



Analyzing Legacy Data from Nuclear Explosions Using Modern Approaches

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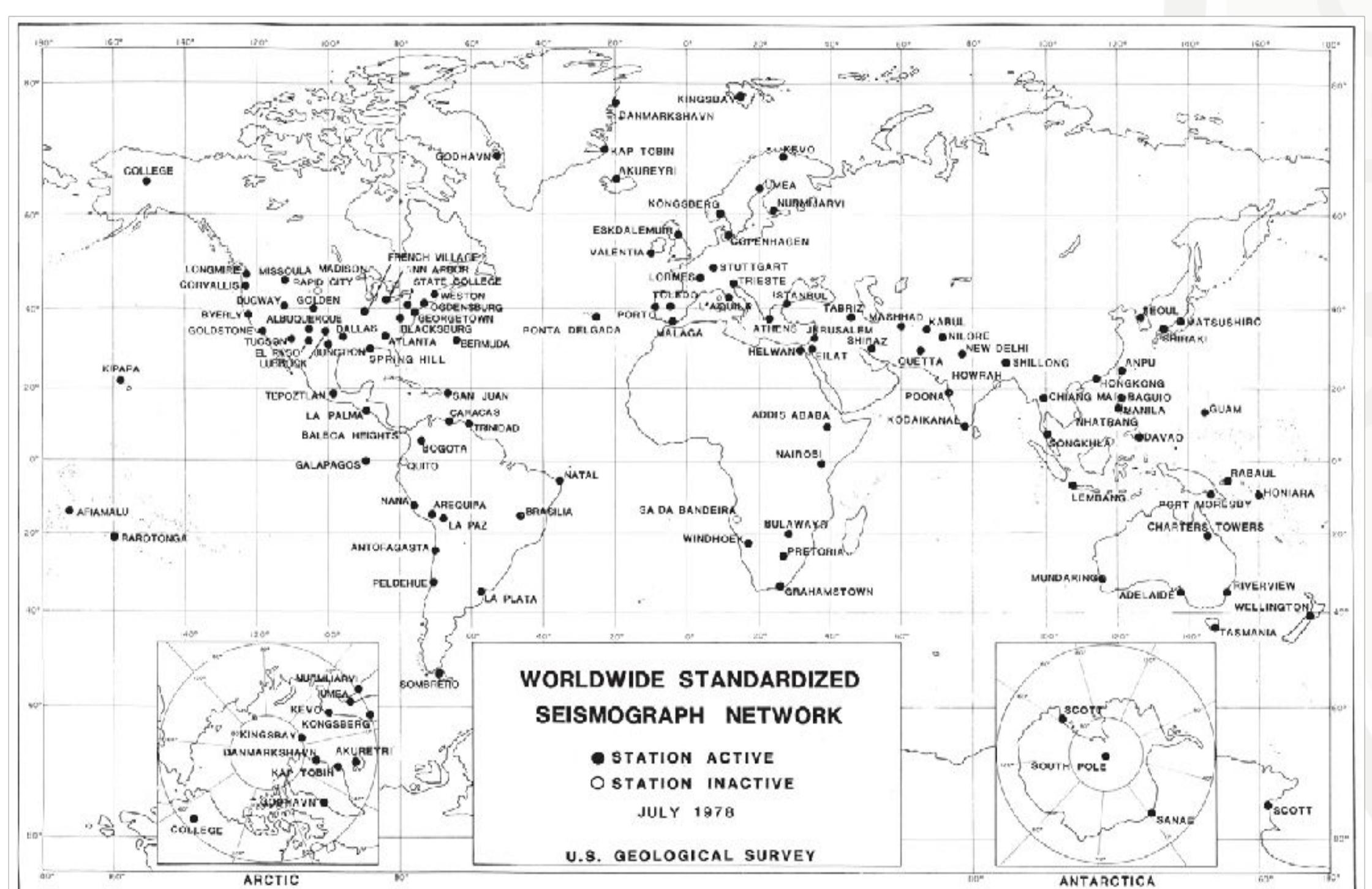
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Introduction and Motivation

The World-Wide Standardized Seismograph Network (WWSSN) was the first global seismic network, chartered in 1960 to monitor nuclear testing activity. At its peak, the WWSSN consisted of more than 100 stations with near-global coverage recording analog traces on photographic paper. Seismograms were recorded on photographic paper of 30 cm x 91 cm, with the seismic signal of a single component recorded as 24 traces, each an hour in length. Time marks, formed as portions of the trace vertically offset for two seconds, occurred once every 60 seconds. Copies of the recorded seismograms were photographed and preserved on 70-mm and 35-mm film chips for storage and distribution. Near-complete collections of these data are currently held at the Albuquerque Seismological Library, the Earthquake Research Institute in Japan, and the Lamont-Doherty Earth Observatory (LDEO) of Columbia University.

This trove of analog data has recently become readily analyzable due to advances in automated digitization, namely the Harvard-developed DigitSeis software. As these data constitute the highest-quality seismic records of a variety of underground and atmospheric nuclear tests, applying modern techniques such as source modeling and relocation could allow us to extend our understanding of seismic and acoustic propagation physics. We are particularly interested in verifying recent results on the relationship between scaled depth of burial and the excitation of long-period surface waves. Furthermore, given the present debate over the future of analog seismological archives, we hope to establish best practices and resources for high-quality digitization.

Here, we present results on the capabilities and limitations of digital analysis performed on legacy data recorded during a 1968 earthquake sequence and a 1965 Semipalatinsk Test Site shallowly buried UNE (Chagan).



Above, a map of WWSSN stations. Source: Peterson and Hutt, 2014. USGS Open-File Report, "World-Wide Standardized Seismograph Network: A Data User's Guide."

Mission Relevance

By comparing observations of surface-wave excitation by UNES with ground truth yield levels and scaled depths of burial, we heighten our ability to seismologically detect and characterize nuclear sources. As seismic signals are among the first detectable indicators of a nuclear test, expanding our understanding of propagation physics in this way supports the nuclear verification capabilities of the NNSA.

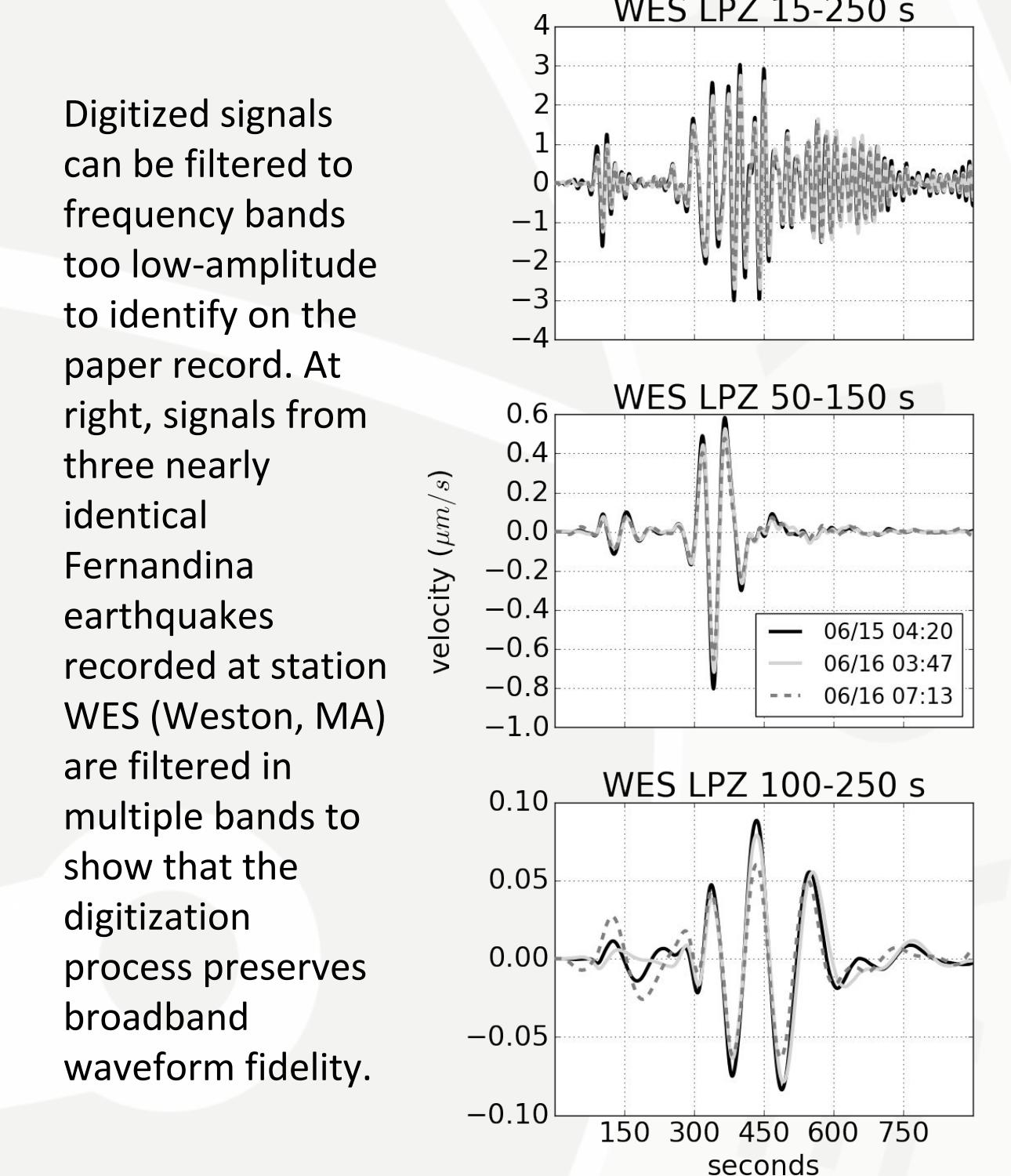
Technical Approach

- We extract film chips from the LDEO archive and scan them at a resolution of approximately 14 pixels/mm on the paper record. The scans are digitized using DigitSeis.
- We digitize 270 hours of three-component data from 30 stations recorded during the 1968 earthquake sequence at Fernandina Island (part of the Galápagos chain). We apply the Global Centroid-Moment Tensor algorithm, currently deployed to analyze global $M \geq 5$ earthquakes, to attempt to resolve the source characteristics of 13 moderate-sized ($M \approx 5$) earthquakes, and we apply a surface-wave-correlation based relative relocation method to improve originally reported location estimates.
- We additionally analyze the WWSSN records which recorded the 1/15/65 Chagan blast, which had a DOB of approximately 200 m and a 140 kt yield, to locate seismic and infrasonic arrivals. We digitize detected signals and present examples below.

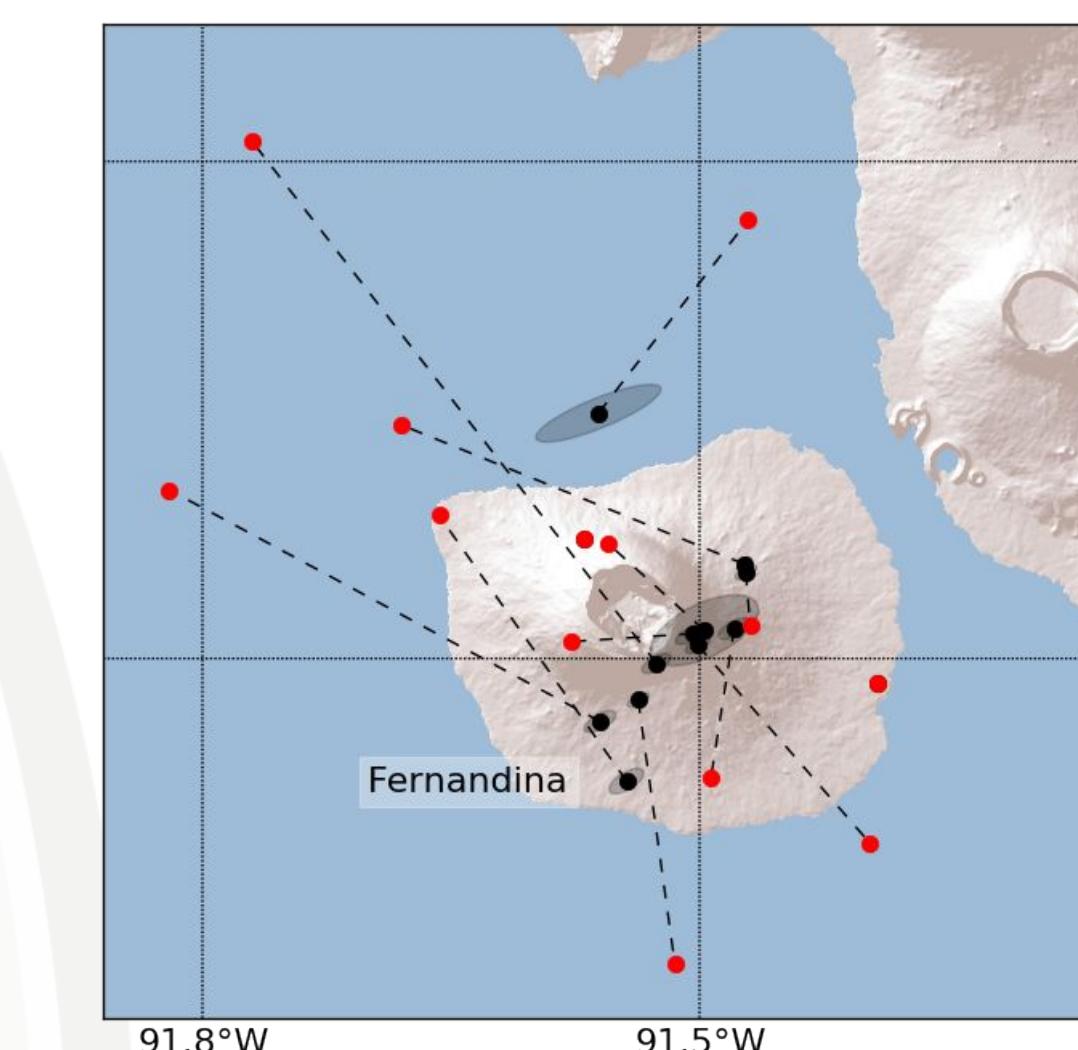
Results



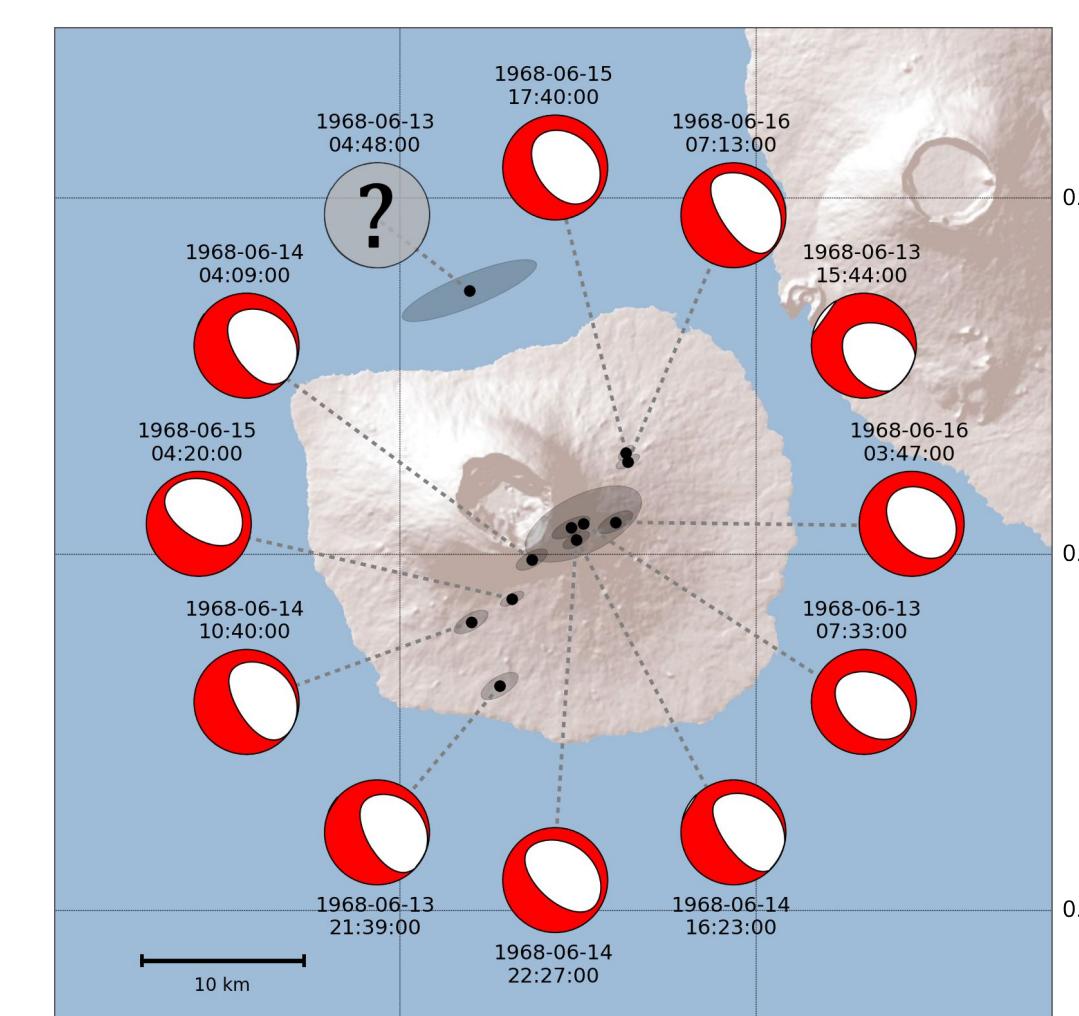
We identify factors affecting the efficiency of digitizing. At left, if the distance separating elevated time marks from the main trace is inadequate, the time to digitize the signal increases and the quality of the digitized signal is potentially degraded (signal from station BKS, Berkeley, CA). At middle, higher-magnification stations are more likely to produce trace crossings, which are time-intensive to correct (signal from station CAR, Caracas, Venezuela). Data from high-quality stations can be digitized as quickly as 5 minutes for 1 hour of data (at right, signal from station AAM, Ann Arbor, MI). Low-quality stations can take up to 25 minutes for 1 hour of data, but their inclusion is sometimes necessitated by azimuthal gaps in station distribution or lack of sufficient high-quality data.



Digitized signals can be filtered to frequency bands too low-amplitude to identify on the paper record. At right, signals from three nearly identical Fernandina earthquakes recorded at station WES (Weston, MA) are filtered in multiple bands to show that the digitization process preserves broadband waveform fidelity.



Surface wave relocations display significantly improved clustering. Above, red dots represent initial locations reported by the International Seismological Centre; 11 of the 13 events were successfully relocated (black dots). Note that these relocations, though robust, are relative. Shaded ovals represent location uncertainties derived from subsampling of the data.



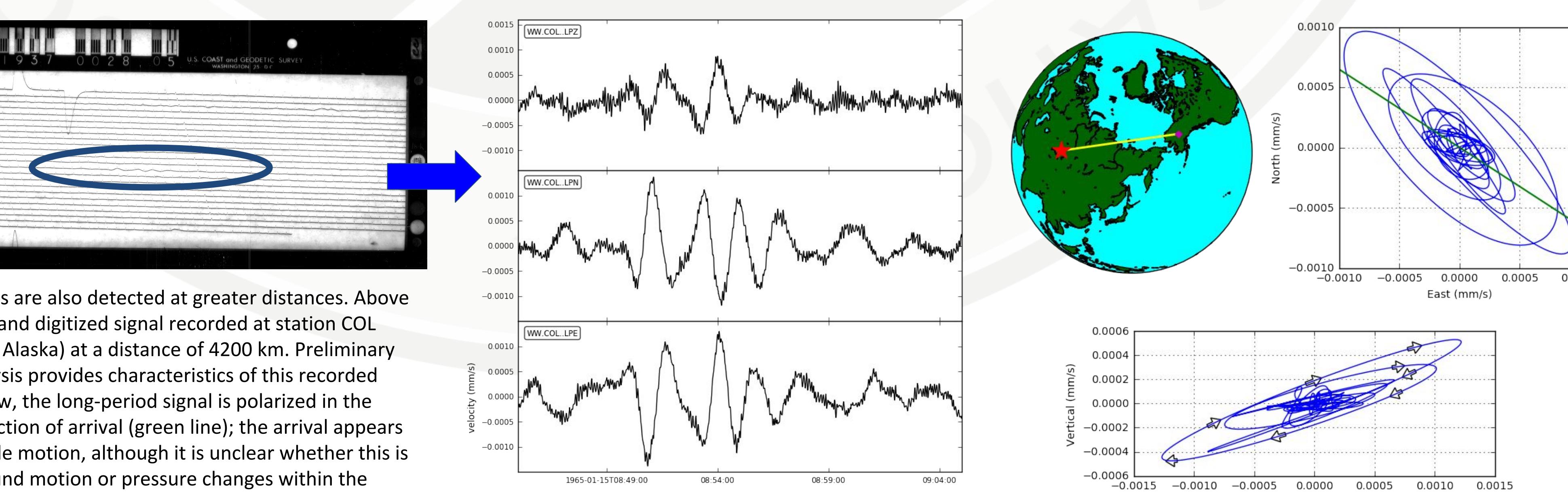
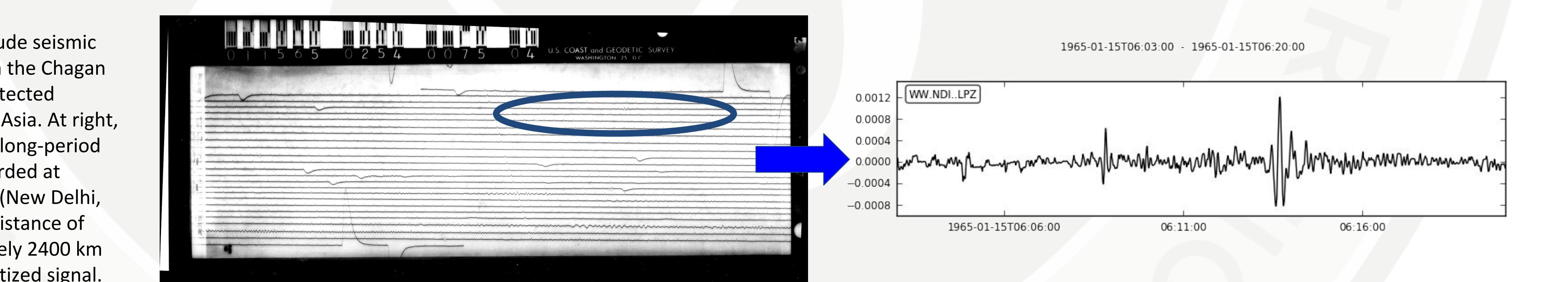
We retrieve 11 moment tensors for 13 moderate-sized earthquakes, illustrated here, using as few as 6 stations. These solutions can capture subtle elements of the source, such as deviations from a double-couple mechanism.

Conclusion

- We determine the feasibility of applying seismological techniques for event characterization to legacy data and provide a framework for improving the efficiency of future digitization projects
- The detection of seismic and infrasonic signals resulting from an UNE opens the door to further physical analysis

Next Steps

- Continue to digitize and analyze data from UNEs to explore relationship between scaled DOB and excitation of long-period surface waves
- Construct model of pressure wave-seismic recorded interaction



Infrasound arrivals are also detected at greater distances. Above and right, record and digitized signal recorded at station COL (College Outpost, Alaska) at a distance of 4200 km. Preliminary polarization analysis provides characteristics of this recorded signal. In map view, the long-period signal is polarized in the approximate direction of arrival (green line); the arrival appears to induce prograde motion, although it is unclear whether this is a function of ground motion or pressure changes within the instrument chamber.

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