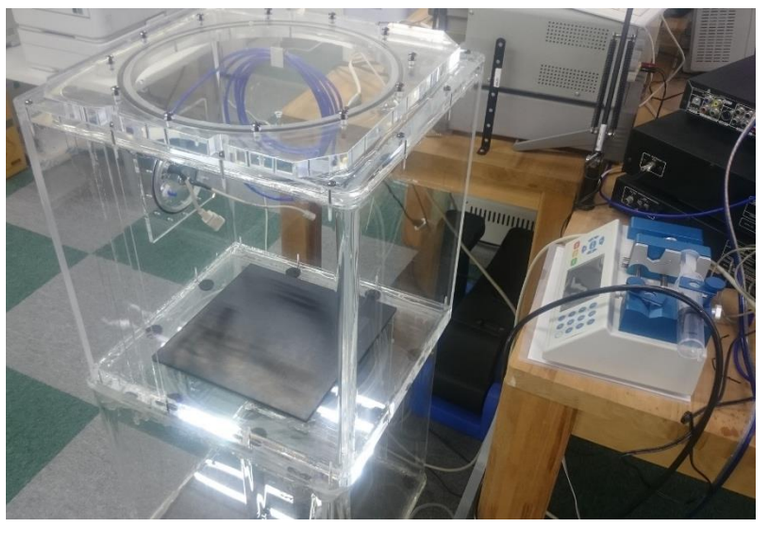
World Bosai Forum 2019, Sendai
Nov. 10, 2019

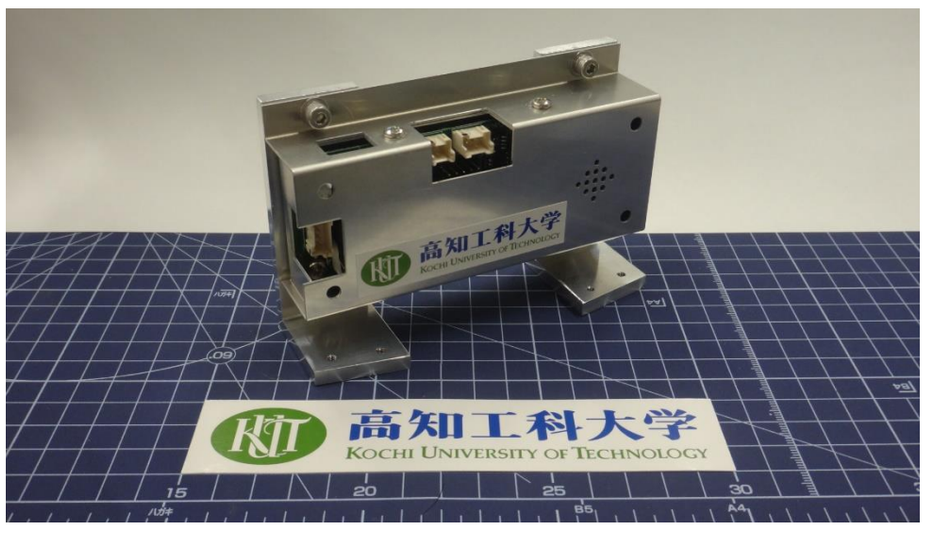
MP1-02

Proposition of a New Ground-based Observation Network of Infrasound for Tsunami Disaster Mitigation

Masa-yuki YAMAMOTO

Kochi University of Technology, JAPAN





Infrasound: long-distant propagating waves

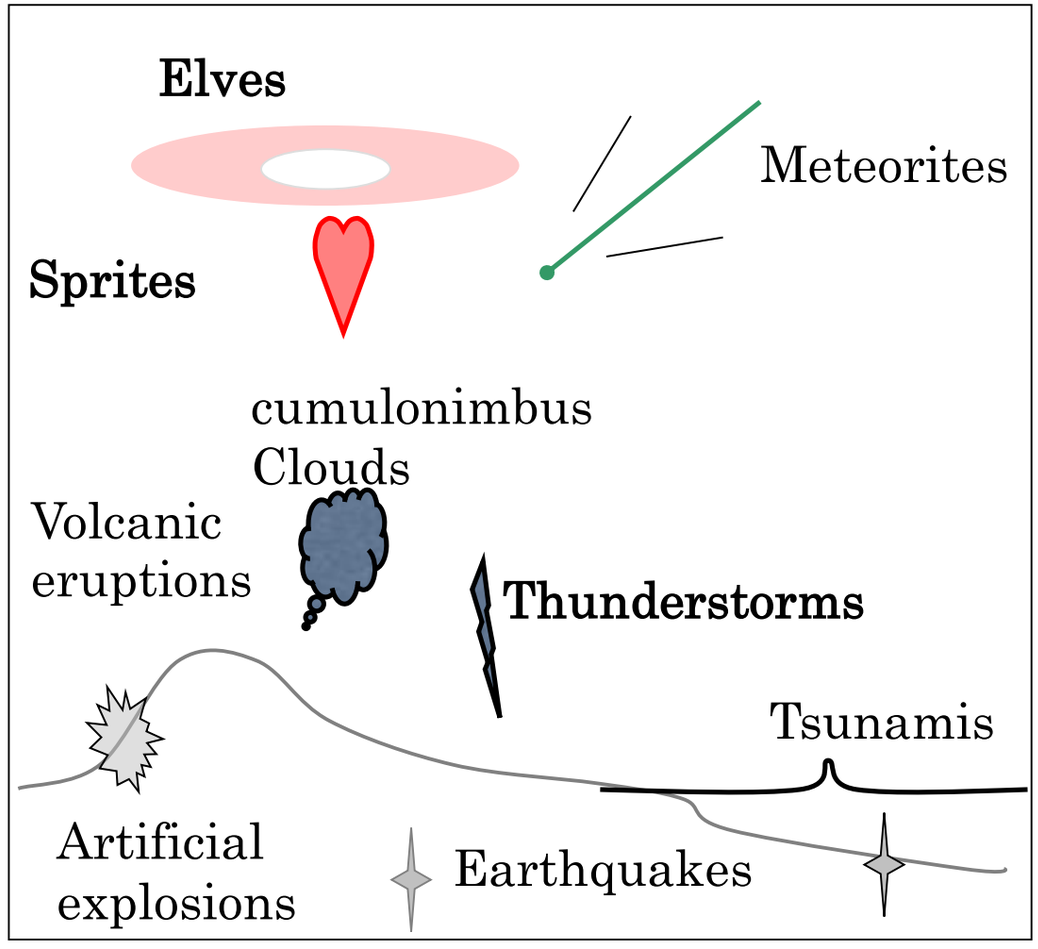
AGW | Sound

- frequency

1. Thunderstorms
2. TLEs (sprites, elves,..)
3. Meteorite falls, artificial reentries
4. Volcanic eruptions
5. Artificial explosions
6. Coupling process from seismic/oceanic waves
7. Earthquakes, Tsunamis

Lower cutoff:

$$f = \frac{1}{2\pi}\frac{\gamma g}{2c}$$



Targets of infrasound observation network

- 25 km scale sensor array distribution in each prefecture

- Obtaining information for Tsunami disaster mitigation
- Remote sensing for local geophysical events

- Thunderstorm
- Heavy rainy band
- Typhoon/Front passage

-> Weather forecast (Alert)

- Volcanic eruptions
- Tsunami, Earthquake
- Meteoroids, Re-entry

-> Disaster Mitigation (Alert)

-> Geophysics, Astrophysics, Aerospace Engineering,

- Microbaroms (oceanic)
- Artificial sources
- Wind Turbine Noise

-> Environmental study, Effect on Human health

Great East Japan Earthquake and Tsunami on March 11, 2011

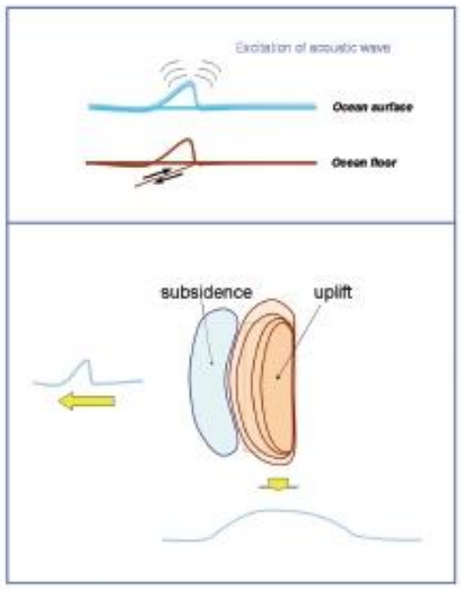
CNN (NHK)

JS – P7

Infrasound signals excited by up
during the tsunami gene

Nobuo ARAI (arai@jwa.or.jp), Takahiko M
(Japan W

*Acknowledgement : We are grateful to Dr. Yuichi
Univ. Tokyo) and Mr. Takuma OI (Toho Mercanti*



Observed i
verification re
earthquake o

Long period a
ocean surfac
at I30JP, I44

-The on-set ti
distance betw
measured cel
have travelle

-The shape o
source estima
along the faul
fault length.
the signals at
relation betwe

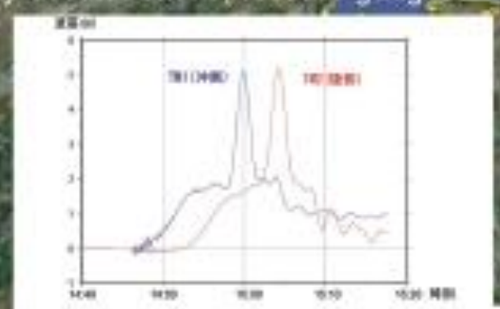
- The shape
observed by
source regior
at I45RU was
during tsunar

-The maximum amplitude of all observed acoustic waves were al
uplift or subsidence of the sea surface (P) can be approximately
surface, c is sound velocity near the sea surface and w is the cor
amplitude at the source region can be roughly calculated as $20P$
tsunami wave height at ocean bottom pressure-gauges in the ts
vertical deformation estimated by the inversion based on seismic
comparable to the theoretical estimate.

When Tsunami early warning are provided to the public, the po
only the hypocenter location and the magnitude and not the infor
source region, therefore, tsunami warnings may not have enough
if an infrasound observation network was deployed along the coa
through the network would improve the tsunami warning informat

Sea level changes observed by ocean bottom pressure-gauges

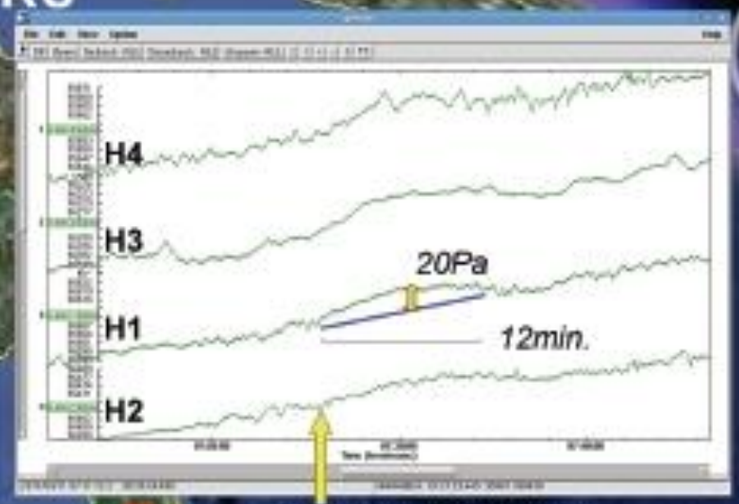
Location of the ocean bottom pressure-gages



At around 14:46:45T, the ground motion of the earthq. (Mw8.0) reaches the pressure-gauge and at TM1(ocean-side), the sea level is gradually rising from that point. The sea level rose 2m, and after 11 minutes, the level went drastically up to 3m, which makes 5m of elevation in total at TM2: located 30km toward the land, a same elevation of sea level was recorded with 4minutes delay from TM1.

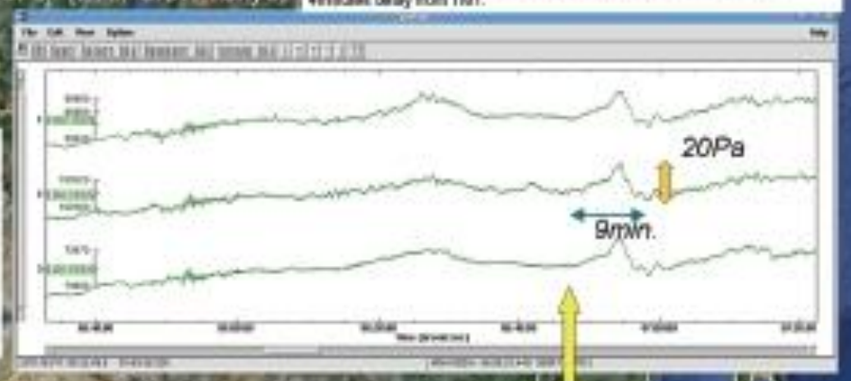
After Shinohara et al. (ERI, Univ. Tokyo)

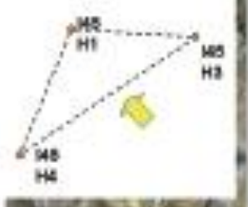
I44RU

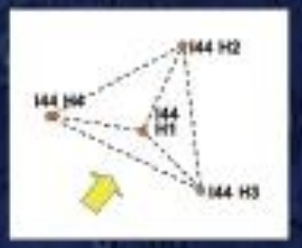


OT of the event + 1hr40min.

I45RU





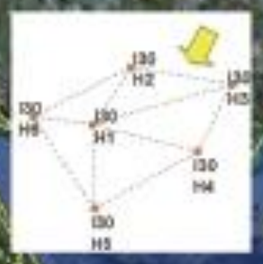


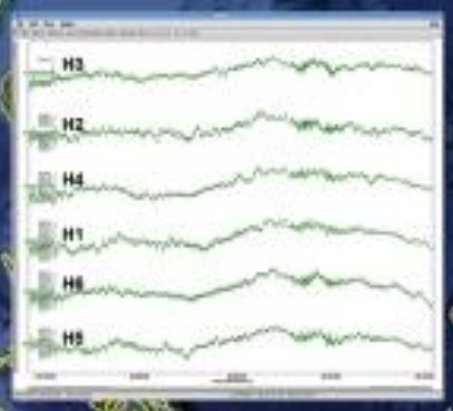
1860km=1hr40min.
(Wave velocity is about 300m/sec)

OT of the event + 1hr

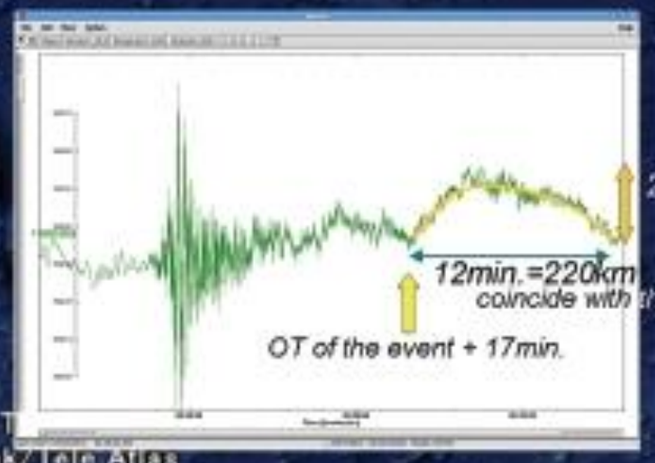
1000km=60min.
(If the velocity is about 300m/sec)

300km=17min.
(If the velocity is about 300m/sec)





I30JP



43° 50'29.64" N 143° 17'02.58" E 標高 511 m

高度 5621.7

Arai et al., 2011

Expectation of an alert system for Tsunami disaster

- Infrasound waves can reach to the land stations earlier than the real Tsunami waves.
- It can be applied not only for the Tsunami alert system but also for any other geophysical event monitor.

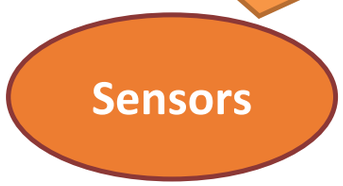
SAYA ADXII-INF01C

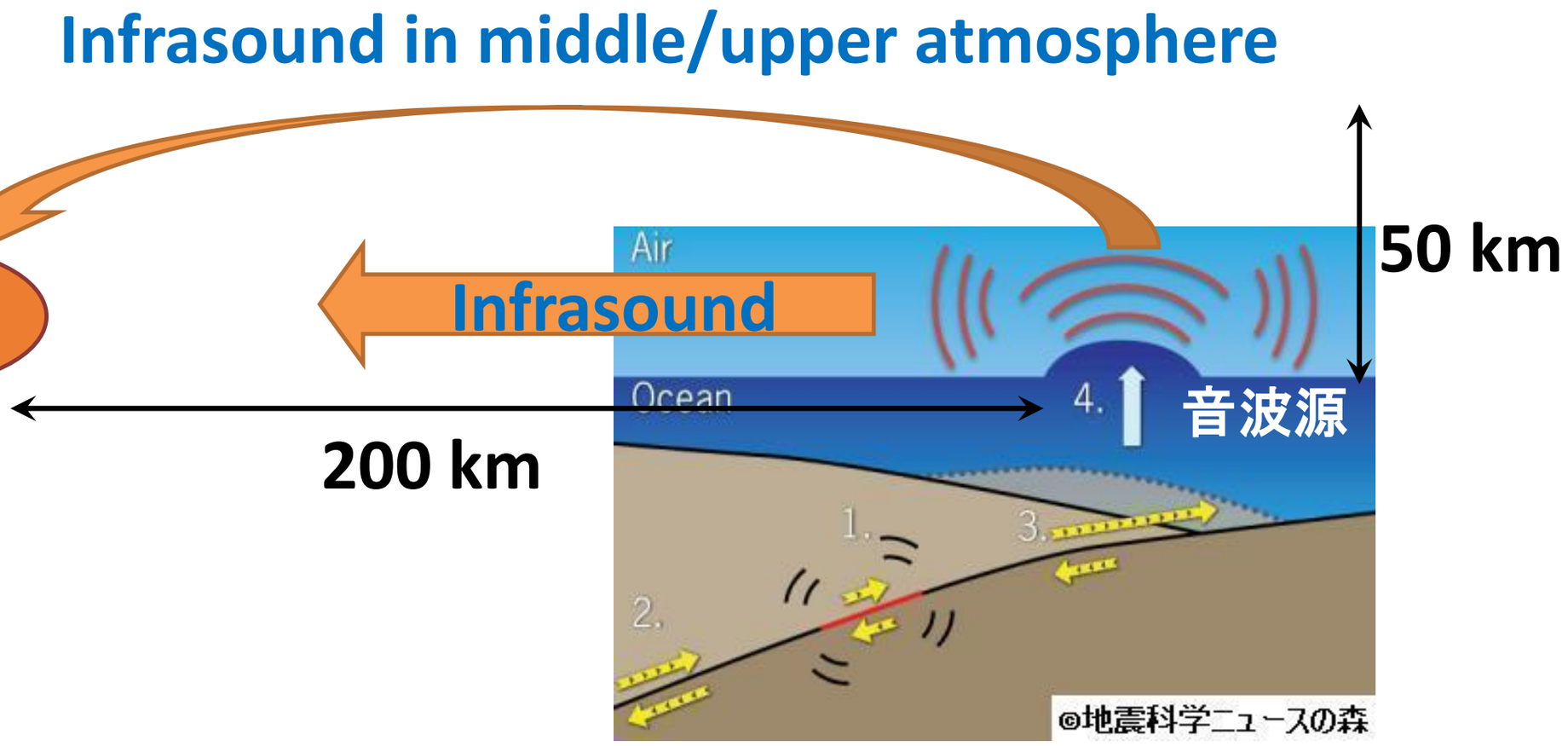
Frequency range:

0.001～6.25 Hz

Pressure sensitivity:

0001 Pa





Infrasonic waves vibrate ionosphere

Tsugawa et al., 2011

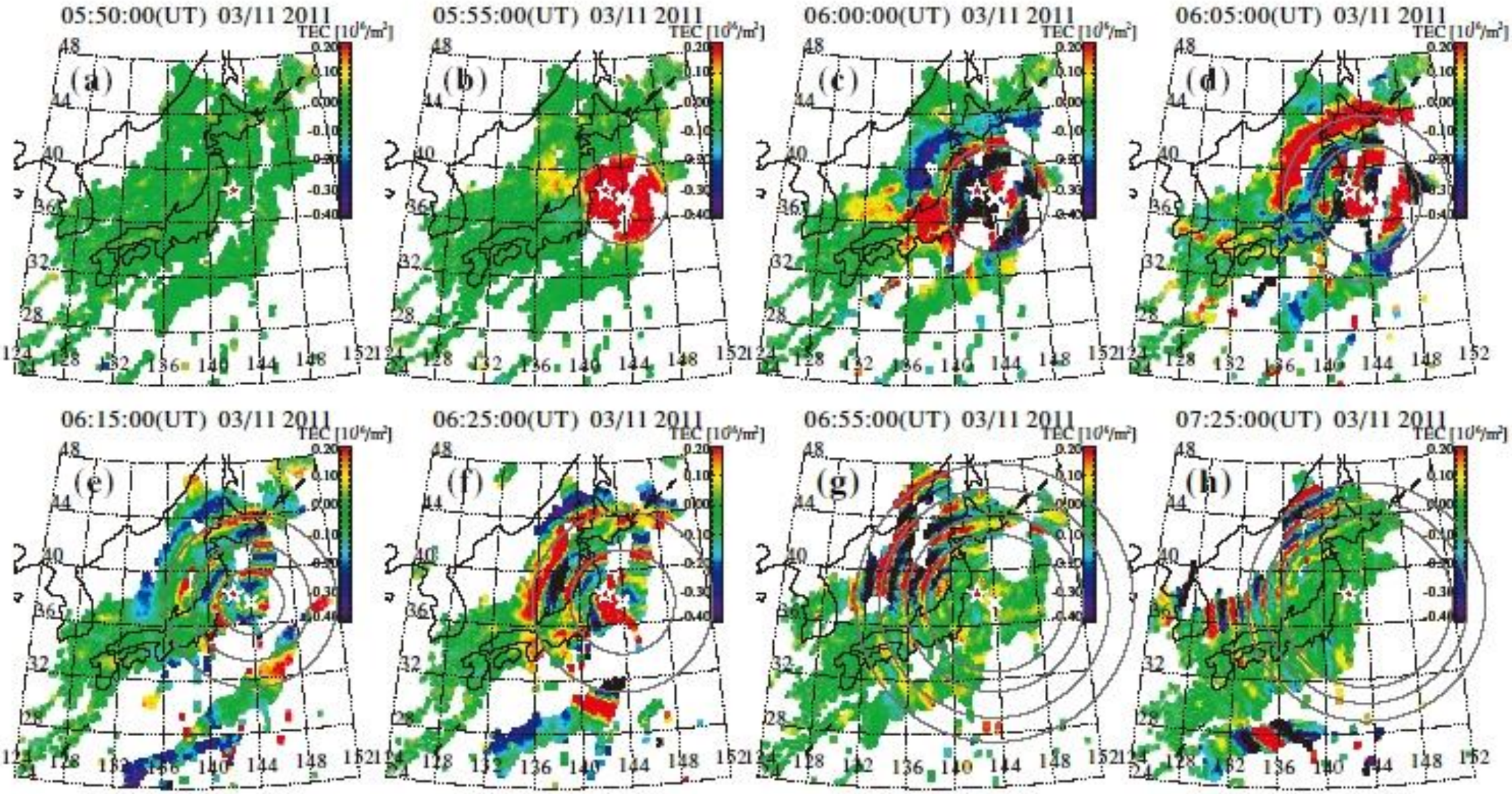
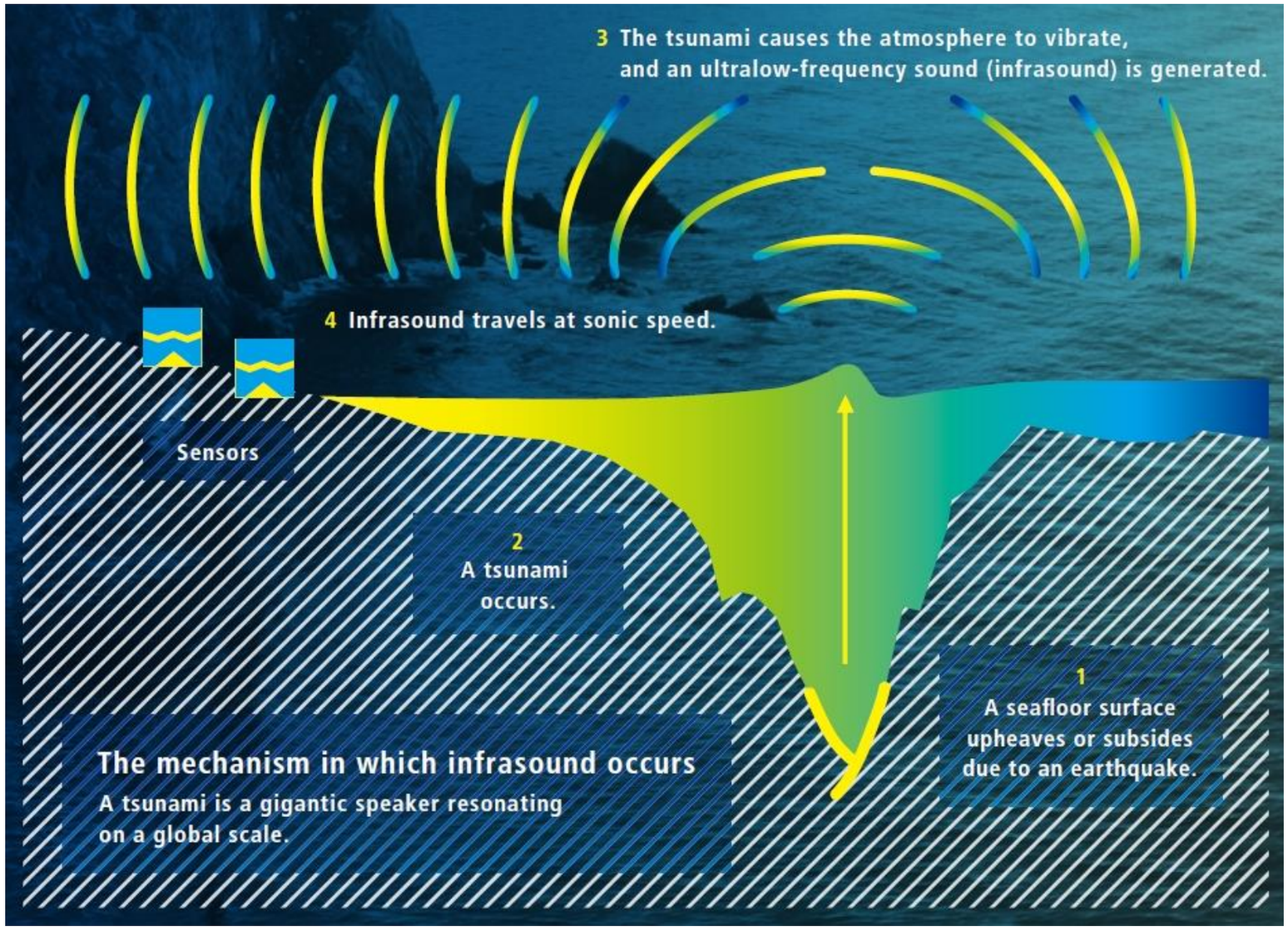


Fig. 2. Two-dimensional maps of the detrended TEC from 05:50 UT to 07:25 UT on March 11, 2011. The interval of figures (a–d), (d–f), and (f–h) is 5, 10, 30 minutes, respectively. The star and cross marks represent the epicenter and the ionospheric epicenter, respectively. Gray circles represent concentric circles with the ionospheric epicenter. A movie of the detrended TEC maps with 30-second resolution is available at the NICT website (http://www.seg.nict.go.jp/2011TohokuEarthquake/).

For an application for disaster prevention/mitigation

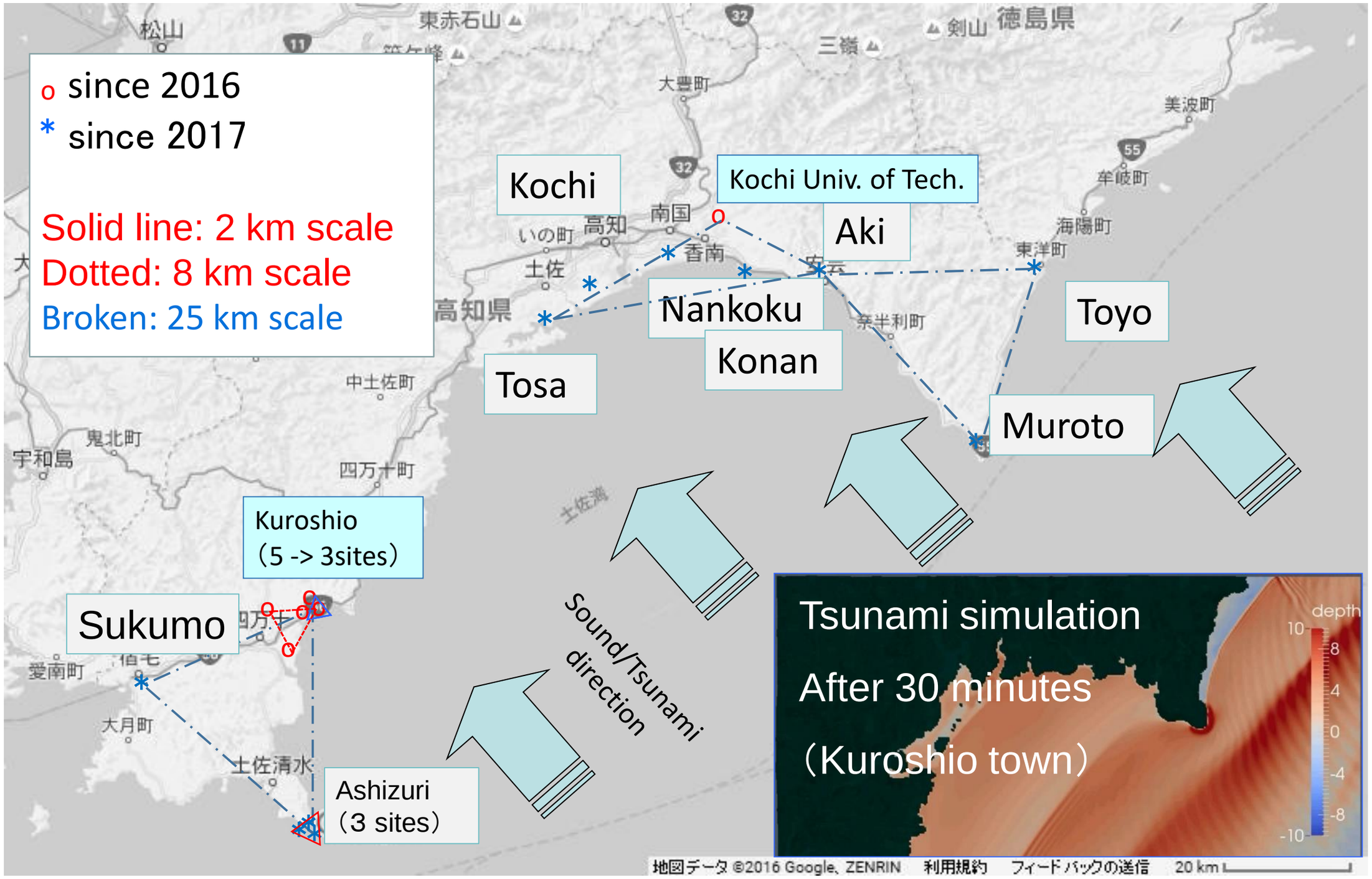
- Infrasound observation is one of the useful remote-sensing methods in the atmosphere.
- In particular, for the Tsunami disaster, it can propagate source region information by sound speed faster than the real sea waves, thus an advantage in early warning system can be expected.

SAYA ADXII-INF01C
Frequency range:
0.001～6.25 Hz
Pressure sensitivity:
0001 Pa



Prefecture level dense infrasound observation network in Kochi

15 sites in operation mainly for Tsunami disaster mitigation

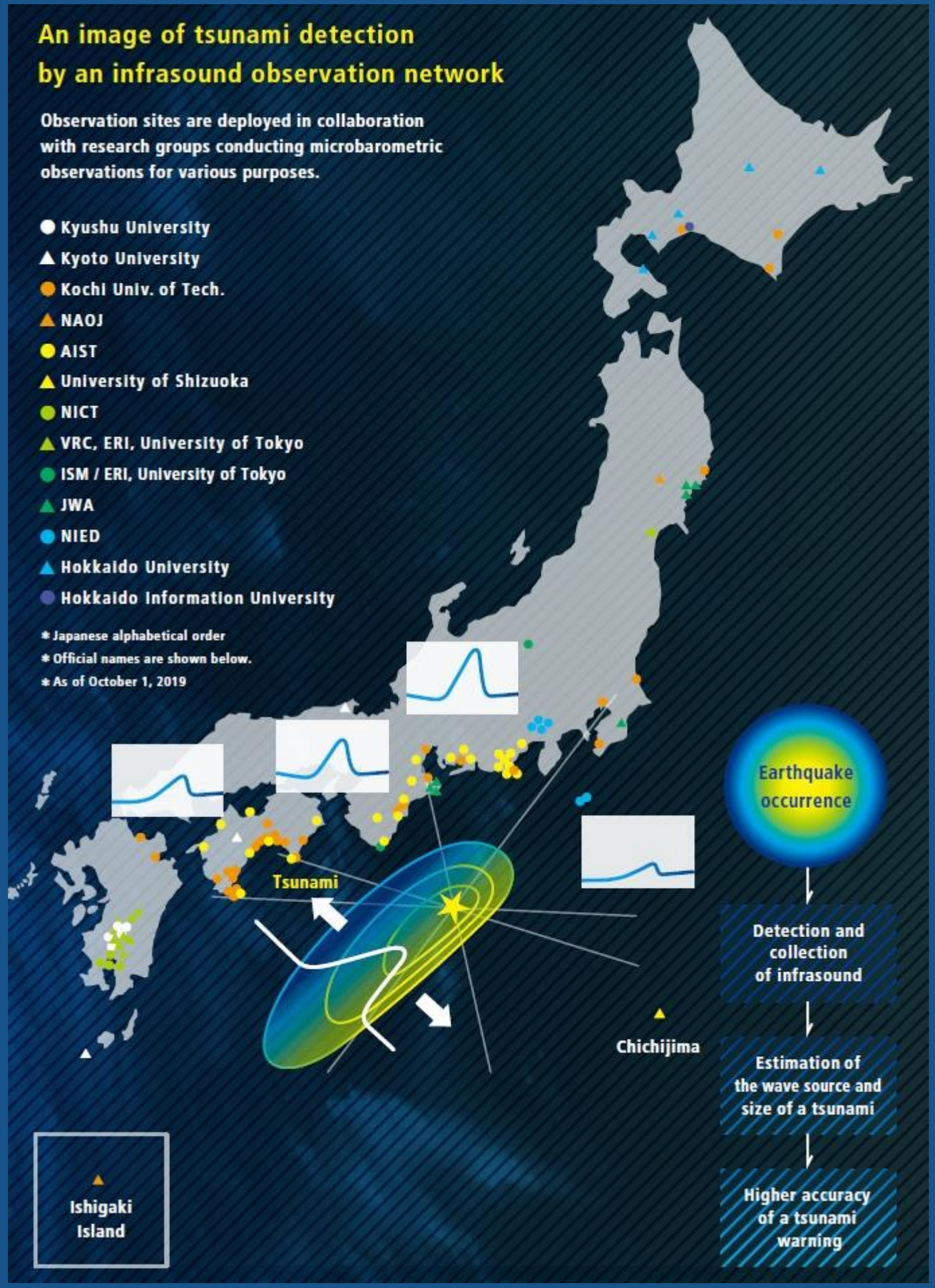


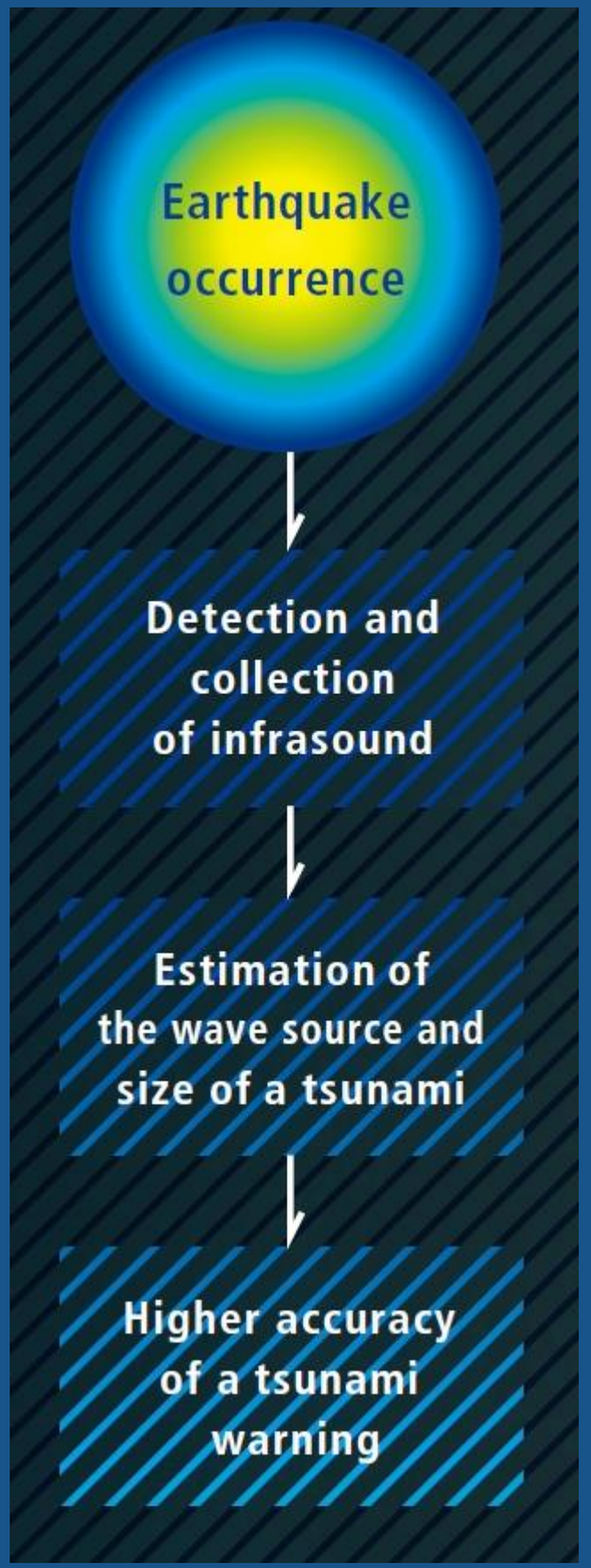
An image of tsunami detection by an infrasound observation network

Observation sites are deployed in collaboration with research groups conducting microbarometric observations for various purposes.

- Kyushu University
- Kyoto University
- Kochi Univ. of Tech.
- NAOJ
- AIST
- University of Shizuoka
- NICT
- VRC, ERI, University of Tokyo
- ISM / ERI, University of Tokyo
- JWA
- NIED
- Hokkaido University
- Hokkaido Information University

* Japanese alphabetical order
* Official names are shown below.
* As of October 1, 2019





Quick Look web page for infrasonic observation is on web.

高知工科大学インフラサウンド観測ネットワークシステム

Kochi university of technology InfraSound Observation Network System.

高知県黒潮町入野海岸

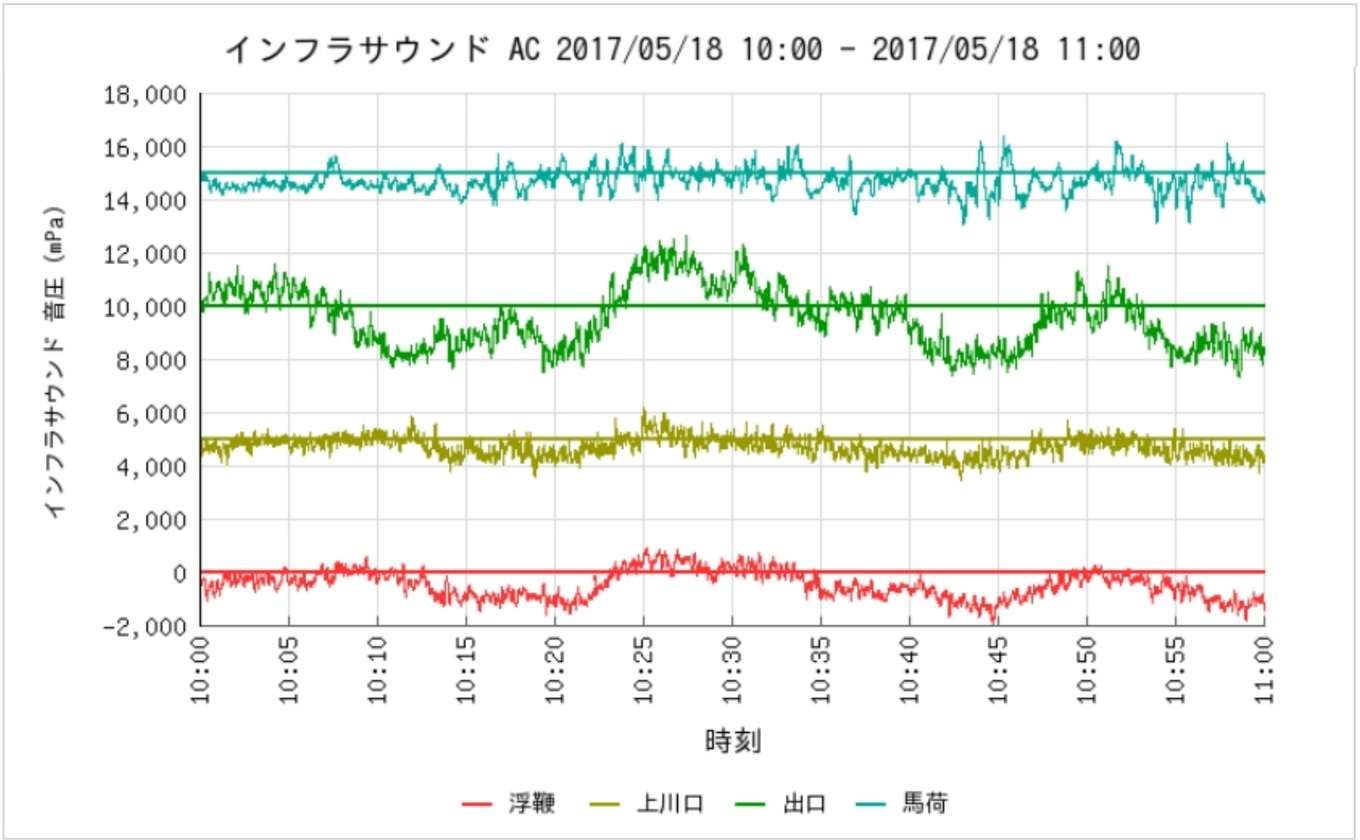
KISONSについて　準リアルタイムグラフ　インフラサウンド観測事例　著作権について　お問い合わせ

インフラサウンド 準リアルタイムグラフ

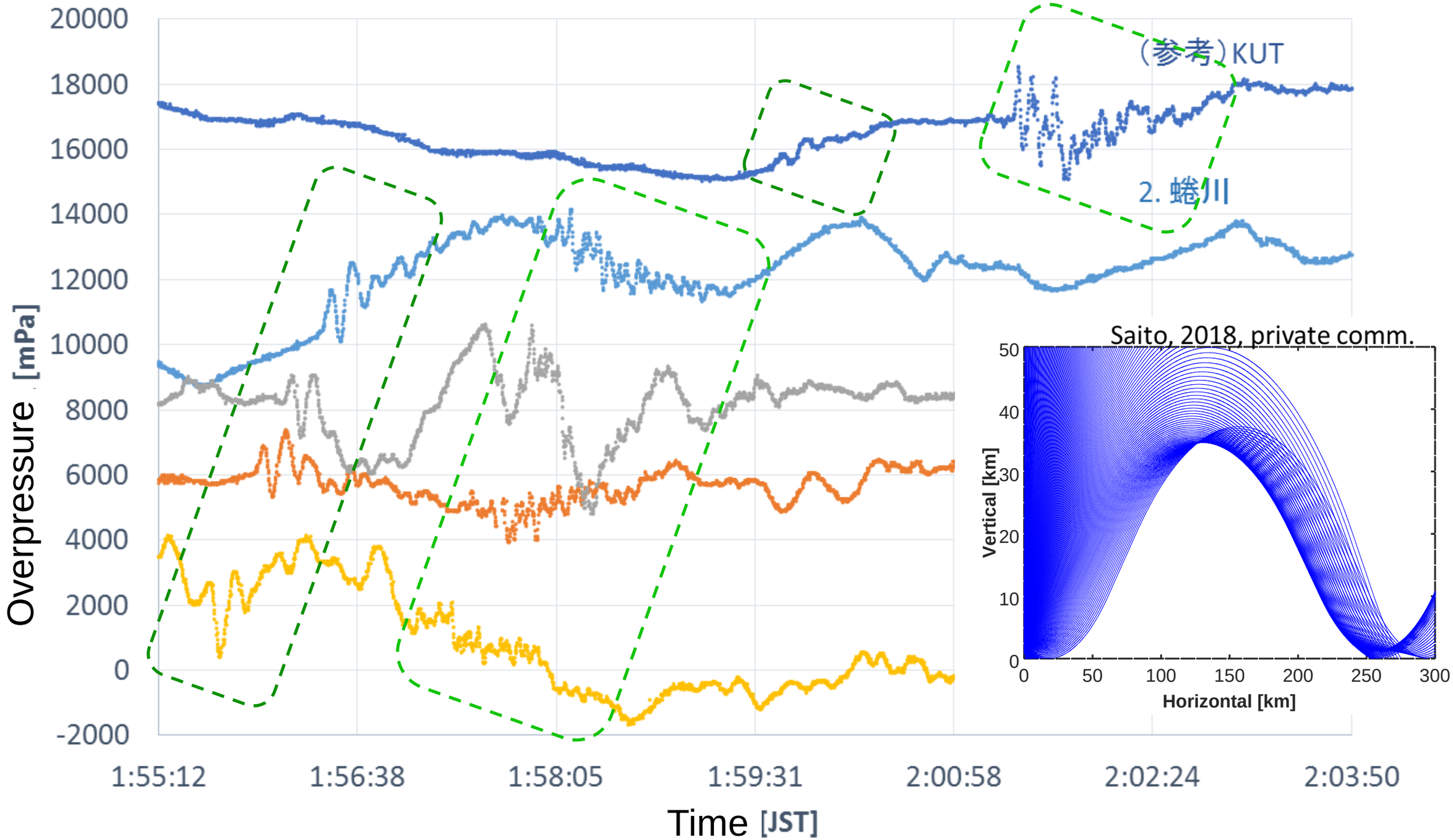
作図設定

作図期間	2017/05/18 10 時 0 分(JST)から 1時間 作図期間を長くすると表示されるまでに時間がかかります。(1週間で約15分)
作図項目	インフラサウンドAC
作図順序	浮鞭 / 蜷川 / 上川口 / 出口 / 馬荷 / なし
レイアウト	○シフト表示なし ◉シフト表示あり　シフト量: 5,000 mPa
観測地点	◉浮鞭 ○蜷川 ○上川口 ○出口 ○馬荷 ○船橋(千葉県)
グラフの幅	◉600ピクセル ○800ピクセル ○1200ピクセル ○1600ピクセル
グラフの高さ	◉300ピクセル ○400ピクセル ○600ピクセル ○800ピクセル
ページ更新	□このグラフを定期的にに更新する　更新間隔: 5分毎

グラフ作成



Infrasound coming from Mt. Aso　2016/10/08 01:46 JST

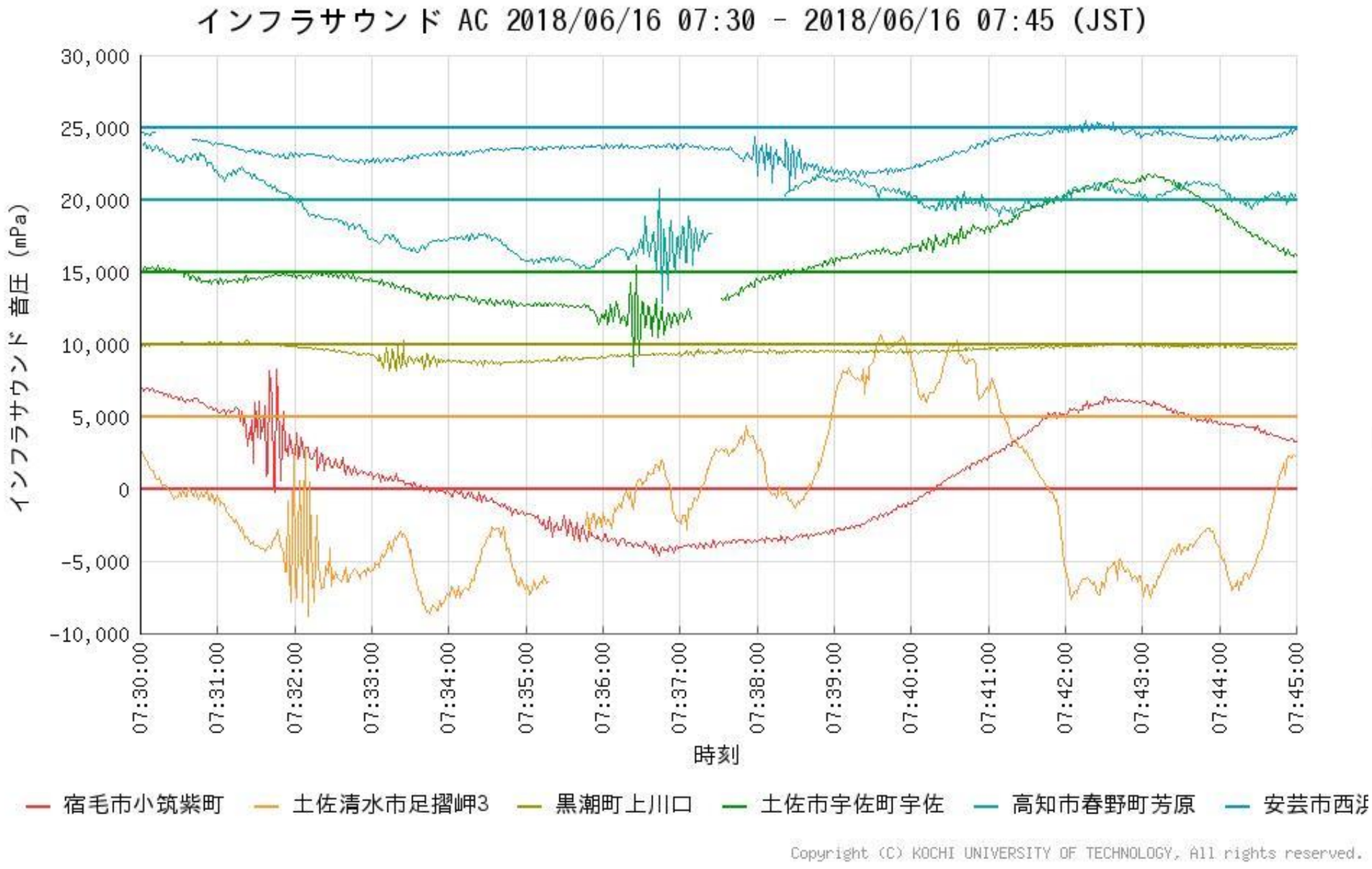


Infrasound signal coming from a volcanic eruption of Mt. Aso (Oct. 8, 2016)

Overpressure of 189 Pa was observed at 1:46:41 at 1.2 km from the chamber. (JMA)

Mt. Aso -> Kuroshio town：180 km, Surface path @340 m/s（15℃）1:55:26
Mt. Aso -> KUT campus：257 km, Stratospheric path @317 m/s（-24℃）2:01:23

Volcanic eruption of Mt. Sakurajima



Ash top: 4700 m
© Kyodo Press

Infrasound:
24 Pa at JMA Yokoyama site

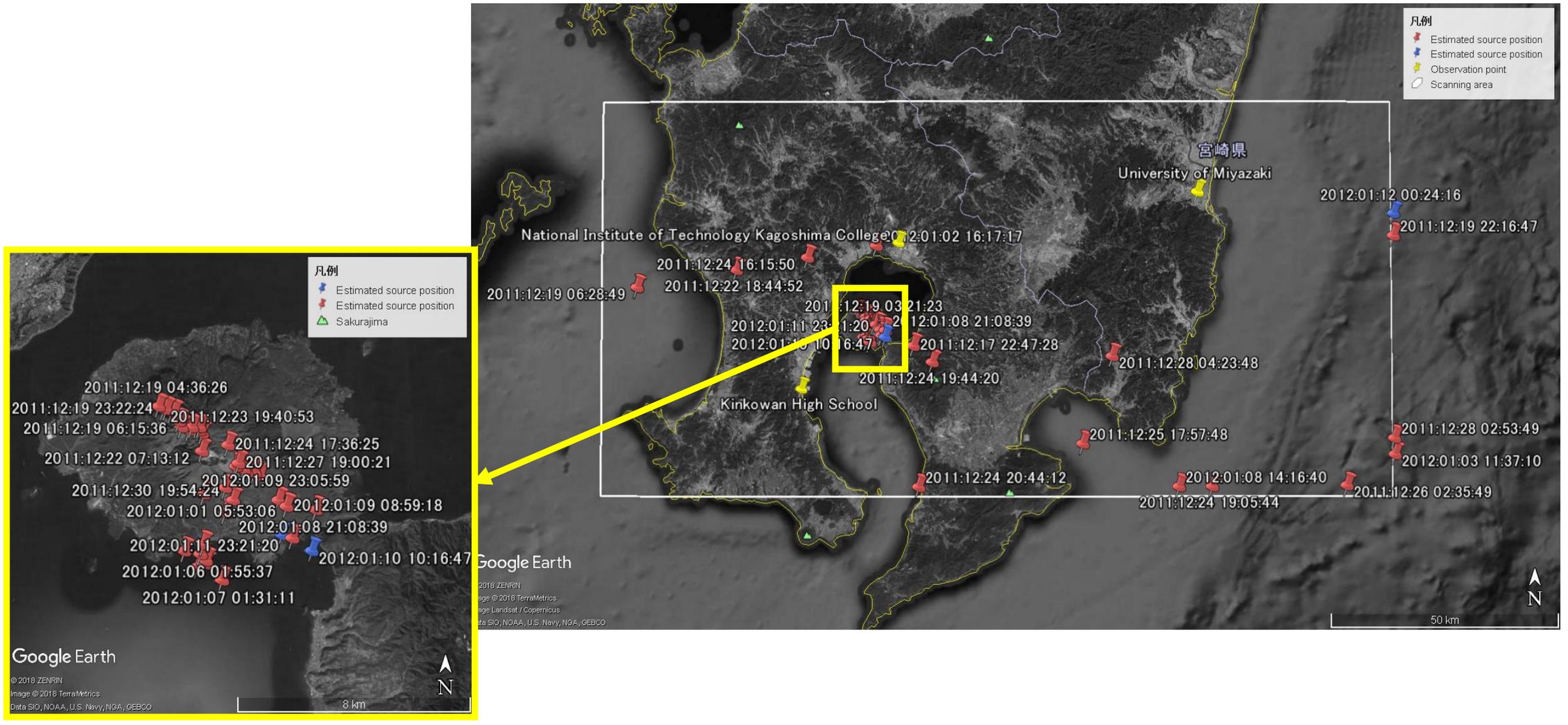
<u>Distance from Sakurajima</u>

243 km	Sukumo
255 km	Tosashimizu 3
275 km	Kuroshio 3
332 km	Tosa
341 km	Kochi
372 km	Aki

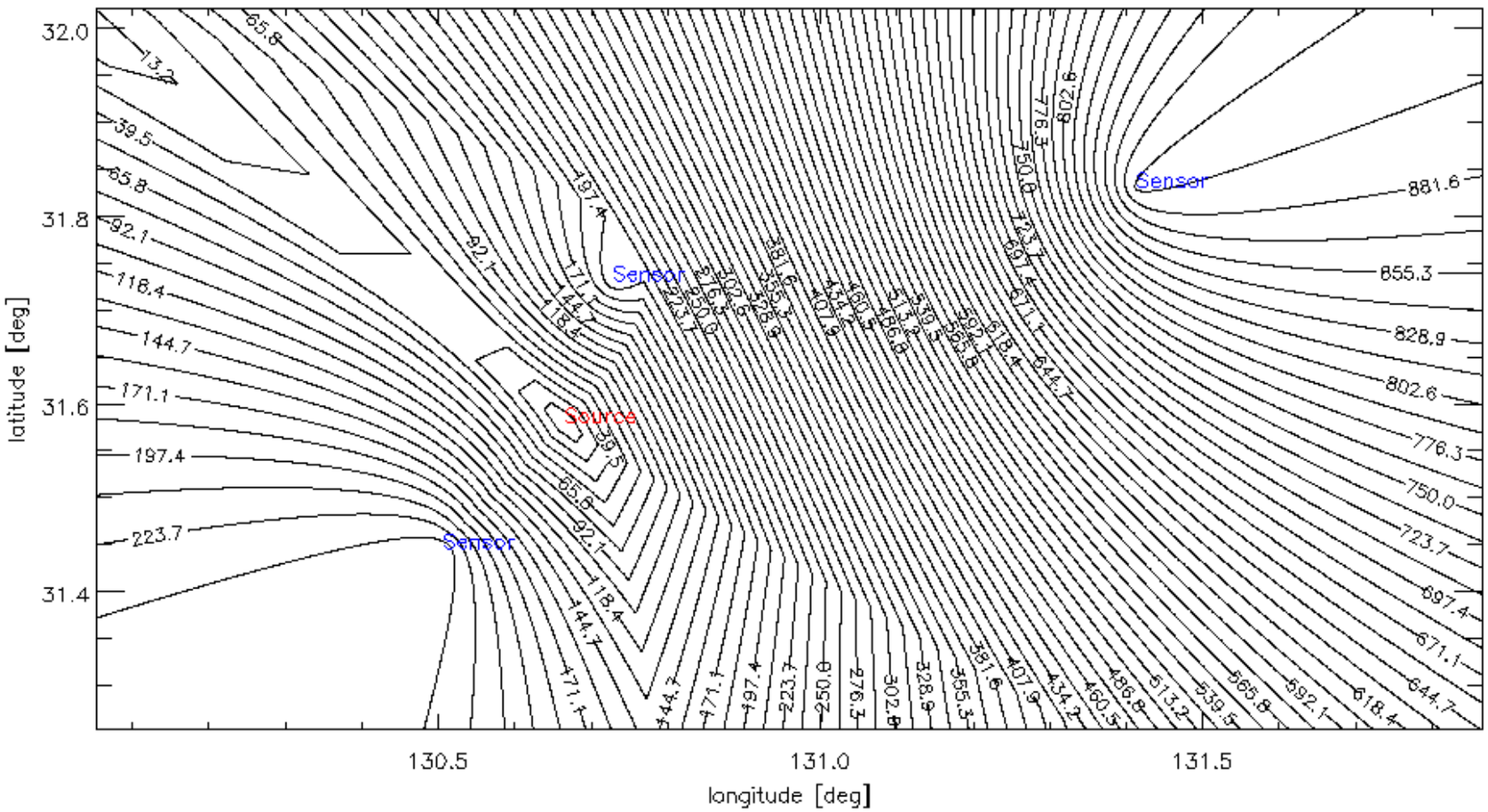
Examples of estimating Sakurajima volcanic eruption sound source

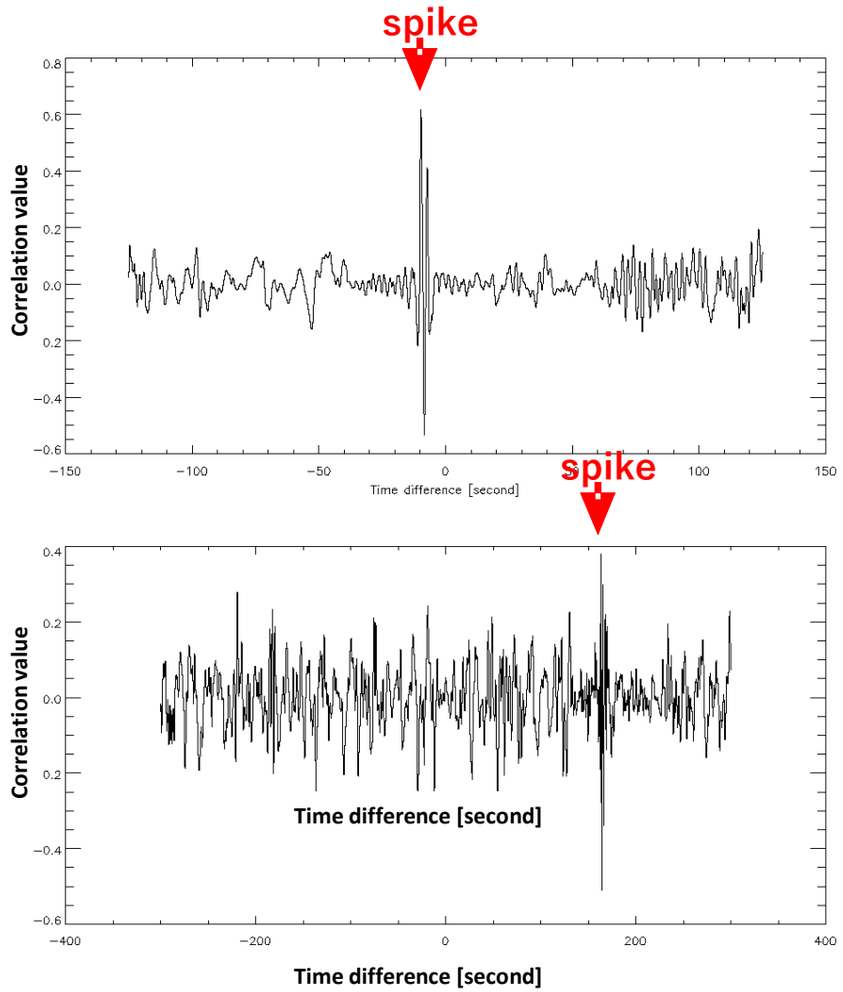
Assuming sound velocity of 336.2 m/s　(by using our previous dataset in 2012)

- 55 events are found by N-type signal detection software.
- 38 cases are found near the volcanic center within a few km by using the Grid search method.



An example of Grid search for volcanic infrasound



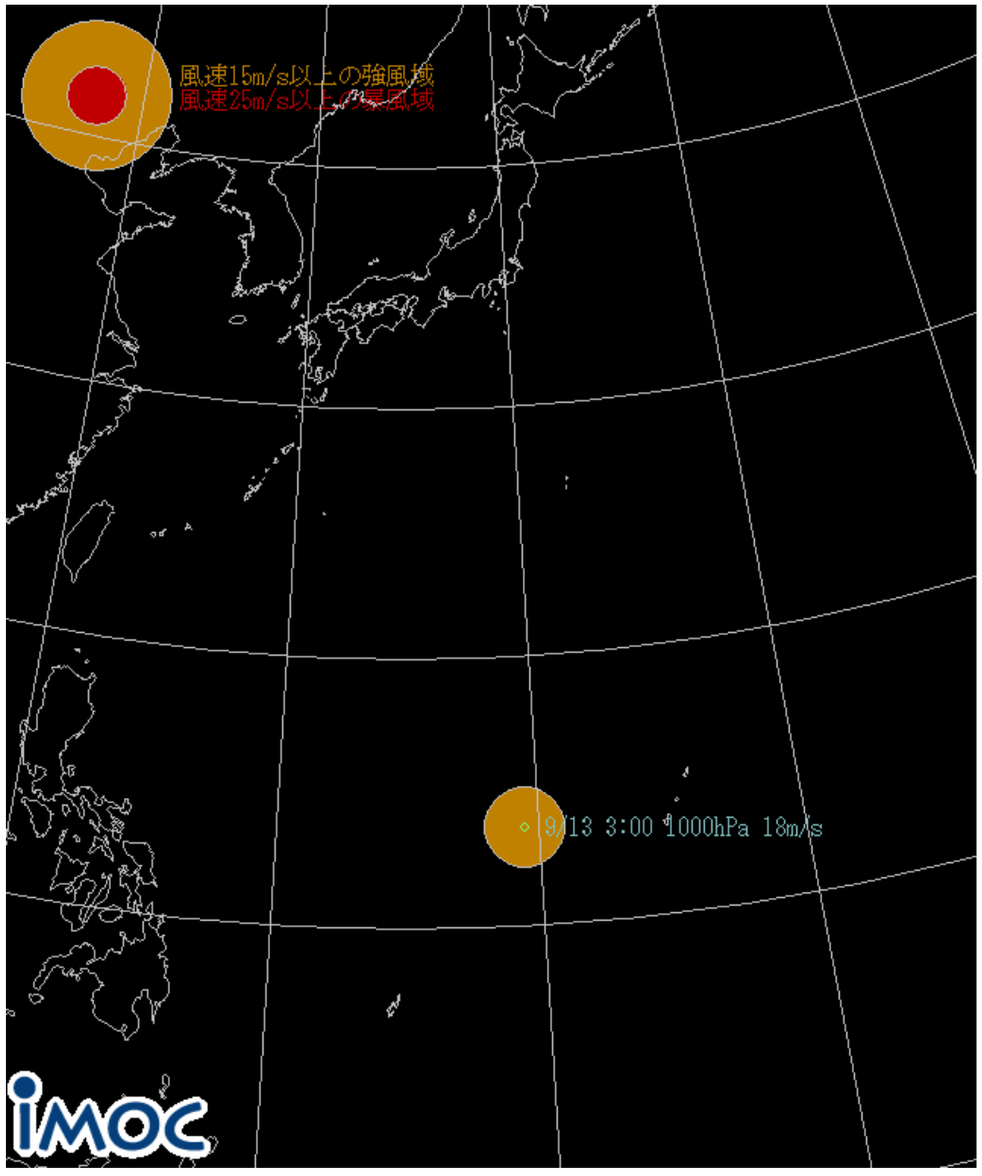


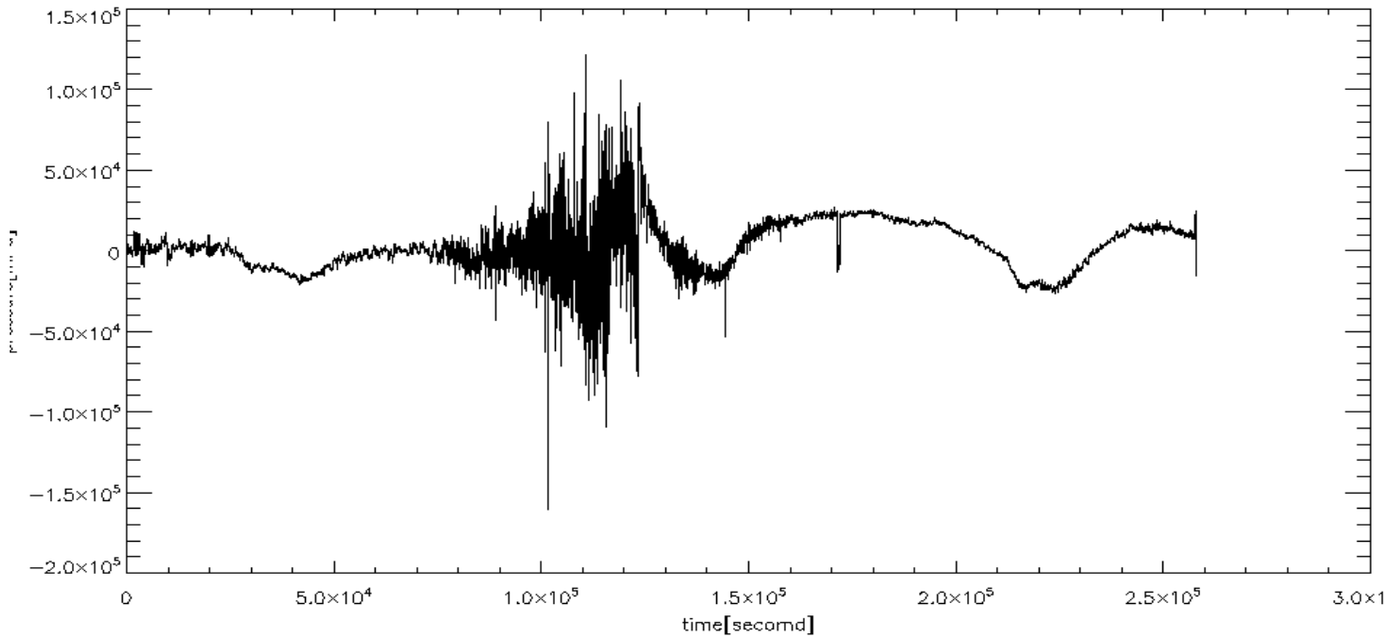
T_a: Arrival time of sound waves from any points to the sensors
T_r: Sonic wave detection time
N: Number of sensors

$$error = \sum_{i=0}^{N-1}\left[\sum_{j=0}^{N-1} abs\{((T_r(i) - T_a(i)) - (T_r(j) - T_a(j))\}\right]$$

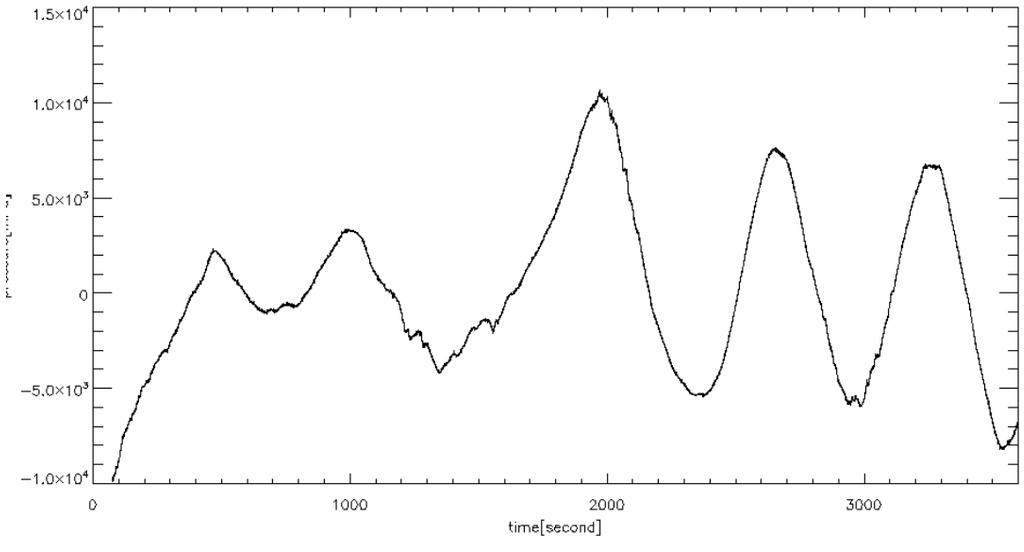
- The method is usually used in seismology.
- Grid search is a method of dividing a region into multiple grids (here, 749 × 1766 grids) and searching for a grid with the smallest error

Infrasound data before and during a Typhoon passage in 2016

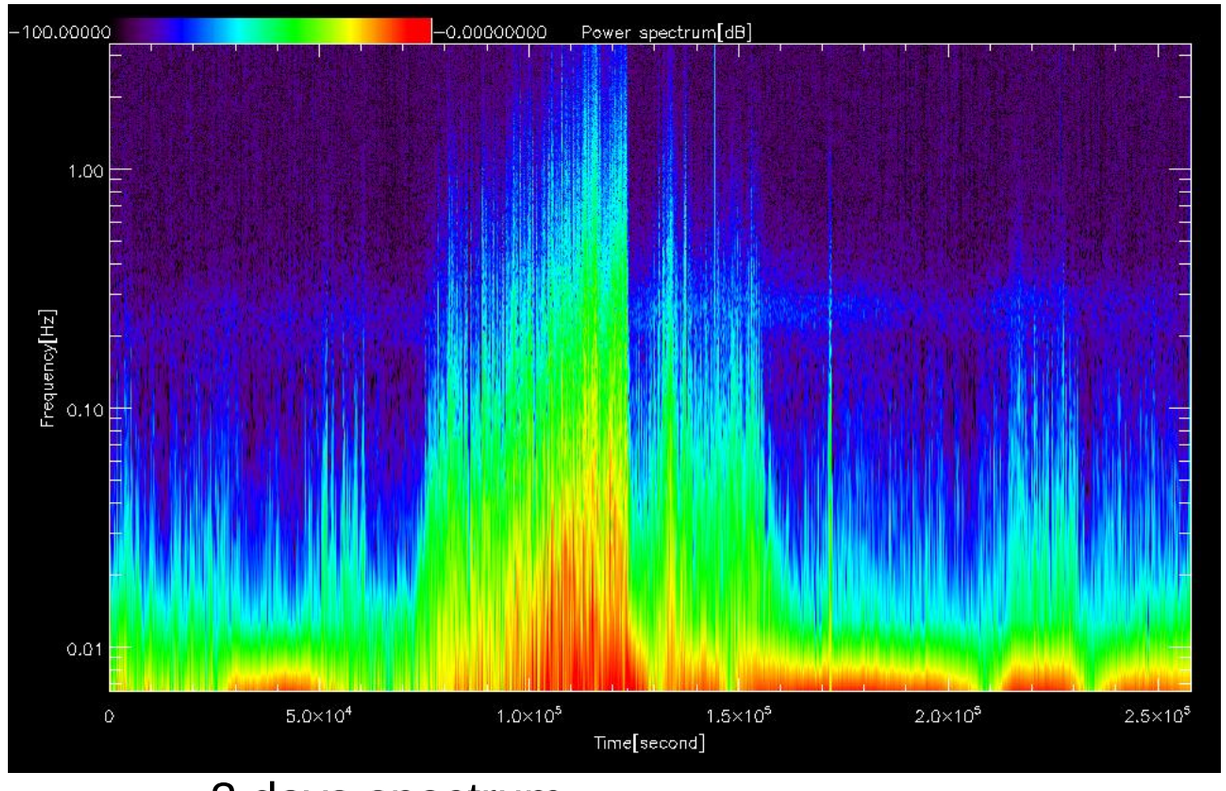




3 days trend

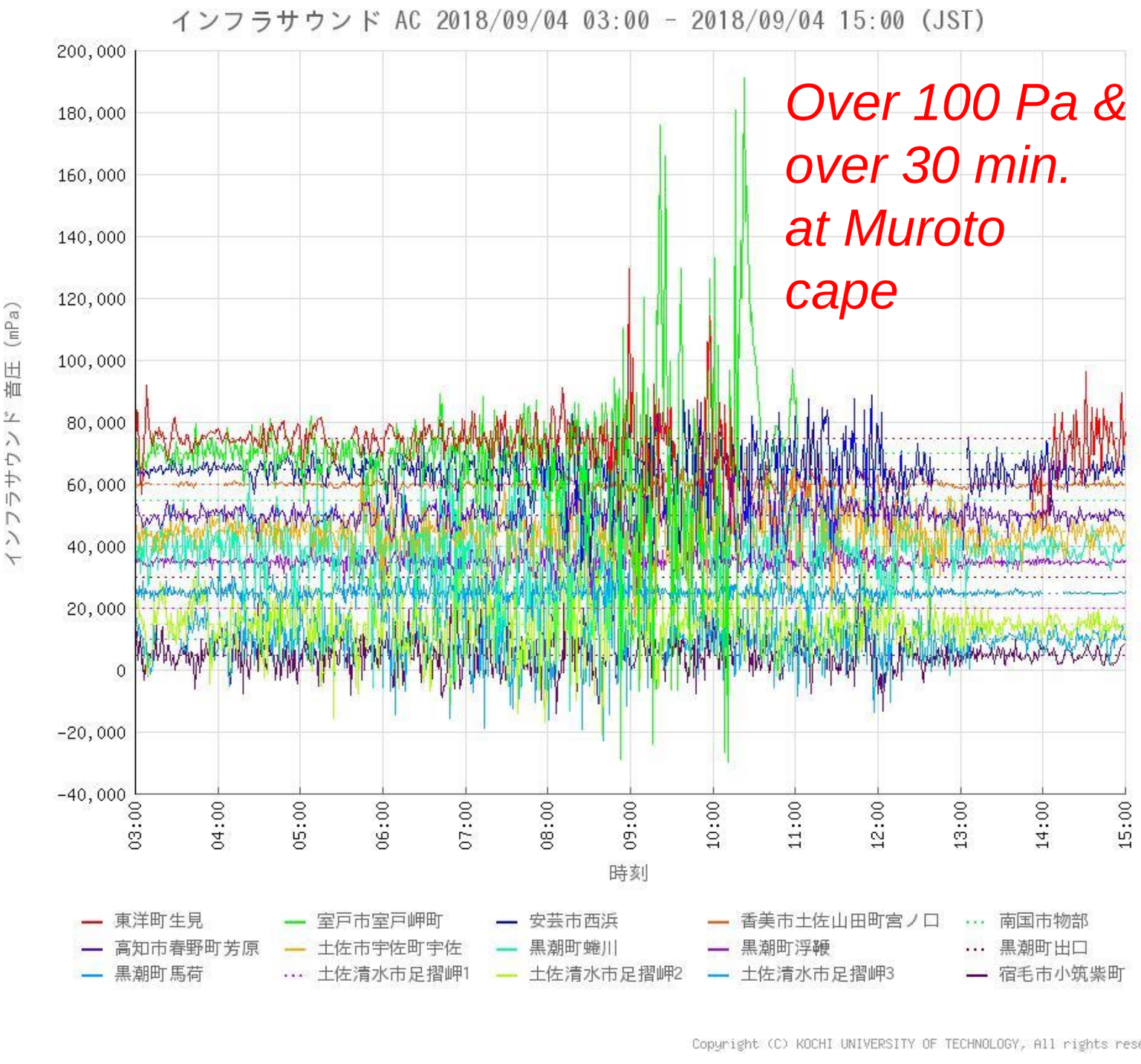


1 hour wave form



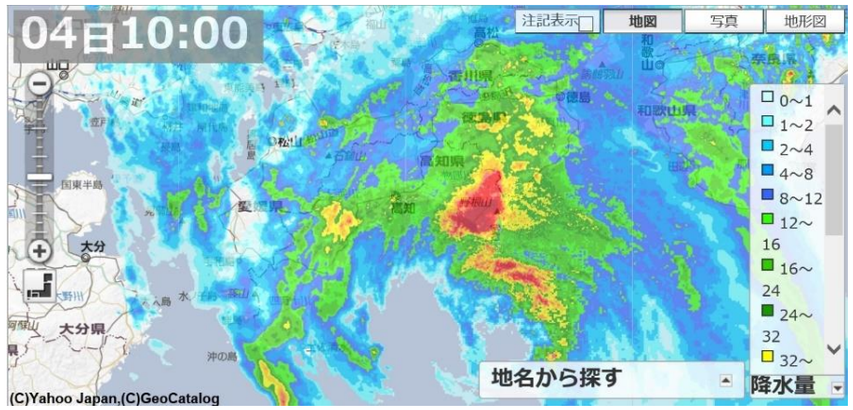
3 days spectrum

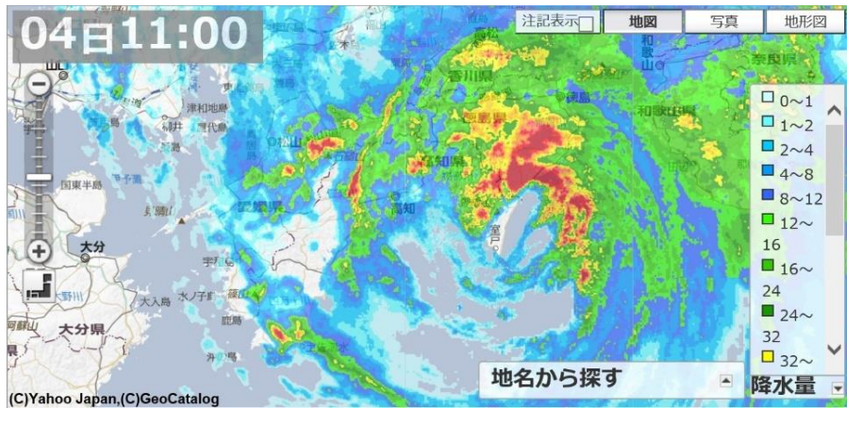
Infrasound signal detected when a Typhoon strikes Kochi prefecture on Sep. 4, 2018



Over 100 Pa & over 30 min. at Muroto cape

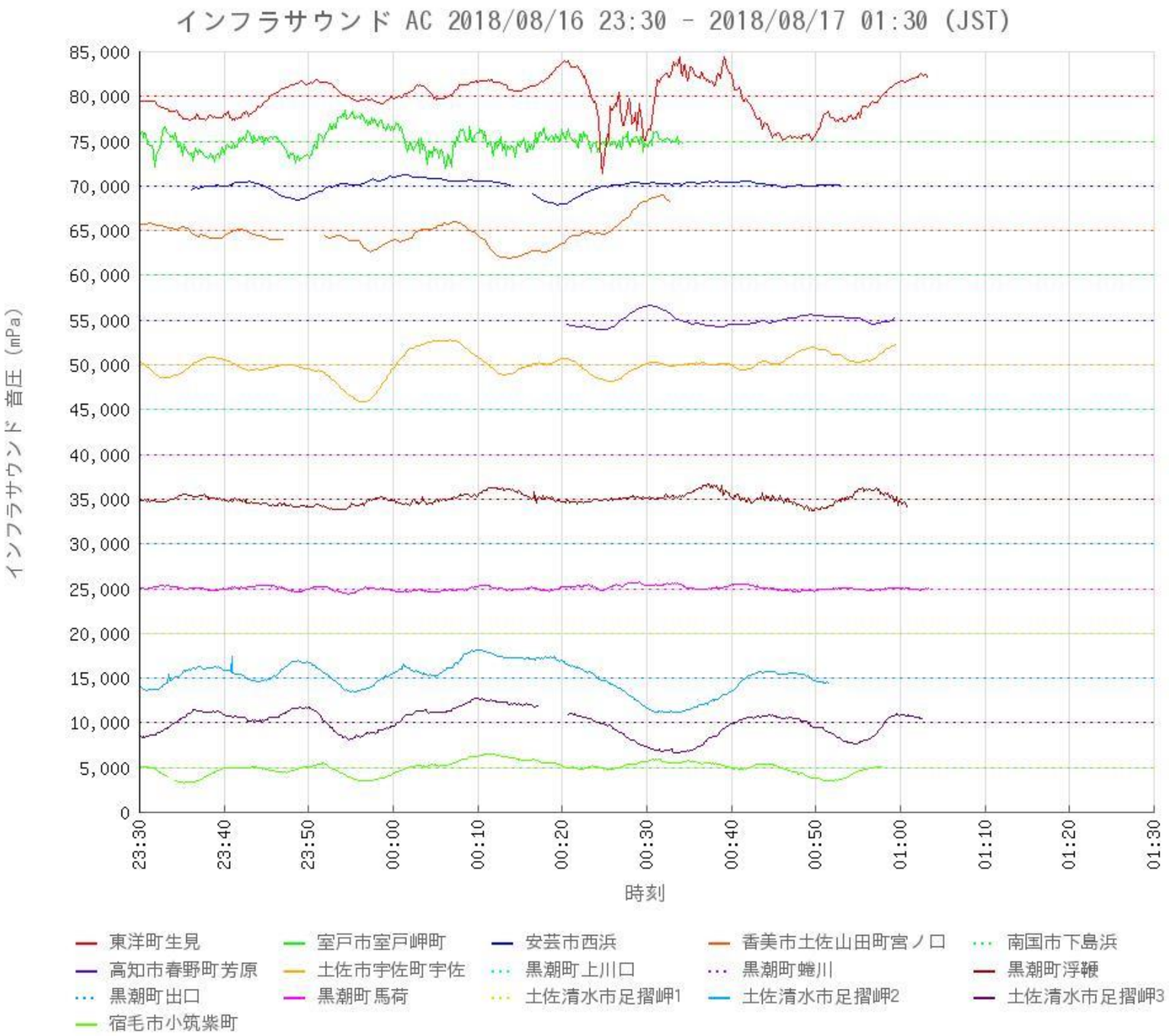
Typhoon passage (No.21)





Rain band radar © Yahoo JAPAN

Local heavy rain band passage was only/clearly observed at Toyo town on Aug. 17, 2018.



Rain band radar © Yahoo JAPAN

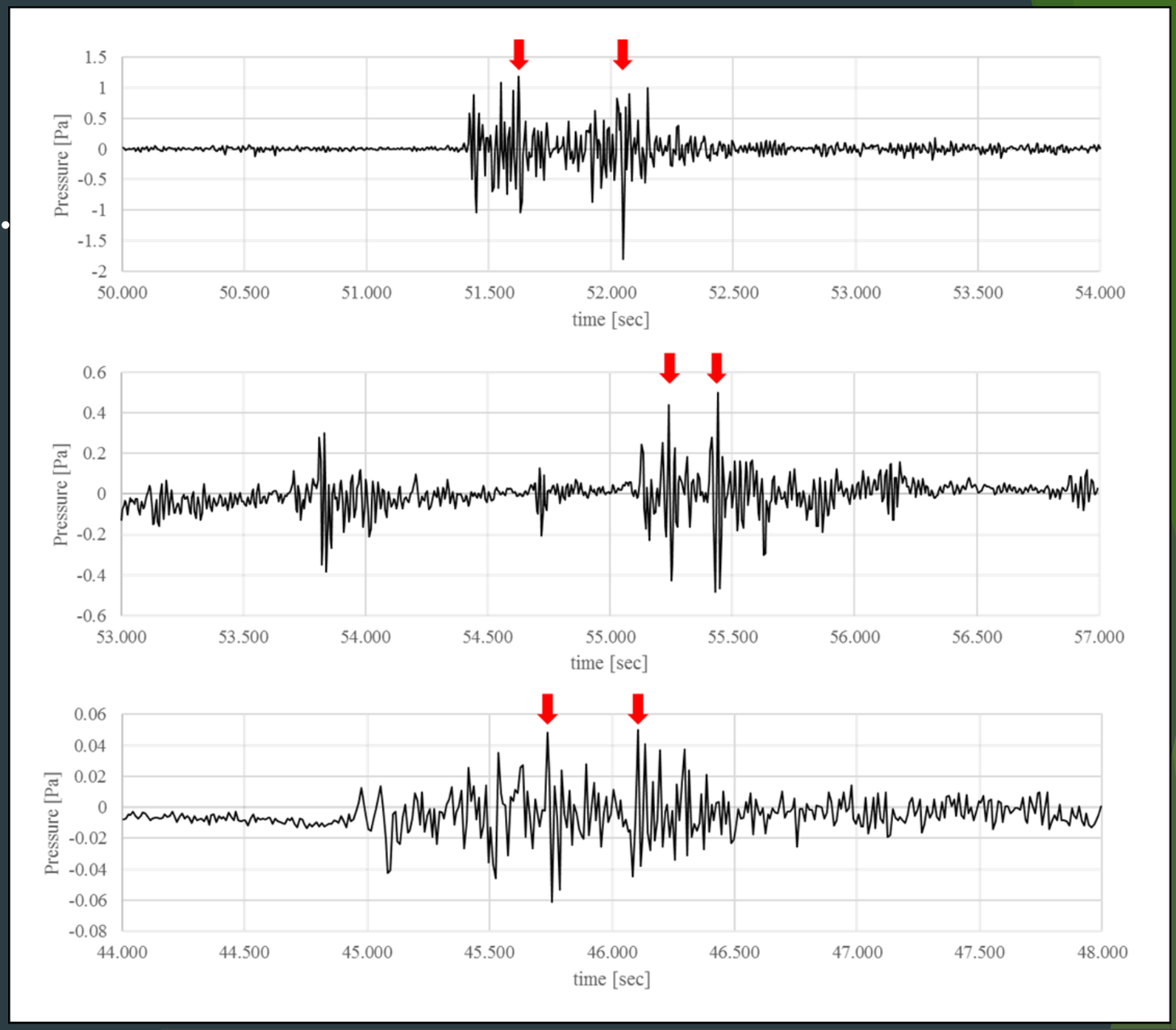
Thunder monitoring via Infrasound

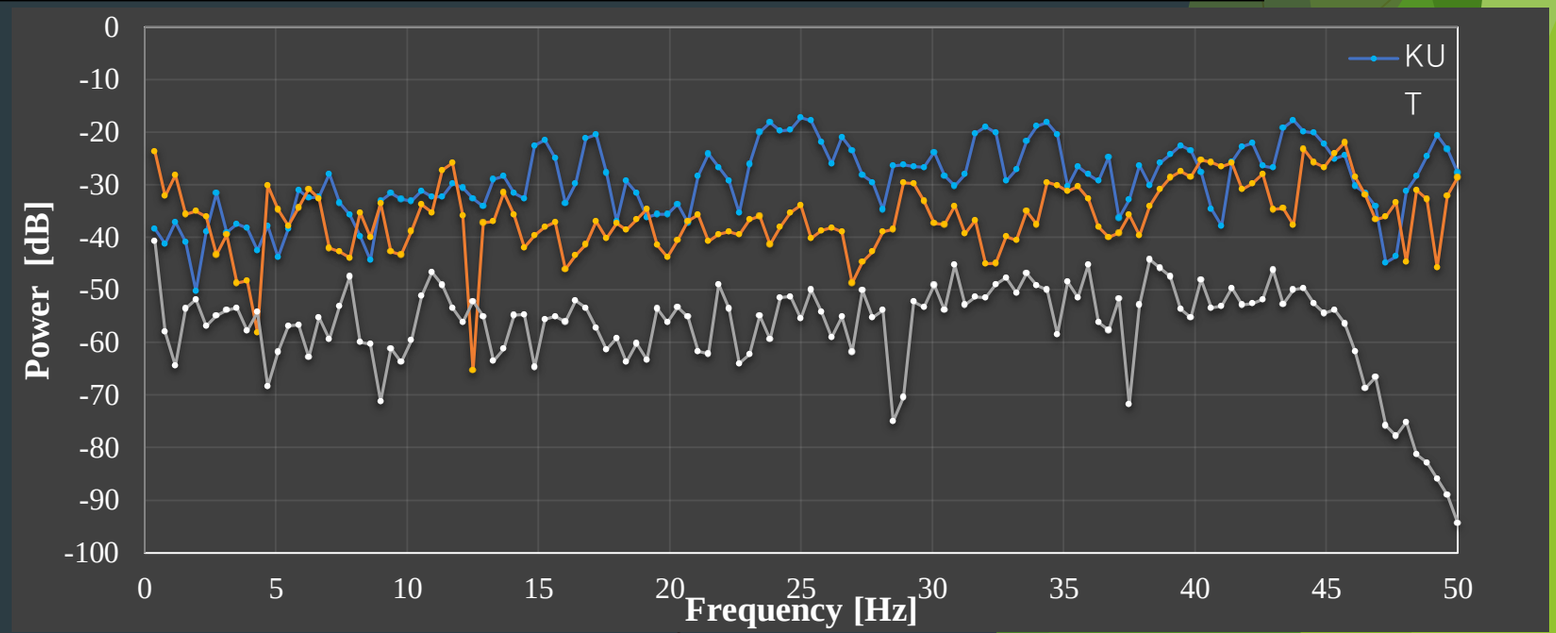
- Kochi Univ. of Tech.
  - 5 ch meteor interferometer
  - Infrasound sensor
  - Video camera
- Geisei observatory
  - Meteor radio observation
  - Infrasound sensor
  - Video camera
- Otoyo town
  - Meteor radio observation
  - Infrasound sensor

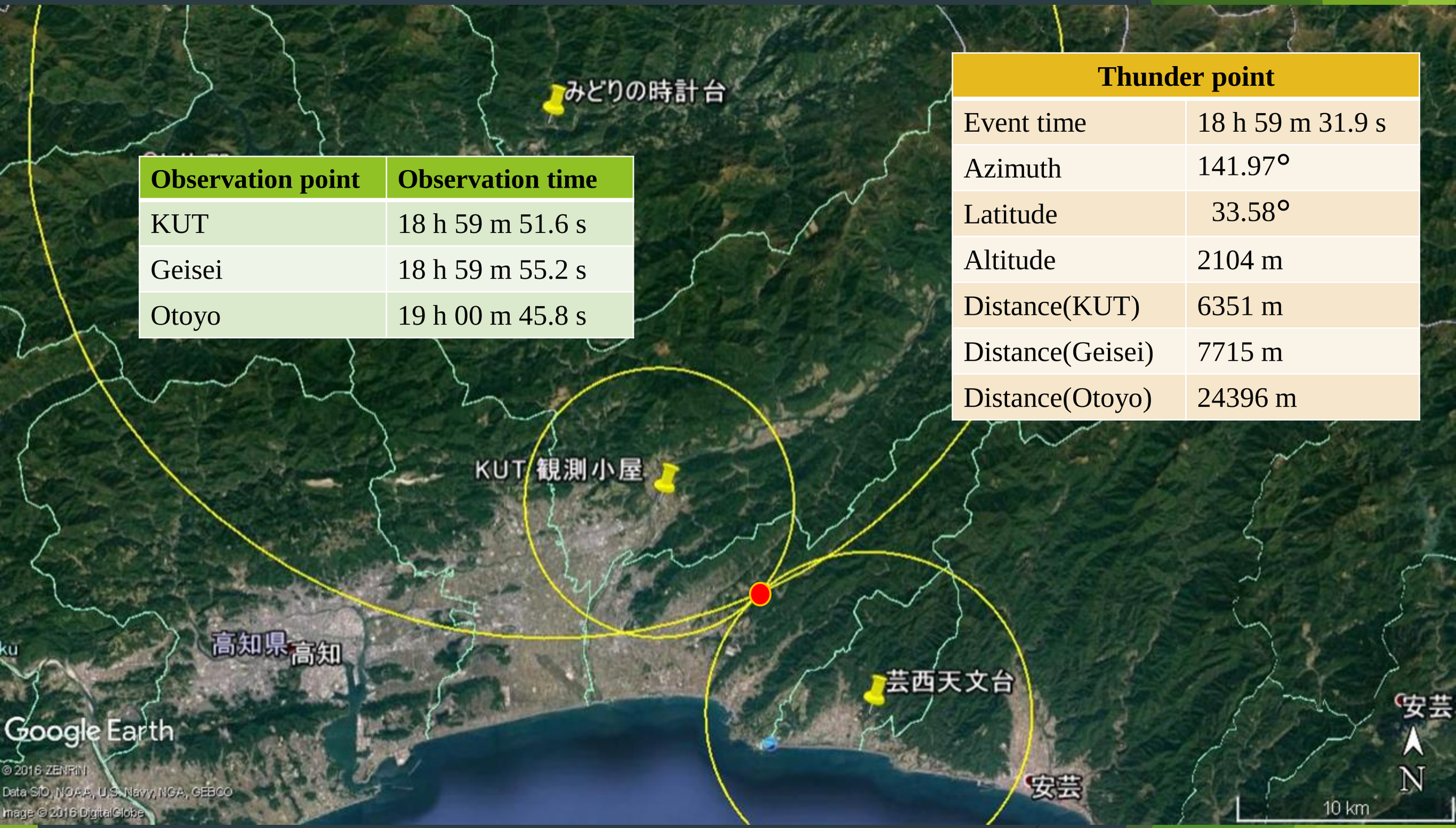
Kochi Univ. of tech.

Geisei observatory

Otoyo town



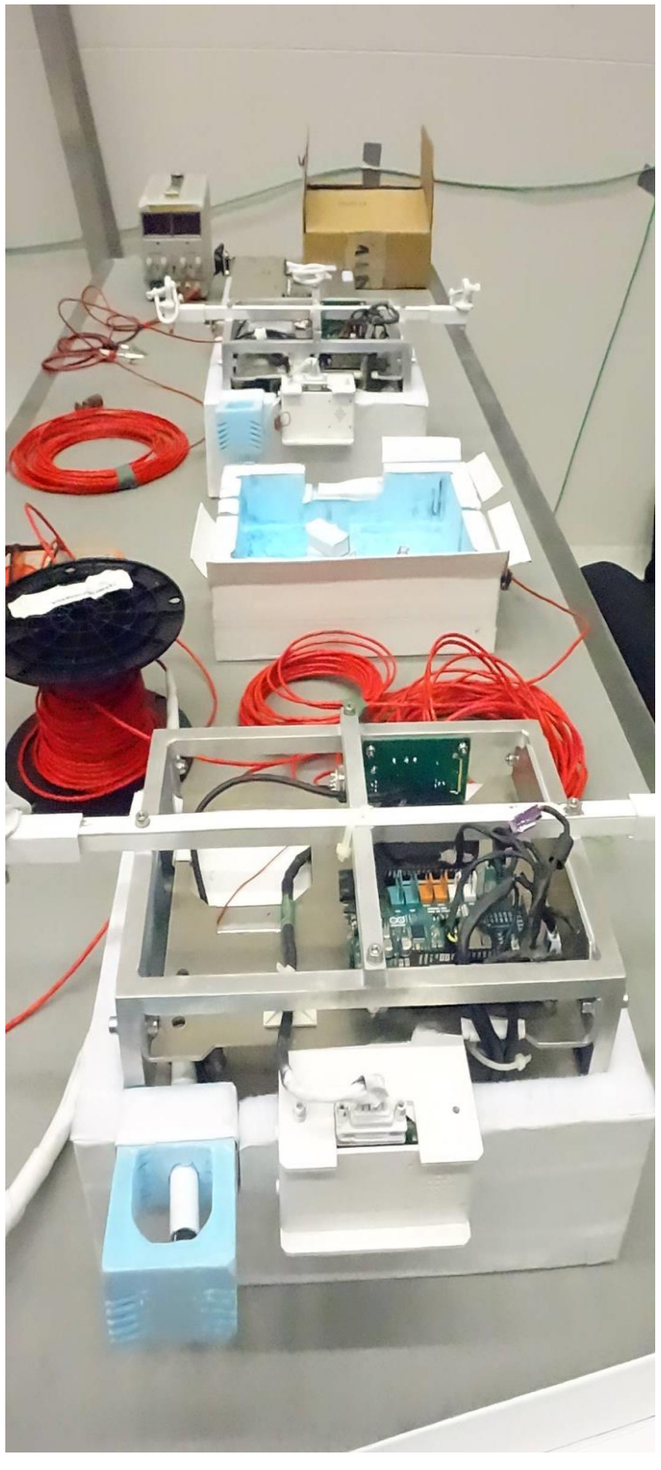




Observation point	Observation time
KUT	18 h 59 m 51.6 s
Geisei	18 h 59 m 55.2 s
Otoyo	19 h 00 m 45.8 s

Thunder point	
Event time	18 h 59 m 31.9 s
Azimuth	141.97°
Latitude	33.58°
Altitude	2104 m
Distance(KUT)	6351 m
Distance(Geisei)	7715 m
Distance(Otoyo)	24396 m

Sweden-Japan collaborative balloon experiment BEXUS-EXIST (Oct. 2017)



REXUS/BEXUS

Experiment Proposal Form

Team/Short experiment name	**EXIST**
Full experiment title	**E**xamination of **I**nfrasound in the **S**tratosphere and **T**roposphere

☐ **REXUS** ☒ **BEXUS**

☐ spinning with 4 Hz

☐ despun with Yo-Yo to about 0.08 Hz

☐ not of importance for our experiment

Science & Organisation

Team Information	
Student team leader:	**Robert Persson**, Swedish, Luleå University of Technology, Space Engineering – Spacecraft and Instrumentation, Master Program, Fifth year, 06-01-1993
Contact information of team leader:	Address: Ringvägen 45A, 98137 Kiruna, Sweden Telephone: +46 70 511 64 64 E-mail: robper-2@student.ltu.se
Members of your team (In order of team role):	**Lucas Svensson,** Swedish, Luleå University of Technology, Space Engineering - Spacecraft and Instrumentation, Master Program, Fourth year, 05-04-1994 **Role: Electrical Set-up Responsible** **Sarah Zayouna**, Swedish, Luleå University of Technology, Space Engineering - Spacecraft and Instrumentation, Master Program, Fourth year, 24-07-1992 **Role: Electrical**

Page 1 of 23

SAYA INF03

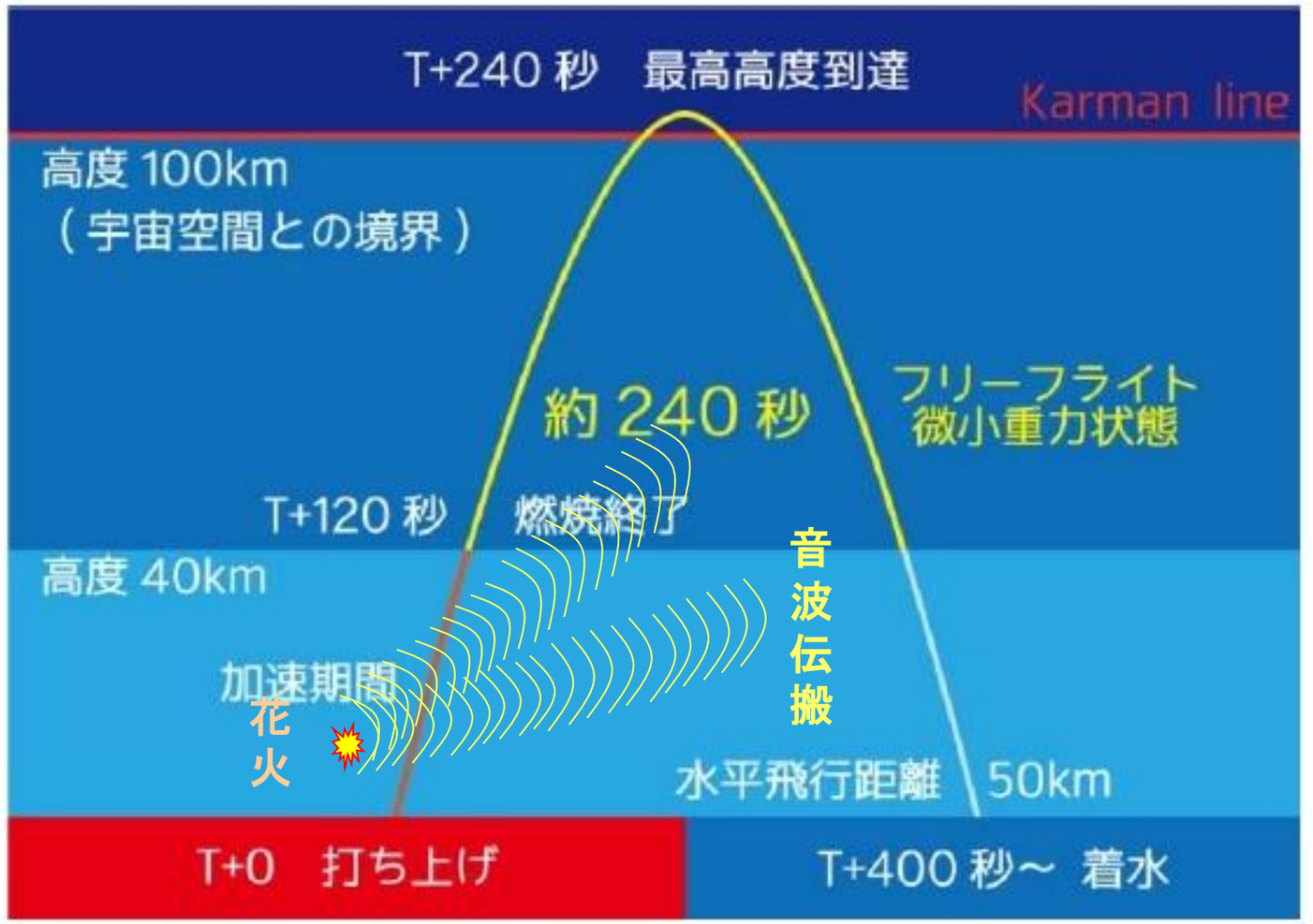
Microphone array for BEXUS/EXIST

Mass: 127 g

Freq.: 0.01 Hz – 20 Hz

MOMO2 sounding rocket
June 30, 2018
–> Exploded!!

観測ロケット「MOMO２号機」



観測ロケット「MOMO2号機」の飛行経路

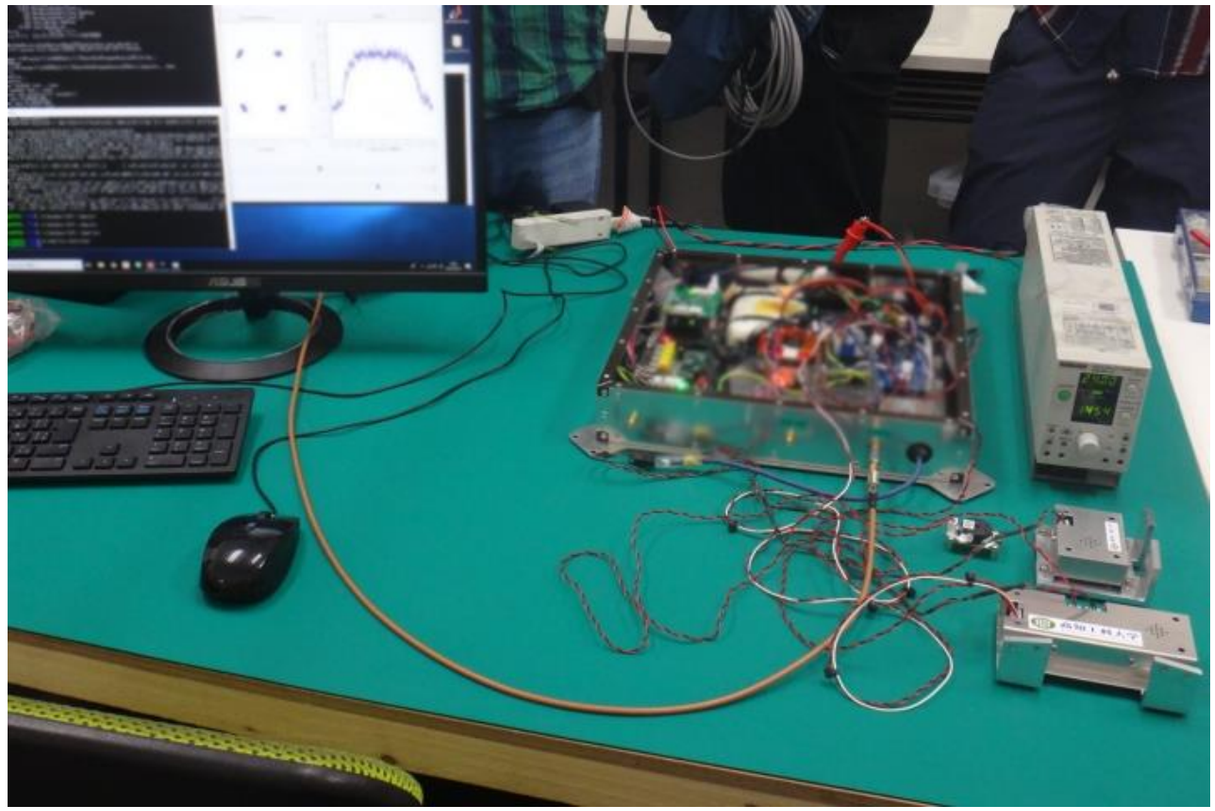
1月22日 東京で開催された「MOMO２号機」打ち上げ発表会

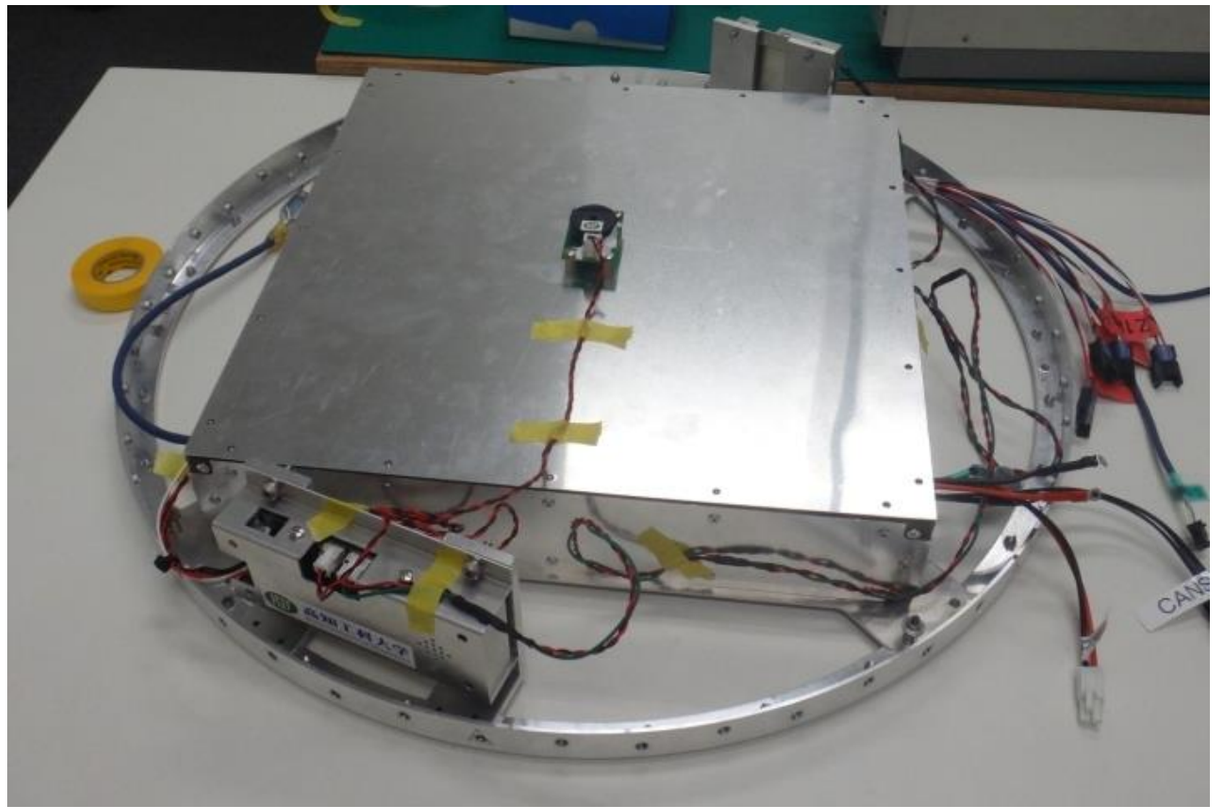
観測ロケットを用いた高層大気中における音波伝搬の計測

Momo2 観測ロケット　協力：インターステラテクノロジズ（株）

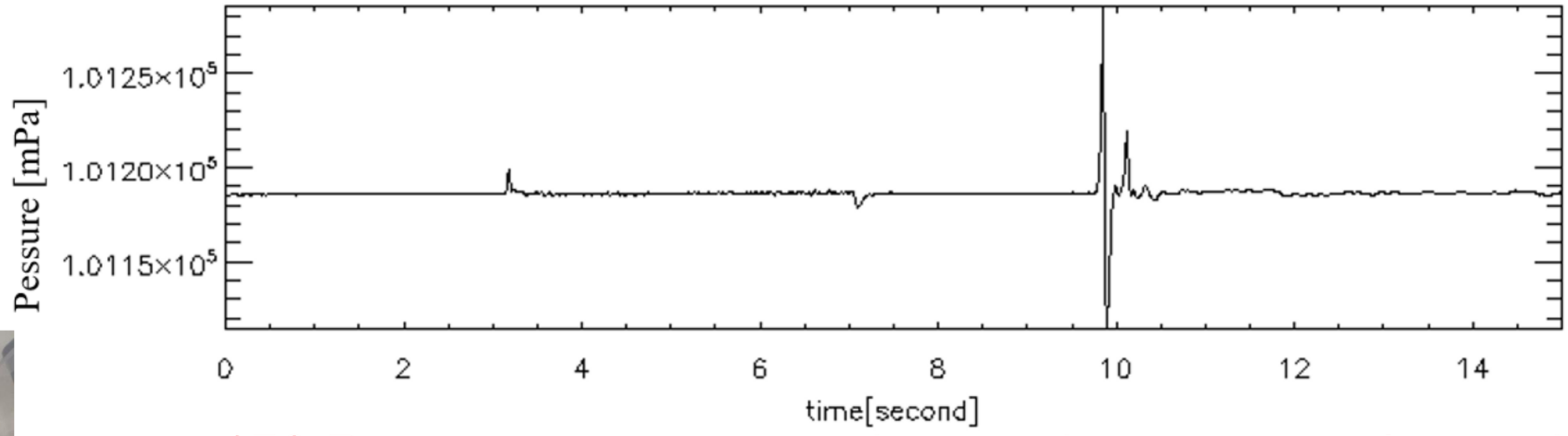
観測ロケットに搭載されたインフラサウンド・センサー

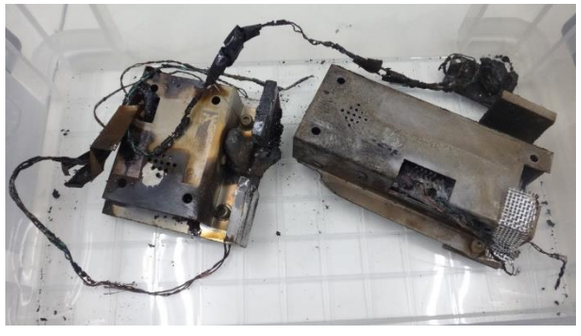
MOMO2 rocket on June 30, 2018





Energy estimation of MOMO2 rocket explosion





170 Pa p–p overpressure detected at a sensor located at 50 m from the rocket explosion point on ground.

The energy was about 710 kJ.
(170 g of TNT bomb level)

It seems NO severe explosion.

Only liquid Oxygen tank broken.

Without mixing full of fuel and liquid Oxygen.

We successfully measured energy of the rocket explosion…(-_-)

Momo3: 1st Japanese venture company's rocket over 100 km in space!
(with our microphones) on May 4, 2019

Test infrasound measurement in Europe (Sep. 8, 2019 at Mechelen, Belgium)

New sensor:
SAYA INF04LE

Summary

- We believe infrasound observation is extremely important for disaster mitigation for many types of geophysical events like tsunami or thunderstorm.
- By using prefecture level dense infrasound sensor network in Kochi, a typhoon strike and its affection on infrasound measurement was clearly observed.
- We checked overpressure datasets for MOMO2 rocket explosion and estimated explosive energy by using calibrated infrasound sensors on ground.
- Artificial explosions of fireworks were measured in upper atmosphere by infrasound sensors aboard MOMO3 sounding rocket.

Acknowledgements

- Infrasound research projects shown here are partly supported with JSPS KAKENHI (Grant-in-Aid for Scientific Research B), JST Matching Planner scheme, MIC SCOPE scheme, and research grant by SECOM Foundation for Science & Technology.