Infrasound from natural phenomena observed by infrasound observation network for study on early detection of tsunami

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At the time of the 2011 off the Pacific coast of Tohoku Earthquake, several microbarographs around focal region recorded pressure changes associated with atmospheric boundary wave excited by large scale sea-level change in tsunami source region (Arai et al., 2011). We have decided to study infrasound monitoring technique to detect large tsunami generation, then have started experimental infrasound observation using microbarographs in Ofunato city and Shima district since July 2013, June 2015 respectively. We are now planning to make those data available on the web to facilitate study on infrasound by any researchers.
Since a variety of phenomena can excite infrasound as well as large scale sea-level change, such infrasonic signals are frequently observed at the infrasound observation sites mentioned above. In this presentation, we will introduce some cases of detected signals traveling from known sources such as a volcanic eruption, a bolide and so on. Through the analysis on observed signals from a variety of phenomena, it is expected to accumulate useful information for application to source identification and propagation characteristics of signals.

Keywords: Infrasound, Tsunami, Volcanic eruption, Bolide, Microbarograph

Consideration on the Exciation of Lamb Waves, Internal Gravity Waves, and, Acoustic Gravity Waves

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See Japanese abstract.

Keywords: Lamb waves, internal gravity waves, acoustic gravity waves, infrasound, earthquake

Ionospheric volcanology: GNSS-TEC observation & modeling of the 2015 Kuchinoerabujima eruption

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Efforts in last decade prove that ionosphere, mainly observed by GNSS measuring the total electron content (TEC), is sensitive to geophysical phenomena as earthquakes, tsunamis, and, more recently, volcanic explosions.
Kuchinoerabujima is a volcanic island located in ~200 km southwest of Kyushu, Japan. The volcano erupted at 0:59 UT May 2015 (VEI 3).
We found a concentric acoustic wave following the eruption in GNSS-TEC time series. We used 1 Hz GEONET (GSI) data for this analysis. The observed wave seems include high frequency (5–10 mHz) pulse disappearing in the first ~300 km around the volcano and a monochromatic wave (~5 mHz) observable for more than ~20 min and reaching the distance of ~400 km. The traveltime indicates the wavefront is almost spherical. We interpreted those signals as a combination of, first, the direct shock wave propagating within the atmosphere/ionosphere and, second, the acoustic wave trapped in the lower atmosphere/ionosphere by the effect of the cut-off frequency change with the altitude.
Our observation are also supported by various ground observations: barometers (NIED; AIST), microphones (NIED; JMA) and broadband seismometer (NIED). We detected ~1 hPa wide frequency range (2–70 mHz) air wave in near-field and ~15 mHz perturbation reflecting or refracting once or twice at ~100 km from the volcano. The difference of frequency components derives from the instruments noise level or dispersion of the wave.
In order to validate our hypothesis we support and discuss our observations with the light of the modeling with the main goal of constrain some physical parameters of interest in volcanology.

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Keywords: Ionosphere, GPS, GNSS, Volcano

Observation of shockwave from the 17 December 2013 Biwako bolide using 3D seismic array

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There are many reports of observation of bolides by using seismic record. Compared with other approaches such as video camera or acoustic microphone, seismological observations have advantages in terms of their ease of multipoint observations and their independence on weather conditions (e.g. Ishihara et al. EPS 2003). In these reports, there is a case of unclear onsets and no distinct N shape in waveforms (Yamada and Mori EPS 2012). That case, a velocity of the fireball was not determined. Here we report seismic records of shockwave from the fireball that appeared on the night of 17 December 2013 around Biwako and determine the moving velocity by using a dense three dimensional seismic array.
We performed a 3D array observation in Mie prefecture since February 2011 to monitor non-volcanic low frequency tremor activity (e.g. Takeda et al. JpGU 2015). The array is composed of a 3-level vertical seismic array at a depth of 25m, 164m, and 595m (Imanishi et al. 2011), and a 46-element surface array centered on the vertical array. The radius of the surface array is 10 km, with a station spacing of about 50 m to 5 km. Seismograms recorded at the surface array show clear onsets of the shock wave with a downward polarity, while those of the vertical (borehole) array have unclear onsets. Therefore, we used only seismograms of the surface array for the determination of a source trajectory.
We manually picked arrival times of the shock wave, and estimated the source location by a grid search, assuming a point source or a moving source with a constant velocity. Theoretical arrival times for the moving source model show better fit to the observations than those for the point source model. We estimated the velocity of source to be 27km/s and an incident elevation angle to be 43 degree. Our result agrees with the estimation by video camera records, which are 25km/s and 47 degree (SonotaCo Network Japan).

Keywords: bolide, seismic array

Remote Sensing by Multi-site Observation of Infrasound

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1. Introduction: We have been observing the infrasound generated by earthquakes, tsunami, thunder and other geophysical phenomena as wave sources. Some of the geophysical phenomena occur rarely, while the others occur at a relatively high frequency per year. In order to establish stationary monitoring observations of infrasonic waves with detectable intensities, we started comprehensive multi-site observation with infrasound sensors, cameras and radio wave reception system installed at 3 sites in Kochi pref. In this paper, we report the observation results and considerations about thunder and a bright meteor (fireball) simultaneously observed by the system.

2. Multi-site observation: Since December 2016, we have been operating multi-site comprehensive observation at three points of Kochi University of Technology (KUT) (Kami City), Geisei Astronomical observatory (Geisei Village), Midori Clock Tower (Otoyo Town) with infrasound sensors (Chaparral Physics Model 25), optical cameras, radio wave receiving systems. There is infrasound and radio wave observation system at Otoyo, and all three observation systems are constantly in operation at two other points. Operation status of each device at each remote site can be confirmed at KUT through the mobile network connection, and file transmission and reception is also possible.
Here, observatioal result of the lightning strike (thunder) occurred on 13th December 2016 and a meteor observed on 5th January 2017 are described. Sonic waves of thunder strikes occurred at 18:59 on December 13, 2016 were observed at every 3 observation site, and the lightning strike position and time were calculated from the time difference between them. In addition, the camera installed at KUT and radio wave receiving systems at each observation site observed luminescence and impulsive radio waves. N type atmospheric pressure waveform with on amplitude of 0.06 Pa was detected at Otoyo 24 km away from the lightning strike point.
Sonic waves generated by the meteor observed at 22:33 on January 5, 2017 were detected at two sites. A pressure waveform similar to a shock wave with an amplitude of 0.05 Pa was observed at Geisei. Radio waves (steady transmitted from Fukui National College of Technology) reflected by the ionizing column formed during the meteor entry into the atmosphere were observed at 2 sites and meteor video movie was observed by the camera at KUT.

3. Results and discussion: We found a one second delay between the thunder striking time obtained from the observed time-difference of infrasound impulse among each site and the time when the radio system observed the radio wave impulse. It is considered that this is due to assumptions such as constant sound speed, uniform wind direction, direction of discharge path, etc. In addition, there are some factors of the measurement error of the calculated lightning strike position, and an error of ±300 m is considered in this analysis. Sound amplitude attenuation by distance was calculated from the power spectrum of each site. There were 20 dB difference between KUT and Otoyo where the distance difference from the lightning strike point was 18 km at the maximum case.
Infrasound generated by the meteor entry into the atmosphere was observed at Geisei with shock wave type waveform of a period of 1.53 seconds. The power spectra of 10 seconds before and after the event about were compared, and it was confirmed that the power spectrum amplitude in lower frequency range of 10 Hz or less was 10 dB larger. It could be considered that this is because the detection of very low frequency disturbance when the shock wave occurred in the upper atmosphere passed. The camera

installed at KUT confirmed about 3 times of erupting light emission, which is considered to be relatively larger meteor (fireball) than the normal one. It is extremely rare to be observed for an infrasound generated by an object entering from the outer space into the atmosphere, and such observation is extremely difficult unless there exists stationary operated remote sensing.

4. Conclusion: When calculating the time and position of the event by the acoustic observation, the wind speed has a great influence as an error factor, so it is necessary to set a temperature sensor in each observation site in the future and take temperature information. Moreover, frequency attenuation can be confirmed by sensing the audible range. We have succeeded in observing very low frequency sound generated by geophysical phenomena by conducting steady remote sensing. We will continue to accumulate various observation data by comprehensive observation.

Keywords: Infrasound, Lightning, Thunder, Meteor

Shaking table tests on seismic response of microbarograph

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As already discussed in the papers, sensitive Microbarographs can detect seismic waves without going off the scale and supplemental measurements made with accelerometers.Pressure change response to seismic acceleration is considered to be made by gravitational pressure by which barograph move up and down and air vibration (dynamic pressure) excited by earthquake ground motion and instrument response by earthquake directly shake barograph.

Earthquake of Mj3.7 occurred at a depth of 5.2km, and its seismic signal was observed by both the microbarograph and accelerometer. The distance between the epicenter and the observation site is approximately 20 km. This case showed that in start shaking the microbarograph recorded similar waveforms to that of the accelerometer, and pressure change was much greater than gravitational pressure. To learn component of pressure change in detail, we vibrated vertically and horizontally the above microbarograph and accelerometer on the shake table. This microbarograph is attached a coiled tube tipped with air joint at air hole as a dumper, in order not to destroy inside mechanism by a mechanical shock while installing a microbarograph in a case and excessively torque while tightening air joint. We introduce the result of vibration experiment, such as the effect of a tube by fixed the tube to the shake table and instrument response by covered a tube to block outside air.

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Keywords: Sensitive Microbarograph, Shake table, instrument response of microbarograph by vibration

Dense infrasound observation network planned in Kochi prefecture

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Infrasound is known as pressure waves in atmosphere with its frequency lower than the human audible limit of 20 Hz. Due to its distant propagation characteristics without large attenuation, the infrasound can be used as a remote-sensing tool for the huge scale geophysical events closely coupled with atmospheric environment. Tsunami is one of the most dangerous geophysical phenomena for human life and the Japanese originated word of TSUNAMI shows Japan is one of the most dangerous regions for tsunami disasters in the world. Kochi prefecture is located in Shikoku island and, at along the southern coast of Kochi, we have many dangerous sites of tsunami invasion once a huge earthquake happens in Nankai Trough in the pacific ocean, just near the southern coast of Japan. Infrasound observation network has currently been installing in Kochi region since 2016 for disaster prevention, taking account mainly for tsunami disasters. As for the pilot arrangement, we installed 5 sensors in Kuroshio Town in western district in Kochi pref. with a separation of about 2 and 8 km, making two-sized triangle arrays there. The infrasound sensor arrays reveal us some important feature of the detected signals coming from Typhoons and volcanic eruption of Mt. Aso in Kyushu island. Moreover, in 2017, we have a plan to install 11 more sensors in Kochi pref. to make the densest infrasound observation network in such specific small area in Japan. In this talk, we will introduce our observation design of the network and previously obtained datasets for consideration of tsunami disaster prevention.

Keywords: Infrasound

Low frequency detection experiment by microphone array for infrasound measurement

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1.Abstract: Human audible frequency is between 20 Hz and 20 kHz. Low frequency sound waves of 20 Hz or less are called infrasound, which are caused by large-scale natural phenomena such as volcanic eruption, tsunami, meteorite entry into the atmosphere, and artificial explosions such as rocket launches. In a region of low frequency,there is low attenuation due to the small viscosity of air and has characteristics of long-distance propagation, so it is focused as remote sensing technology.
At Kochi University of Technology Yamamoto Laboratory, low-cost infra sound sensors using piezo and PSD devices have been developed. However, since these sensors have a container with a membrane having a certain volume and the expansion and shrinkage of the membrane surface due to small atmospheric pressure fluctuation is detected, there is a problem of performance changing due to deterioration of the film surface. Therefore, we propose to detect the infrasonic waves by a combination of condenser microphones without using film surface, and here, we are conducting experiments.

2.Experiment: Although it is difficult to detect low frequencies such as infrasound with only one condenser microphone, low frequency sensitivity is improved by arranging multiple microphones in an array. In the present experiment, a few types microphone arrays using 16 condenser microphones each was prepared and evaluation experiments used them were carried out. Each microphone element can be placed on a 2 mm thick styrene board and the arrangement can be freely changed by using the round pin socket as a connector to each microphone. Arduino UNO was used as an A/D converter (sampling frequency: 40 Hz).
We conducted an experiment of low frequency detection using a vacuum chamber and a syringe pump in our laboratory. The vacuum chamber was used only as a rigid volume container and infrasound was generated in a pseudo manner by slightly varying the pressure inside the chamber only with the push and pull of small volume air by the connected syringe pump. The syringe pump can input a fixed volume to be injected in 1 minute, so that the frequency to be generated can be determined. In this experiment, the experiment was conducted by changing the frequency at 0.1 Hz, 0.05 Hz, and 0.01 Hz.
We also conducted experiments to confirm the sound receiving performance of audible sound of the microphone array produced. We fixed the distance from the speaker to the microphone in a quiet room as 1, 2, 3, and 5 m, and confirmed the attenuation of sound waves. Experiments were conducted without anti-aliasing filter while sequentially changing the frequency at 200, 150, 100, 75, 50, 40, 30, 20, and 10 Hz at each distance.

3.Results: The shape of the microphone array used in this experiment was a circle with a diameter of about 9 cm placed on a 10 cm square styrene board and a circle with a diameter of about 19 cm arranged in a 20 cm square styrene board, and another curved shape arranged in a 20 cm square that 3 microphone rows are extended while curving at 120° intervals from the center. In the chamber experiment of infrasound, low frequency detection of 0.01 Hz was succeeded only in the microphone array of the curved shape.
In the room experiment of audible sound measurement, the attenuation of the sound wave by the distance was seen, and the attenuation due to the array shape was also observed. Everything from 1 to 3 m attenuated in the same way, with a difference in attenuation at 5 m. The attenuation was large in the

order of a circle with a diameter of 9 cm, a circle with a diameter of 19 cm, and a curve shape in that order. Moreover, since it was largely attenuated from 200 Hz to 20 Hz, it seems to be the effect of cutting the high frequency by the shape of the array arrangement. Especially, the effect in the curve shape was large.

4.Conclusions: Infrasound can be detected by arraying multiple condenser microphones through several experiments and it was confirmed that the performance could be determined by devising the shape of the array arrangement. In the future experiments, we plan to verify the effects on sonic waves from the obligue direction with respect to the microphone array, resolve the noise aflection, and improve the circuits.

Keywords: Infrasound, Microphone array

Experimental verification of acoustic characteristics under simulated Martian surface environment

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Introduction: In 2020s, launches of Mars explorers is planned, and realization of the series-like Mars explorations is expected. As of 2016, the sonic wave observation in Martian atmosphere has never been carried out. Not only measuring Martian atmospheric sound with the dust events but also sensing of physical parameters in Martian atmosphere could be realized if a few small microphones are equipped on a Rover for the exploration based on an appropriate design and development.

Purpose: We aim to measure the sound attenuation and the sound velocity experimentally under the Martian atmospheric condition in the large science space chamber excluding the temperature control with operating the microphone evaluation model to be mounted on Mars probe.

Experiment outline: As a Martian surface atmosphere condition, nighttime temperature of -120 degree Celsius operation and calibration tests including infrasound detection in an environment simulating the harsh environment of CO_2 component occupying 95%, ground surface pressure of 7 hPa and the similar environment were carried out at Chiba Institute of Technology, Kochi University of Technology and ISAS/JAXA. We measured sound propagation characteristics in Martian atmosphere in ISAS/JAXA large-scale science space chamber using microphones arrays that had been confirmed under the simulated Martian conditions. Air, argon, and carbon dioxide were set to 7 hPa and 70 hPa, respectively, as the experimental conditions, and measurements were made including only atmospheric pressure of air. This chamber was about 2 m in diameter and 4.5 m in length, with a moving arm inside. Measurement was also carried out by installing a speaker at the terminal end of the arm, outputting a certain frequency, and moving it laterally within the movable 3 m range of the arm by 0.25 m step. The sound speed was calculated from the standing wave of half wavelength generated in the chamber. Also, attenuation was calculated by comparing amplitudes under different pressures by the same method.

Experimental result: In the experiment of this time, since it was found that it is difficult to calculate the measurement of the sound velocity, by the spaced microphones the sound speed is calculated from the data acquired to confirm the position of the antinode and the node of the standing wave. Because the number of data was too small to calculate accurate values. However, when the interior of the chamber was set to 7 hPa with carbon dioxide, the theoretical value of sound velocity was 269.7 m/s, whereas the experimental result was 280 m/s. For argon, the theoretical value was 322.1 m/s,experimental one was 350 m/s. For the air, 350 m/s was measured with respect to the theoretical 326.4 m/s. From this result it was possible to obtain the sound speed with an error within 8% of the theoretical value. In addition, when comparing sound intensities at 70 hPa and 7 hPa with argon, an amplitude difference of 10.41 times on average was obtained if the pressure difference was 10 times. Moreover, with the air, the amplitude difference of 8.9 times was obtained under the same condition.

Discussion: Since the value of sound velocity under the simulated Martian surface condition was measured and values close to the theoretical ones were obtained for three species of CO_2, Ar, and Air. It is considered that it is possible to derive a more accurate value by increasing the number of observation points by the same method. Also, regarding sound attenuation, when the sound velocity, gas and temperature are the same as the dynamic viscosity = absolute viscosity / density, since the pressure is a function of density, it is consistent with the idea that the attenuation becomes large when the pressure is small, so the result seems roughly to be correct.

Conclusion: Sonic speed and sound attenuation were measured under simulated Mars environment using an evaluation model of the microphone array. Since the speed of sound is close to the theoretical value, the sound speed in the Martian atmosphere can be considered to be almost the same as the theoretical equation. In the future we will have microphone arrays on the balloon and will conduct an experiment in the stratosphere comparatively close to the Martian atmosphere without a boundary surface at ESRANGE in Sweden in October, 2017.

Keywords: Sound, Mars

