LOCAL MAGNITUDE COMPUTATION IN ICELAND

EFFECT DUE TO STRONG MICROSEISMIC NOISE AND RICHTER ATTENUATION

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Introduction-Objective

This document introduces the problems of consistent local magnitude computations in Iceland.

Microseismic noise / Ambient seismic noise

Ambient seismic noise can be recorded constantly on Earth. Its largest energy contribution comes from surface waves (Friedrich et al. 1998) and its intensity varies according to seasonable activities in the ocean (Gutenberg, 1936). When analyzing the noise spectrum, two main peaks are observed which have been explained as the consequence of long-period ocean waves (Lee et al., 2013).

Since the ocean-surface interaction is the driven force of the noise, a site surrounded by robust oceanic activity is strongly affected. That is precisely the case of Iceland. Such noise is present on seismic measurements recorded on the surface.

Case 1: Low magnitude Event

When a seismic event of low magnitude occurs, the energy of the noise is such that it can mask the energy of the small earthquake. Figure 1 shows how the spectrum of the ambient noise overlap the spectrum of the seismic event. One can observe how the energy contain of the noise is larger than the one of the event. Thus, if no filter is applied, the magnitude of the event will be overestimated, because it is considering a lot of energy from the noise. In such case a band pass filter will help to separate the noise from the signal.

In figure 1 a high pass filter (allows high frequencies, i.e., low periods) is applied, removing most of the noise energy. This allows a more adequate computation of the magnitude of the low seismic event.

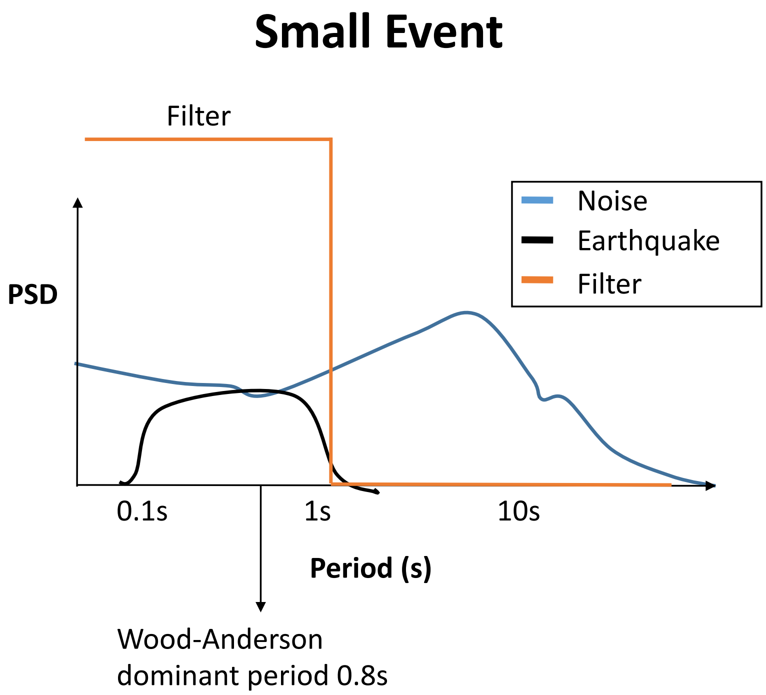

Fig 1. Power spectral density (PSD) of a small seismic event and ambient noise. A high frequency pass filter is considered.

Case 2: Large magnitude Event

When the event is large, the energy contain in the spectrum (and in the power spectral density) will be larger than the one of the noise. Thus, if we apply the same filter as in the previous case we will neglect a considerable amount of the energy event (observe figure 2). The result is an underestimated magnitude computation for large events.

As we observe, depending on the event the application of a filter or none will have different implications in the magnitude computations. Ideally, we should have a dynamic filter specific for each type of event in order to remove the influence of the noise as accurate as possible.

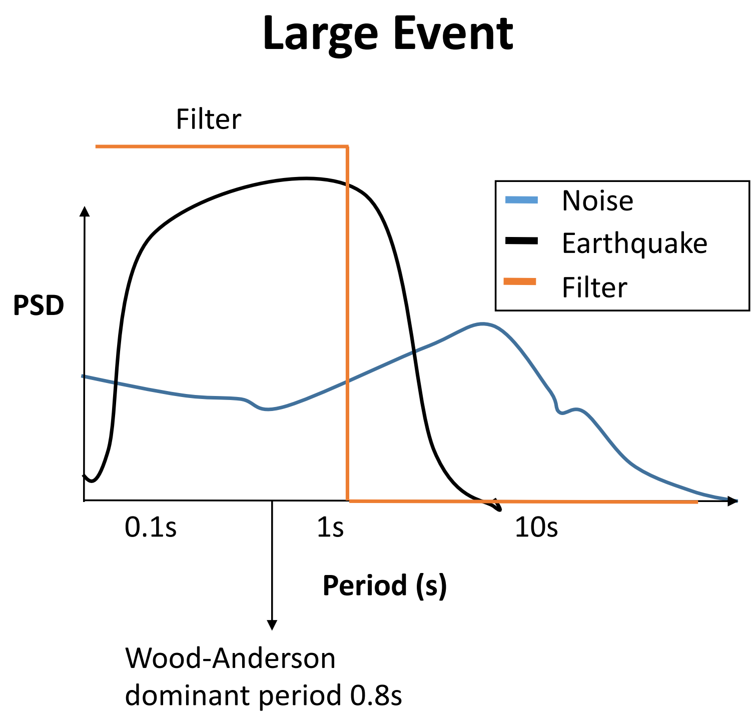

Fig 2. Power spectral density (PSD) of a large seismic event and ambient noise. A high frequency pass filter is considered.

Examples from the COSEISMIQ project

Figure 3 shows an example for the case of a low magnitude event on 04.07.2019 at 1:56:34 am. It shows the waveform recorded on a fixed station (2C.SKA10) of the SED network deployed in Iceland. The magnitude of the event is computed using all available stations, however in the figure only the recordings of one station are presented.

When the magnitude is computed from the raw data (no filter applied) the result is 0.9ML. It is considering the energy contain of the noise and might be an overestimated value. After applied a moderate high pass filter with a cut-off on 2s (i.e., 0.5Hz) the magnitude is computed again. We observe then a lower value of 0.7ML. This case is similar to the sketch showed in figure 1. When increasing the frequency cut-off of the hp filter we consider less and less energy. Thus, the computed magnitude is reduced even more. For hp 2Hz we observe a value of 0.1ML and for hp 5Hz even a negative value of -0.1ML.

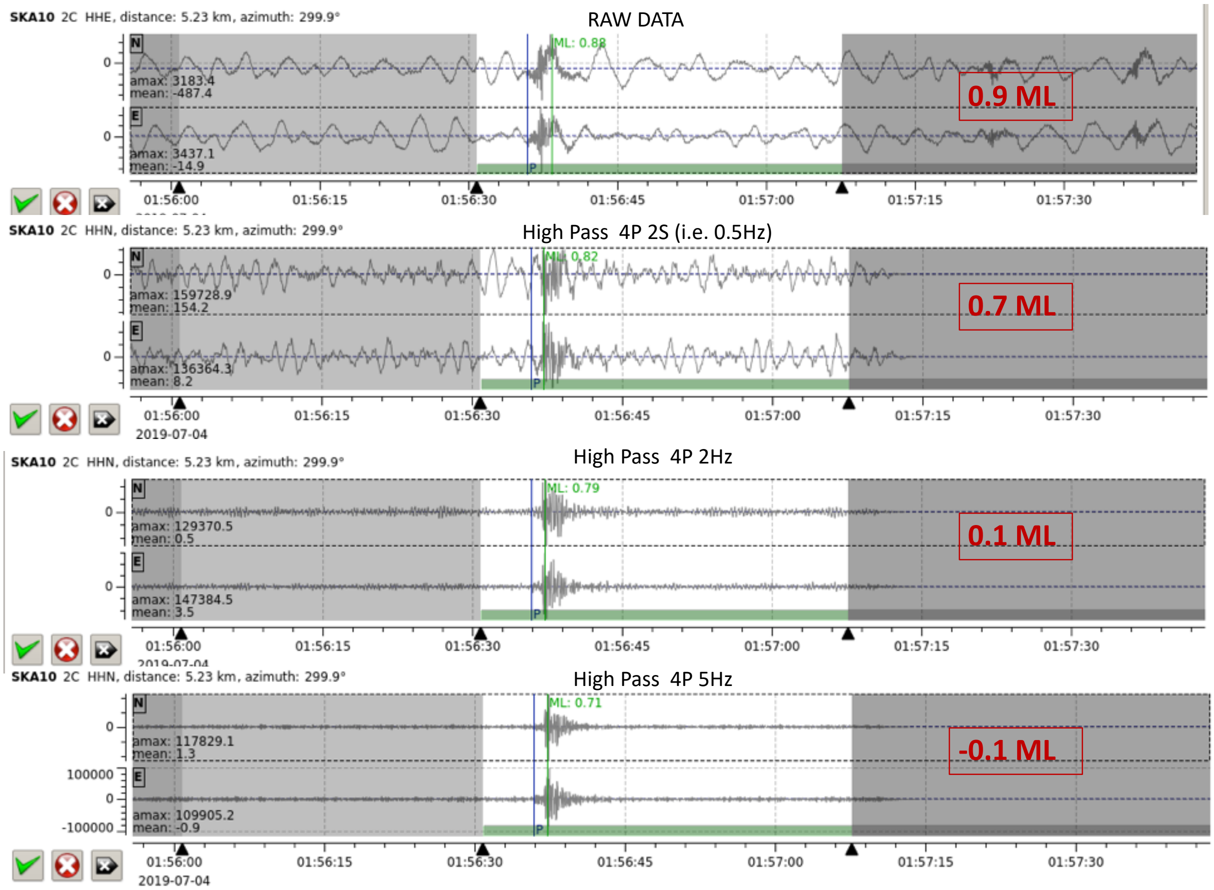

Fig 3. Waveform recorded on a fixed station for a low magnitude seismic event before and after applying various filters. The magnitude of the event is recomputed using all stations and it is showed in red font.

The problem of Richter magnitude computation

The main idea of computing the magnitude of a seismic event is to relate the maximum amplitude recorded in a seismogram with the energy released in the event and correct for the attenuation of the wave which travels from the source (earthquake) to the receiver. The Richter scale was the first one implemented. It fixed the scale as follows: an event is of magnitude 3ML for a 1mm maximum amplitude recorded in a Wood-Anderson (WA) seismometer located at 100km epicentral distance. Richter showed calibration values to correct for the attenuation. However, those values are specific for California, where they were studied. Additionally, the earthquakes were assumed to occur at the same focal depths.

The magnitude can be written as

$$ML = \log\big(A(\Delta)\big) - \log\big(A_0(\Delta)\big),$$

Where A is the maximum amplitude in millimeters measured in a WA seismogram, which depends on the epicentral distance (Δ). The term $-\log\big(A_0(\Delta)\big)$, is the correction term. This is an empirical expression which corrects for the attenuation of the wave amplitude (geometrical spreading, intrinsic attenuation and scattering attenuation, others?) when reaching the station. Since Richter scale uses a correction term obtained from data in Southern California, the computation of local magnitudes in other regions need, in principle, the use of the particular correction for the attenuation.

I think this can be done by measuring the amplitudes on a WA converted seismogram and plotting $\log\big(A(\Delta)\big)$ for several events and epicentral distances (Δ). Perhaps we would need to use events with a shallow focal depth(?), although many of the events in the COSEISMIQ project are already shallow. We would obtain also an empirical relation between amplitude and distance (attenuation) for a particular region.

In Iceland, this correction term which recalibrates the attenuation is missing. The magnitudes computed from stations located at short distances from the event are not accurate. For this near stations, the attenuation relation is not linear anymore (figure 4) and there is a sudden jump in the magnitude computation between short and long offset stations (figure 5).

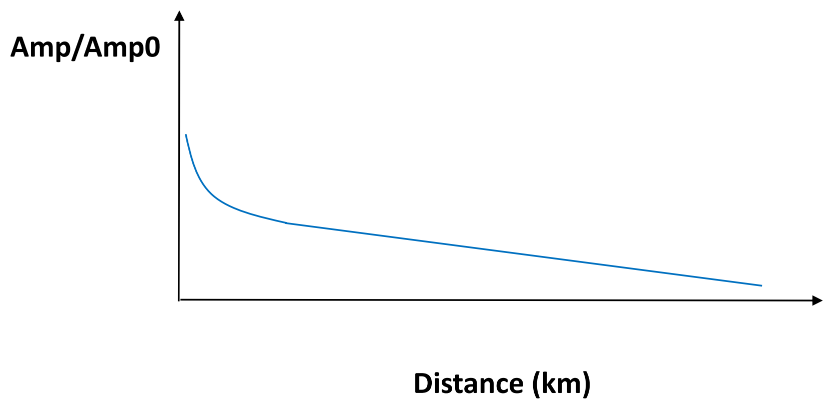

Fig 4. Attenuation of seismic waves with distance. For stations close to the earthquake the relation is no longer linear.

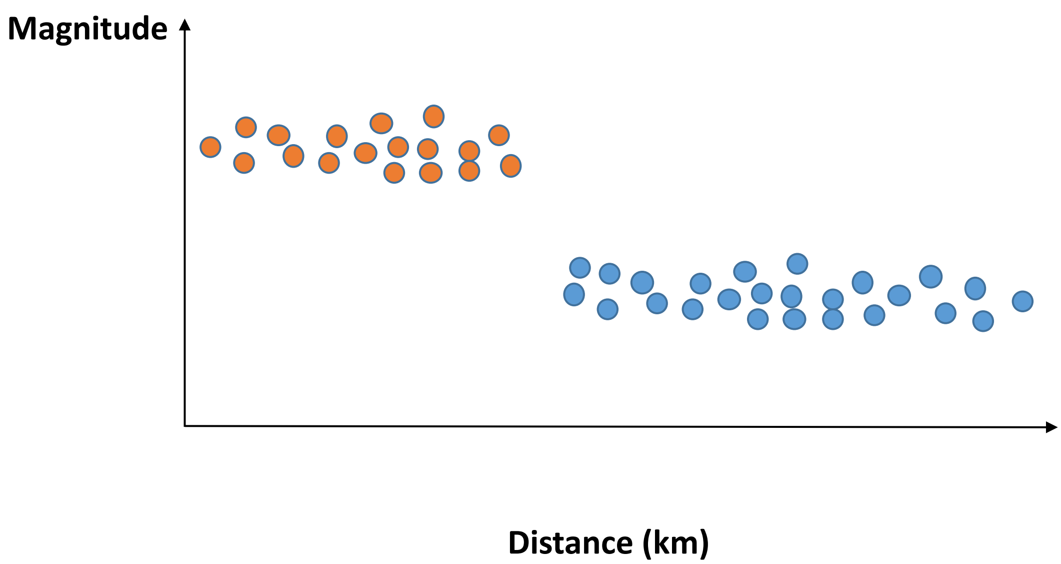

Fig 5. There is a sudden jump in the magnitude computation between stations of near and far offset.

Implications of inaccurate magnitude computations for FMD, b-values and ATLS

Applying HP filter might underestimate the magnitude of large events. However, not applying HP causes the small events to be overestimated. Similar problems appears when using ML computation with a wrong attenuation correction (stations close to the microevents are significantly overestimated). This has strong implications for advance traffic light systems (ATLS).

The objective of ATLS in Iceland is to operate the fluid injection sites to its maximum productivity and send a warning whenever earthquakes of a given threshold are likely to be induced. Thus, in order to estimate the probability that an earthquake of a given magnitude occur in the next *t* hours, it is important to consider the Gutenberg-Richter relation: the b-value. At the same time, the b-value is accurate only if the magnitude of the seismic events are accurately computed. Otherwise, we would undermine the production with unnecessary warnings or we would underestimate the magnitudes of the events.

Application of Band Pass filters

An ideal BP filter would completely vanishes the signal for frequencies outside the selected bandwidth and it would be flat (no gain or attenuation) within its passband. In reality the filter attenuates the undesired frequencies but not fully neglect them, especially for frequencies just outside the passband. The regions at the borders of the passband are known as the filter roll-off. If the roll-off is steep attenuating several dB per octave we would get close to the boxcar function (as the 'ideal' filter) but at expenses of creating ripples to the output signal as observed in figure 4. A filter designed as a tapered function will have less steep roll-off and the ripples will be reduced in the impulse response (Fig 5b). In a more general sense, the ripples can be named as artifacts due to bandlimit the signal.

Another way to study the filter roll-off is to introduce the concept of poles. Mathematically, I understand them as the singularities (values which makes the function goes to infinity) of the transfer function. The transfer function is the impulse response of the filter in the frequency domain. Thus, by finding the poles and zeros (values which makes the function turns zero) of the transfer function one could study the maximum and minimum where frequencies will be amplified or attenuated, respectively. In practice, we can focus on the numbers, such that a 2-pole filter has a roll-off slope of 12dB/octave while a 4-pole filter has a slope of 24dB/octave. The last is the slope used in the filters I observed on SeisComP3 for the COSEISMIQ project.

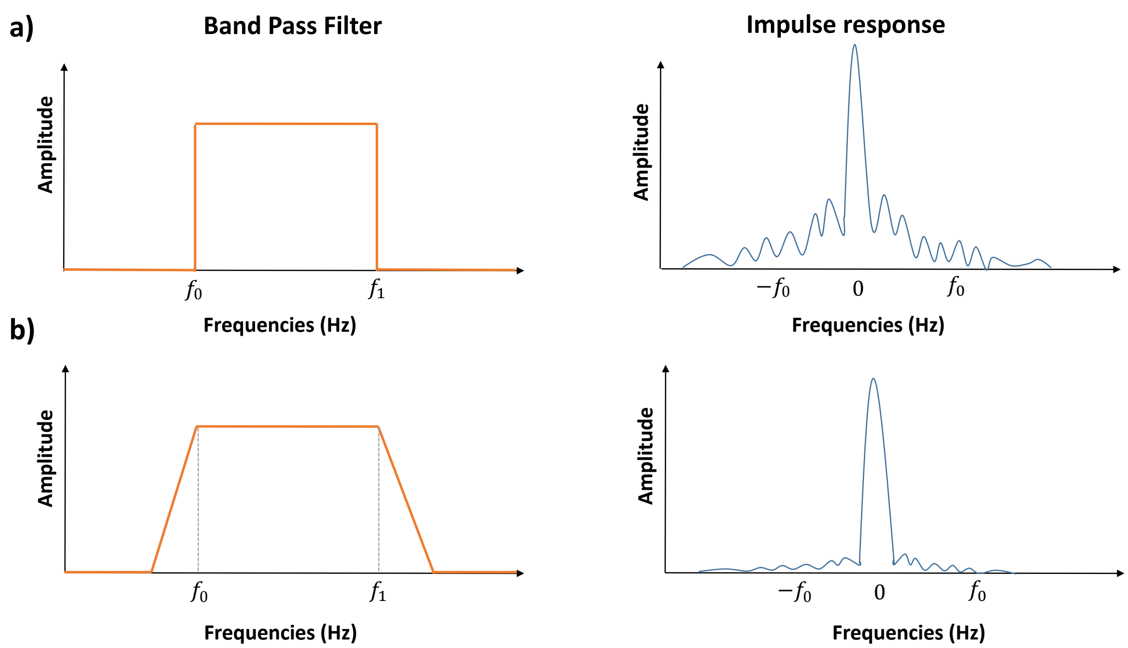

Figure 5. Band pass filter and its impulse response for a a) fully steep roll-off and b) a tapered function, not that steep.