Ambient Seismic Noise

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Abstract

For earthquake-monitoring and detection purposes it is important to know the ambient seismic nose levels experienced by a network of seismic stations. In this paper, we present global ambient noise levels using 159 worldwide broadband stations within the Global Seismographic Network (GSN) and the Advanced National Seismic System (ANSS). To determine ambient noise conditions, we analyze the distribution of seismic noise as a function of period and determine the highest probability power levels. While it may be scientifically interesting to determine the absolute quietest noise levels achieved by a network, we find that these low noise levels are generally very low probability occurrences (1-3%) and do not closely track significantly higher probability (20-30%) "ambient" noise conditions determined by the mode of the power distribution. In fact, statistical mode noise levels are as much as 25dB above the minimum at higher frequencies (1-10Hz) significant to earthquake monitoring.

Introduction

In this paper, we analyze ambient seismic noise levels, as defined by the highest probability power levels at each period, for worldwide and U.S. broadband stations within the global seismographic network (GSN) and the Advanced National Seismic System (ANSS). Earth noise models have been used as baselines for evaluating seismic station site characteristics and design, instrument design, and noise sources since the published high and low seismic background displacement curves of Brune and Oliver (1959) and Franti et al., (1962). Recently, the standard Peterson low noise model (LNM) (Peterson, 1993) was updated by analyzing the absolute quietest conditions for stations within the GSN during a one-year period in 2002-2003 (Berger et al., 2005). The original Peterson LNM was constructed using minimum noise levels from representative quiet periods at continental interior stations distributed around the world. Many seismic stations are surrounded by urban areas and have considerably higher noise levels for frequencies significant to earthquake monitoring (1-20Hz). This is the principle reason that the noise levels of the LNM have such low probabilities of occurrence for stations worldwide (Figure 1). For many stations such low levels of noise are unattainable suggesting that for routine earthquake monitoring purposes a global noise threshold based on higher probability noise levels is needed.

Noise Processing System and Methods

In June 2004, new software was made available to the seismology community that allows users to evaluate the long-term seismic noise levels for any broadband seismic data channel streaming into the buffer of uniform data (BUD) within the Incorporated Research Institutions for Seismology (IRIS) data management system (DMS). BUD is the IRIS DMS acronym for the online data cache from which the DMC distributes near-real time miniSEED data holdings prior to formal archiving. The new noise processing software uses a probability density function (PDF) to display the distribution of seismic power spectral density (PSD). The algorithm and initial software were first developed at the United States Geological Survey (USGS) as a part of the data and network quality control (QC) system for the Advanced National Seismic System (ANSS) (McNamara and

Buland, 2004). Further development, supported by IRIS, allowed us to implement the algorithm against the BUD dataset utilizing the QUACK framework. QUACK is a software package under development at the IRIS DMC for analyzing real-time seismic data flowing into the BUD (see http://www.iris.washington.edu/servlet/quackquery/).

The PDF noise analysis software is applied against the entire continuous data-stream available within the BUD. There is no need to screen for system transients, earthquakes or general data artifacts since they map into a background probability level. In fact, examination of artifacts related to station operation and episodic cultural noise allows us to estimate both the overall station quality and a baseline level of earth noise at each site. The output of this noise analysis tool is useful for characterizing the current and past performance of existing broadband sensors, for detecting operational problems within the recording system, and for evaluating the overall quality of data for a particular station. The advantages of this new approach include (1) providing an analytical view representing the distribution noise levels rather than a simple absolute minimum, (2) providing an assessment of the overall health of the instrument/station, and (3) providing an assessment of the health of recording and telemetry systems.

Employing the system discussed above, which implements the algorithm used to develop the USGS Albuquerque Seismological Laboratory (ASL) low noise model (LNM; Peterson, 1993), we computed power spectral density (PSD) for 159 worldwide seismic stations in the GSN and ANSS backbone networks (Table 1). In this algorithm, hour-long, continuous, and overlapping (50%) time series segments are processed. Since we are interested in the distribution of power levels from noise sources, there is no removal of hourly segments with earthquakes, system transients, minor gaps and/or data glitches. However, hourly segments with significant gaps, greater than 1 sec, are removed from the statistical calculations. The instrument transfer function is then removed from each segment, yielding ground acceleration (for easy comparison to the LNM). Each hour-long time series is divided into 13 segments, each about 15 minutes long and overlapping by 75%, with each segment processed by (1) removing the mean, (2) removing the long period trend, (3) tapering using a 10% sine function, and (4) transforming using an FFT algorithm (Bendat and Piersol, 1971). Segments are then averaged to provide a PSD for each one-hour time series segment.

For each channel, raw frequency distributions are constructed by gathering individual PSDs in the following manner (1) binning periods in 1/8 octave intervals, and (2) binning power in 1 dB intervals. Each raw frequency distribution bin is then normalized by the total number of PSDs to construct a Probability Density Function (PDF). The probability of occurrence of a given power at a particular period for several stations in the GSN and ANSS are plotted for direct comparison to the Peterson high and low noise models (HNM, LNM; Figure 1). We also compute and plot the minimum, mode, and maximum powers for each period bin. A wealth of seismic noise information can be obtained from this statistical view of broadband seismic noise (Figure 1). For a more detailed discussion of the noise processing methods see McNamara and Buland (2004).

GSN and ANSS PDFs

Our first observation is that noise power estimates are distributed over a wide range of powers at all periods. Note that for all stations the maximum power (blue lines, Figure 1) is well above the HNM. Since we make no attempt to screen the seismic waveforms for earthquakes and system transients, this high power region of the PDF is dominated by low probability, yet high power occurrences of naturally occurring earthquakes, cultural noise, data gaps, calibration pulses, mass re-centers and sensor glitches. Several PDF noise sources, of this type, are labeled in figure 1. For a more detailed discussion of the features observed in the PDFs see McNamara and Buland (2004).

The second observation we note in the PDFs is that the minimum powers (red lines, Figure 1) are often near the LNM and very low probability (1-2%). We also observe compression of the probability observations into a narrow power range suggesting that each station can have a characteristic minimum level of background Earth noise. We also note that the highest probability "ambient" noise levels, represented by the mode (black line), are often affected by diurnal variations in the cultural noise band (0.1-1s, 1-10Hz) and variations in the microsiesm peak (5-10s). At shorter periods, higher frequencies, the mode and minimum are often divergent suggesting that the minimum does not represent common station noise conditions. At periods greater than 10s, the mode and minimums closely tack one another.

For example, at station LTX 3797, hours of data were used to generate the PDF (Figure 1). As observed, the LTX minimum noise level has a probability of occurrence of roughly 1%, suggesting that only 38 hours of data ever experienced such low levels of noise. On the other hand, at periods of interest to the earthquake monitoring community (0.1-1s, 1-10Hz), LTX noise levels were approximately 20dB higher than the minimum for roughly 760 hours (see LTX mode figure 1) and roughly 30dB higher for an additional 380 hours. The high frequencies at LTX are an extreme example of the differences between the PDF minimums and modes however, it plainly illustrates our point that "ambient" site conditions are better represented by the highest probability of occurrence noise levels (i.e., PDF modes) (black lines Figure 1) than by the very low probability minimum noise levels.

Ambient Earth Noise

In an effort to determine ambient Earth noise levels that are useful to the earthquake monitoring and seismic network design community, we computed a PDF from the modes of 159 GSN and ANSS BHZ channels (Figure 2). The plot shows the probabilistic distribution of the highest probability occurrence noise levels (PDF modes) at 159 worldwide broadband seismic stations for periods from 0.1 to 100s. We also computed additional statistics on the PDF modes (min, max, mean, median, mode) to illustrate the distribution of the observations. The maximum noise level (dark blue line Figure 2) is dominated by just a few, high noise, GSN stations located on islands (5-10s) and ANSS stations with high levels of cultural noise (0.1-1s). For all periods considered, except at the microseism peak (8sec), the maximum from this analysis, is higher than the Peterson HNM. The minimum (red line Figure 2) at short periods (high frequencies) is lower than the Peterson HNM but at periods greater than 10 seconds, the minimum is higher than the Peterson LNM. However across the entire spectrum, it is evident from Figure 2 that, the minimum has a very low probability of occurrence (1-2%). The minimum (red line figure 2) is dominated by one station in Antarctica, QSPA, at the higher frequencies (1.0-10Hz, 0.1-1s). Anderson et al. (2004) have determined that the high-frequency low power level at QSPA is actually a spectral hole at 4Hz due too the thick surface ice layer, and does not represent ambient noise conditions at the station. The median (pink line figure 2) and mean (yellow line figure 2) noise levels are smooth and closely track one another at power levels that range from 10-30dB above the LNM. The mode (white line figure 2) is considerably less smooth due to the variation of noise levels across the networks but tracks along approximately 10-20dB above the LNM. The mode represents the noise conditions at roughly 10-20% of the stations analyzed in this study. The remaining stations display a wide range of powers for periods from 0.1-100s.

For comparison, we have also plotted the mode low noise model (MLNM Figure 2) from McNamara and Buland (2004). This noise model was constructed for earthquake monitoring purposes from the minimum of the vertical component PDF modes of 65 broadband ANSS stations within the continental United States. It is interesting to note that the minimum for stations restricted to the continental US (MLNM figure 2) is generally 5-10dB higher than the minimum using global stations in this study (red line Figure 2). The minimum noise level of all 159 stations (red line figure 2) closely tracks the low powers of the Peterson LNM but are generally very low probability occurrences (1-2%). For this reason the higher probability noise levels, represented by the median and mode of the two networks give us an estimate of “ambient” Earth noise that is more appropriate when designing seismic networks for earthquake monitoring.

Conclusions

We present a new approach to evaluate “ambient” noise levels at worldwide seismic stations, based on the power spectral density methods used to generate the NLNM of Peterson (1993) and statistical methods previously discussed in McNamara and Buland (2004). The GSN and ANSS stations in our analysis exhibit considerable variations in noise levels as a function of time of day, season, geography and sensor and installation type. “Ambient” earth noise levels for global earthquake monitoring networks are determined by analyzing the statistical distribution of the highest probability noise levels (PDF modes) at GSN and ANSS stations throughout the world. The results of our noise analysis are useful for characterizing the performance of existing GSN and ANSS stations, for detecting operational problems, and should be relevant to choosing future locations of ANSS backbone stations within the United States and optimizing the distribution of regional network stations.

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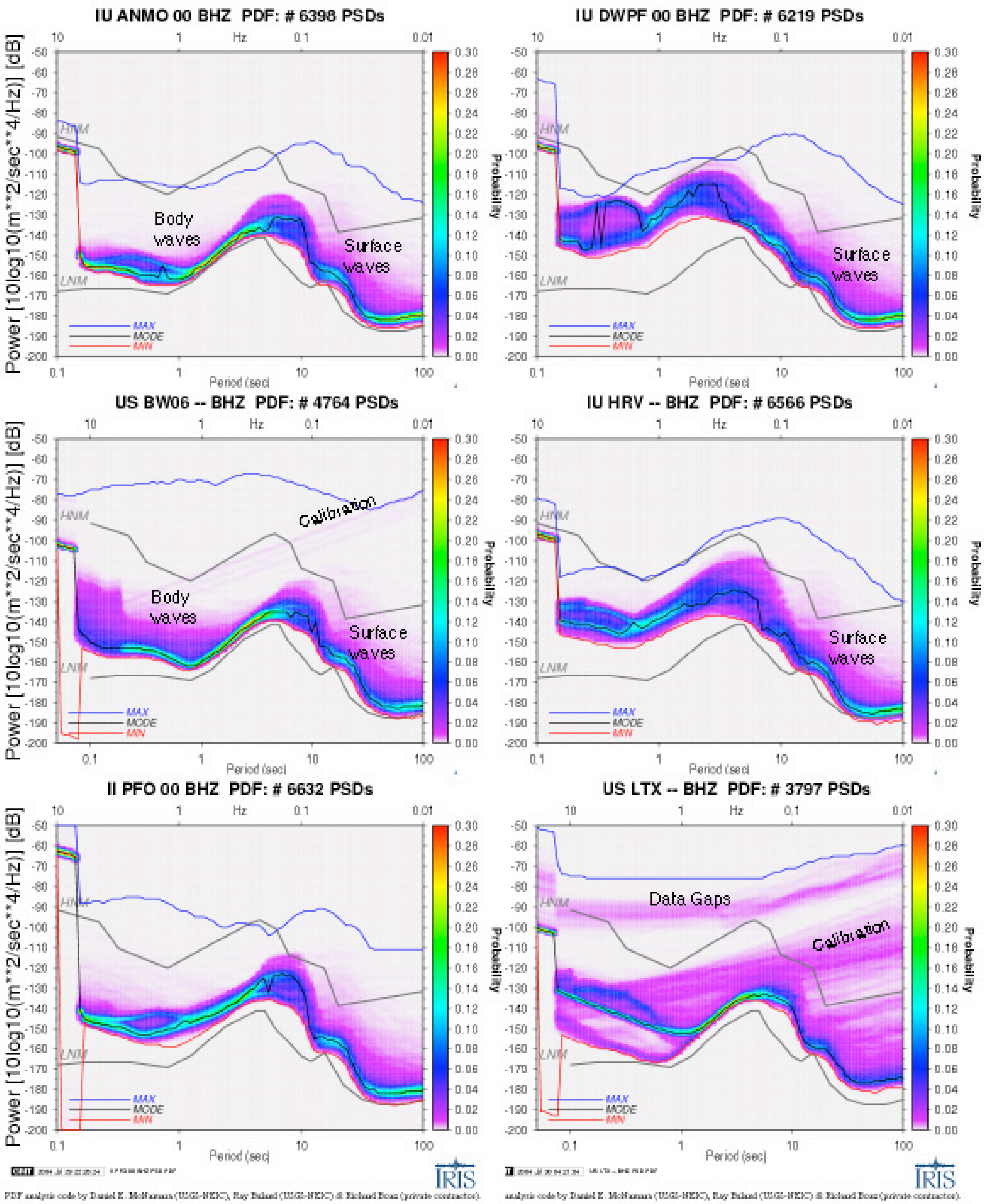
Figures

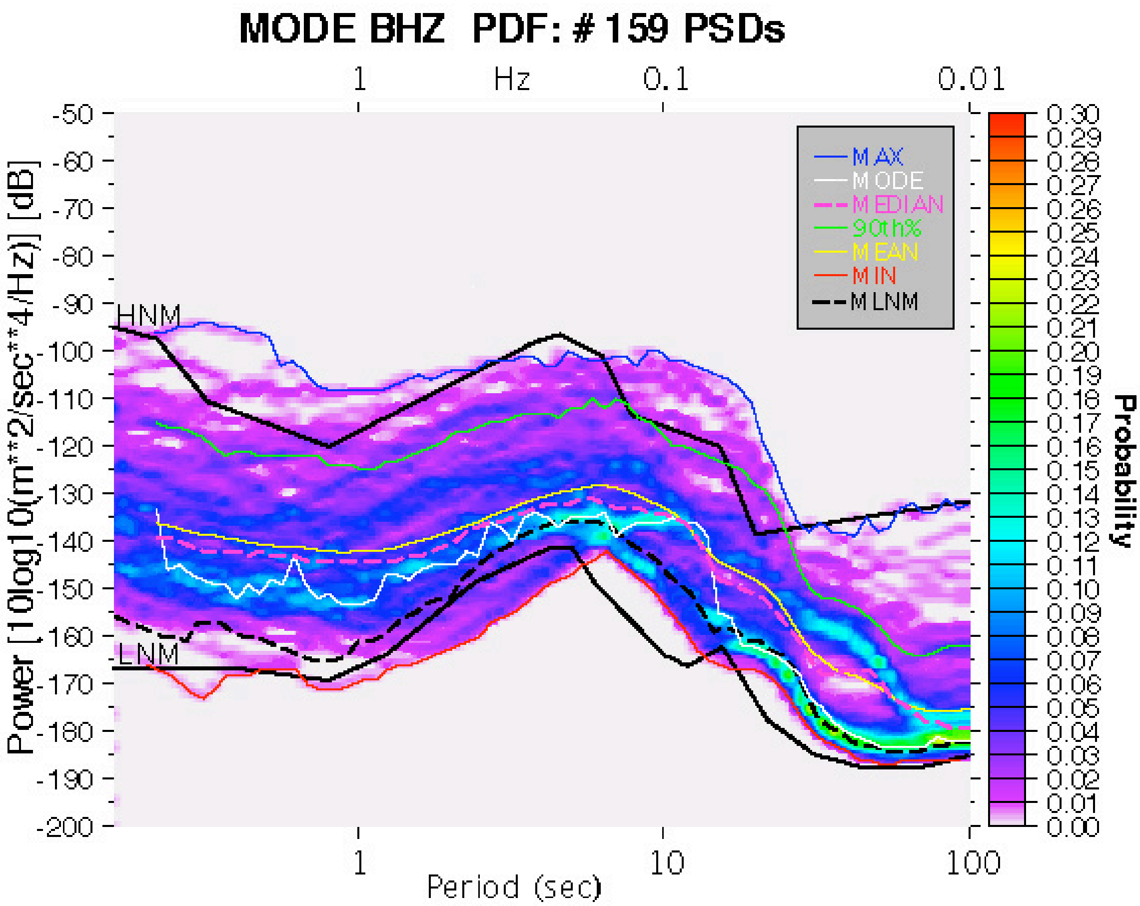
Figure 1: GSN and ANSS individual station PDF examples. BHZ.

Figure 2: PDF of individual GSN and ANSS station modes. BHZ.

Table 1: Listing of stations used in this analysis.



(Figure 1: McNamara et al., 2004)



(Figure 2: McNamara et al., 2004)

Table 1: Stations Used in Noise calculations

STA	NET	LOC
BJT	IC	00
ENH	IC	00
ENH	IC	10
HIA	IC	00
LSA	IC	00
LSA	IC	10
MDJ	IC	00
MDJ	IC	10
QIZ	IC	00
QIZ	IC	01
AAK	II	00
ARU	II	00
BFO	II	00
BORG	II	00
BORG	II	10
BRVK	II	00
CMLA	II	00
COCO	II	20
DGAR	II	00
DGAR	II	10
EFI	II	00
ESK	II	00
FFC	II	00
JTS	II	00
JTS	II	10
KDAK	II	00
KDAK	II	10
KIV	II	00
KURK	II	00
KWAJ	II	00
KWAJ	II	10
MBAR	II	00
MBAR	II	10
NNA	II	00
PALK	II	00
PALK	II	10
PFO	II	00
PFO	II	10
RPN	II	00
RPN	II	10
SACV	II	00
SACV	II	10
SUR	II	00
SUR	II	10
TAU	II	00

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WRAB II 00
ADK IU 00
ANMO IU 00
ANMO IU 10
ANTO IU 00
BBSR IU 00
BBSR IU 01
BILL IU 00
CASY IU 00
CASY IU 10
CCM IU 00
COLA IU 00
COLA IU 10
COR IU 00
CTAO IU 00
DWPF IU 00
GNI IU 00
GRFO IU --
GUMO IU 00
GUMO IU 10
HKT IU 00
HRV IU --
INCN IU 00
INCN IU 10
KBS IU 00
KBS IU 10
KIP IU 00
KIP IU 10
KMBO IU 00
KMBO IU 10
KONO IU 00
KONO IU 10
LSZ IU 00
LSZ IU 10
LVC IU 00
LVC IU 10
MA2 IU 00
MAJO IU 00
MBWA IU 10
MIDW IU 00
NWAO IU 00
OTAV IU 00
OTAV IU 10
PAYG IU 00
PAYG IU 10
PET IU 00
PMG IU 00
PMG IU 10
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PMSA IU 00
PTCN IU 00
PTCN IU 01
QSPA IU 00
QSPA IU 10
QSPA IU 20
QSPA IU 30
RAR IU 00
RAR IU 10
RSSD IU 00
SBA IU 00
SJG IU 00
SNZO IU 00
SNZO IU 10
SSPA IU 00
TATO IU 00
TATO IU 10
TEIG IU 00
TIXI IU 00
TRQA IU 00
TRQA IU 10
TUC IU 00
ULN IU 00
WCI IU 00
WVT IU --
YAK IU 00
YSS IU 00
AAM US --
ACSO US --
AHID US --
BINY US --
BLA US --
BOZ US --
BW06 US --
CBKS US --
CBN US --
CMB US --
DUG US --
ELK US --
HAWA US --
HLID US --
HWUT US --
ISCO US --
JCT US --
JFWS US --
LBNH US --
LRAL US --
LTX US --

MCWV US --
MIAR US --
MNV US --
MSO US --
NCB US --
NEW US --
NHSC US --
OCWA US --
OXF US --
RSSD US --
SAO US --
SDCO US --
WCI US --
WDC US --
WMOK US --
WUAZ US --
WVOR US --
WVT US --