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The first attempt at cataloguing tsunami-like waves of meteorological origin in Croatian coastal waters

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A catalogue of waves, which belong to the same frequency band as tsunamis but are of meteorological origin, is compiled for the Croatian part of the Adriatic Sea. The catalogue presently includes 21 flooding events observed between the years 1931 and 2010. The areas most often affected were Vela Luka on the island of Korčula and Stari Grad on the island of Hvar. A majority of the events occurred in the warm part of the year. The events tended to start either early in the morning or late in the afternoon, to last between 1 and 6 hours, and to be dominated by sea-level oscillations of 10-40 min periods. The largest trough-to-crest height of 6 m was observed in Vela Luka on 21 June 1978.

Key words: cataloguing, tsunami-like waves, meteorological origin, Croatian coastal waters

INTRODUCTION

This study addresses the waves that belong to the same frequency band as tsunamis but with two important differences: their cause originates in the atmosphere rather than at the sea bottom, and they usually represent a mixture of forced and free waves and are therefore distinguishable from the pure free waves. In the Croatian language, a wave of this type is called "šćiga", and the corresponding terms in other languages are meteotsunami, abiki, rissaga, marrubbio or marrobbio…

The causes of these waves are various mesoscale atmospheric phenomena, such as gravity waves, squall lines, and convective systems. More often than not, the atmospheric forcing processes are relatively weak, and the generation of pronounced waves in the sea depends on the resonant transfer of energy from the atmosphere to the sea. Two types of resonance have been found to play roles. In one case, the frequency and wave number of the forcing equals the frequency and wave number of a wave in the open sea; in the other case, the frequency of the forcing equals the frequency of a normal mode in the coastal basins.

Both types of resonance were originally studied by tidal theorists (e.g., AIRY, 1845) and have subsequently been considered by researchers interested in the atmosphere-sea interaction. In the latter sub-discipline, several milestones were reached: the study of coastal resonance by HONDA *et al.* (1908), the investigation of the open-sea resonance by PROUDMAN (1929), the first numerical modeling of the open-sea resonance by PLATZMAN (1958), and the early numerical modeling of the combined open-sea and coastal resonance by HIBIYA & KAJIURA (1982); these studies were inspired by events observed in Kushimoto Bay (1904), the English Channel (1929), Lake Michigan (1954), and Nagasaki

Table 1. The list of tsunami-like waves of meteorological origin in Croatian coastal waters. Only the cases with a trough-to-crest height larger than approximately 1 m are included in the list. The meaning of all entries is obvious except in the next-to-the-last column where the indicators of the quality of available information are (1) elementary description of sea-level variability, (2) advanced description of sea-level variability, (3) description of sea-level variability combined with an analysis of meteorological data, (4) analysis of oceanographic and meteorological data supplemented by oceanographic or meteorological modeling, and (5) analysis of oceanographic and meteorological data combined with both oceanographic and meteorological modeling

Number	Location	Date	Height (m)	Onset time (LT)	Duration of the event (h)	Period of oscillations (min)	Comment	Quality indicator	Source
1	Vela Luka	21/7/1931	/	/	/	/	/	1	TABAIN & TABAIN (1994)
2	Vela Luka	28-29/5/1935	/	/	/	/	/	1	TABAIN & TABAIN (1994)
3	Vela Luka	12/9/1937	/	/	/	/	Storm surge at Bakar	1	TABAIN & TABAIN (1994)
4a	Vela Luka	11-12/11/1951	/	/	/	/	Storm surge at Bakar	1	TABAIN & TABAIN (1994)
4b	Stari Grad	11-12/11/1951	/	/	/	/	Storm surge at Bakar	1	*Slobodna Dalmacija* (14/11/1951)
4c	Vrboska	11-12/11/1951	/	/	/	/	Storm surge at Bakar	1	*Slobodna Dalmacija* (14/11/1951)
4d	Jelsa	11-12/11/1951	/	/	/	/	Storm surge at Bakar	1	*Slobodna Dalmacija* (14/11/1951)
5	Vela Luka	21/7/1956	/	/	/	/	/	1	TABAIN & TABAIN (1994)
6	Korčula and the channel	27/8/1966	1.65	16:00	2	15	/	2	*Vjesnik* (29/8/1966)
7	Vela Luka	4/11/1966	/	/	/	/	Storm surge at Bakar	1	TABAIN & TABAIN (1994)
8	Vela Luka	10/2/1972	2	11:00	5.5	/	/	2	TABAIN & TABAIN (1994)
9	Vela Luka	21/8/1977	4	/	/	/	/	2	*Slobodna Dalmacija* (24/8/1977)
10	Vela Luka	19-20/9/1977	4	22:00	4.5	25	/	2	*Vjesnik* (21/9/1977), *Slobodna Dalmacija* (22/9/1977)
11a	Vela Luka	21/6/1978	6	5:15	3	15	/	5	ORLIĆ (1980), VUČETIĆ & BARČOT (2008), ORLIĆ *et al.* (2010)
11b	Ubli	21/6/1978	4	/	/	/	/	5	VUČETIĆ & BARČOT (2008), ORLIĆ *et al.* (2010)
11c	Slano	21/6/1978	4	/	/	/	/	5	VUČETIĆ & BARČOT (2008), ORLIĆ *et al.* (2010)
11d	Koločep	21/6/1978	4	/	/	/	/	5	VUČETIĆ & BARČOT (2008), ORLIĆ *et al.* (2010)
11e	Komolac	21/6/1978	4	5:15	/	/	/	5	VUČETIĆ & BARČOT (2008), ORLIĆ *et al.* (2010)
11f	Gruž	21/6/1978	4	/	/	/	/	5	VUČETIĆ & BARČOT (2008), ORLIĆ *et al.* (2010)
11g	Vis	21/6/1978	2	6:15	/	/	/	5	VUČETIĆ & BARČOT (2008), ORLIĆ *et al.* (2010)
11h	Cavtat	21/6/1978	2	/	/	/	/	5	VUČETIĆ & BARČOT (2008), ORLIĆ *et al.* (2010)
12	Vela Luka	6/7/1978	2	/	/	/	/	2	*Slobodna Dalmacija* (7/7/1978)
13	Vela Luka	12/2/1979	2	13:00	6	/	Storm surge at Bakar	2	TABAIN & TABAIN (1994)
14a	Stari Grad	10/7/1980	2.5	5:00, 17:30	/	40	Storm surge at Bakar	2	*Slobodna Dalmacija* (11/7/1980), *Vjesnik* (11/7/1980), *Večernji list* (11/7/1980), *Slobodna Dalmacija* (12/7/1980)
14b	Vela Luka	10/7/1980	/	/	/	/	Storm surge at Bakar	1	*Vjesnik* (11/7/1980)
15	Ist	5/10/1984	4	/	/	/	Storm surge at Bakar	2	VILIBIĆ & ŠEPIĆ (2009)
16a	Rogoznica	26/7/1987	/	/	/	/	/	1	ZORE-ARMANDA (1988)

16b	Nečujam	26/7/1987	/	/	/	/	/	1	ZORE-ARMANDA (1988)
16c	Milna	26/7/1987	/	16:00	/	/	/	1	ZORE-ARMANDA (1988)
16d	Korčula	26/7/1987	/	/	/	/	/	1	ZORE-ARMANDA (1988)
17a	Stari Grad	27/6/2003	3.5	6:00	/	/	/	5	*Slobodna Dalmacija* (28/6/2003), *Večernji list* (28/6/2003), *Vjesnik* (28/6/2003), VILIBIĆ *et al.* (2004), BELUŠIĆ *et al.* (2007)
17b	Mali Ston	27/6/2003	/	7:15	/	/	/	5	*Slobodna Dalmacija* (28/6/2003), *Vjesnik* (28/6/2003), VILIBIĆ *et al.* (2004), BELUŠIĆ *et al.* (2007)
18	Vrboska	24/5/2006	/	/	/	/	/	1	Personal communication of Vera Irving to M. Orlić (16/12/2006)
19	Ist	22/8/2007	4	17:30	1	10	/	4	Interviews of M. Orlić with eyewitnesses on the island of Ist (24/8/2007), *Večernji list* (24/8/2007), *Jutarnji list* (24/8/2007), *Slobodna Dalmacija* (24/8/2007), VILIBIĆ & ŠEPIĆ (2009), ŠEPIĆ *et al.* (2009)
20	Mali Lošinj	15/8/2008	3.5	18:50	1	20	/	3	*Večernji list* (16/8/2008), *Slobodna Dalmacija* (17/8/2008), *Vjesnik* (18/8/2008), Interview of M. Orlić with harbor master Zoran Tomić (21/8/2008), BELUŠIĆ & STRELEC MAHOVIĆ (2009)
21	Stari Grad	19/2/2010	3	/	/	/	Storm surge at Bakar	3	*Slobodna Dalmacija* (21/2/2010), *Jutarnji list* (21/2/2010), *Večernji list* (21/2/2010), ŠEPIĆ & VILIBIĆ (2011)

Bay (1979), respectively. The studies were later enhanced in response to many more events observed all around the world (see, e.g., RABINOVICH, 2009; and references cited therein).

The two types of resonance were often found to coexist, which thus supports the occurrence of sea waves that are highly localized. Consequently, it is difficult to document the waves with the standard tide-gauge networks, and observations – as opposed to measurements – are still an important source of information on these waves.

In the present study, a list of tsunami-like waves of meteorological origin, which were observed in Croatian coastal waters from the 1930s onwards, are presented. The note is dedicated to the memory of the late Dr. Mira ZORE-ARMANDA. Although her research interest mostly focused on hydrographic properties and the residual circulation of the Adriatic Sea, she wrote about tsunami-like waves on several occasions, and although Mira ZORE-ARMANDA tended to interpret most of these waves as tsunamis, which did not stand the test of time except in one case, she helped to preserve the memory of many of the cases and to render the present catalogue as complete as possible.

AN OVERVIEW OF THE EVENTS

The initial information used to build the present catalogue is contained in a couple of papers (ZORE-ARMANDA, 1988; TABAIN & TABAIN, 1994), as well as in the notes kept by the author over the last thirty or so years. For all the dates when tsunami-like waves possibly occurred, newspapers were inspected to find articles describing the waves. The first cases considered were from the early 1930s because prior events were usually attributed to the year only and are therefore not easily verified.

Two verifications were performed for all of the dates. The first check was a comparison with an earthquake catalogue (HERAK *et al.*, 1996, with updates) to ensure that an event in the sea was

Fig. 1. Photographs illustrating important flooding events in the Croatian part of the Adriatic Sea.

not preceded by a major earthquake. It turned out that only one of the initial cases – the event of 15 April 1979 – was a tsunami, and it was therefore not included in the present catalogue. The second check was a comparison with sea-level records from Bakar, the oldest Croatian tide-gauge station, with the aim of detecting a possible storm surge in the Adriatic on the day considered. Because the occurrence of tsunami-like waves of meteorological origin may coincide with the development of storm surge, inexperienced observers may easily confuse the two phenomena. Consequently, all cases when the sea level at Bakar surpassed the mean sea level by 50 cm were marked in the catalogue to indicate that additional data and/or modeling may be needed to verify their true nature.

To each event, an indicator of the quality of available information was assigned. The indicator was selected from a five-grade scale as follows: 1) elementary description of sea-level variability; 2) advanced description of sea-level variability; 3) description of sea-level variability combined with an analysis of meteorological data; 4) analysis of oceanographic and meteorological data supplemented by oceanographic or meteorological modeling, and 5) analysis of oceanographic and meteorological data com-

bined with both oceanographic and meteorological modeling.

The list of events is presented in Table 1, and some of the floods are illustrated in Fig. 1. Only the waves surpassing ca. 1 m in height are included in the table. Thus, for example, the weaker events that were identified by ŠEPIĆ *et al.* (2012) from the Rovinj tide-gauge records are not included in the present table. All the selected cases are described here in detail in chronological order.

21 July 1931, Vela Luka

The first event in the present catalogue was recorded in the diary of Nikola TABAIN in Vela Luka on the island of Korčula (TABAIN & TABAIN, 1994). His record on this date reads "flood, ebb, waterspout, wind, rain".

28-29 May 1935, Vela Luka

Again, the only source of information is the diary of Nikola Tabain (TABAIN & TABAIN, 1994), and in this case his description mentions "large seiche during the night".

12 September 1937, Vela Luka

This is another early event recorded by Nikola TABAIN (TABAIN & TABAIN, 1994) who described it as "large seiche, rain and wind". It coincided with a storm surge at Bakar.

11-12 November 1951, Vela Luka, Stari Grad, Vrboska, Jelsa

Nikola TABAIN recorded the occurrence of "a large unprecedented seiche, which caused many damage to some people" in Vela Luka (TABAIN & TABAIN, 1994). The event was also mentioned in daily newspaper article (Slobodna Dalmacija, 14 November 1951) in which it is stated that an occasionally high sea level caused heavy damage in Stari Grad, Vrboska and Jelsa on the Hvar Island. Again, the event coincided with a storm surge at Bakar.

21 July 1956, Vela Luka

In his diary, Nikola TABAIN mentions the occurrence of "a large flood in the morning" in Vela Luka on this date (TABAIN & TABAIN, 1994).

27 August 1966, Korčula and the channel off it

This event is described with remarkable details in a newspaper article (Vjesnik, 29 August 1966). It is stated that in the town of Korčula and on the nearby Pelješac peninsula "between 16 and 18 hours sea level suddenly rose and fell eight times. Maximum difference in the height amounted to 165 cm." It is also mentioned that "the boats … remained for a while in the sea and afterwards they were in a danger of being trapped on the land. The area to the east of the Culture Center was … flooded by a half meter of water." The notice finishes with the statement that "nobody offered an explanation of the phenomenon up to now. Otherwise, there was a complete calm in both the sea and atmosphere. The sky was completely covered by clouds."

4 November 1966, Vela Luka

The event is described by Nikola Tabain in his diary as "seiche, stormy sirocco" (TABAIN & TABAIN, 1994). As is well known, the event coincided with one of the largest storm surges in the Adriatic Sea, which resulted in record-breaking sea levels not only in Bakar but also elsewhere in the North Adriatic – for example, in Venice (DE ZOLT *et al.*, 2006).

10 February 1972, Vela Luka

TABAIN & TABAIN (1994) cite a report, issued by the Harbor Master Office, which states "on 10 February 1972 at approximately 11:00 hours sea-level rising and falling was observed in Vela Luka, and it culminated at approximately 16:30 hours with sea level reaching ca. 1 m above mean sea level... When sea level was at the maximum, a part of the road in the area of Kale and Vranac was flooded."

21 August 1977, Vela Luka

It is stated in a newspaper article (Slobodna Dalmacija, 24 August 1977) that the "sea level suddenly rose to a two-meter height, so that the whole Vela Luka wharf was flooded, and the sea entered many basements and thus caused many damage. The sea has "put ashore" several

boats and a yacht… The flood also destroyed approximately 30 square meters of the operational coast."

19-20 September 1977, Vela Luka

The event is covered by two newspaper articles. In one of the articles (Vjesnik, 21 September 1977), it is emphasized that "unprecedentedly large differences between flood and ebb, amounting to four meters, kept in suspense hundreds of inhabitants …in the night between 19 and 20 September." It is mentioned elsewhere in the article that the event started at approximately 22 hours in the evening, that until 2:30 hours in the morning the sea level rose and fell eleven times, and that the phenomenon was accompanied by a large storm, strong wind and heavy rain. In another article (Slobodna Dalmacija, 22 September 1977), it is mentioned that "the sea flooded basements of many residential and other houses, especially in the Kale cove, and it also dragged to the bottom several boats that were tied to the coast. The phenomenon caused a considerable material damage."

21 June 1978, Vela Luka, Ubli, Slano, Koločep, Komolac, Gruž, Vis, Cavtat

This is the most pronounced event observed in the Adriatic Sea so far and is therefore one of the most studied. The basic data on sea-level variability in Vela Luka are provided by ORLIĆ (1980), who carried out interviews with eyewitnesses between 16 and 20 June 1980. The information on the phenomenon as it was observed not only in Croatian towns but also in Italian towns is contained in numerous newspaper articles, a collection of which was published by VUČETIĆ & BARČOT (2008). Based on all these observations, ORLIĆ *et al.* (2010) prepared a map showing both the wave heights and onset times. Also included in the map is information extracted from the available tide-gauge measurements (Fig. 2). It is obvious that tide gauges recorded an intensification of high-frequency sea-level variability, but they did not register the maxima observed by eyewitnesses due to the local nature of the phenomenon. An additional problem with the tide-gauge records was that they had to be inspected visually because the instruments operating in 1978 were analog and the high-frequency signals were blurred in their records.

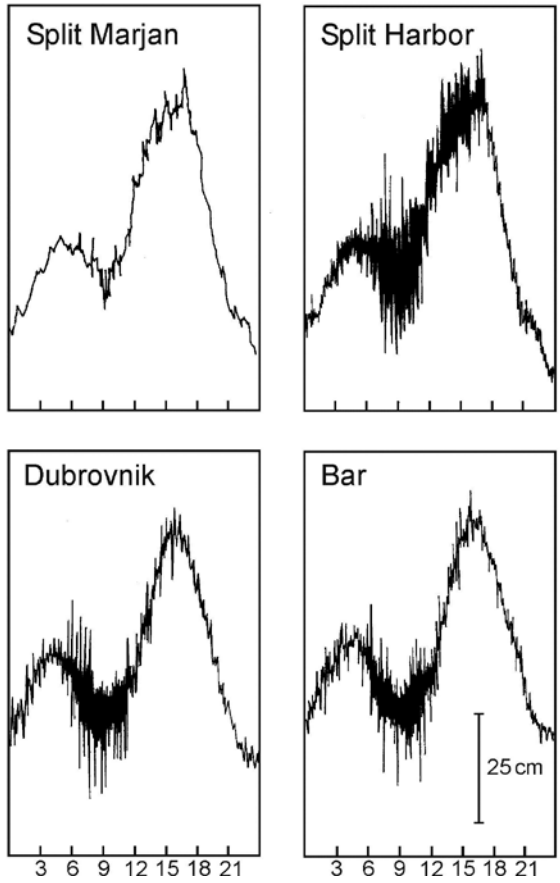

Fig. 2. Sea-level variability recorded by four analog tide gauges on 21 June 1978

The cause of the event was studied on several occasions, which resulted in four hypotheses regarding the generating mechanism. Two of the hypotheses identified the cause to be at the sea bottom: ZORE-ARMANDA (1979) related the event to an earthquake that occurred the day before in the Aegean Sea area, whereas BEDOSTI (1980) connected it with a landslide that presumably occurred off the middle Adriatic coast of Italy. The other two hypotheses placed the cause in the atmosphere: HODŽIĆ (1979, 1988) attributed the event to free waves impulsively generated in the open Adriatic by a cyclone, whereas ORLIĆ (1980) related it to forced waves resonantly driven by an atmospheric gravity wave. Only the last of these hypotheses was supported by a comprehensive modeling effort (ORLIĆ *et al.*,

2010), which showed that small air-pressure forcing could have produced sea-level variability in Vela Luka reaching a few meters and thus surpassing the inverted barometer response by two orders of magnitude.

6 July 1978, Vela Luka

It is briefly stated in a newspaper article (Slobodna Dalmacija, 7 July 1978) that "the sea was rising and falling with amplitude of one meter". The author also comments that a month ago such variability would pass unnoticed but that after the large previous event the local people were alarmed and therefore decided to remove about seventy boats from the inner part of Vela Luka Bay.

12 February 1979, Vela Luka

TABAIN & TABAIN (1994) reproduce the record kept by the Harbor Master Office according to which "at approximately 13:00 hours a gradual rising and falling of sea level was again observed, and at approximately 14:30 hours a part of the road in the port area was flooded… All the time between 14:30 and 19:00 hours the sea was rising and falling, with sea level reaching ca. 1 m above mean value. The ebbs were small." It is also mentioned that the SE wind had a force of 4-5 Bf, the air pressure equaled 984 mbar and it was cloudy and foggy. The event coincided with a storm surge at Bakar.

10 July 1980, Stari Grad, Vela Luka

This is an interesting event because it affected Stari Grad on the island of Hvar more than Vela Luka on the island of Korčula. Its manifestations in Stari Grad are described in four newspaper articles (Slobodna Dalmacija, 11 July 1980 and 12 July 1980, Vjesnik, 11 July 1980, Večernji list, 11 July 1980). It is thus stated that "the strongest sea level rise was the first one that occurred on Thursday at five o'clock in the morning… Sea level rose more than a meter, and in fact surpassed by 80 cm the level of Stari Grad coast… After about twenty minutes the sea suddenly receded, far below the usual level, and then the ropes on the ferryboat Gradac were broken… At approximately 17:30 hours another strong tidal wave flooded, but to a lesser extent, the coasts of Stari Grad Bay, whereupon the sea again receded thus causing damage to numerous boats that hit the dry bottom of the bay." In only one of the newspaper articles (Vjesnik, 11 July 1980) it is briefly mentioned that sea-level oscillations were also observed in Vela Luka but that their intensity was much smaller than that in Stari Grad; consequently, the oscillations did not cause any damage. Again, the event coincided with a storm surge at Bakar.

5 October 1984, Ist Island

This event on the island of Ist is briefly mentioned by VILIBIĆ & ŠEPIĆ (2009), who also publish the wave height as reported by eyewitnesses. Once again, the event coincided with a storm surge at Bakar.

26 July 1987,
Rogoznica, Nečujam, Milna, Korčula

The event is mentioned by ZORE-ARMANDA (1988). The only detail given is the onset time at one of the locations (Milna on the Brač Island).

27 June 2003, Stari Grad, Mali Ston

This is another case in which Stari Grad was affected more than Vela Luka, and it is one of the few Adriatic events that are well studied. The event is described in three newspaper articles (Slobodna Dalmacija, 28 June 2003, Večernji list, 28 June 2003, Vjesnik, 28 June 2003) in which it is stated that "the large tidal wave, which on the Friday morning at about six o'clock flooded the Stari Grad waterfront and even a wider area of the Vorba Park, resulted in enormous damage to the inhabitants of this old town… After the first tidal wave followed an even larger one, unseen up to now in Stari Grad. Its height was ca. 1 m above the columns, which was really frightful, and the wave resulted in vehicles being literally redistributed on the Stjepan Radić Square… While receding, the tidal wave dragged along a wall, having the length of almost 60 m and the height larger than 2 m, whereupon the wall collapsed into the canal." It is also mentioned in the articles that "on Friday between 7:30 and 9 hours a large

tidal wave occurred in Mali Ston Bay. After the large water mass receded, strong currents literally swept away shellfish farm in the area between Mali Ston and Cape Nedilja close to Stonska Duba at a length of about six nautical miles." The event was also recorded by four tide gauges in the area (Split, Sućuraj, Ploče and Dubrovnik), albeit with the amplitudes much smaller than in Stari Grad and Mali Ston (VILIBIĆ *et al.*, 2004).

This event was successfully reproduced by an oceanographic model that was forced by the observed air-pressure perturbation propagating above the sea (VILIBIĆ *et al.*, 2004). It turned out that the small air-pressure forcing, which did not surpass a few millibars, could have supported the sea-level and current variability indicated by the observations in Stari Grad and Mali Ston Bay, respectively. Moreover, the model results were consistent with the data recorded by the four tide gauges. The meteorological aspect of the event was studied – using observations and modeling – by BELUŠIĆ *et al.* (2007). They found that the air-pressure perturbation was related to a mesoscale convective system, which had been triggered above the Alps and then propagated toward the southeast (i.e., along the East Adriatic coast).

24 May 2006, Vrboska

In an e-mail message that the author received on 16 December 2006, Vera Irving says that she "witnessed a series of dramatic waves in Vrboska harbor. Our pilot book had warned us that this could happen in winter, if there was a strong sirocco. That was not the case on 24 May, so we asked the local people (who were also very surprised at the phenomenon), but they could offer no explanation as to why this should happen in May. Then I heard of the "resaca" in Menorca, which destroyed 40 boats, and after a bit of research, discovered that these waves can also happen due to an abrupt change in atmospheric pressure, which was the case in Croatia in May."

22 August 2007, Ist Island

Information on the event is based on data collected during the author's visit to the island of Ist on 24 August 2007. It is interesting that the event also manifested itself in pronounced seiching on the nearby island of Molat where the author vacationed at the time. Additional descriptions of the Ist event may be found in several newspaper articles (Večernji list, 24 August 2007, Jutarnji list, 24 August 2007, Slobodna Dalmacija, 24 August 2007) and in the paper authored by VILIBIĆ & ŠEPIĆ (2009). The newspaper reports are typical: one of them cites an eyewitness who testified that "during the whole day there were some light thunderstorms, but at the time of the tidal wave there was a complete calm, without a breath of wind. Suddenly, in a few seconds, the sea receded some 10-15 m from the coast so that many boats hit the bottom, whereupon some boats were carried to the land by the returning high tidal wave."

The cause of the event was studied in detail by ŠEPIĆ *et al.* (2009), and it was found that a few-millibar air-pressure perturbation propagated above the area at a speed of approximately 21-24 m/s. Somewhat enigmatically, the speed turned out to be almost identical to the speeds previously determined for the 1978 event in Vela Luka (ORLIĆ, 1980) and the 2003 event in Stari Grad (VILIBIĆ *et al.*, 2004). The response of the sea surrounding the island of Ist to the air-pressure forcing observed in the year 2007 has not been reproduced with an oceanographic model.

15 August 2008, Mali Lošinj

The main source of information in this case is Zoran TOMIĆ, harbor master, who was interviewed by the author on 21 August 2008. The descriptions of the event in newspaper articles (Večernji list, 16 August 2008, Slobodna Dalmacija, 17 August 2008, Vjesnik, 18 August 2008) corroborate his observations and also mention a thunderstorm that occurred in the wider Mali Lošinj area at the time. An increase in high-frequency variability was also recorded by a number of digital tide gauges concurrently operating in the North Adriatic (Fig. 3), but nowhere did the amplitudes reach the values reported for Mali Lošinj.

The meteorological conditions coinciding with the event were studied by BELUŠIĆ & STRELEC MAHOVIĆ (2009), who detected a

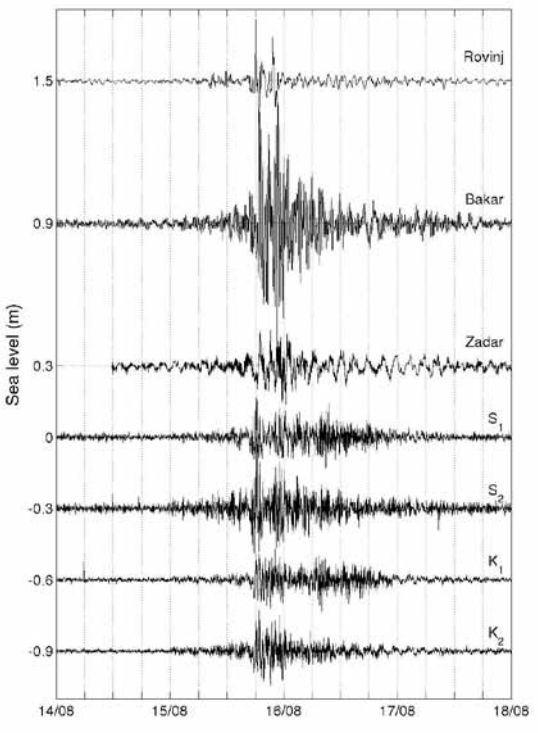

Fig. 3. High-frequency component of the sea-level time series recorded by three permanent tide gauges (Rovinj, Bakar and Zadar) and four temporary pressure gauges (on the island of Ist, Široka Bay – S_1 and S_2, Kosirača Bay – K_1 and K_2) from 14 to 17 August 2008. Low-frequency oscillations were removed by using a digital filter with a cutoff period placed at 2 hours. The offset of the time series is arbitrary.

strongly developed mesoscale convective system in the area.

19 February 2010, Stari Grad

This is one of the rare wintertime events and is described in three newspaper articles (Slobodna Dalmacija, 21 February 2010, Jutarnji list, 21 February 2010, Večernji list, 21 February 2010). The descriptions in this case are rather cursory; thus, for example, it is stated that "a large tidal wave, which on the Friday afternoon flooded a half of Stari Grad, resulted in considerable damage to the citizens... The inhabitants of Stari Grad claim that there were several tidal waves, with no less than 55 cm of the sea being poured out at the very beginning, and the sea, while receding, dragged along cars, containers, cans and everything on the waterfront." The event coincided with a storm surge at Bakar.

The meteorological forcing in this case was studied by ŠEPIĆ & VILIBIĆ (2011), who detected a small air-pressure perturbation that was propagating northeastward at a speed equaling (once again) 22-23 m/s.

DISCUSSION

As is apparent from Tab. 1 and its overview, tsunami-like waves of meteorological origin have been observed at eighteen locations in Croatian coastal waters, most often in Vela Luka (on the Korčula Island) and in Stari Grad (on the Hvar Island). The positions of all locations are indicated in Fig. 4.

It is remarkable that many of the locations coincide with the points for which the maximum wave heights were hindcasted by ORLIĆ *et al.* (2010, their Fig. 16). Because the hindcasts were obtained with a hydrodynamic numerical model subjected to a specific atmospheric forcing, the coincidence suggests that the response of the Adriatic Sea to the mesoscale atmospheric forcing strongly depends on the bathymetry features. As noted by one of the reviewers, Vela Luka dominates the catalogue before 1980, whereas other locations in the central and even northern Adriatic apparently take the lead after that year. However, it is not known whether this should be attributed to a physical process (for example, a shift in trajectories of the air-pressure perturbations) or to a change in observational practice (e.g., appearance of careful observers at some locations and their disappearance elsewhere).

A majority of the Adriatic events occurred in the warm part of the year, i.e., between May and October; however, on three occasions the events were observed in February and twice in November. The phenomenon manifested itself in sea-level oscillations mostly starting either early in the morning or late in the afternoon; the oscillations lasted between 1 and 6 hours and had periods in the range of 10 to 40 minutes. The maximum trough-to-crest height observed was 6 m (in Vela Luka, on 21 June 1978).

The present catalogue, which is the first of its kind prepared for the Croatian part of the Adri-

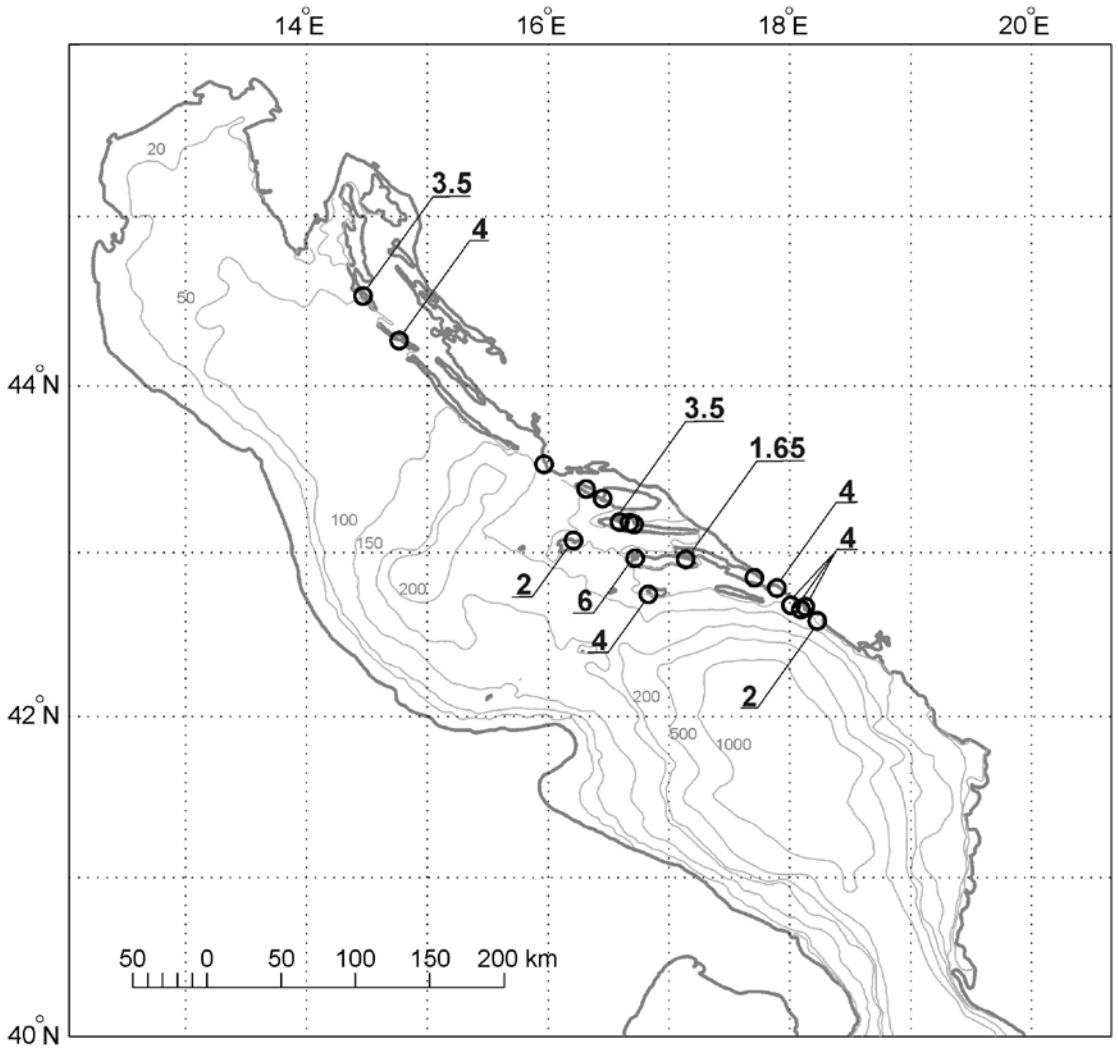

Fig. 4. Distribution of locations where tsunami-like waves of meteorological origin were observed in Croatian coastal waters. Also indicated is the maximum trough-to-crest height (in meters) wherever this information is available.

atic Sea, is likely to be improved in the future. There are two ways to implement improvements. One obvious way is to add the past events that are missing from the catalogue and the future events as they occur in the area. The other way is to analyze in detail the events that are insufficiently documented in the catalogue, especially those events for which it is not clear whether they represent cases of tsunami-like waves coinciding with storm surges or cases of incorrect interpretation of storm surges (these events are distinguished in the catalogue by the coincidence of a low-quality indicator with a storm surge at Bakar). It is anticipated that new meteorological and oceanographic data will become available to aid in the process and that modeling of the coupled atmosphere-sea system – as proposed by ORLIĆ *et al.* (2010) and RENAULT *et al.* (2011) – will become established and thus help to improve forthcoming activities.

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Vjesnik,18 Aug. 2008 (Plimni val ‘potopio’ Mali Lošinj)

Prvi pokušaj katalogiziranja valova sličnih tsunamijima, koje u hrvatskim obalnim vodama uzrokuju atmosferski procesi

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SAŽETAK

Za hrvatski dio Jadranskog mora sastavljen je katalog valova, koji pripadaju istom frekvencijskom području kao tsunamiji, ali su meteorološkog porijekla. Katalog trenutačno uključuje 21 slučaj poplava, koje su opažene između 1931. i 2010. godine. Najčešće je poplavljivana Vela Luka na otoku Korčuli, te Stari Grad na otoku Hvaru. Većina se slučajeva dogodila u toplom dijelu godine. Epizode su pretežno počinjale rano u jutro ili kasno poslije podne, trajale su između 1 i 6 sati, a obilježilo ih je osciliranje morske razine s periodima od 10-40 minuta. Najveća valna visina u iznosu od 6 m opažena je u Veloj Luci dana 21. lipnja 1978. godine.

Ključne riječi: katalogizacija, valovi slični tsunamiju, meteorološko porijeklo, hrvatski dio Jadranskog mora