RISK MANAGEMENT AND VULNERABILITY TO SEA LEVEL RISE IN BRAZIL, WITH EMPHASIS TO THE LEGACY OF THE METROPOLE PROJECT IN SANTOS

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ABSTRACT

Sea Level Rise (SLR) poses a range of threats to natural environments and built infrastructure in coastal zones around the world. Coastal cities in Brazil are vulnerable to the effects of SLR and to the intensity of storms that induce more storm surges and coastal inundation. Studies on vulnerability of coastal cities in Brazil have been developed by multidisciplinary and multinational collaboration between teams of natural and social scientists. Perhaps the best example is the METROPOLE Project (*An Integrated Framework to Analyze Local Decision Making and Adaptive Capacity to Large-Scale Environmental Change),* a partnership between Brazil, United States and United Kingdom developed to evaluate how local government, stakeholders and citizens may decide about adaptation options related to SLR and extreme events projections. In this paper we show how some results of the METROPOLE project have been considered in the definition of public polices of climate change adaptation and for practical actions to increase resilience of Santos by reducing beach erosion, to reduce climate risk.

Keywords: Sea level rise; Climate change; Floods; Coastal erosion; Rainfall.

RESUMO

GESTÃO DE RISCO E VULNERABILIDADE À SUBIDA DO NÍVEL DO MAR NO BRASIL, COM ÊNFASE AO LEGADO DO PROJETO METRÓPOLE DE SANTOS. A elevação do nível do mar (SLR) representa uma série de ameaças aos ambientes naturais e à infraestrutura construída em zonas costeiras em todo o mundo. As cidades costeiras no Brasil são vulneráveis aos efeitos do SLR e à intensidade das tempestades que induzem mais ressacas e inundações costeiras. Estudos sobre vulnerabilidade de cidades costeiras no Brasil têm sido desenvolvidos por colaboração multidisciplinar e multinacional entre equipes de cientistas das ciências naturais e sociais. Talvez o melhor exemplo seja o Projeto METROPOLE (*Uma estrutura integrada para* *analisar tomada de decisão local e capacidade adaptativa para mudança ambiental de grande escala*), uma parceria entre Brasil, Estados Unidos e Reino Unido desenvolvida para avaliar como o governo local, partes interessadas e cidadãos podem decidir sobre opções de adaptação relacionadas a SLR e projeções de eventos extremos. Neste artigo mostramos como alguns resultados do projeto METROPOLE foram considerados na definição de políticas públicas de adaptação às mudanças climáticas e para ações práticas para aumentar a resiliência de Santos, reduzindo a erosão das praias, para reduzir o risco climático.

Palavras-chave: Elevação do nível do mar; Mudanças climáticas; Inundações; Erosão costeira; Chuva.

1 INTRODUCTION

Sea Level Rise (SLR) poses a range of threats to natural environments and built infrastructure in coastal zones around the world, and according to the Sixth Assessment Report of IPCC AR6 (IPCC 2021) "it is virtually certain that global mean sea level will continue to rise over the 21st century". This fact has already been detected by LAI et al. (2021), who observed an increase of concurrent heavy precipitation and storm surges to coastal areas across the world.

LOSADA et al. (2020) warn that in coming decades coastal areas will witness increased climate change effects, such as floods, loss of infrastructure operation, erosion and loss of ecosystem services, especially in coastal cities with port facilities. The loss of ecosystem resilience and factors external to climate change can make the population more vulnerable to environmental degradation and contribute to the growth of social inequality. Therefore, knowledge of the current dynamics of coastal areas and the risks associated with SLR is essential to take assertive measures with a view to combat the effects of climate change.

As in other parts of the world, the 279 Brazilian coastal cities are vulnerable to the effects of SLR and to more intense and frequent storms, which provoke more coastal erosion, coastal inundation and flooding. Studies on vulnerability of coastal cities in the country have been developed by multidisciplinary and multinational collaboration between teams of natural and social scientists. An example is the METROPOLE Project (*An Integrated Framework to Analyse Local Decision Making and Adaptive Capacity to Large-Scale Environmental Change),* an international scientific initiative approved in the scope of the Belmont Forum and financed by research agencies in Brazil, in the UK and in the USA, developed to evaluate how local government, stakeholders and citizens may decide about adaptation options related to SLR projections. Results of METROPOLE helped to identify broad preferences and orientations in adaptation planning, which the community co-developed in a joint effort with the project team. The study has projected climate scenarios and economic impacts for Santos (Brazil), Selsey (UK) and Broward County (USA). Among the main results for Santos, the study showed that even in a low SLR scenario, cumulative damage from climate change between 2010 and 2100 will reach 242 million US dollars in Santos (MARENGO et al. 2017a, b; PATERSON et al 2017; GUTIERREZ 2022).

The METROPOLE Project is based on an innovative approach, as it is a co-production between scientists, decision makers and population, a partnership that facilitates the internalization of the results as well as the implementation of public policies and appropriate legislation, allowing a better management of the area (MARENGO et al. 2017 a, b).

The present study starts presenting a short overview of impacts of SLR in some coastal Brazilian cities based on previous studies, which attest to the urgency of this issue on the national environmental and political agenda. It also discusses some results of the METROPOLE Project, as well as new initiatives post METROPOLE adopted by the Municipal Government of Santos, SP, as environmental policies to cope with the impacts of climate change on SLR were implemented by means of a special committee on climate change and adaptation to SLR in the city, a legacy of the project. Finally, it is presented the general structure of a new project that is independent of the Metropole Project, but also aims to mitigate the process of coastal erosion occurring close to the Port of Santos.

The utmost objectives of these environmental policies are to increase resilience of the city of Santos to coastal erosion, coastal inundation and climate change risks due to SLR, highlighting that despite the rapidity and severity of coastal erosion processes at a time of rising sea levels, a continued partnership between the scientific community, the population, local decision-makers and municipal government is a sure way to mitigate a serious problem that afflicts coastal cities worldwide.

2 TRENDS OF SLR IN BRAZILIAN COASTAL CITIES: AN OVERVIEW

With a coastline of approximately 8,000 km, the Brazilian coastal zone is home to 26.58% of the country's population (IBGE 2011) and plays important ecological functions. Because the area has a prominent role in the national economy, any impact on these locations reverberates in the country's economy. Considering the projections of SLR and the 2010 population growing rate, STRAUSS et al. (2015) found that 8% of the inhabitants of coastal areas in Brazil would be affected because of global warming of 4 ºC until 2080, but this percentage could reach 5% if the warming was limited to 2 ºC. However, as in other parts of the world, the Brazilian coastal zone is a changing agent and requires knowledge and monitoring of shore ecosystem processes and population dynamics.

Trends in SLR for the Brazilian coast is constantly changing and has been reviewed by NEVES & MUEHE (1995); MESQUITA (2003) and MUEHE (2006). LOSADA et al. (2013) examined changes in sea level along with variations in tidal levels, storm surges and extreme events for different historical series and concluded that sea level is rising, storm surges are increasing, especially in the South, and El Niño events positively affect the sea level. The influence of El Niño in storm surges in more southern locations of the country was also pointed out by MACHADO et al. (2019).

Despite the efforts, few studies assess the vulnerability of specific coastal cities in Brazil to rising sea levels and climate changes. Table 1 shows a summary of SLR in some areas of the Brazilian coast

TABLE 1 – SLR in the Brazilian coast (Modified from: KLEIN & SHORT 2016, PBMC 2017). Units are in mm year^{-1}.

Author	*Local*	*Change rate*	*Period*
PIRAZOLLI (1986)	Recife (PE)	3.7	1950-1970
	Salvador (BA)	1.6	
	Canavieiras (BA)	3.1	
	Imbituba (SC)	0.6	
AUBREY et al. (1988)	Fortaleza (CE)	0.3	1950-1970
	Belém (PA)	3.4	
	Recife (PE)	0.2	
	Salvador (BA)	2.7	
	Canavieiras (BA)	4.1	
	Rio de Janeiro (RJ)	3.6	
	Imbituba (SC)	0.7[1]	
SILVA (1992)	Rio de Janeiro (RJ)	1.6	1965-1986
HARARI CAMARGO (1994)	Recife (PE)	5.6	1946-1988
LOSADA et al. (2013)	Salvador (BA)	~2.0^{-}	1950-2009
HARARI et al. (2019)	Santos (SP)	1.3 ± 0.3	1945-1990
	Santos (SP)	2.7 ± 0.6	1993-2014
HARARI et al. (2022a)	Baixada Santista (SP)	2.38 to 3.39 ±0.01	1993-2021
	Ubatuba (SP)	2.24 ± 0.01	1993-2021
HARARI et al. (2022b)	Cananéia (SP)	2.23 ± 0.01	1993-2021

The change rates observed in various Brazilian coastal cities highlight the need for new studies and continuous investments and adaptation measures in face of climate change effects, with a focus on reducing risks to disasters and minimizing the impacts caused by extreme and meteorological-oceanographic events observed in the present and projected for the future (PBMC 2017).

Given the different dynamics of the Brazilian coast, local assessments are needed to identify the processes in each area. The main conclusions of studies undertaken in some coastal cities in Brazil are presented below.

Evaluating the city of Recife, HARARI et al. (2008) found an increase of 0.24 m between 1946 and 1988 due to, among many causes, a SLR rate of about 5.6 mm/year, corresponding to an increase of 0.24 m between 1946 and 1988 and a historically inadequate occupation of the coastline. Future scenarios for the city of Recife are worrisome, since a SLR of about 0.63 m is expected according to results for the RCP8.5 scenario, from an ensemble of CMIP5 models for equivalent to a 4 °C warmer world with focus on Latin America and Caribbean for the period 2081–2100 (CHURCH et al. 2013, LOSADA et al. 2013). For the Metropolitan Region of Recife, which encompasses neighbor towns, COSTA et al. (2010) state that a SLR of 0.5 m. would produce an estimated flooded area of 25.38 km², while a 1 m could inundate an area of 33.71 km². They also indicate that in the entire coast of Recife, 81.8% of urban constructions situated less than 30 m from de shoreline and located 5 m below ground level would be severely affected by changes in sea level.

For Rio de Janeiro city, the SLR could raise between 1.1-1.2 m by 2100 (REYER et al. 2015). According to GUSMÃO (2011), in a scenario of 1.0 m of SLR the accumulated area reached that could potentially be flooded would be 83.02 km², while at a rise of 1.5 m this area could reach 124.67 km², which corresponds to 10.3% of Rio de Janeiro’s territory.

PAULA et al. (2015) analyzed storm surges in Fortaleza, whose coast has about 20 km long with rigid structures of coastal engineering and average wave height of 1.55 m. The authors concluded that the strongest events of storm surges were associated with North Atlantic extratropical cyclones, especially in Azores. In a survey for the period between 1953 and 2010, when there was also a significant urban expansion, it was observed an increasing trend in the frequency of episodes, intensified from 2008.

MONTANARI et al. (2020) evaluated possible economic impacts in the city of Florianópolis (Santa Catarina state) based on the IPCC (2013) global estimates of SLR in 2100 of 0.98 m and on urban and population growth projections for the same period. Results showed that 13.4% of the total area of the city would be affected, mangroves and beaches. Considering the worst scenario of IPCC and the urban and population growth scenario for 2100 a sudden disaster would cause losses of 12 US$ billion. However, the authors alert that this value is underestimated, as many other parameters were not considered, like ecological losses and even the loss of human lives.

EGUCHI & ALBINO (2021) found 208 episodes of storm surges episodes in the state of Espírito Santo for the period 1948 to 2008 and concluded that the combination of the Southern Annular Mode in the positive phase and ENSO in the neutral phase presented the highest values for all storm surges parameters.

It is noteworthy that the increase in the frequency of storm surges in Brazilian coastal cities indicates that this phenomenon would be related to both global climate change and major transformations due to the intense urbanization, such as changes in coastal morphology, increased beach erosion with sediment transfer, and degradation of natural barriers such as mangroves. Further, these effects can be even more dramatic when associated with multiple events such as extreme precipitation.

Adaptation of coastal regions in Brazil poses greater challenge than in developed countries, given the limitations on the adaptation capacity of a developing country (PBMC 2014), the length of the country's coastline and the levels of vulnerability of population, which combined with exposure to meteorological-oceanographic conditions and more severe weather extremes can jeopardize the habitability of a given region (IPCC 2012). However, it is one of the most pressing issues for Brazilian society and cannot be delayed.

3 THE CASE OF SANTOS AND SURROUNDINGS: BETWEEN DEVELOPMENT AND DANGER

Located 60 km south of São Paulo, Santos is a regional leader among the municipalities that encompass the Metropolitan Region of Baixada

Santista (MRBS). The city encloses the most important port of Brazil and the second of Latin America, whose construction initiated in 1888, and has been in continuous expansion since then, being top 46 in world container transport, with a volume in 2019 of 4.17 million TM (WORLD SHIPPING COUNCIL 2020). Besides the port, railways and roads ensure the integration of the production to regional, national and world trade flow. Santos is spread over a total area of 280.7 km², distributed between insular (São Vicente Island) and continental territories (Figure 1). Although only 15% of its area lies on the São Vicente Island, this area concentrates 99.3% of the total municipality population, which are 428,703 inhabitants (FUNDAÇÃO SEADE 2020).

Santos represents well the typical social asymmetry of Brazil, with a clear socio-spatial stratification. Data from the FUNDAÇÃO SEADE (2020) reveal that while some economic and social indicators of Santos are high (its Gross Domestic Product and its Municipal Human Dimension Index are US$ 4,1 billion and 0.840, respectively), its Gini Index (0.55) exposes, unequivocally, the huge social disparities within the city. The Ponta da Praia (Figure 1), located on the Southeast zone of the São Vicente Island represents a region with expensive real estate properties and where the Port and related facilities are located. In comparison, the Northwest zone includes poor regions with low value properties on elevated terrain (MARENGO et al. 2017a).

In turn, the MRBS has a total population of 1,831,884 inhabitants (FUNDAÇÃO SEADE 2020) and although it encompasses nine municipalities, the imbalance among them due the poor process of regional integration is notorious, with distinct speeds and strengths of economic development. Considering the entire MRBS, 5.4% of the population live in areas of very high

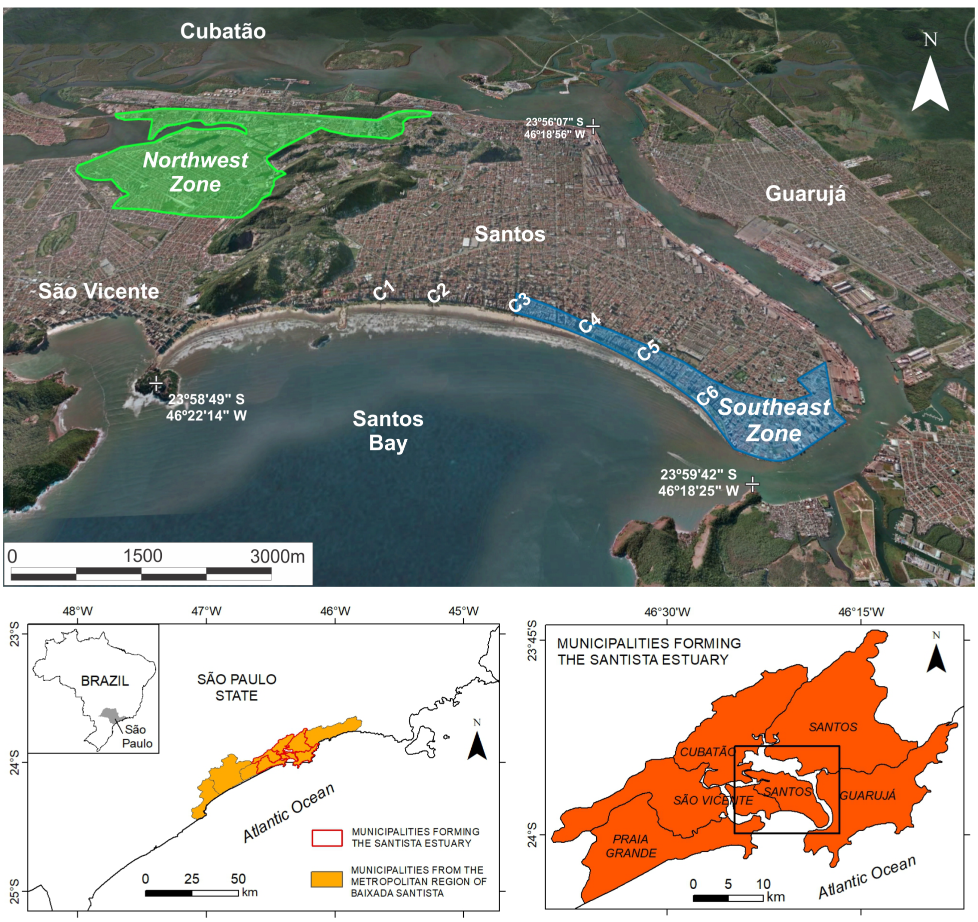

FIGURE 1 – Location of the Santos insular area. Northwest Zone (NWZ) and Southeast Zone (SEZ) are the studied areas in the METROPOLE Project. C1 to C6: drainage canals. (Source: SOUZA et al. 2019). The Ponta da Praia region is in the Southeast zone, as shown in MARENGO et al. (2017b).

vulnerability, 2.3% are in areas of high vulnerability, and 8.7% reside in areas of medium vulnerability (SANTOS et al. 2019). While some municipalities of the MRBS experienced significant increase of population in the last four decades, Santos presented a population decline, largely related to the migration of population to neighboring cities, where the price of land is lower. In addition, as in many other coastal cities of the world, Santos attracts contingents of elderly people, generally with higher incomes.

Landslides, floods, coastal erosion and coastal flooding (Figure 2) as well as gas and liquid leaks from petrochemical plants and oil spills, bring constant risks to the natural environment and the population, although the exposure to some hazards and risks is unevenly distributed in Santos: the most vulnerable groups live outside the formal jurisdictions of municipal government, are ill-served by urban infrastructures like running water, sewer, trash pickup, electricity or paved roads and live in hazardous sites, such as in Northwest Zone (see Figure 1), as the increase of land value of some areas forced part of the population to move to degraded environments in periphery.

Santos and surroundings register high annual total rainfall, particularly concentrated in spring and summer (September to March). The average annual rainfall for the period of 1980-2015 was 2,508.2 mm, but 40% of the years presented above-average volumes of rain, while the other 60% were below the average (SANTOS et al. 2019). For the same period, NUNES et al. (2019) observed that over 40% of the days showed precipitation, which ranged from 0.1 to 332.9 mm, with 25% of the rainy days accounting for 71% of the total rainfall. This concentration is a key element in the outbreak of hazards such as floods and landslides.

SOUZA et al. (2019) evaluated data from extreme/intense storm surge events (SS, involving strong waves) and meteorological tide/rainfalls (MT/R, without strong waves) for the period 1928-2016 in Santos and neighbor towns and found 238 events, among them 115 SS and 113 MT/R (Table 2). The authors concluded that 76.5% of the SS have occurred during the first 16 years of the current century, an increase of 3.3 times (or an average rate of 5.2 events/year) in SS frequency as compared with the 20th century; for MT/R 47.2% have occurred in the 21st century.

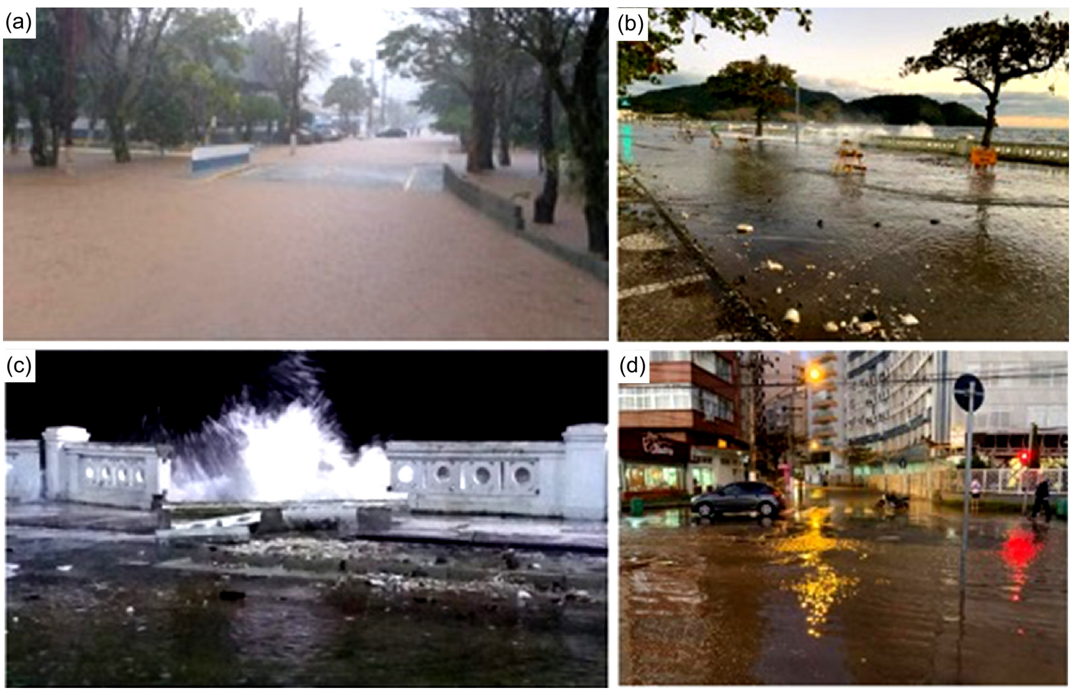

FIGURE 2 – a) Flooding due to concurrent intense rainfall and extreme meteorological tide episode of February 21, 2020 at Ponta da Praia region; b) and c) Overtopping, coastal inundation and coastal erosion caused by a storm surge at the Ponta da Praia region on July 6, 2020; d) Coastal inundation in the Avenida Imperatriz Leopoldina at the Ponta da Praia on July 6, 2020. (Source: Civil Defense of Santos Archive).

TABLE 2 – Summary of the conditions for the occurrence of storm surges and meteorological tide/rainfall extreme/intense events. (Source: modified from SOUZA et al. 2019).

Indicator	*Storm Surges (115 events)*	*Meteorological Tides/Rainfalls (123 events)*
Distribution	Highest nº of events: 2000s (49 = 42.6%); year 2010 (14); 33% in May and July; 76.5% between April and September. 21st century (2000-16): 76.5% of the total; increased by 3.3 times relative to the 20th century.	Highest nº of events: 2000s (34 = 27.6%); years 2006 and 2014 (8 each); 16.3% in March; 50.4% between January and April. 21st century: 47.2% of the total; reduction by 0.9 or constant relative to the 20th century.
Duration	Average: 1.9 days (1-8 days)	Average: 1.8 days (1-5 days)
Lunar Phase	52.2%: during spring tides 34.8%: during neap tides	65.6% during spring tides 18.7%: during neap tides
Meteorological Tide Height	Average 0.35 m (maximum: 0.78 m); predominant 0.41–0.60 m (35.7%); greatest heights (>0.7 m) in January, May and June.	Average 0.38 m (maximum: 0.78 m); predominant 0.41–0.60 m (36.2%); greatest heights (>0.7 m) in January, May and June.
Rainfall Volume	Duration interval: average 33.1 mm; maximum 227.1 mm; 0–60 mm accumulated = 84.3%. Evolution period: average 63.9 mm; maximum 468.4 mm; 0–100 mm accumulated = 83.5%.	Duration interval: average 51.3 mm; maximum 277.8 mm; 0–60 mm accumulated = 72.1%. Evolution period: average 103.0 mm; maximum 468.4 mm; 0–100 mm accumulated = 62.3%.
Winds (offshore data)	Intensity: average 6.2 m/s (moderate breeze); maximum 20.6 m/s (gale); 75.2% between 3.4 and 7.9 m/s (gentle-moderate breeze). Direction: average 204° (SSW) (2–358°); SW/S/WSW predominate (37.8%).	Intensity: average 7.0 m/s (moderate breeze); maximum 17.0 m/s (near gale); 62.9% between 3.4 and 7.9 m/s (gentle-moderate breeze). Direction: average 191° (S-SSW) (2–340°); SW/SSW predominate (30.9%).
Significant Waves (offshore data)	Height: average 2.8 m; maximum 7 m; 75.7% between 1.5 and 3.0 m; 45% between 2.5 and 3.0 m; highest average in May (3.0 m). Direction: average 177° (S) (90–300°); S/SSE predominate (41.8 and 25.5%).	Height: average 2.2 m; maximum 5.5 m; 80.4% between 1.5 and 3.0 m; 50% between 1.5 and 2.0 m; highest average in May–June (2.7 m). Direction: average 162° (SSE) (23–280°); S/SSE predominate (26.7 and 17.1%).
ENSO	El Niño: 54.8%; moderate to weak intensities predominate (40.9%). La Niña: 40%; moderate intensity predominates (21.7%). Neutrality: 5.2%	El Niño: 46.3%; moderate to weak intensities predominate (35%). La Niña: 37.4%; weak intensity predominates (17.1%). Neutrality: 16.3%

Coastal erosion processes in Santos have affected Ponta da Praia since the late 1930s, mainly due to the waterfront avenue construction above the beach sands (Figure 3) (SOUZA et al. 2012). Other contributions include destruction of the dunes, beach ridges and mangroves; alterations to the drainage network; increasing impermeability of the land close to the coastline; landfills on the estuarine channel; installation of hardy structures transverse to the coastline, such as the seven drainage canals which cross the surf zone causing changes in longshore current patterns (see figures 1 and 3); construction of retaining walls and stone bulkheads; dredging in fluvial and estuarine channels and Santos Bay; removal of sand from the beaches; sea-level rise; and increased occurrence of extreme events (storm surges and meteorological tides) (SOUZA et al. 2016a, b; 2019). Figure 4 shows the historical evolution of the beach erosive process.

FIGURE 3 – Beach erosion at Ponta da Praia in the mid-1940s, a few years after the construction of the seafront avenue above the beach sands. C4, C5 and C6 are drainage canals. (Source of the photo: www.novomilenio.inf.br/santos).

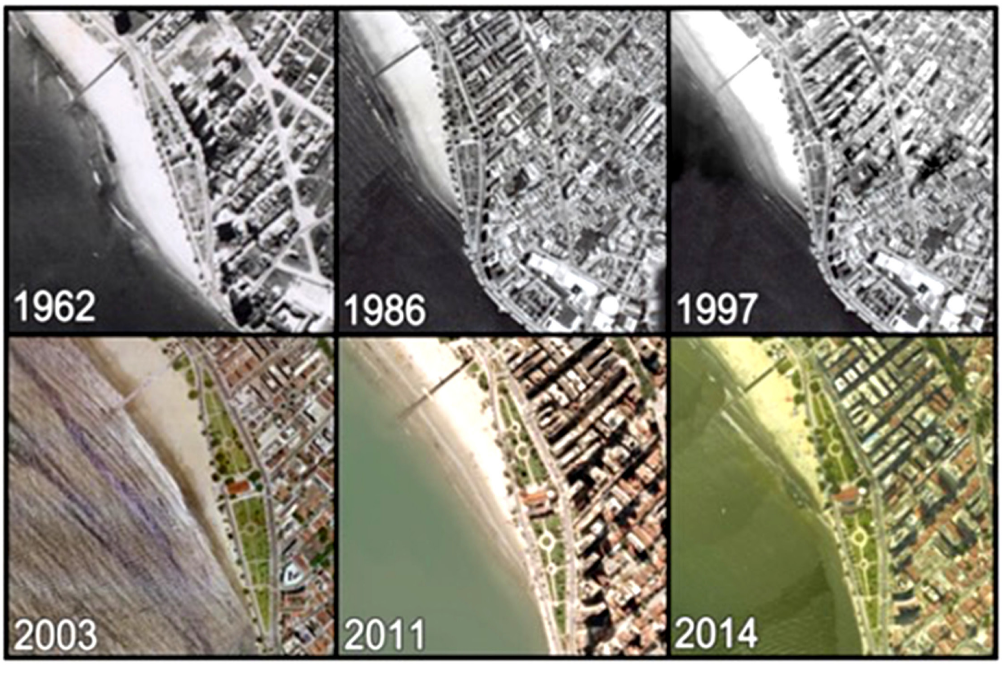

FIGURE 4 – Chronology of beach erosion process at the Ponta da Praia closer to the Canal 6 (Source: Santos Municipality).

4 POST METROPOLE INITIATIVES

4.1 Environmental public policy of climate change and adaptation to SLR in Santos

The Municipality of Santos created in 2015 the Municipal Commission for Adaptation to Climate Change (CMMC) with the support of the Ministry of the Environment of Brazil (MMA) and the German collaboration BMUV/GIZ (SANTOS MUNICIPALITY 2022a). An updated Municipal Plan for Adaptation to Climate Change of Santos (PMCS), now called PACS Climate Action Plan of Santos (SANTOS MUNICIPALITY 2022b), the creation of the Municipal Plan for the Conservation and Recovery of the Atlantic Forest

(PMMA, SANTOS MUNICIPALITY 2022c), the implementation of Nature-Based Solutions (Nbs) in the Ecosystem-based EbA Adaptation Pilot Project at Morro Monte Serrat (SANTOS MUNICIPALITY 2022d) are some actions taken by the municipality of Santos to consider the climate agenda. Another action was the creation of the Climate Change Division in the municipality (By Decree 8.886 of 03/11/2020; https://diariooficial.santos.sp.gov.br/edicoes/inicio/download/2020-03-12).

Thus, there is an effort in Santos to promote a joint action that involves the municipal and federal government, a partnership with the university and the German government, aiming at adaptation. Among the fruits of these activities are the many results generated by the Metropole project, which included scenarios of impacts for 2050 and 2100 if adaptation measures are not taken, and actions that are already being put into practice, such as linear segments of breakwaters to protect against erosion and support the accumulation of sand.

4.2 The Pilot Project for beach protection in Santos coastal region

Threatened by extreme events such as floods and rising sea levels, the coast of Santos was selected for a pilot project by the Ministry of the Environment (MMA). The objective of the pilot project is to stimulate climate resilience across the country, through the project Supporting Brazil in the Implementation of the National Agenda for Adaptation to Climate Change (ProAdapta; https://www.giz.de/en/downloads/2020_10%20-%20ProAdapta_BMU_15.9060.3-001.00_EN.pdf). ProAdapta is one of the projects of the technical cooperation between Brazil and Germany to achieve the commitments assumed in the international agreements on the climate. The Project takes place in the context of the International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Protection and Nuclear Safety (BMU) of Germany.

The region vulnerability is the main reason to choose Santos for the first stage of the project. For example, in episodes of heavy precipitation and storm surges affected the canals that cut through the city overflow and flood the streets. Associated with storms and strong winds, rising sea levels can also damage urban infrastructure and cause economic losses in the Port area. The neighborhood Ponta da Praia was selected to deploy equipment to minimize the impacts of storm surges, showing the municipality is committed to strengthening its capacity to adapt. These measures have the potential to avoid economic and social harm. In the case of Santos, the vulnerability analysis already carried out by the municipality shows that, in one of the points of the city, the economic damages can reach US$ 200 million in the real estate sector only.

Another initiative joined Santos' local government and the University of Campinas (UNICAMP) for the development of a pilot project anchored in blue engineering premises for beach protection. Therefore, the ProAdapta is a beach restoration pilot project designed to protect the beach from further erosion along the Ponta da Praia, in Southeast Santos. For this, submerged breakwaters were deployed keeping the water depths above the crown height of the longitudinal segment at least 0.50 meters in relation to the astronomical tide (GARCIA & GIRELI 2019). This pilot project was defined to provide a solution with a low cost of implementation and, therefore, of limited dimensions. However, it can provide adequate monitoring of the response of the environment to the work in a short term (UNICAMP 2017). The definition of the Pilot Project is supported by studies by OH & SHIN (2006), who implemented work on submerged breakwaters in the city of Young-Jin (South Korea), under similar conditions.

The proposed pilot project consists of two linear axis of breakwaters (Figure 5), the zonal axis being rooted next to the beach wall and following into the sea for 275 m, and the meridional axis extends longshore for 240 m. The main function of the breakwaters designed geometry is to protect and support the accumulation of sand between them and the current coastline, allowing the tidal currents, that flow into the mouth of the Santos estuary in the flood, to pass over the bags, serving as a sediment trap. As it is submerged equipment, it allows the adequate circulation of the surface currents, avoiding the deterioration of the water quality in the area, so that people can enjoy swimming. A total of 49 bags were used to make the breakwaters, each having 20 and 25 m of length and 9 and 12 m of the perimeter, filled with approximately 7 thousand m^3 of local sand and weighing 300 tons (GARCIA & GIRELI 2019).

The meridional axis main function is decreasing the wave energy by breaking over it. In addition, the structure aims to correct the local wave direction that starts to reach the walls with an

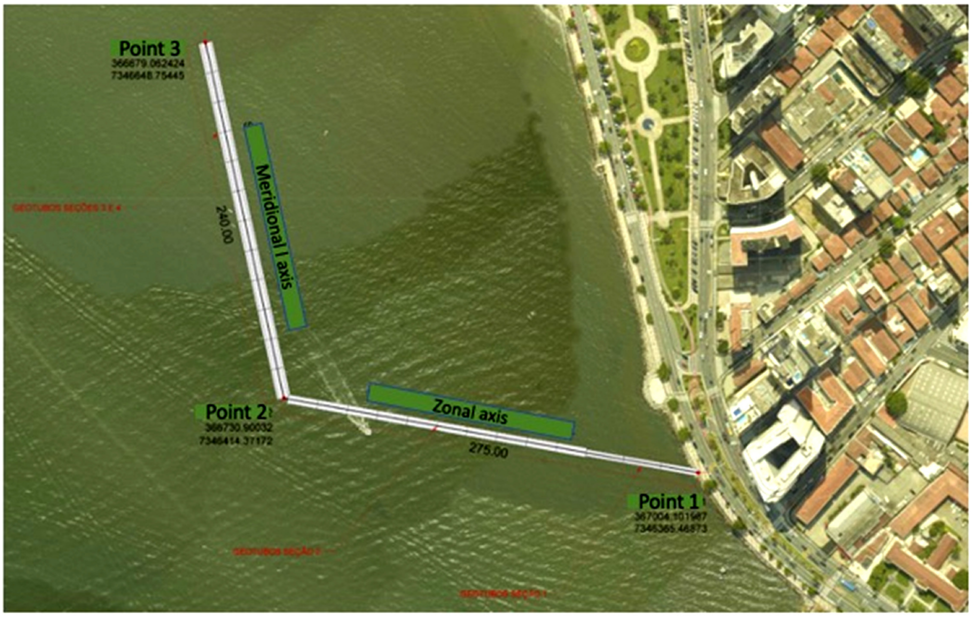

Figure 5. Detail of the Pilot Project for mitigation and monitoring *Ponta da Praia* erosion processes showing the main zonal and meridional axis with the submerged breakwaters (Source: GARCIA & GIRELI 2019).

orthogonal angle, reducing the longshore current, resulting in a beach accretion.

It is worth remembering that extreme events arising from climate change such as storm surges may be more frequent and intense. The main objective of the submerged breakwaters is the restoration and stabilization of the beach profile with the retention of sand inside, restoring its natural capability of decreasing the wave energy and protecting its backward. In addition, it allows to improve in the short term the conditions of the monitored area, to assess the performance of the projected structure against the effects of the storm surges. In other words, the submerged breakwater's function is to reduce the energy of the waves and decrease their impacts on the local urban infrastructure (UNICAMP 2017).

The use of structures of this nature greatly reduces the need for large shipments of material with high costs, causing minimal visual impact, allowing for monitoring and supporting the indication of a definitive configuration of submerged breakwaters. In addition, it protects the stretch of influence of the equipment, if compared to hard engineering works, which require a lot of iron and concrete with extremely high cost. Besides, the used submerged breakwaters were placed in a short period of time, reducing unwanted impacts and allowing an easy demobilization. The adopted solution also serves to increase knowledge about the impacts on adjacent areas and indicate future definitive interventions for the most affected regions.

Meanwhile, more efficient short and medium-term solutions are needed, as the local community calls for more effective measures to contain the advance of the sea. In this sense, the implementation and monitoring of this pilot project carried out in Ponta da Praia is a viable alternative in the short term. More technical details on the dimensions and characteristics of the breakwaters can be found in GARCIA & GIRELI (2019).

The pilot project considers climate risks in policies at the federal, state and municipal levels with the aim of establishing actions at the local level. In addition to Santos, other regions of the country will be covered by the project, which considers the establishment of actions at the local level, in addition to sensitizing the private sector and civil society in the search for solutions.

5 CONCLUSIONS

Seaward hazards associated with climate change like coastal erosion and flooding due to SLR might be amplified, bringing about major risks to coastal cities. Despite the increase in studies that point to the risks of urbanization and environmental change in coastal cities around the world, there is a notorious lack of synchrony among knowledge, collective awareness and action in urban development policy and planning practices, including adaptive measures. And without a coordinated action, the property damage, the compromise of biodiversity, the loss of coastline, of infrastructure, and the impacts in fisheries, port activities, and other industries and enterprises will contribute to diminish human well-being and the ecosystem services provided by the coastal zone.

In Brazil, the population of coastal areas generates about 30% of all national wealth (IBGE 2014). Significant part of this population is engaged in activities related, directly or indirectly, to tourism, oil and natural gas production, ports and navigation fishing and services that meet the economic dynamics generated by these municipalities and others close to the coastal zone.

However, numerous Brazilian coastal cities like Rio de Janeiro, Florianópolis, Recife and Fortaleza have registered an increase in calamitous occurrences associated with SLR, but the adoption of adaptation measures has been slower than the escalation of impacts.

Results from the METROPOLE Project has been used for the municipality of Santos to subsidize measures to face problems arising from climate change and in the formulation of public policies. Therefore, the METROPOLE Project is an important milestone in Santos' environmental agenda, contributing to a new institutional arrangement for Climate Governance in the city, in which the local government not only works with issues involving climate change but creates in its structures a specific sector to manage these actions. Based on the scientific results from this project, since the end of 2015 the Municipality of Santos created the Municipal Commission for Adaptation to Climate Change CMMC and the PACS Climate Action Plan of Santos to put into action a local multilevel governance process of the risks arising from global climate change. These efforts emphasize the need to build a resilient and sustainable city that promotes the effective reduction of the risk of natural disasters in its territory. Santos was the first coastal city of the state of São Paulo to implement a Plan for Climate Change, a METROPOLE project legacy.

Santos has also developed several actions in conjunction with ProAdapta and has provided support for the development of pilot projects to control beach erosion of low impact and cost, such as the submerged breakwaters. In the short term, these actions might monitor the areas under threat and contribute to reducing the damage caused by invasion of sea water into the existing urban infrastructure, such as avenues, walkways, parks and parking lots, as well as apartment buildings, recreational facilities, houses and shops. The designed pilot project resulted in a submerged breakwater was implemented in 2018 and so far, the primary results are promising.

It is widely recognized that SLR is an underlying cause of changes in vulnerability of coastal populations. In the long term, policy makers might evaluate whether current approaches for coastal development and protection need to be modified to reflect the increasing vulnerability to accelerating rates of SLR. This may be a serious problem in Brazil, where there are few existing policies that explicitly address or incorporate SLR into decision making, from the municipal to the national level. In this study we also discuss some actions that the City of Santos implemented to cope with SLR and climate change, and that were considered in the context of scientific results of the METROPOLE Project.

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7 REFERENCES

AECID – AGENCIA ESPAÑOLA DE COOPERACIÓN INTERNACIONAL PARA EL DESARROLLO. 2018: *I Encuentro regional sobre gestión de riesgos vinculados al cambio climático en zonas costeras: experiencias y prioridades de trabajo para los próximos años.* 12 y 13 de diciembre de 2017. Centro de Formación de la Cooperación Española en La Antigua Guatemala, 68 p.

ALMEIDA, L.Q.; WELLE. T.; BIRKMANN, J. 2016. Disaster risk indicators in Brazil: A proposal based on the world risk index. *International Journal of Disaster Risk Reduction*, 17: 251-272. https://doi.org/10.1016/j.ijdrr.2016.04.007

ARAGÃO, L.E.O.; MARENGO, J.A.; COX, P.M.; BETTS, R.; COSTA. D.; KAYE, N.; ALVES, L.; SMITH, L.T.; CAVALCANTI, I.F.A.; SAMPAIO, G.; ANDERSON, L.O.; HORTA, M.; HACON, S.; REIS, V.L.; FONSECA, P.A.M.; BROWN, I.F. 2016. Assessing the Influence of Climate Extremes on Ecosystems and Human Health in Southwestern Amazon Supported by the PULSE - Brazil Platform. *American Journal of Climate Change*, 5: 399-416. http://dx.doi.org/10.4236/ajcc.2016.53030

AUBREY, D.G.; EMERY, K.O.; UCHUPI, E. 1988. Changing Coastal levels of South America in the Caribbean region from tide-gauge records. *Tectonophysics,* 154: 269-284. https://doi.org/10.1016/0040-1951(88)90108-4

BARBIER, E. 2015. Hurricane Katrina's lessons for the world, *Nature*, 524: 285-287. https://doi.org/10.1038/524285a

BURCH, S. 2010. Transforming barriers into enablers of action on climate change: Insights from three municipal case studies in British Columbia, Canada. *Global Environmental Change,* 20(2): 287-297. https://doi.org/10.1016/j.gloenvcha.2009.11.009

CARVALHO, L.M.V.; JONES, C.; LIEBMANN, B. 2004. The South Atlantic Convergence Zone: Intensity, Form, Persistence, and Relationships with Intraseasonal to Interannual Activity and Extreme Rainfall. *Journal of Climate,* 17: 88-108. https://doi.org/10.1175/1520-0442(2004)017%3C0088:TSACZI%3E2.0.CO;2

CAVALCANTI, I.F.A.; NUNES, L.H.; MARENGO, J.A.; GOMES, J.L.; SILVEIRA, V.P.; CASTELLANO, M.S. 2017. Projections of precipitation changes in two vulnerable regions of São Paulo State, Brazil. *American Journal of Climate Change,* 6: 268-293. https://doi.org/10.4236/ajcc.2017.62014

CHOU, S.C.; LYRA, A.; MOURAO, C.V.; DERECZYNSKI, C.; PILOTTO, I.; GOMES, J.; BUSTAMANTE, J.; TAVARES, P.; SILVA, A.; RODRIGUES, D.; CAMPOS, D.; CHAGAS, D.; SUEIRO, G.; SIQUEIRA, G.; MARENGO, J.A. 2014. Assessment of Climate Change over South America under RCP 4.5 and 8.5 Downscaling Scenarios. *American Journal of Climate Change*, 3: 512-527. http://dx.doi.org/10.4236/ajcc.2014.35043

CHOU, S.C.; MARENGO, J.A.; SILVA, A.J.; LYRA, A.A.; TAVARES, P.; GOUVEIA SOUZA, C.R.; HARARI, J.; NUNES, L.H.; GRECO, R.; HOSOKAWA, E.K.; ARAGÃO, L.E.O.; ALVES, L.M.; 2019. Projections of Climate Change in the Coastal Area of Santos. In: L. Nunes, R. Greco, J. Marengo (Eds.) *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options*. Springer, p. 60-73.

CHURCH, J.A.; CLARK, P.U.; CAZENAVE, A.; GREGORY, J.M.; JEVREJEVA, S.; LEVERMANN, A.; MERRIFIELD, M.A.; MILNE, G.A.; NEREM, R.S.; NUNN, P.D.; PAYNE, A.J.; PFEFFER W.T.; STAMMER, D.; UNNIKRISHNAN, A.S. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* IPCC, p. 1137-1216.

COSTA, M.B.; MALLMANN, D.L.B.; PONTES, P.M.; ARAUJO, M. 2010. Vulnerability and impacts related to the rising sea level in the Metropolitan Center of Recife, Northeast Brazil. *Pan-American Journal of Aquatic Sciences*, 5(2): 341-349.

EGUCHI, B.; ALBINO, J. 2021. Influência dos modos de variabilidade climática sobre eventos de ressacas no litoral sul do Espírito Santo, Brasil. *Revista Brasileira de Climatologia*, 17(18): 165-183. http://dx.doi.org/10.5380/rbclima.v28i0.72614

FRANÇA, C.A.S. 2000. *Contribuição ao Estudo da Variabilidade do Nível do Mar na Região Tropical Atlântica por Altimetria por Satélite TOPEX/POSEIDON e Modelagem Numérica.* University of Campinas, Campinas, Ph. Thesis, 274 p.

FUNDAÇÃO SEADE – FUNDAÇÃO SISTEMA ESTADUAL DE ANÁLISE DE DADOS. 2020. *Município de Santos*. Available at www.seade.gov.br. Last acessed in May 22th 2020.

FUNDESPA – FUNDAÇÃO DE ESTUDOS E PESQUISAS AQUÁTICAS. 2012. *Relatório da Variação Espaço-Temporal dos Polígonos Praiais no Período de 1962 a 2009/2011.* Plano Básico Ambiental da Dragagem de Aprofundamento do Porto de Santos – Proposta de Adequações. RVE-231111, 62 p. (unpublished).

GARCIA, P.D.; GIRELI, T.Z. 2019. Um projeto piloto de recuperação de uma praia utilizando um quebramar submerso - Ponta da Praia, Santos, Brasil. A pilot project for beach restoration using a submerged breakwater - Ponta da Praia, Santos, Brasil *Journal of Integrated Coastal Zone Management / Revista de Gestão Costeira Integrada*, 19(1): 43-57.

GRECO, R.; NUNES, L.H. 2019. Population Matters: Listening to Past Experiences and Future Aspirations Regarding Risks and Adaptation Actions. In: L. Nunes, R. Greco, J. Marengo (Eds). *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options*. Springer, p. 269-284.

GUSMÃO, P.P. 2011. *Relatório Megacidades, Vulnerabilidade e Mudanças Climáticas: Região Metropolitana de Rio de Janeiro. Projetos Megacidades, Vulnerabilidade e Mudanças Climáticas, Rio de Janeir*o. 361 p. Available at http://www.poli.ufrj.br/noticias/arquivos/completo.pdf. Accessed on June 23th 2022.

GUTIÉRREZ, E.P. 2022. Local climate change reporting in coastal cities: Selsey (UK), Santos (Brazil) and Broward County (USA). *Ámbitos – Revista Internacional de Comunicación*, 55: 73-96. http://dx.doi.org/10.12795/Ambitos.2022.i55.05

HARARI, J.; CAMARGO, R.; GORDON, M. 1994. On tides and mean sea level of Recife (8° 3.3' S 34° 51.9' W) and Belem (1° 26.2' S 48° 29.6' W). *Afro-America Gloss News*, 1(2): 9-12. http://www.mares.io.usp.br/aagn/12o9.html

HARARI, J.; FRANÇA, C.A.S.; CAMARGO, R. 2008. Climatology and hidrography of Santos Estuary. In*:* R. Neves, J. Baretta, M. Mateus (eds.) *Perspective on Integrated Coastal Zone Management in South America.* IST Press, Portugal, p.147-160.

HARARI, J.; CAMARGO, R.; SOUZA., C.R.G.; NUNES, L.H. 2019. Projection and Uncertainties of Sea Level Trends in Baixada Santista. In: L.H. Nunes, R. Greco, J.A. Marengo (eds.) *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options*. Springer, p. 75-95.

HARARI, J.; YANG, S.H.; CORTEZ, T.; SOUZA, C.R.G. 2022a. Tendências do nível médio do mar por altimetria de satélite na região oceânica do Estado de São Paulo. In: Fórum de Mudanças Climáticas e Recursos Hídricos do Guarujá, 1, Guarujá, *Resumos*. (https://www.guaruja.sp.gov.br/trabalhos-submetidos/).

HARARI, J.; SOUZA, C.R.G.; CORTEZ, T.; YANG, S.H. 2022b. Tendências, variabilidades e correlações do nível do mar e da temperatura de superfície do mar no Litoral Sul do Estado de São Paulo – Brasil. In: Associação Latino-Americana de Pesquisadores em Ciências Marinhas, Congresso Latino-Americano de Ciências Marinhas - COLACMAR, 19, Cidade do Panamá, *Libro de Resúmenes* (em publicação).

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2011. *Atlas geográfico das zonas costeiras e oceânicas do Brasil.* IBGE, Diretoria de Geociências, Rio de Janeiro, 176 p.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2014. *Perfil dos Municípios Brasileiros* 2013. Ministério do Planejamento, Orçamento e Gestão Instituto Brasileiro de Geografia e Estatística – IBGE, Coordenação de População e Indicadores Sociais, Rio de Janeiro, 282 p.

IPCC – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate*

Change. C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.). Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 p.

IPCC – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 2013. Summary for Policymakers. In: T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 2014. Summary for policymakers. In: C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1-32.

IPCC – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 2018. Summary for Policymakers. In: V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.) *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 24 p.

IPCC – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 p.

KLEIN, A.H.F.; SHORT, D. 2016. Brazilian Beach Systems: Introduction. In: A.D. Short, A.H.F.F. Klein (Eds.) *Brazilian Beach Systems,* Series: Coastal Research Library, vol. 17, 1st ed., p. 1-35.

KULP, S.; STRAUSS, B.H. 2016. Global DEM Errors Underpredict Coastal Vulnerability to Sea Level Rise and Flooding. *Frontiers in Earth Sciences,* 4: 36. http://doi.org/10.3389/feart.2016.00036

KULP, S.; STRAUSS, B.H. 2019. New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nature Communications,* N10: 4844 https://doi.org/10.1038/s41467-019-12808-z

LAI, Y; LI, Q.; LI, J.; ZHOU, Q.; ZHANG, X.; WU, G. 2021. Evolution of Frequency and Intensity of Concurrent Heavy Precipitation and Storm Surge at the Global Scale: Implications for Compound Floods. *Frontiers in Earth Sciences,* 9: 660359. https://doi.org/10.3389/feart.2021.660359

LOSADA, I.J.; REGUERO, B.G.; MÉNDEZ, F.J.; CASTANEDO, S.; ABASCAL, A.J.; MÍNGUEZ, R. 2013. Long-term changes in sea-level components in Latin America and the Caribbean. *Global and Planetary Change,* 104: 34-50. https://doi.org/10.1016/j.gloplacha.2013.02.006

LOSADA, I.J.; GOMEZ-ERACHE, M.; LACAMBRA, C.; RIVERA, E.; SILVA, R.; TOIMIL. A. 2020. Coastal Areas. In: J.M. Moreno, C. Laguna-Defior, V. Barros, E. Calvo Buendía, J.A. Marengo, and U. Oswald Spring (eds.) *Adaptation to Climate*

Change Risks in Ibero-American Countries. RIOCCADAPT Report McGraw Hill, Madrid, Spain, p. 541-580.

MACHADO, J. P.; MIRANDA, G. S. B.; GOZZO, L. F.; CUSTÓDIO, M. DE S. 2019. Condições Atmosféricas Associadas a Eventos de Ressaca no Litoral Sul e do Sudeste do Brasil durante o El Niño 2015/2016. Re*vista Brasileira de Meteorologia*, 34(4), 529-545. https://doi.org/10.1590/0102-7786344067

MARENGO, J.A.; NUNES, L.H.; SOUZA, C.R.G.; HARARI, J.; MULLER-KARGER, F.; GRECO, R.; HOSOKAWA, E.K.; TABUCHI, E.K.; MERRIL, S.B.; REYNOLDS, C.J.; PELLING, M.; ALVES, L.M.; ARAGÃO, L.E.; CHOU, S.C.; MOREIRA, F.; PATERSON, S.; LOCKMAN, J.T.; GRAY, A.G. 2017a. A Globally-Deployable Strategy for Co-Development of Adaptation Preferences to Sea-Level Rise: The Public Participation Case of Santos, Brazil. *Natural Hazards*, 1-15. https://doi.org/10.1007/s11069-017-2855-x

MARENGO, J.; MULLER-KARGER, F.; PELLING, M.; REYNOLDS, C.J.; MERRILL, S.B.; NUNES, L.H.; PATERSON, S.; GRAY, A.J.; LOCKMAN, J.T.; KARTEZ, J.; MOREIRA, F.A.; GRECO, R.; HARARI, J.; SOUZA, C.R.G.; ALVES, L.; HOSOKAWA, E.K.; TABUCHI, E.K. 2017b. An Integrated Framework to Analyze Local Decision Making and Adaptation to Sea Level Rise in Coastal Regions in Selsey (UK), Broward County (USA), and Santos (Brazil). *American Journal of Climate Change*, 6: 403-424. https://doi.org/10.4236/ajcc.2017.62021

MARENGO, J.A.; ALVES, L.M.; AMBRIZZI, T.; YOUNG, A.; BARRETO, N.J.; RAMOS, A.M.; 2020. Trends in extreme rainfall and hydrogeometeorological disasters in the Metropolitan Area of São Paulo: a review. *Annals of the New York Academy of Sciences*, 1472(1): 5-20. https://doi.org/10.1111/nyas.14307

MONTANARI, F.; POLETTE, M.; QUEIROZ, S.M.P.; KOLICHESKI, M.B. 2020. Estimating Economic Impacts of Sea Level Rise in Florianópolis (Brazil) for the Year 2100. *International Journal of Environment and Climate Change,* 10(1): 37-48. http://dx.doi.org/10.9734/IJECC/2020/v10i130174

MENEZES, L.S. 2021. *Governança Climática Local para o Avanço da Adaptação + Guia para o Desenho de Arranjos Institucionais Locais*. Realização: Projeto Apoio ao Brasil na Implantação da sua Agenda Nacional de Adaptação à Mudança do Clima (PROADAPTA). Ministério do Meio Ambiente (MMA), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH e Prefeitura de Santos/Comissão Municipal de Adaptação à Mudança do Clima (CMMC). Brasília, 01 de Setembro de 2021, 170 p. Available at http://www.santos.sp.gov.br/

MESQUITA, A.R. 2003. Sea Level Variations Along the Brazilian Coast: A Short Review. *Journal of Coastal Research*, 35: 21-31. https://www.jstor.org/stable/40928745

MMA. 2018. *COP27*. Available at www.mma.gov.br/informma/item/14692-noticia-acom-2018-03-2918.html. Accessed on May 18th 2020

MOREIRA, F.M.; PATERSON, S.; NUNES, L.H.; PELLING M. 2019. Climate Change and Adaptive Capacity in the City of Santos. In: L. Nunes, R. Greco, J. Marengo (Eds.) *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options*. Springer, p. 253-268.

MUEHE, D.; LIMA, C.F.; LINS-DE-BARROS, F.M. 2006. Rio de Janeiro. In: D. Muehe (Ed.) *Erosão e progradação do litoral brasileiro*. Ministério do Meio Ambiente, Brasília, p. 265-296.

NEVES, C.F.; MUEHE, D. 1995. Potential impacts of sea level rise on the metropolitan region of Recife, Brazil. *Journal of Coastal Research*, 14:116-131. https://www.jstor.org/stable/25735704

NICOLODI, J.L.; PETERMANN, R.M. 2010. Mudanças Climáticas e a Vulnerabilidade da Zona Costeira do Brasil: Aspectos ambientais, sociais e tecnológicos/Climate Changes and Vulnerability of the Brazilian Coastal Zone in its Environmental, Social, and Technological Aspects, *Revista de Gestão Costeira Integrada / Journal of*

Integrated Coastal Zone Management, 10(2): 151-177.

NUNES, L.H.; ALVES, L.M.; HOSOKAWA, E.K.; MARENGO, J.A. 2019. Patterns of Extreme Precipitation in Santos, In: L.H. Nunes, R. Greco, J. Marengo (Eds.) *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options.* Springer, p. 45-58.

OH, Y.I.; SHIN, E.C. 2006. Using submerged geotextile tubes in the protection of the East Korean Shore. *Coastal Engineering*, 53: 879-895. https://doi.org/10.1016/j.coastaleng.2006.06.005

OLIVEIRA SANTOS, B.B.; NUNES, L.H.; BANDINI, M.P. 2019. Rainfall Episodes and Local Stability Thresholds in Santos, In: L. Nunes, R. Greco, J. Marengo (Eds.), *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options,* Springer, p. 161-166

OSCAR JR, A.C. 2018. *Governança territorial em nível metropolitano e risco da mudança climáticas no Rio de Janeiro*. Universidade Estadual de Campinas, Campinas, Thesis, 322 p.

PATERSON, S.K.; PELLING, M.; NUNES, L.H.; MOREIRA, F.A.; GUIDA, K.; MARENGO, J. A. 2017. The Scaled Asymmetries of Adaptive Capacity: In Florida, São Paulo and England. *Geoforum*, 81: 109-119.

PAULA, D.P.; MORAIS, J.O.; FERREIRA, O. 2015. Análise histórica das ressacas do mar no litoral de Fortaleza (Ceará, Brasil): origem, características e impactos. In: D.P. Paula, J.A. Dias (Eds.) *Ressacas do Mar, Temporais e Gestão Costeira*. Editora Premius, Fortaleza, p. 173-201.

PBMC – PAINEL BRASILEIRO DE MUDANÇAS CLIMÁTICAS. 2014. *Impactos, vulnerabilidades e adaptação às mudanças climáticas. Contribuição do Grupo de Trabalho 2 do Painel Brasileiro de Mudanças Climáticas ao Primeiro Relatório da Avaliação Nacional sobre Mudanças Climáticas*. E.D. Assad & A.R. Magalhães (eds.) COPPE, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 414 p.

PBMC – PAINEL BRASILEIRO DE MUDANÇAS CLIMÁTICAS. 2017. *Impacto, vulnerabilidade e adaptação das cidades costeiras brasileiras às mudanças climáticas: Relatório Especial do Painel Brasileiro de Mudanças Climáticas*. J.A. Marengo & F.R. Scarano (eds.). PBMC, COPPE – UFRJ, Rio de Janeiro, 184 p.

PELLING, M.; ZAIDI, R.Z. 2013. *Measuring adaptive capacity: application of an indexing methodology in Guyana.* EPD Working Paper #47, Department of Geography, King's College London.

PIRAZOLLI, P.A. 1986. Secular trend of relative sea level (RSL) changes indicated by tide-gauge recoast. *Journal of Coastal Research,* 1: 1-26. https://www.jstor.org/stable/44863318

RIBEIRO, R.B.; SAMPAIO, A.F.P.; RUIZ, M.S.; LEITÃO, J.C.; LEITÃO, P.C. 2019. First approach of a storm surge early warning system for Santos region, In: L.H. Nunes, R. Greco, J.A. Marengo (Eds) *Climate Change in Santos, Brazil: Projections, Impacts and Adaptation Options.* Springer, p. 135-160

SANTOS, B.B., NUNES, L.H., BANDINI, M.P. 2019. Rainfall Episodes and Local Stability Thresholds in Santos. In: L.H. Nunes, R. Greco, J.A. Marengo (Eds) *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options*. Springer, p. 161-178.

SANTOS MUNICIPALITY. 2022a. CMMC – *Comissão Municipal de Adaptação à Mudança do Clima*. Available at www.santos.sp.gov.br/?q=downloads/cmmc-comissao-municipal-de-adaptacao-a-mudanca-do-clima. Last accessed on February 10th 2022.

SANTOS MUNICIPALITY. 2022b. *Plano Municipal de Ação Climática de Santos – PACS*. Available at https://www.santos.sp.gov.br/?q=hotsite/plano-municipal-de-acao-climatica-de-santos-pacs; https://www.santos.sp.gov.br/static/files_www/files/portal_files/hotsites/pacs/plano_de_acao_climatica_de_santos_pacs_sumario_executivo.pdf. Last accessed on February 10th 2022.

SANTOS MUNICIPALITY. 2022c. *Plano Municipal de Conservação e Recuperação da Mata Atlântica – PMMA*. Available at www.santos.sp.gov.br/?q=hotsite/plano-municipal-de--conservacao-e-recuperacao-da-mata-atlantica-pmma. Last accessed on February 10th 2022.

SANTOS MUNICIPALITY 2022d. *AbE subiu o morro: projeto de adaptação baseada em ecossistemas no Monte Serrat em Santos, SP*. Available at https://www.santos.sp.gov.br/static/files_www/files/portal_files/hotsites/pmma/cartilha_abe.pdf. Last accessed on February 10 2022.

SILVA, G.N. 1992. *Variação de longo período do nível médio do mar: causas, consequências e metodologia de análise*. Programa de Engenharia Oceânica, COPPE/UFRJ, Rio de Janeiro, Dissertação de Mestrado, 100 p. https://minerva.ufrj.br/F/?func=direct&doc_number=000174018&local_base=UFR01

SILVA, R.; LITHGOW, D.; ESTEVES, L.S.; MARTÍNEZ, M.L.; MORENO-CASASOLA, P.; MARTELL, R.; PEREIRA, O.; MENDOZA, E., CAMPOS-CASCAREDO, A., GREZ, P.W.; OSORIO, A.F.; OSORIO-CANO, J.D.; RIVILLAS, T. 2017. Coastal risk mitigation by green infrastructure in Latin America. *Maritime Engineering*, 170(2): 1-16. http://dx.doi.org/10.1680/jmaen.2016.13

SOUZA, C.R.G. 2009. A erosão costeira e os desafios da gestão costeira no Brasil. Revista de Gestão Costeira Integrada, *Journal of Integrated Coastal Management*, 9(1): 17-37. http://www.aprh.pt/rgci/revista9f1.html

SOUZA, C.R.G.; LUNA, G.F.C.; SOUZA, A.P. 2012. Causas da erosão na Ponta da Praia de Santos (São Paulo, Brasil). In: Workshop Antropicosta Iberoamerica, 2, Montevideo, Uruguay, *Libro de Resúmenes*, p. 35.

SOUZA, C.R.G.; GOUVEIA, M.L.; SOUZA, A.P. 2016a. Balanço sedimentar da Praia de Santos antes, durante e após as obras de dragagem de aprofundamento do canal do Porto de Santos (São Paulo, Brasil). In: CONGRESSO LATINOAMERICANO DE SEDIMENTOLOGIA, 7, REUNIÓN ARGENTINA DE SEDIMENTOLOGIA, 15, Santa Rosa, Argentina, *Libro de Resúmenes*.

SOUZA, C.R.G.; SOUZA, A.P.; GOUVEIA, M.L. 2016b. Identificação de processos sedimentares em praias por meio da variabilidade temporal de células de deriva litorânea. In: CONGRESSO LATINOAMERICANO DE SEDIMENTOLOGIA, 7, REUNIÓN ARGENTINA DE SEDIMENTOLOGIA, 15, Santa Rosa, Argentina, *Libro de Resúmenes*.

SOUZA, C.R.G.; SOUZA A.P.; HARARI, J. 2019. Long Term Analysis of Meteorological-Oceanographic Extreme Events for the Baixada Santista Region, In*:* L. Nunes, R. Greco, J. Marengo (Eds.) *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options.* Springer, p. 97-134.

STRAUSS, B.H.; KULPA, S.; LEVERMANN, A. 2015. Carbon choices determine US cities committed to futures below sea level. *PNAS*, 112(44): 13508-13513. https://doi.org/10.1073/pnas.1511186112

UCCRN – URBAN CLIMATE CHANGE RESEARCH NETWORK 2018. *The Future we don't want - How Climate Change Could Impact the World's Greatest Cities*. Technical Report, 59 p.

UNICAMP – UNIVERSIDADE ESTADUAL DE CAMPINAS. 2017. *Nota Técnica 1. Proposta de Projeto Piloto para Monitoramento e Contenção da Erosão na Ponta da Praia – Santos (SP)*. ÚNICAMP, Campinas, 41 p.

VILLAMIZAR, A.; GUTIÉRREZ, M.E.; NAGY, G.J.; CAFFERA, R.M.; LEAL FILHO, W. 2016. Climate adaptation in South America with emphasis in coastal areas: the state-of-the-art and case studies from Venezuela and Uruguay. *Climate and Development*, 5529: 1-19. https://doi.org/10.1080/17565529.2016.1146120

WORLD SHIPPING COUNCIL 2020. *The Top 50 Container Ports*. Available at https://www.worldshipping.org/top-50-ports. Last accessed on 21th Feb 2022.

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