

# **Plan for Upgrading the New Madrid Short-period Regional Network from Analog to Digital**

Mitch Withers, September 2022

## **Introduction**

The regional network for the New Madrid Seismic Zone (NMSZ) operated by CERI (Figure 1) is composed of 3 parts: shortperiod, strongmotion, and broadband. The strongmotion network is, of course, designed to capture on-scale recordings of large earthquakes and is not included in this study. The broadband network provides high quality waveform data for scientific research and monitoring. The shortperiod network is denser than the broadband network and provides the high resolution and dense travel paths for high quality hypocenter solutions and detailed travel-time studies. The bulk of the shortperiod network is telemetered to central receive nodes using analog radios. This report examines the shortperiod network to select the optimal configuration to maximize needed investments in converting analog stations to digital.

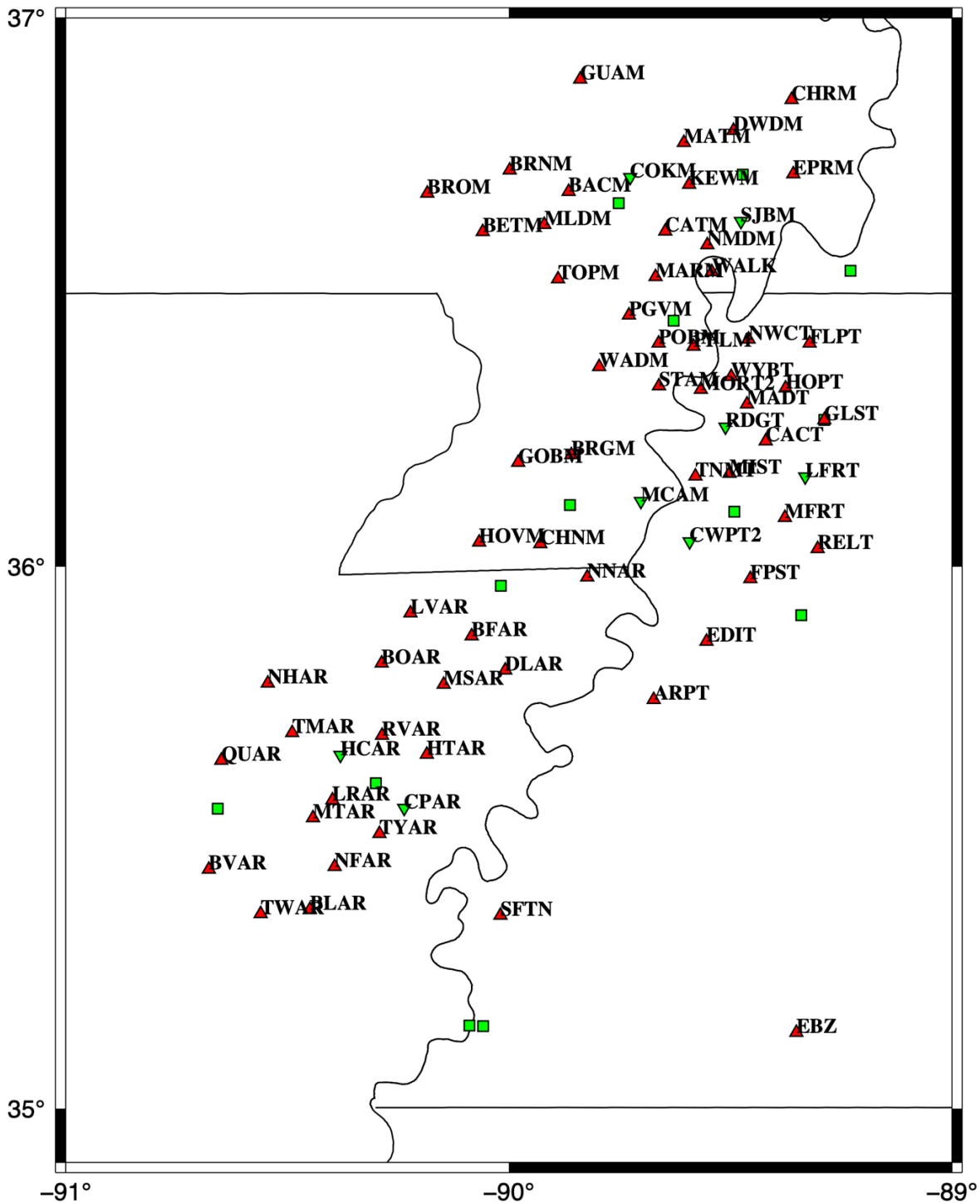


Figure 1. NM Station map showing shortperiod analog stations in red and digital stations in green. Broadband stations are squares without station names.

The primary driver for the dense shortperiod network is the high noise and high attenuation of the loosely consolidated sediments in the Mississippi Embayment (the embayment). This basin traps and resonates cultural noise producing a strong diurnal component. While the impedance contrast across the Paleozoic boundary at the base of the sediments amplifies signals, the sediments attenuate

them along the path to the surface which is particularly prevalent at frequencies greater than 1 Hz (e.g., Anthony et al., BSSA 2022) as shown in Figure 2. The shortperiod network provides the station spacing necessary to maintain a similar level of hypocenter location accuracy and completeness threshold as a sparser network located on rock (e.g., the East Tennessee network).

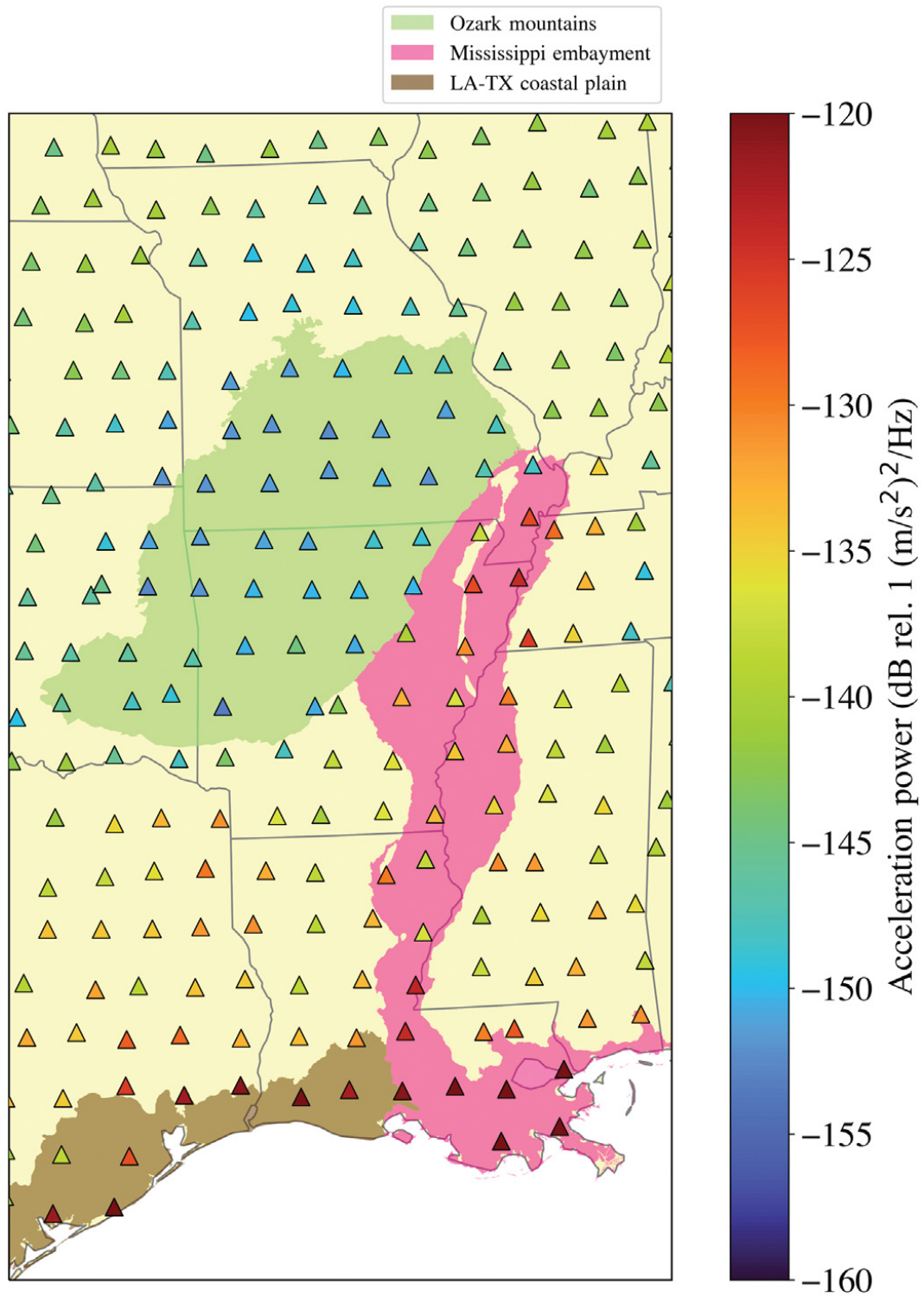


Figure 2. After Anthony et al., BSSA 2022 showing median 1 s background noise for US Array stations deployed in the MS Embayment and Ozark Mts.

We use 3 criteria to classify stations in the analog network.

1. Background noise and network thresholds using Dave Wilson's network modeling software. Which stations can we do without?
2. Telemetry. ISTI was commissioned to conduct a telemetry study to determine feasibility of digital links for each shortperiod station. Which stations have poor telemetry options?
3. Station Counts and Redundancy.

## **Background Noise and Network Thresholds**

We use software developed by Wilson et al. (SRL 2021) that has been improved to allow calculating standard deviation noise values for seismic stations based on PSD's produced by the IRIS Mustang tool (Casey et al., SRL 2018). By using Mustang rather than calculating std directly from waveforms allows us to avoid downloading the continuous waveforms and thus generate the statistics over a much longer time period: an entire month as opposed to an hour or two. The results are fairly clear that we are over-built in the central arm of the NMSZ and less so on the adjacent arms of seismicity. The ANSS performance standards (<https://www.usgs.gov/media/files/anss-performance-standards>) for Hi-Risk Urban Areas specifies a maximum epicenter uncertainty of 2km which is consistent with the observation of being over-built on the central arm.

Results of the network analysis are shown in Figures 3 and 4. No defaults or customization were made in the configuration of the software and it worked well "out of the box." We made plots for January and July for each of 2020, 2021, and 2022. We note that the impacts of the covid pandemic began in the region around March 2020 however lockdowns in the mid-south were largely restricted to schools, government, and office workers and we do not see similar background noise reductions reported by others and this is beyond the scope of this report. There appears to be a significant difference between thresholds calculated for January and July (though there is a change in scale in the plots for Jan 2021 and 2022). January appears to be generally more seismically quiet than July and shows a lower detection threshold over a wider area in Figure 3. It is common practice in the NMSZ to locate stations in the corner of a farm field which can result in significant agricultural seismic noise outside of the winter months.

The horizontal error estimates plotted in Figure 4 are based on a fixed error parameter (0.05) and velocity models (configured to use CEUS) so should be interpreted in a relative rather than an absolute sense. There are changes in scale in Figure 4 but patterns still emerge that highlight dense parts of the network. We also note that eight of the shortperiod stations were converted to digital in November of 2021 which did not make a significant impact on the data; the sensor response of the digital shortperiod systems is similar and the shallow borehole installation remains the same which leads us to anticipate only a minor if any impact on noise. We focus on July 2022 to help identify desirable and less desirable stations to convert to digital from a background noise perspective. Other issues such as security and telemetry are addressed later in this report.

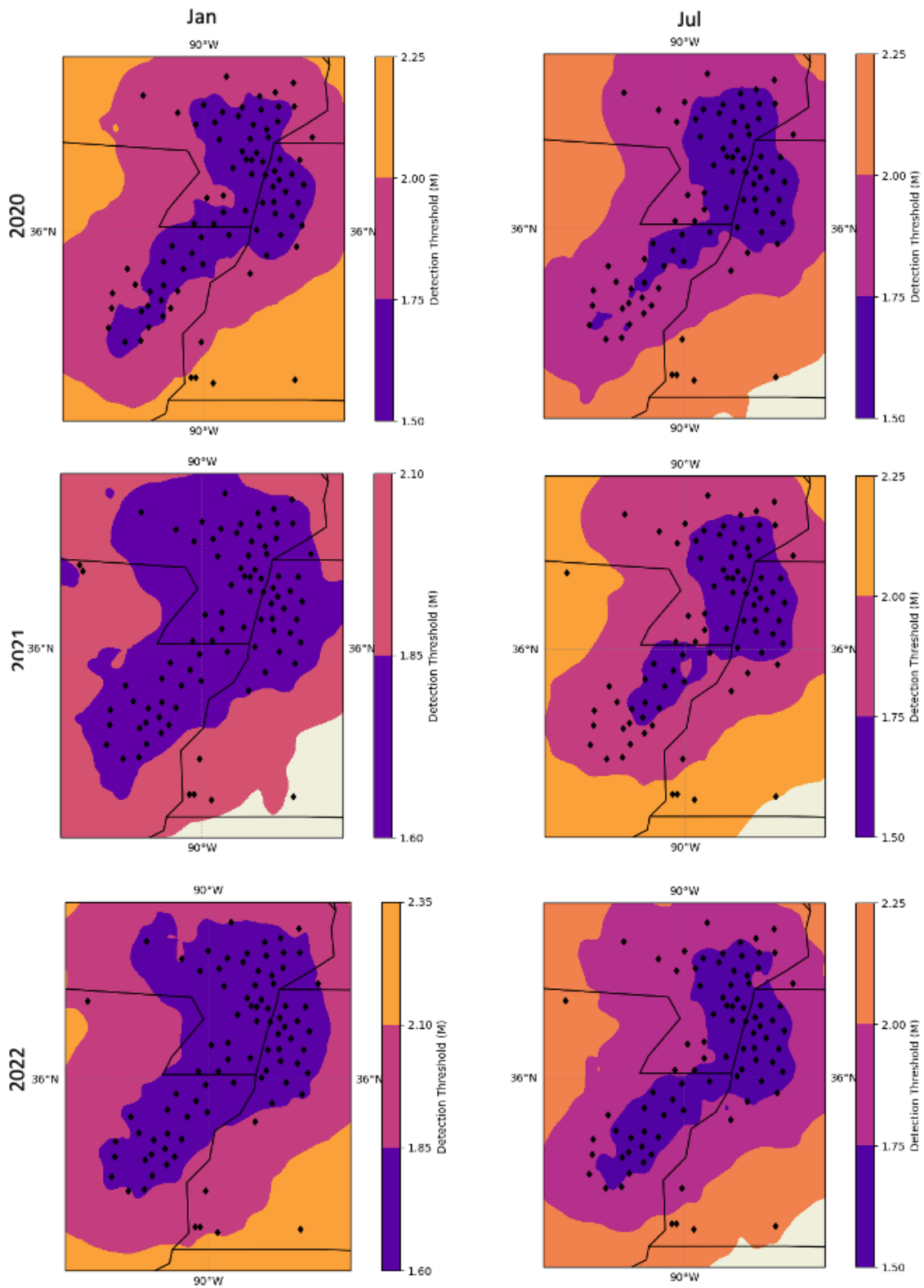


Figure 3 Magnitude detection threshold for the NMSZ using the NM network.

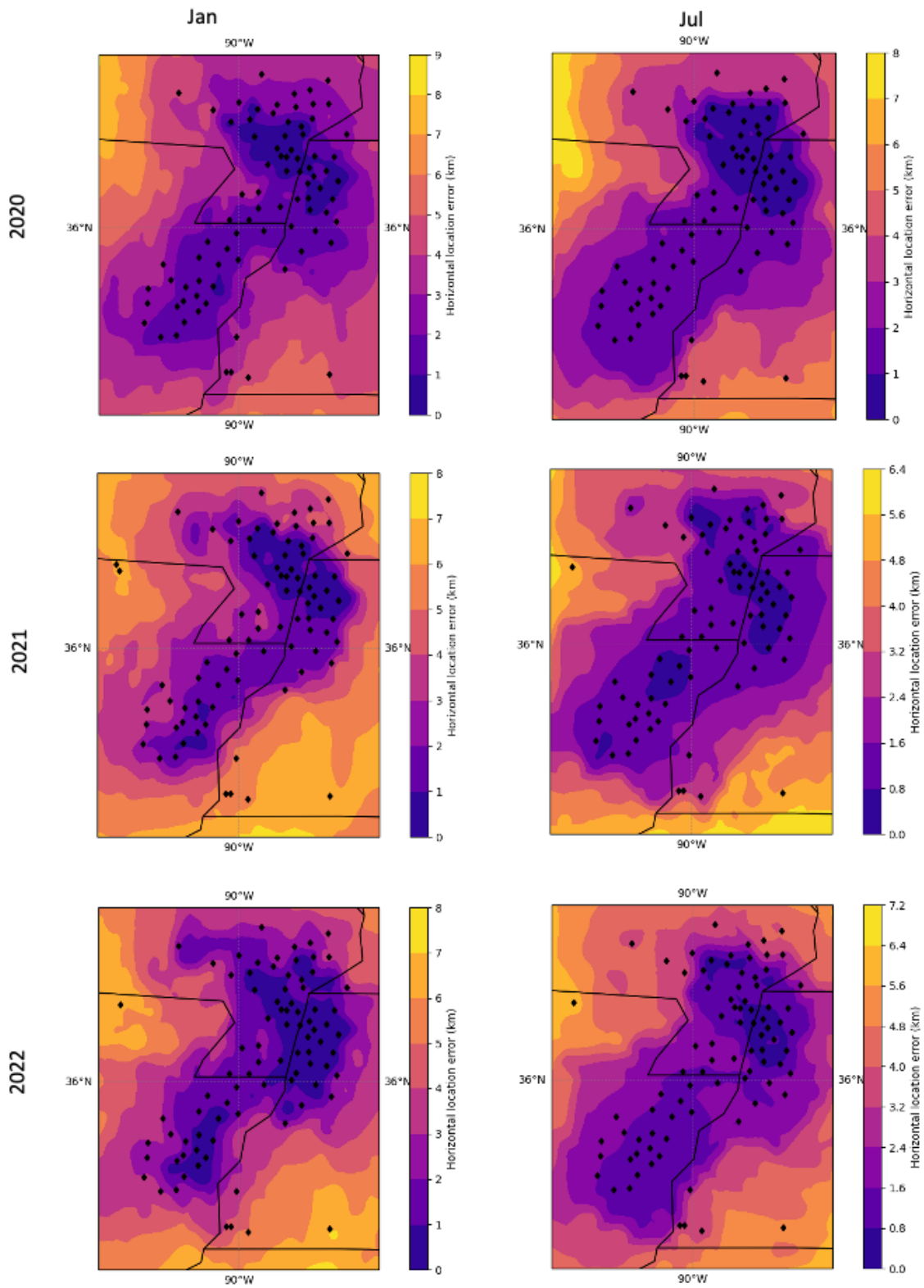


Figure 4. Predicted horizontal error for the NMSZ using the NM network.

We focus on evaluations conducted on data from July of 2022 and for clarity, divide the network into northern and southern sections.

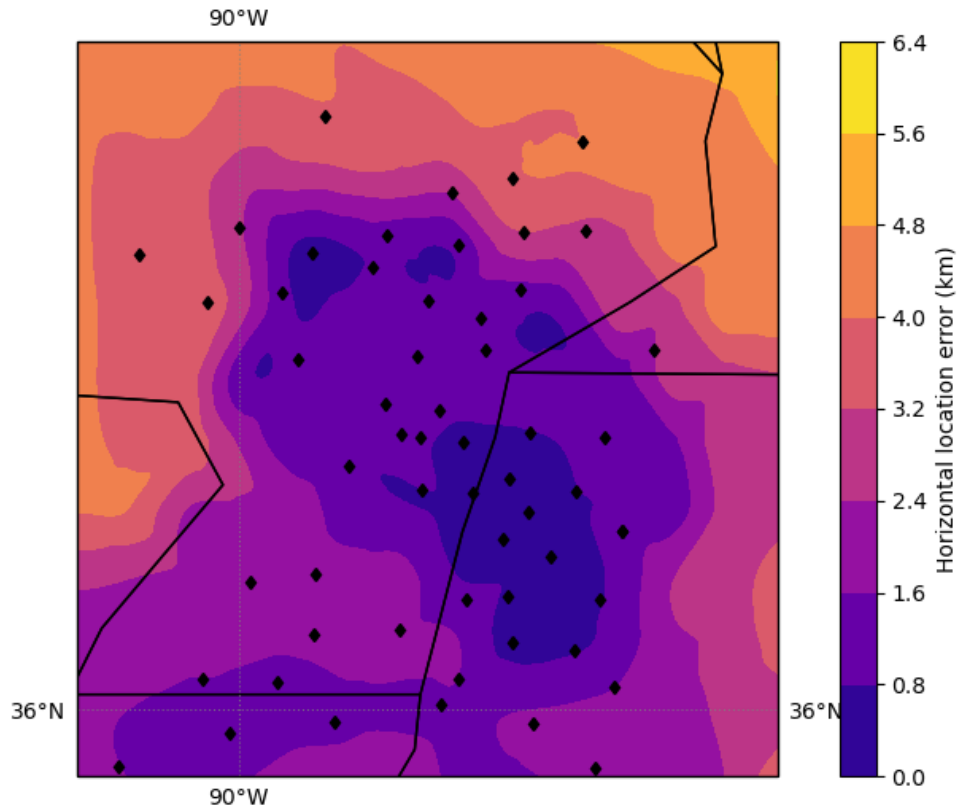


Figure 5. Estimated horizontal error based on July 2022 Mustang pdf values for the northern half of the NMSZ network.

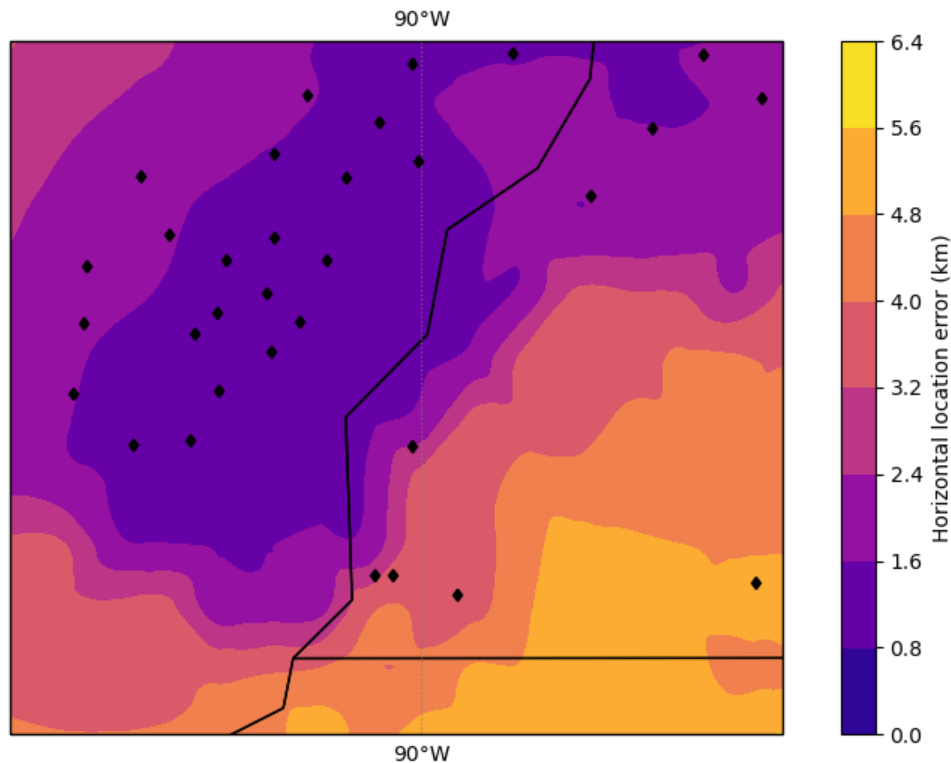


Figure 6. Estimated horizontal error based on July 2022 Mustang pdf values for the southern half of the NMSZ network.

## Telemetry

A comprehensive path profile analysis was conducted by ISTI with USGS Deferred Maintenance funding and is attached in Appendix A. The current analog telemetry operates in a licensed 216-218MHz band which is much more forgiving than the higher frequencies used for digital telemetry. The report recommends 5.8 GHz spread spectrum due to the smaller Fresnel zone which is particularly important for long paths and lower antenna heights at the station. Our standard station antenna heights are a maximum of 11m. A taller tower requires guy lines which are problematic in most farm fields where the bulk of our stations are permitted. ISTI generated a list of 27 links that work best with antenna heights greater than 11m and a list of 9 links that require heights greater than 30m (Section 5.2, Table 3 in Appendix A). We note that other technology (e.g., cell modems) may be suitable for these stations. Those stations are: MLDM, BACM, BROM, EDIT, TNMT, TMAR, BOAR, HOVM, and BLAR.

## Station Usage and Redundancy

We queried the AQMS database to count arrivals from each NM station as a measure of how much each station is used. A low arrival count does not necessarily mean a station is not needed; rather, rarely used stations may be critical for less active areas of the network. High arrival counts to the contrary, are stations we wish to keep. We also recognize that noise and the built environment evolve. New development may dramatically degrade a given station's effectiveness. So, we search the database for arrivals since January 1, 2020 and count only those with quality (as defined in the AQMS database schema) greater than 0.5 (0 is bad, 1 is good). We note that of the stations with poor digital telemetry paths, three have arrival counts greater than 100 making those prime

candidates for alternate communications technologies (e.g., cell modem). Stations with poor paths and their arrival counts are:

TNMT	611
BACM	385
MLDM	106
BROM	92
HOVM	72
EDIT	50
BOAR	45
TMAR	31
BLAR	28

There are 54 stations with arrival counts less than 50 and 35 stations with counts greater than 250. See Appendix B for the complete list. Figure 7 is a map of those stations (not all lie within the bounds of this study). Not surprisingly, they follow the earthquakes and low count stations cluster in the less active southwest portion of the zone and the high counts cluster in the central part. This also suggests that while we are over-built in the central part from a detection threshold perspective, those stations are frequently being used.

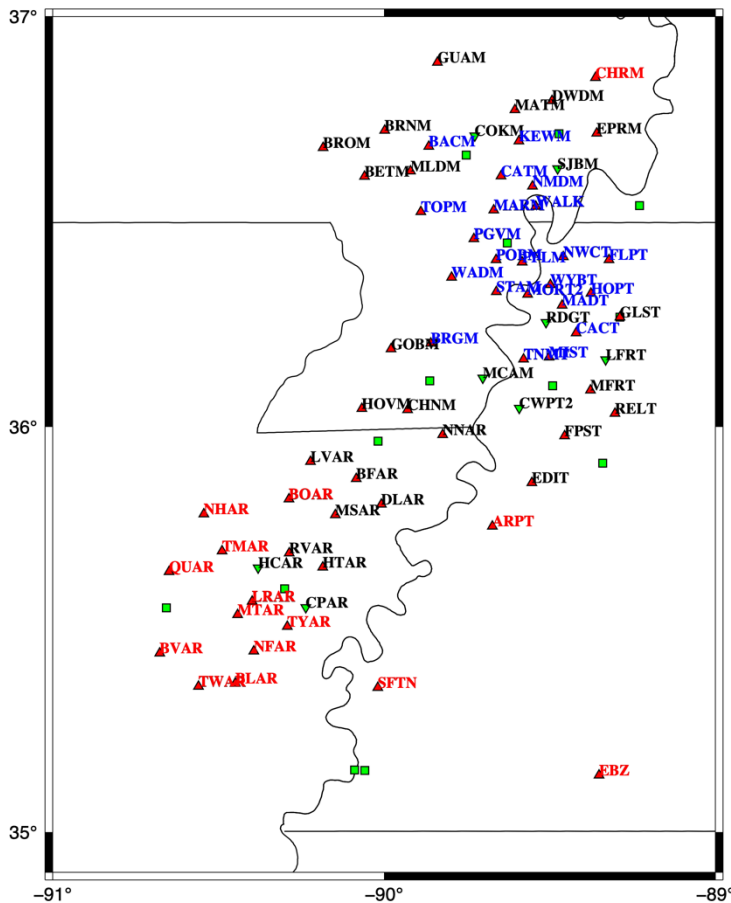


Figure 7. Station map showing stations with arrival counts since 2020 with values less than 50 with station names in red and those with arrival counts greater than 250 in blue.

We next calculate the upper half of the distance matrix for distance between all station pairs in the shortperiod network to find stations that are close to each other. We sort these distances and plot those that are closer than 10km. These are unsurprisingly clustered in the northern part of the network with only a single pair (LRAR and MTAR) to the south.

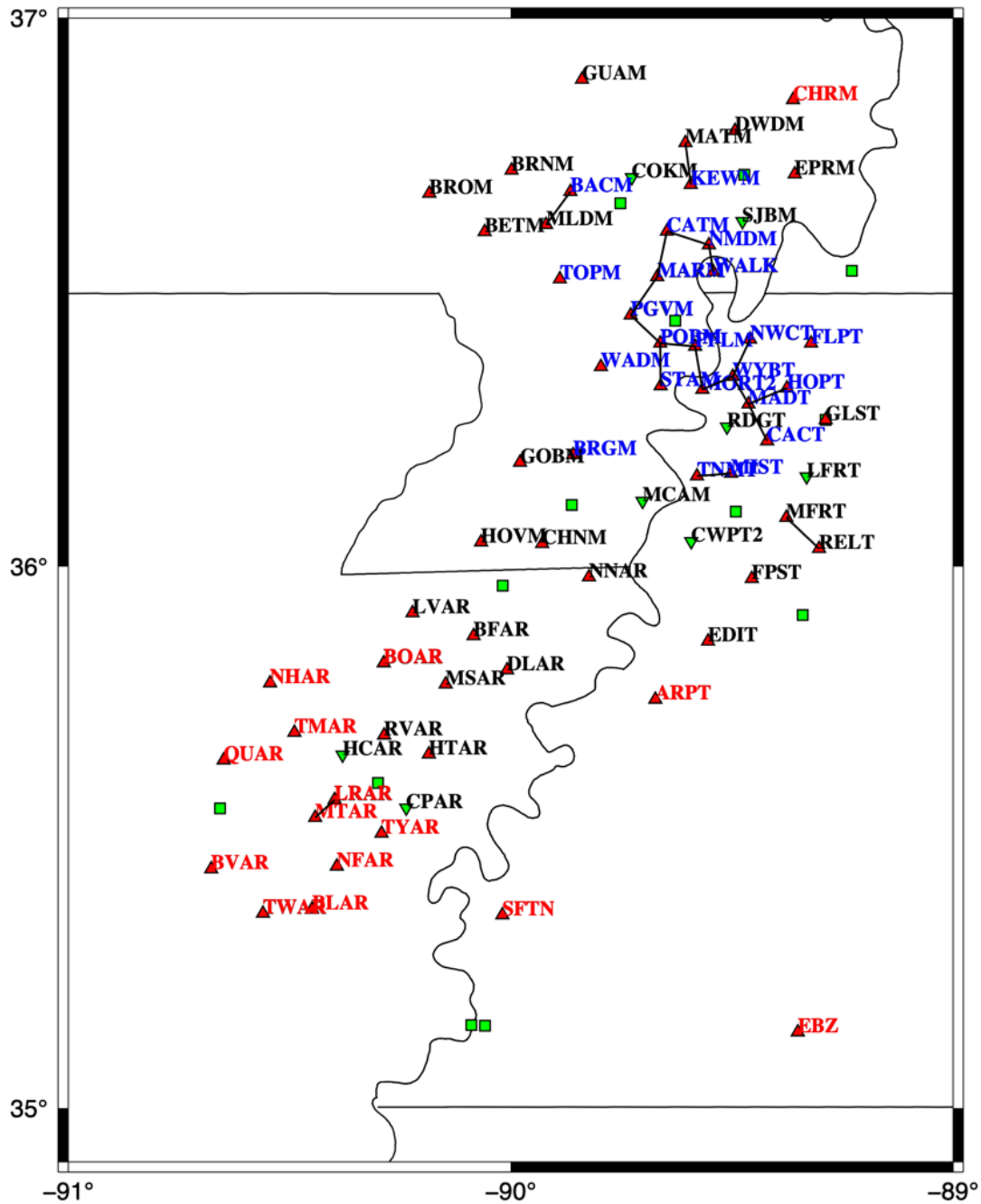


Figure 8. Map with thin black lines linking stations closer than 10km.

Figure 9. Same as previous figure zoomed into the northern portion of the network.

The list of stations with interstation spacing less than ten kilometers is:

MTAR	LRAR	5	STAM	MORT2	8
WALK	NMDM	6	WYBT	NWCT	8
WYBT	MADT	6	MARM	DWDM	9
PPLM	POBM	7	MATM	KEWM	9
TNMT	MIST	7	NMDM	CATM	9
WYBT	MORT2	7	PGVM	MARM	9
MADT	CACT	8	PPLM	MORT2	9
MADT	HOPT	8	RELT	MFRT	9
MLDM	BACM	8	STAM	POBM	9
POBM	PGVM	8			

From this list we considered removal of the following 13 stations: MTAR, MLDM, MATM, NMDM, MARM, POBM, PPLM, STAM, WYBT, MADT, TNMT, RELT, GOBM, and EBZ. (Station EBZ was originally installed as a repeater for PWLA; PWLA has since been converted to broadband digital negating the need for EBZ). Technical and analysis staff met to discuss the list and decided that station WALK is much noisier than MARM and should be closed instead. EDIT is also noisy and FLPT is extremely difficult to access so were also added to the list of stations to close. GLST is collocated with a broadband and not strictly necessary as is analog hardware at RDGT. RDGT was the shortperiod digital prototype so we temporarily operate collocated analog and digital shortperiod hardware at this station for testing and is not included in the count of analog stations in this report; we will remove the analog hardware from RDGT. Our final list of 17 stations to remove from the noise analysis with the Wilson code is: EBZ, EDIT, FLPT, GLST, GOBM, MTAR, MLDM, MADT, MATM, NMDM, POBM, PPLM, RELT, STAM, TNMT, WALK, WYBT. Our final proposed remaining stations are shown in Figure 12.

Estimates of horizontal error from the Wilson code show only a modest reduction in horizontal location error. We are still able to maintain about a 2km horizontal location error with a significant reduction in stations. We have hardware in house acquired from internal sources to convert four additional stations to digital in Fall 2022. Those stations are: HOPT, TOPM, HOVM, and TWAR. This leaves 39 stations remaining that require digital upgrades.

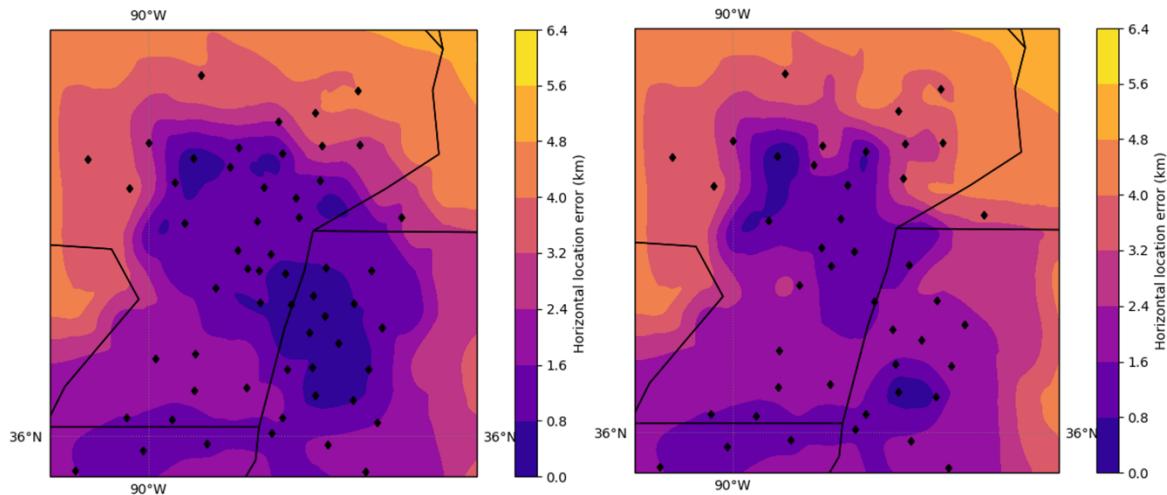


Figure 10. Comparison of estimated relative horizontal location errors with the current network (left) and with the 12 closely spaced stations removed. Jul 22 North.

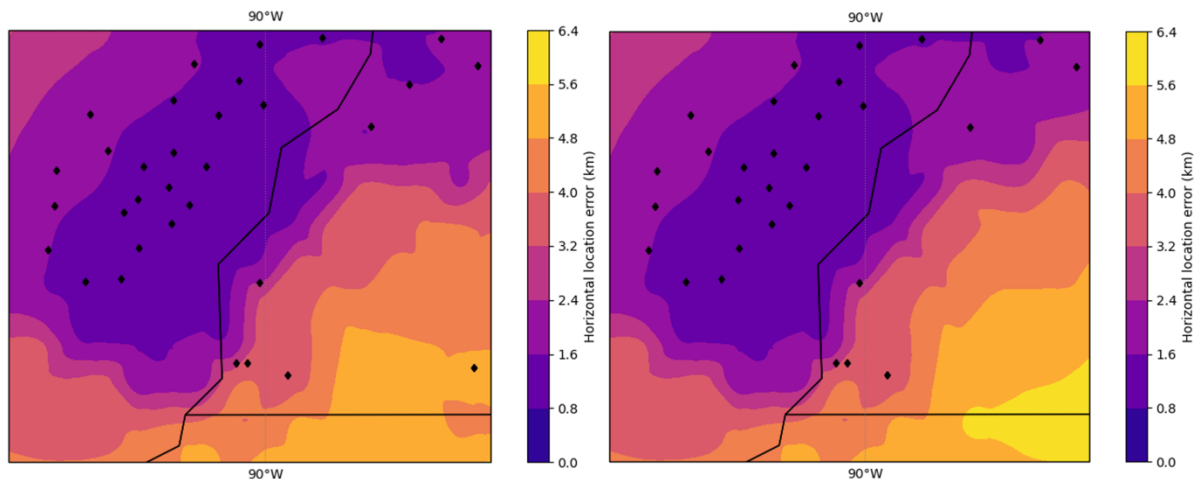


Figure 11 Comparison of estimated relative horizontal location errors with the current network (left) and with the 12 closely spaced stations removed. Jul 22 South.

## Discussion and Conclusions

The original NMSZ network was designed following a successful portable deployment that cataloged more than 700 earthquakes during a two-year deployment of the PANDA Array (Chiu et al., 1992). The deployment showed the promise of producing hypocenters with sufficient accuracy to image the faults of the NMSZ. The density of the deployment temporarily improved the average interstation spacing from about 20 km for the permanent network to 12 km for the PANDA array. This experiment guided the design of a new permanent network based on closely spaced shortperiod stations integrated with a more widely spaced broadband network. That buildout was conducted primarily in the latter half of the 1990's and continues to operate today. The lower detection threshold allows us to build a catalog of high-quality hypocenters relatively quickly despite a seismicity rate 10% of that in California. A large catalog with arrivals allows much improved statistical analysis, imaging, and inversions. Analog hardware has limitations and is unsustainable in the long term so we must now convert this network to digital without significantly reducing performance. Based primarily on a desire to maintain horizontal errors to less than 2km on average,

we believe this goal can be achieved by upgrading 43 stations and closing 17. Four stations will be upgraded in Fall 2022 using hardware already in-house.

Total cost to upgrade the remaining 39 stations is about \$1.3M. The 3-c Geospace GS-ONE geophone stack in a stainless canister suitable to emplace in a 3m borehole and radios is \$8,500. Power, civil works and telemetry is about \$6,500. A 6-c Centaur with Titan and associated cables is about \$14.5k/station. Total cost per station is then \$29,500 and for 39 stations, total direct cost for the conversion is about \$1,150,500. If we conduct the work over a five-year period by upgrading 8 stations each year, direct costs will be about \$236k/year (\$116k/year of which would be GFE). These costs could be reduced by excluding the strongmotion channels and using a less expensive, though less functional and reliable, datalogger. A 3-c Geobit (or Kinometrics Pebble) instead of the 6-c Centaur with accelerometer for example, would reduce the GFE from about \$14k to around \$7k/station or about \$176k/year over five years in direct costs for the upgrades.

A particularly compelling argument for the 6-c upgrade path is the resulting dense network of continuous, real-time strongmotion stations. There are no instrumentally recorded earthquakes in the central and eastern U.S. with magnitude greater than 6 and very few ground motion recordings at epicentral distance less than 50km (Figure 13). The area in the National Seismic Hazard Map with the greatest probability of experiencing large ground motion in the CEUS is the New Madrid Seismic Zone. Replacing the remaining 39 analog stations with 6-c digital stations provides an opportunity to obtain a unique dataset key to improving ground motion prediction equations and earthquake hazard estimates in the CEUS.

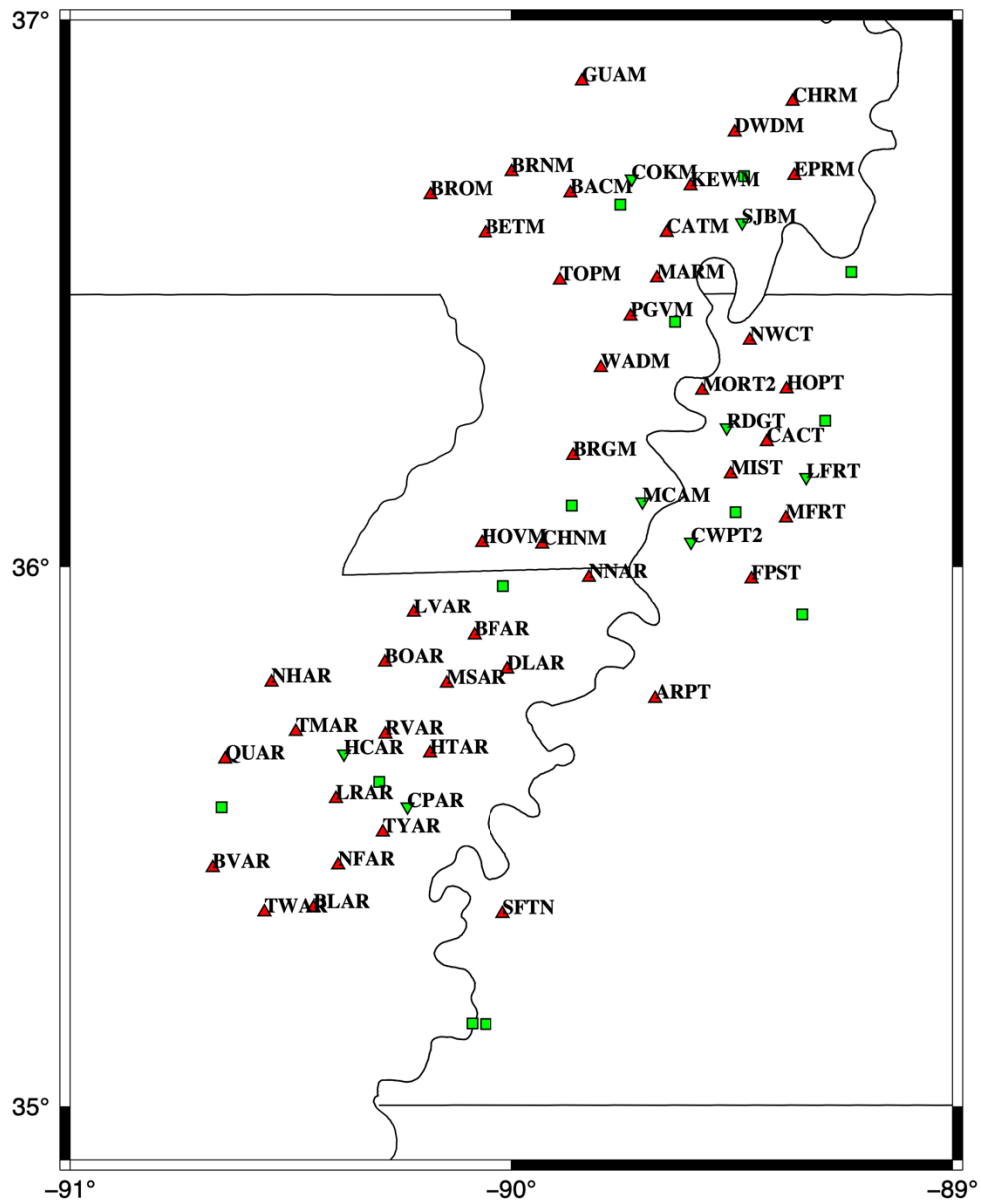


Figure 12. Final proposed network of xx shortperiod stations. Green squares are broadband stations, inverted green triangles are 6-c shortperiod/strongmotion stations. Red triangles are shortperiod analog stations to be converted to digital.

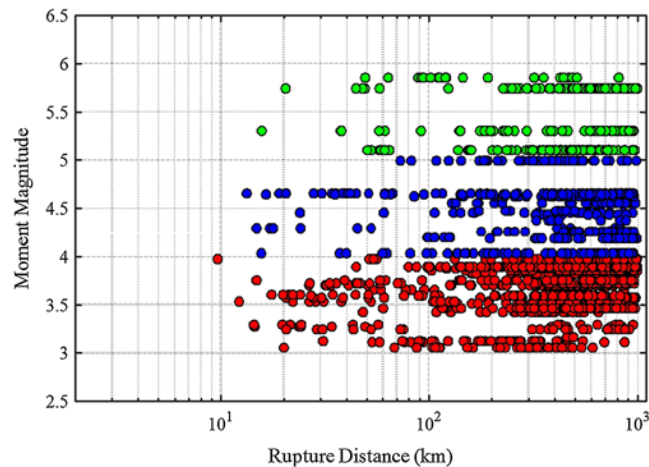


Figure 13. Magnitude-distance distribution of CENA ground motion recordings available for use in GMPE studies from Pezeshk et al., 2018.

## References

- Anthony, R. E., A. T. Ringler, and D. C. Wilson (2022). Seismic Background Noise Levels across the Continental United States from USArray Transportable Array: The Influence of Geology and Geography, **Bull. Seism. Soc. Am.** **112**, 646–668, doi: [10.1785/0120210176](https://doi.org/10.1785/0120210176)
- Casy, Robert, M.E. Templeton, G. Sharer, L. Keyson, B.R. Weertman, and T. Ahern (2018). Assuring the Quality of IRIS Data with MUSTANG, **Seism. Res. Lett.** **89 (2A)**: 630-639. doi: [10.1785/0220170191](https://doi.org/10.1785/0220170191)
- Chiu, J.M., A.C. Johnston, and Y.T. Yang (1992). Imaging Active Faults of the Central New Madrid Seismic Zone Using Panda Array Data, **Seism. Res. Lett.** **63 (3)**: 375-393. doi: [10.1785/gssrl.63.3.375](https://doi.org/10.1785/gssrl.63.3.375)
- Lecocq, T., +66 Authors (2020). Global quieting of high-frequency seismic noise due to COVID-19 pandemic lockdown measures. *Science* v 369, issue 6509: 1338-1343. doi: [10.1126/science.abd2438](https://doi.org/10.1126/science.abd2438)
- Pezeshk, Shahram, A. Zandieh, K.W. Campbell, and B. Tavakoli (2018). Ground-Motion Prediction Equations for Central and Eastern North America Using the Hybrid Empirical Method and NGA-West2 Empirical Ground-Motion Models, **Bull. Seism. Soc. Am.** **108 (4)**: 2278-2304. Doi: <https://doi.org/10.1785/0120170179>
- Wilson, D. C., E. Wolin, W. L. Yeck, R. E. Anthony, and A. T. Ringler (2021). Modeling Seismic Network Detection Thresholds Using Production Picking Algorithms, **Seism. Res. Lett.** **93**, 149–160, doi: [10.1785/0220210192](https://doi.org/10.1785/0220210192).

## Appendix A

Site A	Site B	Freq	Path Length (km)	Issue	Site A Antenna Height (m)	Site B Antenna Height (m)/(ft)	Comment
nmad node (2)							
nmad	MLDM	5.8 GHZ	23.7	Trees	76	34.6/114	
BACM	BRNM	5.8 GHZ	12.5	Trees	35.1/115	11/36	BACM-PARM possible alternative. 14.8m antenna at BACM
BROM	BETM	5.8 GHZ	13.6	Trees, Terrain	54.3/178	11/36	
Inxt node (2)							
Inxt	EDIT	5.8 GHZ	27	Trees, Terrain,	46	38.6/127	
TNMT	MIST	5.8 GHZ	6.8	Trees	35.2/	17.6/58	TNMT-Inxt node alternate, easier route
mkta node (4)							
mkta	TMAR	5.8 GHZ	18	Lots of Trees	43	43.5/143	
mkta	BOAR	5.8 GHZ	34.6	Trees, K-factor	43	82.6/270	Long path, earth bulge increasing factor for reliability, trees  LVAR-BOAR looks good with 6m high antenna at LVAR
HOVM	KQDD	5.8 GHZ	33.5	Trees	39/128	55	
BLAR	NFAR	5.8 GHZ	10.2	Trees	30.6/	20/65	

9 links require antenna heights greater than 30 m

## Appendix B

NM Station arrival counts since January 1, 2020 with quality>0.5. DB query was: *select sta, net, count(\*) from arrival where net = 'NM' and quality > 0.5 and datetime > '1577836800' group by sta, net;*. Note that the list includes all stations not just shortperiod.

sta	cnt	sta	cnt	sta	cnt	sta	cnt
RDGT	1079	GNAR	285	MSAR	69	UALR	19
MADT	992	FLPT	265	RVAR	69	XB01	18
PPLM	944	TOPM	254	LVAR	66	USIN	17
MORT2	879	CWPT	250	HCAR	57	CLTN	16
STAM	869	CHNM	226	HBAR	54	OLIL	16
PENM	838	MFRT	213	CPAR	51	MGMO	14
WYBT	750	EPRM	198	EDIT	50	MKAR	14
MARM	734	NNAR	192	GSAR	48	SFTN	14
CACT	702	DWDM	168	CHRM	47	UTMT	14
MIST	701	HICK	160	BOAR	45	BVIL	11
CATM	669	NMEM	155	SHTN	45	EBZ	11
PGVM	643	GLST	146	CGM3	44	SLM	9
TNMT	611	HALT	139	X901	43	BLO	7
POBM	587	X702	128	PWLA	42	JCMO	7
SJBM	555	GOBM	127	TWAR	42	PLAL	7
NWCT	539	DLAR	122	X602	38	TYMO	7
GLAT	489	BFAR	112	MTAR	37	ATTN	5
WADM	488	FPST	107	FVM	36	TCIN	4
COKM	483	MATM	106	LRAR	36	EDIL	3
LNXT	478	MLDM	106	TYAR	36	SEAR	3
PARM	470	BETM	96	X502	36	OHIN	2
HENM	453	BROM	92	NHAR	33	SCIN	2
LFRT	450	BRNM	89	QUAR	31	CBHS	1
WALK	413	PBMO	82	TMAR	31	GILT	1
MCAM	401	CWPT2	81	BLAR	28	HDAR2	1
HOPT	386	PVMO	81	BVAR	27	HDBT	1
BACM	385	LPAR	80	FFIL	25	MCAR	1
NMDM	362	HTAR	76	NFAR	25	MCIL	1
BRGM	357	GUAM	72	ARPT	24	MPH	1
PEBM	342	HOVM	72	NHIN	21	MPHB	1
KEWM	333	RELT	71	SIUC	19	RDST2	1