Natural Hazards (2021) 106:1087–1104
https://doi.org/10.1007/s11069-021-04679-9

EDITORIAL

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Special issue on the global perspective on meteotsunami science: editorial

Ivica Vilibić[1] · Alexander B. Rabinovich[2,3] · Eric J. Anderson[4]

Received: 4 March 2021 / Accepted: 4 March 2021 / Published online: 17 March 2021

1 Introduction

As the coastal population has grown rapidly in recent decades (Neumann et al. 2015), extreme sea levels become an increasing threat to coastal communities that are projected to have a direct impact (by flooding) on 630 million people by the year 2100. There are a great number of hazards that are affecting coastal regions, including hurricanes and typhoons, storm surges, tsunamis, etc.; some of them affect larger areas and cause damage in billions of US dollars, yet some are more localized and impact relatively limited areas, like meteotsunamis. *Meteorological tsunamis* or *meteotsunamis* are atmospherically generated destructive long ocean waves in the tsunami frequency band, driven by various atmospheric forcing (atmospheric gravity waves, pressure jumps, frontal passages, squalls, hurricanes, etc.) (Monserrat et al. 2006; Rabinovich 2020). They have been documented to impact certain coastlines, mostly specific harbours or bays, for centuries. In some bays, the meteotsunami waves have been recorded with heights of several metres and associated currents of several knots, which may pose a particular threat to low-tidal regions, like the Mediterranean and Black seas (Vilibić et al. 2021) and the Great Lakes (Bechle et al. 2016), where the coastal infrastructure is not adapted to such strong sea-level oscillations. A number of catastrophic meteotsunamis have been recorded in modern times: (1) The Great Lakes, USA, in 1954, killing 7 people in Chicago (Ewing et al. 1954), (2) Vela Luka, Croatia, in 1978, resulting in US$7 million in damage at that time (Vučetić et al. 2009), (3) Nagasaki Bay, Japan, in 1979, killing 3 people and flooding coastal cities (Hibiya and Kajiura 1982), (4) Ciutadella in the Balearic Islands, Spain, in 1984 and 2006, sinking tens of yachts and boats and causing of tens of millions of euros in damage (Jansà and Ramis 2021), (5) Daytona Beach, Florida, USA, in 1992, causing at least 75 injuries and damaging several dozen vehicles on the beach (Churchill et al. 1995), (6) the catastrophic 2007 event in Mostaganem (Algeria) responsible for the death of 12 people (Okal 2021), (7) the

✉ Ivica Vilibić
vilibic@izor.hr

1 Institute of Oceanography and Fisheries, Split, Croatia

2 Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC, Canada

3 P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia

4 Great Lakes Environmental Research Laboratory, Office of Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, Ann Arbor, MI, USA

catastrophic meteotsunamis that affected the north Persian Gulf coastline, Iran, causing the death of 5 people and injuring 22 (Salaree et al. 2018; Heidarzadeh et al. 2020; Kazeminezhad et al. 2021), and several others. Being so destructive, the phenomenon intimidated the inhabitants to such an extent that they gave them particular local names: "abiki" and "yota" in Japan, "rissaga" or "resaca" in Spain, "šćiga" or "štiga" in Croatia, "marrubbio" or "marrobbio" in Sicily, "milghuba" in Malta, "Seebär" in Baltic countries, and more (Monserrat et al. 2006; Rabinovich 2009).

The science of meteotsunamis has been evolving in recent decades from documentation of specific meteotsunami events to regional and global assessments of available high-resolution sea-level and ancillary data. Pioneering investigations have been conducted locally, following observations at the most affected bays or harbours (e.g. Honda et al. 1908; Fontseré 1934; Caloi 1938), while the development of instrumentation in the 1970–1980s boosted studies in some locations, like the Balearic Islands (Jansà 1986), the Adriatic Sea (Hodžić 1979/1980; Orlić 1980) and Japan (Hibiya and Kajiura 1982). With the increase in computing power in the 1980s, simple numerical models for reproducing meteotsunamis were also developed.

Interestingly, the term "*meteorological tsunami*" has not been widely adopted by the science community, although being proposed quite early by Nomitsu (1935) and further promoted by Defant (1961). The two papers in the 1990s by Rabinovich and Monserrat (1996, 1998) further advertised the term "meteotsunami", which was finally accepted by the research community after the review paper by Monserrat et al. (2006). Since then, the science of meteotsunamis has evolved globally, with two special issues published in 2009 (Rabinovich et al. 2009) and 2014 (Vilibić et al. 2014), containing a wide coverage of meteotsunami topics: ocean and atmosphere observations, reproduction of meteotsunami events by atmospheric and ocean models, statistics and climate of meteotsunamis, and others. The first special issue came after the *International Symposium on Meteotsunamis: 30th Anniversary of the Great Flood of Vela Luka (21 June 1978)* that was held in Vela Luka on 19–21 June 2008, while the second special issue came after finishing the project entitled *Towards a Meteotsunami Warning System Along the U.S. Coastline (TMEWS)*, funded by the USA National Oceanic and Atmospheric Administration (NOAA), and the associated special meteotsunami session at the American Geophysical Union (AGU) 2012 Fall Meeting.

Although meteotsunami research encompasses all continents except Antarctica, it has primarily concentrated on the reproduction of specific destructive events. This changed in the last two decades, mostly following the 2004 Great Sumatra tsunami. New digital high-resolution instrumentation installed throughout the world's oceans brought an incredible amount of precise sea-level data and allowed examination of meteorological tsunamis both on regional (e.g. in the Mediterranean Sea, Šepić et al. 2015a, and along the US East Coast, Dusek et al. 2019) and global (e.g. Vilibić and Šepić 2017) scales. It appears that in certain parts of the world, meteotsunamis can occur as the consequence of a chain of events (Šepić et al. 2015b). This puts meteotsunamis out of being purely a local phenomenon, as was supposed earlier, and, in principle, suggests that meteotsunamis can be forecasted. The latter had already been qualitatively implemented for the Balearic Islands at the end of the 1980s (Jansà and Ramis 2021), while recently there were several attempts to create meteotsunami early-warning systems (e.g. the Balearic RIssaga Forecasting System—BRIFS—in the Balearic Islands, Marcos et al. 2009; Renault et al. 2011, or the Croatian Meteotsunami Early Warning System—CMeEWS—in the Adriatic Sea, Denamiel et al. 2019).

With the impetus to document meteotsunami events around the world, to develop early warning or forecast systems, and to further acknowledge meteotsunami science, an international group of scientists recognized the need for a conference to spur global collaboration on these research activities. This effort resulted in *The First World Conference on Meteotsunamis* (www.izor.hr/mts2019) that was held in Split, Croatia, on 8–11 May 2019, attracting 60 scientists from 18 countries. This beacon conference included all aspects of meteotsunami science, state-of-the-art in their research through operational issues and development of early-warning systems, from observational studies and requirements to their reproduction by effective numerical models. The conference was initiated with several overview talks on global and regional meteotsunami research, followed by sessions on meteotsunami observations, atmosphere–ocean modelling, atmosphere–ocean interactions and ocean processes, climatology of meteotsunamis, meteotsunami forecasting and developing of early-warning systems. The conference closed with a round table that discussed all aspects of meteotsunami research and meteotsunami-related future activities, including specific standards for meteotsunami observations and modelling, scientific and applied perspectives for creation of efficient early-warning systems, and a framework for future collaborations, making meteotsunami research more visible in the tsunami community and to the public.

The conference culminated in an agreement to publish a special issue of Natural Hazards on meteotsunamis emphasizing the global breakthrough of research on this phenomenon. A few years ago, Pattiaratchi and Wijeratne (2015) emphasized that “meteotsunamis are an underrated hazard”. The present issue demonstrates that the “rate” of meteotsunamis strongly increased in recent years.

2 Overview of the special issue and meteotsunami cataloguing

Altogether 29 papers geographically covering the Mediterranean and Black seas, North-East Atlantic, North and South Americas, South-East Asia and the Persian Gulf were collected for this special issue, entitled “The Global Perspective on Meteotsunami Science”. By topic, the papers can be split into overviews, case studies of actual events, papers introducing new insights into meteotsunami modelling, both analytical and numerical, papers presenting new techniques in meteotsunami monitoring and detection, and those describing meteotsunami operational and forecast systems. The authors come from 21 countries in Europe, North and South Americas and Asia, being affiliated with research institutions and universities, operational atmospheric and oceanic services and governmental agencies situated in 53 world cities (Fig. 1).

More than half of all papers describe specific meteotsunami events, some others at a rudimentary level recall previous extreme episodes, while several papers contain thorough analysis of either atmospheric conditions or oceanic sea-level response. Figure 2 displays geographical distribution of the described events; the size of the stars is proportional to the meteotsunami intensity. Table 1 introduces detailed information about the events and their succinct description presented in the respective issue papers. Following tsunami cataloguing studies (e.g. Papadopoulos and Imamura 2001) and problems of identification and cataloguing meteotsunami events (Gusiakov 2021), we introduced two parameters that might be used in cataloguing meteotsunamis: intensity and spatial coverage.

Intensity (I) scales meteotsunamis in five categories, following their effects on humans, nature and local infrastructure:

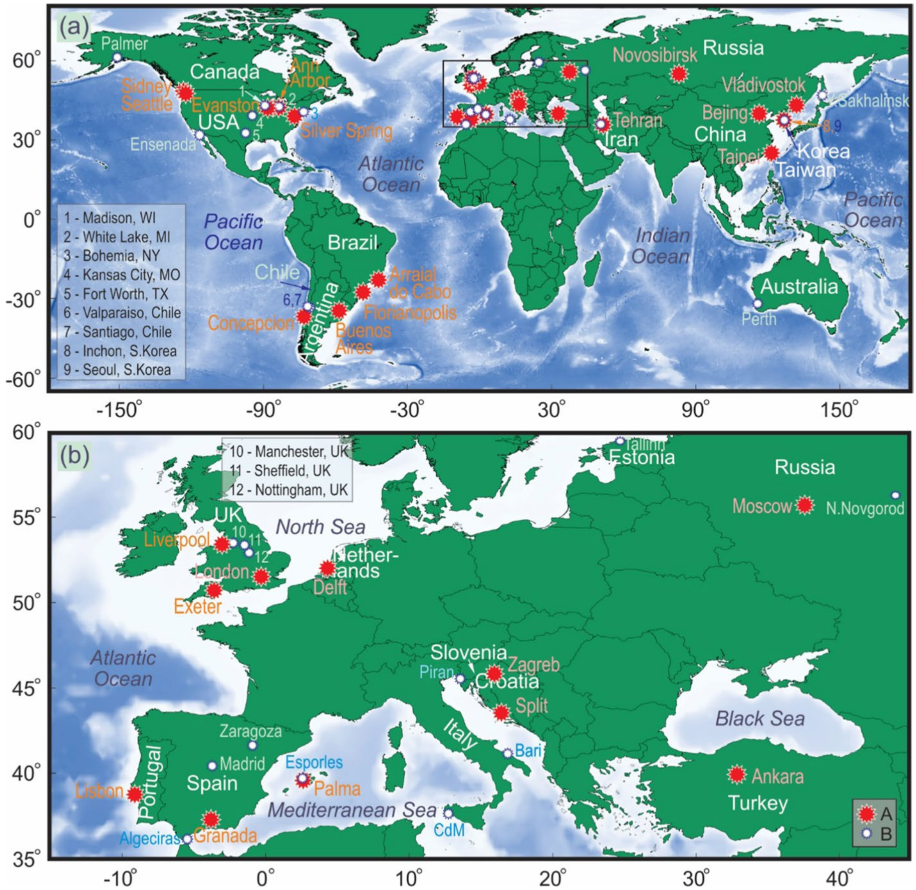

Fig. 1 Geographical distribution of the authors of published papers in the present special issue: **a** the world and **b** Europe. Symbols indicated as "A" and "B" denote cities of the first authors and co-authors, respectively

- $I = 5$ (*catastrophic*): destructive high-frequency sea-level oscillations, substantial damage and/or human casualties;
- $I = 4$ (*damaging*): exceptional high-frequency sea-level oscillation, severe damage, possible human injuries;
- $I = 3$ (*substantial*): substantial high-frequency sea-level oscillations, sporadic damage and coastal flooding;
- $I = 2$ (*evident*): significant high-frequency sea-level oscillations measured by instruments or observed by eyewitnesses, no damage and coastal flooding;
- $I = 1$ (*recognizable*): evident high-frequency sea-level oscillations identified in the measurements.

Spatial coverage (S) scales meteotsunamis in four categories, depending on their occurrence either over broad regions (like the multi-meteotsunami event of 23–27 June 2014 in the Mediterranean and Black seas, Šepić et al. 2015b) or the meteotsunami that

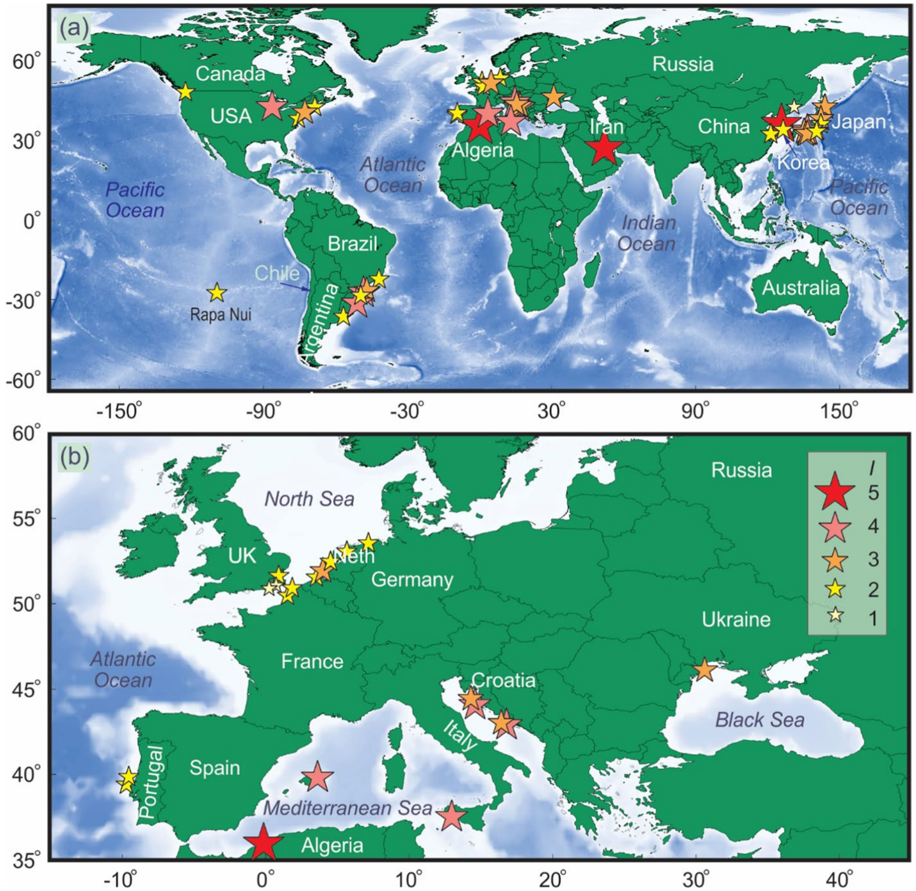

Fig. 2 Geographical distribution of the intensity (*I*) of meteotsunami events described in the present special issue: **a** the world and **b** Europe. The intensity is determined mostly by the destructive consequences of the event

affected the coasts of the Netherlands, France, England and Germany on 29 May 2017 (Sibley et al. 2021), or more space-limited events localized at some bays or inlets only:

- $S=4$ (*region-wide*): meteotsunamis affecting very large areas and regions (> 1000 km).
- $S=3$ (*basin-wide*), meteotsunamis occurring along an extended coast (200–1000 km).
- $S=2$ (*limited*), meteotsunamis occurring along a limited coastline segment or in few neighbouring bays (50–200 km).
- $S=1$ (*local*), meteotsunami is occurring in a single harbour or bay) (< 50 km).

Table 1 and Fig. 2 show that there were three events described in the present issue with the intensity $I=5$:

(1) Mostaganem (Algeria) on 3 August 2007 when 12 people were killed by 7–10 m unexpected run-up (Okal 2021).

Table 1 Description of specific meteotsunami events referenced in this special issue

Place (event)	Country	Lat	Lon	Date (dd/mm/yy)	Height (m)	Intensity (I)	Spatial coverage (S)	Description	References
Ciutadella, Menorca I	Spain	40.00	3.84	21/06/84 15/06/06	5	4	2	Destroyed boats, infrastructure damage; losses of 30 M euros	Jansà and Ramis (2021)
Vela Luka, Korčula I	Croatia	42.96	16.72	21/06/78	6	4	3	The largest flood along the Croatian coast, substantial damage in households, stores and infrastructure	Bubalo et al. (2021)
Stari Grad, Hvar I	Croatia	43.18	16.60	19/02/10	0.8	3	1	Combination of storm surge and meteotsunami; no large damage	Bubalo et al. (2021)
Ist Island	Croatia	44.27	14.77	22/08/07	4	4	1	Significant damage to property and infrastructure; one injured person	Bubalo et al. (2021)
Mali Lošinj	Croatia	44.53	14.47	15/08/08	3.5	3	1	Flooding; damage on cars and shops along promenade	Bubalo et al. (2021)
Mazara del Vallo, Sicily	Italy	37.59	12.54	25/06/14	1.5	4	2	Meteotsunami bore propagated upstream of the Mazaro River	Zemunik et al. (2021)
Mostaganem	Algeria	35.93	0.08	03/08/07	7–10*	5	1	Severe damage, 12 people killed	Okal (2021)

Table 1 (continued)

Place (event)	Country	Lat	Lon	Date (dd/mm/yy)	Height (m)	Intensity (*I*)	Spatial coverage (*S*)	Description	References
Mediterranean and Black Sea	Spain, Italy, Croatia, Ukraine	35.0–47.0	0–35.0	22–27/08/14	1–3	3	4	Multi-meteotsunami event affected several countries	Okal (2021)
From Lagos to Viana	Portugal	37.0–41.7	− 8.5 to − 9.5	06–07/07/10	0.8	2	3	Meteotsunami propagating along the coast of Portugal	Kim and Omira (2021)
English Channel and southern North Sea	Netherlands, UK, France, Germany	50.0–54.0	0–10.0	29/05/17	3	3	3	Widespread meteotsunami propagating northeastwards and affecting popular touristic beaches	Sibley et al. (2021)
US East Coast	USA	36.0–41.5	− 76.0 to − 70.0	13/06/13	1.5	3	3	Intense meteotsunami generated by a derecho; Tsunami Warning announced	Okal (2021), Titov and Moore (2021)
Ludington, Michigan	USA	43.96	− 86.45	13/04/18	2	4	2	Harbour and shoreline infrastructure damage; boat destruction	Anderson and Mann (2021)

Table 1 (continued)

Place (event)	Country	Lat	Lon	Date (dd/mm/yy)	Height (m)	Intensity (*I*)	Spatial coverage (*S*)	Description	References
Strait of Georgia	Canada	48.28	−122.70	01/11/10	0.3	2	2	Significant meteotsunami recorded by tide gauged and multiple micro-barographs; mud flows	Rabinovich et al. (2021)
Santa Catalina	Brazil	−27.60	−48.55	29/10/19	1.2	3	3	Meteotsunami generated by a squall line; coastal flooding and property damage on certain beaches and inside bays	Araujo et al. (2021)
Cassino Beach	Brazil	−31.10	−51.25	08/03/77 09/02/14	2	3	1	Flooding of the beach and parked cars	Candella and Araujo (2021)
Arraial do Cabo	Brazil	−22.97	−42.03	07/09/02	0.7	2	1	Large sea-level oscillations recorded during low tide; no recorded damage	Candella and Araujo (2021)

Table 1 (continued)

Place (event)	Country	Lat	Lon	Date (dd/mm/yy)	Height (m)	Intensity (*I*)	Spatial coverage (*S*)	Description	References
Pântano do Sul	Brazil	−27.78	−48.52	19/11/09	3	4	1	Considerable damage of cars, fishing boats, restaurants and various beach infrastructure; one fisherman slightly injured	Candella and Araujo (2021)
Araranguá	Brazil	−28.94	−49.48	16/10/16	2	2	1	Meteotsunami conjoined with strong winds, surges and rain storm	Candella and Araujo (2021)
Buenos Aires Province	Argentina	−36.64	−56.74	1–2/12/13	0.85	2	2	Meteotsunami waves reproduced by numerical model; no recorded damage	Perez and Dragani (2021)
Rapa Nui (Easter Island)	Chile	−27.11	−109.35	01/19–07/20	1.4	2	1	Multiple observations of strong seiches; the strongest events were driven by the breaking of storm waves	Carvajal et al. (2021)

Table 1 (continued)

Place (event)	Country	Lat	Lon	Date (dd/mm/yy)	Height (m)	Intensity (*I*)	Spatial coverage (*S*)	Description	References
Typhoon Lionrock	Japan	33.0–44.0	138.0–147.0	30–31/08/16	1.7	3	3	Meteotsunamis superimposed to storm surge and extensive rain floods; substantial coastal damage	Heidarzadeh and Rabinovich (2021)
Typhoon Jebi	Japan	32.0–35.0	132.0–137.0	3–4/09/18	2.6	4	3	Meteotsunamis superimposed to storm surge and extensive rain floods; severe coastal damage	Heidarzadeh and Rabinovich (2021)
Typhoon Wipha	Japan	27.0–45.0	127.0–147.0	15–16/10/13	0.5	2	3	Meteotsunami waves preceded the typhoon arrival; no substantial flooding	Lin and Wu (2021)
Jiangsu Province	China	32.0–32.8	120.8–122.0	17/11/09	> 1	2	2	Unexpected significant sea-level changes called "strange tide" identified as meteotsunamis	Wang et al. (2021)
West coast of Korea	South Korea	33.5–37.5	125.5–126.5	04–05/03/18 05–07/04/18	0.7	2	2	Real-time detected meteotsunami generated by strong pressure jumps	Kim et al (2021)

Table 1 (continued)

Place (event)	Country	Lat	Lon	Date (dd/mm/yy)	Height (m)	Intensity (*I*)	Spatial coverage (*S*)	Description	References
West coast of Korea and Jeju Island	South Korea	33.43	126.55	30–31/03/07	2	5	3	Major event, four people killed; severe documented damage	Okal (2021)
Peter the Great Bay	Russia	42.4–42.7	130.7–131.2	05–09/16	0.15	1	1	Observed and modelled seiches	Smirnov et al. (2021)
Dayyer	Iran	27.83	51.92	19/03/17	2.5	5	2	Meteotsunami waves initiated by an intense squall line inundated ~ 100 km of the coastline; 22 injured and 5 killed people	Kazeminezhad et al. (2021)

*Estimated run-up values (Okal 2021)

(2) Dayyer, Persian Gulf (Iran) on 19 March 2017 when 5 people were killed and 22 more were injured by a wave that inundated about 100 km of the gulf coastline (Kazeminezhad et al. 2021).
(3) West coast of South Korea when a 2-m wave on 19 March 2017 killed 4 people and produced severe damage (Okal 2021).

These were the only three events of a catastrophic character, which not only caused considerable destruction in the coastal zone but also resulted in fatalities. However, there were several more events described in various regions of the world (the Adriatic Sea, the Balearic Islands, Sicily, the Great Lakes, Brazil, Japan; see Fig. 2) with $I=4$, when meteotsunamis several metre heights occurred; some of them caused significant damage (e.g. the estimated cost of the meteotsunami damage on 15 June 2006 in Ciutadella Harbour was 30 million euros, Jansà and Ramis 2021; Rabinovich 2020).

Most of the meteotsunami events were relatively local ($S=1$–2); the spatial coverage $S=3$ was mainly associated with hurricanes (Okal 2021; Titov and Moore 2021) and typhoons (Heidarzadeh and Rabinovich 2021; Lin and Wu 2021) and also with intensive squall lines propagating along the coast (Sibley et al. 2021; Araujo et al. 2021). The chain of events on 23–27 June 2014 ($S=4$) observed in many bays and harbours of the Mediterranean and Black seas (Rabinovich 2020; Vilibić et al. 2021; Zemunik et al. 2021; Okal 2021) was probably unique.

Moreover, from Fig. 2 and Table 1 it appears that catastrophic meteotsunamis (with human casualties) are mostly not region-wide or basin-wide, although their inferred spatial coverage is partly influenced by an insufficient number of tide gauge stations and eyewitness reports. Further, it should be noted that the materials in Table 1 and Fig. 2 are limited to the events presented in this special issue only, while a thorough scanning for all available meteotsunamis and their proper cataloguing is a long and demanding process hopefully to be carried out in the near future (see the corresponding discussion in Rabinovich 2020; Gusiakov 2021).

3 Succinct description of the special issue papers

3.1 General meteotsunami papers

The initial paper by Gusiakov (2021) assesses the problems associated with identification and cataloguing of meteotsunami events, in particular of their correct parameterization within the adopted format of the tsunami databases. Therefore, most of the meteotsunamis included in the existing databases lack some basic parameters, such as the origin time, source location and run-up heights. Using land-based seismometers, Okal (2021) applies the deconvolution algorithm developed for seismic tsunamis to a selected set of seven meteotsunami events, assuming that seismic records could play an important role in the further understanding of the meteotsunami structure. Indeed, seismic records suggest that the unexplained waves which killed twelve people in Mostaganem, Algeria, in 2007 had a meteorological origin, despite that no usable oceanic or atmospheric data are available. García-Valdecasas et al. (2021) assess a progressive upgrade of tide gauges to match tsunami warning requirements along the Spanish coast. They present a new operational tool that enables immediate detection, evaluation and understanding of the physical phenomena identified in the raw data, such as meteotsunamis and significant infragravity waves. The idealized simulations of the meteotsunami generation have been conducted by Williams et al. (2021), who found that the growth greater than the Proudman resonance occurred as a result of a positive tidal elevation combined with a tidal current in the opposite direction relative to the wave propagation. They found that the near-Proudman resonant growth can occur over hundreds of kilometres if the effective Froude number is near 1.0 and the resultant wave propagates predominantly in one specific direction. Dogan et al. (2021) test the sensitivity of the generated meteotsunami waves for the idealized bathymetry to the speed of atmospheric disturbances (seen in both air pressure and wind) by the NAMI DANCE SUITE model and achieved fairly good agreement between the numerical and analytical results.

3.2 Mediterranean and Black Sea meteotsunamis

A comprehensive overview of the Mediterranean and Black Sea meteotsunamis is presented by Vilibić et al. (2021) It contains a thorough description of the strongest events in modern times, succinct bibliometric analysis of meteotsunami papers and discussion of meteotsunami sources, the offshore resonant energy radiation, wave propagation onshore and interactions with bathymetry and coastal topography. The review also includes description of meteotsunami monitoring and forecasting systems and assessment of operational and research gaps in the meteotsunami study. The authors present certain ideas for improving observational and modelling tools and for better understanding of various aspects of meteotsunami nature. Jansà and Ramis (2021) attracted attention to the pioneering research of *rissaga*, the Balearic meteotsunamis, which was done in the late 1970s and the early 1980s, followed by a much more solid perspective coming recently through new observational methods, high-quality data and numerical modelling. Altogether, they led to a probabilistic and purely meteorological forecasting method for the rissaga phenomenon based on identification of the favourable meteorological conditions. This approach uses operational coupled atmospheric and oceanic forecasting models. Another rissaga forecasting method, based on neural networks, is presented by Vich and Romero (2021). It distinguishes fairly well between rissaga and non-rissaga situations and shows a skill comparable to that of computationally expensive approach based on direct numerical simulation. In contrast, Mourre et al. (2021) use an ensemble of full realistic high-resolution nested atmosphere–ocean models to predict the Balearic meteotsunamis. They found that the observed magnitude of the extreme sea-level oscillations in 70% of all simulated cases lies within the range of a nine-member ensemble. The authors suggest that this ensemble approach would improve the reliability of meteotsunami predictions compared to single deterministic forecasts.

Using a set of precise microbarographs and tide gauges, Zemunik et al. (2021) quantify the atmospheric and oceanic conditions related to the phenomenon of *marrobbio* occurring along the south-western coast of Sicily, and emphasize the role of coastal topography and shelf bathymetry in generation of extreme meteotsunami waves. Introduction of wetting and drying into a numerical model, is documented by Bubalo et al. (2021). The model is applied to four Adriatic meteotsunami events and mostly leads to increasing the meteotsunami run-up height, up to 70% compared to the standard models (without inundation). Solovieva et al. (2021) describe the ionospheric disturbances recorded during the chain of meteotsunamis affecting the Mediterranean Sea in June 2014 (e.g. Šepić et al. 2015b) and found significant variations with periods ranging from 10 to 40–70 min at various stations, i.e. in the same range as the observed air pressure oscillations and, in fact, generated meteotsunamis.

3.3 North-East Atlantic meteotsunamis

A case study of a meteotsunami that occurred in June 2010 along the Portuguese coastline was conducted by Kim and Omira (2021), who analysed both oceanic and atmospheric data and constructed a high-resolution ocean model to quantify the meteotsunami hazard. The authors demonstrated that meteotsunamis present a real threat for the densely occupied Portuguese coast and identified "hot spots"—specific coastal sites, where the meteotsunami energy is focused. De Jong et al. (2021) described long-term monitoring of coastal seiches and high-frequency oscillations with tsunami frequencies observed in the Port of Rotterdam and updated the height criteria for the alongshore storm surge barriers. These criteria also serve as an input to design protective sea locks for coastal ports. Sibley et al. (2021) examined the physical processes responsible for a strong meteotsunami observed along the English Channel and the North Sea coasts on 29 May 2017. The authors concluded that the event was caused by a rear flank downdraft in association with a mesoscale convective system (MCS). This downdraft led to hydrostatically embedded internal or ducted gravity waves, which then interacted with the sea surface through Proudman resonance causing a wave run-up along the Dutch beaches up to 2 m.

3.4 Meteotsunamis in North America

Angove et al. (2021) reviewed US meteotsunami occurrence in terms of their generation mechanisms, formation and impact on coastal zones. They described an establishment of initial, rudimentary alerting capabilities for the US Great Lakes and US East Coast and emphasized that major challenges and gaps have to be overcome to move the USA towards a comprehensive meteotsunami forecast and warning service. One of destructive meteotsunami events that occurred in Lake Michigan was described by Anderson and Mann (2021); they provided atmospheric and hydrodynamic model simulations of the inertia–gravity waves and associated meteotsunamis to demonstrate the existing US operational capabilities. A significant meteotsunami in the southern Strait of Georgia (British Columbia, Canada) has been examined by Rabinovich et al. (2021). The authors analysed more than a hundred air pressure series collected within the Victoria School-Based Weather Station Network and derived the shape, speed and direction of tsunamigenic atmospheric disturbances. The conducted quasi-realistic numerical simulations of the event agreed with observations. Titov and Moore (2021) performed an assessment of a meteotsunami model forecast in real time, indicating the ability to predict coastal meteotsunami impacts occurring 1–2 h after the model data assimilation phase had ended. They examined a strong meteotsunami event of 13 June 2013 near the US East Coast and demonstrated potential meteotsunami forecast capabilities for warning operations.

3.5 Meteotsunamis in South America

A thorough analysis of known meteotsunamis along the Brazilian coastline between 1977 and 2020 was done by Candella and Araujo (2021) based on media reports and documents describing the impact of extreme waves on coastal communities. One such event (October

2019) has been investigated in detail by Araujo et al. (2021). At least two tsunami-like waves with heights greater than 0.7 m and periods around 15 min generated by a squall line spread northwards along the coast of Santa Catarina. Further south, Perez and Dragani (2021) conducted a series of numerical experiments for coastal waters of Buenos Aires Province, indicating that the amplitude, dominant period and the propagation direction of the train of atmospheric gravity waves are the key parameters determining the simulated meteotsunami amplitude. Carvajal et al. (2021) examined time series of atmospheric and wind-generated wave data at Rapa Nui (Easter Island) and found that the extreme sea levels are ultimately driven by the breaking of large waves near the coastline (i.e. by wave setup), with lesser contribution of barometric setup and even lesser of wind setup.

3.6 Meteotsunamis in South-East Asia and the Persian Gulf

Typhoon-generated meteorological tsunamis are the topic of two papers. Heidarzadeh and Rabinovich (2021) assessed sea-level measurements during two hazardous typhoons, Lionrock (August 2016) and Jebi (September 2018), and found that multiple deaths and extensive floods were caused by the combined effect of low-frequency sea-level rise (storm surges) and intensive high-frequency tsunami-like waves (meteotsunamis), the latter having maximum wave heights up to 2.6 m and contributing up to two thirds of the observed cumulative height. Lin and Wu (2021) documented an unexpected arrival of meteotsunami waves along the eastern coast of Japan prior to Typhoon Wipha in 2013; they assumed that the outer typhoon circulation produced the travelling pressure disturbances and was the main driving force to generate meteotsunamis. An assessment of a fast-moving atmospheric pressure disturbance as the generator of a “strange tide” off the coast of Jiangsu Province, China, has been conducted by Wang et al. (2021), who, through numerical exercises, found that the water level rise can be dynamically amplified more than 40 times through Proudman resonance. Kim et al. (2021) presented a real-time pressure disturbance monitoring system of 89 automatic weather stations, developed for meteotsunami disaster prevention along the Korean coastline, based on the detection of critical air pressure changes. Smirnov et al. (2021) examined spatial structure of eigenmodes in individual bays of the Peter the Great Gulf located in the Sea of Japan, demonstrating that resonant amplification of arriving waves in these bays can destructively multiply the height of both tsunamis and meteotsunamis. Finally, Kazeminezhad et al. (2021) completed the earlier studies of the 2017 Dayyer event (Salaree et al. 2018; Heidarzadeh et al. 2020) and documented weather radar and ancillary atmospheric observations during the catastrophic meteotsunami in the Persian Gulf that killed 5 people and injured 22, focusing on a narrow and intense squall line that was detected in the radar images throughout its propagation over the sea before hitting the coastline.

Acknowledgements The editors would like to express their sincere gratitude to all people that contributed to the organization of The First World Conference on Meteotsunamis (www.izor.hr/mts2019), Split, Croatia, 8–11 May 2019. We thank Petra van Steenbergen, the Executive Editor for Earth and Environmental Sciences in Springer, who arranged and encouraged us to organize this special issue on meteotsunami, and James Goff, the Editor-in-Chief of Natural Hazards, which was under the disposal for all inquiries during the editorial process in this special issue. Viacheslav Gusiakov and Igor Medvedev were of great help in providing concept and creating the figures, respectively. Finally, we would like to thank all authors and reviewers who contributed to this special issue. Work on this issue for Ivica Vilibić was supported by the Croatian Science Foundation (project ADIOS, Grant IP-2016-06-1955), for Alexander Rabinovich by the Russian State Assignment of IORAS #0149-2019-0005, the FAST PTDC/CTA-MET/32004/2017 project funded by FCT (Portugal) and by Croatian Science Foundation project StVar-Adri (IP-2019-04-5875) and for Eric J. Anderson by the National Oceanic and Atmospheric Administration.

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