



**Abstract**

Tokyo VAAC(Volcanic Ash Advisory Center) issued more than 10,000 advisory reports describing volcanic activities in Japan over the past ten years(2009-2018). Around 98.5% of advisory is related to the volcanic eruption/explosion of five volcanoes of Kyushu area, Asosan, Kirishimayama, Sakurajima, Kuchinoerabujima and Suwanosejima. Infrasound signals produced by these volcanoes are well detected at the Korean Infrasound Network(KIN) which is consisted of eight infrasound array stations. Epicentral distance ranges from 495km to 1,019km. We have analyzed the infrasonic records by using PMCC with a reference to the event origin time of advisory reports, focusing on the Sakurajima which is most active. Analysis results show that the annual variations of arrival time and back-azimuth of infrasound signals are well matched to the annual change of atmospheric condition in regional scale. It shows also effects of winter stratospheric sudden warming in 2011/2012 and 2012/2013 in infrasound propagation. To examine possibility of characterizing each volcano, spectral features of beam-formed waveforms of representative infrasound signals are compared each other. It is confirmed that continuous volcanic activities in Kyushu region are excellent sources for infrasound study as well as atmospheric study in regional scale.

**Introduction**

Tokyo VAAC(Volcanic Ash Advisory Center) issued 10,222 advisory reports on the volcanic activities of five volcanoes in Kyushu region (Asosan, Kirishimayama, Sakurajima, Kuchinoerabujima and Suwanosejima) during 2009-2018 (Fig. 1 & 2). Most of the report are related to the volcanic ash which is most important to safety of the airplane. We have listed explosion catalog of Sakurajima in priority based on the advisory report. Many authors have already published excellent study on the infrasound of Sakurajima. But almost all the study were carried out in local scale, not in regional scale. Long-term temporal variation of infrasound propagation were investigated by using volcanic infrasound signals recorded at the permanent station in Korea. We have used data recorded only by 6 stations among 9 with a consideration of data completeness and aperture size of the array etc.(Table. 1).

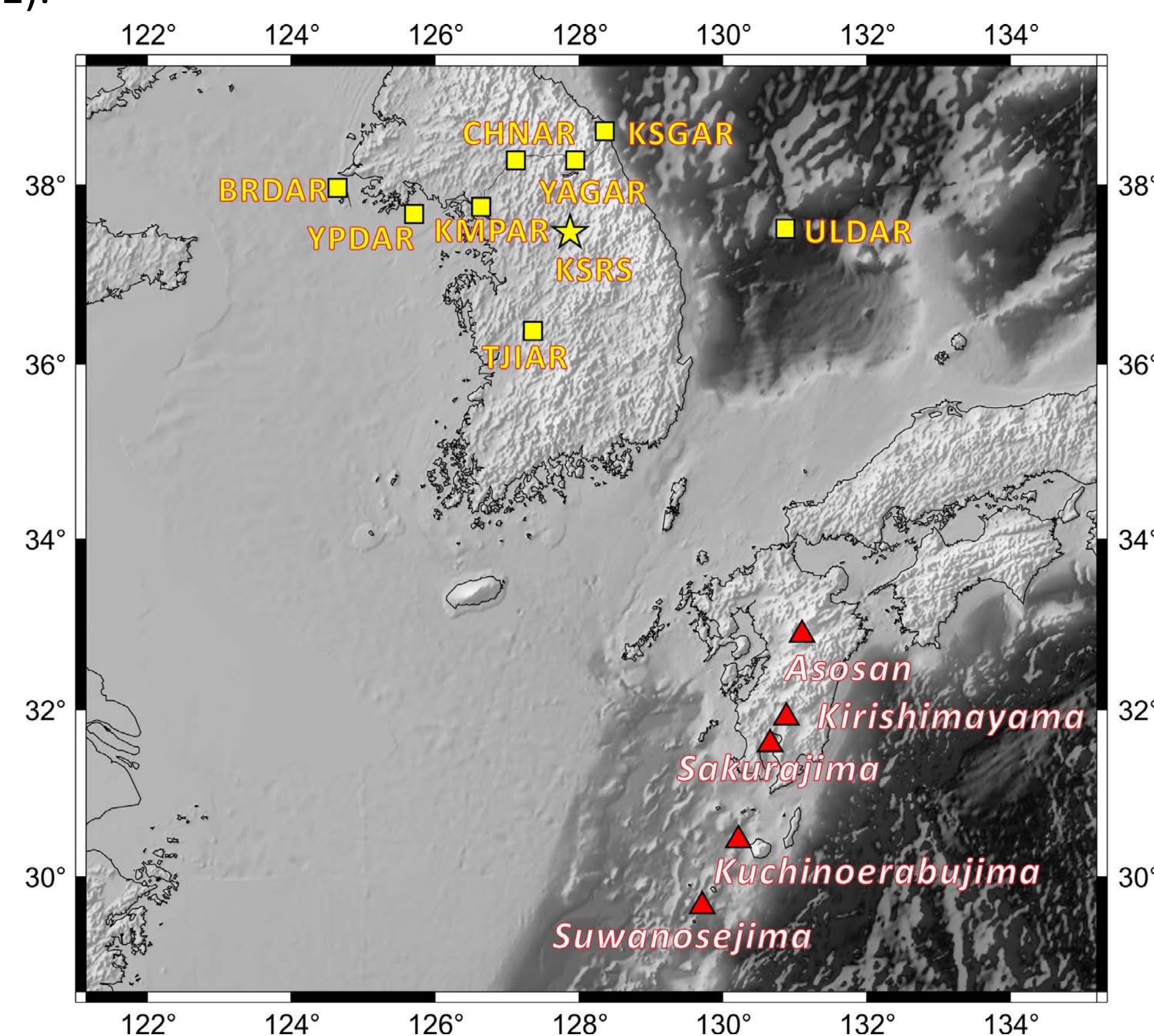


Figure 1. Location map of Korean Infrasound Network and 5 most active volcanoes in Kyushu, Japan. We have added one more station recently at KRSR IMS station at Wonju. The code name is KSIAR. Total 9 infrasound stations are running now.

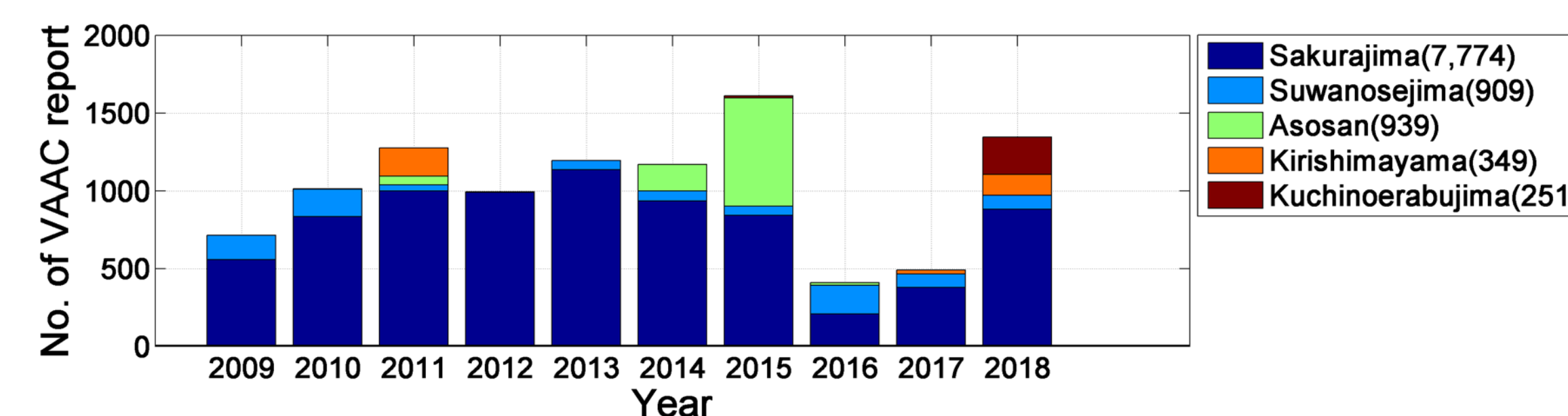


Figure 2. No. of advisory reports on the 5 volcanoes in Kyushu issued by Tokyo VAAC 2009-2018. Figure shows that Sakurajima is most active and volcanic activity of Suwanosejima is persistent, but the rest are sporadic.

Station	No. of Element	Sampling Rate	Aperture Size (km)	Asosan		Kirishimayama		Sakurajima		Kuchinoerabujima		Suwanosejima	
				Distance (km)	Azimuth (°)	Distance (km)	Azimuth (°)	Distance (km)	Azimuth (°)	Distance (km)	Azimuth (°)	Distance (km)	Azimuth (°)
BRDAR	16	40	1.6	799.2	131.0	865.7	137.1	881.5	139.7	963.1	146.2	1,018.9	151.2
TJIAR	4	40	1.2	502.6	136.0	576.2	144.7	612.1	149.3	692.0	156.7	761.0	162.6
CHNAR	11	40	1.5	680.9	146.9	767.0	152.4	791.8	154.9	895.5	160.6	968.7	165.0
YAGAR	18	40	1.5	644.7	152.8	736.7	157.9	764.5	160.3	874.7	165.6	953.1	169.7
KSGAR	13	40	1.2	661.4	157.2	757.3	161.6	786.9	163.9	900.9	168.6	982.1	172.3
ULDAR	7	40	1.0	494.9	177.5	602.9	179.9	640.1	181.8	768.3	184.7	862.1	187.5

Table 1. Station information and distance and azimuth angle from station to volcano. Chaparral sensors are installed at all the stations. Azimuth angle ranges from 131.0° (BRDAR to Asosan) to 187.5° (ULDAR to Suwanoseijima).

**Data analysis and discussion**

Ten years of infrasound data recorded at the six stations were processed to detect explosion signals coming from above mentioned Japanese volcanoes by using Progressive Multi-Channel Correlation (PMCC) developed by CEA. The data processing was carried out semi-automatically due to various reasons, such as dead channel, polarity reversal of some channel, data gaps, etc. 12 linearly-spaced frequency band pass filter between 0.05 to 4Hz was applied. Following event detection criteria are applied: 1) signal arrived within expected arrival time window of stratospheric phase(*Is*) or thermospheric phase(*It*) with back-azimuth angle  $\pm 15^\circ$ , 2) signal detected at least two stations. Fig. 3 is an example of signal detected at TJIAR station, which is the explosion of Sakurajima at 16:40:00 on the Jan. 30, 2015. Traveltime is 36:16:54.

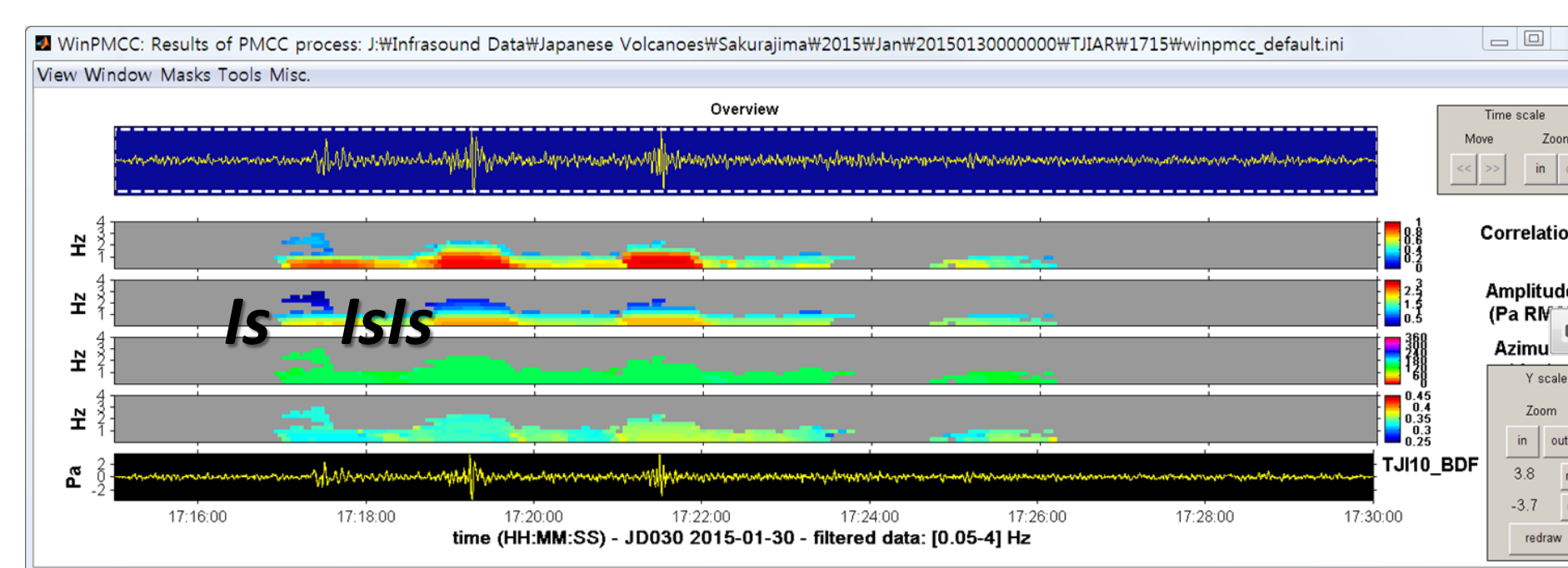


Figure 3. Signal indicating volcanic explosion of Sakurajima occurred at 16:40:00 on Jan. 30, 2015. It was arrived at TJIAR at 17:16:54.

Fig. 4 shows back-azimuth of the volcanic signals of Sakurajima arrived at TJIAR from 2010-01-01 to 2016-7.25 with a background of ECMWF wind profiles. No. of explosions is 1,322. Due to low detection ratio of other stations, we have presented only TJIAR case that shows well continuous temporal variation over the year. In this figure, upper panel shows how daily change of effective sound speed affects the arrival angle of signal when it comes to the station, and lower panel shows the effect of the transversal wind speed and direction to the propagating signal at the atmosphere.

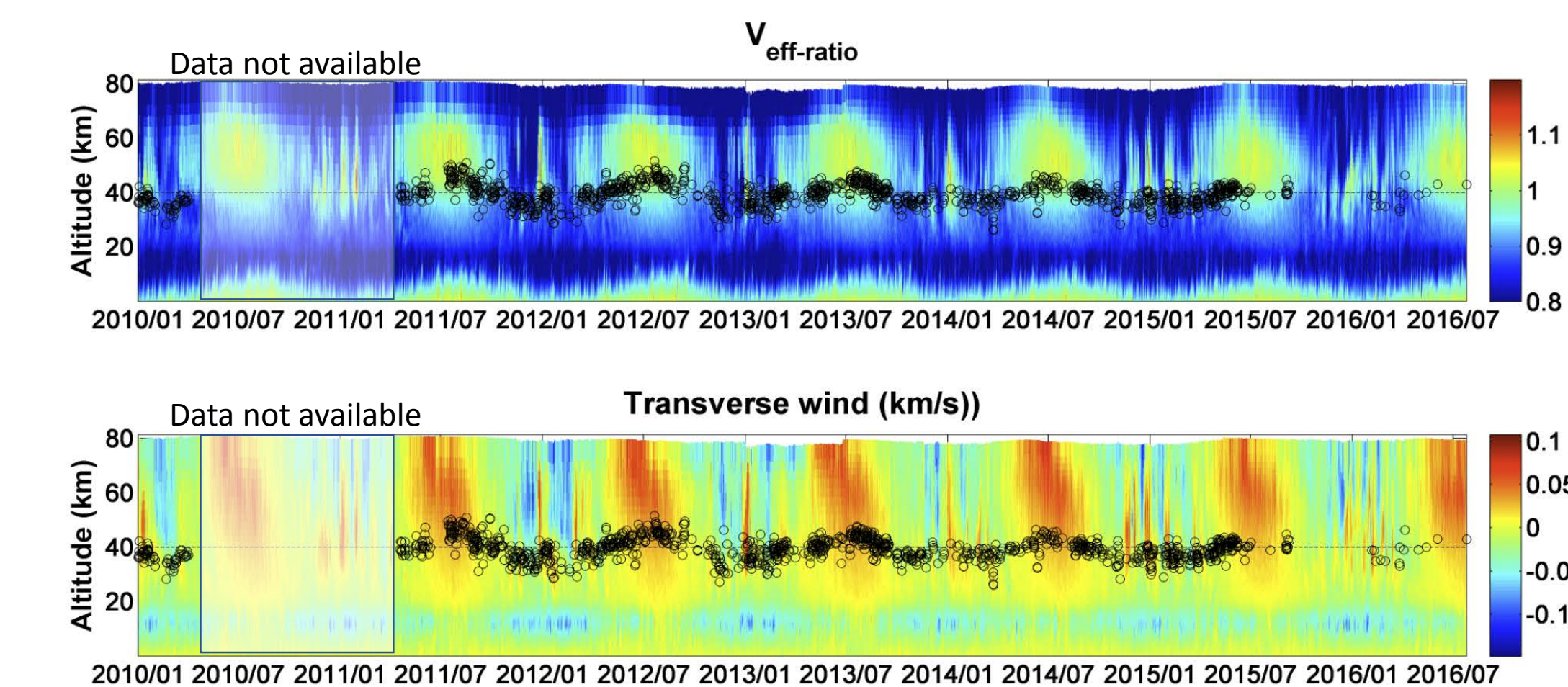


Figure 4. Upper panel shows how daily change of effective sound speed affects the arrival angle when signal comes to the station, and lower panel shows the effect of the transversal wind speed and direction to the propagating signal at the atmosphere. Change of back-azimuth angles matches well to the atmospheric condition.

Fig. 5 represents the comparison of variation of back-azimuth and celerity of signals detected with those of theoretically calculated using ECMWF model. Red circles indicate 1,259 signals detected at TJIAR (2011-1-1~2016-7-26). Blue circles are predicted stratospheric returns and green circles are predicted thermospheric returns. The effect of SSW (Sudden Stratospheric Warming) is shown clearly in winter. Some outliers of in upper panel might be different signals not coming from Sakurajima because back-azimuth and arrival time of nearby volcanoes are within the boundaries of detection criteria.

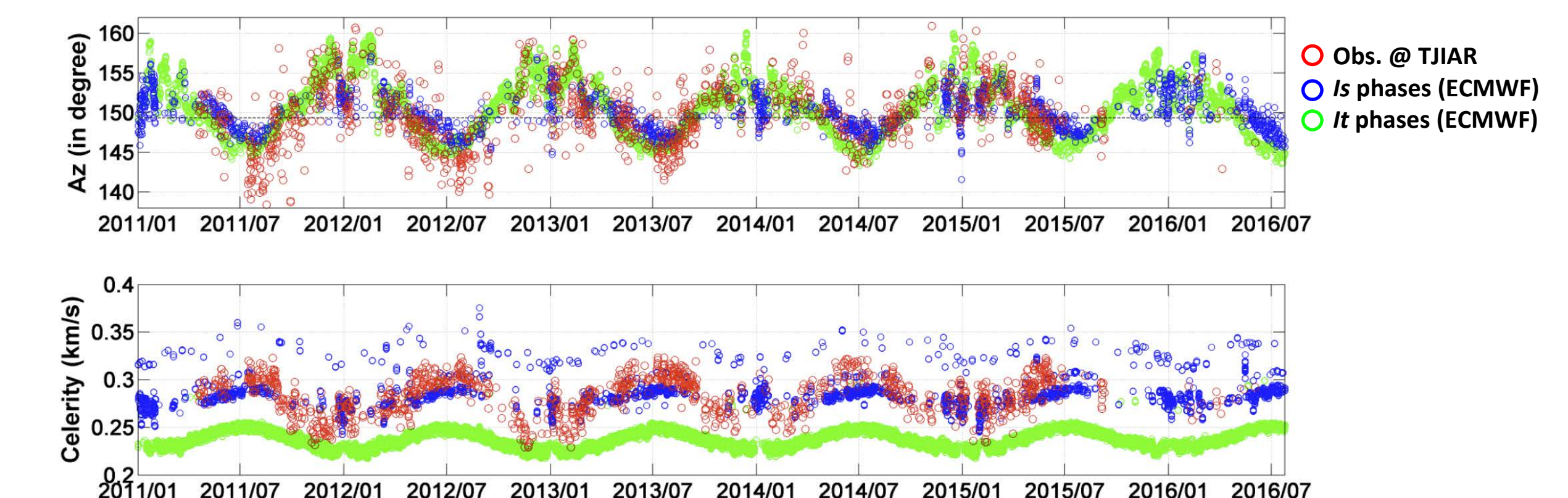


Figure 5. Comparison of the back-azimuth and celerity of 1,259 signals observed at TJIAR. Figure shows that observations are well matched with the theoretically calculated ones. Effects of SSW to infrasound propagation are clear in winter.

To examine possibility of characterizing the explosion mechanism of each volcano using infrasound signals measured at regional distance, power spectrum density was calculated and compared for selected signals of 5 volcanoes. But we could not find any significant differences among them.

**Summary**

- We have monitored volcanic activities in Kyushu for 10 years and analyzed relevant infrasound data.
- 1,322 explosions of Sakurajima volcano are well detected at TJIAR (2010.1~2016.7). Analysis result reflects well the change of atmospheric condition during the same time period in regional scale.
- Further precise information on the origin time of explosions is required to complete this study.

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