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Meteo-tsunami hazard associated with summer thunderstorms in the United Kingdom

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ABSTRACT

A recent analysis has suggested that meteorological tsunami (meteo-tsunami) have occurred around the coasts of the United Kingdom (UK), generated by a range of source mechanisms, such as seiching related to storm activity in enclosed basins, the arrival of large far-travelled waves generated in the open ocean, and the local generation of large waves near the coast by thunderstorms and squalls. Fatalities have occurred during meteo-tsunami events in the UK, including those of beach users killed by meteo-tsunami arriving unexpectedly at beaches during summer months, when beaches attract large numbers of recreational users, particularly due to thunderstorm-generated meteo-tsunami. This study surveys historic accounts of tsunami-like waves arriving at the coast in association with near-coastal thunderstorms and identifies up to nine meteo-tsunami events that have occurred in the period 1892–1966, up to five of which may have resulted in fatalities. The risk related to such events is discussed and recommends that some measures be made to educate beach users to the meteo-tsunami hazard associated with offshore thunderstorms.

1. Introduction

Meteorological tsunami (or meteo-tsunami) are long-period waves in the tsunami window that have a meteorological origin (Defant, 1961; Rabinovich and Monserrat, 1996, 1998; Bryant, 2001; González et al., 2001). They are known by various local names around the world, such as *rissaga* (Monserrat et al., 1991) in the Balearic Islands (Spain), *abiki* (Hibiya and Kajiura, 1982) in Nagasaki Bay (Japan), *marrobbio* in Sicily (Candela et al., 1999), *Seebär* in the Baltic Sea, and also perhaps as *freak* waves (White and Fornberg, 1998; Wu and Yao, 2004). Meteo-tsunami have the same periods, spatial scales, physical properties and destructive impact as seismically generated tsunami as they refract and shoal along coasts (Bryant, 2001; Monserrat et al., 2006). *Rogue waves* are large relatively short-period meteorological waves that are infamous for sinking ships in the open sea and so differ from tsunami, which are of low-amplitude in the open ocean, but rogue wave formation in coastal waters may be considered as meteo-tsunami if they take on long-period tsunami-like characteristics (Kharif and Pelinovsky, 2003).

There are a number of mechanisms that may result in a meteo-tsunami. These include the passage of cyclones and hurricanes (excluding storm surges), frontal squalls with associated thunderstorms, atmospheric pressure jumps, atmospheric gravity waves, wind waves, tide-generated internal waves, wave superposition, wind and current interaction, and atmospheric shock waves from volcanic activity (Rabinovich and Monserrat, 1996; Lowe and de Lange, 2000; Bryant, 2001). These processes can generate tsunami-like waves if the disturbance propagates at the same speed as any surface ocean wave being generated (Monserrat et al., 2006). Meteo-tsunami are also very sensitive to resonance generated by local coastal geometry and topography, which in enclosed inlets, bays and harbours, can induce high-amplitude seiches (Rabinovich and Stephenson, 2004; Rabinovich, 2009).

Meteo-tsunami have recently been recognised to have impacted around the coast of the British Isles (Haslett and Bryant, 2009), caused by a variety of mechanisms, such as seiching in enclosed basins associated with significant winter storms, far-travelled long-period waves from Atlantic depressions, and waves locally generated by offshore squalls and thunderstorms during summer months. Fatalities have occurred, particularly during winter storm-induced seiching events, where they are superposed on storm surges; however, damage and deaths have also occurred during summer thunderstorm-generated meteo-tsunami when beach users, often outside the immediate area affected by the thunderstorm, are unexpectedly struck by meteo-tsunami and swept off beaches. This last category is the subject of this paper

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as the authors consider it to be an entirely neglected hazard in the UK; a hazard that has caused more fatalities than earthquakes in the UK and yet beach users are unaware of the dangers.

Haslett and Bryant (2009) recognised three thunderstorm-generated events in their study (occurring 1892, 1929 and 1966), which were often referred to by newspapers as 'tidal waves'. In this present study, a wider survey of newspaper reports of 'tidal waves' has been made and yields a number of additional occurrences of meteo-tsunami generated by squalls and thunderstorms during the summer months (May–September) in the UK. These additional events combine to contribute further information regarding the frequency and geography of these events around the UK coast and provide coastal managers with data to better inform local hazard risk assessment for beach users and coastal communities. It also contributes to a wider ongoing study of tsunami occurrences around the coast of the British Isles (Haslett and Bryant, 2008).

2. Meteo-tsunami events

Events have been identified for inclusion in this study mainly through an extensive survey of the *The Times* newspaper online archive that spans 1785–1985 (issues after 1985 are not available for analysis), and also other events brought to the authors attention. The database was searched using the terms 'tidal wave' and 'tidal waves'. The results were then scrutinised and events occurring during the summer months (May–September) in the UK, and linked to thunderstorms, were selected (the association of coincident thunderstorm activity and large wave(s) very strongly suggests a causal link, although other mechanisms may not be ruled out entirely, such as tsunami generated by an submarine slide). From this survey, up to nine possible meteo-tsunami occurrences have been identified, three of which were previously reported by Haslett and Bryant (2009). For completeness, all events are presented and discussed here. Fig. 1 shows locations of places mentioned in the text and Table 1 summarises the events.

2.1. Yealm (Devon) and Fowey estuaries (Cornwall), 18th August 1892

Haslett and Bryant (2009) present newspaper reports stating that "a series of tidal waves" occurred along the western English Channel coast in the estuary of the River Yealm where "a good deal of damage was done to boats moored in the river" (Penny Illustrated, 1892, p. 6). The Times (1892a) also reports this event in the River Yealm as well as stating that "there was a rapid rise in the River Fowey as a great tidal wave, but this immediately subsided" (p. 4). These waves do coincide with an earthquake that occurred in the Bristol Channel, with which the newspaper reports make a connection; however, these waves are more likely to be related to squalls. The Times (1892b) report thunderstorms in the English Channel that day and Davison (1924) considers that they generated the large tsunami-like waves.

2.2. Folkestone (Kent) and Brighton (Sussex), 20th July 1929

Haslett and Bryant (2009) review this event that occurred around 7.30 pm (c. 1 h and 15 min after low tide), when a large tsunami-like wave struck the Kent and Sussex coasts, busy with tourists, and drowned two people. The Times (1929) describes the event at a number of locations, where at Brighton and Worthing the wave was accompanied by sudden downpours of rain and high winds, but at Folkestone and Hastings, where one person drowned at each, the weather was clear and the unexpected wave was estimated to be c. 3.5 and 6 m high, respectively. Uniquely, at Folkestone, eight large waves were observed entering the harbour, picking up motor-boats lying on sand-flats, exposed close to low

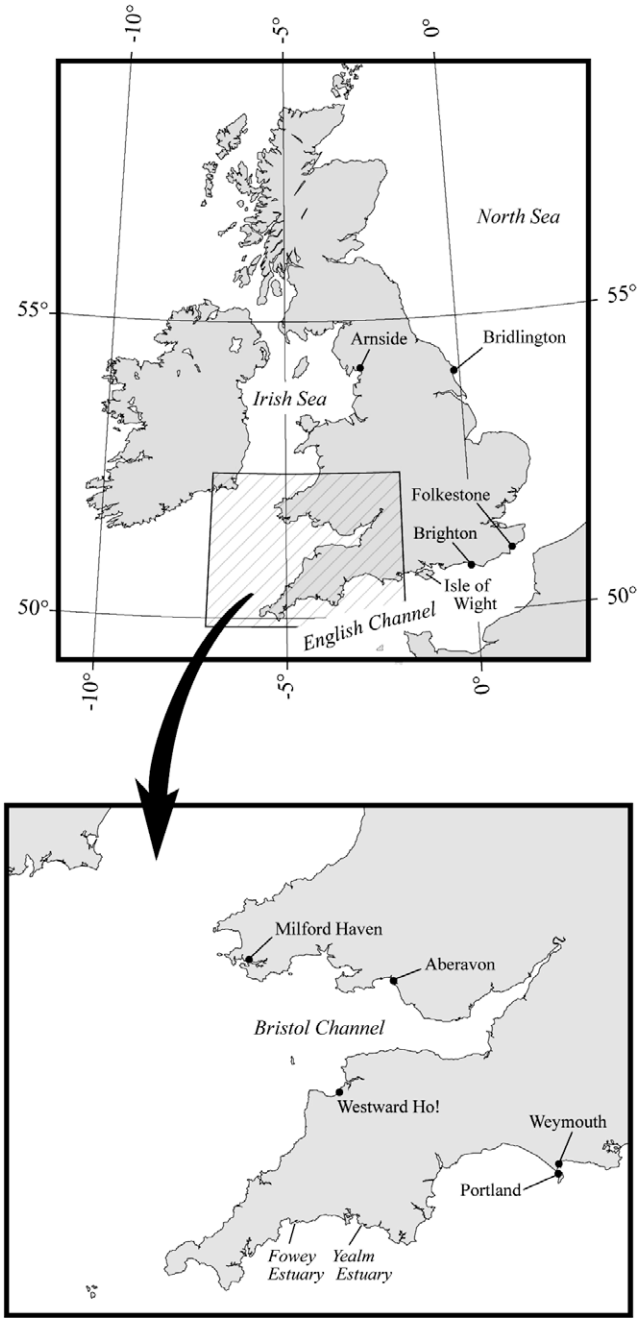

Fig. 1. Location of places in the United Kingdom mentioned in the text.

tide, and transporting them over 180 m along the length of the inner harbour (Fig. 2). A 16-year old boy, Arthur Barrett Balkham, fishing from the breakwater here, was washed off and his body was never recovered. If this event had coincided with high tide then the number of casualties is likely to have been much greater and damage more extensive. Douglas (1929) suggests the wave was caused by a squall-line travelling up the English Channel, coincident with thunderstorms, and so may be referred to as a meteo-tsunami.

Further specific details from The Times (1929, p. 14) give a fuller picture of the event. At Brighton, "a line of foam rushed towards the beach, while pleasure boats raced for safety. Almost before the crowds realised what was happening torrential rains poured down and the wave rushed far up the beach, carrying away chairs and bathers' clothes". At Folkestone, "a number of bathers and people

Table 1
Summary of possible meteo-tsunami events in the United Kingdom.

Date and time	HT, port, time (GMT) and height (m)	Areas effected	Origin	Impacts
18th August 1892	Yealm: 01:34 (4.2) and 14:15 (4.4) Fowey: 01:16 (4.2) and 13:57 (4.4)	Yealm (Devon) and Fowey (Cornwall) estuaries	Linked to a thunderstorm/ squall in the English Channel	A series of large waves, damaged boats
20th July 1929, c. 19:30	Folkestone: 10:08 (6.4) and 22:30 (6.4) Brighton: 10.33 (5.7) and 22:43 (5.8)	Folkestone (Kent) to Brighton (Sussex)	Squall-line in the English Channel	Large wave struck beaches killing two people
2nd August 1932	Port Talbot: 06:10 (8.8) and 18:24 (9.3)	Aberavon (Glamorgan)	Unknown, but thunderstorm occurrence elsewhere	Large wave struck beach killing four people
5th August 1938, c. 08:00	Bridlington: 11:57 (4.7)	Bridlington (Yorkshire)	Thunderstorm	Significant sea outrush and inrush in harbour, and large wave
4th July 1939, c. 00:30	Milford Haven: 19:25 (6.7, on 3rd) and 07:42 (6.4)	Milford Haven (Pembrokeshire)	Squally weather	Overturned rowboat close to shore, killing three people
5th July 1939	Portland: 08:46 (1.8) and 20:56 (1.9)	Weymouth and Portland (Dorset)	Freak weather and violent (thunder) storms	Large wave tore boats from moorings
6th July 1957, c. 19:30	Bembridge, Isle of Wight: 19:22 (4.4)	East coast of the Isle of Wight	Thunderstorm	Two large waves moved boats in harbour; possible injury and one death?
17th May 1964	Arnside: 04:15 (9.1) and 16:54 (8.6)	Kent Estuary, Arnside (Westmorland)	Unknown, but scattered thunderstorms noted	Two people swept to their deaths by large wave
31st July 1966	Appledore: 04:59 (6.3) and 17:19 (6.7)	Westward Ho! (Devon) and Pembrokeshire	Probably a squall-line in the Bristol Channel	Large wave struck, bowling people over up the beach at Westward Ho!, and damage along Pembroke coast

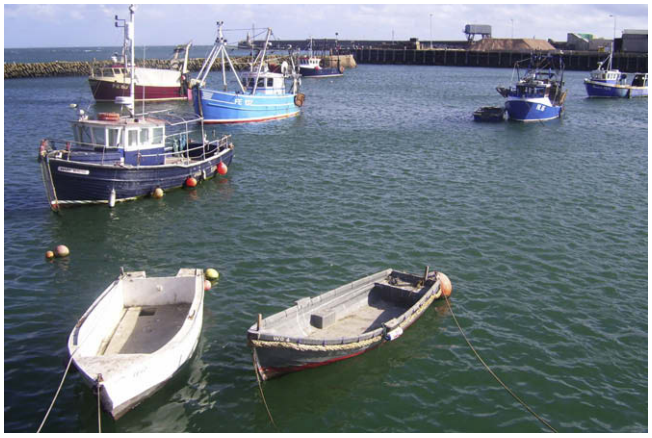

Fig. 2. Folkestone Harbour, Kent, where "eight large waves were observed entering" on 20th July 1929, washing one boy from the harbour wall to his death (photo taken September 2007; view towards south).

Fig. 3. Folkestone Beach, Kent, where a "number of bathers and people paddling were caught by the tide and were in danger of being drowned" during the event of 20th July 1929 (photo taken September 2007; view towards east).

paddling were caught by the tide and were in danger of being drowned [see Fig. 3]. Mrs. Ruth Kirby ... and her 5 and 6 year old daughters, Sylvia and Eileen, were injured by being cast on the rocks and had to be taken to hospital for treatment. The mother was only able to catch her two children as they were submerged by the sea, but was fortunately able to retain her hold on them. Mrs. Elizabeth Hill ... and two Folkestone boys named Whiting and Pryor were also injured by being thrown on the rocks ... A small boat with two men in it was lifted up on to the rocks at East Cliff and left high and dry". At Hastings "Mrs. Lillian Pollard ... was drowned when the boat in which she was a passenger capsized ... The wave overturned the boat and all its occupants went under ... At St. Leonard's two boats were capsized by the wave and all the occupants were thrown into the sea". On the east side of the Isle of Wight "a bank of sand swept along the sea front with considerable force. Many boats were overturned on Sandown beach". Finally, at Worthing "the sea was churned up into a wave quite 6 ft high, which came sweeping towards the shore at an alarming pace. It extended as far as the eye could see and within 5 min the sea had risen from low to half full tide. The people on the front and those who were bathing or paddling ran for shelter".

2.3. Aberavon (Glamorgan) 2nd August 1932

On Tuesday 2nd August, again during school summer vacation, a tsunami-like wave hit Aberavon beach on the Bristol Channel coast of South Wales. The Times (1932a) reports that "Charles Bayliss, 16, William James, 14, and Oswald Hopkins, 16, were washed out to sea by a sudden tidal wave at Aberavon yesterday and drowned. A large number of bathers were near the pier. The boys were believed to have been holding hands when they disappeared. Later it was found that a fourth boy, Arthur Gage, aged 14, was missing, and it is believed that he also was a victim of the tidal wave. His clothing was found on the sand dunes. It was stated that

all boys could swim, but were unable to reach land owing to the strong current. Boats were launched and a search was made for the bodies and two were recovered. The boys all lived at Cymmer, near Port Talbot" (The Times, 1932a, p. 12).

Although there is no mention of weather conditions in this report, it appears that this event occurred within a period of extensive thunderstorm activity, as The Times (1932b) reports that on the previous day there were no less than 12 thunderstorm affected areas in the UK. The weather report for South Wales on the 2nd August simply states that the weather is "cloudy", and generally "unsettled" (The Times, 1932c, p. 12). Given the close, although not direct, association of thunderstorms with this event, it is likely the wave was created by an offshore thunderstorm, perhaps in the outer Bristol Channel. This event appears to be the most recent of a number of large wave events to affect the Bristol Channel in the past (Bryant and Haslett, 2003, 2007; Haslett and Bryant, 2005, 2007).

2.4. Bridlington (Yorkshire), 5th August 1938

This account describes what is undoubtedly a meteo-tsunami that occurred at Bridlington on the coast of Yorkshire in northeast England. It represents the first record of any meteo-tsunami, that the authors are aware of, occurring in the North Sea basin. The Times (1938) report states that "at Bridlington a tidal wave swept into the harbour. Although it was 4 h from high water the sea receded suddenly for about 15 ft (4.57 m), leaving vessels high and dry, only to return with renewed force and refloat other craft farther up the harbour. A small fishing boat which was returning to harbour when the storm broke was swept against the south pier by the wave, carried out again, and brought into the harbour again by the sea. Mr. Herbert Hutchinson, a member of the lifeboat's crew, was rowing up the harbour with some empty petrol tins when his boat was left high and dry. 'The water,' he said, 'went down about 4 ft (1.22 m) in a minute. It swept out of the harbour like a mill race and then came back. Ships that were high and dry were immediately refloated.' The wave brought into the harbour large quantities of flat-fish, which were left wriggling on the shore." (The Times, 1938, p. 10).

This occurrence of a meteo-tsunami at Bridlington is directly linked to thunderstorms that severely affected the region on the day. Indeed, it appears that a thunderstorm occurred around the same time as the wave in Bridlington harbour. The detail in the vivid description of the wave is typical for a tsunami, where the sea recedes prior to the arrival of the tsunami wave crest, and the stranding of numerous flat-fish suggests effective onshore transport processes entraining material, including fish, from the sea-bed.

2.5. Weymouth (Dorset) 5th July 1939

This event occurred in association with "freak weather and violent [thunder] storms [that] swept many parts of Britain yesterday [Wednesday] following an exceptionally hot night" (The Times, 1939a, p. 16). "At Weymouth [see Fig. 4] scores of yachts and small boats were torn from their moorings in what was described as a tidal wave. A wave 6 ft [1.83 m] high came roaring up the narrow harbour, tearing moorings out of the sea-bed and throwing boats in confusion under the town bridge. The boom defence across the entrance to Portland Roads was moved some distance into Portland Harbour [see Fig. 5] by the pressure of the sea" (The Times, 1939a, p. 16). This account is similar to the event in the Yealm and Fowey river estuaries in 1892, again in the English Channel, where such waves appear to be a hazard for moored boats and yachts.

Also on the previous day (Tuesday 4th August), squalls in the Bristol Channel overturned a boat close to shore killing three people at Milford Haven, Pembrokeshire. The Times (1939b, p. 4) reports:

Fig. 4. Weymouth Beach, Dorset, where "a wave 6 ft (1.83 m) high came roaring up the narrow harbour, tearing moorings out of the sea-bed and throwing boats in confusion under the town bridge" during the 5th July 1939 event (photo taken October 2007; view towards east).

Fig. 5. Portland Harbour, Dorset, where "the boom defence across the entrance to Portland Roads was moved some distance into Portland Harbour by the pressure of the sea" during the 5th July 1939 event (photo taken October 2007; view towards north). Chesil Beach is visible in the west (left).

"the bodies of the wives of two local trawler skippers were washed ashore at Milford Haven on Tuesday. They were Mrs. Jack Bennett and Mrs. Alice Riley. James McDougall, aged 23, Mrs. Bennett's son, is also missing and believed drowned. The women left their homes at midnight with McDougall in a small boat to row to a motorboat which was to take them out into the Haven to greet their husbands, whose boats had just returned from the fishing grounds. The weather was squally at the time and it is believed the boat was swamped." There are similarities between these deaths and that of Mrs. Lillian Pollard at Hastings in the July 1929 event. The question should be asked, whether this small row boat in Milford Haven would have launched if the weather was generally poor, particularly at night? It is conceivable that, as in Hastings in 1929, the weather was fine, but meteo-tsunami propagating from a distant squall took the party unawares after disembarkation and overturned their small craft. However, this is one possibility only.

2.6. Isle of Wight, 6th July 1957

The Isle of Wight is situated in the English Channel. The event in question is reported by the Isle of Wight County Press (1957): "on

Saturday evening in Bembridge Harbour there occurred what appeared to be two miniature tidal waves caused, it is thought, by electrical storms and leaving in their wake a whirlpool just off Bembridge S.C. Similar occurrences have been experienced there before, but not with such intensity and the last was about 6 or 7 years ago. They have coincided with heavy thunderstorms over the sea off the east end of the Island. The strange part about Saturday's occurrence was that there were no breakers on the beach although the tide on the sands at The Point flowed up the beach for a distance of 20 ft and then receded twice in less than an hour. Small boats near the shore in other parts of the harbour were swept up the beach and left on their sides and then with another rise of tide 5 min later were afloat again. The first disturbance came not very long before high water at about 7.30 pm when the tidal gauge of the railway quay showed a sudden fall of 15 in. (381 mm) within 5 min, followed by a rapid rise of 18 in. (457 mm). In another 5 min it dropped about 15 in. (381 mm) and then a little later rose 18 in. (457 mm) and remained at about normal level at high water. The evening was sultry and overcast and the general effect was uncanny as there seemed to be no motion of the sea to accompany the rise and fall save at the entrance of the harbour where the water was in a turmoil. The two waves seemed to strike in across the sands and harbour channel towards St. Helens sea wall and the water poured over the breakwater at Attrill's Point into the harbour just like a weir. Five minutes later it was pouring out in the opposite direction, and on the second ebb the rush of the sea was even more pronounced. The effect on yachts and small boats in the harbour was curious and almost alarming. An auxiliary yacht, Sea Wraith, of about nine tons, in which there were several naval men, was just entering the harbour and became uncontrollable. She was swept back to within a hair's breadth of the big ketch Lady Armanda, which was anchored, and then carried into the harbour by the first sudden rise and collided with a Fairey Atlanta boat and had her large outboard motor torn off, thus losing her means of propulsion. The harbour pilot (Mr. E. Wade) went to her assistance and towed her to St. Helens Quay. At midnight, when the tide had receded, her motor was recovered from the harbour bed. Several boats which were underway were swept sideways up towards St. Helens Quay and then back. Craft anchored in the harbour spun round their moorings in circles and then back the other way. The most ludicrous sight of all was a small fleet of Scows which were racing but which were carried stern first and then swung round in a big circle entirely at the mercy of the tide. Capt. R.R. Caws who was entering the harbour in his yacht, Any Lessen, found himself being swept out to sea and then borne into the harbour and with the second fall in the tide was only just able to make way against it" (Isle of Wight County Press, 1957).

The same event may also have been recorded at a different location along the coast through the recollections of an eye-witness: "the incident took place at Horseshoe Bay, Bonchurch, near Ventnor on the Isle of Wight. At the time the wave hit the shore I was swimming in the sea with other children, and my younger sister was standing with my father on a jetty that projected into the sea. My sister remembers seeing a 'wall of water' coming towards her, and I can remember the wave being up to my fathers shoulders [who was standing on the jetty] ... the effort of preventing my sister from being swept away was such that my father injured his leg and was unable to walk for several days afterwards. The weather was fine enough for children to be swimming and the sea also cannot have been that rough .... My sister remembers being told or overhearing that one person was killed by the wave" (D. Hill, 2009, personal communication). However, the eye-witness is uncertain about the date stating that "the year could have been any of 1957, 8 or 9" and so could be referring to a separate event.

2.7. Arnside (Cumbria) 17th May 1964

Arnside is situated on the Cumbrian coast of the Irish Sea in northwest England. Few details exist for this event, other than a brief mention in The Times which states that "a man and his son aged seven were swept to their deaths by a tidal wave while bathing in the Kent estuary, near Arnside, south Westmorland [now part of the county of Cumbria]" (The Times, 1964, p. 8). Although there is no mention of weather conditions in the report, the weather forecast does predict "scattered thunderstorms" in the area that day (The Times, 1964, p. 9). It is likely that this event is a meteotsunami occurrence, however, it must be noted that the Kent Estuary, where this event took place, does experience tidal bores, which presents an alternative explanation.

2.8. Westward Ho! (Devon), 31st July 1966

Haslett and Bryant (2009) present a previously unpublished eye-witness account of a large wave that states "on the beach at Westward Ho! (see Fig. 6) in North Devon in August, 1966, as far as I can now ascertain the date ... I was in the water with my small surf board, 'catching' waves to bring me into shore. Suddenly, with my back to the sea ... I found the water had dropped from waist level to around my ankles. I turned to look out to sea and saw a huge wave coming in ... When it arrived, I had the surf board ripped from my hands, and I was bowled over and over in the foaming water. The wave ran up the beach, soaking everyone who had not seen it coming, and stealing all possessions laying on the stones there ... I remember thinking I would surely drown in this giant wave, but found myself still alive, but pretty battered ... I remember looking over my shoulder when the wave was very close, and realising, with horror, that it was enormous. I am 5 ft 4 in. (1.63 m) tall, and I would estimate the wave to have been something in the region of 8–10 ft (2.44–3.05 m) in height ... if it had been hitting the coast of Devon in any other place than Westward Ho!, then the results could have been quite devastating. The huge stones and sea defences behind probably dissipated the force of the vast amount of water" (J. Murray, 2005, personal communication).

Although one cannot be certain, an examination of weather events in the outer Bristol Channel region around August 1966 reveals a candidate for the event occurring on the afternoon and early evening of Sunday 31st July. The front page of The Times (1966) ran the headline '40 yachts hit by freak squall' and describes how a damaging squall with wind speeds up to 45 m/s (160 km/h, 100 m/h) struck the Pembrokeshire coastline across the Bristol

Fig. 6. Westward Ho! Devon, where a large wave caused damage and injury to bathers on 31st July 1966 (photo taken January 2007; view towards the north).

Channel from Westward Ho! Rescue services searched for hours for people missing as yachts were blown away from their moorings and in some instances were washed out to sea and/or overturned; eventually everyone was accounted for.

The link between the Pembrokeshire squall and the Westward Ho! wave is reasonable and constitutes another instance of a meteo-tsunami being generated by the passage of a frontal squall in southern Britain. Indeed, this wave appears similar to that experienced in Kent and Sussex in July 1929, and Aberavon in 1932, where the wave unexpectedly struck coasts where the meteorological effects (heavy rain and strong winds) were absent. Haslett and Bryant (2009) suggest that an alternative, or contributory, factor in this Westward Ho! event may be the positioning of Hurricane Dorothy in the mid-North Atlantic on the 30th and 31st July (Erickson, 1967; Sugg, 1967) that may have generated far-travelling, long-period waves. However, they felt this to be unlikely given the occurrence of a local squall and the geography of the wave impact.

3. Discussion

This wider survey of possible meteo-tsunami occurrences, linked to squalls and thunderstorms, in the UK supports one of the conclusions made by Haslett and Bryant (2009) that the public should be made aware of the dangers associated with the passage of frontal squalls that can generate meteo-tsunami unexpectedly on summer days when beaches attract many recreational users. Indeed, in some instances, meteo-tsunami strike beaches outside the area affected by the squall or thunderstorm taking beach users completely by surprise.

This study identifies up to nine events that could be attributed to meteo-tsunami, but it is likely that this is an underestimate'. This is likely because The Times online archive is available to 1985 only and, although a national newspaper, The Times may have had a southern England bias reducing the coverage of events happening in northern Britain. From an analysis of events for which the timing of the wave arrival is known (Table 1), or may be inferred in relation to tidal levels, it is clear that six of the nine events occurred when the tide was below mean tide level, if not near low tide. A sudden wave inrush on low-gradient beaches and in harbours would be more apparent under these conditions than at high water, especially where the intertidal zone on beaches would be occupied by recreational users, or where boats grounded in harbours by the ebbing tide are suddenly refloated by the arrival of a large wave. It is under these conditions, where the appearance and effects of the waves are clear to observers, that the term 'tidal wave' (to describe a tsunami-like wave) is more likely to be used by reporters. Therefore, meteo-tsunami generated by thunderstorms and squalls that coincide with high tide may not be so readily noticed as damage and casualties are likely to be less, and are less likely to warrant the use of the term 'tidal wave' by observers/reporters and would, therefore, not appear in our survey results.

Descriptions of the arrival of waves in some reports clearly indicate the tsunami-character of these waves, with two instances (Bridlington and Westward Ho!) documenting a rapid recession of the sea (e.g. harbour outrush at Bridlington) followed by the arrival of a large wave. A drop in sea-level is also noted at Bembridge prior to an inrush. Furthermore, tsunami processes are indicated in some of the accounts, such as effective sea-bed scouring, onshore sediment transport, coastal erosion, and backwash (Bryant and Young, 1996).

This study also indicates that the potential meteo-tsunami identified represent a hazard to beach users. If we accept that all the events listed here are meteo-tsunami caused by squalls and thunderstorms, then 12 fatalities have occurred since 1892. Although this appears a relatively small number, only 12 deaths, in comparison, have occurred due to earthquakes in the UK since 1580 (Musson, 2003), and so is probably of greater significance. Fatalities from natural disasters in the UK are fortunately low, but for many common hazards (e.g. flooding) the public are educated in the risks and so may take action to reduce the risk; however, the majority of beach users are likely to be unaware of the danger that meteo-tsunami present in the UK and, without education or warning, are unlikely to vacate a beach if they see a thunderstorm offshore, for example.

Within the Atlantic, meteo-tsunami due to squalls and thunderstorms are not restricted to the UK, and so present a wider hazard. Sallenger et al. (1995) document a large wave that struck Daytona Beach (Florida, USA) in 1992, which they suggest may have been generated by the passage of a squall-line offshore. More recently, a series of large waves came ashore in Boothbay Harbour (Maine, USA) around 3 pm on 28th October 2008. Reports state that a giant wave rushed into the harbour and water levels rose 12 ft (3.66 m) within 15 min. The sea then receded, but a further two waves occurred, each time damaging docks and pilings (Woolhouse, 2008; Anon, 2009). Although the cause of these waves is debated, their occurrence coincides with a storm that may have had several fast moving squalls situated in the Gulf of Maine (Anon, 2008), and so may be a meteo-tsunami.

This survey was conducted using the search term 'tidal wave' in The Times online archive, and so only wave events that warrant such a description (meaning tsunami-like) would be returned. Further surveys of The Times and other online newspaper archives, as they become available in the UK and elsewhere, using a selection of search terms are likely to yield further events for consideration that will help to further construct an understanding of the frequency and geography of this hazard. From this study, it appears that potential meteo-tsunami associated with thunderstorms and squalls have occurred in the English Channel and Bristol Channel as suggested by Haslett and Bryant (2009), and now also in the Irish Sea and North Sea. Temporally, there is a concentration of events in the decade 1929–1939 (five events) and two in the 1950s–1960s, with the remaining one in 1892. It is not clear whether there is a climatological link to these periods, but further surveys may help in exploring any potential link.

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