Journal of Coastal Research	SI	85	766-770	Coconut Creek, Florida	2018

Determining Shoreline Response to Meteo-oceanographic Events Using Remote Sensing and Unmanned Aerial Vehicle (UAV): Case Study in Southern Brazil

Miguel da G. Albuquerque[†*], Deivid C. Leal Alves[‡], Jean M. de A. Espinoza[‡], [§]Ulisses R. Oliveira, and [§]Rodrigo S. Simões

[†]Federal University of Rio Grande do Sul
Institute of Geoscience
Porto Alegre, Rio Grande do Sul, Brazil

[‡]Federal Institute of Rio Grande do Sul
Departament of Geoprocessing
Rio Grande, Rio Grande do Sul, Brazil

[§]Federal University of Rio Grande
Institute of Human Sciences
Rio Grande, Rio Grande do Sul, Brazil

www.cerf-jcr.org

ABSTRACT

Albuquerque, M.; Alves, D.C.L.; Espinoza, J.M.A.; Oliveira U. R., and Simões R. S., 2018. Determaning shoreline response to meteo-oceanographic events using remote sensing and unmanned aerial vehicle (UAV): case study in southern Brazil. *In:* Shim, J.-S.; Chun, I., and Lim, H.S. (eds.), *Proceedings from the International Coastal Symposium (ICS) 2018* (Busan, Republic of Korea). *Journal of Coastal Research*, Special Issue No. 85, pp. 766–770. Coconut Creek (Florida), ISSN 0749-0208.

www.JCRonline.org

Meteo-oceanographic events are characterized by low pressure centers and intense winds. These systems are responsible for transferring a huge amount of energy from the atmosphere to the ocean that could cause serious socioeconomics damages to the coastal zones. Some of the consequences of these events propagation are an occurrence of large amplitude waves and an increase in the coastal water level. This study aims to characterize the effects of the extratropical cyclone in the southern Brazil occurred in October 2016, seeking a relationship between this event and the recent erosive episodes. Using satellite images and data obtained by unmanned aerial vehicle (UAV), it was possible to trace the shoreline behavior at time intervals, where occurred actions of extratropical cyclones during the year of 2016. The comparison of the shoreline position data, obtained by the image of July 2016, and the UAV (obtained in September and November 2016) presented an approximated shoreline retraction balance of 5.91 m associated for the cyclone that occurred between October 26th and 27th, 2016. This event was associated with synoptic pattern, which have feature cyclogenesis in the Southern Uruguayan coast with a displacement to the east and trajectory between 28° and 43°S, with winds of 17.9 m s^{-1} and SW direction. Associated with the meteorological aspects, erosive process is frequently accelerated or augmented by anthropogenic action, which is mainly related to building constructions activities and sometimes contributes to the destruction of dunes. After the passage of cyclone there was a partial or total destruction of 40% of beachfront houses and 65% of coastal protection structures. Therefore, this type of study constitutes a basic tool of general interest in the coastal management, contributing to understanding of the impacts and risks associated with the coastal dynamics and effects of the meteo-oceanographic events, along the Soutrhern Brazil.

ADDITIONAL INDEX WORDS: *Extreme events, coastal erosion, geotechnologies, coastal management.*

INTRODUCTION

Extratropical storms are atmospheric disturbances characterized by low pressure centers and intense winds (Usace, 2002). These systems are responsible to transfer a lot of energy from atmosphere to the ocean, so that the results can been cause serious socioeconomic damage to the littoral zones. One of the consequences of the process of propagation of these events is an occurrence of large amplitude waves and an increase the water level in the coast. The occurrence of large waves associated to storm surges, according Stone and Orford (2004), is a major factors linked with the coastal evolution. The coastal response to extreme events is characterized by a significant spatial variability, which depends on the number of incidents events and their intensity (Burvingt *et al.*, 2017). In this process, the most rapid and abrupt changes in the coastal landscape occur, generally, during high energy events (Almeida *et al.*, 2010). However, storm concentration in time (storm groups, regardlles of their medium-low intensity) has demonstred to be sometimes more effective in eroding the coast at the medium term that the energetic level reached by one single event (Ferreira, 2006). In southern Brazil, intense cyclonic weather systems generate ocean storms which can, in a temporal scale varying from few hours to a day completely erode a beach profile from its maximum accretion state (Machado *et al.*, 2010). Since 1990, changes in the climate cycles, which are determining factor in oceanographic parameters, have been observed in such a way that these changes are translated by increasing the intensity of frontal systems, whose arrival causes rapid climatic changes.

The exact extent and impact of the extreme events in the southern Brazil is still inconclusive so, actions of the coastal managers should be directed to the mapping of the frequency and the mode of occurrence of these events. In this sense, this study aims at evaluated the impact of the cyclones on southern Brazil, describing the impacts of the cyclone occurred in October 26th and 27th, 2016.

DOI: 10.2112/SI85-154.1 received 30 November 2017; accepted in revision 10 February 2018.
*Corresponding author: migueldaguia@gmail.com

Study Area

The Brazilian southern littoral is exposed to small semidiurnal micro tides, with an average height of 0.30 m (Calliari *et al*., 1998). The coast is dominated by waves and the prevailing wind is NE. Periods of storm surges are registered more frequently in the months of April and May, being associated with the passage of cold fronts near the location (Albuquerque *et al*., 2013). The region is influenced by the South Atlantic Tropical Anticyclone, which is a high pressure system that acts more intensely in the summer. Another anticyclone system of polar origin propagates towards lower latitudes, presenting high mobility and transporting air masses of polar origin (Saraiva *et al*., 2003). When cold fronts arrive, its change 180° in the wind direction generates wind track most intense (Calliari *et al*., op cit.). This effect combined by low pressure centers in the ocean and high pressure centers at the continent cause a pilling up of water at the coast due to coriollis effect (*i.e.* Ekman transport). During the passage of could fronts from south or southeast, ocean waves are characterized as medium to high energy, with significant wave height of 1.5 m and the most frequent peak period is from 6 to 8 s (Calliari and Toldo Jr., 2016).

In the southern of Brazil is located the Hermenegildo beach, focus of this study (Figure 1). The region is located 16 km from the border with Uruguay, at the southern tip of Rio Grande do Sul and has an urbanized coastal length of 2.5 Km. The Hermenegildo beach is characterized by Holocene and Pleistocene barriers, formed during the Quaternary by juxtaposition of the sedimentary deposits of four barrier/ lagoon systems (Lima *et al.*, 2013).

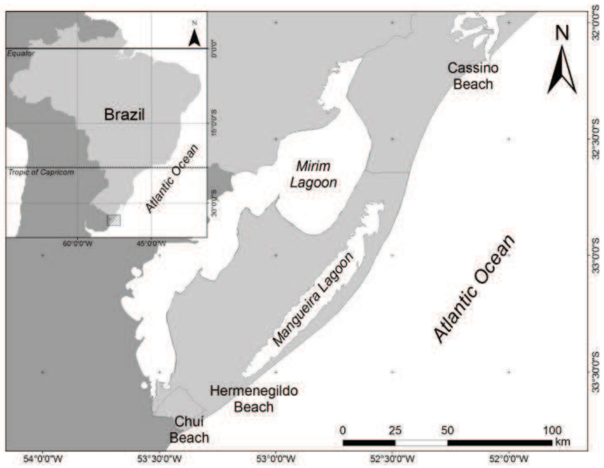

Figure 1. Map of study area.

Based on the morphodynamic classification proposed by Wright and Short (1984), the area was classified oscillating among the dissipative modal state and intermediate state. The first constructions began in 1964 with the urbanization in the beach/ dune system. Currently, buildings in the beachfront suffer constantly with the action of the waves due to beach profile retraction. In the last years the problem grow due to the conflicts between the action of extreme events and anthropogenic activities, which has led to a shoreline retraction and destruction of local structures.

METHODOLOGY

For the monitoring of the cyclone effects that occurred in October 26th and 27th, 2016, on Hermenegildo beach, data from Geoeye sensor and unmanned aerial vehicle (UAV) were used (Figure 2B). The Geoeye sensor image was collected in July 2016, with spatial resolution of 0.5 m. The campaign with UAV were made in September 27 and November 30, 2016 and collected, approximately, 446 million points, with spatial resolution of 0.21 m. The monitoring required flights which covered nearly 2.5 Km² with 60% overlap and fixed height of 40 m. In a flight with a overlap of 60%, the sensor scale was 1.86 mm, corresponding to a base-height ratio of 0.43 according Gonçalves and Henriques (2015). The high overlap provides a multu-ray intersection that can improve the accuracy and density of point clouds (Haala *et al.*, 2013). The Agisoft Photoscan® software was used to orientate the images, extract point clouds, build a digital surface model and produce orthoimage mosaics. The processing of aerial triangulation, camera calibration and model generation was automated, and whole process used a GPS-RTK (Figure 2A) to achieve the best positional accuracy (Figure 2C).

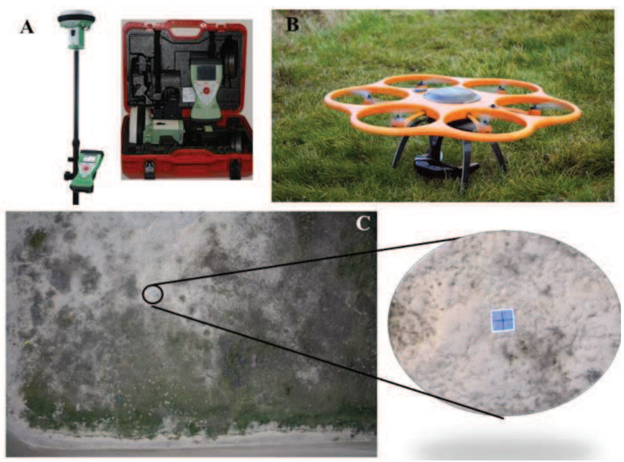

Figure 2. A- GPS-RTK used for the positional accuracy. B – UAV used for data collection. C – GCPs utilized for the positional accuracy.

According Anfuso *et al.* (2016) there is a wide range of methods and studies related to erosion and coastal variability that are chosen based on scale of project involved. For this study the rates shoreline retraction were calculated using the Change Polygon Method (Smith and Cromley, 2012; Albuquerque *et al.*, 2013; Anfuso *et al.*, 2016). The methodology consists to extract erosional and accretional areas, using two distinct shorelines previously vectorized, through the generation and subtraction of polygons (Figure 3).

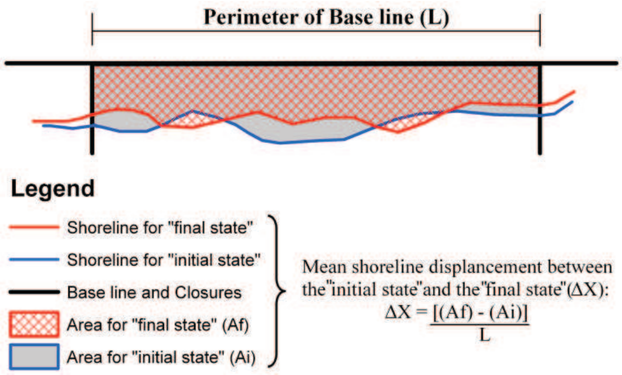

Figure 3. Representation of change polygon method.

In the polygon algebra, every shoreline variation region is quantified, as was show in Figure 3. The analysis using is based on areas and enables the calculus of shoreline retraction using the area of coastal segment (Δx) divided by the shoreline length (L) (Anfuso *et al.*, 2016).

Atmospheric pressure and wind data came from meteorological station situated near the study area. To calculate the wind speed, the zonal (u) and meridional (v) components at a height of 10 m were utilized, according to Bowden (1983) proposition. Wave data were originated from the outputs of the model Wave Watch III NCEP/NOAA, and the data provide by the buoy situated approximately 80 Km from the coast. Significant wave height (Hs) and wave period (T) were considered to the resolution of 1 x 1.25°, with temporal interval of January to December 2016. A more detailed description of the model, its equations and the numerical method used can be found in Tolman (2002).

RESULTS

For the event occurred in October 26th and 27th, 2016, the the wind velocity (V) was 17.9 m s^{-1} with SW direction and wind gusts of 22.2 m s^{-1} (Figure 4A). The significant wave height (Hs) data, obtained by Wave Watch III model, showed values around 5.69 m, during the passage of the cyclone (Figure 4B). The shoreline recorded average displacement of 5.91 m towards the mainland (Figure 5B), according to the data obtained by Remote sensing and UAV images.

Among the four synoptic patterns (Table 1) capable of generating extreme wave events, in the southern Brazil (Machado *et al.*, 2010), the characteristics of synoptic situation for the event occurred in October 26th and 27th, are associated with the cyclogenese pattern II. This condition features cyclogenesis in the southern Uruguayan coast with a displacement to the east and trajectory between 28° and 43°S. For the shoreline displacement, previously the event, when comparing images obtained in July and September 2016, the area presented a growth of 2237.75 m² along the littoral. This increase represented an average shoreline gain of 0.84 m (Figure 5A). Between September and November 2016, according images data, the region presented sedimentary losses of 17741.22 m² of area (Figure 5B). This great loss occured due to the passage of a cyclone in the southern Brazil on October 26th and 27th, 2016.

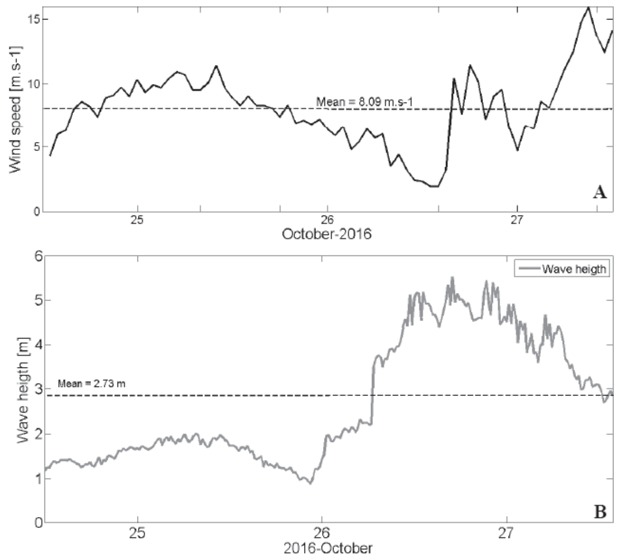

Figure 4. A – Wind data for October 2016. B – Wave height data for October 2016.

Table 1. *Sinoptic patterns capable of generating extreme events by waves*.

Synoptic situation	Characteristics
Pattern I	Cyclogenesis in the southern Argentinean coast with a displacement to the east and trajectory between 47.5 and 57.5° S.
Pattern II	Cyclogenesis in the southern Uruguayan coast with a displacement to the east and trajectory between 28° and 43° S.
Patern III	Cyclogenesis in the southern Uruguayan coast with a displacement to the southeast and trajectory between 32° and 57.5° S.
Pattern IV	High-pressure center generating an easterly wind.

In October 2016, the mean sea level pressure showed value of 1013 hPa, and the values during the extreme event between 1000 hPa and 1010 hPa (Figure 6A and 6C). This event caused extensive physical (beach and dune erosion) and socio-economic (flooding and damage to infrastructure) impacts throughout study area (Figure 6B).

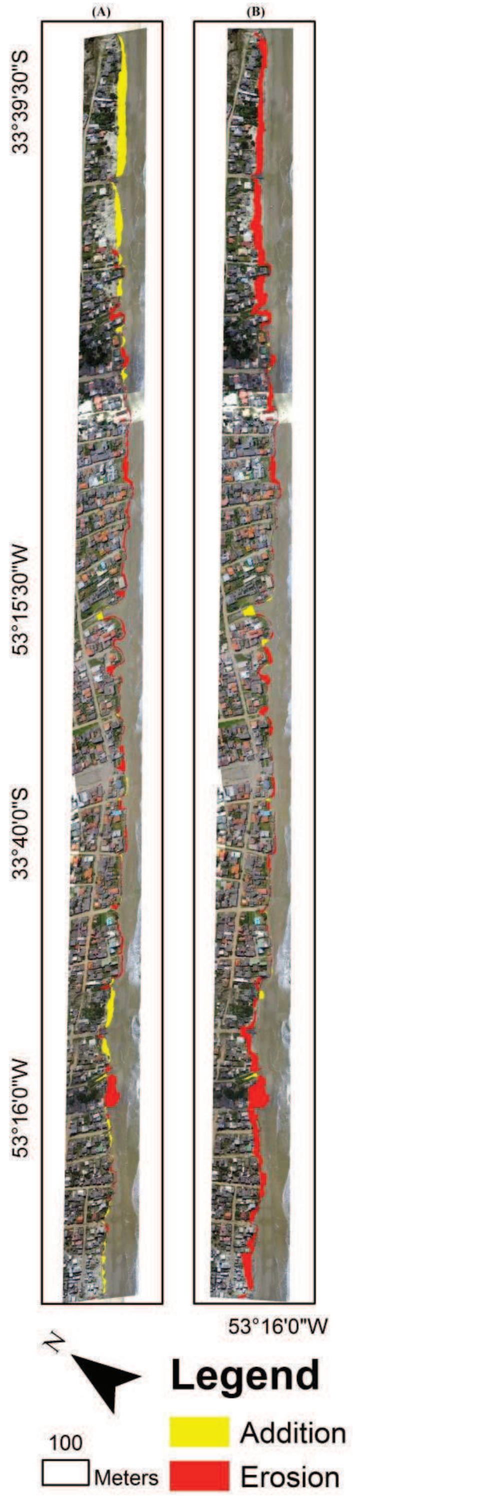

Figure 5. A- Accretional and eroded area to July and September 2016. B- Accretional and eroded area to September and November 2016.

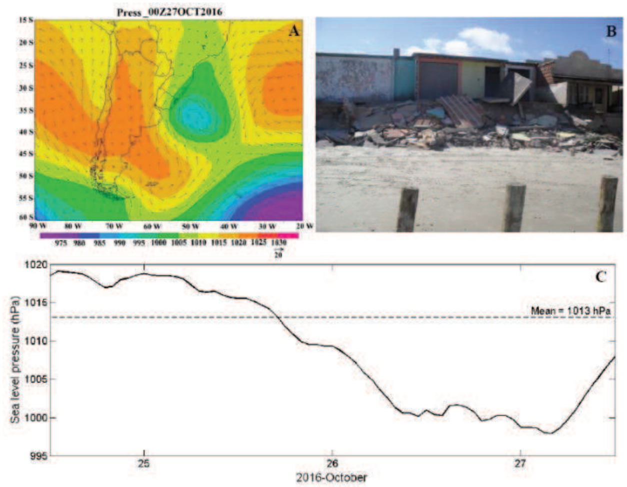

Figure 6. A- Synoptic situation in October 27th, 2016. B- Damage to infrastructure after the cyclone. C- Sea level pressure during the event occurred in October 27th, 2016.

The northern portion of Hermenegildo beach was the hardest hit, with a high retraction of the dune field, and toward the south, 40 residences were destroyed or highly damage.

DISCUSSION

For the southern Brazil, when the high and low pressure centers are situated, respectively, in the continent and atmosphere, a parallel wind track SW/NE is formed (Parise *et al.*, 2009). This process is responsible for the rise of water on the coast, resulting in events of higher intensity and significant impacts on the sediment volume.

The extent of beach erosion induced by a storm depends on a series of phenomena (Karunarathna *et al.*, 2014). Associated with the meteorological aspects, erosive process is frequently accelerated or augmented by anthropogenic action, which is mainly related to building constructions activities and sometimes contributes to the destruction of dunes and other natural protections. When these factors are associated with the passage of cyclones, the level of destruction increases. For the cyclone that occurred in October 26th and 27th, 2016 there was a partial or total destruction of 40% of beachfront houses and 65% of coastal protection structures.

In southern Brazil, the winds of NE and SW are the major responsible to the erosive process and shoreline retraction. However, although it present an NE wind condition along the year, the high erosion rates presented for the event in October 2016 is not associated with the action of winter storms, which generally had already eroded the coastal segment. This statement corroborates the rates of movement of the shoreline prior the passage of the cyclone showed in this study. For the period from July to September 2016, the coastal segment presented an average shoreline increase rate of 0.84 m, with NE wind condition during the period. However, in October 26th and 27th, 2016 the wind condition was SW, and the shoreline showed a retraction of the 5.91 m.

About the cyclogenesis patterns linked with high rates of shoreline retraction, Machado *et al.* (2010) and Albuquerque *et al.* (2013) showed that cyclones associated with wind direction SW was responsible for a higher erosion in the southern Brazil. These pattern of cyclogenesis and its relationship with the erosive process corroborate with the data obtained in this study, where the event studied presented the same characteristics describe to Machado *et al.* (*Op cit.*), and high rates of coastal retrogradation, principally in the northern portion of Hermenegildo beach.

CONCLUSIONS

Significant shifts in coastal morphology can occur during extreme events (single large storms or storm clusters), reducing the protection offered to subsequent storm events and elevating risks of coastal erosion. To the Brazilian south littoral, shoreline changes along the passage of cyclones show great spatial and temporal variability. Other factors such as local hydrodynamic and favorable bathymetric conditions for a greater wave convergence contribute to the erosion process, with elevation in the shoreline retreat rates.

Gaining knowledge on shoreline change processes increases the capability of coastal managers to manage risks, especially shoreline erosion associated by storm surges, affecting the increasing population living in coastal areas. Therefore, this type of study constitute basic tools of general interest in the municipal coastal management, can thus contribute to reduce the impacts and risks associated with the coastal dynamics and effects of the cyclones along the Southern Brazilian littoral, specially in Hermenegildo beach.

ACKNOWLEDGEMENTS

The authors thanks to Ulisses Oliveira and Rodrigo Simões of the *Universidade Federal do Rio Grande* (FURG), for the image disponibilized, and to the *Instituto Federal do Rio Grande do Sul, Campus Rio Grande,* for the logistic support.

LITERATURE CITED

Albuquerque, M.G.; Espinoza, J.; Teixeira, P.;De Oliveira, A.; Corrêa, I., and Calliari, L., 2013. Erosion or coastal variability: an evaluation of the DSAS and the change polygon methods for the determination of erosive process on sandy beaches. *Journal of Coastal Research*, 65(SI), 1710-1714.

Almeida, L.P.; Ferreira, O., and Pacheco, A., 2010. Thresholds for morphological changes on an exposed sandy beach as a function of wave height. *Earth Surface Processes and Landforms,* 36(4), 523-532.

Anfuso, G.; Bowman, D.; Danese, C., and Pranzini, E., 2016. Transect based analysis versus area based analysis to quantify shoreline displacement: spatial resolution issues. *Environment Monitoring Assessment*, 188, 1-14.

Bowden, K.F., 1983. *Physical oceanographic of coastal waters*. Elis Horwood Ltd, Chichester.

Burvingt, O.; Masselink, G.; Russell, P., and Scott, T., 2017. Classification of beach response to extreme storms. *Geomorphology*, 295, 722-737.

Calliari, L.J., and Toldo Jr., E.E., 2016. Ocean beaches of Rio Grande do Sul. In: A.D. Short, and A.H.F. Klein (Eds). *Brazilian Beach Systems*, 507-542. Springer, Dordrecht.

Calliari, L.J.; Speranski, N., and Boukareva, I., 1998. Stable focus wave rays as a reason of local erosion at the southern Brazilian coast. *Journal of Coastal Research*, 26(2), 19-23.

Ferreira, O., 2006. Storm groups versus extreme single storms: predicated erosion and management consequences. *Journal of Coastal Research,* 42(SI), 221-227.

Gonçalves, J.A. and Henriques, R., 2015. UAV photogrammetric for topographic monitoring of coastal areas. *ISPRS Journal of Photogrammetry and Remote Sensing,* 104, 101-111.

Haala, N.; Cramer, N., and Rothermel, M., 2013. Quality of 3D point clouds from highly overlapping UAV imagery. *International Archives of the photogrammetry, Remote Sensing and Spatial Information Sciences,* 40(1W2), 183-188.

Karunarathna, H.; Pender, D.; Ranasinghe, R.; Short, A.D., and Reeve, D.E., 2014. The effects of storm clustering on beach profile variability. *Marine Geology*, 348, 103-112.

Lima, L.G.; Dilenburg, S.R.; Medeanic, S.; Barboza, E.G.; Rosa, M.L.C.C; Tomazelli, L.J.; Dehnherdt, B.A., and Caron, F., 2013. Sea-level rise and sediment budget controlling the evolution of a transgressive barrier in southern Brazil. *Journal of South American Earth Sciences,* 42, 27-38.

Machado, A.A.; Calliari, L.J.; Melo, E., and Klein, A.H.F., 2010. Historical assessment of extreme coastal sea state conditions in southern Brazil and their relation to erosion episodes. *Pan-American Journal of Aquatic Sciences,* 5, 105-114.

Parise, C.K.; Calliari, L.J., and Krusche, N., 2009. Extreme storm surges in the south of Brazil: atmospheric conditions and shore erosion. *Brazilian Journal of Oceanographic*, 57(3), 175-188.

Saraiva, J.M.B.; Bedran, C., and Carneiro, C., 2003. Monitoring of storm surges on Cassino beach, RS, Brazil. *Journal of Coastal Research*, 35(SI), 323-331.

Smith, M.J., and Cromley, R.G., 2012. Measuring historical coastal change using GIS and the change polygon approach. *Transactions on GIS,*16, 3-15.

Stone, G.W., and Orford, J.D., 2004. Storms and their significance in coastal morpho-sedimentary dynamics. *Marine Geology,* 210, 1-365.

Tolman, H.L., 2002. *Use manual and system documentation of Wave Watch III*, Washington, version 2.22, pp 133.

Usace (US Army Corps of Engineers), 2002. Water levels and long waves. In: Usace (Ed) *Coastal Engineering Manual, Part II*, Vicksburg, Mississipi, EM 1110-2-1100, pp 76.

Wright, L.D., and Short, A.D., 1984. Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geology,* 56, 93-118.