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Data Report: TurboWave I and II Data Release

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ABSTRACT

The TurboWave I and II infrasound campaigns were conducted to examine short term variability in acoustic propagation at local and regional distances. The tests were conducted in nearly co-located regions at the Energetic Materials Research and Testing Center in Socorro, NM between 2019 and 2020 and recorded across a variety of acoustic microbarometer sensors. This report details the waveform data recorded from the experiment and coincides with data archival at the Incorporated Research Institutions for Seismology. The report includes a description of the experiment along with the types of data and instruments. The data release includes raw waveform data as well as metadata information.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The TurboWave (TW) I and II test series were conducted by Sandia National Laboratories (SNL) to investigate the effect of minute to second scale atmospheric structure on the propagation of acoustic waves. The project consisted of two repeating sequences of above ground chemical explosive tests conducted at the Energetic Materials Research and Testing Center (EMRTC) in Socorro, New Mexico.

The first test sequence (TW I) was conducted on October 15, 2019 and consisted of three 1 metric ton trinitrotoluene (TNT) equivalent yield chemical sources detonated on the surface. Sources were detonated at 20:59:59.88, 21:01:29.98 and 21:03:00.12 Coordinated Universal Time (UTC).

The second and final test sequence (TW II) was conducted on July 10, 2020 and consisted of six 1 metric ton TNT equivalent yield chemical sources detonated on the surface. Sources were detonated in three sequences of two shots each, separated by 30 seconds. The sequences began at 15:39:59.84 UTC (Table 1).

Both test series were recorded by acoustic instrumentation at local (within 20 km of the source) and regional (up to 300 km from the source) distances. The local instruments consisted of surface Gem and Chaparral 60 infrasound microbarometers. The regional network consisted of digital Hyperion infrasound microbarometers.

This report coincides with the public release of these data for analysts and organizations that are not participants in this program. This report describes the two TW tests and the various types of waveform data that are available. Assembled data sets are accessible through:

> Incorporated Research Institutions for Seismology, Data Management Center 1408 NE 45th Street, Suite 201, Seattle, Washington 98105 USA.
> http://www.iris.washington.edu/ds/nodes/dmc/data/types/waveform-data/#assembled

Description: TurboWave experiments I and II to study the short-term variability in atmospheric propagation of acoustic waves from surface explosions.

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ACRONYMS AND TERMS

Acronym/Term	Definition
EMRTC	Energetic Materials Research and Testing Center
GZ	Ground Zero
IRIS	Incorporated Research Institutions for Seismology
SNL	Sandia National Laboratories
TNT	Trinitrotoluene
TW I	TurboWave I
TW II	TurboWave II
UTC	Coordinated Universal Time

1. OVERVIEW

The TurboWave I (TW I) and TurboWave II (TW II) infrasound campaigns were conducted by Sandia National Laboratories (SNL) to investigate the effect of minute-to-second scale atmospheric structure on the propagation of acoustic waves. The experiment controlled for topographic effects by locating the acoustic sources as close together as possible. Two regimes were investigated: the local (<20 km) range, where turbulent scattering ("Turbo") was hypothesized to drive variations in acoustic waves, and the regional (150-200 km) range, where gravity wave activity ("Wave") is believed to drive variations in acoustic waves. The tests were conducted in nearly co-located regions at the Energetic Materials Research and Testing Center (EMRTC) in Socorro, NM in 2019 and 2020 (Figure 1). The test series was sponsored by the U.S. Department of Energy, National Nuclear Security Administration's Office of Defense Nonproliferation Research and Development (NNSA DNN R&D). This dataset prompts the examination the time scales of acoustic variation, the ranges at which it is manifested, and the influence of small-scale topography and dynamic atmospheric structure on the resulting waveforms. The execution dates for the TurboWave tests are listed below.

- TW I – October 15, 2019
- TW II – July 10, 2020

TW I consisted of three 1 metric ton TNT-equivalent sources detonated on the surface at 30-second intervals. TW II consisted of six 1 metric ton TNT-equivalent sources detonated on the surface in three sequences of two shots each. The shots within each sequence were separated by 30 seconds and the sequences extended over the course of 4 hours. An additional 1 ton TNT-equivalent ground explosion at the TurboWave location was executed on 09/23/20219 at 17:44:59.56 UTC. EMRTC often conducts other explosive tests at various locations on the test range. This report documents available acoustic waveform data recorded on surface stations associated with the experimental campaigns. As implied above, additional activity on and off of EMRTC may have generated acoustic signals that some or all of the network was able to detect. Fransiska Dannemann Dugick, SNL point of contact (fkdanne@sandia.gov), can be contacted for further information.

Initial analysis of the TurboWave data is noted in recent studies (Bowman & Kim, 2020), and a comparison of TurboWave data with a balloon-borne recording of an underground chemical explosion is provided in Bowman & Krishnamoorthy (2021). Finally, Obenberger et al. (2022) investigated the ionospheric signature of the TurboWave events using radio sounding.

2. EXPERIMENT DETAILS

TW I and TW II were both conducted at the Energetic Materials Research and Testing Center (EMRTC) at the New Mexico Institute for Mining and Technology in Socorro, NM. Table 1 details ground truth information for both campaigns while Figure 1 details source location information. All shots were 1 ton TNT-equivalent chemical explosives.

Table 1. Ground Truth Information for Above-Ground Shot Series

	Shot #	Date	Time (UTC)	Latitude	Longitude
TurboWave I	1	10/15/2019	20:59:59.88	34.060116	-106.99209
	2	10/15/2019	21:01:29.98	34.0596244	-106.99109
	3	10/15/2019	21:03:00.12	34.0595865	-106.99026
TurboWave II	1	07/10/2020	15:39:59.84	34.05952	-106.99005
	2	07/10/2020	15:40:29.98	34.05953	-106.99118
	3	07/10/2020	16:40:00	34.05959	-106.99018
	4	07/10/2020	16:40:30	34.05958	-106.99106
	5	07/10/2020	19:29:59.94	34.05966	-106.99031
	6	07/10/2020	19:30:29.86	34.05968	-106.99113

Figure 1. GZ Location Information for TW I (red diamonds) and TW II (purple diamonds)

A comprehensive set of local and regional acoustic instrumentation was deployed for both test series. The following sections of this report provide additional details for the local and regional data sets. The waveform data and metadata were complied, archived and distributed by technical staff members at SNL. The full data sets for both TW sets, along with associated metadata, are available from the Incorporated Research Institutions for Seismology (IRIS) Data Management Center. This report is intended to complement the data sets.

Assembled data sets are accessible through:

Incorporated Research Institutions for Seismology, Data Management Center
1408 NE 45th Street, Suite 201, Seattle, Washington 98105 USA. www.iris.washington.edu

3. TURBOWAVE I WAVEFORM DATA

The TurboWave I experiment was performed on October 15, 2019. It consisted of three 1 metric ton TNT equivalent surface chemical explosions at EMRTC in Socorro, NM. The explosions were separated by less than 100 m and took place every 90 seconds (Table 1). Seven local (<25 km range; Figure 2; Table 2) and two 4-element regional (<300 km range; Figure 3 ground microbarometers recorded the events.

Local stations SLVR, LUTH, EDSA and NRMN consisted of a single Gem microbarometer recording at 100 samples per second (Anderson et al., 2018). Local stations MMTN and WCYN each consisted of a single Chaparral 60x infrasound sensor recording at 250 samples per second and digitized on Reftek 130 recorders. Local data was recorded from July 31, 2019 to October 28, 2019. Table 2 details locations of the stations. Figure 4 details data availability for the local network.

Regional stations were originally deployed to the west of the source (blue symbols in Figure 3). Regional stations PIES and HANA consisted of singular seismically-decoupled digital Hyperion microbarometers recording at 250 samples per second (blue diamonds in Figure 3). Stations QM and RH consisted of two-element arrays with seismically-decoupled Hyperion microbarometers recording at 250 samples per second (blue triangles in Figure 3). On September 20, 2019 stations were re-deployed and re-named to locations east of the source (red symbols in Figure 3) due to a reversal in the stratospheric jetEastern regional stations FS and VN consisted of two 4-element arrays comprised of seismically-decoupled digital Hyperion microbarometers recording at 250 samples per second (red triangles in Figure 5). Stations FSSW and VNSE consisted of digital Hyperion Ultralight sensors. Table 3 details locations and recording dates for these stations. Figure 5 details data availability for the regional network.

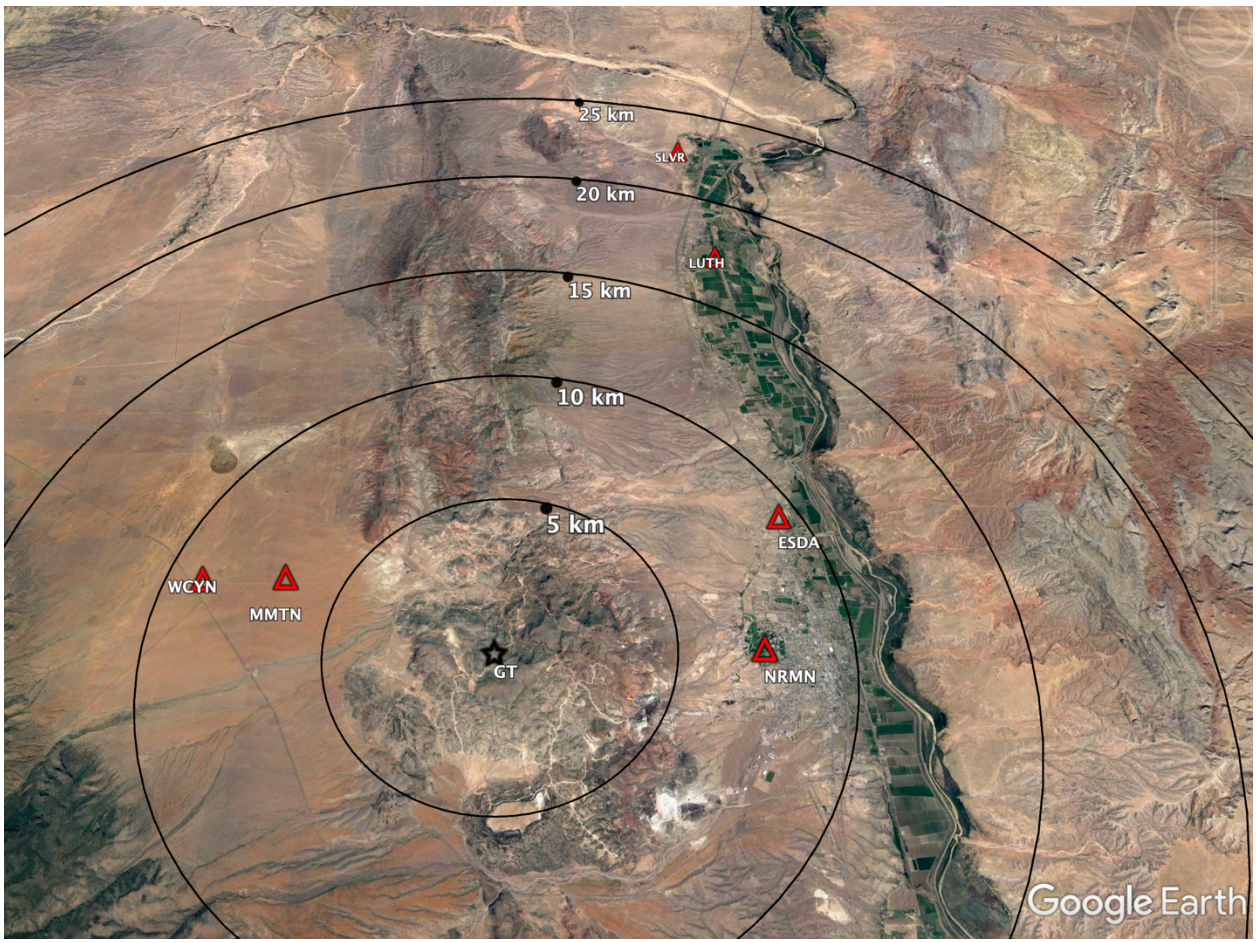

Figure 2: Locations of TurboWave I local infrasound network relative to GZ.

Table 2: TurboWave I Local Distance Ground Station Locations

Station Name	Sensor	Latitude	Longitude	Elevation (m)	Distance from GZ [km]	Backazimuth from GZ [deg.]
MMTN	Chaparral	34.08393	-107.05762	1,809	6.7	113.8
NRMN	Gem	34.06192	-106.91	1,424	7.5	268
WCYN	Chaparral	34.08355	-107.08359	1,846	8.94	107.4
ESDA	Gem	34.10181	-106.9	1,412	9.63	240.8
LUTH	Gem	34.20325	-106.91	1,414	17.61	205.1
SLVR	Gem	34.25623	-106.92	1,440	22.78	196.7

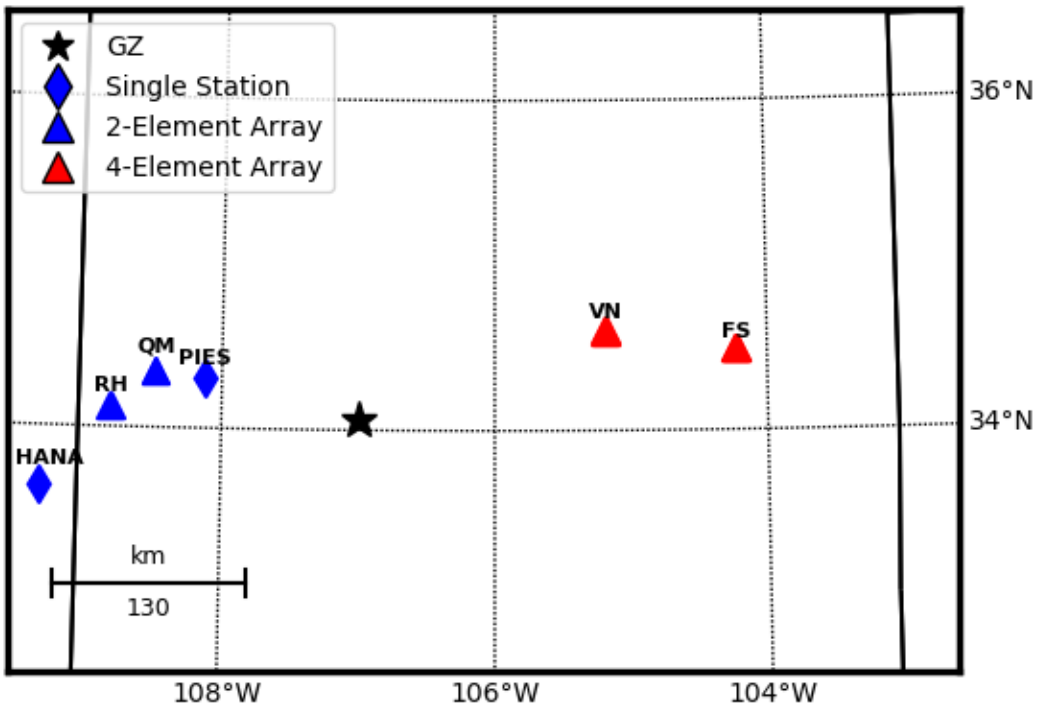

Figure 3: Locations of TurboWave I regional infrasound network. Blue symbols indicate instruments deployed prior to September 2019 while red symbols indicate instruments deployed during the shot campaign.

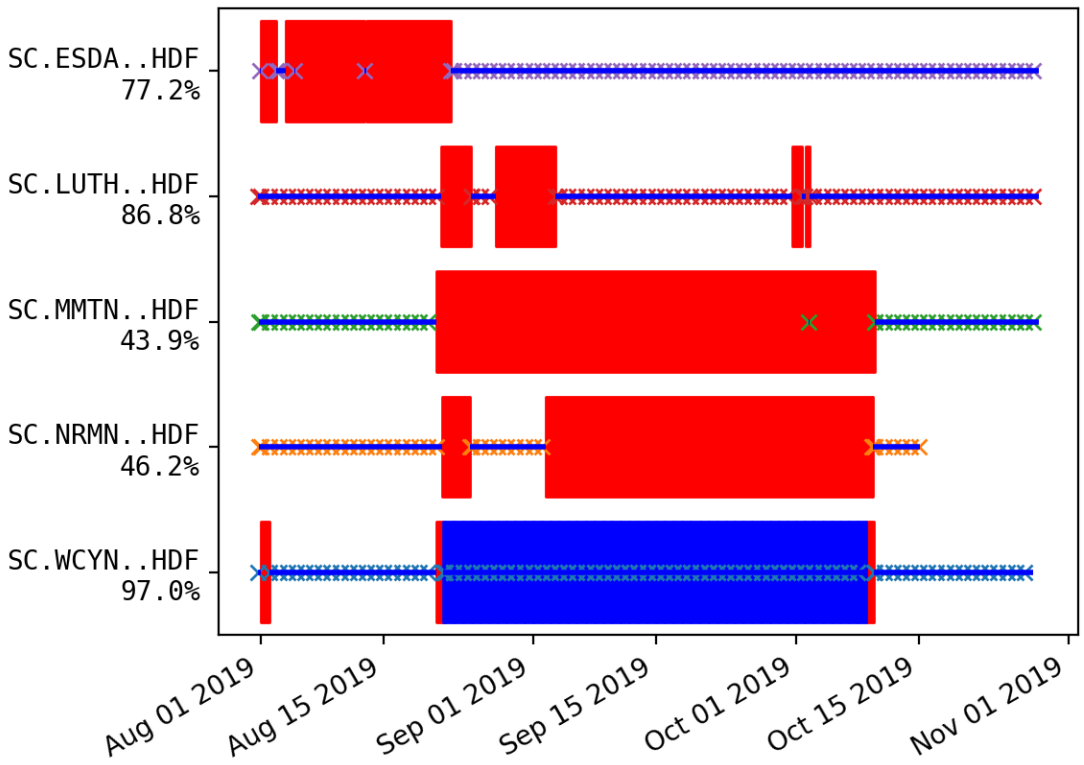

Figure 4: Data availability for the TW I Local Network. Red vertical bars indicate temporal periods with data gaps. Figure generated using obspy-scan (Beyreuther et al., 2010).

Table 3: TurboWave I Regional Distance Ground Station Locations

Station Name	Sensor	Latitude	Longitude	Elevation (m)	Date On (Year.Julian Day)	Date Off (Year.Julian Day)
FSNE	Hyperion Digital	34.4957	-104.22	1,263	2019.263	2019.303
FSNW	Hyperion Digital	34.49573	-104.23	1,262	2019.263	2019.303
FSSE	Hyperion Digital	34.49225	-104.22	1,262	2019.263	2019.303
FSSW	Hyperion Ultralight	34.49248	-104.23	1,260	2019.263	2019.303
HANA	Hyperion Digital	33.63643	-109.32	2,790	2019.222	2019.260
PIES	Hyperion Digital	34.30036	-108.13	2,386	2019.225	2019.257
QMD1	Hyperion Digital	34.3454	-108.49	2,113	2019.225	2019.260
QMD2	Hyperion Digital	34.34469	-108.49	2,115	2019.225	2019.260
RHL1	Hyperion Digital	34.12325	-108.81	2,229	2019.225	2019.257
RHL2	Hyperion Digital	34.12316	-108.82	2,270	2019.225	2019.257
VNNE	Hyperion Digital	34.60548	-105.18	1,797	2019.258	2019.303
VNNW	Hyperion Digital	34.60576	-105.19	1,800	2019.258	2019.303
VNSE	Hyperion Ultralight	34.60137	-105.18	1,798	2019.258	2019.303
VNSW	Hyperion Digital	34.60173	-105.19	1,808	2019.258	2019.303

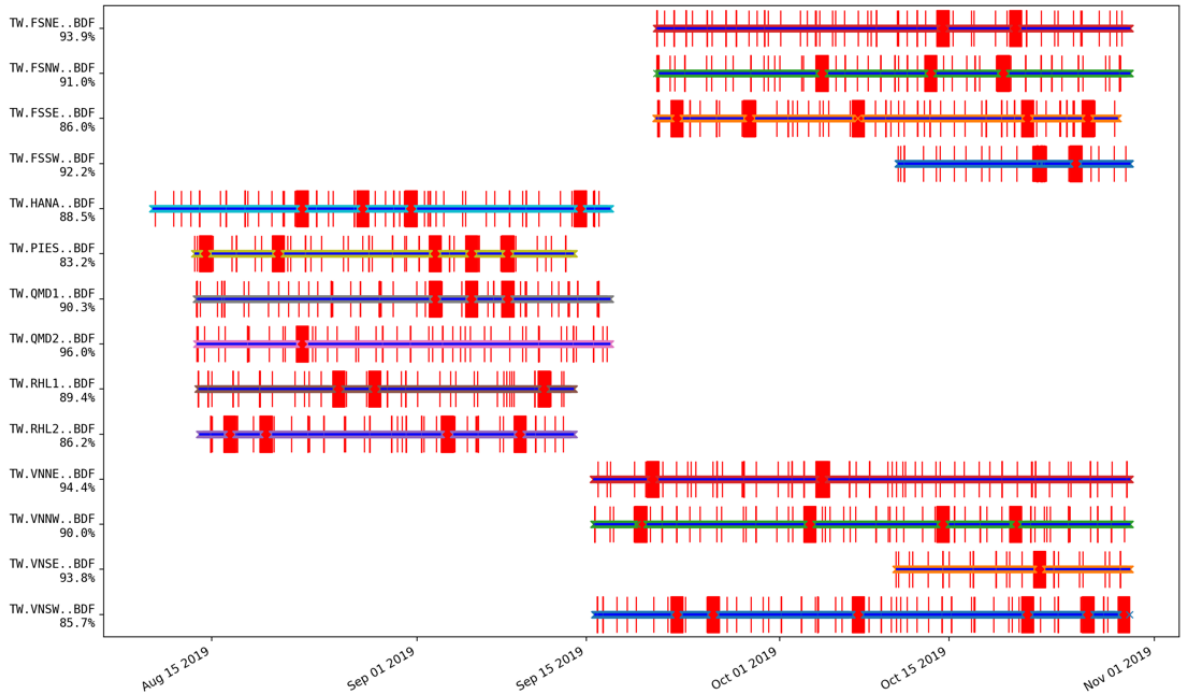

Figure 3: Data availability for the TW I Regional Network. Red vertical bars indicate temporal periods with data gaps. Figure generated using obspy-scan (Beyreuther et al., 2010).

4. TURBOWAVE II WAVEFORM DATA

TurboWave II was executed on July 10, 2020. This event consisted of three sets of two 1 metric ton TNT equivalent surface chemical explosions at the EMRTC facility, with each pair of shots separated by 30 seconds and less than 100 m. Thirteen local (<25 km range) and two 4-element regional (<300 km range) ground microbarometers recorded the events. In addition, two balloon-borne aeroseismometers were fielded to further investigate the prospect of single-station acoustic direction of arrival estimation. The balloons were funded via the NASA Flight Opportunities Program, which supports the deployment costs required to test scientific payloads on suborbital platforms. Aerial acoustic data is not included within this data release, contact Daniel C. Bowman at dbowma@sandia.gov for more information.

All local stations consisted of a single Gem microbarometer recording at 100 samples per second (Anderson et al., 2018). Local data was recorded from June 30, 2020 to July 14, 2020. Table 4 details locations of the stations. Figure 6 details spatial station locations while Figure 7 details data availability for the local network.

Table 4: TW II Local Distance Ground Station Locations

Station Name	Sensor	Latitude	Longitude	Elevation (m)	Distance from GZ [km]	Backazimuth from GZ [deg.]
PICO	Gem	34.06852	-106.96819	2,114	2.34	244.8
MMTN	Gem	34.08385	-107.05757	1,809	6.7	113.8
NRMN	Gem	34.06195	-106.91171	1,424	7.34	267.9
WCYN	Gem	34.08358	-107.08351	1,846	8.93	107.4
ESDA	Gem	34.10182	-106.89757	1,412	9.83	241.5
DUNT	Gem	34.16152	-106.90153	1,412	14.01	216.1
LUTH	Gem	34.20327	-106.91249	1,414	17.52	204.5
DRKN	Gem	34.20072	-106.90143	1,415	17.71	207.8
GRDY	Gem	34.14515	-106.80302	1,542	19.79	241.3
BLDY	Gem	33.97529	-107.18013	3,153	19.8	61.9
ANTO	Gem	33.89815	-106.87841	1,406	20.71	329.8
SLVR	Gem	34.25632	-106.9169	1,440	22.88	197.4

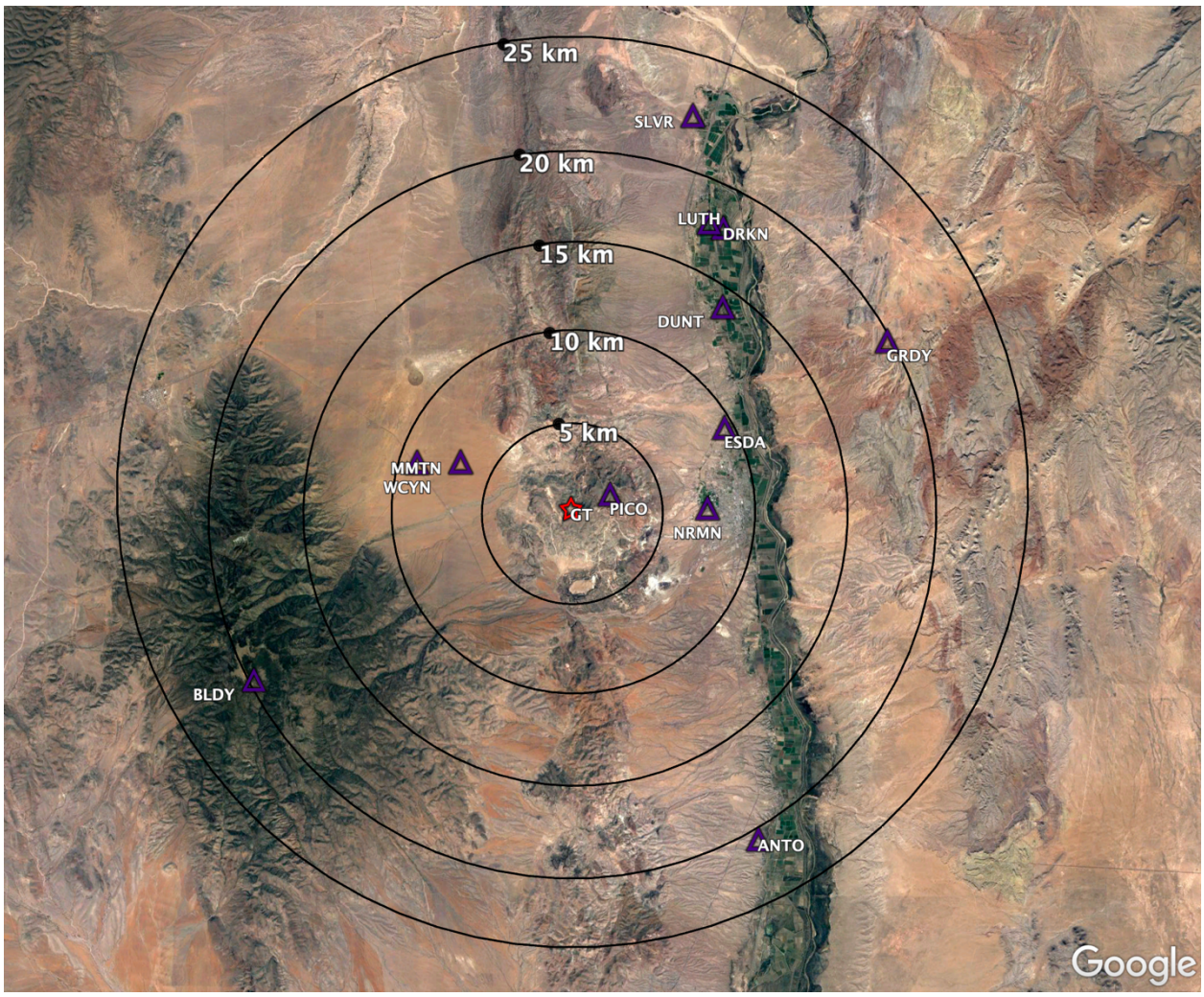

Figure 4: Locations of local infrasound network relative to GZ.

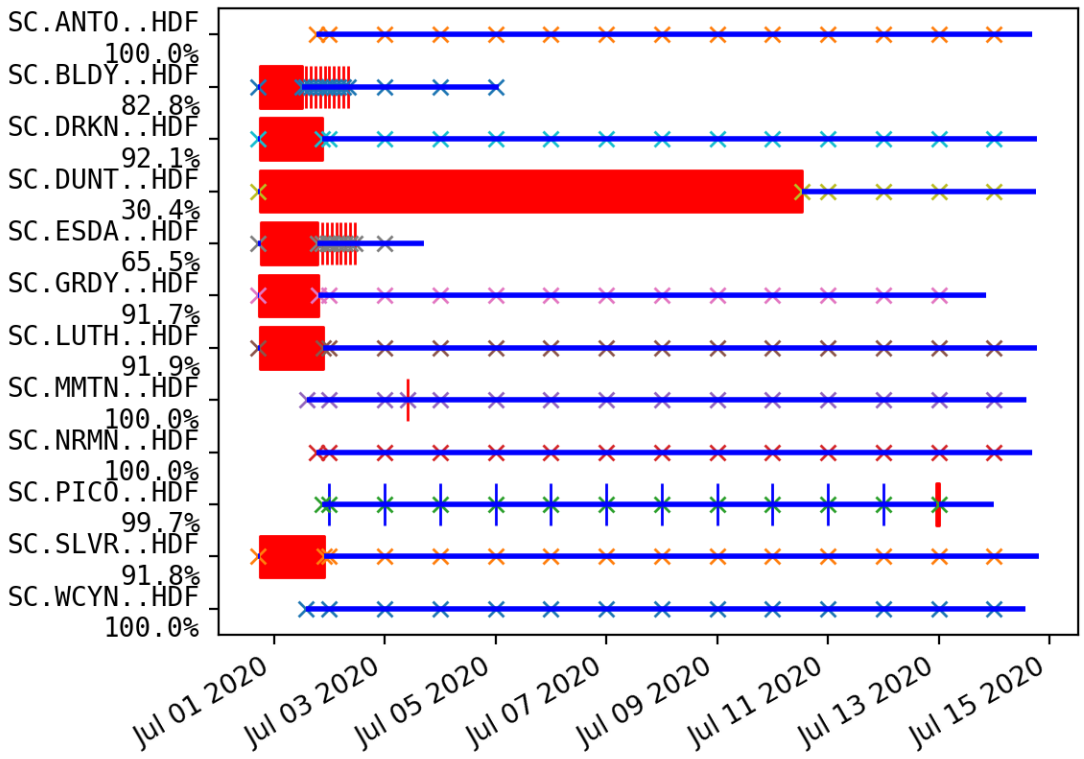

Figure 5: Data availability for the TW II Local Network. Red vertical bars indicate temporal periods with data gaps. Figure generated using obspy-scan (Beyreuther et al., 2010).

Two regional arrays were deployed to the west of the source, re-occupying the QMD and RHL array sites from TW I, but now with four-element arrays as opposed to the two-element arrays used in TW I. Sites used seismically-decoupled Hyperion microbarometers recording at 250 samples per second (Figure 8) for background, and the sampling rate was increased to 1000 Hz the week of the experiment. Table 5 details location information for these stations while Figure 8 details data availability for the regional network. Regional stations recorded continuous data from June 22, 2020 to November 22, 2020.

Table 5: TW II Regional Sensor Locations

Station Name	Sensor	Latitude	Longitude	Elevation (m)
QMDE	Hyperion Digital	34.29516	-108.51087	2,160
QMDN	Hyperion Digital	34.29562	-108.51087	2,150
QMDS	Hyperion Digital	34.29439	-108.51348	2,154
QMDW	Hyperion Digital	34.29498	-108.5136	2,154
RHLE	Hyperion Digital	34.123172	-108.81058	2,231
RHLN	Hyperion Digital	34.125866	-108.81405	2,224
RHLS	Hyperion Digital	34.120466	-108.81444	2,225
RHLW	Hyperion Digital	34.1231569	-108.81708	2,230

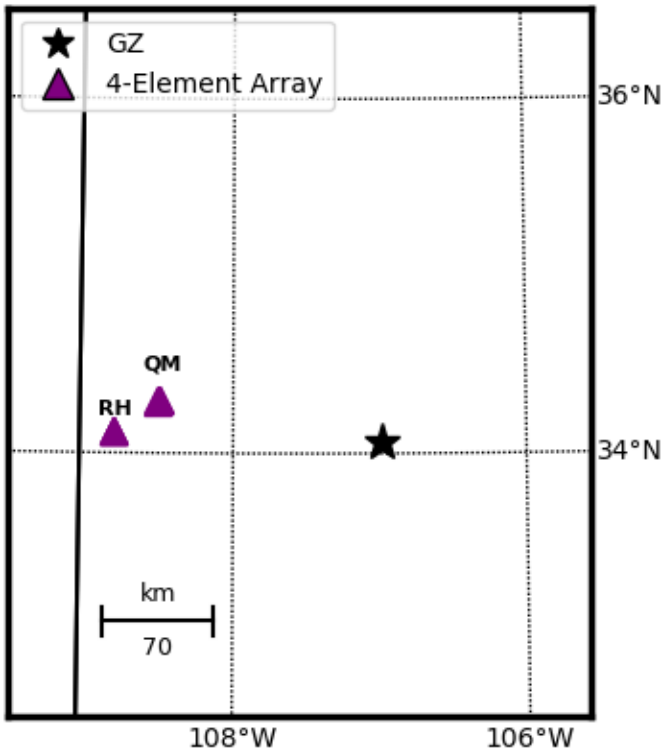

Figure 6: Locations of regional infrasound network for TW II.

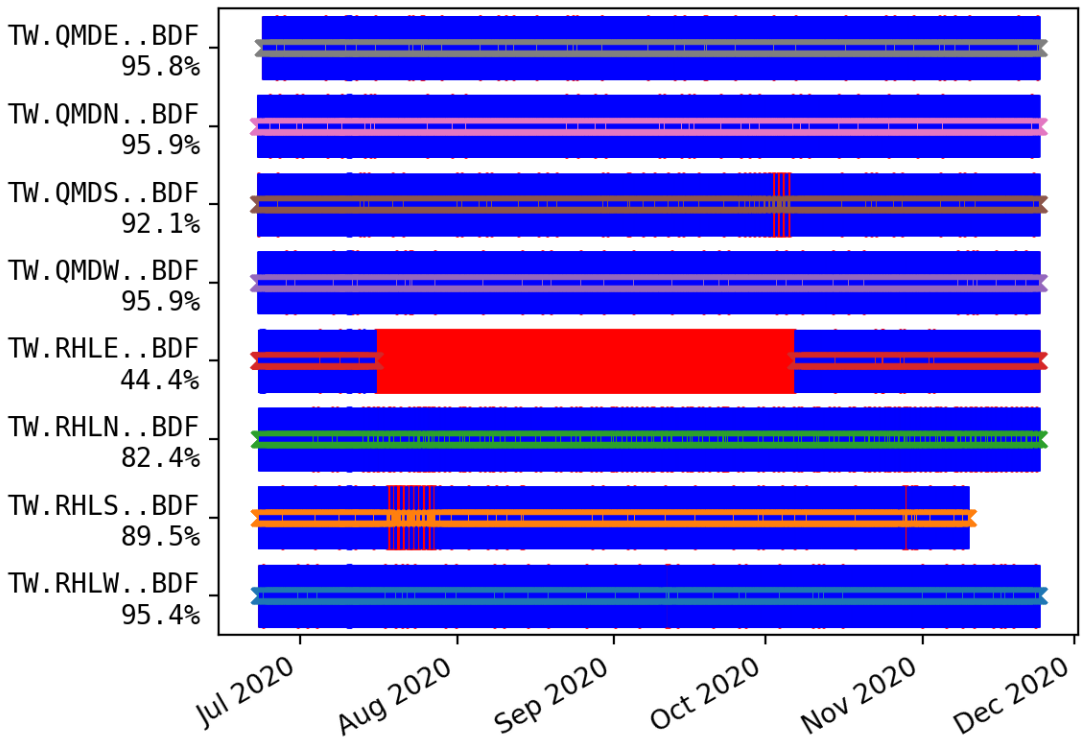

Figure 7: Data availability for the TW II Regional Network. Red vertical bars indicate temporal periods with data gaps. Figure generated using obspy-scan (Beyreuther et al., 2010).

5. SUMMARY

This report coincides with the official release of local and regional acoustic data for TurboWave I and II. The report includes a description of the experiment along with the types of data and instruments. This data release includes raw waveform data as well as metadata information.

Data Release Contents:

1. tw1.local.tar.gz
    a. 08212019_mseed.tar.gz – local waveform data from 08.01.2019-08.21.2019
    b. 10092019_mseed.tar.gz - local waveform data from 08.21.2019-10.09.2019
    c. 10282019_mseed.tar.gz - local waveform data from 10.09.2019-10.28.2019
    d. wcyn_mmtn_mseed.tar.gz – local waveform data for WCYN and MMTN from 08.01.2019-10.28.2019
    e. 08_21_inventory.xml – stationXML for 08212019 mseed data
    f. 10_09_inventory.xml - stationXML for 010092019 mseed data
    g. 10_28_inventory.xml - stationXML for 10282019 mseed data
    h. wcyn_mmtn.xml – stationXML for WCYN and MMTN
2. Tw1.regional.tar.gz
    a. Mseed.tar.gz – regional waveform data (dates detailed in Table 3)
    b. tw1_regional_no_response.xml – stationXML for all stations without response information
    c. tw1_regional_responses.xml – stationXML for all stations with response information
3. Tw2.local.tar.gz
    a. 07142020_mseed.tar.gz – local waveform data from 07.01.2020-07.14.2020
    b. 07_14_inventory.xml – stationXML for local stations
4. Tw2.regional.tar.gz
    a. mseed.tar.gz – regional waveform data (dates detailed in Table 5)
    b. tw2_regional_no_response.xml – stationXML for all stations without response information
    c. tw2_regional_responses.xml – stationXML for all stations with response information

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