Attachment of natural lightning flashes to trees: Preliminary statistical results

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Why study lightning attachment to trees?

- Much anecdotal information, but little systematic research.
- Trees preserve information on details of the attachment process.
- Economic: Forest fires, but also infrastructure damage.
  - Many of the collected cases resulted in damage to property
- Lightning protection
  - Role of trees can be significant, but has not been studied (to our knowledge).
- Ground truth for lightning detection networks
  - A. Mäkelä et al, COST 2009 symposium

What has been done earlier?

- Literature exists, but is scattered
  - Some published reports of individual cases, particularly ~1920’s
  - Laboratory studies (Darveniza 1980)
  - Large statistical study (Taylor 1964), over 1000 trees, no information on flashes
  - Biological and ecological studies
  - Research on lightning-caused forest fires (Larjavaara et al 2005)
- With one exception (Heidler et al 2005), no one has tried to correlate flash and/or meteorological characteristics with damage

- Bias towards severe damage: Minor damage not reported; damageless flashes will not get reported at all

Methodology in 2007 (2008 Internet-based only)

- Identify probable strike points in real time, send observers quickly to see what damage has been caused
  - High-accuracy location needed (uncertainty ideally < 200 meters); Large, geographically dispersed set of competent volunteers; Standardized set of questions

- Finland especially suited for such a study
  - Well-established lightning detection network; Huge forests but good roads; Very few types of trees; Lightning storms are rare and mild enough that flash-by-flash correlation is possible.

- Observers found trees 3-72 hours after the flash; high probability that the correct flash had been identified.

- Only used in 2007, as workload inhumane (3% of searches got results)

Classification of data

- Based on work of Taylor 1964, three quite clear types of damage expected for evergreens:
  - **Bark-loss:** strips of bark torn off (current path along cambium)
  - **Wood-loss:** wood torn off in addition to bark (current path has inside tree)
  - **Explosive:** Whole tree splinters (current path?)
  - (Also burning: leading to a forest fire. Not observed in this study)
  - (Also nil: known that sometimes no damage at all is caused, but nothing known about probability. Only 3% of searchers found damaged trees).

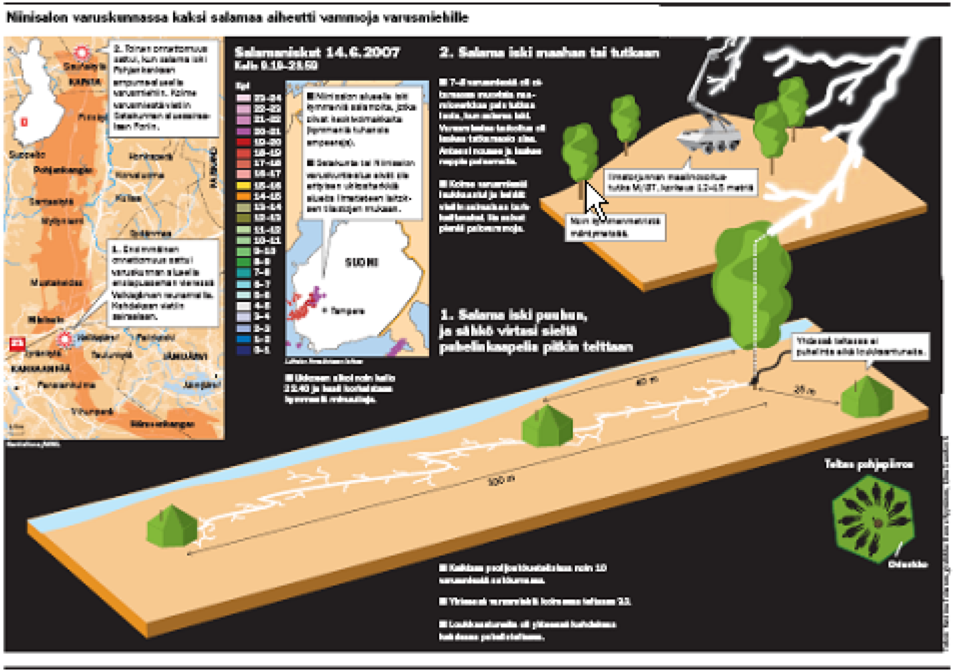
- For deciduous trees, same classifications used
  - “Most typical” damage is scattered bark loss, classified as bark-loss

Classical bark loss on pine tree

+11 kA x 1, Sandy forest, dry ground, creek

Caused minor injuries to a group of soldiers

Source: Satakunnan Kansa (newspaper)



Larch

-51 kA kA x 1,

rain-saturated,

caused furrow

Source:

Eero Karvinen

Bark-loss on birch

Wood loss on fir tree

-13kA x1, ground saturated

Source: Matti Mäkelä

Explosive

-12 kA x 2, sandy and dry ground

Source: Mats Kommonen

Multiple-damage case (not in statistics)

Photographed flash, no damage

Photographed with luck

<u>No damage at all to the tree.</u>

Cable TV interrupted

Flash: -6kA x 1,

15 mm/24 , ground saturated

multiplicity 1

Rain: 15mm/24h, ground saturated

Surroundings: Higher buildings nearby

Source: Niklas Montonen

Photographed flash, bark-loss damage

Source: Antti Tiihonen

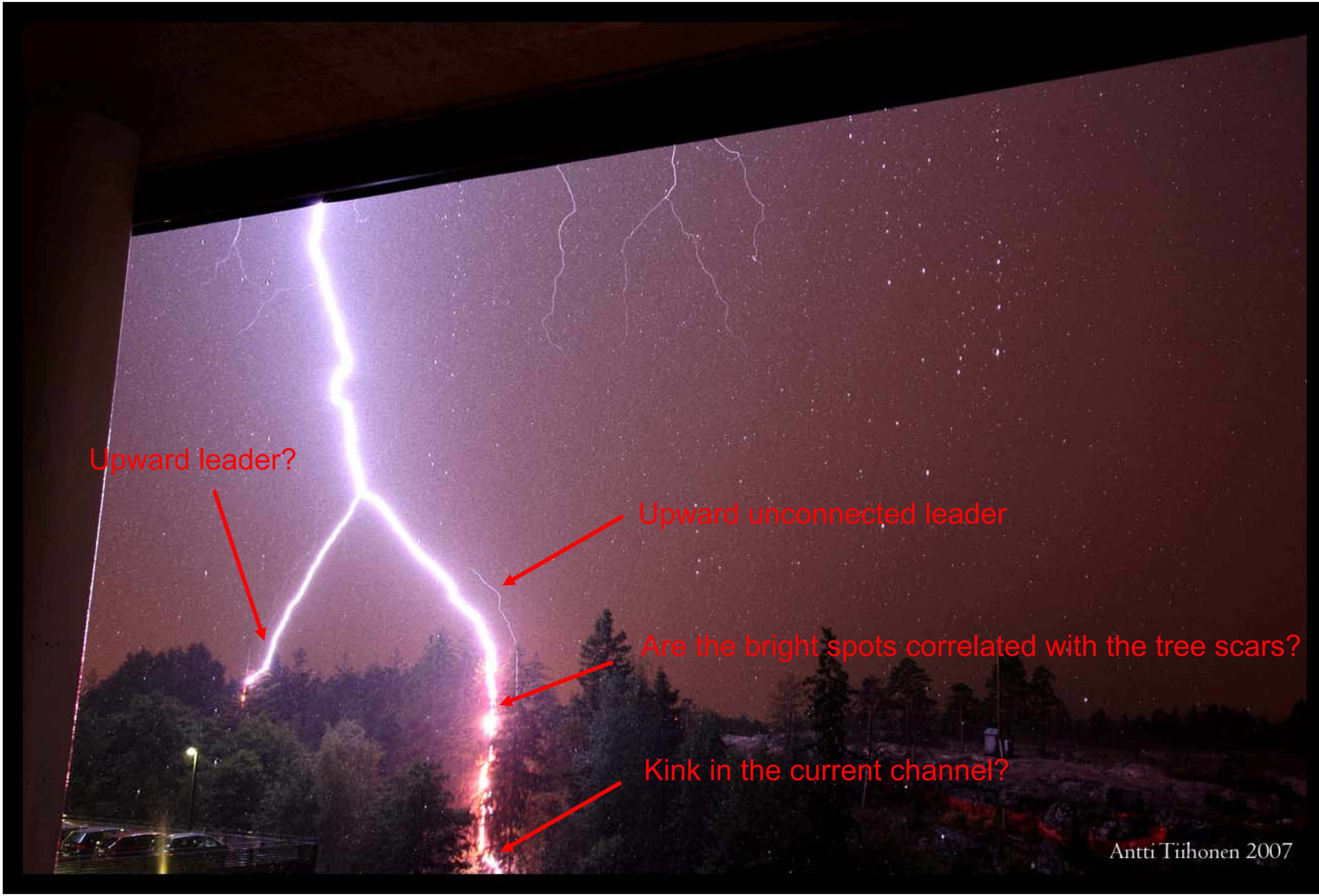
Bark-loss damage to tree

Flash: -13kA, multiplicity 3

Rain: 15mm/24h, ground saturated

Terrain: soil

Surroundings: Higher buildings nearby; hit tree was not the highest



Bark-loss damage from previous flash

- Minor bark-loss damage very high in tree.
- No visible damage to the tree with unconnected leader

Data collection

- Several parameters evaluated qualitatively by observers and from photographs
  - Tree quality; height of tree compared to surroundings; terrain type
  - Tried to identify the complete current path from upward attachment point to electrical ground; Ideal electrical ground assumed to be groundwater
- Flash parameters from FMI IMPACT network
  - Location and time had to correspond with observer notes; only those cases chosen where a single flash can be identified to be the almost certain cause. This is only possible because of low flash rate in Finnish storms
  - Peak current, multiplicity, uncertainty recorded
- Rainfall data from FMI radar data
  - 3hr and 24 hr rainfall estimated

Data set

- Total of 37 trees, summers 2007&2008 (ongoing 2009)
- Damage types:
  - 1 (2%)no damage, hit known from photograph
  - 17 (45%) bark-loss
  - 11 (30%) wood-loss
  - 8 (21%) explosive

- Observer effect overestimates dramatic cases
  - Taylor (1964): less than 10% wood-loss/explosive
  - Here: Almost all wood-loss and explosive observations are from 2008, when data collected by Internet (over-reporting of dramatic cases)

Year	Nil	Bark	Wood	Explosive	Anomalous	Multi-tree
2007	1	9	4	1	10	--
2008	--	8	7	7	--	4
TOTAL	1	17	11	8	10	4

Hypothesis testing

- To allow quantitative analysis, a number of falsifiable hypotheses defined
  - Most important hypotheses presented here
- Damage type quantified
  - 0=nil, 1=barkloss, 2=woodloss, 3=explosive
- Completely quantitative analysis possible for some parameters
  - Flash parameters, rainfall data
- Subjective estimates from photos needed in some cases
- Even if 2007-8 data cannot prove some of these hypotheses, they are the basis for future work

“The highest trees are most likely to be struck”: Inconclusive, but may not be true

- Multiple cases in which e.g. higher buildings next to trees were not struck
- Quantification extremely difficult from photographs and observations
- Must leave this open for now, but will focus in future data collection

“Ground moisture affects damage”: True, with moistness protecting tree

- Quantitatively extremely clear
- Wood-loss and explosive cases almost exclusively on dry ground
- Intuitively understandable: wet surface means current most likely to pass along surface.
- But not completely clear why it would then pass through the cambium at all!
- Modeling needed to understand this

Damage type	3-hour rainfall (mm)	24-hour rainfall (mm)
Nil	15.0	15.0
Bark-loss	7.4	11.2
Wood-loss	5.0	8.9
Explosive	1.5	2.5
Average	**5.6**	**8.7**

“Closeness of ground water affects damage”: Inconclusive

- Whole path from tree to electrical ground should be followed
- Hypothesis: if current has a high-conductivity path all the way to the ground, it should affect the tree minimally
    - A well-grounded lightning conductor leaves no trace on tree
- Groundwater is the ultimate electrical ground, so any structure nearby that is close to groundwater should protect tree (creek, river, pond)
- Present data set too small to falsify or support the hypothesis

“Poor-quality trees are more likely to be destroyed”: True

- Had to rely on subjective estimates and photos.
  - +1 if tree old, -1 if young, 0 if undetermined
  - 0.34 correlation with damage
- Stronger evidence: All explosive cases involved trees which were very large (old) or decayed

“Positive currents cause more damage”: Indirectly supported

- Data set too small to prove this directly
- However, 28% of the damage-causing flashes positive
- Average ratio of positives in Finland is 16% (Tuomi&Mäkelä 2007)
- Thus, positive flashes over-represented

“High peak current causes large damage”: Supported
“High multiplicity causes large damage”: Not supported

- Absolute value of peak current had 0.45 correlation with damage
- Explosive cases had higher peak currents (over 30 kA).
- Multiplicity (as measured by NORDLIS) had no effect

	Number of flashes	Positive flashes	Mean positive current	Negative flashes	Mean negative current	Mean multiplicity
Bark-loss	17	5	+22 kA	12	-16 kA	1.4
Wood-loss	11	1	+19kA	10	-20 kA	2.6
Exposive	8	4	+37 kA	4	-32 kA	1.5
Average	**36**	**10**	**+28 kA**	**26**	**-20 kA**	**1.5**

Conclusions

- Tree damage correlates with some remotely measurable parameters

- Somewhat unexpectedly, rainfall is very good predictor of damage
    - (Dry ground -> high damage)

- Flash parameters are less consistently correlated
    - Extreme damage associated with large peak currents (positive or negative)

- Tree characteristics affect at least probability of extreme damage

- The surroundings of the tree also affect the results, but quantitative analysis not possible with this data set yet
    - Similar to forest fires: the flash is just a “spark”, and fuel is what matters

Open questions

- Given that the tree characteristics are so dominant, will the tree recordings actually “preserve” any information on the flash as we hoped?
  - Microscale effects will be studied with an extended data set

- Should lightning attachment models be refined for variable conductivity?
  - Conductivity of trees has effect on damage and possibly strike probability

- Should lightning-protection schemes consider trees more explicitly?
  - In five cases, houses were theoretically protected but still suffered damage

Future steps

- The searches are by far the most valuable source of data, since they have less observer bias
  - However, effort too huge to be repeated soon (~100 m accuracy needed)
- Internet-based search will continue
  - Statistics will be improved, and microstructure studied
- Perhaps some of the three open questions will be attacked