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Warnell School of Forestry & Natural Resources

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Lightning Strike Probability Risks

Dr. Kim D. Coder, Professor of Tree Biology & Health Care / University Hill Fellow
University of Georgia Warnell School of Forestry & Natural Resources

Risk assessment processes for when and where trees could be struck by lightning are complex. Examining probabilities for any one tree being within a charge exchange path requires a set of assumptions, most derived from research on free-standing communication towers. The lightning strike probability formula used here is from Bazelyan & Raizer (2000). In most simple terms, a lightning ground strike probability is dependent upon historic lightning strikes in the area, height of a tree, and presence of any surrounding tall objects.

Figure 1 provides the historic number of lightning strikes per square mile per year expected for the Southeastern United States -- a lightning strike density map. Lightning strike density maps are available for most areas on Earth and can be used to generate lightning strike probabilities. Figure 2 is a list of the number of years between lightning strikes on a single tree growing at a given height above its surroundings under a specific lightning strike density. The formula used to determine strike probabilities is:

Number of Years Between Lightning Strikes =

$$\frac{1}{(\text{N mile}^2 \text{ per year}) \ \text{X} \ \{[(3.142) \ \text{X} \ ((\text{HT feet}) \ \text{X} \ (3))^2] \ / \ (5{,}280)^2\}}$$

N mile^2 per year = Number of ground strikes per square mile per year.
HT feet = Tree height in feet above its surroundings.

The annual probability of a tree lightning strike is given by the following formula, the inverse (1/X) of the number of years between lightning strikes given above:

Annual Probability of a Lightning Strike =

$$(\text{N mile}^2 \text{ per year}) \ \text{X} \ \{[(3.142) \ \text{X} \ ((\text{HT feet}) \ \text{X} \ (3))^2] \ / \ (5{,}280)^2\}$$

N mile^2 per year = Number of ground strikes per square mile per year.
HT feet = Tree height in feet above its surroundings.

Note values in years have been rounded or truncated to provide a whole number. These calculated values can be used to estimated how many years (X) between lightning strikes for a single isolated tree in a flat area, or for a given tree height above its surroundings. The inverse of this number (1/X) is the annual probability of a strike.

For example, if the number of ground strikes per square mile per year is 15, and tree height above its surroundings is 60 feet, then the estimated number of years between strikes to the tree would be 18 years. The inverse of 18 is the annual probability of a lightning strike on the tree, or 0.056 (5.6% per year).

Remember strike probabilities are based upon an estimate of lightning attraction by ground field enhancement effects and a highly summarized map of historic lightning ground strike data. These values are intended to help tree health care providers understand lightning strike probabilities on trees of various heights above their surroundings. These probabilities are a rough estimate of dynamic natural events. Use of this information can assist tree health professionals decide if lightning protection systems would be appropriate and cost-effective for a tree in a given position within a landscape.

Strike Distances

To better understand why lightning strikes one tree and not another requires an appreciation of lightning attraction or strike distances. There are many ways to determine strike distances. The two critical features of estimating lightning strike distances are current level of charge exchange and tree height. The purpose of examining strike distances is to estimate lightning strike probability areas around a tree. The methods used to calculate lightning strike distances all change the probability of a strike.

The lightning striking distance measure is shown in Figure 3. It represent not the final jump between ground streamers and cloud leaders, but the distance between a cloud leader and the origination source of the ground streamer.

Figure 4 shows the lightning strike distance above a tree. Remember the striking distance is increased above a tree due to its enhanced electrical field compared with a flat soil surface. To calculate the lightning striking distance, Figure 5 presents a graph of striking distance in feet per peak lightning current in kA. The specific formula for the graph is provided.

Another formula for striking distance is given in Figure 6, which shows the general formula and averaged input coefficients from six different examinations. (Uman 2008). Figure 7 provides a graphical view of striking distance showing the wide range of potential values found by different research groups. Note the original distance values have been converted into feet. (Uman 2008).

Current Loads

Figure 8 provides the probabilities for three types of lightning strikes occurring with different currents. The three lightning descriptions shown are: 1) a negative polarity first stroke; 2) followed by multiple (average of three to four) negative polarity secondary strokes; and, 3) a positive polarity single stroke (usually with no secondary strokes).

For example, a single cloud/ground charge exchange of positive polarity has a 20% chance of carrying 100,000 amps. A more common negative polarity first stroke has a 20% chance of carrying 60,000 amps, with secondary strokes having a 20% chance of carrying 20,000 amps. Common first stroke lightning averages about 35,000 amps. It is possible, though highly unlikely, to have a charge exchange approaching 300,000 amps. Note the large differences in current between lightning types shown.

Four Methods

There are four common methods of gauging lightning attraction distances. These attraction distance models are called the "Golde current" method, the "double height" calculation, the "equidistance process," and the "electromagnetic process."

The Golde current method (Golde 1977) of determining lightning attraction distance uses only current of the lightning strike. The other three lightning attraction distance formula use tree height, and so are better suited for this manual. The Golde current method for determining lightning strike distances uses the formula:

$$\textbf{Lightning Attraction Distance in feet} \;=\; \textbf{32.8} \;\; \textbf{X} \;\; (\textbf{ lightning current in kA })^{0.65}$$

The double height calculation method can be used for short structures like trees to gauge lightning attraction distances. Tree height in feet is simply doubled (2X tree height) resulting in the attraction distance. This calculation method is seldom used except for rough site estimates. (Rakov & Uman 2003)

The equidistance process also uses tree height in estimating attraction distances. Figure 9 demonstrates tree height multiplied by three (3X tree height) and five times tree height (5X tree height) is the range of lightning strike attraction height. The air distance between 3 and 5 times tree height is where the charge exchange connection is expected to occur in a ground strike. The equidistance process is considered a highly simplified lightning attraction distance estimation and is usually used for calculating attraction distances for relatively short objects like trees.

Electromagnetic

A more commonly used model for estimating lightning strike distances in trees is called the electromagnetic process. The electromagnetic process, like most of the rest of the striking distance methods, uses lightning current (kA) and tree height as variables. The greater the current, the greater the distance over which lightning can affect and be affected by objects raised above the ground. The electromagnetic model begins with determining the current distance (CD) based on the current contained in an average lightning strike.

Figure 10 presents two different estimates for CD for various lightning current levels, and shows an older version which allows CD to level out as current values climb, and a slightly more recent set of CD values which increase at a constant rate (linear). Both data sets are provided to demonstrate the great variability of lightning attraction distances, especially at larger current values.

Figure 11 provides calculated examples of lightning attraction distances using current distances (CD) to project a horizontal attraction distance onto the ground around a tree for several current loads. The formula used is:

$$\textbf{Lightning Attraction Distance in feet} \;=$$

$$(((\textbf{2} \;\; \textbf{X} \;\; \textbf{CD in meters} \;\; \textbf{X} \;\; \textbf{tree ht in meters}) \;-\; ((\textbf{tree ht in meters})^{2} \;))^{0.5}\;) \;\; \textbf{X} \;\; \textbf{3.28.}$$

CD = current distance in meters
'74 = calculation method #1 uses 1974 data for CD.
'67 = calculation method #2 uses 1967 data for CD.

The lightning attraction distance above a tree in this electromagnetic model is about six times the tree height above the ground (6 X tree height in feet). Note under this model the lightning attraction distance above the tree extends a tree height above the general lightning attraction distance of a surrounding flat area.

Figure 12 illustrates the application of values for the electromagnetic model on lightning attraction distances surrounding a 70 feet tall tree (35,000 amp strike, using the 1974 data). Note the height of attraction is greater (420 feet height in this example), but the horizontal radius (202 feet) is smaller than the tree lightning strike distance in the equidistance method (i.e. 3 X tree height all around the tree). Many sources suggest using the electromagnetic process for determining lightning strike distances.

Striking

Figure 13 provides another way of thinking about attraction distance to a tree. In this figure, attraction distance is also tied to tree height over various peak current values. The taller the tree, the more the electrical field is enhanced over a greater distance. In many ways the significant difference between attraction distance and tree height is small.

Figure 14 provides a view of the lightning attraction distance, or the height of electric field enhancement, a tree standing above the landscape provides. The attraction height (striking distance) is dependent upon the peak current of the lightning strike. For a current increase of 29kA, an medium / tall tree attraction height is increased by ~150 feet. The value of this information in tree protection is small, as tree height is not adjustable and the lightning peak current is unknown (except through probability). It is clear tree height does modify the ground electric field.

Figure 15 provides another way of considering how tree height impacts the number of lightning strikes for a given strike density. This represents the collection area of a tree, or the enhanced area for lightning strikes based upon added tree height. (Uman 2008). Figure 16 illustrates how the tree collection area is calculated using tree height and crown diameter. Four times (4X) tree height is used traditionally for estimating lightning strikes to trees under 50 feet tall. Six times (6X) tree height is used as an area calculation for international lightning protection standards and trees over 50 feet. Figure 17 shows the lightning strikes per year and number of years between strikes based upon tree height. (Uman 2008).

Years Between Strikes

Figure 18 presents the estimated number of years between strikes to trees of a given height using the electromagnetic model. The formula used is:

Estimated Number of Years Between Lightning Strikes to a Tree =

$$\left[\frac{1}{[\,(3.142)\ \text{X}\ ((((\,2\ \text{X}\ \text{CDm}\ \text{X}\ \text{tree ht m})\ -\ ((\text{tree ht m}\,)^2\,))^{0.5}\,)\ \text{X}\ 3.28)^2\,]\ /\ (5280)^2} \right]\ \text{X}\ \ \text{HS}$$

CDm = current distance in meters.
'74 = calculation method #1 using 1974 data for CD.
'67 = calculation method #2 using 1967 data for CD.
HS = historic lightning strikes per square mile per year.

For example, a 70 feet tall, single isolated tree, assuming a 35,000 amp lightning strike, using the 1974 data for current distance (CD), and in an area where the number of ground strikes per square mile per year is 15, would be expected to be struck once every 14 years (7.1% chance per year). This probability value is slightly larger than earlier ones where lightning current values were not considered.

Citation:

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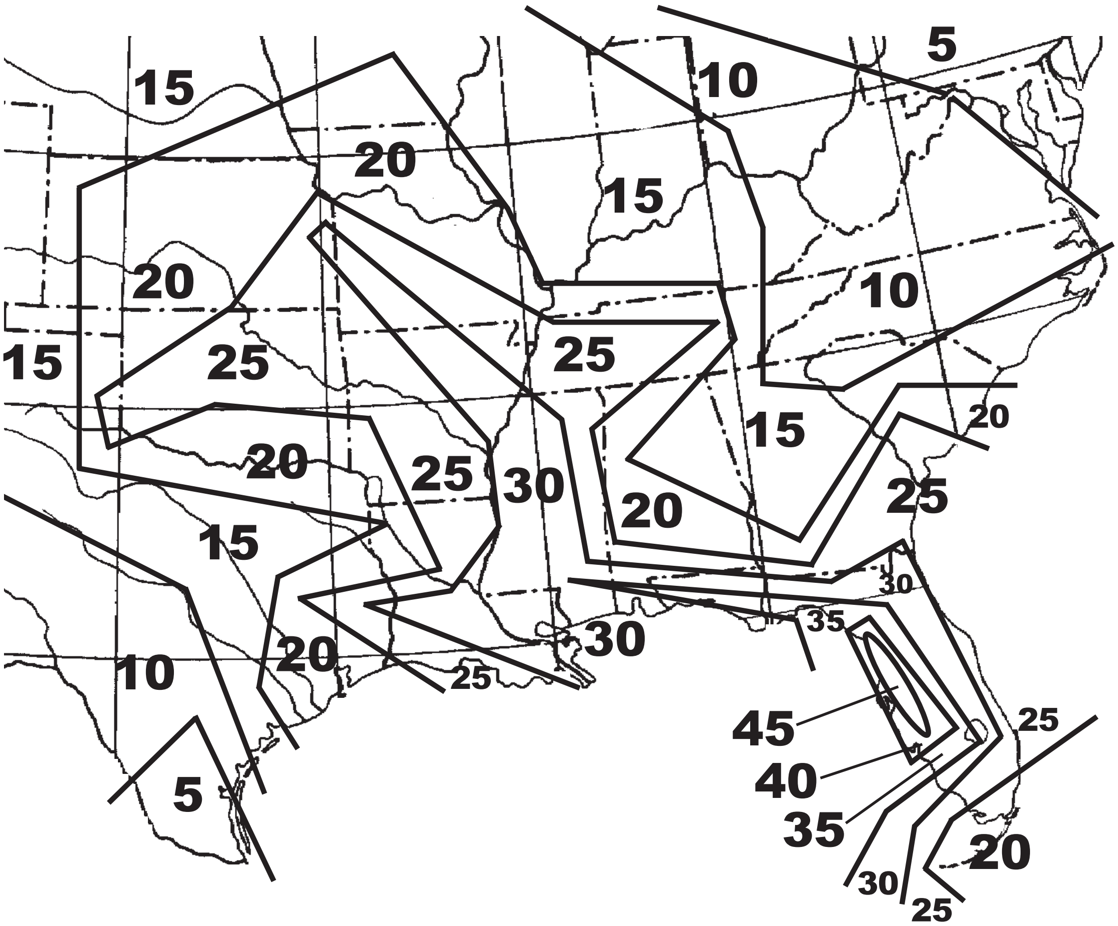


Figure 1: Average historic number of lightning strikes (clound to ground strikes) per square mile per year for the Southeastern United States.

YEARS BETWEEN STRIKES

tree height (feet)	lightning strikes per square mile per year									
	2	5	10	15	20	25	30	35	40	45
5 ft	9,999	8,000	4,000	2,500	2,000	1,500	1,300	1,100	1,000	900
10	5,000	2,000	1,000	650	500	394	328	281	246	219
20	1,200	500	246	164	123	98	82	70	61	54
30	550	219	109	73	54	43	36	31	27	24
40	308	123	61	41	30	24	20	17	15	13
50	197	78	39	26	19	15	13	11	9	8
60	136	54	27	18	13	10	9	7	6	6
70	100	40	20	13	10	8	6	5	5	4
80	77	30	15	10	7	6	5	4	3	3
90	60	24	12	8	6	4	4	3	3	2
100	49	19	9	6	4	3	3	2	2	2
120	34	13	6	4	3	2	2	1	1	1 yrs

Figure 2: Estimated number of years between a single lightning strike (ground strike) impacting a tree of a given height (in feet) standing by itself (i.e. no trees or structures within three tree heights in any direction), or for a tree of a given height above its surroundings, in an area with a specified historic lightning ground strike count per square mile per year. (Bazelyan & Raizer 2000)

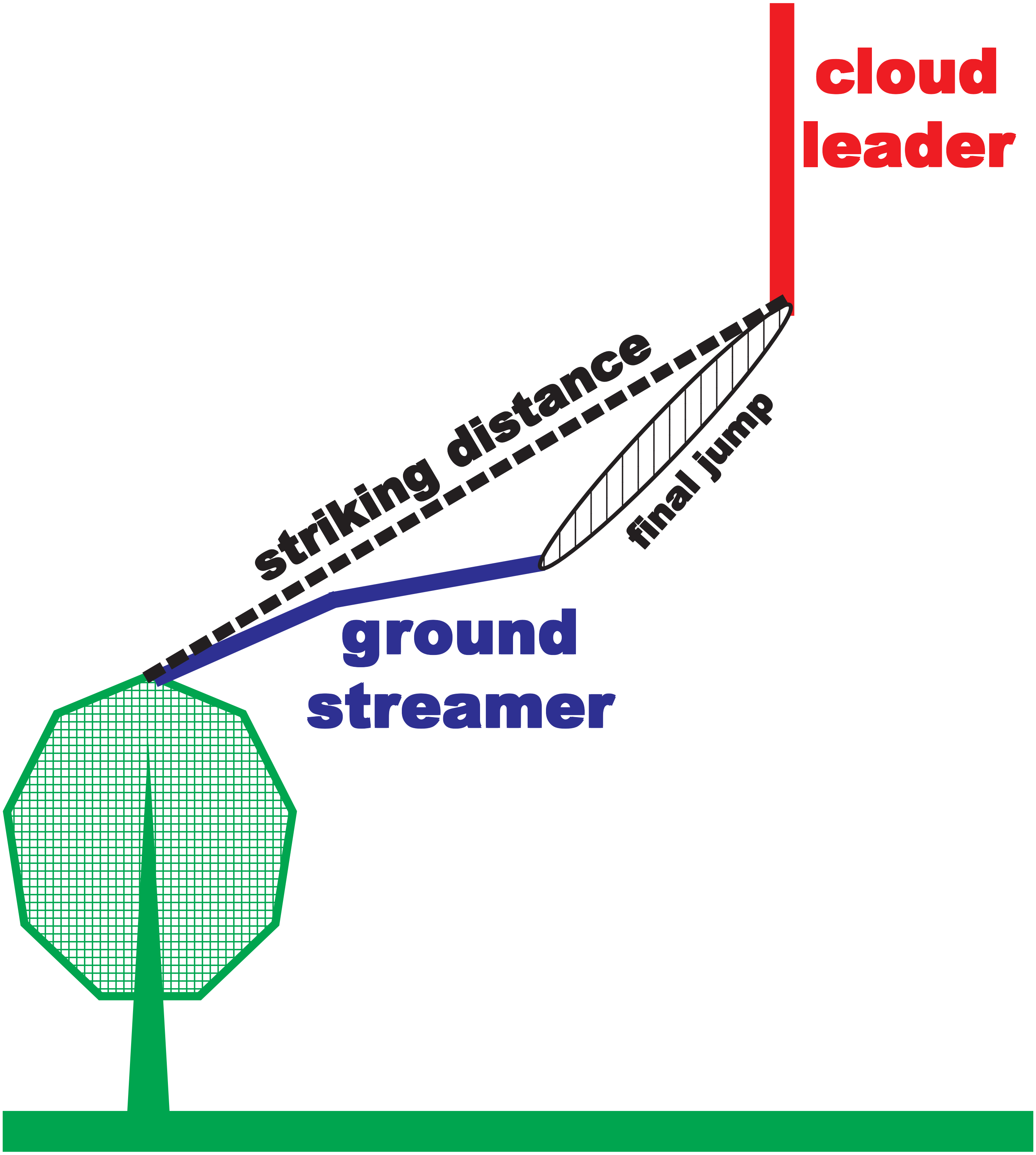


Figure 3: Striking distance definition. (Cooray 2012a)

LIGHTNING STRIKING DISTANCE (SD)

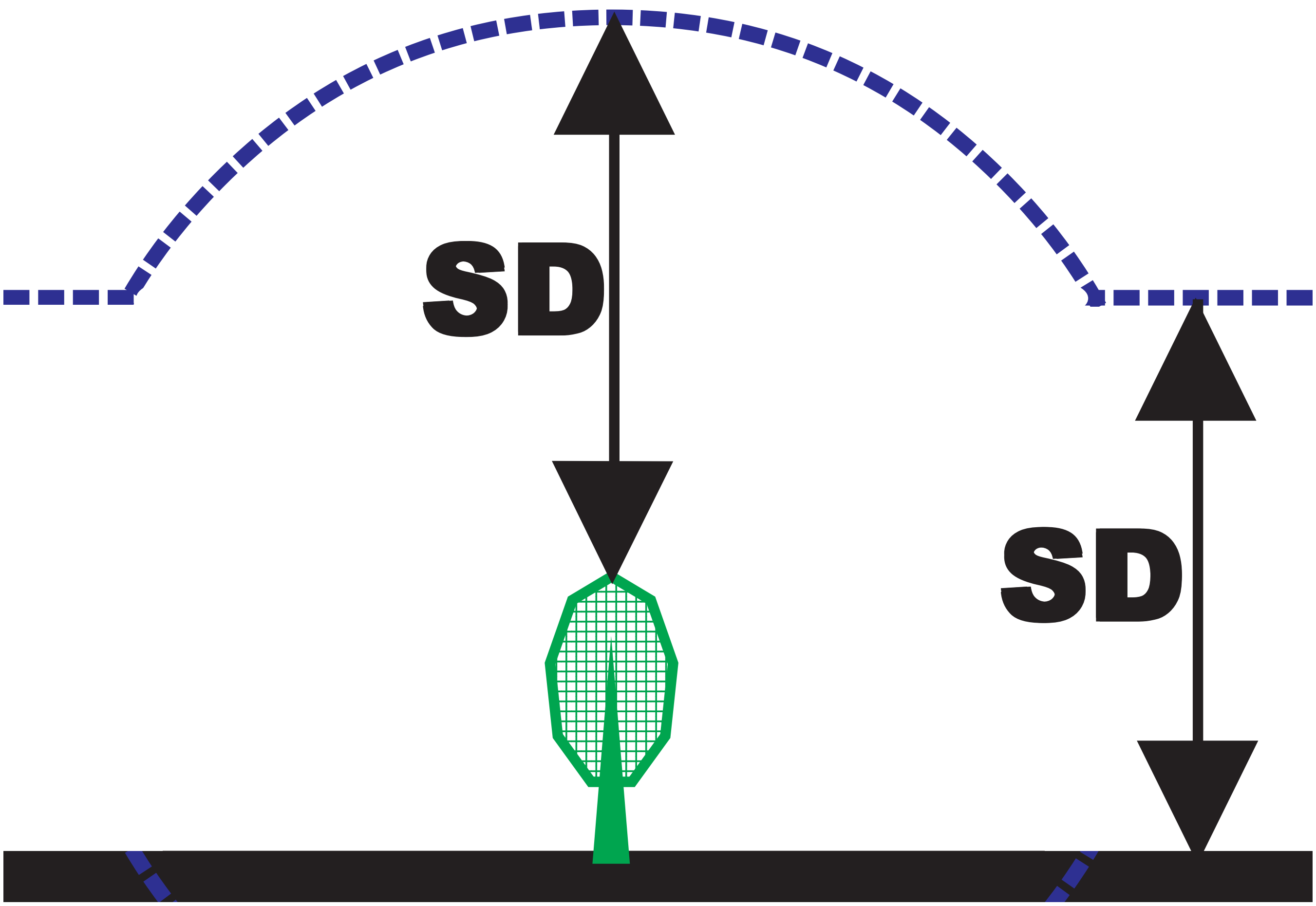


Figure 4: Lightning striking distance for the Earth surface and a tree. (Rakov 2012)

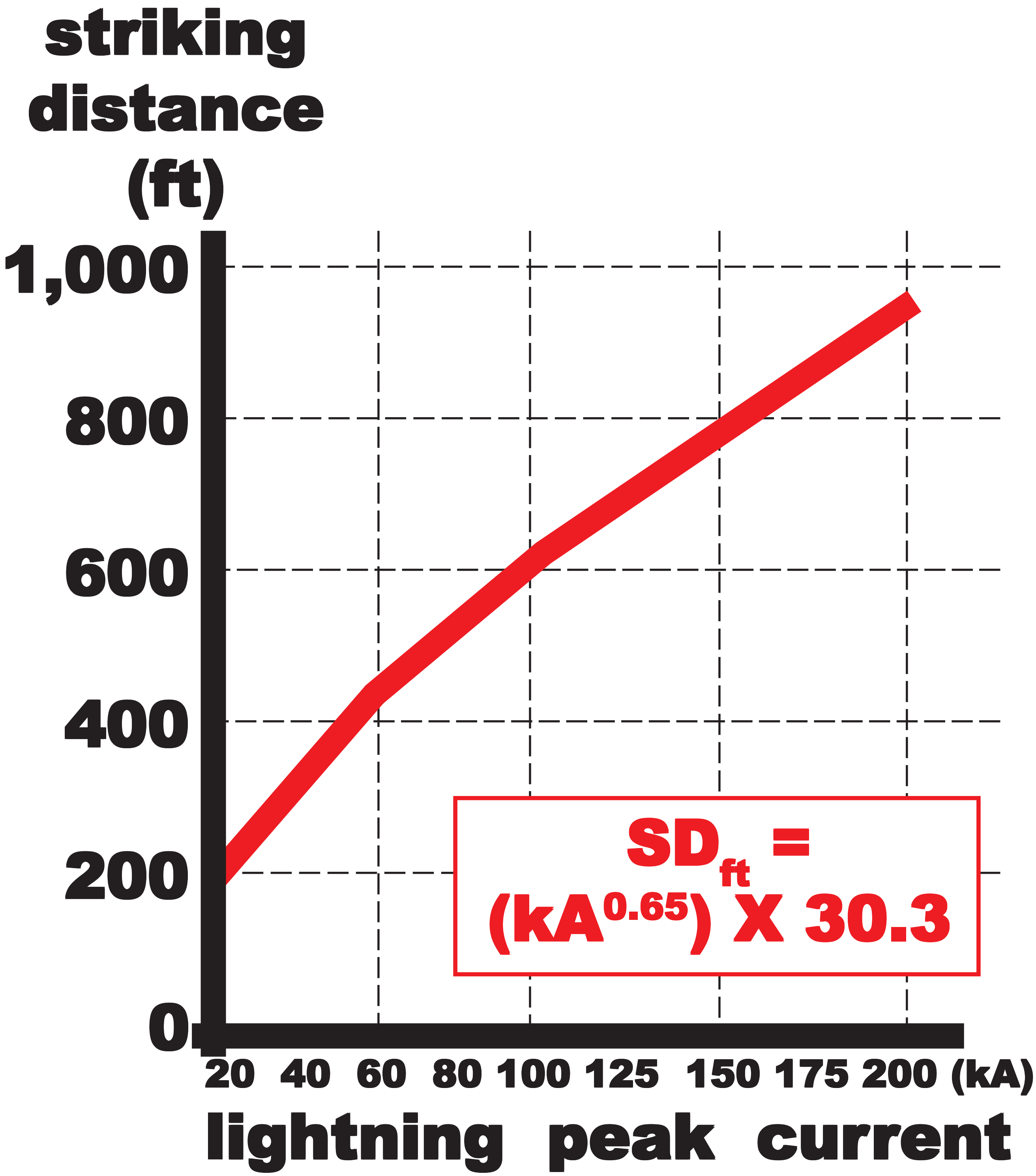


Figure 5: Lightning striking distance in feet for lightning peak current in kA. (Rakov 2012)

Striking Distance $_{(feet)}$ **=**

$$SD_{ft} = [\, a \times (IkA)^{b} \,] \times 3.28$$

a **= 6.5 (range 1.9 - 10)**
b **= 0.76 (range 0.65 - 0.9)**

IkA = first lightning stroke peak current

Figure 6: Standard formula for striking distance among five coefficient sets. (Uman 2008).

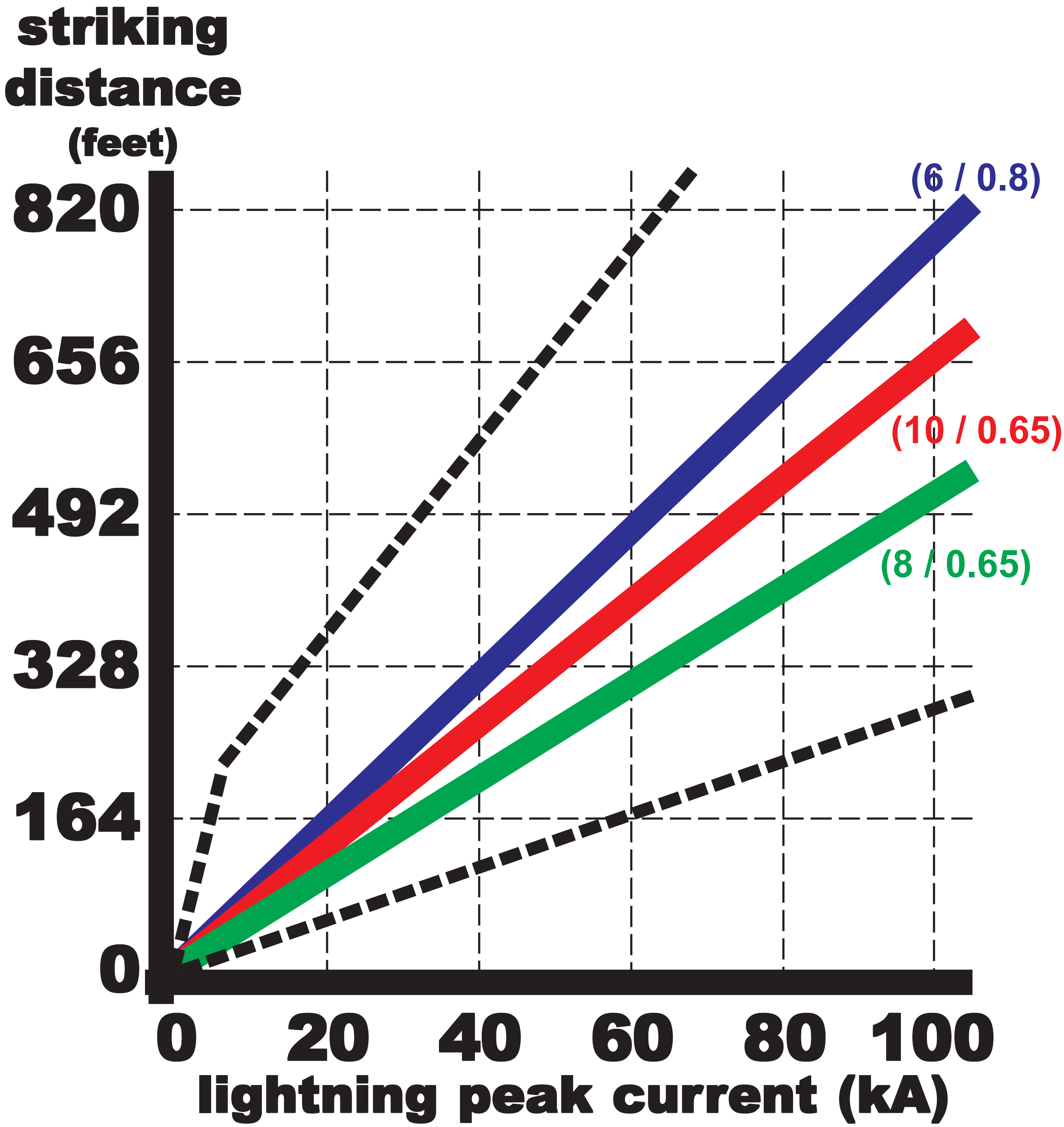


Figure 7: Graphical representation of the wide range of strike distances generated by different research group's formulae (*a* / *b* coefficients). (Uman 2008)

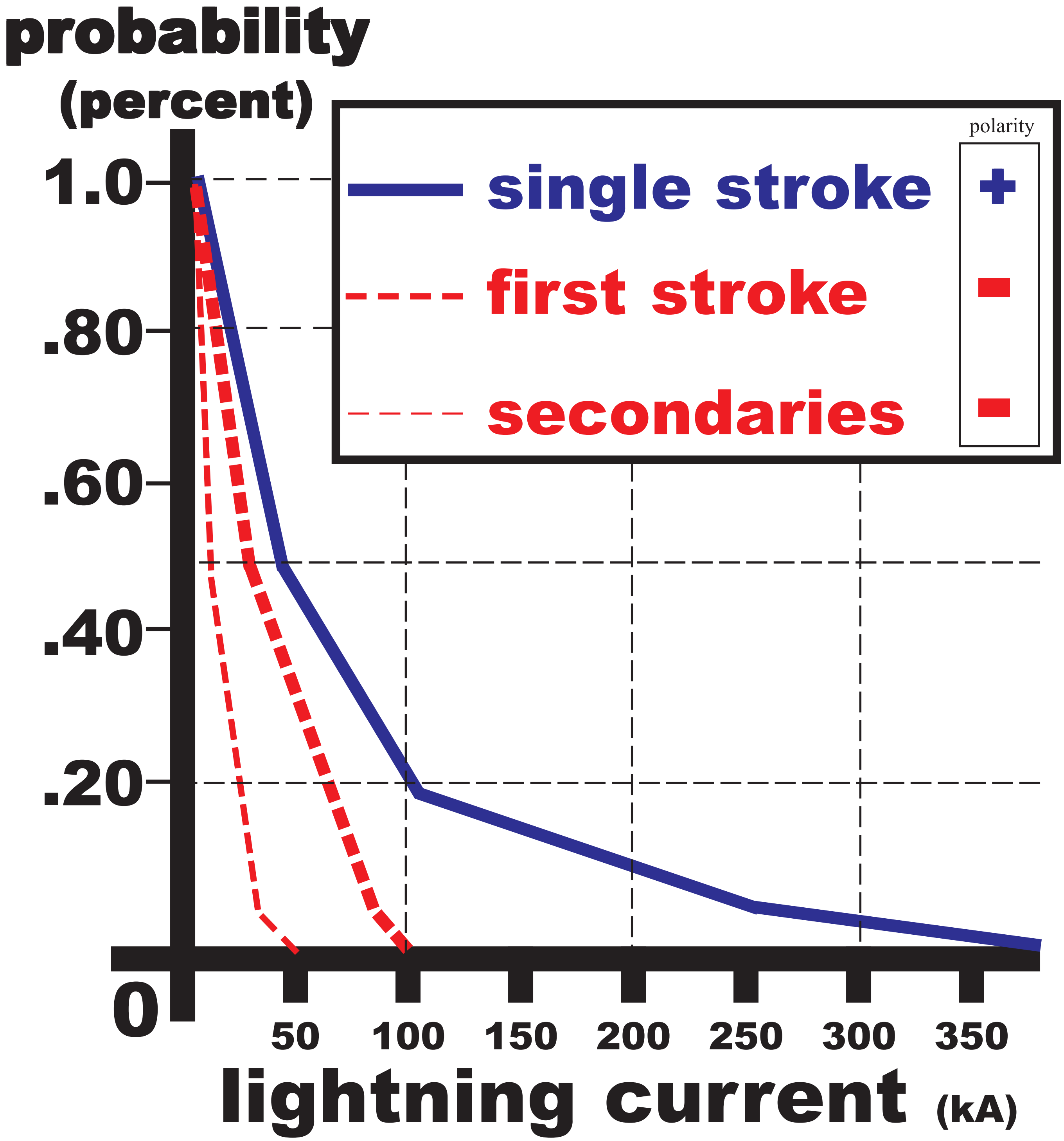


Figure 8: Estimated probabilities for three types of lightning strikes / strokes at various current levels (kA).

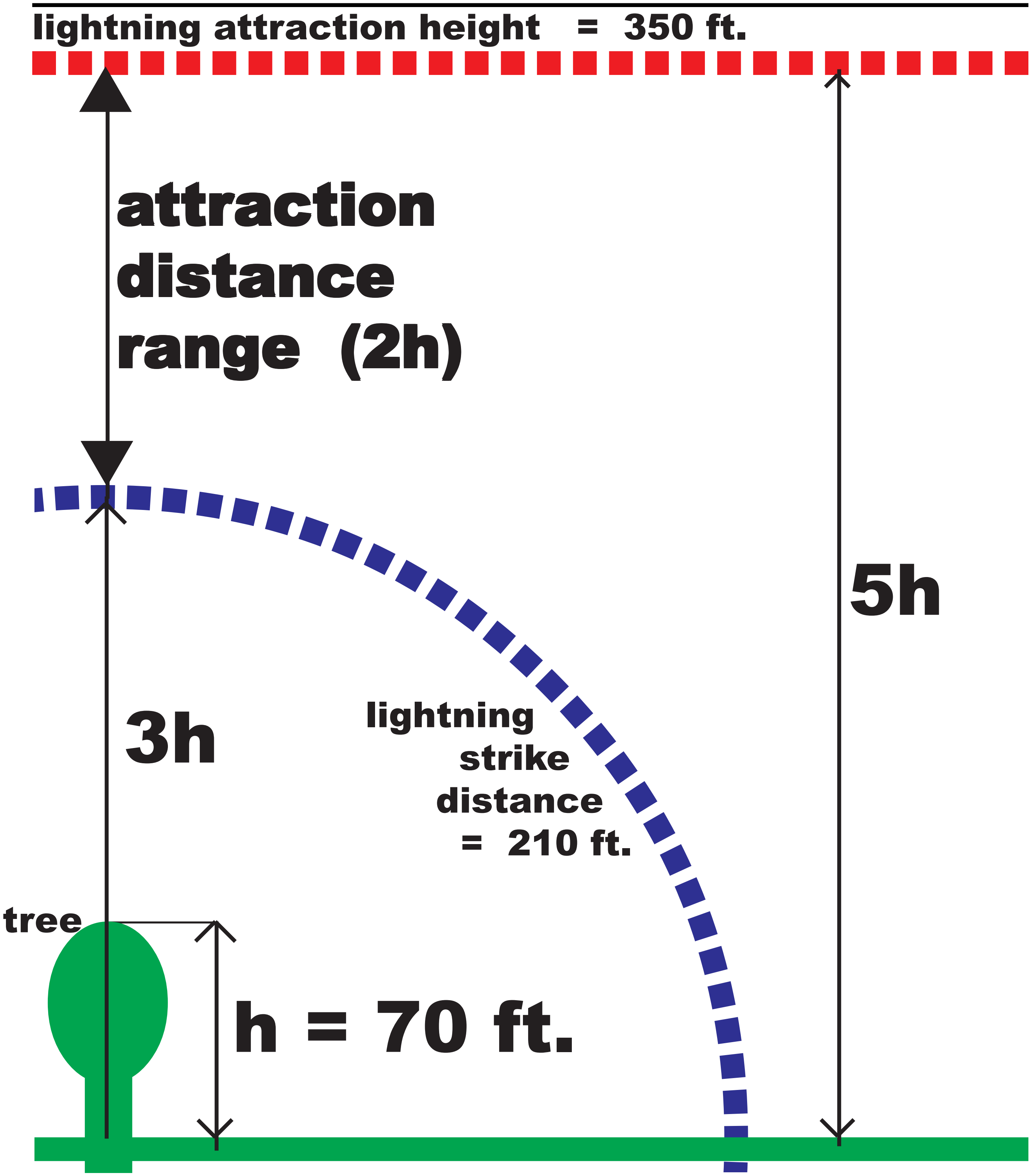


Figure 9: Example lightning attraction distance for a single isolated tree using the equidistance method based upon a tree height (h) of 70 feet.

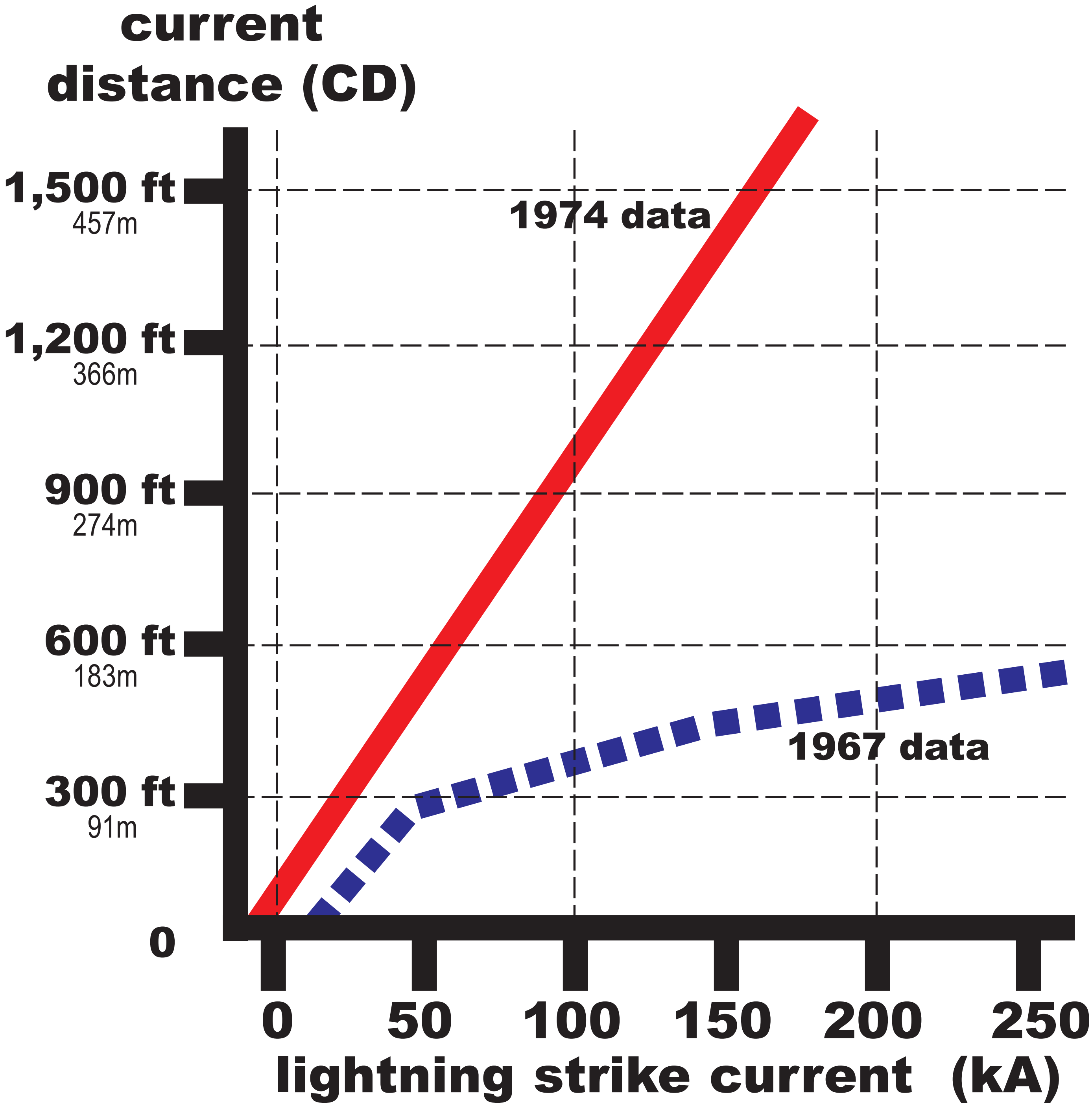


Figure 10: Estimating current distance (CD) in feet based upon lightning current (kA) from two different standard sources. Note current distance is highly variable depending upon the data base used and methodology employed.
(from Bazelyan & Raizer 2000.)

tree height (feet)	lightning strike current & analysis year					
	35kA		50kA		100kA	
	'74	'67	'74	'67	'74	'67
20	112	86	138	100	197	115
30	136	104	168	121	240	140
40	156	118	194	139	277	160
50	173	130	215	153	309	178
60	188	141	235	166	337	193
70	202	150	252	178	363	207
80	214	158	268	188	388	220
90	225	165	283	197	410	231
100	235	171	296	205	431	242
120	253	181	321	220	470	260
140	268	188	343	231	505	276ft

Figure 11: Estimated horizontal distance (in feet) away from a tree which the lightning strike distance extends for a tree of a given height at several lightning current values for both electromagnetic data sets ('74 & '67).

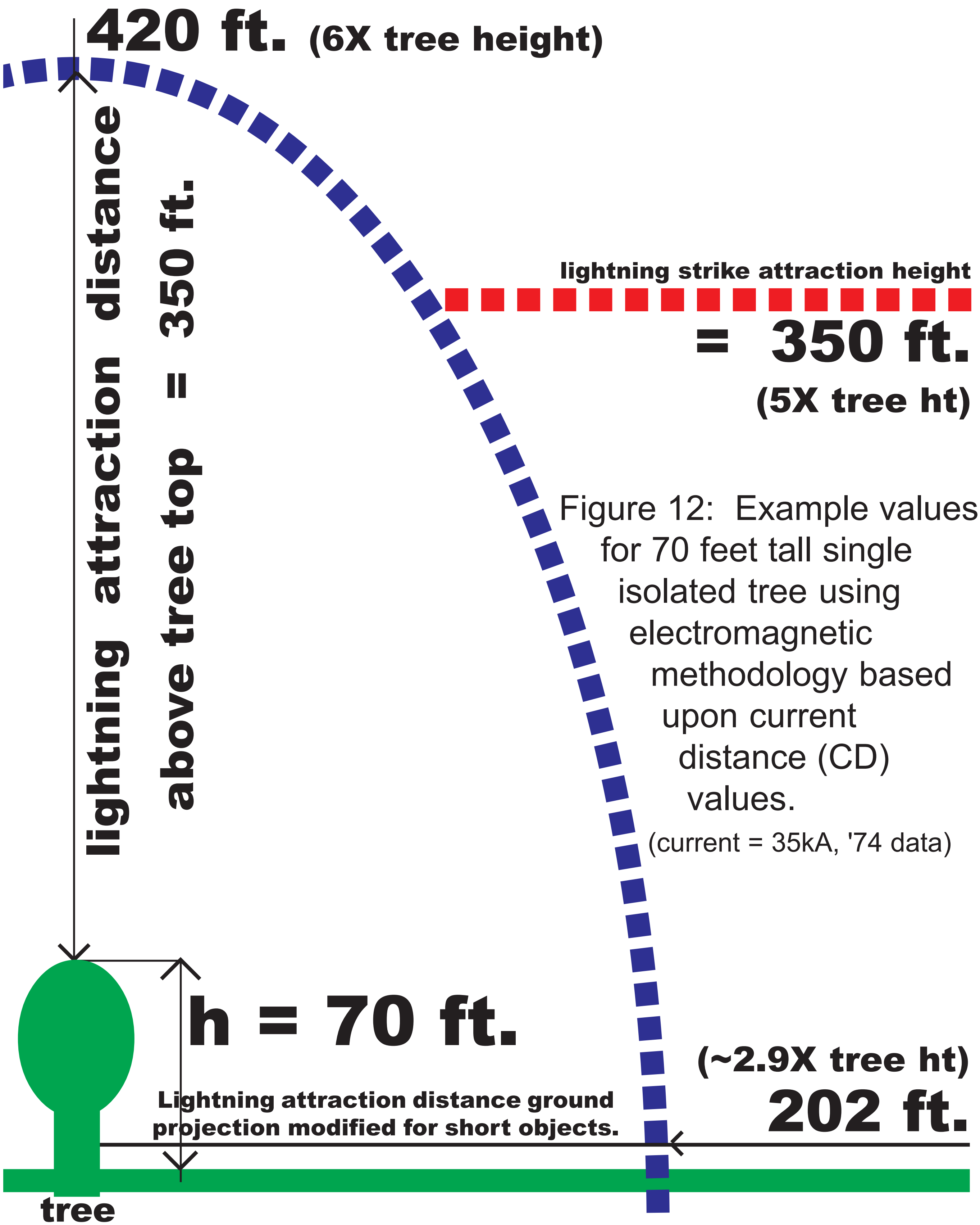


Figure 12: Example values for 70 feet tall single isolated tree using electromagnetic methodology based upon current distance (CD) values.
(current = 35kA, '74 data)

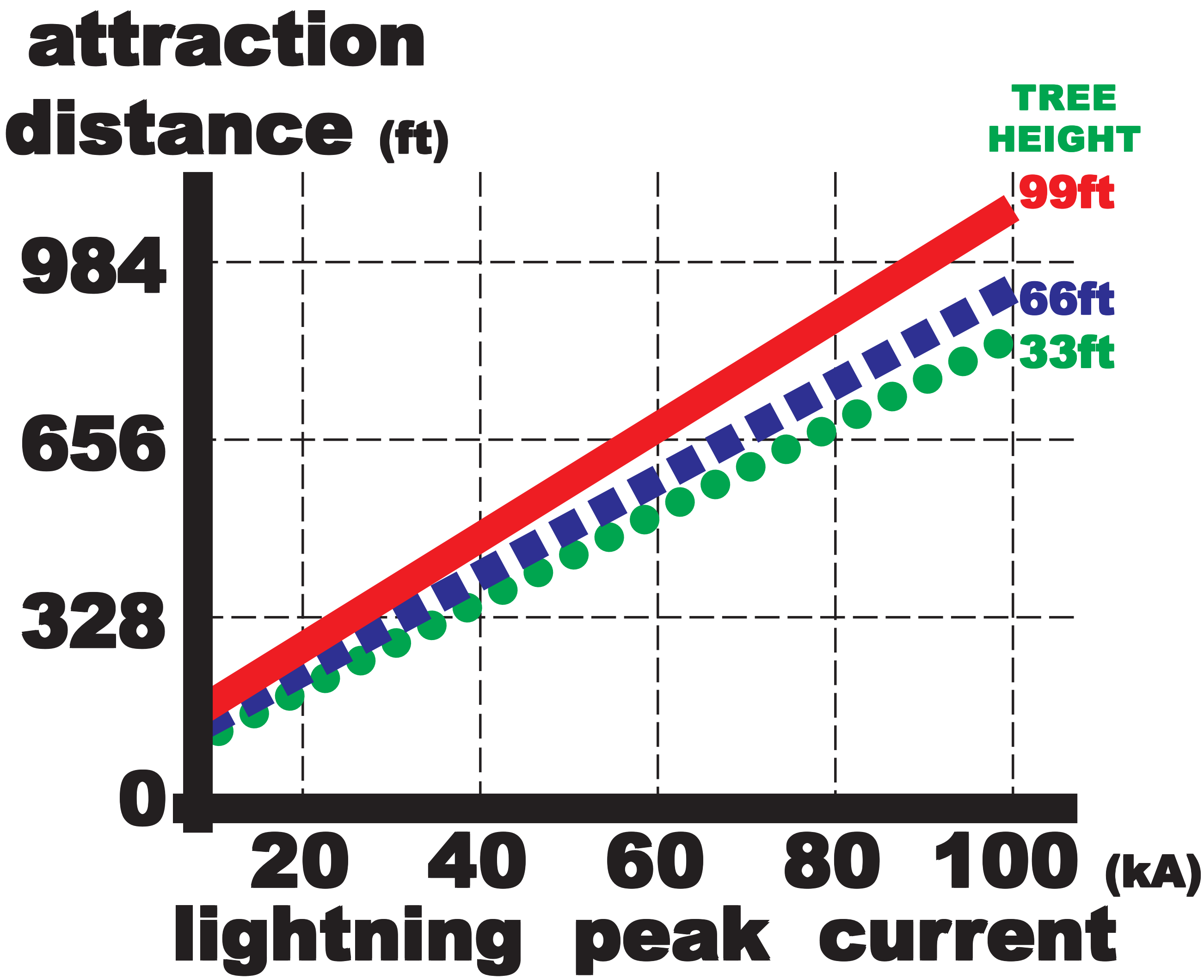


Figure 13: Attraction distance in feet for trees of different heights in feet under various peak currents. (Cooray 2012a)

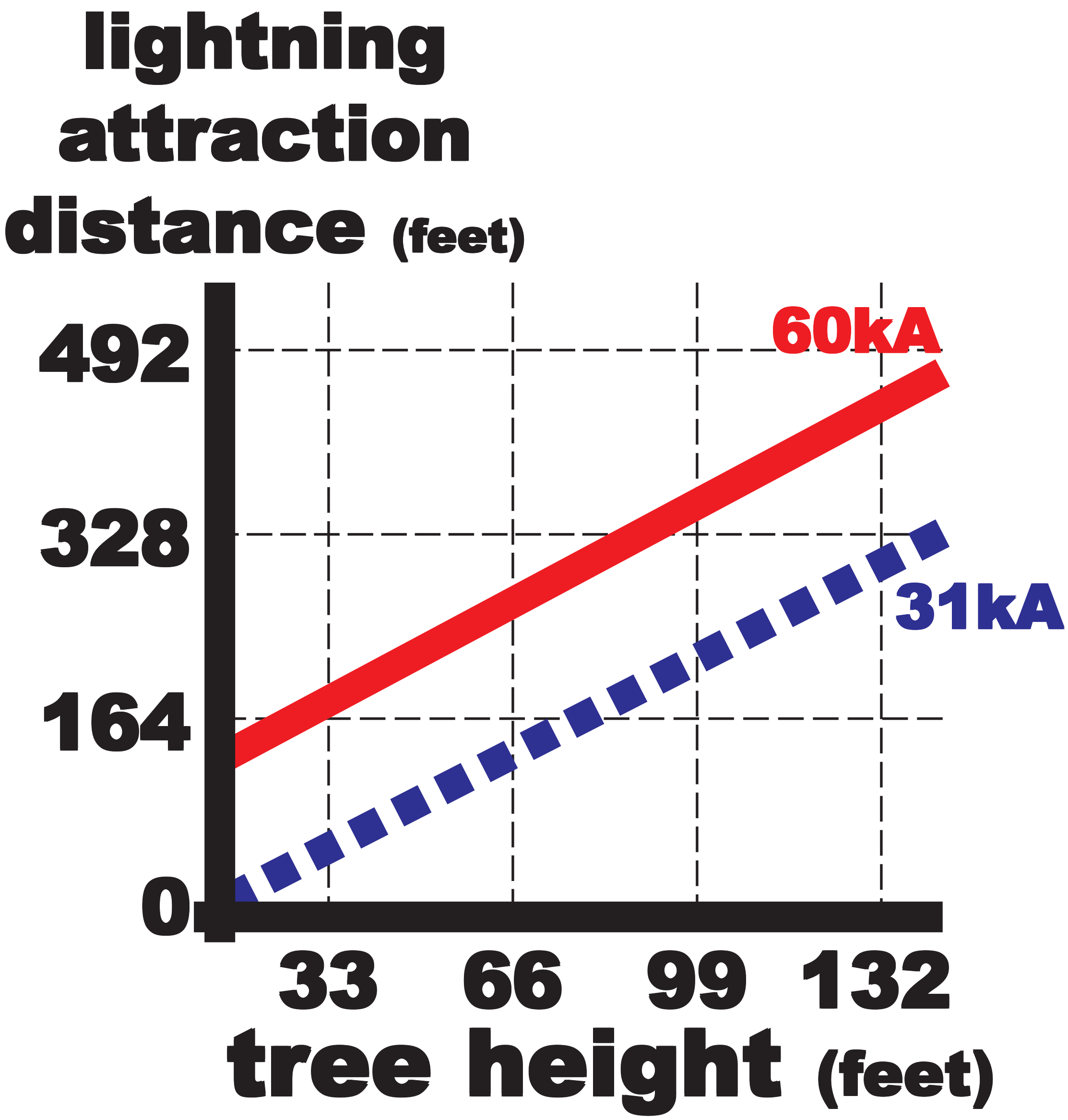


Figure 14: Lightning attraction distance for different tree heights at two peak currents. (Cooray & Becerra 2010)

Collection Area of Tree =

CA in square miles =

$$\frac{((\text{tree height}_{ft} \times Z) + \text{crown diameter}_{ft})^2}{35{,}514{,}000.}$$

Z = 4 (traditional value & trees <50ft)
Z = 6 (international standards & trees >50ft)

$$CA_{sq.mi.} \times N_{sq.mi.\ per\ year} =$$

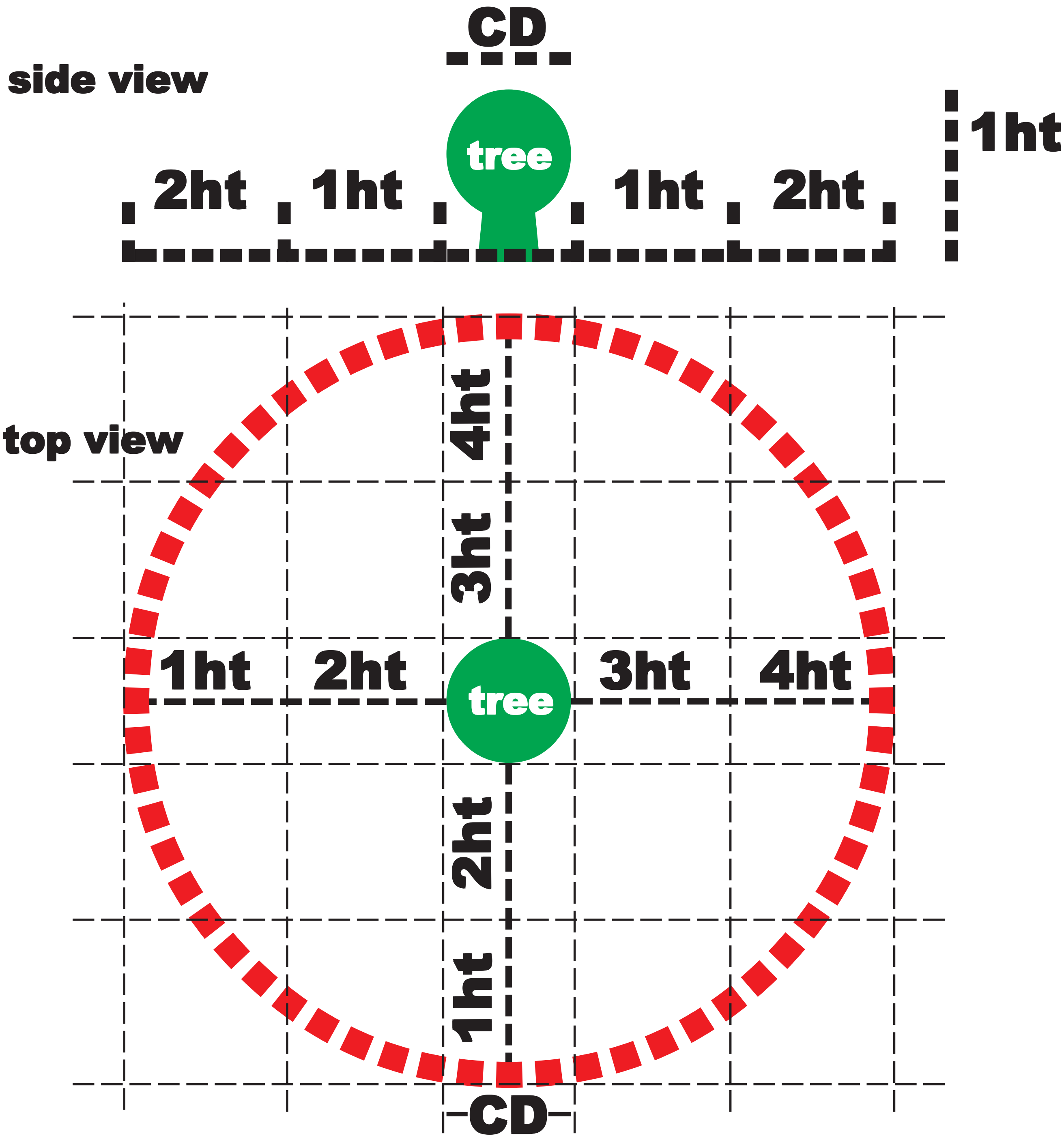
tree strikes per year.

N = annual number of lightning strikes per mile^2

1 / tree strikes per year =

years between tree strikes.

Figure 15: Tree collection area for calculating number of lightning strikes to trees of different heights.
(derived from Uman 2008)



$(4ht_{ft} + CD_{ft})^2$ / 35,514,000 = tree collection area$_{sq.\ miles}$

Figure 16: Diagram of tree collection area for determining number of lightning strikes to trees of different heights. Z = 4.

(derived from Uman 2008)

tree height (feet)	number of strikes per year	years between strikes
10	0.002	483
20	0.005	196
30	0.009	105
40	0.015	66
50	0.022	45
60	0.064	16
70	0.086	12
80	0.11	9
90	0.14	7
100	0.17	6
110	0.20	5
120	0.24	4

Figure 17: Tree lightning strikes determined by tree collection area for various tree heights using 15 annual lightning strikes per square mile and crown diameter of 30 feet.
(derived from Uman 2008)

tree height (feet)	years between strikes '74	'67
20	46	79
30	31	54
40	24	41
50	19	34
60	16	29
70	14	26
80	12	23
90	11	21
100	10	20
110	9	18
120	9	18
140	8	16 yrs

Figure 18: Estimated number of years between lightning strikes to a tree of a given height using two different data sets. (35kA average strike current & number of historic strikes per square mile per year of 15).