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Earth, Atmospheric and Planetary Sciences

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Dear Professor Michal Malinowski,

Thank you for the invitation to review the PhD thesis written by Michal Chamarczuk "Development of body-wave seismic interferometry imaging for mineral exploration". Overall, the quality of the thesis is great in terms of writing and scientific contents. Each thesis chapter has been published as independent scientific papers, and all chapters are cohesive and inter-related each other well. Detailed comments are below.

The topic of the thesis is a state-of-the-art technique in seismology to extract body waves from ambient noise and continuous seismic data. Also in the thesis, seismic ambient noise has been studied intensively in the last 20 years for imaging subsurface structure and its monitoring. Most of the work has been done using surface-wave components of ambient noise. This is possibly based on two reasons that (1) surface waves are dominant energy in ambient noise due to the mechanisms of sources and (2) surface waves are more coherent than body waves especially when we have surface sensors. Using only surface waves provide a limited depth resolution of images. His work of extracting body waves is very important to overcome the resolution limit and extend the application of ambient-noise imaging and monitoring into engineering scales such as mining exploration.

Although mineral exploration is not under my main research topic, I have worked on it for seismic aspects. Recently, there is a demand of using seismology and seismic waves to monitor the stability of subsurface mines. His approach of using body waves should provide a new monitoring tool in this application with high spatial resolution, which is necessary for engineers.

As I already mentioned, the thesis is based on four papers, which are already published in high impact journals. Each paper presents a new processing technology for body wave extraction, and some are using advanced signal processing and others are machine learning. Needless to say, machine learning is a hot topic in seismology now. Another key word of the thesis is using a large number of sensors (Large-N), which is based on the recent

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development of sensor technologies.

Paper I:
Michal develops a machine-learning-based data scanning algorithm for continuous seismic recordings. With this algorithm, he detected more than 1000 body-wave events, possibly related to mine blasts. This is based on the fact that body waves are not consistently existing in the ambient noise data, but more local in time due to anthropogenic activities. His algorithm can detect them efficiently.

Paper II:
This is another machine-learning-based approach to scan ambient-noise recordings. The concept is similar to Paper I, but he uses unsupervised learning for this paper. For the input of data to machine learning, he uses a beamforming technique, and then construct a new data matrix. This approach seems efficient and unique.

Paper III:
This paper presents how to use the extracted body waves for subsurface imaging. From Papers I and II, we understand that we can extract body waves, and then they are ready to use subsurface characterization. In this paper, he applies reflection seismology techniques to image impedance contrast, and compares with synthetic tests. The results are not very easy to interpret to me. I still believe that without applying the algorithms developed above, this imaging is not possible at all, and therefore the results are encouraging.

Paper IV:
In this paper, using similar seismic interferometry techniques with data scanning algorithms are applied to image subsurface reflectors. This paper really tries to utilize and visualize the large volume of data for subsurface imaging.

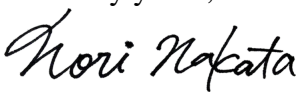
One important aspect of all these papers is that he always applies the developed algorithm to field data, which is not always the case in geophysics, and I am impressed.

Overall, I have no doubt for Michal's skill for data processing, handling big data, machine learning, logical thinking, basic physics knowledge, and writing, which are all important for PhD, and he surpasses the average. One point he, or our community, needs to work on is that extraction of body waves is becoming possible nowadays, but using them is still not easy. Michal's algorithms are all in advance, but still subsurface imaging is a challenging task. I do not understand well the reason, possibly the combination of signal-to-noise ratio,

misunderstanding of physics, or sparsity of waves in time. Hopefully I can see more applications using the extracted body waves for real field problems.

Please feel free to contact me if you would like to discuss. I would welcome the opportunity to speak with you.

Sincerely yours,



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