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TECHNICAL COMMUNICATIONS

Changes in the Regime of Storm Surges at Buenos Aires, Argentina

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ABSTRACT

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Located on the west margin of the Rio de la Plata estuary, the capital city of Buenos Aires is often affected by positive and negative storm surges due to strong southeasterly and northwesterly winds, respectively, which sweep the estuary. While positive surges cause severe flooding, negative surges affect navigation and drinking water supply. Since Buenos Aires is densely populated, a quantitative assessment of the variations in the regime of storm surges will help to develop policies for reducing their impacts. Changes in frequency, duration, and height of storm surges over the period 1905–2003 were determined from statistical analyses of hourly water levels. Calculations of the tidal constants used harmonic analyses of 19 y periods to account for any variation in the astronomical tide. Positive and negative surges were chosen from the residuals between observed levels and the predicted tide. The results show that the decadal averages of frequency and duration for positive surges have increased in the last three decades, but they have decreased for negative surges. The average decadal trends of the maximum positive and negative surges in each year, +1.46 ± 0.08 mm/y and +1.02 ± 0.09 mm/y, respectively, compare well with the relative mean water-level rise for Buenos Aires: +1.68 ± 0.05 mm/y. However, the height of positive surges has decreased in the last decade, and negative surges have become more intense in the last two decades.

ADDITIONAL INDEX WORDS: *Estuaries, mean water level, flooding.*

INTRODUCTION

The capital city of Buenos Aires is located on the west margin of the Rio de la Plata, a very extensive and shallow estuary with a NNW-SSE orientation shared by Argentina and Uruguay (Figure 1). Formed by the confluence of the Parana and Uruguay Rivers, the Rio de la Plata has a length of about 300 km, widening from ~40 km at its upper end to 220 km at its outlet on the Atlantic Ocean. Because of its extension, shallow depth, and funnel-like shape, the Rio de la Plata is highly affected by strong southeasterly winds that push its waters upriver, causing severe flooding on the Argentine shore. This frequent phenomenon, locally known as "sudestada" (southeaster), is characterized by a gradual increase in the SE-SSE wind velocity accompanied by a sky completely covered by nimbostratus and persistent rainfall (SERVICIO DE HIDROGRAFÍA NAVAL, 1999). On the other hand, big ebb tides occur when strong winds blow from the NNW, N, and NNE (BALAY, 1961; SIMIONATO *et al.,* 2004). These ebb tides have a significant impact on navigation safety and the supply of drinking water to Buenos Aires, the population of which is now over 2,760,000 (INSTITUTO NACIONAL DE ESTADÍSTICA Y CENSO, 2001).

A dramatic example of a catastrophic "sudestada" in Buenos Aires and its surroundings occurred on April 15, 1940. The maximum tidal height predicted for that day was 1.20 m above the Riachuelo Tidal Datum (RTD) (Figure 1), but the observed level was 4.44 m above RTD (D'ONOFRIO *et al.,* 1999). Conversely, on November 10, 2002, seven districts of

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Figure 1. The Rio de la Plata estuary.

Buenos Aires ran out of drinking water, and several ships had to remain anchored close to the Buenos Aires harbor due to a large ebb flow. The tidal height predicted was 0.74 m above the RTD, but the observed level was −2.63 m below RTD. This was the lowest level observed in 19 years. On that occasion Buenos Aires was affected by strong westerly winds (40–55 km/h), with gusts of 80 km/h.

Several authors have studied southeasters in the Rio de la Plata (CELEMIN, 1984; CIAPPESONI and SALIO, 1997; ESCOBAR *et al.,* 2004; FIORE *et al.,* 2001; SELUCHI, 1995; SELUCHI and SAULO, 1998). The purpose of this work is to quantitatively assess the changes in frequency, duration, and height of positive and negative storm surges in Buenos Aires over the last century and to evaluate their possible relation to the present trend in relative mean water-level change. Because Buenos Aires and its surroundings constitute a densely populated area, the analysis of these extreme storm surges would help to develop suitable policies for reducing their severe impacts on the population.

MATERIALS AND METHODS

The basic data set consists of hourly water levels of the Rio de la Plata from the period 1905–2003. Measurements were made with a float-operated tide gauge (UNESCO, 1985) by the Ministry of Public Works at the Riachuelo River mouth (1905–1959), and by the Naval Hydrographic Service at Palermo, 9 km to the north of the Riachuelo River (1957–2003), with three years of overlap: 1957–1959. Both stations are located within the limits of Buenos Aires (Figure 1), and the coastline between them shows no morphological differences. Tide gauge levels are referenced to the RTD, which is periodically checked by accurate geodetic leveling to local benchmarks. Although the series have a 13 y gap (1926–1938) and two 1 y gaps (1942 and 1963), mean water levels are available for the whole period. The amplitudes and phases of the harmonic tide constituents and the surge at both stations showed no significant differences (D'ONOFRIO *et al.,* 1999). The residuals between observed hourly levels and the corresponding predictions were used to obtain the surge sample. Considering the length of the studied period (99 years) and any possible variation of the astronomical tide, harmonic analyses for 19 y periods (1906–1924, 1943–1961, 1966–1984, and 1982–2000) were done following the method of FOREMAN (1977) to obtain the tidal constants. Associated errors were calculated using the computational method of PAWLOWICZ *et al.* (2002). In this way, any possible trend due to variations in tidal amplitudes over the last century was minimized.

The distribution of the residual levels is approximately Gaussian (Figure 2) and has positive skewness (0.52). The tails contain the major surge events. The highest positive residual occurred on November 12, 1989, with 3.48 m. It was produced by the most severe coastal cyclogenesis event in recent decades over eastern South America, which yielded strong southeasterly gales over Buenos Aires that raised the water level up to 4.06 m above RTD (second maximum level in the last century) (SELUCHI and SAULO, 1998). The lowest negative residual was −4.61 m on May 29, 1984, when a low water of −3.66 m below RTD was observed. This was the lowest low water ever recorded since 1905.

Statistical Analysis

Storm Surges

The positive surges were obtained from the residuals considering the events that satisfied the following two criteria: (i) residual levels that never fell below 0.30 m, and (ii) a highest residual value equal to or greater than 1.60 m. The last value was adopted because, when combined with a height close to the mean water level (0.79 m above RTD) during a rising semidiurnal tide, it leads to warning levels in Buenos Aires and its surroundings.

Similarly, for the negative surges, the following two criteria were used: (i) residual levels that were always lower than −0.30 m, and (ii) a lowest residual value equal to or less than −1.20 m. The value of −1.20 m was adopted because a height close to the mean water level during a falling semidiurnal tide produces heights lower than −0.40 m during at least 6 h, thereby affecting navigation and drinking water supply in the Rio de la Plata.

The value of ±0.30 m as a threshold value for positive and negative storm surges was adopted because when the meteorological surge is negligible, the difference between the observed and the predicted tide has always been within ±10 cm (SERVICIO DE HIDROGRAFÍA NAVAL, personal communication, Flooding Prevention Center, Buenos Aires, Argentina). So, to ensure that the chosen residuals corresponded to positive or negative surges, the threshold value adopted was three times the aforementioned difference.

D'ONOFRIO and FIORE (2002) have shown that mean water level at Buenos Aires is not much affected by the Parana and Uruguay Rivers' discharge into the Rio de la Plata. This is because the upper Rio de la Plata changes its geometry by remarkably increasing its width, thereby causing the river water to spread over a greater area without significantly changing the mean water level. According to these authors, the largest positive anomalies in the mean water level do not correspond in general to the largest runoffs. Although during

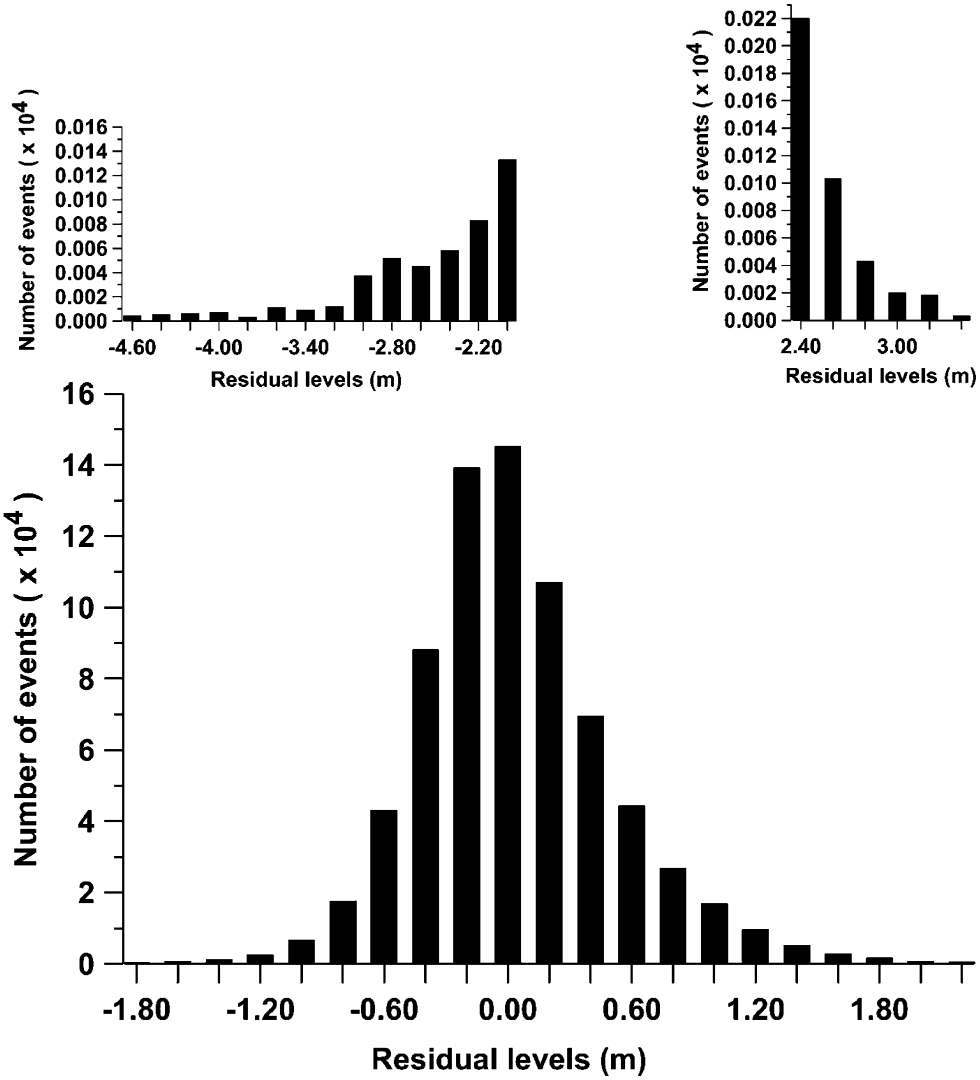

Figure 2. Distribution of residuals (*i.e.,* water levels minus predicted tide, where the predicted tide has the same mean water level).

the El Niño–Southern Oscillation (ENSO) events of 1983, notable positive anomalies were recorded, a negative anomaly was also observed on that occasion. In spite of the large runoff received by the Rio de la Plata, the contribution of storm surges is more relevant as far as mean water level anomalies are concerned. Only during the largest floods of the twentieth century (ENSO events of 1983 and 1998) did the runoff of the Parana and Uruguay Rivers contribute appreciably to the mean water level at Buenos Aires. From the time series analyzed, D'ONOFRIO and FIORE (2002) concluded that only for annual maximum river discharges greater that 64,000 m^3/s and annual mean river discharges greater than 41,000 m^3/s could annual mean water-level anomalies be on the order of 0.15 m. These two conditions were met only during the 1983 and 1998 ENSO events.

In addition, the analysis of almost 100 y of water-level records for Buenos Aires does not show the existence of long-period waves. These types of waves occur in the Atlantic continental shelf waters to the south of the Rio de la Plata and are most likely due to atmospheric gravity waves associated with the passage of atmospheric fronts (DRAGANI *et al.*, 2002). Tsunamis have not been detected by tide gauges at Buenos Aires.

Figure 3 shows the average frequencies of positive and negative surges arranged in decades from 1906. There has been an increase in the frequency of positive surges during the last three decades (1974–2003). Considering all the positive surge events of the period 1906–2003, the frequency percentage for the last three decades is 47%. The decadal frequency trend for positive surges is +0.35 ± 0.19 events/y over the whole period. Conversely, the frequency of negative surges for the last three decades was less than for the previous five, while the decadal trend for the whole period was −0.50 ± 0.10 events/y.

Figure 4 shows the decadal average of maximum annual

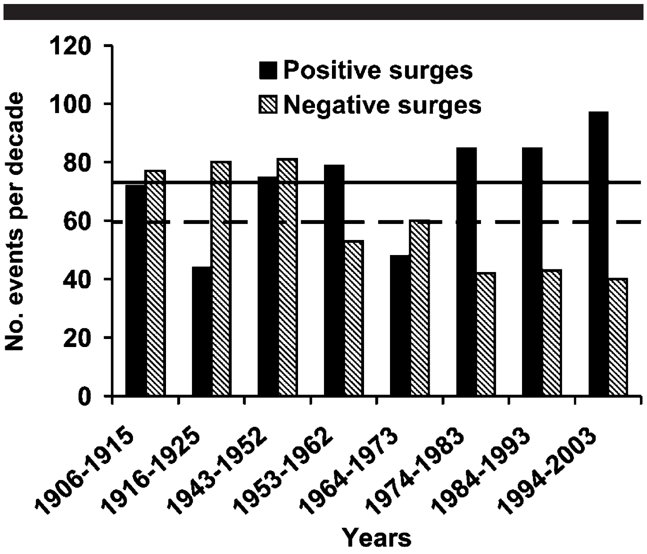

Figure 3. Decadal average frequency of positive and negative surges. The solid and dashed lines represent the mean values for positive and negative surges, respectively.

duration for positive and negative surges. The decadal trend for positive surges is +0.22 ± 0.12 h/y. In the last three decades, the average duration is over 3 d. The highest duration of positive surges was observed in the end of July and the beginning of August 1976 with 175 h. On the other hand, the decadal average of maximum annual duration for negatives surges has decreased from the beginning of the last century and has remained essentially constant during the last four decades. The decadal trend for the whole period was −0.23 ± 0.08 h/y. The highest duration for negative surges occurred in September 1955 with 109 h.

Figure 5 illustrates the decadal averages of the maximum positive and negative surges in each year. Positive surges show an increasing height from the 1950s, with a general trend for the whole period of +1.46 ± 0.08 mm/y. Furthermore, the decadal average for the last four decades (2.34 m) is greater than that corresponding to the previous decades, which is below 2.25 m. On the other hand, the decadal trend for negative surges (1.02 ± 0.09 mm/y) indicates that as a general rule, they are increasingly less negative, although observed water levels have become more negative during the last 20 y.

Relative Mean Water-Level Rise and Acceleration

Tide gauge data show that global average sea-level rise during the last century was in the range 1–2 mm/y. No significant acceleration in sea-level rise has been detected in the last century (IPCC, 2001). LANFREDI *et al.* (1998), PUGH and MAUL (1999), and D'ONOFRIO *et al.* (2003) determined a relative sea-level rise of the same order on the Argentine coast. An updated (1905–2003) value of water-level rise and its acceleration for Buenos Aires was calculated from a record of annual mean water levels obtained from hourly levels. To reduce the variance in the data and to have a smoother mean water-level series, a low-pass 17-element filter was devised from the Kaiser-Bessel window (HAMMING, 1977) with a cut-off frequency of 0.076 y^{-1}. The linear regression of the filtered series of annual mean water levels shows a trend of +1.68 ± 0.05 mm/y for the aforementioned period (Figure 6). A least-squares regression fit according to a simple quadratic parameterization (WOODWORTH, 1990) gave an acceleration of + 0.0194 ± 0.0050 mm/y^2.

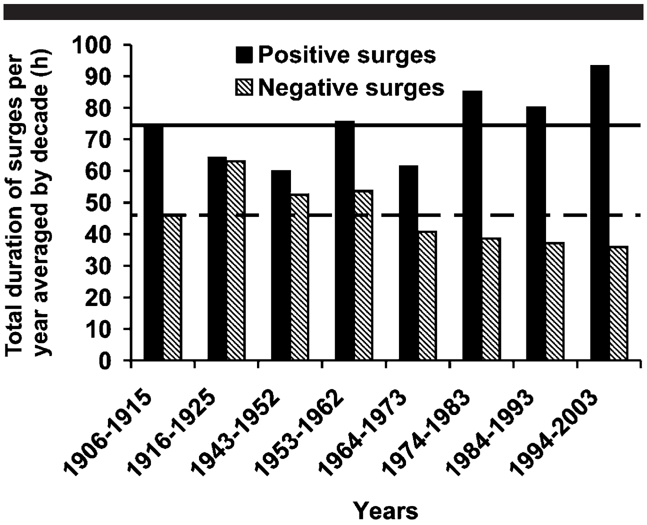

Figure 4. Decadal average of maximum annual duration of positive and negative surges. The solid and dashed lines represent the mean values for positive and negative surges, respectively.

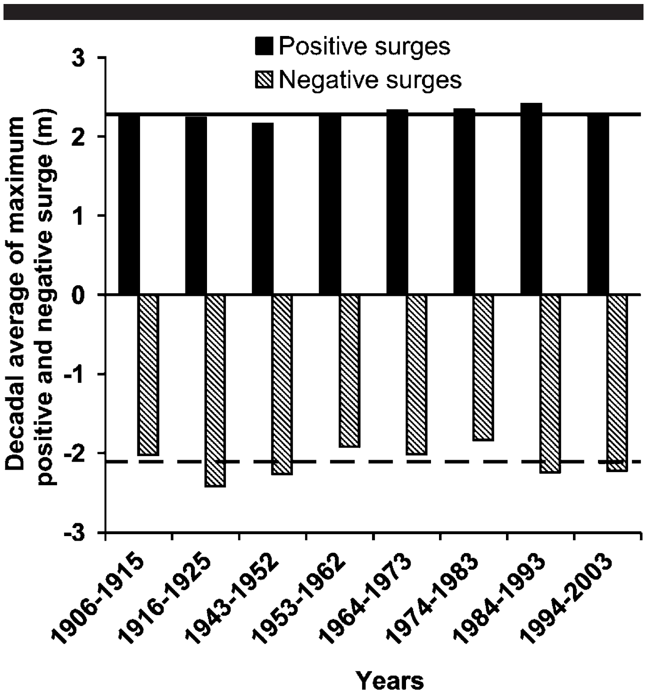

Figure 5. Decadal averages of the maximum positive and negative surges in each year. The solid and dashed lines represent the mean values for positive and negative surges, respectively.

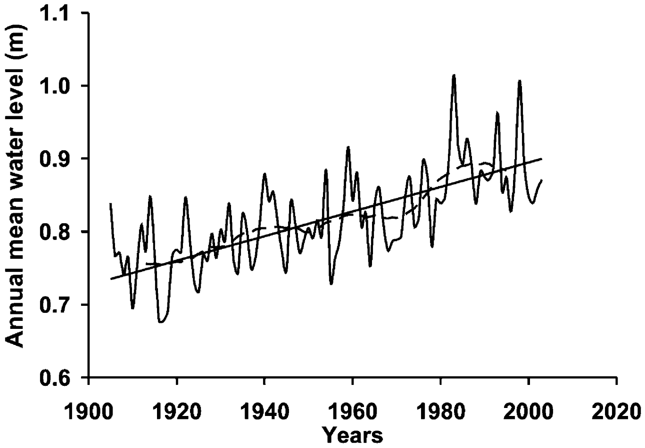

Figure 6. Linear regression (straight solid line) calculated from filtered data (curved dashed line) of the annual mean water levels for Buenos Aires (curved solid line).

It is worth noting that acceleration of mean water-level trend at Buenos Aires for the period 1950–1995 was +0.0524 ± 0.0054 mm/y^2. Although calculated on a larger timescale (46 y), this result seems to be in accordance with those from HOLGATE and WOODWORTH (2004), which show that coastal sea-level rise has accelerated over the last decade.

DISCUSSION AND CONCLUSIONS

Our analysis shows an increase in frequency and duration of positive surges in the last three decades, and a decrease in the same variables for negative surges. The decadal averages of frequency and duration of positive surges were 64 events and 67 h for the first five decades, and 89 events and 86 h for the last three decades. For negative surges, the decadal averages were 70 events and 51 h for the first five decades, and 42 events and 37 h for the last three decades.

The decadal averages of maximum and minimum heights for positive and negative surges show an increasing trend. However, the height of positive surges has decreased in the last decade, and negative surges have become more intense in the last two decades. This fact was responsible for the 14 occasions during 1984–2003 where the observed water level was less than −1 m below RTD, a troublesome situation for the supply of drinking water to Buenos Aires.

A possible explanation of the changes in frequency and duration of storm surges at Buenos Aires would seem to lie in the relative mean water-level rise. According to FLATHER *et al.* (2001), an increase in water depth will affect the generation, propagation, and dissipation of storm surges. In addition, ESCOBAR *et al.* (2003) suggested that there has been a slight southward movement of the western border of the South Atlantic semipermanent high-pressure system. This would seem to have increased the frequency of easterly winds over the Rio de la Plata, thereby increasing the number of positive surges. On the other hand, there are no analyses on any possible changes in NNW, N, and NNE winds for the last decades. From the observation of negative surges, it would seem that N and NNW winds are more effective. All these variations in the regime of storm surges could perhaps be due to the global climatic change.

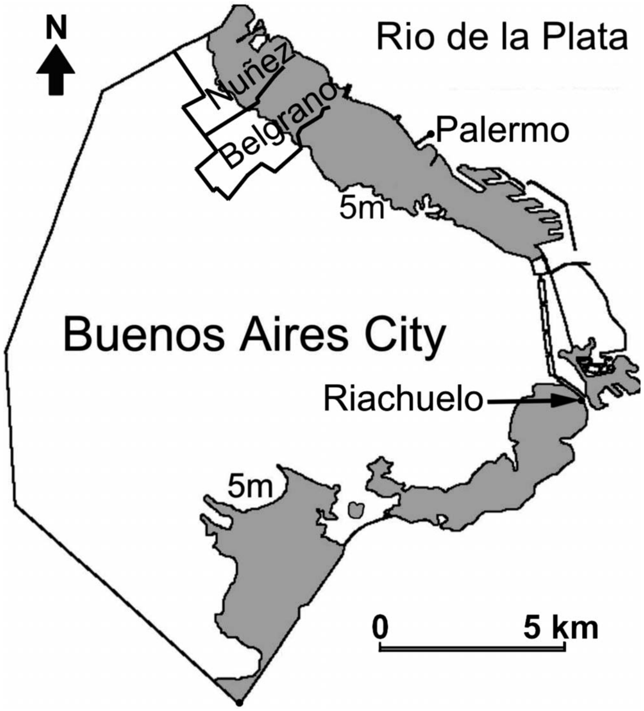

Figure 7. The city of Buenos Aires with the areas (in gray) that would be flooded if water level reached a height of 5 m with respect to RTD.

Apart from any possible change in the storm regime, a relative mean water-level rise causes the threshold chosen for classifying a meteorological event as a storm surge to be exceeded an increasing number of times and for more hours. The changes in frequency and duration of positive surges will worsen their impact on Buenos Aires, reduce the effect of coastal defenses, and increase the probability of flooding. For example, the Belgrano and Nuñez neighborhoods in Buenos Aires (Figure 7) are severely affected when the Rio de la Plata is higher than about 2.80 m (with respect to RTD), and they are completely flooded when the water level reaches 3.50 m. From the records of the last 50 y, it was found that on 126 occasions, the maximum water level was higher than 2.80 m, and on nine occasions, it exceeded 3.50 m. Global mean sea level is projected to rise by 0.09 to 0.88 m between 1990 and 2100, for the full range of scenarios considered by the IPCC (2001). For the scenario A2 and a mean sea-level rise of 0.60 m for the present century, D'ONOFRIO and FIORE (2003) calculated a return period of 150 y for a height of 5 m by the end of the century. Figure 7 shows in gray the zone of Buenos Aires city that would be flooded for a water level of 5 m with respect to RTD (RIMOLDI, 2001). This does not mean that the zones lower than 5 m are going to remain permanently flooded. However, these values should be taken into account when projecting drainage systems in Buenos Aires for the discharge of rainwater into the Rio de la Plata, as those systems will be hindered more frequently and for longer periods.

Because the acceleration of mean water-level rise at Buenos Aires is small, the impacts would take place in decades, thus making it difficult to assess them before damage is irreversible. In addition, a rise in mean water level in the Rio de la Plata would be followed by an increase in salinity from the Atlantic Ocean, which would also affect the coastal and estuary environments and the supply of drinking water.

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LITERATURE CITED

Balay, M.A., 1961. El Río de la Plata entre la Atmósfera y el Mar. Buenos Aires, Argentina: Servicio de Hidrografía Naval, Armada Argentina, H-621, 166p.

Celemin, A., 1984. *Meteorología Práctica,* Edición de Autor. Mar del Plata, Argentina: 311p.

Ciappesoni, H. and Salio, P., 1997. Pronóstico de sudestada en el Río de la Plata. *Meteorológica,* 22(2), 67–81.

D'Onofrio, E.E. and Fiore, M.M.E., 2002. Influencia de los caudales aportados por los ríos Paraná y Uruguay en el nivel medio del puerto de Buenos Aires. Report for the project: Assessment of Impacts and Adaptations to Climate Change. A Global Environment Facility project implemented by the United Nations Environment Program. *Informe Técnico No. 06/02.* Buenos Aires: Departamento Oceanografia, Servicio de Hidrografia Naval, 7p.

D'Onofrio, E.E. and Fiore, M.M.E., 2003. Estimación de niveles extremos en el Puerto de Buenos Aires contemplando el ascenso del nivel medio. *Resúmenes V Jornadas Nacionales de Ciencias del Mar.* Mar del Plata, Argentina, December 2003. Poster.

D'Onofrio, E.E.; Fiore, M.M.E., and Romero, S.I., 1999. Return periods of extreme water levels estimated for some vulnerable areas of Buenos Aires. *Continental Shelf Research,* 19, 1681–1693.

D'Onofrio, E.E.; Fiore, M.M.E., and Ruiz, E.H., 2003. Tendencia relativa del nivel medio del Río de la Plata en el Puerto de Buenos Aires. *Contribuciones a la Geodesia Aplicada,* (Buenos Aires, Argentina, FIUBA), pp. 7–14.

Dragani, W.C.; Mazio, C.A., and Nuñez, M.N., 2002. Sea level oscillations in coastal waters of the Buenos Aires Province, Argentina. *Continental Shelf Research,* 22, 779–790.

Escobar, G.; Camilloni, I., and Barros, V., 2003. Desplazamiento del anticiclón subtropical del Atlántico sur y su relación con el cambio de vientos sobre el estuario del Río de la Plata. *Anales de II Congreso Cubano de Meteorología y X Congreso Latinoamericano e Ibérico de Meteorología.* Sociadad Meteorológia de Cuba (SOMETCUBA) y Federación Lationamericana e Ibérica de Sociedades de Meteorología (FLISMET) (La Haba, Cuba, March 2003). CD-ROM.

Escobar G.; Vargas, W., and Bischoff, S., 2004. Wind tides in the Rio de la Plata estuary: meteorological conditions. *International Journal of Climatology,* 24, 1159–1169.

Fiore, M.M.E.; D'Onofrio, E.E.; Di Biase, F.A.V., and Stadelmann, M.A., 2001. Statistical analysis of storm surges in Buenos Aires. *2001 Joint Assemblies of the International Association for the Physical Sciences of the Oceans and International Association for Biological Oceanography* (Mar del Plata, Argentina, October 2001). Poster IB01-51.

Flather, R.A.; Trevor, B.; Woodworth, P.; Vassie, I., and Blackman, D., 2001. Integrated effects of climate changes on coastal extreme sea levels. Liverpool, UK: Proudman Oceanographic Laboratory Internal Document No. 140, 20p.

Foreman, M.G.G., 1977. Manual for tidal heights analysis and predictions. Institute of Ocean Sciences, Patricia Bay, Sydney, Canada. *Pacific Marine Science Report 77–10,* 97p.

Hamming, R.W., 1977. *Digital Filters.* Englewood Cliffs, New Jersey: Prentice Hall, 219p.

Holgate, S.J. and Woodworth, P.L., 2004. Evidence for enhanced coastal sea level rise during the 1990s. *Geophysical Research Letters,* 31, L07305, doi: 10.1029/2004GL0 19626.

Instituto Nacional de Estadística y Censo, 2001. Censo Nacional de Población, Hogares y Viviendas 2001. http://www.indec.mecon.ar.

IPCC (Intergovernmental Panel on Climate Change), 2001. Climate change 2001: the scientific basis. *In*: Douglas, B.C. and Ramírez, A. (review eds.), *Changes in Sea Level. Contributions of Working Group I to the Tirad Assessment Report of IPCC,* Chapter 11 pp. 639–693.

Lanfredi, N.W.; Pousa, J.L., and D'Onofrio, E.E., 1998. Sea-level rise and related potential hazards on the Argentine coast. *Journal of Coastal Research,* 14(1), 47–60.

Pawlowicz, R.; Beardsley, B., and Lentz, S., 2002. Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE. *Computational Geosciences,* 28, 929–937.

Pugh, D.T. and Maul, G.A., 1999. Coastal ocean prediction. *Coastal and Estuarine Studies,* 56, 377–404.

Rimoldi, H.V., 2001. Carta geológica-geotécnica de la Ciudad de Buenos Aires. Beunos Aires: Dirección de Geología Ambiental y Aplicada, Servicio Geológico Minero Argentino (SEGEMAR). Contribuciones Técnicas-Geología Ambiental No. 3, 29p.

Seluchi, M., 1995. Diagnóstico y pronóstico de situaciones sinópticas conducentes a desarrollos ciclónicos sobre el este de Sudamérica. *Geofísica Internacional,* 34, 171–186.

Seluchi, M.E. and Saulo, A.C., 1998. Possible mechanisms yielding an explosive coastal cyclogenesis over South America: experiments using a limited area model. *Australian Meteorological Magazine,* 47, 309–320.

Servicio de Hidrografía Naval, 1999. *Derrotero Argentino, Parte I, Río de la Plata.* Buenos Aires, Argentina: Armada Argentina, H-201, 296p.

Simionato, C.G.; Dragani, W.; Meccia V., and Nuñez M., 2004. A numerical study of the barotropic circulation of the Rio de la Plata estuary: sensitivity to bathymetry, the Earth's rotation and low frequency wind variability. *Estuarine, Coastal and Shelf Science,* 61, 261–273.

UNESCO, 1985. *Manual on Sea-Level Measurement and Interpretation.* Paris, France: International Oceanographic Commission, 83p.

Woodworth, P.L., 1990. A search for acceleration in records of European mean sea level. *International Journal of Climatology,* 10, 129–143.

□ RESUMEN □

La ciudad de Buenos Aires, situada en la margen occidental del estuario del Río de la Plata, se ve sometida, a menudo, a la acción de ondas de tormenta positivas y negativas debidas a fuertes vientos del sudeste y noroeste, respectivamente, que barren el estuario. Mientras que las ondas de tormenta positivas provocan severas inundaciones, las negativas afectan la navegación y el suministro de agua potable. Puesto que Buenos Aires es una ciudad densamente poblada, un estudio cuantitativo de las variaciones en el régimen de las ondas de tormenta ayudará a desarrollar medidas para aminorar sus impactos. Partiendo del análisis estadístico de niveles horarios del agua, se determinaron los cambios de frecuencia, duración y altura de las ondas de tormenta en el período 1905–2003. El cálculo de las constantes armónicas de la marea se llevó a cabo mediante análisis armónicos por períodos de 19 años para tener en cuenta cualquier variación de la marea astronómica. Las ondas de tormenta positivas y negativas fueron seleccionadas de los residuos entre los niveles observados y la marea predicha. Los resultados muestran que los promedios por década de frecuencia y duración para las ondas positivas se han incrementado en los últimos tres decenios, pero han disminuido para las ondas negativas. Las tendencias por década de las máximas ondas positivas y negativas, +1.46 ± 0.08 mm/año y +1.02 ± 0.09 mm/año, respectivamente, están en buen acuerdo con el aumento relativo del nivel medio del Río de la Plata para Buenos Aires: +1.68 ± 0.05 mm/año. Sin embargo, la altura de las ondas de tormenta positivas ha decrecido en la última década, mientras que las ondas de tormenta negativas han sido más intensas en los últimos dos decenios.