Characterizing Seismic Sources

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Introduction and Motivation

Seismological monitoring and analysis is imperfect

- Many small seismic events are not detected
- Location uncertainties are routinely large (many km)
- Discrimination methods do not always work
- Seismological yield estimates disagree
- Understanding of elastic waves from UNEs is incomplete

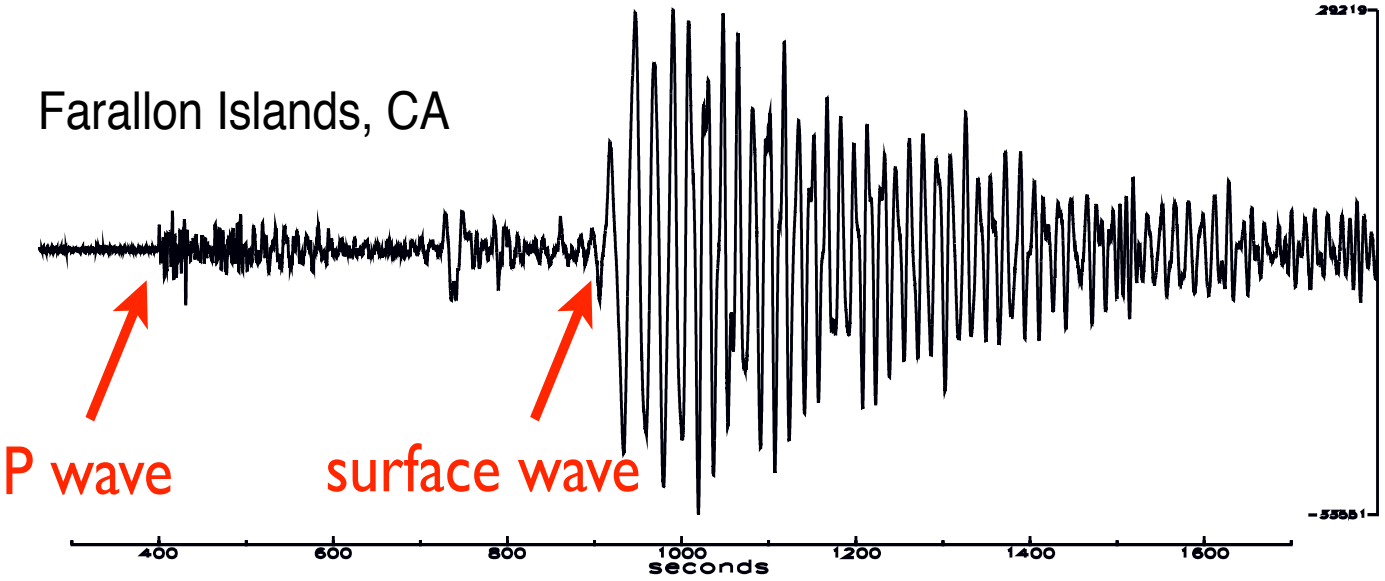
Mission Relevance

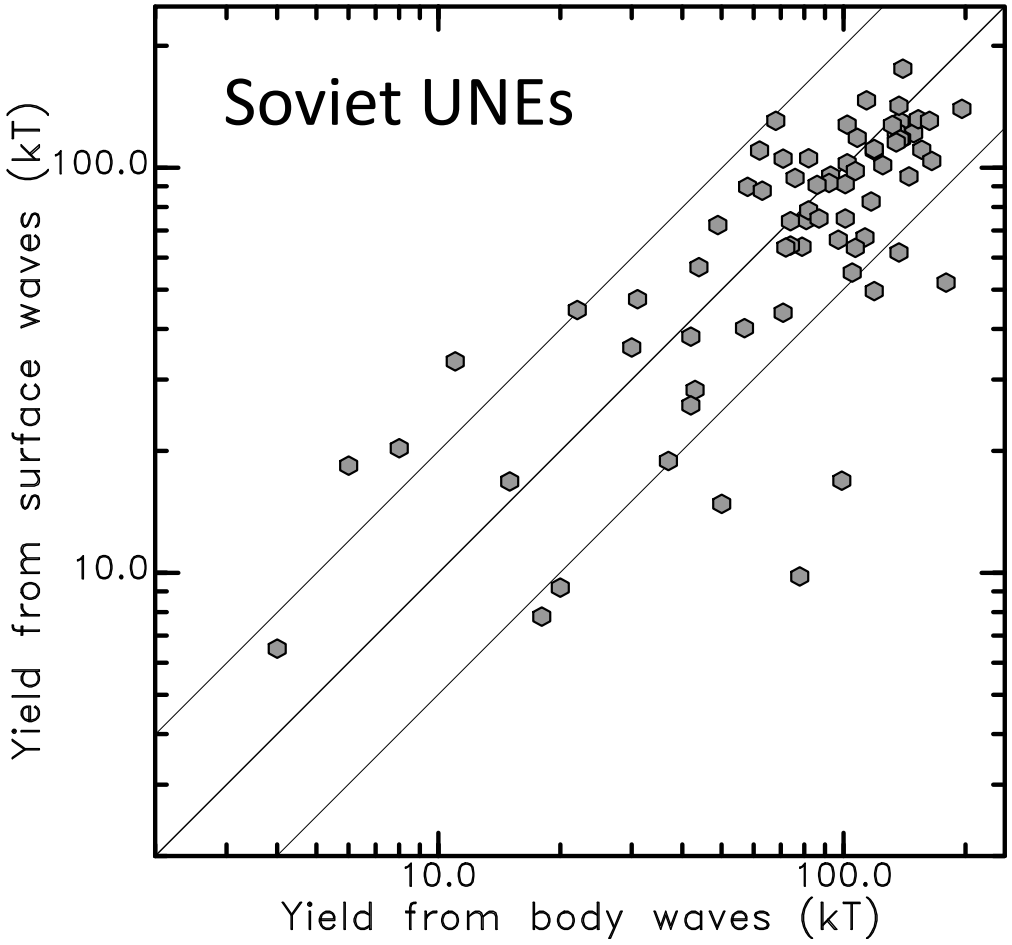
Improved seismological capabilities will

- Enhance the ability to monitor nuclear testing
- Improve the characterization of underground nuclear tests
- Build confidence and trust in monitoring capabilities
- Build preparedness for future testing, or claims of testing

Technical Approach

- mb and MS give different size estimates
- not due to observational uncertainties
- problem is with UNE source model



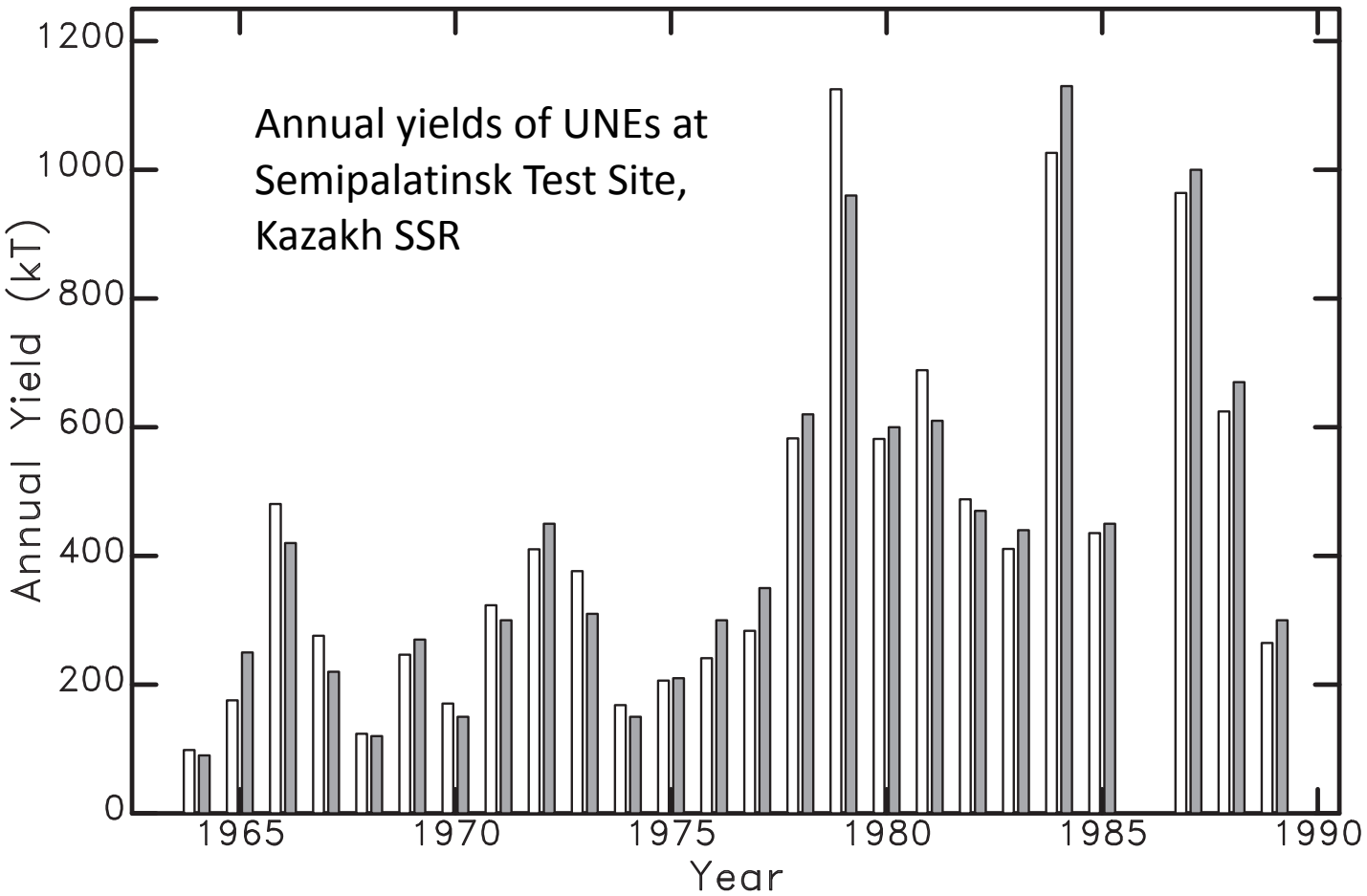


Ekström and Richards, 1994

Technical Approach

- mb predicts cumulative yield well
- mb = 4.55 + 0.75 log Y
- problem is with long-period waves

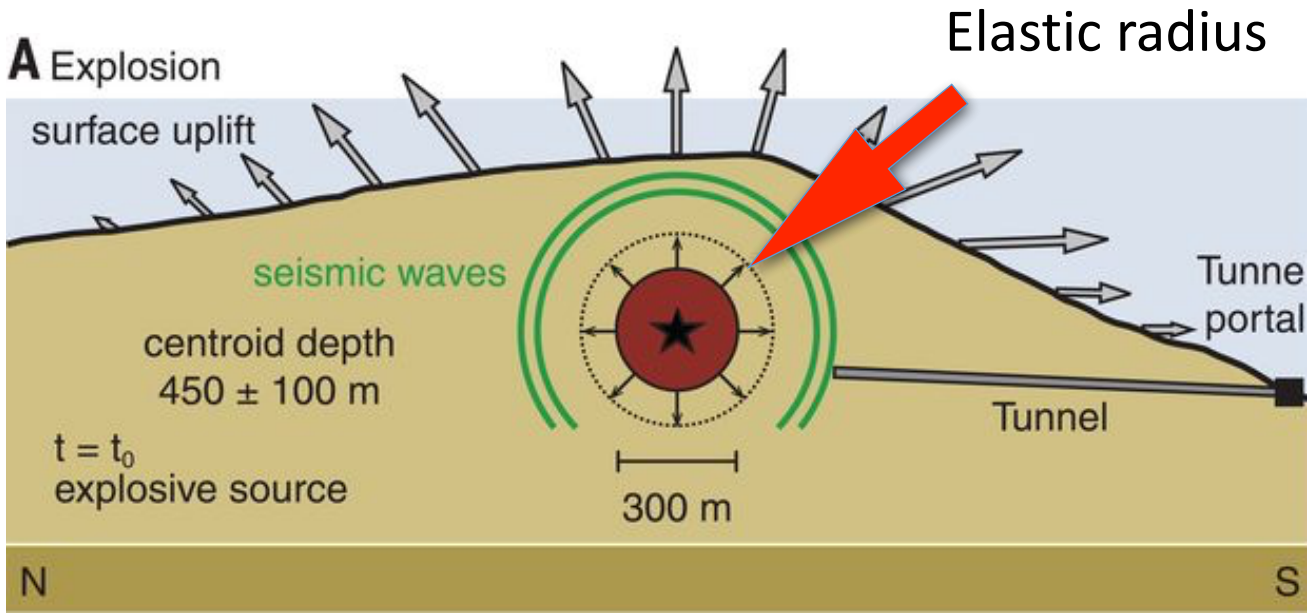
This is surprising, since we typically find that seismic sources are easier to model and understand at long periods



Howe, Ekström and Richards, 2020

Technical Approach

Mount Mantap, DPRK



modified from Wang et al., 2018

Classic UNE source model:
Pressure at the elastic radius

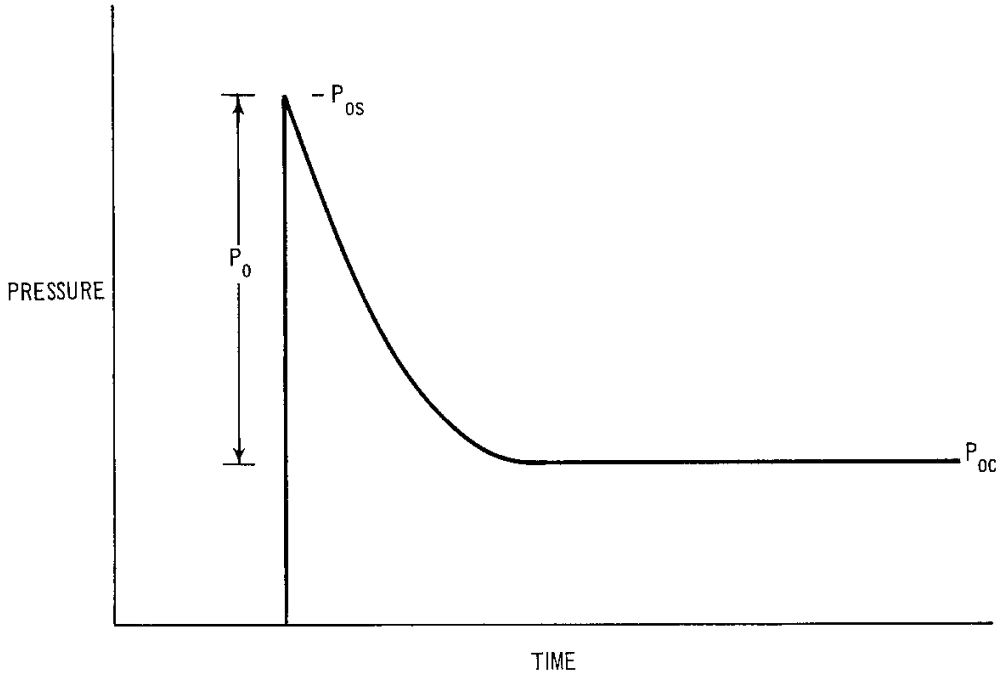


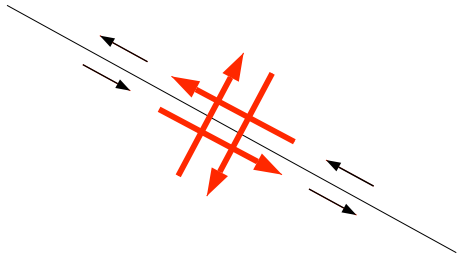
FIG. 1. Pressure profile at the elastic radius.

Mueller and Murphy, 1971

Technical Approach

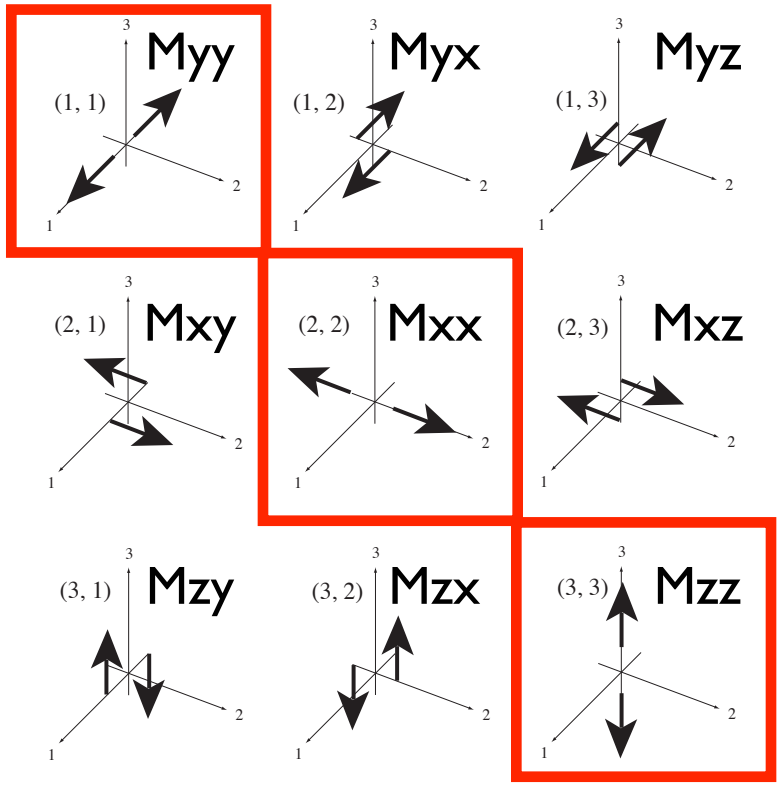
Seismologists understand very well how forces and force couples make elastic waves

Faulting force model



The elastic stress release in an earthquake is described by a double couple of forces

The nine dipoles of the seismic moment tensor



(Aki and Richards, 2002)

Technical Approach

An exotic example

A vertical impulse

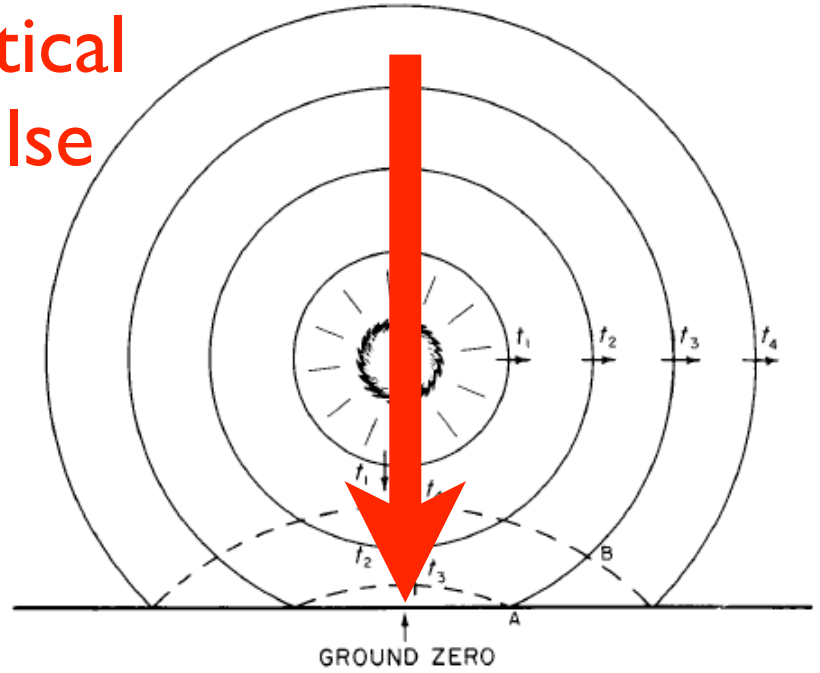


Figure 3.21. Reflection of blast wave at the earth's surface in an air burst; t_1 to t_4 represent successive times.

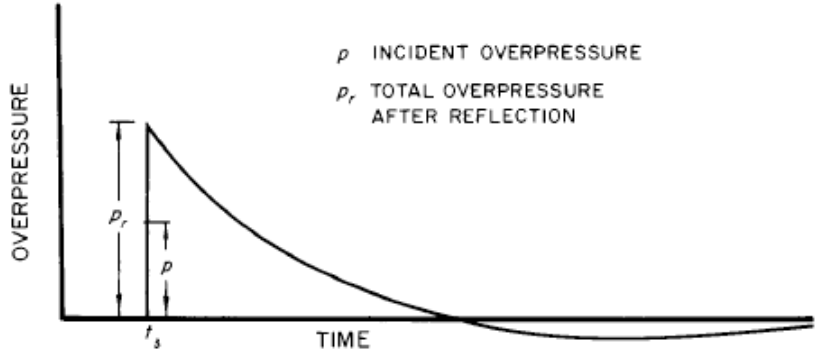
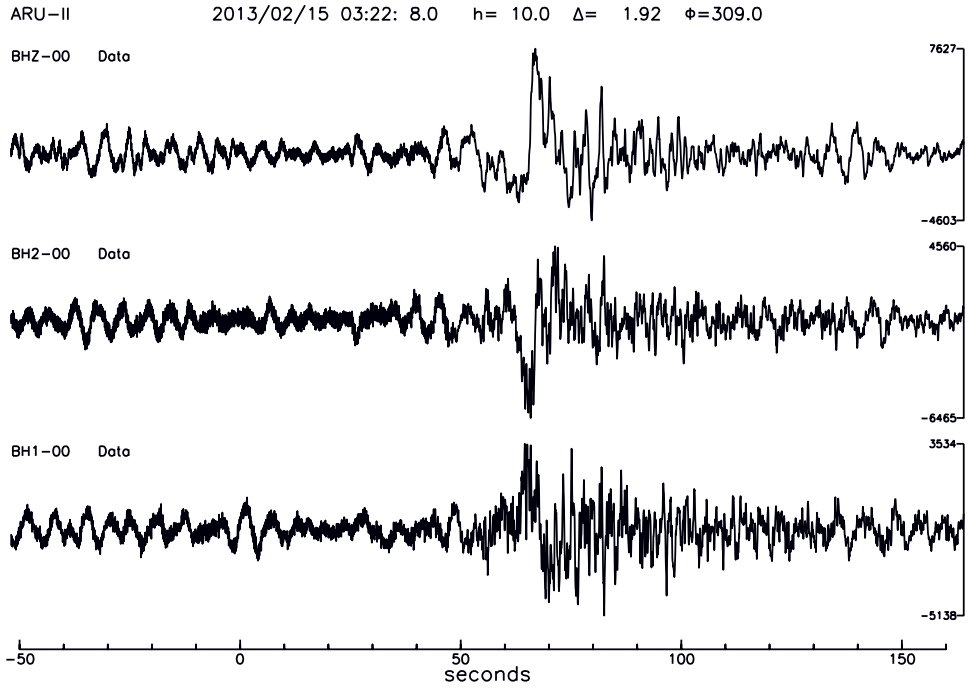


Figure 3.22. Variation of overpressure with time at a point on the surface in the region of regular reflection.

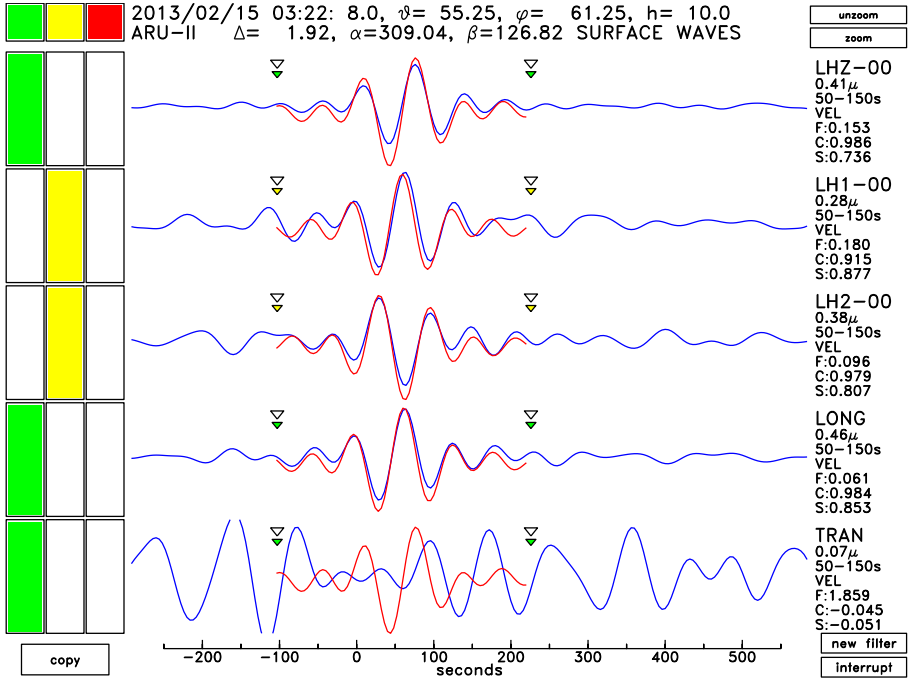
Technical Approach

Estimating the impulse on Earth from seismic data

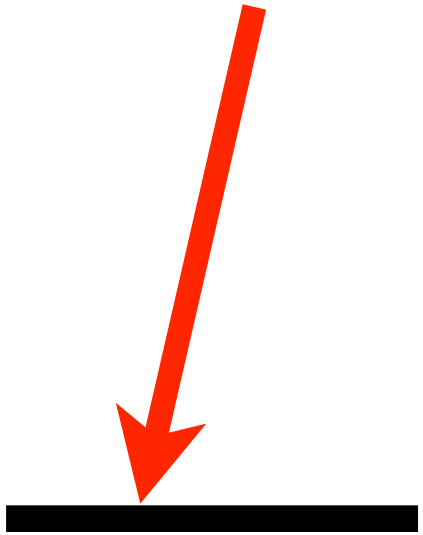
Collect available seismic signals



Invert using model seismograms



Result



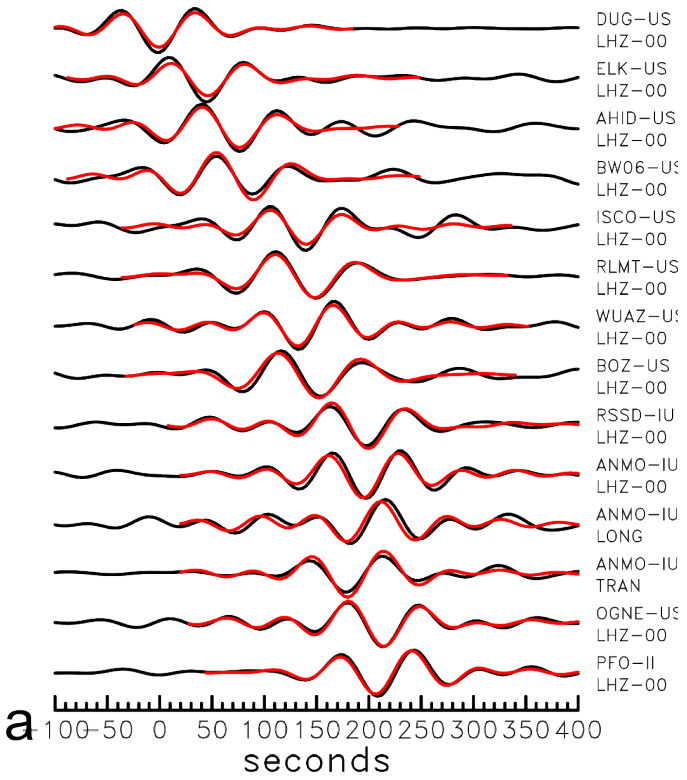
plunge 76 deg;
2.8×10^{17} dyne-s

Technical Approach

A second exotic example

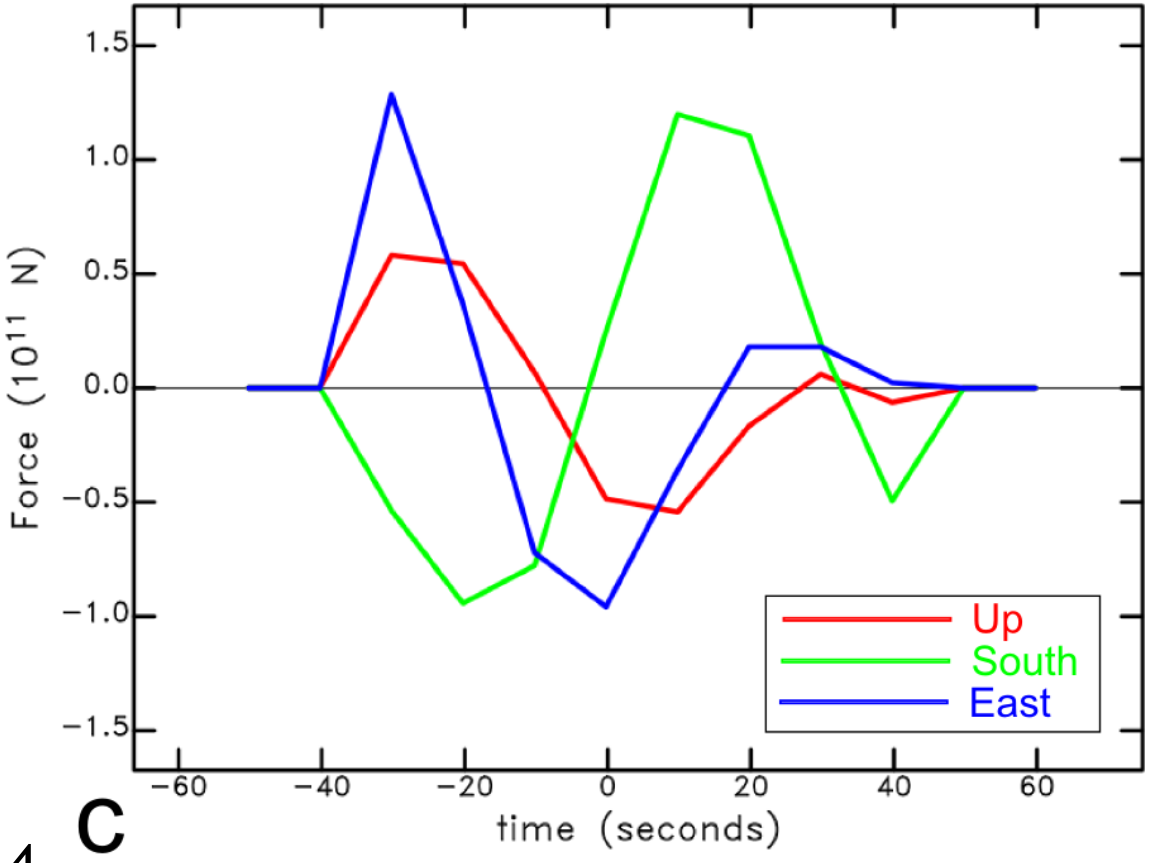
Technical Approach

Model the seismograms



Hibert, Ekström and Stark, 2014

Quantify the history of forces



Technical Approach

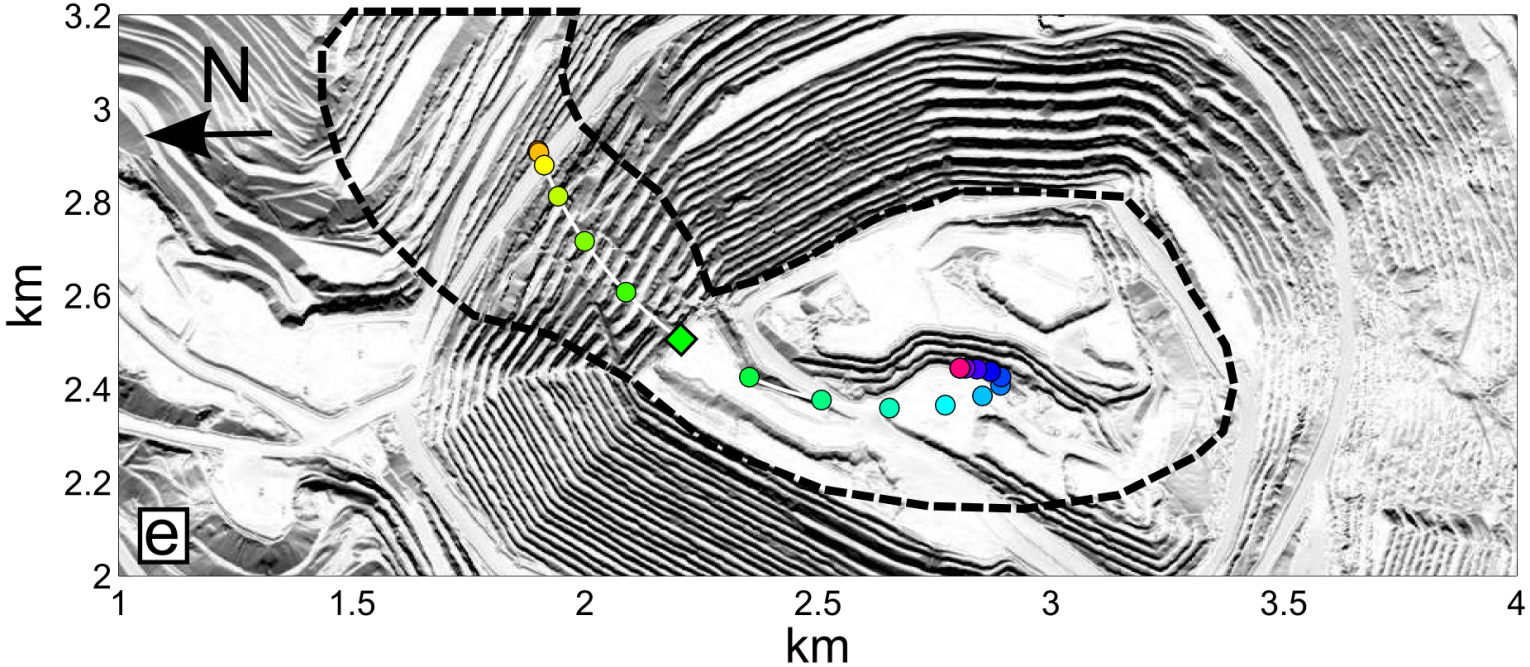
Physics

$$\mathbf{F}(\mathbf{t}) = -\frac{d(m\mathbf{v}(t))}{dt} = -\frac{d\mathbf{p}(t)}{dt}$$

$$\mathbf{I}(t) = \int \mathbf{F}(t)dt = -\mathbf{p}(t)$$

$$\int \mathbf{I}(t)dt = -\int \mathbf{p}(t)dt = -m\mathbf{D}(t)$$

Inverted geometry and mass agree with ground truth

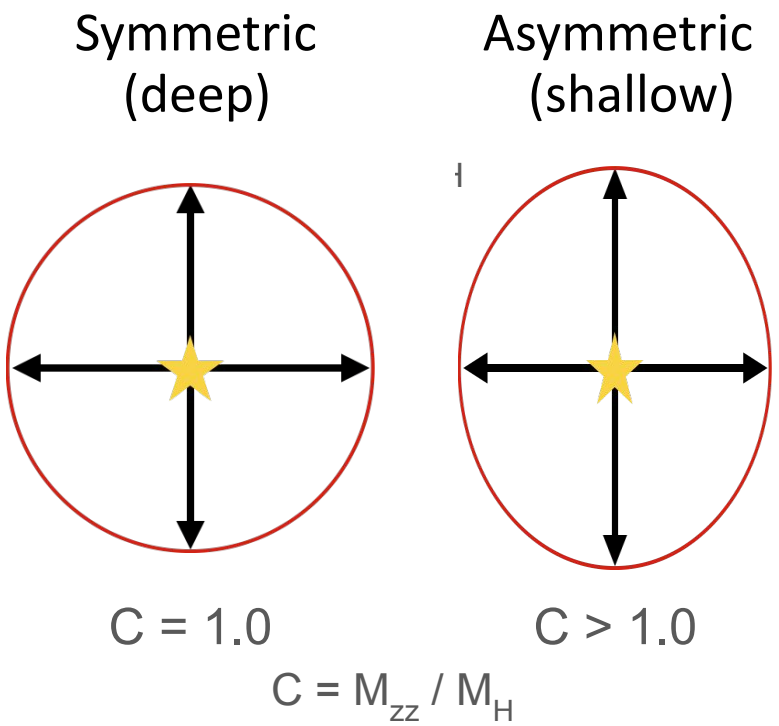


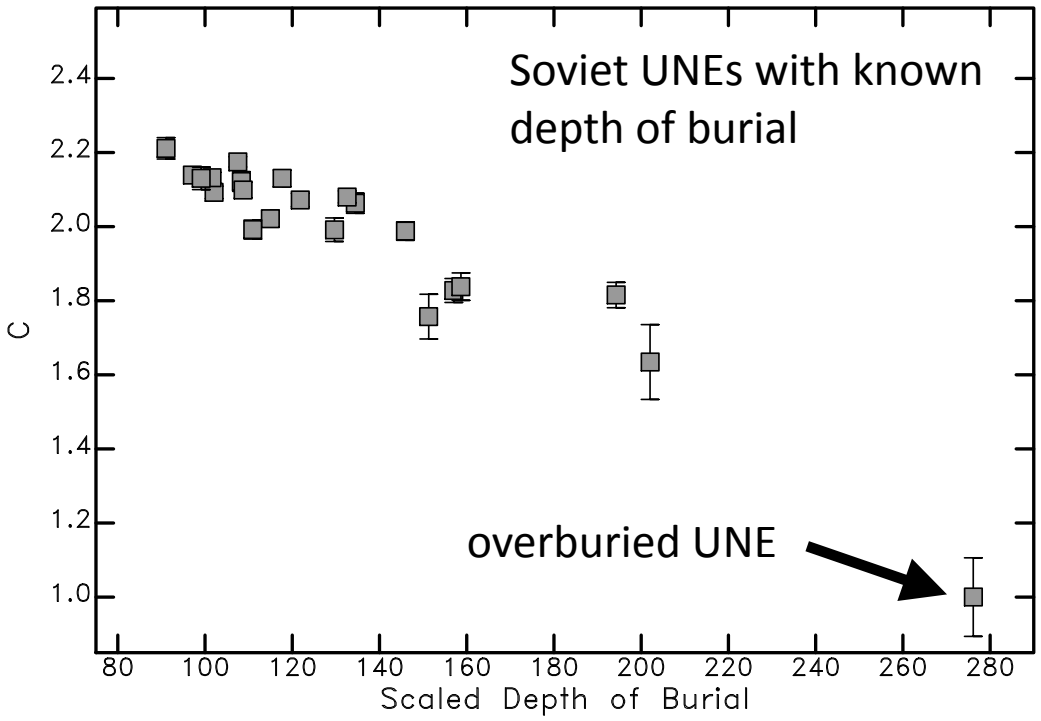
First slide: 70 million tons

Hibert, Ekström and Stark, 2014

Results

Strong sensitivity of explosion elastic source to depth of burial





Howe, Ekström and Richards, 2020

→ Large variations in surface-wave amplitudes (> 10)

Conclusion and Next Steps

1. The amplitude of long-period surface waves (used for MS) is very sensitive to the scaled depth of burial
2. Shallow explosions are described better with a dominant vertical force couple (C > 1.0) than an isotropic source
3. This explains scatter in yield estimates based on MS
4. This explains poor discrimination of deep UNEs

Continued work on this topic:

1. Investigation of other UNEs using legacy data
2. Comparison with Source Physics Experiment

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Kazakh NNC

Acknowledgements

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