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Wind-wave climate change and increasing erosion in the outer Río de la Plata, Argentina

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ABSTRACT

The coastal area of Samborombón Bay ends in a short cliff which, during the last decades, has been undergoing an increased retrogression of approximately 8.2 m decade^{-1}. The aim of this paper is to investigate whether this accelerated erosion can be related to an apparent wind-wave climate change, which has been recently reported for the Río de la Plata region. A numerical study with SWAN wave model for the period 1971–2005 drives to positive trends in the frequency of occurrence and heights of waves propagating from the E and ESE. Particularly, the number of cases of high waves from those directions displays a significant increment. In addition, previous papers have reported an increment of the frequency, height and duration of the storm surges in the Río de la Plata, so as a rise of the mean sea level in the region. It is concluded that the combination of those three factors acting together constitutes a powerful and effective mechanism which is likely responsible for the observed increasing erosion in Samborombón Bay.

1. Introduction

Studies of coastal impacts of climate change have received considerable attention from the Intergovernmental Panel on Climate Change (IPCC). The IPCC Working Group (WG) II stated that the analysis of risks to coastal population and ecosystems requires the inclusion of a broader range of coastal drivers of change. One of those drivers, which have received little attention to this date, is the change in the global wind-wave climate. In fact, impact studies of climate change, particularly in the coastal zone, have been hampered by the lack of assessment of potential changes in wave climate. Moreover, the IPCC WG I stated that more information on projected wave conditions are required to enable assessments of the effects of climate change on coastal erosion (http://www.jcomm.info/COWCLIP).

More than 4000 km of the Argentine coast (from approximately 5000 km of its total extension) are being affected by gradual, natural and evident erosive processes (Codignotto et al., 1992; Codignotto and Aguirre, 1993). Kokot (1997) reported an increase in the erosive processes along the coast of Buenos Aires province (Fig. 1) during the last three decades of the 20th Century. This author linked the enhanced erosion with changes in atmospheric and oceanic processes which seem to be a consequence of climate change. Simultaneously, a number of changes in atmospheric processes have been reported in the Southwestern Atlantic Ocean. For instance, Gibson (1992) detected a 3° poleward shift of the maximum wind at 500 hPa during the period 1976–1991. Van Loon et al. (1993) found a 2° change in the latitude of the zonal average of the subtropical ridge over the Southern Hemisphere, during the period 1976–1990. Direct observations collected over the Patagonian continental shelf waters (Argentina) indicate that during the 90's, winds were 20% stronger than during the 80's, and that their direction shifted towards the northwest (Gregg and Conkright, 2002). Barros et al. (2000, 2006) found that the western border of the South Atlantic High and the atmospheric circulation over South-eastern South

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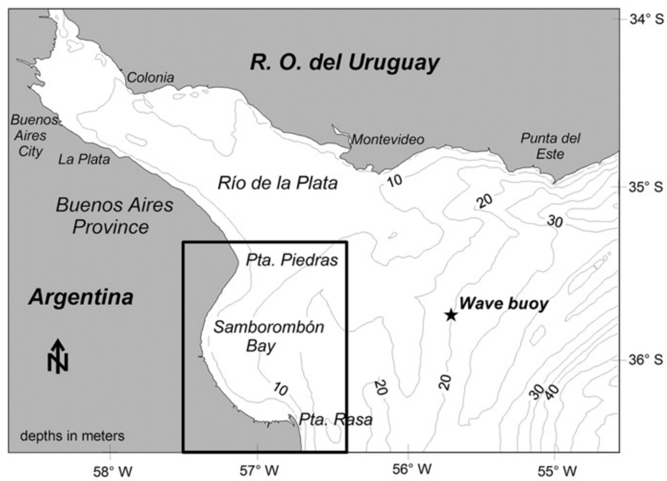

Fig. 1. Study area: Samborombón Bay, demarked by a heavy solid line rectangle, in the outer Río de la Plata. Wave buoy position is pointed out with a star. Depth contours in meters.

America have slowly shifted towards the south during the last decades. This displacement produces, as a consequence, a higher frequency of easterly winds over the Río de la Plata region. In addition, an enhancement of the easterly winds during summer and winter months over the Río de la Plata estuary and the adjacent shelf was reported by Simionato et al. (2005). Statistics of surface winds observed at the Jorge Newbery Airport (Buenos Aires City, Fig. 1) show a slight increase in the easterly winds' frequency and speed between 1981–1990 and 1991–2000. A comparison of the observations between both decades shows that the frequency of easterlies and north-easterlies has risen from 18.4% to 22.0% and from 11.5% to 13.5%, respectively. The mean speed of winds blowing from the east has risen from 4.4 m s^{-1} to 5.3 m s^{-1} (SMN, 1992; SMN, 2009).

The changes observed on winds have, clearly, a direct effect on waves. Cox and Swail (2001) performed a global wave hindcast for the period 1958–1997 and obtained a slight but significant change in the annual mean and 99th percentile wind speeds and wave heights in the continental shelf offshore Buenos Aires Province and the Río de la Plata mouth (Plates 5 and 6 of their paper). Recently, Young et al. (2011) used a 23-year database of calibrated and validated satellite altimeter measurements to investigate global changes in oceanic wind speed and wave height. They estimated a general global trend of increasing values of wind speed and, to a lesser extent, wave height.

The possibility that wind wave heights are actually increasing in the South-eastern South American Continental Shelf was explored by Dragani et al. (2010). These authors analyzed time series of *in situ* (1996–2006) and Topex (1993–2001) annual mean significant wave heights gathered over the continental shelf and the adjacent ocean; even though the available series are too short to statistically assess changes, they display apparent positive trends. To further study the occurrence of a possible trend, the authors implemented SWAN wave model forced by the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) surface winds in a regional domain, and performed a long term run for the period 1971–2005. The simulated annual root-mean-square wave showed significant positive trends at most of the inner continental shelf and the adjacent ocean. The most significant increase occurred between the 80's and the 90's, and the largest difference between both decades (0.20 m, 9%) is observed around 34°S–48°W. The wave height increase resulted slightly lower (7%) over the continental shelf and the outer Río de la Plata. This study did not include the analysis of wave height trends considering the different directions of propagation.

The fact that increased erosion in Samborombón Bay, outer Río de la Plata, has been observed during the last decades on the light of the above mentioned changes on winds and waves (Dragani et al., 2010) is suggestive. In this sense, the motivation for this paper has been to investigate thoroughly whether an increment of the heights and frequencies of occurrence of wind waves might be actually occurring at Samborombón Bay, and affecting its coast. Unfortunately wind wave data records are scarce, incomplete and rather short in this region; consequently such an investigation can only be faced by means of numerical simulations.

2. Study area

The coast of Samborombón Bay is approximately 140 km long. Its coastal area is a wetland covering 3000 km^2 which is, on average, one meter above the mean sea level and which constitutes a typical low-lying area coastal system (Nicholls et al., 2007). For this reason, the occurrence of floods during storm surge events is quite frequent there. Fossil barrier islands, approximately 3 km wide and 5 m tall above the mean sea level, extend along the coast between Punta Piedras and General Conesa (Fig. 2). They are mainly constituted by sea shells and, in a lower proportion, by sands (Codignotto and Aguirre, 1993). Between the fossil barrier islands and the coast, there are younger fossil berms composed by fine sand, silt and clay. The bottom of Samborombón bay is mainly composed by fine sediments, specially mud and organic matter. The beach displays a very gentle slope ($\sim$0.001–0.003) and ends in a cliff less than one meter high. The morphodynamics of the coast essentially respond to the effects of the wave attack on the cliff. In general, there are no evidences of landforms originated by longshore currents, with the exception of Punta Rasa, a sandy spit located at the southernmost tip of the bay, where a northward predominant longshore transport can be clearly appreciated. Because of its composition of non consolidated very fine sand and silt, the coastal cliff is highly vulnerable to erosion. In opposition, Punta Piedras (location 4, Fig. 2), located at the northernmost tip of the bay, is mainly constituted by old consolidated sediments and, in consequence, it is more resistant to erosive

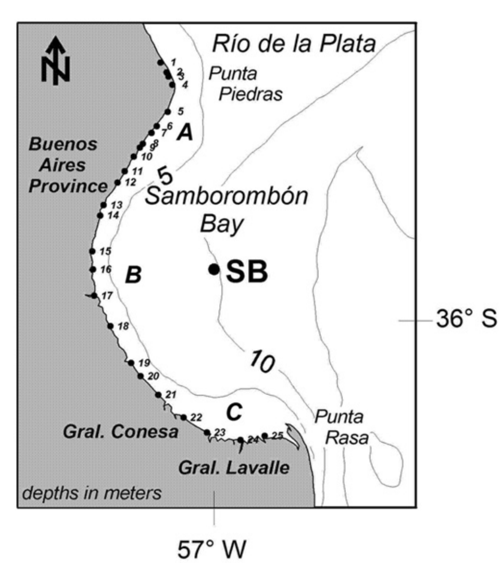

Fig. 2. Samborombón Bay. Locations where values of cliff retrogression were estimated (Table 1) are pointed out. Depth contours in meters.

effects. The coastal area of the bay is undergoing significant erosive processes which cause serious damage to local inhabitants due to the evident loss of land, property and coastal infrastructure; erosive processes also affect fauna, particularly crabs.

3. Evidence of coastal erosion at Samborombón Bay

With the aim of quantifying the cliff erosion, several field studies and nonsystematic measurements have been carried out at Samborombón Bay since the 70's. Most of those observations were done by measuring the distance from the top of stakes, precisely positioned and fixed at selected locations of the adjacent flat beach, to the cliff upper edge. Since January 2010, systematic bimonthly measurements of the cliff retrogression have being made at the locations denoted as 1, 7 and 21 in Fig. 3. Maximum values were registered at the points 21 and 7, where a cliff retrogression of 1.25 m was observed between February and April, 2010, and a reduction of the level of the beach of 0.10 m was registered between April and June, 2010. For this paper, the available measurements were complemented with cadastral information, aerial photography taken by the Servicio de Hidrografía Naval of Argentina and Landsat satellite images to estimate reliable values of retrogression at the 25 coastal locations of the bay displayed in Fig. 2. Results are provided in Table 1. Maximum erosion (more than 300 m) is observed along the central part of the bay and, in general, retrogression becomes lower towards the north (Punta Piedras) and south (Punta Rasa). Minimum erosion (from 0 to 20 m) is observed near the mouths of the dredged channels that discharge the excess of water and fine sediments from the Depressed Pampa, which seem to act as "natural traps" for the fine littoral transport. Those points are the only locations of Samborombón Bay where the general erosion might be masked by deposition of fine sediments. Nevertheless, the accretion due to fine sediments deposition is neither significant nor generalized, but limited to the zones close to the artificial dredged channels. Therefore, there is evidence enough supporting the conclusion that Samborombón Bay is undergoing progressive and generalized erosion. In general terms, and considering the last 49 years of observations, the mean value of the cliff retrogression in Samborombón Bay can be estimated in approximately 40 m or 8.2 m decade^{-1}. A comprehensive analysis of the available information suggests that the erosive processes are neither regular nor constant in time; there are indications that retrogression enhanced during the 80's and 90's. This fact is consistent with the most significant trend in wind wave heights in the region reported for the same decades by Dragani et al. (2010).

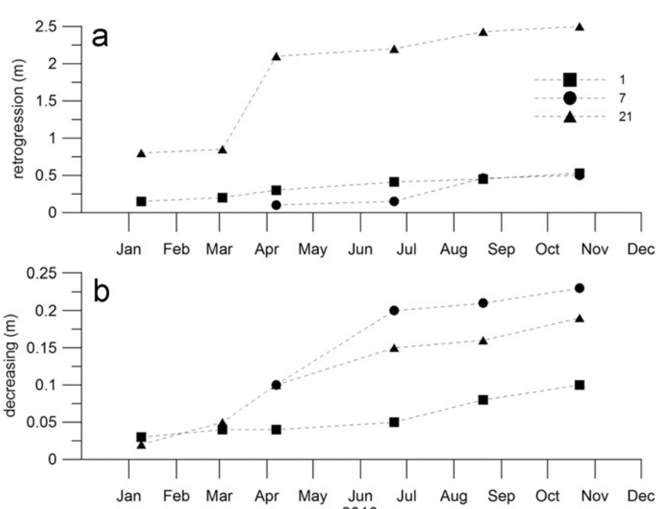

Fig. 3. Observed (a) horizontal distance (in m) measured shoreward, from fixed stakes and (b) vertical height of the beach level (in m) measured downward from the top of the stakes at locations 1, 7 and 21 (denoted in Fig. 2). Period: January–October, 2010.

Table 1
Estimated values of retrogression (m) at twenty-five locations along the coast of Samborombón Bay (Fig. 2). Latitude and longitude of each point is included. (Compiled information from 1970 to the present).

Location	Latitude (°)	Longitude (°)	Retrogression (m)
1	35.358	57.172	200
2	35.383	57.153	100
3	35.395	57.146	40
4	35.416	57.134	40
5	35.486	57.148	40
6	35.524	57.184	60
7	35.542	57.200	30
8	35.570	57.228	130
9	35.580	57.238	50
10	35.603	57.257	120
11	35.642	57.286	160
12	35.671	57.308	20
13	35.730	57.353	300
14	35.757	57.364	> 300
15	35.851	57.389	> 200
16	35.898	57.387	> 200
17	35.966	57.383	> 50
18	36.046	57.331	> 100
19	36.142	57.263	> 50
20	36.176	57.234	~0
21	36.225	57.176	50
22	36.284	57.095	50
23	36.323	57.019	80
24	36.343	56.911	160
25	36.332	56.832	50

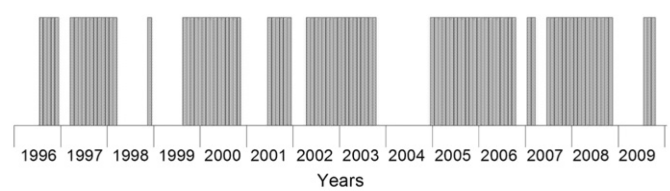

Fig. 4. Performance of *in situ* wave data acquisition (Datawell wave buoy). Grayish bars indicate months in which the acquisition was greater than 90%.

4. Wave height trend—direct observations

The only set of long-term *in situ* observations of directional wave available for the region was collected between 1996 and 2009 with a Datawell Waverider directional wave recorder (Datawell, 1997) moored in the outer Río de la Plata estuary at 35°40'S and 55°50'W (Fig. 1), approximately 90 km to the east of Samborombón Bay. The instrument was programmed to measure 20 min sea level records with a 0.5 s sampling interval every 2 h and 40 min. The record has several gaps, one of them longer than one year (from October 2003 to November 2004), three eight months long (March 1998 to October 1998; November 1998 to June 1999; November 2008 to June 2009) and other six of between two and seven months. The lapses of data acquisition and gaps are displayed in Fig. 4. Dragani and Romero (2004) made a directional bi-dimensional (heights and periods) analysis of these data and concluded that SE, followed by E and S, are the dominant directions of propagation, with 41%, 28% and 14% of occurrence, respectively, whereas the frequency of waves from other directions is less than 5%. Fig. 5 shows the annual mean significant wave height; due to the gaps in the data set, values

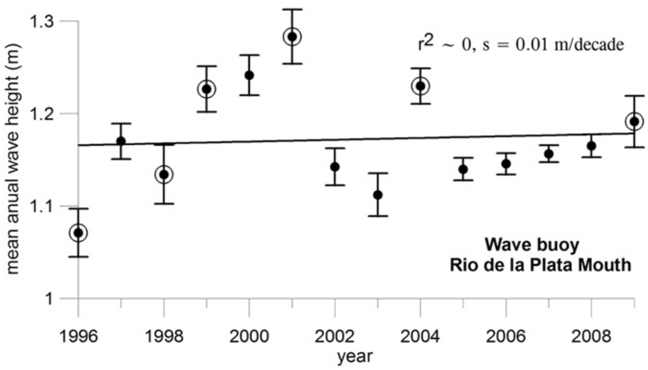

Fig. 5. Annual mean heights of measured waves at the Río de la Plata mouth. 95% confidence interval is indicated. Mean height corresponding to years of low data acquisition (see Fig. 4) are indicated with a circle. Least-square regression line is also included.

corresponding to 1996, 1998, 1999, 2001, 2004 and 2009 might be misleading and, therefore, were marked with circles. The least-square regression line for the period 1996–2009 is shown as a solid line in the figure. The slope (s) reveals a slight positive trend which, nevertheless, is statistically not different from zero. The maximum negative (-0.14 m) and positive ($+0.12$ m) inter-annual variation occurs between 2001 and 2002, and 2003 and 2004, respectively. A clear and statistically significant positive trend is observed between 1996 and 2001, even though should be emphasized that four of the six values during those years derive from incomplete data series. In opposition, between 2002 and 2009, the slope is very low and not statistically significantly.

Even it cannot be concluded from these data the occurrence of a statistically significant trend in the wave height in the Río de la Plata, it must be taken into account that the series is short and has many gaps. Therefore, data are insufficient to detect a weak trend even if it exists, and there is evidence which suggests that it might be occurring. As mentioned in the Introduction, there is strong evidence of changes in the low atmospheric circulation in this region of the Southern Hemisphere which should impact the oceans, and which effects might be masked and might be difficult to quantify in the short and incomplete available data set. To further study the possibility of occurrence of changes in the mean wind wave heights in Samborombón Bay, a regional application of SWAN wave model was implemented. It was forced by NCEP/NCAR 10 m wind and run for the period 1971 and 2005. In what follows this application is described and results are discussed.

5. Simulation description and results

SWAN is a numerical wave model that provides realistic estimates of wave parameters in coastal areas (Booij et al., 1999; Ris et al., 1999; Holthuijsen et al., 2004). The particular implementation of the model to the study region spans the area between 30°S and 42°S, and 40°W and 65.5°W, with a grid spacing of 22.7×20.0 km (100×70 grid points). A complete validation of SWAN wave model in this computational domain was presented by Dragani et al. (2008). The model domain includes regions as dissimilar as the very shallow Río de la Plata, the Uruguayan continental shelf, part of the adjacent Argentinean and Brazilian continental shelves, the continental shelf break and a portion of the South-western Atlantic Ocean. Bathymetric data for the model were obtained as a combination of $1' \times 1'$ resolution depth data set coming from GEBCO (2003) for the continental shelf break and the deep ocean, and from digitalized nautical charts of the Río de la Plata (SHN, 1986, 1992, 1993, 1999a, b) for the continental shelf and coastal areas. Those depths were interpolated to the model grid applying the inverse square-distance method.

Surface wind data from NCEP/NCAR Reanalysis I were used to drive the simulation. Full details of NCEP/NCAR project and the dataset are given in Kalnay et al. (1996) and discussions about product quality over the Southern Hemisphere can be found in Simmonds and Keay (2000), among others. NCEP/NCAR reanalysis has been successfully utilized as forcing in several numerical regional studies in the area (see, for instance, Simionato et al., 2006 a, b, 2007; Meccia et al., 2009; Dragani et al., 2010). A bilinear (linear) interpolation was used to generate appropriate wind fields to match the spatial (temporal) resolution of SWAN wave model.

To study the evolution of the wave heights in the region, it was decided to analyze the annual root-mean-square of the significant wave height (Hs) instead of the annual mean significant height (Hs is the variable provided by the simulations), because it gives proper weight to the larger wave conditions and, therefore, will probably be a more sensitive discriminator of changes (Dragani et al., 2010). Time series of the simulated annual root-mean-square of the significant wave height ($Hrms$) were obtained for 16 directions, 22.5° apart (N, NNE, NE and so on) at 35° 50′ S - 57°W, a representative point (grid node) located in the center of the bay (denoted as SB in Fig. 2). 95% confidence intervals for annual mean values are less than ± 0.02 m and, therefore, are not shown in the figures. Least-square regression lines for the period 1971–2005 were fitted to every series. The computed gradients only resulted statistically different of zero at a 95% of confidence for three propagation directions: E, ESE and SE. The calculated gradients of the best fit lines and the corresponding 95% confidence limits were 0.04 ± 0.02, 0.02 ± 0.02 and 0.03 ± 0.02 m decade^{-1}, respectively. The determination coefficients (the correlation coefficients squared) were rather low, 0.24, 0.12 and 0.23, indicating a relatively high dispersion of the annual mean heights (Figs. 6–8). The gradients of the frequency of occurrence of waves (cases) from the different directions only resulted statistically different from zero at a 95% of confidence level for the E and ESE directions. The calculated gradients of the best fit lines and the corresponding 95% confidence limits were 10 ± 6 and 7 ± 6 cases decade^{-1} and the determination coefficients were 0.23 and 0.11, respectively, evidencing again a relatively high dispersion (Figs. 9 and 10).

Contour diagrams displaying the annual sequence of height distributions for every analyzed direction were built using the 4-daily heights derived from the numerical simulations. These figures illustrate, simultaneously, the trends of the height and frequency of waves propagating from every direction. The

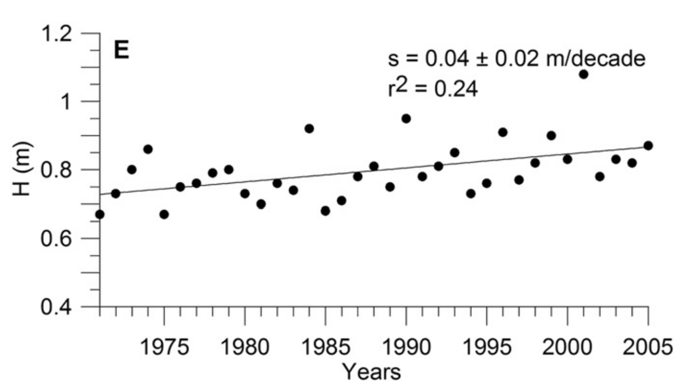

Fig. 6. Modeled (SWAN) annual root-mean-square of the significant wave heights for wind waves propagating from the E (1971–2005 period) at SB point (Fig. 2). Corresponding least-square regression line is also included.

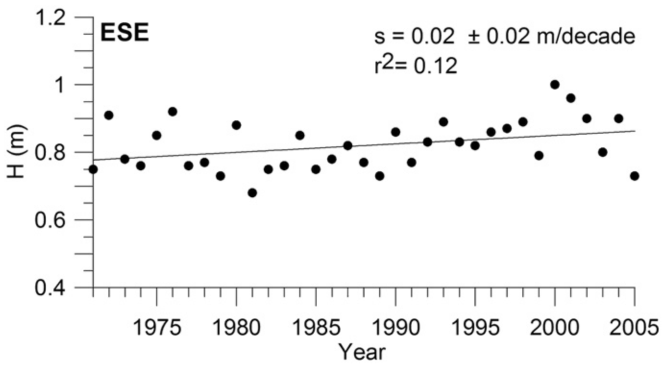

Fig. 7. Modeled (SWAN) annual root-mean-square of the significant wave heights for wind waves propagating from the ESE (1971–2005 period) at SB point (Fig. 2). Corresponding least-square regression line is also included.

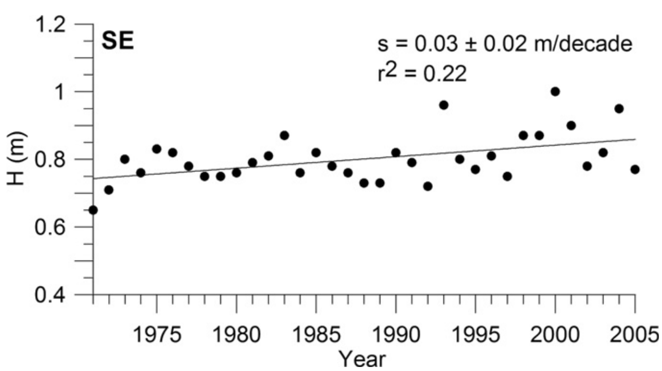

Fig. 8. Modeled (SWAN) annual root-mean-square of the significant wave heights for wind waves propagating from the SE (1971–2005 period) at SB point (Fig. 2). Corresponding least-square regression line is also included.

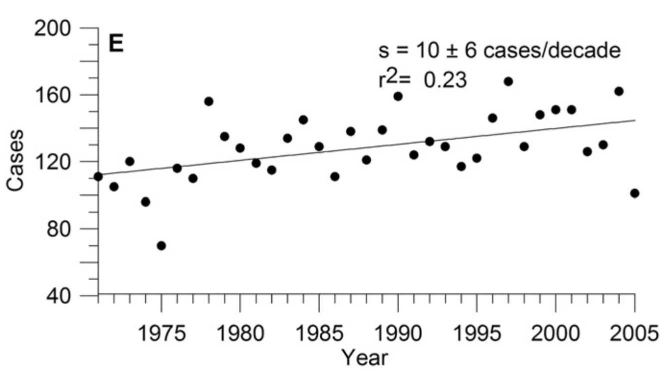

Fig. 9. Modeled (SWAN) annual frequency of occurrence (cases) for wind waves propagating from the E (1971–2005 period) at SB point (Fig. 2). Corresponding least-square regression line is also included.

diagrams corresponding to the E and ESE directions resulted very similar and therefore, because of length reasons, only the one corresponding to the E is shown in Fig. 11. In this figure, the contours display the number of cases (as annual frequency of occurrence) of wind waves propagating from the E. An elongated area with maximum frequencies (40–50), characterized by heights of 0.6 m, is highlighted with a dashed line. Therefore, ~0.60 m is the most frequent height for waves traveling from the E. To the left of the dashed line, the frequencies gradually decay to minimum heights, whereas to the right, the contours spread more irregularly towards larger values. The largest heights (more than 1 m) occur over an area marked between two solid lines in Fig. 11, which has been gradually widening from 1971 (from 0.95 to

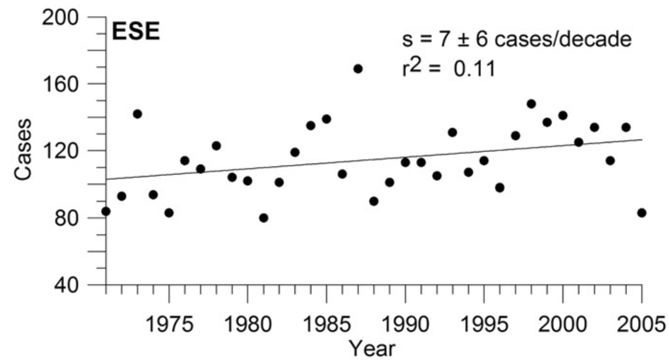

Fig. 10. Modeled (SWAN) annual frequency of occurrence (cases) for wind waves propagating from the ESE (1971–2005 period) at SB point (Fig. 2). Corresponding least-square regression line is also included.

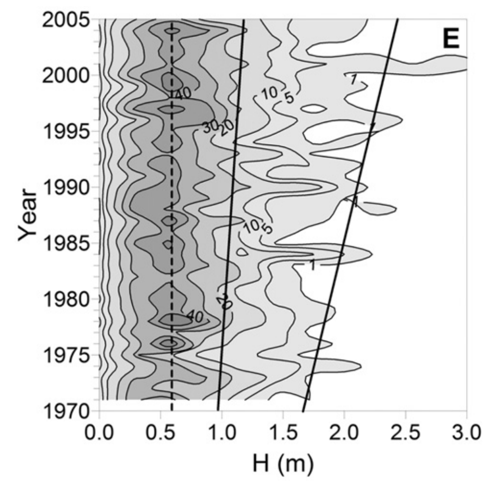

Fig. 11. Annual sequence of (SWAN) wind wave height distributions at SB point (Fig. 2). Contours indicate the frequency of wind waves propagating from the E (1971–2005 period). Dashed line points out an elongated area with maximum frequency. Solid lines delimit areas with wind wave heights greater than 1 m.

1.70 m) to 2005 (from 1.20 to 2.50 m). The figure reveals, therefore, that since 1971 the number of waves traveling from the E, particularly the highest, has been increasing. It would be the result either of a possible increase in wind speed and/or a shift in wind direction in the region. This way, the simulations support the hypothesis that higher waves propagating from the E (and ESE) are more frequent in Samborombón Bay; they would be more energetically impacting the cliff along the coast of the bay.

Considering the positive trends of the wave parameters for the dominant directions of propagation and the particular geometry of the bay, it seems reasonably to suppose that the alongshore wave energy flux factor (*Pls*) might present a significant trend and large spatial gradients along the coast. *Pls* is usually estimated using the simple formulation $\rho g^{3/2} H_s^{5/2} (\cos\theta)^{1/4} (\sin 2\theta)/20$ (CERC, 1984), where ρ is the water density, g is the acceleration due to gravity, and H_s and θ are the significant wave height and the angle between wave crest and the shoreline, respectively. The flux was computed using the simulated parameters at three coastal locations of Samborombón Bay, denoted as points A, B and C in Fig. 2. In general, it is assumed that the total amount of material moved along the shoreline is proportional to *Pls*. Our results indicate that the net annual *Pls* is directed towards the southwest at the northernmost portion of the bay, whereas it is directed to the west/northwest and is one order of magnitude higher at the southernmost sector of the bay. The net annual flux is very weak and its direction variable (northward or southward) at the middle

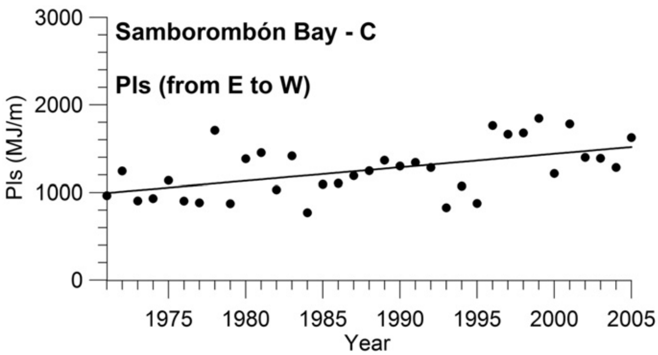

Fig. 12. Computed annual longshore energy flux factor (*Pls*), 1971–2005 period, at point C of Samborombón bay (Fig. 2). Corresponding least-square regression line is also included. 1 MJ = 10^6 J.

of the bay, what suggests that the annual net *Pls* inverts its direction in this region. Given that Samborombón's coast is mainly composed by very fine sediments, it is generally assumed that the sediment eroded from the cliff is initially transported as suspended material along the coast, which is gradually incorporated to the main flow of the Río de la Plata. There is no evidence about the presence of sand along Samborombón Bay's coast. Field observations indicate that the long shore transport of sand along Buenos Aires Province ends at Punta Rasa creating a system of submarine sand banks (for instance, Cabo, Tuyú and San Agustín banks) which can be clearly appreciated in the nautical charts (SHN, 1999b).

The availability of the 35-years long numerical simulation permitted the estimation of potential trends in the alongshore energy flux. Results show very weak trends at points A and B, whereas, *Pls* displays a marked increase of $+150$ MJ m^{-1} per decade (1 MJ = 10^6 J) at point C, located at the southernmost portion of the bay. This last can be explained considering the predominantly E–W orientation of the coast and the aforesaid increase in the wave heights and the number of cases of waves propagating from the E–ESE, which would produce a significant increase in the long shore energy wave flux at the southern part of the bay (Fig. 12).

In addition to the above discussed changes in the wave climate, numerical simulations (Meccia et al., 2009) and observations (Escobar et al., 2004; D'Onofrio et al., 2008) reveal changes in the frequency and height of positive and negative storm surges in the Río de la Plata. Escobar et al. (2004) studied the annual mean frequency of "sudestadas", defined as the positive storm surges over $+1.60$ m, during the last five decades of the 20th century, and observed a positive trend in the absolute frequency during the last decades, rising from 44 cases in the 60's to 79 cases in the 90's. D'Onofrio et al. (2008) studied the variability of the frequency, duration and height of the storm surges in the Río de la Plata during the period 1905–2003 from *in situ* hourly water levels. Their results reveal that during the last 30 years the decadal averages of both the frequency and the duration of the positive surges have increased.

On the other hand, sea level has been slowly but monotonically increasing in the study area. Lanfredi et al. (1998), reported a long term trend in the water level of $+1.6 \pm 0.1$ mm yr^{-1} for Buenos Aires city (analyzed period: 1905–1992) and $+1.4 \pm 0.5$ mm yr^{-1} for Mar del Plata (analyzed period: 1954–1992).

Considering a length of Samborombón Bay's coast of approximately 140 km, our estimation of the annual mean value of the cliff retrogression of 0.82 m yr^{-1} and a mean value of the cliff height of 0.80 m, the annual volume of eroded sediment can be estimated in around 90,000 m^3 yr^{-1}. Visual evidence suggests that part of that volume might be retained in the artificial channels, which would be acting as effective traps of sediment. Nevertheless, a particular sedimentary analysis would be necessary in order to determine the source of the materials and to discriminate the portion of sediment that actually comes from Depressed Pampa from that originated by erosion of the bay's cliff.

6. Conclusions

In this paper, a long term wind wave simulation was analyzed with the aim of providing clues to understand the observed erosive processes which are affecting Samborombón Bay, located at the Río de la Plata estuary. The analysis of the 35 year-long simulation shows a significant increment of the frequency (10 and 7 cases decade^{-1}) and height (0.04 and 0.02 m decade^{-1}) of the waves propagating from the E and ESE directions towards the bay. The increase of the number of cases is larger for the highest waves. Therefore, the simulation supports the hypothesis that higher waves from the E and ESE are becoming more frequent in the coastal area of Samborombón Bay. As a consequence, the coastal cliff would be more frequently exposed to higher levels of wave energy, driving to larger erosion. Also, the increase in the frequency and height of the easterly and southeasterly waves would increment the long shore energy flux factor (*Pls*), enhancing the capability of transporting sediments along the coast, particularly at the southern sector of the bay. The increased erosive processes currently observed in Samborombón Bay are consistent with those arguments.

In addition to the above mentioned changes in the wave climate, an increase in the frequency, duration and height of the positive storm surges has been also reported, so as a slight but significant sea level rise. Evidently, the combination of those factors must have a significant impact on the low Samborombón Bay. During positive storm surges ("sudestadas") the water floods an extensive coastal area and if, in addition, higher waves strike on the cliff, they can produce a larger burst in the coast. Observations indicate that at some locations, retrogression can be more than one meter in a few days. This is the case, for instance, of the maximum retrogression of 1.25 m observed at the site labeled 21 in Fig. 2, which occurred during a strong "sudestada" between February and April, 2010 (Fig. 3).

In summary, the increment of the frequency and height of the wind waves propagating from the E and ESE discussed in this paper, acting in addition to the increase in the frequency, height and duration of the storm surges and the sea level rise reported by other authors and all of them, directly or indirectly, consequence of climate change constitute a powerful and effective mechanism of interrelated, complex and efficient forces which, we hypothesize, are responsible for the observed accelerated erosion in Samborombón Bay.

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