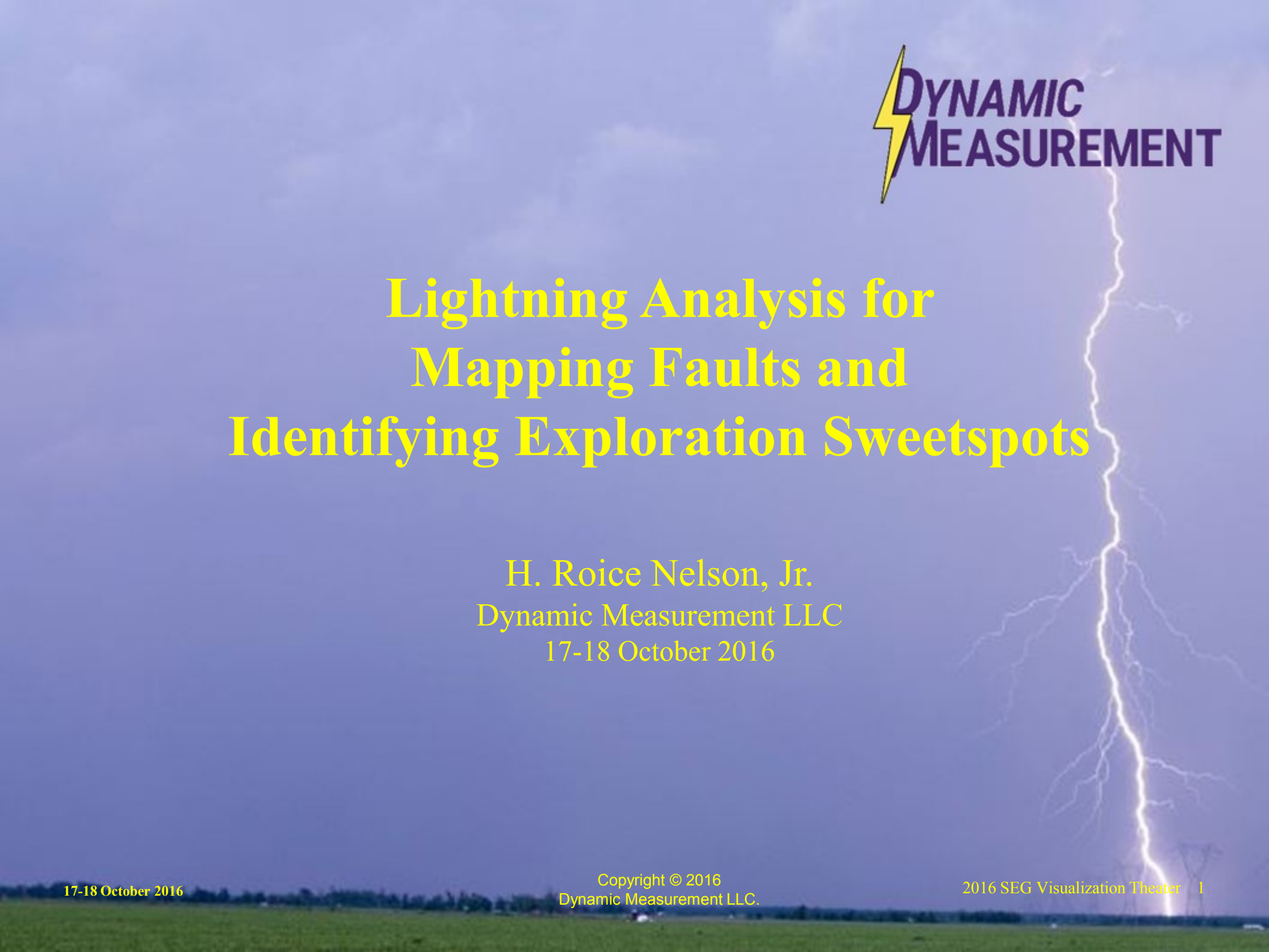
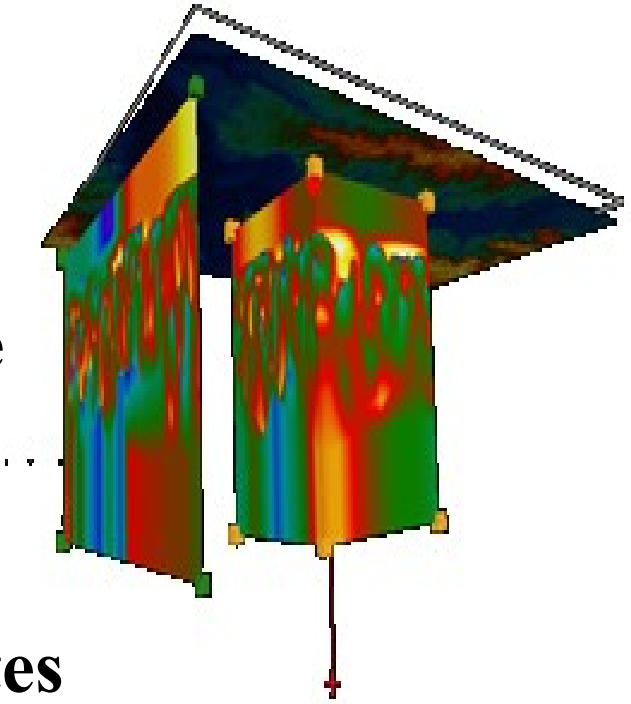


Lightning Analysis for Mapping Faults and Identifying Exploration Sweetspots

H. Roice Nelson, Jr.
Dynamic Measurement LLC
17-18 October 2016

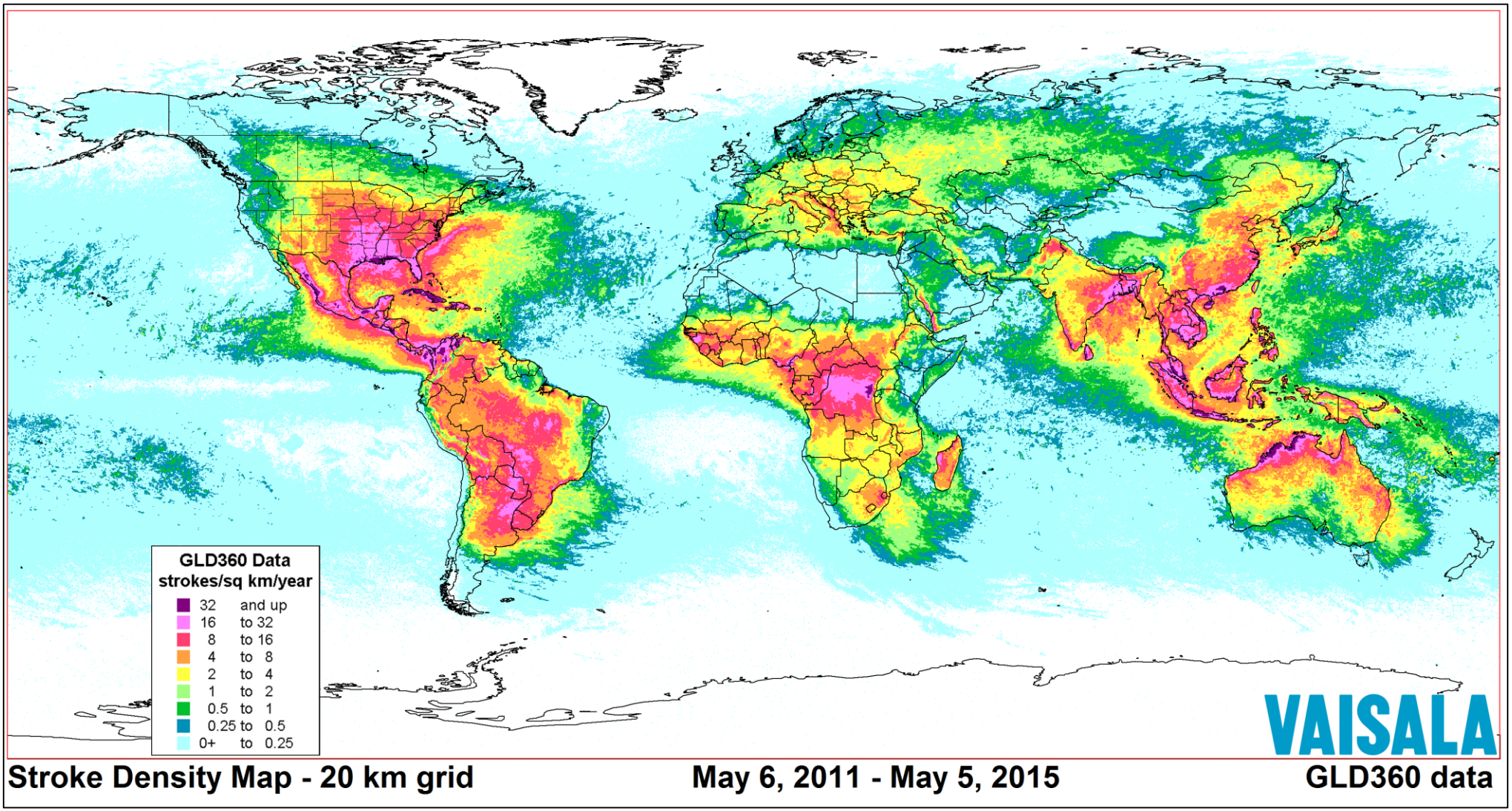
Presentation Outline



1. Lightning Occurs Everywhere
2. Lightning Database Analytics
3. Lightning Analysis & Attributes
4. Rock Property & Attribute Maps & Volumes
5. Arizona, Louisiana, Michigan, & Texas Examples

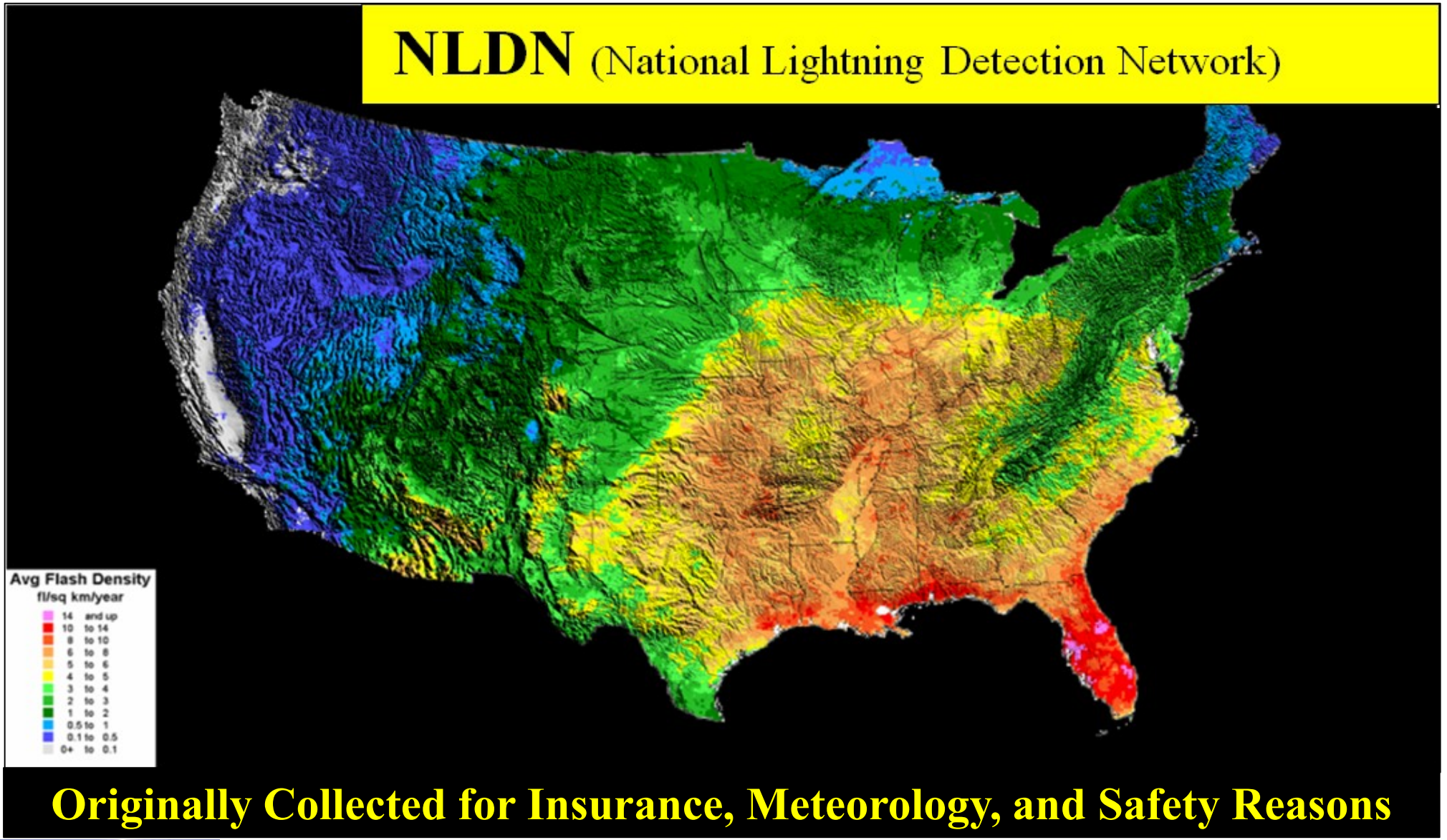
1. Lightning Occurs Everywhere

5+ Years of Data in GLD-360 Data Base



The U.S. has the most complete database

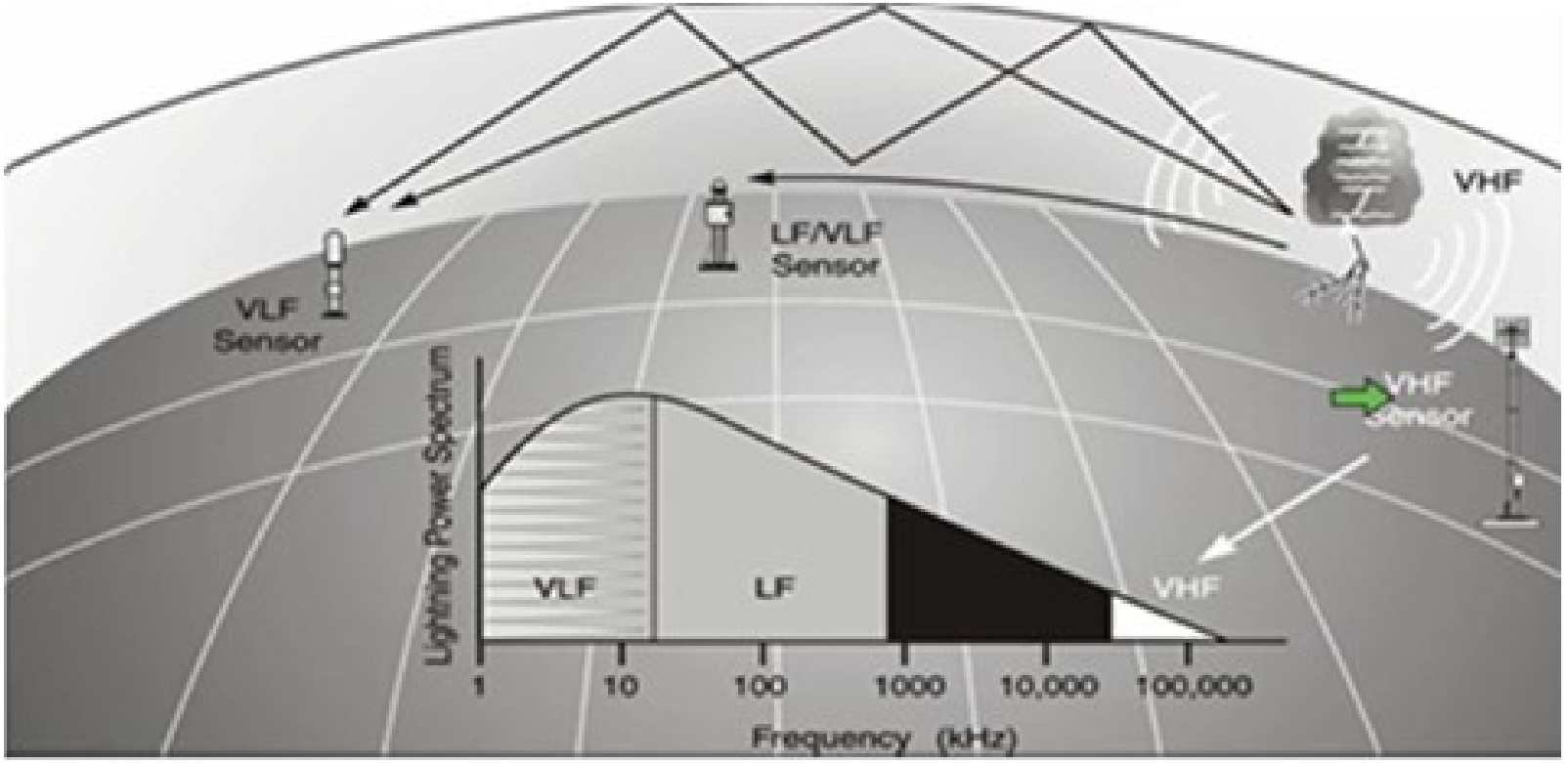
18+ Years of Data in the NLDN Data Base



Originally Collected for Insurance, Meteorology, and Safety Reasons

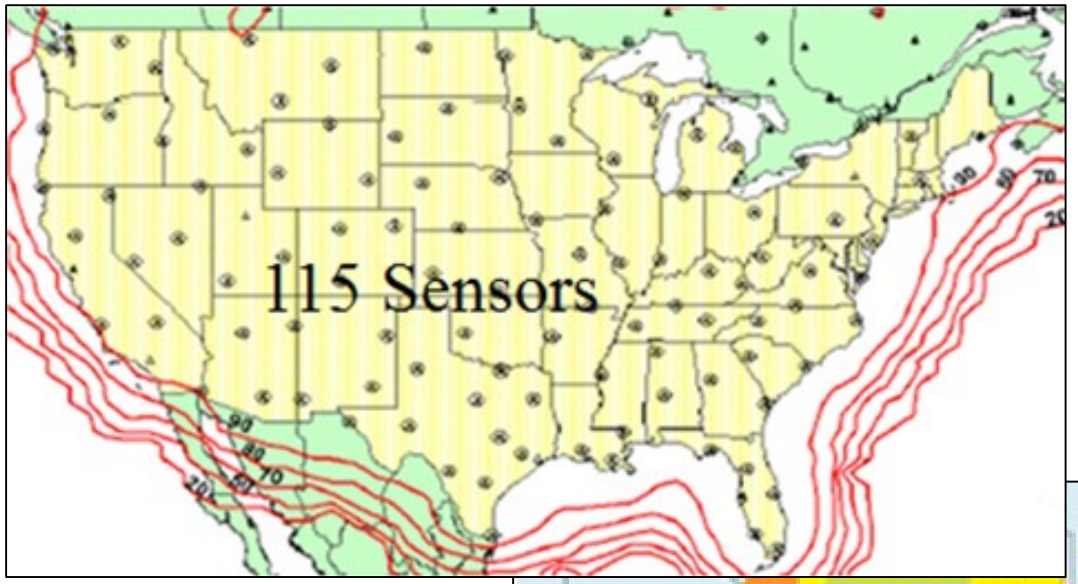
Sensors measure Direction to strike & Lightning Attributes

Strike Triangulated & Measurements Reconciled



Vaisala: Martin Murphy
2016 Webinar used with permission

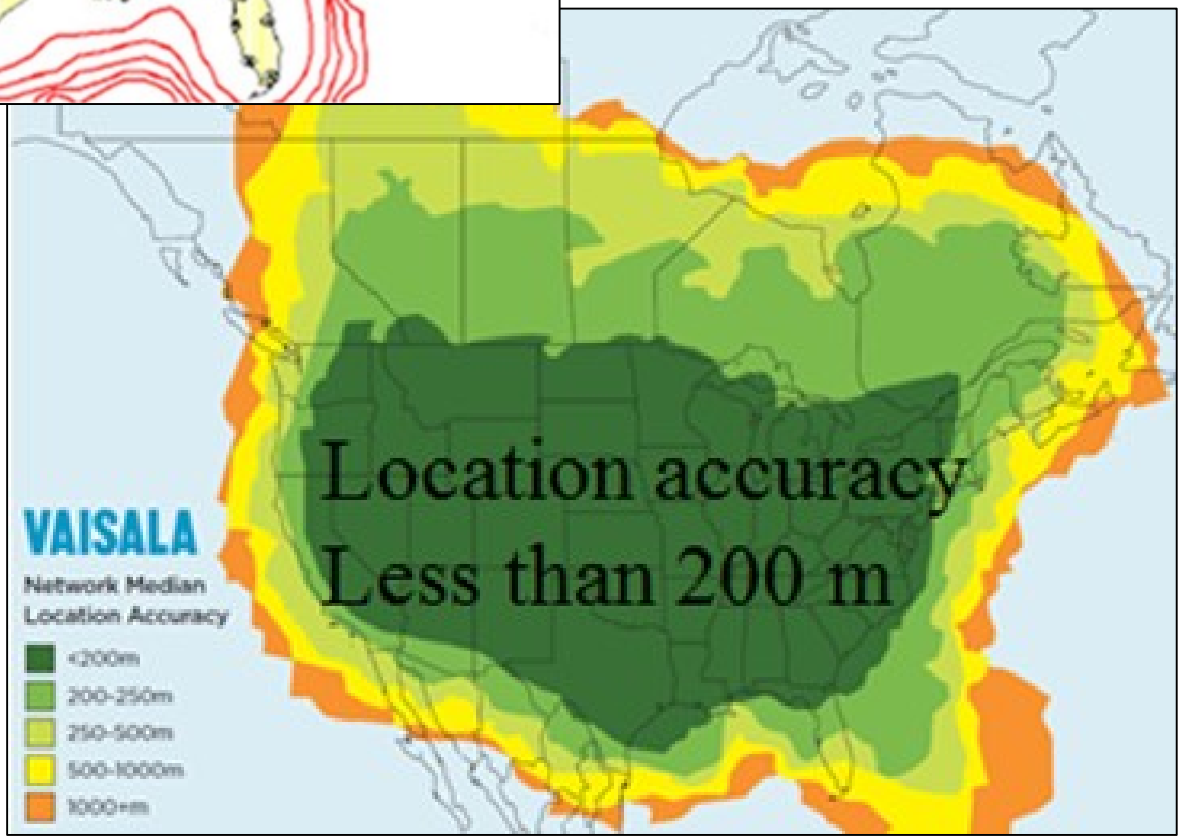
Vaisala's NLDN Lightning Detection Network



In Texas 12-24 Sensors record each Lightning Strike

Location Accuracy: 150-600 feet

Lineament Accuracy: 10-100 feet



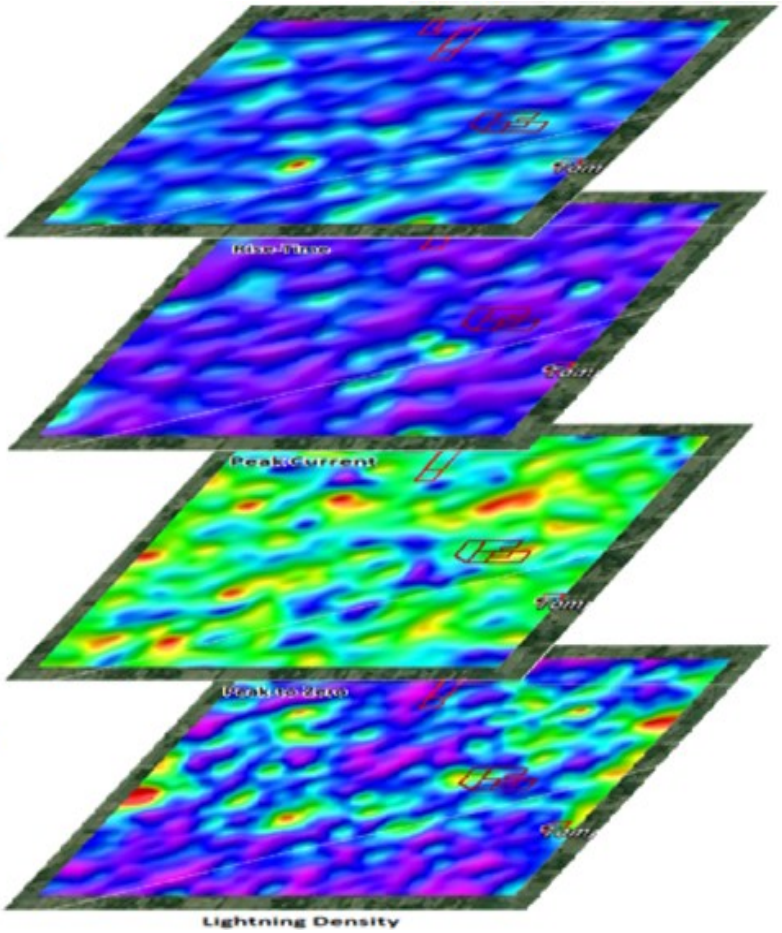
From 2016 Vaisala Webinar: Martin Murphy, used with permission

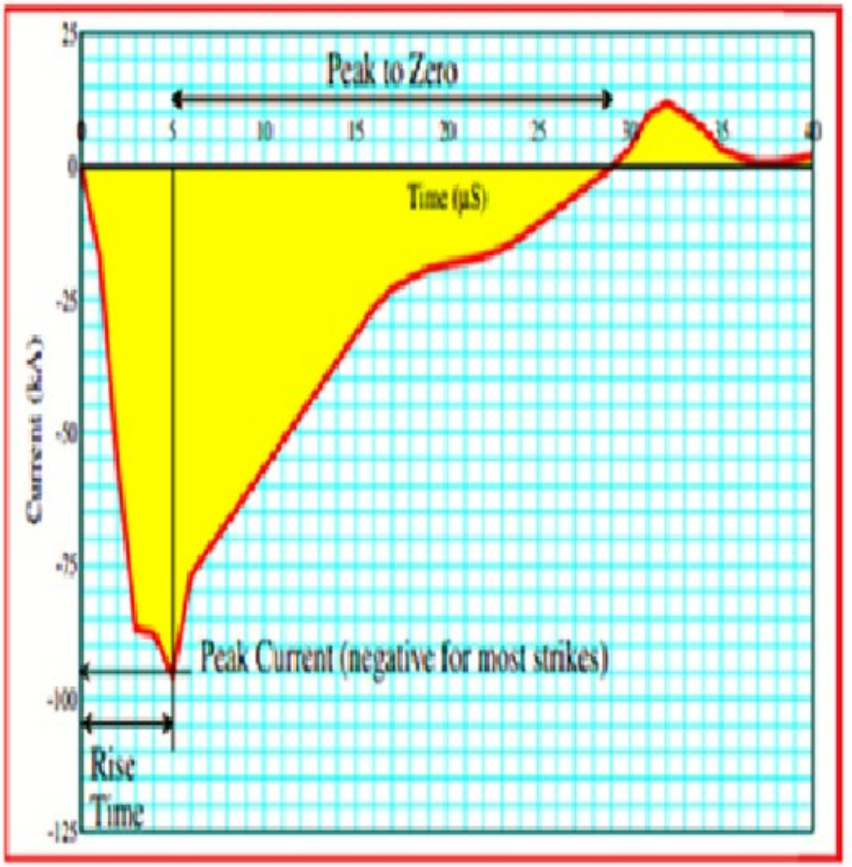
2. Lightning Database Analytics

- Typical projects have millions of lightning strikes.
- To date all projects have tied subsurface control.
- Attributes are measured or calculated for lightning strike locations, then contoured or gridded.
- Lightning strike density and attribute values cluster, and these clusters are somewhat consistent over time.
- Lineaments, like fault scarps, have been mapped with 30 foot horizontal location accuracy.

Lightning Measurements

- Location
- Time and Duratic
- Rise Time
- Peak Current
- Polarity
- Peak-to-Zero
- Density
- Major/Minor Axe
- Chi-Squared

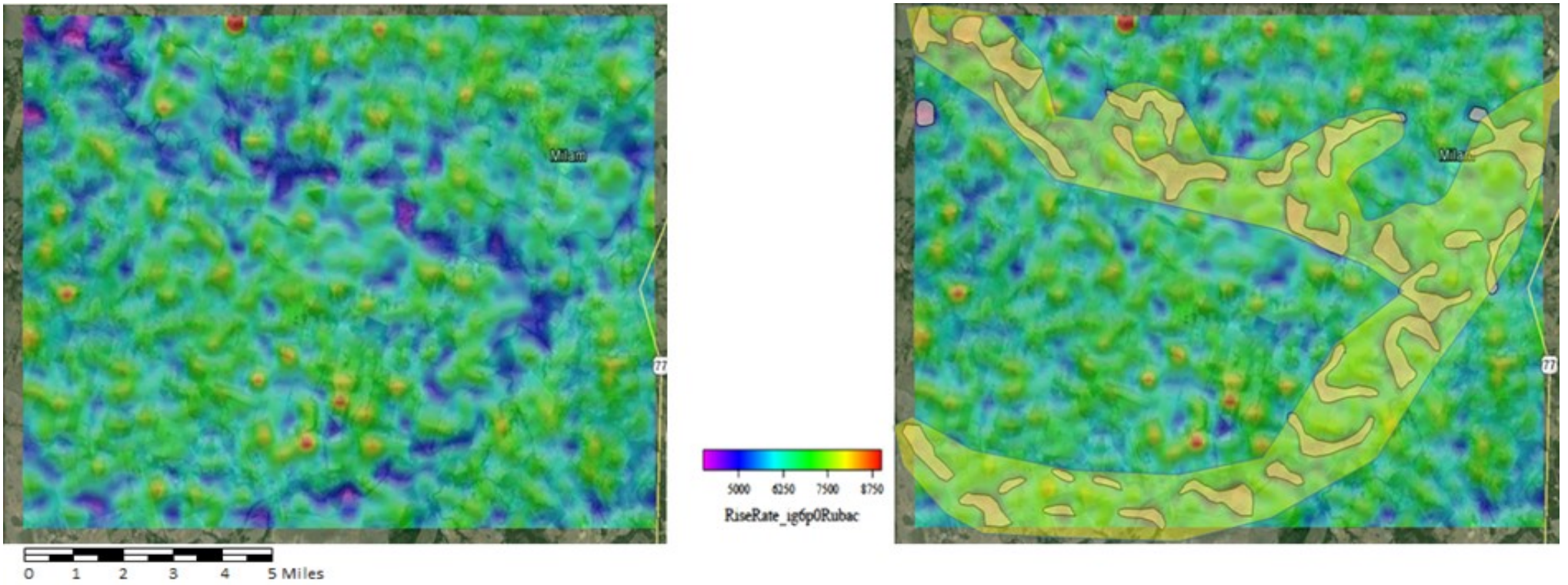




- Other attributes calculated from these measurements.
- The time of the lightning strike is correlated with solar and lunar tides.
- Measurements separated by time.

3. Lightning Analysis & Attributes

1. **Analysis area selected.**
2. **Patented and Patent-Pending Processes produce maps and volumes of derived rock properties and lightning attributes.**
3. **Existing geology and geophysics integrated with new data.**

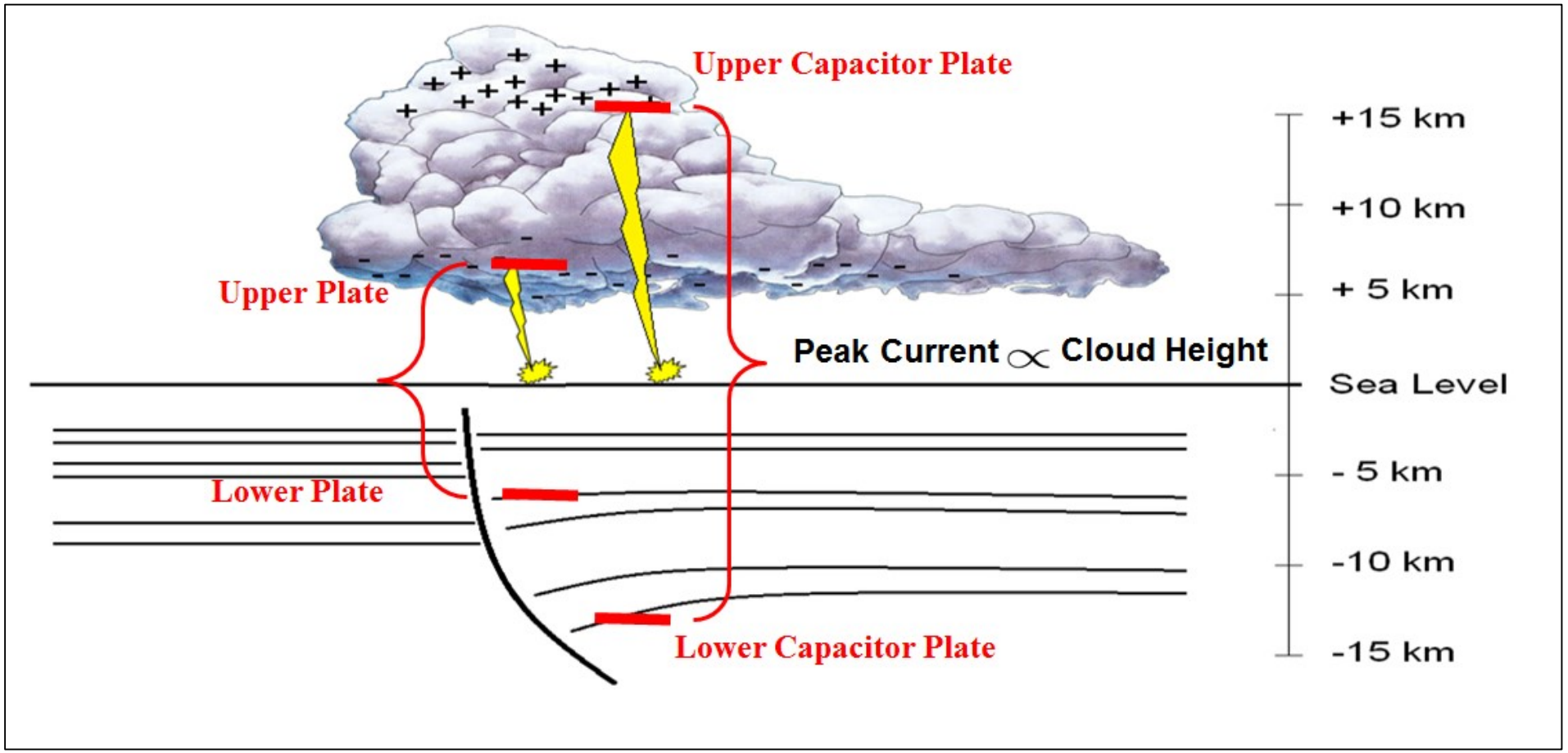


Lightning Attribute: Rate of Rise-Time – Milam County, Texas

4. Rock Property & Attribute Maps & Volumes

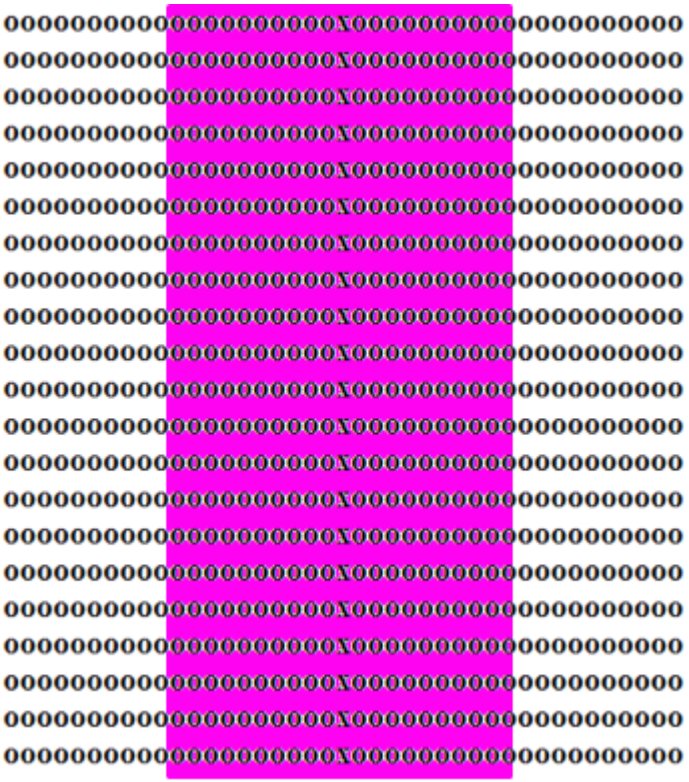
Key Assumptions:

1. Lightning occurs when there is sufficient charge to bridge the capacitor.
2. Lightning is affected by geology to a depth proportional to cloud height, as derived from Peak Current



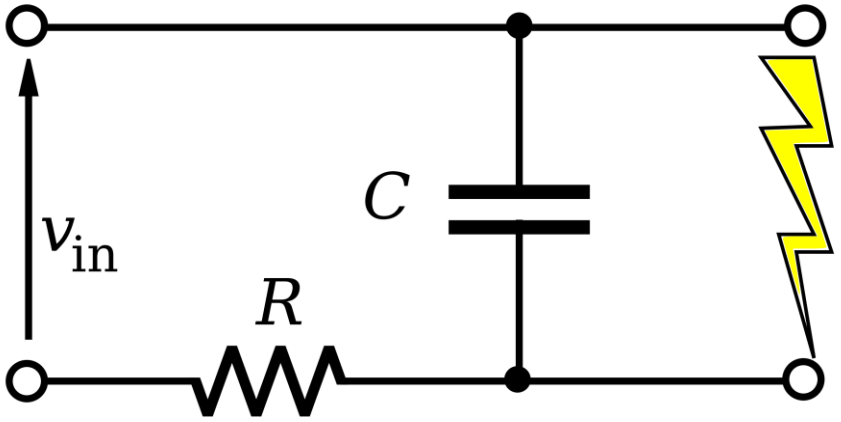
Compare 3-D Seismic Acquisition to Lightning Strike Database Population

1 column of sources with hundreds of receivers creates the purple CMP data below:



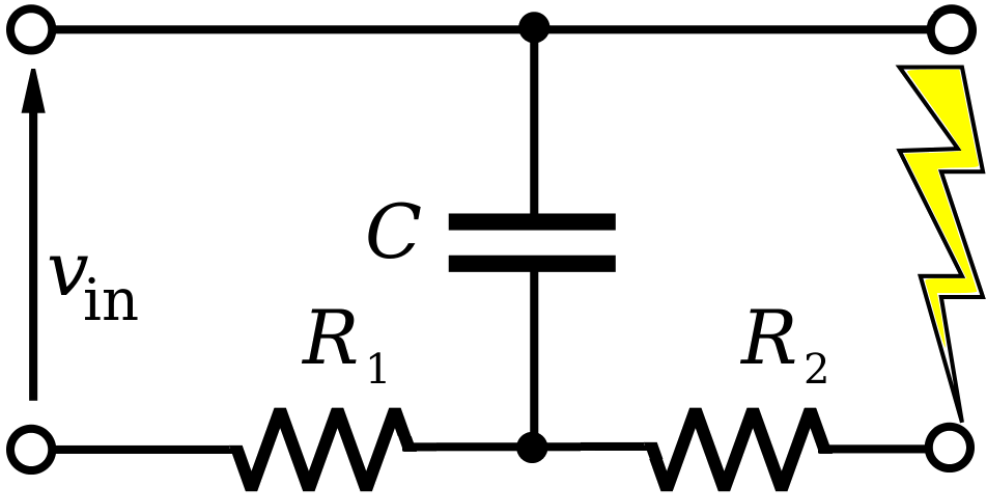
12-26 sensors, up to hundreds of miles away, captures a data point for each lightning strike, as above:

Relaxation Oscillator Physics and Lightning (a giant neon tube)

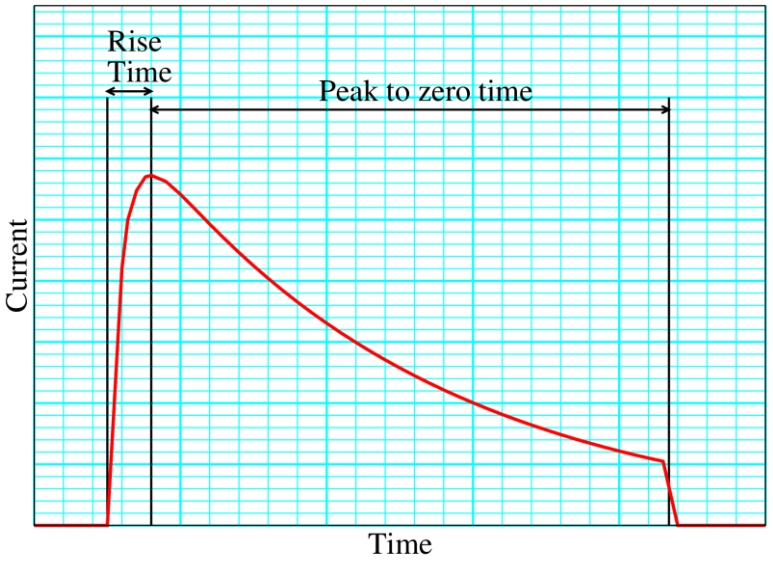


- The atmospheric capacitor is like a relaxation oscillator
- Just an additional resistance (R_2) limiting the current

- R_2 is the resistance between the lightning strike point and the bottom plate of the capacitor

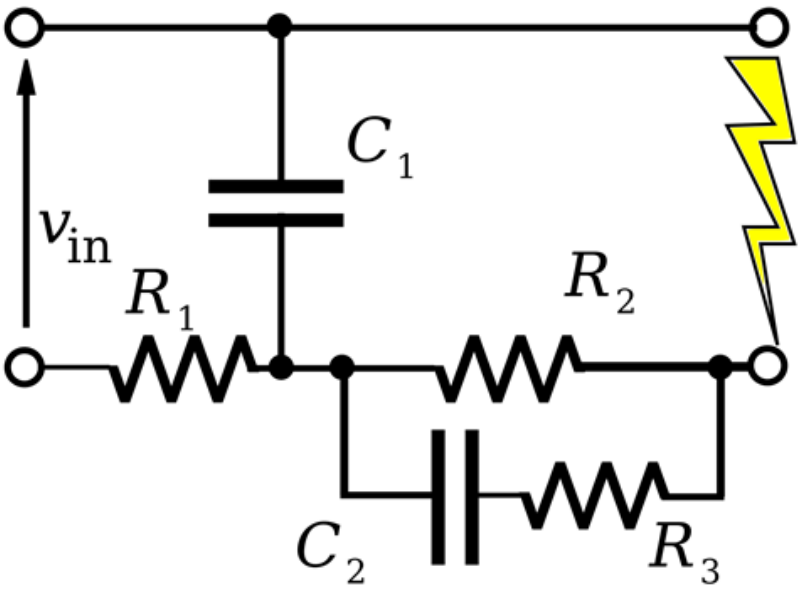


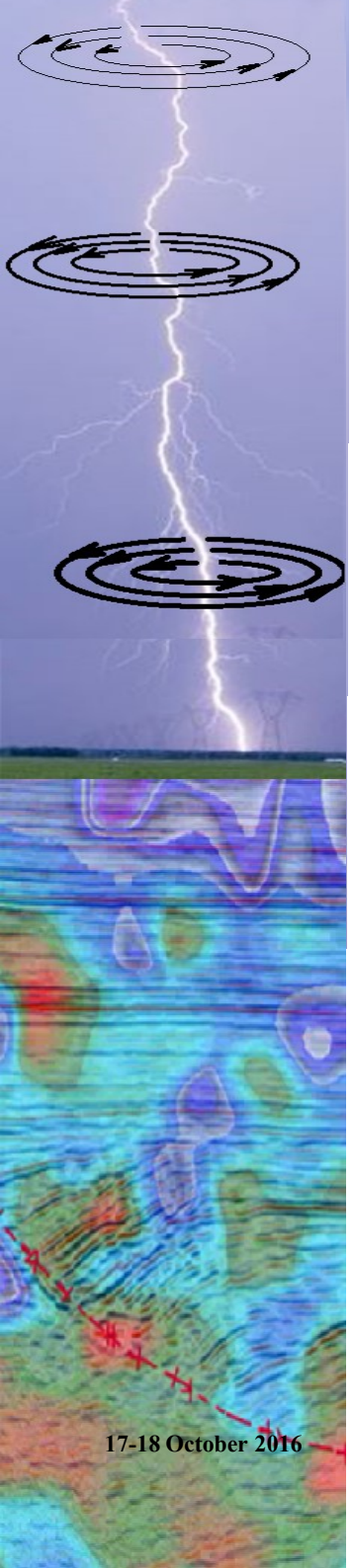
Lightning and the Induced Polarization Effect



- 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

- By treating this steep onset as charging a capacitor (C2) through a resistor (R3), an apparent capacitance can be calculated.
- From the apparent capacitance a value for average permittivity can be calculated





Skin Depth is NOT the Controlling Factor

Charging Telluric Currents:

Lightning strikes are passive energy pulses, and contain all frequencies.

The skin effect of the high frequency information recorded in the ~50 microsecond total wavelet time does not control the depth electrical energy interacts with telluric currents.

Interval of Interest:

Traditional lightning does not occur in clouds less than ~1,500 feet in height, nor for clouds higher than ~30,000 feet.

The depth interval where lightning volumes are useful is typically from 1,500-30,000 feet.

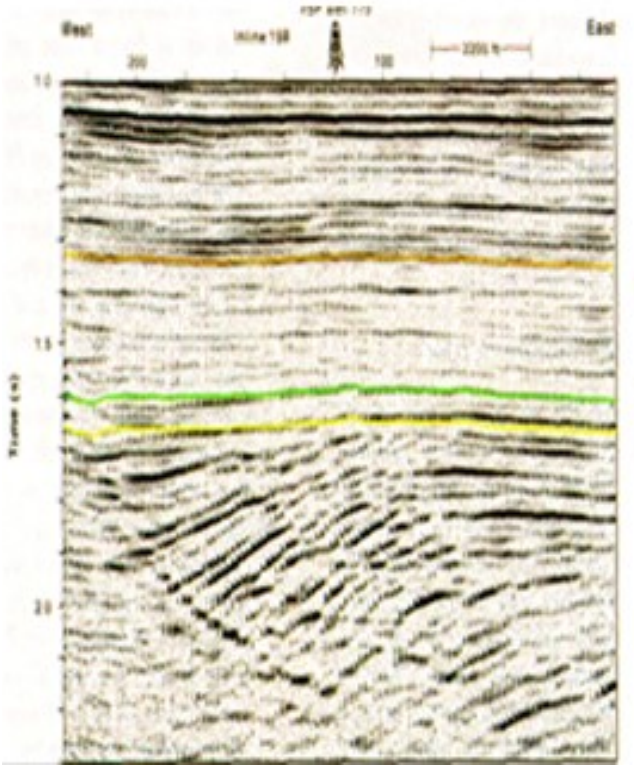
Data Distribution:

Volumes converted to SEG-Y files for workstations.

Volumes interpolated to match aeromagnetic or 3-D seismic surveys.

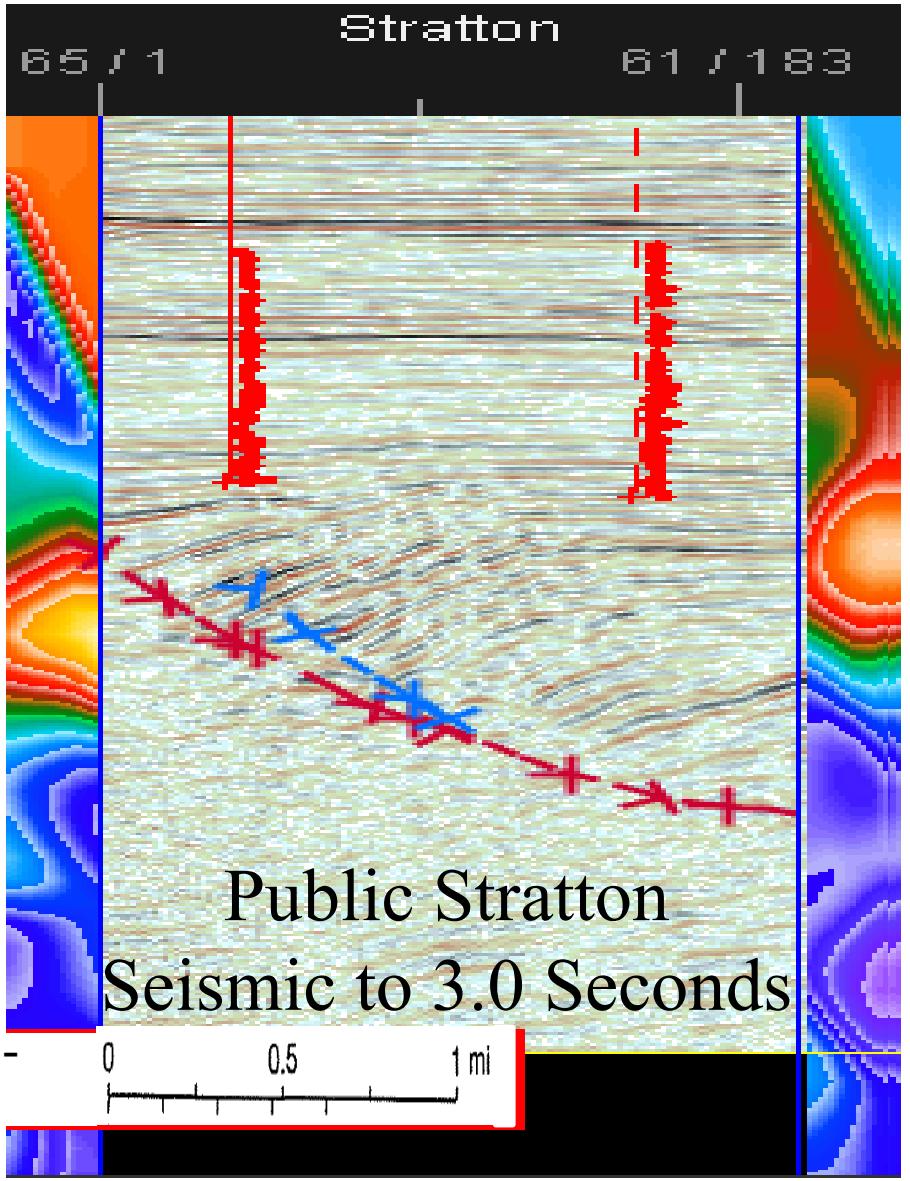
Resulting rock property or lightning attribute volumes are overlaid on the seismic or other geologic cross-sections like a velocity volume.

Stratton Seismic Sections, South Texas



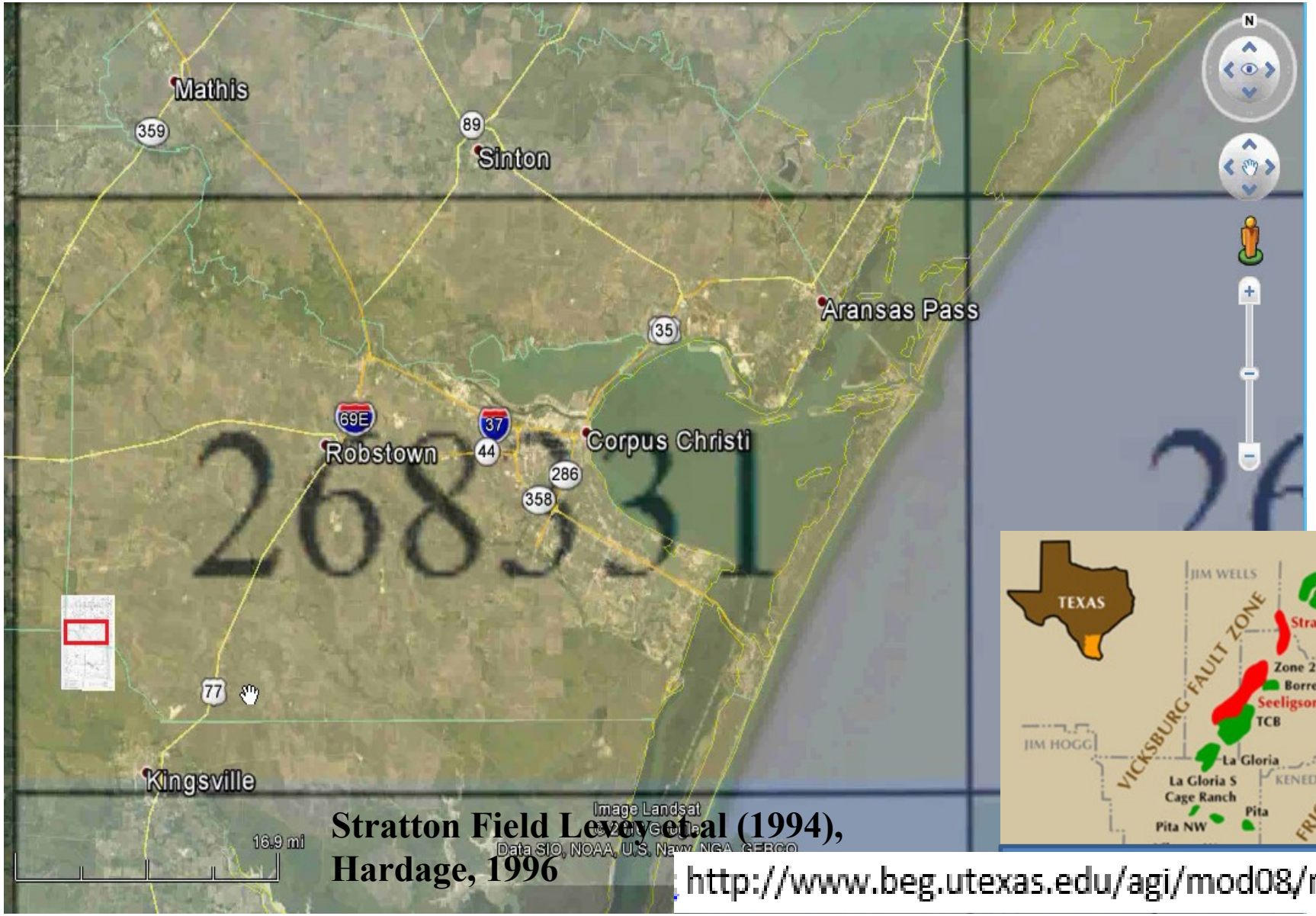
Frio Horizons
Fluvial – Deltaic
Sands

Published BEG Stratton
Data to 2.3 seconds
(Hardage, 1986)



Public Stratton
Seismic to 3.0 Seconds

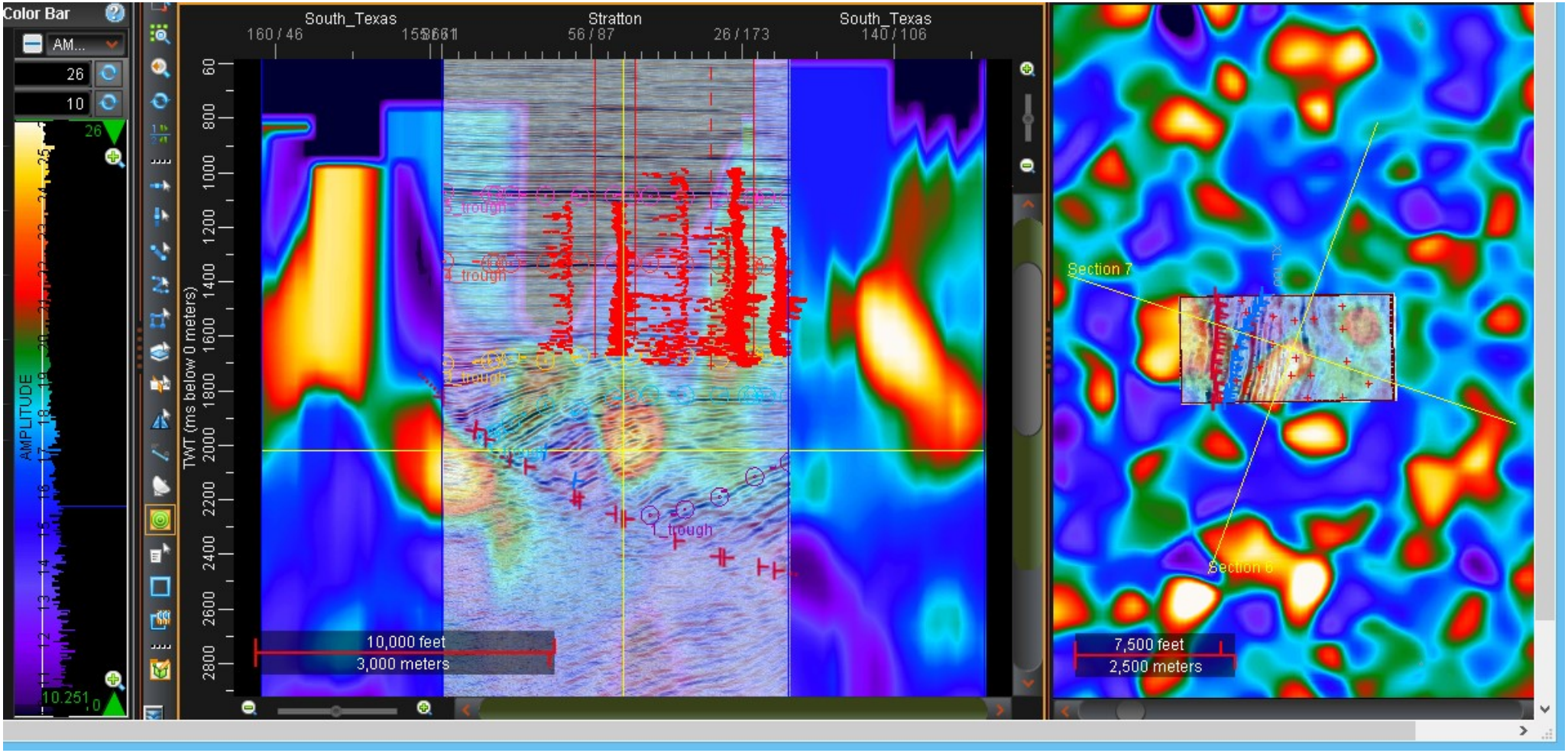
Study Area around Corpus Christi



Stratton Field Level et al (1994), Hardage, 1996

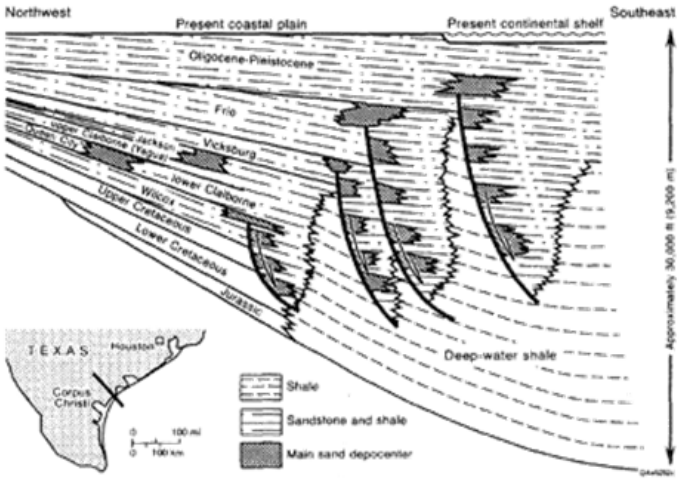
http://www.beg.utexas.edu/agi/mod08/m08-kb02.htm

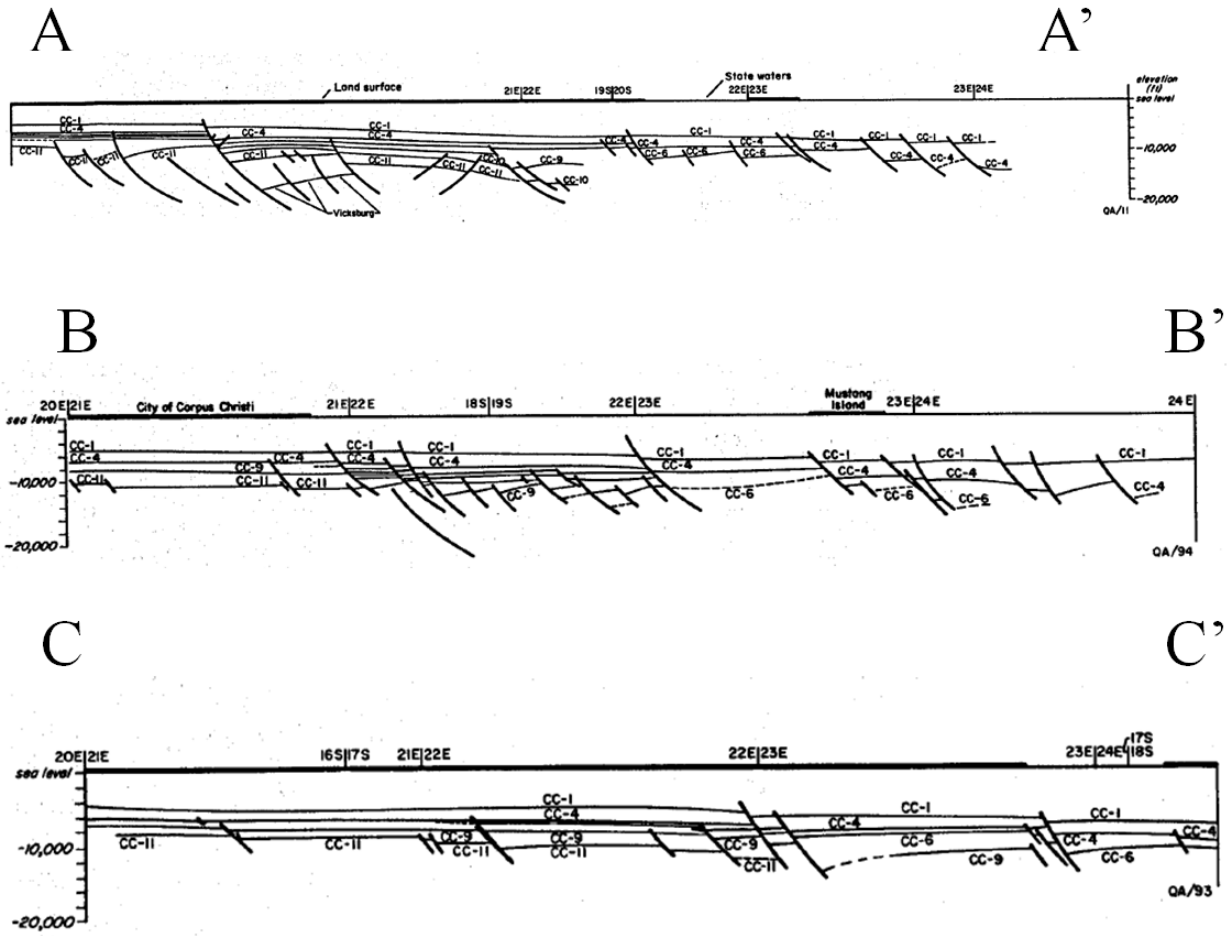
Stratton Apparent Resistivity Sections



Working on calibrating depth and calculated vs. measured resistivity

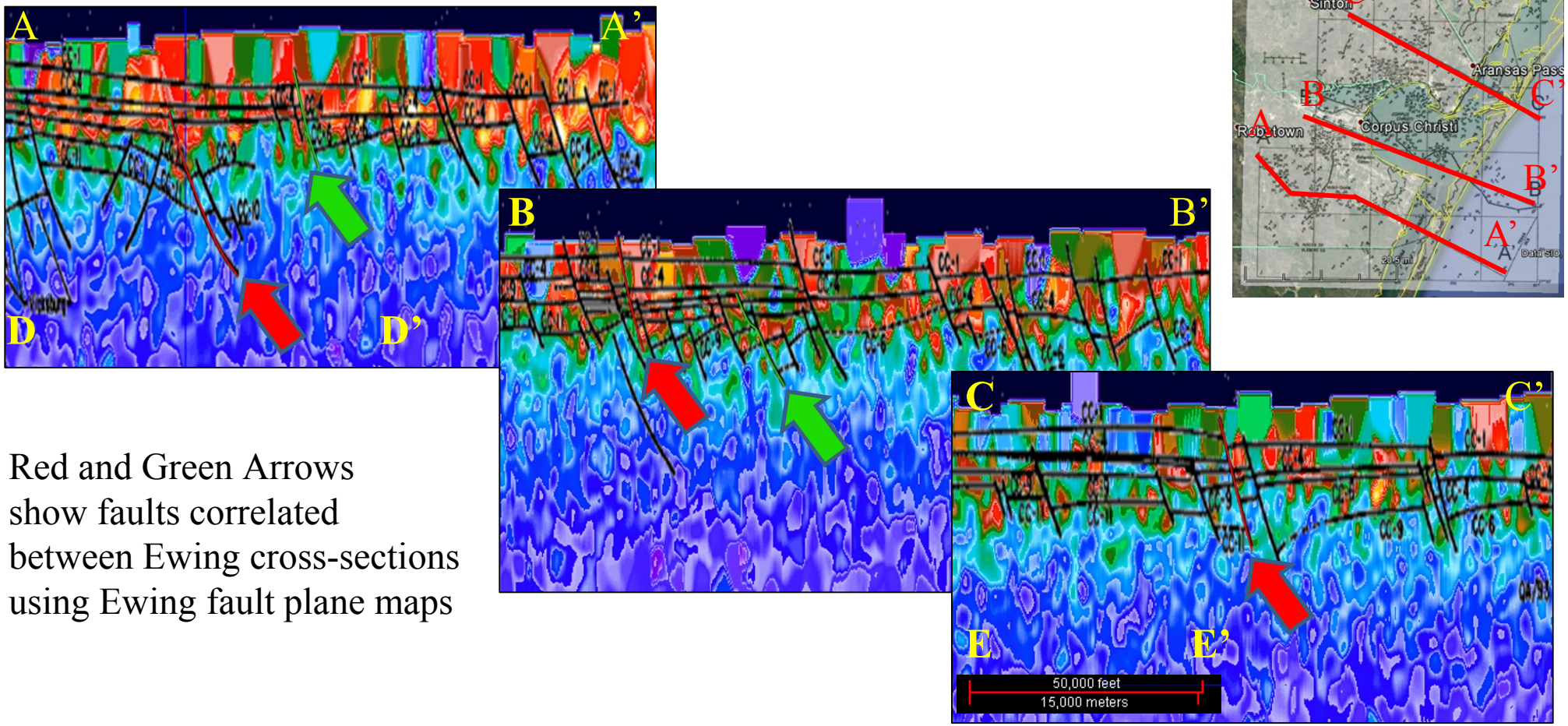
Study Area - Geology and Structure Corpus Christi from Ewing (1986)





From Levey, et al,1994
Bebout and others,1982

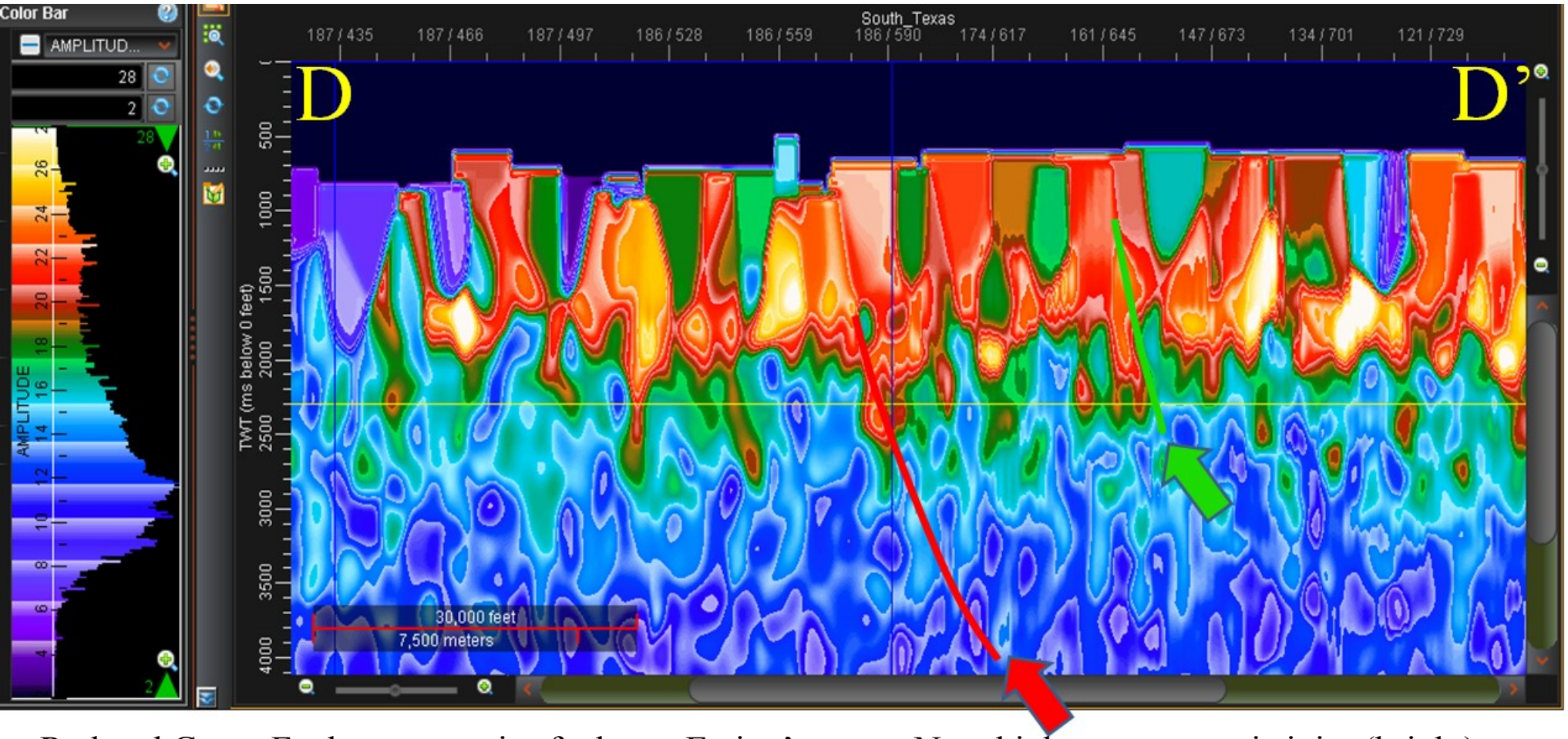
2016 Lightning Derived Resistivity Cross-Sections Match Geology on 1986 Ewing Interpretation Overlay



Red and Green Arrows show faults correlated between Ewing cross-sections using Ewing fault plane maps

(Fault Overlays Ewing 1986)

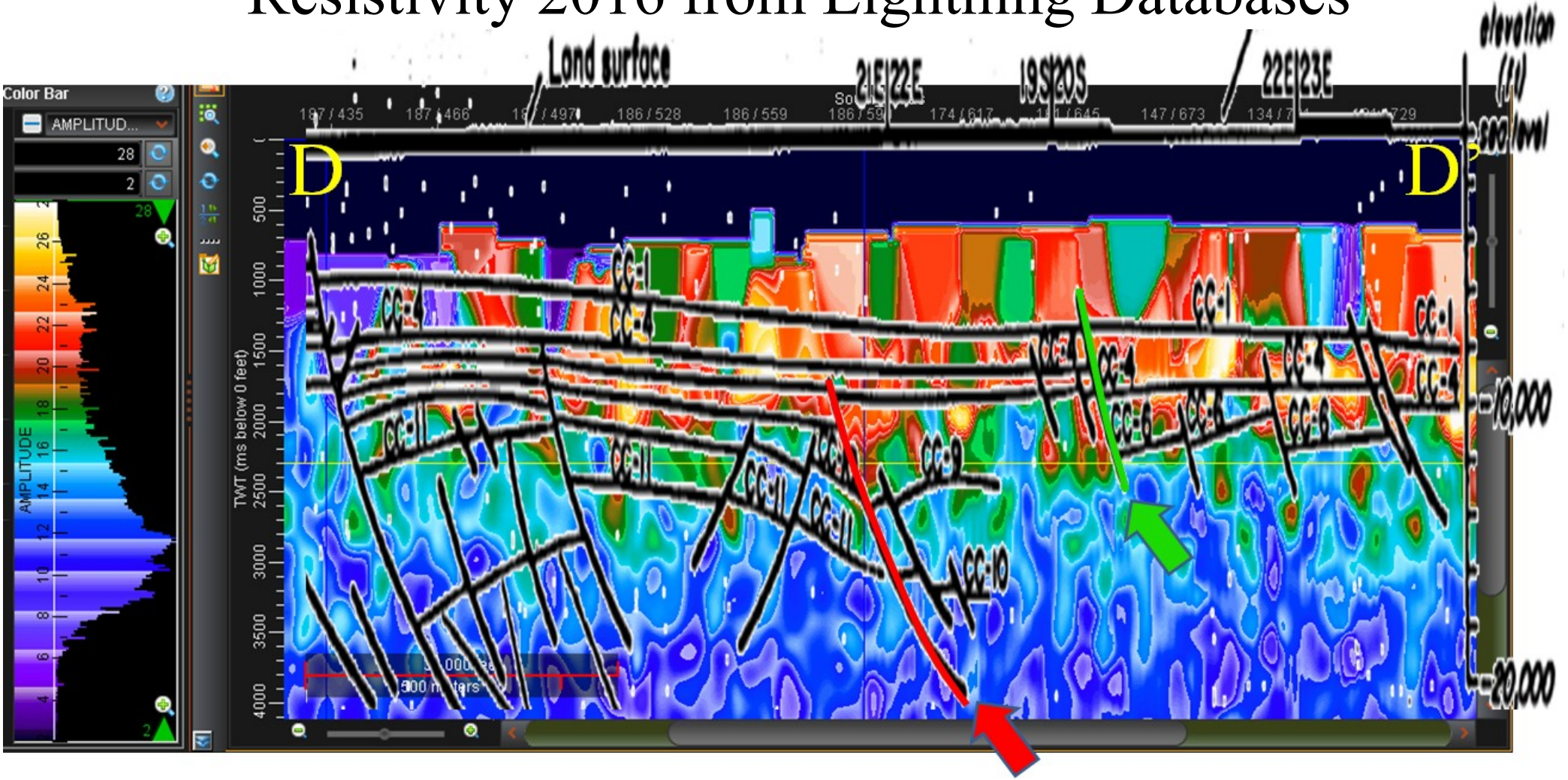
D-D' Close-Up on Graben on A-A' without overlay



Red and Green Faults were major faults on Ewing's maps. Note high apparent resistivity (bright) appear to have plumes above these faults.

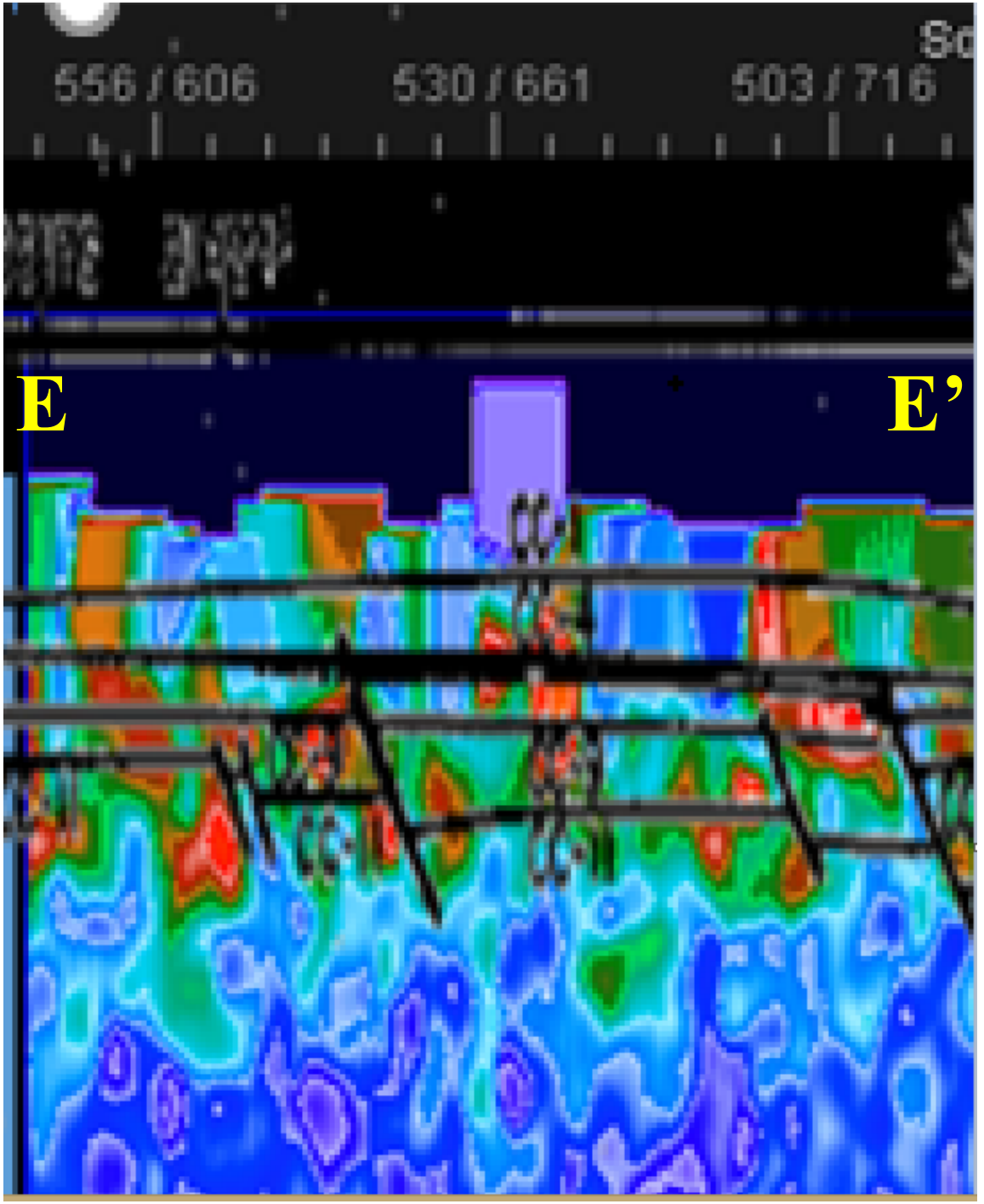
D-D’ Close-Up on Graben to the west

Interpretation 1986 by Tom Ewing, Apparent Resistivity 2016 from Lightning Databases



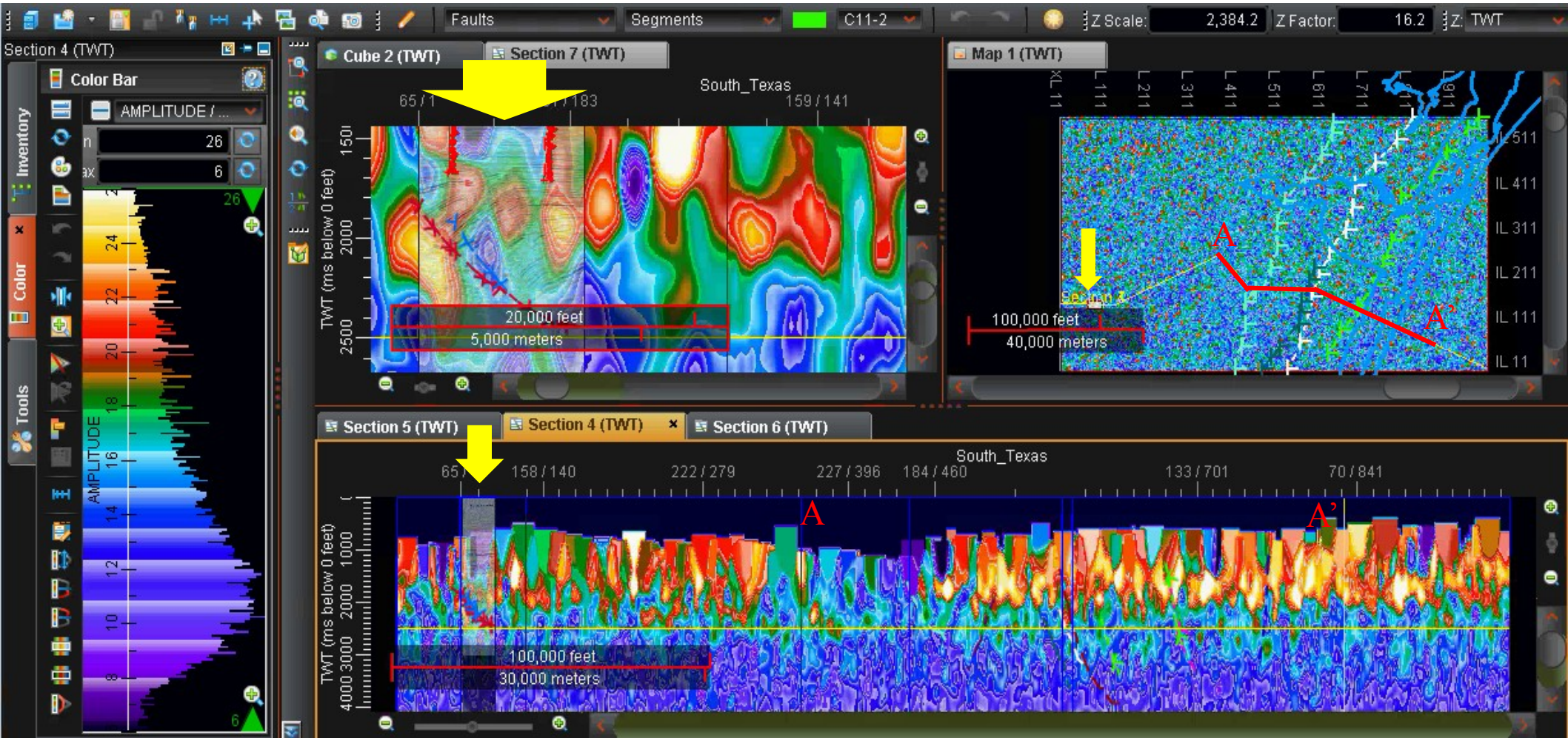
Note: interpretation by Tom Ewing in 1986. The resistivity section calculated from lightning in 2016. Co-located sections show breaks where faults were interpreted. There are resistivity plumes tied to faults.

E-E’ on the Northwest End of Ewing’s C-C’



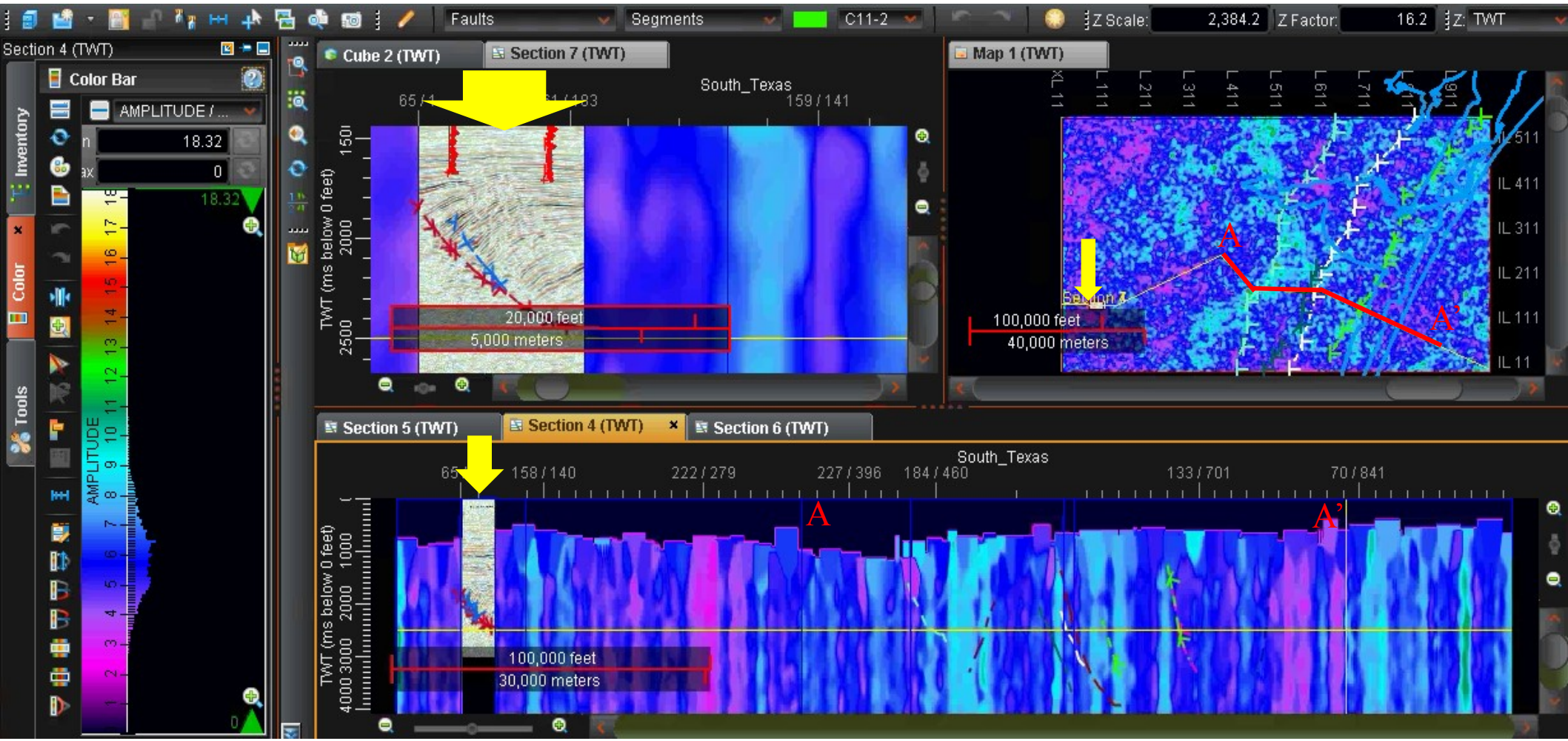
Note offsets in adjacent “Packages” of Higher Values of Apparent Resistivity

Apparent Resistivity Extension of Ewing (1986) A-A' through Stratton seismic data



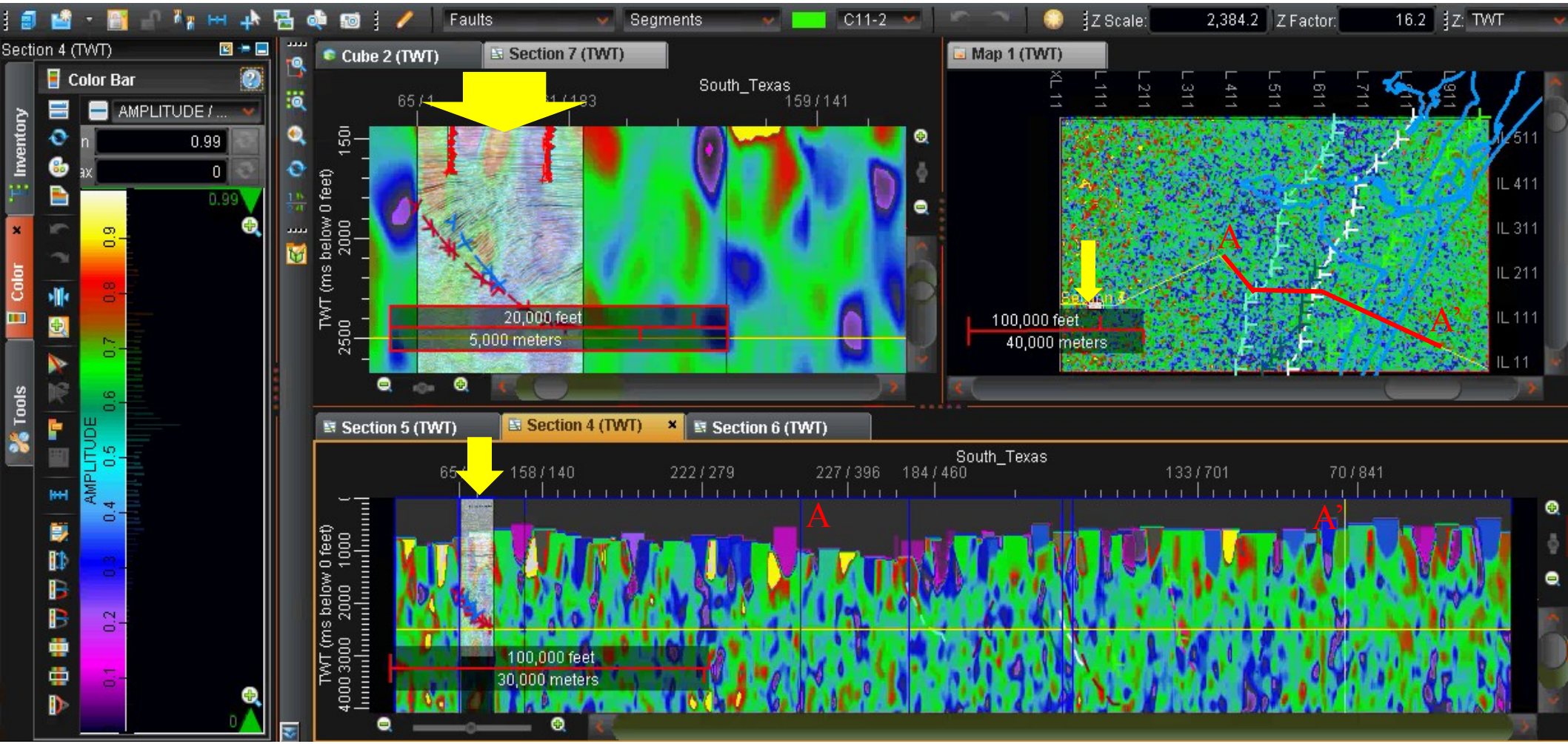
(ohm-meters)

1 of 18 Lightning Attributes - Density



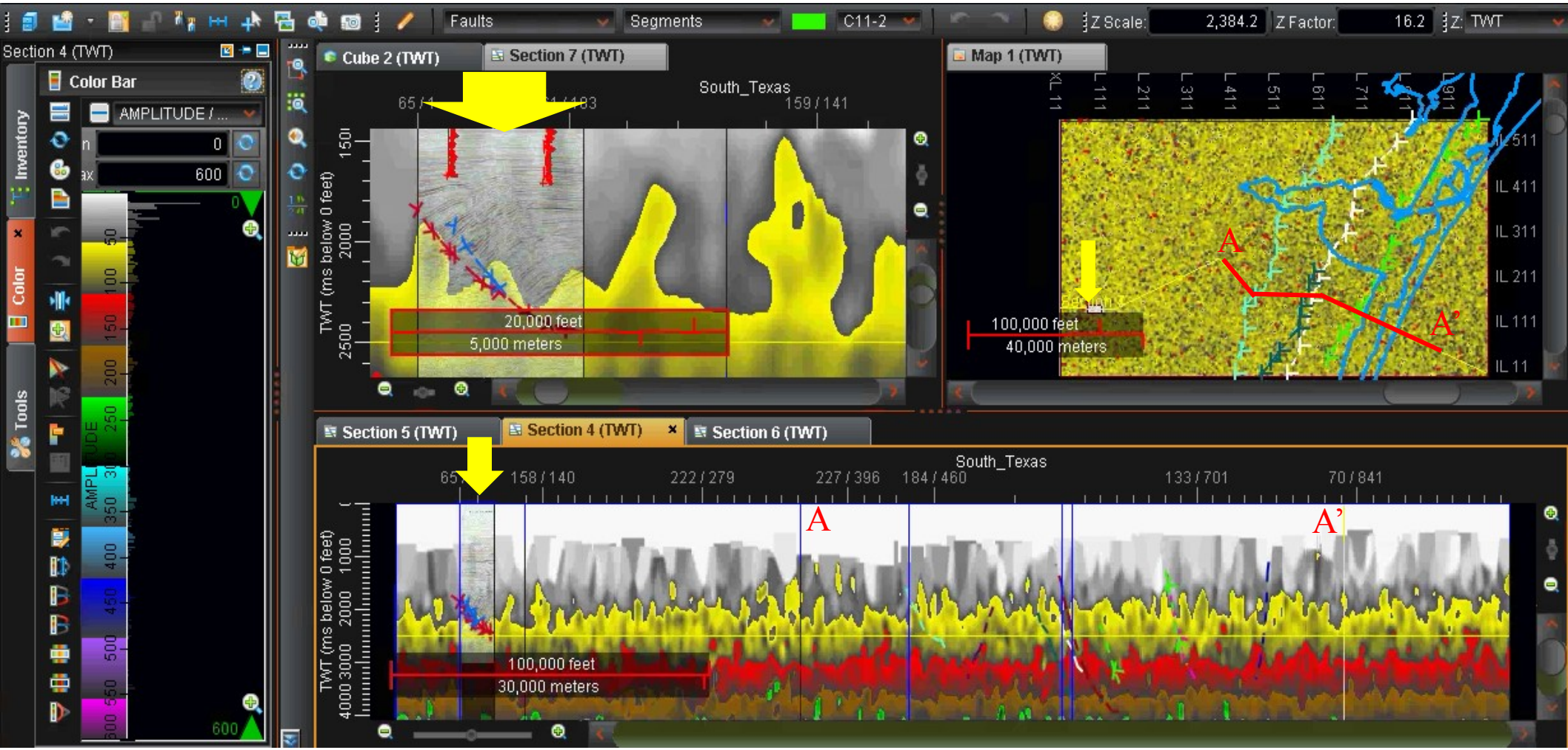
(Strikes per square kilometer)

2 of 18 Lightning Attributes - Day of Year



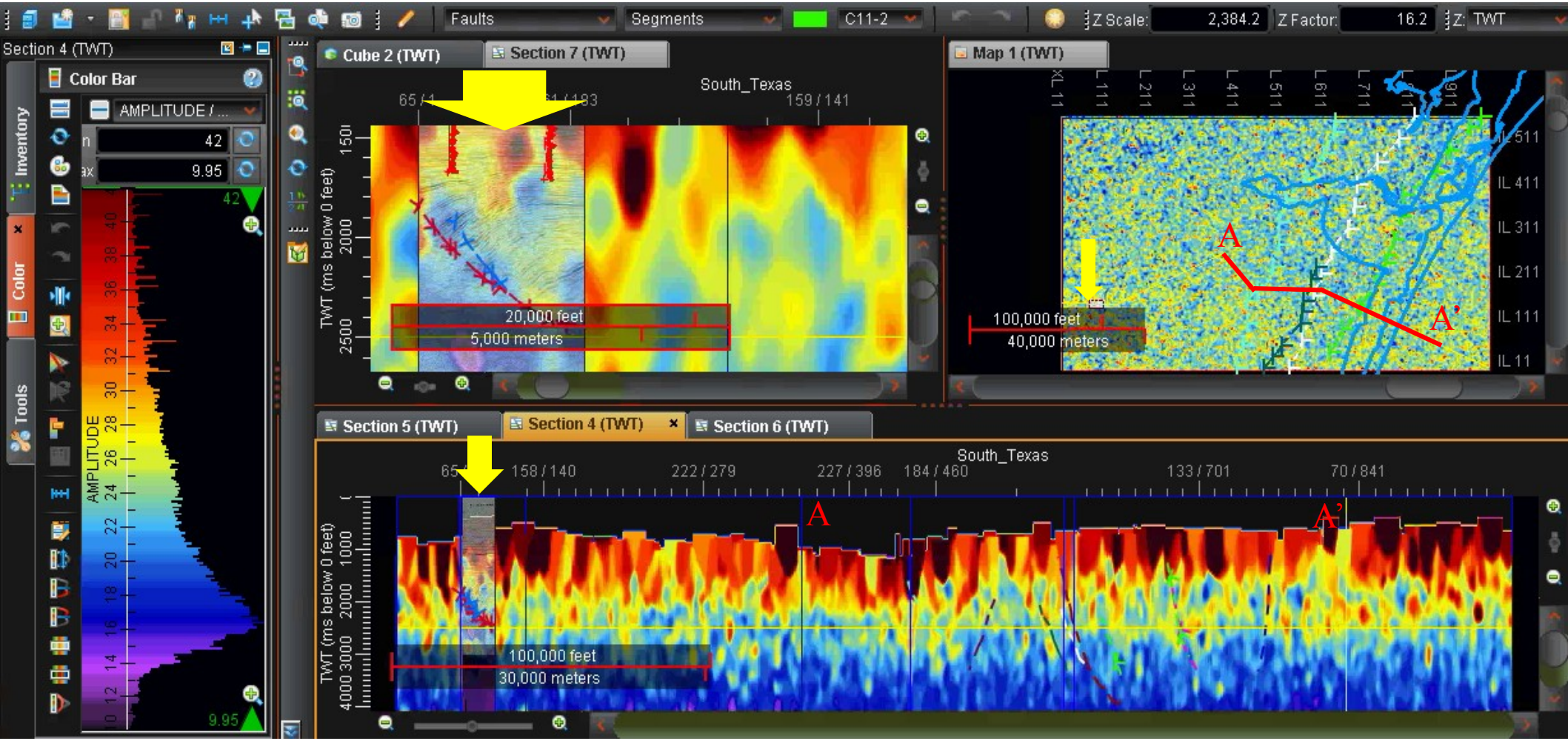
(Decimal fraction calendar year)

3 of 18 Lightning Attributes - Energy



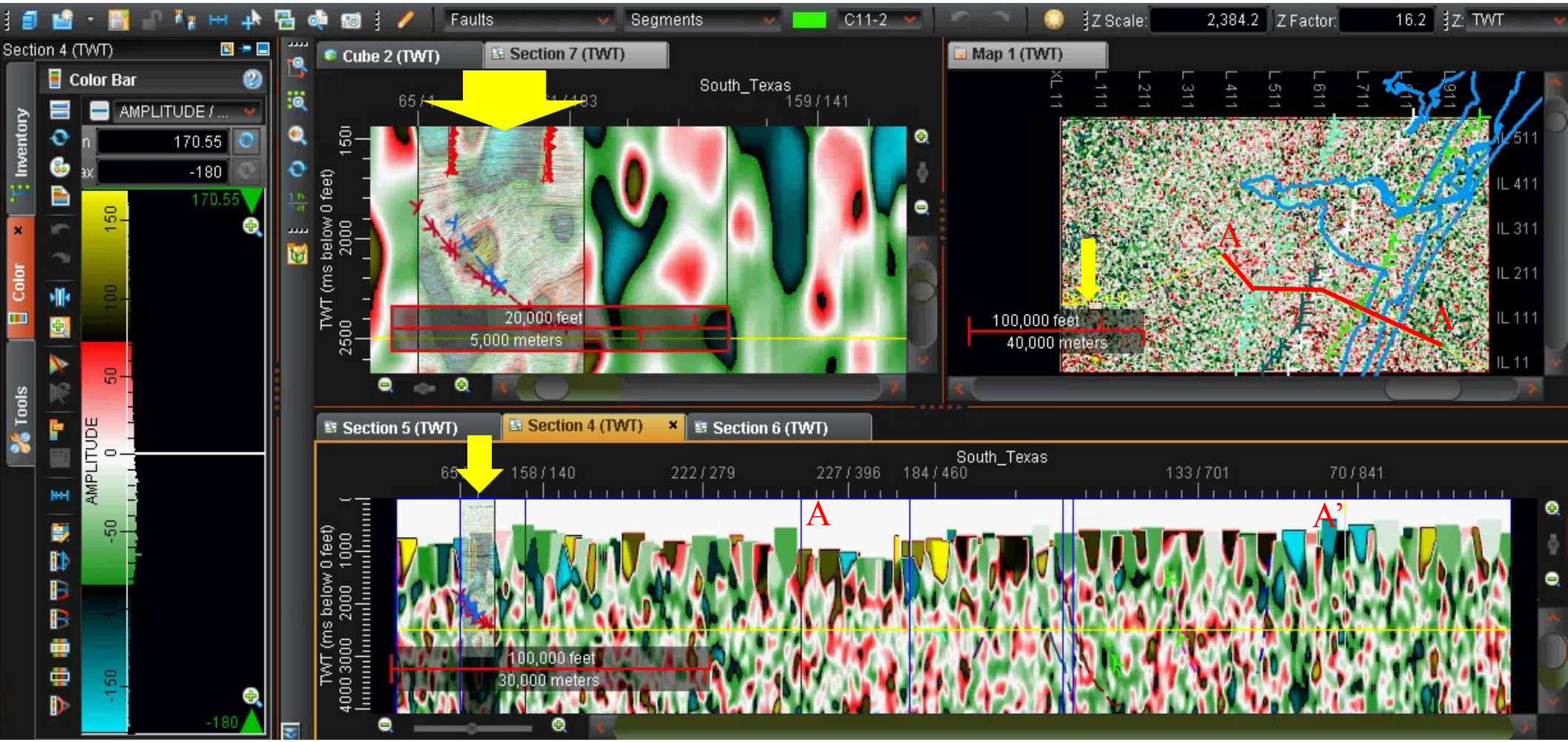
(milli-ampere-seconds)

4 of 18 Lightning Attributes - Frequency



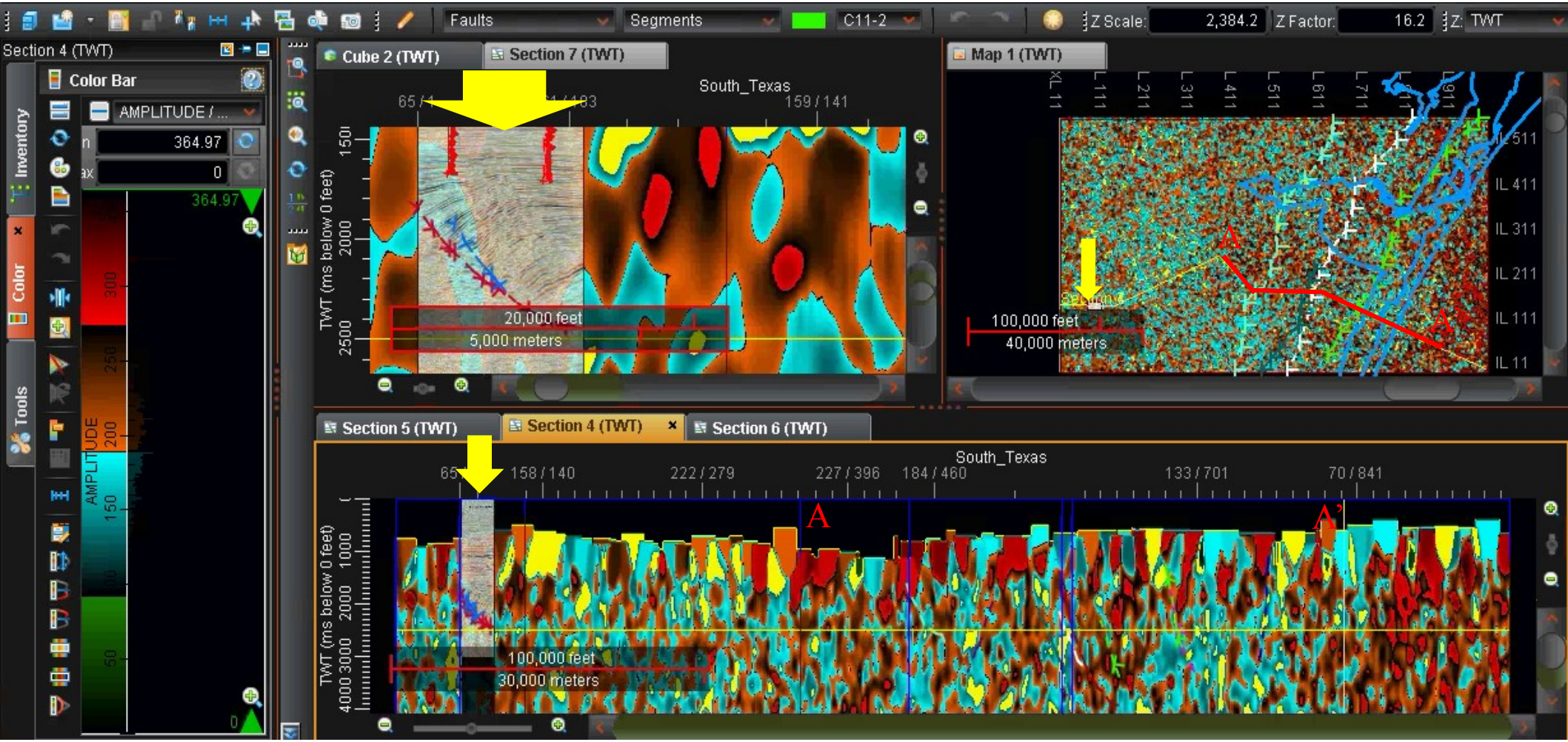
(kilohertz)

5 of 18 Lightning Attributes - Moon Local Longitude



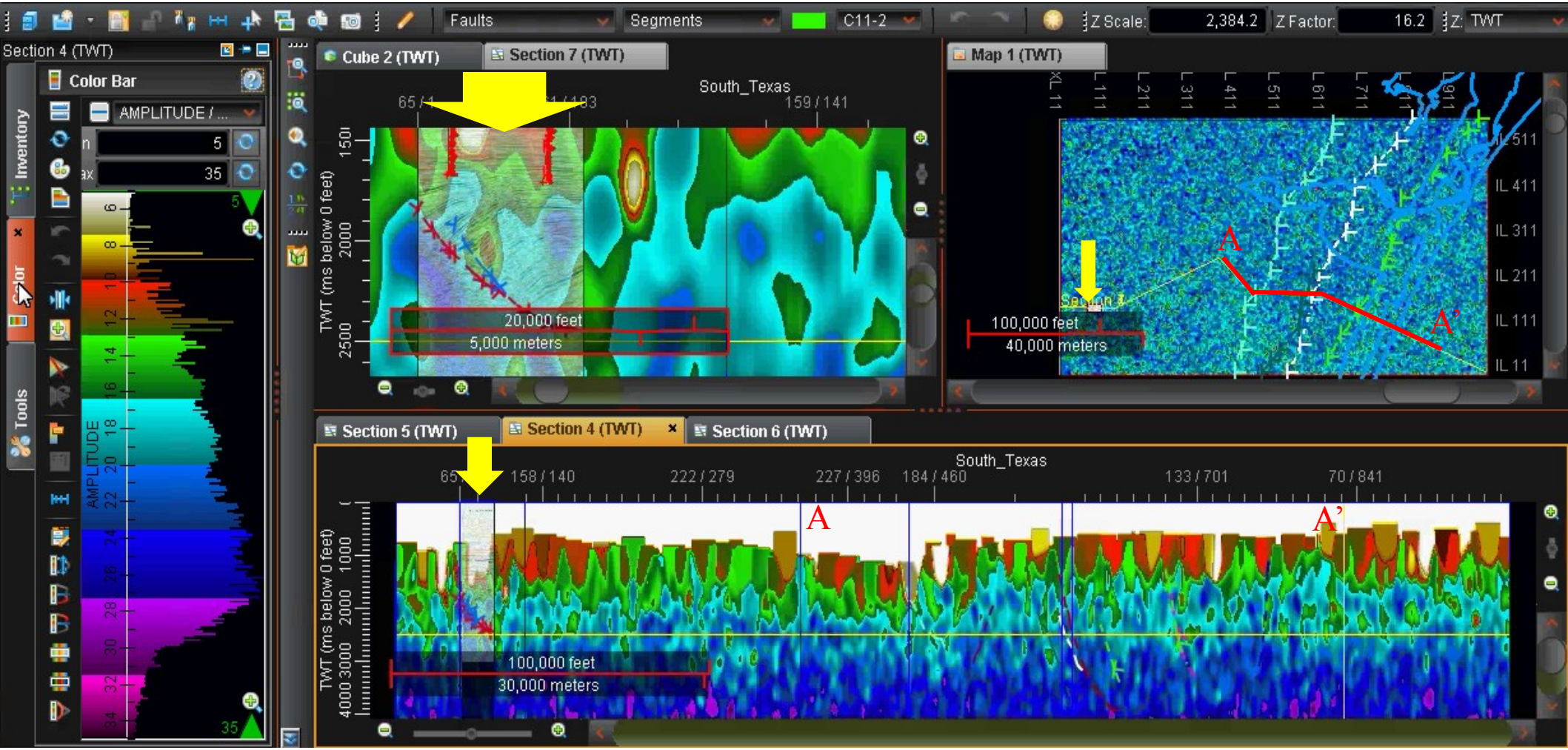
(degrees [-180 to 180]s)

6 of 18 Lightning Attributes - Moon Phase



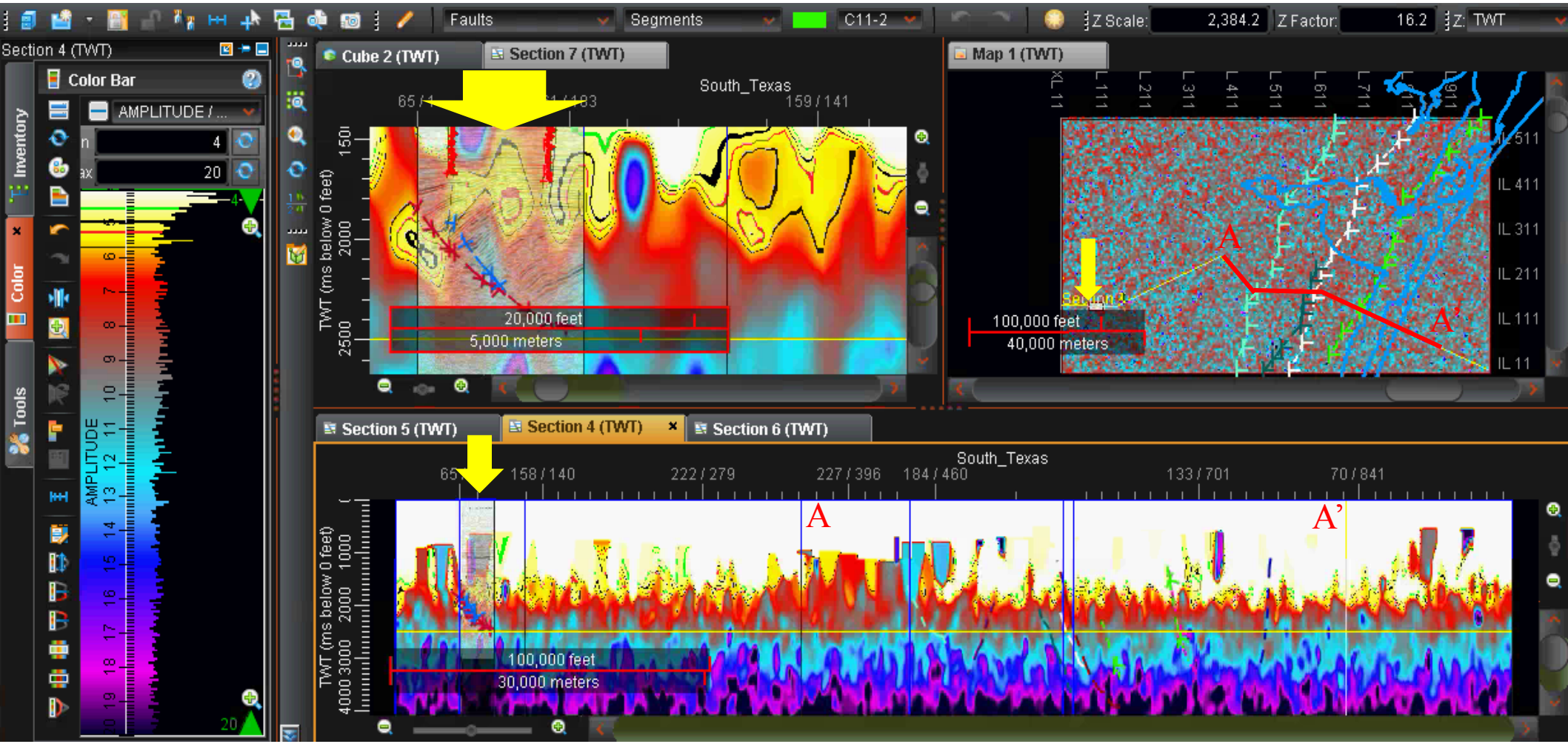
(degrees [0-360])

7 of 18 Lightning Attributes - Peak to Zero



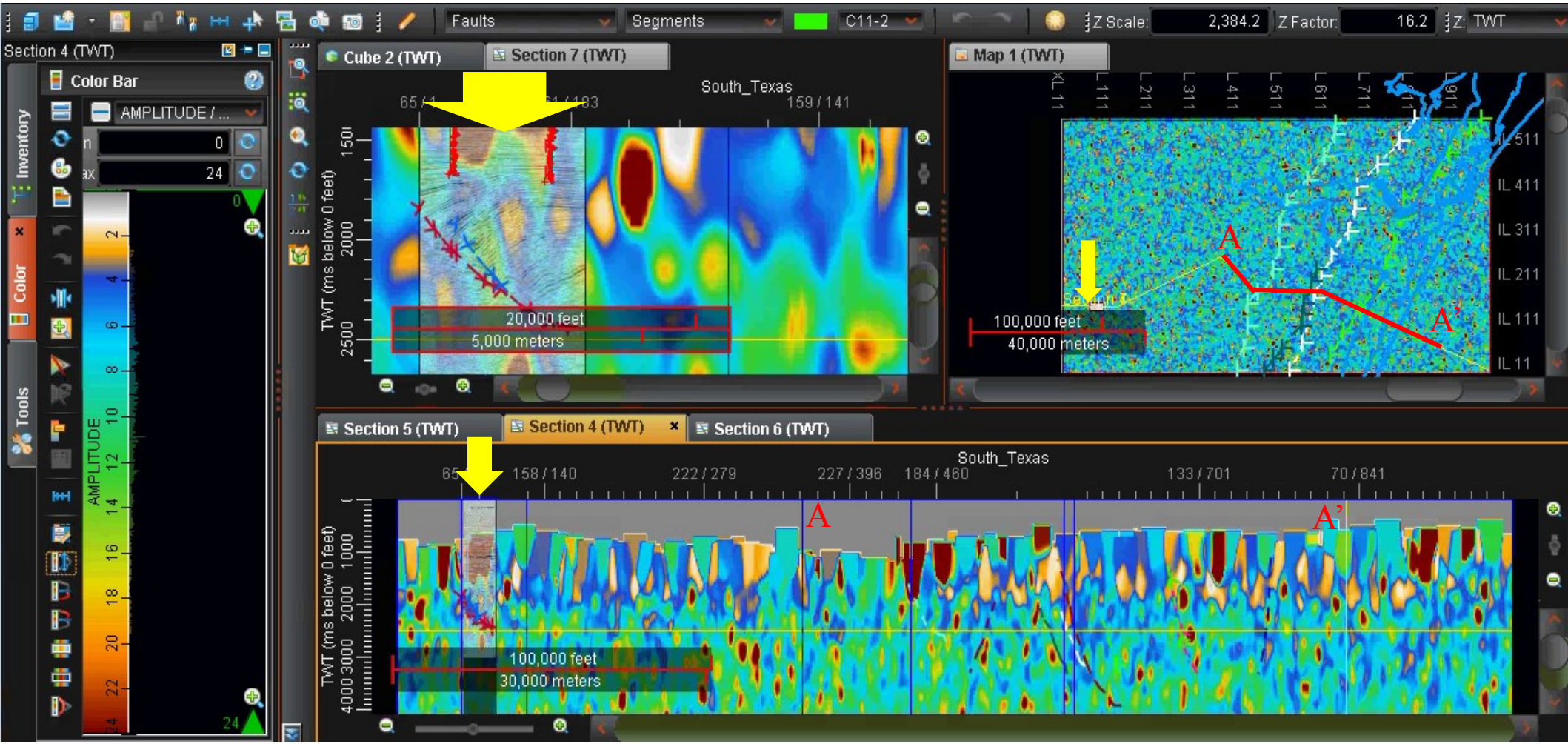
(microseconds)

8 of 18 Lightning Attributes - Peak Current



(kilo-amperes)

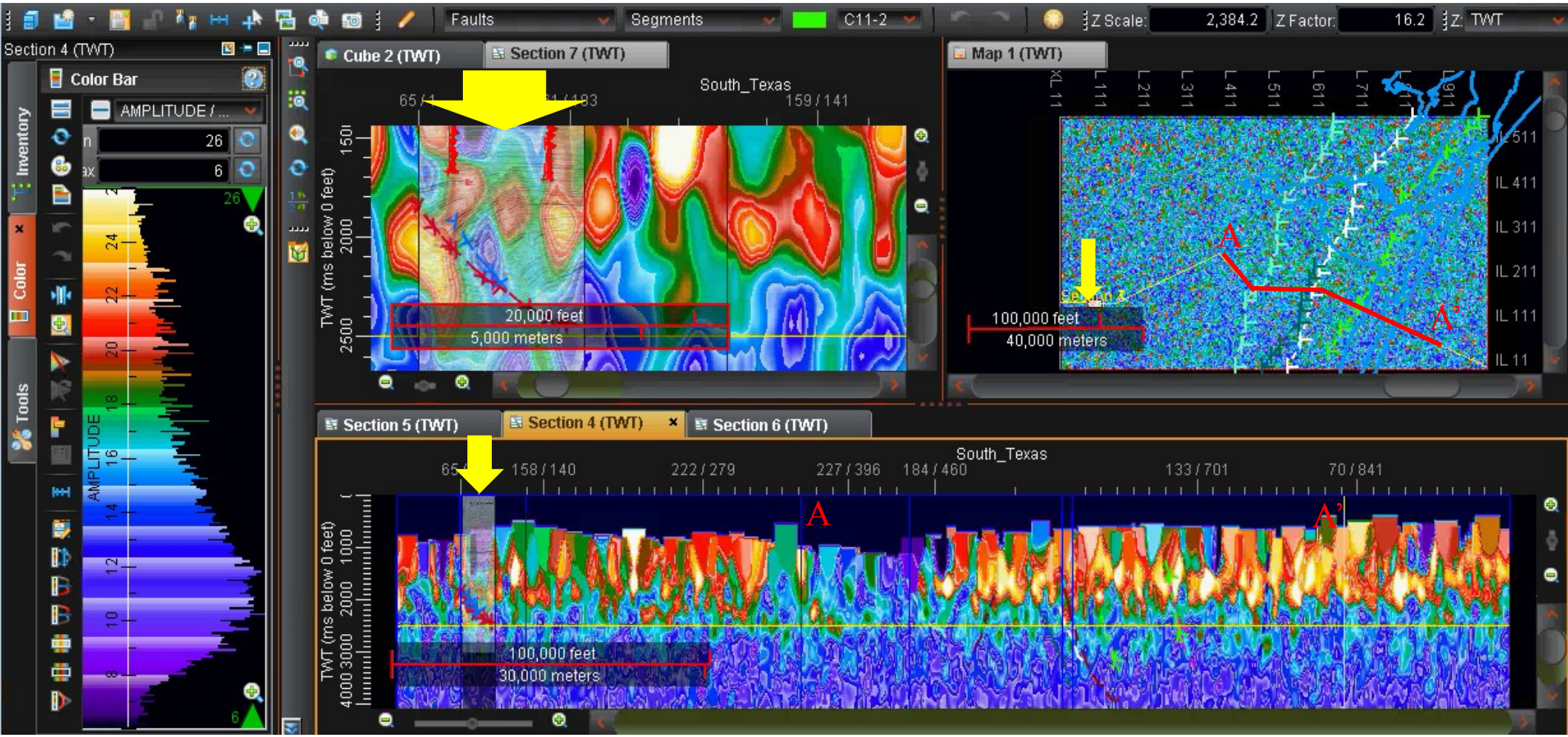
9 of 18 Lightning Attributes - Apparent Permittivity



(microfarads per meter)

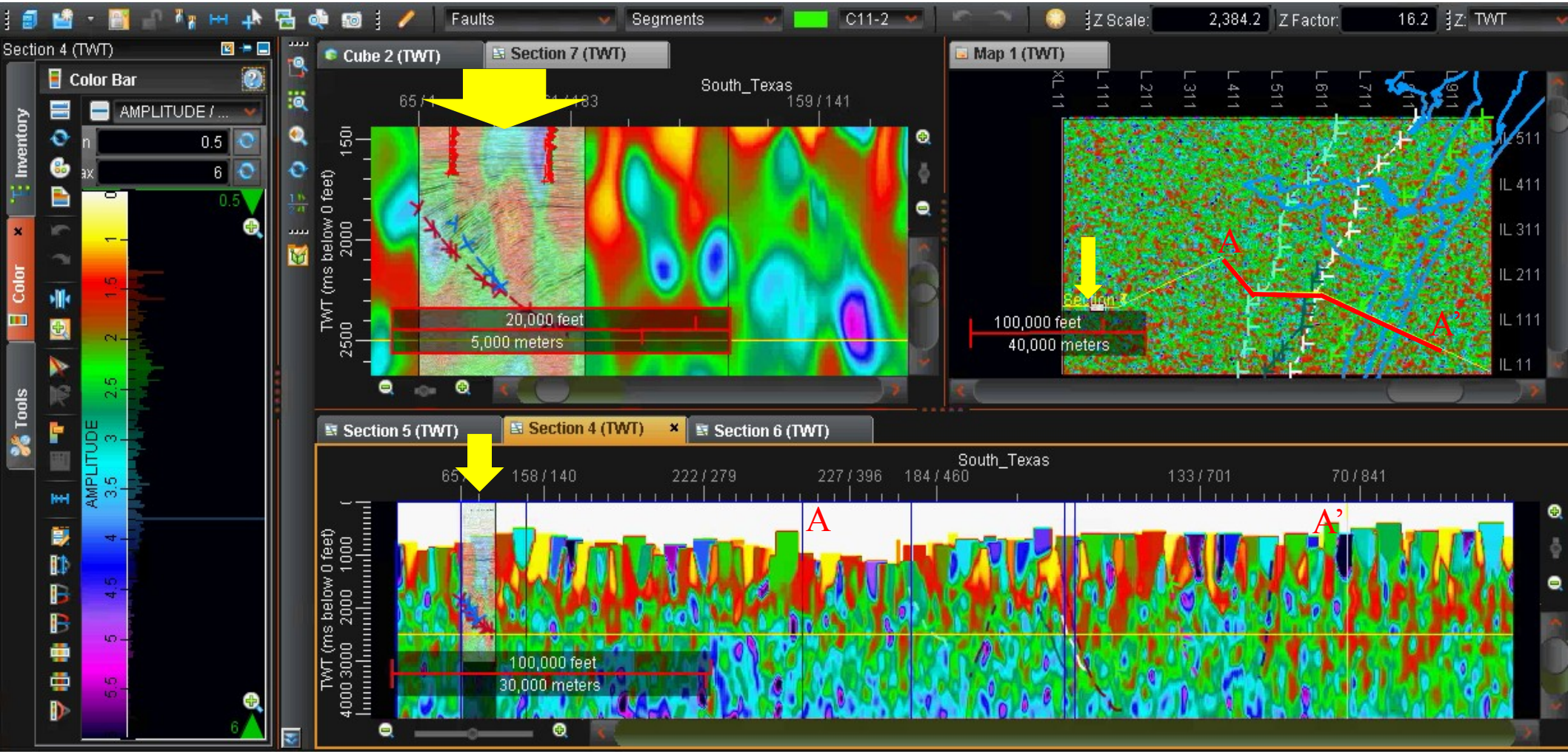
10 of 18 Lightning Attributes - Apparent Resistivity

Used to correlate Ewing's 1986 cross-sections



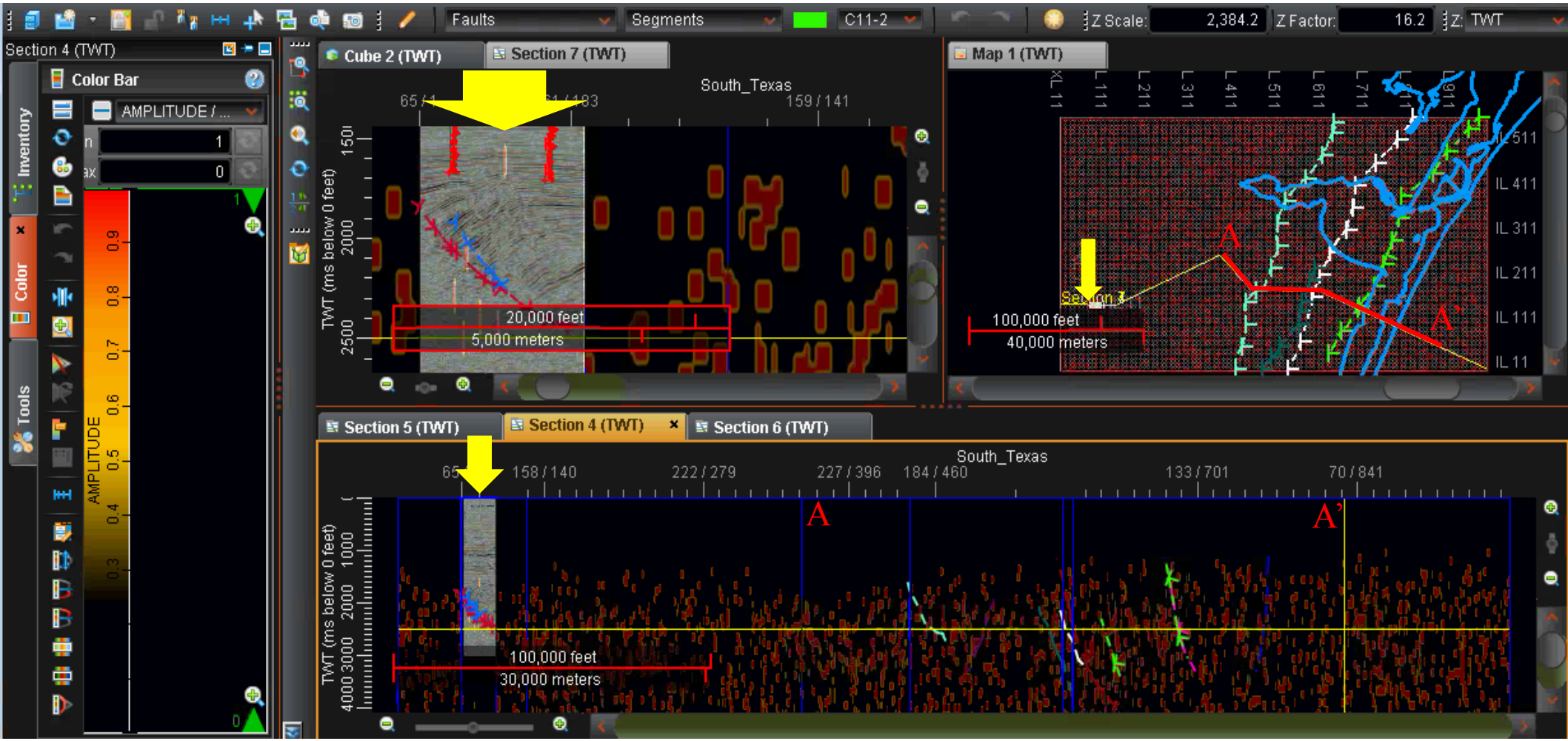
(ohm-meters)

11 of 18 Lightning Attributes - Rise Time



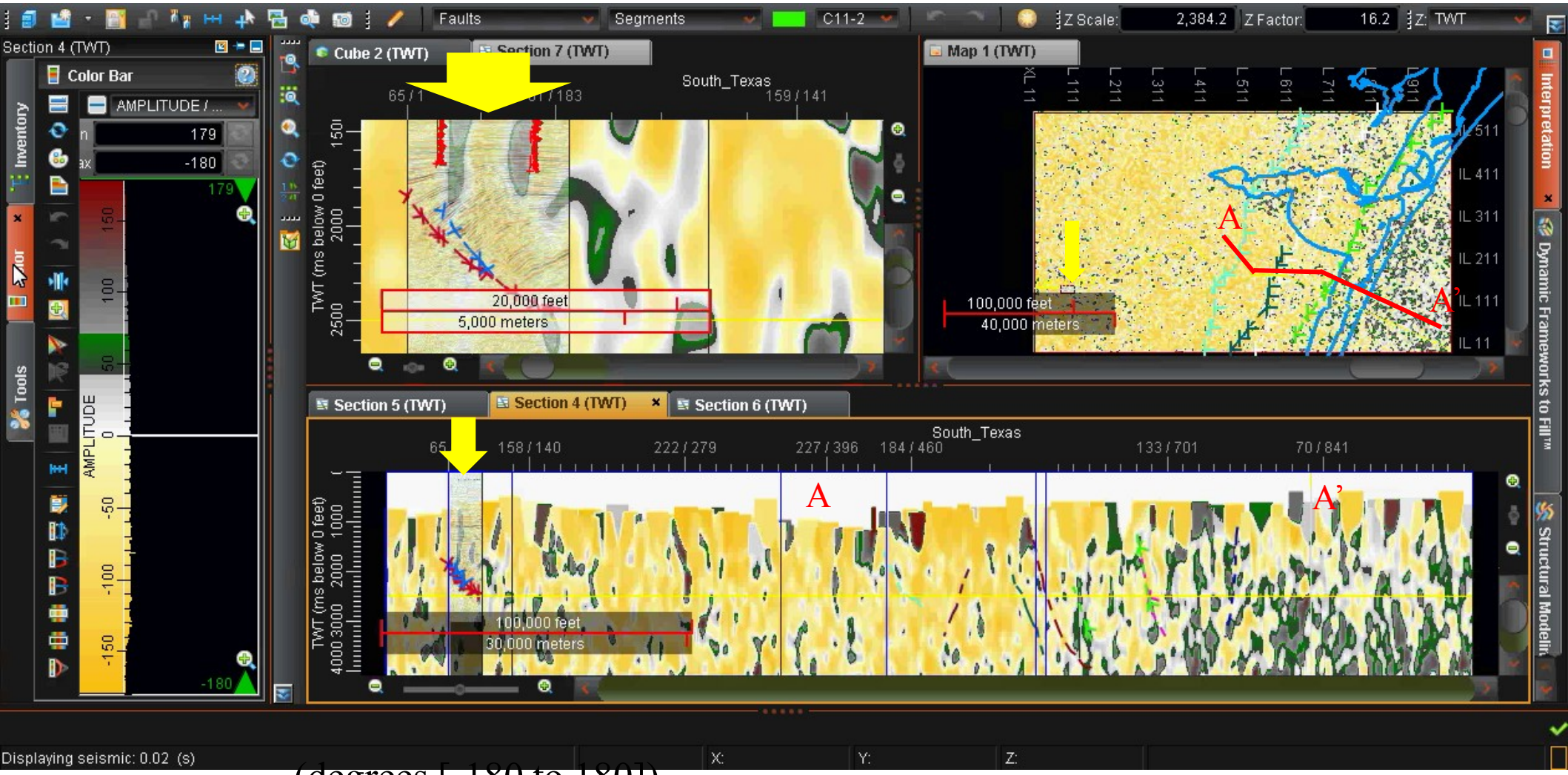
(microseconds)

12 of 18 Lightning Attributes - Spike



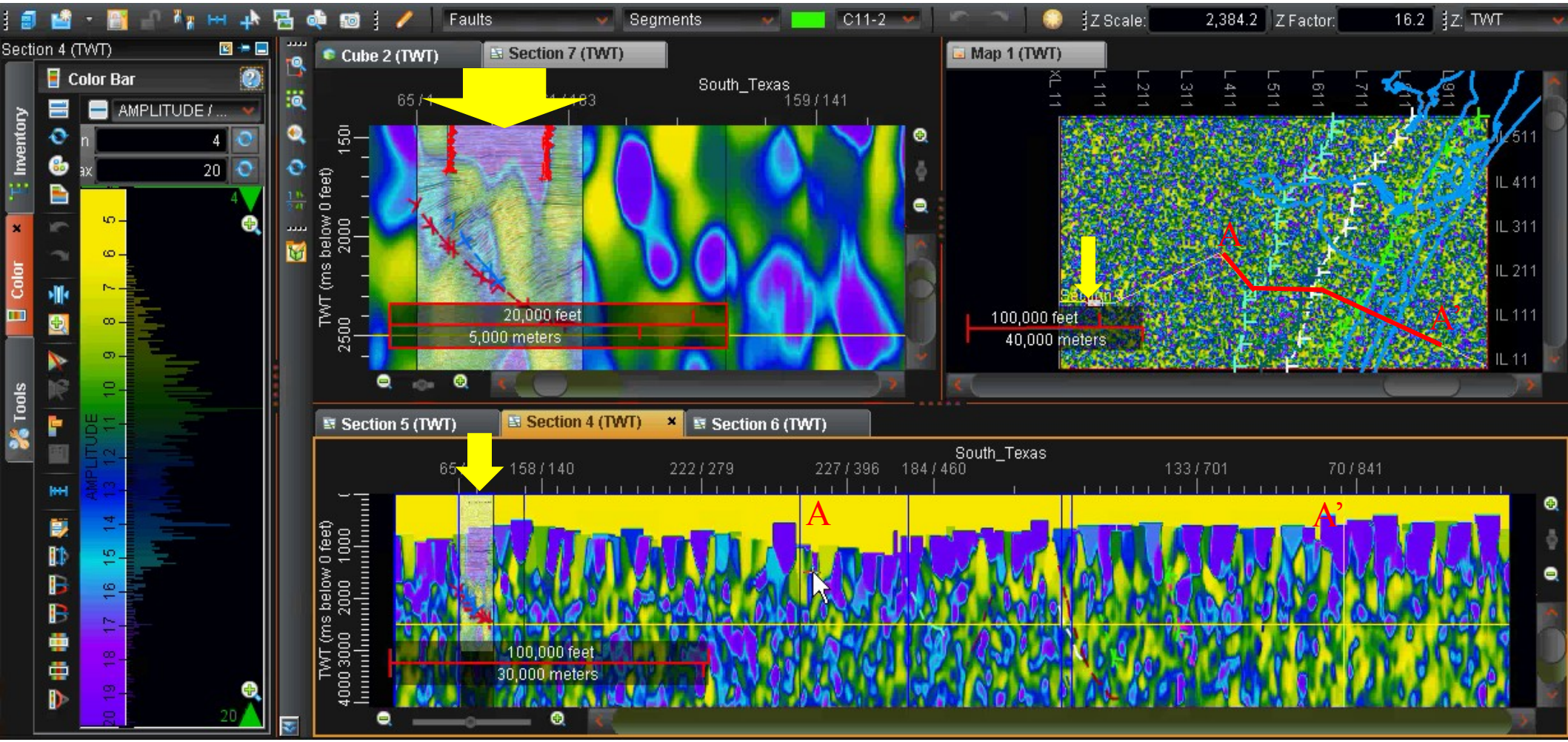
(position of strike)

13 of 18 Lightning Attributes - Sun Local Longitude



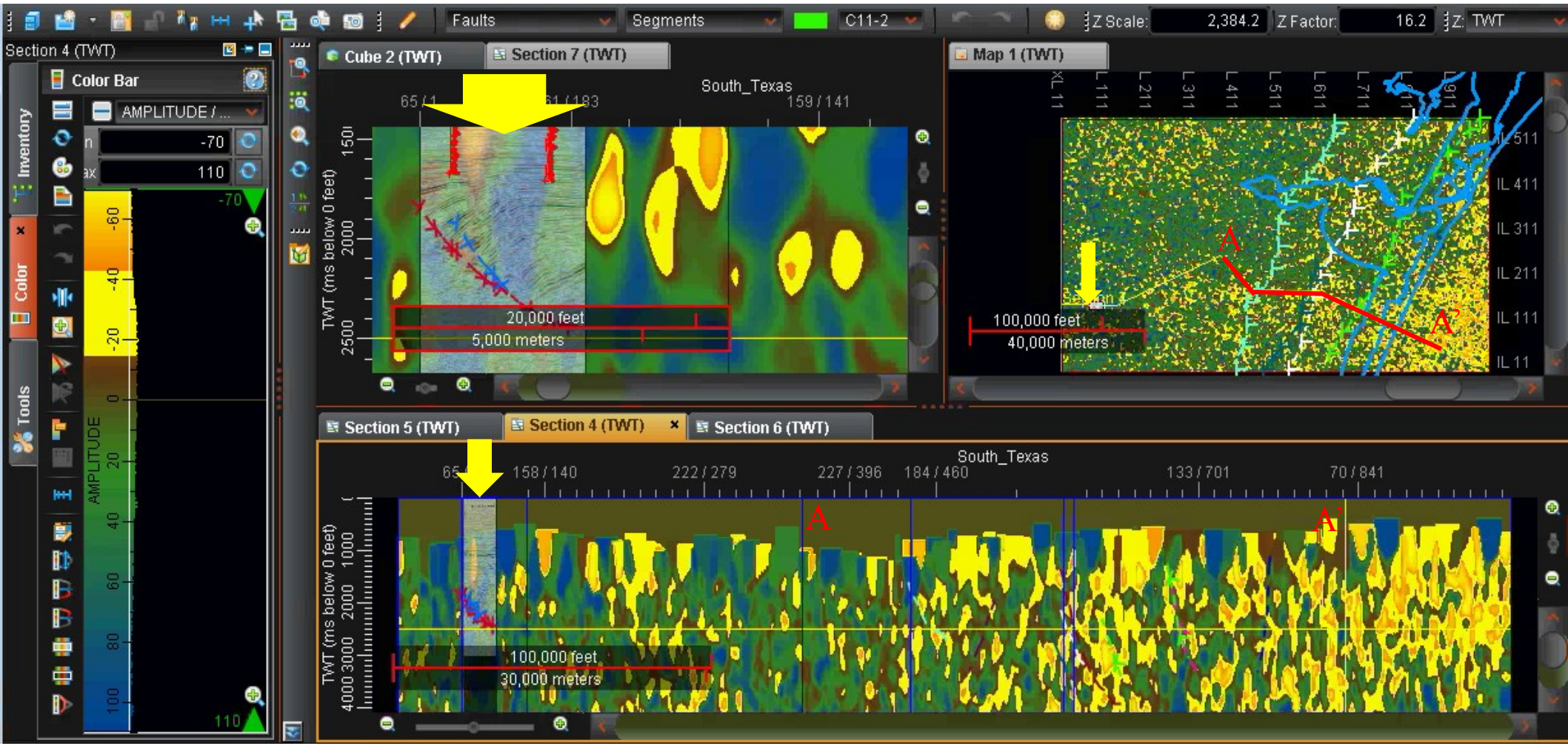
(degrees [-180 to 180])

14 of 18 Lightning Attributes - Symmetry



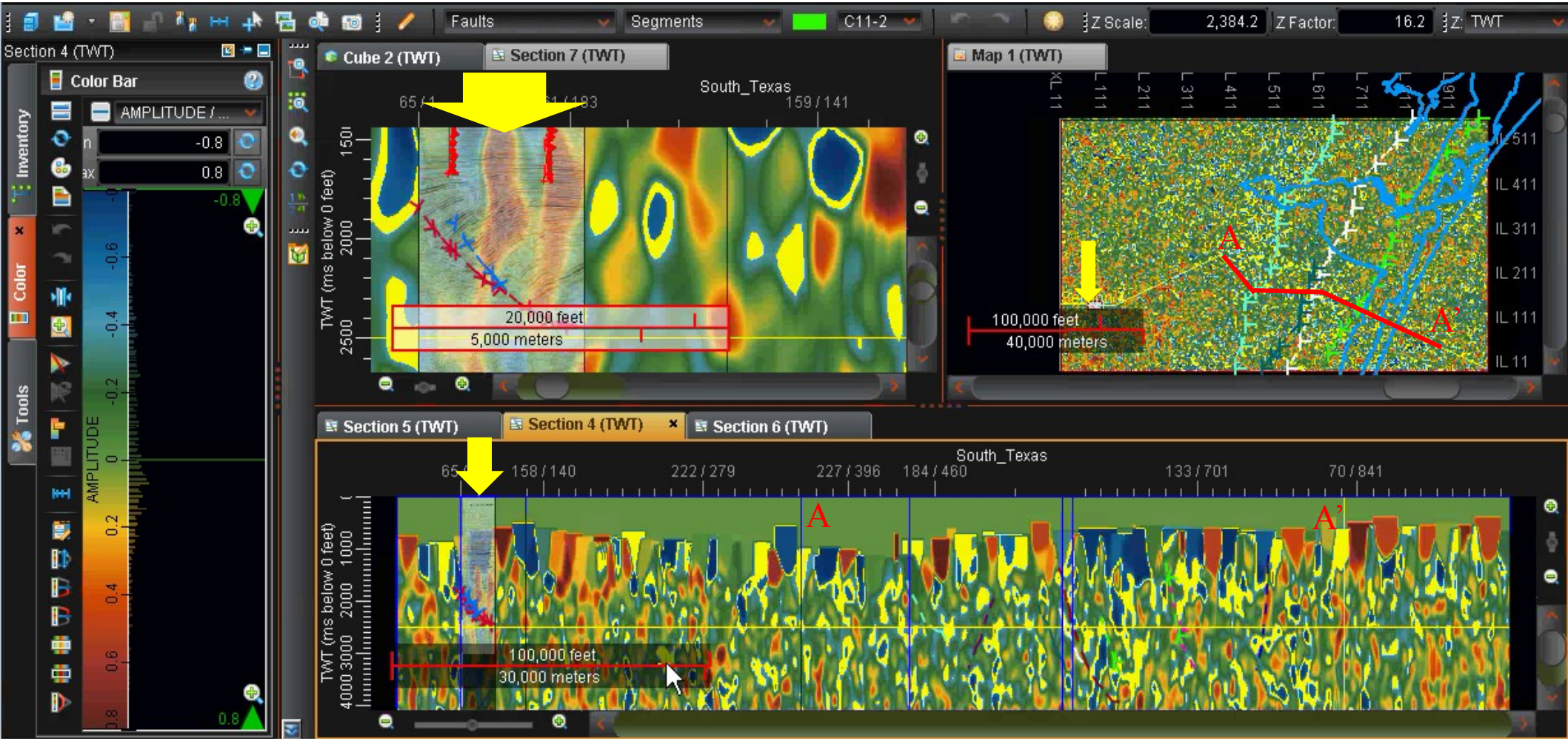
(% [<50: rt<pz; 50: rt=pz; >50: rt>pz])

15 of 18 Lightning Attributes - Tidal Gravity



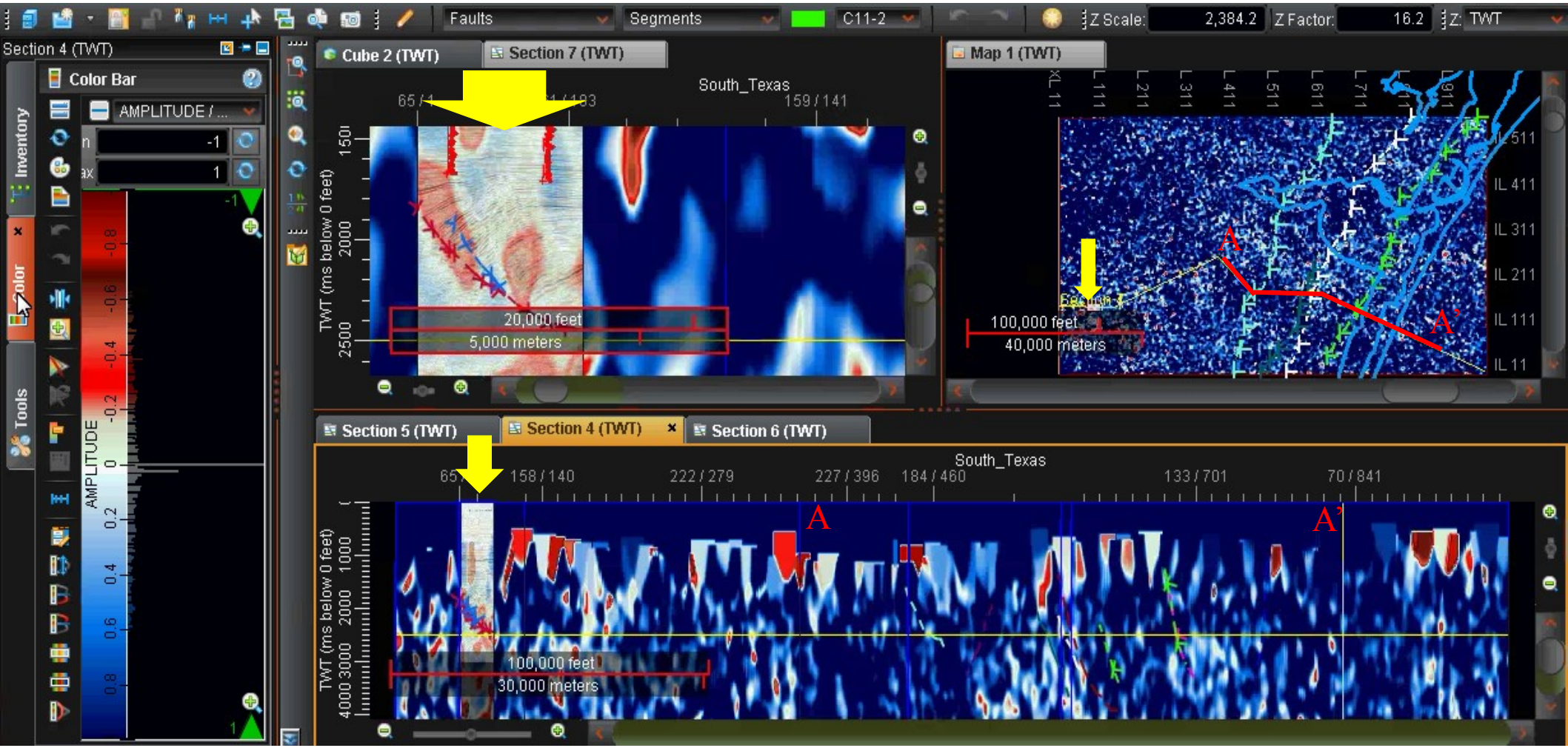
(microgals)

16 of 18 Lightning Attributes - Tide



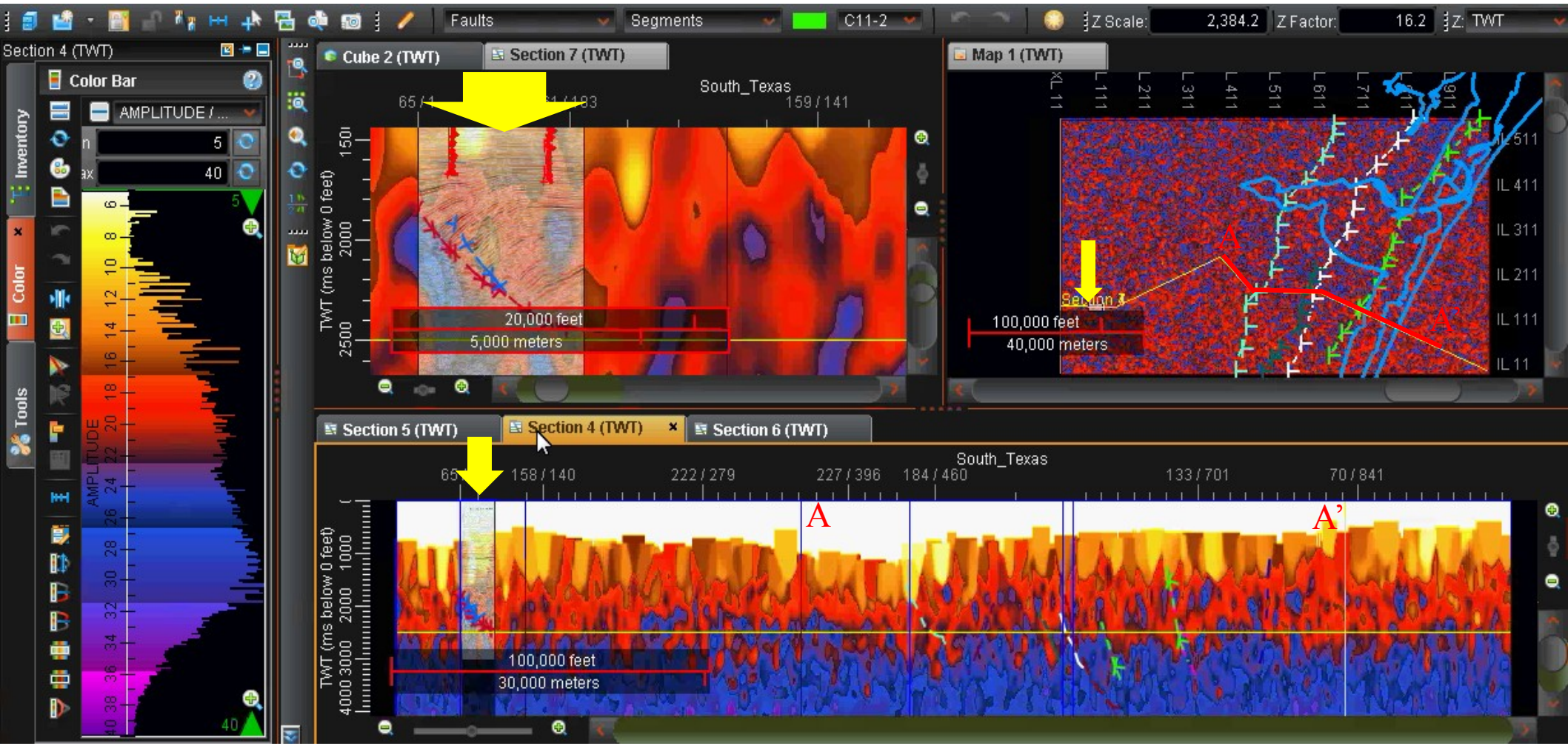
([-1.0: low spring tide; 0.0: mean tide; 1.0: high spring tide])

17 of 18 Lightning Attributes - Tide Gradient



(first derivative of Tide)

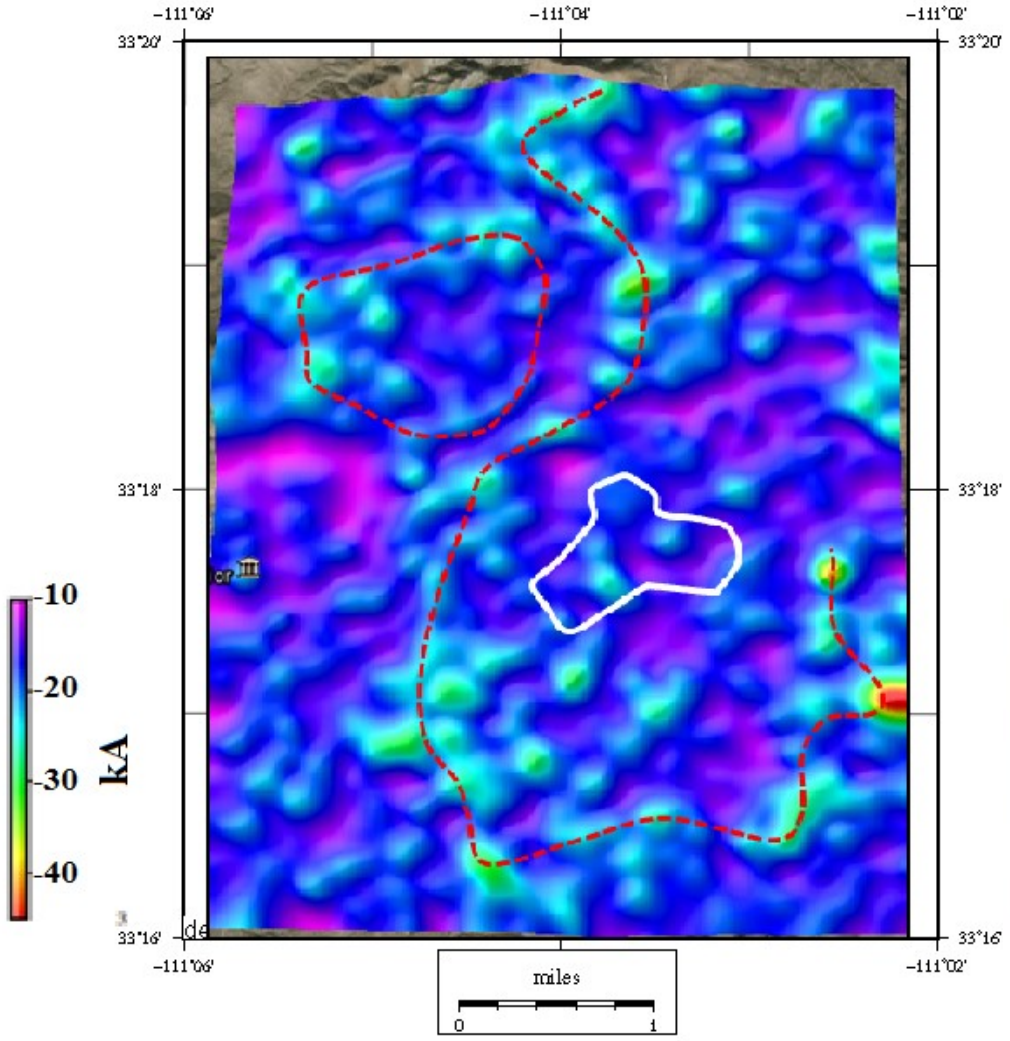
18 of 18 Lightning Attributes - Total Wavelet Time

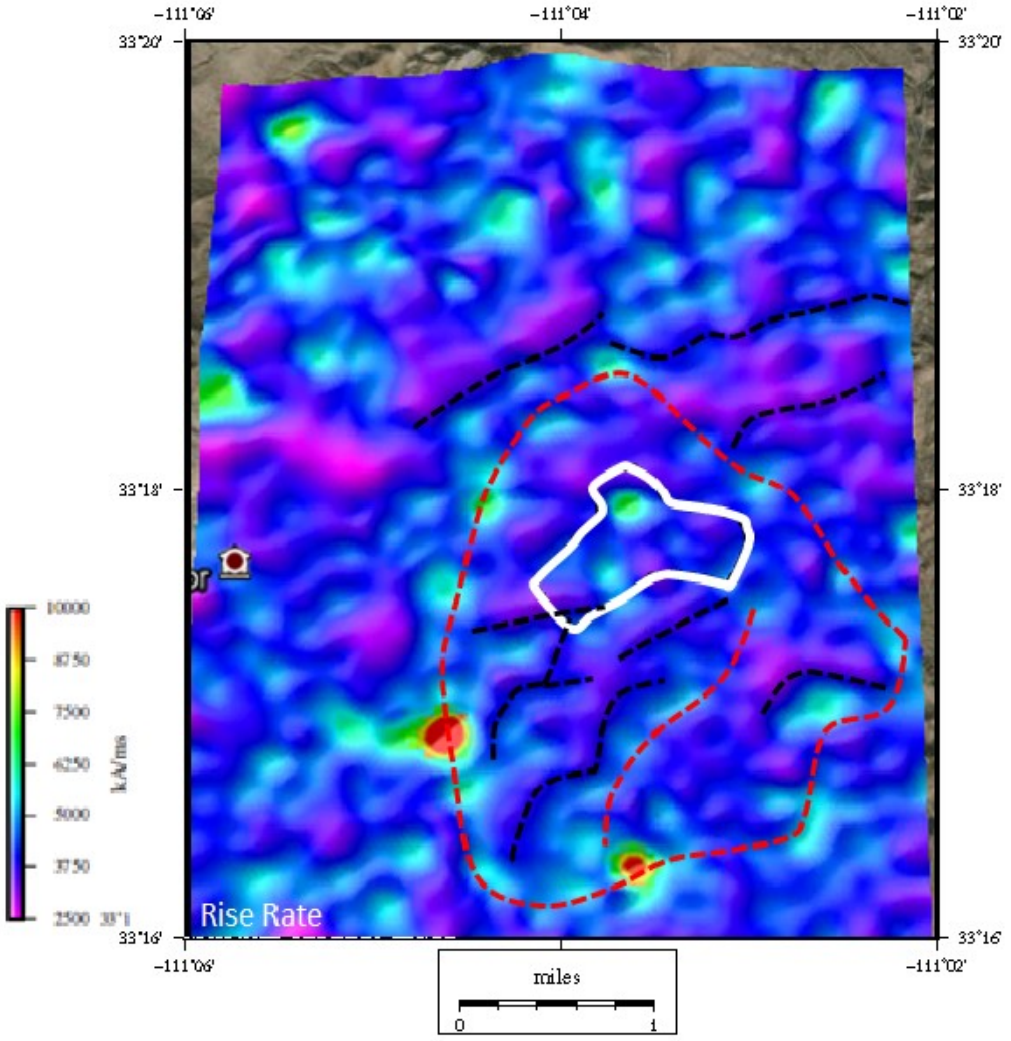


(microseconds)

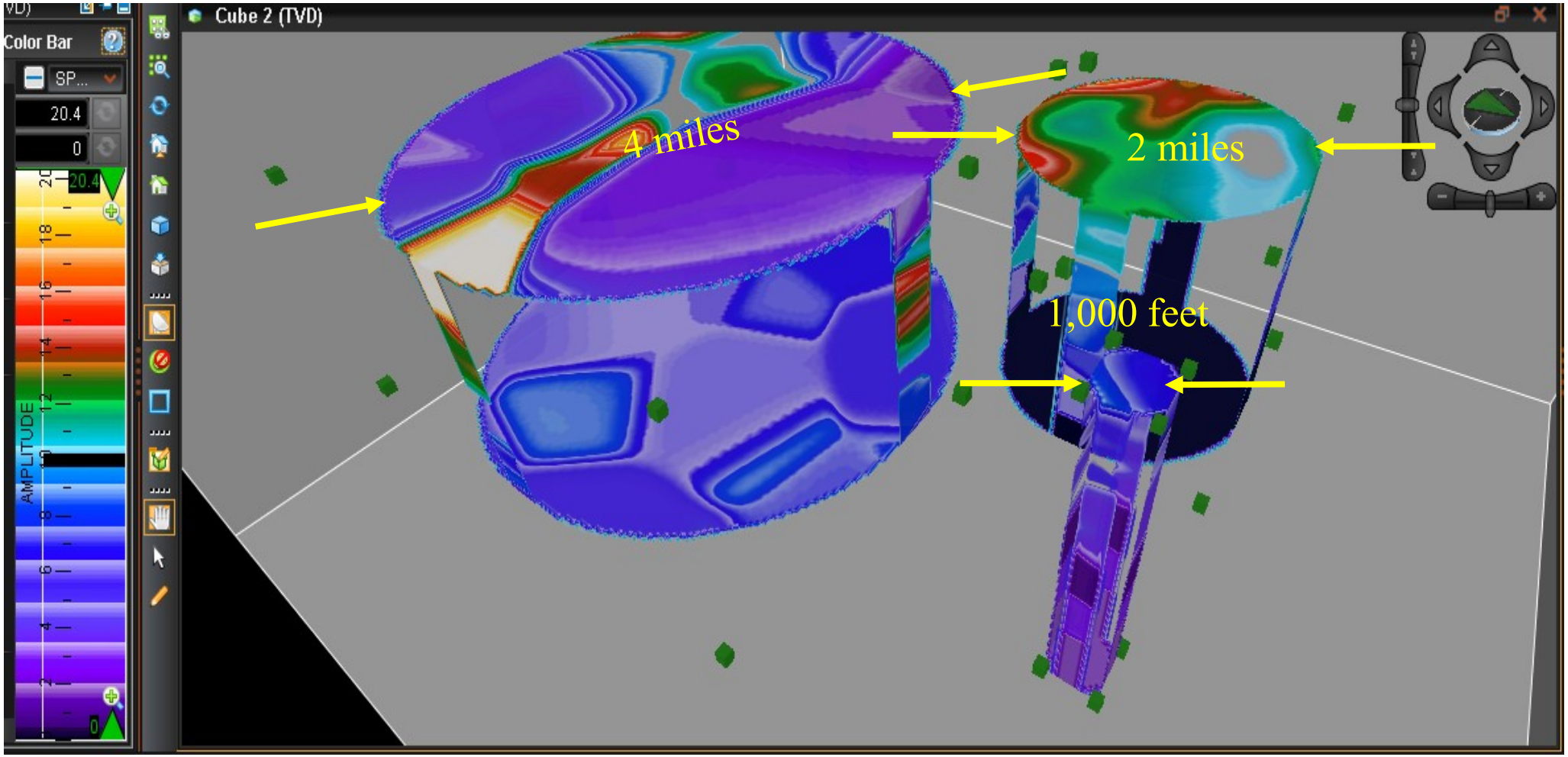
5a. Arizona Examples: Resolution Copper

NLDN Peak Current & Rise-Rate

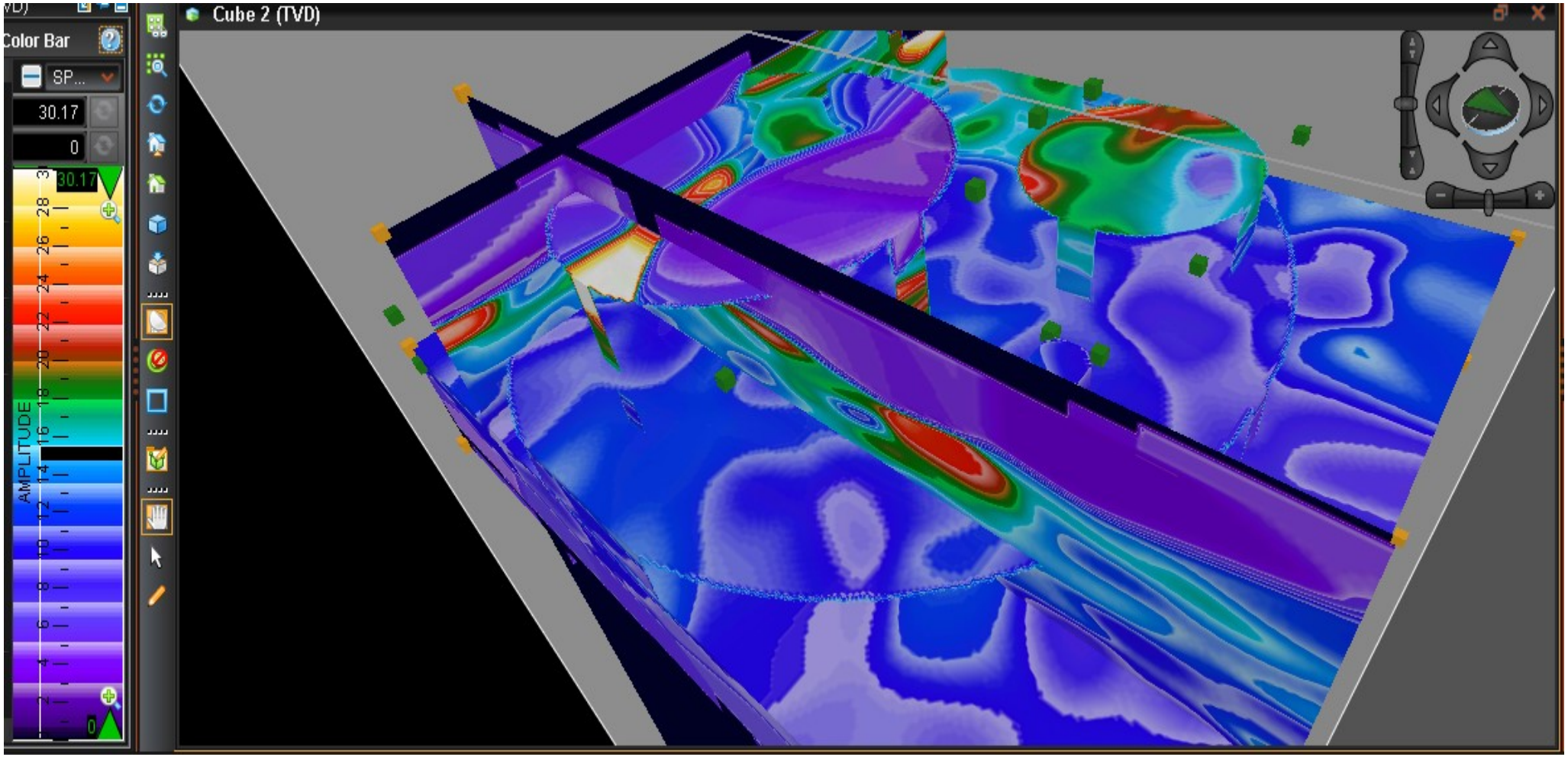




3 Example SPOT^{SM} Apparent Resistivity Cylinders

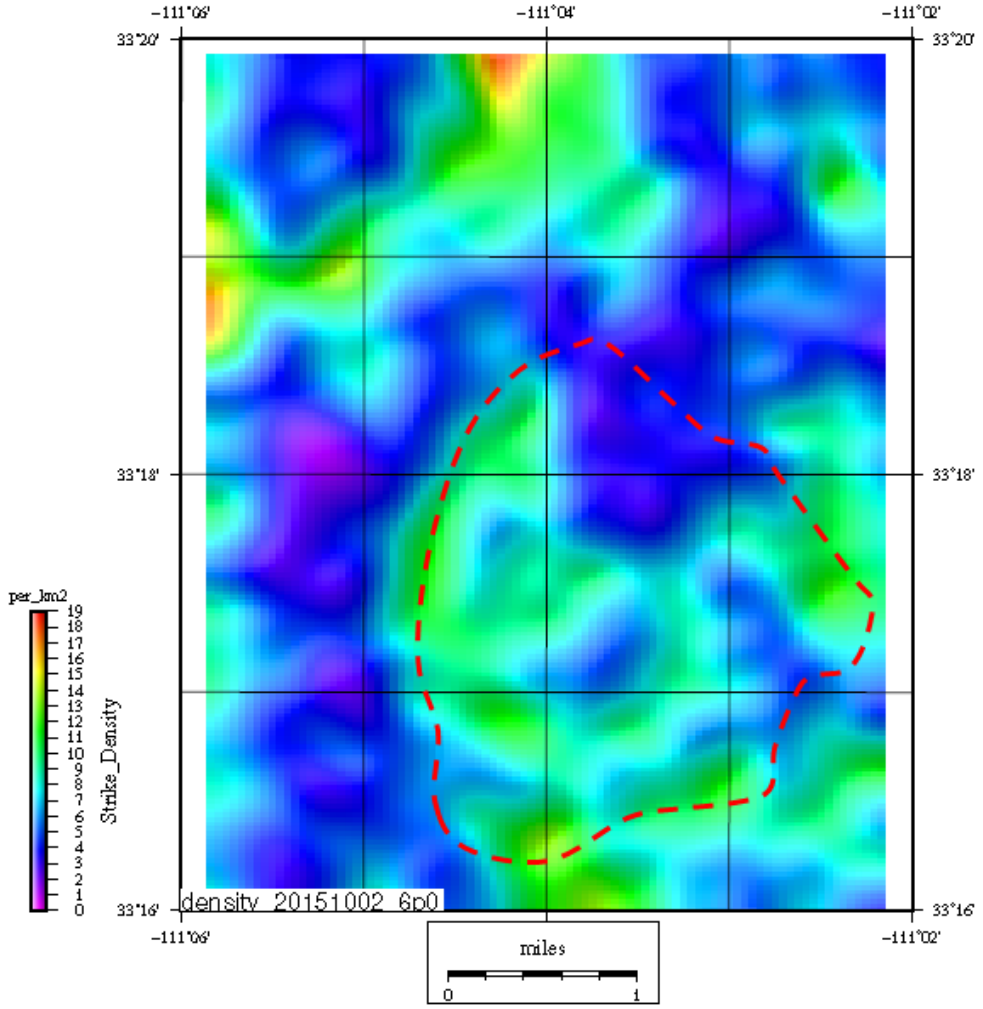


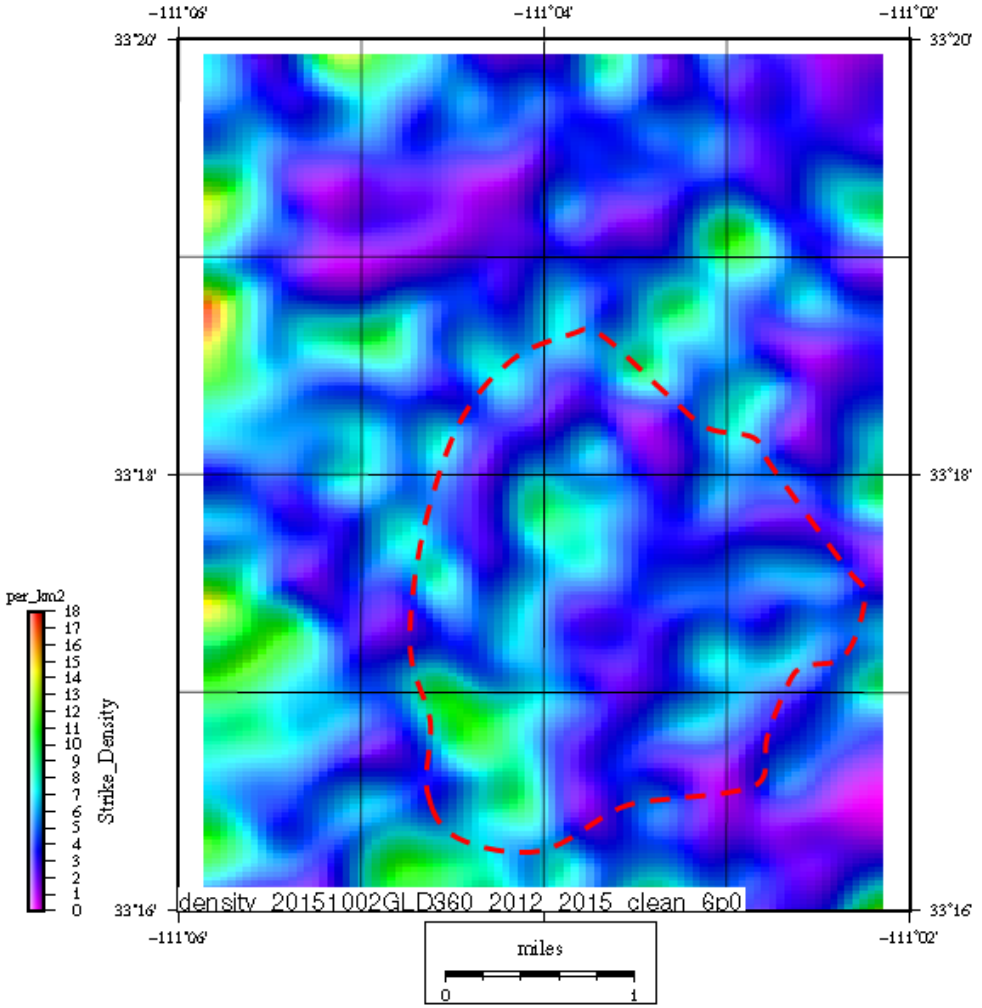
Integrating Resistivity in Three-Dimensions



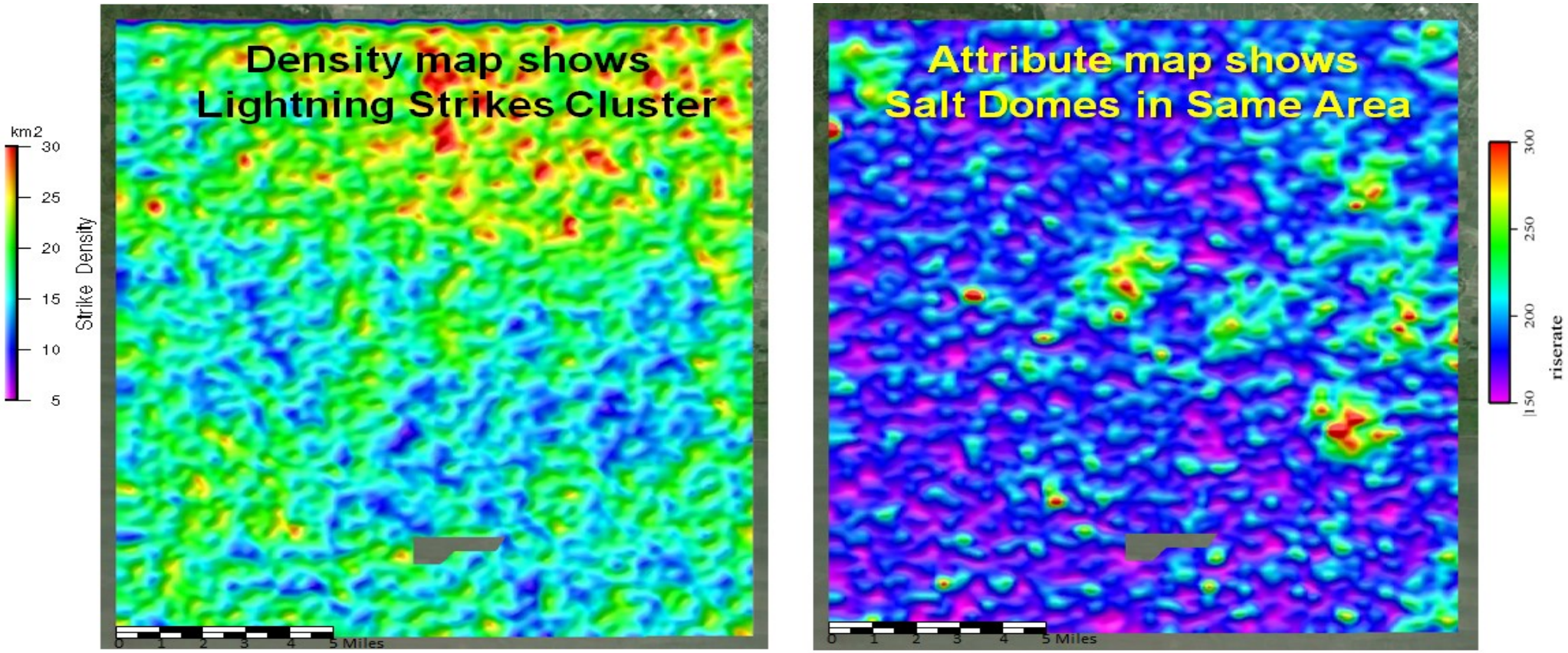
Comparing NLDN and GLD-360 data

NLDN Density 1998-2015 & GLD-360 Density 2012-2015



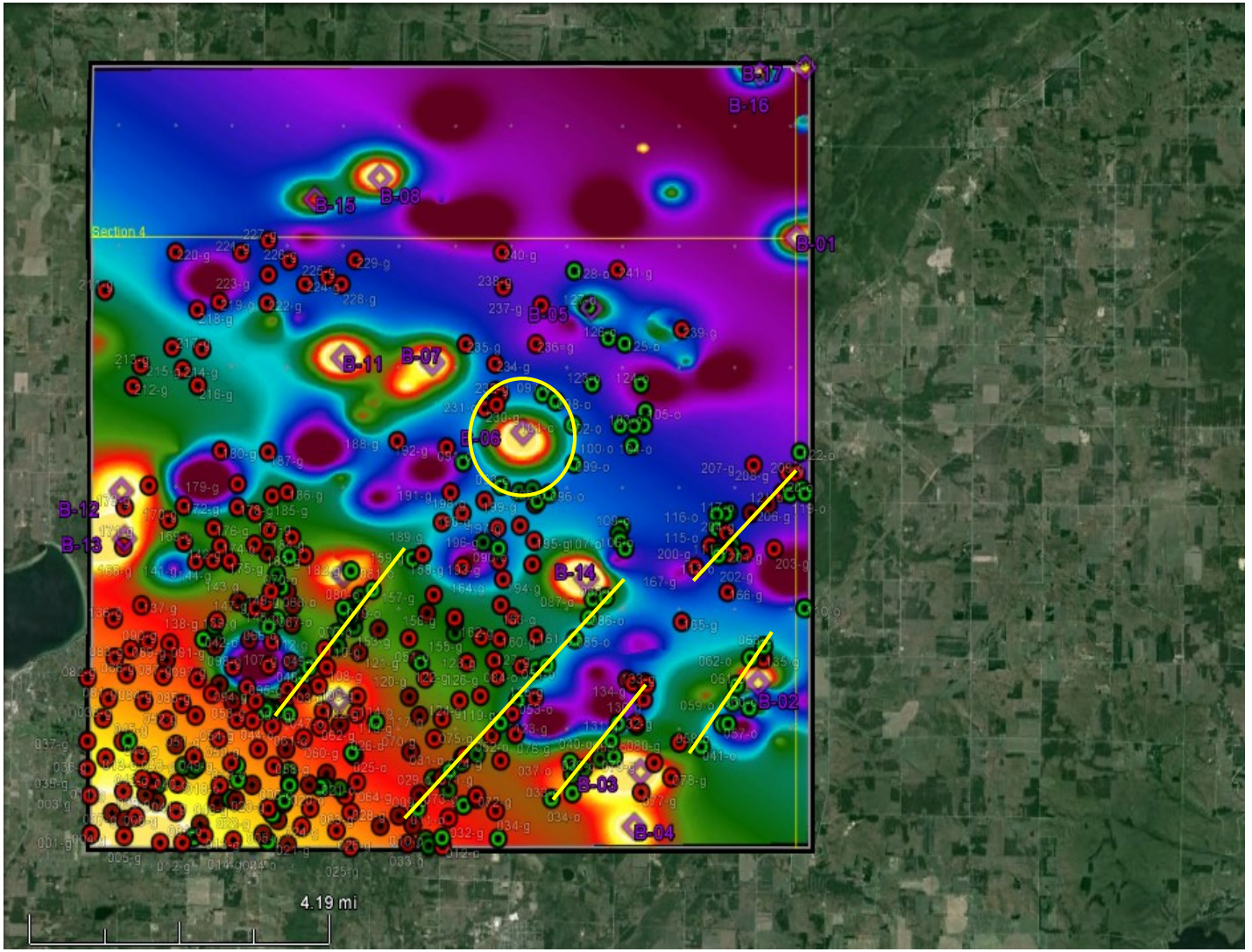


5b. Louisiana Example

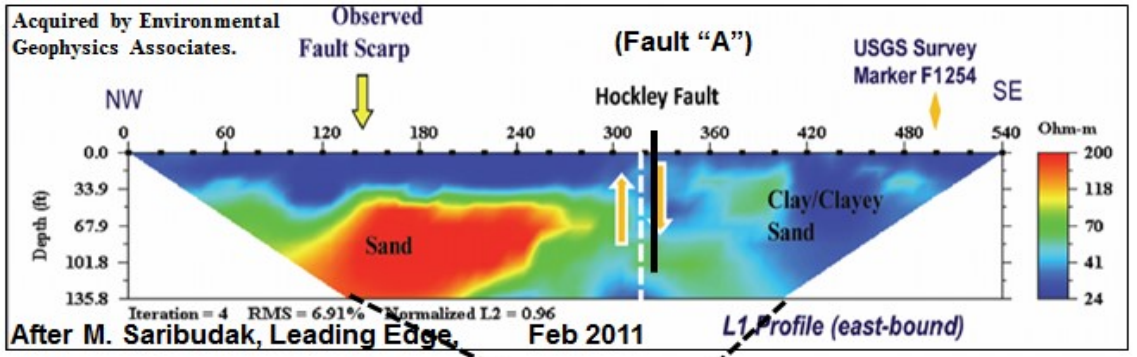


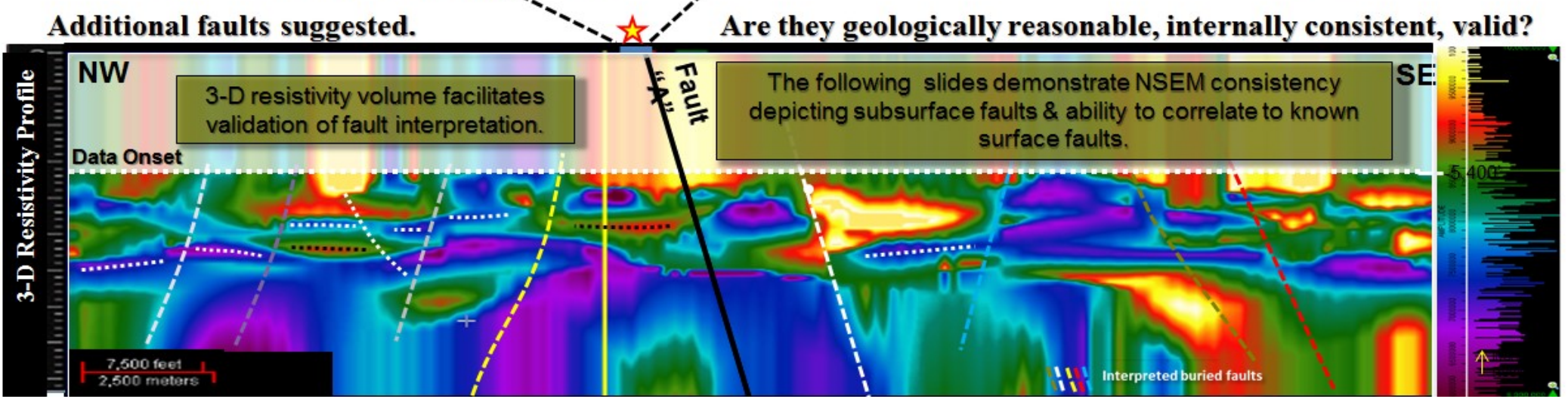
Density Map & Rate-of-Rise-Time Map

5c. Michigan Example
High Resistivity to SW on B-2 Horizontal-Slice
with Oil & Gas Wells in Analysis Area posted (note lineaments)



5d. One Last Texas Example





2-D Resistivity Survey ties Lightning Derived Resistivity Cross-Section

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