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MORPHO-STATISTICAL CHARACTERIZATION OF EMBAYED BEACHES AND THEORETICAL INFERENCE OF MEGA-RIP CURRENT POTENTIAL ALONG THE COAST OF SANTA CATARINA, BRAZIL

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ABSTRACT

This study characterizes the morphometric configuration of embayed beaches along the coast of the state of Santa Catarina, southern Brazil, and offers a theoretical assessment of rip current potential based on the degree of coastal confinement. A total of 74 embayments were analyzed using the embayment scale parameter (δ′), which combines shoreline length, bay width, and wave breaking height to quantify the topographic control on coastal circulation. High δ′ values correspond to morphologically exposed beaches with diffuse circulation, whereas low δ′ values correspond to highly embayed beaches with a greater likelihood of developing topographically controlled rip cells. Principal Component Regression (PCR) confirmed that δ′ effectively represents the morphometric gradient and differentiates the three dominant circulation regimes — normal, transitional, and cellular – along the northern, central, and southern coastal segments. The analysis also revealed regional contrasts, with a higher concentration of highly embayed beaches in the central and southern portions of the coast, particularly around Santa Catarina Island. The results reinforce the role of coastal morphology in shaping circulation patterns and provide a quantitative basis for identifying embayments with greater theoretical susceptibility to mega-rip formation. The proposed methodology represents a practical, low-cost tool to support coastal zoning and risk management in morphodynamically diverse environments.

Keywords: Embayed Beaches. Beach Morphodynamics. Rip Current. Brazilian beaches. Mega Rip. Santa Catarina coast.

1 Introduction

Embayed beaches, or pocket beaches, are bounded by rocky headlands that shape their morphology and control wave energy dissipation. This configuration produces well-defined curvatures resulting from the interactions between coastal topography, sediment supply, and local hydrodynamics (Jackson et al., 2005; Klein et al., 2010). Such environments are common along medium to high-energy rocky coasts and play a crucial role in modulating coastal circulation and shoreline stability (Short & Masselink, 1999; Klein et al., 2010).

Topographic confinement modulates wave refraction, diffraction, and reflection, generating complex coastal circulation patterns. Among these, rip currents represent the primary mechanism for draining incident flow across the surf zone, with their intensity and shape varying according to the degree of embayment (Short & Masselink, 1999; Klein et al., 2020). In general, more open beaches tend to exhibit less confined longshore circulation, whereas highly embayed beaches display cellular flow structures and more complex recirculation zones (Castelle & Coco, 2012; Loureiro et al., 2012). Under high-energy conditions, these systems can generate mega-rip currents capable of extending over 1 km offshore and inducing intense sediment transport (Martens et al., 1999; Thornton et al., 2007).

In the state of Santa Catarina, southern Brazil, where the coastline alternates between straight segments and deeply embayed stretches, rip currents are associated with more than 90% of drowning incidents (Klein et al., 2005; Mocellin et al., 2007). Despite this, the influence of embayment on the spatial variability of these circulation patterns remains poorly quantified at a regional scale. Existing studies are mostly local or observational analyses that do not explore the geomorphological role of embayments as a controlling factor of coastal circulation. Furthermore, although there are specific studies on rip currents in Santa Catarina, no statewide assessments have yet characterized the theoretical potential for mega-rip occurrence on embayed beaches.

Therefore, this study aims to characterize the morphology and degree of embayment of Santa Catarina's beaches and theoretically assess the potential for mega-rip currents across different geomorphological contexts. The approach focuses on morphometric and statistical analyses of 74 embayed beaches distributed across the three main coastal sectors – northern, central, and southern, to identify patterns associated with topography and wave conditions. The results are intended to improve understanding of the geomorphological factors controlling mega-rip formation and to support safety strategies, coastal risk zoning, and monitoring initiatives for embayed beaches in Santa Catarina.

2 Material and Methods

2.1 Study Area

The study encompasses 74 embayed beaches distributed along the entire coastline of Santa Catarina (SC), Brazil (Fig. 1), representing the three main coastal sectors within the state. These beaches were selected because they exhibit different degrees of embayment and wave exposure orientations, forming a diverse set of morphodynamic conditions ranging from dissipative systems to reflective and intermediate beaches (Klein, 2004; Oliveira et al., 2014).

The Santa Catarina coastline shows significant morphological variability, and is commonly subdivided into coastal compartments. In this study, the compartmentalization proposed by Klein et al. (2016) was adopted, which defines three main sectors: northern, central, and southern, based on geological and morphodynamic characteristics. The northern sector includes more exposed and straight beaches developed over sedimentary plains; the central sector is characterized by embayments bounded by rocky headlands, particularly around Santa Catarina Island; and the southern sector comprises extensive sandy barriers interspersed with widely spaced headlands and active dune systems. This division reflects the main morphodynamic contrasts along the Santa Catarina coast and was used as the spatial framework for the comparative analysis of the studied beaches.

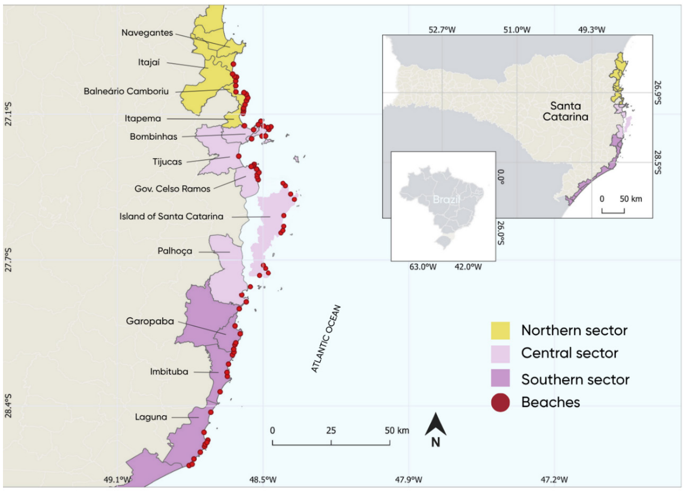

Figure 1. Study area showing the main coastal segments of Santa Catarina, Brazil, and the analyzed beaches.

This geomorphological diversity makes Santa Catarina an ideal setting for comparative analyses across different degrees of embayment, allowing the assessment of how variations in coastal configuration influence circulation patterns.

The studied beaches are predominantly oriented toward the east and southeast and are subject to a microtidal regime, with an average tidal range of 0.8 m and peaks reaching up to 1.2 m (Stech & Lorenzetti, 1992). The coast receives both short, low-energy sea waves (Hs < 1 m) and longer, higher-energy swell waves (Hs > 1.5 m), mainly from the southern and southeastern quadrants (Alves & Melo, 2001). These conditions, combined with the topographic control of the embayments, result in high morphodynamic variability along the state's coastline.

2.2 Embayment Scaling Parameter

The circulation pattern on embayed beaches was evaluated using the embayment scaling parameter (δ′), proposed by Martens et al. (1999). This parameter relates the geomorphological configuration of the embayment to the incident wave conditions in the surf zone, as expressed by the equation:

$$\delta' = S_l^2/100 \cdot C_l \cdot H_b \quad (1)$$

where S_l represents the shoreline length of the embayment (m), C_l the distance between the headlands (m), and H_b the mean wave breaking height in the surf zone (m) (Fig. 2).

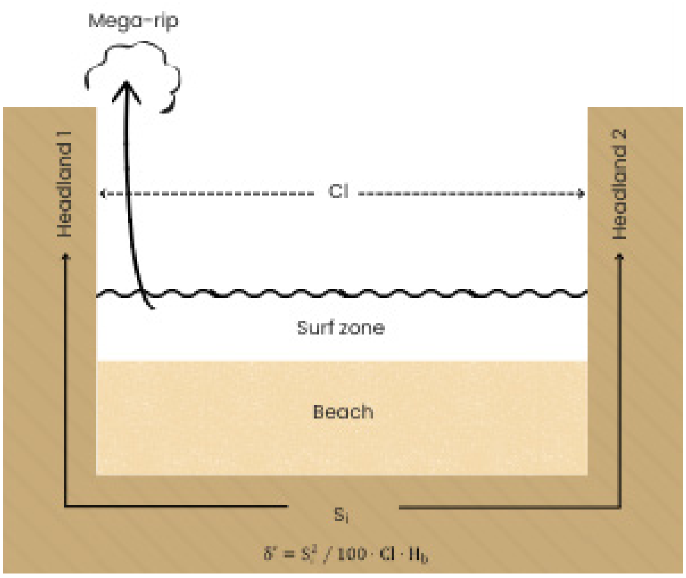

Figure 2. Schematic diagram showing the definition of the parameters used to calculate the non-dimensional scaling parameter. Modified from Short (1999).

The parameter δ′ expresses the degree of morphological control exerted by headlands on coastal circulation patterns, allowing the identification of three characteristic regimes (Short, 1999):

δ′ > 19: *Normal circulation*, similar to open beaches, with little or no topographic influence.

8 ≤ δ′ ≤ 19: *Transitional circulation*, with moderate influence from headlands.

δ′ < 8: *Cellular or topographically controlled circulation*, in which hydrodynamic processes are strongly conditioned by coastal morphology and may favor the development of mega-rip currents under high-energy conditions.

The values of S_l and C_l were obtained from the morphometric classification proposed by Kuhnen (2021). The author analyzed 90 embayed beaches along the Santa Catarina coast, vectorially delineating headlands, indentations, and embayment areas. The beaches were grouped into three geomorphological classes according to the embayment parameter (γ_e), which is a function of the embayment setback (*a*) and the total embayment area (A_e):

Class I: more exposed beaches, with larger areas and smaller setback.

Class II: intermediate beaches, with moderate influence from headlands.

Class III: highly embayed beaches, with greater setbacks and smaller areas, more sheltered from coastal hydrodynamics.

In the present study, 74 beaches from that database were selected, maintaining consistency with the original variables and standardizing the extraction of geometric parameters according to the same methodological criteria. This classification served as a reference for the comparative analysis of the δ′ values obtained for each embayment type.

The H_b values were derived from regional estimates by Short & Klein (2016), who characterized Brazilian beach systems based on buoy records and numerical wave propagation modeling. The significant wave heights in deep water (H_s were adjusted according to beach orientation and degree of embayment, considering the effects of refraction, diffraction, and wave energy dissipation along the beach arc.

Although the values used were derived from previous studies, all were obtained through methodologies compatible in both scale and approach, ensuring comparability across the analyzed beaches. The integration of morphometric and hydrodynamic datasets enabled the consistent and regionally standardized application of the δ′ parameter. The use of secondary data sources is justified by the lack of continuous, in situ time series for all Santa Catarina beaches, and δ′ is widely recognized as a robust theoretical indicator for assessing the degree of morphodynamic confinement on embayed beaches (Short, 1999; Fellowes et al., 2019). Accordingly, the results presented here reflect a comparative, theory-based characterization rather than the direct measurement of coastal circulation processes.

2.3 Statistical Analyses

The relationships between geomorphological parameters and the theoretical circulation behavior were analyzed using Principal Component Regression (PCR), with the aim of identifying which variables explain the variation in the embayment scaling parameter (δ′). This approach enables an integrated assessment how morphometric variables influence the theoretical hydrodynamic configuration of the beaches, while minimizing collinearity among predictors.

The independent variables included shoreline length of the embayment (S_l), the distance between headlands (C_l), the embayment parameter (γ_e), and the geomorphological class (I, II, III). The dependent variable was the δ′ value calculated for each of the 74 beaches.

Prior to the analysis, all the continuous variables were standardized using the z-score method to ensure scale homogeneity. Principal components were extracted from the correlation matrix of the independent variables. The first two axes accounted for approximately 85% of the total variance, representing the morphometric gradient from open to highly embayed beaches.

Given that δ′ is a direct function of morphometric variables, complementary analyses were conducted to: (i) examine the relationship between δ′ and circulation type (normal, transitional, and cellular); (ii) evaluate the influence of embayment size and degree of confinement on δ′; and (iii) identify the spatial distribution of circulation patterns across the three coastal sectors of the state (northern, central, and southern).

These integrated steps enabled quantitative characterization of regional trends along the Santa Catarina coast, highlighting the variables that most strongly influence the degree of embayment and, consequently, the theoretical potential for mega-rip current formation.

3 Results

Classification of the 74 beaches (Appendices A) revealed a predominance of the normal circulation pattern (≈47%), followed by the cellular (≈39%) and transitional (≈14%) patterns.

PCR results (Fig. 3) indicated that the first principal component (PC1) represents the dominant morphometric gradient from open to highly embayed beaches, reflecting a progressive increase in δ′ values toward more exposed beach configurations. This axis synthesizes the relationships between the geometric variables, embayment length (S_i), headland spacing (C_l), and degree of embayment ($γ_e$), and demonstrates that greater morphological exposure is directly associated with higher δ′ values.

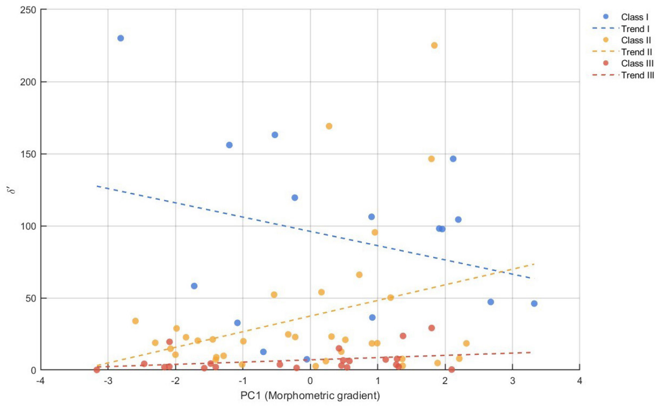

Figure 3. Relationship between the nondimensional embayment parameter (δ′) and the first principal component (PC1) by morphometric class, with linear trend lines.

The distribution of δ′ along PC1 reveals distinct behavior among morphometric classes: Class II beaches exhibit the strongest positive relationship between δ′ and PC1, suggesting that intermediate embayments are the most sensitive to changes in exposure. Class I beaches (open systems) maintain high δ′ values with only slight variation toward more open morphologies, whereas Class III beaches (highly embayed) remain nearly constant with very low δ′ values, indicating lower hydrodynamic energy and reduced circulation cell size.

To assess whether the observed differences in δ′ among circulation types were statistically significant, a one-way Analysis of Variance (ANOVA) was performed. The test indicated a significant difference between groups ($F = 23.21$; $p < 0.001$), confirming that the mean δ′ values vary consistently among the cellular, transitional, and normal circulation patterns. Although expected, this result provides statistical support for the theoretical classification proposed by Short (1999), reinforcing the relationship between the δ′ parameter and the observed coastal circulation regimes.

To determine whether this theoretical trend is reflected in the actual circulation patterns, a cross-analysis was conducted between circulation type and morphometric class (Fig. 4). It was observed that strongly embayed beaches (Class III) concentrate nearly all cases of cellular circulation, whereas open beaches (Class I) predominantly exhibit normal circulation. However, a single occurrence of cellular circulation was recorded on a Class I beach, suggesting that hydrodynamic conditions and headland positioning may generate rip cells even in morphologically open systems. These results reinforce that, although geomorphological confinement is a key factor in the formation of mega-rips, it does not act in isolation, as local morphodynamic factors also contribute.

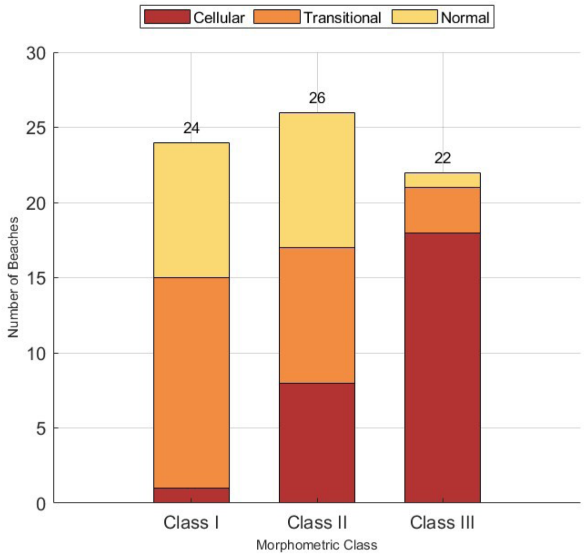

Figure 4. Distribution of circulation types by morphometric class. Distribution of circulation types (δ′) by morphometric beach class in Santa Catarina. Strongly embayed beaches (Class III) are mostly associated with cellular circulation, while open beaches (Class I) predominantly exhibit normal circulation. Transitional patterns occur mainly in intermediate embayments (Class II).

The distribution of circulation types along the coastal segments reveals a latitudinal gradient in confinement (Fig. 5). The northern sector concentrates most of the beaches with normal circulation, associated with more extensive and exposed beach systems. In the central and southern sectors, cellular circulation predominates, reflecting the increased degree of embayment and the topographic control exerted by coastal headlands. In the central sector, four beaches located within small bays exhibit predominantly cellular circulation, confirming the theoretical relationship between smaller embayments and a greater tendency toward hydrodynamic confinement.

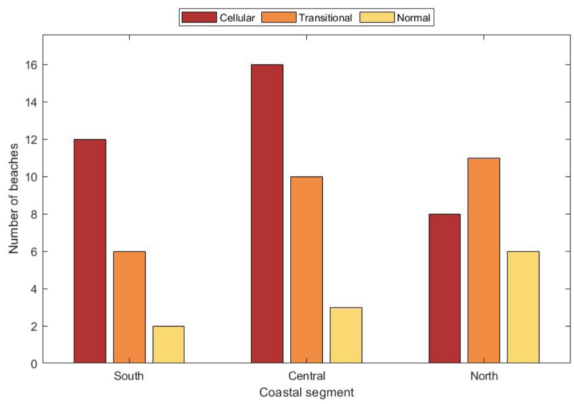

Figure 5. Comparison between circulation types by coastal segment.

4 Discussion

The first principal component (PC1) synthesized the morphometric gradient between open and highly embayed beaches, reflecting the dominant role of topographic confinement in modulating circulation patterns. Beaches with higher δ′ values generally correspond to more exposed systems, with less lateral influence from headlands and greater surf-zone development, consistent with the classification proposed by Martens et al. (1999). This behavior aligns with the classical theory of beach morphodynamics, according to which incident wave energy and the effective length of the embayment control the type and scale of rip currents (Short & Wright, 1983; Lippmann & Holman, 1990; Masselink & Hughes, 2003).

The positive relationship between δ′ and PC1 confirms that morphology exerts a primary control over the type of circulation, reflecting a theoretical trend of increasing potential for mega-rip occurrence as a function of geomorphological configuration. Highly embayed beaches (δ′ < 8) show greater propensity for lateral flow concentration and the formation of localized rip cells, whereas open beaches favor more diffuse circulation patterns. This transition between states has been described in several studies on embayments (Brander & Short, 2000; Castelle et al., 2014), which indicate that the topographic control exerted by headlands determines both the direction and extent of rip cells.

The results obtained are also consistent with the trends described by Loureiro et al. (2012) and Wahyudi et al. (2024), who analyzed high-energy embayed beaches in Portugal and Indonesia, respectively. Loureiro et al. (2012) observed that low δ′ values correspond to the presence of persistent mega-rips controlled by the topography of headlands, whereas Wahyudi et al. (2024) reported δ′ values between 4 and 6 in narrow embayments associated with structural rip currents. Although the present study did not include hydrodynamic measurements, the identified morphometric patterns indicate that Santa Catarina beaches with low δ′ values (Class III) share geomorphological characteristics conducive to the theoretical development of mega-rips under high-energy wave conditions.

On the other hand, the occurrence of cellular circulation on some more open beaches (Class I) demonstrates that morphological confinement, although a determining factor, is not the sole controlling mechanism. Shoreline orientation, wave incidence angle, and local variations in surf-zone depth may generate temporary convergence zones and topographically induced rip cells even in less embayed systems. This variability reinforces the need to interpret δ′ as a probabilistic rather than a deterministic geomorphological indicator, whose applicability depends on the energetic and morphodynamic context of each beach.

The distribution of circulation types across the different coastal sectors reveals marked regional contrasts along the Santa Catarina coast. The northern sector shows a predominance of beaches with normal circulation and high δ′ values, reflecting its more open morphology and direct exposure to east–northeast wave directions. In contrast, the central and southern sectors show a higher frequency of cellular and transitional beaches, associated with smaller embayments bounded by granitic headlands.

In the central sector, this trend is reinforced by the presence of Santa Catarina Island, whose complex geological configuration and fragmented coastline promote the formation of short, sheltered embayments. The four bays identified in this segment (all within the same municipality) exhibit low δ′ values, three classified as cellular and one as transitional. This predominance of highly embayed morphologies on the island explains the observed pattern, where circulation tends to be more compartmentalized and locally controlled. The southern sector, although also featuring several cellular beaches, differs by its long, straight sandy barriers separated by widely spaced headlands. This configuration of alternating open and embayed systems results in a spatial alternation of patterns, with intermediate beaches combining features from both morphodynamic extremes.

According to Klein et al. (2005), approximately 82% of drownings in Santa Catarina are associated with moderate to strong rip currents near headlands. The authors note that such incidents occur more frequently on embayed beaches in the central and northern regions, precisely those where this study identified the lowest δ′ values (<8) underscoring the existence of a high theoretical risk in these sectors. Although Klein et al. (2005) did not analyze circulation in detail, the morphometric patterns observed here suggest that part of these incidents may be related to mega-rip currents induced by embayment confinement.

High-energy or oblique wave conditions tend to amplify this risk by increasing lateral flow concentration and rip-cell intensity (Castelle & Coco, 2012). Furthermore, studies such as Loureiro et al. (2012) and McCarroll et al. (2016) indicate that smaller embayments favor more persistent rip currents, which may help to explain the high number of drowning incidents recorded on highly embayed beaches along the Santa Catarina coast.

The mean breaking wave height (H_b = 0.79 m) estimated for the embayments indicates a moderate energy regime, typical of average swell conditions. This suggests that most of the analyzed beaches remain under stable circulation patterns, with δ′ effectively representing their characteristic behavior. However, higher-energy events, especially those under oblique wave incidence, may temporarily alter surf-zone three-dimensionality and modify circulation patterns, causing transitional beaches (8 ≤ δ′ ≤ 19) to behave similarly to more highly embayed systems. As demonstrated by Loureiro et al. (2012), these transitions occur when increased incident energy intensifies flow return, favoring the formation of mega-rips even in intermediate embayments.

These regional differences suggest that, in addition to local control exerted by morphological confinement, structural, geological, and hydrodynamic factors also influence the potential for mega-rip occurrence on a statewide scale. In the north, greater exposure and shoreline continuity limit the formation of fixed rip cells, whereas in the central and southern sectors, where highly embayed beaches predominate, the geomorphological conditions are more favorable to the generation of topographically controlled rip currents.

Representative examples of these three regimes can be observed in the beaches illustrated in figure 6. Moçambique and Armação (Santa Catarina Island) and Rosa (Imbituba) beaches represent open systems with normal circulation and high δ′ values, typical of exposed environments. Matadeiro (Santa Catarina Island, Barra (Garopaba), and Prainha (Palhoça) beaches exhibit intermediate configurations, characterizing transitional circulation. Sissial, Ouvidor, and Galheta (Garopaba) beaches correspond to strongly embayed systems, where morphological confinement favors cellular circulation patterns and a higher potential for mega-rip formation.

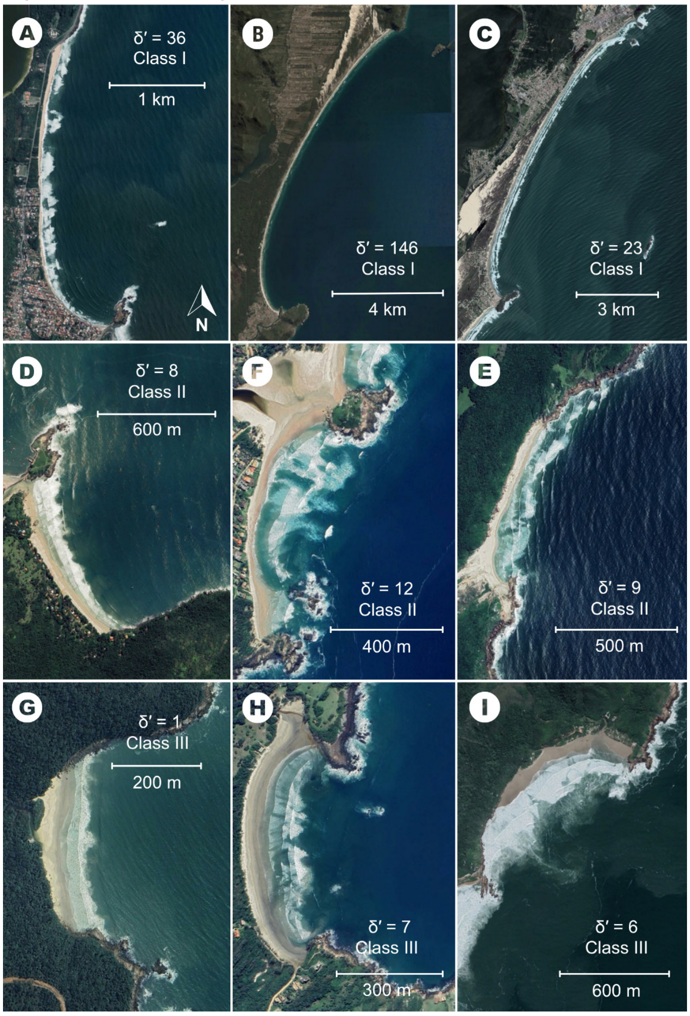

Figure 6. Representative embayments from the three morphometric classes in Santa Catarina. (A–C) Class I – Normal circulation; (D–F) Class II – Transitional circulation; (G–I) Class III – Cellular circulation. Praia da Armação (A - Santa Catarina Island); Moçambique (B - Santa Catarina Island); Praia do Rosa (C - Imbituba); Matadeiro (D - Santa Catarina Island); Praia da Barra (E - Garopaba); Prainha (F - Palhoça); Praia do Sissial (G - Garopaba); Ouvidor (H - Garopaba); Galheta (I - Garopaba). Image source: Google Earth.

Although the results demonstrate patterns consistent with previous studies, it is important to acknowledge the inherent limitations of using secondary data and the absence of in situ measurements. The use of parameters derived from morphometric datasets and regional modeling introduces uncertainties related to data scale and resolution, which may underestimate local variations in energy and circulation. Nevertheless, the consistency of the observed patterns indicates that δ′ is a robust theoretical indicator capable of representing geomorphological control over the potential for rip current formation at a regional scale. Future studies integrating hydrodynamic monitoring and field observations will allow validation of the trends identified here and improve the understanding of the mechanisms that govern mega-rip formation on embayed beaches.

5 Conclusion

The degree of embayment (δ′) constitutes an effective morphometric indicator for theoretically inferring the potential occurrence of mega-rip currents on embayed beaches. The analysis applied to 74 beaches in Santa Catarina revealed a clear gradient between open and highly embayed systems, in which δ′ increases proportionally with morphological exposure and the dissipation of incident energy. This behavior reflects the topographic control exerted by headlands on coastal circulation, showing that strongly embayed beaches have a greater tendency toward the formation of localized rip cells.

The results revealed consistent regional patterns, with a predominance of normal circulation along the northern coast and cellular circulation in the central and southern regions, which are more favorable to the formation of mega-rip currents. This distribution reflects the contrast between open systems and short, highly embayed beaches, particularly around Santa Catarina Island, but also regulates the potential for mega-rip formation, making the central and southern sectors key areas for coastal risk management in the state. These findings reinforce the role of morphology as a primary control of circulation processes and provide a basis for identifying coastal zones potentially more susceptible to mega-rip formation.

From an applied perspective, the proposed approach contributes to improving coastal safety and risk management by offering a quantitative and low-cost method for mapping beaches with greater hydrodynamic vulnerability. The results can also support public policies aimed at better planning of recreational beach use and the placement of warning signs, particularly in highly embayed beaches with δ′ < 8.

It is recognized, however, that inferences based solely on geomorphological parameters do not replace direct field measurements. Factors such as wave direction and energy, seasonal variability, and anthropogenic interventions may significantly alter local circulation. Future research integrating hydrodynamic measurements and numerical modeling will allow validation of the theoretical relationship proposed here between δ′ and the potential for mega-rip formation, establishing this parameter as an operational tool for risk assessment and morphodynamic characterization of embayed beaches.

References

Alves, J.H.G.M., Melo, E. 1999. On the Measurement of Directional Wave Spectra at the Southern Brazilian Coast. Applied Ocean. Res., 21(6), 295–309.

Alves, J.H.G.M., Melo, E. 2001. Wind Waves at the Northern Coast of Santa Catarina. Rev. Bras. Oceanogr., 49(1/2), 13–28.

Bruno Castelle, Giovanni Coco. 2012. The morphodynamics of rip channels on embayed beaches. Continental Shelf Research, 43, 10–23.

Castelle, B., Marieu, V., Bujan, S., Splinter, K.D., Robinet, A., Sénéchal, N., Ferreira, S. 2015. Impact of the winter 2013–2014 series of severe Western Europe storms on a double-barred sandy coast: Beach and dune erosion and megacusp embayments. Geomorphology, 238, 135–148.

Castelle, B., McCarroll, R.J., Brander, R.W., Scott, T., Dubarbier, B. 2016. Modelling the alongshore variability of optimum rip current escape strategies on a multiple rip-channelled beach. Natural Hazards, 81, 664–686.

Fellowes, T. E., Vila-Concejo, A., Gallop, S. L. 2019. Morphometric classification of swell-dominated embayed beaches. Marine Geology, 411, 78–87.

FitzGerald, D.M., Cleary, W.J., Buynevich, I.V., Hein, C.J., Klein, A.H.F., Asp, N.E., Angulo, R.J. 2007. Strand plain evolution along the southern coast of Santa Catarina, Brazil. Journal of Coastal Research, SI 50, 152–156.

Jackson, D.W.T., Cooper, J.A.G., Rio, L. 2005. Geological control of beach morphodynamic state. Marine Geology, 216(4), 297–314.

Klein, A. H. F. 2004. Morphodynamics of Headland Bay Beaches: Examples from the coast of Santa Catarina State, Brazil. Doctorate Thesis – Universidade do Algarve, 257p.

Klein, A. H. F., Mocellin, O., Menezes, J.T., Berribilli, M., Vintém, G., Dafferner, G., Dhiel, F.L., Sperb, R. M., Santana, G. 2005. Beach Safety Management on the Coast of Santa Catarina, Brazil. Zeitschrift für Geomorphologie. Supplementband, 141, 47–58.

Klein, A.H.F., Freitas, D., Araújo, R.S., Menezes, J.T. 2010. Quantification of coastal hazards and projection of future shoreline positions for the Itapocorói embayment – SC [in Portuguese]. Brazilian Journal of Aquatic Science and Technology, 14, 39–49.

Klein, A. H.F., Silva, G. da V., Taborda, R., Silva, A.P., Short, A. D. Headland bypassing and overpassing: form, processes and applications, Editor(s): Derek W.T. Jackson, Andrew D. Short. Sandy Beach Morphodynamics. Elsevier, 23, 557-591p.

Kuhnen, V. H. de M. 2021. Morphometric classification of embayed beaches of Santa Catarina State, Brazil [in Portuguese]. Undergraduate Thesis, Universidade Federal de Santa Catarina, Centro de Ciências Físicas e Matemáticas, Florianópolis, 64p.

Leatherman, S. P. 2013. Rip Currents. In: Finkl, C. (ed.) Coastal Hazards. Coastal Research Library, vol. 1000. Springer, Dordrecht.

Loureiro, C., Ferreira, O., Cooper, J.A.G. 2012. Extreme erosion on high energy embayed beaches: Influence of megarips and storm grouping. Geomorphology, 139–140, 155–171.

Maia, J., Pereira, P., Lessa, R. 2014. Spatio-temporal variation of rip currents in municipalities of the metropolitan region of Recife [in Portuguese]. Quaternary and Environmental Geosciences, 5(2), 166–176.

Martens, D., Williams, T., Cowell, P.J. 1999. Mega-rip dimensional analysis on the Sydney coast, Australia, and implications for beach-state recognition and prediction. Journal of Coastal Research, 17, 34–42.

McCarroll, R. J., Brander, R. W., Turner, I. L., Van Leeuwen, B. 2016. Shoreface storm morphodynamics and mega-rip evolution at an embayed beach: Bondi Beach, NSW, Australia. Continental Shelf Research, 116, 74–88.

Mocellin, O., Klein, A. H. F., Santos, J.R. 2007. Determination of the public bathing risk level on sandy beaches of the central-northern coast of Santa Catarina [in Portuguese]. In XII Latin American Congress of Marine Sciences (XII COLACMAR), Florianópolis, 2007. p. 445.

Oliveira, U.R., Barletta, R.C., Horn Filho, N.O. 2014. Geosciences Research [in Portuguese]. Pesquisas em Geociências, 41(2), 89–103.

Parsons, T.R., Takahashi, M., Hargrave, B. 1984. Biological oceanographic process. 3ª ed. Pergamon Press, Oxford, 330p.

Short, A.D. 1985. Rip current type, spacing and persistence, Narrabeen Beach, Australia. Marine Geology, 65, 47–71.

Short, A.D. 1999. Handbook of Beach and Shoreface Morphodynamics. John Wiley and Sons, 379p.

Short, A. D., Klein, A. H. da F. 2016. Brazilian beach systems. Springer - Coastal Research Library, 74.

Sonu, C. J. 1972. Field observation of nearshore circulation and meandering currents. Journal of Geophysical Research, 77(18), 3232–3247.

Stech, J.L., Lorenzzetti, J.A. 1992. The Response of the South Brazil Bight to the Passage of Wintertime Cold Fronts. Journal of Geophysical Research, 97, 9507–9520.

Thornton, E.B., Sallenger, A.H., MacMahan, J.H. 2007. Rip currents, cuspate shorelines and eroding dunes. Marine Geology, 240, 151–167.

Tomazzoli, E. R., Pellerin, J. R. G. M., Horn, N. O. F. 2018. Geology of Santa Catarina Island, Santa Catarina, Brazil [in Portuguese]. Geociências, v. 37, n. 4, 715–731.

Trucollo, E.C. 1998. Meteorological tide and local atmospheric forcing in São Francisco do Sul – SC [in Portuguese]. Master's Dissertation, Programa de Pós-graduação em Engenharia Sanitária e Ambiental, Universidade Federal de Santa Catarina, 100p.

Wahyudi, V.K.T., Mulyadi, Y., Armono, H.D., Sambodho, K., Sembiring, L.E., Nguyen, T.V. 2024. Morphometric analysis of embayed beaches for identification of rip current hazard potential: A case study from southern Java, Indonesia. IOP Conference Series: Earth and Environmental Science, 1298, 012035.

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

10.14210/bjast.v28n2.20725

Appendices A. List of analyzed beaches, respective municipalities, embayment parameter (δ′), morphometric class and circulation type.

Beach	Municipality	Segment	Embayment parameter (δ′)	Morphometric class	Circulation type
Praia Grande	Laguna	South	46.1	I	Normal
Praia da Galheta	Laguna	South	47.2	I	Normal
Praia Teresa	Laguna	South	3.7	III	Cellular
Praia do Manelome	Laguna	South	12.6	I	Transitional
Praia do Gravatá	Laguna	South	7.3	III	Cellular
Praia do Tamborete	Laguna	South	3.1	III	Cellular
Praia do Mar Grosso	Laguna	South	97.7	I	Normal
Praia do Sol	Laguna	South	104.3	I	Normal
Praia de Itapirubá	Imbituba	South	7.4	I	Cellular
Praia do Porto	Imbituba	South	225.1	II	Normal
Praia D'água	Imbituba	South	23.6	III	Normal
Ribanceira	Imbituba	South	230.1	I	Normal
Praia do Rosa	Imbituba	South	23.2	II	Normal
Praia Vermelha	Imbituba	South	2.3	III	Cellular
Praia do Ouvidor	Garopaba	South	7.7	III	Cellular
Praia da Barra	Garopaba	South	12.7	II	Transitional
Ferrugem	Garopaba	South	20.4	II	Normal
Silveira	Garopaba	South	22.9	II	Normal
Siriú	Garopaba	South	156.0	I	Normal
Gamboa	Garopaba	South	106.2	I	Normal
Prainha	Palhoça	Central	9.8	II	Transitional
Pinheira	Palhoça	Central	146.4	II	Normal
Naufragados	SC Island	Central	29.2	III	Normal
Açores	SC Island	Central	52.3	II	Normal
Lagoinha do Leste	SC Island	Central	19.9	II	Normal
Matadeiro	SC Island	Central	8.9	II	Transitional
Armação	SC Island	Central	36.4	I	Normal
Mole	SC Island	Central	54.0	II	Normal
Galheta	SC Island	Central	6.2	II	Cellular
Moçambique	SC Island	Central	146.4	I	Normal
Santinho	SC Island	Central	21.2	II	Normal
Ingleses	SC Island	Central	66.0	II	Normal
Praia Brava	SC Island	Central	50.2	II	Normal
Ponta das Canas	SC Island	Central	4.8	II	Cellular
Prainha da Ilha de Anhatomirim	Gov. Celso Ramos	Central	0.3	III	Cellular
Camboa	Gov. Celso Ramos	Central	18.6	II	Transitional
Praia das Cordas	Gov. Celso Ramos	Central	34.0	II	Normal
Praia do Sissial	Gov. Celso Ramos	Central	1.8	III	Cellular
Praia das Palmas	Gov. Celso Ramos	Central	32.7	I	Normal
Gancho de Fora	Gov. Celso Ramos	Central	1.3	III	Cellular
Gancho do Meio	Gov. Celso Ramos	Central	19.5	III	Normal
Tijucas	Tijucas	Central	285.9	III	Normal
Praia Triste	Bombinhas	Central	1.5	III	Cellular
Quatro Ilhas	Bombinhas	Central	22.7	II	Normal
Retiro dos Padres	Bombinhas	Central	4.3	III	Cellular
Praia de Bombinhas	Bombinhas	Central	7.7	II	Cellular
Praia de Bombas	Bombinhas	Central	28.9	II	Normal
Araçá	Porto Belo	North	2.3	III	Cellular
Praia Grossa	Itapema	North	3.8	II	Cellular
Praia da Ilhota sul	Itapema	North	21.0	II	Normal
Praia da Ilhota Norte	Itapema	North	6.7	III	Cellular
Estaleirinho	Balneário Camboriú	North	18.9	II	Transitional
Estaleiro	Balneário Camboriú	North	24.7	II	Normal
Praia do Pinho	Balneário Camboriú	North	2.7	II	Cellular
Praia de Taquaras	Balneário Camboriú	North	18.4	II	Transitional
Praia das Laranjeiras	Balneário Camboriú	North	3.8	III	Cellular
Praia Central	Balneário Camboriú	North	95.4	II	Normal
Praia do Buraco	Balneário Camboriú	North	14.8	II	Transitional
Praia Brava	Itajaí	North	58.3	I	Normal
Praia da Solidão	Itajaí	North	2.0	III	Cellular
Praia do Morcego	Itajaí	North	7.1	II	Cellular
Praia do Atalaia	Itajaí	North	15.0	III	Transitional
Meia Praia	Navegantes	North	98.1	I	Normal
Praia de São Miguel	Penha	North	6.3	III	Cellular
Galhetinha	Penha	North	0.1	III	Cellular
Praia Vermelha	Penha	North	2.9	II	Cellular
Praia do Monge	Penha	North	7.9	II	Cellular
Praia do Poá	Penha	North	18.5	II	Transitional
Praia do Quilombo	Penha	North	169.1	II	Normal
Praia do Alegre	Penha	North	10.6	II	Transitional
Praia de Piçarras	Balneário Piçarras	North	163.1	I	Normal
Ubatuba	Blumenau	North	119.5	I	Normal
Praia da Figueira	Gov. Celso Ramos	Central	2.0	III	Cellular
Armação da Piedade	Gov. Celso Ramos	Central	4.5	III	Cellular