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COASTAL AND MARINE ENGINEERING AND MANAGEMENT  
CoMEM

FEASIBILITY OF A MARINA PORT ALONG THE  
BUENOS AIRES COAST, ARGENTINA

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Ricardo Amaury Camarena Calderon

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Prof. Dr. Ir. Marcel J.F. Stive  
Delft University of Technology  
Faculty of Civil Engineering and geosciences  
P.O. Box 5048  
2600 GA Delft  
The Netherlands





# Feasibility of a marina port along the Buenos Aires coast, Argentina

## MSc candidate

Ricardo Amaury Camarena Calderon

## Thesis committee

Prof.dr.ir. M.J.F. Stive	(Chairman TU Delft)
Prof.dr.ir. L.C. van Rijn	(Deltares)
Ir. Pieter Koen Tonnon	(Deltares)
Ir. Jan-Joost Schouten	(Deltares)
Dr.ir. Gerben de Boer	(TU Delft/Deltares)





## CoMEM thesis

This thesis was completed by

*Ricardo Amaury Camarena Calderon*

under the supervision of

*Prof.dr.ir. M.J.F. Stive (TU Delft)*

*Prof.dr.ir. L.C. van Rijn (Deltares)*

*Ir. P.K. Tonnon (Deltares)*

*Ir. J.J. Schouten (Deltares)*

*Dr.ir. Gerben de Boer (TU Delft / Deltares)*

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*Delft, The Netherlands*
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*Barcelona, Spain*

at which the student has studied from August 2010 to June 2012.



## Abstract

This study attempts to determine which location along the Buenos Aires coast is better suited for the development of a Marina port, taking into account physical, environmental and economic features.

A literature review related to port development, dimensioning, and port/coast interaction was completed. It was defined that the most relevant criteria to select a location were the water depths near shore, longshore transport rates, and the impact on the adjacent coast. Following this section, the preliminary port dimensions were defined based on the (Unified Facilities Criteria (UFC), 2009) and the (California department of boating and waterways, 2005).

Each initially feasible location was selected based on the information obtained from the literature study, the expertise of the people involved in the project in Argentina, and the two week visit to the Buenos Aires coast.

The reviewed literature provided some insight on the morphology and dynamics of the coast, although the reliability of the different studies was limited in many cases. Near-shore wave values were almost non-existent along the coast, and only a few studies had a more thorough methodology to estimate waves, longshore transport rates and coastline change.

In this thesis study Delft3D-WAVE model was implemented, forced by offshore wave/wind data from the NOAA Wave Watch data base, including 18 offshore wave/wind points used as spatially varying boundary conditions. The bathymetry of the area was built based on the nautical charts obtained from (Servicio de Hidrografia Naval, 2012), and the (GEBCO, 2008) global bathymetry. The NOAA wave and wind data was classified in 125 scenarios by using ORCA tools.

To show the results of the wave model, each scenario was plotted showing the distribution of the significant wave height, and the peak wave period. Added to that, 36 near-shore wave roses were created at the 7m water depth contour, covering the coast from Punta Rasa to Miramar. A strong dominance of south storms was found, it was also concluded that the coast further north had a weaker wave climate and consequently smaller transport rates, mainly due to energy dissipation induced by bottom friction of the extensive shallow areas near the north section of the coast.

By using the calculated near-shore wave climate, longshore transport rates, and coastline changes along the coast were calculated by implementing UNIBEST-CL+. The sediment properties as the  $D_{10}$ ,  $D_{50}$  and  $D_{90}$  used for the model were derived from the samples extracted during the field visit in Argentina that were later measured at the TU-Delft Geoscience laboratory. The calculated longshore transport rates showed a good

agreement when compared to the values obtained by (Van Rijn, L.C, 2008) and (Scalise, A.H., Schnack, E.J., 2007).

After implementing the wave and coastline models, an evaluation of the locations was completed. All the locations were compared by using a multi-criteria table, and it was concluded that Pinamar was the most promising location, since it provided moderate wave and longshore transport rates, short distance from the shore to the required depths, and existing infrastructure to accommodate and entertain the different marina users.

Different layout alternatives were derived and compared; for the selected alternative, extra insight was provided, estimating the dredging volumes, and proposing coastal protection structures.

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# 1. Introduction

## 1.1. Significance of the study

The country of Argentina is located in South America facing the Atlantic Ocean to the East, other South American countries as Chile, Bolivia, Uruguay, Paraguay and Brazil border the country in the other directions (North, West and South).

The 4,665 km long Atlantic coast has been a popular local vacation area for over a century, and varies between areas of sand dunes and cliffs. A huge opportunity for development is still open, as specified on a study by (Dennis, K.C., Schnack, E.J., Mouzo, F.H. and Orona, C.R., 1995) only 2% of the Argentinian coast is developed.



Figure 1 Geography of Argentina

In the past decades erosion started to be a significant problem on the coast of the Buenos Aires province. Not only natural erosion occurred in the area; human activities, city drainage systems, bad management of coastal zone, as well as illegal mining enhanced the erosion of the coast (Isla, F.I., 2010). Coastal defence structures as groins solved the erosion problems locally, but affected the adjacent coasts. (Isla, F.I., Fasano, J.L., 1987).

The development of a port could negatively affect the coast and increase erosion problems, therefore the effects of the port along the coast should be studied in detail, to avoid damaging the coast.

## **1.2. Problem description**

Studying the feasibility of constructing a port in the area has a paramount importance for the “Fundacion Bolsa de Comercio de Mar del Plata” (Chamber of Commerce Foundation of Mar del Plata); therefore they contacted Deltares via Prof.dr.ir. L.C. van Rijn, who in fact visited Mar del Plata previously and did some work related to the coast of the Buenos Aires province.

This project has an utmost importance for the Fundacion Bolsa de Comercio de Mar del Plata, but also for the province of Buenos Aires, Argentina. The development of a port between Buenos Aires and Mar del Plata would create jobs, increase tourism, and would allow people to travel by sea from the capital to Mar del Plata; all these factors would certainly boost the economy of the province, and consequently lead to economic stability throughout the year.

It is known that part of the coast of the province of Buenos Aires is suffering from erosion (Isla, F.I., 2006); thus the most suitable locations to develop a port have to be analysed and compared, in order to determine which location is more beneficial, and has more advantages to develop a port.

It is important to highlight, that for many years tourism has been the most important economic activity for cities on the coastal stretch under analysis; consequently the construction of a marina port should not negatively affect the coast, and should boost the economy.

### 1.3. Objectives

The general objective of this thesis is to study the coast of the Buenos Aires province, and determine which locations are best suited to develop a port, and whether or not those locations are feasible for port development.

The following sub-objectives were derived in order to achieve the main objective of this study.

- Provide a comprehensive description of the Buenos Ares coast
- Obtain near-shore wave information
- Estimate longshore transport rates along the coast
- Build a matrix for location comparison
- Undertake a preliminary design of the marina port

### 1.4. Approach

In order to achieve the previously set objectives the following approach was followed.

First a literature review related to port design guidelines, classification and wave/port interaction was completed.

Then to analyse the coast, a broad literature review related to existing studies of the coast of Buenos Aires was finalized, supplemented by a field visit to Argentina lasting two weeks, during which various locations along the coast were visited, meetings with local authorities and stakeholders arranged, and valuable information collected after meeting with local experts.

To obtain near-shore wave data, a spatial varying wave model (Delft3D-WAVE) was setup, driven by offshore boundary points covering the entire coast of the Buenos Aires province.

After computing the near-shore wave climate, a longshore transport model was setup, including also an estimation of the coastline change in the different coastal stretches of the province.

Using the results of the wave and longshore transport modelling, a matrix to compare to locations was created, in order to decide which locations was more suitable for a new port development.

Once the most promising locations were selected, a preliminary layout and dimensioning of the port was completed, including an estimation of dredging volumes and impact on adjacent coasts.

## 1.5. Report structure

This project was undertaken as a collaborative project supervised by Deltares and Technische Universiteit Delft (TU Delft). The succeeding section provides a description of the tasks that were completed, and the assessment approach that was adopted.

1. **Chapter 1 Introduction:** In this introductory chapter the problem definition, research objectives and client specifications were discussed.
2. **Chapter 2 Theoretical framework:** This segment of the study covers a broad review of the most relevant topics related to the thesis. Formed by aspects like sediment/port interaction, port design guidelines, and marina port classification.
3. **Chapter 3 Site description:** This section describes the general characteristics of the area under analysis; Geographical location, development, population are a few of the described aspects. And the selection process of the initial feasible locations. Site visit information was also analysed and added to this section.
4. **Chapter 4 Data collection & analysis:** During this study task data related to the coast was collected and prioritized. Included in this section is the description of the current state of the coast of Buenos Aires province. Information gathered during the site visit was also analysed and used for this section.
5. **Chapter 5 DELFT3D-WAVE:** DELFT3D-WAVE numerical model was applied to obtain near-shore wave data. This section includes the model set-up, the description of the different runs, as well as the explanation of the obtained results.
6. **Chapter 6 UNIBEST CL+:** UNIBEST CL+ numerical model was employed as a tool to determine longshore transport rates, as well as coastline change. Description of the model set-up, runs, and results are shown and explained on this section.
7. **Chapter 7 Evaluation of locations:** This section focuses on the comparison and analysis of the different locations and the development of their corresponding layout alternatives. Finally the selection of the best alternative for further study.
8. **Chapter 8 Preliminary Port Design:**  
This part of the study includes the definition of: type of coastal protection structures, and a general layout of the port mentioning briefly the channel geometry, port facilities, and an estimation of the expected sediment transport.
9. **Chapter 9 Conclusions and Recommendations:** Explain major findings, summarize the most important results of the study and give recommendations for further study in the area.

## 1.6. Marina specifications

The following specifications were set by the “Fundacion Bolsa de Comercio de Mar del Plata” as a starting guideline for the preliminary design of a port along the coast.

- Expected ship sizes: The marina port should be capable to allow ships of up to 15 metres length with a maximum submerged depth of 3 metres. Although most ships found in existing Argentine marina ports today are in the range of 5 to 7 metres long.
- Expected berthing places: The number of ships that should be able to make berth simultaneously at the port should be between 400 and 450.
- Expected traffic: The marina port should be accessible throughout the year in all the different seasons. The busiest time is expected to be in the summer months.

## 2. Theoretical framework

### 2.1. Port design guidelines

The design depths and widths of various water areas of a recreational marina must take into account the sizes and types of boats that are expected to make berth, the wave action, currents, water level variations, site deposition rates and anticipated maintenance dredging works. (California department of boating and waterways, 2005)

As stated in the Unified Facilities Criteria design manual for Military Harbours and Coastal Facilities, the primary concerns when designing a port are: the water wave mechanics, the estimation of near-shore waves, and the surf zone hydrodynamics. This manual also gives a list of ideal features that a location should provide:

- Shelter from open-sea waves.
- Minimum tidal range and moderate currents.
- Freedom from troublesome long-wave agitation.
- Freedom from fog and ice.
- Access through one or more safe navigational channels under all weather conditions.
- Adequate room and depth to manoeuvre ships within the sheltered area.
- Space for an adequate number of fixed moorings.
- Shelter from strong winds from all directions.
- Minimum maintenance dredging.
- Room for future expansion.

Realistically it may not be feasible to provide all of the desirable characteristics, but the design should always take into account these fundamental features to define the scheme of the approach. (Unified Facilities Criteria, 2001)

In a later design manual of the UFC for the design of small craft berthing facilities it is explained that the most desirable locations are those that require the least amount of excavation, dredging, filling, breakwater construction, disturbance of sensitive habitat and environmental remediation. (Unified Facilities Criteria (UFC), 2009)

Table 1 Principal factors in harbour siting, includes the description of the most important features and the corresponding considerations.

**Table 1 Principal factors in harbour siting<sup>1</sup>**

Factor	Considerations
External Access	<ol style="list-style-type: none"> <li>1. Adequate depths and clearance for safe navigability</li> <li>2. Land access developed to provide required land transportation linkage.</li> </ol>
Size and Depth	<ol style="list-style-type: none"> <li>1. Protected water depth and space adequate to accommodate intended vessel traffic.</li> <li>2. Land areas of sufficient size and elevation.</li> <li>3. Potential for future enlargement or change in harbour use.</li> </ol>
Physical and Topographic	<ol style="list-style-type: none"> <li>1. Sheltering from winds and ocean waves; natural sheltering features such as headlands, offshore reefs, and islands will reduce both artificial sheltering requirements (breakwaters) and costs.</li> <li>2. Limited fetch. The protected water area shall not contain segments of sufficient fetch.</li> <li>3. Bottom. Heavy, stiff, or over consolidated clays furnish the best holding ground for anchors. Sands will provide acceptable holding ground.</li> <li>4. Dredging. Avoid locations involving dredging of large quantities of rock or other hard bottoms.</li> <li>5. Shoreline relief. Land adjacent to shoreline should gradually slope away from beach. Avoid locations with pronounced topographic relief (cliffs) adjacent to shoreline.</li> <li>6. Upland drainage. Preferably, the upland area should be naturally well drained.</li> </ol>
Hydrographic and Hydrological	<ol style="list-style-type: none"> <li>1. Variations in water level. The range between water level extremes due to cumulative effects of astronomical and storm tides as well as flood flows in river-affected harbours should be minimized as far as practicable.</li> <li>2. Currents. Current velocity should be minimum and, except for localized areas and/or special considerations, should not exceed 4 knots.</li> <li>3. Water circulation. Water basins should have sufficient natural circulation.</li> <li>4. Sedimentation. The effect of the harbour site on natural regimes of coastal and riverine sediment transport and supply must be thoroughly evaluated. It is desirable not to interfere with the natural regime of sediment movements. The effects of harbour development on the sediment system may require maintenance dredging and/or shore-stabilization needs that must be considered as part of the overall development effort.</li> </ol>
Meteorological	<ol style="list-style-type: none"> <li>1. Storm. Avoid locations subject to the direct effects of pronounced, severe, and frequent storms.</li> <li>2. Fog. Consider local variation in fog intensity and avoid the more severe sites where practicable.</li> <li>3. Ice. Avoid locations that might be ice-locked for several months a year.</li> </ol>

After reviewing the UFC manual and the California Department of Boating and Waterways design manual the following set of tables were derived, with the goal to give a good understanding on how to set the initial dimensions of the major areas of a port.

For the width and depth of the entrance and inner channel the minimum limits are shown in Table 2 Port dimensioning together with similar tables that were developed based on the (California department of boating and waterways, 2005) for the Fairway and Berth design criteria.

<sup>1</sup>Tables 1,2,3,4 were based on the specifications of (Unified Facilities Criteria, 2001), (California department of boating and waterways, 2005)

**Table 2 Port dimensioning<sup>2</sup>**

Channels	Entrance Channel	Interior Channel
Minimum bottom width	75 ft = 23 m	75 ft = 23 m
Minimum depth below design low water	1 m below deepest draft boat or 1.5, whichever is greater.	0.75 m below deepest draft boat or 1.25 m, whichever is greater.
Fairways	Without side-ties	With side ties
Minimum width	1.75 Lb Lb= Length of longest berth perpendicular to the fairway.	1.5 Lbb Lbb= Length of longest boat side-tied parallel to fairway.
Berth length	Minimum berth water depth	
	Powerboats	Sailboats
Up to 14 m	1.85 metres	1.85 metres
Up to 17 m	2.5 metres	2.5 metres
Up to 20 m	2.5 metres	3.0 metres
Over 20	Site specific determination	

More detailed information on the equipment and facilities that a marina should contain can be found in (California department of boating and waterways, 2005), and (Unified Facilities Criteria (UFC), 2009).

## 2.2. Port classification

Different authorities and national institutes have classified harbours with different perspectives; a categorization done by (Sciortino, J.A., 2010) was used as a foundation for further development of this thesis work, together with the design manuals from the (Unified Facilities Criteria (UFC), 2009). The classification by Sciortino, J.A. consists of ports in four different categories, the major factors for the classification taken into account by the author were: size of the design ship, operational capacity, fleet size. Based on the previously mentioned main factors, other factors can be derived; perhaps duration of journeys, type of port equipment, required channel dimensions, facilities, etc.

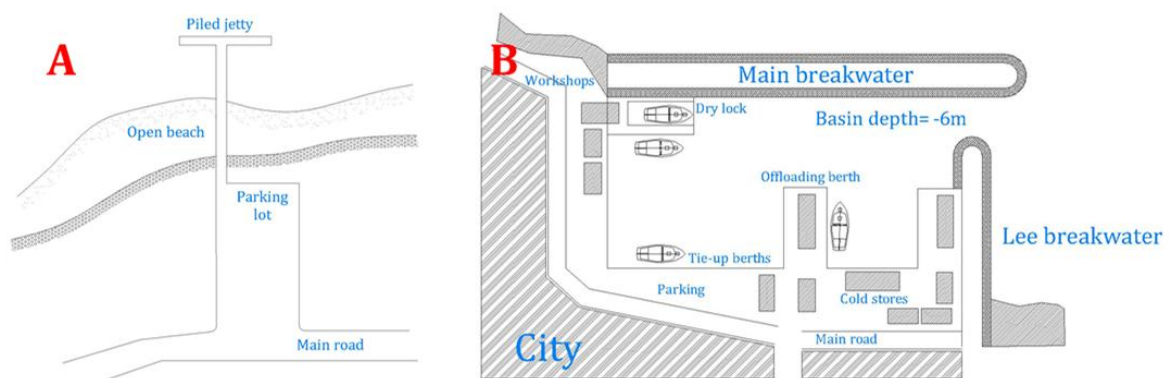
<sup>2</sup> (California department of boating and waterways, 2005), (Unified Facilities Criteria (UFC), 2009).

In fact, the four branches in which harbours were divided by the author are: Artisanal, Coastal, Offshore and Distant waters, and are summarized as follows.

**Table 3 Port classification by facilities<sup>3</sup>**

Feature	Artisanal	Coastal	Offshore	Distant waters
Type of vessels handled	Paddle canoes, motorized canoes.	Large motorized canoes. Vessels up to 10 tonnes weight.	Large motorized canoes, trawlers. Vessels up to 100 tonnes in weight.	Large trawlers and factory vessels.
Minimum water depth	No depth limit, beached for unloading	At least 2.5 metres.	At least 5.0 metres.	At least 6.0 metres.
Breakwater protection	No breakwaters.	Generally required, unless port is in a bay or river.	Generally required.	Generally required
Hinterland	Resident village nearby.	Resident village or town nearby.	Town community nearby with full facilities.	City with full facilities nearby.

As a schematization of the previously shown in Table 3 Port classification by facilities shows an example of a typical Artisanal port, compared with a Distant waters port. It can be observed that an artisanal port consists of very basic and traditional methods, using small boats, and without structures to protect from incoming waves. In the other hand a distant waters port represented on the right side of Figure 2 Artisanal & Distant waters port, consists of a more complex layout, with different offices, mooring facilities, berthing facilities, ice storage, processing facilities, large breakwater structures to protect the port basin, larger ships, and accordingly deeper waters.



**Figure 2 Artisanal & Distant waters port**

<sup>3</sup> Fishing harbor classification parameters obtained from: (Sciortino, J.A., 2010).

Another classification of ports based on the Unified Facilities Criteria (UFC), classifies ports depending on the type of coastal features that the area offers. The classification covers open coastlines that require artificial impoundments to natural bays, estuaries, and navigable rivers that need a minimum of manmade structures to protect the port basin against waves and storms. A summary of the most relevant factors to determine the port classifications is shown in Table 4 Port classification by coastal features. (Unified Facilities Criteria, 2001)

**Table 4 Port classification by coastal features<sup>4</sup>**

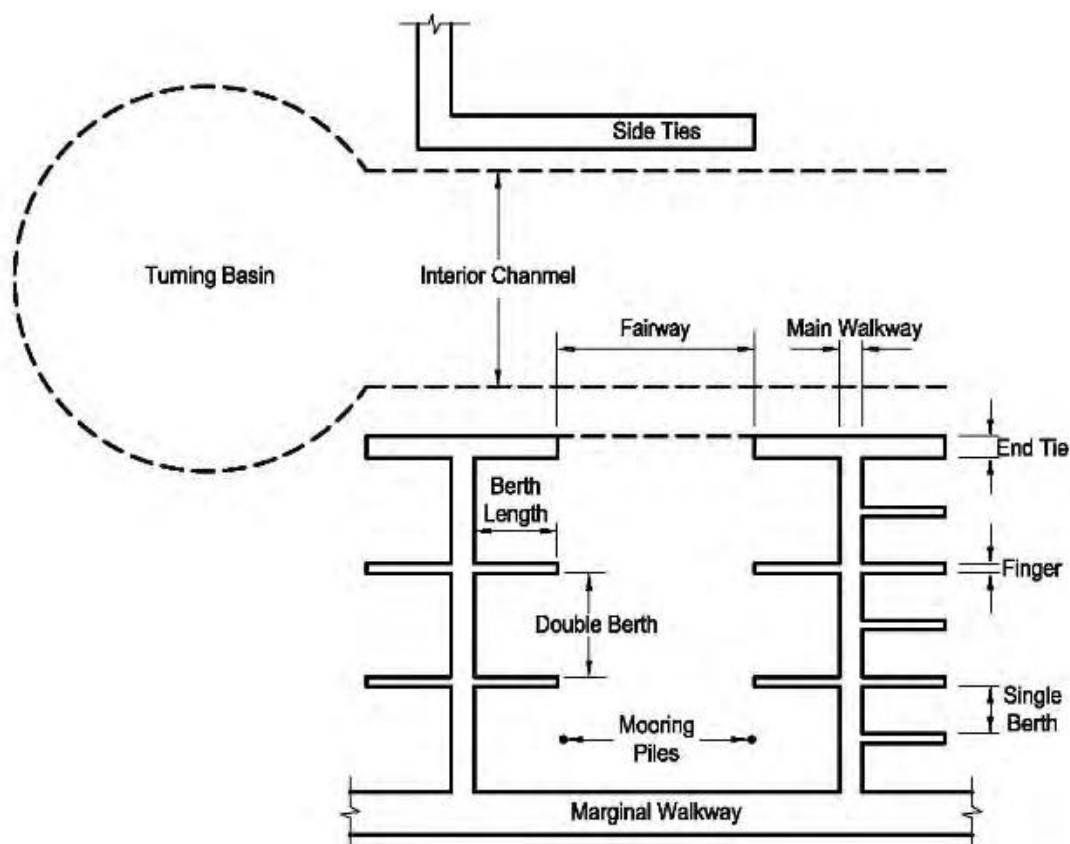
Type	Characteristics	
Artificial. Inland basin.	Needs:	Low elevation; economical excavation.
	Advantages:	Less breakwater cost; feasibility of expansion.
	Concerns:	Low ground may contain poor soils; distance to offshore navigational water depth; littoral drift; silting.
Artificial. Offshore basin.	Needs:	Adequate sources for extensive breakwater construction material.
	Advantages:	Normally good foundation conditions can be developed with minimal dredging.
	Concerns:	Construction cost relatively high for harbour size; minimum expansion capability littoral drift; shoaling.
Protected	Needs:	Shoreline relief features help to reduce storm-waves exposure.
	Advantages:	Less breakwater development cost.
	Concerns:	Can be same as other locations.
Natural	Needs:	Natural ocean access passage of adequate dimensions leading to embayment protected from storm waves.
	Advantages:	Minimal effort required for developing protected water area.
	Concerns:	If not historically used as ship refuge area, ascertain reason natural sediment regime should be thoroughly investigated if extensive deepening of natural depths is proposed.
River	Needs:	Historically stable river of adequate natural depths and widths to accommodate proposed vessel sizes.
	Advantages:	Minimal effort required for developing protected water area.
	Concerns:	Currents and water-level fluctuations due to variation in river stages; effects of new works on rivers natural alluvial regime require thorough analysis, including effects of salinity changes; extensive basin dredging and channel deepening should be avoided where possible.

<sup>4</sup> (Unified Facilities Criteria, 2001)

## 2.3. Marina dimensions

This section of the study attempts to provide some insight related to the main dimensions of a marina port. These dimensions are schematized in Figure 3 Schematization of marina facilities distribution, where the different terms used for water areas and berthing infrastructure are shown.

- Entrance channel: Is a waterway, external to a marina, through which boats travel between a marina and a water body (in this case the open coast of Buenos Aires).
- Interior channel: Is the watercourse, within a marina, through which boats travel between an entrance channel and fairways.
- Fairway: It is a waterway, within a marina, through which boats travel between an interior channel and the berthing places.
- Berth: Is a delineated water surface mooring area, delineated by either floating or fixed dock structures, for the purposes of embarking, disembarking, and the wet storage of a recreational boat (also known as boat slip or boat dock).



**Figure 3 Schematization of marina facilities distribution**

Sailing and motor boats in Argentina are mainly in the range of 6 to 8 metres long, with a few exceptions of ships that reach the 15 to 20 metres length. As mentioned previously on the study, the marina port should be able to receive around 400-450 vessels. To achieve the established requirements the following preliminary dimensioning of the port was completed in order to give a good approximation and understanding of the major features of a marina port.

**Table 5 Port dimensions<sup>5</sup>**

Marina dimensions (m)				
Design ship	Largest "design ship"		Common "design ship"	
Length	18.29		6.10	
Beam	6.10		2.44	
Draft	2.74		1.22	
Berth length	18.29		9.14	

Fairways	w/o side ties	w/ side ties	w/o side ties	w/ side ties
Minimum width	32.00	27.43	16.00	13.72

Berths	Powerboats	Sailboats	Powerboats	Sailboats
Depth	3.49	3.74	1.97	2.12
Single berth width	7.01	7.01	3.35	3.35
Double berth width	14.02	14.02	6.71	6.71

Channels	Entrance	Interior
Minimum width	30.48	22.86
Preferred width	30.48	30.48
Depth	4.50	4.0

Walkways	Main	Marginal
Length	213.36	304.80
Minimum Width	1.83	1.83
Preferred width	2.44	3.66

Fingers	Main
Preferred width	1.52
Width	1.52

Number of accessible berths	
301 to 400	6
401 to 500	7

All the given values were established based on tables of recommendations given by the (California department of boating and waterways, 2005) and the (Unified Facilities

<sup>5</sup> Water depths are referenced to lowest astronomical tide level, which in fact is 0.91m lower than MSL.

Criteria (UFC), 2009). The dimensioning of the port was completed taking into account two different design vessels. Shown in Table 5 is the largest expected ship to make berth in the marina port. The second design ship is a more common boat; therefore a greater number of berthing spots for this type of ship were allocated in the preliminary design. The required water depths for the entrance channel and fairways were derived based on the dimensions of the largest design ship. Making reference to the selected layout, the largest ships make berth closer to the entrance; consequently the areas closer to the shore can be shallower and should only provide the required water depth needed for the “common” design ship.

The defined water depths are referenced to the lowest astronomical tidal level.

For the design of the marina port, a fishing vessel was also considered, the size of the largest fishing vessel was assumed equal to the size of the largest sailing boat. To make the port a multi-use port it was determined that even if the marina facilities were arranged as the main contribution, the use of a few fishing vessels would also be productive and provide an extra income.

The depth required for the largest fishing boat is 5m therefore it was determined that the depth at the mouth of the port should at least be of 5m during lowest astronomical tide level.

## 2.4. Wave propagation

Waves propagate from deep into intermediate and shallow water depths, changing in wave height, length and direction until the point where they break and lose their energy. Wave transformation occurs because waves are affected by the seabed through processes such as refraction, shoaling, bottom friction, diffraction and wave breaking.

Waves start to be affected by depth restriction when the wavelength is two times larger compared to the depth. Various software packages are available to transform offshore wave conditions towards the near-shore. An example is the SWAN model, which was developed at Delft University of Technology and is used in this study.

### *Shoaling*

Wave shoaling occurs when waves propagate into shallower waters. The phenomenon can be described as the effect by which surface waves increase in wave height. It is caused by the change in group velocity, which in fact is directly related to the reduction in water depth.

In a coast with parallel depth contours that become gradually shallower, a decreasing water depth yields a decreasing wave speed and wave length accordingly to the dispersion relationship. In reality the wave height increase in the shoaling zone is limited by dissipation due to wave breaking.

### *Refraction*

Refraction is the bending of waves because of varying water depths underneath. When a wave approaches underwater contours at an angle, it is evident that the section of the crest in the deeper parts travels faster than those in the shallower sectors. This causes the wave crest to turn towards the depth contour.

When waves are near the coast they converge in headlands or salients. An opposite effect happens when waves are approaching a bay, for this situation waves diverge and dissipate energy in a larger area.

### *Diffraction*

If obstructions to the wave propagation or abrupt changes in the bottom contours are present, there is a large variation of wave energy along a wave crest which leads to transfer of energy along the wave crests. When a part of a wave is blocked by a structure than it is reflected seaward, the other part of the wave will bend around the structure and thus penetrate into the sheltered zone.

The degree of diffraction depends on the ratio of a characteristic lateral dimension, for example the length of the offshore breakwater to the wavelength.

### *Wave breaking*

A wave crest becomes unstable and starts breaking when the particle velocity exceeds the velocity of the wave crest. When the deep water steepness exceeds a certain ratio the effect called white-capping occurs and dissipates energy.

Near-shore wave breaking starts when the wave height becomes greater than a certain fraction of the water depth. This is called depth-induced breaking since the increase of the wave height by shoaling effect is limited by the water depth.

The decrease in water depth and increase in wave height results in a significant increase of the horizontal particle velocities with respect to the wave celerity. Different breaker types have been identified in previous literature; Surging, plunging, collapsing, spilling breakers depend on the type of sea bed slope and on the wave energy of each location.<sup>6</sup>

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<sup>6</sup> Shoaling, Refraction, Diffraction and Wave breaking were based on: (Bosboom J., Stive, M.J.F., 2011), (USACE, 2002), (USACE, 2006), (Van Rijn, L.C., 1998), (Van Rijn, L.C, 2010)

## *Sediment transport*

Sediment transport at a point in the near-shore zone is a vector with both longshore and cross-shore components. It appears that under a number of coastal engineering scenarios of interest, transport is dominated by either the longshore cross-shore component.

Longshore sediment transport is the net movement of sediment particles through a fixed vertical plane perpendicular to the shoreline. The direction of this transport is parallel to the shoreline and the depth contour lines. (Bosboom J., Stive, M.J.F., 2011)

Longshore transport induced by waves depends on the hydrodynamics in the breaker zone and on the sediment properties. However, for longshore transport to exist there must be sediment availability.

This transport is among the most important processes that control the beach morphology, and determines in large part whether shores erode, accrete, or remain stable. An understanding of longshore sediment transport is essential for coastal engineering projects. (USACE, 2002)

Cross-shore sediment transport encompasses both offshore transport, such as occurs during storms, and onshore transport, which dominates during calmer wave activity. Transport in these two directions happens in different modes and with differing time scales.

Cross-shore sediment transport is relevant to a number of coastal engineering problems, including beach and dune response to storms, beach nourishment, shoreline response to sea-level rise, and scour immediately seaward of shore-parallel structures, among others. (USACE, 2006)

## **2.5. Coast/Port interaction**

### *General interaction*

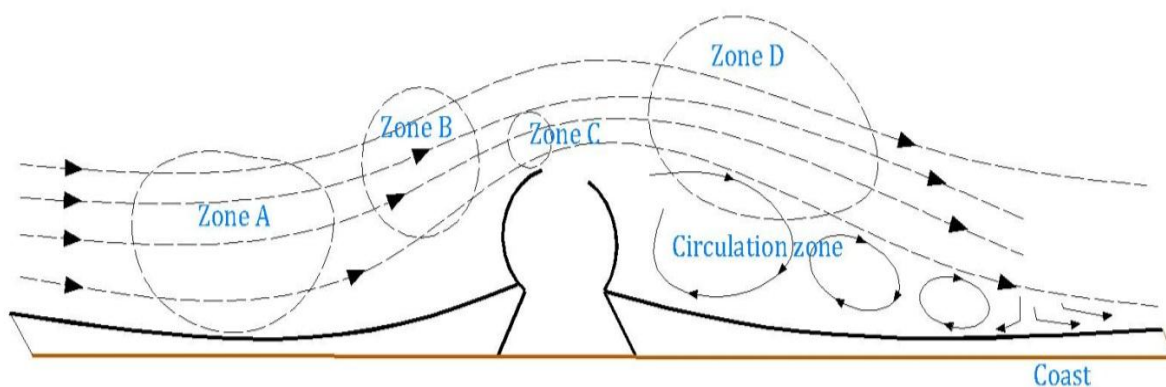
Sediment transport rates vary along the coast depending on the wave, tide, wind conditions. Another major factor that influences the behaviour of sediment transport is the existence of coastal structures, e.g.: Groyne fields, detached breakwaters, artificial islands, harbour breakwaters. One of the most important issues when designing a port of any kind is the prediction of the sedimentation rates, considering that most operating ports have minimum water depth requirements, and are normally located on populated areas, where the coast has other purposes; consequently affecting the coast could lead

to further problems. The different effects and transformations that take place around coastal structures are explained as follows.

### *Twin-armed breakwaters*

Sedimentation in harbour entrance channels is often a problem for exposed coastal ports protected by means of twin-armed breakwaters. The breakwaters generally block the longshore sediment transport. Depending on the shape, length and material of the breakwaters the longshore transport blocking will differ. In general when these types of structures are constructed it is required to either use sediment bypassing methods or beach nourishment on the down-drift side to mitigate possible erosion problems. The different processes acting near shore and interacting with the breakwater move sediment around the structure, enhanced by turbulence and eddy formation, the sediment is lifted up and transported inside the port basin.

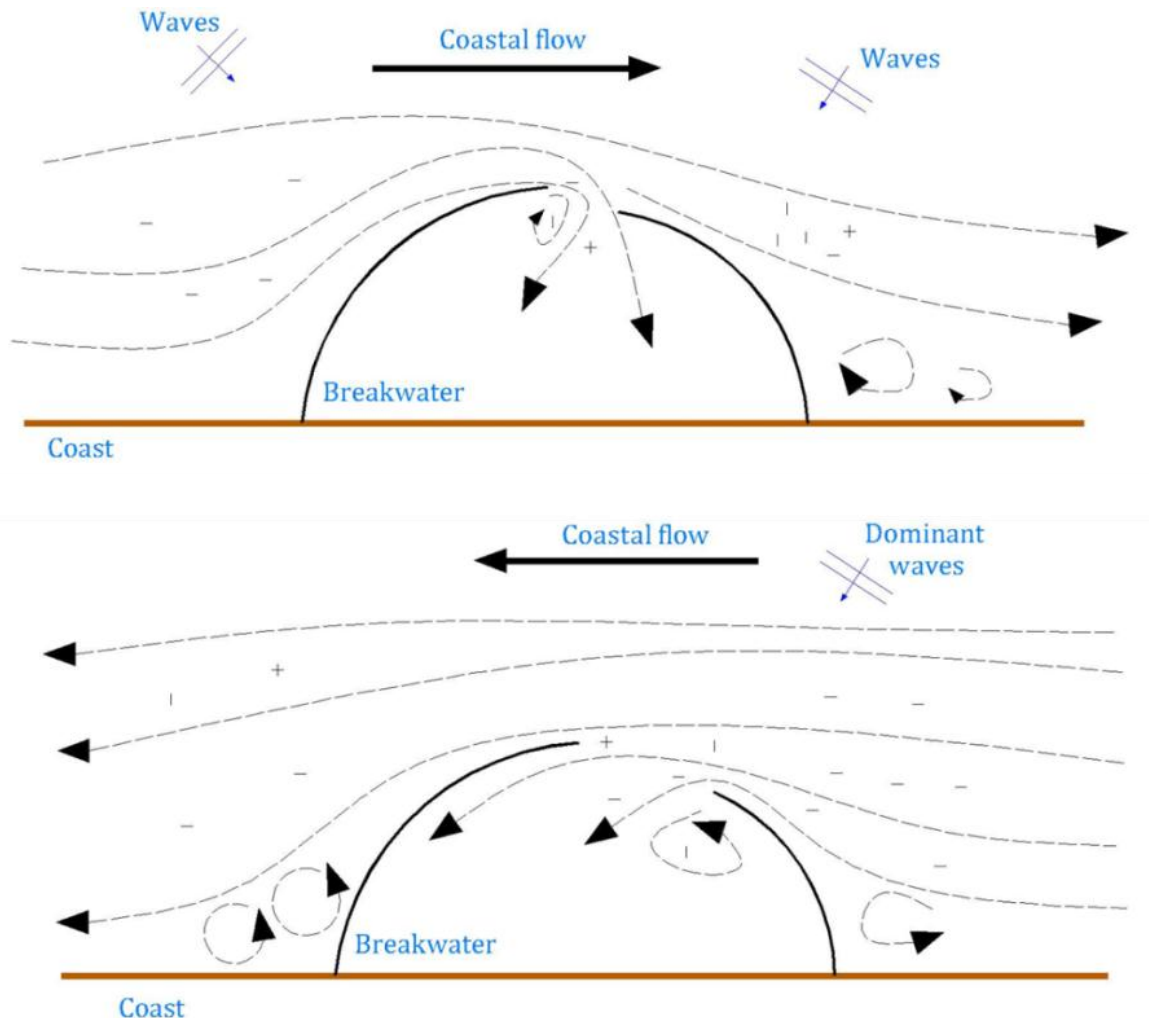
The presence of a coastal harbour with twin-armed breakwaters extended into the sea is an obstruction for the shore-parallel tidal current resulting in an increase of the longshore current velocity in front of the harbour entrance. As a consequence the current will be accelerated on the upstream side of the harbour basin and decelerated on the downstream side. The overall flow pattern near a coastal harbour is show in Figure 4 Overall flow patterns near coastal harbour basin. It can be seen that circulation patterns are induced by the structure that abruptly blocks the flow. (Van Rijn, L.C., 1998)



**Figure 4 Overall flow patterns near coastal harbour basin**

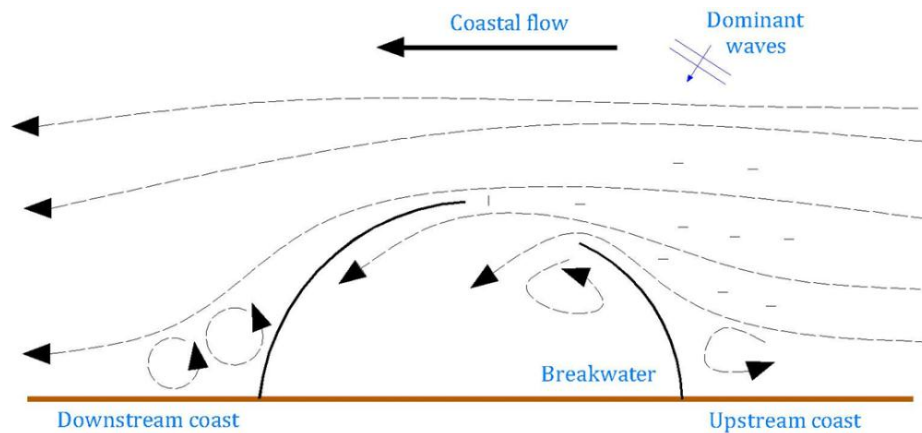
Depending on the geometry of the harbour basin, flow separation and circulation zones will occur along the downstream side of the breakwater. Similarly, flow separation and eddy formation may occur in the entrance of the basin as shown in Figure 5 Tidal flow pattern near coastal harbour basin (+ = sedimentation; - = Erosion). Generally, the tidal

filling of the harbour basin takes place with water from near-shore areas where the wave height and sediment concentration are relatively large, resulting in sedimentation in the entrance basin. During storm events, the current velocities along the up-drift side of the breakwater will increase substantially due to the generation of strong wave-driven current in the surf zone.



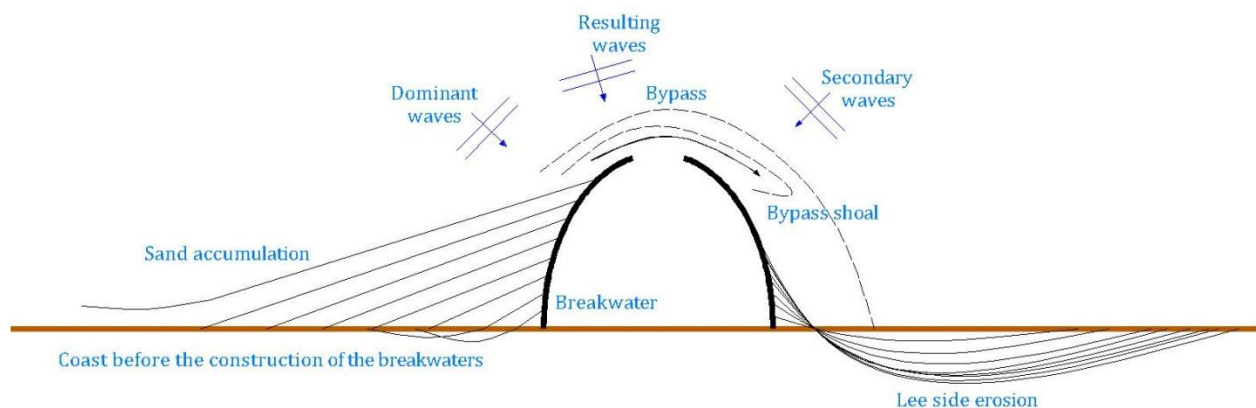
**Figure 5 Tidal flow pattern near coastal harbour basin (+ = sedimentation; - = Erosion)**

Sedimentation in the harbour entrance mainly depends on: Direct supply from the longshore drift, upstream sediment entering the port by means of eddies or density currents (As shown in Figure 6 Basic sediment processes in harbour entrance), sediment from upstream directly entering the port area, sediment coming from the down-drift section transported by recirculating currents, sediment supplied by diffraction wave effects around the tip of the breakwaters, and finally bar migration near-shore.



**Figure 6 Basic sediment processes in harbour entrance<sup>7</sup>**

For a wave climate dominated by a typically dominant wave direction the sedimentation in one side and erosion on the other would be as shown in Figure 7 Port time varying erosion/accretion. For the scenario where many wave directions are dominant, the erosion/accretion balance on both sides of the twin-armed breakwaters could be more balanced; consequently showing a mirror type behaviour, where both sides have similar changing rates.



**Figure 7 Port time varying erosion/accretion<sup>8</sup>**

### *Groyne fields*

Structures designed to trap moving sand are called groynes. They are low walls constructed perpendicular to the shoreline which extend out into the water. Their main function is to promote beach build-up by trapping sand or slowing down its movement along the beach.

Two main types of groynes can be distinguished: First the high crested (1m above sea level), which are used to keep the sand within the compartment between the adjacent

<sup>7</sup> Figures 3, 4, 5, and their corresponding descriptions were obtained from (Van Rijn, L.C, 2008).

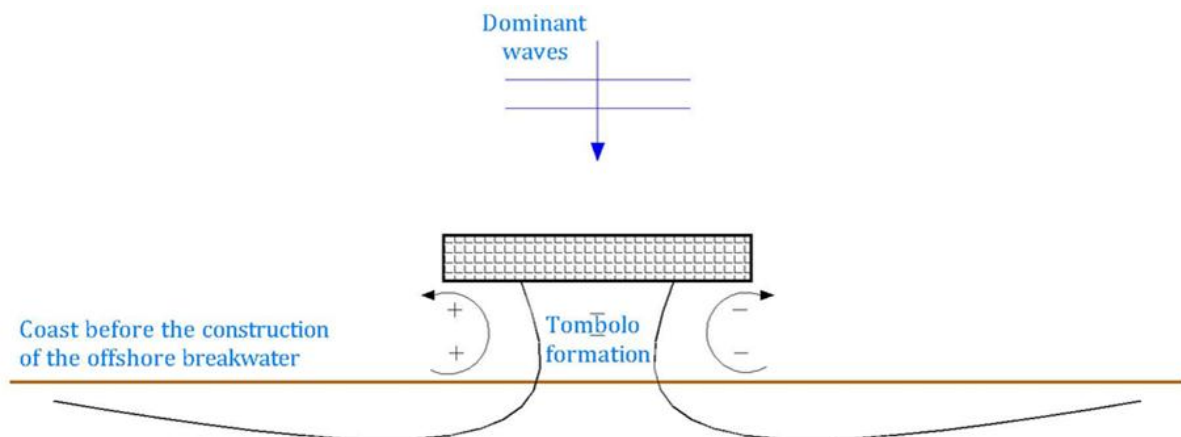
<sup>8</sup> Figure 6 was based on a figure shown in the Coastal Dynamics book by (Bosboom J., Stive, M.J.F., 2011).

groynes. Secondly a permeable low crested groyne, which will slightly decrease the littoral drift in the inner surf zone and will create a more regular coastline. These structures are normally built with sheet piles or wooden piles.

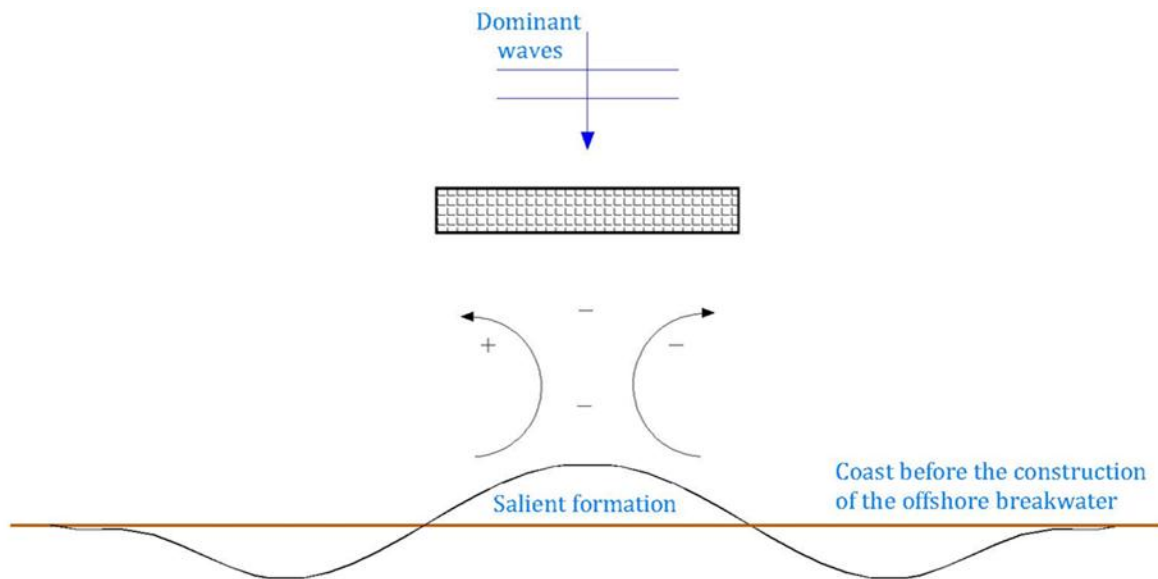
Groyne length, height and permeability are the most important factors for a proper design. A spacing of a few times the length of the groyne is common. Nowadays, the design of groyne fields is generally combined with nourishment works, the trapping efficiency can be enhanced by using 'L' or 'T' shaped structures, groynes preferably extend only until the inner surf zone, spacing should be in the range of 1.5 to 3 times the length. (Van Rijn, L.C, 2010).

### *Offshore structures*

An obstacle in front of a coast such as a rock outcropping, an offshore breakwater, or even a sunken ship will reduce the wave activity in the zone between the structure and the coast. The minimized wave energy will consequently result in a reduced sediment transport capacity, therefore material being carried along the shoreline will settle in the shadow zone due to the lack of wave energy. Depending on the wave conditions and the distance from the object to shore a salient or a tombolo can be created. Figure 8 Tombolo formation behind offshore breakwater and Figure 9 Salient formation behind offshore breakwater shows the tombolo and salient characteristics. (UNESCO, 2012)



**Figure 8 Tombolo formation behind offshore breakwater**



**Figure 9 Salient formation behind offshore breakwater<sup>9</sup>**

The decrease in wave height is not the only effect that enhances deposition near structures, also the current patterns created by the set-up differences. This additional effect also enhances deposition on the lee side of the structures. A tombolo is more likely to be created if the structure is located just outside the surf zone, and if its length is relatively large. As a rule of thumb it is said that if the length of the structure is two times larger compared to the distance to the shore, the transport capacity will not be enough to maintain the lee zone passage open. In the other hand for a short breakwater, the equilibrium shoreline will take the form of a salient. In the case of submerged structures salients and tombolos may be created, however the deposition may also be counteracted by the effect of wave induced current patterns.

Another option is to build low crested or submerged breakwaters, although the response of the coast has to be studied in further detail, considering the fact that in some locations the implantation of offshore submerged breakwaters caused a greater erosion rate, instead of enhancing deposition to recover the coast. Of course it is undoubtedly that the structure will decrease the wave height, but the induced currents by set-up and set-down differences could transport sediment out of the lee side of the breakwater. (Bosboom J., Stive, M.J.F., 2011).

### *Sediment bypassing*

A counteractive measure against the blocking of sediment transport by a barrier, as the ones explained previously is the mechanical bypassing of sediment. Bypassing consists

<sup>9</sup> Figures based on: (Bosboom J., Stive, M.J.F., 2011)

of four elements: intake point, removal equipment, bypassing line and finally the discharge area.

The intake point can be located in the up-drift, downdraft or mouth of the port. Depending on the available equipment (land/water based), the circulation patterns, the wave climate, and the importance of the port, different bypassing systems can be adopted. Bypassing based on land equipment is normally used in small ports, where sedimentation is close to the shore and consequently it is possible to use excavators or small cranes to extract the sediment and place it on the lee side of the port. In some cases the deposition area is too far from shore, and placing a crane on the breakwater structure is not feasible, therefore for that scenario water based equipment is mostly used, for example by placing a crane on a pontoon. A more sophisticated option is to use a dredger to extract the sediment on the accreted side of the port, and transport it to the eroded part. An even more complex system is the use of jet-pumps that carry the sediment from one side of the port to the other in pipes placed below the sea bed

## 3. Site description

### 3.1. General overview

#### *Geographic location*

Argentina is the second largest country in South America by land area, only after Brazil. It is formed by 23 provinces and the autonomous city of Buenos Aires, which is also the largest city and capital of the country. The continental area of Argentina is bounded by the Andes to the West and the Atlantic Ocean to the East.

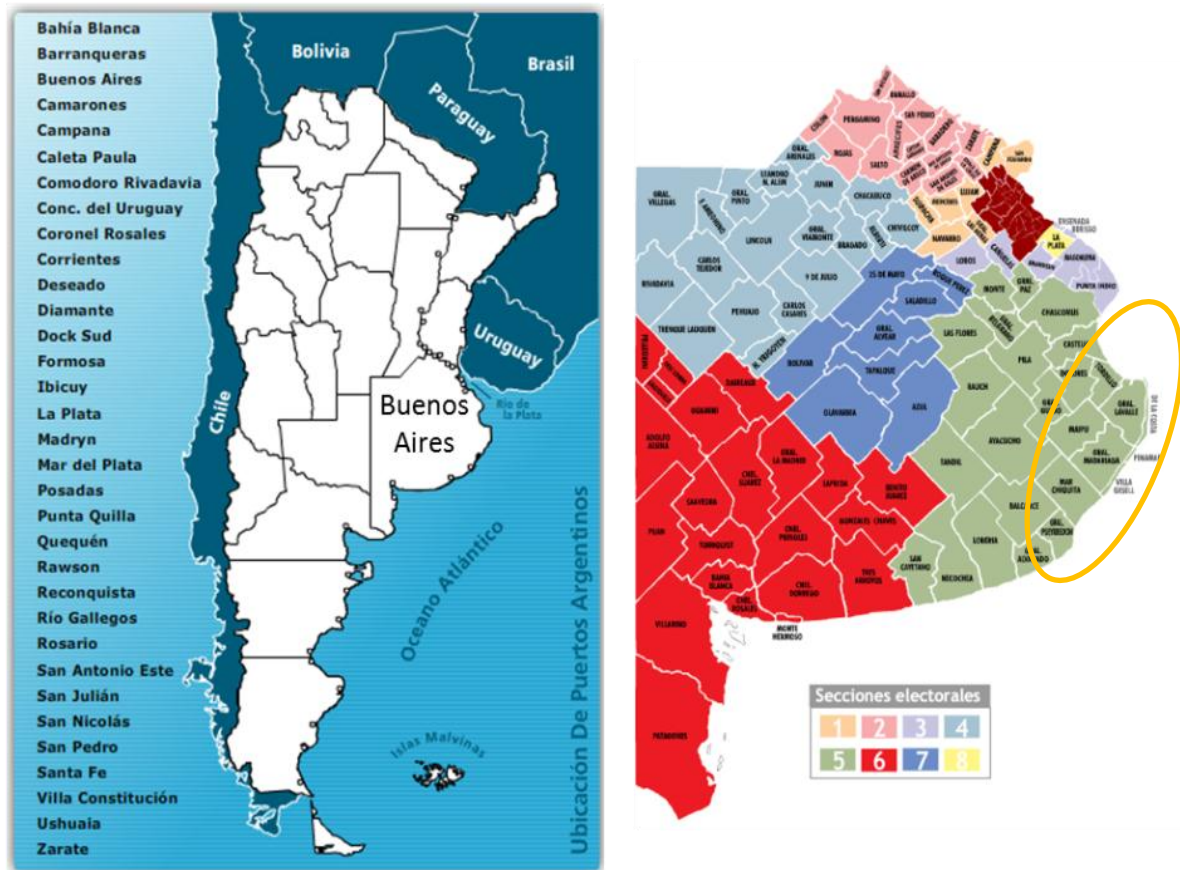
Argentina ranges in latitude from (21°46'S - 66°13'W) in the northern part to (55°03'S - 66°31'W) in the furthest south point. Ranging from warm and fertile environment, to rough mountains, to ice covered areas in the far south. Examples of these are the Pampas plains, source of the agricultural wealth of the country, and for instance the Mount Aconcagua, classified as the highest mount outside the Himalayas.

The total surface of Argentina is of 3,761,274 km<sup>2</sup>, although a large part of the area is located in the Antarctic, the land surface of Argentina in the South American continent is 2,791,810 km<sup>2</sup>. Argentina is the 7th largest country in the World and the 4th largest in America. A stretch of coast covering 4,665 km facing the Atlantic provides an enormous possibility for construction of new developments in the coast, and could be of great benefit for the country, and consequently the population of Argentina. (Presidencia de la Nacion, 2012)

Figure 10 Geographic location of the project area, shows the map of Argentina, and how the provinces are delimited. For this study the area of interest is located on the Buenos Aires province facing the Atlantic Ocean shown in further detail in the right side of Figure 10 Geographic location of the project area.

The map on the left has a list of the existing ports of Argentina. According to the "Consejo Portuario de Argentina" (Argentina's Port Council), the ports of Bahia Blanca (25.31% of the total cargo), Dock Sud (25.20%) are the most important for the province of Buenos Aires. (Consejo Portuario Argentino, 2012)

The province of Buenos Aires has more than 1500 km of coastline, and it is highly populated, it is therefore considered by far the most important coastal province of Argentina. (Monica M.E. Fiore, Enrique E. D'Onofrio, Jorge L. Pousa, Enrique J. Schnack, German R. Bertola, 2009)



**Figure 10 Geographic location of the project area<sup>10,11</sup>**

The province of Buenos Aires is divided into 8 different zones. The area to be analysed is located in the 5th zone, identified by the green colour of the map placed on the right side of Figure 10 covering the coastal stretch from the Samborombón Bay to the city of Mar del Plata. The largest cities adjacent to the case study locations are Buenos Aires on the North and Mar de Plata in the South.

### *Population*

Argentina has a population of 40,117,096 inhabitants as measured by the “Instituto Nacional de Estadística y Censos” (National Institute of Statistics and Census) in 2010. A population growth of about 10% can be seen when comparing the population of the last national census in 2001, when the population was 36,260,130. A similar growth rate applies to the province of Buenos Aires, where the population grew from 13,827,203 to 15,625,084 inhabitants in the past decade, these showing that the province is still growing at a fast pace and that new infrastructure could enhance the economic stability of the area.

<sup>10</sup> (Consejo Portuario Argentino, 2012) <http://www.consejoportuario.com.ar/ubicacion.aspx>

<sup>11</sup> (Portal Oficial, Buenos Aires La Provincia, 2012) <http://www.gba.gov.ar/municipios/mapa.php>

Also important to mention that the larger cities located near the coast under review, meaning Buenos Aires and Mar del Plata, also grew but at a different rhythm. For instance Buenos Aires increased its population by a 4.1%, now consisting of 2,890,151 residents. This shows that the growth outside the large cities is having a boom, and that the time for smaller cities to grow in infrastructure is in process. (Instituto Nacional de Estadística y Censos, 2012)

### *Economic activities*

Argentina's most important economic activities are divided in different sectors. For instance; agriculture covering citrus fruits, vegetables and cereals was 9% of the total GDP in 2010. Another important activity is fishing, catching up to a million tons of catch per year in average during the past years (before 2010), mostly catching Argentine Hake (50%), as well as other species like squid and crab. Although fishing is a strong industry, the amount of exports was reduced in the past year (2010), probably due to the lack of proper infrastructure outside the larger cities, where the market is full, and the biodiversity and quantity of fish is decreasing. <sup>12</sup>

Opposite to fishing, a growing activity in the country is mining, which now provides 4% of the GDP. The most used areas to extract the diverse minerals are located near the mountain range of the Andes. Oil and natural gas extraction and exportation, is another main activity covering nearly 10% of the income for the country.

The World Economic Forum estimated that in 2008, tourism generated around US\$25 billion in economic turnover, and employed 1.8 million, moreover made a prediction that in future years the tourism will keep increasing. It was estimated that 8% of the GDP in 2008 was profit related to tourism. (World Economic Forum, 2012)

However, the most important activity is the service sector, gathering 60% of the GDP. Involved in this category are services like corporate finance, insurance, real estate, transport, and communication services

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<sup>12</sup> The information on the section of Argentina's economy was obtained partially from: (United Nations, 2009-2010)

## 3.2. Specific overview

### *Promising locations*

A general reading review accompanied by a site visit of two weeks, in which initial feasible locations were visited, and meetings were arranged with local authorities, was completed in order to select specific locations by investigating which cities in the coast between Buenos Aires capital city and Miramar had any coastal development, access roads, or other features that could be directly related with the functionality and feasibility of a port. Also navigation on Google Earth was used as a tool to analyse the coastal orientation and broad coastal elements. (Google Maps, 2012)

Firstly most of the Samborombón Bay was disregarded from the main options, because no main access roads are built to connect the port with the other larger cities, and for instance availability of fresh water could be a negative issue, labour would be more expensive to get since it is not a very populated area, the area has a high content of mud due to the discharge of rivers; therefore for these and other reasons (area named as natural reserve) the area is not considered as feasible for port construction. (Bertola, G.R., 2009).

In fact the only sections of the Samborombón Bay considered for this study were the area near San Clemente del Tuyú called Bahia San Clemente and General Lavalle, the initial advantage that these locations offer is a sheltered area, which has low wave energy. Bahia San Clemente is located 6-8km away from San Clemente city and has a small set of piers constructed by locals for fishing purposes, while General Lavalle is approximately 30km away and has a larger fishing quay wall where fishing boats make berth. The quay wall is approximately 800 metres long and is being renovated at the moment (April, 2012).

When analysing the coast further north it can be observed that the ports of Buenos Aires and La Plata, already have infrastructure and facilities for the area, therefore it would not be wise to construct another port in an area. Considering that the demand of the area is already covered, and the availability of land is highly restricted compared to other coasts in the Buenos Aires province.

After the previously determined, the range of coast available is now down to the stretch from General Lavalle (South end of the Samborombón Bay) to Miramar. Cities along the coast that were visited and selected as preferred locations initially were:

- Miramar
- Mar del Plata
- Mar Chiquita
- Villa Gesell
- Pinamar
- Mar de Ajó
- Santa Teresita/Mar del Tuyú
- San Clemente del Tuyú (Punta Rasa and Bahía San Clemente)
- General Lavalle.

These locations were initially selected because they are small cities, under development. These locations have some available infrastructure; consequently the investment would mainly be focused on the construction of the port, and no other major developments like access roads would be initially needed in order to make the port sustainable.

Another advantage that these locations display, is that when compared to other cities in the area, population has a more constant behaviour, in contrast to other cities where the population comes and goes with the different seasons, and therefore locations are mainly populated and used during summer season for tourism purposes. The selected cities are mainly touristic as well, but perhaps other activities are practiced in order to sustain the economy. (Scalise, A.H., Schnack, E.J., 2007)

### *Geographic location*

As mentioned before the selected locations are distributed along the Atlantic coast of the province of Buenos Aires. Figure 11 shows the exact location of the potential alternatives for the possible port construction. All the locations are between the Samborombón Bay and the city of Miramar. It can be observed that Miramar is located furthest south, followed by Mar del Plata, Mar Chiquita, Villa Gesell, Pinamar, Mar de Ajo, Santa Teresita/Mar del Tuyú, San Clemente del Tuyú, and finally General Lavalle further along the coast.

The city of Miramar located in the southern limit of the boundaries defined previously in the study, is 50km south of Mar del Plata, in the other end of the boundary; General Lavalle (north boundary) is 231 North of Mar del Plata, and 306km south of Buenos Aires city. All the other locations considered for further study are located within these

boundaries; also it is important to mention that highway 11 connects all the cities of the coastal area under review. (Google Maps, 2012)



Figure 11 Geographic location of initially feasible locations. <sup>13</sup>

<sup>13</sup> Map of the Geographic location of the cities to be analysed obtained from: (Portal Oficial, Buenos Aires La Provincia, 2012) <http://www.gba.gov.ar/municipios/mapaCosta.php>

## *Population*

Regarding population, these cities have their differences; varying from 1,472 inhabitants in General Lavalle (local fisherman), to 614,350 in Mar del Plata. The other locations under consideration have a similar population, for instance Miramar has 30,100 inhabitants; Mar Chiquita 17,908; Villa Gesell 23,257; Pinamar 20,175; Mar del Ajo 13,769; Mar del Tuyu/Santa Teresita 19,950; and San Clemente (Including Bay and Punta Rasa) 11,174.<sup>14</sup>

Pinamar doubled its population in the 90's, going from 10,316 to 20,666 inhabitants in ten years. This caused important changes, and construction of new infrastructure. Awareness regarding Education, health, fresh water, and transport was initialized during those years. (Scalise, A.H., Schnack, E.J., 2007)

It is important to recall that all of the cities have a large variation of their population, the numbers provided by the "Instituto Nacional de Estadística y Censos" (National Institute of Statistics and Census) are associated to the people that live in the cities year-round. (Instituto Nacional de Estadística y Censos, 2012)

## *Economic activities*

As mentioned in the previous section, the cities located near the coast that is under review are mainly touristic, and only a limited number of other activities are practiced. Each city has been developed in a different way; consequently different types of tourism visit each city.

Cities like Pinamar focused more on the quality and organization of the city, as well as the security issues in order to receive the high class tourists (which in fact could be a great advantage for a marina port); in the other hand Villa Gesell is known for the teenager festivals and wilder vacation site.

The municipalities of the Buenos Aires province counted the number of visitors per year in 2007, Pinamar had 990,000 visitors, Villa Gesell 1,250,000, and the coastal stretch of "Partido de la Costa" formed by all the cities from Punta Rasa to Mar de Ajó had 2,330,885 visitors. (Scalise, A.H., Schnack, E.J., 2007)

The city of General Lavalle is the only city where the main activity is not tourism. The most important economic activity is fishing; it has the advantage that is located in a small river therefore coastal protection is not needed as in most of the other locations.

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<sup>14</sup> (Instituto Nacional de Estadística y Censos, 2012)

But perhaps the dredging cost and the lack of infrastructure for marina users are negative issues.

The largest city under consideration is Mar del Plata, which was the first city of the Atlantic coast of Argentina to be developed as a vacation site. Similar to the other locations of the Buenos Aires province located in the coast, Mar del Plata also has a large variation of population throughout the year, and most of the profit for the city comes in the summer holidays. Important to point out that even if the main activity of MDP is tourism, also other activities support the economy.

Another interesting location is Mar Chiquita; this city receives mainly ecological tourism, and people that practice all kinds of aquatic sports. A summary of the most important activities and the number of people that work on each of them is shown below:

**Table 6 Economic activities.<sup>15</sup>**

Economic activity	Province of Buenos Aires	La Costa	Pinamar	Villa Gesell
<b>Agriculture</b>	152,076	158	222	145
<b>Fishing</b>	4,450	58	0	6
<b>Manufacturing Industry</b>	184,649	1,145	554	675
<b>Construction</b>	99,268	2,008	1,122	1,114
<b>Commerce</b>	141,917	2,070	695	864
<b>Not touristic commerce</b>	2,940,255	4,191	1,394	1,710
<b>Transport</b>	61,548	646	214	321
<b>Public administration</b>	144,439	1,523	424	503
<b>Teaching</b>	145,250	1,385	539	545
<b>Domestic cleaning</b>	116,089	756	582	484

It can be observed in Table 6 that for La Costa, Pinamar and Villa Gesell, the main activities (without considering tourism) are related to public administration including transport, and education as well as commerce. It is quite surprising that fishing is almost non-existent for all the coastal areas. Perhaps the lack of infrastructure and motivation to invest in the fishing industry is part of the issue.

A study by (Diez, P.G., Perillo, G.M.E., Piccolo, M.C., 2007) mentions that the province of Buenos Aires is the most important socioeconomic coastal province of Argentina, including various types of environments on the coast as; low flood plains (Río de la Plata

<sup>15</sup> Values of table obtained from: (Scalise, A.H., Schnack, E.J., 2007)

estuary), wetlands (Samborombón bay), sand barriers (La costa), and cliffs (Mar del Plata).

### 3.3. Analysed locations

The first developments on the coast between Villa Gesell and General Lavalle were during the 1930's until the 1940's when the different investors and entrepreneurs decided to use the coast as a tourist attraction. Locations as Miramar and Mar del Plata were developed some decades before. Locations taken into account for the study are further explained starting at Miramar in the southern stretch of the coast, and ending with General Lavalle which is the locations further north along the coast.

#### *Miramar*

Miramar was founded the 20th of September of 1888; it is called the city of children nowadays. The city has nourished beaches contained by groyne fields, also a fishing pier that is currently under renovation. The fishing pier of Miramar can be seen on the left side of Figure 12, in the centre and right side of the same figure the two sections of the coast where groyne fields are constructed can be observed. Groynes in the area vary in shape, and in dimensions; for instance some are "T" groynes, others are "L" shaped, and some are just "I". The largest groynes were detected to be located in the central beaches of the city, while further north groynes gradually became smaller. A change on the coast was detected after the last groyne (north side), where the coast changed from dunes with pocket beaches to cliffs with narrow beaches.



**Figure 12 Coastal development of Miramar**

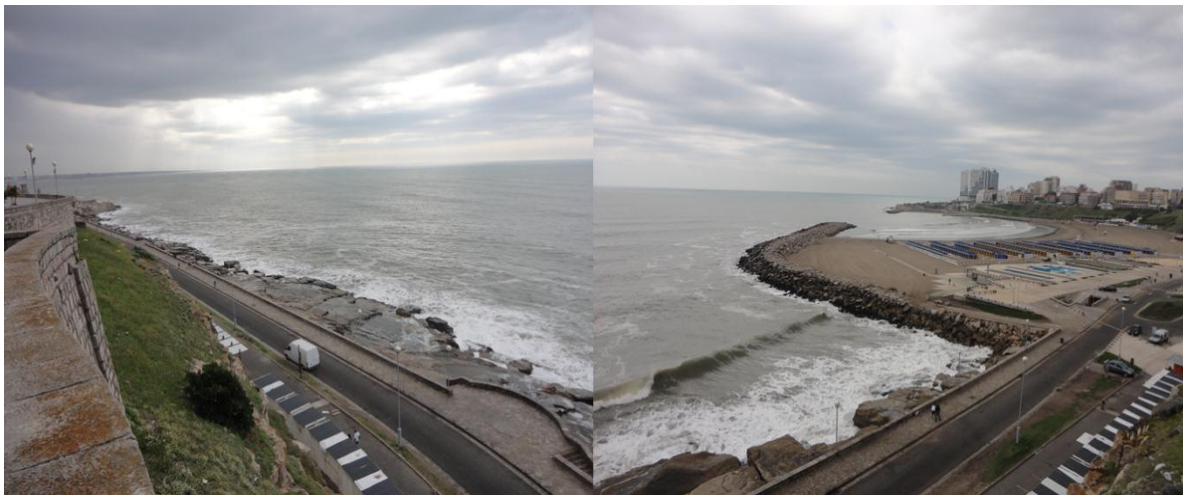
#### *Mar del Plata*

Mar del Plata was founded in 1874, is the most important vacation city in the province of Buenos Aires. It has one of the largest ports along the coast; problems related to sedimentation have deteriorated the accessibility and the activities of the port in the past years. Groyne fields were also constructed in MDP with the purpose to trap sand

and recover beaches. Cliff protection was also placed along the northern section of the MDP coast since the cliffs were eroding at very fast rhythms.

One of the advantages of Mar del Plata compared to other locations is that groynes and the existing port already contain a large amount of the sediment that is transported by the longshore currents, added to that the fact that steeper profiles (when compared to “La Costa”) provide deeper waters without going far from the coast.

The following figure shows the section of the coast that seemed promising for a future development of a marina port.



**Figure 13 Coastal development of Mar del Plata**

It is important to mention that the city of Mar del Plata already has a Marina port, although it was mentioned by the authorities in Argentina that in order to make the marina profitable, a campaign to promote the facilities had to be completed, together with a renovation of the existing facilities.

### *Mar Chiquita*

A quite smaller city as Mar Chiquita does not offer the same advantages when compared to MDP, but perhaps the lagoon area and the existing groyne field could be used as part of the coastal protection for a marina port. The delicate issue of this location is that the lagoon area is considered as a natural reserve; consequently large dredging works or large development of infrastructure inside the lagoon could have a negative result. In fact the local authorities are concerned about the current situation of the lagoon, and according to them, the sedimentation inside the lagoon has increased considerable in the past years; therefore with an ideal design, the combination of a marina port with some dredging works could restore the flow in the lagoon entrance, and consequently take the lagoon to its previous state.

The pictures shown below display the current situation of the outer section of the lagoon mouth (left), and the inner sheltered area (right). The lagoon is approximately 30km long and with varying width between a maximum of 5km and narrow channels of a few meters in the narrower parts.



**Figure 14 Coastal development of Mar Chiquita**

### *Villa Gesell*

Villa Gesell was founded in 1931, by Carlos Idaho Gesell, who initially did not plan to build a city, in fact he moved out of Tigre because he wanted to buy cheap land to plant pines, and sell the wood. He was one of the first to control de erosion of the dunes by planting different vegetation on top of them.

The city of Villa Gesell has a fishing pier that can be seen on the right side of Figure 15, the city has wide beaches with low lying dune field on the back side. Urbanisation maintained a setback line behind the dunes, and only a few beach houses are constructed on top of the dunes.



**Figure 15 Coastal development Villa Gesell**

### *Pinamar*

Pinamar was inaugurated as a resort in 1943, in contrast with Villa Gesell; Pinamar did have a proper urban design, where the streets and access roads for the city were planned beforehand, and services for the community were taken into account, although nowadays the water supply is a problem during summer season, when all the tourist go for vacations.

Pinamar is now considered the main resort for wealthy Argentinians, also contrasting with Villa Gesell where the tourism is mainly for youth and middle level economic class. Pinamar has wide beaches along its coast, a fishing pier, and many beach resorts to allocate the tourist during summer season.



**Figure 16 Coastal development Pinamar**

### *Mar de Ajo*

When analysing the city of Mar de Ajó it was found that it is a traditional fishing town, with one of the largest piers in Argentina with a length of 270m built in 1936, just one year after the city was founded. Similar to the other locations of “La Costa” this city also has erosion hot spots. Sports like kite surfing are practiced on its coast.

### *Santa Teresita & Mar del Tuyu*

Santa Teresita located further north compared to the previously described locations has a fishing pier of 200 metres built in 1947 and renovated in 1973, golf courses, hotels and resorts. The adjacent city of Mar del Tuyú was considered together with Santa Teresita since the city limits are directly adjacent to each other. Each of these locations has a fishing pier for locals and tourist, it can be observed in the left side of Figure 17

that the fishing pier is higher near the dunes than on the water side, the pier was constructed like that because the dunes used to be 2-3 metres high in that section along the beach (Present situation shows a flat beach, and the only remaining dunes are further back). The picture in the middle of Figure 17 shows the outfall of a drainage system directly on the beach, it can be seen that there is also beach erosion induced by the rain flow. The picture on the right side of the figure shows the actual state of the beach.

During the visit to Mar del Tuyú it was detected that the beach was very narrow especially in the section in front of “Prefectura” (Coastal office), many buildings were within the reach of high water; consequently bags, construction scraps, concrete units, rocks, and other kinds of heavy units are used as protection.



**Figure 17 Coastal development Mar del Tuyú**

### *San Clemente del Tuyú*

San Clemente del Tuyú has a variety of touristic developments, and it's the only location where the beach is not the main attraction, the main activities of the tourism in San Clemente del Tuyú are “Mundo Marino” (An aquarium, also with live shows of ocean species), and the thermal water resort. San Clemente covers the bay area with sheltered waters, as well as the exposed coast of Punta Rasa (limit of the Rio de la Plata estuary).

During the field visit it was observed that the area in the bay had a high percentage of mud, shallow waters, and a few fishing boats. When talking to the local fisherman they explained that most of the fishing they do is inside the bay, due to the fact that the open coast is too dangerous for the small ships. The access road to San Clemente is made of asphalt all the way to the water; in contrast the access road to Punta Rasa (open coast side of San Clemente) is a sandy/muddy road that goes through low lying areas with small vegetation, and ponds that are filled up during high tide.

### *Punta Rasa*

Punta Rasa is large dune area, it is the northern section of the “Partido de La Costa”, submerged bars were observed near the coast where waves were breaking. This part of San Clemente is exposed to wave action, whereas the area on the bay has natural protection against storms.

The larger dune area of Punta Rasa is where the light house is place, surrounded by larger vegetation. The following figure shows the small fishing piers in San Clemente bay (left), and the flat extended beaches of Punta Rasa (middle), and on the right the access road to the tip of Punta Rasa where it changes from open coast to the bay area with a sand spit formation.



**Figure 18 Coastal development San Clemente area**

### *General Lavalle*

General Lavalle is a fishing village, with an 800 metres long quay wall to allow fishing ships to load and unload their catch. Lavalle’s main activity is fishing, in contrast with all the other described cities, this location does not receive much tourism; consequently the development of marina is not as feasible, but perhaps the adaptation of a few berthing spots would be a good idea, considering that the trip from Buenos Aires or Atalaya takes some time and if the sea conditions are not suitable for sailing then the boats could make berth for protection or to recharge goods or fuel.



**Figure 19 Coastal development General Lavalle**

Three small airports operate in the region, one located near the city of Villa Gesell, other located by Santa Teresita, and a larger one in Mar del Plata.

The stretch of coast from Punta Rasa to Villa Gesell has very local hot spots with erosion and accretion spots, none of them are related to coastal structures since no structures to block the long-shore currents have been construed in the area. Essentially erosion spots are mainly due to the incorrect urbanization (Bertola, G.R., 2009). When considering the coast further south, it was observed during the field work visit that the coast from Mar Chiquita to Miramar has a good amount of groyne fields, the port of MDP, cliff protection with rocks, and more recently offshore breakwaters in “Los Acantilados” constructed to recover the beach. As stated before large problems related to sedimentation and erosion take place along this stretch of coast.

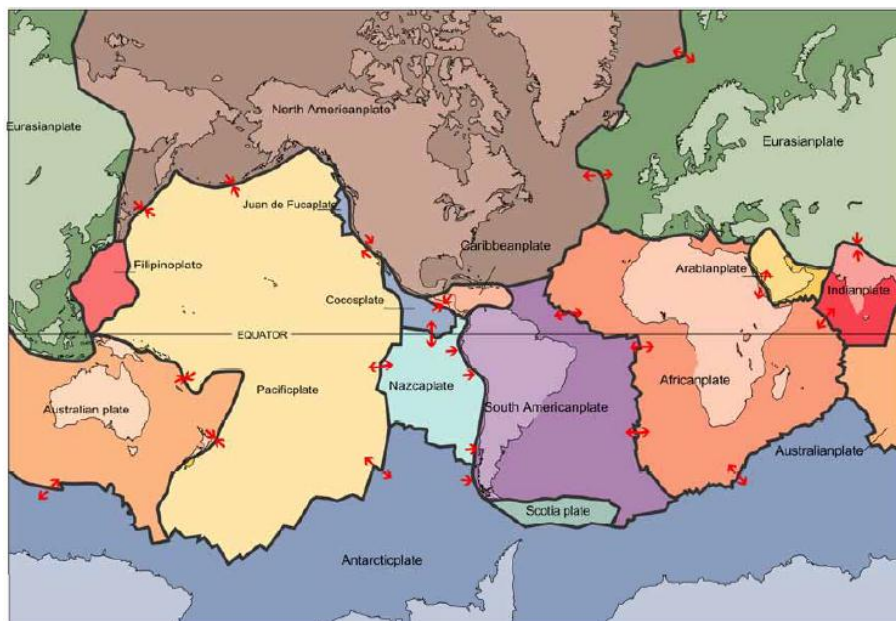
## 4. Data collection & analysis

### 4.1. Buenos Aires coast

#### *Coast characterization*

The Atlantic coastline is categorized as a trailing edge coast, this means that the tectonic margins are passive and away from the plate boundaries; therefore are tectonically stable because the dry land and the water covered part of the continent is in the same plate. Trailing edge coast are known to have wide continental shelves, in the other hand leading edge coasts are normally very close to the limit of the tectonic plate and consequently the continental shelf is quite narrow. (Inman, D.L., Nordstrom, C.E., 1971)

The Americas are categorized as Amero-trailing edge coasts, coastal plains, deltas and barriers are common in the coast. The Amero-trailing edge coasts are the most mature coastal areas, with a supply of sediment from diverse rivers forming a gentle continental slope. (Bosboom J., Stive, M.J.F., 2011) In the case of South America the Amazon and the La Plata rivers are the most important suppliers of sediments.



**Figure 20 Movements of the tectonic plates<sup>16</sup>**

Figure 20 Movements of the tectonic plates, shows the arrangement of the tectonic plates around the world. It can be observed that the East coast of South America (purple colour plate) is far from the limit of the tectonic plate boundary. As explained by

<sup>16</sup> Source: (United States Geological Survey, 2012) <http://pubs.usgs.gov/gip/dynamic/slabs.html>

Federico I. Isla and Enrique J. Schnack South America is a plate moving westward and away from the Mid-Atlantic ridge, specifically in Argentina an uplift of the land of around 8 to 9cm/kyrs has been detected. (Isla, F.I., Schnack, E.J., 2010)

The formation of the Buenos Aires sandy coast is relatively new; it was mainly shaped after the Holocene fluctuation period. For instance the sand bars located from Punta Rasa to Mar Chiquita did not exist 6500 before present, in fact studies show that the formation started around 2,000 years ago. During the past 2,000 years the shape of the dune barrier has changed into a steeper profile on the off-shore side, while the lee side shows sedimentation. (Bertola, G.R., 2006)

A study by (Bertola, G.R., 2006) shows a classification of the type of beaches in Pinamar and Villa Gesell, it was concluded that the coast has similar characteristics. In fact by using classifications of different authors it was derived that the coast is mostly intermediate, with dissipative beaches.

In accordance to what German R. Bertola concluded in his study in 2006, Scalise, A.H. and Schnack, E.J., 2007 obtained similar results, they concluded that the coast is mostly dissipative. And used Pinamar and Villa Gesell as examples of coasts with high energy dissipation and stable dune fields.

### *Bathymetry*

The area of interest for this study has a peculiar bathymetric shape, especially near shore between Punta Médanos and Villa Gesell where sand ridges are formed with a NW-SE alignment. In the northern section of the region under review the bathymetry shows more parallel depth contours. For the southern section from Mar del Plata to Miramar the profiles are steeper; consequently deeper waters are closer from shore.

The bathymetry of Villa Gesell shows long extended sand banks, the width of these banks varies. When using the 12 m depth contour as reference, the width ranges from 2-3km, the corresponding length is of more than 5 km.

The sector of Pinamar is variable; the dominant feature of the area is a large elongated sand bank. This sand structure extends from the North side of Pinamar to the South-East a distance of about 9 km, with a width of 2 km.

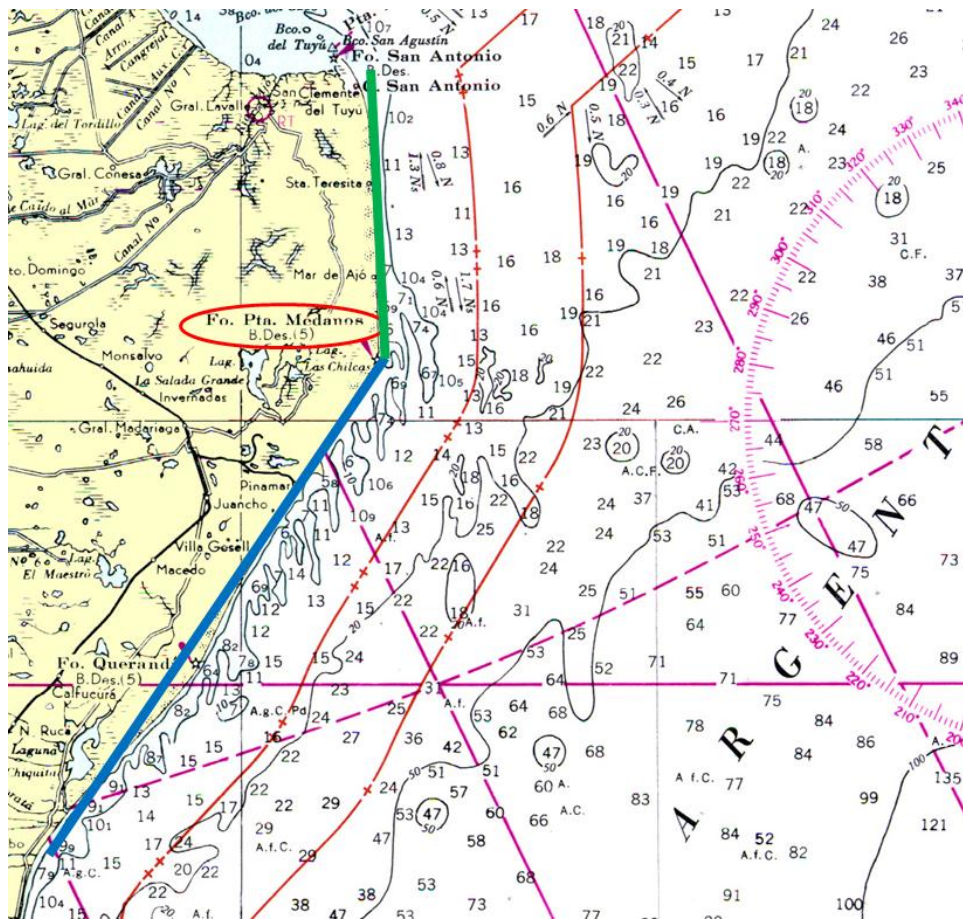


Figure 21 Bathymetry of the coast under analysis<sup>17</sup>

As it can be seen in Figure 21 that the coast changes greatly from North to South, an inflexion point can be observed in Punta Médanos, where the orientation and shape of the near-shore bathymetry changes.

### Storm seasonality

Seasonal changes depend on the variability of the wave climate, for instance swell dominated coasts have a constant wave height throughout the year, in the contrary, environments with high seasonality like the Dutch coast, experience a calm season and a storm season. During the calm season, waves carry sediment on-shore to recover the beach, while during storm season the beaches are eroded. It is important to make clear that the eroded volumes during storms could reach large values, and in the other hand the recovery of the beach by the on-shore waves is a slow more constant process. (Bosboom J., Stive, M.J.F., 2011)

As German R. Bertola explain on his work in 2006 the coast of Buenos Aires experiences some type of seasonality. He catalogued the Autumn/Winter and Winter/Spring seasons

<sup>17</sup> Bathymetry picture file provided by Federico Ignacio Isla.

as erosive, and perhaps the Summer/Autumn the recovery season, also noticed that the Spring/Summer period is neutral, since no net tendencies of transport were recorded as dominant. (Bertola, G.R., 2006)

The province of Buenos Aires receives westerly storms, generated between 30° and 60° south. Observations by (Monica M.E. Fiore, Enrique E. D'Onofrio, Jorge L. Pousa, Enrique J. Schnack, German R. Bertola, 2009) show that winter months (June, July, August) exhibit the greatest number of storm events for the coast of Mar del Plata and the adjacent coastal areas.

### Tides

Tide characteristics vary globally, the two main variables on the basis of which tidal environments can be classified are: the magnitude of the tide (tidal range, vertical variation), and the tidal character (semi-diurnal and diurnal components).

Tides are distorted by local differences in water depth, for instance the shape of the coast (slope, geometry, coastal orientation, etc.). Figure 22 Tidal range environments and Characterization of tides of the world, shows that for example semi enclosed seas enhance tidal amplification, and consequently a lot of times experience large tidal ranges. In the other hand open coasts generate micro-tidal environments. It can also be detected in the figure that the area under study has a mean spring tidal range below 2m; therefore is classified as a micro-tidal environment.

The second variable used to characterize coasts is the type of tide (semi-diurnal, diurnal, mixed). Most coastlines experience either semi-diurnal or mainly diurnal mixed tides.

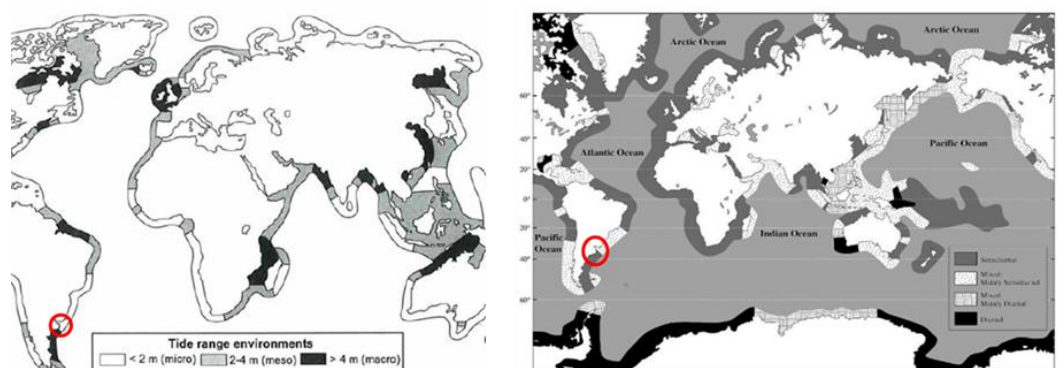


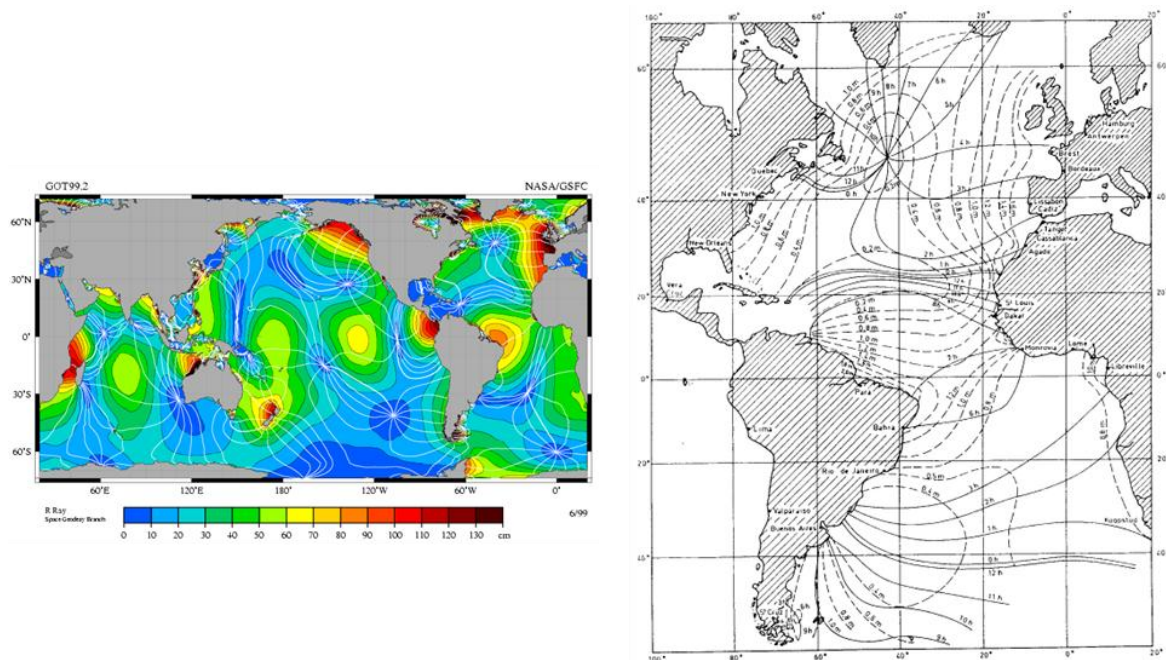
Figure 22 Tidal range environments<sup>18</sup> and Characterization of tides of the world<sup>19</sup>

<sup>18</sup> Figure source: (Masselink, G., Hughes, M.G., 2003)

<sup>19</sup> Source: (Roshanka R., Charitha P., 2000)

It can be seen in Figure 22 Tidal range environments and Characterization of tides of the world, that the coastal area under study has a mainly semi-diurnal type of tide. Therefore the final classification of the coast would be semi-diurnal with a micro-tidal range (Two high + two low tides per day, and a tidal range of maximum 2 m). Federico Ignacio Isla confirmed that the maximum tidal range in the area is below 2m, and gives a maximum value of roughly 1.6 meters in his tide classification. (Isla, F.I., 2006)

Another important matter to consider is the propagation of the tide, which is influenced by friction and resonance. Since the movement of the tides is deflected by Coriolis and blocked by the continents, rotary movements are formed in the ocean basins, a clockwise rotation is observed in the southern hemisphere. Such rotary systems are called amphidromic systems. (Bosboom J., Stive, M.J.F., 2011)



**Figure 23 Amphidromic points<sup>20</sup>**

Figure 23 Amphidromic points, shows the propagation pattern followed around the world (left), and more in detail for the Atlantic Ocean (right). The solid lines represent the co-tidal lines of simultaneous high waters, while the dashed lines are the co-range lines of equal tidal range.

The tidal variation within the area of study is not very large; since the coastal characteristics are similar, and also the distance in relation to the other locations under analysis is relatively short.

<sup>20</sup> Sources: Left: (NASA Goddard Space Flight Center, 2012)  
Right: (Bosboom J., Stive, M.J.F., 2011)

Tidal measuring buoys were deployed by the “Servicio de Hidrografía Naval” in order to record tides along the coast of Argentina; some of the locations under review have their own measuring buoy. For the remaining locations tidal ranges can be estimated based on the values of the adjacent coasts, in fact variation from one location to another is not very significant as it can be seen in Table 7.

Table 7 Tidal amplitudes measured in meters is a summary of the data provided by “Servicio de Hidrografía Naval” database, It can be observed that the mean sea level value is 0.91 m, also that the variation of tidal ranges and maximum amplitudes only varies by a few centimetres.

**Table 7 Tidal amplitudes measured in meters<sup>21</sup>**

Location	Mean Level	High Tide		Low Tide		Amplitude	
		Max	Mean	Lower	Mean	Max	Mean
<b>Mar del Plata</b>	0.91	1.89	1.33	0.20	0.52	1.66	0.81
<b>Pinamar</b>	0.91	1.77	1.25	0.15	0.56	1.39	0.69
<b>Mar de Ajo</b>	0.91	1.72	1.24	0.08	0.54	1.42	0.70
<b>Santa Teresita</b>	0.91	1.80	1.31	-0.01	0.49	1.65	0.81
<b>San Clemente del Tuyu</b>	0.91	1.79	1.28	0.04	0.49	1.52	0.79

All locations are categorized as mixed semi-diurnal dominated tides by the “Servicio de Hidrografía Naval”, meaning that two tidal cycles are completed in one day.

As addressed by Federico Ignacio Isla, the tidal environment of the coastal zone under review can be classified as micro-tidal environment, since the fluctuation of the water level does not exceed 2 m; the maximum variation is around 1.80 meters (Isla, F.I., 2006).

### *Storm surge levels*

Storm surge levels consists of an additional elevation of the water level (added to the tide), caused by differences in atmospheric pressure and strong onshore winds, which consequently piles up the water towards the coast. In fact certain environments are more susceptible to large storm surge levels, for instance shallow areas with enclosed bays as the Río de la Plata area. (Located north from the coastal stretch under review).

In accordance to (Scalise, A.H., Schnack, E.J., 2007) the storm surge levels in the Buenos Aires province tend to last various days, producing important modifications to the coast. Historical storm surges in the coast were analysed in the same study, showing a table with maximum expected storm surges with return periods of 50, 100, 200 years that

<sup>21</sup> (Servicio de Hidrografía Naval, 2012)  
[http://www.hidro.gov.ar/Oceanografia/Tmareas/Form\\_Tmareas.asp](http://www.hidro.gov.ar/Oceanografia/Tmareas/Form_Tmareas.asp)

correspond to 3.29 m, 3.43 m, and 3.57 m. (values obtained using Annual Maxima method)

A study by (Monica M.E. Fiore, Enrique E. D'Onofrio, Jorge L. Pousa, Enrique J. Schnack, German R. Bertola, 2009) reviewed the water levels, and storm surges at Mar del Plata and the adjacent coasts. Their results show that an average of twenty five significant storms per year, were observed from 1956 to 1995. Although from 1996 to 2005, the number of storms of the same magnitude increased, reaching an average of thirty five per year. Other findings shown in their study demonstrate that mean storm duration has also increased throughout the years, from 26 hours in the 1950's to 28 hours in the last decade. In the other hand the maximum observed water levels from 1956 to 2005 have been more constant only ranging a few centimetres, with a decadal average of annual maximum positive storm surge of 1.45 m.

Storm surges calculated by (Dragani, W., Alonso, G., 2011) at Mar del Plata show elevations exceeding the astronomical tide by 1.75 m, this extreme storm surge level was observed in 1999.

A study by W.C. Dragani, C.A. Mazio and M.N. Nuñez studied the sea level oscillations for the Buenos Aires province; they compared sea levels in different locations (Pinamar, Mar de Ajó and Mar del Plata). Sea level oscillations were generally first observed in Mar del Plata and, subsequently further north at Pinamar and Mar de Ajó, this propagation direction was associated to the predominant propagation direction of atmospheric perturbation. (Dragani, W.C., Mazio, C.A., Nuñez, M.N., 2001)

### *Sea level rise*

Advances in climate change modelling now enable best estimates and more likely uncertainty ranges for projected sea level rise. Diverse scenarios have been set up taking into account different possibilities and by using various methods of calibration for the models. A summary table done during the Fourth Assessment of the Intergovernmental Panel on Climate Change is shown below in Table 8 Expected sea level rise. The results found, basically illustrates that the anticipated global sea level rise is expected to be in the range of 0.18 for the best scenario, or up to 0.59m in the worst case for the year 2099. (Pachauri, R.K., Reisinger, A., 2007)

**Table 8 Expected sea level rise<sup>22</sup>**

Scenario	Sea Level Rise (m at 2090-2099 relative to 1980-1999)
<b>B1</b>	0.18-0.38
<b>A1T</b>	0.20-0.45
<b>B2</b>	0.20-0.43
<b>A1B</b>	0.21-0.48
<b>A2</b>	0.23-0.51
<b>A1FI</b>	0.26-0.59

Cautious consideration of these values will be further analysed when working on the design of the marina port to be built along the coast of the Buenos Aires province.

Isla and Schnack published sea level rise records based on (Pousa et al., 2006), who based his conclusions on the water levels recorded at Mar del Plata from 1954 to 2002 showing a trend of +1.4mm/year. It was also mentioned that sea level rise would affect the South American coast greatly since low laying areas are common, and no infrastructure is built to avoid hazards in the coast. (Isla, F.I., Schnack, E.J., 2010)

## 4.2. Wind and Waves

### *Wind*

Winds and ocean currents develop as a consequence of heat on the earth's surface. The major wind systems are the Polar Easterlies, Westerlies, and the Trade winds. In fact the winds that are related to the area of study are the South-East Trades (from 0° to 30° South) and the Westerlies (from 30° to 60° South), since the coast under analysis is between 35° and 39° South. Westerly winds are strong and variable, while trade winds are more constant and persistent throughout the year.

Wind generates ocean waves; consequently it can be expected that global wind systems determine the global wave environments. (Bosboom J., Stive, M.J.F., 2011)

Air flow circulation patterns around the world vary in direction and magnitude. When referring to Argentina the circulation during January and circulation in July follows a similar pattern of directions, the variation of pressure locally is large compared to other locations around the world, although not as large as the variation in the storm zone of the northern hemisphere. (Bosboom J., Stive, M.J.F., 2011)

<sup>22</sup> Source: (Pachauri, R.K., Reisinger, A., 2007)

Figure 25 Wind roses (1997-2010) shows the wind roses that were used as input for the wave modelling in this study. Wind data was extracted from the NOAA Wave Watch III model, covering data from 1997 to 2010. The most common wind velocity is in the range of 8m/s to 10m/s. Wind directions are from all directions as seen in the wind rose, but perhaps a dominance of wind coming from north it is easier to detect in the following table.

		Wind direction																									
		352.5-7.5	7.5-22.5	22.5-37.5	37.5-52.5	52.5-67.5	67.5-82.5	82.5-97.5	97.5-112.5	112.5-127.5	127.5-142.5	142.5-157.5	157.5-172.5	172.5-187.5	187.5-202.5	202.5-217.5	217.5-232.5	232.5-247.5	247.5-262.5	262.5-277.5	277.5-292.5	292.5-307.5	307.5-322.5	322.5-337.5	337.5-352.5		
Wind magnitude	>20			0.00		0.00	0.00	0.00	0.00			0.00	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00						0.07
	19-20			0.01				0.00		0.00	0.01			0.00	0.01	0.01	0.01	0.01	0.00						0.00		0.07
	18-19	0.01	0.00	0.00			0.00	0.00	0.01			0.01			0.00	0.01	0.01	0.02	0.02	0.01							0.10
	17-18	0.01	0.00	0.01		0.01		0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.05	0.02	0.02	0.01		0.00	0.01			0.21
	16-17	0.01	0.01	0.00		0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.04	0.04	0.04	0.02	0.00	0.01				0.28
	15-16	0.02	0.02	0.01	0.00	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.03	0.03	0.06	0.08	0.09	0.04	0.03	0.02	0.02			0.01	0.00	0.57
	14-15	0.02	0.03	0.03	0.02	0.01	0.02	0.03	0.02	0.04	0.03	0.03	0.04	0.03	0.12	0.12	0.17	0.11	0.07	0.05	0.03	0.03	0.06	0.01	0.01		1.11
	13-14	0.06	0.06	0.06	0.02	0.02	0.03	0.02	0.05	0.04	0.04	0.06	0.08	0.10	0.16	0.21	0.19	0.18	0.10	0.06	0.04	0.07	0.07	0.05	0.08		1.81
	12-13	0.13	0.14	0.07	0.04	0.06	0.06	0.02	0.06	0.09	0.08	0.09	0.08	0.12	0.20	0.35	0.36	0.27	0.16	0.14	0.09	0.12	0.17	0.17	0.12		3.17
	11-12	0.23	0.23	0.16	0.09	0.07	0.07	0.06	0.06	0.08	0.10	0.13	0.20	0.18	0.32	0.41	0.39	0.26	0.18	0.11	0.19	0.29	0.28	0.29	0.29		4.66
	10-11	0.50	0.41	0.32	0.18	0.13	0.08	0.07	0.10	0.15	0.18	0.15	0.24	0.31	0.39	0.53	0.53	0.33	0.23	0.18	0.19	0.34	0.40	0.47	0.54		6.94
	9-10	0.78	0.56	0.45	0.23	0.21	0.13	0.15	0.19	0.18	0.23	0.26	0.30	0.33	0.48	0.58	0.51	0.42	0.31	0.23	0.27	0.40	0.55	0.64	0.79		9.18
	8-9	0.96	0.76	0.60	0.33	0.28	0.20	0.24	0.22	0.25	0.27	0.34	0.37	0.45	0.56	0.65	0.51	0.45	0.35	0.33	0.35	0.47	0.61	0.78	0.91		11.13
	7-8	0.93	0.77	0.66	0.44	0.32	0.26	0.24	0.33	0.31	0.39	0.36	0.44	0.56	0.56	0.70	0.50	0.41	0.43	0.39	0.37	0.50	0.71	0.76	0.96		12.30
	6-7	0.82	0.78	0.58	0.47	0.44	0.38	0.31	0.33	0.35	0.34	0.48	0.48	0.46	0.50	0.48	0.54	0.44	0.43	0.41	0.40	0.51	0.61	0.74	0.82		12.10
	5-6	0.71	0.64	0.52	0.52	0.44	0.36	0.32	0.43	0.35	0.38	0.49	0.42	0.44	0.46	0.46	0.47	0.47	0.41	0.37	0.42	0.44	0.47	0.54	0.68		11.20
	4-5	0.52	0.51	0.44	0.50	0.45	0.39	0.39	0.39	0.44	0.36	0.37	0.44	0.39	0.40	0.40	0.42	0.38	0.33	0.37	0.32	0.31	0.48	0.44	0.53		9.96
	3-4	0.35	0.37	0.31	0.32	0.36	0.37	0.30	0.31	0.31	0.29	0.28	0.24	0.30	0.24	0.32	0.34	0.29	0.23	0.24	0.20	0.30	0.27	0.29	0.36		7.18
	2-3	0.15	0.19	0.18	0.19	0.20	0.22	0.18	0.17	0.20	0.19	0.15	0.17	0.18	0.24	0.23	0.20	0.22	0.18	0.20	0.19	0.17	0.19	0.21	0.16		4.55
	1-2	0.11	0.10	0.13	0.11	0.09	0.12	0.14	0.11	0.09	0.10	0.12	0.13	0.10	0.10	0.08	0.10	0.10	0.11	0.12	0.11	0.09	0.11	0.11	0.09		2.53
0-1	0.04	0.05	0.04	0.02	0.04	0.04	0.05	0.03	0.04	0.03	0.03	0.04	0.03	0.06	0.05	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.04	0.02		0.89	
		6.23	5.62	4.55	3.47	3.16	2.71	2.52	2.84	2.93	3.02	3.38	3.68	4.04	4.90	5.71	5.46	4.57	3.69	3.28	3.21	4.11	5.01	5.56	6.36	100.00	
		Entire dataset																								Total	

Figure 24 Wind magnitude/direction table

The darkest colours represent a higher percentage of occurrences of that certain combination (magnitude and direction); it can be derived from this table that the wind magnitude for this position has a variation of magnitude mostly between 7-10 seconds and coming from the north.

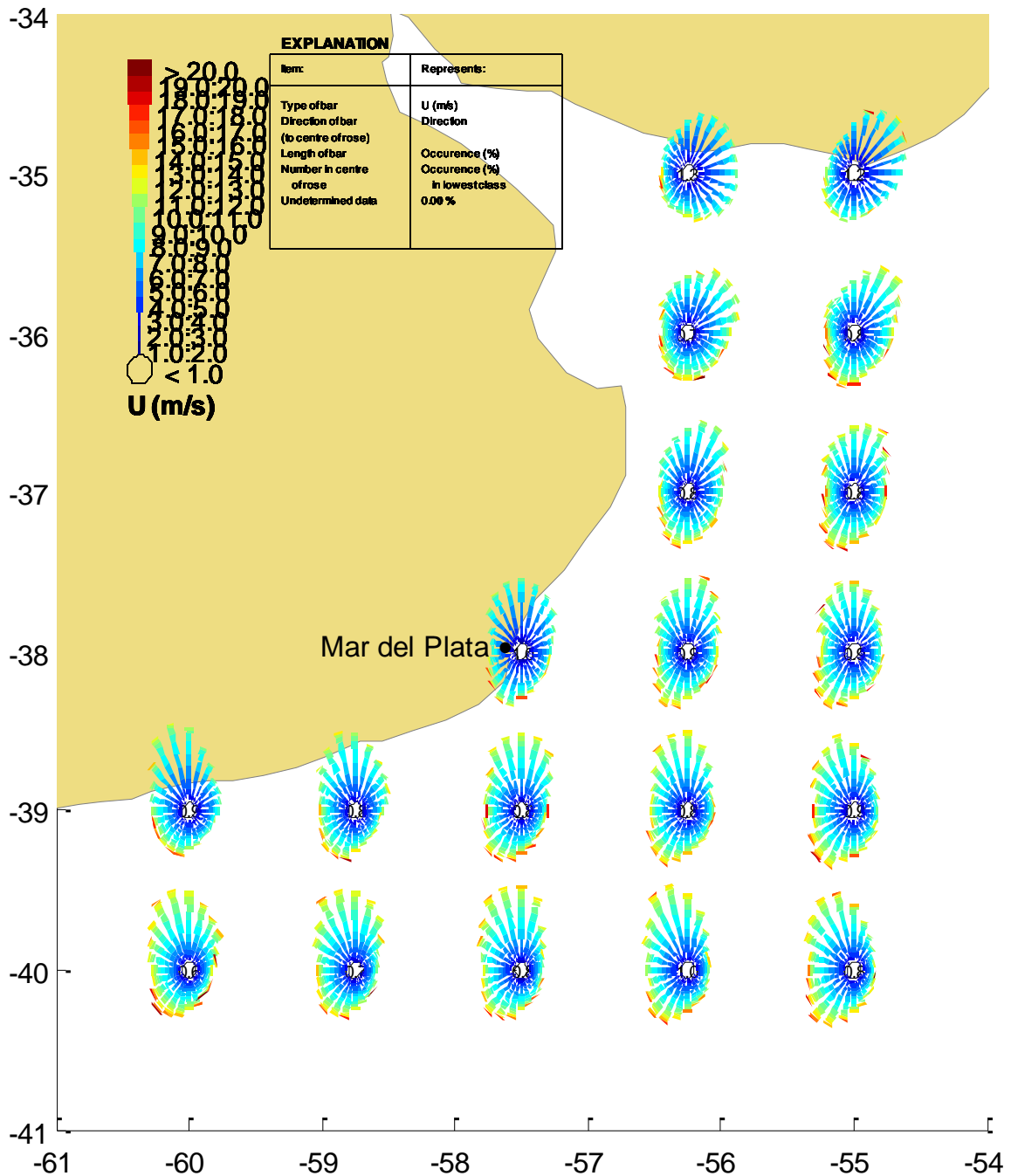


Figure 25 Wind roses (1997-2010)<sup>23</sup>

- The length of the arms of the wind roses represents the percentage of occurrence of the situation
- The colour of each cell represents the magnitude of the wind velocity
- The alignment of each arm of the wind roses denotes the direction of which wind is “coming from”.

<sup>23</sup> (National Weather Service (NWS), National Oceanic and Atmospheric Administration, 2012)

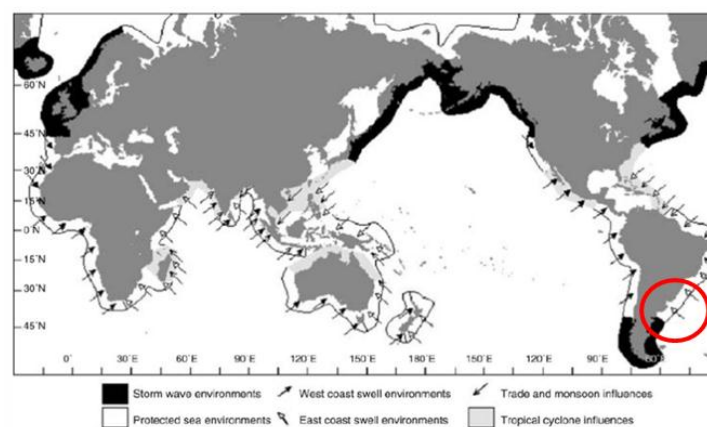
## Waves

Ocean waves are generated by wind. Global wave environments are those zones of the seas and the oceans that have similar wave characteristics, perhaps wave heights, and seasonality.

Wave heights are highest in mid-latitudes due to the effect of the strong westerly winds; larger waves are observed in the Southern hemisphere because waves propagate freely since the landmasses do not fully block the propagation as in the North. Important to notice that even if the waves are larger in the South, the seasonality is much greater in the Northern hemisphere. Wave climates can be categorized as low when the yearly significant wave height is below 0.6 m, medium in the case were the waves are between 0.6 m and 1.5 m, or as high wave energy environment when the yearly significant wave height reaches values above 1.5 m. (Bosboom J., Stive, M.J.F., 2011)

Davies, J.L. in 1980 published some work, where he identified four major groups of deep water wave environments, consisting of: Storm wave environments, West coast swell environments, East coast swell environments and Protected sea environments. All these can be observed in Figure 26 World distributions of wave environments and their dominant directions. For the coast under review it can be observed that East coast swell environments dominates, but it is also important to notice that the storm wave climate boundary is very close; therefore some type of combination between the two can be expected. (Davies, J.L., 1980)

According to National Oceanographic Centre of Southampton, the yearly mean wave height in the area of study is of about 2-2.5 meters offshore, and varies around 1 meter throughout the year. <sup>24</sup>



**Figure 26 World distributions of wave environments and their dominant directions<sup>25</sup>**

<sup>24</sup> Source: (National Oceanographic Center of Southampton, 2012)

The country of Argentina in general has a lack of reliable wave data, studies performed by different authors like (Lanfredi, N.W., Pousa, J.L., Mazio, C.A., Dragani, W.C., 1992), (Dragani, W.C., Garavento, E., Simionato, C.G., Nuñez M.N., Martin, P., Campos, M.I., 2008), (Dragani, W.C., Martin, P.B., Simionato, C.G., Campos, M.I., 2010) have analysed the wave conditions in Argentina, and give values based on: ship observations, in-situ observations, altimeter based measurements, data from a few accelerometers, wave rider buoys for short periods, and on the NCEP/NCAR data.

Firstly (Lanfredi, N.W., Pousa, J.L., Mazio, C.A., Dragani, W.C., 1992) did a study related to wave power potential along the province of Buenos Aires. The study was completed based on wave data obtained from accelerometers (4 years), pressure sensors (1 year), and a visual observation program that lasted 10 years. Wave heights were measured at the following five locations: Mar de Ajó (Water depth of the position where the waves were measured not specified), Punta Médanos (12 m depth), Pinamar (Not specified), Mar del Plata (11 m depth) and Puerto Quequén (7 m depth).

The results of their study are summarized in Table 9 Annual average of mean and maximum wave height, period, wave power, the large difference in wave heights from one location to the other was deduced to be related to the local bathymetry, in fact for Mar de Ajo a gentle parallel sea bed slope can be found, while for Punta Médanos sand ridges are dominant, and therefore affect the propagation properties of the wave.

**Table 9 Annual average of mean and maximum wave height, period, wave power<sup>26</sup>**

Location	Wave height (m)		Period	Wave power (kW/m)	
	Mean	Max		Lower	Mean
<b>Mar de Ajo</b>	0.68	1.31	8.40	2.30	8.20
<b>Punta Medanos</b>	1.15	4.10	7.00	5.50	69.00
<b>Pinamar</b>	0.89	1.90	8.70	4.20	18.50
<b>Mar del Plata</b>	0.91	2.30	9.50	4.30	34.20
<b>Puerto Quequen</b>	1.33	3.61	8.00	7.5	61.3

A wave data set of twenty minutes corresponding to Punta Médanos (only location with accelerometer data) was analysed spectrally using three different methods. The

<sup>25</sup> Source: (Masselink, G., Hughes, M.G., 2003) Modified from (Davies, J.L., 1980)

<sup>26</sup> (Lanfredi, N.W., Pousa, J.L., Mazio, C.A., Dragani, W.C., 1992).

calculated significant wave height with Blackman & Tukey, and Tucker & Draper methods was 3.48 meters, when applying the Fast-Fourier Transform method the significant wave height resulted equal to 3.39 meters.

A later study by (Dragani, W.C., Garavento, E., Simionato, C.G., Nuñez M.N., Martin, P., Campos, M.I., 2008) intended to evaluate the use of SWAN model in the outer Río de la Plata estuary.

The model input data was forced by NCEP/NCAR<sup>27</sup> reanalysed 10 m winds (more than 30 years of data), as well as a set of thirteen month in situ collected data series. Wave parameters were measured in the outer Río de la Plata (35°40'S and 55°50'W) with a Datawell Waverider directional wave recorder. Bathymetry was completed with a 1' × 1' resolution depth data set coming from GEBCO (2003), and supplemented by digitalized nautical charts from (Servicio de Hidrografia Naval, 2012). Two grid sizes were implemented, the first covering only the Río de la Plata estuary consisting of a grid of 2.7 × 3.3 km resolution, while the second grid had a grid resolution of 22.7 × 20.0 km covering the coast from 30°S to 42°S.

Waverider buoy records show the minimum, maximum, and mean observed  $H_s / T_{M01}$ <sup>28</sup> were 0.18 m, 4.55 m, and 1.23 m with corresponding periods of 1.7 s, 10.7 s, and 4.8 s. The mean observed wave direction was 135.2° (South-easterly). In general the SWAN model simulated smaller wave heights compared to the observed values, a correction factor was applied to the wind drag coefficient in order to minimize the difference, after doing so the agreement between the simulated and the observed wave heights was satisfactory, but the average period was still underestimated by an order of magnitude of around 2 s.

(Dragani, W.C., Martin, P.B., Simionato, C.G., Campos, M.I., 2010) completed a study with the objective to evaluate if the wind wave heights were increasing in the southern hemisphere, specifically between 32°S and 40°S.

Wave data obtained with in situ observation from 1996 to 2006 had several gaps and consequently was considered as too short and incomplete to show a trend of increasing wave heights, similar results were found with the Ocean Topography Experiment data covering the period from 1993 to 2001. Nevertheless the authors explain that it is difficult to assess the wave height trend with the short span of data.

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<sup>27</sup> NCEP: National Center for Environmental Prediction. NCAR: National Center for Atmospheric Research.

<sup>28</sup>  $H_s$ : Significant wave height.  $T_{M01}$ : Average period.

In the other hand when the SWAN model was applied to simulate waves based on wind data from 1971 to 2005 from the NCER/NCAR, a positive trend was found. The highest difference was more than 0.20 m and occurred at around 34°S - 48°W, the increase in the significant wave height for this site was of 9%.

A study by (Waterman, R.E., 1994) related to sediment bypassing in the entrance of the port of Mar del Plata, used a wave climate based on visual observations from ships. The area for the observations covered from 36° S to 42° S and 53° W to 58° W. Wave climate was separated in swell and wind waves to recognize the dominance of each of them, it was concluded by the author that swell waves have a very dominant effect on the coast of Mar del Plata, and that the difference in incoming wave angles (swell and wind) could fluctuate by up to 90°.

Based on the wave distribution shown in Figure 27 the author concluded that the north going littoral drift as experienced in the Buenos Aires province is mainly driven by swell waves. Since the swell waves are higher and have longer wave lengths when compared to the locally generated wind waves.

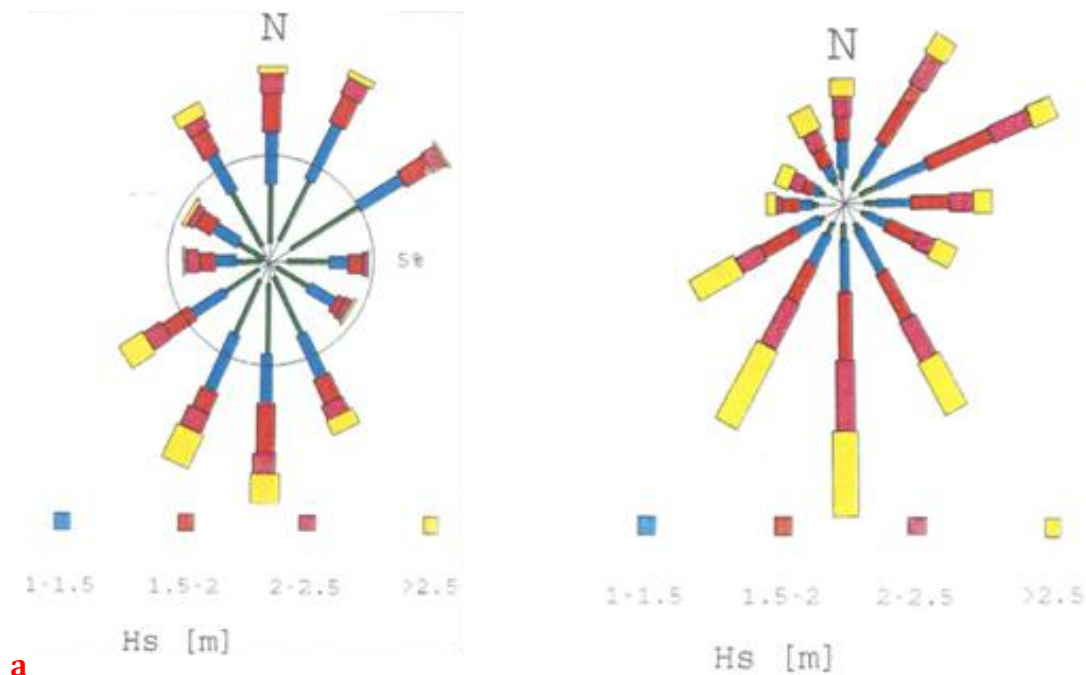


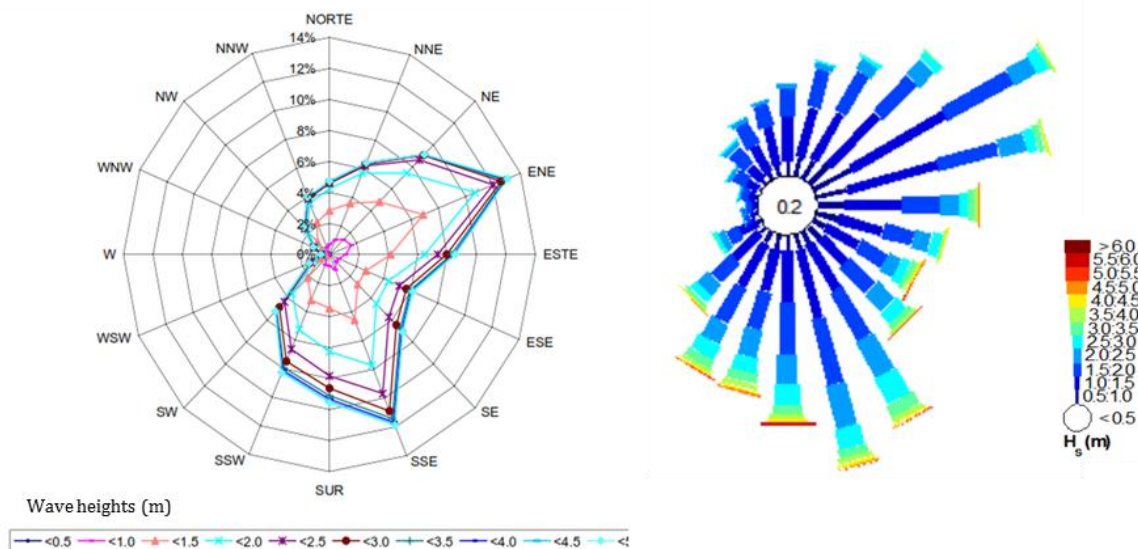
Figure 27 Ship observation wave climate<sup>29</sup>

Figure 27 Ship observation wave climate, shows the swell (right) and wind (left) wave roses for the area, it can be observed that South and Northeast directions are the most dominant for incoming waves. This data is very coarse but the major directions and

<sup>29</sup> (Waterman, R.E., 1994)

magnitudes have a strong correlation when compared to the wave climate used for this study, which is explained in further detail in the following part of this section.

The National University of Cordoba and the county of General Pueyrredon completed a study related to a breakwater system for Punta Mogotes, a beach located south of Mar del Plata. The wave climate used for that project was based on the National Oceanographic & Atmospheric Administration (NOAA) from the United States, using values from 1997-2006. Wave data was extracted from the same source for this thesis study, covering records from 1997 to 2010, meaning that an extra 4 years of data were added. To validate the correct extraction and processing of data, wave roses were compared. It can be seen in Figure 28 that the correlation between them is adequate (Dominant directions and magnitudes are similar).



**Figure 28 Comparison of wave data<sup>30</sup>**

Wave roses shown in Figure 28 Comparison of wave data correspond to the same data point, located 38° S and 57.5° W. Picture on the left corresponds to the study completed by the National University of Cordoba, while the one on the right corresponds to the extracted data for the present study. Wave data and characteristics are explained in further detail as follows.

Wave data used as input for this study comes from the NOAA global data base, this data covers from 1997 to 2010 with records every 3 hours. Wave data is generated with the deep water wave propagation model (WAM) that was developed at Delft University of Technology and NASA Goddard Space Flight Center.

<sup>30</sup> (Universidad Nacional de Córdoba y Municipalidad General Pueyrredon, 2007)

19 data points were extracted from the database in order to fully cover the area of study from  $-35^{\circ}$  S to  $-40^{\circ}$  S. Each grid point has values for significant wave height, peak period, wave direction, wind speed, and wind direction. It can be seen that the dominant wave direction for the area is waves coming from the South, and Northeast as a secondary wave direction. It can also be detected that the data points further north have a larger East component since the Northeast waves are blocked by the land boundary (Uruguay). The data points located closer to the coast have less percentage of occurrence for waves coming from the West; this can be explained by the fact that the fetch area to generate wind waves is restricted. Another important thing to point out is that larger offshore waves can be observed closer to the south, especially in the ( $-40^{\circ}$  S,  $-55^{\circ}$  W) data point.

As it can be seen in Figure 29 Significant wave heights roses (1997-2010); where waves propagating from deep to shallower waters start refracting and consequently East and Southeast incoming wave directions have a greater frequency. These directions are expected since the alignment of the Buenos Aires coast is perpendicular to them. Important to notice that wave heights are also larger near the southern area, in fact waves exceeding 4.0 metres in the northern section are hardly visible, while in the south some waves of up to 6.0 metres are observed.

- The length of the wave roses represents the percentage of occurrence of the situation.
- The colour of each cell of the roses represents the magnitude of either: significant wave height for Figure 29, or peak wave period for Figure 30.
- The directions of wave propagation are represented by the alignment of each arm of the roses. Directions are "coming from" the end of the arm to the centre of the rose.

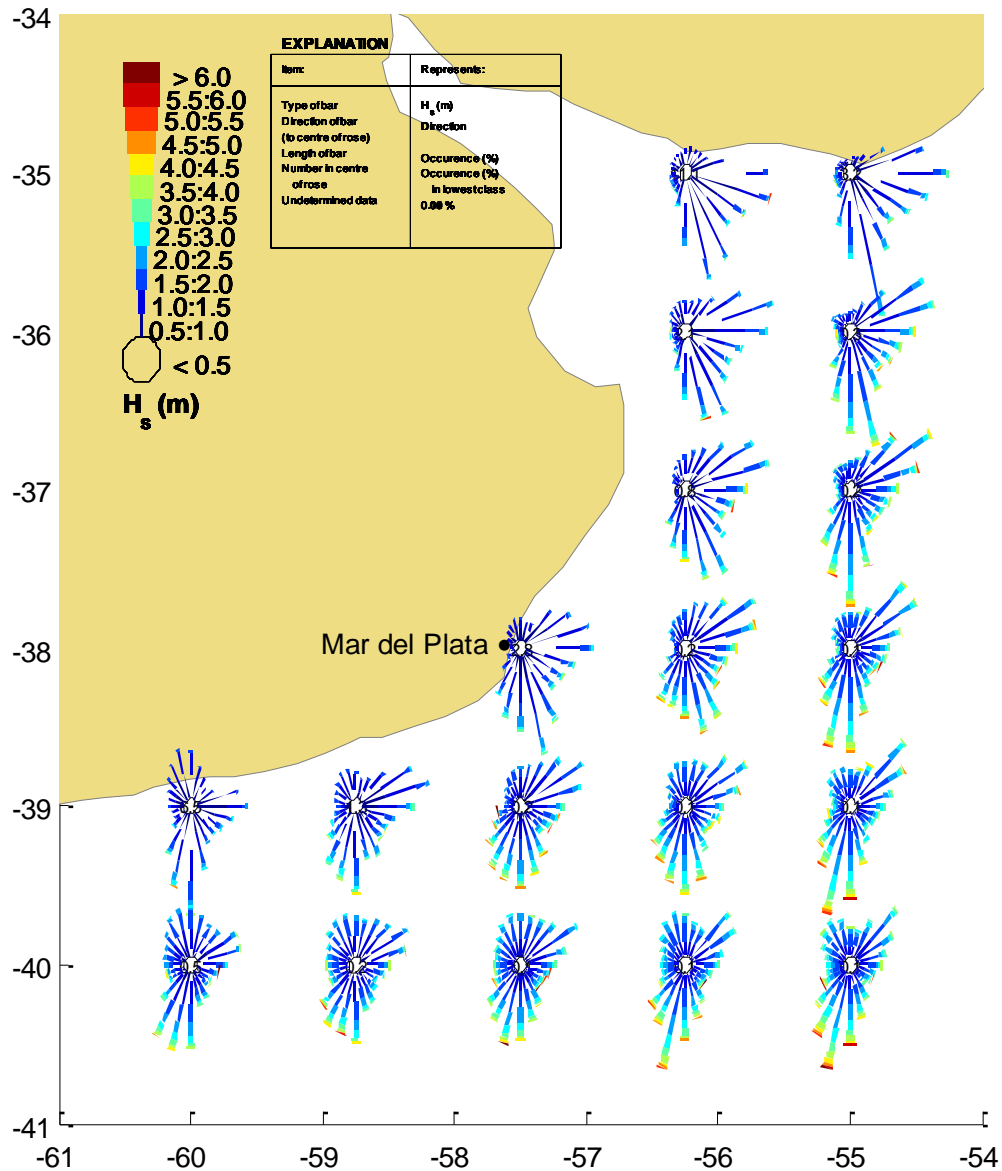


Figure 29 Significant wave heights roses (1997-2010)<sup>31</sup>

Figure 30 Significant wave periods roses (1997-2010) shows the wave periods for the same wave data set, it can be detected that the larger wave periods are only observed from South to Northeast, and smaller wave periods are more dominant in the West segment of the wave roses. This can be explained by the fact that wind waves generated near shore are short and steep and thus represented most of the waves coming from the West, while the wave periods of waves coming from the Northeast to South segments are a combination of longer swell waves with some wind generated waves.

It can also be deduced by looking at the wave period roses that the most frequent periods are in the range of 5 to 7 seconds.

<sup>31</sup> (National Weather Service (NWS), National Oceanic and Atmospheric Administration, 2012)

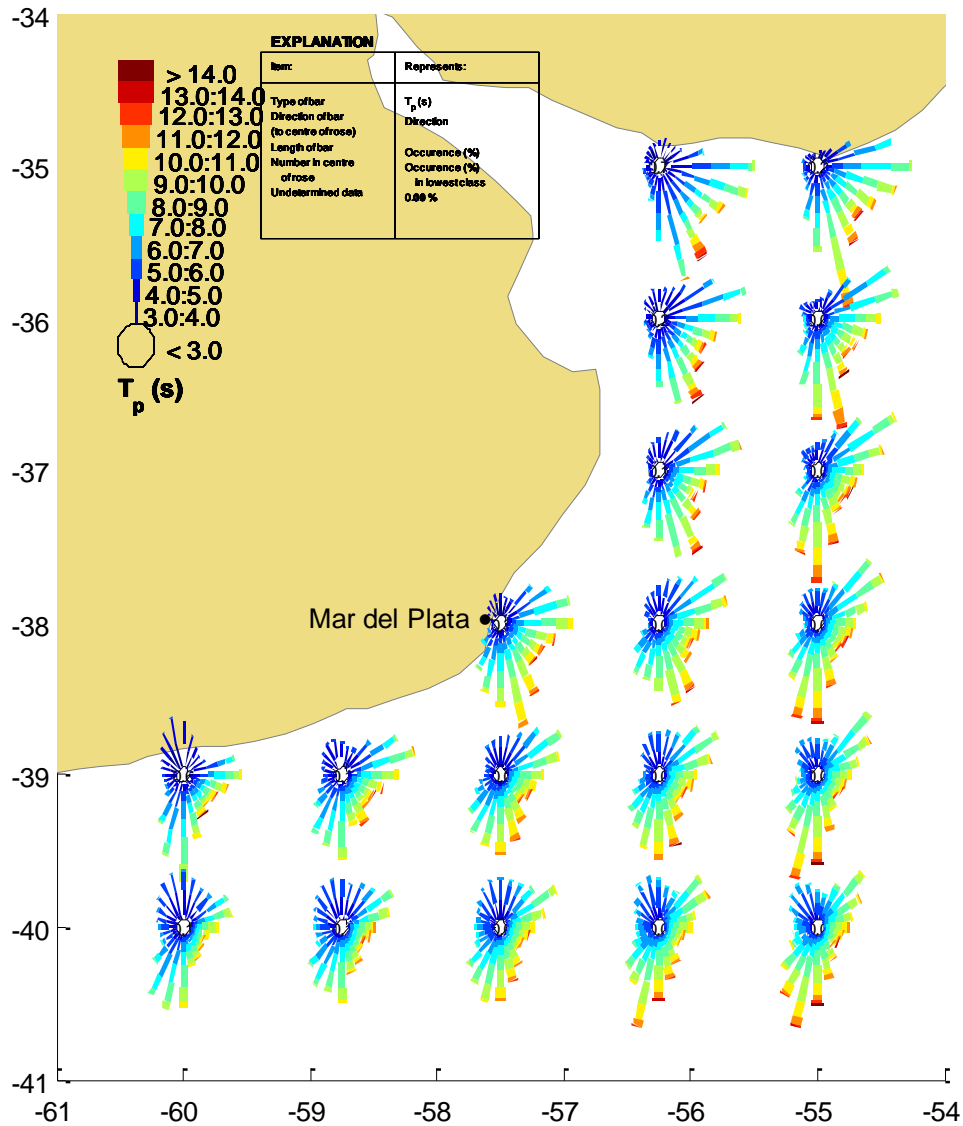


Figure 30 Significant wave periods roses (1997-2010)<sup>32</sup>

### 4.3. Coastal dynamics

#### *Sediment*

The major type of continental sediments around the world is sand, previously formed from weathered continental rock, usually granite. Most of the continental sediments do not come from the current rivers, but consist of older Holocene sediments. Classification by Hayes(1967) shows that sediments vary with latitude, for instance mud is most abundant in the tropics, where it is humid and with high temperature, on the other hand gravel is most common in areas where temperatures are low, like the poles. For the area of study the sediment classification would fall in the classification of an intermediate

<sup>32</sup> (National Weather Service (NWS), National Oceanic and Atmospheric Administration, 2012)

zone with moderate temperatures and rainfall, normally located in the mid-latitudes (between 20° and 40°) where sand is the most abundant source. (Bosboom J., Stive, M.J.F., 2011)

The presence or absence of large rivers also determines the availability of sediments in a coastal area, a general classification by (Davies, J.L., 1980) shows that the discharge of rivers is maximum around 40° North and 40° South. Also important to say that the type of weathering determines whether the coast receives sand or mud.

The coarser the sediment the steeper the slope in the coast will become. For instance muddy environments are normally quite flat, and rocky environments form cliffs or abrupt slopes. Even different grain sizes of sands can modify the slope of beaches.

A wide variety of conclusions and opinions related to sediment dynamics of the Buenos Aires province were analysed, summaries of the most relevant information are explained in the following part of this section.

#### *Coastal erosion/accretion*

A study by Federico I. Isla and German R. Bertola shows a summary of the coastal characteristics of the Buenos Aires province, they divided the coast in three sections, the section called “Barrera Médanosa Oriental” covers from Villa Gesell to Punta Rasa; some of the locations under review are within this range, that they catalogued as a coast with punctual erosive spots. They deduced that the most critical erosion sites are in the most developed areas, implying that the human activities (urbanization, sand mining, and tourism) are the main factor for erosion. (Isla, F.I., Bertola, G.R., 2005).

Different authors have analysed the coast of Buenos Aires province, a summary table of the coastline position change is shown below.

**Table 10 Summary of coastal position<sup>33</sup>**

Location	Erosion (-) Accretion (+) (m/year)	Reference
Villa Gesell	-7 to +4	Isla et al (1998)
Pinamar	-1.1 to +4.4	Schnack, E.J., O'Neil (2002)
San Bernardo	-2.1 to +0.7	Schnack, E.J., O'Neil (2002)
Santa Teresita	-2.3 to +0.9	Schnack, E.J., O'Neil (2002)
San Clemente del Tuyu	-7.7 to +12	Schnack, E.J., O'Neil (2002)

<sup>33</sup>Source: (Isla, F.I., Bertola, G.R., 2005)

Ranges of erosion and accretion shown in Table 10 Summary of coastal position, vary significantly, especially for the coast of San Clemente del Tuyú, where the Erosion/Accretion range goes from -7.7 to +12 metres per year. For the other locations the range is not as large, and it can be seen that erosion and accretion happens in all the locations along the coasts, perhaps the erosion rates were measured during storm season, and the accretion during calm season. (It was not indicated in the study)

German R. Bertola studied the morphodynamics of the beaches in the southeast of the Buenos Aires province, he gathered data from 1983 to 2004 in order to compare and analyse the coast. First he classified the coast with respect to its morphology in two different types, sandy beaches with dunes and pocket beaches. The coast from Villa Gesell and Pinamar fall in the sandy beach with dunes category. He observed that the sand barriers located near the coast modify the incoming wave angle; consequently the waves converge and induce a greater impact in certain spots. In the other hand he classified the coast from Mar Chiquita to Miramar as an erosive coast with pocket beaches.

During the period of measurements (from 1983 to 2004) he detected an average beach width of 72m. During this same period Pinamar recorded accretion of 27,580m<sup>3</sup>, Villa Gesell also registered accumulation (18,200m<sup>3</sup>), only in certain spots of the coast near the most urbanized area erosion occurred. Topographic surveys were done every four months to understand the development.

Summary tables shown in the study have the results of the surveys, for eight of the beaches in Villa Gesell and Pinamar, where the grain size ranges from 1.00 Phi<sup>34</sup> to 1.82 Phi, with a corresponding range of slopes between 3.15% and 5.68%. The beach width was around 64 m and 83 m respectively.

Five of the eight measured beaches analysed on his study presented accretion of up to 33,431 m<sup>3</sup>, while the beach with more significant erosion lost 18,045m<sup>3</sup>. These volumes were obtained from the difference in profile width and elevation, and therefore include all the factors affecting the beach (sand mining, eolian transport, etc.), not only the wave/current induced transport.

As some of the previously mentioned authors, this study concludes that in the touristic beaches erosion is induced by unplanned coastal developments, also that the beaches

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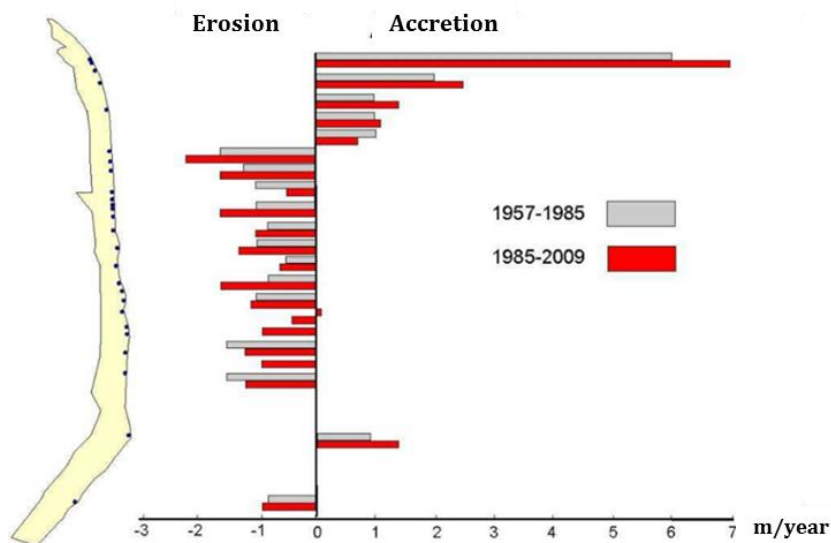
<sup>34</sup>  $\phi$  is a unit to measure grain size equal to  $\phi = -\log_2\left(\frac{D}{1mm}\right)$ , sand is in the range of  $-1\phi$  and  $4\phi$ . Further information can be found at: (Harris, C.K., 2003)

under erosion have slopes greater than 4%, while the beaches receiving more sand, have milder slopes. (Bertola, G.R., 2006)

A report by “UCO-Ministerio de Economía, provincia de Buenos Aires” was published in the website of Coastal erosion of the province of Buenos Aires in September 2011. The report intends to design a strategy to avoid coastal erosion in the province. To achieve so, a comparison of aero and satellite images from 1950-1987 and 2004-2009 was completed in order to estimate coastline position change (retreat/advance).

In general the authors state that the erosion problems occur due to natural and human induced factors, it is stated that for instance storms from south-east produce the larger damages to the coast. The coast from San Clemente del Tuyú to Mar Chiquita is categorized as a sandy soft coast, with accelerated erosion spots induced by city development too close to the coast, drainage systems with outfalls on the beach were also considered as an important factor enhancing erosion.

Figure 31 and Figure 32 show the erosion/accumulation rates for the coast from Punta Rasa to Villa Gesell, grey colour corresponds to images from 1957 to 1985 while red corresponds to images from 1985 to 2009.



**Figure 31 Erosion/Accumulation rates for "La Costa", based on aero images**

It can be observed in Figure 31 that erosion is dominant for the coastal stretch under review. For instance for “La Costa” the only locations that show mainly accumulation since the 1950’s are San Clemente (up to 7m/year average) and Punta Médanos (around 1.5m/year), in the contrary Santa Teresita/Mar del Tuyú present the higher erosion rates, with averages around 1.6m/year of coastal retreat.

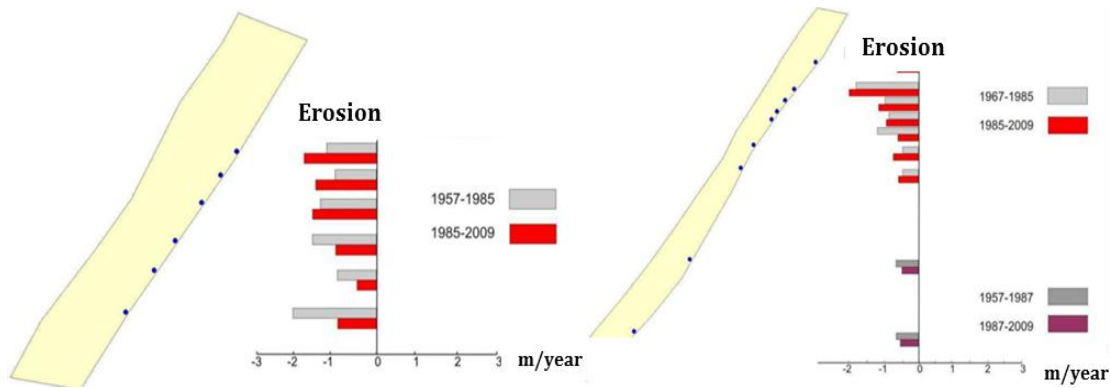


Figure 32 Erosion/Accretion rates for Pinamar and Villa Gesell<sup>35</sup>

Figure 32 Erosion/Accretion rates for Pinamar and Villa Gesell, shows the erosion rates for the cities of Pinamar and Villa Gesell. For Pinamar it can be observed that erosion rates range around 0.5 to 1.7m/year. Villa Gesell presented erosion rates varying from 0.5 to 2m/year. (UCO-Ministerio de Economia, Provincia de Buenos Aires, 2011)

A study undertaken by Luis Cortizo published in 2011 on the website of coastal erosion and management of the Buenos Aires coast (Erosion Costera Provincia Buenos Aires, 2012), shows a map of the erosion rates by location in the province of Buenos Aires. A summary table of the present situation of each of the locations is added in Figure 33 Erosion rates by location, together with the map showing the Buenos Aires province erosion ranges.

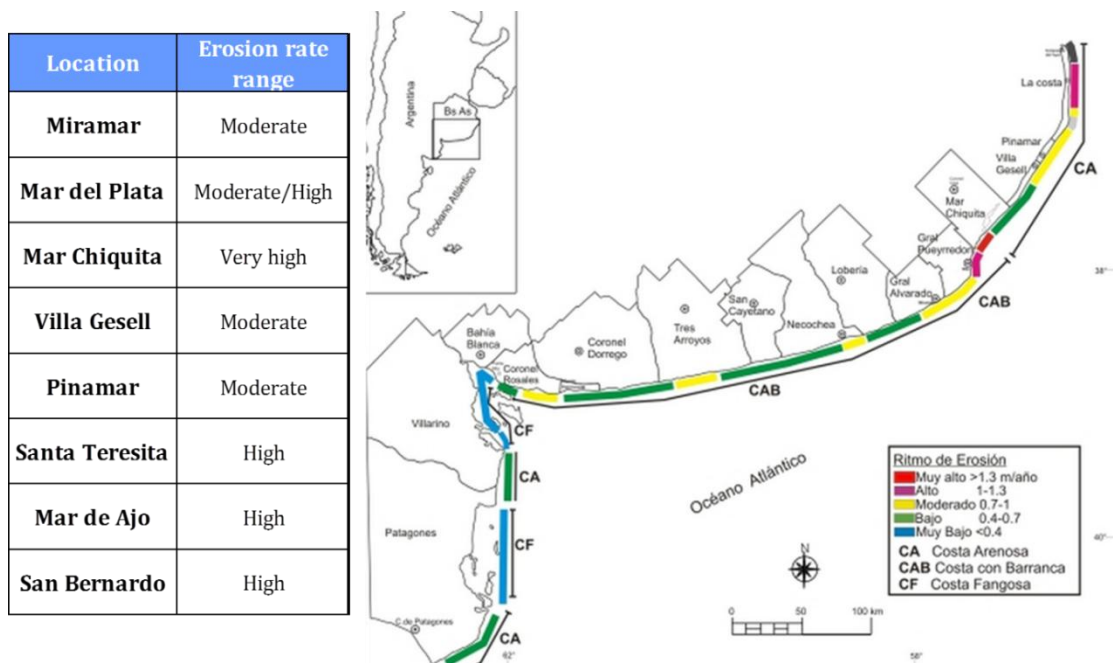


Figure 33 Erosion rates by location<sup>36</sup>

<sup>35</sup> Figure 31 and Figure 32 were obtained from (UCO-Ministerio de Economia, Provincia de Buenos Aires, 2011)

Red colour in the map shows locations with very high erosion rates (1.3m/year or more), Purple shows the range between 1 and 1.3 m/year (high), Yellow means 0.7 to 1 m/year erosion (moderate), Green 0.4 to 0.7 m/year (low), and finally Blue shows coasts with less than 0.4m/year erosion or accretion (very low).

The coast was also classified as sandy, muddy, or with cliffs. For the area of interest in the present study it can be seen that the coast is formed by sand (marked with CA in the map “Costa Arenosa”) from San Clemente to Mar Chiquita, in the other hand Mar del Plata and Mirama fall in the coastal cliff classification (marked with CAB in the map “Costa con Barranca”).

A related study by Silvia C. Marcomini and Ruben Lopez, presents a map of the coast of the province of Buenos Aires being classified by the type of dunes and the coastline retreat. Villa Gesell as well as the coast from municipality of “La Costa” are taken into account in the study, it is explained in detail that mining in the area used to have a major impact, and induced a lot of the erosion in the past decades.

The classification for dunes depended on the development of the dune (height, width). The ‘A’ type dune represents dunes with a height of 2 metres with a beach width around 40 m to 70 m, with constant slopes. Type ‘B’ dune is described as a set of dunes with larger grain size and steeper slopes, with berms, and a varying beach width of 80m to 150m.

The results show a coastal retreat of 2 to 3 m per year in Villa Gesell and Pinamar, while for the locations in the municipality of “La Costa” the retreat is calculated to be of less than 1 metre. The dune field in “La Costa” covering the cities of Mar de Ajó, Santa Teresita, San Bernardo and San Clemente del Tuyú, was classified as type ‘A’ dune, in the other hand Villa Gesell and Pinamar were perceived as type ‘B’ dunes.

The authors blame the government and the managing authorities for the lack of planning of the coastal developments, as well as the authorized permits to extract sand from the area for construction purposes, and consequently the erosion problems in the coast. (Marcomini, S.C., Lopez R., 2006)

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<sup>36</sup> Summary table based on the results shown in the map published by: (Erosion Costera Provincia Buenos Aires, 2012) under the link of <http://erosioncoasterapba.com.ar/mapa-de-ritmos-de-erosion.html>

### Longshore transport rates

Values for long-shore sediment transport calculated by (Scalise, A.H., Schnack, E.J., 2007) show total transport rates with an average of 526,000m<sup>3</sup>/year between Punta Rasa and Punta Médanos (stretch of coast covering Santa Teresita, Mar de Ajó, Punta Rasa and San Clemente del Tuyú), with a net long-shore transport towards the North in the range of 90,000m<sup>3</sup>/year and 150,000m<sup>3</sup>/year. Table 11 Annual long-shore transport rates in m<sup>3</sup>/year shows a summary of the long-shore transport rates calculated for some specific locations in the coast of Buenos Aires. The transport rates were based on wave data from 1995 to 2000 recorded with accelerometers, combined with visual observations, and adding an assumed tidal current of 0.3 m/s.

**Table 11 Annual long-shore transport rates in m<sup>3</sup>/year<sup>37</sup>**

Location	Net transport towards the North	Total transport	Net transport including tidal currents towards the North	Total transport including tidal currents
Villa Gesell	-18,760	112,100	85,070	149,400
Pinamar	22,390	123,200	562,900	564,200
Mar de Ajo	101,300	741,100	548,300	940,700
Santa Teresita	153,000	847,300	370,000	926,600

The transport rates vary a lot, with and without the tidal current, Villa Gesell and Pinamar show similar results, same happens between Mar de Ajó and Santa Teresita, perhaps the orientation of the coast could explain these similarities. In one hand Villa Gesell and Pinamar are oriented NE-SW and the later mentioned have orientation N-S consequently the North directed transport rates are increased as well as the total rates. As pointed out by (Scalise, A.H., Schnack, E.J., 2007) it is important to notice that transport rates are much greater when the orientation of the coast changes to N-S. During the field visit currents were measured at the port of Mar del Plata during different tidal conditions, the maximum speed was in the order of 0.1 m/s, based on this it can be detected that the assumption of 0.3 m/s of the authors overestimated the tidal current transport capacity.

<sup>37</sup> Source: (Scalise, A.H., Schnack, E.J., 2007), Negative sign means transport towards the south.

## 4.4. Sediment samples

### *Samples*

During the measuring campaign in Argentina (April 2012), sediment samples were extracted from different locations along the coast, including: San Clemente, Punta Rasa, Mar del Tuyu, Pinamar, Villa Gesell, Mar Chiquita, Mar del Plata, Los Acantilados and Miramar. A small Van Veer grab with a rope was used to extract the sediment samples in the port area, while for the other locations a simple sampling bucket was used.

Sediment samples were extracted to have input information for the coastline modelling that was completed in the study, and that is explained in further detail in chapter 6.

### *Sediment analysis*

Samples were measured in the Laboratory of Geoscience & Engineering of Delft University of Technology. The procedure to obtain the sediment size distribution was completed in two phases: First all the samples were placed on separate containers on the oven at a constant temperature of 100°C, and were left for drying for 36 hours, since the sieving method (method used for sediment analysis), is easier if the sediment is fully dry. Wet or humid sediment tends to stick to the sieves, and therefore lead to errors in grain size distribution.

The second phase of the measuring process consisted on sieving the material through the different sieves. The selected sieving standard was the EN 933-1(European), using the 0.50mm, 0.425mm, 0.250mm, 0.150mm, 0.105mm, 0.075mm and the 0.063mm mesh sizes.

Each sieve was weighted empty, then placed in the correct order from largest spacing (top) to smallest spacing (bottom), also including a closed plate at the lower end to capture all the fine sediment that was not hold by the 0.063mm mesh. Each sample was placed on the top sieve of the tower, making sure all the sediment was fully dry and that the particles were not sticking together. Each sieving tower was placed on the vibration machine for at least 5 minutes depending on the weight of each sample.

After sieving the sediment sample by using the vibration machine, each mesh was weighted with the corresponding amount of sediment, with this weight the real amount of sediment was then calculated by subtracting the loaded and empty weight of each mesh. The following table shows the main properties of each sample.

**Table 12 Sediment samples properties**

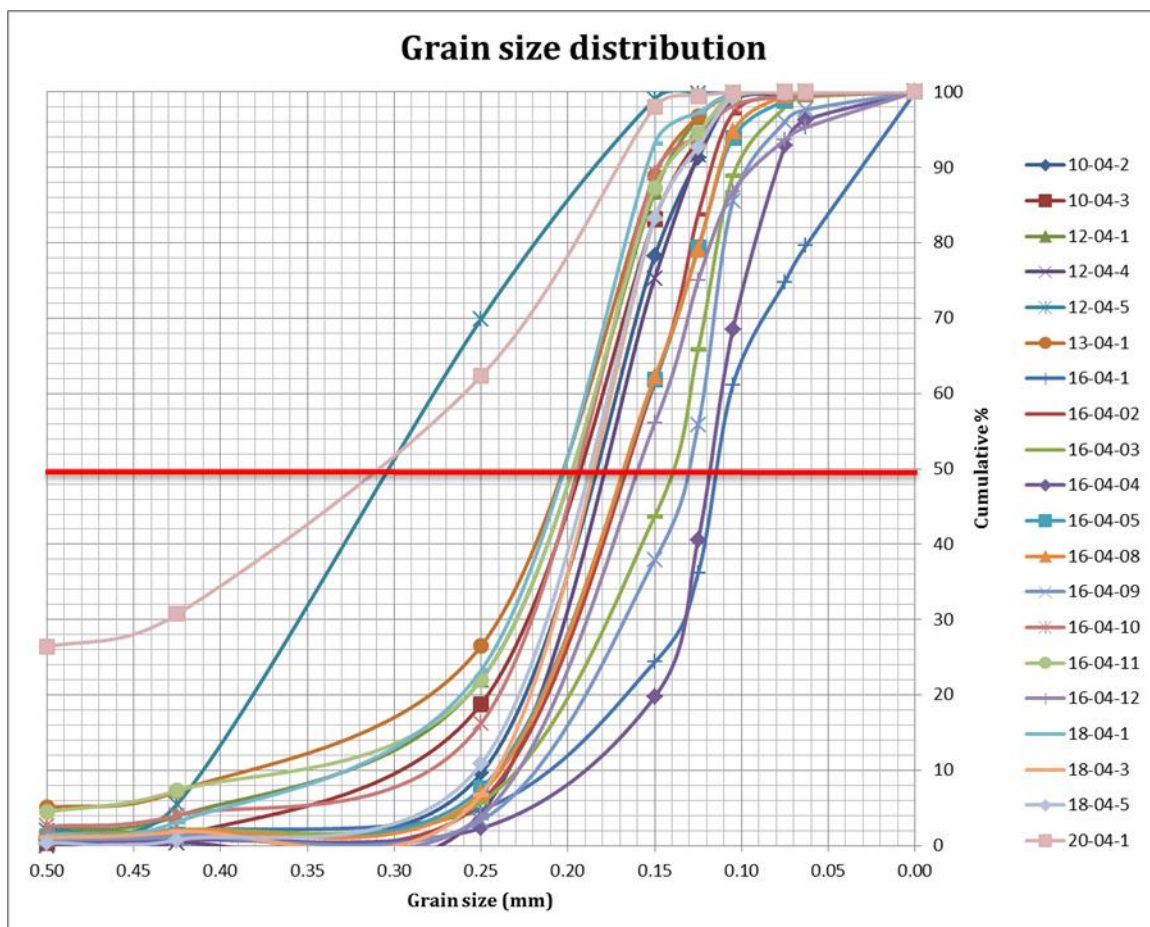
Location	Sample #	Coordinates	On-site description	D10	D50	D90
Punta Rasa	10-04-2	36.2940°S 56.7736°W	Sand	0.127	<b>0.191</b>	0.249
San Clemente bay	10-04-1	36.3412°S 56.7470°W	Muddy material	-	-	-
Mar del Tuyu	10-04-3	36.5691°S 56.6869°W	Sand	0.134	<b>0.202</b>	0.337
Pinamar	13-04-1	37.0918°S 56.8326°W	Coarse sand with shells	0.147	<b>0.212</b>	0.400
Villa Gesell	20-04-1	37.2802°S 56.9820°W	Coarse sand with shells	0.172	<b>0.318</b>	> 0.5**
Mar Chiquita Lagoon	12-04-2	37.7420°S 57.4157°W	Sand	-	-	-
Mar Chiquita coast	12-04-1	37.7429°S 57.4149°W	Sand	0.142	<b>0.207</b>	0.366
Mar del Plata A	18-04-1	38.0513°S 57.5328°W	Coarse Sand	0.155	<b>0.212</b>	0.365
Mar del Plata B	18-04-3	38.0284°S 57.5306°W	Sand	0.132	<b>0.193</b>	0.246
Mar del Plata C	18-04-5	38.0150°S 57.5295°W	Sand	0.132	<b>0.196</b>	0.264
Mar del Plata Port A	16-04-1	38.0344°S 57.5133°W	Polluted sand / Sand	0.031	<b>0.114</b>	0.223
Mar del Plata Port B	16-04-2	38.0360°S 57.5190°W	Sand	0.116	<b>0.171</b>	0.243
Mar del Plata Port C	16-04-3	38.0522°S 57.5290°W	Sand	0.101	<b>0.143</b>	0.239
Mar del Plata Port D	16-04-4	38.0596°S 57.5314°W	Sand	0.079	<b>0.118</b>	0.206
Mar del Plata Port E	16-04-5	38.0601°S 57.5336°W	Sand	0.110	<b>0.172</b>	0.246
Mar del Plata Port F	16-04-8	38.0398°S 57.5170°W	Sand	0.111	<b>0.172</b>	0.244
Mar del Plata Port G	16-04-9	38.0383°S 57.5131°W	Sand	0.092	<b>0.133</b>	0.231
Mar del Plata Port H	16-04-10	38.0366°S 57.5220°W	Sand	0.146	<b>0.204</b>	0.339
Mar del Plata Port I	16-04-11	38.0376°S 57.5189°W	Sand	0.141	<b>0.207</b>	0.393
Mar del Plata Port J	16-04-12	38.0342°S 57.5245°W	Sand	0.091	<b>0.162</b>	0.238
Los Acantilados cliff	12-04-3	38.1164°S 57.5896°W	Muddy material	-	-	-
Los Acantilados beach	12-04-4	38.1189°S 57.5926°W	Nourished sand	0.128	<b>0.186</b>	0.242
Miramar beach	12-04-5	38.2651°S 57.8158°W	Coarse sand	0.181	<b>0.304</b>	0.413
Miramar cliff	12-04-7	38.2594°S 57.8050°W	Muddy material	-	-	-
Miramar dune	12-04-6	38.2649°S 57.8159°W	Sand	-	-	-

Sample numbers on the sediment properties table correspond to the day when the sample was extracted, all the samples that were brought back from Argentina were measured at the TU Delft lab, while the samples that were left in Argentina with client are still pending to be analysed. The D<sub>10</sub>, D<sub>50</sub> and D<sub>90</sub> were used for the longshore

transport modelling later in the study as input for the Van Rijn (2004) sediment transport formulation.

Most samples were extracted from the beach of the corresponding locations, only the samples of the port of Mar el Plata were extracted at different depths, ranging from 5 to 13 metres water depth.

In Figure 34 it can be seen that most sediment samples have a  $D_{50}$  within the range of 0.150mm and 0.225mm, only a few of the locations like Villa Gesell are outside of this range (beaches with coarser sand).



**Figure 34 Gran size distribution**

Based on the study by (Scalise, A.H., Schnack, E.J., 2007), the sand particles are mainly composed by quartz, which in fact is the most common sand.

## 5. Delft3D-WAVE modelling

### 5.1. Delft3D-WAVE model

The SWAN model is a fully-spectral 2-dimensional wave propagation and generation program that was developed by Delft University of Technology as the successor of the HISWA wave model. Deltares has integrated the SWAN model with its Delft3D program suite where it is called Delft3D-WAVE. (Deltares, 2012)

Delft3D-WAVE is a third generation shallow water wave model, which is based on the discrete spectral action balance equation. The model is fully spectral and solves for the total range of wave frequencies and wave directions, which implies that short-crested random wave fields propagating simultaneously from widely different direction can be accommodated. The wave propagation is based on linear wave theory, including the effect of currents. The processes of wind generation, dissipation and non-linear wave-wave interactions are represented explicitly with state-of-the-art third generation formulations. The model includes all relevant physical processes of wave propagation, generation and dissipation, such as:

- Refraction due to variation in depth and currents.
- Shoaling.
- Wave growth due to wind.
- Wave dissipation due to white-capping.
- Dissipation due to surf-breaking.
- Dissipation due to bottom friction.
- Wave-blocking due to an opposing current.
- Non-linear wave-wave interaction in deep water.
- Non-linear wave-wave interaction in shallow water.
- Transmission and reflection of wave energy at obstacles.

Diffraction is not modelled explicitly by Delft3D-WAVE, but the effects of directional spreading and growth of waves due to wind dominate diffraction effects in many cases. A more complete description of SWAN wave model can be found in (Booij, N., Ris, R.C., Holthuijsen, L.H., 1999)

## 5.2. Modelling strategy

As measured near-shore wave data is missing, the Delft3D-WAVE model was used to compute the near-shore wave data based on the available offshore wave climate data.

In order to simulate wave conditions in the area of interest from the Bay of Samborombón to Miramar a Delft3D-WAVE model is set up. Bathymetry data was obtained from the Argentine nautical charts, more specifically from chart H-210, H-115, H-114 and H-113 (Servicio de Hidrografia Naval, 2012), and from the General Bathymetric Chart of the Oceans data base (GEBCO, 2008). Afterwards the data was combined to generate the model bathymetry. The wave and wind conditions obtained from the NOAA Wave watch III database, described in the previous section, are used for boundary conditions forcing for the Delft3D-WAVE model.

The boundary for Delft3D-WAVE model was placed at a sufficient distance from the coast to ensure that boundary condition errors do not directly affect the area of interest. In order to meet this condition and achieve a high level of accuracy for the coast under analysis (from the Bay of Samborombón to Miramar), a series of two nested model grids is set up. In this series of grids, the largest grid is forced using the offshore Wave Watch III NOAA wave data. Different wave scenarios to run the model were derived by using ORCA, which is a software/package/tool to analyse metocean data, and are explained in further detail in the following sections.

The results of the wave propagation on the largest grid are used to determine accurate wave boundary conditions on a smaller grid. The smaller grid is used to propagate wave boundary conditions towards the coast in order to obtain wave data near shore, where it was used as input for UNIBEST CL+ coastline model.

All the data used as model input was converted to 'Cartesian Coordinates', by using the Delft Dashboard system. The corresponding zone for the area of study is WGS 84 / UTM21S zone.

## 5.3. Delft3D-WAVE model input

### *Model grids*

The Delft3D-WAVE model requires a spatial grid on which to calculate the wave propagation. In this study a series of two nested wave grids is set up in order to obtain sufficient accuracy in the area of interest, as described previously.

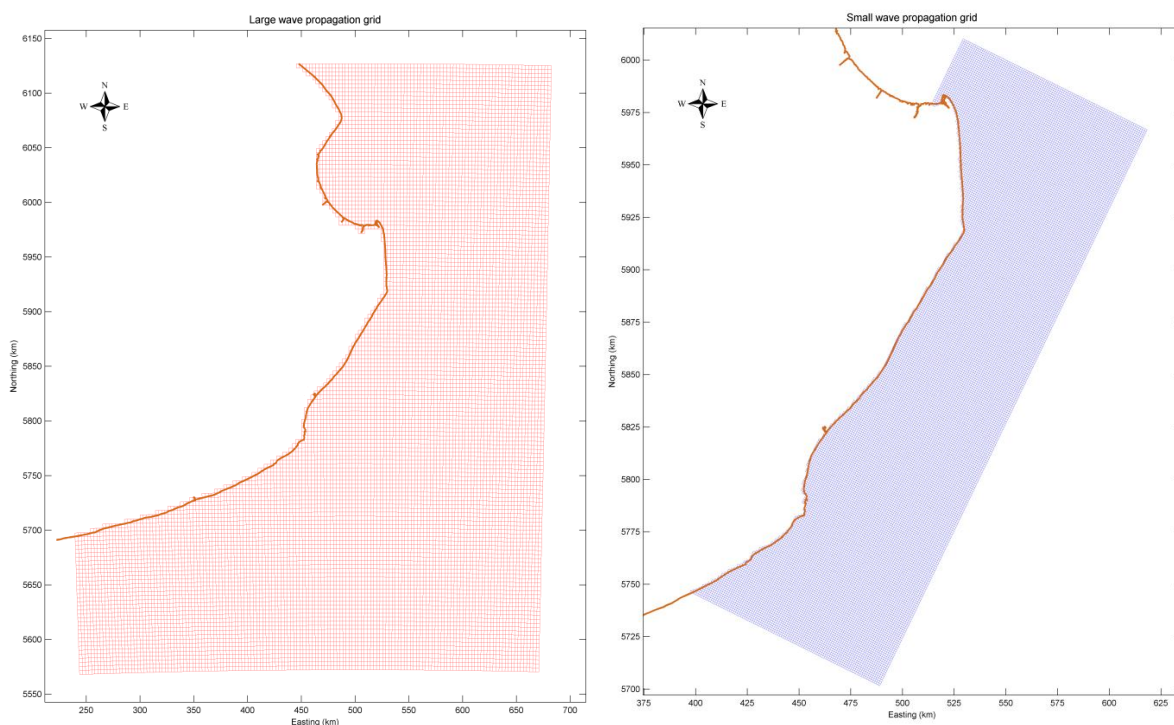
The large wave grid is rectangular shaped and ranges from  $-40^{\circ}\text{S}$  to  $-35^{\circ}\text{S}$  in the vertical, and from  $-60^{\circ}\text{W}$  to  $-55^{\circ}\text{W}$  in the horizontal, covering from the north of the Samborombón bay until around 200km south of Mar del Plata, as shown in the left side of Figure 35 Buenos Aires wave grids. The corner points of the grid coincide with the outer wave and wind data points. The grid is formed by 13,612 grid cells, with constant size of 3000 (x-axis) by 3700 metres (y-axis) in deep and shallow water.

The smaller grid covers the area from the Bay of San Clemente to Miramar (as shown in the right side of Figure 35, it is a rectangular grid with a rotation from the base point (lower left corner) of  $25^{\circ}$  degrees with respect to the north in order to cover the coastal area under analysis in a precise way. The grid contains 22,834 cells of equal size ( 1,000 by 1,000 metres). Propagated wave data is used later in the study as input for the UNIBEST CL+ numerical model of coastline change.

A summary of the properties of the wave grids is given in Table 13 Wave propagation grid properties, to illustrate the difference between each of the grids.

**Table 13 Wave propagation grid properties**

Grid	Total number of cells	Cells in x	Cells in y	dx (metres)	dy (metres)	Grid rotation
Large	13,612	151	151	3,000	3,700	$0^{\circ}$
Small	22,834	103	296	1,000	1,000	$25^{\circ}$



**Figure 35 Buenos Aires wave grids**

## *Model bathymetry*

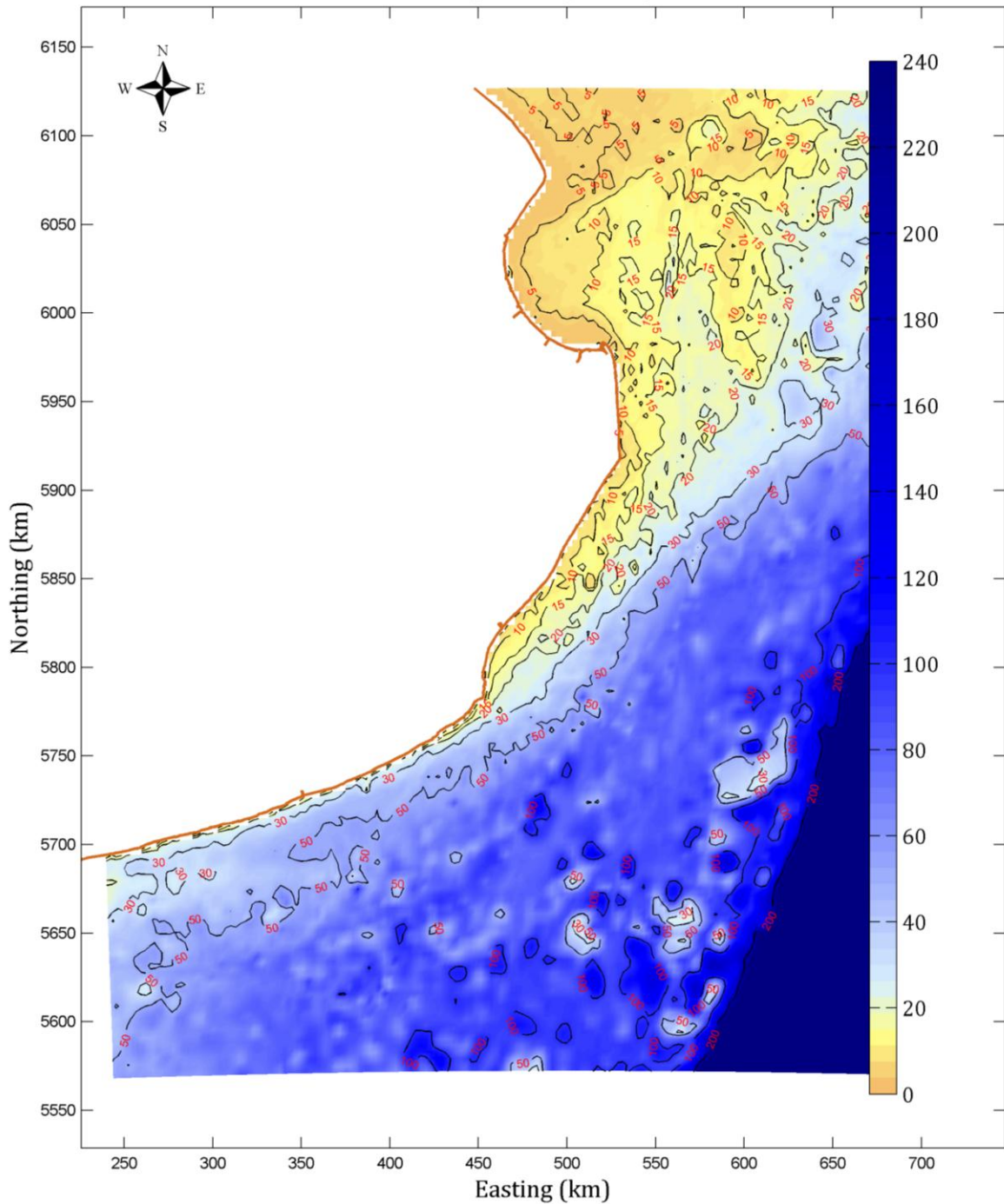
Good bathymetric data is needed for the Delft3D-WAVE model to accurately simulate wave propagation and transformation towards the area of interest. In this study, bathymetric data of the Buenos Aires province was obtained from (GEBCO, 2008) with the Delft-Dashboard system. Since the resolution of the GEBCO data is quite coarse for the wave propagation study, data from Argentine nautical charts was used as a supplement in order to obtain a more detailed bathymetry.

Nautical chart H-113, H-114, H-115 and H-210 (Servicio de Hidrografia Naval, 2012) were used as supplement to the (GEBCO, 2008) bathymetric data. In order to combine the data from both sources, the nautical charts had to be digitalized; each contour line of the map was saved as an '.xyz' file, and then calibrated with the same reference point to enhance precision, the tool used to digitalize the nautical charts was Oziexplorer, supplemented by a MATLAB script to create the bathymetry file. After all the depths were calibrated a file with all the nautical chart points was loaded into Delft3D-QUICK IN suite, to edit and combine with the GEBCO data. The methods used to interpolate the depth points were triangular interpolation, and grid cell averaging. The sand ridges located from Punta Rasa to Villa Gesell were the most complex part of the bathymetry; therefore these sections were interpolated separately by using polygons to limit the triangular interpolation area. After these sections were completed, the bathymetry was created for each grid by combining both "Nautical Chart" and "GEBCO" information. Although it is important to mention that the only existing nautical charts for the coast of Argentina are from 1994, 1997 and 2003, and the resolution of them is relatively coarse, but for this coast it is still the most detailed bathymetry.

The bathymetries for the two wave model grids are shown in Figure 36 Buenos Aires bathymetry, and Figure 37 Detailed bathymetry. All model bathymetry data is relative to the mean sea level, which in fact is 0.91 metres higher than the lowest astronomical level used in the nautical charts that were converted to include in the bathymetry generated for this study.

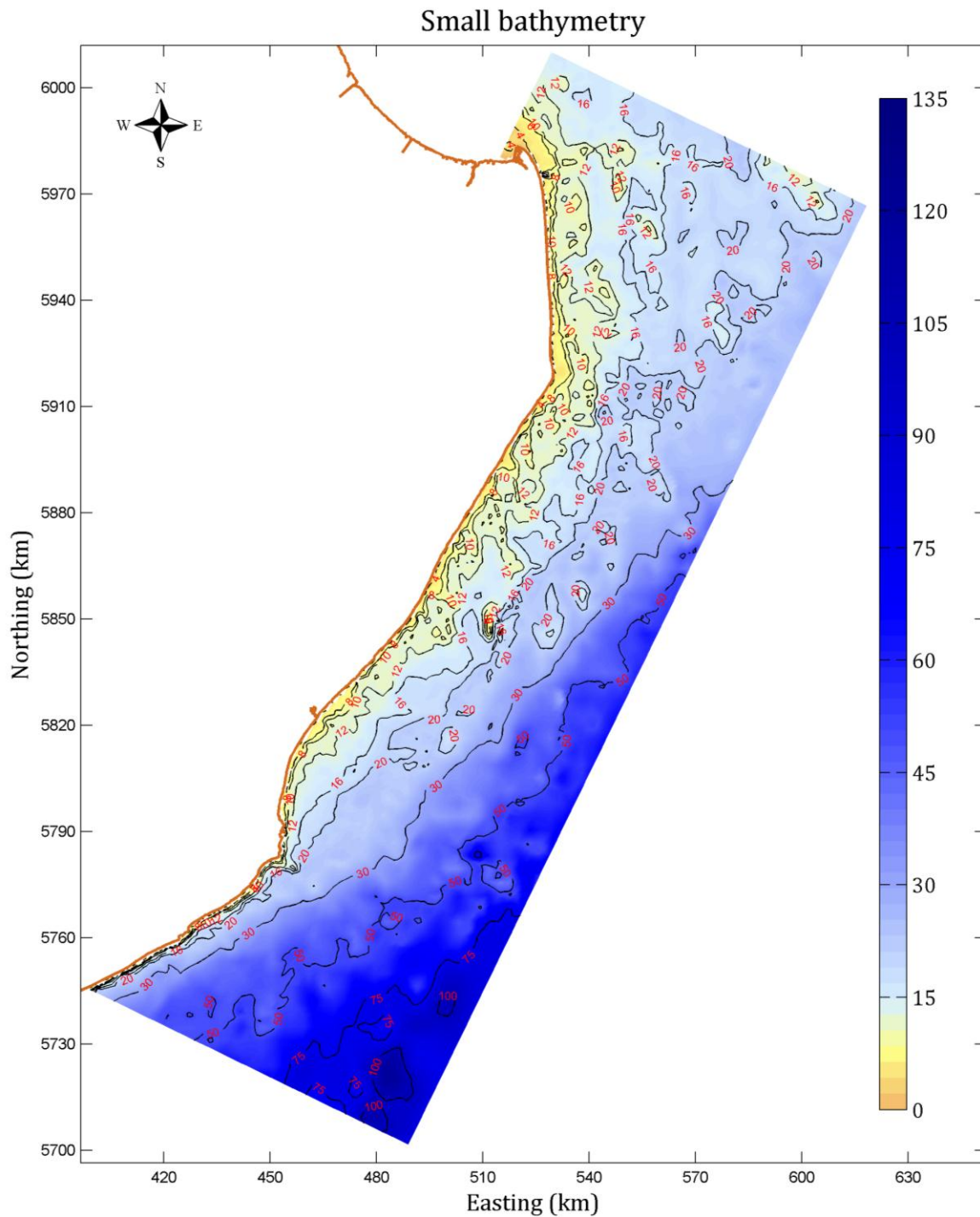
Figure 36 shows the bathymetry covering the entire Buenos Aires province, extending until depths of more than 240 meters. It is easy to notice that the area in the mouth of the Rio de la Plata has very shallow waters in comparison to the areas in the south as Miramar and Mar del Plata.

Large bathymetry



**Figure 36 Buenos Aires bathymetry**

In the following figure that shows the detailed bathymetry for the area of study, the difference in water depths can be observed. As mentioned before the north section has much shallower waters and in the area of Pinamar and Villa Gesell the large sand ridges can be seen. Important to notice that the scale of the bathymetries is different, in the case of the detailed bathymetry the largest water depths go up to 135 metres.



**Figure 37 Detailed bathymetry**

### *Waves and wind*

Offshore wave and wind data used as input for Delft3D-WAVE comes from the NOAA Wave Watch III model, this information provides data for the entire world, and it is proven to be accurate enough for large scale wave propagation modelling. In this study 19 points with data are used, and 12 of those points are defined as boundary data points to generate the spatial varying wave conditions. The spatial varying conditions were

necessary for this project because the extent of coast under analysis is very large; consequently using the same wave data for the entire coast would be inadequate and would probably lead to uncertain results. For instance in projects where the coast stretch under analysis is less than 80-100 km one wave source could still be used, but for projects like this, where it is more than 500km of coastline under analysis the wave and wind conditions can vary significantly from one location to another as it was shown previously with the wind and wave roses.

To generate the spatial varying wind conditions it was necessary to interpolate between data points, and generate new data points based on the adjacent conditions, also since no wind data is available on land it was necessary to extrapolate the wind conditions to the adjacent area in land.

#### **5.4. Wave scenarios**

In order to accurately determine the local wave climate at the Buenos Aires province, the Delft3D-WAVE model needs to be forced using realistic and accurate wind and wave boundary conditions. To achieve accurate results, the wind and wave conditions were analysed by using ORCA, which is a tool to arrange, combine and create wave and wind scenarios, based on: significant wave height, peak wave period, peak wave direction, wind magnitude and wind direction.

The classes for wave conditions were divided as shown in Table 14 ORCA classes to create scenarios, taking into account the significant wave height and the peak wave direction. With reference to those values the corresponding peak wave periods, wind magnitudes and directions were derived to create the different scenarios to reproduce the wave propagation along the coast of the Buenos Aires province.

As it can be seen in Table 14, the significant wave height variation has 8 different ranges. Since most of the conditions fall between 1 and 3.5 metres of wave height the variation of this range is every 0.5 metres. For the rest of the wave conditions different ranges were derived. In the case of the peak wave direction of propagation, all of the bins have a constant range of 22.5°, starting from north, and turning clockwise to cover the 360° of wave propagation directions.

**Table 14 ORCA classes to create scenarios**

Range	Significant wave height limits (m)
1	0 - 1
2	1 - 1.5
3	1.5 - 2
4	2 - 2.5
5	2.5 - 3
6	3 - 3.5
7	3.5 - 4.5
8	4.5 < X

Range	Peak Direction limits (°)
1	348.8 - 11.25
2	11.25 - 33.75
3	33.75 - 56.25
4	56.25 - 78.75
5	78.75 - 101.25
6	101.3 - 123.75
7	123.8 - 146.2
8	146.3 - 168.75
9	168.8 - 191.25
10	191.3 - 213.75
11	213.8 - 236.25
12	236.3 - 258.75
13	258.8 - 281.25
14	281.3 - 303.75
15	303.8 - 326.26
16	326.3 - 348.75

125 scenarios were created covering the conditions of the 13 year long wave data set. Each scenario consists of wind and wave characteristics for all the data points, with the corresponding percentage of occurrence for that situation. After creating the scenarios it was simple to identify that the wave heights and directions could vary significantly from one point to another.

To create the 125 scenarios a reference point had to be selected, this point is located (55° S - 38° W), after defining that starting point the wave and wind conditions for the other data points were assigned with the values of the corresponding conditions at the same time.

As mentioned before 125 wave/wind driven scenarios were created by using ORCA. An example of the output of ORCA is shown in Figure 38 Example of ORCA scenario of the Buenos Aires coast. Wind can be identified by the red colour arrows, while wave corresponds to blue coloured arrows, the length of the arrow represents the magnitude of the wind and the significant wave height, arrows also represented the wind/wave propagation direction (direction to which waves and wind are propagating to). It can also be seen in the following figure that the reference point is located offshore of Mar del Plata, and is highlighted with light green colour.

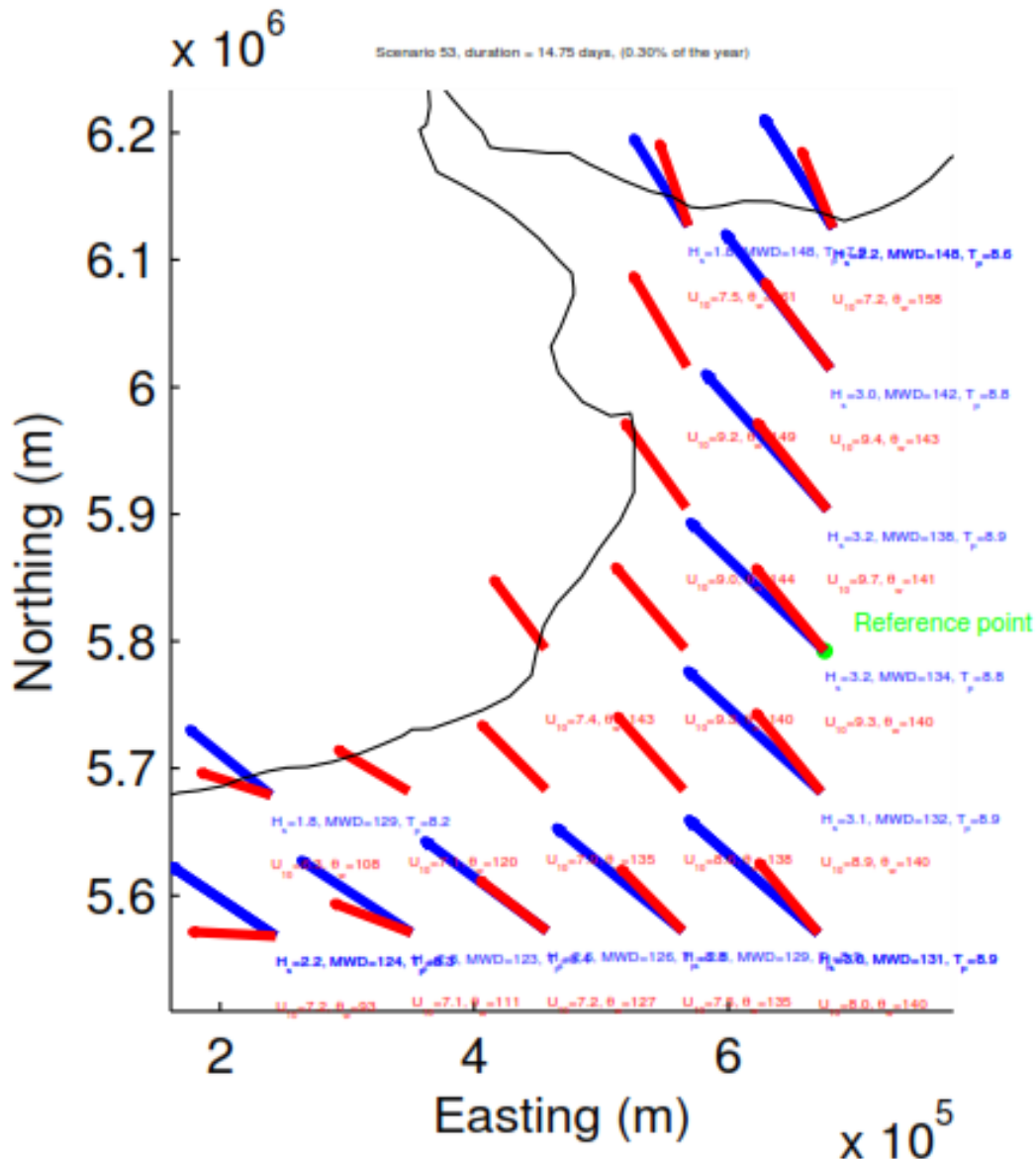


Figure 38 Example of ORCA scenario of the Buenos Aires coast.

The full distribution of conditions in the 125 scenarios is shown in the appendix of this study.

An example of the input file created by ORCA that provides Delft3D-WAVE the necessary information to extract the wave and wind data is shown in Figure 39. The first column represented the distance from the corner point of each boundary, second column is the significant wave height, followed by peak wave period, mean wave direction, and dissipation coefficient. The last columns are related to the wind data, which is overruled by the file that in this case is called 'SWAN0001.wnd' that indeed contains wind magnitude and direction for the entire area of study. Each row corresponds to the data in each wave boundary point, starting from the north, and going around the boundaries clockwise.

```

*Name of offshore SCO file:
VARBOUND *(MORSYS/UNIBEST)
125 *total number of wave conditions
* Distance      Hm0      Tp      theta      ms      H0      U10      theta_w
* (m)           (m)      (s)      (N^o)      (-)      (m)      (m/s)      (N^o)
*              0.00      0.96      4.60      38.24      2.00      0.00      0      0 'SWAN0001.wnd'
114087.49      1.13      5.75      59.26      2.00      0.00      0      0
0.00           1.13      5.75      59.26      2.00      0.00      0      0
110950.38      1.71      5.72      28.51      2.00      0.00      0      0
221918.15      2.02      5.68      9.61       2.00      0.00      0      0
332903.51      2.19      5.86      0.24       2.00      0.00      0      0
443906.62      2.29      6.10      353.91     2.00      0.00      0      0
554927.61      2.45      6.43      345.29     2.00      0.00      0      0
0.00           2.45      6.43      345.29     2.00      0.00      0      0
106718.10     2.33      6.42      353.96     2.00      0.00      0      0
213413.00     2.10      6.19      356.15     2.00      0.00      0      0
320109.37     1.82      5.84      346.80     2.00      0.00      0      0
426831.87     1.63      5.56      336.85     2.00      0.00      0      0
0.00           1.63      5.56      336.85     2.00      0.00      0      0
111071.60     1.01      5.56      336.85     2.00      0.00      0      0

```

Figure 39 md-vvac file

### Delft3D-WAVE runs

Delft3D-WAVE runs were completed with the Delft3D-WAVE version 3.28.04, based on the 'md-vvac' files that were generated with ORCA, which contained wave and wind information as it was explained in further detail in the previous section.

Different coefficients and variables were changed during the process of applying the wave model; each run consisted of changing one variable to see the effect on the wave propagation, variables as bottom friction, depth induced breaking coefficients, and non-linear interaction coefficients. Also different processes were activated and de-activated to understand their effect on the output.

Table 15 Delft3d-WAVE parameters

Diffraction	Wind growth	Whitcapping	Quadruplets	Refraction
De-activated	Activated	Activated	Activated	Activated
Wave set-up	Forces	Depth induced breaking	Non-linear triad interactions	Bottom friction
Activated	Radiation stress	Activated	Activated	Activated
		Alpha: 1	Alpha: 0.1	Type: JONSWAP
		Gamma 0.73	Beta: 2.2	Coefficient: 0.067

## 5.5. Delft3D-WAVE results

The Delft3D-WAVE model results provide wave conditions for every grid cell in the wave grids. The most relevant conditions are the near-shore waves. Wave direction, period, and height are the most relevant parameters; therefore these are shown in the wave output figures in the Appendix for each modelled scenario. The most relevant and dominant conditions are explained in this chapter.

First, the most occurring wave class created with ORCA is shown in Figure 40 Scenario 20 Delft3D. This scenario was forced using an offshore climate with wave heights in the

range of 1 to 1.5m and wave direction between 33.75 and 56.25° with respect to the north. As mentioned previously this scenario has the largest percentage of occurrence out of all the 125 scenarios, occurring 1,610 times throughout the 13 years of available wave data (4.033%).

It can be seen in the figure that the wave heights offshore in the southeast corner are the highest reaching an  $H_s=1.4\text{m}$ , while the section in the north has an offshore boundary with wave heights of around 1m. Wave heights near the coast especially in the north section start to lose their energy far from the coast, and consequently when they reach the coast the wave heights are smaller (0.6m). In the other hand for the coast near Mar del Plata and Miramar, waves approach the coast and lose their energy relatively close to the shore, with wave heights in the range of 0.8 to 1.0m. The corresponding periods for these conditions are very short, approximately 3 to 4 seconds.

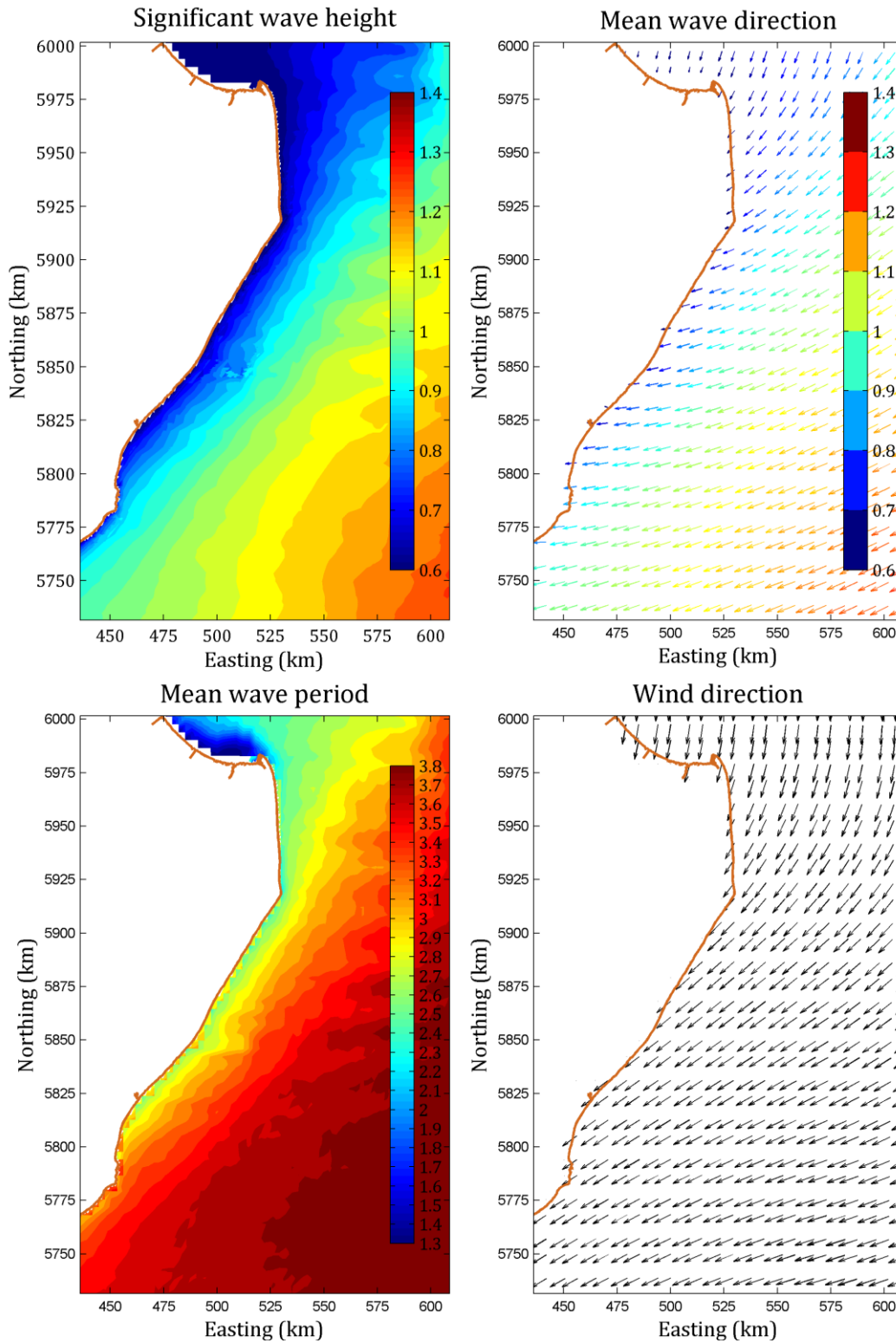
The wind and wave directions are almost aligned in this scenario, it can be seen that the upper section has incoming direction from north, a rotation of wind and wave conditions can also be observed when moving south; almost reaching an East incoming propagation direction (rotation from North to East clockwise). The values of the propagated wave and wind conditions can be observed in Figure 40.

The top left schematization shows the values of the significant wave height in the different areas offshore and near the coast of the Buenos Aires province, as mentioned before it can be seen that the north has much smaller waves, and that the dissipation of wave energy starts further offshore when compared to the areas in the south. It is also visible that Mar del Plata is an outcrop of the coast; therefore wave energy concentration induced by the bathymetry near the coast (refraction) can be detected.

The top right picture shows the mean wave direction, together with the significant wave height distribution. These parameters are shown with coloured arrows. The colour bar in the right shows the colour assigned to the different wave height magnitudes, while the arrows show the direction of propagation. Dark red colour corresponds to larger waves (1.4m), while dark blue refers to the smaller wave observed in the bay area (0.6m).

Lower left output figure shows the mean wave periods throughout the wave propagation grids. Finally the lower right figure shows the wind propagation direction for the coast of Buenos Aires, since this model includes wind growth the wind induced setup and wave growth is very important to accurately compute reliable wave

conditions. Especially because over a large domain the wind effect is more relevant since large fetch areas can induce large differences. In this study one of the previous wave runs did not include wind growth, and it was detected that wave heights decreased considerable if no wind was applied to the domain.



**Figure 40 Scenario 20 Delft3D**

The second most occurring scenario is shown in Figure 41, the conditions at the reference point located offshore of Mar del Plata are driven by waves in the range of 1.5 to 2m, with incoming wave directions covering from  $167.75^\circ$  to  $191.25^\circ$  (Southeast waves). These conditions happened 1,505 times during the 13 years available of wave data.

The distribution of the significant wave height, mean wave direction, mean wave period and wind direction is shown with the same distribution as before. The significant wave height in this case is larger, especially for the southern section reaching the coast of Mar del Plata with height in the range of 1.3 to 1.5 metres, while for the north section wave heights are significantly smaller (0.4 to 0.6m)

The wave directions are shown in the top right, it can be seen that the dominant directions is from the southeast, only the north boundary has a shift in incoming wave direction to northeast. It is visible that refraction takes place especially for the coast from Punta Medanos to Punta Rasa, the southeast direction shift to east and approaches the coast in an almost perpendicular angle.

In the other hand in Mar del Plata the wave angle near-shore is almost the same as the offshore angle, this allows the waves to propagate freely and consequently larger wave heights are observed near the shoreline.

The corresponding wave periods for these waves are in the range of 1.3s to 5.7s, the distribution of larger waves coincides with the distribution of larger periods. Shorter periods are found in the north section, especially in the bay area.

For this scenario the wind and wave directions are not aligned as they were in the previously explained scenario. Waves are dominant from southeast, while wind is mostly dominant from East. Similar to the wave propagation direction, the wind directions are also shifted in the north boundary where the dominant direction is northeast.

The rest of the scenarios show incoming waves from northeast and southeast, this could lead to believe that the longshore transport is relatively balanced, in fact that was an expected situation, but it is also visible that the wave conditions from the southeast have larger wave heights, therefore a larger volume of sediment can be transported with the same number of conditions.

The following figure shows the previously explained parameters of scenarios 63 (2<sup>nd</sup> most occurring scenario).

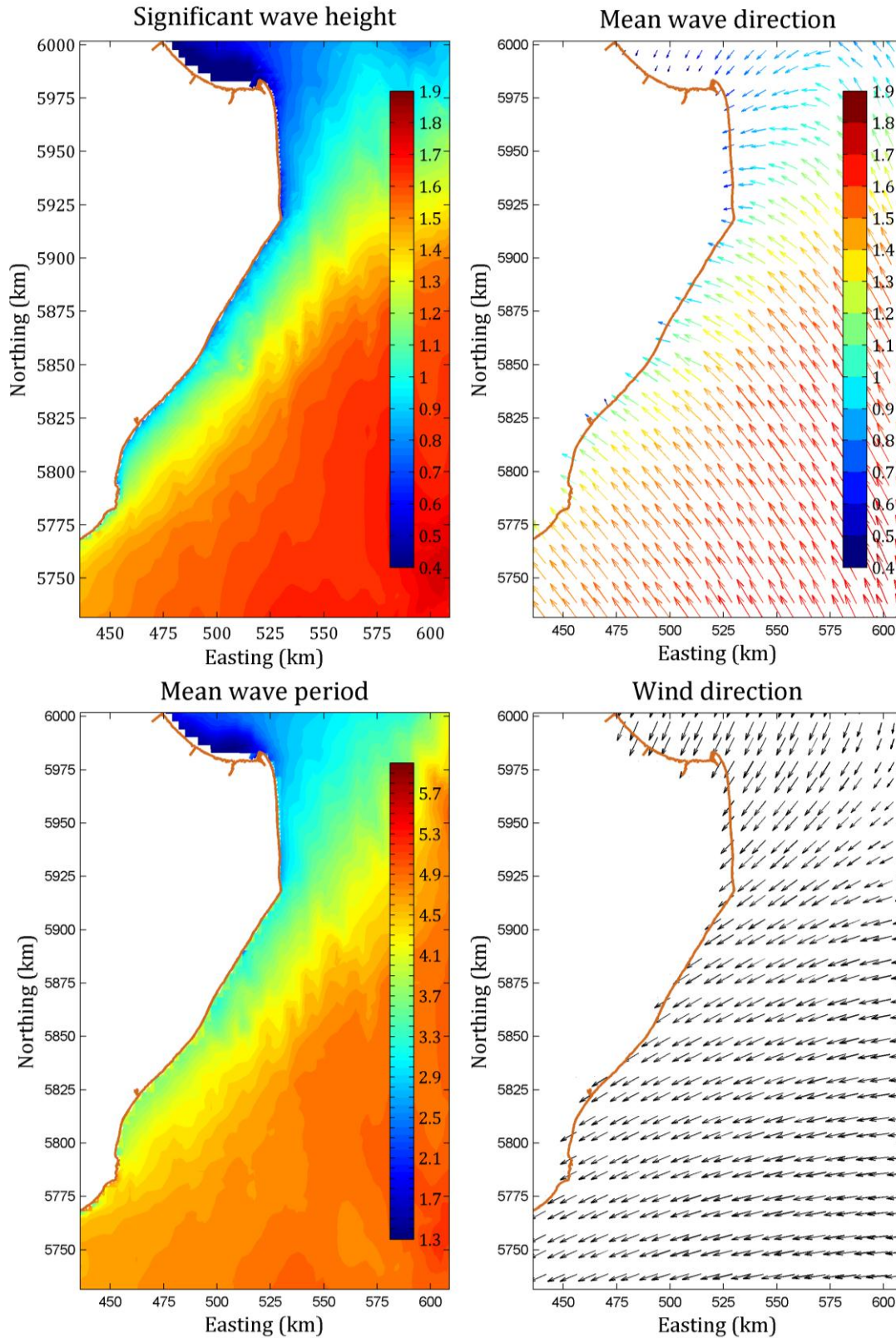


Figure 41 Scenario 63 Delft3D

The next figure shows another dominant scenario, perhaps the number of events is not as large as in the previous two cases, but the wave heights observed in this case are

much larger, and will consequently have a larger effect on the coast of the Buenos Aires province.

Firstly it is important to say the this scenario occurred 434 times in the same 13 years of available wave data, this is approximately 3 times less compared to the previous two cases, but since larger waves cause much greater impacts on the coast, it was of paramount importance to explain this wave climate. Indeed large waves affect the coast greatly; stronger longshore currents, larger cross-shore erosion volumes, larger undertow velocities, and perhaps stronger rip-currents contribute to transport sediment out of the surf-zone areas along the coast. Another important effect is the impact on coastal structures, which in fact for this project, and for the design of a port is highly important.

When waves approach the coast their energy is mainly dissipated due to bottom friction, this lifts up sediment particles, which are transported by the longshore currents also induced by waves. Wave steepness, period and breaking coefficient are also important parameters to determine how much sediment is transported.

Figure 42 Scenario 68 Delft3D, shows significant wave height, mean wave direction, mean wave period and wind direction. The first box shows the distribution of the wave height in the domain. The largest waves are observed in the south boundary reaching 4.5 metres, while the sheltered area in the bay in the north looks very similar when compared to the previously explained scenarios. In this case the coast of Mar del Plata receives waves in the order of 3m, while the coast of Mar Chiquita waves near 2.2m and the coast further north like Pinamar, Villa Gesell and La Costa waves of approximately 2m.

The dominant incoming wave angle is south in the entire wave grid, the wind direction is from the south to southwest.

The wave periods that correspond to these conditions are in between 2s and 8.5s, but it is important to state that the majority of the area shows periods higher than 6s.

As stated before the 125 scenarios that were modelled using Delft3D-WAVE, are attached in the appendix, to show the full description of the offshore wave climate, and the corresponding near-shore conditions.

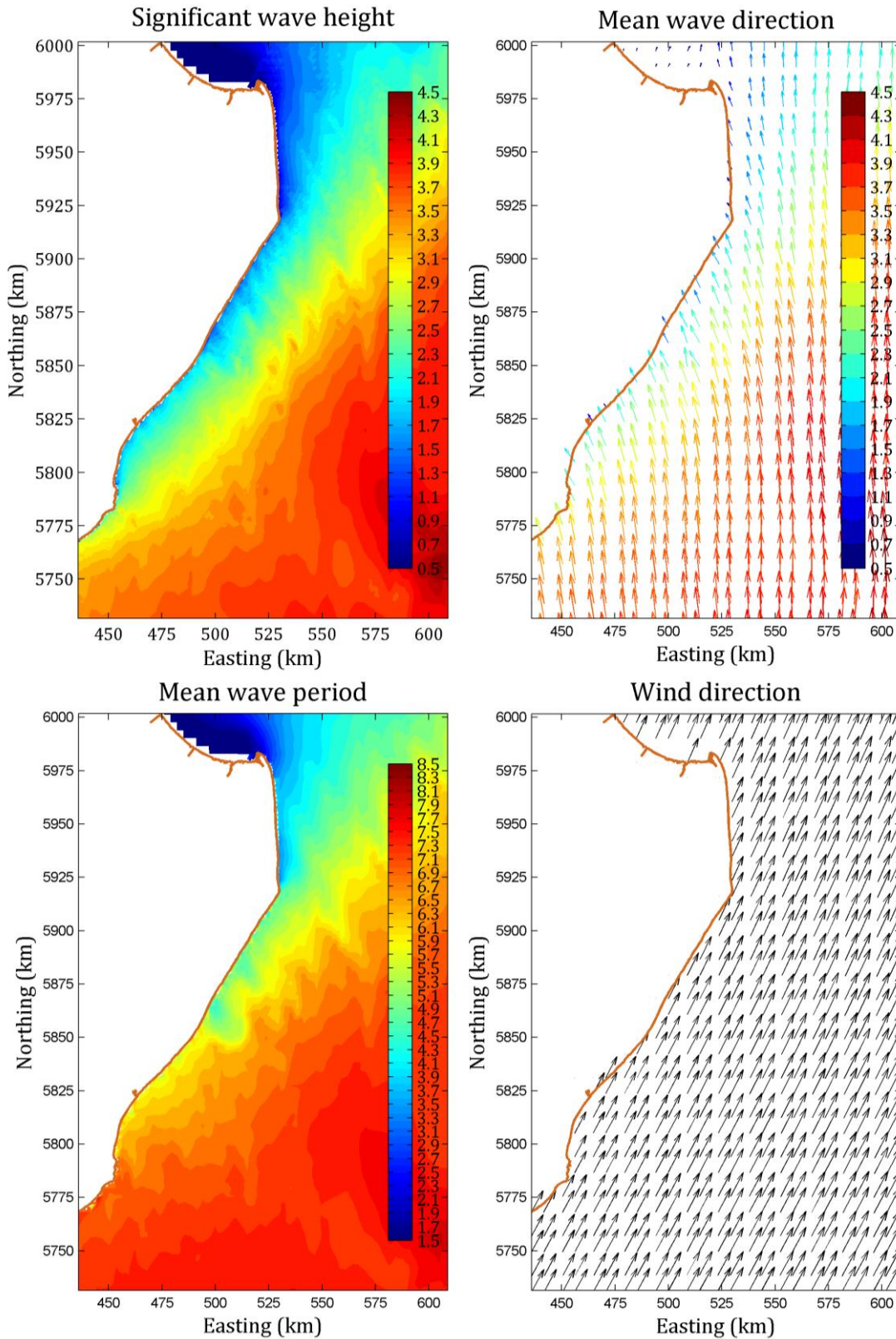
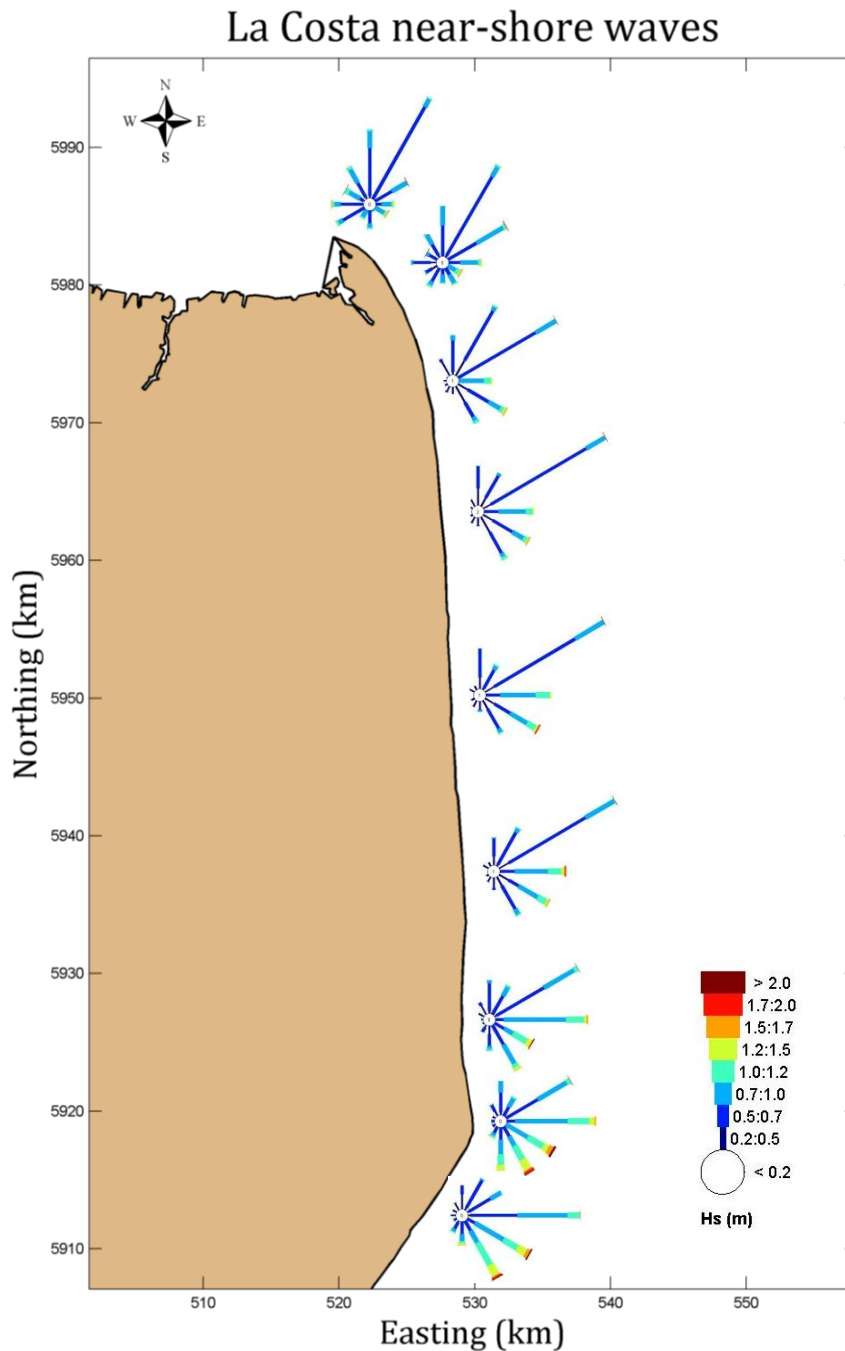


Figure 42 Scenario 68 Delft3D

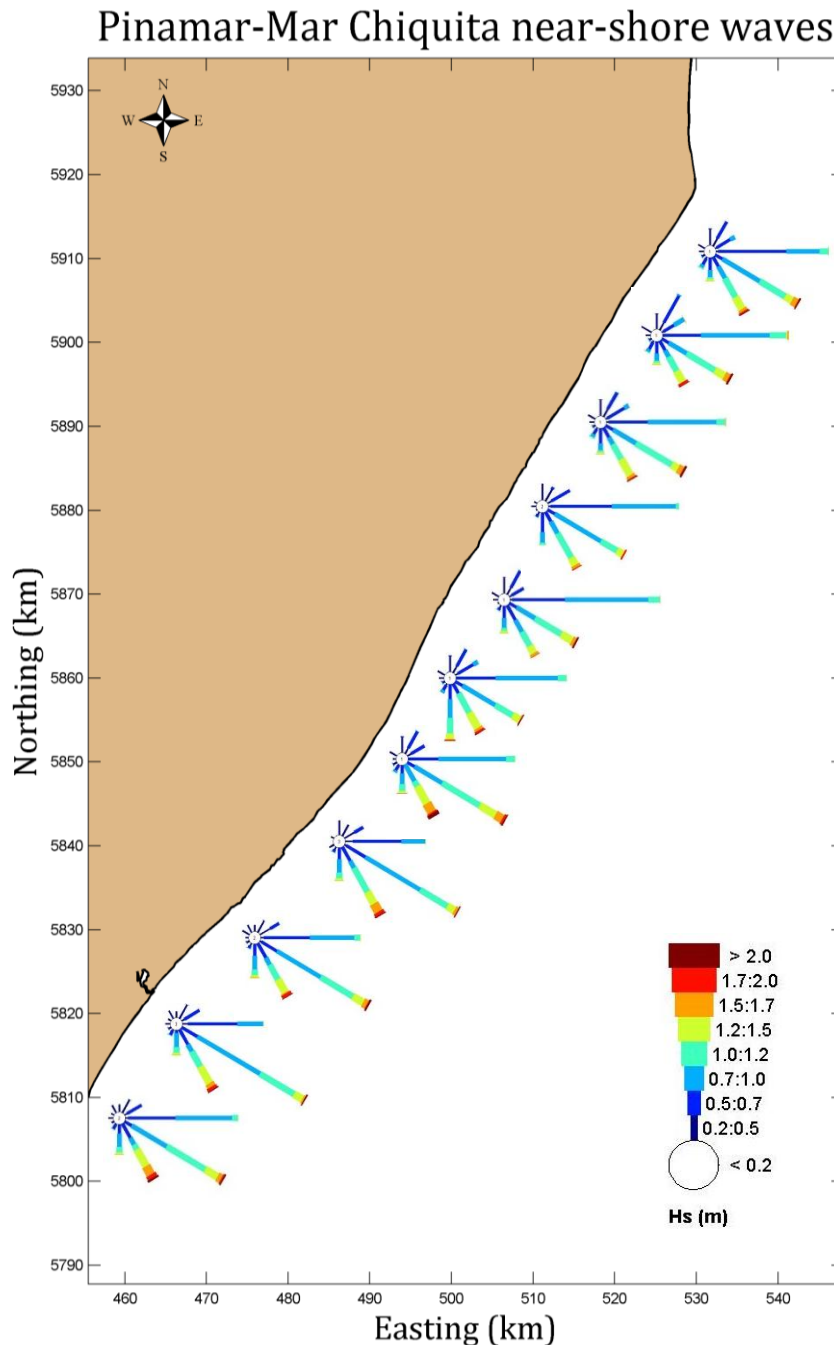
To present the wave conditions along the coast in the 7m water depth contour, the near-shore wave roses shown in the coming figures were developed. The first figure shows

the section of La Costa, covering San Clemente, Mar del Tuyu, Mar de Ajo and Punta Medanos, it can be seen that the incoming wave angle variation from north to south is quite significant, going from northeast to south east (from San Clemente to Punta Medanos), it is also noticeable from the wave roses that the area of San Clemente and Punta Rasa mainly has small waves of up to 1.2-1.4 metres height, and as you look down to the other locations the heights increase, and perhaps Punta Medanos shows a larger bin of red colour representing wave above 2 metres



**Figure 43 La Costa near-shore wave roses**

Figure 44 Pinamar-Mar Chiquita near-shore wave roses, shows the wave climate obtained by implementing the Delft3D-WAVE model. This section of the coast covers the cities of Pinamar Villa Gesell, and Mar Chiquita. As in the previous case it can be seen that larger waves approach the coast in the southern section, also the percentage of occurrence of this larger wave conditions is higher compared to the locations in the north. The directions of incoming wave angles shows a similar dominance (waves coming from southeast).



**Figure 44 Pinamar-Mar Chiquita near-shore wave roses**

The third section of the coast is shown in Figure 45, where the near-shore wave roses corresponding to Mar Chiquita and Mar del Plata are shown. The same southeast dominance of near-shore waves can be observed; also an increase on the wave heights in the southern boundary is visible. For the area where the port of Mar del Plata is built, wave from East direction are also dominant. It can be seen that the incoming wave angle is linked to the shape and orientation of the coast.

### Mar Chiquita-Mar del Plata near-shore waves

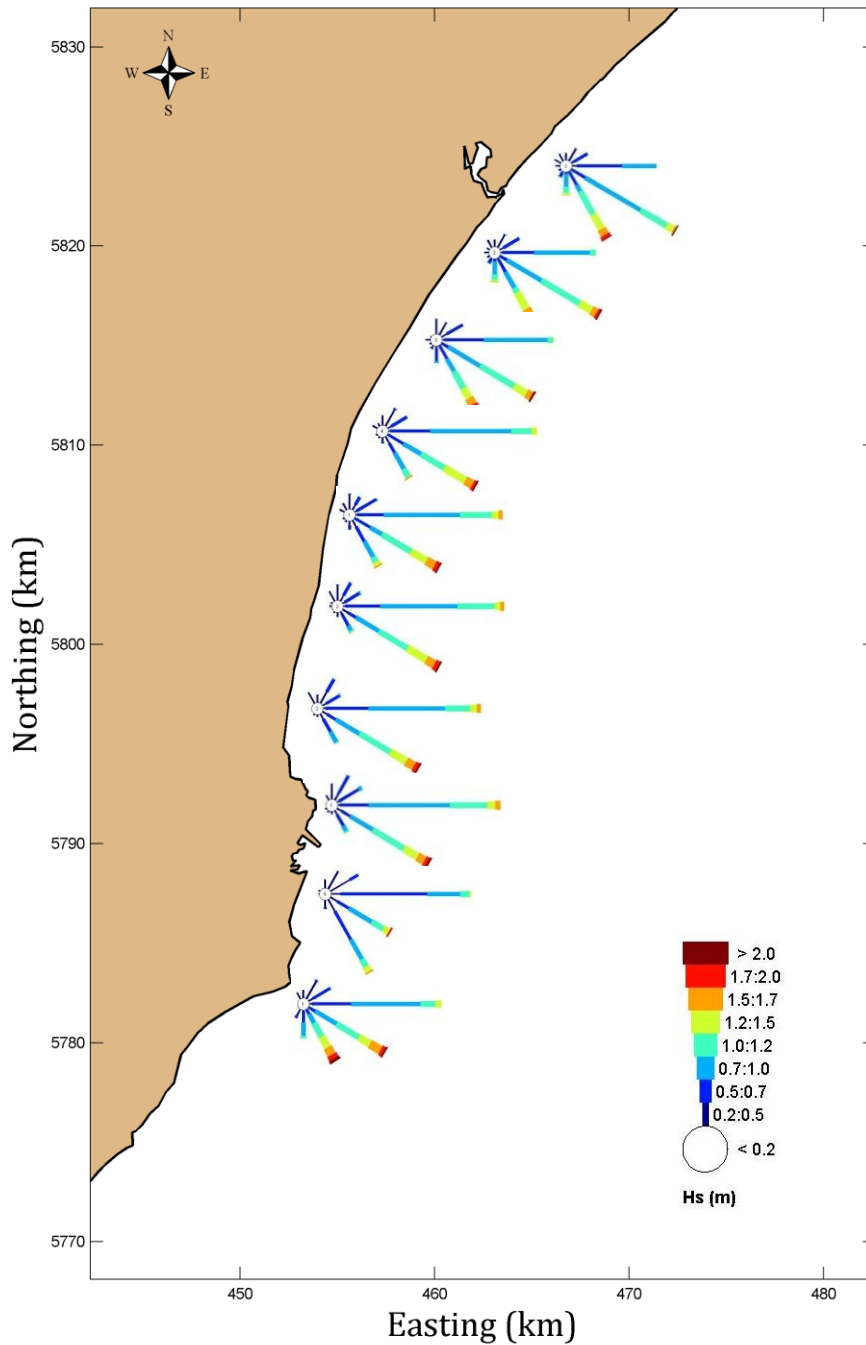
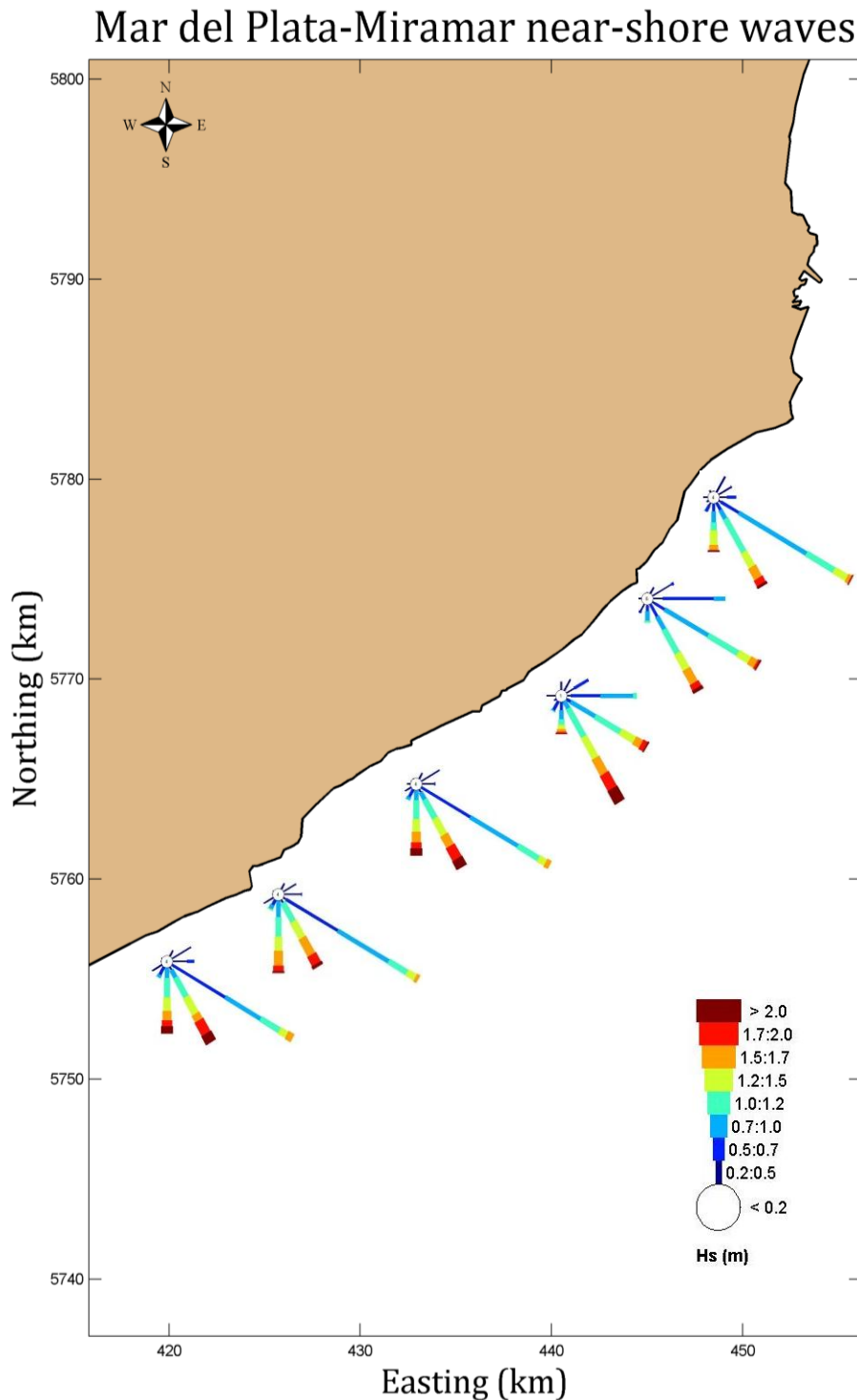


Figure 45 Mar Chiquita-Mar del Plata near-shore wave roses

The last section of the coast is shown in Figure 46, covering Mar del Plata , Los Acanilados, and Miramar. It can be detected in this last figure that the occurrence of larger storms is much more frequent. The bins of wave of more than 2 metres are quite larger especially for waves coming from south and southeast directions. Almost no waves coming from the north can be observed in this area.



**Figure 46 Mar del Plata-Miramar near-shore wave roses**

Based on the extracted wave conditions near shore (at 7m water depth) the following table was developed. It shows the mean wave height and the maximum wave height at different locations along the coast based on the 13 year wave climate.

It can be seen that the larger wave heights occur further south, and that the area of La Costa has significantly smaller wave. These results are very similar to the values calculated by (Lanfredi, N.W., Pousa, J.L., Mazio, C.A., Dragani, W.C., 1992). In fact in that study the measured values with an accelerometer recorded 1.21m as a maximum wave height for Mar de Ajo, 1.90 for Pinamar, and 2.30m for Mar del Plata. It is important to mention that the time interval was much shorter (only 4 years, while for this study the time interval was 13 years); consequently larger waves as the ones calculated seem consistent.

**Table 16 Near-shore wave conditions (7m water depth)**

Location	$H_s$	$H_{max}$
San Clemente north	0.906	1.82
Mar del Tuyu	0.9036	1.88
Mar de Ajo	0.9946	2.01
Pinamar	1.1942	2.14
Villa Gesell	1.1865	2.24
Mar Chiquita	1.2742	2.37
Mar del Plata	1.2439	2.3
Mar del Plata port	1.2513	2.36
Los Acantilados	1.5915	2.67
Miramar	1.5093	2.32

## 6. UNIBEST CL+

### 6.1. UNIBEST-CL+ model

The coastline model UNIBEST-CL+ (Uniform Beach Sediment Transport-CoastLine) is designed for the simulation of coastline changes due to longshore sediment transport gradients. The longshore sediment transport is induced by wave driven currents. It consists of two integrated modules, which are:

- Longshore Transport (LT module)
- CoastLine model (CL module)

The longshore sediment transport is computed and schematised with the LT-module separately for a number of cross-shore profiles along a coast. These schematised transports are the used in the CL-module to perform coastline evolution simulations.

The LT-module is designed to compute tide and wave induced longshore currents and resulting sediment transport for a specific cross-shore beach profile assuming that the beach is uniform in alongshore direction. The surf zone dynamics are derived from a built-in random wave propagation decay model, which transforms offshore wave data to the coast taking the principal processes of linear refraction and non-linear dissipation by wave breaking and bottom friction into account. The longshore sediment transports and cross-shore distribution are evaluated according to various transport formulas, which enables a sensitivity analysis for local conditions.

The CL-module is designed to simulate coastline changes due to longshore sediment transport gradients of an alongshore nearly uniform coast, on the basis of the single line theory. Various initial and boundary conditions may be introduced as to represent a variety of coastal situations. Along the modelled coastline sediment sources and sinks may be defined at any location, to cater for river sediment yield, subsidence, offshore losses, beach mining, etc. Furthermore, it is capable of modelling the morphological impacts of various coastal engineering measures, such as headlands, permeable and non-permeable groynes, coastal revetments and seawalls, breakwaters, harbour moles, river mouth training works, artificial sand by-pass systems and beach nourishments.

## 6.2. Modelling strategy

In order to estimate the longshore transport rates and coastal evolution, the UNIBEST-CL+ was implemented. The longshore transport rates and coastal evolution rates are of paramount importance to determine which location is more feasible for a possible port construction; perhaps the maintenance cost and construction cost can be significantly reduced.

First the Longshore transport model was set up, cross-shore profiles were completed based on the same bathymetric information that was used for the wave study, while the coastal orientation was obtained by placing each cross-shore profile on Google Earth, and measuring the orientation. The next step was to add the sediment parameters as  $D_{10}$ ,  $D_{50}$ ,  $D_{90}$  from the sediment samples extracted during the field work visit in Argentina. This information was used as input. The next step in the process of setting up the longshore transport model, was to select and adjust the wave propagation parameters (to propagate wave information from the selected near-shore point from Delft3D-WAVE to the coast), in a later stage the wave current information was extracted from the Delft3D-WAVE output for each cross-shore profile, and the percentage of occurrence of each situation (125 scenarios) was added.

After the LT-module was finished, and the output information was saved in the 'RAY' files, the CL-module was set up. For the coastline modelling each cross-shore profile was used as input to estimate the longshore transport rates along the coast in different rays, by interpolating between each given ray. For the CL-module the coastal orientation for longshore transport calculations is overruled by the orientation of the land boundary (which in theory should be very similar); which in fact is also the guiding line for the coastline modelling part, since the coastline representation line is drawn on top of the land boundary and the reference line is drawn parallel to it on the dune field, or just landward near the coast. The same wave conditions used on the LT-module are used in the CL-module.

For this study the coastal stretch was divided in two different models. The "north" section covers from Punta Rasa to Mar Chiquita that as mentioned before, is mainly sandy beaches with dunes protecting the hinterland. The other section was considered separately on the modelling since it contains a large number of coastal structures as groynes, offshore breakwaters, Mar del Plata port, and also bearing in mind that the

profile shape is also significantly different since for most of the coast south of Mar del Plata cliffs are dominant.

All the data used as model input was converted to 'Cartesian Coordinates', by using the Delft Dashboard system. The corresponding zone for the area of study is WGS 84 / UTM21S zone

### 6.3. UNIBEST-LT input

#### *Profiles*

For the longshore transport modelling completed with UNIBEST-LT, the profiles at each location had to be specified; each profile was created based on the near-shore bathymetry created with the GEBCO and Nautical chart information. Depending on the complexity of each profile different intermediate points were set to enhance precision of the longshore transport calculations.

Another important feature that was determined was the coastal orientation; which in fact was derived based on the current coastal orientation on the specified profile. The angle was estimated by using (Google Earth 6.2, 2012) tools.

Every profile was extended until the 7 metres depth contour line, this depth was selected after an iterative process of running the model and identifying until which extend the transport seemed to decay. The initial estimations were done by using a so called "rule of thumb" that states that the active depth of approximately 3 times larger than the largest wave heights, which for this coast in shallow waters range from 2 to 3 metres.

Another feature of the longshore transport model requires the determination of a dynamic boundary, and the truncation transport boundary which are normally used in case of existence of reefs, solid sea beds, or to delimitate transport in certain areas.

#### *Sediment*

Sediment size determination for each ray along the coast was another main activity of the model set-up process. Different runs were finished to see how the differentiation of sediment particle size induced changes in the transport rates. This are fully explained later, in the longshore transport modelling section.

The first runs were completed using  $D_{50}=150$ ,  $D_{50}=200$  and  $D_{50}=250$  and the Van Rijn (2004) formulae shown in the UNIBEST-CL+ manual. This formulation gives a prediction for the convective part of the transport and is of the shear-stress type. The

total transport consists of a bottom transport and a suspended transport. Other factors that are taken into account for this longshore transport formula are sediment density, water density, porosity, current related transport coefficients, and wave related transport coefficients.

The second run was set-up with the measured sediment information, of the samples gathered during the field work visit, which were later measured at the TU Delft Applied Earth Science laboratory, and are shown in section 4.4 Sediment samples. For most locations under analysis sediment samples were obtained and used as input for the model, for the intermediate rays the nearest sediment properties were used.

The  $D_{50}$  varies along the coast, although most locations are in the range of 186 and 212 microns, and only some locations like Villa Gesell fall out of the range with coarser sand with up to 318 microns, which is actually compatible with the observed beach profile (steeper profiles in Villa Gesell than other locations).

Important to state that the sediment samples were extracted from the beach front at the different locations, and the only samples extracted at different water depths were near the port, where a boat was provided by the “Fundacion Bolsa de Comercio de Mar del Plata”.

### *Waves*

To determine the wave conditions for each ray along the coast, the coordinates of the end of each profile were obtained. Afterwards they were used as input for the wave data extraction tool on UNIBEST-LT; this tab of the model requires to load the full wave output from the wave model (Delft3D-WAVE), and can extract the wave climate at any given coordinates. It was important to give the exact coordinates of the wave data point, to avoid propagating the waves two times in the same area (since UNIBEST also has near-shore wave propagation).

Since the output of Delft3D-WAVE does not include the percentage of occurrence of each scenario, a ‘dummy’ file that was then overwritten by the real conditions was created including the percentage of occurrence of each of the scenario. The near-shore wave climate was extracted for each ray location following the same process. (Bas Huisman, Jan Kramer, 2009)

It is important to mention that the longshore transport and coastline modules were forced by wave driven currents, and that no tidal currents were taken into account,

since it was assumed that the currents induced by tidal variation did not have a significant effect.

## 6.4. UNIBEST-LT results

### Rays

After selecting all the input parameters, a ‘Ray’ file is created for each profile; this file saves the longshore transport computation results. 20 ray files were created, each corresponding to a certain profile, sediment and wave conditions. The profiles computed for the “North” section can be observed in Figure 47 Rays along the coast.

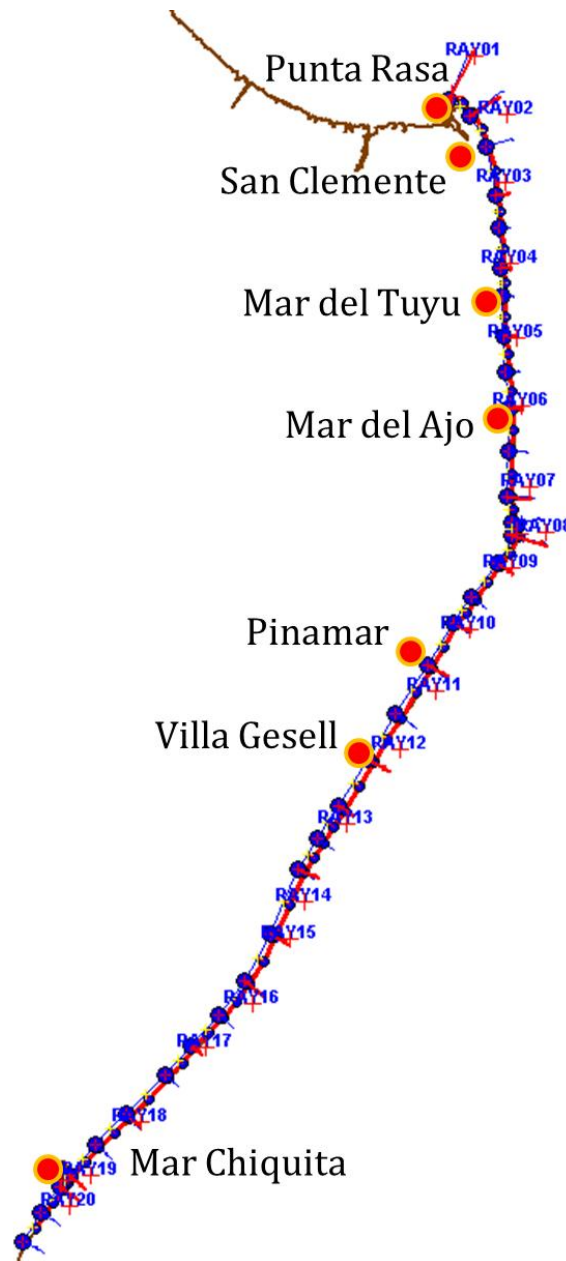
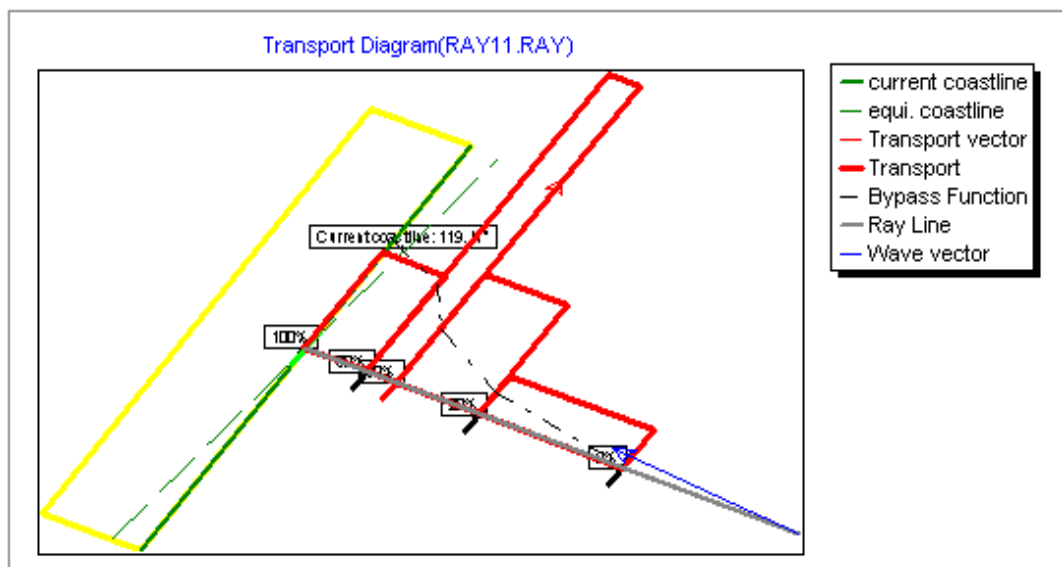


Figure 47 Rays along the coast

Each 'Ray' file gives information related to the wave conditions, the current coastline angle, the equilibrium angle (angle at which the transport is zero), and divides the transport volumes in different blocks to show at which depths the transport is larger. Also the net longshore sediment transport direction is shown, as it can be seen in Figure 48 Longshore transport schematization. This schematization corresponds to the coast of Pinamar.

In this figure it can be seen that the difference between the current angle and the equilibrium angle is not very large, this normally means that the coastline is relatively stable, and that the transport rates are balanced (northward and southward transport). For this specific location the net longshore transport is in the range of around 85,000m<sup>3</sup>/year towards the north. It is also simple to detect that the dominant incoming wave angle is almost perpendicular to the coast; this explains also the fact that the angle difference between equilibrium and existing coast is small.



**Figure 48 Longshore transport schematization**

Another useful and interesting figure created by UNIBEST-LT module is the S-phi curve. This curve shows an 'S' shaped curve of the net longshore transport rates in relation to the coastal orientation. The S-phi curve for 'Ray 11' is shown in Figure 49 S-phi curve. This curve is very important to understand how significant the coastal orientation is for longshore transport computations. It can be observed that under the same wave, and sediment conditions and only changing the coastline angle by some degrees the transport can be significantly different. The rest of the ray files computed along the coast of the Buenos Aires province are shown and explain in the appendix.

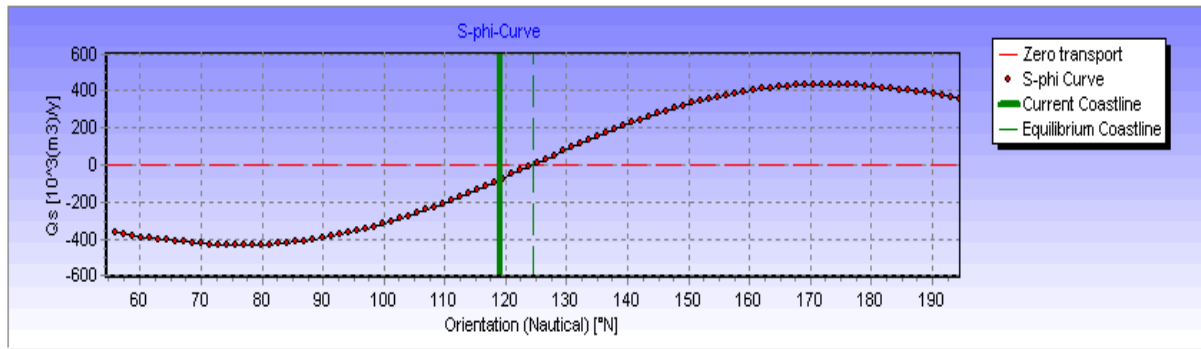


Figure 49 S-phi curve

### Longshore transport rates

Longshore transport calculations were completed at each of the rays; the results were summarized and are shown in Table 17 Longshore transport rates, "North".

Since most locations along the coast had a  $D_{50}$  between 0.150mm and 0.250mm the longshore transport computations were done for three different standard sediment sizes inside that range, and also with the size of the collected samples that were then measured at the TU Delft laboratory. The idea was to compare the results and estimate the effect of sediment size variation for longshore transport computations. It can be detected by looking at the different values, that the higher net-longshore transport rates are linked to the smaller sediment sizes.

Table 17 Longshore transport rates, "North"<sup>38</sup>

Longshore transport variation	"North section"		D <sub>50</sub> as measured	0.150mm	0.200mm	0.250mm
	Ray	Coastline Orientation	Net longshore transport			
Location	#	°	1,000 m <sup>3</sup> /year	1,000 m <sup>3</sup> /year	1,000 m <sup>3</sup> /year	1,000 m <sup>3</sup> /year
Punta Rasa	1	27	4.1	8.0	4.8	3.9
San Clemente	2	58	-45.8	-51.1	-47.3	-40.4
	3	83	-27.8	-36.3	-27.4	-25.0
Mar del Tuyu	4	87	-20.8	-26.0	-17.8	-15.3
	5	86	-40.1	-56.2	-37.4	-32.2
Mar de Ajo	6	88	-24.9	-30.8	-22.6	-24.6
	7	95	-36.1	-49.9	-36.1	-34.8
Punta Medanos	8	105	-233.7	-331.9	-233.7	-248.9
	9	123	-31.8	-78.2	-35.7	-25.4
Pinamar	10	119	-107.5	-191.5	-113.0	-104.8
	11	119	-80.8	-133.7	-82.2	-78.4
Villa Gesell	12	122	-88.7	-128.9	-82.7	-77.1
	13	121	-51.4	-80.5	-42.5	-37.9
Mar de las Pampas	14	112	-124.1	-195.1	-124.1	-117.2
Mar Azul	15	117	-233.3	-357.6	-233.3	-226.4
No development	16	128	-90.3	-169.2	-90.3	-76.0
	17	130	-113.9	-210.6	-113.9	-96.2
	18	132	38.1	49.6	39.3	36.7
Mar Chiquita	19	131	-69.4	-125.2	-72.0	-63.2
	20	125	-173.9	-298.6	-178.4	-164.7

<sup>38</sup> Negative sign in the net longshore transports refers to transport towards the north.

The percentage of variation in the transport rates obtained with the different sediment sizes is relatively constant (proportional difference). Transports calculated at Pinamar in ray 11 vary from 78,000m<sup>3</sup>/year with 0.250mm, to 133,000m<sup>3</sup>/year with 0.150mm, an increase of around 70% is obtained, showing that the transport calculations are very sensitive in relation to the sediment size. When computing the same relation in Mar del Tuyu (Ray 5), a 75% increase in sediment is observed; then if a similar computation is done for Mar Chiquita in ray 20, rates of 164,000m<sup>3</sup>/year to 298,000m<sup>3</sup>/year can be found. This shows an increase of the transport of 81%.

The results shown in the column called “Measured D<sub>50</sub>” show the results of the longshore transport computations when using the measured sediment properties of the different locations along the coast.

Coastal orientation is another major factor that influences the volumes of sediment that are transported. Two dominant orientations cover the coast from Punta Rasa to Mar Chiquita; the first section (Punta Rasa-Punta Medanos) has an approximate orientation of 90°, and then starting at Punta Rasa and to the south, the orientation changes to a range of 115-130°. The only location along the “North” section of the coast that has a net longshore transport towards the south is located between Mar Chiquita and Mar Azul, this locations is also the only one with an orientation above 130°, it can be concluded that the threshold orientation for the stretch of coast is around 130°.

As expected, the transported volumes increase from north to south, this can be explained by the fact the southern section of the Buenos Aires coast has steeper profiles, and the wave conditions offshore are larger. Dissipation of the wave energy caused by bottom friction throughout the mild slopes in the north reduces the amount of transport near the coast, since the transport formulations are directly related to the wave heights. The velocity of the transport layer is another variable that is compute to obtain the longshore sediment transports.

As mentioned briefly in literature, the net longshore of the coast from Mar Chiquita to Punta Rasa has a northward dominant direction, this explains the formation of the sand spit in Punta Rasa, and could also be related to the sand ridges formed near the coast (in front of Pinamar and Villa Gesell).

As it was observed in the previous chapter, most wave conditions in the northern section of the coast near Punta Rasa start losing energy far from the coast, consequently when the waves approach the coast their energy is not strong enough to lift up, and

carry the sediment along the coast. The opposite happens in the southern sections of the coast, where the waves have sufficient energy to lift up the sediment, and longshore currents are able to keep it suspended to transport it. Sediment transport is directly related to the current velocity, larger waves induce stronger currents, which in consequence will transport a larger amount of sediment.

When looking at the results of the “South” section of the coast starting at Mar Chiquita and ending at Miramar shown in Table 18, it can be observed that the longshore transport rates estimated for the area are of a larger magnitude compared to the coast in the north. Especially at Mar del Plata and Los Acantilados, very large longshore currents were calculated; reaching net longshore transport values in the range of 315,000m<sup>3</sup>/year to 510,000m<sup>3</sup>/year. Similar to this results a report by Leo van Rijn from Deltares completed in 2008, calculated a net longshore transport at Los Acantilados of 400,000m<sup>3</sup>/year, and also gave a range between 300,000m<sup>3</sup>/year to 500,000m<sup>3</sup>/year for the coast of Mar del Plata in another study completed in 2008 after a site visit (Van Rijn, L.C, 2008).<sup>39</sup>

**Table 18 Longshore transport rates, "South"**

Longshore transport variation	"South section"		D <sub>50</sub> as measured	0.150mm	0.200mm	0.250mm
	Ray	Coastline Orientation	Net longshore transport			
Location	#	°	1,000 m <sup>3</sup> /year	1,000 m <sup>3</sup> /year	1,000 m <sup>3</sup> /year	1,000 m <sup>3</sup> /year
Mar Chiquita	1	131	-80.1	-139.8	-82.6	-73.9
	2	125	-182.3	-309.6	-186.8	-173.7
Santa Clara	3	110	-298.6	-409.3	-308.9	-289.2
Playa Dorada	4	100	-279.3	-378.1	-279.3	-255.9
Mar del Plata North	5	96	-316.2	-419.9	-316.2	-300.5
	6	85	-376.0	-591.3	-375.2	-340.3
	7	70	-430.6	-678.6	-431.7	-391.3
Mar del Plata port	8	76	-510.1	-700.0	-507.0	-439.1
	9	113	-49.8	-92.1	-55.0	-51.5
	10	110	-345.6	-437.1	-343.5	-299.6
Mar del Plata South	11	151	163.7	237.6	159.8	162.7
Los Acantilados	12	128	-202.7	-351.1	-179.3	-149.1
	13	132	-421.6	-572.8	-421.6	-369.7
Miramar	14	155	108.3	106.2	102.2	100.8
	15	156	106.7	99.9	98.1	96.4
	16	148	-78.0	-257.2	-202.2	-174.7

It was observed that for the calculated wave climate in the different locations, a coastal orientation above 150° shifts the net transport direction to the south, as it happens for some locations south or Miramar (Ray 15 and 16).

<sup>39</sup> Negative sign in the net longshore transports refers to transport towards the north.

Rays 5 to 11 correspond to different beaches along Mar del Plata, the locations with larger transport volumes are near the port and north of the port, although, the existing coastal structures will reduce the amount of sand that is transported towards the north, and consequently cause erosion problems, that are now being contained by foot protection of the cliffs north of Mar del Plata.

The coast from Mar Chiquita to Miramar has a large number of coastal structures that might block large volumes of sediment; this will obviously lead to deposition and erosion in certain areas, causing negative and positive effects along the coast.

Longshore transport volumes computed with the varying sediment sizes give comprehensible transport rates, giving larger transport rates for smaller sediment.

The active height of the profiles in the different locations also changes the amount of sediment that is transported, perhaps in locations like Mar Chiquita during high tide, and with storm surge the height can be up to 2.5 metres above mean sea level, but in other locations like the section of Mar del Plata with cliff protection the active height is always the same since no transport occurs in the protected section of the cliff.

## 6.5. UNIBEST-CL input

### *Land boundary*

The land boundary file used to delimitate the previous wave modelling runs, is also used as input for the coastline modelling. Based on the land boundary file, two lines had to be drawn to be able to predict the longshore transport rates between the ray files given as output in the LT-module. The first line called “Reference line” is placed on top of the dunes or in the land located near the actual coastline. The second line is called “Coastline” this line as the name says represents the coastline; therefore it is drawn exactly on top of the existing coastline.

The use of the “Reference line” and the “Coastline” lines is completed to allow coastal orientation variation without overlapping the ray profiles.

### *Rays from LT module*

Furthermore, between the lines that were drawn based on the land boundary, sections were added to obtain a greater number of longshore transport rays along the coast. Once the lines are defined the model uses the orientation of them to re-run the longshore transport computations. Later the results are used as input to model the coastline change of the coast of the Buenos Aires province.

The number of rays and added sections was determined based on the complexity of the coast; due to the fact that the coastal orientation plays a very important role in the longshore transport and coastline modelling computations. When the orientation changed significantly in a few kilometres, more rays were added. In the other hand for coastal stretches with very smooth changes in orientation and with constant sloping profiles each ray could be placed further away.

## 6.6. UNIBEST-CL results

### *Longshore transport along the coast*

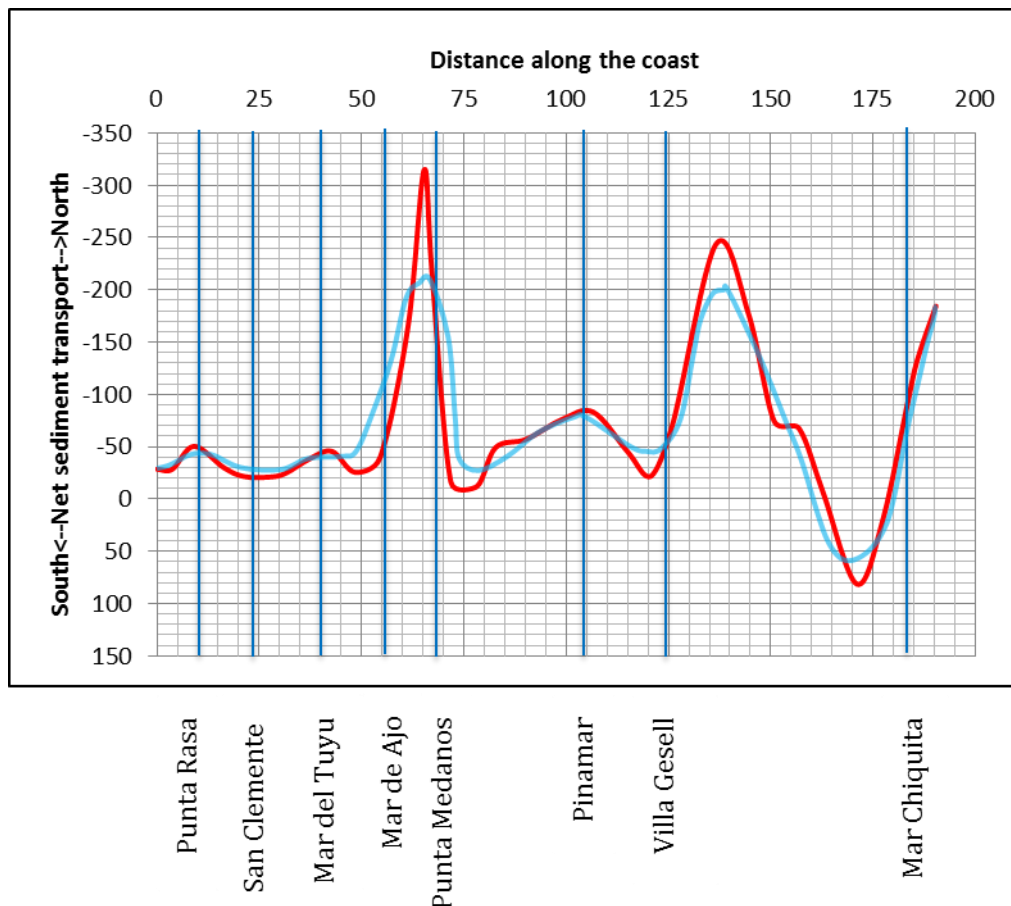
The CL module of UNIBEST-CL+ is able to model the coastline change throughout a given period of time, in this case the total time was set to 15 years, with 100 time steps per year.

The output of this computation shows the net longshore transport rates along the coast, and the expected coastline retreat and advance produced by the induced longshore currents. In Figure 50 Net longshore transport rates “North”, the longshore transport rates for the north section can be observed. For this area of the Buenos Aires province it is visible that the northward sediment transport is very dominant, and that only at a few locations like Punta Medanos and Mar Chiquita the transport rates are significantly higher, mainly due to the coastal orientation, and perhaps for the case of Mar Chiquita the relatively deeper waters (compared to the “Partido de La Costa”) near the coast that allow waves to come closer to the coast. Sediment transport is directly related to the longshore current velocity, furthermore longshore current velocity is strongly dependent on the wave height; therefore if the waves are larger, the current will be stronger, and consequently the transport capacity in the area will also be greater.

For most of the county of La Costa transport rates are between 25 and 100 thousand cubic meters per year. Punta Medanos is the only exception, reaching a net longshore capacity of 315,000 cubic metres per year. As mentioned before in the study, this location is situated where the coastal orientation changes approximately 40°.

Pinamar and Villa Gesell have somewhat larger transport rates in the range of 75 and 200 thousand cubic metres per year; the large variation in this section could be explained by the fact that the sand ridges located near shore produce wave refraction and concentration in certain areas, in which currents become stronger, and consequently the transport is larger.

The coast in the north of Mar Chiquita is the only location along the coast of the “North” coastal section that has net longshore transport to the south in some sections, although it can also be seen that the transport direction changes abruptly south of Mar Chiquita. The units of the net sediment transport rates in figure Figure 50 Net longshore transport rates “North”, are given in 1,000m<sup>3</sup>/year. The negative sign of the longshore transport rates means it is going towards the north. The ‘x’ axis shows the distance in Km.



**Figure 50 Net longshore transport rates “North”**

The light blue line going from north to south along the ‘x’ axis shows the smoothed net longshore transport rates, since the fast change in coastal orientation in Punta Rasa gives a very large peak that might overestimate the transport rates.

For the coastal stretch from Mar Chiquita to Miramar, referred to in the study as “South”, the transport rates vary significantly. Most of the coast is dominated by the south waves that produce a net longshore current towards the north.

Abrupt changes in the longshore transport could be explained by the fact that the orientation along the city of Mar del Plata varies in very short distances; consequently transport directions and net magnitudes also do.

Transport rates go up to 450,000m<sup>3</sup>/year (towards the north) at Mar del Plata, and in some very particular spots along the coast near Mar del Plata the transport direction switches direction, but then rapidly decays and follows the same dominant direction (north).

Further south along the coast of the Buenos Aires province Miramar can be found, at this location transport rates also vary. During the field visit it was observed that coastal structures were present almost covering the entire coast of Miramar. Further south of Miramar there is a coastal stretch that seems to have a southward net longshore sediment transport direction.

The previously mentioned results are summarized in the following figure, where the net longshore transport is placed in the 'y' axis, and the distance along the coast (starting at Mar Chiquita and moving south to Miramar) is in the 'x' axis. The units of the net sediment transport rates are given in 1,000m<sup>3</sup>/year.

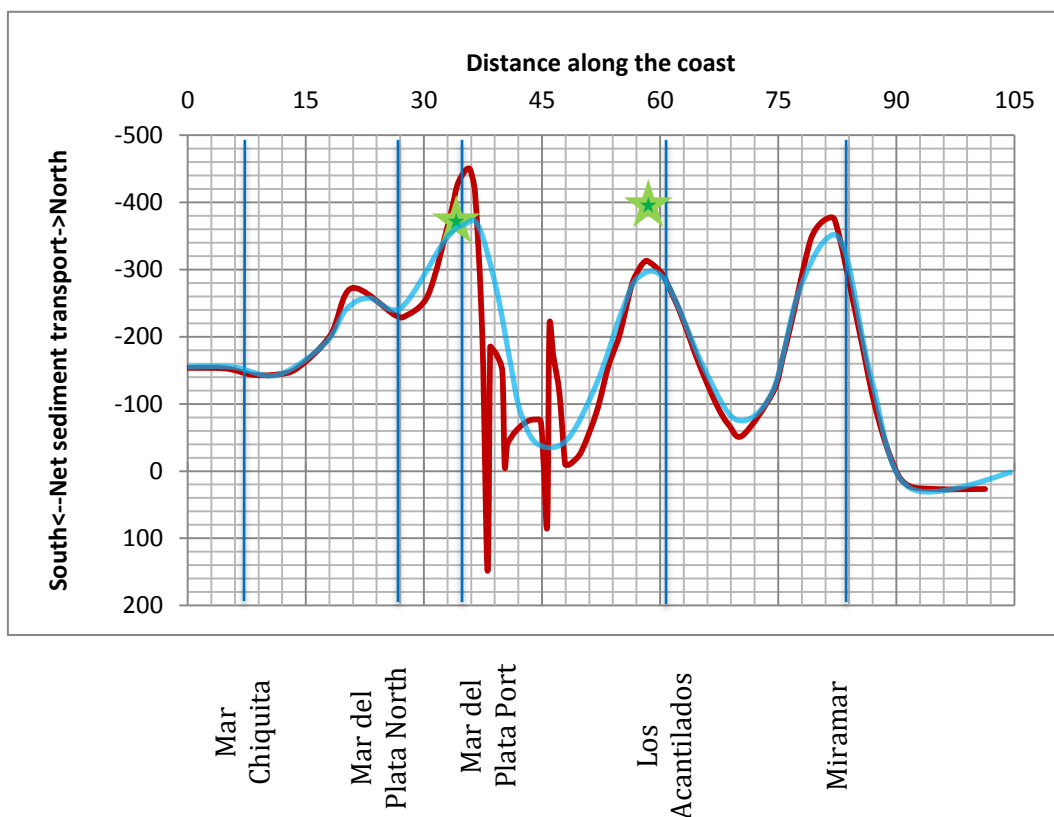


Figure 51 Net longshore transport rates "South"

The green stars shown in the figure represent the net longshore transport rates obtained by in the studies by Leo van Rijn for the coast of Mar del Plata and Los Acañilados. (Van Rijn, L.C, 2008)

The light blue line going from north to south along the 'x' axis shows the smoothed net longshore transport rates, this line was derived because the abrupt coastal orientation variation along the coast of Mar del Plata computed very local transport rates.

### *Coastline change*

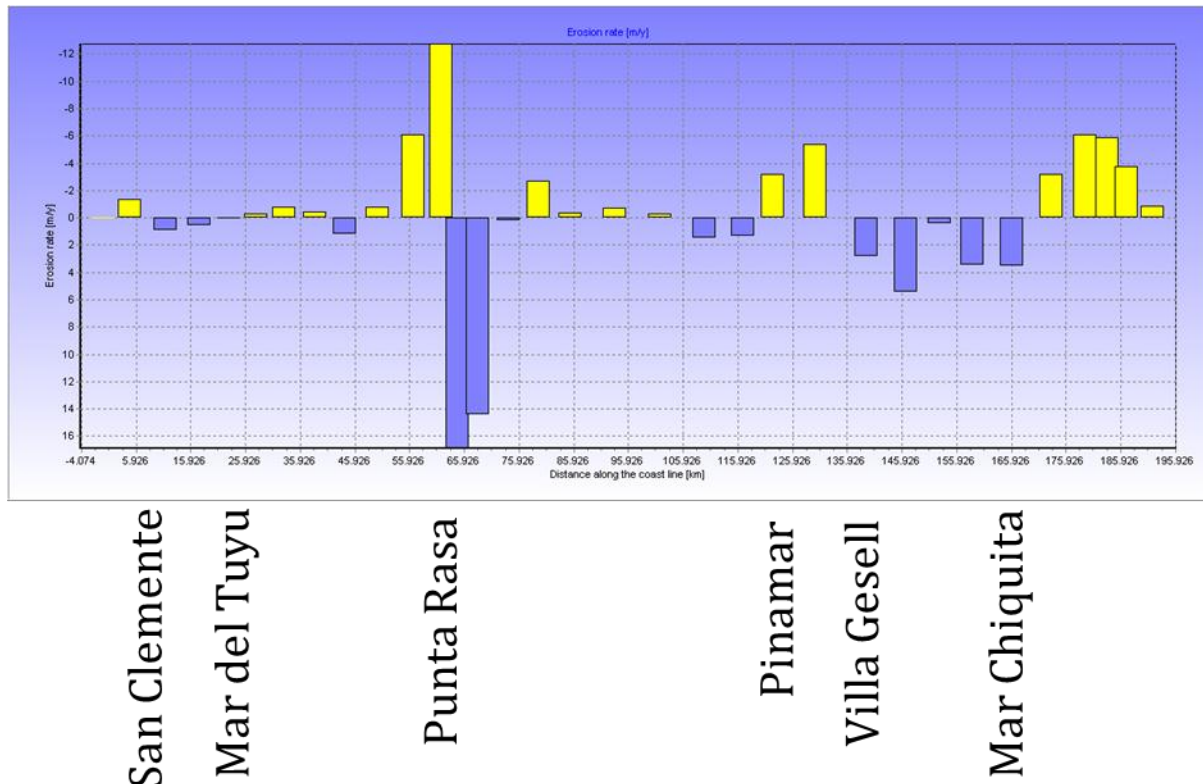
The previously explained longshore currents will induce a certain coastline change; this change was also computed with the CL module. Although, as mentioned earlier in this chapter it was only computed for the "North" section of the coast under analysis, since the stretch of coast from Mar Chiquita to Miramar has a large number of coastal structures; for example, groynes, cliff protection, offshore breakwaters and the port of Mar del Plata, that could not be included in the modelling since the wave propagation grid was too large (in relation to the size of the groynes), and the available bathymetric data was not detailed enough to accurately simulate the effect of this structures.

Since the area from Punta Rasa to Mar Chiquita is structure free, it was possible to assess the coastline change over the 15 year period. Figure 52 Erosion rates (Measured sediment), shows the estimated erosion/accretion rates along the coast. For most locations in the county of La Costa the erosion is slightly dominant, which could lead to think that man induced erosion (unplanned urbanization too close to the coastline, drainage systems, etc.) are also quite significant since the current state of some locations is very critical.

For San Clemente and Punta Rasa it can be observed that deposition rates of up to 2 meters per year were calculated, similar to the accretion rates estimated near Pinamar. In the other hand, locations like Punta Medanos present a larger magnitude of variation, getting deposition to the north and erosion to the south with respect to the inflexion point where the coastal orientation changes. As mentioned before the orientation of the coast plays a main role in the modelling of longshore transport rates, and consequently in the modelling of the coastline evolution.

The other section of the coast that presents erosion rates is the coast south of Villa Gesell and north of Mar Chiquita, were some rays computed coastline retreat of up to 5 m/year.

When comparing the values obtained with the coastline module with the values calculated by (Erosion Costera Provincia Buenos Aires, 2012) it can be seen that the trends of erosion and accretion are placed in the same locations; although, the erosion rates vary in some locations. The other available study giving coastline retreat or advance rates was based on aerial images; this study shows larger coastline changes similar to the ones computed in this study. The corresponding figures are shown in chapter 4 in the longshore transport section.



**Figure 52 Erosion rates (Measured sediment)**

Yellow bars represent accretion, while blue bars represent erosion in metres per year; the 'x' axis represents the distance along the coast from San Clemente in the north section of the coast.

## 7. Evaluation of locations

In this chapter the comparison of locations is completed, showing and explaining the different criteria used to compare and determine which location is best suited for a port development.

### 7.1. Summary of alternatives

The following bullets summarize the main features of each location.

- Miramar: Is a location with erosion problems partially solved with coastal structures, large waves and deep waters near the shore.
- Mar del Plata: Location with a lot of infrastructure for tourism, existing marina, deep waters near the coast, suffers deposition and erosion problems in different sectors of the city. Is considered one of the main touristic locations of Argentina.
- Mar Chiquita: Tidal inlet with very shallow waters inside in the lagoon, unstable entrance, erosion problems controlled by structures. No dredging allowed inside the lagoon, since it is considered natural reserve.
- Villa Gesell: Touristic location, with moderate waves, and moderate estimated sediment transport rates. Existing fishing pier, coarser sand compared to most of the locations along the coast of the Buenos Aires province.
- Pinamar: Touristic city with infrastructure, moderate waves and sediment transport conditions, almost ideal geographic location. Vacation site for the wealthy Argentinian people, which in fact could well be a majority of the marina users.
- Mar del Tuyu: Location with erosion problems, small to moderate waves, and relatively small transport rates.
- Mar de Ajo: Locations with severe erosion problems, low to moderate wave energy, moderate development and infrastructure. Unplanned urbanization near the coast generated great problems in the coast.
- San Clemente north: Coast with deposition rates recorded, very gentle beach slopes, some basic infrastructure can be found, relatively small waves and longshore transports.
- San Clemente bay: Muddy bay area, with shallow protected water areas. Very basic infrastructure, the main touristic activity is provided by “Mundo Marino” Marine Park.

- General Lavalle: Fishing village with some existing infrastructure, protected from waves, formed by shallow muddy areas.

## 7.2. Evaluation criteria

To be able to compare the different location, first the development of a list with the most important factors and features had to be completed. The most relevant factors covering technical feasibility are taken into account, supplemented by socio-economic factors that are also relevant for the decision making process.

Each of the factors considered as essential for the multi-criteria analysis is described below, stating why each of them could have a negative or a positive impact on the decision making process.

### *Sediment transport*

Sediment transport rate is one of the main factors to decide whether a port is feasible or not. If a certain location has large longshore transport rates, the construction of the port will very probably negatively affect the dynamics of the area in a very significant way; especially if the transport direction is very dominant towards one direction. When this happens large volumes of sediment are deposited on the up-drift side of the coastal protection structures, and consequently a sediment starvation occurs in the down-drift side of the port.

Another important thing to take into account is the port sedimentation. If the area has large sediment transport rates, deposition in the access channel will eventually occur, and will lead to an increase of the maintenance cost for the port.

### *Coastal stability*

As stated before the coast of Buenos Aires is very active, some locations suffer erosion problems, some others are relatively stable, and in a few more accretion is dominant. These features are highly important to determine if a location is feasible for port construction, perhaps a location with high erosion rates would need extra infrastructure to protect and counteract the negative effect that a new port could induce.

On the other hand, locations that have a sedimentation tendency could be better suited for a port construction; considering that the erosion problems induced by the port would not be as critical.

### *Bathymetry*

Another main feature that was used for the comparison was the bathymetric situation of each area. Perhaps locations like Mar del Plata with deeper waters near shore have a certain advantage over locations like San Clemente with very shallow waters. Inferring that locations with steep profiles are more suitable compared to locations with gentle slopes. This criterion also includes the coastal shape of each location, where for instance locations like General Lavalle or Mar Chiquita have a certain advantage over the other locations since sheltered water areas are naturally provided. Although one of the limitations of all the locations with sheltered areas is the lack of water depth.

### *Wave climate*

Waves induce longshore transport rates (discussed previously), but are also very important for the design of the coastal protection structures. Larger wave heights lead to higher, larger, and stronger coastal structures, which means more investment to ensure protection inside the port.

In the other hand the dominant direction of propagation of waves near-shore is highly important to determine the orientation of the coastal structures. Long period waves are also a common problem for ports, and should be avoided.

### *Impact on adjacent coast*

This criterion refers to the possible impact that the construction of the port could create on the adjacent coastal areas. Perhaps areas that are highly populated near the coast (in the up-drift side) are less suitable.

### *Geographic location*

Since one of the objectives of building a marina port along the coast is to connect Buenos Aires and Mar del Plata, the distance to both locations is also important. Perhaps locations very close to any of the large cities are considered less practical. Involved in this criterion is also the traveling time; for many sailors traveling long distances without have a safe place to make berth could be dangerous and unpleasant.

### *Infrastructure*

Another very important factor that was taken into account in the decision making process was infrastructure. Existing infrastructure, as access roads, hotels, leisure facilities, and other developments that could be beneficial for all the tourism brought by a marina port are an advantage. The activities offered by each location are considered under the extent of this point as well.

**Table 19 Comparison of criterion**

Location/Criterion	Sediment transport (1,000m <sup>3</sup> /year)	Coastal stability (m/year)	Distance to 5m depth (m)	Waves (m)	Distance to BA and MDP (km)
General Lavalle	Bay area				305-230
San Clemente bay	Bay area				332-223
San Clemente north	-27	+1.7	1661	0.90	328-215
Mar del Tuyu	-40	-1.2	661	0.90	349-190
Mar de Ajo	-36	-1	732	0.99	365-173
Pinamar	-80	+1	332	1.19	357-127
Villa Gesell	-89	+2	413	1.18	376-108
Mar Chiquita	-174	N=-3 S=+4	479	1.27	446-36
Mar del Plata	-431	Fixed coast	214	1.25	410-0
Miramar	-422	Fixed coast	428	1.50	470-61

Table 19 Comparison of criterion, shows some of the facts corresponding to each location, based on these values the multi-criteria table was setup to determine which location is more suitable for the development of a marina port.

Sediment transport column shows the net sediment transport rates for each location (- sign means northward transport).

Coastal stability gives an approximation of the coastline retreat or advance in metres.

The column called water depths refers to the distance from the shore to the required water depth at the entrance of the marina.

The wave values given show the average wave height of the 13 years of available wave data (at 7 metres water depth).

The last column provides the distance to Buenos Aires and to Mar del Plata by road.

### 7.3. Multi-criteria analysis

Plus (+) and minus (-) signs were assigned to the different locations for each criterion.

The (+) sign means positive impact (beneficial conditions), following the same understanding (++) is the best score and (--) is the worst (least beneficial) score.

The first criterion taken into account was sediment transport. For locations with sediment transport rates below 30,000m<sup>3</sup>/year a (++) grade was assigned, (+) for the locations in the range of 30,000m<sup>3</sup>/year and 100,000m<sup>3</sup>/year. The (-) sign was set for coastal areas with rates between 100,000m<sup>3</sup>/year and 200,000m<sup>3</sup>/year, and finally (--) for the location with larger net transport rates.

In relation to the coastal situation the erosion/accretion rates were taken into account. The (+) sign was assigned to the locations with a stable coast, in the case of Mar del Plata the coast was considered more-less stable since coastal protection structures are already build along the coast, and maintain the coastline relatively stable. The (++) sign was only given to the locations with accretion rates, while the (-) and (--) signs were assigned to locations with erosion, and extreme erosion problems respectively.

The third criterion used to compare the locations of the Buenos Aires coast was water depths. Values were assigned based on the distance to the 5 metres depth from the coastline. Since the locations in the bay area do not reach this depth naturally, a (--) sign was assigned. In locations with very gentle slopes a (-) sign was applied, while locations with moderate and steep profiles were set to (+) and (++).

The fourth criterion considered for the location comparison was waves. Even though this criterion is directly related to the water depths near the coast is quite significant to consider it, bearing in mind that coastal structure design is mainly based on the wave conditions. (++) was appointed to locations with very low wave energy, (+) for locations with low wave energy, (-) for coasts with moderate wave conditions, and (--) to locations that are directly exposed to large waves.

The fifth criterion was more subjective and only depended on danger of causing coastal problems to adjacent coastal areas.

Geographic location is the 6<sup>th</sup> criterion that was taken into account, and it mainly considers the distance to the larger cities (Buenos Aires and Mar del Plata). Considering that one of the objectives of building a marina along the coast is to connect these two cities by sea, the ideal point is located in the intermediate distance between them. Approximately 250km from both cities is the ideal distance.

The last but not less important criterion parameter is based on the existing infrastructure. The (++) value was given to locations with enough infrastructure to allocate the tourist, and with numerous activities to entertain the visitors. In the other hand the (--) score was given to locations with no infrastructure and no beneficial activities that could enhance the use a marina port.

All these criteria are summarized in Table 20 Multi-criteria comparison, for every location.

**Table 20 Multi-criteria comparison**

Comparison	Sediment transport	Coastal stability	Distance to 5m depth (m)	Waves	Adjacent coast	Geographic location	Infra-structure	Score
General Lavalle	++	+	--	++	+	--	--	0
San Clemente bay	++	+	--	++	+	-	--	1
San Clemente north	++	+	--	++	++	++	-	6
Mar del Tuyu	+	--	+	+	--	++	+	2
Mar de Ajo	+	--	+	+	--	++	+	2
Pinamar	+	+	+	+	+	++	++	9
Villa Gesell	+	+	+	+	--	+	++	5
Mar Chiquita	-	-	+	-	+	-	+	-1
Mar del Plata	--	+	++	--	+	--	++	0
Miramar	--	-	++	--	+	-	+	-2

To compare each location with a different scheme and to validate the results obtained with the multi-criteria comparison shown in Table 20 Multi-criteria comparison, another comparison table was developed, in this case including a weighted value for each criterion, and also giving a certain grade to each location based on the computed values, the acquired knowledge from the field visit, and on the expectations of the client. Table 21, shows the assigned scores for each location corresponding to each criterion, also in the bottom row of the table the weighted value of each criterion is given. The scale for the comparison was set from 0 to 5; five representing the best possible score.

**Table 21 Assigned scores for each criterion**

Location/Criterion	Sediment transport	Coastal stability	Distance to 5m depth	Waves	Adjacent coast	Geographic location	Infrastructure
General Lavalle	5.0	4.5	1.0	4.7	3.7	3.0	3.0
San Clemente bay	5.0	4.5	1.0	4.7	3.7	3.0	2.0
San Clemente north	4.5	4.5	3.0	4.5	4.3	4.5	2.0
Mar del Tuyu	4.0	3.0	3.5	4.5	2.7	4.5	3.0
Mar de Ajo	4.0	3.0	3.3	4.2	2.7	4.5	3.0
Pinamar	3.8	4.0	4.2	4.2	4.0	4.5	4.2
Villa Gesell	3.8	4.0	3.7	4.2	2.5	4.0	4.2
Mar Chiquita	3.0	3.0	3.7	4.0	3.6	3.0	3.3
Mar del Plata	2.5	3.5	4.5	4.0	4.2	2.5	4.5
Miramar	2.5	3.5	4.0	3.5	3.7	3.0	4.0
<i>Criterion weight</i>	4	3	4.5	2.5	3.5	3	3.5

After assigning values for each location in relation to each criterion the following table was computed, it shows the weighted scores for every location, it also includes an overall score.

It was also concluded by using this comparison matrix that the most beneficial location is Pinamar, followed by San Clemente north, and Villa Gesell. An important thing to notice is that Pinamar has moderate to good scores in every category, while locations like San Clemente north, have very high and very low scores.

**Table 22 Weighted scores**

Location/Criterion	Sediment transport	Coastal situation	Bathymetry	Waves	Adjacent coast	Geographic location	Infrastructure	Total Benefit
General Lavalle	20	14	5	12	13	9	11	82
San Clemente bay	20	14	5	12	13	9	7	79
San Clemente north	18	14	14	11	15	14	7	92
Mar del Tuyu	16	9	16	11	9	14	11	85
Mar de Ajo	16	9	15	11	9	14	11	84
Pinamar	15	12	19	11	14	14	15	99
Villa Gesell	15	12	17	11	9	12	15	90
Mar Chiquita	12	9	17	10	13	9	12	81
Mar del Plata	10	11	20	10	15	8	16	89
Miramar	10	11	18	9	13	9	14	83

## 7.4. Promising locations

After comparing each location it was concluded that the most feasible locations are Pinamar and San Clemente north; scoring the highest out of the locations along the coast of the Buenos Aires province (Pinamar = 9 & 99 and San Clemente north= 6 & 92) .

### *San Clemente north*

San Clement north is located in the north of La Costa, this location is the geographical limit of the Rio de la Plata and the Atlantic ocean. The large sand spit formation has been growing in the past decades (Bertola, G.R., 2009), and based on the coastline modelling completed in this study it seems that the coast will continue to advance towards the sea. Waves in the area are relatively small ( $H_s=0.906\text{m}$ ;  $H_{max}=1.82\text{m}$ , at 7m water depth) in comparison to other locations along the coast of the Buenos Aires province; this is due to the fact that the sand banks near the coast dissipate the energy of incoming waves. The low wave energy is also reflected on the small net longshore transport rates of the area (approx.  $45,000\text{m}^3/\text{year}$  towards the north). Another important factor is that incoming wave directions are quite balanced; therefore the erosion/accretion problems derived after the construction of the port would be less significant.

One of the disadvantages of San Clemente north is that the required water depths for the marina port are far away from the coast, and to counteract this, either long breakwaters or large dredging works would be needed. The 5m depth contour is approximately 1800m away (during lowest astronomical level) from the coastline. Depending on the availability of materials and the cost of dredging, an ideal combination should be set.

In the other hand on of the main advantages of San Clemente north is that the adjacent coast is not developed; consequently the possible negative effect that the port

construction could cause is not as significant when compared to other locations along the coast, that have high value developments in their corresponding adjacent coast.

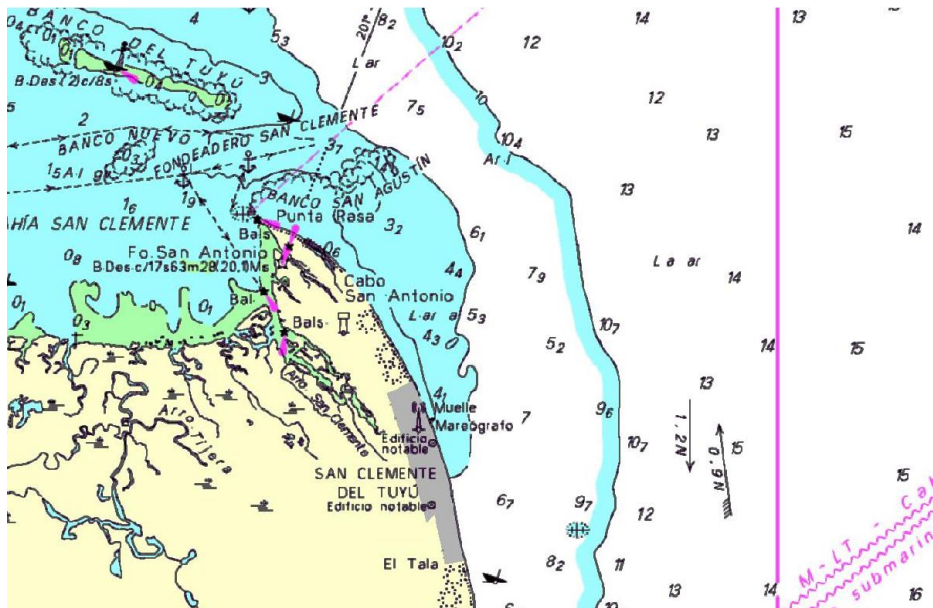


Figure 53 Near-shore bathymetry, San Clemente north

San Clemente north has one of the best geographic locations along the Buenos Aires coast, considering that is approximately 250km south of Buenos Aires city, and 220km from Mar del Plata (by sea) providing an intermediate point with similar distances in both directions.

Wave conditions and longshore transport rates in the area are relatively small, this together with the fact that the impact on the adjacent coast is not as significant are the key factors to make this location feasible. The largest disadvantage is the shallow water depths.

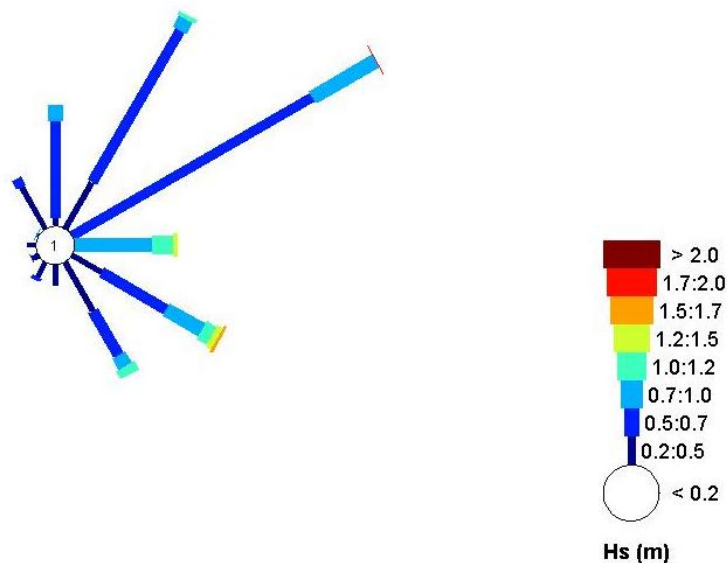


Figure 54 Near-shore wave rose San Clemente north

## *Pinamar*

When comparing Pinamar with San Clemente north, the main difference is the development and the existing infrastructure of both locations. Pinamar is already a consolidated city with plenty activities and resorts for tourism, like: beach clubs, hotels, beach cabins, restaurants, and golf courses.

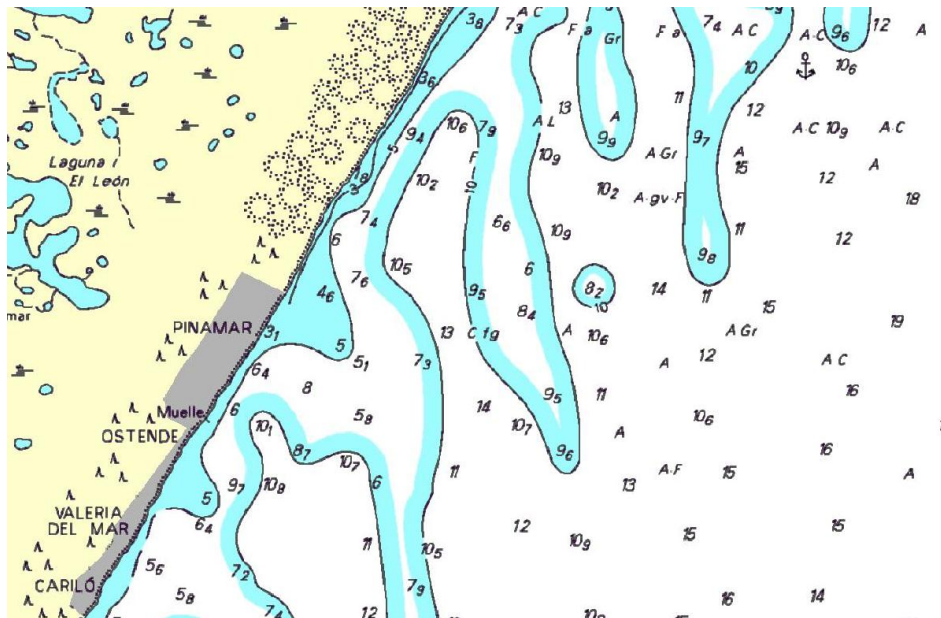
The net sediment transport rates in Pinamar vary between 80,000 and 107,000 m<sup>3</sup>/year towards the north. The coast of Pinamar is fairly stable, recording erosion only in certain spots, but mainly keeping its coastline position fixed, as shown the results of the coastline modelling; this is considered a neutral/positive situation, implying that erosive coasts create greater problems when a port is constructed. Wave conditions are slightly larger in Pinamar ( $H_s=1.1942\text{m}$ ;  $H_{\text{max}}=2.14\text{m}$ , at 7m water depth). No major difference in the height (above water level), and size of the armour units of the coastal structures is expected.

Another advantage over San Clemente north is that the required water depths are much closer to the coast; therefore shorter breakwaters could be used to reach the natural depths, added to that the dredging volumes would also be decreased.

Pinamar has wide and long beaches that cover the entire coast, building a port in the north side of the city would enhance deposition in the city and could partially solve the focal erosion problems, but in the other side of the port some erosion is expected. Similar to San Clemente north, a big advantage of this locations is that no developments near the coast are found in the adjacent coast to the north; in fact the nearest development along the coast is Nueva Atlantis and its located approximately 40km to the north, therefore there is not direct negative effect on any other city, and perhaps the area that could be affected could be protected with other coastal structures as groynes or offshore breakwaters, and if that is not sustainable, a maintenance program of nourishments could be implanted; although the ideal solution to the problem would be to create a sediment bypass system.

The geographic location of Pinamar is not as good as San Clemente north, but the distance between Mar del Plata and Pinamar could allow the users of the marina in Mar del Plata to travel more often to Pinamar, but in the other hand sailing from Buenos Aires city could be a greater challenge. Earlier in the study it was proposed that more than one port could be developed to properly connect the major cities of the Buenos Aires province, perhaps constructing a marina in San Clemente north with basic

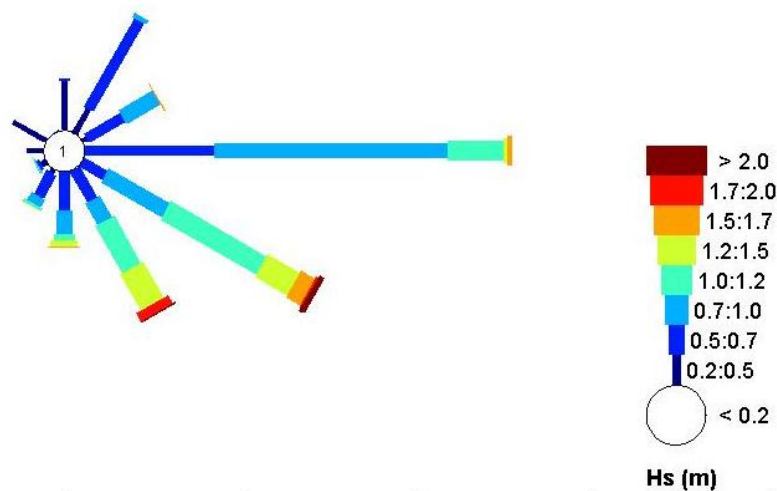
facilities, and the marina with full facilities and infrastructure in Pinamar could be a long-term planning solution. San Clemente north could be used as a pit stop in case of bad weather, or dangerous sailing conditions; and Pinamar for longer holidays, taking advantage of all the existing infrastructure of the city, which could ensure the tourist comfort and fun.



**Figure 55 Near-shore bathymetry, Pinamar**

The 5m depth contour line is located approximately 350 metres from the coast. A considerable difference when compared to San Clemente north where the beach slope is very gentle and the required water depths are very far from the shoreline.

It can be seen that the wave conditions are larger compared to the north area of La Costa, consequently the transport rates are also higher. A stronger dominance from the southeast waves can be seen in Figure 56 Near-shore wave rose Pinamar.



**Figure 56 Near-shore wave rose Pinamar**

## 8. Preliminary port design

### 8.1. Port layout alternatives

Different preliminary layouts were developed to deliver an idea of the orientation and distribution of berthing places in the marina area. The ideal layout should avoid sedimentation problems in the entrance channel of the port, and at the same time evade damaging the adjacent coast. Since this is very hard to obtain in an open coast like the Buenos Aires province, the next step in the design process is to compare the benefits and drawbacks of each alternative.

The following sketches were completed based on other existing marina ports around the world, to explain the different features that have to be taken into account in a more detailed design process.

#### *Alternative A*

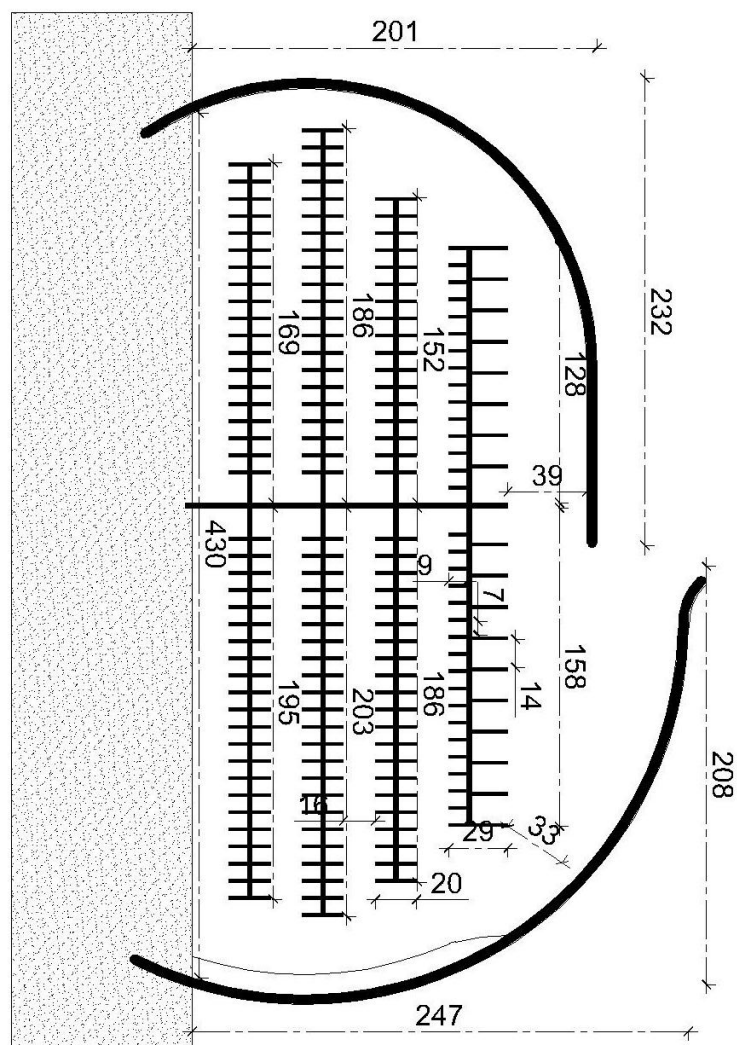


Figure 57 Marina layout A

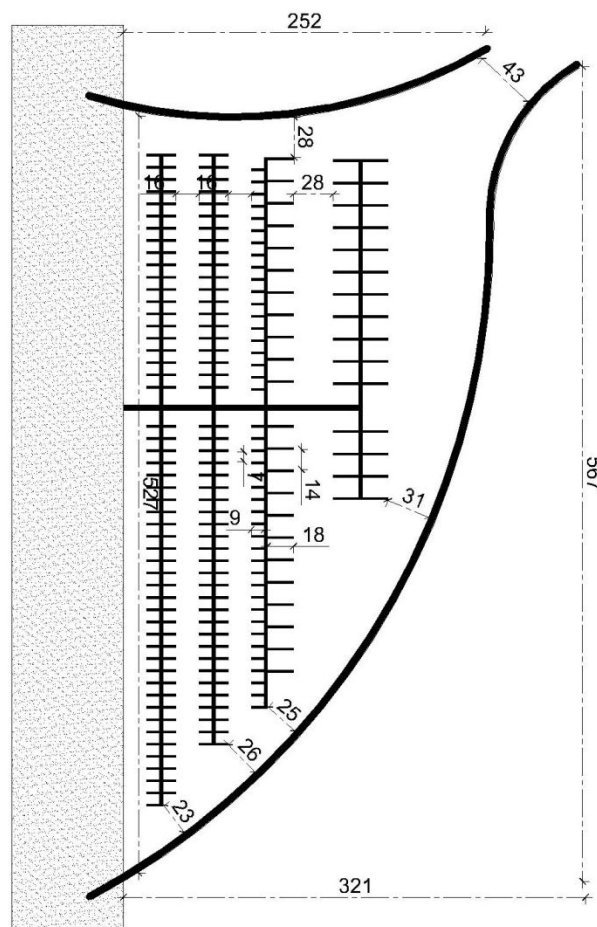
This layout consists of two main breakwaters to protect the port area, against: waves, currents, and wind. Larger yachts are expected to make berth near the entrance to avoid dredging as much as possible.

The protected water area is approximately 83,000m<sup>2</sup>; the design fulfils the previously determined dimension for channel, fairway, and berthing places. Approximately 400-450 ships can make berth simultaneously at the marina (depending on the ships size).

The southern breakwater has a length of 408 metres, and 400 metres on the up-drift side.

Since the dominant transport direction is from south to north, the southern breakwater extends further into the water to avoid sedimentation inside the entrance as much as possible. The ideal solution to sedimentation problems would be to extend the breakwaters until the necessary water depth (around 5metres at the entrance); although that would block a larger volume of sediment, that eventually should be dredged and deposited in the up-drift side of the port to avoid erosion problems.

*Alternative B*



**Figure 58 Marina layout B**

The preliminary design shown in Figure 58 Marina layout B, has two breakwaters; the southern breakwater is the main one since it's the one protection the port from most waves, with a length of 705 metres, and extending out to the sea approximately 320 metres. In the other hand the northern breakwater is a secondary structure to protect against waves coming from the north and north east, the length of this breakwater is of approximately 250 metres.

Different to the previous design, the entrance channel of this port is oriented to the north-east. Larger waves in the area come from the south and south-east, and while they propagate to the shore the incoming angle becomes almost perpendicular to the coast.

The protected area of this design allows 450 ships to make berth simultaneously, in an area of 103,00m<sup>2</sup>.

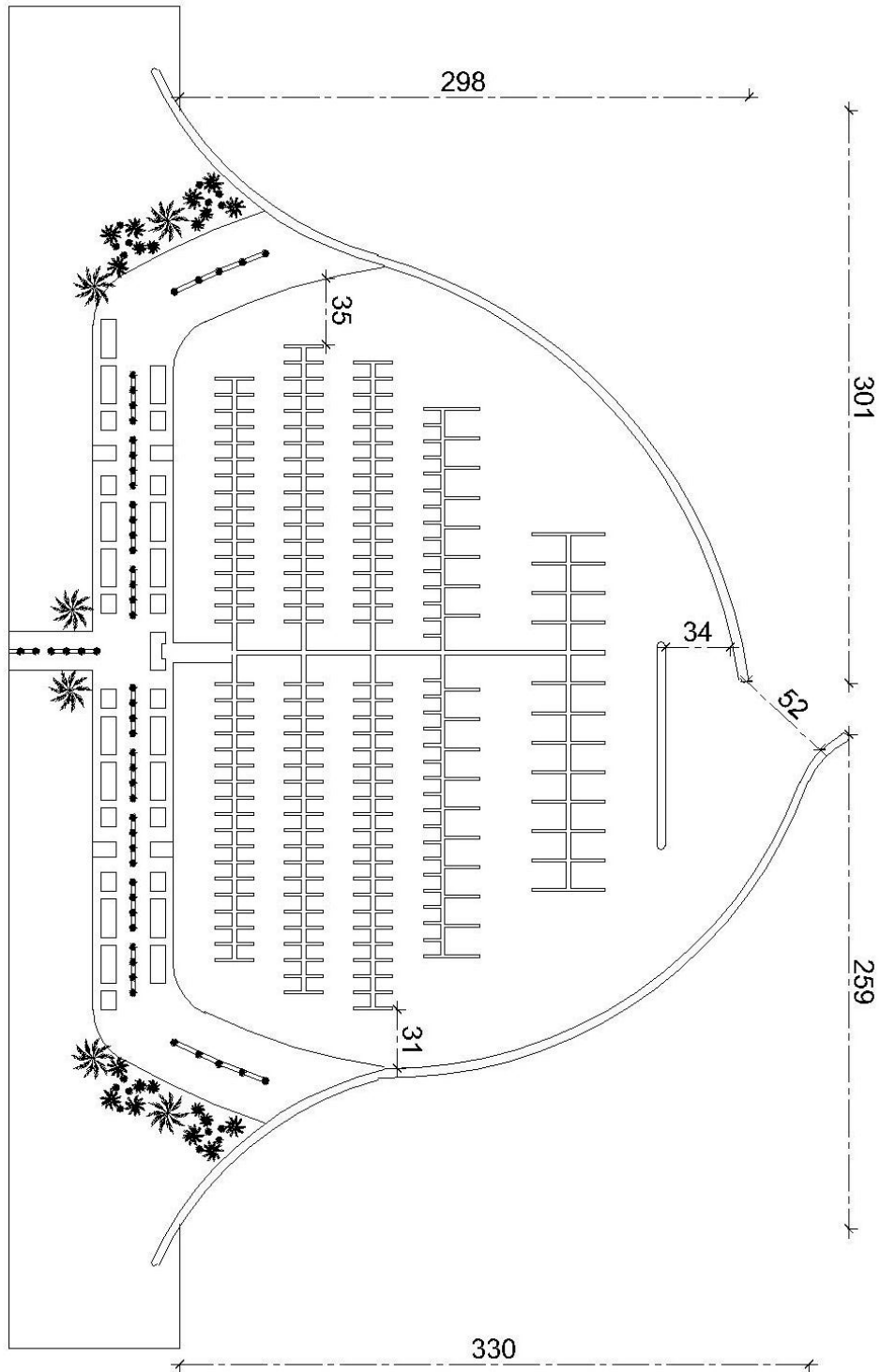
One advantage of this design is that the length of the breakwaters almost reaches the 330m that are required to place the mouth of the port near the required water depths (5m for Pinamar)

### *Alternative C*

Layout C shows a combination of the previous layouts. One of the important advantages is that the length of the breakwaters is extended until the required natural water depths like layout B (for Pinamar), which offers a smaller dredging volume, and less sedimentation problems. One other feature that was added in this layout was the use of a detached breakwater as a protection structure for waves approaching the port and entering thru the mouth.

As in layout A, loading facilities for fishing vessels or cargo vessels were placed near the coast on both sides of the port. This will offer an extra source of income during the low tourism seasons.

This layout requires 907m of breakwaters, covering an area of 107,000m<sup>2</sup>.



**Figure 59 Marina layout E**

## 8.2. Selected layout

### *Distribution*

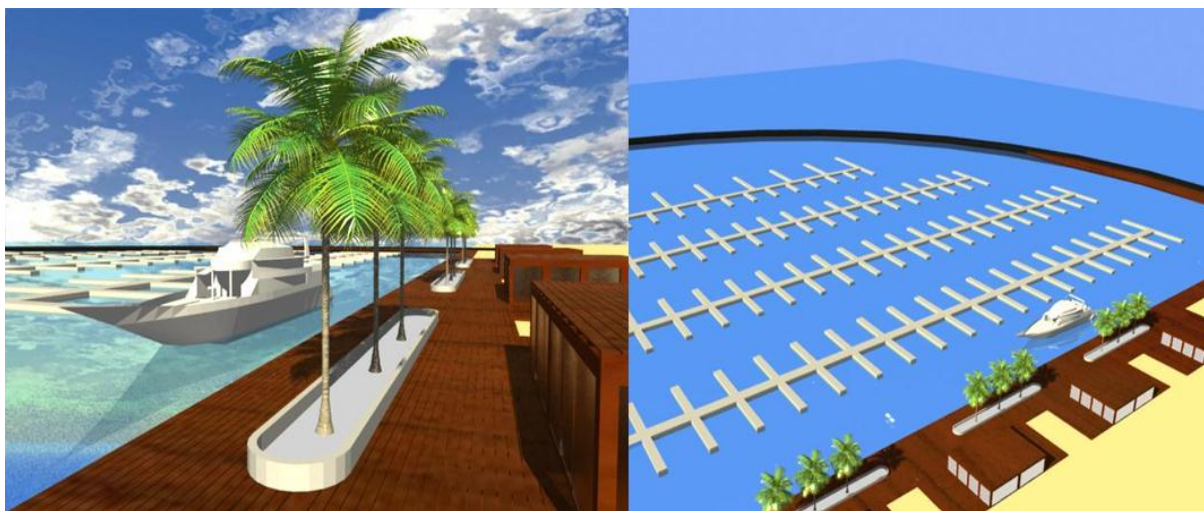
It was determined that the best layout alternative was layout C; since it provides a great advantage in relation to water depths and sedimentation problems, requiring smaller

dredging volumes, and relatively short breakwaters when compared to the other alternatives.

The design would specially fit for Pinamar, where the required water depths are closer to the shoreline. Adaptations and changes to the design are expected, since the idea of this design is only to provide insight on the minimum required dimensions and distribution of facilities.

One solution to avoid sedimentation problems inside the port would be to extend the breakwaters until the natural required depths are reached; for San Clemente north this distance is approximately 1,500 metres from the shore, while for Pinamar the distance is around 330m (So with this design it is reached).

Figure 60 Marina design, shows a schematization of how the marina could look like.



**Figure 60 Marina design**

The sketch shown in Figure 60 Marina design, attempts to show the marina distribution. It can be observed that larger berths are located near the entrance where natural water depths are larger, also a small loading and unloading berth is observed on the down-drift side of the port, and it is designated mostly for fishing vessels.

### *Berths*

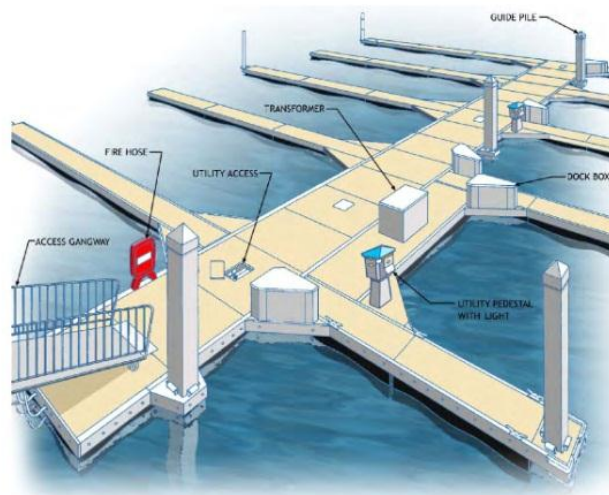
The dimensions of a marina port depend directly on the design ship for the port. Other structures like the pier systems (fixed-on piles, or floating-floating decks with guiding piles) depend largely on the tidal variation. The (Unified Facilities Criteria (UFC), 2009) design manual sets a limit on 3 feet (1 metre) of tidal variation as a maximum to use fixed piers, and for variations larger than 1 metre a floating system is recommended.

Floating fingers can be aligned and guided by wooden piles, concrete piles, steel piles, or a combination of the previously mentioned. The material depends on the availability of

the material itself for each location, and the climatic conditions; perhaps using wooden piles is initially cheaper, but in the long run the treatment to maintain the wood in good condition is a drawback (especially for countries without a well prearranged maintenance program). Steel piles in the other hand and initially more expensive, but need less maintenance, these are typically round piles of different thicknesses, depending on the horizontal loads induced by the moored vessels.

By far the most common and used worldwide system of piles, is concrete. Concrete piles are used in a cylindrical form and also with a square cross-section. Both shapes have advantages; for instance a round pile can be easily driven into the soil, while square piles tend to rotate and consequently affect the alignment of the floating deck. Although a disadvantage of the circular piles is that they are more costly, and that they tend to wear down the rollers that are used to guide the pile during the water level fluctuations. Taking into account the recommendations of the (Unified Facilities Criteria (UFC), 2009) it was concluded that the most feasible alternative for the Buenos Aires coast is to use floating finger piers, considering that the tidal range is larger than 1 metre (which is the recommended limit), and that the variations induced by storm surge could also increase the water level difference.

The following figure shows a schematization of a floating finger pier system with rectangular piles.



**Figure 61 Schematization of floating finger pier system.**

### *Dredging*

The dredging volumes required for the port largely depend on the near-shore bathymetry. An approximation can be done, by assuming a constant sloping bottom profile shape from the minimum design water depth (4.50m during lowest astronomical

tide) at the entrance channel to the shallower area of the port where the required depths is smaller (4.00m).

In fact, by looking at the near shore bathymetry it was deduced that for Pinamar the depth 330m away from the shore is approximately 5m, fairly similar to the required depth. Only some minor dredging works near the entrance would be necessary, but inside the port a larger volume of approximately 400,000m<sup>3</sup> of sand would need to be dredged to obtain the required water depths inside the port; although if the design is modified and the breakwaters extended further out, the required dredging volume could be decreased, and the sedimentation rates in the entrance channel also reduced. The negative effect of extending the breakwaters is that a larger percentage of the longshore transport would be blocked and consequently erosion and depositions problems adjacent to the port enlarged.

If this same design is used for San Clemente north a larger dredging volume would be needed, and added to that, the creation of an exterior access channel. The existing depths 250m away from the shoreline in San Clemente north are of approximately 2.5m; therefore an extra 1.25m would need to be dredged in the entrance channel, to reach the required design depths. This is definitely more work, and initially less feasible, but in fact since the coast near San Clemente north has smaller waves, and calmer conditions in general, the maintenance dredging could be done within a longer period of time.

### *Coastal protection*

For the design of the coastal structures in the area, a return period has to be set, mainly depending on the lifetime of the structure. From this, the corresponding wave and wind conditions can be estimated. After calculating these values, different empirical formulations can be applied; for example Hudson (1953), Van der Meer (1988), or Van Gent (2003) equations can be used to estimate the armour sizing that would enhance stability of the breakwater.

Other processes that have to be taken into account in the design approach are for example: Wave transmission, long wave propagation inside the port, wave reflexion and wave overtopping. (Thoresen Carl. A, 2010)

Since the proposed marina is relatively small, using concrete units would not be feasible, taking into account that all the casting for the concrete is expensive, as well as the experienced labour to build and place the units with a proper packing density. It is

considered that a rubble mound breakwater is the best option for the area, as stated during the visit the cost of the rock is mainly affected by the transportation cost. A solution that might help reduce the cost of the transportation would be to load the rocks into barges and transport them by sea. This greatly depends on the distance from the quarry to the site. Another advantage of the rubble mound breakwaters is that the placement of the rocks can be done with different types of equipment, even with excavators placed on top of pontoons, or with any available larger cranes.

## 9. Conclusions and Recommendations

This research sought to analyse the coast of the Buenos Aires province and determine which location along the coast is more feasible for the development of a marina port. To accomplish these goals, a broad literature review was completed, followed by a field visit, and supplemented by the core part of this thesis study, which contains the set-up and the results of the wave model (Delft3D-WAVE) and the coastline model (UNIBEST-CL+). This was followed by the comparison of locations and the development of preliminary layouts of the marina port.

### 9.1. Conclusions

#### *Port dimensions*

The marina capacity was defined based on the requirements provided by the “Fundacion Bolsa de Comercio de Mar del Plata”. Afterwards the preliminary dimensioning of the port was completed based on the (California department of boating and waterways, 2005) and the (Unified Facilities Criteria (UFC), 2009), using two design ships, one considered as the largest expected vessel (up to 20m length), and the other considered as the most common sailing boat (6m length) for the coast of Argentina. It was concluded that the width of the exterior channel should be of at least 30.5m and of 23m for the inner channels, it was also defined that the berth spacing for large vessels should be at least 14m wide, and 7m for the common design ship (when using double berthing). It was also determined that the minimum required water depth at the entrance of the port should be 4.5m, and 4m inside the port during lowest astronomical tide.

#### *Buenos Aires coast*

Based on the literature review, the site visit to Argentina, and the expertise of the people involved in the project the following locations were considered as feasible:

- General Lavalle
- San Clemente del Tuyú (bay area and open coast)
- Mar del Tuyu
- Mar de Ajo
- Pinamar
- Villa Gesell
- Mar Chiquita
- Mar del Plata
- Miramar

The coast was classified as an Amero-trailing edge coast, formed by a wide continental shelf, meaning that the coastline is far from the tectonic plate boundary; therefore is considered as a stable coast. It was also discovered based on previous studies of the Buenos Aires coast that the coast was mainly shaped in the late Holocene period (last 2,000 years).

The coast of the Buenos Aires province can be divided in three sections. First the section in the north covering from Punta Rasa to Punta Medanos showing relatively parallel and gentle beach slopes, and small dune fields; the second section going from Punta Medanos to Mar Chiquita composed by wider beaches, more complex and steeper profiles, and sand ridges near the coastline of up to 10km length and 2km width. Finally from Mar Chiquita to Miramar the coast was classified as a less stable coastline with cliffs, pockets beaches, and steeper beach profiles.

The tidal regime in the area was classified as a mixed semi-diurnal tide with mean amplitude of 0.81m and maximum amplitude of 1.66m.

Storm seasonality for the area is not very significant, but larger storms were recorded during winter months, with storm surges of up to 1.75m during very severe storms, as the one recorded in 1999 and presented by (Dragani, W., Alonso, G., 2011)

The extracted wind field from the NOAA data base shows wind coming from different directions, with slight dominance of north winds (in percentage of occurrence), it also shows that the stronger winds come from the south, reaching up to 20m/s velocities.

Offshore waves along the Buenos Aires coast have a slight variation from north to south, showing a larger percentage of northeast waves in the north section, and a stronger dominance of south waves near the south; although it was also concluded that the larger wave heights were mostly coming from the south along the entire offshore boundary. The extracted offshore wave climate shows a good correlation with previous reports from (Waterman, R.E., 1994), and (Universidad Nacional de Córdoba y Municipalidad General Pueyrredon, 2007), in which offshore wave data was also used.

Maps of erosion and accretion rates along the coast, together with longshore transport rates were analysed, although it was hard to conclude trends or rates since most of the studies presented different methodologies and contradicting results. One of the conclusions that was derived based on the previous studies as the one completed by

(Scalise, A.H., Schnack, E.J., 2007), was that erosion problems along the coast were significantly enhanced by urbanization near the shoreline.

### *Wave modelling*

By implementing the wave propagation model (Delft3D-WAVE), the near-shore wave climate was obtained, forced with the offshore wave data obtained from NOAA, and classified in 125 scenarios with ORCA tools. Based on this it was concluded that:

- Wave energy dissipation is very significant in the northern section of the coast, due to the large area of very shallow waters
- Wave heights increase from north to south, mainly due to the changes in the steepness of the near-shore bathymetry, since the coast in the north has very gentle slopes, and in the other hand the coast near the south is composed by very steep profiles
- Larger storms come from the southern boundary, which in fact also explains the fact that locations like Miramar and Mar del Plata receive the largest waves
- Waves coming from the northeast are the most occurring in the north section, while waves from south and southeast are the most dominant for the southern section of the Buenos Aires coast
- Coastal orientation has a significant effect on wave height variation, since less friction is encountered if the depth contours are perpendicular to the wave propagation direction (as it is in Miramar, where wave almost have no refraction and reach the coast with an angle very similar to the offshore angle)
- The sand ridges located near the coast of Punta Medanos, Pinamar and Villa Gesell induce wave energy concentration in certain areas
- Most occurring scenario along the entire coast are represented by northeast waves of up to 1.5 offshore, with wind coming from the same direction (1,610 events during the 13 years period of wave data)
- Second most occurring scenario (1,505 events) shows waves coming from the southeast with heights of up to 2m offshore, and wind from the east. Reaching the coast with heights of up to 1.4m in Mar del Plata and with wave heights as low as 0.3m in the northern bay area

### *Longshore transport and coastline modelling*

Using UNIBEST-CL+ as a tool to estimate longshore transport rates along the coast the following conclusions were derived:

- The variation in the wave climate is directly proportional to the longshore transport rates
- Slight changes in the coastal orientation can produce large differences in net longshore transport rates
- The dynamic boundary depth has to be selected carefully, since the variation of the transport rates is also directly dependent on it
- Sediment size is another major parameter to carefully define when estimating longshore transport capacities
- The longshore transport rates increase from north to south, mainly due to the fact that the wave are stronger in the southern section of the coast
- Transport rates calculated in Punta Medanos vary significantly, probably due to the fact that the coastline orientation changes rapidly over a short distance, and also considering that the profiles are steeper near the coast
- Estimated transport rates for Mar del Plata and Los Acantilados show a good correlation with the results obtained in the study by (Van Rijn, L.C, 2008)
- Transported volumes along the coast of Mar del Plata may vary, since the groyne and the existence of the Mar del Plata port block large volumes of sediment
- The estimated accretion and erosion rates along the coast fit with the results obtained by (UCO-Ministerio de Economia, Provincia de Buenos Aires, 2011) and (Erosion Costera Provincia Buenos Aires, 2012), showing deposition rates along the northern section of La Costa, erosion rates in Mar del Tuyu and Mar de Ajo, a more-less stable coast in Pinamar and Villa Gesell, and more significant coastline changes north of Mar Chiquita

### *Location selection*

Each locations was compared by using a multi-criteria table, in which weighted factors were assigned for each criterion, another table to compare each location was developed assigning + and – signs in relation to each location and the corresponding criterions. By

addressing the situation in these different ways it was concluded that the most feasible location for port development along the Buenos Aires province, is Pinamar.

It was defined as a location with moderate longshore transports rates, mild to moderate wave conditions, also providing the required water depths (5m) in a distance of 330m from the shoreline which compared to most locations along the coast is relatively close.

Another major advantage of Pinamar over the rest of the locations that were considered is that it already has sufficient infrastructure to allocate and entertain marina users.

Its coastal stability (no large erosion or accretion rates) were also considered as positive since no significant erosion problems take place near the area. Added to all the previously mentioned advantages, another feature that makes Pinamar more suitable than other locations is that it has no urbanization to the north of the city, and since the net longshore transport is towards the north, the negative effect that the port could create, would not have a very significant effect, and perhaps could be counteracted by a groyne field, nourishments, or ideally by using a sediment by-pass system.

#### *Preliminary port design*

Three layout alternatives were derived based on literature, and other examples of marina ports around the world. The most promising layout consists of a marina with a capacity for over 400 vessels, allowing vessels of up to 20m length. It was concluded that this layout was the most feasible because the required water depths are reached at the mouth of the port without any dredging works; it is also more feasible because it provides a large area for berthing and navigation, by constructing relatively short breakwaters (approximately 907m), and a detached breakwater behind the entrance, to stop the incoming waves that might propagate through the entrance the port.

The other advantage of this layout was that the entrance was further outside the surf-zone; consequently smaller sedimentation rates near the entrance are expected.

Based on the tidal range and the local conditions of the area, it was also concluded that floating fingers (aligned by either squared or circular concrete piles) were the most suitable berthing system, since the tidal variation is over 1m, which in fact is the recommended limit to use fixed structures. (California department of boating and waterways, 2005)

## 9.2. Recommendations

The main recommendations for further study are mainly linked to the availability of data, and are listed as follows:

- Obtaining an updated more detailed bathymetry of the entire coast would allow the wave model to better simulate the wave climate near-shore, and enhance the precision of the longshore and coastline results
- Measure profiles along the coast to have a full description of the coastal development in the upper beach and beach section
- Collection of sediment samples along more locations of the Buenos Aires coast, and at different water depths
- Deployment of wave buoys along the coast would be a good way to obtain near-shore wave data. And would also provide a comparison set of data to validate the estimated wave climate based on offshore data
- Implement monitoring campaigns to obtain retreat and advance rates of the coastline position along the coast, including detailed near-shore bathymetries in the most relevant locations of the Buenos Aires coast

In relation to the design of the port it is recommended to:

- Use a smaller wave propagation grid in the area to obtain a more detailed wave climate near-shore
- Further analyse the longshore transport rates of the selected area (Pinamar), including net and gross transport rates in different rays near the city
- Obtain a detailed bathymetry to be able to accurately estimate the dredging volumes
- Depending on the orientation of the coast, vary the orientation of the breakwaters and arrange the berthing facilities
- Predict sedimentation rates
- Predict wave propagation and reflexion inside the port
- Define in a more detailed way the number of berthing places, design ship, and expected use of the marina throughout the different season of the year
- Do stability calculations for the breakwater structures
- Define and estimate wave transmission and overtopping rates
- Once the layout of the port is finalized, use a wave and flow model to estimate the effect of the construction on the coast

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## Appendix A: Buenos Aires Coast

### Sea level rise:

A study related to sea level rise completed by Paula G. Diez, Gerardo M.E. Perillo and M. Cintia Piccolo, analysed the coastal vulnerability of the Buenos Aires province. The province was divided in three sections; the mid-section covers the whole area of the present study, consequently only the results of this section are explained. The physical variables taken into account to determine the vulnerability of the coast were:

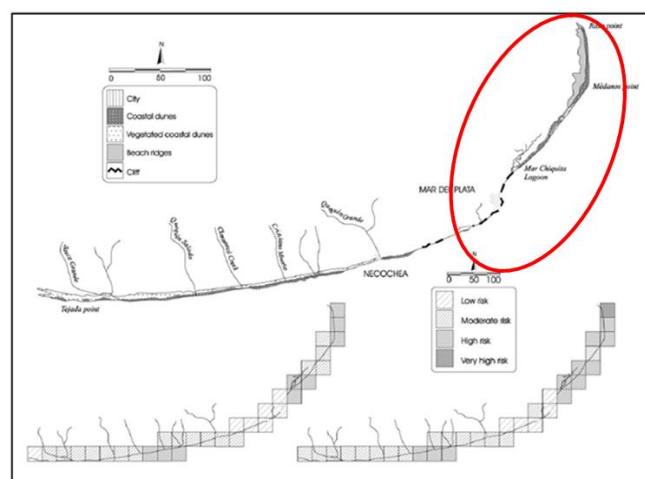
- A. Elevation (m) of the areas near the coast.
- B. Sea level rise rates (mm/year).
- C. Geology, related to the resistance of the substratum.
- D. Geomorphology, consisting of the characteristics and eroding levels of the area.
- E. Shoreline erosion/accretion (m/year)
- F. Average wave height (m).
- G. Mean tidal range (m).

The two equations used to analyse the vulnerability are as follows:

$$CVI5 = \sqrt{X_1 \times X_2 \times X_3 \times X_4 \times X_5 \times X_6 \times X_7}$$

$$CVI6 = 4X_1 + 4X_2 + 2(X_3 + X_4) + 4X_5 + 2(X_6 + X_7)$$

Were each variable was assigned a value between 1 and 5 (1 representing the lowest risk and 5 the highest).



**Figure 1 Map of Coastal Vulnerability Index (CVI).<sup>1</sup>**

<sup>1</sup> (Diez, P.G., Perillo, G.M.E., Piccolo, M.C., 2007)

Figure 1 shows the results of both equations, and the characteristics of the coast. It can be seen that the coast from Villa Gesell to San Clemente del Tuyú is classified as a dune coast with beach ridges. In the other hand the coast near Mar del Plata is classified as cliff coast. Related to the vulnerability to sea level rise, the coast was classified between the moderate and high risk with equation CVI5, and moderate to very high with the CVI6 equation. The very high risk section is located in the northern part covering San Clemente del Tuyú. Conclusions of this study explain that an increase in the sea level rise would enhance erosion of the dunes and flooding of low areas. (Diez, P.G., Perillo, G.M.E., Piccolo, M.C., 2007)

#### *Influence of vegetation on dune fields:*

A study by (Isla, F.I., Bertola, G.R., Farenga, M.O., Serra, S.B., Cortizo, L.C., 1998), where the goal was to analyse the influence of planted vegetation in the dunes of Villa Gesell concludes that no significant erosion is observed. Results of coastline variation were obtained based on photographs taken during the previous 24 years.

Perhaps it is explained that the dominant sediment transport of the area is towards the North-East with rates varying from 400 to 700m<sup>3</sup>/year. Indeed dunes in the area were affected by the vegetation, proof of the effect of vegetation is shown by shape of the dunes, which went from being perpendicular to the coast to a more parabolic shape. Eolic transport has an important effect in the area as well, wind takes the finer sand up to the dunes where it is captured by the vegetation, whereas the coarser sand stays on the beach front.

#### *Profiles:*

A study by (Bertola, G.R., Cortizo, L.C., 2005) did a schematization of the different profile types in the coast of the Buenos Aires province based on a previous classification by (Isla, F.I., Cortizo, L.C., Turno Orellano, H.A., 2001), it is explained in the article that most of the transport replenishing the dunes is sediment driven by wind. In order to measure the sediment transport in the dune area, devices made out of wood sticks marked with dimensions every centimetre, were planted in the dunes with a separation of 10 meters. The typical profile shape of each location is shown in the following figure.



Figure 2 Profile classification and shape<sup>2</sup>

The coast of Santa Teresita and locations nearby like San Clemente del Tuyú shows profiles typically formed by long and high dunes with gentle slopes and continuous form, profiles further south in Pinamar and Villa Gesell are shaped by a stable profile, normally not as wide when compared to the northern part of the coast. The classification from the same study also shows that the coast in Pinamar, Villa Gesell and Santa Teresita has sediment supply starvation. At Mar del Plata the profiles start changing into cliffs with and without beaches on the foot of the cliff.

The coastal profiles of the area were also analysed and measured in consecutive years (20/11/2006 and 23/03/2007) by Armando Hector Scalise and Enrique Jorge Schnack. For the coast of Villa Gesell three profiles were analysed, the first called “North profile” had a significant reduction from 60m of beach to 35m (Although it is mentioned that the tide levels were not equal). For the second profile called “Central profile” accretion was observed, while for the third profile named “Profile South” a balanced situation was detected. In general, during the measured period the beach increased its volume.

The same study was completed in Pinamar, measuring three profiles 100m away from one another. The three dune profiles were accreted during this period, although the frontal beach suffered some erosion. It was also observed that the slopes were increased, compensating by the shortening of the beach.

<sup>2</sup> (Bertola, G.R., Cortizo, L.C., 2005)

For the coast of Mar de Ajó, the slope in general went from being of 4.4% to 8.62%. While for the frontal beach the slope was almost doubled (2.2% to 4.13%). During the measured period the beach lost sand, it is interesting to point out, that this location was the only location of the coast under study that had negative balance of sediment.

For the city of San Bernardo results show that slopes in both dune and frontal beach were increased, also the sediment balance was positive. It was observed that the submerged bar migrated on-shore during the period.

In Santa Teresita/Mar del Tuyú the beach width was increased by 15m (65m to 80m), it was also noticed that more irregular profile was created compared to the situation in 2006. A sand bar was observed 50m away from the measuring station in 2006, for the 2007 measurement the bar had migrated on-shore to a distance of about 40m from the station. Slopes in the area were constant, and in general the coast had accretion.

The profile in San Clemente del Tuyú was the widest beach measured, with more than 175 m. The dune area suffered no changes; perhaps all the morphodynamic changes occurred in the beach front, particular small depressions in the beach observed in 2006 were covered by sand in 2007. Also on-shore bar migration was observed. A positive balance of sediment was recorded for the location.

The last section that was measured by Armando Hector Scalise and Enrique Jorge Schnack in 2007 was Santa Teresita and San Bernardo del Tuyú. The conclusions of their study show that the area has a constant flat bottom with parallel depth contours.<sup>3</sup>

The sediment type observed in the dunes of the coastal stretch from Punta Rasa to Villa Gesell is in the range of  $2.70\phi$  and  $1.60\phi$ , with an average of  $2.36\phi$ . The sand grain size variation was also related to the location, beaches near the south like Villa Gesell and Pinamar had the coarser sand, and in the other hand beaches towards the north in "Partido de la Costa" had finer sand.<sup>4</sup>

Sediment samples taken from the frontal beach had a maximum of  $2.7\phi$  and a minimum grain size of  $1.95\phi$  with an average of  $2.41\phi$ .<sup>5</sup>

Another article that focused on the profile change, was completed by Walter Dragani and Guadalupe Alonso, they analysed some locations on the Buenos Aires province. The SBEACH model for profile evolution was used in order to determine the profile change

<sup>3</sup>Information under the Bathymetry section was obtained from: (Scalise, A.H., Schnack, E.J., 2007)

<sup>4</sup> (Scalise, A.H., Schnack, E.J., 2007) was used for the section on Sediment issues.

<sup>5</sup>  $\phi$  is a unit to measure grain size equal to  $\phi = -\log_2\left(\frac{D}{1\text{mm}}\right)$ , sand is in the range of  $-1\phi$  and  $4\phi$ . Further information can be found at: (Harris, C.K., 2003)

after a “large storm” (72 hours). The input parameters used for the study were obtained based on field measurements and existing data. For instance the tidal range and storm surge levels were obtained from the (Servicio de Hidrografia Naval, 2012).

In the other hand, the wave data used was obtained after observing 10 waves at the breaking point and averaging the wave heights. For the wave period a similar method was used, the total time elapsed between eleven consecutive waves was measured, and then divided by the total number of waves to obtain the average period. The incoming wave angle was also assumed after observing waves and assuming a straight coast.

The oceanic climate was assumed equal for all the locations, and only the profiles and grain sizes were changed for each corresponding profile. Some of the locations analysed by Walter Dragani and Guadalupe Alonso were; Mar de Ajó and Villa Gesell (locations also selected as initial alternatives for fishing port development in this study). For the first it was observed after running the SBEACH model, that the berm disappears, the profile descends a few decimetres, and it retreats considerably (decimetres), erosion rates of around  $23\text{m}^3/\text{m}$  are observed. Important to say, a sand bar is formed with eroded sediment coming from the upper profile section. For Villa Gesell same situation is observed, but perhaps with a greater impact on the coast, causing erosion rates of up to  $43\text{m}^3/\text{m}$ . (Dragani, W., Alonso, G., 2011)

#### *Danger/Vulnerability/Risk of the coast:*

German R. Bertola and Alejandra Merlotto analysed the coast of the Buenos Aires province, from Punta Rasa to Partido de Necochea, their goal was to classify the coast in three different terms; Risk, Danger, and Vulnerability.

Risk can have different meanings depending on the authors, for this study risk was defined as the damage or expected loss, related to the probability of occurrence of natural hazards, as well as the vulnerability of the elements exposed in a specific location, during a given time.

Danger was represented as a latent danger associated with a phenomenon of natural or technological origin, which could happen during a given period in a selected location.

The other aspect used in the study by German R. Bertola and Alejandra Merlotto, was vulnerability, defined as the ability of a person or group to adjust, resist, anticipate, and survive a natural hazard.

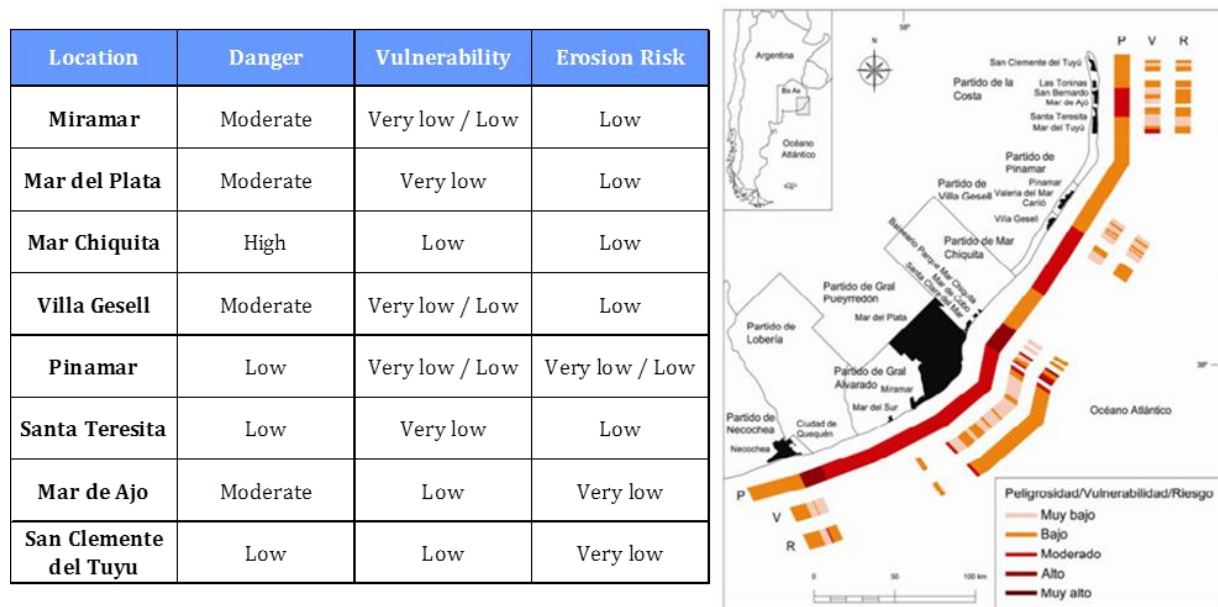
To calculate danger and vulnerability, some factors related to the coast and to the locations were compared; values were assigned for each location. The factors

determining the danger and vulnerability were: Storm surge, Tidal range, Wave height, Wave breaking type, Grain size, Beach width, Slope, as well as some social and economic factors like population and infrastructure. Danger was classified as low and moderate around the coast. Perhaps vulnerability had a greater variation, showing a coastal classification from very low to moderate. (Merlotto, A., Bertola, G.R., 2011)

The risk was calculated as shown below:

$$Risk = (Danger\ index + Vulnerability\ index) / 2$$

The risk assessment shows that the province of Buenos Aires has a predominant low risk, with some small sectors of the coast with moderate and high risk. A summary table was completed based on the results by German R. Bertola and Alejandra Merlotto.



**Figure 3 Danger/Vulnerability/Risk map of the Buenos Aires coast.**<sup>6</sup>

It can be seen that all the locations taken into account for the detailed study of feasibility of small ports in the coast of Buenos Aires, are categorized as “Low” and “Very low” locations in relation to coastal erosion risk.

*Coastal protection alternatives:*

A report by (Van Rijn, L.C., 2008) explains the broad coastal characteristics of Mar del Tuyú. A beach width of around 20 to 40m was observed in the field visit, buildings on the coast were located close to the high water line without any protection against storm waves. Proposed solutions to avoid erosion were: restoration of frontal dune, or the placement of a rock revetment. For the dune restoration plan, coarser sand should be

<sup>6</sup> Summary table and Danger/Vulnerability/Risk map obtained from: (Merlotto, A., Bertola, G.R., 2011)

used to create a dune of around 5m high to withstand a large storm. In the rock revetment scenario the rock structure should be 5 metres high and nourishment works should also be carried out. (Van Rijn, L.C., 2008)

Some nourishment works have been executed in the coast of the Buenos Aires province; for instance for the city of “Las Toninas” located a few kilometres away from San Bernardo, two nourishments have been done. The first in 1998, incorporated 20,000m<sup>3</sup> in the dune and beach area over a distance of 540m, the second work was completed in 2007, and consisted on placing 30,000m<sup>3</sup> in the same dune area, supported by a geotextile in the dune foot. Other used methods to counteract erosion in the dune field are wind barriers; consisting of wooden sticks placed together to capture sand that habitually would be transported by wind. (Marcomini, S.C., Lopez, R.A., 2010)

As a consequence of coastal erosion, the management policies of the “La Costa” area changed in 1997, when it was established as forbidden to extract sand from the dunes or the beach front. After that policy was implemented cities like San Clemente del Tuyú decided to enhance accretion in the dune areas by placing wooden and plastic fences to capture sand. Fences were placed with different alignments to find out which orientation and shape had more favourable results. Type A: parallel to the coast on foredune crest, type B: parallel to the coastline on the seaward base of the dune, type C: crossing the foredune, and type D: with a certain angle with respect to the foredune.

Results of this study completed by (Lopez, R.A., Marcomini, S.C., 2006) shows that the maximum efficiency of the structures was between 150 and 250 days after placement, reaching accumulation rates of 0.12 m<sup>3</sup>/m/day and vertical accretion of 0.04cm/day. Regarding the effectiveness of the different fences, all the fences that were parallel to the main wind direction had excavation; it was recommended by the authors that perhaps using a device with zig zag shape would counteract this problem.

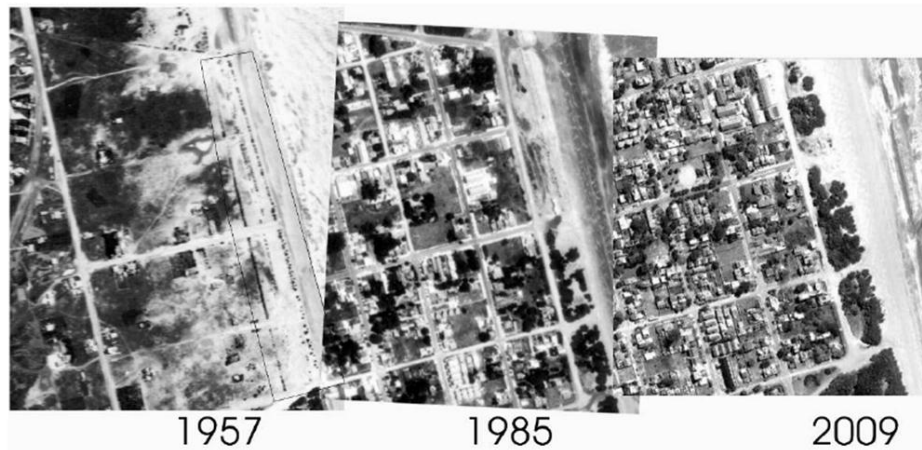
An estimation of the total volume accumulated in the dune area, shows that about 800,000m<sup>3</sup> of foredune had been recovered along a coastal stretch of 15km of coastline in the first year.

#### *Aero & Satellite images:*

According to picture comparison (from 1975 to 1987) done by Federico I. Isla in 1987, the dune migration of Villa Gesell and Pinamar is minimum. Later a study by Federico I. Isla, Luis C. Cortizo and Horacio A. Turno Orellano related to dune migration shows that in the past years the dune barrier is being altered by forestation, urbanization and

drainage systems, causing erosion and water quality problems in the Buenos Aires coast. (Isla, F.I., Cortizo, L.C., Turno Orellano, H.A., 2001)

Aero images were also analysed by (UCO-Ministerio de Economia, Provincia de Buenos Aires, 2011), and correspond to the periods between 1950 and 1987, while satellite images refer to the years 2004 and 2009.



**Figure 4 San Clemente coastal evolution**

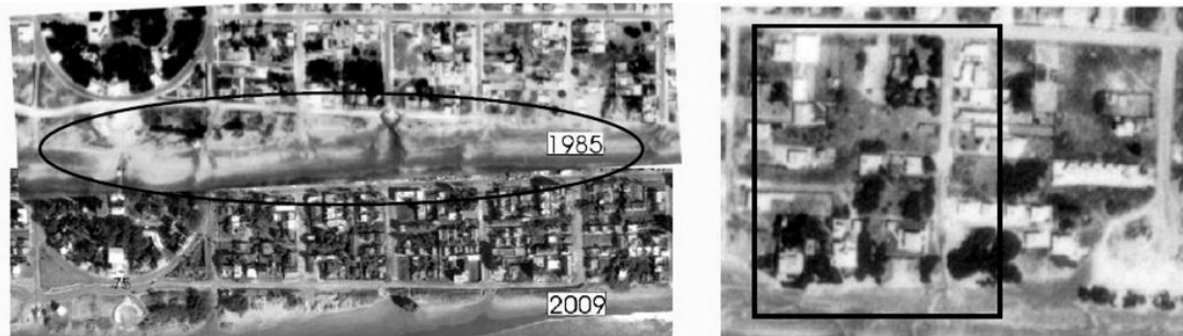
The picture above shows the coast of San Clemente del Tuyú, it can be seen that the coast has been changing over the years, even in the 1950's it can be seen that vegetation was planted to protect and stabilize the dune area.

The following picture shows the change in Santa Teresita from 1957 to 1975, growth of the vegetation planted in the dunes, as well as new city developments can be observed.



**Figure 5 Coastal evolution of Santa Teresita.**

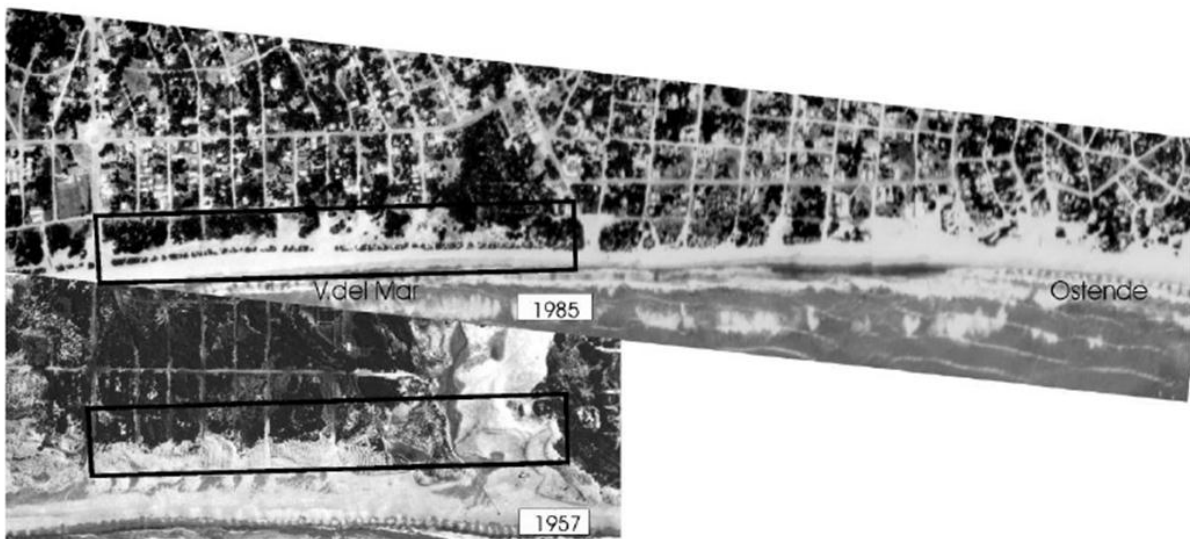
The picture that follows shows the evolution of the coast from 1985 to 2009 in Mar del Tuyú, a closer view of a section of the beach without dune is observed in the right hand side of the figure.



**Figure 6 Coastal evolution at Mar del Tuyú.**

In the picture that corresponds to the coast of San Bernardo; it is very noticeable by looking at the different pictures that drainage outfalls on the beach generate weak and unstable spots.

The following picture shows the coast of Pinamar, it can be detected with the pictures that the coastline retreat is significant, also noticeable that on the south side no measures were implemented to avoid construction on the coast, while for the north side a set-back line was established in the earlier years; consequently the southern part of Pinamar suffered more erosion problems.



**Figure 7 Coastal evolution at Pinamar.**

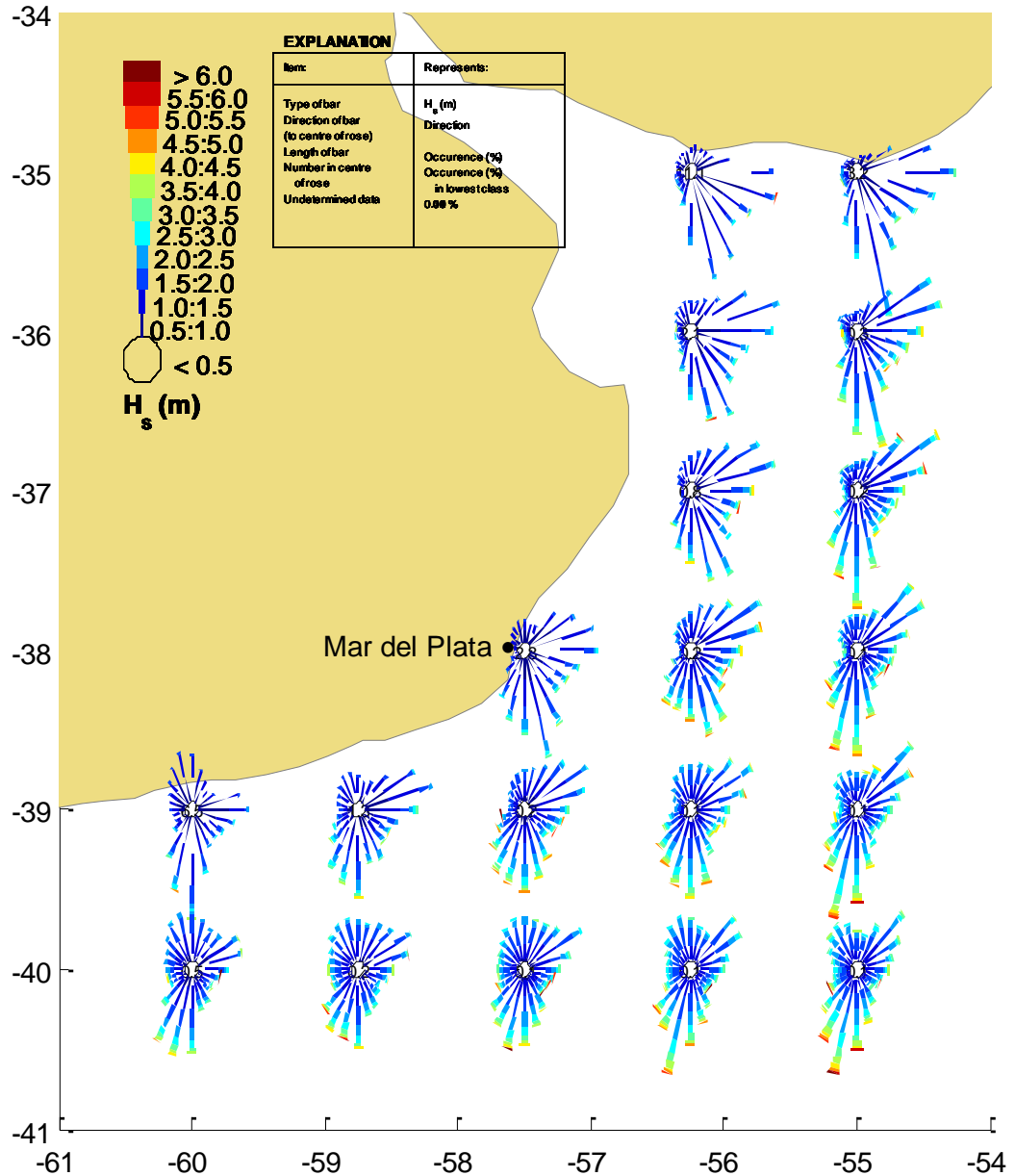
The last picture shown in this section corresponds to Villa Gesell, it can be seen that access road to the beach, as well as urbanization have affected the beach.



**Figure 8 Coastal evolution Villa Gesell**

## Appendix B: Wave & Wind roses

### Wave height roses



**Figure 9 Significant wave height roses**

Representation of the offshore wave data obtained from the NOAA Wave Watch database. Figure 9 shows significant wave height, percentage of occurrence, and dominant direction of propagation.

Wave period roses

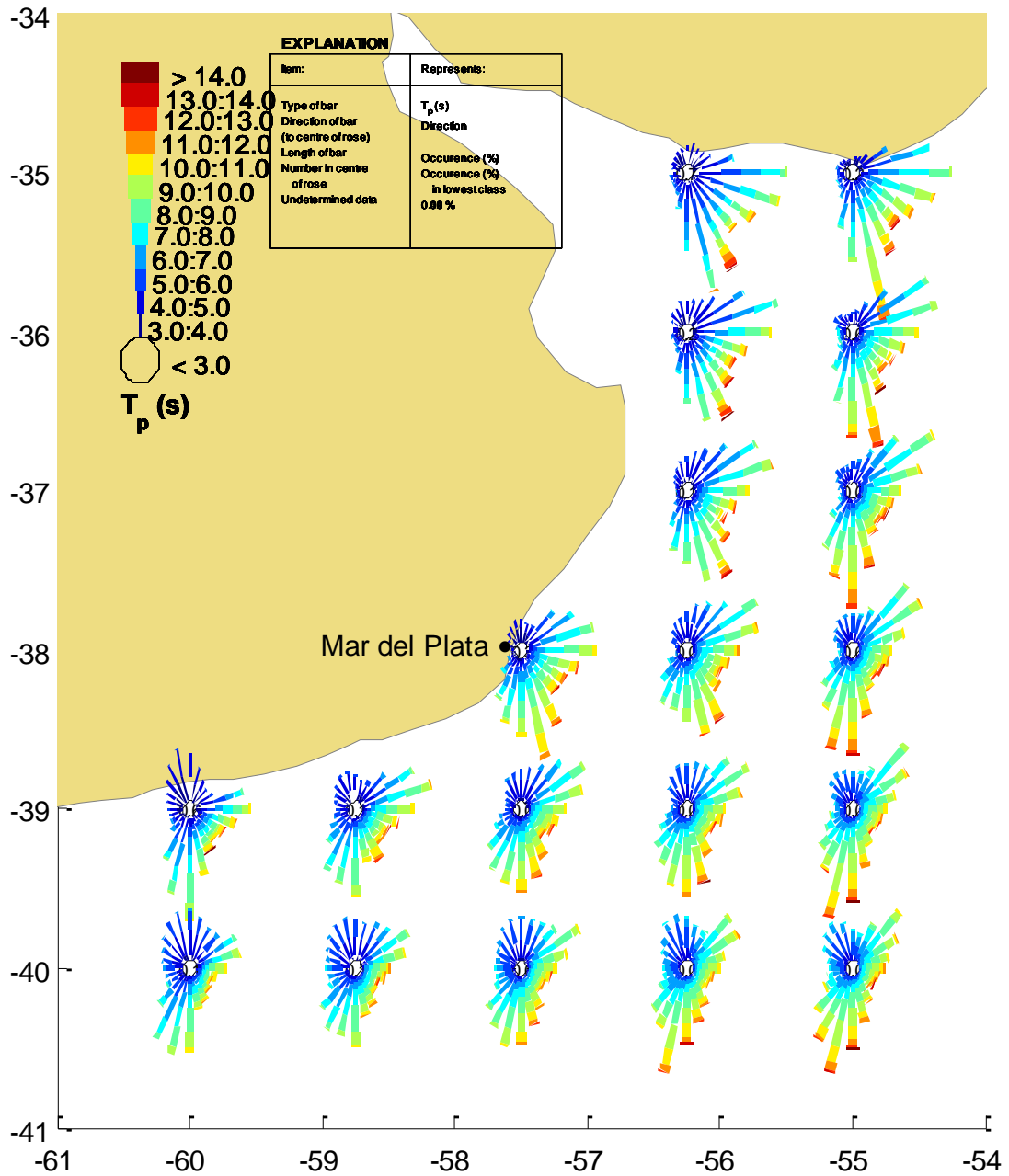


Figure 10 Peak wave period roses

Wave roses showing wave period variation along the coast of the Buenos Aires province, including the percentage of occurrence, and the direction distribution.

Wind roses

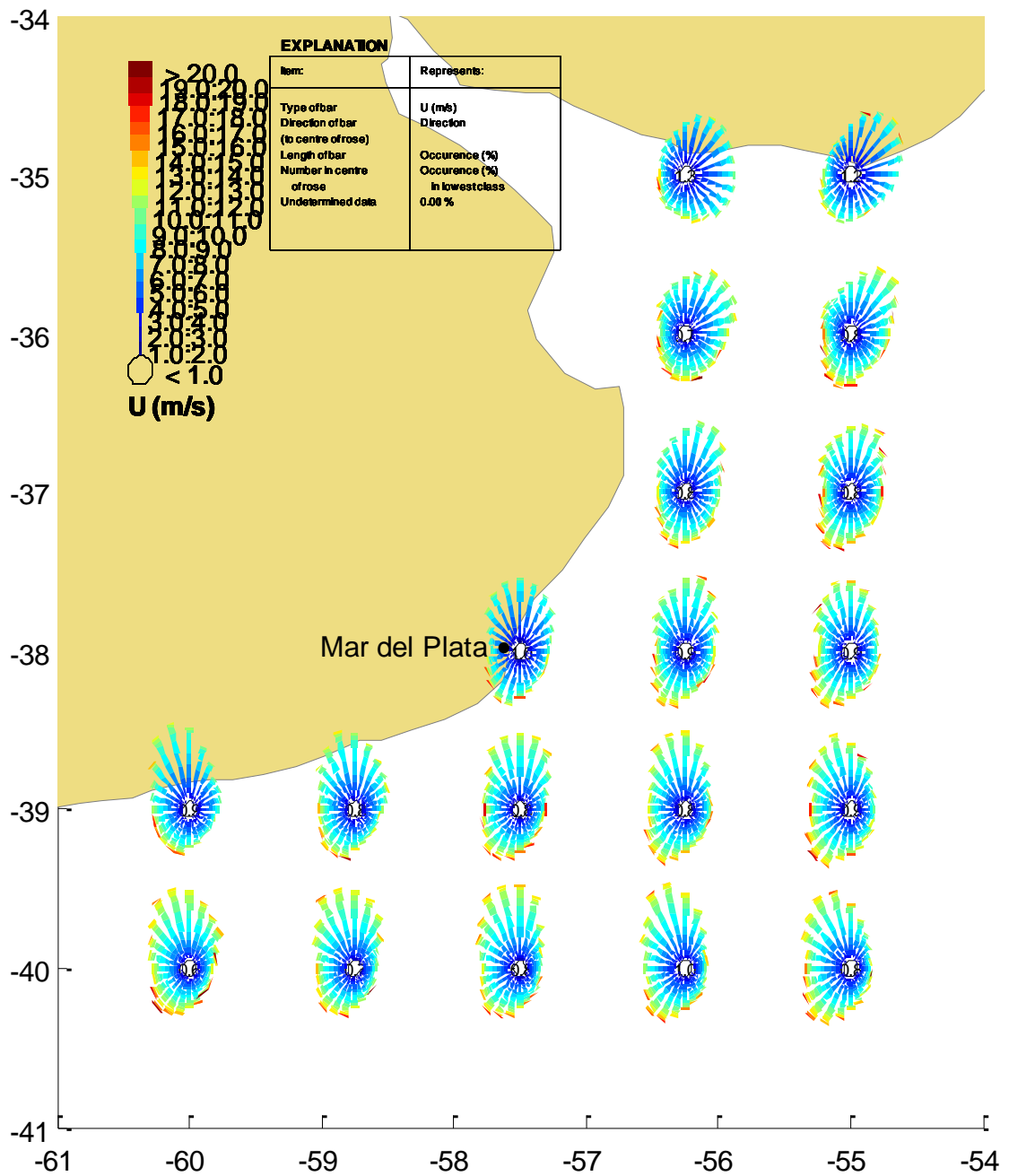


Figure 11 Wind magnitude roses

Figure 11 shows the wind roses representing the wind magnitude and direction; this data was also interpolated into land to use as input for the wind-growth formulations of the wave modelling.

Reference point wave height rose

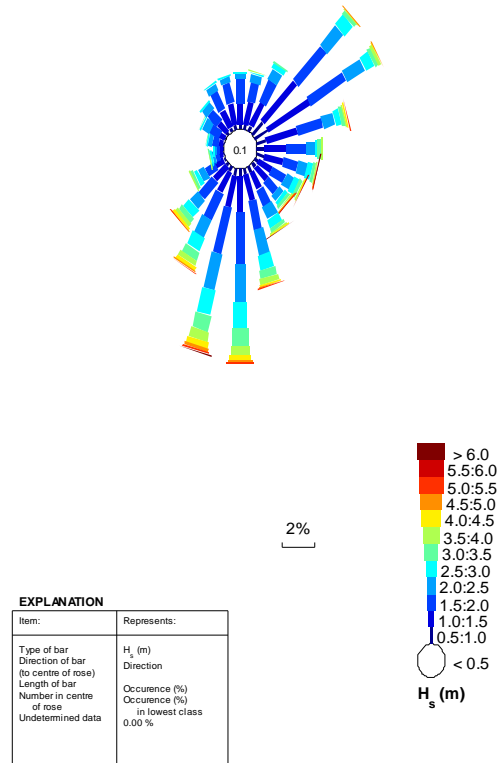


Figure 12 Significant wave height rose (Reference point)

Reference point wave period rose

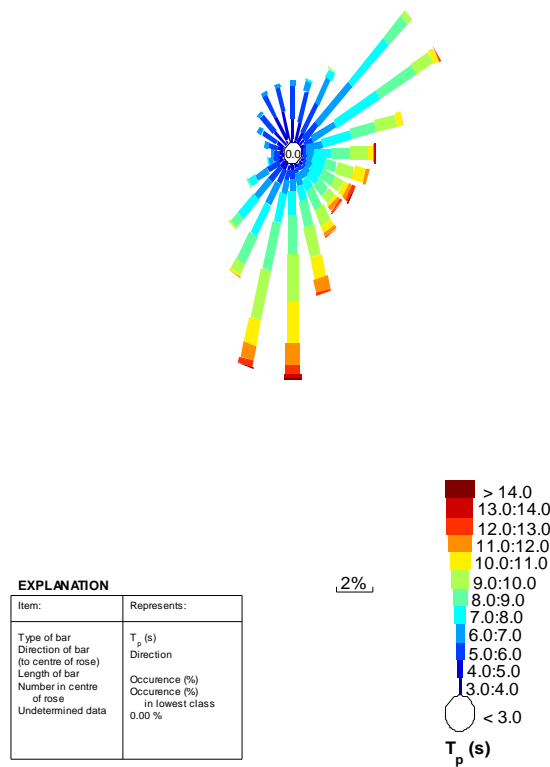


Figure 13 Peak wave period rose (Reference point)

Reference point wind rose

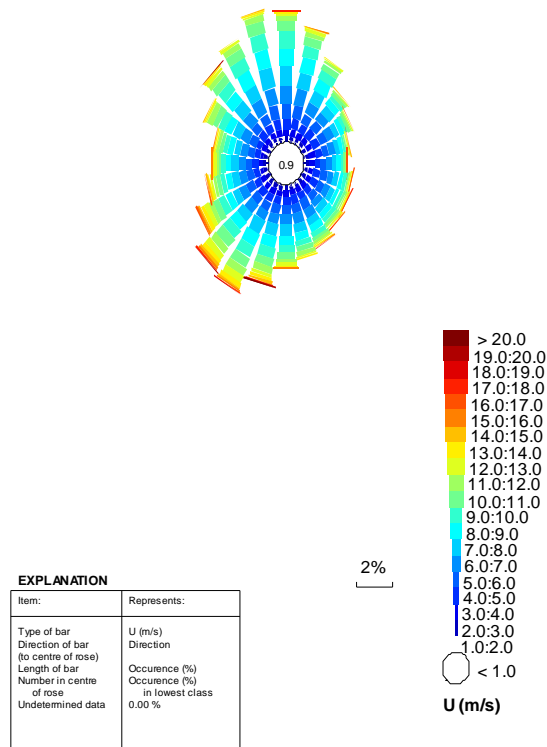


Figure 14 Wind rose (Reference point)

## Appendix C: Orca scenarios

Table 1 Orca wave classes

ORCA	Delft3D	Class boundaries	Events	%	Days	Days/yr
4	1	2.0<Hs>2.5 , 348.8<Dp>11.3	191	0.479	23.880	1.748
2	2	1.0<Hs>1.5 , 348.8<Dp>11.3	650	1.628	81.250	5.947
7	3	3.5<Hs>4.5 , 348.8<Dp>11.3	5	0.013	0.630	0.046
6	4	3.0<Hs>3.5 , 348.8<Dp>11.3	6	0.015	0.750	0.055
14	5	3.5<Hs>4.5 , 11.3<Dp>33.8	16	0.040	2.000	0.146
8	6	0.0<Hs>1.0 , 11.3<Dp>33.8	177	0.443	22.130	1.620
11	7	2.0<Hs>2.5 , 11.3<Dp>33.8	278	0.696	34.750	2.543
10	8	1.5<Hs>2.0 , 11.3<Dp>33.8	629	1.576	78.630	5.755
9	9	1.0<Hs>1.5 , 11.3<Dp>33.8	729	1.826	91.130	6.670
13	10	3.0<Hs>3.5 , 11.3<Dp>33.8	33	0.083	4.130	0.302
12	11	2.5<Hs>3.0 , 11.3<Dp>33.8	99	0.248	12.380	0.906
15	12	4.5<Hs>Inf , 11.3<Dp>33.8	3	0.008	0.380	0.028
23	13	4.5<Hs>Inf , 33.8<Dp>56.3	10	0.025	1.250	0.091
21	14	3.0<Hs>3.5 , 33.8<Dp>56.3	131	0.328	16.380	1.199
20	15	2.5<Hs>3.0 , 33.8<Dp>56.3	380	0.952	47.500	3.477
19	16	2.0<Hs>2.5 , 33.8<Dp>56.3	728	1.824	91.000	6.660
18	17	1.5<Hs>2.0 , 33.8<Dp>56.3	1363	3.414	170.380	12.470
22	18	3.5<Hs>4.5 , 33.8<Dp>56.3	45	0.113	5.630	0.412
16	19	0.0<Hs>1.0 , 33.8<Dp>56.3	470	1.177	58.750	4.300
17	20	1.0<Hs>1.5 , 33.8<Dp>56.3	1610	4.033	201.250	14.730
27	21	2.0<Hs>2.5 , 56.3<Dp>78.8	632	1.583	79.000	5.782
24	22	0.0<Hs>1.0 , 56.3<Dp>78.8	458	1.147	57.250	4.190
26	23	1.5<Hs>2.0 , 56.3<Dp>78.8	1241	3.109	155.130	11.354
28	24	2.5<Hs>3.0 , 56.3<Dp>78.8	300	0.752	37.500	2.745
25	25	1.0<Hs>1.5 , 56.3<Dp>78.8	1418	3.552	177.250	12.973
30	26	3.5<Hs>4.5 , 56.3<Dp>78.8	123	0.308	15.380	1.126
29	27	3.0<Hs>3.5 , 56.3<Dp>78.8	133	0.333	16.630	1.217
31	28	4.5<Hs>Inf , 56.3<Dp>78.8	60	0.150	7.500	0.549
36	29	2.5<Hs>3.0 , 78.8<Dp>101.3	146	0.366	18.250	1.336
34	30	1.5<Hs>2.0 , 78.8<Dp>101.3	702	1.759	87.750	6.423
32	31	0.0<Hs>1.0 , 78.8<Dp>101.3	293	0.734	36.630	2.681
38	32	3.5<Hs>4.5 , 78.8<Dp>101.3	79	0.198	9.880	0.723
35	33	2.0<Hs>2.5 , 78.8<Dp>101.3	311	0.779	38.880	2.846
33	34	1.0<Hs>1.5 , 78.8<Dp>101.3	796	1.994	99.500	7.283
39	35	4.5<Hs>Inf , 78.8<Dp>101.3	17	0.043	2.130	0.156
37	36	3.0<Hs>3.5 , 78.8<Dp>101.3	116	0.291	14.500	1.061
40	37	0.0<Hs>1.0 , 101.3<Dp>123.8	230	0.576	28.750	2.104
44	38	2.5<Hs>3.0 , 101.3<Dp>123.8	178	0.446	22.250	1.629
43	39	2.0<Hs>2.5 , 101.3<Dp>123.8	278	0.696	34.750	2.543
47	40	4.5<Hs>Inf , 101.3<Dp>123.8	40	0.100	5.000	0.366
41	41	1.0<Hs>1.5 , 101.3<Dp>123.8	614	1.538	76.750	5.617
42	42	1.5<Hs>2.0 , 101.3<Dp>123.8	509	1.275	63.630	4.657

ORCA	Delft3D	Class boundaries	Events	%	Days	Days/yr
45	43	3.0<Hs>3.5 , 101.3<Dp>123.8	99	0.248	12.380	0.906
46	44	3.5<Hs>4.5 , 101.3<Dp>123.8	59	0.148	7.380	0.540
54	45	3.5<Hs>4.5 , 123.8<Dp>146.3	83	0.208	10.380	0.760
53	46	3.0<Hs>3.5 , 123.8<Dp>146.3	118	0.296	14.750	1.080
52	47	2.5<Hs>3.0 , 123.8<Dp>146.3	168	0.421	21.000	1.537
50	48	1.5<Hs>2.0 , 123.8<Dp>146.3	503	1.260	62.880	4.602
51	49	2.0<Hs>2.5 , 123.8<Dp>146.3	283	0.709	35.380	2.590
49	50	1.0<Hs>1.5 , 123.8<Dp>146.3	531	1.330	66.380	4.858
48	51	0.0<Hs>1.0 , 123.8<Dp>146.3	165	0.413	20.630	1.510
55	52	4.5<Hs>Inf , 123.8<Dp>146.3	39	0.098	4.880	0.357
56	53	0.0<Hs>1.0 , 146.3<Dp>168.8	202	0.506	25.250	1.848
57	54	1.0<Hs>1.5 , 146.3<Dp>168.8	672	1.683	84.000	6.148
60	55	2.5<Hs>3.0 , 146.3<Dp>168.8	368	0.922	46.000	3.367
58	56	1.5<Hs>2.0 , 146.3<Dp>168.8	722	1.809	90.250	6.606
59	57	2.0<Hs>2.5 , 146.3<Dp>168.8	574	1.438	71.750	5.252
63	58	4.5<Hs>Inf , 146.3<Dp>168.8	39	0.098	4.880	0.357
61	59	3.0<Hs>3.5 , 146.3<Dp>168.8	207	0.519	25.880	1.894
62	60	3.5<Hs>4.5 , 146.3<Dp>168.8	141	0.353	17.630	1.290
65	61	1.0<Hs>1.5 , 168.8<Dp>191.3	987	2.472	123.380	9.030
64	62	0.0<Hs>1.0 , 168.8<Dp>191.3	232	0.581	29.000	2.123
66	63	1.5<Hs>2.0 , 168.8<Dp>191.3	1505	3.770	188.130	13.770
67	64	2.0<Hs>2.5 , 168.8<Dp>191.3	1149	2.878	143.630	10.513
69	65	3.0<Hs>3.5 , 168.8<Dp>191.3	497	1.245	62.130	4.547
68	66	2.5<Hs>3.0 , 168.8<Dp>191.3	750	1.879	93.750	6.862
70	67	3.5<Hs>4.5 , 168.8<Dp>191.3	434	1.087	54.250	3.971
71	68	4.5<Hs>Inf , 168.8<Dp>191.3	146	0.366	18.250	1.336
79	69	4.5<Hs>Inf , 191.3<Dp>213.8	142	0.356	17.750	1.299
77	70	3.0<Hs>3.5 , 191.3<Dp>213.8	399	1.000	49.880	3.651
75	71	2.0<Hs>2.5 , 191.3<Dp>213.8	804	2.014	100.500	7.356
76	72	2.5<Hs>3.0 , 191.3<Dp>213.8	583	1.460	72.880	5.334
74	73	1.5<Hs>2.0 , 191.3<Dp>213.8	1123	2.813	140.380	10.275
73	74	1.0<Hs>1.5 , 191.3<Dp>213.8	883	2.212	110.380	8.079
78	75	3.5<Hs>4.5 , 191.3<Dp>213.8	379	0.949	47.380	3.468
72	76	0.0<Hs>1.0 , 191.3<Dp>213.8	207	0.519	25.880	1.894
87	77	4.5<Hs>Inf , 213.8<Dp>236.3	38	0.095	4.750	0.348
84	78	2.5<Hs>3.0 , 213.8<Dp>236.3	303	0.759	37.880	2.773
81	79	1.0<Hs>1.5 , 213.8<Dp>236.3	579	1.450	72.380	5.298
83	80	2.0<Hs>2.5 , 213.8<Dp>236.3	414	1.037	51.750	3.788
82	81	1.5<Hs>2.0 , 213.8<Dp>236.3	688	1.723	86.000	6.294
85	82	3.0<Hs>3.5 , 213.8<Dp>236.3	191	0.479	23.880	1.748
80	83	0.0<Hs>1.0 , 213.8<Dp>236.3	115	0.288	14.380	1.052
86	84	3.5<Hs>4.5 , 213.8<Dp>236.3	184	0.461	23.000	1.683

ORCA	Delft3D	Class boundaries	Events	%	Days	Days/yr
94	85	3.5<Hs>4.5 , 236.3<Dp>258.8	33	0.083	4.130	0.302
91	86	2.0<Hs>2.5 , 236.3<Dp>258.8	171	0.428	21.380	1.565
89	87	1.0<Hs>1.5 , 236.3<Dp>258.8	240	0.601	30.000	2.196
90	88	1.5<Hs>2.0 , 236.3<Dp>258.8	246	0.616	30.750	2.251
93	89	3.0<Hs>3.5 , 236.3<Dp>258.8	67	0.168	8.380	0.613
92	90	2.5<Hs>3.0 , 236.3<Dp>258.8	104	0.261	13.000	0.951
88	91	0.0<Hs>1.0 , 236.3<Dp>258.8	51	0.128	6.380	0.467
95	92	4.5<Hs>Inf , 236.3<Dp>258.8	6	0.015	0.750	0.055
102	93	3.5<Hs>4.5 , 258.8<Dp>281.3	4	0.010	0.500	0.037
101	94	3.0<Hs>3.5 , 258.8<Dp>281.3	22	0.055	2.750	0.201
97	95	1.0<Hs>1.5 , 258.8<Dp>281.3	104	0.261	13.000	0.951
98	96	1.5<Hs>2.0 , 258.8<Dp>281.3	150	0.376	18.750	1.372
100	97	2.5<Hs>3.0 , 258.8<Dp>281.3	26	0.065	3.250	0.238
96	98	0.0<Hs>1.0 , 258.8<Dp>281.3	32	0.080	4.000	0.293
99	99	2.0<Hs>2.5 , 258.8<Dp>281.3	85	0.213	10.630	0.778
103	100	4.5<Hs>Inf , 258.8<Dp>281.3	1	0.003	0.130	0.010
110	101	3.5<Hs>4.5 , 281.3<Dp>303.8	5	0.013	0.630	0.046
109	102	3.0<Hs>3.5 , 281.3<Dp>303.8	21	0.053	2.630	0.192
105	103	1.0<Hs>1.5 , 281.3<Dp>303.8	184	0.461	23.000	1.683
108	104	2.5<Hs>3.0 , 281.3<Dp>303.8	75	0.188	9.380	0.687
104	105	0.0<Hs>1.0 , 281.3<Dp>303.8	40	0.100	5.000	0.366
106	106	1.5<Hs>2.0 , 281.3<Dp>303.8	289	0.724	36.130	2.644
107	107	2.0<Hs>2.5 , 281.3<Dp>303.8	205	0.514	25.630	1.876
111	108	4.5<Hs>Inf , 281.3<Dp>303.8	1	0.003	0.130	0.010
118	109	3.5<Hs>4.5 , 303.8<Dp>326.3	1	0.003	0.130	0.010
117	110	3.0<Hs>3.5 , 303.8<Dp>326.3	22	0.055	2.750	0.201
116	111	2.5<Hs>3.0 , 303.8<Dp>326.3	62	0.155	7.750	0.567
115	112	2.0<Hs>2.5 , 303.8<Dp>326.3	271	0.679	33.880	2.480
114	113	1.5<Hs>2.0 , 303.8<Dp>326.3	466	1.167	58.250	4.263
112	114	0.0<Hs>1.0 , 303.8<Dp>326.3	95	0.238	11.880	0.870
113	115	1.0<Hs>1.5 , 303.8<Dp>326.3	392	0.982	49.000	3.586
124	116	3.0<Hs>3.5 , 326.3<Dp>348.8	5	0.013	0.630	0.046
125	117	3.5<Hs>4.5 , 326.3<Dp>348.8	3	0.008	0.380	0.028
122	118	2.0<Hs>2.5 , 326.3<Dp>348.8	191	0.479	23.880	1.748
121	119	1.5<Hs>2.0 , 326.3<Dp>348.8	618	1.548	77.250	5.654
123	120	2.5<Hs>3.0 , 326.3<Dp>348.8	50	0.125	6.250	0.457
120	121	1.0<Hs>1.5 , 326.3<Dp>348.8	618	1.548	77.250	5.654
119	122	0.0<Hs>1.0 , 326.3<Dp>348.8	139	0.348	17.380	1.272
5	123	2.5<Hs>3.0 , 348.8<Dp>11.3	36	0.090	4.500	0.329
1	124	0.0<Hs>1.0 , 348.8<Dp>11.3	146	0.366	18.250	1.336
3	125	1.5<Hs>2.0 , 348.8<Dp>11.3	711	1.781	88.880	6.505

Each scenario was simulated using Delft3D-WAVE to obtain a full description of the wave conditions near the coast of the Buenos Aires province in Argentina. As mentioned before the data set of wave data consisted of 13 years with data every 3 hours. This table represents the conditions in 125 scenarios.

- **Hs**= Significant wave height
- **Dp**=Peak wave direction
- **Events**= Number of times the conditions happened during the full data set
- **%**= Percentage of occurrence
- **Days**= Number of days during the 13 years of data

## Appendix D: Delft3D-WAVE

This appendix shows the 125 wave conditions that were modelled by using Delft3D-WAVE. Left hand side of the each figure shows the significant wave height distribution throughout the different areas of the coast, while right hand side shows the peak wave period.

Their corresponding characteristics are shown in Appendix C, where every scenario class is defined. Giving a certain range of wave height, wave direction, wave period, number of events, and the percentage of the duration of each condition during the 13 years of wave information that were available in the NOAA Wave Watch III data base.

ORCA and Delft3D-WAVE arrange the scenario conditions in relation to different variables, to allow the easy comparison of information tables in Appendix C, shows both numbering orders corresponding to each scenario conditions.

The same scale was used for all figures to allow the reader to compare all the conditions. Wave height scale goes from 0m to 4m, and peak wave period from 0s to 10 seconds.

The same colour map was used in both of the figures that describe each scenario. Dark pink represents larger waves and longer periods while dark blue means very small wave conditions and short wave periods.

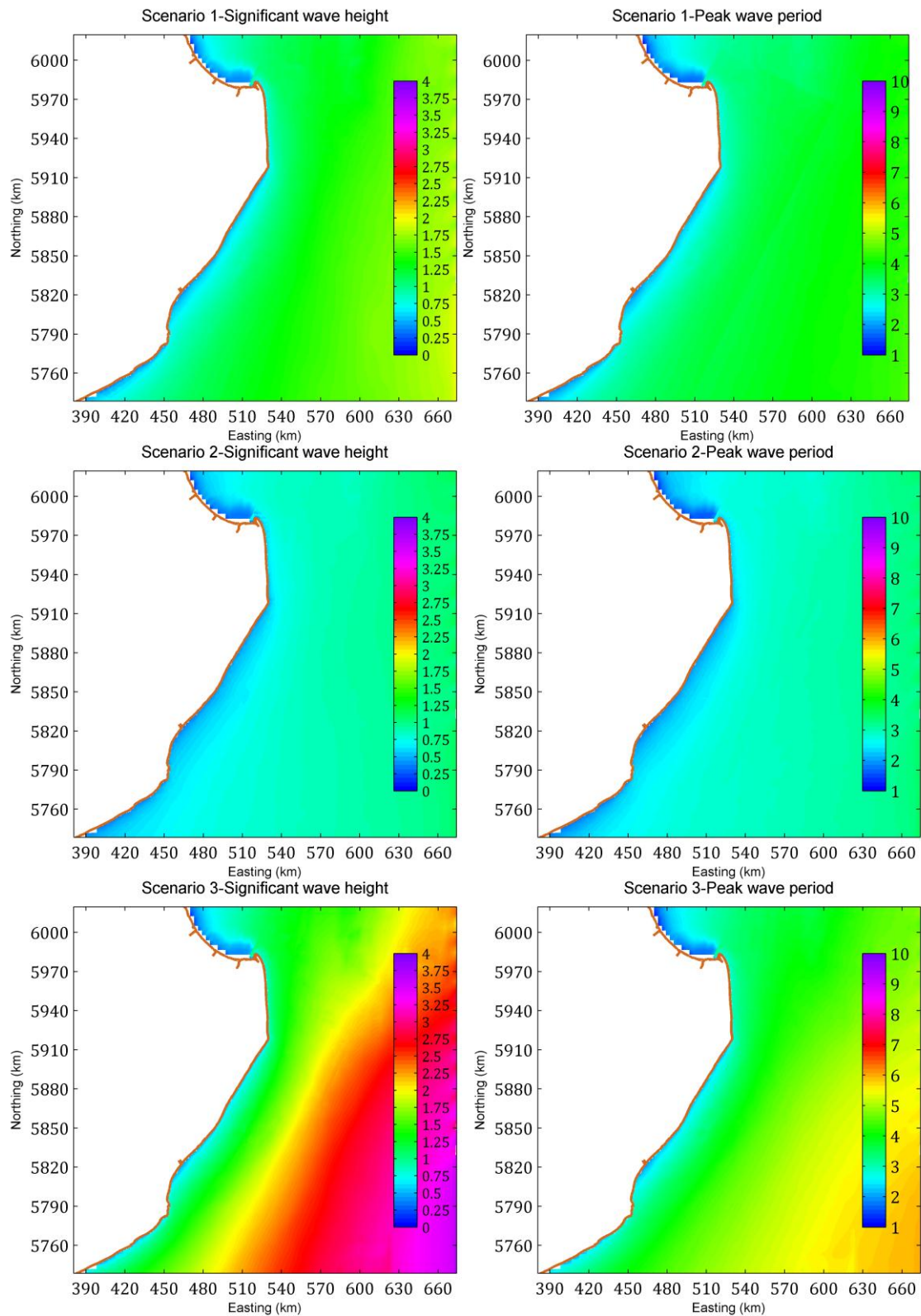


Figure 15 Scenario 1-3

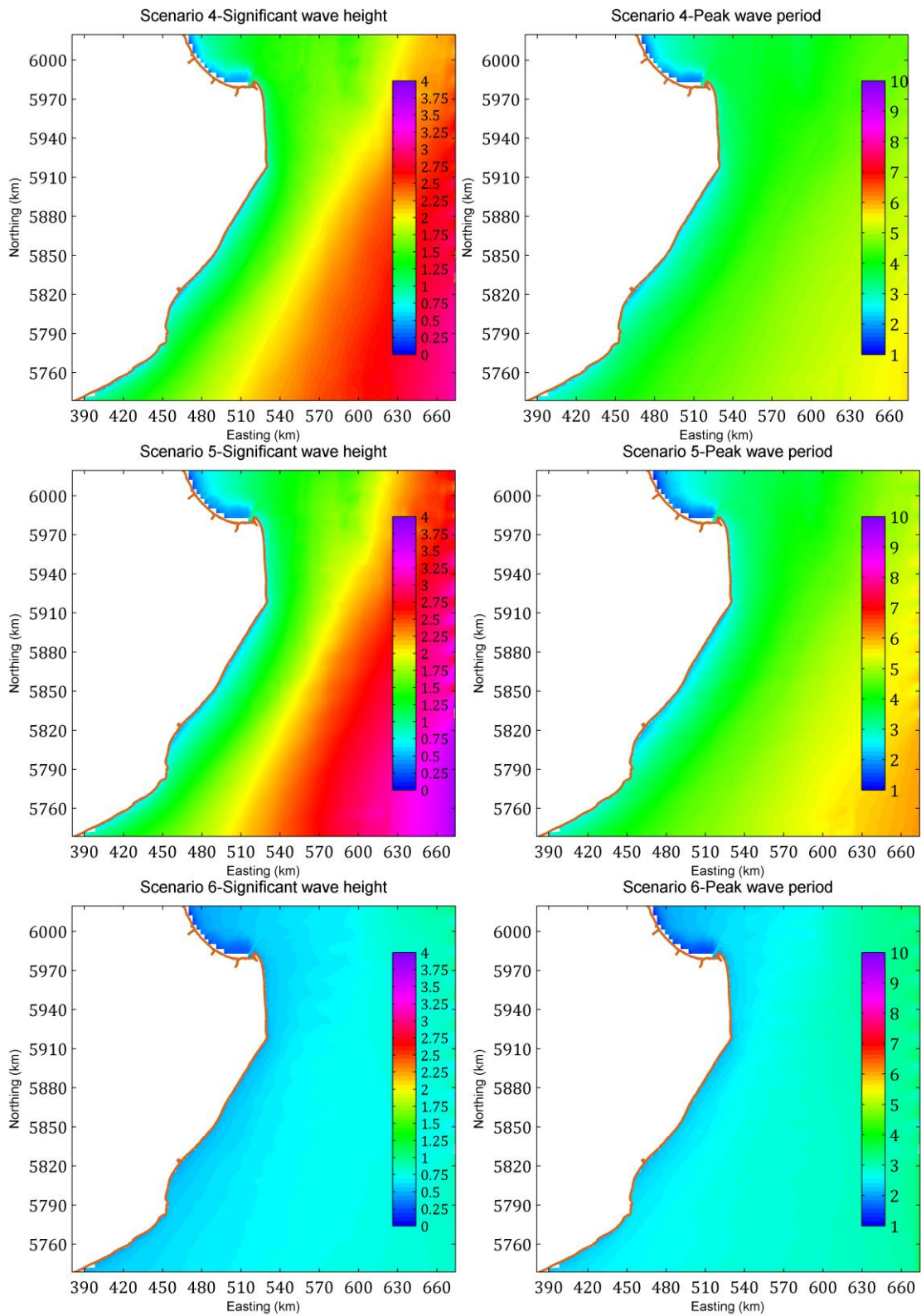


Figure 16 Scenario 4-6

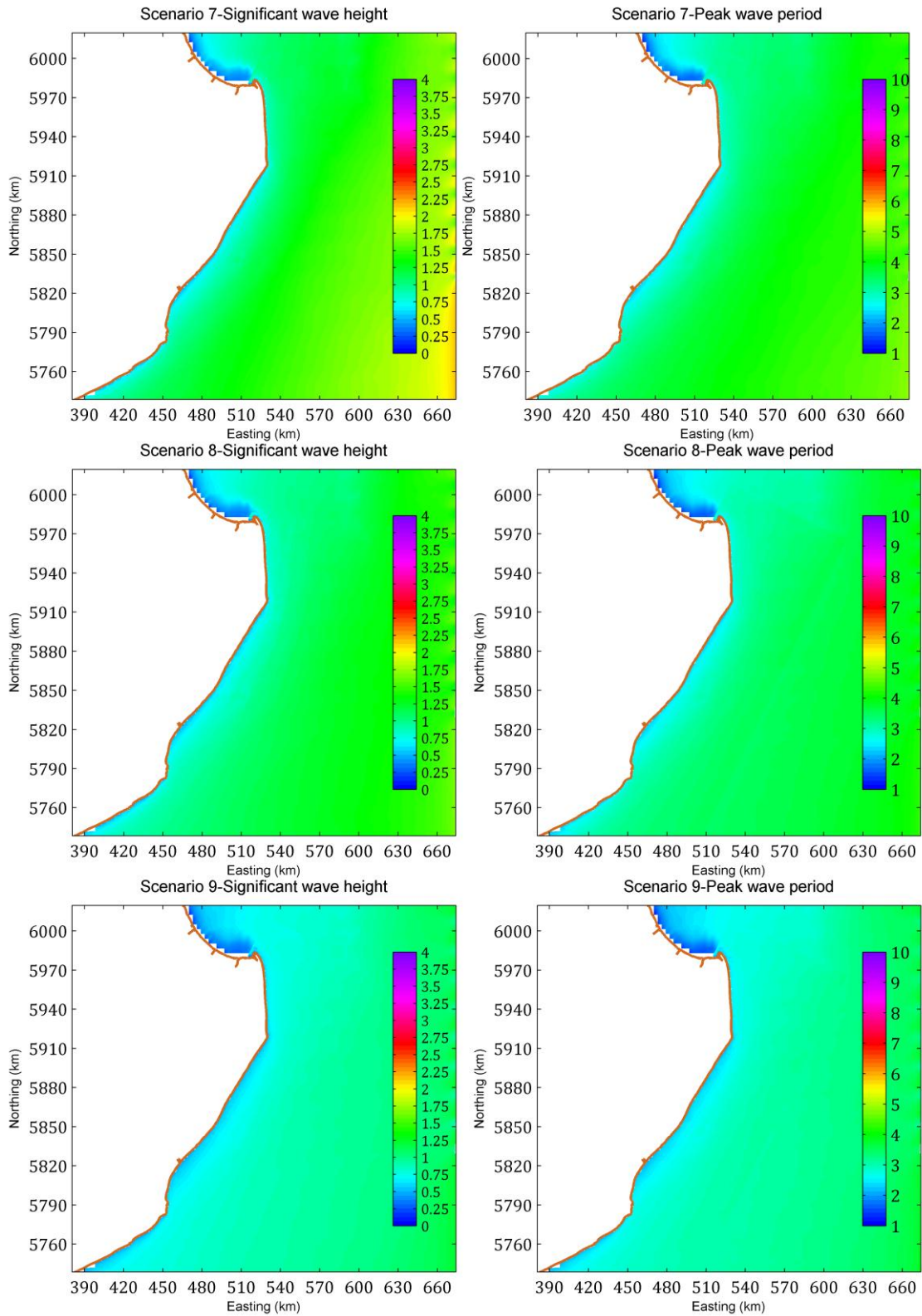


Figure 17 Scenario 7-9

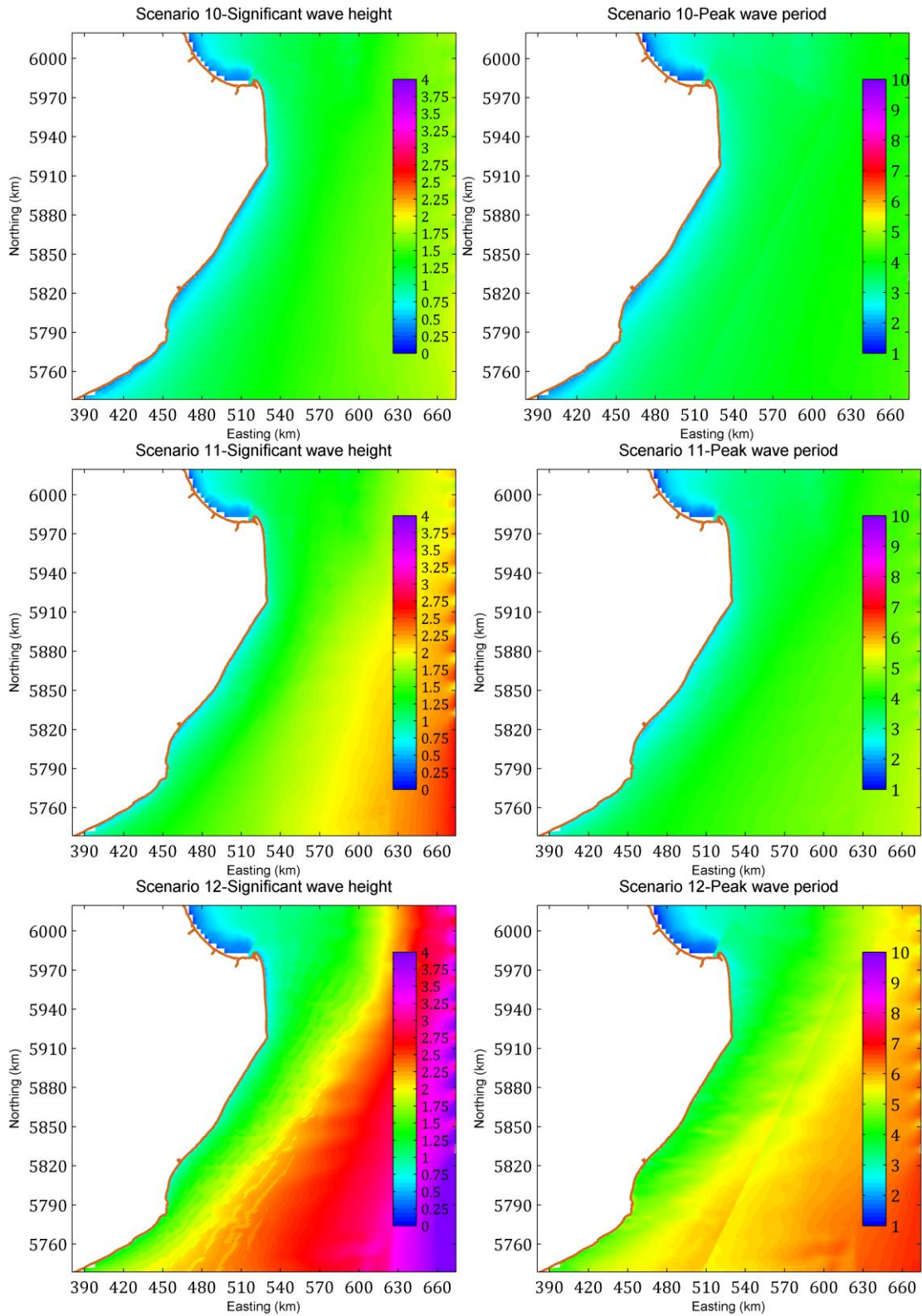


Figure 18 Scenarios 10-12

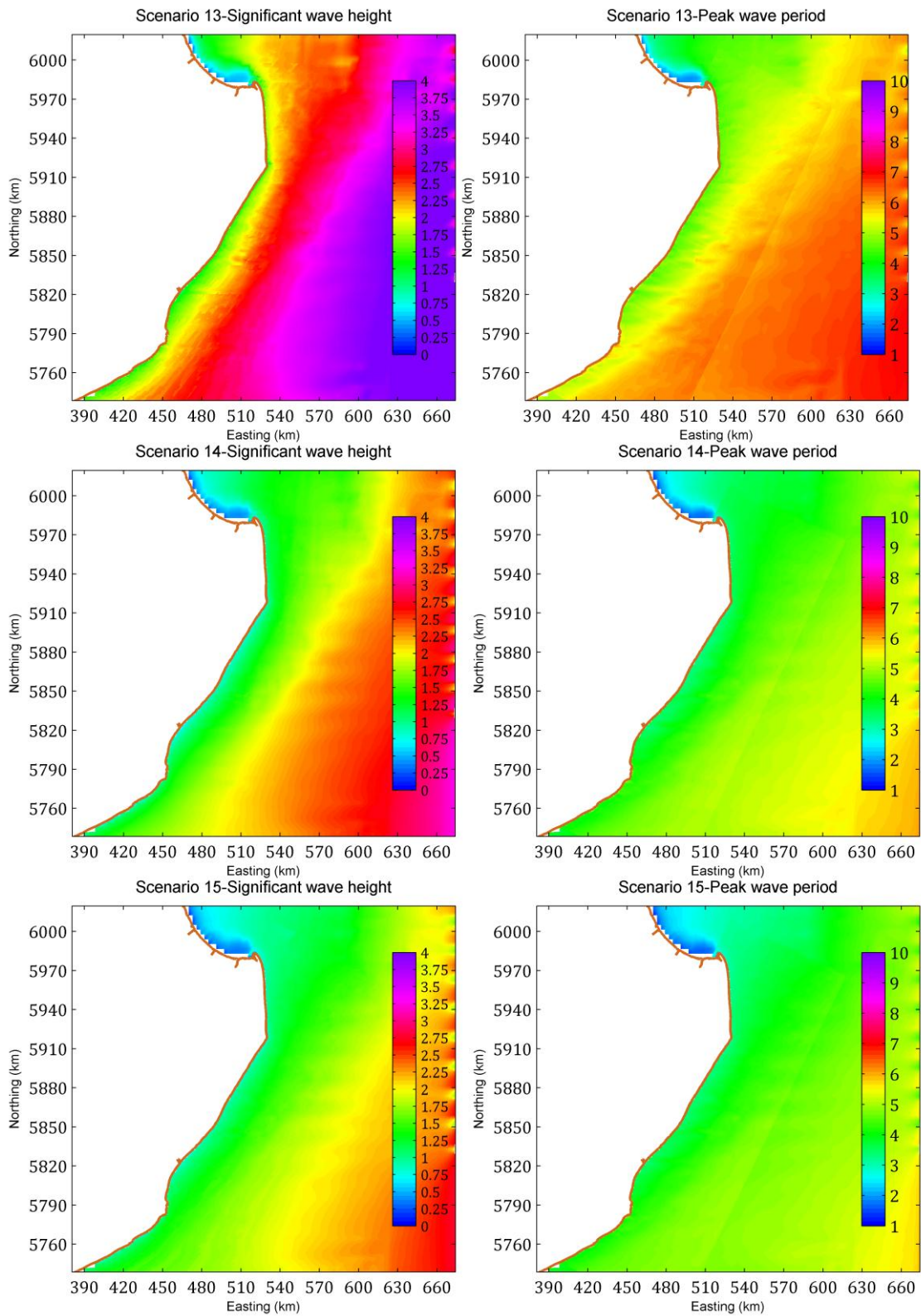


Figure 19 Scenarios 13-15

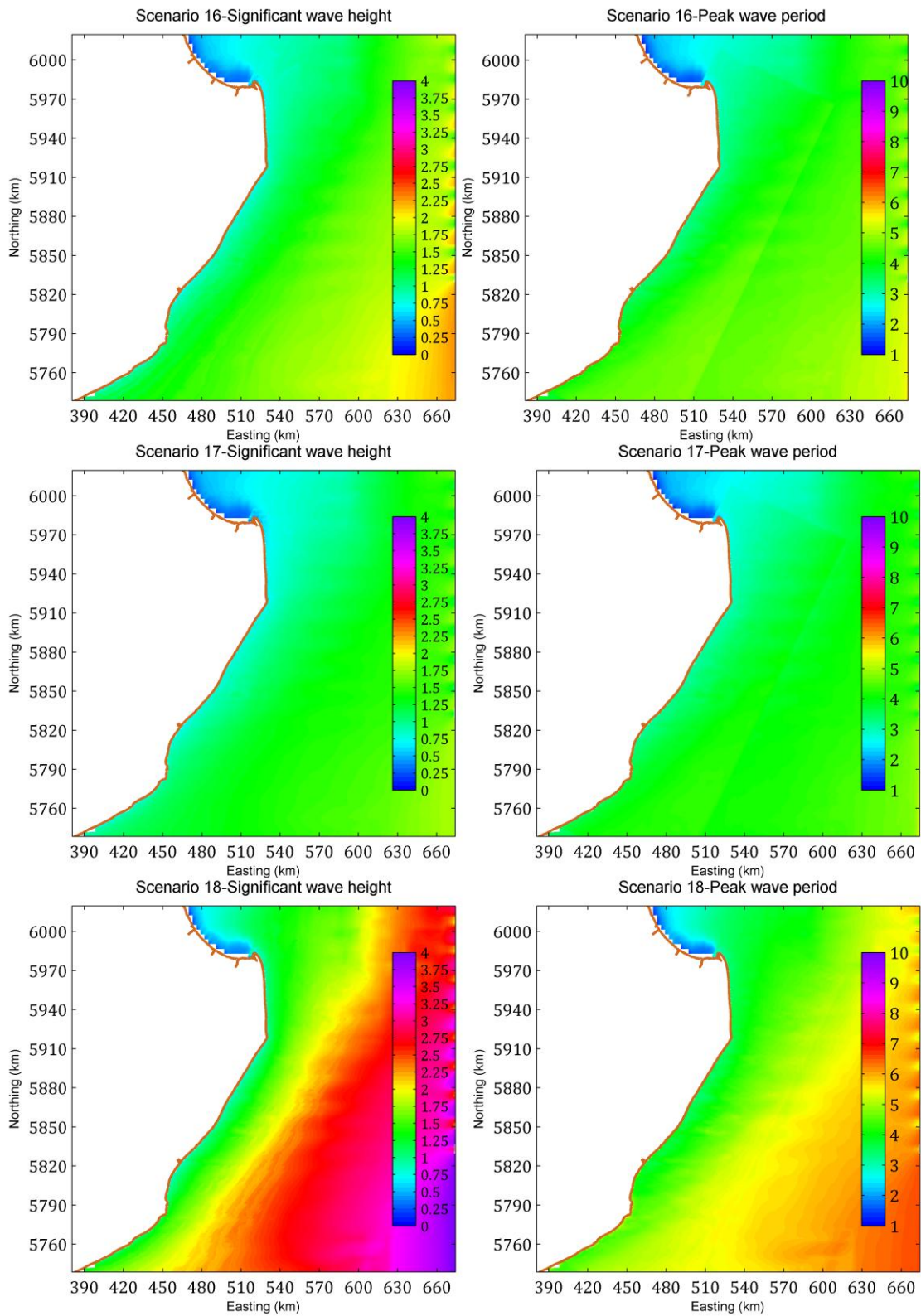


Figure 20 Scenarios 16-18

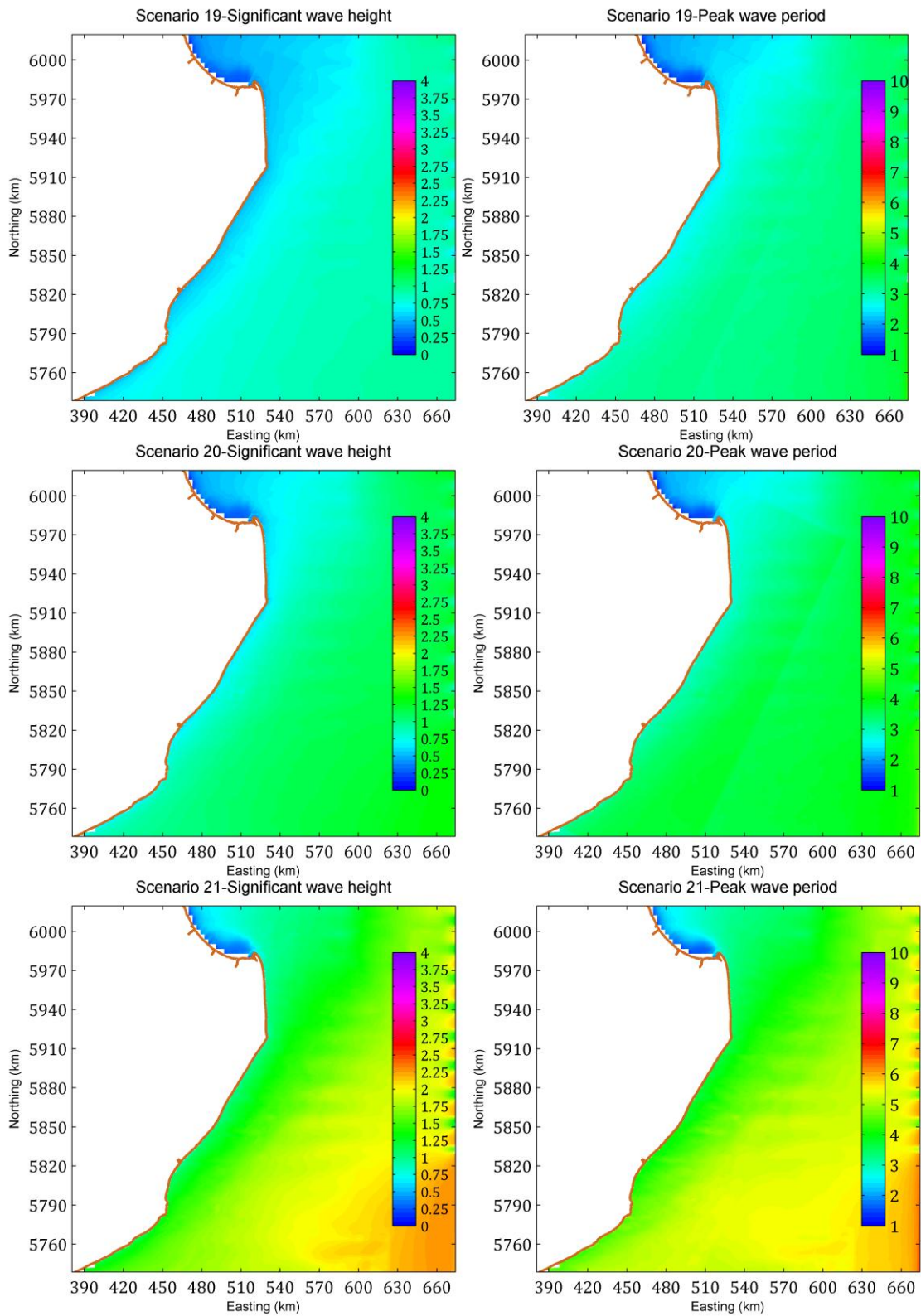


Figure 21 Scenarios 19-21

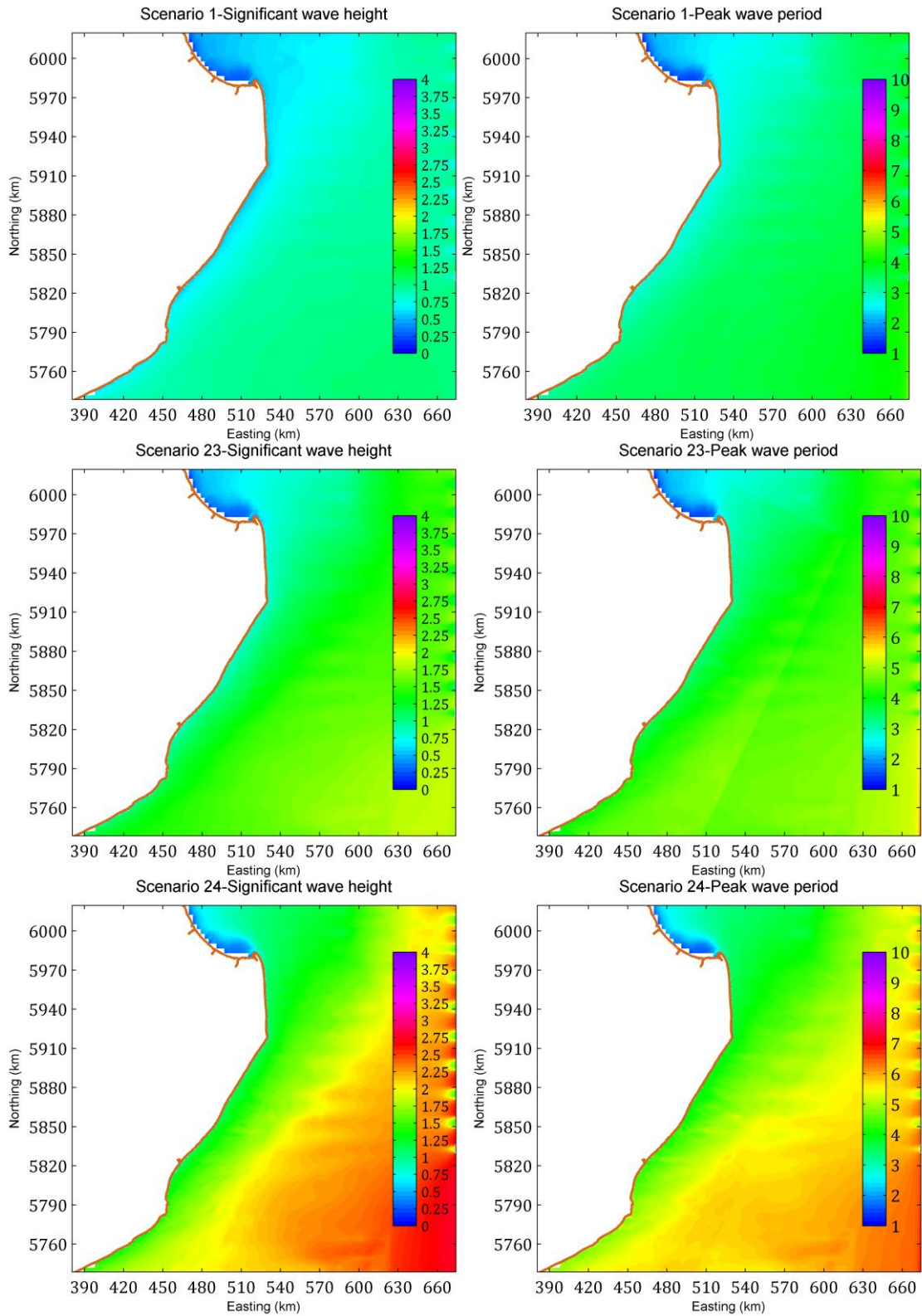


Figure 22 Scenarios 22-24

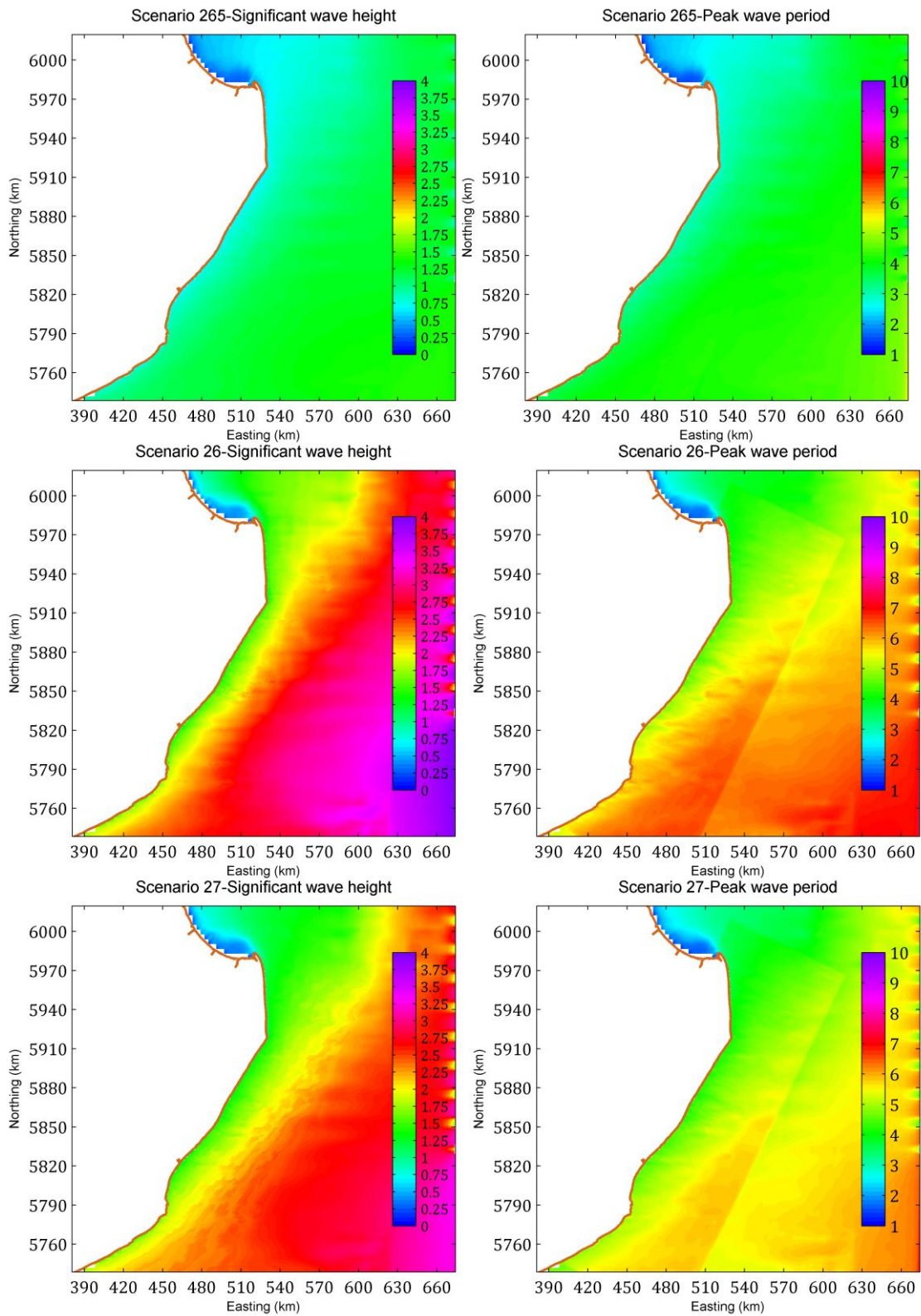


Figure 23 Scenarios 25-27

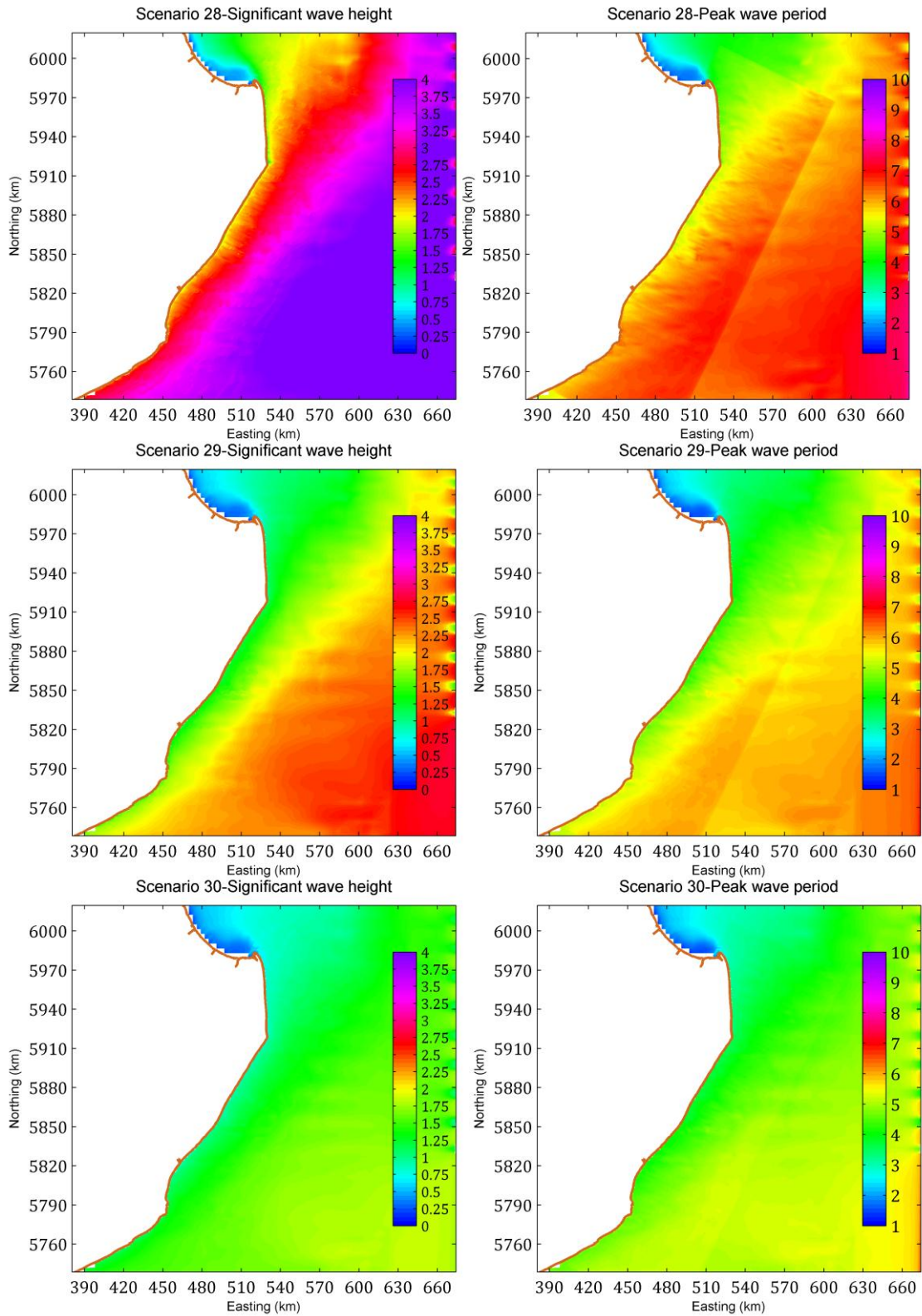


Figure 24 Scenarios 28-30

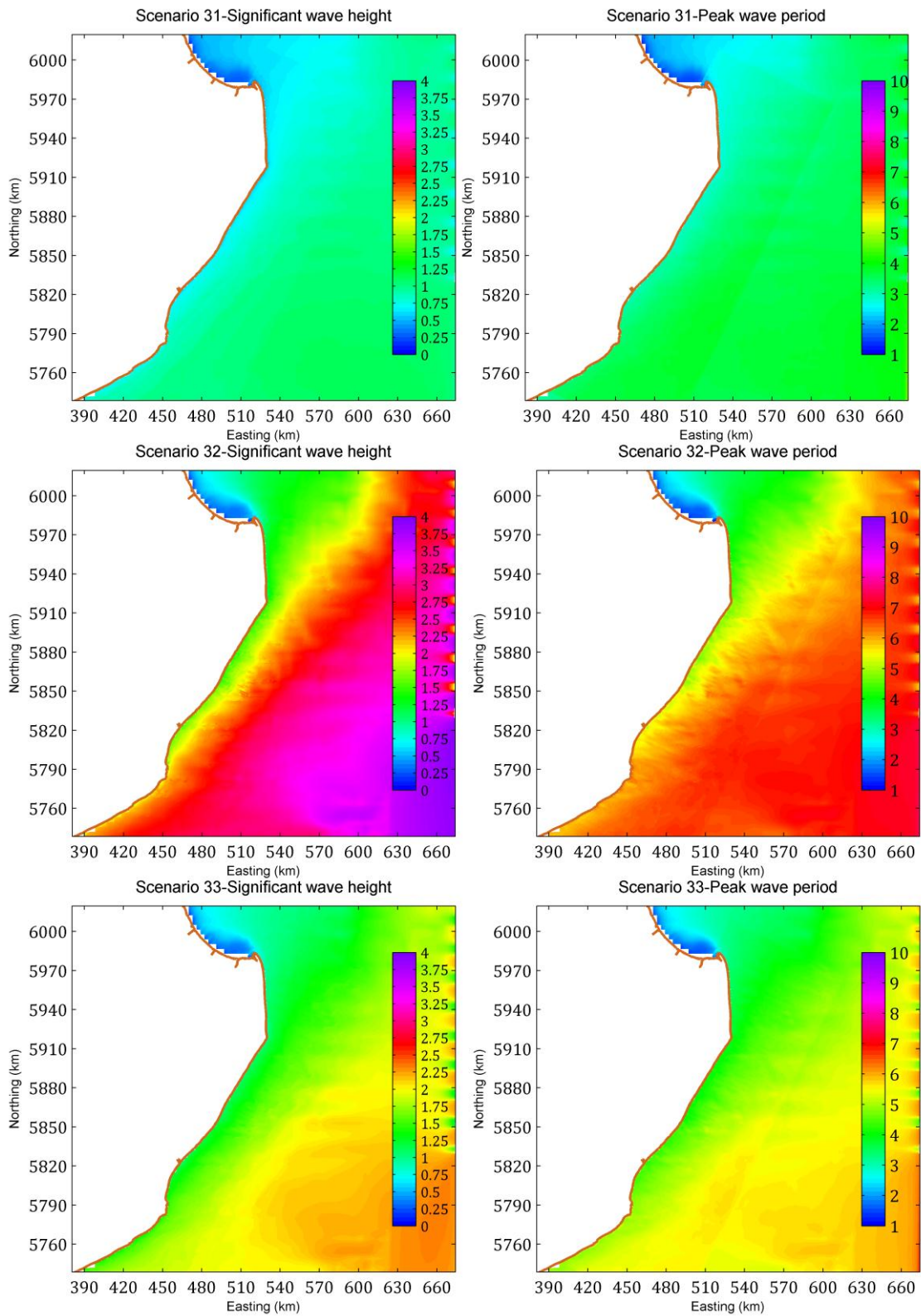


Figure 25 Scenarios 31-33

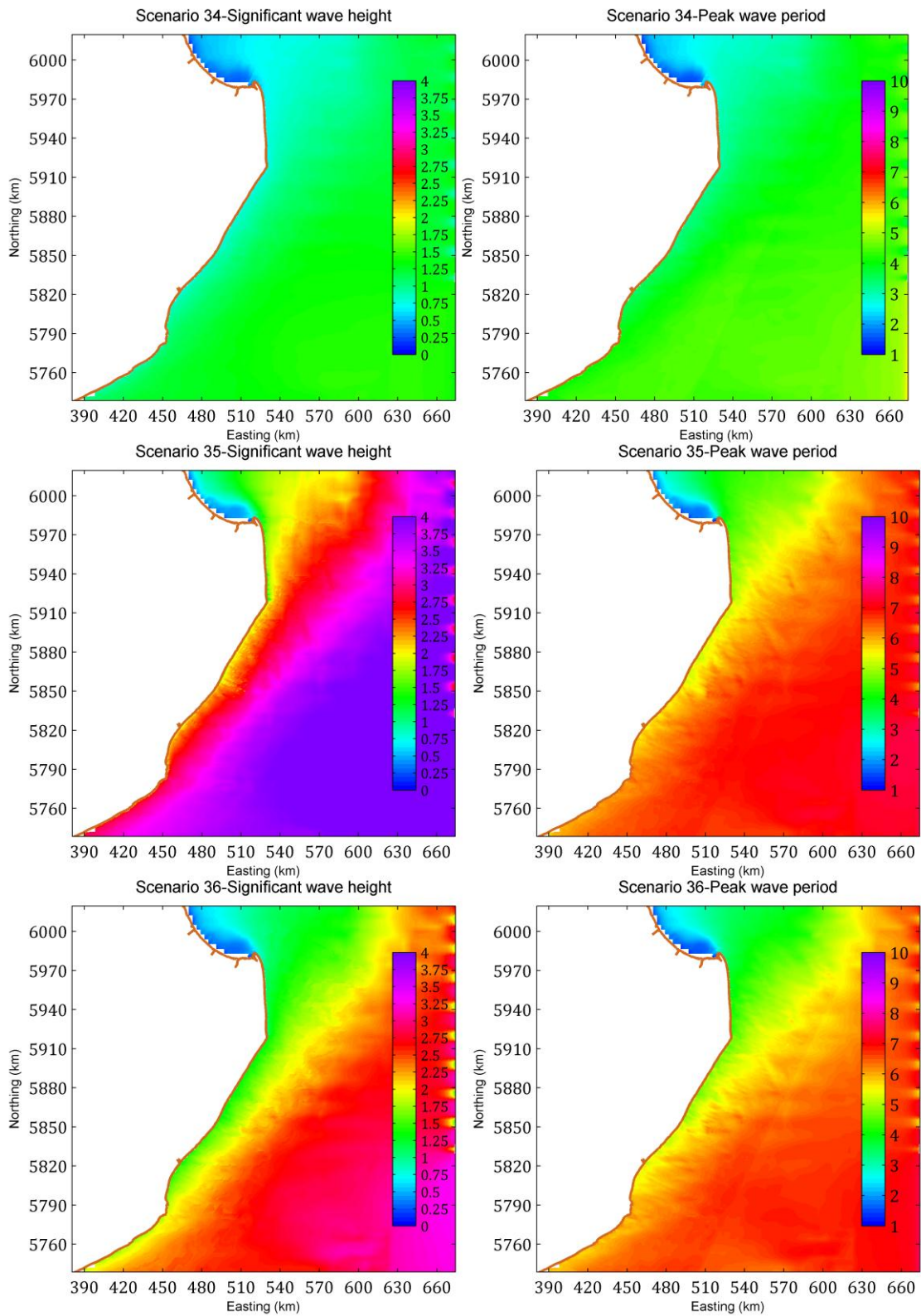


Figure 26 Scenarios 34-36

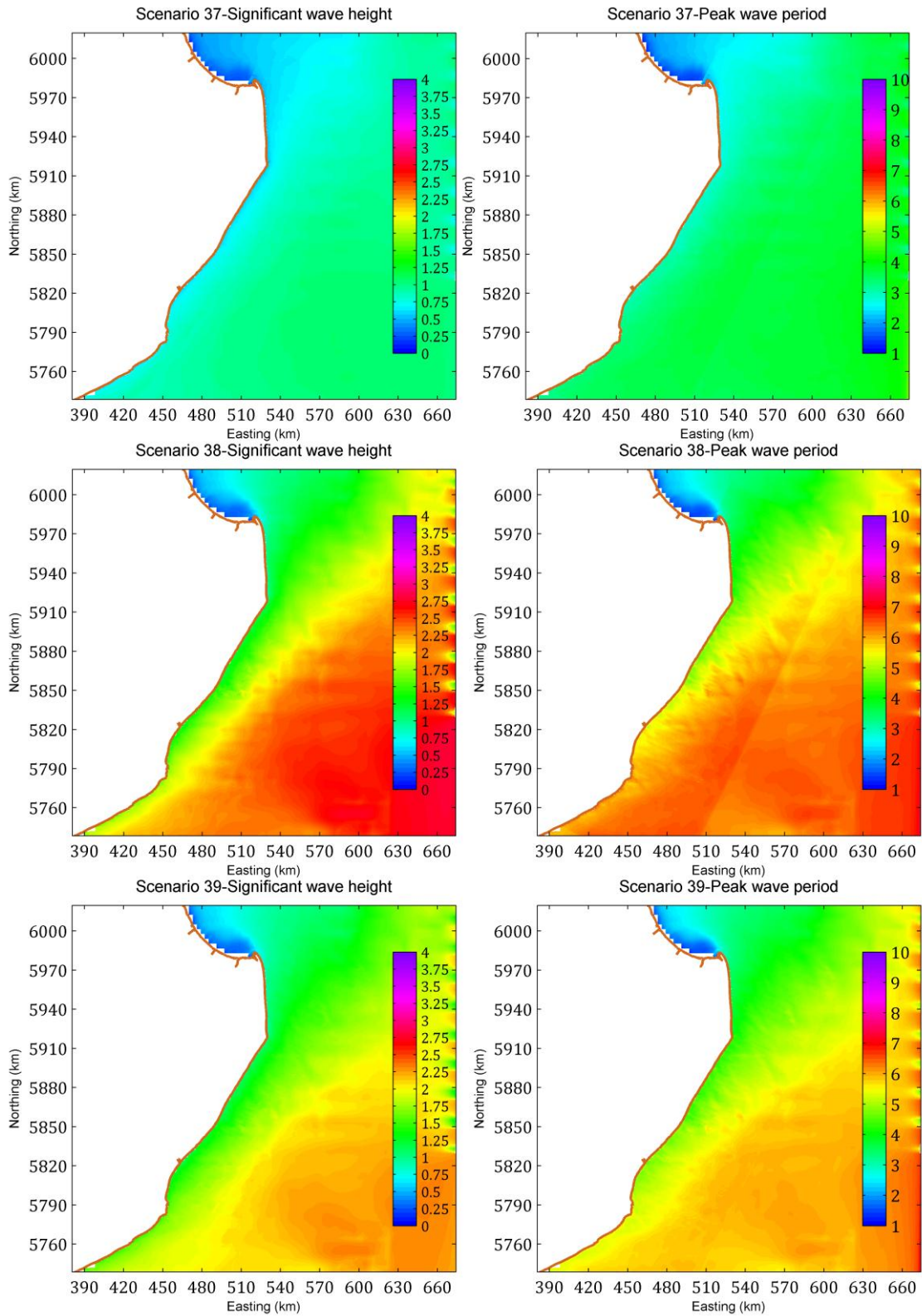


Figure 27 Scenarios 37-39

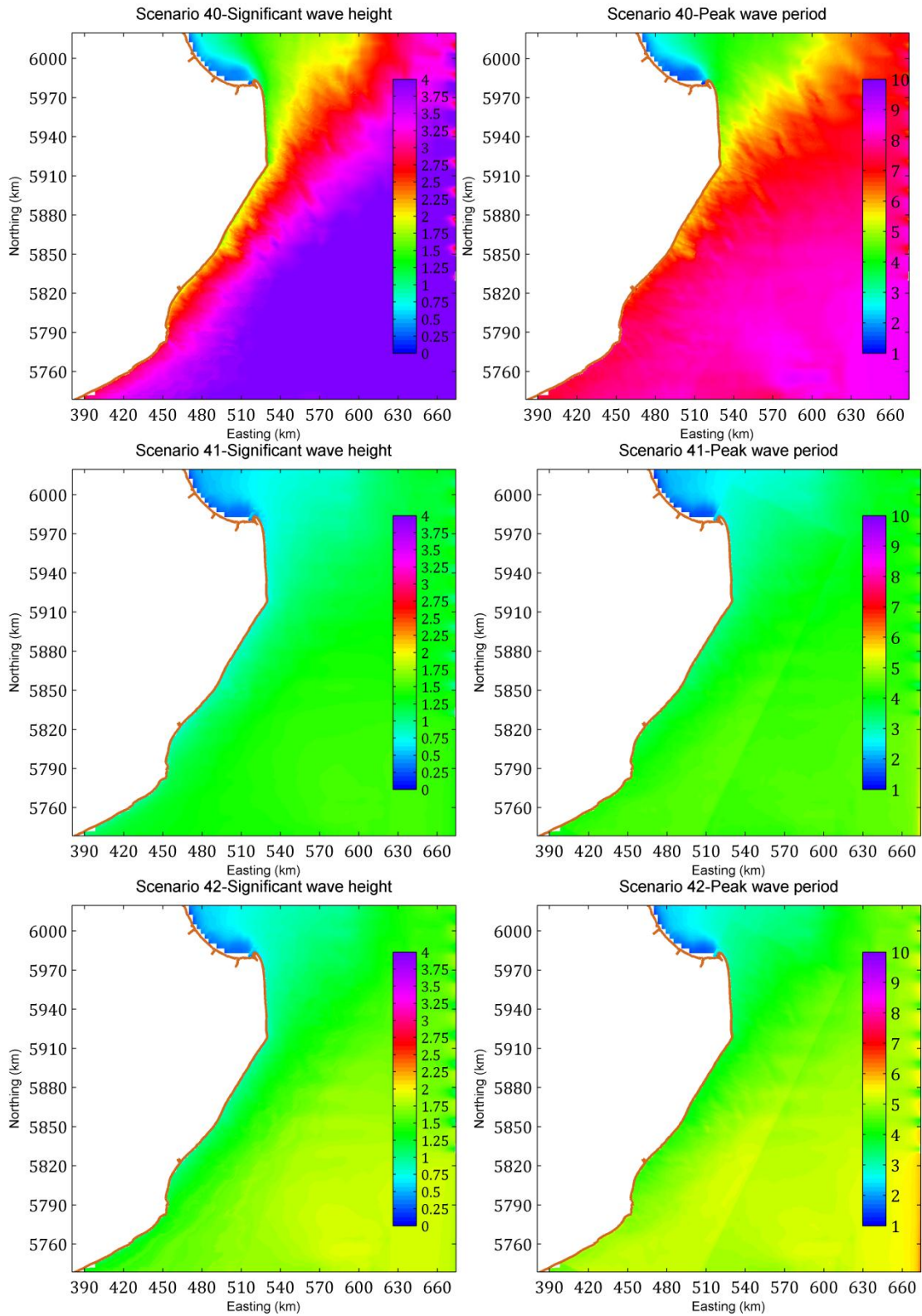


Figure 28 Scenarios 40-42

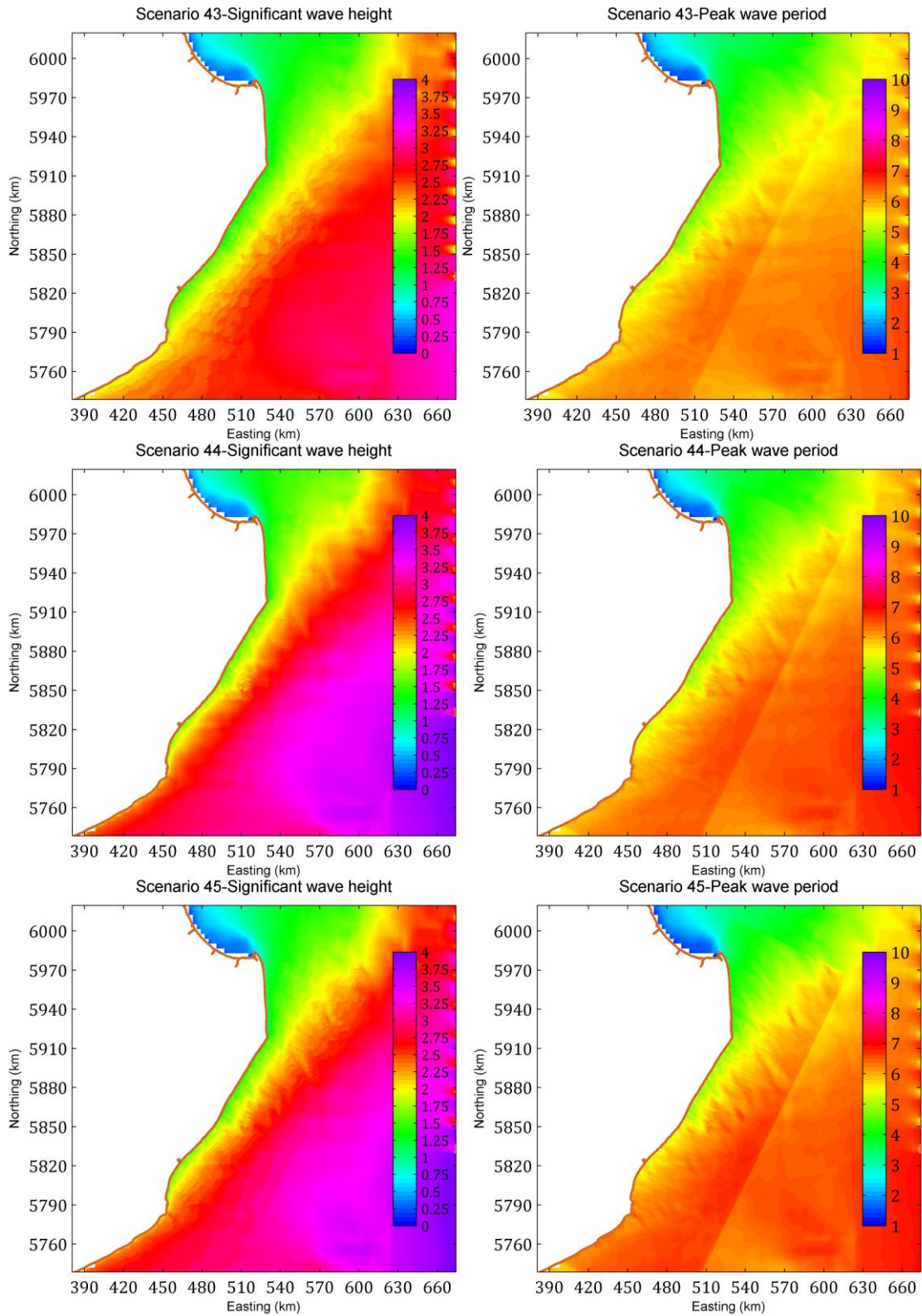


Figure 29 Scenarios 43-45

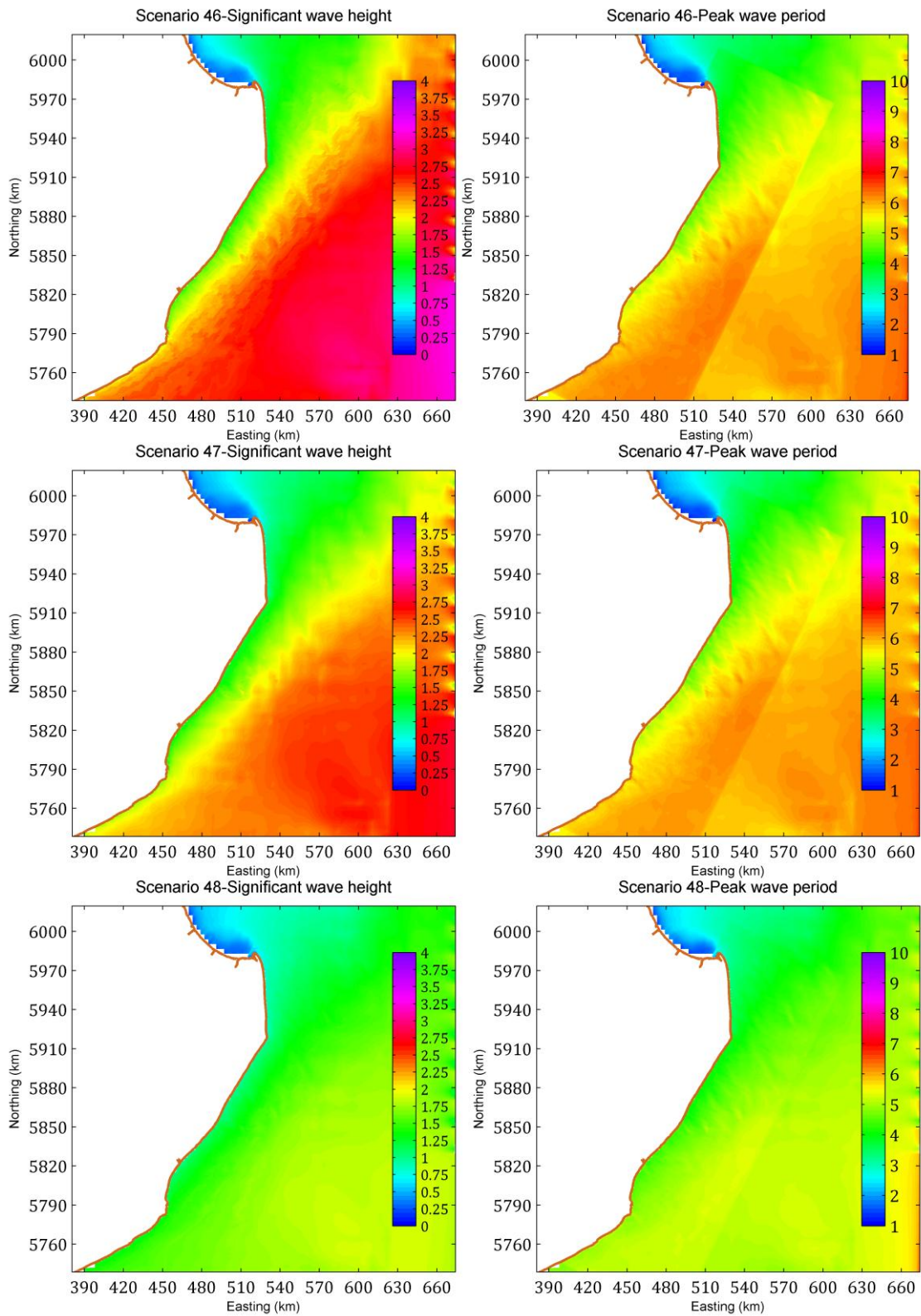


Figure 30 Scenarios 46-48

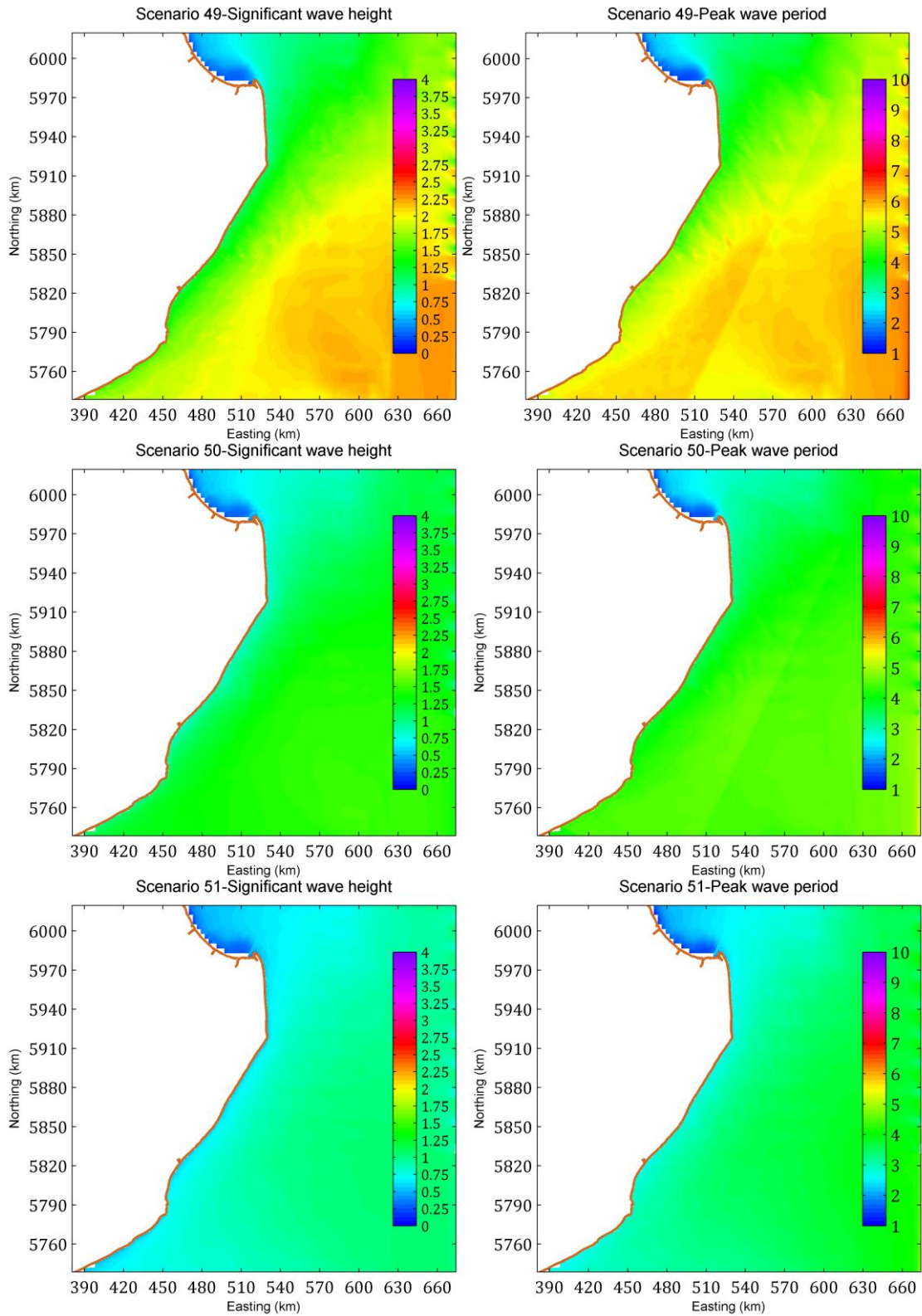


Figure 31 Scenarios 49-51

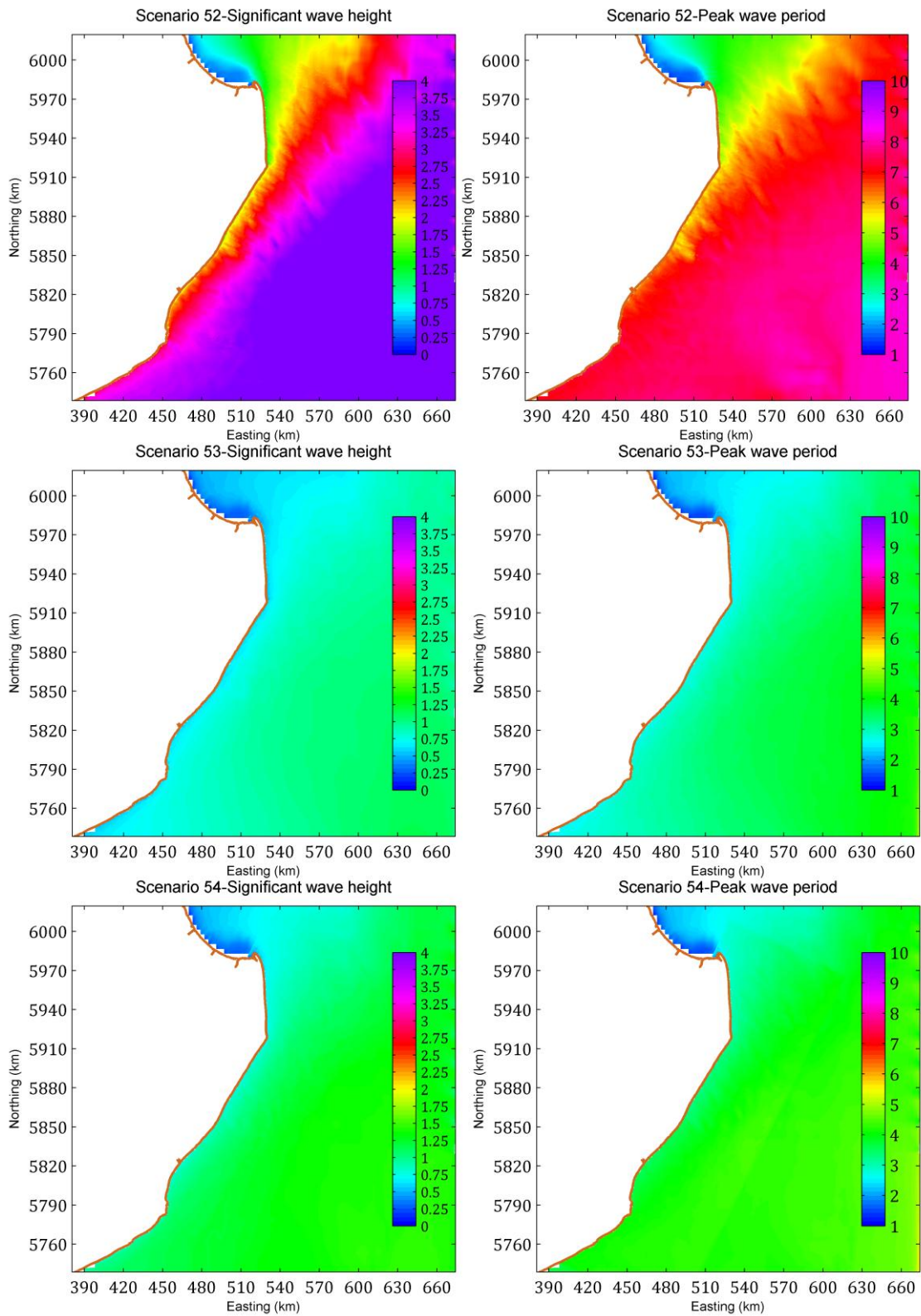


Figure 32 Scenarios 52-54

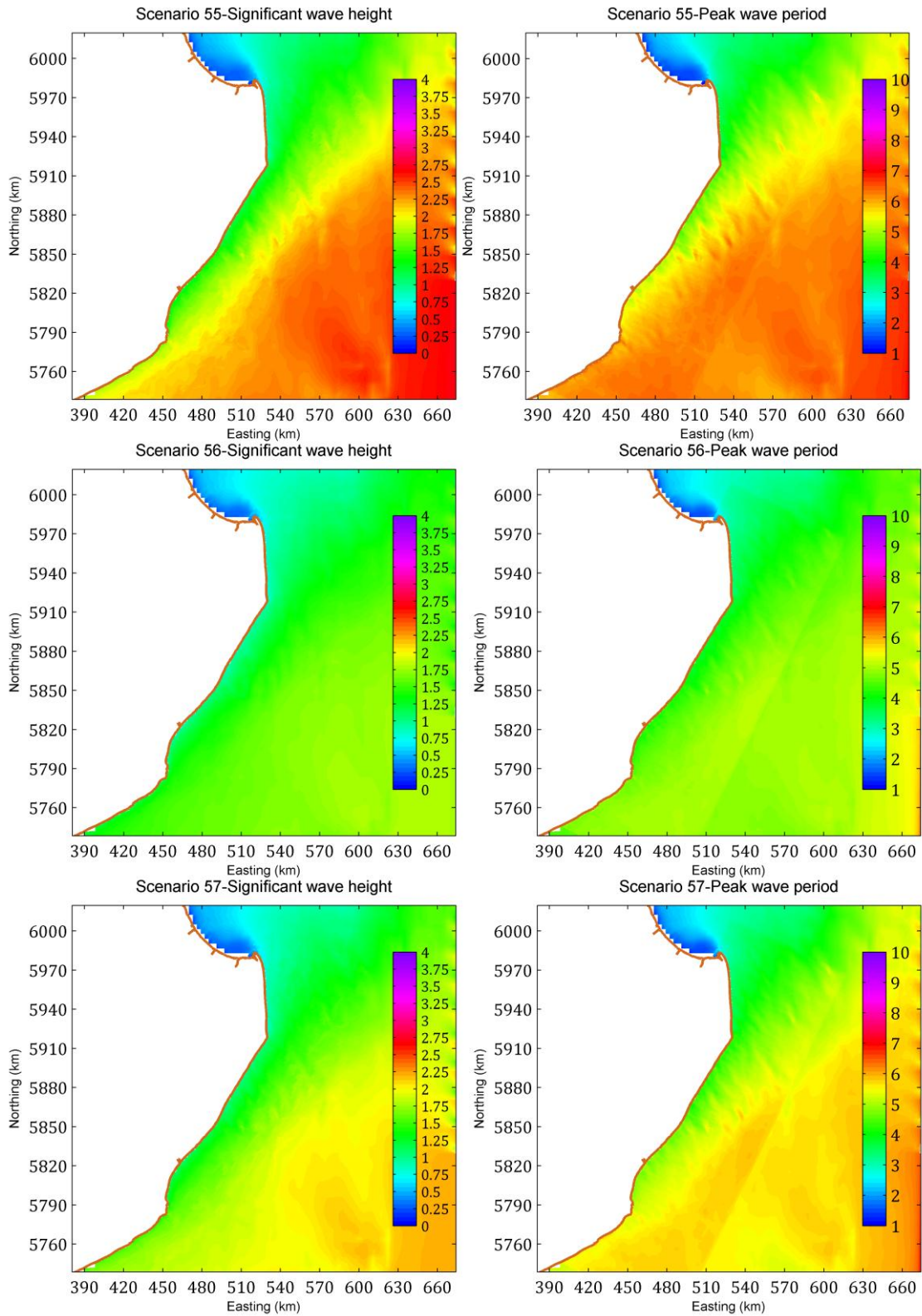
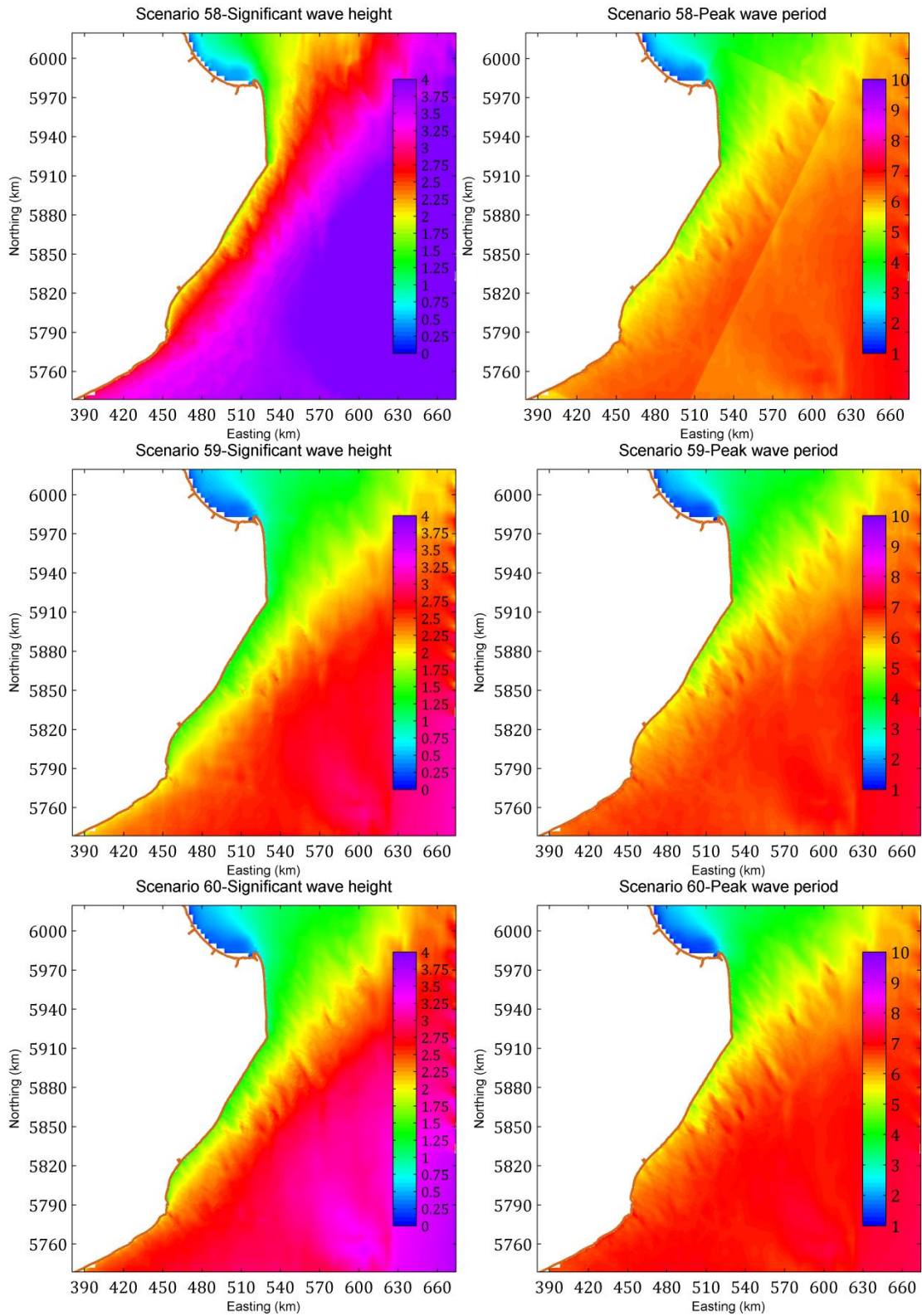


Figure 33 Scenarios 55-57



**Figure 34 Scenarios 58-60**

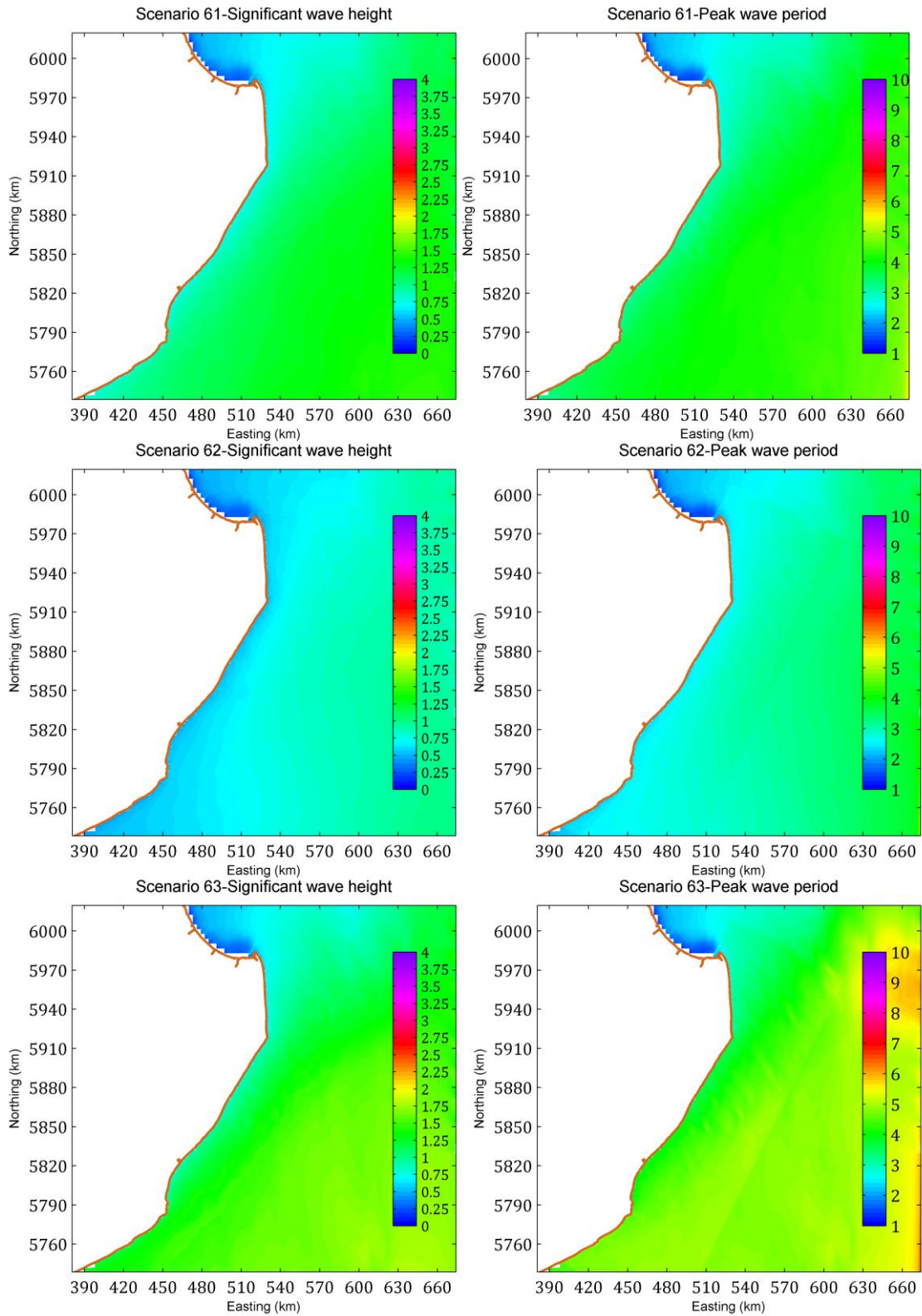


Figure 35 Scenarios 61-63

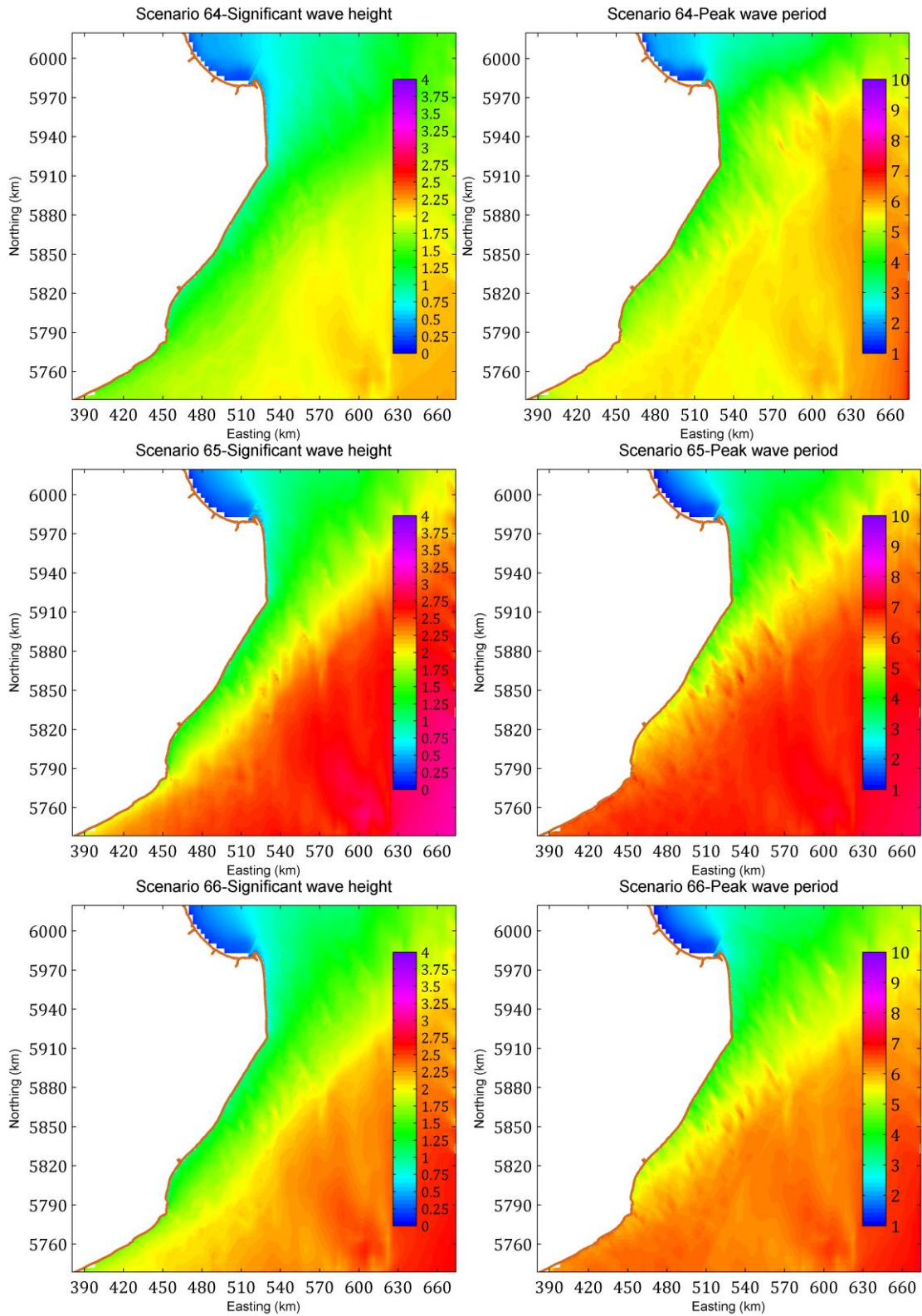


Figure 36 Scenarios 64-66

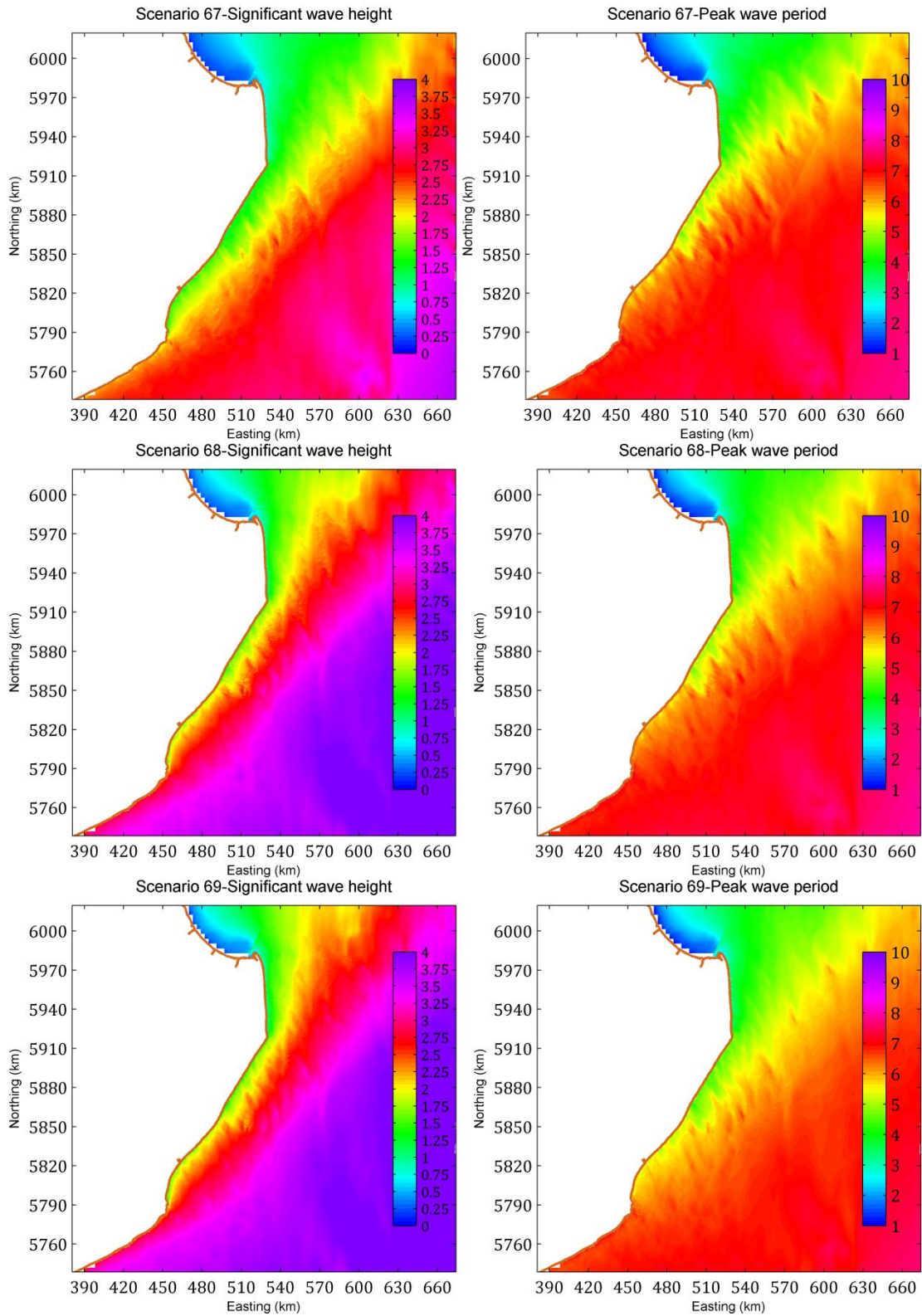


Figure 37 Scenarios 67-69

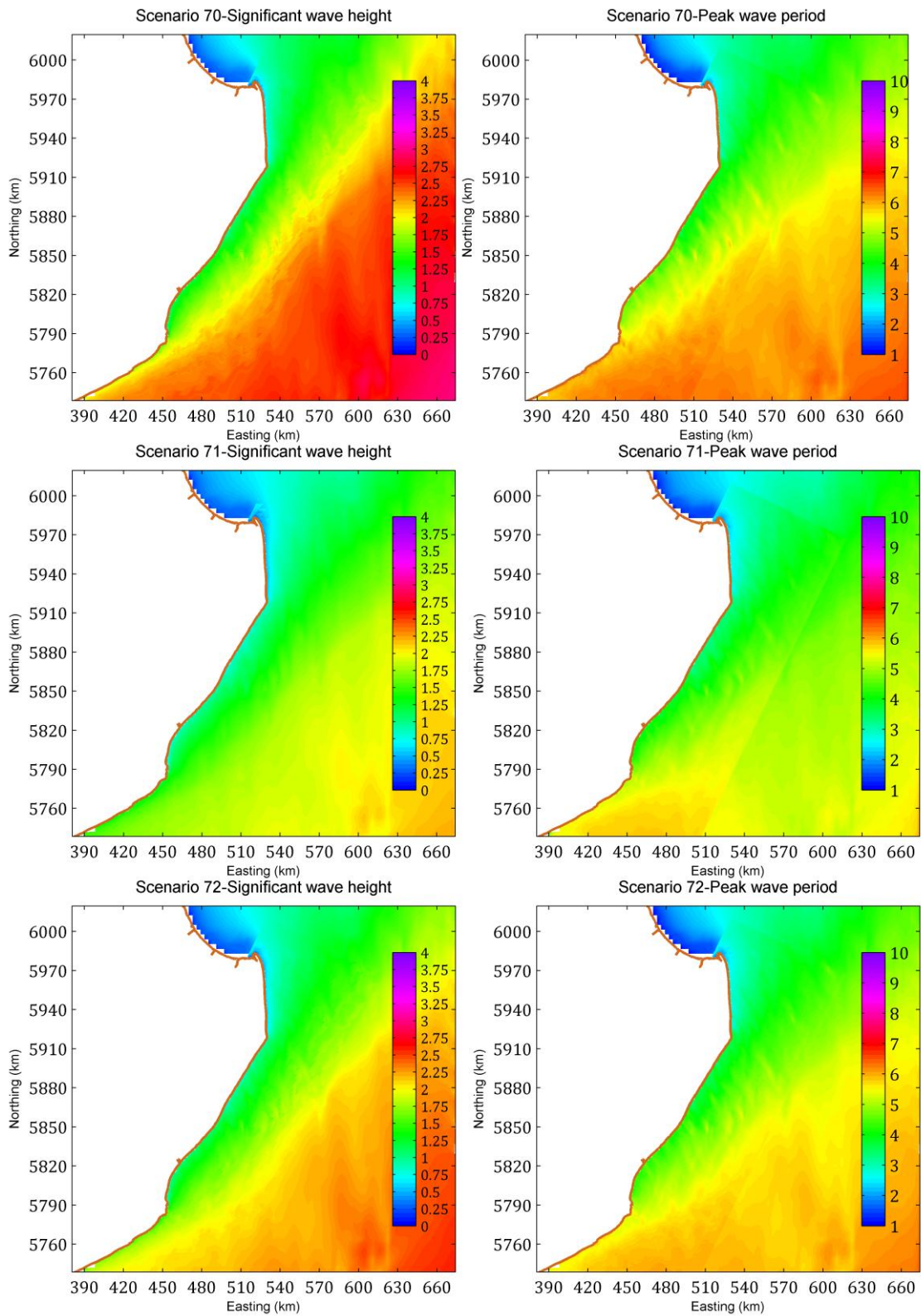


Figure 38 Scenarios 70-72

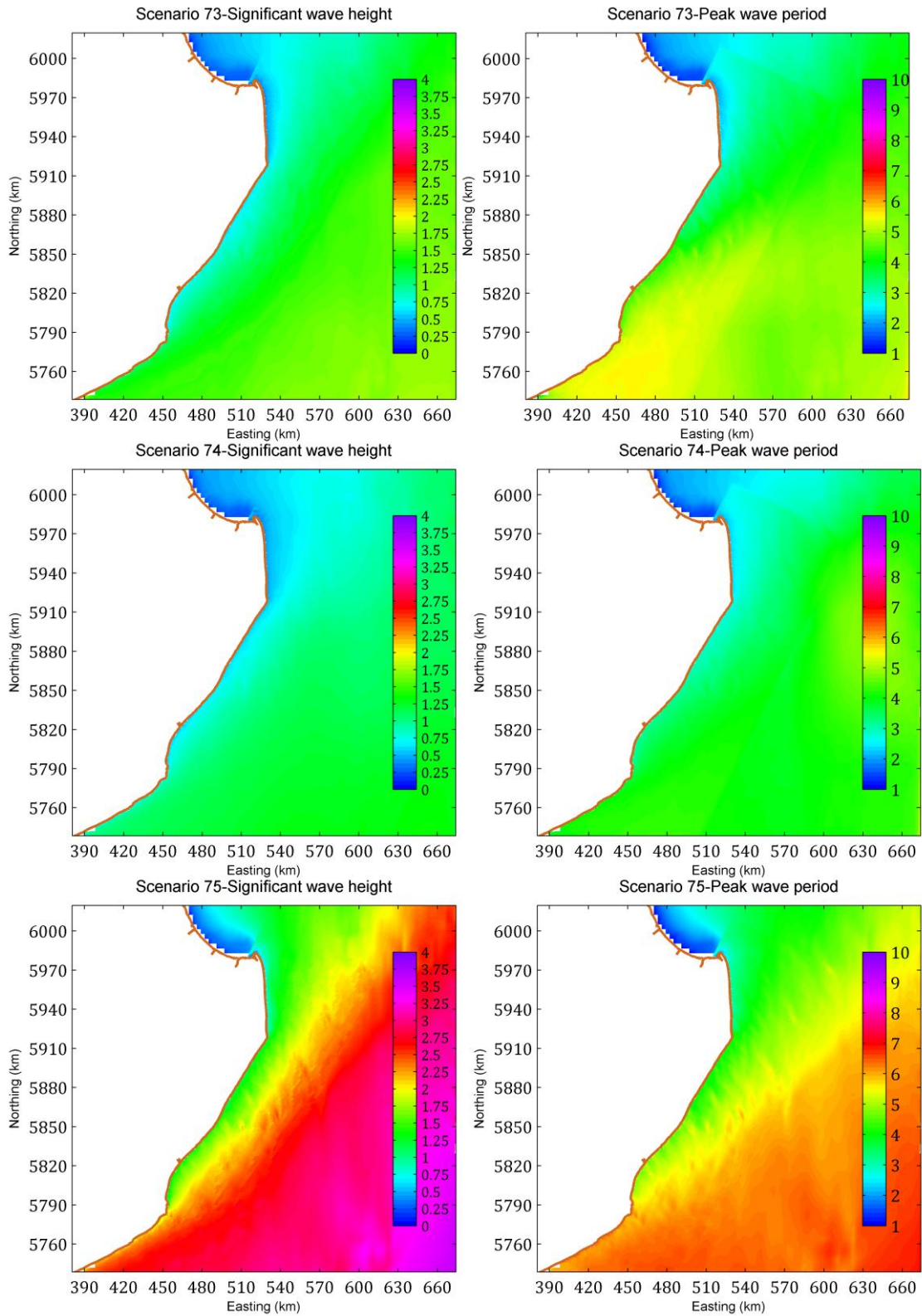


Figure 39 Scenarios 73-75

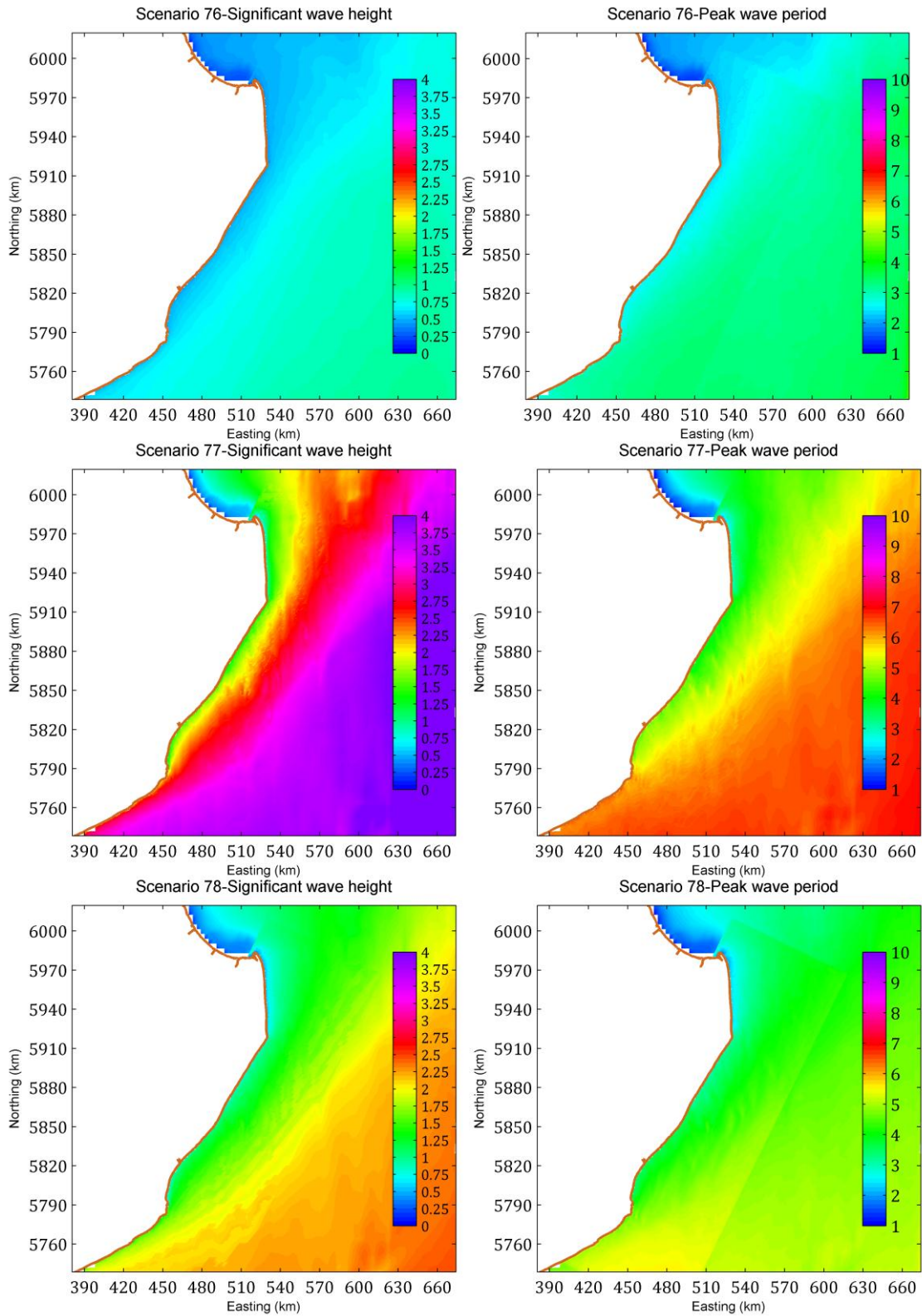


Figure 40 Scenarios 76-78

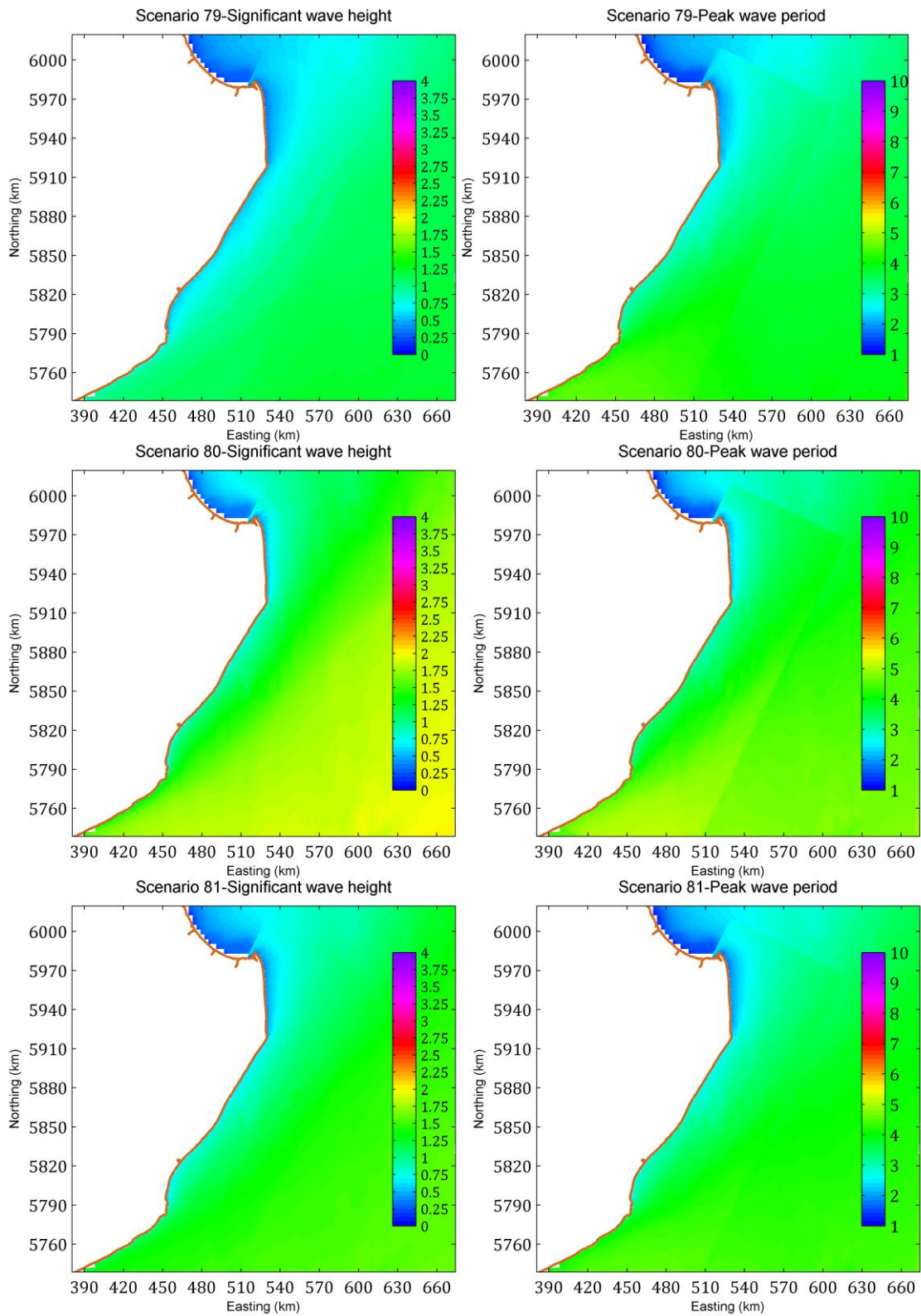


Figure 41 Scenarios 79-81

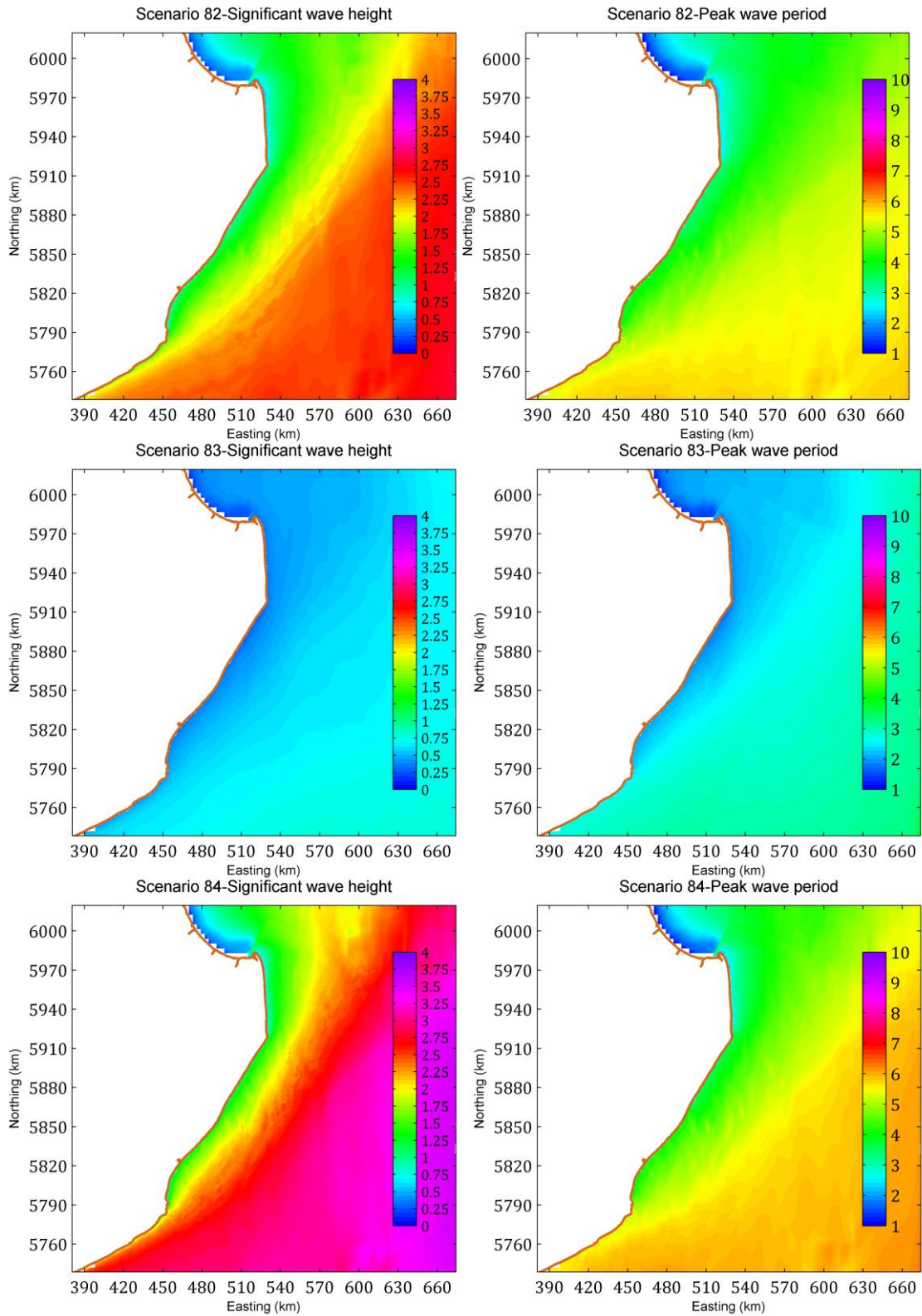


Figure 42 Scenarios 82-84

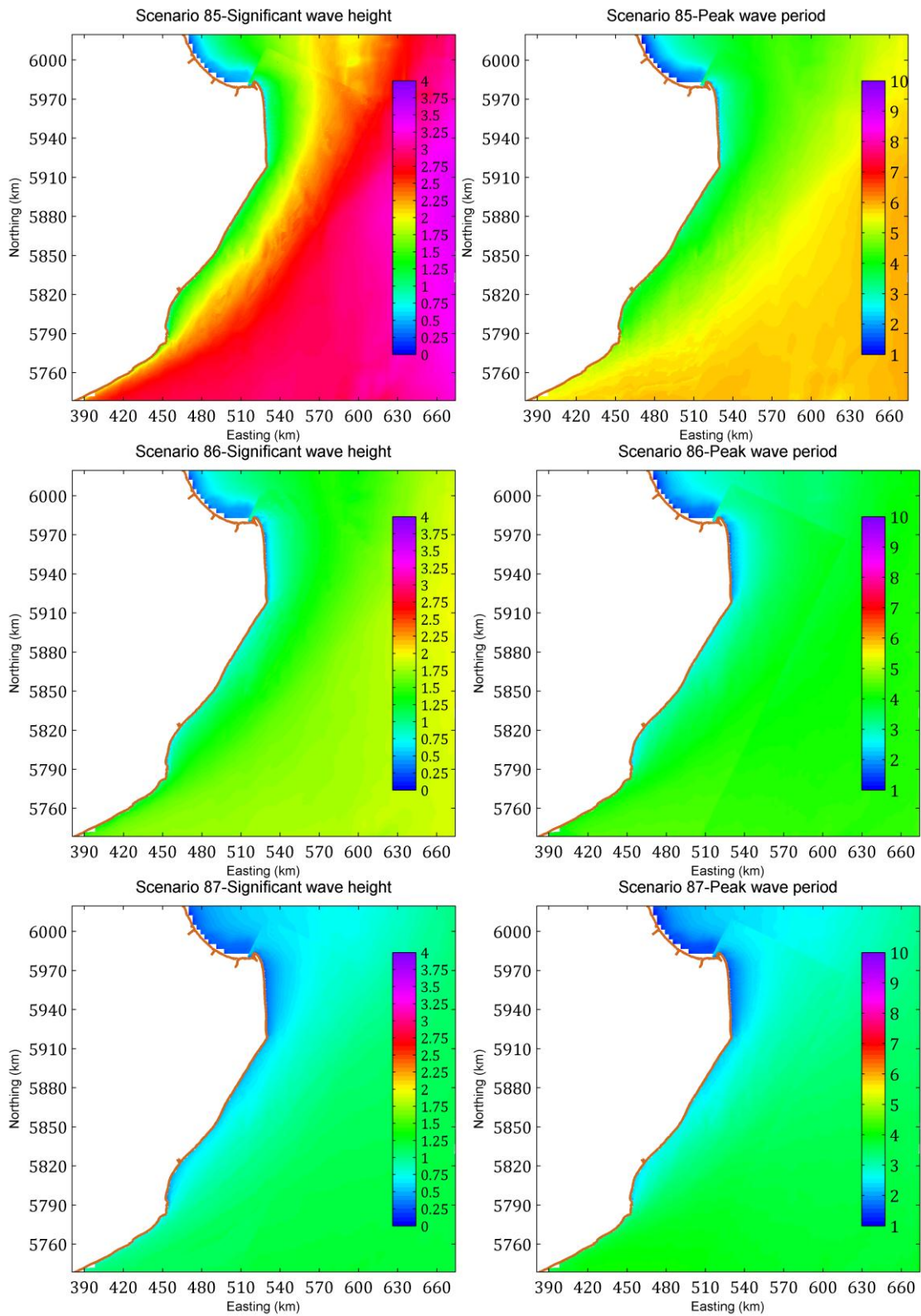


Figure 43 Scenarios 85-87

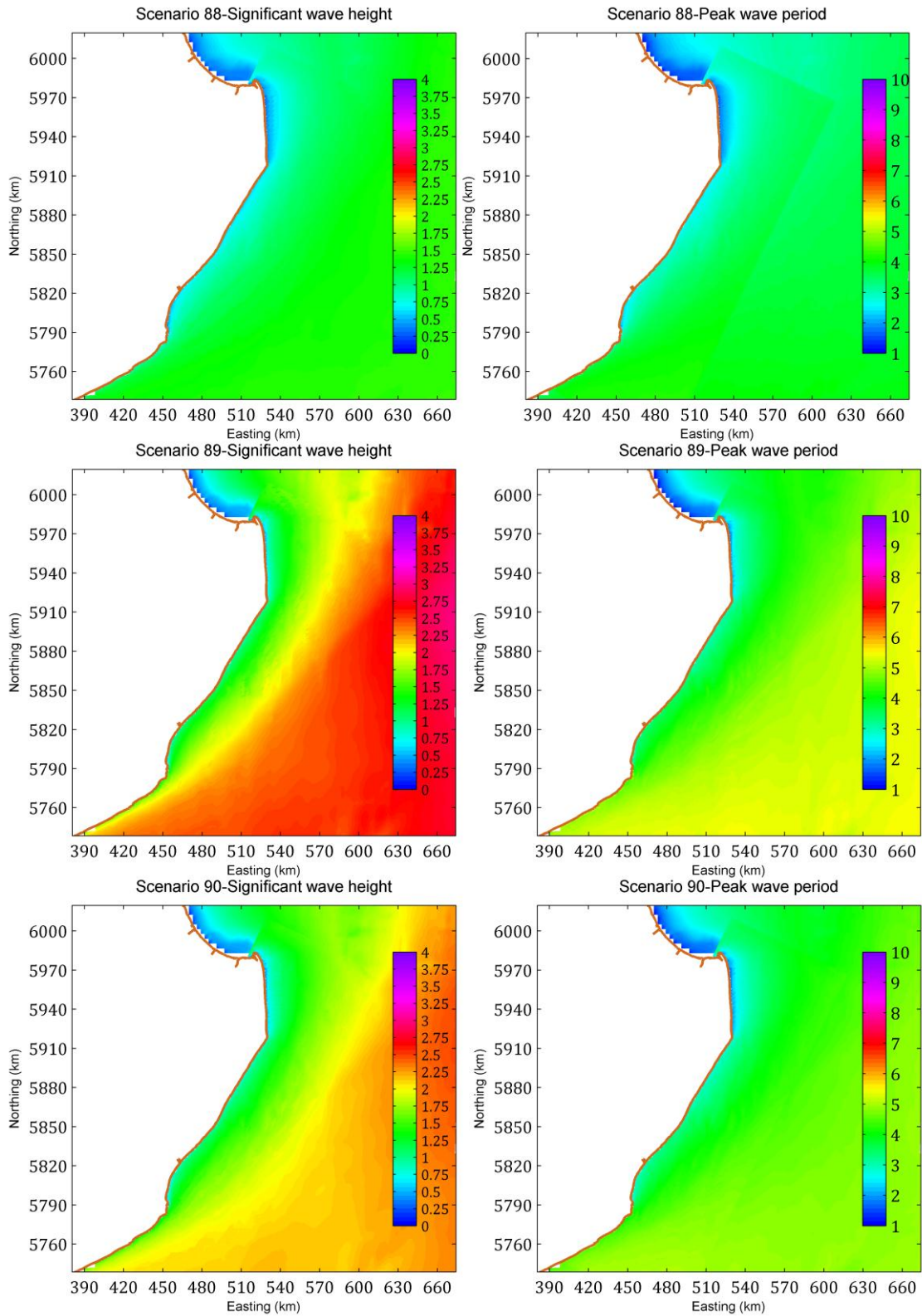


Figure 44 Scenarios 88-90

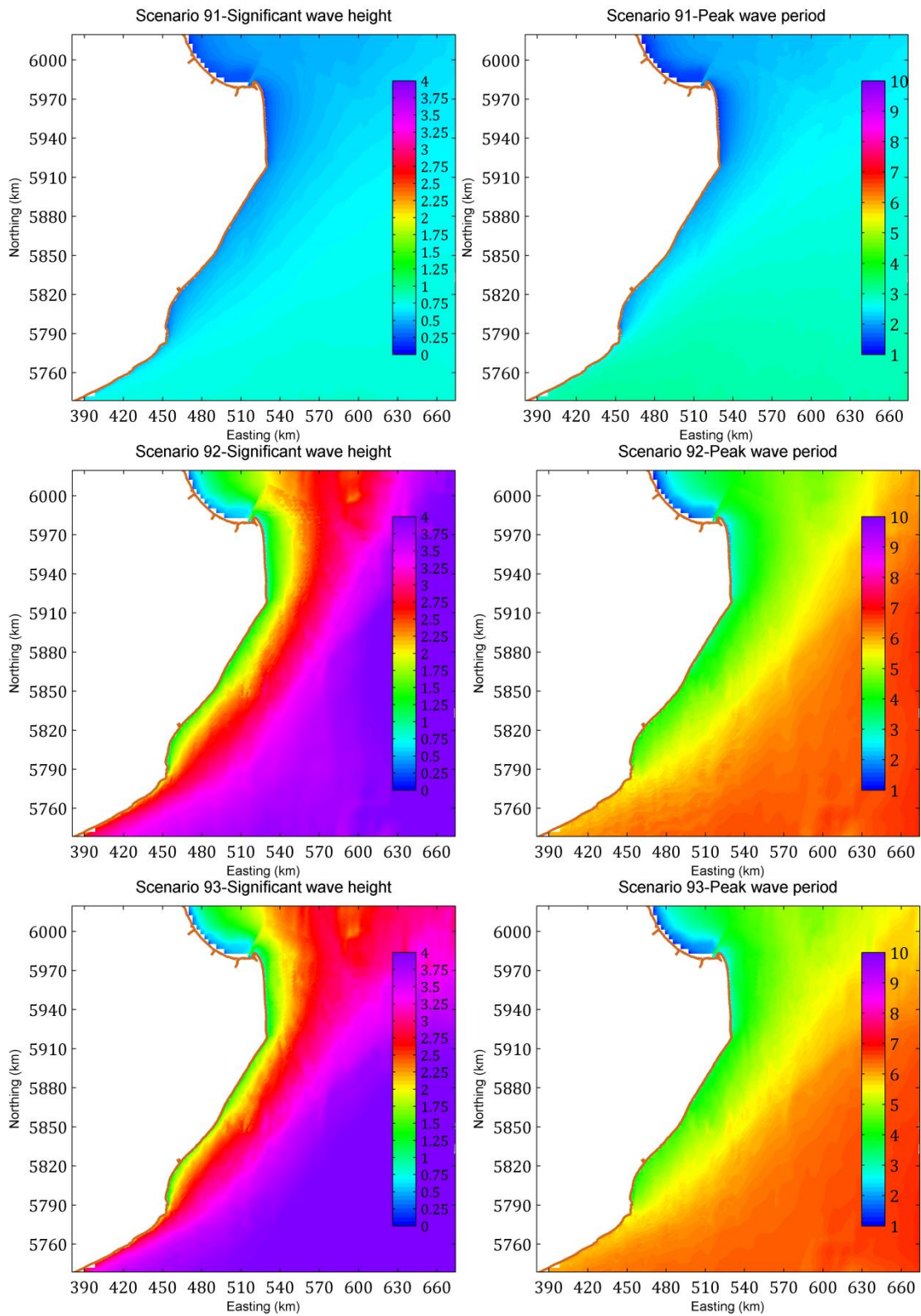


Figure 45 Scenarios 91-93

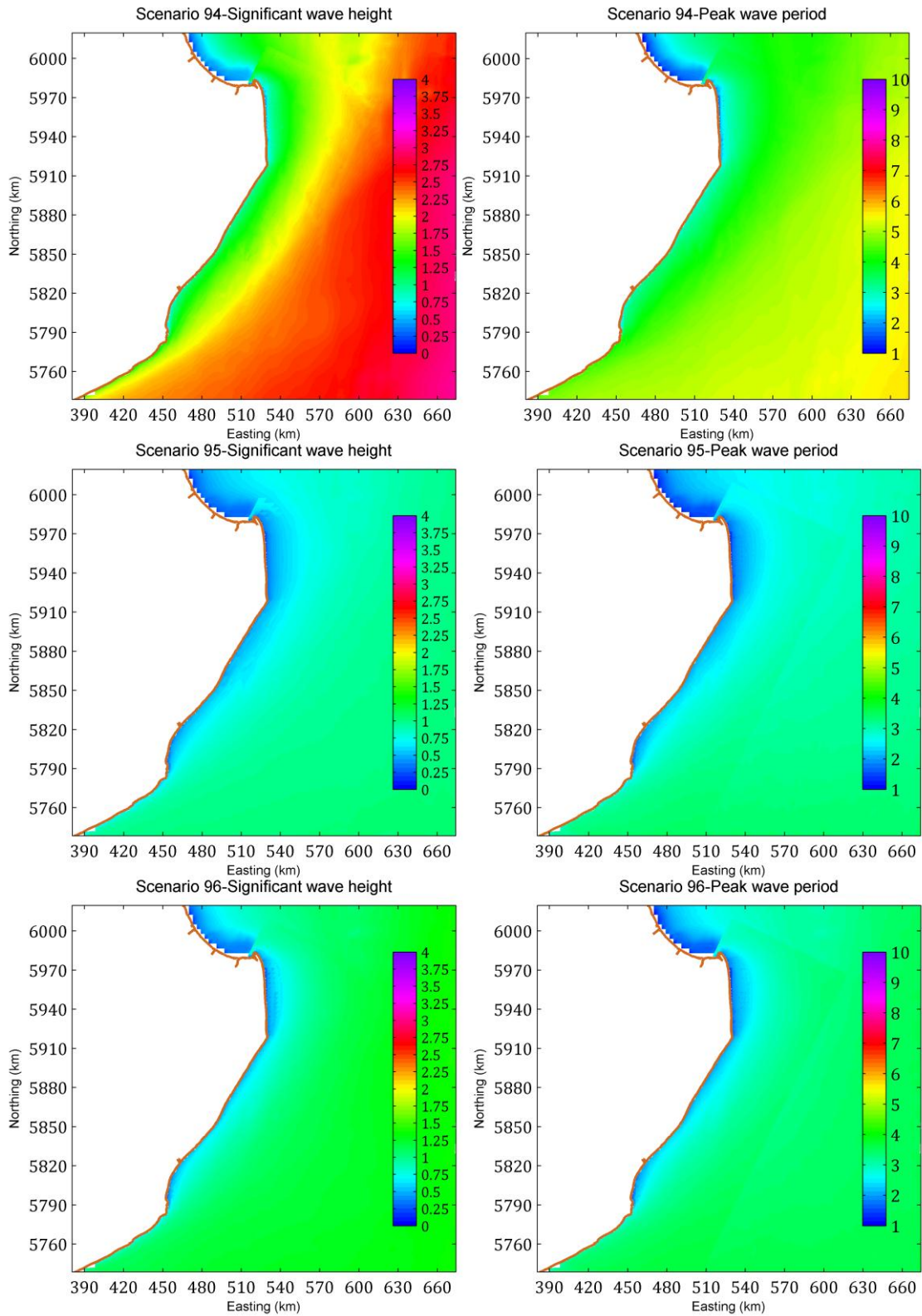


Figure 46 Scenarios 94-96

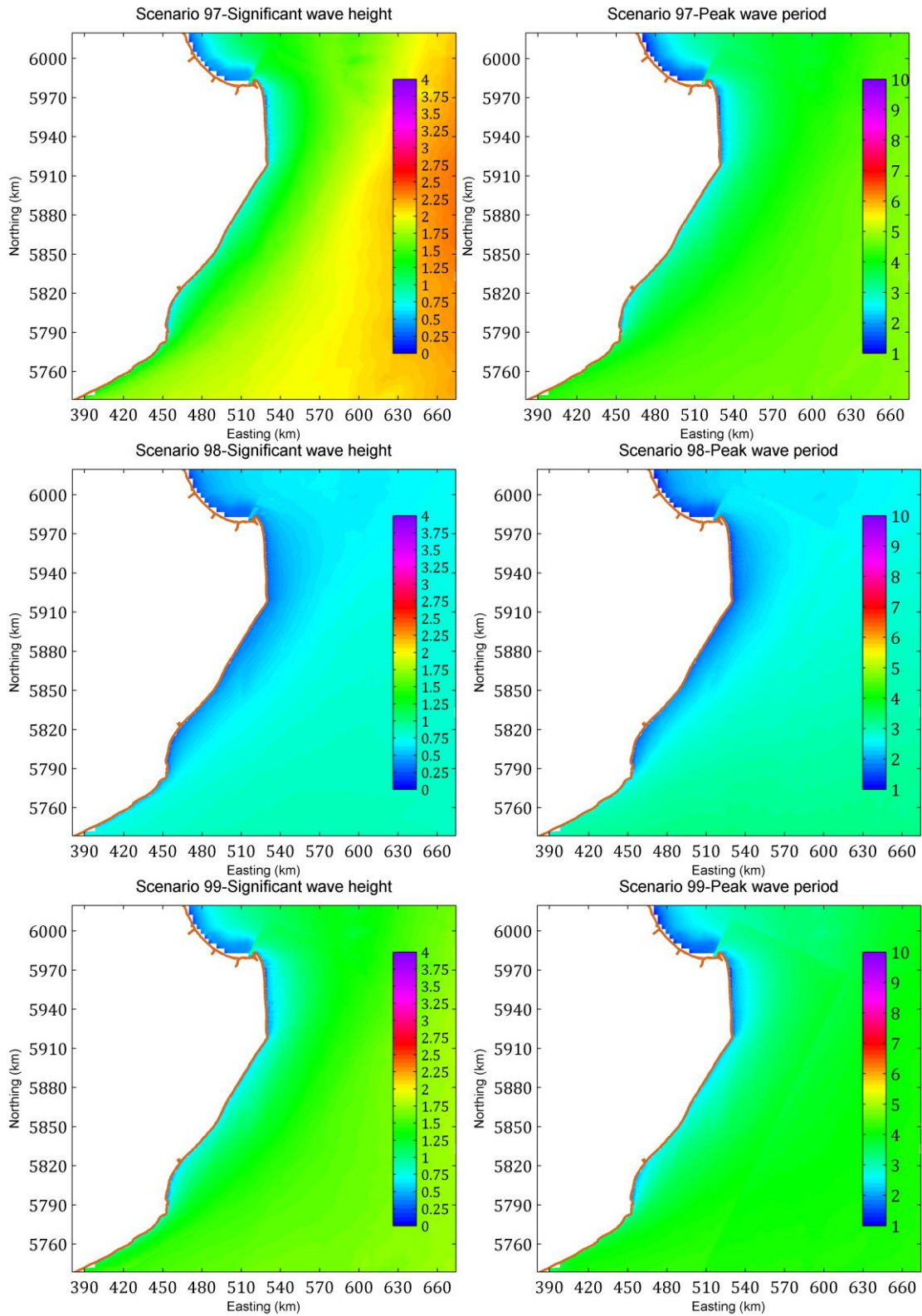


Figure 47 Scenarios 97-99

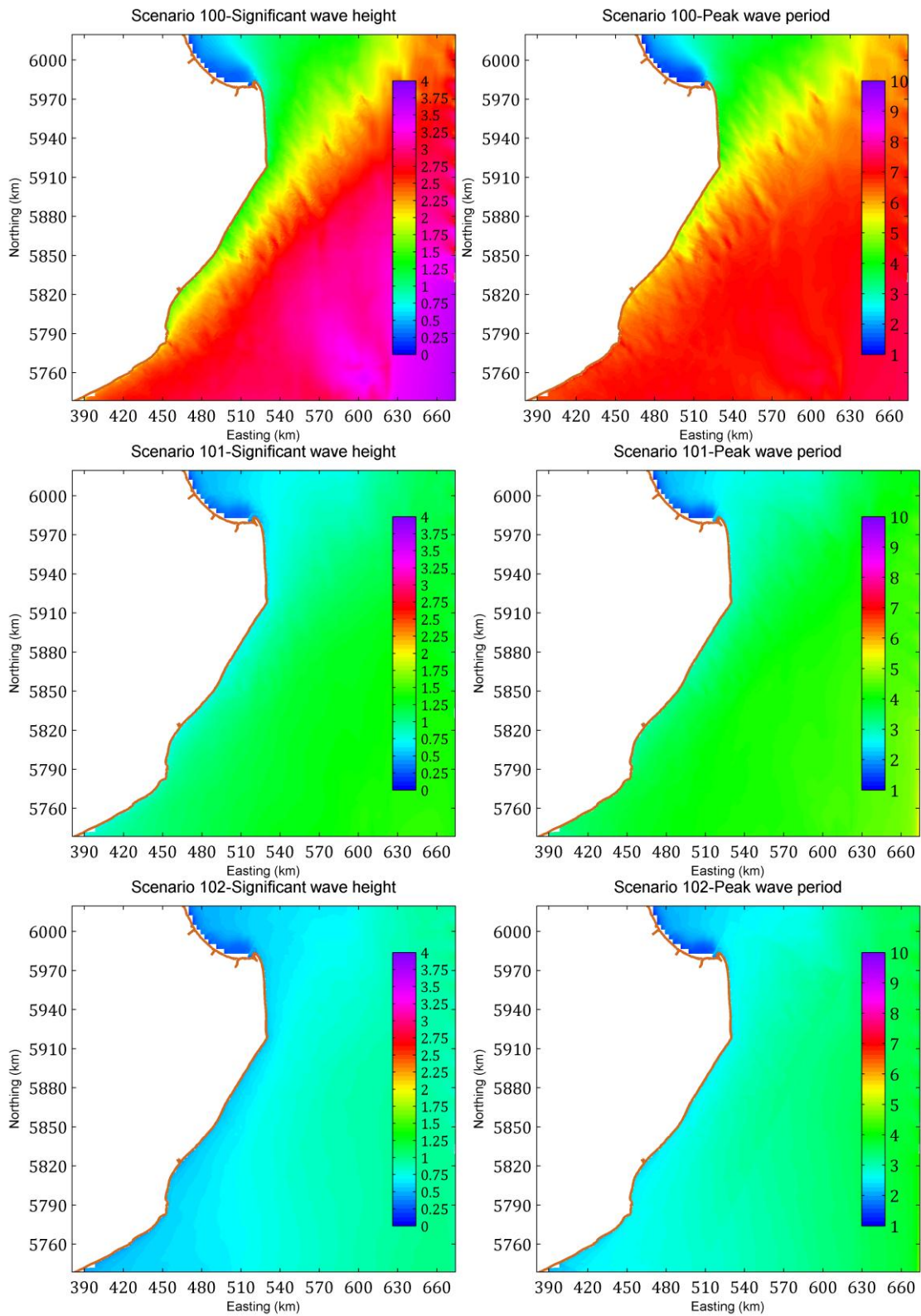


Figure 48 Scenarios 100-102

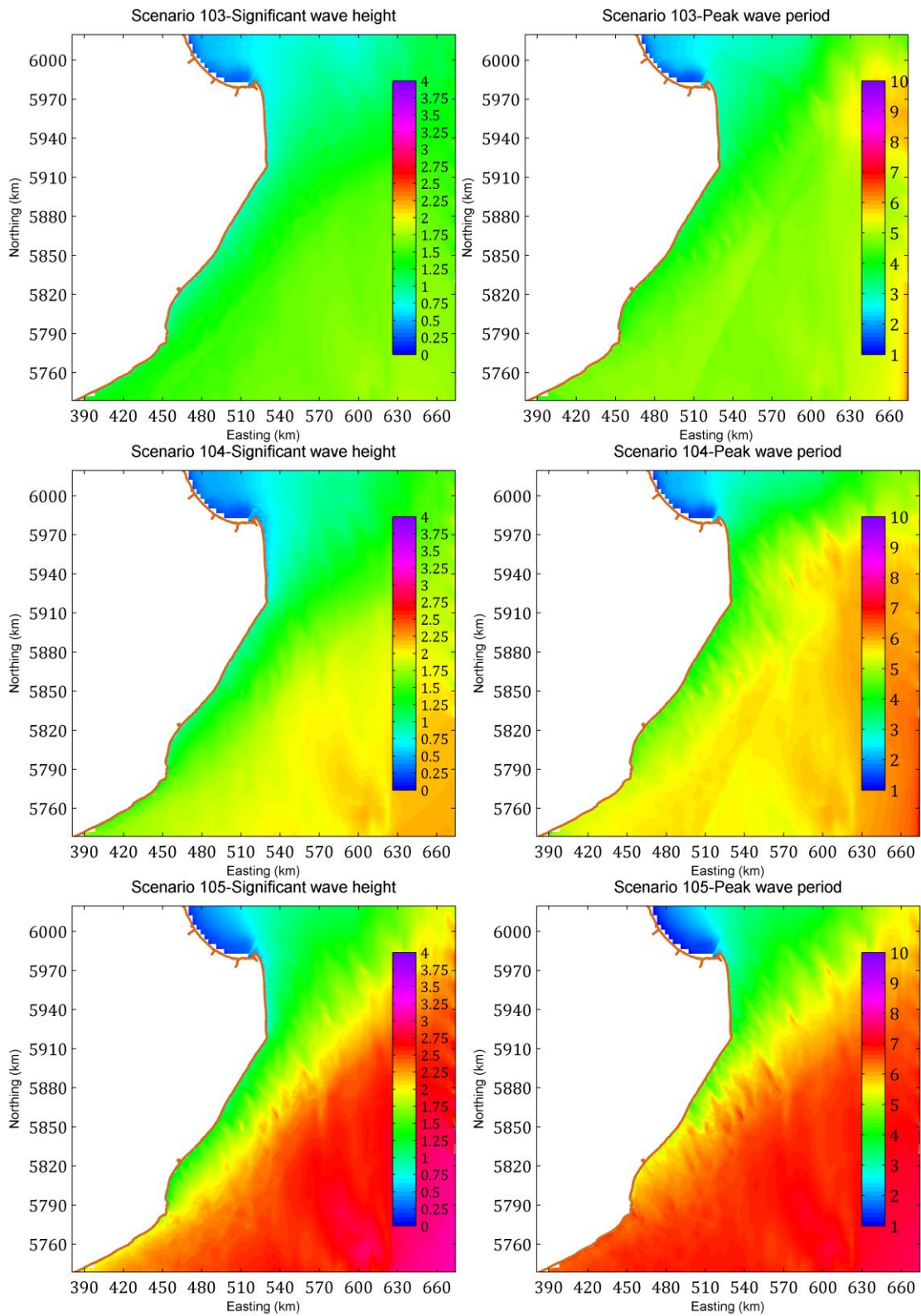


Figure 49 Scenarios 103-105

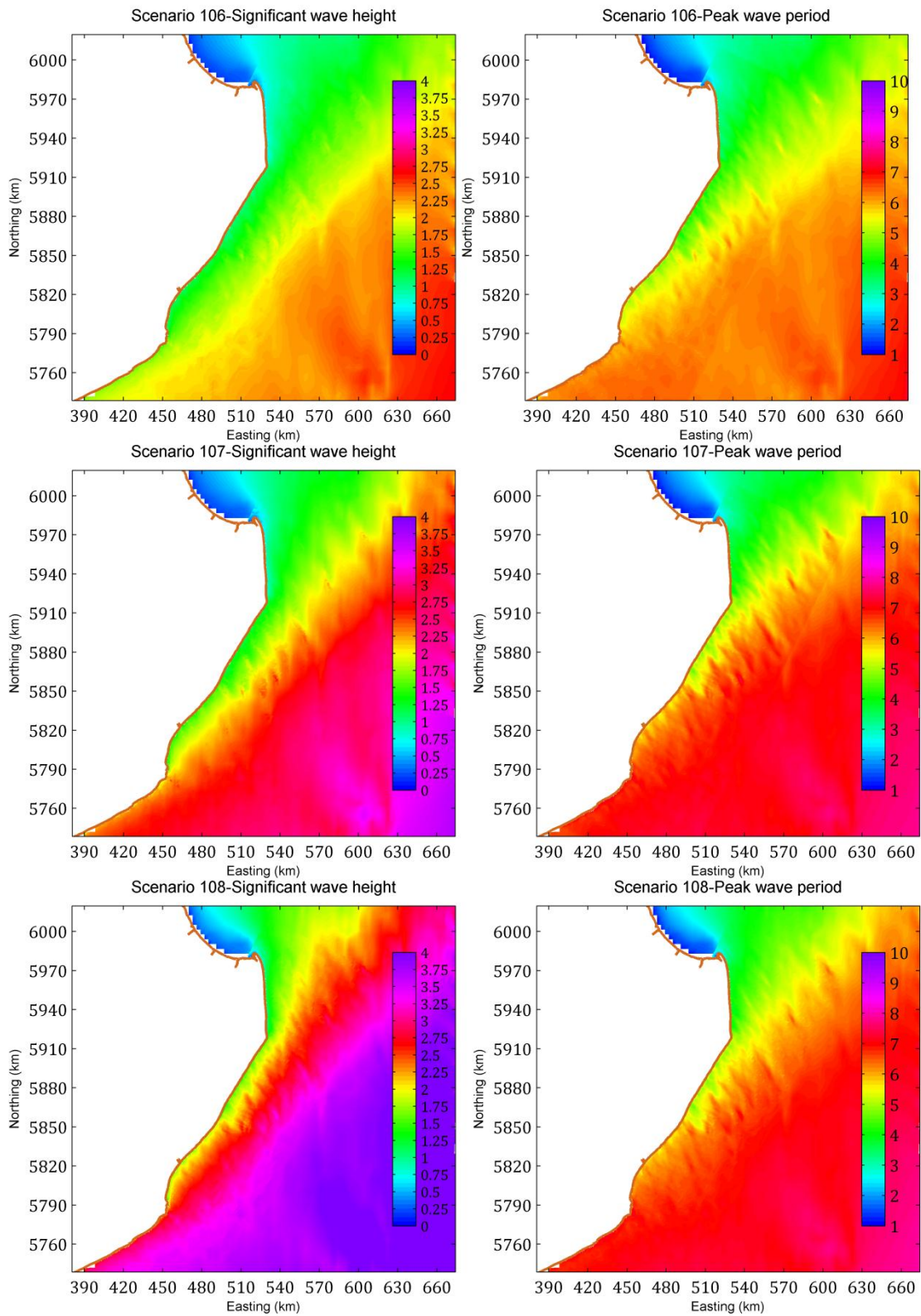


Figure 50 Scenarios 106-108

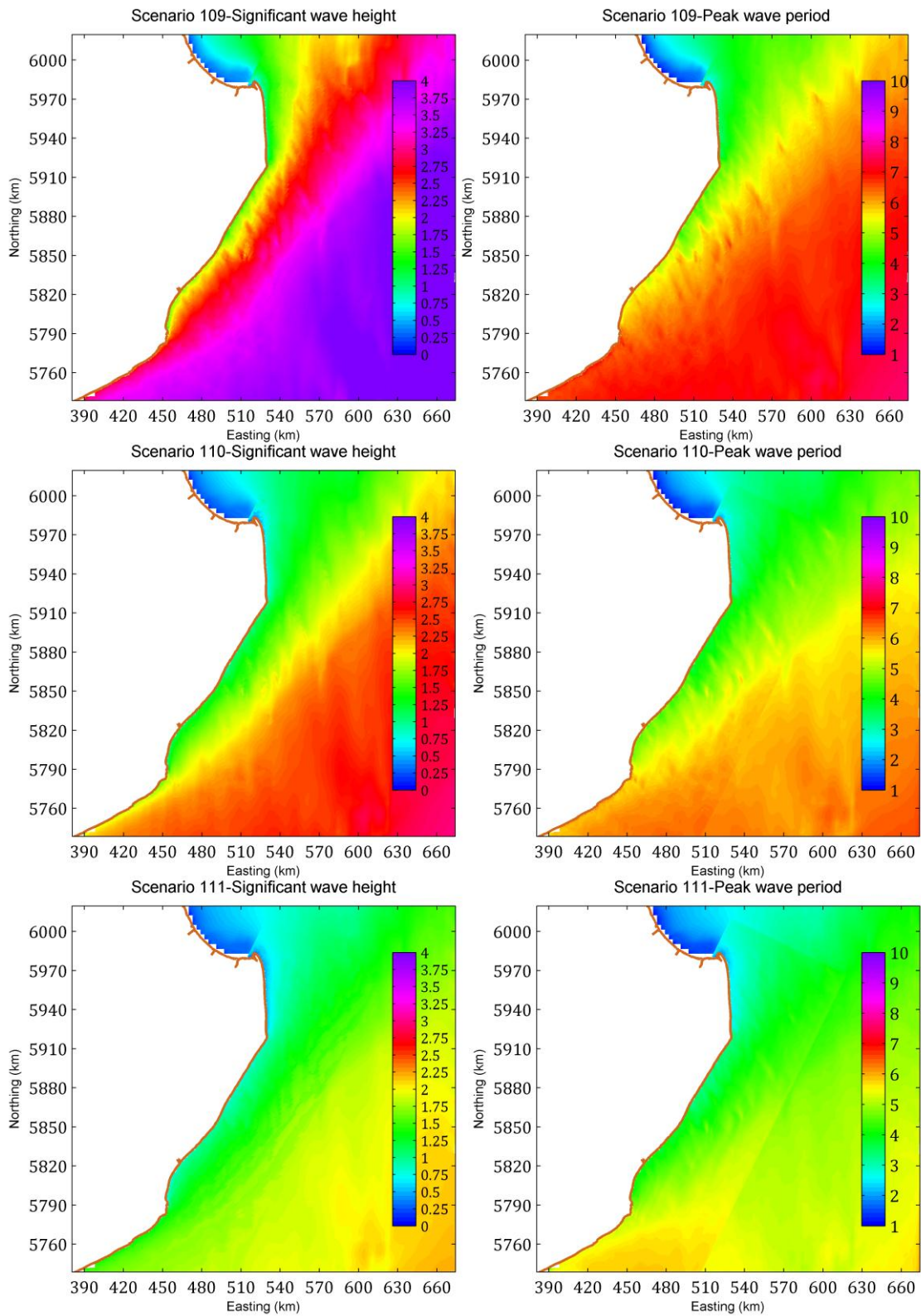


Figure 51 Scenarios 109-111

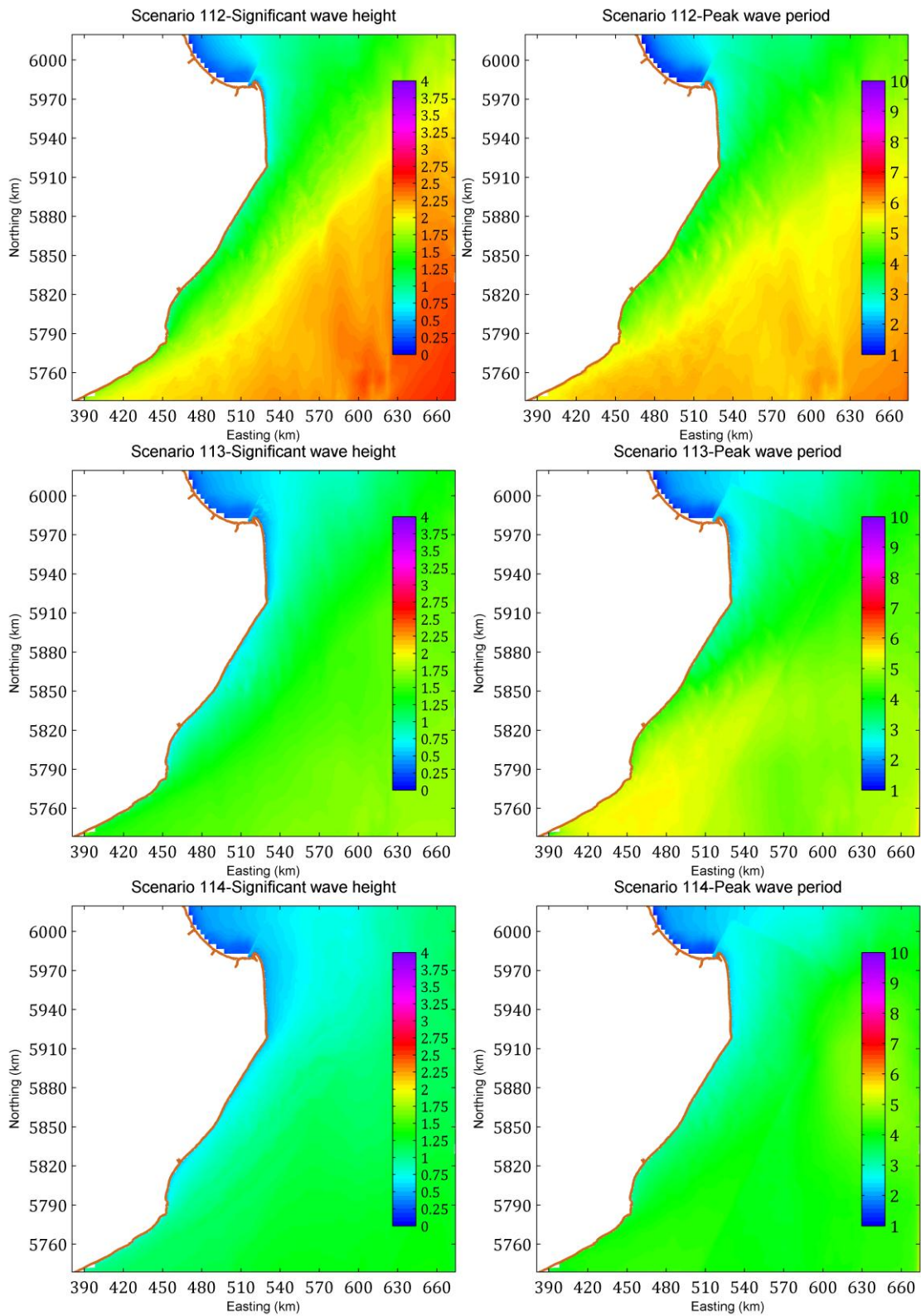


Figure 52 Scenarios 112-114

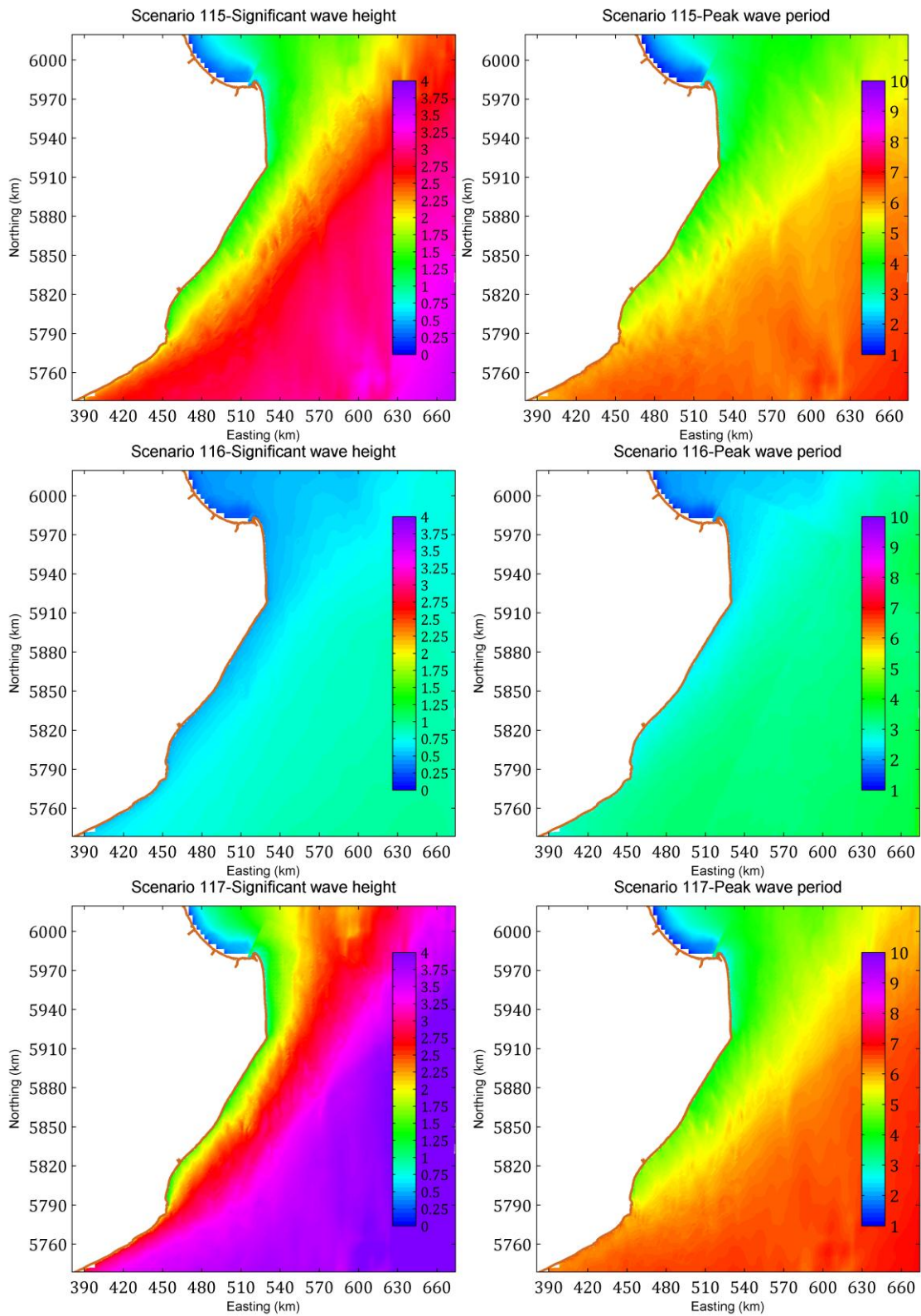
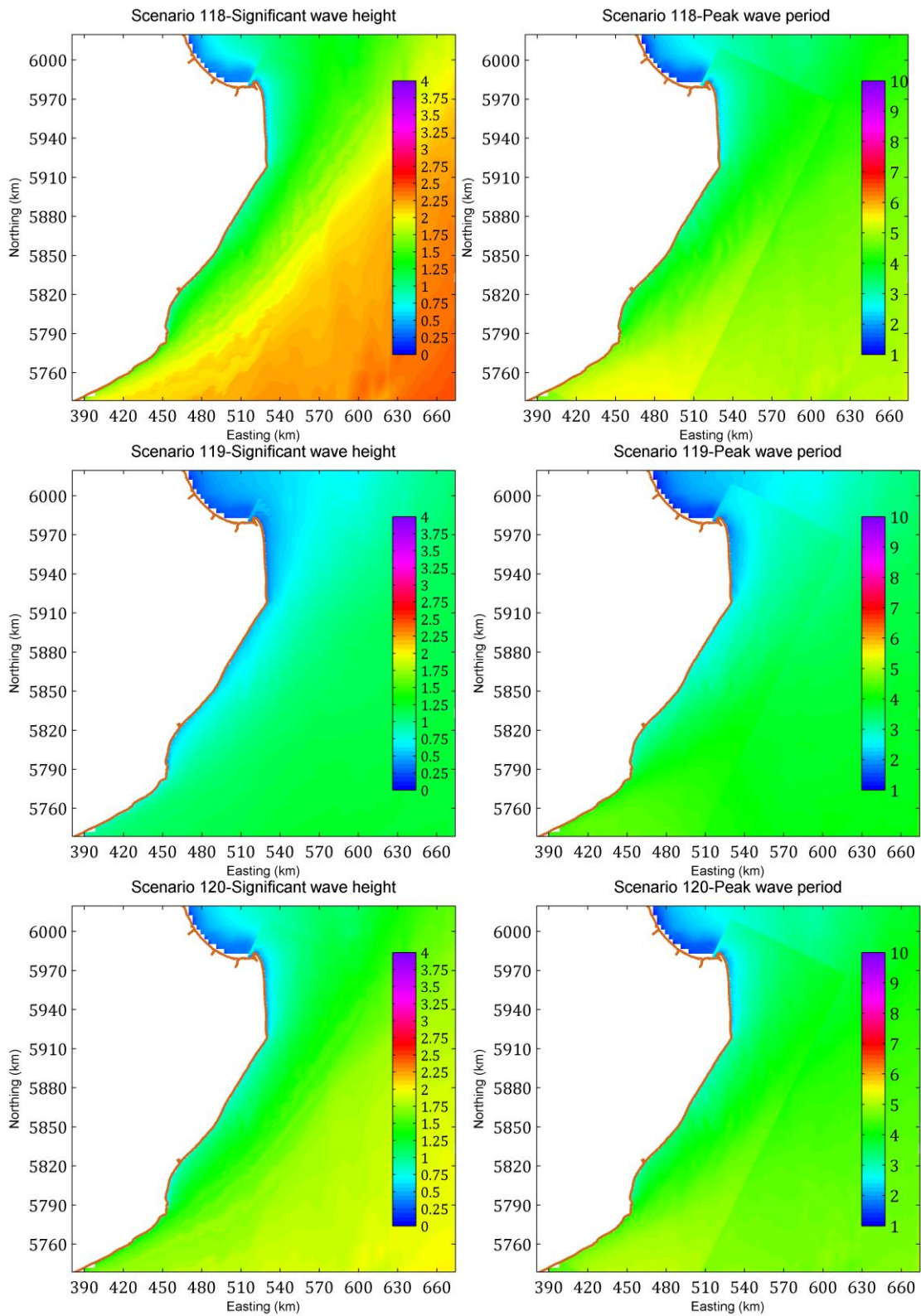


Figure 53 Scenarios 115-117



**Figure 54 Scenarios 118-120**

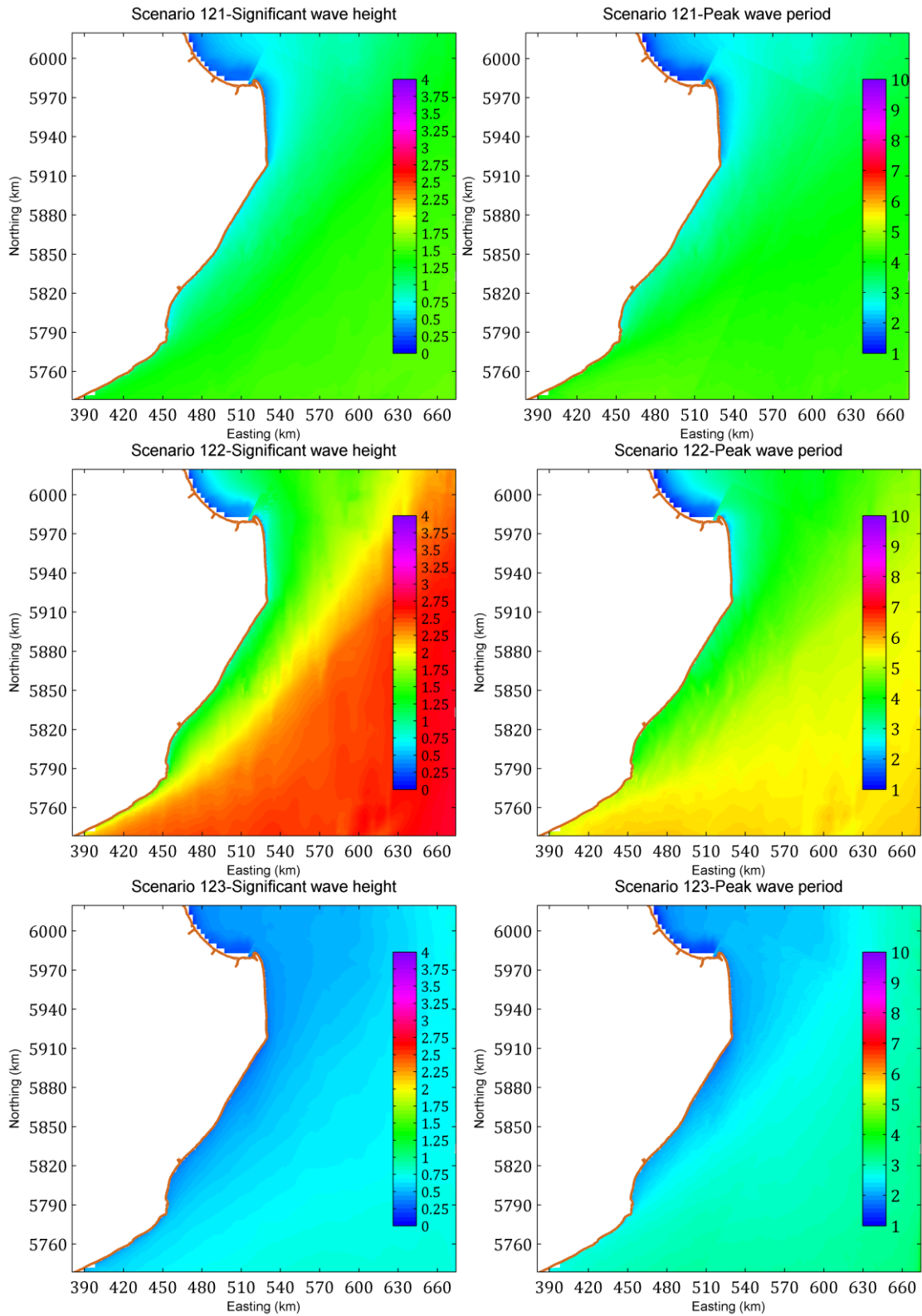


Figure 55 Scenarios 121-123

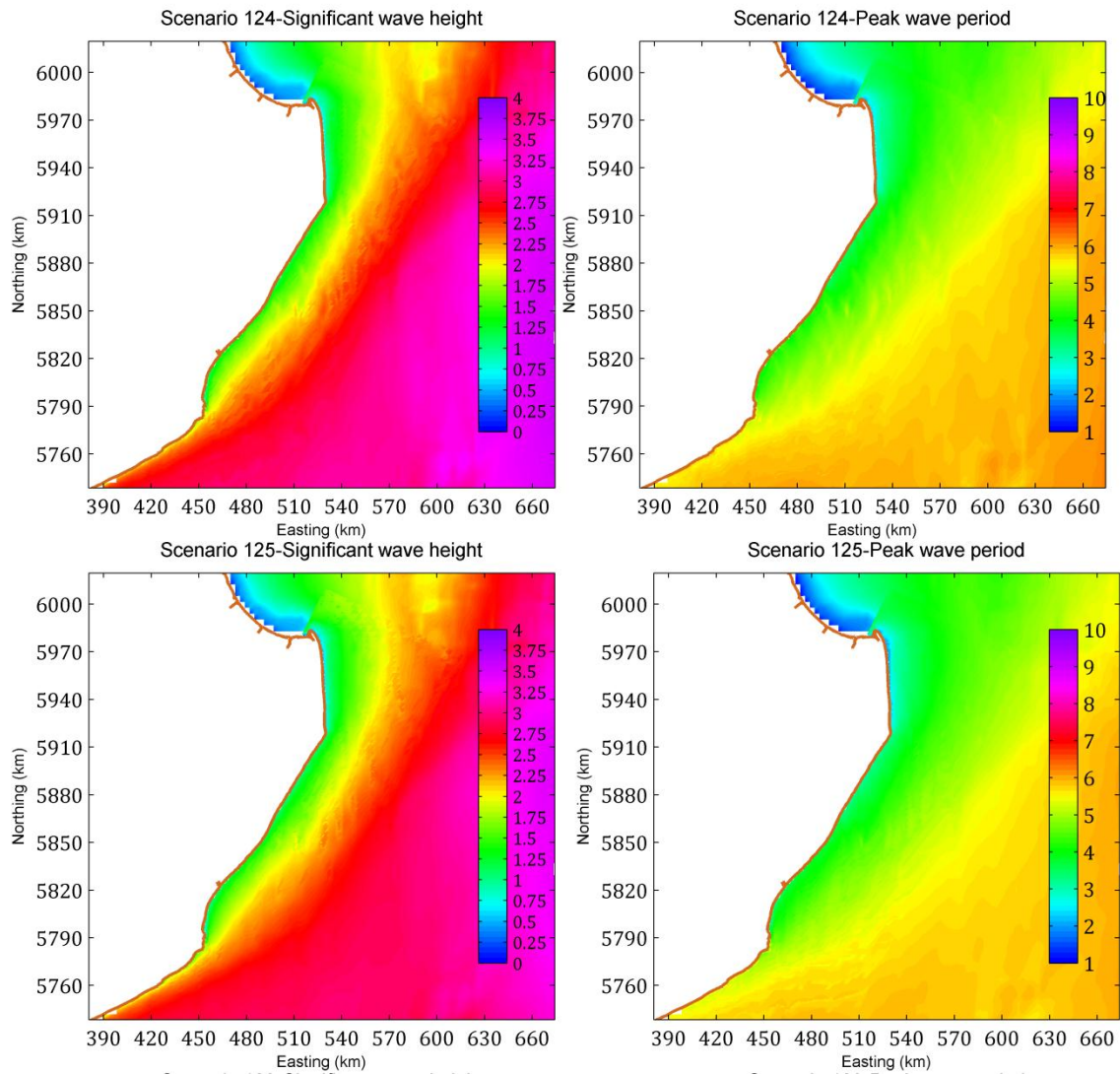
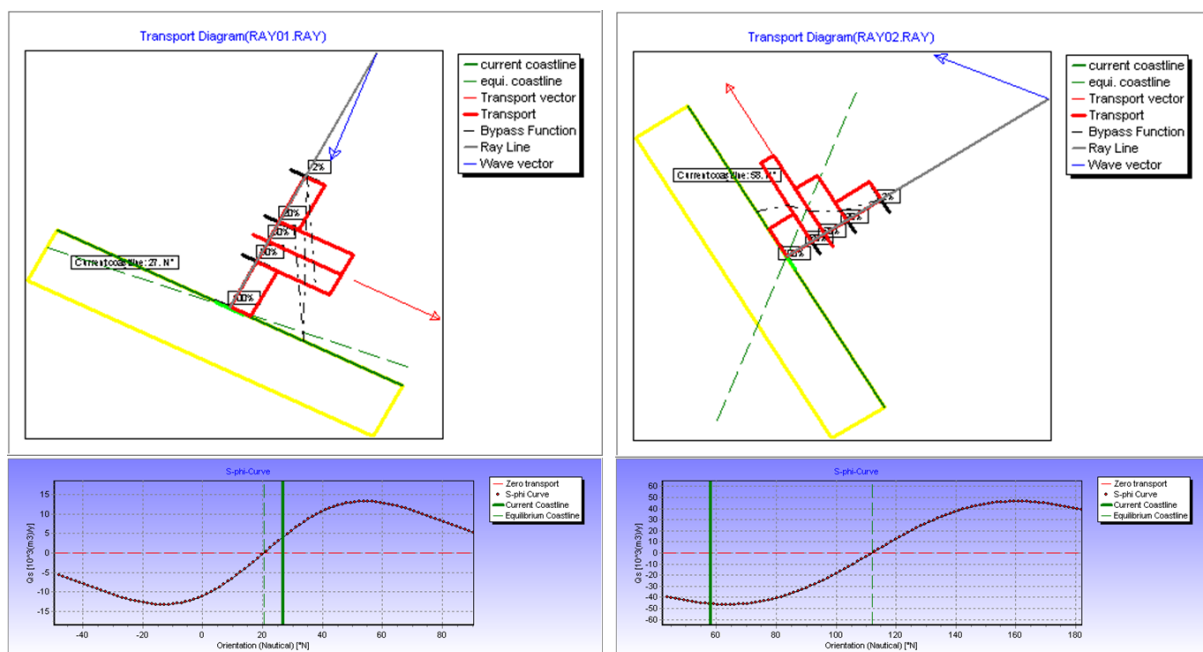


Figure 56 Scenarios 124-25

## Appendix E: UNIBEST-CL+

Ray 1 corresponds to the area located north of Punta Rasa, at the tip of the spit formation. At this location sedimentation is expected; since north and south rays demonstrate that sediment comes into this cell. Ray 1 towards the south, and Ray 2 towards the north. It can also be seen in the figure that the equilibrium coastline angle is quite different when compared to the existing coastal angle; this could be explained by the fact that spits are very dynamic coastal areas; always moving and shifting directions. Perhaps also the sand banks located near-shore in the area induce differential changes.



**Figure 57 Longshore transport rays 1-2 “North”**

Ray 3 and 4 correspond to the section between San Clemente and Mar del Tuyu, for these locations the incoming wave angle is almost normal to the coast; consequently the equilibrium coastline angle does not differ as much as in the previous locations where wave and coast were not aligned. Both rays present a northward transport direction, which in fact is dominant along the coast of the Buenos Aires province.

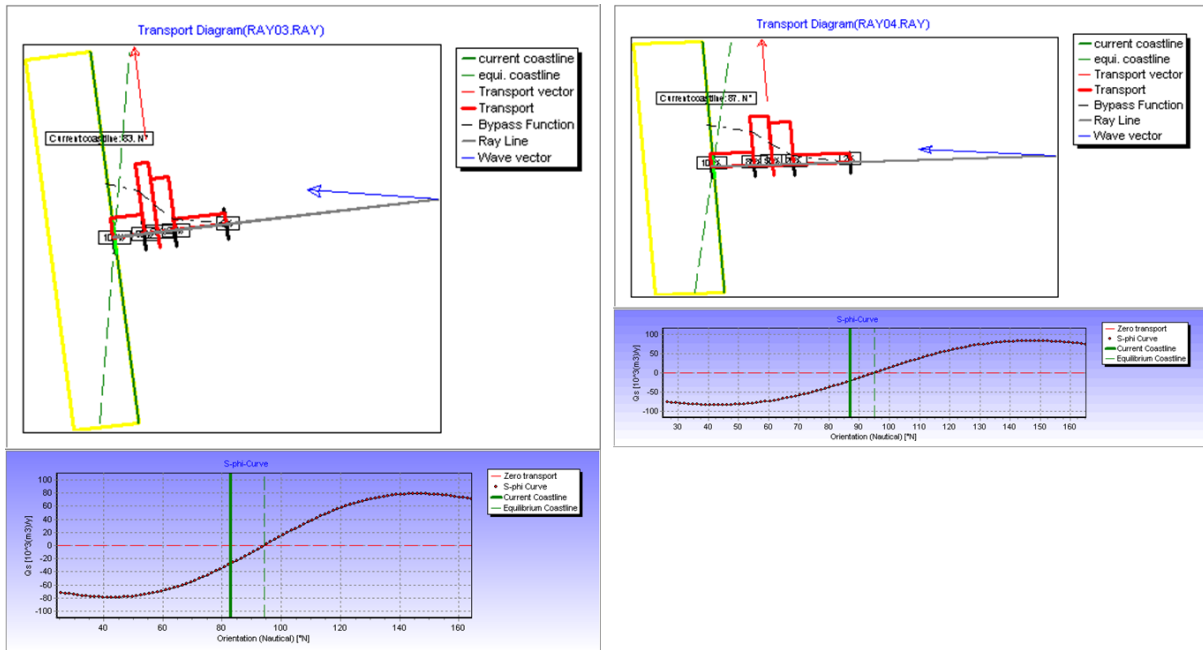


Figure 58 Longshore transport rays 3-4 “North”

Rays 5 and 6 correspond to the city of Mar de Ajo. Ray 5 corresponds to the north section of Mar de Ajo, where the coast suffers erosion, on the figure it can be seen that transport is dominant to the north. Ray 6 represents the south of Mar de Ajo, where the coast is almost normal to the incoming wave angle consequently smaller transports are observed.

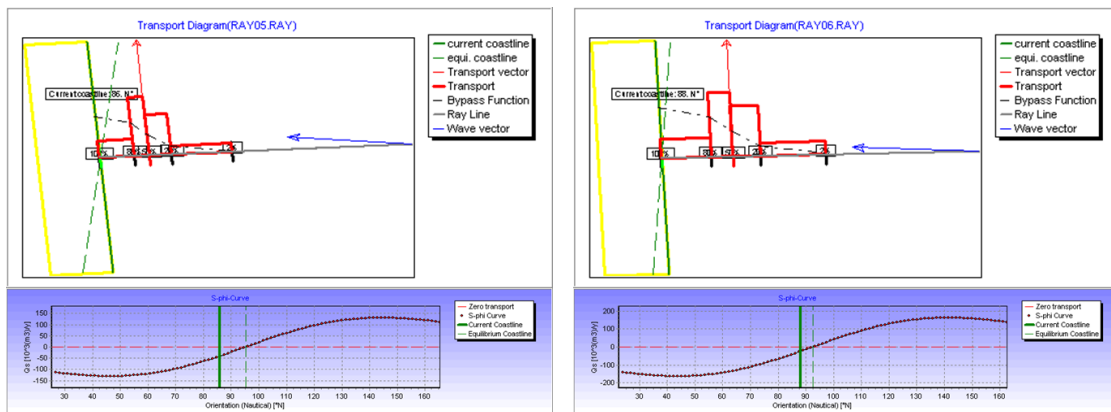


Figure 59 Longshore transport rays 5-6 “North”

Ray 7 and Ray 8 cover from the north of Punta Medanos, to the point in Punta Medanos where the coastal orientation changes. Ray 7 is a point between Punta Medanos and Mar de Ajo that shows results very similar to the ones seen in Ray 6. The figure in the right schematizes the transport for the tip of Punta Medanos; this location has the peculiarity that it is where the coast changes angle, larger sediment transport rates were estimated for this section of the coast.

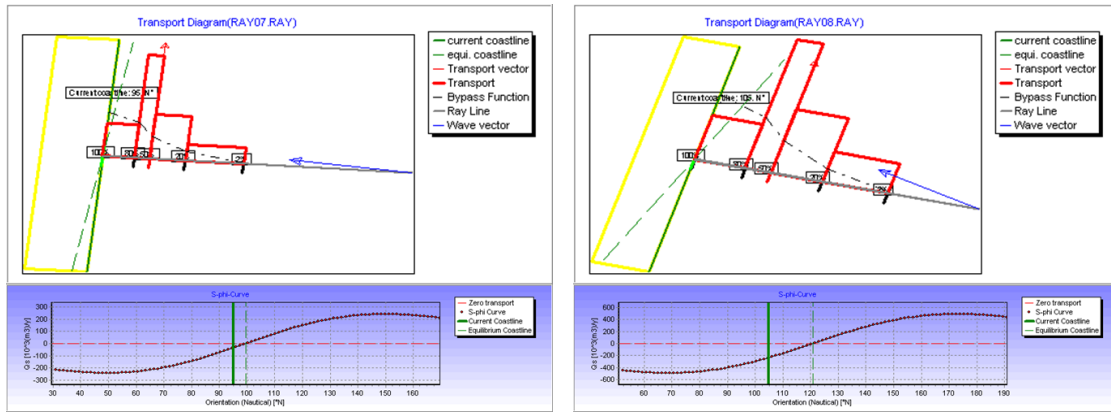


Figure 60 Longshore transport rays 7-8 “North”

Figure 61 Longshore transport rays 9-12 “North”, shows the longshore transport rays computed with UNIBEST-LT that cover the coastal stretch from the south of Punta Medanos to the south of Pinamar. This coastal section has a net longshore transport rate of around 75-100 ( $10^3 \text{ m}^3//\text{year}$ ).

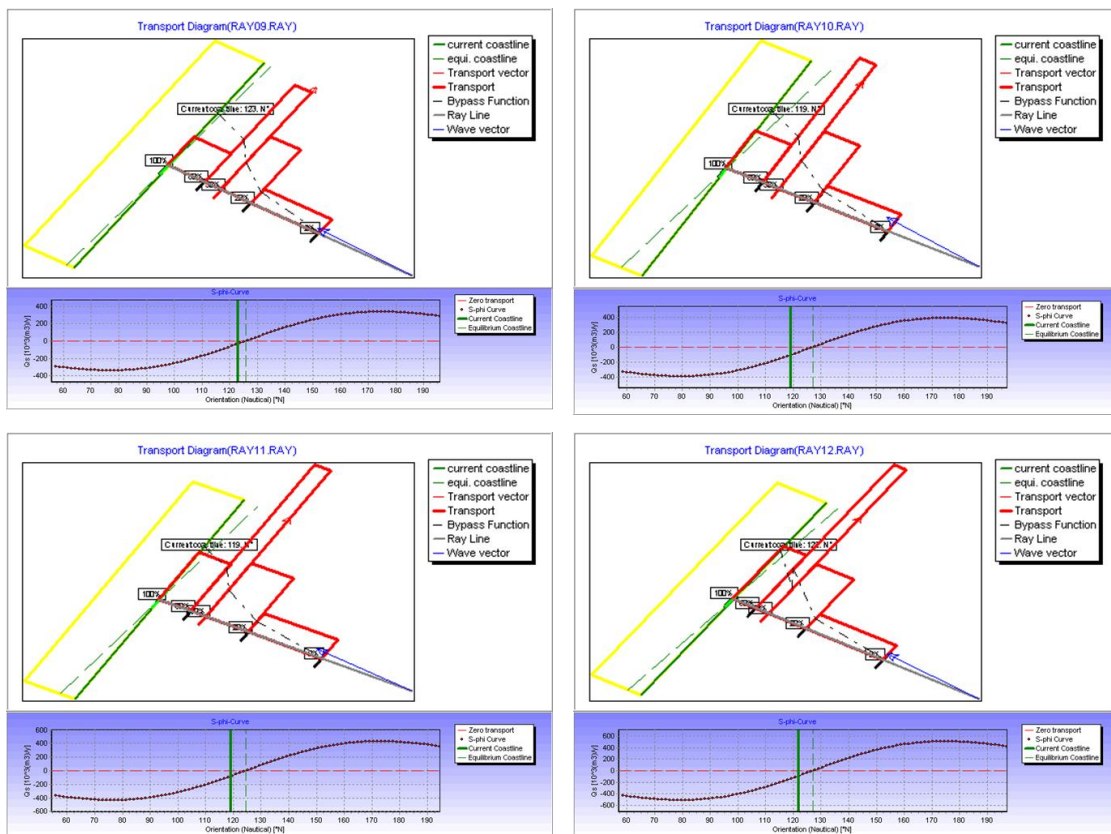
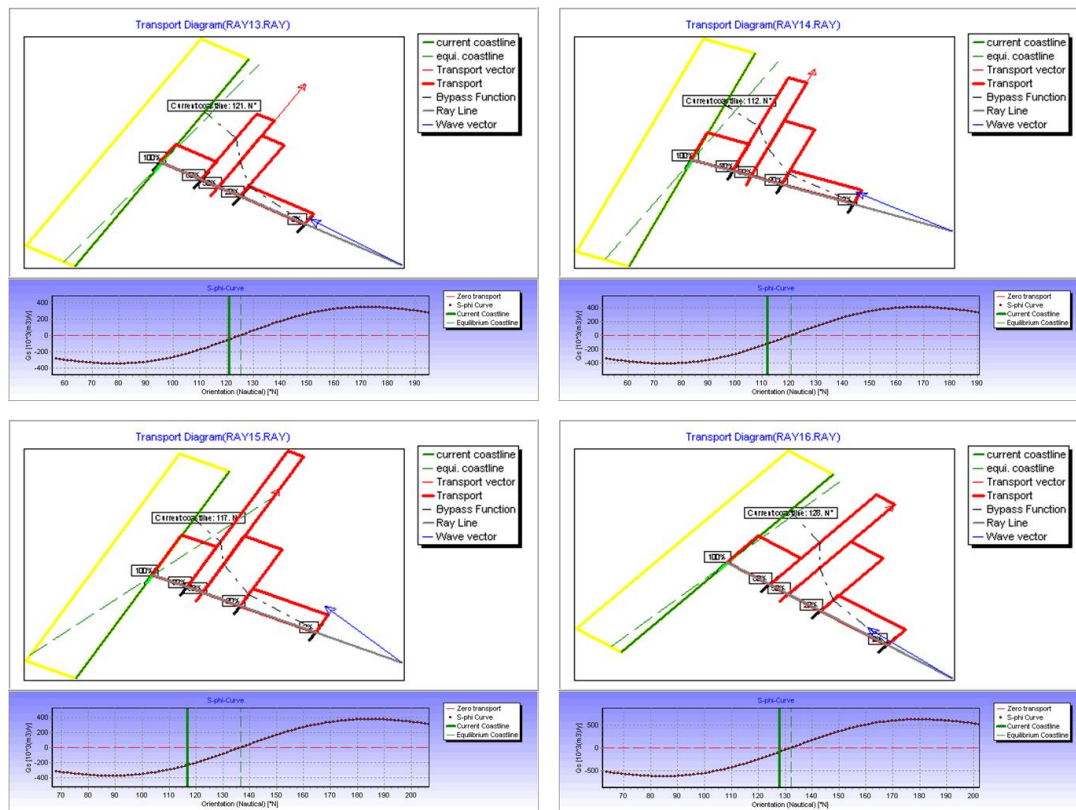


Figure 61 Longshore transport rays 9-12 “North”

The following figure shows Rays13 to Ray 16, this represents the coast between Villa Gesell and Mar Chiquita, in fact Ray 13 is just south of the city of Villa Gesell. Results are similar in direction and magnitude when compared to the results showed in Ray 11 and 12. Very small developments are located in this stretch but these rays were computed to

have the full coastal longshore transports for the simulation of the coastline change in the CL module.



**Figure 62 Longshore transport rays 13-16 “North”**

Rays 17 to 20 are from the north of Mar Chiquita (25km north) to the south of the lagoon mouth. This area showed larger transport rates when compared to all the previous locations. The coastal orientation in these sections varies in shorter distances and for Ray 18 the computed net longshore sediment transport was towards the south (only location with net transport towards the south). Also the orientation of the coast south and north of the lagoon entrance induces a transport magnitude difference. Added to the previously mentioned the deeper waters are now located closer to the coastline; consequently larger wave heights come near the coast and create stronger longshore currents.

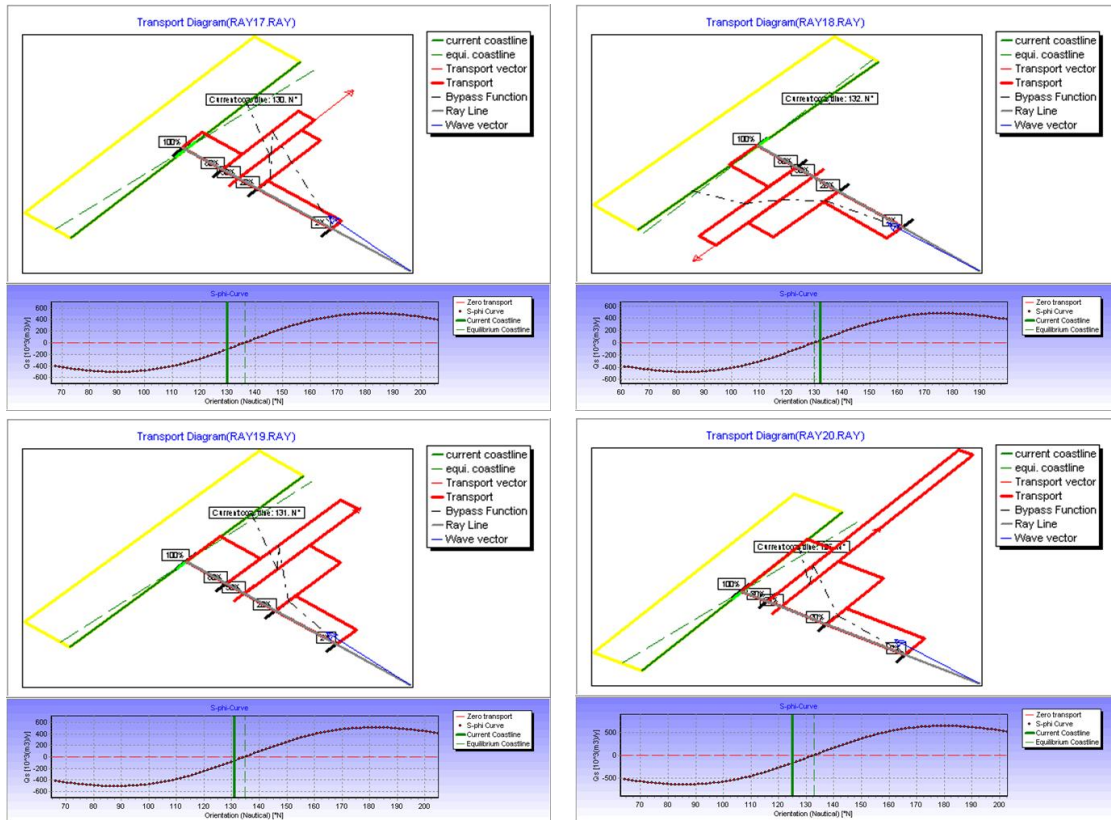


Figure 63 Longshore transport rays 17-20 "North"

### South section longshore transport results

As mentioned in the report the coast was divided in two sections due to the large difference of the profile shape, the number of coastal structures, and the coastal orientation changes.

The following figure has the Rays corresponding to the coastal stretch between Santa Clara del Mar and Playa Dorada, for these locations the coastal orientation has a large variation, and larger transports were calculated. It can already be seen that the coastline is less stable (compared to the locations of "La Costa") based on the difference between the equilibrium coastline shown in green dashed line and the current coastline.

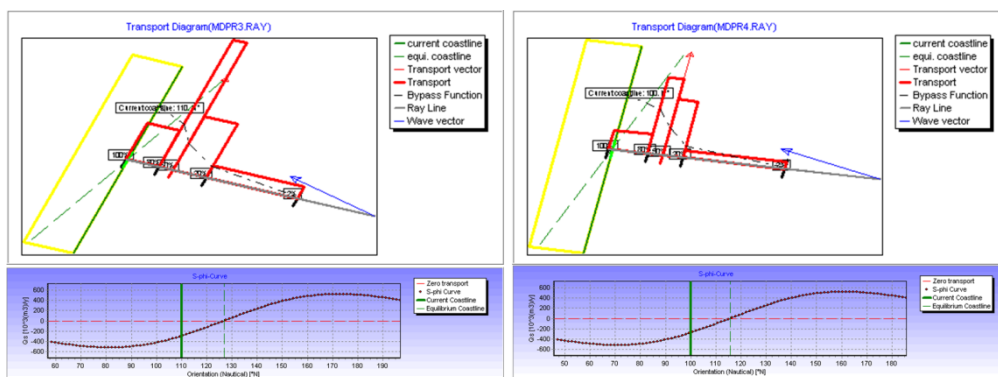


Figure 64 Longshore transport rays 3-4 "South"

Rays 5 and 6 are located at the north of Mar del Plata showing longshore transport directions towards the north, and dominant wave direction coming from an angle of around 120 degrees with respect to the north (nautical convention).

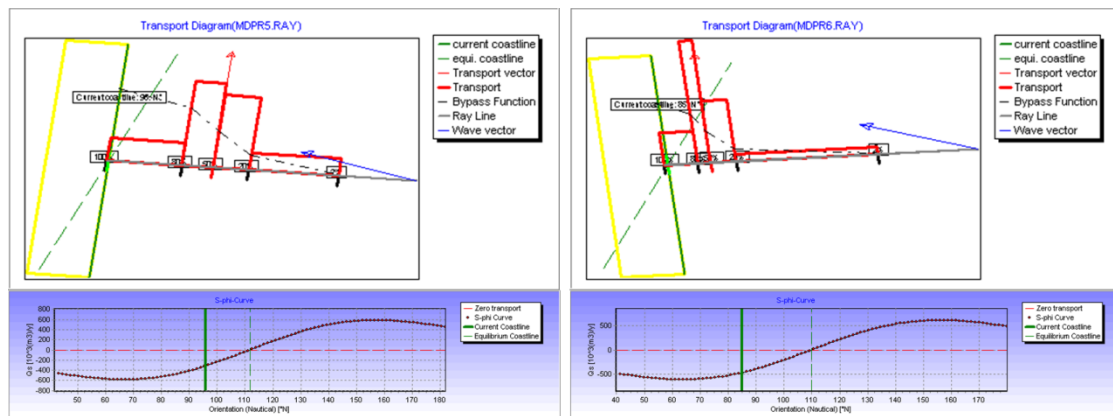


Figure 65 Longshore transport rays 5-6 "South"

Rays 7 and 8 are located north of the Mar del Plata port, covering some of the beaches with groynes. This section also has a net northward sediment transport. The variation of the coastal angle with respect to the equilibrium angle is very large. For this specific case this is not as relevant as for other locations, since the coast is already fixed by structures.

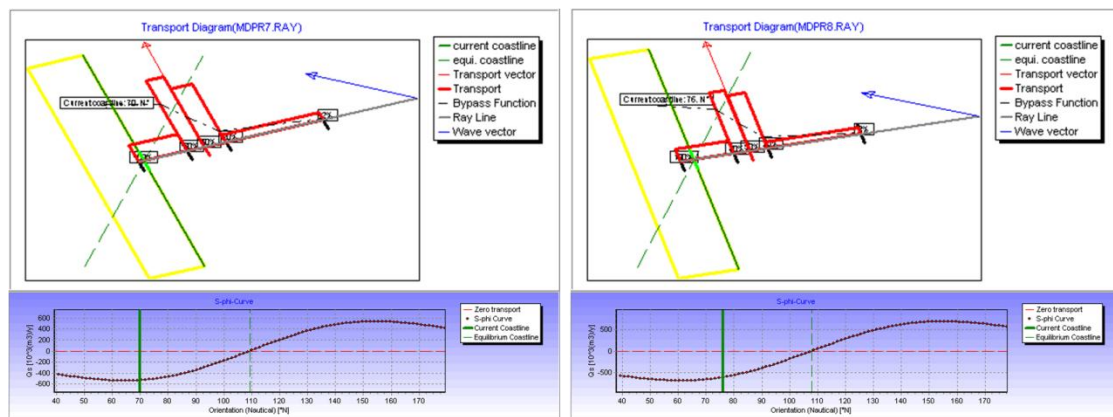
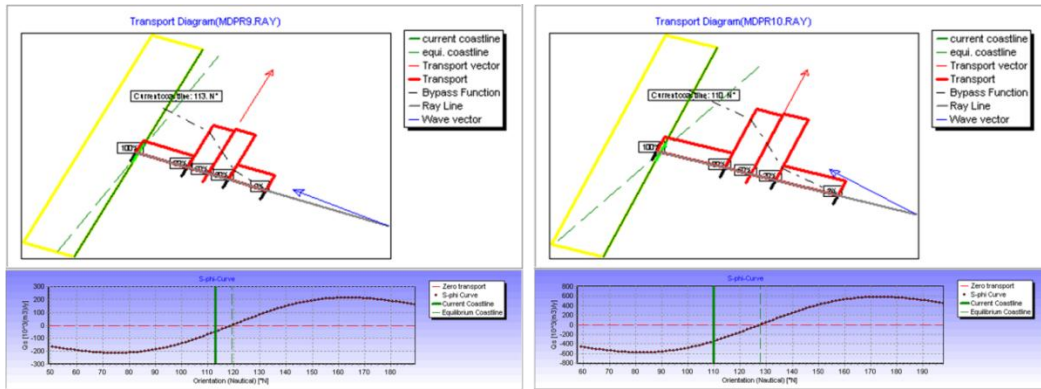


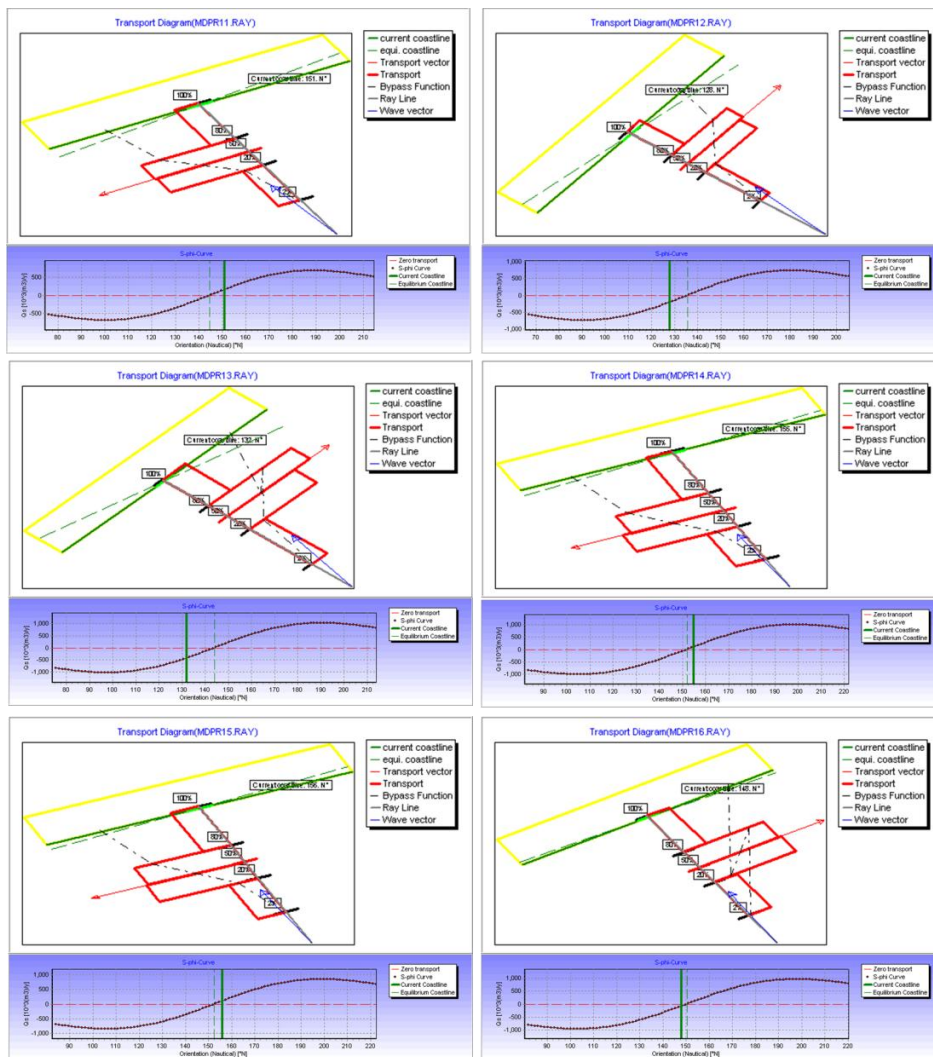
Figure 66 Longshore transport rays 7-8 "South"

Rays 9 and 10 shown below are located south from the port, also computing transport towards the north, which in fact are the currents that cause the sedimentation problems in the port area. An important thing to look in all the output figures of UNIBEST-LT is the S-phi curve (shown in the lower part of each ray); this curve represents the longshore transport rate in relation to the coastal orientation. The dashed red line represents the zero net longshore transport orientation.



**Figure 67 Longshore transport rays 9-10 "South"**

The rest of the figures represent the coast from Los Acantilados to the south of Miramar, in general the longshore transport is dominant going to the north, but there are some sections where transport is switched towards the south depending on the near-shore wave climate, and the local coastal orientation, although it is important to take into account that the bathymetry data for this area is relatively coarse.



**Figure 68 Longshore transport rays 11-16 "South"**