Revista Brasileira de Geografia Física v.10, n.05 (2017) 1419-1434.

ISSN:1984-2295

Revista Brasileira de Geografia Física

Homepage: www.ufpe.br/rbgfe

Coastal geoindicators and anomalous precipitation patterns associated with variations in the SAM and the ENSO

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Artigo recebido em 18/04/2017 e aceito em 10/09/2017

A B S T R A C T

The interaction between ocean, continent and atmosphere submits the beaches to intense sedimentary dynamics. All processes of transport, erosion and sedimentary deposition are under direct influence of the climate and its variability. This papper expound variations in geoindicators by remote sensing in three different sectors of the Rio Grande do Sul Coastal Plain during periods of precipitation anomalies (PP) associated with the Southern Annular Mode (SAM) and El Niño - Southern Oscillation (ENSO), by the MEI index. Data from the satellite TRMM were used between 1998 and 2013, correlated to the two indexes by classification matrices and t student test. Geoindicators were compared between periods of precipitation above and below average. The results show a negative correlation between PP anomalies on the central and south coast and the SAM, and a positive correlation between PP anomalies on the south coast and the MEI. No similar correlations are found between the north coast and either of the two indexes. The majority of events are PP (78%) and can be simultaneously related to a SAM+ and a MEI- or only MEI+. All PP+ events were concomitant with MEI+. The geoindicators presented observable variations by remote sensing between the below and above average rainfall periods. The greater number of PP events in the areas of the geoindicators studied may represent a lower volume of sediments transported from the backshore to the shoreline changing the sedimentary budget. Wind can transport dry sands from dune fields and fill lakes and lagoons of the study area, unbalancing the ecosystem.

Keywords: climate variability; climate change; coastal environment; remote sensing.

Introduction

The Rio Grande do Sul Coastal Plain (RGSCP) is an extensive coastal strip (615 km) in the south of Brazil (Figure 1) that is composed of intermediate and dissipative beaches (Calliari et al., 2006). Like the entire coastal region, it is characterized as an environment susceptible to human activity and alteration. The increase/decrease in precipitation resulting from natural climatic variations (Baily and Nowell, 1996; Morton et al., 2000), for example the El Niño-Southern Oscillation (ENSO) phenomenon, is also a cause of changes to regional coastal morphology. Climate change is intensifying the modes of climate variation, and one of the consequences is the alteration of precipitation patterns around the world (Barry and Chorley, 2012). Grimm et al. (1998, 2000) confirms that in southern Brazil, positive or negative ENSO influences precipitation anomalies. Reboita et al. (2009) found a relationship between cyclogenesis and SAM: a strengthening of cyclogenesis and an increase in precipitation anomalies with SAM- on the southeast coast of South America (SA), as well as a weakening of cyclogenesis and a decrease in precipitation during SAM+.

According to Berger (1998), many impacts of climate change can only be observed in the long term. In contrast, this paper shows that the use of geoindicators allows us to see short-term variations (<100 years).

Berger (1997) listed six coastal geoindicators, two of which are common in RGSCP: washouts and lakes. Washouts act as stream channels and exist due to precipitation. According to Zeltzer (1976), washouts function as outlets for occasional excess water during periods of high precipitation. Figueiredo and Calliari (2006) state that the geomorphology of the RGSCP coastal barrier determines the distribution and number of washouts; the presence of lakes and coastal lagoons reduces the number of washouts due to the drainage that occurs in their direction. Coastal lakes and lagoons, as well as washouts and stream channels, can be considered important geoindicators of hydrological variations in the RGSCP.

This paper analyzes the occasional hydrological variations during anomalous precipitation events in the RGSCP. For this analysis, washouts in the south and north coasts and a coastal lake in the central coast were examined using Landsat Thematic Mapper™ and Enhanced Thematic Mapper (ETM+) images. For the study of geoindicators, a Tropical Rainfall Measurement Mission (TRMM) series provided data of monthly precipitation from 1998 to 2013. Correlations between anomalous precipitation events in each sector of RGSCP and climatic variability indexes (SAM and the Multivariate ENSO Index – MEI) were tested to identify any associations with the geoindicators in the RGSCP.

Material and methods

Berger (1997) created a list to verify the susceptibility of geoindicators. Table 1 includes washouts and coastal lakes susceptibility. In total, three geoindicators were used, one for each sector of RGSCP (Figure 2B, 2C, 2D).

To correlate the precipitation in the RGSCP with the SAM and ENSO variability, monthly precipitation anomalies (PP) were calculated for three parts of the coast (south coast - SC, central coast - CC and north coast - NC) from regularly gridded Tropical Rainfall Measuring Mission (TRMM) satellite data

SAM is the monthly normalized difference of pressure at the sea surface between 40ºS and 70ºS (Gong e Wang, 1999). The index used is from Nan and Li (2003), obtained at LASG (National Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Beijing,China)(http://ljp.lasg.ac.cn/dct/page/6552).

The index used for ENSO, MEI, was made through observation of six variables in the tropical Pacific; it is available on the NOAA website (*National Oceanic and Atmospheric Administration*, *United States, Department of Commerce*, EUA, http://www.esrl.noaa.gov/psd/enso/mei/index.html).

The relationships between precipitation anomalies, SAM, and MEI were statistically investigated using discrimination analysis on 3x3 contingency tables. The scores were applied to the Hit the Hit Rate (the percentage correctly classified by the discrimination plots) (Equation 1). Student's *t*-test was applied (Equation 2) for precision of classification in discrimination analysis for each matrix.

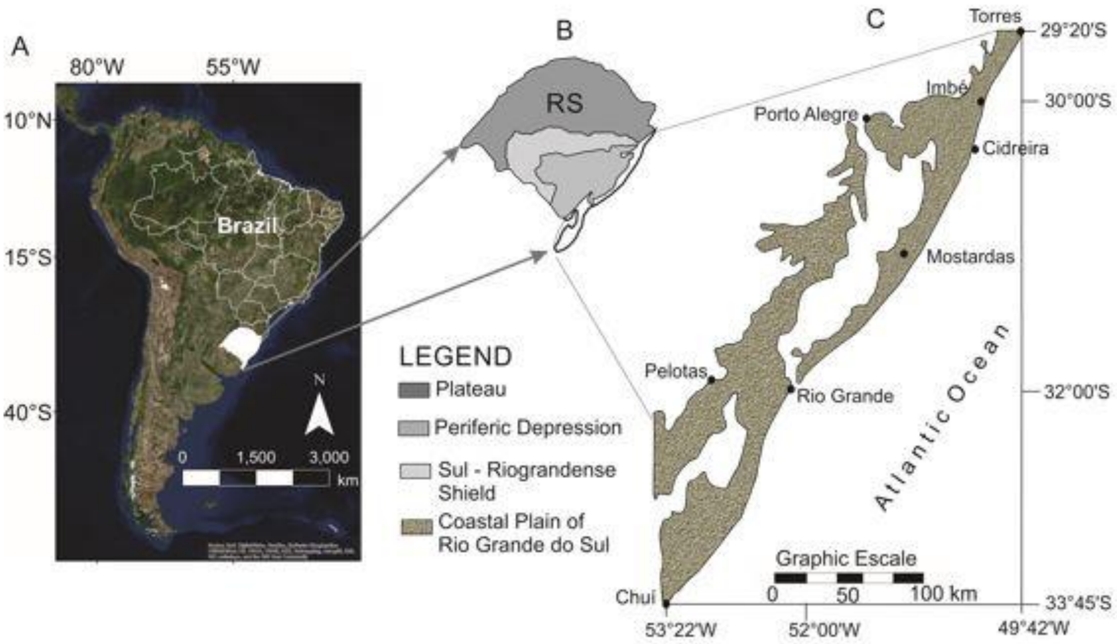

Figure 1. The Rio Grande do Sul State (RS) in Brazil and in South America (A), geomorphological division of the state (B) according to Carraro et al. (1974) and the location of the Rio Grande do Sul coastal plain (C).

Table 1. Susceptibility and characterization of geoindicators with hydrological variation in the study area, adapted from Berger (1997).

Name	Washout	Lagoon
Description	Coastal stream formed on a coastal barrier, due to precipitation	Shallow, coastal body of water, connected to the sea by a channel
Significance	When dry (wet), indicates a period of low (high) precipitation	
Natural or anthropic cause	Associated with periods of anomalous precipitation related to climatic variability	
Applicable environment	Coast	
Monitored environment	shoreface/berm/dune field	Depression on the coastal barrier
Spatial scale	Regional (south, central and north coasts)	
Measurement method	Remote sensing/visual interpretation	
Measurement frequency	Annual/seasonal	
Data/monitoring limitations	Availability of images/spatial resolution	
Past and future applications	Allows analysis of evolution of variability in precipitation related to climate change	
Possible input	Dry completely or spill into the original channel	Dry completely or fill up until it breaks the barrier of channel, drowned spits and sand banks.

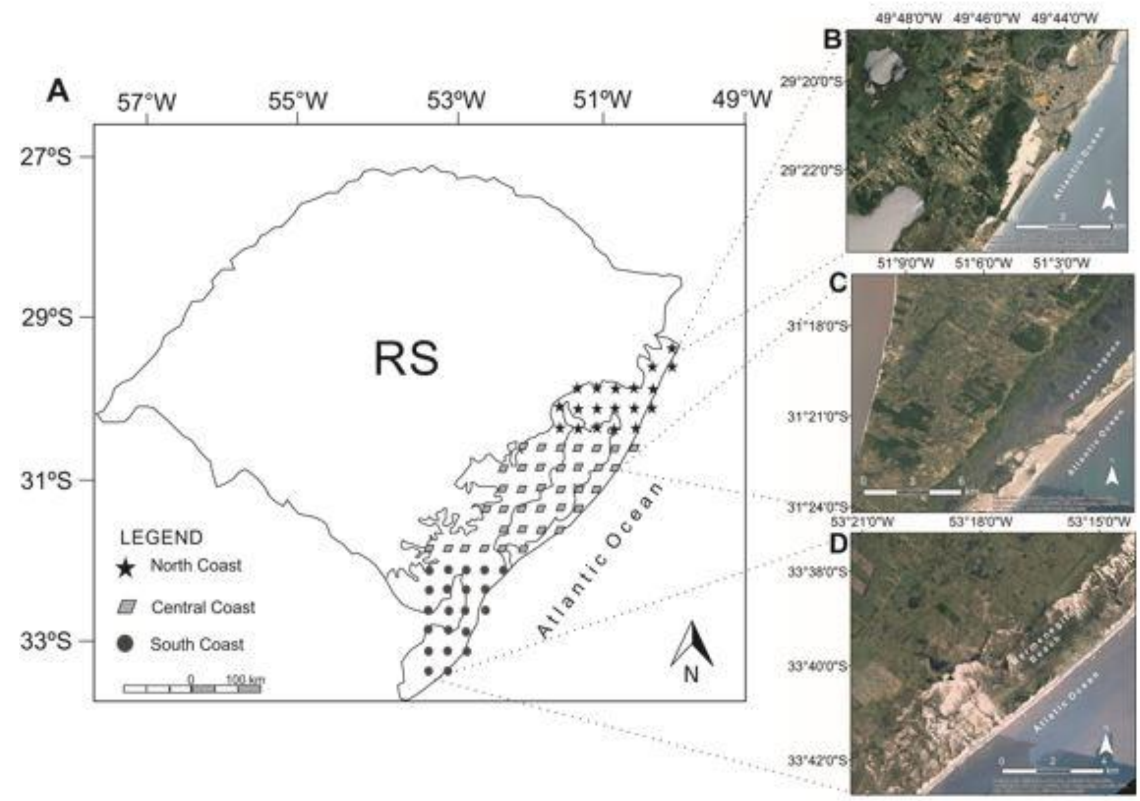

Figure 2. Locations of geoindicators and mesh data of precipitation: A) division of the Rio Grande do Sul Coastal Plain into 3 sectors, and location of 77 precipitation data points obtained from satellite *Tropical Rainfall Measuring Mission* from 1998–2013; B) washout location in the Itapeva State Park on the North coast; C) location of Peixe Lagoon on the Central coast; D) washout locations in the town of Hermenegildo on the South coast.

The matrices were organized into three groups (-1, 0, 1), classifying each tertile as follows: below average PP (-1), average (0), and above average (1). When the '*t*' result was higher than 1.96, a correlation existed between the two indexes because its significance is less than 0.05 (Hair et al., 2009).

$$p = \frac{n}{N} \times 100 \qquad (1)$$

$$t = \frac{p - 0{,}33}{\sqrt{\frac{0{,}33(1-0{,}33)}{N}}} \qquad (2)$$

Where:

p = percentage correctly classified

t = *t*-test

N = sample size

n = correctly classified number

To interpret and analyze the hydrological variation of the geoindicators, 22 PP events were identified, from 5 months or more, in the simultaneous positive/negative phases of SAM and MEI indexes. Once the events were characterized, Landsat images (TM and ETM+ products) of the geoindicators were selected for the relevant time period, available free of charge on the Brazilian National Institute of Spatial Research (INPE) website (http://www.dgi.inpe.br/CDSR/).

Only images (≈ 50) from events during warm months (November to April) were selected from the study area (Krusche et al., 2003) to standardize images under the same weather conditions, due to increased evaporation during this period (Figueiredo and Calliari, 2006). Thus, it was easier to identify anomalous PP events in the geoindicators. RGB-543 color composites were created from the images to improve the distinction between water bodies and humid soils. This facilitated the interpretation and description of each geoindicator variation, according to the influence of each mode of climatic variability.

Results

Influence of the climate variability modes in the RGSCP precipitation

Seasonal precipitation in the RGSCP is not well distributed throughout the three coasts. The SC is the driest during summer, winter, and spring but has the highest precipitation in the fall. The CC has the highest summer precipitation, and the NC has the highest precipitation in winter and spring and is also the driest in the fall. From 1998 to 2013, both the CC and SC showed a reduction in precipitation. No such trend was observed for the NC.

Total annual precipitation oscillates from 1.252 mm to 2.155 mm in the 1998–2013 period. The largest positive anomaly, 2.155 mm in 2002 (Figure 3), occurred during a moderate El Niño and a SAM- year. Peaks and troughs in the total annual precipitation series in the RGSCP coincide with ENSO events (precipitation peaks during El Niños, troughs in La Niñas) as well as some years with SAM phases (lower in positive SAMs, peaks with negative SAMs).

The *t*-test indicates that the NC is the only sector that does not show a significant statistical relationship between the PP and the SAM. The variation in the CC is negatively correlated with SAM (t = 2.77; $\alpha < 0.05$); however, there was no relationship with the MEI index. The SC was the only section that presented a negative correlation between PP and the SAM (t = 2.41; $\alpha < 0.05$) and a positive correlation between PP and the MEI (t = 2.14; $\alpha < 0.05$), just as there is a negative correlation between the total PP in RGSCP and the SAM (t = 2.77; $\alpha < 0.05$) and a positive correlation between the total PP in RGSCP and the MEI (t = 2.11; $\alpha < 0.05$). The NC was the sector with the lowest number of anomalous precipitation events, presenting the highest mean precipitation in all of the RGSCP—almost 200 mm more than the SC.

During the 1998–2013 period, 22 events of PP+ and PP- were recorded in the RGSCP. These events occurred primarily (40%) from the beginning of spring to the end of summer the following year and secondarily (32%) at the end of winter extending to the summer. Both the SC (Figure 4A) and the CC (Figure 4B) had almost twice as many anomalous events as the NC (Figure 4C). Proportionally, the three sectors have more PP- events than PP+ events. In the SC, the majority of events began in the spring, while in the CC, the majority began in the winter. The NC did not show a preferred season for anomalous events. It can be seen in Figure 4 that 78% of the events were PP-. A positive SAM phase, coupled with a negative MEI phase (La Niña events), results in the occurrence of long periods of drought in the region.

Interpretation of geoindicator variations associated with precipitation events in each RGSCP sector

The interpretation of geoindicator variations in each sector of the RGSCP coastal plain is based on the analysis of Landsat images, and associated with anomalous events of PP correlated to SAM and ENSO modes of variability.

South Coast

Figure 5 shows 9 PP events that occurred from 1998 to 2013. Events 1, 4, 5, 7, 8, and 9 are PP-. Event 1 (1999-2000) was the only event in which SAM+ and MEI- occurred in every month. Events 4 (2004-2005), 5 (2006-2007), and 9 (2012) were MEI+ in every month. Event 7 (2010-2011) was SAM+ in every month, and event 8 (2011-2012) was MEI- in every month. Events 2 (2002-2003), 3 (2003-2004), and 6 (2009-2010) were PP+ and MEI+ in every month

The geoindicator for SC, the washouts on a dune field south of Hermenegildo beach (33°39'S, 53°15'W), shows increasing shoreline erosion (Albuquerque, 2013) and, according to Toldo et al. (2006), is in the process of accentuated retrogradation. For this reason, the dune fields and the washouts south of this village are important to the local sediment budget: as the longshore transport brings sand from the dunes and backshore back to the shoreface, the currents in the region transport sediments toward the coast (Albuquerque, 2013).

The characteristics of the anomalous PP events from chosen images that exemplify the hydrological variation in washouts at Hermenegildo Beach can be seen in Table 2. During the PP- month, it rained only 31% of the November mean, while during the PP+ month, it rained 98% above the December mean for the south coast.

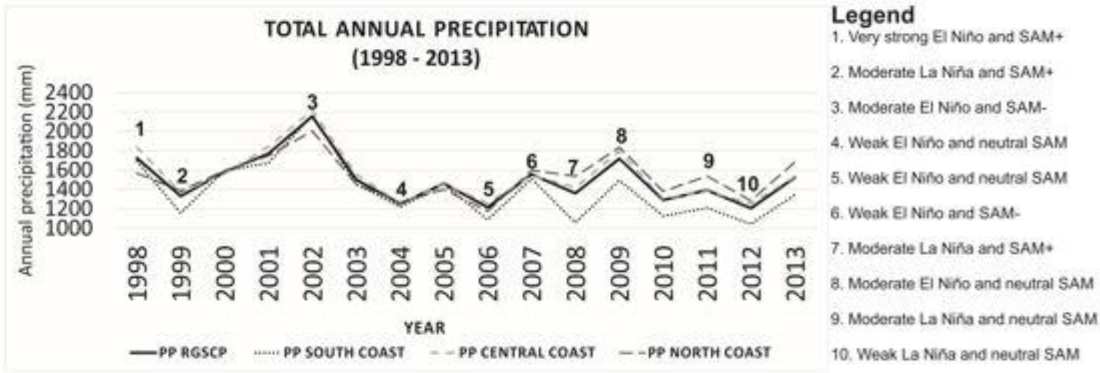

Figure 3. The total annual precipitation series (1998–2013), for the entire Rio Grande do Sul Coastal Plain (RGSCP) and for each of its sections.

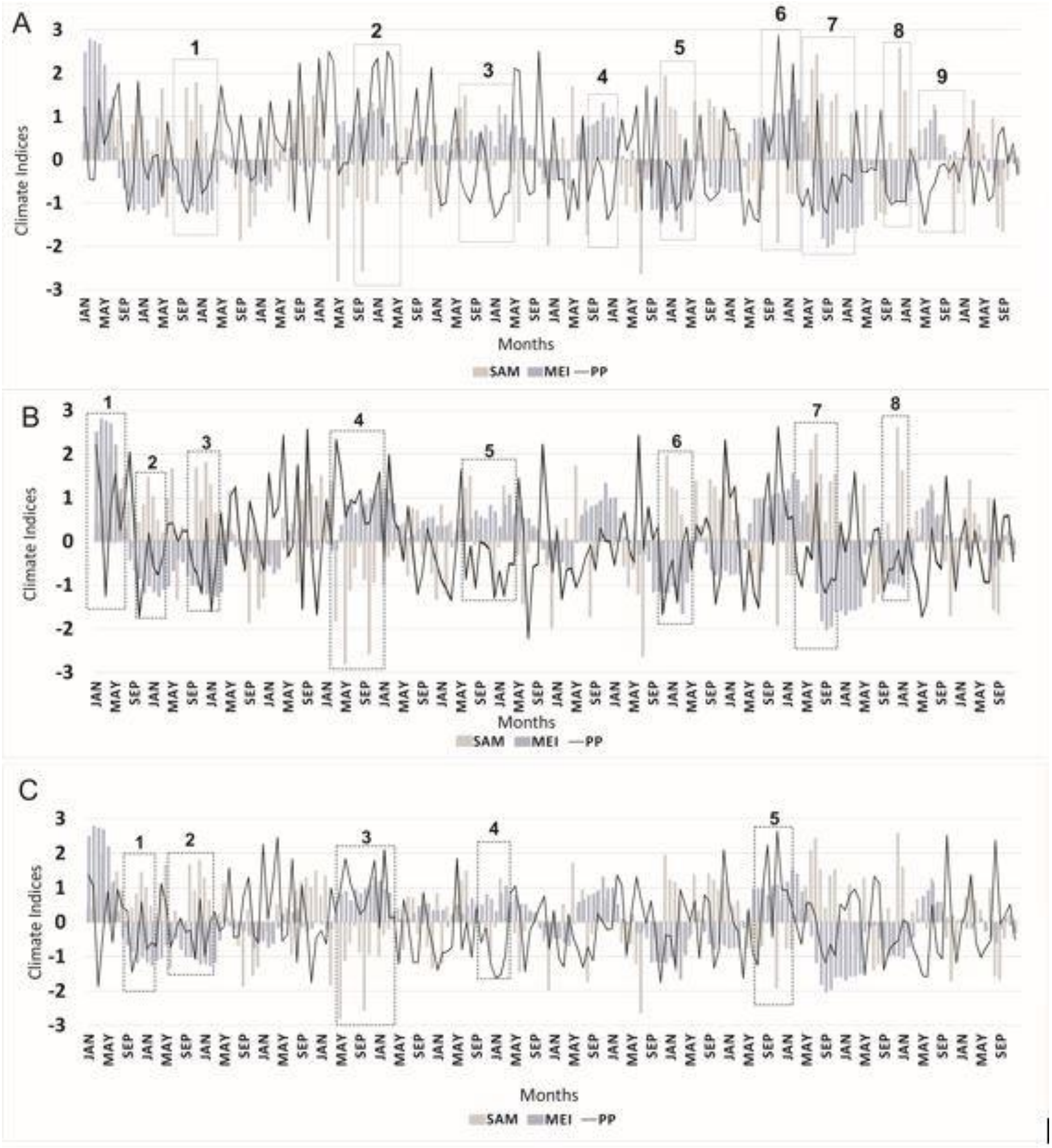

Figure 4. Monthly precipitation anomalies (black line) associated with the respective SAM (light gray column) and MEI (dark gray column) indices, for the three different sectors of Rio Grande do Sul Coastal Plain (RGSCP): A) south coast, B) central coast and C) north coast (1998 – 2013). Dotted rectangles are anomalous precipitation events.

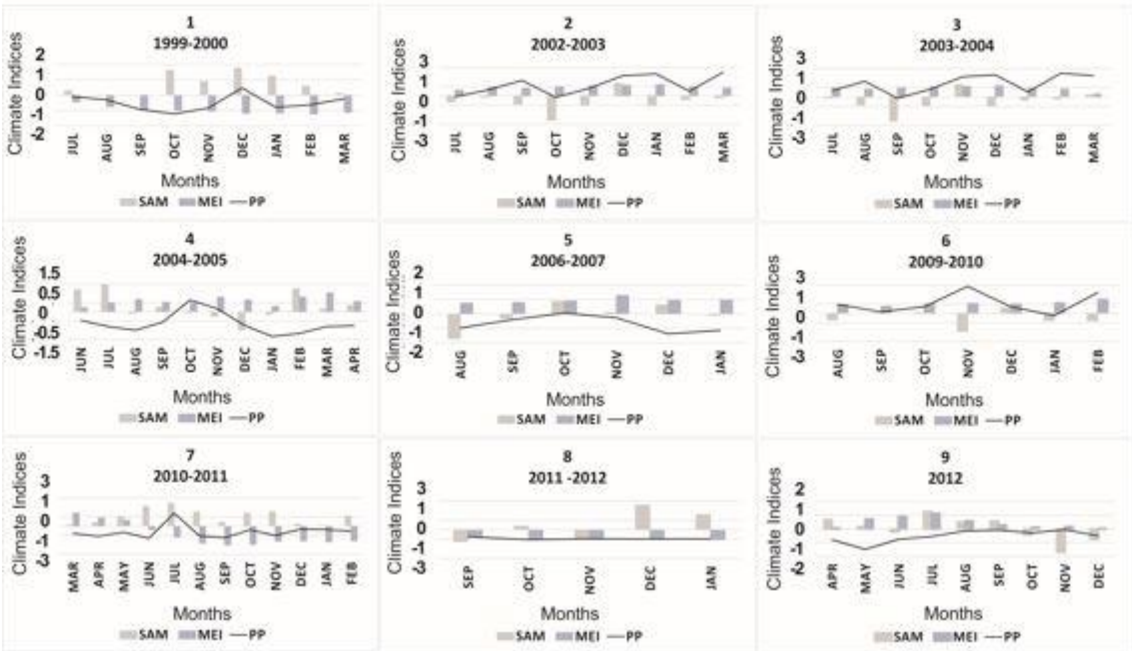

Figure 5. Sequence of anomalous precipitation (PP) events in the South Coast (SC) associated with SAM and MEI variations.

Table 2. Comparison of two anomalous precipitation events and the geoindicators in the south coast (SC).

Hydrological condition	Image date	Nº of events	Monthly precipitation averaged for the image (mm)	Total monthly precipitation for the image (mm)	Anomaly index
PP-	November 26, 2010	7	112	35	-1.0
PP+	December 21, 2002	2	82	163	+2.1

Figure 6A, which shows a PP- event in the SC, shows the dune fields and the dry and inactive washouts. The largest washout, in the extreme south, still has a narrow stream of water flowing to the sea. The light blue color of the water, as shown by the used color composite, indicates suspended sediments. The deeper the layer of water, the lower the reflectance in blue. This allows us to conclude that in the PP- image, washouts and dune fields were dry, which can increase erosion and aeolian sediment transport.

The PP+ image (Figure 6B) shows active washouts and humid dune fields. The surplus of precipitation over the dune fields and backshore favor sediment transport in the direction of the beach and ocean. Longshore currents will transport some of these sediments, and some will be deposited and reworked on the beach face, which contributes to a positive sediment budget on the beach. According to Maia (2011), many washouts on Hermenegildo Beach were artificially closed to construct roads, interfering with the sediment budget of the region.

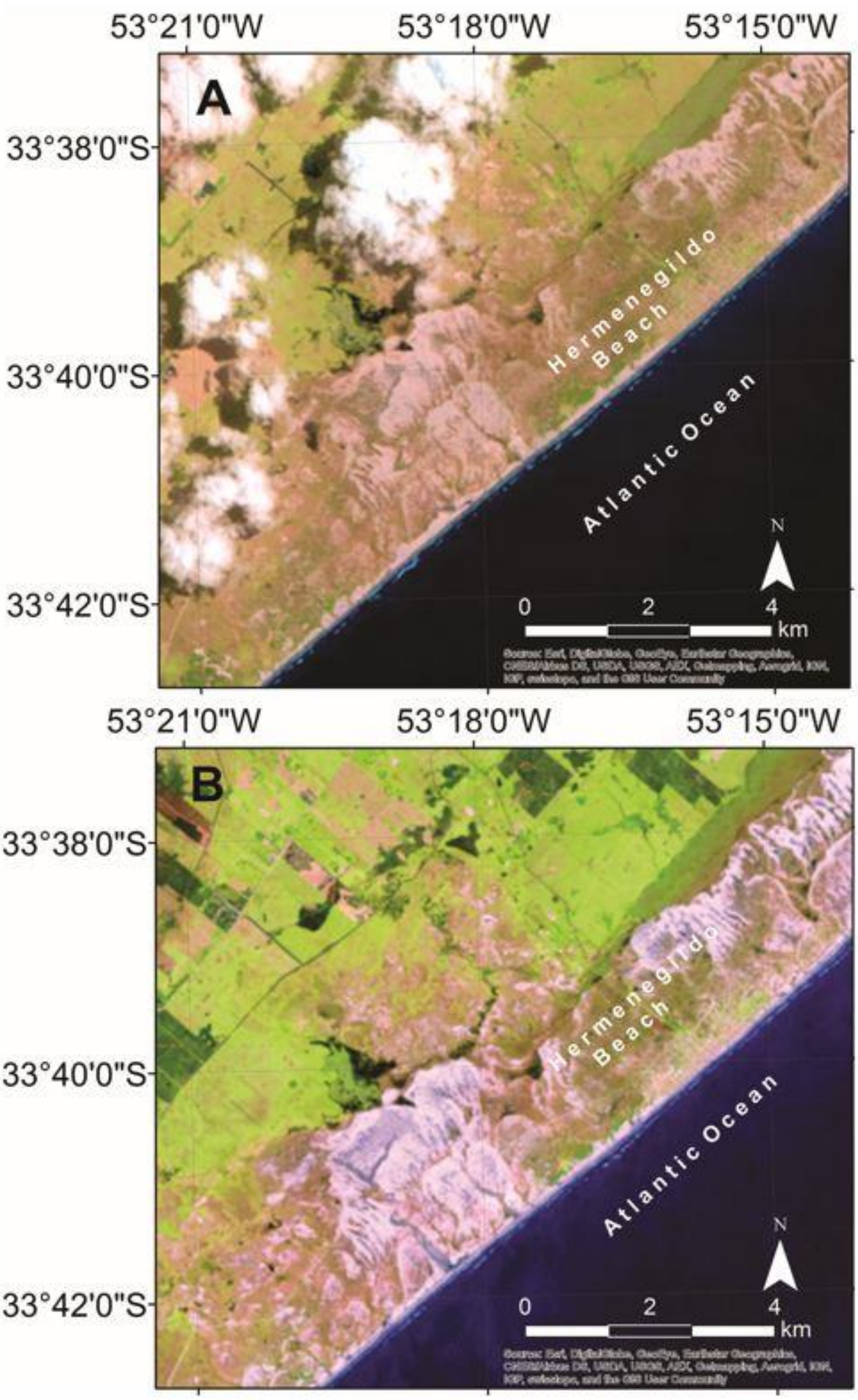

Figure 6. Landsat TM and ETM+ images to compare washouts and dune fields at Hermenegildo Beach under different hydrological conditions: A) a dry geoindicator during a PP- event 7; B) a humid geoindicator and humid area surrounding it during a PP+ event.

Central Coast

The events identified in the PP series on the CC are presented in Figure 7. Events 2 (1998-1999), 3 (1999-2000), 5 (2004-2005), 6 (2007-2008), 7 (2010), and 8 (2011-2012) are PP-. Events 2 and 3 were SAM+ and MEI- during all months. Event 5 was MEI+ in all months, events 6 and 8 were MEI- in all months, event 7 was SAM+ in all months. Events 1 (1998) and 4 (2002) were PP+. While MEI+ and SAM+ occurred simultaneously during event 1, event 4 was MEI+ and SAM- for almost all months.

Peixe Lagoon (PL) was chosen as a geoindicator on the CC. This shallow body of water (30 cm mean depth) is in a preservation area: Peixe Lagoon National Park (PLNP). The PL has an intermittent channel that connects to the Atlantic Ocean and tributaries that depend exclusively on precipitation to maintain their water level (Schossler et al., 2017). Even with the channel open, the rising tides would not be able to introduce sufficient water to the lagoon, due to the microtidal environment in the RGSCP. The shallow coastal lake maintains low water levels, with the exception of the channel, which can reach depths of 3 m. Low precipitation volumes for long periods of time may increase the salinity of the lake water (saltwater intrusion), destabilizing the ecosystem equilibrium. Conversely, rainfall above the mean opens and widens the channel, which is a rare occurrence.

Table 3 describes characteristics of images chosen to exemplify hydrological variation in PL. During the PP- month, it rained only 69% of the January mean, while during the PP+ month it rained 72% above the April mean on the central coast.

The selected image shows a period of drought for January 2005. In Table 3, we can observe that the anomaly index is not very high; however, the drought lasted for 8 months. In Figure 8A, it is possible to see the bottom of the PL completely exposed. Water only remained in the deepest part of the lagoon, such as the connecting channel and its southern portion (Arejano, 2006). In Figure 8A, the dune field is dry, and in Figure 8B, the dune field is humid and the lagoon banks and spits are partially submerged. Figure 8B represents a period of high precipitation in 2002, just after a PP+ event in April. However, the total precipitation in the first 3 months of that year (January to March) was only 58 mm above the first three months' mean on the CC. The preceding year, 2001, had an elevated precipitation of 1,842 mm total, while the mean precipitation on the CC for the series was 1,530 mm.

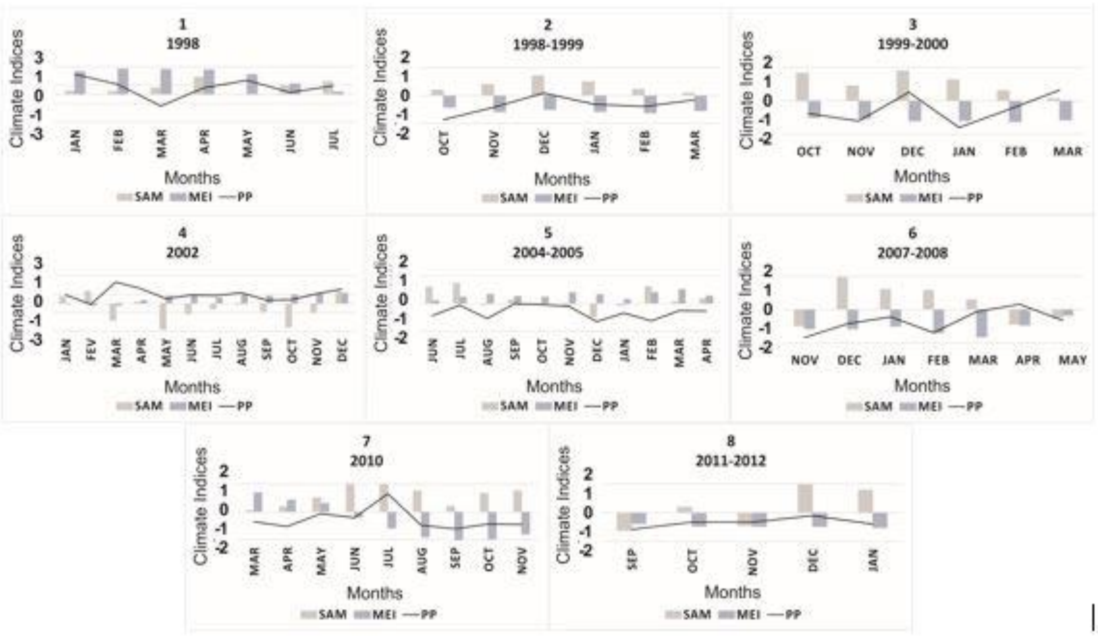

Figure 7. Sequence of anomalous PP events in the central coast (CC) associated with the SAM and the MEI variations.

Table 3. Comparison of two anomalous precipitation events and the geoindicators in the central coast (CC).

Hydrological condition	Image date	Nº of events	Monthly precipitation averaged for the image (mm)	Total monthly precipitation for the image (mm)	Anomaly index
PP-	January 12, 2005	5	132	92	-0.7
PP+	April 2, 2002	4	140	242	+1.6

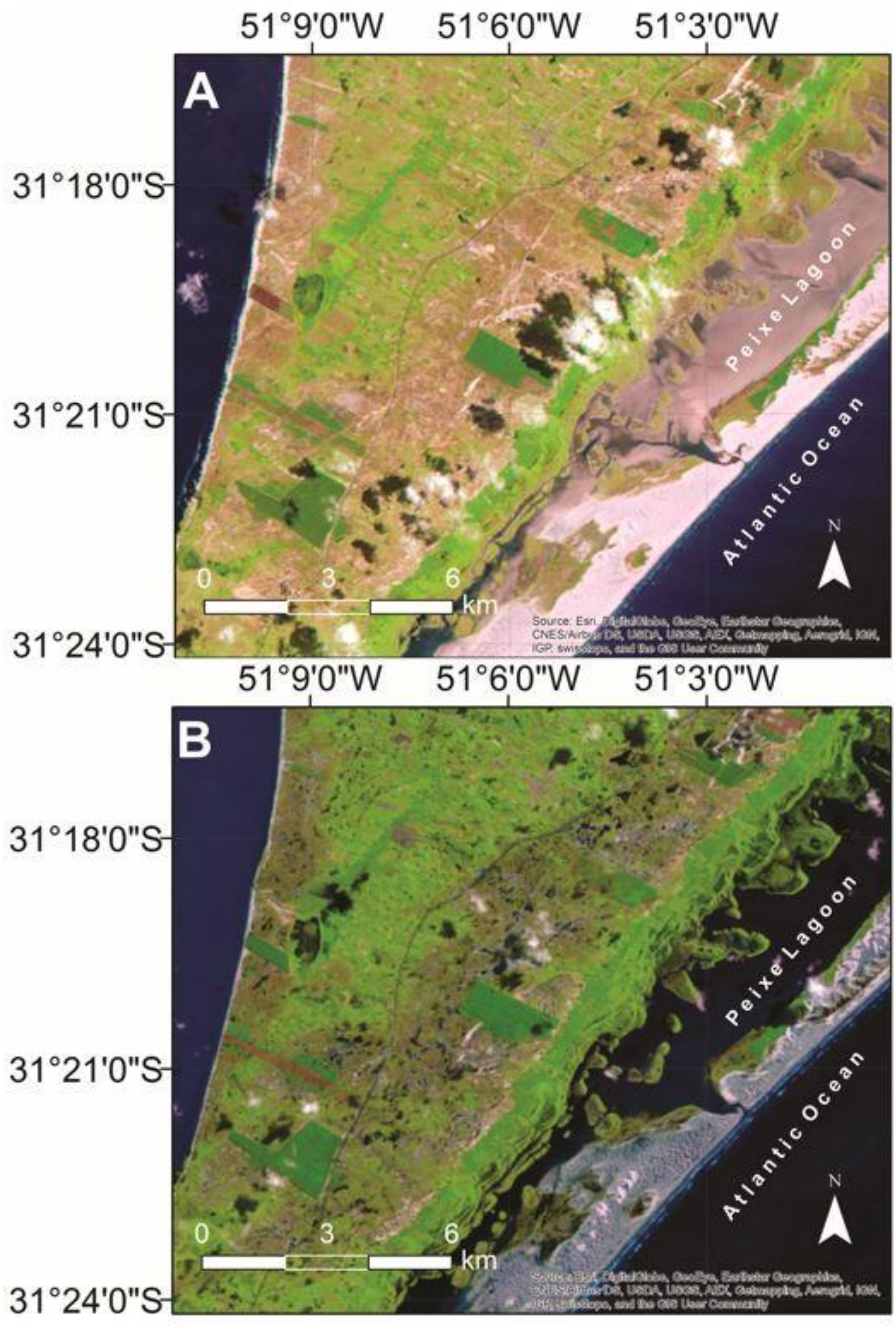

Figure 8. Landsat TM images used to compare the Peixe Lagoon study area under different hydrological conditions: A) PP- event 5, showing a geoindicator completely dry with various exposed spits; B) PP+ event 4, showing a wet geoindicator and its surrounding area, with spits partially submerged.

North Coast

Five anomalous PP events in the NC are shown in Figure 9, with their relationships to the three climate variability indexes. There were fewer events than in the SC or the CC (Figures 5 and 7). This may reflect the lack of correlation of the anomalous PP events in the NC with the SAM and ENSO variability. Events 1 (1998-1999), 2 (1999-2000), and 4 (2004-2005) are PP-, with SAM+ and MEI- during the first two events, and MEI- on the last event. The two PP+ events (3 and 5) were associated with MEI+; however, only event 2 had a continuous SAM- The NC is the most urbanized sector in the RGSCP. To the south of Torres city (29°20'S, 49°43'W) is the Itapeva State Park, a conservation area of 10 km^2, which protects endemic species of the Atlantic Forest biome. According to Toldo et al. (2006), the shoreline adjacent to this park shows a moderate retrogradation. Speranski and Calliari (2006) state that this shoreline is stable and still presents foredunes. The washout in this location has relatively pure water coming from the water table and precipitation (Fundação Zoobotânica do Estado do Rio Grande do Sul, 2006). As stated above, an increase in precipitation transports sediments from the backshore and the dune fields, while periods of drought expose the dry dune fields to wind action, reducing sediment transport to the ocean and shoreface.

Table 4 presents characteristics of precipitation events from images chosen to exemplify hydrological variation in the washout area at the Itapeva State Park. During the PP- month, it rained just 40% of the February mean and during the PP+ month, it rained 16% above this mean for the north coast.

Landsat images show the washout (Figure 10) completely dry (Figure 10A), with a very small humid area in the shoreface. In Figure 10B, the geoindicator area is wet during the month that was only 16% above the mean precipitation. In total, there was a 6-month period of anomalous precipitation in the region.

Discussion

The results show evidence on the influence of the SAM on the variability of the pluviometric precipitation (PP) in the RGSCP. The NC precipitation shows no correlation with the SAM variability. Conversely, both the CC and the SC showed significant negative correlations, primarily with the SAM+. Silvestri and Vera (2003) explain that due to the occurrence of anticyclonic (cyclonic) anomalies of low frequency, in positive (negative) phases of the SAM, a reduction (intensification) of cyclonic activity and precipitation occurs in the southeast of the SA. Several studies (*e.g.*, Thompson and Wallace, 2000; Thompson and Solomon, 2002; Gupta and England, 2006) show that SAM+ periods have been more common recently due to climate change, a trend related to a reduction of the stratospheric ozone (*i.e.*, the "ozone hole") over Antarctica (Garreaud et al., 2009).

In relation to the MEI, precipitation anomalies in the RGSCP show significant positive correlations only in the SC. El Niño (EN) events could increase the precipitation in southern Brazil, and La Niña (LN) events could reduce it due to strengthening or weakening, respectively, of the subtropical jet stream in the spring with the formation of cyclones or anticyclones, which are most common during PP- events related to MEI-, rather than to PP+ events related to MEI+ (Grimm et al.., 1998). According to Garreaud et al. (2009), when the sea surface temperature (SST) and the humid convection are similar to LN (EN) years or when there is an increase (decrease) in tropical intraseasonal (monthly) variability, the SAM will be predominantly in a positive (negative) phase, suggesting that there is an interaction between the two modes of climate variability.

The 22 PP anomalous events described here begin generally in the spring, extending to the end of summer. The majority of events (68%) were PP-, of which 40% were concomitant with SAM+ and MEI-, while another 40% of PP- events were MEI+. Seven other events were PP+ and were mostly (86%) concomitant with MEI+ and SAM-, while one was only MEI+. It is possible, therefore, to confirm that periods of drought are related to the MEI (positive or negative), and a SAM+. No PP+ event occurred during SAM+ and no PP- event occurred during SAM-, confirming the findings of Silvestri and Vera (2003).

According to Morton (2002), variations in precipitation tend to cause changes in geoindicator behavior. The study area is a humid subtropical environment, where precipitation is well distributed throughout the year (Nimer, 1977). By standardizing the Landsat images, using months with the highest evaporation rates in the RGSCP – November to April (Krusche et al., 2003) – it was possible to identify hydrological variations in the three geoindicators. In the SC and the CC, hydrological variations between PP- and PP+ conditions were observed, while in the NC, geoindicator variations are less clear. For this reason, there was no correlation of these PP events on the NC with the SAM and MEI indexes. This could be explained by the orographic influence on precipitation in the NC, as this is the only sector in RGSCP adjacent to the Sul-Riograndense plateau (Figure 1) (Viana, 2009) that reaches 1000 m above sea level, approximately 35 km from the city of Torres.

Serpa (2013) studied two washouts in the RGSCP (one in the SC and the other in the CC). The results indicated that these washouts were active during or soon after storms (from May to June). The features were inactive during October and November due to factors such as evapotranspiration and storm surges. We used images from months without opening or closing of washouts to facilitate the identification of abnormal behavior related to the described precipitation events.

In the PP- image on the SC (6A) from November 2010, the washout is dry, due to the increase in evaporation in December associated with a period of LN and SAM+. In the PP+ image (6B) during December (one month after the closing of the washouts, according to Serpa 2013), the washout is very active. This PP+ event occurred during a SAM- and EN period, which can increase the shoreline retrogradation at Hermenegildo Beach (Toldo et al., 2006).

Haines (2008) classifies lagoons and coastal lakes by the morphodynamics of their channels' mouths. This author states that their water levels, as well as the opening of their channels, depend completely on precipitation and evaporation. The PL, geoindicator in the CC of the RGSCP, is susceptible to precipitation anomalies and all their consequences (*e.g.*, lagoon silting and variations in opening/closing of their inlet, Schossler et al., 2017). In the image referring to the PP- event in January, the Peixe Lagoon was completely dry. Periods like this can intensify the amount of sand transported by wind, leading to the slow and complete silting of the water body, the final evolution of the PL as described by Arejano (2006). The silting of the PL would be disastrous for the whole ecosystem, as migrating birds would lose an area for nesting, resting and feeding.

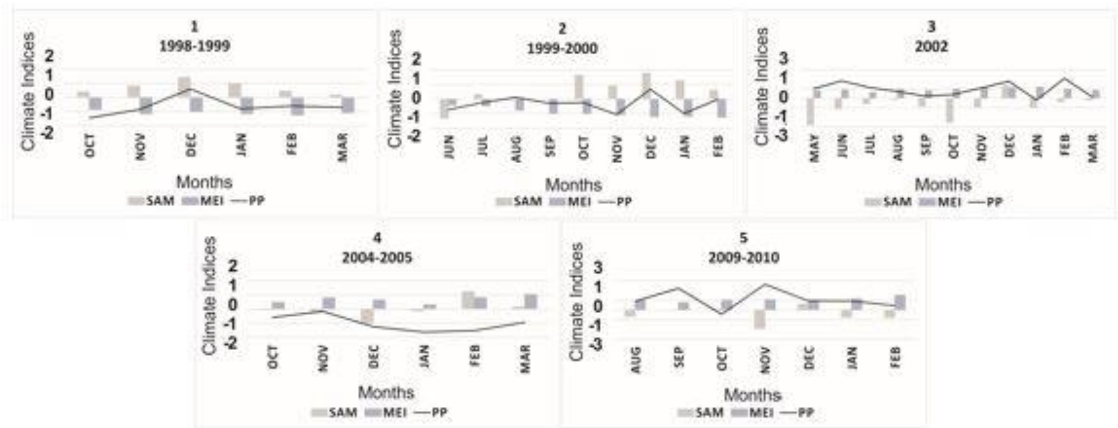

Figure 9. Sequence of anomalous PP events in the north coast (NC) associated with the SAM and MEI variations.

Table 4. Comparison of two anomalous precipitation events and the geoindicators in the north coast (NC).

Hydrological condition	Image date	Nº of events	Monthly precipitation averaged for the image (mm)	Total monthly precipitation for the image (mm)	Anomaly index
PP-	February 6, 2005	4	133	54	-1.5
PP+	February 4, 2010	5	133	155	+0.4

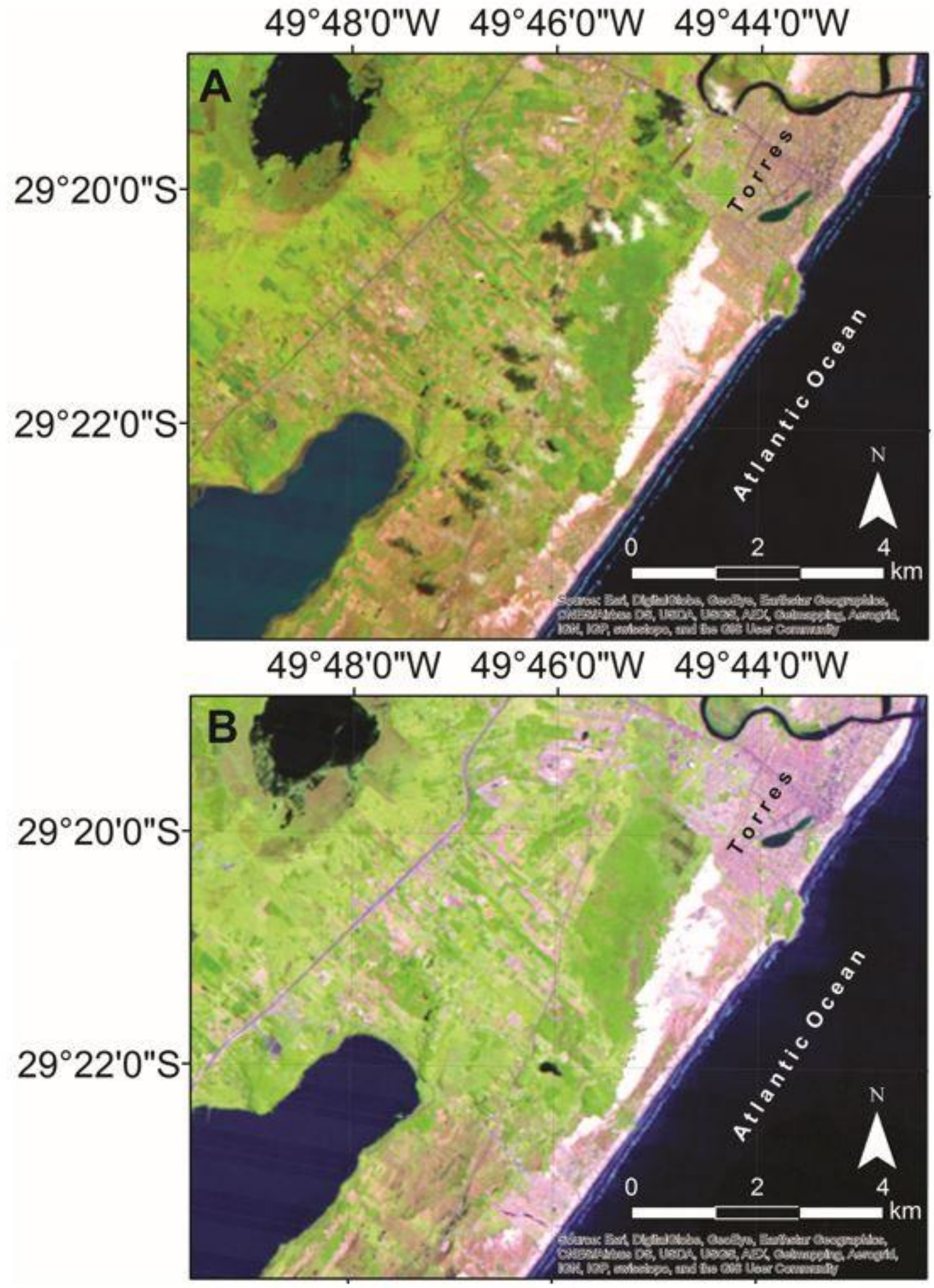

Figure 10. Landsat TM images comparing the washout and dune fields in Itapeva State Park under different hydrological conditions: A) PP- event 4, showing a completely dry geoindicator; B) PP+ event 5, a humid geoindicator and surrounding area.

Conclusions

The evolution of three coastal geoindicators (two washouts and a lagoon) observed in satellite images from the SC, CC, and the NC in the RGSCP, show hydrological and morphological variations associated with anomalous precipitation events influenced by the SAM and ENSO variability.

The precipitation anomalies in the NC of the RGSCP have no correlation with the SAM or the MEI. The anomalies in the CC are negatively correlated with the SAM variations, and the anomalies in the SC were the only anomalies negatively correlated to the SAM and positively correlated to the MEI. The SC mean precipitation was 200 mm smaller than the other two sectors, and this part of the coast also showed the greatest number of precipitation anomalies, a large part of which were PP- (67%).

It was possible to quantify the majority of anomalous PP- events as either related simultaneously to SAM+ and MEI-, or related only to MEI+. There were few PP+ events (all related to a MEI+), and of those few, some were accompanied by SAM-. Thus, the PP- events were more common (78%), but every PP+ event was related to an MEI+.

The geoindicators for the SC and CC presented clear hydrological variations in all images under PP+ and PP- conditions. The NC did not show the same relationship, probably because the precipitation anomalies were not correlated to the SAM or the MEI variability. This precipitation above the mean could instead be explained by recurring orographic precipitation (Viana, 2009).

Both the CC and the SC showed during the study period (1998–2013) a trend for decreasing mean annual precipitation. The two regions also had the PP negatively correlated to the SAM. The greater the number of PP- events found in these two areas, the greater the frequency of SAM+ periods, attributed to global climate change, for example, the depletion of the Antarctic ozone layer (Thompson and Wallace 2000; Thompson and Solomon 2002; Gupta and England, 2006). The greater number of drought periods at the Hermenegildo Beach, related to SAM+, MEI+, and MEI- can intensify the shoreline erosion as washouts dry up and stop transporting sediment toward the beach.

The increase in PP- events in the Hermenegildo beach region would increase the eolic erosion, reducing the vegetal cover and sediment transport to the backshore and shoreface by washouts. In the CC, the silting of the PL would accelerate.

The greater occurrence of PP- events in the RGSCP can be interpreted as one of the severe consequences of the SAM+ and ENSO intensifications.

Acknowledgments: The authors thank the Brazilian National Council for Scientific and Technological Development (CNPq) and the Brazilian National Institute of Science and Technology of the Cryosphere (INCT da Criosfera) for technical and financial support.

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