



Calculating Resistivity Volumes from Lightning Databases

A Seminar by Wipro and Dynamic Measurement LLC

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

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

Plate 1

Dielectric

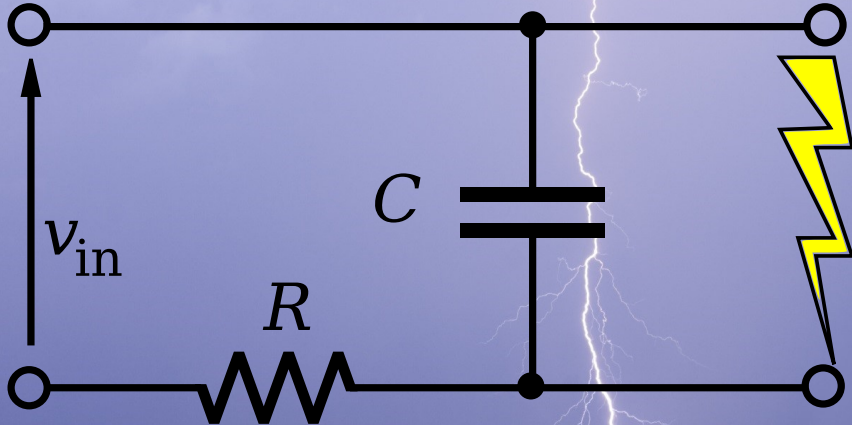
Plate 2



Can we separate rock resistance?

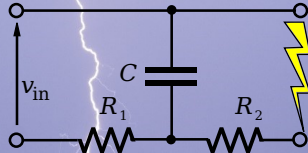
- ▶ The physics of lightning discharge are similar to the physics of a neon-tube relaxation oscillator
- ▶ In each case, voltage builds across a capacitor until an insulating gas ionizes and becomes a conductor

Relaxation Oscillator

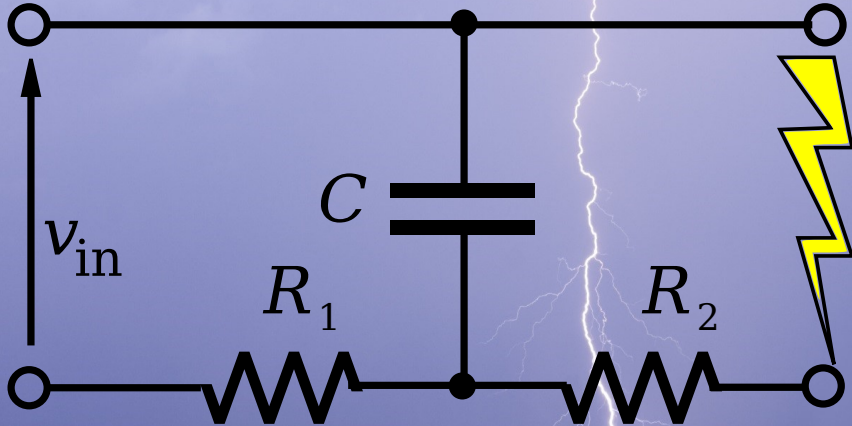


Lightning

- ▶ 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



Lightning



Relaxation Oscillator Physics

- ▶ When a relaxation oscillator triggers, the discharge current decays exponentially

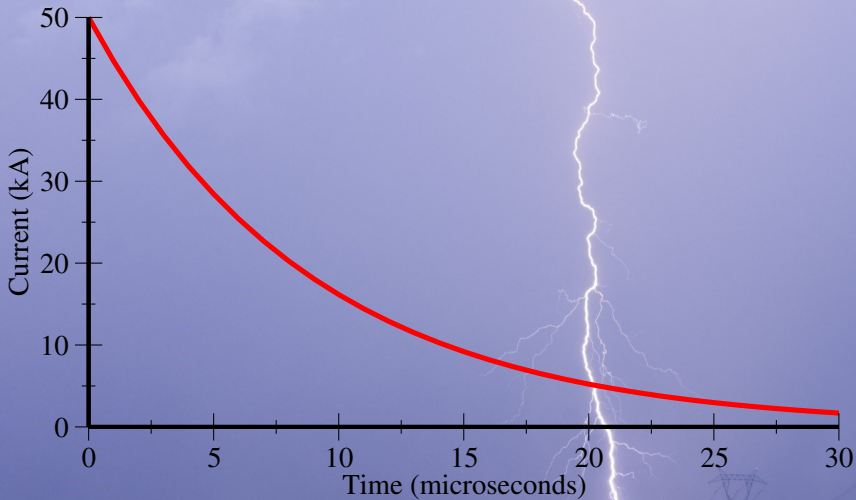
Relaxation Oscillator Physics

- ▶ When a relaxation oscillator triggers, the discharge current decays exponentially
- ▶ The rate of decay is given by $I_t = I_0 e^{-t/RC}$

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

Exponential Decay



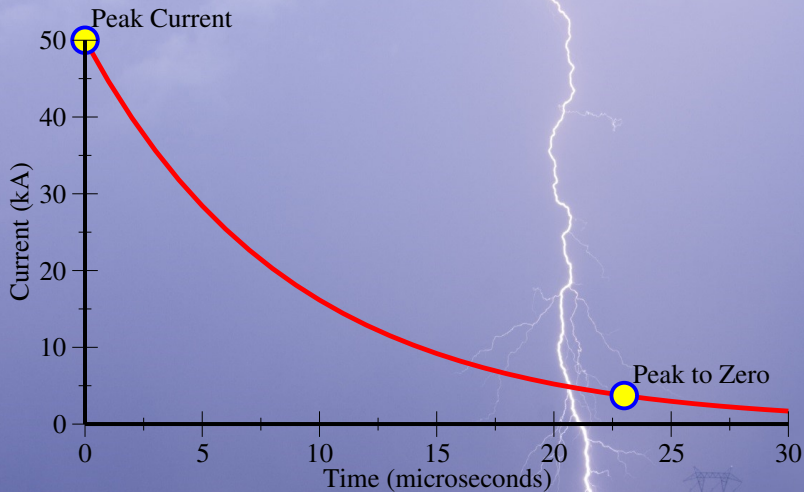
How do we Measure Decay?

- ▶ Lightning data measurements do not give this kind of continuous curve

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



The Available Measurements

Two points on an exponential curve will define the curve

Peak Current



The Available Measurements

Two points on an exponential curve will define the curve

Peak Current

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

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 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 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

The Available Measurements

Two points on an exponential curve will define the curve

Peak Current

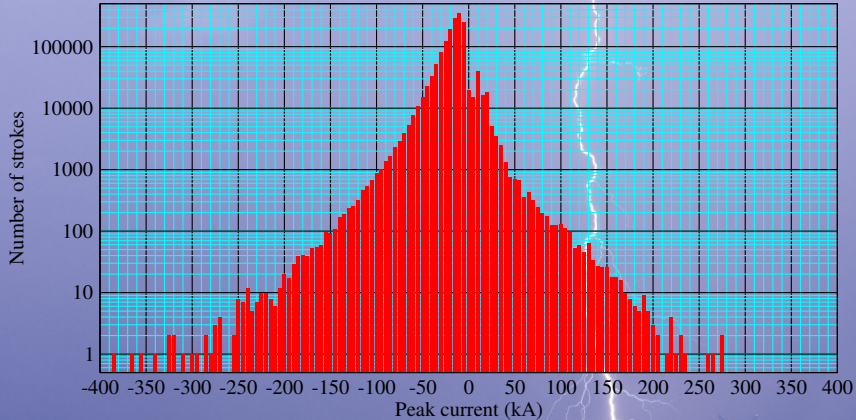
- ▶ The maximum recorded current, when decay starts (I_0)

Peak to Zero time:

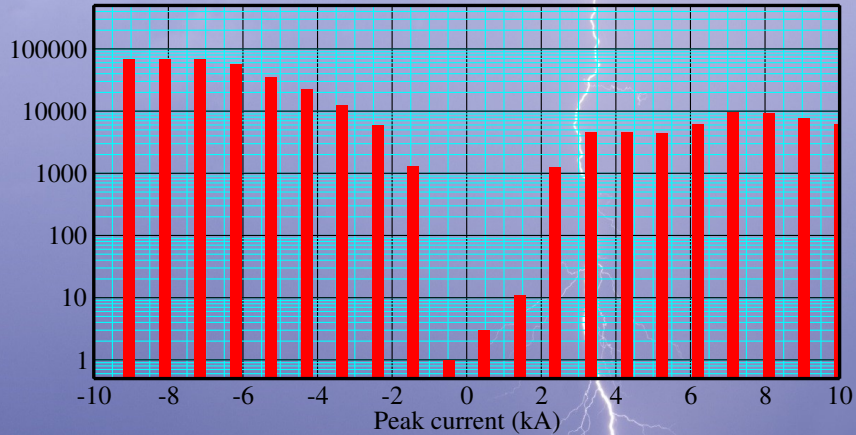
- ▶ The elapsed time from the instant of Peak Current until the recorded signal disappears into the background noise
- ▶ This gives us the time t
- ▶ But what is the current (I_t)?
- ▶ The time for current to decay to a real zero is infinite
- ▶ We need an estimate of the magnitude of the “zero” current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

What is “Zero” Current?

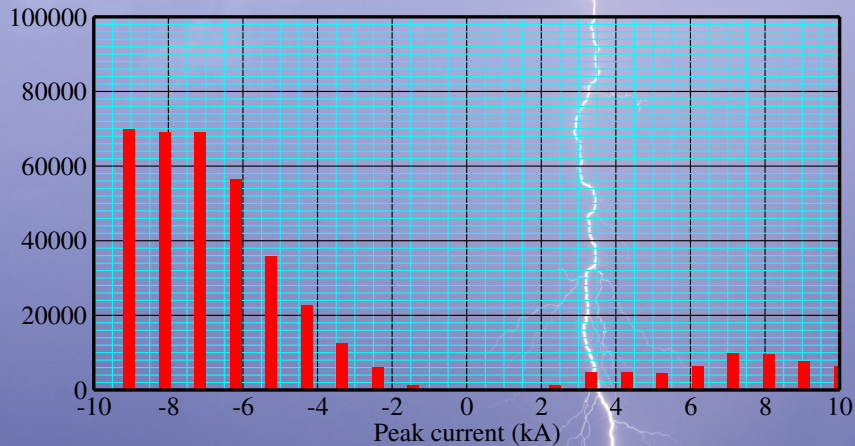
Histogram of peak current for 1.6 million strikes



What is “Zero” Current?



What is “Zero” Current?



What is “Zero” Current?

- ▶ Total strikes 1.6 million



What is “Zero” Current?

- ▶ Total strikes 1.6 million
- ▶ 320,000 less than 10 kA absolute peak current

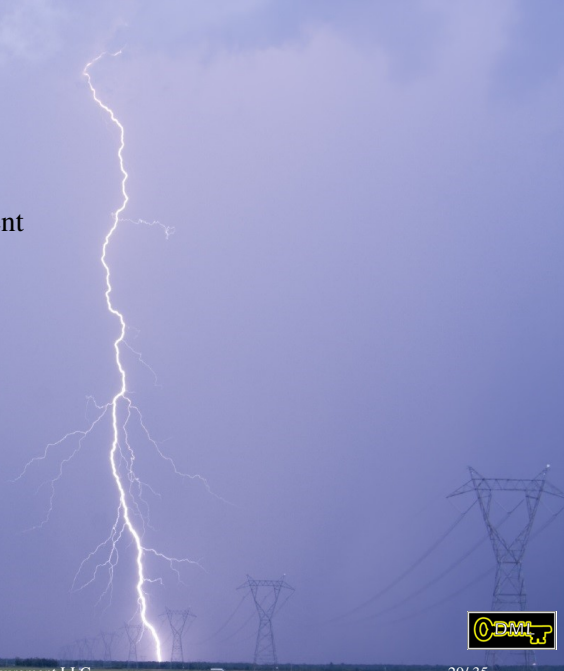


What is “Zero” Current?

- ▶ Total strikes 1.6 million
- ▶ 320,000 less than 10 kA absolute peak current
- ▶ 30,400 less than 5 kA absolute peak current

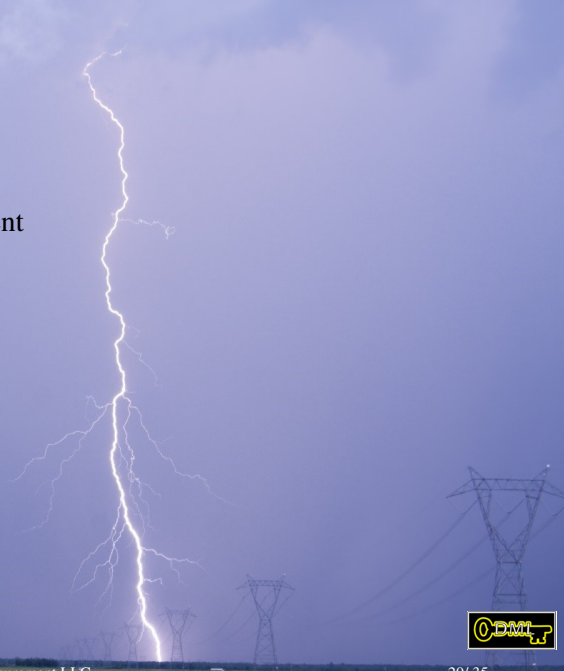
What is “Zero” Current?

- ▶ 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



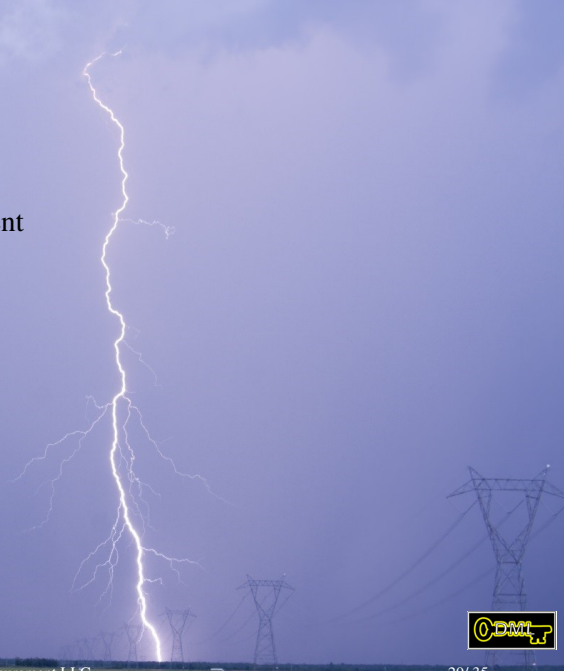
What is “Zero” Current?

- ▶ 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



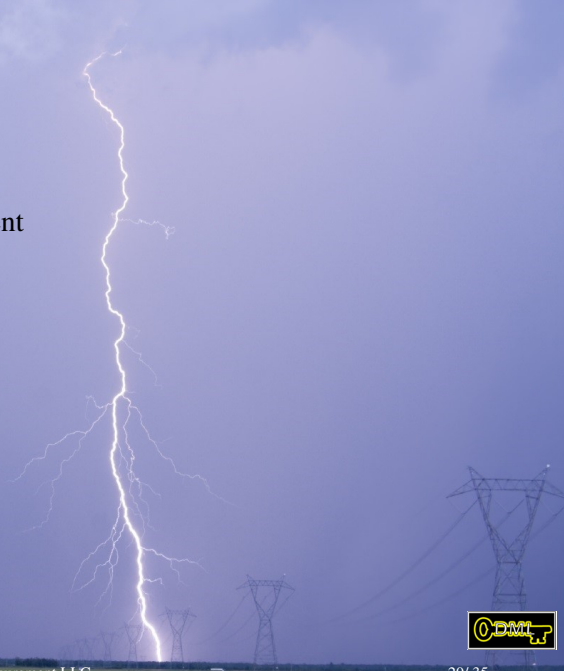
What is “Zero” Current?

- ▶ 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



What is “Zero” Current?

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



What about Voltage?

- ▶ Resistance is equal to voltage/current



What about Voltage?

- ▶ Resistance is equal to voltage/current
- ▶ Our measurements are of current only

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

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?

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

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. Peak current is proportional to voltage (within a local area)

The Assumptions

1. Peak current is proportional to voltage (within a local area)
2. Voltage is proportional to cloud height because the dielectric strength of air is more or less constant

The Assumptions

1. Peak current is proportional to voltage (within a local area)
2. Voltage is proportional to cloud height because the dielectric strength of air is more or less constant
 - ▶ This gives plate separation for the atmospheric capacitor

The Assumptions

1. Peak current is proportional to voltage (within a local area)
2. Voltage is proportional to cloud height 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.

The Assumptions

1. Peak current is proportional to voltage (within a local area)
2. Voltage is proportional to cloud height 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

The Assumptions

1. Peak current is proportional to voltage (within a local area)
2. Voltage is proportional to cloud height 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 cross-sectional area of a conductor divided by its length or
$$\rho = R \times \frac{A}{l}$$

What is resistivity?

- ▶ Resistivity is resistance cross-sectional area of a conductor divided by its length or
$$\rho = R \times \frac{A}{l}$$
- ▶ 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 is much longer

What is resistivity?

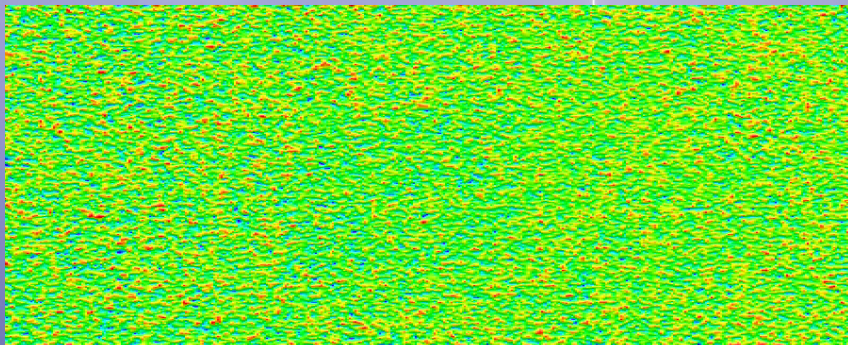
- ▶ Resistivity is resistance cross-sectional area of a conductor divided by its length or
$$\rho = R \times \frac{A}{l}$$
- ▶ For the lightning energy dissipating in the ground:
 - ▶ The area is very small at the strike point, but increases rapidly
 - ▶ The length is very short for discharging the charge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

What is resistivity?

- ▶ Resistivity is resistance cross-sectional area of a conductor divided by its length or
$$\rho = R \times \frac{A}{l}$$
- ▶ 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 is much longer
- ▶ 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



02 September 2014

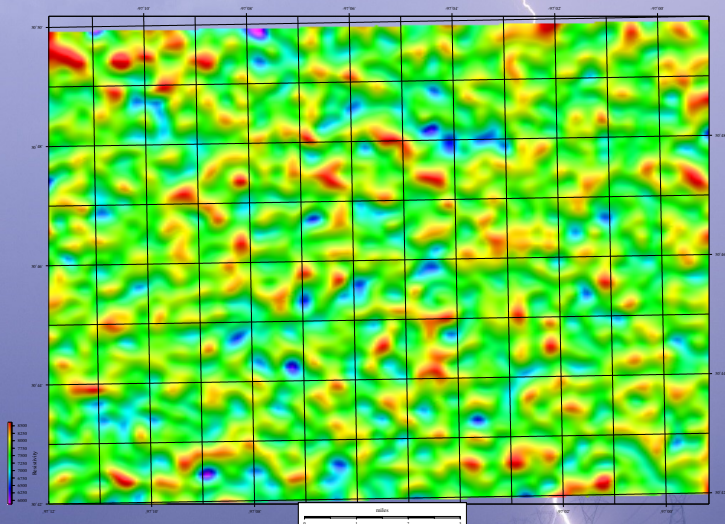
Copyright © 2014 Dynamic Measurement LLC



24/ 35

Another Resistivity Map

Covering part of Milam County



02 September 2014

Copyright © 2014 Dynamic Measurement LLC



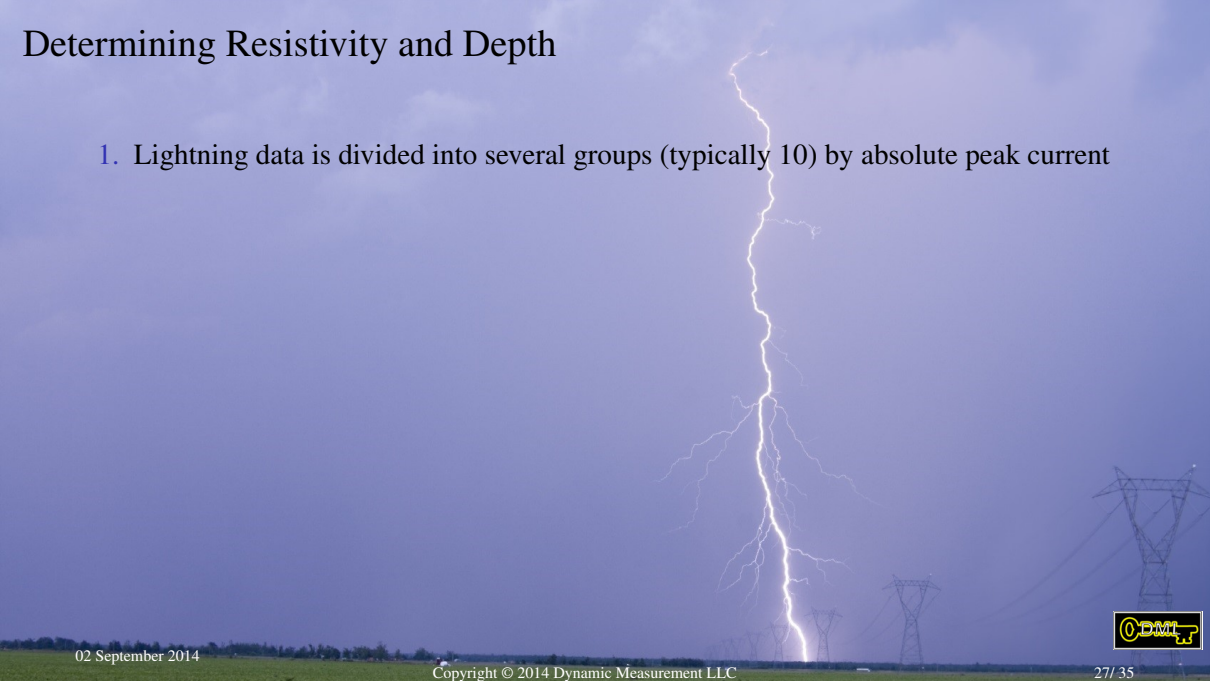
25/ 35

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



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 $0.03\text{-}0.04 \text{ km}^2$) cells by latitude and longitude
 - ▶ Not all cells will contain a lightning strike, but some cells will contain more than one lightning strike

Determining Resistivity and Depth

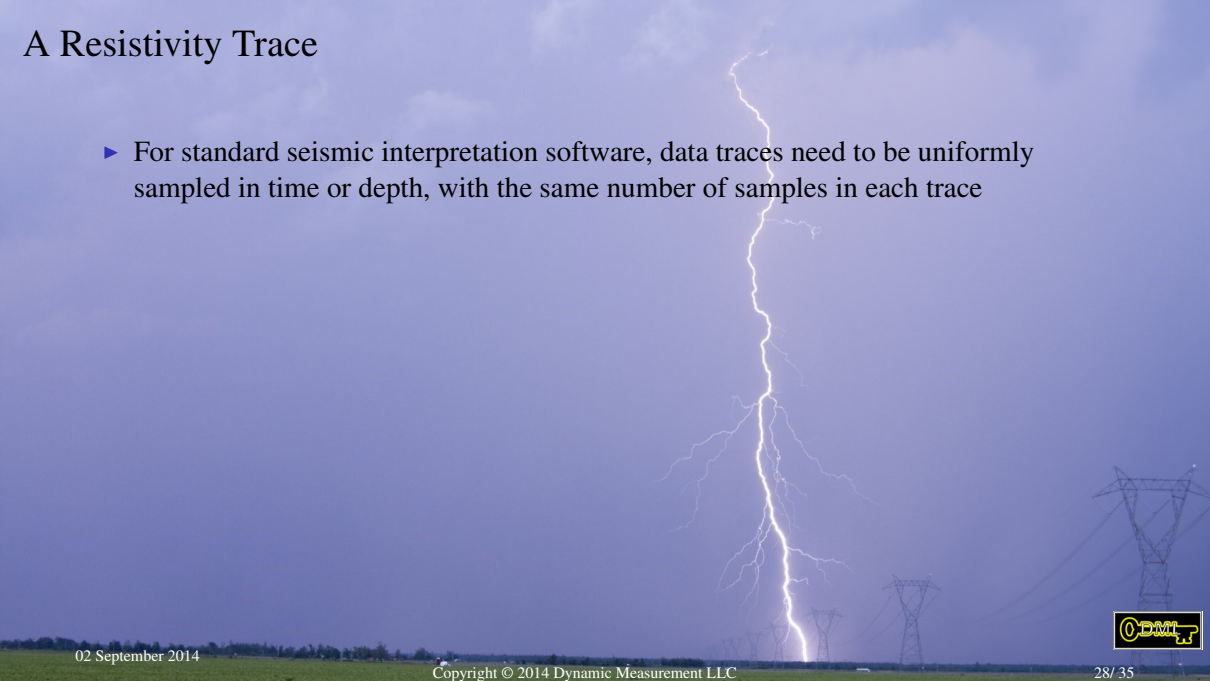
1. Lightning data is divided into several groups (typically 10) by absolute peak current
2. Each peak current group is divided into small (typically $0.03\text{-}0.04 \text{ km}^2$) cells by latitude and longitude
 - ▶ Not all cells will contain a lightning strike, but some cells will contain more than one lightning strike
3. For each cell in each group, resistivity and depth values are computed from the lightning data

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 $0.03\text{-}0.04\text{ km}^2$) 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



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
1. At latitude and longitude for the trace, each depth grid is sampled and each resistivity grid is sampled

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
- 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)

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)

1. Locations are converted to latitude and longitude

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)
1. Locations are converted to latitude and longitude
 2. Trace locations are interpolated as needed to give a location for each trace

A 2D Resistivity Line

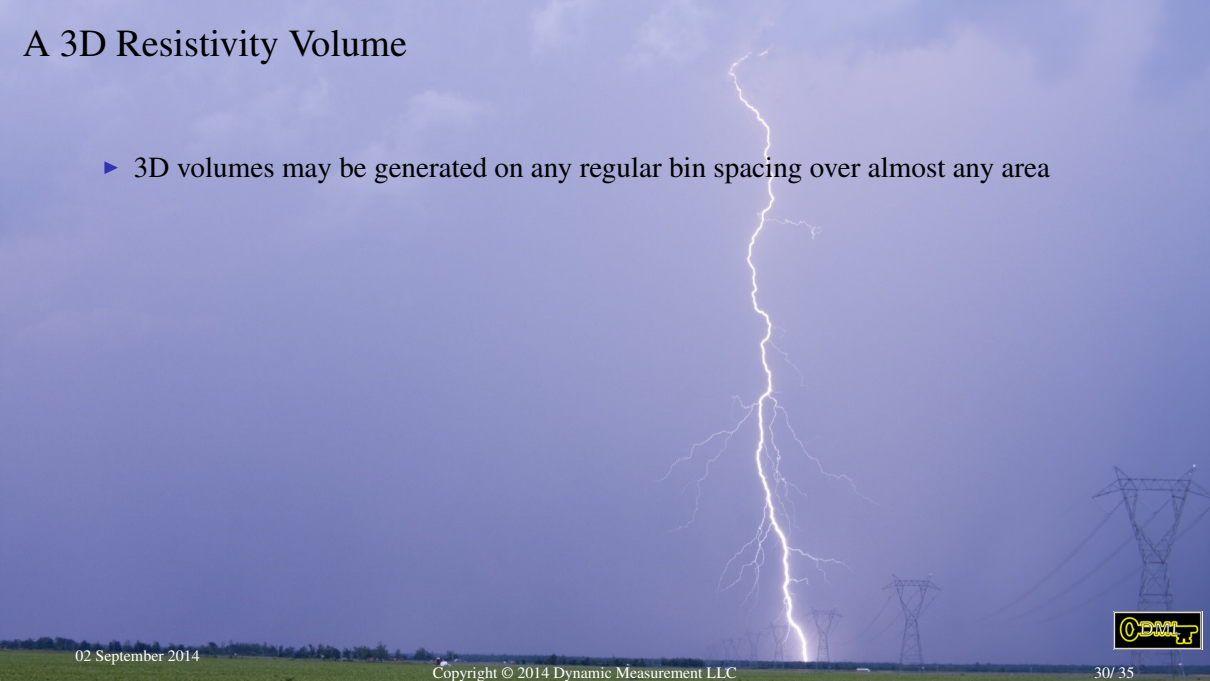
- ▶ A straight or crooked 2D line, following an existing seismic line, joining wells, or simply in a geologically interesting location, is easily prepared
 - ▶ Required input is the location of the line, in the form of a SEG-P1 or similar file, giving locations in a known projection, or as latitude and longitude, for defined trace numbers (or defined surface point numbers with a defined relationship between surface point numbers and trace numbers)
1. Locations are converted to latitude and longitude
 2. Trace locations are interpolated as needed to give a location for each trace
 3. A trace is generated at each location

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)
1. Locations are converted to latitude and longitude
 2. Trace locations are interpolated as needed to give a location for each trace
 3. A trace is generated at each location
 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



A 3D Resistivity Volume

- ▶ 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

A 3D Resistivity Volume

1. Generate a location file containing latitude, longitude, inline number and crossline number for every trace in the volume

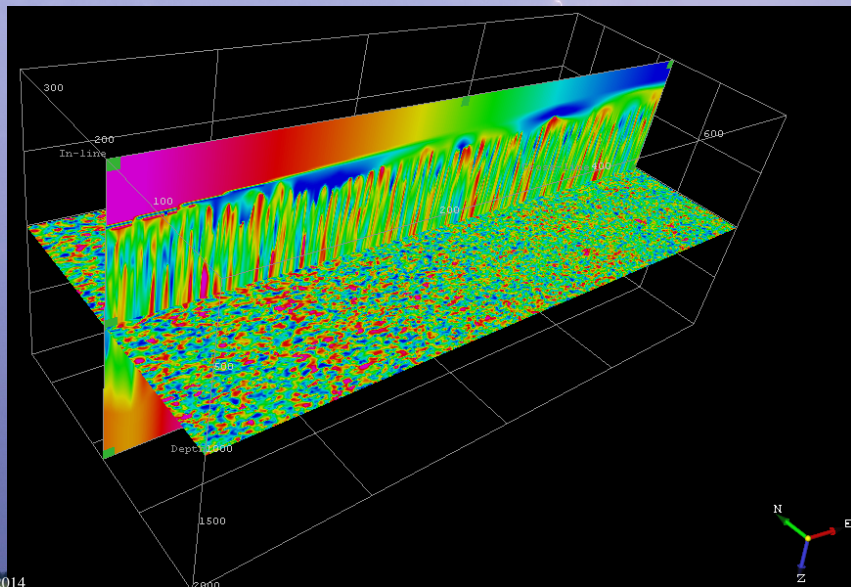
A 3D Resistivity Volume

1. Generate a location file containing latitude, longitude, inline number and crossline number for every trace in the volume
2. Generate a trace at each location

A 3D Resistivity Volume

1. Generate a location file containing latitude, longitude, inline number and crossline number for every trace in the volume
2. Generate a trace at each location
3. Write the traces to a SEG-Y file

A Resistivity Volume



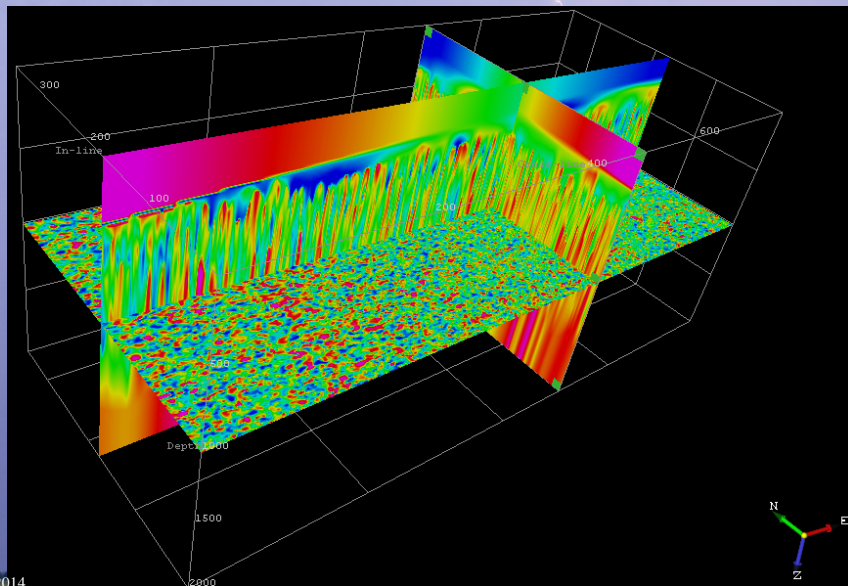
02 September 2014

Copyright © 2014 Dynamic Measurement LLC



32/ 35

A Resistivity Volume



Conclusions

1. Subsurface resistance can be estimated from recorded lightning characteristics

Conclusions

1. Subsurface resistance can be estimated from recorded lightning characteristics
2. Resistivity can be estimated from resistance

Conclusions

1. Subsurface resistance can be estimated from recorded lightning characteristics
2. Resistivity can be estimated from resistance
3. Depth of penetration of resistivity estimates varies with energy of a lightning strike

Conclusions

1. Subsurface resistance can be estimated from recorded lightning characteristics
2. Resistivity can be estimated from resistance
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

Conclusions

1. Subsurface resistance can be estimated from recorded lightning characteristics
2. Resistivity can be estimated from resistance
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

