IS THE RISK OF A LIGHTNING CASUALTY ACTUALLY LESS IN AN OPEN FIELD THAN A FOREST?

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1. Introduction

The fundamental principle of lightning safety is '**NO** Place Outside Is Safe When Thunderstorms Are In The Area!' Lightning safety education should emphasize planning to avoid the threat and knowing when and where to go for safety. However, while no place outside is safe, some outside locations are riskier than others. While teaching lightning safety to the public, a frequent question has been whether an open field or a forest is safer from lightning. Common wisdom within the lightning safety community has been that a large dense forest is safer from lightning than a flat open field, since a direct lightning strike to a person is more likely in the field since the person would be the tallest object, i.e. the trees in a forest would be struck by lightning rather than the person. However, a direct lightning strike is only one of five mechanisms that cause lightning casualties and is the source of only a few percent of those casualties.

A model that considers all the lightning casualty mechanisms was developed previously to estimate the effectiveness of one procedure for no-notice personal backcountry lightning risk reduction. This model is now applied to estimate the effectiveness of that same procedure in a large dense forest. In addition, the previous model for a wide flat field is updated with the newest estimates of the relative contribution of lightning casualty mechanisms. The model suggests that given the same lightning rate, a wide flat field is slightly safer than a large dense forest, but the difference is not statistically significantly since the risk reduction lies just outside the inter-quartile error bars of each other, i.e. 53% $\pm$ 7% for a wide flat field and 65% $\pm$ 9 for a large dense forest. These percentages are relative to taking no action, so that lower numbers represent less risk.

This result is contrary to previous common wisdom. In addition, the model is admittedly simplistic with several assumptions and subjective estimates, but is the only method developed so far to objectively estimate outdoor lightning risk reduction and provides a reasonable first approximation. However, because of the assumptions and subjective estimates, further research is needed to verify these results.

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It should be reemphasized that any discussion of relative lightning risk of outdoor locations is risk reduction, not safety. Remember, **NO** Place Outside Is Safe When Thunderstorms Are In The Area! True lightning safety emphasizes scheduling outdoor activities to avoid thunderstorms and knowing when and where to go for lightning safety. Full details on lightning safety are available elsewhere (Roeder et al., 2011; Hodanish et al., 2008; Roeder, 2008a, 2007a; Holle et al., 1999).

2. No-Notice Personal Backcountry Lightning Risk Reduction

No-notice personal backcountry lightning risk reduction is a multi-step process. It is meant to be used only as a desperate last resort. If you have made one or more bad decisions and find yourself outdoors, unprepared, far from a safe place when thunderstorms are threatening, you should proceed quickly to the safest place you can find. Places of greatest risk from lightning include elevated places, open areas, tall isolated objects, and large bodies of water. The safest places from lightning are a large fully enclosed building with wiring and plumbing, and a vehicle with solid metal roof and solid metal sides. While on the way to the safest place you can find, if in a group, spread out with about 3 m between people so that if lightning strikes, at most only one person will likely be hurt and the rest can apply first aid. But people should be close enough so they can communicate verbally easily. That way one person can shout a pre-agreed warning if the sings of imminent lightning are detected. While on the way to the safest place available, watch for the signs that lightning may be about to strike: hair standing up, light metal objects vibrating, or a crackling static-like sound from the air. If any of those signs are detected, everyone should immediately use the lightning crouch. The lightning crouch consists of putting your feet together, squatting, tucking your head, and covering your ears. After about 10 seconds, slowly stand while looking for the signs that lightning may still be about to strike. If you can stand up, continue on to the safest place available. The lightning crouch is also commonly known as the 'lightning squat', the 'lightning desperation position', and other names. Procedures for when you reach the safest place are under consideration, perhaps incorporating that part of the guidance from Gookin (2010).

No-notice personal backcountry lightning risk reduction has been discussed extensively in the lightning safety community. The debate focused on what constitutes good lightning risk reduction, its effectiveness, and whether it should be taught. The consensus was it should no longer be taught to the general public for four reasons. First, it is not applicable in most situations since in over 90% of the cases a place safe from lightning was nearby—the emphasis should be on running to safety at the appropriate time. Second, the procedure is long and complicated and could be misremembered or misapplied long after the training, especially under the stress of an imminent lightning threat. Third, the size and complexity of the procedure takes limited training time away from other more effective lightning safety information. Fourth, people tend the fixate on outdoor risk reduction and any positive discussion might be used to justify staying outside longer than justified for true lightning safety. These reasons are summarized in Table-1.

It should be reemphasized that this no-notice personal backcountry lightning risk reduction procedures should only be used as a desperate last resort. You are much safer to plan ahead and avoid such situations.

TABLE 1.

Reasons not to teach no-notice personal backcountry outdoor lightning risk reduction to the general public. This risk reduction may still be worth teaching to groups that spend significant time far away from locations that provide lightning safety.

Weakness	Repercussion
Devastating consequences of lightning striking a person	Death or life-long debilitating injuries in many of the cases. Even a risk reduction of about half is not enough.
Fixation on lightning crouch	May lead people to ignore more effective lightning safety procedures.
Over confidence in effectiveness	May lead people to spend too much time under unsafe conditions.
Subtle distinction between outdoor lightning risk reduction and safety	Lightning crouch may undermine credibility of lightning safety training by appearing to contradict fundamental principle that 'no place outside is safe near a thunderstorm.'
Too complicated	People may misremember, especially under stress, such as when a lightning strike is imminent.
Too complicated	People may misapply, especially under stress, such as when a lightning strike is imminent.
Too complicated	Not cost effective to teach. Takes time away from more effective lightning safety training.
Relatively few lightning casualties in remote locations away from safe place	Not cost-effective to teach. Training time better spent on lightning safety procedures with more impact.

3. Lightning Risk Reduction In A Flat Open Field As Compared To A Forest

A simple model to evaluate the effectiveness of one procedure of no-notice personal backcountry lightning risk reduction was developed previously (Roeder, 2008b, 2007b). This model is updated here to include the most recent estimate of the relative contribution of the five lightning casualty mechanisms, which are listed in Table-2) (Cooper and Holle, 2010). The previous percentage contributions of the lightning casualties are at Cooper et al. (2008, 2007, 2006). The risk reduction of the procedure is estimated for each mechanism, weighted by that mechanism's percentage of all casualties, and summed to give the total risk reduction relative to performing no risk reduction.

3.1 Flat Open Field

This model was previously applied to a flat open field. The calculated risk was 47% $\pm$ 7% of taking no protective action, i.e. a risk reduction of 53% (Roeder, 2008b). The error bars are an inter-quartile range, i.e. a fifty percentile confidence interval. The details of this calculation are in Table-3. While this risk reduction may sound significant, it is still too risky to be relied upon, given the devastating impacts lightning.

TABLE 2.

The lightning casualty mechanisms and the percentage of lightning casualties due to them. These are based on the most recent updated estimates (Cooper and Holle, 2010).

Casualty Mechanism	Range of Percentage Of Casualties (%) (Cooper and Holle, 2010)	Mean Percentage of Casualties (%)	Scaled Mean (%) (scaled to sum to 100%)
Direct Strike	3-5	4.0	3.8
Contact Voltage	3-5	4.0	3.8
Side Flash	30-35	32.5	30.8
Step Voltage/ Ground Streamer	50-55	52.5	49.8
Upward Leader	10-15	12.5	11.8

TABLE 3.

Estimated risk of lightning casualty in a **wide flat field** using no-notice personal backcountry lightning risk reduction procedures. The total risk is 53% of taking no action, i.e. a 47% reduction of risk.

Lightning Casualty Mechanism	**Percent Of Lightning Casualties Of Average Behavior**	**Estimated Relative Risk If Using Last Minute Outdoor Lightning Risk Reduction** (lower = less risk)	**Estimated Casualty Rate Vs. Average Behavior** (%-casualties x relative risk)
Direct Strike	3.8%	76% (87.9% to 64.2%)*	2.9% (3.3% to 2.4%)*
Contact Voltage	3.8%	0% (0 to 0)*	0% (0% to 0%)*
Side Flash	30.8%	0% (0 to 0)*	0% (0% to 0%)*
Step Voltage/ Ground Streamer	49.8%	83% (91.3% to 74.7%)*	41.3% (45.5% to 37.2%)*
Upward Leader	11.8%	76% (87.9% to 64.1)*	9.0% (10.4% to 7.6%)*
			SUM = 53.2% (59.2% to 47.2%)* $\cong$ 53% $\pm$ 6%

* The risk depends on how frequently the signs that imminent lighting are perceived with sufficient lead-time. The number before the parentheses is the best estimate, assuming that half of the events will have adequate lightning precursors. The first number in the parenthesis is a first quartile estimate that assumes lightning precursors are perceived only 25% of the time, halfway from the best estimate to the extreme case that lightning precursors are never perceived. The second number in the parenthesis is a third quartile estimate that assumes lightning precursors are perceived 75% of the time, halfway from the best estimate to the extreme that lightning precursors are always perceived. The perception of lightning precursors does not apply to the 'contact voltage' and 'side flash' mechanisms in a large flat open field with the recommended risk reduction procedure in section-2. The sum of errors is assumed to add linearly, rather than the more likely RMS addition, to provide a conservative estimate of the total error and to help allow for other sources of error not accounted for here. Additional error from the uncertainty of the relative contributions of the various lightning casualties is considered in section-3.3.

3.2 Large Dense Forest

The model is now applied to a large dense forest using the no-notice personal lightning risk reduction procedure discussed in section-2. The risk reduction for the five lightning casualties is calculated below. Using the risk reduction in a large dense forest reduces the risk to 48% $\pm$ 5% of the risk of doing nothing. The calculation is summarized in Table-4.

3.2.1 Direct Strike

As its name implies, a direct strike is a casualty caused by the lightning striking a person directly. Although this is usually the casualty mechanism most people envision, it is actually the cause of only about 4% of all lightning casualties, i.e. the other lightning casualty mechanisms are much more important that direct strike (Table-1).

The height and density of trees is assumed to be large enough that the chance of a direct strike to a person is zero, i.e. the lightning will strike the taller closely packed trees before striking the person. This is less chance of a casualty than in a flat open field. However, the key point is that the risk of a direct strike is inherently low and so any reduction in the chance of a direct strike ultimately makes little difference in the total risk of a lightning casualty, i.e. the other lightning casualty mechanisms are more important than a direct strike.

TABLE 4.

Estimated risk of lightning casualty in a **large dense forest** no-notice personal backcountry lightning risk reduction procedures. The total risk is 65% of taking no action, i.e. a 35% reduction of risk.

Lightning Casualty Mechanism	**Percent Of Lightning Casualties Of Average Behavior** (Cooper and Holle, 2010)	**Estimated Relative Risk If Using Last Minute Outdoor Lightning Risk Reduction** (lower = less risk)	**Estimated Casualty Rate Vs. Average Behavior** (%-casualties x relative risk)
Direct Strike	3.8%	0% (0% to 0%)*	0% (0% to 0%)*
Contact Voltage	3.8%	0% (0% to 0%)*	0% (0.0% to 0%)*
Side Flash	30.8%	78% (89.0% to 67.0%)*	24.0% (27.4% to 20.6%)*
Step Voltage/ Ground Streamer	49.8%	83% (91.5% to 74.85%)*	41.3% (45.6% to 37.1%)*
Upward Leader	11.8%	0% (0% to 0%)*	0% (0% to 0%)*
			SUM = 65.3% (73.0% to 57.7%)* ≅ 65% ± 8%

* The risk depends on how frequently the signs that imminent lighting are perceived with sufficient lead-time. The number before the parentheses is the best estimate, assuming that half of the events will have adequate lightning precursors. The first number in the parenthesis is a first quartile estimate that assumes lightning precursors are perceived only 25% of the time, halfway from the best estimate to the extreme case that lightning precursors are never perceived. The second number in the parenthesis is a third quartile estimate that assumes lightning precursors are perceived 75% of the time, halfway from the best estimate to the extreme that lightning precursors are always perceived. The perception of lightning precursors applies only to the 'step voltage/ground streamer' mechanism in a large dense forest and the recommended risk reduction procedure in section-2. Additional error from the uncertainty of the relative contributions of the various lightning casualties is considered in section-3.3.

3.2.2 Contact Voltage

A contact voltage casualty is caused by a person being in direct contact with an object struck by lightning. Although the lightning doesn't strike the person directly, part of the lightning current is diverted into the person, especially if they have a lower electrical impedance than the object being struck directly. About 4% of all lightning casualties are due to contact voltage.

The risk reduction procedure would normally keep a person as far away from trees as possible when thunderstorms are in the area. Even in a dense forest, one should be able to avoid touching trees directly. Therefore, the chance of a contact voltage is assumed to be zero in this calculation. This is the same as in a flat open field, where it is even easier to avoid a contact voltage casualty.

3.2.3 Side Flash

A side flash is caused by a person being close enough to an object struck by lightning so that some of the lightning arcs sideways to the person. About 31% of all lightning casualties are due to side flash.

The risk reduction procedure requires one to stay away from tall objects. However, in a dense forest, it may not be possible to stay far enough away from the trees to avoid the risk of side flash, especially while one is rushing to the safest place available. The distance side flash can travel through air varies with the peak current of the lightning but has an upper limit of about 3 m.

However, one can also reduce the risk of side flash by using the lightning crouch since reducing your height reduces the chance of a side flash. In calculating the effectiveness of the lightning crouch in an open flat field, the assumption was made that an average standing person was 1.8 tall and a crouching person is typically 0.8 m. Since the crouched height is 56% of the standing height, the risk of side flash compared to standing is assumed to be the roughly same percentage.

However, this assumes that people detect the indications of an imminent strike a few seconds before the lightning strikes and use the lightning crouch. The frequency with which these indications are occur and occur with enough lead-time is not known. In lieu of any information, a frequency of 50% is assumed to minimize the likely error. A frequency weighted average yields the overall risk reduction for side flash in a large dense forest. Half the time the lightning precursors are perceived in time and the risk is abut 56% of not taking action and half the time the precursors are not perceived and no risk reduction is achieved. The overall risk reduction is then 78% of taking no action. The inter-quartile error bars from the uncertainty is perceiving the lightning precursors can be estimated by using weighted averages with different frequencies. The lower-quartile error bar assumes the precursors are perceived with enough lead-time in 75% of the cases and not perceived in 25% of the cases. The upper quartile error bar reverses those percentages. As a result, the inter-quartile error bars for side flash due to perception lightning precursors is 20.6% and 27.4%.

3.2.4 Step Voltage/Ground Streamer

The return stroke in cloud-to-ground lightning can cause casualties through a step voltage or ground streamer. As the return stroke occurs, a strong voltage gradient is created along the ground. If a person is standing near the return stroke, there can be enough voltage between the feet to drive enough electric current across the body to cause a casualty. Since the amount of current is determined in part by the distance between the feet, this is called a step voltage. In some cases, the voltage gradient from the return stroke is so strong that it causes electrical arcs across the ground, which are called ground streamers. The step voltage and ground streamers can cause casualties up to a few tens of meters from the return stroke. Step voltage and ground streamer account for about 50% of lighting casualties.

The lightning crouch reduces the chance of a casualty from step voltages by reducing the distance between the feet. It also reduces the chance of a casualty from a ground streamer by reducing the area touching the ground. The risk reduction from step voltage and ground streamer is the same for a forest and a flat open field.

3.2.5 Upward Leader

The fifth and final source of lightning casualty is upward streamer. Upward leaders account for about 12% of lightning casualties. As with direct stroke, the chance of a person inducing an upward leader while standing in a dense forest is zero.

3.3 Error Estimate

The error bars due to the uncertainty in people perceiving the precursors of imminent lightning were calculated for a wide flat field and a large dense forest in Table-3 and Table-4, respectively, and repeated below in Table-5. A second source of error is the relative frequency of lightning casualties resulting from the lightning mechanisms. An inter-quartile variation is calculated for both sources of error, i.e. a 50 percentile confidence interval centered on the best estimate. Since the two sources of error are independent, the total inter-quartile error is calculated by orthogonal vector addition, i.e. the root sum of the squares of the two errors. These results are summarized in Table-5.

TABLE 5.

Error estimates of no-notice personal backcountry lightning risk reduction for a flat open field and a large dense forest. All the error estimates are inter-quartile ranges.

Source Of Error	Flat Open Field	Large Dense Forest
Frequency that lightning precursors are observed with enough lead-time to take action	±6% (from Table-3)	±8% (from Table-4)
Uncertainty in the relative frequency of lightning casualties from each lightning casualty mechanism	±3%	±3%
Total Error (root sum of squares of two errors above)	**7%**	**9%**

4. Future Work

There is considerable uncertainty in the analysis of the effectiveness of last minute outdoor lightning risk reduction. The estimate of how frequently the precursors to a lightning strike occur in the few seconds before the strike and are observed by people in time to take action is especially uncertain. The relative contribution of the five lightning casualty mechanisms to the total casualty rate is also not well known. Therefore, the estimate of the risk reduction from the last minute personal backcountry lightning risk reduction is only a rough approximation. All these estimates need to be refined.

Other future work could include comparison of the lightning risk reduction in a wide flat field and a large dense forest when no lightning risk reduction is done. This may yield the counter-intuitive result that the wide flat field is actually less risky in the absence of lightning risk reduction is done. Also, the no-notice personal backcountry risk reduction procedure should be varied in the risk reduction model. In particular, the model should be run without the lightning crouch in the model. The details of the calculations suggest that the lightning crouch contributes relatively little to the overall reduction in risk. If the model with the modified procedures confirms this suggestion, then the recommended procedure might be modified to remove the lightning crouch since a simpler procedure should be easier to teach and easier to remember and apply.

Another project for the future is to apply the risk reduction analysis to locations other than a flat open field and a large dense forest, e.g. mountains above and below the tree line, small stand of trees, uneven terrain, small groups of people versus just individuals, etc.

Finally, the estimate of frequency of lightning casualties that were near a safe location should be refined since that is one of the key arguments in recommending last minute outdoor lightning risk reduction not be taught to the general public.

These topics and other research required to improve lightning safety are listed at Roeder (2009a, 2009b). This list has been significantly updated and is available from the author (william.roeder@patrick.af.mil).

5. Summary

The model to evaluate the effectiveness of no-notice personal backcountry lightning risk reduction has been applied to a large dense forest. Previously, the model had been applied only to an open flat field. The model indicates that the a wide flat field is slightly less risky than a large dense forest when using he recommended risk reduction procedure, but the difference is not statistically significant (Table-6).

The risk reduction as compared to taking no action is 53% ± 7% for a wide open field and 65% ± 7% for a large dense forest, where lower numbers indicate less risk. While a wide flat field appears to be slightly less risky than a large dense forest, the risk reductions are just outside the inter-quartile error bars of each other. Thus the differences are not statistically significantly different when using the recommended risk reduction procedure. This result is contrary to previous common wisdom within the lightning safety community so further research should be conducted to confirm these results.

Once again, the fundamental principle of lightning safety should be repeated—'**NO** Place Outdoors Is Safe When Thunderstorms Are In The Area!' The no-notice personal backcountry risk reduction procedure does not provide lightning safety, only risk reduction, and should be taught only to people that spend large amounts of time far away from safe places from lightning.

Table 6.

Risk reduction from a lightning casualty for a wide flat field and a large dense forest while using the no notice personal backcountry lightning risk reduction procedure in section-2 as compared to using no risk reduction. A lower number indicates less risk.

Location	Risk Using Risk Reduction
Wide Flat Field	53% ± 7%
Large Dense Forest	65% ± 9%

6. Acknowledgements

The risk reduction from a direct lightning strike from using the lightning crouch versus standing upright in a wide flat field was provided by Dr. Mata of ASRC Aerospace, Inc. at NASA Kennedy Space Center. He used a Monte Carlo model that simulates 1,000 years of lightning strikes, varying the lightning strike distances based on the climatological distribution of peak currents for negative and positive polarity cloud-to-ground lightning and the relative frequency of those lightning polarities (Mata and Rokov, 2008).

7. Disclaimer

This paper is presented for informational purposes only and no guarantee of lightning safety is stated or implied by the procedures.

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