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Formation of Lightning Ground Strikes

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The formation of a negative polarity cloud to ground lightning strike containing two exchange strokes begins with a strong energy concentration and separation of charges, both in the cloud and on the ground. Figure 1. Next, a negative cloud leader forms and begins to push toward the positive charges near the ground. Figure 2.

The negative cloud leader continues to cross the distance between cloud and ground, following a zig-zag path of lowest resistance. Side charge channels also are formed and push downward. Figure 3. The positive electric field near the ground begins to form short streamers upward toward the negatively charged cloud leader, side leader, and cloud negative electric field. Figure 4.

Flash

The two charge fields meet and attach, making a single charge exchange channel. Figure 5. The massive current exchange causes a light flash (arc) and neutralization of some cloud and ground charges. Figure 6. After a short pause, a second stroke of current exchange follows the same (or nearly the same) pathway, causing a second light flash and further neutralizing cloud and ground charges. Figure 7.

The timing between the first and second stroke (i.e. negative polarity lightning) beginning in the cloud negative charge center is given in Figure 8. The times listed across the figure top are in milliseconds.

Cloud Leaders

Most lightning begins as nearly invisible fingers of negative charge pushing downward from close to the base of storm clouds. The bottom portion of the cloud has collected a large negative charge field potential. Because positive and negative charges attract, there is a positive charge field potential which swells below the cloud base on the ground and follows along across the landscape beneath a storm. This effect can be visualized as a charge wave flowing across the landscape below storm clouds. Figure 9

Fingers of negative charge potential pushing out below a cloud base are called "cloud leaders." Cloud leaders rapidly stretch downward through the air following a pathway of least electrical resistance. Precipitation, other lightning paths, and even cosmic rays help determine the path cloud leaders descend. (Uman 1971,1987). The leader jumps forward in ~150 feet segments. (Uman 2008).

The jagged nature of lightning comes from the zig-zag pathway followed by the nearly invisible cloud leaders rapidly pushing downward toward the ground. Cloud leaders push out toward the ground at 450,000 miles per hour. Each leader step produces some visible light, radio waves, and x-rays. (Uman 2008). Some cloud leaders are always pushing downward below a cloud base. Figure 10.

Ground Streamers

Enhanced field effects concentrated along the Earth's surface below storm clouds, are pulled (or stream) upward toward the negative cloud charge. These positive charges streaming off the top of tall structures are called "ground streamers." These streamers can be thought of as flowing up and off the top of tall topographic features and structures like trees. Ground streamers are a simple construct to explain the ground field enhancement which occurs around and over tall ground structures. (Rakov & Uman 2003)

Ground charges mount up in a standing wave following the storm base over the landscape. Over the top of tall structures (taller than neighboring objects) ground steamers present an enhanced positive charge field available for connection with negative charged cloud leaders. Trees and other tall structures provide ground attachment points for ground streamers.

Figure 11 shows an open field, fair weather (normal) electrical field through the atmosphere down to the ground. The dotted equal voltage lines allow charge flow evenly to the ground as shown with the solid lines. Figure 12 represents how an electrical field is enhanced or intensified by tall ground objects. In this figure, equal voltage lines (dotted lines) are concentrated above and around the ground object and the charge flows are curved toward the object. Anywhere the dotted voltage lines are closely stacked, the electrical field is enhanced and atmospheric charge flow will be concentrated on and around the object.

Hair Raising

Until a charge exchange channel is connected / opened, little can be seen of the lightning initiation process. Events leading to lightning occur over extremely short time intervals. Some people have experienced the unnerving sensation of being part of an enhanced charge field under storm clouds. Various reactions and sensations have been cited from being within a ground charge wave. Observers in fire towers know the feeling of being near a strong ground steamer as storms pass over.

Connections

Long cloud leaders push downward from the cloud base and short ground streamers flow upward off tall objects. As a cloud leader approaches the ground, it connects with a ground streamer. An electrical connection between a cloud leader and a ground streamer occurs about 100 - 1,000 feet above the ground surface or above the tip of a structure, depending upon current load. The charge exchange path is now open and charges are rapidly exchanged. The charge difference between cloud and ground is temporarily neutralized. The massive electrical charge exchange generates light (both visible and unseen wavelengths) which we see and describe as lightning.

Charge Channel

When charge paths connect, a visible stroke moves within the charge channel at 1/3 the speed of light, spewing light and instantaneously heating air. Usually several strokes, or charge exchanges, occur in one complete lightning strike to neutralize charge differences. Because of rapid changes in air resistance, wind movement of ionized air, and the strongest ground streamer location, various strokes within one lightning strike may not follow the same pathway. Several trees in a row may show damage from different strokes following different paths within one lightning strike. Other trees may have been struck by many strokes in one lightning strike. The ground streamer characteristics connecting the first strike (or first stroke) can facilitate one to many additional electric charge exchanges. (Uman 1971,1987)

Multiple Strokes

Many lightning strikes contain multiple strokes. Figure 12 provides attributes of these multiple strokes for negative and positive polarity lightning. Both the average number of strokes, maximum number of strokes, and interval between strokes are significantly different between negative and positive lightning. The maximum number of strokes in negative lightning would show a decreasing current exchange with each stroke.

The multiple strokes within one lightning strike do not necessarily follow the same path and connect / terminate at the same point on the ground. The distance in miles between different strokes within the same lightning strike is given in Figure 14. Stroke separation can be as much as 5 miles, and averages ~2 miles apart for the same lightning strike.

Forks

One research topic in need of further study, and not easily recorded by instruments, is forked lightning. Forked lightning is defined as a strike with multiple ground termination points. Figure 15 is a summary of forked lightning's average attributes. Note almost half of all strikes have multiple termination points separated by as much as 4.5 miles. Some strikes have more than two termination points. Figure 16.

Side Flashes

As the charge exchange channel develops, lightning may jump from the side of tall structures onto adjacent houses or through people. The path of a lightning strike is unpredictable because the strike itself changes local air and material resistances to electrical charge exchange. Each millisecond presents a new potential pathway for electricity flow which could be almost the same as the last pathway, or could be completely different. (Uman 1971,1987)

Being Positive

For positive polarity strikes, charge exchanges occur over greater distances between storm cloud tops and the ground. These positive lightning strikes can be several times more powerful, impact a larger ground area, and last longer than the common negative (polarity) cloud-ground strikes. Tree and tree clump damage can be especially severe when along positive lightning strike paths. Fire ignition is a significant possibility.

Strike & Strokes

A lightning strike is made up of a number of individual strokes. Each stroke can last many 10's of milliseconds. The duration of a complete flash of lightning, including periods between individual strokes, is usually around one-half second. The human eye can just visualize individual strokes within each strike making lightning appear to flicker.

Average electrical values for a single strike are around 100 million volts and 35,000 amps. The lightning strike core size ranges from 1/5 to 1/2 inch in diameter surrounded with an ionized, glowing envelope 4-6 inches in diameter, and a bright light corona of 1-5 feet in diameter.

HOT!

The energy liberated by a lightning strike is more than just a current exchange and a bright light arc. The temperature inside the narrow core of the lightning strike can be hotter than the surface of the Sun. Figure 17. (Uman 1971; MacGorman. & Rust 1998) For example with a lower than average current exchange (20kA over 90 microseconds), core temperature reached 50,000^{o}F dwindling quickly to <1,000^{o}F within an inch of the core. Figure 18.

EXPLOSIVE!

The explosive nature of this almost instanaeous temperature jump can be seen in the amount of pressure generated. Figure 19. The instantaneous heating of air in the lightning core to such extreme temperatures generates a supersonic shockwave (10X the speed of sound) over a short distance. Figure 20 shows the air pressure wave generated by superheating air in the lightning core. Again, in a lower than average current strike (20kA over 90 microseconds), pressure was greater than 24 atmospheres at the core declining to near normal air pressure by 1.5 inches from the core. Figure 21.

Boom

The flash of individual lightning strokes and sound of thunder are generated by the same event. Because light travels faster than sound, the flash is seen first and then thunder is heard. The thunder sound wave (an acoustic wave) is travelling nearly 770 miles per hour at 70^{o}F. If you count the number of seconds between flash and thunder, you can tell how far away the lightning strike occurred. Every second, thunder sound waves move 1/5 of a mile (actually 0.214 mile). For example, if you count 5 seconds (4.7 seconds) between the light flash and thunder, then lightning flash was one mile away. (Uman 1971)

Ground

When the charge exchange pathway is opened, energy races over and into soil, and is dissipated across soil surfaces and volumes. Most soils can channel and dissipate large electric charges. The electrical grounding process is comprised of soil water and atmosphere components electronically capturing energy in unoccupied electron shells and within chemical bonds. This energy is converted to heat, temporarily held by various atoms, or permanently associated with higher energy chemical bonds.

Arcing

When lightning strikes a tree, due to massive current exchange, some of the energy generates a surface flash-over or ground arcing. Figure 22. This arcing can radiate out from the ground connection of the strike as much as 65 feet. Most lightning strikes over 15kA will surface arc, especially when soil is completely saturated and without air pore spaces. This arcing is across the soil surface and is not part of internal soil dissipation. Severe damage to animals / people and surface tree roots can occur.

Citation:

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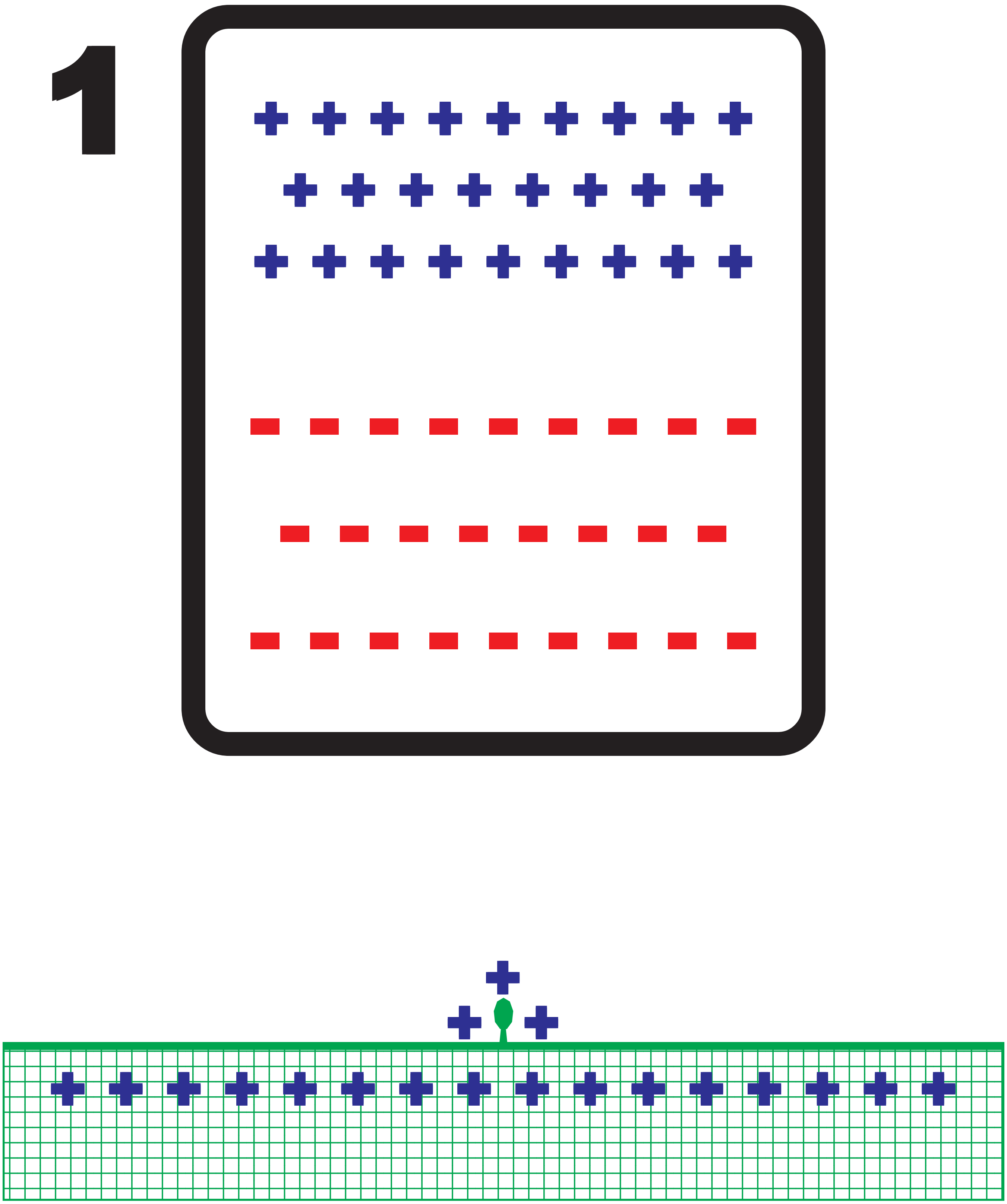

Figure 1: Formation of a negative cloud to ground lightning strike. (Rakov & Uman 2003)

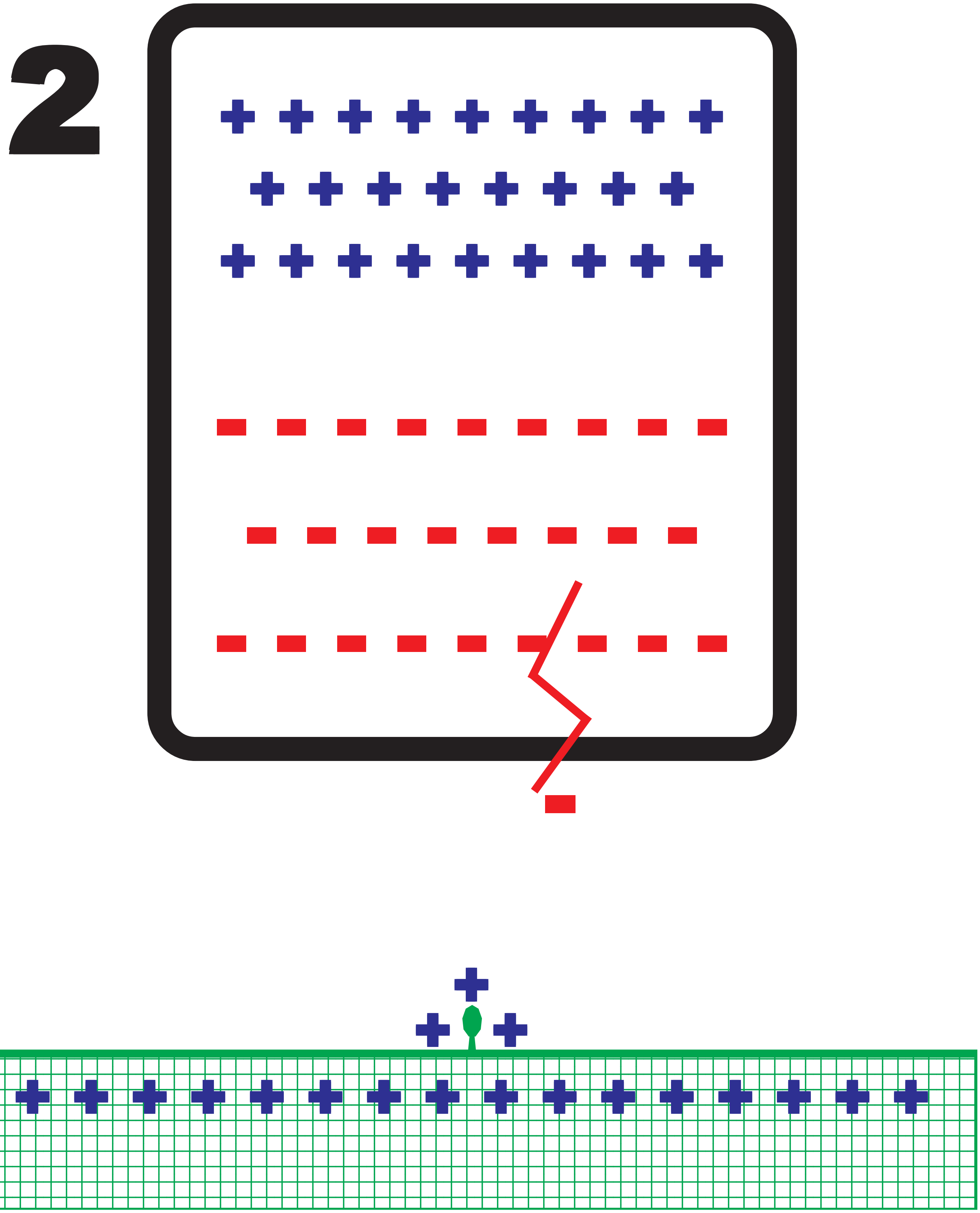

Figure 2: Formation of a negative cloud to ground lightning strike -- negative cloud leader. (Rakov & Uman 2003)

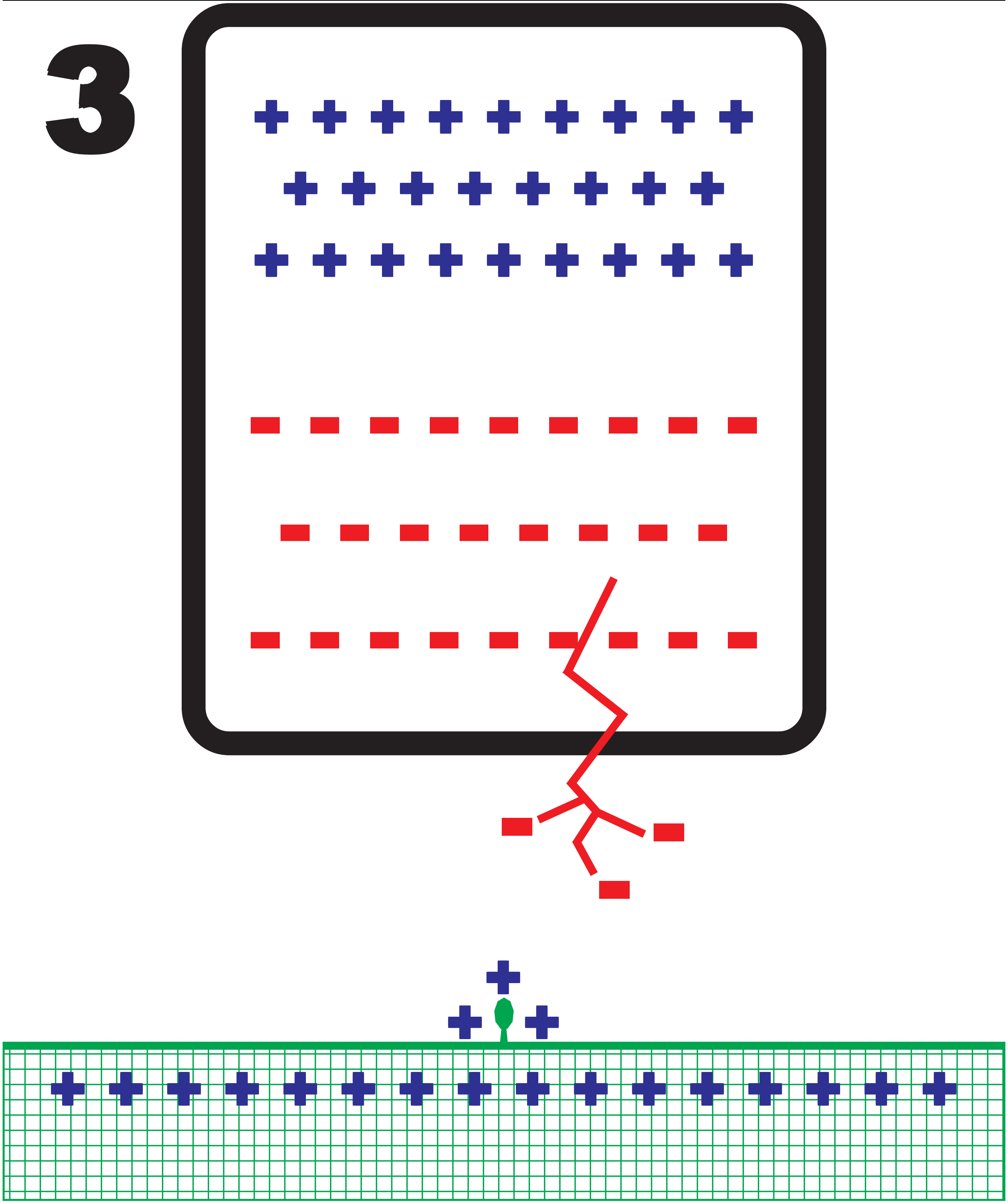

Figure 3: Formation of a negative cloud to ground lightning strike -- cloud leader stepped propagation. (Rakov & Uman 2003)

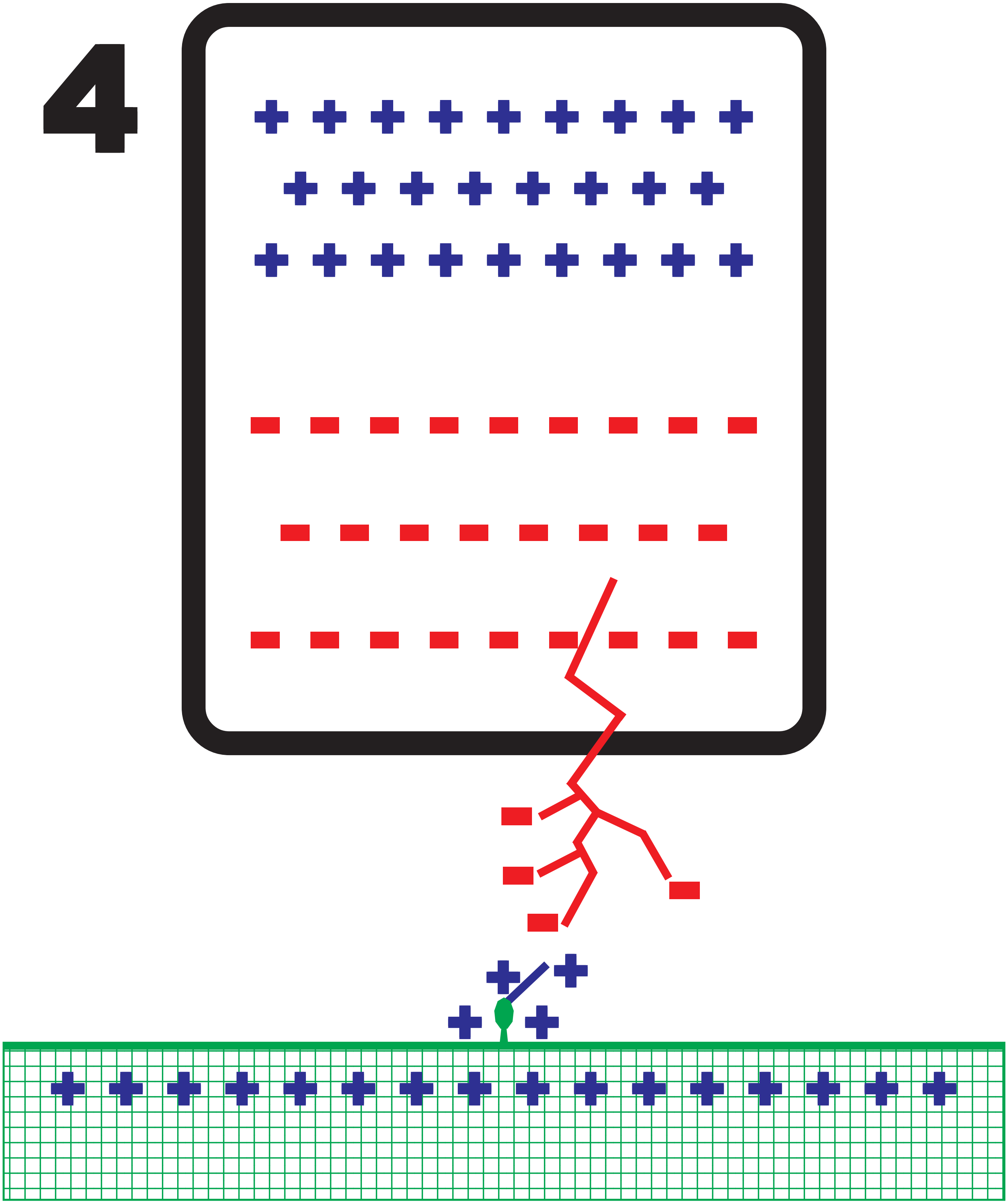

Figure 4: Formation of a negative cloud to ground lightning strike -- approach with ground streamer. (Rakov & Uman 2003)

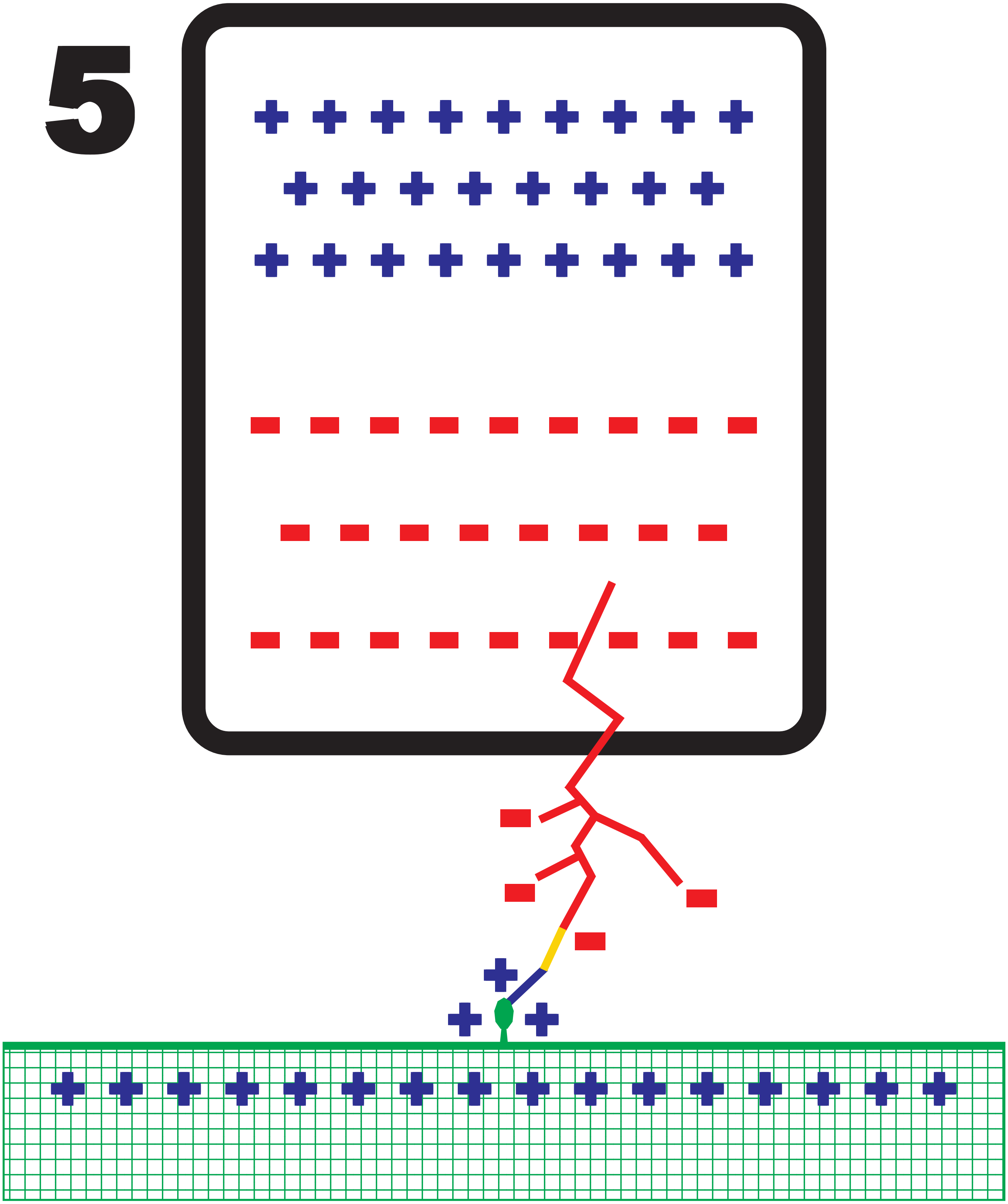

Figure 5: Formation of a negative cloud to ground lightning strike -- attachment. (Rakov & Uman 2003)

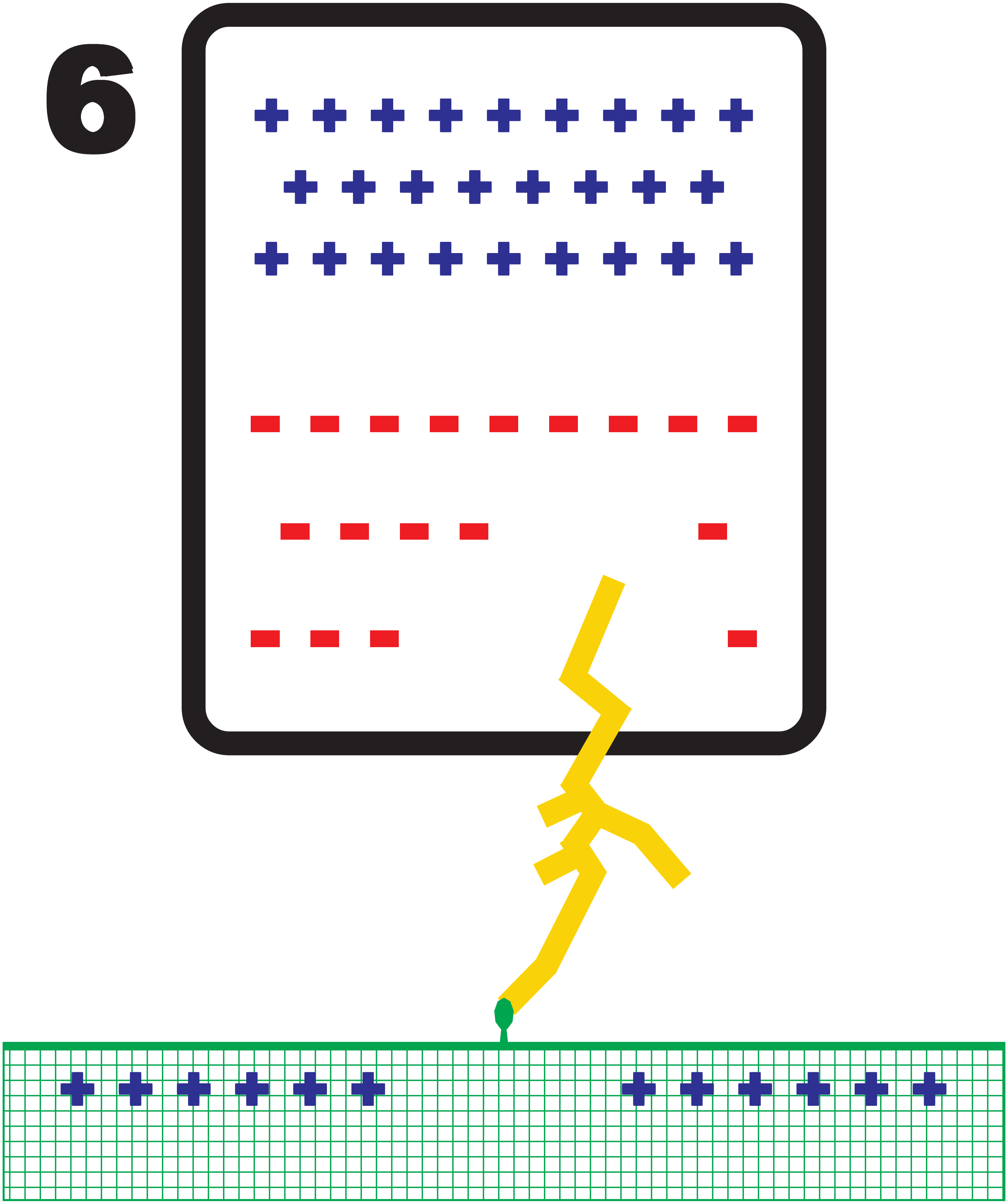

Figure 6: Formation of a negative cloud to ground lightning strike -- first stroke exchange. (Rakov & Uman 2003)

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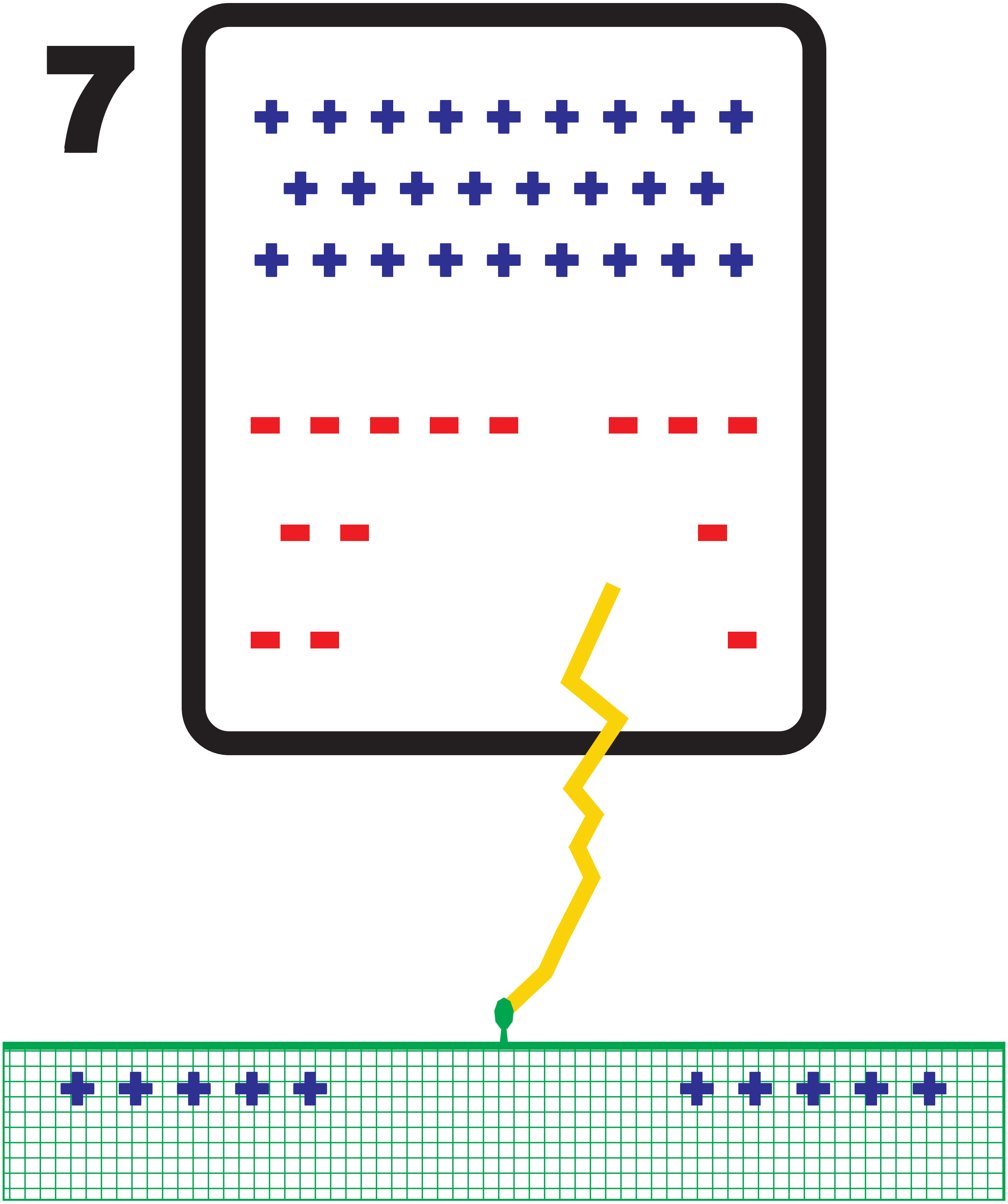

Figure 7: Formation of a negative cloud to ground lightning strike -- second stroke exchange. (Rakov & Uman 2003)

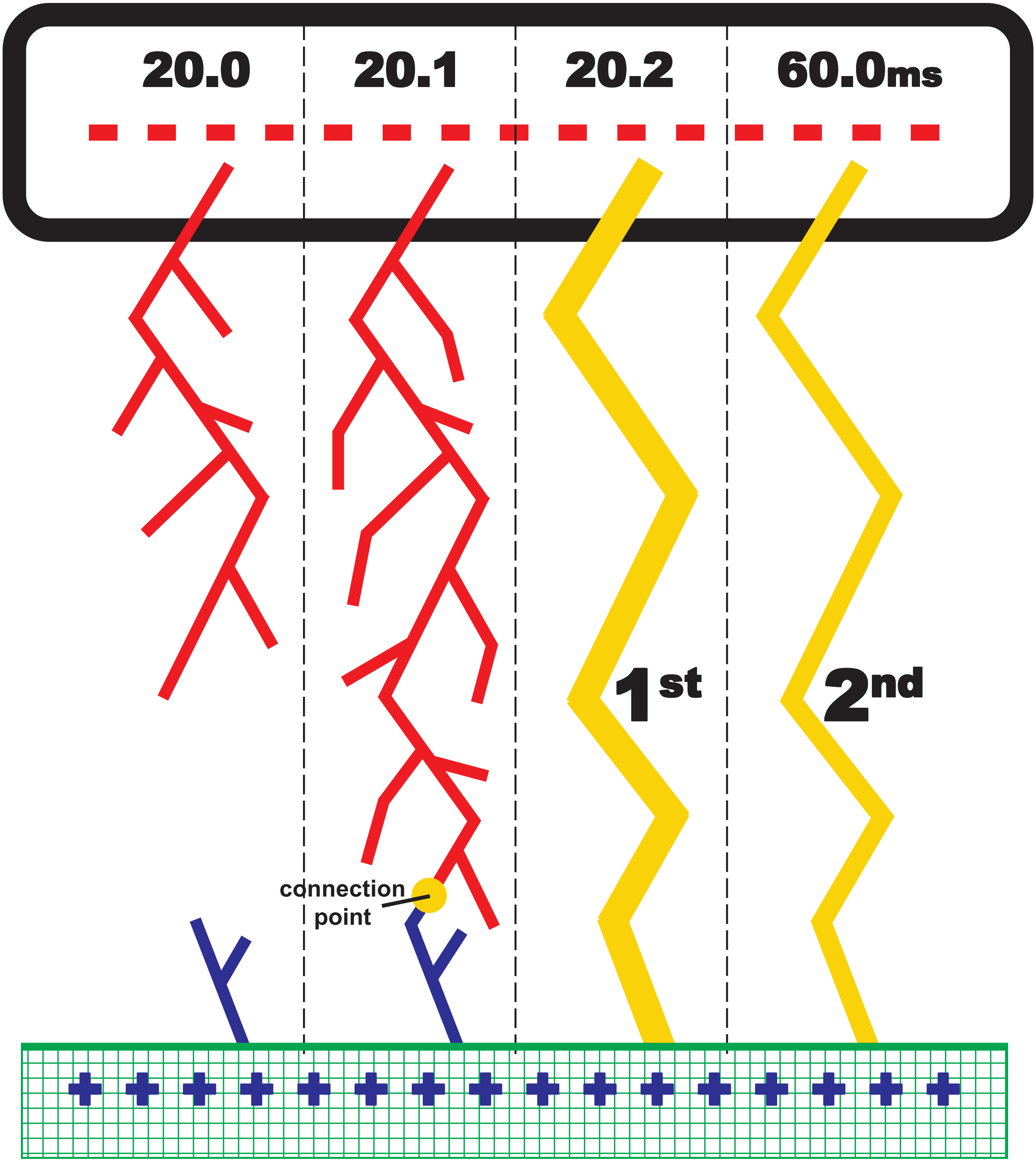

Figure 8: Timing in milliseconds of first and second negative cloud to ground lightning strokes from starting in cloud base.
(Rakov & Uman 2003)

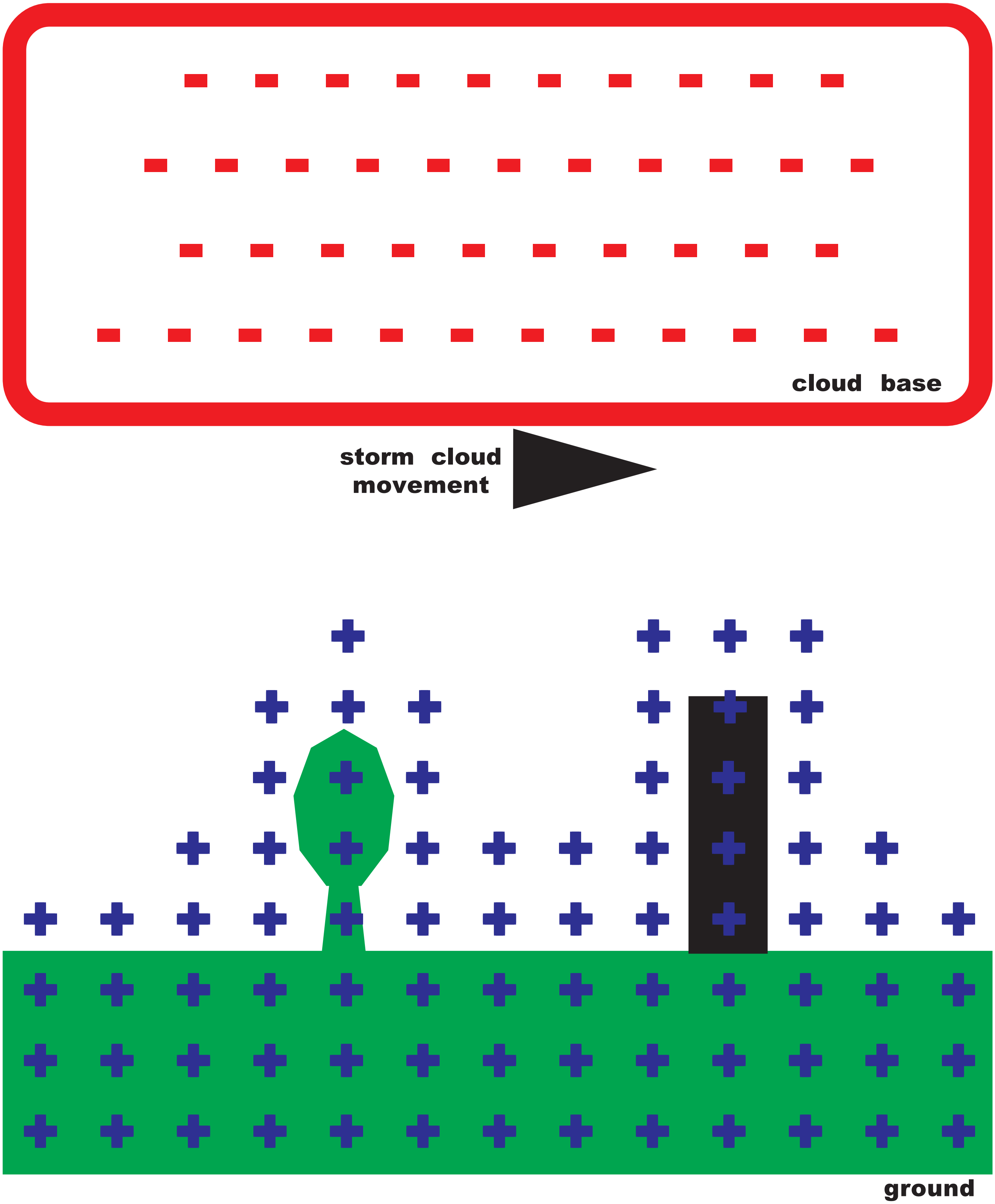

Figure 9: Charge wave sweeps over landscape, and up trees and structures, in response to charge concentration in cloud.

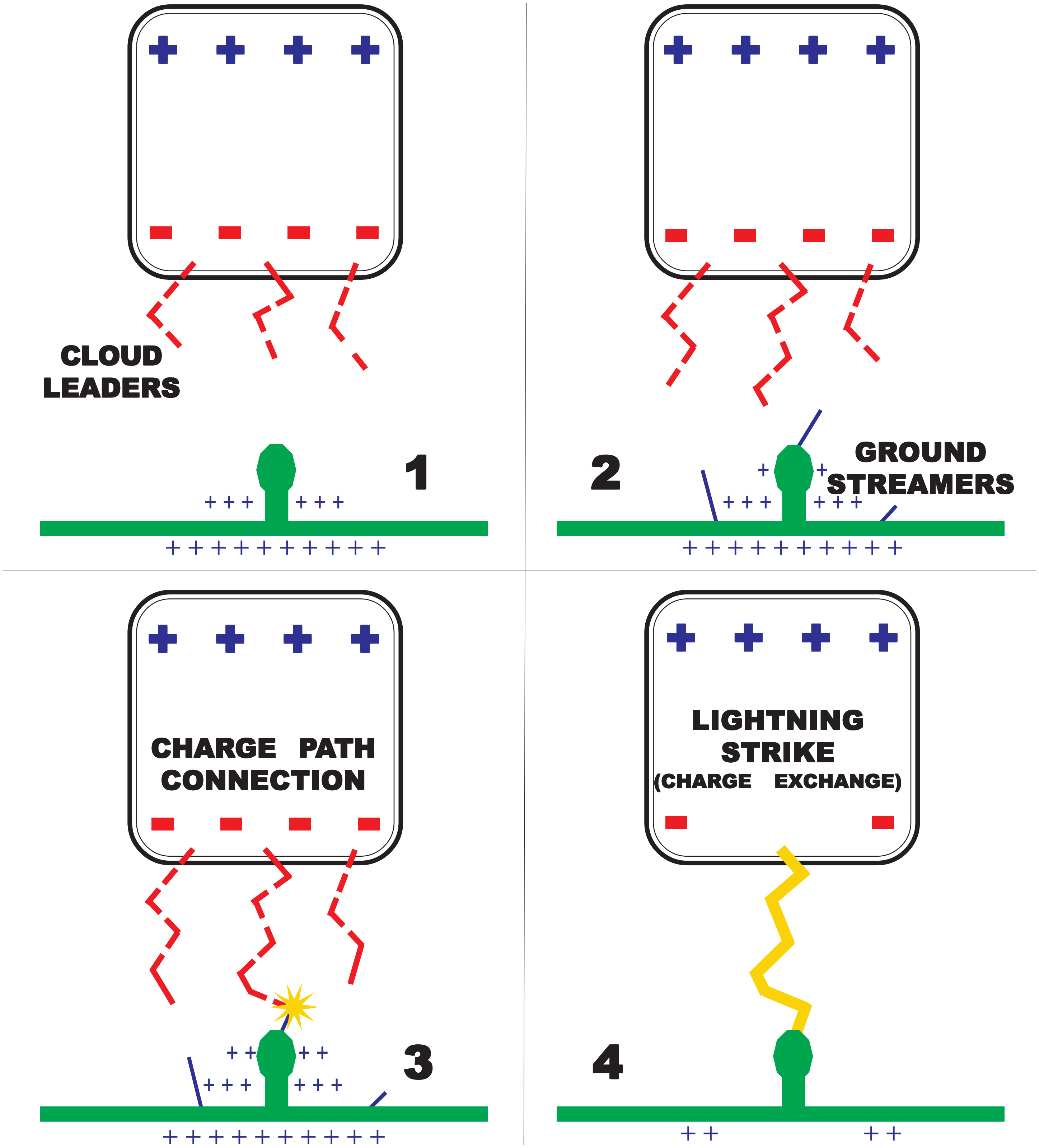

Figure 10: Components of lightning strike with negative polarity: 1) cloud leaders; 2) ground streamers; 3) connection of charges; and, 4) massive charge exchange & light emission.
(Uman 1987)

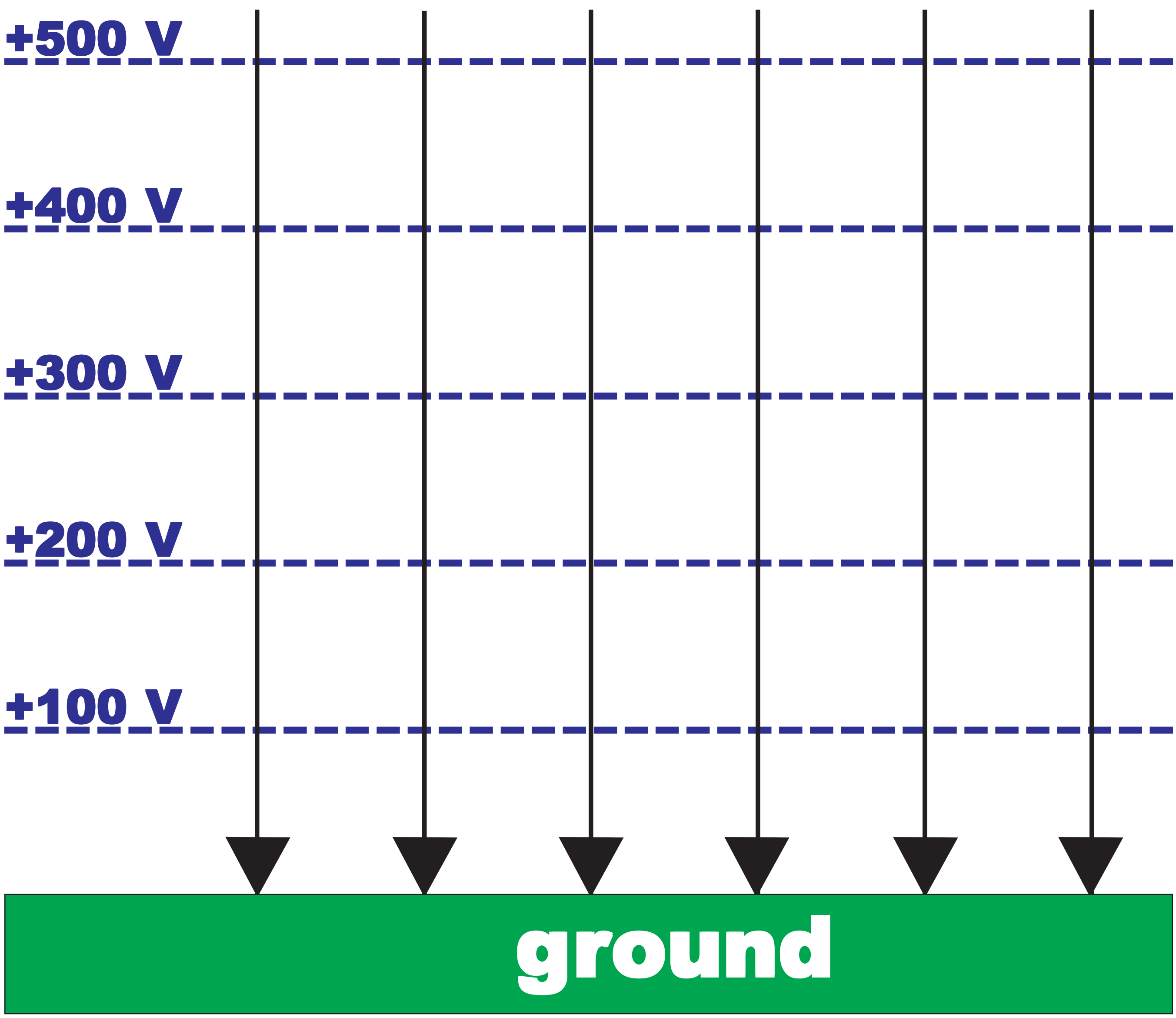

Figure 11: Fair-weather electric field over ground.
(Bouquegneau & Rakov 2010)

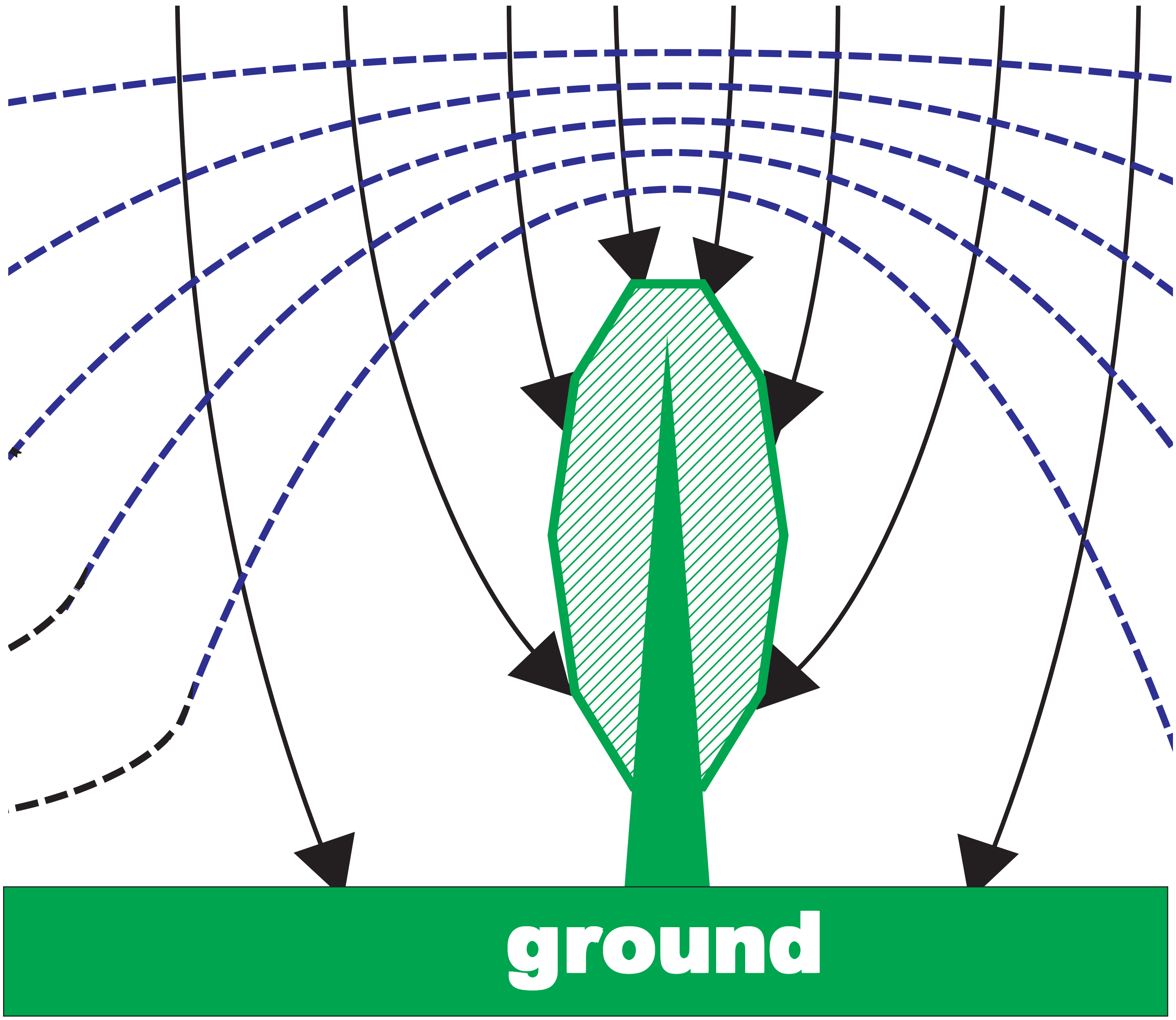

Figure 12: Electric field enhanced by ground structure.
(after Bouquegneau & Rakov 2010)

Negative Ground Strike

single stroke flashes	~15%
multiple stroke flashes	~85%

average strokes	=	5.5
maximum strokes	=	22
stroke interval	=	~58ms

Positive Ground Strike

single stroke flashes	~75%
multiple stroke flashes	~25%

maximum strokes	=	3
stroke interval	=	~96ms

Figure 13: Lightning stroke characteristics for positive and negative polarity strikes. (Cooray & Fernando 2010)

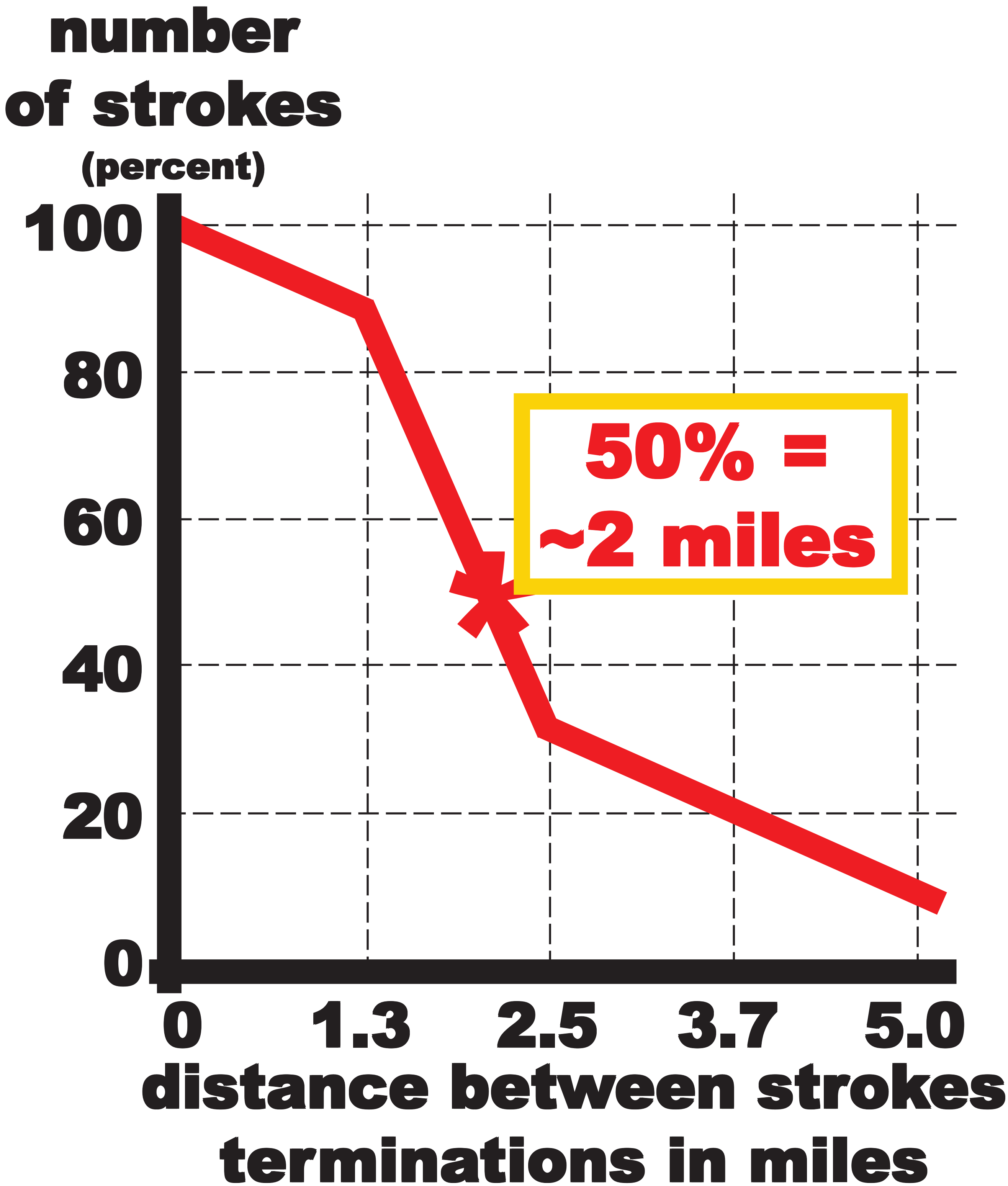

Figure 14: Distance in miles between strokes terminations within the same lightning strike. (Rakov & Uman 2003)

Fork Lightning

lightning with >1 termination point

lightning strikes with multiple termination points = 45%

termination point average separation distance = ~1.05 miles apart

(range = 0.18 to 4.5 miles apart)

Figure 15: General attributes of fork lightning (multiple termination points on the ground). (Cooray & Fernando 2010)

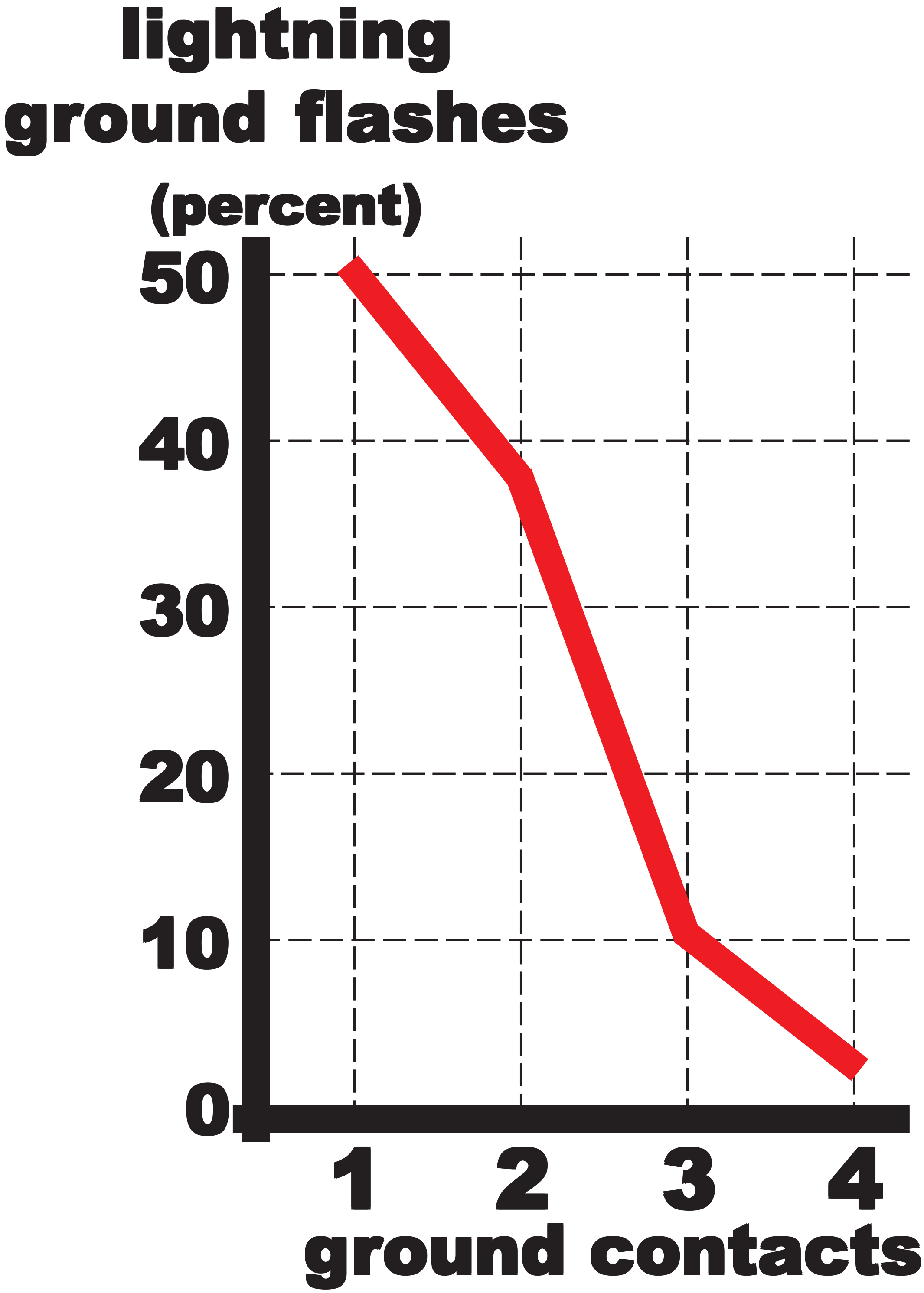

Figure 16: Percent of ground strikes (fork lightning) generating a given number of multiple ground termination points. (Cooray & Fernando 2010)

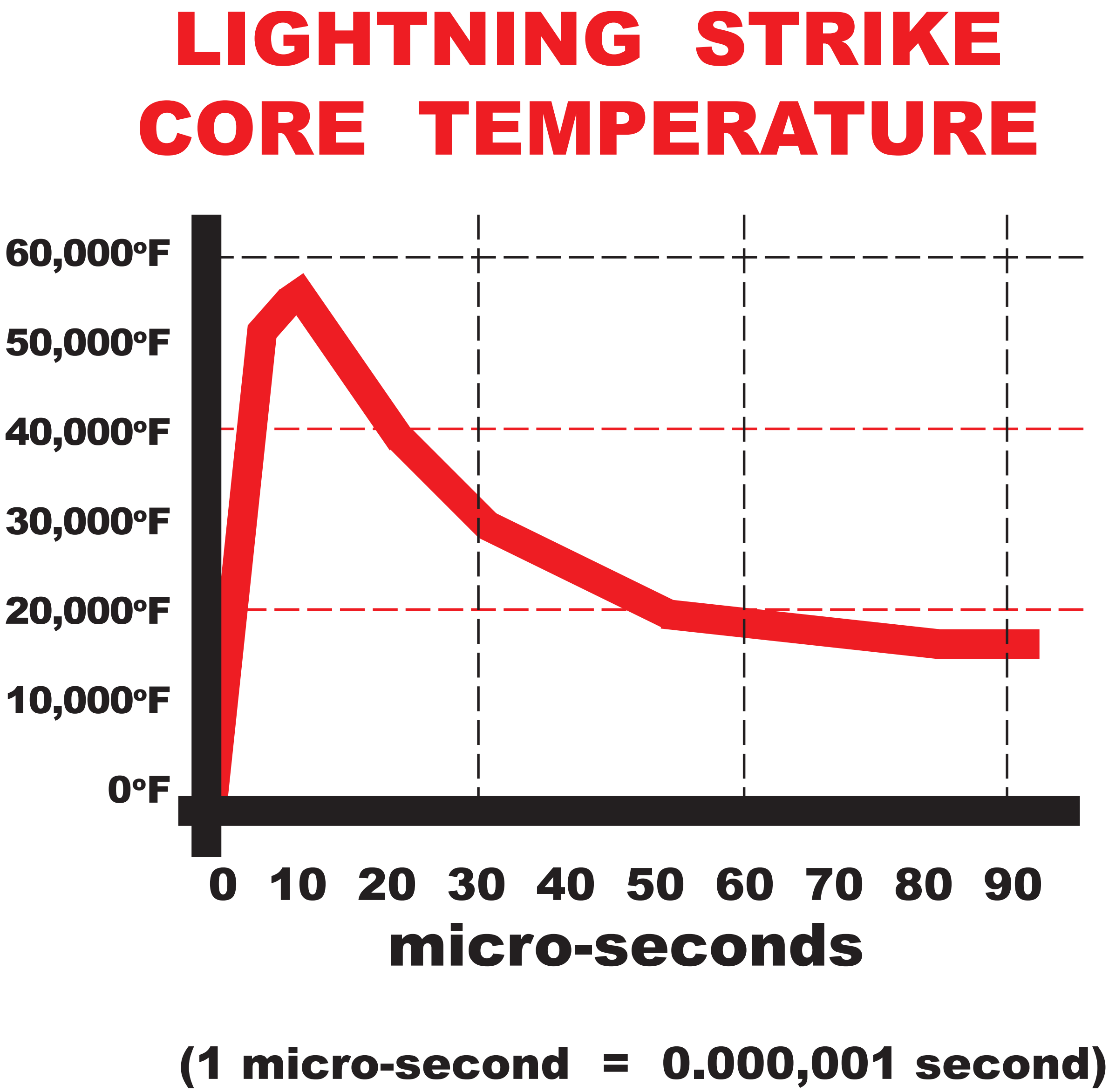

Figure 17: Lightning core temperature in degrees Fahrenheit (°F) over time in micro-seconds (millionth of a second).
(Few 1995; MacGorman. & Rust 1998; Uman 1971,1987)

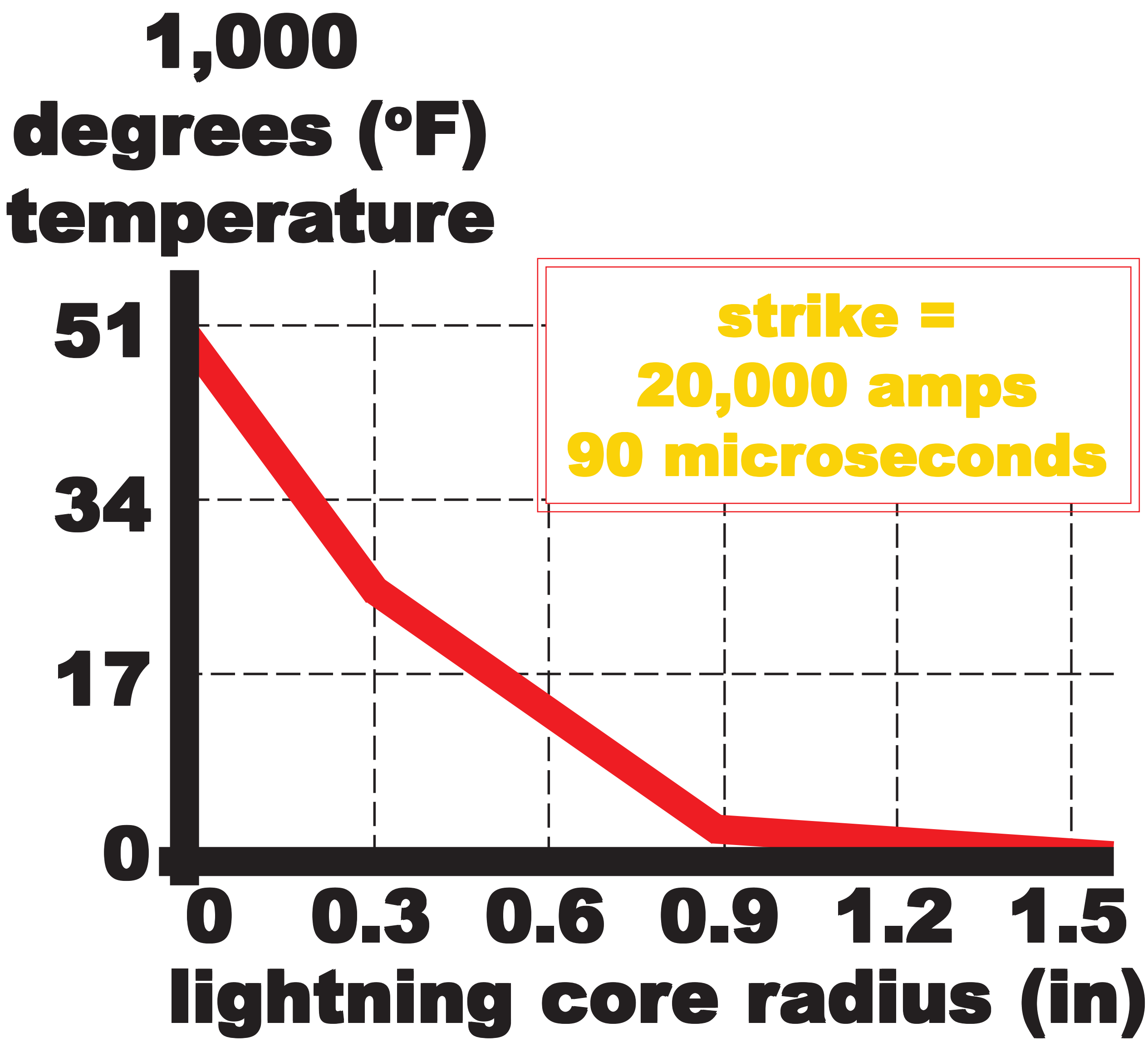

Figure 18: Temperature of lightning strike core away from its center. (derived from Rakov & Uman 2003)

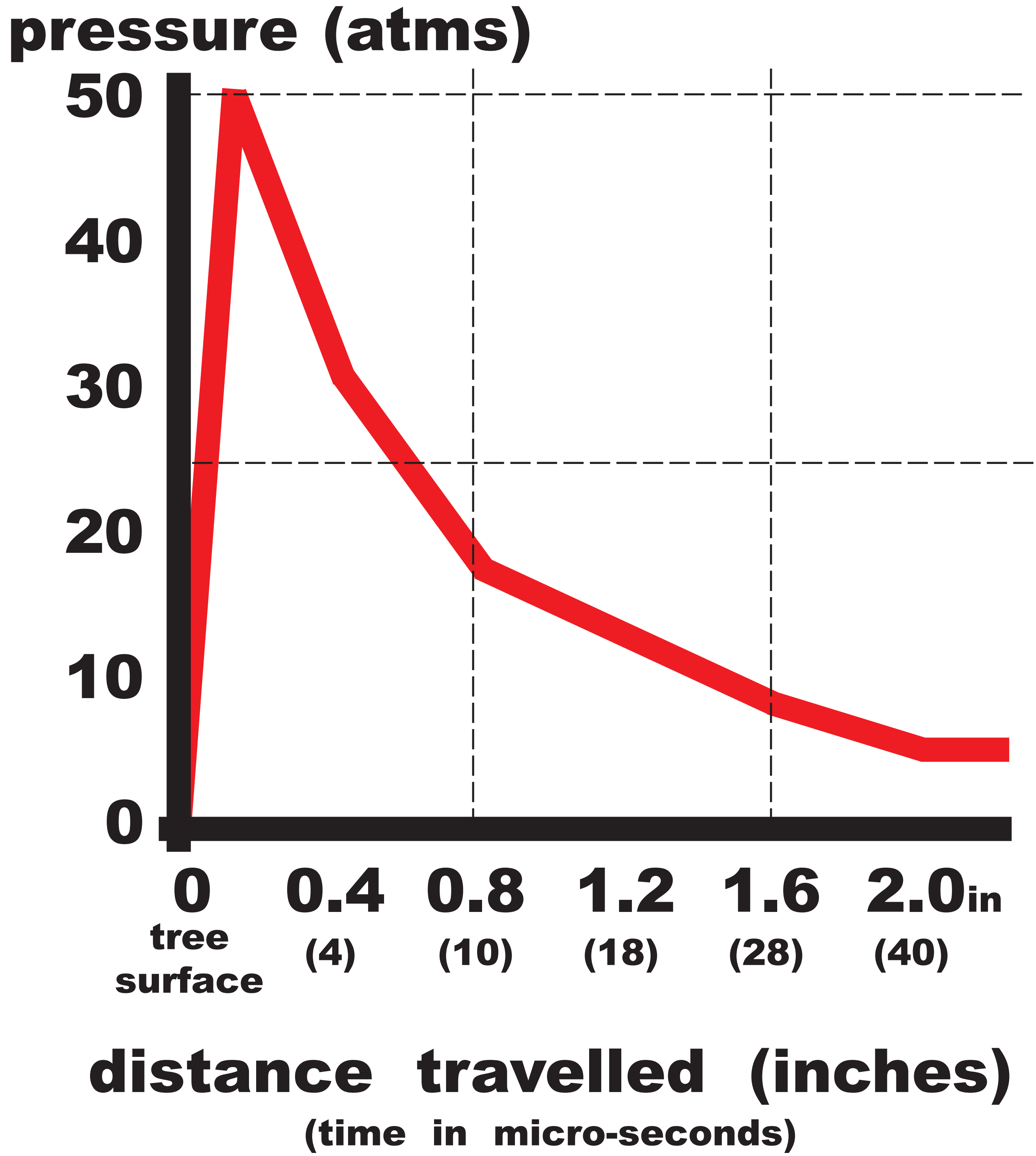

Figure 19: Shock wave pressures,decaying into anacoustic wave over time and space, spreading away from a lightning core. (derived from Few 1995; MacGorman. & Rust 1998)

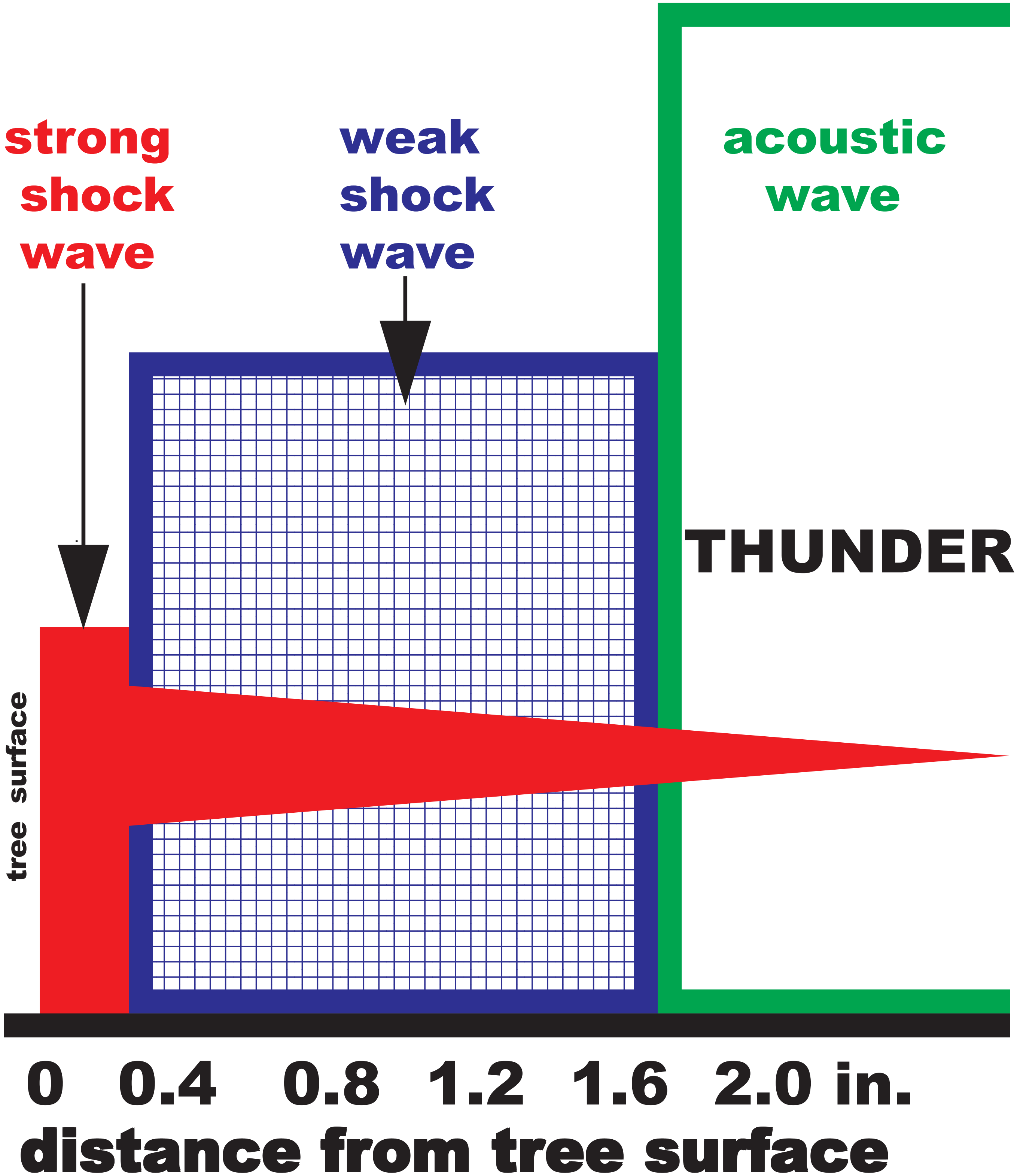

Figure 20: Pressure wave expanding from lightning core.
(Few, 1995)

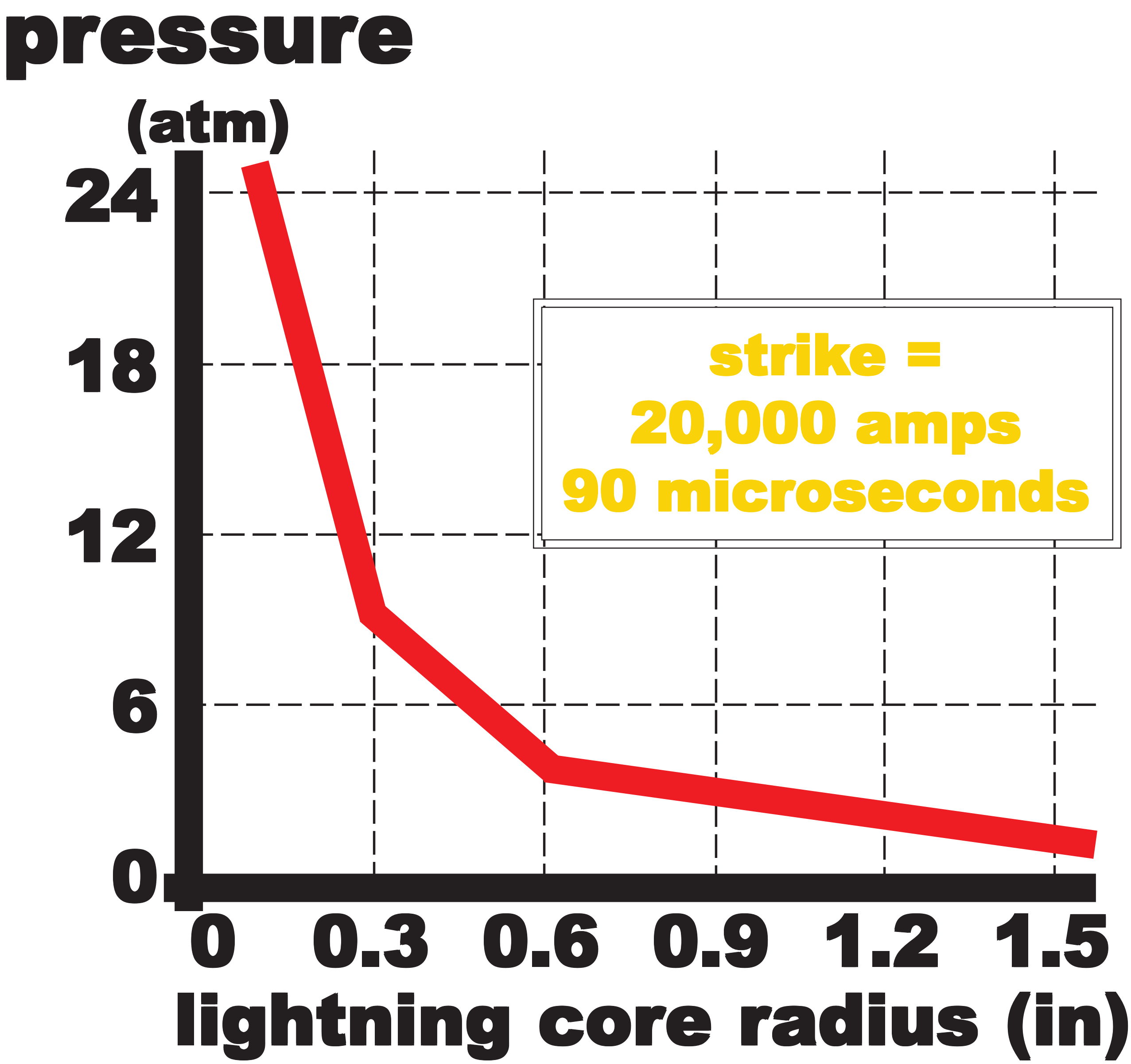

Figure 21: Pressure around lightning strike core moving away from its center. (derived from Rakov & Uman 2003)

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Surface Flash Over / Arcing (maxiumum distance ~65ft)

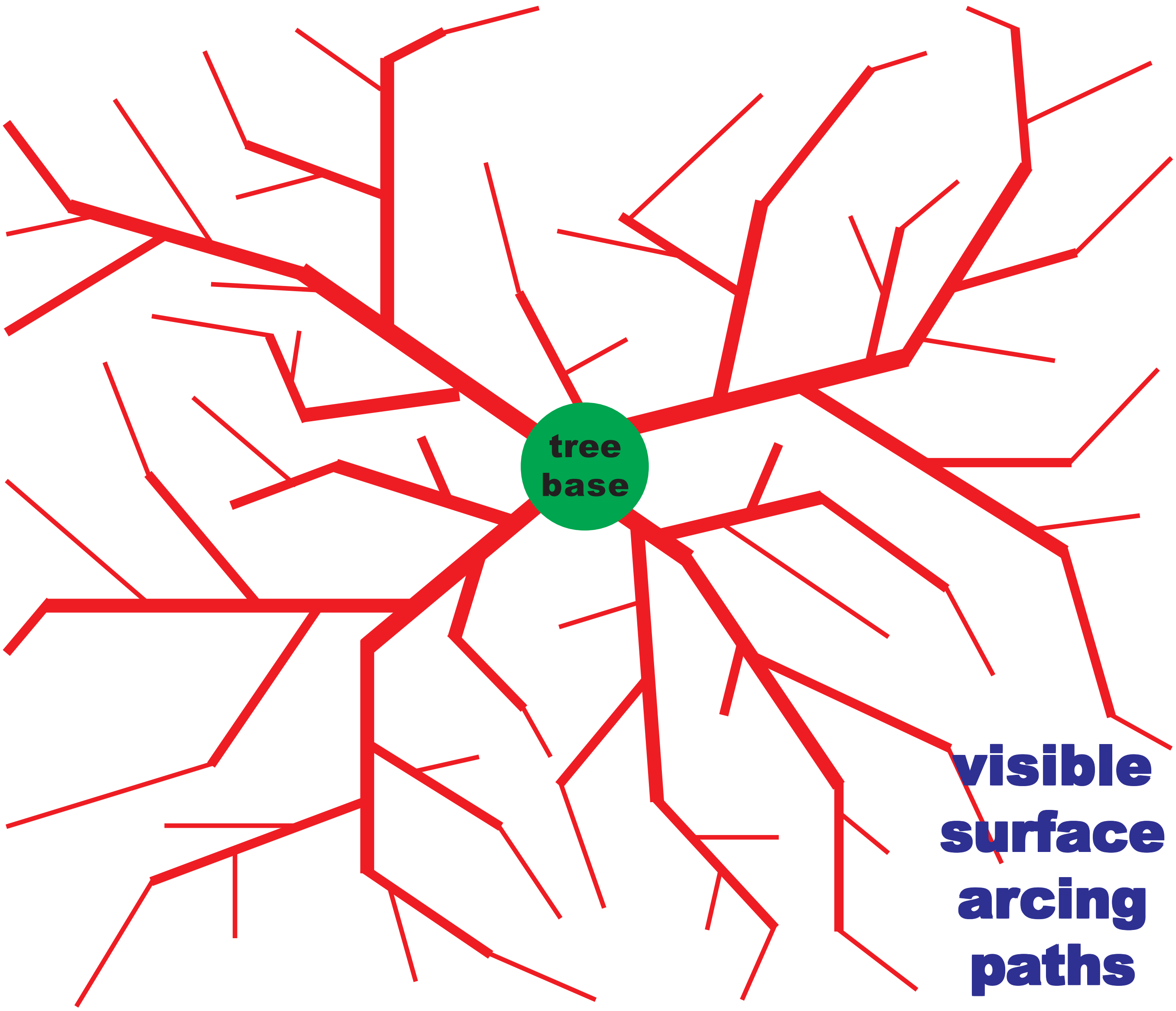

Figure 22: Diagramatic view from above of tree stem base (dark circle in middle above) struck by lightning. Most lightning strikes with peak current over 15kA, especially under wet / rainy conditions, arc across soil surface.

(Cooray & Fernando 2010)