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Case Report

Swell Conditions at Potential Sites for the Colombian Antarctic Research Station

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Abstract: The objective of this paper was to characterize swell conditions in the coastal zone of the South Shetland Islands, where our preliminary analyses evaluated potential locations for the Colombian scientific station. The Simulating Waves Nearshore (SWAN) spectral model was implemented for the Bransfield Strait. The boundary conditions were selected by a cluster analysis of the wave climate from global hindcasting obtained with the WAVEWATCH III model. Some comparisons between the model and wavemeter measurements were made. The results demonstrated that optimal sea state conditions for the scientific base are present in the South Bay, Livingston Island.

Keywords: Antarctic Station; Bransfield Strait; South Shetland Islands; swell; wave model

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1. Introduction

The Republic of Colombia aims to be an advisory member of the Antarctic Treaty System. The Colombian expeditions, which started in 2014, were performed in the Gerlache Strait and on the South Shetland Islands with a wide oceanographic program [1]. One of the goals of these expeditions is to find a suitable site for a temporary Antarctic base to be initially active during the austral summer in the Southern Hemisphere.

The optimal location for the station should be defined by various criteria such as land relief, soil stability, easy access from the water, and costs of the scientific activities. Initially, these criteria were studied employing the Fuzzy TOPSIS algorithm [2]. The cited study focused on the South Shetland Islands in the Bransfield Strait (Figure 1) with possible locations along the Livingston and King George Islands and between the Robert and Greenwich Islands. Greater interest was given to South Bay (Livingston I).

An important consideration while choosing the optimal location is the meteorological and oceanographic conditions, particularly the sea state or wave climate. The latter may be estimated based on wave propagation from a hindcasting reanalysis of a global model system such as WAVEWATCH III [3]. This reanalysis provides decades of hourly resolved pseudo-data of the wave climate on the open boundaries of our numerical domain. The propagation within the area of interest, with a fine spatial resolution, gives the local swell conditions related to the high-energy waves coming from Drake's Passage. The objective of this paper was to characterize the swell conditions near the coasts of the islands where the preliminary analyses [2] evaluated the potential locations for the scientific station.

This paper is organized as follows. First, the methodology is presented in the next section. Some comparisons between the model and the available data are made, and boundary conditions on the open contours are determined. Then, Section 3 displays the results of the study, followed by a discussion in Section 4.

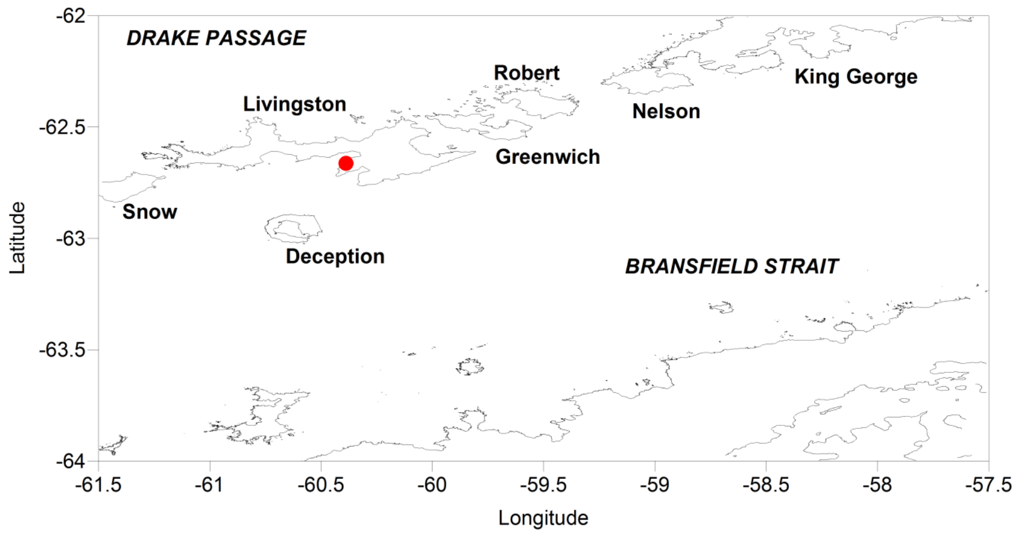


Figure 1. Study area and alternative locations for the Colombian Antarctic Scientific Station in the South Shetland Islands. The red point indicates the Juan Carlos I Base (Spain) in the South Bay, Livingston Island.

2. Materials and Methods

The model domain (Figure 2) was set to latitudes between 62° S and 64° S and longitudes between 57.5° W and 61.5° W to cover the locations 1–7 along the coasts of Livingston, King George, Robert, and Greenwich islands and to properly represent the spatial resolution of bathymetry and wave output from the spectral model.

The coastal lines were extracted from the *Antarctic Digital Database Map Viewer* (NSIDC, [4]), and the bottom relief was reproduced from GEBCO-0.5 [5]. In this way, the domain was covered with a mesh of 30-min arc bathymetric data, later interpolated to a numerical grid of 0.02° of latitude. Hence, the applied numerical grid had an approximate resolution of 1.01 km (latitude) by 2.23 km (longitude). Therefore, the computed grid was prepared for 201 × 101 nodes, and the SWAN spectral model [6] was implemented.

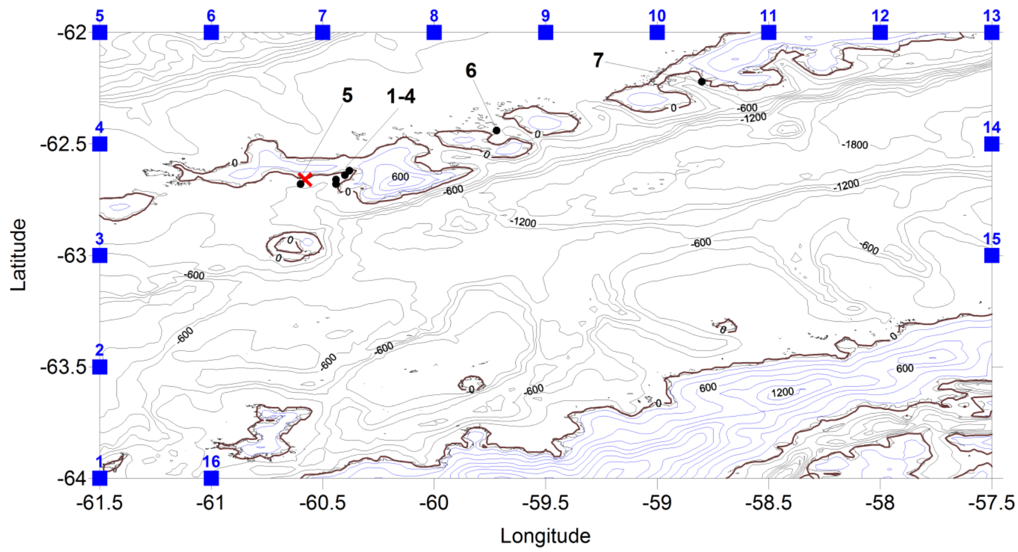


Figure 2. Bathymetry of the SWAN domain, obtained from [5], wave-meter position (x in red), WW-III open boundary nodes (1–16), and output model points (·) near alternate station locations (Figure 1).

The WAVEWATCH III (WW-III) wave reanalysis was used on the open boundaries of the model domain [3]. WW-III is a third-generation wave model developed by NOAA/NCEP [7–9] in the spirit of the WAM [10], and its global reanalysis with a resolution of 0.5° is available from February 2005 until the present. The earliest version of the WW-III hind-cast has pseudo-data starting from 1997 with a course resolution (1°) and it was thus not taken into account in our model. Therefore, the analysis period included only the WW-III model outputs from 2005 to 2018 with a time interval of three hours. The position of the WW-III nodes is illustrated in Figure 2. The reanalysis variables were significant wave height, spectral peak period, and direction during the months of the austral summer in the Southern Hemisphere (from November to February).

Wind information has not been included in this paper. The principal interest of this stage was swell conditions due to the poor knowledge of the local winds and the strong influence of the waves from the Drake Strait on the Bransfield Strait. Nevertheless, some additional considerations of wind sea and swell are included in Section 4.

The model configuration was as follows. The numerical scheme for the non-stationary mode was BSBT, whereas SORDUP was implemented for the stationary climate [11]. The bottom friction was defined by Collins [12], and depth-induced wave breaking and white-capping were set as the default [13]. The frequency range was specified between 0.04 and 0.5 Hz with 51 frequencies, and the spectral angular resolution was 3°. Finally, the width of the directional distribution of incident wave energy was set to 17.1°.

Figure 2 shows the position of the RBR_duo wavemeter employed during the period between 22 December 2018 and 13 January 2019 (62.66° S, 60.58° W) in "Wave" mode at 4 Hz at a depth of 4.7 m. Each burst had a length of 4096.

Figure 3 shows the comparison of wave height and the period between measured and modeled results during the aforementioned period of 23 days. The non-stationary model mode was used. Although the RBR instrument data calculated the significant wave period ($T_{1/3}$), the model results were analyzed with the peak period (T_p). There are several differences between these two periods; usually, $T_{1/3}$, calculated in the same way as $H_{1/3}$, should be 10–20% less than T_p, and this circumstance must be considered. However, there are two main considerations when understanding the greater differences between the model and the data. First, the simulated fields correspond to swell, and although sea waves may be important, the wind reanalysis (from the WW-III database) does not reflect the local winds and squalls observed by the expedition members. Second, the GEBCO-0.5 data grid is not fine enough to correctly reproduce the processes of shoaling and bottom friction.

The next methodological step was to define the wave climate characteristics (wave height, period, and direction) along the open boundaries (Figure 2). For this aim, the WW-III datasets were submitted for cluster analysis [14], classifying only two principal centroids.

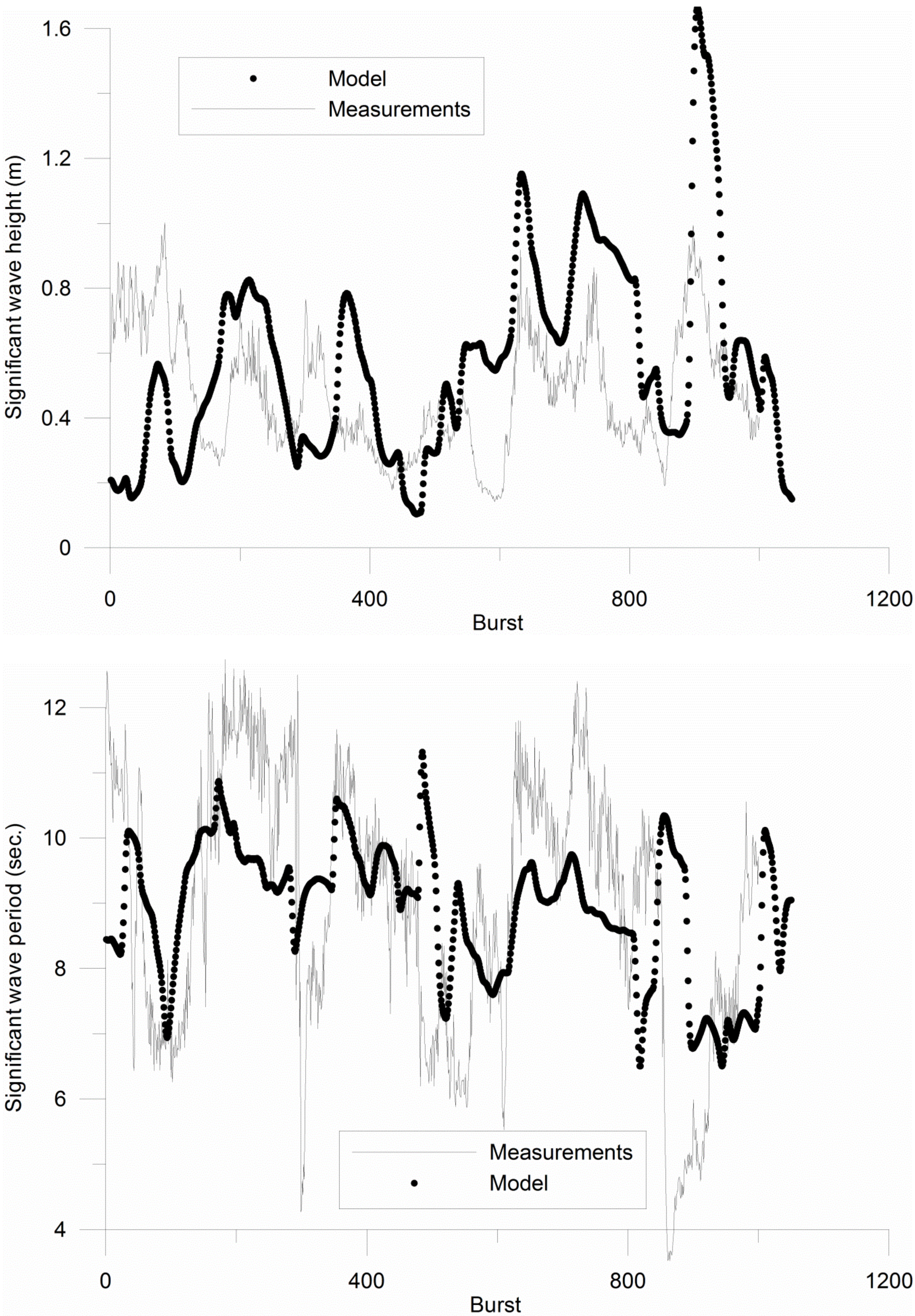


Figure 3. Significant wave height (**above**) and wave period (**below**), measured and calculated by the model. Burst interval: 30 min.

3. Results

Figure 4 shows some examples of the cluster analysis from the 16 boundary points (WW-III nodes), where one may observe two different directions of incident waves in the Bransfield Strait. The first pattern propagated from the NW (281–288°) with a significant wave height of 3.0–3.5 m and a peak period of 10.4–10.8 s, whereas the second one corresponded to a NE direction (58–69°), a wave height of 2.6–2.9 m, and a wave period of 8.7–8.9 s. It is clear that the energetically highest pattern was the NW swell from Drake's Passage. When clustering by only two directions, a bimodal opposite behavior (NW vs. NE patterns) appeared. However, by separately clustering the wave height–period space, we found two respective wave periods for each node in the model.

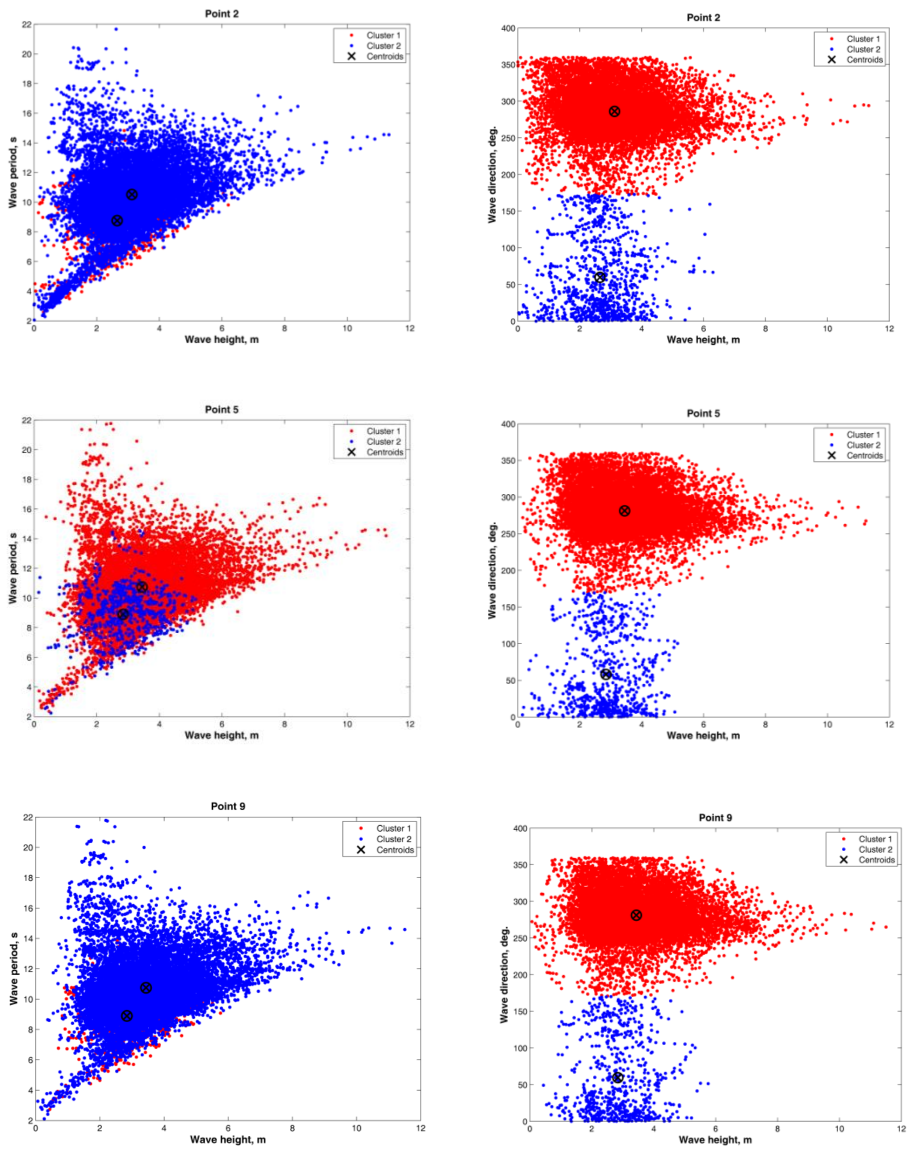


Figure 4. *Cont.*

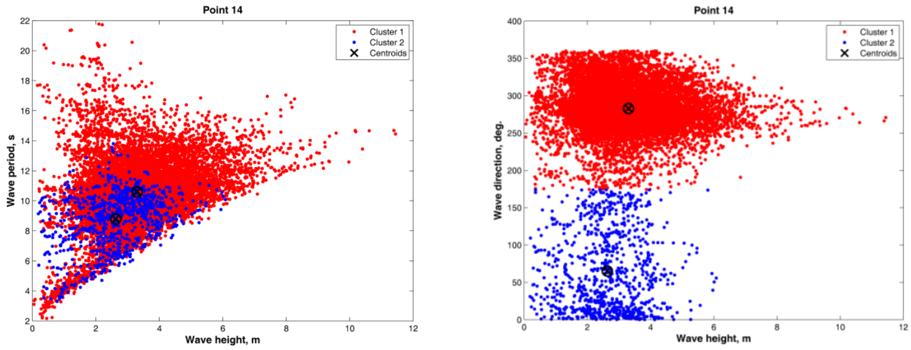


Figure 4. Cluster analysis of the wave height, peak period, and direction at the open boundary points 2, 5, 9, and 14 shown in Figure 2.

It was also observed that the austral summer period on the specified boundaries was characterized predominantly by long waves from the NW with periods of up to 22 s. In contrast, the waves propagated from the NE direction were limited to 12–14 s. Furthermore, the respective ranges of the significant wave heights exceeded 10 m (NW) or were between 4 and 6 m (NE).

Figure 5 compares the NW pattern versus the NE pattern's significant wave height corresponding to swell propagation in the stationary mode from the open boundaries of the model. The relationship between wave height (H_s) and wavelength (λ), referred to as wave steepness (H_s/λ), is demonstrated in Figure 6 since it is a good energetic characteristic of wave fields. Moreover, the directions of the incident waves for each pattern are presented in Figure 7. Herein, the mean wavelength λ was defined as a first-order inverse wavenumber weighted by the 2D energy spectrum.

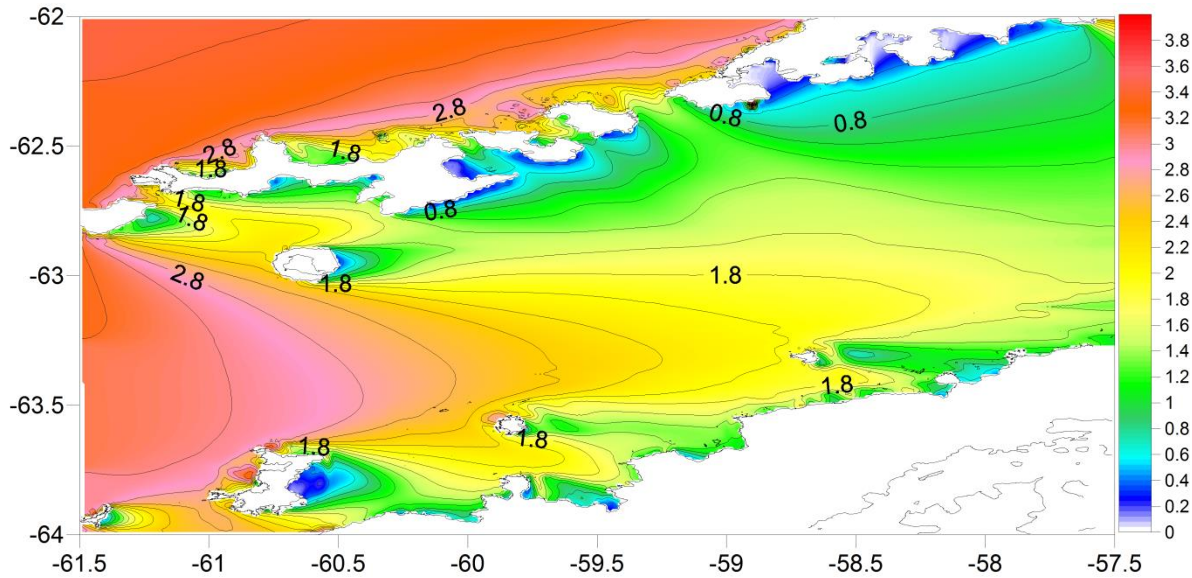


Figure 5. *Cont.*

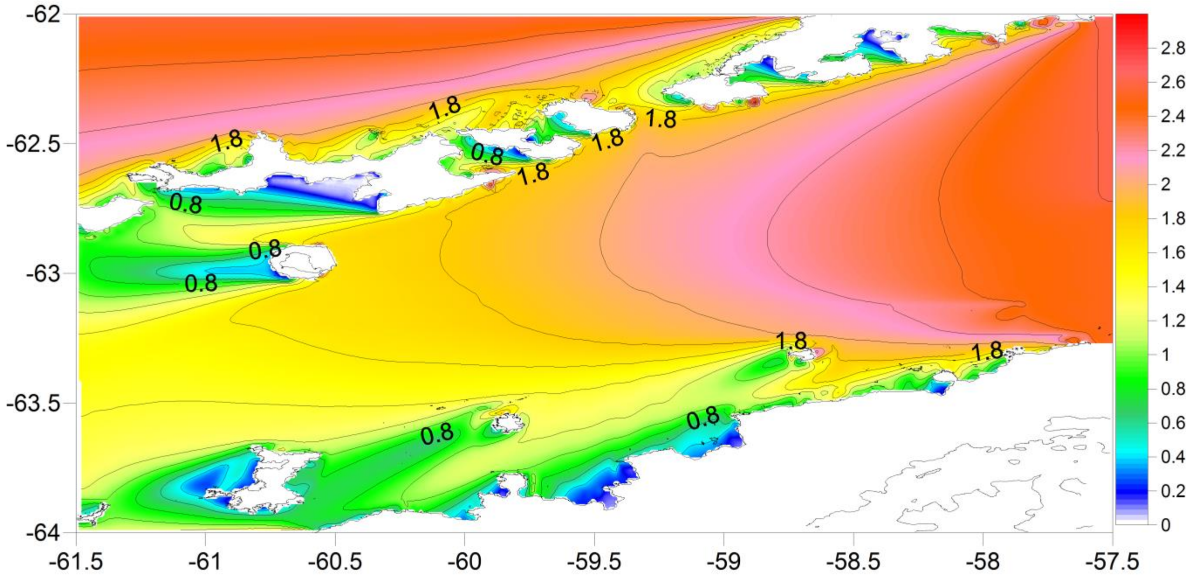


Figure 5. Swell significant wave height for cluster 1 (**top**) and cluster 2 (**bottom**).

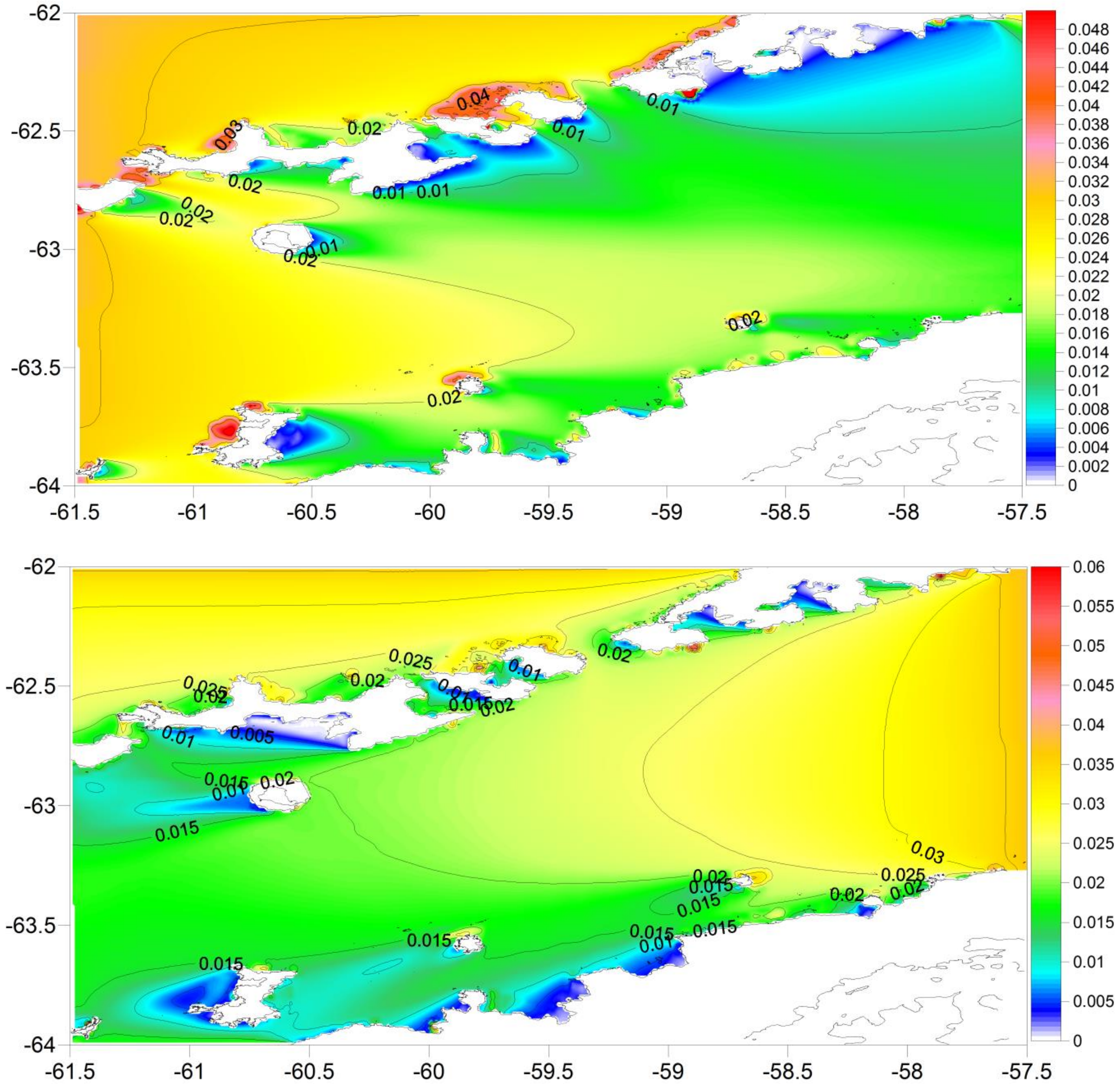
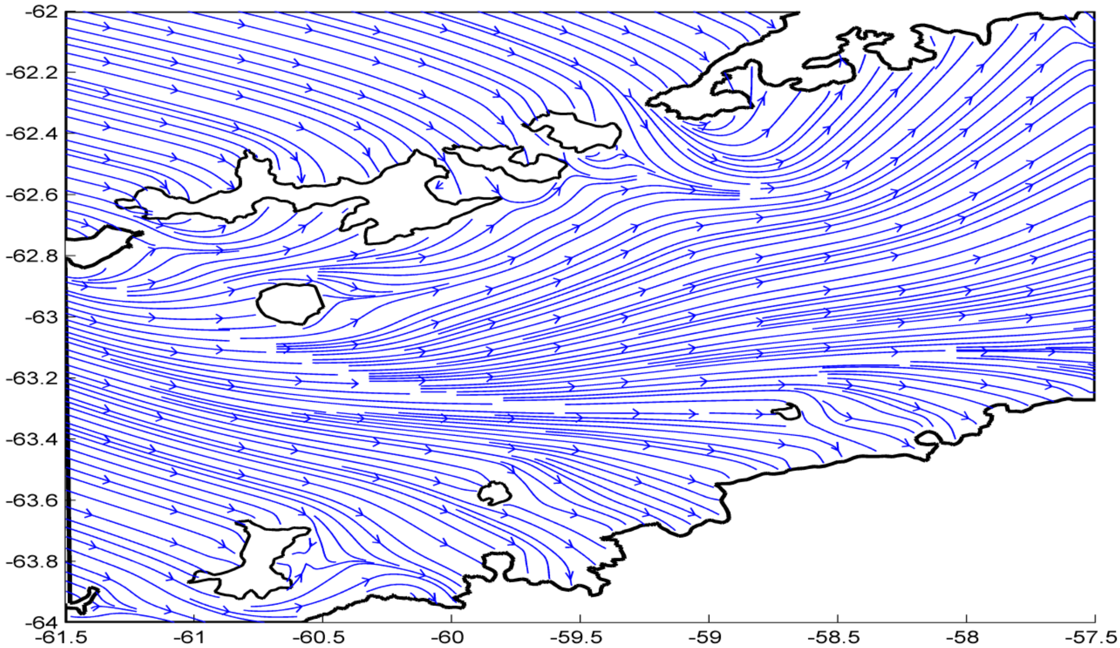


Figure 6. Wave steepness for cluster 1 (**top**) and cluster 2 (**bottom**).



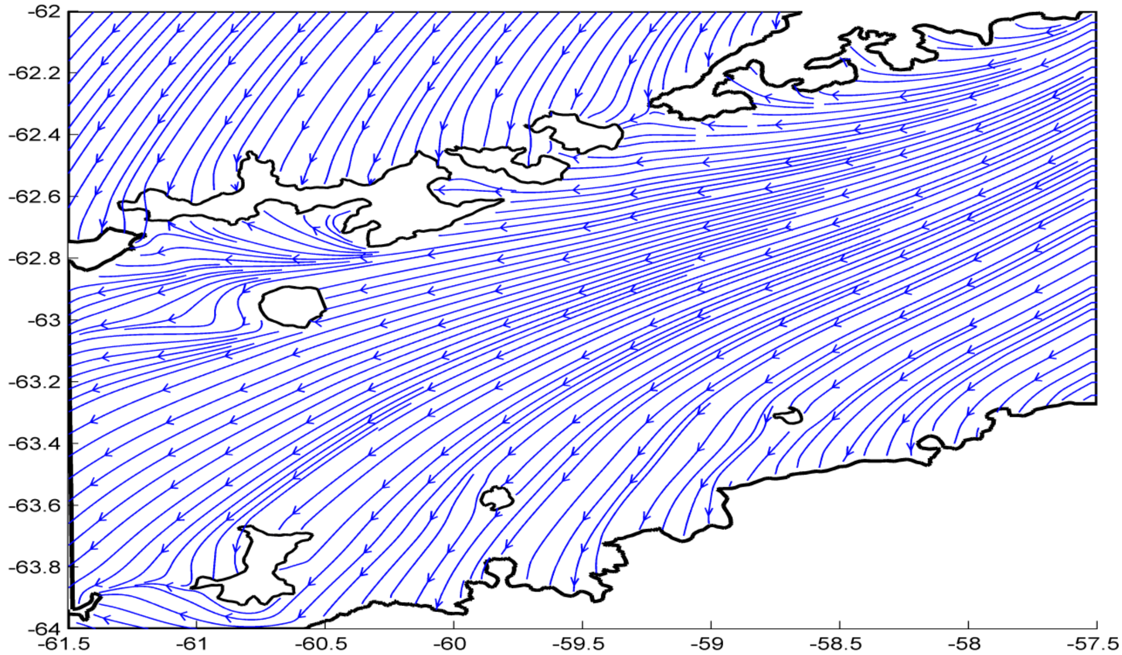


Figure 7. Swell direction (nautical) for cluster 1 (**top**) and cluster 2 (**bottom**).

Table 1 presents the numerical results for local wave conditions, obtained for the patterns of cluster analysis.

Logically, the criteria for locating the station should be examined with more available information. The comparison between wave-meter data and the SWAN model, made in Figure 3, is not sufficient if one proceeds only with a swell analysis without considering wind sea data. Some preliminary data on wind behavior in the South Bay (Figure 8) demonstrate the fast variability of the atmospheric conditions with average wind speeds of 4–8 m/s having instant squalls of up to 20 m/s (and sometimes more) during less than one year of observations. Although winds predominantly come from the SW (from the continent), the land topography of Livingstone Island (Figure 2) reaches elevations of 600 m, which could cause strong katabatic winds.

Table 1. Significant wave height (Hs), peak period (Tp), and direction (dd) for the points shown in Figure 2.

Cluster Number	Point	Hs (m)	Tp (s)	dd (Degrees)
1	1	1.22	10.5	239
1	2	1.15	10.5	236
1	3	0.79	10.5	235
1	4	0.32	10.5	233
1	5	1.17	10.5	235
1	6	2.41	10.7	316
1	7	0.10	10.7	197
2	1	0.04	8.9	238
2	2	0.03	8.9	254
2	3	0.02	8.9	254
2	4	0.01	8.9	251
2	5	0.11	11.1	127
2	6	0.88	8.8	024
2	7	0.26	8.7	131

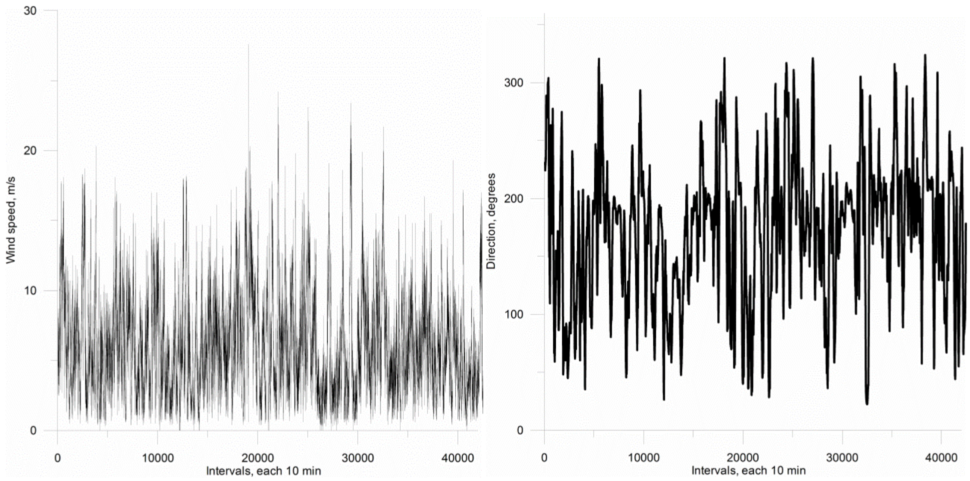


Figure 8. Wind speed (**left**) and wind direction (**right**) at Luis Carlos I station (Figure 1), located in the South Bay, measured between 23 March 2018 and 12 January 2019. The direction was the running average inside a 24-h window.

A fine-resolution atmospheric model is required to describe local wind conditions, but some specific phenomena, such as katabatic winds, may play an important role in the wave dynamics and can be physically difficult to reproduce by a model.

4. Conclusions

Upon looking for the best site among locations 1–7 in Figure 2 from the point of view of the wave climate, it seems better to consider the South Bay (Livingston Island). The wave conditions in the bay are moderate, with wave heights lower than 1.2 m, yet the open sea orientation does not shelter the bay completely from the NW waves (Table 1). The other oceanographically optimal site would be point 7 (Figure 2), located between the Nelson and King George islands. Although both sites have minimum wave steepness, point 7 has slightly more favorable conditions due to lower wave periods (8.9 s versus 10.5 s at points 1–4).

Other logistical aspects examined in the previously cited study [2] describe the South Bay as the best option for a new base.

It is clear that to assess the local wave model properties, the bathymetry should be well defined. GEBCO-0.5 data may still be insufficient to achieve an adequate spatial resolution to resolve shallow water processes such as wave breaking, shoaling, and friction.

Nevertheless, we consider swell conditions to be of greater prime interest because the regional effect of incident waves from the Drake Strait on the domain is undiscussable. The local fetch area in the Bransfield Strait is around 200 km, so the mean wind speed of 10–15 m/s would need to last more than 10–24 h to saturate the wave spectra and produce wave heights of 1.0–2.5 m with relatively low periods between 5 and 7 s. This would be shorter in comparison to the waves under the swell conditions discussed in this paper.

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Data Availability Statement: GEBCO data set: https://www.gebco.net (accessed on 14 February 2021); WAVEWATCH III ® Hindcast and Reanalysis Archives: https://polar.ncep.noaa.gov/waves/hindcasts/; Meteorological data from the Luis Carlos I station: https://opendata.aemet.es/centrodedescargas/productosAEMET (accessed on 14 February 2021).

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