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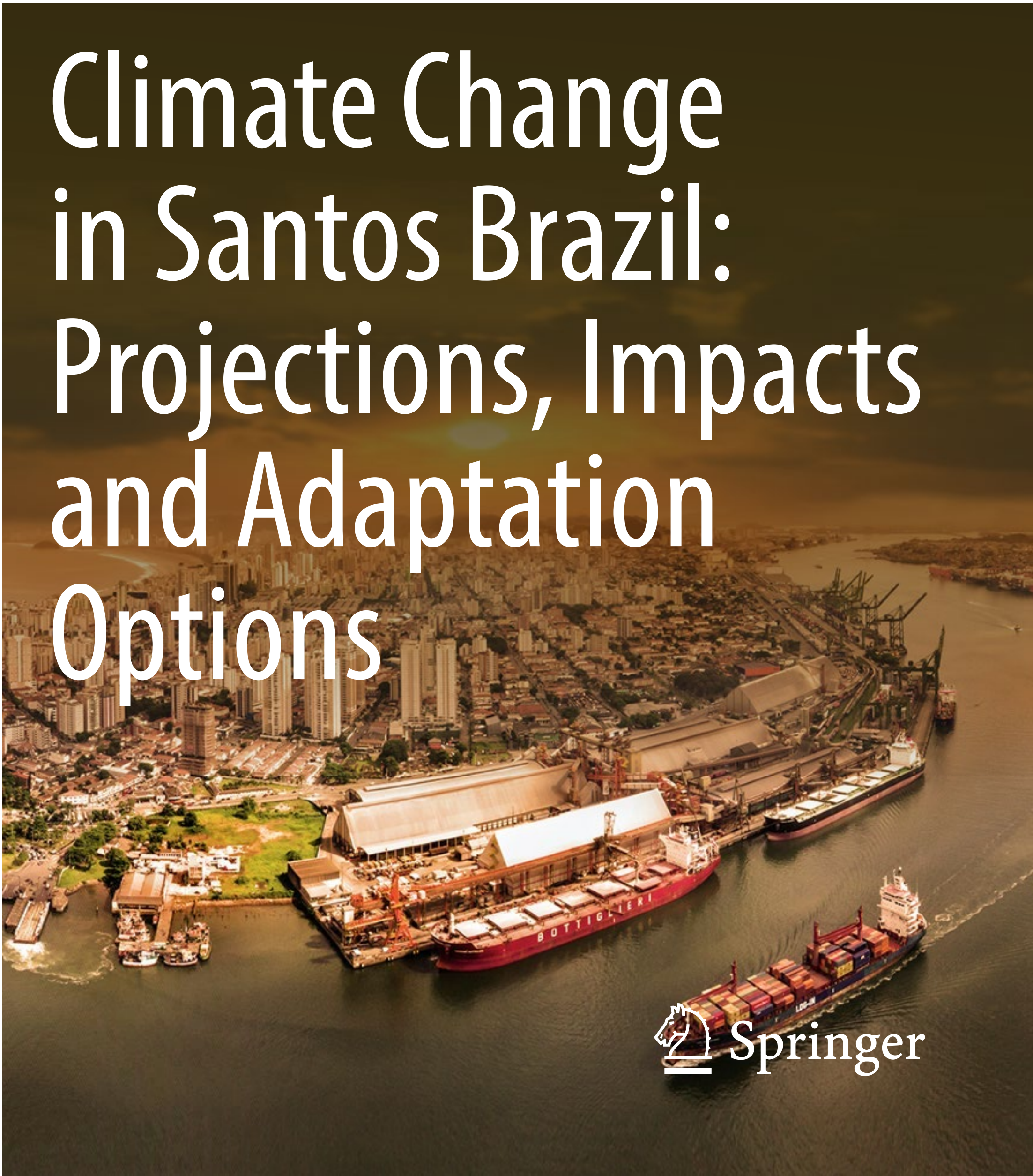
Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options



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To my mother Maria Carolina, to my father José (in memoriam) and to my sister and brother, Lení and Marcos.
Lucí H. Nunes
To my mother Deanna (in memoriam), to my father Remo and to my sisters Cristina and Francesca.
Roberto Greco
This book is dedicated to my beloved wife Angela Cristina and son José Antonio, without whose
love, encouragement, support and inspiration I would never have made it this far. I also wish to dedicate this book to my mother and brothers for their continuous love and support all the way since the beginning.
José A. Marengo

Foreword

The entire world is challenged to find answers regarding adaptation to ongoing global environmental modifications, among them, climate change. At the same time, it has increased the perception that the processes observed at local scale are controlled by regional and global processes. Therefore, increasing knowledge at local level of processes arising from global changes, providing adaptive responses and finding solutions to the social and economic impacts associated is timely and needed.

Climate change operates throughout the world in different manners and at different rates and thus affects the areas differently. Therefore, understanding how the physical processes of a given place can respond to large-scale environmental modifications and knowing the capacity of society to adapt to these transformations are of utmost importance for local development.

These aspects were central issues in the Project Metropole, an international consortium involving Brazil, the UK and the USA, linked to the Belmont Forum: Call Coastal Vulnerability. Based upon an integrated multidimensional framework encompassing the social, cultural, political, economic, environmental and physical dimensions, the project evaluated local decision-making processes and provided feedback to local policy makers and society on possible actions towards adaption to sea level rise.

This book is rooted in the results of Project Metropole for Brazilian case study: the dynamic city of Santos, state of São Paulo. The initial step of the Project was to establish sea level rise scenarios for Santos. Prior to the project, the municipality counted on the IPCC projections only, which proved more alarming than the more realistic local evaluation provided by Project Metropole.

Having the projections of sea level rise, their impacts associated with storm surges were simulated by using an interactive computer-based scenario through the platform CoAST (Coastal Adaptation to Sea level rise Tool). The evaluation was performed for two contrasting sectors of Santos: the Southeastern Zone, with upscale neighbourhoods closer to the shoreline, and the Northwestern Zone that clusters poor quarters encroached in mangrove areas.

It is important to highlight that the Project Metropole is anchored in some assumptions. One of them is that the partnership with the local government facilitates the internalisation of the results and the implementation of public policies and appropriate legislation, allowing a better management of the area. Another important premise is that the involvement of population in the process of adaptation is crucial. Thus, several meetings were organised by the scientific community of Metropole together with the city council, engaging policy decision-makers, militaries, civil defence, NGOs, other academics and representatives of different sectors of civil society. In the first part of the first stakeholder engagement workshop, on 30 September 2015, the damages to assets from expected 100-year storms for 2050 and 2100 was presented. In the second part of the meeting, attendees discussed possible adaptation measures feasible for Santos and voted to model two of them for each zone. Between the two meetings, platform CoAST run again using the two more voted actions for each zone. These results were presented in the second stakeholder engagement on 1 December 2015 and showed how much building damage might be avoided over time if the actions chosen by population are implemented. During both meetings, attendees respond to a survey elaborated to define values, attitudes and perceptions related to climate change and adaptive responses. The questions evaluated aspects such as individual and community experience with coastal hazards, preferences for several potential adaptation actions and for public finance mechanisms for adaptation and perceptions about barriers to implementation. In a third general meeting, on 17 August 2017, a comprehensive overview of the Project Metropole was provided. Representatives of the federal government also showed efforts towards adaptive measures at the national level, underscoring the importance and novelty of the Project Metropole, which may inspire other coastal municipalities in Brazil.

The involvement of the civil society in the process of adaptation was also promoted within the Project Metropole by the use of the Adaptive Capacity Index (ACI), which reveals the performance of risk reduction related to adaptation to climate change. The index is established through a series of interviews with people representing key institutions from the public, private and nongovernmental organisation sectors of the municipality, with questions that allow a choice of responses. The performance of a given aspect is compared over time, in order to observe the evolution concerned to the adaptive capacity of a given institution. In a final meeting, held on 15 December 2016, the results were presented to the interviewees, who once again could discuss, this time together, issues related to the adaptive capacity of institutions based in Santos.

The importance of the results of the Project Metropole is amplified by the fact that the case study was the municipality of Santos. One of the oldest cities of Brazil, Santos is inserted in the humid tropics, with rich ecosystems like the Atlantic Rainforest and mangroves, and extensive topographic diversity. However, the entire region underwent transformations since the beginnings of the discovery of Brazil, which affected and compromised its ecosystem and increased its natural fragility.

Connected with the main consumer markets in the country by a multimodal transport system and located just 60 km away from São Paulo, the largest Brazilian city, the region has an undeniable strategic position that contributed to the installation in the 1950s of an important petrochemical and steel industrial complex in Cubatão – a nearby city located in a valley surrounded by the Serra do Mar mountain range, a quite unsuitable area for the dispersal of pollutants. The industrial park brought both benefits to the economy and deficits in the infrastructure: part of the labour force attracted by the industries began to live on the unstable hillslopes of Serra do Mar and mangrove areas, and the pollution generated by the industrial complex, for decades without control, caused damages to vegetation, speeded up mass movements and reduced the water retention capacity of the soil, contributing to urban floods.

In the decade of 1980, Cubatão became the most pollutant city of the world. It is of note that this informal land occupation with low-income settlements affects the ecological balance of the area and the life quality of the inhabitants. Problems such as the direct discharge of sewage into the water bodies and thus contamination of water resources, which affect the health of residents, especially children, and clearance of the Atlantic Rainforest and destruction of mangroves, which affect the local stability, are but some examples of the deleterious problems caused by this pattern of occupation, which is outside legal standards and beyond the local environmental capacity.

This situation of little or no concern for the environment began to change due to reasons of different natures. One of them was the end of the dictatorial period that had been in force in Brazil for more than two decades, which allowed for greater mobilisation of society in favour of a safer and healthier environment. Another aspect that contributed to this change was a severe precipitation event in late January 1985 that caused numerous landslides in the Serra do Mar, near the industrial park. If industries had been affected and toxic material had been escaped, an unprecedented tragedy could have occurred and hit a large area, fact that has influenced the adoption of measures to reduce pollution by the government of the state of São Paulo, which launched the first initiatives to pollution control in the same year.

At the same time, pressures imposed by urbanisation driven by speculative interests of the higher social classes led to a clear socio-spatial pattern of land use and land occupation in Santos, with low-income population installed in hillslopes and mangrove areas, while the wealthiest classes settled closer to the beach. The rapid transformation of the space and the disregard of land use and land occupation laws contributed to increase the physical susceptibility of the area and consequently to enlarge the vulnerability of all sectors of the population in the face of problems caused by storm surges, floods and landslides.

More recently, the discovery of oil in the ocean in a super deep layer called pre-salt has attracted new investments, including the expansion of the Port of Santos, and led to an exacerbated land valuation in the urban area, which in a few years changed the urban configuration of the city, with vertiginous increase of verticalisation that has altered the local climate and consequently the thermal comfort in a city that is naturally hot and humid throughout the year.

This scenario of economic vitality contrasts with the current environmental disruption and affects all sectors of the population of Santos albeit in a different way, as demonstrated by the results of the Project Metropole for two contrasting areas: the Northwestern and the Southeastern sectors of Santos.

Additionally, Brazil is experiencing a profound political, economic and value crisis, which must be seen by the local government as an opportunity to change various behaviours towards a fairer society and a healthier environment and, therefore, a sustainable development. This can only be achieved with scientific knowledge and popular participation. In this sense, the results of the Project Metropole can contribute for valuing and consolidating the important role of the municipality of Santos in the country.

The next chapters present the results obtained by this project, which was developed over 4 years, with the participation of researchers from different institutions in Brazil, as well as the valuable contribution of the municipal government and the population of Santos. Some chapters are contributions from other researches developed in the area that addressed additional issues and therefore help to compose a more general framework.

São Paulo, Brazil Lucí H. Nunes

Preface

The book is divided in three parts. Part I contains an introductory chapter, with information of the Project Metropole (An Integrated Framework to Analyse Local Decision Making and Adaptive Capacity to Large-Scale Environmental Change), which aimed to identify the factors that facilitate a shift in knowledge, attitudes, values and decision-making about local climate risks and adaptation strategies among decision-makers and stakeholders in case study of coastal communities in Brazil, the UK and the USA. The goal was to combine expertise from diverse scientific backgrounds to develop an integrated framework to analyse local decision-making and the adaptive capacity to local environmental change driven by large-scale processes like climate.

Part II has six chapters which evaluate the current environmental pattern and projections in Santos, Brazil. Chapter 2 explores the characteristics, detection and frequency of frontal systems in South and Southeast Brazil (pressure, temperature and wind fields) and response of the ocean to the atmospheric forcing. It also explores simulation and prediction of frontal systems with focus in Santos and surroundings. Chapter 3 evaluates the current patterns of extreme precipitation events at different temporal scales in Santos, whether the patterns are systemic and, in particular, whether they present some regularity. Complementing the analysis of extreme events, it also evaluates parameters such as standard deviation, coefficient of variation and number of rainy days, as well as the degree of concentration of daily rainfall. The objective of Chap. 4 is to assess the trend of storm surges that hit the coast of the Baixada Santista in the future climate. The assessment is based on the observed trend of the storms and the future change of the storm surges reproduced by the downscaling of global climate model simulations using the Eta Regional Climate Model at 20-km and 5-km resolutions. The downscaling reproduces, at higher resolution, the simulations from the HadGEM2-ES and MIROC5, under RCP4.5 and RCP8.5 scenarios. The number of storm surge detected in the present climate simulations is compared against observations. The extratropical cyclone located off the coast of South Brazil is simulated generally weaker and less frequent than reanalysis data. Chapter 5 provides a general overview of the causes of sea level variations, discussing how these variations are measured and analysed, the most important periodicities and long-term trends in sea level, with emphasis in the region of Santos. Aspects such as accuracy and space– time coverage of measurements and decadal and secular projections of the mean sea level are presented along the discussion. Chapter 6 presents and discusses patterns and trends of surfaces and "high tides" events in the region of Baixada Santista, where Santos is located, between 1961 and 2016. The evaluation of meteorological and oceanographic events such as storm surges and positive meteorological tides is of great importance for understanding coastal processes and the effects of current sea level rise and ongoing climate change, for the understanding of the vulnerability of coastal cities. Chapter 7 presents the first approach of a storm to the early warning system for Santos region. The system is based on the AQUASAFE platform and provides daily meteo-oceanographic forecasts for up to 5 days, detailed for the Bay and estuary scale of Santos, as well as providing meteo-oceanographic information in real time of the sensor network installed in the port region.

The four chapters of Part III analyse the impacts of sea level rise in Santos and surroundings. Chapter 8 evaluates the recent patterns of temporal distribution of extreme rainfall events and their impacts in the municipality of Santos and discuss the correlation between the occurrence of events (landslides) from the application of a technique which associates daily accumulated rainfall with the total amount that triggered landslides in the past and estimates the local stability thresholds due to accumulated precipitation. Chapter 9 offers an analysis of the Metropolitan Region of Baixada Santista, where Santos is inserted, from the perspective of global environmental changes, with emphasis on changes in land cover and land use. Images of the LANDSAT satellite were used for the years 1996, 2005 and 2011, from which it was possible to detect changes in the land cover, as well as projection of a trend scenario for the year 2021. The study also evaluates socioeconomic, as well as the carbon emission estimates. From this analysis, it is possible to identify the main transforming agents, impacts and challenges of the territorial management of the metropolitan region in the face of a challenging scenario of global environmental changes. Chapter 10 presents an overview of environmental risk management, associating the concepts with case studies of how dengue fever outbreaks respond to climate variability. It also discusses the main factors that can influence future patterns of dengue fever in São Paulo State and the macro region of Baixada Santista and the city of Santos. Study cases are focused on the period from 2008 to 2015 to show how these patterns are associated to weather fluctuations.

The focus of Part IV is adaptation, discussed in the three final chapters. Chapter 11 examines the impact of the construction of terminals between 2006 and 2014 along the Port of Santos navigation channel, located in the complex of Santos Estuary, in the stability of Port of Santos inlet. The Port of Santos is an estuarine port in Southeast Brazil which has received a great deal of investments for deepening dredging and for construction and expansion of port terminals in the past two decades. The port is under constant pressure for receiving larger vessels, one of the reasons to deepen the channel and to construct new terminals. Yet, land reclamation and basin reduction in bays or estuarine area decreases the tidal prism (the amount of water entering and leaving the inlet, so it works as a flow that controls sand deposit on bars). Chapter 12 carries out vulnerability studies for the Santos/SP region, applying the vulnerability index for coastal areas (SEVICA) under scenarios 4.5 and 8.5 of the IPCC AR5 report (IPCC, 2013). In the light of the vulnerability scenarios, critical infrastructure for the municipality, such as hospitals, highways and port structures, was analysed for situations of extreme events. Evaluations of Chap. 13 are based on the results of the Adaptive Capacity Index that incorporates the influence of structure and agency as defining characteristics in an attempt to move the discussion away from simply measurement into a more practical niche, generating an actor-identified solution mechanism through social learning upon which to create pro-active change in how climate change issues are addressed. Chapter 14 analyses the results of a survey applied for attendees in two engagement workshops in which projections of sea level rise and storm surges for 2050 and 2100 were presented for Santos, in view of identifying links between risk experiences, beliefs, values and attitudes about local government priorities for possible adaptation actions and public finance. Chapter 15 explores the creation of the Municipal Committee for Adaptation to Climate Change (MCACC) by the local government, in 2015, analysing the creation of local public policy in Santos coastal municipality focused on climate change adaptation. An initial evaluation of the decision-makers and local community perception were developed by interviews and participation in MCACC meetings. Local community perception was focused on current intense storm surges in the region. The community perception was about structural damages and economic losses in events related flooding and sea level rise.

In sum, the different chapters of this book offers insights to connect the knowledge on climate change – in special, the impacts due to sea level rise – in a coastal city under constant pressure of urbanisation, globalisation and land use changes. Because the problems faced for Santos are common to other coastal cities, this book aims to inspire other studies that, like Project Metropole, intend to strength the linkages among science, community and decision-makers.

In this book, the authors take this risk analysis approach to analyse in particular the impacts of climate change in the environment and in built-up areas, as well as in the health in a coastal city of Brazil. Its importance cannot be underestimated. The editors and authors have brought together a full range of appropriate experts to evaluate the risks that Brazil faces unless actions are taken quickly across the whole world to manage the challenges.

The pledge of the Paris Agreement, to keep the average global temperature rise to less than 2 °C and to aim for no more than 1.5 °C rise, is now a common commitment of 195 signatory countries. No other issue has brought such universal agreement for action. But this agreement is not matched by universal actions to meet the challenge. This book underlines the importance for all of us, as individuals, as urban, regional and national citizens, as city mayors and regional governors and as politicians and heads of government, to act now to help to avoid the severe risks set out here.

Therefore, the aim of this book is to explain how changes in the physical climate can lead to multiple complex changes in human systems, many of which are hard to predict and which tend to have adverse consequences when the changes fall far outside the normal range of variability.

São Paulo, Brazil

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The book, *Climate Change in Santos Brazil: Projections, Impacts and Adaptation Options*, is a result of contributions from a wide range of experts from across Brazil, the USA and the UK. We thank everyone who contributed to its richness and multi-disciplinary outlook.

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Acronyms

CEMADEN	National Center for Monitoring and Early Warning of Natural Disasters
UNICAMP	University of Campinas
IMaRS	Institute for Marine Remote Sensing
INPE	National Institute for Space Research
IG-SMA/SP	Institute of Geology – Secretariat for the Environment of the State of São Paulo
FFLCH-USP	Faculty of Philosophy, Languages and Human Sciences – University of São Paulo
USP	University of São Paulo
NPH-UNISANTA	Núcleo de Pesquisas Hidrodinâmicas – Universidade Santa Cecília
UERJ	Rio de Janeiro State University
UNISANTOS	Catholic University of Santos
ITA	Technological Institute of Aeronautics
UNESP	Universidade Estadual Paulista

Part I
Introduction

Chapter 1
The METROPOLE Project – An Integrated Framework to Analyse Local Decision Making and Adaptive Capacity to Large-Scale Environmental Change: Decision Making and Adaptation to Sea Level Rise in Santos, Brazil

José A. Marengo, Frank Muller-Karger, Mark Pelling, and Catherine J. Reynolds

Abstract Assessment of the risks due to exposure and sensitivity of coastal communities to coastal flooding is essential for informed decision-making. Strategies for public understanding and awareness of the tangible effects of climate change are fundamental in developing policy options. A multidisciplinary, multinational team of natural and social scientists from the USA, the UK, and Brazil developed the METROPOLE Project to evaluate how local governments may decide between adaptation options associated with SLR projections. METROPOLE developed a participatory approach in which public actors engage fully in defining the research problem and evaluating outcomes.

Using a case study of the city of Santos, in the coast of the State of Sao Paulo in Southeastern Brazil, METROPOLE developed a method for evaluating risks jointly

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with the community, comparing 'no-action' to 'adaptation' scenarios. At the core of the analysis are estimates of economic costs of the impact of floods on urban real estate under SLR projections through 2050 and 2100. Results helped identify broad preferences and orientations in adaptation planning, which the community, including the Santos municipal government, co-developed in a joint effort with natural and social scientists.

Keywords Sea-level rise · Adaptation options · Adaptive capacity · Participatory approach · Santos · METROPOLE project

1.1 Introduction

How decision makers and the public perceive and respond to potential local impacts of large-scale change, including economic and health risks, depends on social, cultural and political context and on how scientific evidence is presented. The METROPOLE (*An Integrated Framework to Analyse Local Decision Making and Adaptive Capacity to Large-Scale Environmental Change)* project focuses on identifying the factors that facilitate a shift in knowledge, attitudes, values and decision making about local climate risks and adaptation strategies among decision-makers and stakeholders in case study of coastal communities in Brazil, United Kingdom, and the United States (Marengo et al. 2017a, b; Paterson et al. 2017). The Belmont Forum-G8 Initiative Collaborative Research through grants from the FAPESP-Sao Paulo State Research Foundation, the US National Science Foundation and UK Natural Environment Research Council and Economic and Social Research Council, supported this project. The goal was to combine expertise from diverse scientific backgrounds to develop an integrated framework to analyse local decision-making and the adaptive capacity to local environmental change driven by large-scale processes like climate.

The hypothesis is that risk knowledge is best understood as being co-produced by science and by the social, political and cultural context. The research developed at METROPOLE concurrently analysed social context factors that affect adaptation planning and policy changes (adaptive capacity) and responses by local stakeholders when presented with interactive computer-based scenario simulations in participatory planning meetings to cope with sea level rise (SLR) and coast flooding. The project used (1) state-of-the-art visualization tools developed in the US and Brazil, (2) sophisticated survey and choice evaluation tools, and (3) a risk assessment Adaptive Capacity Index developed in the UK. The visualization tools integrate scientific and economic data at the community level for local jurisdictions, and illustrate potential impacts, economic risk, adaptation options, and cost-benefits analyses projected over time. The data included changes in sea level, temperature, storm frequency, precipitation and other variables in the past decades and high resolution projections in 5–10 year increments to 2100 under the IPCC AR5 sea level scenarios.

Expected results include a new framework to evaluate the impact of integrating scientific, economic, and cultural context data on adaption planning and decision-making. This will improve the ability of scientists to interact with stakeholders by developing an understanding of social context, and garner knowledge of best practices for the Brazilian case study.

1.2 Background

Nearly 7% of all human communities have developed in areas where the elevation is less than 5 m. from historical sea level (McGranahan et al. 2007; Wong et al. 2014; Reguero et al. 2015). Most of the world's 60 million poor people living in low elevation areas reside in just 15 countries, including Brazil, the United States of America and the United Kingdom (Barbier 2015). Urban low elevation coastal zones are expanding faster than elsewhere and this trend is expected to continue into the future (Seto et al. 2011). Globally, between 660,000 and 1,200,000 km^2 of land, 93–310 million inhabitants and 3100–11,000 billion USD of built capital are currently located at elevations less than the present 100-year sea level flooding event, but by mid-century there could be an increase in global flood losses for the 136 largest coastal cities (Reguero et al. 2015). Of these, approximately 40 million are exposed to major flood risks, and these risks are expected to increase over the next 50 years.

One of the clear signals of present climate change is sea level rise. There is mounting evidence of other changes, including warmer temperatures in many localities, and changes in the intensity and frequency of extreme meteorological events, including wind, rain, storms and waves that can generate coastal flooding. Damages are compounded when tidal fluctuations and surges due to severe storms are superimposed on these estimates. A rising sea level combined with high tides and storm surges is expected to impact the human built environment along coastal zones of the world as well as coastal ecosystems such as wetlands, coral reefs, beaches, and estuaries. Higher sea level typically leads to increase in coastal erosion, high risk of flooding, and contamination of fresh water sources through saltwater intrusion (Mcleod et al. 2010). Many of these coastal ecosystems are already impacted by human uses that have weakened their resilience (Hinkel et al. 2010). Extremes in meteorological events can also lead to erosion of coastal areas, landslides, and floods. These can have direct impacts on human communities, but also important indirect impacts through changes in biodiversity and other ecosystem services (IPCC 2014).

Sea-level rise is a tangible and tractable effect of climate change that poses significant challenges to society from the next 50 to 100 years, or earlier (Hauer et al. 2016). Global mean sea level rose by 0.19 (0.17–0.21) mm $year^{-1}$ over the period 1901–2010 based on historical tide gauge records; these rates are observed globally on average, as measured using satellite data collected since 1993. Between 1993 and 2010, the average global sea level rise rate was near 3.2 (2.8–3.6) mm $year^{-1}$.

Similarly high rates likely occurred between 1920 and 1950 (IPCC 2014). A gradual increase in average sea level of 1 m often cited as a possible scenario within a 100-year timeframe (Rhein et al. 2013; Wong et al. 2014), would seriously affect some coastal populations in Brazil (ECLAC 2011), the USA, and the UK (GEI Consultants 2015, 2016).

1.3 The METROPOLE Project

To improve resilience, policymakers need to understand current adaptation processes and obstacles, and plan accordingly to be effective. These processes depend in great measure on how decision-makers and the public perceive and respond to changes and the perception of risk. In order to evaluate how local government may respond to risks associated with sea level rise projections, a group of natural and social scientists from the United States (US), United Kingdom (UK), and Brazil developed the *METROPOLE* Project.

The METROPOLE study goals were to determine to what extent stakeholder beliefs, values, and preferences regarding adaptation options and funding choices may facilitate or hinder adaptation. The METROPOLE project encompassed a three-part, integrated environmental, economic, and social analysis embedded in a municipal planning effort involving stakeholders and decision makers in Brazil, the UK and the US. The first part included the use of the COastal Adaptation to Sea Level Rise Tool (COAST) model (Catalysis Adaptation Partners 2015) to show visualizations of SLR, infrastructure impacts, costs/benefits for adaptations, and small group discussions to define stakeholder estimates for action. The second piece involved administering pre- and post-workshop surveys to participants, to identify links between risk experiences, beliefs, values and attitudes about local government priorities for possible adaptation actions and public financing, and to assess change after seeing the COAST visualizations and discussing scenarios. The third element was the Adaptive Capacity Index (ACI), an assessment of institutional and individual interactions that shape local and regional adaptive capacity. The project was conducted in: the city of Santos (state of São Paulo, Brazil), city of Selsey (West Sussex, United Kingdom), and cities in Broward County (Florida, United States). The three study sites present both similarities (coastal cities threatened by the risk of sea-level rise) and differences (the size of the population and of the local economy), which make the comparison of the attitudes and values about local climate risks and adaptation strategies among decision-makers and stakeholders particularly challenging. This paper focuses on the Brazilian component in the city of Santos.

METROPOLE used the approach of Daniels and Walker (2001) and Burch (2010)) to explore the complex issue of how communities of different cultural backgrounds respond to risk and adaptation related to climate change. The IPCC defined this as the process of adjustment to actual or expected climate and its effects, including either moderate harm, or the opportunity to exploit beneficial opportunities. For this study, the IPCC Glossary (IPCC 2012) was adopted to establish the theoretical framework for adaptation and evaluation of risks, hazards, and vulnerability. The exception is that in the context of METROPOLE, "mitigation" means risk management or reduction of risk due to a hazard, and not reduced emissions of greenhouse gases.

The METROPOLE project involves developing visualization tools that integrate scientific information and socioeconomic data at the municipal level in each country, and illustrate the potential impacts, economic risks, adaptation options and analyses of cost-benefit projected over time. The central theme of the METROPOLE project is, therefore, to show, in an integrated way, how some coastal areas under different climate regimes and human pressures would be affected by SLR caused by climate change, and if society and the government would be prepared or not to take proper and fast adaptation measures. Recent studies on climate adaptation enhance the importance of engaging or activating communities and supporting community roles in understanding climate change and adaptation needs (Ross et al. 2015). Responses from cities to improve their resilience are urgent but policymakers need to understand current adaptation to plan comprehensively and spend effectively (Georgeson et al. 2016).

On the three case studies, Santos is a coastal city in the State of Sao Paulo in southeastern Brazil. Santos and areas adjacent to the city is strategic economic center for Brazil, with a large concentration of industries located along the coastal zone. The Port of Santos, the key economic asset for the municipality of Santos, is responsible for the transport of products from the largest industrial park in Brazil and handles some 25% of Brazil's foreign trade. Founded in 1546, Santos is one of the oldest settlements of Brazil. It occupies an area of 281 km^2, of which 39.4 km^2 lies in the insular domain (São Vicente Island) and 231.6 km^2 correspond to the mainland part of the municipality (Marengo et al. 2017a). Around 99.3% of the Santos population live in the insular domain. The Port of Santos alone is responsible for the transport of products from the largest industrial park in Brazil, handling around 25% of Brazil's foreign trade (ICF-GHK 2012).

The municipality of Santos is also a portrait of the social asymmetry of the country, featuring upscale neighbourhoods especially closer to the shoreline and poor neighbourhoods concentrated at the Northwestern Zone of the island, on the hill-slopes and the wet lowlands. The irregular occupation of the hill-slopes and mangroves, the pollution generated by industries located around the area, and deforestation of the Atlantic Rainforest, which reduced the water retention capacity of the soil and increased the continental runoff, accelerated common processes in the area such as landslides, mudslides and floods, putting a large contingent of the population under constant threat. The region is affected by tropical, subtropical and mid-latitude weather systems. During summer, when convective activity is greater, the SACZ (South Atlantic Convective Zone) influences the rainfall regime, with a cloud band and rainfall remaining semi-stationary for several days. Frontal systems are common in the area, mainly during autumn-winter. Storm surges have historically affected this region. Nowadays, storm surges typically cause destruction or urban infrastructure and damages related to traffic interruption at the southeastern ending of the Santos coastline (ICF-GHK 2012).

1.4 Sea Level Rise and Adaptation Options: The Case of Santos, Sao Paulo/Brazil

For the Latin America and the Caribbean Atlantic coast, SLR between 1950 and 2008 rose ~2 mm year^{-1} (Losada et al. 2013) and the Brazilian coastal areas are being affected by coastal erosion and coastal inundation (Souza et al. 2005; PBMC 2014), with the southern part of the State of São Paulo and Rio de Janeiro seeing rates of between 1.8 and 4.2 mm year^{-1} since the 1950s (Alfredini et al. 2013; Harari et al. 2007). According to (Harari and Camargo 1995), the mean sea level in Santos has risen at a rate of 1.2 mm year^{-1} since 1940s, with an increasing trend in the past decade. This rate is slower than the global mean sea level rise rate. This suggests that additional factors such as estuarine circulation patterns, land subsidence and/or anthropogenic interferences like dredging may be affecting local sea level rate.

Flooding events normally occur in two main areas of Santos: at the Northwestern Zone NWZ and at the Southeastern Zone SEZ. The latter is closer to the mouth of the Santos estuarine channel, along the seafront (Marengo et al. 2017a). At the NWZ, flooding is caused by the combination of heavy rainfall and high tides, so that the waters from the watersheds discharges summed to the superficial continental runoff flowing down towards the estuarine channel are blocked by the tidal waters rising into the existing drainage system. At the SEZ, flooding is caused by coastal inundation related to storm and tidal surges, in general associated to extra-tropical cyclones passage. SLR may affect the Port of Santos, the key economic asset for the municipality. Most sections are built to withstand water level increases of as much as 3 m above the current mean sea level (ICF-GHK 2012). The interaction between SLR and flood frequency may be of greatest concern.

The METROPOLE project incorporated an evaluation of risks and impacts of SLR and tested the city's Adaptive capacity. SLR risks were estimated using the COAST platform (Merrill et al. 2008; Marengo et al. 2017a). The METROPOLE project incorporated an evaluation of risks and impacts of SLR and tested the city's Adaptive capacity. SLR risks were estimated using the COAST platform. COAST estimates SLR and storm surge impacts by calculating damage from storm surge events cumulatively over time, given a changing base water level. It then calculates relative benefits of various adaptation scenarios in terms of cumulative *avoided* damages over time. The model is intended to be used by municipalities, state agencies and other groups interested in benefit-cost analysis for adaptation strategies aimed at reducing damages from SLR and storm surge.

COAST allows users to (a) calculate how much building damage may be avoided over time if such strategies are implemented; (b) confirm whether the projected benefits outweigh the costs; and (c) evaluate which strategies seem the most cost-effective. The process includes creation of data projections for coastal changes and potential economic and environment consequences of flooding scenarios resulting from a rise in sea level and extreme storm surge events. Financial ramifications are calculated using inputs from local stakeholders and confirmed by expert engineering review. Use of the tool in public process also allows stakeholders to articulate and modify potential adaptation strategies. The conceptual model developed for application of COAST in both the NWZ and SEZ affected by hydrometeorological risks in Santos is shown in Marengo et al. (2017a) . Data required to run COAST for the two case studies (district, land area, construction area, assessed value of the land, value of construction and value of the property) was obtained from the Municipality of Santos.

To advance the understanding of connections between stakeholder beliefs, values and preferences regarding adaptation options and funding choices, as well as to improve understanding of barriers to adaptation in Santos, decision makers, citizens, representatives of public and private sectors and of NGOs of Santos were engaged with the METROPOLE process through two stakeholder workshops. These workshops were directed to engage decision makers, citizens, and representatives of the public and private sectors to develop and evaluate adaptation options for NWZ and SEZ of Santos. To create the data for the workshops, our team and municipal managers reviewed the estimated SLR/flood risks and discussed potential adaptation actions. After consulting with other staff and elected officials, the municipal managers selected several realistic and potentially useful combinations of actions to be discussed by stakeholders at Workshop 1. The workshops presented and discussed maps of future flooding projections due to sea level rise for 2050 and 2100. Workshop participants were shown the respective estimates of economic damages to real estate for the SEZ and NWZ zones of Santos. The small group discussions at these workshops focused on adaptation options for the community of Santos. As a result of these workshops, participants coming from various sectors of society living in Santos proposed some adaptation measures, that were later on incorporated in the COAST model (Marengo et al. 2017a b).

For the city of Santos, the most preferred adaptation options were fortification (66%) and accommodation (30%). For the NWZ, the fortification (50%) and accommodation (43%) actions were also preferred, while relocation was the least preferred option, with 4% in the SEZ and 7% in the NWZ (Marengo et al. 2017a). Table 1.1 shows that the adaptation measures selected by participants (i.e. fortification and accommodation) would be cost effective in both the lower scenario of sea level rise (0.36 m; for the period 2010–2100) and for the higher scenario (0.45 m by 2100). Santos adopted dredging and mangrove restoration for the northwestern sector, while for the southeastern sector reinforcement of existing walls and beach nourishment were the selected options. The community evaluated beach nourishment, dune restoration, structural enforcement of existing sea-walls, water pumping and improvement of tide control gates in existing drainage canals. In the southeastern sector of the city the damages from a 100-year flood in 2050 under low and high SLR scenarios would be US$34 and US$38 million, while in 2100 these damages could reach US$60 and US$75 million, respectively (Table 1.1).

However avoided damages for the NWZ might be greater than was modelled because of challenges encountered in obtaining accurate real estate valuation data from the Municipality of Santos. According to the Municipality of Santos, the NWZ shows buildings up to four floors, and there are a lot of commerce activities (stores,