

Lightning Radiolocation

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WD1O

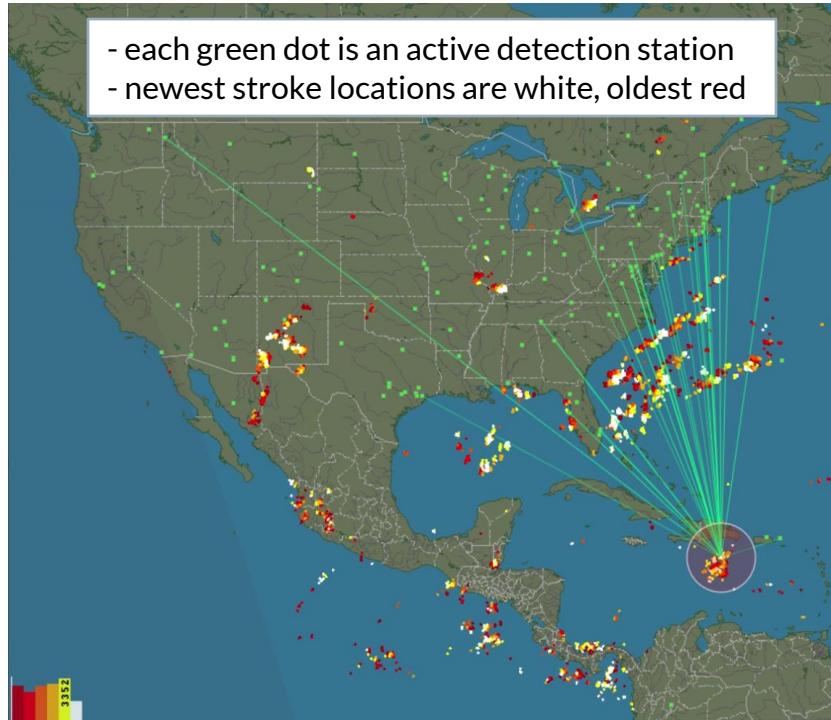
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- Detection station equipment
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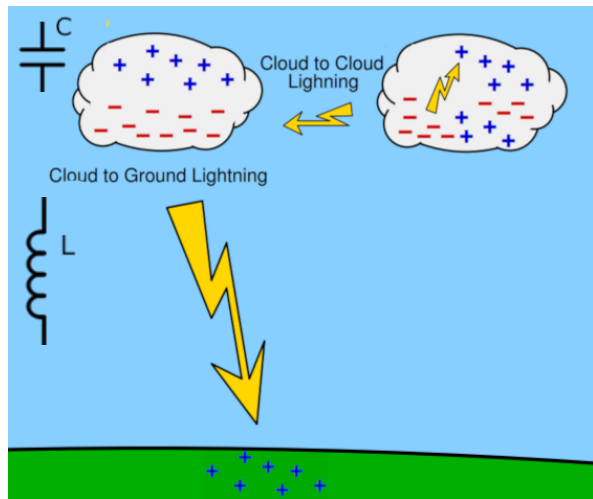
Introduction



- There are ~ 300 active volunteer lightning detection stations around world
- These stations report their exact location and arrival time of each detected “Cloud to Ground” stroke to a central server
- World-wide there are an average of 5 strokes each second
- Strokes can be detected thousands of miles away
- The lightning location is figured from these reports – typically ~50 reports per stroke

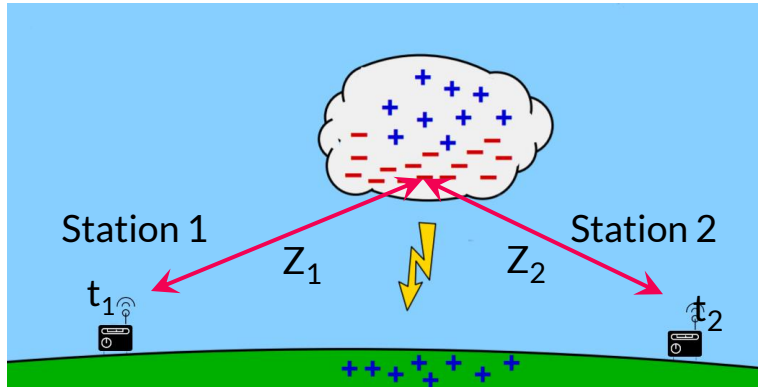
from http://en.blitzortung.org/live_lightning_maps.php?map=30

Lightning - basics



- In a typical “Cloud to Ground” stroke (R stroke), a charge $Q \sim 1 \text{ C}$ reaches the ground in $\tau \sim 100 \mu\text{s}$, so peak current $\sim 10 \text{ kA}$
- “Cloud to Cloud” strokes (K strokes) typically occur $4 \times$ more often than R strokes, but are typically $100 \times$ weaker
- Sferics – the short pulse of electromagnetic radiation from lightning
- Simulated approximately by the electromagnetic radiation field of a vertical Hertzian dipole antenna
- R stroke maximum spectral energy around $1/\tau = 10 \text{ kHz}$ or $\lambda \sim 30 \text{ km}$
- Beyond this maximum, spectral amplitude decreases as $1/f$ (theory) or faster (Sommerfeld ground wave)
- The energy is reflected and attenuated on the ground as well as within the ionospheric D layer

Radiolocation Theory - 1

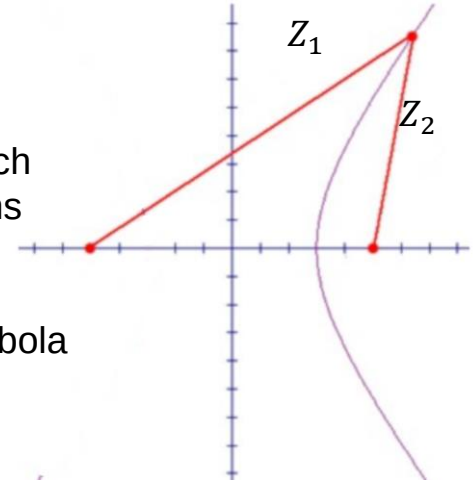


Stroke travels distance Z_i to reach Station i at time t_i

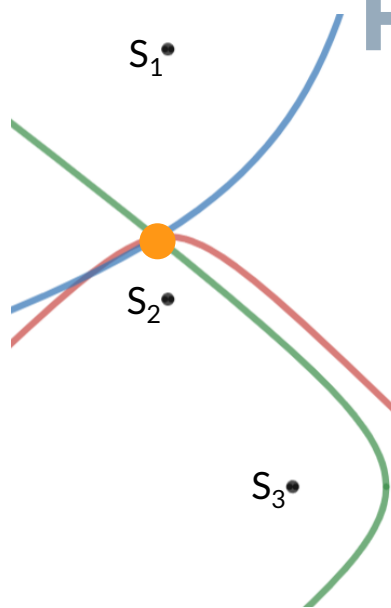
so that $(Z_1 - Z_2) = (t_1 - t_2) \cdot c$ (1)

where c = speed of light

- Equation 1 is a hyperbolic curve, since it defines a set of points such that the difference in the distance from the stroke to the two stations ($Z_1 - Z_2$) is constant.
- Two stations locate the stroke somewhere on surface of this hyperbola



Radiolocation Theory - 2



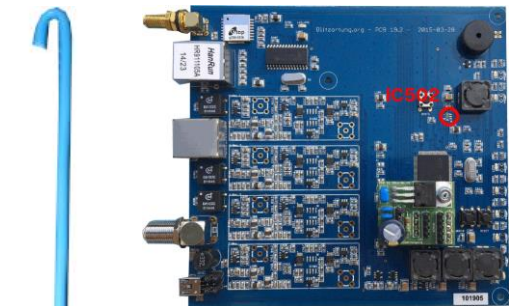
- With time stamps from 4 stations one defines 3 hyperbolic surfaces:
 - Stations S_1 and S_2 define the **red** surface
 - Stations S_3 and S_4 define the **green** surface
 - Stations S_1 and S_4 define the **blue** surface
- The **orange** dot marks their intersection point – the lightning stroke

The computations at the server are carried out in two steps:

1. A starting point is computed using the method from the Koshak & Solakiewicz paper applied to the time stamps from the first 4 stations
2. A numerical method is used to minimize the sum of all squared distances to the hyperbolic curves.

W.J. Koshak and R.J. Solakiewicz, "Time of Arrival Lightning Location Retrieval on Spherical and Oblate Spheroidal Earth Geometries", American Meteorological Society, February 2001.

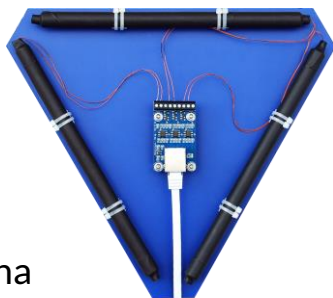
Detection Station Equipment



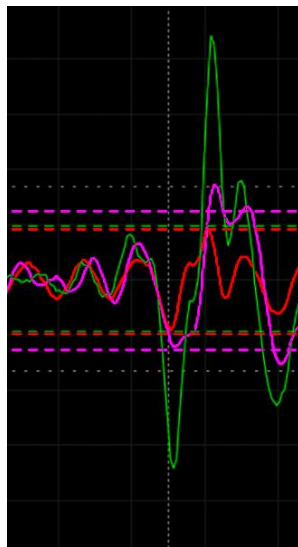
Mostly surface-mount components



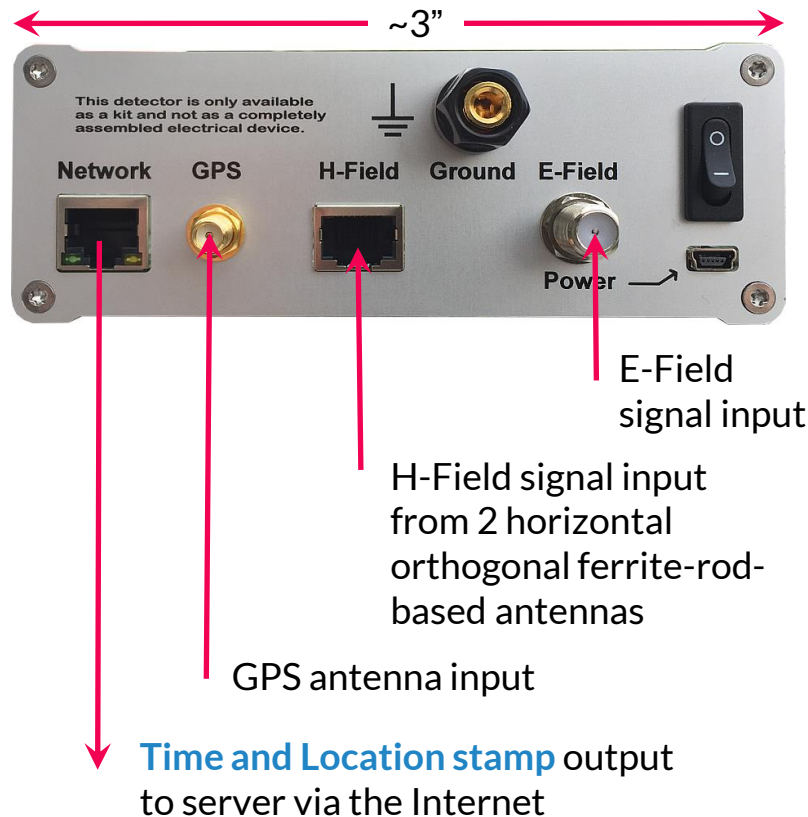
E-field antenna & pre-amp



H-field antennas & pre-amps

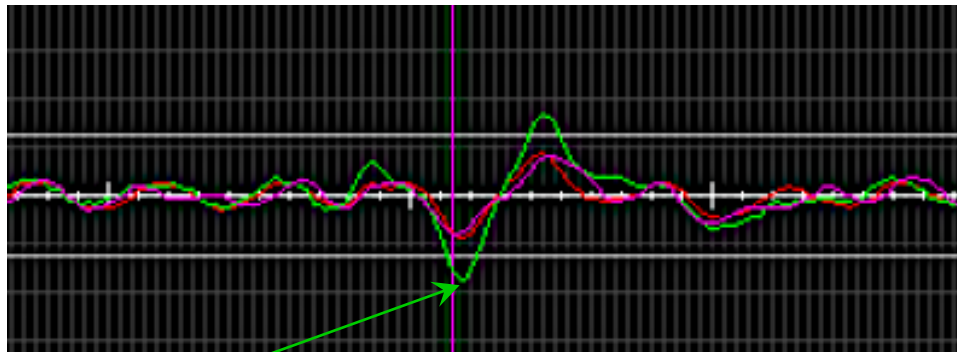


Example stroke detected in H-1, H-2 & E path



Examples of Data - 1

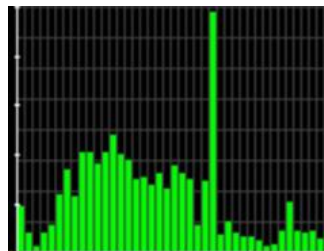
Station: 2575 (system blue) Latitude: 43.98xxxx
User: 2004 Longitude: -69.26xxxx
Date: 2019-08-24 Altitude: 18
Time: 22:25:49.282946769
Regions: North America
Country: United States / Maine
City: St. George
Comment: Two 200x15 mm Ferrites; 100 mm E-probe
Controller: 19.5
Firmware: 9.2



H-1 signal

$100\mu\text{s}$

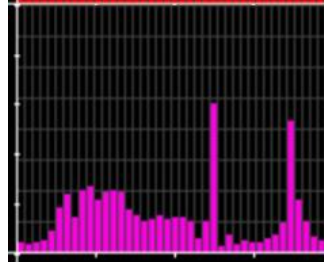
Time Response of a Stroke and the
Corresponding Frequency Response



H-1 signal



H-2 signal

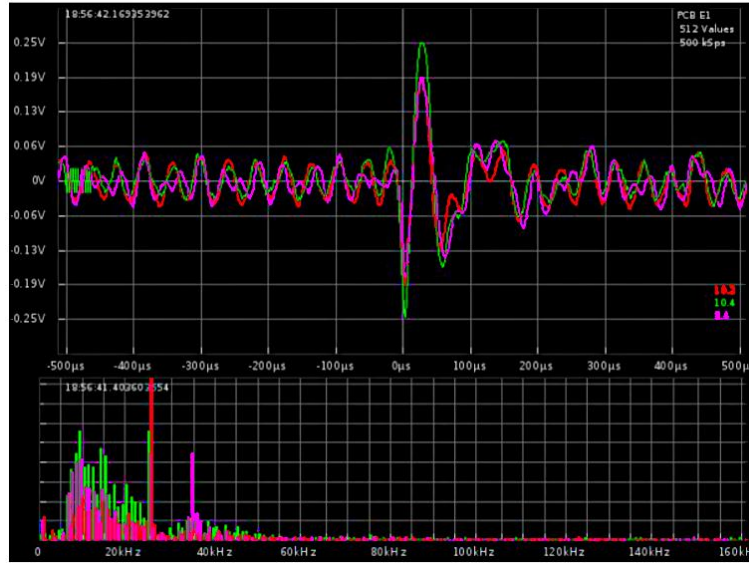


E signal

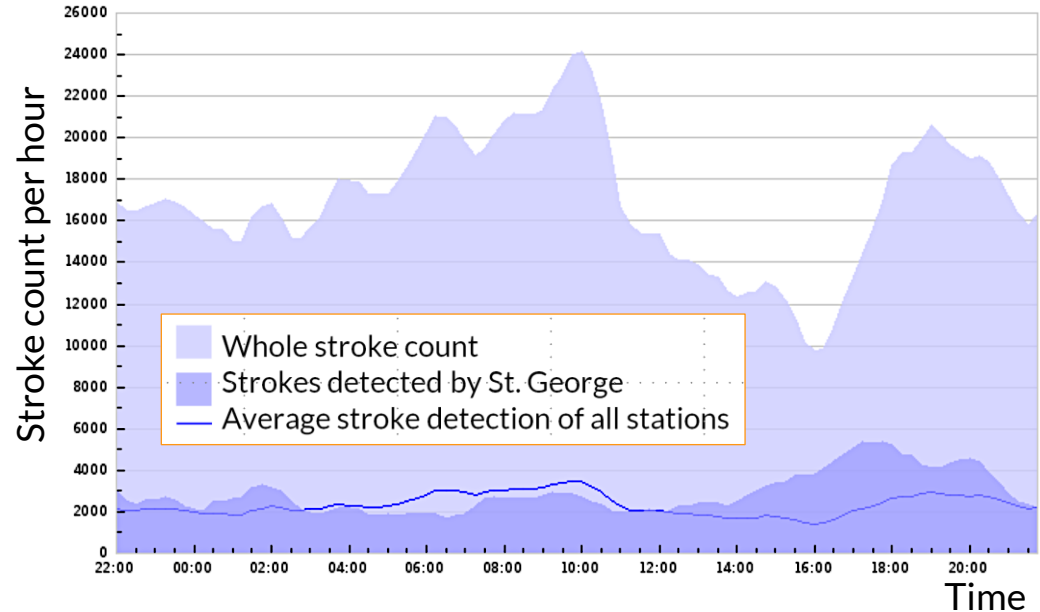
0 kHz

40 kHz

Examples of Data - 2

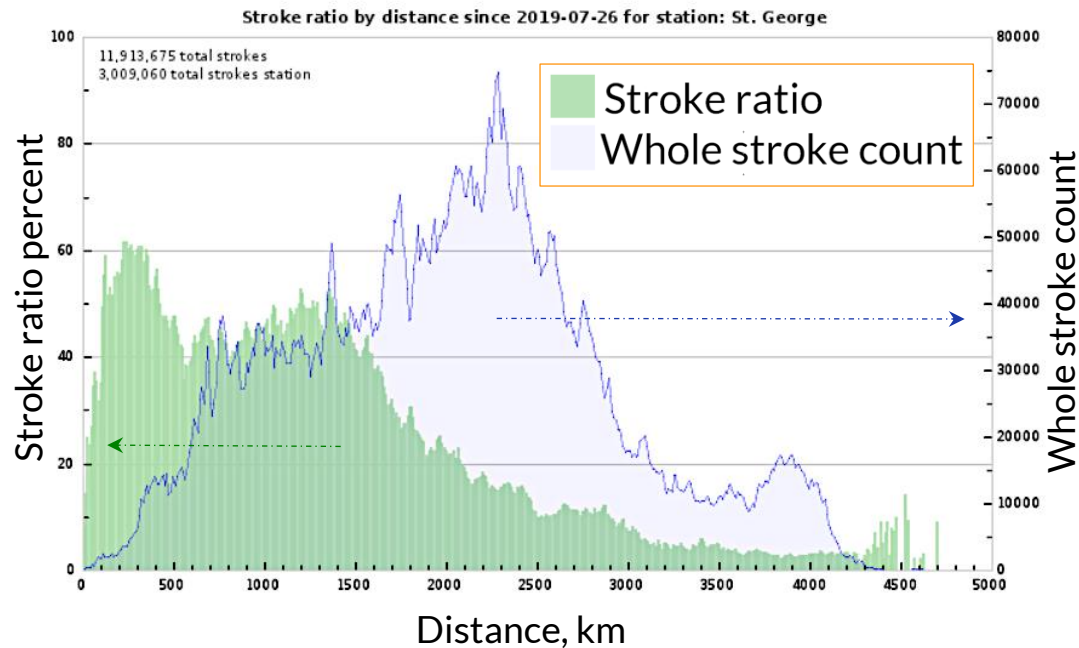


Another stroke example:
channels superimposed in both time
and frequency



Strokes over a 24 hour period:
St. George compared to all stations

Examples of Data - 3



Station St. George (United States / Maine)

Record longtime data since:	2019-07-26 23:07:28 UTC
Strokes detected:	3,009,852
Station active:	29.1 days
Station inactive:	0.5 days (0.5 hours without GPS)
Max stroke count per hour:	17,820
Minimum distance:	7.5km
Maximum distance:	13,584.1km
Signals detected:	12,275,979
Stroke ratio:	25.3%
Locating ratio:	24.5%
Max signal count per hour:	33,966

[Station 2575](#)

Stroke ratio = (detected strokes of the station) / (network stroke count)

Single Station Distance Accuracy - 1

Let the estimated time of the lightning stroke, using data from many stations = $\hat{t}_s$

and the estimated position of this stroke, again using the data from many stations, = $\hat{P}_s$

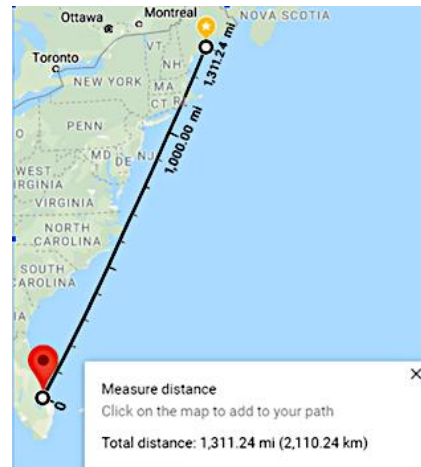
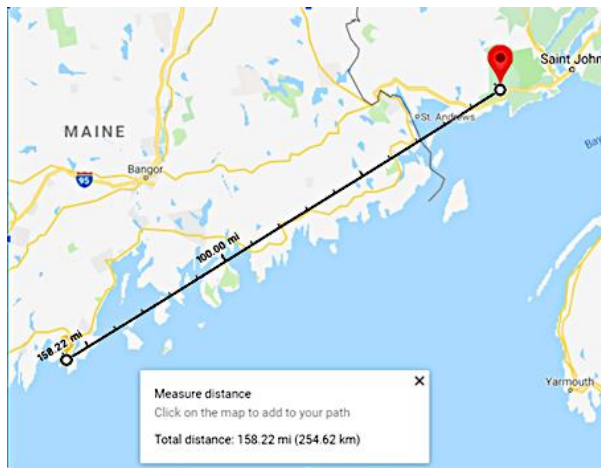
Now the estimated position of station i from the GPS data = $\hat{P}_i$

So the **best estimated distance** from the stroke to the station $\hat{Z}_i = \hat{P}_s - \hat{P}_i$

But if station i measures the arrival time to be t_i

then the **single station estimate** of the distance from the stroke to station i, $z_i = (t_i - \hat{t}_s) \times c$

Single Station Distance Accuracy - 2



From	To	# stations	Best Estimate $\hat{Z}_i$	Single Station Estimate Z_i	Difference, %
St. John's, New Brunswick	St. George, Maine	57	254.6 km	255.5 km	0.35
West Palm Beach, Florida	St. George, Maine	124	2,110.2 km	2,119.7 km	0.45

Alternative Lightning Detection Methods



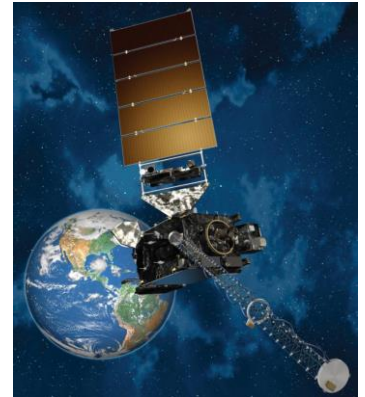
Portable Lightning Detector :

It appears to be based on AS3935 Franklin Lightning Sensor IC - its lightning algorithm is broken up into three sub blocks:

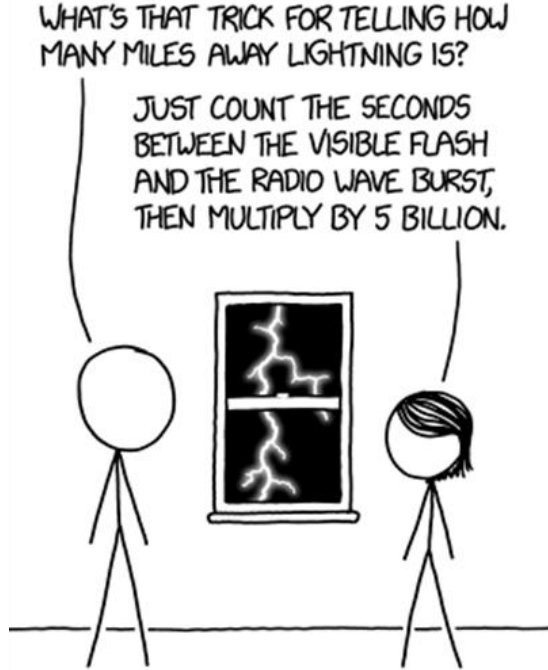
- 1. Signal validation: Verification that the incoming signal can be classified as lightning.
- 2. Energy calculation: Calculation of the energy of the single event.
- 3. Statistical distance estimation: According to the number of stored events (lightning), a distance estimate is calculated.

Geostationary Lightning Mapper (GLM) – part of GOES-16 satellite:

- A single-channel, near-infrared optical transient detector
- Measures total lightning (in-cloud, cloud-to-cloud and cloud-to-ground) activity continuously over the Americas and adjacent ocean regions
- Near-uniform spatial resolution of approximately 10 km
- Operated by NOAA National Weather Service



Obligatory xkcd.com Reference



from <https://www.xkcd.com/2027/>

- Refractive index of air is higher for VLF radio than at optical wavelengths, so radio propagates more slowly
- Speed of visible light (777 nm) in air at 15°C is ~ 299,710 km/s
- Speed of VLF radio waves in same conditions is ~ 299,698 km/s
- Hence time difference of arrival between visible flash and radio wave burst ~ 0.2 ns/mile
- For comparison, difference of arrival between visible flash and thunder clap ~ 5 s/mile

Summary

- “Cloud to Ground” strokes typically have peak spectral energy ~ 10 kHz that propagates within the ionospheric D layer
- blizortung.org – a world-wide amateur network of ~ 300 lightning detection stations
- Stations use magnetic and electric field antennas to detect “Cloud to Ground” strokes
- Signal processing in each station discriminates against noise and detects stroke peaks
- Server computes location of strokes by triangulation, using time and location data from detection stations
- Single station distance accuracy, even several thousand km from strokes, is within 0.5%