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Exploring the Earth

A Seismic Event Relative Location Benchmark Case Study

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EGU

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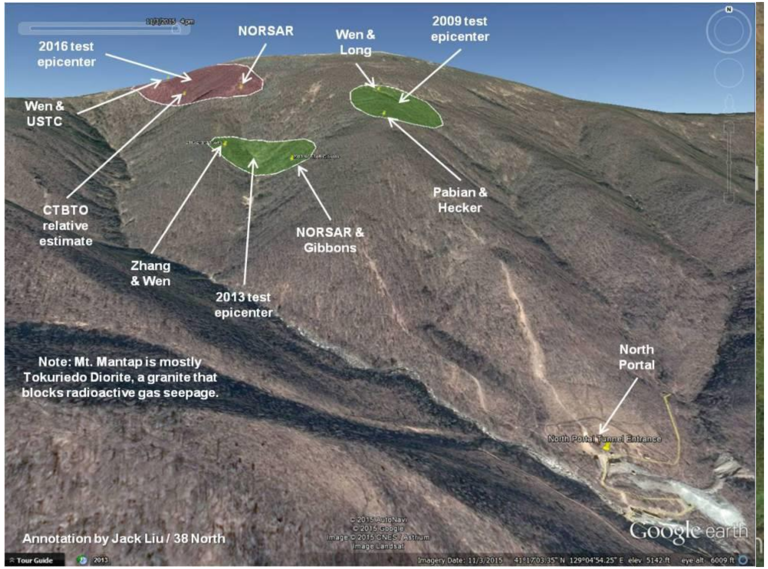
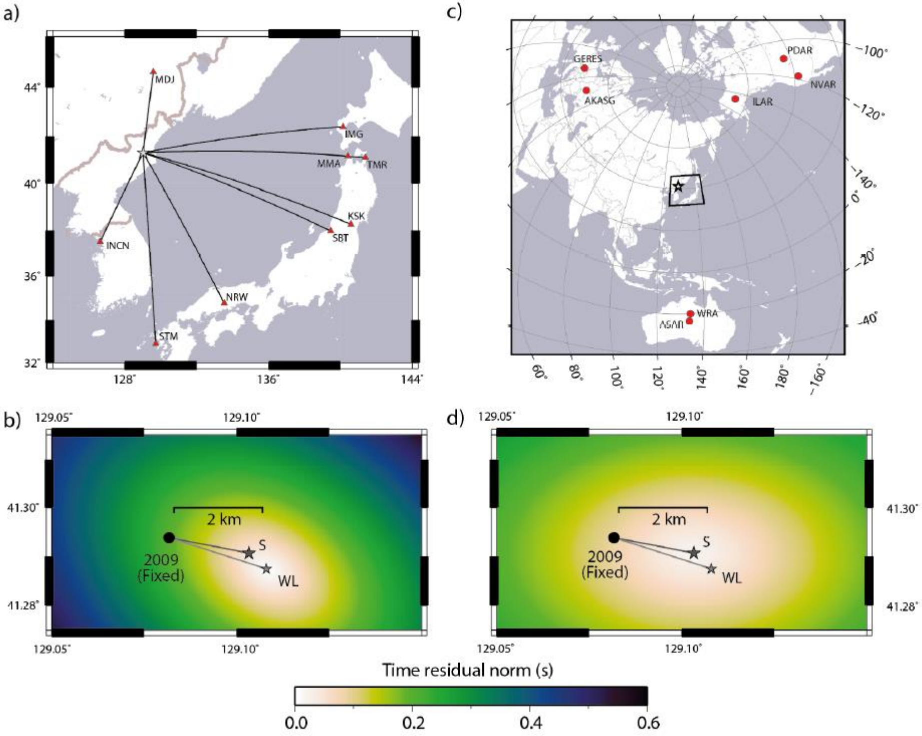
Why is relative event location important in nuclear explosion monitoring?

Can place constraints on emplacement and depth with possible consequences for yield estimation.



Differences in relative location estimates of DPRK explosions found in different studies.

What are the location uncertainties?



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GT data:

- A set of 55 military surface explosions in northern Finland in 2007
- All took place within 300 meters of each other.

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Exact coordinates of 55 explosions at Hukkakero were provided by the Finnish military

Table 1. Ground Truth coordinates for 55 explosions at Hukkakero between 15 August and 16 September 2007. Note that the sources have dimensions of the order of many meters such that there are only likely 4 significant figures in the latitude and longitude for the effective seismic source. mm-dd indicates the month and day-of-month in 2007, and hh.mm gives the hour and minute of the origin time, UT.

mm-dd	evID	hh.mm	lat.	lon.	evID	hh.mm	lat.	lon.
08-15	H01	08.00	67.93590	25.83491	H02	12.00	67.93354	25.83291
08-16	H03	08.00	67.93580	25.83511	H04	12.00	67.93352	25.83229
08-17	H05	07.30	67.93577	25.83428	H06	11.00	67.93351	25.83215
08-18	H07	07.30	67.93490	25.82991	H08	11.00	67.93352	25.83167
08-19	H09	08.00	67.93471	25.82915	H10	11.30	67.93344	25.83108
08-20	H11	07.30	67.93588	25.83496	H12	11.00	67.93362	25.83100
08-21	H13	07.30	67.93573	25.83528	H14	10.30	67.93354	25.83079
08-22	H15	07.30	67.93487	25.82938	H16	10.30	67.93355	25.83246
08-23	H17	07.30	67.93499	25.82933	H18	10.30	67.93370	25.83242
08-24	H19	07.30	67.93510	25.82961	H20	11.00	67.93344	25.83229
08-25	H21	07.30	67.93486	25.82948	H22	10.30	67.93367	25.83288
08-26	H23	08.45	67.93385	25.83475	H24	11.30	67.93597	25.83472
08-27	H25	07.30	67.93373	25.83438	H26	10.30	67.93607	25.83409
08-28	H27	07.30	67.93364	25.83402	H28	10.30	67.93590	25.83355

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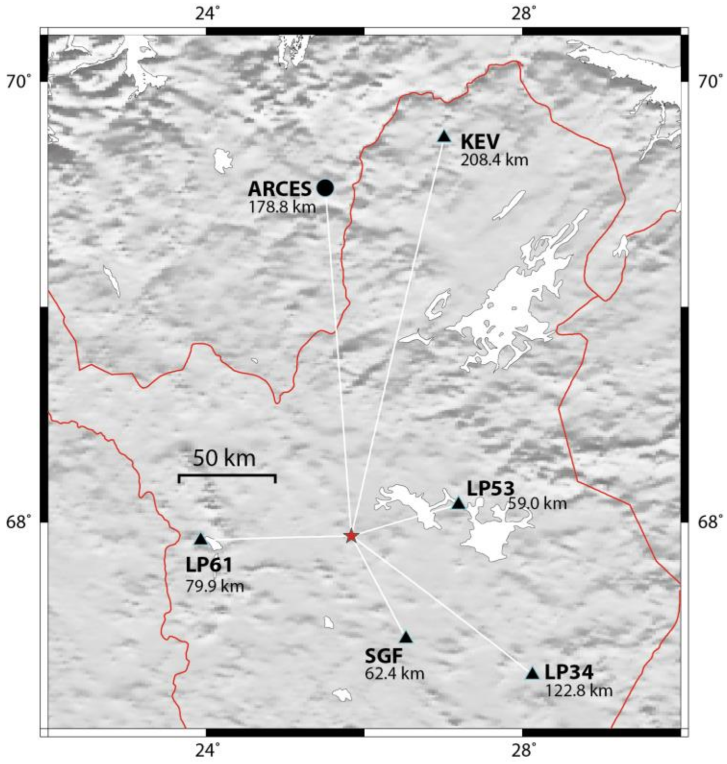
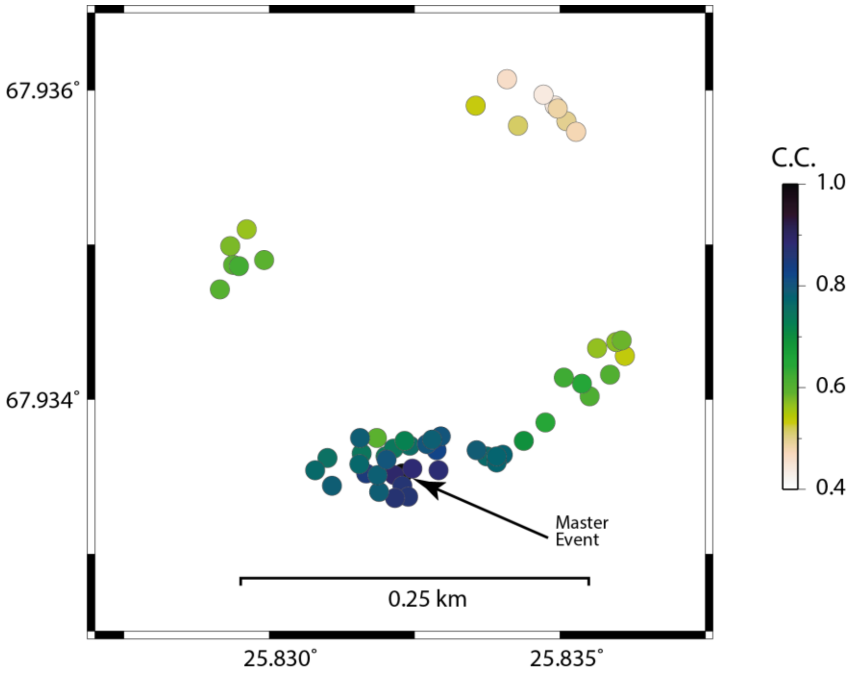
Observing stations



GT locations of 55 explosions

- ARCES CC-coeff. relative to a master event



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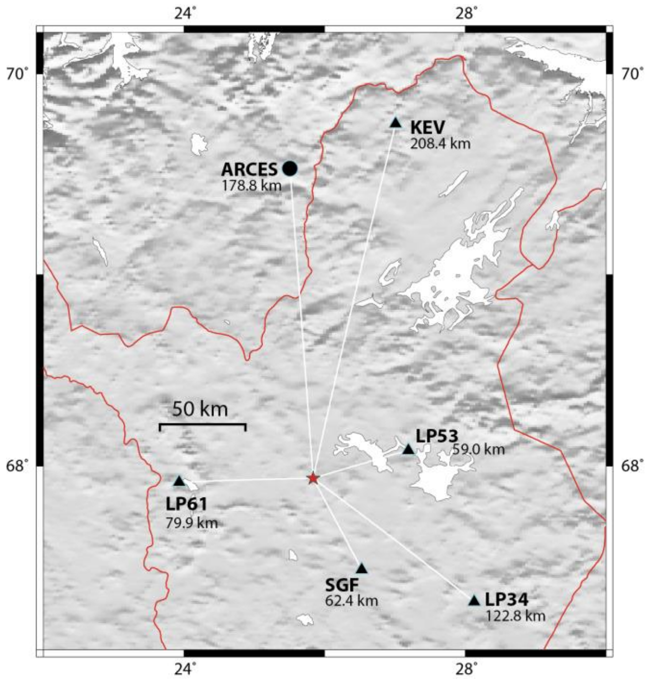
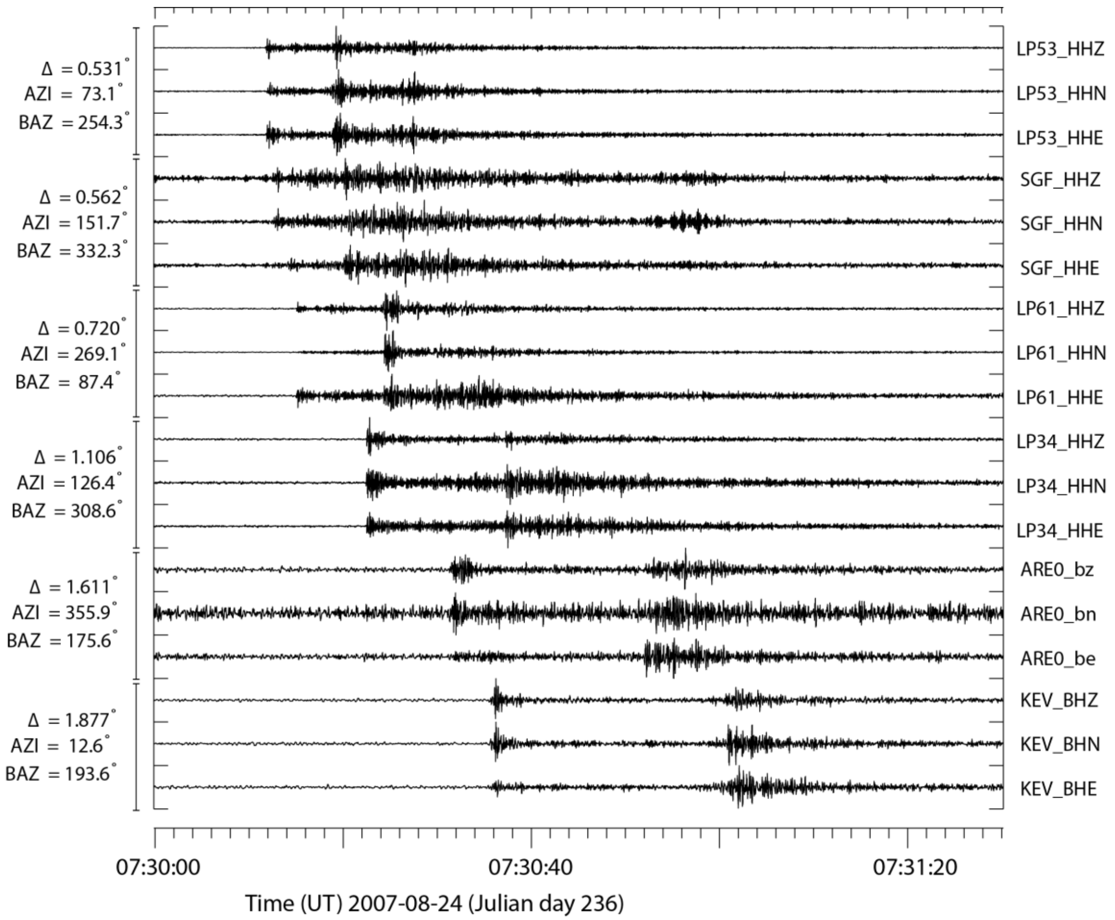
Observations at local/regional distances





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High precision differential time measurements are provided for P and S at all 6 reference stations for all event pairs

H01	H02	2007-08-15T08:00:27.857	2007-08-15T12:00:28.110	ARCES	P1	0.828
H01	H02	2007-08-15T08:00:48.693	2007-08-15T12:00:48.956	ARCES	S1	0.755
H01	H02	2007-08-15T08:00:32.148	2007-08-15T12:00:32.407	KEV	P1	0.808
H01	H02	2007-08-15T08:00:55.371	2007-08-15T12:00:55.641	KEV	S1	0.796
H01	H02	2007-08-15T08:00:19.109	2007-08-15T12:00:19.299	LP34	P1	0.850
H01	H02	2007-08-15T08:00:33.100	2007-08-15T12:00:33.286	LP34	S1	0.798
H01	H02	2007-08-15T08:00:08.467	2007-08-15T12:00:08.709	LP53	P1	0.926
H01	H02	2007-08-15T08:00:15.228	2007-08-15T12:00:15.476	LP53	S1	0.813
H01	H02	2007-08-15T08:00:11.736	2007-08-15T12:00:11.945	LP61	P1	0.678
H01	H02	2007-08-15T08:00:21.048	2007-08-15T12:00:21.232	LP61	S1	0.731
H01	H02	2007-08-15T08:00:09.053	2007-08-15T12:00:09.243	SGF	P1	0.658

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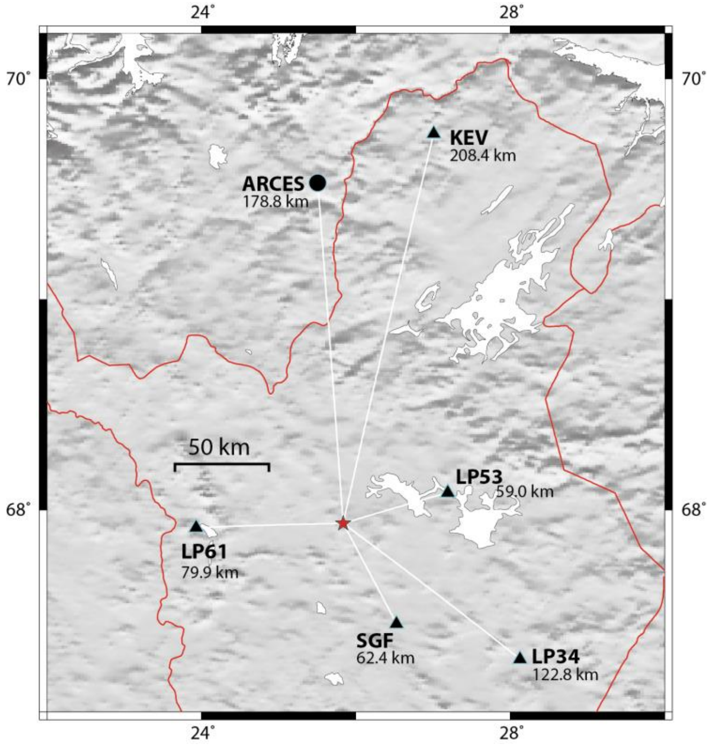
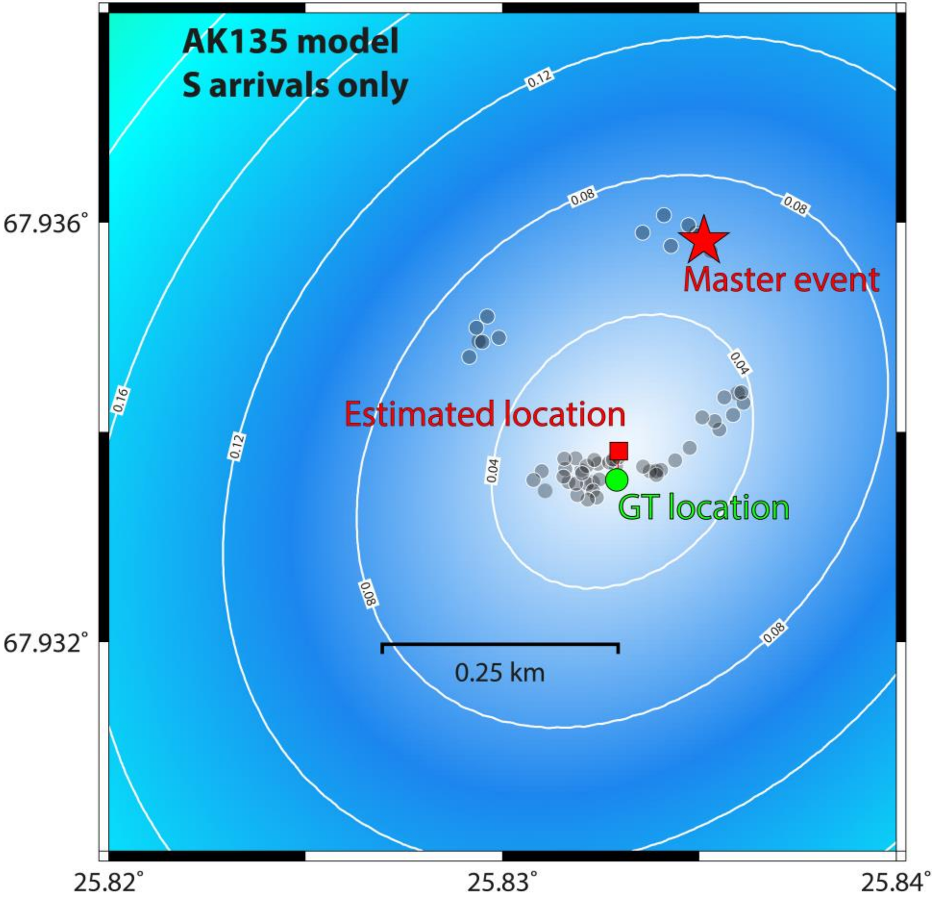
Estimate relative locations relative to a fixed master event

Contours of L2 norm





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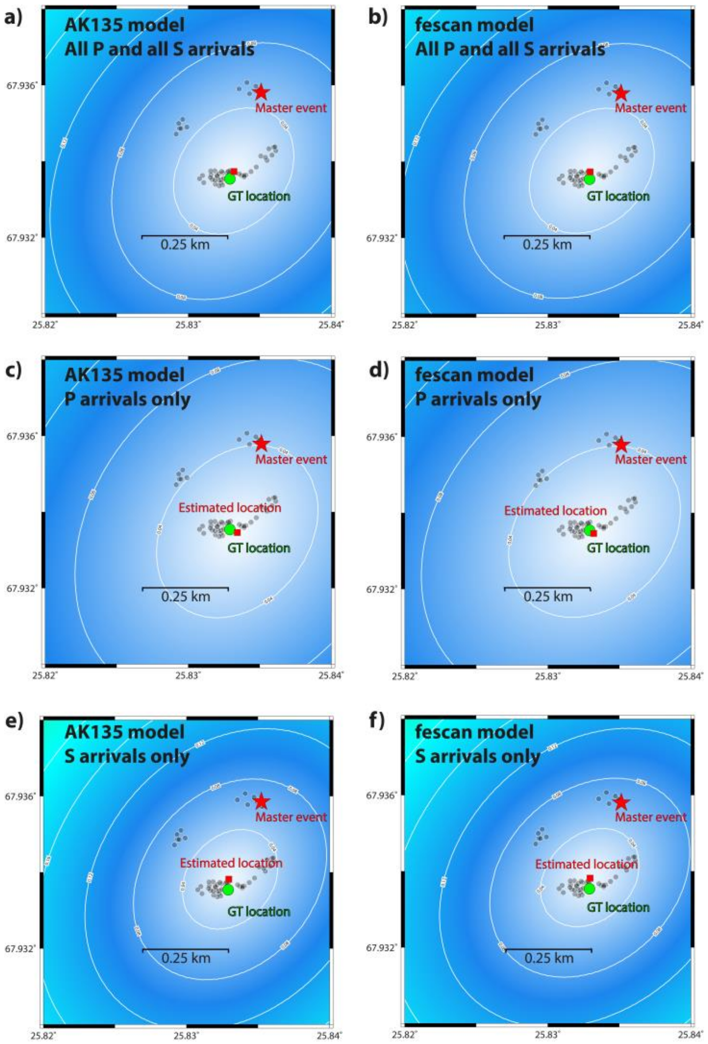
Estimate relative locations relative to a fixed master event

- Select one master event (at GT location)
- Estimate relative locations using:

  - two propagation models (AK135, fescan)

  - different phases (P and S, P only, S only)



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Relative location estimates

- GT location of master event

- Estimated locations

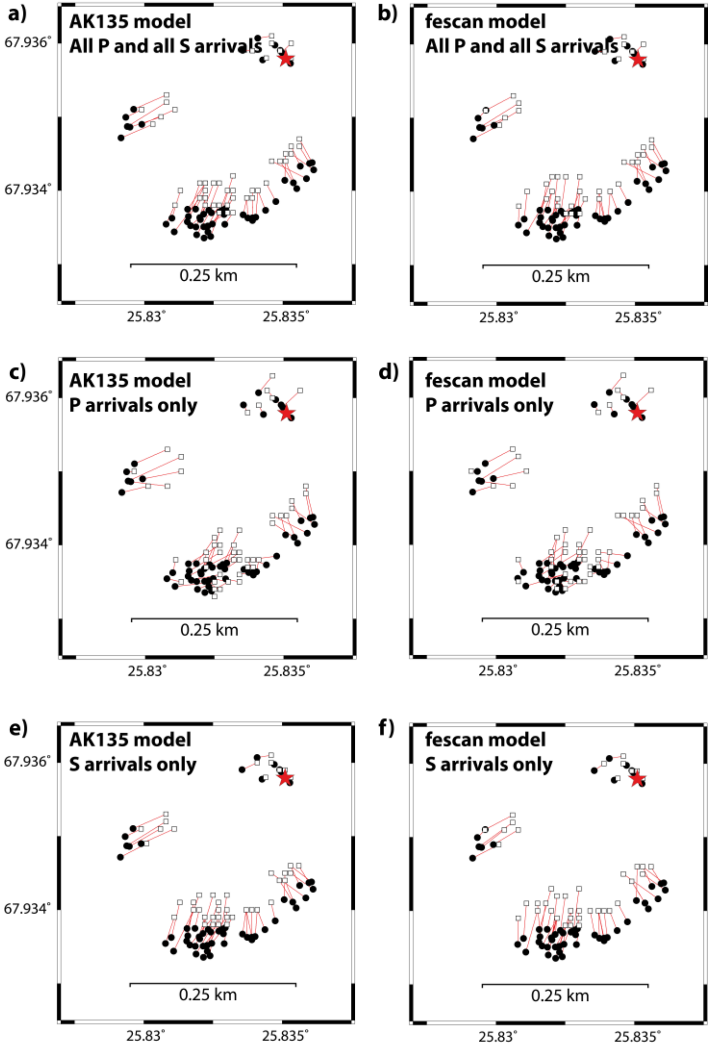
- GT locations

Observations:

- Consistent mislocation vectors within each cluster
- Generally different structure of the mislocation vectors for the different clusters

Hypothesis:

- Mislocations as caused by the use of too simple (1-D) propagation models for the outgoing wavefield



Origin times are calculated as accurately as possible using Bayesloc

- This allow us to make direct measurements of the slowness vectors of the outgoing wavefield using so-called source-array analysis.

- Source-array analysis can be viewed as treating each event as a sensor observation at the coordinate of the event, where the data first are time-shifted to a common origin time.

- In this way, standard array processing methods can be applied.

mm-dd	evID	hh.mm.ss.sss	evID	hh.mm.ss.sss
08-15	H01	07.59.59.936	H02	12.00.00.150
08-16	H03	08.00.00.275	H04	12.00.00.374
08-17	H05	07.30.00.774	H06	11.00.00.380
08-18	H07	07.30.00.369	H08	11.00.00.667
08-19	H09	08.00.00.684	H10	11.30.00.937
08-20	H11	07.30.01.185	H12	11.00.01.234
08-21	H13	07.30.01.571	H14	10.30.01.187
08-22	H15	07.30.01.742	H16	10.30.01.481
08-23	H17	07.30.01.885	H18	10.30.01.830
08-24	H19	07.30.02.157	H20	11.00.02.229
08-25	H21	07.30.00.357	H22	10.30.00.682
08-26	H23	08.44.59.193	H24	11.29.58.999
08-27	H25	07.29.59.073	H26	10.29.58.938
08-28	H27	07.29.59.148	H28	10.29.59.313

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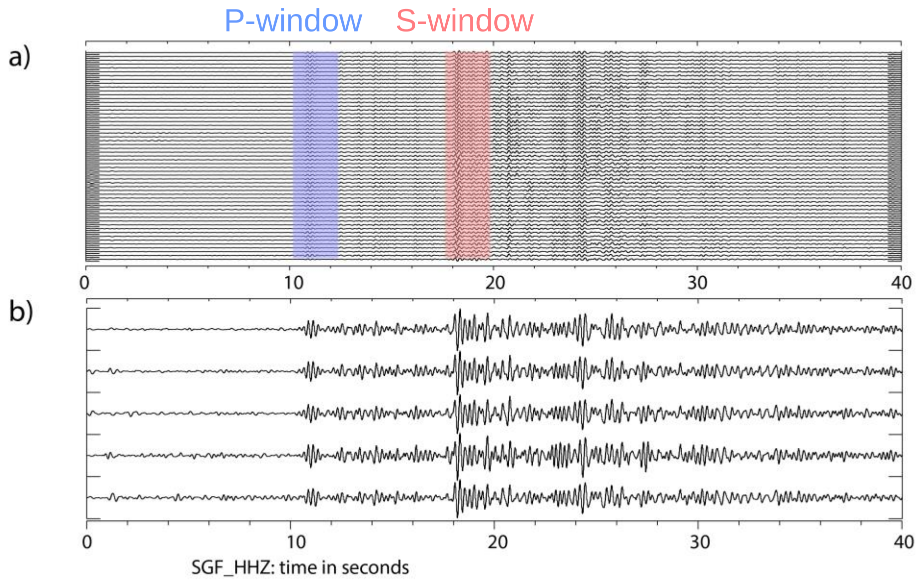
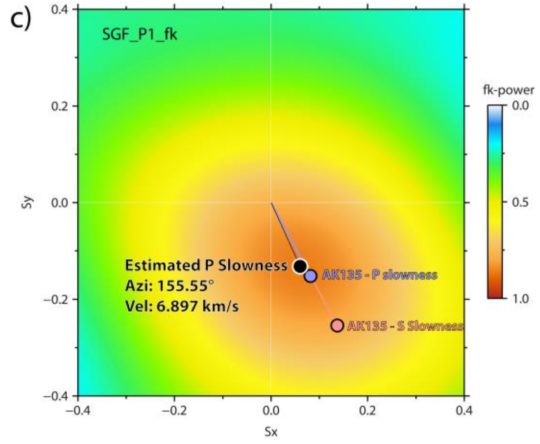
Source array analysis of GT events observed at the SGF (Sodankylä) station

a) Time-aligned SGF observations of 55 GT events

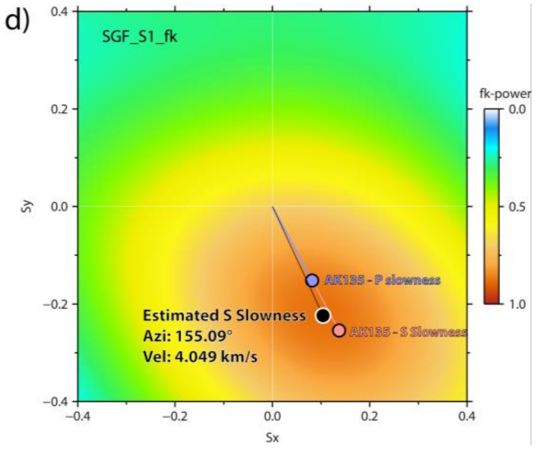
b) Zoom-in on 5 events (2-4 Hz bandpass)



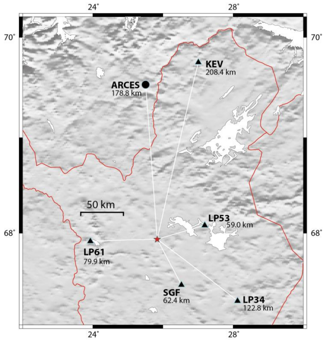
c) Source-array analysis of SGF P-phase



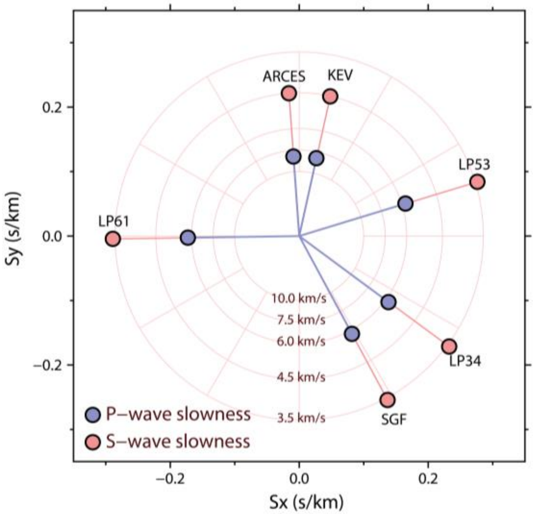
d) Source-array analysis of SGF S-phase



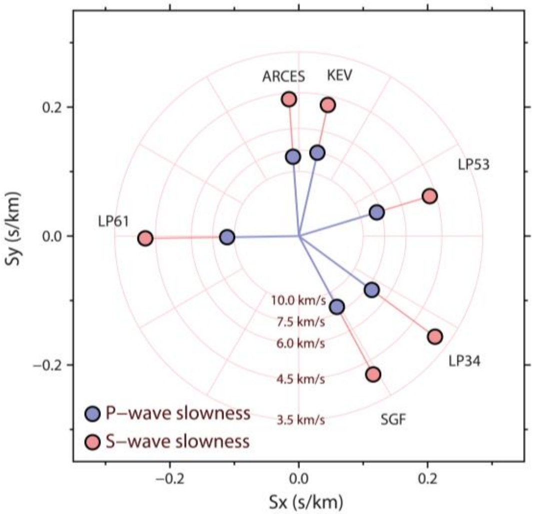
Source array analysis of the outgoing P- and S-wavefields



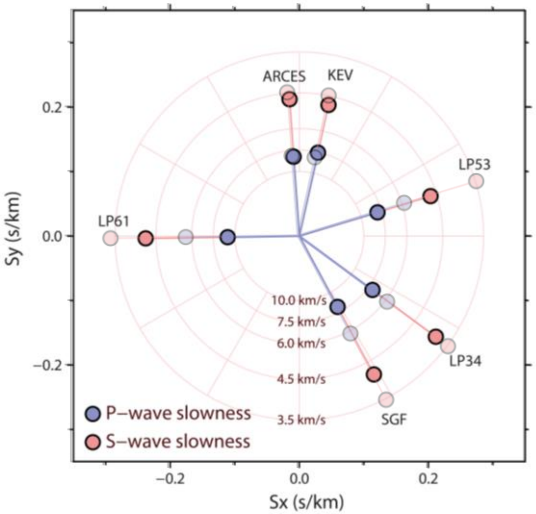
a) Theoretical slownesses from AK135 model



b) Estimated slownesses from source array analysis



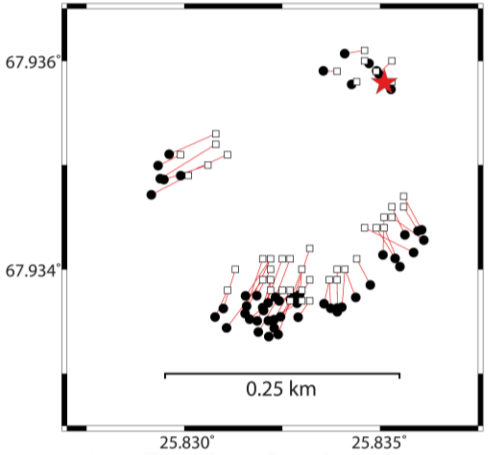
Overlays of a) and b)

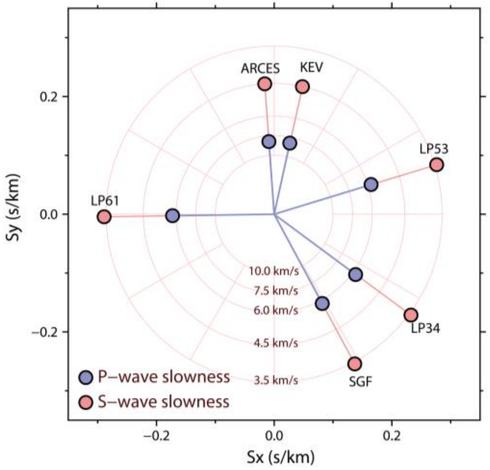


Restimation of relative locations using empirical slowesses for the source area

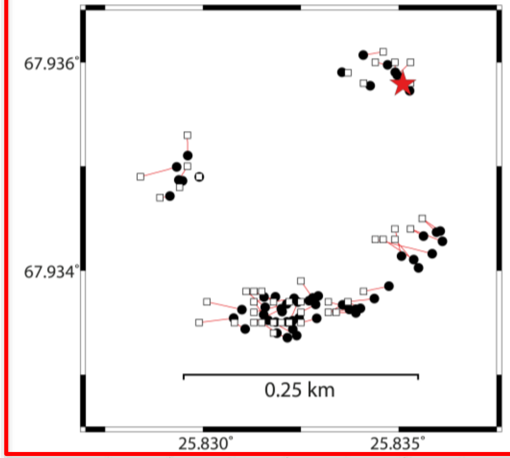
- The reestimated location estimates are far closer to the Ground Truth locations than those using AK135.

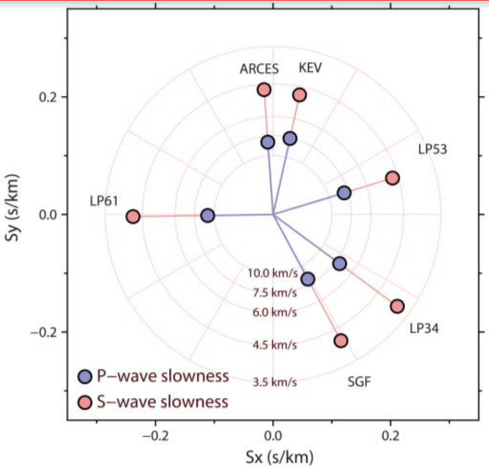
Mislocation vectors using AK135 model





Mislocation vectors using empirical slownesses





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Conclusions

- We have developed and made publicly available a ground truth database of surface explosions as a benchmark for evaluation of relative event location algorithms (paper submitted to GJI).
- Systematic mislocations may be introduced by incorrect assumptions about the speed of the outgoing wavefield to each of the stations used.
- All approaches to estimation and interpretation of accurate relative event locations should to take this into account.

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Thank you

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