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# Broadband Seismic Background Noise at Temporary Seismic Stations Observed on a Regional Scale in the Southwestern United States

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Abstract Background noise power spectral density (PSD) estimates for 54 PASSCAL Colorado Plateau/Rio Grande Rift/Great Plains Seismic Transect (LA RISTRA) stations were computed using data from 1999 to 2000. At long periods (0.01–0.1 Hz), typical vertical noise levels are approximately 12 dB higher than the nearby Global Seismic Network (GSN) borehole station ANMO, but horizontal power spectral density (PSD) noise levels are approximately 30 dB higher. Long-period noise levels exhibit essentially no spatial correlation along the LA RISTRA transect, indicating that local thermal or atmosphere-driven local slab tilt is the dominant source of noise in this band. Between 0.1 and 0.3 Hz, typical noise levels are dominated by naturally occurring microseismic noise and are essentially identical to those observed at ANMO. At short periods, 0.3–8 Hz, typical noise levels along the network exceed ANMO levels by approximately 15 dB, with the highest levels corresponding to proximity to cultural noise sources. No significant day/night variations were observed in the microseismic band; however, both low- and high-frequency noise levels show an increase of up to 8 dB in median midday versus midnight noise levels. We find that the major shortcomings of these shallow PASSCAL-style temporary vaults relative to a GSN-style borehole installation are increased susceptibility to long-period horizontal (≥20 sec) noise and to surface noise sources above approximately 2 Hz. Although the high-frequency near-surface noise field is unavoidable in shallow vaults, we suggest that increased understanding and mitigation of local tilt effects in shallow vaults offers the possibility of significantly improving the long-period noise environment.

## Introduction

With the advent of ever larger campaign deployment of broadband seismometers (e.g., Kennett and van der Hilst, 1996; Henyey, 2000) for periods of several months to years, it is increasingly imperative to rapidly identify high signal-to-noise sites and to standardize and optimize the design of portable seismometer vaults. We examine ambient background noise levels from the Rio Grande Rift/Great Plains Seismic Transect (RISTRA) experiment, a relatively long (950.7 km) and densely occupied (18.1 ± 3.6 km) network of IRIS PASSCAL broadband seismic stations, to investigate factors that influence noise levels. RISTRA and similar broadband deployments are commonly designed to image mantle and gross crustal structures by recording high signal-to-noise teleseismic signals ranging from long-period surface waves to short-period body waves.

Although noise can be dominated by the recording system in rare instances (e.g., Rodgers *et al.*, 1987), or at extremely quiet sites, system noise levels with currently standard 24-bit dynamic range recorders and broadband seismometers such as those used in the PASSCAL program are typically well below those of the ambient natural and cultural seismic noise field.

Principal natural noise sources include microseisms, diurnal temperature, and other atmospheric conditions (Zurn and Widmer, 1995; Beauduin *et al.*, 1996), flow and waves associated with regional rivers and lakes, and wind. Principal cultural sources of noise are generally transportation corridors (roads, railways, pipelines, etc.). At high frequencies (above 0.3 Hz), the seismic noise field is commonly dominated by cultural or wind-generated noise (e.g., Rodgers *et al.*, 1987; Given, 1990; Gurrola *et al.*, 1990; Given and Fels, 1993; Peterson, 1993; Withers *et al.*, 1996; Young *et al.*, 1996; Vila, 1998; Uhrhammer, 2000), with wind noise being the predominant high-frequency noise source at remote sites (e.g., Withers *et al.*, 1996).

## RISTRA Seismic Data

To address the regional tectonic questions of mantle and crustal rifting processes in the Rio Grande rift and geophysical conditions underlying the Colorado Plateau (e.g., Baldridge *et al.*, 1995), the RISTRA team recently (May, 2001) completed the collection of seismic data along a 950.7-km transect running northwest-southeast from Lake Powell, Utah, near the center of the Colorado plateau, across the central Rio Grande rift, and into the Great Plains near Pecos, Texas (Fig. 1a). RISTRA consisted of 57 continuously recording PASSCAL broadband stations deployed between August 1999 and May 2001.

Locating RISTRA stations uniformly along a great-circle path aligned with teleseismic source zones along a western South American–Alaskan transect resulted in very diverse local site conditions, ranging from remote sites on Colorado plateau bedrock to culturally compromised sites on deep alluvium in sight of dwellings and highways (Fig. 1b). Due to experimental design preferences, such as uniform station spacing, and access issues, local cultural noise sources such as oil field operations, ranch improvements, and roads could not always be avoided. Although RISTRA occupied sites on private, National Forest, Bureau of Land Management, New Mexico State Land Office, Navajo Nation, Laguna Pueblo, and Isleta Pueblo lands, we note that with informational mailings coupled with preliminary on-site visits with landowners and land managers beginning approximately 1 year before deployment, we encountered no significant problems in obtaining permission for an extensive passive seismic experiment with a duration of about 18 months.

All sites were configured with Streckeisen STS-2 (120 sec) seismometers and a sampling rate of 20 samples/sec. Three off-line stations deployed parallel to and southwest of the main network (Fig. 1a) are not considered in this study. RefTek 24-bit recording systems (72A-07 and 72A-08) were used at all sites. There were two types of seismometer vault construction that we found to be approximately equally good in terms of noise and other characteristics. Most vaults in the southern part of the network were constructed from plywood with 2.5-cm-thick polystyrene insulation, whereas vaults at sites northwest of the Rio Grande rift used medical styrofoam containers with 10-cm-thick walls. Seismometers were mounted on 10-cm-thick premix concrete pads with a diameter of approximately 0.3 m. Up to 0.4 m of dirt was mounded on top of each vault to provide further insulation and thermal mass. Local power supplies consisted of two 30 W solar panels and approximately 110 A hr of lead-acid battery capacity.

## Noise Power Spectral Density Estimation

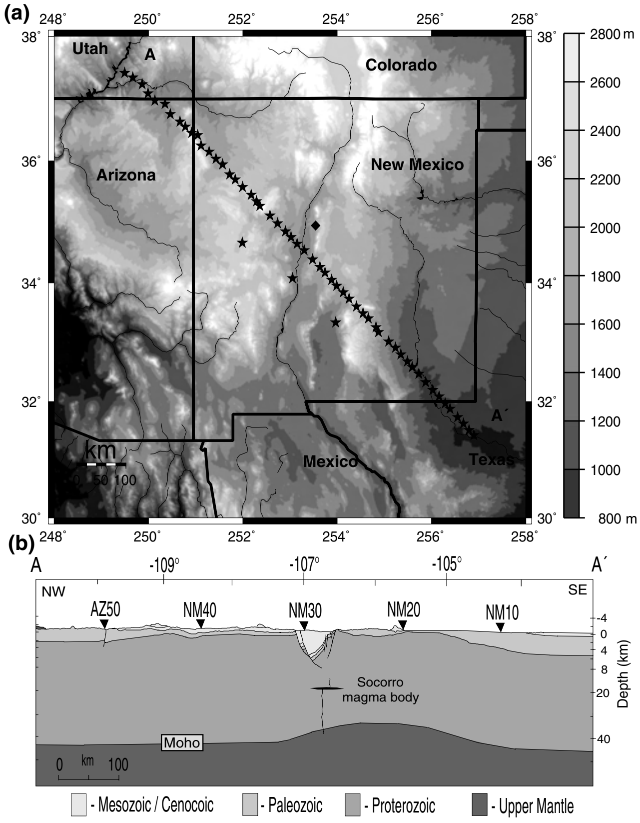

Figure 1. (a) Topographic map with RISTRA station locations. Gray-scale indicates elevation in meters. Stars show main transect station locations and the diamond shows the location of the Global Seismic Network borehole station ANMO. (b) Geological cross section along the RISTRA main transect.

Median noise acceleration power spectral density (PSD) estimates between 0.01 and approximately 8.5 Hz (the approximate onset of the antialiasing filter transition band) were calculated for each component of each RISTRA station using 1-hr data windows between August 1999 and November 2000. Times between data windows ranged from about 1 to approximately 5 weeks. Preliminary determinations of epicenters reported by National Earthquake Investigation Center (NEIC) were referred to in selecting each data window to avoid earthquake signals according to (1) no earthquakes with $M_\mathrm{b} \geq 6.0$ reported in the preceding 24 hr; (2) no earthquakes with $M_\mathrm{b} \geq 5.0$ reported with $\Delta \leq 70°$ in the preceding 24 hr; (3) no earthquakes with $M_\mathrm{b} \geq 4.0$ reported for $\Delta \leq 20°$ in the previous 12 hr; (4) no earthquakes with $M_\mathrm{b} \geq 3.0$ reported for $\Delta \leq 15°$ in the previous 3 hr. Midnight (between 23:00 and 00:00 local time) and midday (between 11:00 and 12:00 local time) periods that met the previous criteria were sampled from each month of data collected between August 1999 and November 2000. All prospective data windows were visually inspected to ensure that obvious signals from local microearthquakes or other obvious cultural contaminants (e.g., mining explosions) were excluded. An identical selection procedure was performed for data recorded at ANMO, a 100-m borehole IRIS/USGS Global Seismic Network (GSN) station incorporating a Teledyne Geotech 54100 three-component seismometer. ANMO is located approximately 55 km from the midpoint of the RISTRA line (H. Bolton, personal comm., 2001) (Fig. 1a).

Noise PSD estimates for all data windows were obtained for each component of each station using Welch's (Welch, 1967) averaging method with a Hanning taper and 18 375-sec windows with 50% overlap. A median PSD was then calculated at each frequency for each component of each station. Overall median PSD estimates calculated for the entire RISTRA network and for ANMO are shown in Figure 2. The ratio of background noise for each station compared to the network median is shown in Figure 3. The spatial autocorrelation of the data in Figure 3 is shown in Figure 4. Differences between midday and midnight median noise levels were calculated for the network median (Fig. 5a), for ANMO (Fig. 5b), and for individual RISTRA stations (Fig. 5c).

## Results and Discussion

At long periods (0.01–0.06 Hz) RISTRA vertical-component median noise levels were approximately 10–12 dB above ANMO and 17 dB above the USGS low-noise model of Peterson (1993) (Fig. 2a–c), with 95% variation limits (1.96 × standard deviation) ranging up to approximately 10 dB for horizontal and 17 dB for vertical components (Fig. 2d). The higher variation limits for the vertical component is because some sites have a very quiet vertical component (Fig. 3) so that more variation is seen across the network than on the horizontal components that are uniformly noisier. The noise environment is highly anisotropic in that that horizontal components are much noisier at long periods, 25–30 dB higher than ANMO and 40 dB higher than the USGS low-noise model. This is due to the sensitivity of surface-mounted broadband seismometers to local tilt caused by thermal and/or barometric effects and has been ubiquitously observed in nonborehole broadband sites, even examples located in tunnels (e.g., Given and Fels, 1993). Site testing at the USGS Albuquerque Seismological Laboratory has shown that even a shallow borehole installation (a few meters) is capable of greatly reducing this effect (H. Bolton, pers. comm.). Long-period background noise levels also show considerable (up to 15 dB) variation across the network (Fig. 3), further demonstrating the local aspect of this component of the noise environment. Such local variation is reflective of surface site conditions, and systematic tests to further illuminate this local noise process should consider differences in slope, diurnal shading conditions, soil type, and moisture content, as well as vault design. Removing the barometric pressure signal and/or vault temperature from seismic data has been shown to lower background noise levels by up to 20 dB between 0.001 and 0.03 Hz (Beauduin, 1996; Zurn and Widmer, 1995); this suggests that a similar noise/barometric correlation/removal process might be useful for PASSCAL-style vaults, perhaps also incorporating temperature fluctuations. To our knowledge, this has not been done for typical shallow vaults, although it has shown great promise in ocean-bottom seismographs (e.g., Crawford and Webb, 2000).

At microseismic frequencies (0.06–0.3 Hz), RISTRA network median noise is 5 to 20 dB above the USGS low-noise model (Figure 2a–c) and is essentially indistinguishable from ANMO. Ninety-five percent variation intervals in the microseismic band span a range up to approximately 7 dB (Fig. 2d).

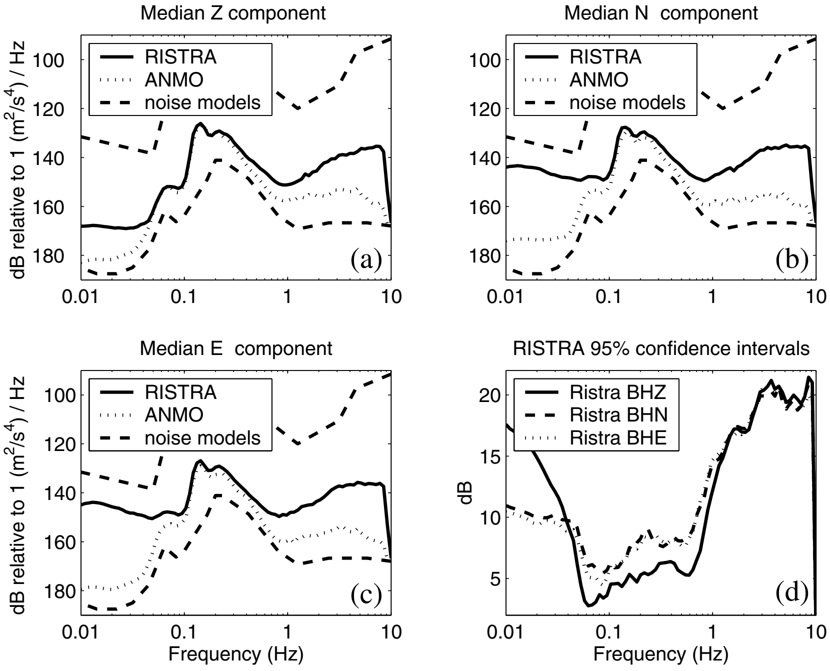

Figure 2. (a,b,c) Median seismic noise levels. Solid lines show RISTRA network median levels for each component; dotted lines show estimates for ANMO. The dashed lines are the USGS high- and low-noise models of Peterson (1993). (d) Symmetric 95% variation intervals (1.96 × standard deviation) on the RISTRA median seismic noise levels of (a–c).

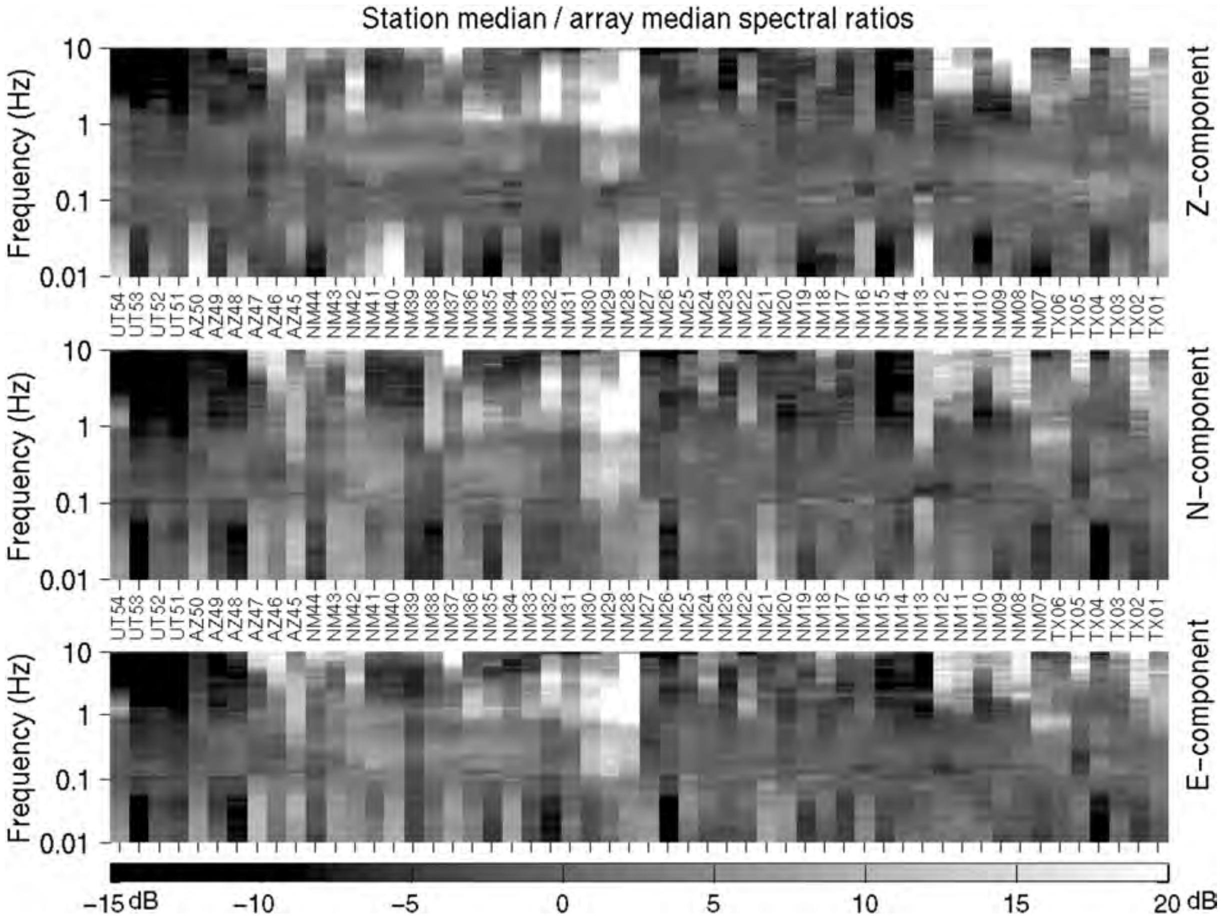

Figure 3. RISTRA station-by-station median noise levels, relative to network median PSD levels shown in Figure 2a–c. Maximal deviations from network median PSD level are approximately (+20 dB, −15 dB), as indicated by the gray/scale.

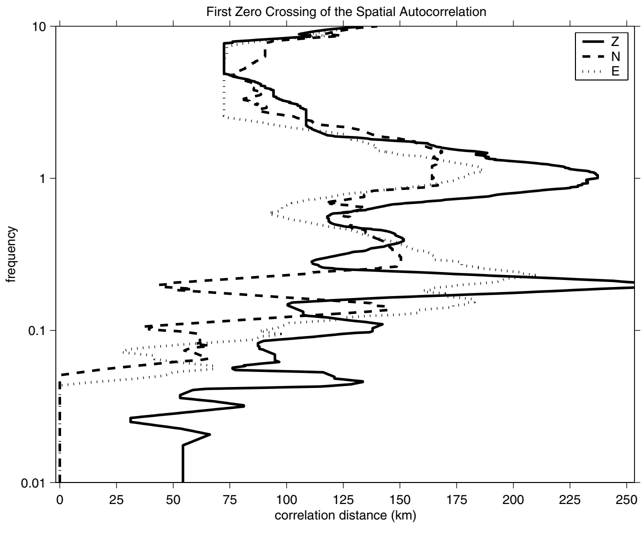

Figure 4. Spatial autocorrelation of the noise levels of Figure 3 (first zero crossing of the autocorrelation function).

At high frequencies (0.3–8.5 Hz), RISTRA noise levels are approximately 30 dB above the USGS low-noise model and approximately 15 dB above ANMO noise levels (Fig. 2a–c). Predictably, stations most isolated from cultural activity, for example, AZ50-UT54 on the Colorado Plateau (Figure 3), are the quietest sites at high frequencies. The noisiest stations in this frequency band are those in the densely populated and major transportation corridor along the deep sedimentary basin of the Rio Grande rift valley (NM28-NM30) and those unavoidably deployed near oil and gas production in southeast New Mexico and west Texas (NM12-TX01). Rift stations are up to 20 dB noisier in the high frequency band than the network median. 95% variation limits span a range of approximately 18 dB at high frequencies (Fig. 2d).

To further characterize the local versus regional aspects typical of the RISTRA noise environment, we examined the spatial autocorrelation of the station median to network median levels of Figure 3. Figure 4 shows the distance to the first zero crossing of the autocorrelation function for each component. Long-period noise ($\leq$0.1 Hz) exhibits no sig-

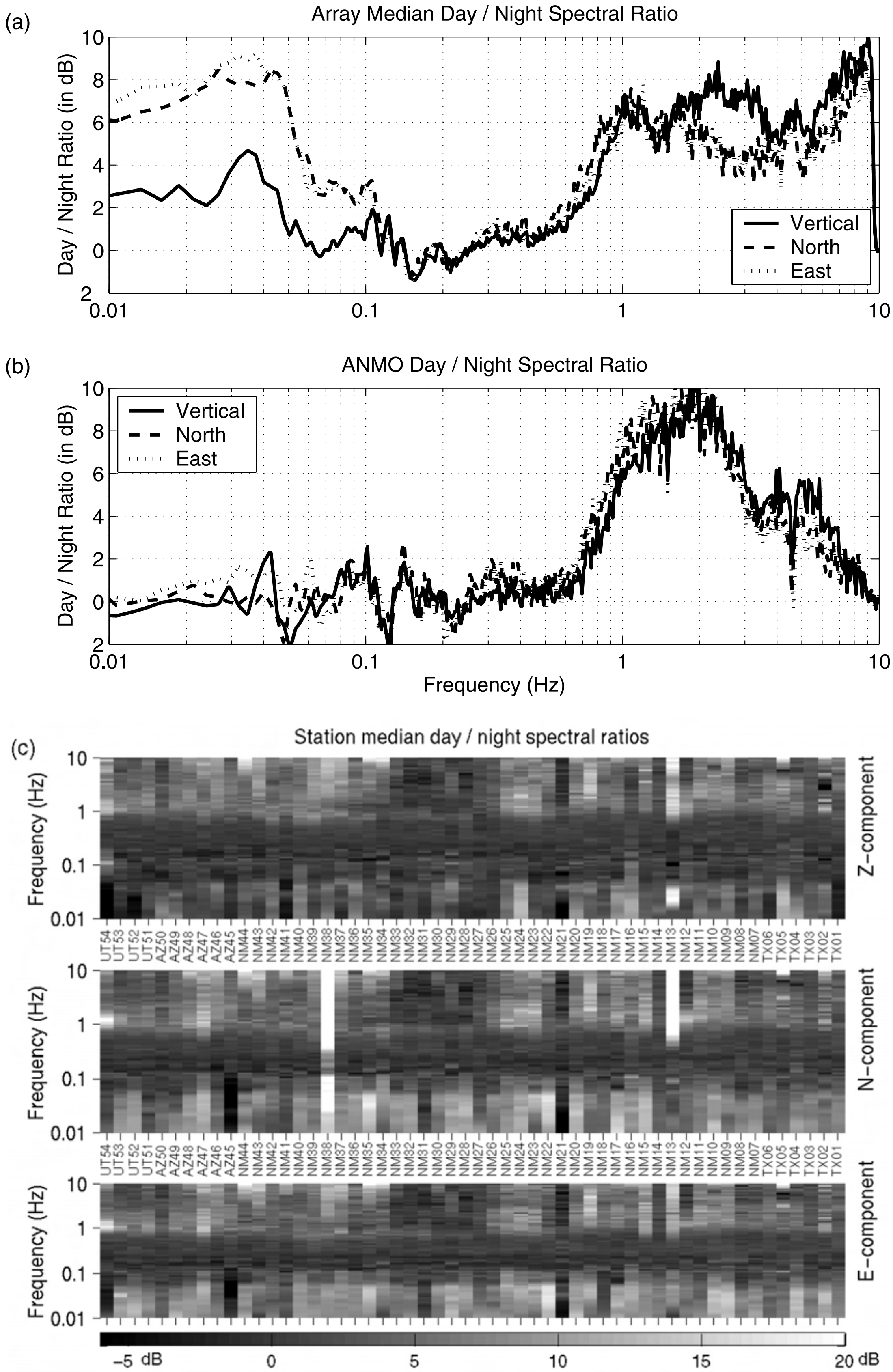

Figure 5. Midday versus midnight noise differences for (a) RISTRA stations and (b) ANMO (c) Individual station median midday versus midnight differences.

nificant spatial correlation (Fig. 4) along the network at the station spacing resolution of about 18 km, confirming that this component of the noise environment is effectively local. At microseismic frequencies (0.06–0.3 Hz), background noise correlates up to approximately 250 km (13 stations) on the vertical component and 175 km on the horizontal components. At high frequencies (0.3–8.5 Hz) vertical-component noise levels correlate up to 225 km, and horizontal component background noise correlates up to 175 km. We attribute the spatial correlation of high-frequency noise levels with regional weather patterns and extended regions of cultural noise along the network, especially those of the high-population, high-noise, Rio Grande rift and producing oil and gas fields of southwestern New Mexico and west Texas (Fig. 3).

We also examined the spatial noise level autocorrelation of several synchronous time windows across the network. At microseismic frequencies (0.06–0.3 Hz), synchronous time windows showed similar results to the autocorrelation of station median spectra (Fig. 4). However, at high frequencies, synchronous time window autocorrelations were highly variable, some roughly matching the correlation lengths of Figure 4, and others having no significant spatial correlation. This is most likely because the high frequencies are dominated by weather-generated noise and cultural noise, which can be highly variable from day to day, either being local or regional depending on wind and other factors. At long periods, we observed neglible noise level correlation for the synchronous time windows, similar to the station median spectra (Fig. 4).

Comparing median midday and midnight noise levels (Fig. 5a,c), we note that at long periods (0.1–0.06 Hz), RISTRA vertical component midday noise levels are only approximately 2 dB above night levels, while the observed increase for the horizontal components is in excess of 7 dB. Increases in daytime long-period horizontal component noise have been noted previously at surface stations (e.g., Butler and Hutt, 1992) and attributed to diurnal variations of wind, barometric pressure, and temperature. Comparison with ANMO noise levels (Fig. 5b) from the same period shows the clear superiority of the borehole installation in reducing diurnally varying long-period noise levels.

In the microseismic band (0.06–0.3 Hz) there are no day/night variations in excess of about 1 dB at either RISTRA or ANMO sites.

At high frequencies (0.3–8.5 Hz), we observe an average increase of up to 8 dB in midday vs. midnight noise levels. The performance below 1 Hz is comparable to ANMO, but ANMO shows significantly better performances at higher frequencies. Both RISTRA and ANMO show a midday/midnight increase in vertical versus horizontal noise between about 2 and 5 Hz. The greatest diurnal increases in RISTRA high frequency noise are seen above approximately 5 Hz. Although the rift stations, NM28-NM30, are the noisiest at high frequencies (Fig. 3), they do not exhibit strong day to night noise ratios (Fig. 5c); evidently the high-frequency cultural noise sources are not significantly linked to the workday cycle and may be linked to more continuous pipeline and regional rail activity.

## Conclusions

Long-period (0.01–0.06 Hz) typical (median) noise levels at these shallow broadband sites are controlled by very local site conditions (as exhibited by a negligible spatial correlation) and are typically 10–12 dB (vertical) and 25–35 dB (horizontals) higher than the highest quality site that is likely achievable in this region (the ANMO GSN borehole station). The horizontal long-period noise environment shows an increase in excess of 7 dB during midday relative to midnight, not observed at ANMO, that we conclude is driven by temperature and/or other atmospheric effects interacting with the vault geometry and/or soil conditions to produce slab tilt. We note that this long-period noise is conceivably partially removable at the longest periods through the application of temperature or barometric correlations and that this possibility should be tested for general application in PASSCAL-style deployments.

RISTRA microseism (0.06–0.3 Hz) noise shows comparable noise levels to ANMO, with negligible midday/midnight variations, and significant correlation out to approximately 250 km, indicating both regional and local aspects to this noise band.

High-frequency (0.3–8.5 Hz) median noise levels are controlled by proximity to local cultural noise sources, particularly the relatively developed Rio Grande rift south of Albuquerque and the oil and natural gas producing regions of southeastern New Mexico and west Texas. The lowest noise levels are correspondingly observed at the most culturally remote sites on the Colorado Plateau. Midday versus midnight typical noise ratios at high frequencies were not always correlated with absolute noise levels. Sites within the relatively noisy Rio Grande rift, for example, were equally noisy even during midnight periods. Because of the extended nature of the principal high-frequency noise regions in this network (the Rio Grande rift and the southwestern oil and gas fields), high-frequency noise levels also display a general correlation out to approximately 225 km, but correlations during synchronous time periods do not always show this effect.

We conclude that the most likely prospect for significantly improving the broadband noise environment in shallow portable broadband deployments below about 0.1 Hz lies in a more detailed understanding of the local long-period noise environment. This is especially notable for horizontal components, where key details include improved understanding of how slab tilt effects are related to thermal, atmospheric pressure, and ground effects interacting with vault design and near-surface site geology.

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