6.6 Utilizing Lightning Locations to Optimize and Quality-Control Seismic Data

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1. ABSTRACT

The University of California, San Diego's Array Network Facility (ANF) has teamed with Earth Networks in order to utilize detections from their Earth Networks Total Lightning Network (ENTLN) for seismic data analysis purposes. The combination of real-time seismic data, ranging from 40 to 200 samples per second, and ENTLN detected events provides researchers with an enhanced perspective of seismic signals recorded by the array. This directly translates to higher efficiency in automated processing, analyst reviewing, and verification of solutions of seismic and acoustic events. Having identifiable events spread across multiple stations and traveling through multiple mediums (ground and atmosphere) also improves the quality of the network by allowing a better evaluation of the signals and correlation with ground-truth events. The lightning source locations from ENTLN make it possible to identify signals within the seismic data that might otherwise be impossible to categorize. With this multidisciplinary integration of data sources it may also be possible to complement current severe weather detection systems utilizing real-time seismic data.

2. INTRODUCTION – ANF BACKGROUND

The ANF team at UC San Diego specializes in real-time data acquisition, quality control, and dissemination of seismic and meteorological data from two main seismic networks: Anza and USArray. The Anza network comprises broadband seismic stations across Southern California that have been in operation through UC San Diego since 1982. The USArray Transportable Array Network is part of the National Science Foundation's Earthscope initiative and is characterized by a rolling deployment of over 400 stations equipped with broadband seismometers, surface pressure and infrasound equipment (Tytell et al., 2011, Vernon et al., 2011, Vernon et al. 2012). The ANF also collaborates with the High Performance Wireless Research and Education Network (HPWREN), an Applied Network Research (ANR) project at UC San Diego. HPWREN utilizes cameras and additional environmental sensing equipment on remote sites throughout Southern California to monitor environmental conditions in real-time as well as to aid research, education, and public safety.

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3. MAIN ISSUE: THUNDER NOISE IN SEISMIC DATA

A seismic data analyst is trained to identify characteristic features within the waveforms of velocity or acceleration of ground motion in order to isolate an earthquake signature. Seismometers can detect very small ground motions regardless of their cause. Seismic recordings always include "noise" signatures (any detectable movement in the data that is unrelated to earthquake features) resulting from mechanical, anthropogenic, wildlife and even natural sources. The seismic data analyst must be able to decipher what is noise and what is an actual earthquake observation, though sometimes the noise feature itself can mimic an earthquake signature and disrupt the analysis process. This is where thunder noise becomes an issue.

A typical earthquake signature from a local seismic event located at less than 1 degree from an array of stations can easily be confused with a series of thunderclaps from lightning strikes up to a few kilometers away from the same array. Figure 1a depicts a typical local seismic event within the center of the Anza network on August 13th, 2012 (UTC time). Figure 1b depicts a series of thunderclaps that occurred only a couple of minutes before this earthquake resulting from an air-mass thunderstorm that also passed through the center of the Anza network. For the purpose of this paper we will be examining several lightning events from this same air mass thunderstorm. The time window shown in both figures is one minute. In some cases the emergence of the initial thunderclaps and the length of the noise events appear very similar to a local earthquake signature. It is this reason why the ANF began collaboration with Earth Networks and their ENTLN so that thunder noise features resulting from nearby storms can easily be isolated from seismic data.

4. CHALLENGE – LIGHTNING EVENT COVERAGE AREAS

A lightning event is usually comprised of multiple lightning strikes that are detected within the same fraction of a second. Regardless of inter-cloud (IC) or cloud-to-ground (CG) strikes within the event, or a combination therein, the usual result is a large coverage area in both the vertical and horizontal planes. This is vastly different from a local earthquake signature that can be easily pinpointed to a specific epicenter. With a lightning event the entire length of each lightning strike is generating a range-sourced thunderclap as one part of an acoustic collection of thunderclaps.

To help illustrate the difficulty that this poses for noise identification we use an example from the August 13th air mass thunderstorm. HPWREN station Mesa Grande, located in northeast San Diego County (Figure

2 – daylight picture) easily captures one lightning event with its rapid-response motion capture camera (Figure 3). The time of the observed event is approximately 3:07:14 UTC according to the camera.

Turning to the ENTLN data, we are able to parse out a lightning event with three CG strikes occurring at 3:07:13 UTC, and when mapped reveal a similar pattern to the camera observation (Figure 4). The approximate distance between the further of the two CG strikes is 7.5 km at the surface, and this is in addition to the vertical ranges that are expected to exceed 14 km. With ground-truth now established, we have to assume that this entire range produces a uniform acoustic source.

5. THUNDER APPEARANCE IN SEISMIC

The main problem involving the range-source of lightning has been identified and we need to determine how the resulting thunderclap noise signatures are represented in the seismic data. We can start with one lightning event containing four individually detected strikes within the Anza network, the first two of which factor more prominently (Table 1). As a point of reference we can also plot these first two strikes on a map to determine where the nearest stations are located (Figure 5). We can then look at the seismic waveforms using the general range-source of this lightning event as the reference origin, and then sort the waveforms to display in order of sound propagation travel times of 340 to 350 m/s (Figure 6). We then see the noise features from this thunderclap group stand out clearly even though it is difficult to determine which specific portions of the noise plumes are associated with which lightning flash from the main event. It is expected that there will be signal interference, amplification and general distortion as the acoustic signals are generated over a period of several seconds.

6. EARTHQUAKE EXAMPLE

The previous example demonstrates the feasibility of loading lightning events into a companion database to seismic events. From that point it is much easier for the seismic data analyst to isolate lightning noise detections from seismic observations.

Figure 7 shows a series of seismic waveforms from the same earthquake example described earlier, except now the earthquake and the thunder noise preceding it are unsorted. Without knowledge of the air mass thunderstorm system passing through the network the seismic analyst can easily mistake the preceding thunder noise as another earthquake. When we load the ENTLN data as a detection source, however, we find there is a lightning event that matches the noise plumes with a move-out of 340 to 350 m/s. The waveforms are re-sorted using that lightning event as the detection source and the thunder noise plumes can then be isolated from the earthquake event (Figure 8).

7. DISCUSSION AND CONCLUSION

Seismic data analysts need to be able to identify sources of noise within seismic data that originate from a variety of sources. Of these various noises, thunder can prove to be the greatest challenge. The large coverage area and extended duration of thunder noise signatures from lightning events can be difficult to determine without proper tools or methods. Utilizing a comprehensive lightning detection database, such as Earth Network's ENTLN, it is possible to isolate thunder noises from seismic data and facilitate more efficient data processing from the seismic data analyst. Therefore it is very feasible to build a database of detections based on lightning events and to load that as a tool for seismic data processing. Furthermore, these seismic detections of thunderclap noise can potentially be used as an additional ground-truth catalog provided to now-casters for severe storm and lightning verification.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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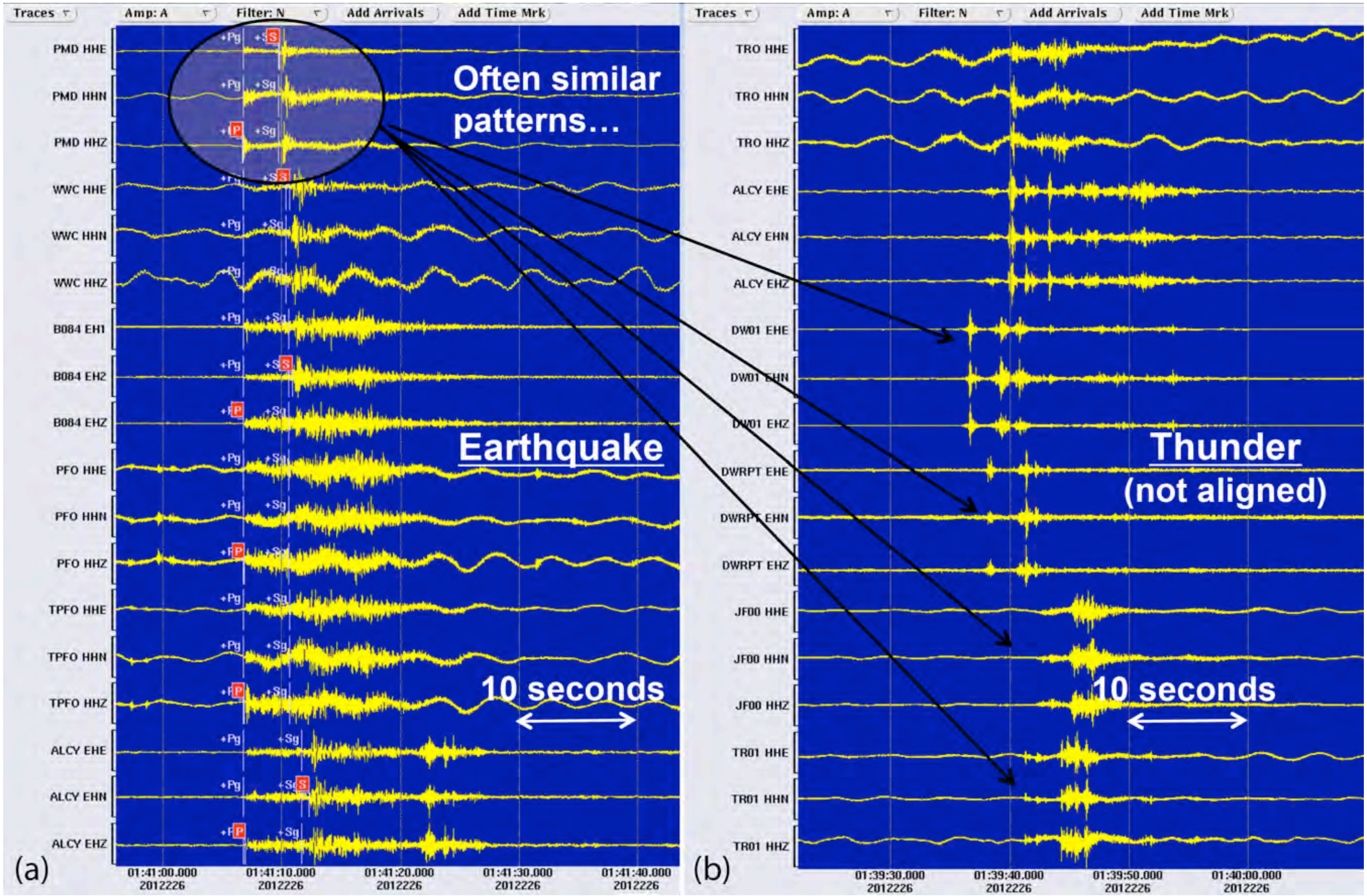

Figure 1 – Vertical (HHZ or EHZ) and horizontal (HHE, HHN or EHE, EHN) channels at each station depict a standard local earthquake (a) and thunder noise from an air mass thunderstorm (b). HH channels are sampled at 100 sps, while EH channels at 200 sps. The patterns can often appear very similar. Reference time is 10 seconds between time bars.

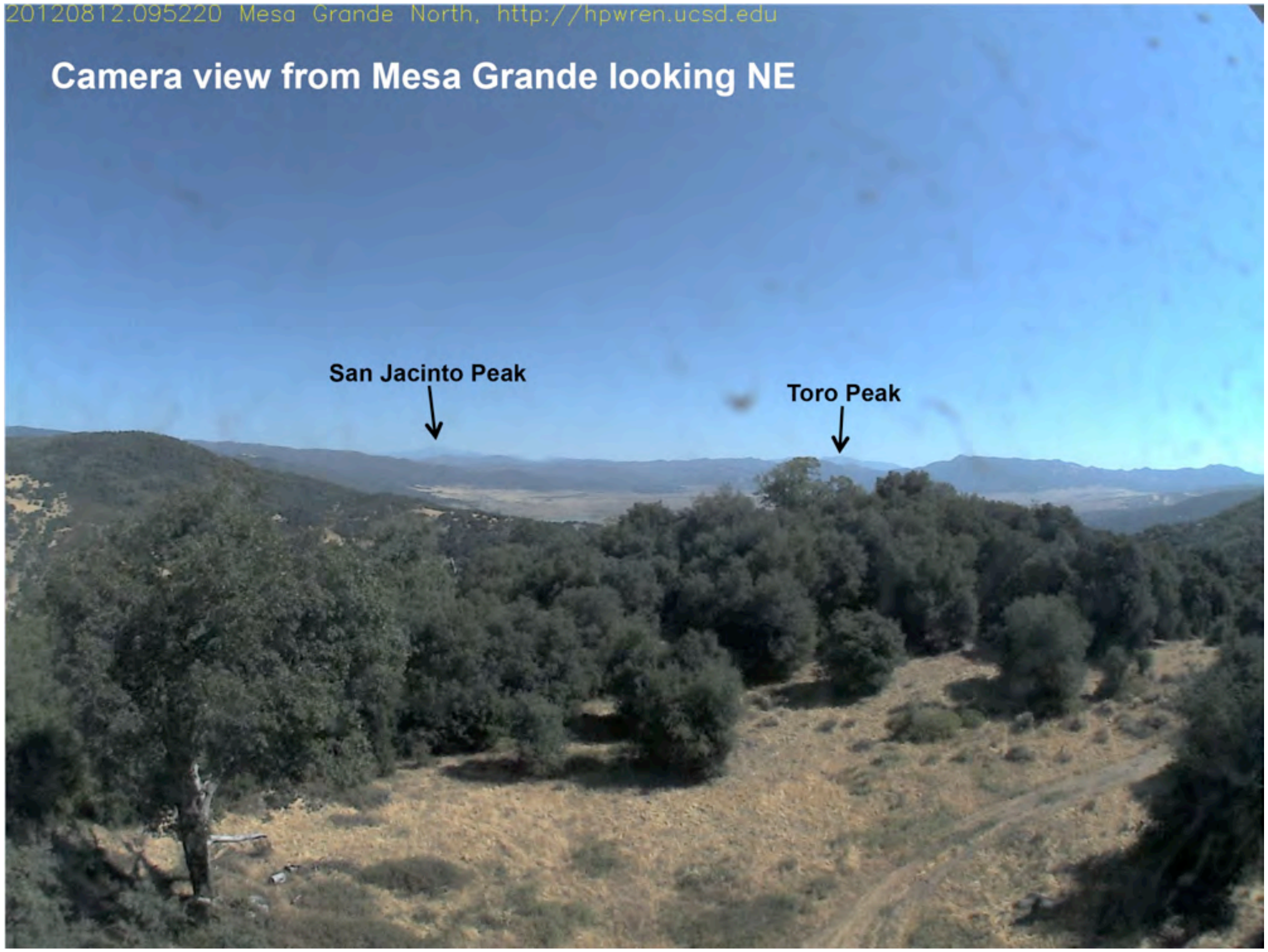

Figure 2 – HPWREN camera on Mesa Grande mountain ridge looking northeast to Toro Peak and San Jacinto Peak in Southern California.

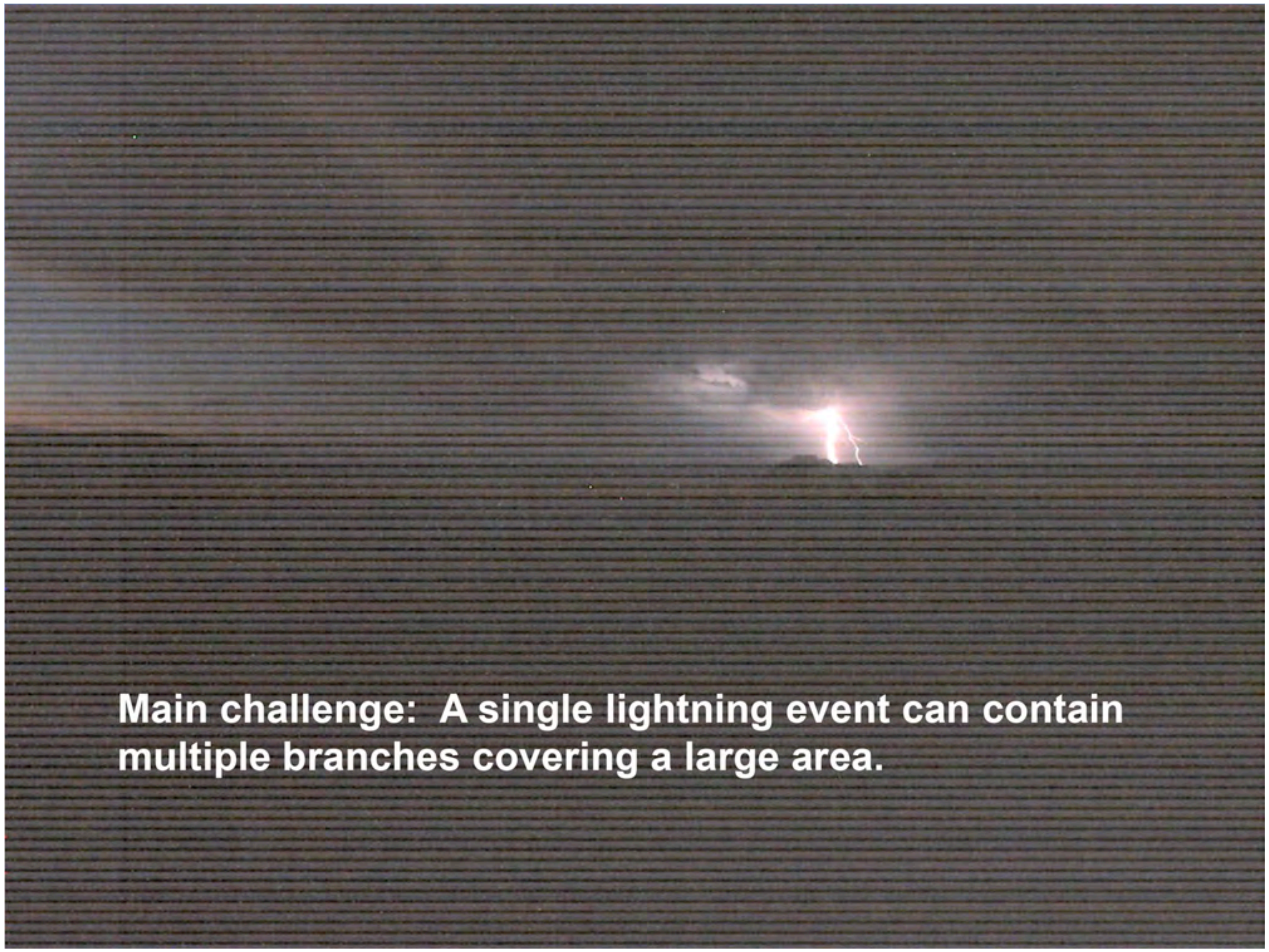

Figure 3 – Same as Figure 2 but motion-capture detection of lightning strike from air mass thunderstorm at ~ 3:07:13 UTC.

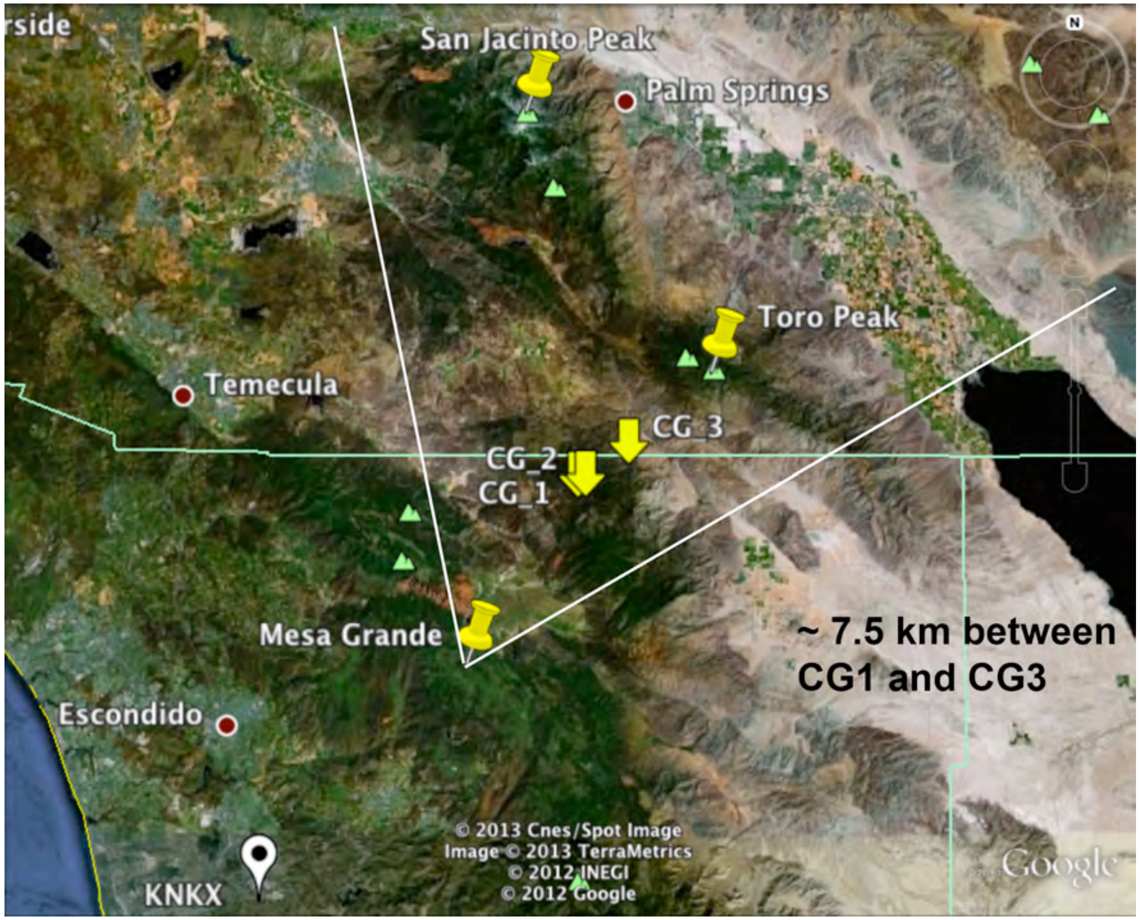

Figure 4 – Approximate view range of HPWREN's Mesa Grande camera with Toro Peak, San Jacinto Peak and the three CG branches of the motion-captured lightning event displayed.

lat	lon	altitude (km)	time	type
33.5243	-116.4387	14.4427	8/13/2012 (226) 2:34:15.32626	IC
33.5169	-116.4508	0	8/13/2012 (226) 2:34:15.37642	CG
33.5008	-116.5121	0	8/13/2012 (226) 2:34:15.46867	CG
33.5201	-116.3625	0	8/13/2012 (226) 2:34:15.52661	CG

Table 1 – A different lightning event group with 1 IC branch and 3 CG branches (hereby referenced as IC_1, CG_4, CG_5 and CG_6 respectively). IC_1 and CG_4 (the first two rows) factor more prominently in this example.

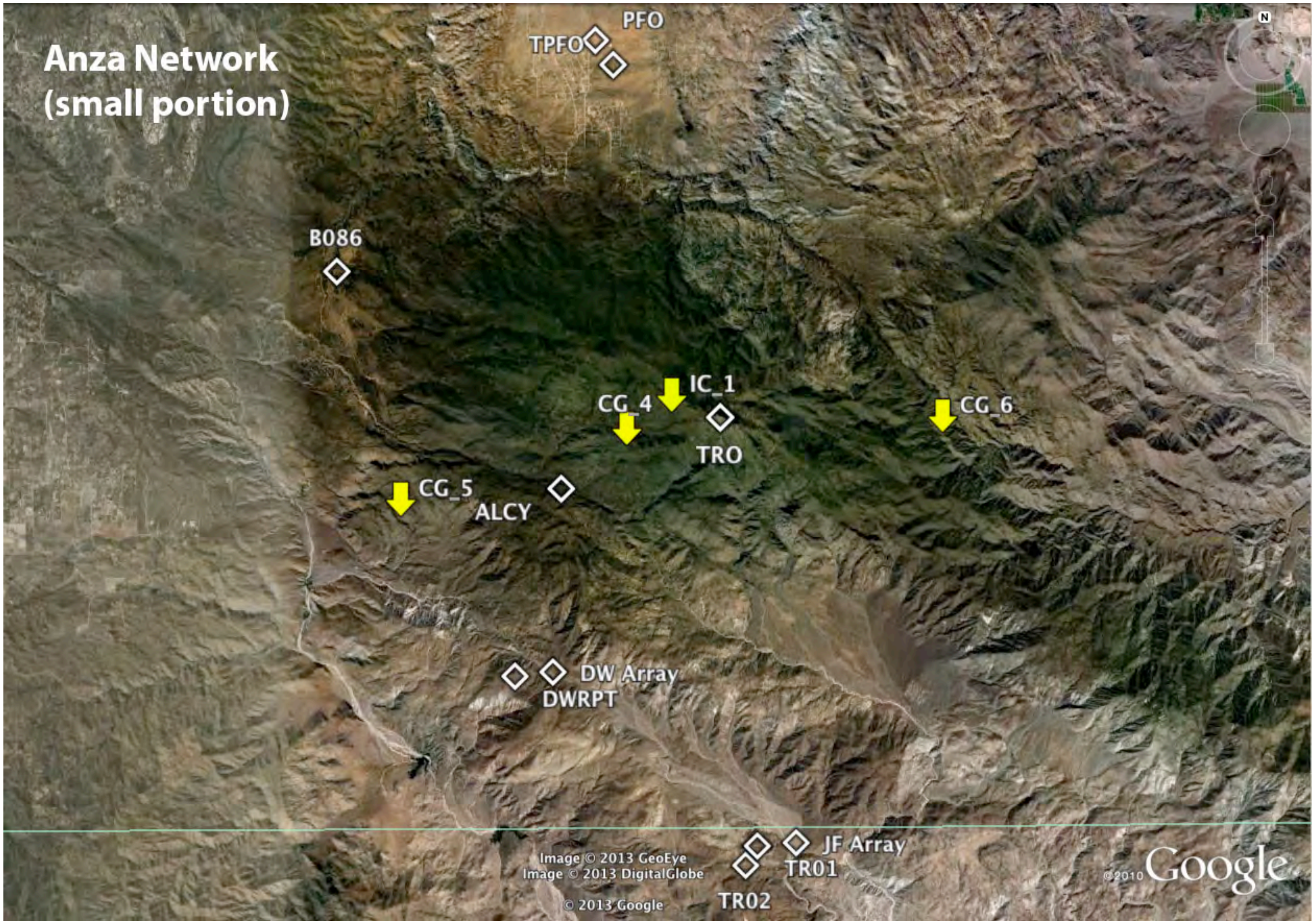

Figure 5 – The lightning event from Table 1 mapped onto Toro Peak within a small portion of the Anza seismic network.

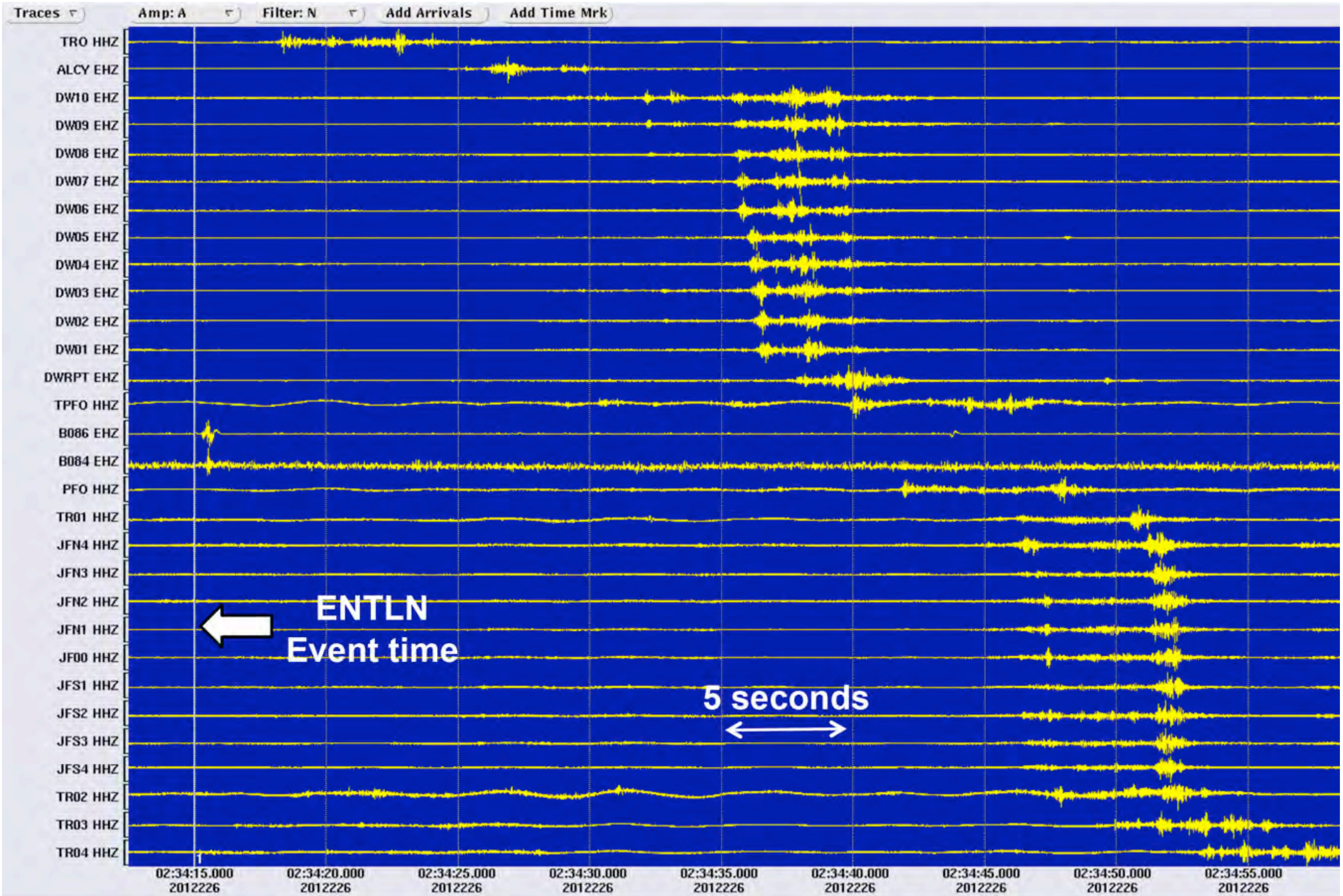

Figure 6 – Waveform data from the Anza stations mapped in Figure 4 but rearranged to display the travel-time move-out of the lightning event indicated in Table 1. The event time from the ENTLN is shown. The noise plumes match a speed-of-sound move-out of 340 to 350 m/s for IC_1 and CG_4.

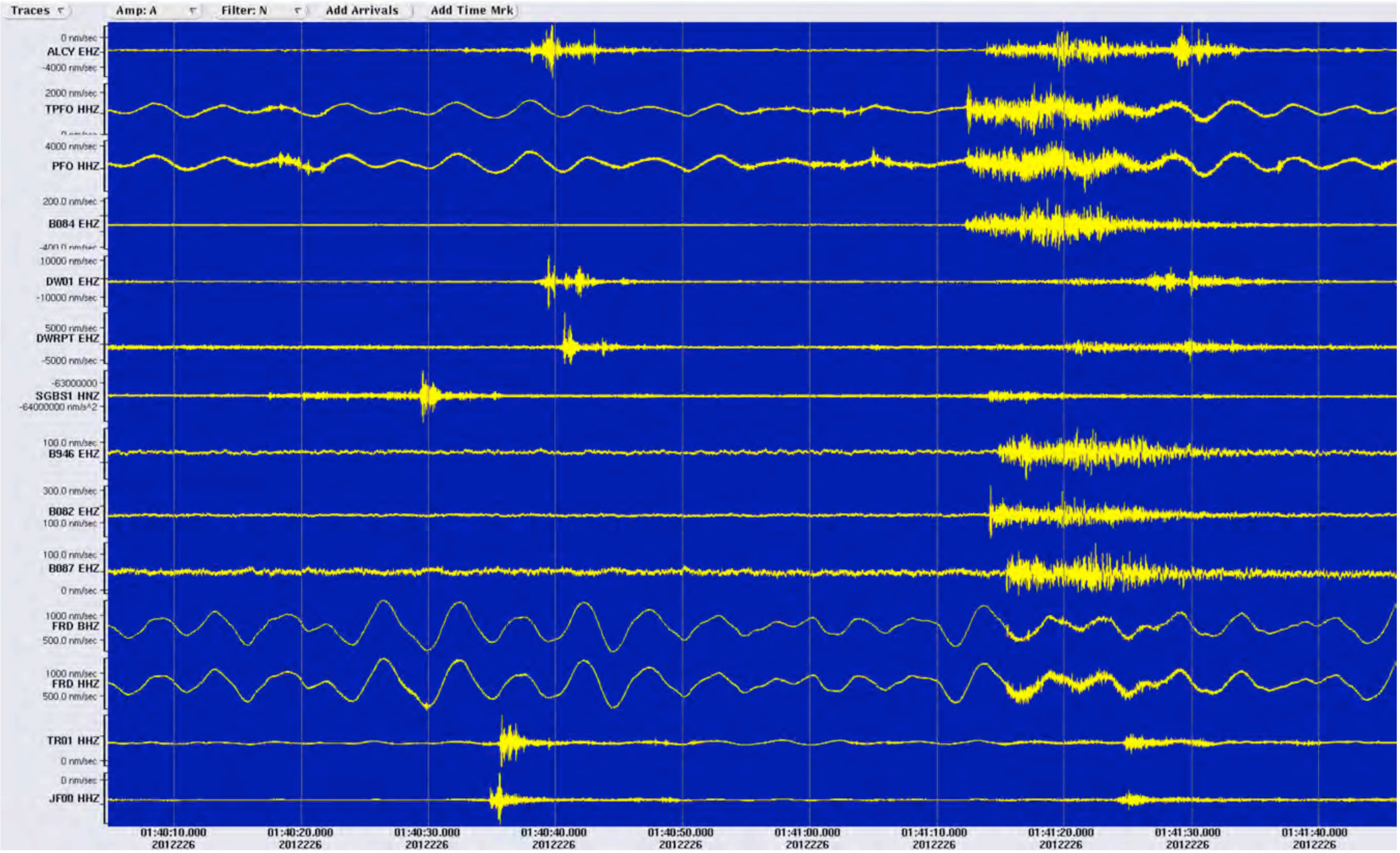

Figure 7 – The earlier earthquake and thunder noise from Figure 1 displayed in the same time window and not sorted in any specific order.

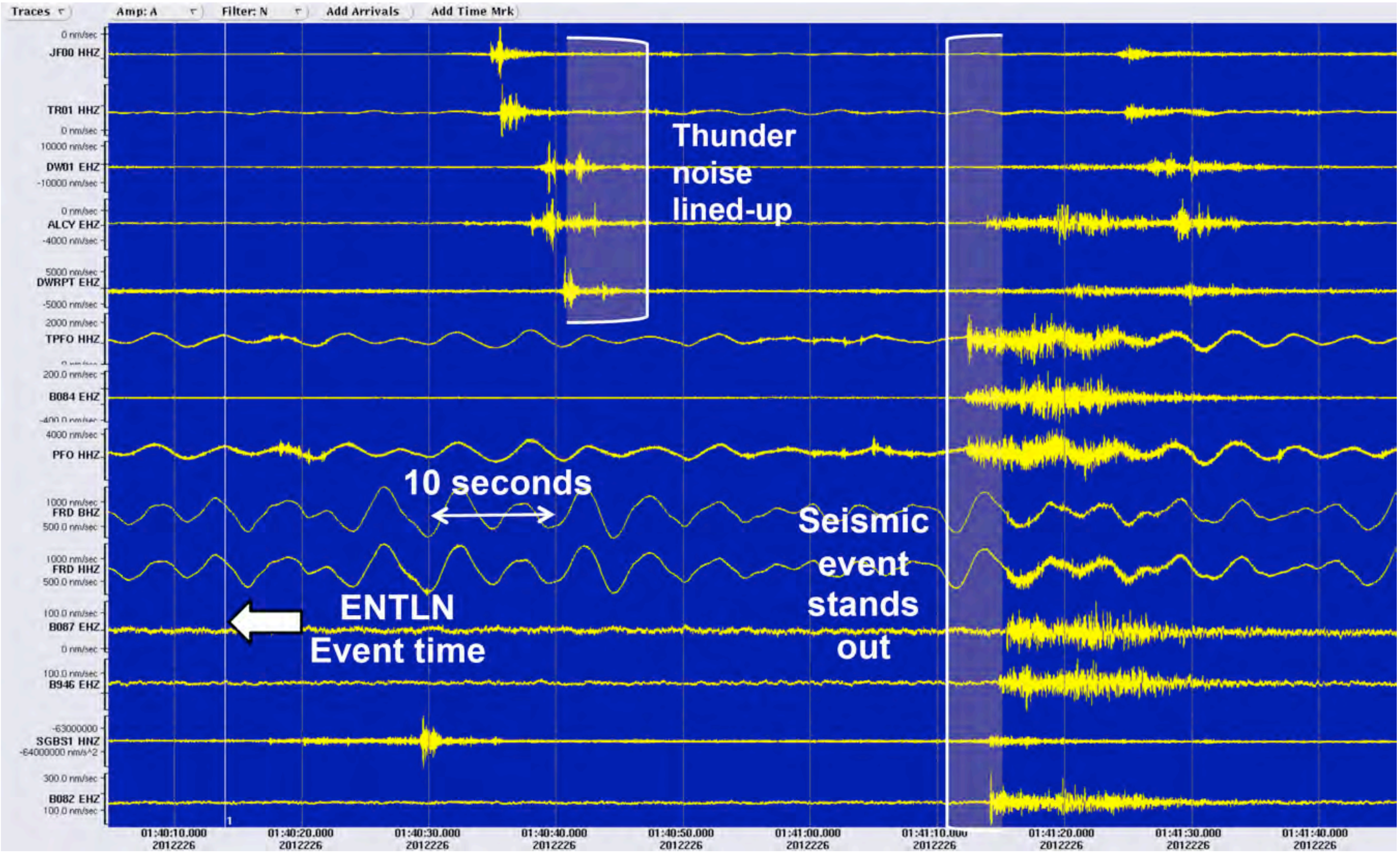

Figure 8 – Same as Figure 7, but reordered according to a lightning event from the ENTLN database (event time indicated to the left). The thunder noise plumes also match a speed-of-sound move-out of 340 to 350 m/s. Seismic event stands out more clearly to the right.