Comparison of nonlinear wavelets observed by both infrasound and seismometers in polar regions

*Masaki Kanao[1], Masa-yuki Yamamoto[2], Yoshiaki Ishihara[3], Takahiko Murayama[4], Takeshi Matsushima[5], Mitsuru Matsumura[1]

1.National Institute of Polar Research, 2.Kochi University of Technology, 3.JAXA, 4.Japan Weather Association, 5.Kyushu University

Several characteristic waves detected by seismographs in Antarctic stations have been recognized as originating from the physical interaction between the solid-earth and the atmosphere - ocean - cryosphere system surrounding the Antarctic and may be used as a proxy for characterizing ocean wave climate. An infrasound sensor was installed at Syowa Station, Antarctica, in April 2008 during the IPY2007-2008. Continuous infrasound data for 2008-09 includes background signals - microbaroms- with a broad peak in the wave period between the values of 4 and 10 seconds. Signals with the same period are recorded by the broadband seismograph as microseisms. On the infrasound data, stationary signals are identified with harmonic overtones at a few Hz to lowermost human audible band, which we suggest is due to local effects such as sea-ice cracking and vibration. Microseism measurements are a useful proxy for characterizing ocean wave climate, complementing other oceanographic and geophysical data. In Antarctic stations, continuous monitoring by both broadband seismograph and infrasound contribute to the Federation of Digital Seismographic Networks, the Comprehensive Nuclear-Test-Ban Treaty in the high southern latitudes, and the Pan-Antarctic Observations System under the Scientific Committee on Antarctic Research. In particular, this presentation focuses on the characteristic harmonic tremors observed both by infrasound and seismic sensors at Syowa Station, Antarctica during the period from February to April 2015.

Keywords: infrasound, seismic waves, nonlinear wavelets, harmonic tremor, polar region

Detection of infrasound from the landslide and earthquakes in Taiwan –primary results

*Yoshihiro Kakinami[1,2], Masa-yuki Yamamoto[2], Chun-Rong Chen[1], Horng-Yuan Yen[1], J. J. Dong[1], Chung-Pai Chang[1]

1.National Central University, 2.Kochi University of Technology

After large earthquakes and tsunamis occur, infrasound emitted from the epicenters and tsunami source areas are often observed. Using triangulation method, identification of the sources are being attempted. Since such phenomena accompanying large motion of ground/sea surface often emit infrasound, landslide is also highly expected to emit the infrasound. In fact, people often reported some uncertain noise just after the landslide occurred. Although less scientific report of infrasound observation from the landslide has been done so far, we try to detect the infrasound emitted from the landslide. In order to achieve the purpose, we started observation of the infrasound in Taoyuan (23.1607°N, 120.7658°E) and Dabu (23.3005°N, 120.6296°E), Taiwan from July 2015. In this paper, we introduce our observation sites and primary results of power spectrum and landslides identification from the infrasound. Furthermore, the infrasound emitted accompanying the M6.4 Kaohsiung (Meinong), Taiwan earthquake (22.871°N, 120.668°E) occurred 33 km away from the Taoyuan observatory at 19:57:27 UTC on 5 February 2016 was observed. The results before and after the earthquake are also shown.

Keywords: infrasound, landslide, Taiwan, Kaohsiung earthquake

Locating snow avalanches by using of infrasound array data

*Nobuo Arai[1], Toshiaki Imai[2], Masaya Otsuki[2], Yoshihiko Saito[2], Takahiko Murayama[3], Makiko Iwakuni[3]

1.Disaster Mitigation Research Center, Nagoya University, 2.Yukiken Snow Eaters Inc., 3.Japan Weather Association

Infrasound observation measures the energy radiated by the snow avalanche in the atmosphere and is able to detect snow avalanches over large areas. The use of infrasound for snow avalanche monitoring has increased in the last decades, with significant improvements on snow avalanche dynamics research.
Our research team has conducted infrasound observation in the last 3 winter seasons in Tokamachi, Niigata. Firstly, we deployed an infrasound sensor in front of the specific slope between Jan. and April 2013 with visual observation by using a web camera and grasped infrasound signals characteristics generated by snow avalanches. And in the second season (2013-2014 winter season), we deployed two infrasound sensors with about 1 km distance and caught the distance attenuation characteristics of infrasound signals. In the last 2014-2015 winter season, we deployed 3 sensors with a triangular geometry spaced 1 to 2 km apart and tried to extract signals associated with snow avalanches from observed raw data automatically by using time domain processing. And for extracted signals, locations of snow avalanches were estimated by using cross-correlation method. 12 events were picked up and located. Estimated locations were in the area with many steep slopes. Infrasound array monitoring system with real time processing might deliver significant information on snow avalanche activity to us.

Keywords: Snow avalanche, Infrasound, Array observation

Comparison of seismic waveforms observed by microbarograph with broadband accelerometer

*Makiko Iwakuni[1], Takahiko Murayama[1], Nobuo Arai[2], Mie Ichihara[3], Kazutaka Mannen[4], Jerome M. Paros[5], Takuma Oi[6]

1.Japan Weather Association, 2.Disaster Mitigation Research Center, Nagoya University, 3.Earthquake Research Institute, University of Tokyo, 4.Hot Spring Research Institute of Kanagawa Prefecture, 5.Paroscientific, Inc. and Quartz Seismic Sensors, Inc., 6.Toho Mercantile co., Ltd.

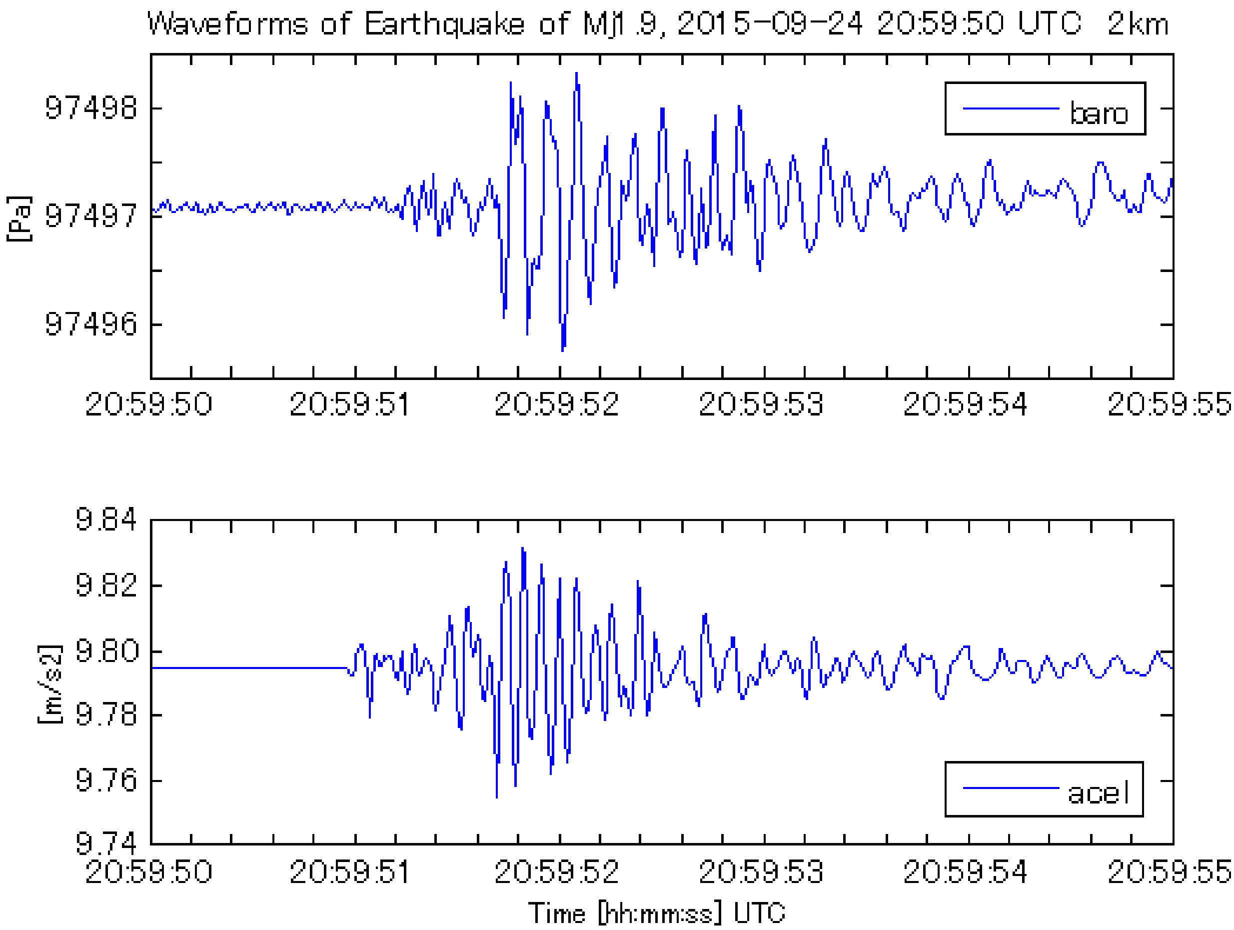
As already discussed in the papers, sensitive Microbarographs can detect seismic waves without going off the scale and supplemental measurements made with accelerometers.

Hakone volcanic activity increased from April 2015. To monitor Hakone volcanic activity, we started to measure seismic and pressure signals using a seismo-acoustic sensor that is a combination of a Broadband Accelerometer (Developed by Quartz Seismic Sensors, Inc., USA) and a Sensitive Microbarograph (Manufactured by Paroscientific, Inc., USA) in August. Both sensors use precise quartz crystal resonators to archive parts-per-billion resolution. The single axis accelerometer records the vertical component of ground accelerations.

Earthquake of Mj1.9 occurred at a depth of 2km in Hakone volcano area at 20:59:50 UTC on the 24th of September 2015, and its seismic signal was observed by both the microbarograph and accelerometer. The distance between the epicenter and the observation site is approximately 2.4 km. The microbarograph recorded similar waveforms to that of the accelerometer.

In this presentation, we discuss the similarities and differences of the seismic signals observed by the microbarograph and accelerometer.

Keywords: Sensitive Microbarograph, Broadband Accelerometer, seismic response


Waveforms of Earthquake of Mj1.9, 2015-09-24 20:59:50 UTC 2km
baro
[Pa]
97498
97497
97496
20:59:50
20:59:51
20:59:52
20:59:53
20:59:54
20:59:55
acel
[m/s2]
9.84
9.82
9.80
9.78
9.76
9.74
Time [hh:mm:ss] UTC

Relationship Between Amplitudes of Infrasound and Ionospheric TEC Disturbances by Vulcanian Volcanic Explosions

*Yuki Nakashima[1], Yosuke Aoki[2], Kiwamu Nishida[2], Shingo Fujita[1], Kosuke Heki[1]

1.Natural History Sciences,Graduate School of Science, Hokkaido University, Earth and Planetary Dynamics, 2.Earthquake Research Institute, University of Tokyo

We will compare infrasound records and TEC (Total Electron Content; number of electrons integrated along the GNSS line-of-sight) perturbations caused by the 2015 Kuchinoerabujima volcano eruption, and will evaluate the usefulness of the volcanic explosion scale inferred from TEC perturbations. Infrasound from a vulcanian volcanic eruption shakes ionospheric electrons at altitude of ~300 km. Heki (2006, GRL) investigated ionospheric disturbances by the 2004 September eruption of the Asama volcano using the GNSS-TEC method. We will compare such TEC changes with infrasound records, and study their quantitative relationship.
We compare amplitudes of changes of slant-TEC and infrasound (JMA volcanic activity reports) of five recent cases of vulcanian eruptions in Japan (the 2004 Asama, the 2009 Sakurajima, the 2011 Shinmoe (twice), the 2015 Kuchinoerabujima). The correlation coefficient was 0.5. We normalized the STEC change amplitude with the local vertical-TEC value inferred from GIM (Global ionospheric maps), and call it “F-scale”.
To confirm the usefulness of this scale, we checked the frequency spectra of infrasound records of the 2015 Kuchinoerabujima eruption. Generally speaking, infrasound by volcanic explosions is considered to have a peak around the period of 2-3 sec (Sakai et al., 2000, Kenshin-jiho [in Japanese]). However components with frequencies higher than ~0.1 mHz attenuate before it reach the ionosphere (Blanc, 1984, Ann. Geophys). Hence, it would be important to know such infrasound frequency spectrum to compare records of the two sensors (TEC and infrasound).
Information on infrasound recorded in volcanic eruptions is available in the JMA volcanic activity reports and Coordinating Committee for Prediction of Volcanic Eruptions reports. According to these documents, two JMA microphones (ACO TYPE7144, TYPE3348) and two NIED barometers (Vaisala PTB100) are installed in the Kuchinoerabujima. The JMA stations are located 2.3 km NE (>62.2 Pa) and 2.8 km NW (13.9 Pa) from the crater and the NIED barometers are located 1.7 km SE (350 Pa) and 1.5 km SW (280 Pa). The JMA microphone is sensitive to frequency band of 0.1-100 Hz, while the sampling interval of the NIED barometers is 1 sec.
We also try to improve observations of TEC oscillations, e.g. by converting slant TEC to vertical TEC and by correcting for the geometric attenuation caused by the propagation distance.

Keywords: GNSS, GPS, Volcano, Ionosphere, Earthquake

Power spectral density distribution of micro-barometric variation around the transition region between acoustic mode and internal mode gravity waves

*Toshihiko Iyemori[1], Yoko Odagi[2], Tadashi Aoyama[3], Yasuharu Sano[2], Yoshikazu Tanaka[3]

1.Data Analysis Center for Geomagnetism and Space Magnetism, Graduate School of Science, Kyoto University, 2.Asahi University, 3.Graduate School of Science, Kyoto University

The vertical acoustic resonance between ground and upper atmosphere having period around 200 -280 seconds has been observed during Earthquakes, volcanic eruptions, tornadoes, etc. (Kanamori and Mori, 1992; Iyemori et al., 2005; Saito et al., 2011; Nishioka et al., 2013) These periods are shorter than the Brunt-Väisälä period and close to the acoustic cutoff period. On the other hand, more slow variation around 10 minutes to 20 minutes are often observed during stormy weather, and they may belong to the internal gravity waves. In this paper, we show statistically the power spectral density distribution of micro-barometric variations near the transition region around 5 -10 minutes.

Keywords: Micro-barometric variation, acoustic gravity waves, internal gravity waves, power spectral density

Calibration experiment for infrasound sensors by a space chamber

*Masa-yuki Yamamoto[1]

1.School of Systems Engineering, Kochi University of Technology

Infrasound monitoring is important for atmospheric study and disaster prevention for destructive geophysical events such as volcanic eruptions, thunderstorms, landslides, tsunamis, etc. We have been developed a kind of infrasound sensor in our laboratory since 2007, then most recently, a combined type infrasound sensor was successfully developed, collaborating with a company of *RESONA ALES* in 2015. At a time of infrasound sensor construction, precise calibration with simulated infrasonic waves is significant for evaluation. Here we introduce a method of calibrating infrasonic waves with precise pressure amplitude and frequency with using a space chamber in laboratory. The space chamber is usually used at a scene of testing rocket-borne instruments and satellites in extremely severe rarefied environment before the launch with using multiple vacuum pumps to create space environment in laboratory. However, we use the chamber as an extremely rigid volume without having any surrounded surface change during the calibrating experiments. The infrasound is understood as pressure waves in the atmosphere, thus the same kind of waves can be simulated if we inject a fixed small volume into the fixed amount of atmospheric volume enveloped by the rigid chamber. The simulated pressure level can easily be calculated by using a ration between the injected small volumes per the large amount of enveloped space. A small space chamber in Kochi University of technology (KUT) with 240 litter volume was used for this kind of calibration with a small syringe with giving $1/10^8$ of the 240 litter per a fixed time constant. The syringe can be accurately controlled by a motor-driven push-pull motion mechanics with a long time period up to 1000 s. Therefore, sinusoidal pressure waves with a pressure level of 0.001 Pa as well as extremely slow frequency of 0.001 Hz was realized for calibration. By using such facilities in KUT, precise calibration with the developed infrasound sensor as well as any other infrasound sensors, microphones, and barometers can be realized. In this paper, calibrating datasets for various types of sensors will be shown.

Keywords: Infrasound, Calibration, Space chamber

Development of automatic detection software for N-type waveform events of infrasound

*ryosei sorimachi[1], Masa-yuki Yamamoto[1], Yoshihiro Kakinami[1]

1.Kochi University of Technology

1.Background
The lower frequency sonic wave less than 20 Hz is called as infrasound. The infrasound has a long distance propagation characteristics because of its weak attenuation feature in the atmosphere, therefore it is considered as the future technique for disaster prevention for volcanic eruptions and tsunamis, for example It has been studied on the infrasound in Yamamoto lab. in Kochi University of Technology since 2005, with developing direction-finding technique for incoming waves. Applying the direction-finding technique into the observation system, the source area of infrasound waves was fixed with multiple-site array observation of infrasound (Komatsu, 2012). However, the automatic detection of the N-type waveform events in the case of encountering explosive natural phenomena such as the eruptions of the volcano or thunders is essential to make the realtime observation of the infrasound for disaster prevention.
2. Purpose
The purpose of this study is to develop automatic detection software for N-type waveform infrasound events as well as to inspect the precision of the software for the real datasets of N-type waveform events.
3. Developed software
This software outputs the event detection time and number of counts by inputting five parameters including the trigger to detect the events with drawing spectrogram.The N-type waveform event shows broad spectrum in wide frequency range without any specific peak periods. Thus, the software divides long-time observational data into short-time blocks then performs FFT (Fast Fourier Transform) sequentially and calculates mean parameter of the spectrum strength in whole frequency range in the spectrum in order to detect a point (time) of enhancing as N-type waveform events.
4. Evaluation
Using observed infrasound data for firework events by Komatsu (2012), 11 events were confirmed by human viewing. We inspect the software with adding a kind of pseudonoise on these data gradually and tried to find out detection points of the N-type events with changing trigger parameter so that the number of the detection becomes 11. Thus, we evaluated the software with respect to the volume of noise included in the real infrasound data.
5. Consideration by the inspection result
It was recognized that the software could detect half of the N type wave form events even if the SNR was less than 1 from a result of the inspection. The software could detect a part of N-type events that had difficulty in confirmation by the human viewing.
6. Conclusion
We conclude that the purpose was confirmed successfully because the software can detect the N-type events from the noisy dataset
Reference:
Komatsu,Takayasu, Construction of multi-site arrayed-sensor system for infrasound observation and estimation of sound source coordinates, Special research report at graduated school of Kochi University of Technology, 2012.

Keywords: infrasound, N-type waveform event, automatic detection

The current status of the infrasound observation network for improving the tsunami warning system

Takahiko Murayama[1], Nobuo Arai[2], *Makiko Iwakuni[1], Yuichi Imanishi[3], Shingo Watada[3]

1.Japan Weather Association, 2.Disaster Mitigation Research Center, Nagoya University, 3.Earthquake Research Institute, University of Tokyo

Sensitive microbarographs in and around Japan recorded unequivocal signals associated with the 2011 Off the Pacific Coast of Tohoku, Japan earthquake (Mw = 9.0).
We identify them as atmospheric boundary waves excited by the uplift and subsidence of the ocean surface (tsunami generation), on the basis of the waveform characteristics as well as similarity with the data from ocean-bottom pressure gauges.
It is noted that the atmospheric boundary waves, once excited, travel in the atmosphere significantly faster than the tsunami waves in the ocean. In addition, they retain the original shape of the tsunami, because they are little dispersive. Establishment of a network of infrasound observation along the coast line facing the subduction zone would improve the tsunami warning system, because it would provide information on the tsunami source.
In order to achieve this conception, we have developed a prototype system of the infrasound observation network and started to observe the atmospheric pressure changes associated with tsunami generation by deploying of three infrasound observation sites in Ofunato city of Tohoku region on July 2013. In addition we caused expansion of this network by newly deploying of infrasound observation sites in Mie prefecture of Tokai region on Jun 2015.
Now, based on the findings of the observation, we are discussing what the observation network should be, where and how a prototype system would be deployed.
In this presentation, we would introduce our discussing.

[References]
[1] Arai, N., M. Iwakuni, S. Watada, Y. Imanishi, T. Murayama, M. Nogami (2011), Atmospheric boundary waves excited by the tsunami generation related to the 2011 great Tohoku-Oki earthquake, Geophys. Res. Lett., 38, L00G18, doi:10.1029/2011GL049146.

Keywords: Atmospheric boundary wave, Tsunami source, Infrasound, Microbarograph

