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DIURNAL VARIATION OF SEISMIC NOISE AND ITS EFFECT ON DETECTABILITY

by

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During a time period of 80 weeks in 1972-73, data on the diurnal variation both in the number of reported seismic events at NORSAR and in the noise within the processing frequency band has been studied. The two distributions are exactly 180 deg out of phase, but with a relatively stronger diurnal effect in the event distribution. No correspondence was found between local (epicentral) time of day and the number of events reported by NORSAR. Thus it has been concluded that the diurnal variation in the number of reported events is caused by local noise effects at NORSAR, although we have not succeeded in explaining the varia-

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ABSTRACT

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INTRODUCTION

A commonly observed phenomenon is that the seismic background noise of the earth for frequencies above 1 Hz are subject to diurnal variations, where the noise power has a maximum around noon local time. This variation is usually attributed to man-made activity, resulting in so-called cultural noise, although local wind at some recording sites also would be a contributing factor here.

A diurnal variation in number of reported events has also been observed, as e.q. by Shimshoni (1971), who found based on three years of NOAA (National Oceanic and Atmospheric Administration) data that significantly more events were reported during local nighttime than during other hours of the day. Shimshoni (1971) suggested that the position of the sun could be the cause of the phenomenon, while it was pointed out in three comments to the paper, by Davies (1972), Flinn *et al* (1972) and Knopoff and Gardner (1972), that the diurnal variation in the seismic noise was a more likely explanation. The mechanism would then be that the

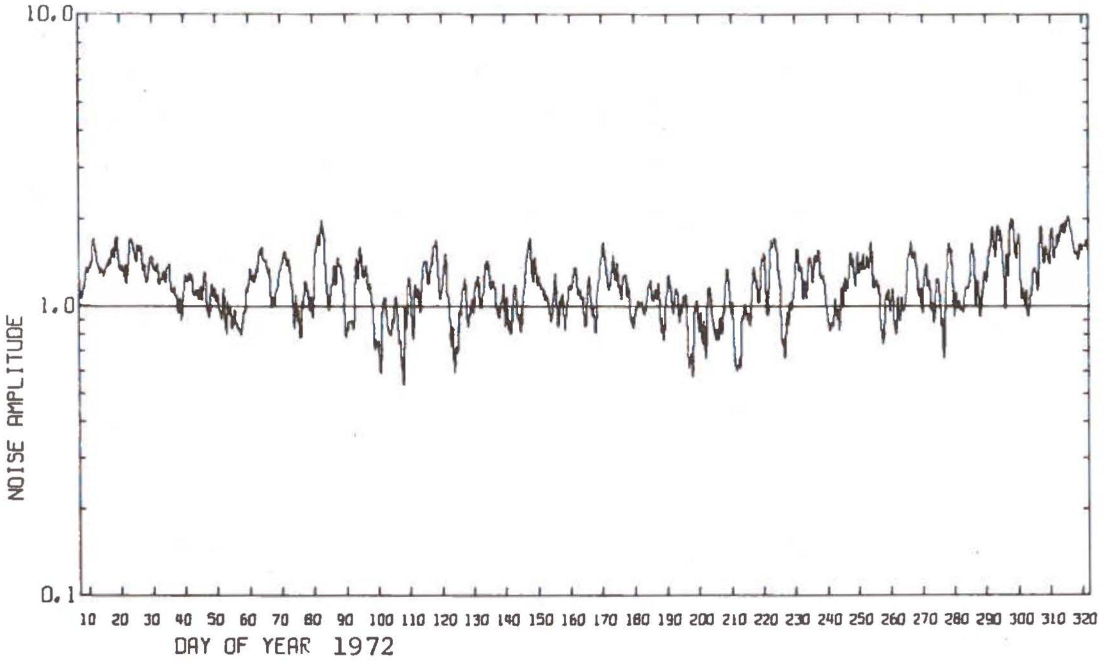

Fig. 1 Beam average of LTA in quantum units for the time period 7 Jan - 22 Nov 1972. The sampling rate is 20 s/day and the frequency filtering of the data from which the LTA is computed is 1.2-3.2 Hz.

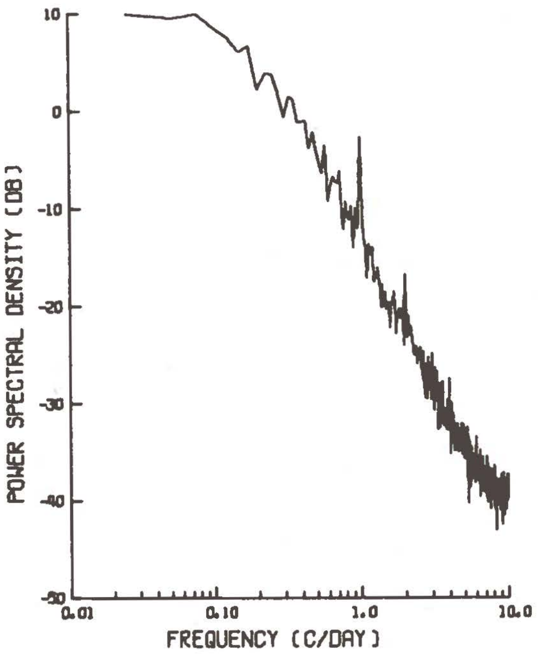

Fig. 2 Power spectral density of the LTA time series covering a time period of 45 weeks in 1972 and 35 weeks in 1973. The sampling rate is 20 s/day, and the spectrum is estimated using the method of block-averaging.

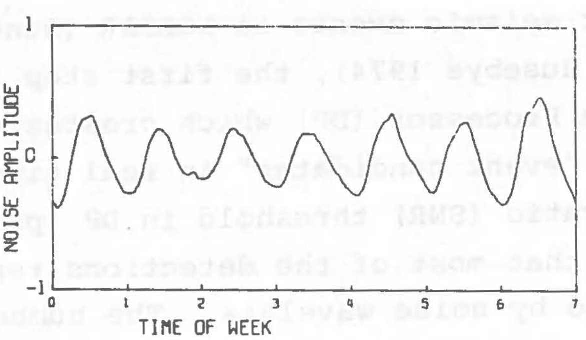

Fig. 3 LTA in relative units as a function of time of week, where the first day (0-1) is Friday. Average is made over 80 weeks, and a trend-removal is applied to the LTA time series by subtraction of daily averages. The sampling rate is 20 s/day.

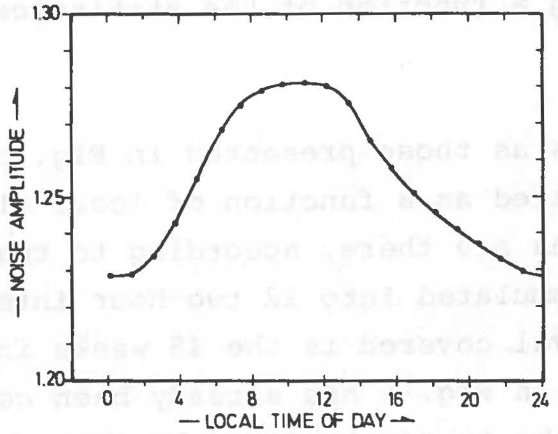

Fig. 4 LTA in quantum units as a function of local time of day. Average is made over 560 days in 1972 and 1973, and the sampling rate is 20 s/day. The individual data points are indicated.

DIURNAL VARIATION IN DETECTABILITY

In the search for seismic events at NORSAR (Bungum *et al* 1971, Bungum and Husebye 1974), the first step is an on-line Detection Processor (DP) which creates a queue of detections or "event candidates" in real time. The signal-to-noise ratio (SNR) threshold in DP (presently 10 dB) is so low that most of the detections reported are actually triggered by noise wavelets. The number of detections, reduced so that only one is accepted within a time window of 30 seconds, are plotted as a function of SNR in Fig. 5, giving both the incremental and the cumulative distribution. The distribution is seen to follow a straight line with slope -1.1 down to around 12 dB in SNR. Below this threshold, the number of detections is seen to increase much more rapidly, following a cumulative distribution with a slope around -15.0. The reason for this is that pure noise detections now have started to influence the distribution, being a function of the statistical properties of the noise.

The same detections as those presented in Fig. 5 have in Fig. 6 been plotted as a function of local time of day. The detections are there, according to their time of occurrence, accumulated into 12 two-hour intervals, and the time interval covered is the 45 weeks in 1972. The observed curve in Fig. 6 has already been corrected for the fact that the system tends to be down more during day than night. Also, corrections has been made for the many explosions during daytime, causing detections. Finally, all detections known to be caused by natural earthquakes have also been removed, leaving the observed curve in Fig. 6 to be as close as possible to the distribution of noise detections. The 90% confidence interval indicated on the plot is computed based upon the assumption

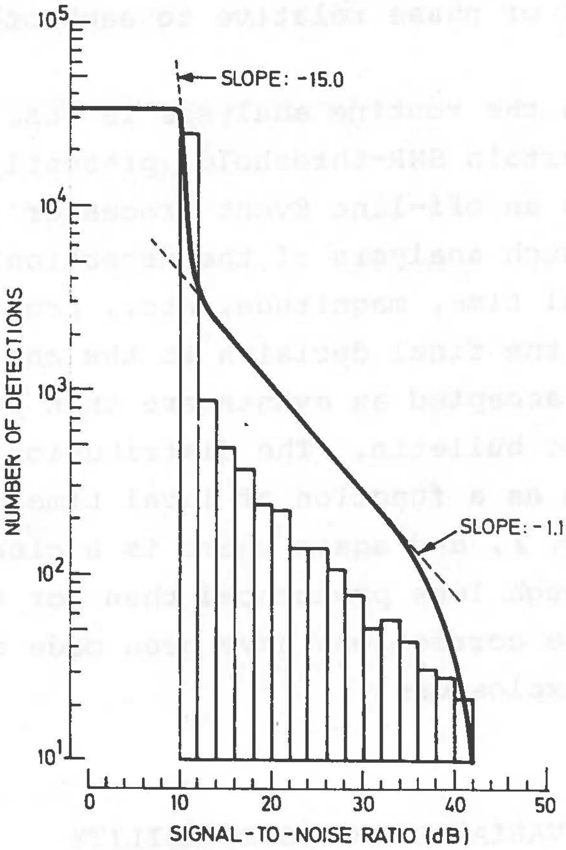

Fig. 5 Incremental and cumulative distribution of number of detections as a function of SNR. The data is from the time period July-December 1972.

that the data within the different time intervals are independent of each other, each following a Poisson distribution. It is seen from Fig. 6 that the diurnal variation is very strong, and a comparison with the noise variation in Fig. 4 shows that the two curves are almost exactly 180° out of phase relative to each other.

The next step in the routine analysis is that the detections above a certain SNR-threshold (presently 11-12 dB) are passed on to an off-line Event Processor (EP), which performs a thorough analysis of the detection, computes location, arrival time, magnitude, etc., produces a plot and then leaves the final decision to the analyst. The detections thus accepted as events are then presented in the final seismic bulletin. The distribution of the events in this bulletin as a function of local time of day is presented in Fig. 7, and again there is a clear diurnal variation, although less pronounced than for the detections. Also in this case corrections have been made for system down times and explosions.

EFFECT OF NOISE VARIATION ON DETECTABILITY

It is natural now, especially based on the good correlation between noise variation and detectability (Figs. 4, 6 and 7), to make the assumption that the diurnal variation in detectability is caused by the noise variation. Obviously, this assumption must be valid for the variation in noise detections or false alarms (Fig. 6), since otherwise the sun would have to affect the statistical properties of the noise. Then, in order to make the appropriate corrections, we need a model for the noise variation. It has repeatedly been demonstrated that the cultural noise is high frequent, often with its main influence in the band 2-6 Hz. NORSAR is no exception in this respect; in fact, the one subarray (14C) which is surrounded by most cultural activity is so much troubled by high frequent noise that it is usually excluded from on-line processing during working hours (but the data is recorded). The noise can there be easily seen on the plots of the time traces, and from the high time stationarity and complexity in frequency it is reasonable to assume that the noise is caused by a large number of independent sources working together, i.e., machinery of various kinds, including the traffic on nearby roads. Also, by ranking the subarrays according to the degree of high-frequent noise we get the same list as when the subarrays are ranked according to population and road density.

In the NORSAR on-line processing, the estimates of STA are obtained by rectifying and integrating the 1.2-3.2 Hz filtered data within a sliding time window of length 1.5 seconds. LTA is then obtained by summing up the STA estimates in a recursive exponential filter (Bungum _et al_ 1971). Therefore, from what we know about the noise added during daytime, which for our purposes is stationary within the integration time window, we can simply set up the relation

$$\mathrm{LTA(day)} = \mathrm{LTA(night)} + C \qquad (1)$$

We also assume that most detections are triggered either by real events or by noise wavelets. Furthermore, in our model the seismic noise cycles are not subject to diurnal variations. Thus, SNR of noise cycles will decrease when the added cultural noise is superimposed; this causes a drop in the false alarm rate as well as in the number of real events detected.

The number of false alarms (FA) exceeding a certain SNR (in dB) is, according to Fig. 5

$$FA(SNR) = C \cdot 10^{(b \cdot SNR/20)} \qquad (2)$$

where b = -15.0 is the slope of the frequency-SNR curve. Thus it is possible to compute the expected drop in the false alarm rate as the cultural noise increases (and the SNR decreases). If N_O and N_C are the observed and corrected number (of detections), respectively, and A is the noise level, the correction formula will become

$$N_C(A) = N_O(A)/A^b \qquad (3)$$

Fig. 6 shows the effects of adjusting the hourly number of detections by compensating for the diurnal noise level variation in this way. It is seen that the model works very well in this case; in fact, a test with different b-values shows that the chi-square value is minimized for b=-15.4, or very close to the value found in Fig. 5. One can thus explain the diurnal variations in the number of (noise) detections as caused by high-frequent cultural noise superimposed on the seismic background noise.

Fig. 7 shows the result of a similar attempt to compensate for the effects of noise variation on the number of reported events. Since the slope in this case, as seen from Fig. 5, is only -1.1, only a small change in the number of events can be caused by the diurnal noise variation. Fig. 7 shows that the variation in number of reported events at NORSAR cannot be fully explained by this factor alone.

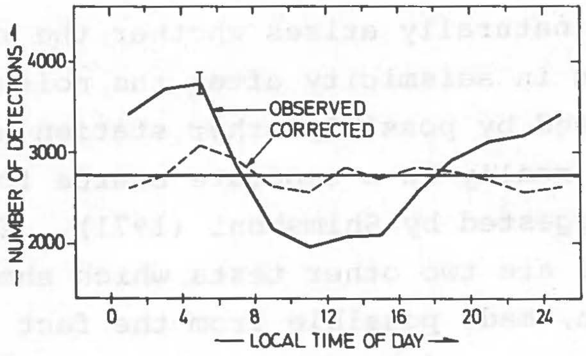

Fig. 6 Number of noise detections versus local time of day. The observed curve has been corrected for system down times and influence from seismic events. In the dashed curve a correction for diurnal noise variation has been made in accordance with equation (3). The data cover 45 weeks in 1972. The vertical bar indicates a 90% confidence interval.

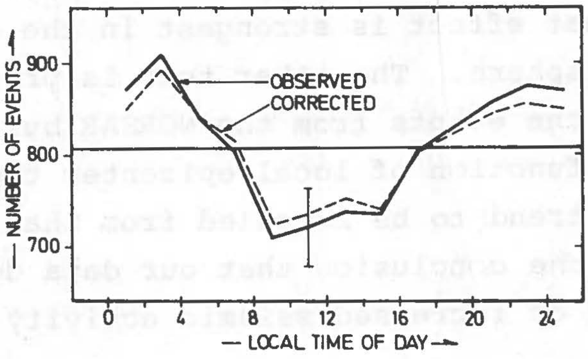

Fig. 7 Number of reported events versus local time of day. The observed curve has been corrected for lack of detectability due to system down times and occurrence of local events. In the dashed curve a correction for diurnal noise variation has been made in accordance with equation (3). The data cover 80 weeks from 1972 and 1973. The vertical bar indicates a 90% confidence interval.

DISCUSSION

The question now naturally arises whether the remaining diurnal variation in seismicity after the noise compensation is caused by possibly other station effects, or whether there really is a separate source for these variations as suggested by Shimshoni (1971). In the latter case there are two other tests which should give a good indication, made possible from the fact that only one station has been used in the sampling of the seismicity. The first one is presented in Fig. 8, where the seismicity is divided into two groups, one with epicenters within the hemisphere of ±90 degrees distance in longitude from NORSAR (80^{o}W-100^{o}E) and one covering the rest of the world. The first group would on the average have a local daytime consistent with NORSAR, while local daytime for the second group would correspond to NORSAR nighttime. It appears from Fig. 8 that the recorded number of events from each hemisphere reaches a minimum during NORSAR daytime; in fact, that effect is strongest in the data from the opposite hemisphere. The other test is presented in Fig. 9, where the events from the NORSAR bulletin are plotted as a function of local epicenter time. There is no particular trend to be revealed from that curve. This leads us to the conclusion that our data does not give any evidence of increased seismic activity during local nighttime.

A consequence of the preceding considerations is that the observed variations instead must be explained by local NORSAR effects other than the hourly variation in the absolute noise level. In fact, we know that the diurnal noise variation causes some side effects, in the following sense:

1) Noise stability is lower at night than during the day, thus causing a much larger number of false alarms to exceed the fixed EP prethreshold. It is

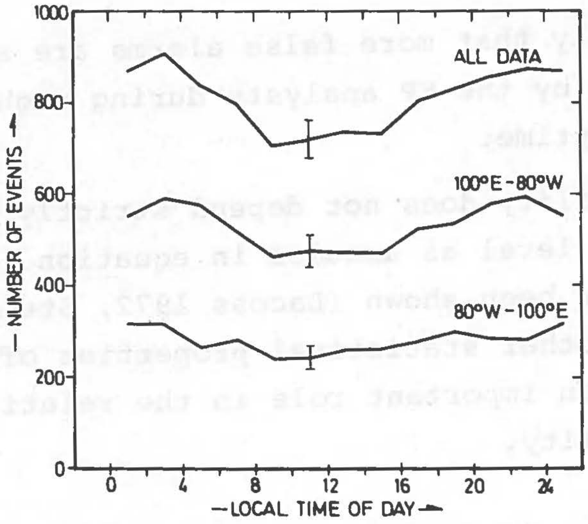

Fig. 8 Number of reported events versus local time of day. The data are corrected for system down times and local events, and cover 80 weeks in 1972 and 1973. The first or uppermost curve gives the total distribution, the second and third the distribution of the data falling in two different hemispheres. The vertical bars indicate 90% confidence intervals.

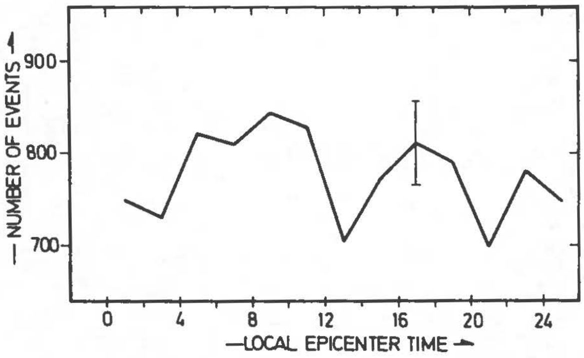

Fig. 9 Number of reported events versus local epicenter time. The data are corrected for system down times and local events, and cover 80 weeks in 1972 and 1973. The vertical bars indicate 90% confidence intervals.

therefore likely that more false alarms are accepted as real events by the EP analysts during nighttime than during daytime.

2) Event detectability does not depend strictly upon the absolute noise level as assumed in equation (3). In fact, it has been shown (Lacoss 1972, Steinert _et al_ 1974) that other statistical properties of the noise may also play an important role in the relationship with detectability.

The data presented by Shimshoni (1971) was taken from NOAA earthquake catalogues, based on data reported by conventional analog stations. We believe, however, that an analyst reading an analog seismogram is affected by the diurnal noise variation in the same way as the combined automatic detector/analyst at NORSAR. Our conclusions on the relationship between noise and detectability should therefore in general be valid also for a system of analog stations.

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