Future Sea Level Rise Scenarios and the Shoreline of Mar del Plata, Argentina: Assessing Socioeconomic Impacts and Relief Measures

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Abstract

This paper employs simulation models to gauge the effects of sea level rise (SLR) on the shoreline of Mar del Plata, Argentina, considering different scenarios. The analysis follows the findings and recommendations of the Intergovernmental Panel on Climate, as well as other relevant studies. We combine the information generated by the SLR simulation models with geo-referenced census data to characterize the socioeconomic context were the impacts of SLR will take place, in order to help identify appropriate relief measures for the different sea level rise scenarios. Specifically, we attempt to answer the following questions: Where the coastal damage will take place? To what extent the effects of SLR will vary spatially? And, what is the present socioeconomic context of the areas in the city that will be most heavily exposed to SLR? The paper concludes with recommendations on relief measures.

Keywords: Sea Level Rise, Coastal Damage, Shoreline Retreat, Relief Measures, Coastal Planning, Mar del Plata, Argentina

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Table of Contents

Figures

Tables

Future Sea Level Rise Scenarios and the Shoreline of Mar del Plata, Argentina: Assessing Socioeconomic Impacts and Relief Measures

Introduction

The coast of much of the Americas is threatened by global sea level rise (SLR), and the problem is attracting the attention of researchers around the world (Feagin et al. 2005). In order to effectively assess risks, coastal cities are using models to simulate the scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC). It is estimated that 1.2 billion people, or approximately 23 percent of the world's population, live within 100 meters of sea level and at 100 km. from a coast and are thus vulnerable to sea level rise (Cooper et al. 2005). A global review of the population and urban settlement in Low Elevation Coastal Zones (LECZ), that is. the contiguous area along the coast that is less than 10 meters above sea level, found that it covers 2 percent of the world's land area but contains 10 percent of the world's population and 13 percent of the world's urban population (McCranahan et al. 2007).

The IPCC suggested a rise of 0.09 to 0.88 meters by the year 2100 unless greenhouse gas emissions are reduced substantially (Intergovernmental Panel on Climate Change 2001). More recent studies indicate that the melting of ice sheets could be faster and hence more challenging for society (Overpeck et al. 2006). Current ice discharge data show that melting ice may cause a sea level rise of 1 to 3 meters by 2100. New data on rates of deglaciation in Greenland and Antarctica suggest greater impacts from glacial melt, and a possible revision of the upper-bound estimate for SLR in this century. A World Bank Research Working Paper (Dasgupta et al. 2007) cites numerous authors including Ringot and Kanagaratnam (2006), Hanna et al. (2005), and Krabill et al. (2004) who concur with the finding that the contribution of the Greenland ice sheet to SLR is roughly double the rate assumed in the IPCC Third Assessment report. Other investigations indicate that a collapse of the West Antarctic ice sheet would raise average sea level by approximately 5 to 6 meters (Dasgupta et al. 2007, citing Tol et al. 2006). Similarly, Velicogna and Wahr (2006) the ice sheet in Antarctica is decreasing faster than the IPCC suggests.

Dasgupta et al. (2007) add broader perspectives to the SLR problem by modeling new information. Their research on precautionary planning suggests that a SLR in the range of 1 to 3 meters should be regarded as realistic. Their models were calculated using Geographic Information Systems (GIS) and satellite images (SRTM 90 m) for SLR scenarios ranging from 1 to 5 meters.

The spatial distribution of the impacts of climate change will not be uniform. Some regional changes in climate are expected to be much more pronounced than changes in the global average and others less so (CBO 2005). Besides SLR, it is well established that climate-change-induced risks will affect human health in a variety of ways and will more than double by the year 2030 (Patz et al. 2005).

Although no model is capable of capturing the whole range of the SLR impacts, they provide the basic first steps toward mitigating such impacts. For example, flood risk can be mitigated at low cost through risk-based development planning. Such initiatives use new flood maps and amended building codes to address climate change. The future costs of reducing climate change can also be addressed by taking action to reduce greenhouse gas emissions, and this must also continue to be a major global focus. Reduction in greenhouse gases, however, will slow the effects of climate change over the coming century, not prevent or reverse them. At the very least, such reduction will buy time to implement the necessary adaptation to protect society from the effects of climate change (Herweijer et al. 2008).

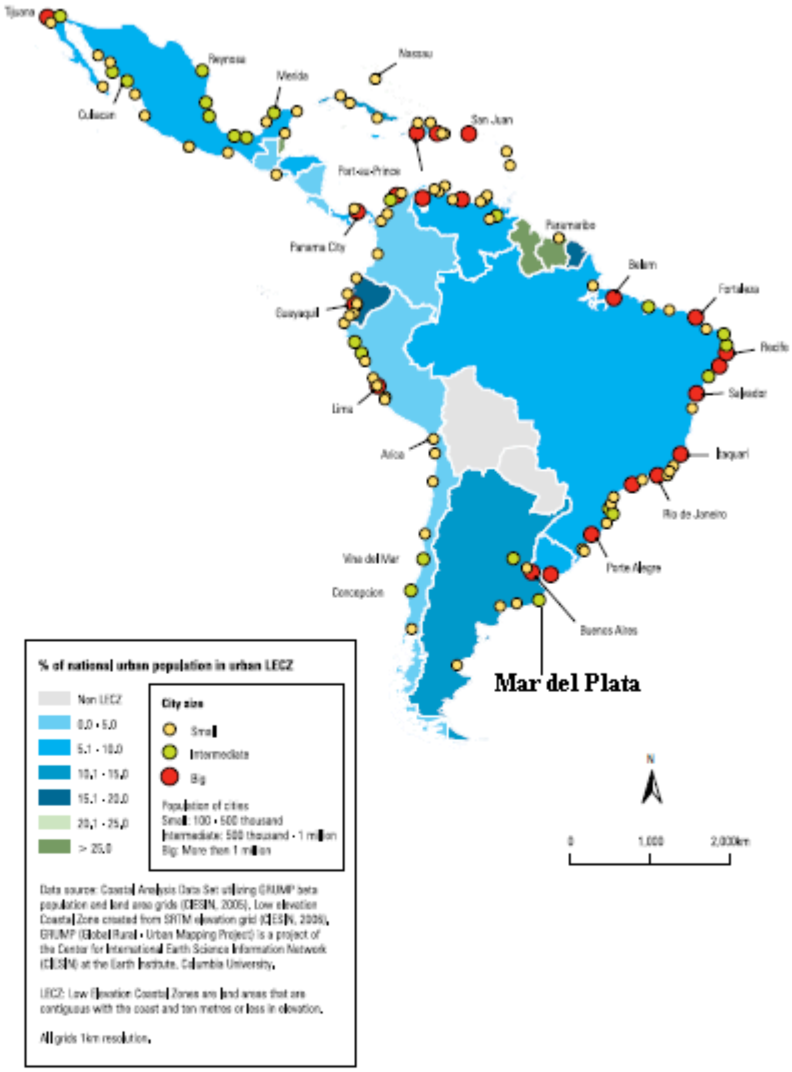
Insurers can play an important role together with policymakers to disseminate information on the risks, especially in fast growing coastal cities. Cities that engage in coastal management efforts should take into account nonstructural approaches, such as beach nourishment, dune construction and stabilization as well structural initiatives (Herweijer et al. 2008). However, misinformation is still widespread. Based on the differing interpretations of the same knowledge base, there are the "optimists" who argued that human adaptation will reduce the magnitude of the impacts to a level where SLR becomes almost a trivial problem. This argument seems a modified version of the idea that pollution is not a major problem because at some point in the future humanity will have the resources to eliminate it. Meanwhile, "pessimists" argue that SLR and climate change in general are a major threat for the twenty-first century (Nicholls and Toll 2006).

In addressing climate change, researchers and policymakers face various sources of uncertainty. There are still hurdles to be overcome before it is possible to conduct comprehensive impact and response analyses including: incomplete knowledge of the relevant processes affected by SLR and their interactions; insufficient data on existing conditions; difficulty in developing the local and regional scenarios of future change; and lack of appropriate analytical methodologies to assess some the impacts (Nicholls and Nimura 1998). Although the most traumatic consequence of SLR is permanent flooding, there are several other visible processes that ought to be considered, such as coastal erosion, episodic flooding from storm surges and salinization of aquifers, and these, in some aspects, require more urgent attention.

Erosion caused by climate change will affect two of the core functions of beaches, namely tourism and coastal defense. The risk SLP negative affecting the tourism industry is high in the eastern and southern Caribbean and along the east coast of Brazil, but also in some areas of Argentina, Chile, Ecuador, Mexico, and Peru (CEPAL 2010).

The uncertainty and complexity associated with climate change tends to produce conflicting information. Argentina is a case in point. Vafeidis et al. (2011) indicates that the land surface in low coastal areas is 3,463 square km, housing a total population of 3.8 million in 2000, projected to rise to 5.1 million in 2030 and 5.8 million in 2060. The same research calculates the number of people exposed to SLR in Argentina to be about 725 thousand in 2000, projected to increase to about 763 thousand by 2030 (10 cm SLR scenario) and 804 thousand by 2060 (21 cm SLR scenario). This study uses different types of satellite images to establish the different SLR projections. Similarly, the UN-Habitat Urban Global Observatory identifies Mar del Plata as one of the coastal cities in Argentina, among others, that is at risk due to SLR (figure 1). In contrast, Dasgupta et al. (2007) suggests that the area, the population, and the gross domestic product (GDP) of Argentina will not be significantly impacted by SLR.

Figure 1. Latin America and Caribbean Cities at Risk Due to Sea Level Rise



Source: Modified from UN-Habitat Global Urban Observatory, 2008

A European research points out that in the low-lying coastal regions and estuaries in Argentina and Uruguay, an increase in sea level could reduce biological diversity and the surface of coast, damaging infrastructure and leading to saltwater intrusion into aquifers, estuaries, and wetlands (Europe Aid 2009). The same studies indicates that if SLP were to block the flow of rivers on the plains towards the ocean, the risk of flooding could increase in these basins

Mar del Plata with 616,142 inhabitants is the seventh largest city of the Republic of Argentina and the head of the Municipality of General Pueyrredon and is located 400 km south of Buenos Aires. The city faces the Atlantic Ocean and has an important role in the argentine tourism industry. Tourism is one main economic activities of Mar del Plata, receiving millions of visitors during the summer season. The city also harbors the most active fishing port of the country. Tourism and recreation continue to grow at fast-pace encouraging human settlement developments along the shoreline. As a coastal city, Mar del Plata faces several of the problems associated with SLR. Some research has been conducted in relation to the erosion of its shoreline. Alvarez and Ferrante (2000) quantified the coastal erosion in Mar del Plata during the period 1970–1998 and determined significant coastal retreat values of the shoreline. Similar results were found for other smaller cities in the province of Buenos Aires, such as Quequen and Necochea. However, to our knowledge, no prior research has simulated the scenarios described by the IPCC or by Dasgupta et al. (2007) for Mar del Plata.

This study proposes to develop models that consider different sea level increases for the shoreline of Mar del Plata building upon the scenarios suggested by the IPCC, which are: a low rise scenario (0.09 m by 2100), a moderate rise scenario (0.48 m by 2100), and a high rise scenario (0.88 m by 2100). We also model other hypotheses that anticipate a more drastic increase estimated at 1 m, 2 m, and 3 m by 2100, following the World Bank Research Working Paper (Dasgupta et al. 2007). The overlaying of the resulting maps with socioeconomic data could provide answers for the central questions of this study, namely: Where will coastal damage take place and to what extent its effects will vary spatially? What is the present socioeconomic context of the sectors of the city that are vulnerable to the sea rising scenarios? What are the relief measures that can be implemented in the short and long terms?

Methodology

The main instrument to model SLR is a digital elevation model (DEM). Currently there are two free-access digital terrain models at global scale: the Shuttle Radar Topography Mission (SRTM, with 90 m resolution) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)[1] Global Digital Elevation Model (GDEM, 30 m resolution). The Version 2 (GDEM V2) released on October 17, 2011, was used in this study. It was downloaded from NASA Reverb ECHO, a free tool for exploring and downloading Earth Science data sets.[2] We also resorted to free GIS software for the image processing (gvSIG) which was developed in Spain[3] and allows eventual integration of climatological and socioeconomic data sets (Gornitz 1990).

A preliminary DEM of Mar del Plata was presented last year (Celemín 2011) using SRTM images (figure 2). That image shows the geomorphology of the city and the differential elevation of the city's shoreline, but not the sea level. Over the DEM we outline the neighborhoods of the city.

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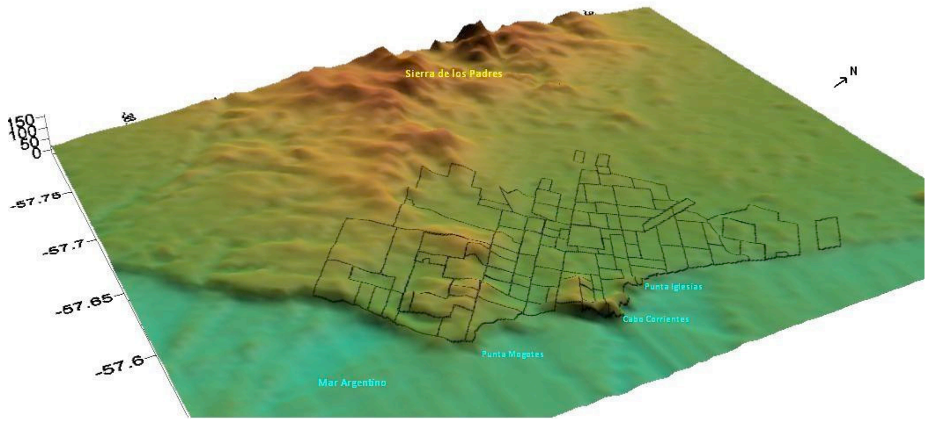
[1] GDEM is a product of The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA).

[2] http://reverb.echo.nasa.gov/reverb/

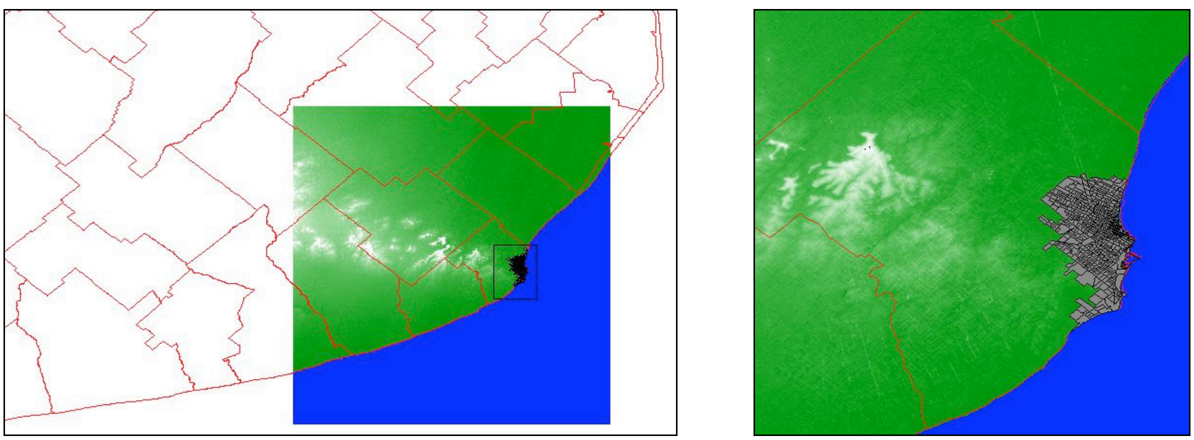
[3] It is our intention to use free datasets as well as free software which can be accessible to anyone interested in climate change research—especially scientists from developing countries.

Figure 2. Preliminary DEM of Mar del Plata, 3D



Source: Celemin in Atlas Socioterritorial de Mar del Plata (Lucero 2011)

Figure 3. DEM of the Study Area, 2D



To obtain the different SLR scenarios we followed these steps:

a) Elaboration of a mosaic of GDEM images comprising the south east of Buenos Aires province (figure 3).

b) Demarcation of contour lines for the study area (figure 4).

c) Detection of areas exposed to SLR at 0.09 m, 0.48 m, 0.88 m, 1 m, 2 m, and 3 m (figure 5).

Figure 4. Study Area Contour Lines

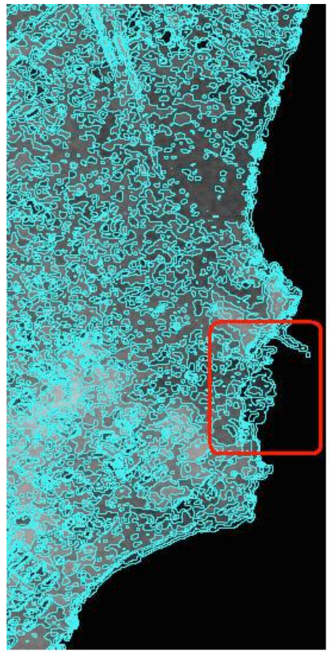
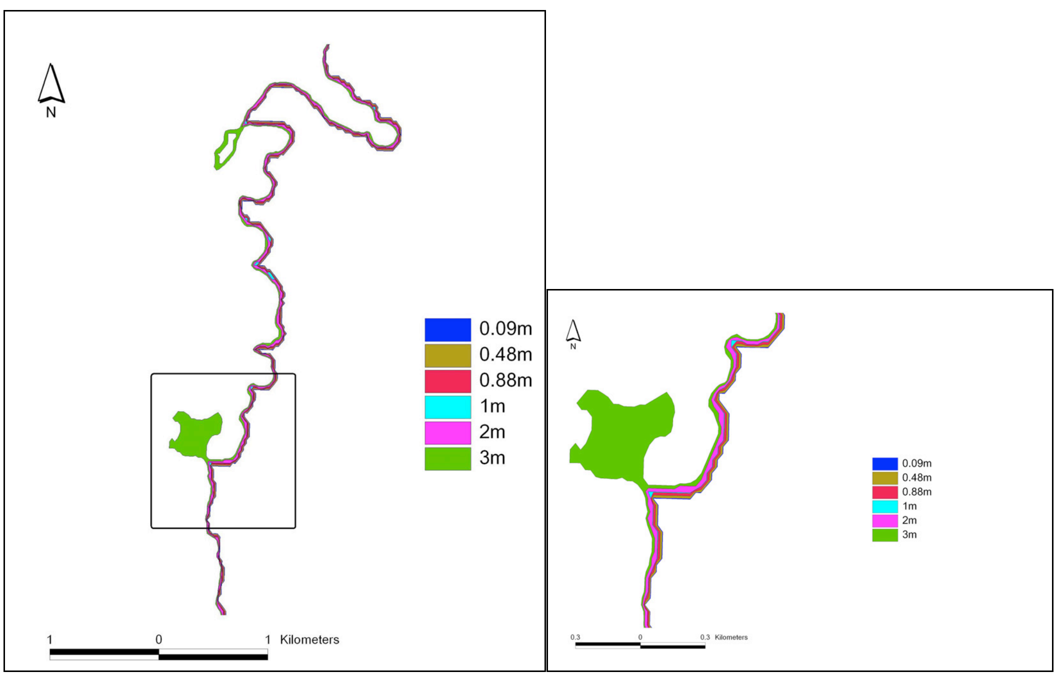


Figure 5. Details of Areas Exposed to SLR (Red Box of Previous Image)



To identify the socioeconomic structure of the city we apply an index called Unsatisfied Basic Needs (UBN) build upon Census data. This index is provided by the National Institute of

Statistics and Census[4] and covers a group of dichotomous variables to identify poor areas. A person is considered poor if they live in a household having one or more of the following characteristics (Hick 1998, 105).[5]

- More than three persons per room (crowding).
- Living in a house made of irregular materials, or in rental quarters (housing).
- Not having an indoor flush toilet (sanitation).
- Having a child between 6 and 12 years of age that is not attending school (school attendance).
- Having four or more persons per person working and a household head with two or less years of primary school (subsistence capacity).

The combination of this information with the DEM is intended to help select the relief measures in relation to the different sea level rise scenarios that are appropriate to the socioeconomic context.

Impacts of Sea Level Rise in Mar del Plata

Sea Level Rise

Using the IPCC estimates, the more conservative SLR covers less than a hectare of the city of Mar del Plata, while the more drastic scenario affects almost six hectares. The World Bank Working Paper (Dasgupta et al. 2007) takes into account a higher SLR with a minimum and maximum of 10,403 and almost 15,000 hectares respectively for Mar del Plata. The city has a LECZ of 40,460 hectares (table 1).

Table 1. Area of Mar del Plata affected by SLR

Sea level rise	*Affected area (hectares)*[6]
0,09m	0,604
0,48m	3.266
0,88m	5,722
1m	6,401
2m	10,403

[4] This index was obtained from the 2001 census. The last census was conducted in 2010 and the disaggregated data at radio census scale is expected to be published later this year. However preliminary results indicate that the spatial configuration has changed very little in the last intercensal period.

[5] Technically is considered as an index of poverty despite having variables related to education and housing. More information about this index can be found in Abaleron (1995) and Hicks (1998).

[6] 1 Hectare = 10,000 sq. meters

3m	14,970
LECZ	40,460

These values are not large enough to have significant impact on the inland area of Mar del Plata. In other words, the worst case scenario related to the climate change for a coastal city (permanent flooding) does not seem to be a major concern for the study area. However most of the area that may be affected by permanent flooding is beach sand. If this were to take place, the economy of Mar del Plata would be seriously impaired since the magnet for tourism is the beaches and that industry is of great importance in this seaside resort.

Damages Caused by Storm Surges

Episodic inundation results from storm surges, which are anomalously high tides produced by a combination of low atmospheric pressure and wind-driven waves (Gornitz 1990). Storm surges are expected to be more frequent due to climate change. Because the near-shore wave height varies directly with water depth and the wave energy varies with the square of wave height, accelerating sea level rise will strongly increase the force of breaking waves in newly deepened near-shore waters, further exacerbating erosive losses (Caldwell and Segall 2007, 538). Mar del Plata has seen an increase in the average number of positive storm surge events per decade.[7] A possible explanation of the changes in frequency, height and duration of positive storm surges in Mar del Plata would seem to lie in the relative mean SLR (Fiore et al. 2009).

The study area also experiences a climatological phenomenon called “sudestada” which consists of very strong winds from the southeast that occur more frequently between July and October. The “sudestadas” mean higher high tides with subsequent coastal damage. The historical record occurred in the year 1911 with 3.25 m.

Aquifer Salinization

Coastal aquifers are very sensitive to sea level rise. As it was seen on Figure 2, the NE shoreline of the city is vulnerable because the impermeable basement is too deep not forming a physical barrier that could contain the marine intrusion. An appropriate measure of protection is the implementation of a hydraulic barrier[8] that would prevent the marine intrusion. However there is limited knowledge about the forecasts available for Mar del Plata in relation to climate change and saline intrusion, therefore a conservative attitude regarding future projection of sea level is needed. The local agency in charge of water management is considering a scenario of 38 cm. SLR for the year 2020 (Mérida 2002).

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[7] The following web site contains photographs showing the damage caused by a storm surge in Mar del Plata: http://www.erosioncosterapba.com.ar/general_pueyrredon.html

[8] A general term referring to modifications of a ground-water flow system to restrict or impede movement of contaminants or other fluids.

Socioeconomic Structure of Mar del Plata

The spatial configuration of the Unmet Basic Needs index shows a descending gradient from the periphery to the center of the city (figure 6). The distribution replicates the traditional socioeconomic structure of mid-sized Latin American cities where the worst-off population resides in the outskirts of a city.

From the harbor to the north, the coastal census blocks show very low values for the index. Most of this area is very attractive, comprising an area that combines with relative harmony the city buildings and the shoreline. Nevertheless, this part of the coast is where the potential effects of climate change could be more harmful; where the loss of beaches due to erosion and SLR would change dramatically the structure and identity of Mar del Plata causing significant social, economic and environmental impact.

Coastal Erosion

For Mar del Plata, coastal erosion is not a new event, but rather a problem that has affected the city for over a century and, despite the efforts made to contain erosion, there is no definitive solution in sight. The construction of the port caused a blockage of the littoral drift that still affects the northern beaches. For years, the building of breakwaters (structural technique) seemed to be the permanent and ultimate solution. Today, however we can see its harmful effects to the extent that breakwaters increase the surface of the beaches by capturing the littoral drift thus limiting its path. As a result, the defenses aimed at obstructing the littoral drift were able to recover some beaches but in turn led to the erosion of other beaches (Isla et al. 2001; Isla 2006). Therefore it became necessary to build a successive set of breakwaters (figure 7).

Figure 6. Unmet Basic Needs Index for Mar del Plata

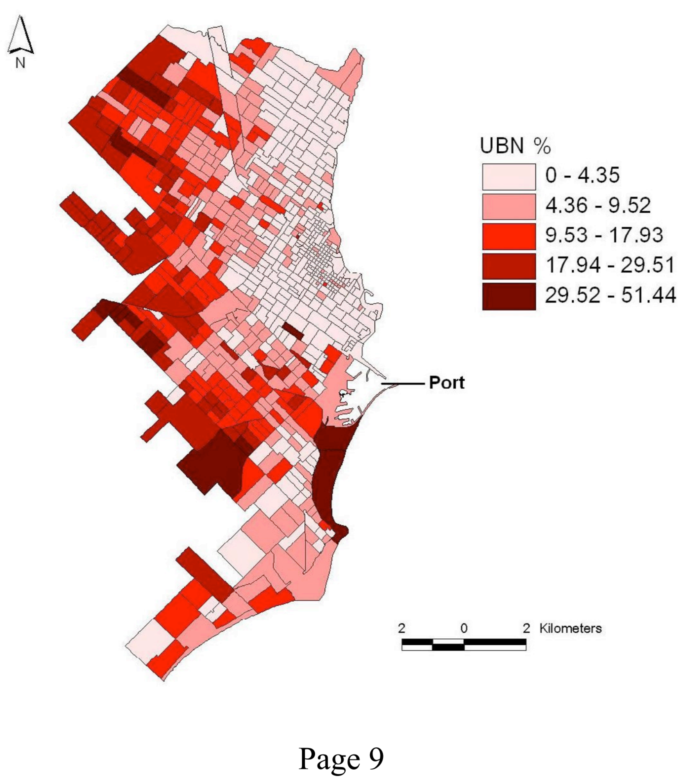
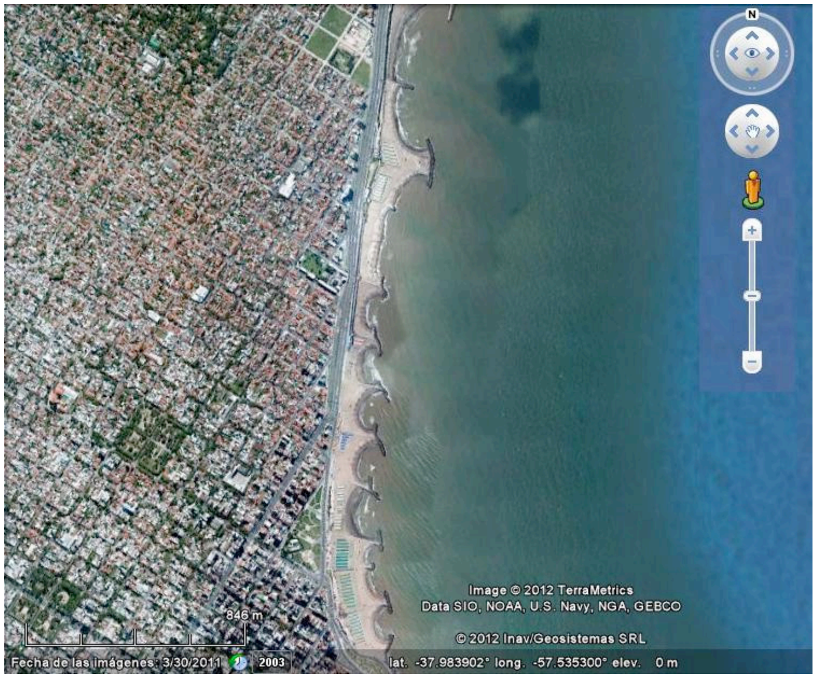


Figure 7. Image of Breakwaters in the Northern Shoreline of Mar del Plata



Source: Google Earth

Although the extraction of beach sand for building purposes was banned in 1985, the coastal erosion progresses about half a meter per year for Mar del Plata's northern shoreline.[9] The erosion became critical in the nineties to the point that in 1998 a beach nourishment plan was implemented (non-structural technique) using the sand trapped at the entrance of the port—which also limits the littoral drift. Even though the results were highly satisfactory, this type of practice is not definitive and requires repetitive proceedings since it does not take away the physical forces that cause erosion, but just moderates their impacts.

The coastal erosion problems motivated the development of a master plan, implemented by the Municipality of General Pueyrredon in 2005. The problem is expected to grow in complexity over time, since the rate and extent of coastal erosion will intensify as a result of increased SLR. However, erosion trends are not easily predicted, because of the interplay among numerous factors, including the sediment and the oceanographic climatic variables (Gornitz 1990, 396). To date the most visible outcome of the plan is the building of new breakwaters which are currently underway in vulnerable areas.

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[9] Diario el Atlántico. http://www.diarioelatlantico.com/diario/2011/08/30/32558-aseguran-que-la-falta-de-arena-en-playas-fue-provocada-por-la-accion-del-hombre.html

Concluding Remarks

The sea level rise effects encompass several geomorphological, ecological and socioeconomic aspects. The most serious physical impacts of this event are permanent inundation, coastal erosion, increased coastal storm flooding and salinization. Natural disasters resulting from or facilitated by climate change undermine or destroy the achievements in urban development. Coastal cities are particularly vulnerable to natural disasters such as flooding resulting from SLR or extreme weather events (He et al. 2010).

For Mar del Plata, permanent flooding caused by SLR does not seem to be the major threat associated with climate change. Our models show that the inland impact will be minimal since the impact will be primarily on the beaches of the city. Mar del Plata has resorted to both structural and non-structural measures in its long lasting struggle with coastal erosion with mixed results. Increased coastal erosion exacerbates pressure to armor the new stretches of the coast and to strengthen existing armoring (Caldwell and Segall 2007). The construction of breakwaters significantly reduced coast erosion in specific locations, but increased the problem elsewhere as they interfere with the littoral drift. A non-structural, beach nourishment, proved to be a successful measure although it is more expensive and requires repeated interventions since it is not a definitive solution as the positive effects tend to wear off over time.

During storms, sea water level raises furthest beyond historic norms; wave strength and energy also increase markedly, amplifying erosive force (Caldwell and Segall 2007). Since these episodic phenomenon have caused repeated damage to the infrastructure of Mar del Plata and coastal walks are closed during these events. Even though this problem is well known by the local population, they do not associate it with SLR. There is a worrying lack of knowledge among the residents of the potential impacts of climate change. This issue should be addressed by the local authorities through educational programs designed primarily for children. After all, it is them who will face most of the negative consequences of climate change.

One of the challenges in designing and implementing relief measures is the number of actors involved in the process, including the national, provincial and local governments, the private business sector, and communities. Both within and among these actors, there are differences in preference for different measures (Meffert 2008). For instance, in the study area the beaches are under provincial jurisdiction therefore the implementation of any mitigation measure requires an agreement between the local and the provincial government. These authorities should design a plan that considers which approach should be used in the different SLR scenarios. Such plan should contemplate the utility, time duration and economic viability of each proposed measure. For example, at what rate of SLR the non-structural measures are no longer an option?

The local government has to anticipate scenarios where tourism could be seriously affected by SLR and ask questions such as: What amount of beach surface would be lost? How would it impact the local economy? What other economic strengths can the municipality promote? Although tourism has a great importance for the city, Mar del Plata possesses a relatively diverse economic base. Industrial activities (specially fisheries), education and healthcare services are sectors that can increase their growth rates. Mar del Plata has two national universities (one with a technical emphasis) that are promoting closer ties with the productive community. Also, given an important presence of older population, Mar del Plata stands out for the services rendered to the elderly.

The Unmet Basic Needs Index for Mar del Plata indicates that the people living in coastal areas have a good socio-economic status. In general, this group has the resources to deal with some of the effects that may result from SLR. For example, they may purchase insurance or receive tax abatements that compensate for loss of property value if their nearby landscape is altered by SLR, especially the beaches. But the citywide economic impact of a decline in the tourism industry is less readily addressed.

The increasing availability of satellite images with better spatial resolution and software platforms that are accessible free of charge allows the development and application of relatively simple methodologies to model the impacts of rising sea levels, mainly permanent flooding. The resulting risk maps are the fundamental input for appropriate coastal land use planning. Without research and interventions that ensure sustainable development, economic growth in itself may strongly aggravate the impacts of climate change on coastal areas (Herweijer et al. 2008).

Updating, adaptation and validation of models is a necessary activity in modeling-based scientific research (Dickey and Watts 1978). We should be careful with some of the existing global and regional models. Although a regional perspective provides a useful link between research and policy at the national and global scales, these regional models require further national assessments for validation purposes (see appendix). In particular, there is a need for more assessment of the impacts of sea level rise, including better integration of the natural and social sciences so that the relative role of climate change on non-climate-change factors can be more fully understood; leading to more realistic evaluation of the range of possible response strategies (Nicholls and Nimura 1998). There must be a thorough analysis when extrapolating global models to local scales; if it is not done properly, the uncertainty associated with climate change may be potentiated.

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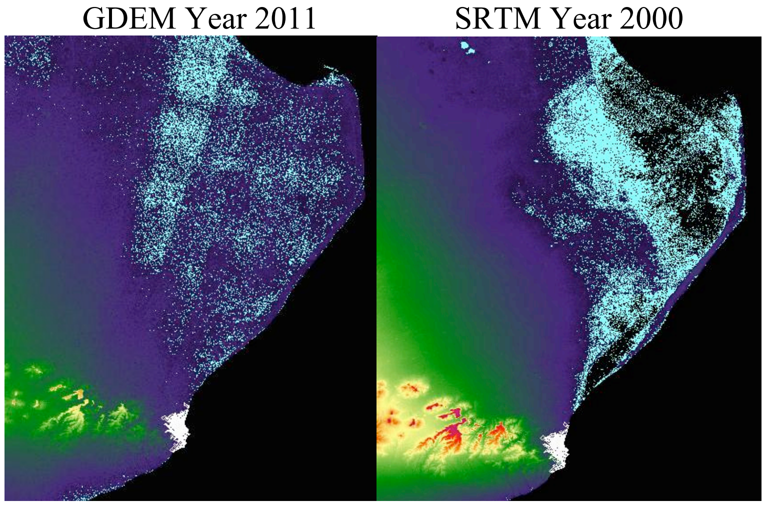
Appendix

Figure 8. Example of Updating and Validation of Models



In both images (figure 8) the light blue color indicates areas with an altitude of 1 to 3 m in the SE of Buenos Aires province. The GDEM images with 30 m of spatial resolution became available last year while the SRTM 90 m dates back to the year 2000. SRTM images were used by numerous studies to model the SLR following the IPCC report. As can be seen, there are differences between the two types of data and there is a necessity to validate the previous models once new data becomes available.

However, SRTM images can be found for the United States with 30 m, but it is intentionally degraded for the rest of the world reaching 90 m. of spatial resolution. Unlike optical images which can be downloaded from various web sites, DEM’s are not easily obtainable. There are some restrictions in their availability due to security reasons and only national agencies can distribute them. For example the German Aerospace Center provides SRTM images including a sensor called X-SRTM with very high resolution. Unfortunately these data cover most of Buenos Aires province but not Mar del Plata.