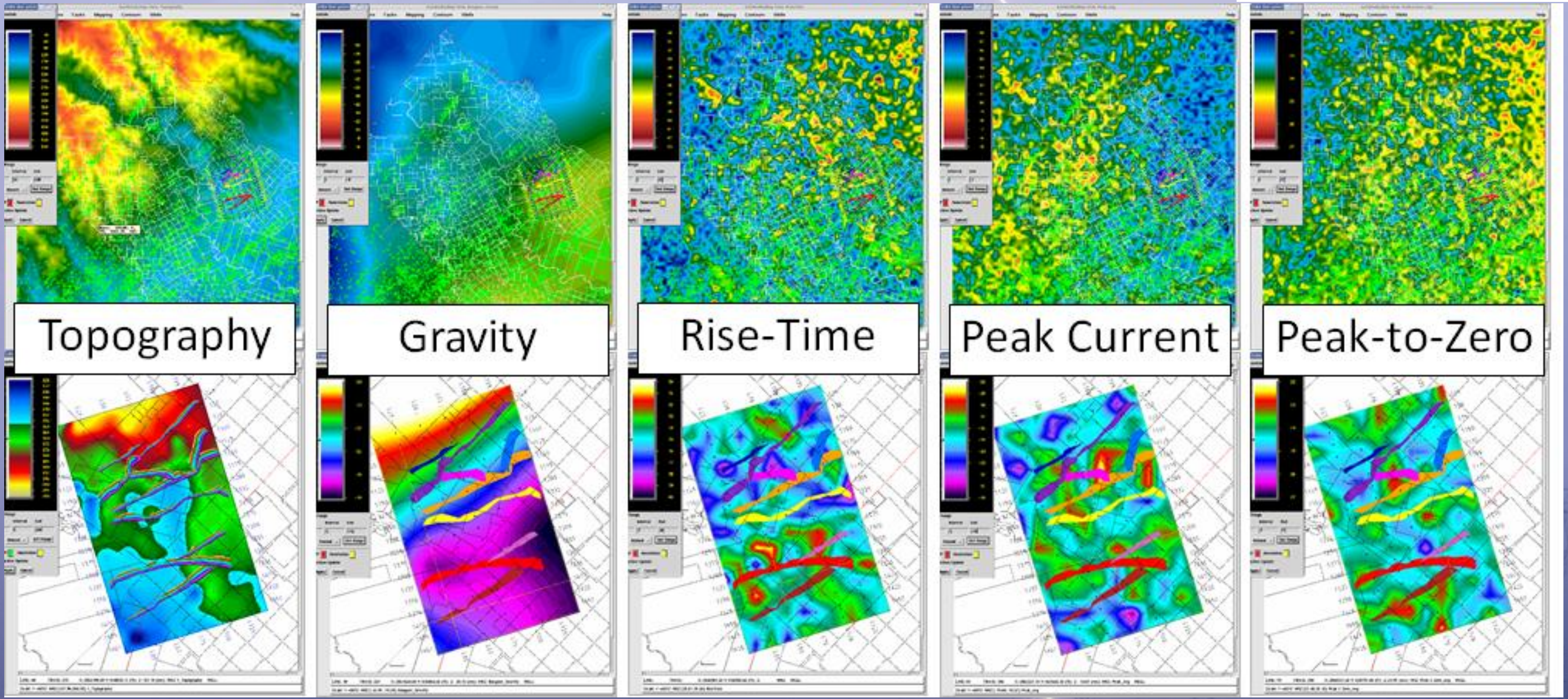
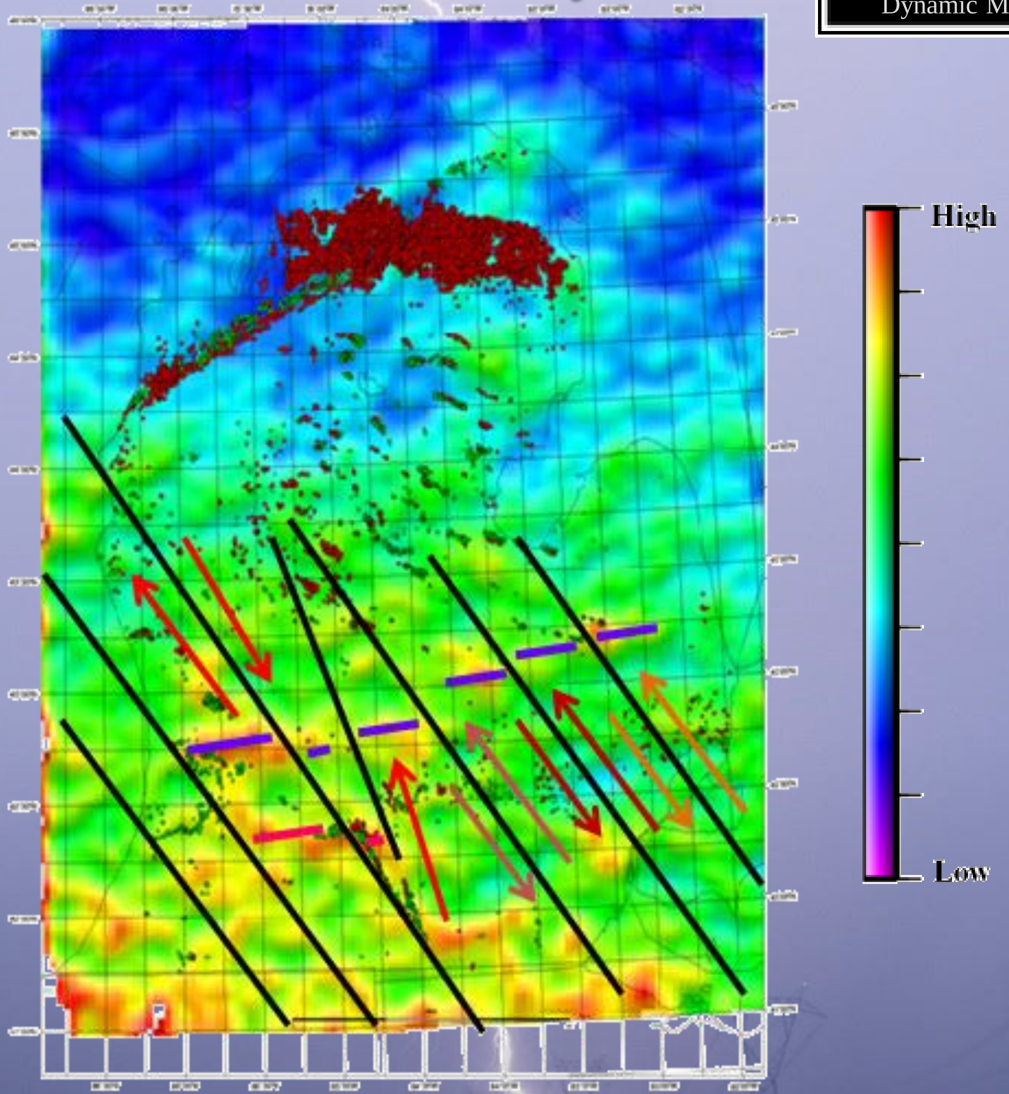
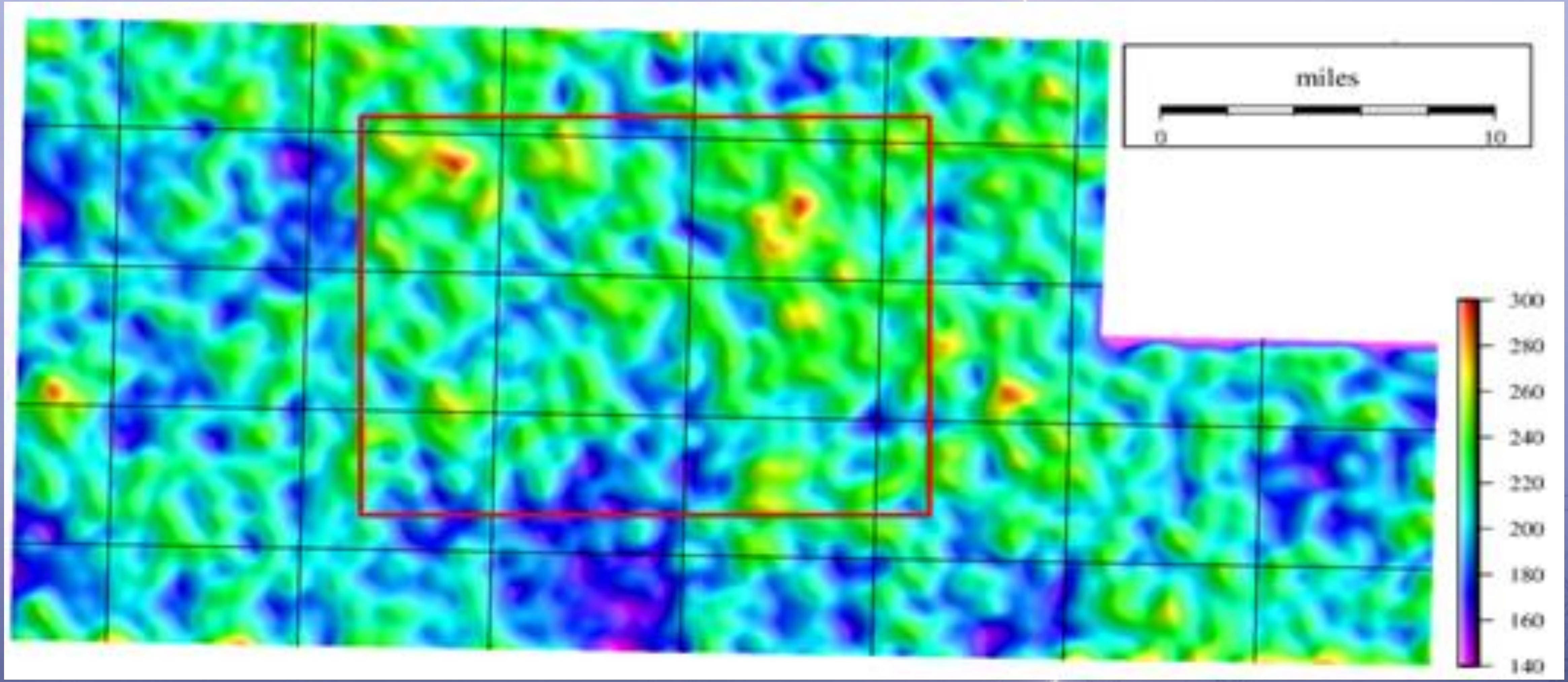


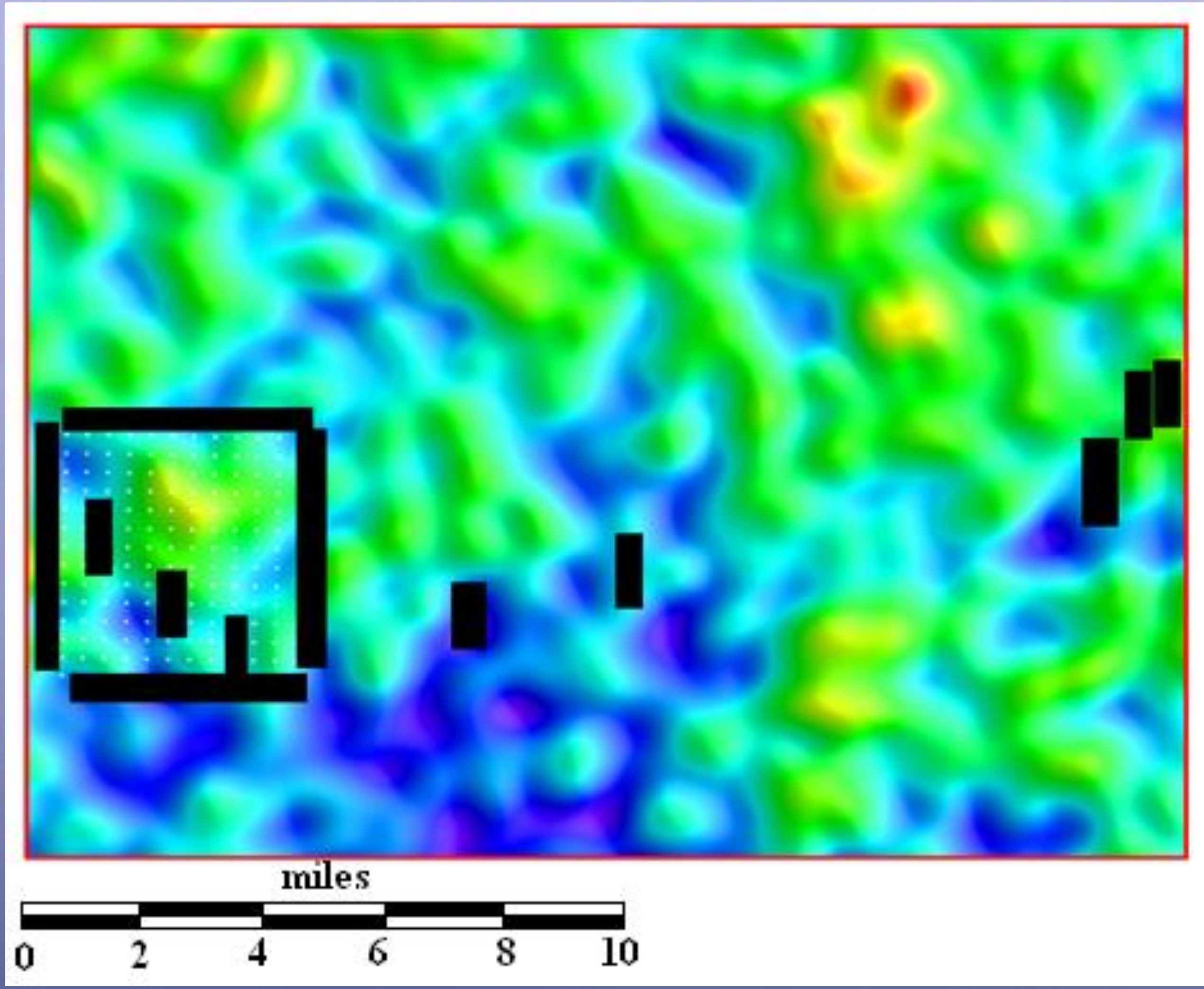
Michigan Basin Topography & Strike Density

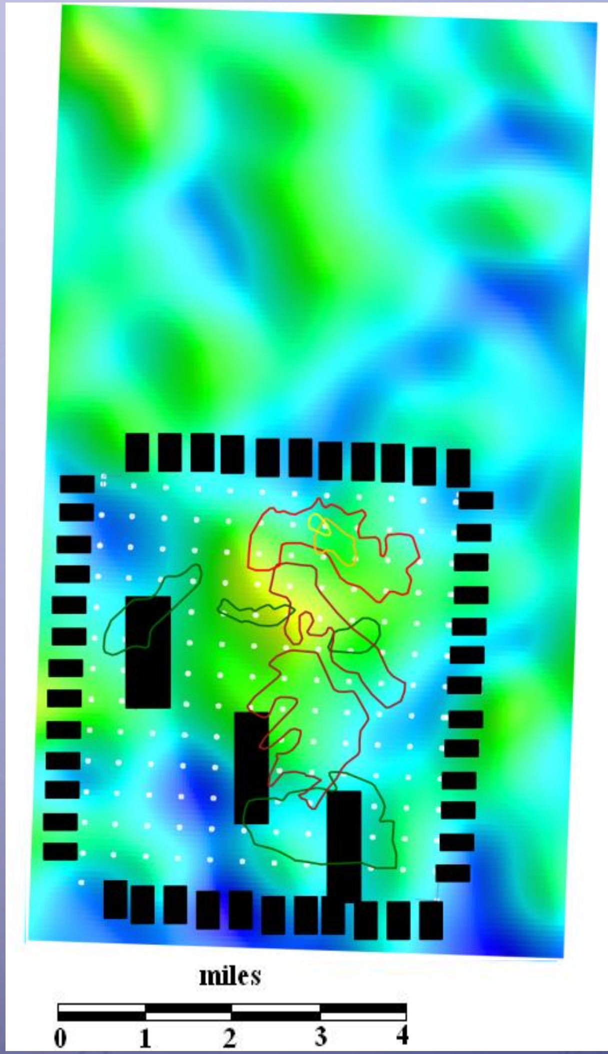


Lightning Analysis Gives Quicker Regional Overview

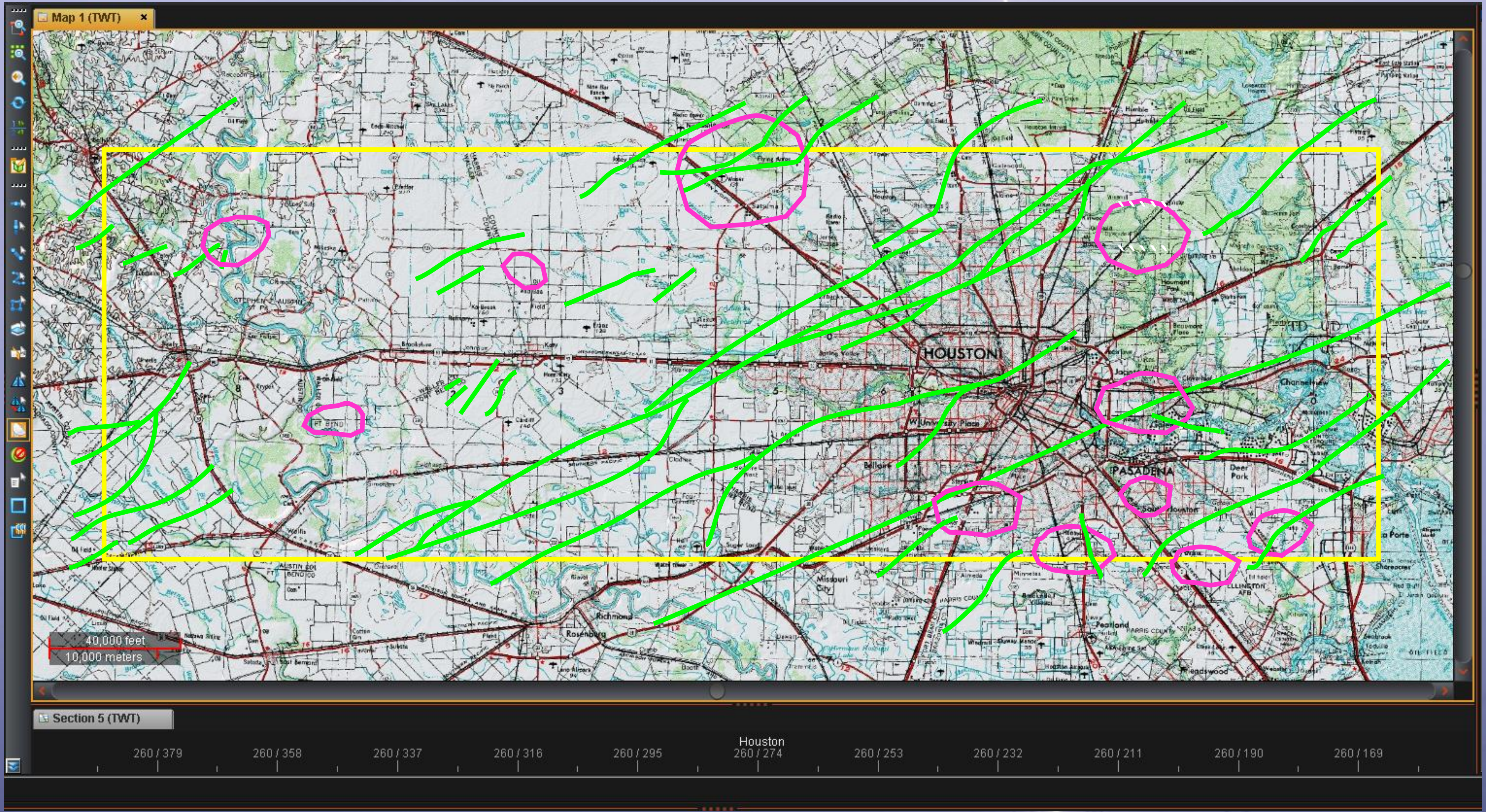


More details at Play Fairway & Prospect Scales





Imagine collecting a 3-D seismic survey here!



USACE George Bush Park Pipeline Animation

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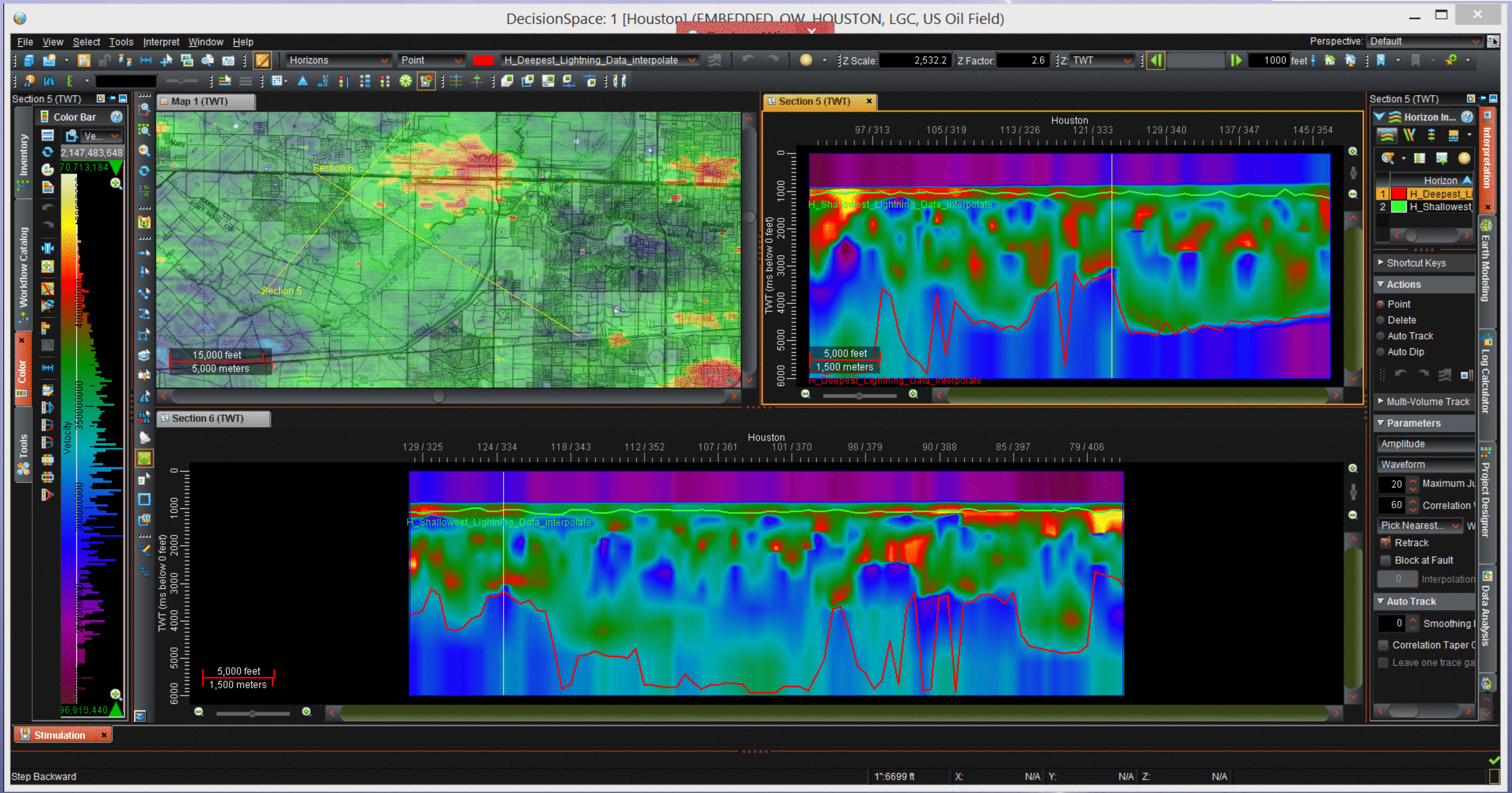
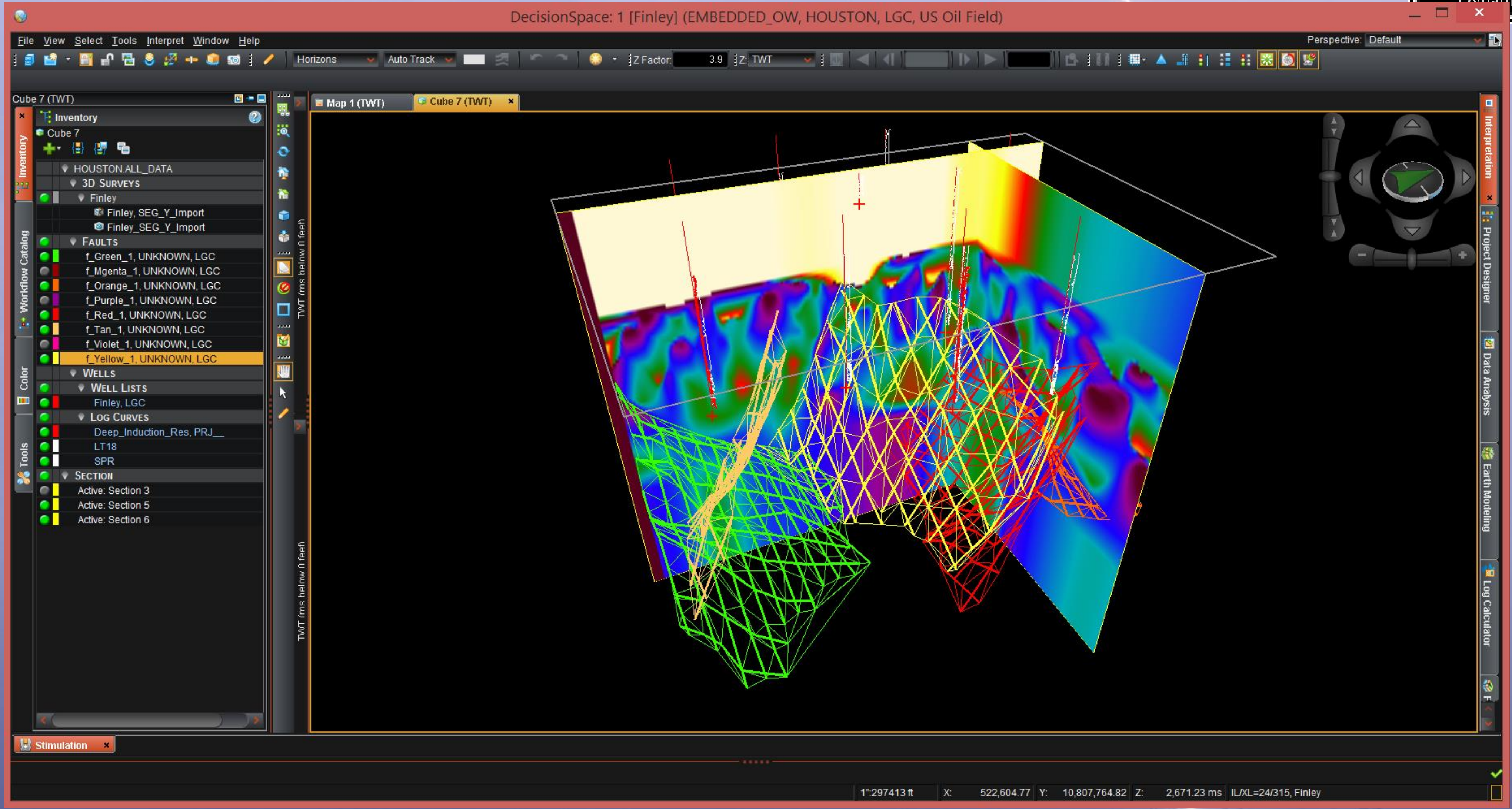


Texas Resistivity Fault Interpretation - 1



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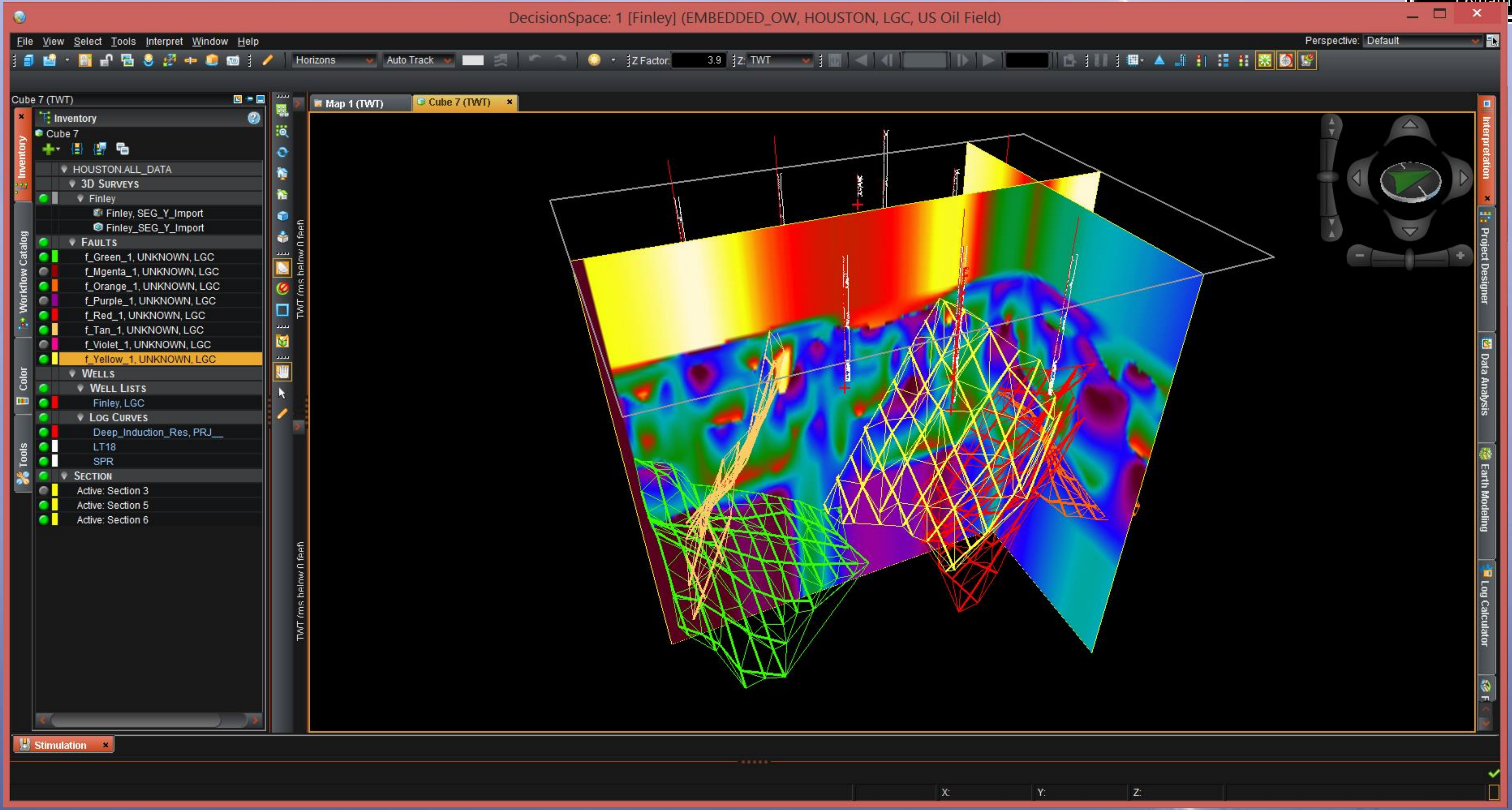
Texas Resistivity Fault Interpretation - 2



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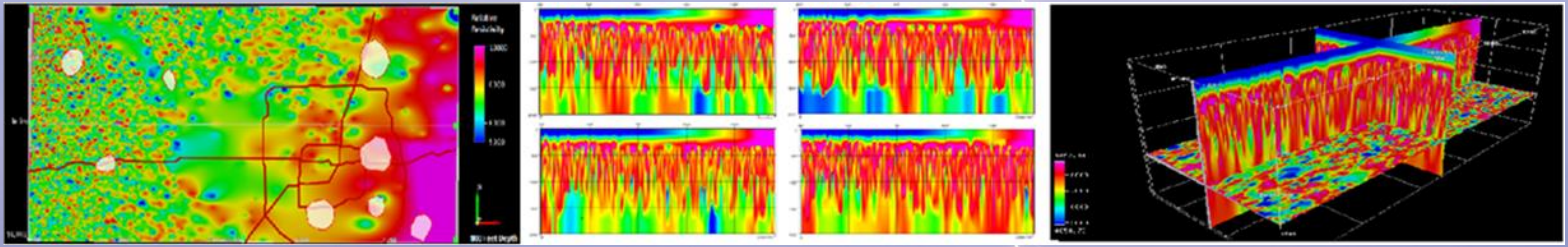
NSEM and Resistivity Volumes are a Technology Breakthrough



- Attribute maps identify lineaments related to faulting
- Resistivity volumes provide an independent view of geology
- Resistivity volumes can be created to match 3-D geometry
- We anticipate a merger of resistivity volumes and lithology predictions

Questions & Answers & Discussion

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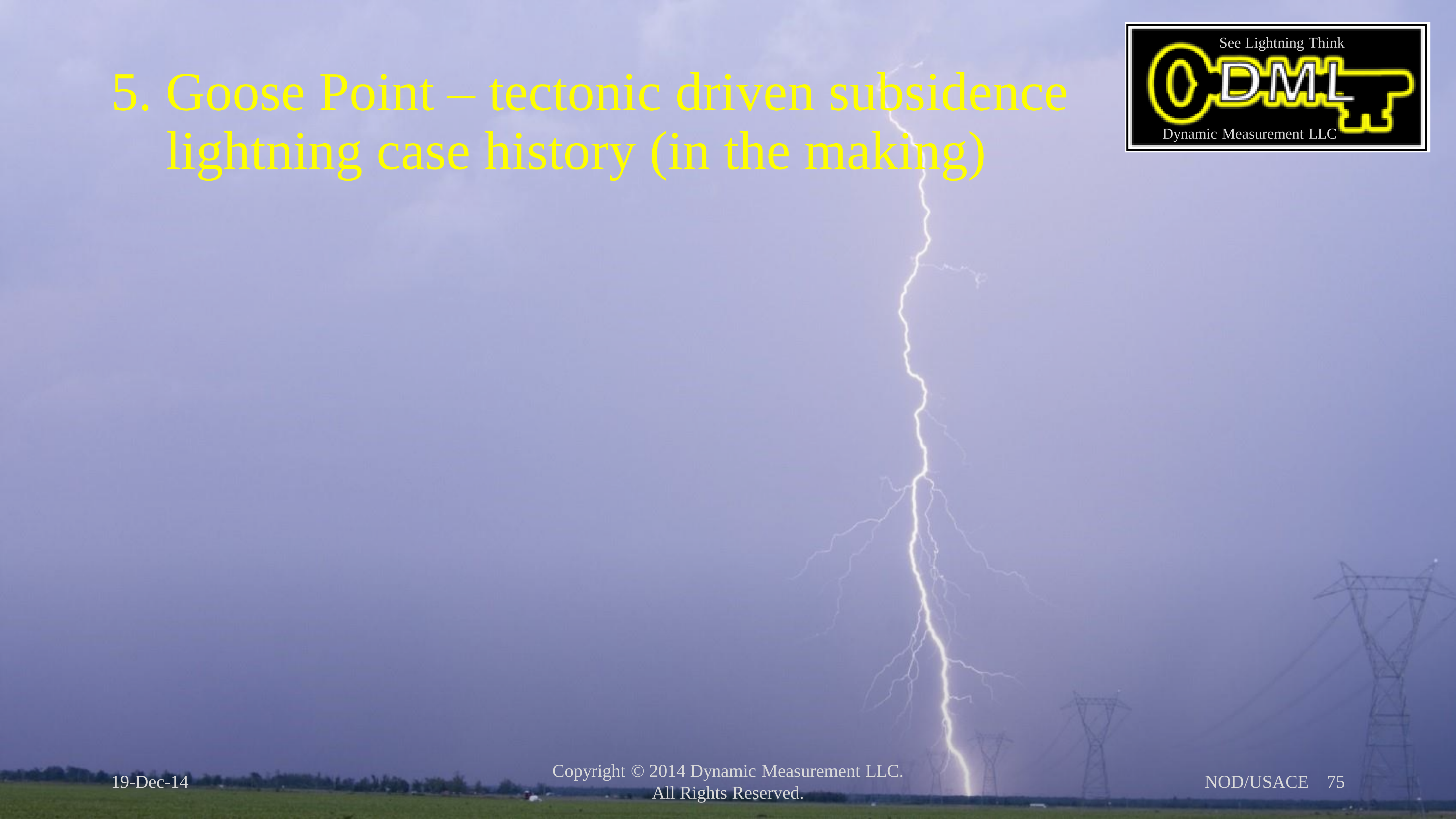
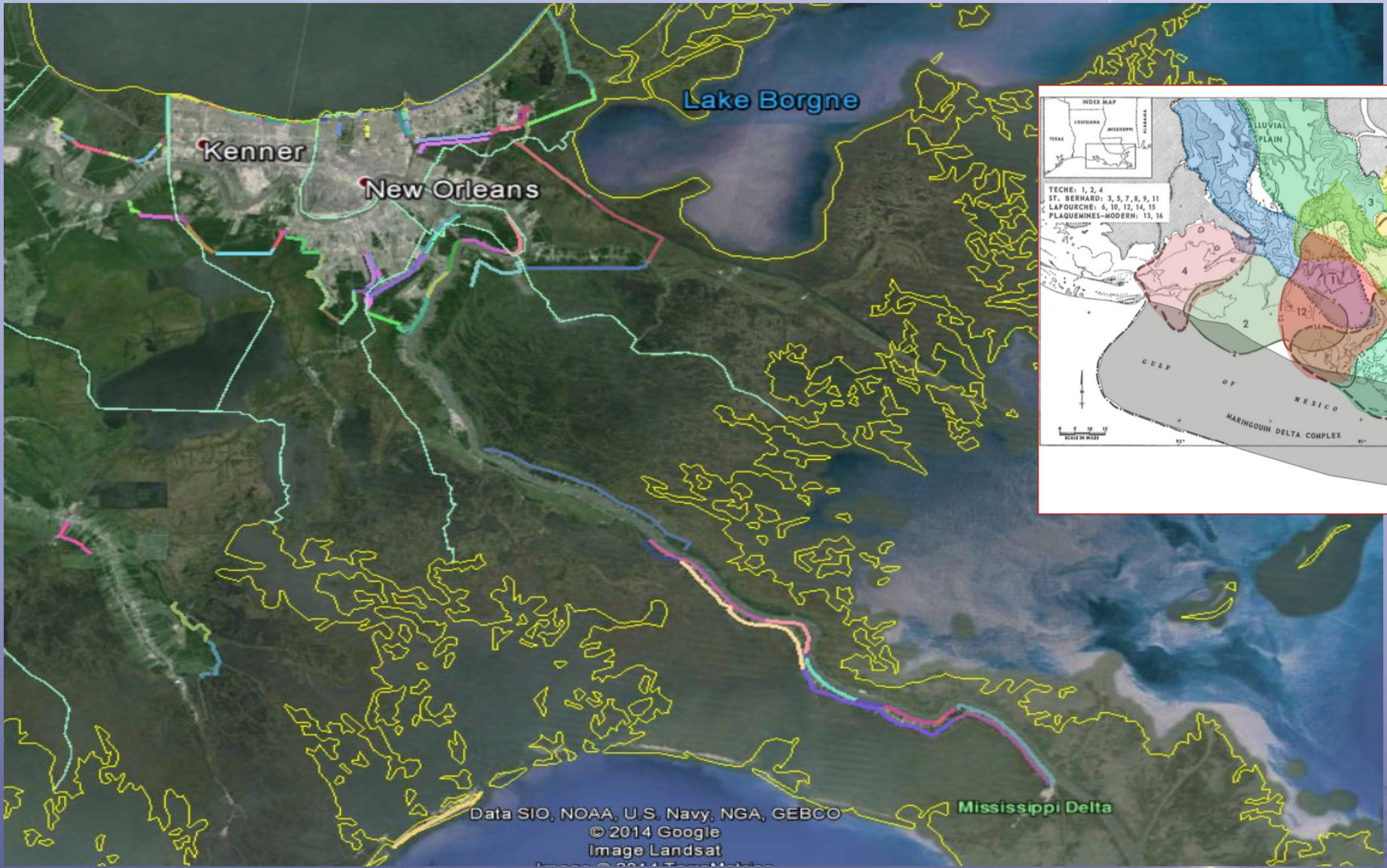
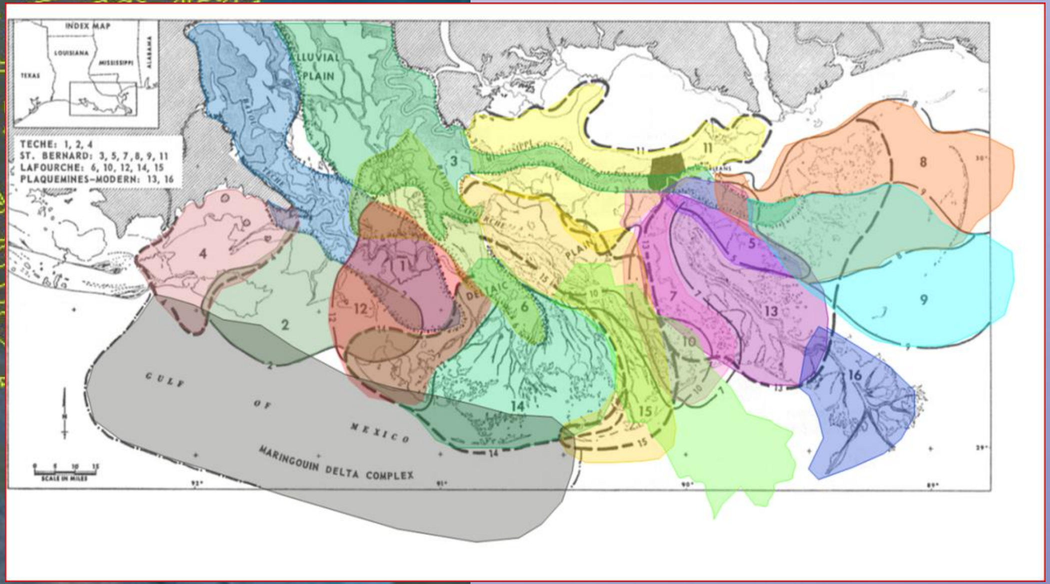
5. Goose Point – tectonic driven subsidence lightning case history (in the making)

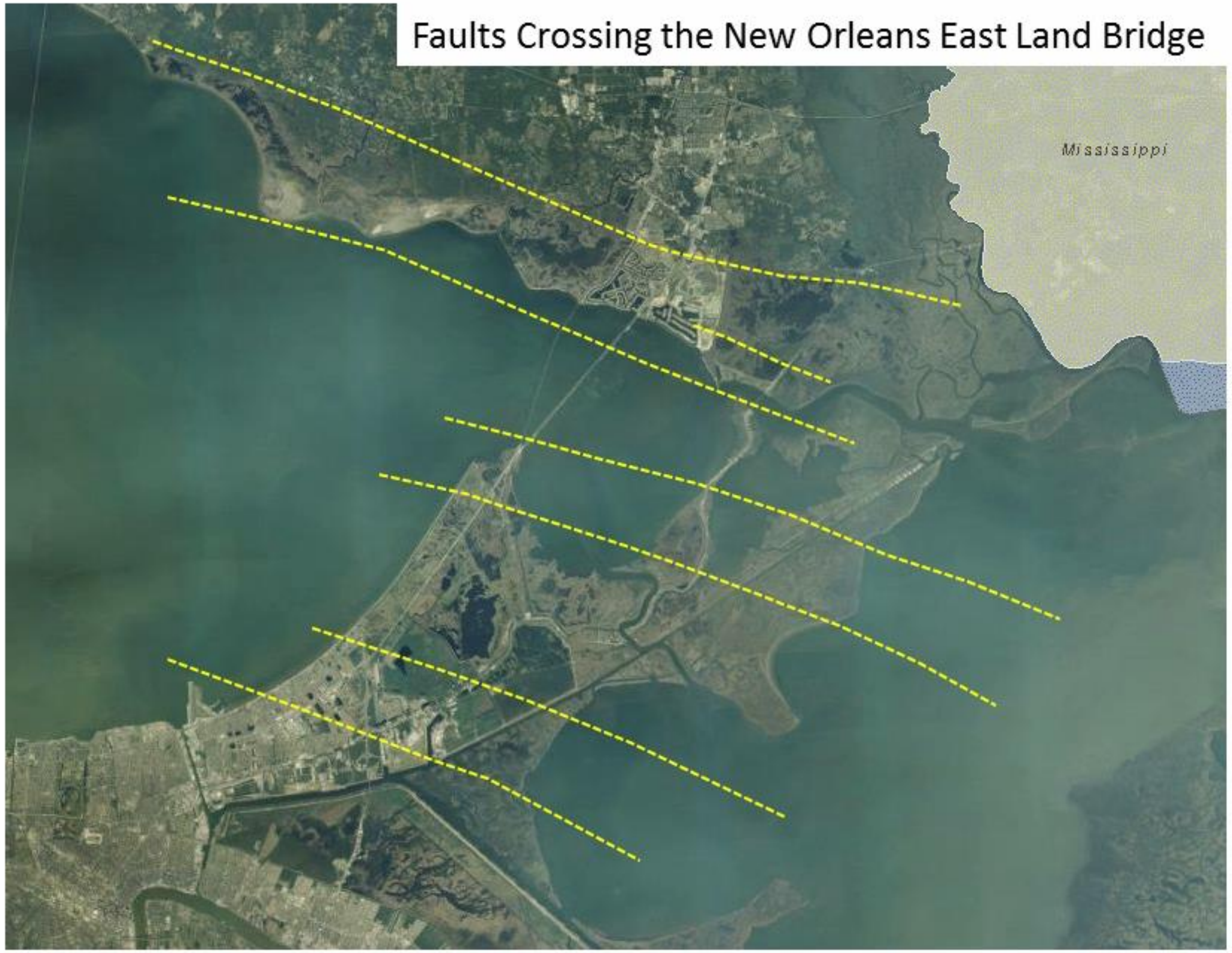


SLFPA-W Levees and Deltas





Land Bridge Subsidence and Faulting



Sedimentation Growth Cycles

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Delta Cycle

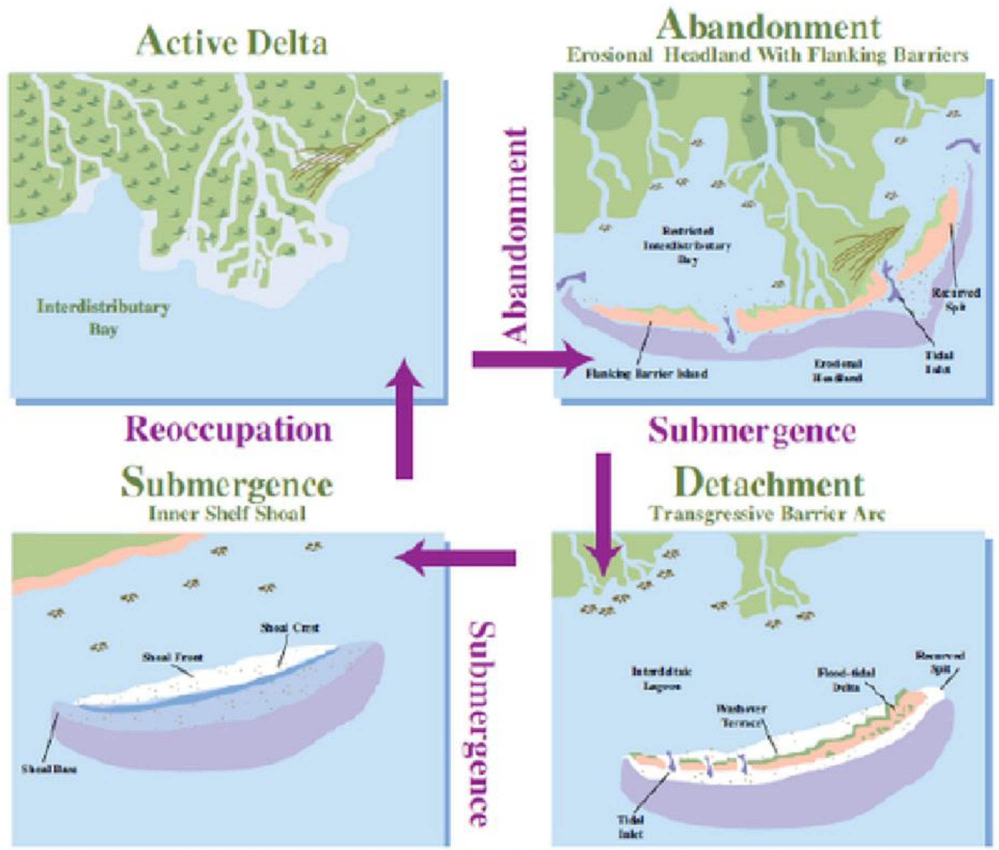
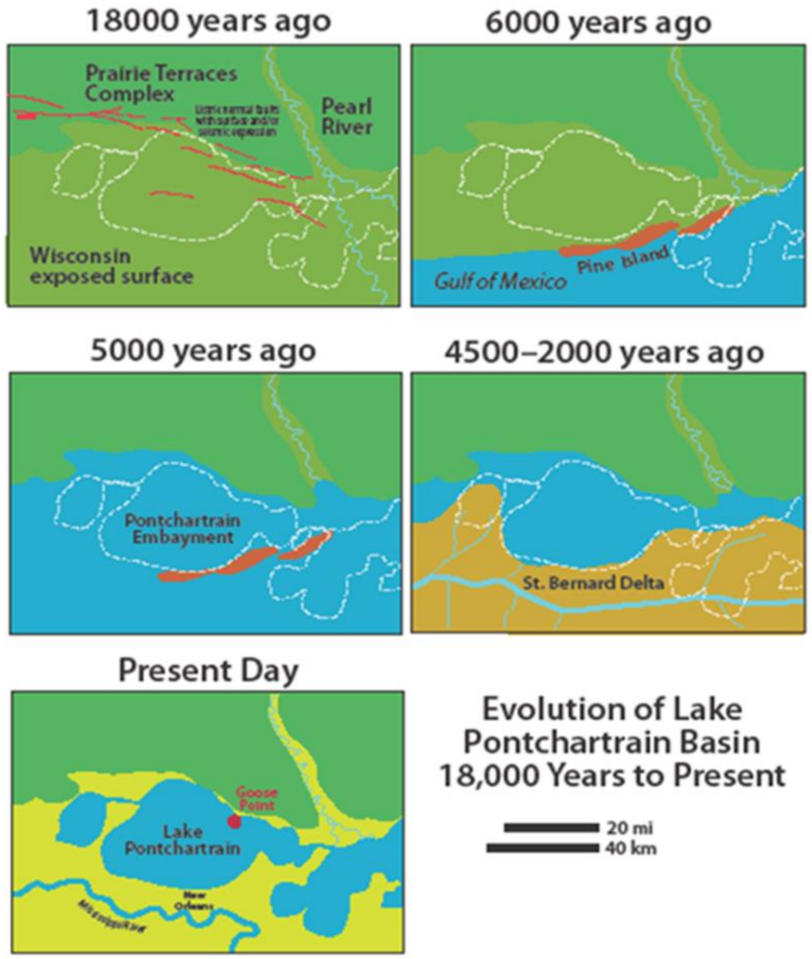


Figure 2. Three stage evolution of a deltaic barrier island. (Barrier Islands Educators Guide: model from Penland and Boyd, 1981.)

Penland, S., Boyd, R., 1981. Shoreline changes on the Louisiana barrier coasts. IEEE Oceans, Marine Technology Society. pp. 209-219.

http://mississippidelta.wmwikis.net/Isles+Dernieres+-+Trinity+Island

Coastal Evolution



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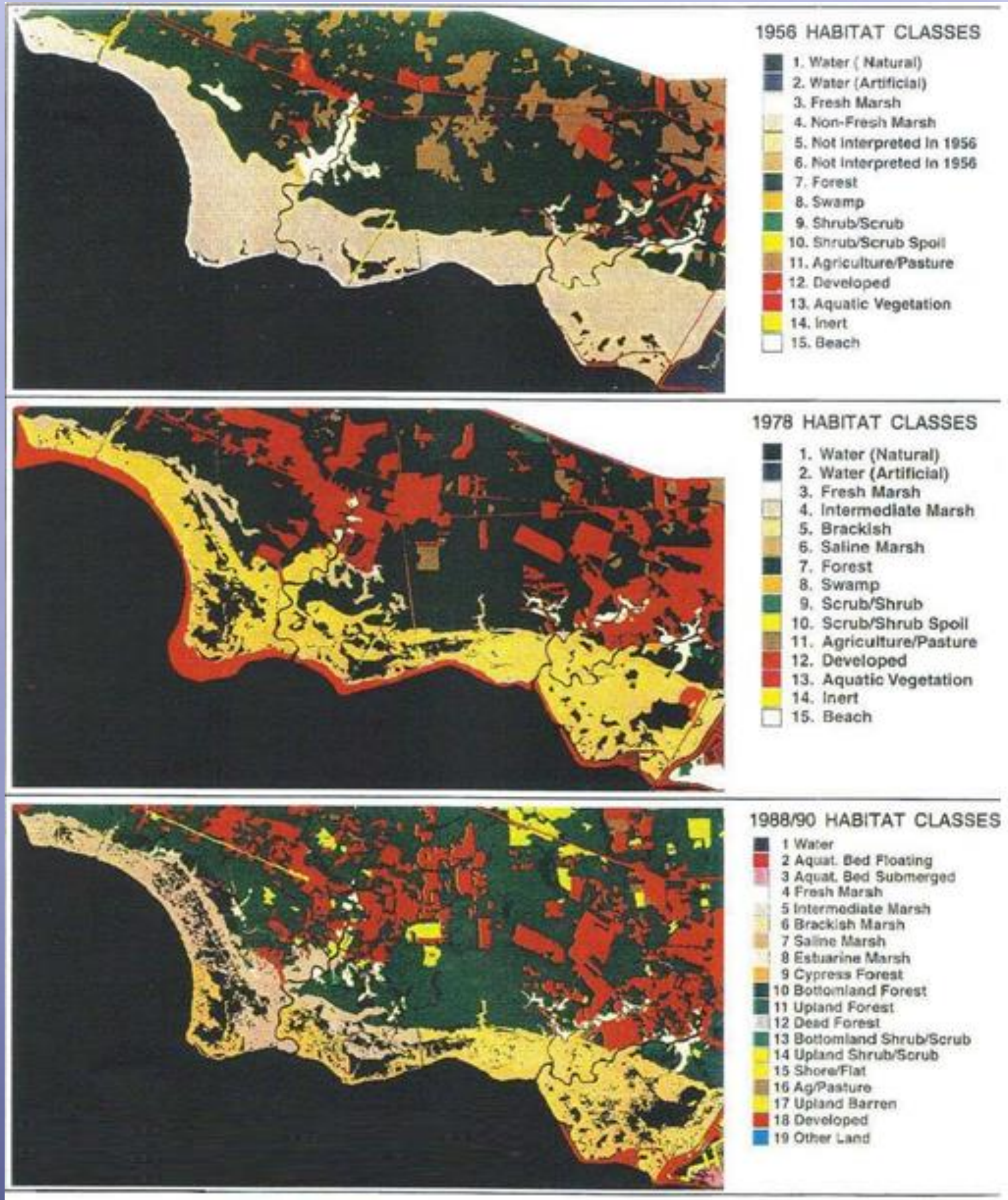
Faults disrupt the surface all across Louisiana



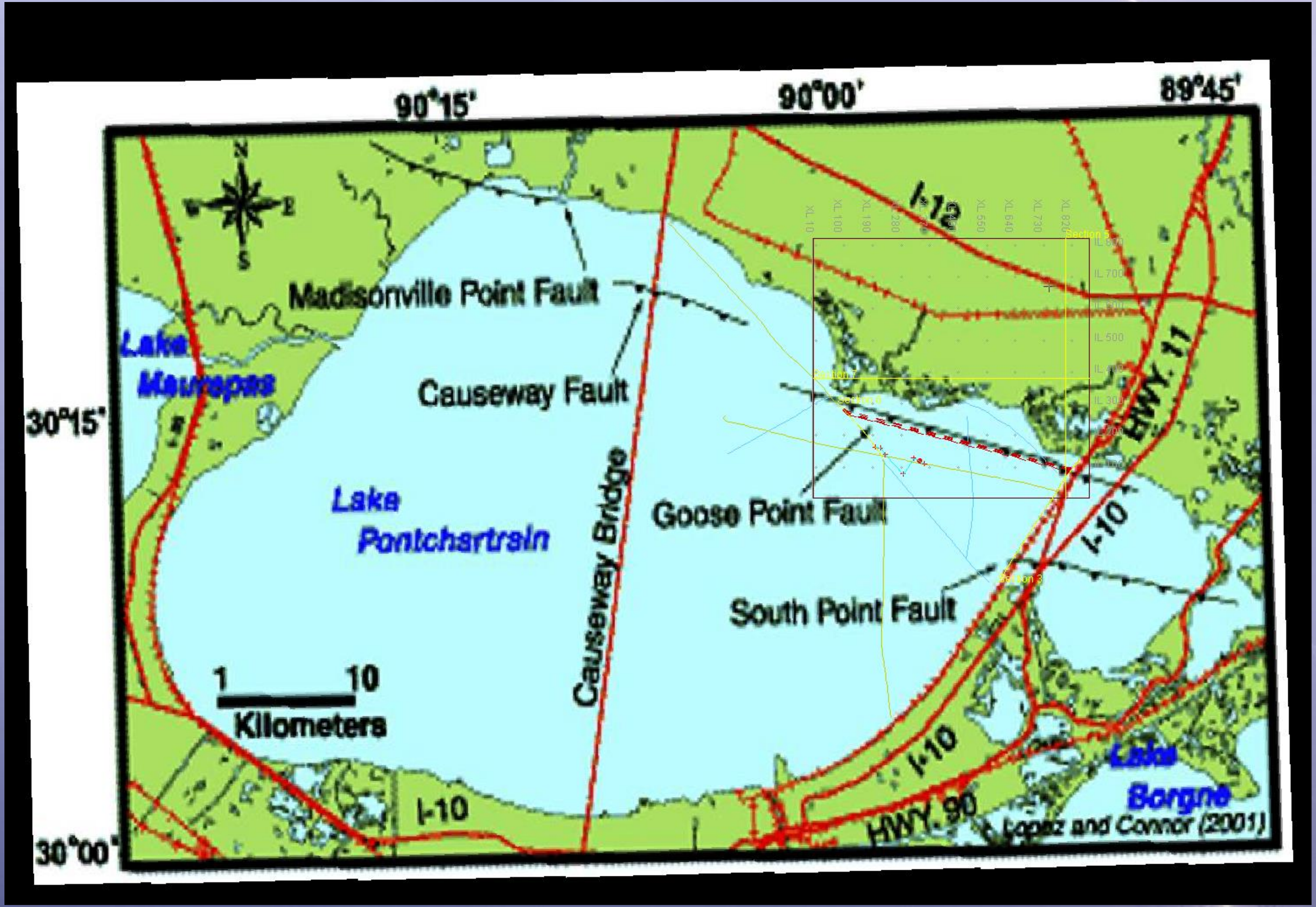
1956

1978

1988-90

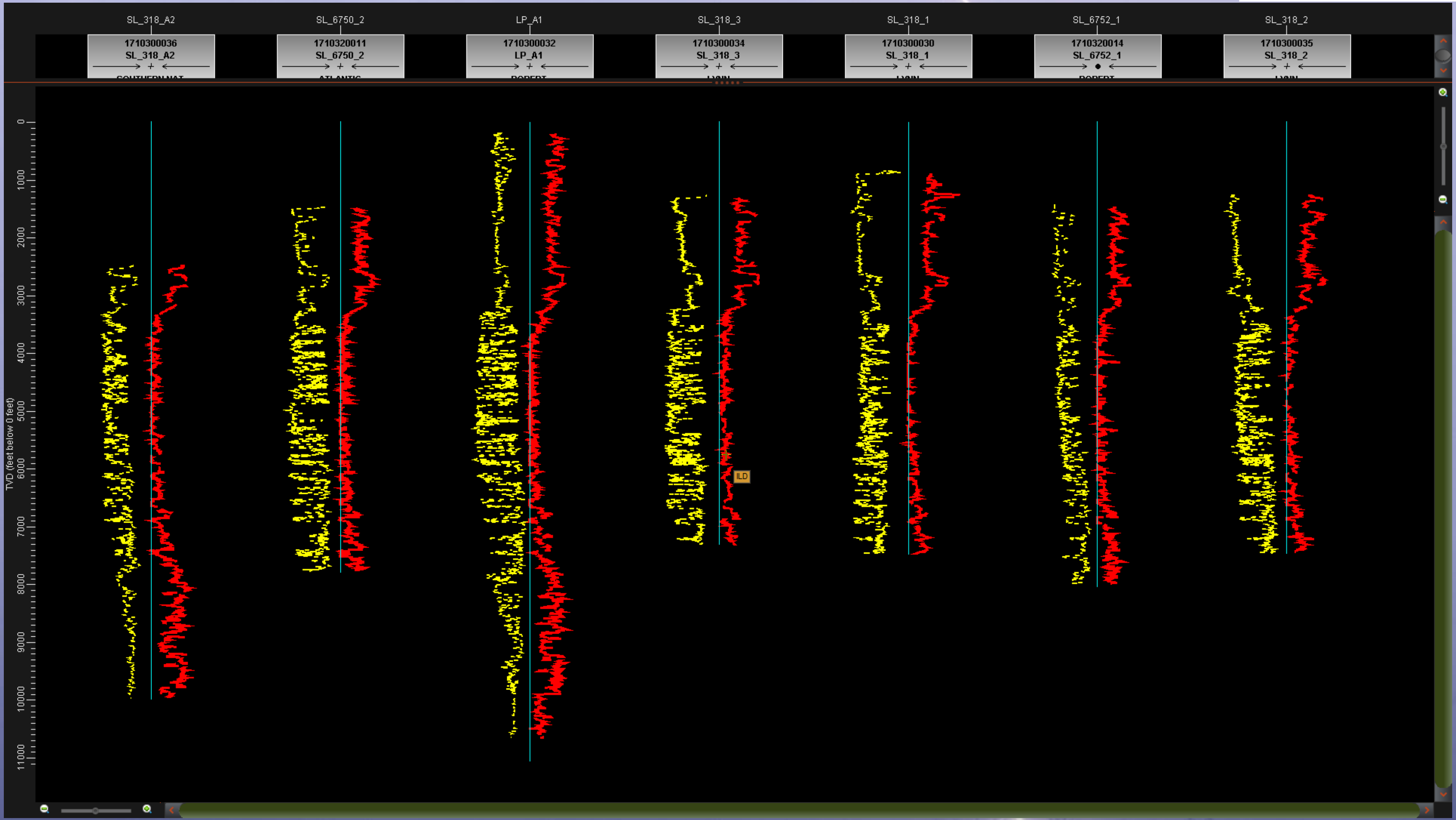
Landscape changes rapidly enough to be noticed

DML is creating a Goose Point Case History



- Wells and Logs
- Sparker Seismic
- Lighting Attributes
- Resistivity Volumes
- All other relevant data

Wells and Logs



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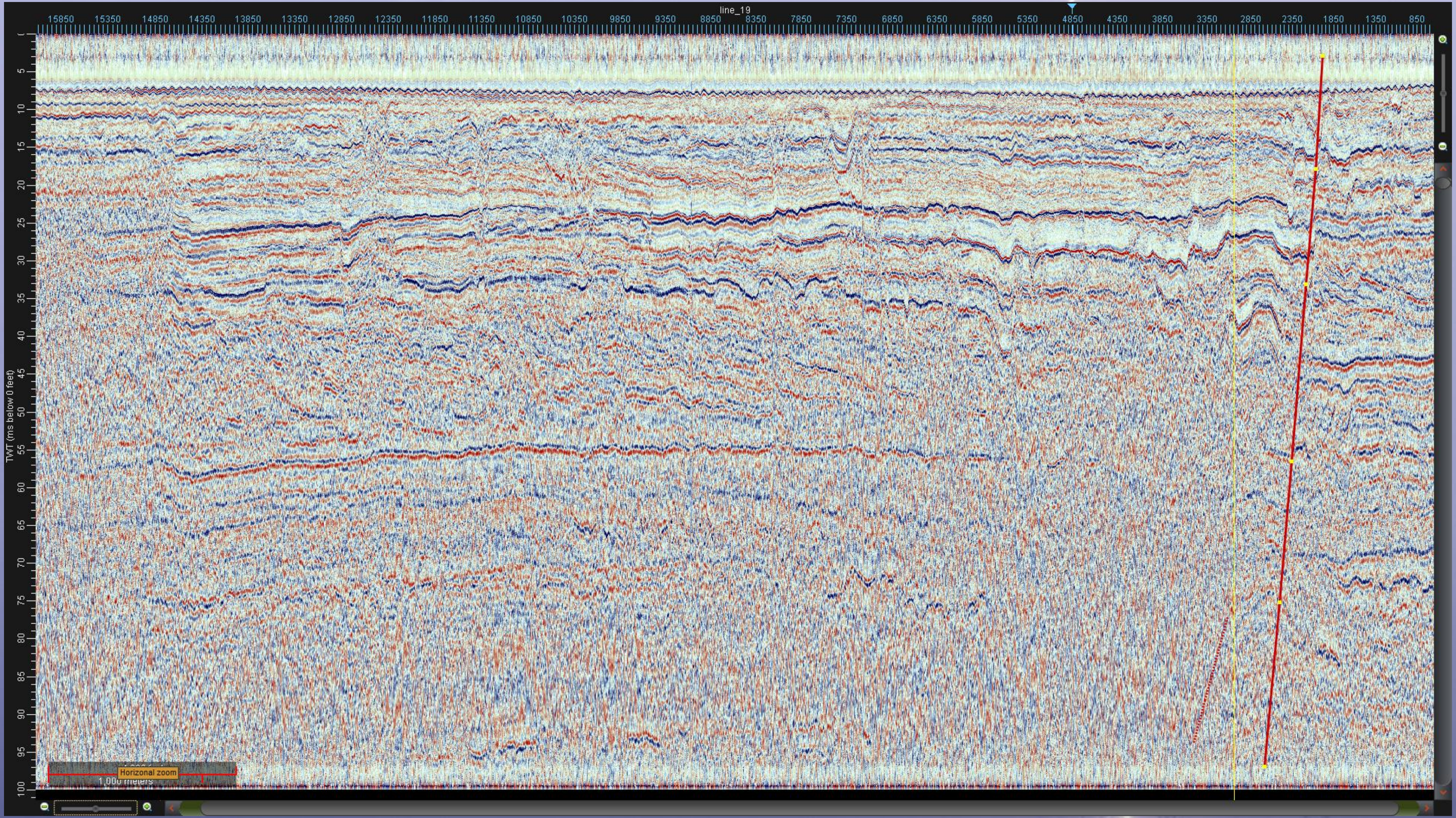
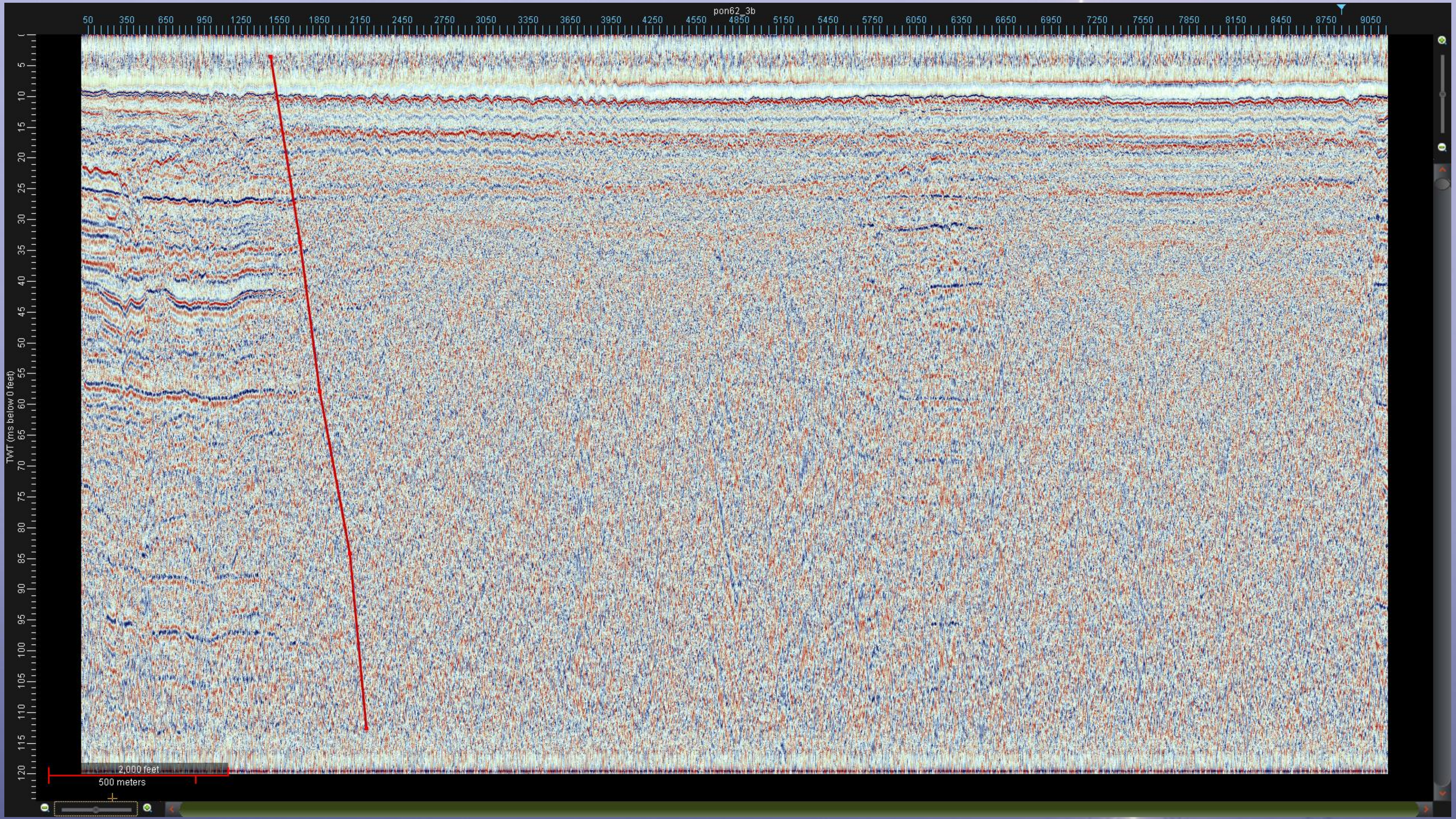
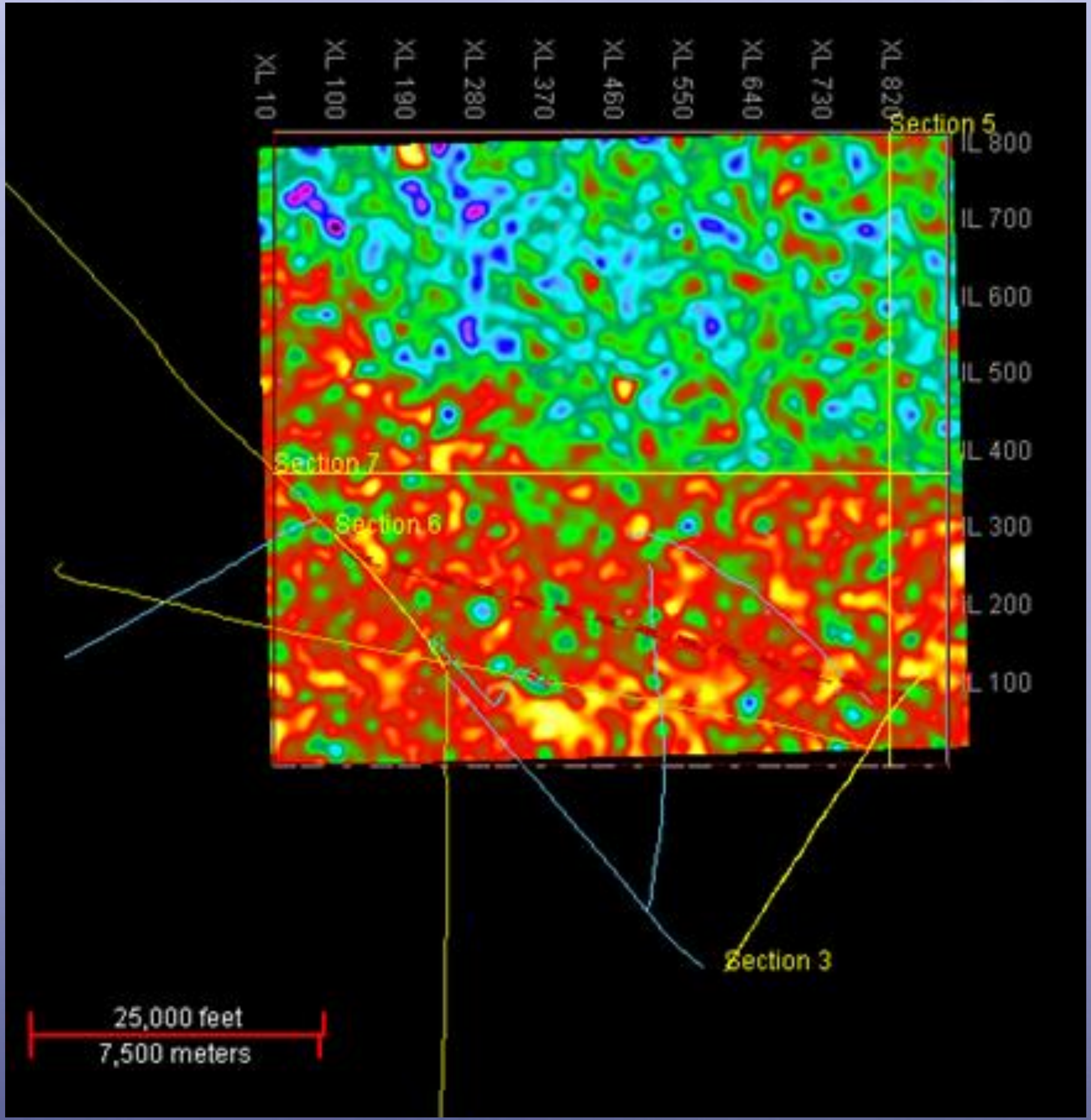
Sparker Line 19



Sparker Line 3b





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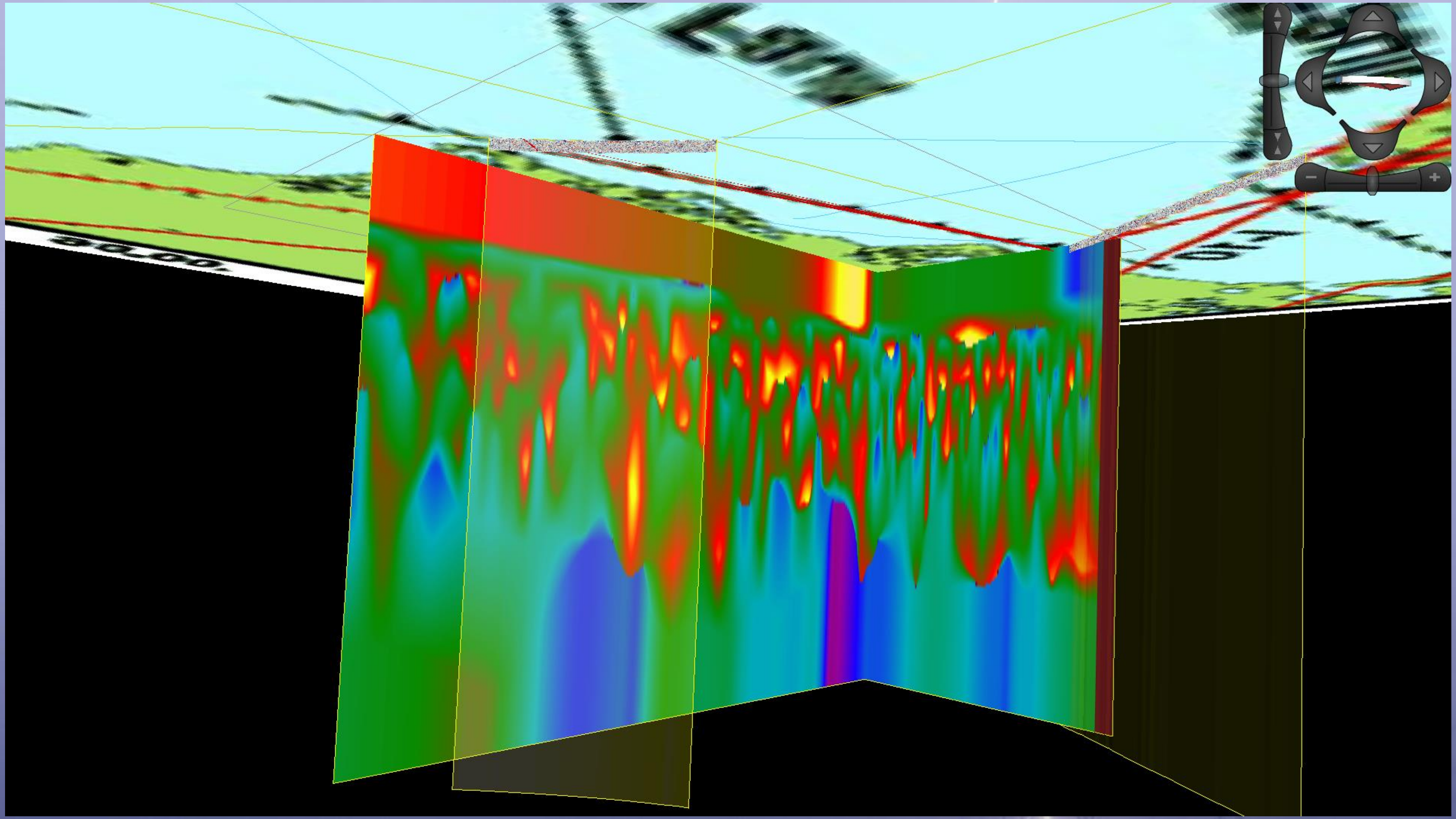
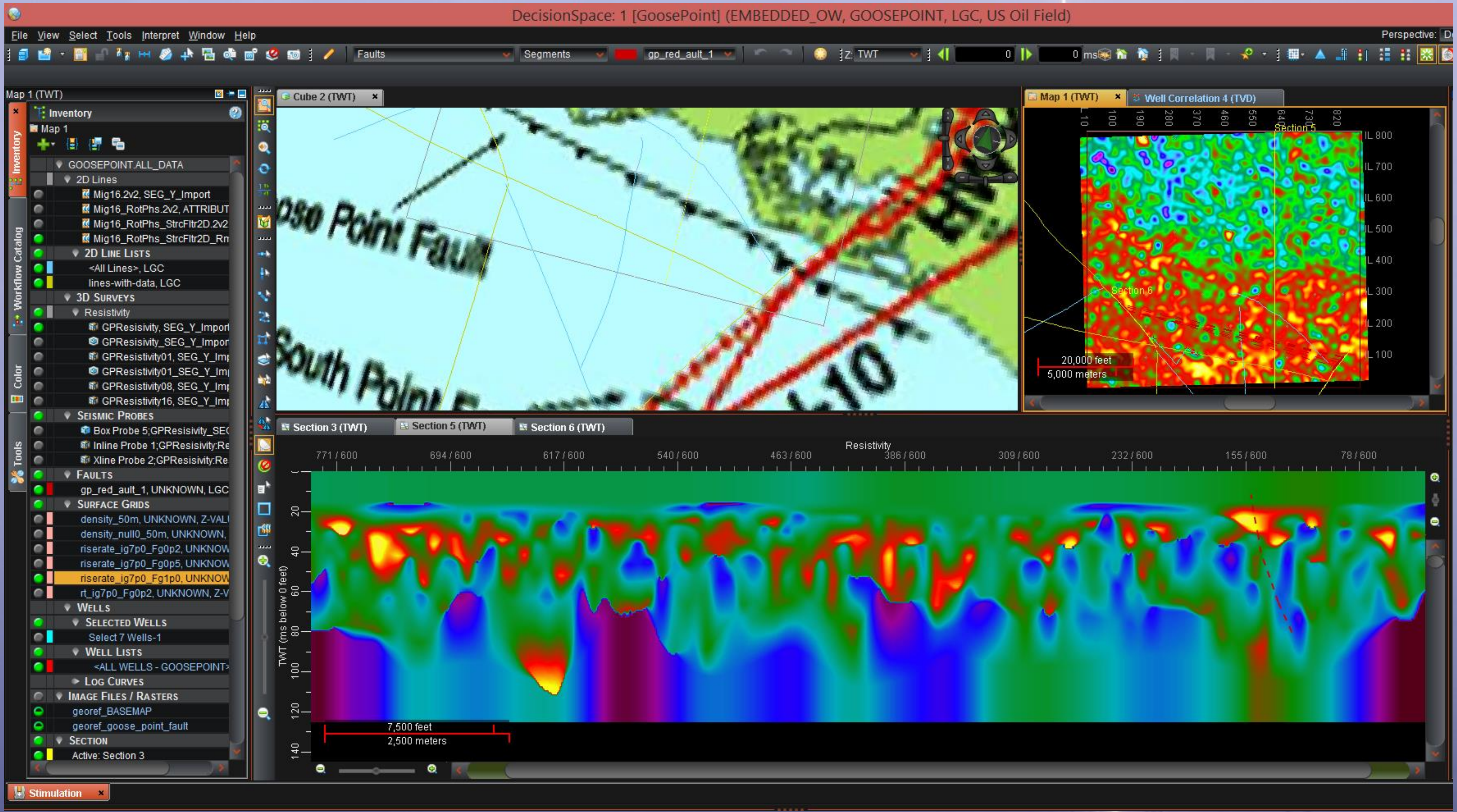
Rate of Rise-Time Lightning Attribute

Resistivity Volume Cross-Sections



We hope the Corps will seek regular updates on the development of the Goose Point Case History



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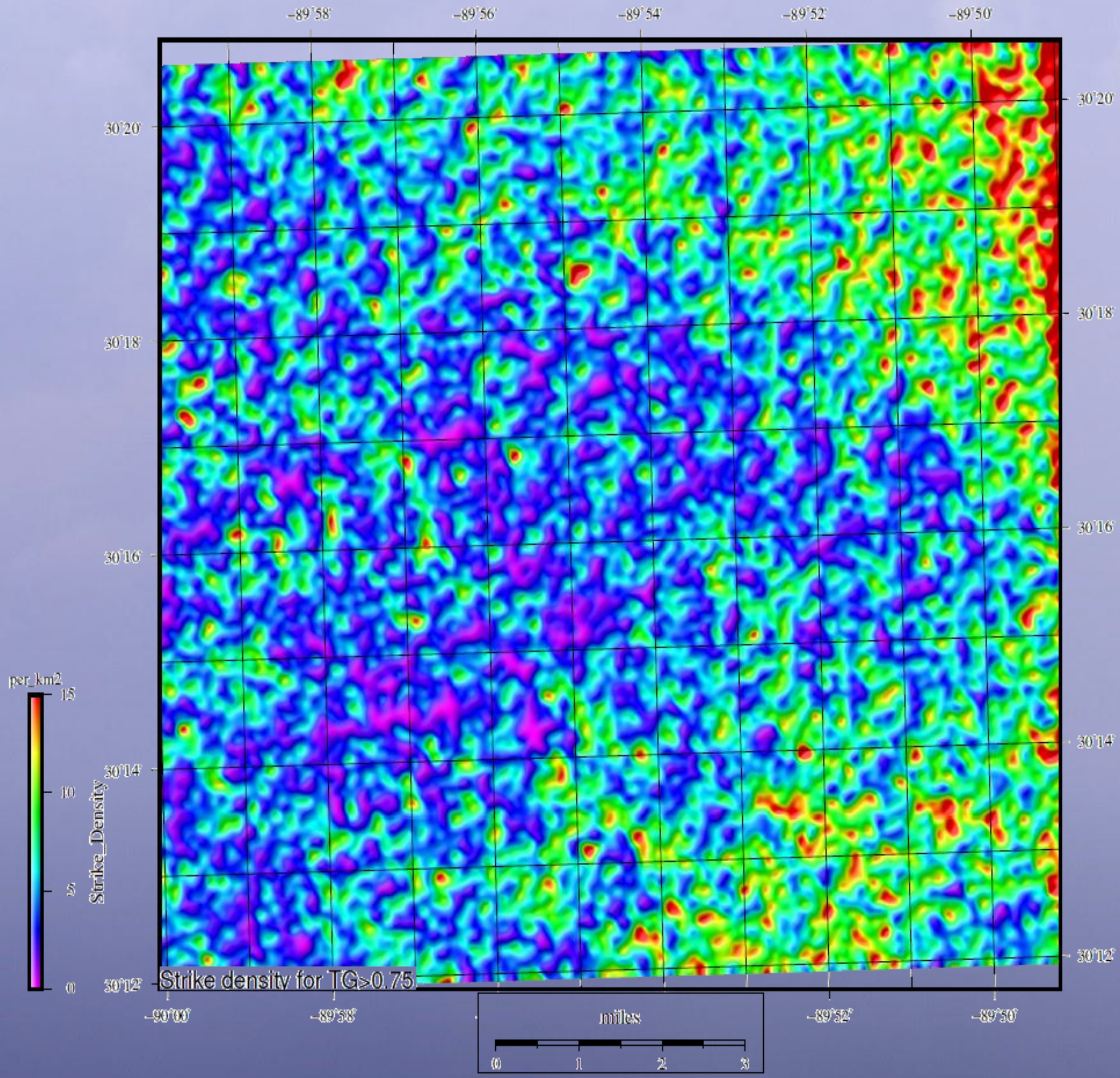
Strike Density



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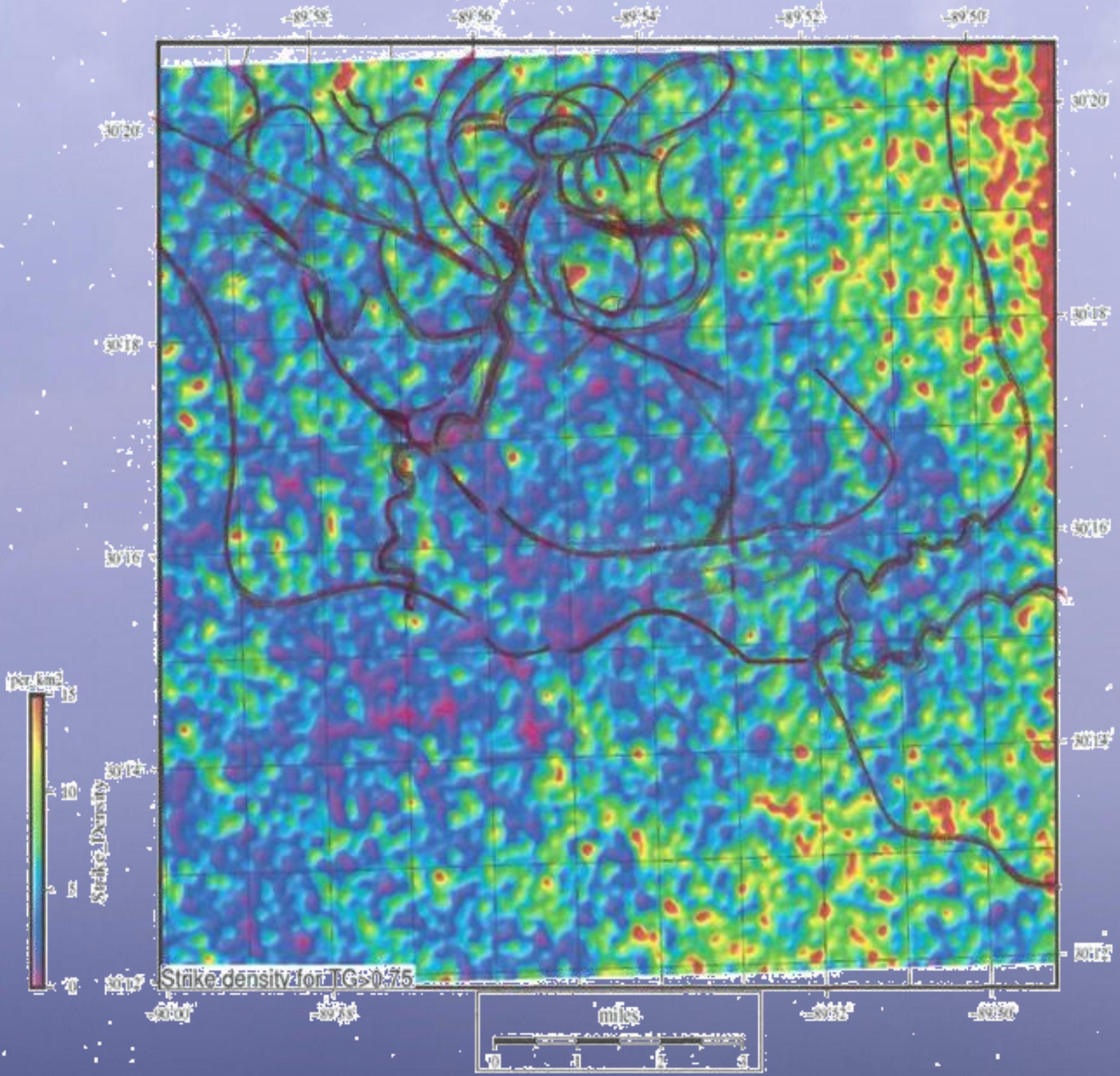
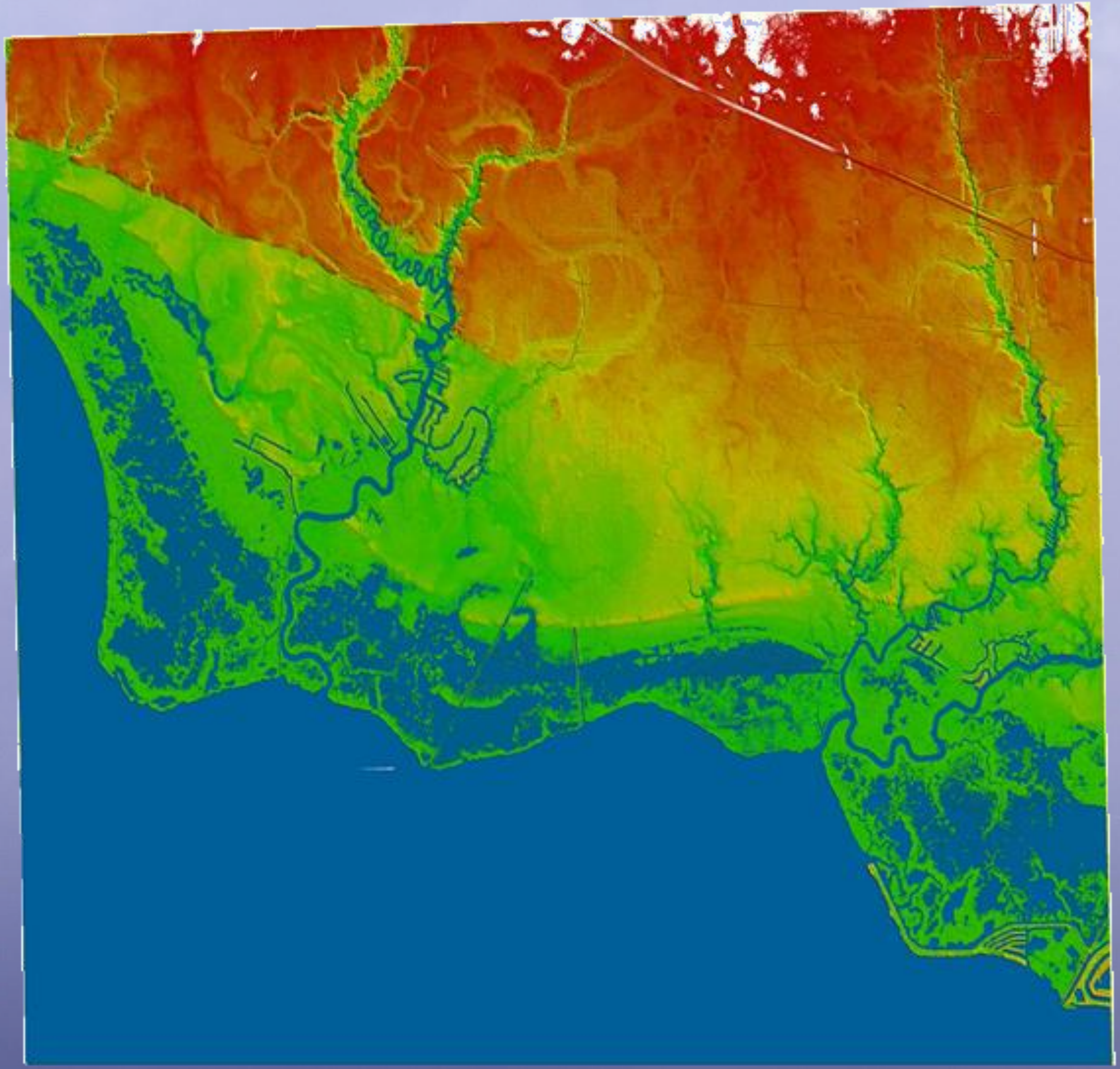
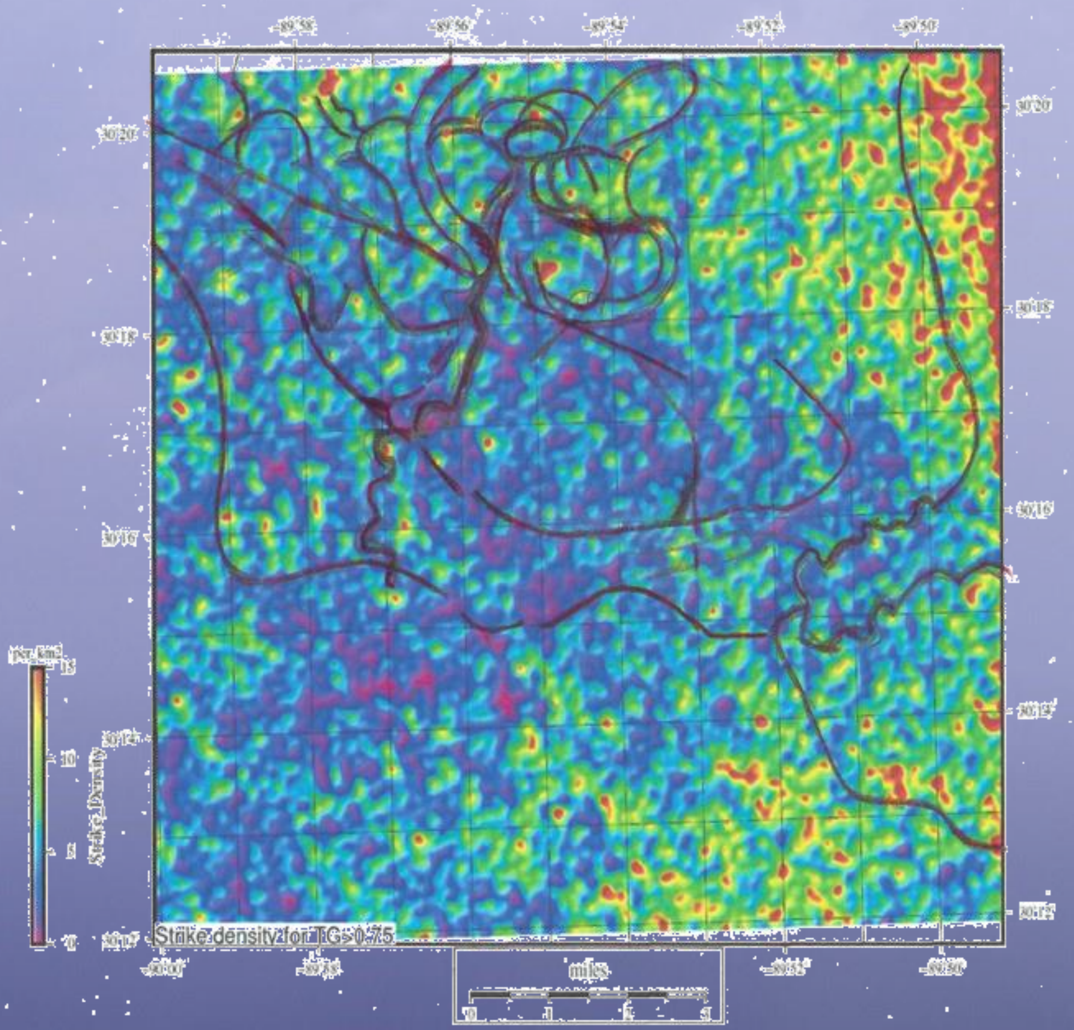


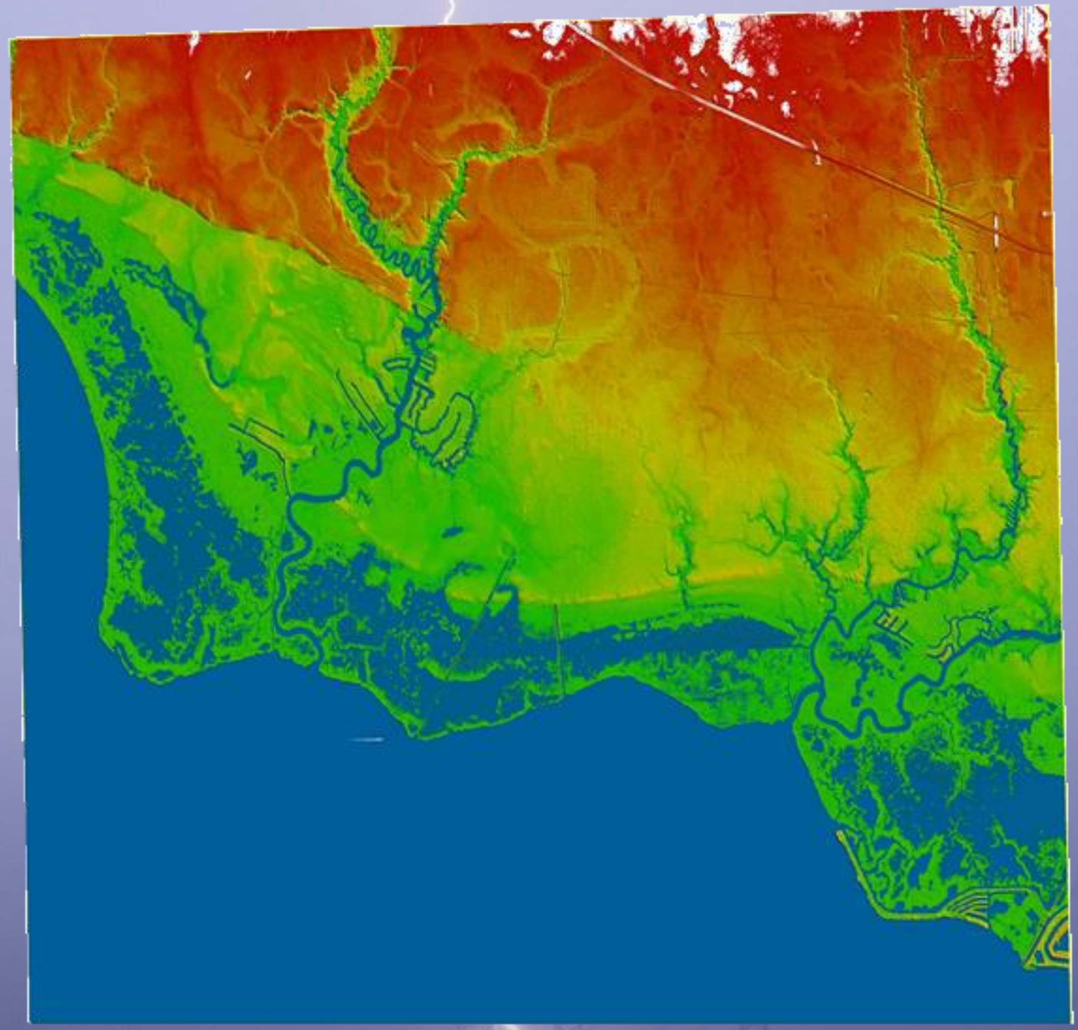
Interpretation of Strike Density



LIDAR over the same area

Side-by-Side Comparison





Questions & Answers & Discussion

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What we have covered:

1. NSEM - A new technology to identify geologic hazards
2. The meteorology behind lightning databases
3. Calculating resistivity volumes from lightning databases
4. Examples of using lightning databases to map geology
5. Goose Point – tectonic driven subsidence lightning case history

See Lightning, Think DML

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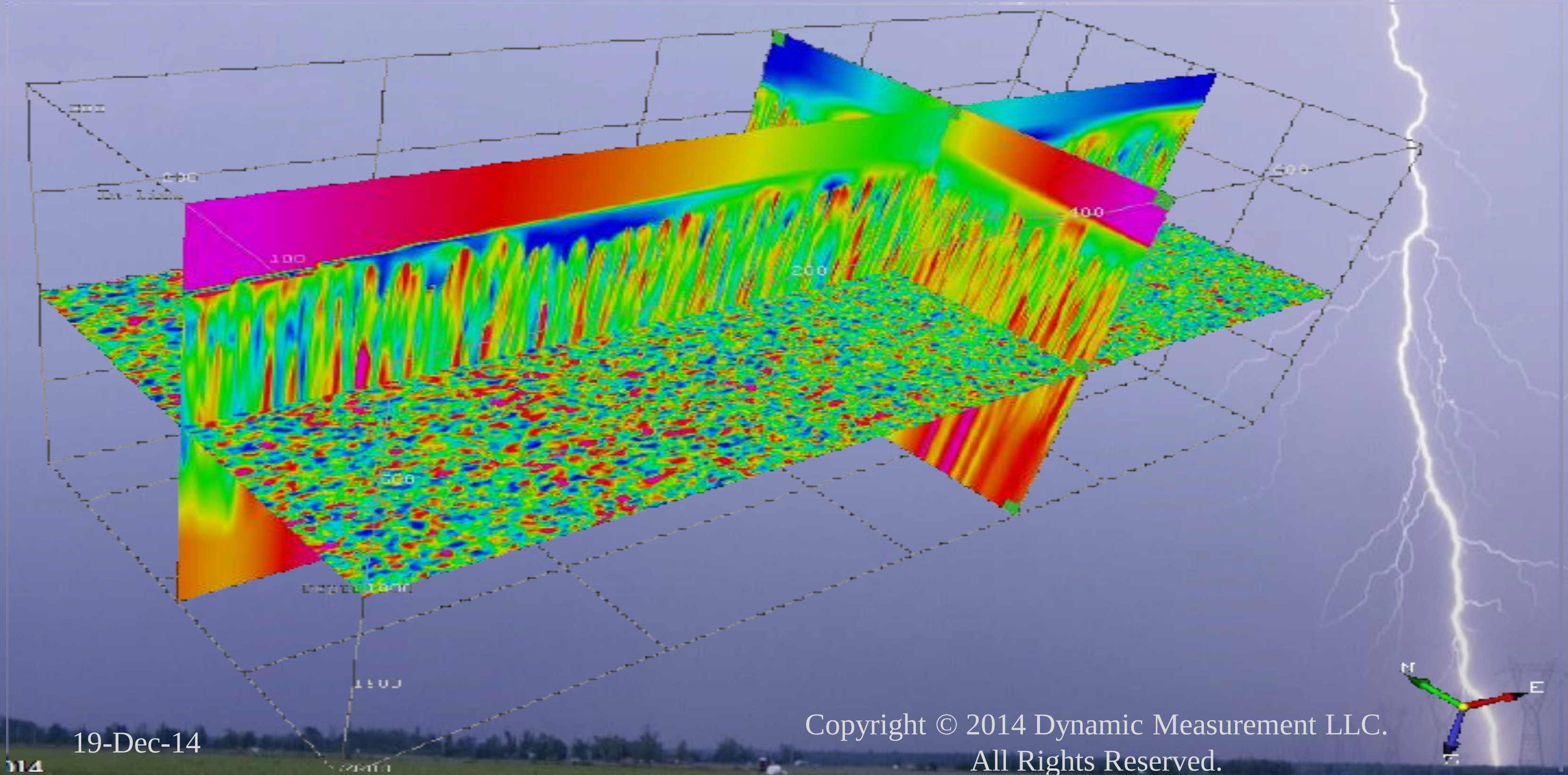
  Baton Rouge, LA 70835

Find out more at

http://www.dynamicmeasurement.com/USACE

http://www.dynamicmeasurement.com/TAMU

Thank You!



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