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 #3:

The manuscripts documents a climatology of meteotsunami events, by a systematic examination of sea level and air pressure data in a 10-years period. I found the presented material interesting, worth of publication, yet - as Reviewer #2 commented - the level of language is really not at satisfactorily level, which does not apply only to pure syntax and grammar, but also on sentence constructions and some terminology. So, the language should be improved before eventual acceptance.

I will not repeat comments of other reviewers, in particular of these being the result of language problems, but to add the following:

→ We want to thank the reviewer for his/her valuable comments and considerable contribution for improving the quality of the research. As you commented, we will use one more round of English proofing when submitting the revised manuscript. Please also check "Response to Comments (figures, tables, and equations)".

[Specific comments]

1. "monitoring guidelines" should be omitted for the title, as this is not examined but only discussed in the manuscript.

   → This comment is planned to be modified after the final response.

2. Line 13. "Spatially frequent" cannot be used to describe something happening at a single tide gauge, please rephrase.

   → This comment is planned to be modified after the final response.

3. Line 126 and more. "meteotsunami event of accident" - it should be better to say "destructive meteotsunami events" or else. Even more, for classification of meteotsunami events you may use the newly proposed classification of meteotsunami intensities by Vilibic et al. (NH, 2021, https://doi.org/10.1007/s11069-021-04679-9).

   → The comments about rephrasing are planned to be modified after the final response. We thank the reviewer for providing the literature reference. The intensity scale and spatial coverage scales are useful but need to be adapted to our study area. We plan to apply that scale in our next study.

4. Lines 248-250. Several problems in this sentence, including "yellow sea" with small letters ... Change to something like "... is expected to be a beacon tide gauge.", and

omit "under any pressure disturbances" (as not necessary). What is "first meteotsunami"? (again clumsiness in language)

→ This comment is planned to be modified after the final response.

5. Lines 278-280. That is for sure, and even quantified for the Adriatic - see Fig. 7 in Denamiel et a. (2020, JPO, https://doi.org/10.1175/JPO-D-19-0147.1) .

   → As you commented, we will refer to the publication. Of the six parameters of the atmospheric disturbance (amplitude, direction, speed, period, start location, and width), it seems possible to discuss about five variables except for the start location. Thank you for your advice.

6. Line 325-326. Why? As it is known that it is not key factor in some other parts of the world (see previous comment)

   → [Similar comments from Reviewer #1 (major comment #2)]

   → 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.

   - Kim, M.-S., Eom, H., You, S.-H., Woo, S.-B., 2021a. Real-time pressure disturbance monitoring system in the Yellow Sea: pilot test during the period of March to April 2018. Nat. Hazards. https://doi.org/10.1007/s11069-020-04245-9

   - 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

7. Lines 334-347. Is it necessary to provide the explicit formula for computation of air pressure disturbance and speed.

   → The propagation patterns of the classified 42 meteotsunami events were analyzed as follows:

(1) The intensity and movement of rain rate exceeding 5 mm/h were confirmed by visual inspection (Kim et al., 2021a).

(2) Arrival time list and isochrone map of air pressure jump were estimated in the area where the high rain rate propagated (Figure 9).

(3) Direction and speed were assessed using the three points of AWSs based on the explicit formula suggested by Šepić et al. (2009). Equations are specified in Response to Comments (figures, tables, and equations).

- Kim, M.-S., Eom, H., You, S.-H., Woo, S.-B., 2021a. Real-time pressure disturbance monitoring system in the Yellow Sea: pilot test during the period of March to April 2018. Nat. Hazards. https://doi.org/10.1007/s11069-020-04245-9

- 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

8. Lines 363-367. Can you discuss eventual connection between synoptic patterns and meteotsunami occurrence also in Yellow Sea? I.e. by examining climate of synoptic patterns above Yellow Sea or Korean Peninsula (as published in literature) or similar?

→ We will discuss possible connection between the following synoptic patterns and meteotsunami occurrences based on previous results (Kim et al., 2016, 2017). According to previous results, the spring season (March to May) in the Korean peninsula has the seasonal characteristics of a migratory anticyclone and an extratropical depression generated in the Tibet and Mongolian plateau passing through the Yellow Sea every three or four days. The spatial distribution of the atmospheric pressure system generally increases the potential atmospheric instability in the Yellow Sea. Atmospheric instability (e.g., pressure jump, low-level jet), which can lead to fluctuations of the sea level, often increase when a cold front in an extratropical depression passes through the Yellow Sea.

- Kim, H., Kim, M.-S., Lee, H.-J., Woo, S.-B., Kim, Y.-K., 2016. Seasonal characteristics and mechanisms of meteo-tsunamis on the west coast of Korean Peninsula. J. Coast. Res. 75, 1147–1151. https://doi.org/10.2112/SI75-230.1

- Kim, H., Kim, M.-S., Kim, Y.-K., Yoo, S.-H., Lee, H.-J., 2017. Numerical weather prediction for mitigating the fatal loss by the meteo-tsunami incidence on the west coast of Korean Peninsula. J. Coast. Res. 79, 119–123. https://doi.org/10.2112/SI79-025.1

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

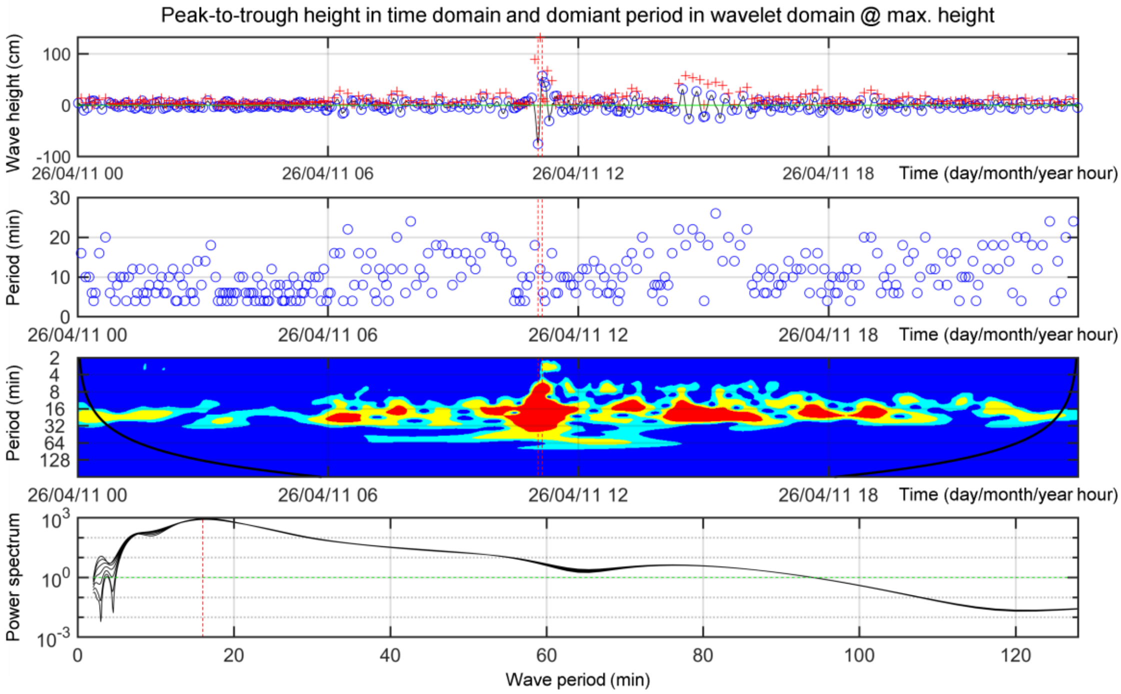
Radar image analysis through visual inspection + linear speed and direction using 2 AWS → radar image analysis through visual inspection + pressure tendency method using 3 AWS (Šepić et al., 2009)

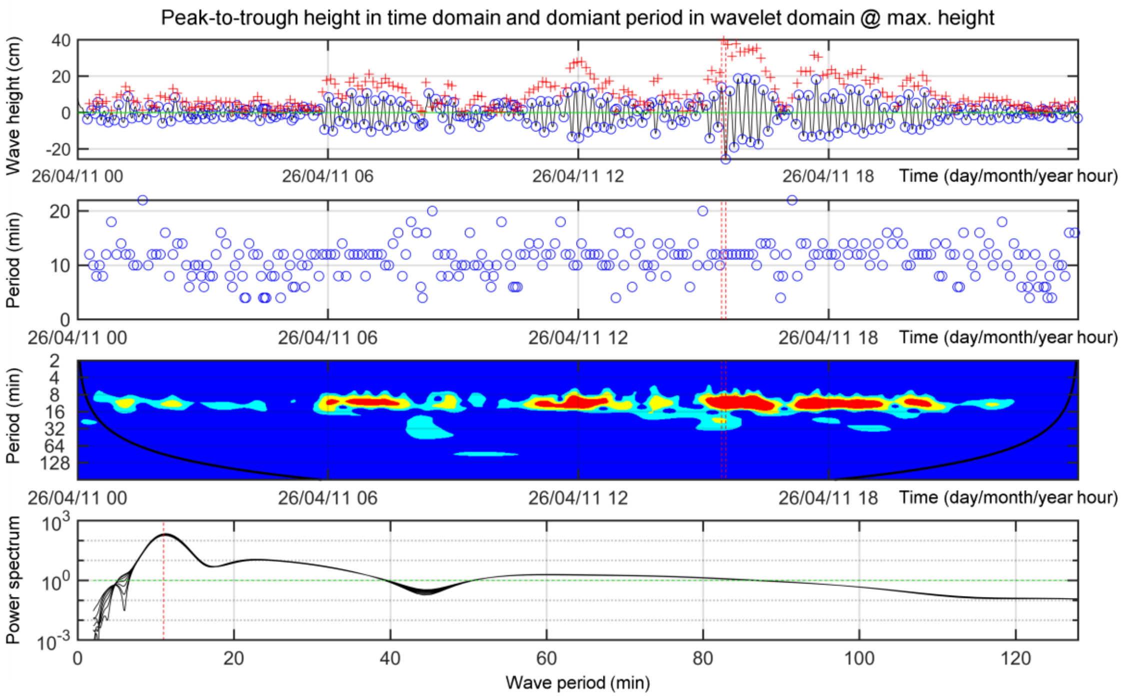
(5) Local amplifications in multiple harbors

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.



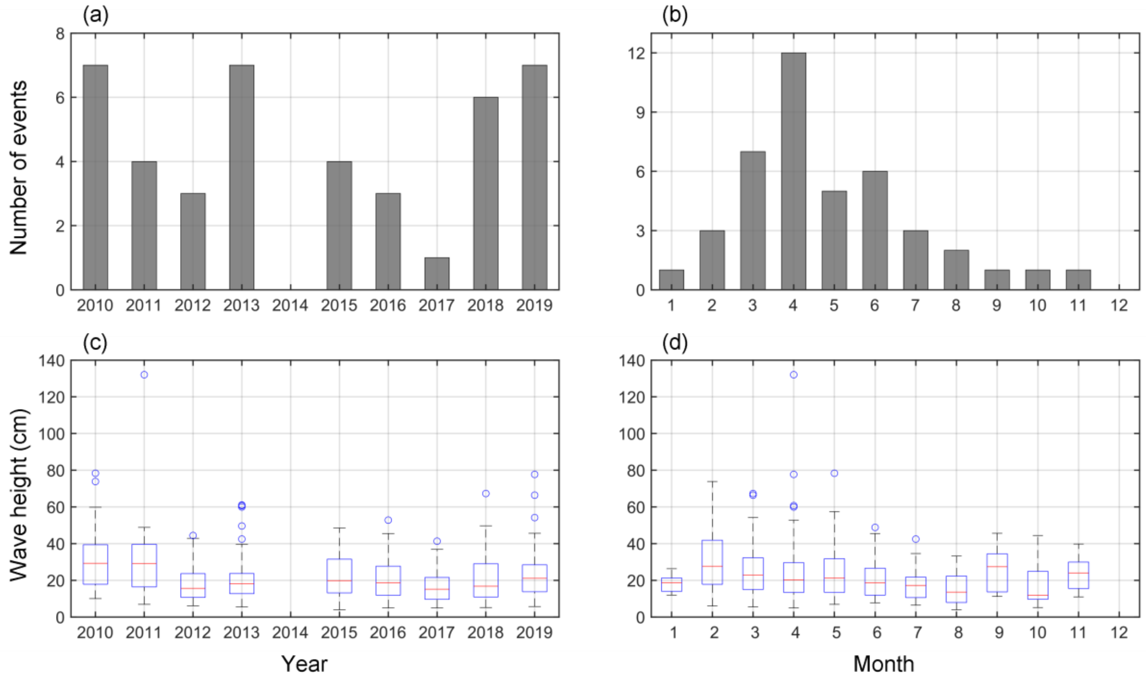


[Table 2: modified] Daily maximum wave height (cm) during 42 meteotsunami events. The reported events since 2010 are denoted by superscript. The strongest intensity of each event are marked by underlined and bold text. The events are indicated as Day/Month/Year.

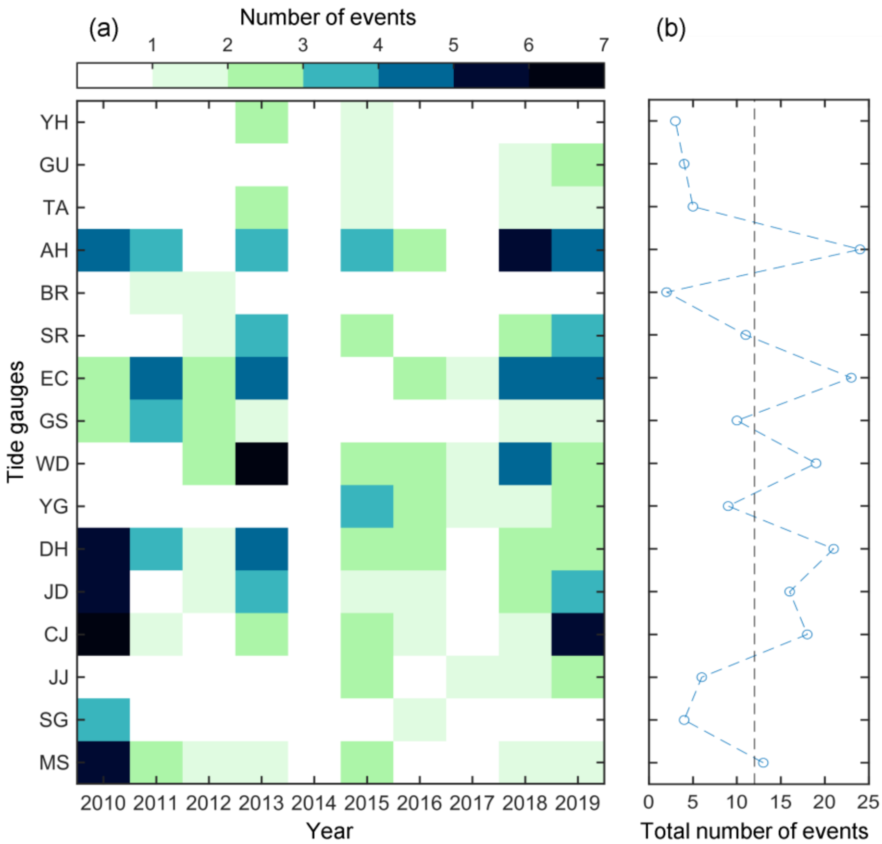
Event date		Lat. A			Lat. B			Lat. C				Lat. D			Lat. E	
	YH	GU	TA	AH	BR	SR	EC	GS	WD	YG	DH	JD	CJ	JJ	SG	MS
10/02/2010	-	-	-	30.6	17.8	-	-	42.2	-	-	43.1	24.6	33.5	-	-	**59.8**
11/02/2010	-	-	-	28.4	11.6	-	-	17.9	-	-	40.9	27.1	49.8	-	53.2	**73.9**
01/03/2010	-	-	-	28.3	-	-	34.9	-	-	-	37.7	24.7	**51.5**	-	-	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.



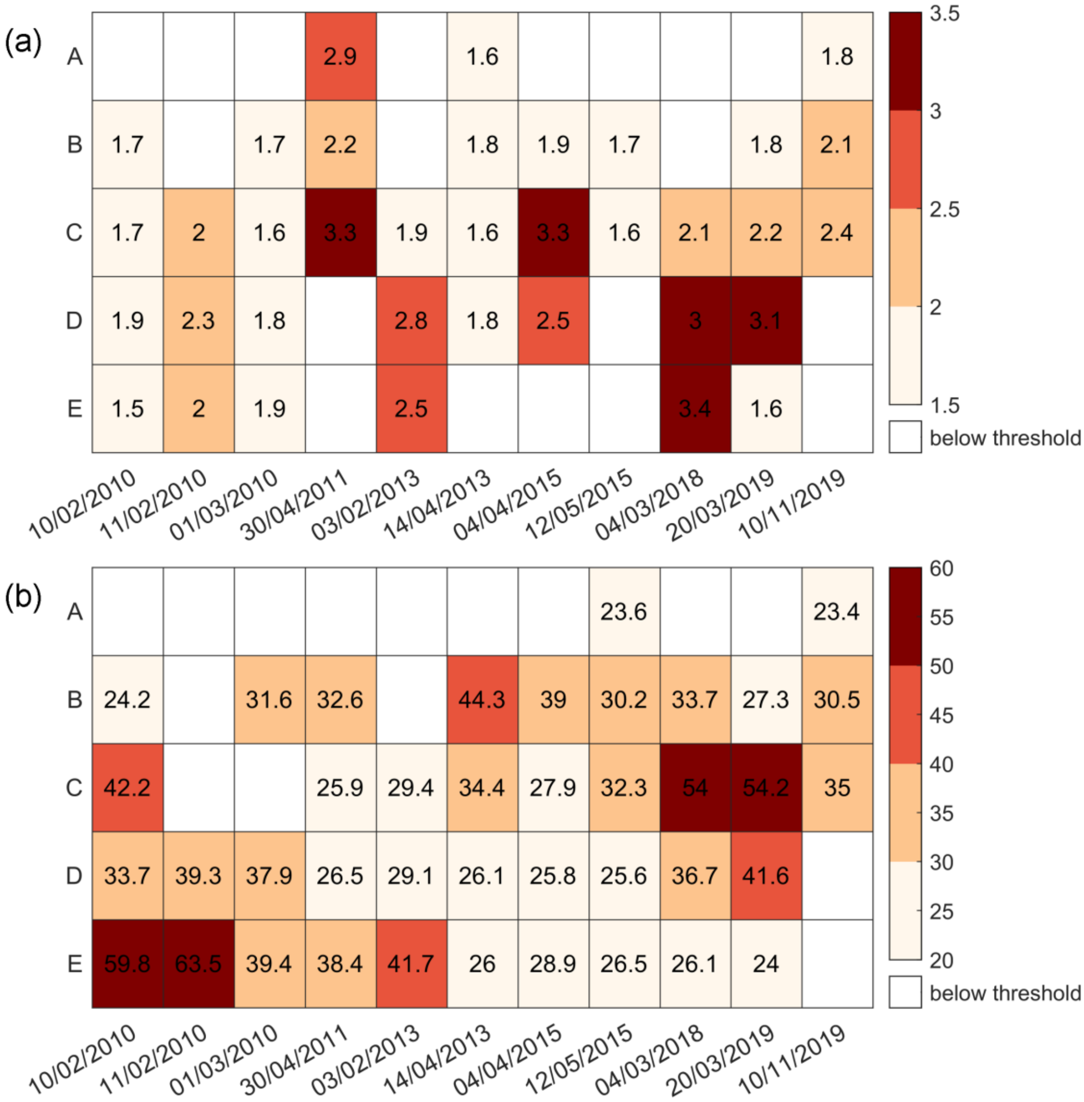
[Figure 7: modified] Spatial meteotsunami occurrences between 2010 and 2019: (a) number of events at each tide gauge per year, (b) total number of events at each tide gauge.



[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:

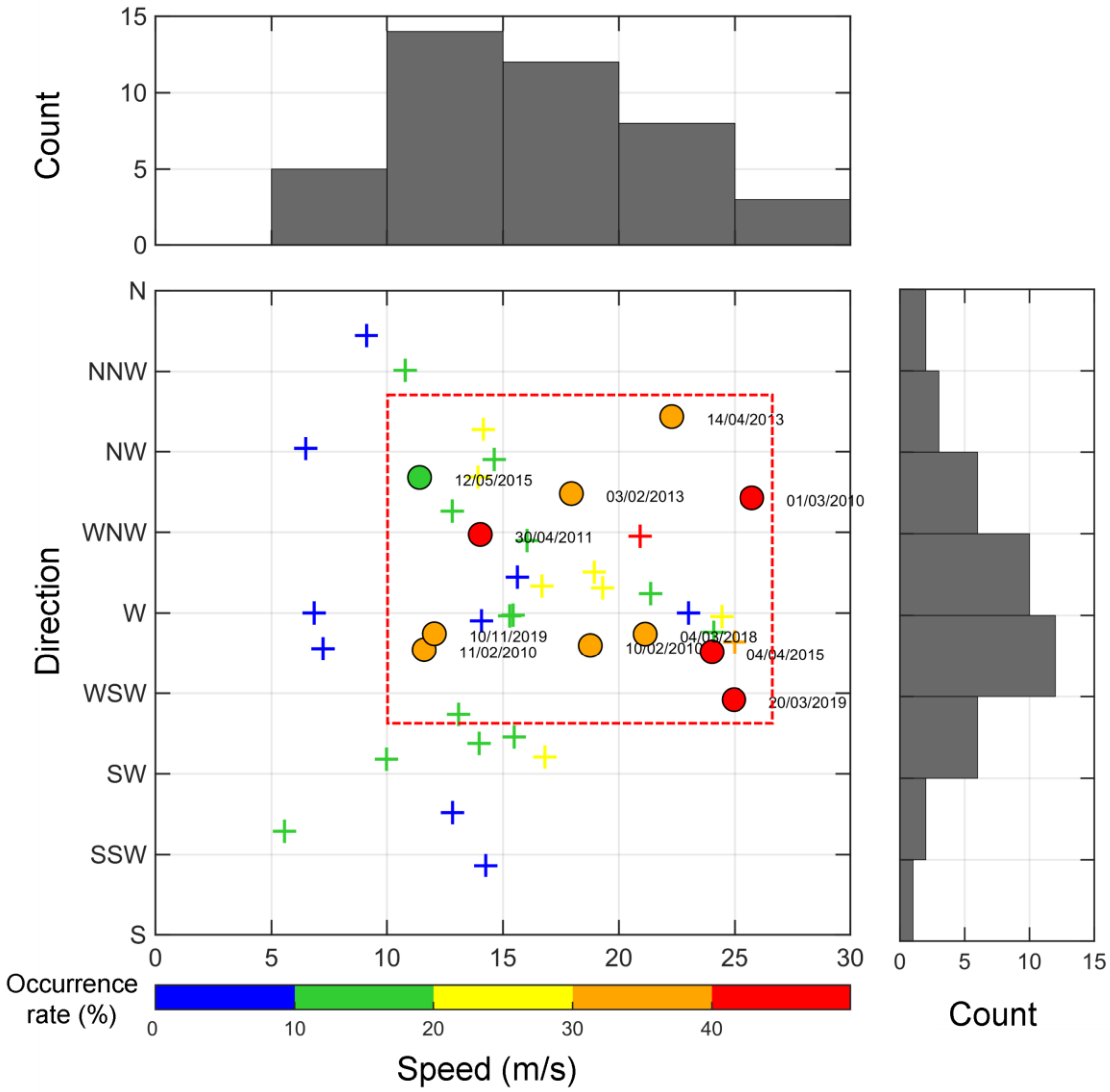
$$tan\theta = a = \frac{\Delta t_{12}\Delta y_{13} - \Delta t_{13}\Delta y_{12}}{\Delta t_{13}\Delta x_{12} - \Delta t_{12}\Delta x_{13}}, \quad (1)$$

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

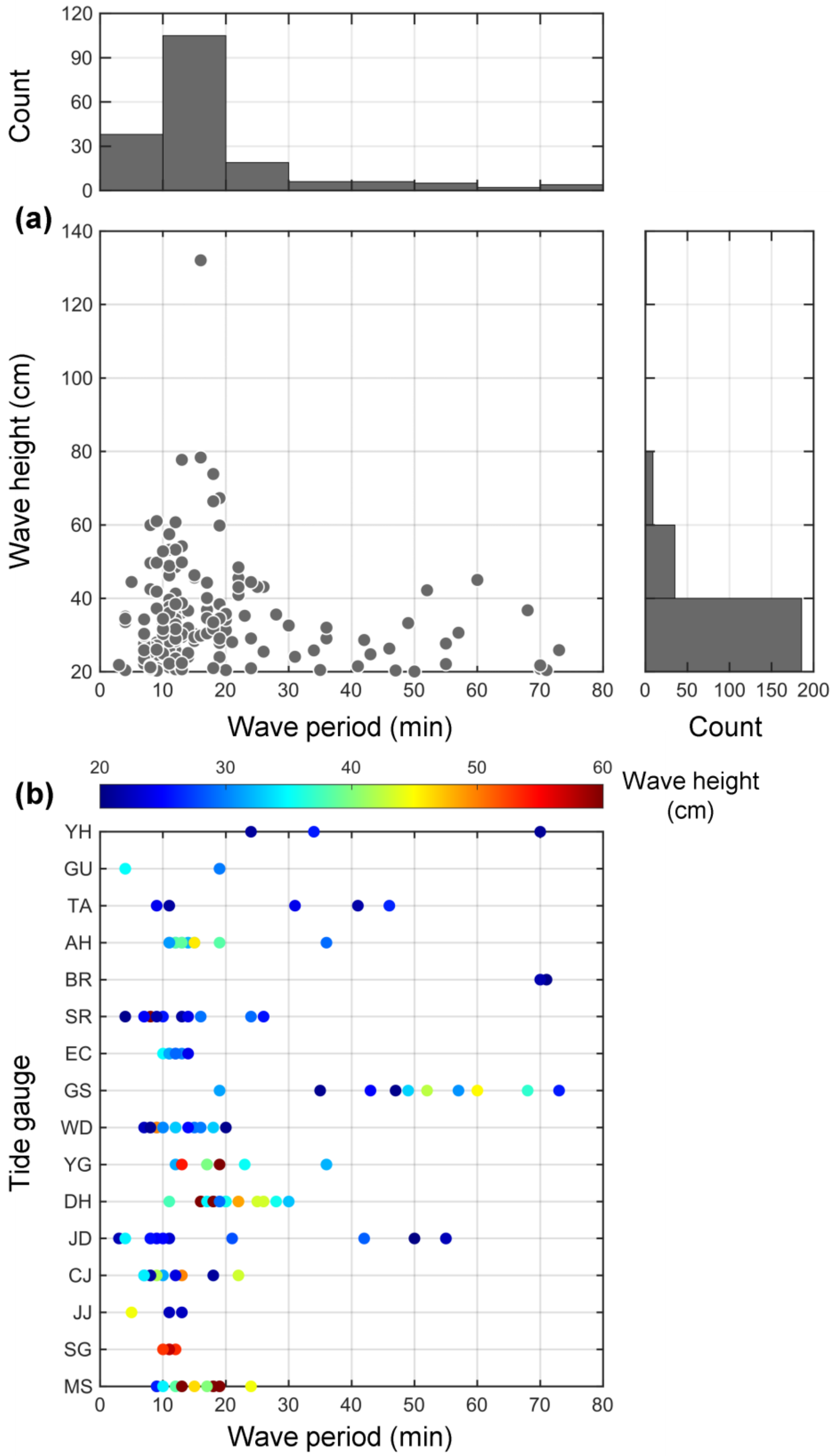
where Δt_{12} and Δt_{13} are the time lags between each AWS; Δx_{12}, Δx_{13}, Δy_{12}, and Δy_{13} are distances between each AWS in the east-west and north-south direction, respectively.

- 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.