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# Infrasound research activities in Kochi University of Technology – Infrasound observation network by using multiple comprehensive sensors and its application for disaster mitigation as well as safe human life -

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## ABSTRACT

Infrasound research activities in Kochi University of Technology will be presented. Infrasound observation network by using multiple comprehensive-type infrasound sensors was established recently in Kochi, Japan. Main purpose of the sensing network is for disaster mitigation/prevention mainly for tsunami, indicating a good application of infrasound sensing. If we can detect infrasonic waves before coming real tsunami waves to sea shore, it can effectively be used for saving human lives from the flood of sea water. However, the sensors can also detect many types of natural and artificial low-frequency audible sound and infrasound. It means the network sensing system can be applied to safe human life by means of emergency level alert to local citizens like weather forecasts. Moreover, we recently tried to evaluate wind turbine low-frequency audible/infrasonic noise affection for human health. In a vicinity of two wind turbines we measured sound field environment by using audible/infrasonic sensors together with biological information sensing system with multiple methods with respect to more than 30 human subjects/testers. With recent progress of biological information sensor technology, we can use them freely outside but many kinds of artifacts can also affect real signals of heart beat and brain wave measurements like our noise hearings.

Keywords: Infrasound, Sensor network, Tsunami, Disaster mitigation, Wind turbines

## 1. INTRODUCTION

Infrasound is known as large wavelength sonic wave that frequency is below the human audible lower limit of 20 Hz. The infrasound can be used for possible remote-sensing in atmosphere especially for the huge scale explosive events. In the infrasound laboratory in Kochi University of Technology, it has been used for detection of Hayabusa reentry in 2010 (1) as well as some icy environmental proxy monitoring in Antarctic (2), for example.

If we imagine the infrasound of 1 Hz with assuming the sound speed of 340 m/s, the wavelength becomes also 340 m hence the half-wavelength becomes 170 m. If we imagine again that a massive iron plate with 170 m square is suddenly uplifted, the plate can push the air on the plane to upward then it makes infrasound of 1 Hz because of the resonance between the scale size of uplifted plate and the half-wavelength of the sound. It is like a huge drum or a huge speaker on the surface of the plate. Therefore, in an analogy to the larger scale size, if we have any geophysical events like landslide, avalanche, thunder, volcanic eruption, earthquake, and tsunami, resonance infrasound can effectively generated on their surface and propagate in the atmosphere. As the infrasound can propagate with the speed of sound as same as the audible sound, it can be used as the remote sensing in the Earth's atmosphere. Moreover, infrasound or low frequency sound itself has characteristics of long distant propagation because damping/attenuating by molecule viscosity is inverse proportional to a square of frequency. In nature, it was observed that the infrasound induced by tsunami just after the main shock of the 3.11 Tohoku earthquake (M=9.0) in 2011 propagated more than half globe of the Earth. Here we show a possibility of using infrasound for disaster mitigation for estimating source region and energy of some geophysical events. We currently tried to construct a prefectural level dense infrasound sensor network in Kochi, Japan for testing such activities.

Another topic is for investigating the wind turbine noise in infrasound and low-frequency audible

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range. The infrasound sensor can be used with some biological information sensing devices that can easily in use outdoors. We investigated the correlation between the degrees of stress/relaxation at the both sites of experimental places with/without wind turbines for 29 subject persons for the experiment.

## 2. DENSE INFRASOUND SENSOR NETWORK FOR DISASTER MITIGTION

### 2.1 Silent Sound Generated by a 100 km Scale Loud Speaker on Ocean Surface

When the huge earthquake happens at the deep location in the crust of the Earth beneath the seabed, uplift or subsidence is occurred, then it makes also uplift or subsidence on ocean surface, triggering the tsunami. As the speed of tsunami wave is proportional to the square root of the ocean depth, it can became effectively slow when it reaches continental shelf to sea shore region and sea water coming afterward can catch up the former water then makes the wave amplitude higher and attack the sea coast as a severe disaster. At the same time, induced infrasound can propagate in the atmosphere to the sea coast with a speed of sound without any slowdown (Figure 1). Thus, if we can observe the variation of the infrasound signal at along the coast lines, some information of the tsunami source area might be obtained before the tsunami attacks. Since the region of uplift/subsidence is about 100 km scale for the huge scale tsunami, 1 wavelength of resonant infrasound should be about 200 km, namely 1 period of 600 s. The frequency of this infrasound is 1/600 Hz, about 1.6 mHz.

In order to detect the infrasound induced by the tsunami source area, we developed an infrasound sensor with SAYA Co. in 2015. The specification of the SAYA ADXII-INF01C sensor is as shown in Figure 1. Important thing is to measure 1 mHz order pressure change for tsunami infrasound, whereas if the cases of volcanic eruptions, for example, frequency range is about 2-order higher than that of tsunami because of the scale size of a volcanic crater. It is like an Earth scale pipe organ.

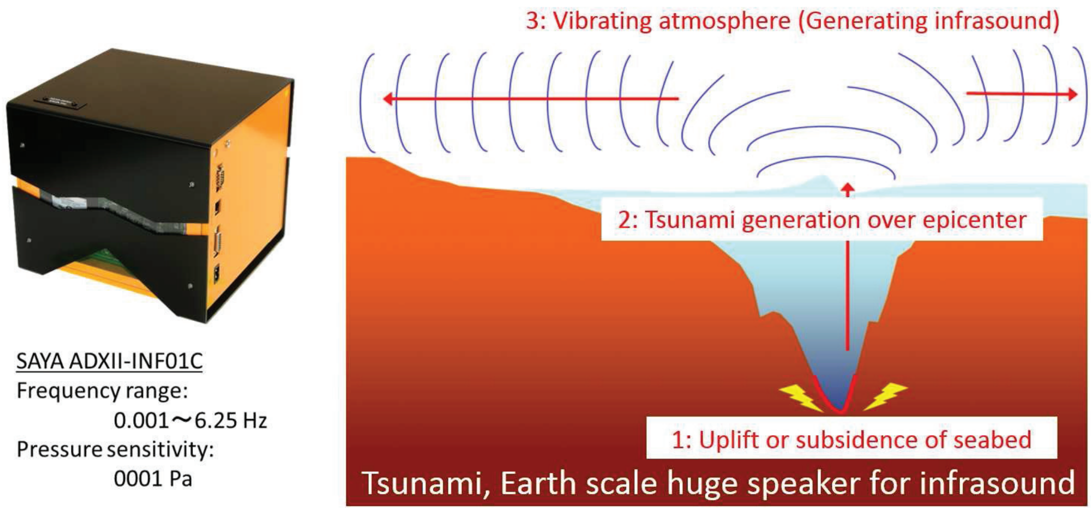


Figure 1 – Infrasound sensor and possible mechanism of infrasound generation by tsunami

### 2.2 Sensor Network Distribution in Japan

When we imagine the detection of the tsunami induced infrasound signal for disaster mitigation, dense sensor network should be constructed depends on the scale of corresponding geophysical events. As for the tsunami disaster mitigation we need to expand our infrasound sensors as in a scale of 25 km, therefore we designed 3-scale arrayed distribution for dense sensor network in our region. Here, we constructed 2 sets of 2 km scale arrays, some sets of 8 km scale ones, and 2 sets of 25 km scale ones.

Inside Kochi prefecture shown in an orange rectangle in Figure 2, we distributed 15 infrasound sensors in 2017. The sensor network was spread to the other area in Japan as is also shown in the figure (yellow filled circles). With combining multiple-site infrasound observations, it can be expected that an appropriate scale and shape of the tsunami uplift region will be able to be measured with using the remote infrasonic sounding. Currently we are trying to know the infrasound signal pattern to be measured at any of the expecting observatories in Japan area by using the precise seabed topographic map information with having the largest assumption of the Nankai Trough earthquake.

The sensor itself has a measurement function not only of the infrasound sensor with 5 Hz sampling but also of MEMS 3-axis accelerometer, thermometer, barometer, and GPS time, thus we call it a comprehensive infrasound sensor. The data handling by using a network rooter with a SIM card is applied for usual operation, which can be confirmed on web pages in quasi real time (3).

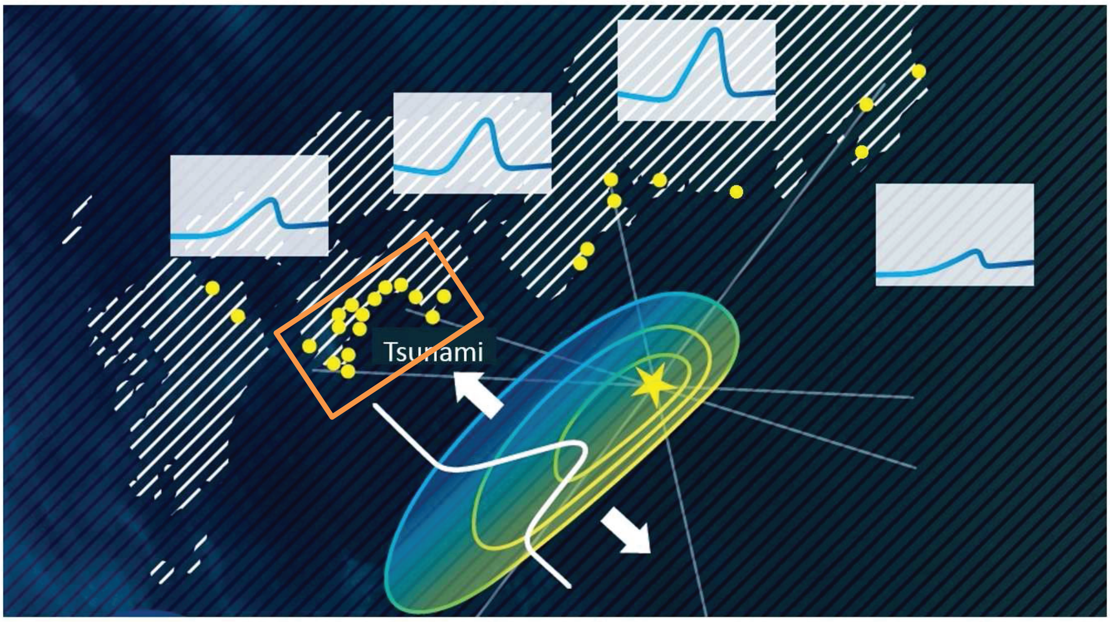


Figure 2 – Infrasound sensor network established in Japan as of May 2019

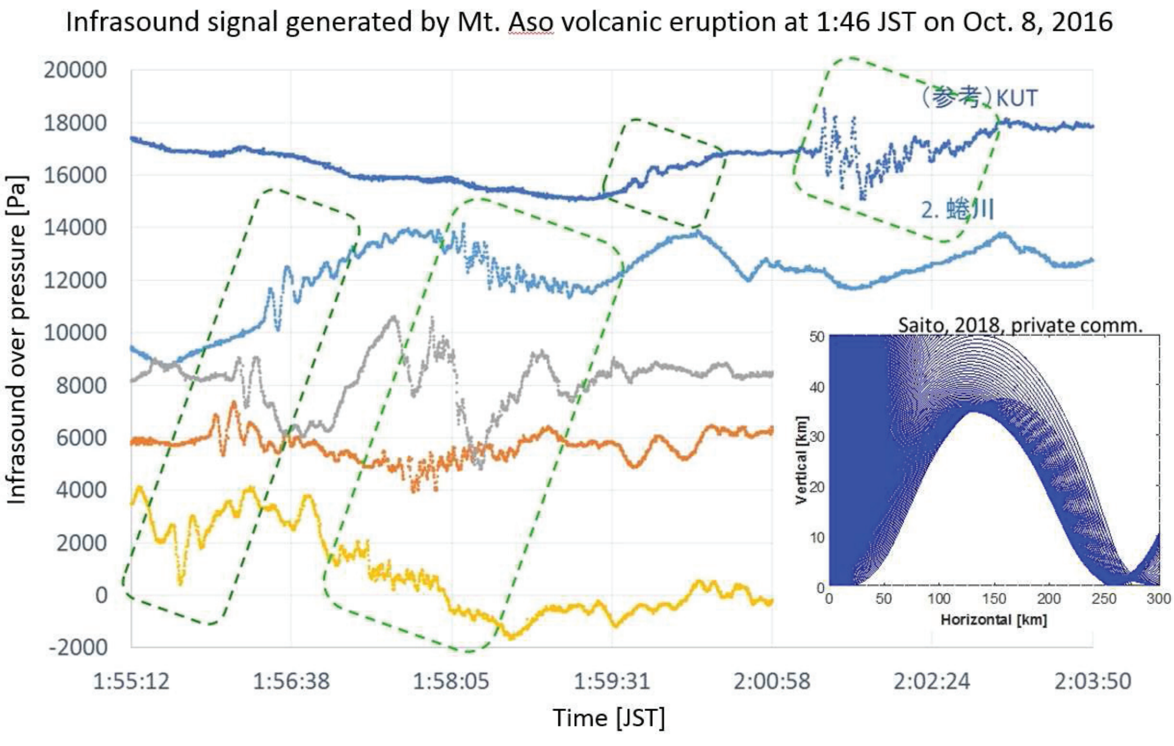


Figure 3 – Infrasound signal of Mt. Aso volcanic eruption by arrayed sensor network in Kochi

## 2.3 Infrasound sensing and simulation in upper atmosphere

In 2017, we developed a small microphone type infrasound sensor SAYA INF03 in order to try to measure the infrasound aboard a large balloon of ESA BEXUS-24 launched from ESRANGE, Sweden and successfully measured low-frequency audible sound and infrasound up to 11 km. Then, the infrasound microphone type infrasound sensor was extended to the rocket-borne type and successfully launched on May 4, 2019 to the thermosphere at about 113 km by using the first venture company sounding rocket (Interstellar Technologies, Momo3) reached to the space (above 100 km) in Japan. The infrasound sensor detected fluctuated sound pressure change induced by fireworks that were exploded at about 100 m from the ground prior to the rocket launch.

As for the sound propagation in the Earth's atmosphere, it has been investigated since the space era from 1950's. Currently, we have already studied on atmospheric parameter profiles in basics and some atmospheric model can also be used for scientific researches. However, if we try to investigate the precise propagation process of the sound/infrasound in the middle and upper atmosphere. It is clearly affected by the vertical profile of the local wind velocity and direction as well as atmospheric temperature.

We investigated some of the dataset of infrasound signal observed at Kochi area during 2016-2018, with searching any volcanic eruption signals detected on the multiple-site infrasound records. Moreover, we have developed a sound propagation model in 3D space with using some available model atmosphere with changing local wind profiles. The comparison between the simulated infrasound propagation and the real observation datasets provides us some fruitful information in sound propagation mechanism in rafefied upper atmosphere.

Grid search algorithm was also applied to the volcanic eruption datasets previously observed in Kyushu Island by using 3 infrasound sensors, and successfully found the location of Mt. Sakurajima with the developed algorithm (4).

### 2.4 The other application of infrasound sensing

As for the other application of the infrasound sensing, we recently tried to obtain environmental information about the infrasound generated at the wind power plant and propagated in the atmosphere in the vicinity of the wind turbines. The wind turbine is known as one of the existing artificial sound/infrasound source, however, due to the limitation of available infrasound sensors, the information about the wind turbine infrasound is limited. In the previous studies, even in the situation of lower amplitude of the low-frequency sound range rather than the ISO sensitivity curve of the human audible sound, some reports described possible effect of the low-frequency sound or infrasound on the human health, nevertheless the sound cannot be listened to.

We developed a recorder system with using an electroencephalography (EEG) sensor for brain waves as well as the pulse wave sensor (PWS). Since the both of EEG and PWS are low-cost and portable sensors, we can use the recorder system with the both sensors outdoor, thus we can conduct biological information sensing at the appropriate places with/without wind turbines (5). The result is rather variated than that we expected before and we have to summarize it with having medium values for 29 subjects, however, the slight tendency of the infrasound influence was found although it might be still argued.

## 3. CONCLUSIONS

In this paper we introduced the recent research activities with infrasound sensing in Kochi University of Technology. We developed some types of infrasound sensors with SAYA Co. since 2015 and distributed 30 comprehensive infrasound sensors of ADXII-INF01C, etc. with making arrayed sensor network in 2 km, 8 km, and 25 km scale in Kochi in 2017. Many geophysical events as volcanic eruptions, thunder storms, typhoon passages, meteorites, etc. have been recorded in multiple-site arrayed observation and successful analyses of source direction/position finding by using grid search algorithm as well as comparison to 3D simulation of infrasound propagation in middle and upper atmosphere.

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