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ORIGINAL PAPER

# Investigating the occurrence of an unusual tidal event along the north–west coast of Ireland

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## Abstract
The study investigates the occurrence of an unusual tidal event recorded at Portsalon Golf Club on 21st February 2022 at 08:50 UTC. The event followed the passage of Storm Franklin and was described by the videographer as a "rather unusual storm surge", prompting the evaluation of multiple event types to identify the most likely cause: Storm Surge, High-Tide Seiching, Freak Wave, Meteotsunami or Tsunami. Through the use of 5-min tidal observations, 1-min meteorological station data and ERA5 reanalysis products, sea-level and atmospheric variability and synoptic conditions prior to and during the videoed event were examined. Results highlight evidence of elevated non-tidal variability coinciding with strong winds and high wave height (~12 m) near the mouth of Lough Swilly following the passage of Storm Franklin. Oscillations recorded at Letterkenny tidal gauge on the approach to high tide suggest the possibility of seiching within Louch Swilly. Background conditions often associated with Meteotsunamis, such as the presence of a strong jet stream and area of high relative humidity, were present, however no clear or particularly rapid atmospheric pressure disruption was found that temporally aligned with the observed wave. Neither the prevailing wind or wave direction suggested a freak wave was a contributing factor, and no spatially or temporally relevant seismic activity was recorded. The most likely explanation of the videoed event is the combination of a weakening storm surge amplified by high-tide seiching in Lough Swilly. Limitations in analysis highlight the need for higher-frequency coastal monitoring to aid the classification of such hazards.

**Keywords** Meteotsunami · Storm surge · High-tide seiching · Lough Swilly · Ireland

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## 1 Introduction

At 08:50 UTC on the 21st of February 2022, a video was captured and posted on Twitter (now X.com) titled “A rather unusual storm surge this morning” (Fig. 1). The recording of such phenomena in recent years has raised public awareness of unusual sea-level related events in Ireland (McCarthy and Berry 2022) and has increased the consciousness of the associated hazard. The video shows a propagating wave travelling inland from a sea inlet and flooding the Golf Course of Portsalon next to Lough Swilly, Co Donegal, Ireland. The videoed phenomena resembles that of several different events such as a storm surge event, high tide seiching, a freak wave, a meteotsunami, or a tsunami.

During February 2022, in the week preceding the video, Ireland was struck by three named storms: Storm Dudley on the 16th, Storm Eunice on the 18th, and Storm Franklin on the 20th (Met Eireann 2023). This was attributed to the presence of a highly active North Atlantic jet stream flowing towards Ireland during that period (Met Eireann 2022).

Due to the proximity of storm Franklin in particular, there is a potential that this was a storm surge event caught on camera. Storm surges are defined as the anomalous escalation in seawater level during a storm. Storm surges are calculated as the height of the water level exceeding the astronomical tide (NOAA 2023a). Storm surges in Irish waters are typically greater along the west coast compared to the east coast due the prevailing origin of Atlantic Storms from the west and the open geography of the west in comparison to the more sheltered Irish Sea (Olbert and Hartnett 2010). They typically occur on longer timescales than meteotsunamis and tidal bores and are not usually associated with wave-like phenomena. However, there is the possibility that storm Franklin triggered extreme seiching in Lough Swilly or a freak wave.

A seiching event is typically caused by strong winds or sudden atmospheric pressure changes which act to push water from one end of an enclosed or semi-enclosed body of

**Fig. 1** Still framed images showing the ‘unusual storm surge’ conditions during the videoed event recorded at Portsalon golf club, county Donegal on the 21st February 2022 at 08:50 UTC. 2022*Source* Shields (2022)

water, such as a lough, to the other. The water can oscillate back and forth for hours or even days after the initial event, with periods exceeding three and four hours (NOAA 2024a). Seiches can be identified via a distortion in the tidal curve, and have been documented to occur during the approach to high tide (Bowers et al. 2013). Freak or Rogue waves on the other hand are characterized as anomalously large waves (>2 times the Significant Wave Height [$H_s$]) that often travel in the opposite direction to the prevailing winds and waves making them very unpredictable (NOAA 2024b). Reports of freak waves are particularly high along the coast of Ireland and the UK (Didenkulova et al. 2023). For freak waves that occur in water of greater depth than 20 m, modulation instability is often regarded as the main generating force behind their formation, however wind and gust strength can also affect the magnitude of freak waves (Didenkulova et al. 2023).

Meteotsunamis can generally be divided into two groups based on how they are formed. “Good-weather” meteotsunamis are typically generated by a propagating atmospheric wave or air pressure disturbance during which the surrounding weather is described as ‘nice’. “Bad-weather” meteotsunamis form due to storms and high winds (NOAA 2023b; Vilibic and Šepić 2017; Rabinovich 2020). In this “bad-weather” case, extreme storm seiches where the trough-to-crest wave height is greater than 30–40 cm are often regarded as meteotsunamis (cf. Pattiaratchi and Wijeratne 2015; Olabarrieta et al. 2017; Dusek et al. 2019). The literature also points to numerous synoptic conditions that tend to be observed at, or around, the time of previously documented meteotsunamis, such as the occurrence of a fast moving jet stream overhead (Šepić 2015; Heidarzadeh 2020; Kubota 2021), heavy precipitation event prior to the meteotsunami (Williams 2021) and very high levels of relative humidity (Rabinovich 2021). As meteotsunamis reach the coast, they begin to alter the water level in a similar fashion to a seismically formed tsunamis, causing rapid drops and sudden rises in the water level (Lewis et al. 2023). While both share a high frequency of 2 min to 2 h (Kim et al. 2022), most meteotsunamis are typically much smaller than recorded tsunamis and often go unnoticed or are misclassified, especially in winter months during unsettled weather where their effect on the water level is often hidden within intensive waves or storm surge (NOAA 2023b; Heidarzadeh et al. 2025a, b). Stronger meteotsunamis can pose a significant threat, causing severe flooding and fatalities, with their strength often influenced by the magnitude of the pressure disturbance, shelf depth, or the coastline shape (Renzi et al. 2023). The occurrence of meteotsunami events in Irish waters is common and these events tend to be some of the largest meteotsunamis experienced across north-western Europe (Williams et al. 2021). One such event occurred on the 18th June 2022 and was observed across the whole of the south coast of Ireland and southern Wales (McCarthy and Berry 2022; Sibley 2022; Renzi et al. 2023). Public awareness of this was high due to eyewitness and social media reports of the unusual event which stood out due to otherwise calm conditions.

In some cases, a low-frequency storm surge and high-frequency meteotsunami can combine, resulting in extreme sea level variation (Heidarzadeh and Rabinovich 2021). This was the case along the coast of Japan during typhoon Lionrock and Jebi where strong winds generated storm surge and meteotsunami conditions that claimed multiple lives and caused extensive flooding damage (Heidarzadeh and Rabinovich 2021). A major challenge exists when attempting to quantify the combined effect of a low-frequency storm surge and high-frequency meteotsunami as they differ on a temporal and spatial scale. While storm surge events can be analyzed using 1-h intervals of sea level data, seiches or meteotsunamis typically require much finer intervals (0.5–2.0 min) (Vilibić et al. 2016). As such there are very few papers examining the combination of these two phenomena.

Seismically triggered tsunamis typically only occur following a megathrust earthquake, the most powerful magnitude earthquakes (>6 magnitude on the Moment Magnitude scale), and are thus infrequent in Irish waters but do remain in popular consciousness (Geological Survey Ireland 2026). The last major tsunami to hit Irish waters and affect the island of Ireland was the 1755 Lisbon tsunami, which was generated by a massive earthquake of magnitude 8.5–9 (Mendes-Victor et al. 1994). This tsunami hit the coast of Ireland and saw the creation of an island out of Aughinish, south of Galway Bay, and severely damaged Galway's Spanish Arch located within Galway Harbour (Giles et al. 2020; Kearns 2020). Tsunamis can also be formed by the occurrence of a volcanic eruption. The Hunga-Tonga Volcanic eruption that occurred in January 2022 sent powerful atmospheric and oceanic disturbances around the globe which caused both tsunamis and meteotsunamis (Villalonga et al. 2023). Submarine landslides have also been known to cause tsunamis in the past. In 1998, Papua New Guinea was devastated by a 15-m-high tsunami which was attributed to a sudden shift in the seabed off the northern coastline (Tappin 2017). Heidarzadeh and Satake (2015) used four tide gauge records recovered from 1998 to directly show evidence of the tsunami caused landslide occurring 12–17 min after the main earthquake shock.

The following sections of this study contextualizes and describes the event that featured in the video from the 21st February 2022, collates available meteorological and sea-level observations to establish the broader environmental setting, and evaluates whether the observed wave can be attributed to storm surge, high-tide seiching, a freak wave, meteotsunami, or a tsunami. Section 2 outlines the data and methods used to analyse the origin of the strange wave activity seen at Portsalon. Section 3 presents the results of the analysis carried out, which is followed by a discussion in Sect. 4 and conclusion in Sect. 5.

## 2 Data and methods

### 2.1 Tidal data

Tidal data was collected from two separate sources, the Office of Public Works (OPW) HYDRO-DATA interactive map (OPW 2025) and from the Irish Marine Institute's Real Time Tidal Observations (Marine Institute 2022). In total five tidal stations: Malin Head, Letterkenny, Aranmore Island, Killybegs, and Ballyglass (Fig. 2), located along the northwest coast of Ireland provided 5-min-high frequency data that was used in this analysis. All stations are fully tidal, except for Letterkenny, which is partially fluvial, being situated at the head of Lough Swilly on the River Swilly. To avoid the possibility of false tidal readings, the Newmills water level station located further upstream was analysed and compared to the Letterkenny tidal data. Tidal harmonics were fitted to the fully tidal stations over time periods of at least 1 year, using the TideHarmonics package in R, fitting at least 64 tidal constituents to ensure goodness of fit. Non-tidal anomalies were calculated in two different ways. The first method computed non-tidal anomalies by subtracting the raw sea level from the predicted Astrotide produced from the TideHarmonics package.

The second method involved the tide gauge data being filtered using a fifth-order Butterworth high-pass filter with either a cut-off period of three or four hours depending on the

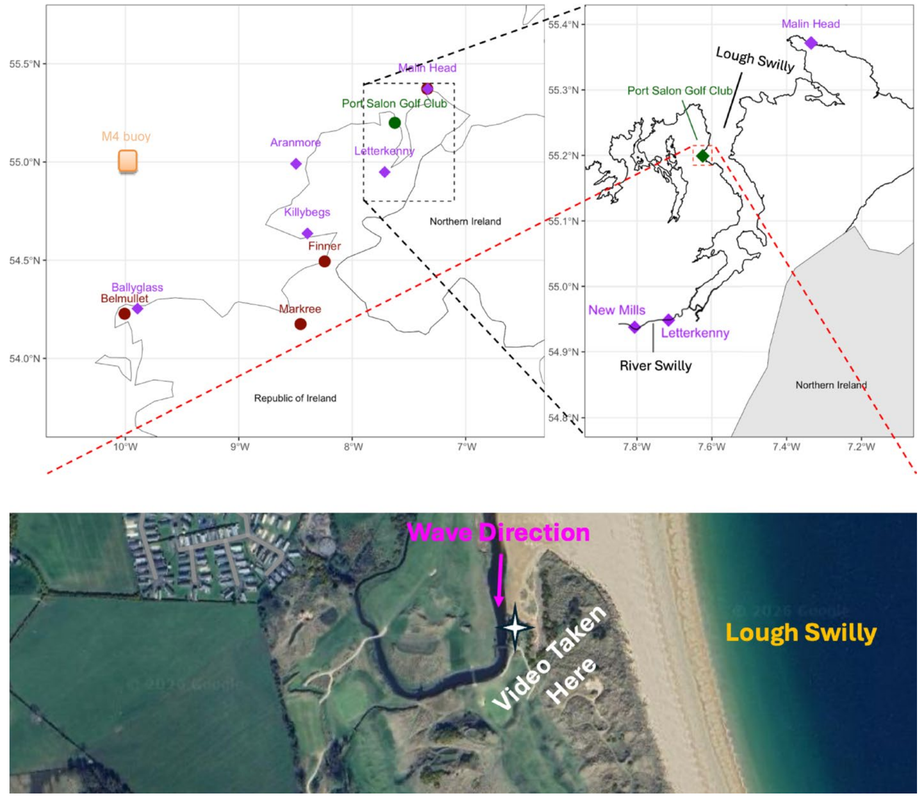


**Fig. 2** Location of (purple filled diamonds) tide gauge stations, (dark red filled circles) weather stations, the M4 buoy, and Portsalon Golf Club where the video was recorded. Satellite imagery highlights the approximate location of where the video was taken and the direction of the propagating wave

analysis carried out. The cut-off period allows the naturally occurring tides to be removed, while the high order of the filter allows the frequencies in the stop-band to be attenuated effectively. Therefore, only higher-frequency non-tidal changes are left in the tide gauge data to be analysed.

In addition, the continuous wavelet transform (CWT) was used to analyse the time–frequency characteristics. The method follows Torrence and Compo (1998), Renzi et al. (2023) and Heidarzadeh et al. (2025a, b) where

$$W(\tau,\sigma) = \int x(t)\frac{1}{\sqrt{\sigma}}\psi^{*}\left(\frac{t-\tau}{\sigma}\right)dt.$$

Here, $\sigma$ is the frequency scale, $\tau\tau$ is the time shift, $x\left(t\right)$ is the input time signal, and denotes the complex conjugate. In this study, the Morlet function was chosen to be the mother wavelet: $\psi\left(t;\tau,\sigma\right)$. In addition, wavelet power was calculated as

$$P(\tau,\sigma) = \left|W(\tau,\sigma)\right|^{2}.$$

### 2.2 Atmospheric pressure & wind speed and direction data

Atmospheric data from weather stations were provided by Met Eireann (2024). The 1-min high frequency Met Eireann data provided wind speed and direction data and atmospheric pressure data from 00:00:00 on the 19th February 2022 to 23:59:00 on the 22nd February 2022 at Markree Castle (Only atmospheric pressure), Mace Head (Only Wind Speed and Direction—not shown in Fig. 2), Malin Head, Finner, and Belmullet (Fig. 2).

In a similar methodology to the tidal data, a fifth-order Butterworth high-pass filter with a cut-off period of six hours was used to filter the air-pressure data, in line with Renzi et al. (2023). This ensures any low-frequency variability, like diurnal or semi-diurnal scales, are removed, while retaining the high-frequency oscillations associated with the formation of a meteotsunami.

Once again, the CWT was used to analyse the time–frequency characteristics, but this time of the atmospheric pressure data. Therefore, the dominant modes of variability, and how these modes vary in time, can be identified.

Finally, U10 and V10 wind components were obtained from the ERA5 reanalysis data (Hersbach et al. 2023a, b) and used to produce a synoptic chart of the conditions near the time of the videoed event (09:00 UTC).

### 2.3 Seismic and volcanic data

Earthquake observations from the 21st of February 2022 were gathered from the USGS Earthquake Hazards program (USGS 2022) and the British Geological Survey (British Geological Survey 2022) in order to assess whether a seismically triggered tsunami could explain the videoed wave. Reports of volcanic activity from the Smithsonian Institution's Global Volcanism Program (Global Volcanism Program 2025) and NOAA's NCEI Hazard Volcano Event repository (NOAA 2022) provided insight into whether the videoed event could have been the result of a pressure wave originating from a large volcanic eruption.

### 2.4 Ocean wave data

To help assess whether a Storm surge event or freak wave might have been the cause of the videoed phenomena, the mean direction of wind waves, the significant height of combined wind waves and swell ($H_s$) and the significant height of wind waves ($H_s$ww) were acquired from the ERA5 reanalysis data (Hersbach et al. 2023a) and analysed.

ERA5 $H_s$ can be defined as

$$H_s = 4\sqrt{m_0}$$

where $m_0$ is the integral over all directions and all frequencies of the two-dimensional wave spectrum (ECMWF n.d.a).

ERA5 $H_s$ww can be defined similarly, however $m_0$ represents the integral over all directions and all frequencies of the two-dimensional wind-sea wave spectrum. The wind-sea wave spectrum only considers the components of the two-dimensional wave spectrum that are influenced by the local wind (ECMWF n.d.b).

### 2.5 Jet stream and relative humidity data

Past literature has shown the occurrence of a fast-moving Jet stream and area of very high relative humidity directly over or positioned nearby during a meteotsunami. The U wind component at 500 hPa and relative humidity readings at 850 hPa were obtained from the ERA5 reanalysis data (Hersbach et al. 2023b) and analysed.

## 3 Results

The following results section highlights a range of meteorological and oceanographic findings that might have contributed to the formation of the unusual wave event recorded on 21 February 2022. The influence that wind speed and direction, atmospheric pressure, and wave parameters had on the formation of a storm surge event are shown in Sect. 3.1. Analysis of Letterkenny's tidal observations are outlined in Sect. 3.2 to assess evidence of high tide seiching in Lough Swilly. Water depth and wave characteristics are reviewed in Sect. 3.3 to help examine the possibility of a freak wave travelling into Lough Swilly. Further tidal and atmospheric analysis, partnered with ERA5 reanalysis data focusing on high atmospheric wind speed (Jet Stream) and relative humidity, is outlined in Sect. 3.4 with the goal of investigating the occurrence of a meteotsunami. Finally, Sect. 3.5 explores seismic activity, originating from either an earthquake or volcanic eruption, to assess whether the videoed event might have been a tsunami.

### 3.1 Storm surge

As storm Franklin transitioned past Ireland in the late hours of the 20th and early hours of the 21st February 2022 (Fig. 3), weather stations along the west and northwest coastline experienced winds of over 60 km/h. This coincided with a noticeable increase in non-tidal variability at Malin Head, a symptom of the development of a positive storm surge, peaking (largest variability) close to low tide on the morning of the 21st.

However, as storm Franklin moved away from Ireland, wind speeds reduced, dropping to ~ 40 km/h at Malin Head (closest weather station to Portsalon) at the time of the videoed event (Fig. 4). At the same time, the positive surge rapidly reversed leading to a significant water level drop of ~ 1 m at Malin Head between successive low tides occurring on the 21st (Fig. 5).

Wind direction readings at the weather stations show winds traveling towards the south-east as storm Franklin passed by. At the time of the event, all stations read a south-east direction before transitioning to a more north-easterly direction in the hours that followed (Fig. 4). ERA5 reanalysis U10 and V10 winds at 09:00 UTC further indicate the winds around the time of the event over the coast of Malin Head were travelling from north-west to south-east between 12–16 m/s [40–60 km/h] (Fig. 6).

The mean direction of wind waves align well with the station data and the U10 & V10 reanalysis data. Waves were traveling towards Malin Head in a south-easterly direction (from 300–340 degrees) at 09:00 UTC on the 21st February 2022 (Fig. 7). These waves were between 5—9 m height, and grow closer to 12 m high when factoring in the swell (Fig. 7).

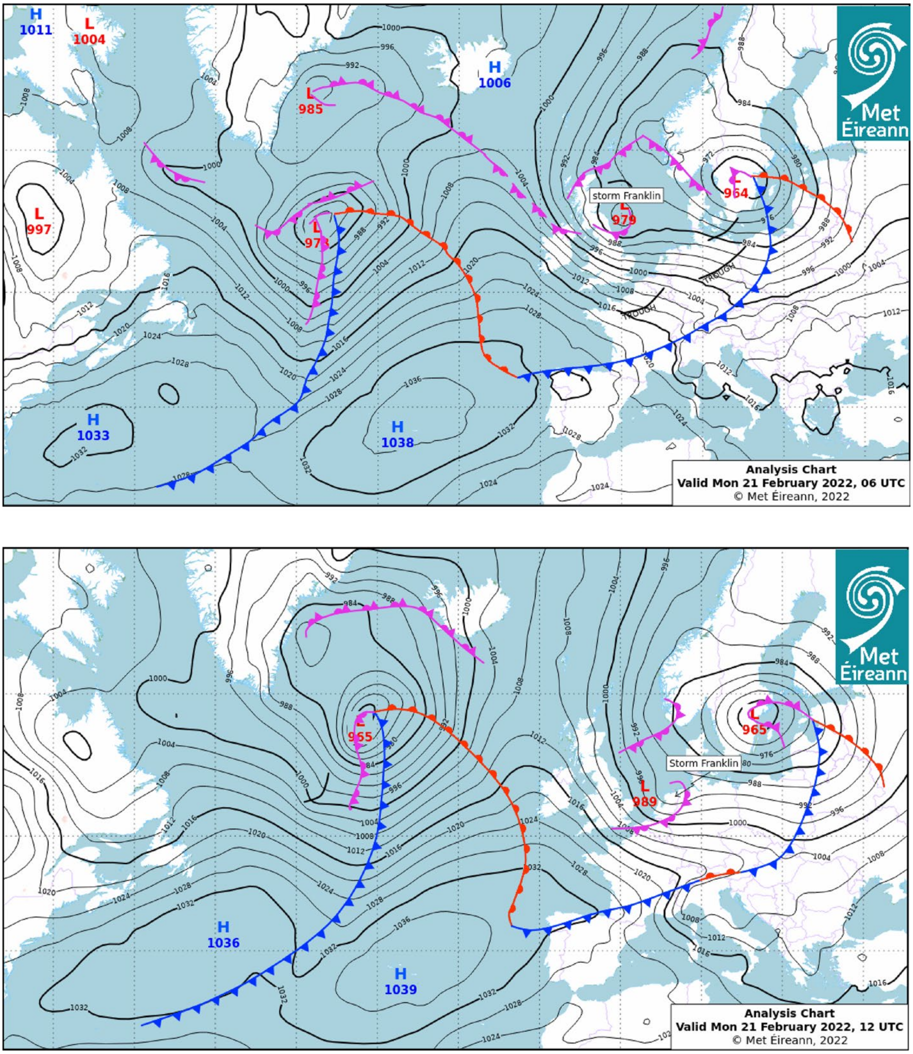


**Fig. 3** Synoptic weather charts from 06:00 UTC and 12:00 UTC on the 21st February 2022. Major high and low pressure systems are highlighted with bold text. Isobars are drawn in black, with red, blue and purple symbols representing warm, cold and occluded weather fronts. *Source* Met Éireann (2022)

## 3.2 High-tide seiching or a tidal bore

Another possibility is that the wave was due to seiching or a tidal bore in Lough Swilly. Both phenomena can occur at high tide, which is when the event was observed. The Letterkenny tidal/fluvial station, situated at the semi-enclosed end of the lough, shows oscillatory behavior around high tide that may have been caused by a seiching event. On the high tides of the 19th, 20th and 21st, noticeable distortions are present in the tidal curves as highlighted by sudden and sharp fluctuations in the de-tided record at Letterkenny (Fig. 5). Three to five oscillations of magnitude up to 50 cm are observed as the tide rises to the top

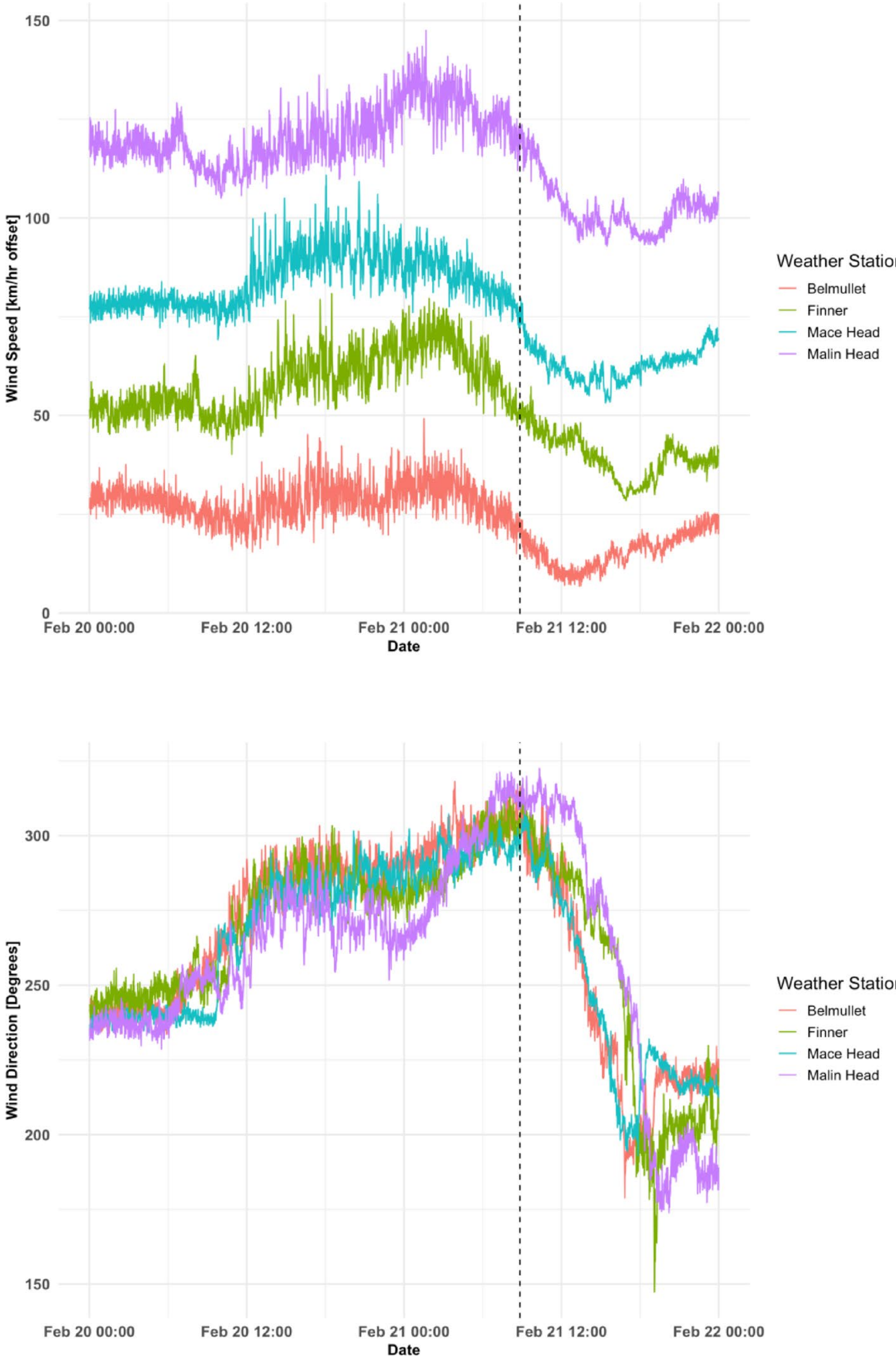


**Fig. 4** (Top), Wind speed (km/h), (bottom), wind direction (degrees) recorded across 4 weather stations located along the western coast of Ireland between the 20th and 22nd of February 2022. Black dotted line represents the timing of the videoed event

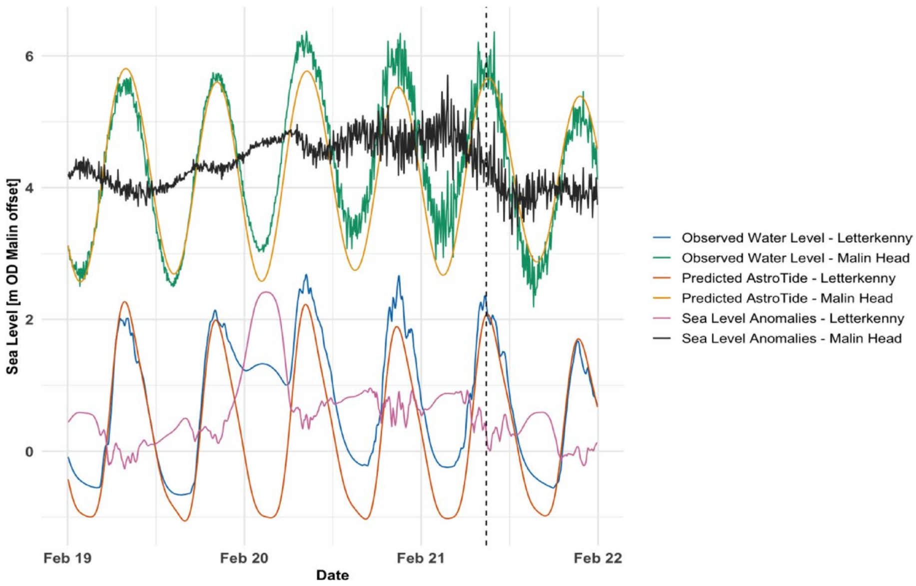


**Fig. 5** Tidal data from the Letterkenny & Malin Head tidal stations between the 19th and 22nd of February 2022. The blue (green) line shows the observed water level at Letterkenny (Malin Head), the orange (yellow) line shows the predicted tide at Letterkenny (Malin Head), the pink (black) line shows non-tidal anomalies at Letterkenny (Malin Head). The black dotted line shows the timing of the videoed event

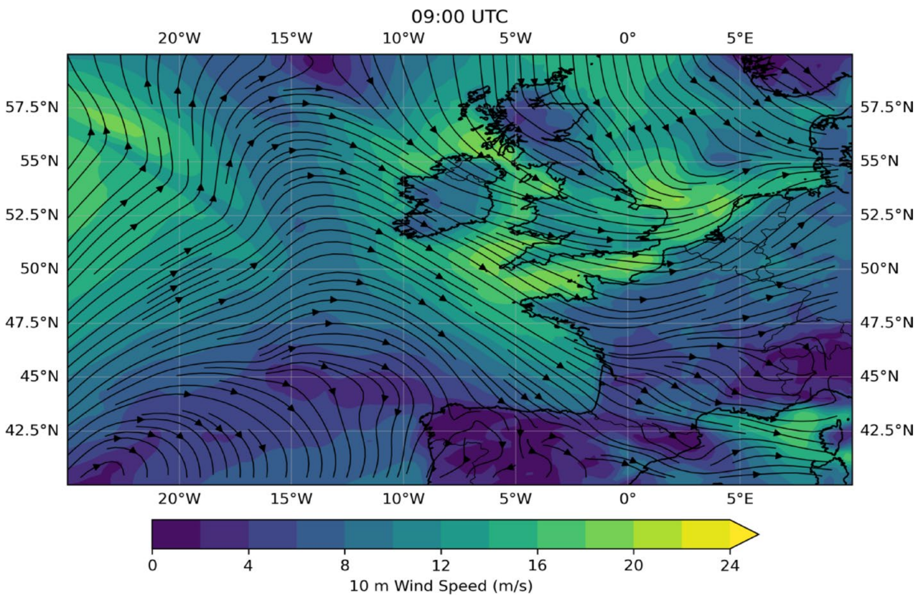


**Fig. 6** ERA5 reanalysis of U10 and V10 component wind speeds (m/s) at 09:00 UTC on the 21st of February 2022

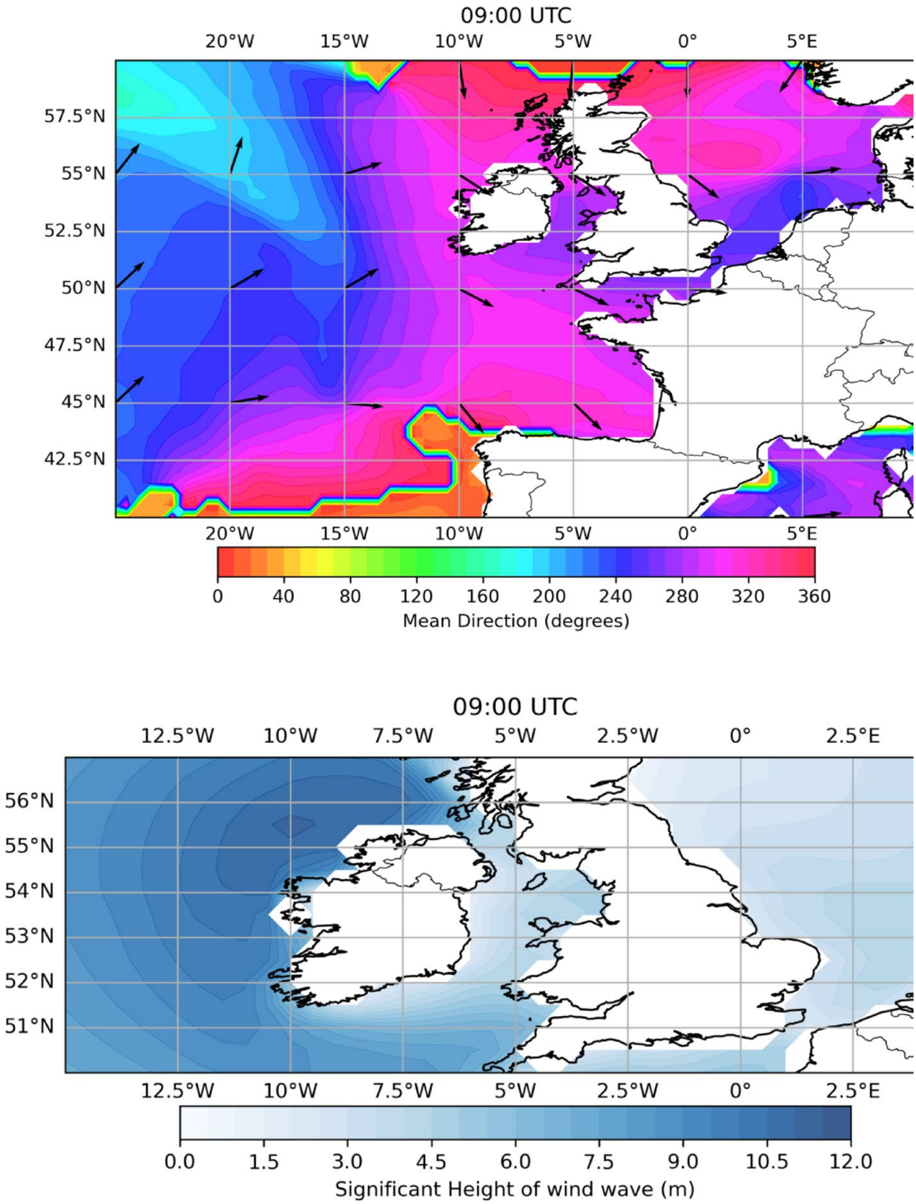


**Fig. 7** (Top), ERA5 reanalysis of mean direction (degrees) of wind waves and, (bottom), significant wave height (m) at 09:00 UTC on the 21st of February 2022. The direction a wave is travelling is the cardinal inverse of the associated direction in degrees e.g. 320 degrees represents a wave travelling towards the south-east

third of the tidal cycle. There is a drop rather than a rise in Letterkenny at the time of the event, but Letterkenny is 30 km from Port Salon so the timing of any seiching would likely be different.

Additionally, a tidal bore could have occurred. Lough Swilly is not noted for any famous bore but the unusual conditions around Storm Franklin could have combined to create conducive conditions.

### 3.3 Freak wave

The water depth within Lough Swilly and out past the mouth of the sea-inlet ranges from between 10–20 m in Lough Swilly to 30–100 m just past the mouth (Gps Nautical Charts 2026), partially meeting the requirements for a freak wave formation via modulation instability. $H_s$ at the time was ~ 12 m near the mouth of Lough Swilly, meaning a wave of height > 24 m would have had to occur to be classified as a freak wave. This is not improbable as an individual wave of 29.5 m was recorded by the M4 buoy off the coast of Donegal (Fig. 2) on the 20th (Met Éireann 2025). The prevailing winds & waves around the time of the event were moving towards the sea-inlet. In the open ocean, this would suggest a freak wave would have been traveling in the opposite direction, however in this case the observations were taken close to the coastline allowing for other mechanisms such as wave reflection and diffraction to influence the height of the waves moving into Lough Swilly (Figs. 4 and 7).

### 3.4 Meteotsunami

High levels of non-tidal sea-level fluctuations were observed across tidal stations in the northwest of Ireland. The rapid and unpredictable shifts in non-tidal sea-level began to occur just before 12:00 UTC on the 20th and did not appear to fully subside until late on the 21st in most stations (Fig. 8). Data from four of the closest tidal gauges is presented in both raw and filtered forms. At these stations, data is recorded every five minutes, and clear fluctuations of the sea level are visible.

By utilising the Butterworth high-pass filter with a three-hour cut-off period the astronomical tide is removed (Renzi et al. 2023), and the non-tidal water-level oscillations can be seen in the top panels of each location in Fig. 8. It is clear that for approximately a 24-h period from the morning of the 20th to the morning of the 21st of February, high levels of non-tidal water level oscillations were experienced in the area. However, they started long before the video was recorded in the morning of the 21st, depicted by the light blue highlight in the figure.

Next, a Butterworth high-pass filter with a four-hour cut-off period is used to remove the naturally occurring tidal data before the remaining data is put through the CWT, as in Renzi et al. (2023). Figure 9 shows the wavelet power spectrum corresponding to the observed sea level at Aranmore, Ballyglass, Killybegs, and Malin Head. At Aranmore and Ballyglass the predominant perturbations appear to be associated with periods close to two hours. However, the perturbations occur around 20:00 UTC at Ballyglass on the 20th of February, and nearly twelve hours later at Aranmore in the morning of the 21st. In contrast, the predominant perturbations associated with Killybegs and Malin Head have periods close to 30 min, with some shorter periods at Malin Head. The Killybegs perturbation slightly precedes the

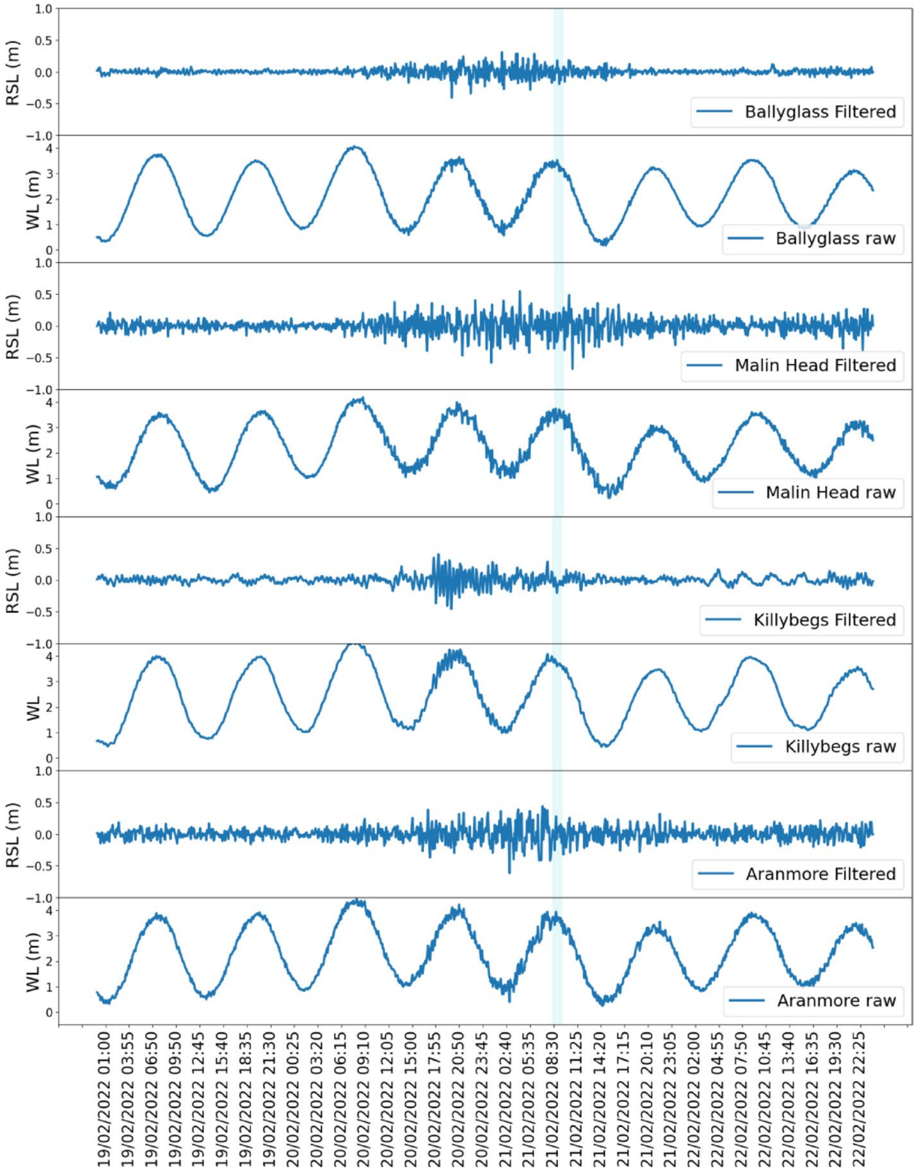


**Fig. 8** The top plot for each location shows the de-tided and high-pass Butterworth filtered data. The bottom plot for each location shows the observed sea level at the tide gauge. The approximate time of the event is highlighted in light blue. RSL = Real Sea Level, WL = Water Level

longer perturbation at Ballyglass, while the Malin Head perturbations cover an almost 24-h period from 18:00 UTC 20th to nearly 18:00 UTC 21st February.

At around the same time as the non-tidal sea-level fluctuations began (12:00 UTC 20th February), atmospheric pressure readings began to rise following the pass of Storm Franklin (Fig. 10). Initially, atmospheric pressure rose relatively slowly, but on the approach to the

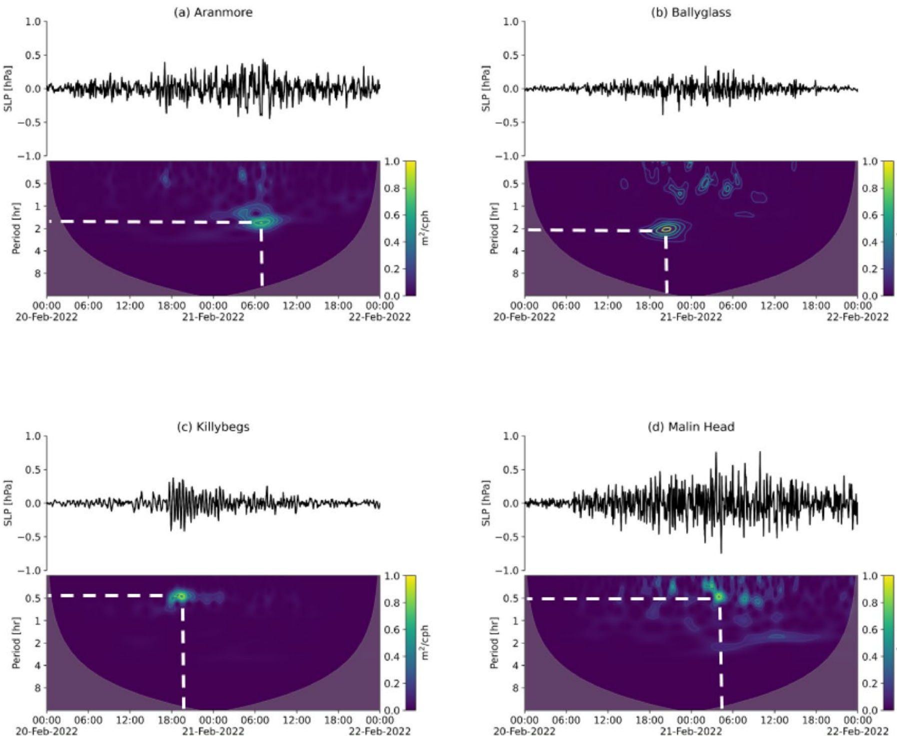


**Fig. 9** Wavelet power spectrum corresponding to **a** Aranmore, **b** Ballyglass, **c** Killybegs, and **d** Malin Head. The top insert of each panel shows the time series of the high-pass filtered sea level signal in meters. The colour scale of the bottom insert, from purple to yellow, indicates the wavelet power spectral density in $m^2$ /cph (cph = cycles per hour). The dashed white lines indicate the most interesting wavelets

videoed event (08:00 UTC–09:00 UTC), Malin Head weather station recorded a larger rise of 2.4 hPa/h. However as depicted in Fig. 10, the largest scale changes in the air-pressure occur nearly 18 h after the recorded abnormal wave. Relatively sharp increases in air pressure are evident preceding and during the wave event, however these do not appear overly unique compared to the surrounding changes.

Again, a fifth-order Butterworth high-pass filter with a cut-off period of 6 h is applied to the air-pressure data and the resulting data is run through the CWT, as in Renzi et al. (2023). The results can be seen in Fig. 11, where most periods are between four and six hours long. Some periods of close to two hours are found at Belmullet, Finner, and Markree. However, the timing of these perturbations does not match for the different weather station locations and largely occurs after the abnormal wave event occurs.

The presence of a highly active North Atlantic jet stream flowing towards Ireland was a significant factor in the occurrence of three named storms arriving within the space of a week. Near the time of the videoed event (09:00 UTC), the jet stream was positioned directly over Ireland, flowing from North-west to South-east across the country at 40 + m/s (Fig. 12).

At the same time, relatively humidity levels of between 80–100% covered much of the country following the heavy rainfall associated with the passage of Storm Franklin (Fig. 13).

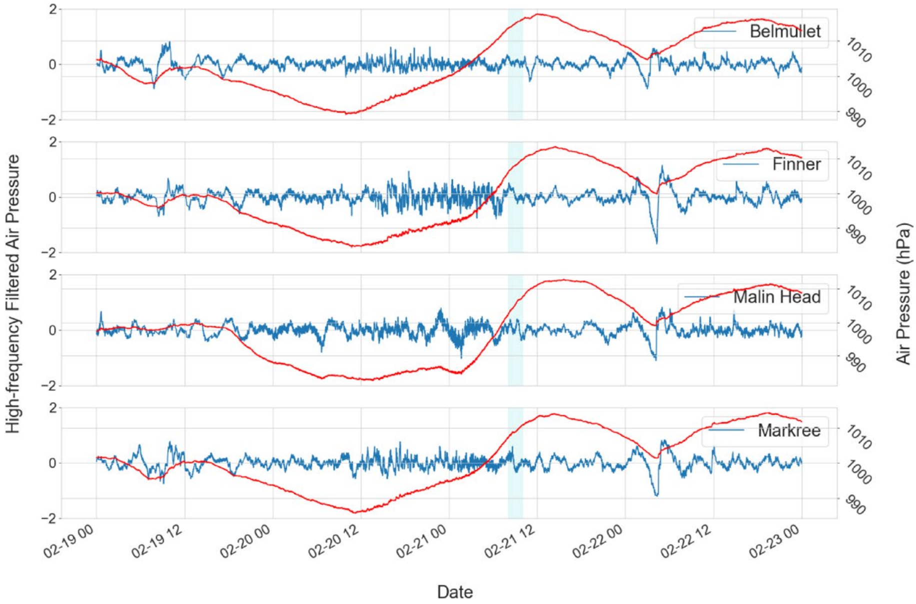


**Fig. 10** Time series of air pressure above sea level (red line) and high-frequency air pressure data generated by using a six-hour Butterworth high-pass filter to remove large period variability (blue line) for all four weather stations. The approximate time of the event is highlighted in light blue. Pressure values are in hPa

Water levels observed at Newmills river station (not shown) and Letterkenny tidal station highlight how water levels rose rapidly by nearly 2 m above expected levels on the 20th (Fig. 5).

### 3.5 Tsunami

On the 21st of February 2022, two magnitude 6 or greater earthquakes occurred around the globe. The first occurred in the Southern Ocean off the coast of the Balleny Islands, Antarctica and the second occurred in the northwestern tip of Argentina. The British Geological Survey reported very minor seismic activity on the 21st, with a 1.4 magnitude tremor occurring at 00:02 UTC in the Scottish Highlands some 200 km away from the videoed event. Neither the Smithsonian Institution's Global Volcanism Program nor NOAA's NCEI Hazard Volcano Event repository suggest any large volcanic eruptions took place on the day of or days recently preceding the 21st.

## 4 Discussion

While wind speeds along the northwestern coast were beginning to lower following the passing of Storm Franklin, the prevailing wind and wave direction (from northwest to southeast) and the significant height of combined wind waves and swell (up to 12 m) suggest the storm's influence had not yet fully subsided at the time of the videoed event and thus a storm

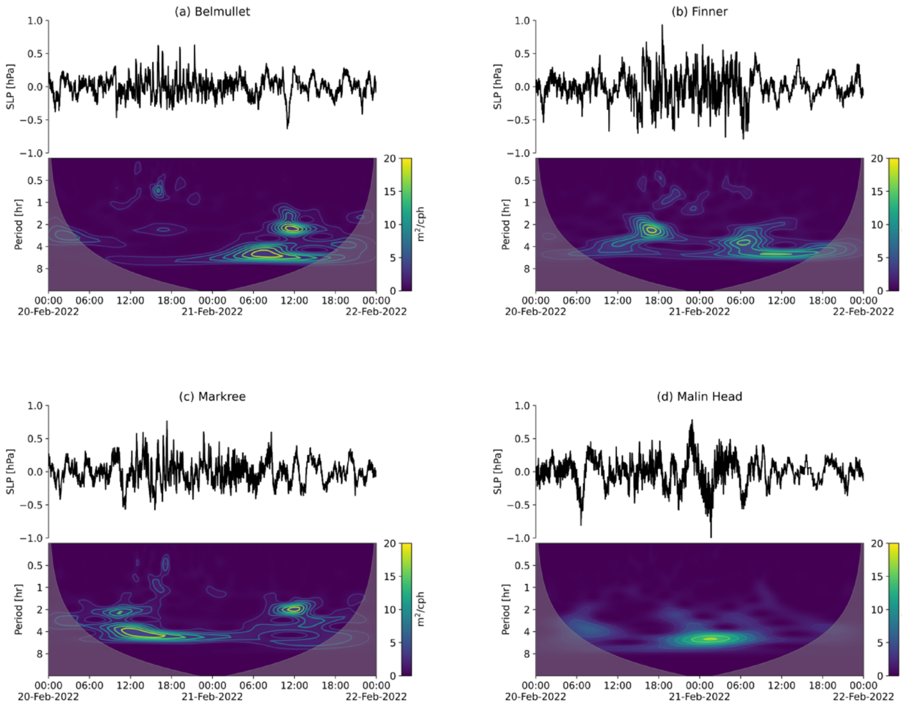


**Fig. 11** Wavelet power spectrum of the sea surface air pressure signal corresponding to **a** Belmullet, **b** Finner, **c** Markree, and **d** Malin Head. The top insert of each panel shows the time series of the high-pass filtered sea surface atmospheric pressure in hPa. The colour scale of the bottom insert, from purple to yellow, indicates the wavelet power spectral density in $m^2$ /cph (cph = cycles per hour)

surge could have been possible. In addition, evidence from Letterkenny's tidal gauge indicate potential seiching at high tide at the time of the event. It is possible that Lough Swilly experiences seiching events at high tide on a regular basis due to the enclosed nature of the water body (NOAA 2024a; Bowers et al. 2013), however as the video's author identified themselves as the manager of the golf course, it is assumed by their definition of the event being "unusual" that this type of event is uncommon. This might suggest that seiching in Lough Swilly at high tide is not a regular occurrence, or that storm Franklin's winds and subsequently generated waves combined with a regularly occurring seiche event at high tide to form the wave seen in the video.

The evidence available suggests a freak or rogue wave could have been possible, but unlikely. The depth of the water situated at the mouth of Lough Swilly and further out towards the North Atlantic is generally deeper than 20 m allowing for freak wave generation via modulation instability (Didenkulova et al. 2023). Wave heights at the time (12 m) would suggest a freak wave by definition would have been > 24 m high, which was certainly possible on the 20th, a day prior, when the M4 buoy recorded a wave 29.5 m high off the coast of Donegal (Met Éireann 2025). However, these observations were taken close to the coastline and not in the open ocean where freak waves typically generate and propagate in the opposite direction to the prevailing winds and waves. As other mechanisms such as wave reflection and diffraction were likely at play, waves exceeding 12 m and potentially

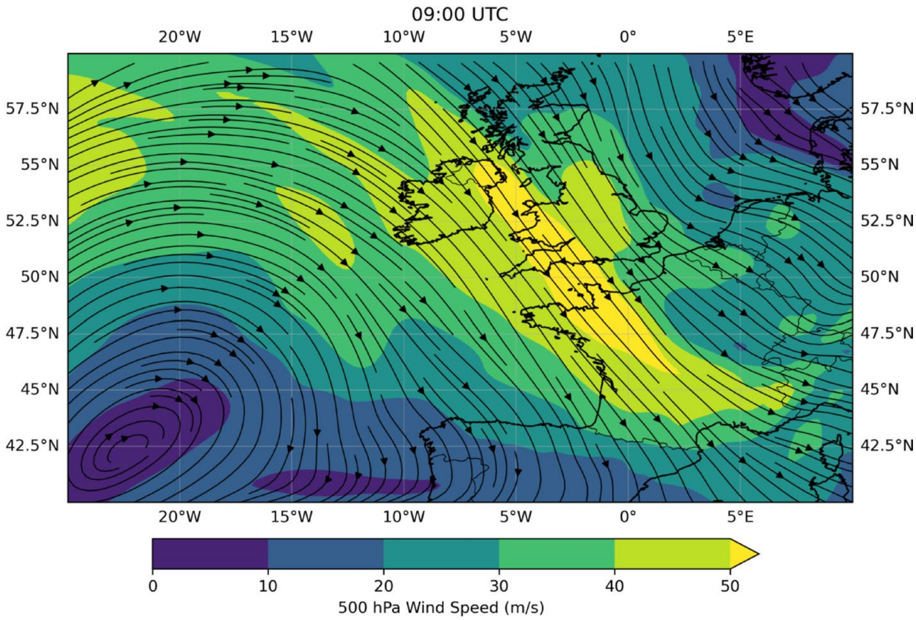


**Fig. 12** ERA5 reanalysis of U & V component wind speed (m/s) at 500 hPa highlights the North Atlantic Jetstream over Ireland at 09:00 UTC on the 21st of February 2022

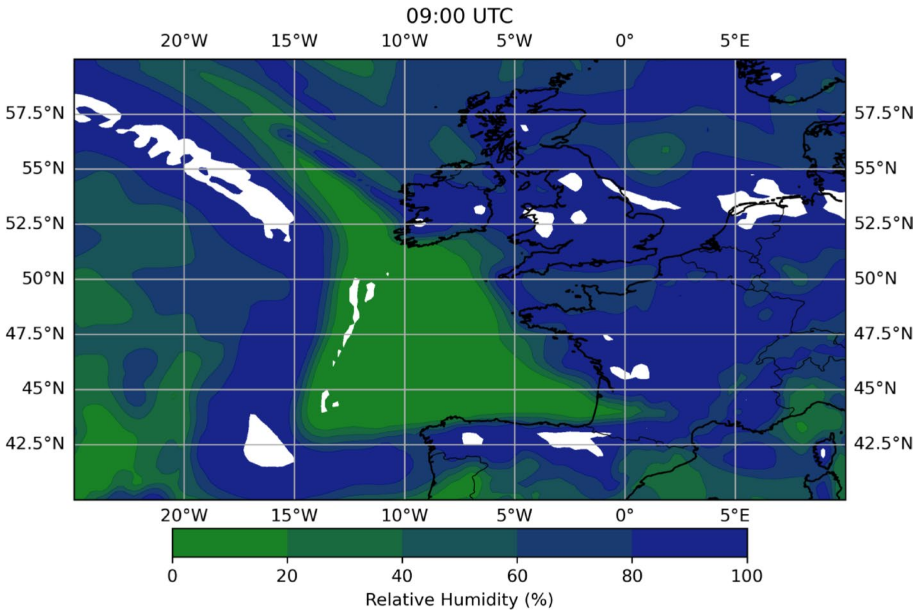


**Fig. 13** ERA5 reanalysis of relative humidity (%) at 850 hPa at 09:00 UTC on the 21st of February 2022. s

over twice the significant wave height could have occurred in the same direction as the prevailing winds and travelled towards the north-west coastline entering the mouth of Lough Swilly as storm surge.

A non-tidal disturbance across multiple stations began to appear at approximately 12:00 UTC on the 20th. This coincided with the rise in atmospheric pressure experienced as storm Franklin moved beyond Ireland. While these two might initially appear to be connected, suggesting a possible meteotsunami, the beginning of the non-tidal anomalies also aligns with when wind speeds began to increase. Furthermore, the rate of atmospheric pressure change was considerably lower than what is normally associated with meteotsunami generation, and the direction of a propagating pressure wave was difficult to discern. Upon analysing the atmospheric pressure data, the timing of the most significant disturbances did not coincide with the timing of the videoed wave event. In addition, the timing and period of the water level disturbances observed in the tidal data were not indicative of a meteotsunami event. However, other conditions often associated with meteotsunami events, such as a period of heavy precipitation before (Williams et al. 2021), the presence of a fast-moving jet stream (Šepić et al. 2015; Heidarzadeh et al. 2020; Kubota et al. 2021) and high relative humidity (Rabinovich et al. 2021) were all observed prior (precipitation event) or during the event. Unfortunately, due to the lack of a tidal and pressure gauge at the location of the videoed event, it is hard to retrieve the necessary high frequency data to confidently confirm this event as a meteotsunami.

Lastly, the two 6+magnitude earthquakes observed on the 21st were situated too far away to have caused any significant water level disturbance at the location of the videoed event. The smaller magnitude tremor (1.4 magnitude) recorded in the Scottish Highlands was unlikely to have caused an effect on the water level some 200 km away at the site of the videoed event as tsunami waves are typically only generated from high magnitude megathrust earthquakes, which this was not (Geological Survey Ireland 2026).

Based on all the evidence presented above, the most likely explanation for the videoed event is that it was a combination of a weakening storm surge reinforced by a potential high tide seiche event in Lough Swilly. We suggest that a wave generated by the prevailing winds off the aftermath of Storm Franklin pushed a water disturbance into Lough Swilly on the approach to high tide where it was potentially amplified by a seiching event resulting in the wave captured on camera. Reproduction of Fig. 4 from Heidarzadeh and Rabinovich (2021) would have provided a valuable comparative reference highlighting the combined effect of a storm surge and seiching event, however the absence of high frequency tidal data, similar to that of Heidarzadeh and Rabinovich (2021), within the Irish coastal gauge network restricted this studies analysis.

## 5 Conclusion

This study aimed to investigate the occurrence of an unusual wave event recorded at Portsalon Golf Club on the 21st of February 2022. Several explanations for the event were hypothesised, storm surge, high-tide seiching in Lough Swilly, freak wave, meteotsunami or tsunami. Through the analysis of tidal, meteorological and ERA5 reanalysis data, and the review of seismic and volcanic activity, this study examined the likely causes of the videoed event.

Results suggest that in the aftermath of Storm Franklin, its residual influences off the north-west coastline were still significant enough to cause water level disturbances. Weakening yet elevated winds and large waves capable of generating a storm surge like sea-level anomaly into Lough Swilly were present at the time of the videoed event. Tidal data from Letterkenny at the time shows what appears to be evidence of high tide seiching or tidal bore, which could have acted to amplify any incoming water level disturbance.

Other possibilities, such as a freak wave or meteotsunami were deemed less plausible due to the prevailing wind and wave direction and the absence of a rapid, propagating atmospheric pressure disturbance normally associated with meteotsunami formation. A seismically generated tsunami was ruled out, as no sufficiently large or suitably located earthquake or volcanic eruption occurred surrounding the time of the event.

Based on the evidence available, the most likely explanation for the observed event is a combination of a weakening storm surge reinforced by high tide seiching in Lough Swilly. Unfortunately, as no tidal or meteorological station was situated near to the site of the event, the generation mechanics of this event are harder to classify, emphasizing the need for more high frequency stations to aid in better capturing these coastal hazards. Meteotsunamis are a significant coastal hazard, but observing systems are not currently equipped with the temporal resolution and spatial density necessary to observe and describe these events accurately. Currently, most tide gauges around the Irish coast sample tidal data with the highest frequency of every five minutes. However, to record meteotsunami events tide gauges must record at intervals of 0.5 to 2 min (Vilibić et al. 2016), we suggest updates are made to the Irish tidal gauge network to accurately record meteotsunamis, and similar high-frequency wave events as these phenomena can cause significant disruption.

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## Declarations

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose.

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