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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Wide sensitive area of small foreshocks" *by* Chieh-Hung Chen et al.

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The manuscript presents results which, in my opinion, can be very relevant for the forecasting challange. However I find that they are not well presented and the discussion appears quite confusing for the following reasons:

The first part of the manuscript is devoted to study spatio-temporal patterns of seismic activity before and after events in a given magnitude range, for Taiwan and Japan. There are many papers which report a similar increase of seismic activity before large earthquakes. The key point is if the observed increase can have a prognostic value or it can be explained within normal aftershock triggering.

Reply:

The authors fully agree with the comment. The results for the increase of seismic

activity close to the epicenter observed in Figs. 1 and 2 are consistent with the observation in the previous studies (Lippiello et al., 2012, 2017, 2019; de Arcangelis et al., 2016). The associated statements have been added in the manuscript (lines 171-174). The agreement suggests that the increase of seismic activity in Figs. 1 and 2 is not contributed by aftershocks but a prognostic value.

I just suggest some papers where this point is detailed discussed, other references can be find therein (Lippiello et al., Scientific Reports 2012, de Arcangelis et al. Physics Reports 2016, Lippiello et al., Pure and Applied Geophys. 2017, Lippiello et al., Entropy 2019).

Reply:

Thank you for the suggestions. The authors have added those references in the manuscript for intensely supporting our results (lines 171-174). Meanwhile, we are glad to find that the similar pattern (i.e., sudden increase and gradual decrease of the seismic density before and after the earthquakes) can be confirmed by using the different method.

In my opinion many of the results of sec.3 are not really interesting since they are probably artifact of the adopted stacking procedure. Furthermore they are not strictly related to what for me are the main findings (see my point 2). Therefore, I believe that this section can be moved to the supplementary materials whereas in the main-text the authors can just summarize some results and discussing recent literature on this specific point.

Reply:

Thank you for the comments. The authors have shortened the statements, which is similar with the observation in the previous study (lines 153-174). In fact, the manuscript focuses on the increase of seismicity density before earthquakes that extends from the fault rupture zone to an external place. The associated statements have been extended and added in the manuscript (lines 175-212).

2) Conversely, I strongly encourage the authors to move fig.S5 from the supplementary to the main-text. I am really impressed by this figure. In particular I find striking the result of the left panel which, if i correctly understand, is for a single M6.6 mainshock and therefore is not contamined by spurious effects caused by the stacking procedure. This figure shows a change in the dominant frequency from roughly 10ËĘ{-4}Hz up to 30 days before, to a much larger value before the mainshock.

Reply:

Thank you very much. Fig. S5 has been moved from the supplementary to Fig. 4 in the main text.

What I find really interesting is the analysis at a fixed frequency (around 10ËĘ{-4}Hz) as function of the time from the mainshock. In this case you find that the mainshock occurrence time is a minimum" point in the sense that the amplitude ratio at the given frequency decreases before the mainshock and increases after, in a quite symmetric fashion. Comparing with the central panel, which is substantially the same of Fig.3, the authors find a similar pattern at a similar frequency for 4<M<5 mainshocks. In this case however the decrease of the amplitude ratio before the mainshock and the subsequent increase after is less pronunced. The same holds for 3<M<4 where the changes of the amplitude ratio are even less pronunced. This is really interesting since it suggests that you can correlate the slope of the amplitude ratio (at a specific frequency) with the magnitude of the incoming mainshock. I invite the authors to focus on this very important result and I suggest some checks to support the scenario.

Reply:

Thank you very much.

i) I don't fully understand the smoothing procedure: "The common-mode vibration is sliced ....". The really important point is that the amplitude ratio plotted at time t only

contains waveforms recorded up to time t. In other words, it is fundamental that quantities evaluated before the mainshock are not contamined by the mainshock signal.

Reply:

Based on the window of 5 days for the slice, the amplitude ratios 5 days before and after earthquakes can be influenced by the mainshock signals. In fact, the enhancements of the amplitude ratios with variable frequency appear more than 20 days earlier than the mainshocks. This suggests that the observed enhancements of the amplitude ratios are not contributed by the mainshock signals.

ii) The authors use the signal from 33 seismometers. What happens if I consider a smaller number? In particular how much results depend on the distance between the seismometer and the mainshock?

Reply:

Based on the pre-earthquake crustal deformation and the numerical model in the previous studies, the seismogeneric areas are considered to be larger than the rupture of the fault zone. In addition, Figs. 1 and 2 also show that the increase of seismicity density before earthquakes that extends from the fault rupture zone to an external place. The radius of the areas with the increase of seismicity density is about 50 km for the M3-4 event and is about 150 km for the M5-6 events. The areas of Taiwan Island are very small. This suggests the signals observed in this study can be recorded in the whole Taiwan island. On the other hand, the upper panel of the Fig. A shows the spatial distribution of amplification ratios in a frequency band between 8 x 10ˆ-5 to 2 x 10ˆ-4 Hz for an interval of 0–25 days before the Meinong earthquake. The enhancements roughly cover the whole Taiwan Island. Therefore, the signals can be retrieved from most continuous waveforms from most seismic station. Note that we also take the vertical component of curst displacements from the GNSS data into consideration (the lower panel in Fig. A). An agreement in variations of the spatial distribution of amplification ratios can also be obtained. This suggests that the amplification ratios distribute in areas with epicentral distance > 250 km. Fig. A has been utilized in the paper that is considered for publication in the other journal.

iii) There is some reason to take the first 20 principal components. What happens if one changes this number?

Reply:

This is a very good question. In the original version, we take the first 20 principal components due to that the threshold of 75% energy is required by other studies. In fact, we can have similar results while the first principal component (12% for energy) is utilized. Note that we have replaced the results in Fig. 4 by using the first principal component in the revision.

iiii) Is there any pattern observed for a single M4+ earthquake, without stacking their signals?

Reply:

Fig. B in below shows the results for a single M4+ earthquake, occurred in the central Taiwan. The enhancements in the frequency between 5x10ˆ-4 Hz and 10ˆ-3 Hz can be found that is in agreement with the observation in the previous study.

3) I am not totally convinced that the mechanism of resonance is the one responsible for the above observation. In my opinion this is a weaker point which can be also moved to supplementary, keeping a small discussion in the text.

Reply:

Thank you for the comments. The associated statements have been reduced (lines 296-310). The associated figure has been moved to the supplementary.

Summarizing, I believe that the direct analysis of seismic waveforms can contain more information than the one extracted from seismic catalogs. This is for instance shown in recent publications (Lippiello et al. Geophys. Res. Lett. and Lippiello et al. Nature

Communications 2019). In this direction, the PCA method used by the authors is very promising. I invite the authors to a global rewriting of their manuscript in order to better stress the main results. I also invite the authors to perform the suggested or similar checks to support their findings.

Reply:

Thank you very much. These important recent publications have been cited in the revision. We have intensely rewritten the more than 50% statements in the manuscript. We have carefully performed the suggested or similar checks to support our findings.

Figure Caption

Fig. A. Spatial distribution of amplification ratios computed from seismic and GNSS data for an interval of 0–25 days before the Meinong earthquake. The upper (a)–(e) and lower (f)–(j) panels denote amplification ratios obtained from seismic and GNSS data. The amplification ratio of > 1 (or < 1) suggests enhancement (or attenuation) of ground vibrations in the particular time period. Time intervals for (a)–(j) indicate distinct time spans until the occurrence of the earthquake during which the data were used for the analysis process. The red star denotes the epicenter. The red lines indicate portions of circles with a radius of 300 km from the epicenter of the earthquake.

Fig. B. The amplitude ratios of the time-frequency-amplitude distribution of one M4.6 earthquake at (121.34E, 23.37N) in the Taiwan region on Dec. 12, 2015.

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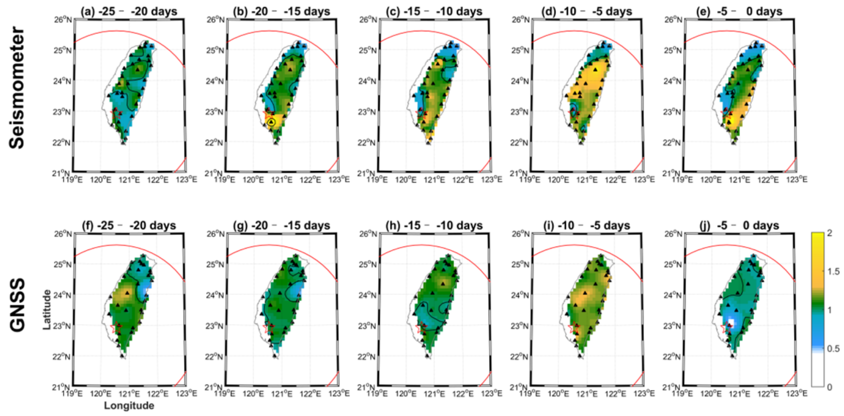

Fig. 1. Fig. A. Spatial distribution of amplification ratios computed from seismic and GNSS data for an interval of 0–25 days before the Meinong earthquake.

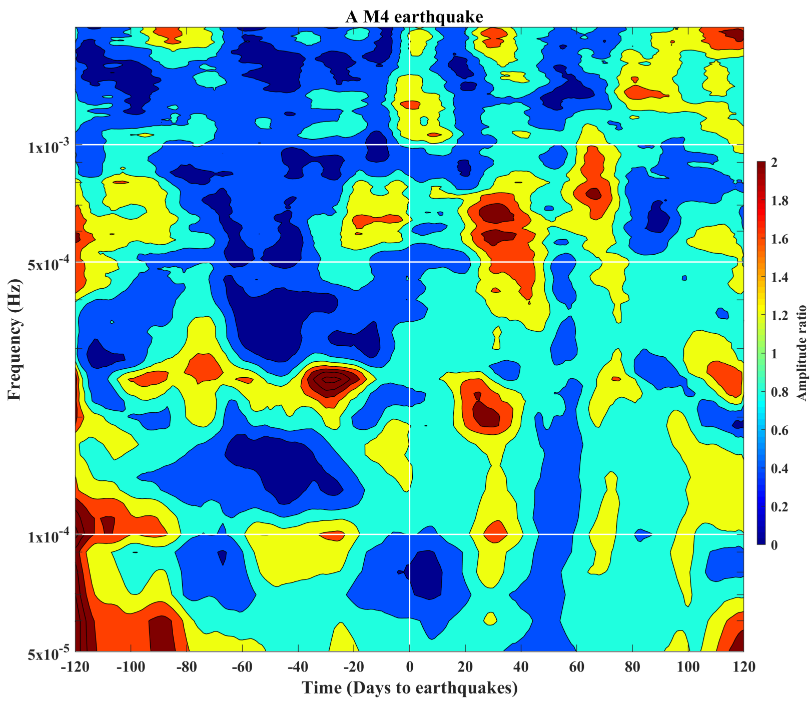

Fig. 2. Fig. B. The amplitude ratios of the time-frequency-amplitude distribution of one M4.6 earthquake at (121.34E, 23.37N) in the Taiwan region on Dec. 12, 2015.