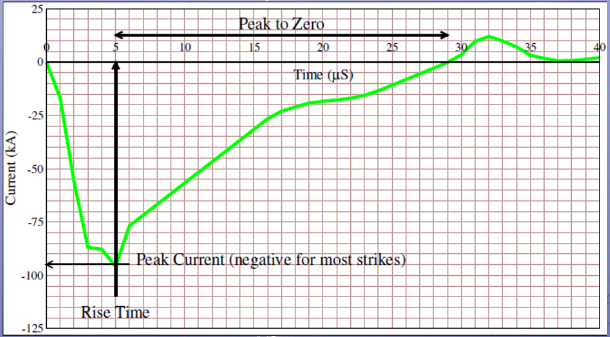
Calculating Resistivity Volumes from Lightning Databases

Dynamic Measurement LLC

11 September 2014

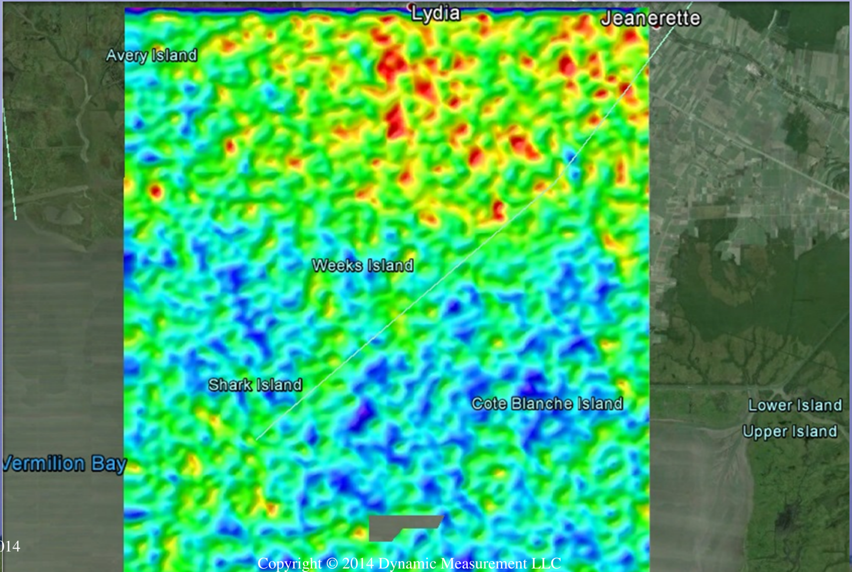
Lightning strike waveform

- Location
- Time and Duration
- Rise Time
- Peak Current
- Peak-to-Zero
- Polarity
- Chi^2
- Number of Sensors



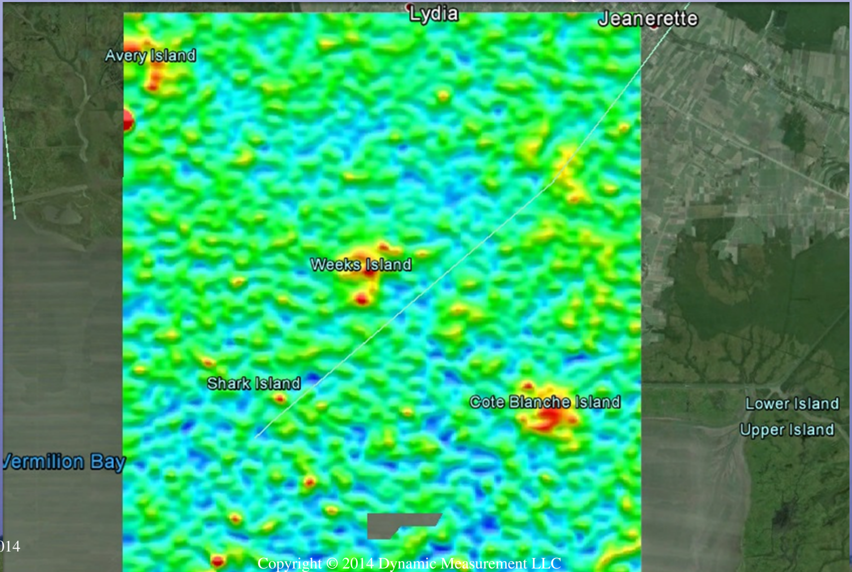
Lightning strike density

Louisiana



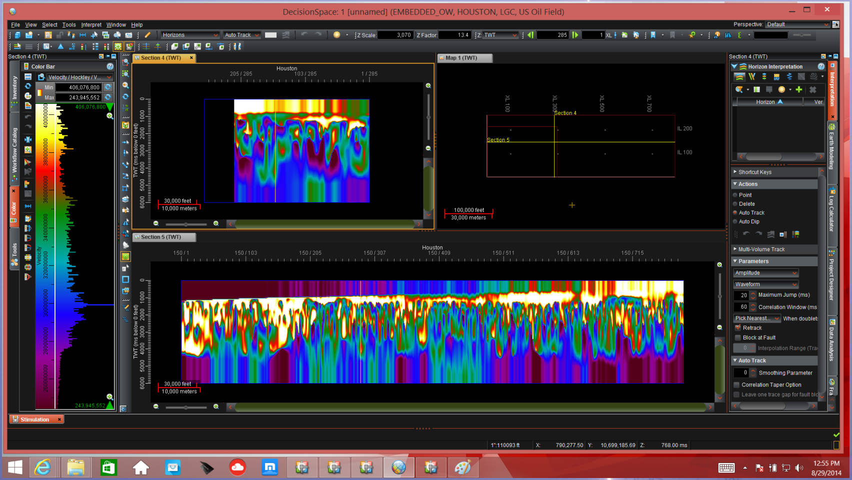
Lightning rate of rise time

Louisiana (identifies salt domes)



A Resistivity Volume

From Sealy to La Porte



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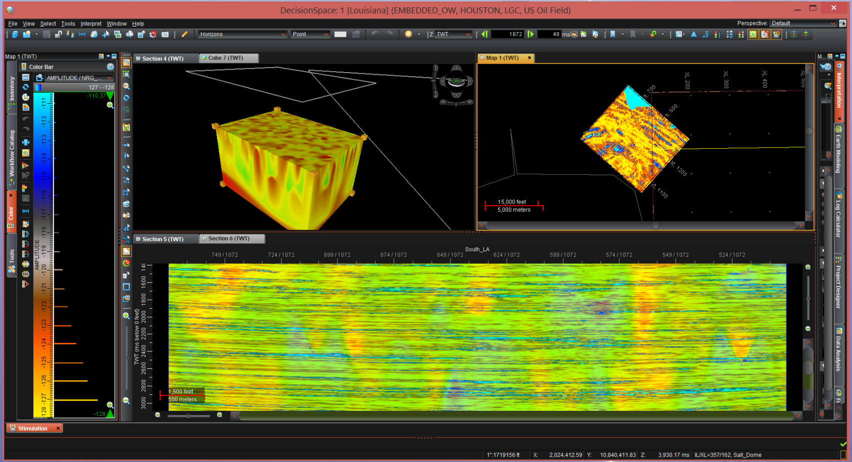
Southern Louisiana



Outline

Introduction

- Objective
- Lightning and its recording

Lightning and rock resistivity

- Calculating earth resistance
- From resistance to resistivity

Resistivity volumes

- Resistivity vs Depth
- Creating a Resistivity “Trace”
- Resistivity lines and volumes

Conclusions

Objective

This presentation explains how archived lightning databases can be used to generate data volumes usable by seismic interpretation systems, either in conjunction with conventional seismic data, 2D or 3D, or by itself.

Recording Lightning

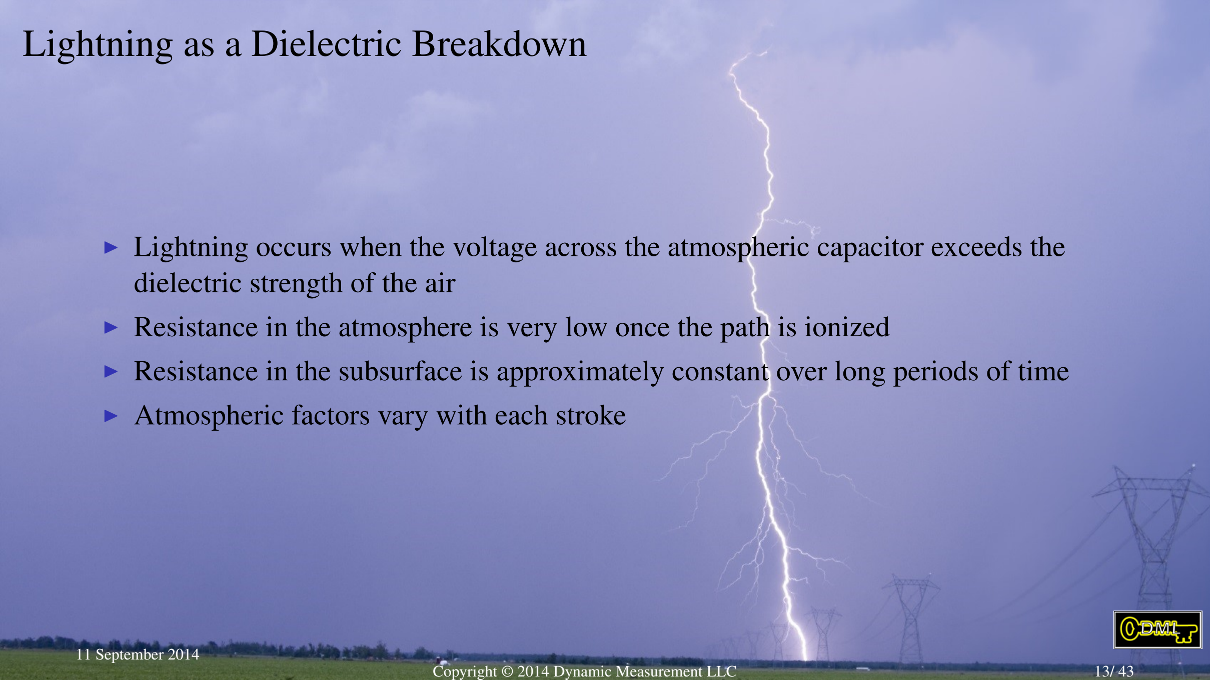
- Cloud-to-ground lightning can be measured and recorded
- Lightning measurements have been made for more than thirty years
- A continuous record of essentially all cloud-to-ground lightning strokes in the contiguous U.S.A has been made for approximately fifteen years.
- A continuous record of cloud-to-ground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

The Atmospheric Capacitor

- A 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

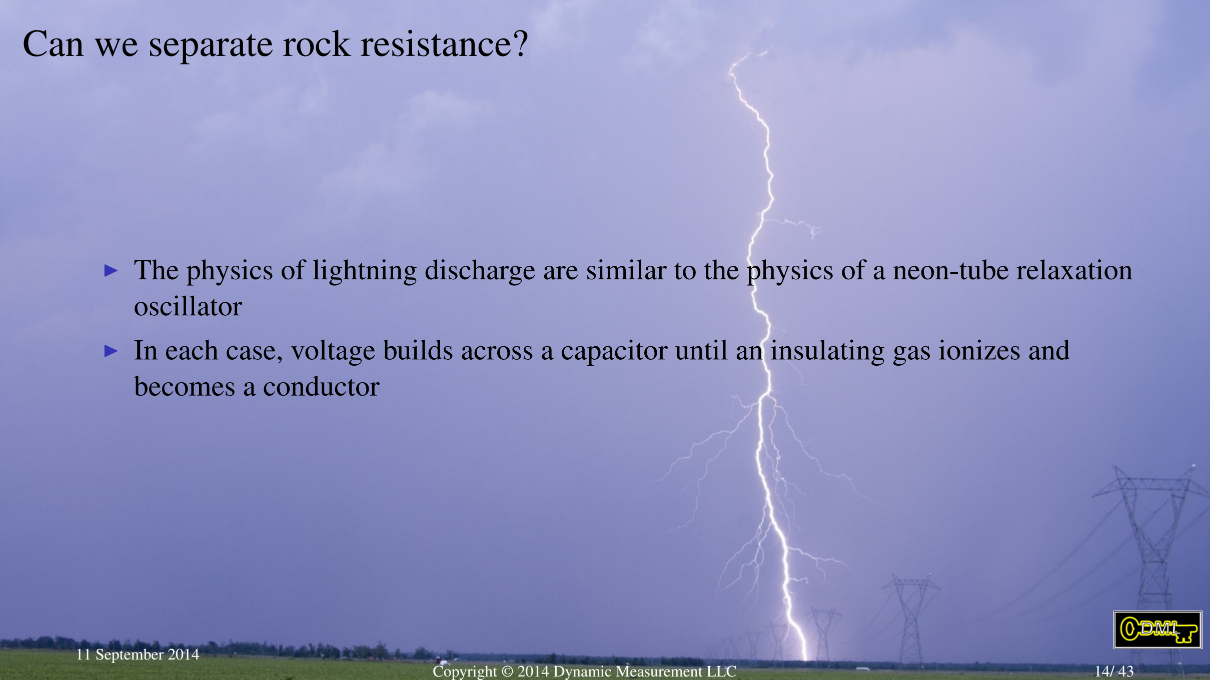

Plate 1
Dielectric
Plate 2

Lightning as a Dielectric Breakdown



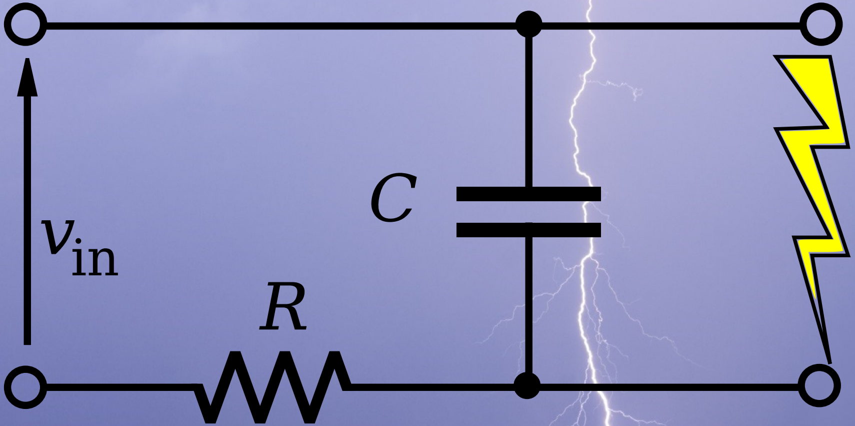
- Lightning occurs when the voltage across the atmospheric capacitor exceeds the dielectric strength of the air
- Resistance in the atmosphere is very low once the path is ionized
- Resistance in the subsurface is approximately constant over long periods of time
- Atmospheric factors vary with each stroke

Can we separate rock resistance?



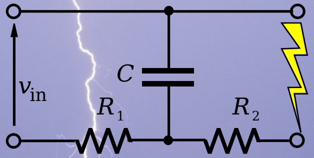
- The physics of lightning discharge are similar to the physics of a neon-tube relaxation oscillator
- In each case, voltage builds across a capacitor until an insulating gas ionizes and becomes a conductor

Relaxation Oscillator



Lightning

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



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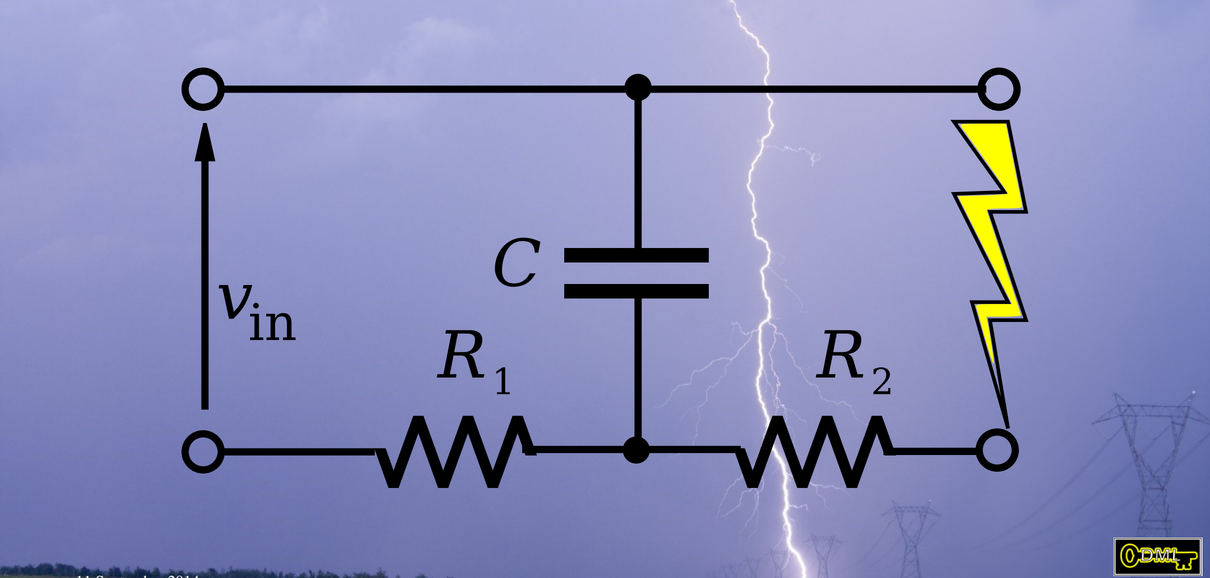

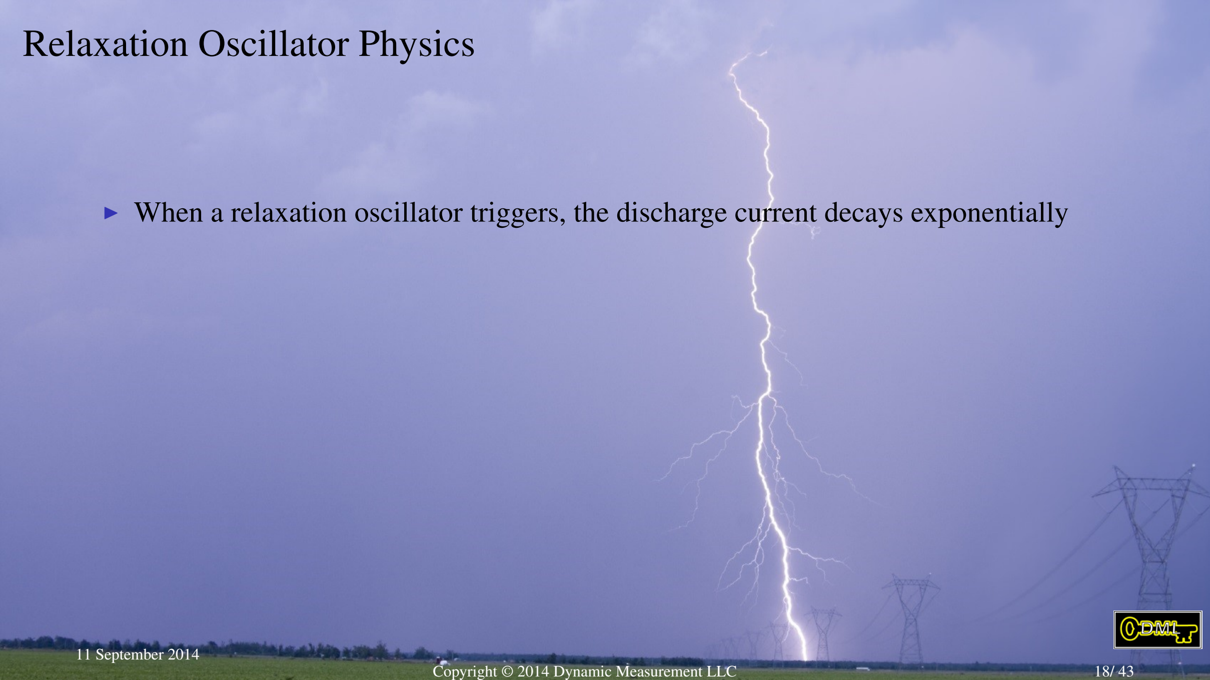

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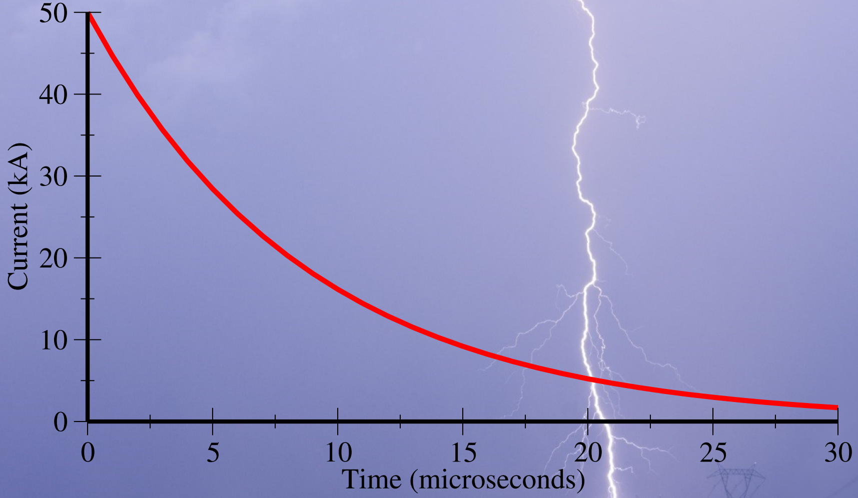
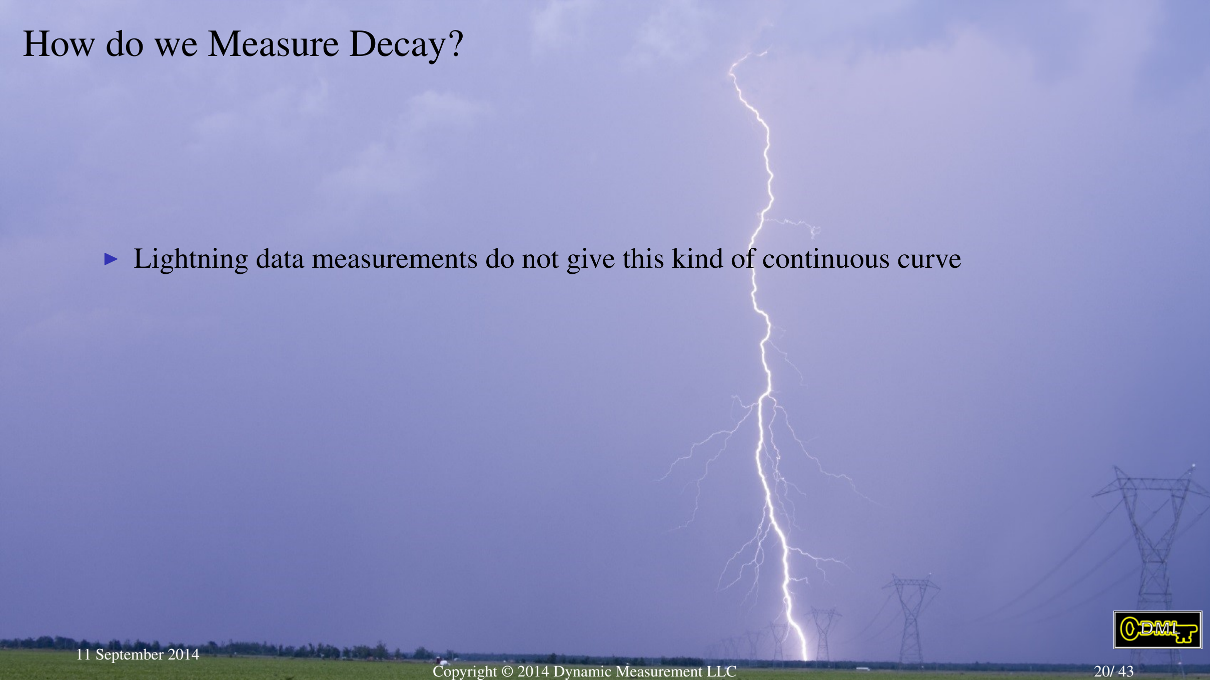
- If lightning is similar, can we use the decay to measure resistance?
  - This equation can be rearranged to $ln(\frac{I_t}{I_0}) = -\frac{t}{RC}$ or $R = -\frac{t}{ln(\frac{I_t}{I_0})C}$
  - All we need is the current at two times (I_0 and I_t), and the capacitance (C) to get the resistance R

Exponential Decay



How do we Measure Decay?



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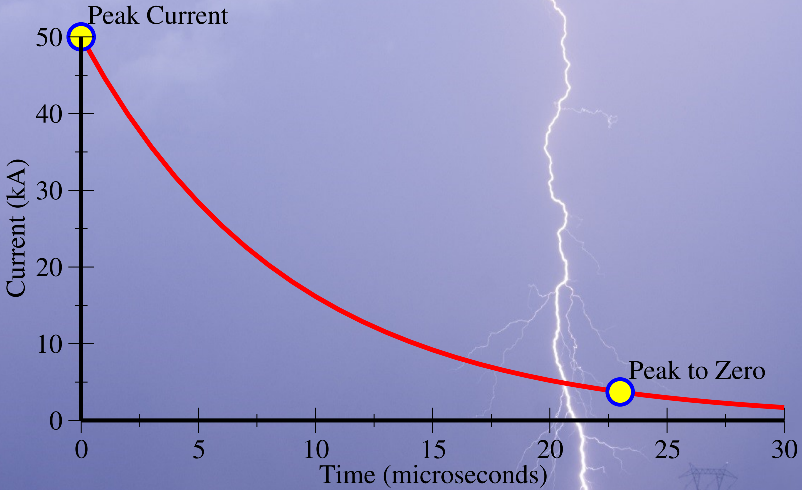
How do we Measure Decay?

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

The Available Measurements



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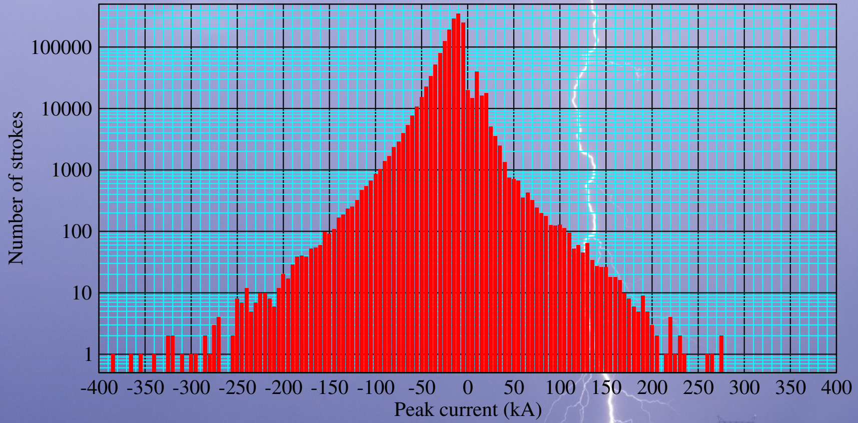
- The time for current to decay to a real zero is infinite
- We need an estimate of the magnitude of the “zero” current (at time t) in order to compute resistance

What is “Zero” Current?

Histogram of peak current for 1.6 million strikes



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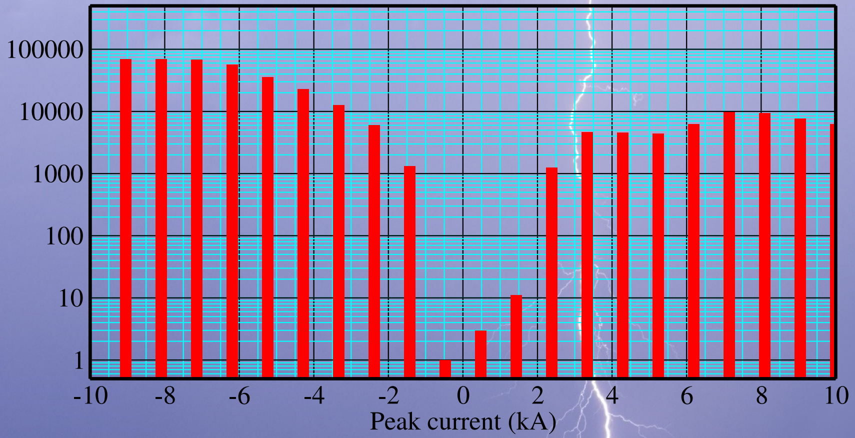

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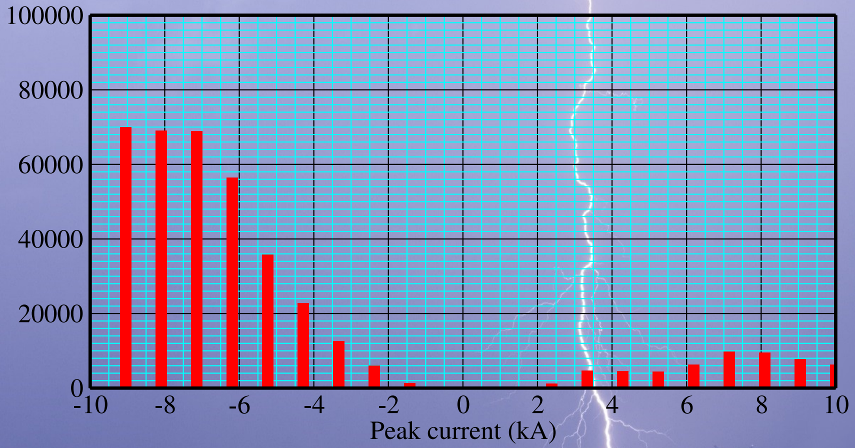

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- But the equation gives a solution with capacitance rather than voltage
- However, how do we find capacitance?
- Capacitance depends on permittivity, plate area and plate separation
- While permittivity is approximately constant and known for air,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

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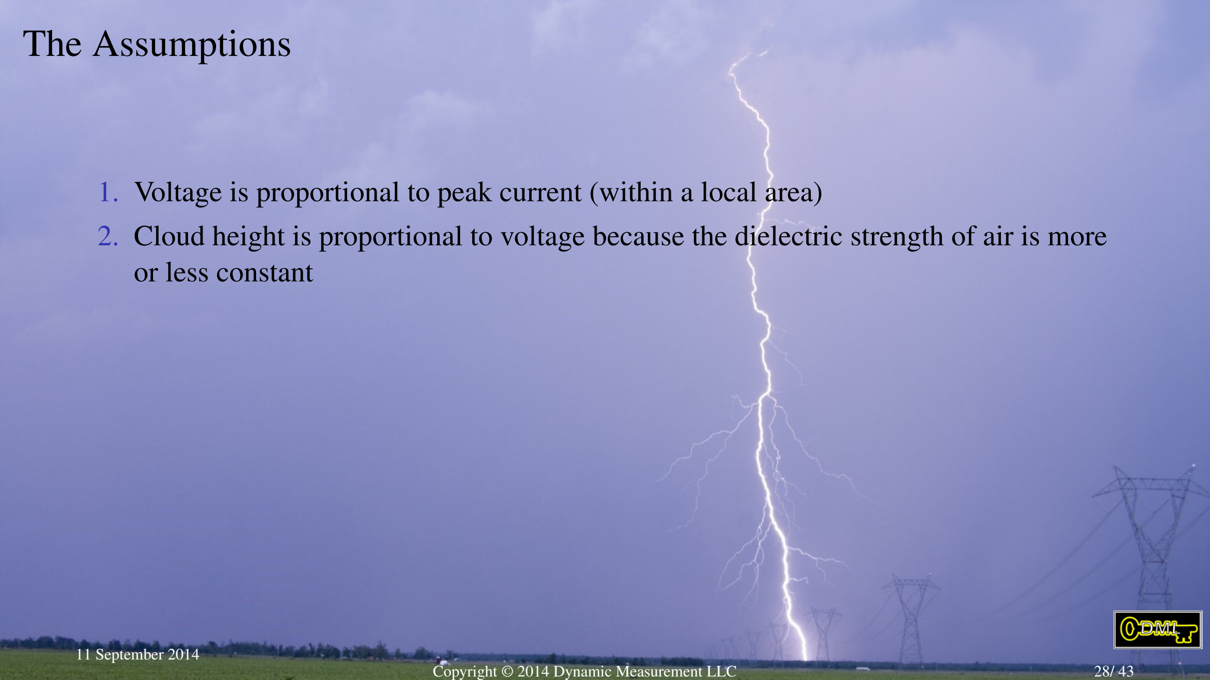

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4. With over 100 lightning strikes per square kilometer per year in many areas, we can stack results to improve signal-to-noise ratio

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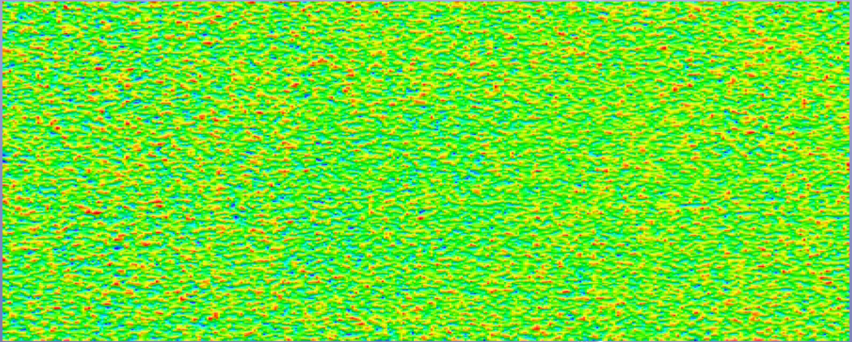
- For low energy lightning, the resistivity measured is that of rocks close to the surface
- For higher energy lightning, the resistivity measured is an average of resistivities to greater depths.

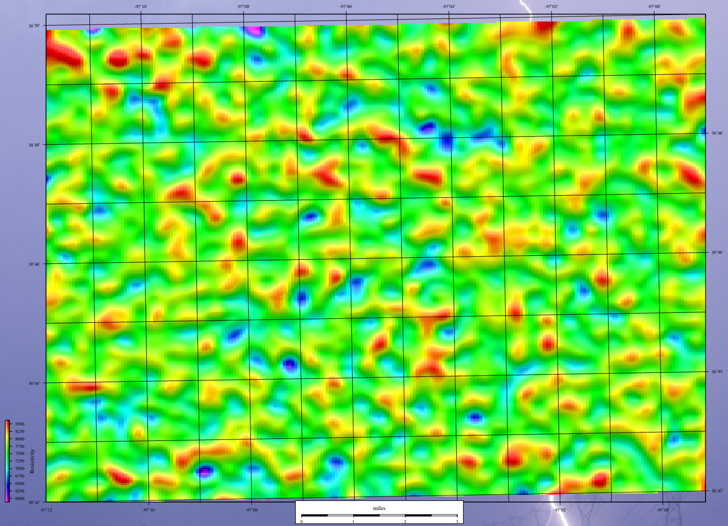
A Resistivity Map

Covering most of Harris County

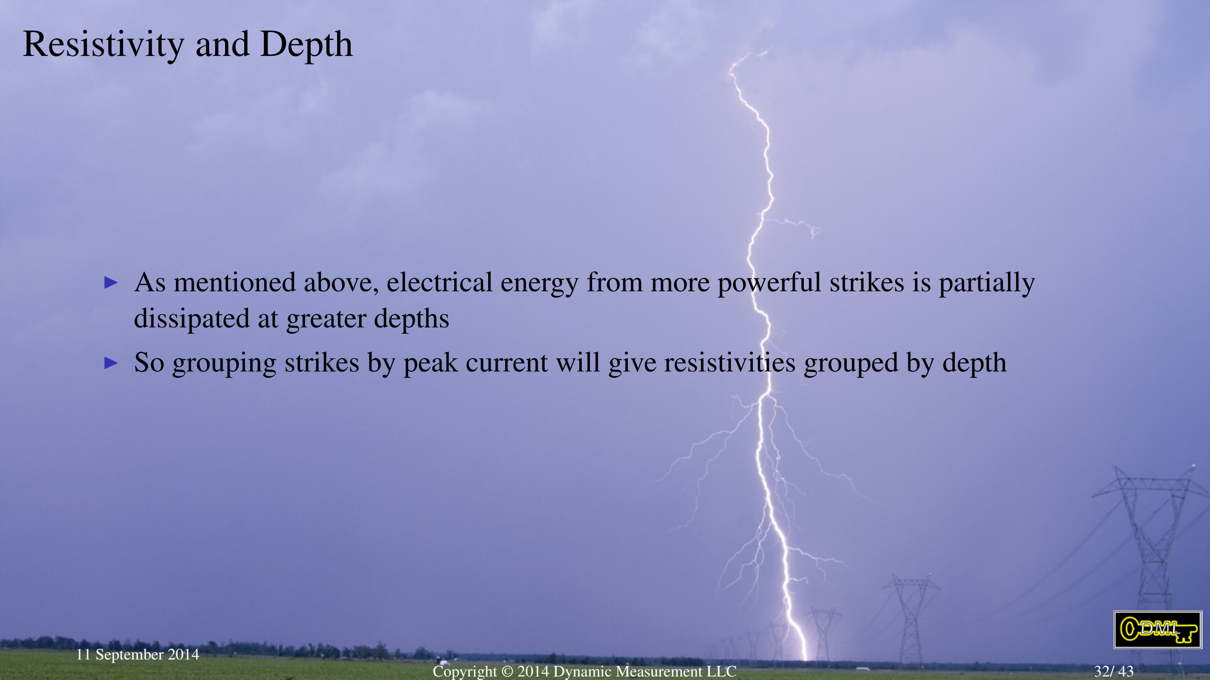


Another Resistivity Map

Covering part of 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

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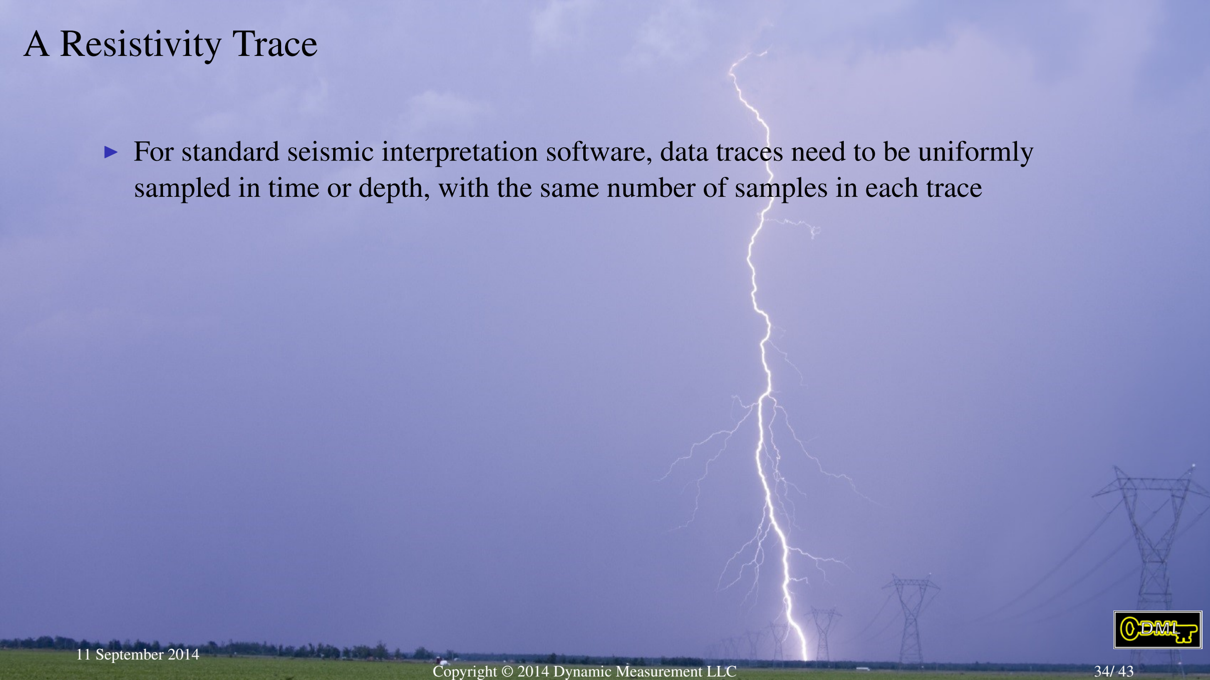
3. For each cell in each group, resistivity and depth values are computed from the lightning data
4. For each group a smooth surface is fitted to the depth values and to the resistivity values
   - At any point in the project area, a number of depth/resistivity pairs equal to the number of groups in 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



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1. At latitude and longitude for the trace, each depth grid is sampled and each resistivity grid is sampled
2. Resistivity values are interpolated with depth between these points to give samples at uniform intervals

- Typical sample interval is 16 m
- Typical trace length is 125 samples
- There is no restriction in sample interval or length beyond those imposed by the SEG-Y format

A 2D Resistivity Line

- A straight or crooked 2D line, following an existing seismic line, joining wells, or simply in a geologically interesting location, is easily prepared
  - Required input is the location of the line, in the form of a SEG-P1 or similar file, giving locations in a known projection, or as latitude and longitude, for defined trace numbers (or defined surface point numbers with a defined relationship between surface point numbers and trace numbers

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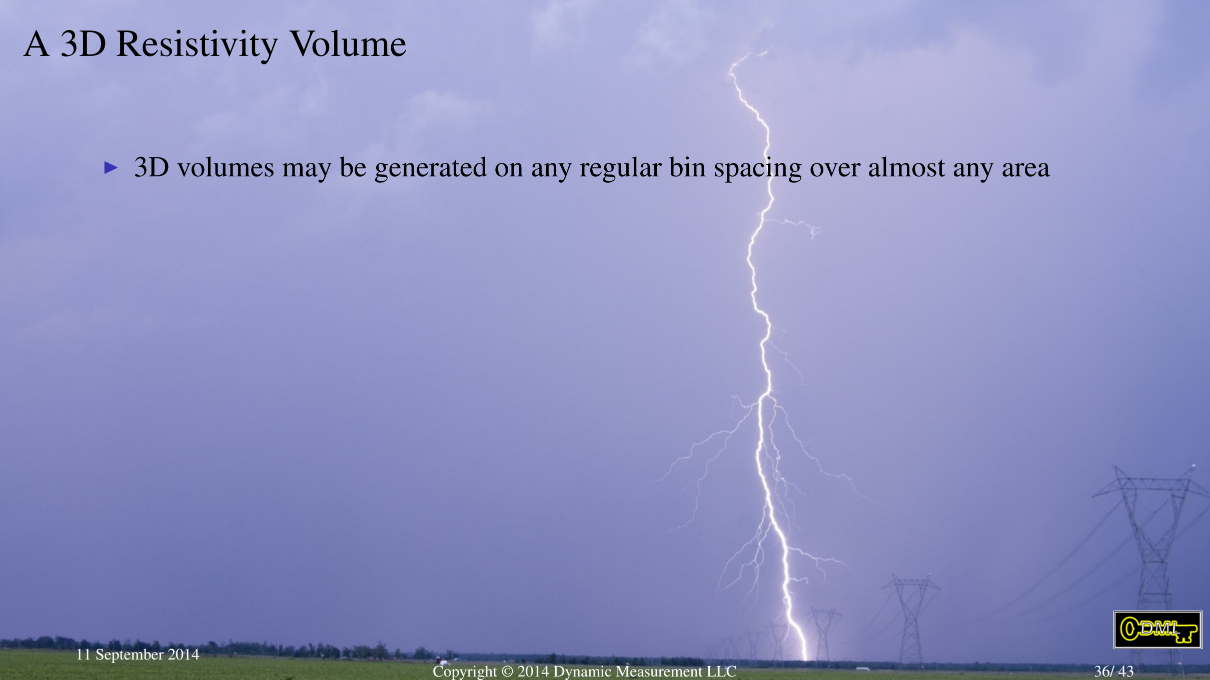
4. The traces are written to a SEG-Y format file

A 3D Resistivity Volume

- 3D volumes may be generated on any regular bin spacing over almost any area



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- 3D volumes may be generated on any regular bin spacing over almost any area
- Required input is a unique definition of the binset such as:
  - The geographic projection for definition of the trace locations (e.g. *UTM 15N*, *NAD27 4204*, or *EPSG 32040*)
  - Line and crossline number of the corner with lowest line and crossline numbers
  - Location of this point in latitude and longitude or X and Y in the defined projection
  - Grid azimuth of inline in the direction of increasing crossline number
  - Direction of increasing line number (*left* or *right*, when looking towards increasing crossline numbers
  - Last line number and last crossline number
  - Line spacing and crossline spacing in feet or meters

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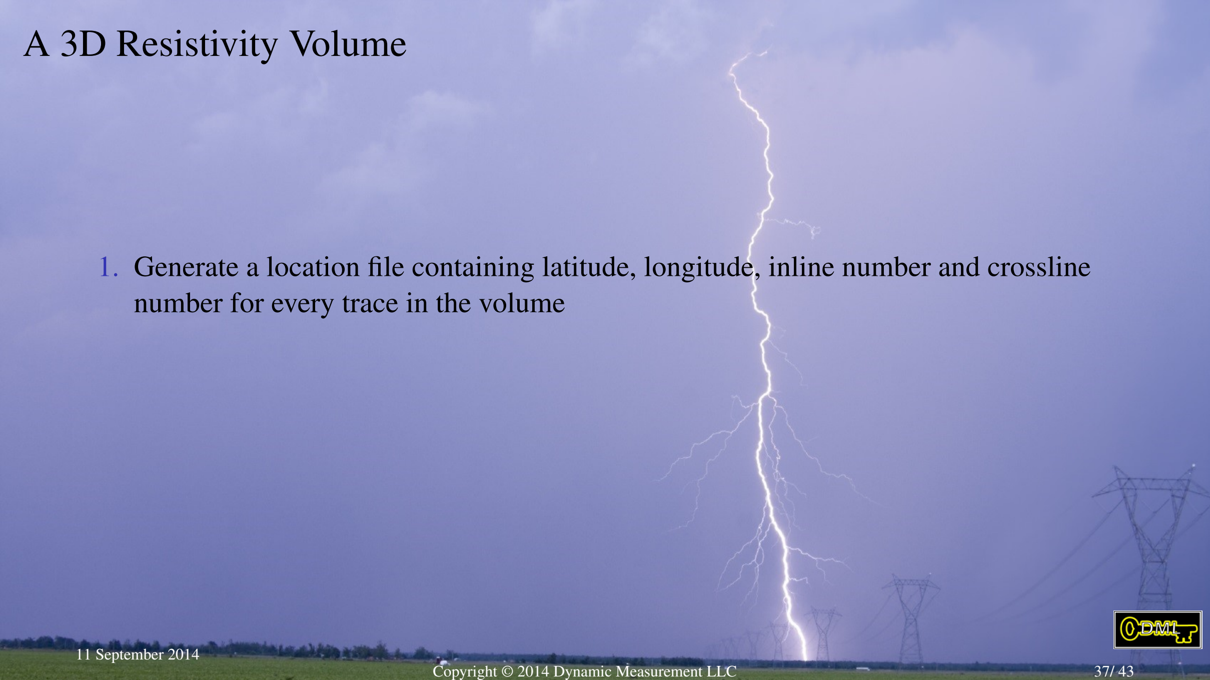

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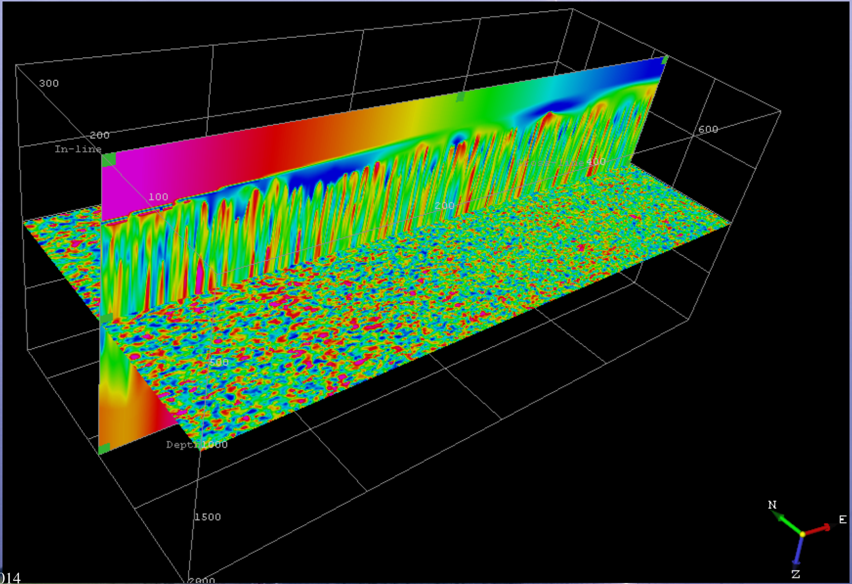

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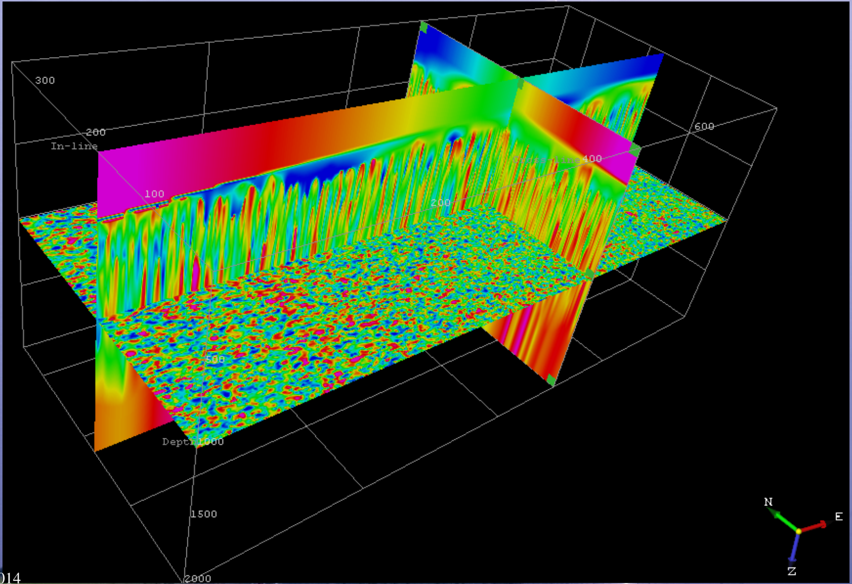

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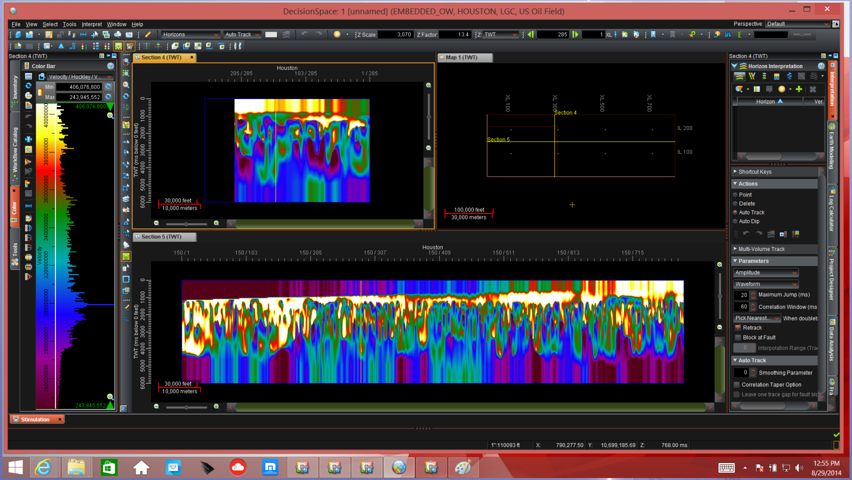

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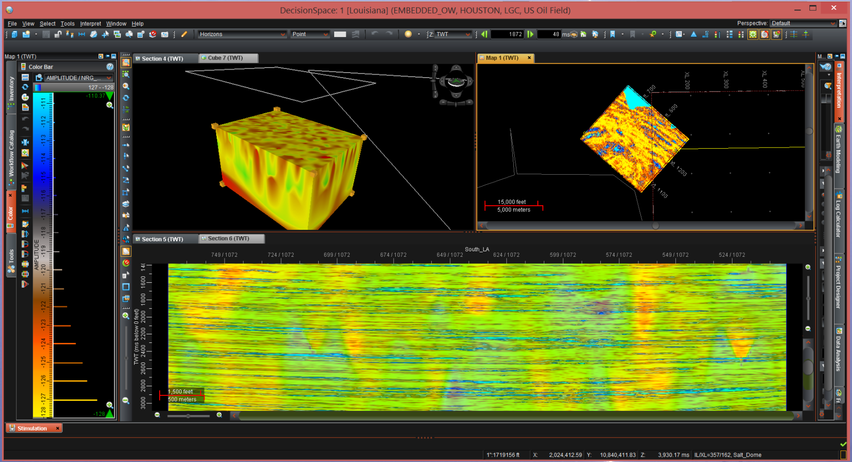
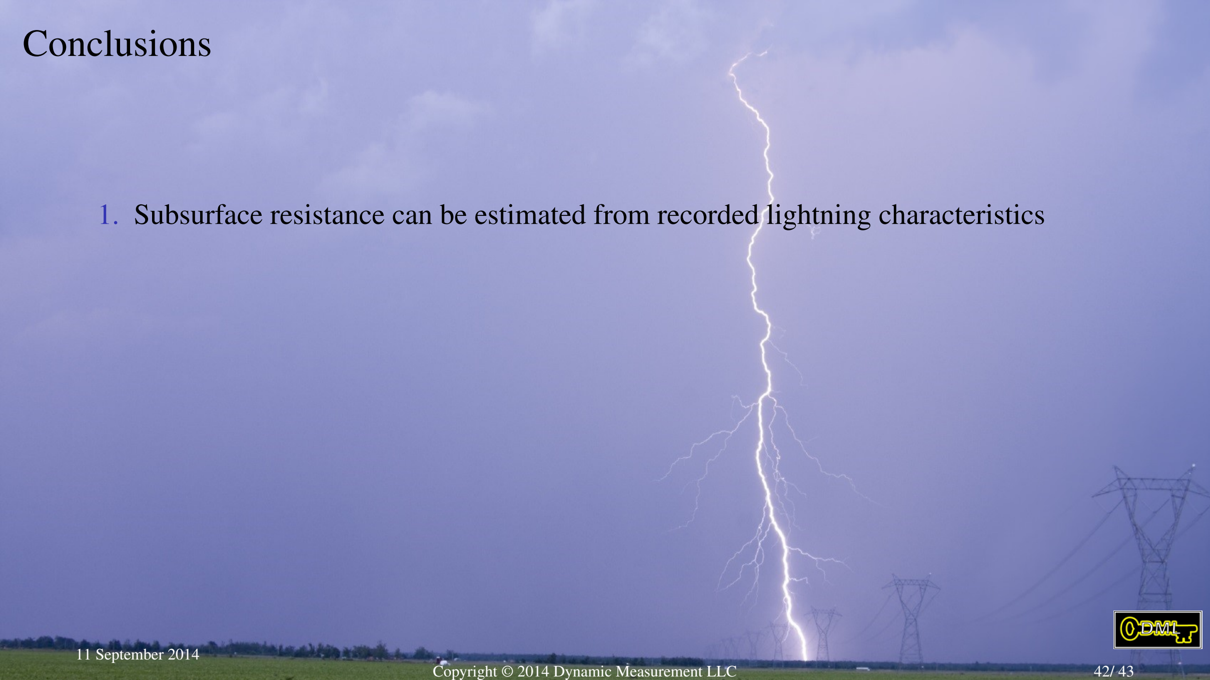


Conclusions



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3. Depth of penetration of resistivity estimates varies with energy of a lightning strike
4. A three-dimensional model of resistivity as a function of X, Y, and Z can be constructed, though scaling for the Z-axis and the resistivity is uncertain
5. Traces similar to seismic traces can be constructed to allow the results to be interpreted using standard exploration workstations


END