Evaluating the Performance of Global Seismic Stations

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INTRODUCTION

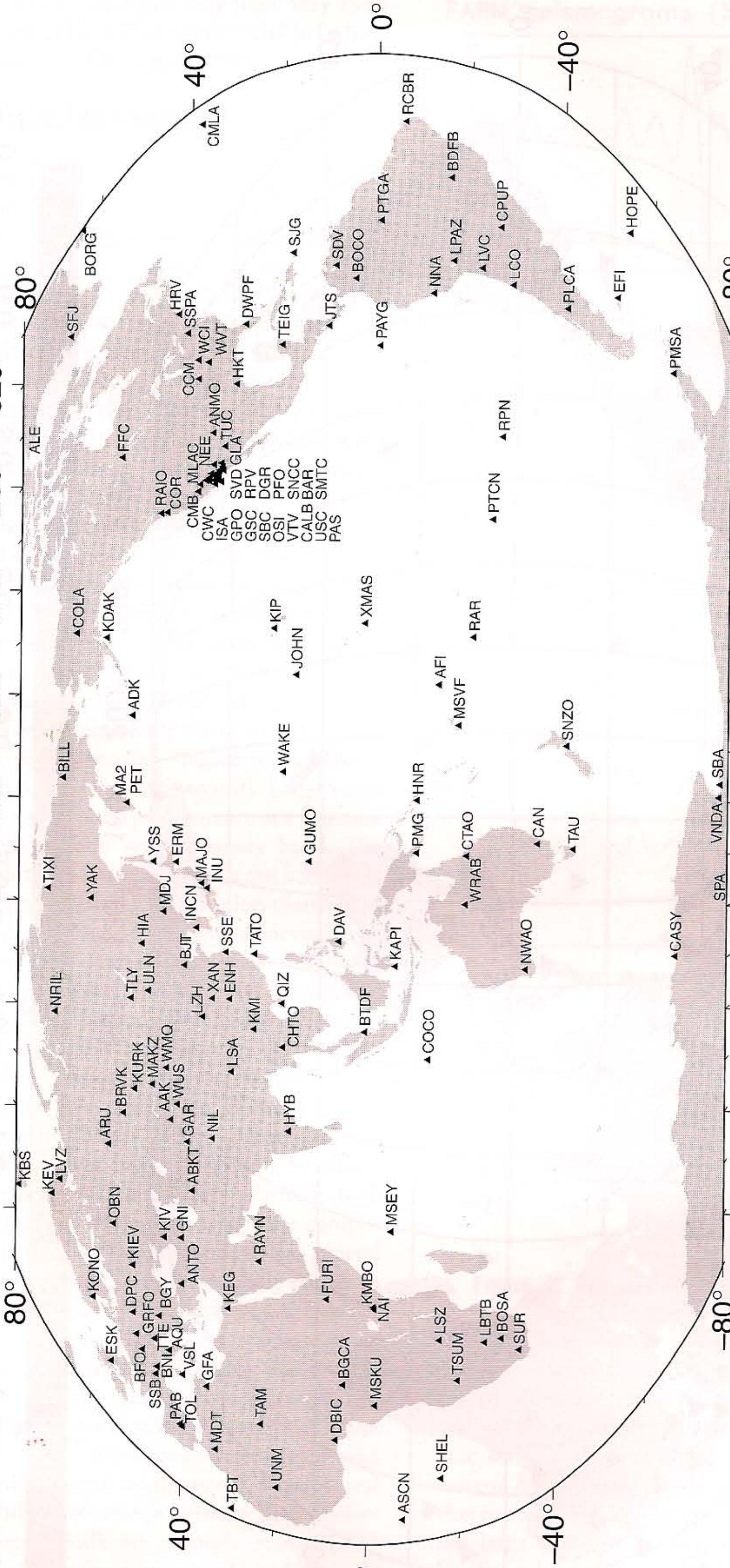
As the number of global seismic stations continues to grow, measuring station performance is of increasing importance for quality control purposes and to provide input into the siting of new stations or the relocation of existing stations. However, the value of a seismic station depends upon many different factors: the quality and quantity of the data that it provides, the location of the site, and the research goals of individual scientists. Although most seismologists would agree that some stations are more valuable than others, they might disagree when evaluating the worth of specific stations. For example, scientists pursuing mantle tomography will benefit from uniform global coverage, making stations on oceanic islands valuable despite their typically high noise levels. These stations would also be of great value to studies of microseism generation in the oceans. On the other hand, these island stations are of little use to researchers interested in the detection of low-yield nuclear tests on the continents. Thus, there can never be a single measure of station value that is appropriate for all end users of seismic data.

Nonetheless, when resources to maintain seismic stations are limited, some evaluation of station performance and usefulness for research is important to maximize the effectiveness of the network. In some cases it may be advantageous to shut down or to move underperforming and/or expensive stations. We estimate the station reliability (*i.e.*, "uptime") by the fraction of events that are recorded during the time of station operation. Another important factor in evaluating the quality of seismic stations is the station noise level as a function of frequency (*e.g.*, Astiz and Creager, 1994; Astiz, 1997). Here we take a slightly different approach and consider the fraction of global events that are actually recorded by individual stations and the average signal to noise that they achieve in these records. Our evaluation criteria thus depend upon the typical noise levels, the global distribution of teleseismic events, and the percent "uptime" of the stations. Our study is limited to data from 134 stations (Figure 1) from the global seismic networks that are available through the Incorporated Research Institutions for Seismology (IRIS) Fast Archive Recovery Method (FARM) facility. This includes data from a variety of global seismic networks for events with $M_b > 5.7$ (shallow events) and $M_b > 5.5$ (deep events) from 1988 to 1999 (see http://www.iris.washington.edu/HTM/farm.htm). We identify large differences in the signal-to-noise performance of the stations as a function of both station location and frequency. These differences, together with variations in the reliability of the stations, translate into differences of factors of ten or more in the number of useful seismic events recorded by individual stations.

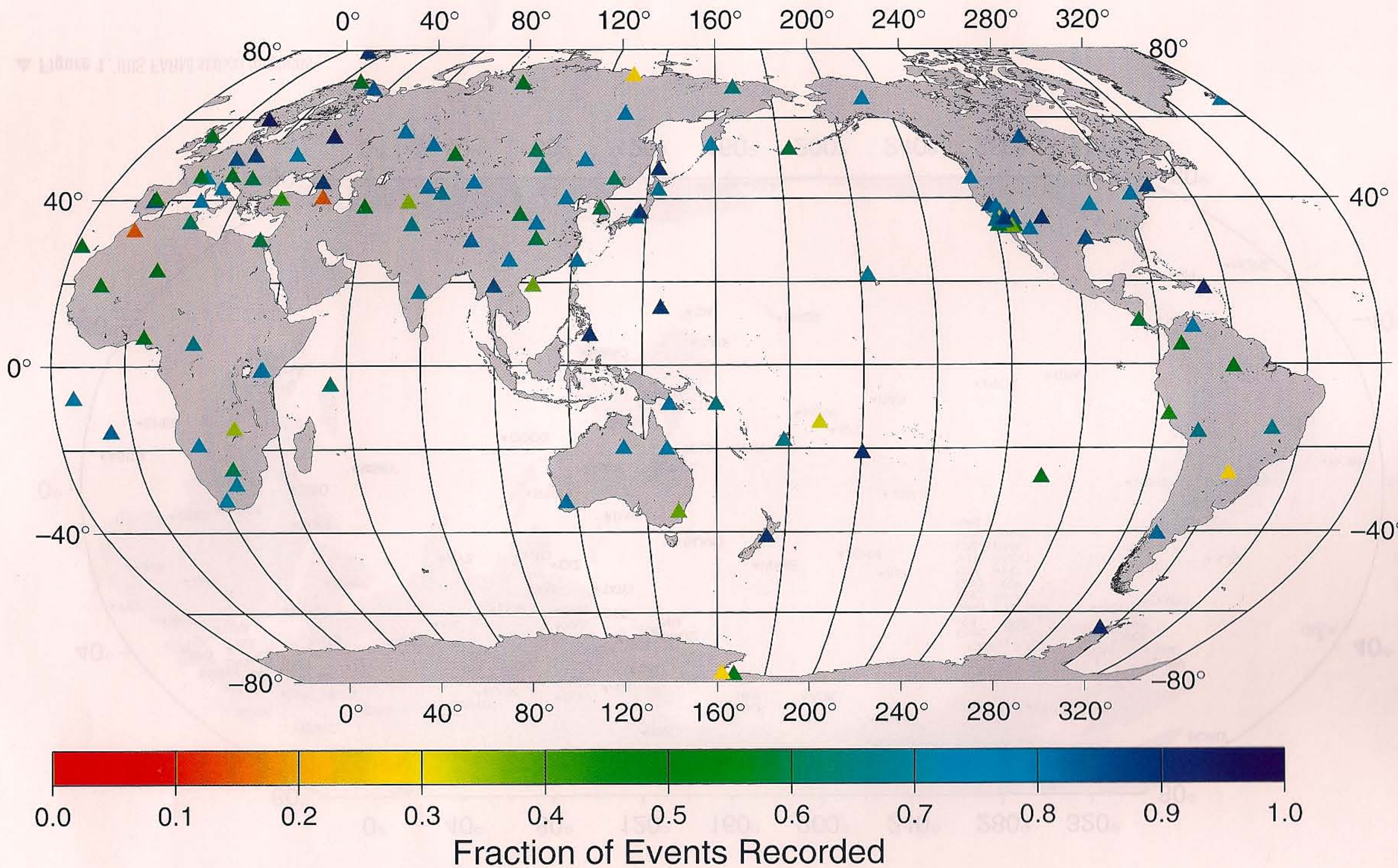
STATION RELIABILITY

Figure 2 shows the fraction of events recorded by each station compared to the number of events that occurred while the station was reporting to the IRIS FARM. This fraction was calculated simply by comparing the number of events actually recorded by the station of interest to the total number of FARM events during the same time period. We check only the time interval between the first and last event for each station in the FARM archive. The purpose is to observe a station's "uptime" as expressed by the fraction of available events that are archived in the FARM, regardless of the quality of the seismograms. The test does not indicate the origin of the data gaps, which could have originated with station and/or archiving problems before or at the IRIS Data Management Center (DMC), but does provide an end-user measure of IRIS FARM station reliability. The total data recovery rate over all stations is 72%. Only 36% of the stations achieved 75% data recovery, and only 83% of the stations achieved 50% data recovery.

The best recovery rate (93%) was achieved by station KONO in Norway, the worst (15%) by stations GNI in Armenia and MDT in northwestern Africa. We emphasize that these data recovery rates do not necessarily indicate the fraction of time that the station was operating; they reflect only the fraction of data present in the FARM at the time of our data requests. Also, in some cases the measures for individual stations are based on very short time intervals. For example, station MDT is archived in the FARM only between June 1990 and September 1991. Station GFA (62% recovery



▲ **Figure 1.** IRIS FARM station locations.



▲ **Figure 2.** The fraction of events in the IRIS FARM archive that are recorded by individual seismic stations. Recovery rates vary from 15% to 93%, with a median value of 69%. For each station, only the time interval between the first and last event in the archive for that station is considered.

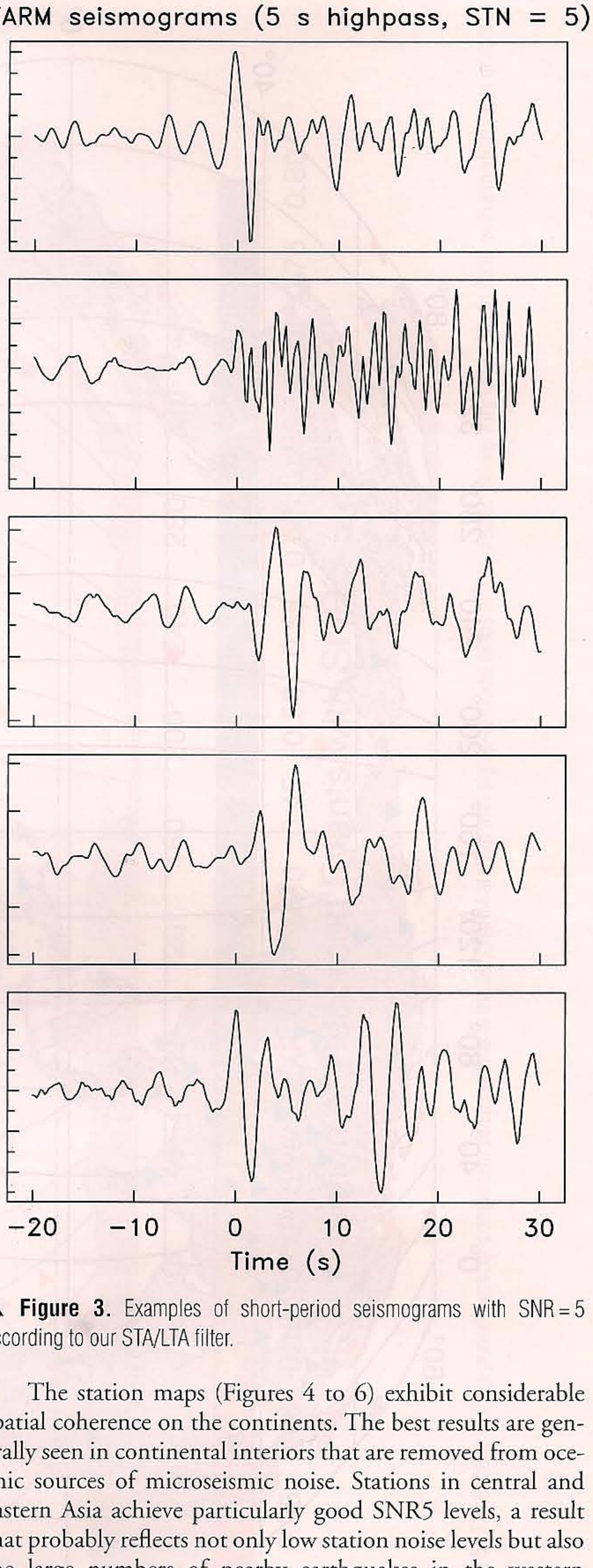
rate) in northwestern Africa is archived only from May 1990 to October 1990. Station HYB (68% recovery rate) in India is archived only from January 1990 to June 1990.

QUALITY OF EARTHQUAKE RECORDS

The station reliability measure discussed above determines only if the FARM archive contains records of individual events; it does not say anything about the quality of these records. To estimate seismogram quality we use a simple short-term-average to long-term-average (STA/LTA) filter as a measure of the signal-to-noise ratio (SNR) of individual body-wave arrivals. At each station, we then compute the fraction of events with at least one arrival of SNR ≥ 5, compared to the total number of recorded events (henceforth we will term this fraction SNR5). Because microseism noise often dominates seismic records at intermediate frequencies, we filter the seismograms to long- and short-period bands (15 to 100 s, 0.2 to 2 Hz, respectively) before calculating the SNR. For the vertical component we examine the *P*, *pP*, *PP*, and *PKP* arrivals; for the transverse component, we examine *S*, *sS*, and *SS*. Figure 3 shows examples of seismograms with SNR = 5. Although weaker phases can certainly be detected, we consider SNR = 5 to be the approximate minimum quality to perform useful quantitative waveform analysis.

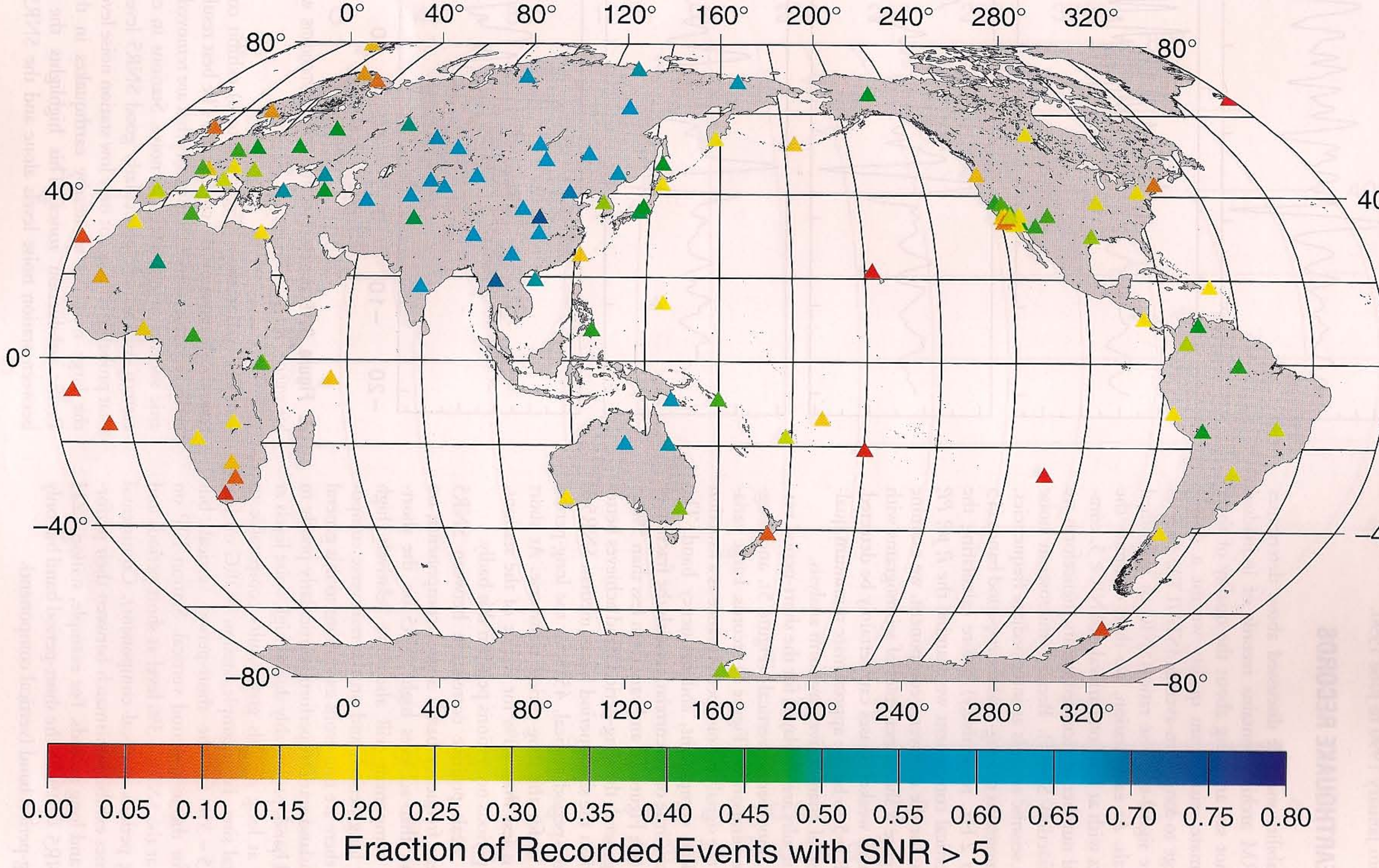
The SNR5 results are displayed for the short-period vertical- (Figure 4), long-period vertical- (Figure 5), and long-period transverse-component (Figure 6) records. Large variations are seen in the signal-to-noise performance as a function of station location, component, and frequency band. The SNR5 values show little or no correlation with the fraction of events recorded (see Figure 2), and vary from less than 5% to nearly 80%. In general, the long-period band achieves better signal-to-noise than the short-period band; median SNR5 is 32% for the short-period vertical, 45% for the long-period vertical, and 41% for the long-period transverse. At short periods, SNR5 is less than 10% for twelve of the stations, whereas at long periods no stations perform this badly.

There is a weak positive correlation between SNR5 results at different frequency bands and/or components; on average a station that achieves high SNR5 on the short-period vertical component will also have relatively high SNR5 values at long periods and on the transverse component. However, there are numerous exceptions to this general trend. Oceanic island stations perform particularly poorly in the short-period band, presumably due to high noise levels at these sites, but at long periods give results comparable to many continental sites. For example, station BORG on Iceland has SNR5 = 3% for the short-period vertical, but achieves 34% for the long-period vertical. Station KIP on Hawaii records at the SNR5 = 3% level at short periods and at 44% at long periods (vertical component). Continental stations sometimes exhibit a mismatch between their performance at short and long periods. For example, station LZH in China has SNR5 = 61% in the short-period band but only 17% in the long-period band (vertical component).

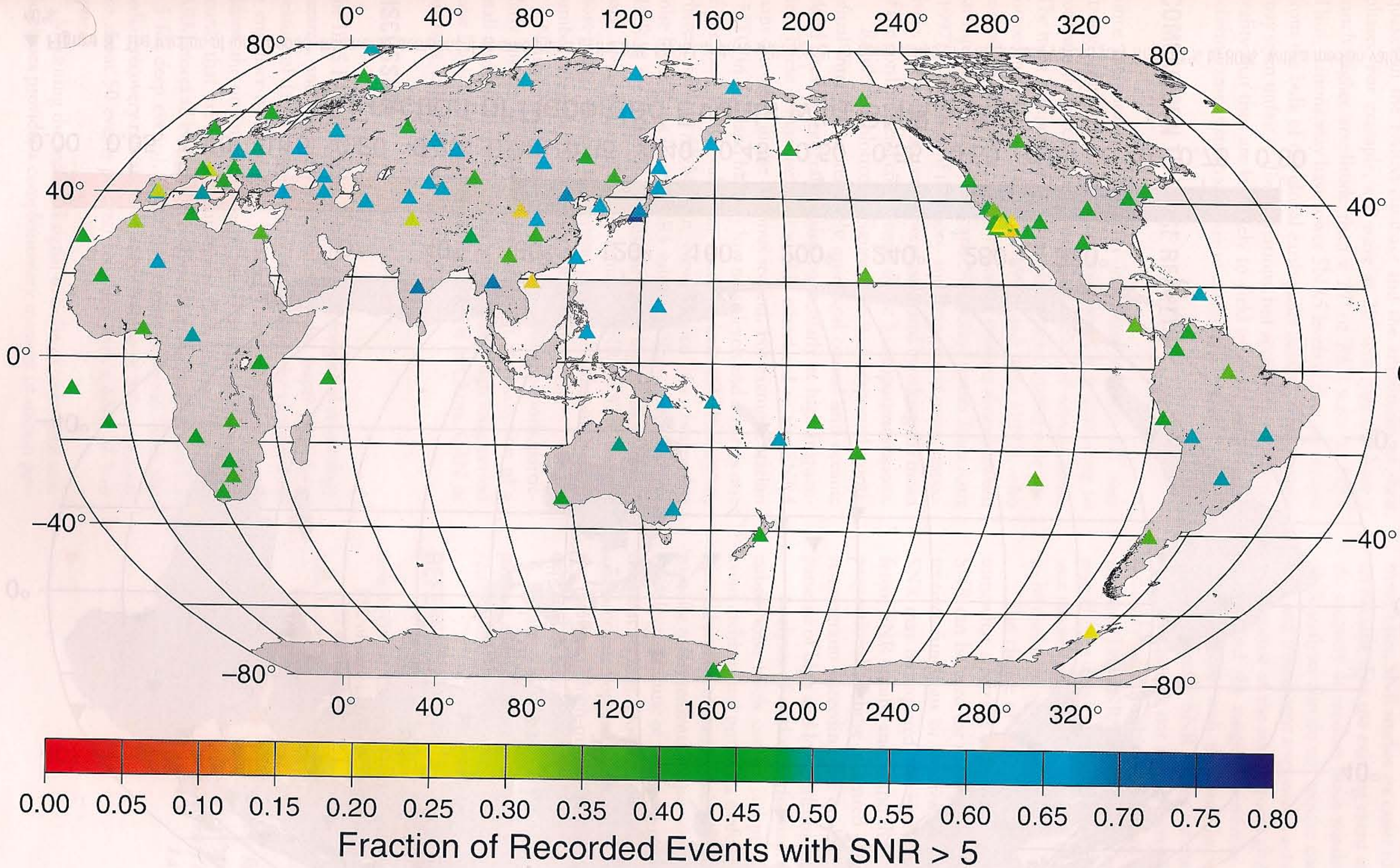


▲ **Figure 3.** Examples of short-period seismograms with SNR = 5 according to our STA/LTA filter.

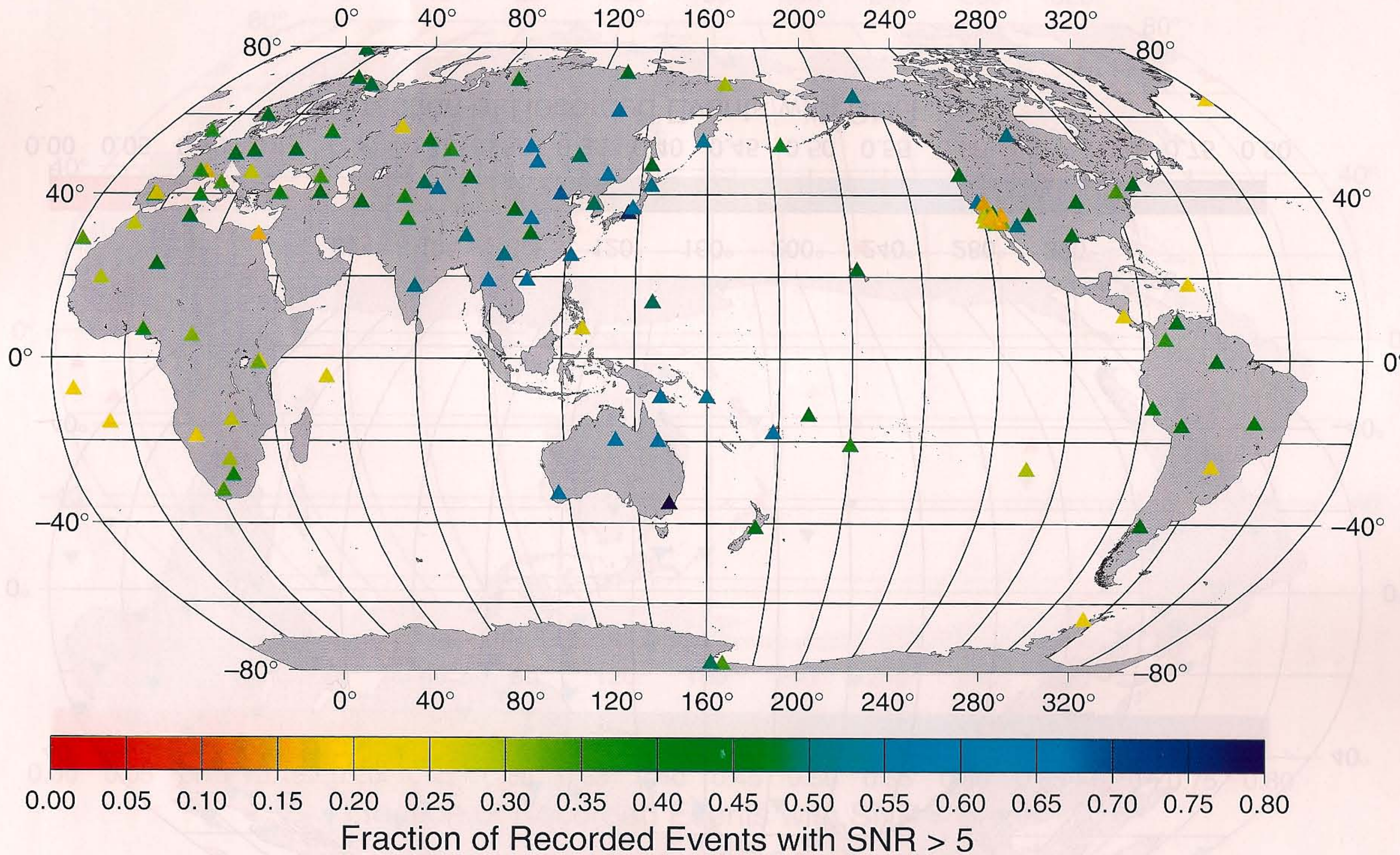
The station maps (Figures 4 to 6) exhibit considerable spatial coherence on the continents. The best results are generally seen in continental interiors that are removed from oceanic sources of microseismic noise. Stations in central and eastern Asia achieve particularly good SNR5 levels, a result that probably reflects not only low station noise levels but also the large numbers of nearby earthquakes in the western Pacific subduction zones. This highlights the difference between station noise levels alone and the SNR5 measure,



▲ **Figure 4.** The fraction of short-period, vertical-component seismograms in the IRIS FARM archive with signal-to-noise ratios of 5 or greater. Values vary from 3% to 72%, with a median value of 32%.



▲ **Figure 5.** The fraction of long-period, vertical-component seismograms in the IRIS FARM archive with signal-to-noise ratios of 5 or greater. Values vary from 16% to 76%, with a median value of 45%.



▲ **Figure 6.** The fraction of long-period, transverse-component seismograms in the IRIS FARM archive with signal-to-noise ratios of 5 or greater. Values vary from 11% to 80%, with a median value of 40%.

which is also sensitive to the global distribution of earthquakes in the FARM database and the amplitudes of their phases. For example, a *P* wave at 20° will typically have a much higher amplitude than a *PP* or *PKP* wave at 120°. Thus, stations may have lower SNR5 levels if they are distant from the bulk of the global earthquake catalog. This analysis may seem unfair to distant stations, but accurately reflects the reality that they are less likely to yield as many high-quality seismograms as stations closer to earthquake regions.

COMPARISON TO NOISE RESULTS

Since the measured SNR on individual records will vary strongly with the background noise level, it is interesting to compare these results with previous studies of seismic noise. The most comprehensive recent global noise studies were performed by Astiz and Creager (1994) and Astiz (1997), who computed noise spectra for a variety of random times between earthquakes. We use the 1 s and 30 s period results from Astiz (1997) as measures of the short- and long-period noise, respectively. The transverse values were estimated by taking the mean of the north and east components of the 3-component stations.

Results are plotted in Figures 7 to 9. As expected, continental interiors are relatively quiet and coastal and oceanic island sites are generally noisy, particularly at high frequencies. These results are only weakly correlated to the SNR5 maps discussed in the previous section. For example, station CHTO in Thailand has very low noise levels and achieves one of the best SNR5 values at short periods (SNR5 = 70%), whereas station ANMO in New Mexico has comparable noise levels but a lower SNR5 value (SNR5 = 36%). Station HNR in the Solomon Islands has much higher short-period noise levels but nonetheless achieves SNR5 = 37% for the short-period vertical component, presumably due to the large number of earthquakes within 90° of this station.

Noise levels exhibit less variability at long periods, particularly for the vertical components, with the exception of a small number of stations with anomalously high long-period noise levels, including, for example, MDJ in China, CAN in Australia, and SMTC in California.

DISCUSSION

The IRIS FARM archive is widely used for global seismology research, and the analysis described in this paper provides a measure of data availability and quality from the viewpoint of an end user of these data. However, our analysis does not address the origin of data gaps or the quality of earthquake records that are not present in the data archive. The IRIS FARM stores all events with body wave magnitudes above 5.7 (5.5 for deep events), about 240 events per year. With the median recovery rate at 69%, a SNR5 value of 30% translates into about 50 events per year recorded with a SNR of 5 or greater.

Measuring the recorded signal to noise of individual seismic phases provides a complementary measure of station performance as compared to standard noise level analyses. In many cases, SNR studies are easier to perform than noise studies because they use existing event archives without requiring the recovery of random noise windows between earthquakes. SNR analyses also do not require corrections for seismometer gain and instrument response to achieve useful results.

Because of the nonuniform global distribution of earthquakes and the range dependence of seismic wave amplitudes, stations with the same background noise levels will obtain different SNR values for the same event. Thus, our SNR5 measure is not a good proxy for station noise level and should be used for this purpose only when comparing nearby stations. The SNR5 measure has the advantage, however, of providing a direct estimate of the annual number of teleseismic records that will be obtained that are of sufficient quality to be useful for research.

The choice of a threshold signal-to-noise ratio of 5 is somewhat arbitrary, and certainly seismograms with poorer SNR can be used for some purposes. In other cases, such as receiver functions or shear-wave splitting studies, a higher SNR may be required. We experimented with applying different SNR cutoffs and found that the results were generally proportional to those presented here; the average fraction of seismograms exceeding the quality threshold varies but the patterns of high and low performing stations appear similar.

Analyses of station performance based on recorded signal-to-noise levels can be computed directly from existing event archives and provide a useful complement to more traditional studies of station noise spectra. Global station signal-to-noise measurements are not always correlated with station noise levels because of variations in average signal level among different regions. However, decisions regarding station siting and continued operation should be based, at least in part, on the number of high-quality seismograms that the stations are expected to record.

A table listing results for the 134 stations analyzed in this paper is available via anonymous FTP to mahi.ucsd.edu in the /pub/SNR5 directory.

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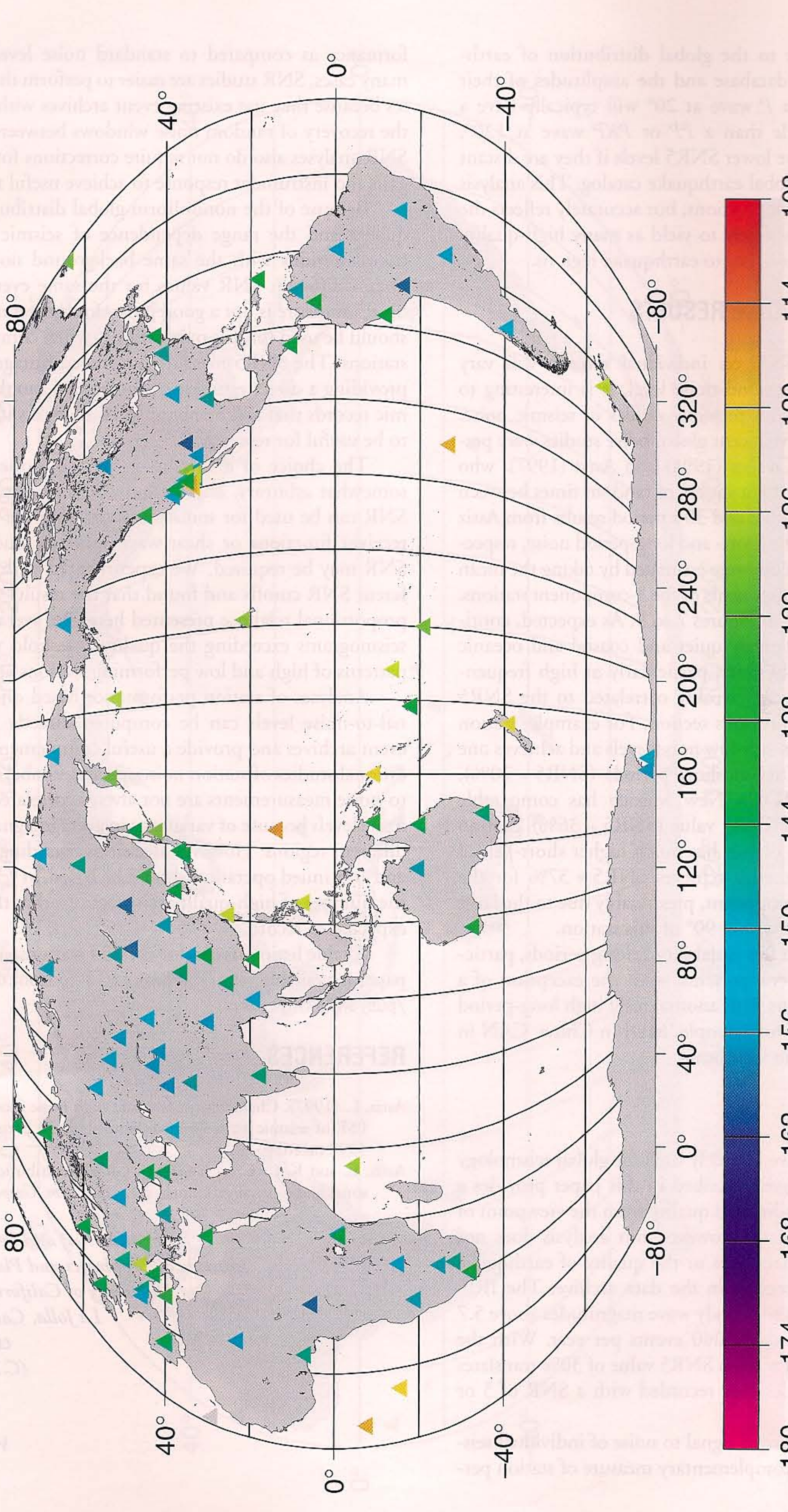
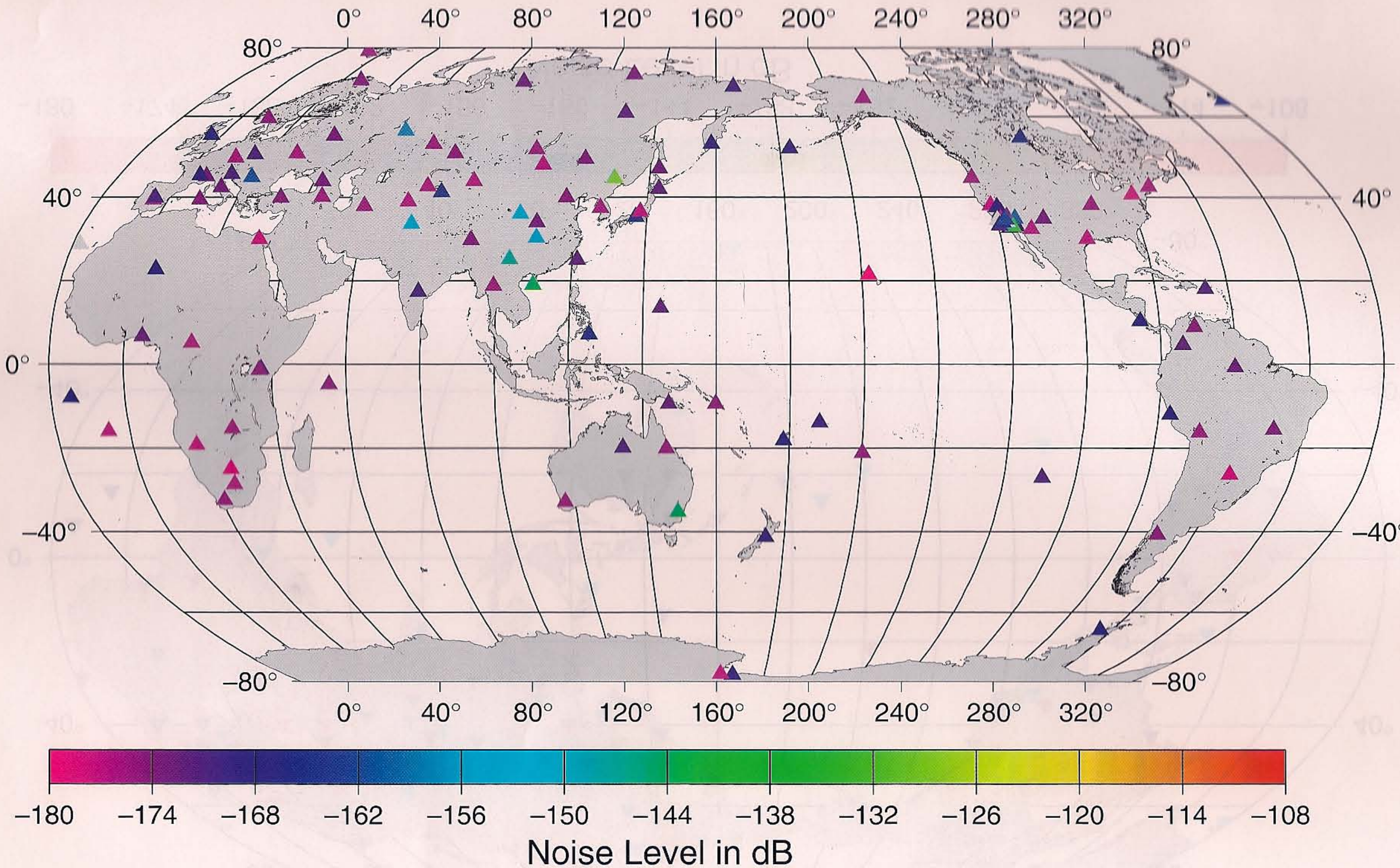
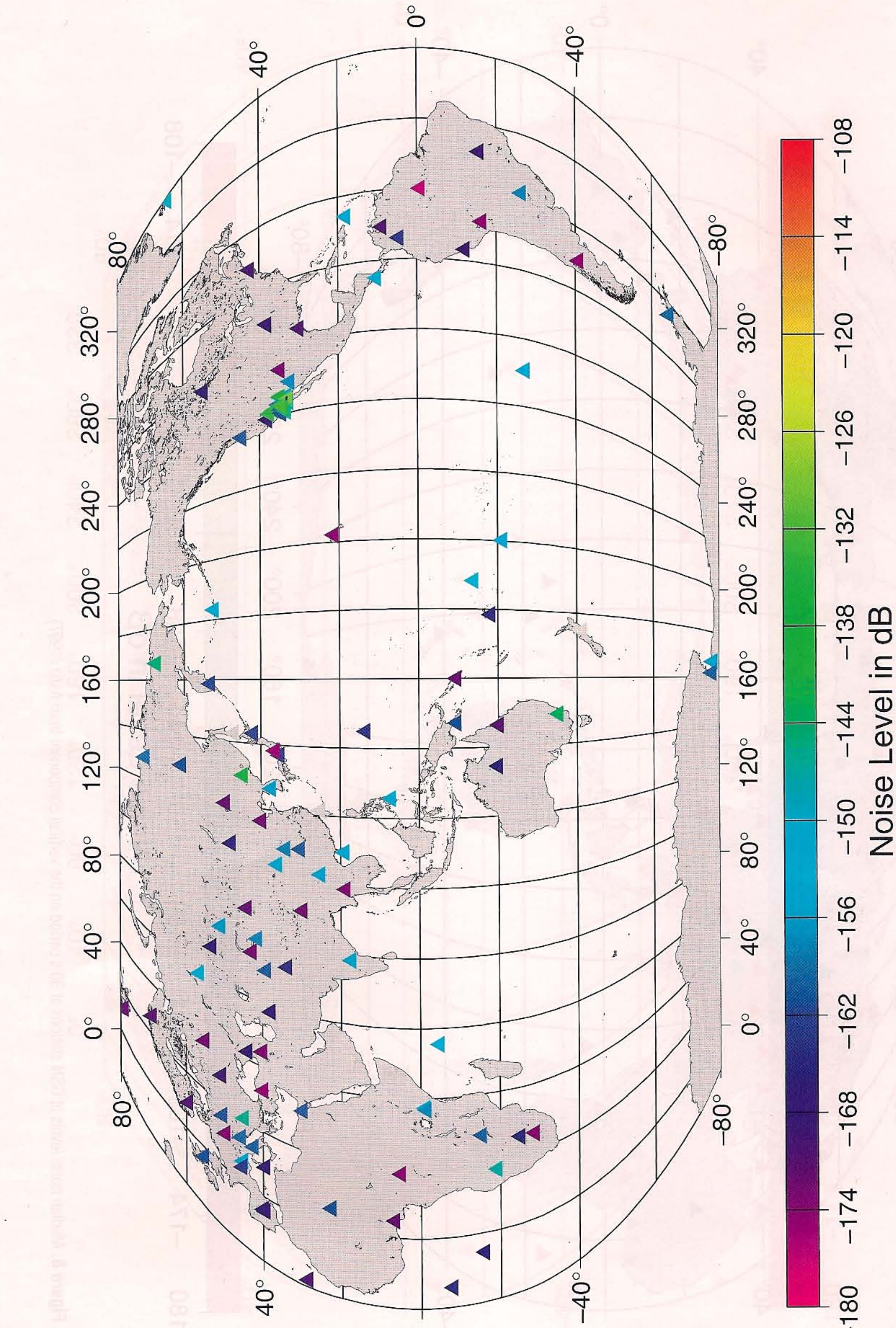


▲ **Figure 7.** Median noise levels at GSN stations at 1 s period on the vertical component from Astiz (1997).



▲ **Figure 8.** Median noise levels at GSN stations at 30 s period on the vertical component from Astiz (1997).



▲ **Figure 9.** Median noise levels at GSN stations at 30 s period on the horizontal components from Astiz (1997).