WSL Big Wave Awards 2020 – Wave Height Estimation and Comparisons

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Executive Summary

In an effort to formalize the methods by which wave heights are determined for the WSL XXL events, researchers at the World Surf League's WaveCo are collaborating with researchers at the Scripps Institution of Oceanography, University of California, San Diego in La Jolla and the University of Southern California, Department of Aerospace and Mechanical Engineering in Los Angeles. The first phase of this collaboration has involved bringing some basic scientific methods of image analysis to help discern the winner of the 2020 Women's XXL event.

1. Introduction

This document details our efforts to help decide the winner of the 2020 WSL Big Wave Awards. There were two candidates, Justine Dupont and Maya Gabeira. Both candidates surfed waves at Nazaré, Portugal on 02/11/2020, within a 2.5-hour time span. The objective is to determine which of the two candidates surfed the bigger wave. The analysis is based solely on video and photo imagery provided by the World Surf League. The video and photo data sets are limited and incomplete, this makes the process of estimating wave height quite challenging. Additionally, the waves will be compared to the current Woman's World Record Wave and an approximation of the nominal wave height will be made.

2. Environmental Conditions and Available Data

2.1. Tides

In the tide chart (Figure 1), one can see that the first high tide was at 3:52 AM and the next high tide at 4:18 PM. The first low tide was at 10:07 AM and the next low tide at 10:21PM. The tidal wave progression presented in Figure 1 yields 3.6m max. amplitude over the entire day. Based on the documented times of the two candidate waves, 9:36 AM and 11:59 AM, we do not believe that the level of the tide (0.4 m difference) could significantly affect the analysis presented here.

2.2. Sunlight

On Tuesday, 11th of February of 2020, the sun rose in Nazaré at 7:33 AM and sunset was at 6:08 PM. Lighting conditions for the different imagery is primarily influenced by the location of the photographer but, the images from the earlier wave at 9:36 AM, show, as expected, higher contrast due to the lower angle of the sun.

2.3. Wave set-up

Potential effects of the wave set-up phenomenon on accuracy of the wave height estimates using the available video data were carefully considered (i.e. local increase and tilt of mean water level in the surf zone due to wave-induced momentum flux). Given the enormous momentum transfer to the surf zone, the wave set-up at Nazaré can be significantly higher than usual. This wave set-up can change between the first and last wave in a set and is influenced by the nature of the coast, be it cliff or beach. It was decided that any effort to include estimates of the instantaneous wave setup based on the available date would not be beneficial to the objectives of this study.

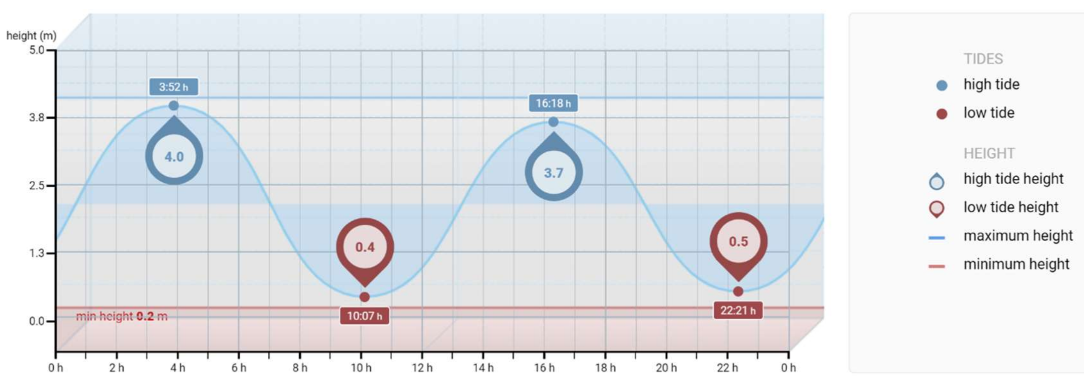

Figure 1: 24-hour tide chart for Nazaré, 02/11/2020.

Time of wave:	Surfer:	Tide height:	Type of tide:
9:36 AM	Maya Gabeira	+0.5m	Ebb tide
11:59 AM	Justine Dupont	+0.9m	Flood tide

Table 1: Tidal conditions summary for the considered waves.

2.4. Available Video and Photographic Data

Video and photographic imagery was provided by the WSL. The data included several different camera angles and camera types, including some drone footage and that from jet-ski mounted cameras. The meta-data available on some of the provided images allowed for determination of some details of the photographic equipment. A site plan indicating some of the camera locations and the believed location of the breaking waves, is shown in Figure 2. Using tide information and image rectification techniques presented in the Methodology section we estimated that the waves were breaking at the zone designated by the WSL in Figure 2 as *Outside Peak 1.*

Source: WSL

Figure 2. Site plan showing the location of the land-based cameras. The cameras are Panasonics with Fujinon 105x lenses.

3. Methodology

All analysis was based on the provided image data. The collinearity equations were used to transform the image coordinates into real-world coordinates based on estimates of the geometric parameters that could be deciphered from the available data.

Firstly, it was important to determine any fixed/constant reference objects present in video/photo data for the contending waves. We started off with the surfers' heights, board dimensions and then estimated their crouching heights (the accuracy of the latter parameter still needs to be refined).

	Surfer's height:	Surfboard length:	Est. surfer's crouching height:
Justine Dupont:	5'11"	6'	4'2"
Maya Gabeira:	5'7"	6'	4'1"

Table 2 : Summary of significant surfers' dimensions used in the analysis.

After reviewing the available data sets, it turned out that the tow-in jet-skis present in some of the videos, might constitute helpful reference objects and improve the accuracy of measurements that were initially based solely on the surfers' dimensions. The make and model of the Jet-skis was determined by reviewing the available footage and we assumed that no significant modifications to the skis were made, see Figures 3 and 4. The length of the Tow-in rope was also considered as a candidate, but further investigation led us to believe that the ropes are elastic and designed to stretch, so as to sling-shot the surfer into the wave. This elastic property makes them unsuitable for use as a measuring stick. A particularly useful dimension was the distance from the front of the ski to the back of the seat. This was consistently visible despite the white water conditions.

	Length:	Width:	Height:
Yamaha FX class Waverunner (2015-2019)	140.9"	50"	48.4"
Yamaha VX class Waverunner	131.9"	48"	46.9"

Table 3 : Jet-ski overall dimensions.

Figure 3: Example jet-ski profile, Yamaha FX class Waverunner dimensions. *Source: Yamaha.*

Figure 4: Typical image taken from video showing jet-ski in profile. The ski turns out to be the most reliable measuring stick in the available data.

With the intent of providing uniformity within the considered fields of view, we grouped the photo data sets based on camera deployment locations and lens parameters/settings, see Table 4. Images taken from farther away with higher magnification were deemed more useful as the perspective errors are limited.

	Canon EOS-1D X Mark II (D. Poullenot)	Sony ILCE-7M3 (H. Antonio)
Focal length [mm]:	400	200
Orig. photo dimensions [px]:	5145 : 3430	5483 : 3655
Resolution [dpi]:	300 : 300	300 : 300
Horizontal viewing angle [deg]:	5°10’	-
Vertical viewing angle [deg]:	3°30’	-
Diagonal viewing angle [deg]:	6°10’	-

Table 4: Camera lens parameter, summary for the most consistent photo-data sets used for mutual comparison of the waves.

Basic geometrical relations were used to provide a preliminary comparative wave height estimates for the considered cases, see Figure 5. The method allowed for estimating the distances between the cameras and the wave breaking and indicated that both waves broke at very similar locations in the horizontal plane. Please note that for some of the cases the image corrections do not include adjustments for 3D water surface that also cause image distortion.

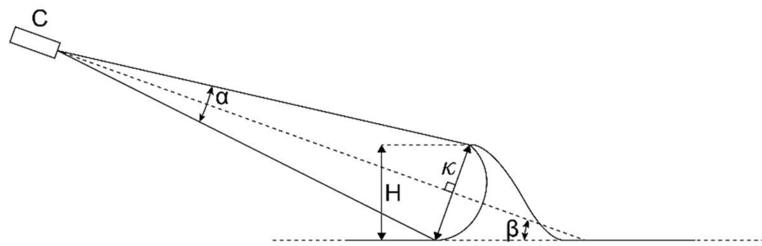

Figure 5: Simplified scheme for apparent vs. real wave height correction method using known camera lens parameters. *C* denotes the camera deployment location, α is the adjusted vertical viewing angle, β is the camera tilt angle, *K* is the apparent wave height and *H* is the wave height.

We were able to calculate the distance D, from Mr. Poullenot to the surfers, using the following relation:

$$D = tan^{-1}\left(\frac{\alpha \cdot Z_{px.ref}}{Z_{px.tot}}\right) \cdot Z_{ref}$$

where:

α	camera viewing angle
$Z_{px.ref}$	vertical dimension of a reference object in [px]
$Z_{px.tot}$	total vertical photo dimension in [px]
Z_{ref}	real vertical dimension of a reference object

At an instant where the photos presented in Figure 6 were taken, the distance D is approximately 585m for Gabeira and 574m for Dupont. This estimate is in line with the map of the observed outside peaks zones provided by the WSL, Figure 2.

Consecutively, knowing the camera elevation Z_c (height of the cliff), the camera tilt angle β was determined from:

$$\beta = sin^{-1}\left(\frac{Z_c}{D}\right)$$

We estimated β to be approx. 10.7deg.

The internal camera parameters (such as the aspect ratio, the optical center, the distortion coefficients and the effective focal length f) are sometimes known. We were able to estimate the camera position and orientation: X_0, Y_0, Z_0 (Z_0- positive upwards), tilt, β, swing, s, and azimuth, γ, by effectively combining the external and the internal camera calibration parameters. These parameters were used at a later stage to convert the acquired video data images from its "flat" form in [px] to a 3D representation of the wave with its height given in units of length. The conversion process involved the collinearity equations Eq.(1) and Eq.(2), see below:

$$X = (Z - Z_0)Q + X_0 \qquad (1)$$

$$Y = (Z - Z_0)P + Y_0 \qquad (2)$$

where

$$Q = \frac{(m_{11}x + m_{21}y - m_{31}f)}{(m_{13}x + m_{23}y - m_{33}f)} \tag{3}$$

and

$$P = \frac{(m_{12}x + m_{22}y - m_{32}f)}{(m_{13}x + m_{23}y - m_{33}f)} \tag{4}$$

where m_{ij} are the elements of the 3x3 camera transform matrix, M:

$$M = \begin{bmatrix} cos(\gamma) & sin(\gamma) & 0 \\ sin(\gamma) & cos(\gamma) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos(\beta) & -sin(\beta) \\ 0 & sin(\beta) & cos(\beta) \end{bmatrix} \begin{bmatrix} -cos(s) & -sin(s) & 0 \\ -sin(s) & cos(s) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5}$$

4. 2020 Big Wave Awards Wave Comparison

In order to determine which of the two candidate waves from the 2020 Nazaré session were bigger, photos from the available data set were located that were taken with the same fixed focal length lens (400 mm), from the same location, by the same photographer. These were chosen as they were believed to be the best assets to use for the comparison. The surfer's silhouettes were overlapped in a single shot (see Figure 6) and carefully inspected pixel-by-pixel. Both surfers are comparable in size, confirming, based on the knowledge of having the same camera lens and photographers location, that the waves are breaking at approximately similar distances from the photographer.

Figure 6: Nazare 2020. Overlapped photos of the surfers silhouettes using the same setting and location.
Data source: Canon EOS (D. Poullenot)

After the mutual validation of the reference points presented in Figure 6, the original full-size photos of both waves were adjusted for slightly differing tilt angles and juxtaposed side-by-side, see Figure 7. The red and yellow lines indicate the determined locations of the crest and trough respectively.

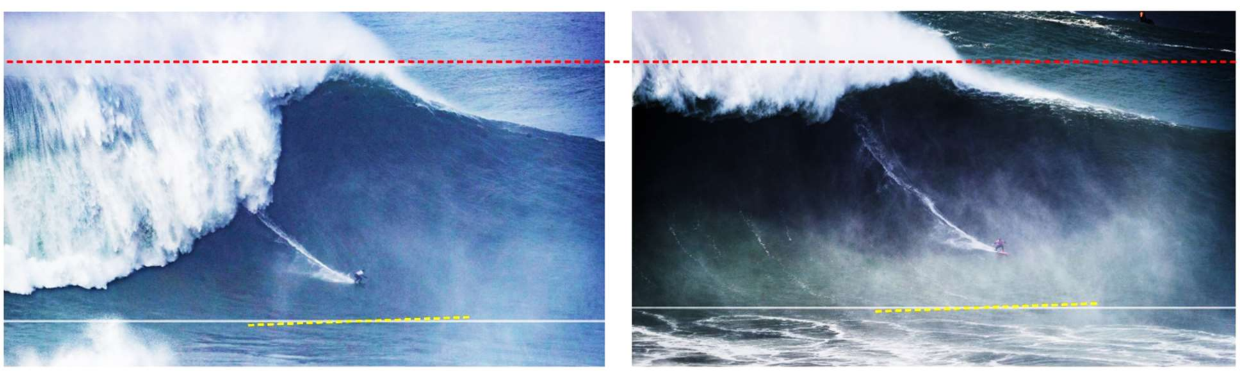

Figure 7: Nazare 2020. Side-by-side wave photo comparison. (LEFT): Maya Gabeira, (RIGHT): Justine Dupont.
Data source: Canon EOS (D. Poullenot)

The difficulty in comparing these two waves comes down to identifying both the crest and the trough of each wave in the images. The location of the crest can be validated by careful examination of the various video streams that show its time progression. The trough is harder to identify, but by comparing video footage from the jet-ski that shows the wave in profile, see Figure 8 below, it is possible to improve ones estimate of the trough location in the frontal images. This procedure allowed improved confidence in the trough locations identified in the above figure.

Figure 8: Nazare 2020. Profile view. (LEFT): Gabeira. Data source a.4: MGaberiaNazFeb11Pujol.mp4. (RIGHT): Dupont. Data source b.4: 1B_RW20Nom_JDupontNazFeb11Pujol.mp4.

The waves presented in Figure 7 are of very comparable in height but as can be seen from the indicated locations of the trough, the wave on the left is slightly larger. Additionally, it seems that the surfer in the left image dropped in closer to the wave peak. The photo on the left (Figure 7), was taken at a later stage of wave breaking – theoretically, a shoaling plunging breaker reaches its maximum height right before its lip starts dropping down, thus, this wave could have been even bigger at its maximum than at the instant presented in Figure 7. **At this preliminary stage of the analysis, it was concluded that Maya surfed a bigger wave than Justine. In the next section we quantify the height of these two waves.**

5. Quantification of Wave Height

In order to get an estimate for the height of the two candidate waves, it was decided to use a statistical approach where several images would be selected from the different video streams, the methods of section 3 would be applied and the results averaged.

Figures (9 – 12) and (13 – 16) present snapshots from the analysis of the available video/photo-data sources for Maya Gabeira and Justine Dupont, respectively. Red lines in the figures denote the identified wave crests and yellow lines denote the approximate wave trough locations. The data sources were designated using the original file names provided. In most cases, jet-skis were used as the measuring stick due to their more reliable length representations. As best as the geometric parameters could be determined, the methods of section 3 were applied to the available images.

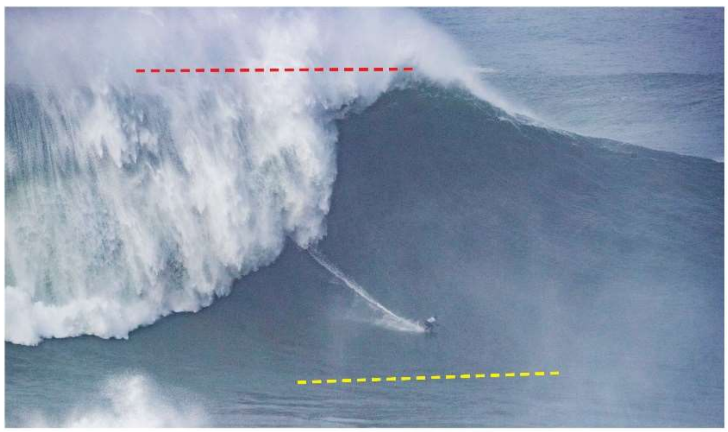

Figure 9: Gabeira 2020, data source a.1, *"3C_XW20_MGabeiraNazFeb11Poullenot.jpg"*.

Figure 10: Gabeira 2020, data source a.2, *"3_XW20Nom_MGabeiraNazFeb11Miranda.mp4".*

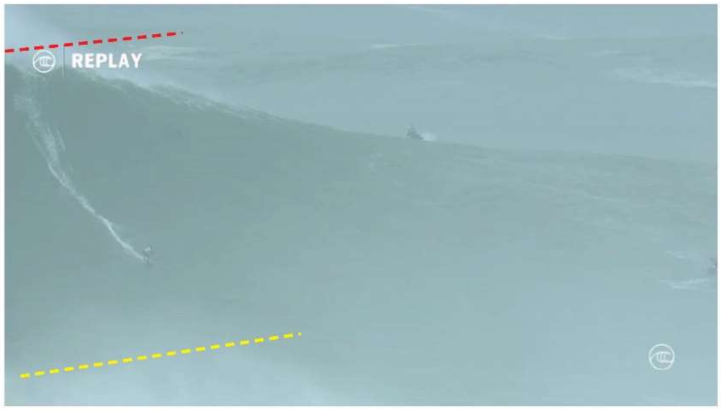

Figure 11: Gabeira 2020, data source a.3 (broadcast video), *"NAZ19_021120_DIRTY_H1.mp4".*

Figure 12: Gabeira 2020, data source a.4, *"MGaberiaNazFeb11Pujol.mp4".*

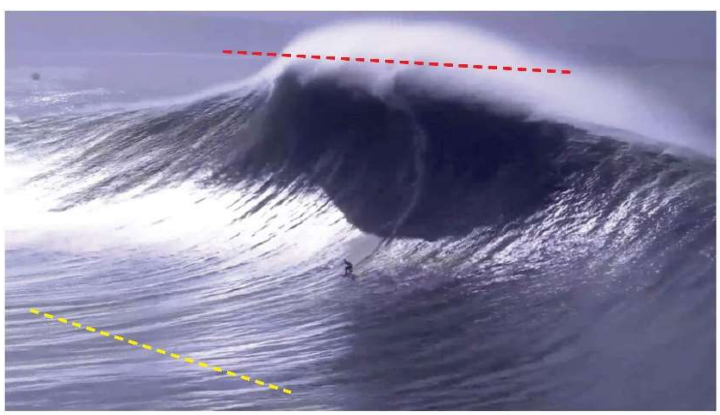

Figure 13: Dupont 2020, data source b.1, *"JDupontNazFeb11AllAngles.mp4".*

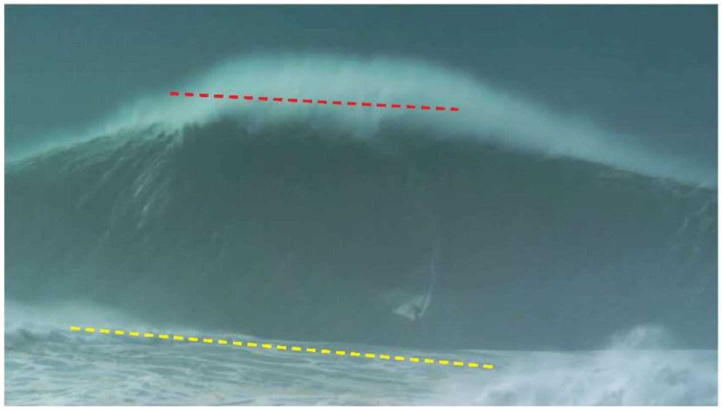

Figure 14: Dupont 2020, data source b.2, *"2_XW20Nom_JDupontNazFeb11Chicoye.mp4".*

Figure 15: Dupont 2020, data source b.3, *"Dupont-j0344Nazare20Poullenot.jpg".*

Figure 16: Dupont 2020, data source b.4, *"1B_RW20Nom_JDupontNazFeb11Pujol.mp4".*

Figure 17 below shows the quantitative data extracted from the above 8 images. The data indicates that the wave Maya Gabeira rode is approximately 2-3 ft larger than that of Justine Dupont. Conservatively, the height of this wave is estimated at 73.5 ft from trough to crest.

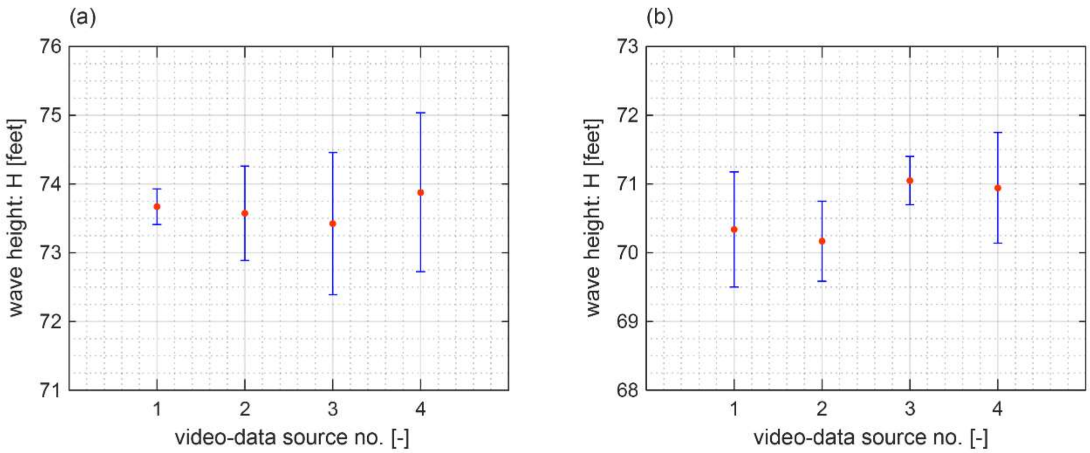

Figure 17: Nazaré 2020 – quantitative wave height estimate using multiple video-data sources. (a): Maya Gabeira, (b): Justine Dupont.

The error bar ranges for the estimated wave heights presented in Figure 17 were established based on video quality, video resolution and uncertainties related to perspective strength, dull lighting etc. Although there are likely other sources of error, the fact that the same procedure was applied to the two waves in question, reaffirms that despite the possibility that numerical values determined for the wave heights could be off, Maya's wave is once again determined to be larger.

6. New World Record?

Yes! The current Women's World Record held by Maya Gabeira is 68 ft and was surfed at the same location in Nazaré in 2018. The quantitative estimates we made indicate that the new WR should be approximately 73 ft.

The WSL provided footage of the 2018 wave allowing for a comparison. An effort to compare these two waves was made. The available data sets were from two different sources. A video frame from 2018 was carefully selected to provide a comparative representation of the wave (at a very similar phase of breaking). Efforts to compare them involved matching the framing (zoom level), this was modified to match the surfer's size as a reference object, see Figure 18.

Figure 18: Overlapped photos of Maya Gabeira, Nazaré. (WHITE wetsuit): current WR 2018, (BLACK wetsuit): the 2020 ride.

Figure 19: Nazare, Maya Gabeira. Side-by-side wave photo comparison.
(LEFT): current WR from 2018, video-frame source WSL. (RIGHT): the 2020 ride, photo source Canon EOS D. Poullenot.

The framing was then panned vertically to match the position of the wave crests see Figure 19. Again – even though it's very challenging to determine the exact wave troughs locations from the limited data set – it appears that although these waves are very similar in size, the 2020 wave is slightly bigger. Another observation based on looking at the surfboards trace in the images, is that in the 2020 wave, Maya dropped into the wave closer to the wave peak (where the wave is taller), solidifying this new World Record.

7. Closing Remarks

Basic methods of image processing were successfully applied to the available image data to determine a winner for the 2020 Women's XXL competition. The results indicated a new world record for largest wave ridden by a woman. There was much learned in this process that should streamline similar analysis in the future.

Emerging remote sensing technologies, such as lidar and stereo cameras, provide new opportunities to map the three-dimensional ocean surface with unprecedented detail. These tools provide a method to more accurately quantify wave height and improve present methods (such as those used here), which are based on single frame photographs and expert judgment. Monitoring systems could range from permanent land-based sensors to rapidly deployed drone or boat-based systems. These systems have potential for near real time wave height output and could provide other wave parameters such as wave steepness and barrel size.

A proposal will be made to the WSL for the implementation of some of these more advanced methods for the 2021 season.