Lightning data and resource exploration

NS/HA E-P1: Multidisciplinary Studies and Applications

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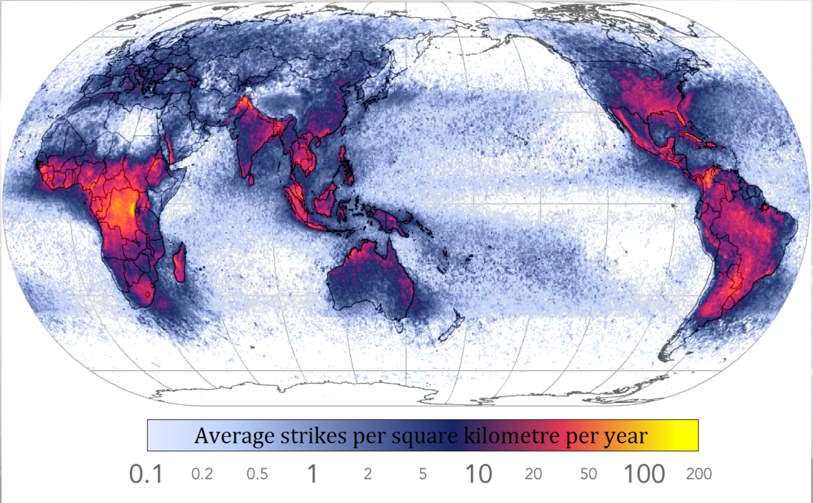
Outline

1. Introduction
   - Lightning and its recording
   - Theory
2. Lightning & Geology
   - Expectations
3. Lightning data
   - Recording the data
   - Observed effects
   - Effects which do not exist
   - Interpretation
   - Work to be done
4. Summary

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

Recorded Lightning

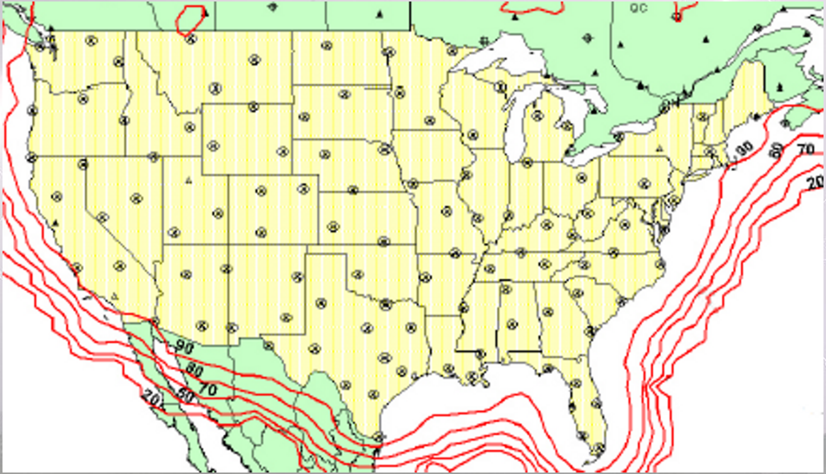


(Citynoise at en.wikipedia)

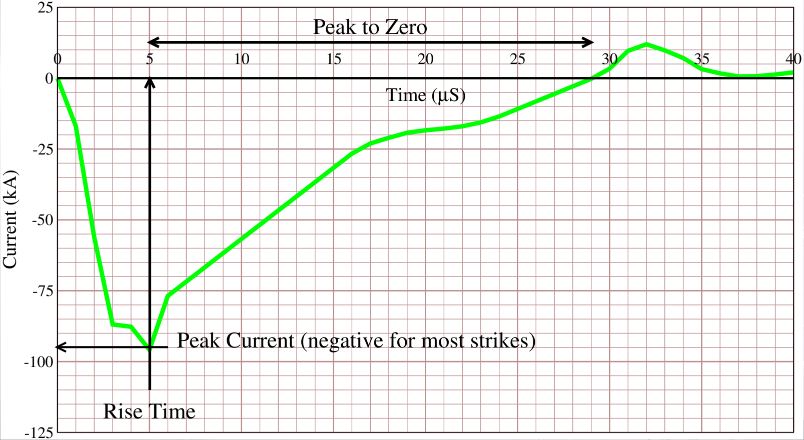
How Lightning Forms

- Ice particles and supercooled water droplets are ionized when they collide in the turbulent conditions inside a cumulonimbus cloud, typically 4500 to 7500 m above ground level
- Positive ions tend to collect at the top of the cloud, and negative ions near the base
- A stepped leader of ions makes its way towards the ground, until there is a continuous low resistance path from the cloud to the ground
- A return stroke from ground to cloud rapidly builds during the rise time of a few microseconds to a peak current of 5 to 300 kiloamperes
- Current decays for a period of up to 30 microseconds

National Lightning Detection Network

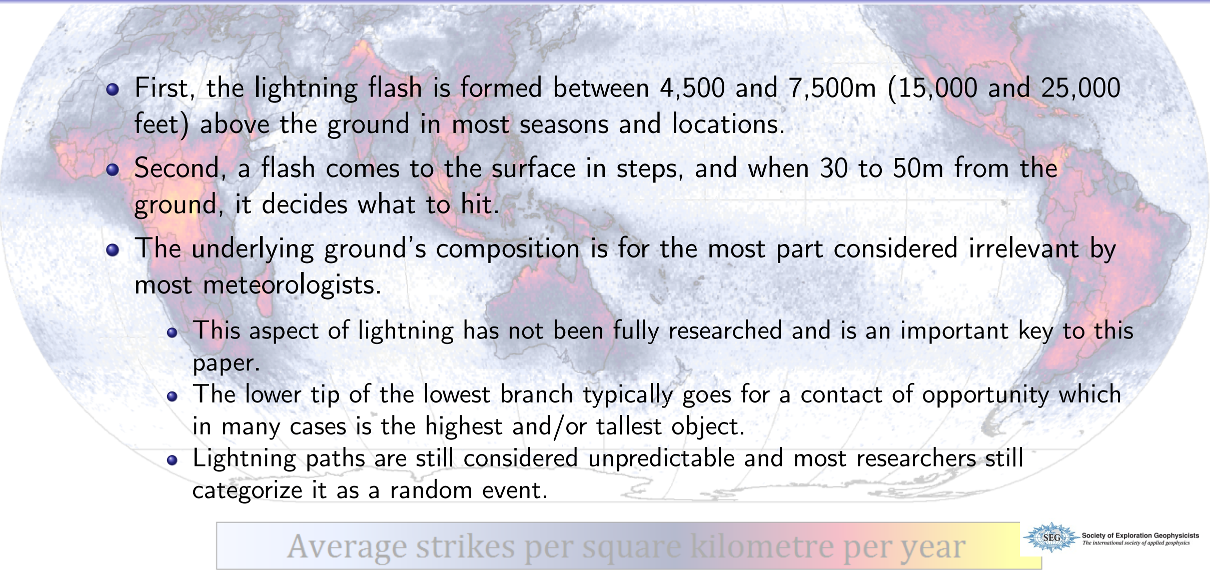


Lightning pulse shape



Where does lightning strike?

- First, the lightning flash is formed between 4,500 and 7,500m (15,000 and 25,000 feet) above the ground in most seasons and locations.
- Second, a flash comes to the surface in steps, and when 30 to 50m from the ground, it decides what to hit.
- The underlying ground's composition is for the most part considered irrelevant by most meteorologists.
  - This aspect of lightning has not been fully researched and is an important key to this paper.
  - The lower tip of the lowest branch typically goes for a contact of opportunity which in many cases is the highest and/or tallest object.
  - Lightning paths are still considered unpredictable and most researchers still categorize it as a random event.



Electrical Field Theory

Field Intensity from an infinite plane

$E = 2\pi k\sigma$

where E is electrical intensity and σ is charge per unit area

Force between two point charges

$F = -\frac{kqq'}{r^2}$

where F is force, q and q' are the two charges and r is distance separating them

Electrical Field Theory

- E=0 for all points within a conductor, when the charges in the conductor are at rest. Therefore the entire excess charge on the conductor must be located on the outer surface of the conductor.
- Charge, q, is uniformly distributed on the surface of a conducting sphere of radius R. Radius of Earth is 6,378.1 km.

What Might Matter

Changes in the ionosphere or the earth

- Lightning can be thought of as breakdowns in a self-repairing capacitor formed by the conducting ionosphere and the conducting earth, separated by the non-conducting lower atmosphere.
- Lightning strikes (dielectric breakdowns) are going to occur where perturbations create larger E and F on the Earth side of the capacitor (or possibly on the ionosphere side).
- Since F is inversely related to r^2, as the distance between the positive (Earth) and negative (Ionosphere) decreases, due to increases in topography, F increases, resulting in additional lightning at higher elevations.
- When E increases because s, the charge per unit area, increases, there will be additional lightning strikes.
- Charge per unit area in the infinite plane sheet of charge (the surface of the earth) is altered by variations in resistivity within the conducting body.

Variations in Resistivity

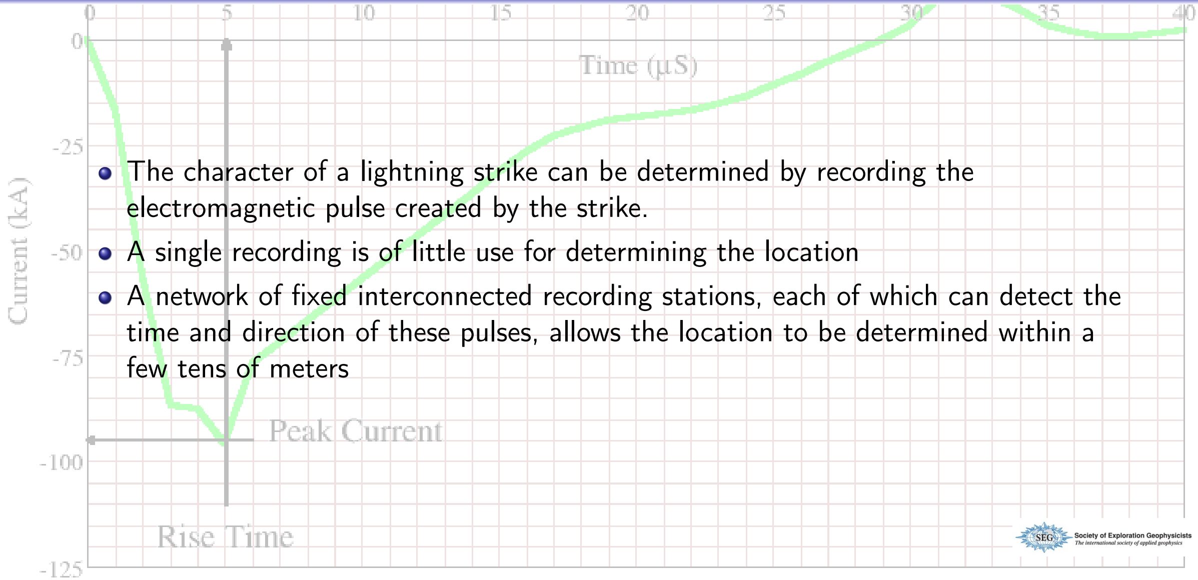
- Chemical reactions or mechanical stresses (Chinese researchers have found a correlation between lightning and earthquakes)
- Movement of rocks or fluids within the pore space of rocks, including magma and groundwater
- Local vertical geological features such as volcanic pipes or dikes
- Changes in pore fluids, including variation of water salinity and presence of other pore fluids such as hydrocarbons
- Variations in mineral composition of the matrix of a porous or non-porous rock
- Phase changes in pore fluids, which depend on temperature and pressure
- Approximately planar and vertical geological discontinuities such as faulting
- Approximately horizontal geological discontinuities such as geopressure depth variations and stratigraphic bedding and unconformities.

Specific Geological Features

- E increases in the infinite plane sheet of charge when:
  - Geothermal alteration or electrically conductive brines along faults create linear conductors
  - High salinity of fluids adjacent to salt domes create circular conductors surrounding circular resistors (salt)
  - Large hydrocarbon accumulations at pinchouts create linear resistors.

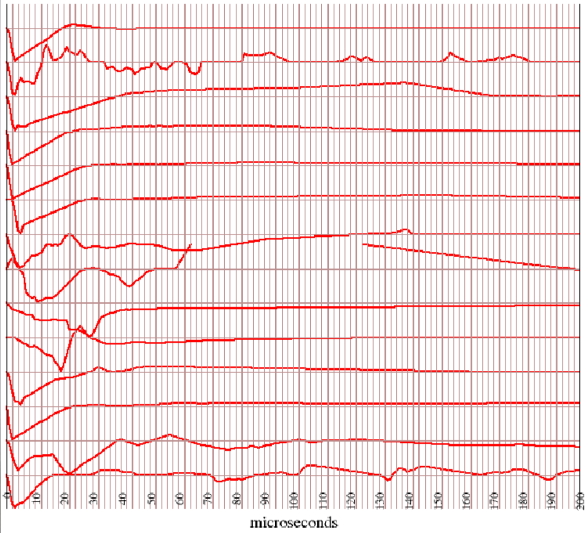
How it's done

- The character of a lightning strike can be determined by recording the electromagnetic pulse created by the strike.
- A single recording is of little use for determining the location
- A network of fixed interconnected recording stations, each of which can detect the time and direction of these pulses, allows the location to be determined within a few tens of meters



The Recorded Waveform

The actual waveform for 14 lightning strikes



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What is Recorded

For ground based detection networks

- The attributes recorded for all cloud-to-ground lightning strokes are:
  - Date and time (UTC)
  - Latitude and longitude
  - Peak current (kA) (signed and absolute)
  - χ^2 for the location parameters
  - Semi-major and semiminor axes of the error ellipse
  - Rise time (μs from the detected onset of the stroke to the peak absolute current)
  - Peak-to-zero time (μs from the absolute peak until the signal from the stroke drops below ambient noise)
  - Number of sensors from the network used for the measurements.

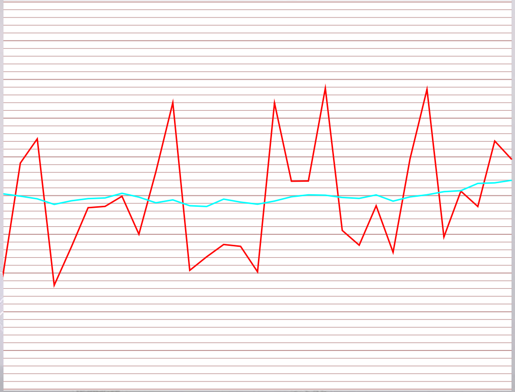
What is Recorded

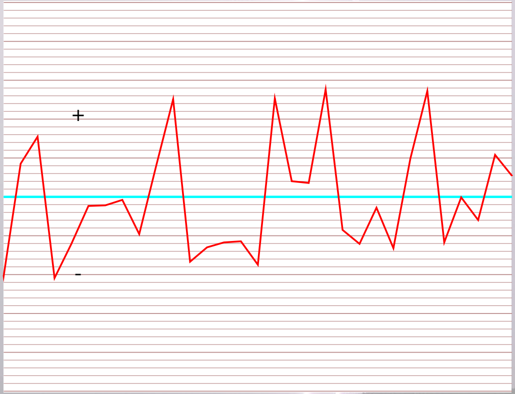
For satellite based detection networks

- The attributes recorded for all cloud-to-ground lightning strokes are:
  - Date and time (UTC)
  - Latitude and longitude
  - Peak current (kA) (signed and absolute)

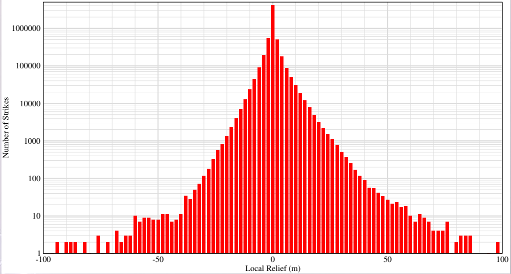
Topography

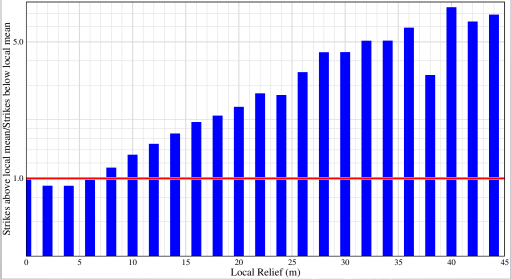
Relief and smoothed relief, flattened on smoothed relief





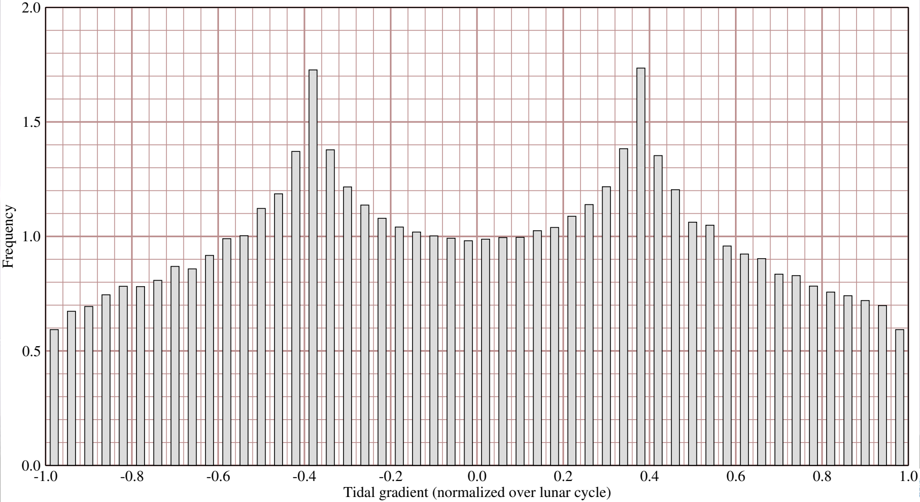
Topography


1000000
100000
10000
1000
100
10
1
Number of Strikes
-100
-50
0
50
100
Local Relief (m)


5.0
1.0
Strikes above local mean/Strikes below local mean
0
5
10
15
20
25
30
35
40
45
Local Relief (m)

Tidal Gravity

Frequency of occurrence of tidal gravity gradient during a complete tidal cycle



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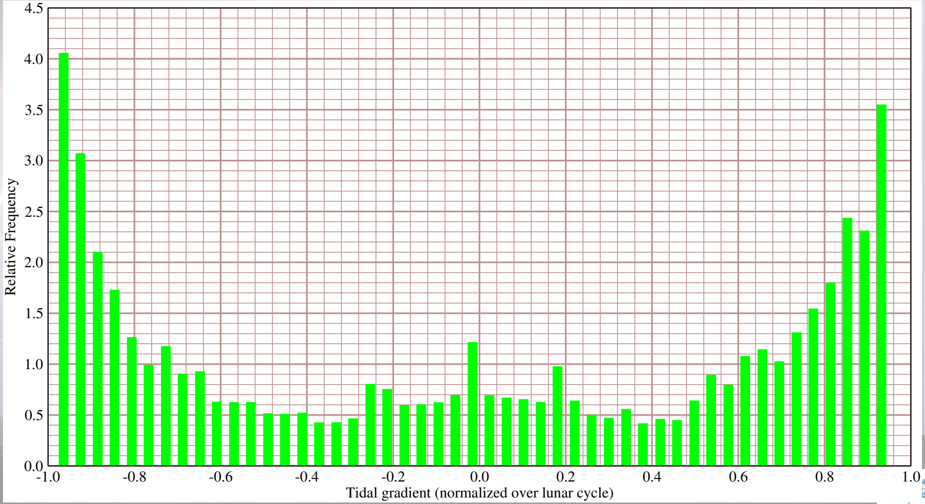
Tidal Gravity

Relative frequency of lightning strikes over a tidal cycle (Plains States)



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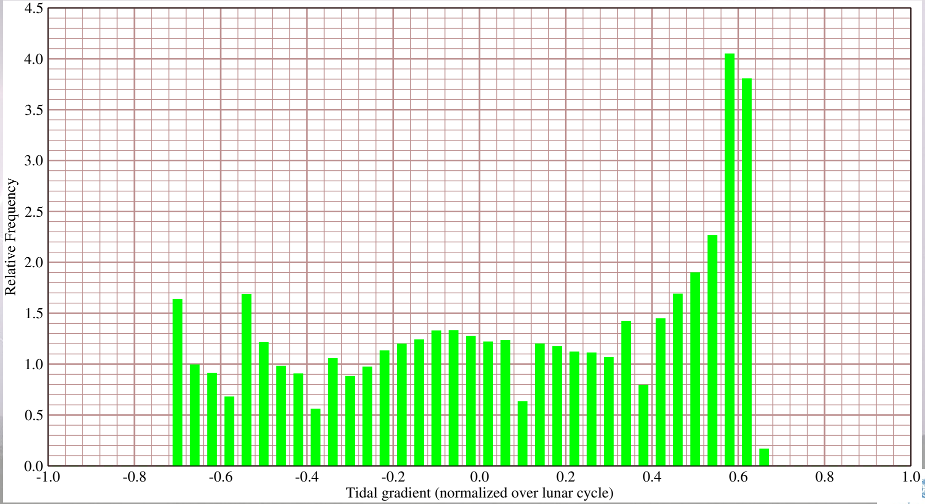
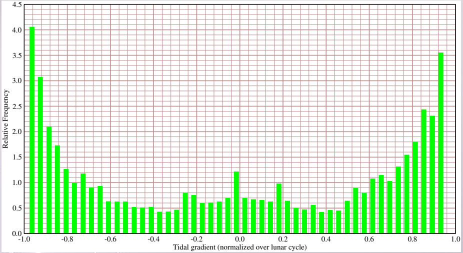
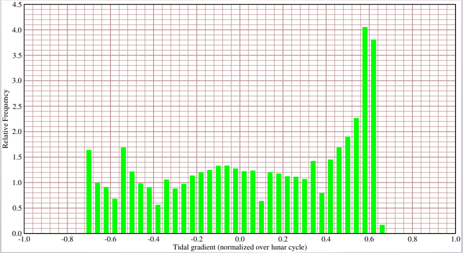
Tidal Gravity

Relative frequency of lightning strikes over a tidal cycle (Southeast)



Tidal Gravity

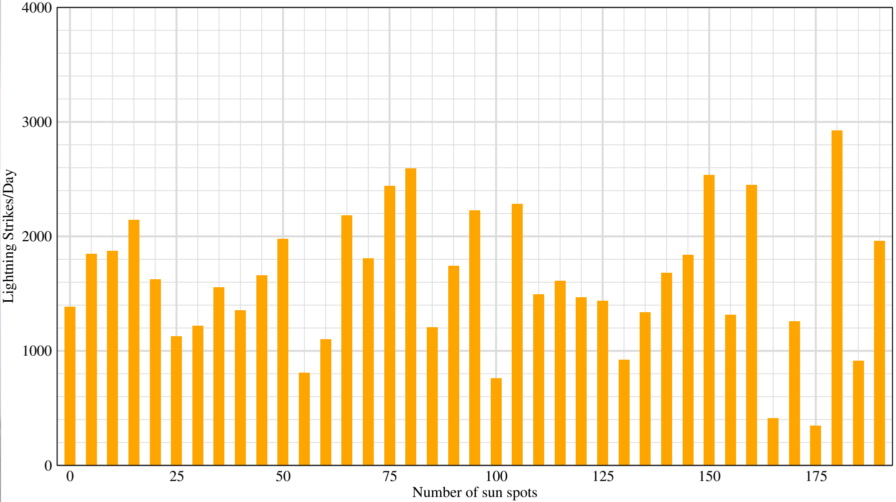




- Tidal gravity is not much different between Plains and Southeast
- Relation to lightning strikes is remarkably different
- The difference is surely geology

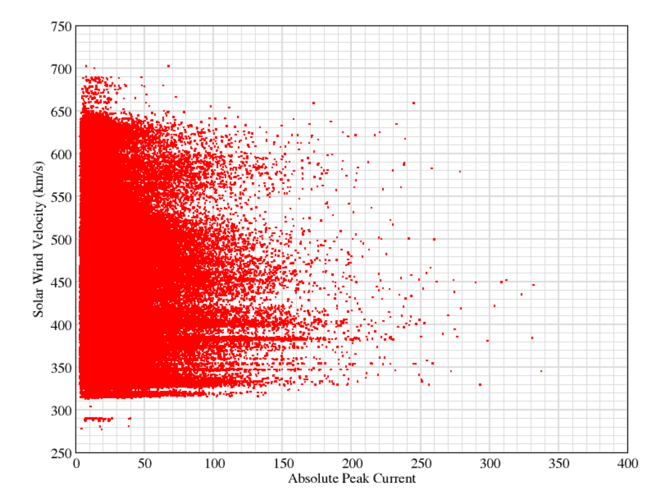
Sunspots

North Dakota 1998-2007



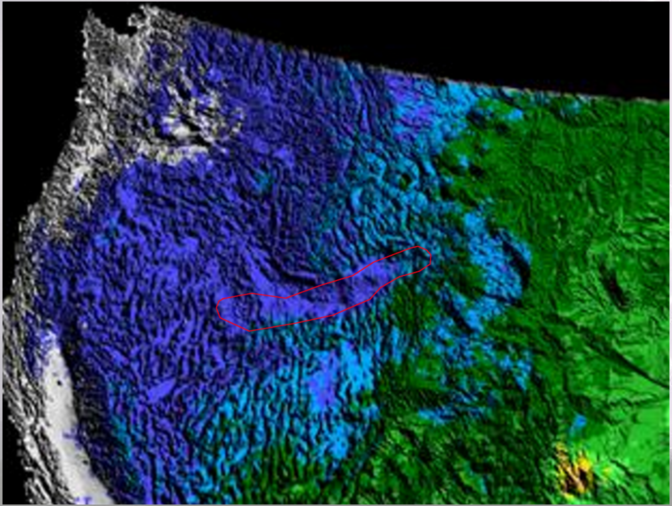
Solar Wind

North Dakota 1998-2007



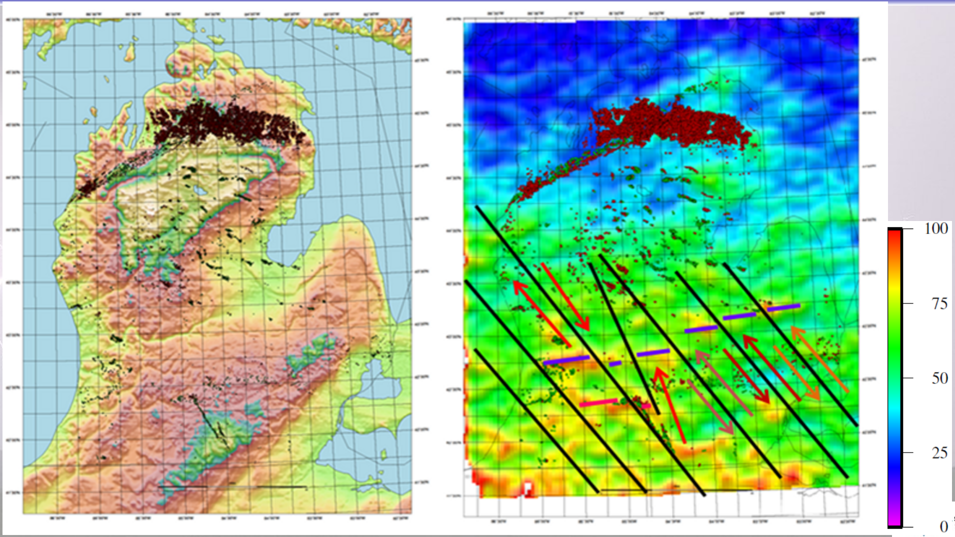
Snake River Plain

Red line shows location of Yellowstone hot spot over last 16MY



Michigan

Topography and lightning strike density



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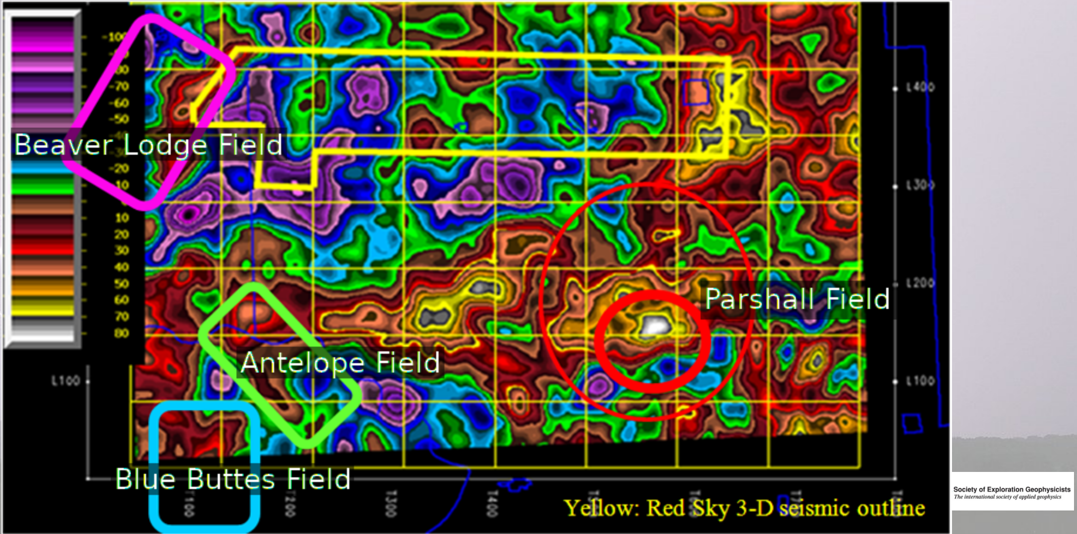
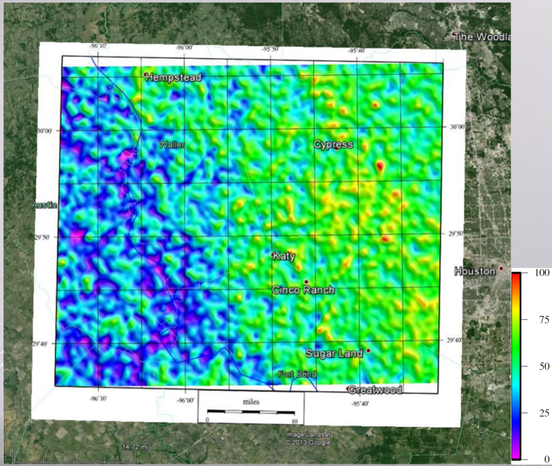
Mountrail Co., ND

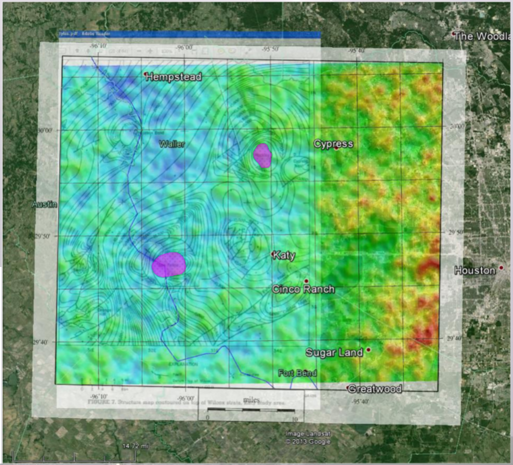
Lightning strike density at high lunar tide



Salt Domes

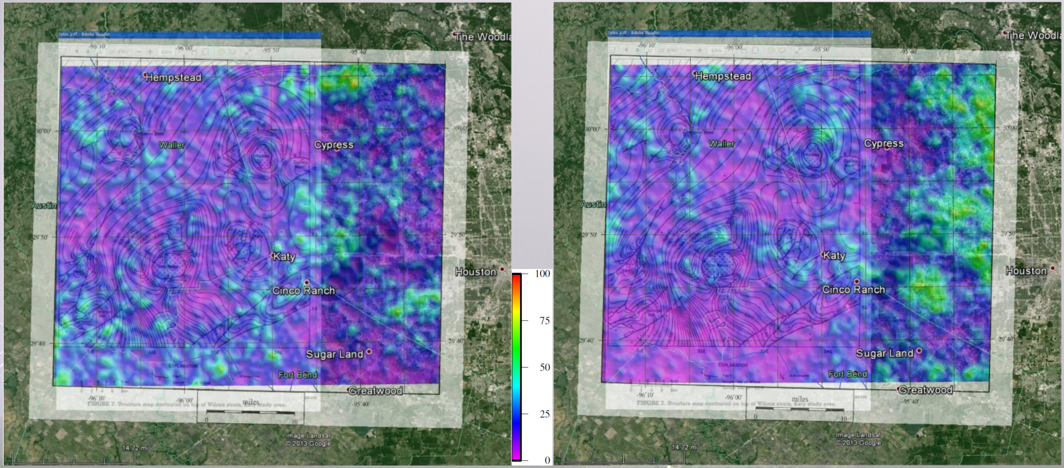
Peak current 2000-2011 and lightning strike density





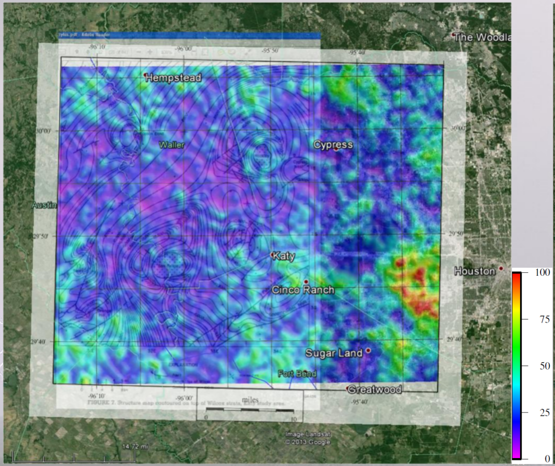
Salt Domes

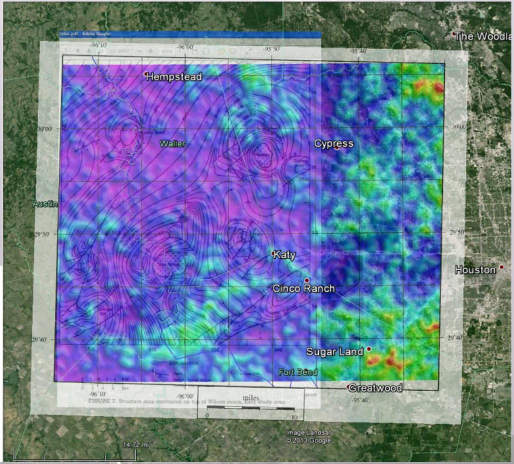
Strike density 2000 and 2001



Salt Domes

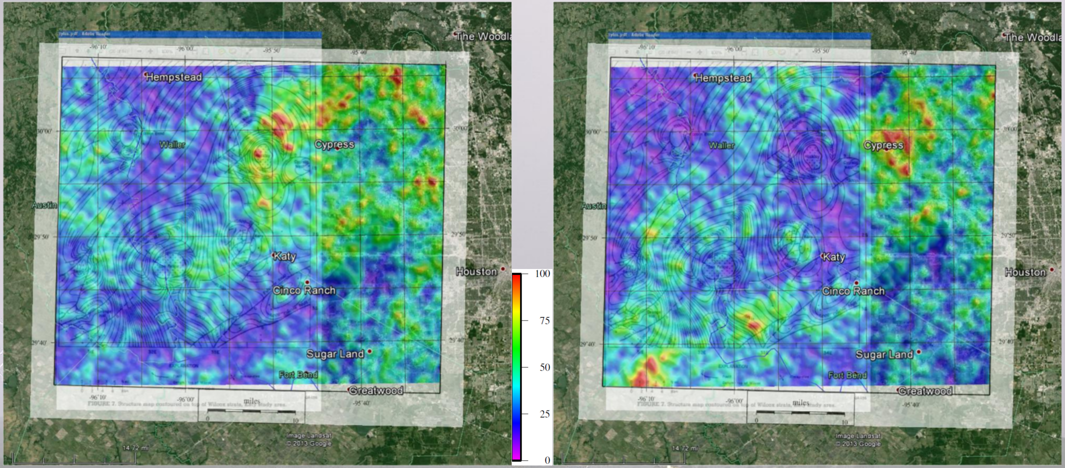
Strike density 2002 and 2003





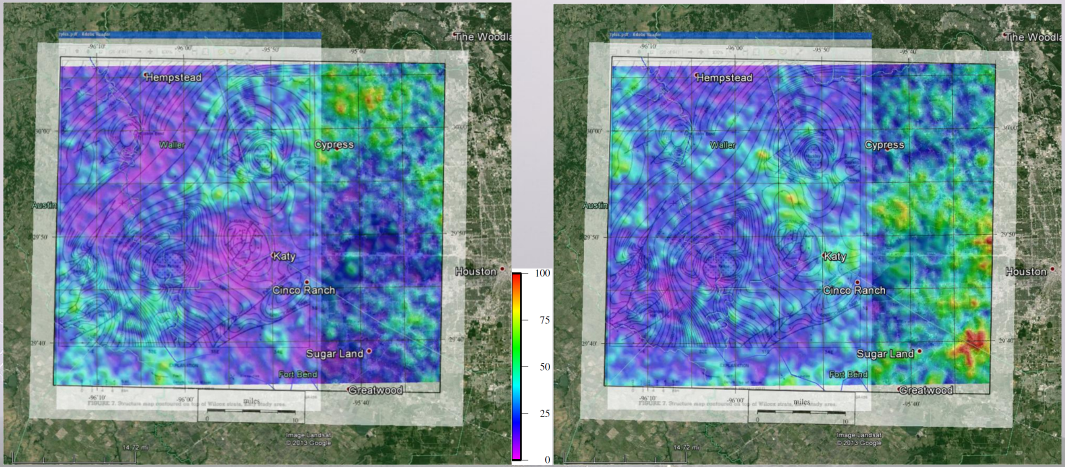
Salt Domes

Strike density 2004 and 2005



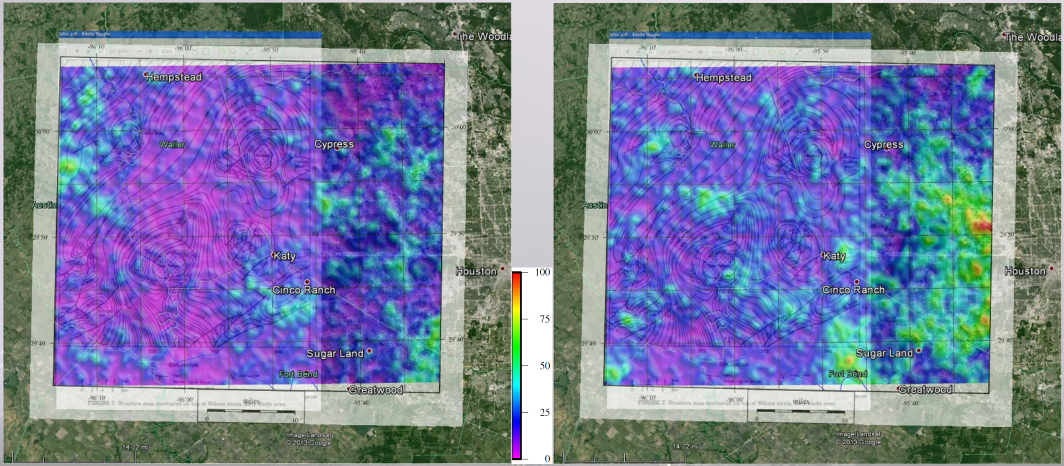
Salt Domes

Strike density 2006 and 2007



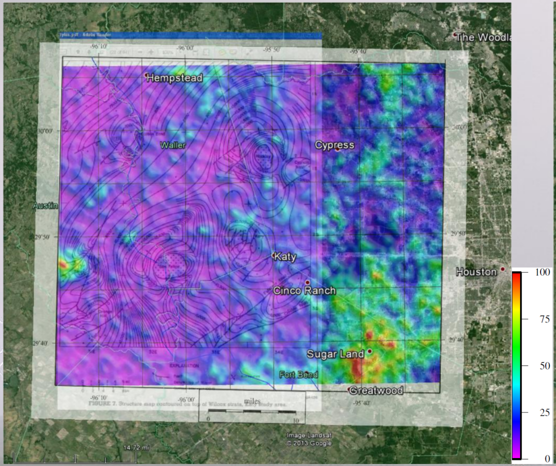
Salt Domes

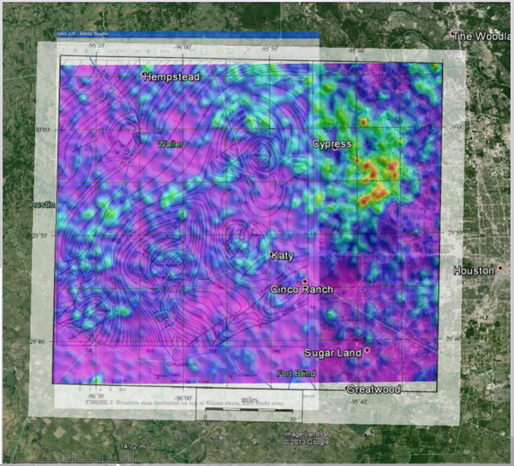
Strike density 2008 and 2009



Salt Domes

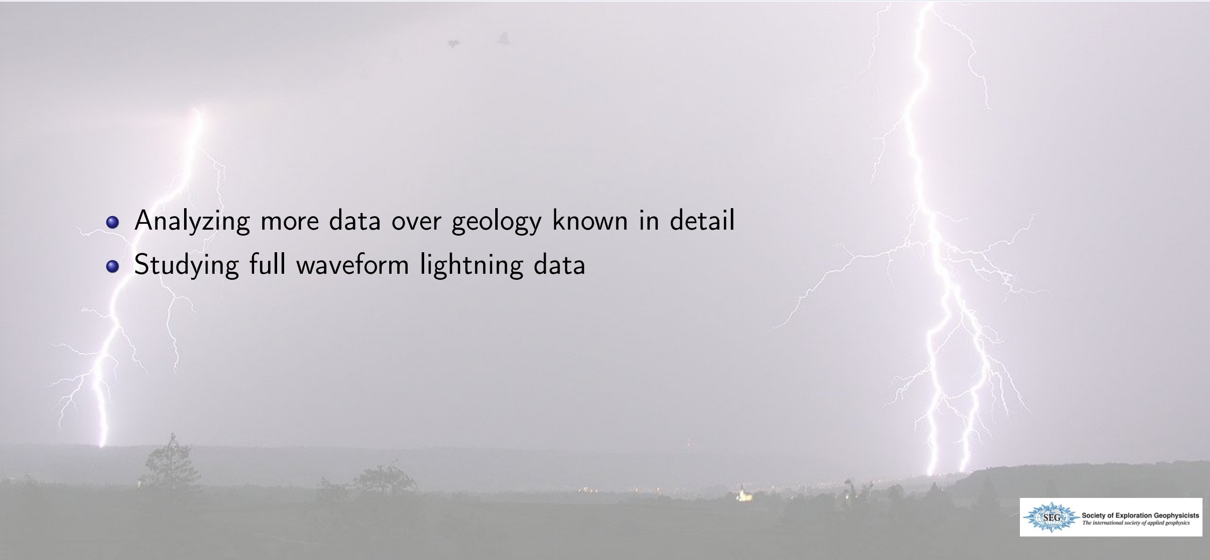
Strike density 2010 and 2011





The Future

More analysis will give better interpretation



- Analyzing more data over geology known in detail
- Studying full waveform lightning data

Summary

- Lightning data is recorded worldwide and can be used for exploration
- Geology affects lightning in both obvious and subtle ways
- Projects have been completed in North Dakota, New York, Michigan, Texas, and Florida

- Outlook
  - Interpretation of geology from lightning records is a low cost exploration tool
  - Further development of interpretation techniques should allow more detailed interpretation

For Further Reading

Rakov, V.A., and M.A. Uman
Lightning: physics and effects.
Cambridge, 2003.

Baba, Y., and V.A. Rakov
Influence of strike object grounding on close lightning electric fields:
Journal of Geophysical Research, **113**. (D12109, doi:10.1029/2008JD009811).

Nelson, H. Roice, Jr., D. James Siebert, and L. R. Denham
Lightning data - the new EM "seismic" data:
Presented at EM Workshop, SEG Annual Meeting, 2012.

Nelson, H. Roice, Jr., D. James Siebert, and Les R. Denham
Lightning Data, A New Geophysical Data Type
AAPG Annual Meeting, 2013.

Xiaobing Jin, Zhongming Chen, Qiming Ma, Yiding Li, and Junwei Pu
The Correlations between the Lightning Density Distribution of Sichuan Province and the Seismic Area:
International Journal of Geosciences, 2013, 4, 380-386. (doi:10.4236/ijg.2013.42036)