Resistivity Volumes

A Seminar by Dynamic Measurement LLC

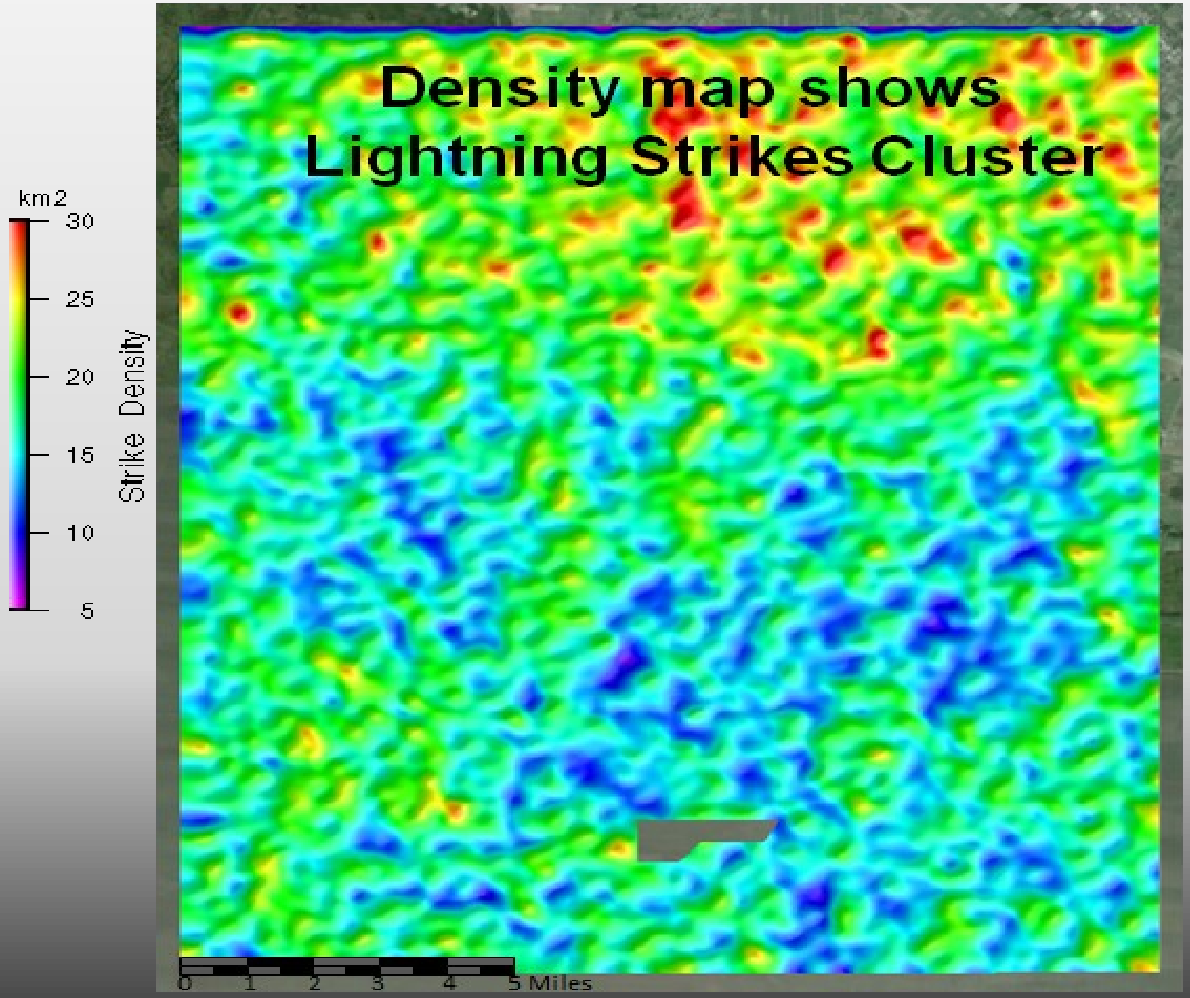
29 October 2014

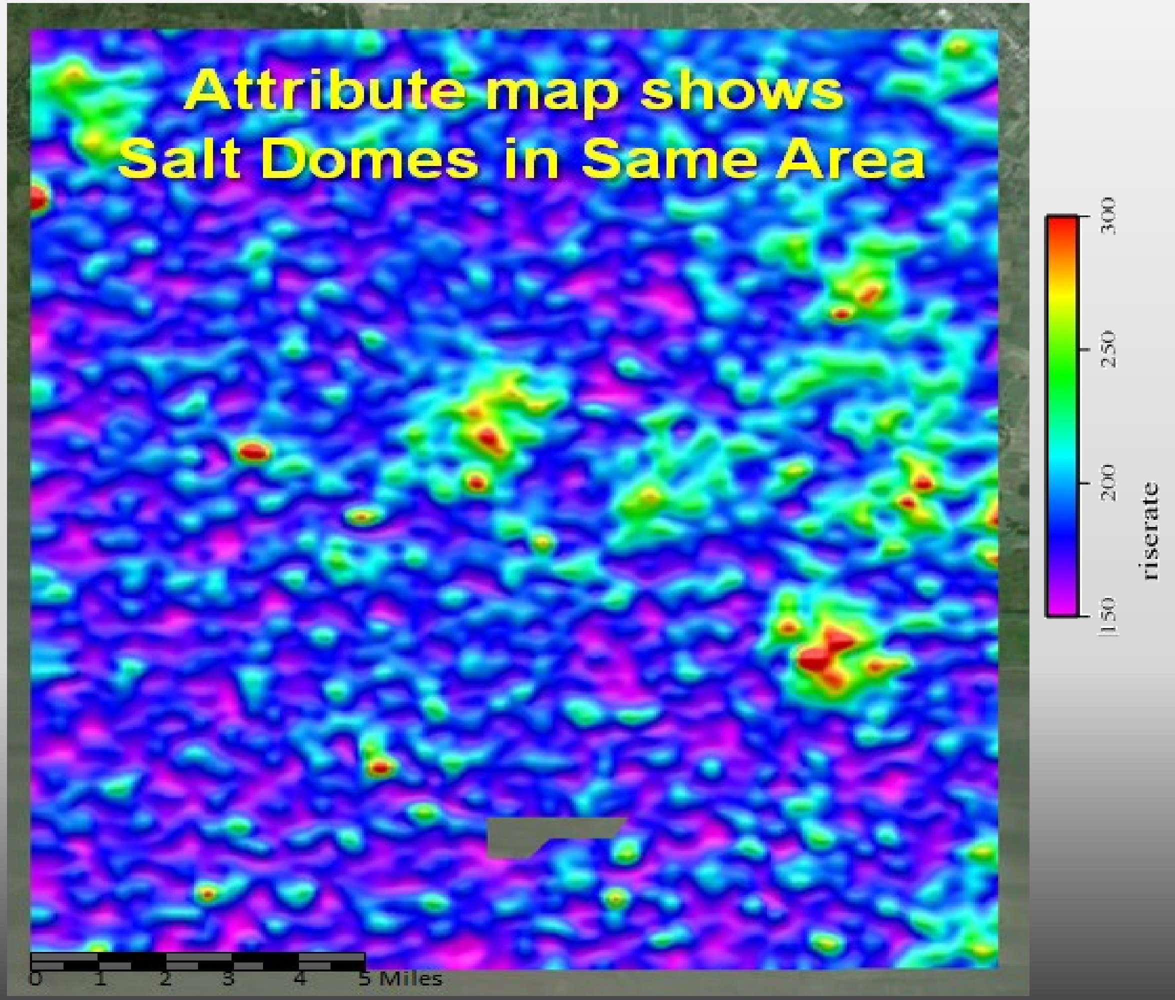
Agenda

3:00 Registration and Introductions
3:30 The meteorology behind lightning databases
3:45 Using lightning databases to explore for natural resources
4:00 Calculating resistivity volumes from lightning databases
4:45 Examples of resistivity volumes and potential applications
- Regional and Play Fairway hydrocarbon migration pathways
- High-grading exploration sweetspots

5:15 Anticipated future developments
- Use with Archie's equation to predict Formation Factor, Porosity, etc.
- Questions and Answers and Discussion among participants

Lightning Data Analysis
Demonstrates Strikes are Tied to Geology

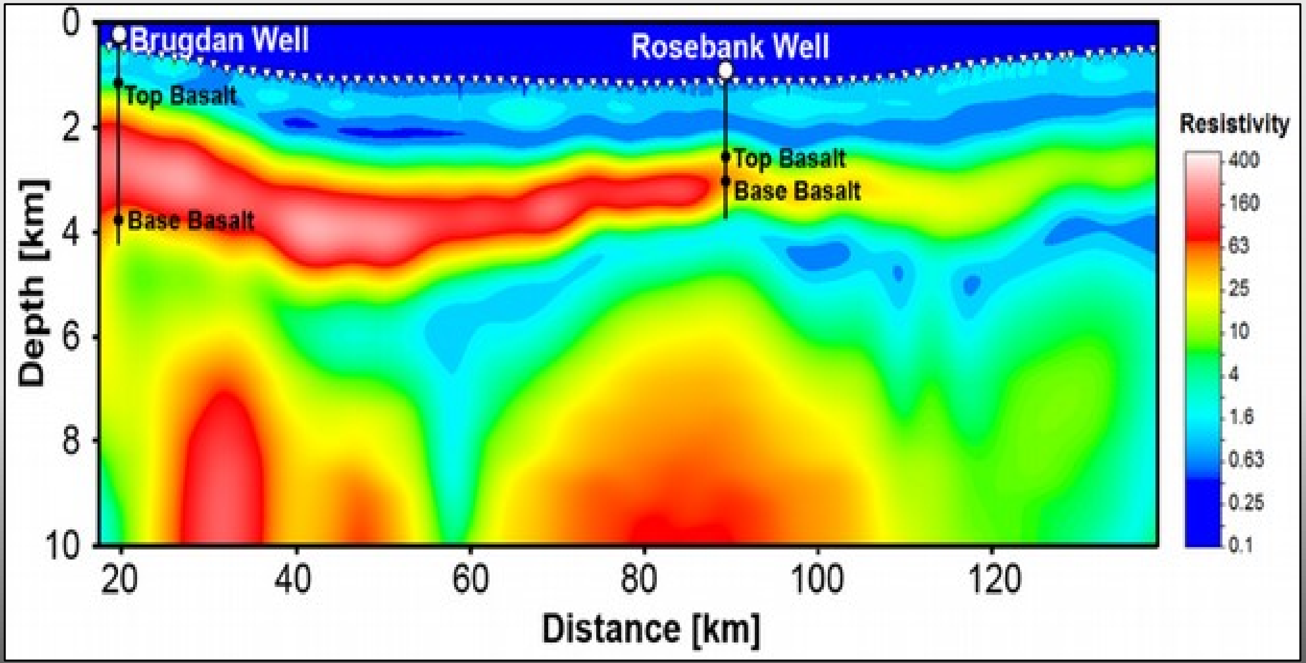




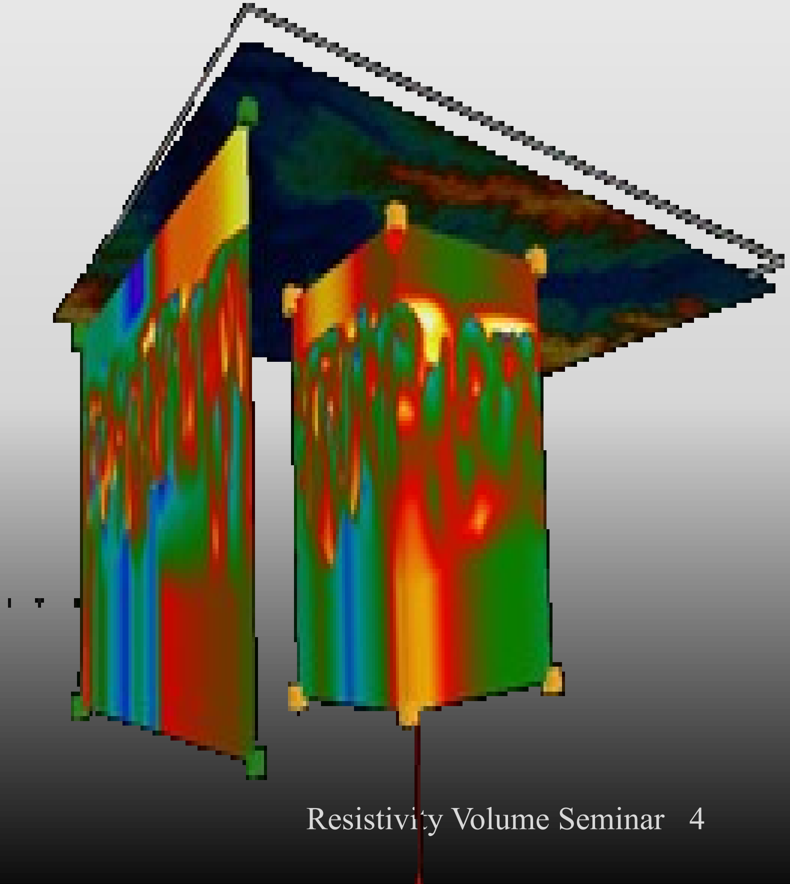
CSEM & NSEM

- Offshore
- > 300 foot water depths
- 1,250-A peak output

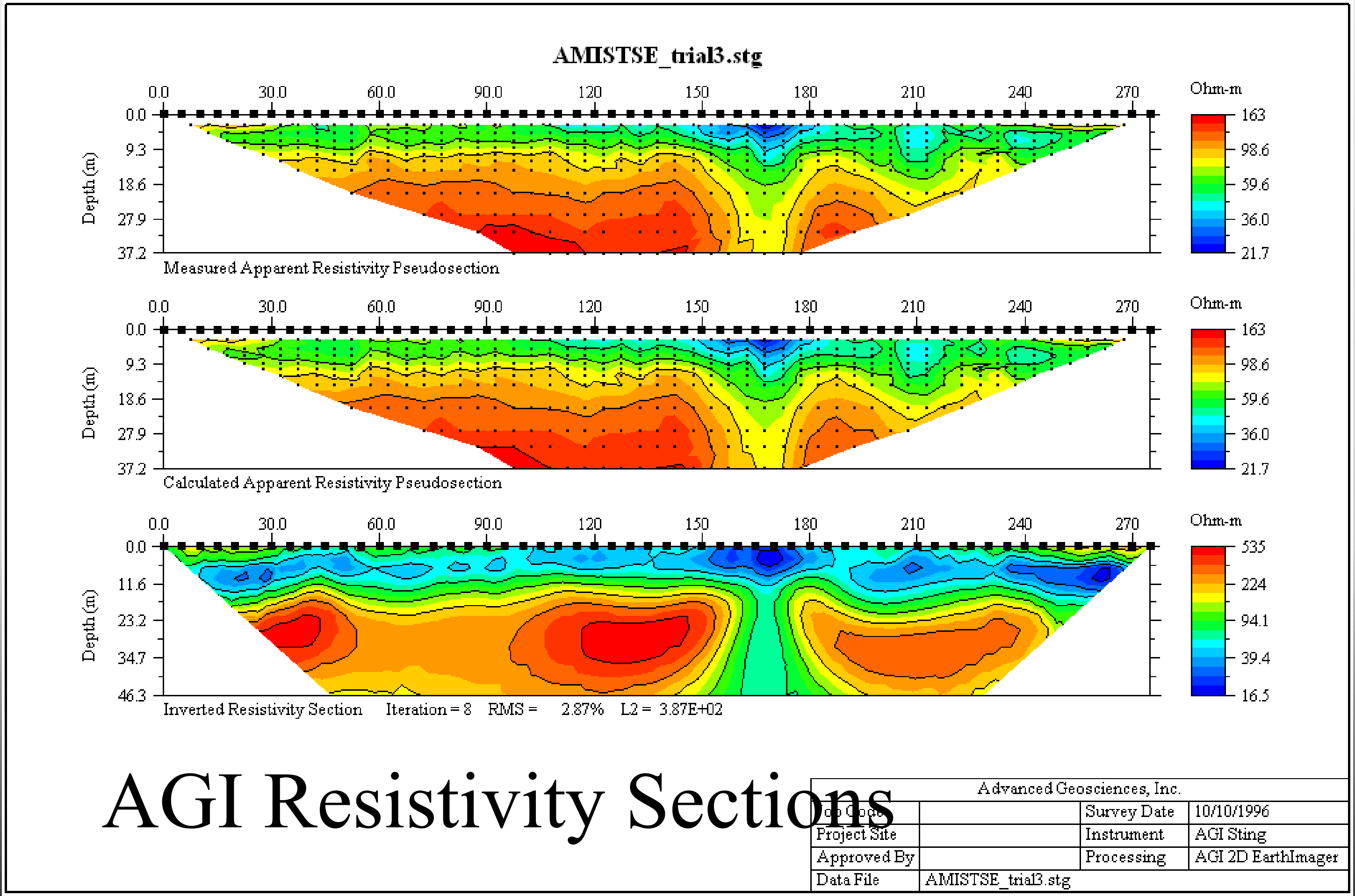
- Onshore
- < 300 foot water depths
- Average 30,000-A per strike



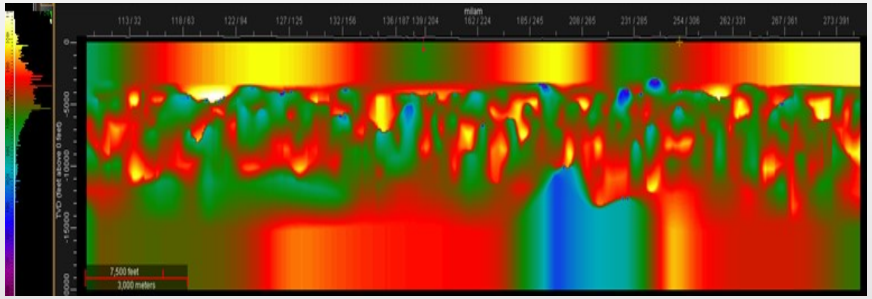
From: http://www.emgs.com/content/870/Structural-imaging



Traditional vs. Lighting Resistivity Analysis



AGI Resistivity Sections



Technical Merit:

- Sections and Volumes
- Evergreen Data
- 16 year database US Canada
- 4 year database worldwide
- Easy to Integrate
- Simple, Patented, & Pending

Economic Benefit:

- 2 month turnaround
- Larger Area – Less Expense

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Area Based Project Pricing
2 Month Project Turn-Around

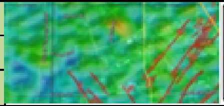
DML Decimal Longitude & Latitude Calculator

Enter Minutes:	17	Enter Seconds:	55	Decimal Calculation:	0.298611111

DML Area Calculator from Longitude & Latitude Input

Data Entry Red Cells (decimal longitude & latitude), Calculations/Parameters Yellow Cells, Results Green Cells

NW Corner Longitude:	-97.30707	W (km)	240.788259	Radius:	6367444.5
NW Corner Latitude:	32.70707	E (km)	240.788259	M2F:	0.30480061
NE Corner Longitude:	-97.10707	N (km)	18.702420	F2Mi:	5280
NE Corner Latitude:	32.70707	S (km)	19.143106	Area (sq km)	4556.379103
SW Corner Longitude:	-97.30707	W (mi)	149.618588		
SW Corner Latitude:	30.5404	E (mi)	149.618588		
SE Corner Longitude:	-97.10707	N (mi)	11.621122		
SE Corner Latitude:	30.5404	S (mi)	11.894951	Area (sq mi)	1759.22077



DML Lightning Analysis Project Price Calculator

Enter Area (sq. km.):		Enter Area (sq. mi.):	85,000	Enter Area (acres)	
Area (sq. km)	220,150			Price ($US):	$496,992.94

Confidential to Dynamic Measurement LLC

Acres	Sq. Miles	Price
640	1	$10,000
4,800	7.5	$20,000
9,600	15	$25,000
16,000	25	$30,000
35,200	55	$40,000
70,400	110	$50,000
224,000	350	$75,000
572,000	800	$100,000
1,120,000	1,750	$130,000
12,480,000	19,500	$300,000
54,400,000	85,000	$500,000
163,200,000	225,000	$700,000

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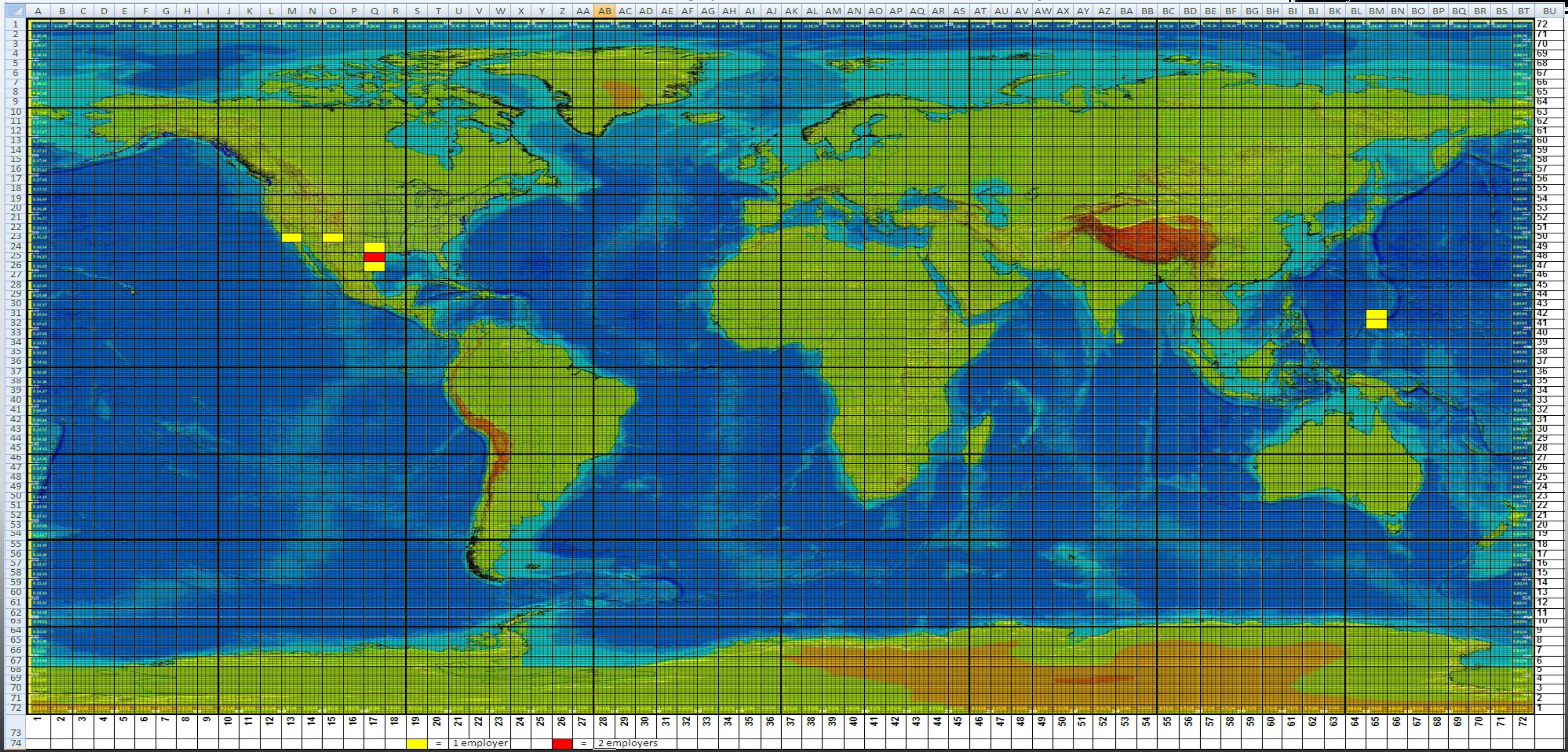
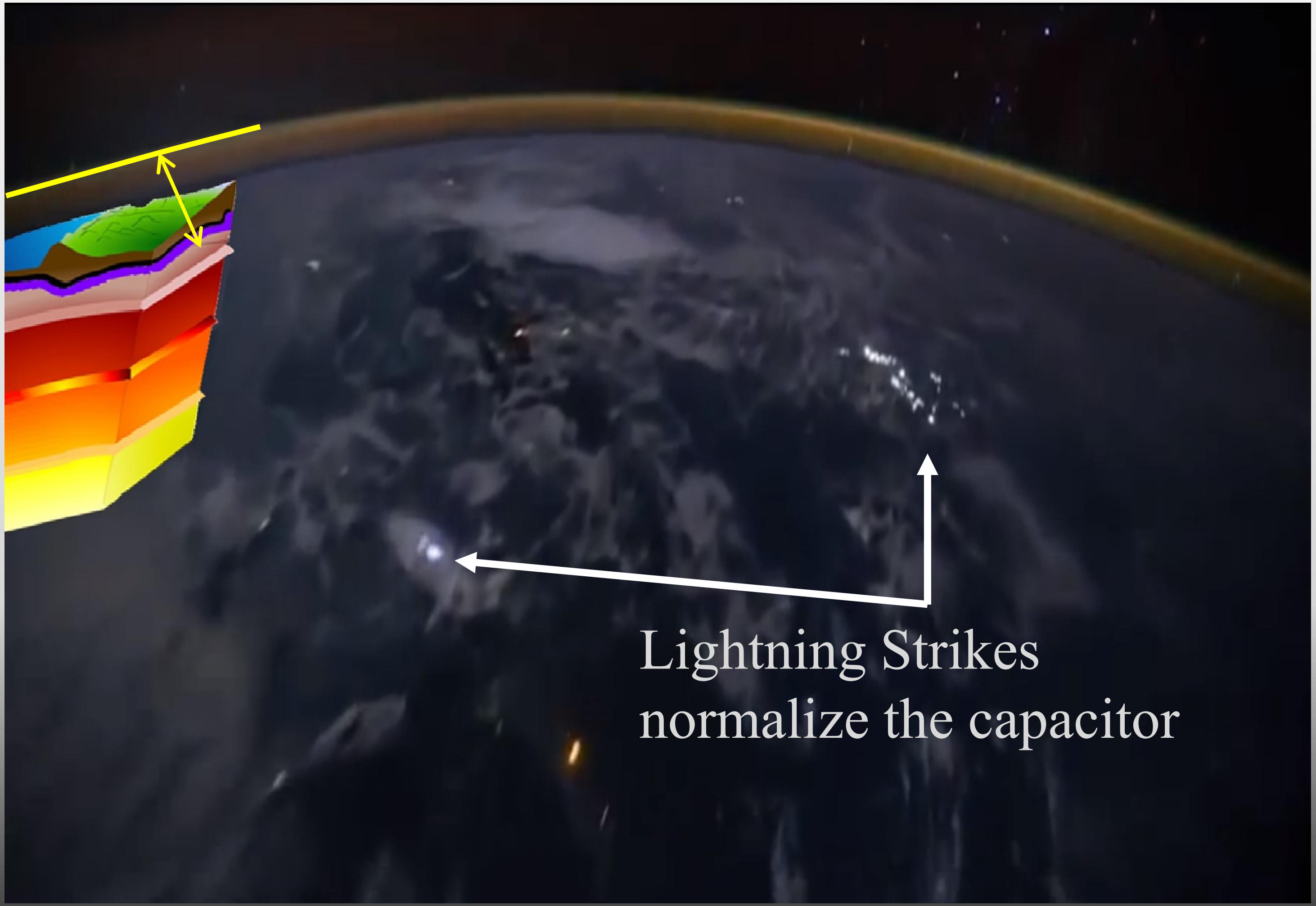
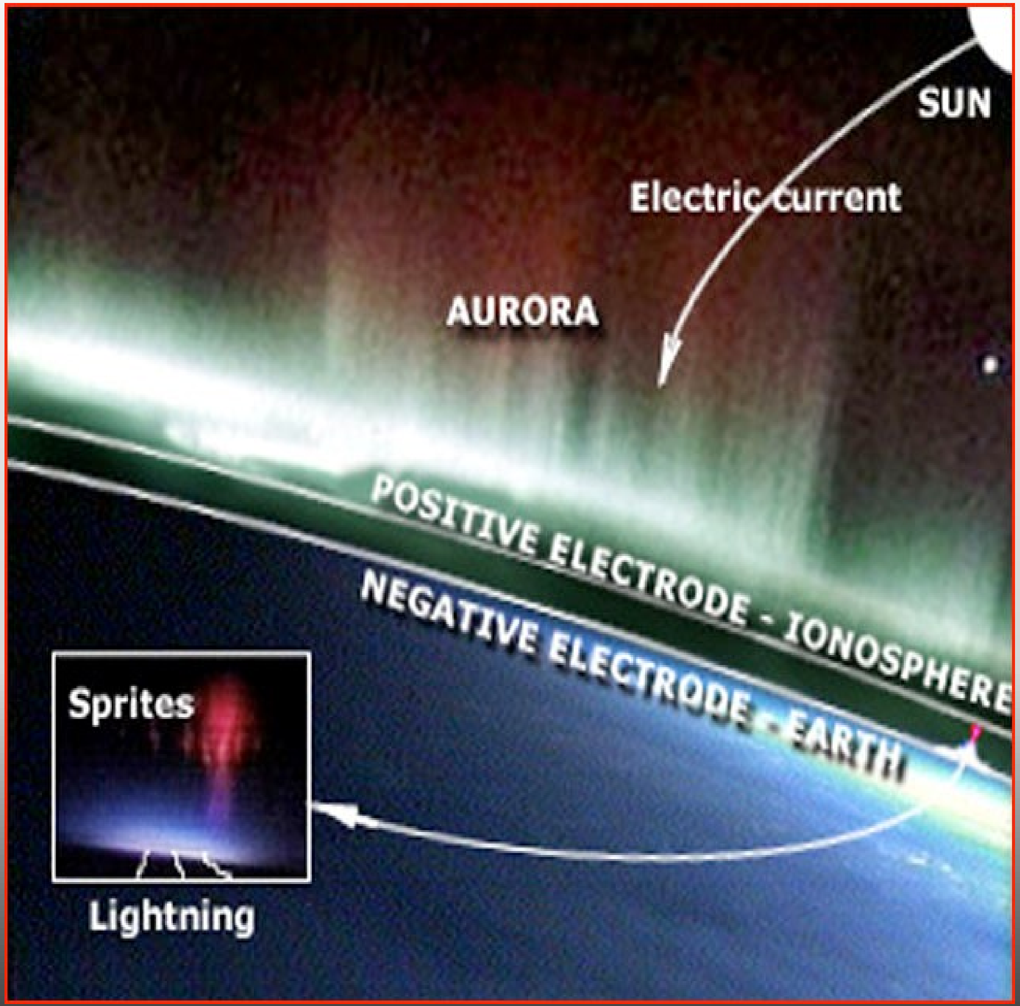
Dr. Jim Siebert Meteorology & Other Projects:



Earth: A Self-Repairing Capacitor





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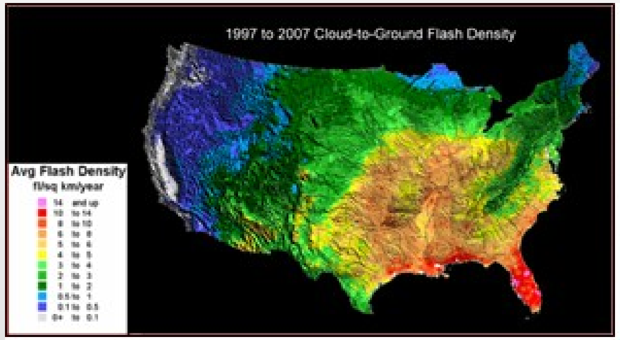
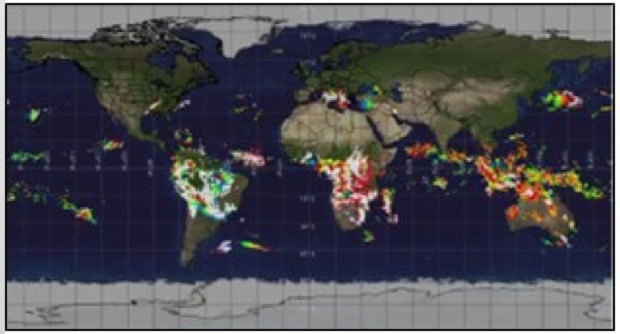
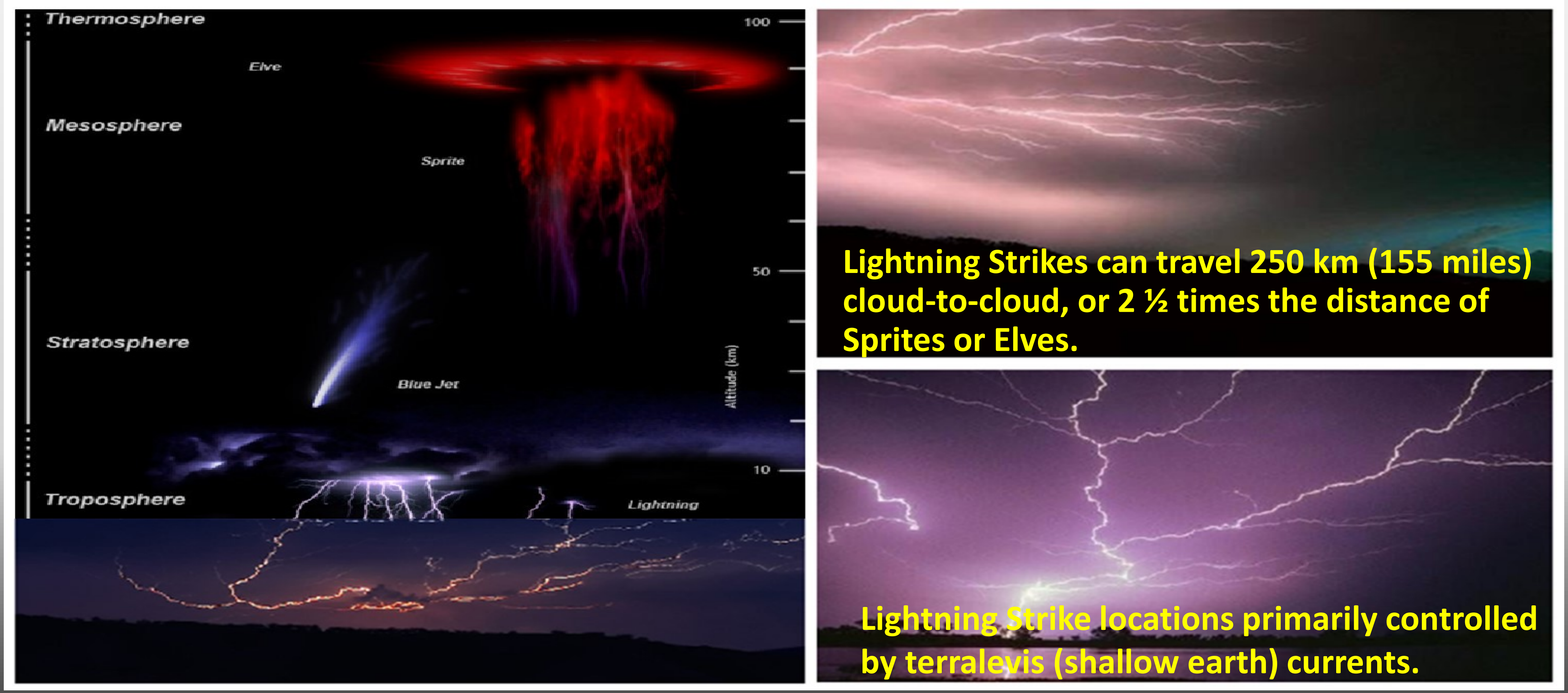
Lightning Occurs Everywhere, data are available in public and private databases





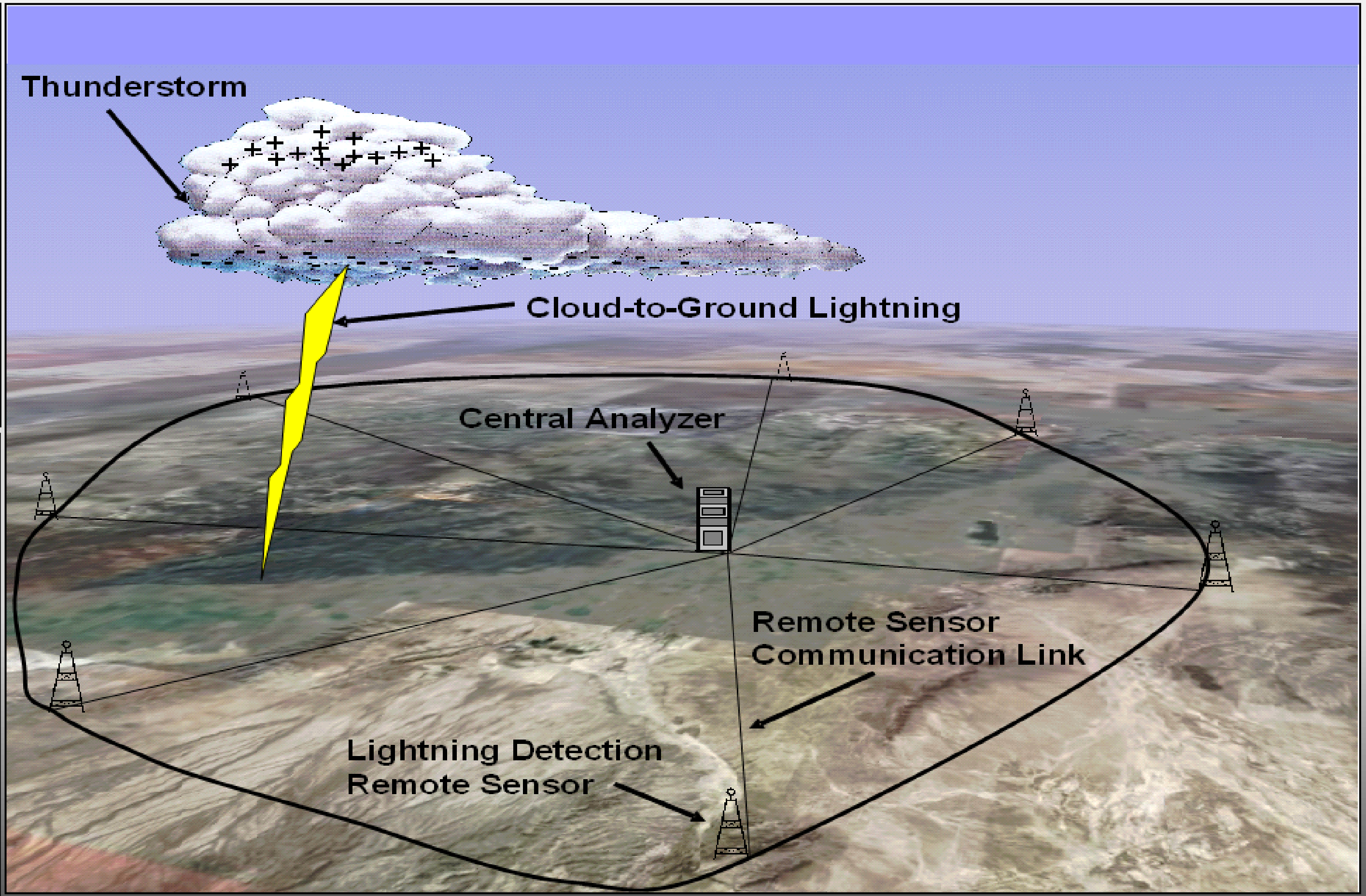
350 million annual Lightning Strikes - a rich database to mine



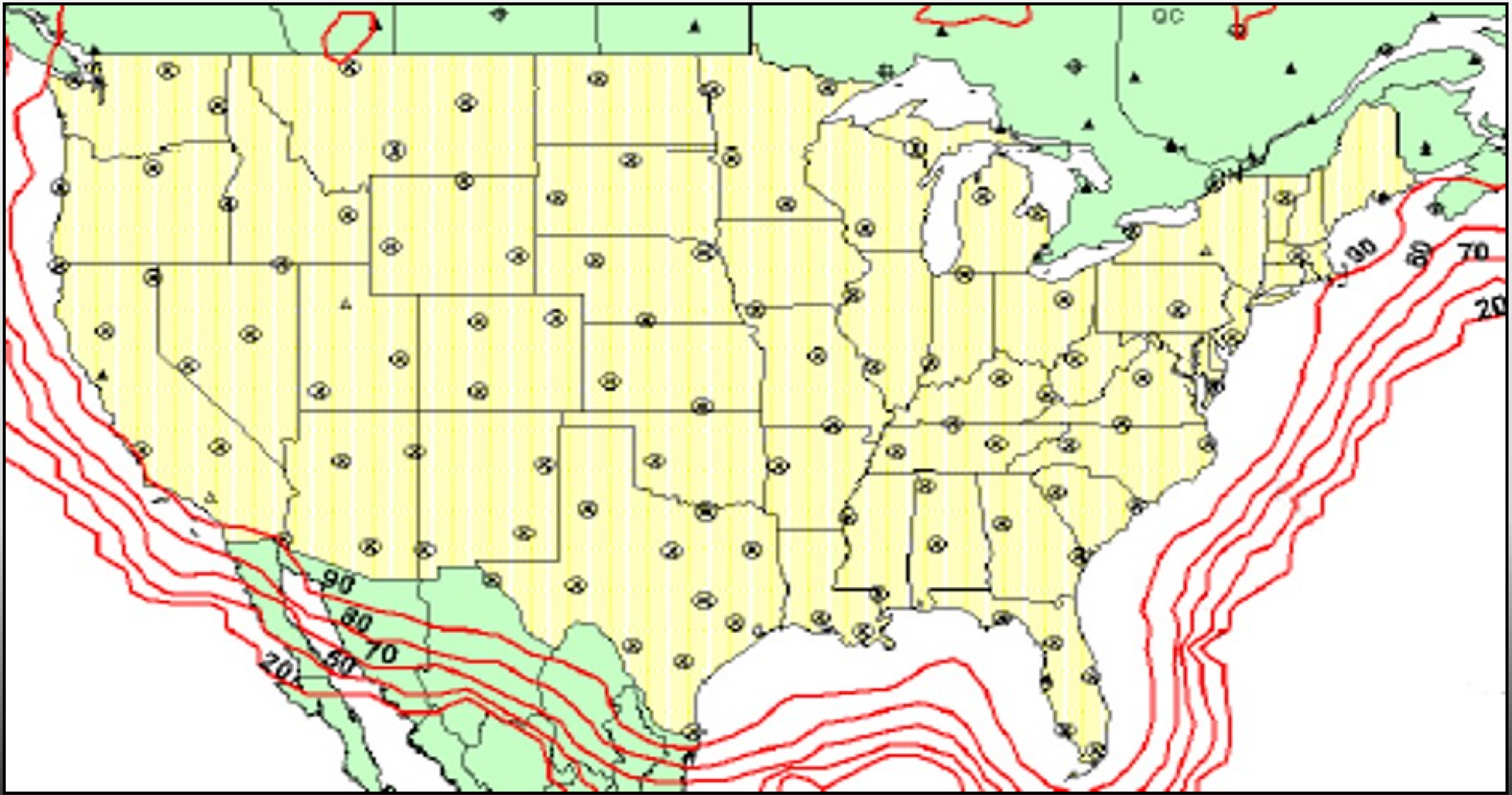
Lightning Strikes can travel 250 km (155 miles) cloud-to-cloud, or 2 ½ times the distance of Sprites or Elves.

Lightning Strike locations primarily controlled by terralevis (shallow earth) currents.

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

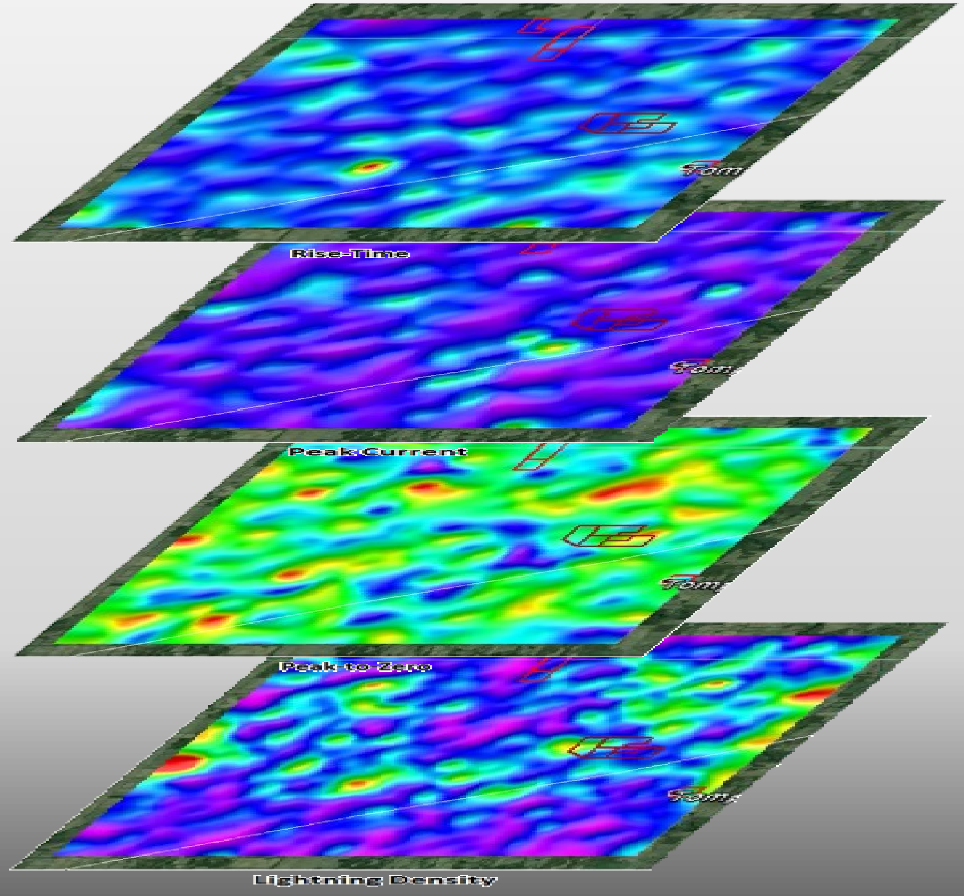


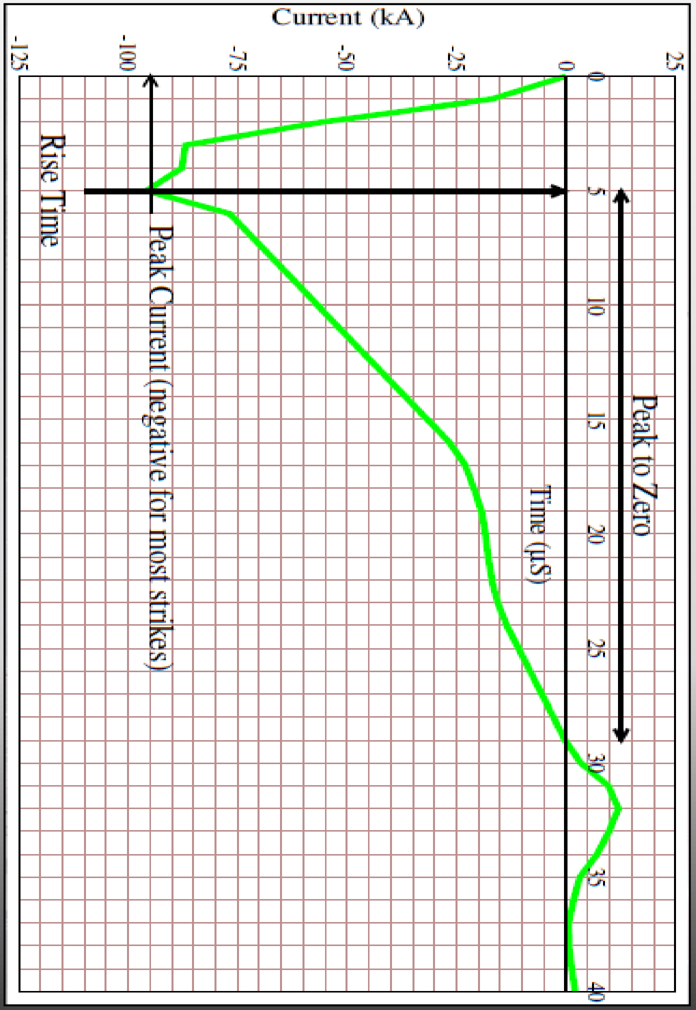
NLDN (National Lightning Detection Network)



Lightning Strike Measurements

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

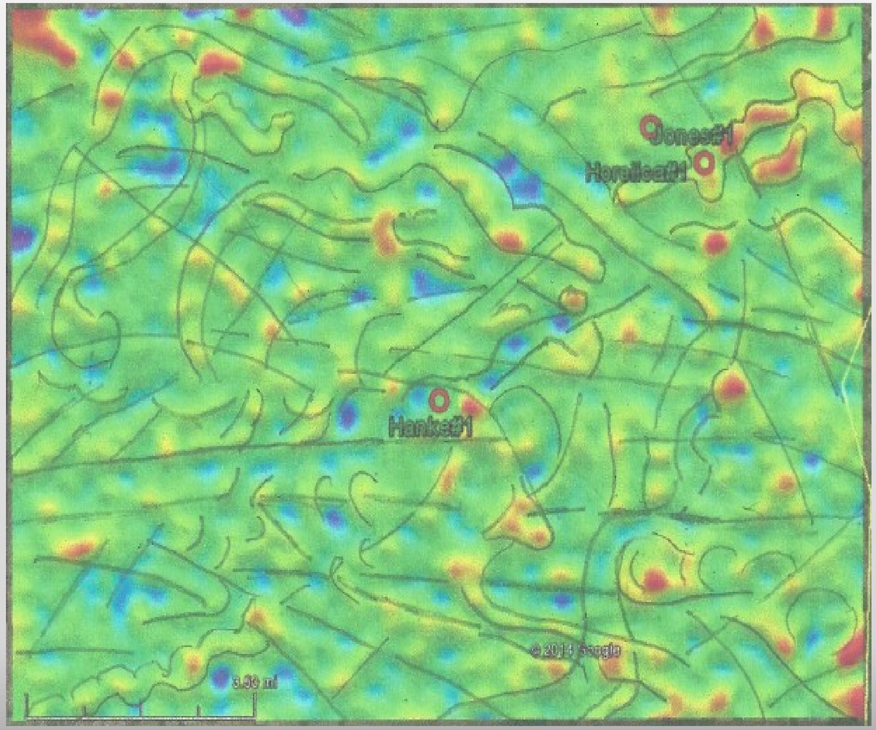




Lightning Strike
Calculated Attributes

- Peak Current Absolute
- Peak Current Negative
- Peak Current Positive
- Total Wavelet Time
- Wavelet Symmetry
- Rate of Rise-Time
- Surface Resistivity
- Earth Tide Density
- Earth Tide Gradient
- Earth Tide Density greater than 75% of monthly maximum
- Earth Tide Density less than 75% of monthly maximum
- Earth Tide Gradient greater than 75% of monthly maximum
- Earth Tide Gradient less than 75% of monthly maximum
- Density, measurement, or attribute maps by hour, day, month, season, or combinations of any of these (e.g. spring + fall strike density)
- Mixed density, measurement, and attribute maps

Peak-to-Zero
Central Texas



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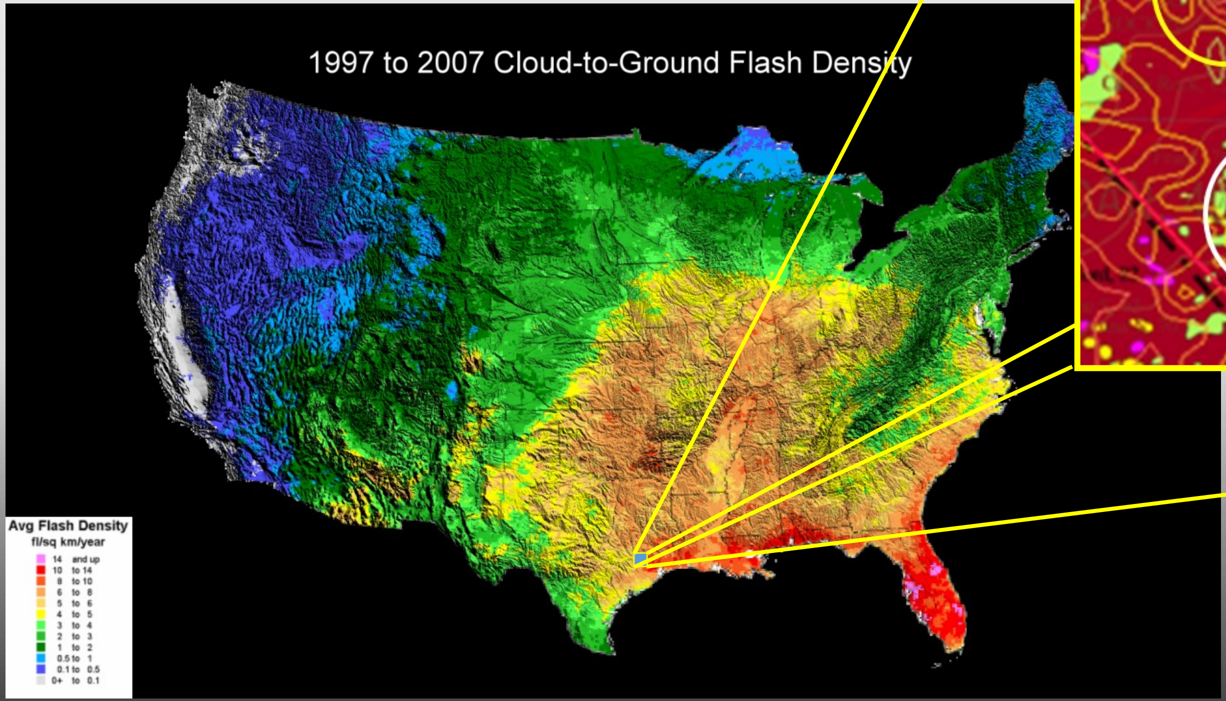
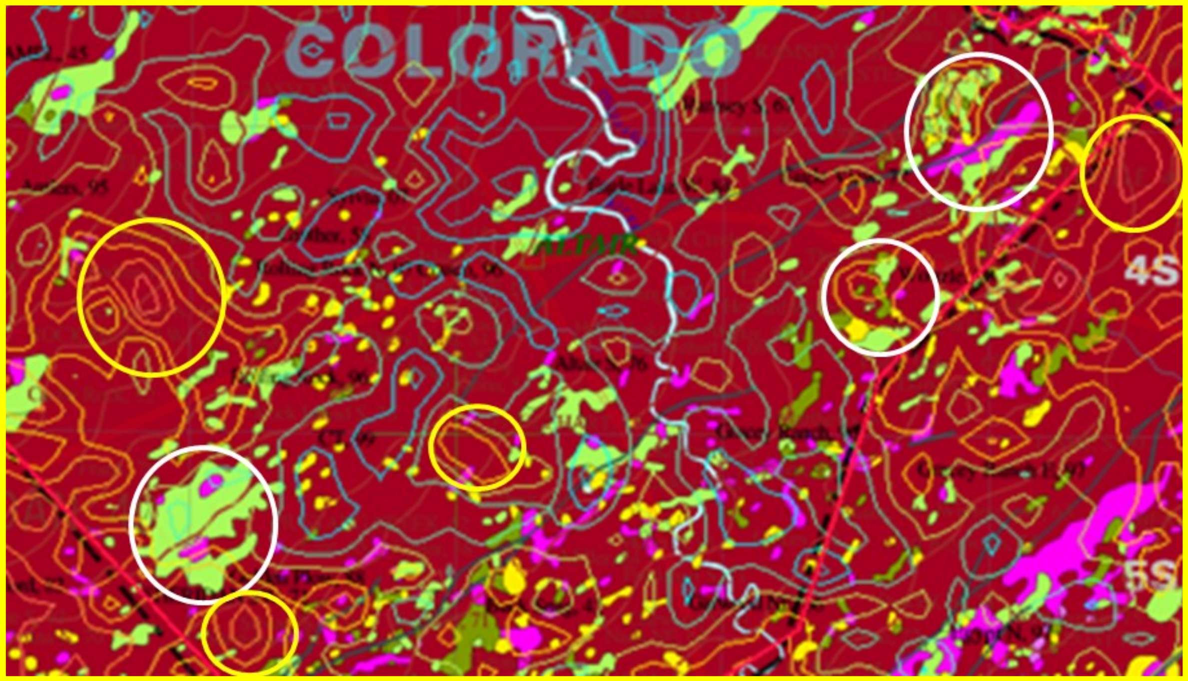
Lightning recorded for early storm warning, safety, **insurance**, and meteorological purposes

Lightning Maps and Natural Resources

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

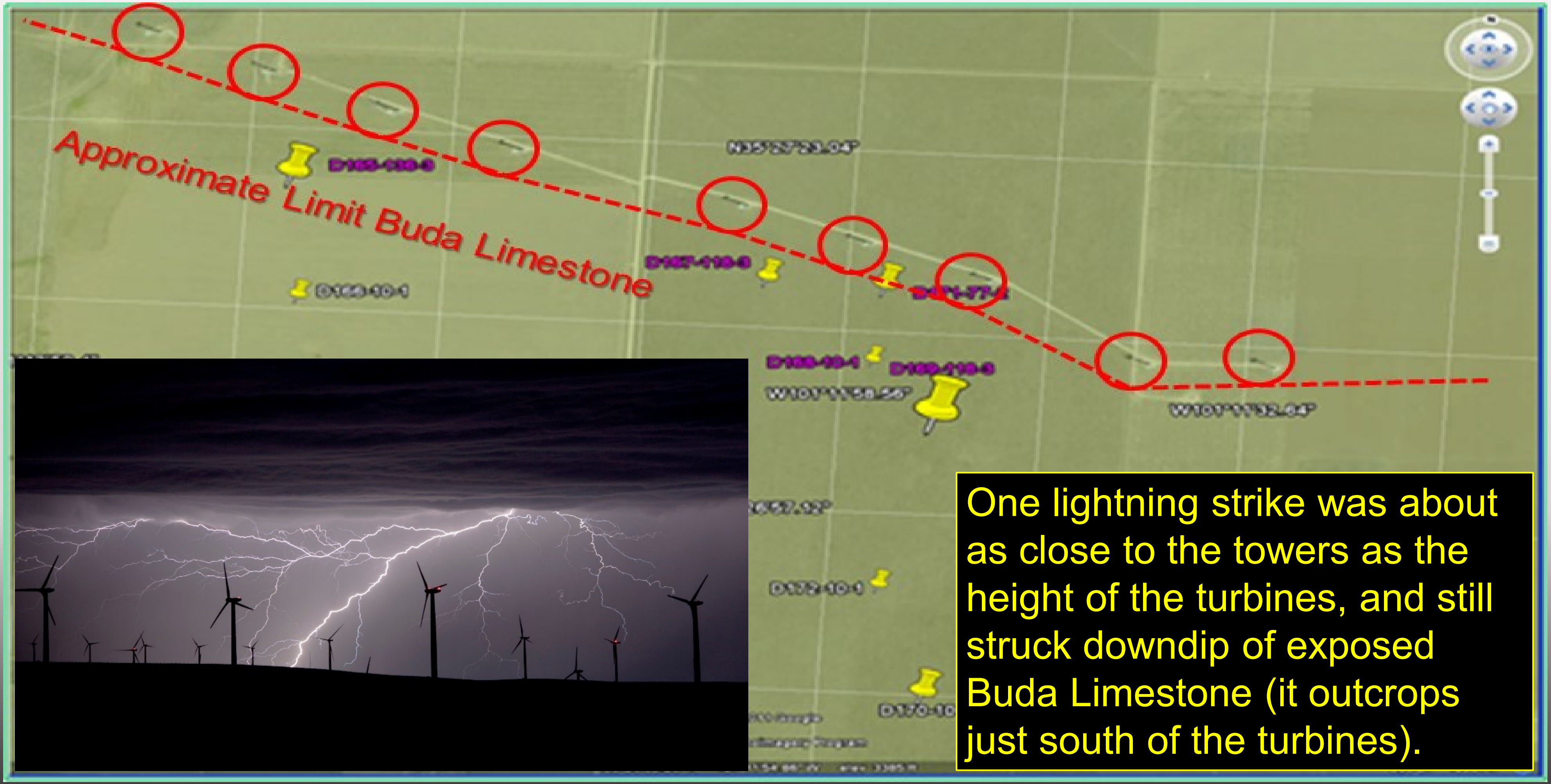




Colorado County, Texas:
White circles known oil & gas fields;
Yellow circles new leads from lightning density.

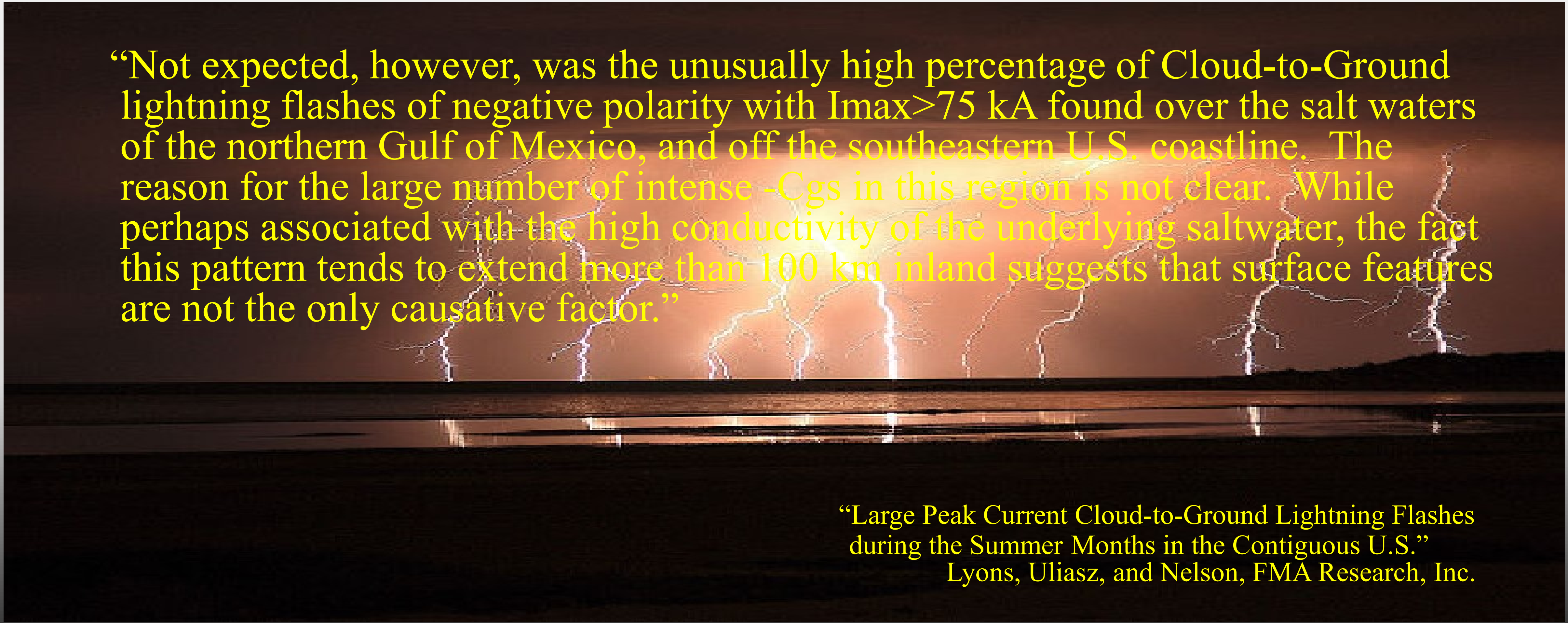
Lightning bypasses tall objects to hit geology

Northwest Texas example:
one hour of strikes on 08 March 2008



One lightning strike was about as close to the towers as the height of the turbines, and still struck downdip of exposed Buda Limestone (it outcrops just south of the turbines).

One of the only article referencing lightning's relationship to the subsurface: a 1998 American Meteorological Society Article where conclusions included:



"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."

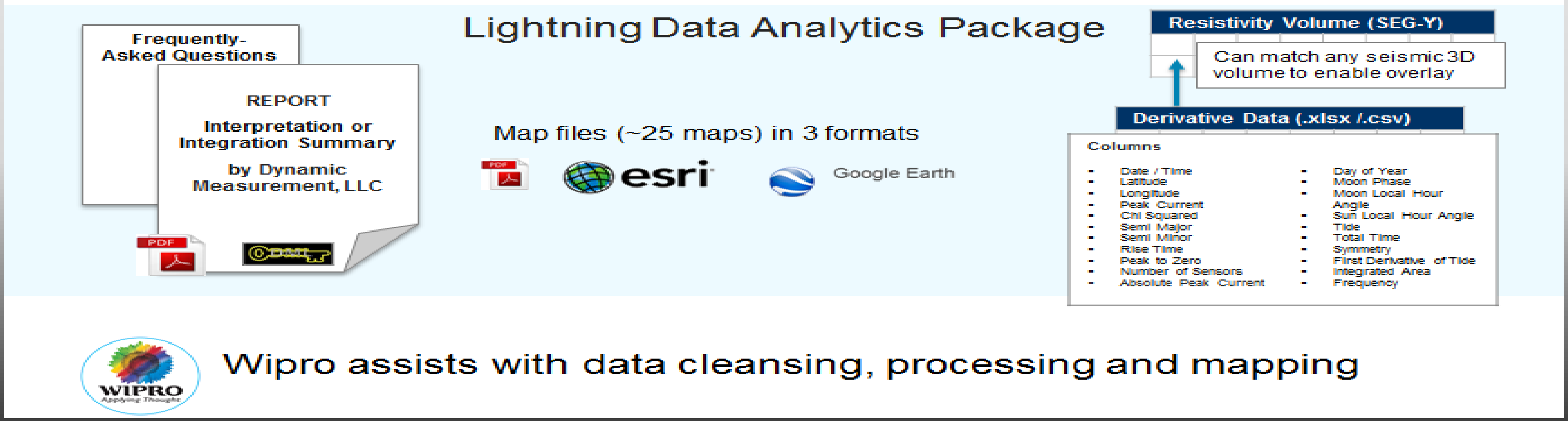
"Large Peak Current Cloud-to-Ground Lightning Flashes during the Summer Months in the Contiguous U.S."
Lyons, Uliasz, and Nelson, FMA Research, Inc.

Two Month Project Workflow

Client Interest → Project Scope → Define Area

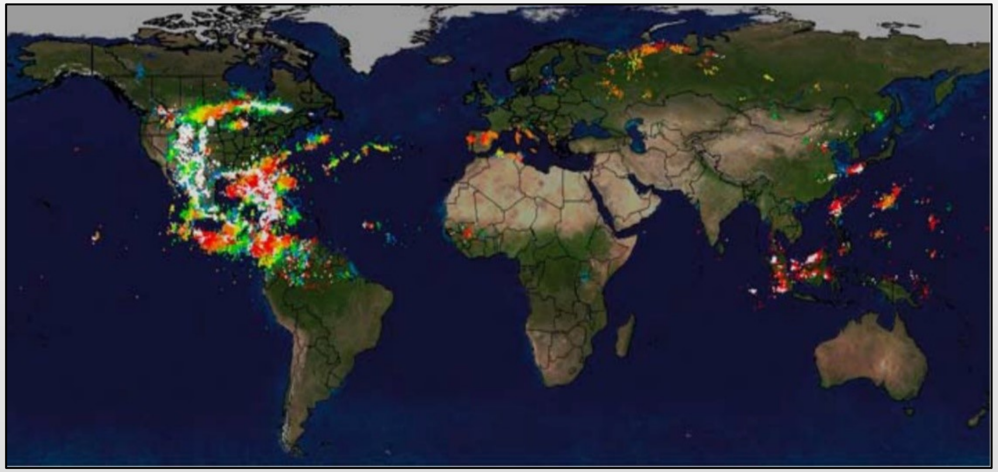
Master License Agreement → Supplemental License Agreement → Pay 50% of Analysis Price

Order Data → Clean & Process Data → Map & Interpret Data → Final Report & Payment

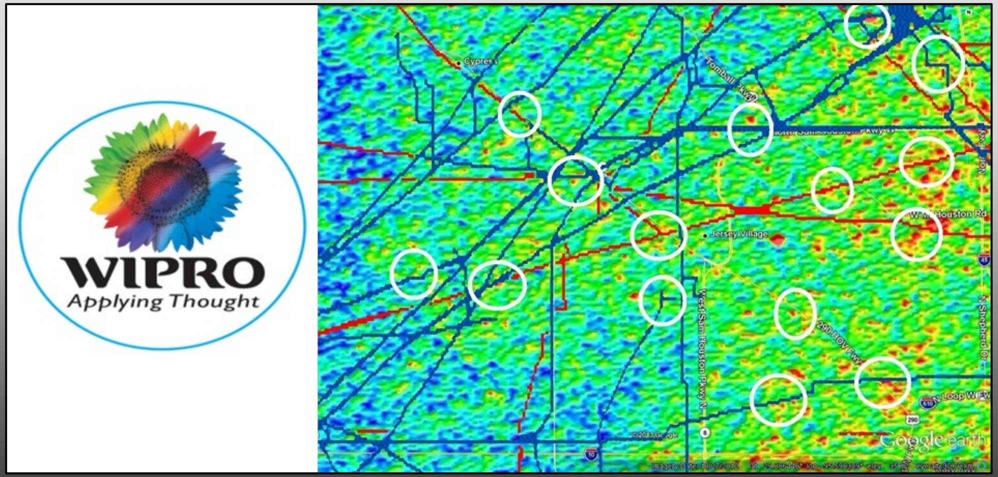


Vaisala and Wipro Partnerships

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



- Agreement with Wipro to clean, process, and handle lightning data according to DML specifications



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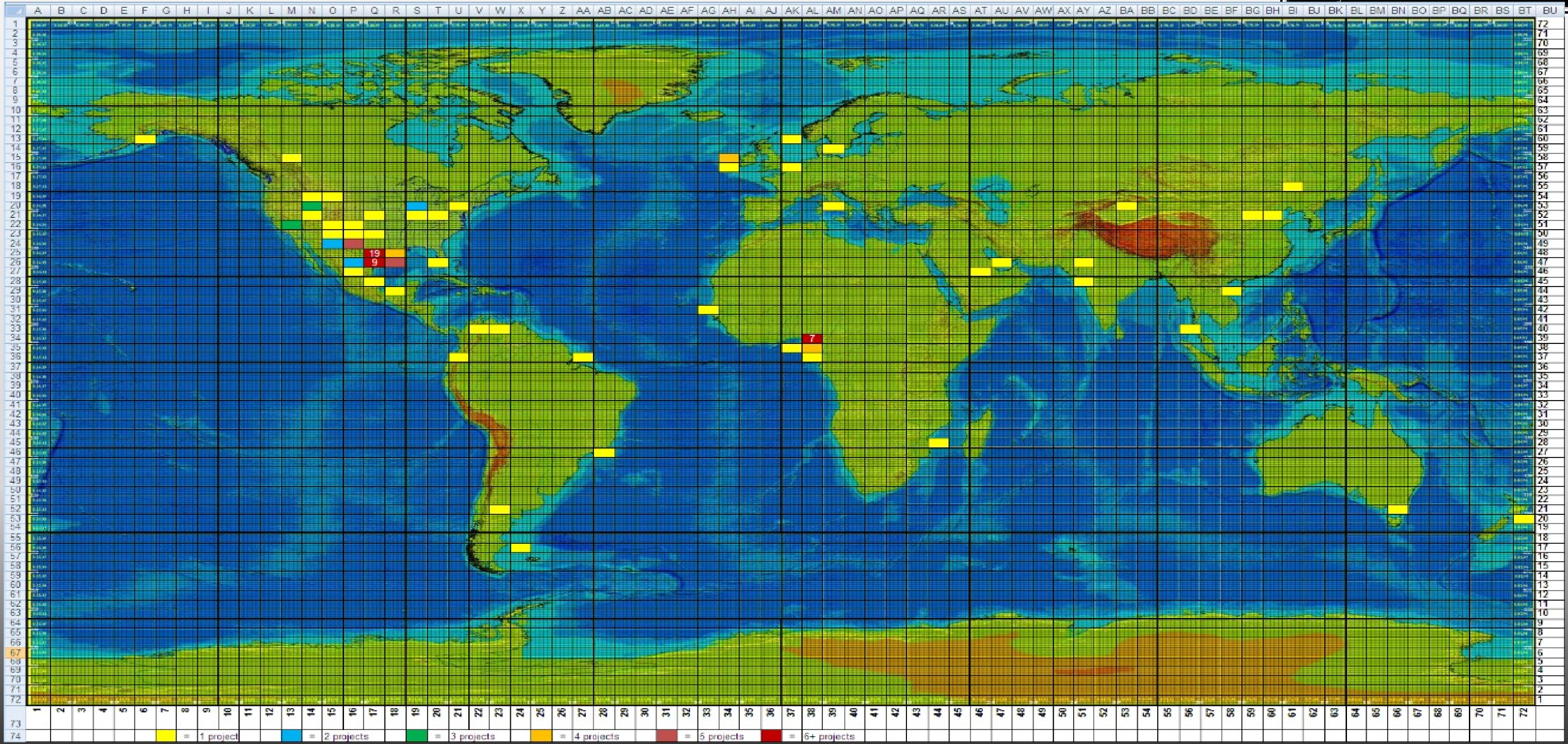
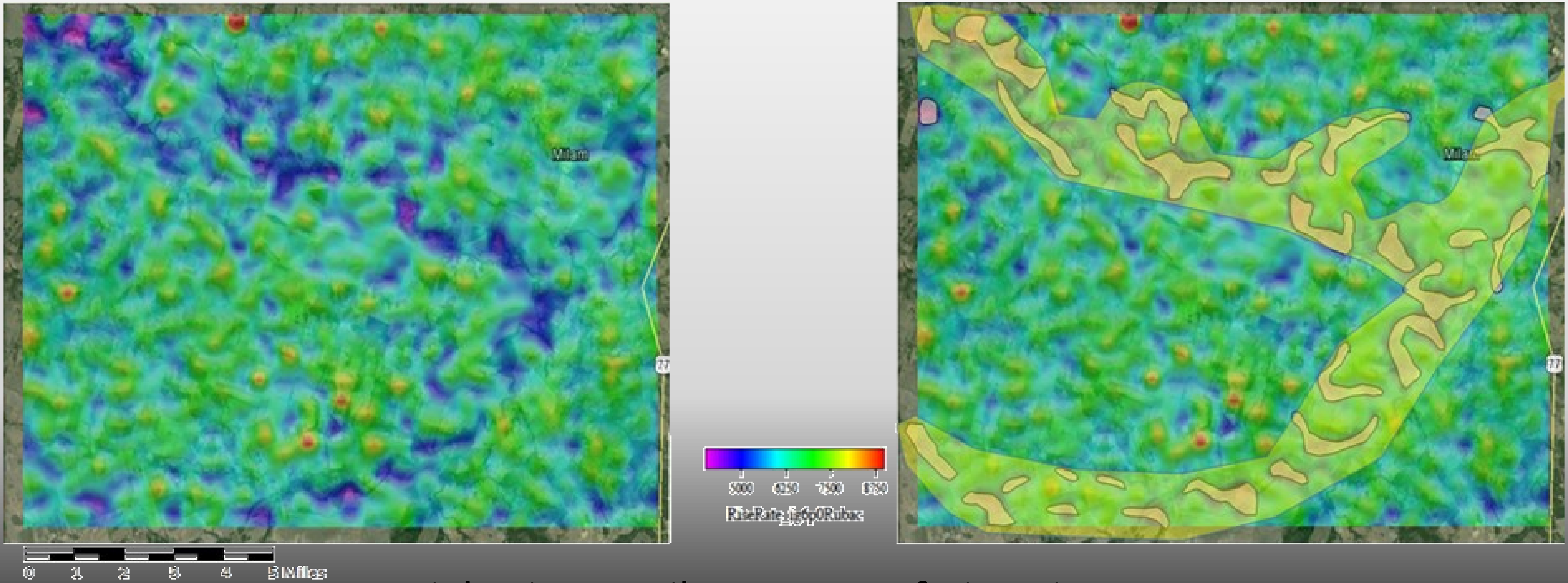
H. Roice Nelson, Jr. Seismic Projects:

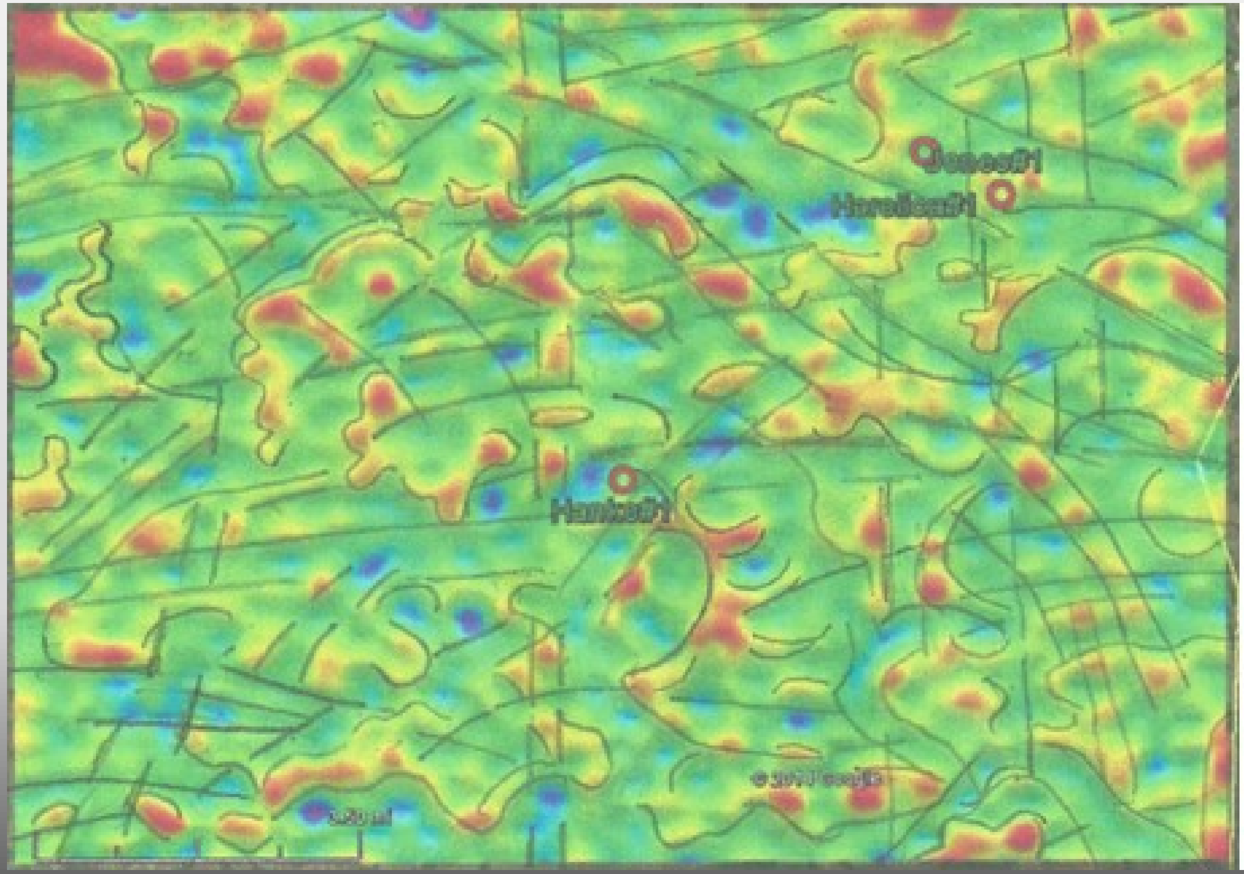
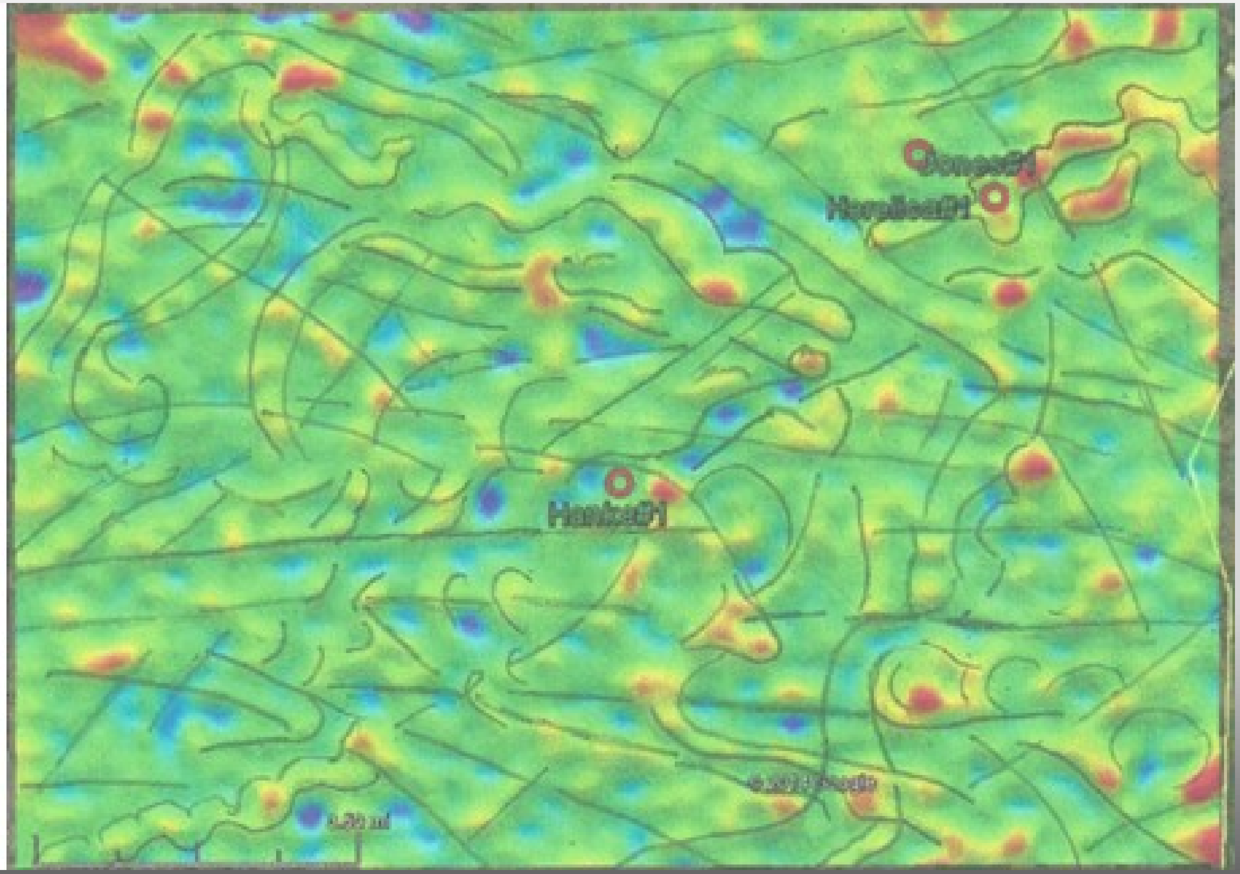


Lightning Analysis
Defines Stratigraphy



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

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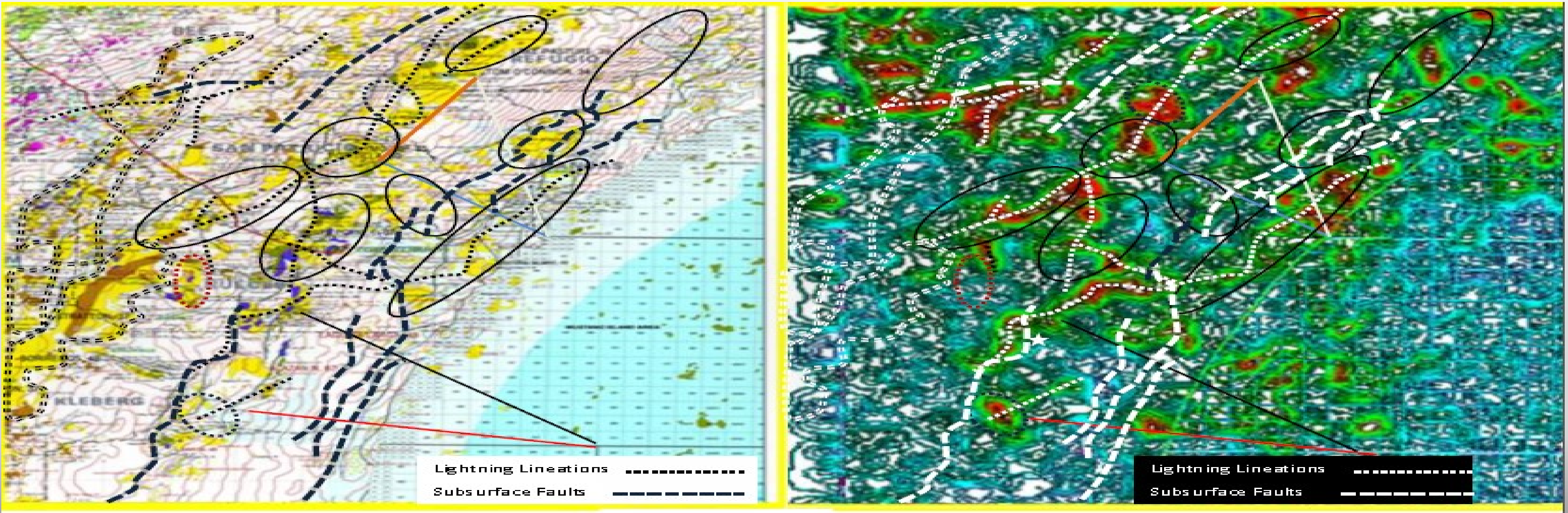


Second Pass

Dark Red — Production but no anomaly.

Black — Anomaly correlates to production.

Red
Black
Dark Blue
Olive Green
— Location Line Aids

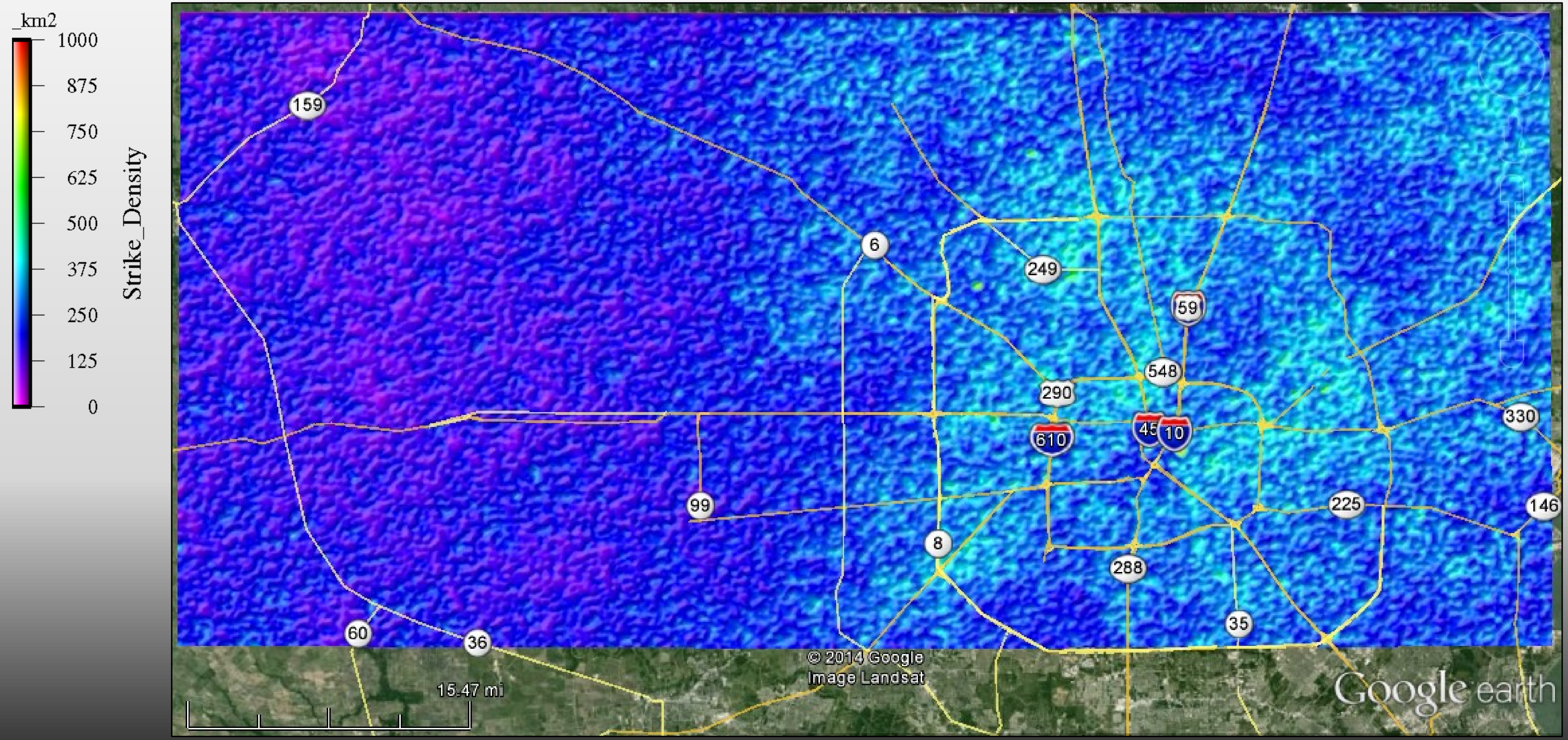
Excellent Examples

Dark Blue — Anomaly but no production.

Black — Production with partial to no anomaly.

Black & White — Field alignment, minimal correlation.

Lightning Density Map Shows Strikes Cluster



Clusters Skew Density Map Color; Normalization Improves Displays

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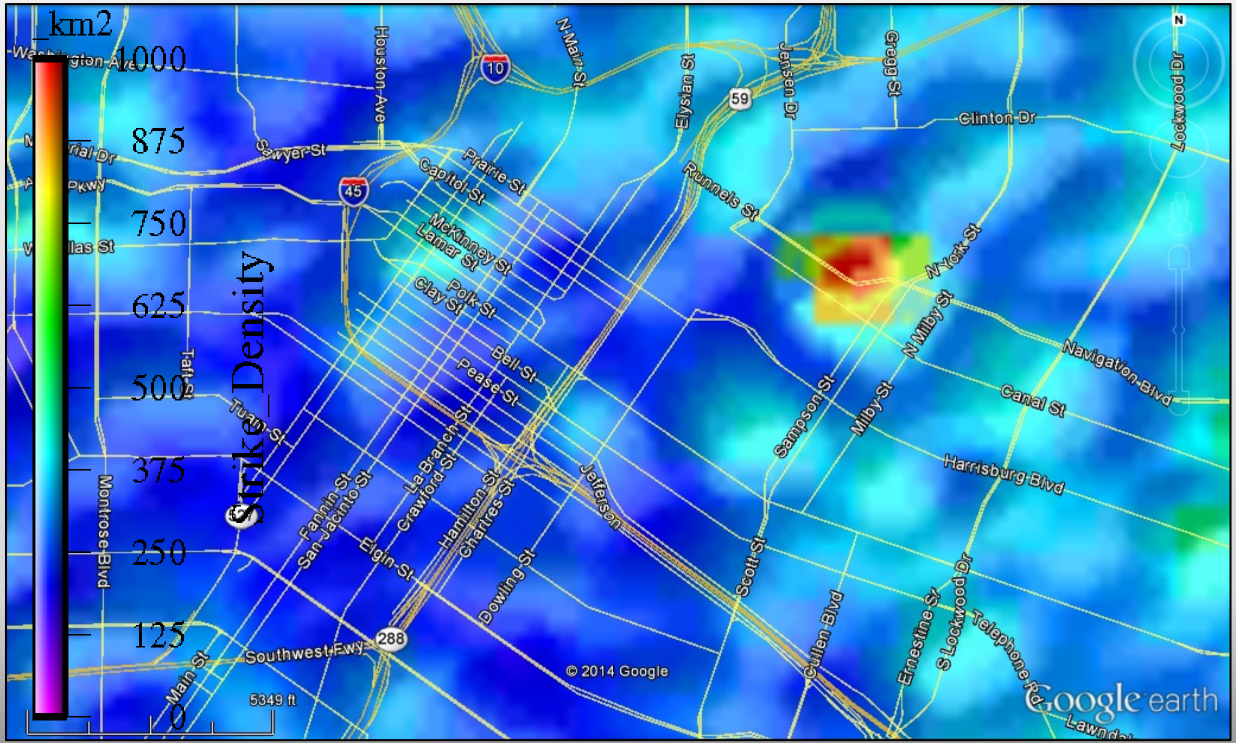
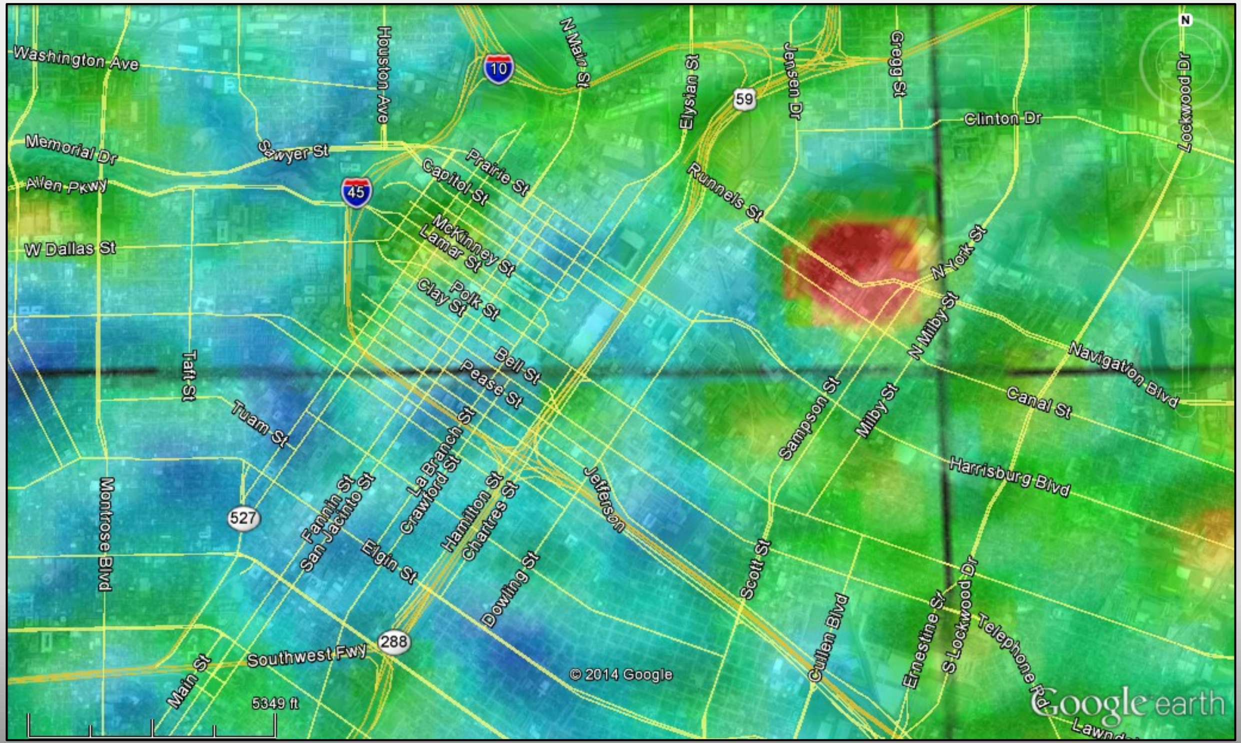
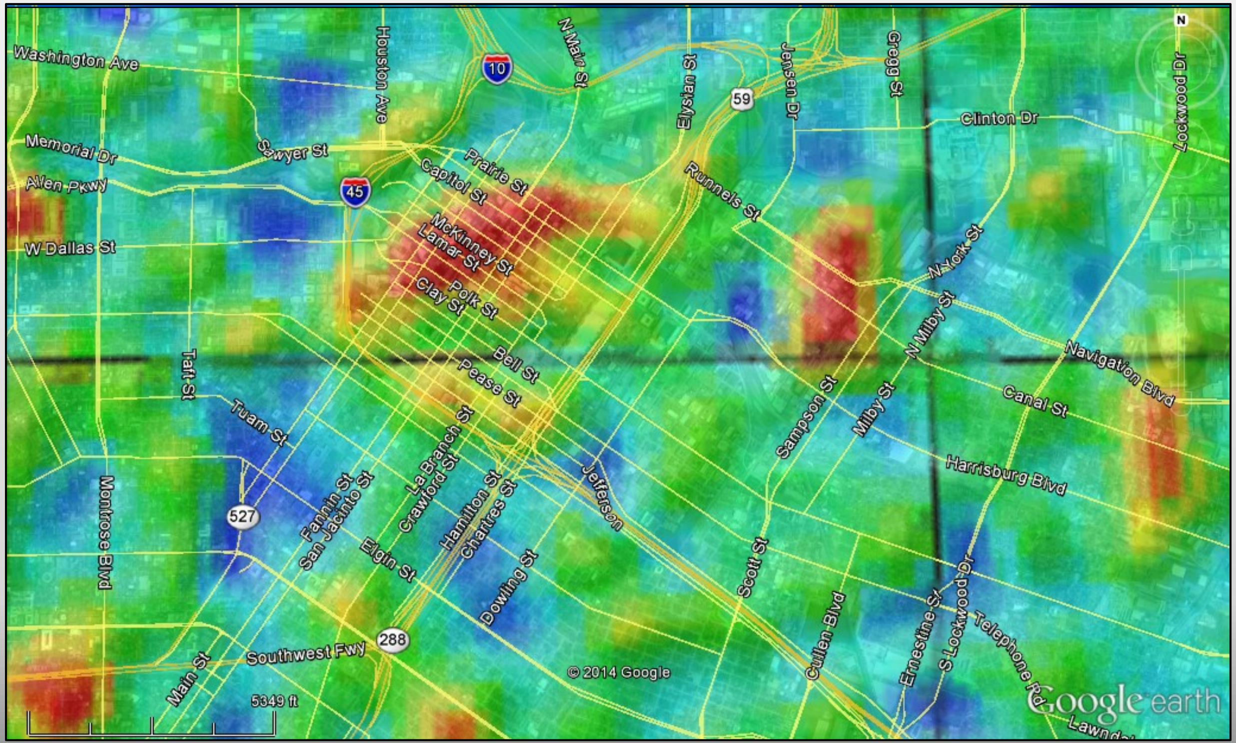
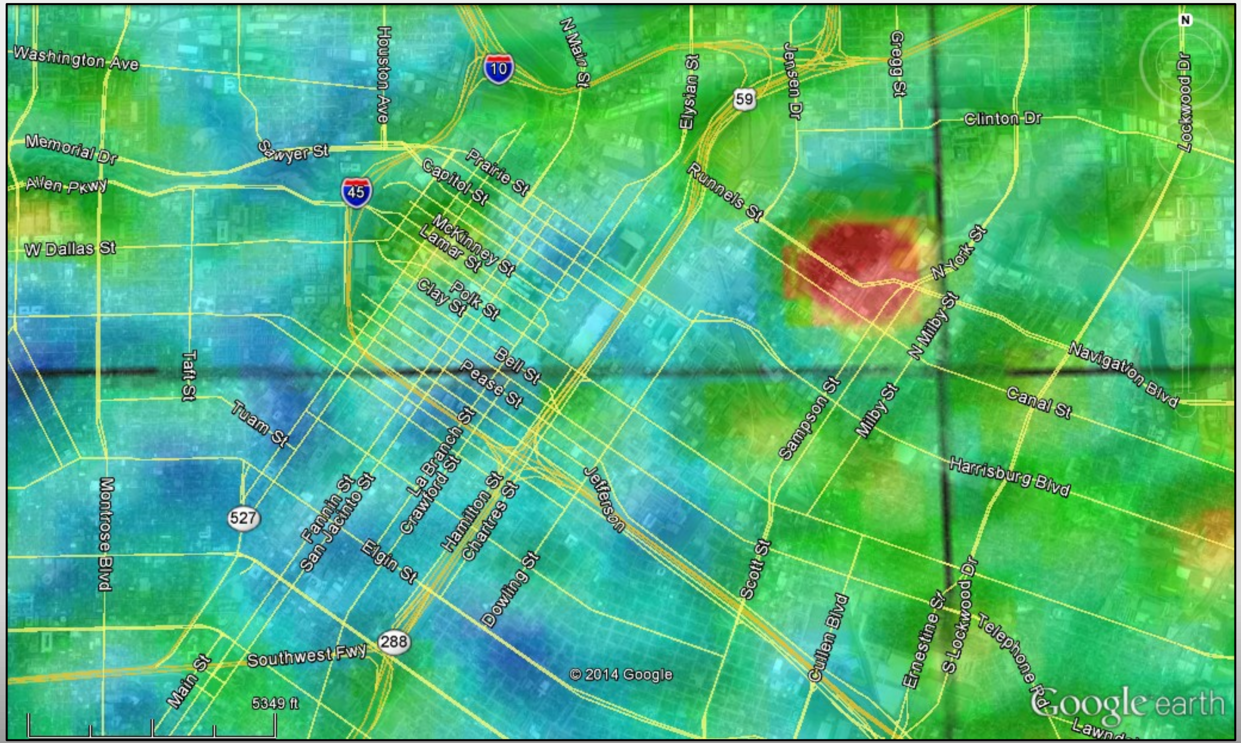


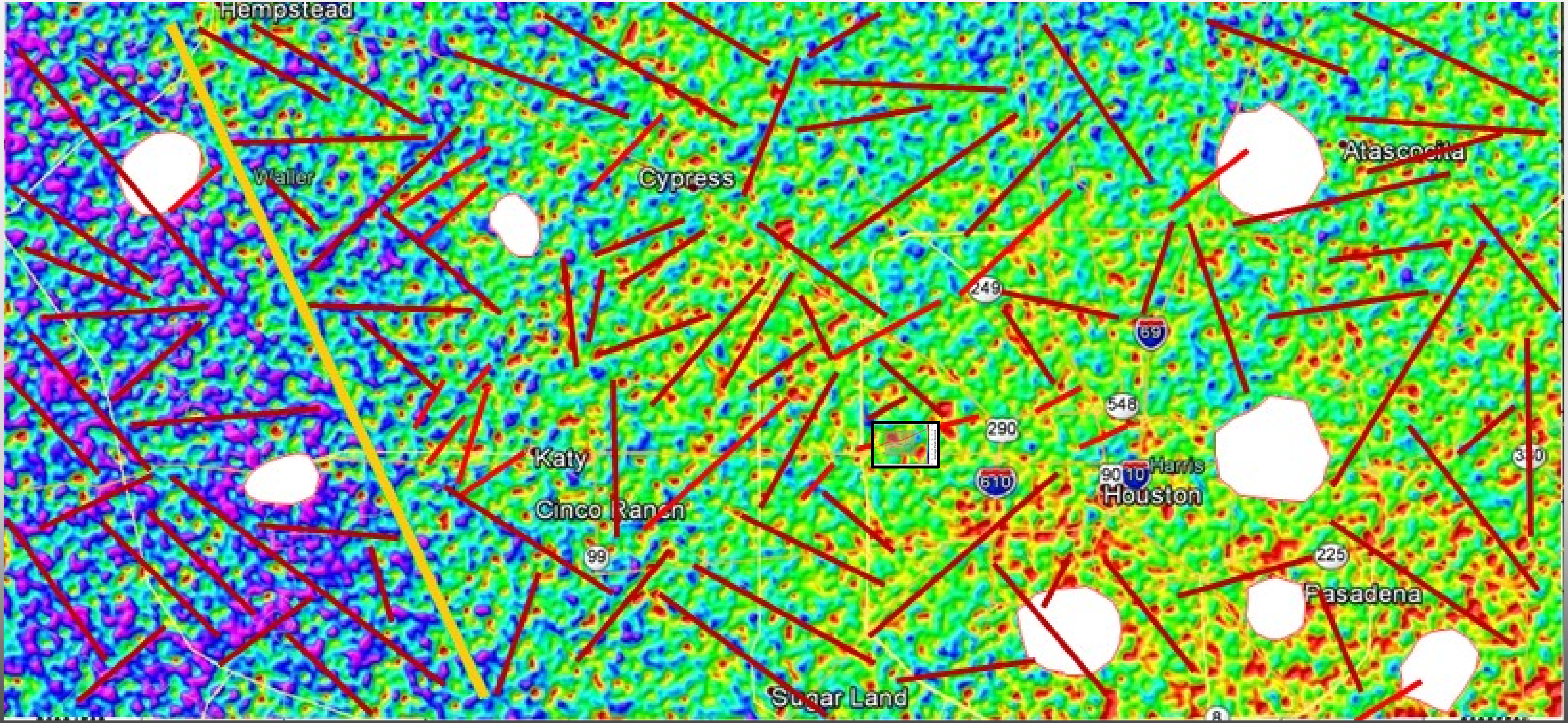


Average Negative Peak Current vs. Peak Current

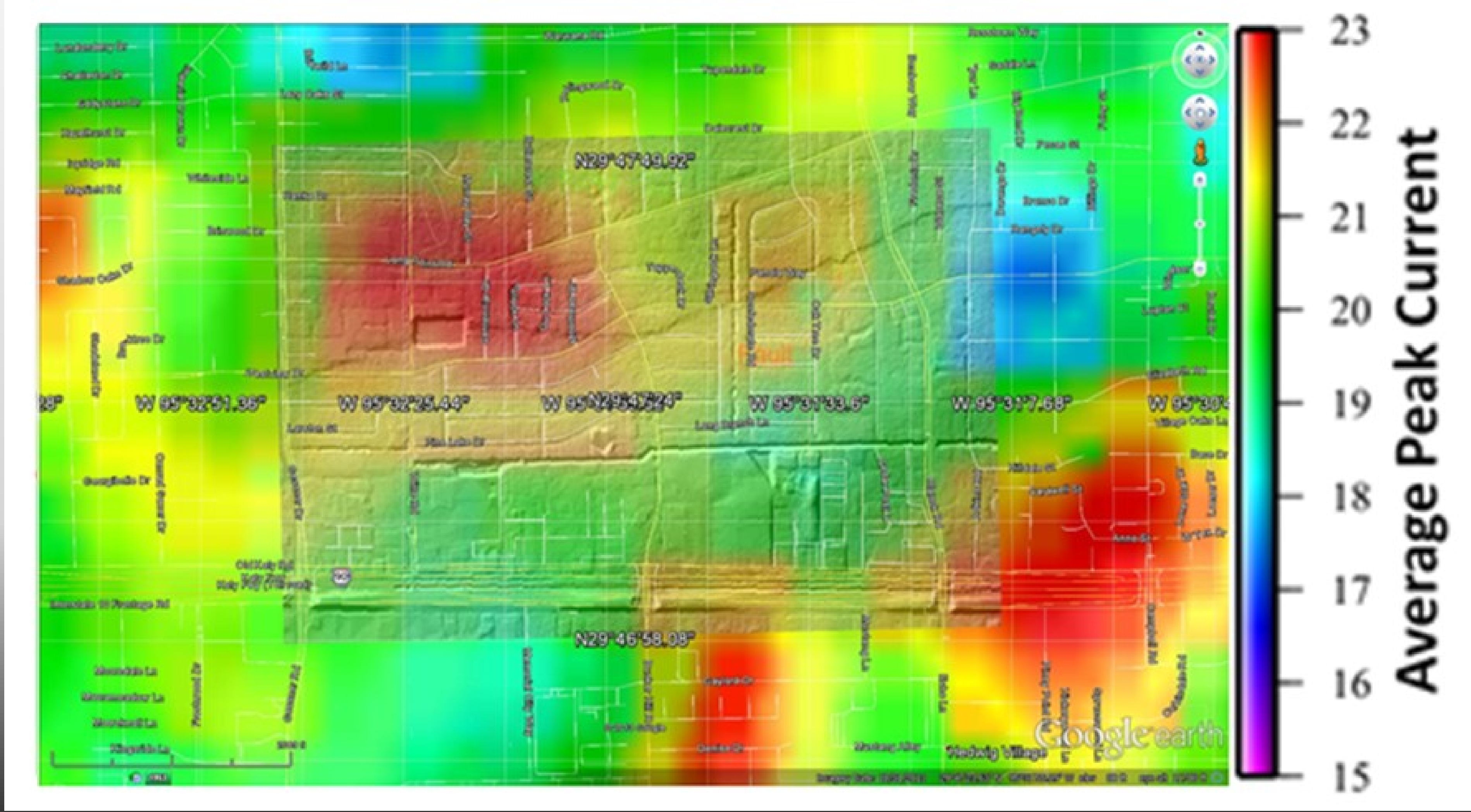




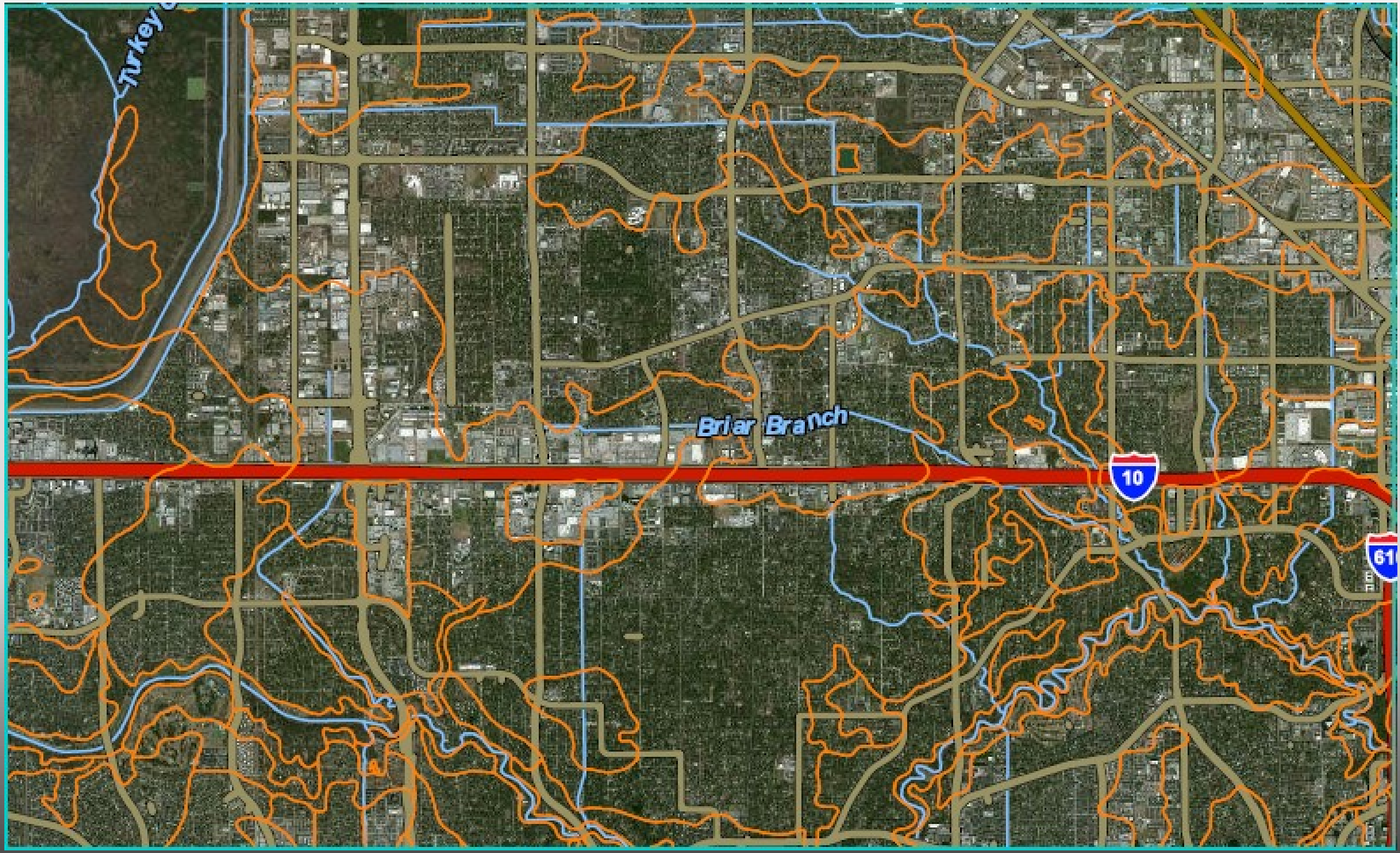
Peak Current from Sealy to East Houston



Peak Current Zoom with LIDAR & Long Point Fault



Soils Map over GoogleEarth^{TM} Map



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

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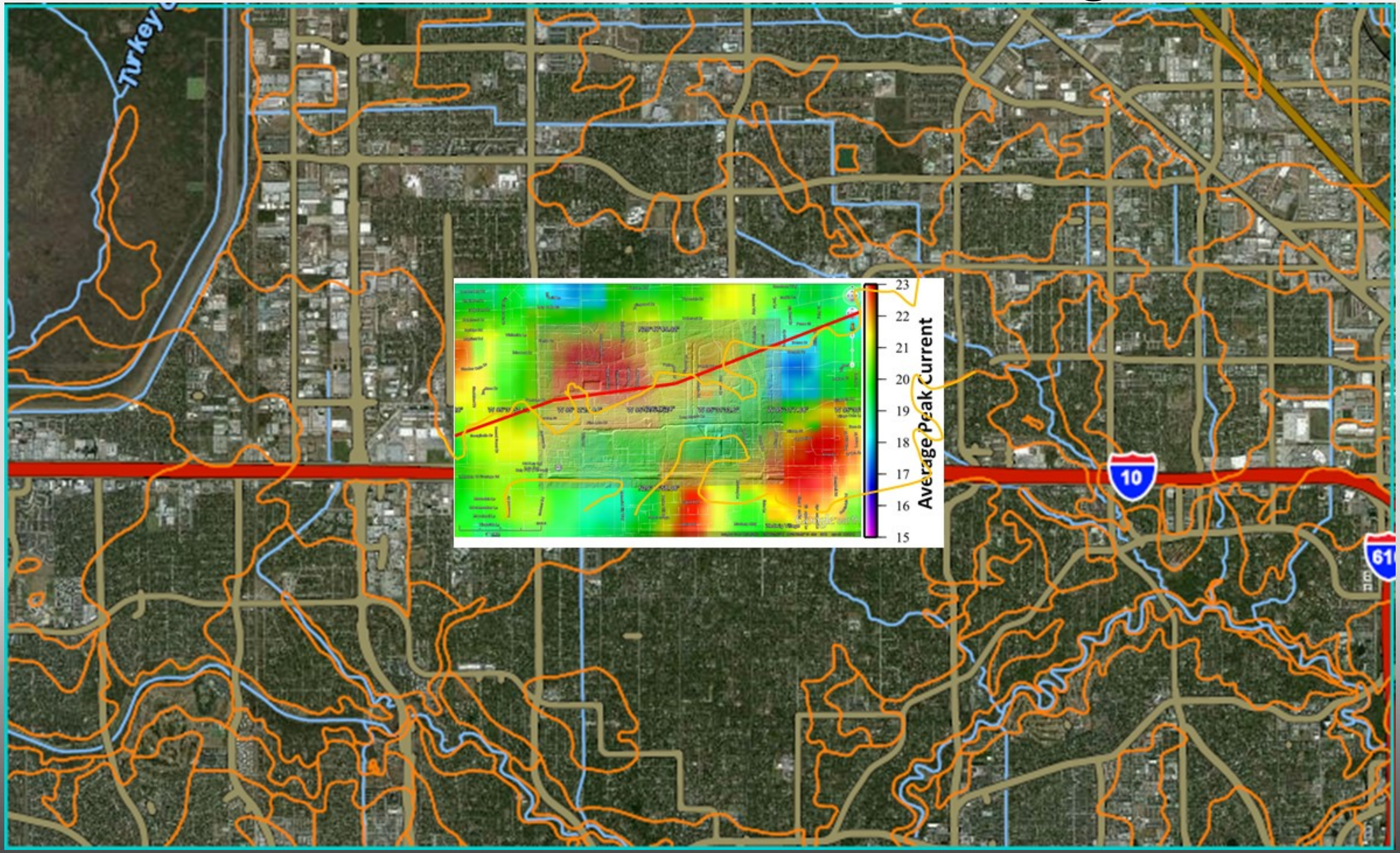

Geological Significance of Density, Rise-Time, & Peak Current Lightning Attributes

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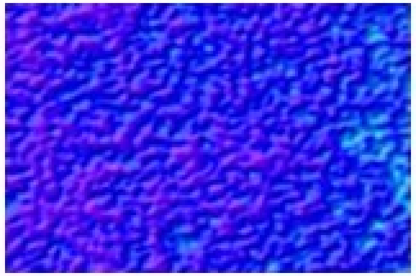
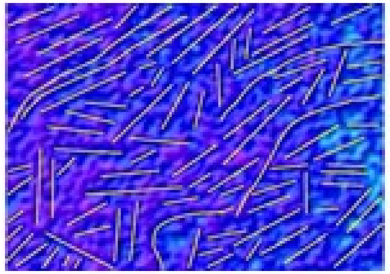
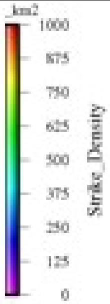
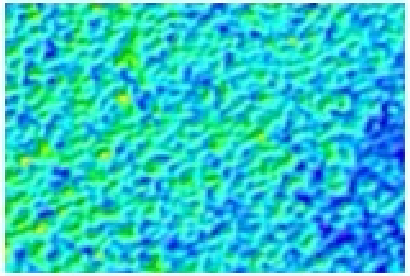
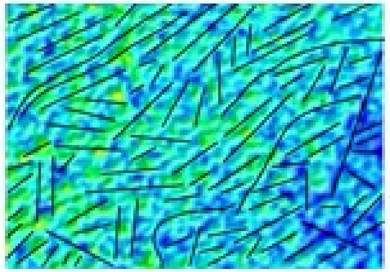
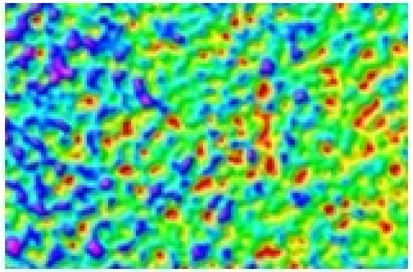
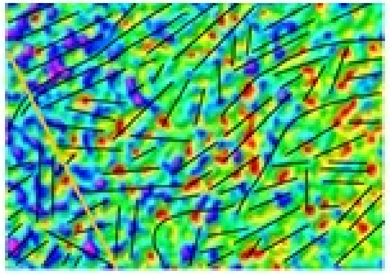
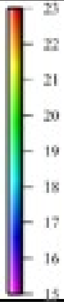
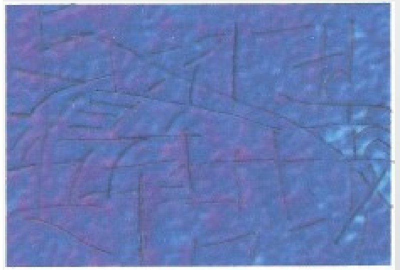
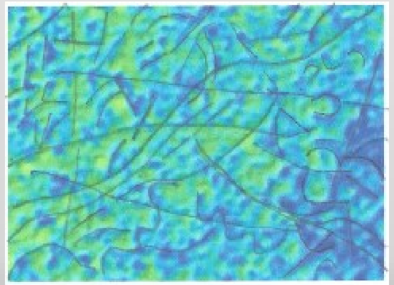
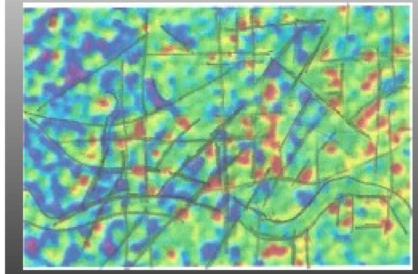
Lightning Attribute	Definition	Geological Attributes	Example	Interpretation	Color Bar
Density	The average number of lightning strikes located in an IG-6 cell (269 x 153 meter or 881 x 503 feet cells at 30° Latitude).	Used to define lineaments which are associated with faulting. Minor topographic effects are distinguished from geologic influences during interpretation.			
Rise-Time	The time to go from background electrical noise to Peak Current in microseconds, averaged over IG6 cells.	Sees areas with higher resistance such as salt domes and fresh water associated with ponds, rivers, and aquifers. In this example, the blue region in the east, suggests the presence of shallow fresh water.			
Peak Current	The average Peak Current in kiloamps of lightning strikes falling in an IG6 cell.	Sees subsurface resistivity and is largely impacted by the negative lightning strikes. Voltage must be higher to get through depth.			







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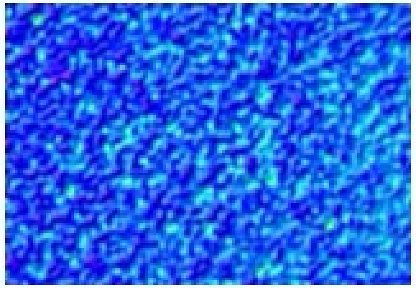
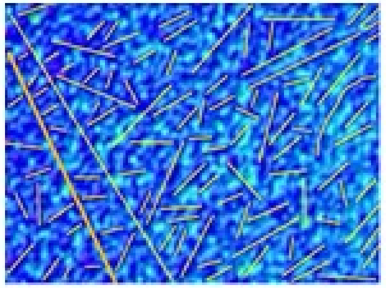
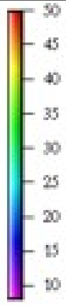
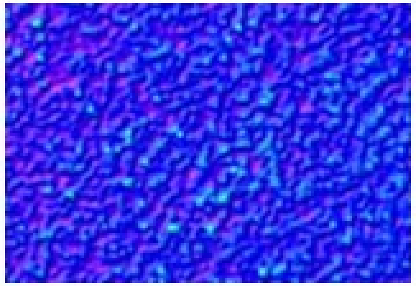
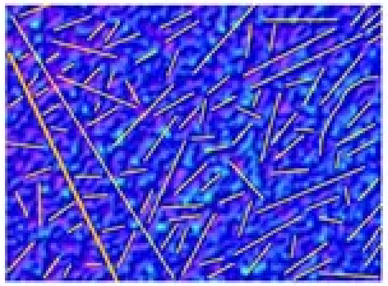
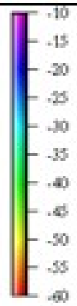
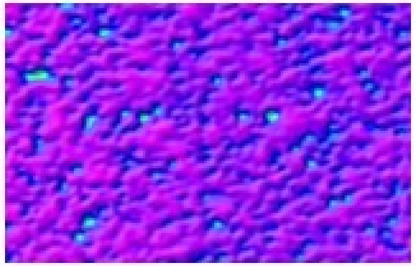
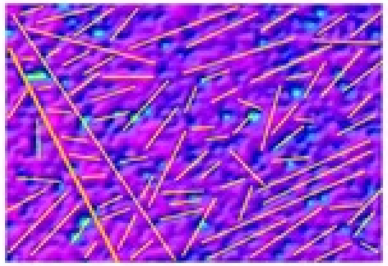
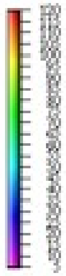
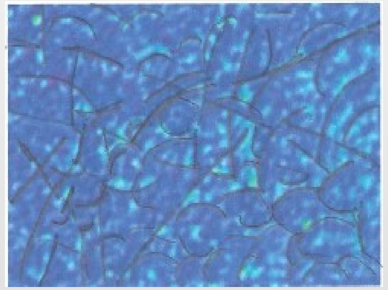
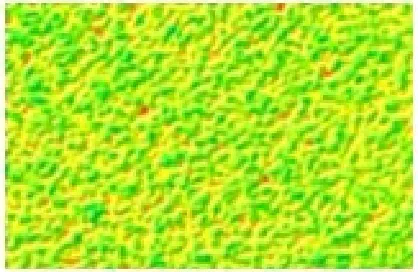
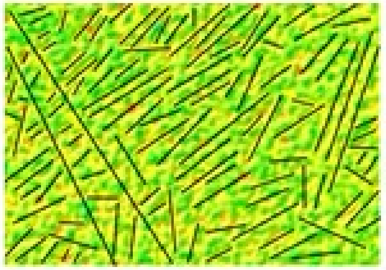
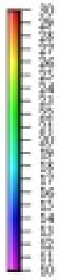
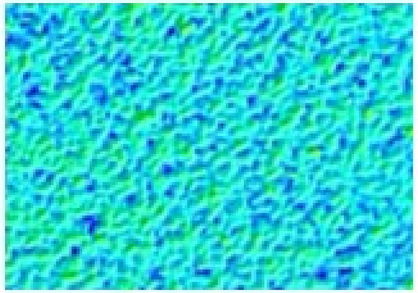
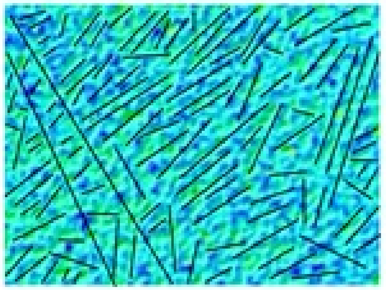
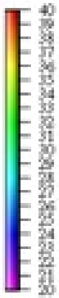
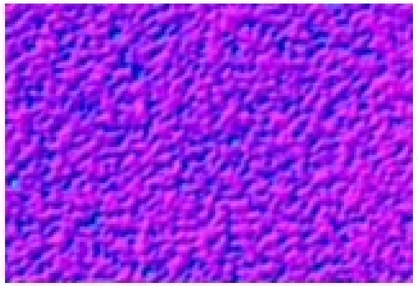
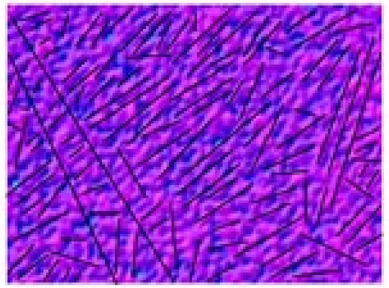
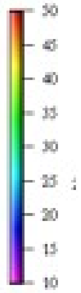
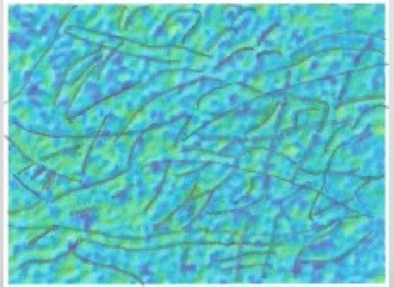
Geological Significance of Peak Current Absolute, Negative, & Positive Lightning Attributes

Lightning Attribute	Definition	Geological Attributes	Example	Interpretation	Color Bar
Peak Current absolute	The average Absolute Peak Current in kilo amps falling in an IG6 cell.	Sees subsurface resistivity and is largely impacted by the negative lightning strikes. Voltage must be higher to get through depth. Note patterns are different.			
Negative Peak Current	The average negative Peak Current in kilo amps falling in an IG6 cell.	Typically sees shallower resistivity, because strikes come at the beginning of a storm and are not as strong.			
Positive Peak Current	The average positive Peak Current in kilo amps falling in an IG6 cell.	Typically sees deeper resistivity because positive peak currents are associated with the most intense strikes occurring at the end of storms. As these strikes are less frequently, interpolation effects may be noticeable.			

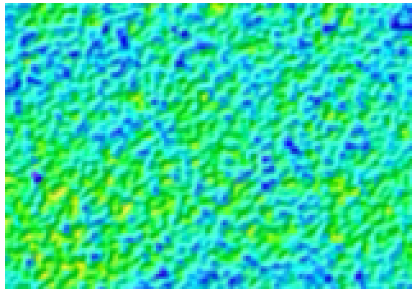
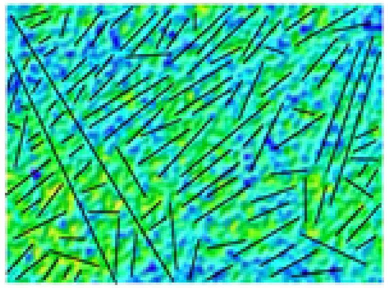
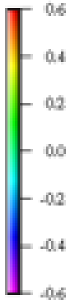
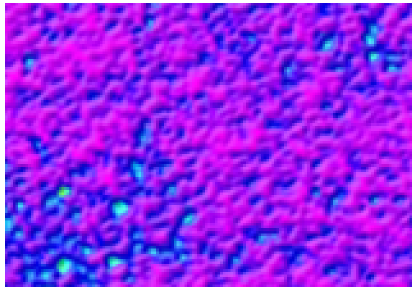
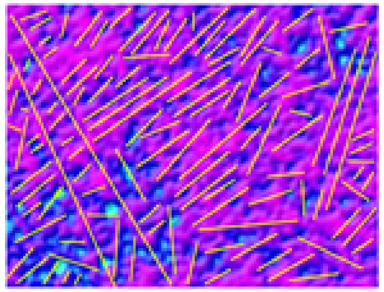
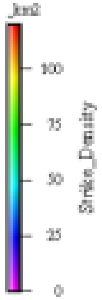
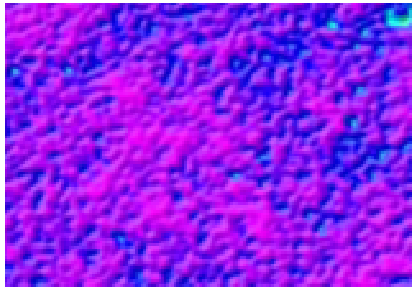
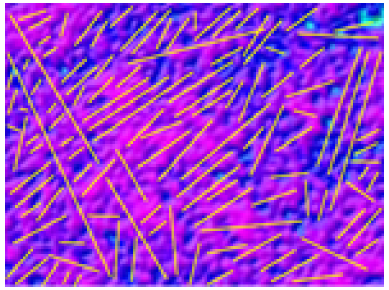
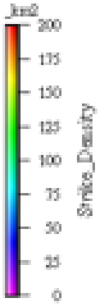


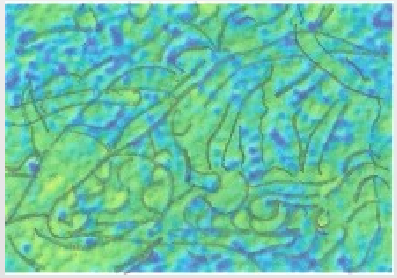
Geological Significance of Peak-to-Zero, Total Wavelet Time, & Wavelet Symmetry Attributes

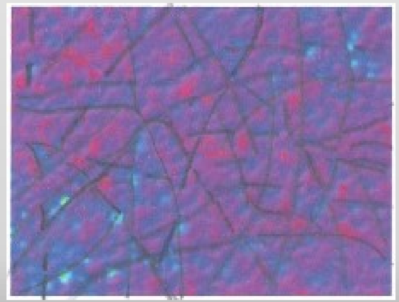
Lightning Attribute	Definition	Geological Attributes	Example	Interpretation	Color Bar
Peak-to-Zero	The time to go from Peak Current to background electrical noise in microseconds averaged over IG6 cells.	Good lineaments and is very closely tied to resistivity. Areas with low resistivity have a low P2Z value.			
Total Wavelet Time	The sum of Rise-Time + Peak-to-Zero Time or the Total Wavelet Time (TWT) as recorded by the NLDN.	Similar to Peak-to-Zero because the Peak-to-Zero time is typically larger than Rise-Time and so would be the dominant component of the Total Wavelet Time.			
Wavelet Symmetry	The ratio of Rise-Time to Total Wavelet Time. Wavelet Symmetry is inversely related to its Peak-to-Zero contribution.	Lineament patterns may be similar to that of Peak-to-Zero and Total Wavelet Time because the Peak-to-Zero time is typically the dominant component of all three of these lightning attributes.			

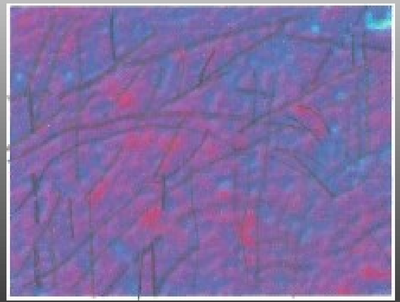


Geological Significance of Earth Tide Density, Greater Than 75%, & Less Than 75% Attributes

Lightning Attribute	Definition	Geological Attributes	Example	Interpretation	Color Bar
Earth Tide Density	The cumulative tidal effect of the sum of lunar and solar gravity creates earth tides. There are more lightning strikes at high and low earth tides near faults.	It appears more conductive clays in the fault scarps, and disruption of shallow earth, terralevis, currents by faults create more lightning strikes at high and low earth tides.			
Earth Tide Density greater than 75% of the monthly maximum rate	The density of lightning strikes which occur at greater than 75% of the monthly maximum earth tide.	As with each of the lightning attributes there are strong lineaments which are emphasized, like the horizontal and the up to the right at 45° from the bright events in the lower left.			
Earth Tide Density less than 75% of the monthly maximum rate	The density of lightning strikes which occur at less than 75% of the monthly maximum earth tide.	With this attribute there are strong dipping to the southwest horizontal lineaments at the top of the example area which are not seen on other attributes.			







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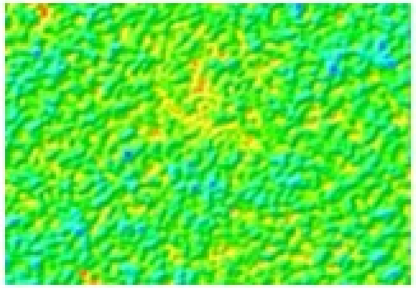
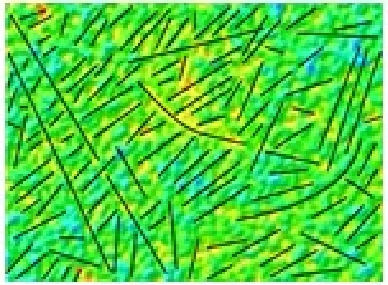
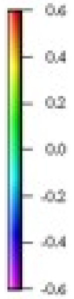
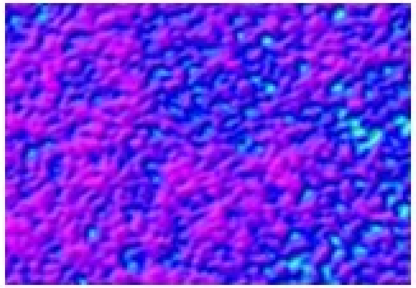
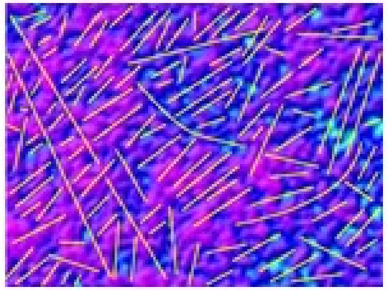
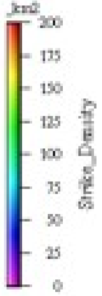
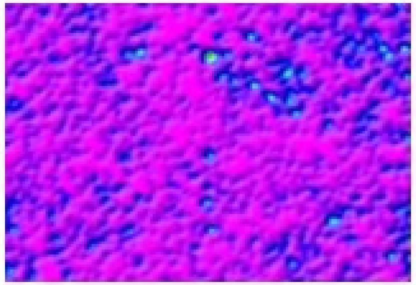
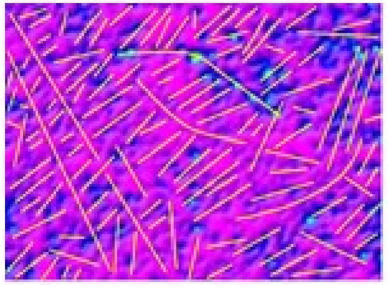
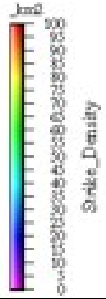
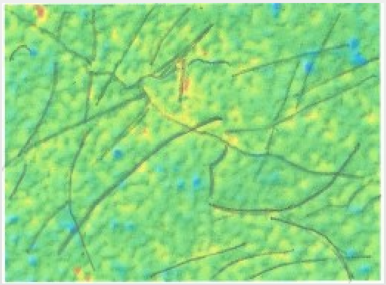
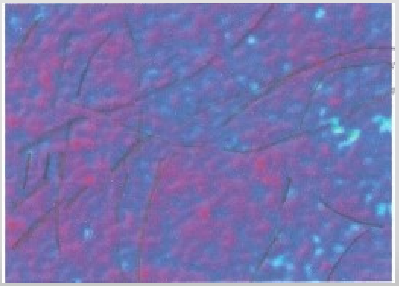
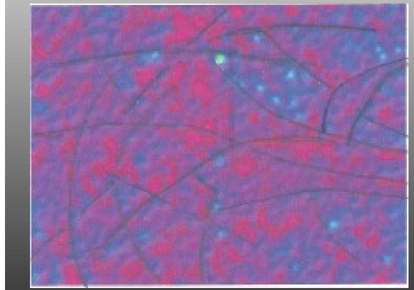
Geological Significance of Earth Tide Gradient Density, Greater Than 75%, & Less Than 75% Attributes

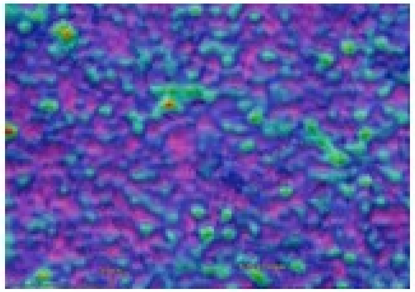
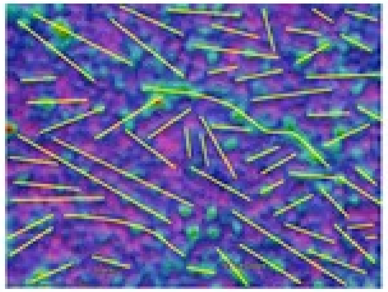
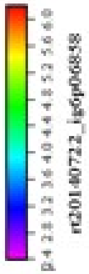
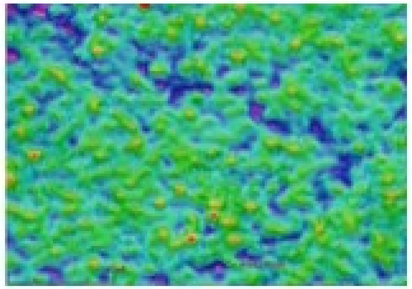
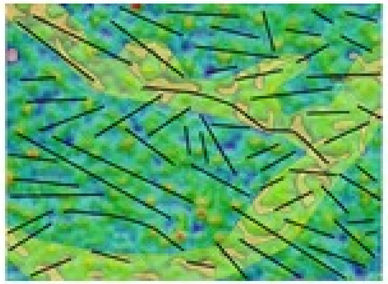
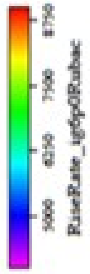
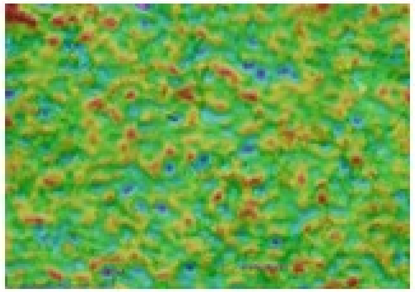
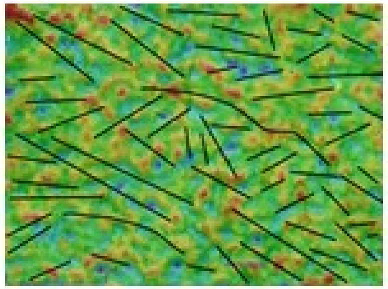
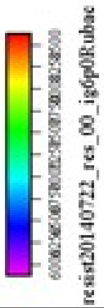
Lightning Attribute	Definition	Geological Attributes	Example	Interpretation	Color Bar
Earth Tide Gradient	Earth Tide Gradient is the first derivative of the Earth Tide, or the maximum ebb and flow of the Earth Tide. This attribute is the density of strikes at the gradient.	On several surveys the density of strikes tied to the gradient appears to highlight faults better than other attributes.			
Earth Tide Gradient greater than 75% of the monthly maximum rate	The density of lightning strikes which occur at greater than 75% of the monthly maximum earth tide gradient.	There are similar patterns to the Earth Tide Gradient and the Earth Tide, although this particular color bar is not very well normalized for data in the example area.			
Earth Tide Gradient less than 75% of the monthly maximum rate	The density of lightning strikes which occur at less than 75% of the monthly maximum earth tide gradient.	Again, this attribute shows a unique lineament in the top center which appears to be a down to the Gulf growth fault.			

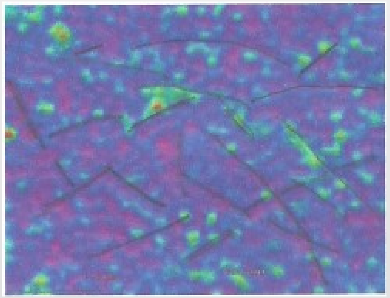


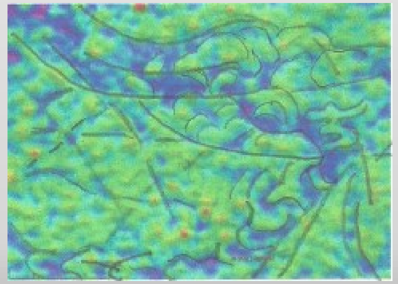


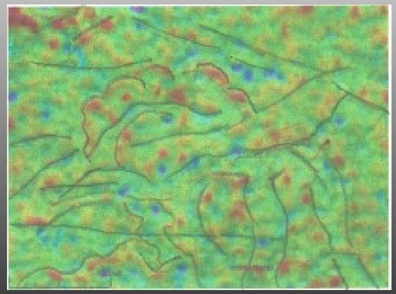


Geological Significance of Rise-Time, Rate of Rise-Time, & Surface Resistivity Lightning Attributes

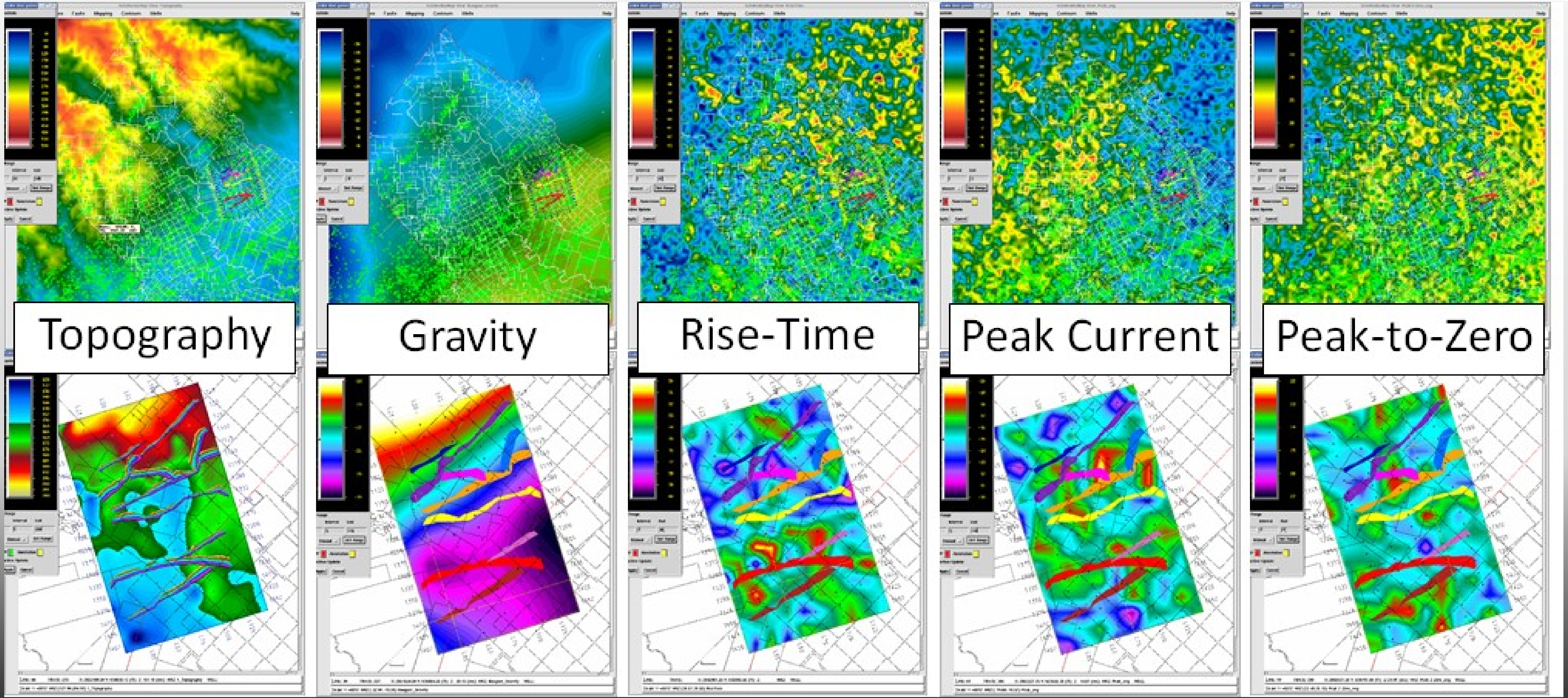
Lightning Attribute	Definition	Geological Attributes	Example	Interpretation	Color Bar
Rise-Time Central Texas	The time to go from background electrical noise to Peak Current in microseconds, averaged over IG6 cells.	Sees areas with higher resistance. In this example there are 4 ponds in the bottom central part of the map which show up as anomalies, and the river is the curved line in the middle.			
Rate of Rise-Time Central Texas	Calculated by dividing the Peak Current by the Rise-Time giving results in kiloamps/ms	Appears to be related to shallow fresh water, and was used to make a detailed shallow stratigraphy map.			
Surface Resistivity Central Texas	Surface resistivity calculated from P2Z and Peak Current as defined in pending patent.	A sum of the resistivity at all depths beneath the surface location. As with other attributes there are lineaments.			



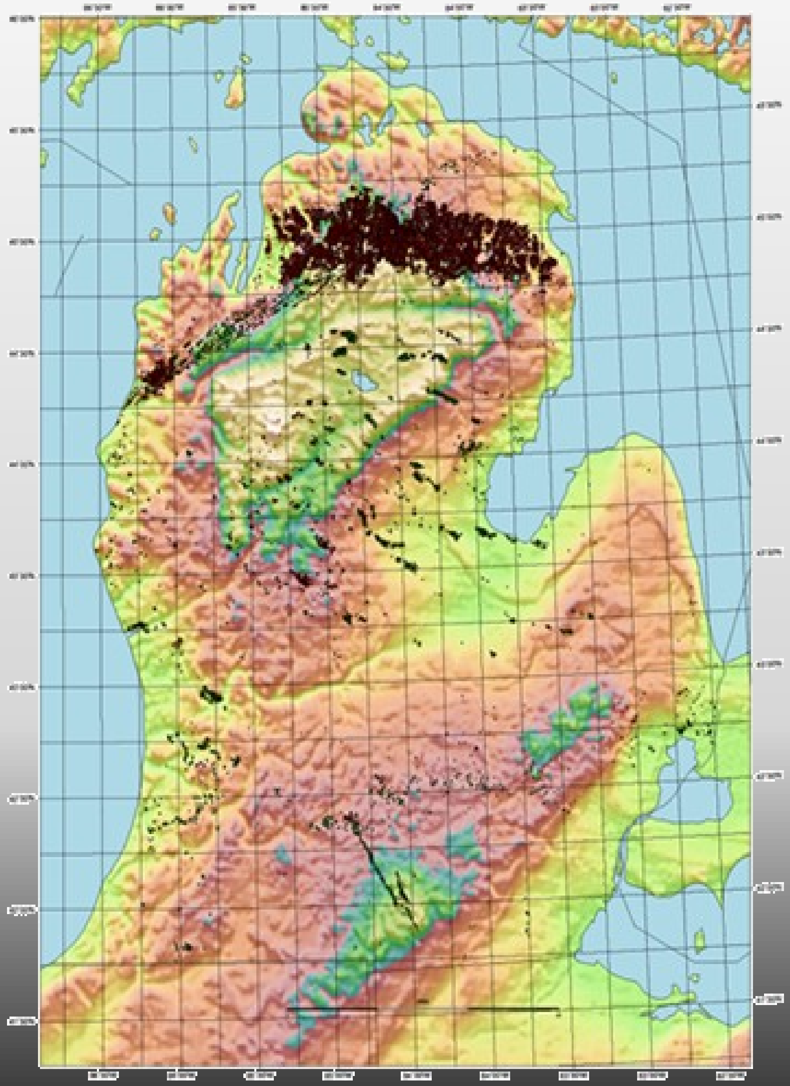


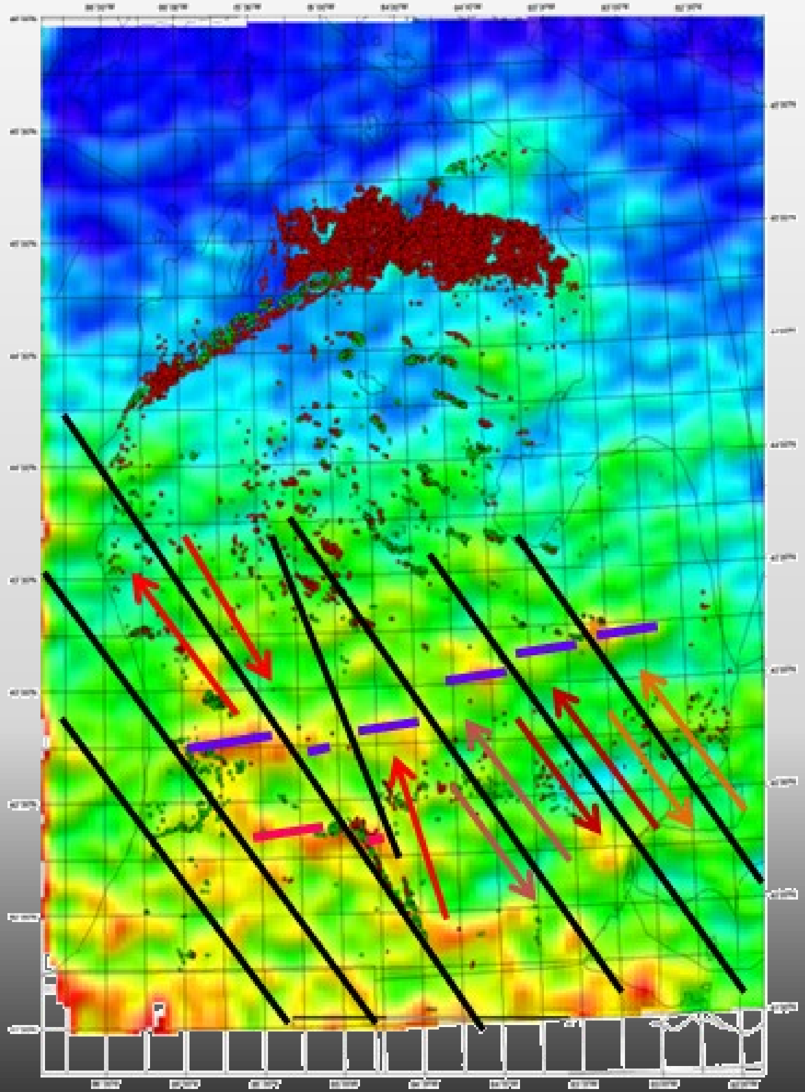


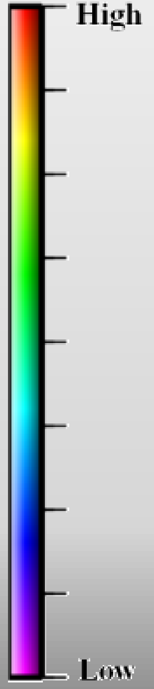
A New Potential Fields Method, Supplementing Gravity & Magnetics



Michigan Basin Topography & Strike Density







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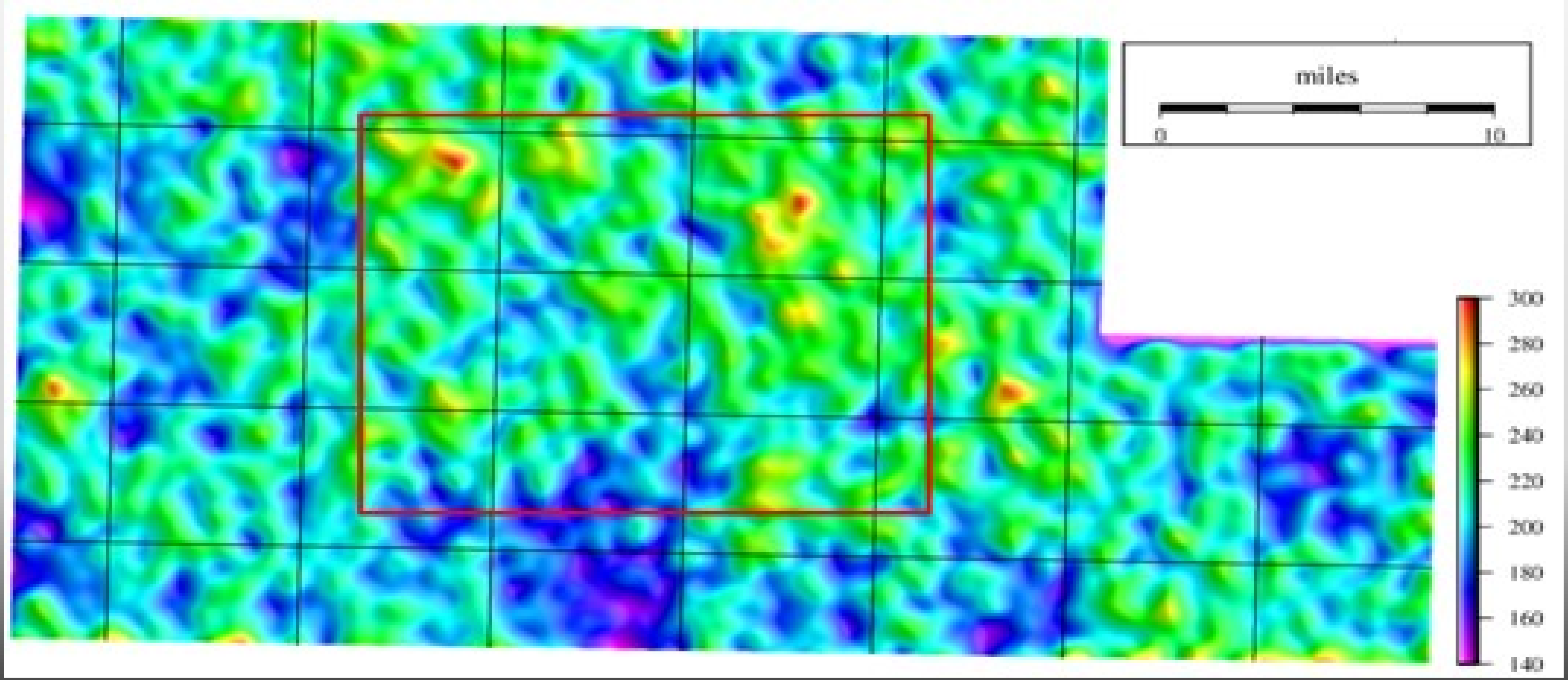
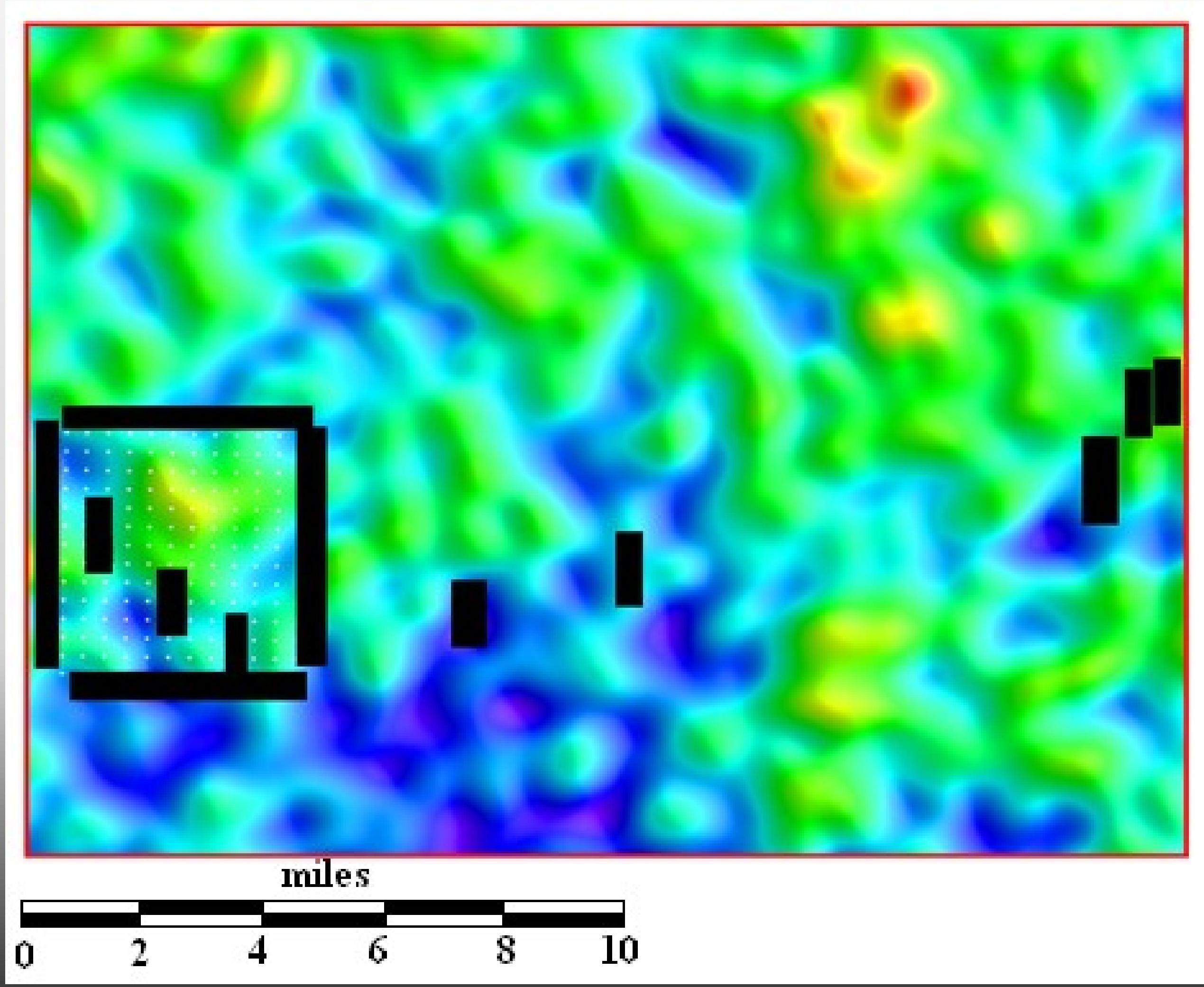
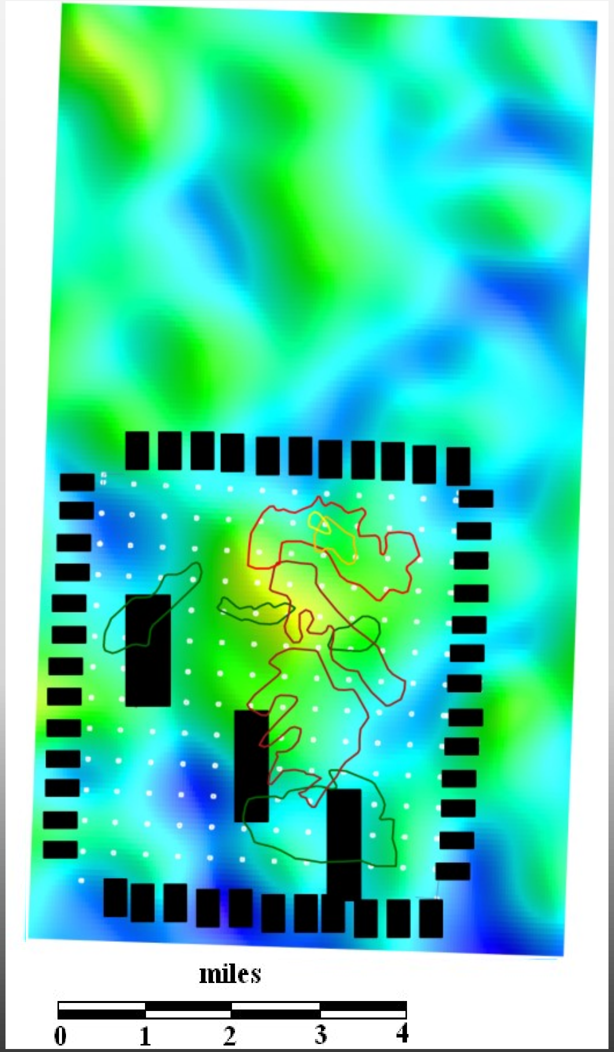
Lightning Analysis Gives Quicker Regional Overview



More details at Play Fairway & Prospect Scales





Agenda

3:00 Registration and Introductions
3:30 The meteorology behind lightning databases
3:45 Using lightning databases to explore for natural resources
4:00 Calculating resistivity volumes from lightning databases
4:45 Examples of resistivity volumes and potential applications
- Regional and Play Fairway hydrocarbon migration pathways
- High-grading exploration sweetspots

5:15 Anticipated future developments
- Use with Archie's equation to predict Formation Factor, Porosity, etc.
- Questions and Answers and Discussion among participants

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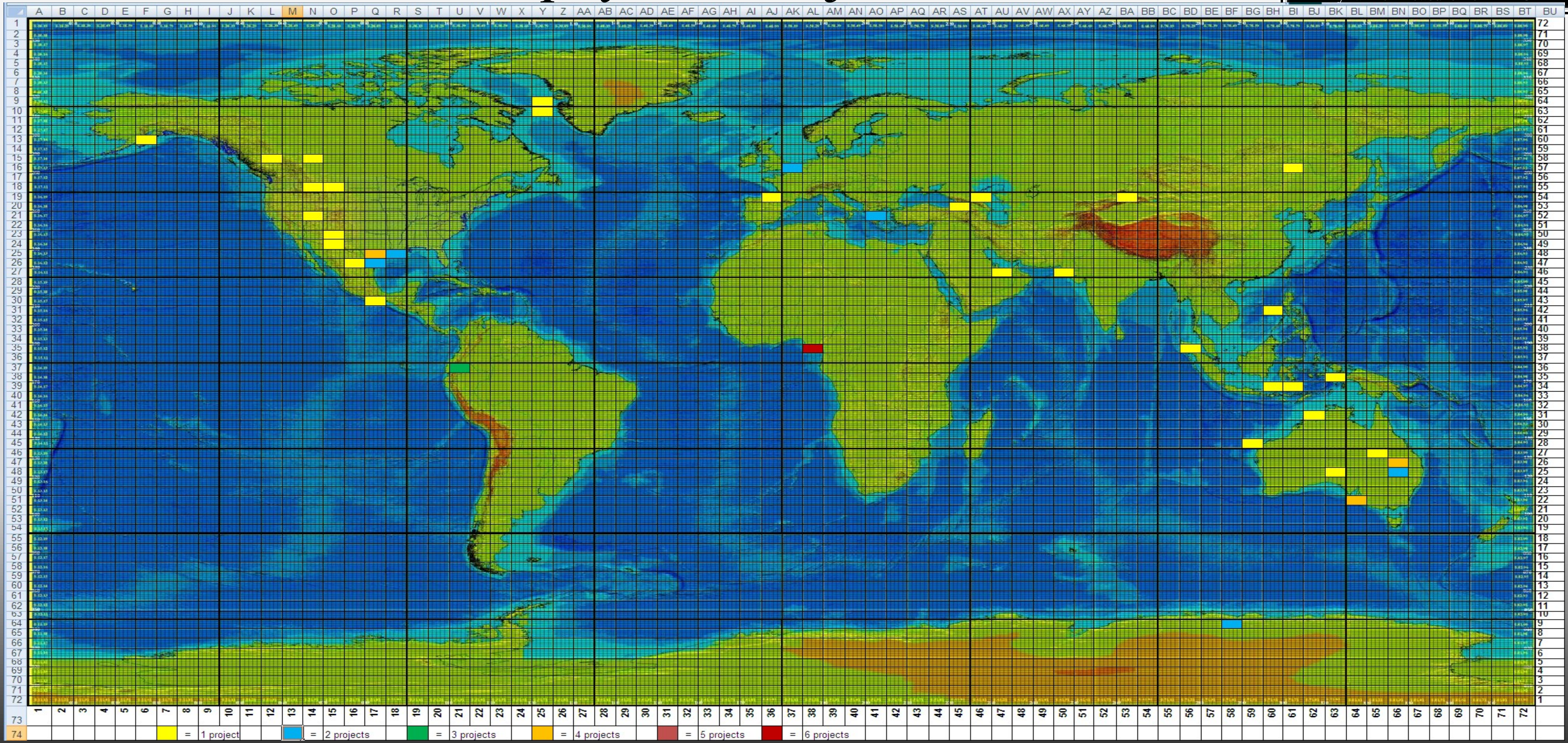
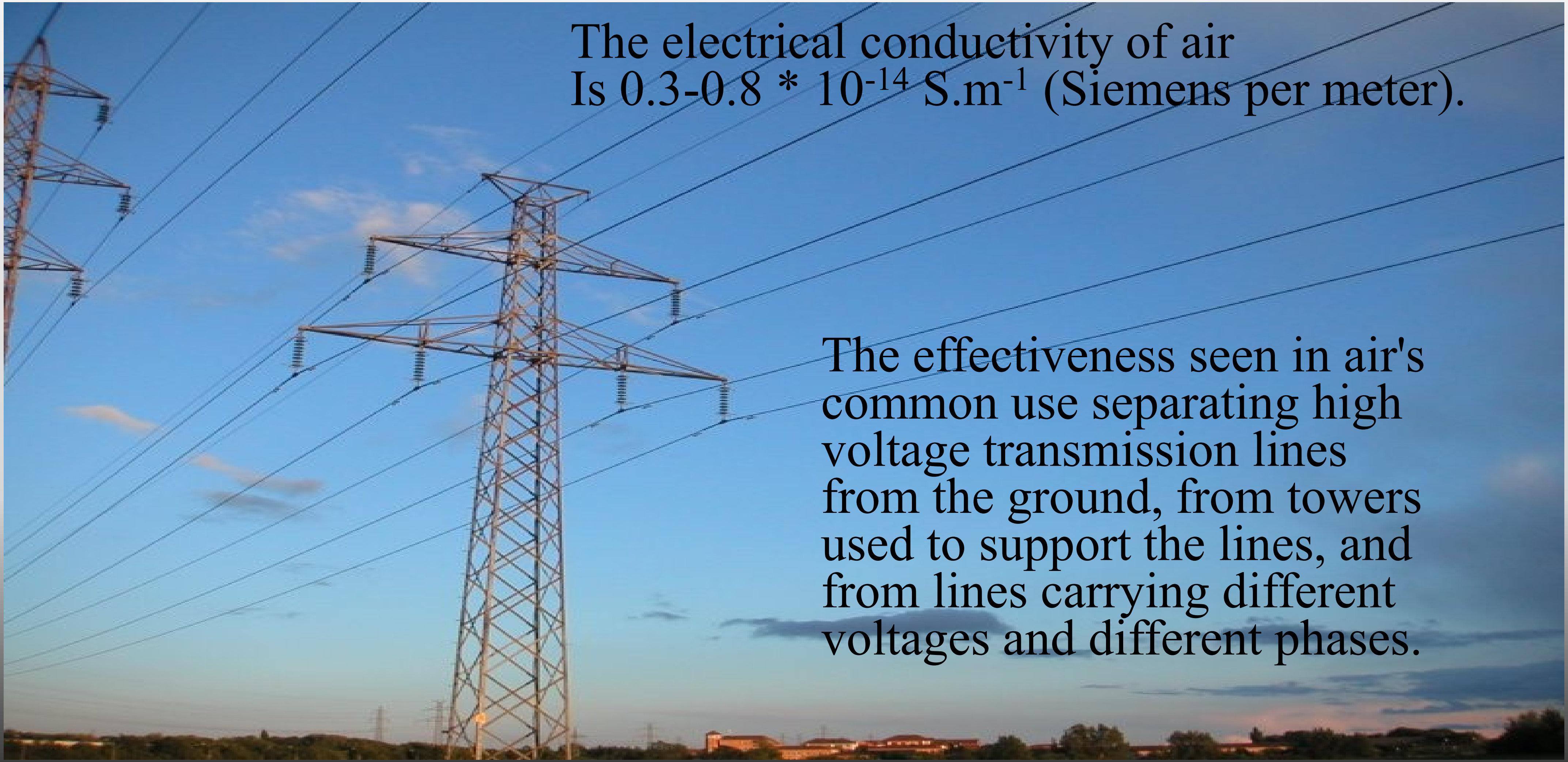
Les R. Denham Geophysical Projects:



Recorded Lightning Data

- Cloud-to-ground lightning can be measured and recorded
- Lightning measurements have been made for more than thirty years
- A continuous record of essentially all cloud-to-ground lightning strokes in the contiguous U.S.A. and Canada has been made for approximately fifteen years.
- A continuous record of cloud-to-ground lightning strokes worldwide has been made for about four years

The atmosphere is an effective insulator

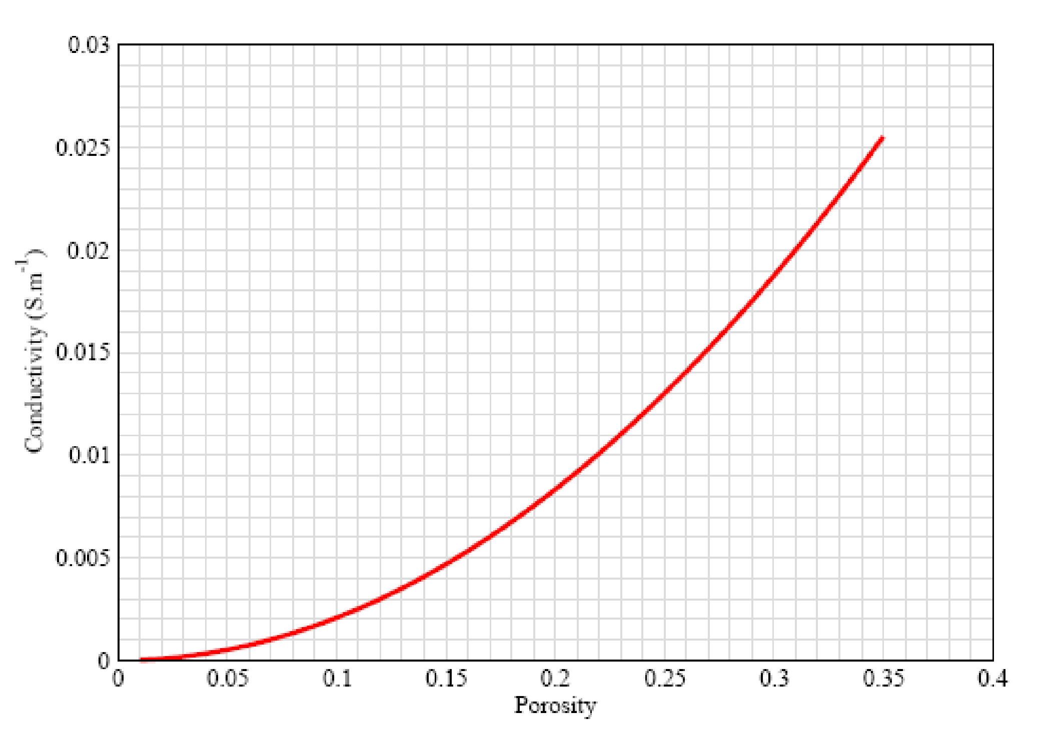


The electrical conductivity of air
Is 0.3-0.8 * 10^{-14} $S.m^{-1}$ (Siemens per meter).

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.

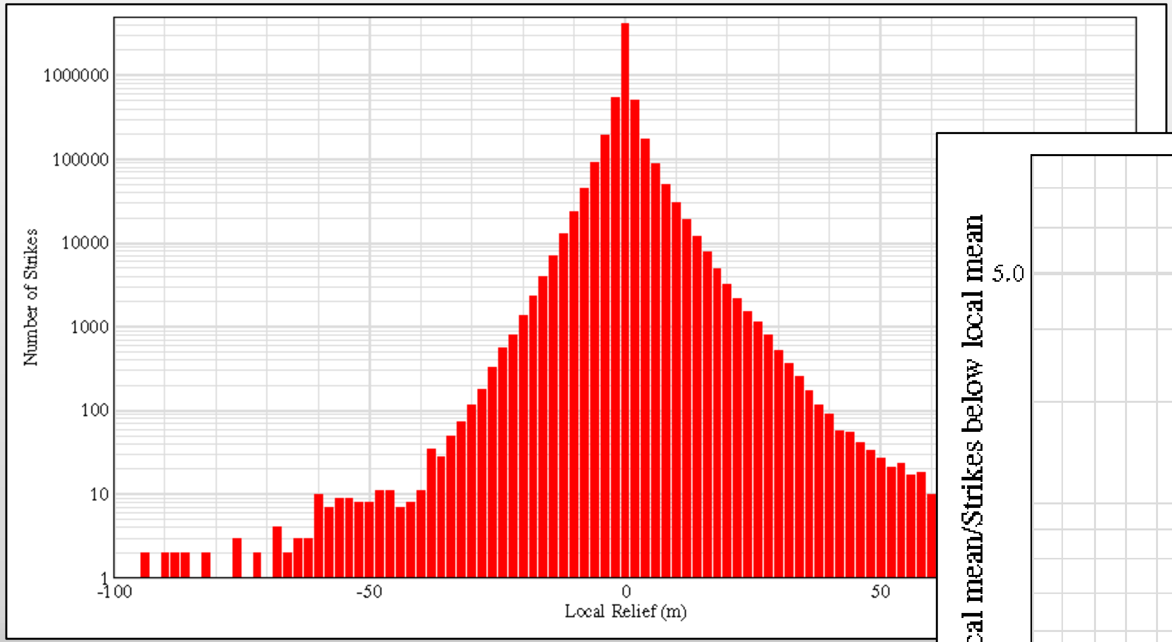
The earth is much more conductive than air

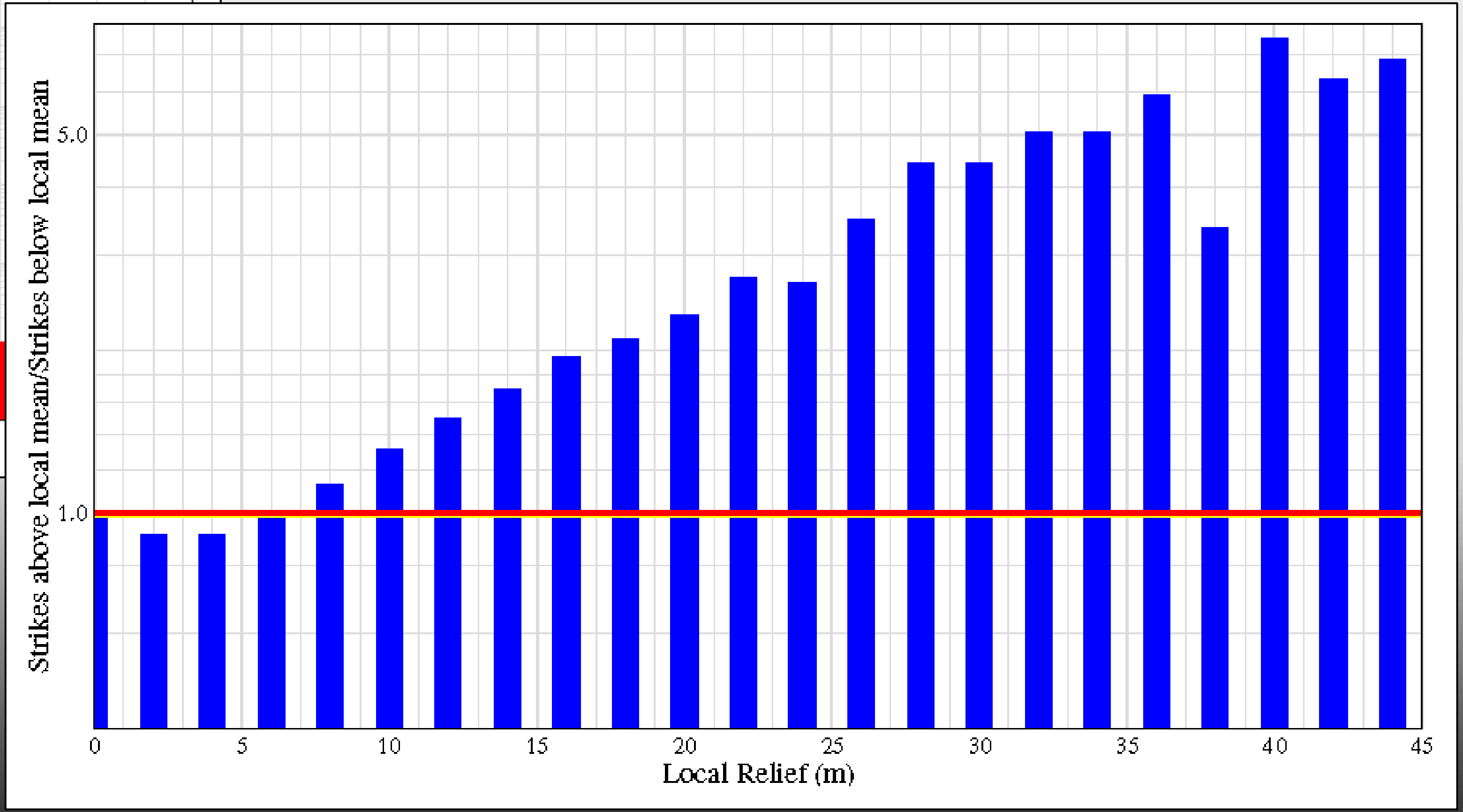
Assuming a typical sedimentary rock has 5% porosity, the electrical conductivity of rocks is $5.0 * 10^{-4}$ $S.m^{-1}$, or about 10^{10} times the conductivity of air.



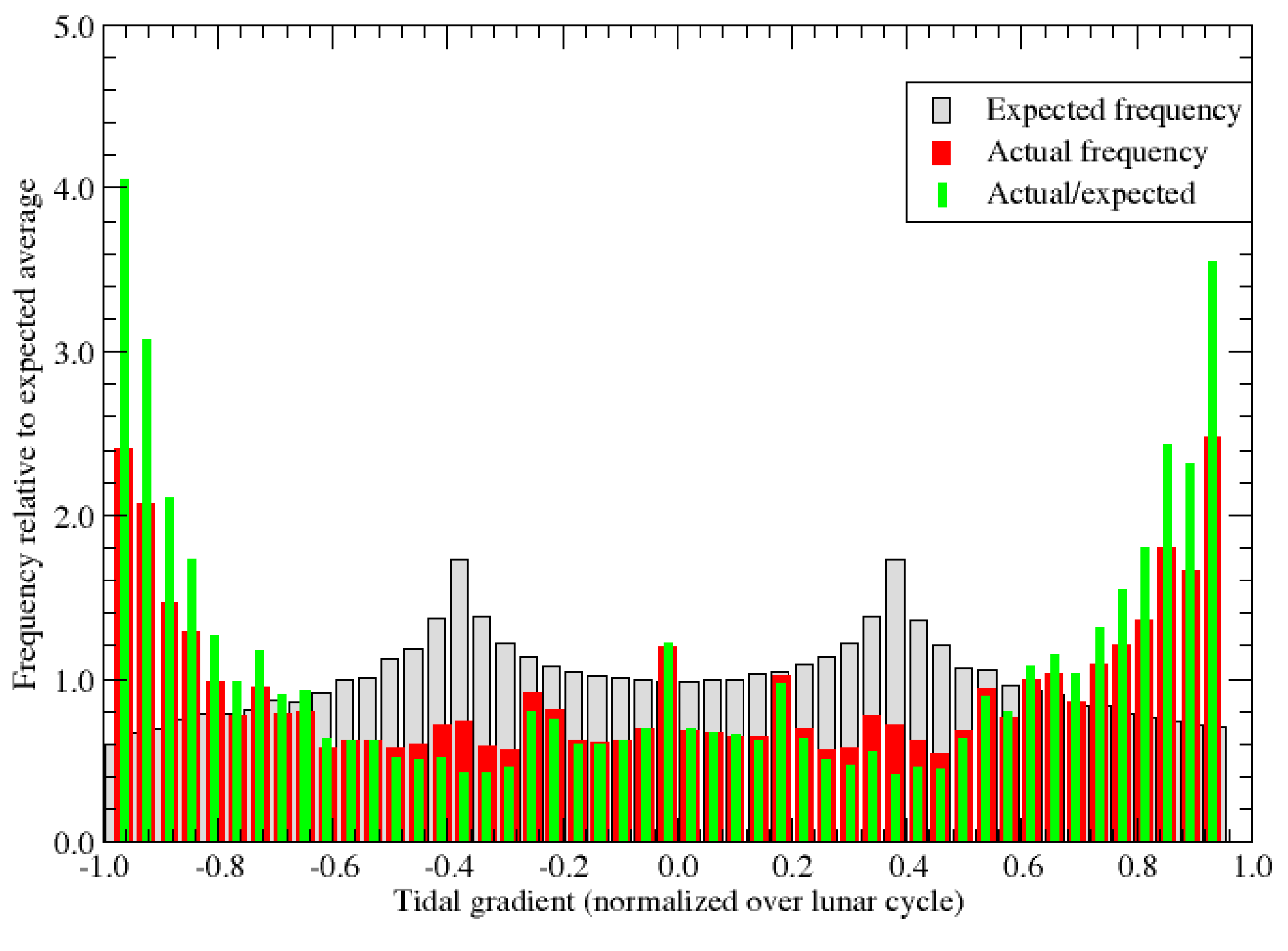
Rock Conductivity Graph computed for a porous rock with 100% brine saturation using Archie's equation

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





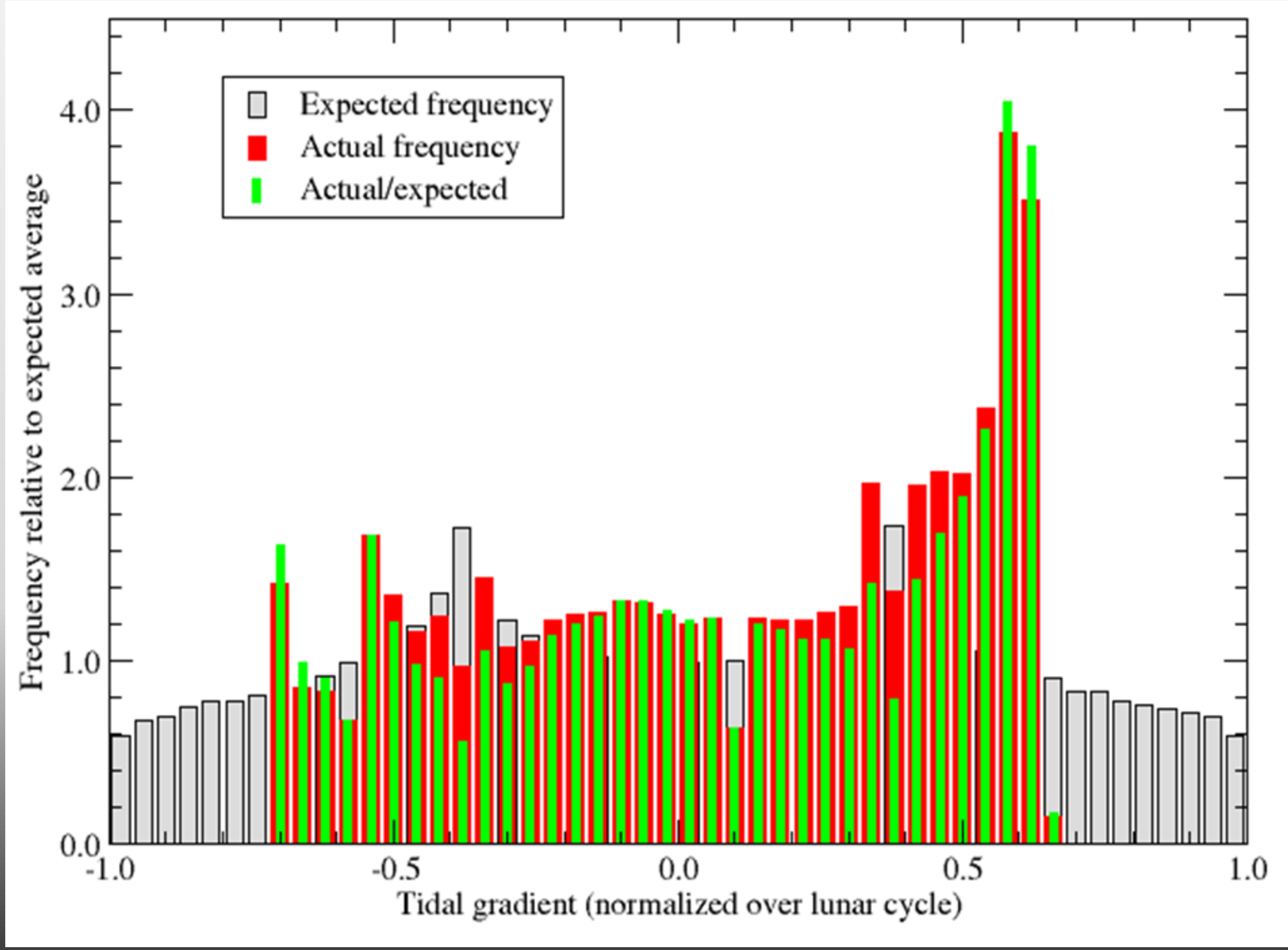
Tidal Gradient North Texas



Similar to several other studies:

- More strikes at both maximum flood and maximum ebb
- Believe it is because tides open or close faults a little bit and increase conductivity

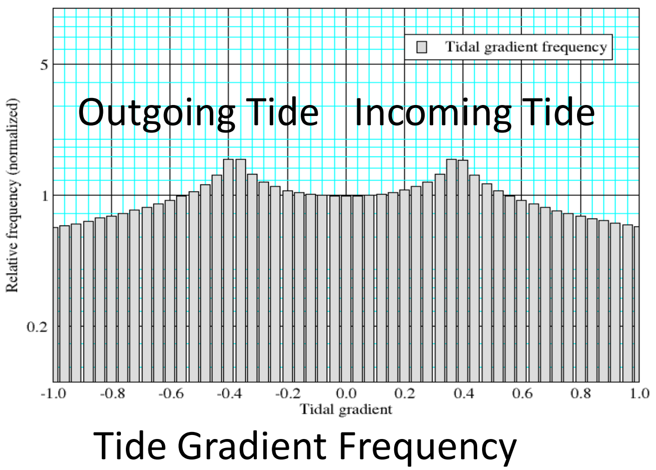
Tidal Gradient in Swampy Area

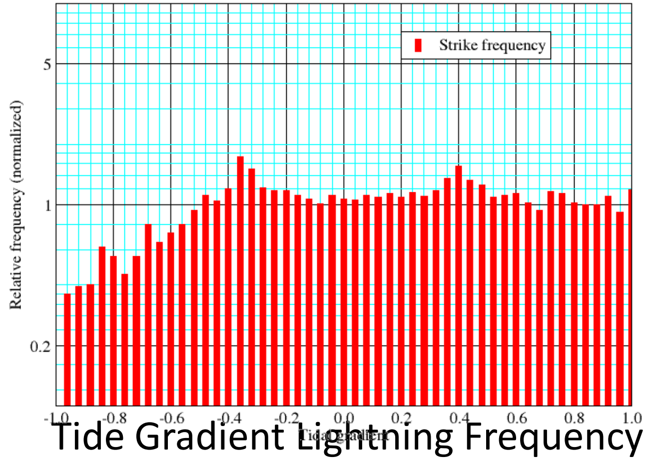


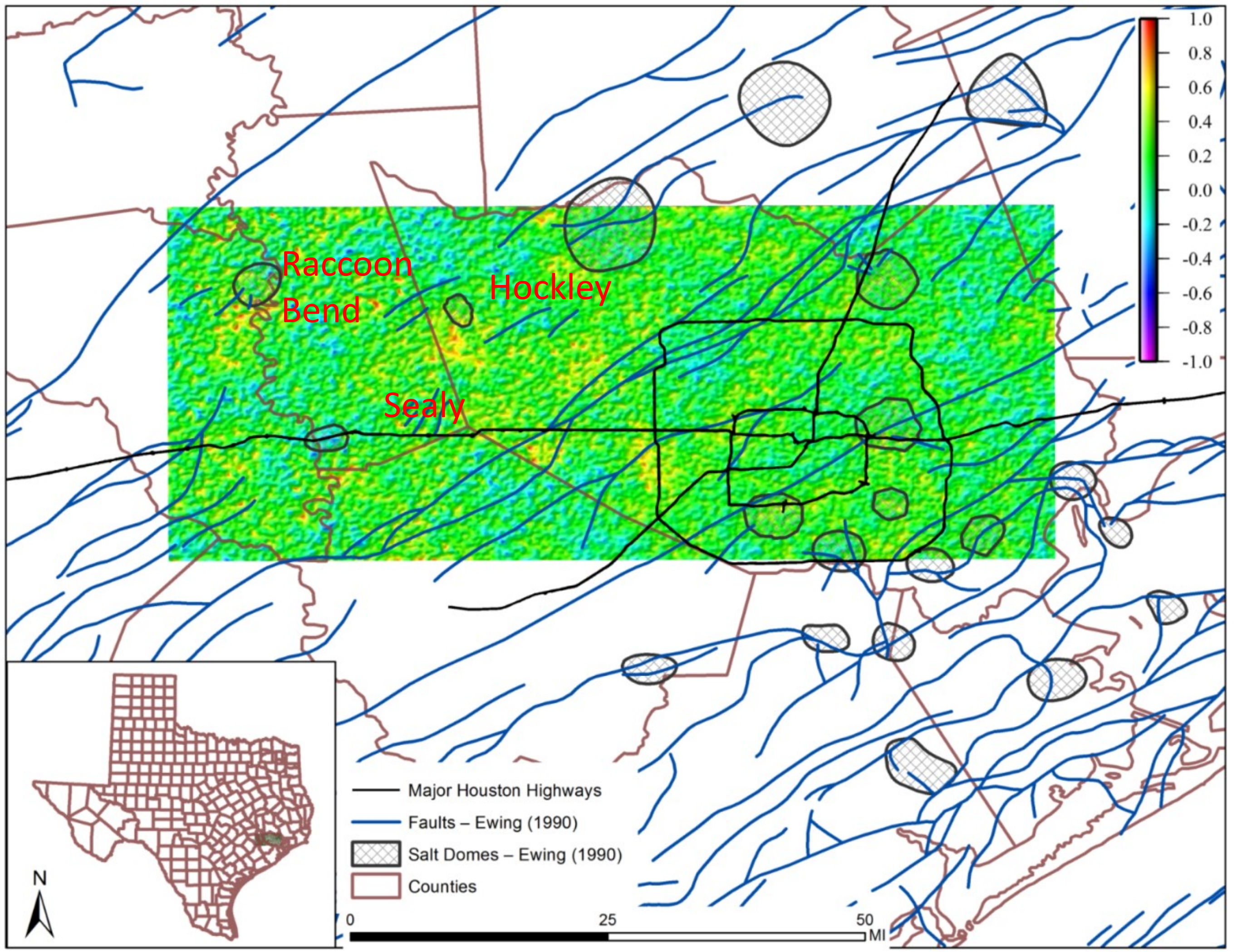
In swamps:

- No strikes at maximum flood or maximum ebb
- Area within a meter of sea level
- Believe tides wash out both biogenic and thermogenic methane
- Most strikes just past half flood

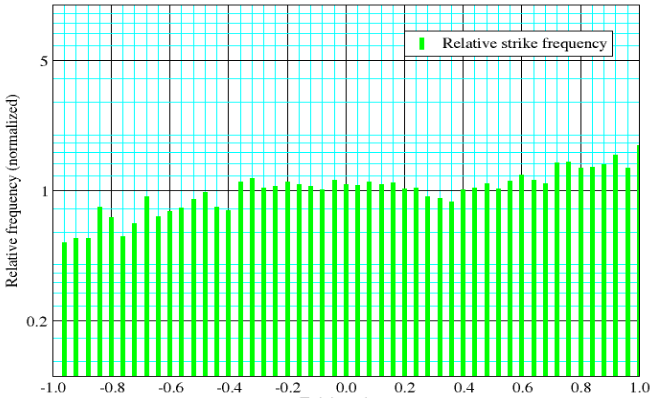
Tidal Gradient when Strikes Occur



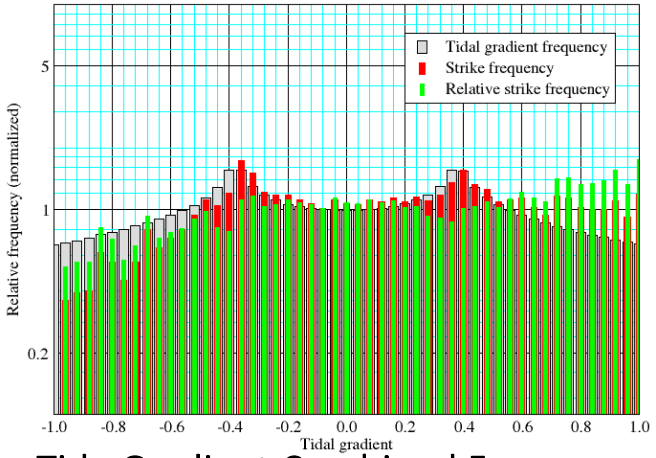




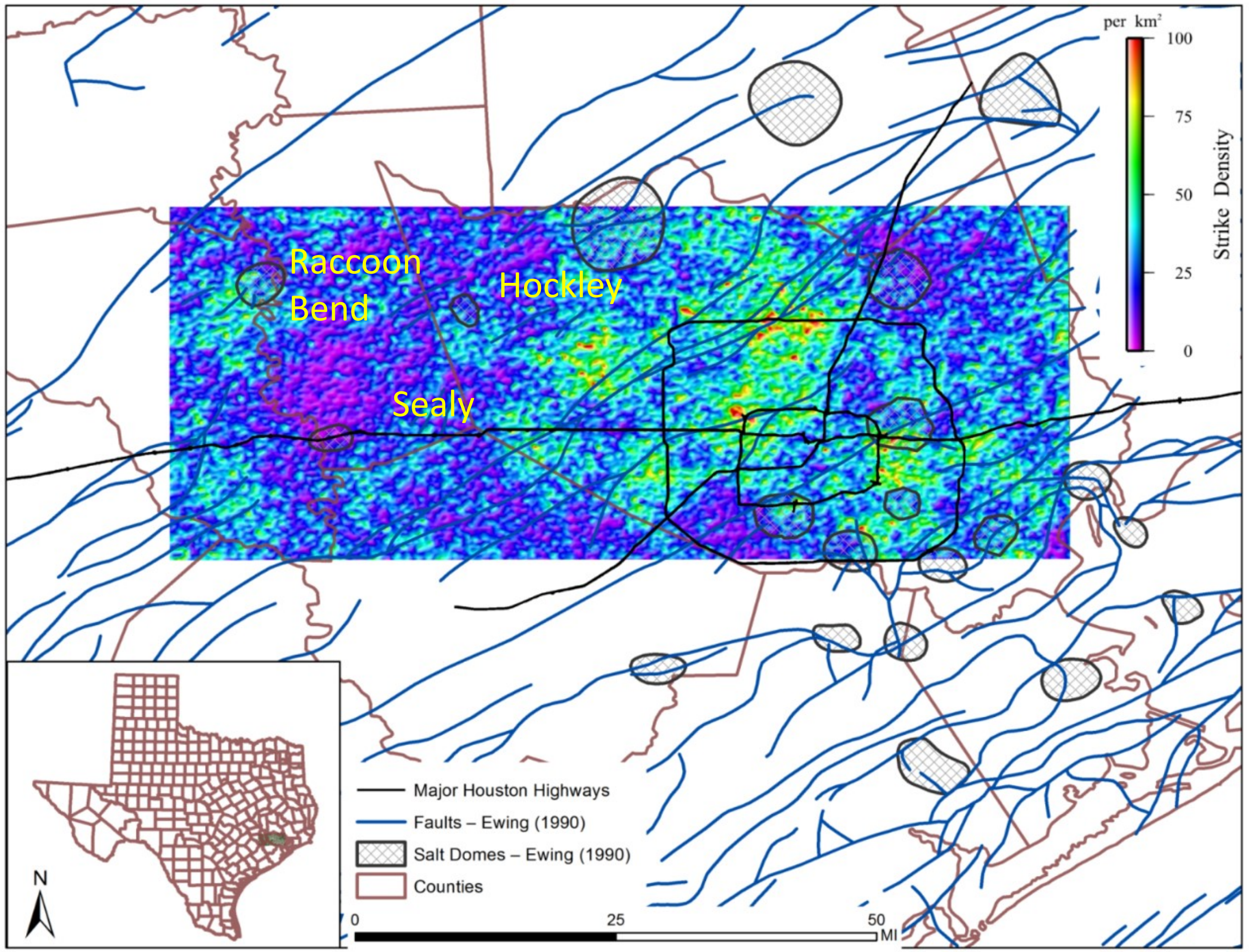
Strike Density at High Tidal Gradient



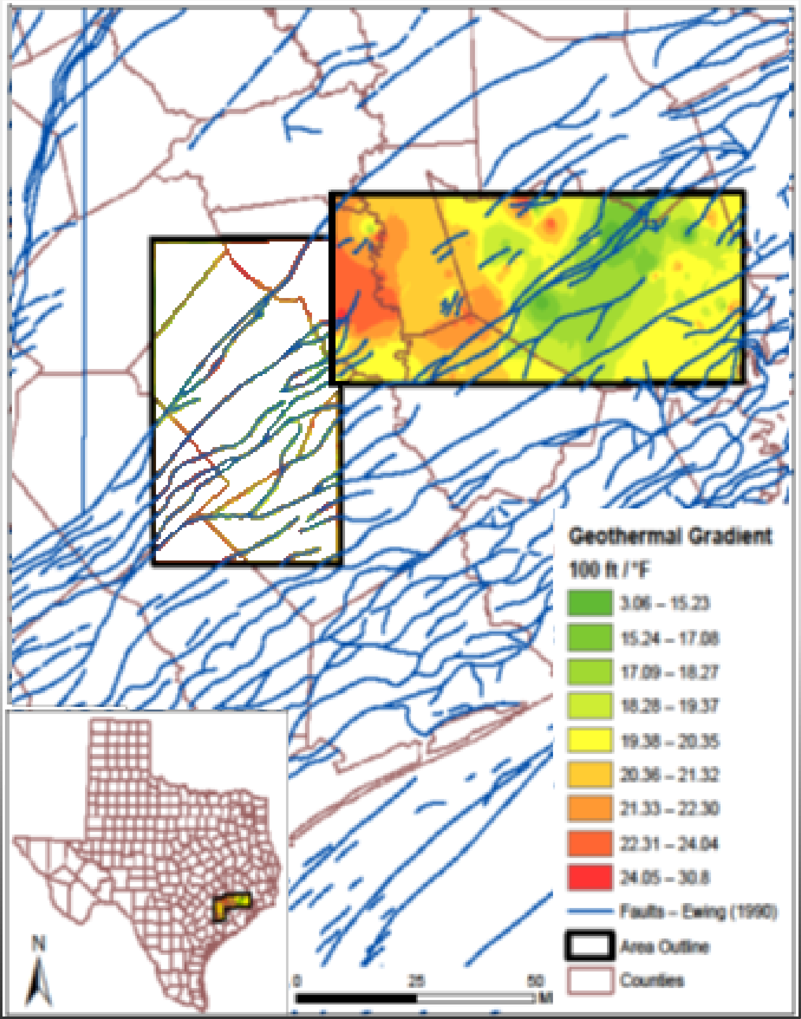
Tide Gradient Normalized Lightning Frequency

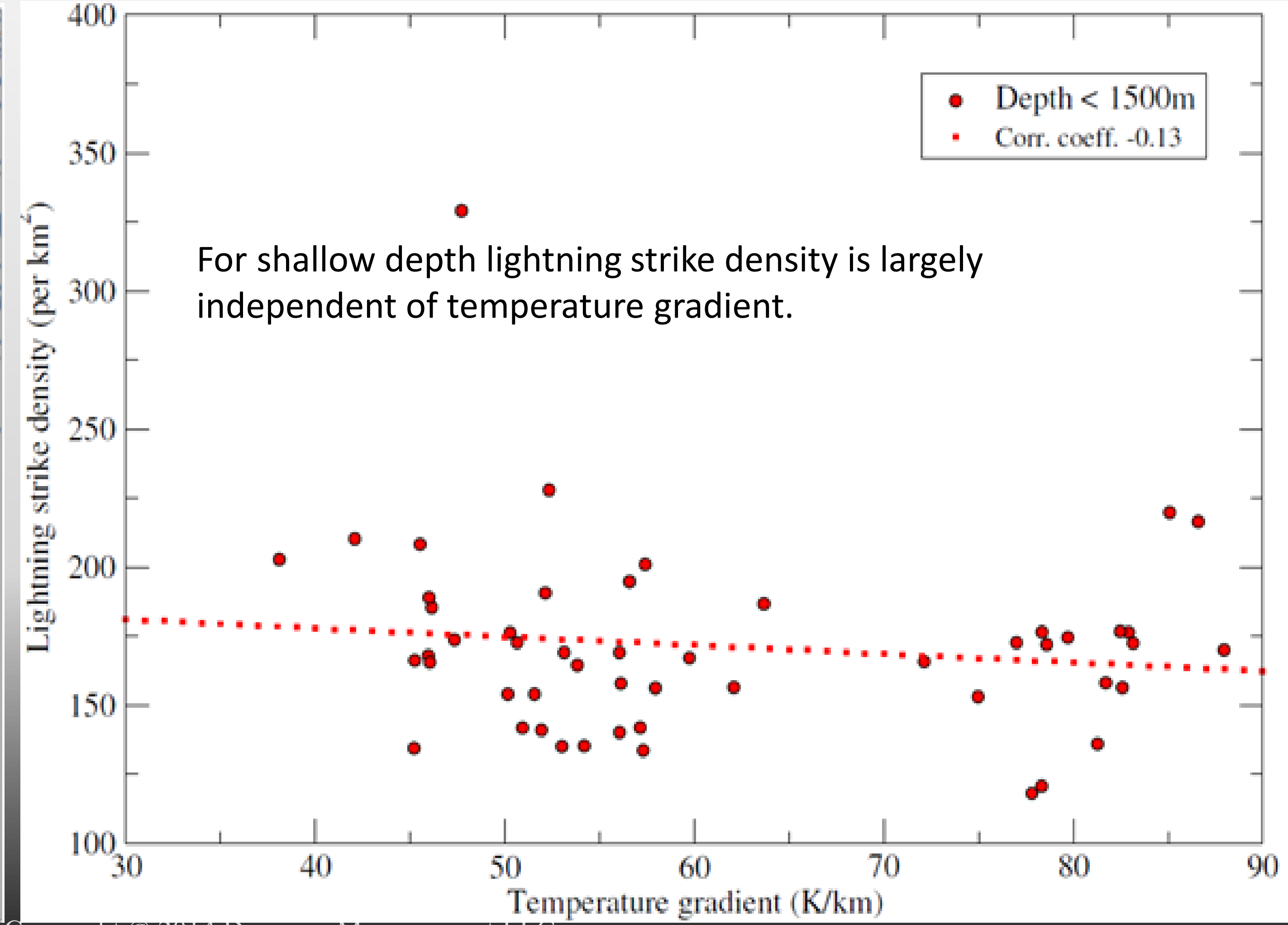


Tide Gradient Combined Frequency



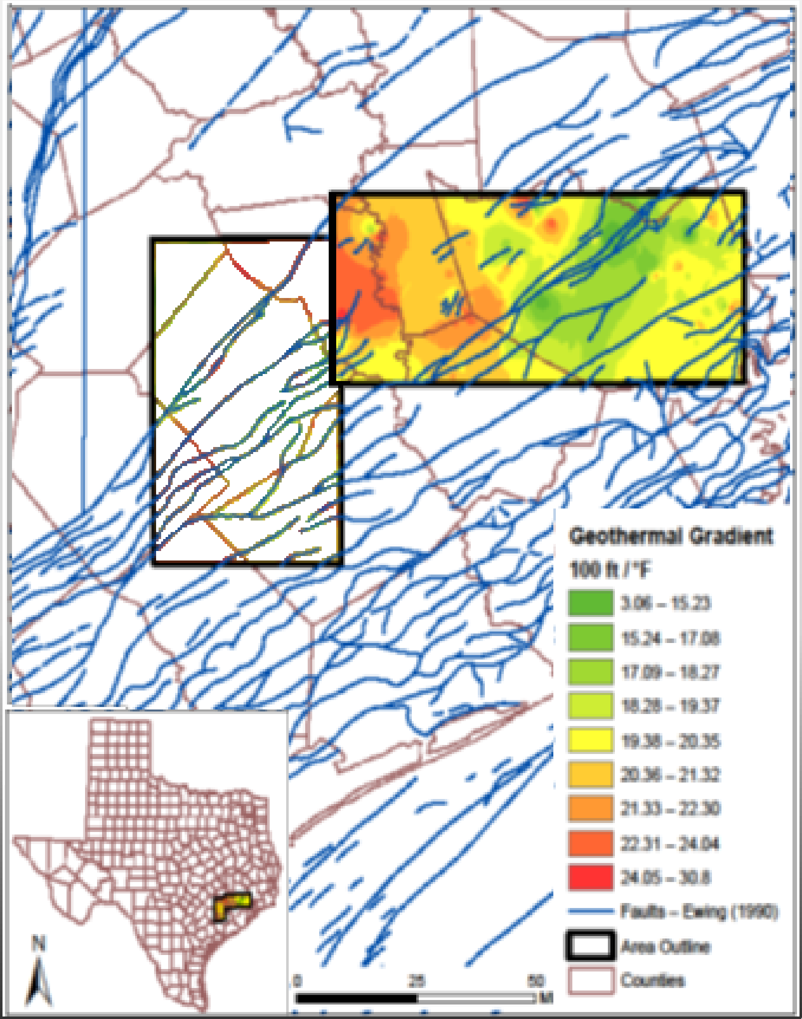
Strike Density Wells Vs. Geothermal Gradient <1,500 m (4,920 Feet)

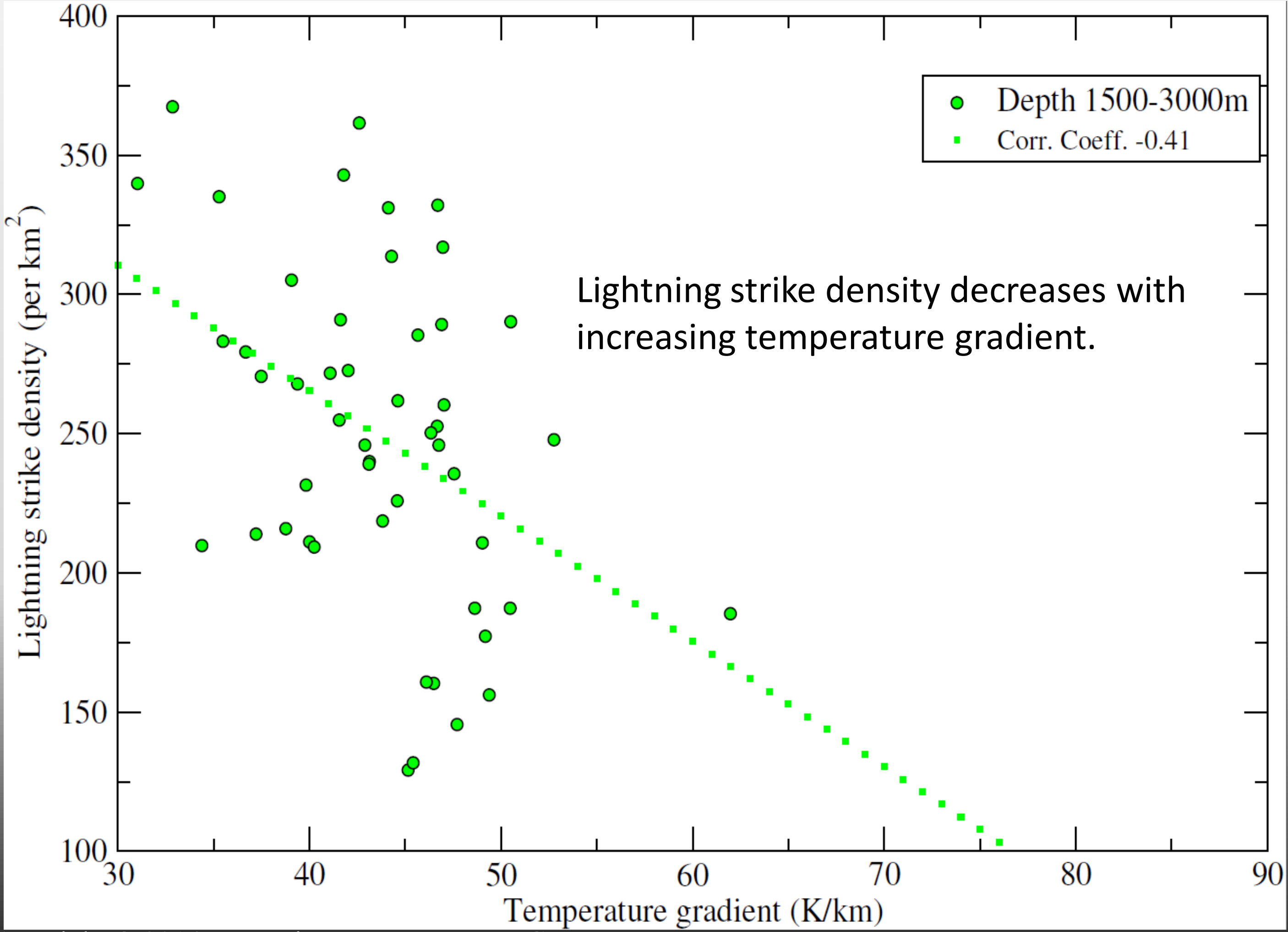




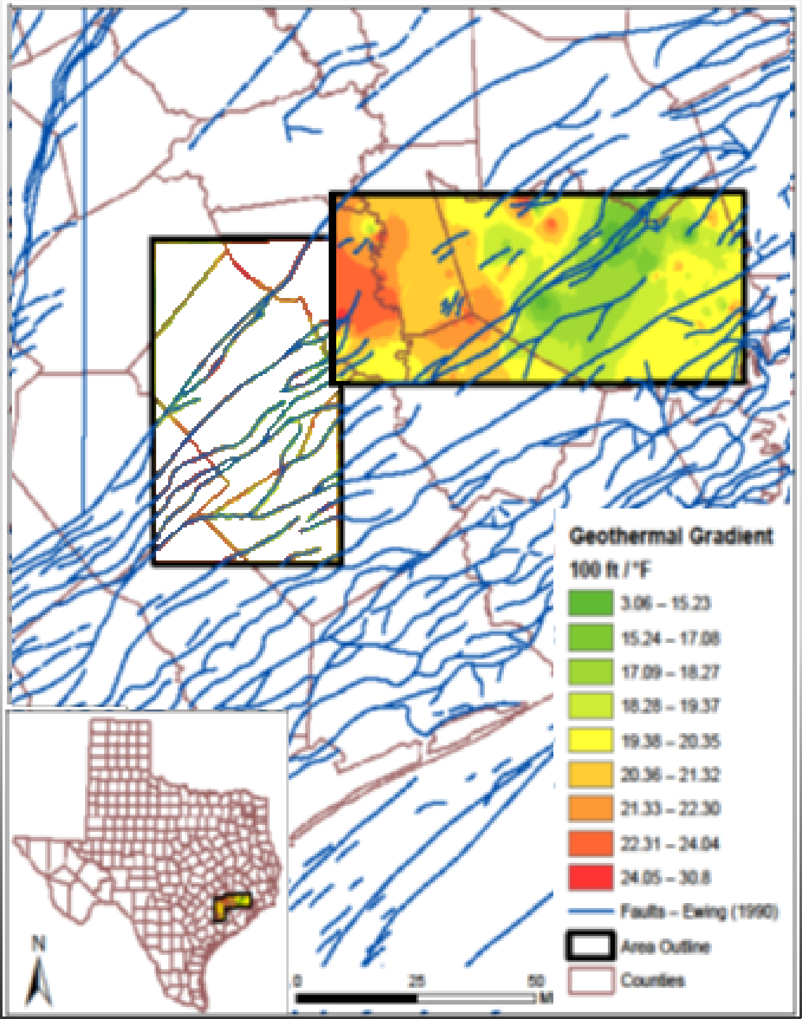
For shallow depth lightning strike density is largely independent of temperature gradient.

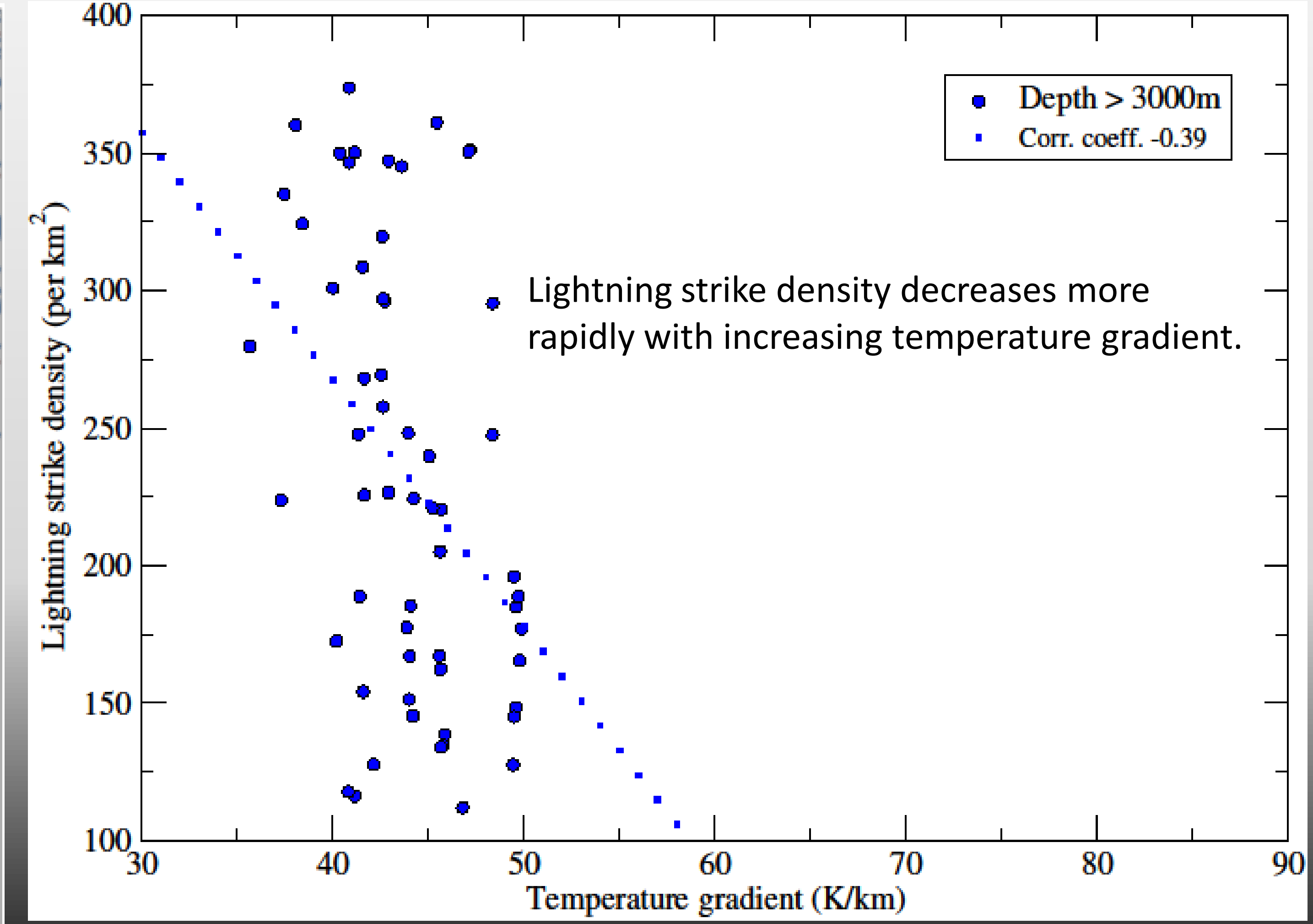
Strike Density for Wells) Vs. Geothermal Gradient 1500-3000m (4920-9843 feet





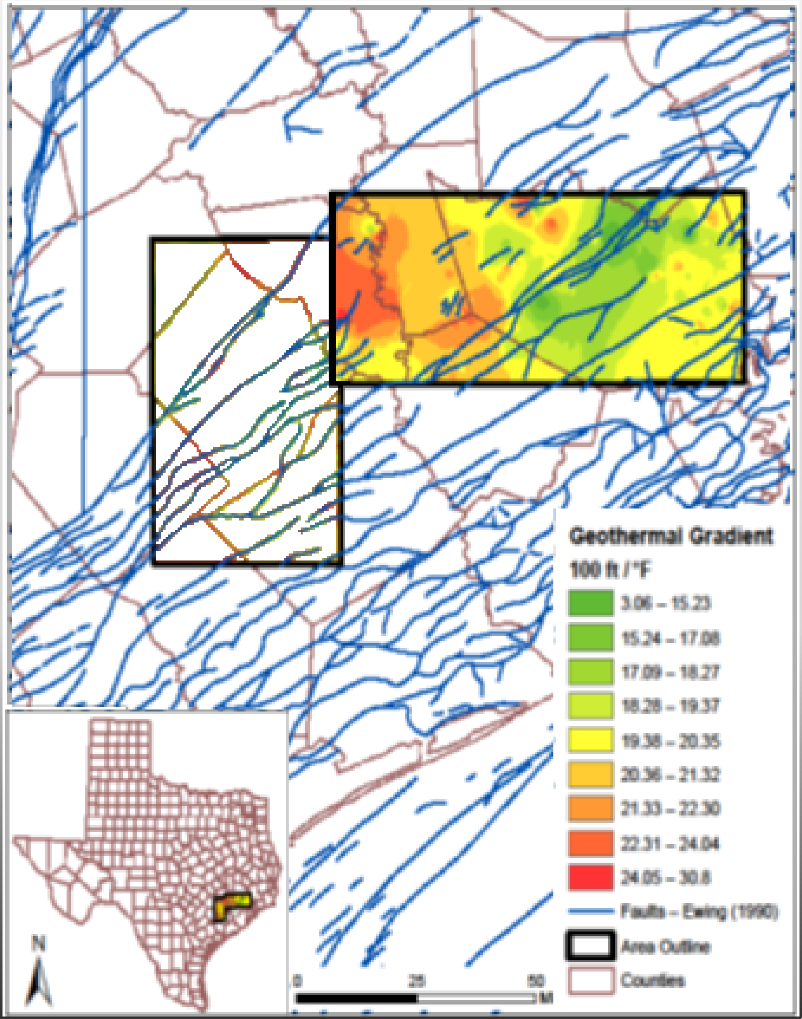
Strike Density for Wells Vs. Geothermal Gradient >3000 m (>9,843 Feet)

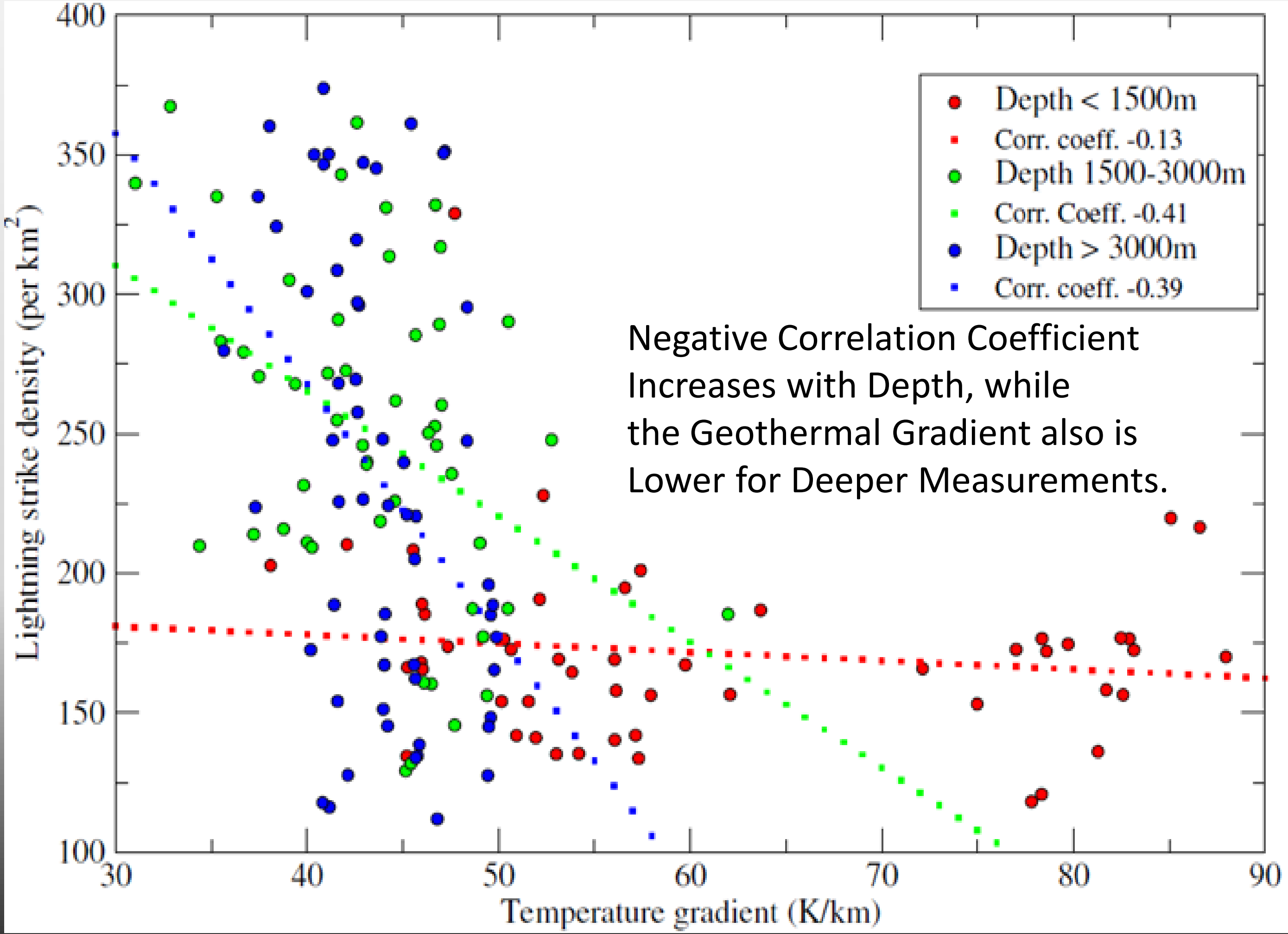




Lightning strike density decreases more rapidly with increasing temperature gradient.

Lightning Strike Density Vs. Geothermal Gradient for All Wells





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

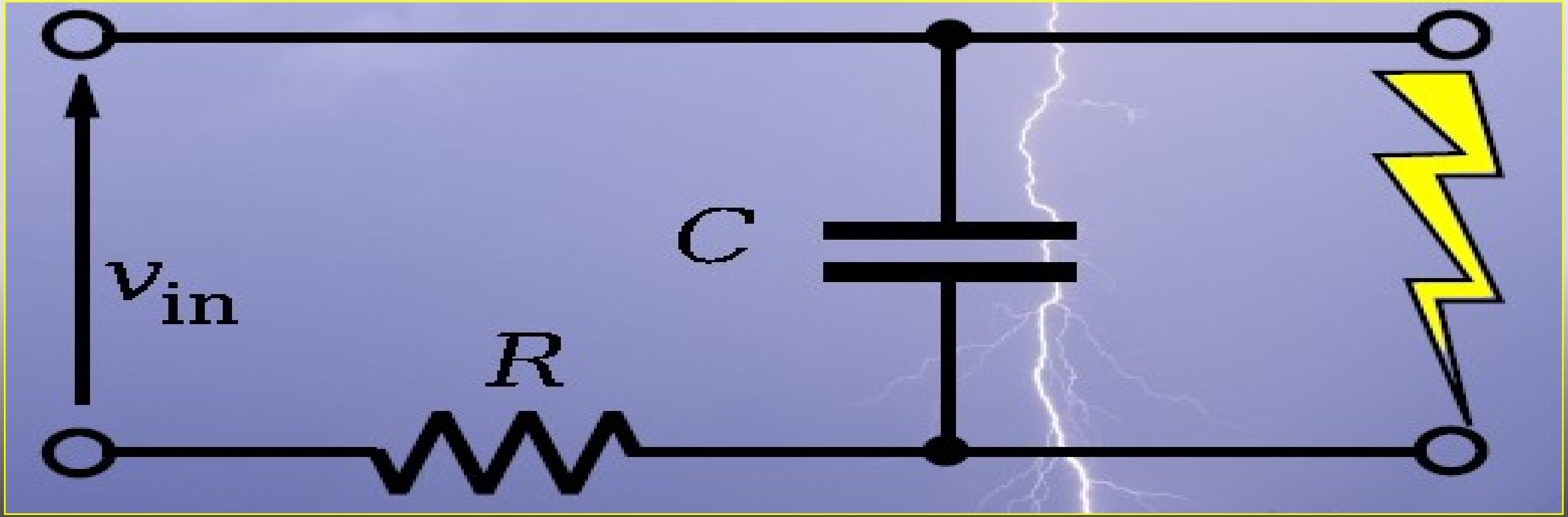
Plate 2

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.

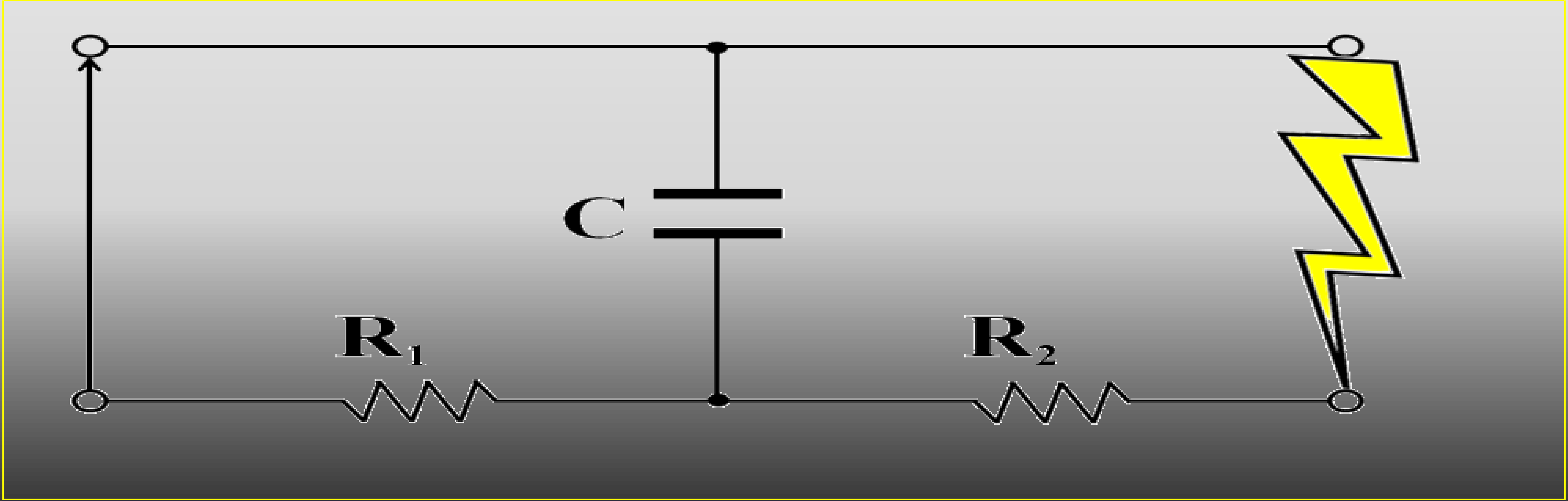
Relaxation Oscillator

- 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



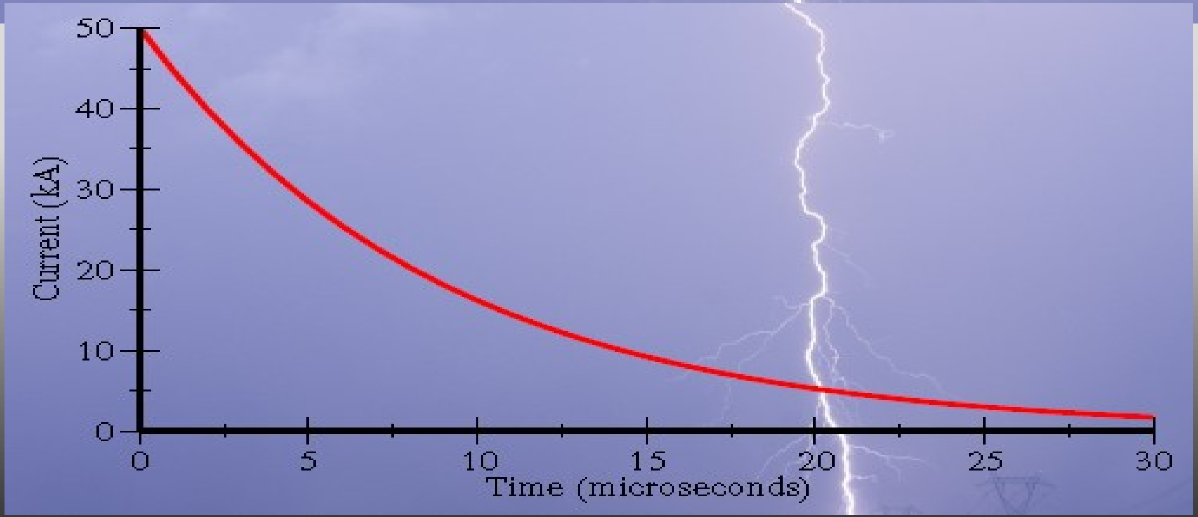
Lightning Physics

- 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



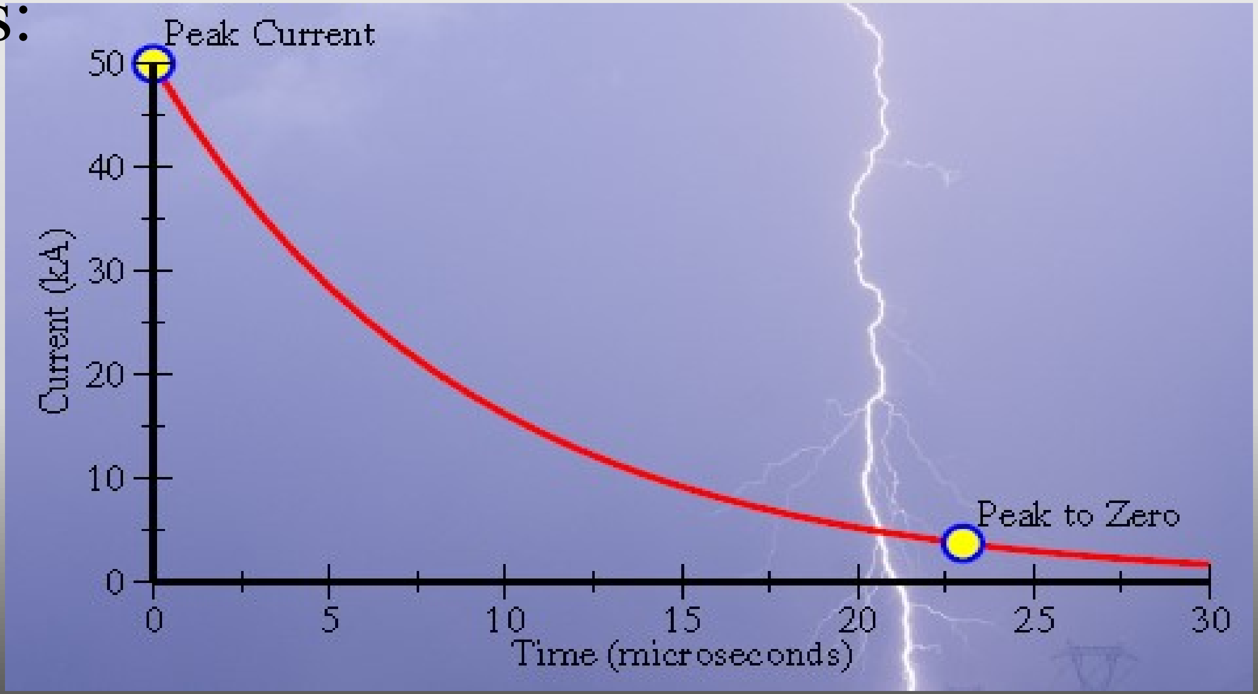
Relaxation Oscillator Physics

- 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



The Available Measurements

- Two points on an exponential curve will define the curve

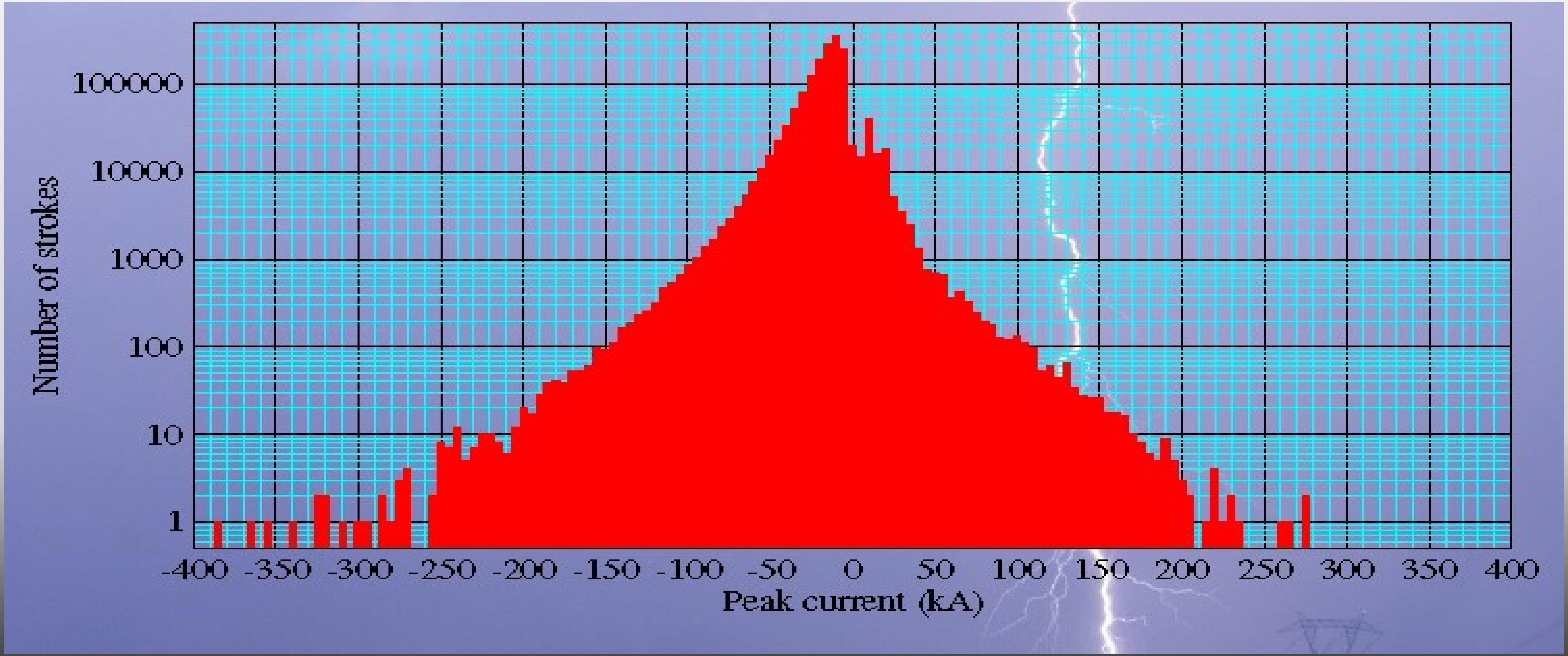
Peak Current:

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

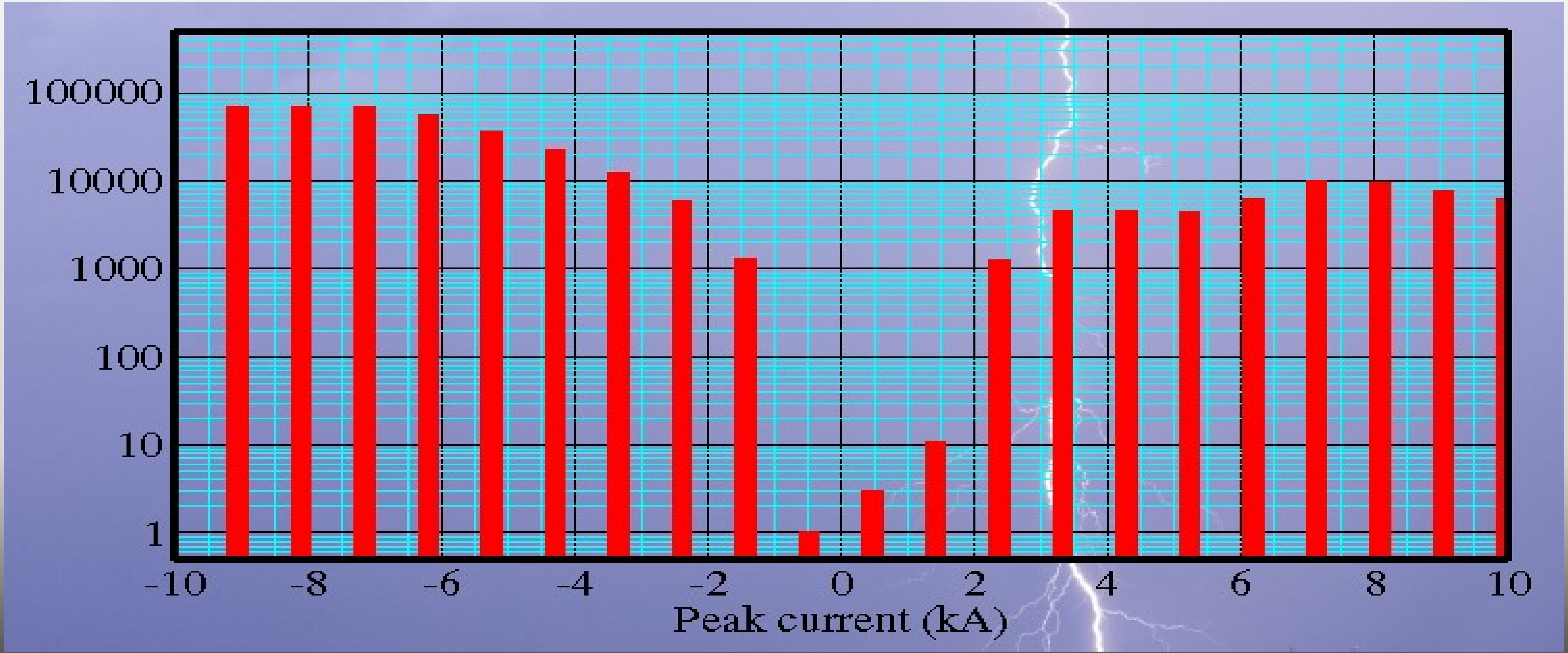
Peak-to-Zero time:

- 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.

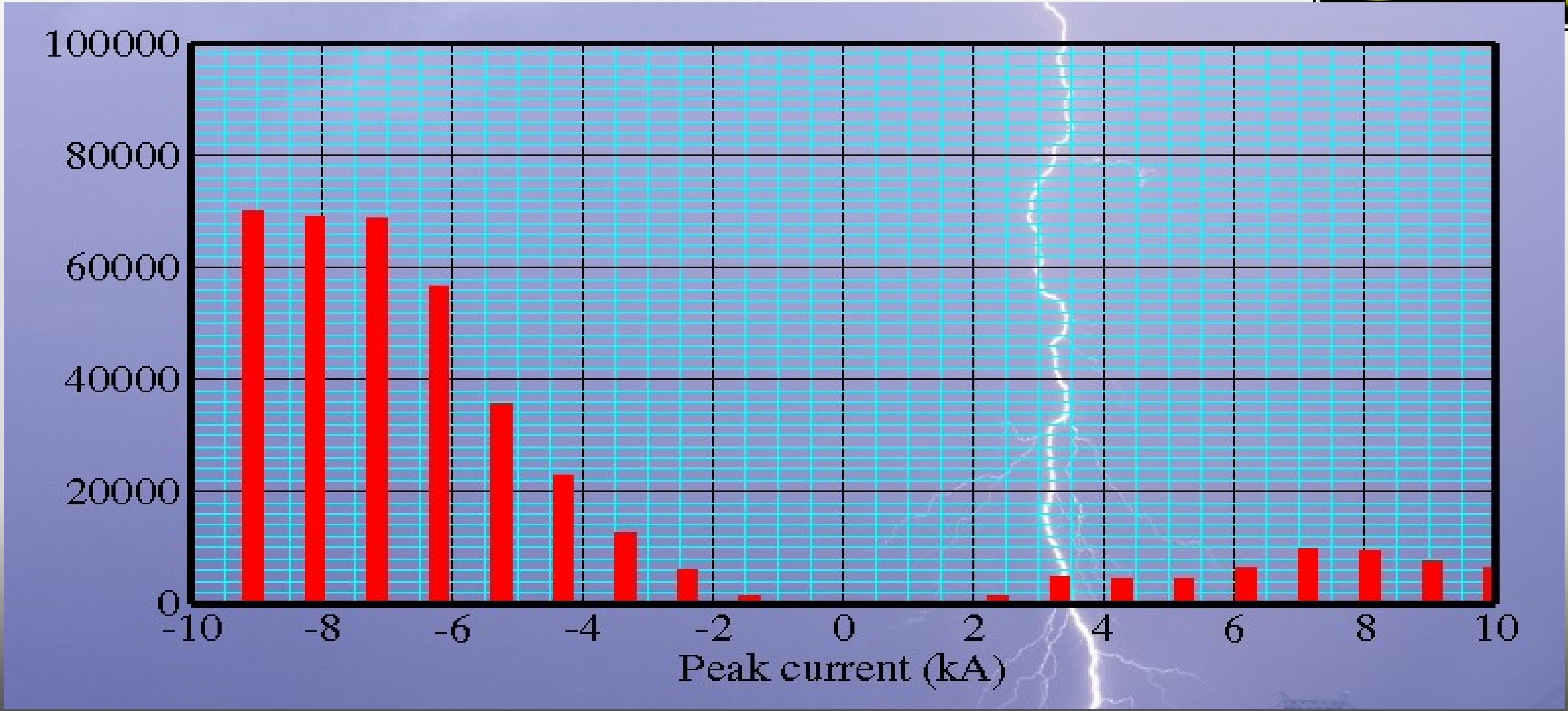
What is "Zero" Current?
Histogram of peak current for 1.6 million strikes



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

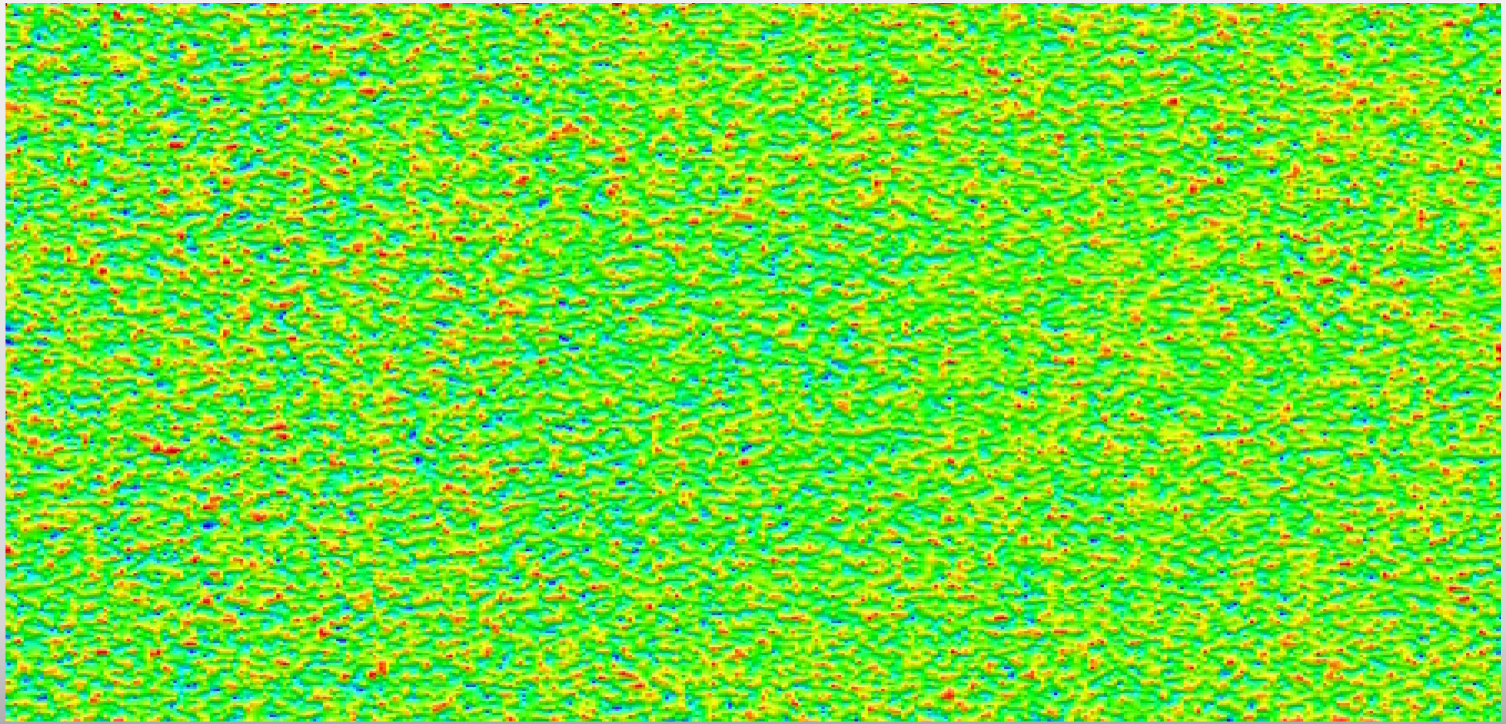
1. Voltage is proportional to peak current (within a local area).
2. Cloud height is proportional to voltage because the dielectric strength of air is more or less constant.
   - This gives plate separation for the atmospheric capacitor
3. The effective capacitor is circular, with a radius proportional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

What is Resistivity?

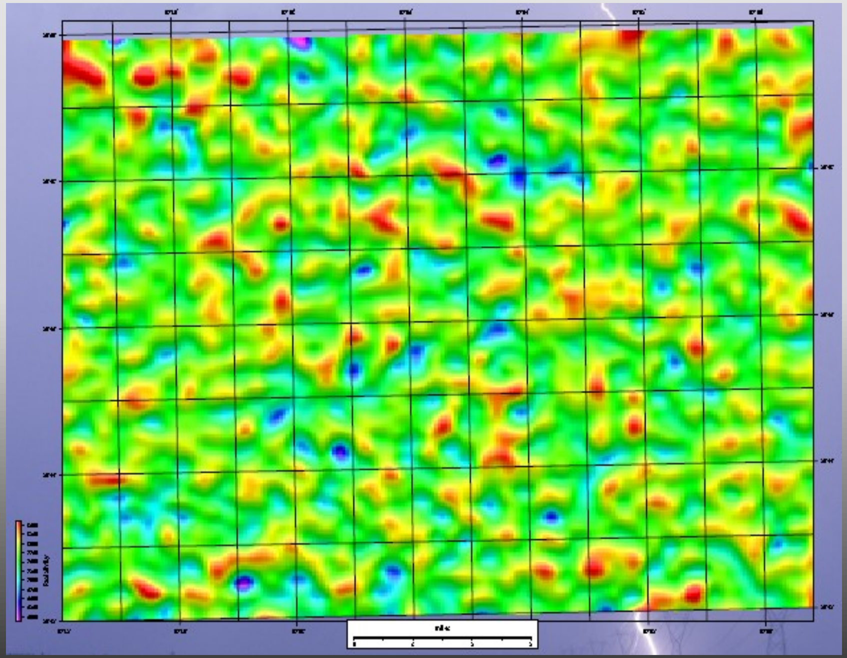
- Resistivity is resistance times cross-sectional area of a conductor, divided by its length; or $\rho = \frac{R \times A}{l}$
- For the lightning energy dissipating in the ground:
  - The area is very small at the strike point, but increases rapidly
  - The length is very short for discharging the charge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

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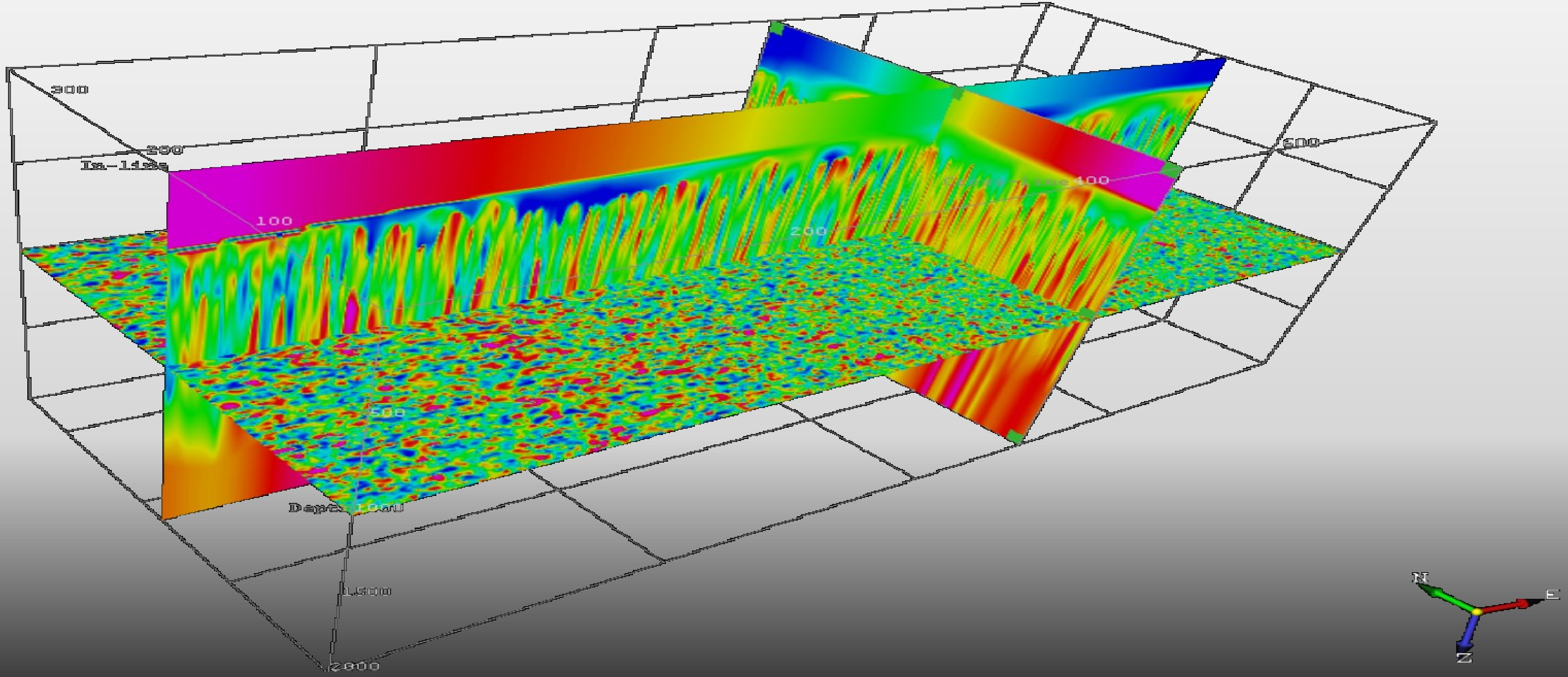
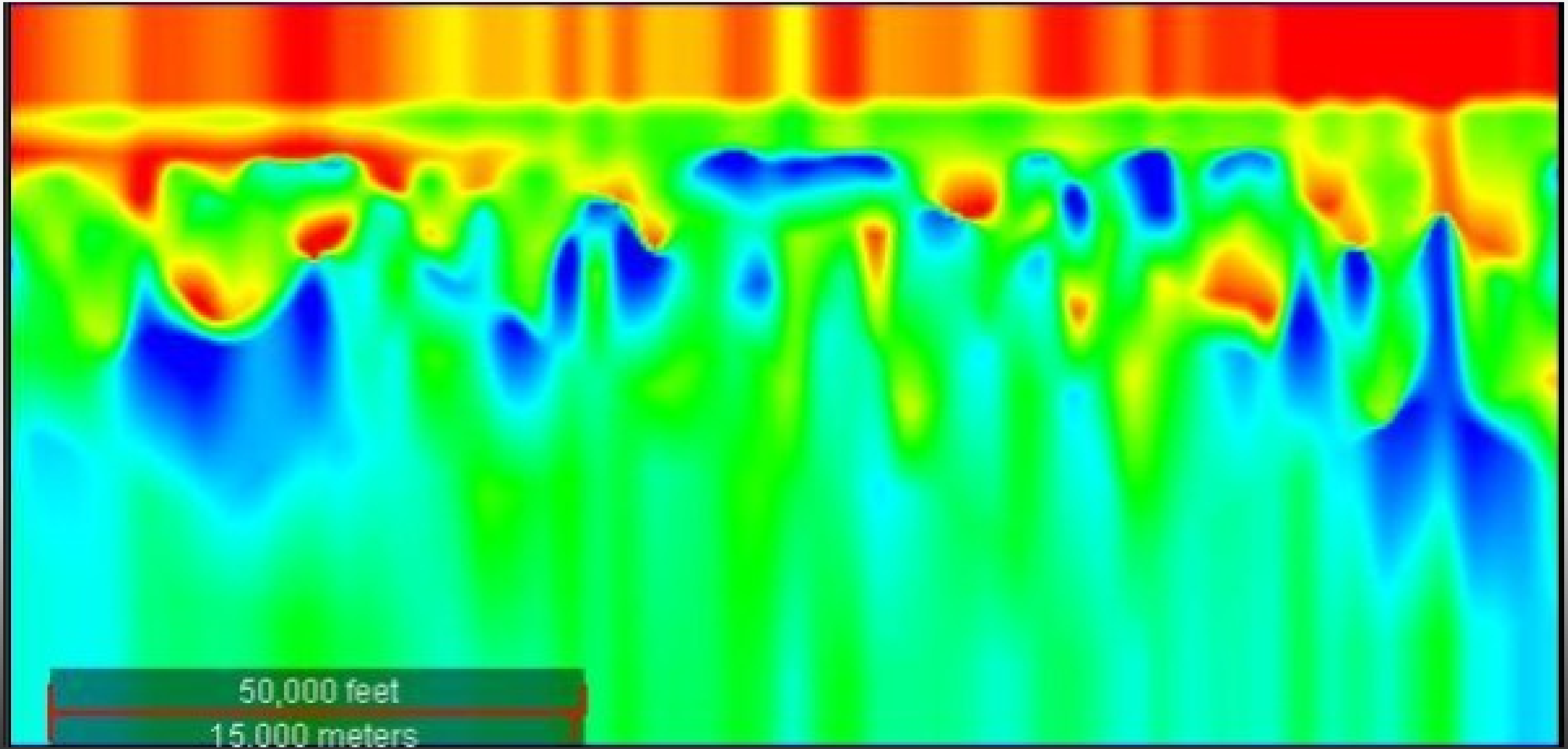
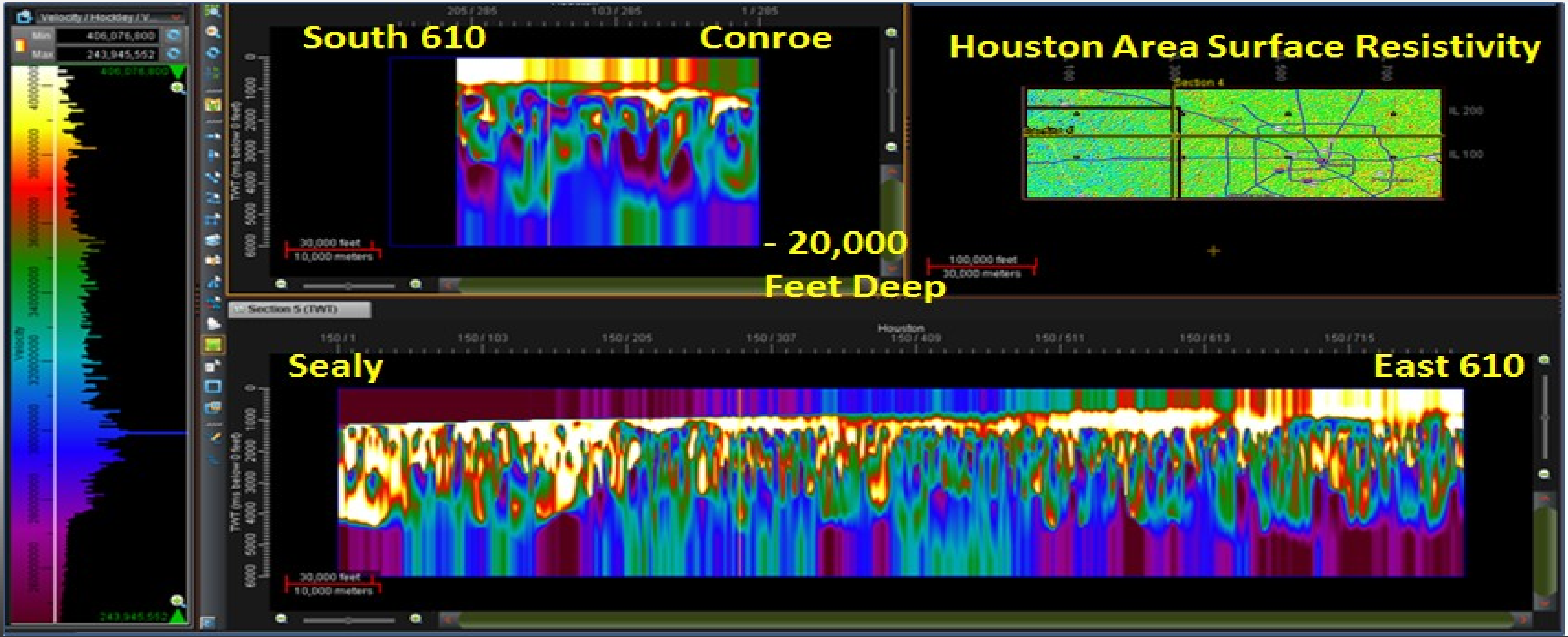
A Resistivity Volume



Resistivity Volume Cross-Section

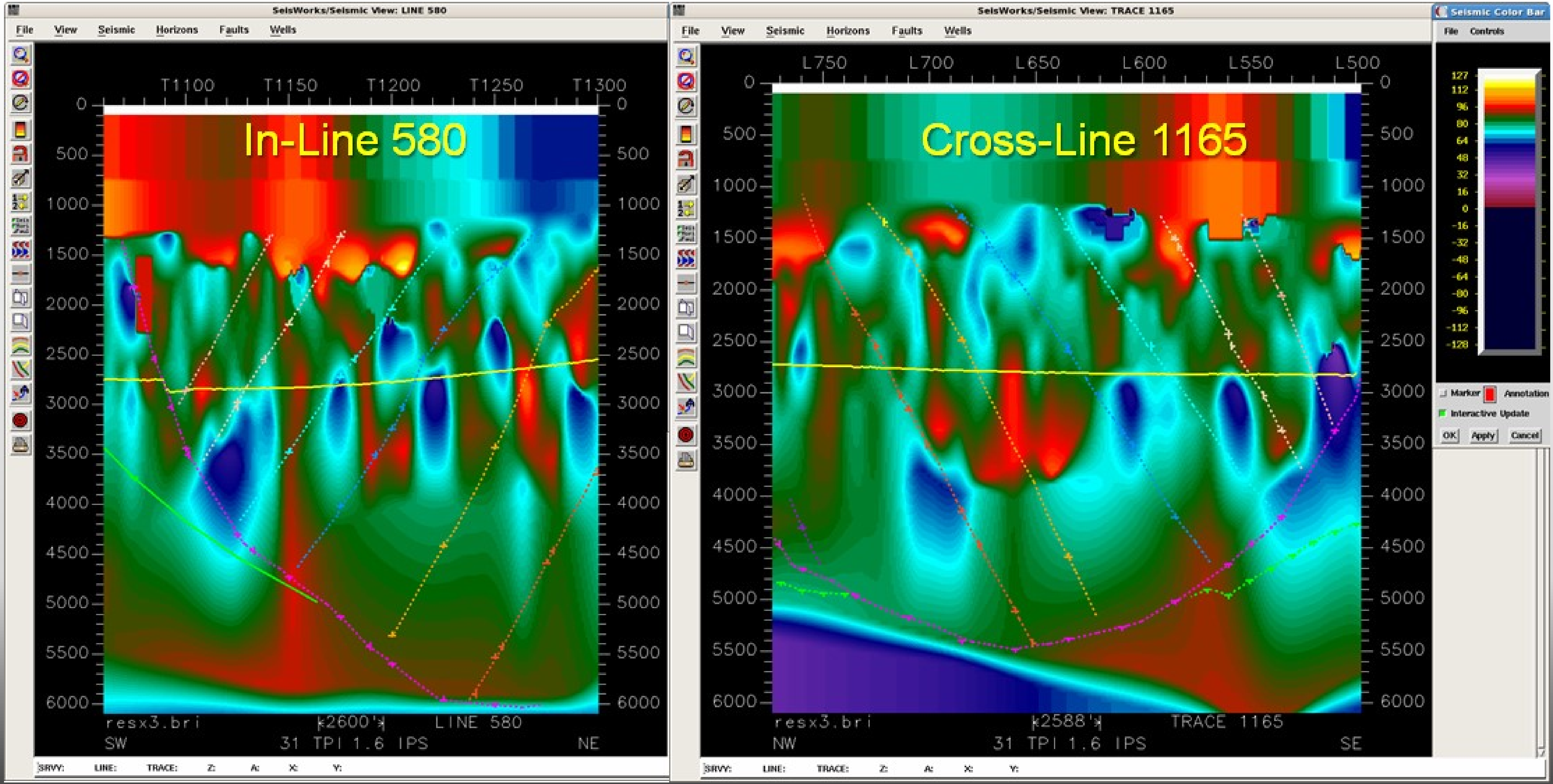


Resistivity Volumes
Define Subsurface Resistivity



Agenda

3:00 Registration and Introductions
3:30 The meteorology behind lightning databases
3:45 Using lightning databases to explore for natural resources
4:00 Calculating resistivity volumes from lightning databases
4:45 Examples of resistivity volumes and potential applications
- Regional and Play Fairway hydrocarbon migration pathways
- High-grading exploration sweetspots
5:15 Anticipated future developments
- Use with Archie's equation to predict Formation Factor, Porosity, etc.
- Questions and Answers and Discussion among participants


SeisWorks/Seismic View: LINE 580
In-Line 580
resx3.bri
LINE 580
SW
31 TPI 1.6 IPS
NE
SeisWorks/Seismic View: TRACE 1165
Cross-Line 1165
resx3.bri
TRACE 1165
NW
31 TPI 1.6 IPS
SE
Seismic Color Bar

In-Line 580 and Trace 1165 from a Louisiana 3-D seismic survey

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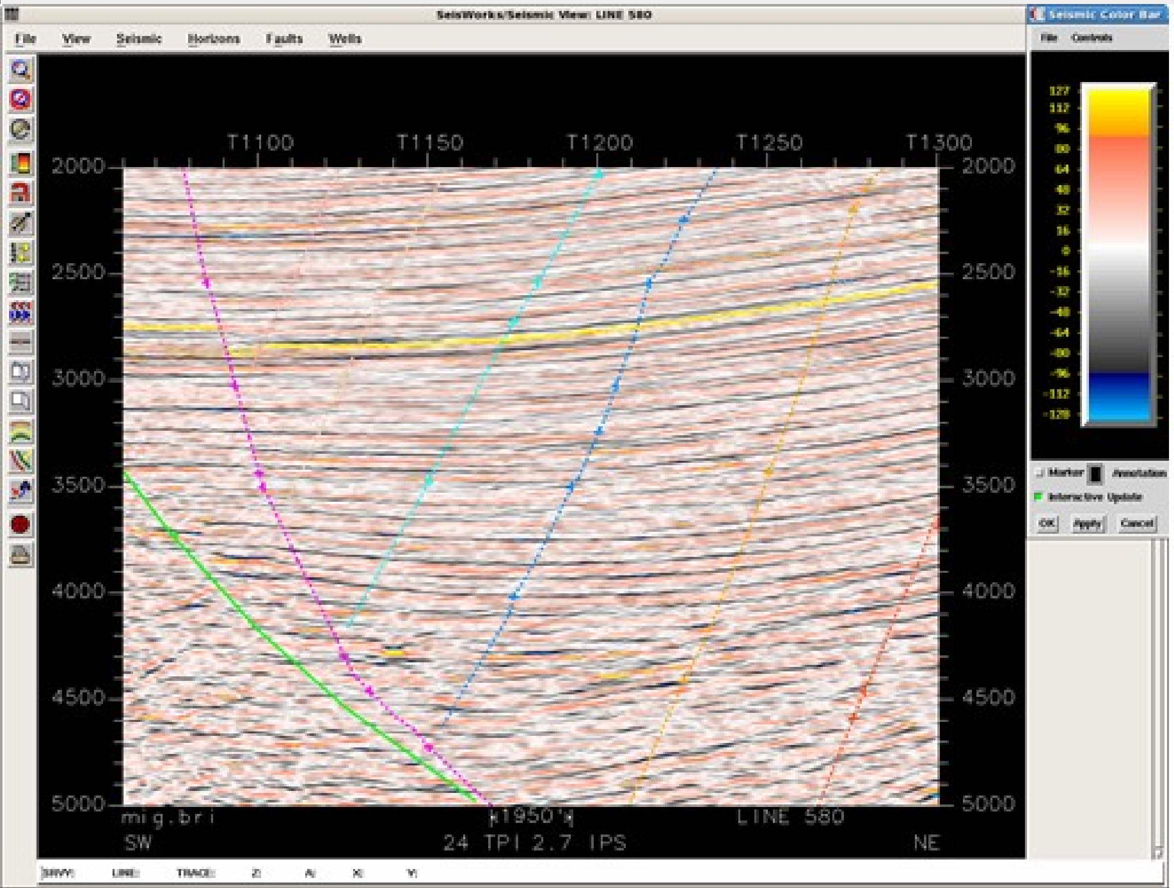
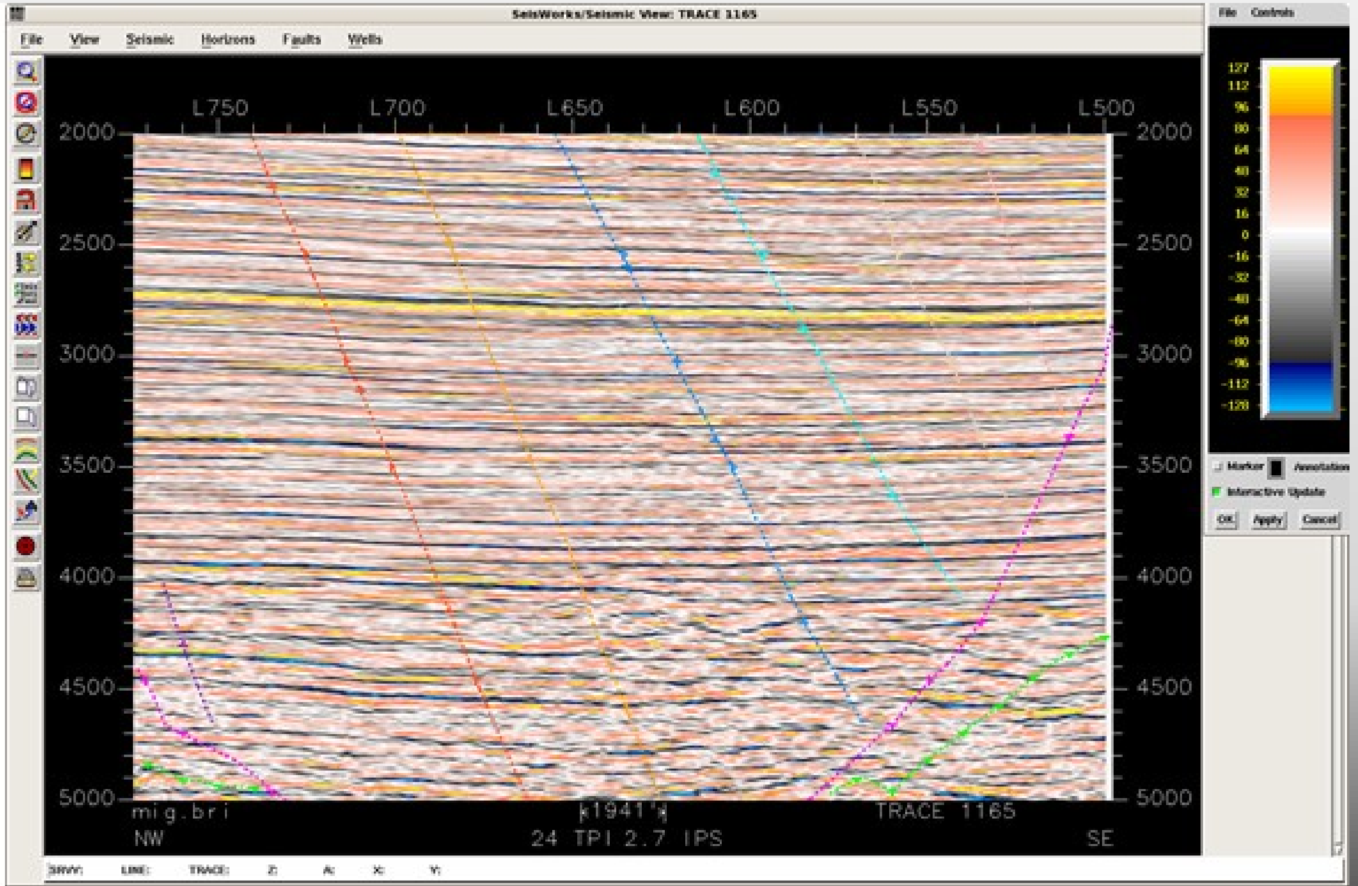
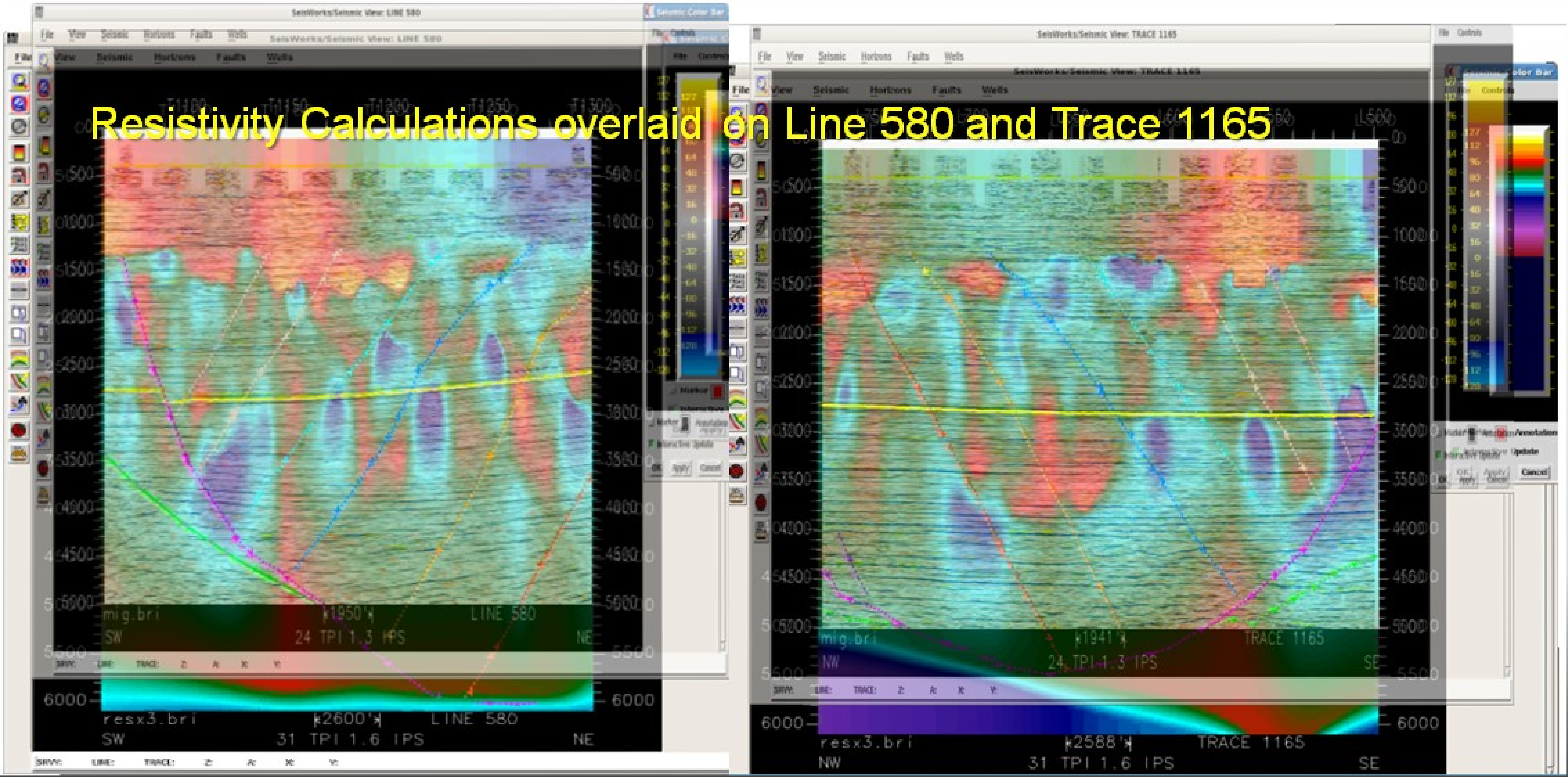
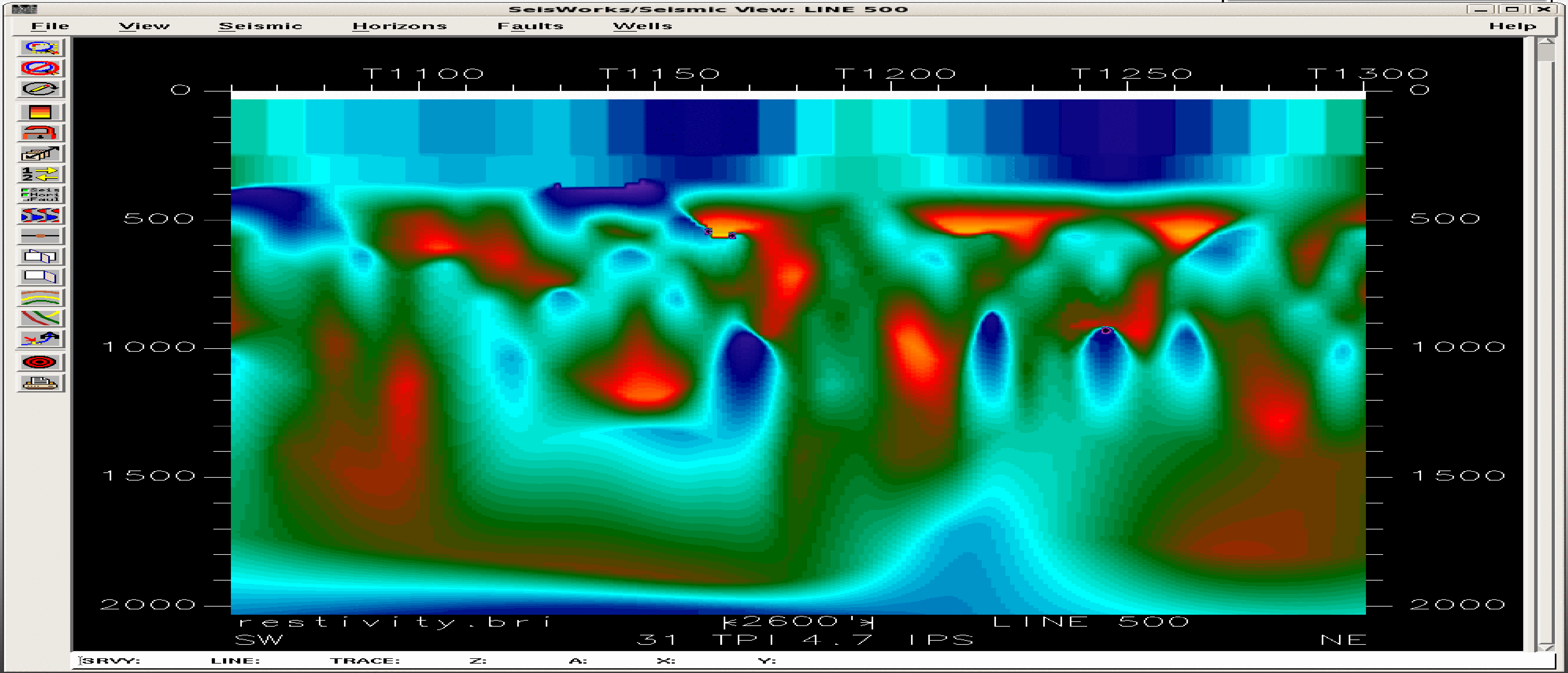




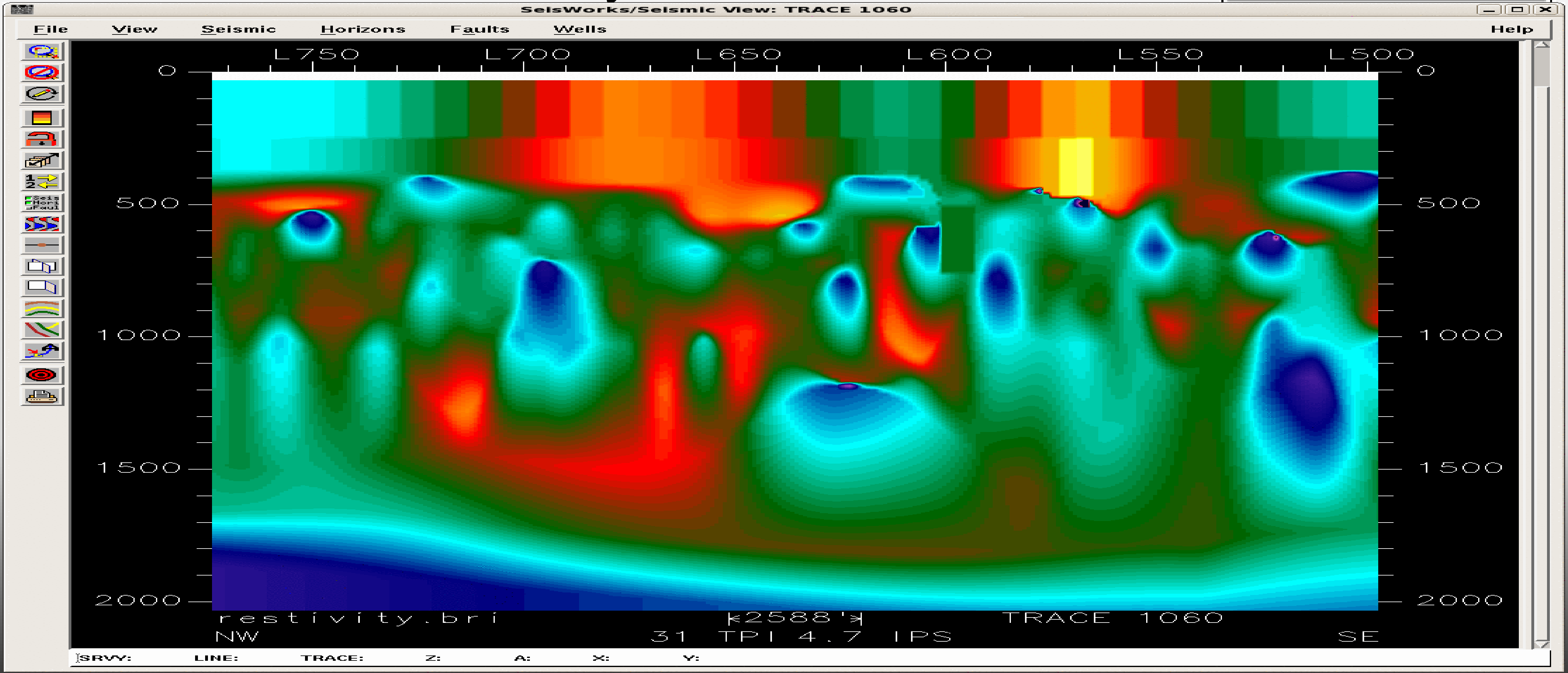
Resistivity Calculations overlaid on Line 580 and Trace 1165



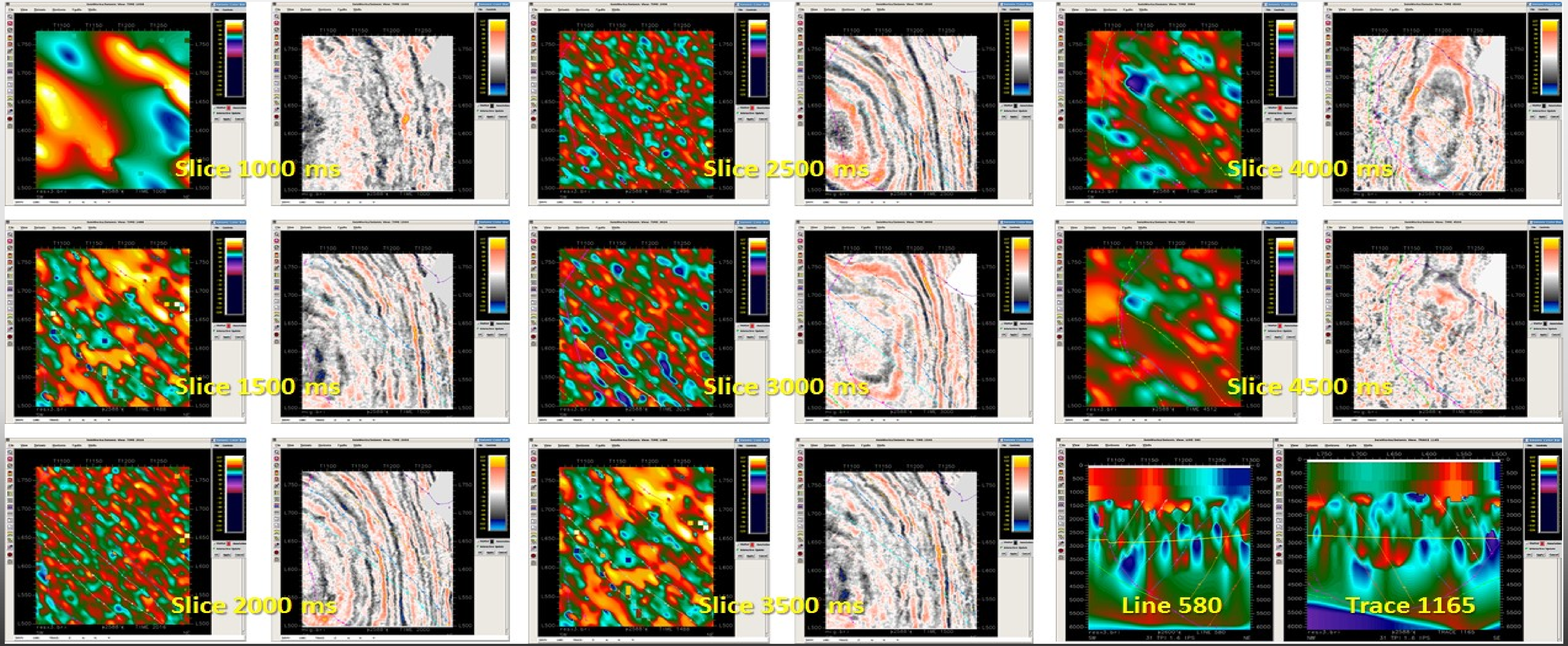
Animation of Resistivity In-Line Sections



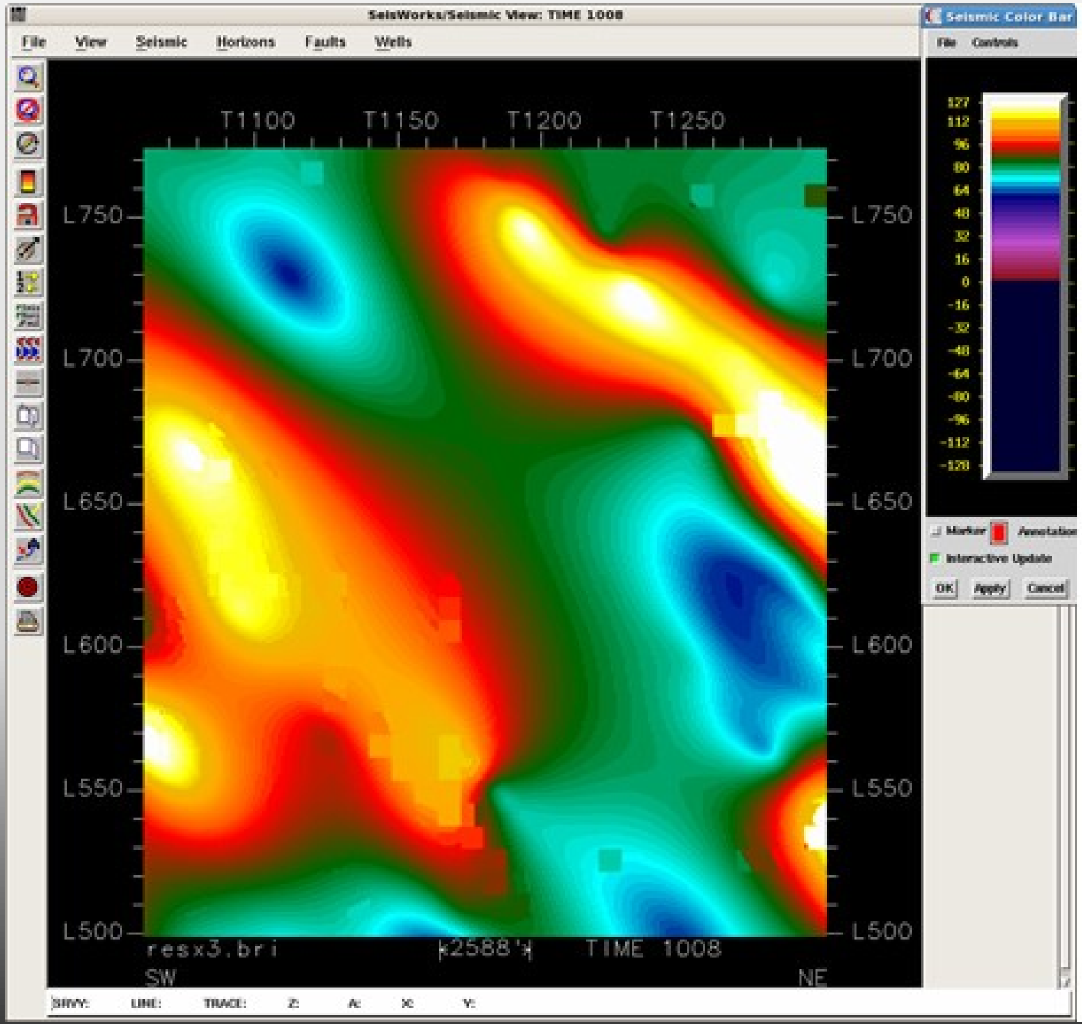
Animation of Resistivity Cross-Line Sections

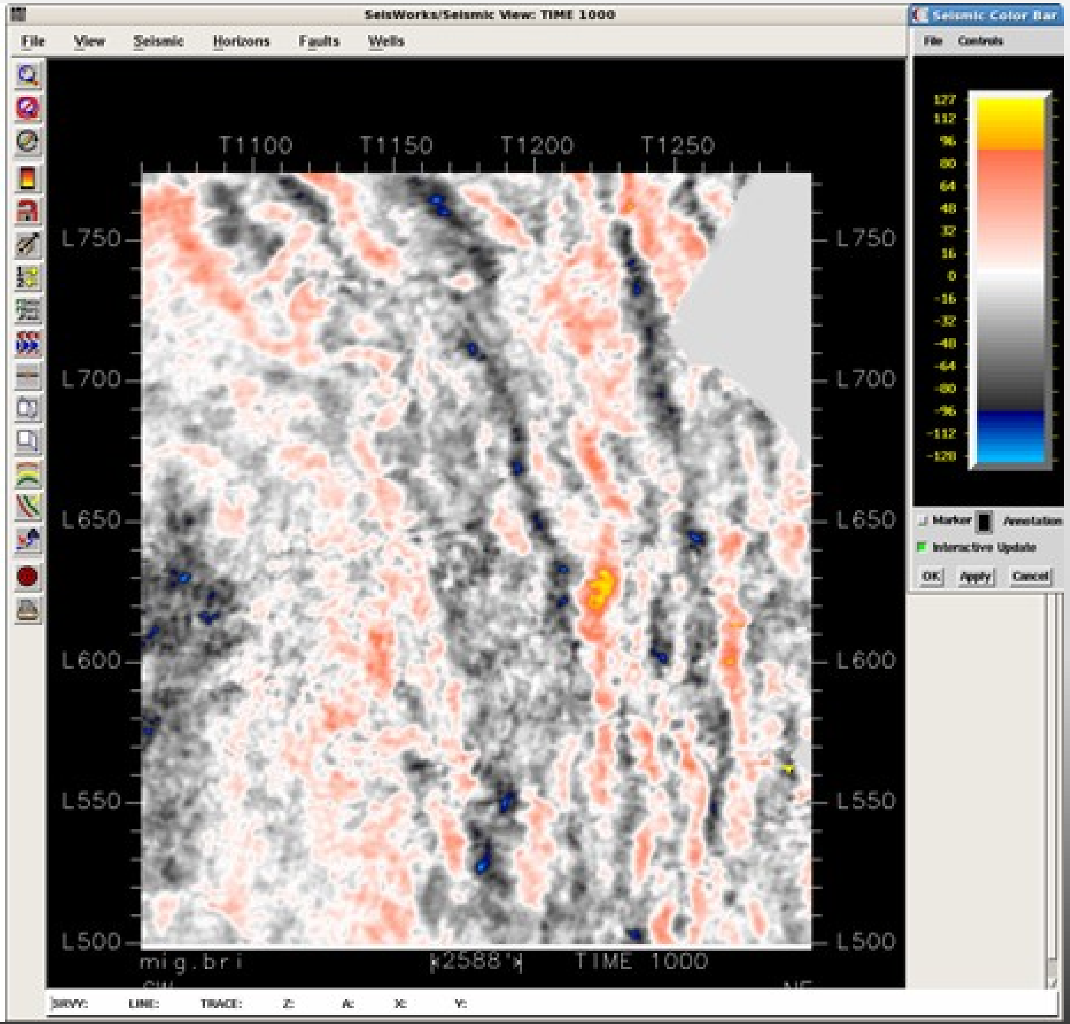


Resistivity Volumes
Correlate with Seismic Surveys



After First Pass Vertical Calibration, Time-Slice 1000 ms





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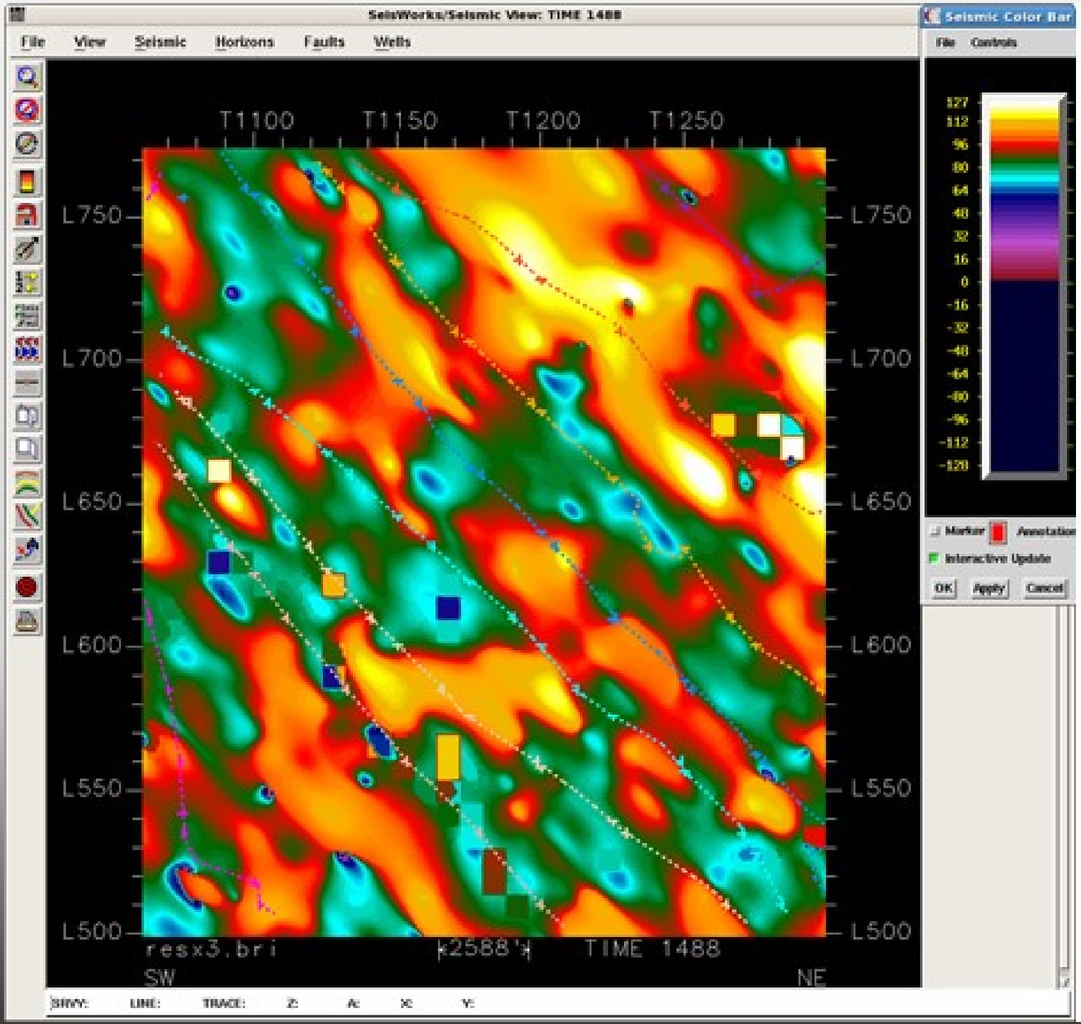
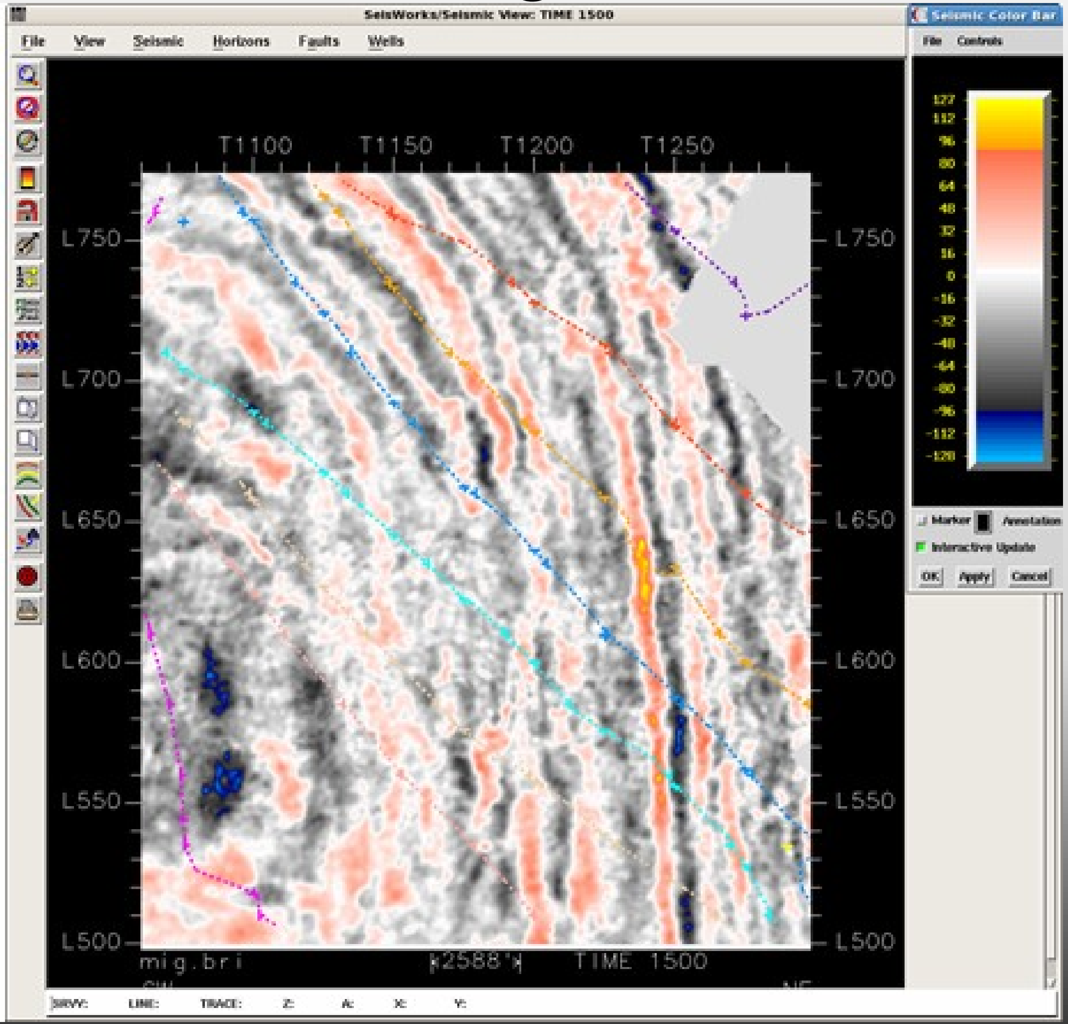
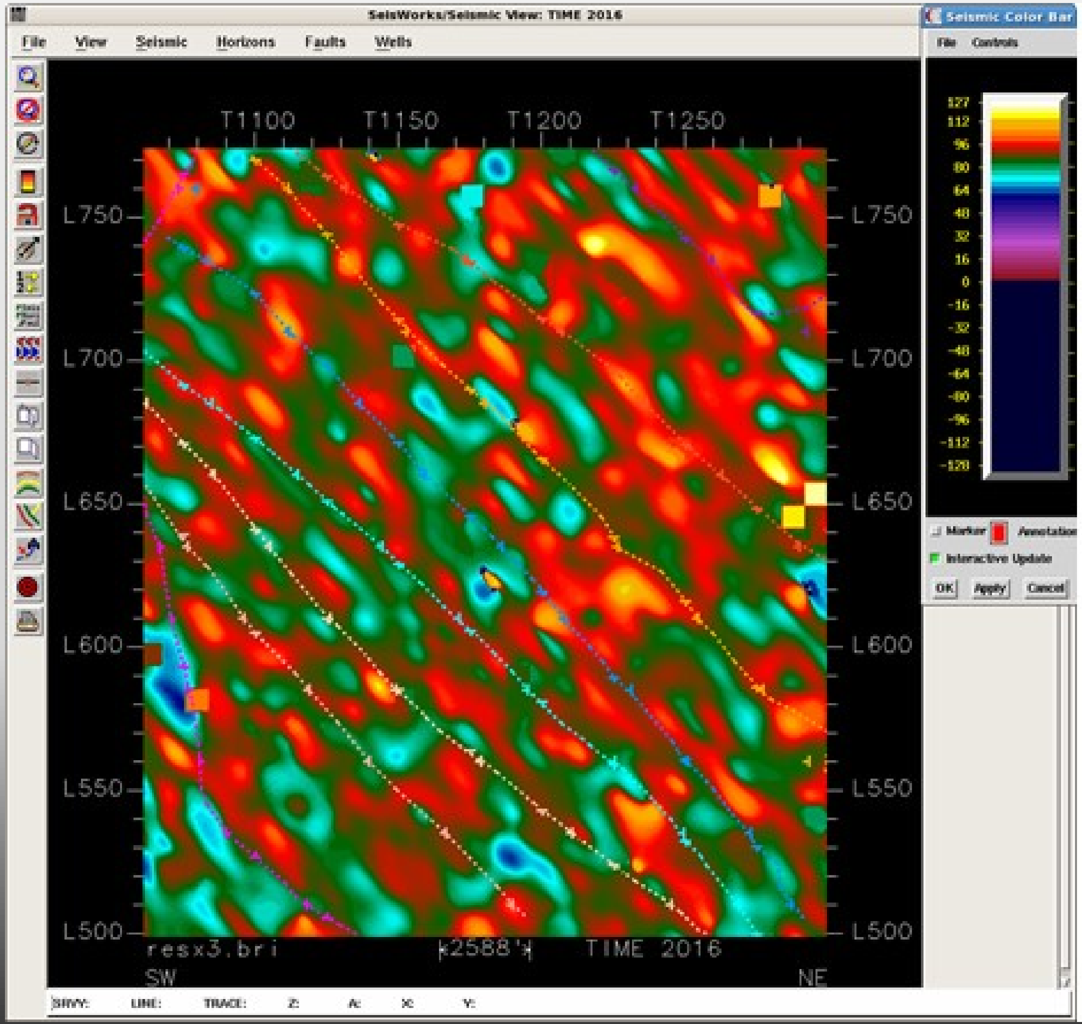
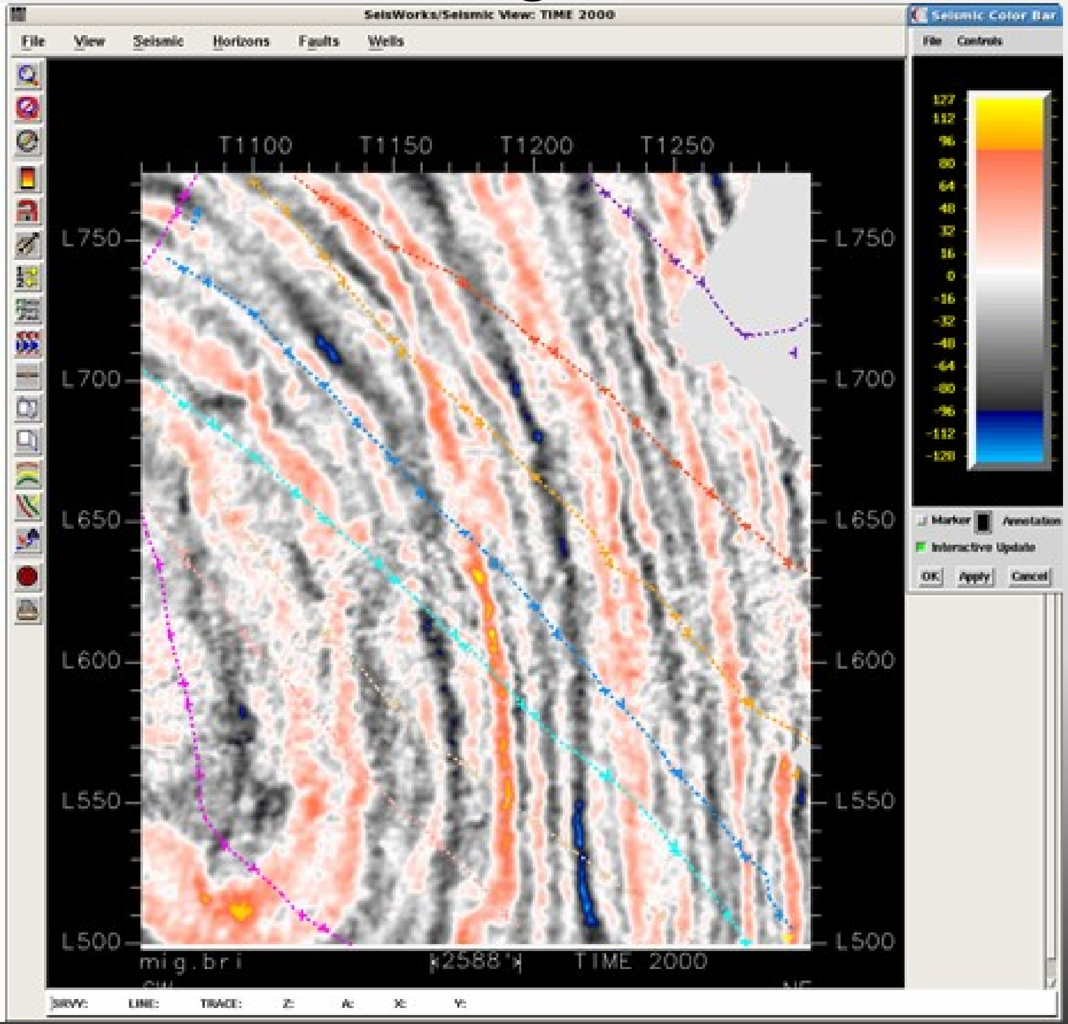
Resistivity-Slice on left and Seismic Time-Slice at 1500 ms on right



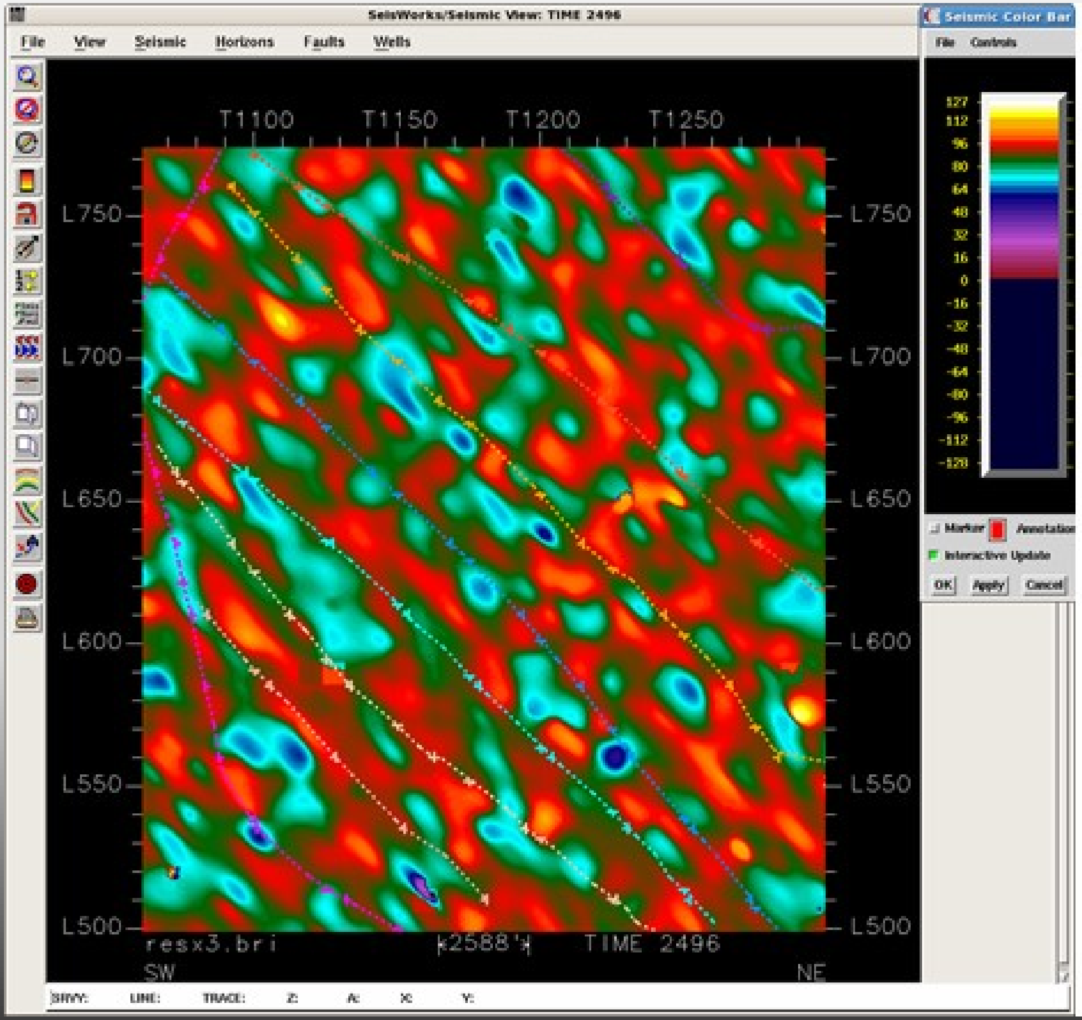


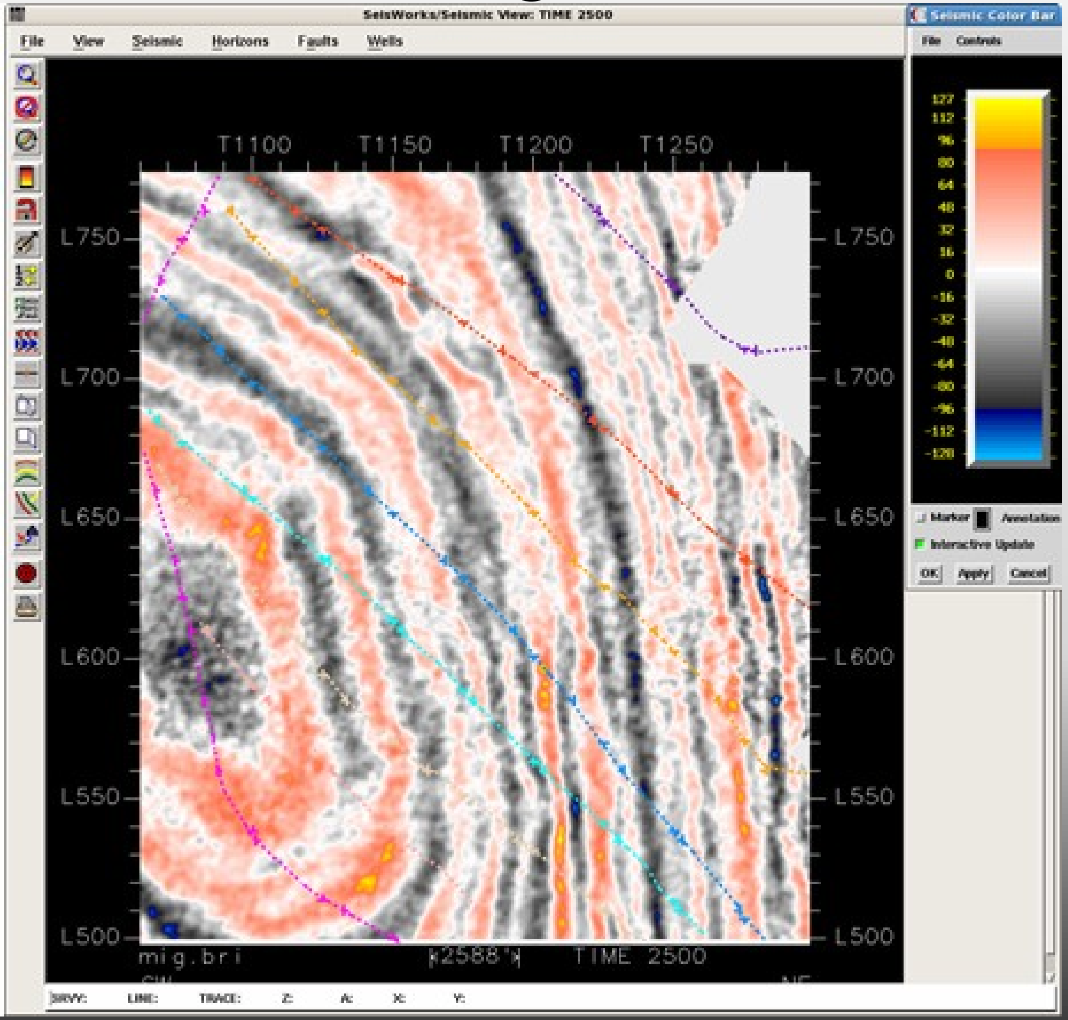
Resistivity-Slice on left and Seismic Time-Slice at 2000 ms on right



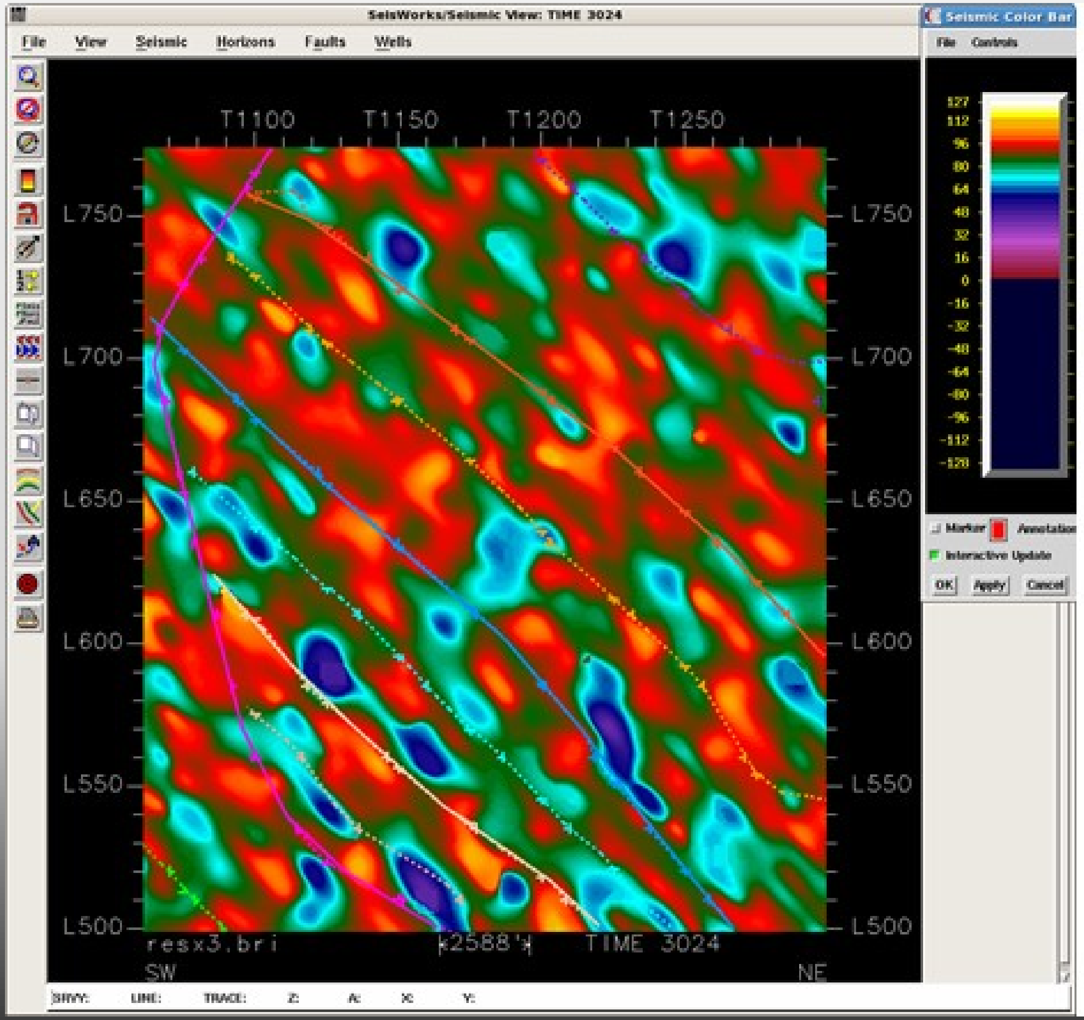


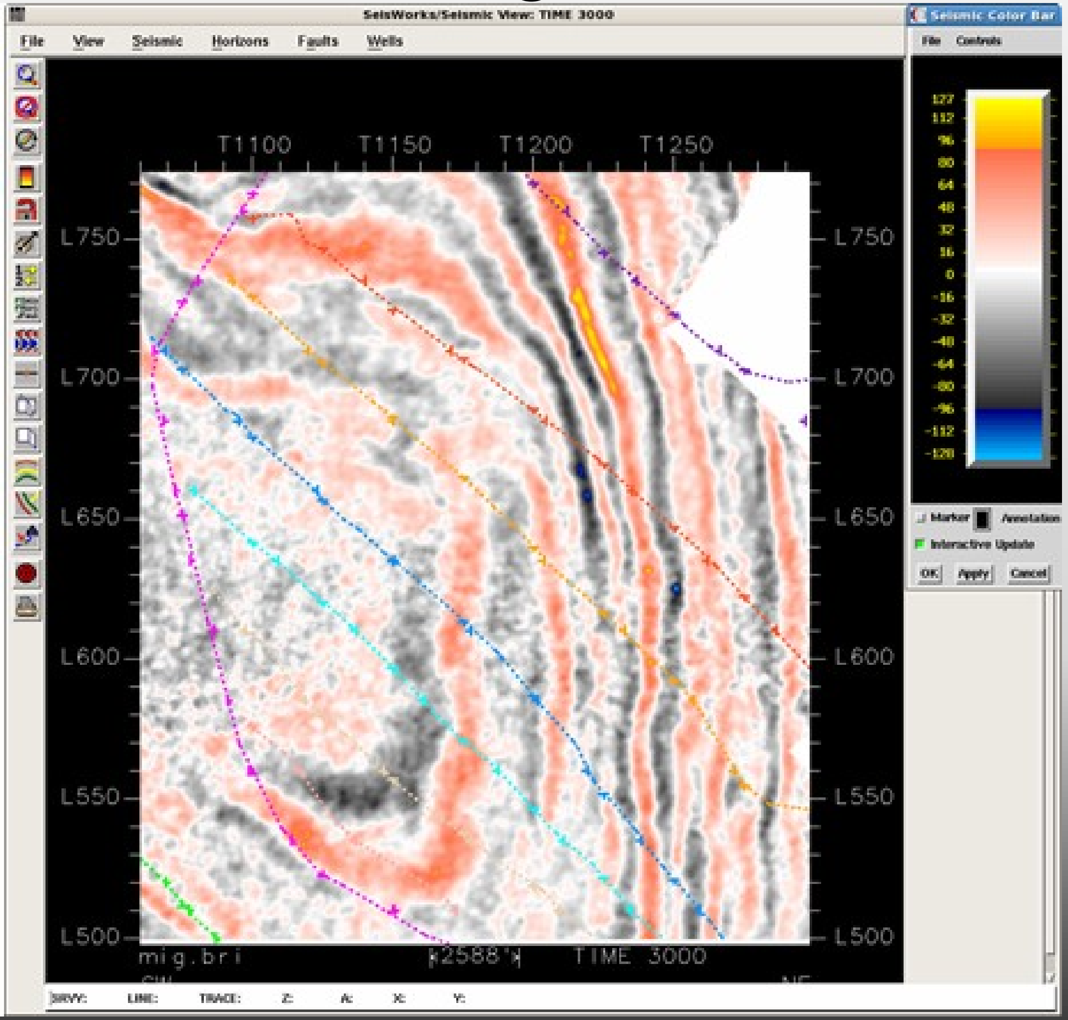
Resistivity-Slice on left and Seismic Time-Slice at 2500 ms on right





Resistivity-Slice on left and Seismic Time-Slice at 3000 ms on right





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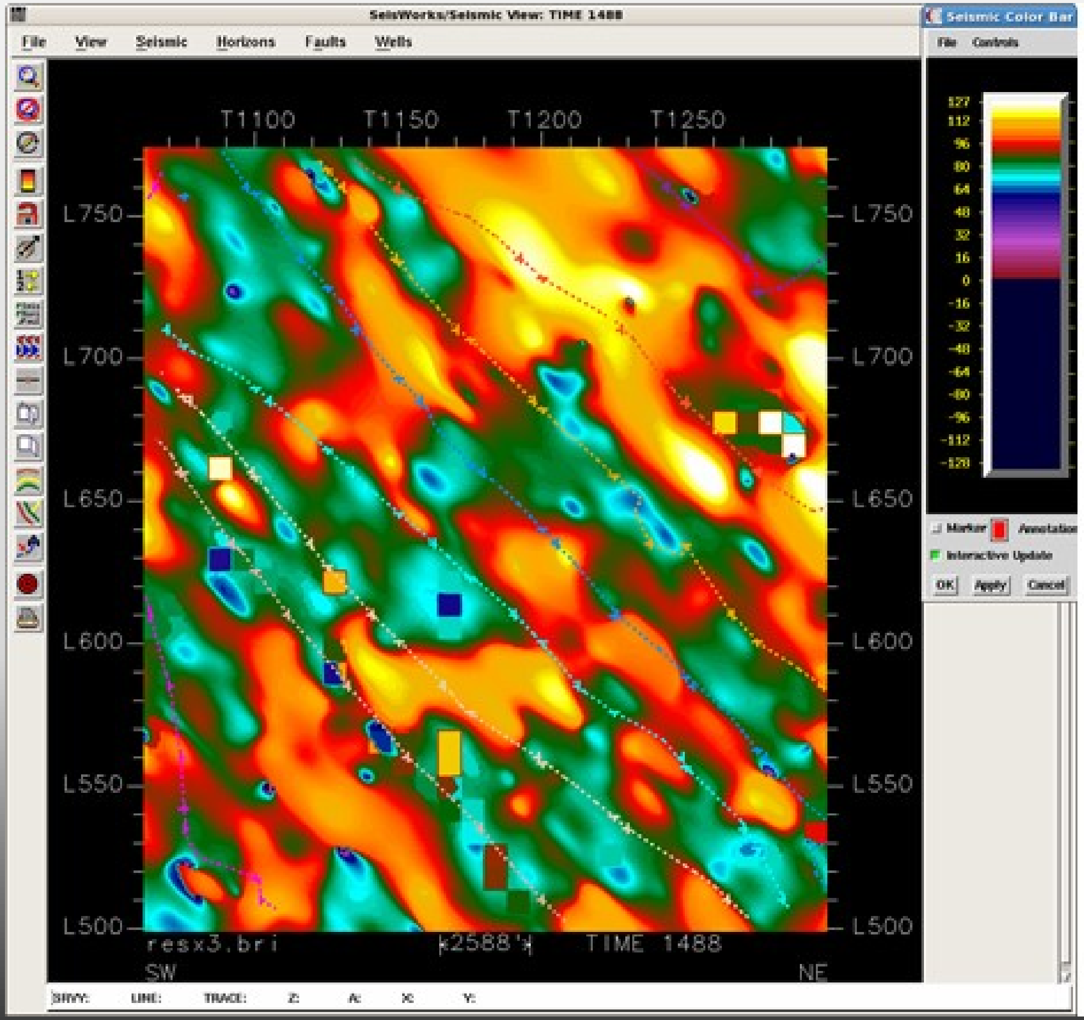
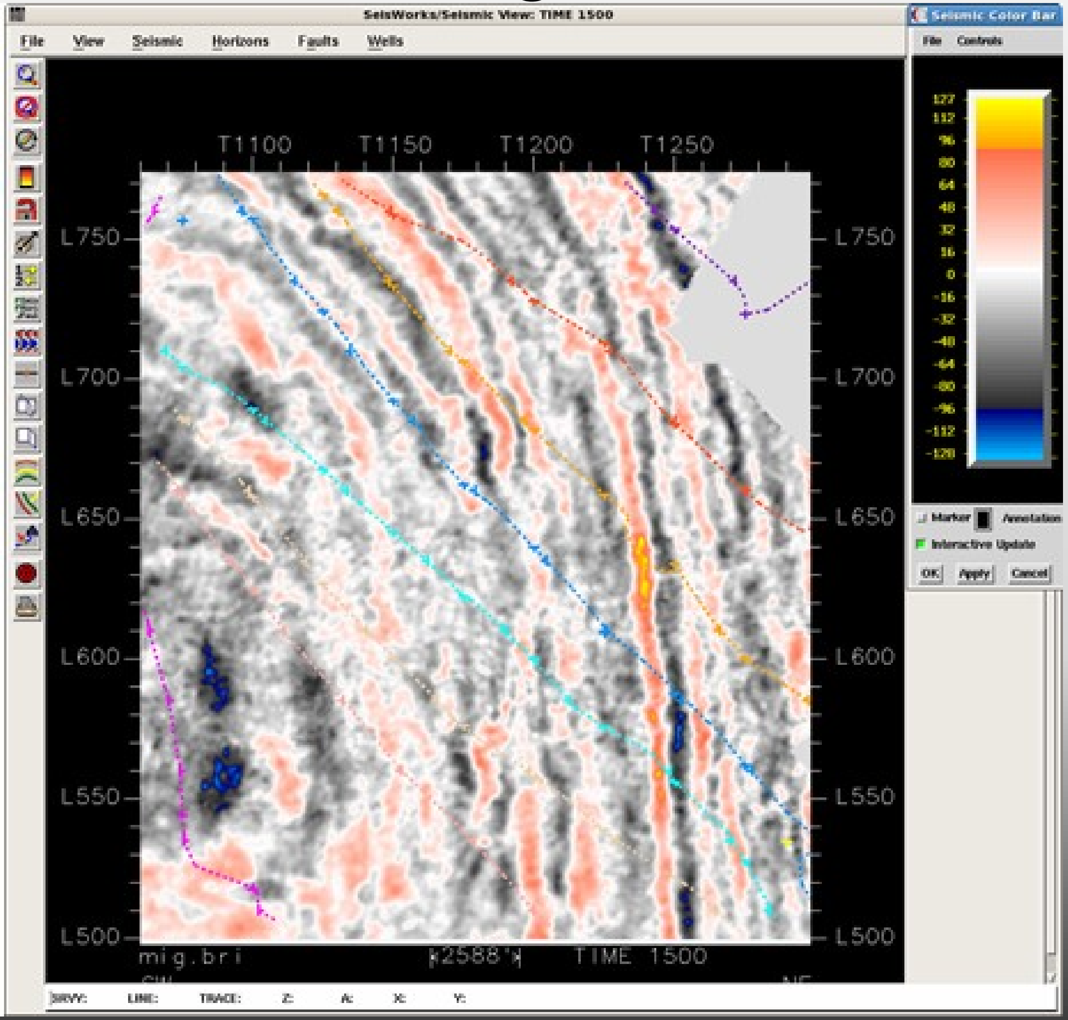
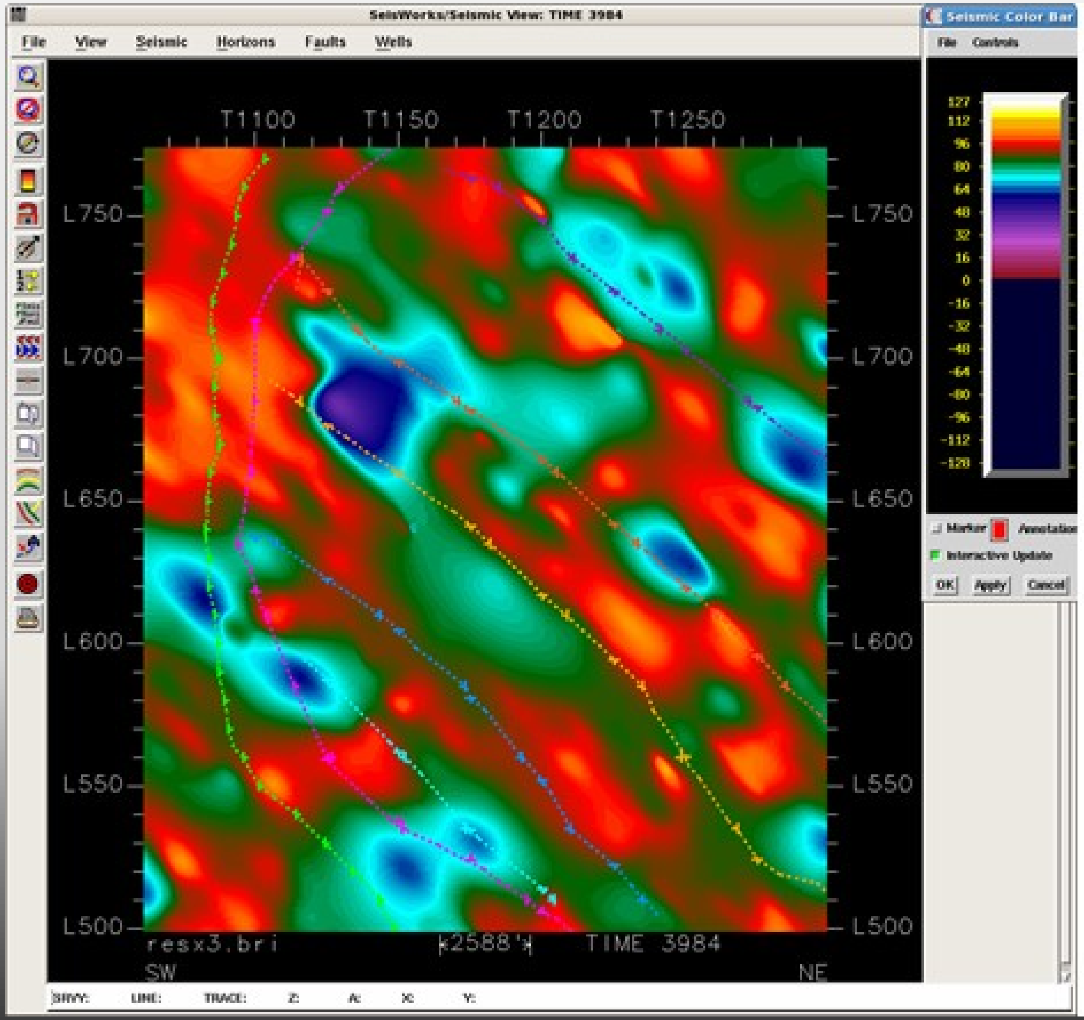
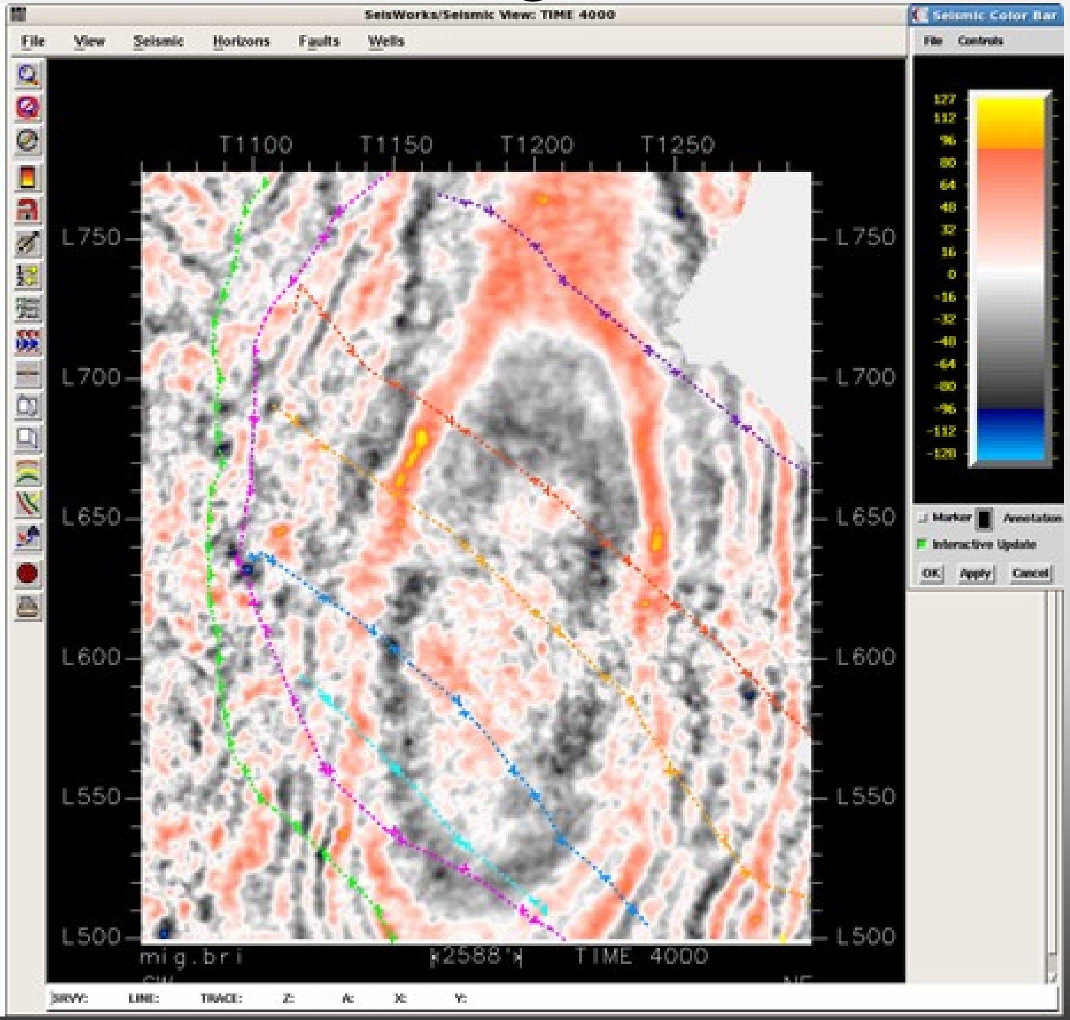
Resistivity-Slice on left and Seismic Time-Slice at 3500 ms on right



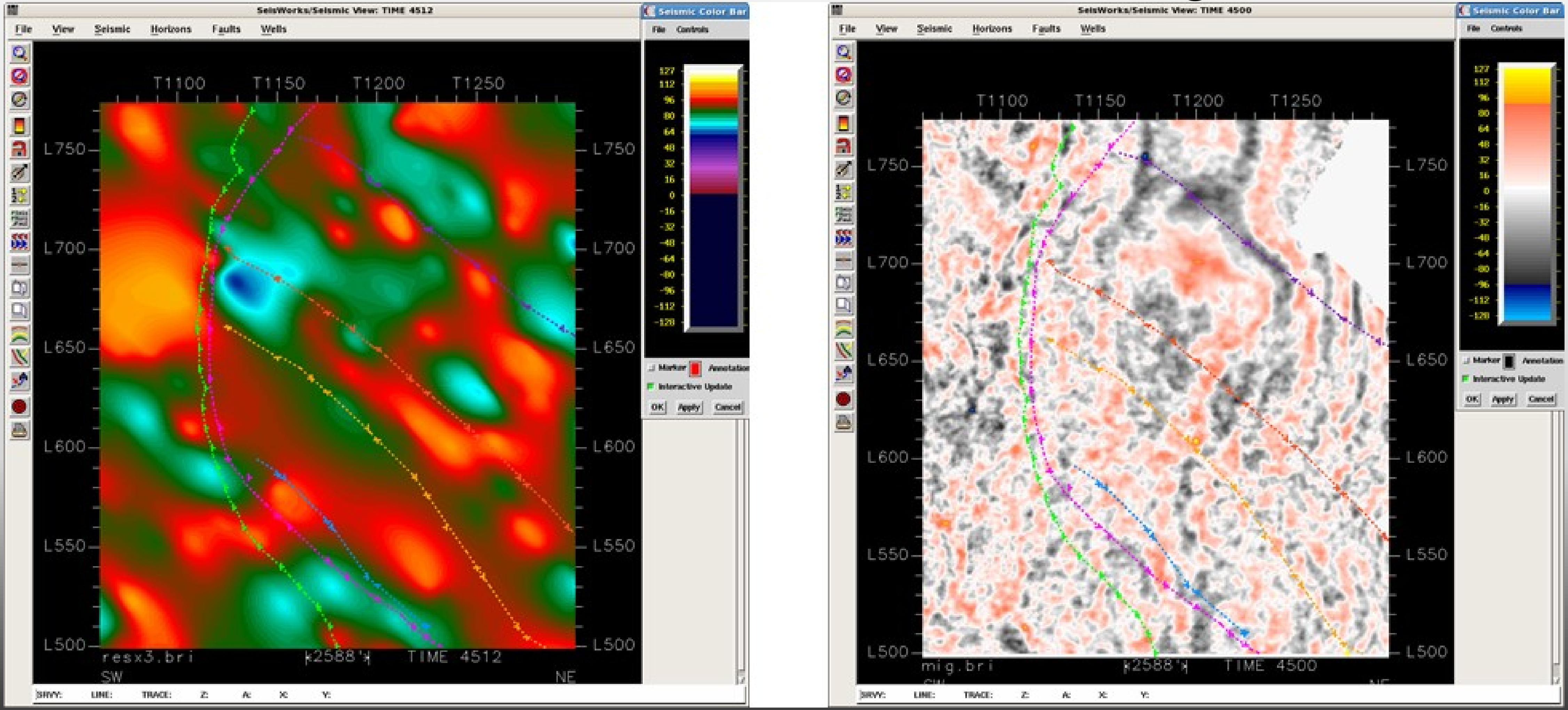


Resistivity-Slice on left and Seismic Time-Slice at 4000 ms on right

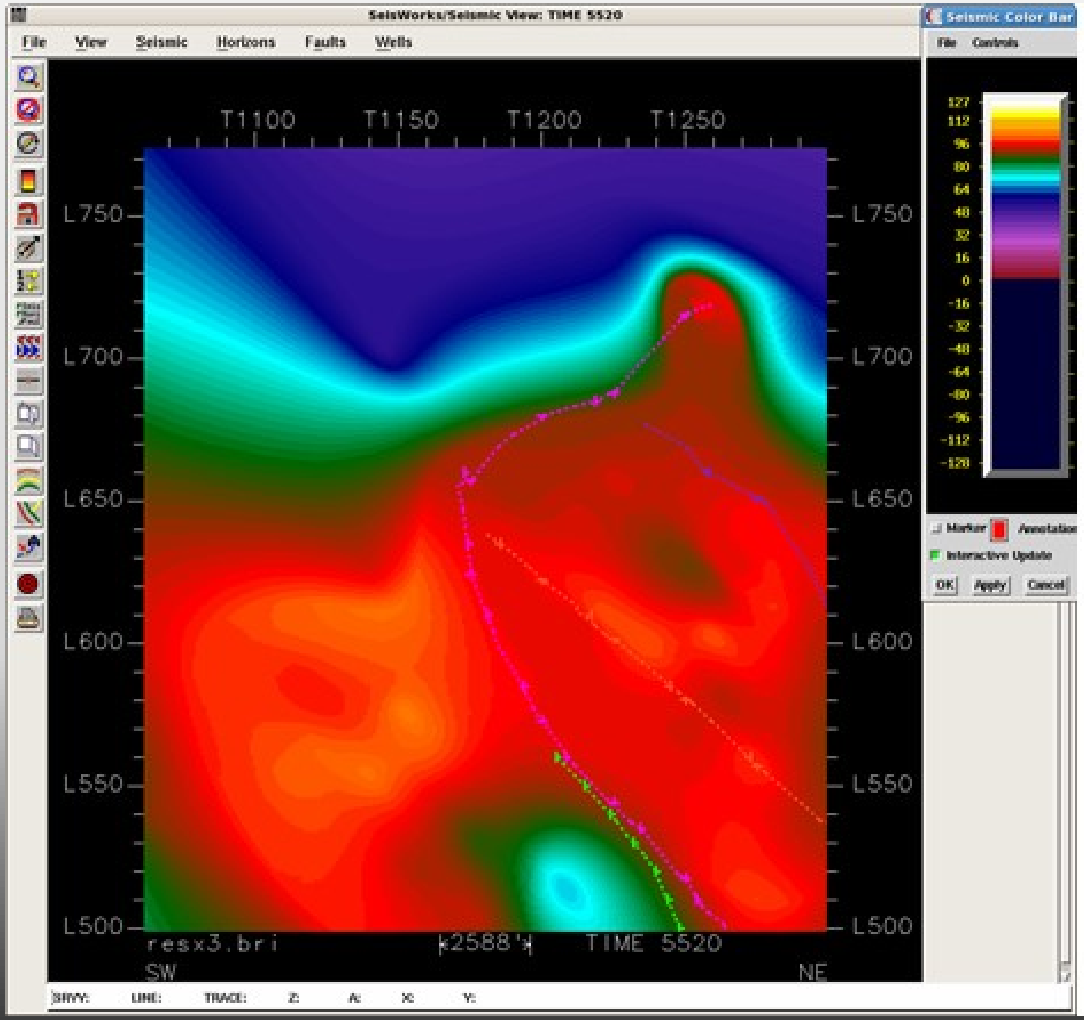


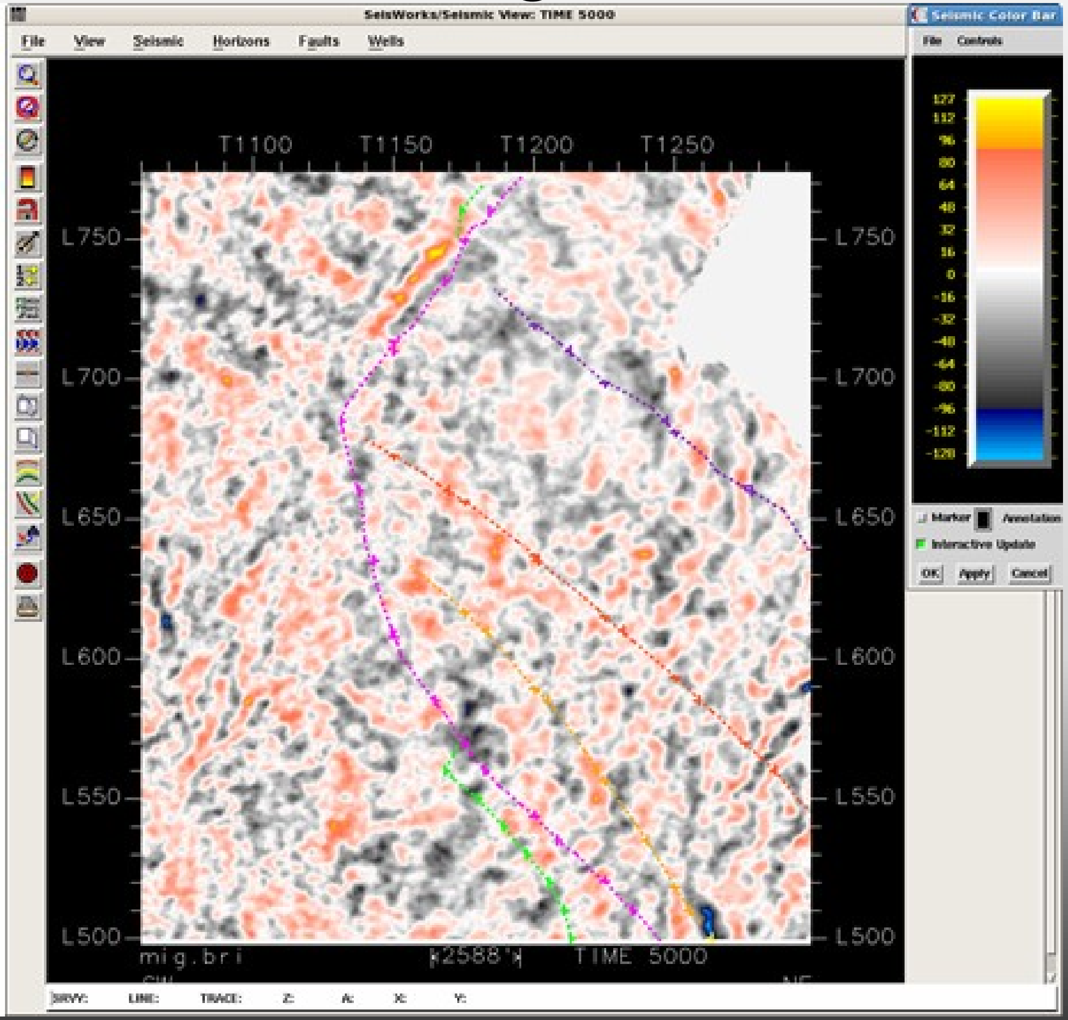


Resistivity-Slice on left and Seismic Time-Slice at 4500 ms on right

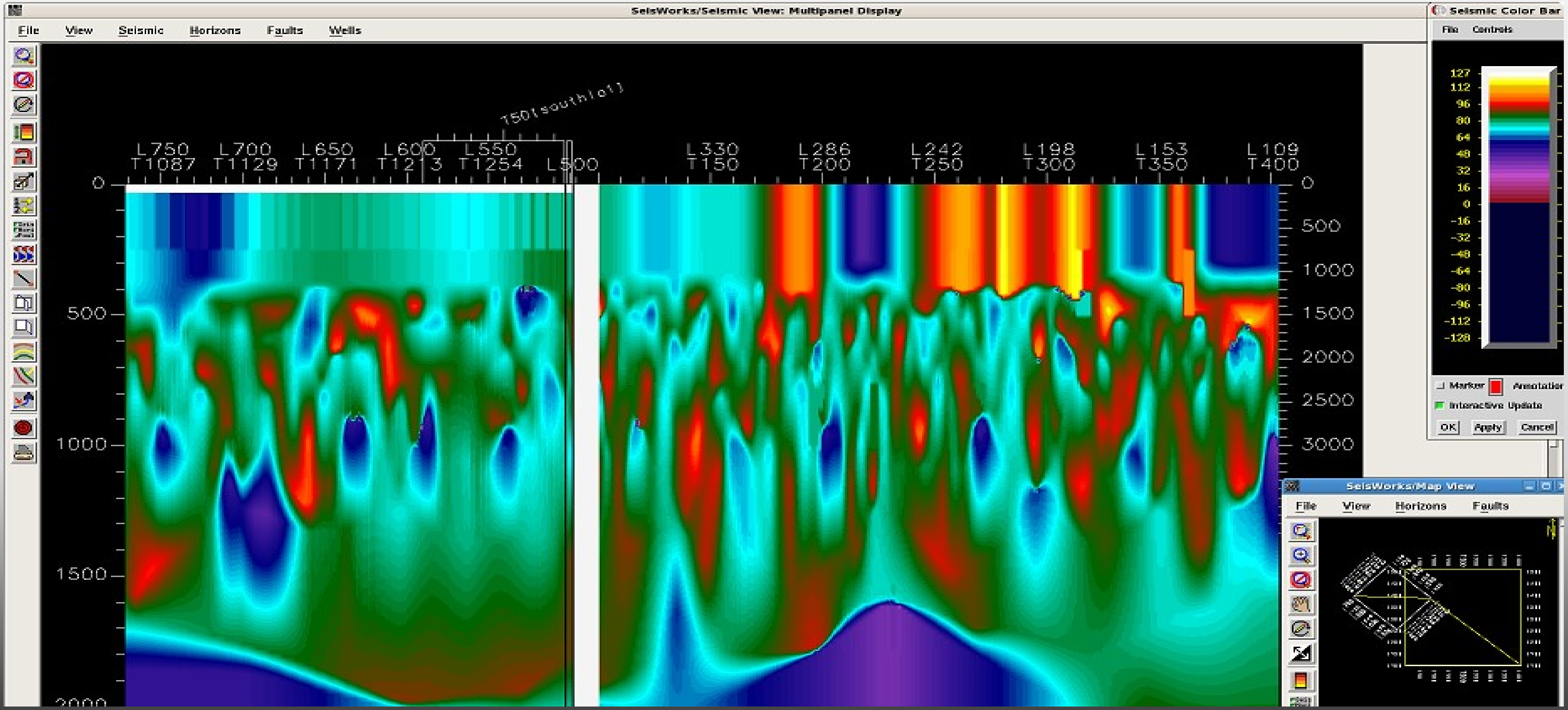


Resistivity-Slice on left and Seismic Time-Slice at 5000 ms on right

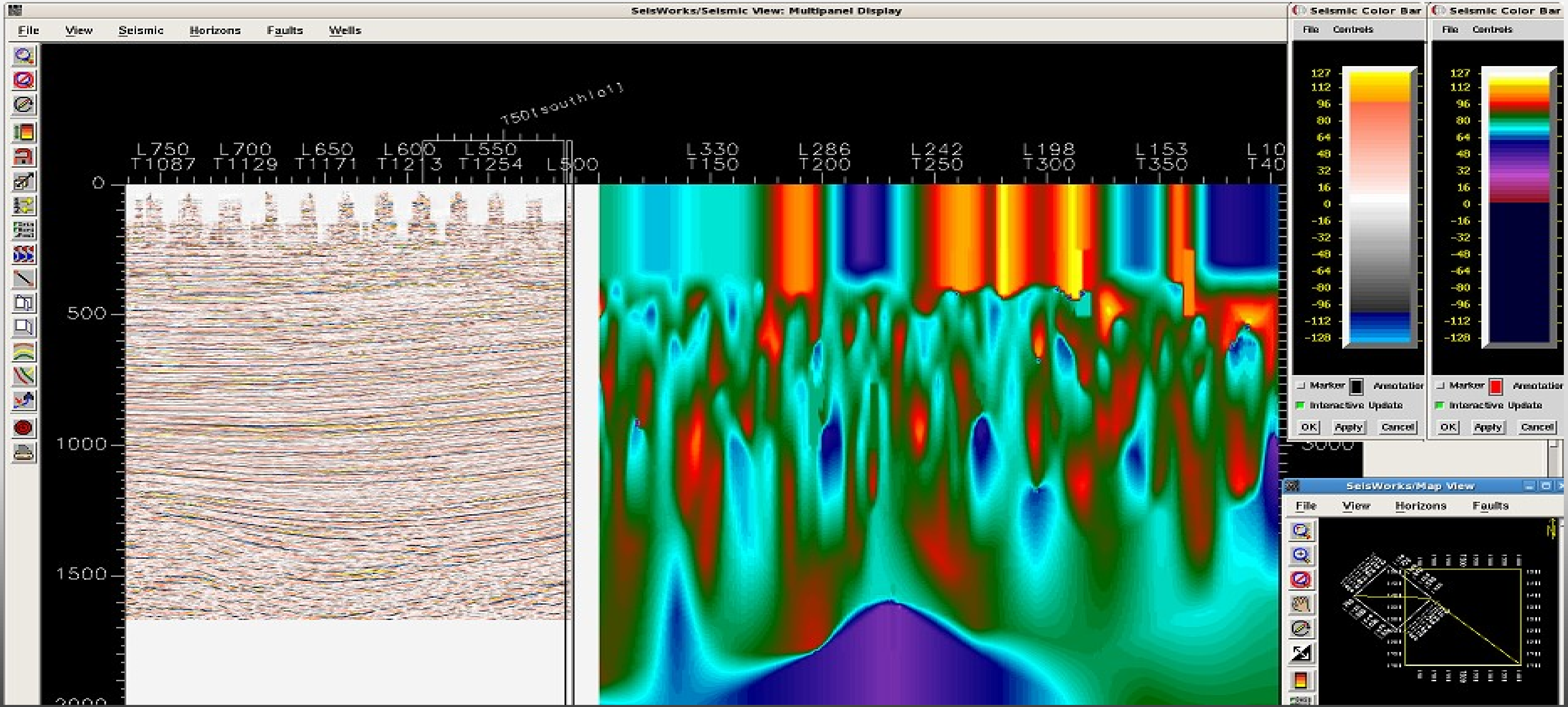




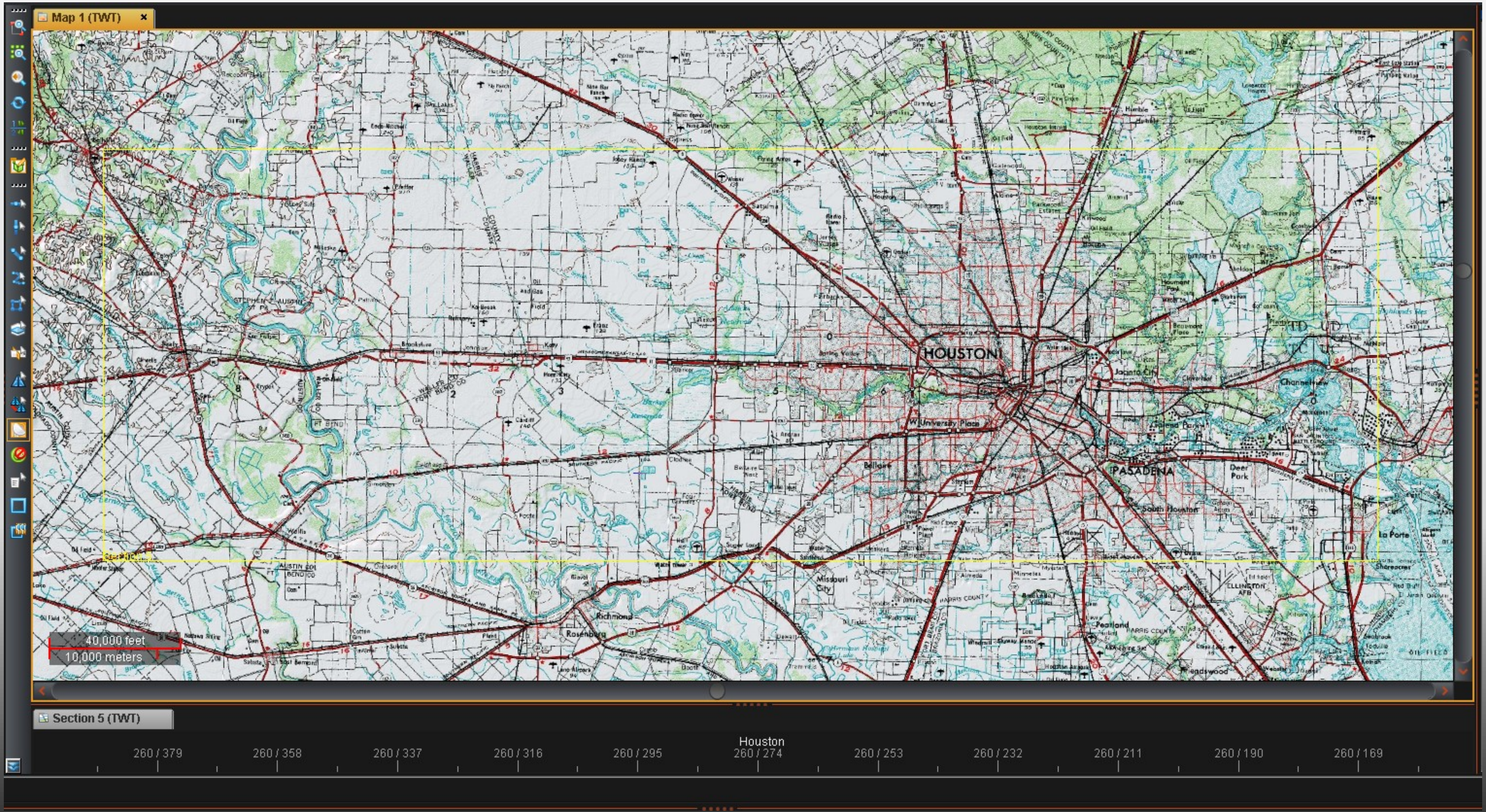
Giant businesses are built on measuring subsurface resistivity



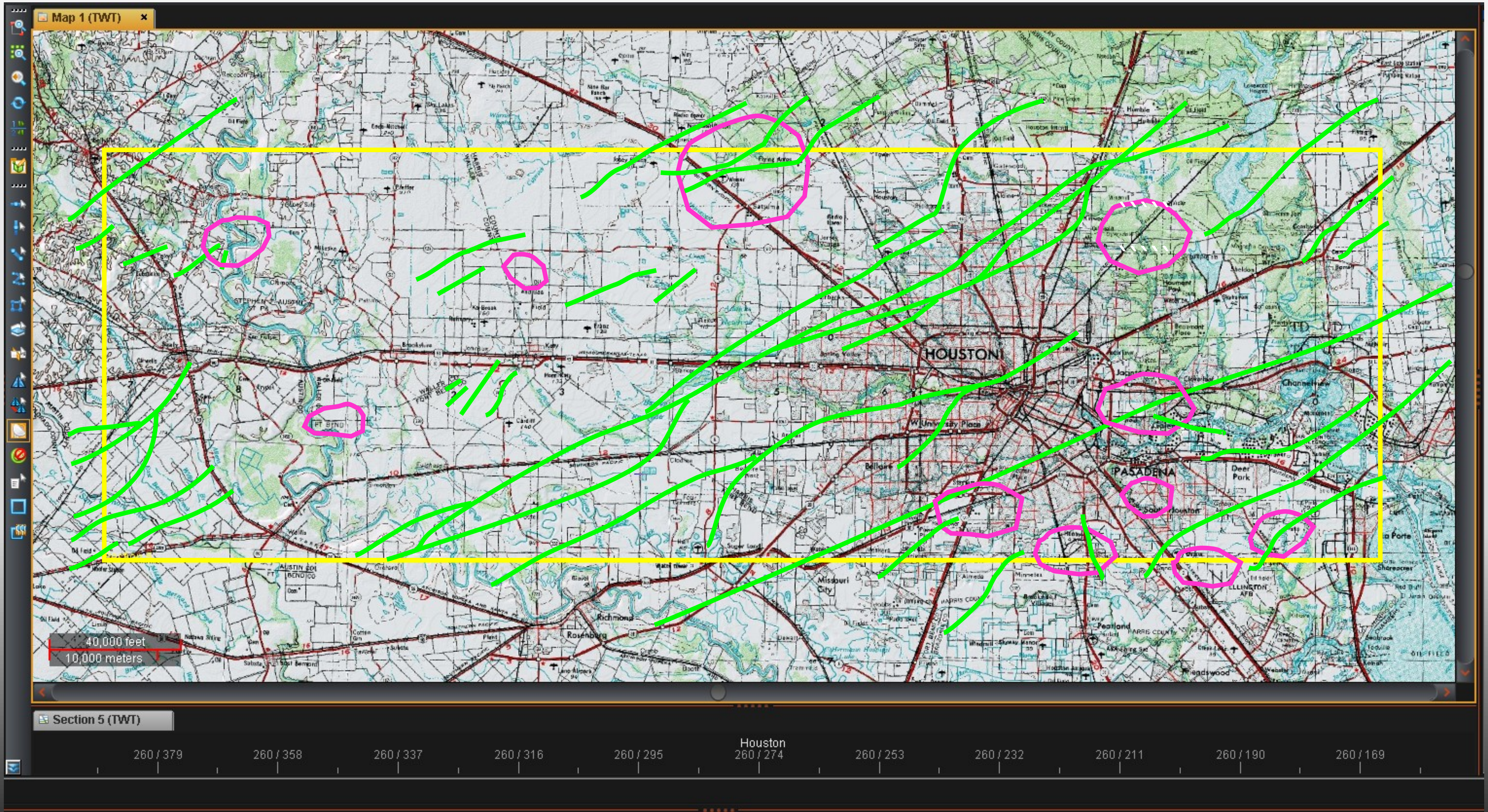
DML calculates resistivity volumes at 3-D seismic line & trace spacing anywhere



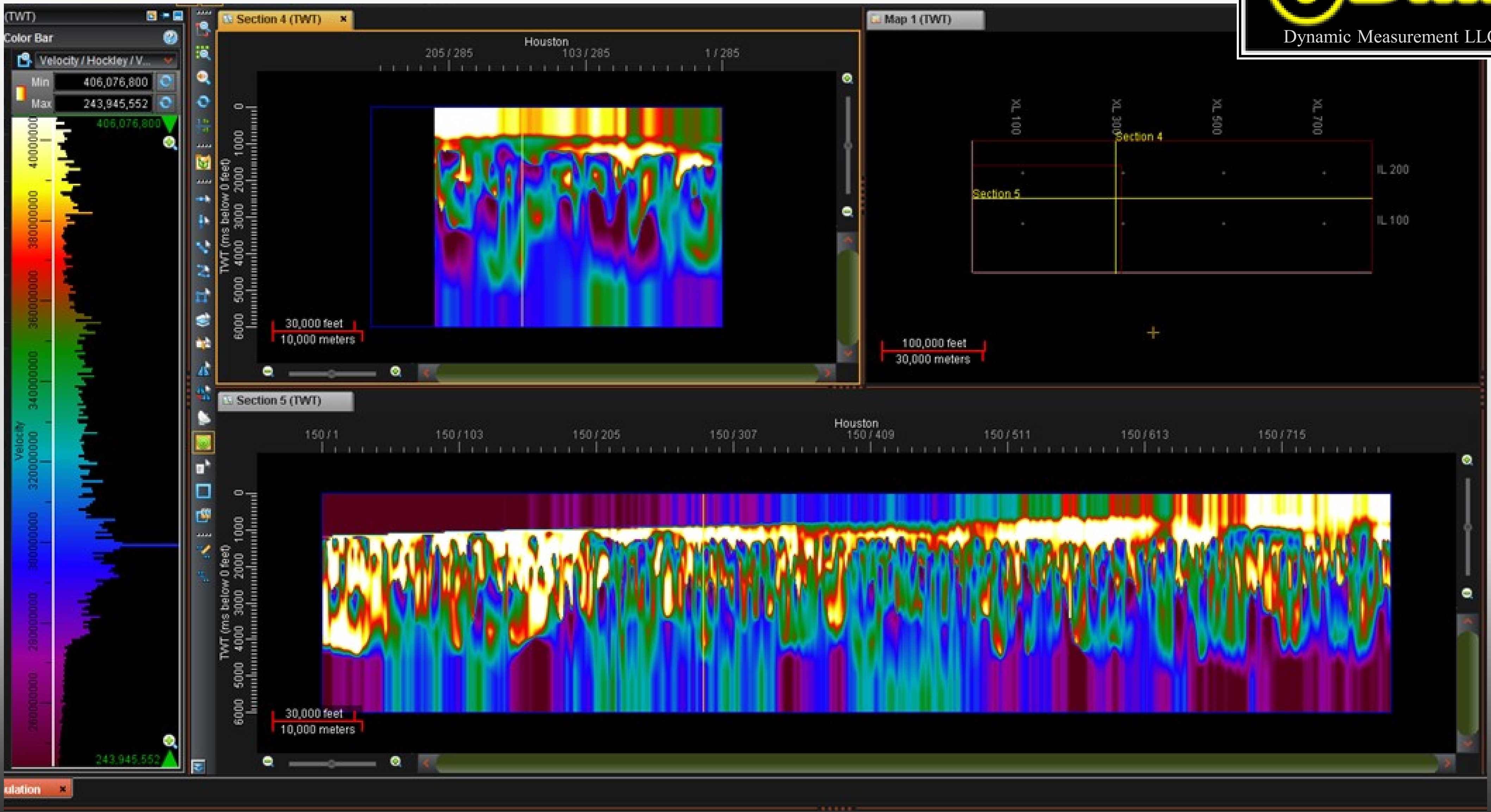
Imagine collecting a 3-D seismic survey here!



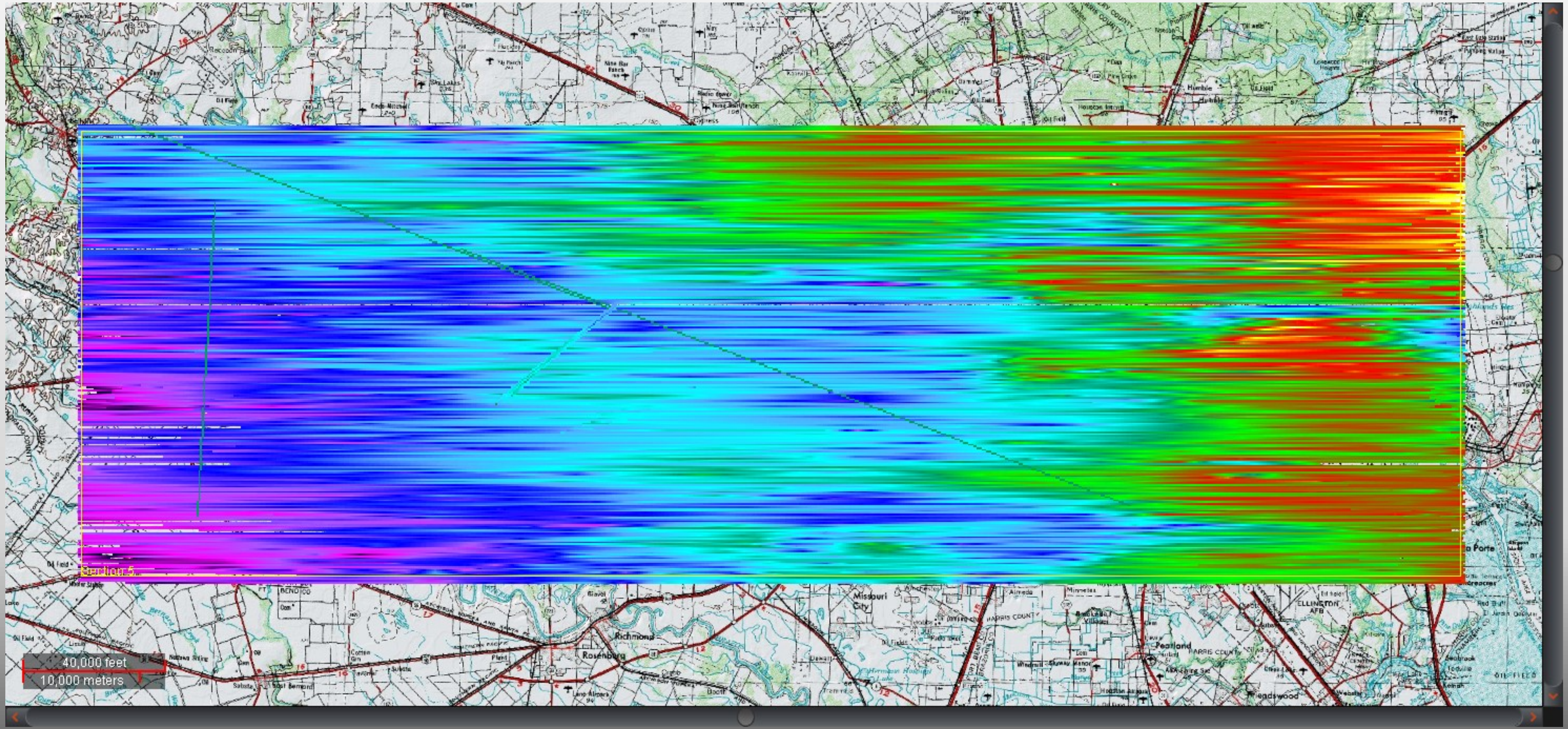
Imagine collecting a 3-D seismic survey here!



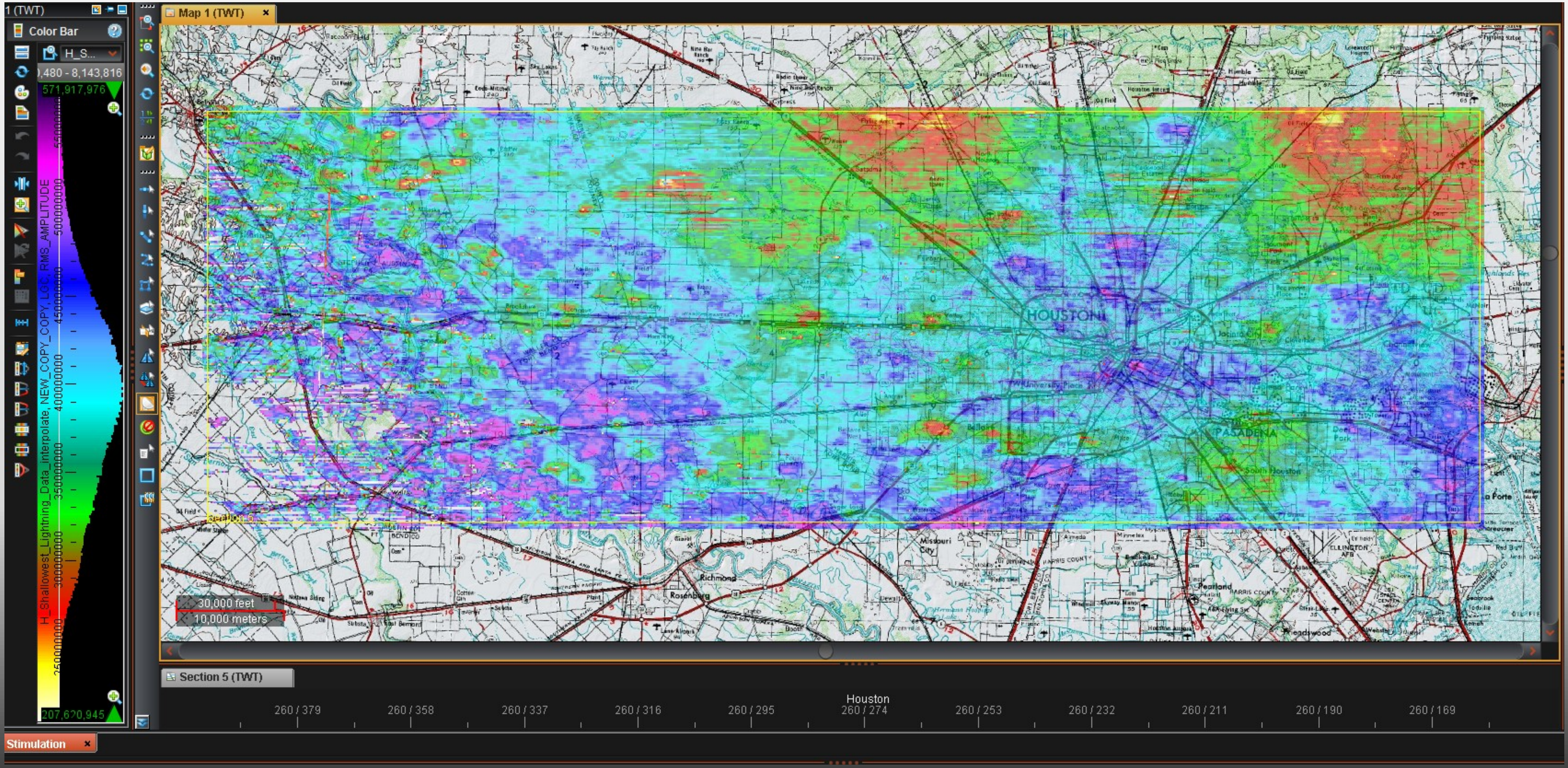
Resistivity Volume Houston Area



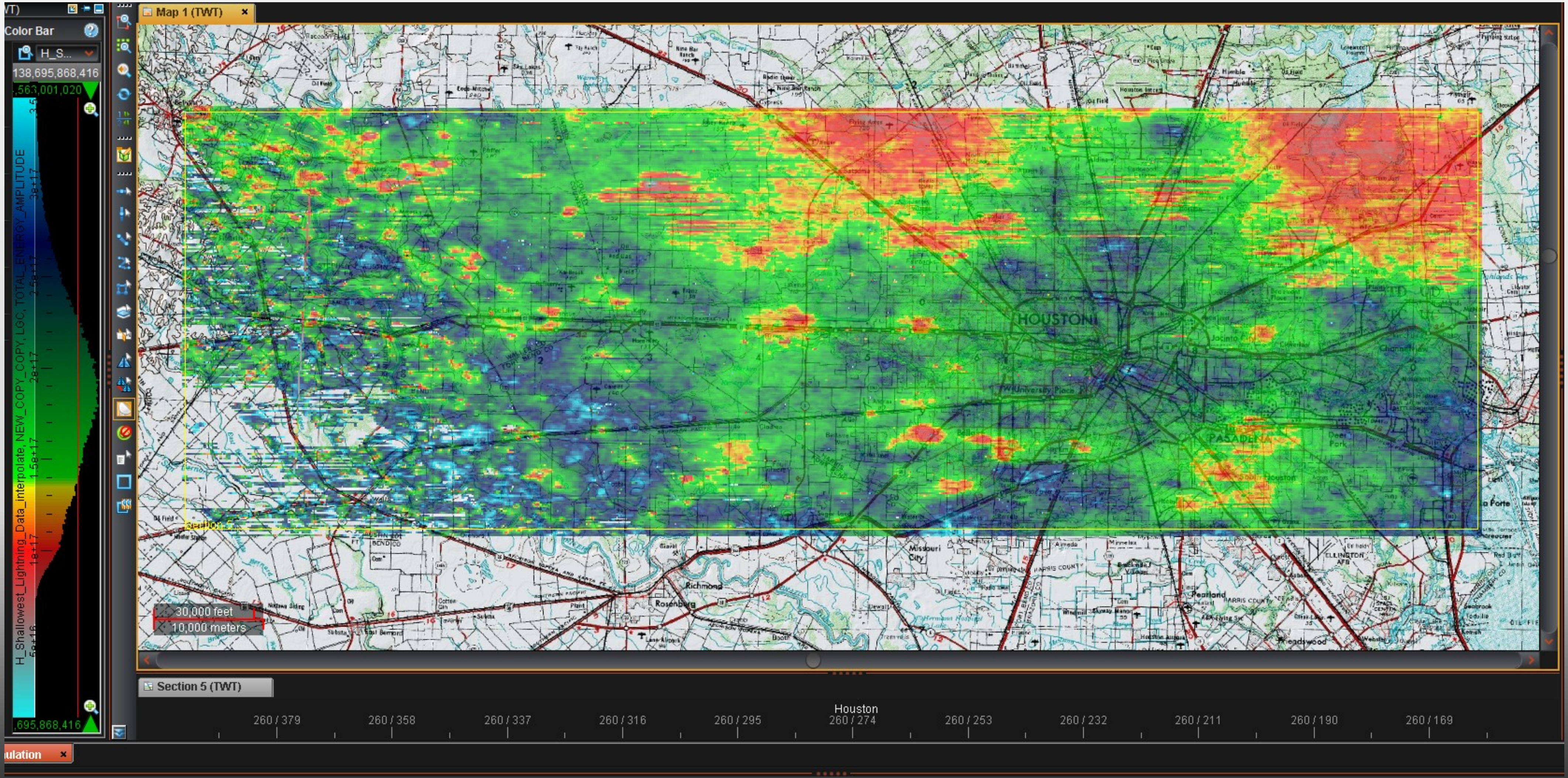
Shallowest Valid Horizon in Resistivity Volume



RMS Amplitude at Shallowest Horizon



Total Energy at Shallowest Horizon



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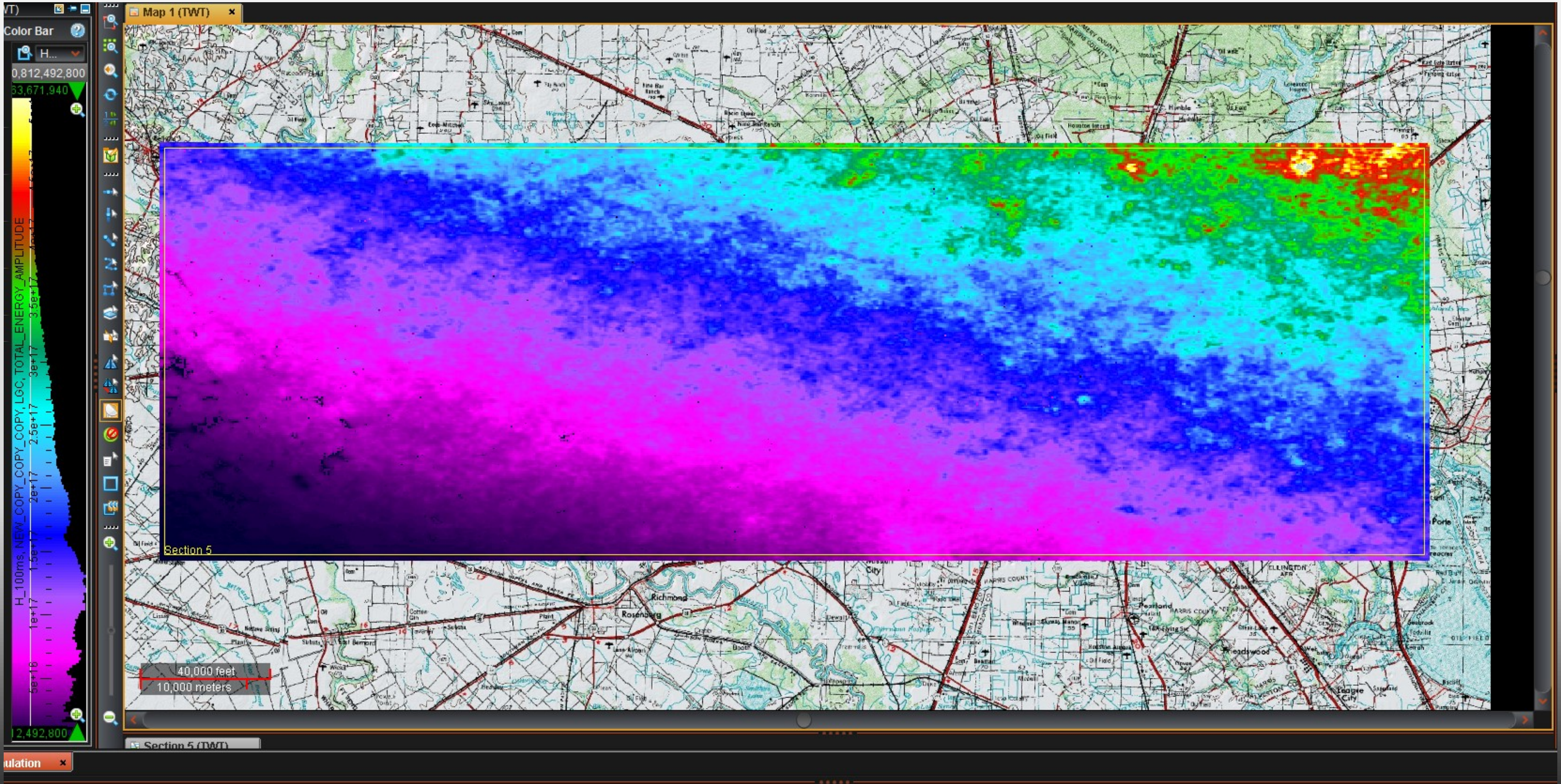
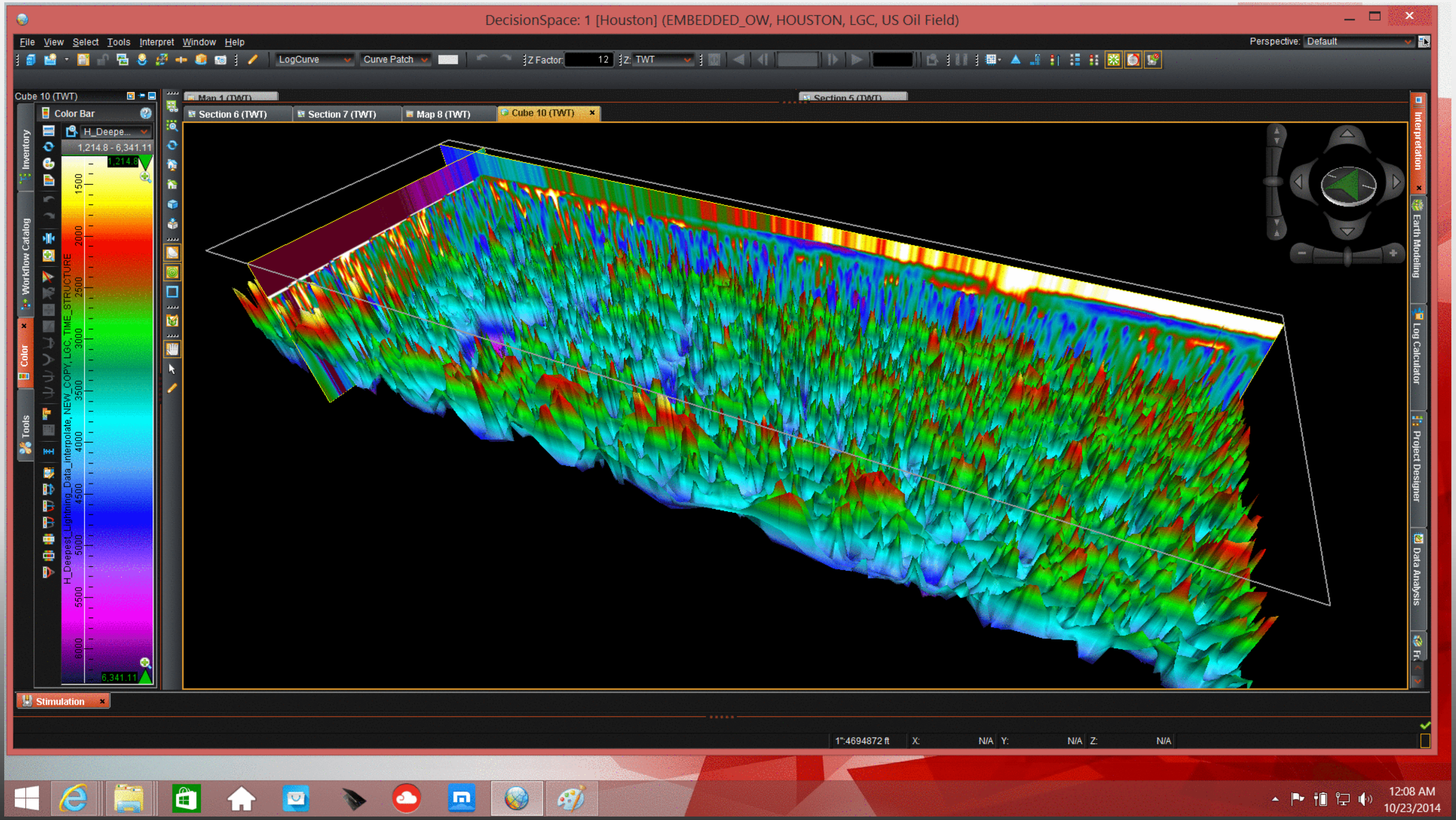
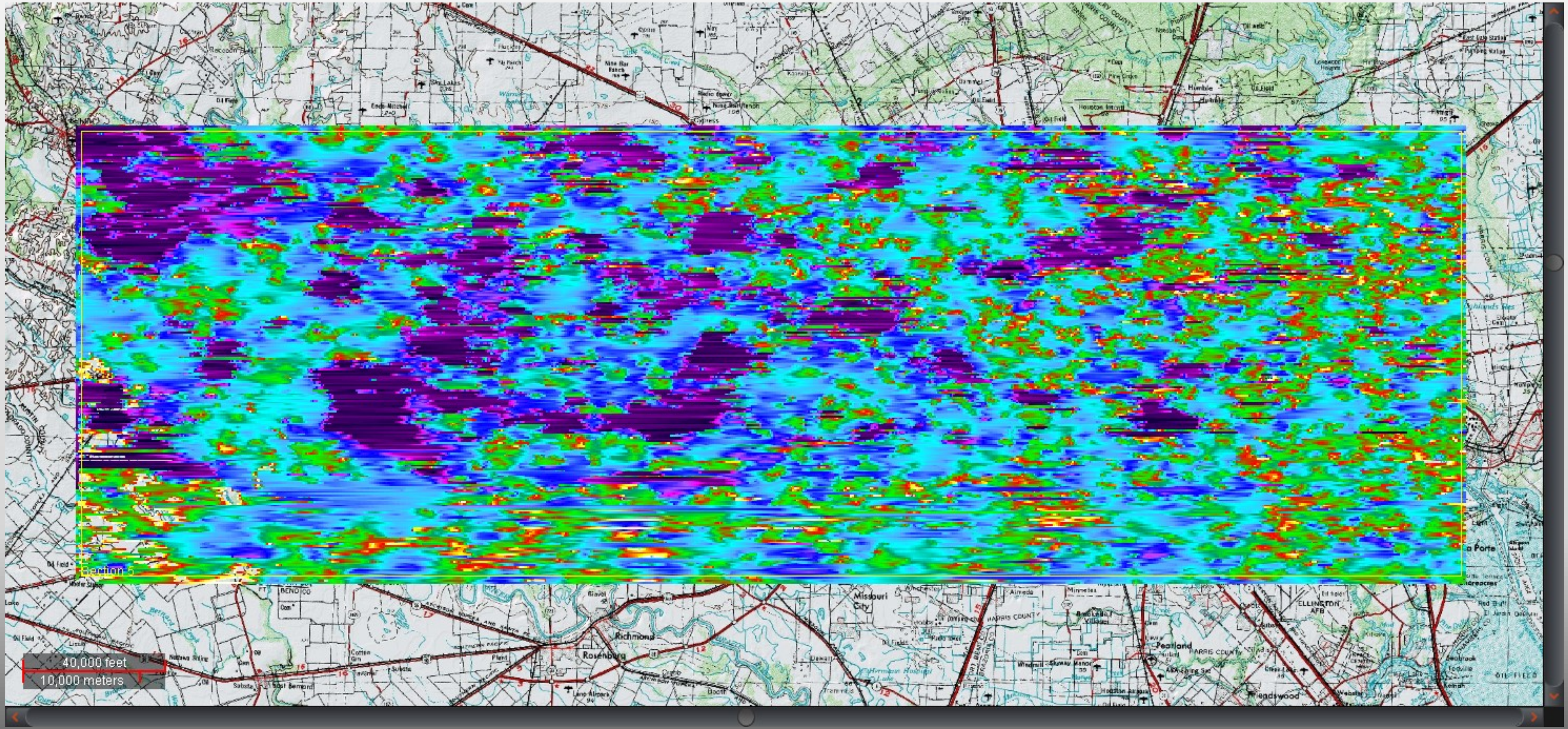
Total Energy 100ms to Shallowest Horizon



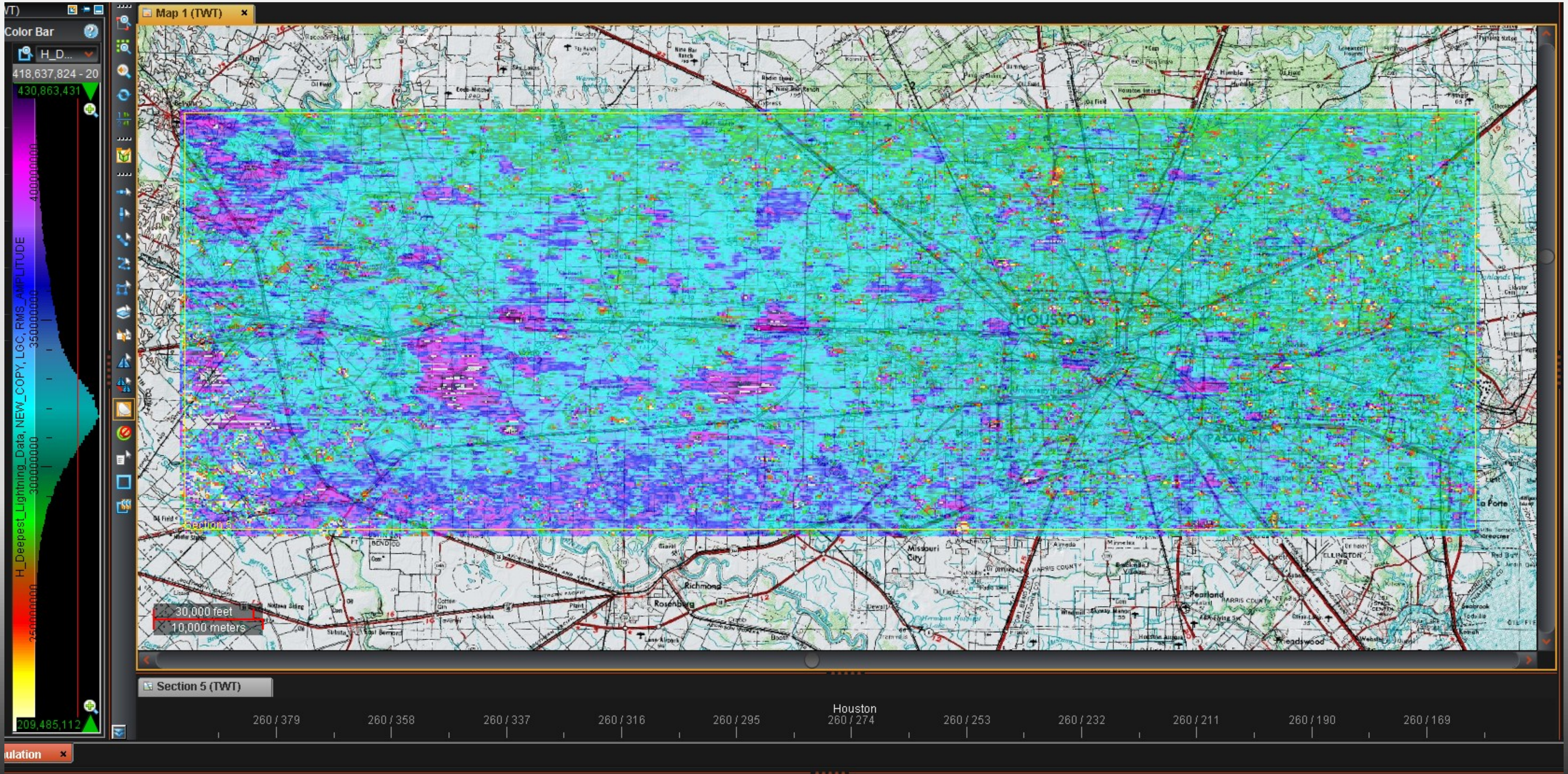
Perspective Displays of Deepest Horizon



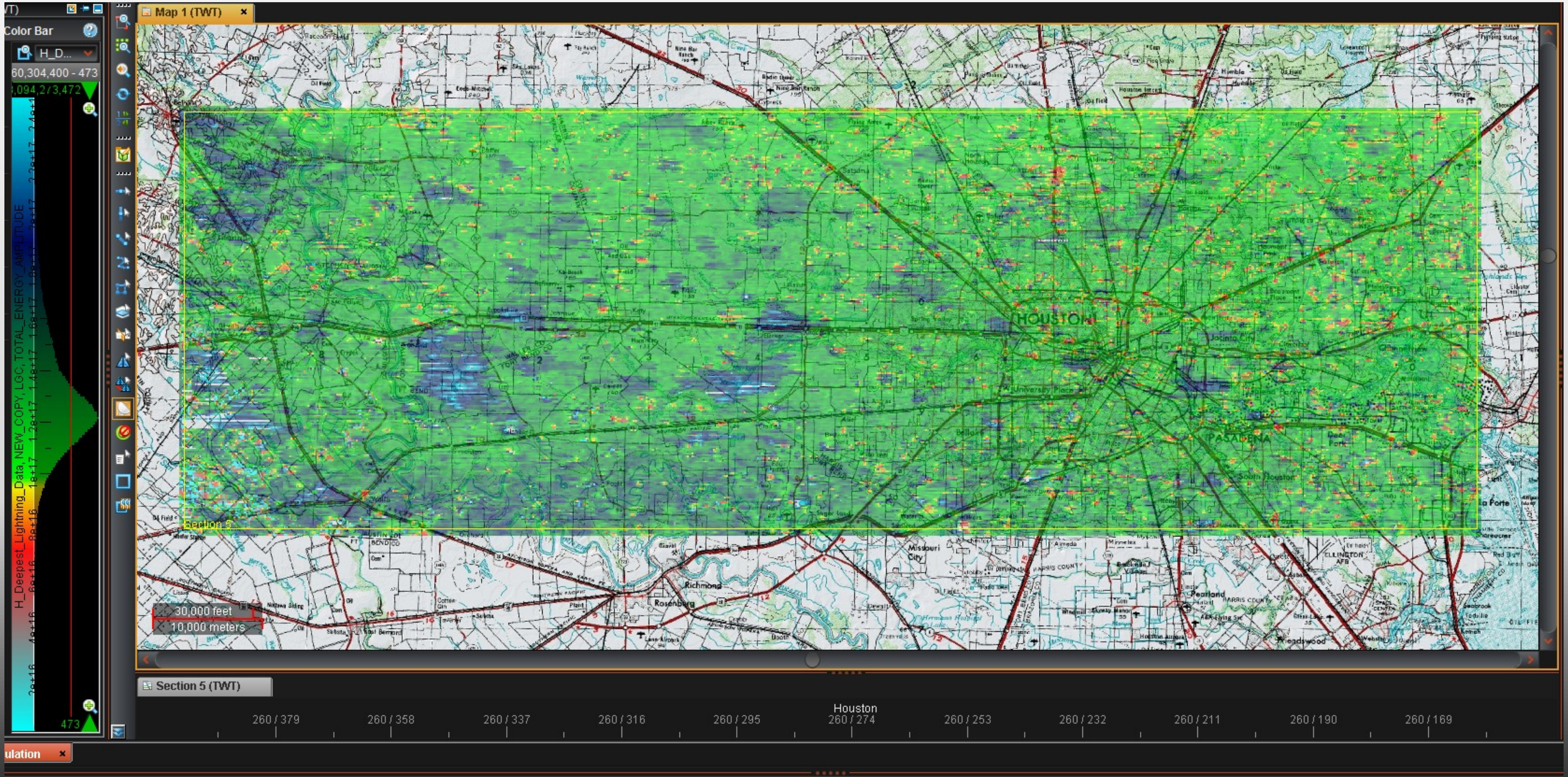
Deepest Valid Horizon in Resistivity Volume



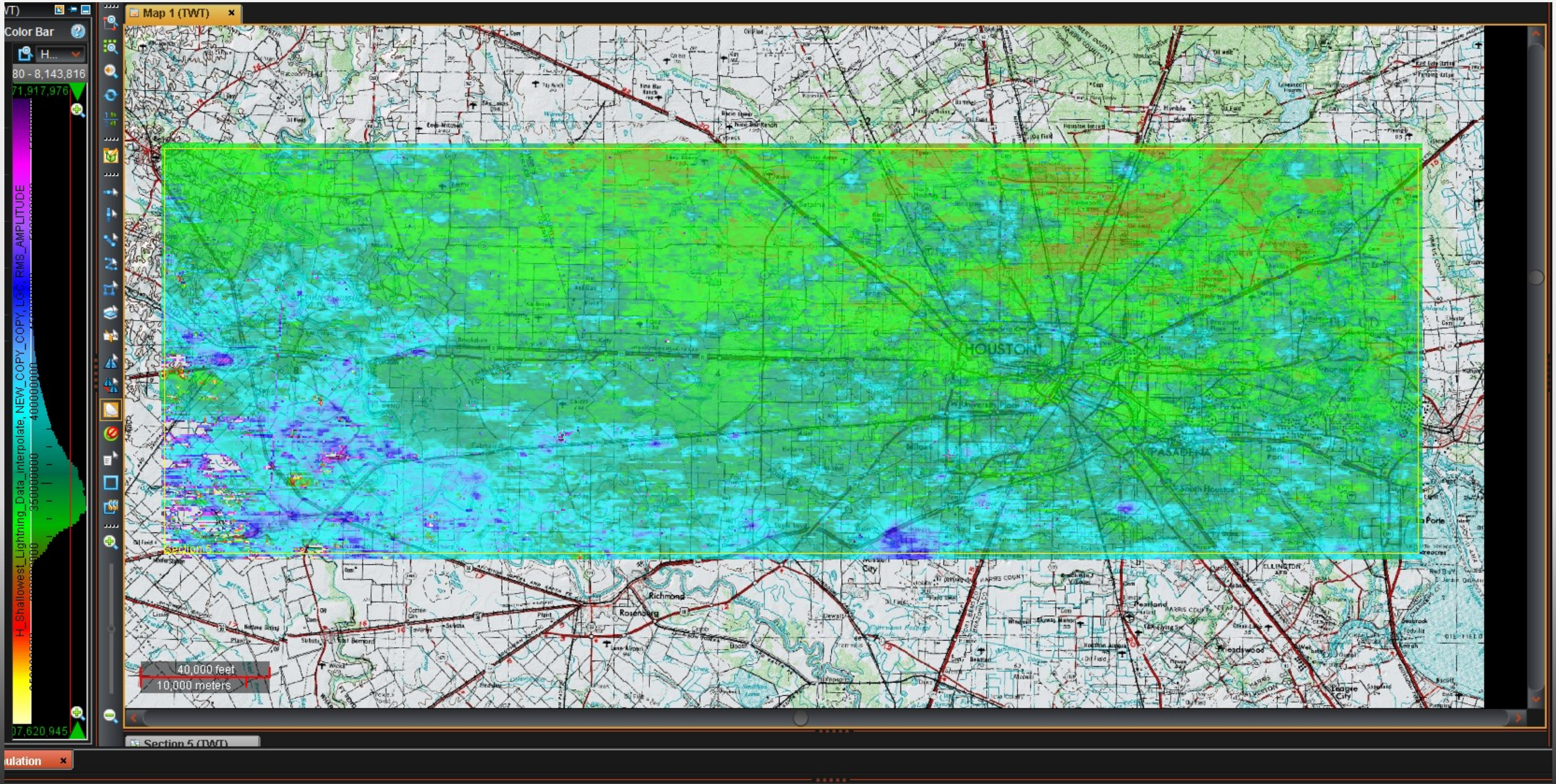
RMS Amplitude at Deepest Horizon



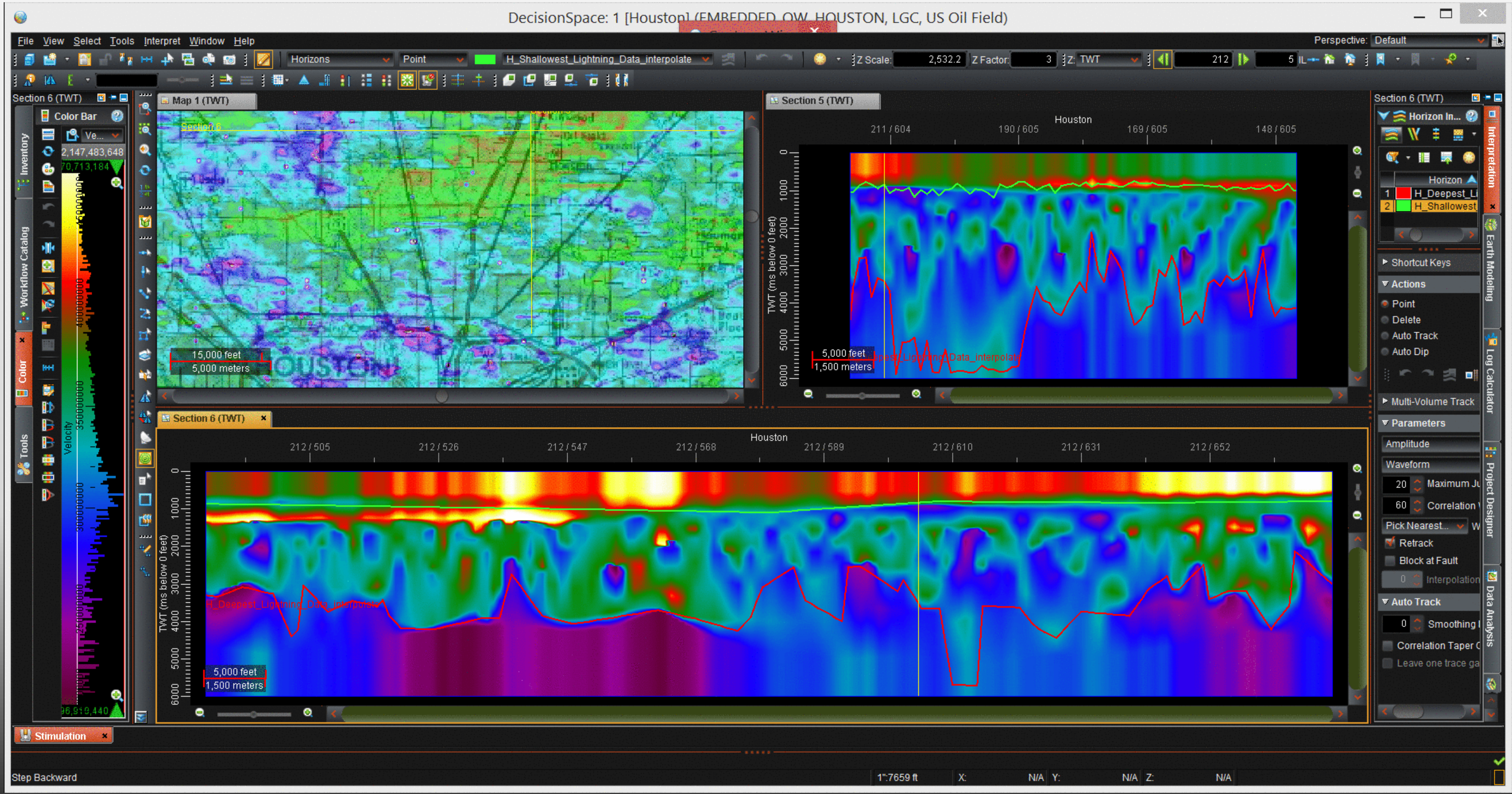
Total Energy at Deepest Horizon



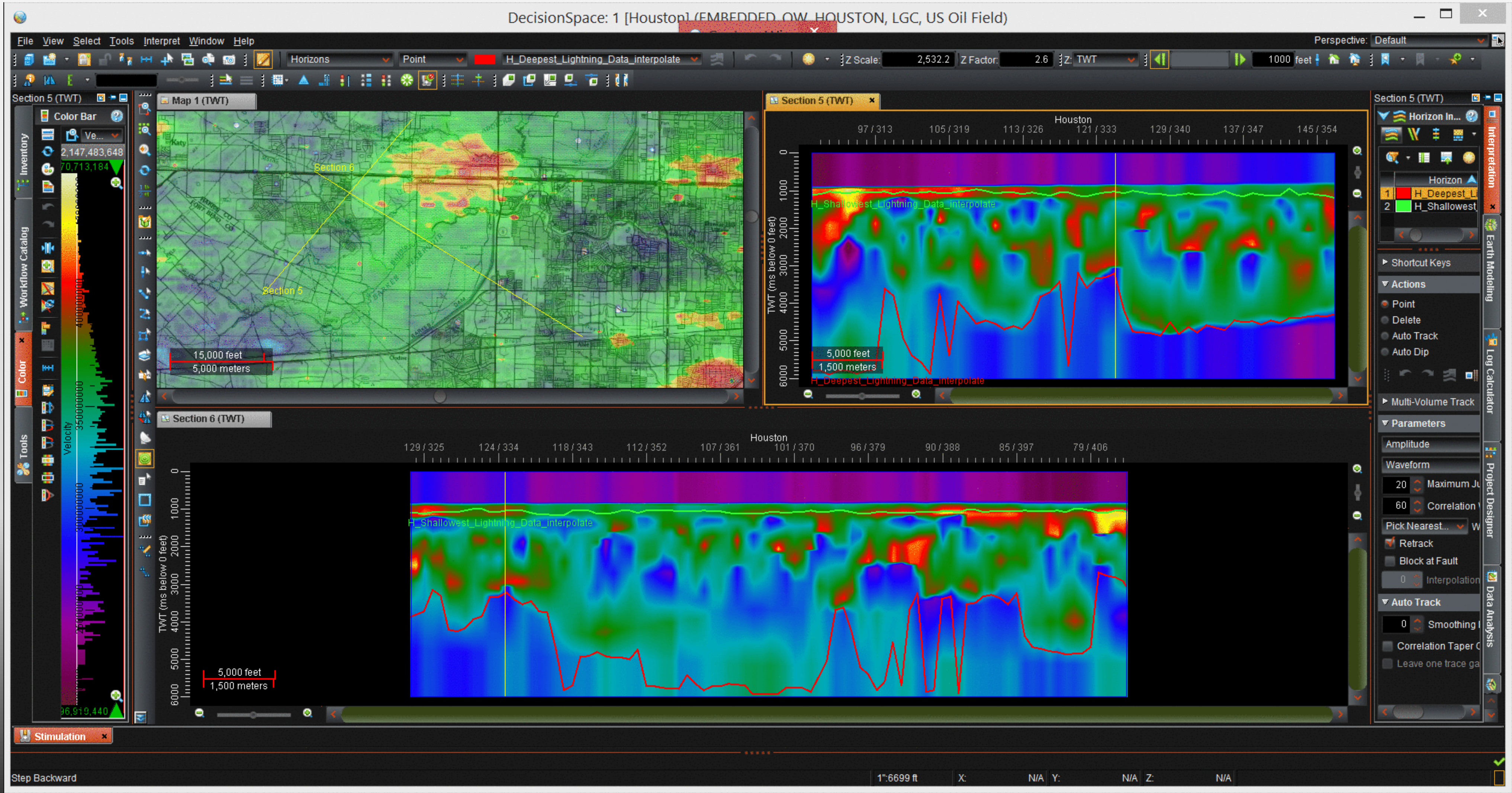
RMS Amplitude Shallowest to Deepest



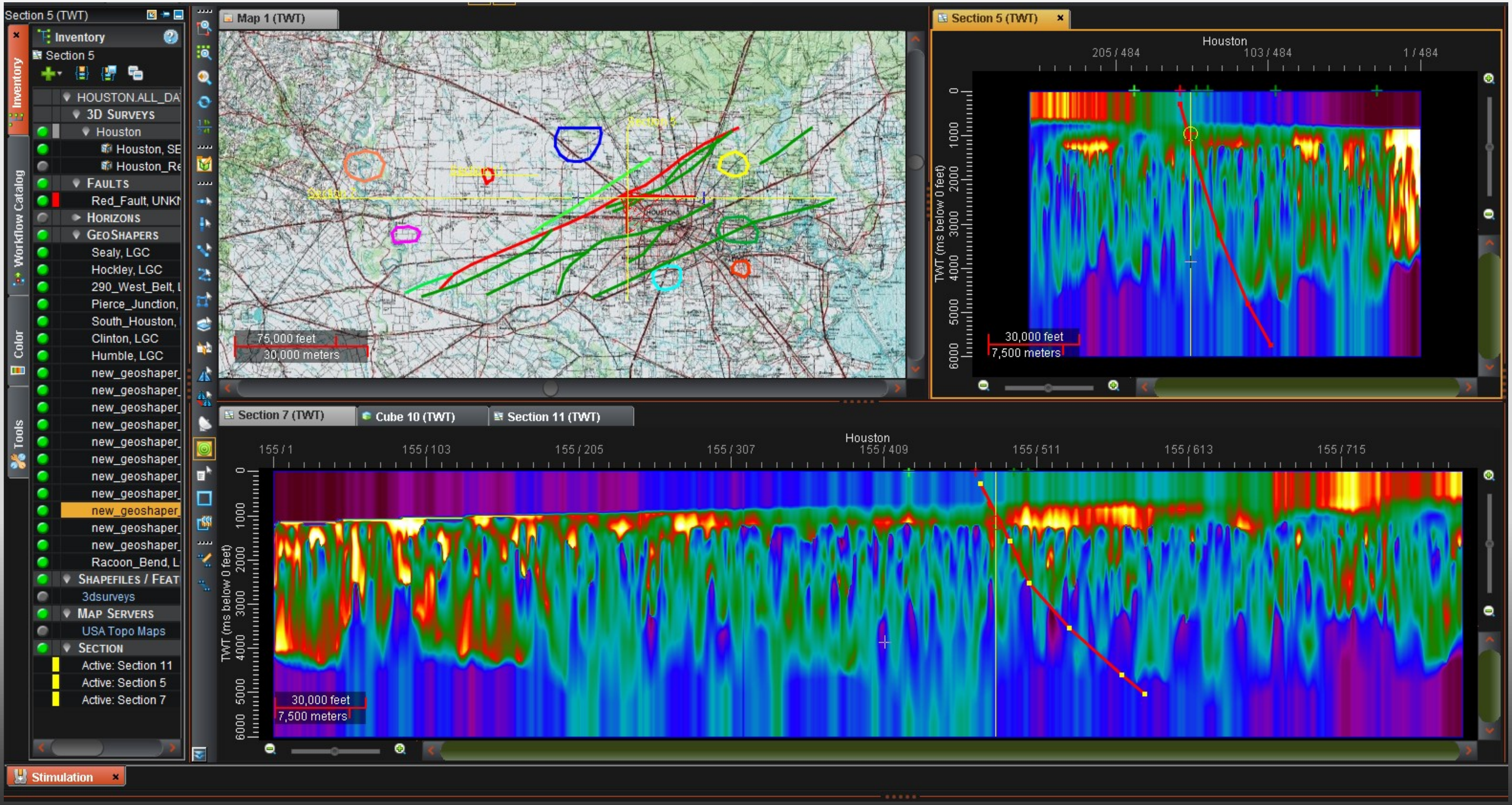
North Houston In-Line Animation



George Bush Park Pipeline Arbitrary Animation



Faults and Salt Domes

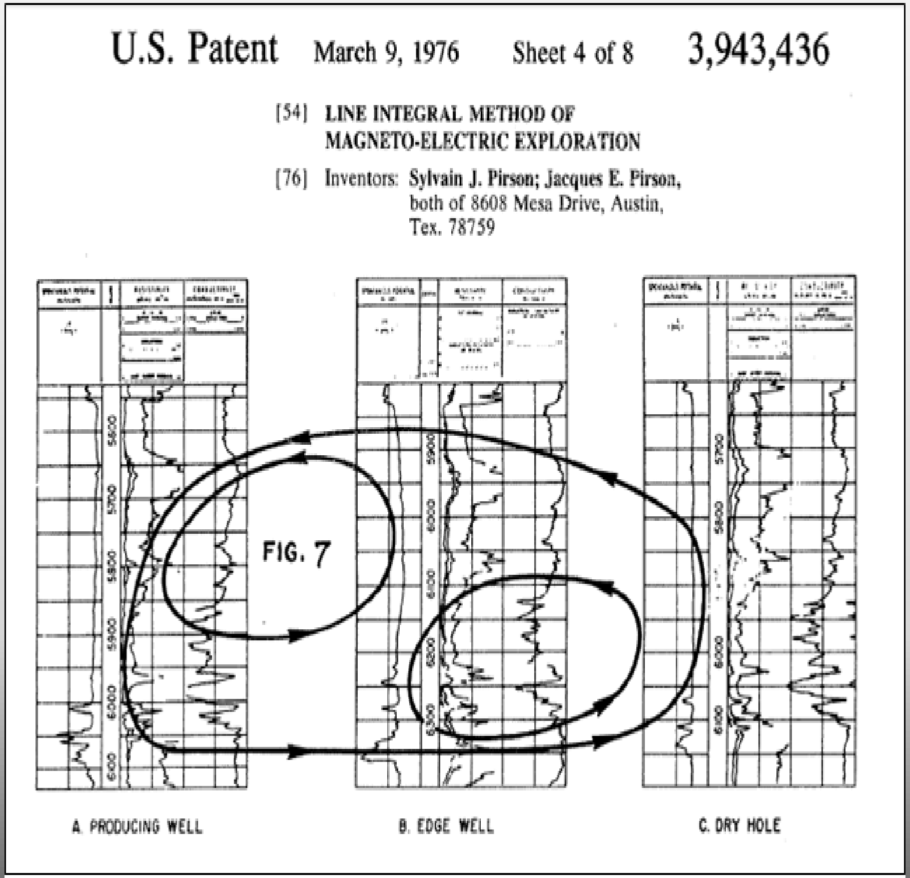


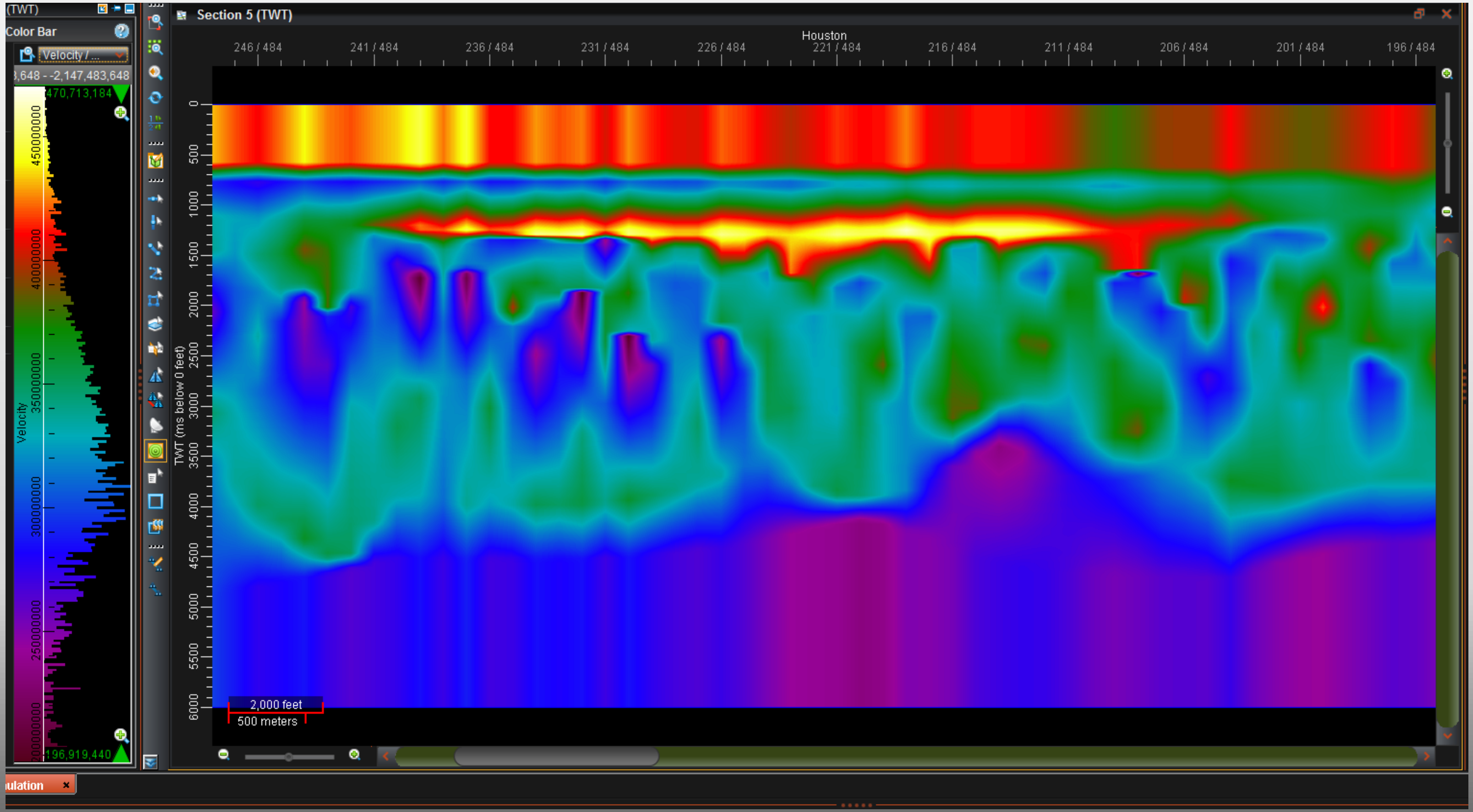
Agenda

3:00 Registration and Introductions
3:30 The meteorology behind lightning databases
3:45 Using lightning databases to explore for natural resources
4:00 Calculating resistivity volumes from lightning databases
4:45 Examples of resistivity volumes and potential applications
- Regional and Play Fairway hydrocarbon migration pathways
- High-grading exploration sweetspots

5:15 Anticipated future developments
- Use with Archie's equation to predict Formation Factor, Porosity, etc.
- Questions and Answers and Discussion among participants

Electrical Currents (Telluric and Terralevis)





Resistivity Volumes
Complement Velocity Volumes

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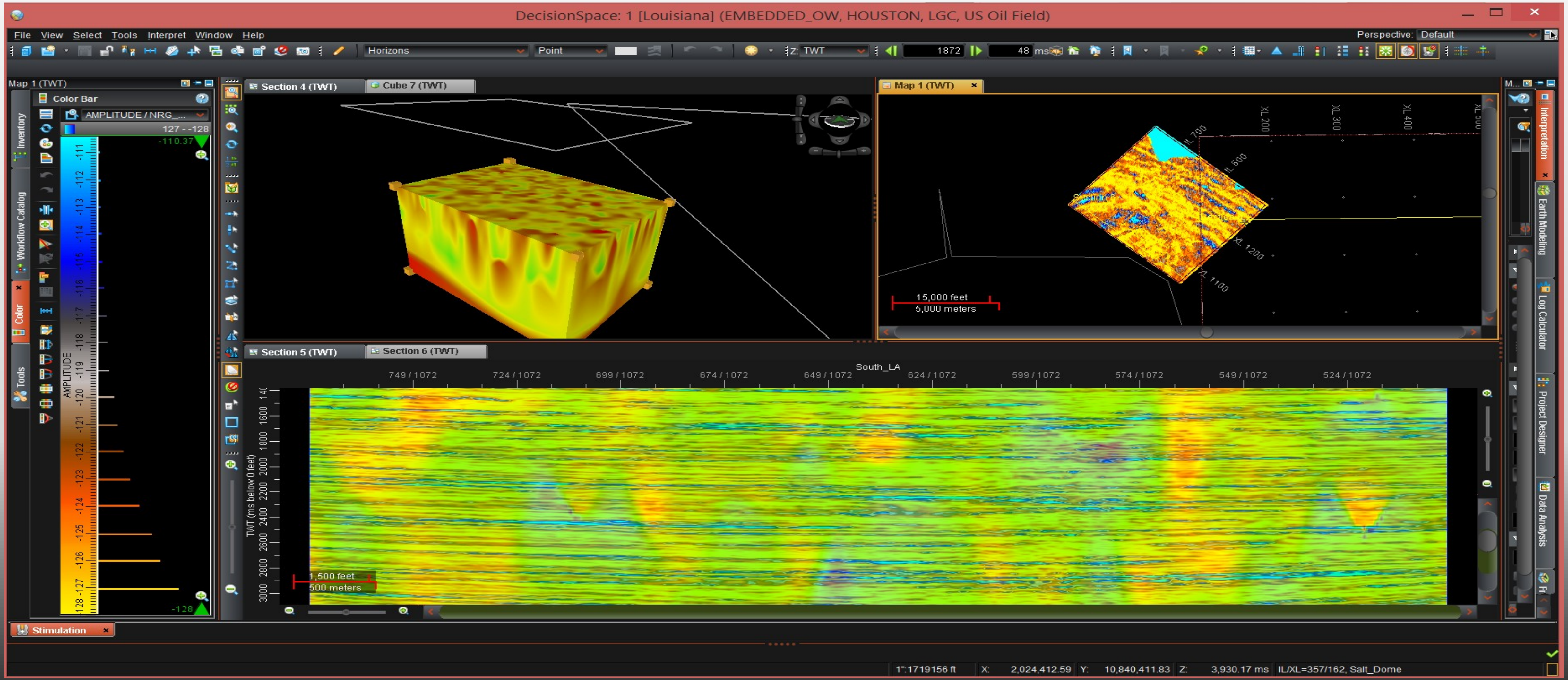
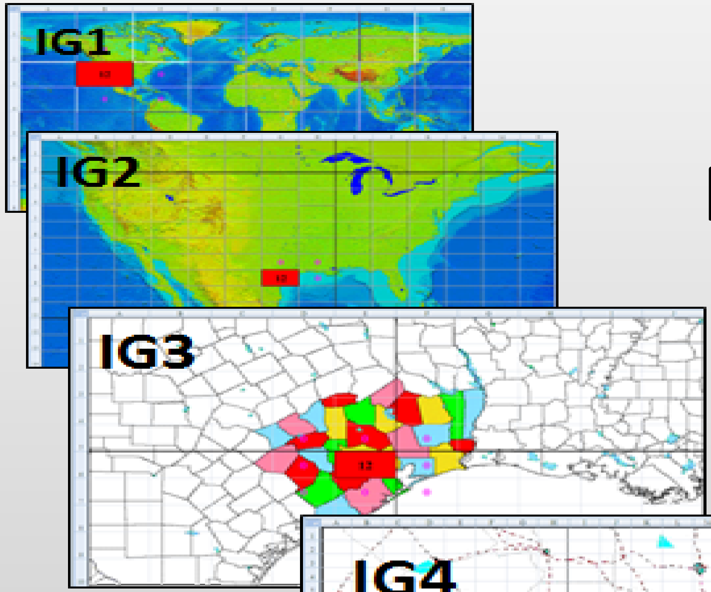
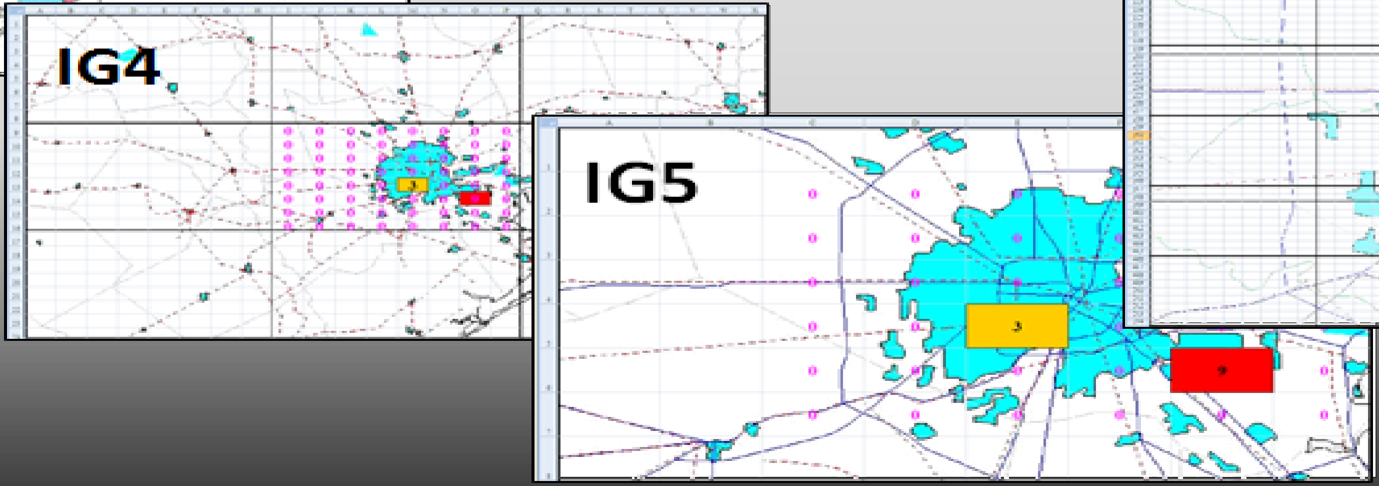


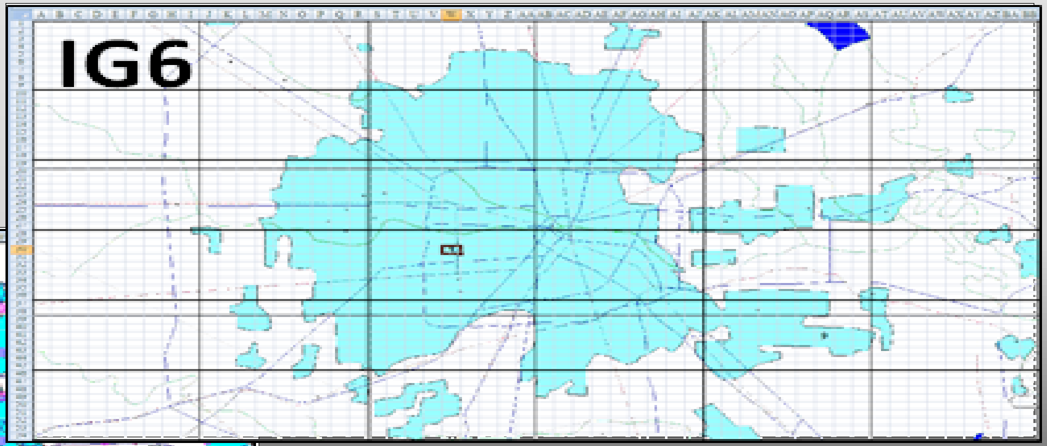
Lightning Data

Infinite Grid^{SM} Organization



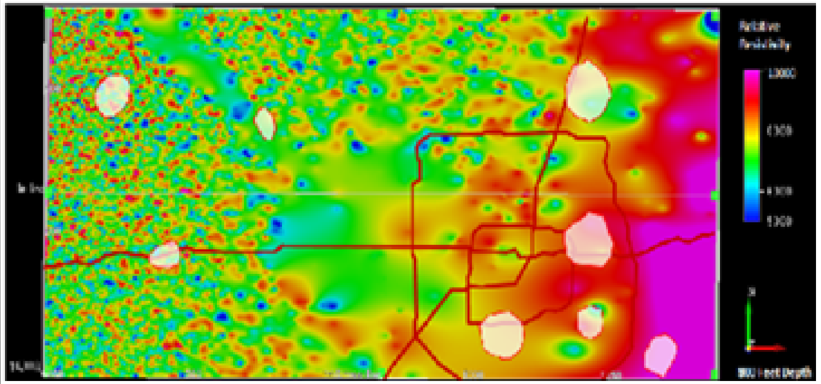
Raster based GIS for indexed input and real time recall

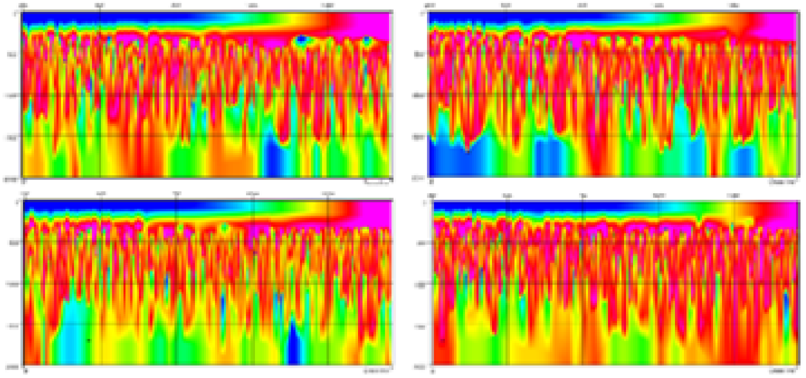


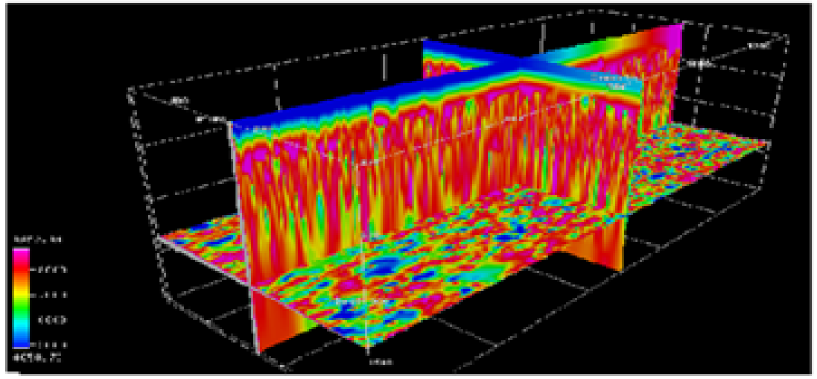


How this new data type can aid reservoir characterization

- Lightning attribute maps identify lineaments related to faulting
- Lightning resistivity volumes provides an independent view of geology
- Lightning resistivity volumes can be created to match 3-D geometry
- We anticipate a merger of resistivity volumes and lithology predictions from velocity volumes via Archie’s equation going forward







The Business Value of Lightning Analysis

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Scenario 1

Company A has a $2 million seismic budget

- Where is the optimal location for new seismic?
- Which of the $2 million worth of spec seismic is best to purchase?

Scenario 2

Company B has millions of acres of leases about to expire

- How do they identify and **rank** the sweet spots?
- What leases need to be retained?

ANSWER: Conduct a lightning analysis

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- Contact Information:
  - H. Roice Nelson, Jr.

    cell: 713.542.2207

    e-mail: roice@dynamicmeasurement.com
  - Dr. Jim Siebert

    cell: 832.423.2355

    e-mail: jim@dynamicmeasurement.com
  - Les R. Denham

    cell: 281.879.6010

    e-mail: les@dynamicmeasurement.com

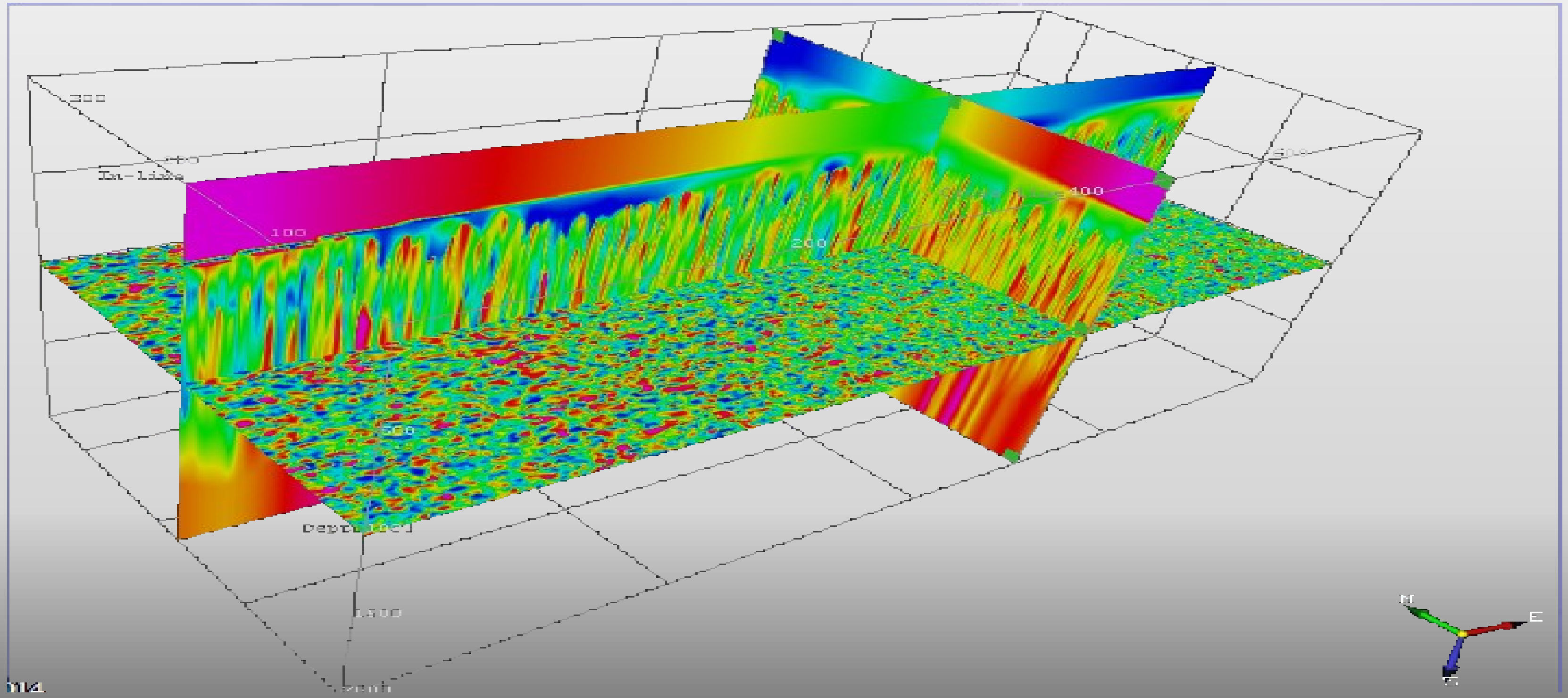
- www.dynamicmeasurement.com

- 211 Baker Road #382
  Barker, TX 77413
  Office: 281.579.0172

- 2155 West 700 South #31
  Cedar City, UT 84720
  Fax: 435.267.2668

Find out more at http://www.dynamicmeasurement.com

Thank You!



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AGI Resistivity Sections

Lightning Databases:
an old & a new geophysical data type

1752 Benjamin Franklin's kite in the Marcellus Shale Resource Play.

1833 First magnetic field measurements.

1920's Seismic refraction & reflection surveys.

1927 Schlumberger's first electrical resistivity well log.

1936 First modern Gravimeter.

1950's Magnetotellurics invented, measuring lightning charged earth currents.

1960's & '70's The first image processing of satellite imagery.

1974 First 3-D seismic survey collected for Gulf Oil.

1982 Landmark Graphics' first stand-alone seismic interpretation workstation.

1997 CSEM (Controlled Source Electromagnetics).

2008 Data mining lightning data as a new Geophysical Data Type.

<u>Each new data type sparked millions of dollars in data sales & services.</u>

Proven and Patented Technology

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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)

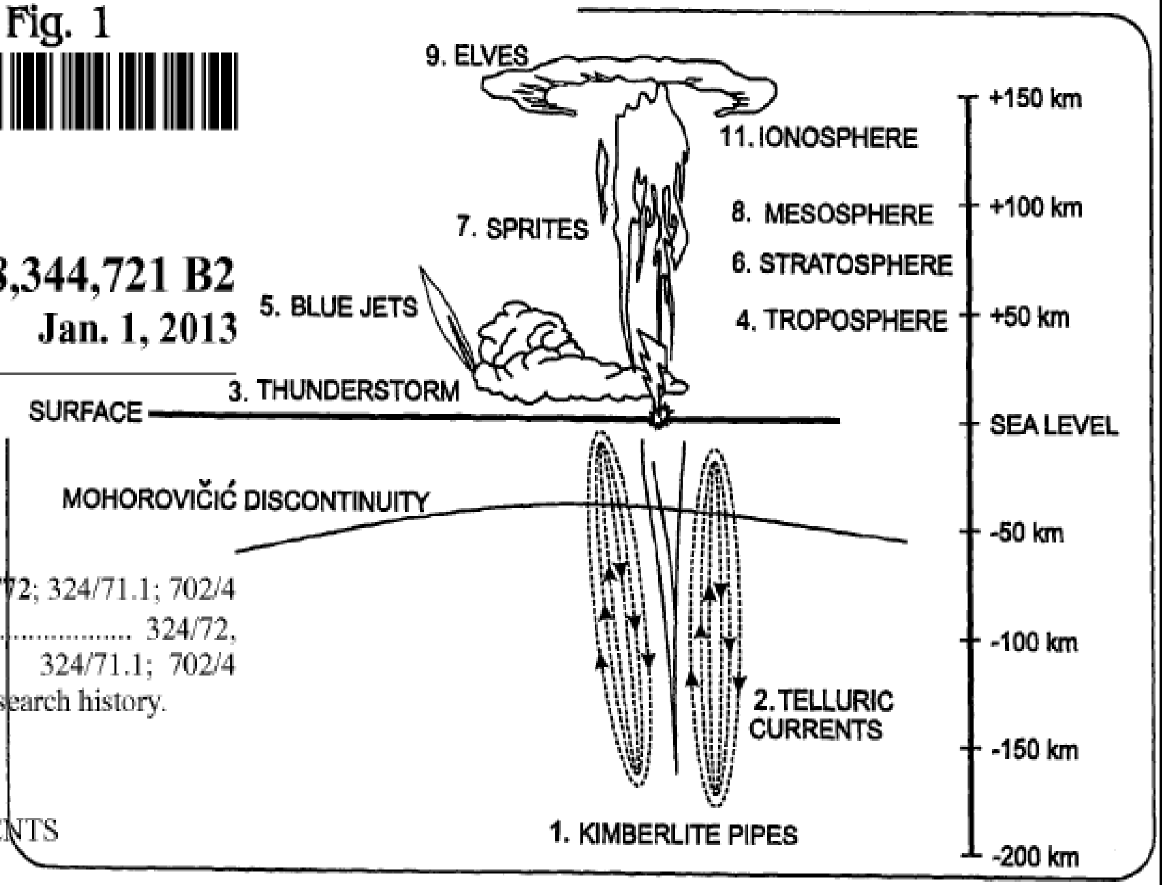
(52) **U.S. Cl.** **324/72**; 324/71.1; 702/4

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

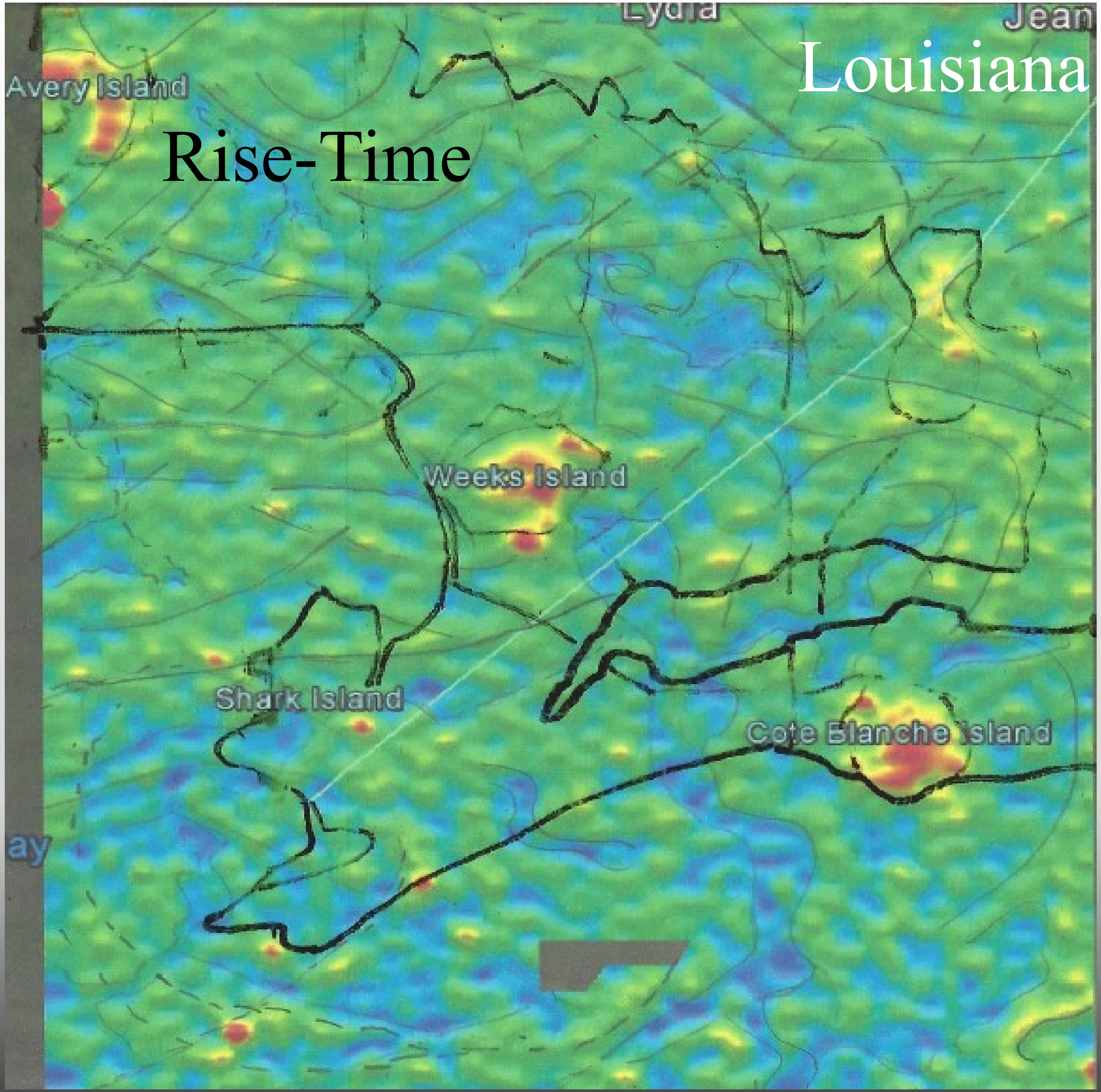
(56) **References Cited**

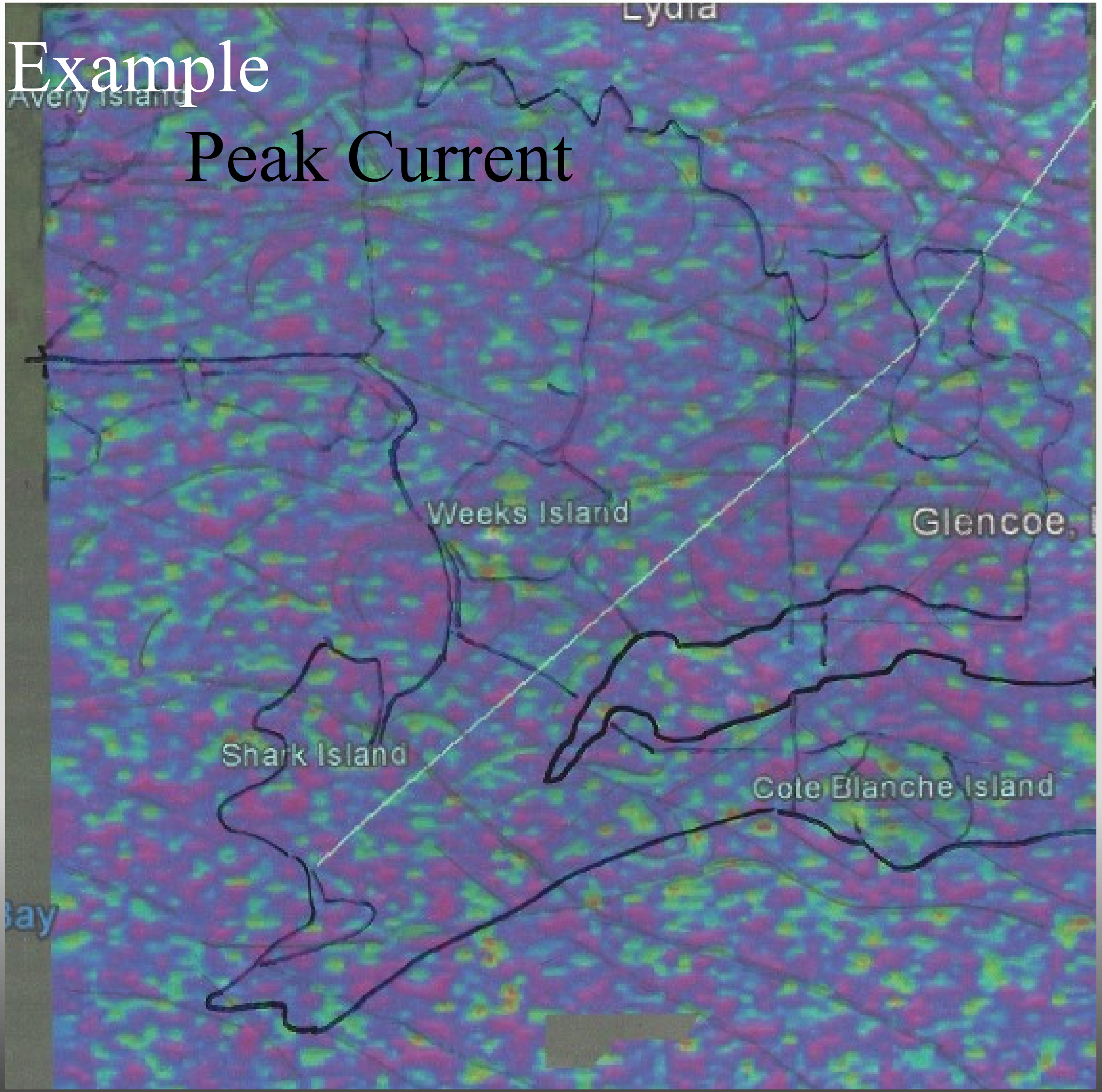
U.S. PATENT DOCUMENTS

Fig. 1



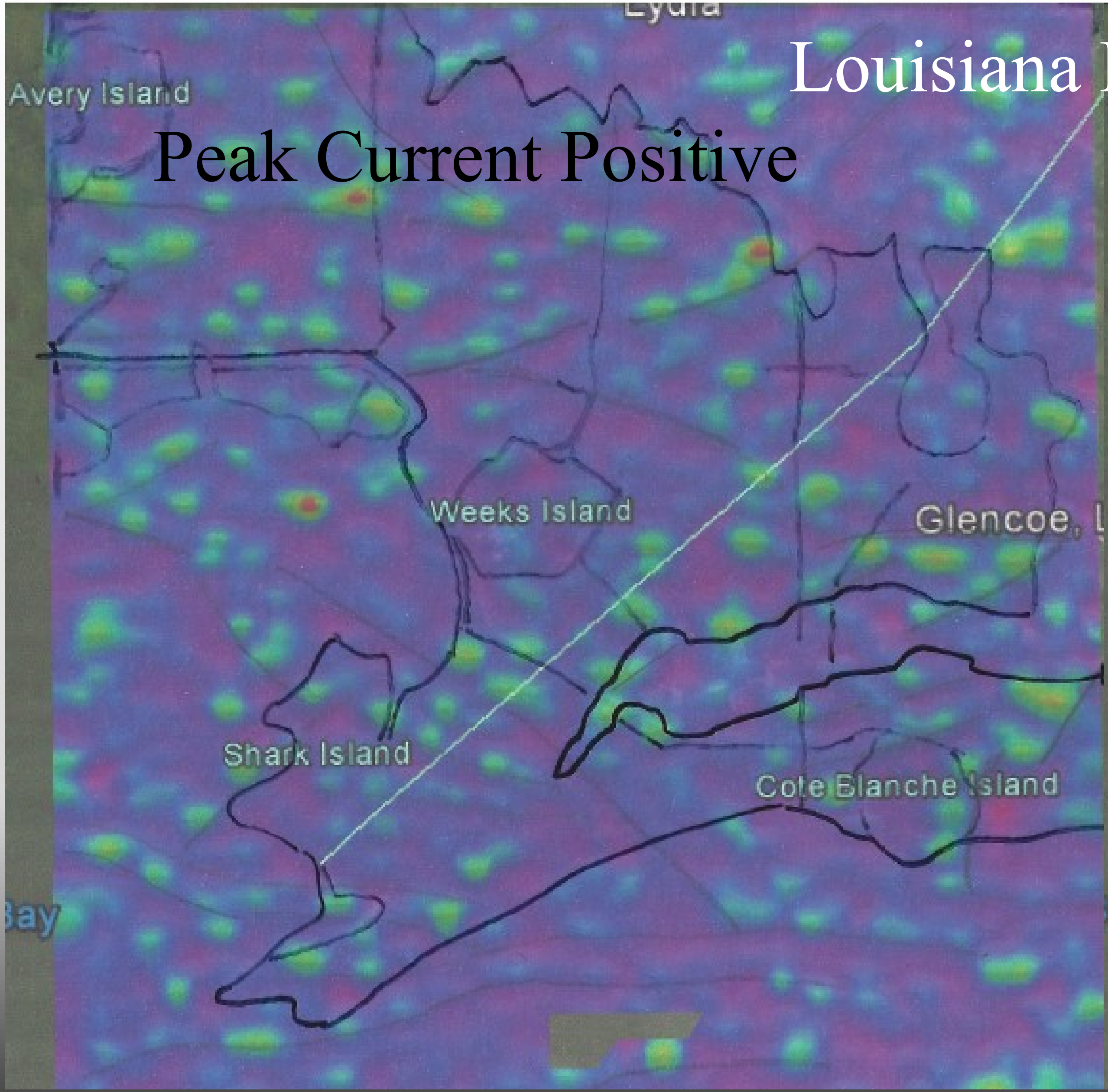
Louisiana Example



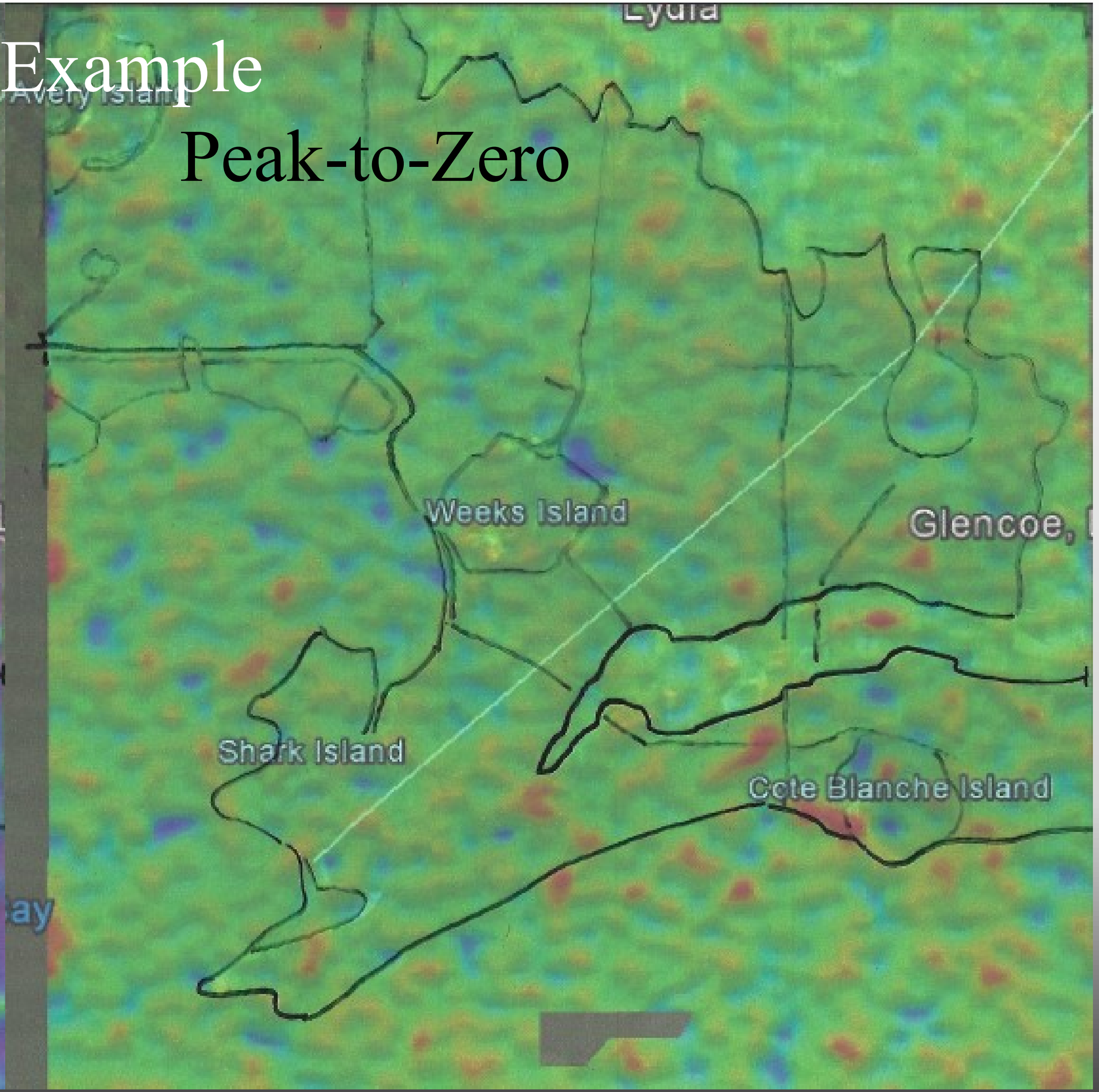


Louisiana Example

Peak Current Positive

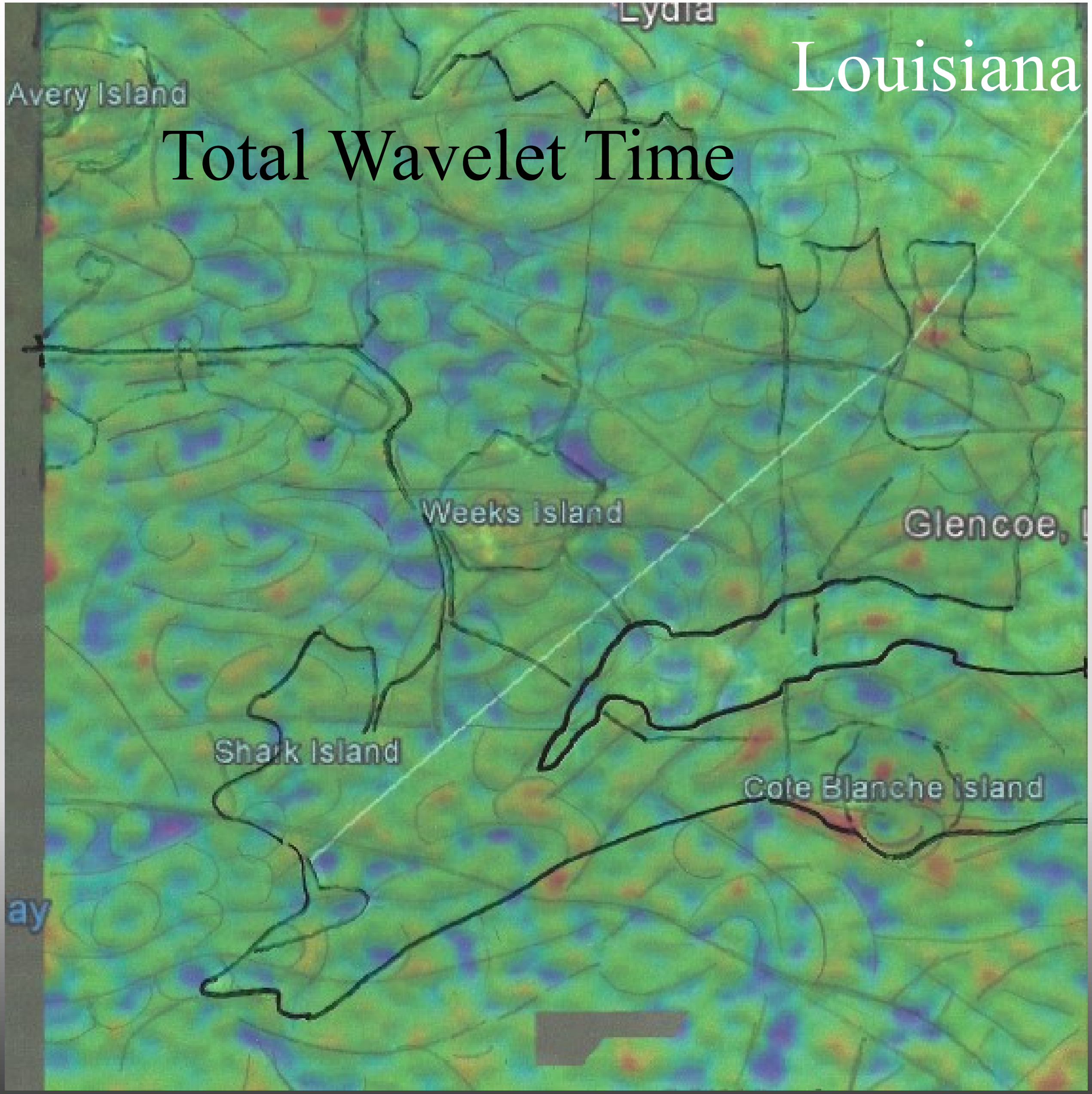


Peak-to-Zero

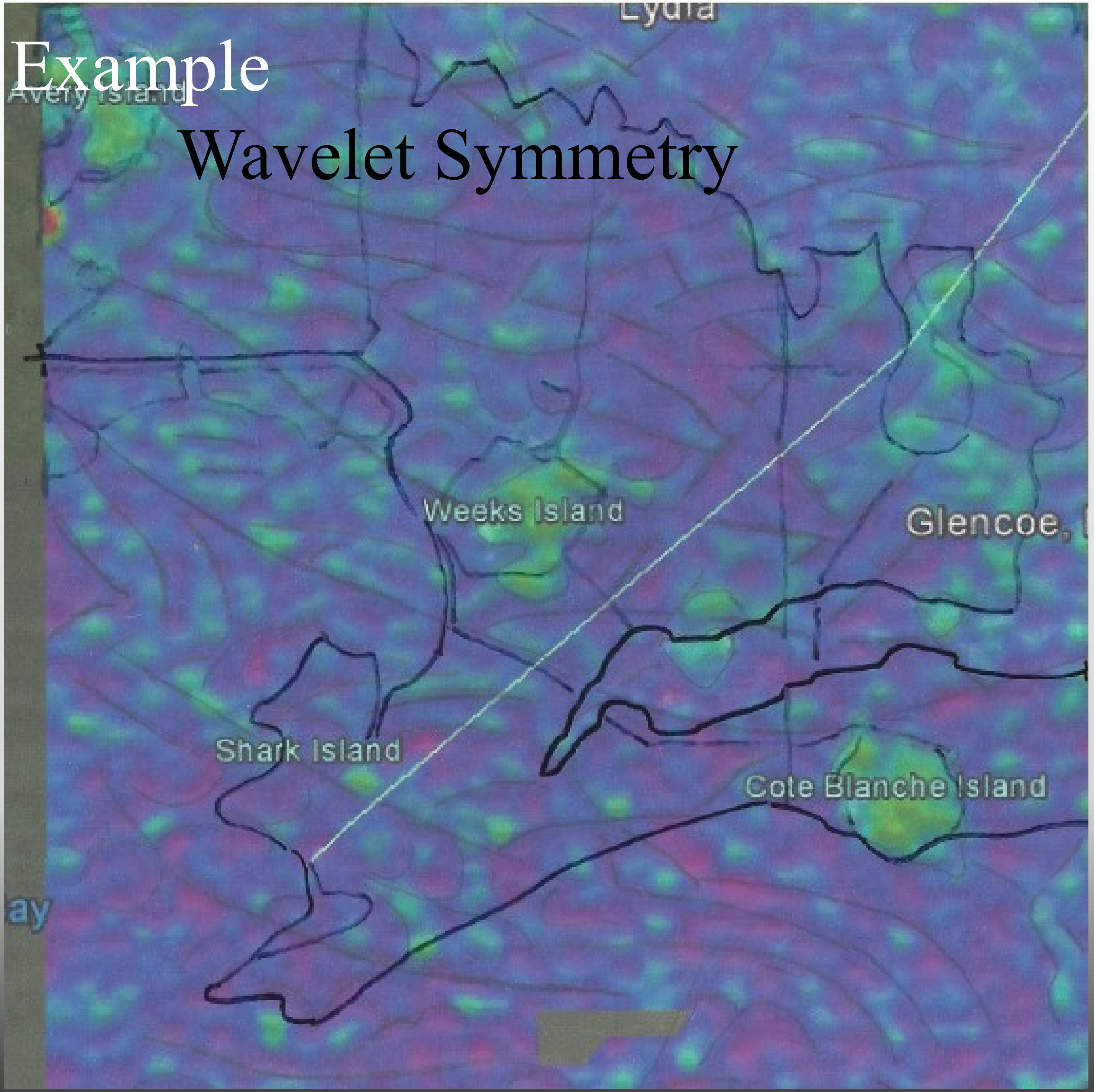


Louisiana Example

Total Wavelet Time

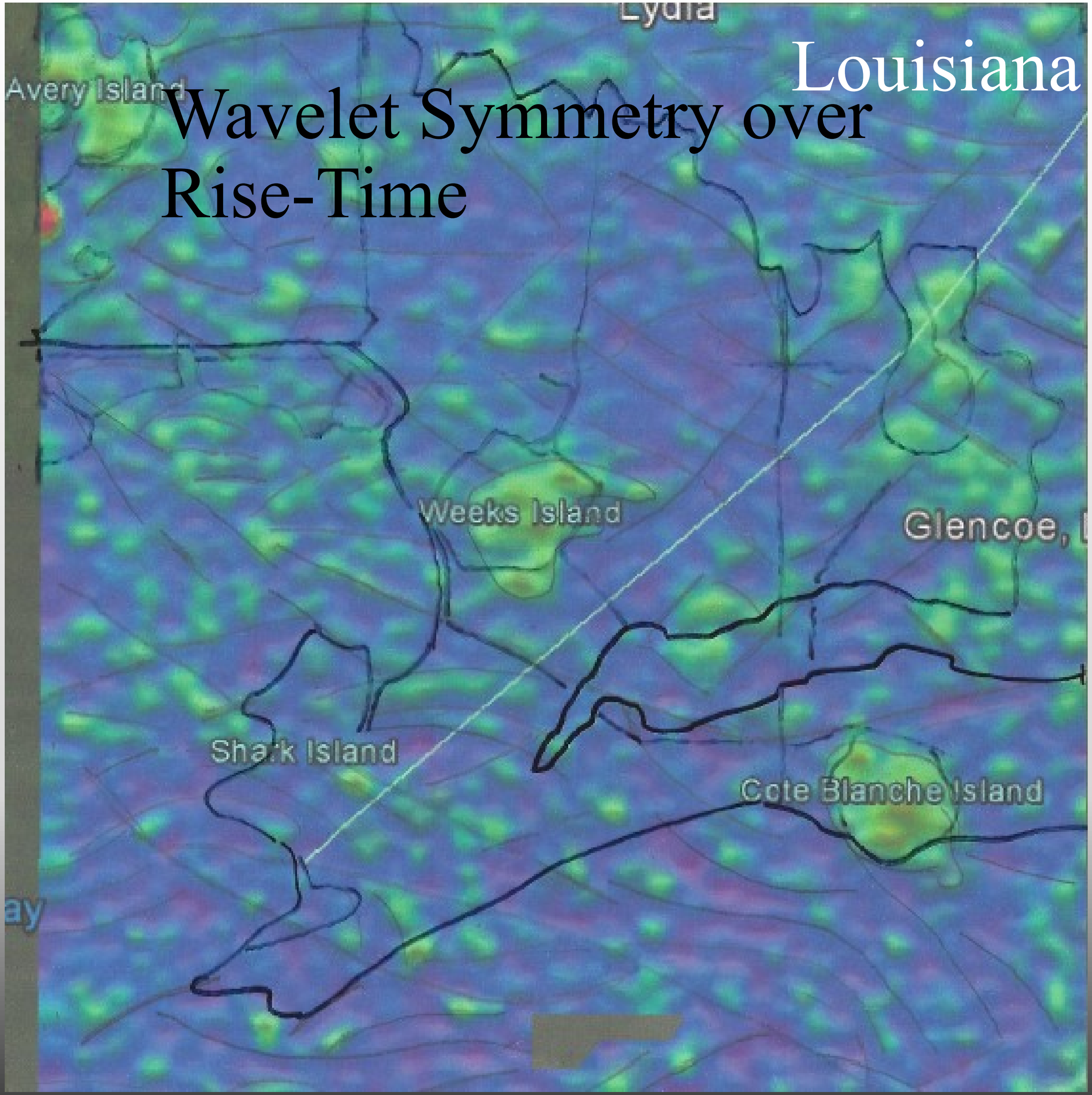


Wavelet Symmetry

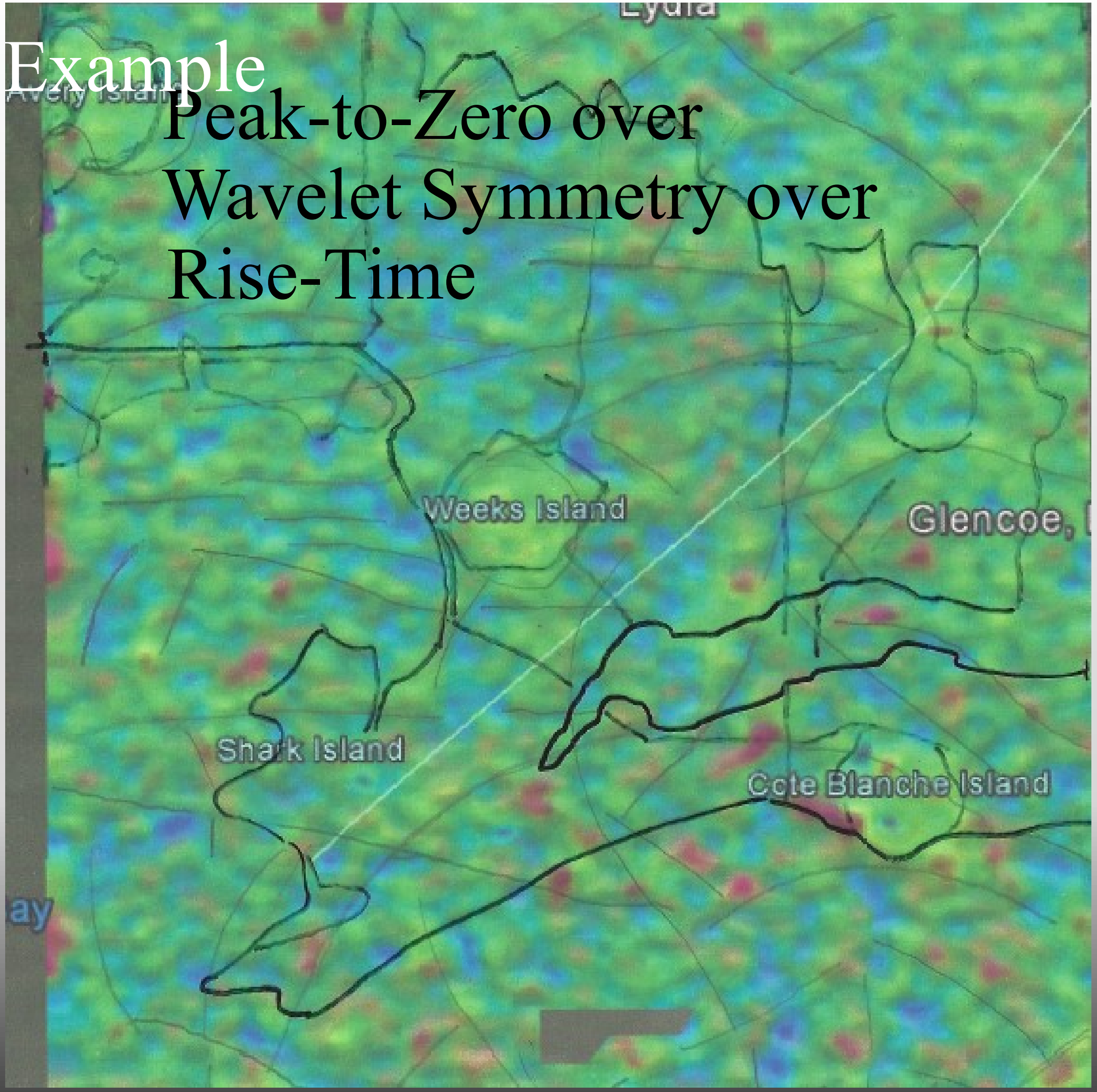


Louisiana Example

Wavelet Symmetry over Rise-Time

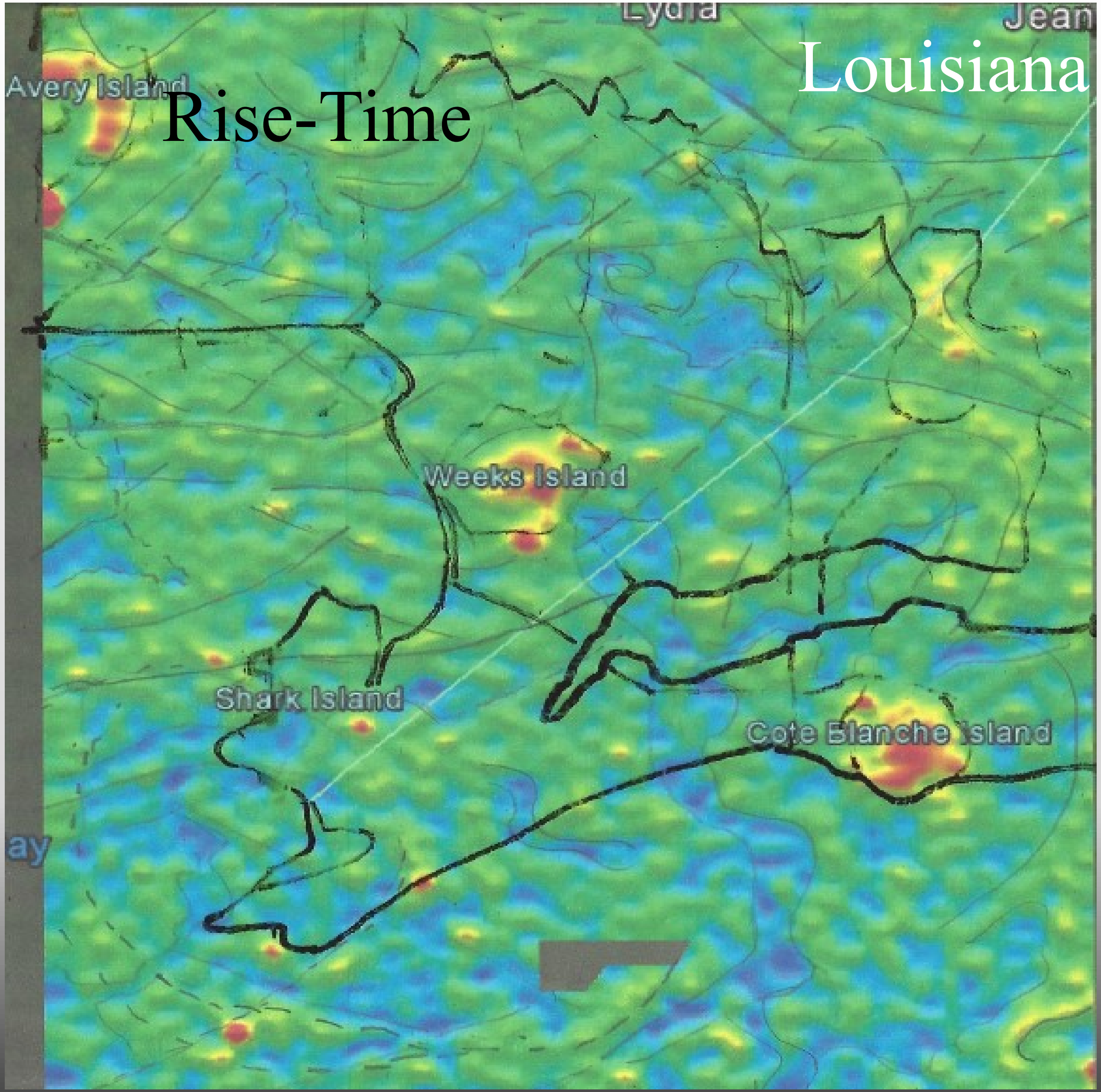


Peak-to-Zero over Wavelet Symmetry over Rise-Time



Louisiana Example

Rise-Time



Wavelet Symmetry over Density