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Dominant processes that amplify the swell towards the coast: the Nazaré Canyon and the giant waves

Processos dominantes que amplificam as ondas em direção à costa: o Canhão da Nazaré e as ondas gigantes

Procesos dominantes que amplifican el oleaje hacia la costa: el Cañón de Nazaré y las olas gigantes

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Abstract

The Iberian Atlantic coast is typically featured by incisions that deeply affect the continental shelf, commonly known as submarine canyons. Among the submarine canyons located off the Portuguese Atlantic coast are the canyons of Porto, Aveiro, Nazaré and Lisboa-Setúbal, being of note the canyons of Nazaré and Lisboa-Setúbal for their dimensions, characteristics and dynamics. Nazaré is a small city located about 100 km north of Lisboa, known worldwide for the occurrence of recently surfed giant waves. The Nazaré Canyon is one of the largest submarine canyons in Europe. It is about 225 km long and 5000 m maximum depth, with several steep slopes. The present work aims to contribute to the general understanding of the canyon systems dynamics throughout the Portuguese Atlantic coast. The Nazaré Canyon and its giant swell are discussed. A brief description of the most recent giant waves surfed and listed in the Guinness book is also provided.

Keywords: Portuguese atlantic margin; Submarine canyons; Nazaré Canyon; Giant waves.

Resumo

A costa atlântica ibérica é tipicamente caracterizada por incisões que afectam profundamente a plataforma continental, vulgarmente conhecidas por canhões submarinos. Entre os canhões submarinos localizados ao largo da costa atlântica portuguesa encontram-se os canhões do Porto, Aveiro, Nazaré e Lisboa-Setúbal, destacando-se os canhões da Nazaré e Lisboa-Setúbal pelas suas dimensões, características e dinâmica. A Nazaré é uma pequena cidade localizada a cerca de 100 km a norte de Lisboa, conhecida mundialmente pela ocorrência de ondas gigantes recentemente surfadas. O Canhão da Nazaré é um dos maiores canhões submarinos da Europa. Tem cerca de 225 km de comprimento e 5000 m de profundidade máxima, com vários declives acentuados. O presente trabalho visa contribuir para a compreensão geral da dinâmica dos sistemas de canhões ao longo da costa atlântica portuguesa. É discutido o Canhão da Nazaré e o seu *swell* gigante. Por fim, é feita uma breve descrição das ondas gigantes mais recentemente surfadas e listadas no livro do Guinness.

Palavras-chave: Margem atlântica portuguesa; Canhões submarinos; Canhão da Nazaré; Ondas gigantes.

Resumen

La costa atlántica ibérica se caracteriza típicamente por incisiones que afectan profundamente la plataforma continental, comúnmente conocidas como cañones submarinos. Entre los cañones submarinos situados frente a la costa atlántica portuguesa se encuentran los cañones de Porto, Aveiro, Nazaré y Lisboa-Setúbal, destacando por sus dimensiones, características y dinámica los cañones de Nazaré y Lisboa-Setúbal. Nazaré es una pequeña ciudad situada a unos 100 km al norte de Lisboa, conocida mundialmente por la aparición de olas gigantes recientemente surfeadas. El Cañón de Nazaré es uno de los cañones submarinos más grandes de Europa. Tiene unos 225 km de largo y 5000 m de profundidad máxima, con varias pendientes pronunciadas. El presente trabajo tiene como objetivo contribuir a la comprensión general de la dinámica de los sistemas de cañones a lo largo de la costa atlántica portuguesa. Se habla del Cañón de Nazaré y sus olas gigantes. También se proporciona una breve descripción de las olas gigantes surfeadas más recientes y que figuran en el libro Guinness.

Palabras clave: Margen atlántico portugués; Cañones submarinos; Cañón de Nazaré; Olas gigantes.

1. Introduction

Submarine canyons are areas of increased exchanges between continental and oceanic domains. They are ubiquitous worldwide features of continental margins that display a large variety of lengths, widths, heights, shapes, and morphological complexities (Canals et al., 2004). The largest canyons are classically 1000 - 1500 m deep, 20 - 50 km wide and several tens of kilometers long (Normark and Carlson, 2003). Their location, morphology and spacing are controlled by a combination of geological structure (e.g. faults), seafloor type (rocky or soft sediments), topography, slope, angle and hydrodynamics (Weaver and Canals, 2003).

A significant number of 5849 separate large submarine canyons in the world oceans have been identified by Harris and Baker (2011). More pronounced continental margins are reported to contain over 50% more canyons (3605) than slightly sloping margins (2244). Typically, the canyons in steeper continental margins are also shorter, more dendritic and more closely spaced. In the Mediterranean Sea alone, almost 518 large submarine canyons were identified, which can be considered key structures for its ecosystem functioning (Harris & Whiteway, 2011; Würtz, 2012).

It should be noted that, against a few clearly active canyons on the continental margins around the world, there are probably a much larger number of canyons that are presently virtually inactive, at least in terms of bulk sediment transport. For the European continental margins, the entire southern margin can be described as a “canyoned margin” showing a rough symmetry along a south-west-northeast axis extending across the Iberian Peninsula and France (Canals et al., 2004).

On the Western Portuguese margin, the canyons seem to have been predominantly controlled by the positions of river discharges, which would have been closer to the canyon heads during sea level low stands. This is still evident nowadays in the case of the Lisboa-Setúbal Canyon and, in the past, the canyons of Porto and Aveiro would also have been a possibility.

This paper has two main goals: to demonstrate the main characteristics and specificities of the Nazaré Canyon unusual waves production; and to demonstrate the conditions and physical processes contributing to the development of giant waves in this canyon. Section 2 describes the Portuguese Atlantic coast in geological terms and wave climate. Section 3 is devoted to the sedimentary and hydrodynamic processes that take place around the Nazaré headland and canyon, leading to the development of giant waves. Physical aspects and analytical developments relevant to wave swelling are briefly developed in section 4. Section 5 addresses the main giant waves that occurred in Nazaré in the past decade. Finally, the key aspects focused throughout this article are identified and summarized in the Discussion and Conclusions section.

2. The Portuguese Atlantic Coast

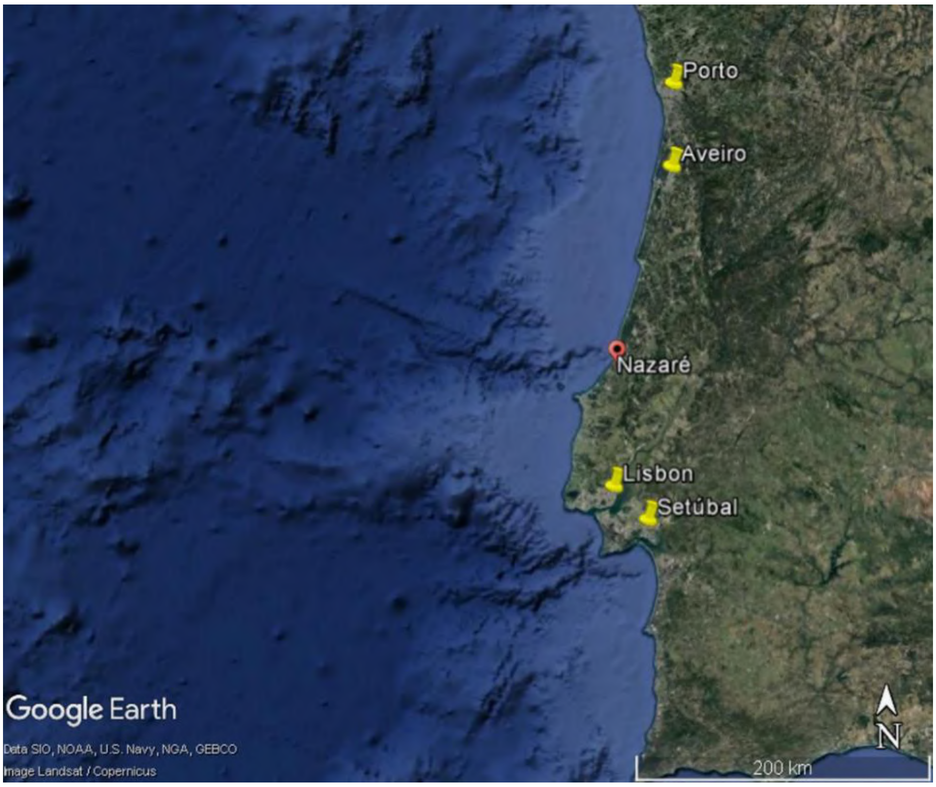
Portugal is a southern European country with a mild Mediterranean climate and is well known for its interannual climate variability. The mean annual precipitation on Portugal’s mainland is around 900 mm, with a very high degree of spatial variation. Its average surface temperature has increased by approximately 0.6ºC since the late 19th century, with 95% confidence limits of nearly 0.4 and 0.8ºC (Miranda et al., 2002; Gomes et al., 2018).

The circulation on the Portuguese continental shelf is strongly influenced by N-NW favorable-upwelling winds occurring during summer period, and S-SW favorable downwelling conditions during winter (Vitorino et al., 2002). The west coast is heavily affected by the extremely energetic climate of the Atlantic. Such conditions make the Portuguese coast particularly vulnerable, especially since two-thirds of the Portuguese population currently lives in areas less than 50 km from the coastline. Indeed, Portuguese coast typical winter wave conditions are swells from NW and SW with significant heights of 3-4 m, often exceeding 5 m during stormy periods, and such conditions can persist for up to 5 days. In winter significant wave heights of 9 m or more are achieved during storms (Rosa-Santos et al., 2009). Examples are the Rafael, Hercules, Stephanie and Joaquin storms, which occurred between 2012 and 2015 (NOAA, 2022; Santos et al., 2018). A history of the most important coastal storms in the vicinity of the Portuguese northwestern coast (years 1842–2016) is presented in Gomes et al. (2018) study.

Keeping in mind that climate is changing, with a significant increase in the number, intensity and size of storms that occurred from the 1930s in the North Atlantic Ocean and linear growth relevant from the mid-1990s (Antunes do Carmo, 2018), a significant increase in the current wave climate is likely to be felt to a greater degree in the near future, most strongly after the 2050s.

The Portuguese coastline is over than 700 km length in the Atlantic (Figure 1) and the continental margin has a relatively narrow shelf, which from a few km to tens of km offshore passes into a mostly steep and irregular slope (De Stigter et al., 2011). In its central part, located in less down 450 km, various canyons with conspicuous differences have been reported, particularly the Porto, Aveiro, Nazaré, and Lisboa-Setúbal Canyons. Figure 1 shows the Portuguese margin and its bottom signature offshore, between Porto and Sagres (the most southwestern part of mainland Portugal).

Figure 1. Bottom signature offshore Atlantic coast of Portugal, showing the onshore locations of the Porto, Aveiro, Nazaré, and Lisboa-Setúbal Canyons (the Nazaré canyon is marked differently because it is the main-focus of this study).



Source: Authors.

The Nazaré Canyon has a large dimension and a relatively low longitudinal slope, cutting across the entire shelf towards the littoral. Porto and Aveiro Canyons are shelf-break canyons classified as minor submarine valleys, since they cut the shelf-break away from the littoral processes (Guerreiro et al., 2009).

Therefore, from the hydrodynamic and energetic point of view, these two canyons do not have a major impact on the present coastal margin. On the contrary, other major canyons in the southern Portuguese Atlantic coast have higher energetic potential and attractiveness for nautical sports, of which surfing is remarkable, particularly the Nazaré Canyon.

According to De Stigter et al. (2011), the existing deep currents in the section between the the Nazaré and Lisboa-Setúbal canyons also have a relevant contribution to the flow dynamics between both canyons and to the dynamics of the canyons themselves.

Conspicuous differences have also been noticed for the major canyons of Nazaré and Lisboa-Setúbal, located less than 200 km from each other (see Figure 1). According to De Stigter et al. (2011), the major differences between these two canyons are:

- The Lisboa–Setúbal Canyon connects to the Tejo River, one of the major rivers of Europe in terms of drainage area and annual water discharge, whereas the Nazaré Canyon has no significant rivers in its direct vicinity.
- The bathymetric characteristics of Nazaré Canyon (valley configuration) provide more favorable conditions for giant waves development. The various bends of the canyon play a role, helping create a more complex scenario of refracting and converging waves.
- The Nazaré Canyon is more dynamic than Lisboa–Setúbal Canyon in terms of sedimentary regime.

3. The Nazaré Headland and the Canyon

Nazaré is a city located 100 km north of Lisboa, with a direction E-W cutting across the continental shelf almost to the beach whose morphology and geographical location allows it to capture (and eventually redistribute) the sedimentary particles derived from the continent (littoral drift and rivers input) (Cunha and Gouveia, 2015). This city is known for the occurrence of giant waves, which is an extremely popular place for surfing with wave heights that can reach more than 30 m.

The Nazaré headland divides the coast into two beaches: North Beach to the north and the Nazaré Beach to the south. The North Beach has a more energetic swell and extremely active dynamics, both in terms of curling and longshore drift of sediment (Cunha and Gouveia, 2015). To the south, the headland shelters the embayment inducing a less energetic wave regime at Nazaré Beach, where the sea currents are weak and do not exceed 0.20 m/s (Bosnic et al., 2014).

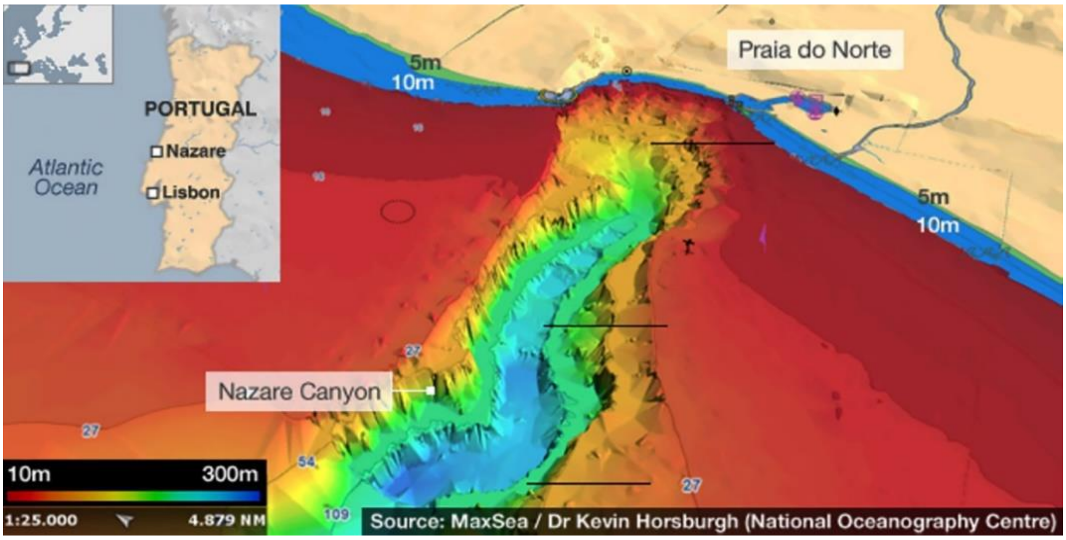
Another important feature of Nazaré headland is that it limits the net southward longshore sediment transport. As is clear from several studies along the Portuguese coast (e.g., Cunha and Dinis, 1998; Duarte-Santos et al., 2017), the sediments are transported from north to south, having an approximate value of $11x10^5$ m^3/year in the sector between Porto and Aveiro (Figure 1).

To the south of Aveiro there are littoral sediment losses to the Aveiro Canyon, periodic retentions by coastal structures and port interventions (dredging) that lead to intense coastal erosion (Santos et al., 2018; Antunes do Carmo, 2019). The available sediments are usually not enough to achieve sediment balance along the coast. In some periods it was possible to estimate the sediment transport in a certain stretch; e.g., at the Figueira da Foz beach, halfway between Aveiro and Nazaré (see Figure 1), between 1987 and 1998, when the average sediment transport was estimated as $5x10^5$ m^3/year (Cunha and Dinis, 1998).

So, towards south of Figueira da Foz, if the littoral sediment starvation could be compensated by sediment gains resulting from coastal erosion, an amount of sediment of about $10\text{-}11x10^5$ m^3/year could arrive at north of the Nazaré headland (Duarte-Santos et al., 2017). By action of the headland and adjacent submarine canyon, this value is mainly lost to the abyssal plain, resulting in a small sediment transport to the south, by littoral drift. For this reason, the Nazaré beach is currently maintained at the expense of artificial feedings, in amounts that reach about 28000 m^3 in a year (Pinto et al., 2018).

In this region, the dominant winds are from NW and SW quadrants, the later associated with atmospheric depressions. Given its orientation E-W, the headland interferes with the winds and has great influence on the dynamic conditions of the sea near the beach (Cunha and Gouveia, 2015). Off the *Praia do Norte* (from the Portuguese, meaning North Beach) coast, the near-shore wave propagation is significantly disturbed by the complex morphology of a special feature - the Nazaré Canyon; this is the biggest underwater valley in Europe (Figure 2) (Silva et al., 2013).

Figure 2. Bathymetry of the Nazaré Canyon and location of *Praia do Norte* (from the Portuguese North Beach).



Source: Authors.

The origin of this submarine canyon is still shrouded in mystery, because it belongs to a complex geological area. It is one of the largest submarine canyons of Europe. It extends about 225 km from a water depth of about 50 m at the continental shelf, just offshore, to about 5000 m at the edge of the Iberian Abyssal Plain westward from the Portuguese coast (Masson et al., 2011). Its morphology comprises steep slopes, scarps, terraces, and overhangs. A deeply incised thalweg is found in the lower part of the canyon. The seabed within the canyon is composed of varying proportions of rock and sediments that range from sand to fine mud (Tyler et al., 2009).

Another relevant aspect of the Nazaré Canyon is that the headboard is less than 1500 m offshore. What this does is not only focus extra swell (especially the longer period) into the region, but it also allows swells to greatly increase in size very close to the coast. From the headboard to the coastline, the seabed rises gradually to become shallow enough for the swell to break.

The Nazaré canyon can be divided into three parts based on its morphology. The upper part, which extends from the canyon head to the shelf break (50 – 2000 m water depth), is narrow and steep sided. The middle part extends from the shelf break to the point where the narrow canyon opens into a broad flat-floored channel on the lower slope (2000 – 4050 m water depth) (Masson et al., 2011). The lower canyon begins where the v-shaped valley abruptly broadens to a 3 km wide flat-bottomed channel at about a 4050 m water depth.

4. Material and Methods

For the swelling process of waves in canyons (as in the case of Nazaré) the phenomenon of refraction contributes a lot. In fact, the difference of depths between the continental shelf and the canyon change swell speed and direction. Fully non-linear hydrodynamic models have been used to propagate waves over canyons, as exemplified by the high-powered computer simulation carried out on the Nazaré canyon bathymetry shown in <https://youtu.be/NW8cYPQ46Fg>. However, these models are complex and require computational resources not always available/accessible.

A simple mathematical model that accounts for refraction, shoaling and breaking, although ignoring the lesser important phenomena such as diffraction and bottom friction, focus on wave rays, which are lines orthogonal to crests, or wave fronts, is the well-known Snell's law.

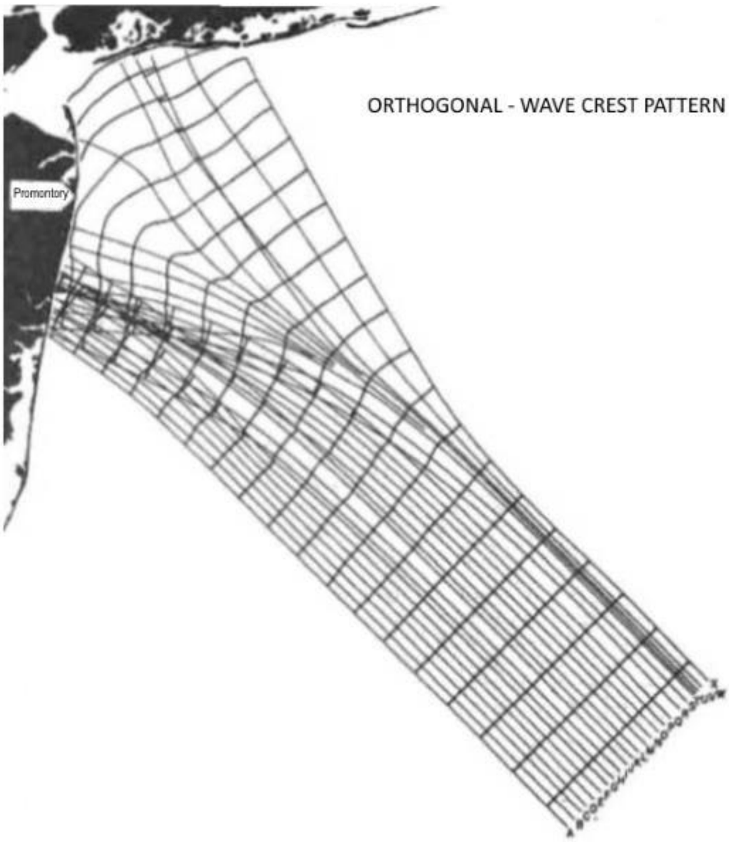
$$\frac{sen\ \alpha}{C} = \frac{sen\ \alpha_0}{C_0}$$

where, for a given incident wave ray path passing a contour line, C_0 and C are phase velocities before and after the wave passes the contour line, α_0 is the angle of incidence, i.e., the angle between the incident ray path and the perpendicular to the contour line, and α is the angle of the refracted ray with the perpendicular to the contour line. Taking both the shoaling $K_s = \sqrt{\frac{0.5\ C_0}{n\ C}}$ and refraction $K_r = \sqrt{\frac{cos\ \alpha_0}{cos\ \alpha}}$ coefficients into account, with $n = \frac{1}{2}\left(1 + \frac{2kh}{senh\ (2kh)}\right)$, where *k* is the wave number and *h* is the water depth, Snell's law allows obtaining the successive directions of wave propagation.

A methodology for applying this model can be found in Antunes do Carmo (2016). A similar procedure was applied to a specific case that takes place in Nazaré, where the occurrence of caustics (overlapping of wave rays) is shown schematically in Figure 3. As explained in Corps of Engineers (1951), the conditions found in Nazaré Canyon give rise to the formation of caustics, i.e., curves or surfaces to which each of the wave rays is tangent, defining a boundary of an envelope of wave rays as a curve of concentrated energy. This process may thus contribute to the wave crest amplification.

The caustic curve begins at a point somewhere near the point where orthogonally interacts and ends on the shore near a point of the last orthogonal which is crossed by an adjacent orthogonal.

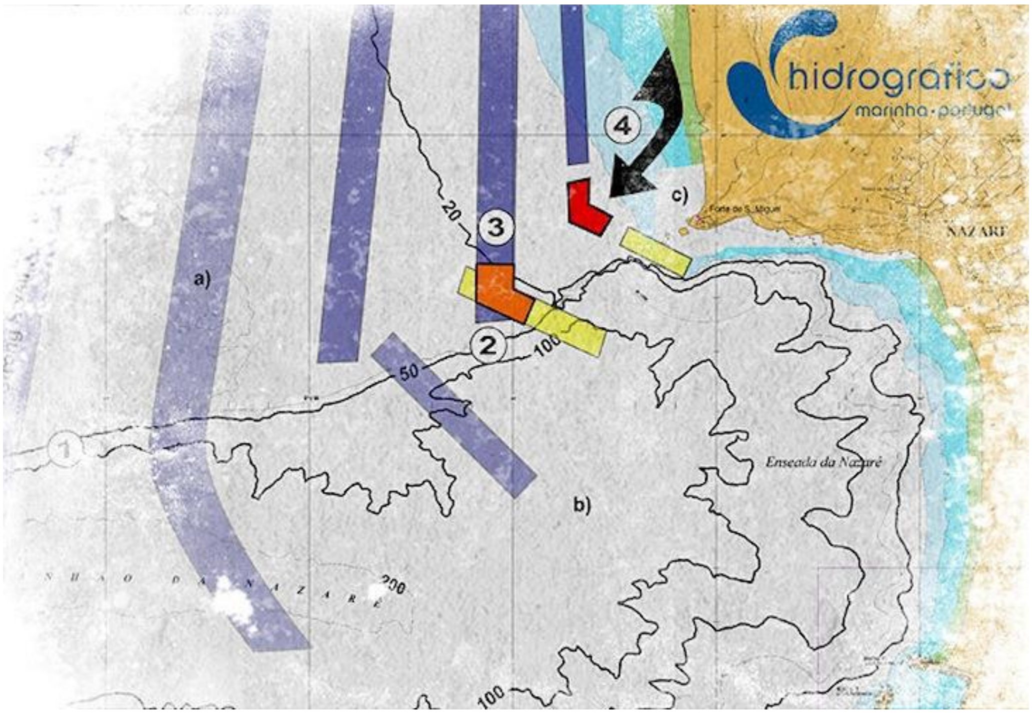
Figure 3. Concentrated energy due to the occurrence of caustics (overlapping of wave rays).



Source: Authors.

The sketch shown in Figure 4, by the Hydrographic Institute of the Portuguese Navy (Portuguese Hydrographic Institute, 2022), clearly identifies the converging wave: the wave from the canyon and the wave from the continental shelf meet and form a higher one.

Figure 4. Converging wave: the wave from the canyon and the wave from the continental shelf meet and form a higher one.



Source: Portuguese Hydrographic Institute (2022).

5. The Giant Waves

The waves form due to a unique combination of factors that help creating the giant swell. When a wave approaches the coast the significant reduction in the ocean depth leads to a decrease in wave propagation speed over the canyon, and a change of kinetic energy into potential energy occurs; i.e., the gradual loss of wave speed is offset by an increase in wave height. This physical process is known as swelling, thus leading to a giant wave.

Most of the west coast of Portugal experiences this wave swelling process, and there are numerous beaches that have become favorite places for surfing. However, this process is here amplified due to the presence and specific characteristics of the Nazaré Canyon and the location of the promontory. Currents through this canyon combine with swell driven by winds from further out in the Atlantic to create waves that propagate at different speeds. They converge as the canyon narrows and drive the swell directly towards the lighthouse that sits on the Nazaré promontory.

Giant waves result from a combination of several effects, such as strong winds, increased speed of the wave that travels in the canyon (channeling effect) followed by refraction, i.e., wave rotation and superposition to the big swells of the North Beach. Actually, the Nazaré Canyon can amplify 3 times the wave size presented by forecasts to the Nazaré zone - typically, wave period equal to or greater than 14 seconds and wave height above 4 meters.

Figure 5, acquired on October 29, 2020, with the Operational Land Imager (OLI) on Landsat 8, shows the huge amount of energy associated with the big-wave conditions. The offshore wave height on that day, measured more than 6 meters high, with a wave period of 17 seconds (Masek, 2022). In some winter storms, the waves off North Beach average about 15 meters (50 feet) high (NASA, Earth Observatory, 2022).

Figure 5. The huge amount of suspended sediment is revealing of the energy associated with big wave conditions on October 29, 2020.

Source: Operational Land Imager on Landsat 8, 2022.

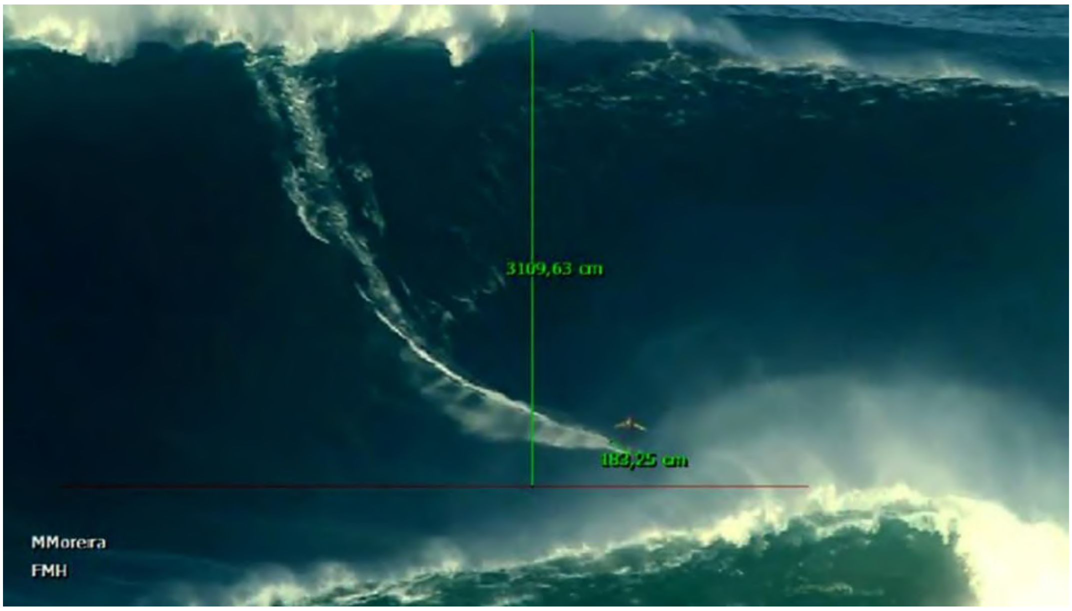
Furthermore, tidal conditions and a current channeled by the shore - from north to south - in the direction of the incoming waves also contribute to increasing wave height. Waves break when their height is approximately equal to the local water depth.

A giant wave has been surfed in 2011 and is registered in the Guinness World Records, 2012. The reason was not because this was an abnormal wave, but because it was the largest wave ever surfed until November 2011. This book registered Garrett McNamara's stunt as the official record: *"78-foot wave surfed by Garrett McNamara confirmed as largest ever ridden"* (Guinness World Records, 2012).

This record, set in 2011 off the coast of Nazaré, Portugal, was confirmed by a panel of experts at the annual Billabong XXL Global Big Wave Awards. In December 28th, 2013, McNamara broke his own world record by surfing an estimated 100-feet (30 m). He also surfed a wave of this size off the coast of Nazaré [Fletcher, in Mirror, 2013; Garrett McNamara, in WIKIPEDIA, 2022], but this record was not ratified.

Waves are measured by the height of their face, as shown in Figures 6-A and 6-B. Figure 6-A shows a 31 m high wave recorded on November 2011 (Guinness World Records, 2012), and Figure 6-B shows the highest wave of 34 m recorded on January 28, 2013 (The Two-Way, Portugal's Monster: The Mechanics of a Massive Wave, 2013).

Figure 6. Giant Wave Measurement: A - Highest wave recorded on November 2011 (31 m), on the same date that Garrett McNamara's record was confirmed at 78 feet (23.77 meters) by the Guinness Book of World Records (Guinness World Records, 2012); B - Highest wave that has already occurred in Nazaré, recorded on January 28, 2013 (34 m).



Source: Adapted from Guinness World Records (2012).

Source: Adapted from The Two-Way, Portugal's Monster: The Mechanics of a Massive Wave (2013).

Massive waves up to 30 meters (100 ft) in height regularly break along the Nazaré rocky coastline. Figure 7 shows a so-called 'monster wave' recorded in 2015 (Kaushik Patomary, 2015). This figure also shows the convergence of waves as they approach the headland/promontory.

Figure 7. A *'monster wave'* recorded at Nazaré, Portugal, in 2015.

Source: Photo credit: Jorge Santos/Flickr (Kaushik Patomary, 2015).

A new record was set by Brazilian Rodrigo Koxa on November 8, 2017, who surfed the biggest wave to that date ever surfed in Nazaré, with 80 feet (24.38 meters), narrowly surpassing Garret McNamara's 2011 record. At the time, he set the world record for the biggest wave ever surfed, listed in the Guinness Record (in Records and Brief history of Nazaré waves and WSL (Records and Brief history of Nazaré waves, 2022; WSL, 2018).

On April 28, 2018, at the World Surf League's Big Wave Awards, Koxa was awarded the Guinness World Record for the biggest wave ever surfed, whose wave was marked at 80 feet (24.38 meters) [Records and Brief history of Nazaré waves, 2022; WSL, 2018] (Figure 8-A).

Even more recently, in 2022, Sebastian Steudtner conquered new Guinness World Record in the category "*Largest wave surfed - unlimited (male)*", surpassing all previous records. The giant wave was surfed on October 29, 2020, measuring 86 feet in height (26.21 meters), after rigorous scientific measurement (Records and Brief history of Nazaré waves, 2022; Largest wave surfed (unlimited) – male, 2020. Figure 5 shows the amount of energy associated with the wave conditions on that day. Figure 8-B) shows the surfed wave.

In 2020, also Maya Gabeira achieved a new Guinness world record in the category of "*Largest wave surfed - unlimited (female)*", surpassing its previous record (of 2018). The giant wave was surfed on February 11, 2020, measuring 73.5 feet in height (22.4 meters), after rigorous scientific measurement (Records and Brief history of Nazaré waves, 2022).

All these waves occur under specific conditions; however, they are an indicator of the extremely energetic wave climate that characterizes the Portuguese Atlantic coast.

Figure 8. Guinness World Records: A - Biggest wave surfed by Rodrigo Koxa until 2017; B - Wave surfed in Nazaré, on October 29, 2020, by Sebastian Steudtner, a wave of 26.21 m.

Source: Records and Brief history of Nazaré waves (2022).

Source: *Photo credit:* Jorge Leal. Valter Leandro (2022).

6. Discussion and Conclusions

The Portuguese Atlantic coast is very exposed to a very energetic wave climate and is particularly vulnerable to climate variability. The Nazaré Canyon has particularly characteristics that distinguish it from the remaining canyons offshore the Portuguese Atlantic coast. The waves form due to a unique combination of various factors and physical processes that help creating the giant waves. The headland and canyon characteristics are described, and the main physical processes are addressed and detailed in this work. The five physical processes are as follows:

- Swelling effects resulting from the wave propagating in a successively narrower and shallower channel;
- Refraction effects, curving the wave crest from deeper zones (higher propagation speed) to shallower zones;

- Caustics formation concentrating energy due to wave rays overlapping, increasing consequently the wave crest;
- Current channeled by the shore in the direction of the incoming waves;
- Tidal conditions are also decisive to define the zones and the breaking wave characteristics.

Changes in the frequency or intensity of extreme weather, and climate events, are likely to have notable effects on an energetic environment such as the Portuguese northwestern coast (Gomes et al., 2018; Santos et al., 2018). Even because on the Portuguese Atlantic coast we can find several deep incisions on the continental shelf, with steep rocky sides giving rise to successively narrower canyons that channel energy and increase the waves towards the coast.

In the most vulnerable sector, between Porto and Nazaré, waves five meters high or more often occur. In winter, storms could present waves nine meters high or even higher.

A number of empirical and modeling studies have found an increase in Atlantic storminess in recent decades, possibly reflecting current climate change. A very significant linear growth increase in the number of storms since the mid-1990s has been found in the North Atlantic Ocean (Antunes do Carmo, 2018). In-depth analyses of long-term instrumental data for the Iberian Atlantic coast have also revealed increasing trends of about 1-2% per year at significant wave heights.

Climate change will aggravate coastal erosion even more; rising sea levels, increased storminess, changes in prevalent wind directions and higher waves will place Portuguese's coast under additional pressure. This panorama will lead to losses of territory and will be reflected on the behavior of the Nazaré Canyon, possibly contributing to an even more pronounced increase in the waves currently produced.

Regarding giant waves, further studies should be carried out with the following guidelines in mind:

- Assess the relative influence of each of the processes that contribute to the formation of giant waves;
- Assess the influence of ongoing climate change (especially the rising sea level) on the behavior of the physical processes most contributing to the current characteristics and dimensions of giant waves.

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