Response to Comments

Manuscript number: NHESS-2021-126
Title: Pressure-forced meteotsunami occurrences in the eastern Yellow Sea over the past decade (2010–2019): monitoring guidelines
Authors: Myung-Seok Kim, Seung-Buhm Woo, Hyunmin Eom, and Sung Hyup You
Journal: Natural Hazards and Earth System Sciences

- Reviewer #1:

This paper studied meteotsunamis in the eastern Yellow Sea, and proposed monitoring guidelines in this area. It is well-structured and the results are presented clearly. But it needs a major revision to be considered as a publication in NHESS journal. The authors need to include the analysis on the period of detected waves and the local resonance at the tidal gauges. Authors have written many sentences in a passive voice, and their claims and explanations sound weak.

→ We really appreciate your detailed review and comment. As you commented, the analysis on the period of detected waves and local resonance at the tide gauges was performed. More detailed results will be discussed in the revised manuscript.

[Major comments]

One of the main characteristics of tsunami waves (including meteotsunamis) is the period of waves since the energy of a tsunami is due to its long period. This study only considered the maximum amplitude waves and did not analyze the period of the waves. The authors need to perform wavelet analysis or Fourier spectrum analysis, and consider peak-to-trough heights rather than maximum amplitudes to confirm meteotsunami cases.

Another important characteristic of meteotsunamis is the local amplification. The local factor can be decisive to forecast the severity of meteotsunamis in the eastern Yellow Sea since the coastline is long and complicated with many islands. The authors can improve this work if they include local factors.

→ Based on wavelet analysis and visual inspection with the meteotsunami events, we examined the dominant periods when the maximum wave heights were detected. As you commented, local amplification is known as an important characteristics of meteotsunamis in the eastern Yellow Sea (Kim et al., 2016, 2021b). Spread of the dominant periods and a quality factor (Q-factor), which is a linear measure of the energy dumping in a basin, will be examined to include local factors. Please also check "Response to Comments (figures, tables, and equations)".

- Kim, M.-S., Kim, H., Kim, Y.-K., Gu, B.-H., Lee, H.-J., Woo, S.-B., 2016. Double resonance effect at Daeheuksando port caused by air pressure disturbances in Yellow Sea on 31 March 2007. J. Coast. Res. 75, 1142–1146. https://doi.org/10.2112/SI75-229.1

- Kim, M.-S., Woo, S.-B., 2021b. Propagation and amplification of meteotsunamis in

multiple harbors along the eastern Yellow Sea coast. Continent. Shelf Res. https://doi.org/10.1016/j.csr.2021.104474

1. The authors studied the local behaviors of tidal gauges (shown in Figure 3), but chose the threshold of 15 cm for all the tidal gauges. Montserrat (2006) suggested 4-sigma and Dusek et al. (2019) suggested 6-sigma and 20 cm (peak-to-trough height) for choosing possible meteotsunami events. Please explain why the authors have chosen the 15 cm threshold.

   → We classified the meteotsunami events by using the maximum amplitude threshold (15 cm) just for the consistency of the threshold used in previous studies in the eastern Yellow Sea. However, we accepted your comments when classifying the meteotsunami events. As you commented, the classification was re-performed using the peak-to-trough wave heights and alternative threshold (20 cm & 4 sigma). The wave height threshold was selected through prototyping with the known meteotsunami events since 2010. As a result, 42 meteotsunami events, which were increased than the previous results (32 events), were classified. Please check the modified figures and tables.

2. In Table 3 and Figure 11, the authors presented average amplitude and occurrence rate to evaluate meteotsunami events. Damages on the coast can occur in a small area, and the occurrence rate can be small. Can these parameters represent the severity of meteotsunamis?

   → In this study, we classified 11 extreme events among 42 pressure-forced meteotsunami events based on the occurrence rate (i.e., spatial scale). The average amplitude was not considered. As a result, the occurrence rate of meteotsunamis was related to the occurrence rate of air pressure jump (modified Figure 11). As you commented, damages on the coast can occur in a small area, and the occurrence rate can be small. However, we considered that meteotsunamis that spread over the large area were more dangerous on the eastern Yellow Sea coast. During the pilot operation of the monitoring system in the Yellow Sea, when the long ocean waves amplified by the Proudman resonance propagated with a wider spatial scale, they were more hazardous than the meteotsunamis with local scale (Kim et al., 2021a). As you know, the eastern Yellow Sea coast is characterized by many harbors along the long and complicated coastline. The long ocean waves forced by the propagating air pressure jumps can generate destructive harbor meteotsunamis, causing local amplification in multiple harbors (Kim et al., 2021b). Therefore, the occurrence rate of air pressure jumps can be considered as one of the parameters representing the severity of meteotsunamis from the perspective of monitoring system operation on the eastern Yellow Sea coast.

   - Real-time pressure disturbance monitoring system in the Yellow Sea - Pilot test during the period of March to April 2018 (Nat. Hazards SI,2021)

   - Propagation and amplification of meteotsunamis in multiple harbors along the eastern Yellow Sea coast (CSR RI,2021)

3. In Table 4, authors proposed guidelines for meteotsunami monitoring. It is unclear why authors choose 30 % occurrence rate for extreme. The occurrence rate cannot be used to forecast events since the occurrence of meteotsunami can be detected after it has

occured.

→ As you commented, the occurrence rate cannot be used to forecast events. The warning level will be divided into three levels (high-moderate-low) by using the speed and direction of the pressure disturbances. Instead, for extreme warning levels, we will choose peak-to-trough wave height at beacon tide gauges in which are outer-located harbors (AH, EC, WD, DH, and MS) to consider the local resonance (i.e., multiple harbor resonances). More detailed results will be discussed in the schematic diagram on how the meteotsunami warning system will be designed (Reviewer #2 suggested).

[Minor comments]

1. L 14 unclear "It appears that the specific characteristics (intensity, occurrence rate, and propagation) of the pressure disturbance are in common on extreme meteotsunami events that are classified by applying the hazardous meteotsunami conditions among the 34 events."
2. L 25 "that dominant" -> that are dominant
3. L 25-26 remove "which are"
4. L 28 remove "as the first stage"
5. L 34 remove "worldwide until recently"
6. L 35 remove "most"
7. L 36 "The meteotsunami event on March 31, 2007, was an event in which" -> On March 31st, 2007,
8. L 40 "It was the event that occurred with the strongest intensity in the largest area of the meteotsunami events reported in the Yellow Sea so far" -> It is the strongest meteotsunami event reported in the Yellow Sea so far
9. L 43 "This event suggests that the timing of meteotsunami occurrence is an important factor that can determine the level of human casualties." - This argument is vague, and the authors need to specify their assertion.
10. L 50 remove "Overall"
11. L 52 remove "besides the accident events"
12. L113 "calculation and threshold" -> calculating the threshold
13. L114 "which known"->which is known
14. L126 remove "was the meteotsunami event of accident since 2010, which"
15. L130-131 remove "In general… and"
16. L149 "We need to check .. as a meteotsunami" It is not clear why we need to find it.
17. L 229-231 Two sentences are inconsistent. Authors explain the occurrence tendency, then claim that they are irregular. I think 10 years are too short to propose any tendency.
18. L 314 "pattern, for example,"->pattern. For example,
19. L 356 "specific year" -> "specific season"
20. L 390-393 "Another pressure jump … the west of Lat. A-C" What is the reference for the Greenspan resonance in this area?

→ The comments about rephrasing are planned to be modified after the final response.

Response to Comments (figures, tables, and equations)

We have significantly revised our results according to your advice. The major revision can be summarized as follows:

(1) Classification of the meteotsunami events

Maximum amplitude → maximum peak-to-trough height
Absolute threshold → combined threshold criterion based on four-sigma value and absolute wave height of 20 cm

(2) Meteotsunami occurrences

Yearly and monthly strength parameter of the meteotsunamis were added using the box-plots. Spatial pattern of the meteotsunamis were estimated based on the number of events per year (2d histogram).

(3) Classification of the extreme meteotsunami events considering only occurrence rate

Average amplitude, meteotsunami occurred-tide gauges of more than six, and occurrence rate of more than 50% → meteotsunami occurred-tide gauges of more than six and occurrence rate of more than 50%

(4) Propagation patterns of air pressure jumps on the meteotsuanmi events

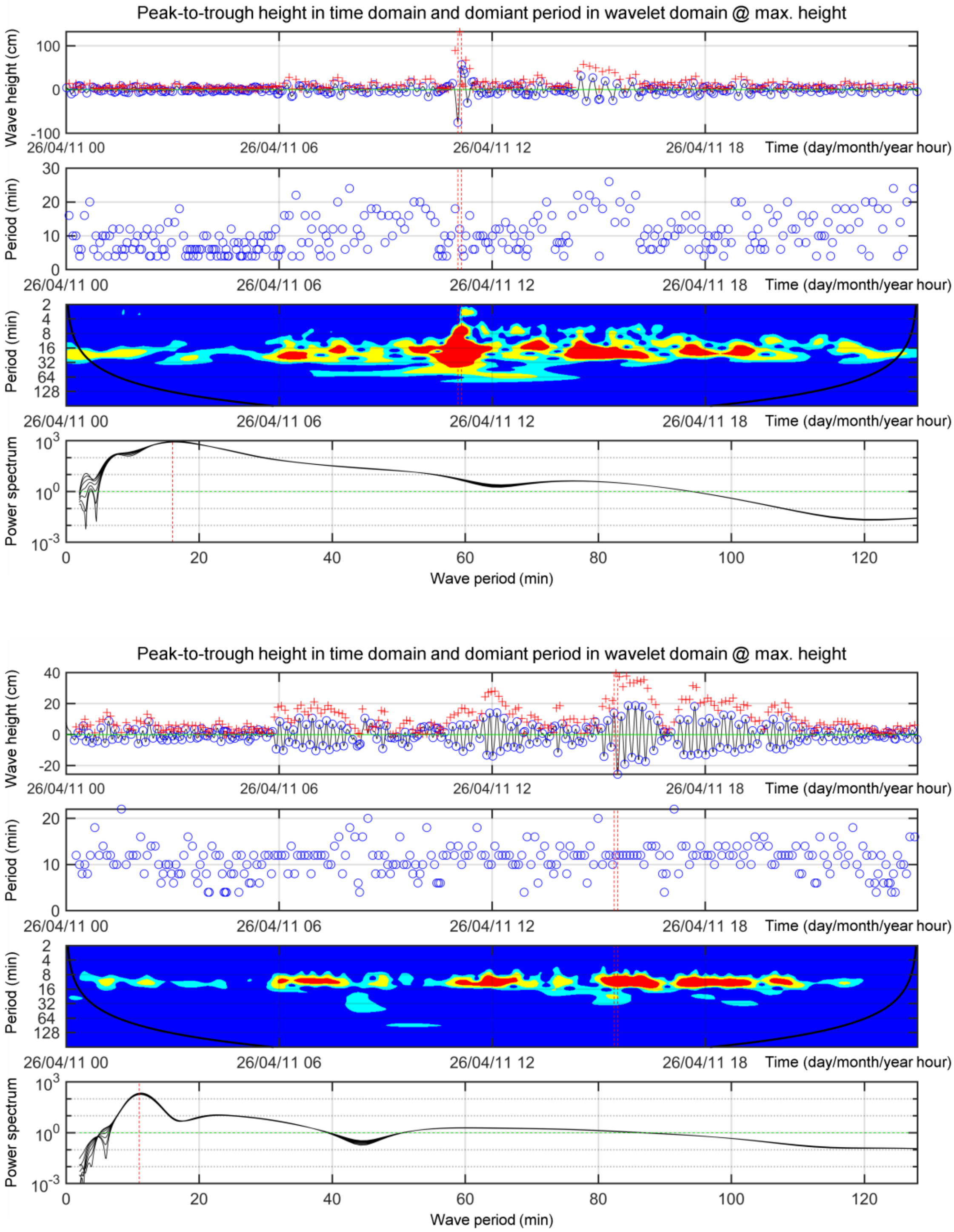
Radar image analysis through visual inspection + linear speed and direction using 2 AWS → radar image analysis through visual inspection + pressure tendency method using 3 AWS (Šepić et al., 2009)

(5) Local amplifications in multiple harbors

Scatter diagram of dominant period of detected waves and maximum wave height was added.

The following figures and tables will be significantly polished to improve the readability after the final response.

[Figure 2: The 3rd and 4th panel in following figure will be added in prior Figure 2] Wave height and dominant period of the meteotsunamis during 26/04/2011 meteotsunami event at the DH (upper) and EC (lower) tide gauge. The 1st panel: peak-to-trough height of the filtered sea level in time domain. The 2nd panel: approximated wave period in the time domain. The 3rd panel: wavelet analysis. The 4th panel: distribution of wavelet power spectrum when the maximum wave height observed.

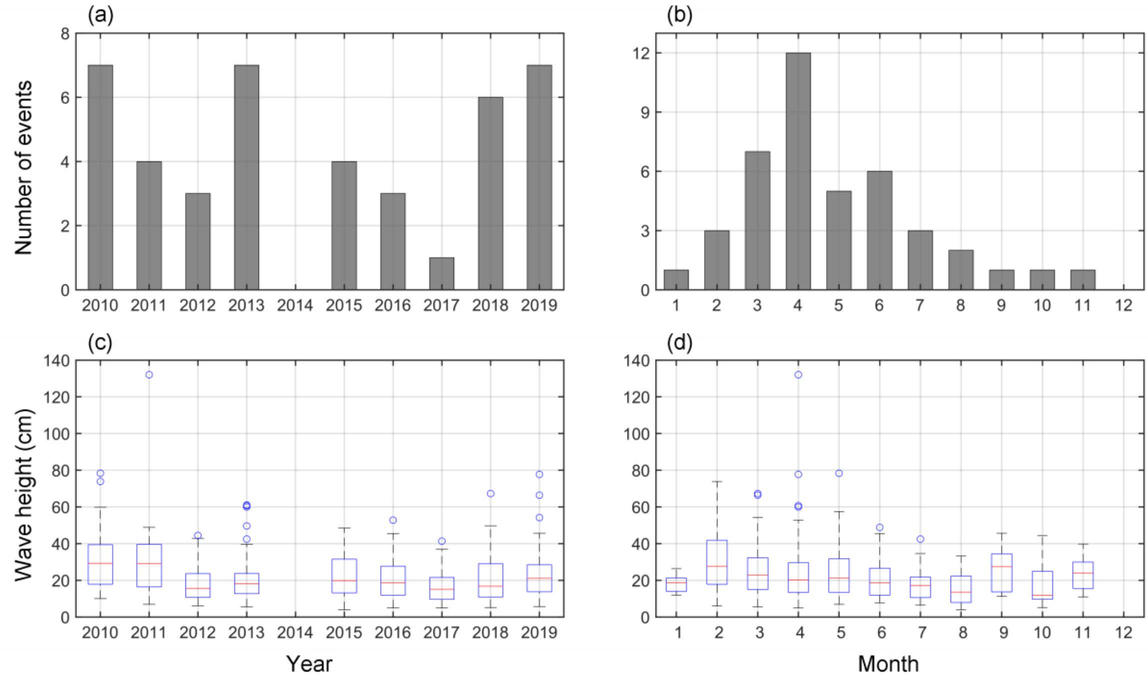


[Table 2: modified] Daily maximum wave height (cm) during 42 meteotsunami events. The reported events since 2010 are denoted by superscript. The strongest intensity of each event are marked by underlined and bold text. The events are indicated as Day/Month/Year.

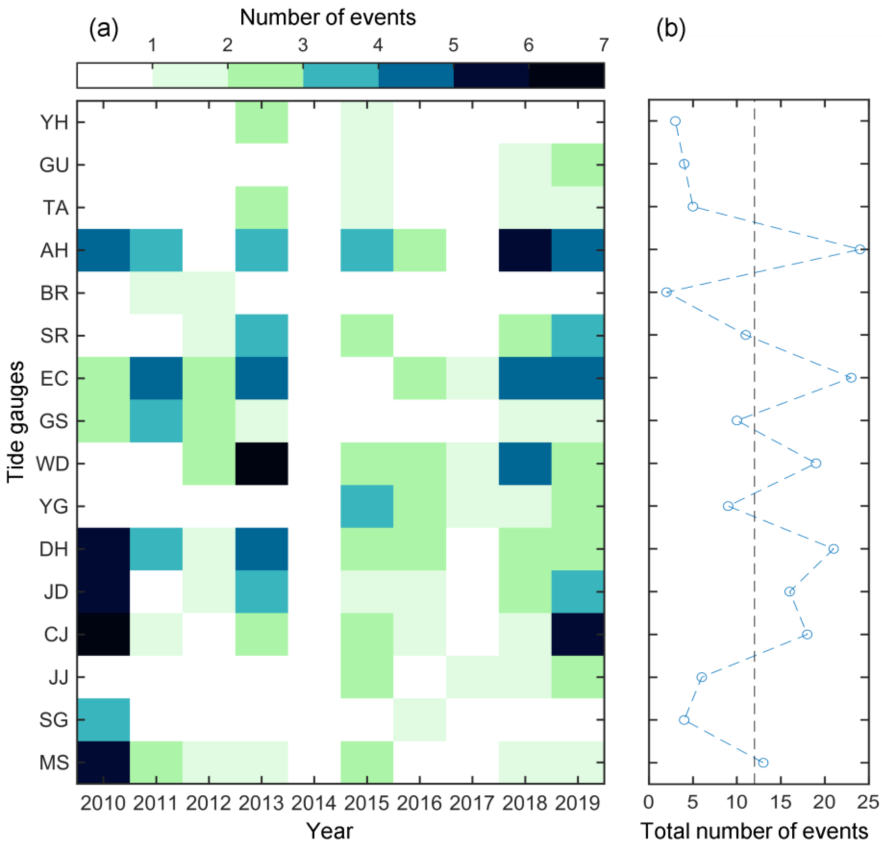
Event date	Lat. A			Lat. B			Lat. C				Lat. D			Lat. E		
	YH	GU	TA	AH	BR	SR	EC	GS	WD	YG	DH	JD	CJ	JJ	SG	MS
10/02/2010	-	-	-	30.6	17.8	-	-	42.2	-	-	43.1	24.6	33.5	-	-	**59.8**
11/02/2010	-	-	-	28.4	11.6	-	-	17.9	-	-	40.9	27.1	49.8	-	53.2	**73.9**
01/03/2010	-	-	-	28.3	-	-	34.9	-	-	-	37.7	24.7	**51.5**	-	-	39.4
03/03/2010	-	-	-	11.4	-	-	15.3	-	-	-	21.6	17.2	21.0	-	**53.3**	37.2
22/03/2010	-	-	-	16.4	-	-	13.9	10.1	-	-	31.5	**36.0**	31.6	-	19.7	24.1
21/04/2010	-	-	-	30.3	-	-	30.2	**33.3**	-	-	24.1	12.2	16.7	-	-	14.9
24/05/2010	-	-	-	-	-	-	19.9	10.5	-	-	**78.4**	28.1	43.1	-	57.5	38.7
26/04/2011[a]	-	-	-	21.3	11.2	-	39.6	18.0	-	-	**132.1**	-	41.8	-	-	46.3
30/04/2011	-	-	-	36.1	20.5	-	41.3	25.9	-	-	**43.1**	16.3	20.2	-	-	38.4
21/05/2011	-	-	-	37.0	-	-	**46.2**	30.6	-	-	24.6	6.9	8.4	-	-	12.0
08/06/2011	-	-	-	36.5	-	-	**48.9**	36.8	-	-	35.6	7.7	11.9	-	27.7	16.4
03/04/2012	9.3	6.1	12.5	13.9	8.3	15.1	13.7	11.7	-	-	27.9	26.7	-	-	42.9	**44.4**
05/07/2012	-	10.1	10.0	-	21.8	29.1	29.7	**31.4**	24.3	-	19.4	8.2	-	-	9.4	17.7
06/07/2012	-	11.3	19.8	-	15.7	14.3	**25.7**	20.5	20.3	-	17.4	10.7	10.7	-	10.5	19.3
20/01/2013	20.8	14.9	**26.3**	23.6	-	12.7	18.2	-	19.4	-	21.7	12.0	13.1	-	15.9	19.2
03/02/2013	6.8	7.8	6.0	15.6	-	14.4	21.2	-	29.4	-	36.0	27.7	23.6	-	22.3	**61.0**
10/03/2013	16.3	–	9.0	–	5.5	13.2	17.5	–	23.7	–	**31.3**	21.6	18.2	–	18.1	29.5
14/04/2013	10.3	15.7	21.5	–	12.1	60.0	**60.7**	19.1	49.6	–	34.2	23.1	21.0	–	–	26.0
29/04/2013	13.3	14.0	15.9	22.3	8.5	25.7	**39.7**	14.8	33.1	–	21.9	8.9	8.9	–	–	11.6
03/07/2013	8.7	6.5	7.5	29.5	–	21.7	17.4	15.7	**42.5**	–	34.6	10.1	15.8	–	10.8	17.1
10/08/2013	**25.8**	–	19.5	–	–	17.0	23.0	20.4	25.1	–	–	7.2	–	–	7.1	5.5
04/04/2015[b]	10.2	16.1	17.7	**48.5**	–	29.5	–	–	20.5	35.3	35.8	20.1	21.7	17.7	29.0	40.1
12/05/2015	–	33.5	13.7	31.4	–	29.0	–	–	32.9	31.6	34.5	18.6	23.6	20.7	**39.2**	19.6
13/06/2015	21.0	18.8	24.1	**38.4**	–	9.8	12.2	–	15.1	22.3	15.2	13.5	9.8	9.3	–	20.9
11/08/2015	5.2	–	4.0	11.2	–	13.6	11.6	4.3	18.2	32.0	17.5	12.8	10.1	31.8	12.1	**33.2**
16/04/2016[b]	5.0	–	6.5	–	5.2	–	11.5	–	11.9	21.1	20.2	25.4	27.6	–	**52.8**	25.8
15/06/2016	12.9	20.5	13.9	**34.4**	11.1	16.3	22.7	–	28.0	30.5	32.6	–	10.9	–	11.8	–
24/06/2016	11.9	11.3	14.7	36.7	–	18.6	26.3	12.8	29.8	44.3	**45.5**	16.5	–	12.4	11.7	22.2
18/04/2017	9.2	15.1	–	–	5.0	15.2	20.7	–	21.8	36.9	–	6.1	–	**41.3**	18.1	11.1
04/03/2018[c]	13.4	–	13.2	33.0	–	–	34.3	45.0	49.7	**67.3**	48.4	25.0	–	–	17.7	34.4
10/04/2018[c]	15.6	–	10.6	**38.2**	–	–	29.6	–	22.2	–	–	8.0	8.6	–	10.5	–
16/05/2018	11.1	13.2	11.2	**32.0**	–	21.2	22.4	–	18.8	–	16.7	7.2	–	–	7.1	9.3
17/05/2018[b]	13.5	24.0	21.2	**35.9**	–	15.5	17.0	15.4	25.6	–	31.7	8.6	15.1	–	10.7	–
09/06/2018	–	–	–	22.2	–	24.6	28.4	–	**32.9**	–	–	11.7	15.0	–	11.5	–
06/10/2018	9.8	–	5.6	17.4	5.2	8.1	10.8	9.7	11.8	13.6	10.4	21.9	25.9	**44.5**	40.0	31.3
20/03/2019[b]	7.9	13.2	14.8	29.1	–	25.5	–	–	–	54.2	**66.4**	28.7	29.8	22.2	25.7	–
30/03/2019	7.6	**35.1**	12.3	21.0	–	11.5	12.0	–	20.8	26.5	29.1	10.3	15.2	11.9	23.6	18.2
07/04/2019	12.8	6.5	5.7	–	–	16.3	18.1	–	14.8	20.2	24.0	22.1	30.3	22.4	30.1	**77.7**
09/04/2019[b]	11.0	19.4	14.7	**31.1**	–	19.5	28.3	–	–	26.4	16.2	15.8	21.6	16.2	23.2	–
06/06/2019	10.7	8.4	8.9	–	–	16.8	24.1	24.8	–	**25.8**	23.3	–	21.2	–	11.8	13.8
07/09/2019	11.2	–	–	**45.6**	–	20.5	31.4	12.8	–	23.4	13.7	34.5	34.3	–	38.8	–
10/11/2019	16.0	29.8	24.3	38.7	–	23.9	29.0	–	30.3	**39.8**	24.1	14.2	–	11.0	11.8	16.0

a: destructive event, b: event revealed by KMA internal reports, c: event captured by KMA real–time monitoring system.

[Figure 6: modified] Temporal meteotsunami occurrences between 2010 and 2019: (a-b) number of events per year and month, (c-d) distribution of wave height according to year and month.



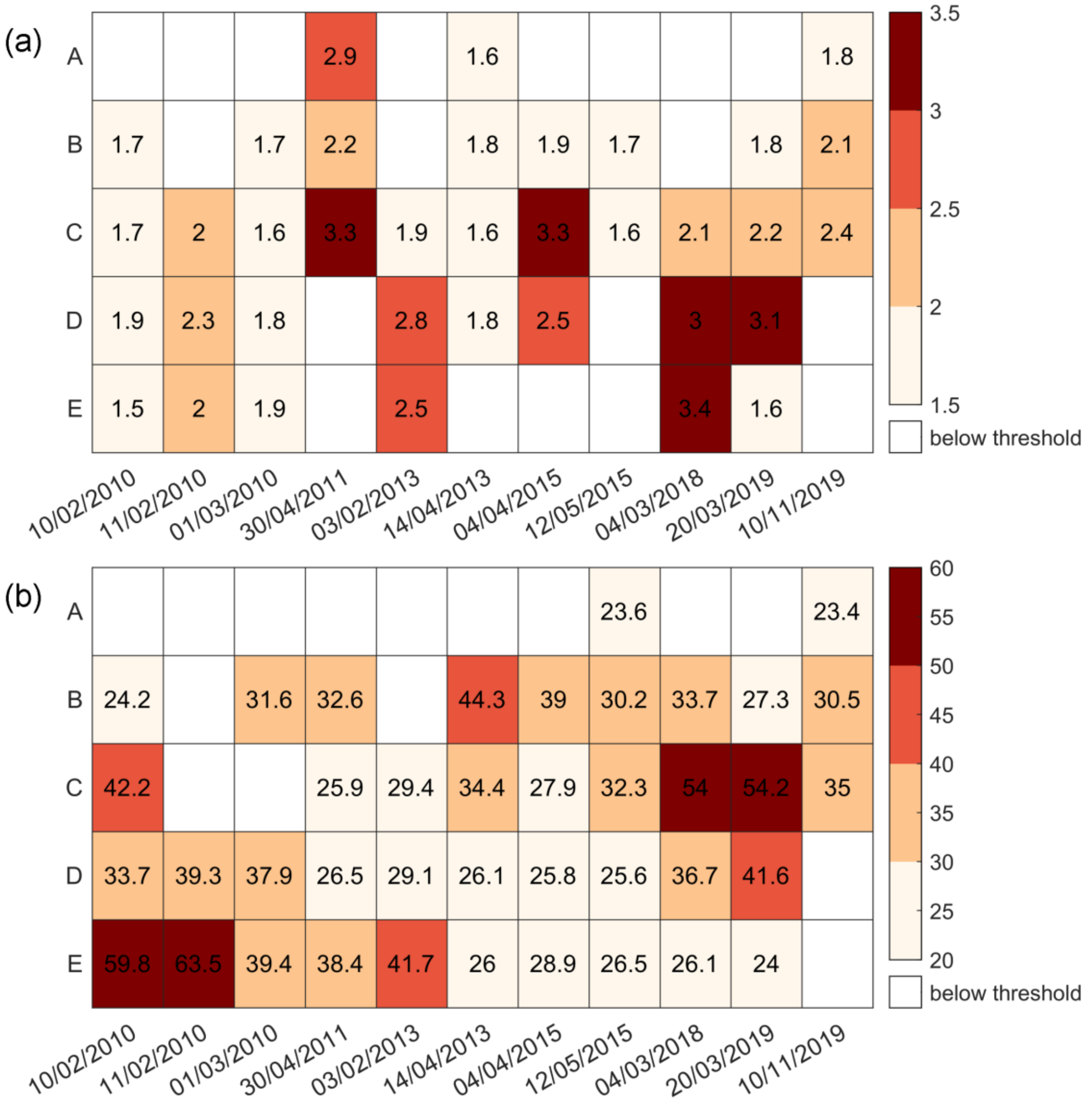
[Figure 7: modified] Spatial meteotsunami occurrences between 2010 and 2019: (a) number of events at each tide gauge per year, (b) total number of events at each tide gauge.



[Table 3: modified] Average intensity and occurrence rate of pressure jump and meteotsunami during extreme meteotsunami events. Extreme meteotsunami event dates are indicated as Day/Month/Year.

Extreme event date	Pressure jump Average intensity (hPa/10 min)	Pressure jump Detected AWSs	Pressure jump Occurrence rate (%)	Meteotsunami Average intensity (cm)	Meteotsunami Detected tide gauges	Meteotsunami Occurrence rate (%)
10/02/2010	1.8	28/87	32	36.0	6/7	86
11/02/2010	2.1	28/87	32	37.9	6/8	75
01/03/2010	1.7	46/86	53	36.1	6/6	100
30/04/2011	2.6	40/86	47	30.2	6/8	75
03/02/2013	2.5	29/88	33	22.7	6/12	50
14/04/2013	1.7	27/88	31	29.4	7/12	58
04/04/2015	2.7	49/88	56	26.3	8/13	62
12/05/2015	1.7	12/89	13	27.4	8/12	67
04/03/2018	2.6	32/89	36	34.7	8/11	73
20/03/2019	2.5	47/88	53	28.9	7/11	64
10/11/2019	2.1	34/87	39	23.8	7/13	54

[Figure 8: modified] Heatmap of extreme meteotsunami events: latitude band-averaged intensity of (a) pressure jump and (b) meteotsunami.



[Equation 1-2: added]

The direction θ and speed U of air pressure jumps were estimated using a triangle of AWSs with coordinates (x_1,y_1), (x_2,y_2), and (x_3,y_3). Šepić et al. (2009) suggested that the traveling air pressure jump can be tracked based on the assumption that (i) air pressure jump does not change during its travel over the domain, and (ii) air pressure jump has a constant direction and speed. The propagation pattern is expressed as follows:

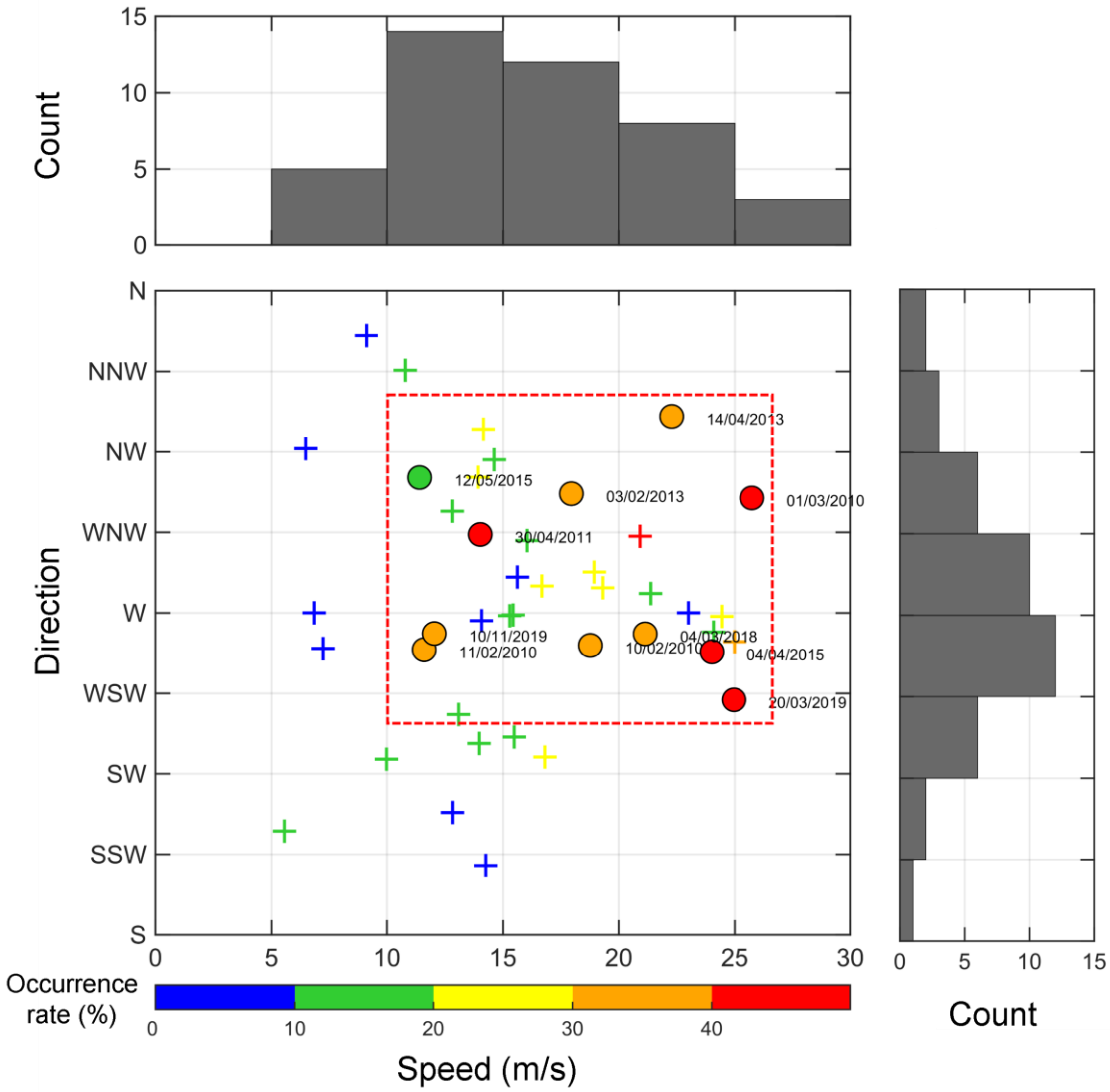
$$tan\theta = a = \frac{\Delta t_{12}\Delta y_{13} - \Delta t_{13}\Delta y_{12}}{\Delta t_{13}\Delta x_{12} - \Delta t_{12}\Delta x_{13}}, \quad (1)$$

$$U = \frac{1}{\Delta t_{12}}\frac{\Delta y_{12} - a\Delta x_{12}}{\sqrt{1+a^2}} = \frac{1}{\Delta t_{13}}\frac{\Delta y_{13} - a\Delta x_{13}}{\sqrt{1+a^2}}, \quad (2)$$

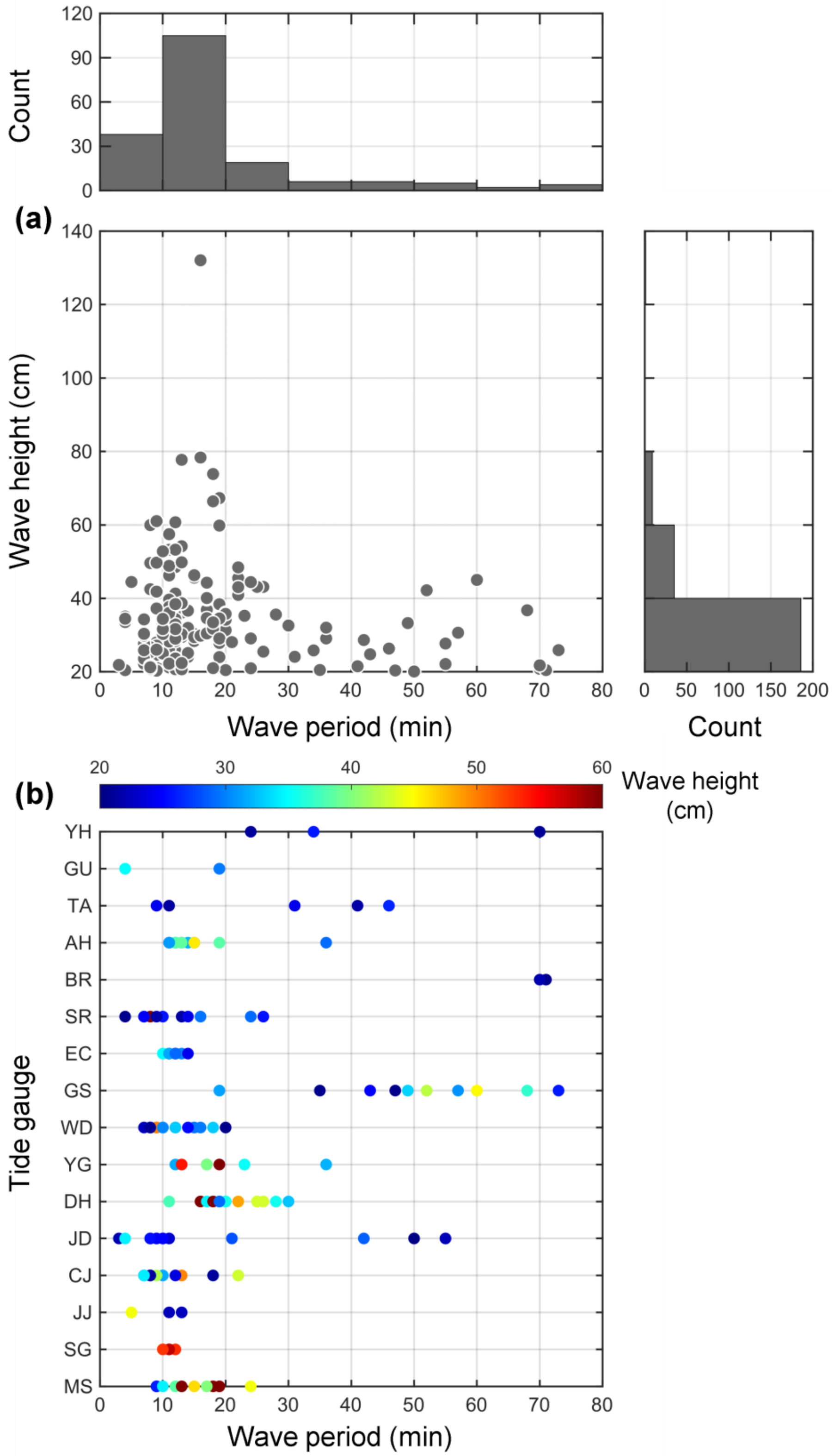
where Δt_{12} and Δt_{13} are the time lags between each AWS; Δx_{12}, Δx_{13}, Δy_{12}, and Δy_{13} are distances between each AWS in the east-west and north-south direction, respectively.

- Šepić, J., Denis, L., Vilibić, I., 2009. Real-time procedure for detection of a meteotsunami within an early tsunami warning system. Phys. Chem. Earth 34, 1023–1031. https://doi.org/10.1016/j.pce.2009.08.006

[Figure 11: modified] Scatter diagram and histograms showing propagation characteristics (speed, direction, and occurrence rate) of air pressure jump on 42 meteotsunami events. Red dashed square encloses dominant range of speed and direction of air pressure jump. Circles mark 11 extreme events classified based on occurrence rate of meteotsunamis. The other 31 events are marked with cross marker. Colors of each marker indicate the occurrence rate of air pressure jumps.



[New Figure] Local amplification of meteotsunamis in semi-closed basins. (a) Scatter diagram of wave period to wave height of the classified 42 meteotsunami events, and histogram. (b) distribution of wave period at each tide gauge.



Other figures and tables will be updated after the final response.

[Figure 1]

[Table 1]

[Figure 3] will be deleted (prior criterion).

[Figure 4] will be modified in the revised manuscript.

[Figure 5] will be modified in the revised manuscript.

[Figure 9] will be modified in the revised manuscript.

[Figure 10] will be modified in the revised manuscript.

[New Figure] indicating the conceptual diagram of the meteotsunami warning system will be added as last figure.

Google Earth satellite images indicating the semi-closed basins in which the tide gauges (red squares) are located will be added as the appendix.