Deriving Exploration Maps and Rock Property Volumes from Lightning Databases

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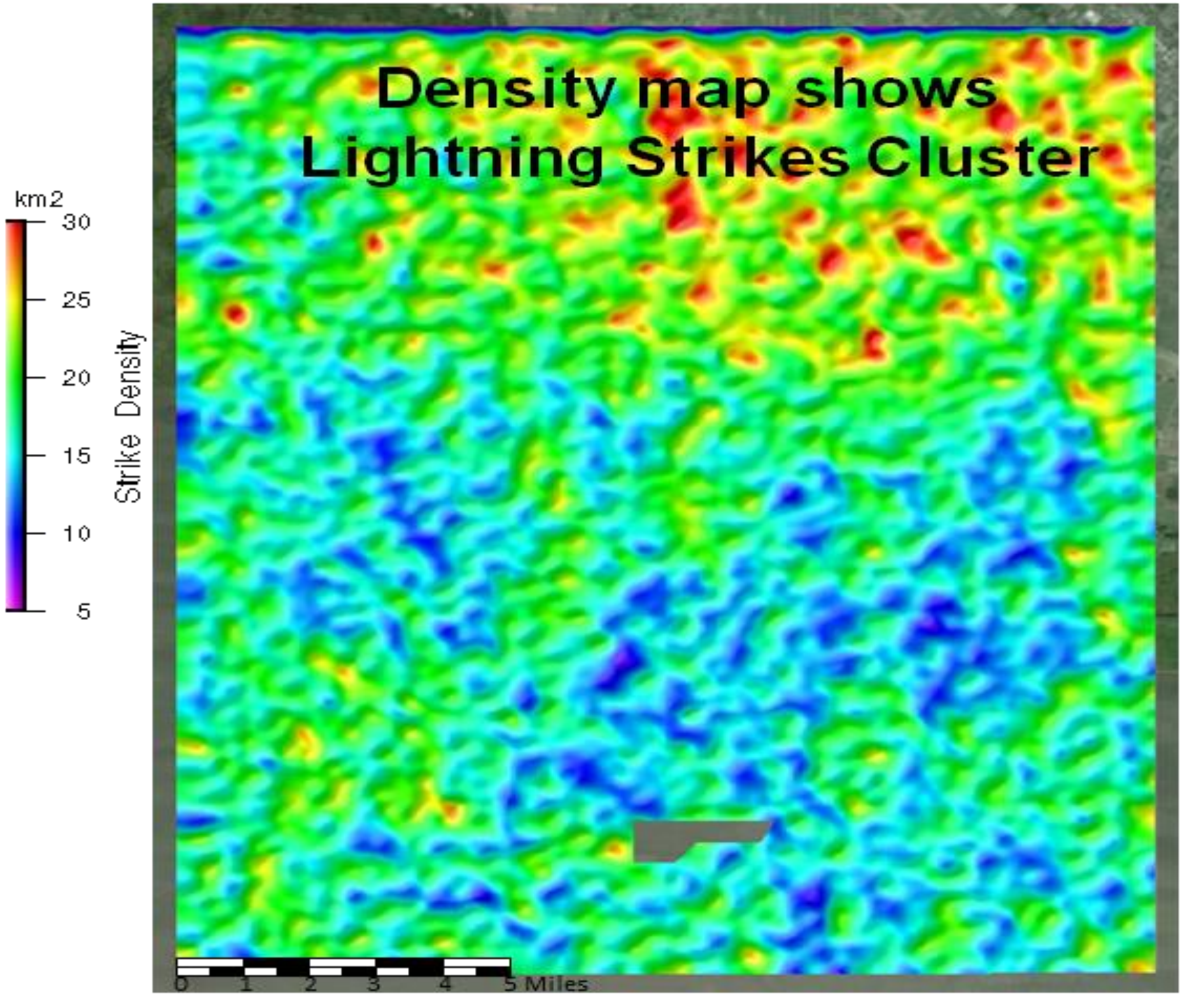
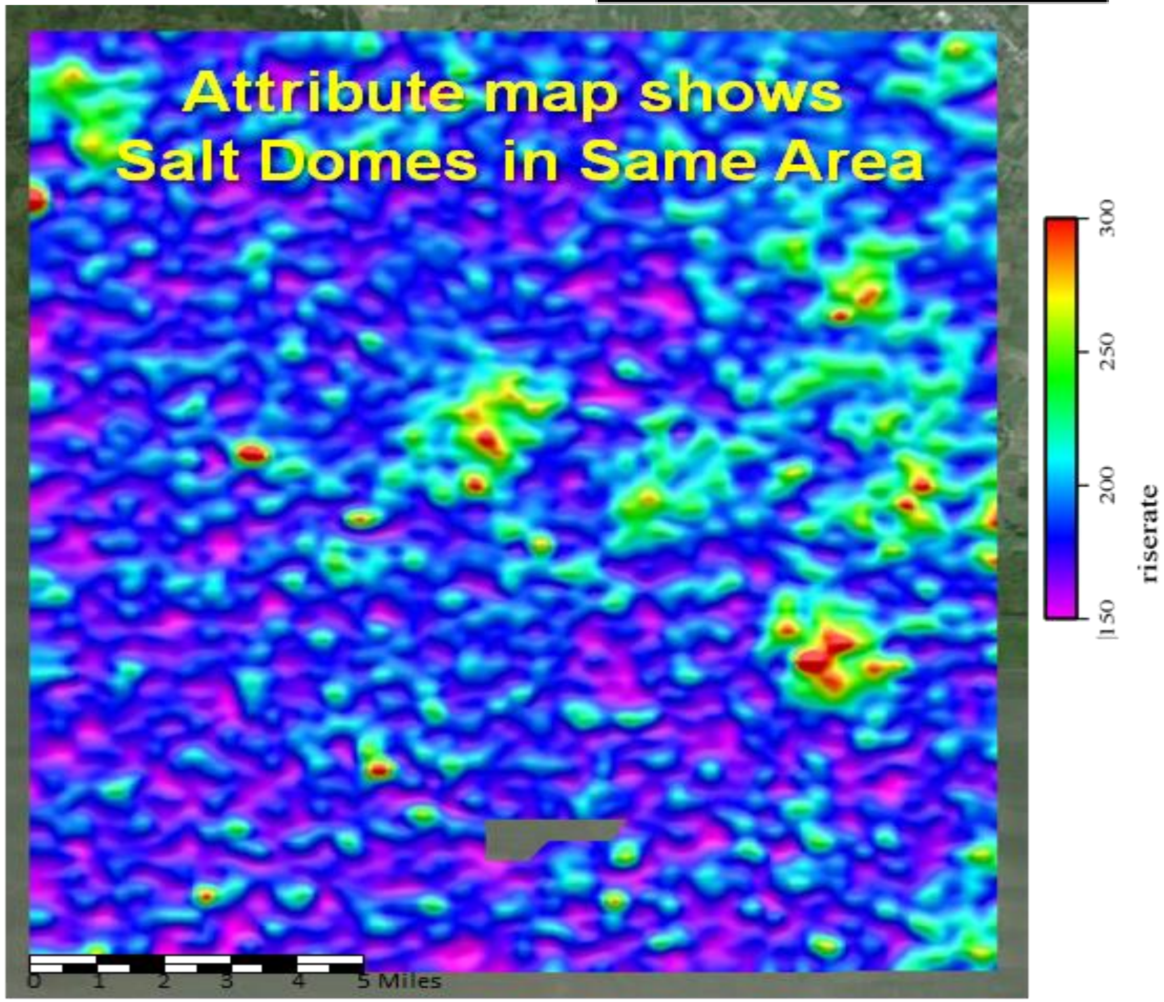
Outline

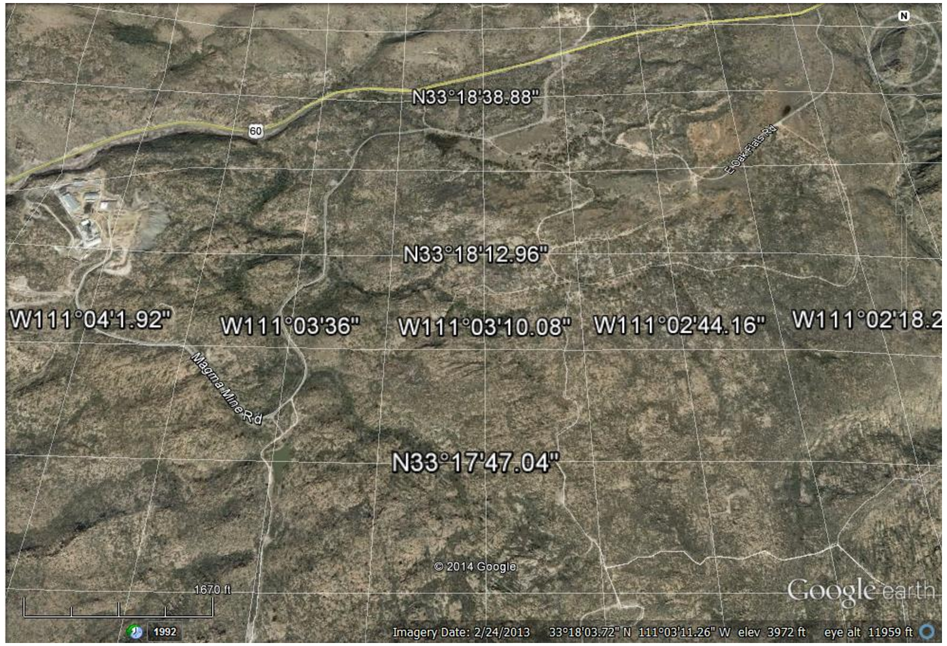
1. NSEM - A new geophysical data type
2. The meteorology behind lightning databases
3. Calculating rock property volumes from lightning databases
4. Examples of using lightning databases to map geology

1. NSEM – (Natural Source ElectroMagnetics) – a new geophysical data type

Lightning Data Analysis
demonstrates strikes are tied to geology

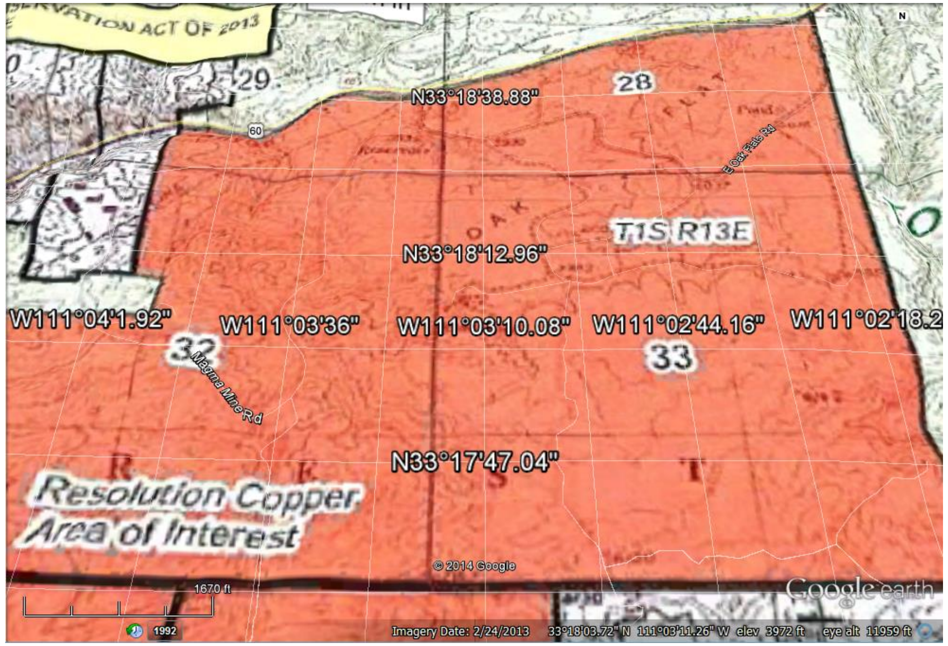


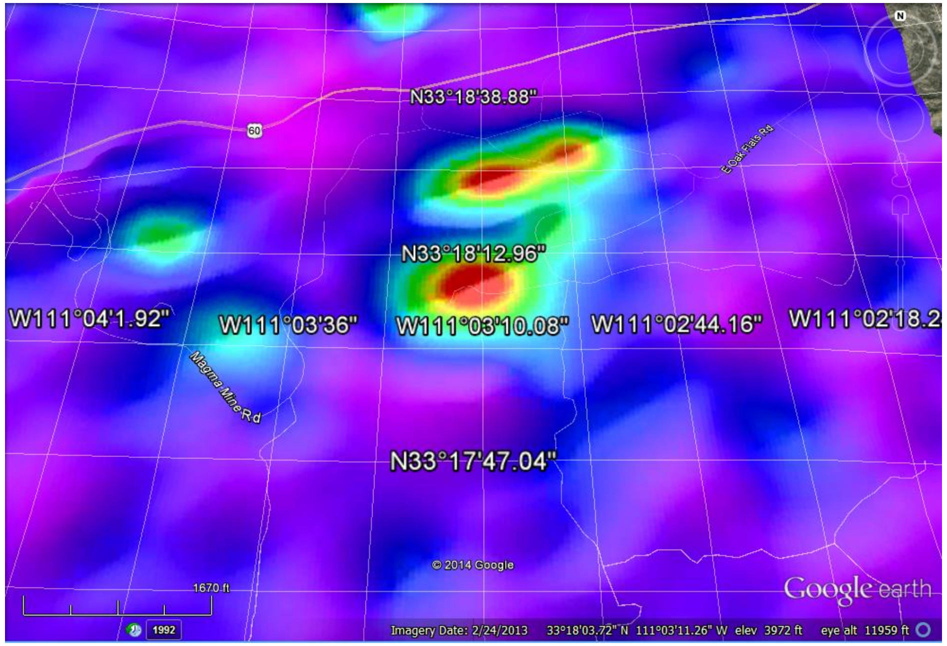


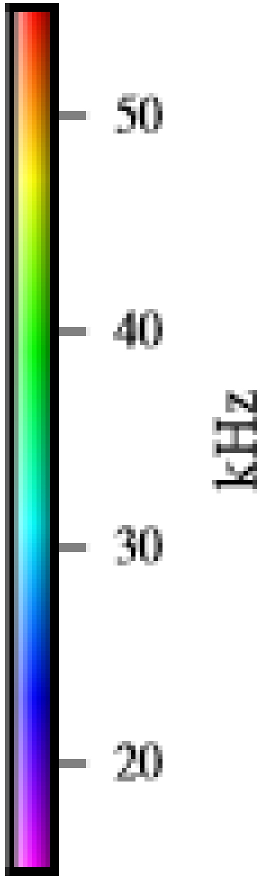


Attribute Maps

related to major copper mine being developed in Arizona



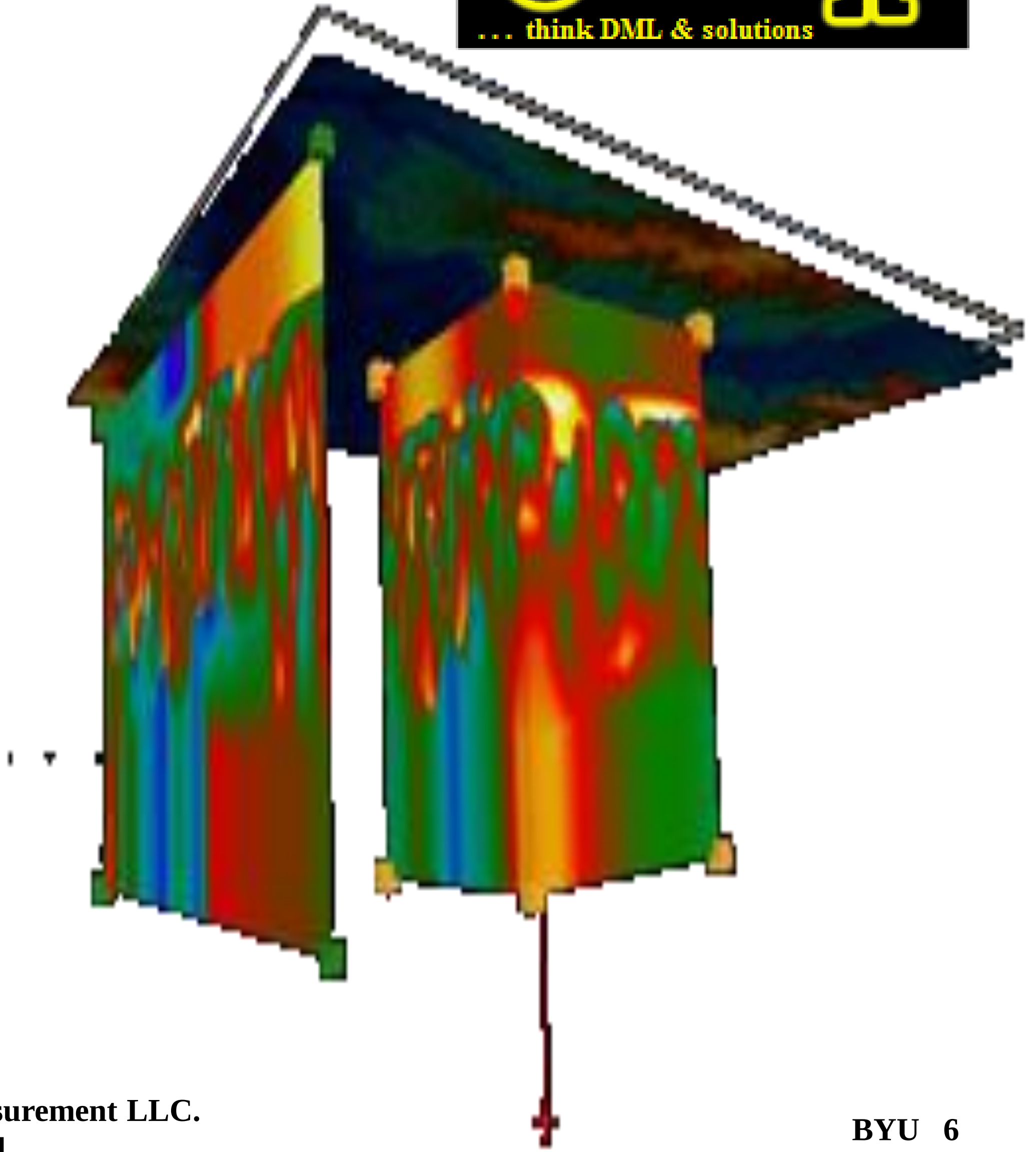




Technical Merit & Economic Benefits

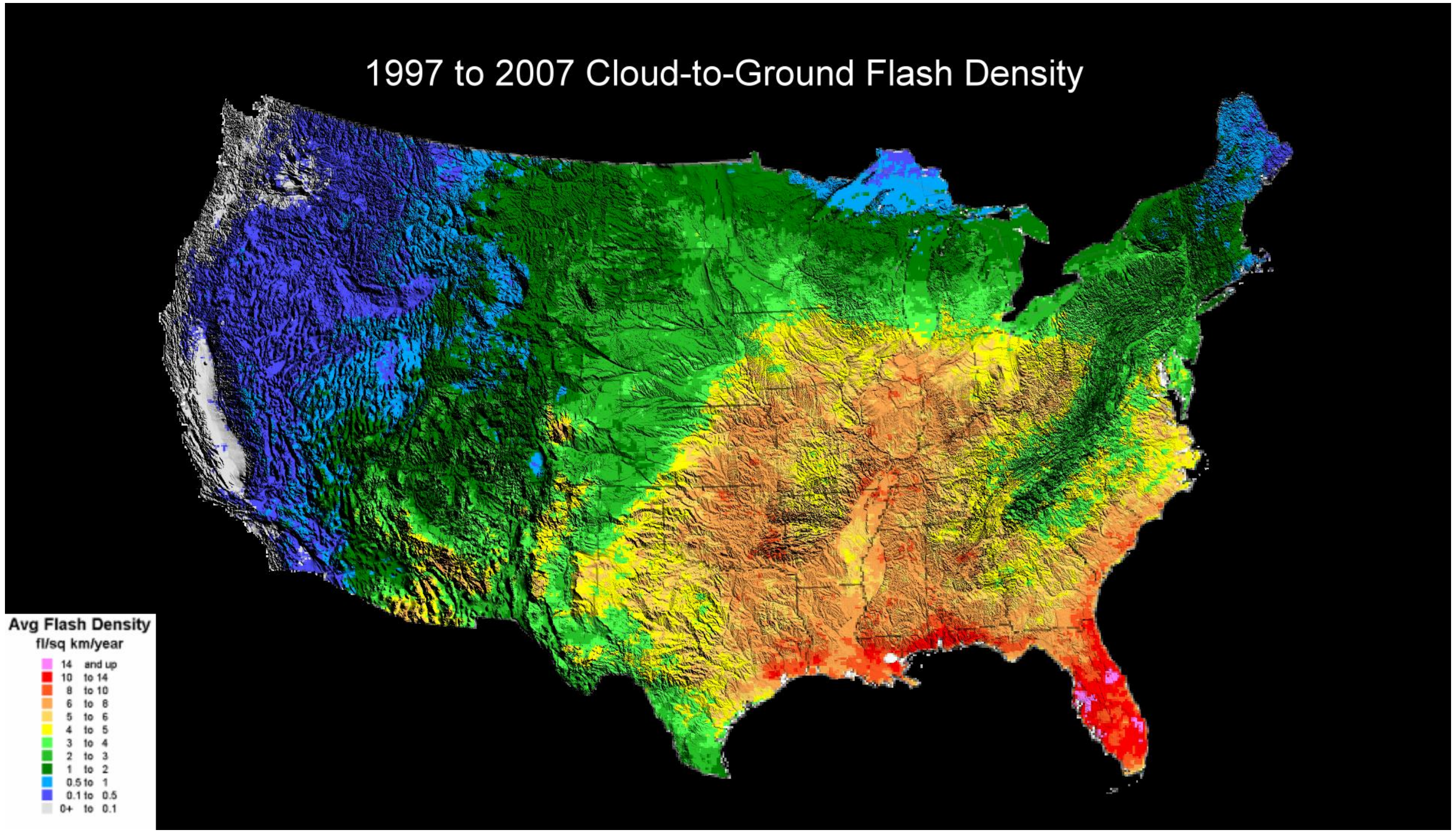
- Maps, Sections, and Volumes
- Evergreen Data
- 17 year database US & Canada
- 4 year database worldwide
- Integrates with other data
- Simple Solution
- Patented, & Patent Pending

- 2 month project turnaround
- Larger Area – Less Expense compared to 3-D seismic



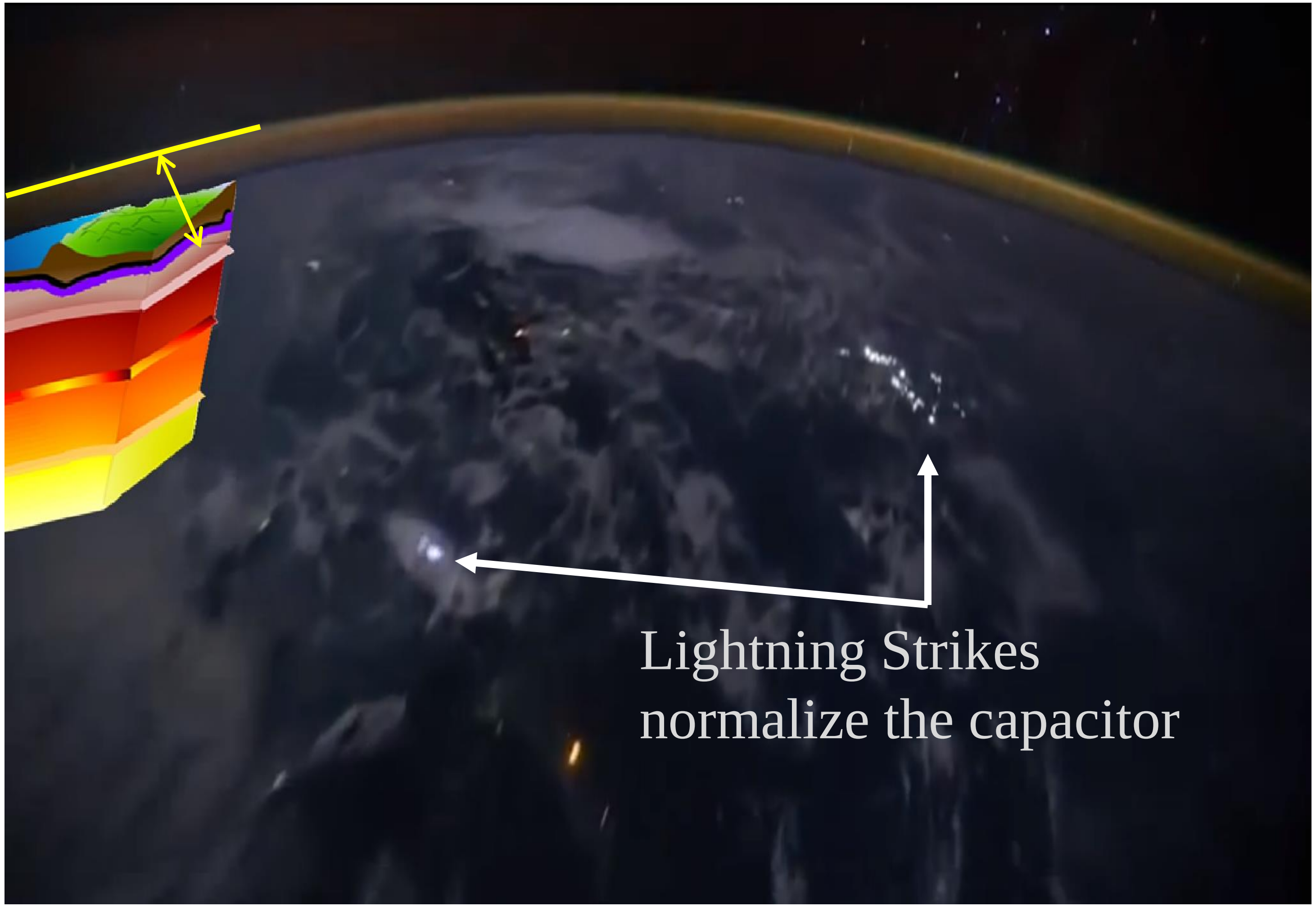
2. The meteorology behind lightning databases

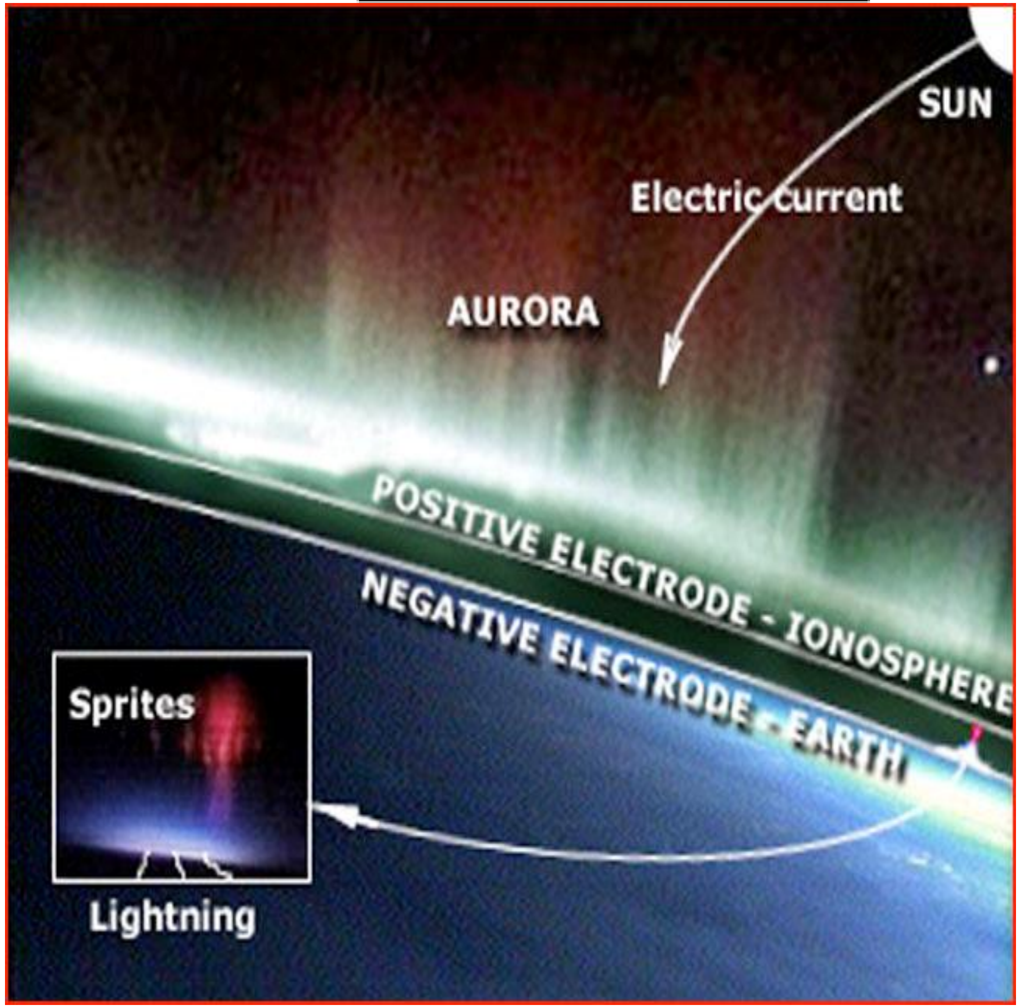
Lightning Maps and Natural Resources



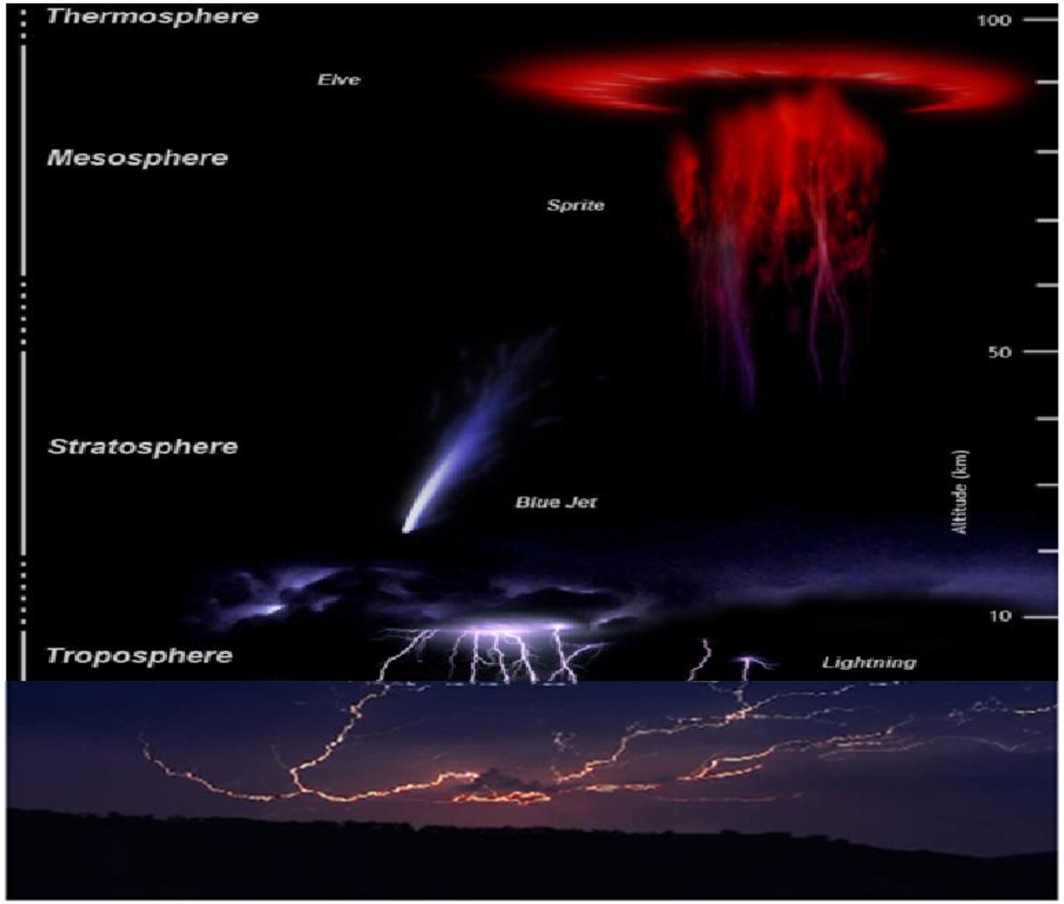
Lightning density regionally controlled by meteorology, and locally controlled by terralevis (shallow earth) currents.

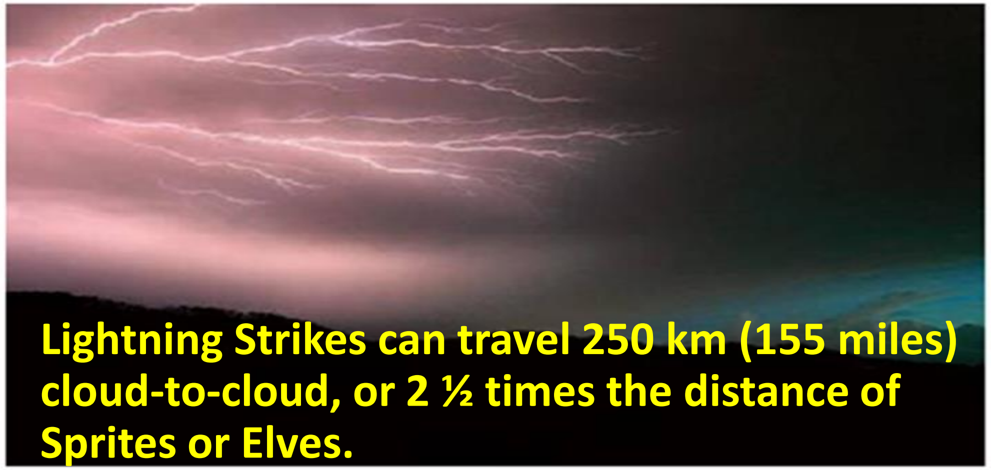
Earth: A Self-Repairing Capacitor





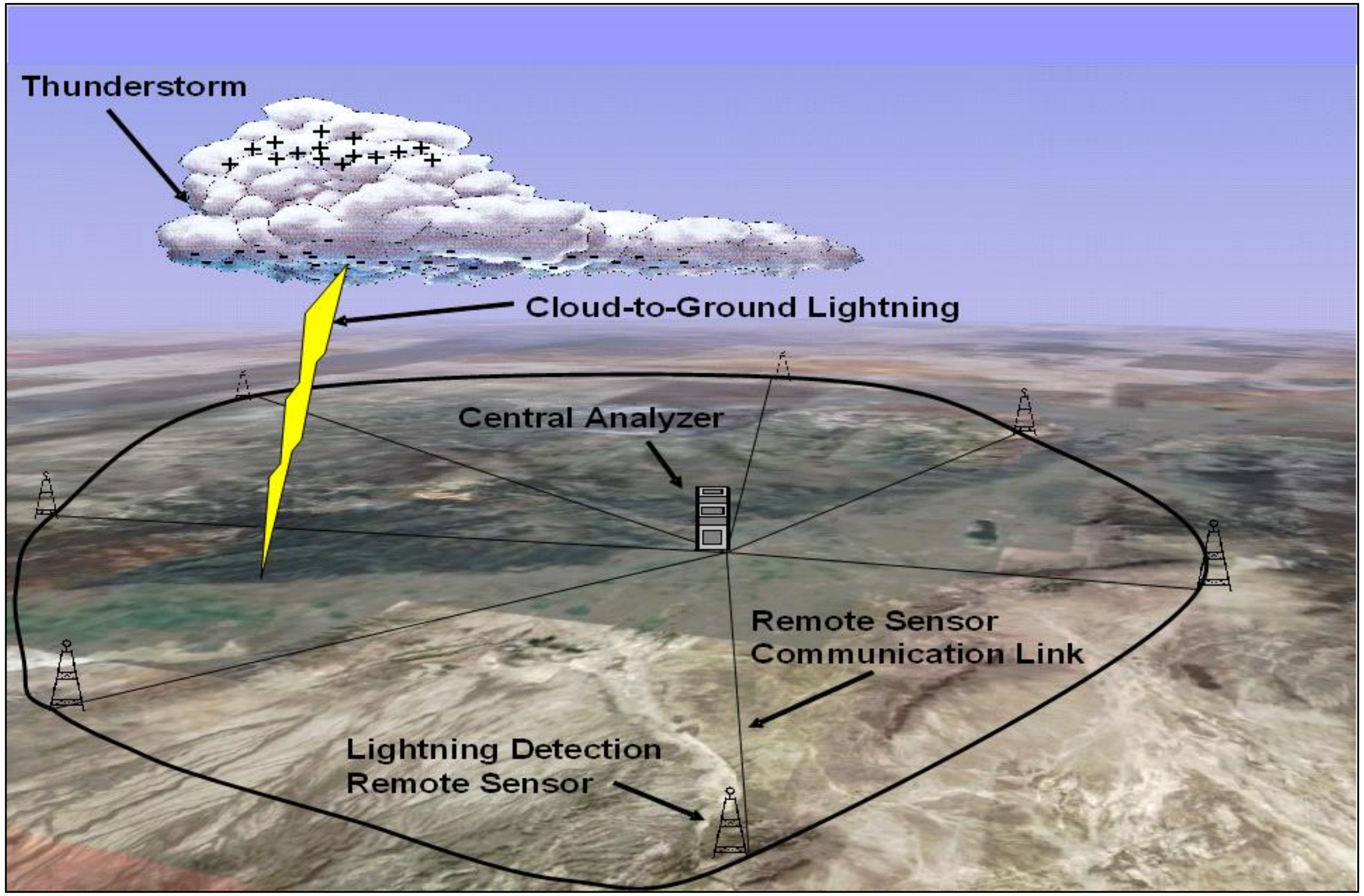
350 million annual Lightning Strikes - a rich database to mine





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

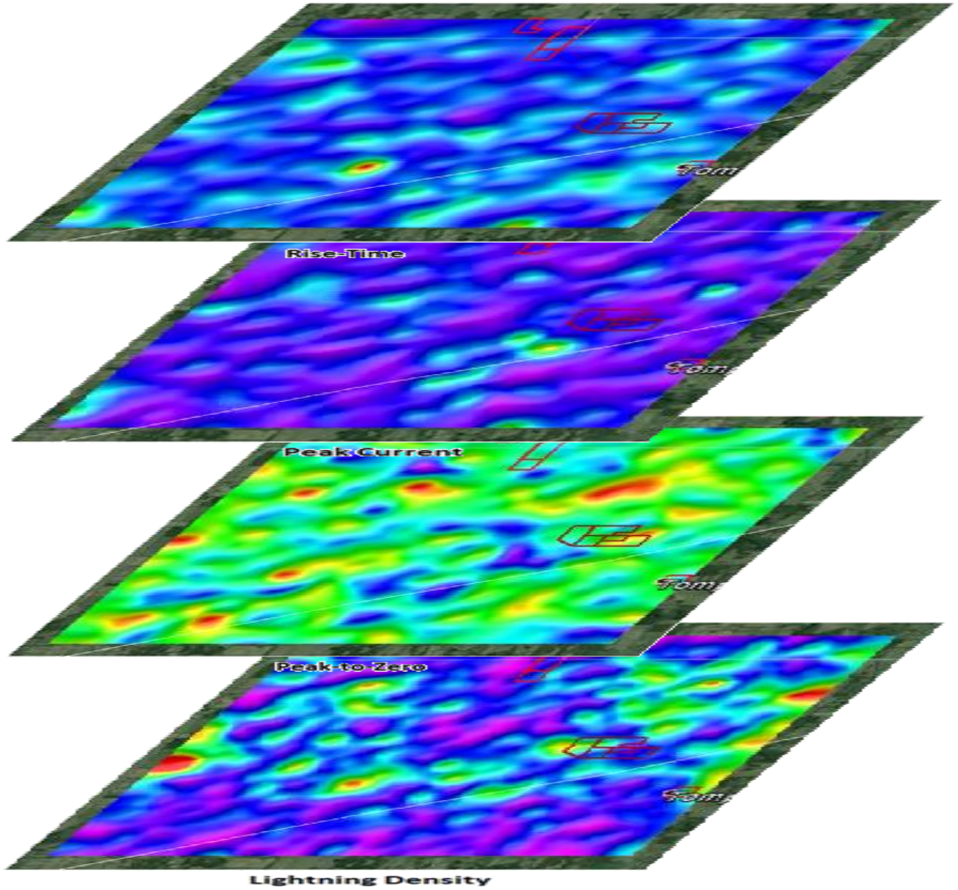
330 Sensors record U.S. lightning strike locations with 650-980 feet (200-300 meter) horizontal resolution

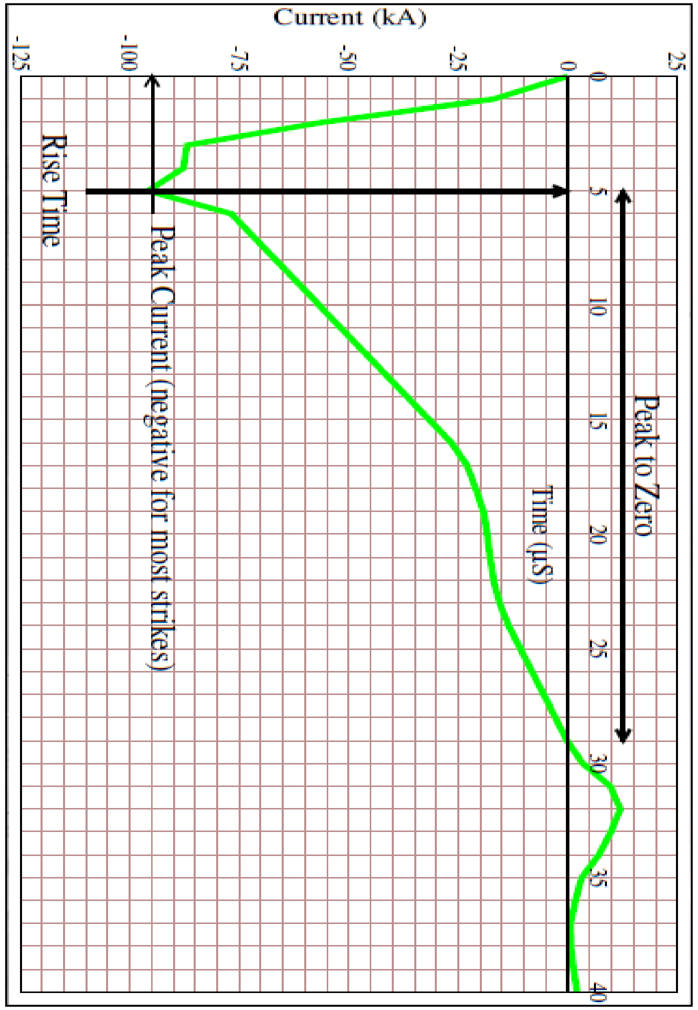


Lightning Strike Measurements

See Lightning . . .
DML
. . . think DML & solutions

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





Upward Lightning tied to geology

Main lightning bolt tied to geology

Proven and Patented Technology

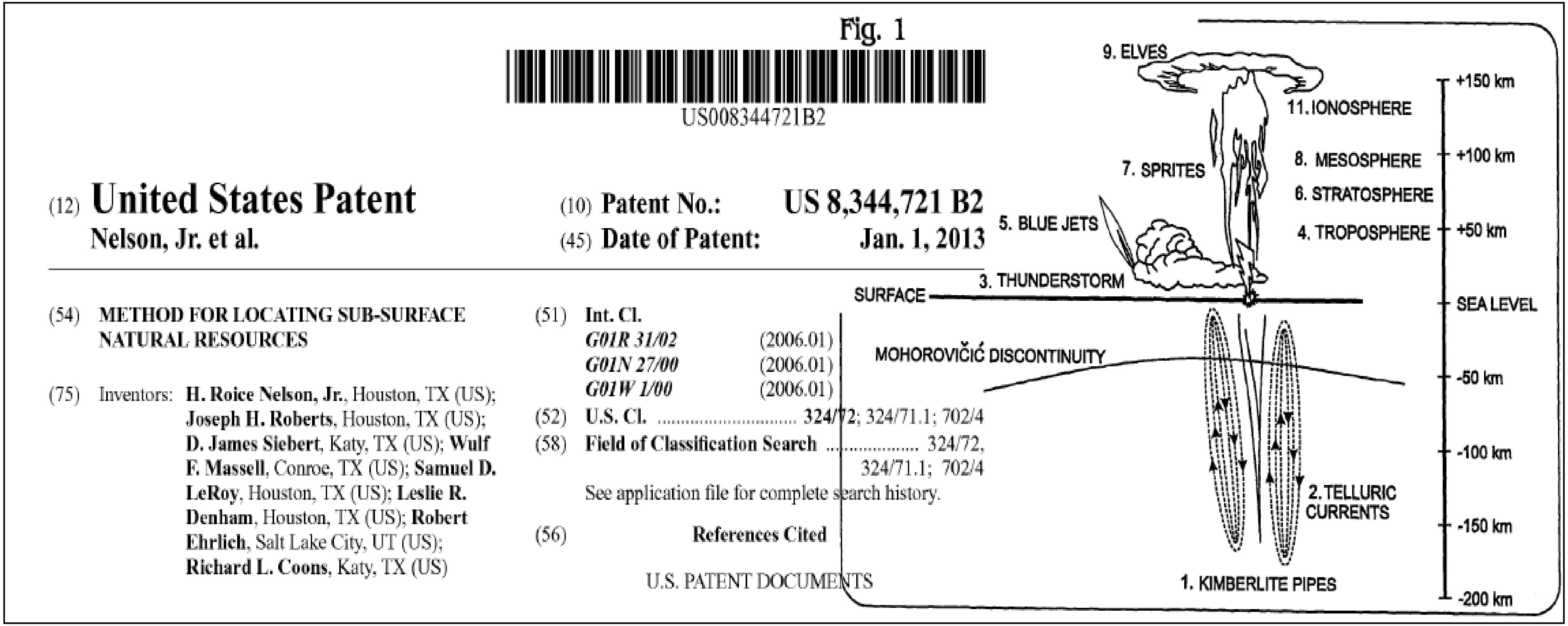


Fig. 1

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**

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(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

GULF COAST ASSOCIATION OF GEOLOGICAL SOCIETIES

www.gcags.org

Dear Kathleen,

Congratulations! You have been selected to receive the First Place Grover E. Murray Best Published Paper Award for your paper, "Aquifers, Faults, Subsidence, and Lightning Databases" published in the 2014 GCAGS *Transactions*.

• • •

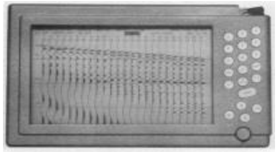
Mary Broussard
2013-2014 GCAGS President
Email: Mary_Broussard@fmi.com

A time-line of new Geophysical Data Types

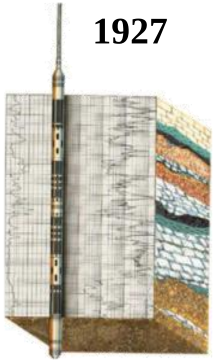
1752

1833

1920s

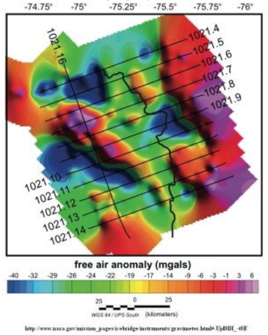


1927



1931

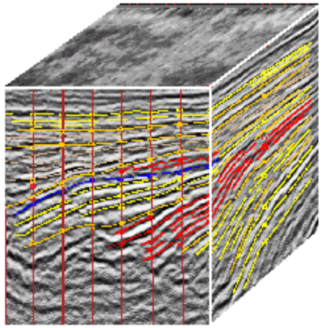
1936



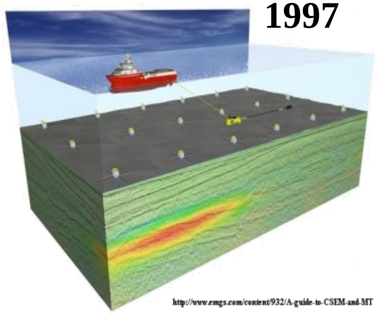
1950s

1960s/70s

1974

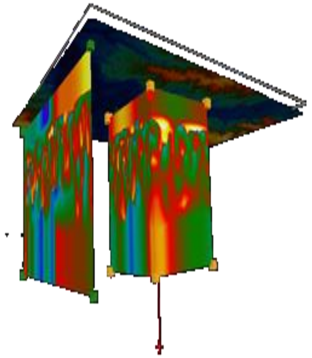


1997



2008

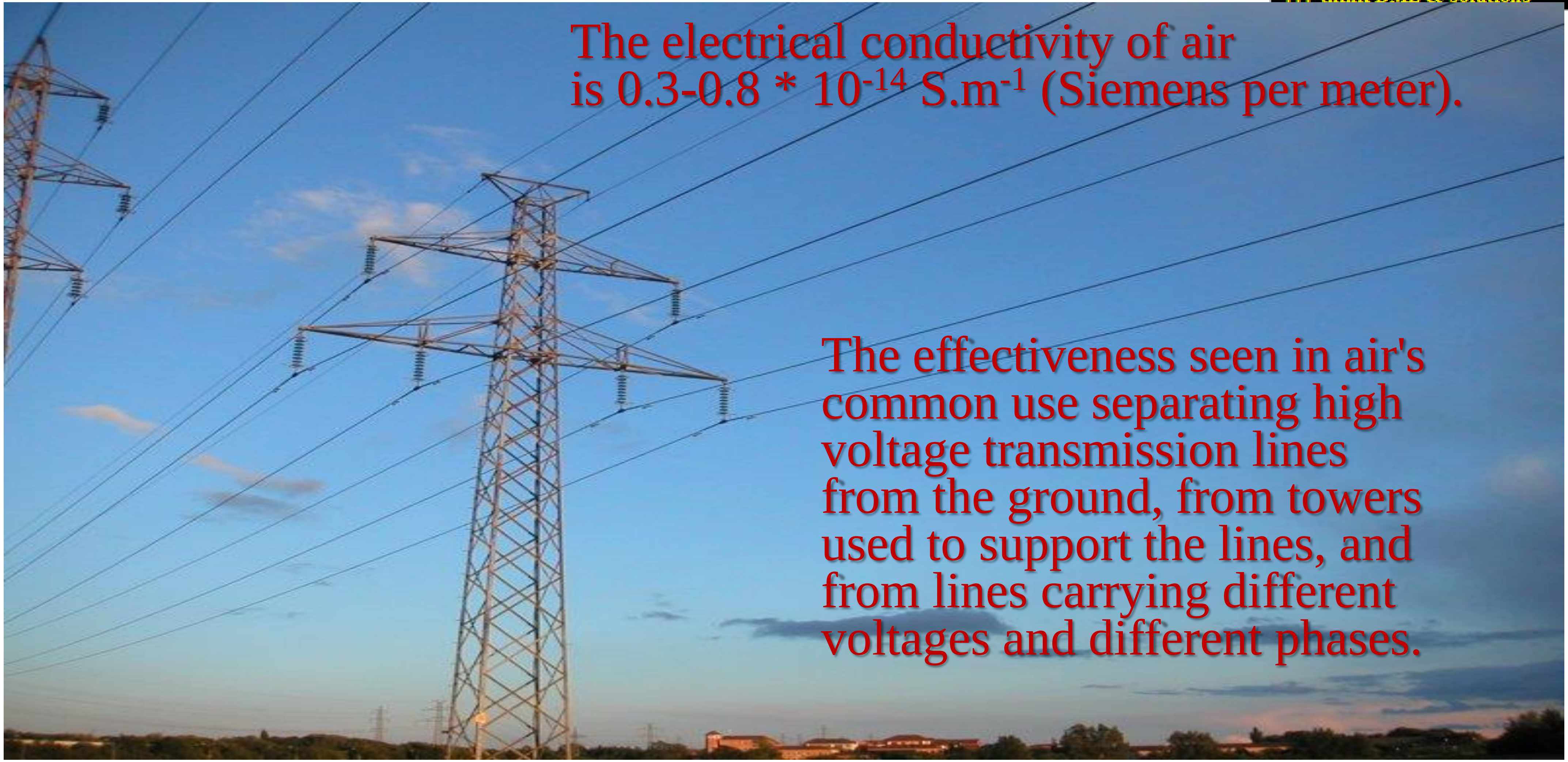
2015



Each new data type has sparked a step change in
new revenues and cost avoidance
for upstream oil and gas companies

3. Calculating rock property volumes from lightning databases

The atmosphere is an effective insulator

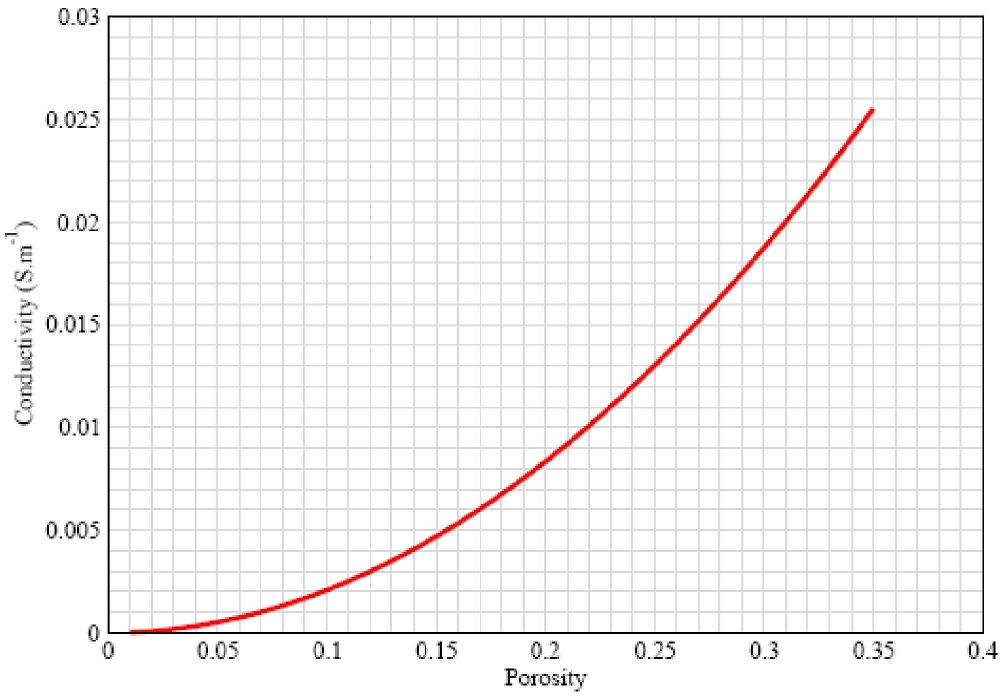


The electrical conductivity of air is 0.3-0.8 * 10^{-14} $S.m^{-1}$ (Siemens per meter).

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.

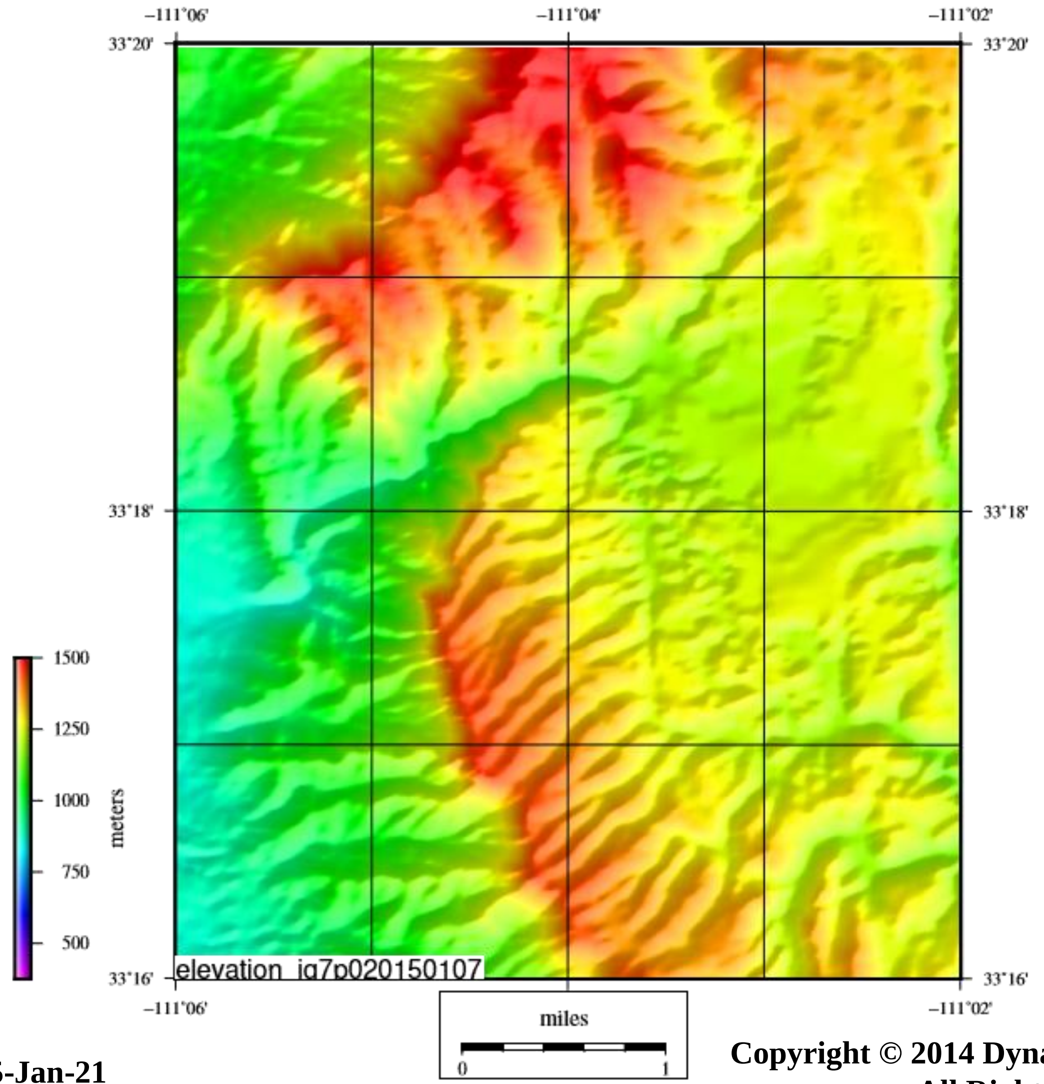
The earth is much more conductive than air

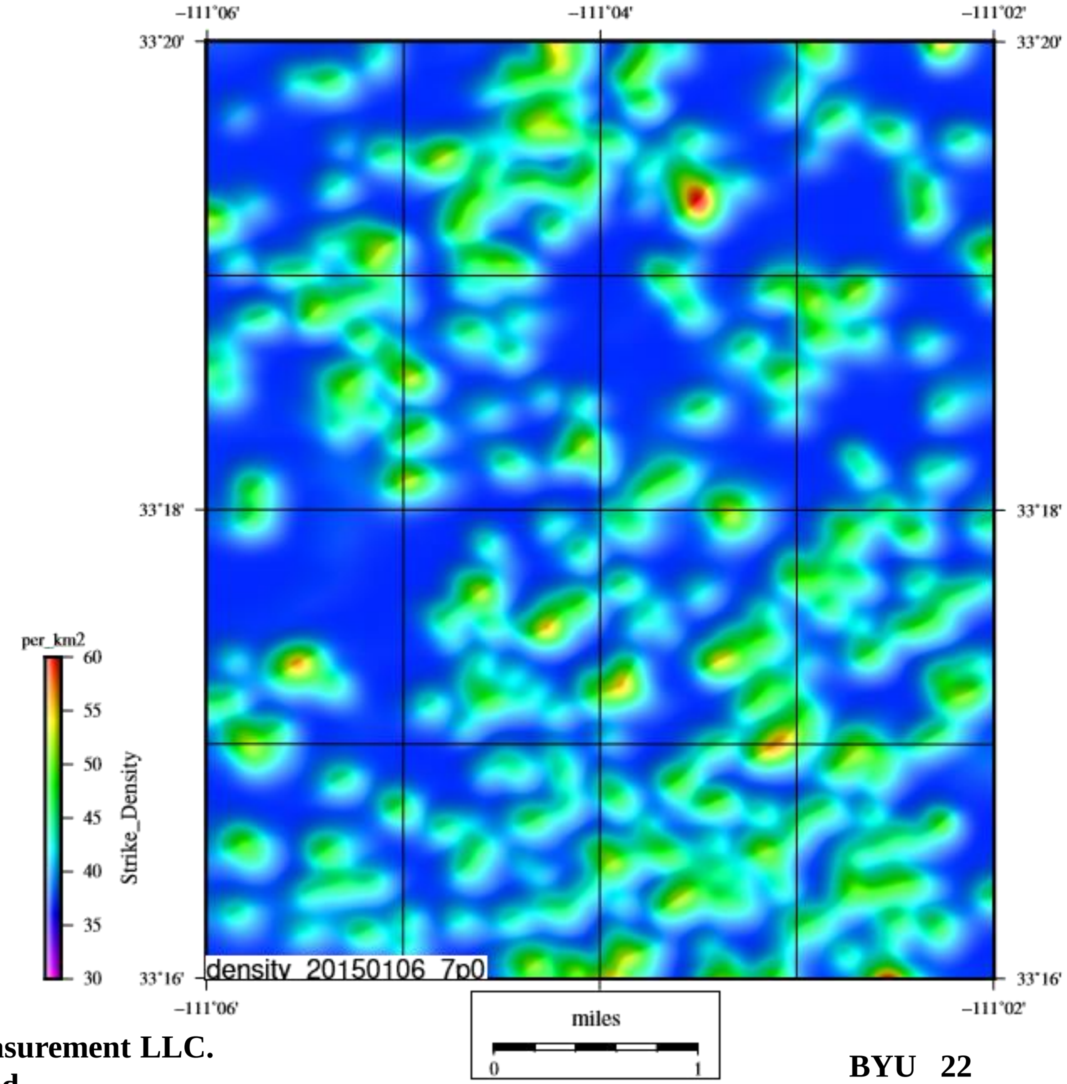
Assuming a typical sedimentary rock has 5% porosity, the electrical conductivity of rocks is $5.0 * 10^{-4}$ S.m^{-1}, or about 10^{10} times the conductivity of air.



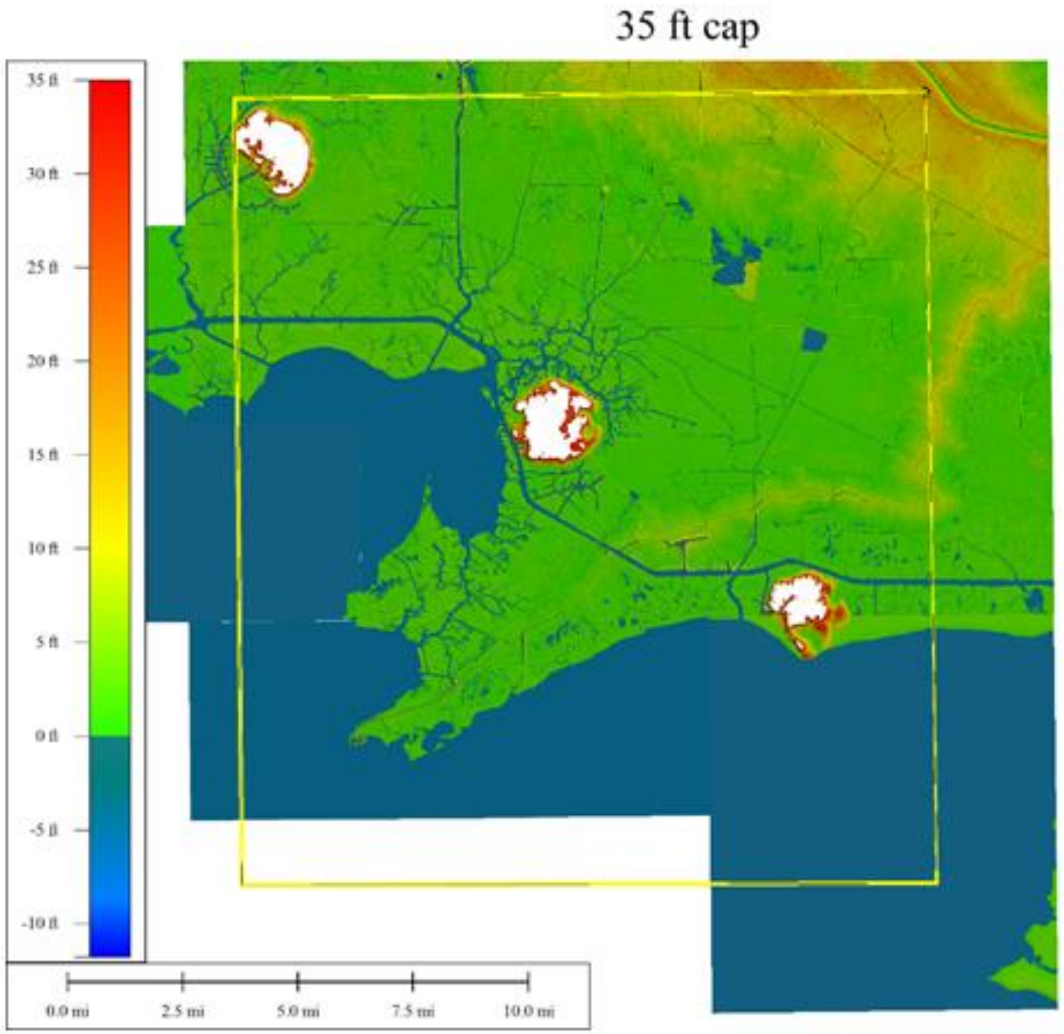
Rock Conductivity Graph computed for a porous rock with 100% brine saturation using Archie's equation

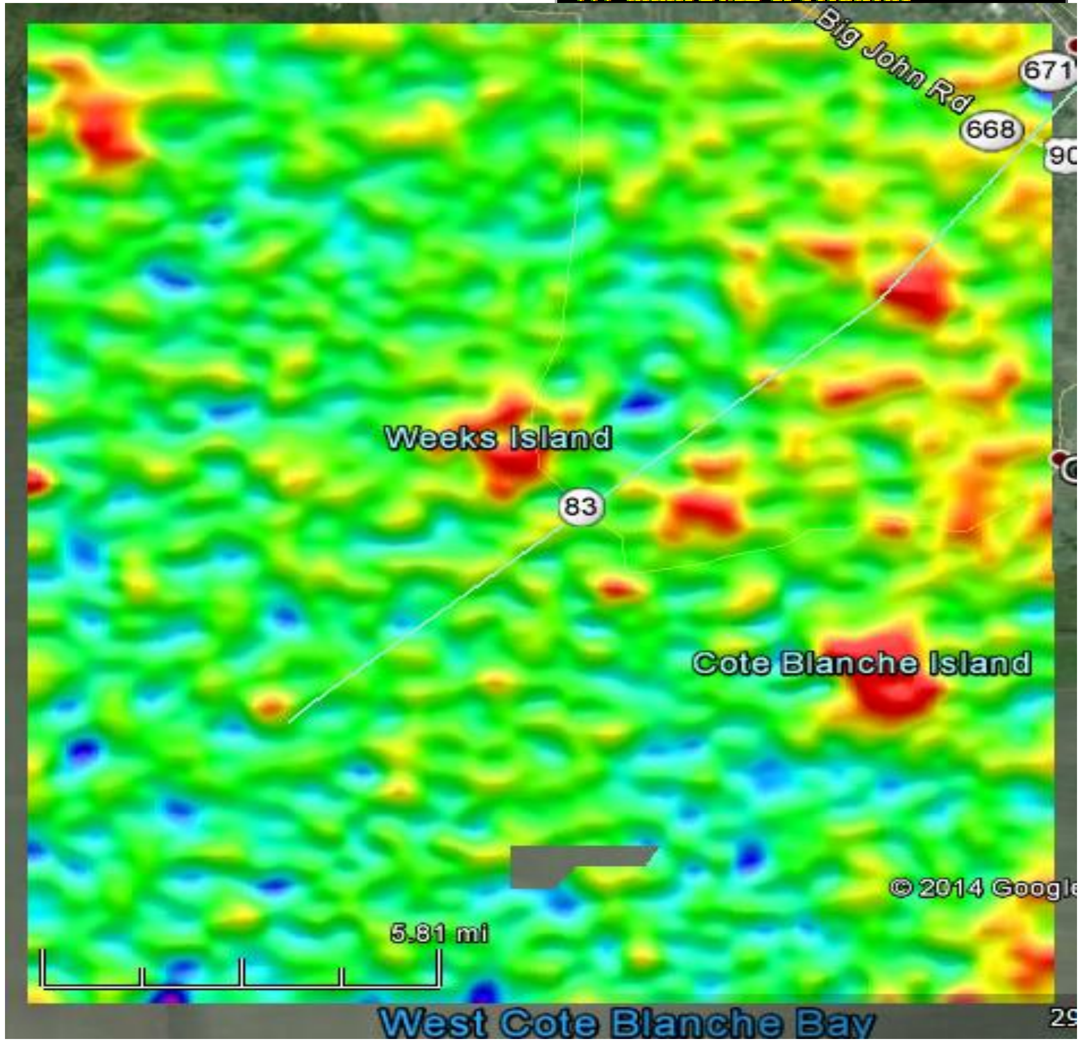
Topography and Lightning Density Arizona



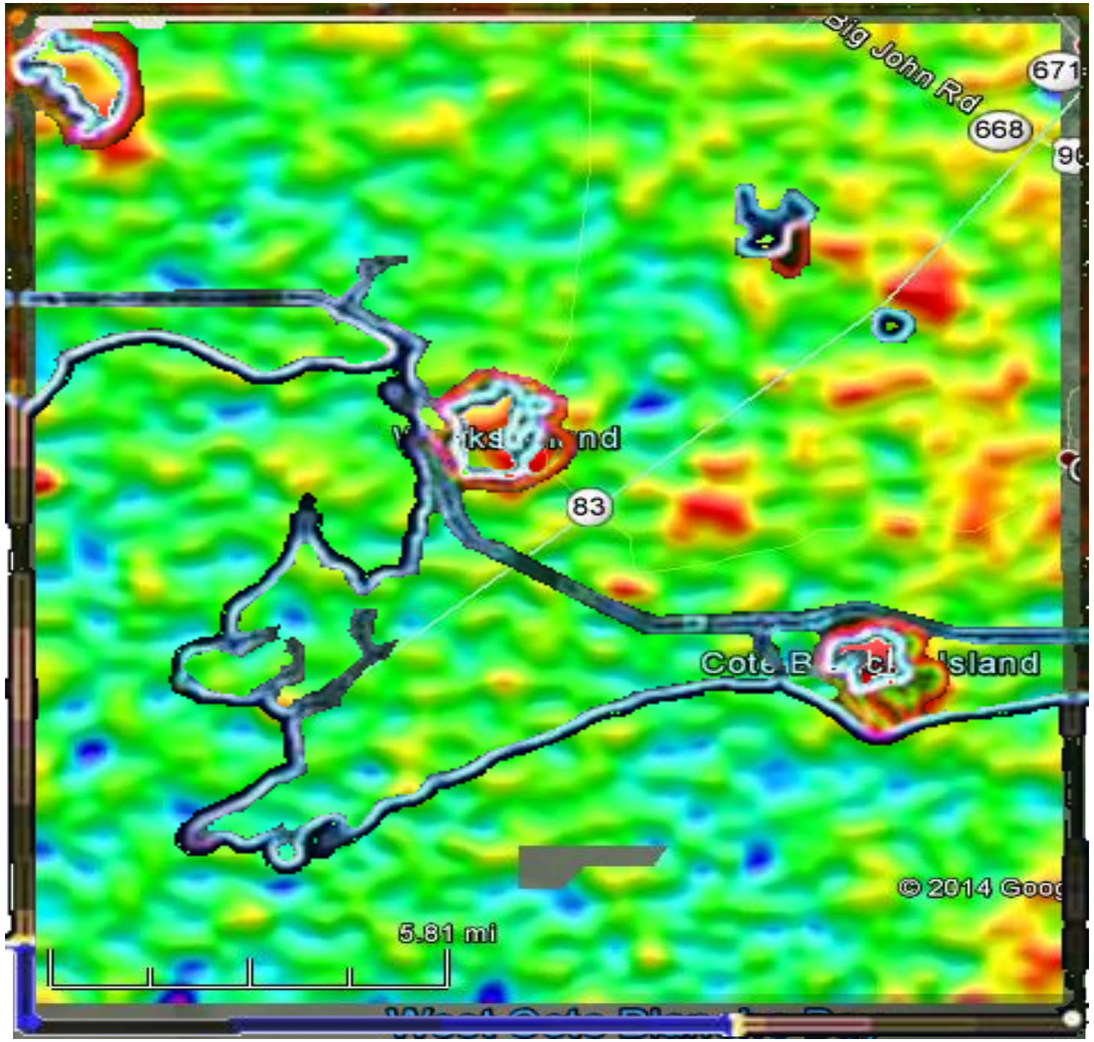


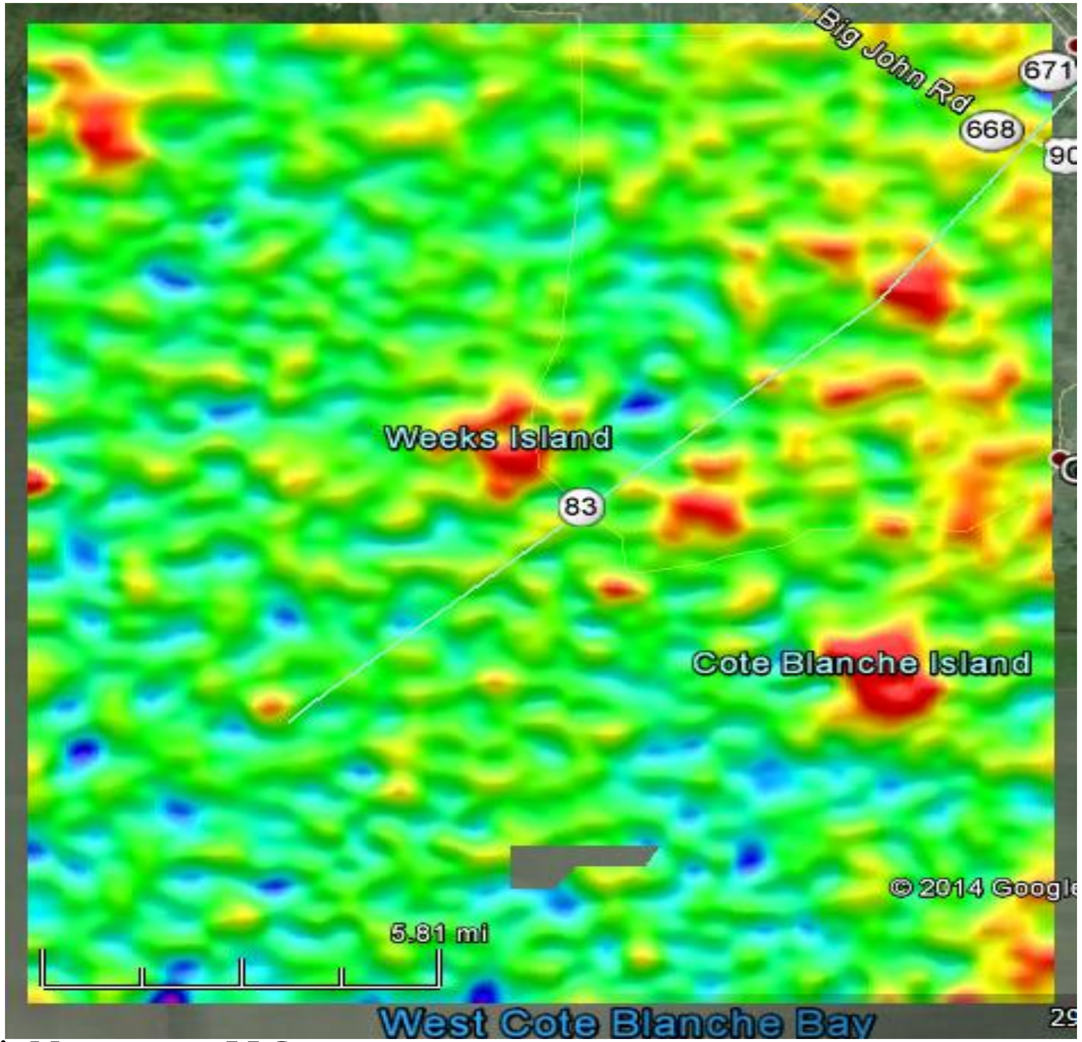
LIDAR Extended with NSEM Analysis





Lateral Strike Resolution 200-300 meters





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

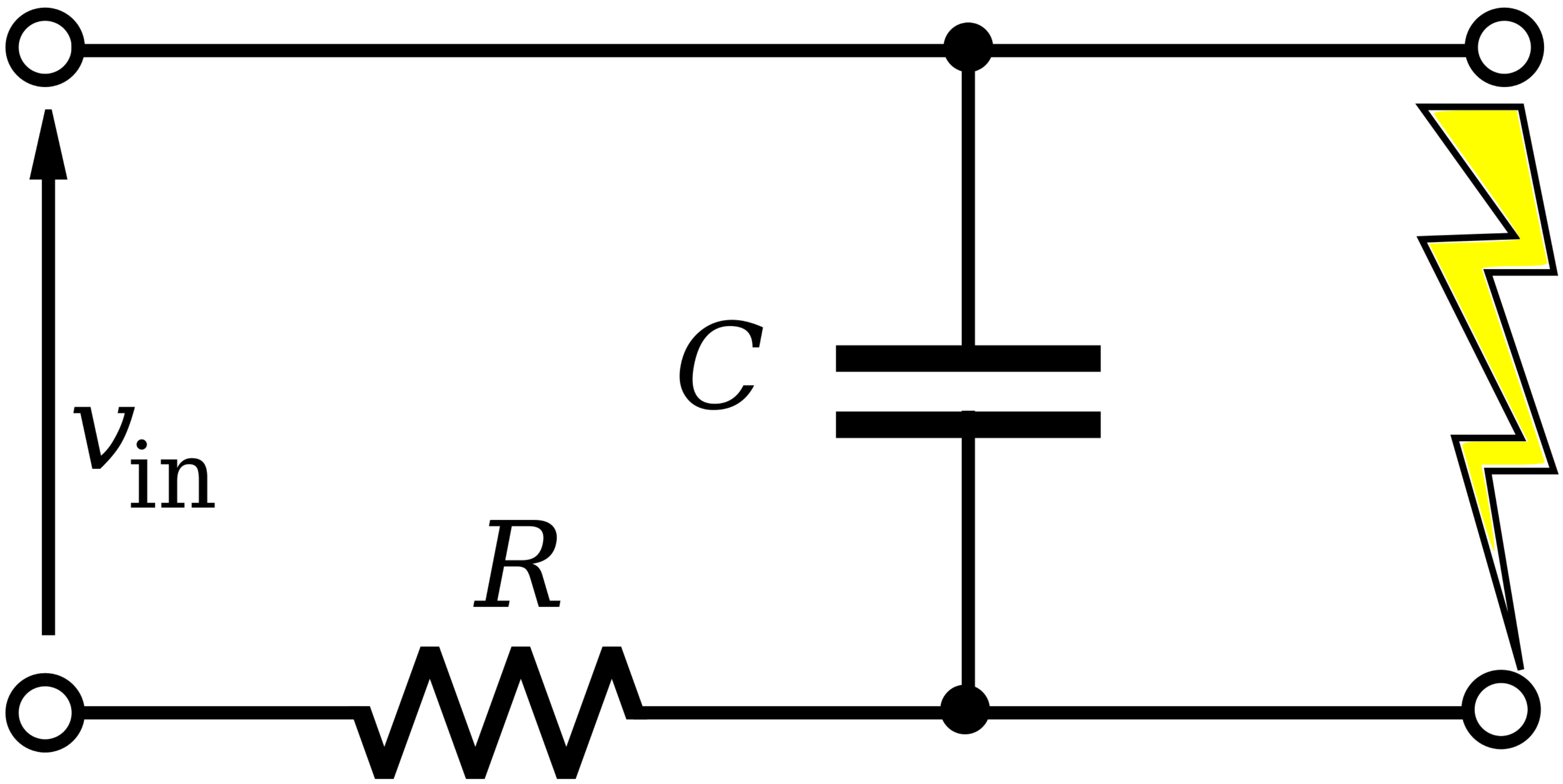
- Lightning occurs when the voltage across the atmospheric capacitor exceeds the dielectric strength of the air.
- Resistance in the atmosphere is very low once the path is ionized.
- Resistance in the subsurface is approximately constant over long periods of time.
- Atmospheric factors vary with each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

Can we separate rock resistance?

- The physics of lightning discharge are similar to the physics of a neon-tube relaxation oscillator.

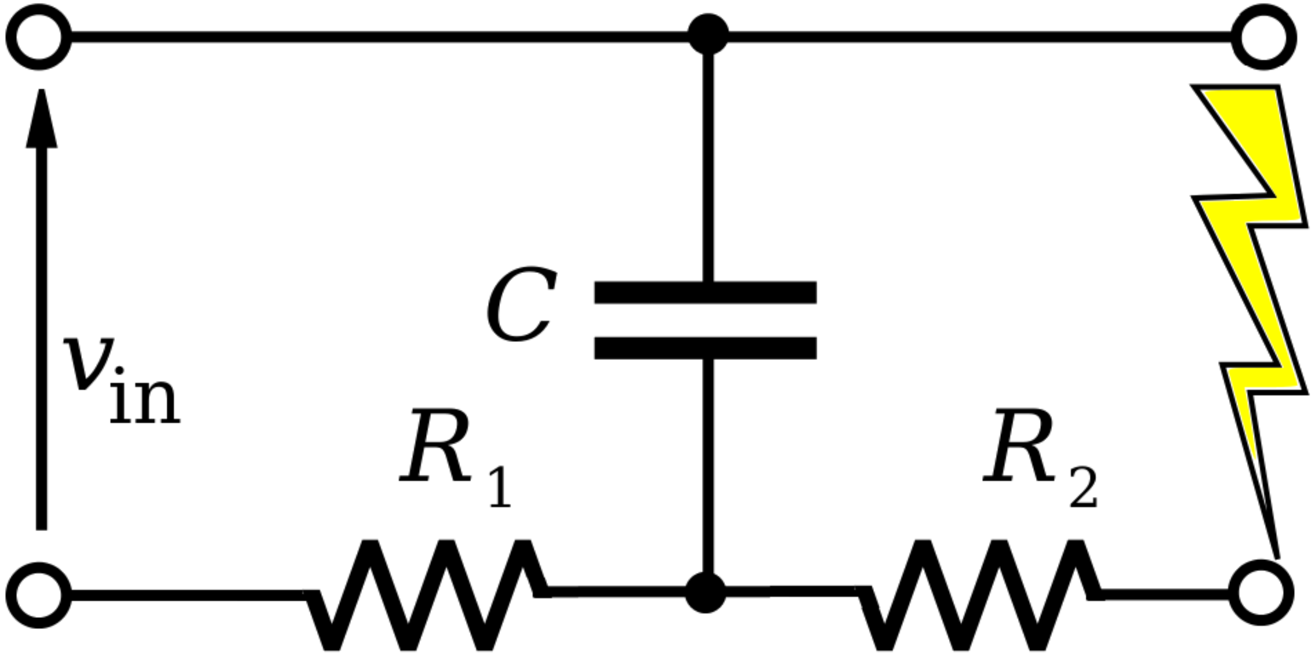
- In each case, voltage builds across a capacitor until an insulating gas ionizes and becomes a conductor

Relaxation Oscillator



Lightning

- 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

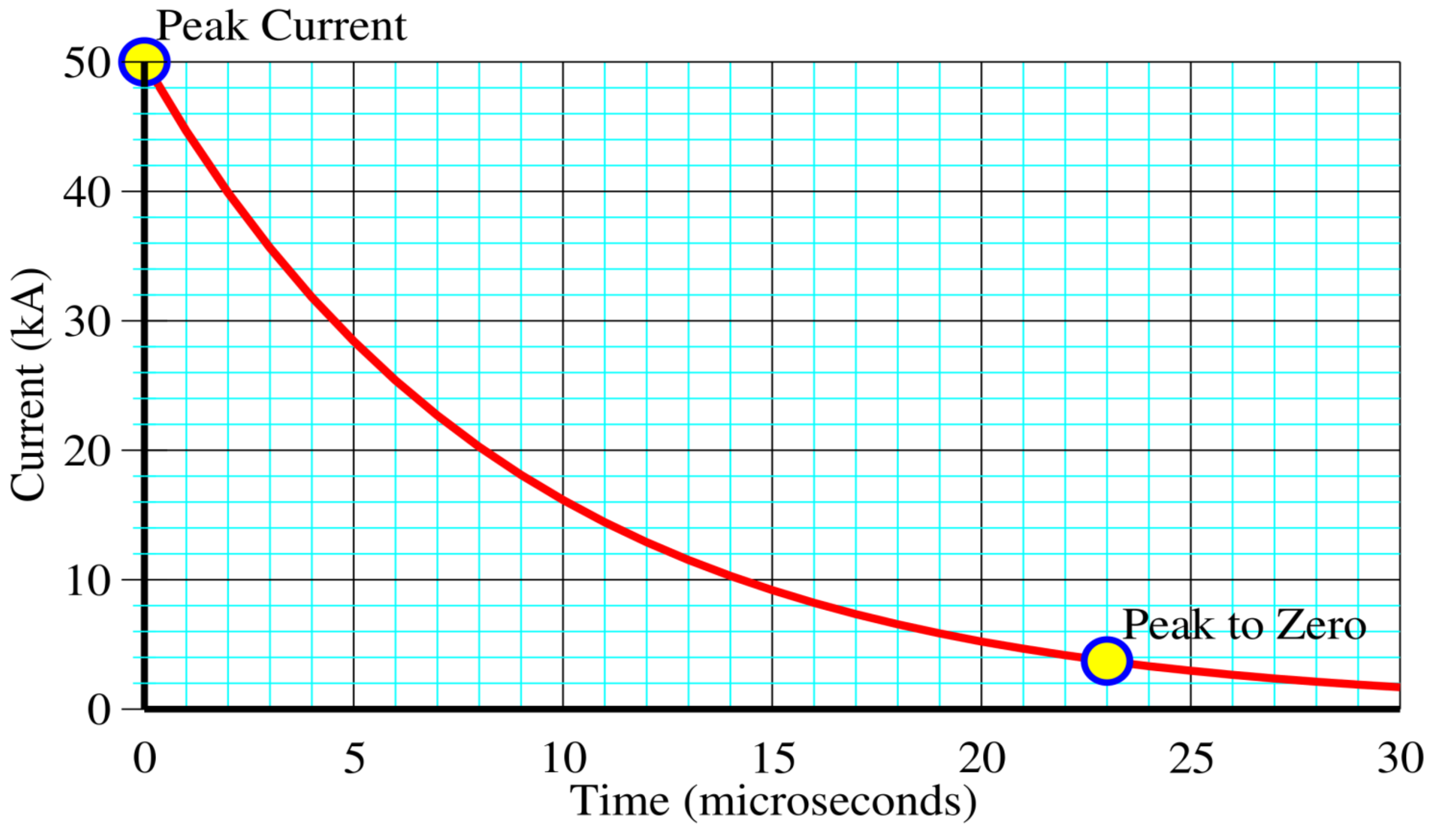


Relaxation Oscillator Physics

- 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



The Available Measurements

- Two points on an exponential curve will define the curve

Peak Current:

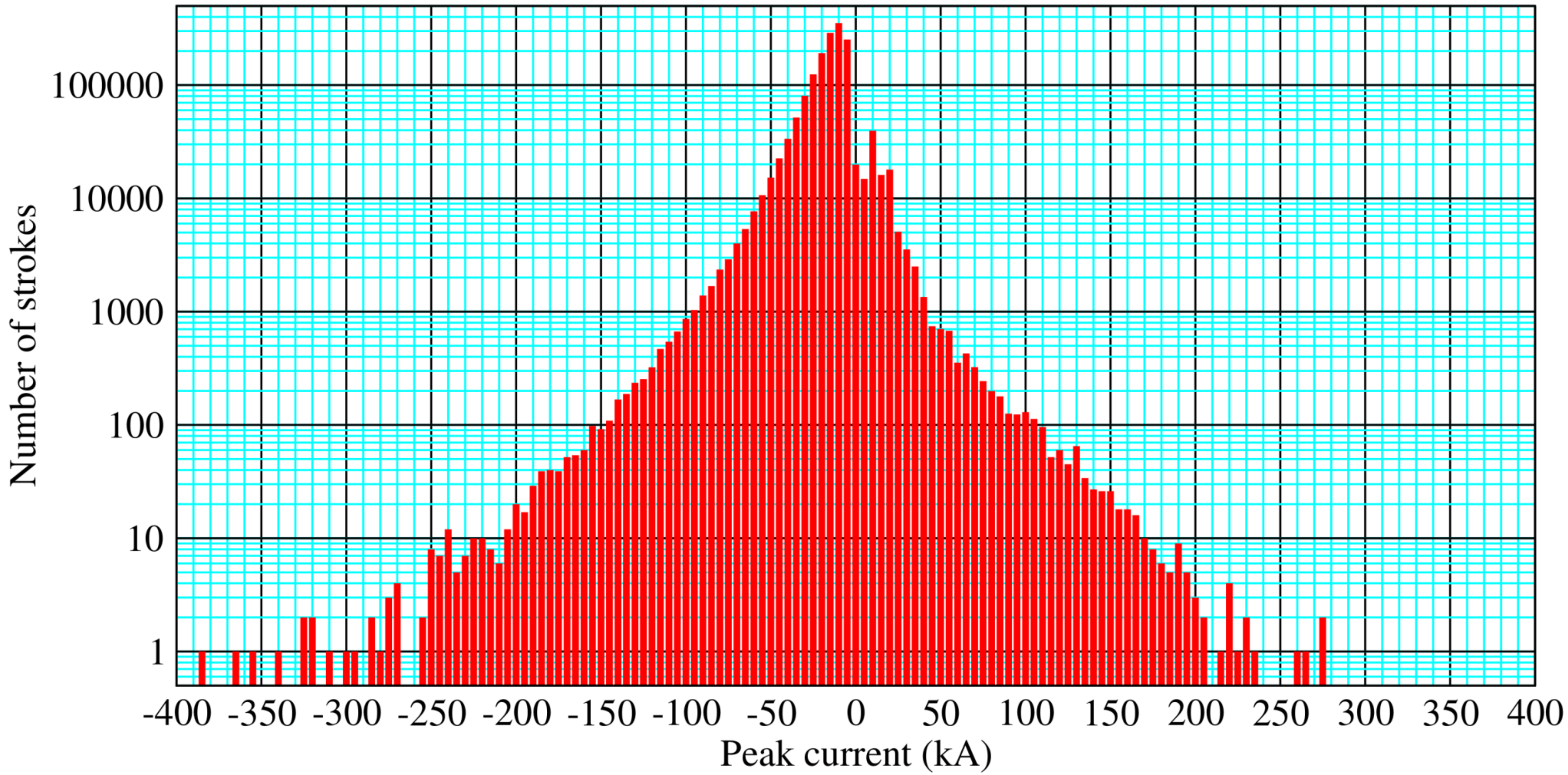
- The maximum recorded current, when decay starts (I_0)

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?

- 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

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

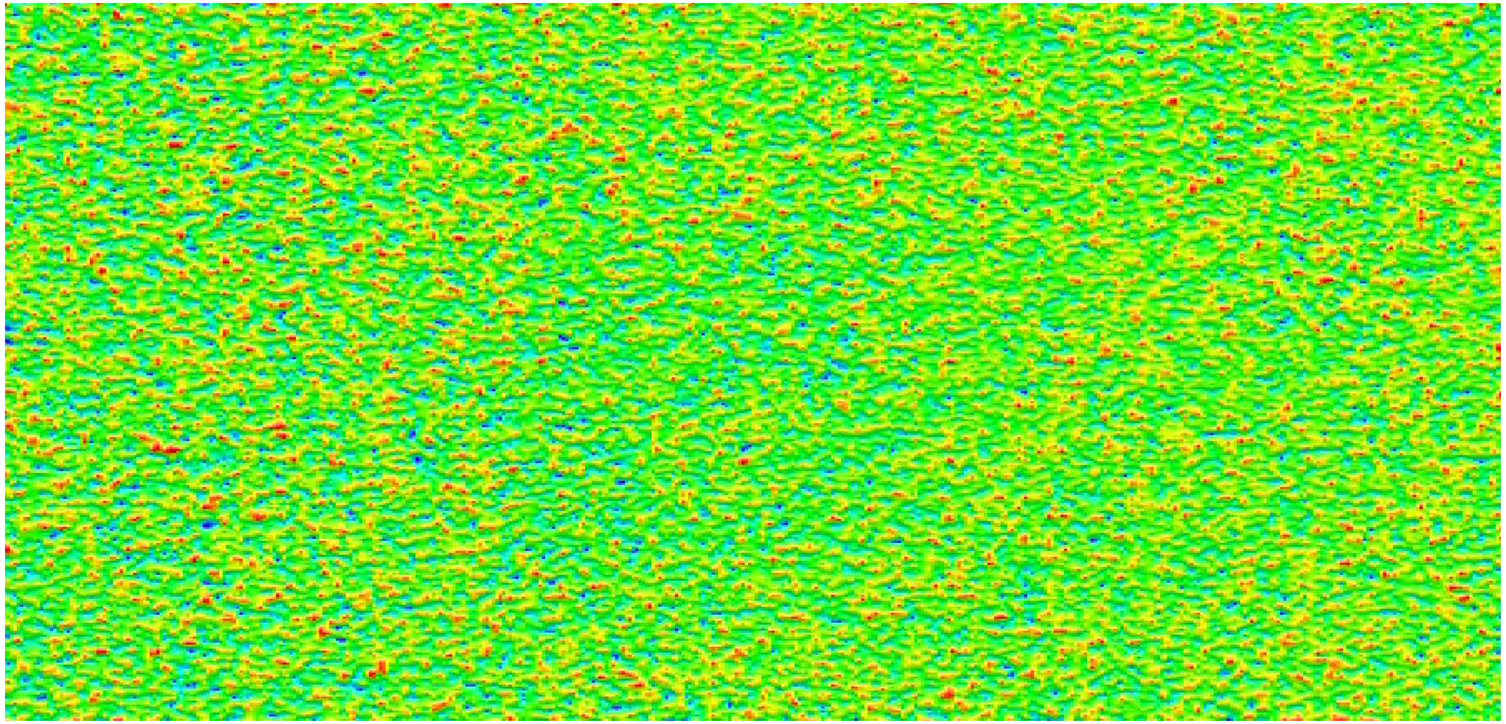
1. Voltage is proportional to peak current (within a local area).
2. Cloud height is proportional to voltage because the dielectric strength of air is more or less constant.
   - This gives plate separation for the atmospheric capacitor
3. The effective capacitor is circular, with a radius proportional 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?

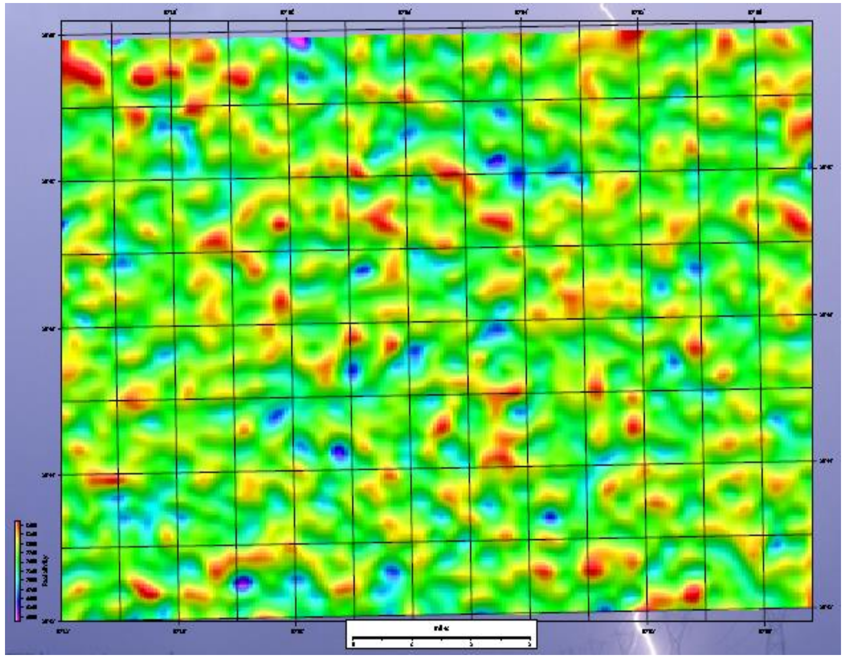
- Resistivity is resistance times cross-sectional area of a conductor, divided by its length; or $\rho = \frac{R \times A}{l}$
- For lightning energy dissipating in the ground:
  - The area is very smal at the strike point, but increases rapidly
  - The length is very short for discharging the charge 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.

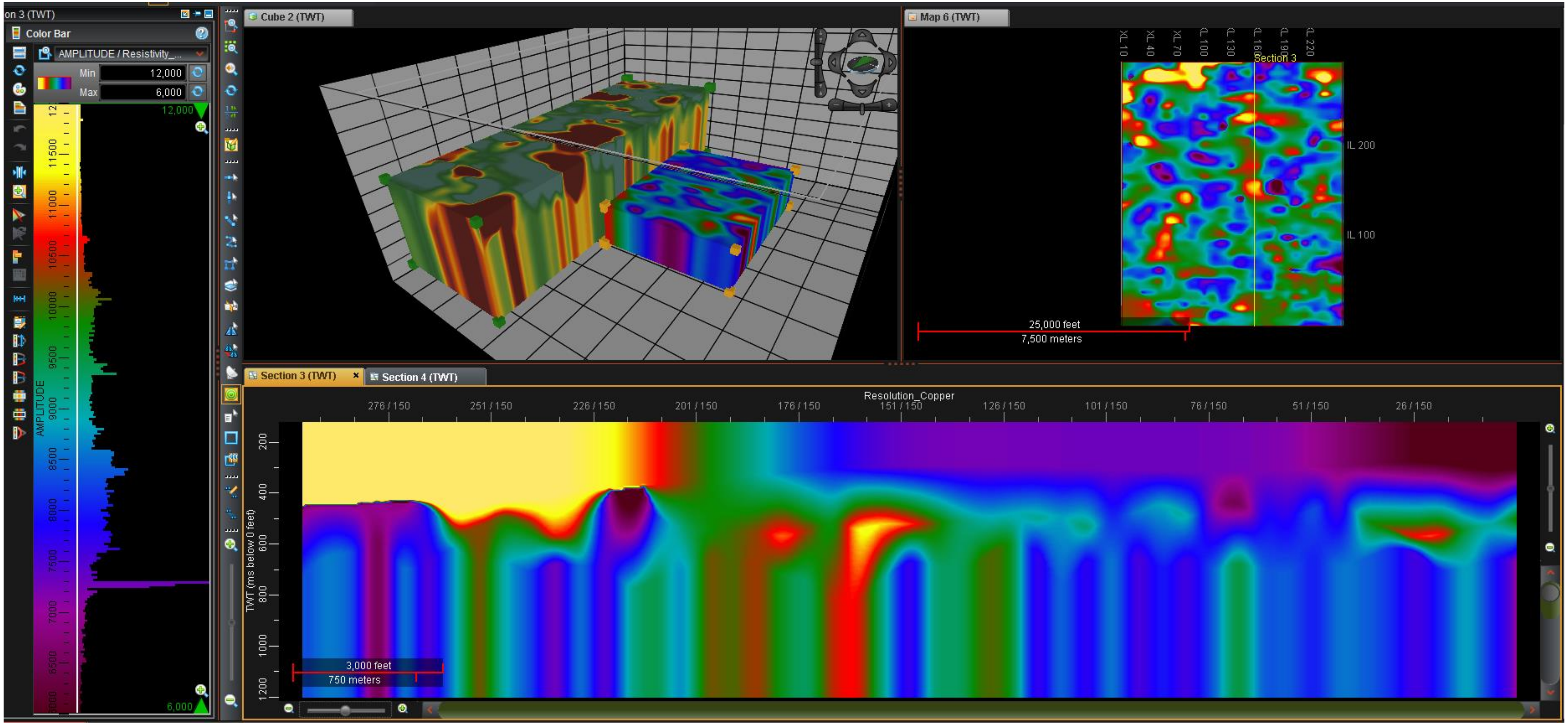
Determining Resistivity and Depth

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.

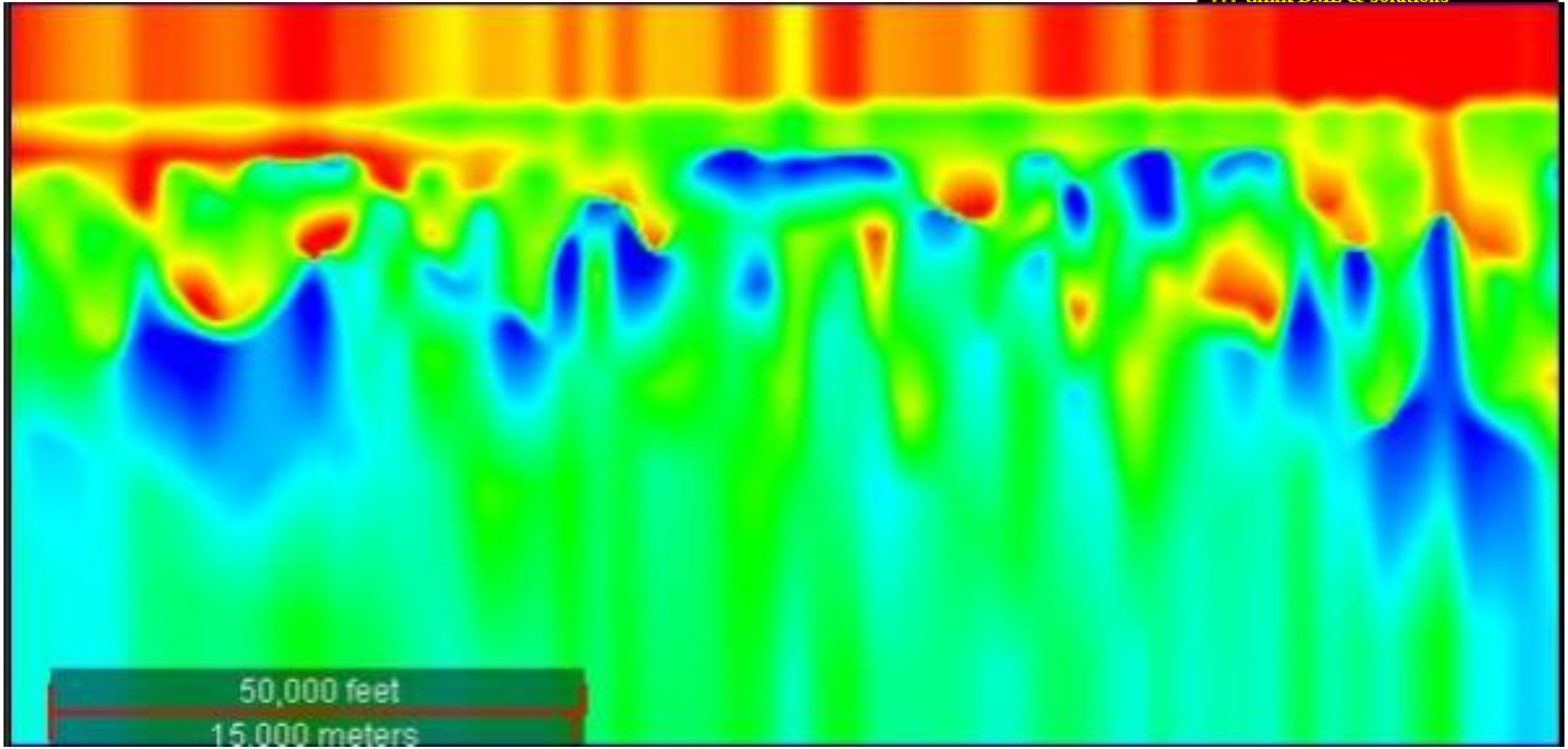
A Resistivity Trace

- 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.

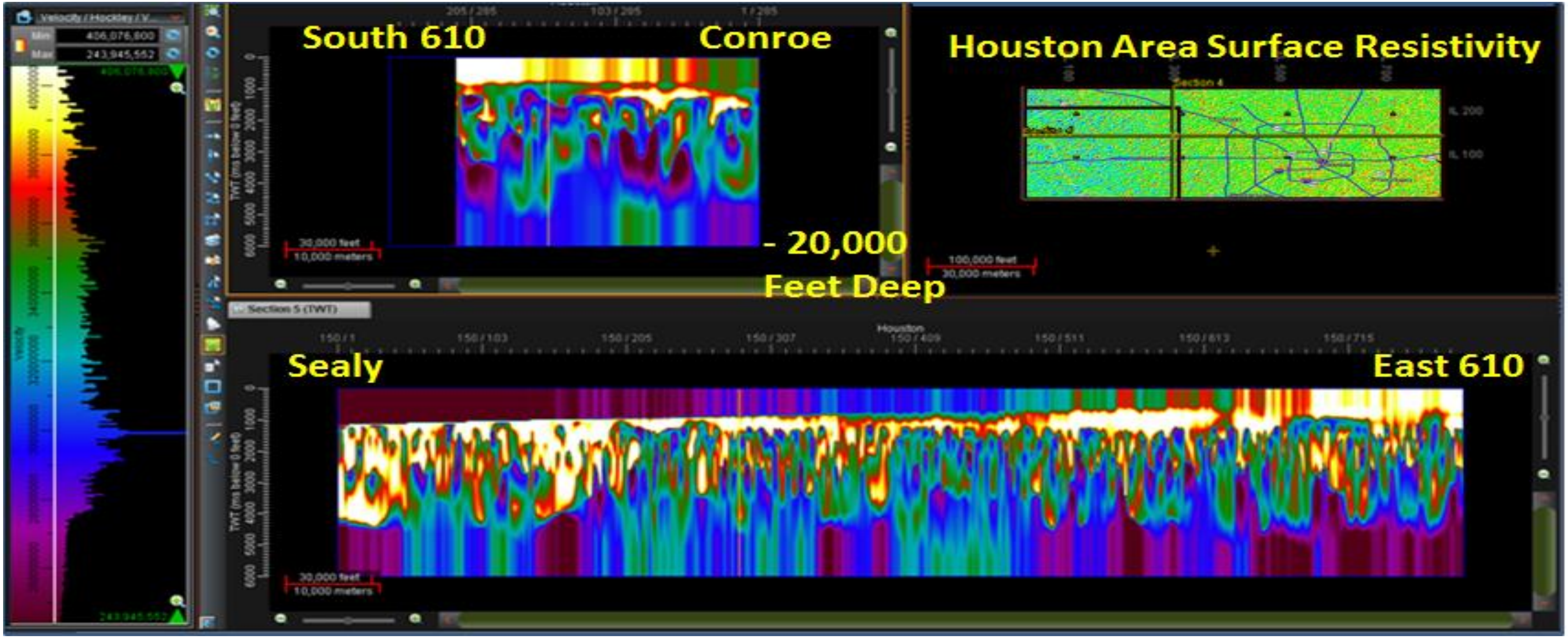
Resistivity Volume Arizona



Resistivity Volume Cross-Section



Houston Area Resistivity Volume Example



IP (Induced Polarization) Effect

- IP Effect is the departure of measured voltage from the square wave input current

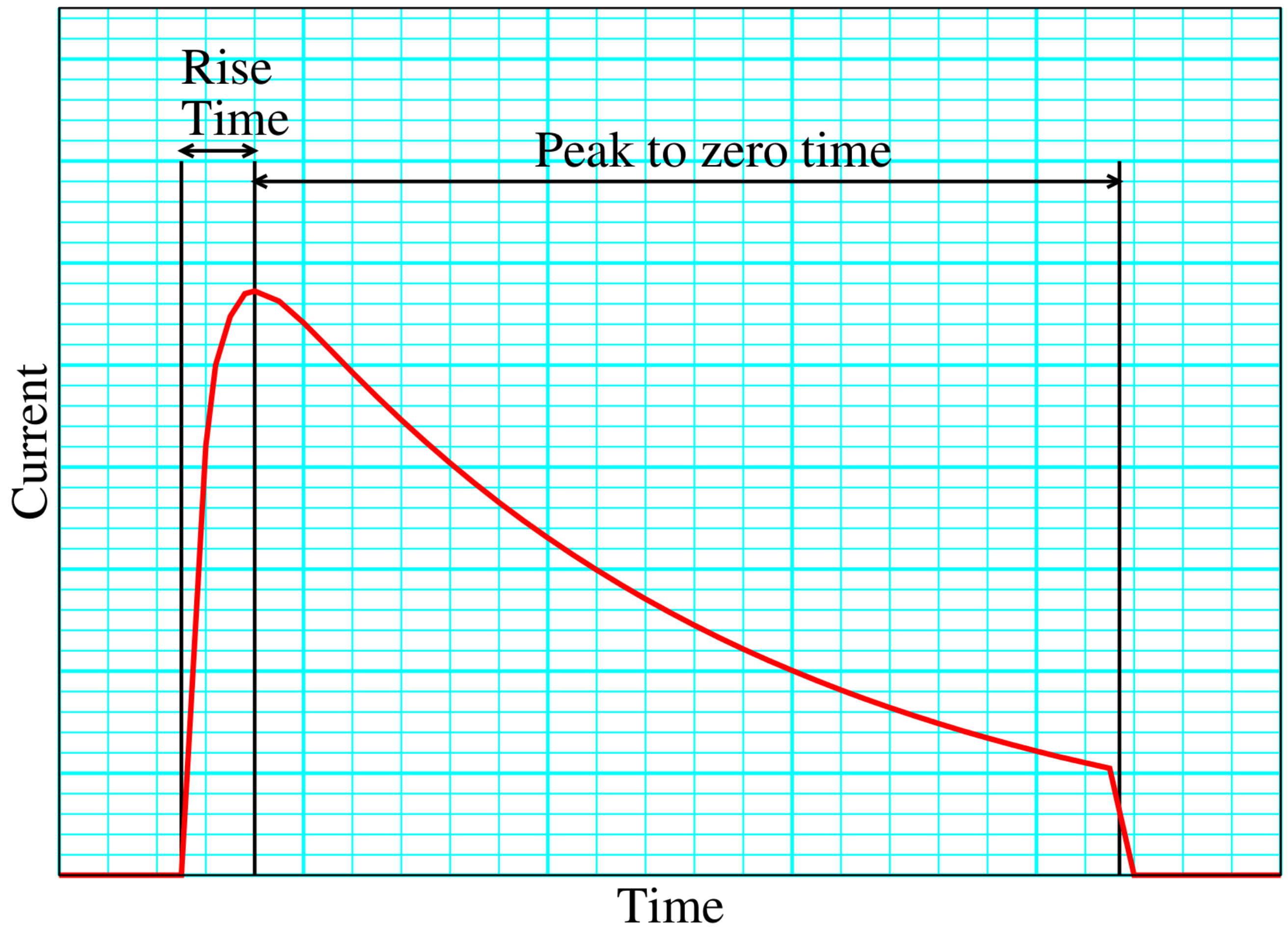
- It can be measured on either the decay curve or on the charging curve

Lightning and the IP Effect

- Lightning does not have a square waveform

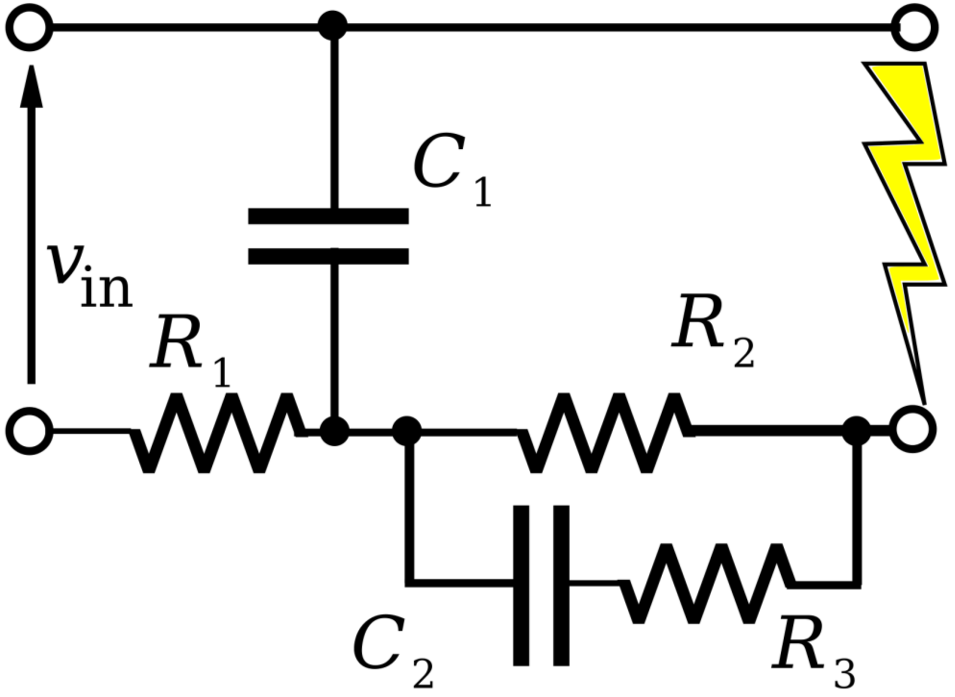
- But it does have a very steep onset

- Variations in the onset as measured (rise-time) show the IP Effect



The equivalent circuit

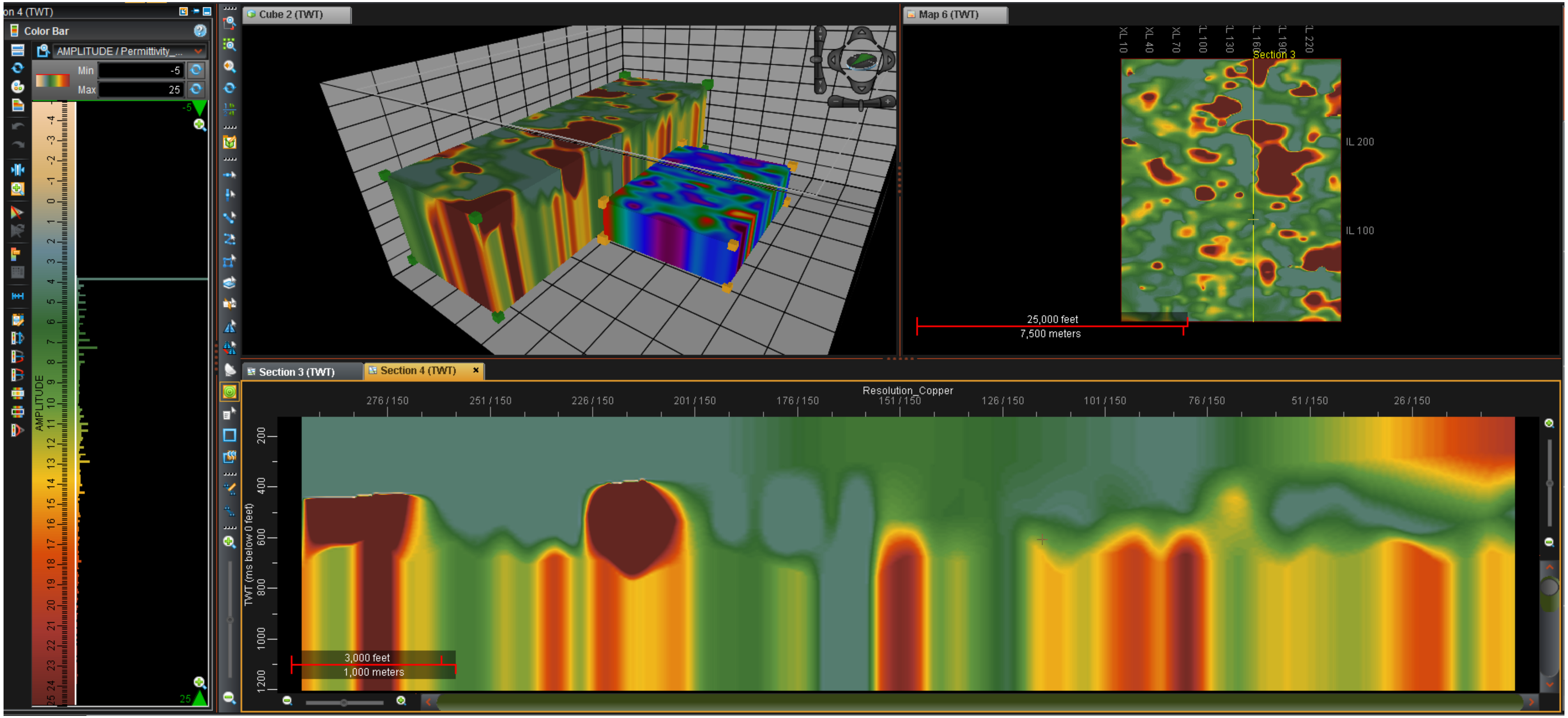
- By treating this as charging a capacitor (C_2) through a resistor (R_3), an apparent capacitance can be calculated
- From apparent capacitance a value for average permittivity can be calculated



Permittivity volumes

- Depth of penetration for permittivity depends on lightning stroke energy
- Lightning strokes at any location vary in energy due to meteorological variations
- Over time a permittivity-depth function can be constructed at any location
- This allows construction of a three-dimensional model of permittivity covering any area and with any geometry
- Resolution and depth range are limited by the number of lightning strikes and the variation in their energy

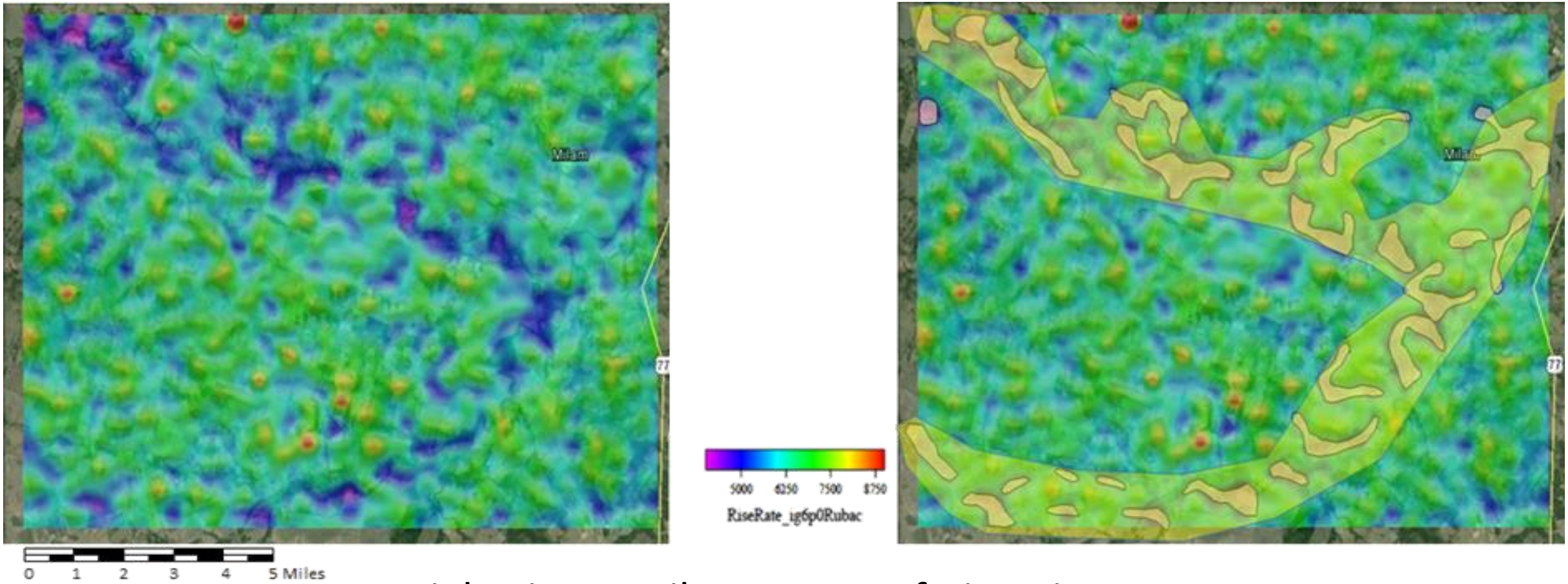
Permittivity Volumes Arizona



4. Examples of using lightning databases to map geology

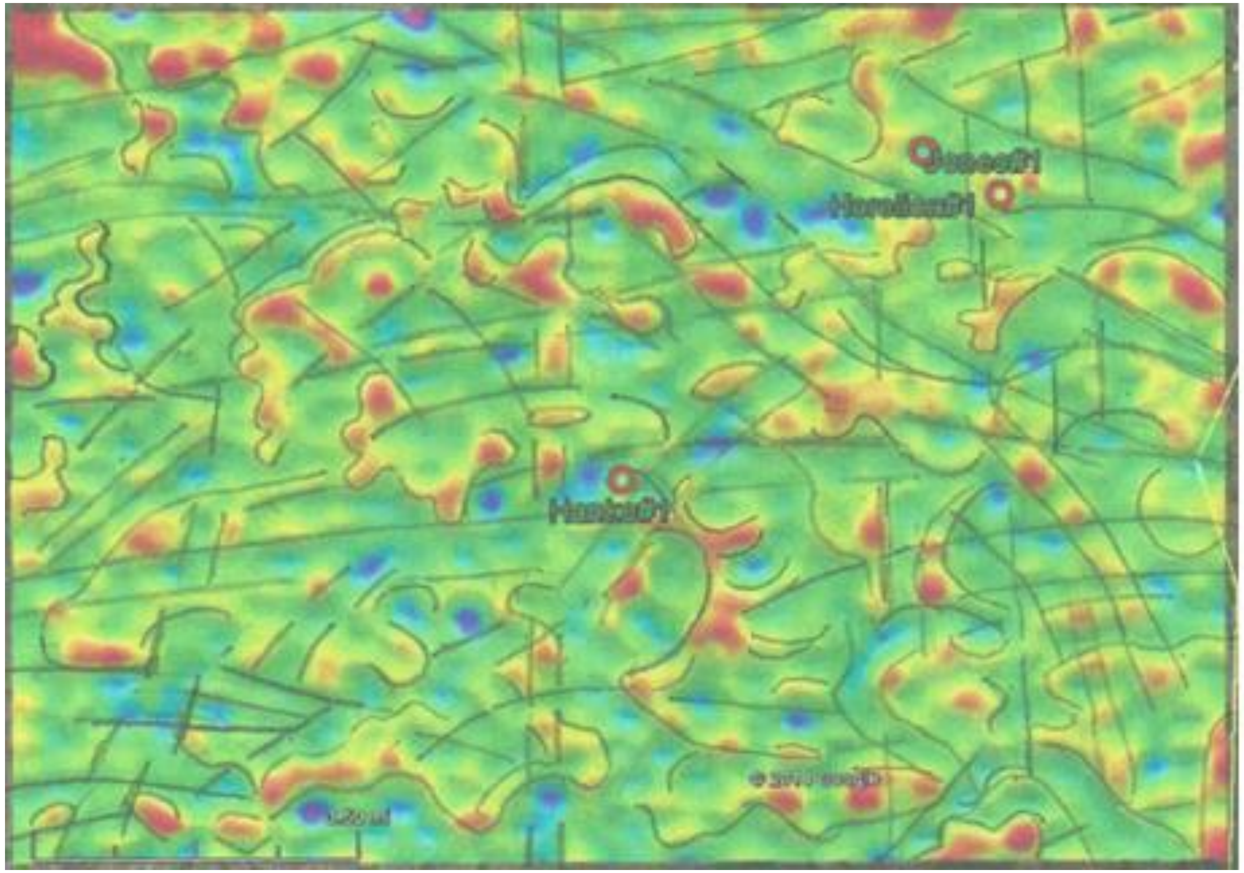
Lightning Analysis
Defines Stratigraphy

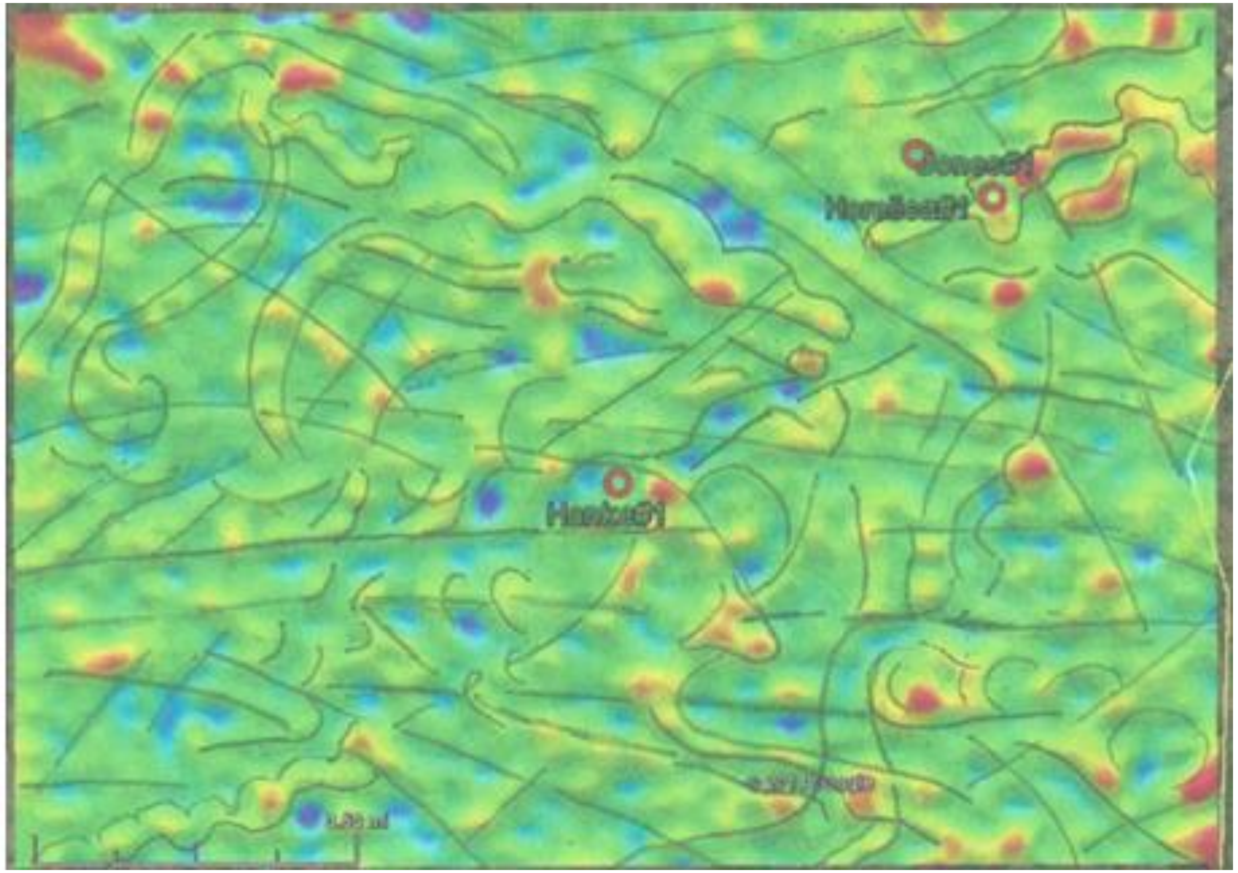
See Lightning . . .
DML
. . . think DML & solutions



Lightning Attribute: Rate of Rise-Time

Lightning Analysis
Interprets Paleochannels and Meander Schrolls

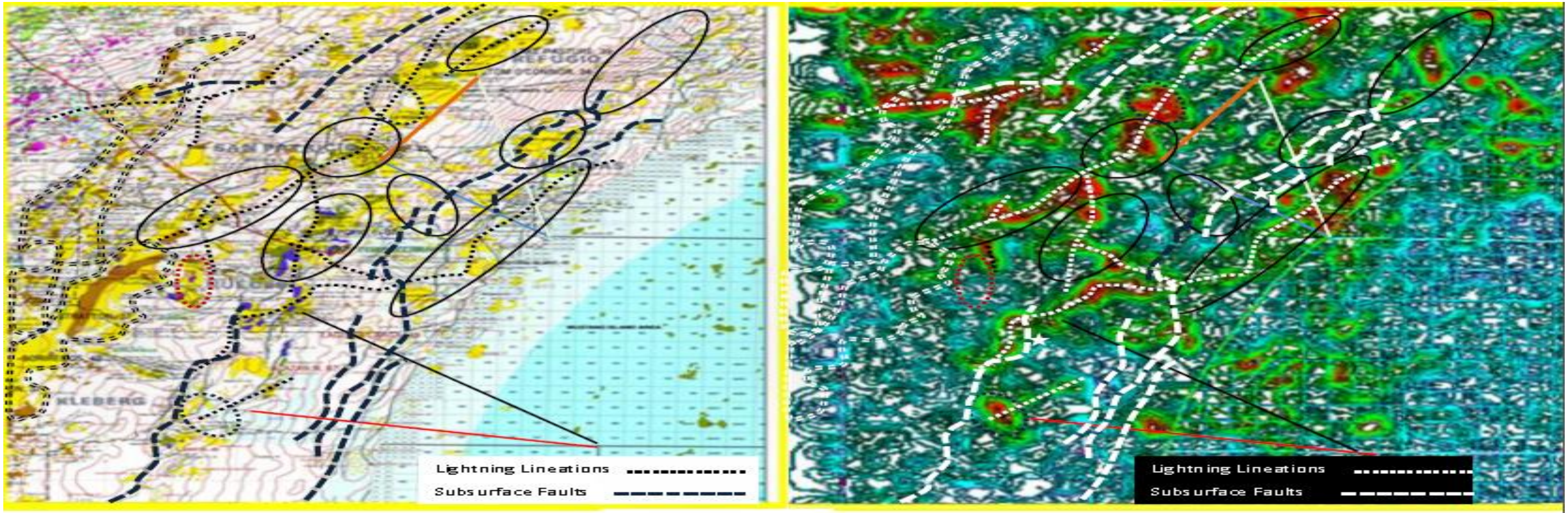




Lightning Attributes: Surface Resistivity (left) Peak-to-Zero (right)

Lightning Analysis
Correlates with Fields

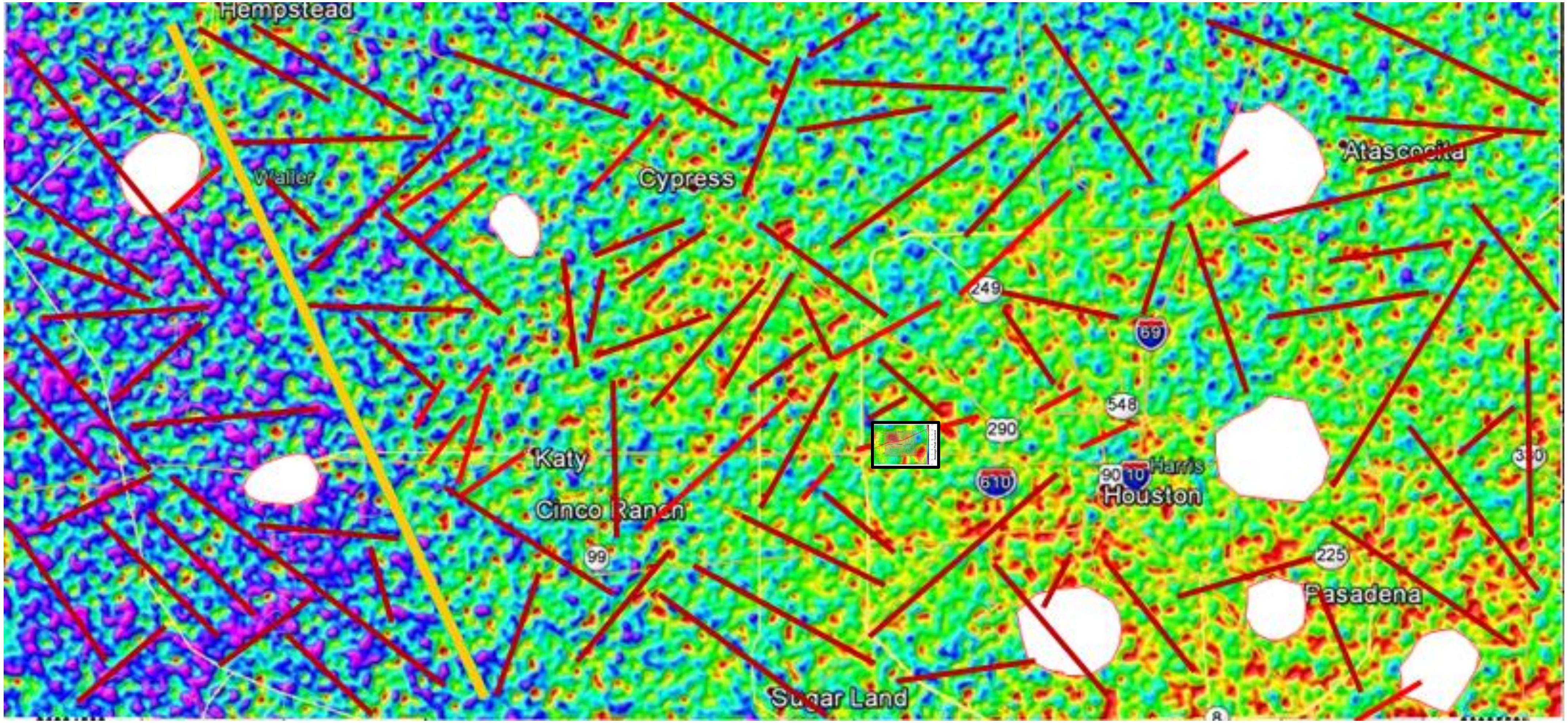
See Lightning . . .
DML
. . . think DML & solutions



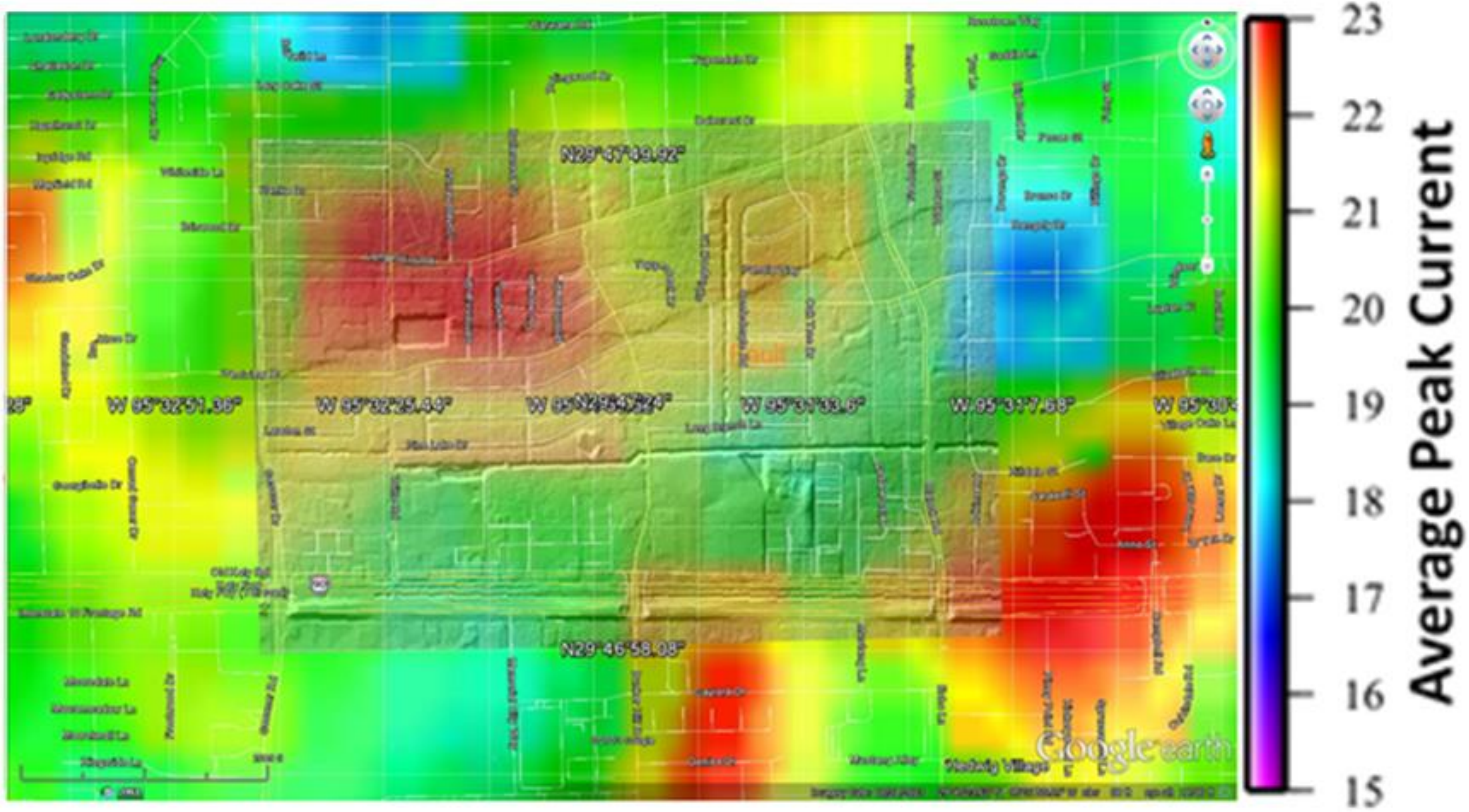
Second Pass

Dark Red	Production but no anomaly.
Black	Anomaly correlates to production.
Red, Black, Dark Blue, Olive Green	Location Line Aids
(star)	Excellent Examples
Dark Blue	Anomaly but no production.
Black	Production with partial to no anomaly.
Black & White	Field alignment, minimal correlation.

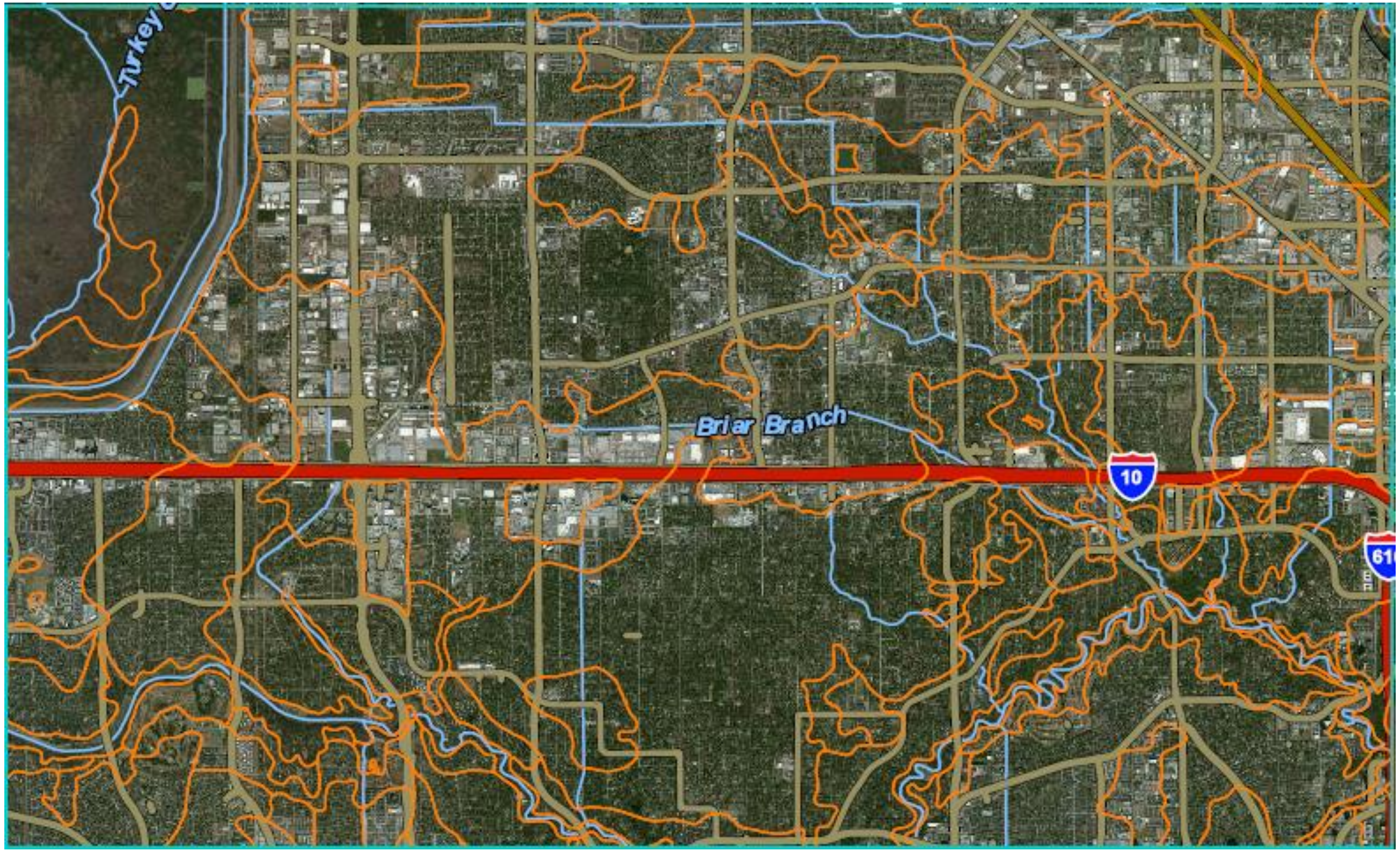
Peak Current from Sealy to East Houston



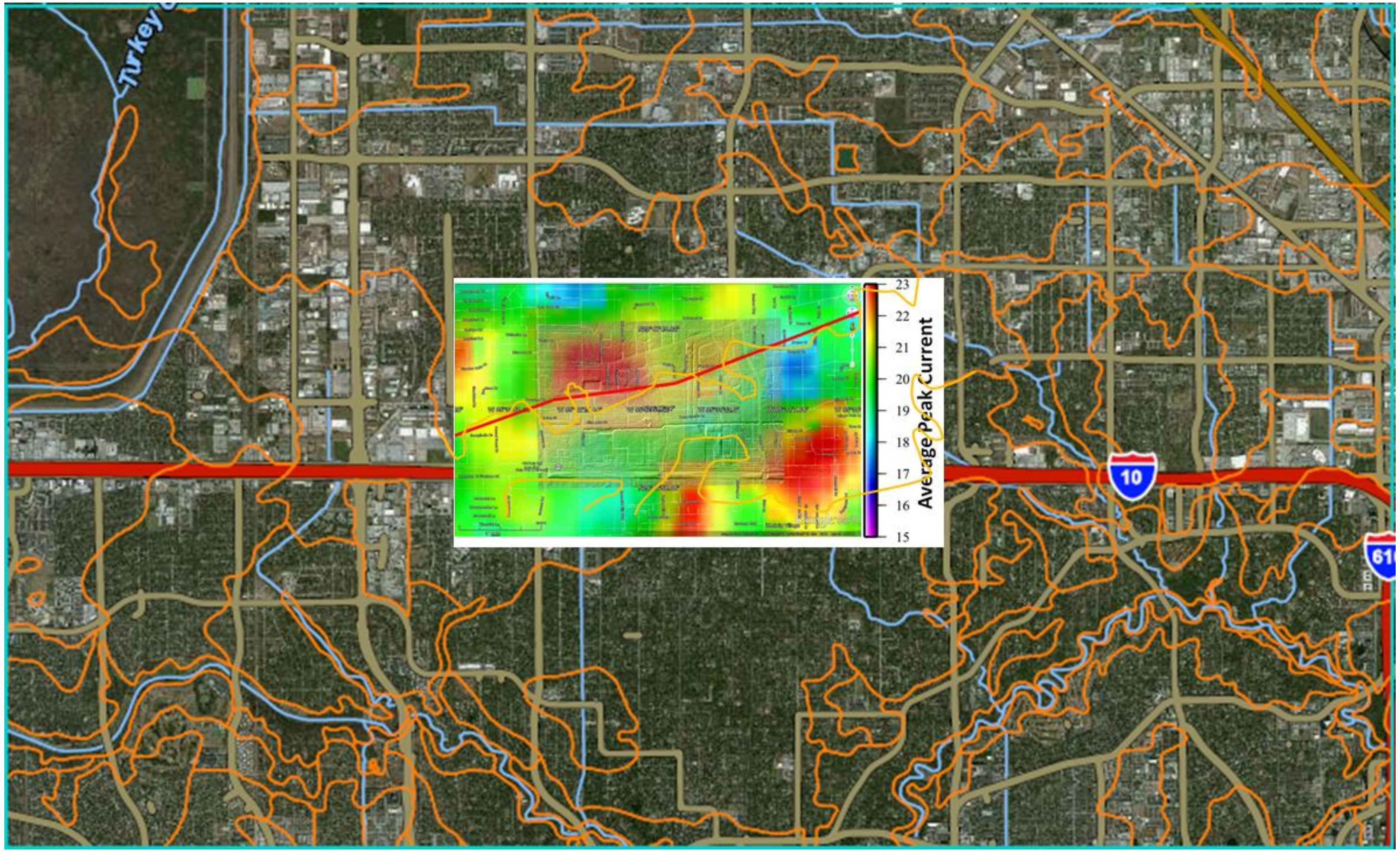
Peak Current Zoom
with LIDAR & Long Point Fault



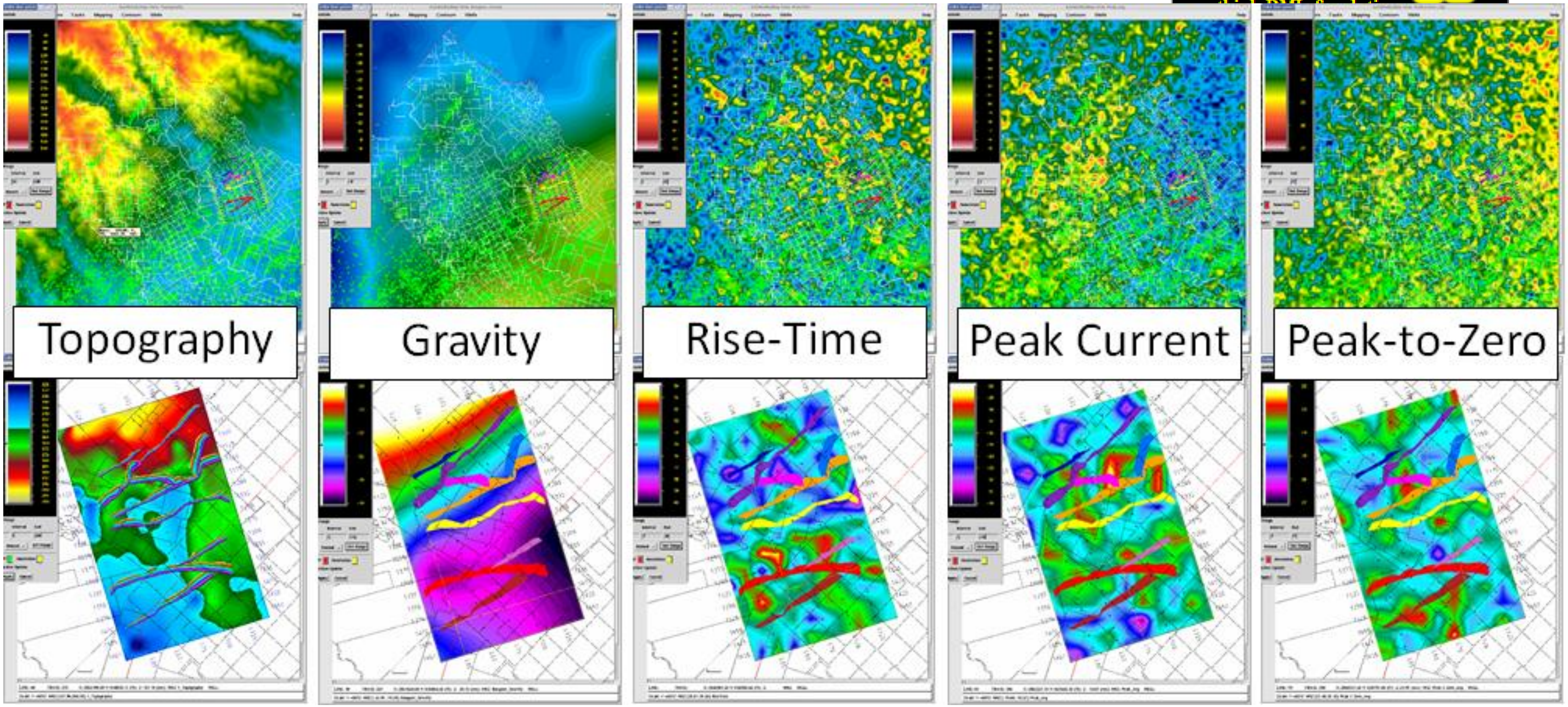
Soils Map over GoogleEarth™ Map



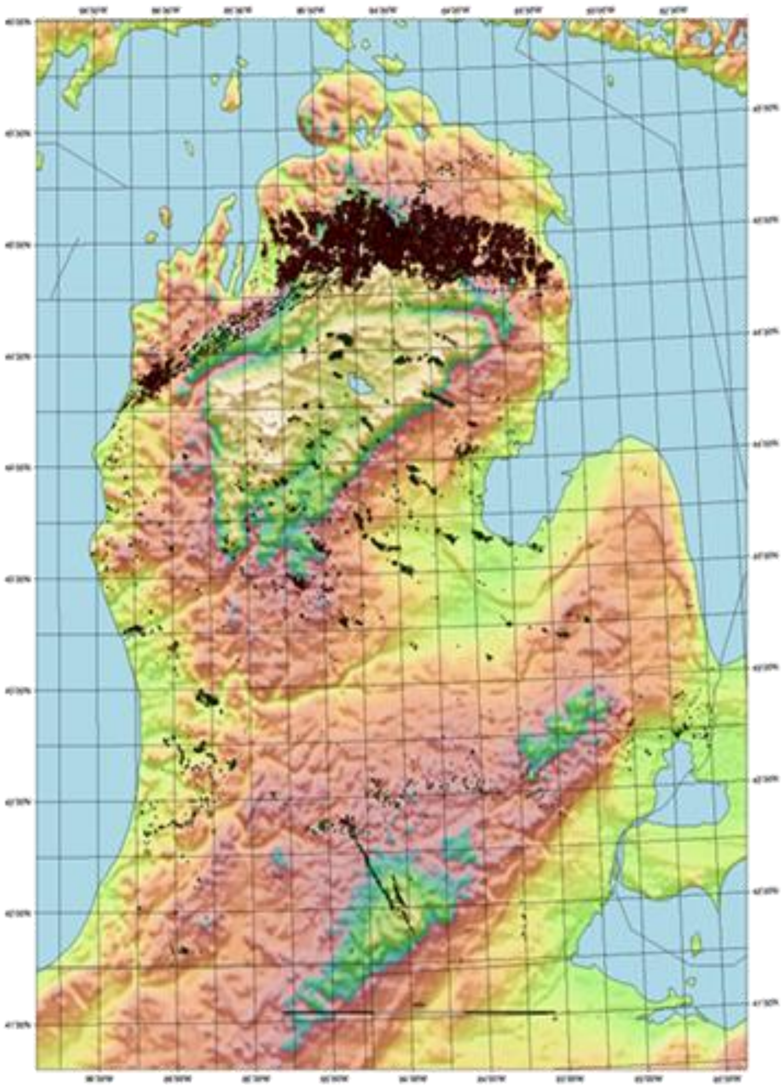
Integration with Long Point Fault over Soils over LIDAR over Peak Current over GoogleEarth™

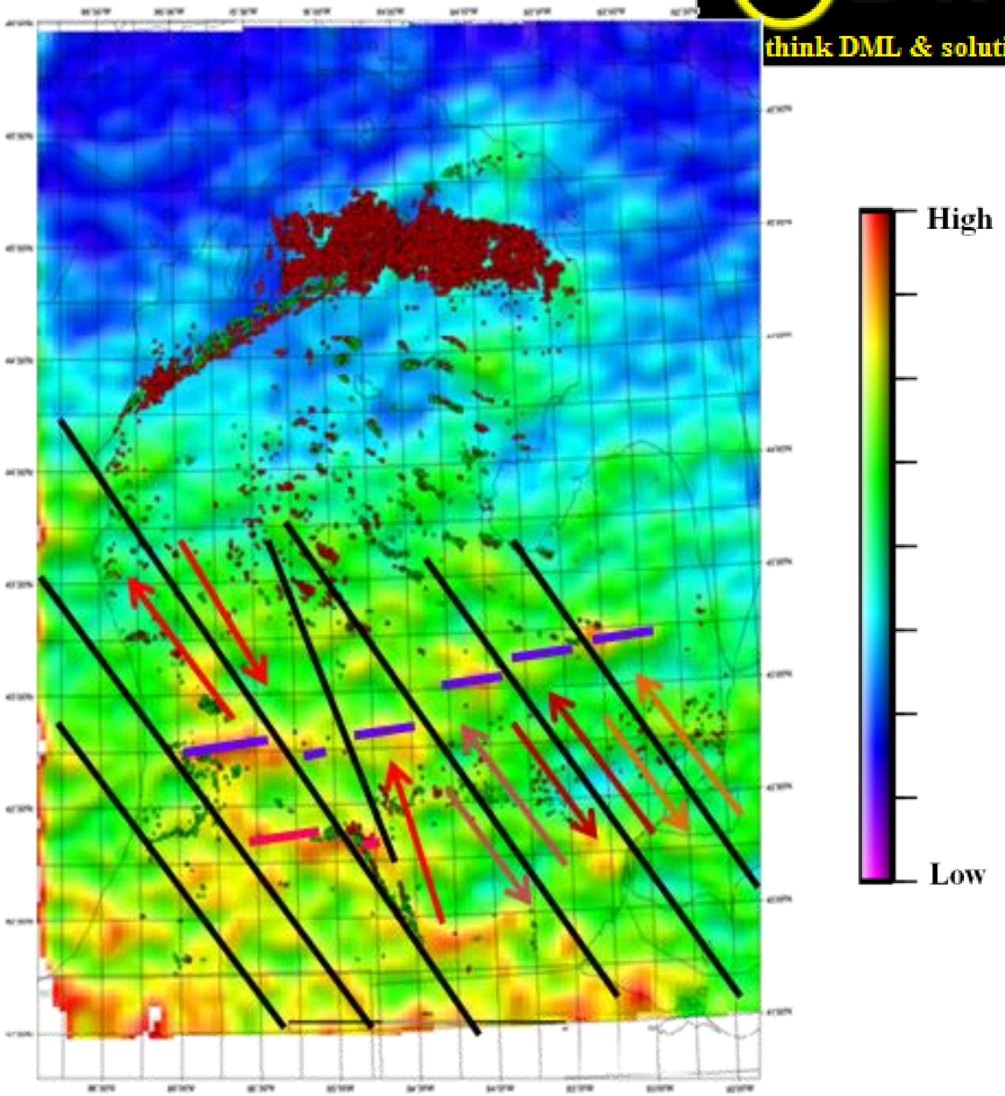


A New Potential Fields Method,
Supplementing Gravity & Magnetics

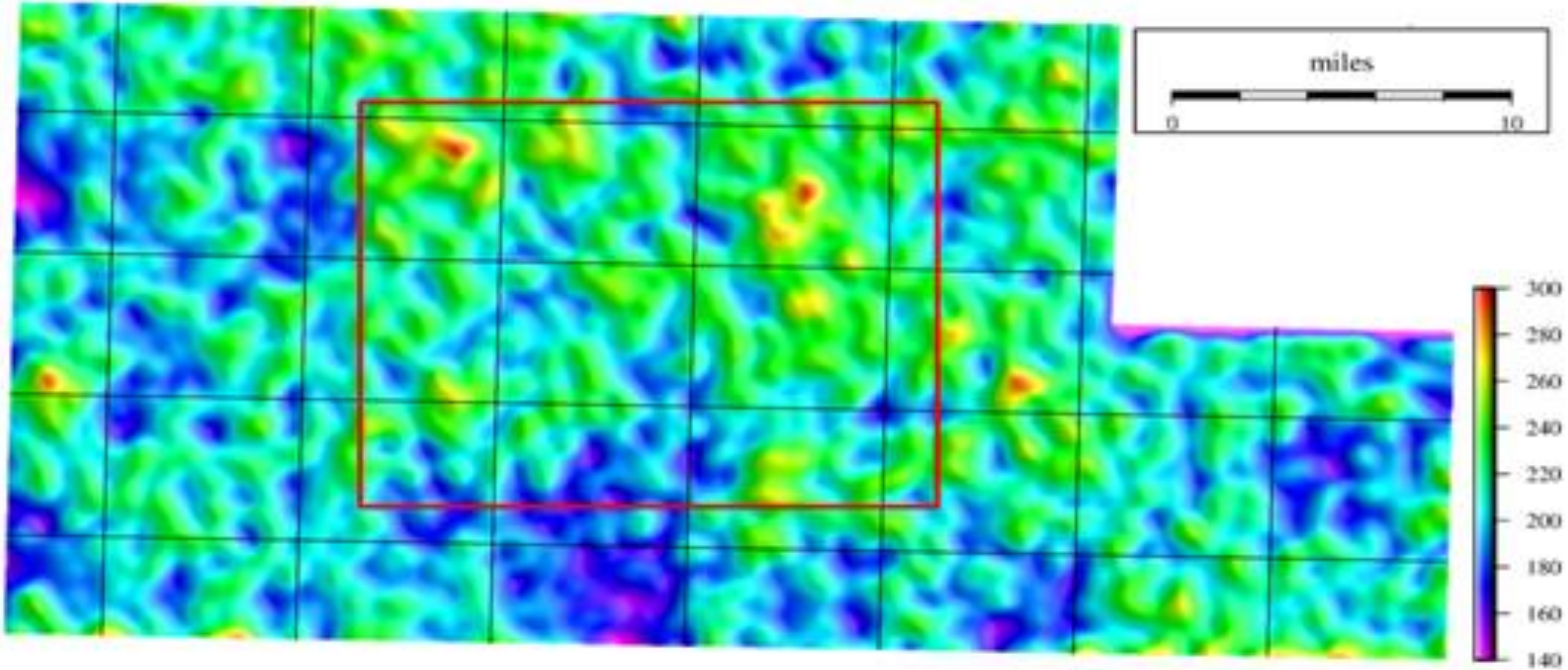


Michigan Basin Topography & Strike Density

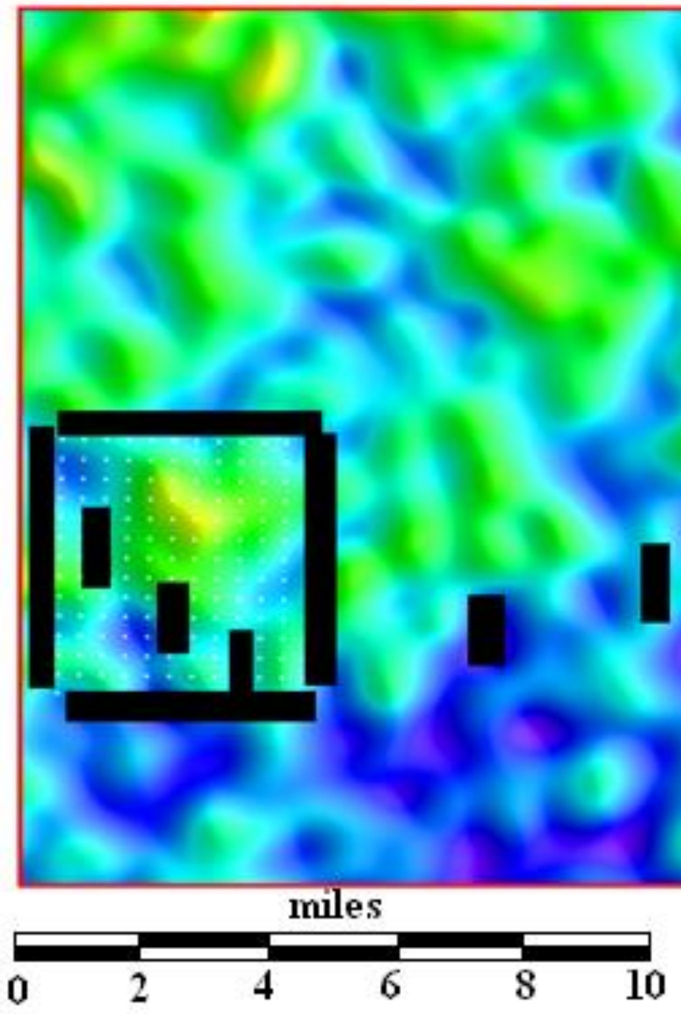


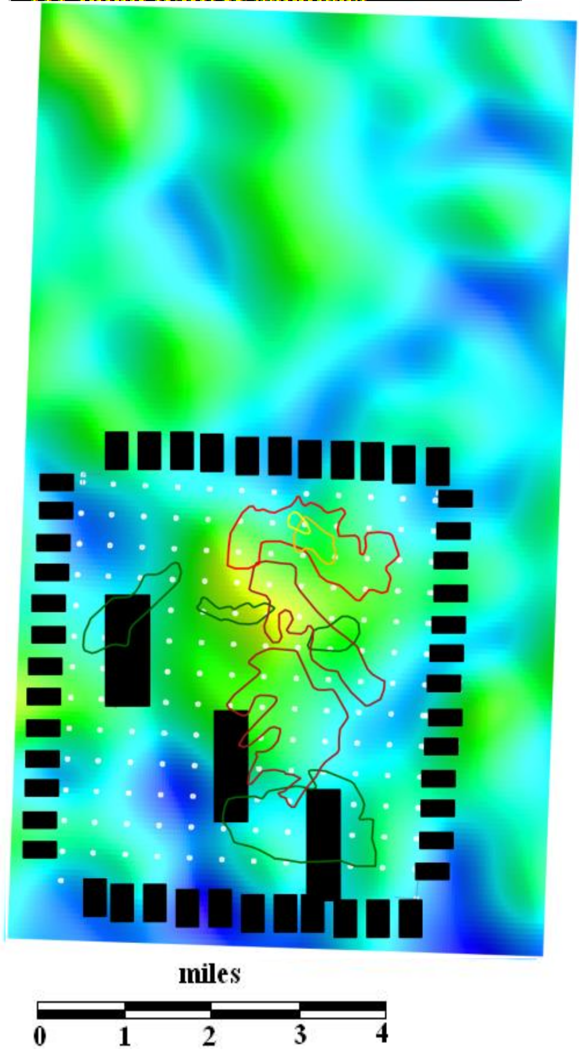


Lightning Analysis - Quicker Regional Overviews

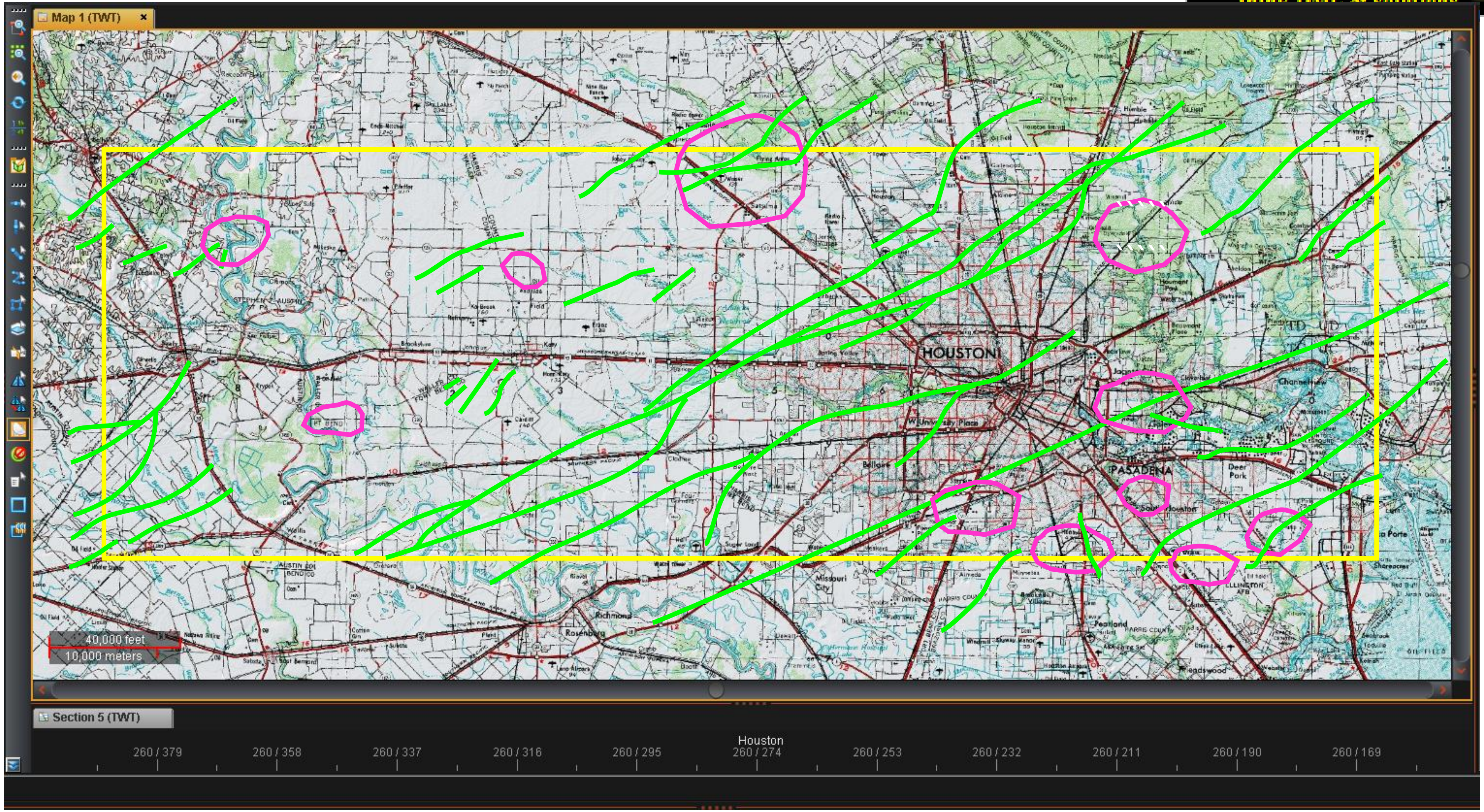


More details at Play Fairway & Prospect Scales

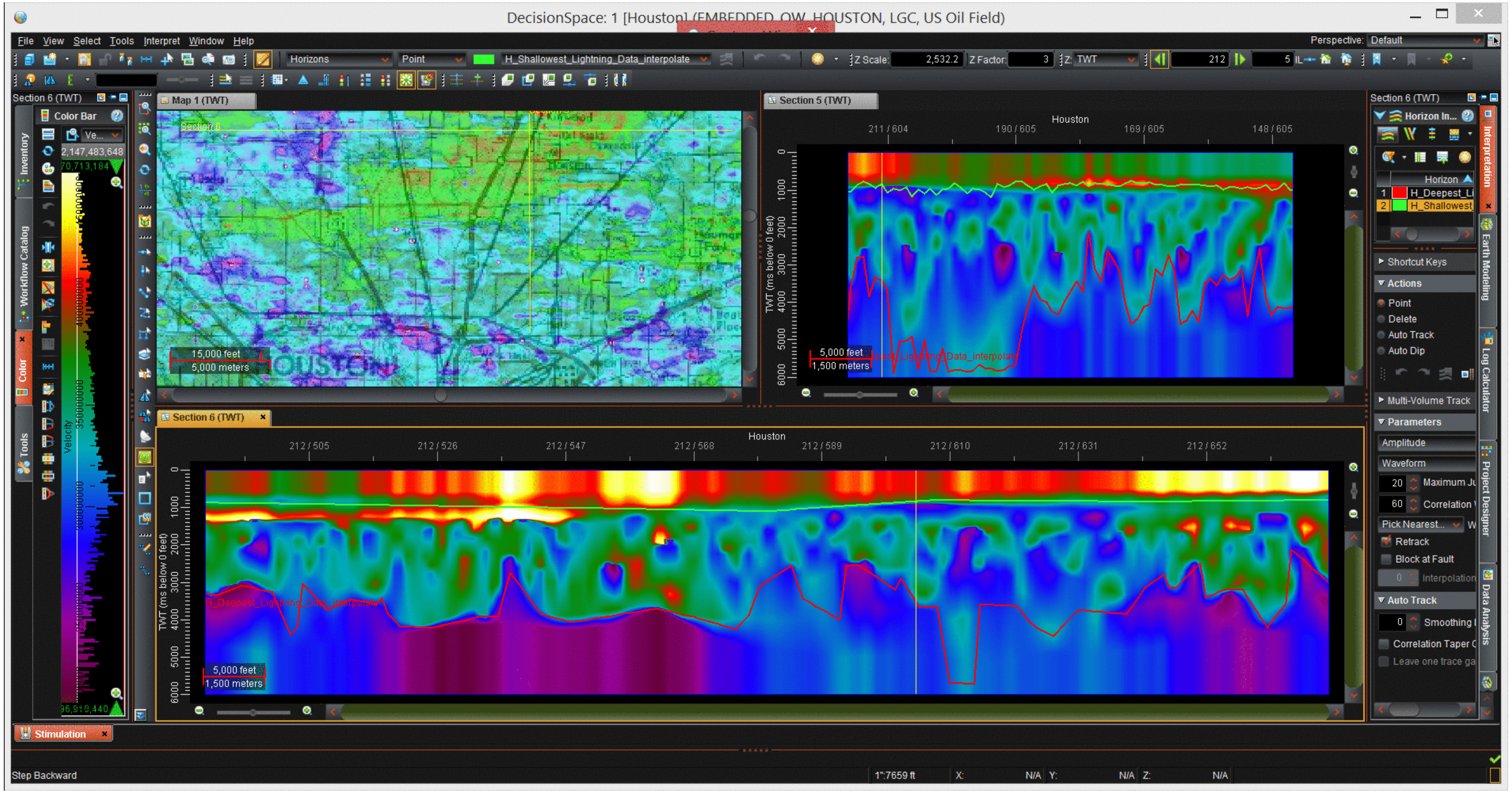




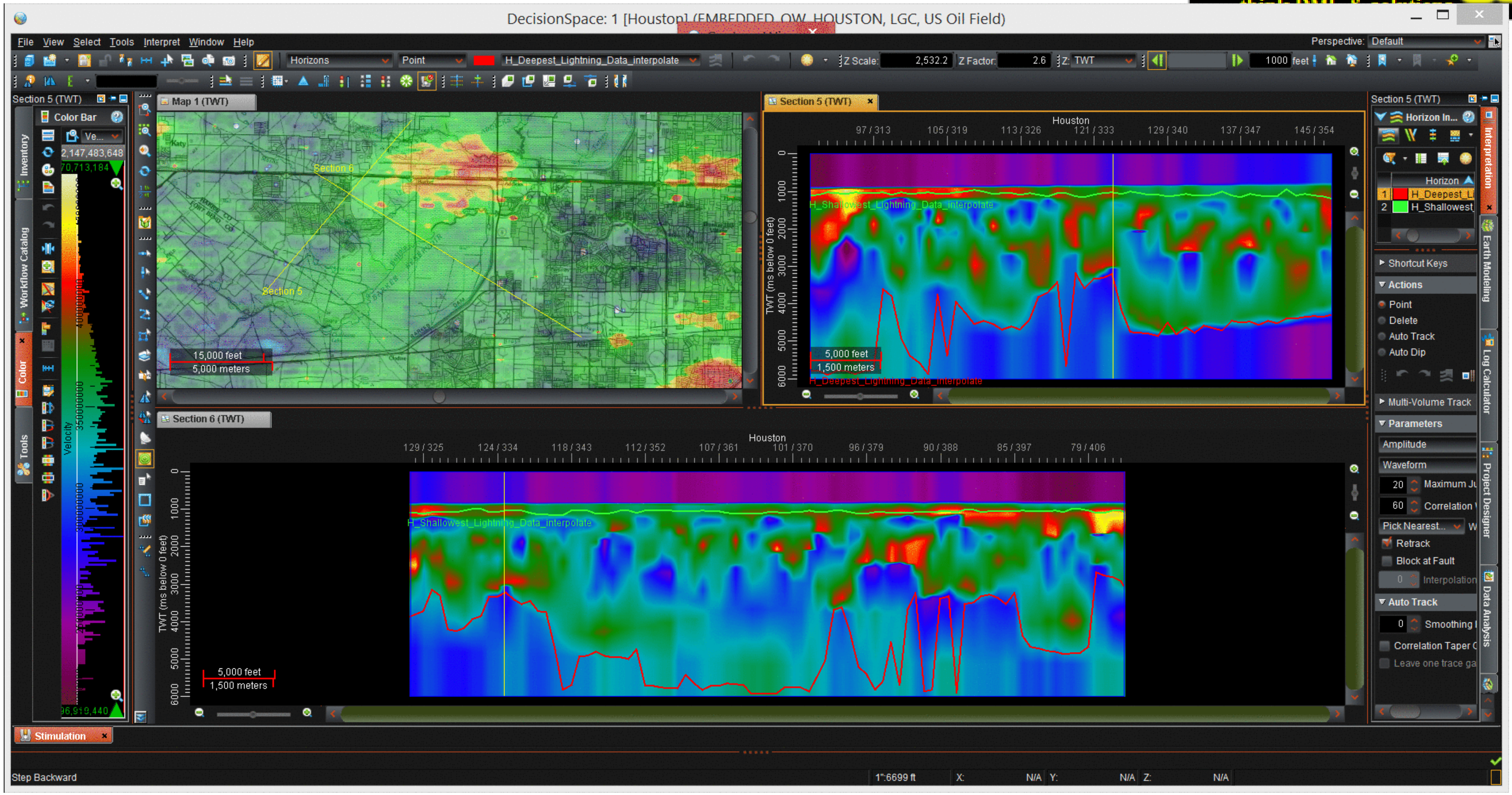
Imagine collecting a 3-D seismic survey here!



North Houston In-Line Animation

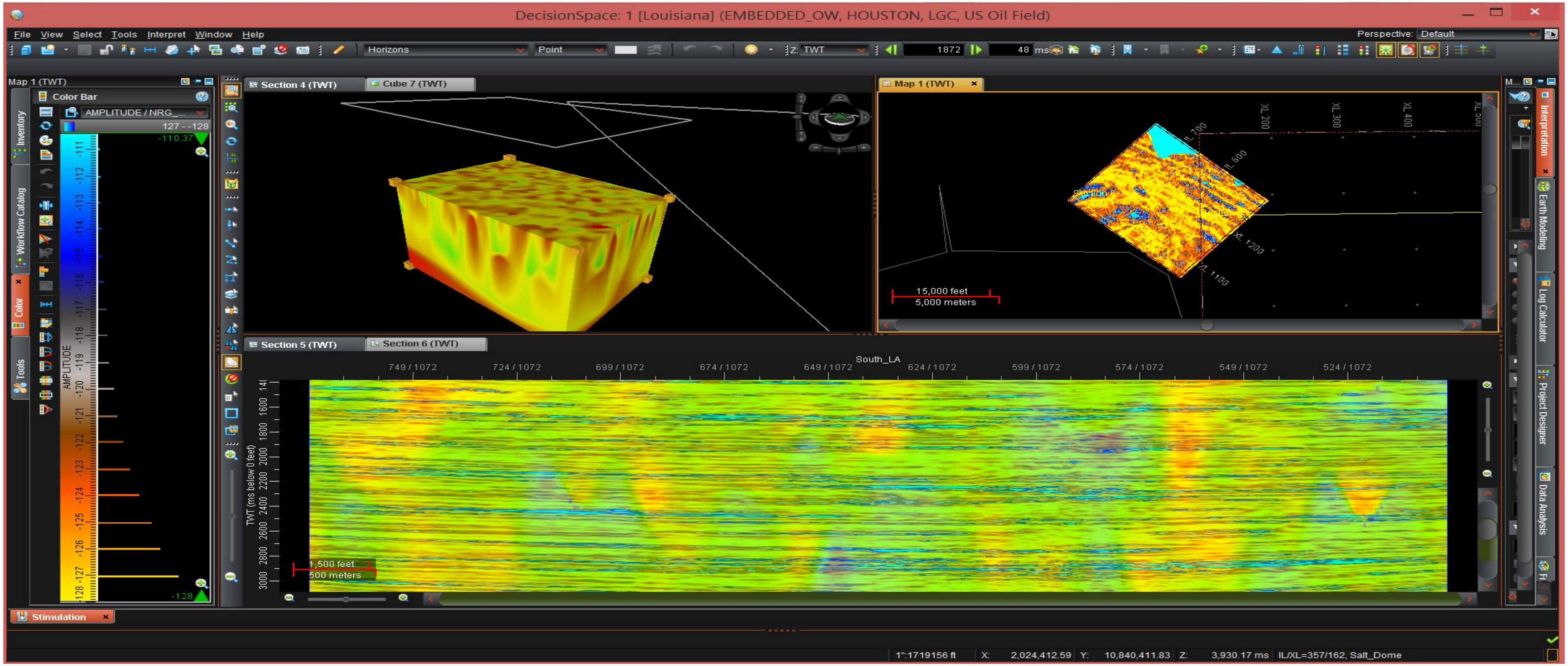


USACE George Bush Park Pipeline Animation

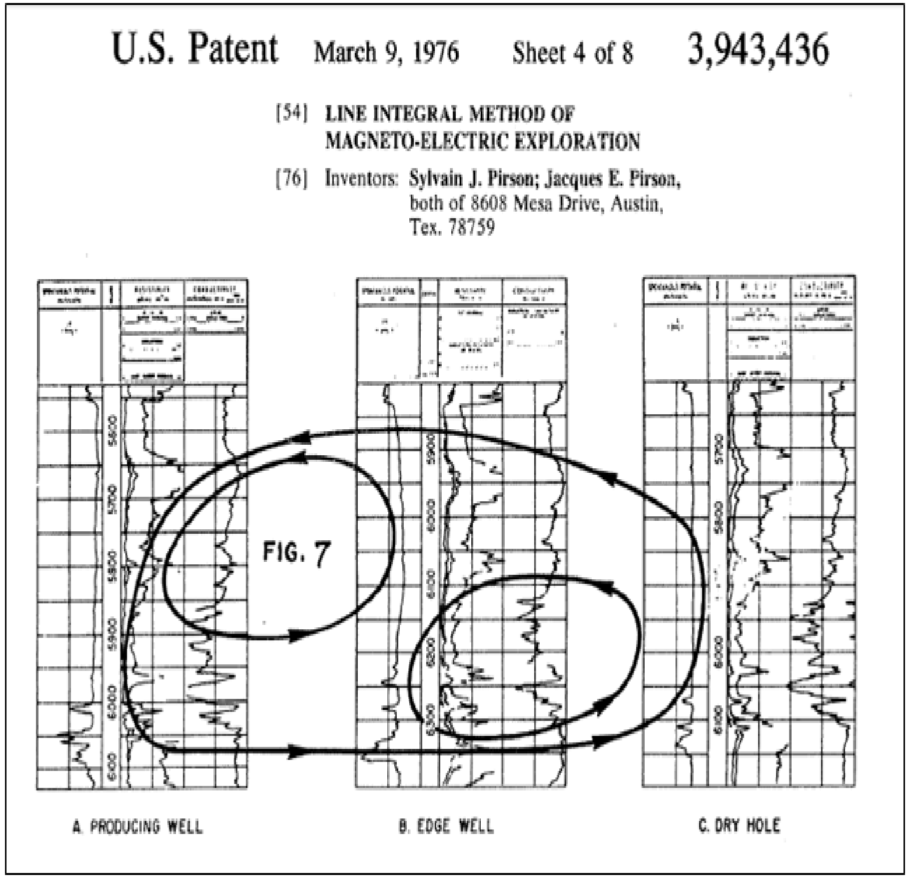


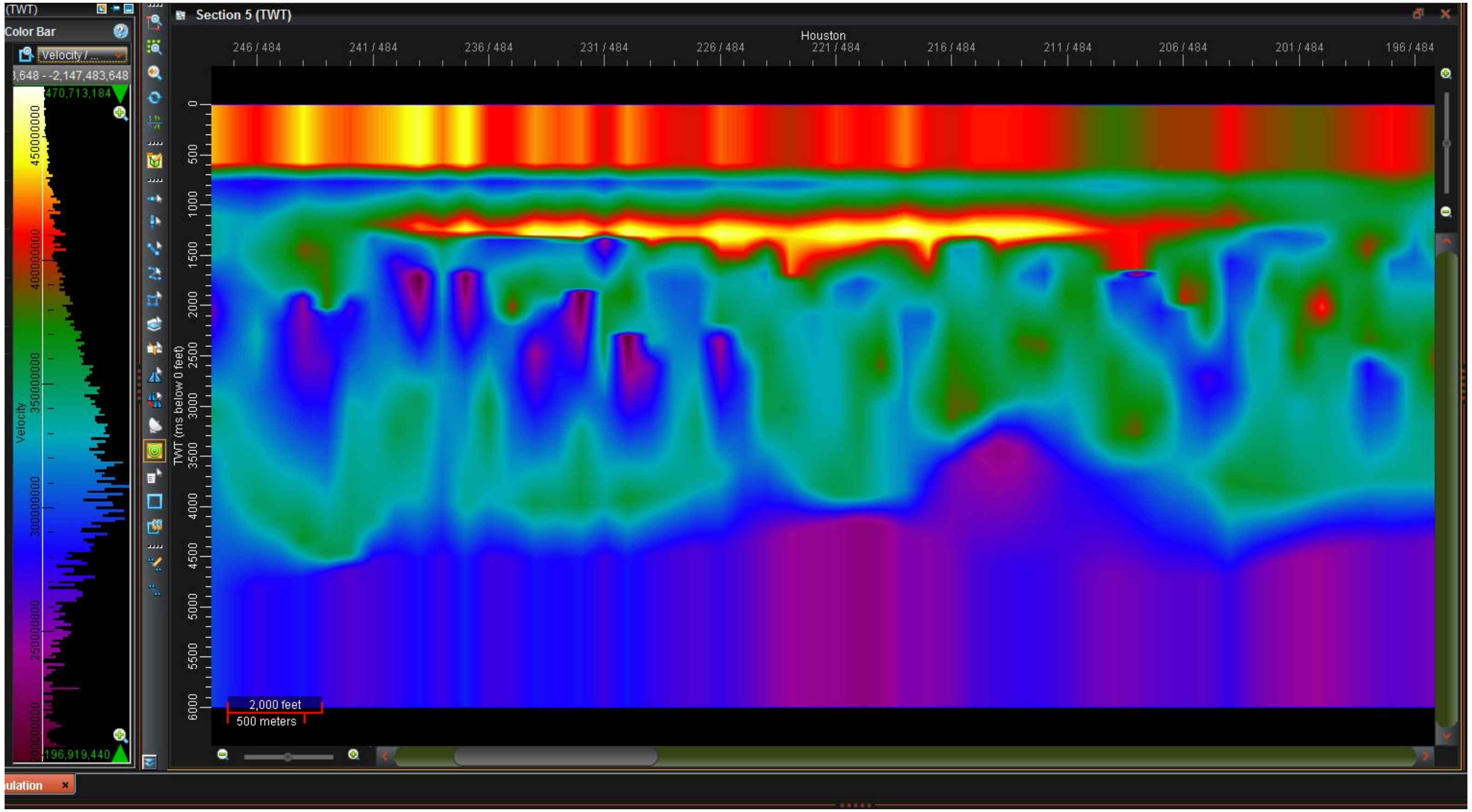
Resistivity Volumes

Complement Velocity Volumes

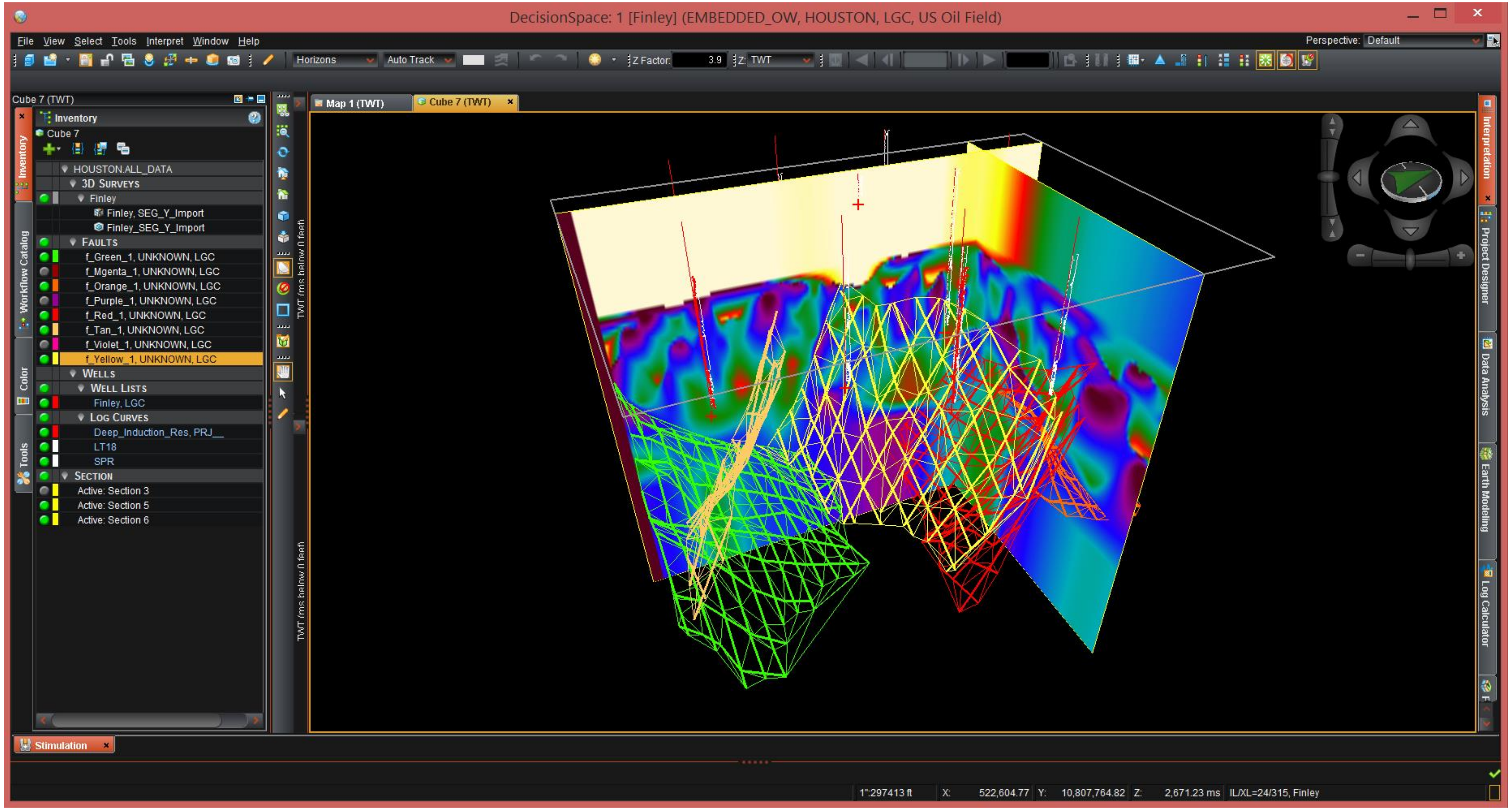


Electrical Currents (Telluric and Terralevis)





Texas Resistivity Fault Interpretation - 1



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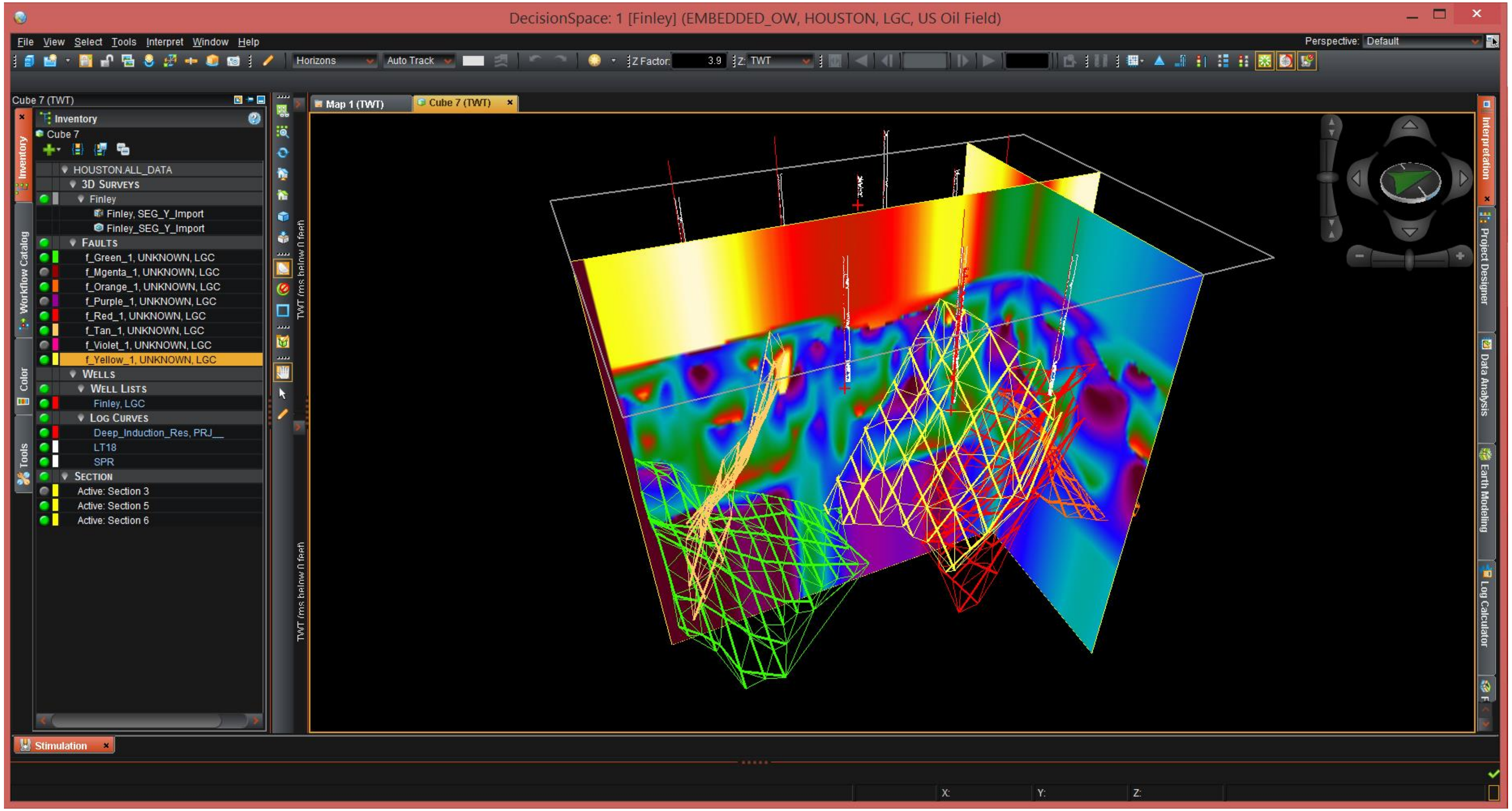
Texas Resistivity Fault Interpretation - 2



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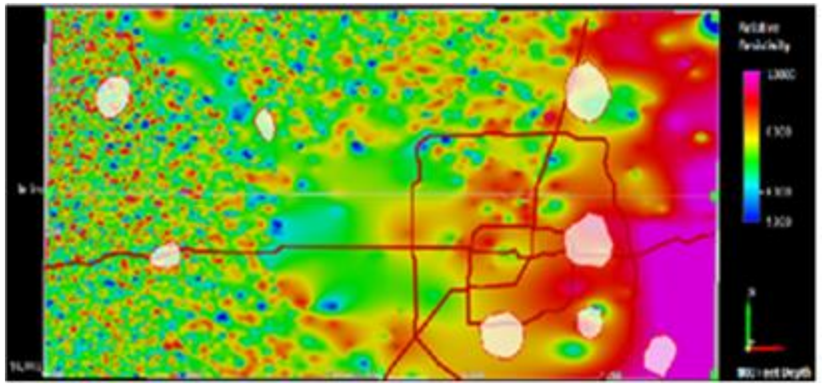
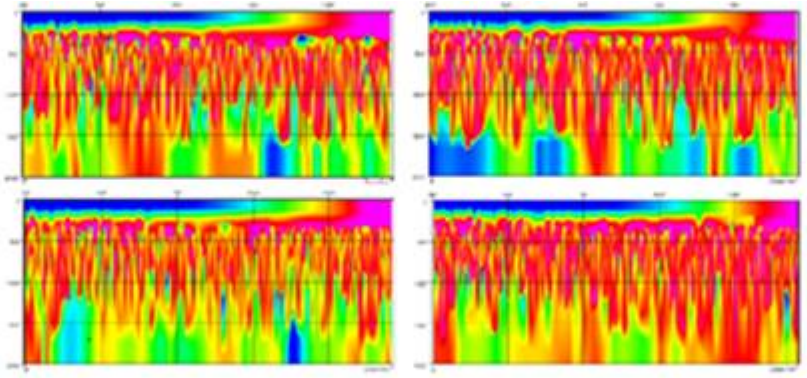
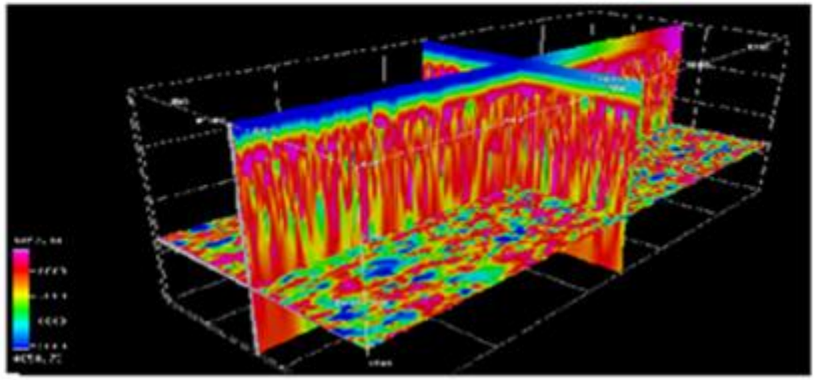
NSEM and Resistivity Volumes are a Technology Breakthrough

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

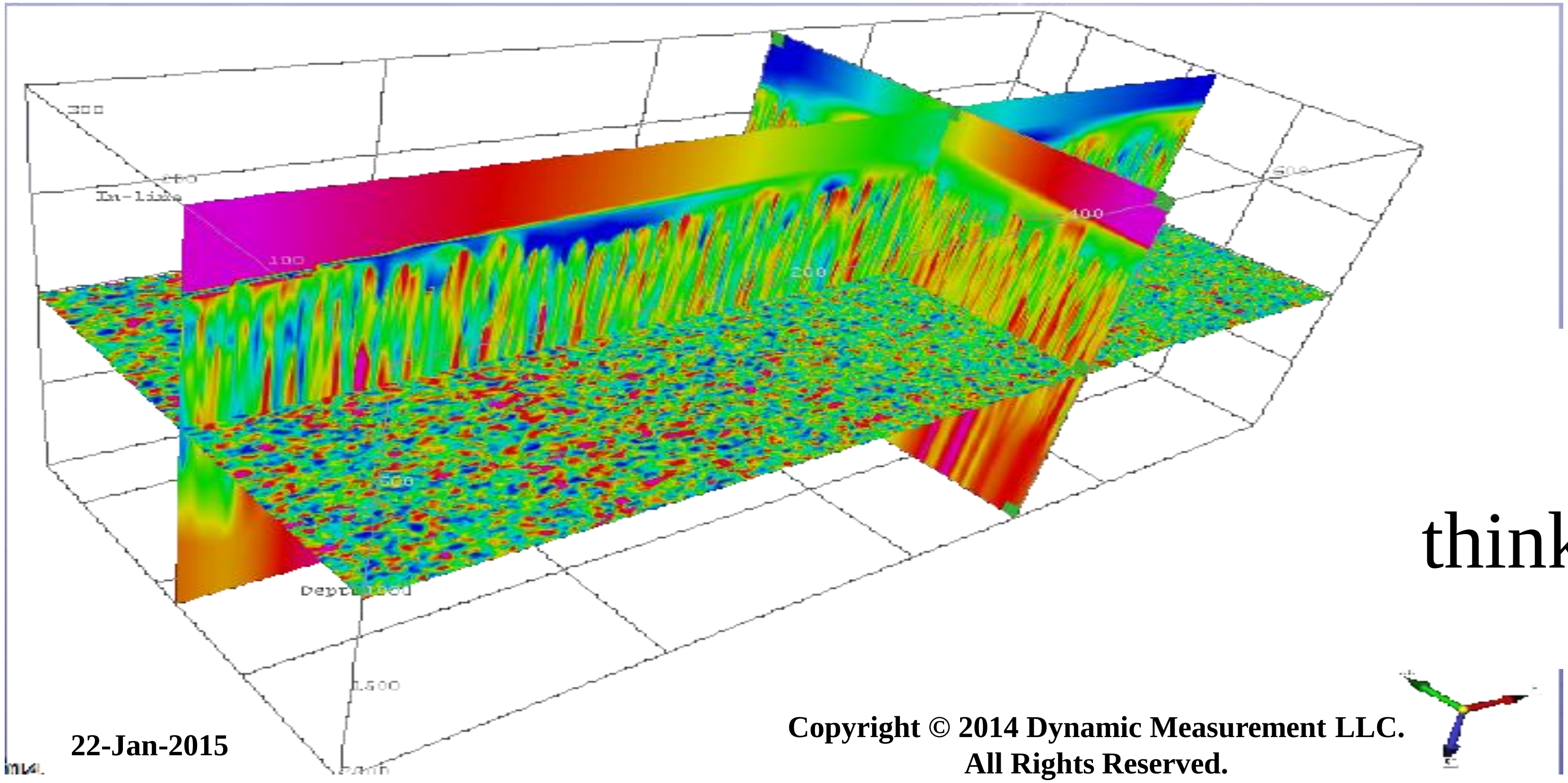
What we have covered:

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

Find out more at

http://www.dynamicmeasurement.com/TAMU
http://www.dynamicmeasurement.com/TAMU/150122_BYU
http://www.dynamicmeasurement.com/TAMU/150122_BYU_Expanded_Presentation

Thank You!



See Lightning,
think DML & solutions!

See Lightning, Think DML

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Discussion