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Exploring the Earth

Seismic Monitoring of Novaya Zemlya: Progress, Challenges, and Prospects

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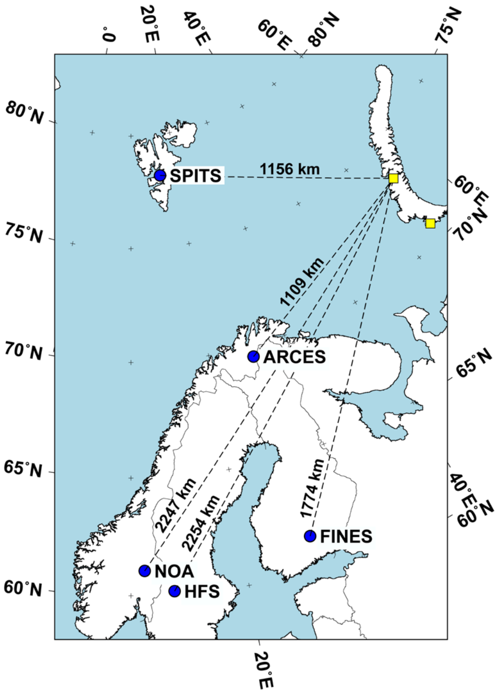
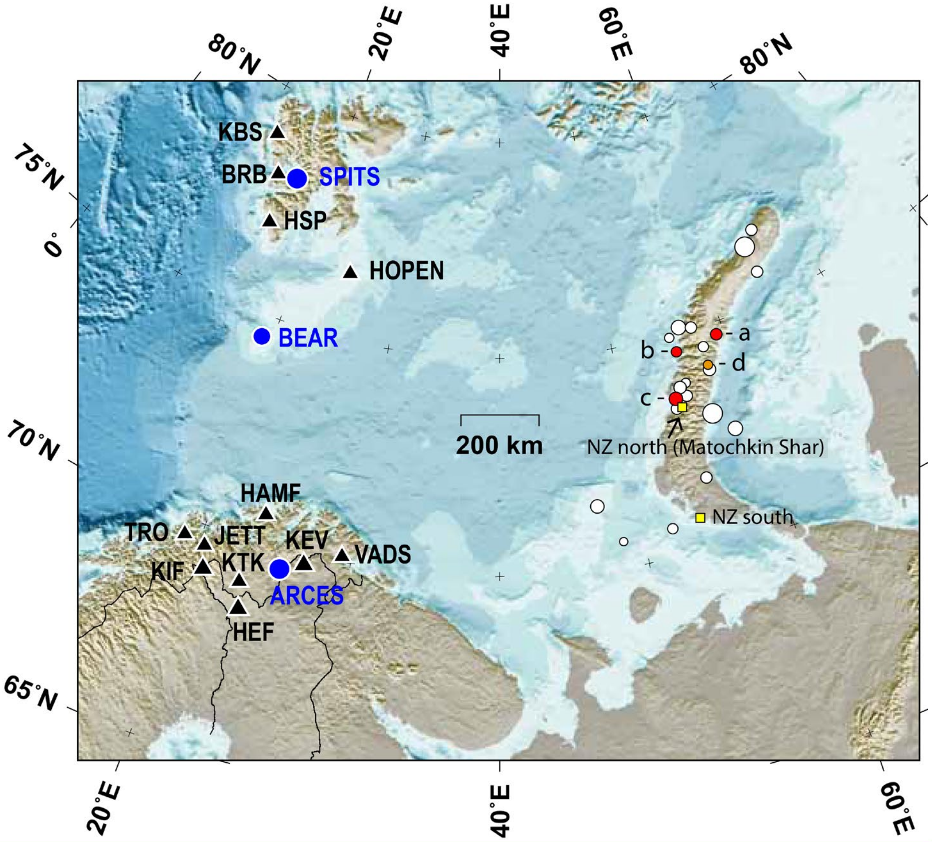
Motivation for focus on Novaya Zemlya (NZ)

- Novaya Zemlya was the site for nuclear testing between 1955 and 1990 and is a region of high interest for verifying compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT)
- Seismic monitoring of NZ is challenging with many hundreds of kilometers of sea separating the test-site from the closest seismic stations available to the international community
- The high-performing seismic arrays ARCES and SPITS detect events on NZ down to magnitude 2 (approx. 1 ton TNT), but the location uncertainty for the smaller events is large
- Recent improvements in the open regional networks of northern Europe, have resulted in an enhanced location capability for seismic events above magnitude 3

Seismic arrays of the International Monitoring system (IMS) operated by the CTBT organization



NZ events (1986 to 2021) and closest seismic stations providing open data



- Seismic arrays

- Three-component stations

- Events before 2019

- Events after 2019

- Nuclear test sites (37 known tests from 1964 - 1990)

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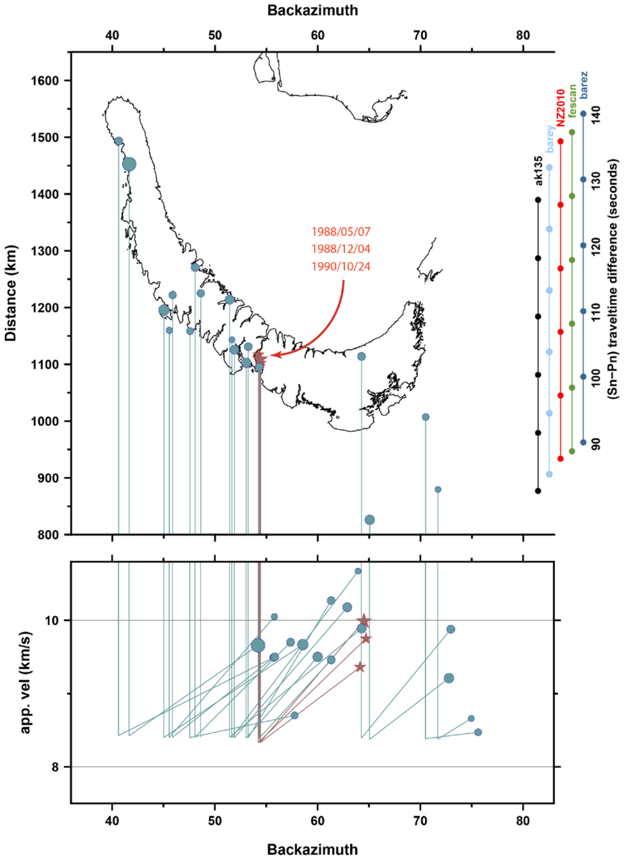
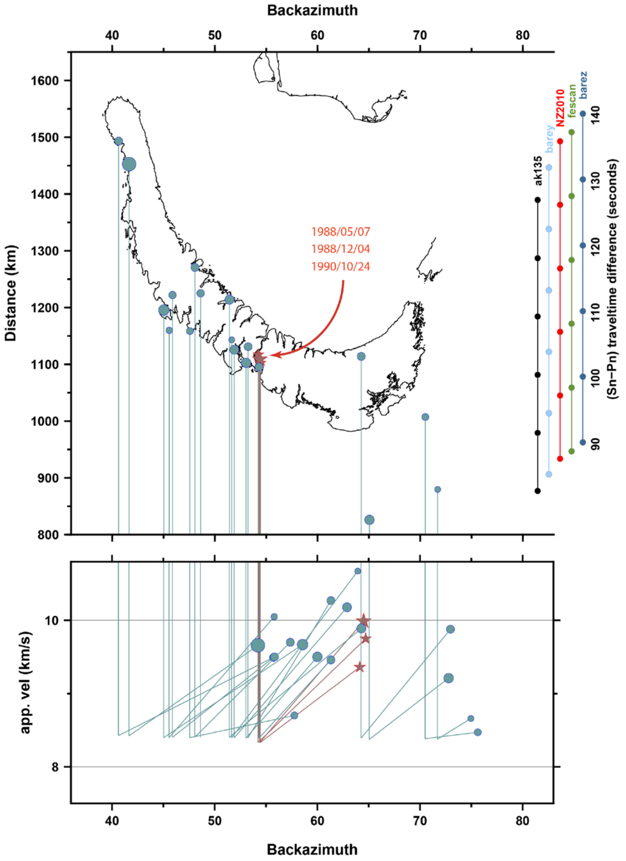
ARCES back-azimuth and slowness anomalies



Issues for location of NZ events

- Systematic Pn back-azimuth and slowness anomalies are observed at the ARCES and SPITS arrays
- At the distances considered (~1000km), event locations based on S-P traveltime differences are highly sensitive to the accuracy of the P and S velocity model
- Events with magnitudes < 3 are generally only observed at the ARCES and SPITS arrays
- It is important to impose realistic uncertainty bounds on the event locations
- Can relative location approaches and comparative waveform analyses improve the interpretation of events in terms of location and source type?

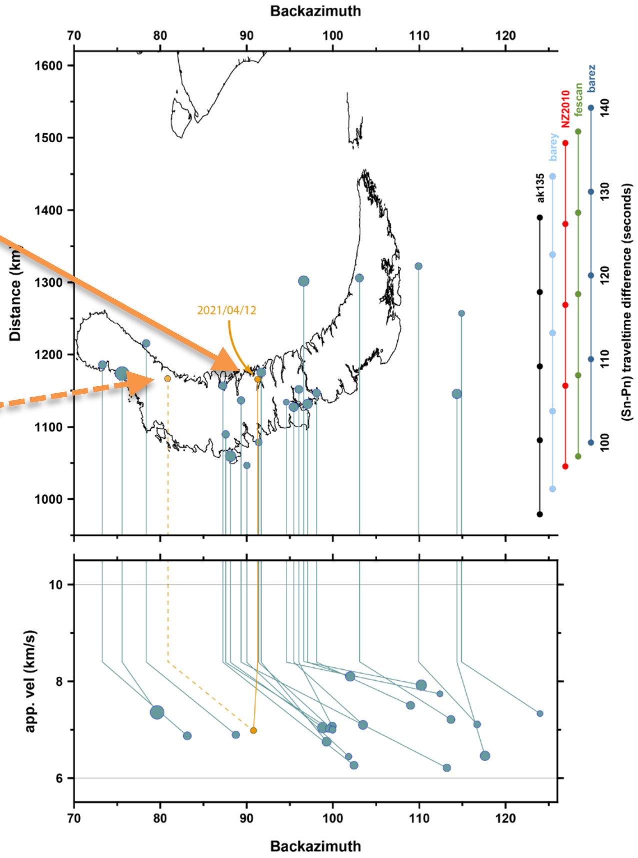
ARCES:
Systematic Pn back-azimuth bias between 5° and 15°



SPITS:
Systematic Pn back-azimuth bias between 5° and 15°

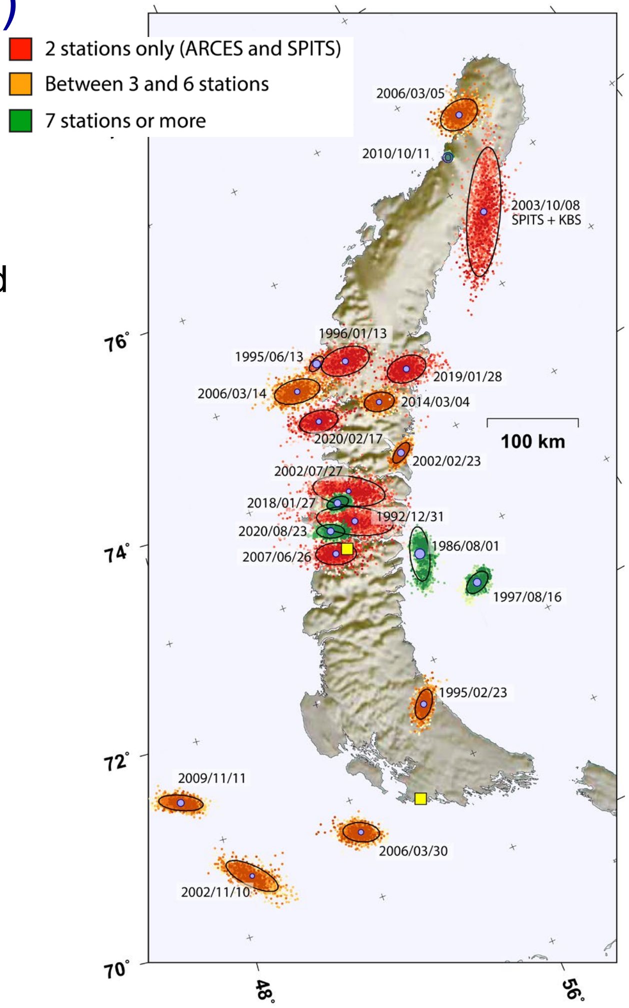
Event located solely with SPITS P and S arrival times and backazimuths

Location after removal of systematic SPITS backazimuth bias



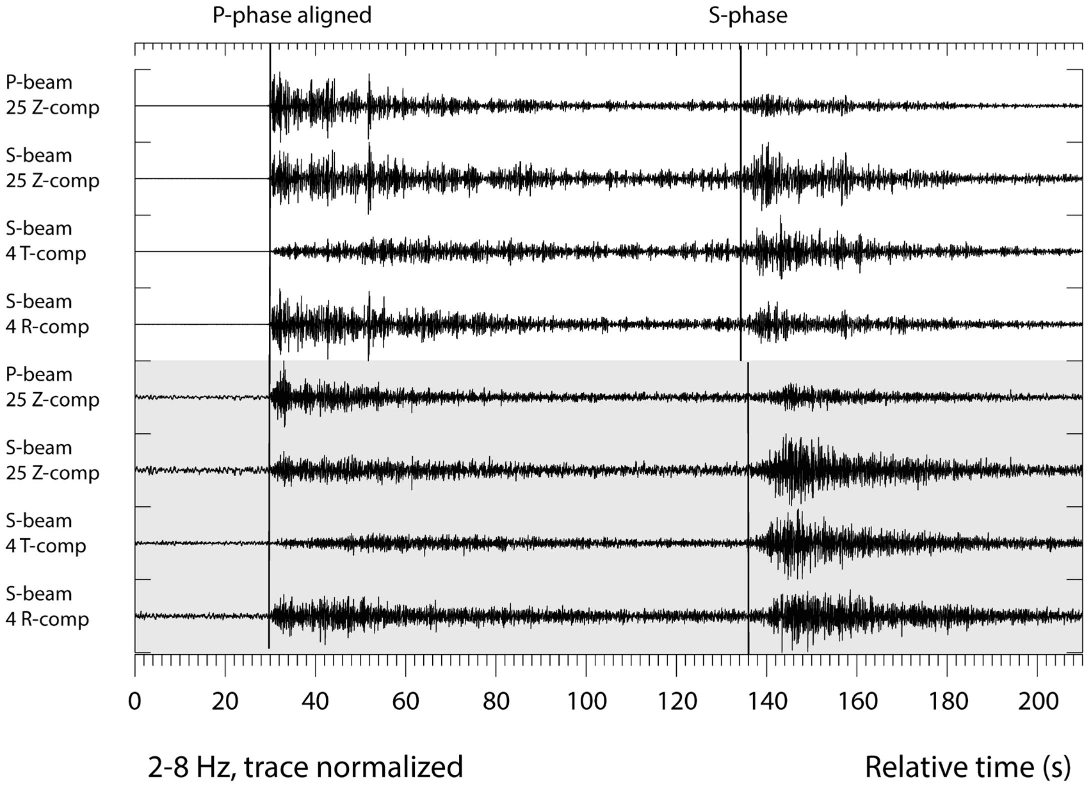
BayesLoc locations of 21 NZ events (1986 -2021)

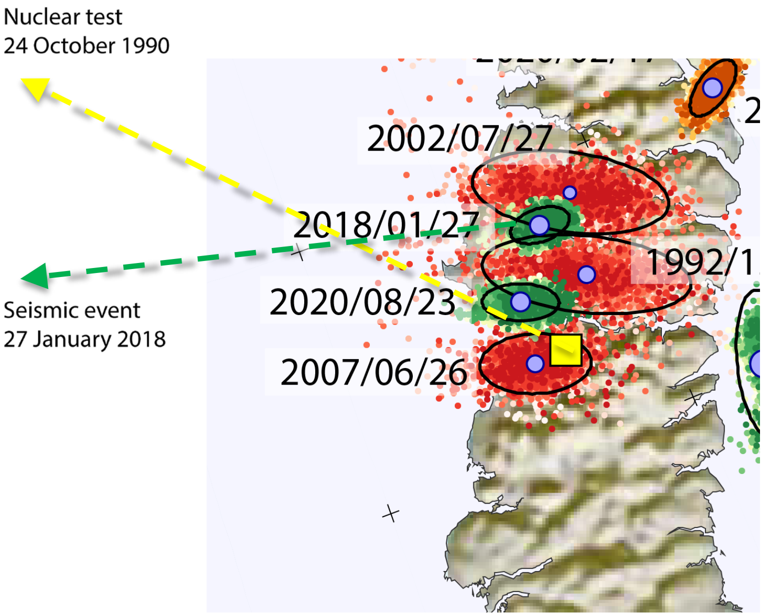
- A probabilistic multiple event location algorithm (Myers et al. 2007)
- Has shown to be effective at reducing bias and uncertainty of clustered locations
- The display of location clouds may better represent the uncertainties
- Will BayesLoc improve locations of the Novaya Zemlya seismicity?
  - *Nuclear test locations are tightly constrained by the priors*
  - *Scattered seismicity with often large distances between events*
  - *Some areas with a denser event distribution*
  - *Situation expected to improve as more events occur*
  - *Events close to the former test site of highest interest*
  - *A small number of arrival times for most events*
  - *Use of array backazimuths not yet implemented in BayesLoc*
- Supplementary information from interpretation of the waveforms?



ARCES observation of 27 January 2018 seismic event

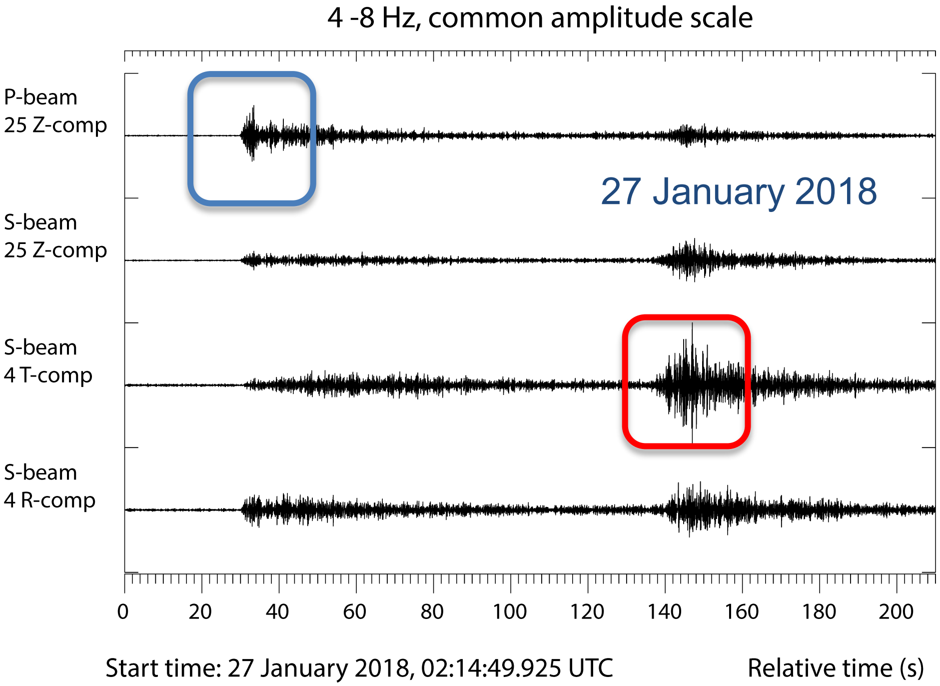
Compare S-P time difference with 24 October 1990 nuclear test

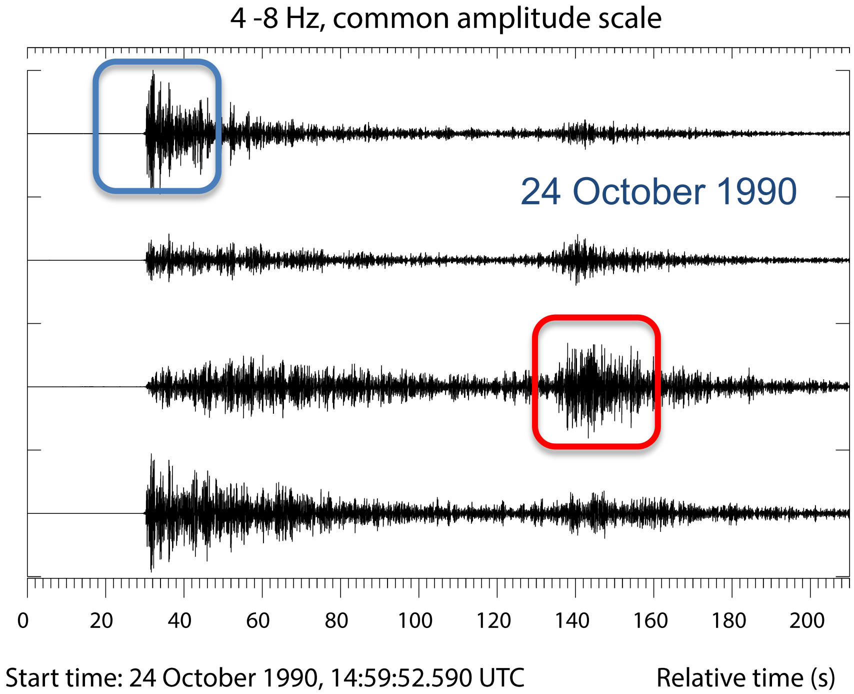




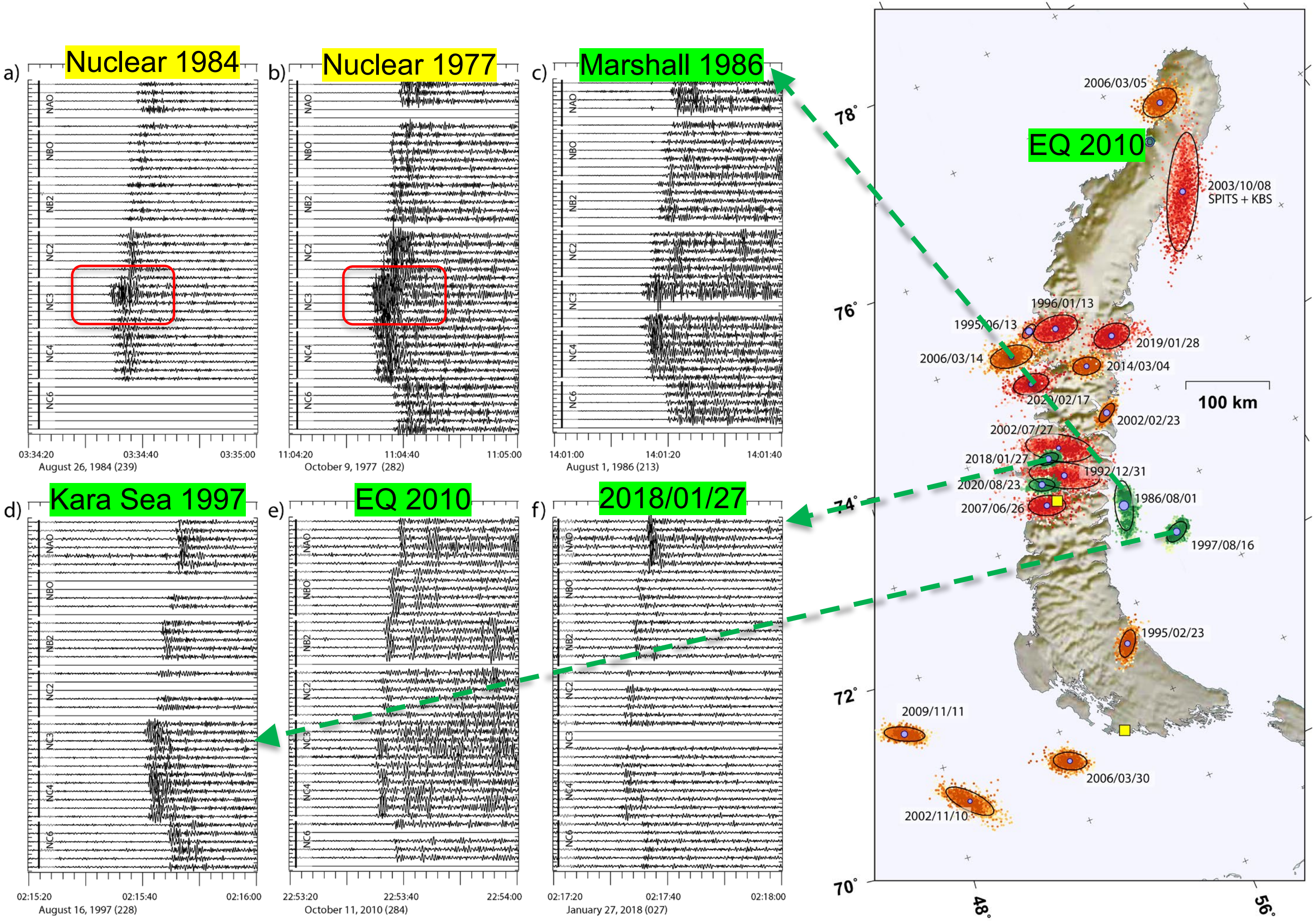
ARCES observation of 27 January 2018 seismic event

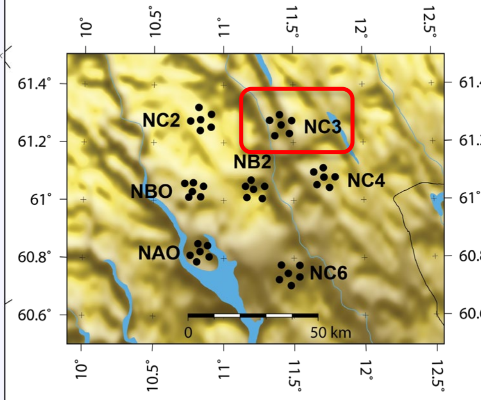
Compare S/P amplitude ratio with the 24 October 1990 nuclear test





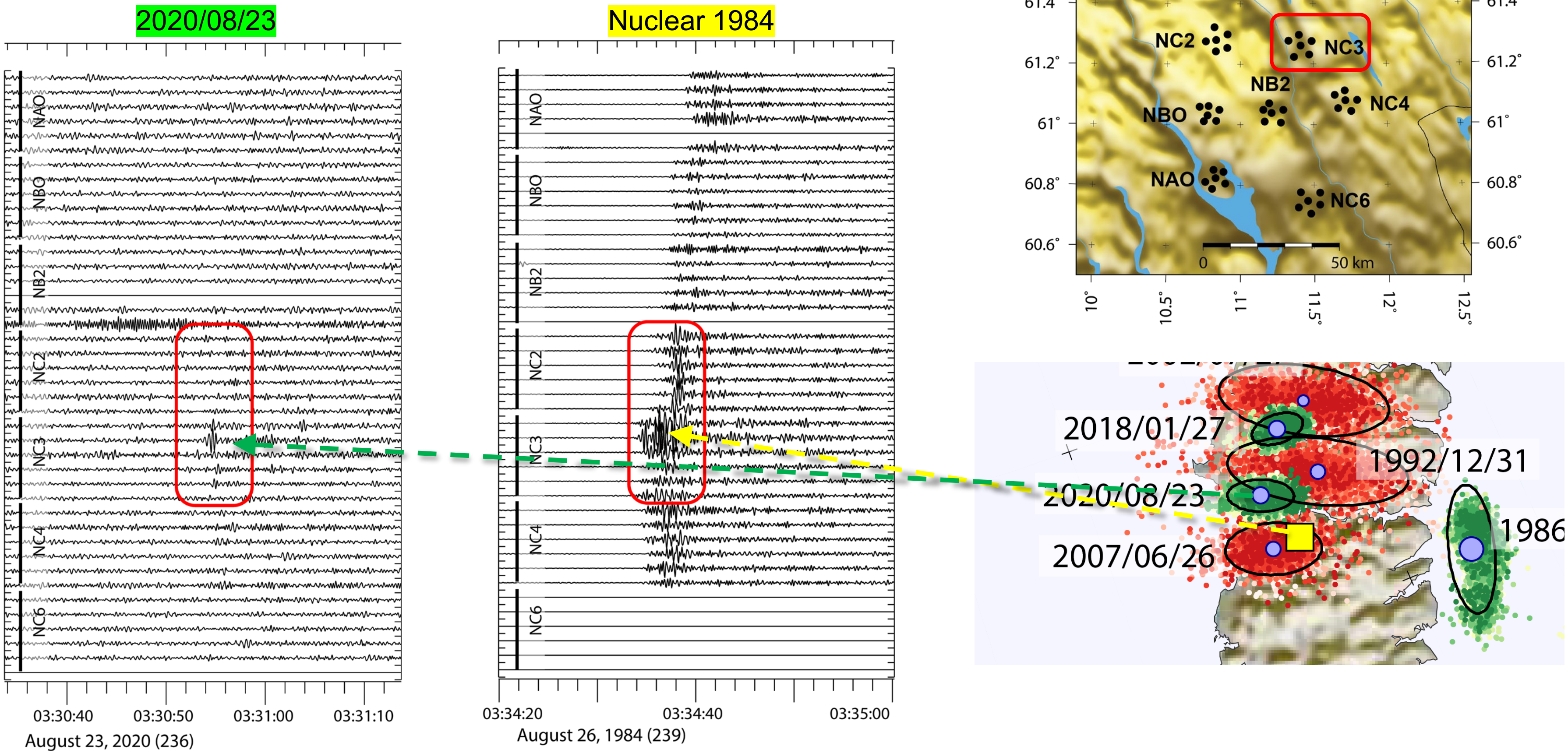
Amplitude patterns of NZ events observed at the NOA array (at ~2250 km distance)





Anomalously large amplitudes observed at sensors of NOA subarray NC3 for historical NZ nuclear tests

2020/08/23 observed at the NOA array
(*magnitude 3.1, 28 km from the NZ test site*)



Summary

- A set of 21 events on and around Novaya Zemlya which occurred between 1986 and 2020 are located using the BayesLoc multiple event location algorithm, and the associated uncertainties are estimated from the probabilistic location clouds
- Recent improvements in seismic station deployments in northern Europe have resulted in enhanced locations for events above magnitude 3
- Events below magnitude 2 are generally observed only at the ARCES and SPITS arrays, at distances of about 10 degrees. The corresponding event locations are associated with relatively large uncertainties
- Comparative analysis of the observed waveforms with historical events can provide additional constraints on the interpretation of the events in terms of location and nature of the event

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