Interpreting resistivity from lightning strikes

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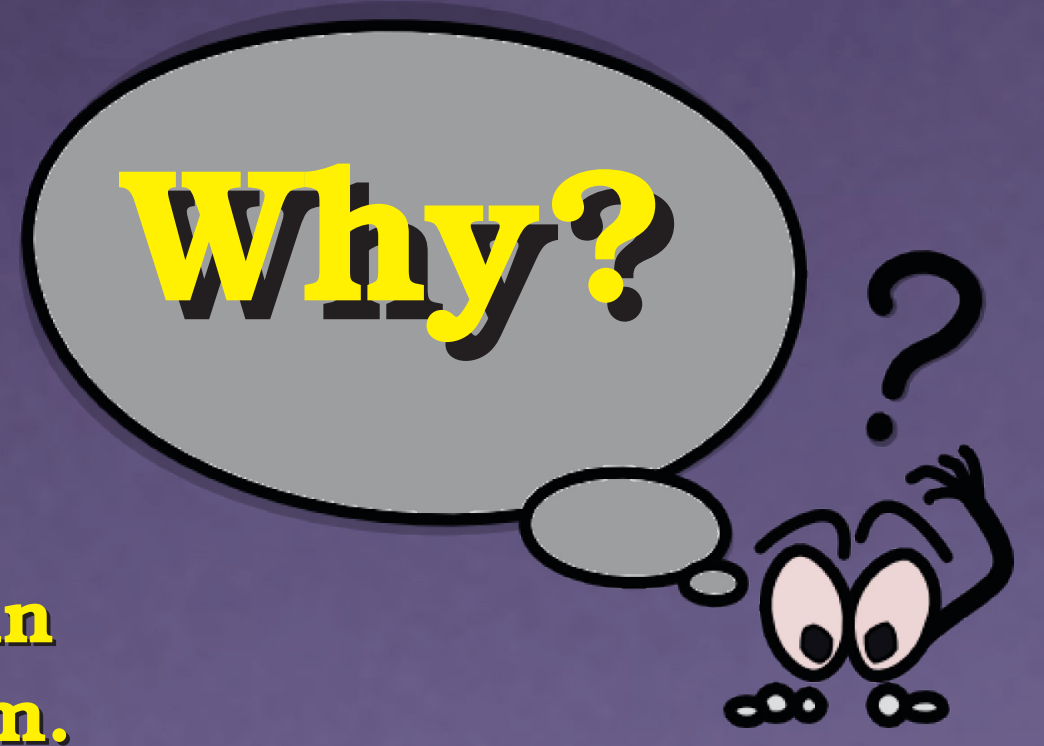
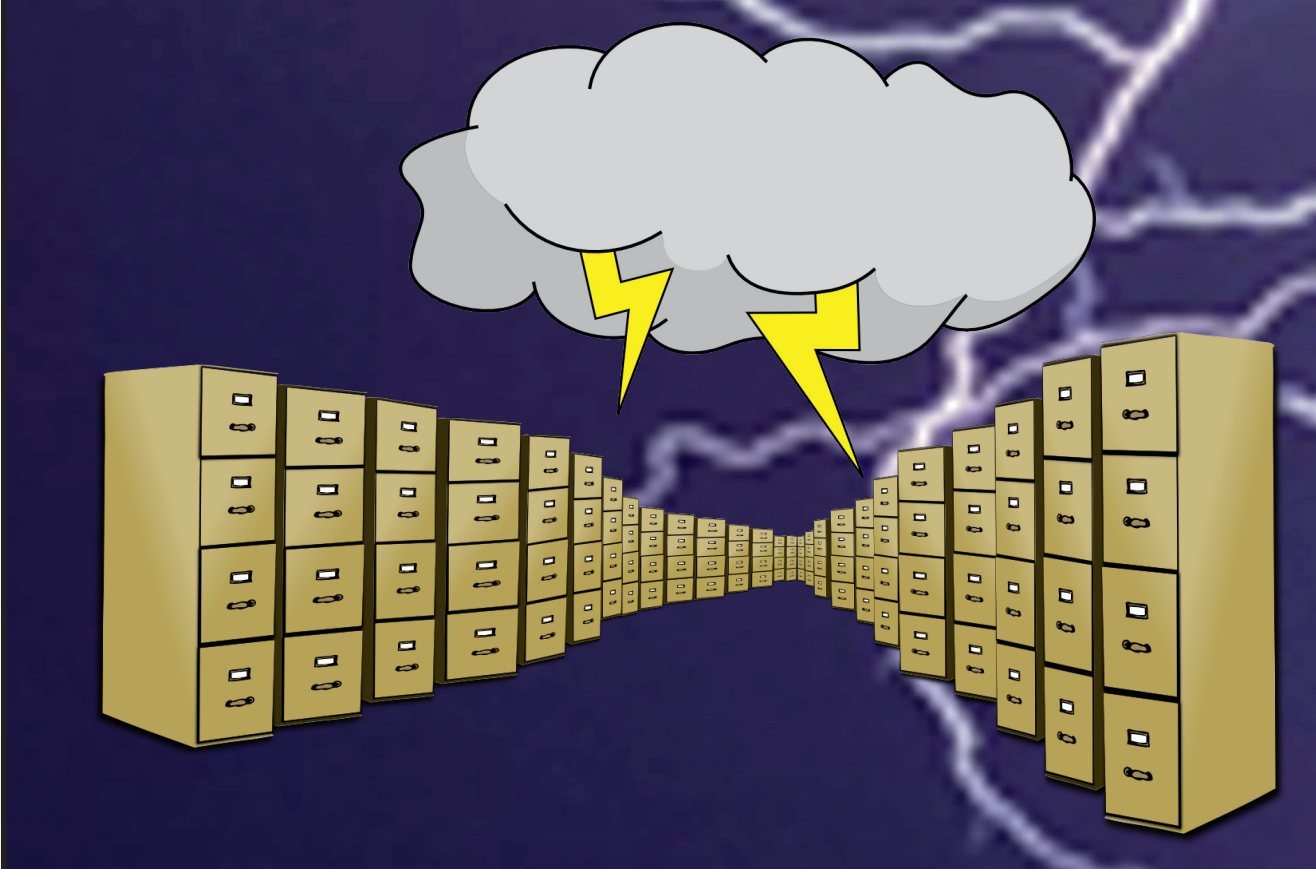


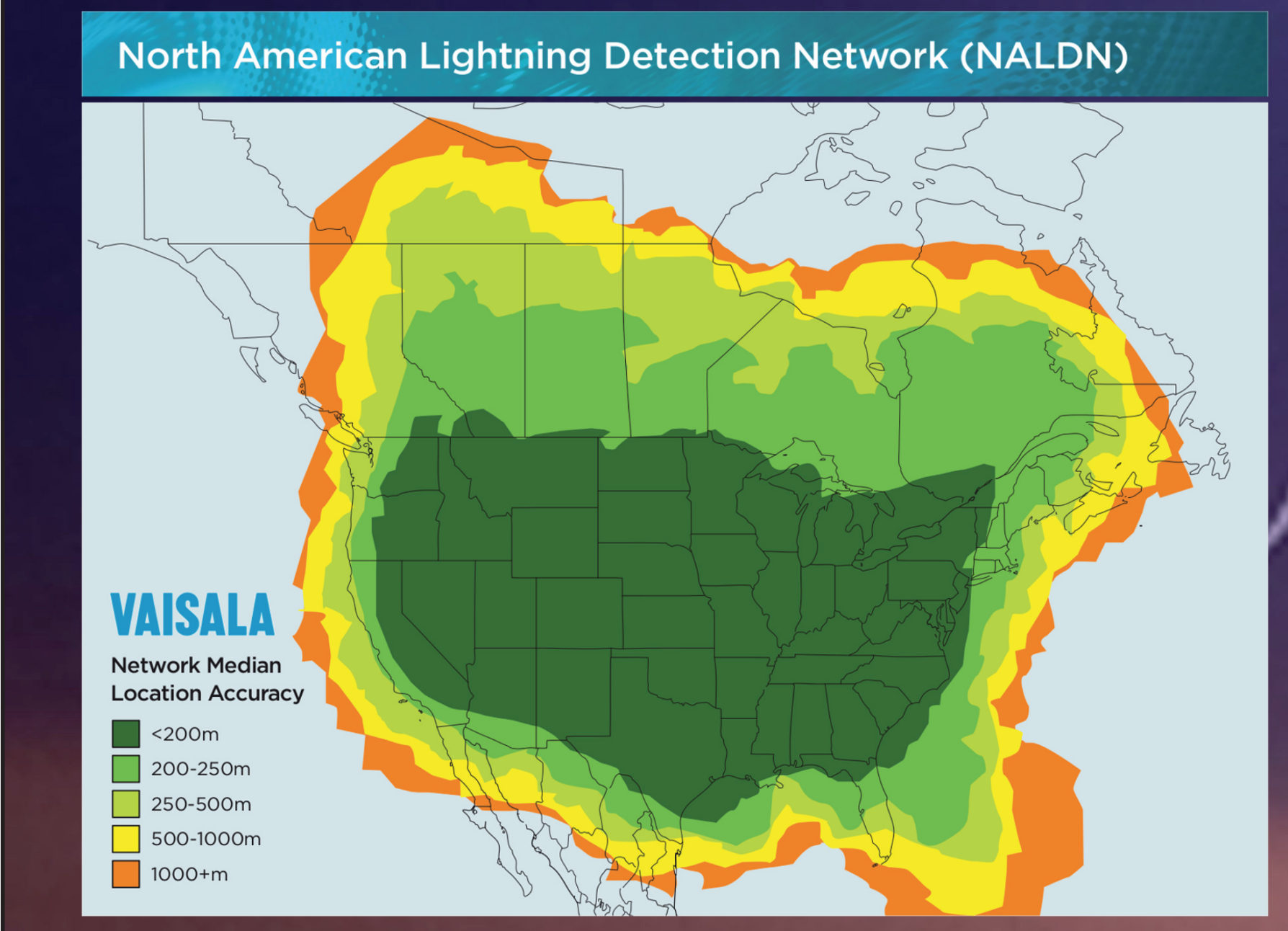
Why?

As geoscientists we know that the earth is not uniform, and in particular that its electrical properties are not uniform. Electrical resistivity variations are the most fundamental property measured in well logging, and these resistivity variations are used (along with other measurements) to identify lithology, porosity, and pore fluid composition. Surely the same variations in resistivity will affect lightning strike characteristics and location. To put it into perspective, a single typical lightning stroke dissipates energy of 100-150 kWh – three to eight days electricity consumption for the average U.S. household--with peak currents measured in kiloamperes and duration measured in microseconds.

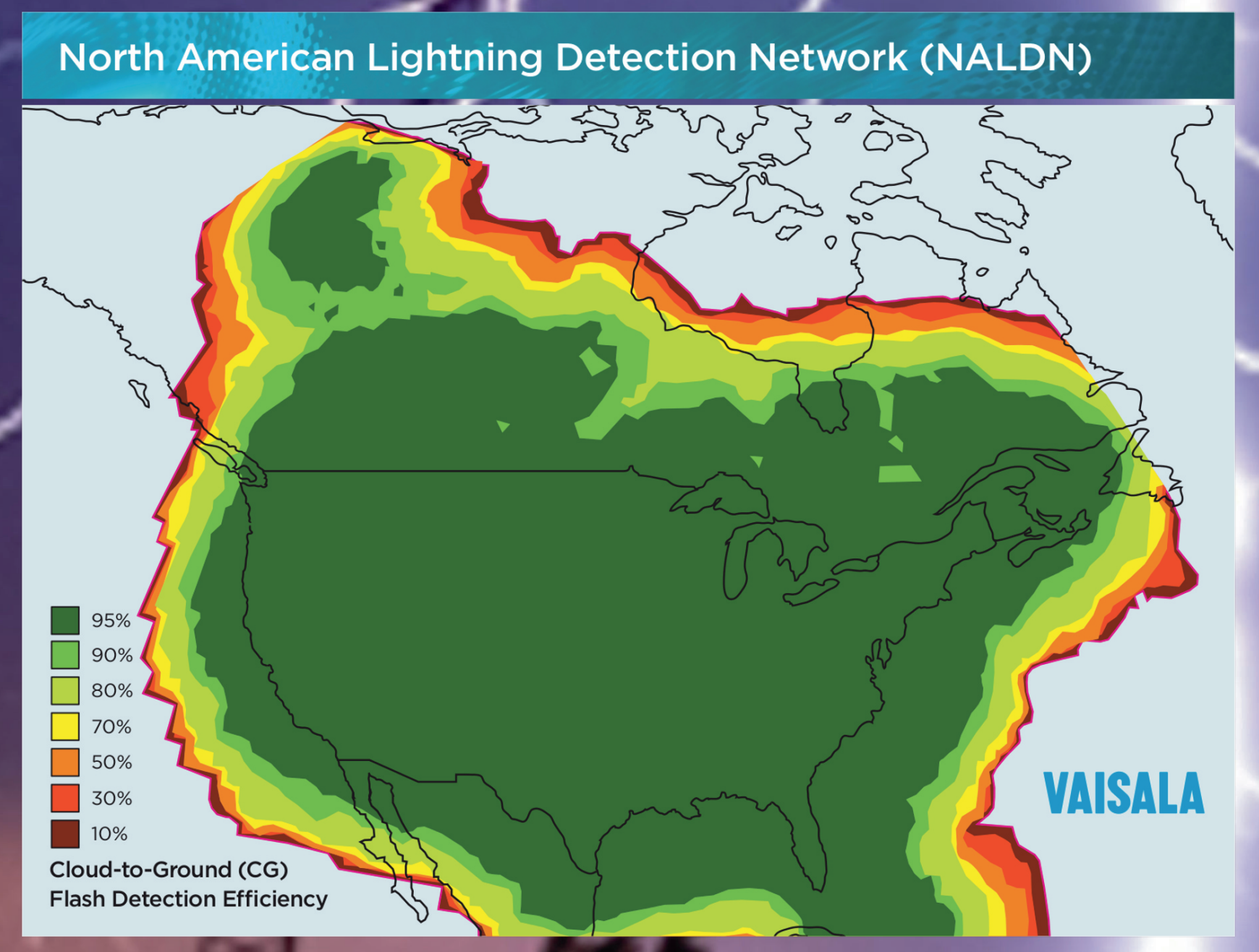
And what's more, someone else recorded the data for us!



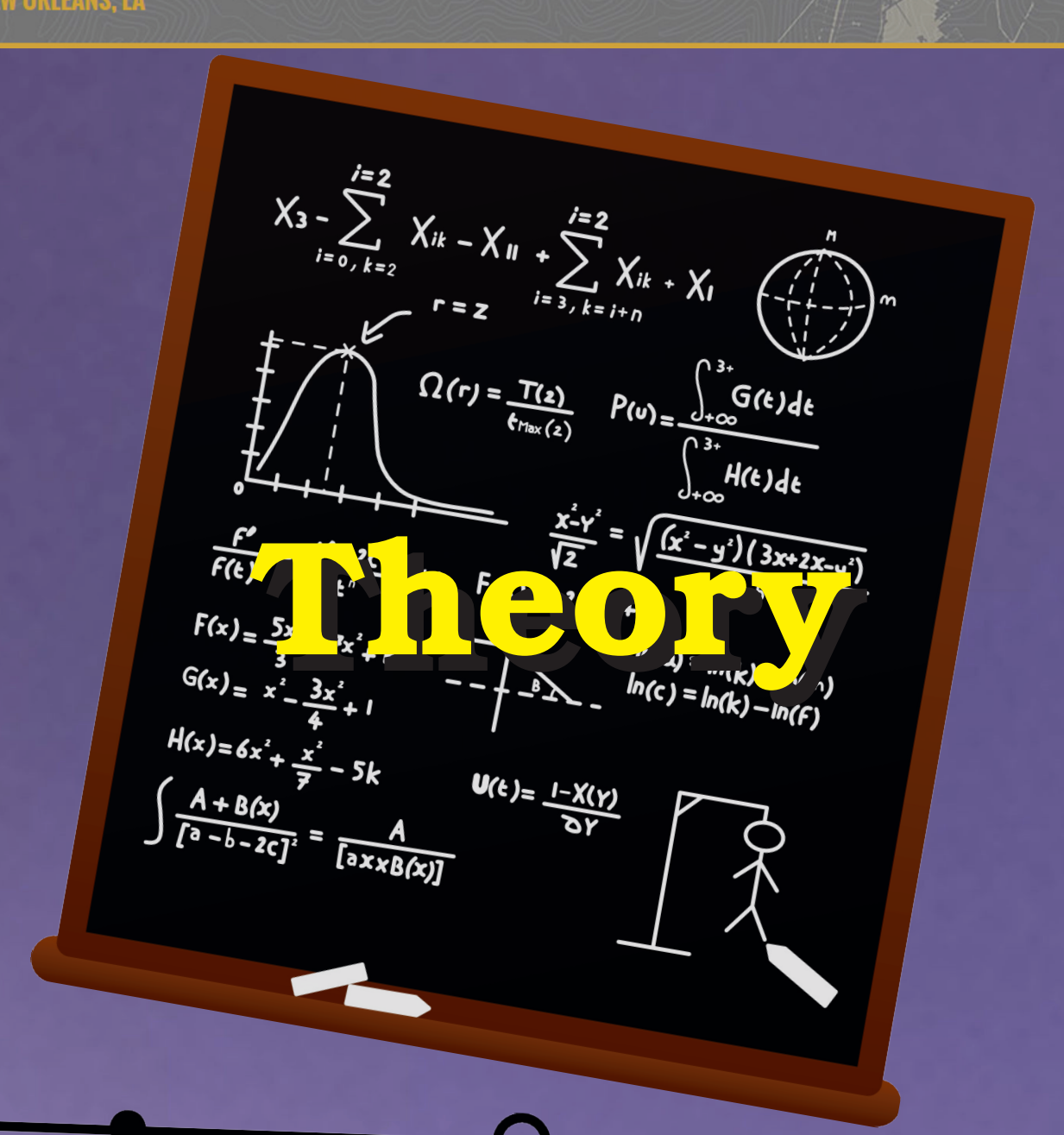
Where's the data?



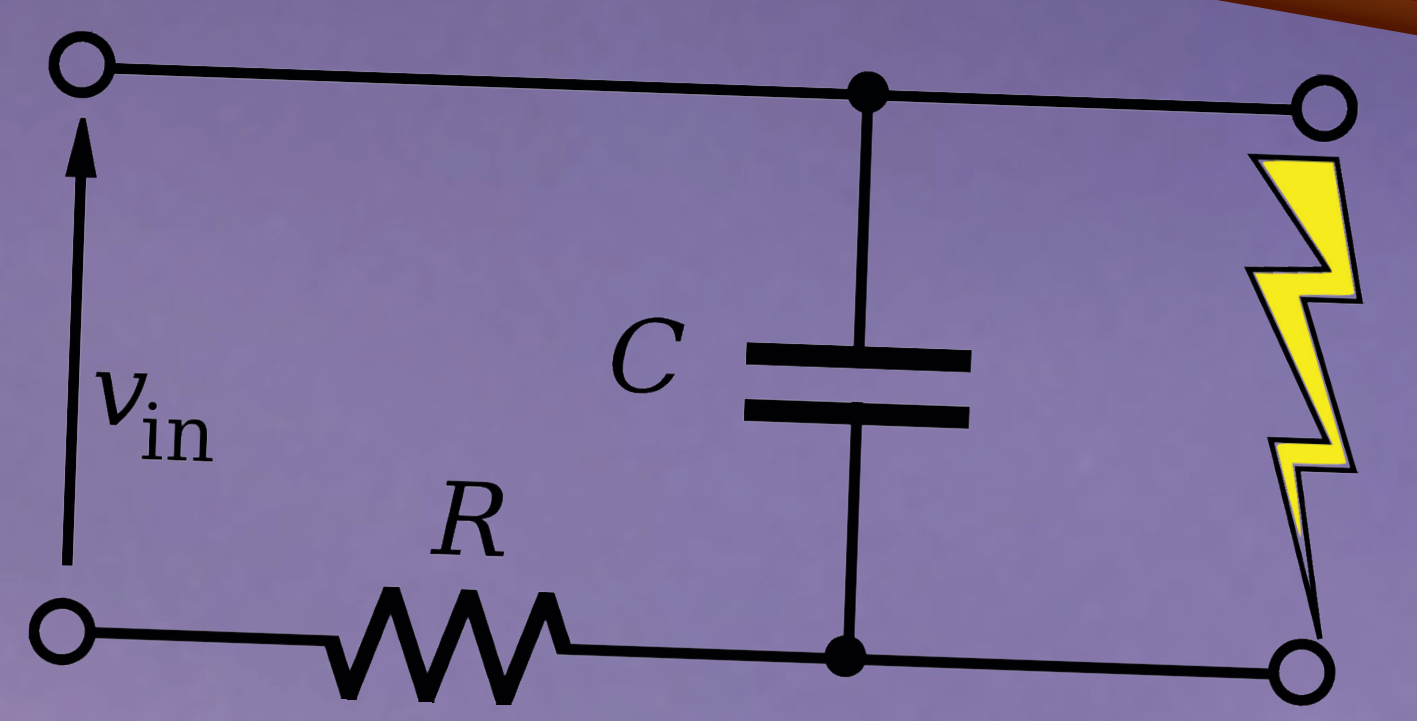
North American Lightning Detection Network (NALDN)
VAISALA
Network Median Location Accuracy
<200m
200-250m
250-500m
500-1000m
1000+m

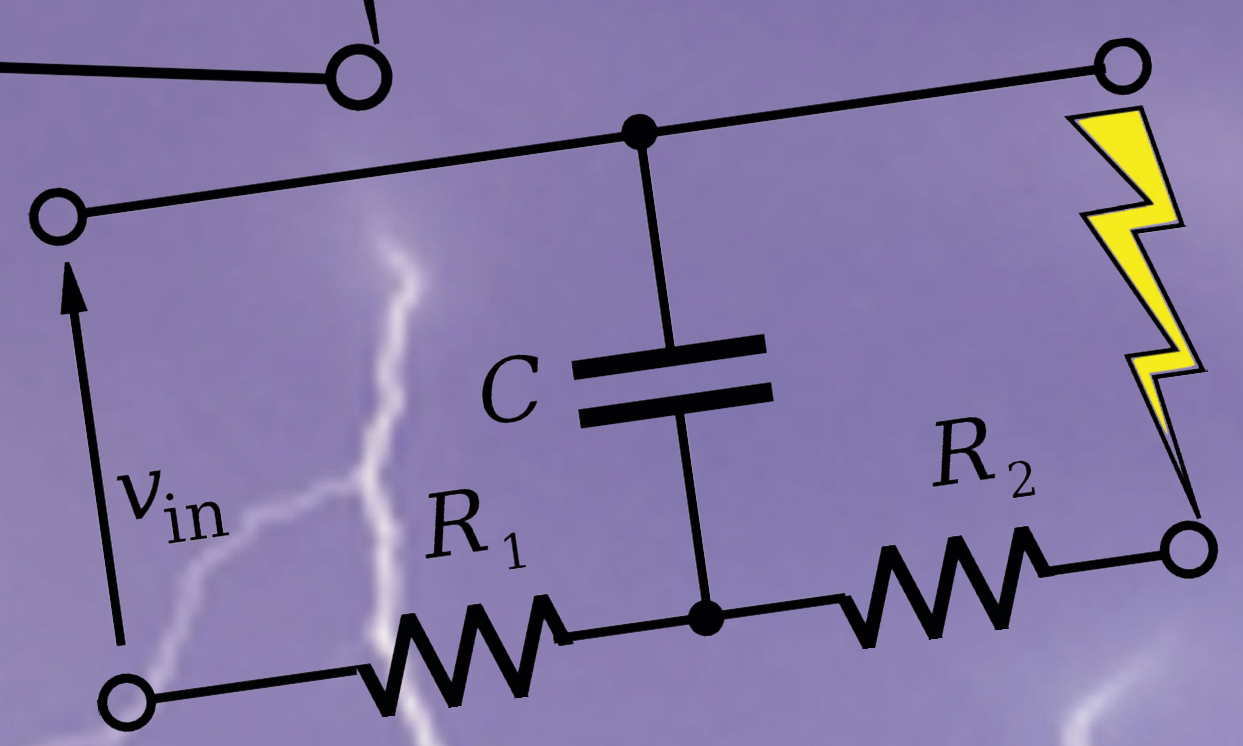


North American Lightning Detection Network (NALDN)
95%
90%
80%
70%
50%
30%
10%
Cloud-to-Ground (CG) Flash Detection Efficiency
VAISALA



Theory





- V_{out} is the lightning stroke
- V_{in} is the static charge

$$R_{0-n} = \frac{1}{\frac{1}{R_0}+\frac{1}{R_1}+\cdots+\frac{1}{R_n}} \tag{1}$$

- C is the capacitor formed by the atmospheric static charge
- R_1 is the resistance as it affects the build-up of static charge
- R_2 is the resistance after lightning completes the circuit.

$$V_t = V_0 e^{-t/RC} \tag{2}$$

- V_0 is the voltage at the instant of the lightning initiation.
- Dielectric strength of air is about 3.0 MV/m ($V_0 = 3.0d$ for megavolts or $V_0 = 3000000d$ for volts)
- $R = \frac{1{,}500{,}000{,}000}{100{,}000}$ or 15 kΩ for a typical peak current of 100 kA.

$$I_t R = I_0 R e^{-t/RC} \tag{3}$$

$$I_t = I_0 e^{-t/RC} \tag{4}$$

$$ln(I_t) = ln(I_0) - t/RC \tag{5}$$

$$t/RC = ln(I_0) - ln(I_t) \tag{6}$$

$$RC = \frac{t}{ln(I_0) - ln(I_t)} \tag{7}$$

$$R = \frac{t}{C(ln(I_0) - ln(I_t))} \tag{8}$$

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d} \tag{9}$$

- C is capacitance in farads;
- ε_r is the relative permittivity of air (1.00);
- ε_0 is the electric constant ($\varepsilon_0 \approx 8.854 \times 10^{-12} Fm^{-1}$);
- A is the area affected;
- d is the distance between the cloud base and the ground.

$$R = \frac{V_0}{I_0} \tag{10}$$

- R is the effective ground resistance and
- V_0 is the breakdown voltage of the capacitor.

$$V_0 = 3000000d \tag{11}$$

$$R = \frac{3000000d}{I_0} \tag{12}$$

$$R = \frac{t}{C(ln(I_0) - ln(I_t))} \tag{13}$$

assuming $\varepsilon_r = 1.0$

$$C = \varepsilon_0 \frac{A}{d} \tag{14}$$

substituting for C

$$R = \frac{td}{\varepsilon_0 A(ln(I_0) - ln(I_t))} \tag{15}$$

$$A = \pi d^2$$

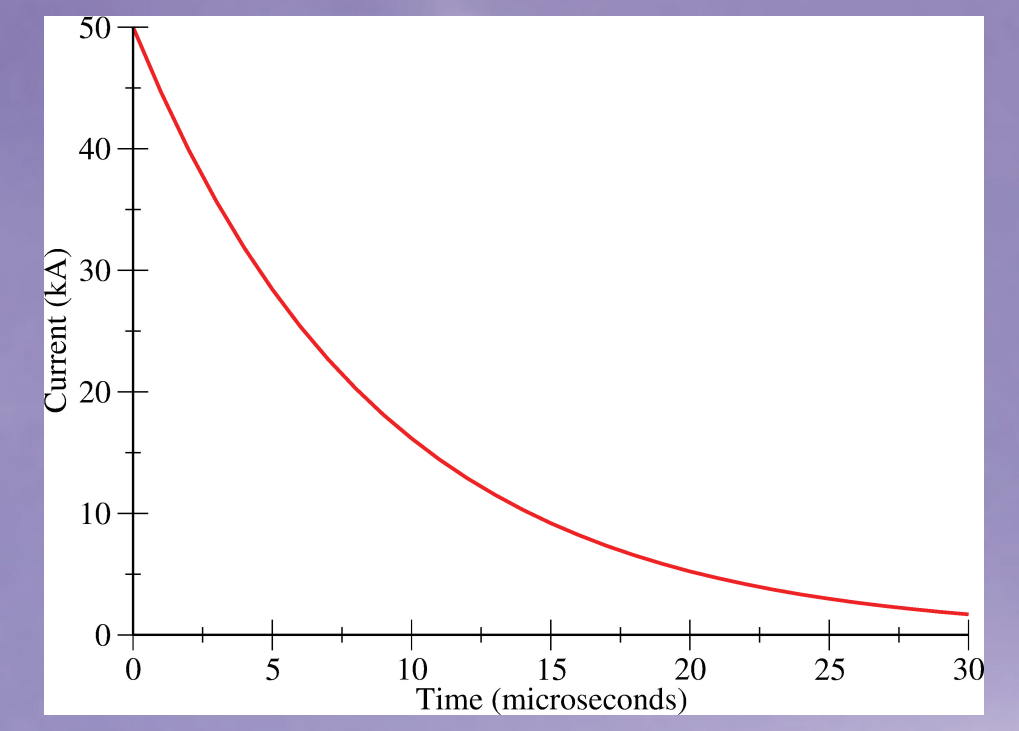
$$R = \frac{td}{\varepsilon_0 \pi d^2(ln(I_0) - ln(I_t))} \tag{16}$$

$$R = \frac{t}{\varepsilon_0 \pi d(ln(I_0) - ln(I_t))} \tag{17}$$

$$\frac{3000000d}{I_0} = \frac{t}{\varepsilon_0 \pi d(ln(I_0) - ln(I_t))} \tag{18}$$

$$d^2 = \frac{tI_0}{3000000\varepsilon_0 \pi(ln(I_0) - ln(I_t))} \tag{19}$$

- I_0 (the peak current)
- t (the peak to zero time)
- I_t (the current at "zero" current)

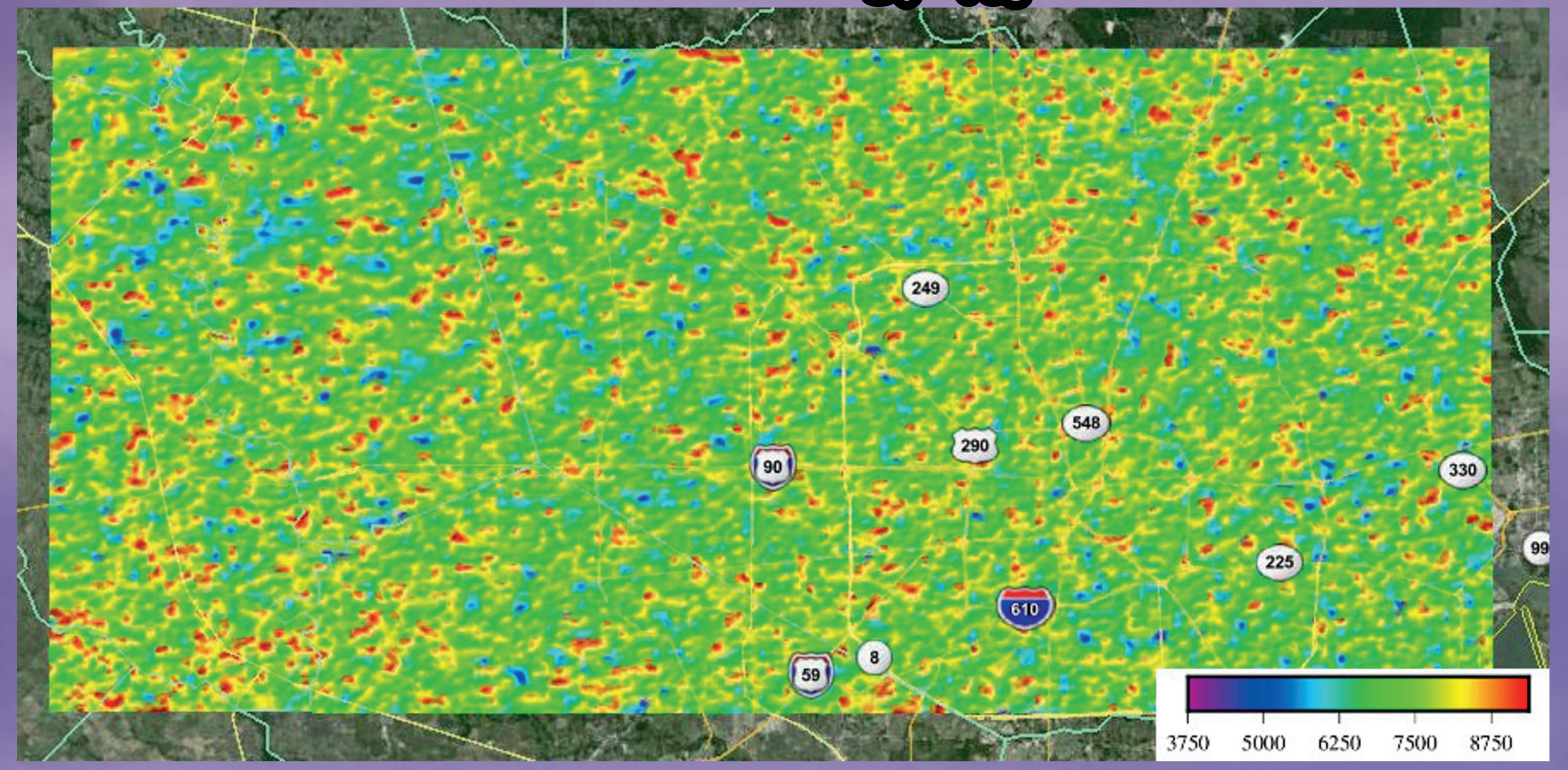


(Details in the Expanded Abstract)

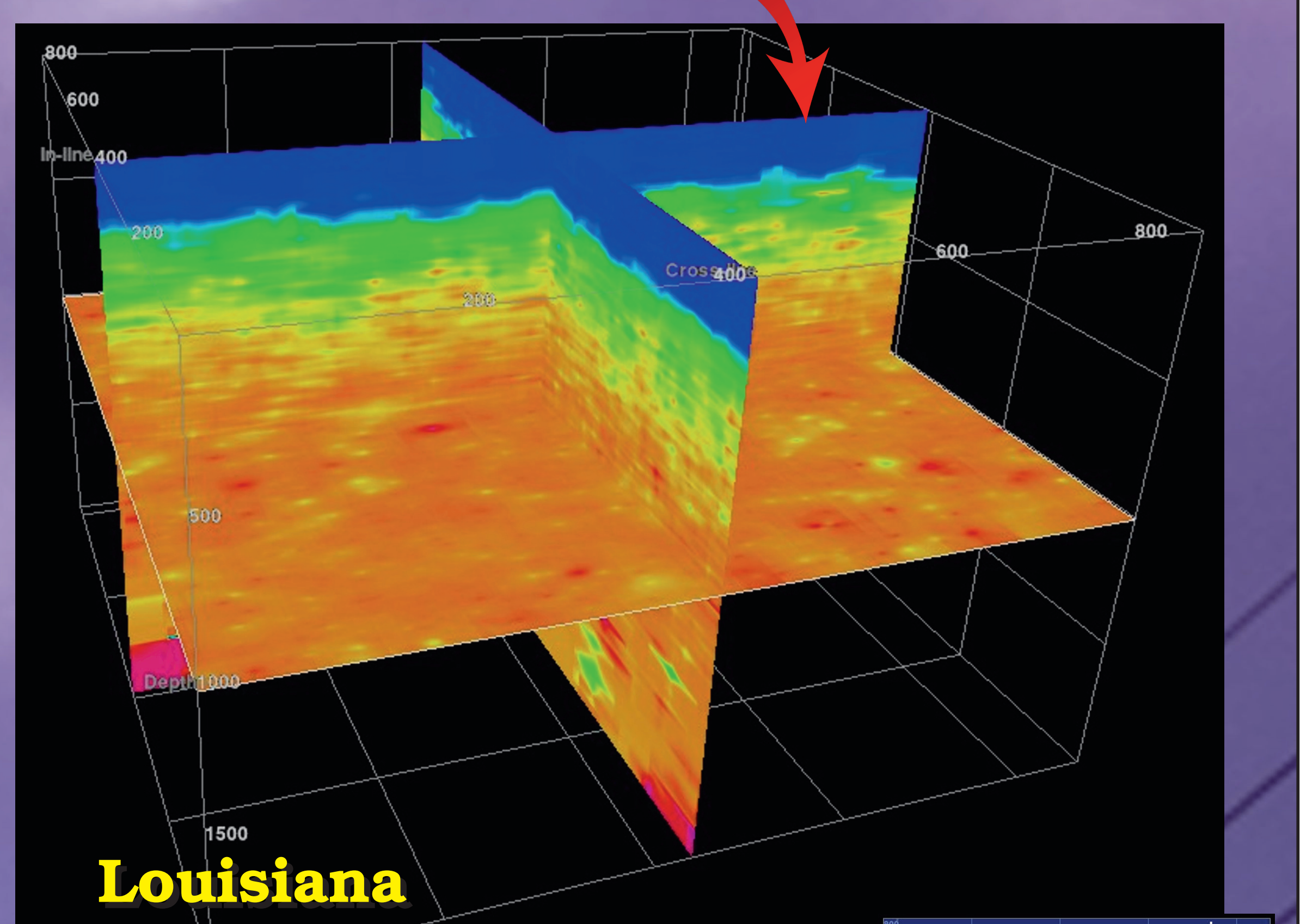
Results

Surface resistivity

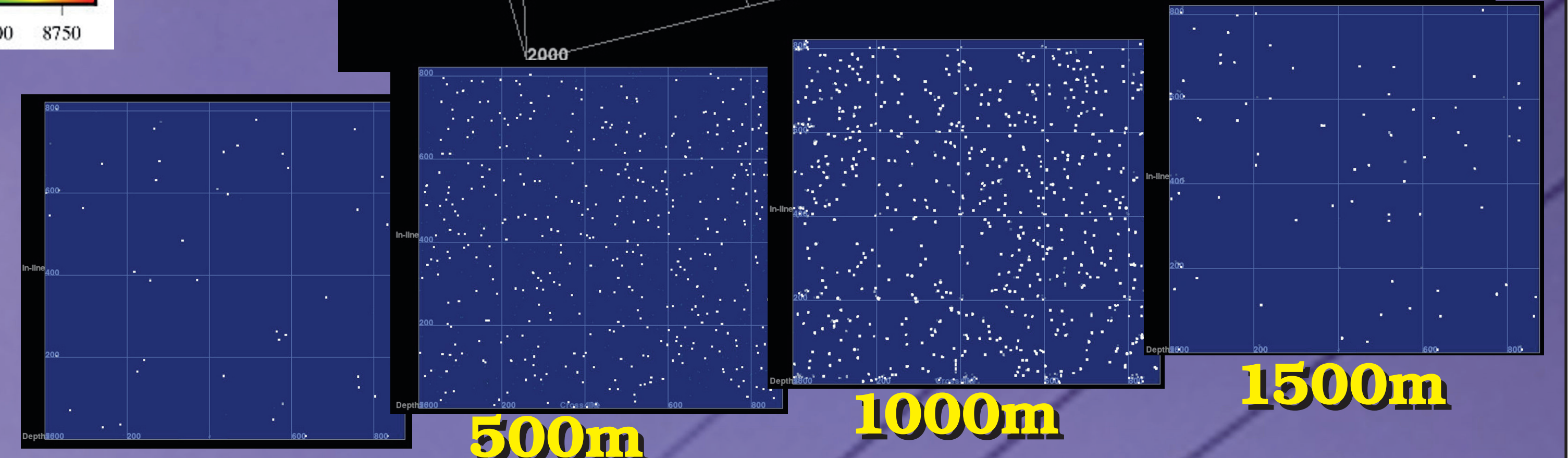
Texas



3D resistivity volume



Louisiana



Individual strikes

Conclusions

- Apparent resistivity maps can be generated from existing lightning databases.
- Apparent resistivity volumes can be generated from existing lightning databases.
- It's fast and cheap.
- No one needs to know you're even looking at the area.

More things to read

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