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Charge Generation For Lightning Ground Strikes

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Storms generate large updrafts and pull moisture laden air up to high, cold altitudes. Various types and sizes of precipitation form in storms. In the simplest terms, electric charge fields generate lightning are concentrated when tiny ice crystals and larger wet ice particles (graupel) collide. These collisions within storm updrafts leave electrical charges on small crystals and opposite charges on larger particles.

Small, charged ice crystals are blown to the top of a storm cloud while larger, opposite charged particles fall toward the middle and base of a storm cloud. Figure 1 shows a simple way of considering how charges are separated within a storm cloud. A lightning ground strike occurs when electric charge fields in storms and at the ground surface connect across the atmosphere.

Separation of Charges

Charge separation in a cloud is accomplished by many different sized particles being slammed against each other in the updraft and turbulence of a storm cloud. Figure 2 shows representations (not to scale) of neutral cloud particles: small water droplets; larger graupel (wet ice); and, tiny ice crystals. Collisions between falling graupel (wet ice particles 1/12 to 1/6 inch in diameter) and rising small ice crystals (ice particles 1/400 of an inch in diameter or smaller) allow electric charge separation. Peak negative charges are concentrated between cloud temperatures of 23^{o}F and -13^{o}F.

Lower in a cloud and at a greater than 5^{o}F temperature, ice crystals (and polarized water droplets) colliding with graupel remove a negative charge from graupel. Figure 3. Higher in the cloud where temperatures fall below 5^{o}F, ice crystals banging into graupel leave a negative charge and carry a positive charge. These unbalanced charges are quickly blown apart by wind / updarfts. Ice crystals are carried toward cloud tops and graupel falls to mid and lower cloud zones. Within a storm cloud, positive and negative charge separations become more pronounced with increasing storm energy. Figure 4 shows positive and negative charges separated in a cloud by miles of air volume.

Tri-Pole

In its most simple form, charge separation within a storm cloud generates three poles: one mid-height negative charge zone; one high height positive charge zone; and one much smaller low height positive charge zone near the cloud base. Figure 5. As the cloud moves over the landscape, its charge centers generate an opposite charged field or wave beneath the cloud following along the ground. The ground charge wave size mirrors the size of the cloud charge centers. Figure 6.

An example of a positive electric field charge flowing along beneath a storm cloud with a well developed negative charge center is given in Figure 7. This positive charge wave follows and flows up and over landscape objects like trees (i.e. enhances local electrical field). The distance away from a storm cloud center electric field can be measured. Because a cloud has tripole charge centers, the total electric field moving on the ground below the cloud has a double positive peak and single negative peak. Figure 8. Negative lightning ground strikes are common just before and just after storm center. Figure 9 summarizes cloud charge centers, altitudes of each center, and temperature zones of charge centers.

Types of Lightning

Lightning occurs in a number of forms or varieties. There are internal cloud, cloud-ground, cloud-cloud, and cloud-air exchanges. Most lightning (60%) is inside one cloud's electrical system. Lightning which damages trees are cloud-ground exchanges. Cloud-ground exchanges begin 90% of the time as a cloud leader with a negative polarity charge. Most of the rest of cloud-ground lightning (9%) begins as a strong positive polarity cloud leader. About one percent of lightning exchanges are initiated from ground streamers. This rare form of ground-cloud lightning can have positive or negative polarity. (Uman 1971,1987). Trees less than 325 feet tall are almost always struck by negative polarity cloud leaders. (Uman 2008). This publication series deals almost exclusively with this most common negative polarity cloud-ground exchanges.

As mentioned above, positive lightning comprises an average of about 9% of all strikes. The positive strike distribution over the year is highly variable. Figure 10 shows positive lighting strike averages over the United States per year. Positive lightning strikes are relatively high (23% of all strikes) in Winter months and low (7%) in Summer months July and August.

Example Real Storm Data

The distribution of negative and positive lightning strikes in a storm varies by storm type and charge center positions location within clouds. Figure 11 provides an example of a storm system which spawned lightning, hail, and a F5 tornado in the Midwest over a 4.5 hour period. Positive lightning occurred early in the storm and peaked just before storm midpoint and just short of major hail and tornado events. The negative lightning peak was much greater in number of strokes than positive lightning, and peaked well after the middle of the storm toward its end.

Strike Strength

Figure 12 provides a comparison of lightning current values of both positive and negative polarity strikes. Note positive lightning can reach extremely large current values compared with negative lightning. The average of negative and positive lightning ground strikes are relatively close to the same (~30,000amps (30kA) negative and ~35,000amps (35kA) positive), but the range expected is much greater in positive lightning.

For negative polarity lightning, there is a significant difference between the first stroke and subsequent strokes within the same strike. Figure 13 provides the probability and currents of first and secondary strokes. With average current loads, the difference between first and secondaries can be greater than 10kA. The first stroke carries the largest current. The international lightning protection standards use a different shaped curve for negative first stroke lighting. Figure 14. This figure places expanded probability tails on the previous curve.

Probabilities

Another means of appreciating different peak currents in lightning is by examining the probability of a larger or smaller strike / stroke. Figure 15 provides the probability of exceeding a given current. For example from the figure, there is a 95% probability of exceeding 14kA for a negative polarity first stroke. In other words, only 1 in 20 negative strikes will be less than 14kA. The 50% probability line provides a functional average of negative first stroke (30kA, secondary negative stroke (12kA), and positive single stroke / strike (35kA).

Note positive polarity lightning can exceed 200kA 5% of the time. Also note the 50% probability values for the time needed to complete each stroke. It is clear from all values, positive lightning is much different from negative lightning and has potential for greater damage to trees.

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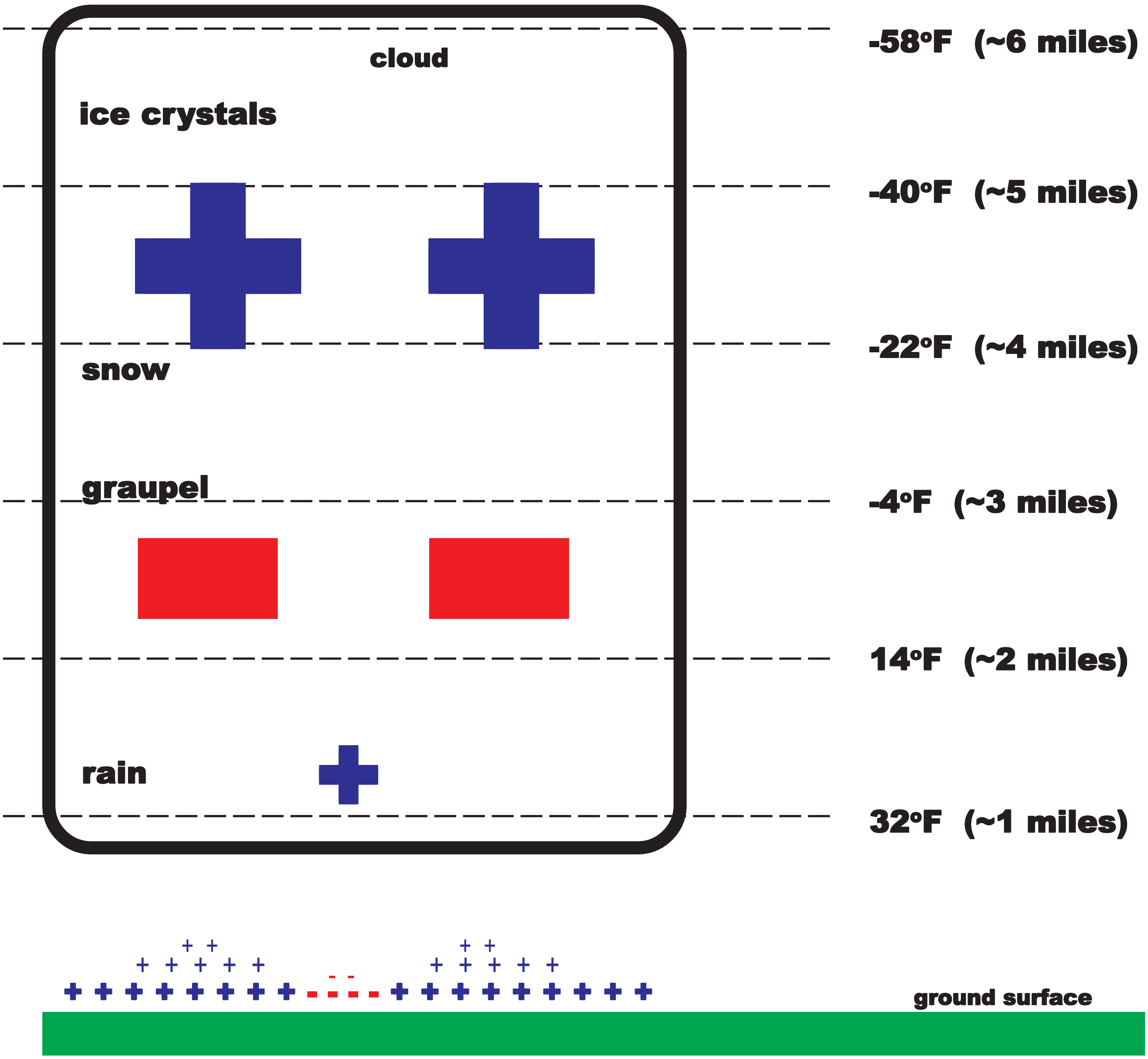

Figure 1: Charge separation inside a cloud leading to lightning strikes. Altitude in miles with temperature and precipitation form given.

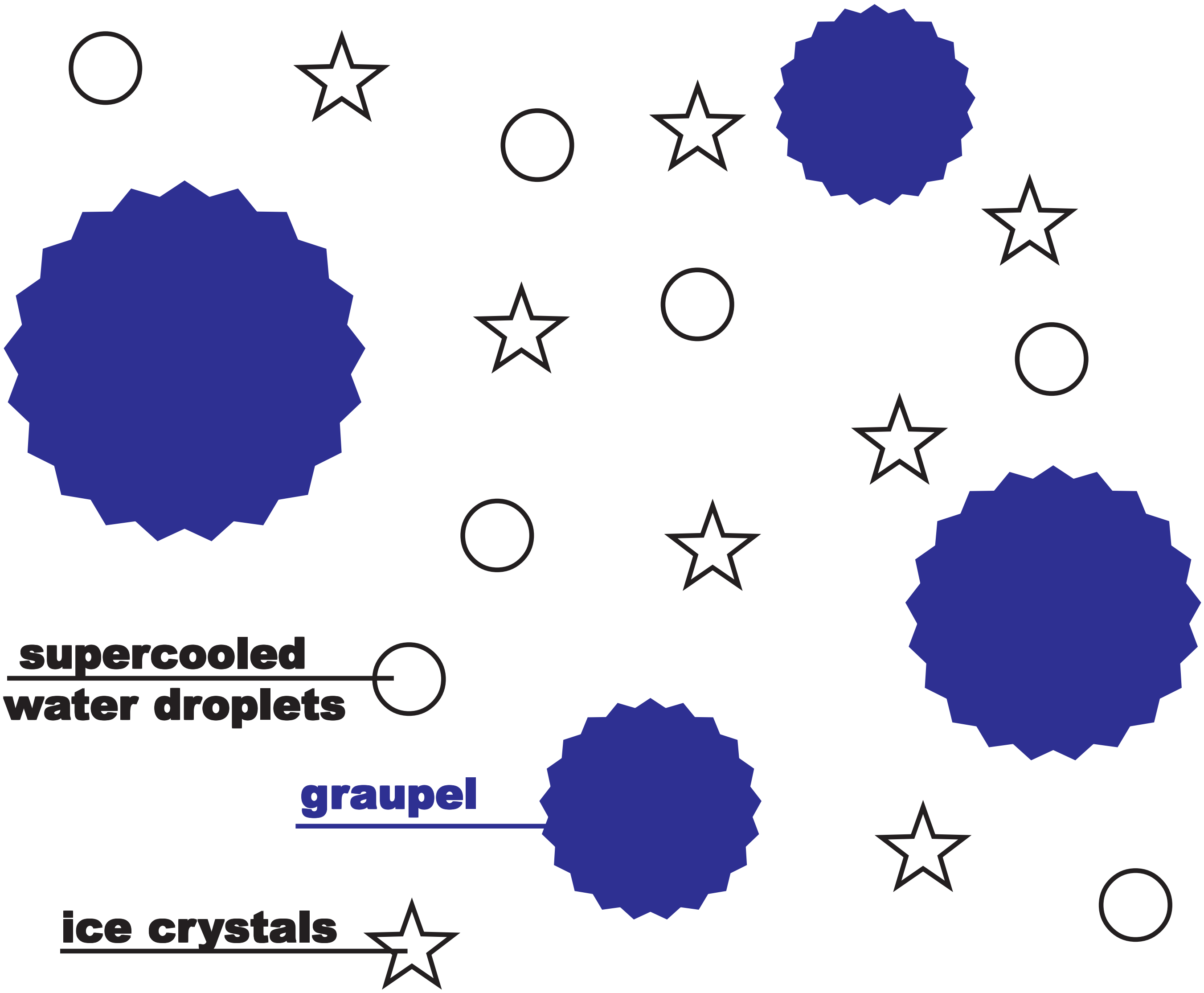

Figure 2: Particles in a cloud include supercooled water droplets,graupel (wet ice), and ice crystals all initially with a neutral charge. (Mansell & MacGorman 2012)

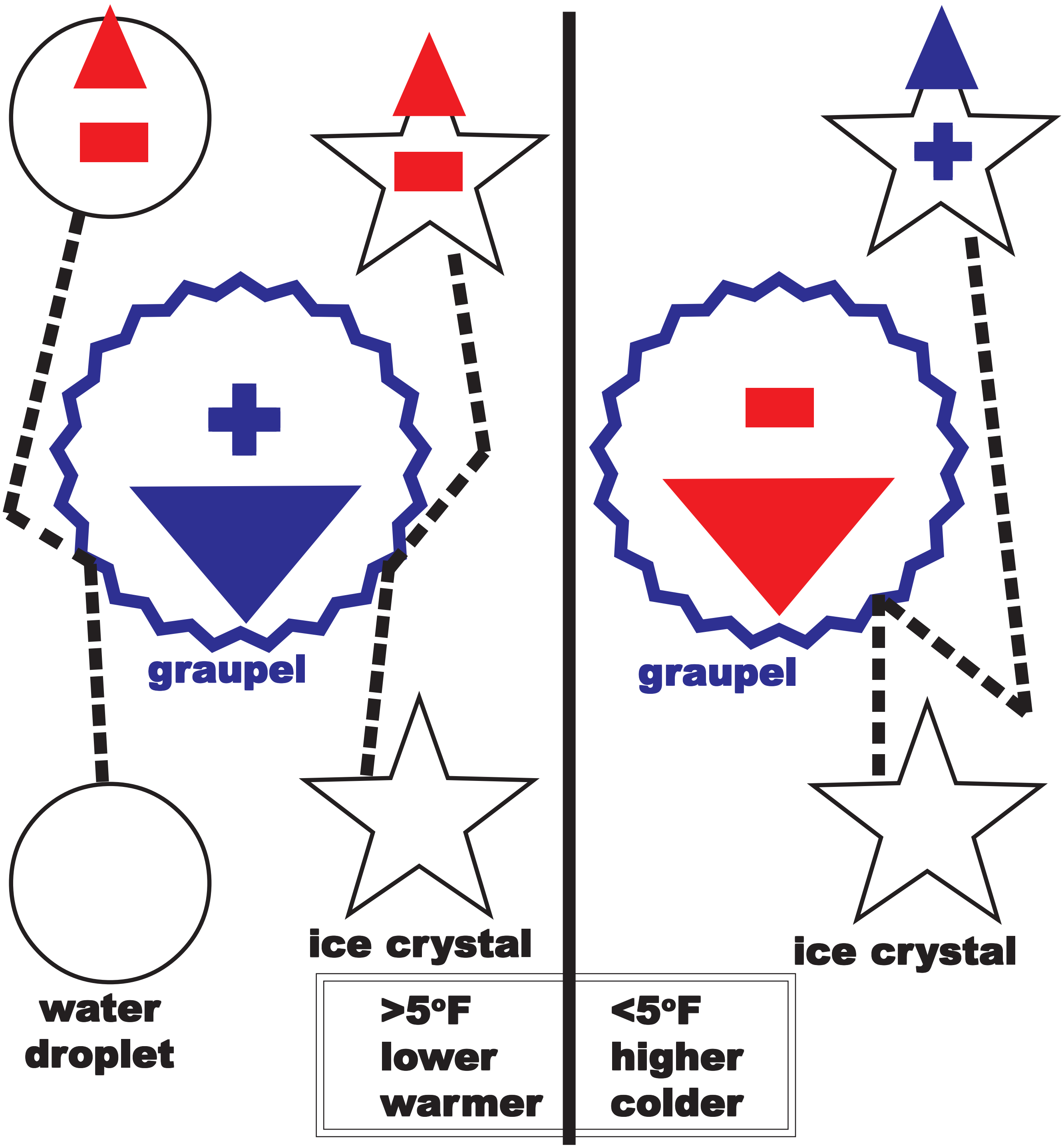

Figure 3: Ice crystals and water droplets in updraft collide with falling graupel particles (wet ice). Depending upon temperature (greater or less than 5°F), graupel, water droplets, and ice crystals collect different charges.
(Mansell & MacGorman 2012; Rakov & Uman 2003)

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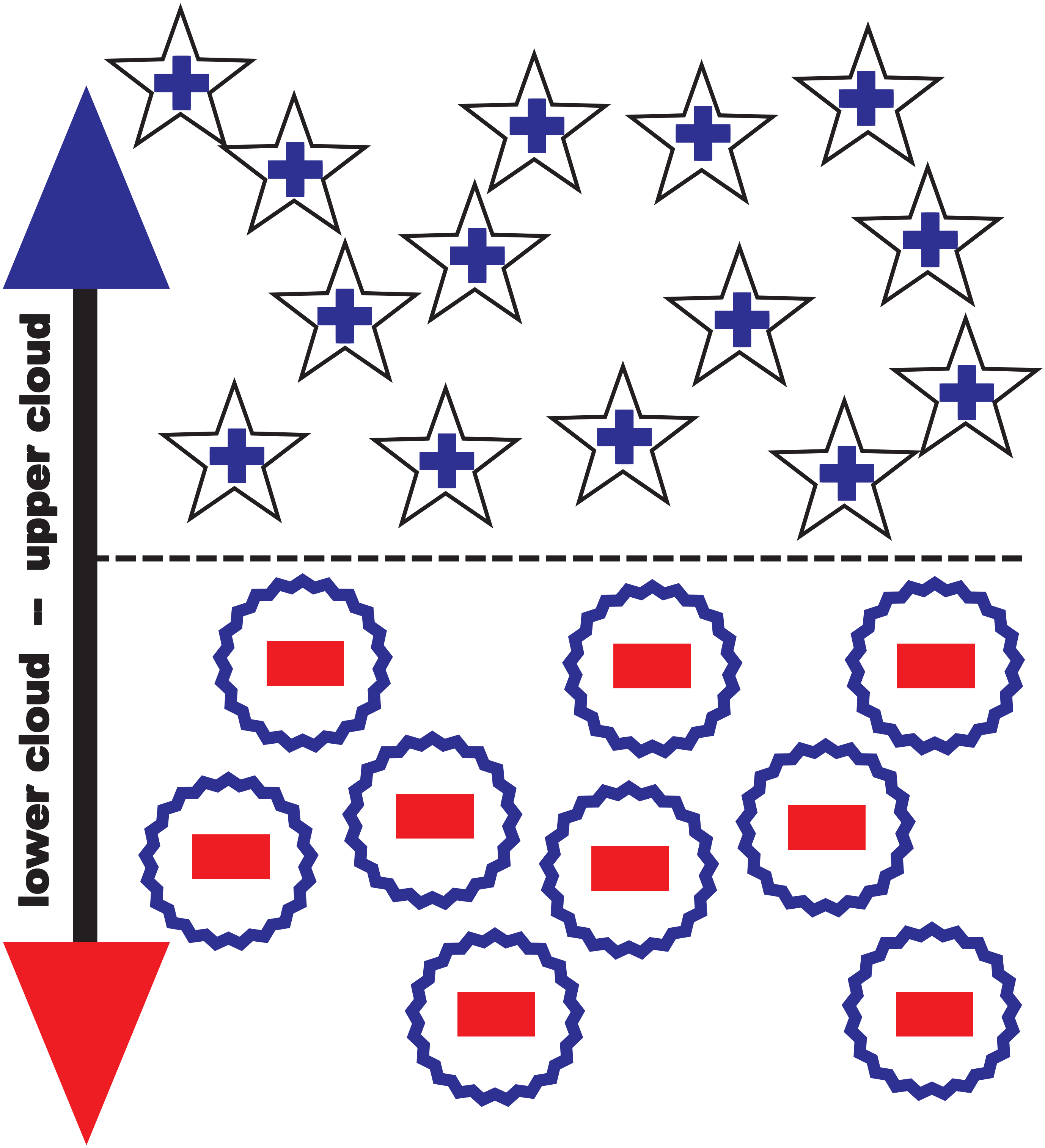

Figure 4: Charged particles become separated and concentrated inside cloud. (Mansell & MacGorman 2012)

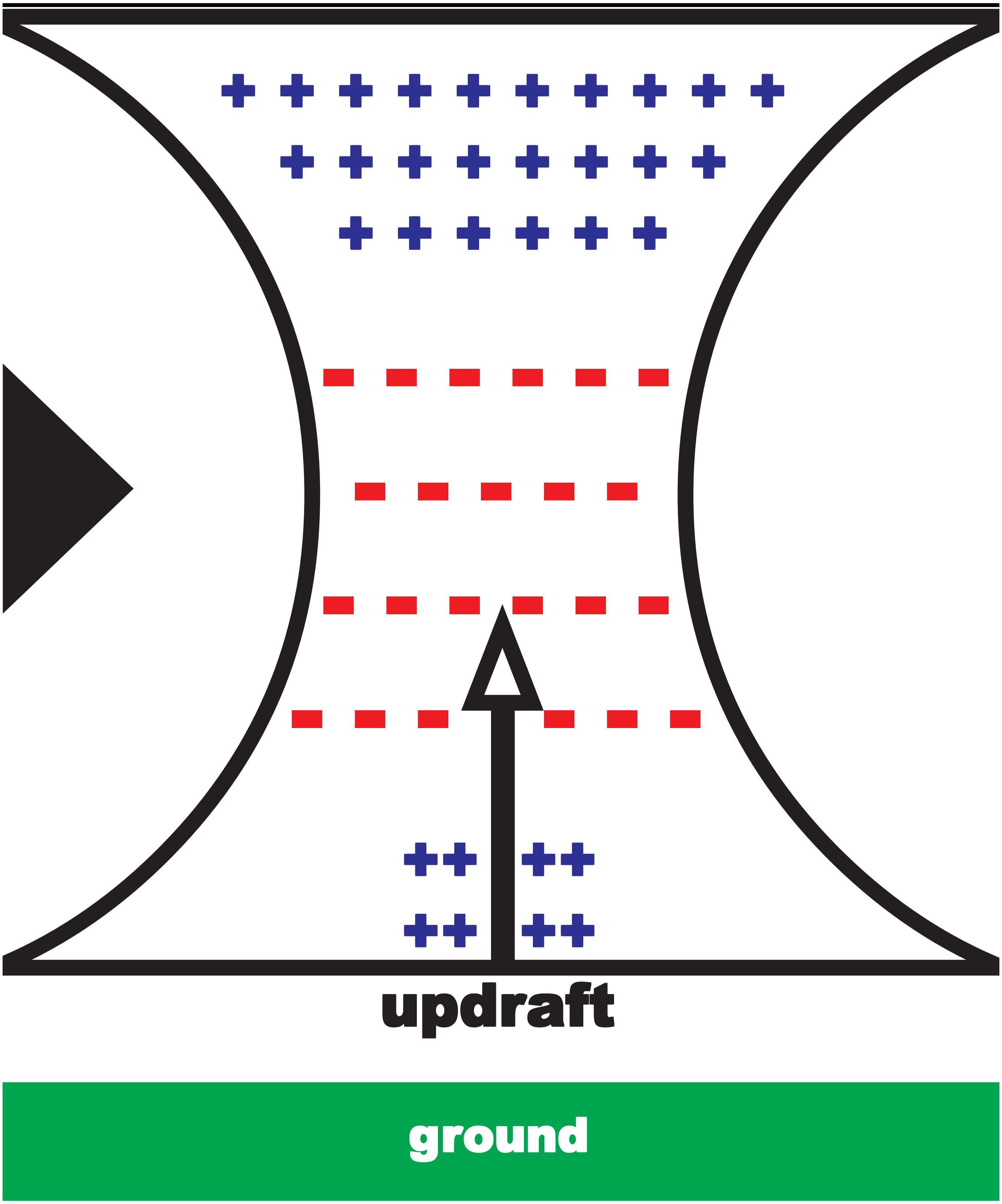

Figure 5: Simplified charge structure of thunderstorm.
(Rakov & Uman 2003)

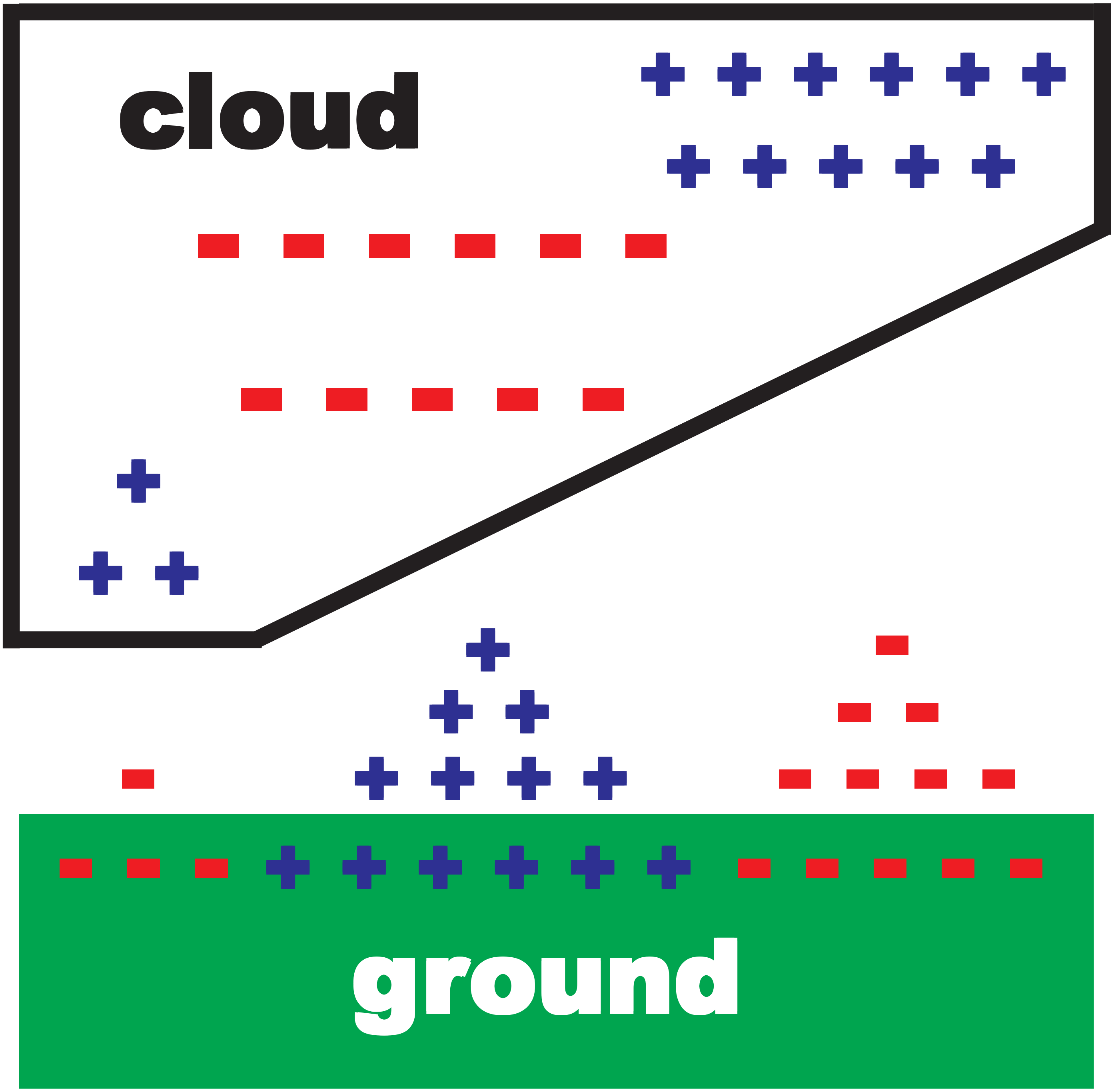

Figure 6: Electric field change along ground in response to cloud charges. (Rakov & Uman 2003)

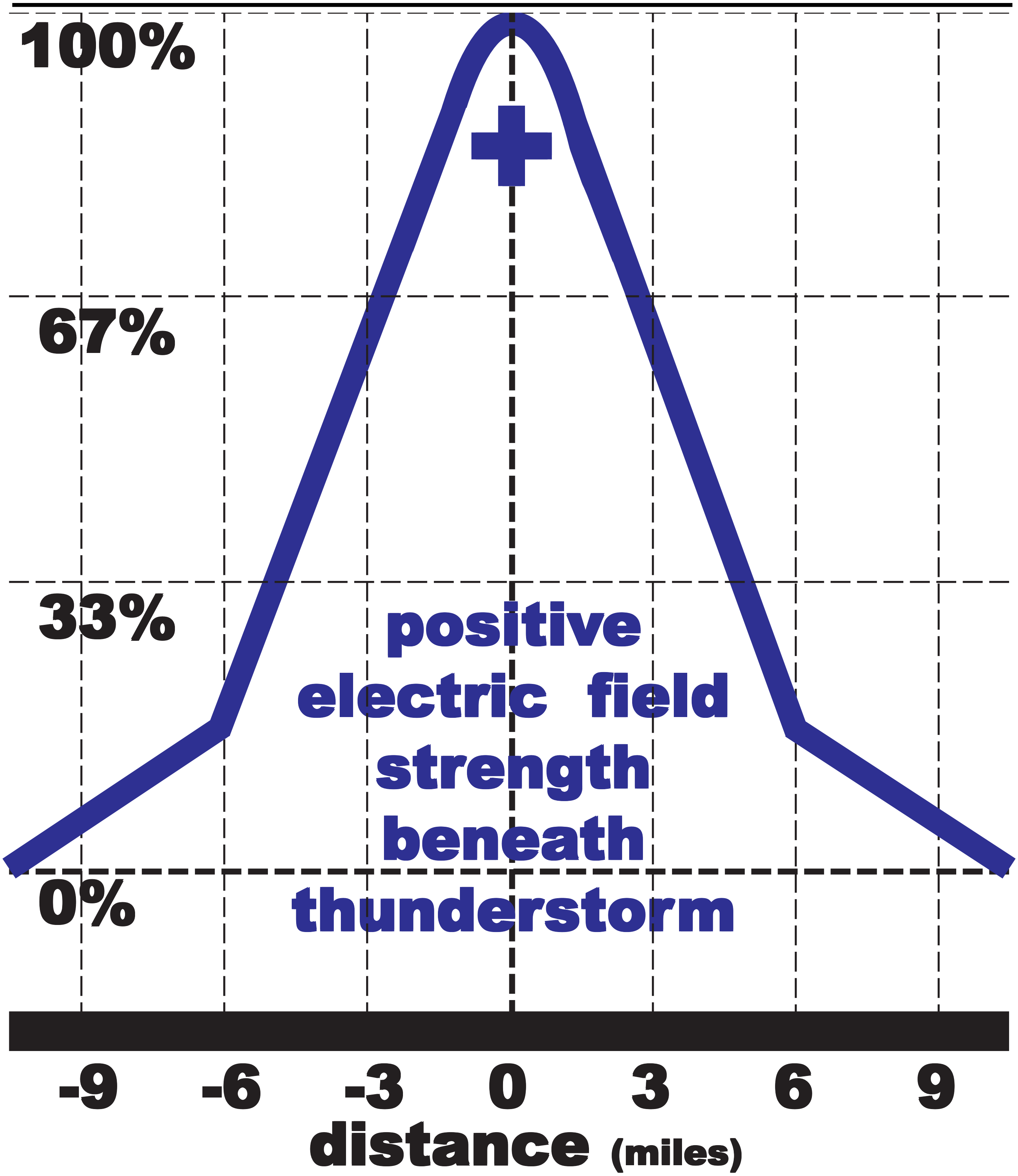

Figure 7: Relative electric field change along ground beneath thunderstorm's negative center as it moves.
(Rakov & Uman 2003)

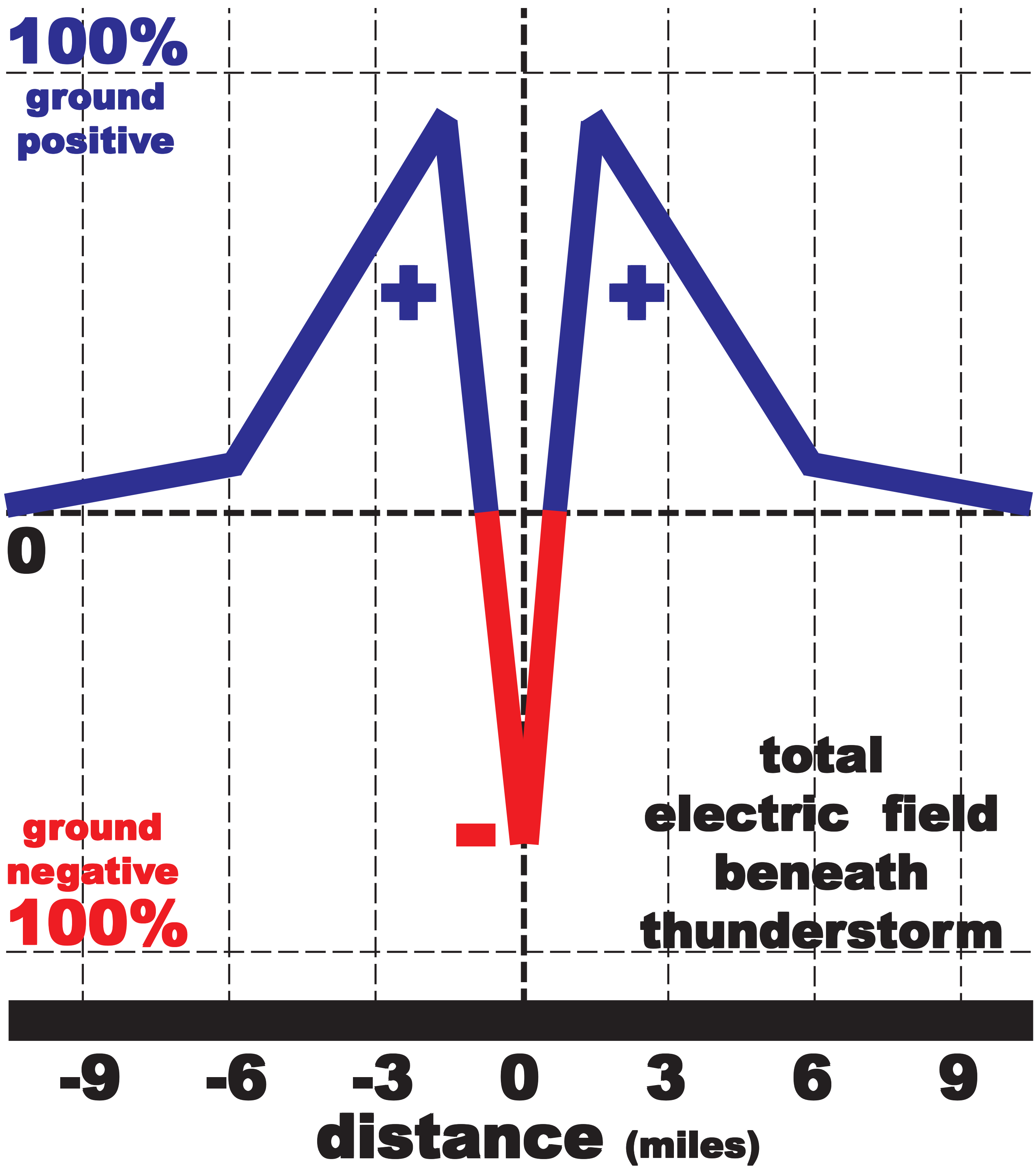

Figure 8: Relative electric field change along ground beneath thunderstorm's primary negative and primary and secondary positive centers as it moves.
(Rakov & Uman 2003)

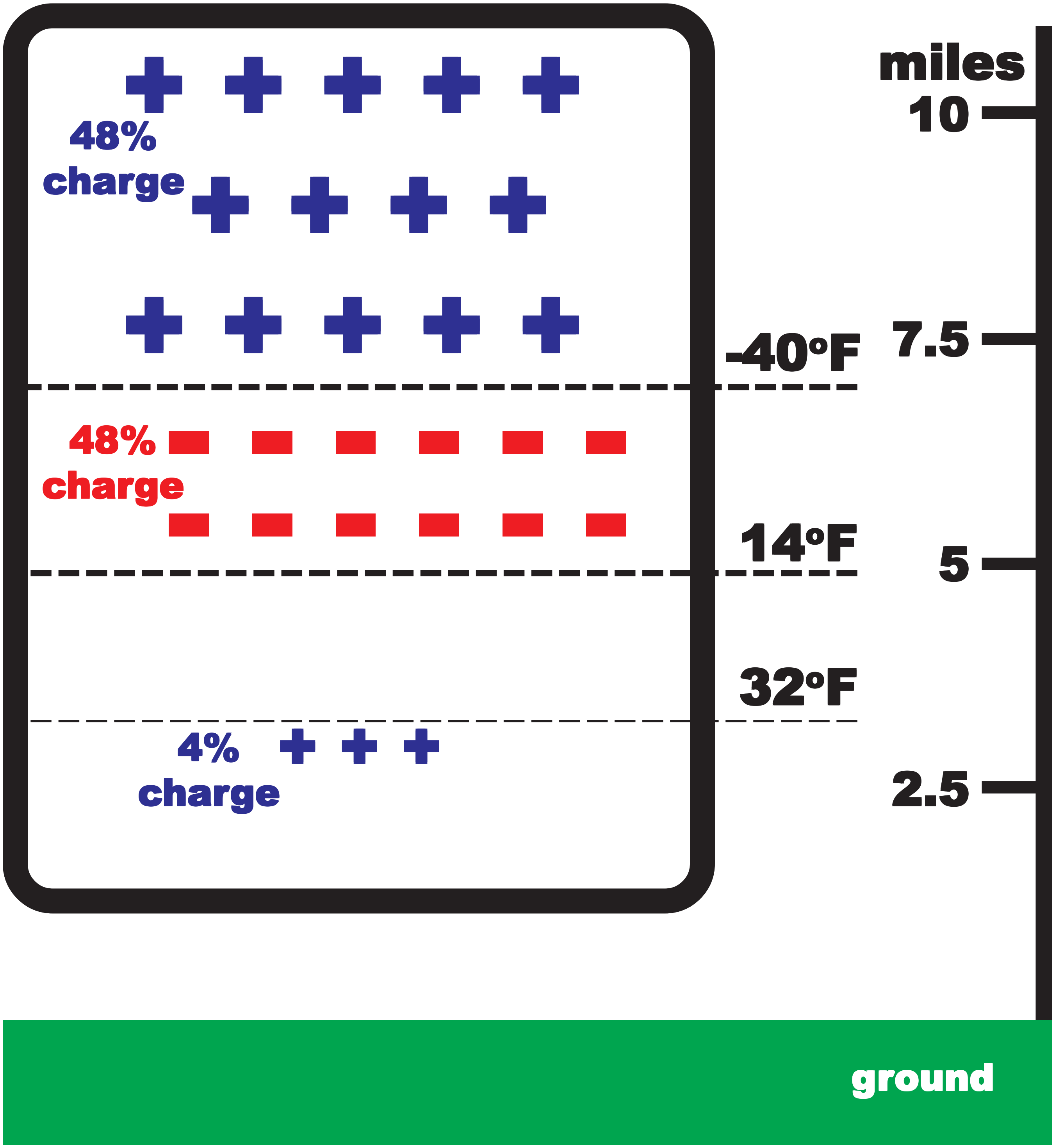

Figure 9: Basic thunderstorm charge structure by altitude and temperature. (Rakov & Uman 2003)

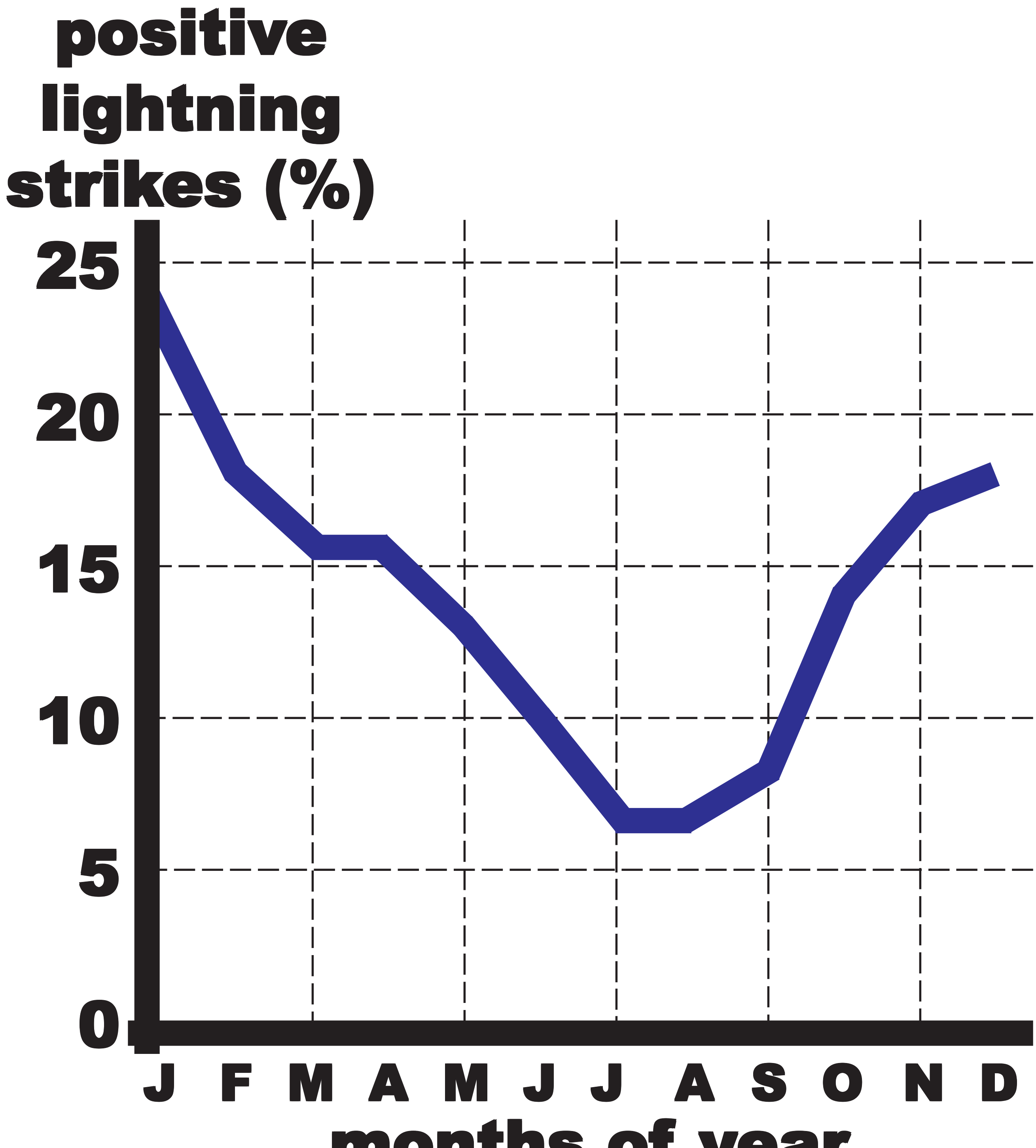

Figure 10: Average percent of positive lightning strikes over the United States annually. (derived from Rakov & Uman 2003)

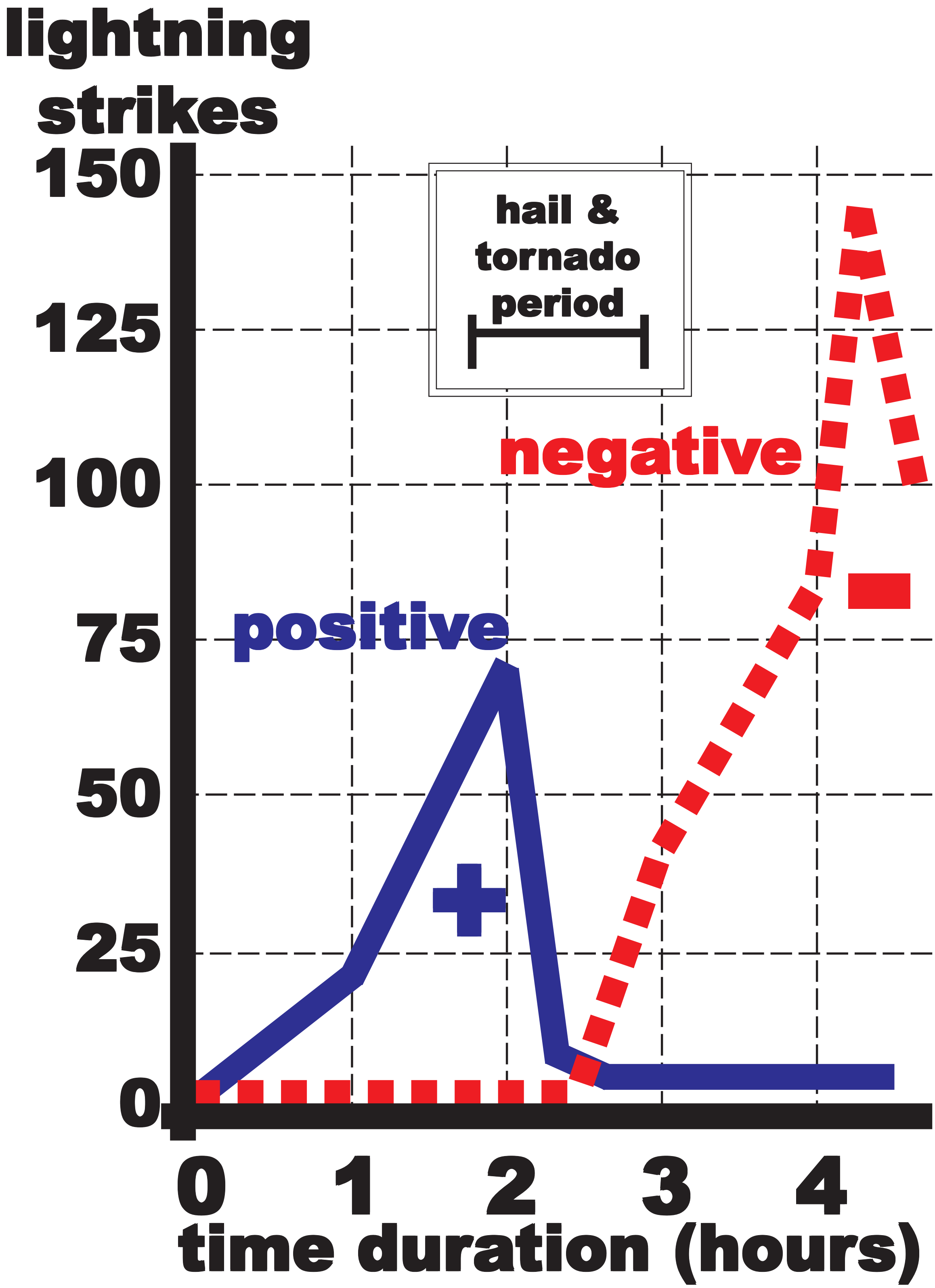

Figure 11: Number of positive and negative cloud to ground lightning strikes in one tornado generating storm.
(derived from Rakov & Uman 2003)

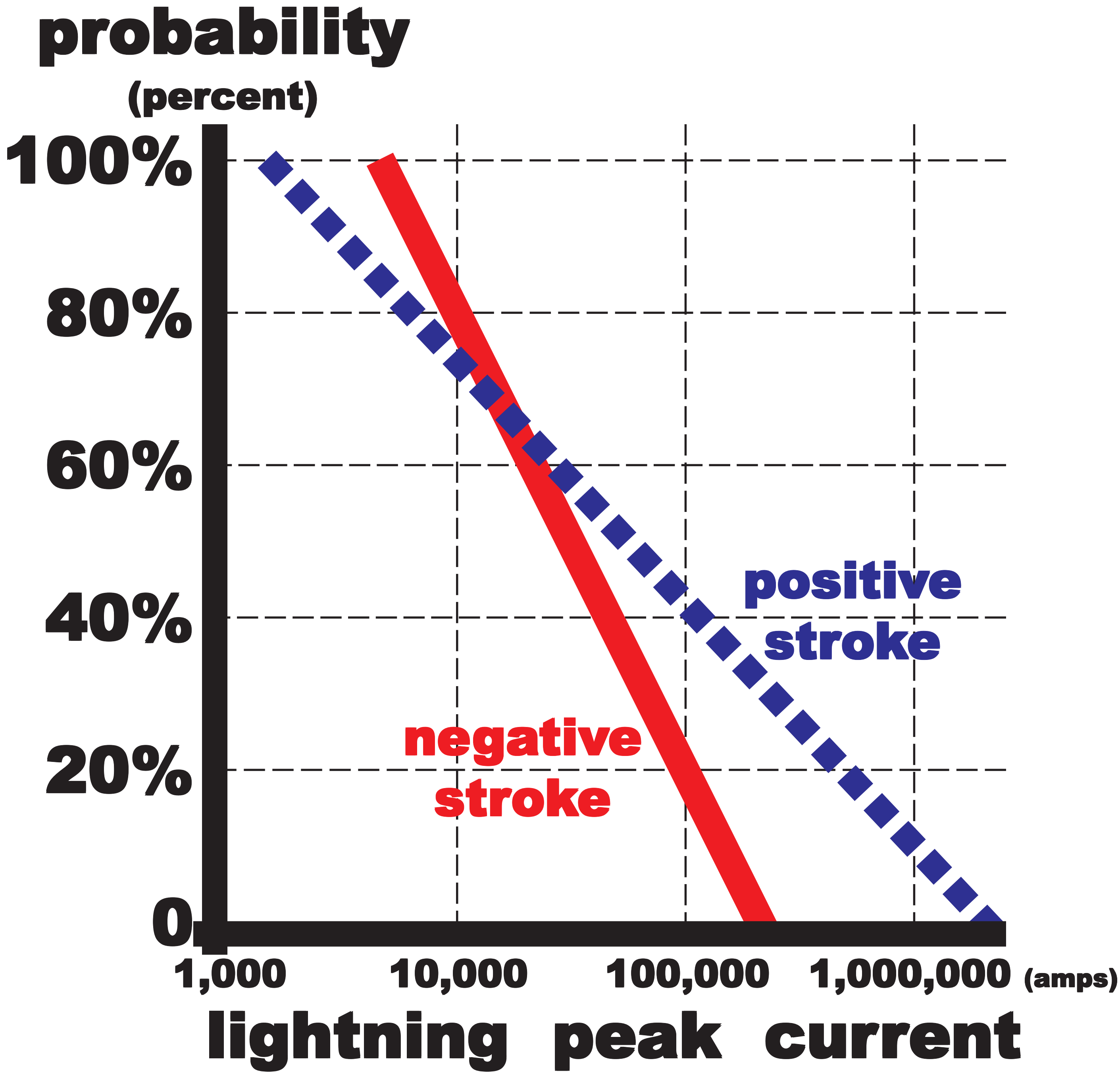

Figure 12: Lightning first stroke peak current percentages.
50% = ~30,000amps negative & ~35,000amps positive
(Rakov 2012)

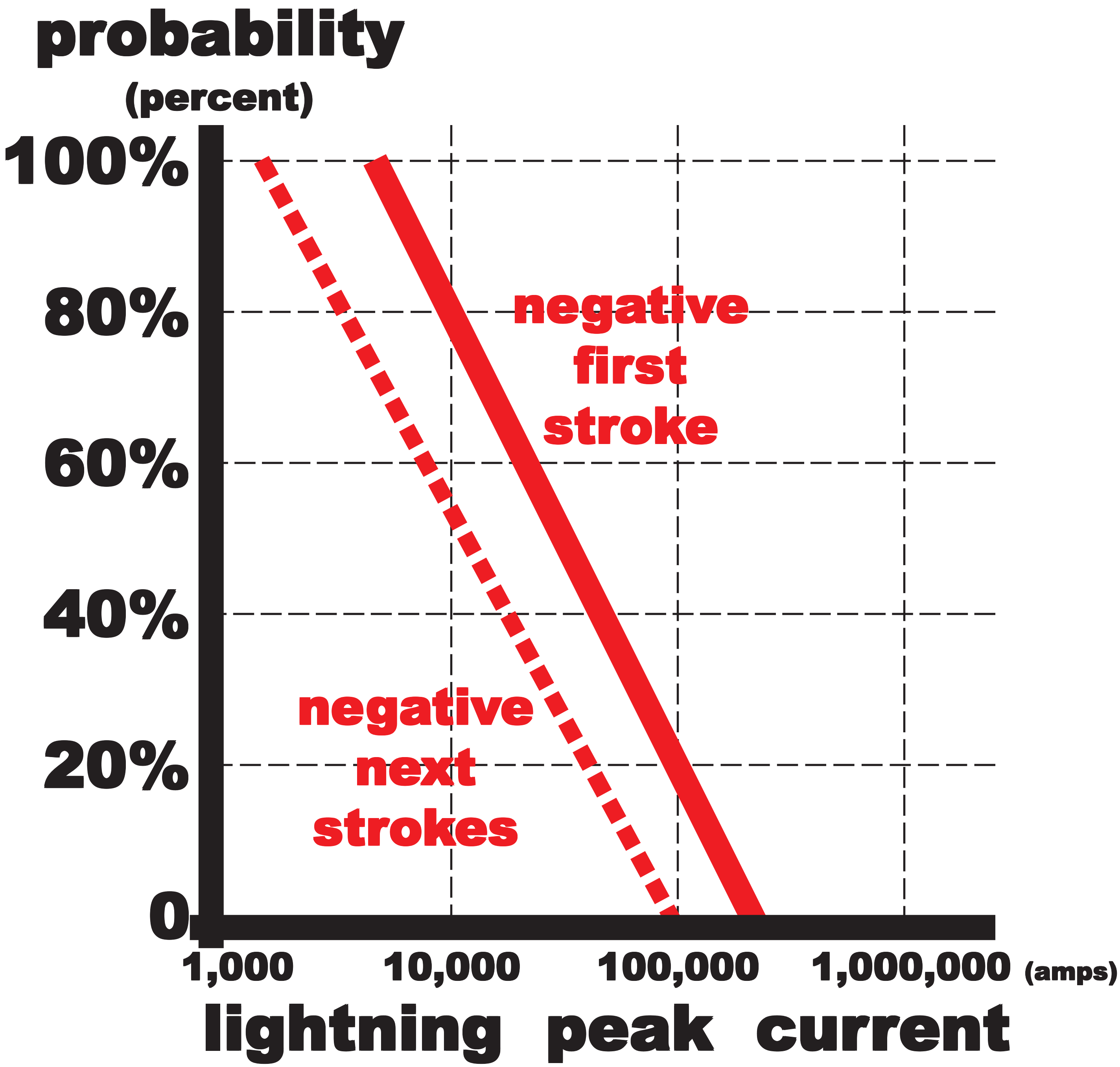

Figure 13: Lightning negative first and subsequent strokes peak current percentages. 50% = ~30,000amps first stroke & ~10,000amps second strokes (Rakov 2012)

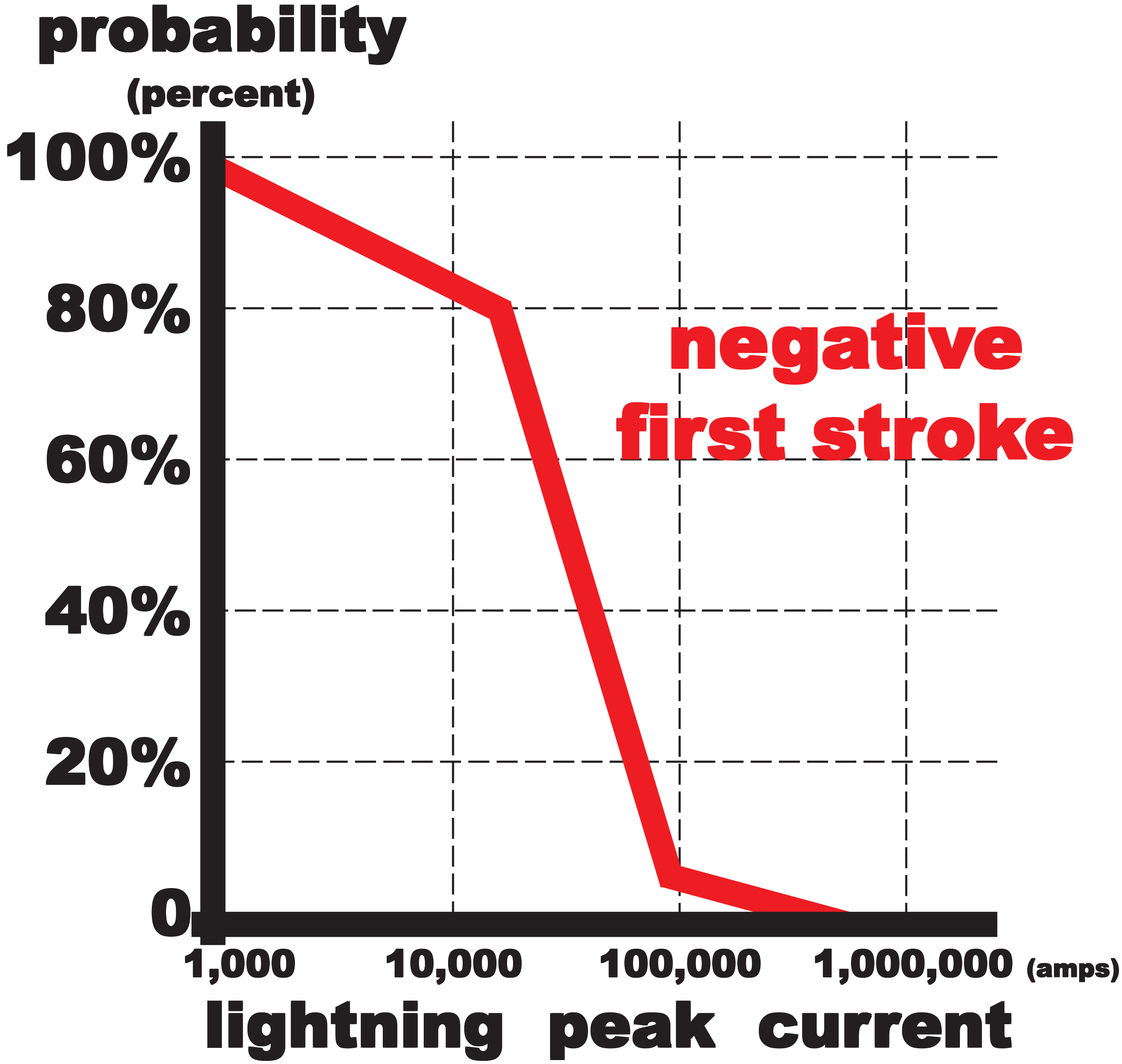

Figure 14: Negative lightning first stroke peak current percentages used in international lightning protection standards. 50% = ~31,000kA.
(Rakov 2012)

	percent exceeding value		
	95%	50%	5%
Peak Current		(kA)	
negative first	14	30	80
negative seconds	5	12	30
positive first	5	35	250
Individual Stroke Duration			
		(microseconds)	
negative first	30	75	200
negative seconds	7	32	140
positive first	25	230	2,000
Complete Strike Duration			
		(milliseconds)	
negative first	0.2	13	1,100
negative seconds	21	180	900
positive first	14	85	500

Figure 15: Expected range of lightning values. The 50% probability value would represent the average.
(Rachidi & Rubinstein 2012; Rakov 2012)