Environmental controls on lifeguard-estimated surf-zone hazards, beach crowds, and resulting life risk at a high-energy sandy beach in southwest France

Bruno Castelle, Jeoffrey Dehez, Jean-Philippe Savy, Vincent Marieu, Sandrine Lyser, Stéphane Bujan, David Carayon, Rob Brander

Environmental controls on lifeguard-estimated surf-zone hazards, beach crowds, and resulting life risk at a high-energy sandy beach in southwest France

October 31, 2023

Bruno Castelle[1], Jeoffrey Dehez[2], Jean-Philippe Savy[3], Vincent Marieu[1], Sandrine Lyser[2], Stéphane Bujan[1], David Carayon[2], Rob Brander[4]

[1] Univ. Bordeaux, CNRS, Bordeaux INP, EPOC, UMR 5805, Pessac, France

[2] INRAE Nouvelle Aquitaine, Cestas-Gazinet, France

[3] SMGBL, Messanges, France

[4] UNSW Beach Safety Research Group, UNSW Sydney, Australia

Abstract

Understanding and predicting surf zone risks is of paramount importance to prevent drowning incidents and severe spine injuries on beaches globally. This study holistically addressed life risk at La Lette Blanche beach, southwest France, during the lifeguard-patrolled summer period (July-August) 2022, where intense rip currents and shore-break waves co-exist at different times and locations along the beach. Beach crowds and the levels of rip current and shore-break wave hazards were estimated hourly by lifeguards during patrolling hours. Wave, tide and weather conditions were also continuously recorded, providing comprehensive insights into the primary environmental controls on surf zone hazards and beach attendance. Results show that the daily average rip current hazard increases with large, long-period and near shore-normal waves, while the shore-break wave hazard is increased for long-period, near shore-normal waves and large tide ranges. Beachgoer crowd numbers increase on warm, sunny and light wind days although a severe heat wave occurring in July 2022 significantly decreased daily average beach crowd and deeply affected beach use. Days characterized by strong hazards and large beach attendance were associated with the largest amount of lifeguard rescues and drowning incidents, although correlations decreased by the end of the summer. This is hypothesized to be the signature of evolving lifeguard strategies (e.g. preferred locations of the supervised bathing zone, prevention measures) as they progressively increase their understanding of the surf zone hazards variability in both time and space at their beach as a function of tidal stage and incident wave conditions. Warm, sunny and light-wind sunny days (maximizing beach crowds), with large, long-period shore-normally incident waves and large tide range (maximizing surf zone hazards) were the most risky days, with shore-break waves and rip current hazards notably peaking at different times of the day. This study shows that lifeguards can be a valuable source of data to improve understanding of the environmental controls on beach crowd, surf zone hazards and life risk at the beach, which provides critical information to the development of holistic beach risk predictors.

Surfzone Risk, Rip Current, Shore-break Waves, Hazards, Water-user Exposure, Lifeguard Estimates, Rescues

1 Introduction

Sandy beaches are highly attractive environments providing a wealth of recreation, tourism and ecosystem services [34, 36, 15, 62]. However, sandy beaches can also pose a deadly threat to water users as breaking wave force, nearshore currents and the risk of collision and impact injury involving surf craft all increase under increasing incident wave energy [55, 56]. The two primary natural hazards causing surf zone injuries (SZI) on beaches, including drowning incidents, are rip currents [19], and shore-break waves which are plunging and dumping waves breaking close to the shoreline on a steep beach face. Rip currents [46, 24, 19] are intense seaward-flowing currents originating in the surf zone and potentially extending hundreds of meters offshore where they dissipate in deeper water. Although they are all fundamentally driven by the action of breaking waves, rip currents can form through a wealth of wave conditions and beach types [19]. The most common type of rips, which are often referred to as *channel rips*, typically flow through channels incised in nearshore sandbars on intermediate beaches [64]. Rip currents are the primary cause of unintentional drowning on many documented surf beaches globally [e.g. 11, 2, 6, 44, 16, 10] as they can rapidly (flow velocity of the order of 1 m/s) transport bathers offshore towards deep water where they may drown through exhaustion or panic [9, 27]. The second natural hazard are shore-break waves which can cause a wide range of injuries, including severe spine injuries [51, 50]. SZI, particularly drowning, are a serious public health problem worldwide. Therefore, together with public education campaign and intervention activities from lifeguards [53, 40], understanding and predicting surf zone risks is of paramount importance to prevent (fatal and non-fatal) drowning incidents and spine injuries [30].

As introduced by [60], life risk at the beach can be defined as a combination of the number of people exposed and the level of life-threatening hazard present. This means that the level of life risk can be potentially modelled indirectly by estimating hazard and exposure [60, 25]. It is well established that daily beach crowds are largely driven by weather conditions. Under normal weather conditions, warm sunny days with low winds typically result in increased beach attendance [32, 23, 38], and thus more SZI [25]. However, it is unclear whether this trend continues during a heat wave, as they are known to deeply affect human behaviour [e.g. 59]. Shore-break waves are associated with longer-period waves and steep beach slopes [7, 5]. As a result, on tidal beaches which typically have a concave intertidal profile, the most hazardous shore-break waves mostly occur around higher water levels and large tide ranges when waves break on the steepest section of the beach [22]. Numerical modelling and field measurements have shown that rip-current flow activity increases for shore-normally incident waves and increasing wave height and period [e.g. 4, 28, 13, 63, 46]. The influence of tide on rip current intensity is more complex. A large body of literature has shown that, for a given wave condition, rip current velocity is maximized at low tide [1, 47, 9, 37]. However, on meso- to macro-tidal beaches rip current flow can be found to decrease during the lowest stage of the tide during spring tide cycles as the intertidal sandbar emerges and waves predominantly dissipate through depth-induced breaking offshore of the bar/rip system [14, 13, 4, 3]. This link between wave and tide conditions is further emphasized by [52] who showed that rip current hazard at the macro-tidal beach of Perranporth, UK, is maximised under average breaking wave conditions and mean low tide, i.e. when wave breaking is concentrated over the bar-rip template morphology.

Recently, an increasing body of studies have addressed the influence of environmental conditions on drowning incidents [e.g. 22, 45, 41] and/or lifeguard rescues [31, 52, 42]. Despite the inconsistent beach lifeguard data collection strategy [43], these studies have similar findings. Most of these studies indicate that the amount of rescues and drowning incidents increase for warm and sunny days [e.g. 54, 22], which are expected to maximize beach crowd, and for wave and tide conditions which are expected to increase rip current intensity [e.g. 22]. A notable exception is [52] who found that on the macrotidal beaches in southwest England rescues occur disproportionately on days with low wave height. Another important contribution of [52] was to show that the wave factor parameter H_sT_p, where H_s is the significant wave height and T_p is the peak wave period, was a key controlling factor determining rip flow behavior and the amount of rip current rescues. Importantly, in previous work physical hazard and water-user exposure have been addressed separately. In addition, the level of hazard and beach crowd concurrent to SZI observations have never been directly or indirectly measured. A possible method to indirectly measure beach crowd and surf zone hazards is to rely on lifeguard estimates. Lifeguards have been found to provide valuable estimation of breaking wave height [12] and rip current velocity [29], and could thus provide fair estimates of beach crowd and hazard level. Finally, rip-current related drowning incidents and shore-break wave related injuries have typically been systematically addressed separately. A notable exception is the southwest coast of France where shore-break wave and rip-current hazards co-exist [16, 22, 25].

For the first time, this study holistically addresses surf zone risk by implementing a cross-disciplinary research approach in close collaboration with lifeguards at a hazardous beach in southwest France. The field site and data collection are described in Section 2, before results are presented (Section 3) and further discussed (Section 4). We show that lifeguards can be a valuable source of data to improve the understanding of the environmental controls on beach crowd, surf zone hazards and life risk at the beach. The primary environmental controls on surf zone hazards and beach crowd are identified, as well as the influence of heat waves on beach use and of the angle of wave incidence on shore-break wave related risk. This continuously building dataset can form the basis of comprehensive, daily and/or hourly, life-risk predictors related to rip current and/or shorebreak wave hazards with quantification of all the components of the risk.

2 Methods

2.1 Field site

La Lette Blanche beach is located in southwest France, in the southern part of a reasonably straight sandy coast. The coastline around La Lette Blanche faces west-northwest ($\theta_c = 281.4°$). It is a meso-macrotidal environment with a mean and maximum tidal range of approximately 2.6 m and 4.4 m, respectively [26]. La Lette Blanche beach is exposed to a high-energy, strongly seasonally modulated wave climate with, at the nearby Cap Ferret directional wave buoy (Figure 1a), a winter-mean significant wave height of over 2.1 m, and a summer-mean wave height of approximately 1.2 m [17]. The beach is intermediate double-barred, with the inner intertidal and outer subtidal bars mostly exhibiting crescentic patterns and a transverse bar and rip morphology, respectively. The inner-bar rip channel spacing is approximately 400 m. La Lette Blanche is a remote beach, located 6 km from the closest village (Vielle Saint-Giron), with only one beach entry and no facilities. In summer, the beachgoer population is therefore mostly made of locals and tourists visiting at nearby camping grounds and hotels.

In terms of surf zone hazards, La Lette Blanche beach is representative of the open coast beaches of southwest France. Rip currents are the primary cause of fatal and non-fatal drownings [16] on this coast, with intense channel rips flowing through the inner-bar rip channels. Rip current intensity is maximized around mean low tide level, under shore-normally incident energetic waves [20], which are the conditions under which drowning incidents are known to disproportionately occur [22, 25]. Mean rip current velocity can be intense even under low- to moderate-energy waves. For instance, the 5-minute average cross-shore component of the rip flow velocity can reach 0.9 m/s around mean low tide level for shore-normally incident waves with a peak wave period T_p and significant wave height

H_s of approximately 12 s and only 0.8 m, respectively [14]. Although there is no direct measurement of shore-break wave intensity along this coastline, empirical evidence indicates that shore-break waves preferably occur at high tide when waves break across the steepest section of the beach profile. This is consistent with observation of shore-break wave related injuries that disproportionately occur around higher water levels and large tide ranges [22].

Given the length of the southwest coast of France, there are large sections of unpatrolled beaches. Along coastal resorts and around the primary beach entries connecting with large inland car parks, long stretches of coast are under the responsibility of a coastal municipality. These beaches are patrolled by lifeguards during the spring-summer-autumn months from 11AM to 7PM, from July to August and from April to October at the most remote and at the busiest beaches, respectively. Within each patrolled sector, one or several supervised bathing zone is/are delimited between two red and yellow flags (Figure 1b,c). The supervised bathing zone is typically less than 100 m wide and located away from potential rip currents. Given the large tide range resulting in rapid changes in location, intensity and type of surf zone hazards throughout the day, the lifeguards can move the supervised bathing zone several times during the day. During patrolling hours, a flag is hoisted on a mast with the color indicating the lifeguard-estimated level of surf zone hazard (rip current and shore-break: (1) green flag means that bathing is supervised with no particular danger; (2) yellow-orange flag means that bathing is dangerous, but supervised; and (3) red flag means that bathing is forbidden.

2.2 Field experiment and lifeguard data

A beach safety field experiment was conducted at La Lette Blanche beach during the lifeguard-on-duty 2022 summer, from July 1 to August 31. The beach morphology was characterized by the presence of a unusually complex rip channel system, facing the lifeguard station (Figure 1b). This resulted in the presence of highly dynamic, strongly tidally-modulated, rip current flow. The rip current system was characterized by a large range of circulation regimes (recirculating versus exit flow) and orientation (southwestward-, westward- or northwestward-directed) and with potentially dramatic changes in direction and activity within less than 30 minutes. Although additional data were collected during this period, in the present contribution we essentially use the data collected by the lifeguards, and the environmental data collected by a nearby directional wave buoy, tide gauge and weather station (Figure 1a).

During each patrolled day, the lifeguard chief (or co-chief on lifeguard chief days off, two days a week) has to document the major beach safety activity, rescues and injuries on a hand written memo book called *Main Courante*. At the end of each patrolled day the total number of rescues are also counted in this memo book. In this contribution, we used the daily number of rip current rescues $\overline{N}_{rip}$ and shore-break rescues $\overline{N}_{sb}$. In addition to the memo book which is used at all patrolled beaches, for

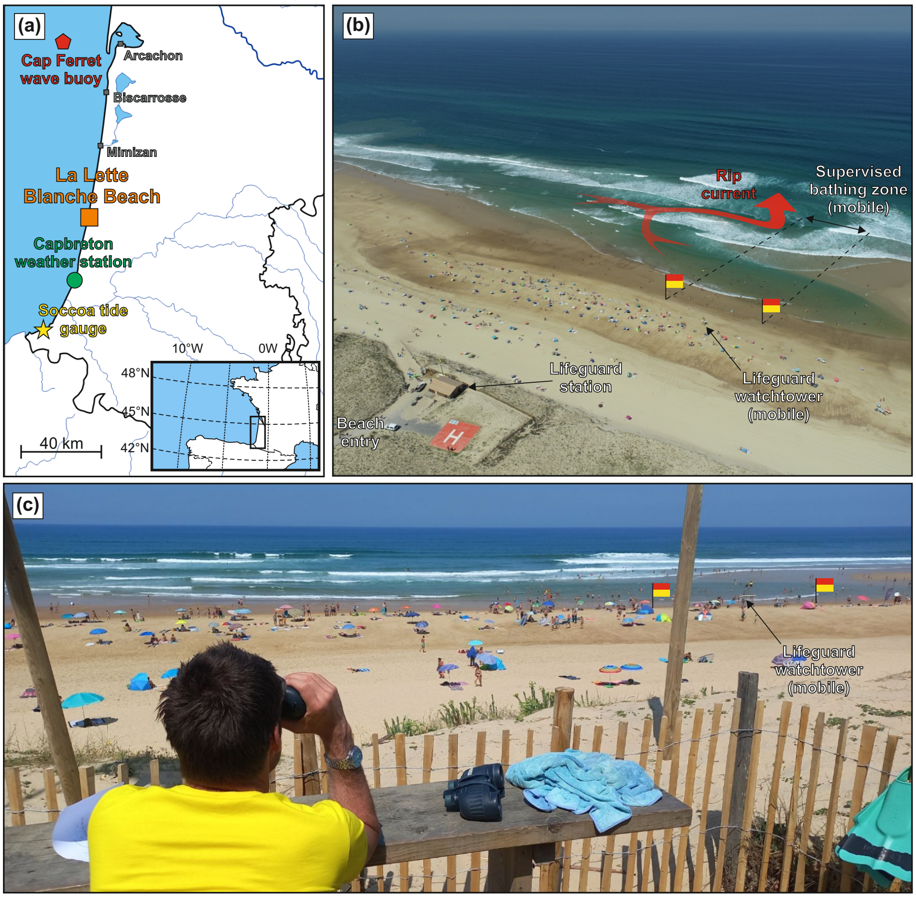

Figure 1: (a) Location map of La Lette Blanche beach, wave buoy, tide gauge and weather station; (b) aerial view of the field site on July 14 at 12PM (Ph. V. Marieu) and (c) concurrent photograph from the lifeguard station (Ph. B. castelle). In (b,c) flags have been added to indicate their location due to poor image resolution

this research the chief (hereafter or co-chief) lifeguard of La Lette Blanche was requested to provide an hourly estimate of rip current hazard H_{rip}, shore-break wave hazard H_{sb} and of the total beach crowd C (number of people on the beach) during the patrolling hours from 11AM to 7PM. Hazards were estimated using a 5-level scale from 0 (no hazard) to 4 (hazard maximized). The chief lifeguard was specifically asked to provide an estimation of the hazard, and not of the risk, thus not the probability that water users expose themselves to shore-break waves and rip currents, but rather the level of environmental hazard present.

2.3 Environmental data

Continuous time series of wave, tide and weather conditions were measured in situ close to La Lette Blanche beach during the entire summer of 2022. Significant wave height H_s, peak wave period T_p and angle of incidence θ were measured at 30-minute intervals in approximately 54-m depth by a directional wave buoy located approximately 100 km north of La Lette Blanche. Despite the distance and given that La Lette Blanche is an open coast beach essentially exposed to the same wave climate, this dataset was considered as representative of wave conditions at our study site. A tidal component analysis of a 10-minute interval 3-month time series of continuous, storm-free, Soccoa tide gauge data (Fig. 1) was performed. The average phase lag between the Soccoa tide gauge and La Lette Blanche beach was estimated using tide charts from the Service Hydrographique et Océanographique de la Marine (France). Errors due to the (time-varying) phase lag and amplitude difference between real and predicted tide result in an estimated maximum error in tide elevation of 0.3 m [22]. The resulting time series of astronomical tide level η at 10-minute intervals was further used. Weather data was collected at the Météo France station of Capbreton (Figure 1a). Hourly data of air temperature (T), mean wind speed (W) and insolation (I) were used to estimate weather conditions at La Lette Blanche beach. Finally, the corresponding daily mean (11AM-7PM) values ($\overline{H}_s$, $\overline{T}_p$, $\overline{\theta}$, $\overline{T}$, $\overline{W}$ and $\overline{W}$) and daily tide range ($\overline{TR}$) were computed.

3 Results

3.1 Rip current and shorebreak hazards

Figure 2 shows the time series of the daily-mean lifeguard-estimated rip current ($\overline{H}_{rip}$) and shore-break wave ($\overline{H}_{sb}$) hazards, as well as that of the oceanographic variable ($\overline{H}_s$, $\overline{T}_p$, $\overline{\theta}$, $\overline{T}$) which are expected to control these hazards. During the summer of 2022, $\overline{H}_s$ ($\overline{T}_p$) ranged from 0.33 m - 2.00 m (4.52 s - 14.29 s) with a mean of 0.97 m (8.35 s). Nearly 2.5 neap-spring tide cycles are observed (Figure 2d) with the daily tide range ($\overline{TR}$) ranging 1.39 m - 4.06 m with a mean of 2.73 m. Figure 2 also shows

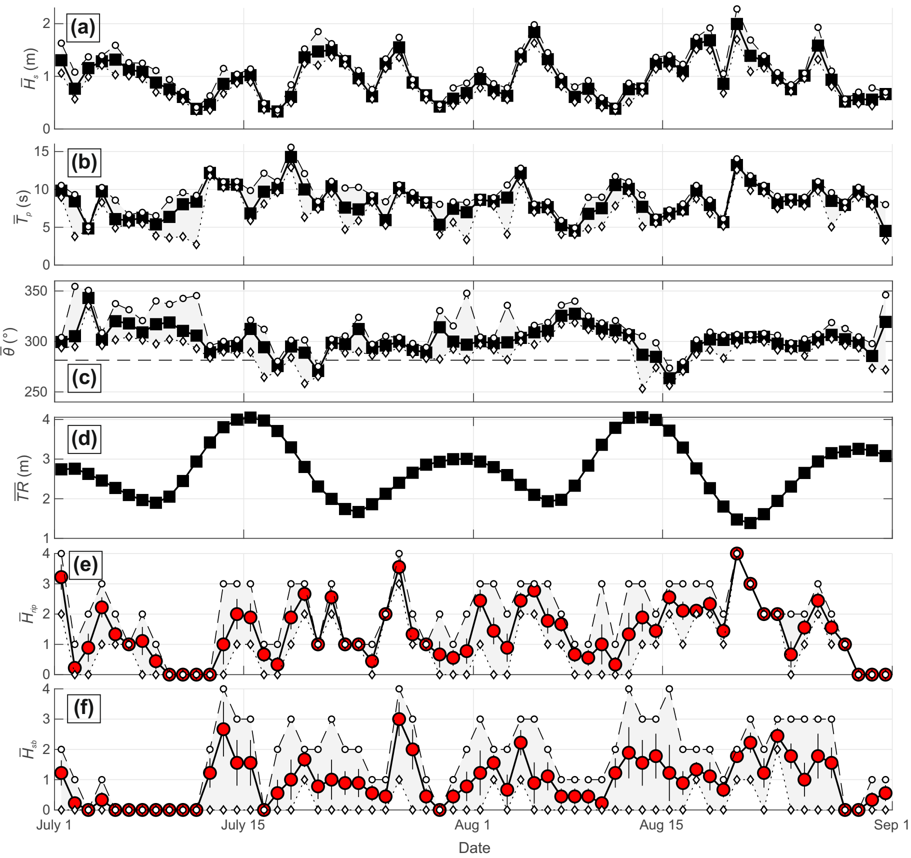

Figure 2: Lifeguard-estimated surf zone hazards and related environmental conditions. Daily-mean (11AM-7PM patrolling hours) time series of (a) significant wave height $\overline{H}_s$; (b) peak wave period $\overline{T}_p$; (c) angle of wave incidence θ with the horizontal dashed line indicating shore-normal incidence ($\theta_c = 281.4°$); (d) tide range $\overline{TR}$; (e) lifeguard-estimated rip current hazard $\overline{H}_{rip}$ and (f) lifeguard-estimated shore-break hazard $\overline{H}_{sb}$. In all panels (except (d)), the light grey area delimits the daily maximum - circles (minimum - diamond) values. In (e,f) the vertical line indicates the standard deviation.

that lifeguard-estimated surf zone hazards are highly variable in time. During prolonged periods of low-energy waves, lifeguard-estimated rip-current and shore-break wave hazards can be absent (July 9-11, Figure 2), while during an entire day of high-energy ($\overline{H}_s = 2.00$ m), long-period ($\overline{T}_p = 13.2$ s) near-shore-normally incident waves ($\overline{\theta} = 302.9°$) and neap tide ($\overline{TR} = 1.48$ m), rip current hazard can be maximized during the entire day (August 20, Figure 2), forcing the lifeguards to hoist the red flag. Interestingly, $\overline{H}_{rip}$ (Figure 2e) and $\overline{H}_{sb}$ (Figure 2f) show similar patterns, with a statistically significant (p-value < 0.02) correlation $R = 0.60$.

Table 1 shows the correlation R computed between lifeguard-estimated rip current and shore-break wave hazards with different environmental parameters. In line with previous work, wave and tide variables show strong correlations with surf zone hazards, while weather parameters mostly show non-significant correlations. For all lifeguard-estimated surf zone hazards, the wave factor $\overline{W}_f = \overline{H_s T_p}$ introduced in its summer-normalised version by [52], and which is here simply a proxy of wave power, shows the strongest positive correlation. It is important to note that, within the wave factor, lifeguard-estimated rip current hazard is more controlled by the significant wave height $\overline{H}_s$ (R = 0.8), while lifeguard-estimated shore-break wave hazard is more controlled by wave period $\overline{T}_p$. Surprisingly enough, a non-significant (p-value = 0.06) correlation (R =0.24) is found between rip current hazard $\overline{H}_{rip}$ and the angle of wave incidence ($\overline{|\cos 2(\theta - \theta_c)|}$), while rip-current velocity is known to increase under shore-normally incident waves. Instead, a statistically-significant positive correlation (R = 0.41) is found between the angle of wave incidence ($\overline{|\cos 2(\theta - \theta_c)|}$) and lifeguard-estimated shore-break wave hazard $\overline{H}_{sb}$. Table 1 also provides statistics for the daily minimum (min{.}) and daily maximum (max{.}) of the lifeguard-estimated surf zone hazard. A statistically significant negative correlation (-0.37) appears between tidal range $\overline{TR}$ and the daily minimum rip current hazard. This suggests that, during a neap tide day when high-water levels are never reached, rip current hazard can be sustained during the entire day, pending enough incident wave energy for the waves to consistently break across the bar/rip system.

Table 1: Correlation coefficients between the primary environmental variables and lifeguard-estimated hazards and beach attendance. For each lifeguard estimate, the largest correlation is in bold. (*) indicates statistically significant correlation (p-value < 0.02)

	$\overline{H}_s$	$\overline{T}_p$	$\overline{\lvert\cos 2(\theta-\theta_c)\rvert}$	$\overline{H_sT_p}$	$\overline{TR}$	$\overline{T}$	$\overline{I}$	$\overline{W}$
$\overline{H}_{rip}$	0.80*	0.36*	0.24	**0.83***	-0.21	-0.29*	-0.08	0.22
$\max\{H_{rip}\}$	0.62*	0.33*	0.23	**0.67***	0.00	-0.15	0.01	0.20
$\min\{H_{rip}\}$	0.82*	0.36*	0.23	**0.86***	-0.37*	-0.33*	-0.15	0.23*
$\overline{H}_{sb}$	0.41*	0.51*	0.41*	**0.57***	0.09	0.00	-0.03	-0.07
$\max\{H_{sb}\}$	0.37*	0.47*	0.45*	**0.48***	0.23	0.06	-0.01	-0.03
$\min\{H_{sb}\}$	0.34*	0.32*	0.17	**0.47***	-0.27	-0.07	-0.03	0.05
$\overline{C}$	-0.27*	0.25*	0.03	-0.10	0.23	0.54*	**0.57***	-0.27*
$\max\{C\}$	-0.20	0.14	-0.05	-0.09	0.16	0.42*	**0.47***	-0.20
$\min\{C\}$	-0.38*	0.32*	-0.01	-0.15	0.37*	**0.73***	0.55*	-0.32*

Table 1 shows the correlation between surf zone hazard and different environmental parameters, which gives a measure of the strength of the, linear, relationship between the two variables. However, there is a wealth of literature showing that relationship between environmental variables and hazard are strongly nonlinear. Following previous work [52, 22] on lifeguard rescues and surfzone injuries, the average frequency distribution of the environmental parameters were compared with those computed from the environmental parameters associated with each surf zone hazard level. Differences between the distributions show under which environmental conditions a given hazard level disproportionately occurs, which are indicated by the colored bars in Figure 3.

Results on lifeguard-estimated rip-current hazard (top panels in Figure 3) are in line with the general findings provided in Table 1, but provide more insight into the nonlinear relationships. Maximized lifeguard-estimated rip-current hazard is observed disproportionately for well above summer-average $\overline{H}_s > 1.5$ m (Figure 3a) and peak wave period $\overline{T}_p > 10$ s (Figure 3b). The distribution patterns are more complex for wave direction (Figure 3d) and tide range (Figure 3e), which explains the poor correlations in Table 1. However, it indicates that maximum lifeguard-estimated rip current hazard disproportionately occur for days when the angle of wave incidence is around 290° (Figure 3d), which is close to shore normal. In addition, low-hazard (green) and high-hazard (red) days are found to occur disproportionately for low (< 2 m) and large (> 3 m) tide range (Figure 3e). Finally, results confirm that the wave factor $\overline{H_s T_p}$ is a powerful indicator of rip current hazard as low- to moderate-hazard days ($\overline{H}_{rip} \leq 2$) and high-hazard days ($\overline{H}_{rip} \geq 3$) largely disproportionately occur for $\overline{H_s T_p} < 10$ m.s and $\overline{H_s T_p} > 10$ m.s, respectively.

Results on lifeguard-estimated shore-break wave hazard (bottom panels of Figure 3) are in line with the general findings provided in Table 1, but provide more insight into the key environmental factors driving high shore-break wave hazards. For instance, despite the high correlation with the wave factor $\overline{H_s T_p}$ in Table 1, Figure 3h shows that it does not explain disproportionately high-hazard ($\overline{H}_{sb} = 4$) days. Instead, long-period ($\overline{T}_p > 10$ s), shore-normally incident ($\bar{\theta} \approx 280°$) and large tide range ($\overline{TR} > 3$ m) are clearly associated with such high-hazard days.

3.2 Beachgoer exposure

Figure 4 shows the time series of the daily-mean lifeguard-estimated beach crowd ($\overline{C}$), as well as that of the weather variables ($\overline{T}$, $\overline{I}$ and $\overline{W}$) which are known to control beach attendance. The summer of 2022 was mostly characterized by warm, sunny and light-wind days. Daily-mean air temperature ranged 19.1° - 35.8° with a mean of 25.1°. Importantly, this summer was characterized by severe drought and heat wave in western Europe [39], with air temperature at the coast largely lower than that inland due to the afternoon sea breeze. Only during a few days (e.g. July 16-18) did the sea breeze not eventuate, resulting in $\overline{T} > 30°$. Daily-mean beach crowd ranged from 43 - 633, with a mean of 367, and with a maximum estimated hourly crowd of 1,000 beachgoers (August 12, Figure 4d).

Table 1 shows the correlation between beach crowd and the different environmental parameters. Not surprisingly, daily mean beach crowd $\overline{C}$ variability is mostly explained by the variability in weather parameters, with by decreasing order insolation $\overline{I}$, air temperature $\overline{T}$ and wind speed $\overline{W}$. The daily minimum crowd ($\min\{C\}$) shows a stronger correlation to air temperature indicating that, while insolation mostly controls the amount of beachgoers, colder temperatures deter people from coming

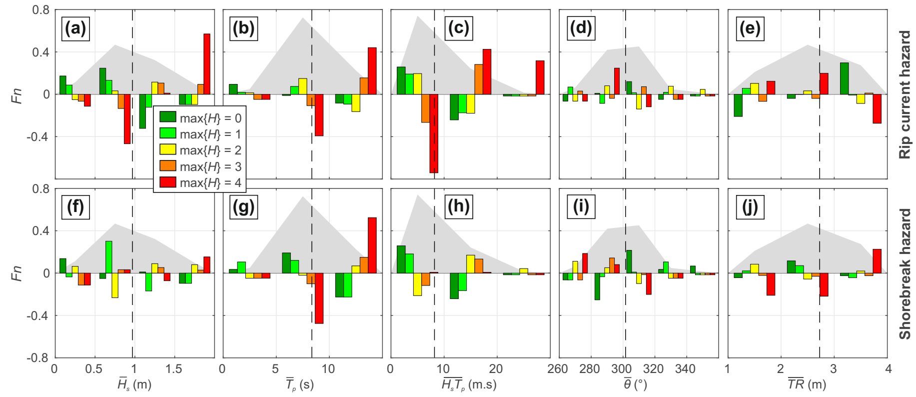

Figure 3: Environmental controls on (top panels) lifeguard-estimated rip current hazard (bottom panels) and lifeguard-estimated shore-break hazards. Normalized frequency distributions Fn (light grey area), referred to as 'average' background distribution, of daily-mean (11AM-7PM) (a,f) 0.5-m binned significant wave height $\overline{H}_s$; (b,g) 5-s binned peak wave period $\overline{T}_p$; (c,h) 10-m.s. binned wave factor $\overline{H_sT_p}$; (d,i) 20° binned angle of wave incidence θ and (e,j) 1-m binned tide range $\overline{TR}$. The colored bars show the difference between perceived hazard-level-related $(\overline{H})$ and average background distributions and the vertical dashed lines indicate background means, with color indicating the daily maximum lifeguard-estimated hazard level (0-4).

to the beach during the early hours of the day. Finally, wave height $\overline{H}_s$ and wave period $\overline{T}_p$ have a low but statistically significant negative and positive correlation with $\overline{C}$, respectively, which will be discussed in Section 4. The influence of weather parameters on beach crowd are further emphasized in Figure 5, which also provides insight into the influence of the weekday. The primary pattern is that days with low beach crowd disproportionately occur on Mondays and Wednesdays, while the most crowded days are typically the four last days of the week, with the notable exception of Saturday (Figure 5d). It is important to note that, given the limited number of days in this dataset, the weekday analysis lacks of statistical significance.

3.3 Surfzone life risk

According to [60] and [25], the life risk at the beach can be modelled indirectly by estimating hazard and exposure [60, 25]. Assuming that the number of water users is well correlated to the total beach crowd, we estimated the daily level of risk, for a given hazard, H, as $R = \overline{HC'}$, where C' is the normalized hourly beach crowd with respect to the the maximum hourly beach crowd $\max\{C\}$ during the 2022 summer (1,000). The resulting estimated rip-current related life risk R_{rip} and shore-break wave related life risk R_{sb} therefore range from 0 (no risk) - 4 (maximized risk).

Figure 6 shows the time series of daily beach crowd, shore-break and rip-current hazards, as well as the comparison of rip-current related life risk $\overline{R}_{rip}$ (Figure 6c) and shore-break wave related life risk

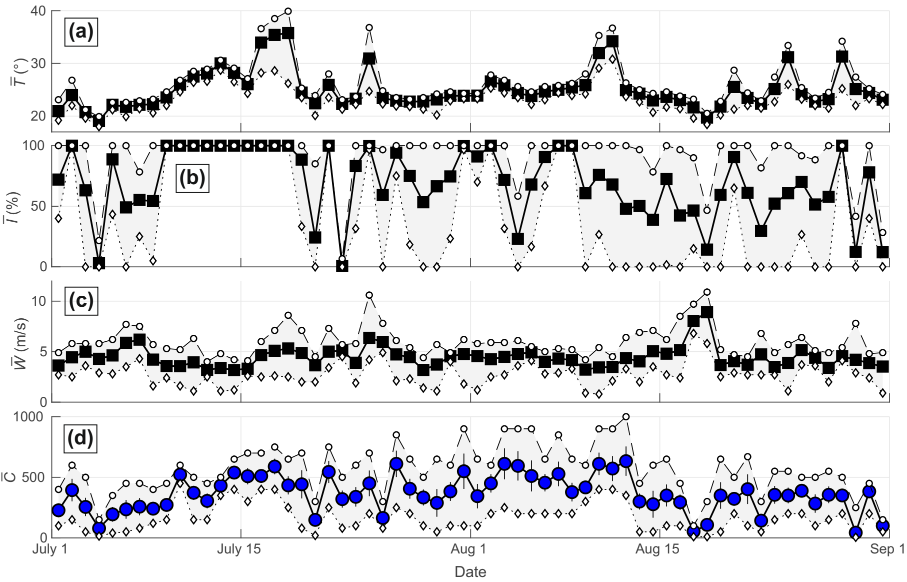

Figure 4: Beach attendance and related environmental conditions. Time series of daily-mean (11AM-7PM) (a) air temperature $\overline{T}$; (b) insolation $\overline{I}$; (c) wind speed $\overline{W}$ and (d) lifeguard-estimated beach attendance $\overline{C}$. In all panels the light grey area delimits the daily maximum - circles (minimum - diamond) values. In (d) the vertical line indicates the standard deviation.

$\overline{R}_{sb}$ (Figure 6c), with the daily number of rip current rescues $\overline{N}_{rip}$ and shore-break related rescues $\overline{N}_{sb}$ which can be considered as a fair proxy for life risk. Overall, a statistically-significant, weak, positive correlation ($R = 0.37$) is found between $\overline{R}_{rip}$ and $\overline{N}_{rip}$, which is slightly better between $\overline{R}_{sb}$ and $\overline{N}_{sb}$ ($R = 0.38$) meaning a positive linear relationship exists between estimated life risk and the number of rescues. In addition, clusters of days with a large number of shore-break rescues are captured by $\overline{H}_{sb}$, and long periods without rescues also correspond to long periods of $R \approx 0$ (July 1-12, Figure 6c,d). These fairly weak correlations and some of the days with no rescues, but high lifeguard-estimated risk will be discussed in Section 4. Finally, despite a statistically significant positive correlation exists ($R = 0.60$) between daily-mean rip current $\overline{H}_{rip}$ and shore-break wave $\overline{H}_{sb}$ hazards, q poor and non-significant correlation ($R = 0.20$) is found between the daily number of rip current $\overline{R}_{rip}$ and shore-break wave $\overline{R}_{sb}$ rescues suggesting that exposure is a critical component of life risk.

4 Discussion

Some of the findings presented herein based on lifeguard (expert) assessment support those of previous work using other approaches. We showed that lifeguard-estimated rip current hazard increases with increasing wave height, long period waves and near shore-normal wave incidence. This agrees with previous work along this coastline based on field measurements [e.g. 21, 14], process-based hydrodynamics modelling [e.g 20, 13] and drowning incident records [22, 18, 25]. Lifeguard-estimated

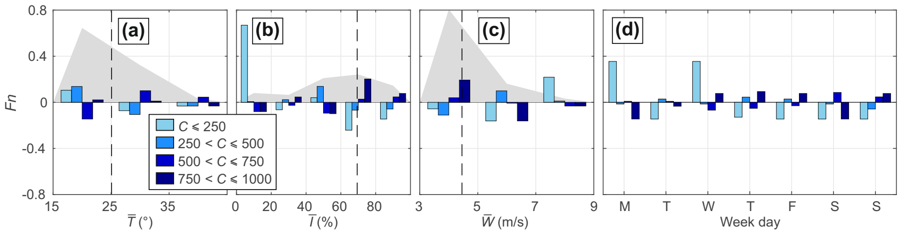

Figure 5: Environmental controls on lifeguard-estimated beach attendance. Normalised frequency distributions Fn (light grey area), referred to as 'average' background distribution, of (a) air temperature $\overline{T}$; (b) insolation $\overline{I}$; (c) wind speed $\overline{W}$; (d) week day. The colored bars show the difference between beach-attendance-related ($\overline{C}$) and average background distributions and the vertical dashed lines indicate background means.

shore-break wave hazard was found to be maximized for long-period waves and large tide range days when waves are more likely to break across the highest, steepest, section of the beach. This is also in line with shore-break waves being associated with longer-period waves and steep beach slopes [7, 5], and maximized occurrence of shore-break related spine injuries in southwest France [22, 25]. In addition, the lifeguard estimate of beach crowd shows that beach user attendance increases on warm sunny days with light winds, which is consistent with indirect beach crowd assessment through Bayesian network modelling in southwest France [25], and direct measurements elsewhere [32, 38, 23]. In other research fields experts were sometimes found to overestimate danger and risks, although much less than lay people [e.g. 58, 57, 33]. Here, the overall agreement with previous work based on other data sources indicates that lifeguard hazard assessment can be a valuable source of data for beach safety studies, similar to previous work on breaking wave height [12] and rip current velocity [29]. This alternative beach safety monitoring approach could, in the long-term, provide more robust insight into surf zone hazards, beach attendance and rescues along the southwest coast of France and on a wider range of beaches.

Our study also provides new insights into beach attendance and surf zone hazards. For instance, while previous work indicated that beach crowd consistently increases with air temperature, insolation and light wind, the analysis during the summer of 2023 shows a substantial decrease of beach attendance during the warmest temperatures associated with the heat wave (Figure 5a). This is further evident in Figure 7 which shows the hourly time series of weather parameters (T, I and W) and that of lifeguard-estimated beach attendance C for a heat wave day (July 18) and a regular summer day (July 26). Both days are sunny (Figure 7b) with light wind (Figure 7c). Despite their strong difference in air temperature ($\overline{T} = 35.8°$ and $22.9°$ on July 18 and 26, respectively, see also Figure 7a), daily average beach attendance was much smaller on the hottest day on July 18 ($\overline{C} = 433$) than on July 26 ($\overline{C} = 611$). Interestingly, Figure 7g also shows that on a regular summer day beach attendance is

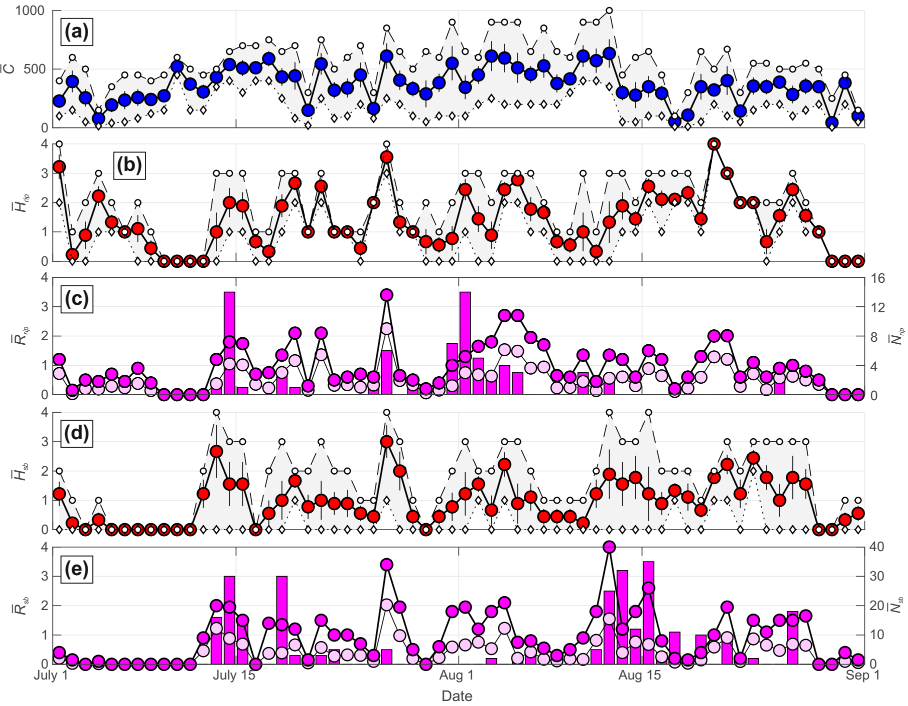

Figure 6: Beach attendance, surf zone hazards and resulting life risks and related environmental conditions. Daily (11AM-7PM) time series of (a) lifeguard-estimated beach attendance $\overline{C}$; (b) lifeguard-estimated rip current hazard $\overline{H}_{rip}$ and (c) resulting rip-current life risk $\overline{R}_{rip}$ and number of surf zone rescues $\overline{N}_{rip}$ (bars); (d) lifeguard-estimated shore-break hazard $\overline{H}_{sb}$ and (e) resulting shore-break life risk $\overline{R}_{sb}$ and number of bather assistance in the shore-break $\overline{N}_{sb}$ (bars).

maximized in mid- late-afternoon (3PM - 5PM). In contrast, in addition to having a smaller daily-average attendance, beach crowds during a heat wave tend to peak during the coolest temperature of the day (morning and late afternoon). This shows that heat wave can deeply affect beach use, and more generally human behavior [e.g. 59]. Whether heat waves increase the risk of fatal drowning, like recently documented in Queensland, Australia [49] could not be explored herein. Beach crowd $\overline{C}$ was also positively and negatively correlated with wave height $\overline{H}_s$ and wave period $\overline{T}_p$, respectively, indicating that beach attendance increases with increasing wave steepness. However, correlation does not mean causation and thus this does not mean that the general public are more keen to go to the beach under low steepness waves. Instead, low-steepness waves are generally associated with remote low pressure systems, and thus high-pressure conditions in southwest France i.e. warm sunny days with light wind. This is evident by the positive (negative) statistically-significant correlation between daily-mean air temperature $\overline{T}$ and peak wave period $\overline{T}_p$ (R = 0.40) (significant wave height $\overline{H}_s$ (R = -0.56)). Therefore, we hypothesize that beach attendance is not affected by wave conditions, but essentially weather conditions. Another interesting result arising from our study based on lifeguard estimates is that shore-break wave hazard is largely affected by the angle of wave incidence, with

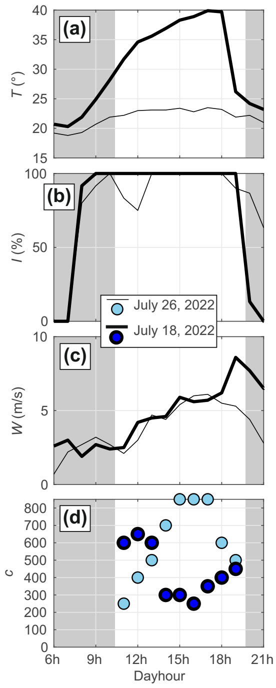

Figure 7: Time series on (Thin line and light blue bubbles) July 26, 2022 and (thick line and dark blue bubbles) July 18, 2022 of (a) air temperature T; (b) Insolation I; (c) wind speed W and (d) lifeguard-estimated hourly beach attendance c.

hazard maximized under shore-normally incident waves. Although the angle of wave incidence did not have any influence on shore-break related injuries along the Delaware coast [50], [22] also found that shore-normally incident waves result in a disproportionate amount of shore-break related spine injuries in southwest France. Measuring the impact of shore-break waves is challenging in the field, but such monitoring would help verifying our findings.

Our results show a statistically significant, but weak, positive correlation between the daily number of lifeguard-estimated rip-current ($R = 0.37$) and shore-break ($R = 0.38$) related rescues and the risk modelled indirectly by combining lifeguard-estimated beach crowd and surf zone hazard [60, 25]. Such weak correlation can be explained by numerous factors. Firstly, here we addressed daily mean hazards while rescues and SZI [22] typically occur in clusters during a couple of hours when rip-current or shore-break wave hazard peaks (Figure 8). This limits the use of daily averages. Secondly, the number of rescues strongly depends on the location of the supervised bathing zone, which is subjectively moved by the lifeguards during the day, and throughout the season, balancing different factors such as : (i) limited likelihood of shore-break wave and particularly rip current hazards; (ii) minimized distance of the supervised bathing zone to the beach entry and lifeguard station; and (iii) minimized probability and distance by which the bathing zone may be moved during the day from a rip-current free to a shore-break wave free location as the tide changes during the day. During the course of the summer, the lifeguards typically progressively increase their understanding of how the surf zone hazards vary in both time and space at their beach as a function of the tidal stage and incident wave conditions. Personal communication with La Lette Blanche lifeguards indicate that such time lag is much longer for the rip current hazards, which was particularly true during the studied summer because of the morphological complexity of the feeder channels (Figure 1c). As a results, by the end of the summer the number of rescues is reduced. This can explain why, after the end of July a large number of days have no or few rescues despite a large lifeguard-estimated risk (Figure 6). This is in line with correlation increasing from 0.37 to 0.55 and from 0.38 to 0.68 for rip-current and shore-break related rescues, respectively, by only accounting for the first three weeks of July. Thirdly, lifeguard prevention also affects the number of rescues, with active prevention actions performed during highly hazardous wave conditions to limit the risk of drowning. An extreme example is August 20, with a maximized lifeguard-estimated rip current hazard during the entire day (Figure 6b) and decent beach attendance (Figure 6a). During this day there was no rip current and shore-break wave rescues because the red flag was hoisted, thus forbidding beachgoers to enter the water and expose to themselves to hazardous rip currents. We hypothesize that the evolution of lifeguard knowledge and the evolving bathing and prevention strategy throughout the summer largely affects our computed correlations between the daily number of rescues and the life risk estimated from surf zone hazard and beach attendance. This can have many implications, as for instance it suggests that it is safer for the people to swim towards the end of the summer. In addition, it suggests that southwest France beaches patrolled by more experienced lifeguards may benefit from optimal prevention and bathing zone strategy earlier in the season. This would affect rescues and surfzone incidents and bias inter-site life risk comparisons at beaches with contrasting lifeguard experience.

An important result was that daily-mean lifeguard-estimated rip-current hazard $\overline{H}_{rip}$ and shore-break wave hazards $\overline{H}_{sb}$ show similar patterns (Figure 2f) with a statistically significant correlation R = 0.60. This may suggest that a single daily predictor encompassing rip current and shore-break wave hazards could be developed for the southwest coast of France. However, it is critical to emphasize that, within a given day, rip current and shore-break wave hazards show contrasting patterns. Figure 8 shows the hourly time series of environmental conditions, beach attendance and lifeguard-estimated surf zone hazards for low to moderate energy offshore wave conditions ($H_s \approx 0.8$ - 1 m and $T_p \approx$ 6-10 s), but for neap tide cycle (July 7, left-hand panels in Figure 8) and spring tide cycle (July 13, right-hand panels in Figure 8). On July 7, only rip current hazard was observed during the lowest stage of the tide, while the limited high tide levels resulted in no shore-break hazard. In contrast, on July 13 with more incident wave energy and spring tide range, lifeguard-estimated rip current and shore-break wave hazards clearly show out-of-phase signals, peaking at low tide and high tide, respectively (Figure 8j,l). This strongly time-varying surf zone hazard patterns together with beach attendance typically peaking during mid-afternoon (see e.g. Figure 8) suggests that two distinct rip-current and

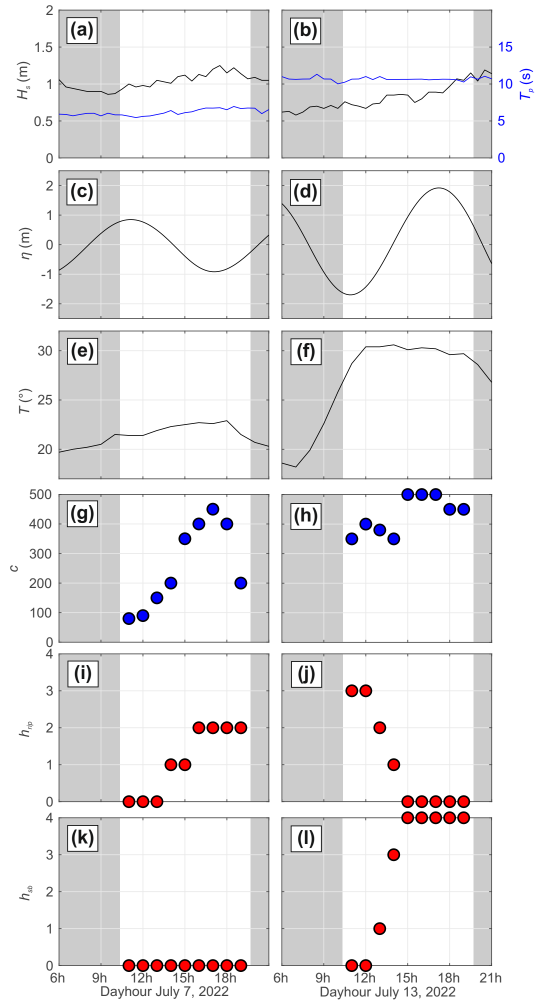

Figure 8: (Left-hand panels) July 7, 2022 and (right-hand panels) July 13, 2022 time series of (a,b) significant wave height H_s and peak wave period T_p; (c,d) astronomical tide elevation η; (e,f) air temperature T; (g,h) lifeguard-estimated hourly beach attendance c; (i,j) lifeguard-estimated hourly rip-current hazard h_{rip} and (k,l) lifeguard-estimated hourly shore-break wave hazard h_{sb}.

shore-break wave hourly risk predictors should be targeted in order to provide insight into the timing and magnitude of surf zone hazards during the day.

Further development of daily or hourly beach risk predictors will, however, require more data on both beach attendance and surf zone hazards. More accurate and quantitative beach attendance estimates can be computed through, for instance, deep learning techniques [8] using video monitoring stations [35]. Machine learning techniques [e.g. 48] should then be developed to predict beach attendance based on weather predictions, and thus indirectly water user exposure. Longer time series of beach attendance, and a larger range of weather conditions (including heat waves), at different sites distributed along the coast to include both remote and busy beaches, with expected different beach use, will be required to develop a comprehensive beach attendance model for the entire coast. This will also allow inclusion of more weekday data. Indeed, with only nearly nine weeks of data, our findings on the influence of weekday on beach attendance (Figure 5d) are unclear while previous work showed that weekday is important to life risk at the beach [61]. Given our understanding in rip current dynamics, previous modelling work and the relative alongshore uniformity of bar/rip morphology, developing an hourly or daily rip current hazard predictor based on wave and tide predictions should be relatively straightforward. This is different for the shore-break wave hazard for which new semi-empirical models could be developed. A next step will also be to model the number of water-users, which is not fully correlated with the number of people on the beach C. For instance, [25] showed, using a water-user exposure hidden variable in a Bayesian network, that in southwest France e.g. large shore-break waves ($H_s > 2.5$ m) can discourage the people on the beach from entering the water. Lifeguard head counts of water-users, in addition to the beach user counts, should help improving our understanding of water-user behaviour. Another approach would be, based on beachgoer survey questionnaires, to model the the probability of beachgoers to bath based on the weather, wave and tide conditions. Such information should also be included in a beach risk prediction. By combining these predictors and further collecting SZI and rescue data along the entire coast, a comprehensive beach risk predictor detailing all the components of the risk could be developed.

5 Conclusions

In this study we combined environmental data with lifeguard-estimated beach attendance and levels of shore-break-wave and rip current hazards at La Lette Blanche beach, southwest France, during the lifeguard-patrolled summer period (July-August) 2022. Such alternative approach, which could be applied to any global coastal location, allowed us to describe the primary weather and wave/tide parameters controlling surf zone hazard, beach attendance and, in turn, the level of life risk on the beach. While some results are essentially in line with previous work on the environmental controls on surf zone hazards and beach attendance, we also show that, for instance, heat waves and angle of wave incidence also affect beach user behavior and shore-break wave hazards, respectively. Days characterized by strong lifeguard-estimated hazards and large beach attendance were associated with the largest amount of rescues and drowning incidents. However, correlations decreased by the end of the summer. This is hypothesized to be the signature of evolving lifeguard strategies (e.g. preferred locations of the supervised bathing zone, prevention measures) resulting from their progressive increase in understanding of the surf zone hazards variability in both time and space at their beach. In addition, hazards and rescues related to rip currents and shore-break waves occur at different times and locations throughout a day due to the combination of complex beach morphology and meso-macrotidal range. We also show that lifeguards can be a valuable source of data to improve the understanding of the environmental controls on beach crowd, surf zone hazards and life risk at the beach. This continuously building dataset will form the basis of comprehensive, daily and/or hourly, life-risk predictors related to rip current and/or shorebreak wave hazards with quantification of all the components of the risk. We anticipate that such a predictor will help decrease the burden of drowning and severe spine injuries in southwest France.

Acknowledgments

We warmly thank the SMGBL (Syndicat Mixte de Gestion des Baignades Landaise), and particularly Stéphanie Barneix and the La Lette Blanche lifeguards who were on duty during the summer of 2022, namely, Jean Philippe Savy (JP) - Chief Lifeguard, Baptiste Tauzin (Tistou) - Co-Chief lifeguard, Camille Grand-Maison (Barry), Lena Barone (Lena), Lison Mathieu (Lisou), Nicolas Beylac (Tigrou), Nicolas Rieppi (Pock), Paul Marleux (Paulo), Romain Blum (Blumy), Tristan Schorsch (Tristan) for their help and support on the field and for making possible this research. We are also thankful to the Vielle Saint-Girons council for providing technical support and access to the lifeguard facilities. We thank Météo-France for providing weather data from Capbreton station through their RADOME (Réseau d'Acquisition de Données d'Observations Météorologiques Etendu) automatic weather station network. The wave buoy data are publicly available through the French Candhis network operated by CEREMA (Centre d'Études et Expérience en Risques, Environnement, Mobilité et Urbanisme), and the tide gauge data are publicly available through to Shom (Service Hydrographique et Océanographique de la Marine).

Declarations

- Funding : This study received financial support from Project SWYM (Surf zone hazards, recreational beach use and Water safetY Management in a changing climate) funded by Région Nouvelle-Aquitaine and the French government in the framework of the University of Bordeaux's IdEx "Investments for the Future" program / RRI Tackling Global Change.
- Conflict of interest : The authors have no relevant financial or non-financial interests to disclose.
- Authors' contributions : BC designed the study and the methodology, prepared the material, collected and analyzed the dataset, produced the figures and wrote the first draft of the manuscript. JD and BC acquired funding for this research. JPS, Chief Lifeaguard of La Lette Blanche, co-designed and collected the lifeguard data. All authors were consulted on the methodology, commented on previous versions of the manuscript, and read and approved the final manuscript.

References

[1] T. Aagaard, B. Greenwood, and J. Nielsen. Mean currents and sediment transport in a rip channel. *Marine Geology*, 140(1-2):25–45, 1997.

[2] I. Arozarena, C. Houser, A.G. Echeverria, and C. Brannstrom. The rip current hazard in costa rica. *Natural Hazards*, 77(2):753–768, 2015.

[3] M.J. Austin, G. Masselink, T.M. Scott, and P.E. Russell. Water-level controls on macro-tidal rip currents. *Continental Shelf Research*, 75:28–40, 2014.

[4] M.J. Austin, T. M. Scott, J. W. Brown, J. A. Brown, J. H. MacMahan, G. Masselink, and P. Russell. Temporal observations of rip current circulation on a macro-tidal beach. *Cont. Shelf. Res.*, 30:1149–1165, 2010.

[5] James H Balsillie. Redefinition of shore-breaker classification as a numerical continuum and a design shore-breaker. *J. Coast. Res.*, 1(3):247–254, 1985.

[6] B. Barlas and S. Beji. Rip current fatalities on the black sea beaches of istanbul and effects of cultural aspects in shaping the incidents. *Natural Hazards*, 80(2):811–821, 2016.

[7] J. A. Battjes. Surf similarity. In *14th Int. Conf. on Coastal Eng.*, pages 466–480. ASCE, 1974.

[8] L. Boominathan, S.S.S. Kruthiventi, and R. Venkatesh Babu. Crowdnet: A deep convolutional network for dense crowd counting. pages 640–644, 2016.

[9] R. W. Brander and A. D. Short. Flow kinematics of low-energy rip current systems. *J. Coast. Res.*, 17:468–481, 2001.

[10] B. C. Brewster, R. E. Gould, and R. W. Brander. Estimations of rip current rescues and drowning in the united states. *Natural Hazards and Earth System Sciences*, 19(2):389–397, 2019.

[11] B. Brighton, S. Sherker, R. Brander, M. Thompson, and A. Bradstreet. Rip current related drowning deaths and rescues in australia 2004–2011. *Nat. Hazards Earth Syst. Sci.*, 13(4):1069–1075, 2013.

[12] M. Browne, B. Castelle, D. Strauss, R. Tomlinson, M. Blumenstein, and C. Lane. Near-shore swell estimation from a global wind-wave model: Spectral process, linear, and artificial neural network models. *Coastal Engineering*, 54(5):445–460, 2007.

[13] N Bruneau, Philippe Bonneton, Bruno Castelle, and Rodrigo Pedreros. Modeling rip current circulations and vorticity in a high-energy mesotidal-macrotidal environment. *J. Geophys. Res. Oceans*, 116(C7), 2011.

[14] N. Bruneau, B. Castelle, P. Bonneton, R. Pedreros, R. Almar, N. Bonneton, P. Bretel, J.-P. Parisot, and N. Sénéchal. Field observations of an evolving rip current on a meso-macrotidal well-developed inner bar and rip morphology. *Continental Shelf Research*, 29(14):1650–1662, 2009.

[15] Angel Bujosa, Antoni Riera, and Pere Josep Pons. Sun-and-beach tourism and the importance of intra-destination movements in mature destinations. *Tourism Geographies*, 17(5):780–794, 2015.

[16] B. Castelle, R. Brander, E. Tellier, B. Simonnet, T. Scott, J. McCarroll, J.-M. Campagne, T. Cavailhes, and P. Lechevrel. Surf zone hazards and injuries on beaches in sw france. *Nat. Hazards*, 93(3):1317–1335, 2018.

[17] B. Castelle, S. Bujan, S. Ferreira, and G. Dodet. Foredune morphological changes and beach recovery from the extreme 2013/2014 winter at a high-energy sandy coast. *Marine Geology*, 385:41–55, 2017.

[18] B. Castelle, T. Scott, R. Brander, R.J. McCarroll, E. Tellier, E. De Korte, L. Tackuy, A. Robinet, B. Simonnet, and L.-R. Salmi. Wave and tide controls on rip current activity and drowning incidents in southwest france. *Journal of Coastal Research*, 95(sp1):769–774, 2020.

[19] B Castelle, T Scott, RW Brander, and RJ McCarroll. Rip current types, circulation and hazard. *Earth Sci. Rev.*, 163:1–21, 2016.

[20] Bruno Castelle and Philippe Bonneton. Modelling of a rip current induced by waves over a ridge and runnel system on the aquitanian coast, france. *Comptes Rendus Geoscience*, 338(10):711–717, 2006.

[21] Bruno Castelle, Philippe Bonneton, Nadia Senechal, Helene Dupuis, Remi Butel, and Denis Michel. Dynamics of wave-induced currents over an alongshore non-uniform multiple-barred sandy beach on the aquitanian coast, france. *Cont. Shelf Res.*, 26(1):113–131, 2006.

[22] Bruno Castelle, Tim Scott, Rob Brander, Jak McCarroll, Arthur Robinet, Eric Tellier, Elias de Korte, Bruno Simonnet, and Louis-Rachid Salmi. Environmental controls on surf zone injuries on high-energy beaches. *Nat. Hazards Earth Syst. Sci.*, 19(10), 2019.

[23] E.G. Coombes, Andy P. Jones, I.J. Bateman, J.A. Tratalos, J.A. Gill, D.A. Showler, A.R. Watkinson, and W.J. Sutherland. Spatial and temporal modeling of beach use: A case study of east anglia, uk. *Coastal Management*, 37(1):94 – 115, 2009.

[24] Robert A. Dalrymple, Jamie H. MacMahan, Ad J.H.M. Reniers, and Varjola Nelko. Rip currents. *Annu. Rev. Fluid Mech.*, 43(1):551–581, 2011.

[25] E. de Korte, B. Castelle, and E. Tellier. A bayesian network approach to modelling rip-current drownings and shore-break wave injuries. *Natural Hazards and Earth System Sciences*, 21(7):2075–2091, 2021.

[26] G. Dodet, X. Bertin, F. Bouchette, M. Gravelle, L. Testut, and G. Wöppelmann. Characterization of sea-level variations along the metropolitan coasts of france: Waves, tides, storm surges and long-term changes. *Journal of Coastal Research*, 88(sp1):10–24, 2019.

[27] D. Drozdzewski, W. Shaw, D. Dominey-Howes, R. Brander, T. Walton, A. Gero, S. Sherker, J. Goff, and B. Edwick. Surveying rip current survivors: preliminary insights into the experiences of being caught in rip currents. *Nat. Hazards Earth Syst. Sci.*, 12(4):1201–1211, 2012.

[28] Nils Drønen, Harshinie Karunarathna, Jørgen Fredsøe, B. Mutlu Sumer, and Rolf Deigaard. An experimental study of rip channel flow. *Coastal Engineering*, 45(3):223–238, 2002.

[29] G. Dusek and H. Seim. Rip Current Intensity Estimates from Lifeguard Observations. *Journal of Coastal Research*, 29(3):505–518, 2012.

[30] G. Dusek and H. Seim. A probabilistic rip current forecast model. *J. Coast. Res.*, 29(4):909–925, 2013.

[31] Gregory Dusek, Harvey Seim, Jeffrey L. Hanson, and David H. Elder. *Analysis of Rip Current Rescues at Kill Devil Hills, North Carolina.* Taylor & Francis Group, Boca Raton, 2011.

[32] Ryan H. Dwight, Mitchell V. Brinks, Gajapathi SharavanaKumar, and Jan C. Semenza. Beach attendance and bathing rates for southern california beaches. *Ocean Coast. Manage.*, 50(10):847 – 858, 2007.

[33] Philip A. Ebert and Ian N. Durbach. Expert and lay judgements of danger and recklessness in adventure sports. *Journal of Risk Research*, 26(2):133 – 146, 2023.

[34] Andrea Ghermandi and Paulo A.L.D. Nunes. A global map of coastal recreation values: Results from a spatially explicit meta-analysis. *Ecological Economics*, 86:1 – 15, 2013.

[35] J. Guillén, A. García-Olivares, E. Ojeda, A. Osorio, O. Chic, and R. González. Long-term quantification of beach users using video monitoring. *Journal of Coastal Research*, 24(6):1612–1619, 2008.

[36] C. Michael Hall and Stephen J. Page. *The Geography of Tourism and Recreation: Environment, Place and Space.* 2014.

[37] C. Houser, R. Arnott, S. Ulzhofer, and G. Barrett. Nearshore circulation over transverse bar and rip morphology with oblique wave forcing. *Earth Surf. Process. Landf.*, 38:1269–1279, 2013.

[38] E.M. Ibarra. The use of webcam images to determine tourist-climate aptitude: Favourable weather types for sun and beach tourism on the alicante coast (spain). *Int. J. Biometeorol.*, 55(3):373–385, 2011.

[39] Chibuike Chiedozie Ibebuchi and Itohan-Osa Abu. Characterization of temperature regimes in western europe, as regards the summer 2022 western european heat wave. *Climate Dynamics*, 2023.

[40] P. Kamstra, B.R. Cook, J.C. Lawes, and H. Calverley. Engaging beachgoers for drowning prevention: the spillover effects on non-participants. *Environmental Hazards*, 2023.

[41] William Koon, Robert W. Brander, Gregory Dusek, Bruno Castelle, and Jasmin C. Lawes. Relationships between the tide and fatal drowning at surf beaches in new south wales, australia: Implications for coastal safety management and practice. *Ocean & Coastal Management*, 238:106584, 2023.

[42] William Koon, Ali Rowhani-Rahbar, and Linda Quan. Do wave heights and water levels increase ocean lifeguard rescues? *American Journal of Emergency Medicine*, 36:1195–1201, 2017.

[43] William Koon, Andrew Schmidt, Ana Catarina Queiroga, Justin Sempsrott, David Szpilman, Jonathon Webber, and Robert Brander. Need for consistent beach lifeguard data collection: Results from an international survey. *Injury Prevention*, 27(4):308 – 315, 2021.

[44] Zhiqiang Li. Rip current hazards in south china headland beaches. *Ocean & Coastal Management*, 121:23–32, 2016.

[45] Y. Liu and C.H. Wu. Drowning incidents and conditions due to hidden flash rips in lake michigan. *Science of the Total Environment*, 827, 2022.

[46] J. H. MacMahan, E. B. Thornton, and A. J. H. M. Reniers. Rip current review. *Coast. Eng.*, 53:191–208, 2006.

[47] J. H. MacMahan, E. B. Thornton, T. P. Stanton, and A. J. H. M. Reniers. RIPEX-observations of a rip current system. *Mar. Geol.*, 218:113–134, 2005.

[48] Batta Mahesh. Machine learning algorithms-a review. *International Journal of Science and Research*, 9:381–386, 2020.

[49] AE Peden, HM Mason, JC King, and RC Franklin. Examining the relationship between heatwaves and fatal drowning: a case study from queensland, australia. *Injury Prevention*, in press.

[50] J.A. Puleo, K. Hutschenreuter, P. Cowan, W. Carey, M. Arford-Granholm, and K.K. McKenna. Delaware surf zone injuries and associated environmental conditions. *Nat. Hazards*, 81(2):845–867, 2016.

[51] L.A. Robbles. Cervical spine injuries in ocean bathers: wave-related accidents. *Neurosurgery*, 58:920–923, 2006.

[52] Tim Scott, Gerd Masselink, Martin J Austin, and Paul Russell. Controls on macrotidal rip current circulation and hazard. *Geomorphology*, 214:198–215, 2014.

[53] Tim Scott, Gerd Masselink, Christopher Stokes, Tim Poate, Adam Wooler, and Steve Instance. A 15-year partnership between uk coastal scientists and the international beach lifeguard community. *Continental Shelf Research*, 241:104732, 2022.

[54] L.E. Segura, I. Arozarena, W. Koon, and A. Gutiérrez. Coastal drowning in costa rica: incident analysis and comparisons between costa rican nationals and foreigners. *Natural Hazards*, 110(2):1083–1095, 2022.

[55] Andrew Short and Robert Brander. *Beach Hazard and Risk Assessment*, pages 287–292. Springer Berlin Heidelberg, Berlin, Heidelberg, 2014.

[56] Andrew Short and Adam Weir. *Beach types, hazards and risk assessment.* 2018.

[57] Michael Siegrist and Heinz Gutscher. Flooding risks: A comparison of lay people's perceptions and expert's assessments in switzerland. *Risk Analysis*, 26(4):971 – 979, 2006.

[58] Lennart Sjöberg. The allegedly simple structure of experts' risk perception: An urban legend in risk research. *Science Technology and Human Values*, 27(4):443 – 459, 2002.

[59] Jonathon H. Stillman. Heat waves, the new normal: Summertime temperature extremes will impact animals, ecosystems, and human communities. *Physiology*, 34(2):86–100, 2019.

[60] Christopher Stokes, Gerhard Masselink, Matthew Revie, Timothy Scott, David Purves, and Thomas Walters. Application of multiple linear regression and bayesian belief network approaches to model life risk to beach users in the uk. *Ocean & Coast. Manage.*, 139:12 – 23, 2017.

[61] E. Tellier, B. Simonnet, C. Gil-Jardiné, M. Lerouge-Bailhache, B. Castelle, and R. Salmi. Predicting drowning from sea and weather forecasts: Development and validation of a model on surf beaches of southwestern france. *Injury Prevention*, 28(1):16–22, 2022.

[62] Niels West. *Beach Use and Behaviors*, pages 307–311. Springer International Publishing, 2019.

[63] G. Winter, A.R. van Dongeren, M.A. de Schipper, and J.S.M. van Thiel de Vries. Rip currents under obliquely incident wind waves and tidal longshore currents. *Coastal Engineering*, 89:106–119, 2014.

[64] Lynn Donelson Wright and Andrew D. Short. Morphodynamic variability of surf zones and beaches: A synthesis. *Marine Geology*, 56:93–118, 1984.