# Lightning Phenomenon and Its Detection

Chapter 1

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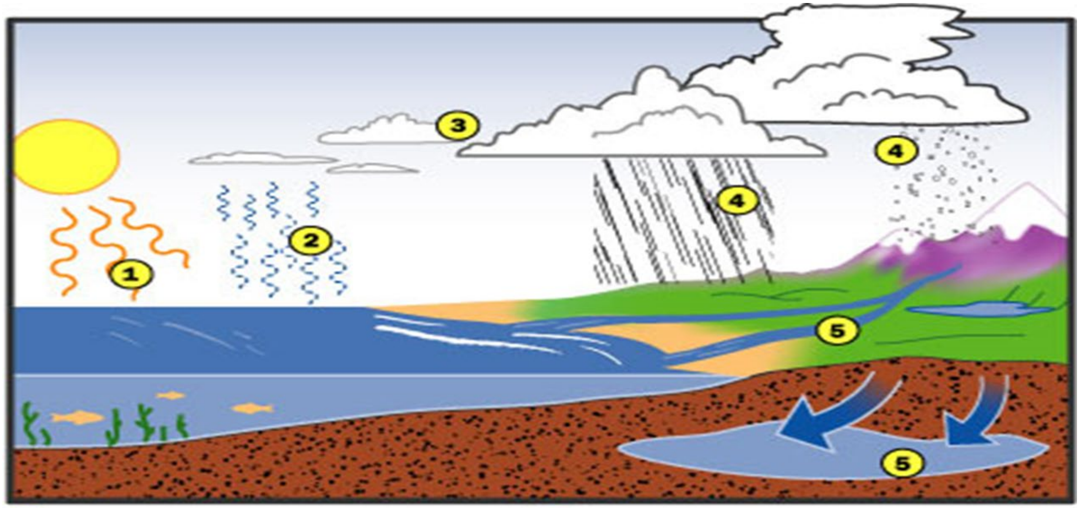
# Lightning Phenomenon and Its Detection

1. Introduction
2. Thunderstorm Formation
3. Lightning Flash
4. Lightning Parameters
5. Striking Distance
6. Lightning Detection
7. Lightning Related Damages
8. Lightning Protection

# Introduction

- 2000 thunderstorms in progress at any time resulting in 100 lightning flashes to ground per second-8 million per day.
- 100 deaths and 250 injuries in the United States per year, more deaths than from any other weather-related phenomenon, be it hurricanes, tornadoes, or floods.
- a plane being struck about once per 5000 flying hours.

# Thunderstorm Formation




1. The sun heats the ocean.
2. Ocean water evaporates and rises into the air.
3. The water vapor cools and condenses to become droplets, which form clouds.
4. If enough water condenses, the drops become heavy enough to fall to the ground as rain and snow.
5. Some rain collects in groundwells. The rest flows through rivers back into the ocean.

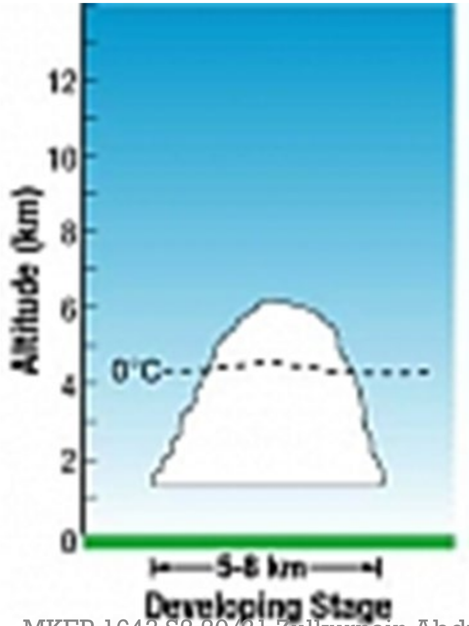
# Thunderstorm Formation

- Most thunderstorms form with three stages: the **cumulus** stage when storm clouds form, the **mature** stage when the storm is fully formed, and then the **dissipating** stage when the storm weakens and breaks apart.

# Thunderstorm Formation

## The Cumulus Stage

- When warm, moist air moves upward in an updraft, puffy cumulus clouds may form in the atmosphere.
- The moisture in the air condenses into water droplets as it rises.
- The cloud will continue to grow as long as warm air from below continues to rise.



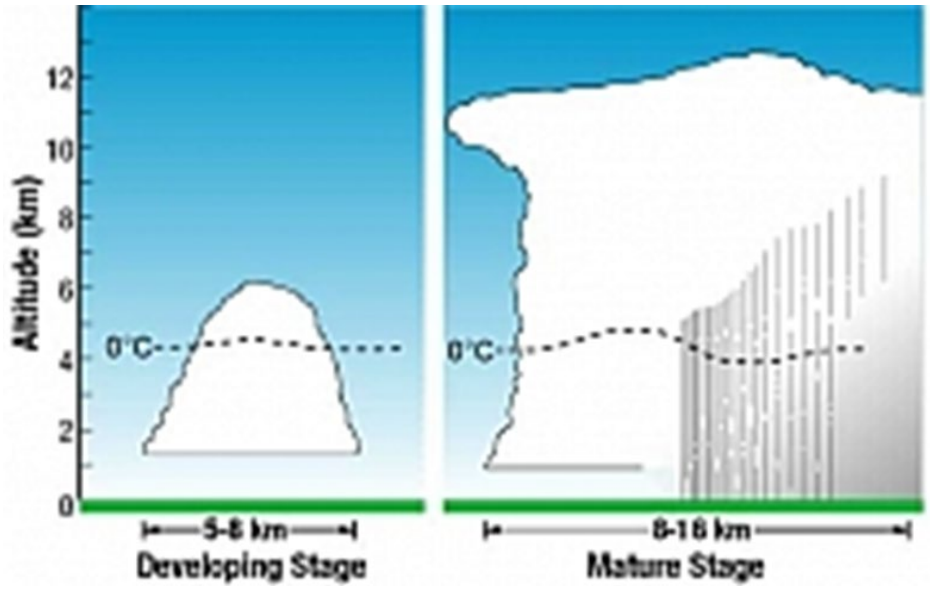
# Thunderstorm Formation

## The Mature Stage

- As the cumulus cloud continues to grow, the tiny water droplets within it grow larger too as more water from the rising air is added to the droplets.
- The cloud starts to look dark and grey as more water is added to it.
- And the growing droplets that make up the cloud become heavy.
- Raindrops start to fall through the cloud when the rising air can no longer hold them up.
- Meanwhile, cool dry air flows downward in the cloud, called a downdraft, pulling water downward as rain.
- With an updraft, downdraft and rain, the cloud is now called a cumulonimbus cloud and the cycling of air up and down is called a thunderstorm cell.

# Thunderstorm Formation
## The Mature Stage

- The moving air within the cloud builds up electric charges as it **slides past** other air.

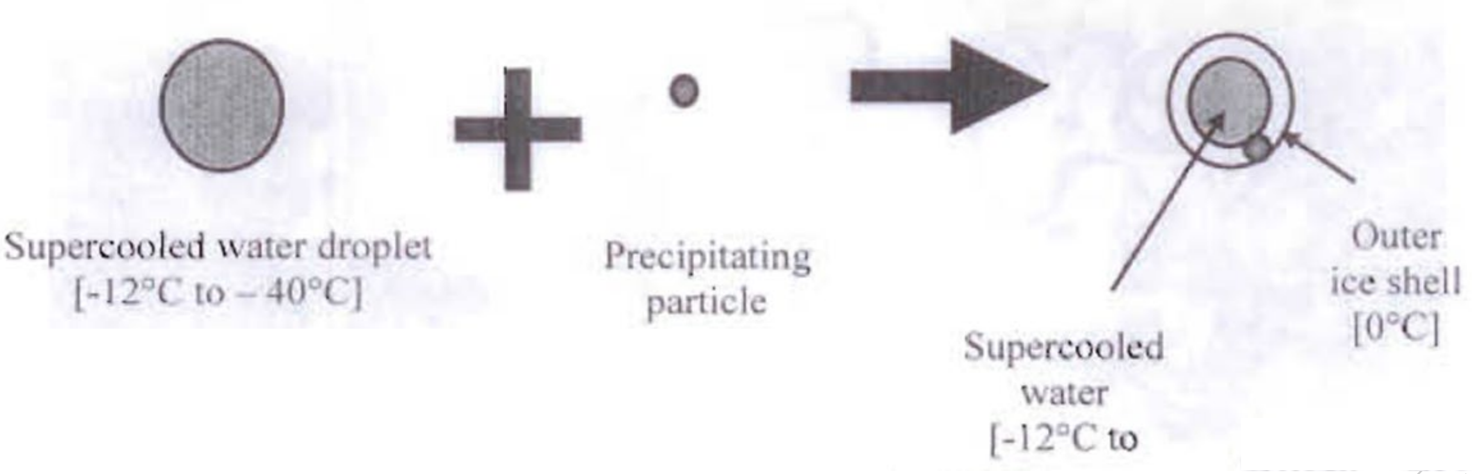


# Thunderstorm Formation

## The Mature Stage

### The Charging Process

- The charging process can be explained using the ice-splinter theory [Mason, 1953]

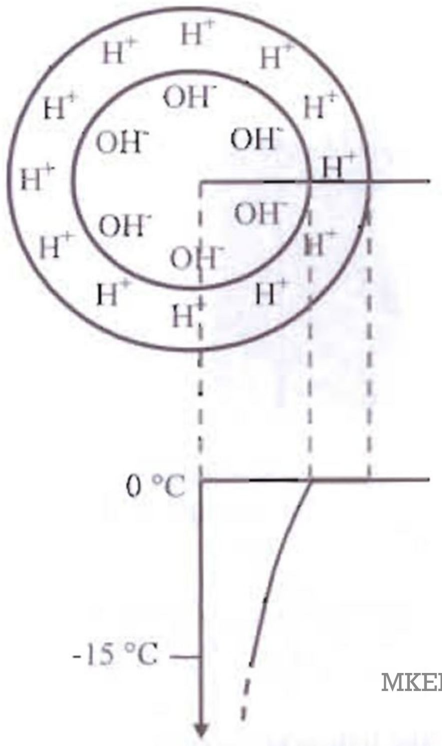


# Thunderstorm Formation

## The Mature Stage

### The Charging Process

- The temperature gradient causes an imbalance of ion migration with H+ ions, which are more mobile, accumulating at the outer warmer cell.
- Due to the expansion of water on freezing, an unequal stress is set up and the ice shell splinters.

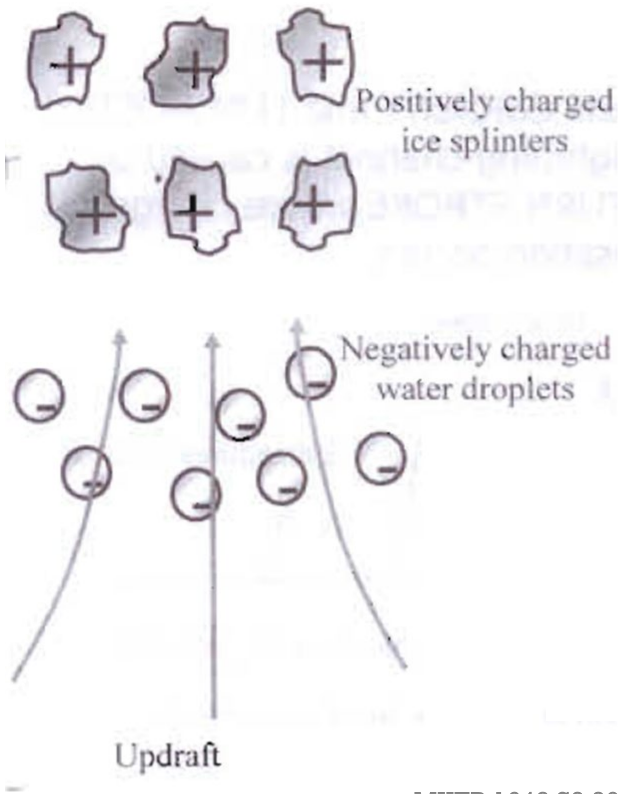


# Thunderstorm Formation

## The Mature Stage

### The Charging Process

- The updraft in the thundercloud then carries the lighter positively charged ice splinters to a higher altitude, leaving the heavier negatively charged supercooled water droplets at a lower altitude.

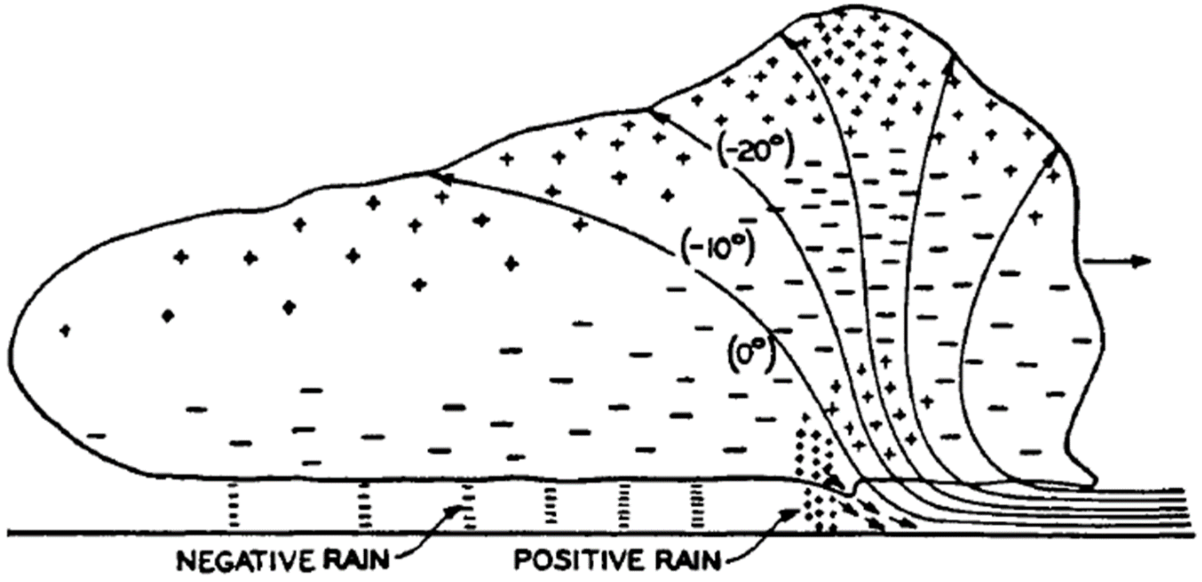


# Thunderstorm Formation

## The Mature Stage

### The Charging Process

- Resultant charge distribution in cloud



# Thunderstorm Formation

## The Mature Stage

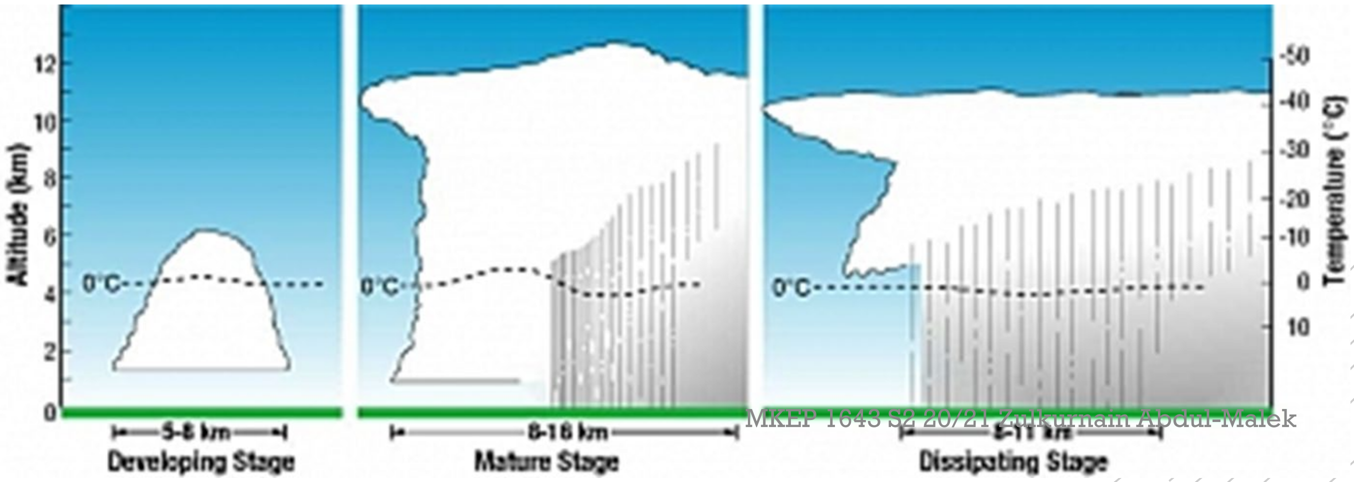
### The Discharging Process

- The build up of electric charges allow lightning to form, much in the same way that you can create a spark after shuffling your feet on a carpet.
- Thunder is the sound that happens when lightning strikes.
- It often happens after you see the bolt of lightning because sound travels more slowly than light.
- There could be more than one strike or discharge process within a lightning flash.

# Thunderstorm Formation

## The Dissipating Stage

- When the downdrafts in the cloud become stronger than the updraft, the storm starts to weaken.
- Since warm moist air can no longer rise, cloud droplets can no longer form.
- The storm dies out with light rain as the cloud disappears from bottom to top.
- The whole process takes about one hour for an ordinary thunderstorm.
- Severe thunderstorms like supercells and squall lines are much larger, more powerful, and last for several hours.

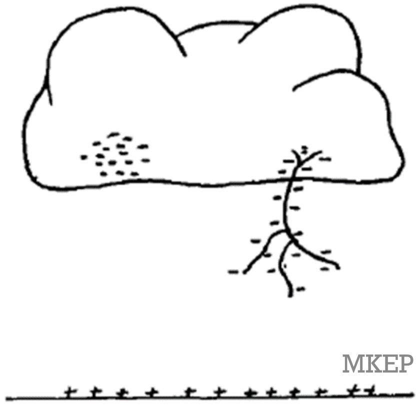


# Lightning Flash
## The Stroke Mechanism

- lower portion of the cloud is negatively charged; the upper portion is positively charged.
- positive charges build up on the ground beneath the cloud
- 60,000 feet have been recorded, average height is about 30,000 to 40,000 feet.
- base of the cloud 5,000 feet.

# Lightning Flash
## The Stroke Mechanism

- a point is reached when air breakdown occurs between the negatively charge region and the lower positively charged pocket or from the major negative and positive charges – these are known as cloud discharges.
- air breakdown also occurs at the edge of the cloud when sufficient voltage gradient occurs, and air breakdown begins from cloud to ground and the stepped leader moves toward ground.
- stepped leader refers to the halting steps formed by the leader, halting steps of about 50 meters.



# Lightning Flash
## The Stroke Mechanism

- After each step, the stepped leader pauses, then proceeds along one or more paths.
- The time for each step is about 50 us near the base of the cloud but decreases to about 13 us as it approaches the earth.
- The velocity of the stepped leader is relatively slow, about 0.10% of the speed of light.
- The leader is not visible to the naked eye and contains a current 50 to 200 amperes.

# Lightning Flash
## The Stroke Mechanism

- upward leader (or return stroke) is initiated that meets the downward leader.
- upward travels upward toward the cloud at a velocity oleaderf between 10 to 30% that of light.
- It is highly visible to the naked eye.
- The current brought to earth by this upward channel may exceed 200 kA but has a median value of about 33 kA.
- The temperature of this channel exceeds 50,000 °F about five times the temperature of the surface of the sun.

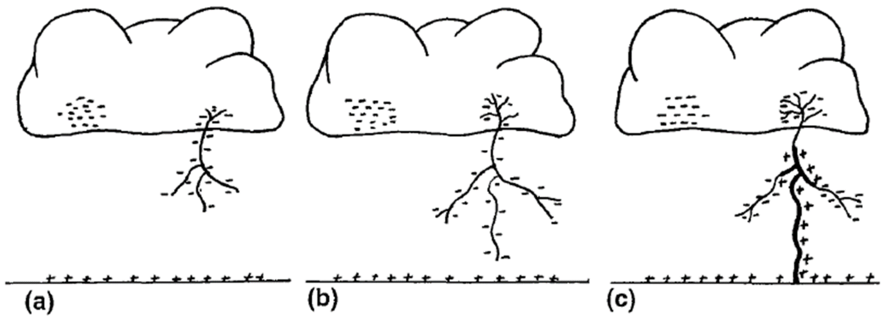



**Figure 2** The first stroke. (a) Stepped leader starts. (b) Stepped leader reaches ground. (c) Upward channel moves toward cloud.

# Lightning Flash
## The Stroke Mechanism

- The rapid increase in temperature to this high value creates shock waves that we hear as thunder.
- The total length of the downward leader or the upward channel averages about 5 to 6 km (3 to 4 miles).
- up to 54 strokes although the average is three strokes per flash.
- Multiple strokes of the flash may be frequently seen by the naked eye. That is, the noticeable pulsations of a flash are caused by subsequent strokes of the flash, i.e., one can count the pulsations.

# Lightning Flash

## The Stroke Mechanism

- After a time between about 10 to 100 ms, a second leader, called a dart leader
- Its velocity of about 1 % that of light is much greater than that of the stepped leader since it follows the ionized path forged by the stepped leader.

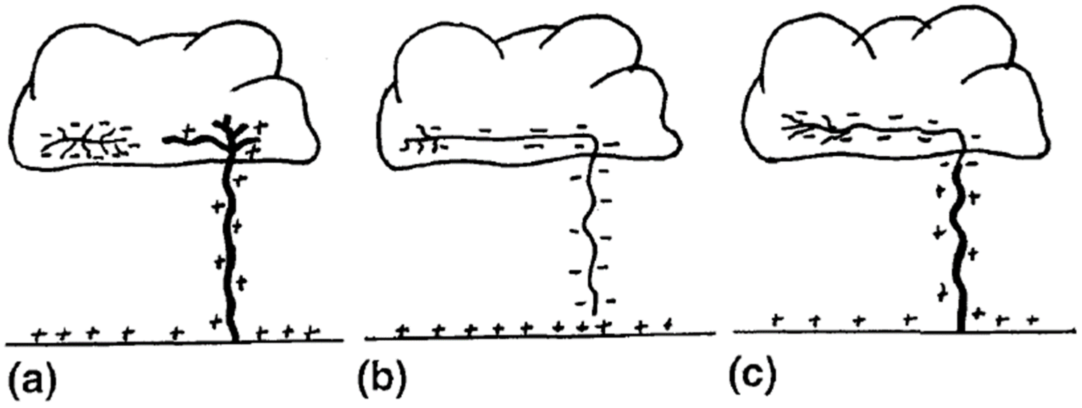



**Figure 3** A second stroke. (a) Upward channel of first stroke reaches cloud. (b) Dart leader progresses to ground. (c) Upward channel begins.

# Lightning Flash
## The Stroke Mechanism

- Lightning striking ground, but at the same time, streamers emit from the electric pole.

# Lightning Flash
## Types

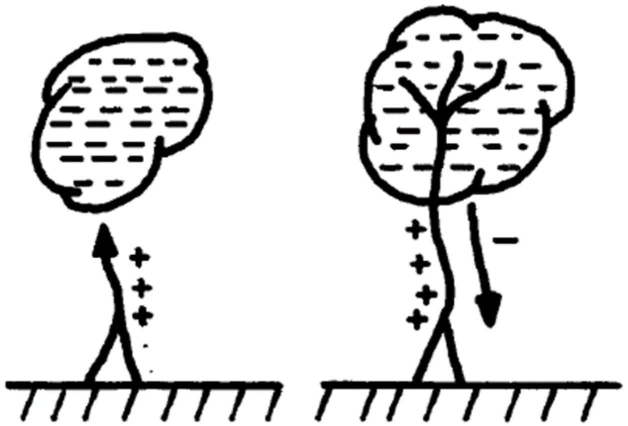
- The simplified description of the last step of the first stroke previously presented assumes a negative down-ward stroke or flash.
- This type of flash is the predominant type to open ground or to structures of moderate height, i.e., up to about 100 meters.
- However, three other types of flashes are possible as defined by Berger.
- The name associated with each type is dependent on (1) the polarity of the charge in the cloud from which the leader is initiated or to which the leader propagates and (2) the direction of the leader.
- Note that the polarity portion of the name also denotes the polarity of the resultant current to ground.

# Lightning Flash

## Types

| Leader | Return Stroke | Name | Comments |
| --- | --- | --- | --- |
|  |  | Negative Downward Flash | "Normal" flash to lines, 85-90%, Median = 33 kA. |

# Lightning Flash
## Types




Negative Upward Flash

First observed at the Empire State Bldg. Current less than Negative Downward.

# Lightning Flash
## Types

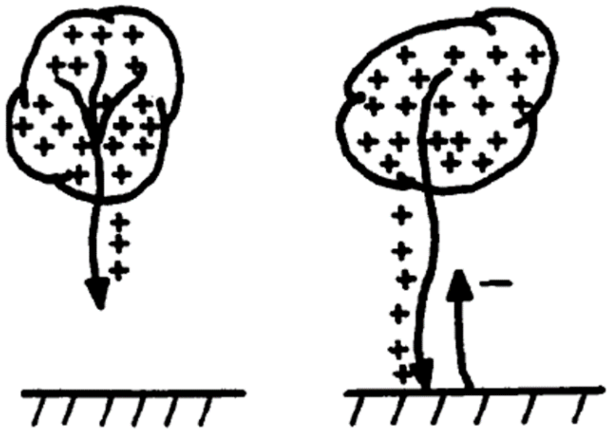


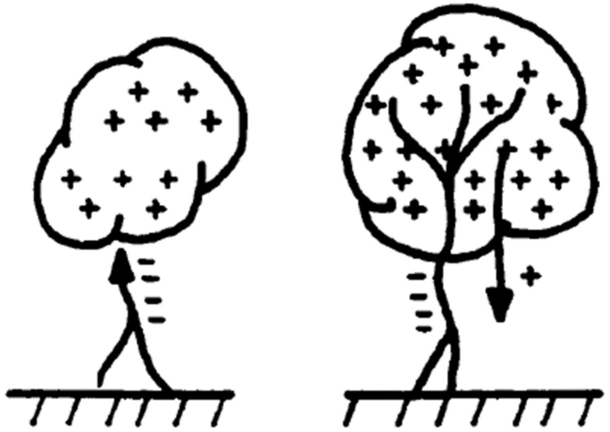

Figure 7 Types of lightning flashes.

Positive **Downward** Flash

None recorded by Berger. Difficult to distinguish between Positive Upward and Downward.

# Lightning Flash

## Types




Super Flash occurs in winter at start and end of storm. Current about 1.2 to 2.2 times Negative Downward.

# Lightning Flash

## Types

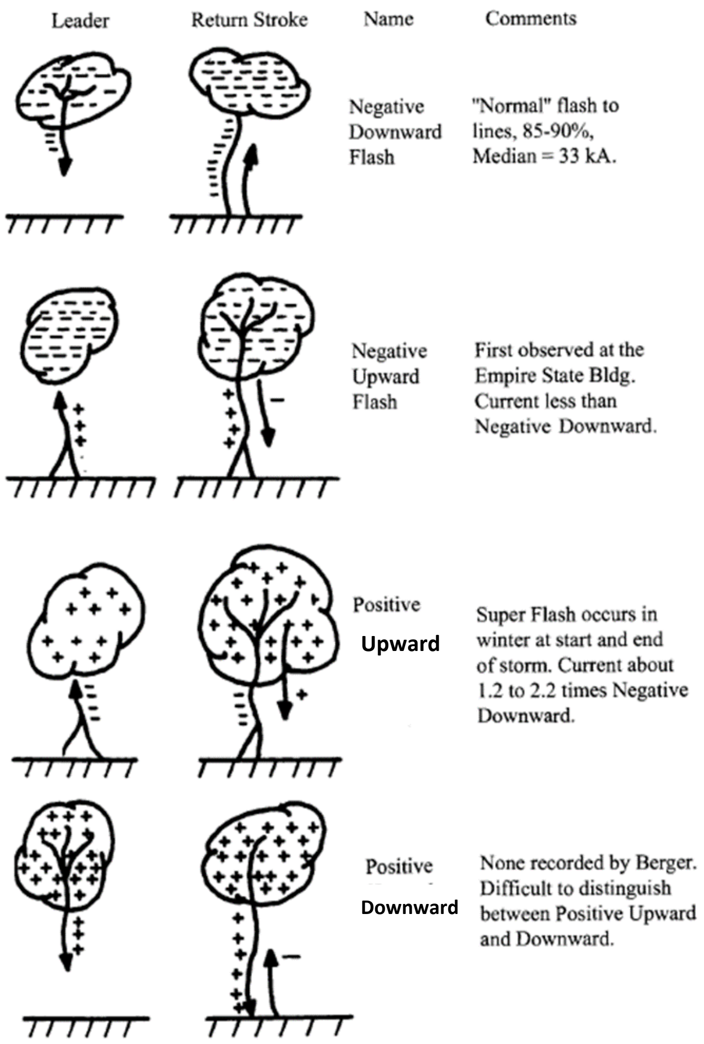
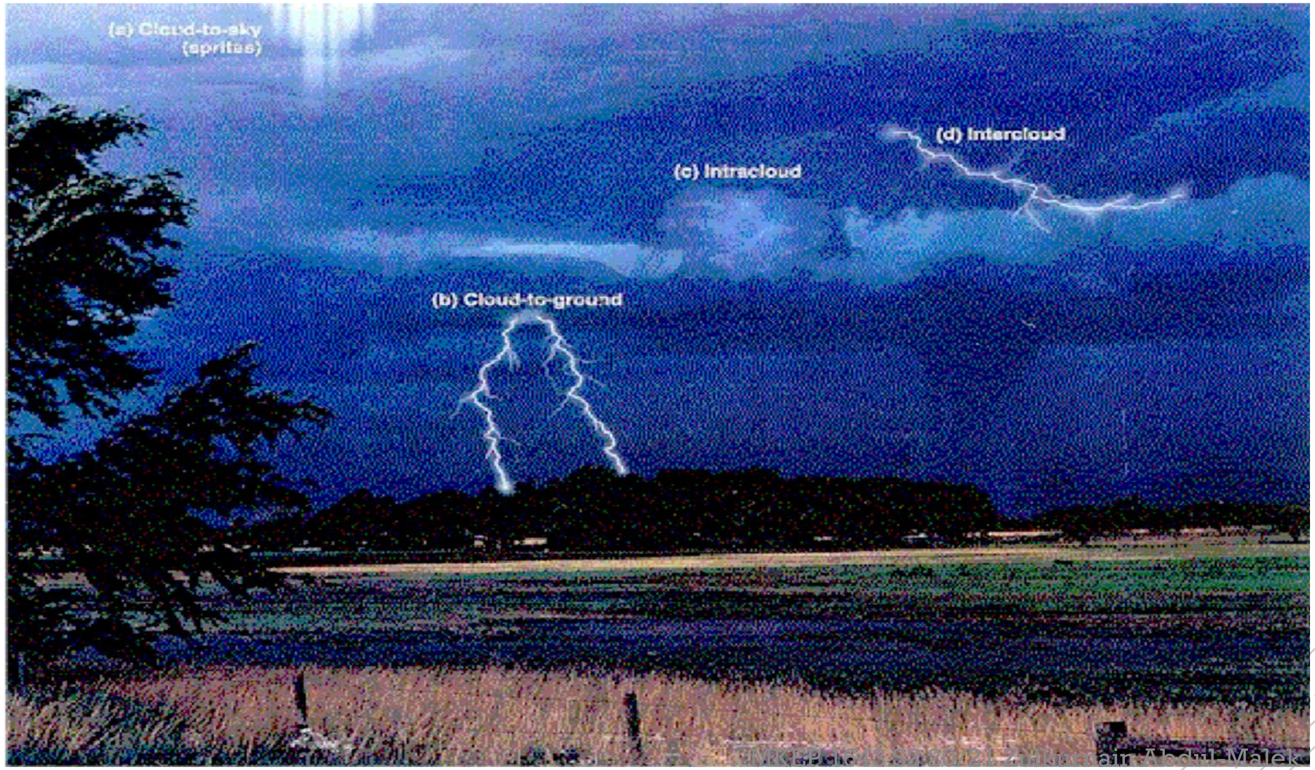



**Figure 7** Types of lightning flashes.

# Lightning Flash
## Types

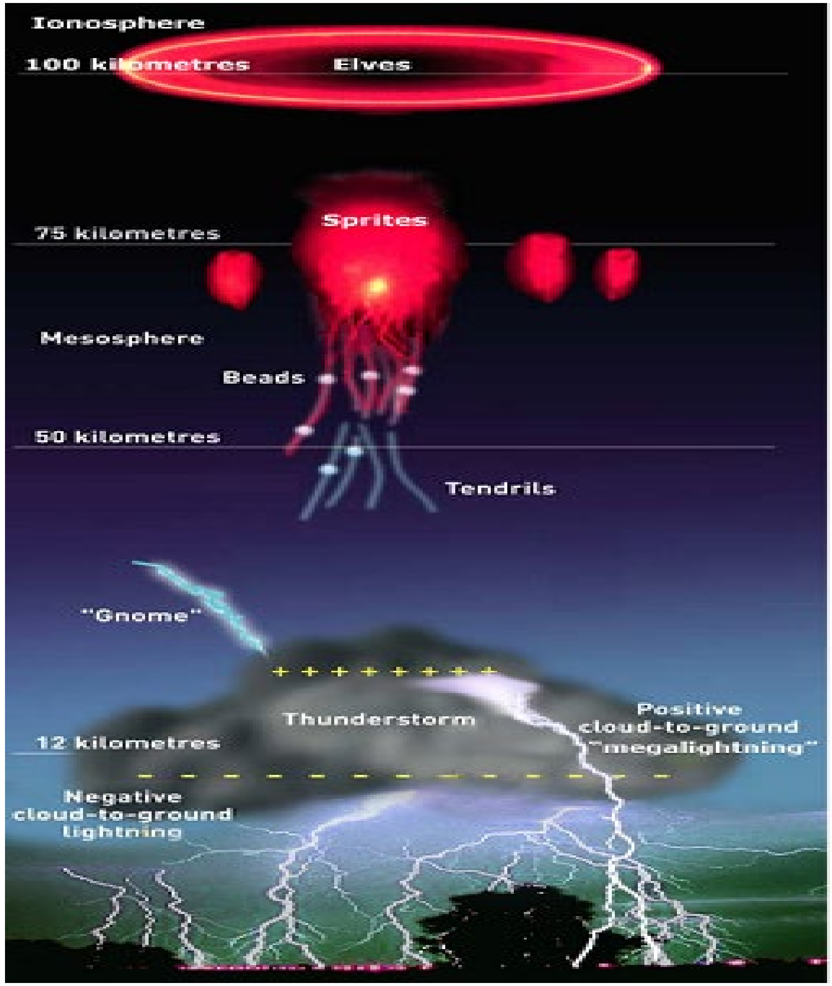
- Cloud-to-ground (CG)
- Intracloud
- Intercloud
- Cloud-to-sky (sprites)



# Lightning Flash
## Types

- A more recently discovered class of lightning occurs above the cloud layer, jumping from the tops of clouds into the stratosphere. There are three types of this rare lightning that have been discovered:
  - Red Sprites
  - Blue Jets
  - Elves
- All are associated with severe thunderstorms.

# Lightning Flash
## Types



# Lightning Flash

## Thunderstorm Developing Stage

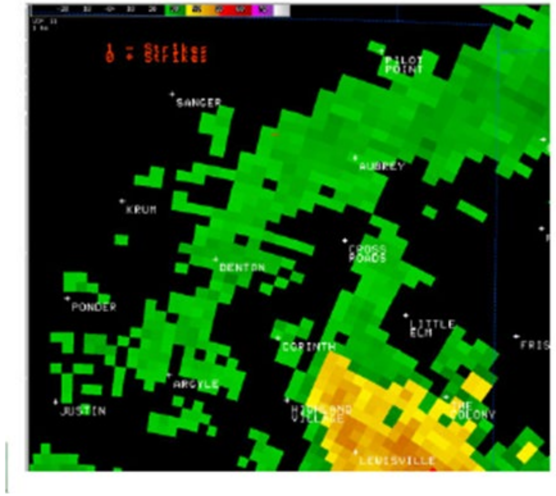
- Cloud lightning precedes CG lightning in most thunderstorms
- Cloud lightning can provide several to ~60 minutes early warning for increasing CG lightning threat

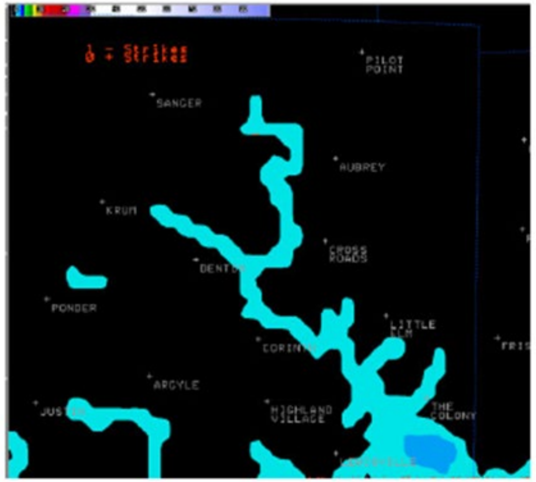
# Lightning Flash
## Mature Thunderstorm

- CG lightning rates start increasing
- Cloud lightning rates high, typically $\geq$ 3 times the CG lightning rate

# Lightning Flash
## Thunderstorm Dissipation

- Isolated CG lightning threat continues in less organized manner



# Lightning Parameters

- To the electric utility engineer, the parameters of the flash that are of primary interest are
  - The crest current for the first and subsequent strokes
  - The waveshape of these currents
  - The number of strokes per flash
  - Flash incidence rates: the ground flash density, flashes per square km-year, symbolized by Ng.
  - Any correlation between the parameters

# Lightning Parameters
## Peak Current

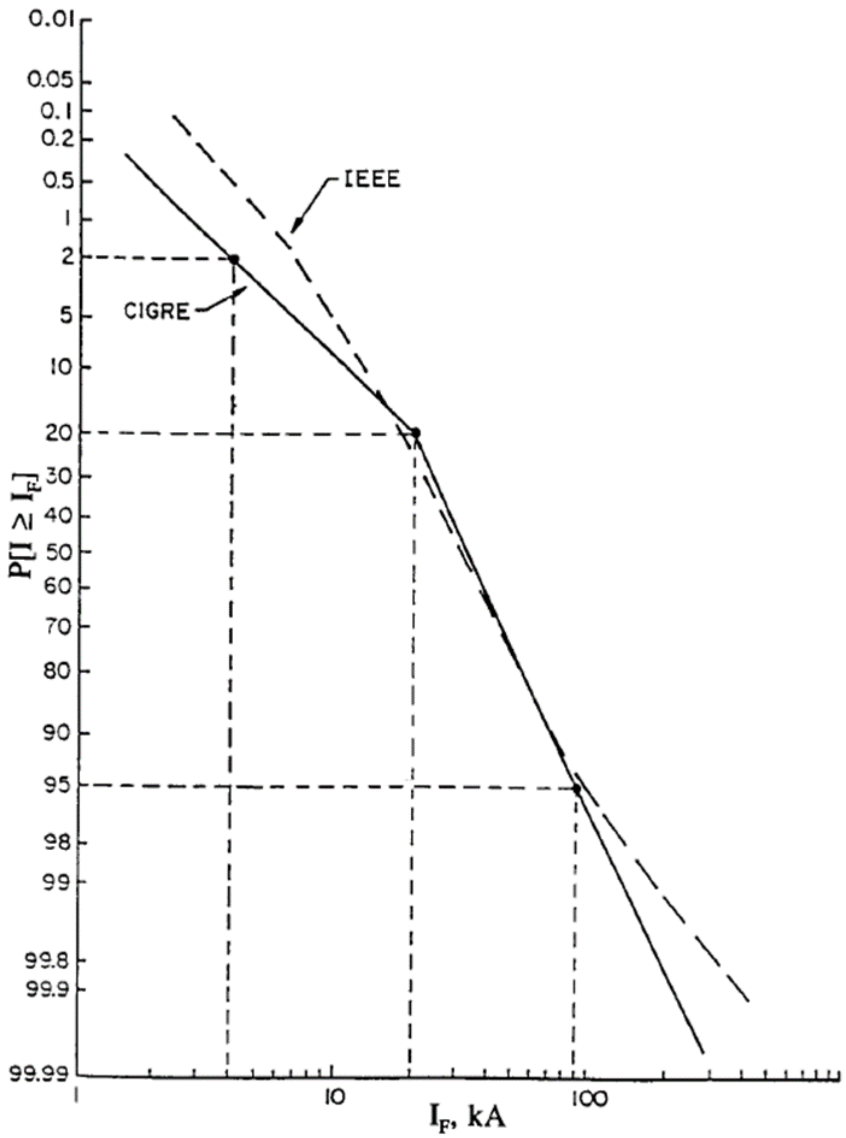



**Figure 11** CIGRE and IEEE stroke current probability curves, first stroke. Negative downward flash [8].

# Lightning Parameters
## Waveshape

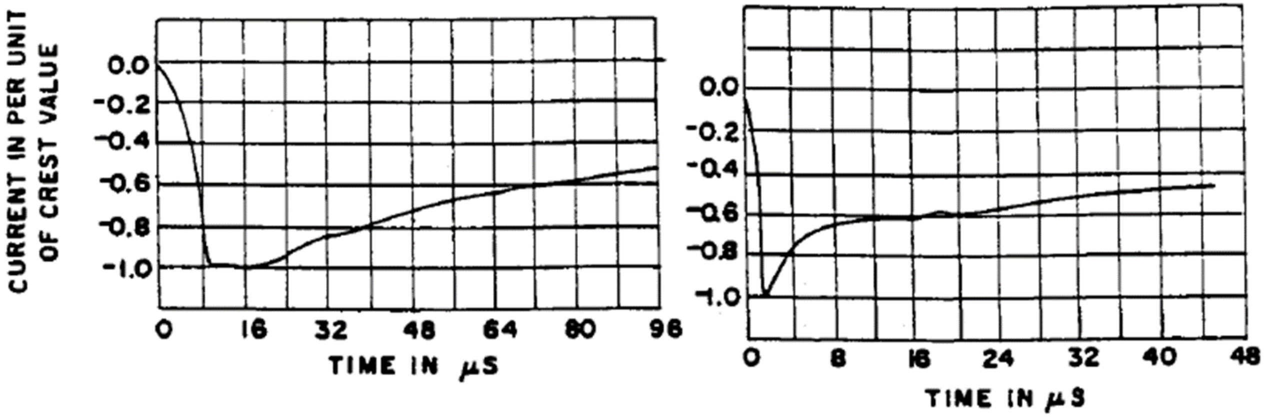


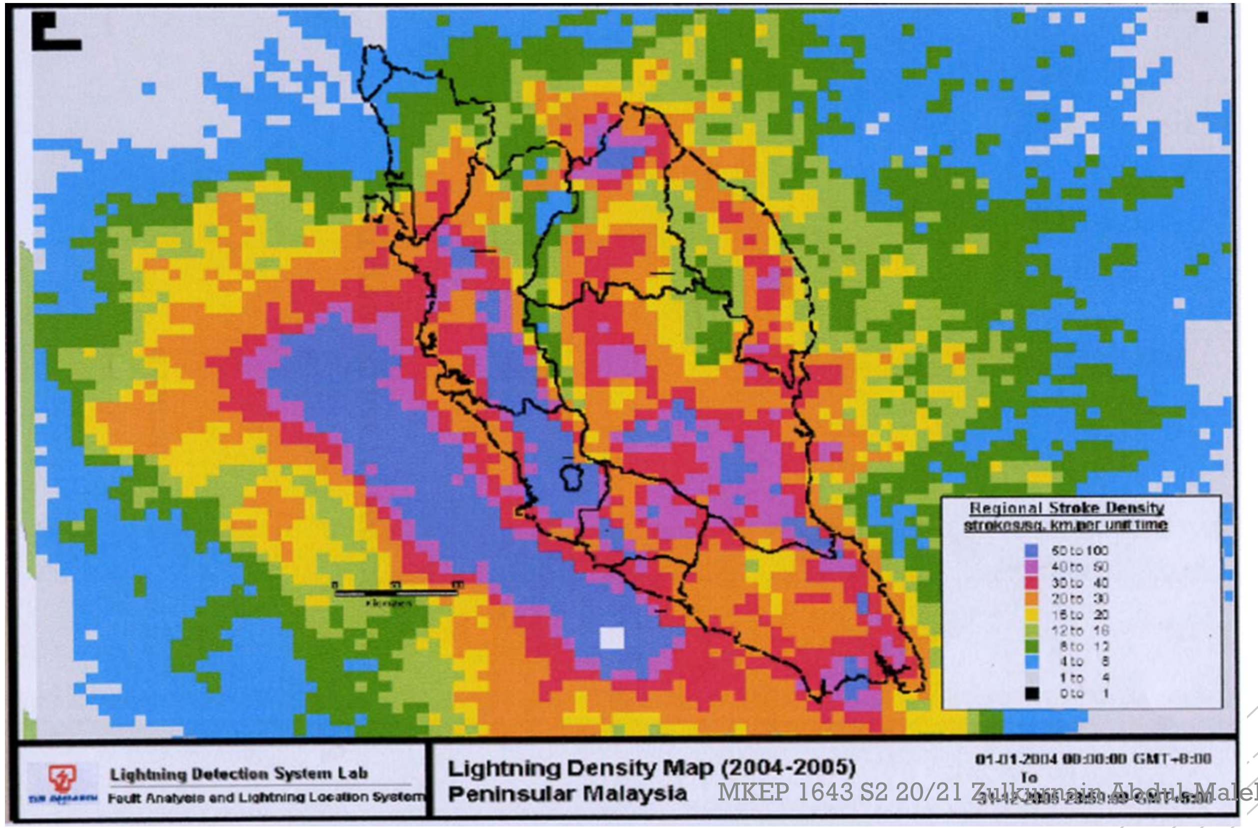

**Figure 9** Average wave shapes of negative downward strokes [8].

# Lightning Parameters
## Number of strokes per flash

- Within one flash, there could be upto 50 strokes.
- Average is 3 strokes.
- Standards consider single stroke when testing

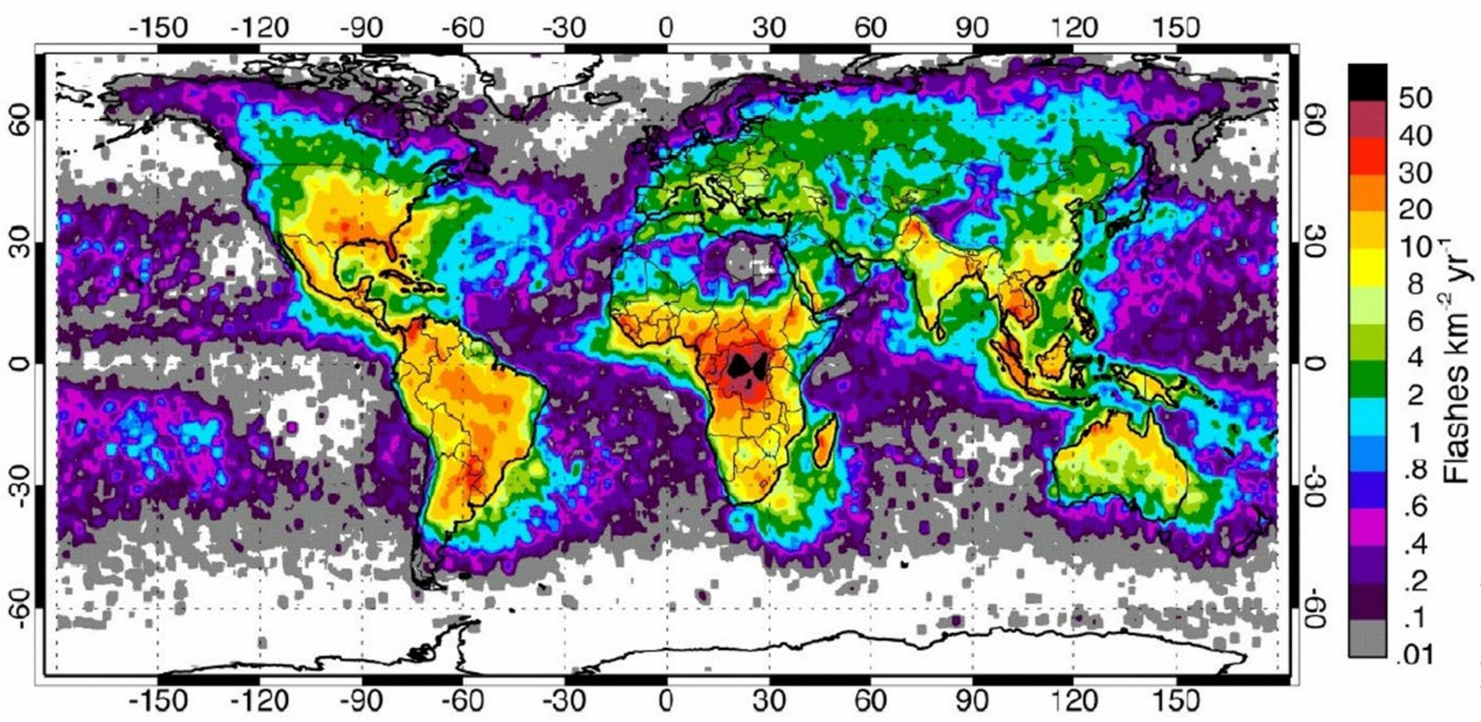
# Lightning Parameters
## Flash incidence rate

- The ground flash density (GFD) means number of flashes per square km-year, symbolized by $N_g$.
- Also, ground stroke density being number of strokes per square km-year



# Lightning Parameters
## Flash incidence rate

- 2000 thunderstorms in progress in the world at any given moment



# Lightning Parameters

## Flash incidence rate

- How to determine GFD?
  - Lightning counter (CIGRE 10 kHz)
  - Lightning locating system
  - Derived from number of storm days per year

$$N_g = kT_d^a$$

where **Td is the number of thunderstorm days per year**, the keraunic level. Many values of the constants k and $\alpha$ have been proposed

# Lightning Parameters

## Flash incidence rate

- Contour maps giving the number of thunderstorm days per year or the keraunic level are general available from weather bureaus.

| Major Towns/Cities | $T_D$-ave | $T_D$-max | $T_D$-min |
|---|---|---|---|
| Langkawi | 101 | 136 | 90 |
| Alor Setar | 165 | 197 | 145 |
| Butterworth | 172 | 183 | 164 |
| Bayan Lepas | 202 | 239 | 185 |
| Ipoh | 165 | 200 | 135 |
| Sitiawan | 193 | 235 | 179 |
| Subang | 188 | 195 | 180 |
| Malacca | 137 | 165 | 103 |
| Kluang | 191 | 222 | 165 |
| Senai | 172 | 206 | 159 |
| Mersing | 171 | 188 | 151 |
| Kuantan | 154 | 173 | 128 |
| Termeloh | 112 | 156 | 92 |
| Kuala Terengganu | 163 | 184 | 141 |
| Kota Bahru | 115 | 146 | 94 |
| Kuala Krai | 161 | 177 | 149 |
| Kuching | 184 | 231 | 151 |
| Sri Aman | 105 | 132 | 78 |
| Sibu | 103 | 115 | 85 |
| Bintulu | 133 | 180 | 102 |
| Miri | 88 | 101 | 68 |
| Labuan | 147 | 164 | 112 |
| Kota Kinabalu | 139 | 158 | 113 |
| Kudat | 79 | 96 | 60 |
| Sandakan | 155 | 193 | 118 |
| Tawau | 84 | 124 | 45 |

Table : Annual Thunderstorm Day for the Period 1993-2002

# Lightning Parameters
## Flash incidence rate

- Contour maps giving the number of thunderstorm days per year or the keraunic level are general available from weather bureaus.

**Figure 14** Annual frequency of thunderstorm days in the world [24].

# Striking Distance

- In 1961, Wagner proposed the simplified model of the 'last step' of the downward leader which progressed toward ground until it reached a "point of discrimination."
- Assuming a critical breakdown gradient of 605 kV/m, and a stroke potential of 50,000 kV, this point was reached when the distance between the core of the downward leader and the top of the tower was 50,000/605 = 83.3 meters or 270 feet.
- That is, the "striking distance" was about 83 meters.
- Assuming that breakdown gradient of 605 kV/m is a good estimate, the an equation or method is needed to estimate the potential of the downward leader.

# Striking Distance

- There is a relationship between the stroke current and the velocity of the return stroke
- There is also a relationship between the velocity of the return stroke with the potential of the downward leader
- Therefore, all is in place to estimate the striking distance:
  - Given the stroke current, the velocity is estimated
  - From the velocity, the potential, V, can be calculated
  - From the leader potential, the striking distance r is found from

$$r = V/G$$

where G is the breakdown gradient of 605 kV/m.

# Striking Distance

- Electrode configuration influences the breakdown gradient, hence a rod-plane gap (core of downward leader to ground) has a higher gradient than rod-rod gap (downward leader to top of tower).
- Consider a ground wire in a transmission line (used for protection)
- In the figure below, which striking distance is longer?

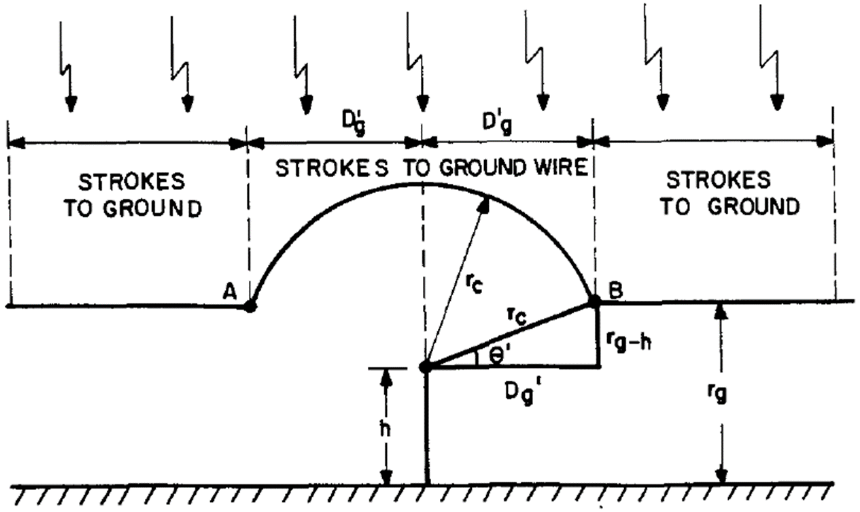



**Figure 20** Geometric model for a single ground wire.

# Striking Distance

- Explain the following statement:

  Any stroke that arrives between A and B will terminate on the ground wire, and any stroke that arrives to the left of A or to the right of B will terminate on the ground.

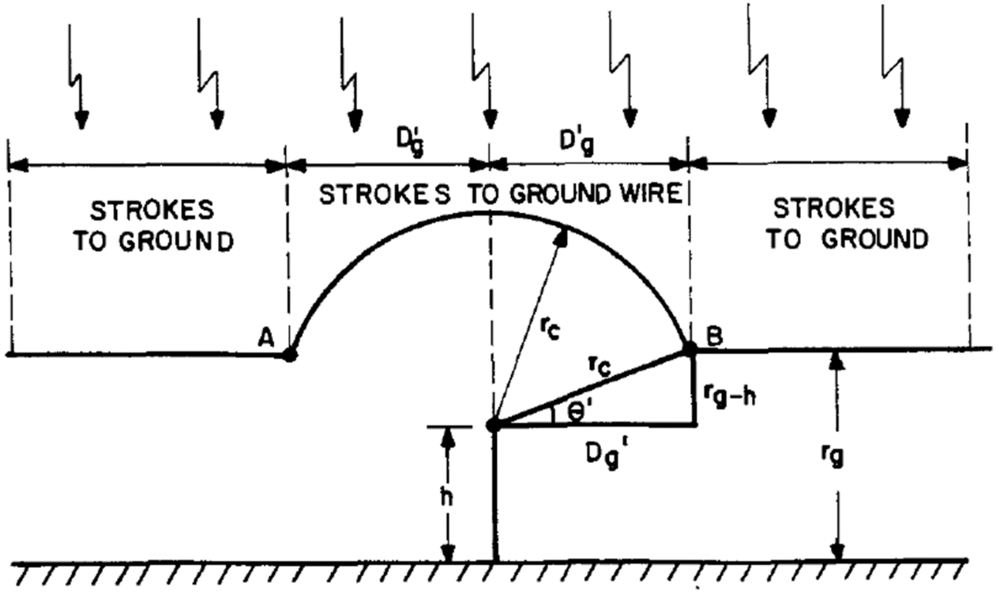



**Figure 20** Geometric model for a single ground wire.

# Striking Distance

- There are several equations proposed for the striking distance.
- For example,

1. IEEE-1992, as suggested by the IEEE Working Group:

$$r_c = 10.0I^{0.65} \qquad r_g = \beta r_c$$
$$\beta = 0.36 + 0.17\ln(43 - h)$$
$$\text{for } h > 40, \ \text{set } h = 40$$

2. Brown–Whitehead, as suggested by the CIGRE Working Group:

$$r_g = 6.4I^{0.75} \qquad r_c = 7.1I^{0.75}$$

# Striking Distance

- For this course, we are using the following equation:

$$r = 10\, I^{0.65}$$

where r is the striking distance in m (rod-plane) and

I is the peak return stroke current in kA

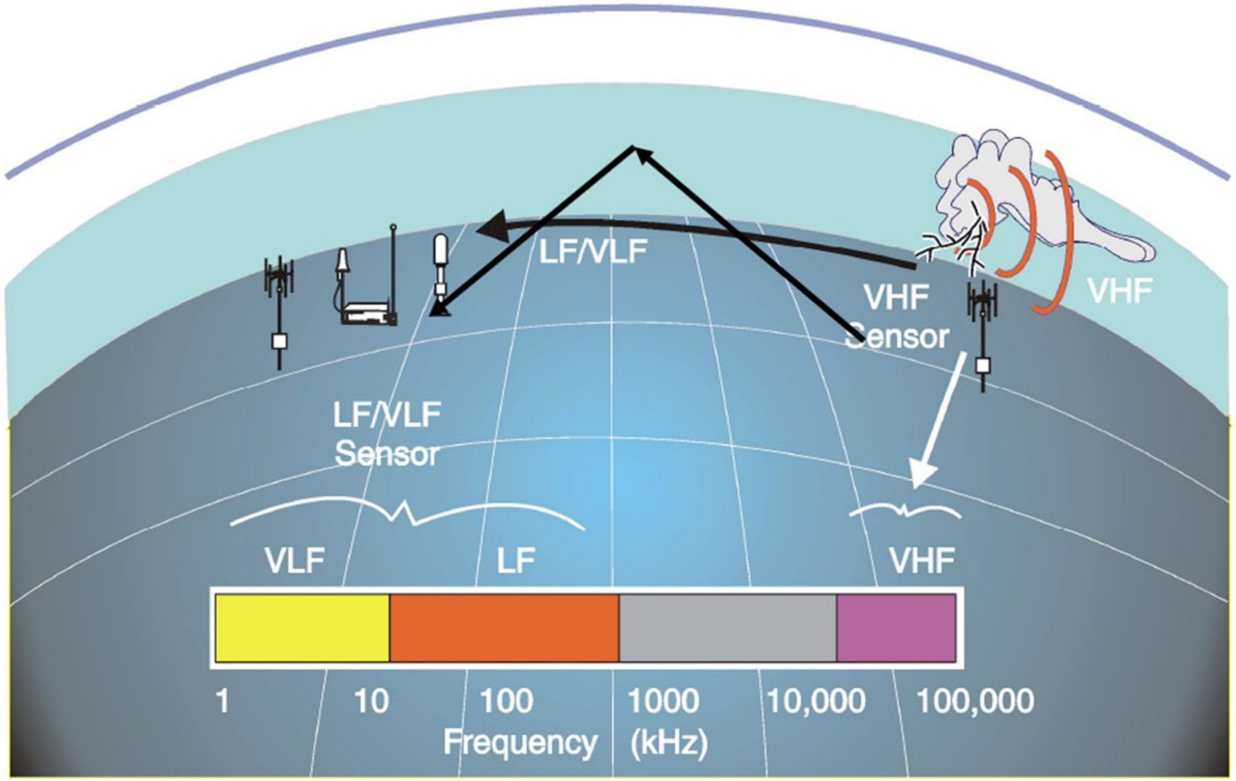
# Lightning Detection

- What is locating a lightning?

  A description of the main lightning location technologies
- Detection efficiency
  - -stroke DE
  - -Flash DE
- Location accuracy
- What do we mean by locating a lightning?
  - Finding the point of impact to ground in real time for cloud-to-ground lightning
  - It could be used to locate a flash, each stroke or even the small discharges within the cloud or along a stroke's channel

# Lightning Detection

- Lightning phenomena produce various electromagnetic fields



# Lightning Detection

- CG lightning emits the highest amplitude pulses in low frequency (LF) to very low frequency (VLF) range due to large amount of current moving over large distance
- Cloud lightning involves short range discharges with very little current- the result is small LF pulses but larger very high frequency (VHF) pulses
- Since the overall electrification and lightning discharge process involves many small electrical events, most of these are not seen in the LF frequency range

# Lightning Detection

- Means of propagation is frequency dependent
  - VLF: Earth-Ionosphere reflections
  - LF: Ground wave propagation
  - VHF: Line of sight propagation
- The dominant frequency is dependent on the type of discharge
  - VHF: provides efficient IC lightning detection
  - LF: provides efficient CG lightning detection and location
- CG lightning is typically detected in the LF range
- The CG lightning has a certain fingerprint that is detected in the waveform

# Lightning Detection Types

- Ground base lightning detection techniques
  - Short range lightning warning systems
    - Usually consists of field mills
      - Measures the local atmospheric electric field, monitoring the development and dissipation of the overhead lightning threat
  - Some time use electric field antenna system connected to electronc circuits – can provide a complete and accurate details of lightning activity by discriminating between cloud and cloud-to-ground lightning events, as well as reporting the range and bearing to individual events
  - Lightning counters
  - Lightning location system
- Satellite base lightning detection techniques

# Lightning Detection Types

- Ground base lightning detection techniques
  - Lightning counters
    - Use to detect the lightning activity within a certain area (usually about 20-30km)
    - Can detect and count cloud flashes and cloud to ground lightning flashes
    - Can be used to determine the ground flash density in a particular region
    - Can be used to determine the ratio between ground flashes and cloud flashes
  - Lightning location systems
    - Lightning location system can provide information such as, the direction of a lightning ground flash, time of occurrence, strength of the flash, polarity of the ground flash etc.

# Lightning Detection Applications

- Meteorology
- Aviation defense
- Electric power utilities
- Telecommunications
- Mission critical
- Space centres, industrial facilities, civil aviation, telecommunication sites
- Dynamic lightning protection
- Recreation/golf
- Forestry
- Insurance
- Research

# Lightning Detection

## Lightning Location System

- Time difference of arrival (TDOA)
- Magnetic direction finding (MDF)
- Combination of TDOA/MDF
- Interferometry
- Time to thunder
- Field component methods

# Lightning Detection

## Lightning Location System

### Time Difference of Arrival

- Can be used to locate the ground flashes
- Need at least four stations to locate a ground flash
- Use the time difference between stations to calculate the location of strike
- Operates by digitizing the waveform of a received lightning signal at each sensor and accurately timing the peak with a resolution of up to 100 nanoseconds
- Accuracy is very good compared with magnetic direction finders (less than 1 km)

# Lightning Detection

## Lightning Location System

### Time Difference of Arrival

- The difference of arrival times of the electric field signals at two antennas satisfy a hyperbolic curve.
- The addition of a third station makes it possible to determine two points of strike, one true and one false.
- Hence, a fourth station is needed to determine a unique point of strike.

# Lightning Detection

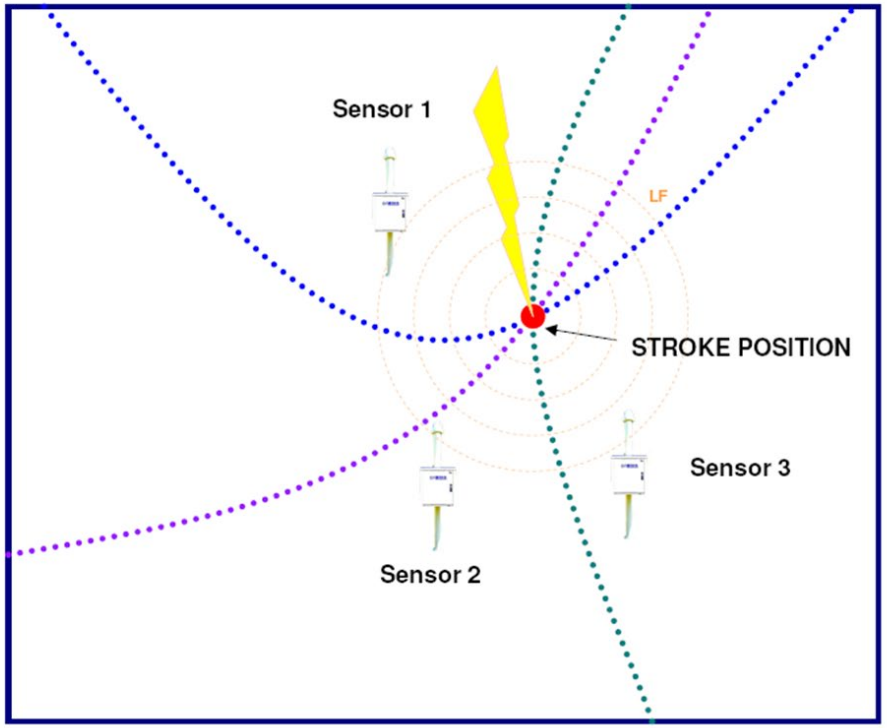
## Lightning Location System

### Time Difference of Arrival

- Synchronization is assumed to be within 2 us (600m)
- Propagation errors were introduced assuming uniform conductivity along the path of propagation
- Low efficiency compared with magnetic direction finders – since it need at least four stations to detect a lightning
- Record low multiplicity (number of return strokes per flash)
- Need global positioning system (GPS) to get the accurate time

# Lightning Detection

## Lightning Location System
### Time Difference of Arrival




1. Lightning makes contact with the ground creating a return stroke.

2. The LF signal propagates in all directions and is picked up by the LF antenna on each sensor. The time of arrival of the LF Signal is time stamped.

3. The equal time difference between sensor 1 and sensor 2 are marked with the **blue** line

4. The equal time difference between sensor 1 and sensor 3 are marked with the **purple** line

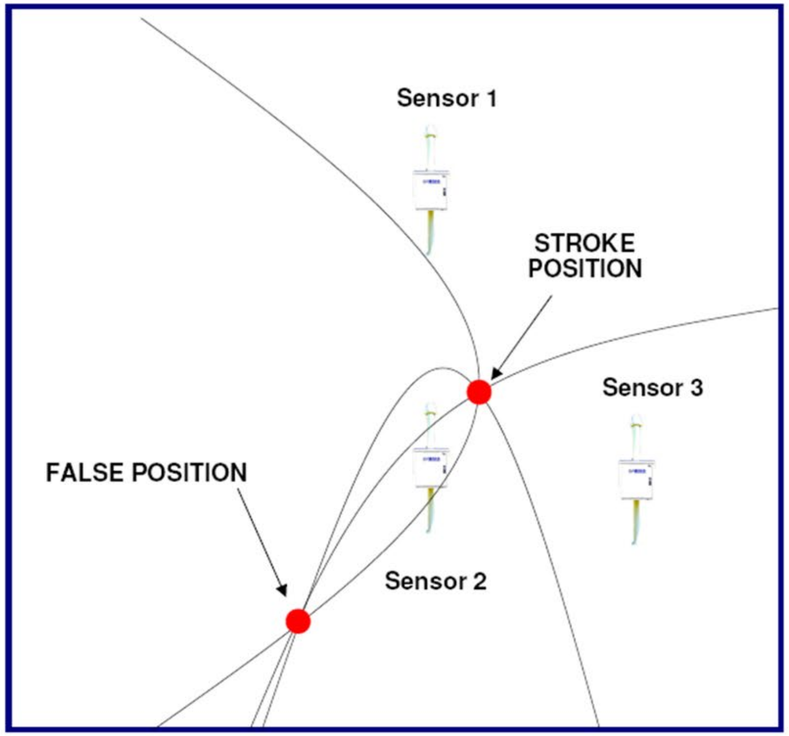
5. The equal time difference between sensor 2 and sensor 3 are marked with the **green** line

6. The intersection of three or more hyperbolas is the stroke location.

# Lightning Detection

## Lightning Location System

### Time Difference of Arrival



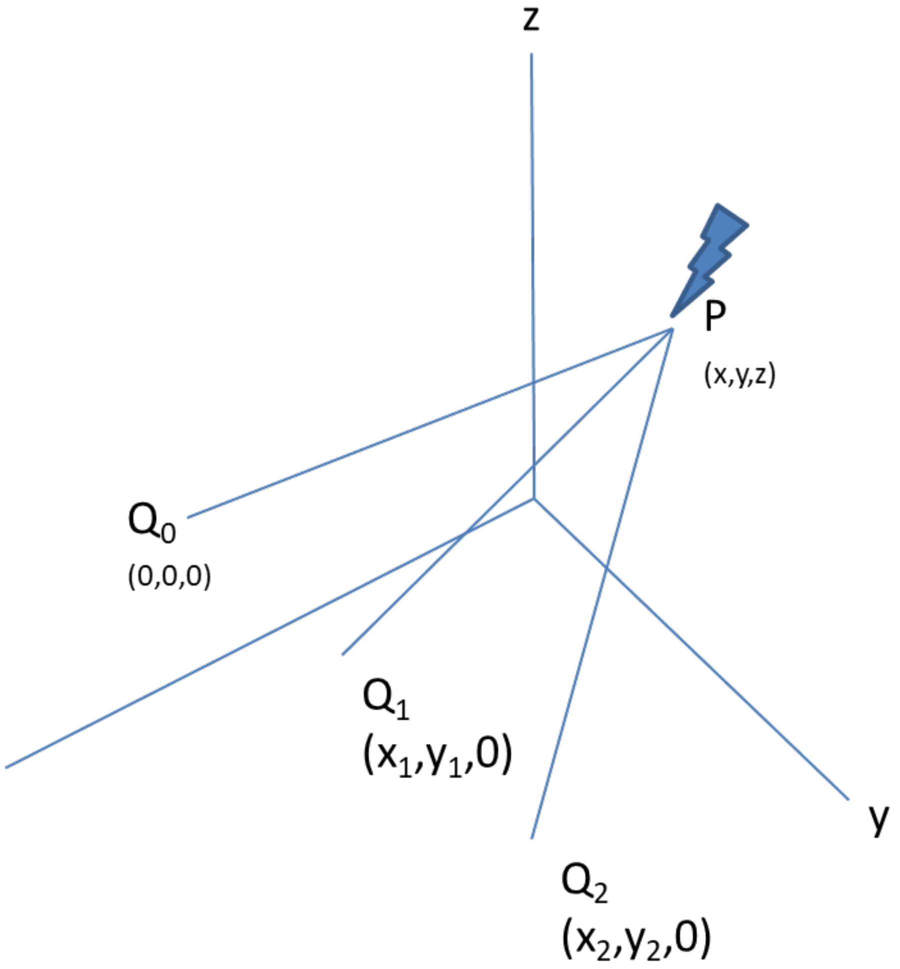

**Example of an ambiguous location for a three-sensor hyperbolic intersection**

- Requires 4 sensors to guarantee a solution. Possibility of false location with less than 4 sensors.
- Often has ghost storms and falsely plotted locations
- Typically works in the low frequency (LF) band so does not detect a majority of cloud lightning
- Older methodology and technology
- Vaisala and Vaisala customers have been operating TOA networks for many years and have each determined that this method has clear shortcomings that needed improvement.

# Lightning Detection

## Lightning Location System

### Time Difference of Arrival



# Lightning Detection

## Lightning Location System

### Time Difference of Arrival

- **Using Pythagoras' Theorem, we get**

$$PQ_0^{\ 2} = x^2 + y^2 + z^2 \qquad (1)$$

and

$$PQ_1^{\ 2} = (x - x_1)^2 + (y - y_1)^2 + z^2 \qquad (2)$$

and

$$PQ_2^{\ 2} = (x - x_2)^2 + (y - y_2)^2 + z^2 \qquad (3)$$

- **Using time difference of arrival, we have**

$$c\Delta t_1 = PQ_0 - PQ_1 \qquad (4)$$

$$c\Delta t_2 = PQ_0 - PQ_2 \qquad (5)$$

$$c\Delta t_3 = PQ_1 - PQ_2 \qquad (6)$$

# Lightning Detection

## Lightning Location System

### Time Difference of Arrival

- Hence, there are 6 unknowns (x, y, z, PQ0, PQ1, PQ2)
- But we have 6 equations, therefore x, y, and z can be solved.
- Simplifying the equations will give us 3 linear equations with 3 unknowns (x, y, and PQ0).
- Hence, with x, y, and PQ0 solved, z can be easily found.
- In this way, the coordinate of lightning strike can be found. However, the solution is NOT unique! There are two coordinates, one is the true one and the other FALSE.
- Task:

  Reduce the above 6 equations into 3 sets of equations in terms of the unknown x, y, and PQ0.

# Lightning Detection

## Lightning Location System

### Time Difference of Arrival

- **Task:**

  Reduce the above 6 equations into 3 sets of equations in terms of the unknown x, y, and PQ0.

$$c\Delta t_1 = PQ_0 - PQ_1$$

$$PQ_1 = PQ_0 - c\Delta t_1$$

$$PQ_1^{\ 2} = \left(PQ_0 - c\Delta t_1\right)^2$$

$$PQ_1^{\ 2} = PQ_0^{\ 2} - 2c\Delta t_1 PQ_0 + c^2\Delta t_1^{\ 2}$$

$$PQ_0^{\ 2} = x^2 + y^2 + z^2$$

$$PQ_1^{\ 2} = (x - x_1)^2 + (y - y_1)^2 + z^2$$

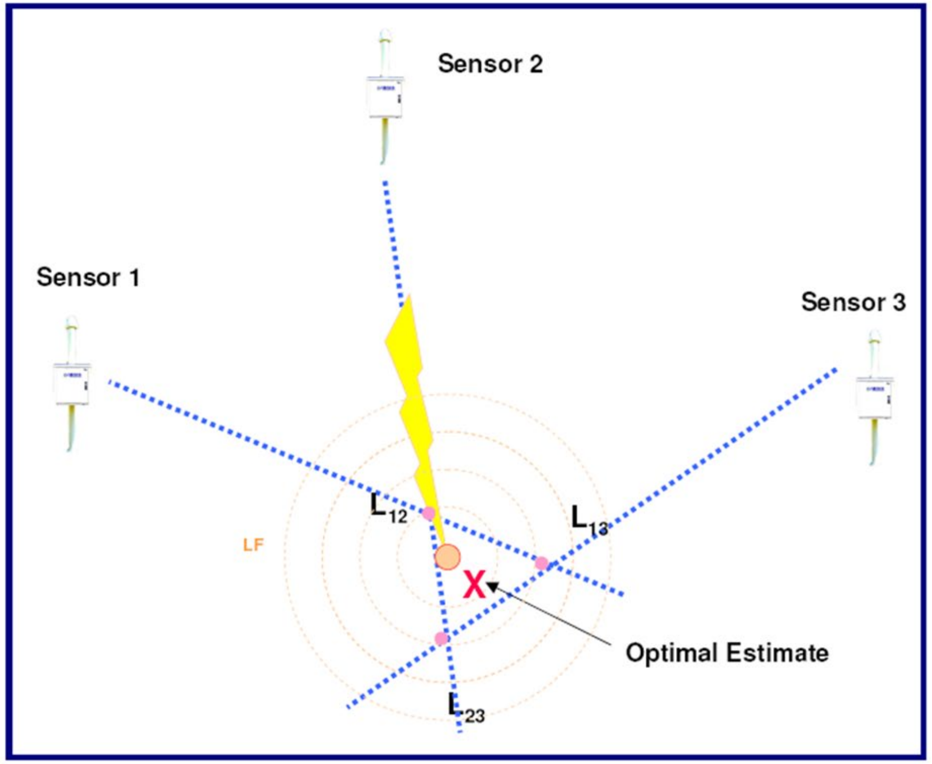
$$(x - x_1)^2 + (y - y_1)^2 + z^2 = x^2 + y^2 + z^2 - 2c\Delta t_1 PQ_0 + c^2\Delta t_1^{\ 2}$$

$$x_1^{\ 2} - 2x_1 x + y_1^{\ 2} - 2y_1 y = -2c\Delta t_1 PQ_0 + c^2\Delta t_1^{\ 2}$$

# Lightning Detection

## Lightning Location System

### Magnetic Direction Finding




1. Lightning makes contact with the ground creating a return stroke.

2. Low Frequency signals propagate in all directions as a result of the return stroke

3. The Magnetic Cross Loop Antenna on the sensor 1, 2 and 3 picks up the magnetic field from the return stroke and determines the direction of the source of the magnetic field

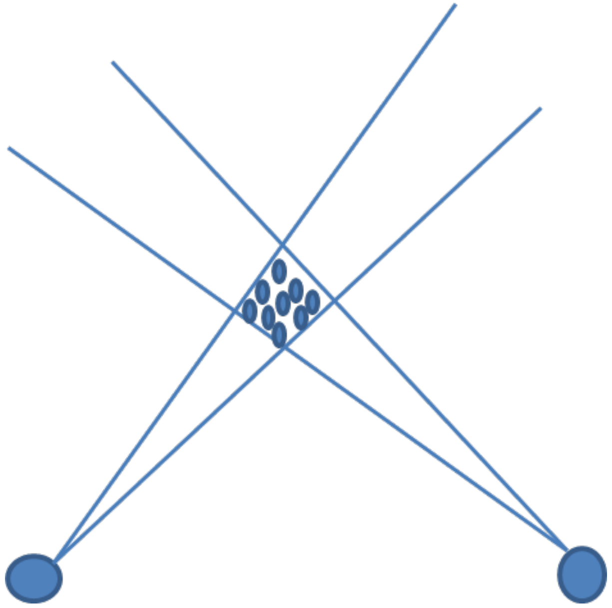
4. The Central processor then triangulates the results from each sensor creating an optimal estimate of location of the lightning

# Lightning Detection

## Lightning Location System

### Magnetic Direction Finding

- Also, if the azimuth error is bounded, one can give a location surface instead of a location point

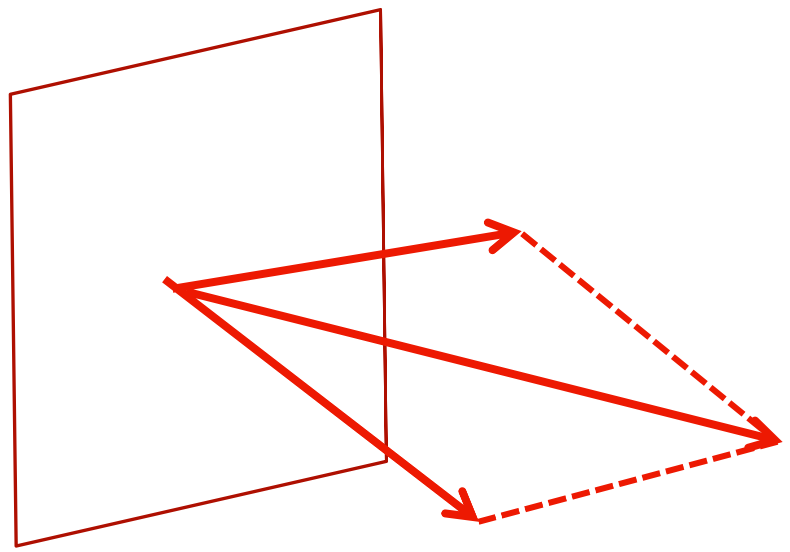


# Lightning Detection

## Lightning Location System

### Magnetic Direction Finding

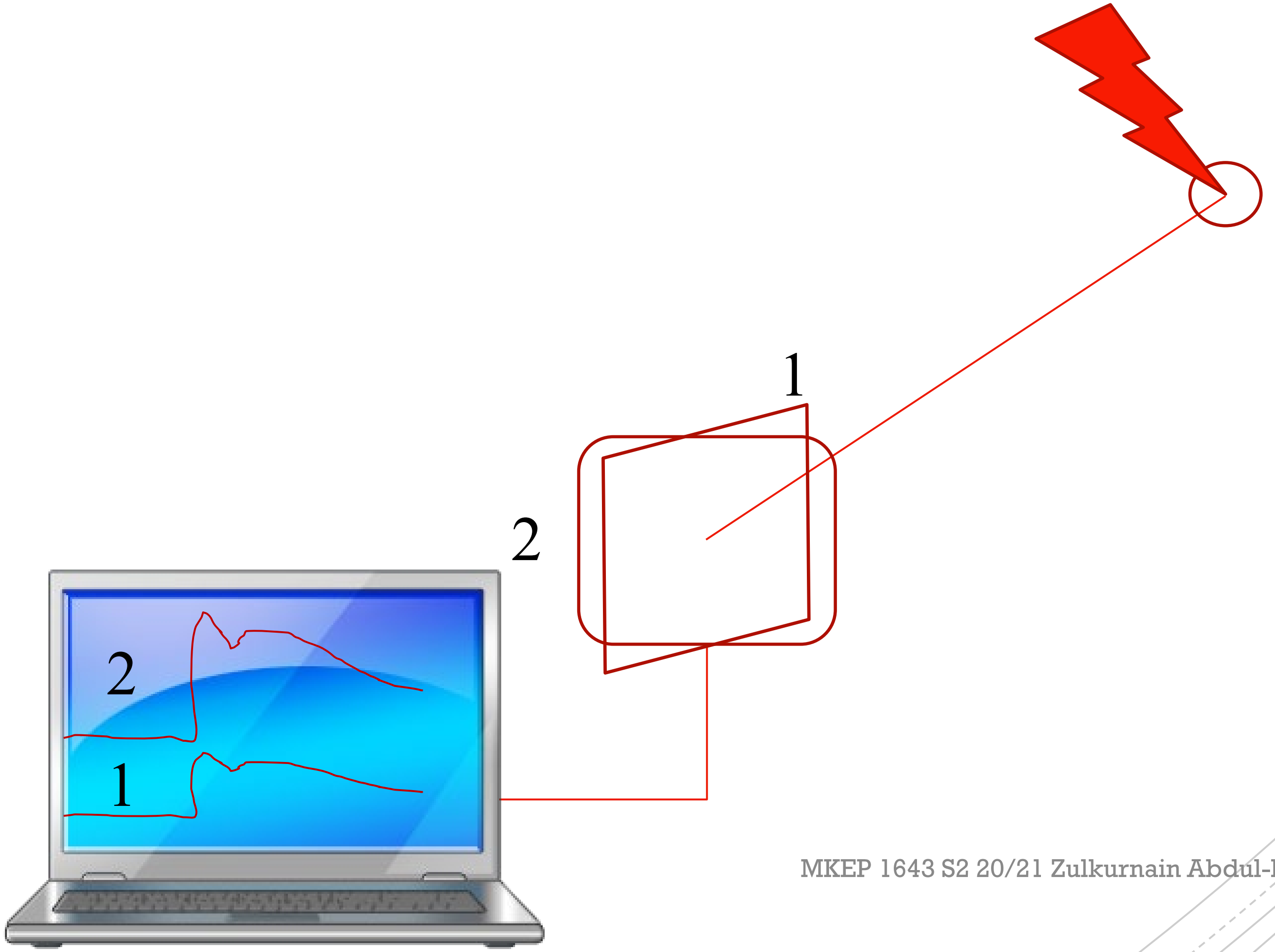
- Consists of two perpendicular  loop antenna and a Flat plate antenna
- A loop can be used to measure one component of the magnetic field



# Lightning Detection

## Lightning Location System
### Magnetic Direction Finding

- Measuring two perpendicular components



# Lightning Detection

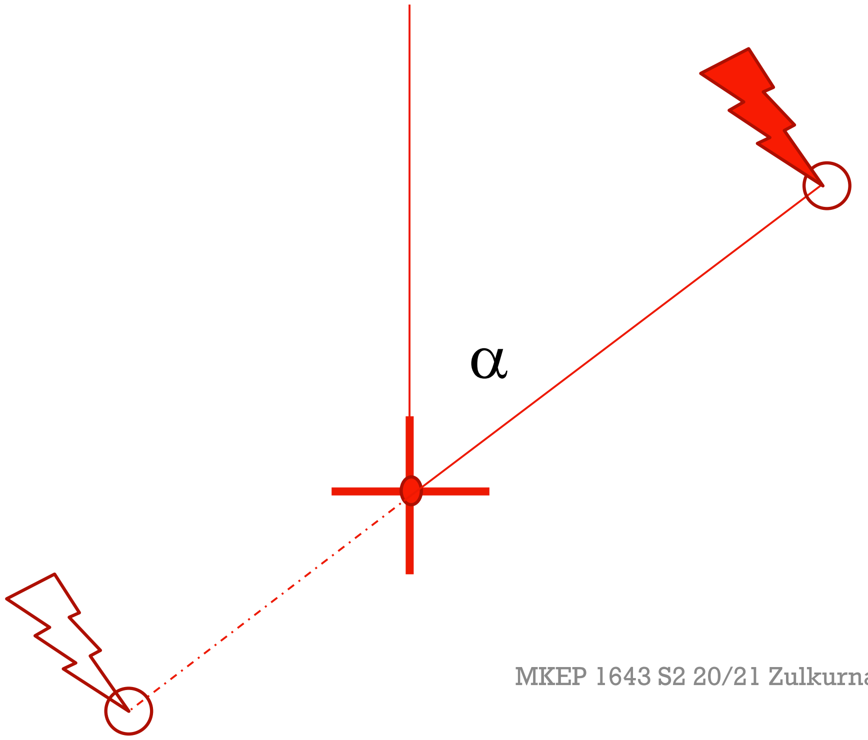
## Lightning Location System

### Magnetic Direction Finding

- It is possible to find the direction of the horizontal magnetic field

$$\alpha = \arctan(H_2/H_1)$$

- Is that enough to find the direction to the lightning?

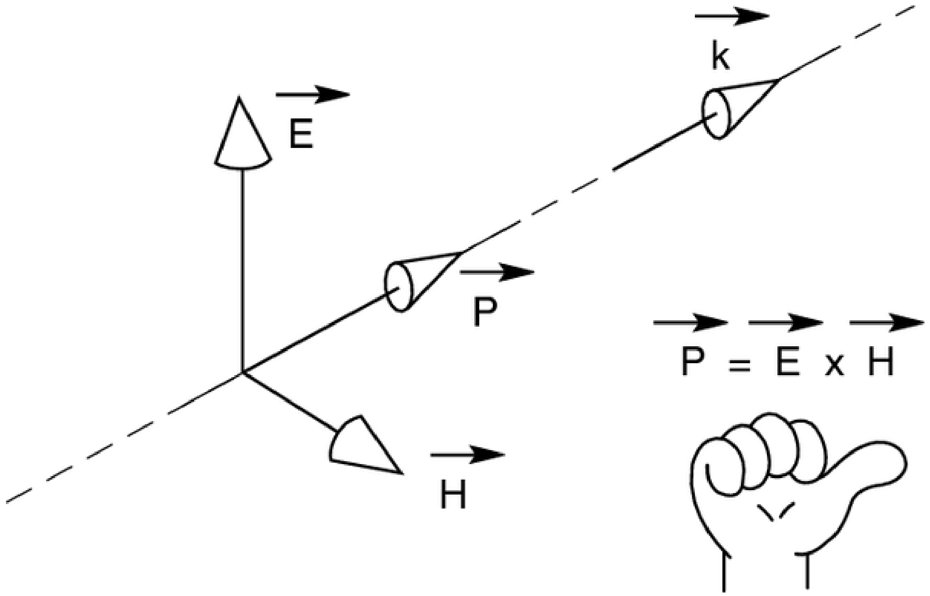


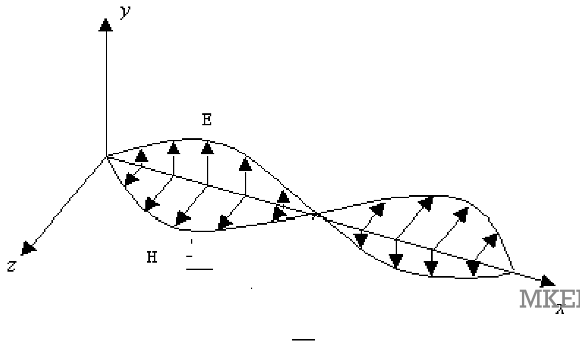
# Lightning Detection

## Lightning Location System

### Magnetic Direction Finding

- The right hand rule



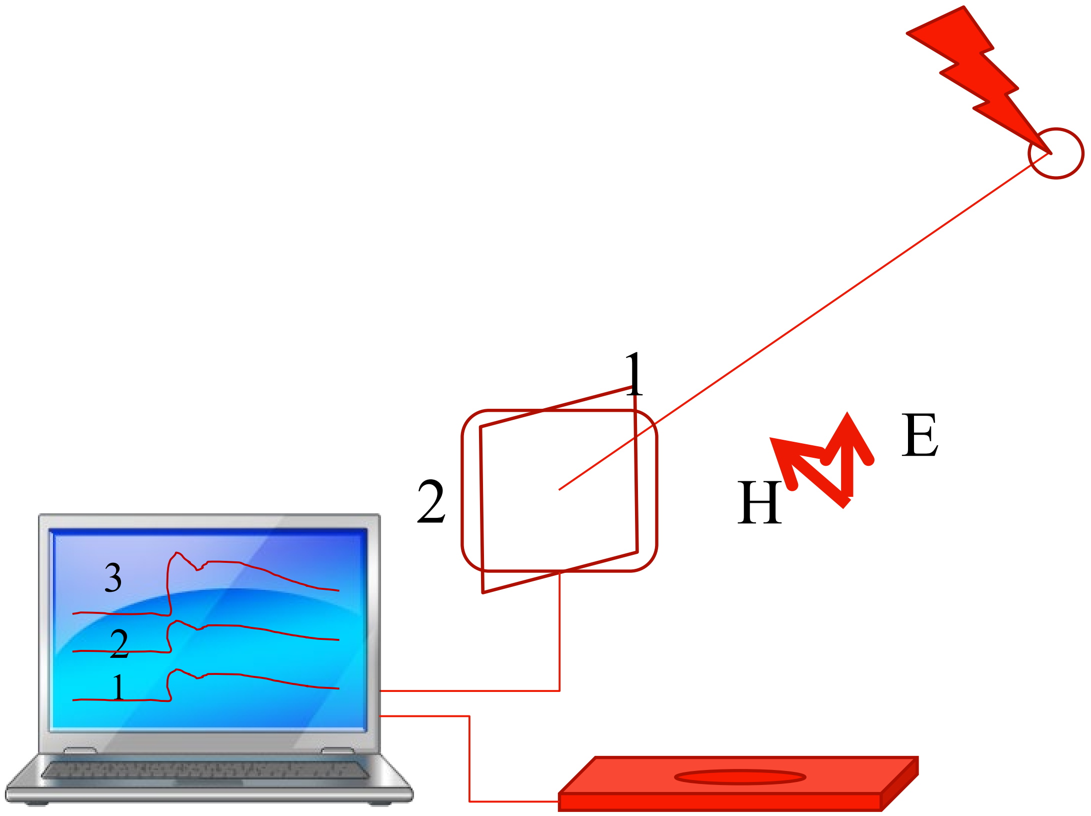



# Lightning Detection

## Lightning Location System

### Magnetic Direction Finding

- To solve the ambiguity in single station location, measure the vertical electric field
- Consists of two perpendicular  loop antenna and a Flat plate antenna



# Lightning Detection

## Lightning Location System
### Magnetic Direction Finding

## Problems with Magnetic Direction Finding

- When 2 sensors see lightning along the same line, the baseline, it is possible that a solution cannot be produced.
- An improperly calibrated sensor might introduce large angle errors to solutions.
- Detects lightning in the low frequency range (LF) so does not see a majority of the cloud lightning.

- What is the best solution then? Combine the two methods!

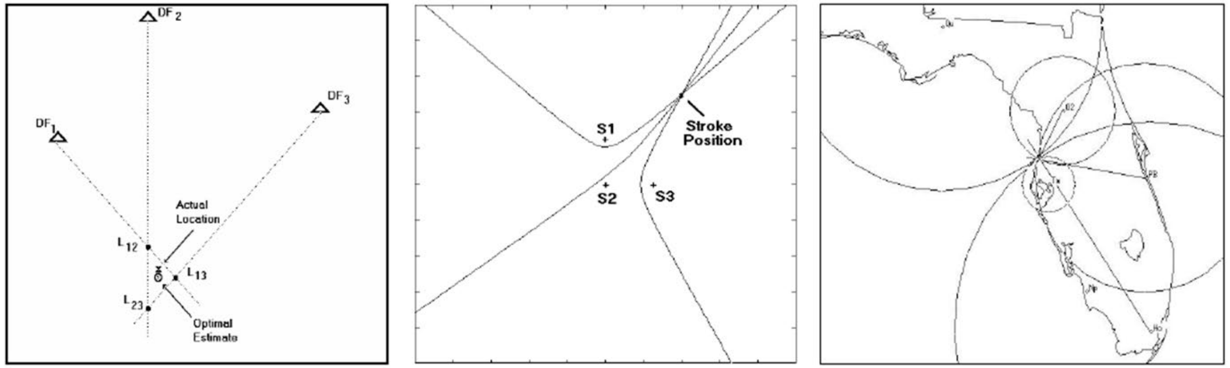
# Lightning Detection

## Lightning Location System

### TDOA/MDF

## Cloud to Ground Lightning – Optimal Solution

**DIRECTION FINDING** | **TIME OF ARRIVAL** | **COMBINED DF+TOA**




**Direction finding:** Individual locations L12, L13, and L23 are triangulated locations for pairs of sensors. The optimal estimate is produced by using the direction information from all reporting sensors.

**Time of arrival:** The location is based on the intersection or hyperbolas produced by arrival-time-differences between pairs of sensors.

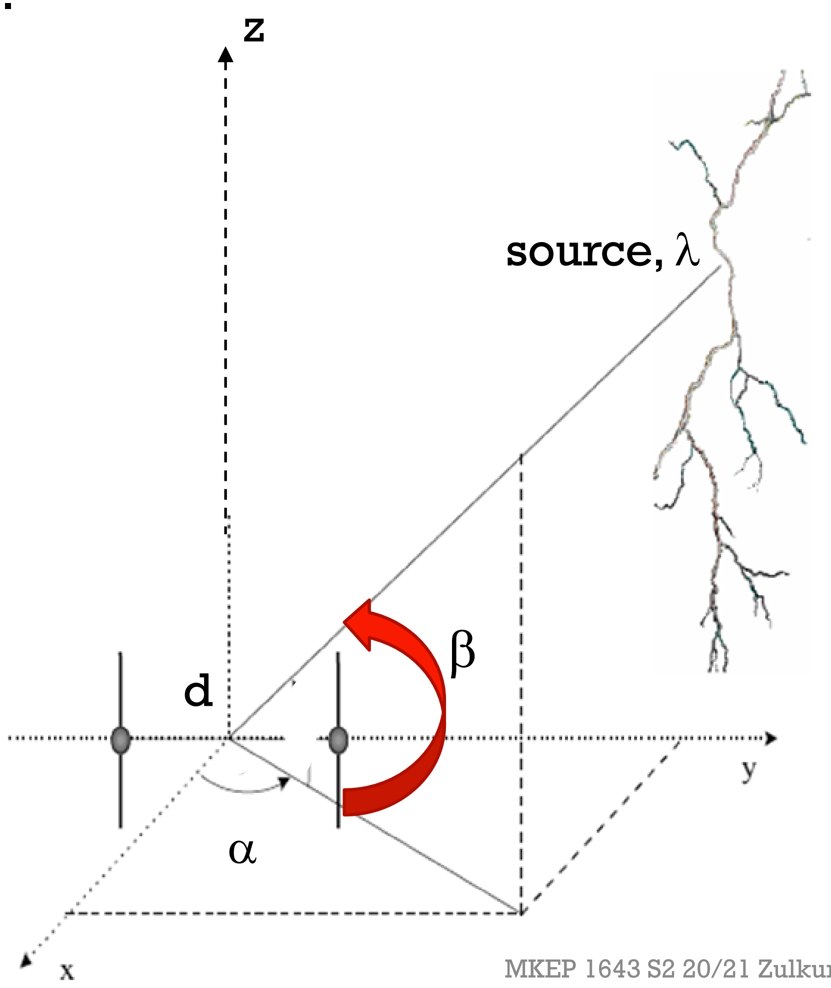
**Combined DF+TOA:** Combined MDF + TOA technology Location with 5 Sensors ( Least-squared Error Combination of Arrival-time and Angle )

# Lightning Detection

## Lightning Location System

### Interferometry System

- In a basic system, using a pair of dipoles located in a horizontal plane, at a distance d from each other, viewing a source with wavelength $\lambda$ located at an azimuth $\alpha$ and an elevation $\beta$.



# Lightning Detection

## Lightning Location System

### Interferometry System

- Phase-interferometry describes a technique that can be used in radar and direction finding applications to accurately estimate the direction of arrival of a signal from the phase difference of the signal measured on two (or more) separated antennas
- That is, the azimuth $\alpha$ and an elevation $\beta$ can then be determined using the signals received by the antennas

# Lightning Detection

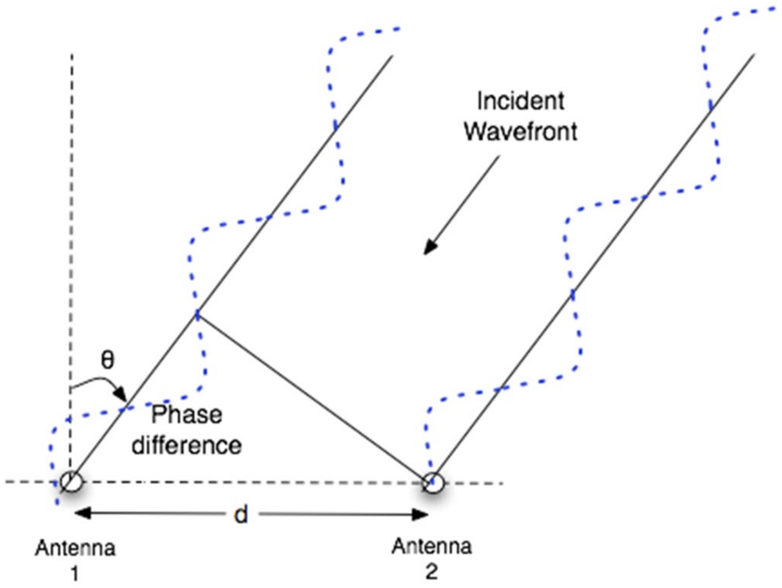
## Lightning Location System

### Interferometry System

- If $\Delta\phi$ is the phase difference between the antenna signals, then $\alpha$ can be computed

$$\propto = 90^\circ - \theta$$

$$\theta = sin^{-1}\left(\frac{\lambda\,\Delta\emptyset}{2\pi d}\right)$$



# Lightning Detection

## Lightning Location System

### Interferometry System

- For unambiguous results, the antennas should be spaced half a wavelength apart, or less.
- The ability to accurately measure a signal's phase depends on the signal-to-noise ratio (SNR), and hence the accuracy of this technique is dependent on the SNR

# Lightning Detection

## Lightning Location System

### Field component method

- Use the features of electric and magnetic fields to estimate the distance
- Eg Magnitude at a given time on the waveform will reduce with distance

# Lightning Detection

## Lightning Location System

### Field component method

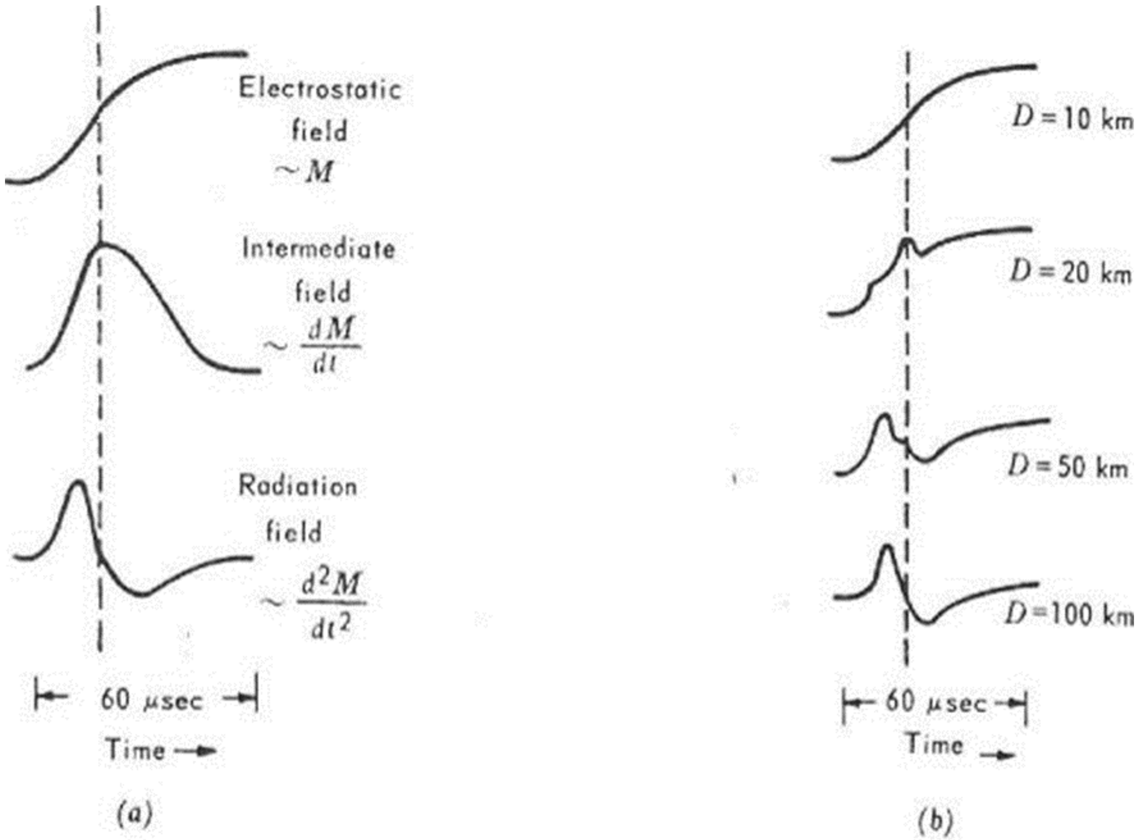



Fig. 3.11 (a) *Electric field components vs. time for a return stroke.* (b) *Total electric field intensity vs. time at several distances for a return stroke.*

# Lightning Detection

## Lightning Location System

### Time to thunder

- Compute the distance of lightning if you hear the thunder 10 seconds after you see it

# Lightning Detection

## Lightning Location System Comparison

| Method | Requirements | Advantages | Disadvantages |
|---|---|---|---|
| **TOA** | **GPS, at least 3, better 4 LF sensors** | **Long distance, wide coverage** | **False location for 3 sensors, accuracy** |
| **MDF** | **Cross-loops** | | **Accuracy** |
| **TOA/MDF** | **Combination of TOA and MDF** | **accuracy** | |
| Interferometry | Short baseline antennas | suitable for IC discharges | Azimuth and elevation angles only, LOS VHF, |
| Time to thunder | Optical/EMF sensor, microphone | LOS if using optical sensor | Propagation medium dependent |
| Field component detection | LF sensor, computation | Long distance | Accuracy |

# Lightning Detection

## Lightning Location System

### Benefits

- Short term
  - Scientific studies
  - As a warning system
    - To switch off sophisticated equipment
    - To keep the service crews of electrical and telecommunication companies on alert
    - To avoid thunderstorms in aviation
- Long term
  - Construct a lightning density map
    - To recognize the high lightning activity areas
    - To understand lightning activity under different weather conditions and geographical conditions

# Lightning Detection

## Lightning Location System Application

- What is the application?
  - Real-time, historical, warning?
- What are the primary requirements
  - CG accuracy & survey level Ground, cloud
  - How large an area to cover
- Where are possible sensor sites
  - Are there siting problems
  - Communication options

# Lightning Detection

## Lightning Location System Application

- VLF
  - Location technique: TOA and DF
  - Coverage: very large coverage
  - Primary application: Aviation, maritime(transoceanic), global met, cyclones, hurricanes
  - Comments: little CLD lightning for aviation, Low accuracy/DE (>5km/20-80%)

# Lightning Detection

## Lightning Location System Application

- LF
  - Location technique: TOA and DF
  - Coverage: large coverage
  - Primary application: Electric power, Forensic/insurance, Recreation, Forestry, Hydrology, Defense
  - Comments: can mix sensor types in a network, good CG location accuracy and DE (<0.5km/>90%), limited CLD detection

# Lightning Detection

## Lightning Location System Application

- VHF
  - Location technique: DF 2D
  - Coverage: medium to large coverage
  - Primary application: Meteorology, Aviation, Recreation, Hydrology, Defense
  - Comments: Intermediate location accuracy, excellent CLD DE (-1km/>90%), requires line-of-sight visibility

# Lightning Detection

## Lightning Location System Technology Selection

- Wide-area network eg. LF/VLF IMPACT
- Regional/City network eg. LF/VLF IMPACT/SAFIR
- Airport network eg. VHF PLWS (EFM)
- Local area AWS eg. TSS928 EFM (Electric Field Mill)

# Lightning Detection

## Lightning Location System

### Technology Selection

Performance of VHF system depends on sites and configuration

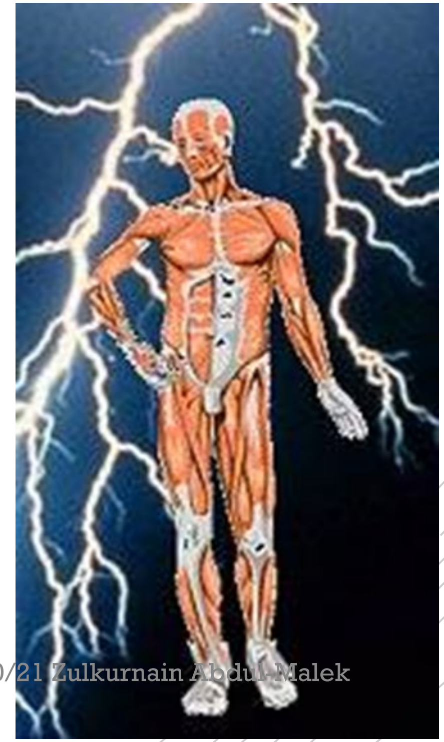
- VHF is very susceptible to:
  - Electronic noise
  - Structural noise
  - Line of sight blockage
  - Sensor baselines
    - Solution – must have optional sites
  - 3 sensor networks have inherent performance risk due to no redundancy-power, communication, equipment
    - Solution –networks will be a minimum of 4 sensors

# Lightning Related Damages

# Lightning Related Damages

To human

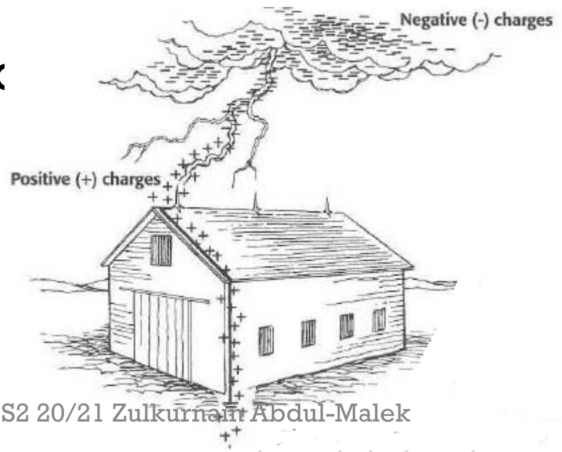
- Cardiovascular and Respiratory Effects
- Central and Peripheral Nervous System
- Dermatologic Effects
- Ophthalmic and Otologic Effects
- Musculoskeletal Effects



# Lightning Related Damages

To assets, facilities & structures

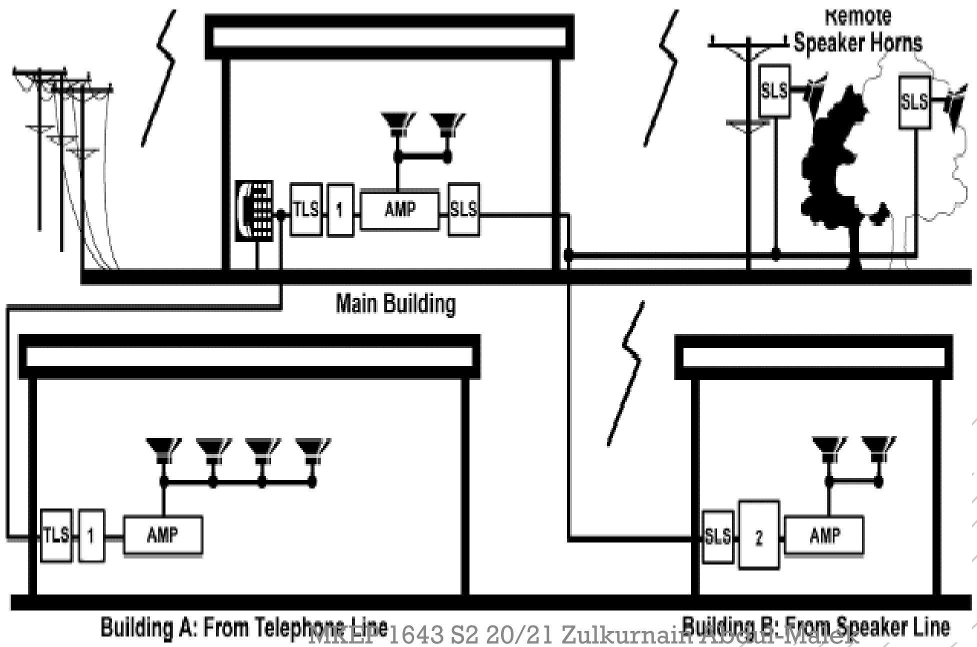
- Ohmic Heating: Thermal Damage
- Ohmic Heating: Disruptive Mechanical Forces
- Arc Root Damage
- Acoustic Shock Wave
- Magnetic Pressure and Forces
- Exploding Arcs and Hydraulic Shoc



# Lightning Related Damages

## Surges from lightning

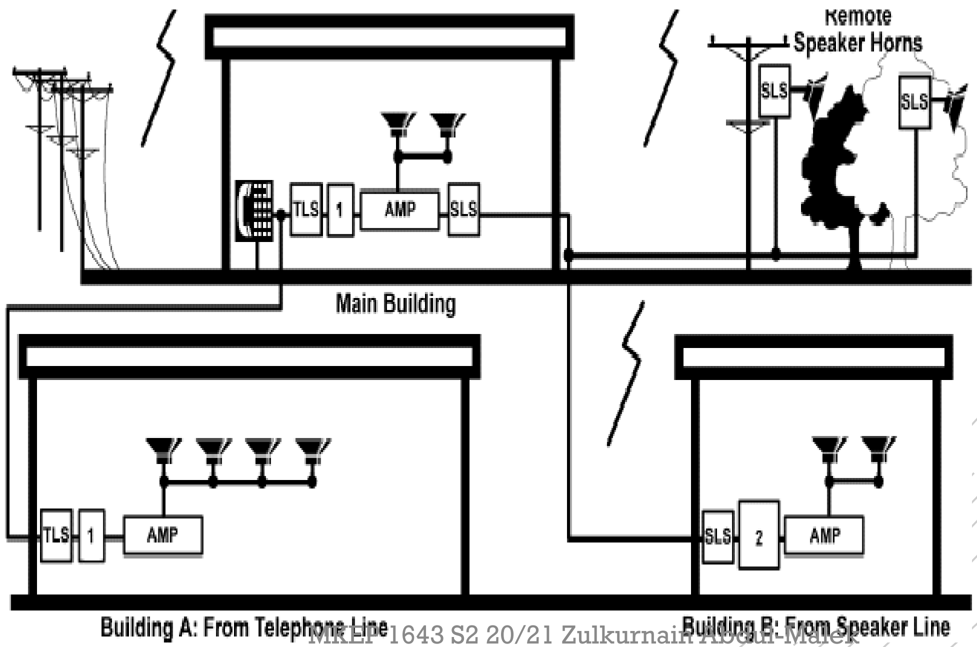
- Surges that usually enter into systems from lightning do damage ranging from small insulation puncture up to explosions from flashovers and even to mechanical stress to conductive structures.



# Lightning Protection

## Surges from lightning

- Surges that usually enter into systems from lightning do damage ranging from small insulation puncture up to explosions from flashovers and even to mechanical stress to conductive structures.



# Lightning Protection

Building & Equipment safety

- Capture the lightning strike
- Conduct the strike to the ground safely
- Low impedance earthing
- Eliminate earth loops and differentials
- Power line protection
- Data line protection

# Lightning Protection

Personal Lightning Safety Tips

- The less known crouch/squat position
- Cover your ears
- Close your eyes

# Lightning Protection

Lightning protection system for buildings and other associated structures is complete with the following:

1. Lightning direct strike air terminal; rods, horizontal copper tape and strip to form mesh or grid like terminals place at roof top.
2. Down conductor; the conductor with the purpose to conduct the lightning energy to the ground once the buildings are struck by lightning.
3. Earth terminal; an interface joining the above the ground LPS with the general mass of earth so that there is a solid bond between the LPS with the soil (where dispersion of lightning energy will take place).
4. The equal potential bonding system serve the purpose of making very point of the system at same potential under transient over voltage condition.
5. Proper placement and coordination of secondary surge protectors so that at very points on the electrical system, surge protector are installed (in compliance with the guidelines as provided in IEC standard).