

Video Monitoring and Field Measurements of a Rapidly Evolving Coastal System: the River Mouth and Sand Spit of the Mataquito River in Chile



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ABSTRACT

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The understanding of morphological processes controlling the evolution of sand spit reformation after a tsunami impact is a challenging and interesting topic, especially in highly energetic and micro tidal environments. A field campaign performed during December 2012 at the Mataquito River mouth in Chile, allowed us to simultaneously monitor topo-bathymetry evolution, wave climate, tidal range, swash zone dynamics and upper beach face evolution over a portion of its sand spit. A video system was set up for a continuous and long-term monitoring of the evolution of the river mouth and sand spit. Primarily, in this work we focus on the application of a video-derived shoreline detection method to assess shoreline evolution and beach cusps migration at hourly scales. We test the method performance on short-term episodic migration of beach cusps recorded during the campaign. Beach face variations at a daily scale were observed, which can be attributed to the migration of beach cusps in the alongshore direction, and linked to wave forcing and alongshore sediment transport.

ADDITIONAL INDEX WORDS, *Coastal monitoring, video system, river mouth, sand spit, beach cusps migration*

INTRODUCTION

The coast of central Chile is characterized by highly energetic wave conditions and micro-tidal range generally affected by strong swells coming from the South West Pacific Ocean. Moreover very often, rivers that come from the Andes provide continuous discharge into the sea supplying abundant amount of sediment into coastal systems. This highly dynamic environment offers the opportunity to witness short-term beach evolution because changes occur very fast. An empirical proof of this was the fast reformation of the Mataquito River sand spit (34°52', 72°09'W) after the Chilean earthquake and tsunami of February 27th, 2010 that hit this area. Before the tsunami, its morphologic configuration was characterized by the presence of a large sand spit (~3 millions m³ of emerged sand) oriented South to North, that forced the river to run parallel to the rocky shoreline over ca. 9 km. During the tsunami, the sand spit was almost completely washed away under the combined action of strong currents and land subsidence (~1 m) thus evidencing the drastic impact that these extreme events can have on coastal morphology (Villagran

et al., 2011). Somewhat surprisingly, the sand spit almost completely reformed during the following year, reaching a very similar configuration as the one that existed before, but with the river outlet slightly updrift. This rapid evolution is suggestive of a strong littoral transport driven by the energetic wave climate of central Chile.

Previous works had investigated the morphologic variation of coastal features using video images. Migration behavior of discharge channels (e.g. Paterson *et al.*, 2003; Morris *et al.*, 2001), the estimation of sand volume changes (e.g. Smith & Bryant, 2007) or the migration of submerged sand bars (e.g. Armaroli and Ciavola, 2011; van Enckevort & Ruessink, 2003; Ruessink *et al.*, 2013; Holland *et al.*, 1997) and shoreline detection (Plant *et al.*, 2007; Almar *et al.*, 2012). These examples had proved the interest of using video monitoring systems to evaluate morphological changes occurring at different time scale along the coast, complementing the data obtained using traditional in situ measurements.

Site Description

The Mataquito River is an Andean river draining a 6,200 Km² basin located 300 km South-West of Santiago de Chile. Main hydrologic and catchment characteristics are summarized in Table 1. The Mataquito river mouth is located 50 km north of the Maule River. The Mataquito river exits north of the Putu dune system (aligned South-East) over a strait shoreline aligned in the South-North direction. The change of direction relative to the more frequent wave climate coming from Southwest direction favors the accumulation of sand and the formation of a long sand spit system and a calm estuary behind it (see Figure 1). This sand spit suffered heavy erosion after the 2010 Chilean tsunami, but was rapidly reformed over the following year (Villagran *et al.*, 2011). We focus on a 3 km long strait beach located at the sea front of the sand spit where a highly dynamic sub-aqueous triple bar system exists. The intertidal bars closely follow the shoreline configuration. The wave height along the sand spit is fairly constant over the year, with strong swells coming from the South Pacific Ocean that produce a highly energetic longshore current. In situ wave measurements are not available, but NOAA nearest node provide a yearly mean significant wave height of 2.7 m with peak period of 11.7 s. The tide in Mataquito is semi-diurnal and micro-tidal with tidal ranges between 0.3 m (neap tide) to 1.5 m (spring tide). During storms, sea level may increase by 1 to 2 m due to storm surges and wind set up.

The plentiful supply of sediment is another important aspect regarding morphological changes. The Mataquito River ensures sand availability, together with the Putu dunes system and the Maule River located to the South. Long-shore currents generated by the dominant Southwest wave climates can transport this loose material to the north.

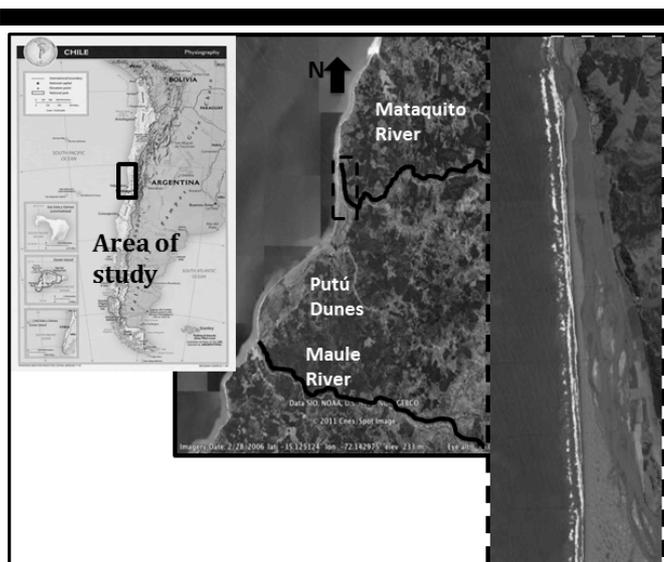


Figure 1. Location of the Mataquito River mouth, shoreline geometry, and zoom over the sand spit barrier.

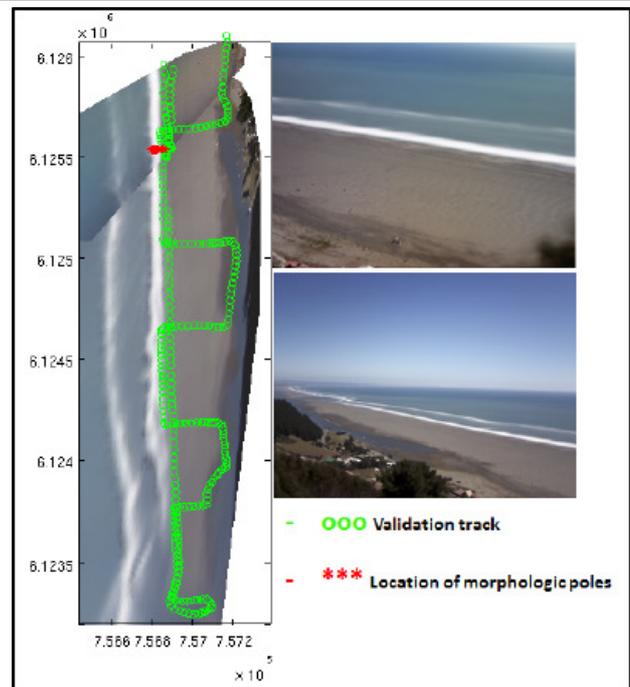


Figure 2. Averaged images provided by the coastal video monitoring system (right panels) and rectified images compared to DGPS tracks (green dots) and surveys at the location where vertical rods were deployed on the beach face (red dots).

METHODS

Instruments and Measurements

Waves, tides and river discharge are the main hydrodynamic factors influencing the morphological changes in the area. Therefore, the first two were measured during our short field campaign to complement the video data, and river discharge are continuously acquired from the Licanten station, which is the closest gauge station to the river mouth whose data is freely available from the internet (www.dga.cl).

In order to better understand the forcing and processes that control the evolution of the sand spit, we conducted, for the first time in Chile, a field campaign in the area of the Mataquito River mouth during 3 weeks. The field campaign took place between November 28th and December 14th of 2012. Different instruments were deployed in the area, and many researchers and students participated in the data collection (more than 30 person in total). It was the first surf zone survey campaign of this extent taking place in Chile ever. During this campaign we performed simultaneous measurements of topo-bathymetry, wave climate, tidal range, swash zone and upper beach face evolution, while a video system was continuously acquiring images of the coastal system.

For topo-bathymetry surveys we used a RTK DGPS instrument and a sonar altimeter with GPS antenna. Wave climate and tidal range was measured with the help of a Teledyne ADCP (1,200Hz) moored at 11.6 m depth and 900 m from the shoreline. The swash and beach face evolution at daily scales were studied using GPS

and topographic levels. Eleven morphological rods were installed in the swash zone to measure beach face evolution in a way similar to Kulkarni *et al.* (2004). The rods were painted in yellow to clearly discriminate them from the grey color of the sand, and a high-resolution video camera was installed on the beach to monitor the waves passing through the rods. Four wired pressure sensors (Kepler, acquisition sampling of 100 Hz) were placed in the intertidal zone to measure water surface elevation around high tide. Additionally, a LiDAR sensor was mounted during low tide at an elevation of 9 m above the beach to provide measurements of the swash free-surface profile for comparison with those detected by the video camera and pressure sensors. Nonetheless, in this work we do not exploit swash dynamics detected through video images, pressure sensors nor LiDAR data, which will be presented elsewhere.

Table 1. Main hydrologic and sediment characteristics of the Mataquito River watershed. Sediment size if representative of the river mouth.

Hydrologic parameter	Units
Basin dimension	6,200 Km ²
Mean monthly river discharge	150 m ³ /s
Maximum peak river discharge observed	Nearly 8,000 m ³ /s
Sediment D ₅₀	0.12 – 0.22 mm
Hydraulic regime	Mixed (rain/snowmelt)
Annual Mean precipitation in the watershed	740 mm/year

The coastal monitoring video system consists of two IP cameras with 2 MegaPixel resolution each (Vivotek IP7161), mounted on a 6 m timber pole located on the top of the hill surrounding the Mataquito River mouth (34°58'28"S 72°10'46,8"O, altitude 155m above msl) pointing towards the Southwest. Moreover, a switch with Power over Ethernet (PoE) energy supply plus a Wifi antenna was installed on the pole to transmit the video signal continuously to a computer station located near the beach. The system is completely autonomous, with power requirements supplied by batteries charged by a dedicated solar panel array. Video images are transmitted during daylight from the tower to the PC housing base. The video signal is post-processed in order to record 15 min averaged images and timestacks from both cameras at an acquisition sampling rate of 2 fps. In order to save batteries, an on/off switch was included on the system to turn it off during night.

Camera 1 (Cam1) was adjusted with a zoom lens, obtaining more detailed images of the beach face, pointing to the north part of the aerial view. Camera 2 (Cam2) has a panoramic view of the whole sand spit system, pointing to the Southward part of it (see Figure 2).

Implementation of photogrammetric post-processing routines was necessary to transform video images into rectified almost undistorted linear coordinate images. This process was necessary to be able to quantify qualitatively and quantitatively the morphologic changes in the study area. Several control points (CCP) were measured using DGPS within cameras field of view, applying a similar methodology as the one described by Holland *et al.* (1997).

A validation of the rectification process was made comparing the rectified images with a survey track of the whole sand spit made

with an RTK mounted on AWD truck (see Figure 2). Both images were merged creating a single view of the sand spit (see Figure 2). We obtained a good level of agreement between the RTK survey and the GPS control points in the rectified images. The average error for Cam1 is about 5 m, while the average error for Cam2 is around 20 m.

DATA ANALYSIS

ADCP's Data Analysis

The data collected with the ADCP allow us to characterize the wave climate during the field campaign. The hydrodynamic conditions observed during the campaign were representative of average wave climates though a superposition of Southwest and Northwest wave climates could be observed, as suggested by the bimodal wave spectrum sample presented in Figure 3. The wave record obtained during the field campaign (see Figure 4) shows the occurrence of an energetic swell between December 3rd and 4th, with a significant wave height reaching 3 to 4 m, a peak period of 14 to 16 s and a wave direction of 270°. The wave direction remained relatively constant during the field campaign (270° on average), while the peak period showed some variations between 10 s and 17 s. Beside the most energetic wave conditions observed between December 3rd and 4th, the rest of the time the significant wave height remained below 2 m.

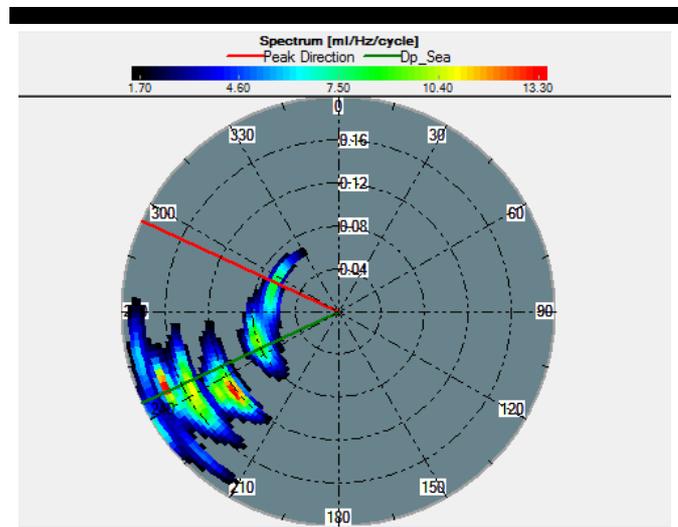


Figure 3. Sample of a 20 minutes wave spectrum at the Mataquito site obtained during the field campaign on December 10th, 2012.

Beach Slope Variation

Using eleven morphological rods for monitoring beach slope variations at daily scale we were able to assess its profile evolution during the surveyed period (see Figure 5). Most of the time, little variations were observed on the beach face. However, during the last 2 days of measurements (December 9th and 10th), 50 cm of accretion was observed at the upper part of the beach slope. This process might be associated to a change on the peak wave period (longer waves) and a bi-modal wave climate (see Figure 3) that should be further analyzed. Moreover the

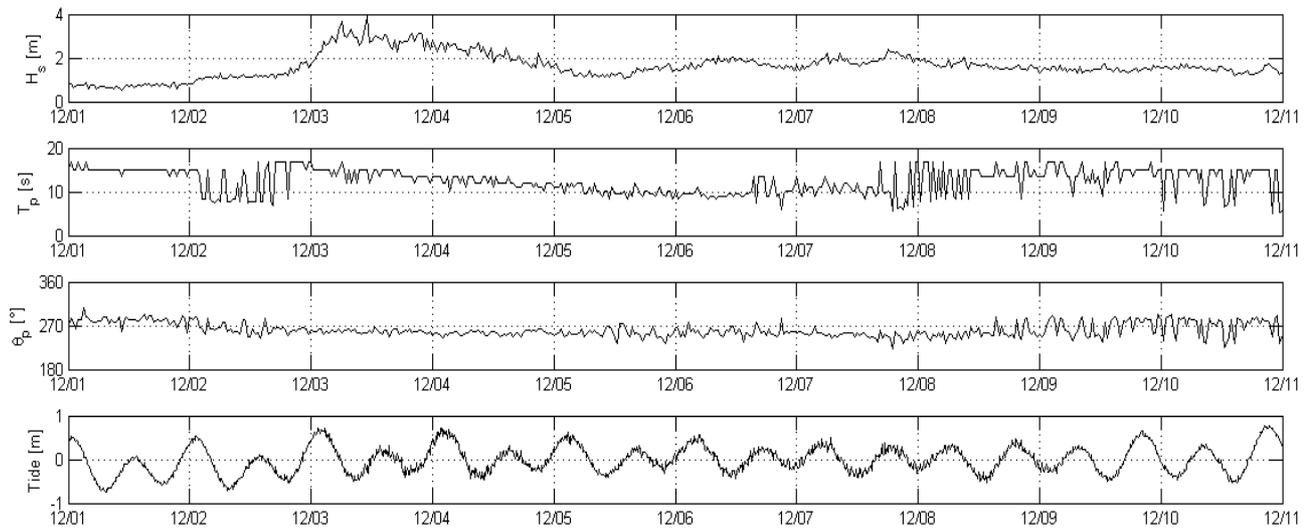


Figure 4. Time series of ADCP record during the field deployment. First panel: Significant wave height, H_s . Second panel: Peak wave period, T_p . Third panel: Peak wave direction, θ_p . Fourth panel: Tidal level.

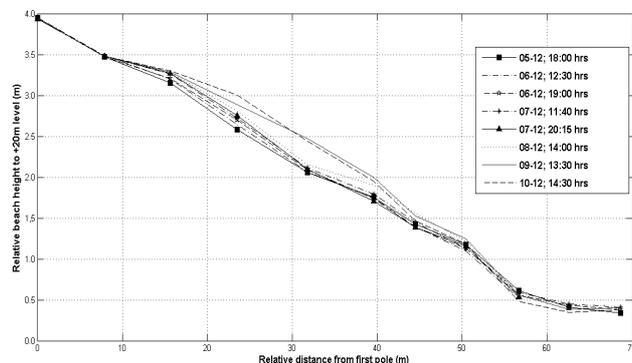


Figure 5. Beach face evolution during the field campaign

bathymetric change (accretion) in the beach face can be attributed to the beach cusp migration observed by video images during December 9th and 10th as will be shown in the next section

Shoreline Detection Using Video

Each averaged video image (one every 15 minutes), corresponding to December 9th and 10th, 2012, was analyzed to detect the shoreline. The chosen shoreline detection algorithm is based on the edge detection gradient operator method from Gonzalez and Woods (2002). Other methods were also explored for comparison (e.g.: Almar *et al.*, 2012) but are not shown here. Pixels corresponding to the shoreline were rectified to compute their corresponding UTM coordinates using the transformation matrix obtained from the rectification process described before

Using a shoreline detection algorithm, a set of shoreline curves was extracted from averaged images of December 9th and 10th for Cam1. In Figure 6 we present an example of the application of the

shoreline detection algorithm. We have tested the method over different video images and light conditions obtaining in general a good agreement between the automated detection process and visual inspections. For the following analysis, we use averaged images obtained from Cam1, which has a better resolution to

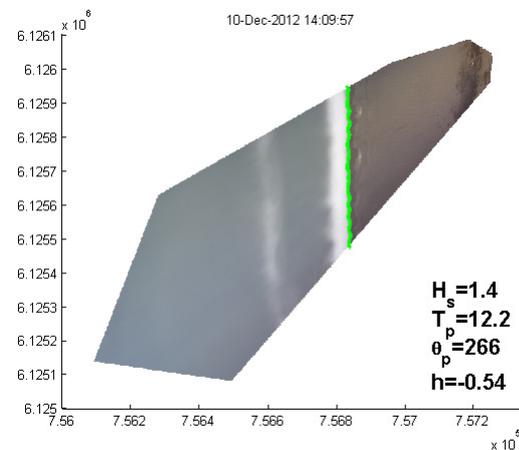


Figure 6. Example of a rectified 15 minute averaged image and the application of the shoreline detection algorithm.

perform the shoreline detection and analysis.

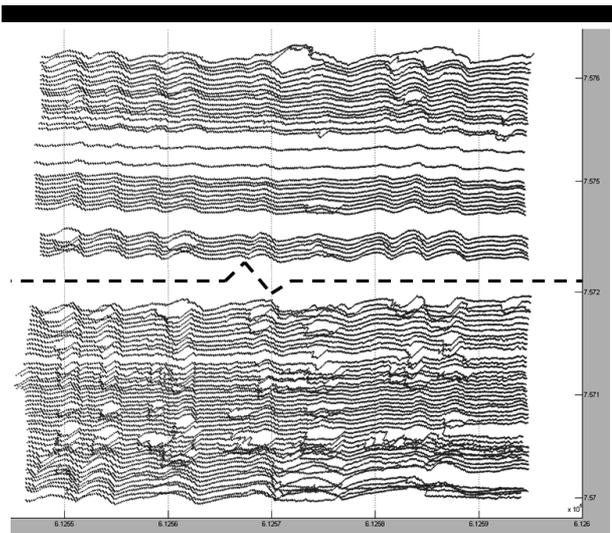


Figure 7. Set of detected shorelines for averaged images during December 9th and 10th. Shoreline curves were shifted to avoid overlapping between them. The dashed line represents the night time that separates both days. Blank spaces between shoreline curves correspond to downtimes of the Cam1.

Shoreline Analysis

Although the algorithm occasionally fails, we succeeded in acquiring a large number of shoreline-detected curves at a high acquisition rate. In Figure 7, time series of shoreline evolution over the two days of observation are presented. It can be seen that cusp evolution and migration is visible at an hourly scale.

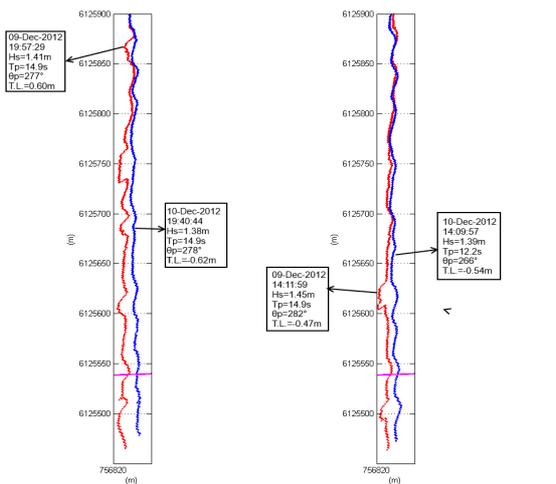


Figure 8. Shoreline evolution between high and low tides in December 9th and 10th. The horizontal line in the low part of the image shows the location of the topographic rods. Left panel: High tides. Right panel: Low tides.

In Figure 8 we show results for the shoreline detection for images obtained under high and low tide conditions over the two days of observation. With the help of this figure we can get an overview of beach evolution at a daily scale. Some variability in the shoreline, both in the onshore-off-shore direction and in the beach cusps' geometry is observed. It appears that the beach is accreted from South to North resulting in an off-shore shoreline migration that could reach 10 m. The latter is consistent with the beach face evolution depicted in Figure 5 for December 9th and 10th. Cusp migration and evolution can also be observed at this short time scales. Note that wave conditions were mild but with long peak periods, that were fairly constant during these days.

Cusp Migration

To assess beach cusp geometry and migration, we use shoreline-detected curves from 15 minutes averaged images taken every hour during December 10th. A zoomed region of the shoreline-detected curves can be seen in Figure 9.

From Figure 9, typical alongshore wavelengths of beach cusps are comprised between 30 to 50 m (validated also with in situ topographical measurements). More interestingly, with the help of the video system, cusp evolution can effectively be observed at hourly scales. The cusp horn migrate towards the North at an estimated rate of 1 – 1.5 m/h., while the alongshore shape of the cusp appears to increase in time in the longshore direction.

In order to better understand beach cusps dynamics and its link with inner and outer bar systems present in the area, longer time series of shoreline and bar evolution are necessary. Indeed, during the field campaign we observed that the cusps' growth could be associated to the formation of a second, more seaward, cusp system as tide cycles progressively shifted from spring to neap. This feature, which certainly deserves more studies, illustrates the complexity and extremely fast evolution of beach morphodynamics in the site.

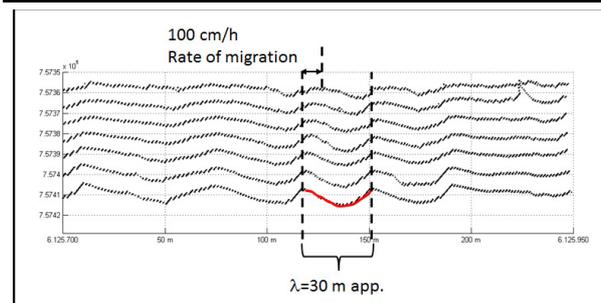


Figure 9. Shoreline-detected curves separated every 1 hour observed in December 10th. Typical wavelength of beach cusps is estimated at 30 m, and its rate of migration in the North direction is comprised between 1 to 1.5 m/h.

CONCLUDING REMARKS

In this work we have described the field campaign that we have conducted in the coastal area of the Mataquito River mouth in the Maule Region in Chile. This coastal system was heavily affected by the 2010 Maule earthquake and tsunami, which produced land subsidence and strong erosion of a large sand spit.

Because a very rapid coastal reformation of this system was observed during the following years, this site attracted our attention and we started making sporadic surveys of its topographic evolution in order to better understand the morphodynamic processes at play. In December 2012, we conducted for the first time a 3-week field campaign where wave conditions were continuously measured with the help of an ADCP, while in situ topo-bathymetric surveys were performed on the beach face of the reformed sand spit. In parallel, we set up a coastal monitoring video system capable of acquiring images in the area of interest.

Using video information, we focused on the detection of shoreline evolution at hourly scales over a 1 km straight beach. The employed shoreline detection algorithm showed a good performance when compared to visual inspections thus enabling us to further analyze the coastal evolution during the campaign. Analysis of a two day time framework under mild wave heights but long peak wave periods, showed an accretive behavior of the beach with an off-shore migration of the shoreline that could reach 10 m within 24 hours, consistent with in situ measurements. Similarly, beach cusp wavelengths could be estimated from video images to be comprised between 30 to 50 m, and a consistent migration pattern was observed. Beach cusp migration to the North at an average rate of the order of 100-150 cm/hr was estimated. Even though longer time series and observations are necessary to understand the conditions that enhance this accretive behavior, the coastal monitoring video system that is currently installed in the area has proven to be a cost-effective method to quantify the morphodynamic evolution of the highly dynamic coast of the Maule Region. Future studies will focus on the understanding of the beach cusps dynamics and its coupling with inner and outer bars.

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