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# SUB-MILLISECOND TIME DIFFERENCES BETWEEN LOCATED STROKES: OCCURRENCE AND EXAMPLES

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# Introduction (1/3)

- Lightning location system of FMI detects LF ground strokes (and VHF cloud discharges, not used here)
- Normal interstroke intervals of (mostly) negative flashes are tens of milliseconds
- A small percentage has intervals < 1 ms
- Sub-ms stroke pairs are often opposite polarity
- Two different types are found:

- long-separation (tens of km, or > 100 km)

- short-separation ( < 10 km )

# Introduction (2/3)

It is suspected that strokes separated by very short time interval involve

- pulses reflected by the ionosphere (generally known)

- return-stroke-induced pulses from leader branches other than the principal channel (Rakov & Uman 1994, JGR 99, p. 8157-)

- complex/distorted return strokes interpreted as two or more strokes

- preliminary/leader pulses interpreted as return strokes

- cloud-discharge pulses interpreted as (ground) strokes

# Introduction (3/3)

Lightning location data routinely collected by FMI will be compared with waveform recordings in another study

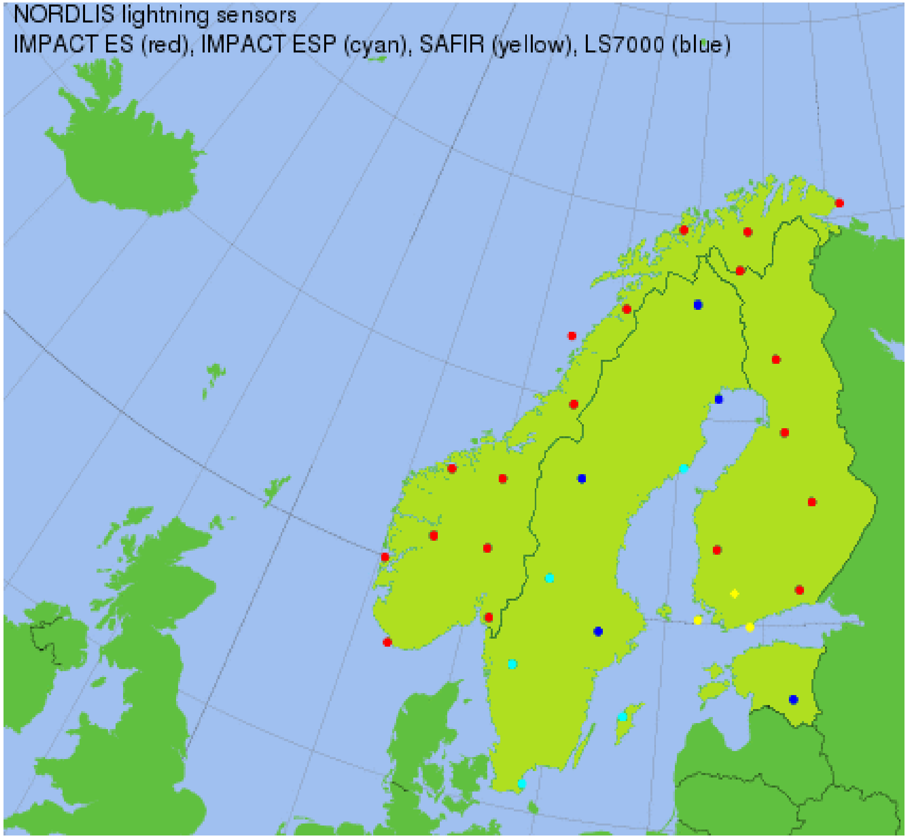
This study takes a look at the FMI data as such:

- how general is the occurrence of short interstroke intervals
- what is the spatial separation of paired strokes
- how the pairing depends on stroke polarity

Two cases are studied more closely

# Lightning location network in 2006

- Sharing LF sensors between N, S, FIN (NORDLIS cooperation)
- Also one LF sensor in EST and 3 LF+VHF SAFIR sensors in SW FIN
- 2006: improved rejection of weak positive strokes



# Effects of NORDLIS network

- Improved detection efficiency and location accuracy: about 30 LF sensors instead of the 5+3 basic ones in Finland
- Most LF sensors have 5 ms dead time; the newest, and SAFIR LF, are faster
- Due to large network and fast sensors, pulse pairs with time difference < 1 ms can be detected
- The question arises: Are these strokes real (ground strokes)? Is the network “too good”?

# Ground stroke intervals

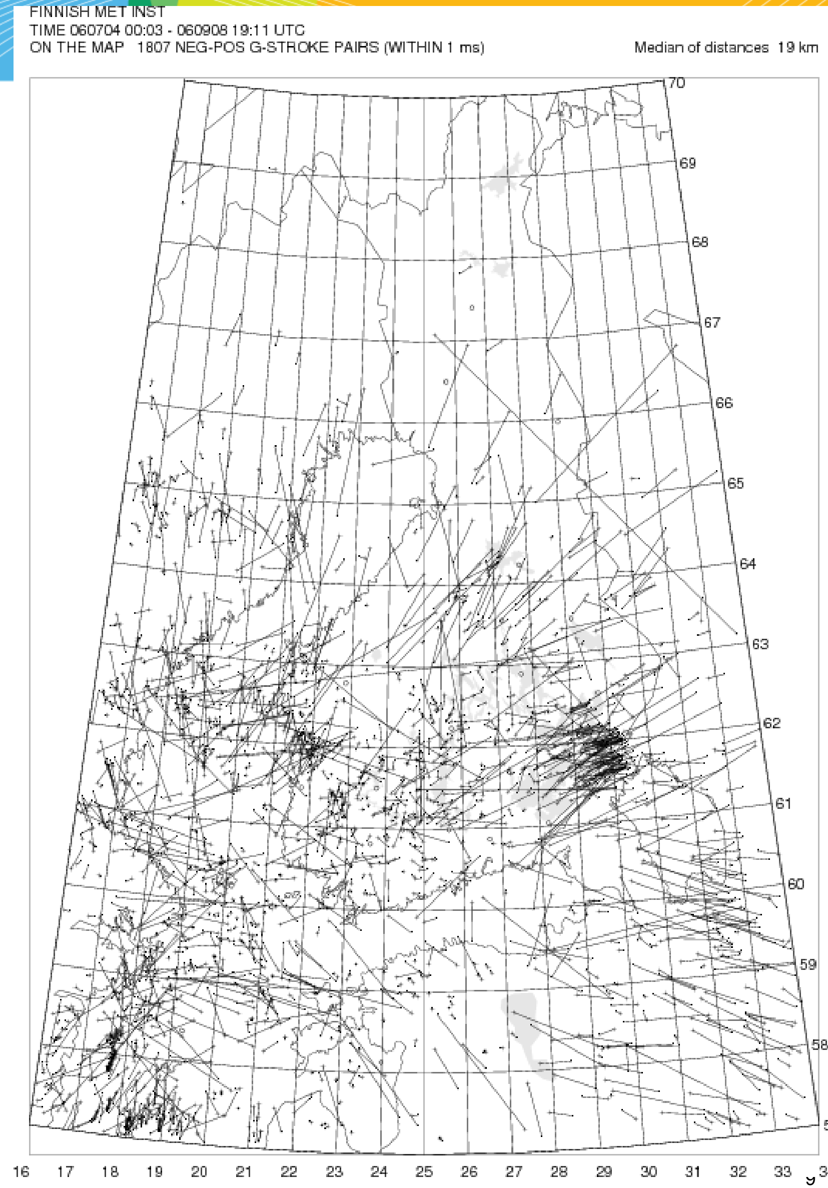
- In 2006, a representative data set (July-Sep) has 116,800 stroke pairs within 0-100 ms (in this time range, random coincidences from independent flashes should be rare)
- Most of them (108,700) normal neg-neg pairs; 3200 neg-pos, 3700 pos-neg, 1200 pos-pos

Subset of intervals 0-1 ms contains:

- 1800 bipolar pairs (neg-pos 1200, pos-neg 600)
- 1400 neg-neg pairs
- 156 pos-pos pairs
- The spatial separations are shown in the following figures

# Neg-pos and pos-neg pairs (0-1 ms):

- separation median 19 km
- long radial separations in the east
- more random long separations in the west
- east cluster Aug. 15-16 (moderate east-west separations)
- short random separations in centre



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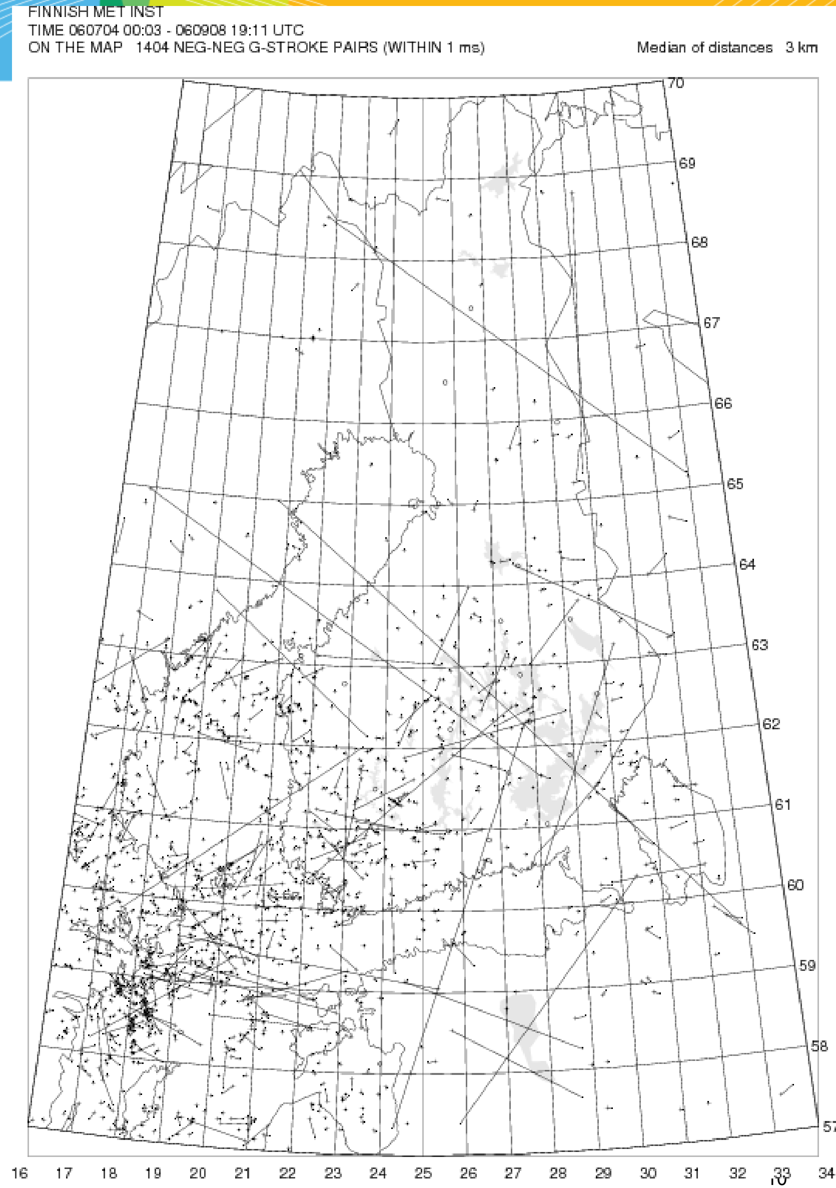
# Neg-neg pairs: random, mostly short

The few very long separations are probably incidental



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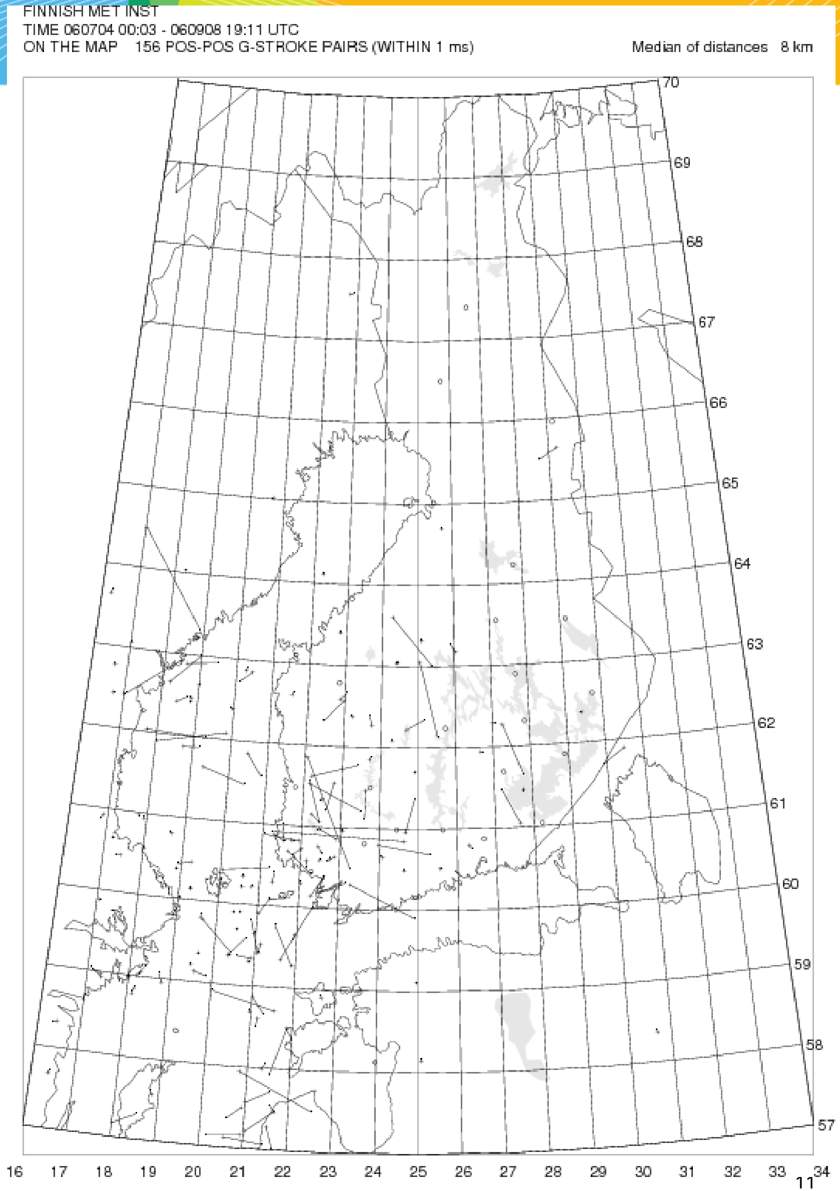
Pos-pos pairs:
rare and random

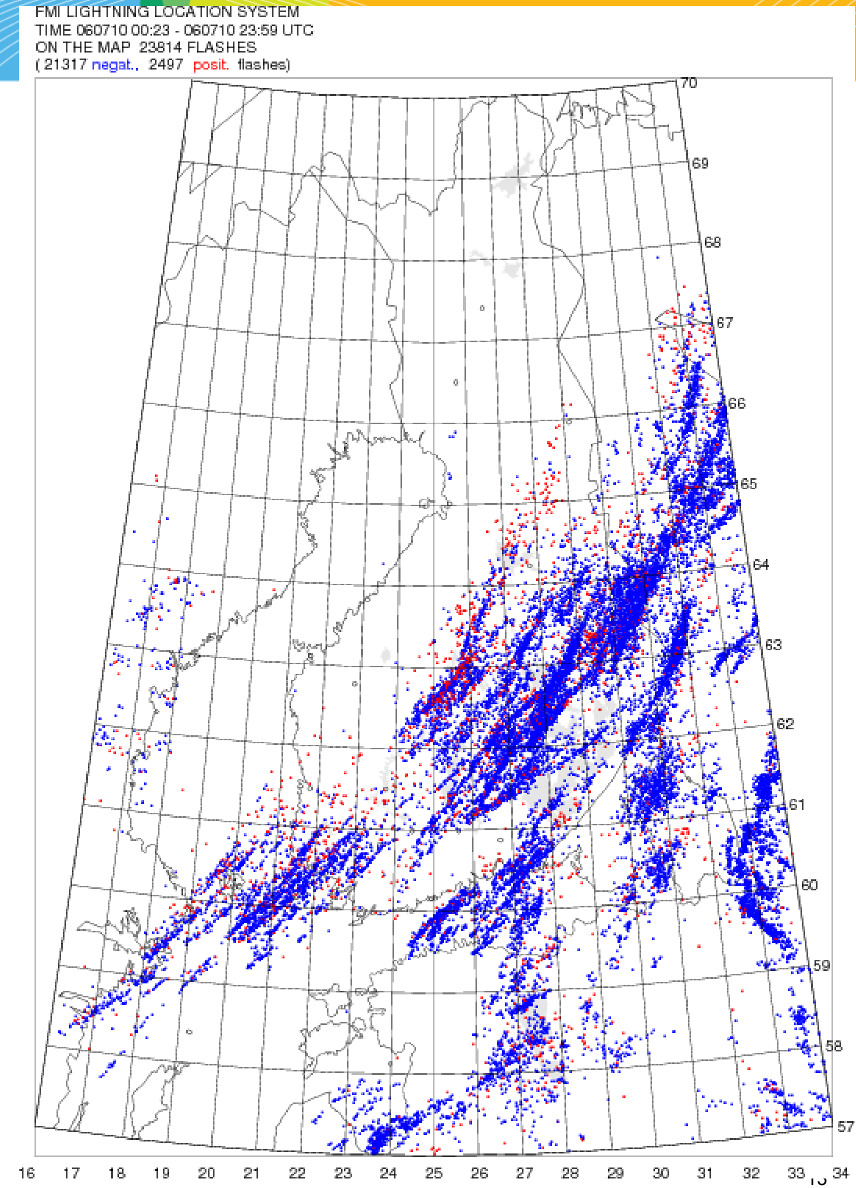


# Mean strengths of paired strokes

- Unipolar negative pair 0-100 ms: first stroke -20 kA, latter -13 kA, normal for neg. multiple flashes
- Unipolar positive pair 0-100 ms: first stroke +25 kA, latter + 19 kA, normal for pos. multiple flashes
- For 0-1 ms interval, latter stroke is not clearly weaker
- However, paired pos. strokes with 0.0 ms interval (i.e. < 0.05 ms) are both 30 kA
- Bipolar pairs: no clear pattern of strengths (except for long separations in Ex. 1, below)

# Example 1: July 10, NE-moving storm (afternoon-evening)

Map shows flashes (= first strokes only), blue = neg, red = pos



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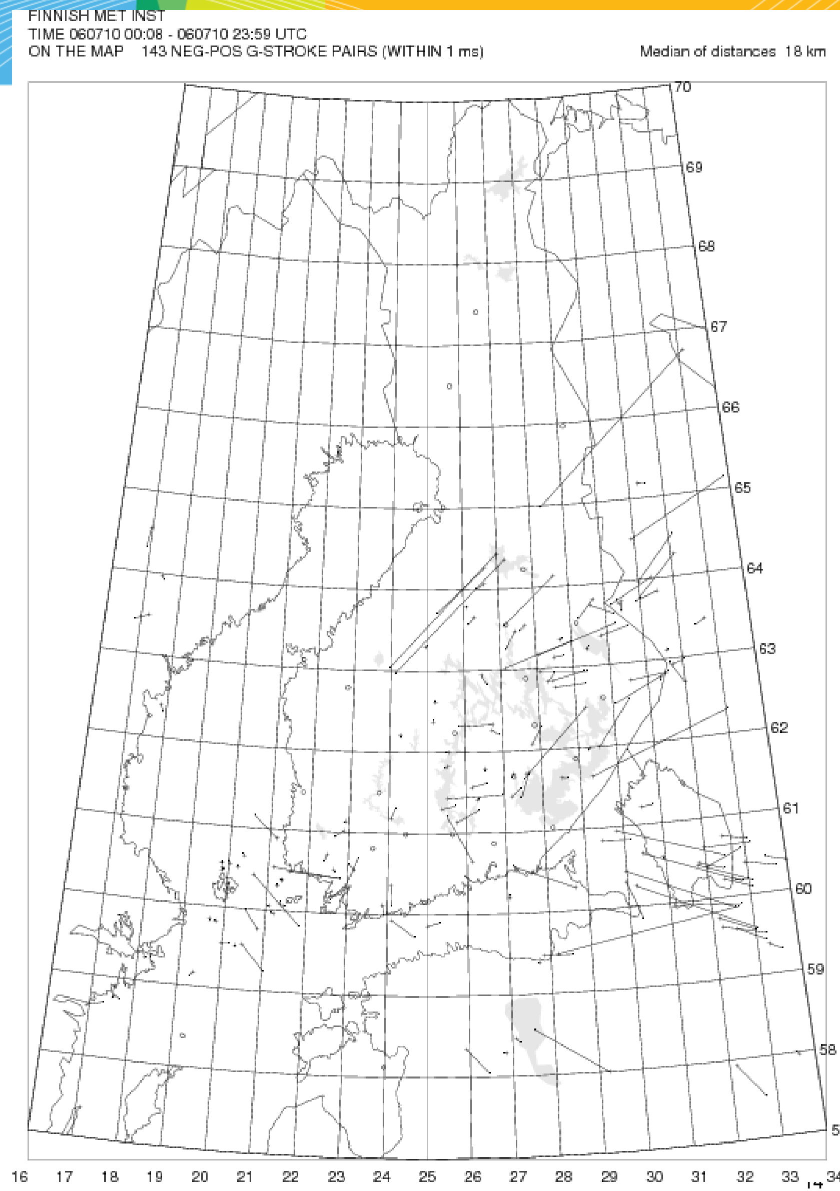
# Example 1: neg-pos/pos-neg separations (1 ms)

- Long radial separations, neg end in E, pos end in W
- separations > 70 km (28 cases) correlate with time diff. (r = 0.96), related by speed of light
- separations < 10 km (35 cases): random; many strokes interpreted by system as cloud discharge



# Example 1, cont.

For long-separation neg-pos/pos-neg pairs, strength of latter stroke (closer to sensors) is 60-70 % of first stroke

Explanation for long-separation pairs: latter stroke is ionosphere-reflected, polarity-reversed signal, detected and mislocated by more remote sensors

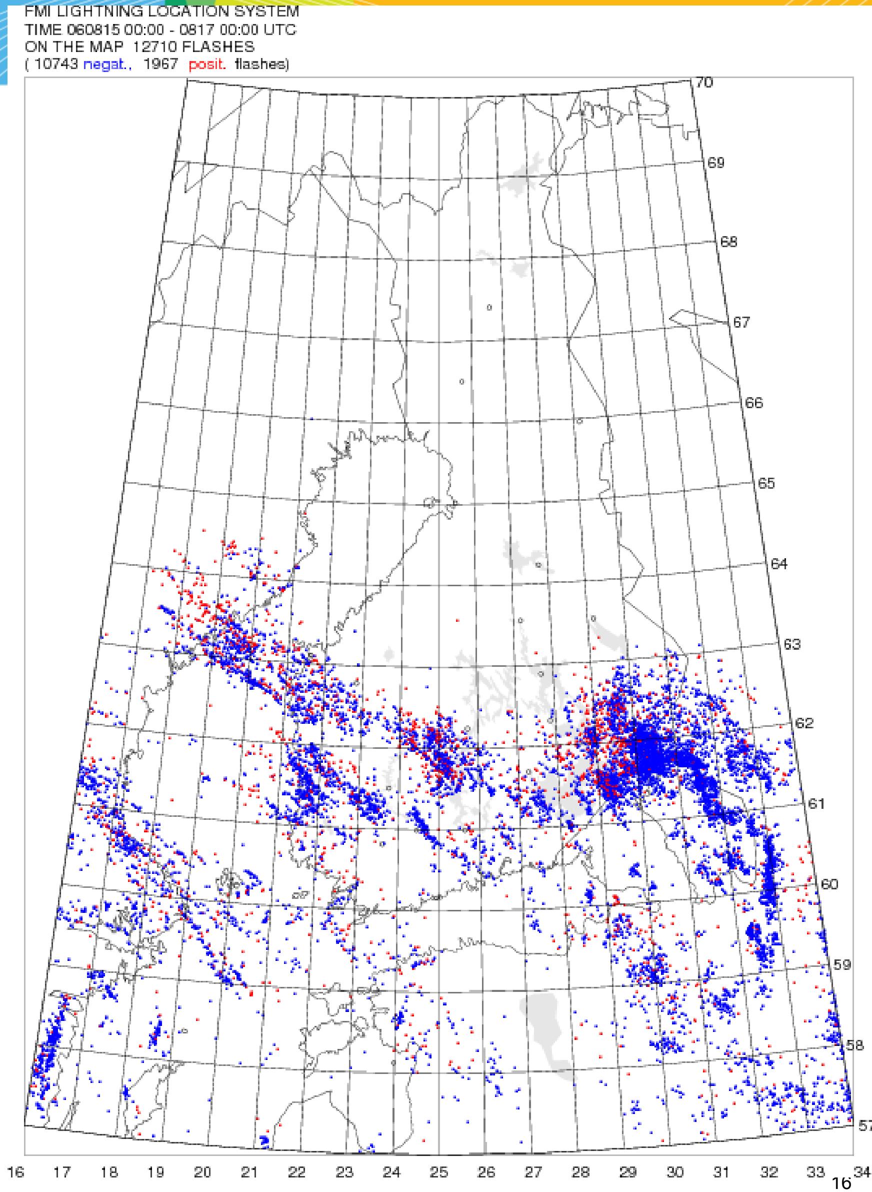
Mislocation causes apparent time difference (figure below)

Neg-neg pairs do not show similar radial long separations, most cases are < 10 km

Number of neg-neg pairs is similar to neg-pos/pos-neg pairs

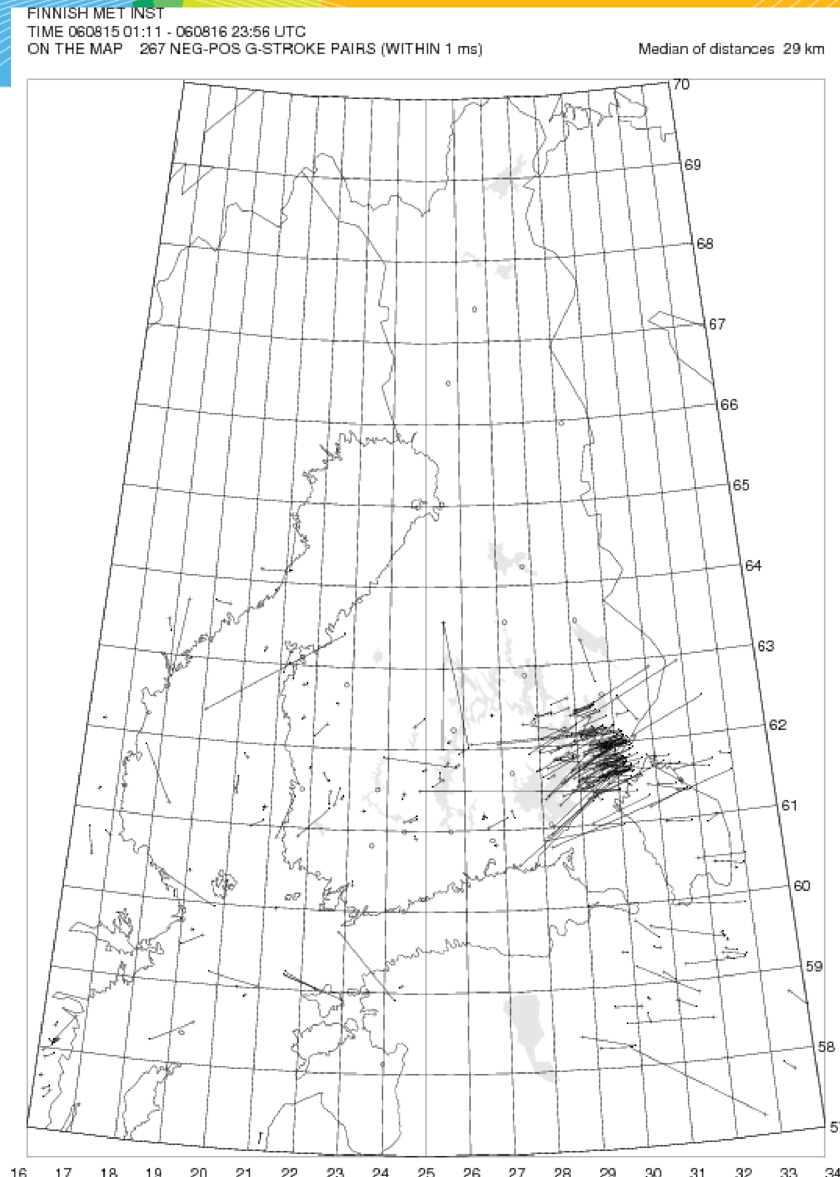
# Example 2: Aug 15-16

Cluster in east occurs near midnight



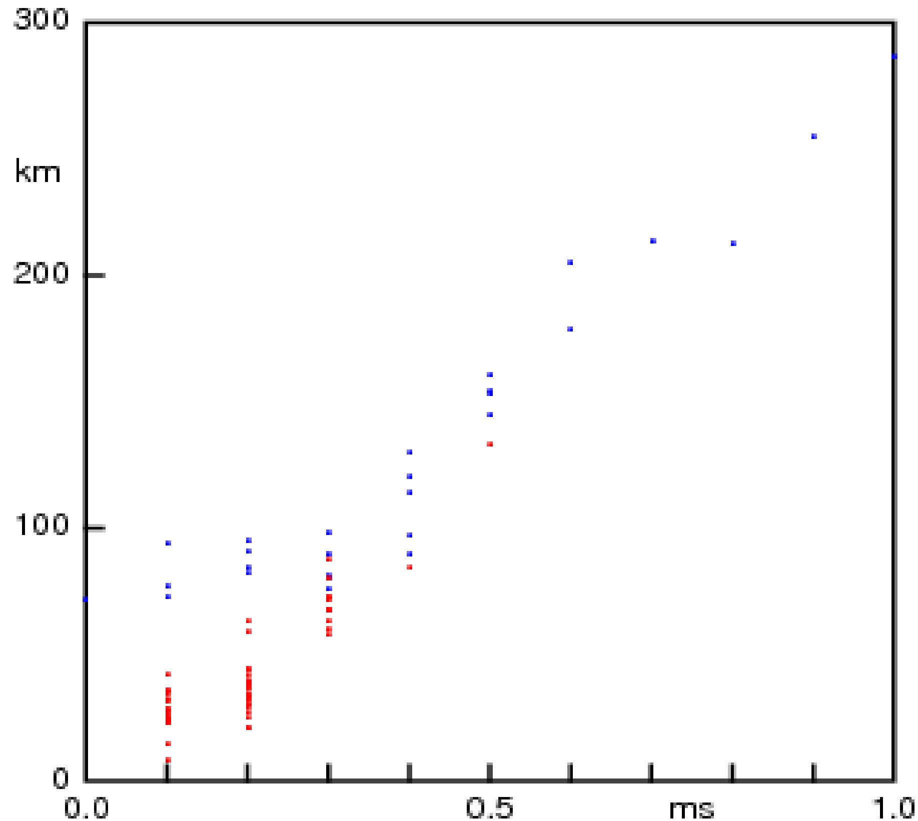
# Example 2: neg-pos/pos-neg separations (1 ms)

- The pairs are clustered near midnight
- The separations are nearly E-W (first stroke E, latter W), a few tens of km
- The separation-timediff relation fits with the long-separation data of July 10 (corr. of this data r = 0.85), see next slide



# Correlation of eastern separations with time difference:

latter stroke (western) is ionospheric reflection, mislocated by remote sensors, consequently erroneously timed




Neg-pos/pos-neg stroke separation vs time difference.
Eastern locations. Blue: July 10 ( > 70 km ), red: Aug 15.

# Example 2, cont.

- First stroke of a pair in E, neg, 6.5 sensors/stroke
- Latter stroke in W, pos, 3.5 sensors/stroke
- Generally, sensor groups are different (SAFIR LF sensors may be common)
- No significant difference in the strengths of the strokes
- Neg-neg pairs (89, not shown): no clustering in E, distances are short (median 2 km)
- Pos-pos pairs (not shown) only 16

# Conclusions

- A data set of over 100,000 stroke pairs (0-100 ms) consists mostly of normal multiple negative flashes
- 7 % are positive or bipolar pairs
- 3 % of the 0-100 ms pairs are within 0-1 ms (in fact, mostly concentrated below 0.3 ms)

For the sub-ms pairs,

- long separation (tens of km): latter stroke is the same but reflected from ionosphere
- short separation ( < 10 km): some may be true forked pairs (Rakov & Uman 1994), but:

Physical explanations are sought in the companion paper