Journal of Coastal Research	SI 39	390 - 394	ICS 2004 (Proceedings)	Brazil	ISSN 0749-0208

Coastal Dunes and Shoreface Width as a Function of Longshore Transport.

E.E. Toldo Jr.†; J.L. Nicolodi ‡; L.E.S.B. Almeida ∞; I.C.S. Corrêa† and L.S. Esteves‡

† Center of Coastal and Geologic Oceanic Studies,
Federal University of Rio Grande do Sul,
Porto Alegre, RS,
91509-900, Brazil
toldo@vortex.ufrgs.br

‡ Geocience Post-Graduated Course,
Federal University of Rio Grande do Sul,
Porto Alegre, RS,
91509-900, Brazil.
jl.nicolodi@zipmail.com.br,
lsestev@terra.com.br

∞ Hydraulic Research Institute,
Federal University of Rio Grande do Sul,
Porto Alegre, RS,
91509-900, Brazil
luiz.almeida@ufrgs.br

ABSTRACT

TOLDO Jr., E. E.; NICOLODI, J. L.; ALMEIDA, L. E. S. B.; CORRÊA, I. C. S. and ESTEVES, L. S., 2006. Coastal dunes and shoreface width as a function of Longshore transport. Journal of Coastal Research, SI 39 (Proceedings of the 8th International Coastal Symposium), 390 - 394. Itajaí, SC, Brazil, ISSN 0749-0208.

Zones of erosion and accretion were delimited by comparing a DGPS shoreline mapping in 1997 and the beach line reproduced from the army chart collection of 1975. The results show extensive shore retreat along of Rio Grande do Sul central coast, while accretion was observed in Mostardas and Dunas Altas beach. Mathematical estimative of the regional longshore transport potential along the Rio Grande do Sul coast, a 630-km long holocenic fine sand barrier, resulted in a large net northward annual sand volume. Additionally, the estimated potential of sediment transport based on the CERC formula predicts a substantial variation of the energy flux into the surf zone, due to little changes in shoreline alignments and in the potential alongshore sediment transport. The reduction in the sediment flux due to changes in the shoreline alignment produce a jam in the longshore transport, meaning that part of the sediment arriving from the upstream stretch may be deposited or diverted offshore. Based on that, it is possible that changes in the net longshore sand transport are responsible for the increase in the shoreface width from less than 1 km to more than 3 km in Mostardas beach and Dunas Altas beach. Interesting to note that wider dune fields are associated to those beaches where shoreface is also wider. In this way, the volume of longshore sand transport and the sediment jam provide by changes on shoreline alignment in Mostardas and Dunas Altas beaches are important for both coastal dune fields and shoreface width.

ADDITIONAL INDEX WORDS: *Southern Brazil, shoreline erosion, coastal jet.*

INTRODUCTION

In this work *coastal dune field width* and *shoreface width* refer to volumetric changes in the subaerial and submarine beach. This paper focuses the beach system enlargement along of Mostardas and Dunas Altas beach in central coast of Rio Grande do Sul, Brazil.

On all types of sandy or unconsolidate coasts, beach deposition or erosion can be considered to be controlled by a dynamic equilibrium involving three major components (DAVIS, 1997): amount and type of sediment supply, physical energy along the coast and rate of sea level change. This paper is a contribution to this discussion with base in the example of the recent shoreline change of the Rio Grande do Sul state, where the short-term erosion and accretion controlled by the wave energy flux is well documented (LIMA *et al.,* 2001, TOLDO *et al.,* 2003). The results here presented include the general pattern and values of the retraction and progradation and the estimated potential of sediment transport based on the CERC formula.

Sand deposits are abundant in the Rio Grande do Sul inner shelf and the longshore current exhibit strong episodic behavior due to the wave forcing from south, closely related to the passage of cold fronts in the winter period. In this paper we also described an episodic coastal event in May 20th 2000 when satellite images reveal the presence of short-term coastal circulation overtopping the shoreface. This circulation is characterized by a strong coastal jet that in some instances can lead to more diffusion process of suspended sediment outwards from surf zone.

STUDY AREA

The state of Rio Grande do Sul has an exceptionally straight and uniform gentle undulating coast that has 630 km (Figure 1) and consists of unconsolidated Quaternary deposits that received no modern sand contributions from the mainland, because most of the bedload carried by the few streams and rivers is trapped in lagoons and others coastal plain environments, e.g. Lagoa dos Patos and Lagoa Mirim lagoon, occupying 13.750 km^2, almost one third of the Coastal Plain area in the state (TOLDO *et al*., 2000, TOLDO and DILLENBURG, 2002). The continental shelf is 150 to 200-km wide with maximum depths varying from 100 to 140 m, and gentle slopes of 0.03º To 0.08º. The shoreface is wide and shallow with seaward limit at 10 to 15 m depth, presenting large offshore bars. The shoreface floor consist mainly of the sandy sediments, and across the beach and the surf zone of well-sorted fine sand, (MARTINS, 1967; MARTINS and CORRÊA, 1996; GRUBER, 2002; NICOLODI e*t al*., 2002,), except along 60 km in the southern coast area where there is bimodal sediments due to the presence of biodetritic gravel (CALLIARI and KLEIN, 1993). The coastline oriented NE-SW is subject to both dominant swell waves generated in the South Atlantic and local wind-generated waves.

Except for the passage of cold fronts from the south and southeast (TOZZI and CALLIARI, 1999), the coast typically experiences medium to high wave energy conditions. The average significant wave height is 1.5 m and the mean wave period ranges from 7 to 9 s. The coast is microtidal with semidiurnal tides that have a mean range of only 0.3 m (ALMEIDA *et al*., 1997). Consequently, sediment transport and deposition along the coast is primarily dominated by wave action. The closure depth is estimated to be at 7.5 m, calculated using two sets of wave data, collected in 1963 and 1996 along the state's northern coast (ALMEIDA *et al*., 1999).

MAPPING ZONES OF EROSION AND ACCRETION

The mapping reports on the changes in the position of the shoreline its local progradation or retreat using aerial photographs and a GPS survey along of Rio Grande do Sul coast. The field work was driven with a GPS installed in a

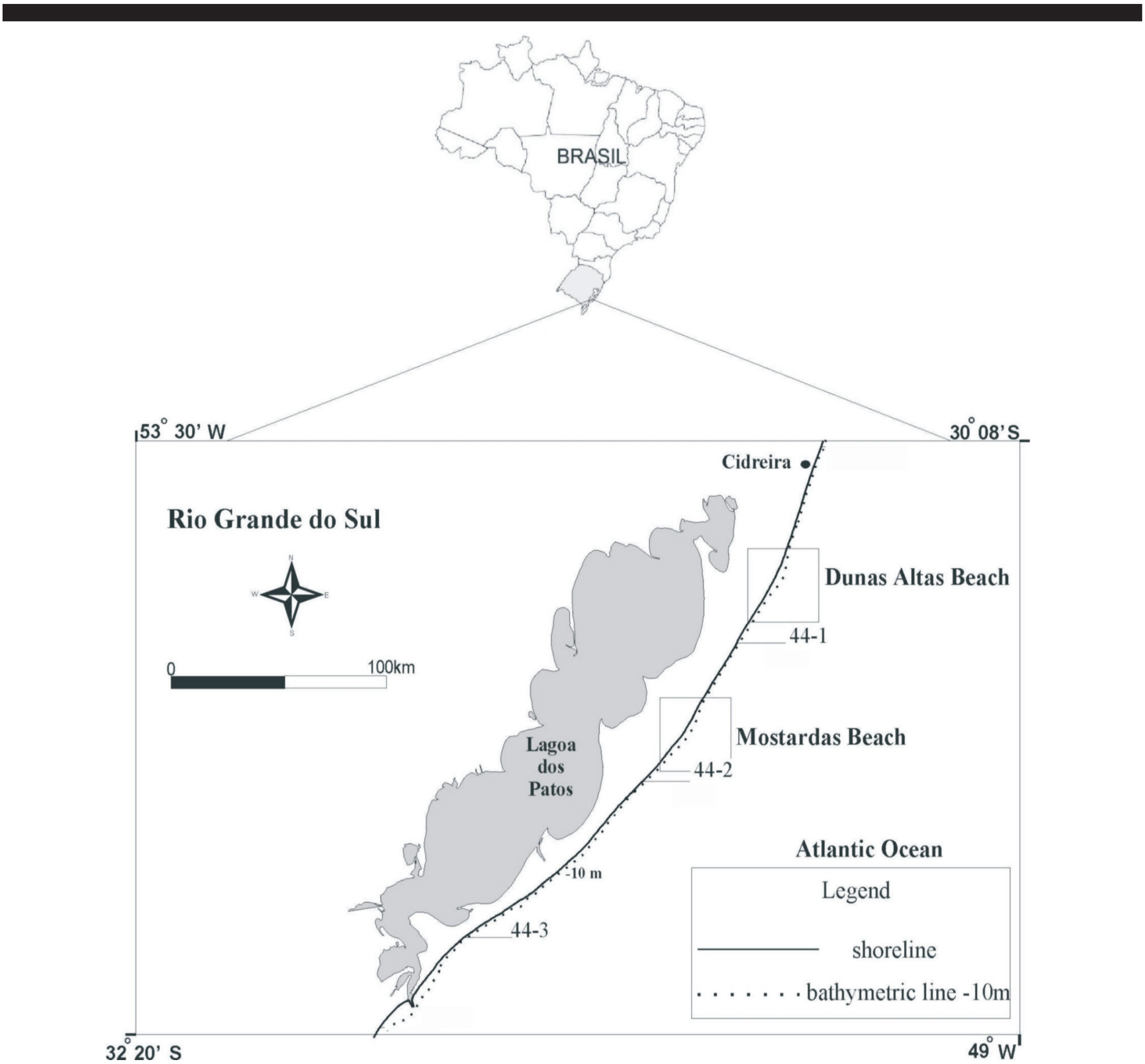

Figure 1. Location and bathymetric map of study area in southern Brazil.

vehicle that run approximately 16 m of distance from mean coast area where there is bimodal sediments due to the presence of biodetritic gravel (CALLIARI and KLEIN, 1993). The coastline oriented NE-SW is subject to both dominant swell waves generated in the South Atlantic and local wind-generated waves.

Except for the passage of cold fronts from the south and southeast, the coast typically experiences medium to high wave energy conditions. The average significant wave height is 1.5 m and the mean wave period ranges from 7 to 9 s. The coast is microtidal with semidiurnal tides that have a mean range of only 0.3 m (ALMEIDA *et al*., 1997). Consequently, sediment transport and deposition along the coast is primarily dominated by wave action. The closure depth is estimated to be at 7.5 m, calculated using two sets of wave data, collected in 1963 and 1996 along the state's northern coast (ALMEIDA *et al*., 1999).

MAPPING ZONES OF EROSION AND ACCRETION

The mapping reports on the changes in the position of the shoreline its local progradation or retreat using aerial photographs and a GPS survey along of Rio Grande do Sul coast. The field work was driven with a GPS installed in a vehicle that run approximately 16 m of distance from mean water line and with a medium speed of 50 km/h, and the other GPS, in the static mode, was positioned in places previously established at the coast and distant each other by 100 km, in order to cover the readings and to increase the precision of data. The sampling rate for both equipments was of 5 seconds, which allowed the generation of files that post-processing show the line traveled accuracy of 3 m (TOLDO *et al.,* 1999, TOLDO and ALMEIDA, 2003).

The beach line established by DGPS in November 1997, was compared with the beach line reproduced from the army chart collection of 1978 year (1:50,000), which are a restitution of an aerophotogrametric study in 1975 years. The temporal analysis among these studies was accomplished through geoprocessing techniques using the IDRISI software (Clark University), and the final map was printed on the scale of 1:1,300,000.

The results of the 22 year-old temporal analysis (1975-1997), show that the all beach line of Rio Grande do Sul coast is characterized by erosive and accretionary states, with 442 km of beaches in retreation, 173 km under progradation conditions and 6 km wIthout significant variations. The erosive processes with rates larger than 80 m extends through of 257 km, while the accretional areas presents smaller values (TOLDO *et al*., 1999; ESTEVES *et al*., 2002). The figure 2 show the coastline mobility behavior in the central coast of the state. In fact here a very little stretches has been mapped as accrecionary states, approximately 31 and 35 km, for Dunas Altas and for Mostardas beach, respectively.

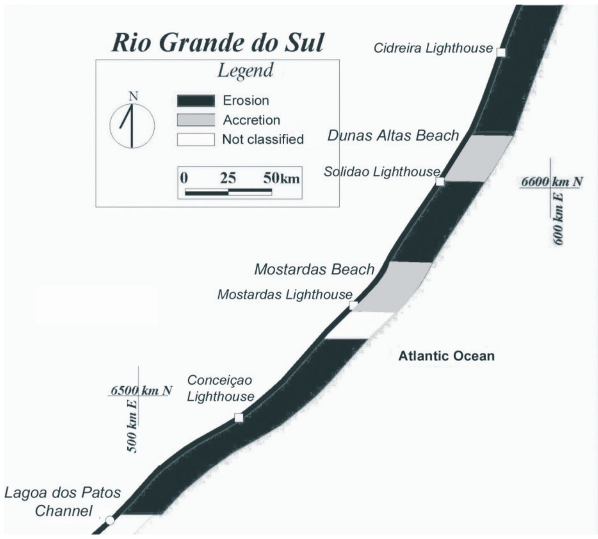

Figure 2. Map of the central coast of Rio Grande do Sul showing the general pattern of erosion and accretion areas (modified from Toldo *et al*., 1999) .

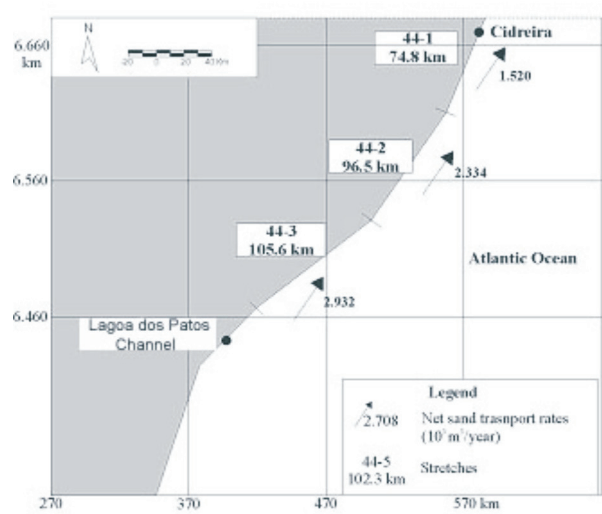

Figure 3. Prediction of regional net longshore transport rates (modified from Lima *et al.,* 2001).

ESTIMATE OF LONGSHORE TRANSPORT

A net northward littoral drift is evident in coastal geomorphic features along of Rio Grande do Sul coastal zone (TOMAZELLI and VILLWOCK, 1992). The results of mathematical estimation of the longshore transport potential (LIMA *et al*., 2001) agree qualitatively with such observations.

The mathematical estimation was based on the CERC formula, where the energy flux of computing longshore transport rate is based on the empirical relationship between thecomponent of wave energy flux entering the surf zone and the immersed weight of sand moved (U.S. Army 1984, p. 4-96). Both have units of force per unit time, thus:

$$Il = K\,Pl\,s \qquad (1)$$

where Il is the immersed weight transport rate (force/time), K a dimensionless coefficient, and Pls the longshore energy flux factor (force/time).

In order to verify the calculations of longshore sediment transport, a study was carried out along 630 km of the Rio Grande do Sul coast. The whole coast was divided into eight stretches based on differences of shoreline alignment. This model predicts a substantial variation of the energy flux into the surf zone due to the little changes in the shoreline alignments, and consequently on the transport potential along the coast (Fig. 3). The mean yearly wave energy flux into the surf zone was analyzed based upon representative long-term wave statistics organized by Hogben and Lumb (1967, In: LIMA *et al.,* 2001). In the coastal waters the incident waves have the following offshore directional distribution: 30% from NE quadrant and 9% from the south direction. The short waves coming from the NE, generated by local winds, are responsible for less than 2% of the sediment transport. The longshore current exhibit strong episodic behavior due to the wave forcing from south, which are responsible for more than 30% of the sediment transport.

This study focuses mainly on the sand longshore transport along three coastal stretches in the central coast, numbered from south to north as 44-3 to 44-1, extending from the Lagoa dos Patos channel to Cidreira beach. The southernmost stretch (44-3) is 105-km long and its longshore transport was estimated in about 2.9 million m3/year. The adjacent segment (44-2) is 96-km long and the longshore transport was estimated in about 2.3 million m3/year, decreasing to 1.5 million m3/year along the 44-1 stretch (Figure 3).

Variability of Shoreface Width

The shoreface topography consists of a broad area of smooth bottom surface and with mean slopes of 1:100. The 10 m isobath was used as shoreface seaward limit as presented in the Brazilian navy bathymetric map surveyed on 1963. The mean shoreface width changes from less than 1 km along coastal stretches 44-3, 44-2, and 44-1 to 3 km along the southern sectors of stretches 44-2 and 44-1 (Figures 1 and 3).

Measurements of changes in shoreline position and beach system morphology show extensive shore retreat along of all stretches 44-3 and 44-2. This eroded areas correspond to the stretches where there is an increase on the longshore flux energy, e.g., where the shoreline alignment is more exposed to the southerly wave attack (Figure 3). The resultant energy flux into the surf zone and related longshore transport decreases to the north, from 2.9 million m^3/year on stretch 44-3 to 1.5 million m^3/year on stretch 44-1 (Figure 3). Dette (2001), studying the morphological processes along a 40-km long coastal segment in the Baltic sea, revealed that a reduction in transport flux due to changes in the shoreline alignment implies a jam in the longshore transport. It means that part of the sediment arriving from the upstream stretch must be deposited or diverted offshore.

The above descriptions indicate a coupling between the net longshore balance evolved into stretches 44-3, 44-2 and 44-1 and the spatial change on the shoreface width in south sides of the stretches 44-2 and 44-1, (Figures 1 and 3). Also, the previous results acquired about short time scale of shoreline displacement along of Mostardas and Dunas Altas beach, confirm the process that part of the sediment that was eroded along of stretches 44-3 and 44-2, arrive from this stretches is deposited and diverted offshore along this two beaches.

Besides these morphological elements we found specific hydrodynamics processes associated with changes in the shoreline alignments, as illustrated bellow. Analyses of satellite images in this area reveal the presence of short-term coastal currents circulation overtopping the shoreface, that has not been studied in detail before, but suggests that in some instances this current can lead to more diffusion process of suspended sediment outwards from surf zone a strong alongshelf jet characterizes this coastal current. The occurrence and evolution of this jet are closely related to the passage of cold fronts, which are formed early in the winter.

This paper focuses on an episodic event in may 20th 2000 that is illustrated on figure 4 at that time, the characteristics of the circulation pattern over the shoreface consisted of two segments, the northward coastal current intensified by the south and southeast winds and a wide plume clockwise - rotating gyre.

The conceptual model is that sediments are supplied to the surf zone and shoreface from shoreline erosion, similarity to the episodic events on nearshore-offshore transport in the Great Lakes described by EADIE *et al.,* (1996). Initially, these sediments are transported into temporary sinks within the

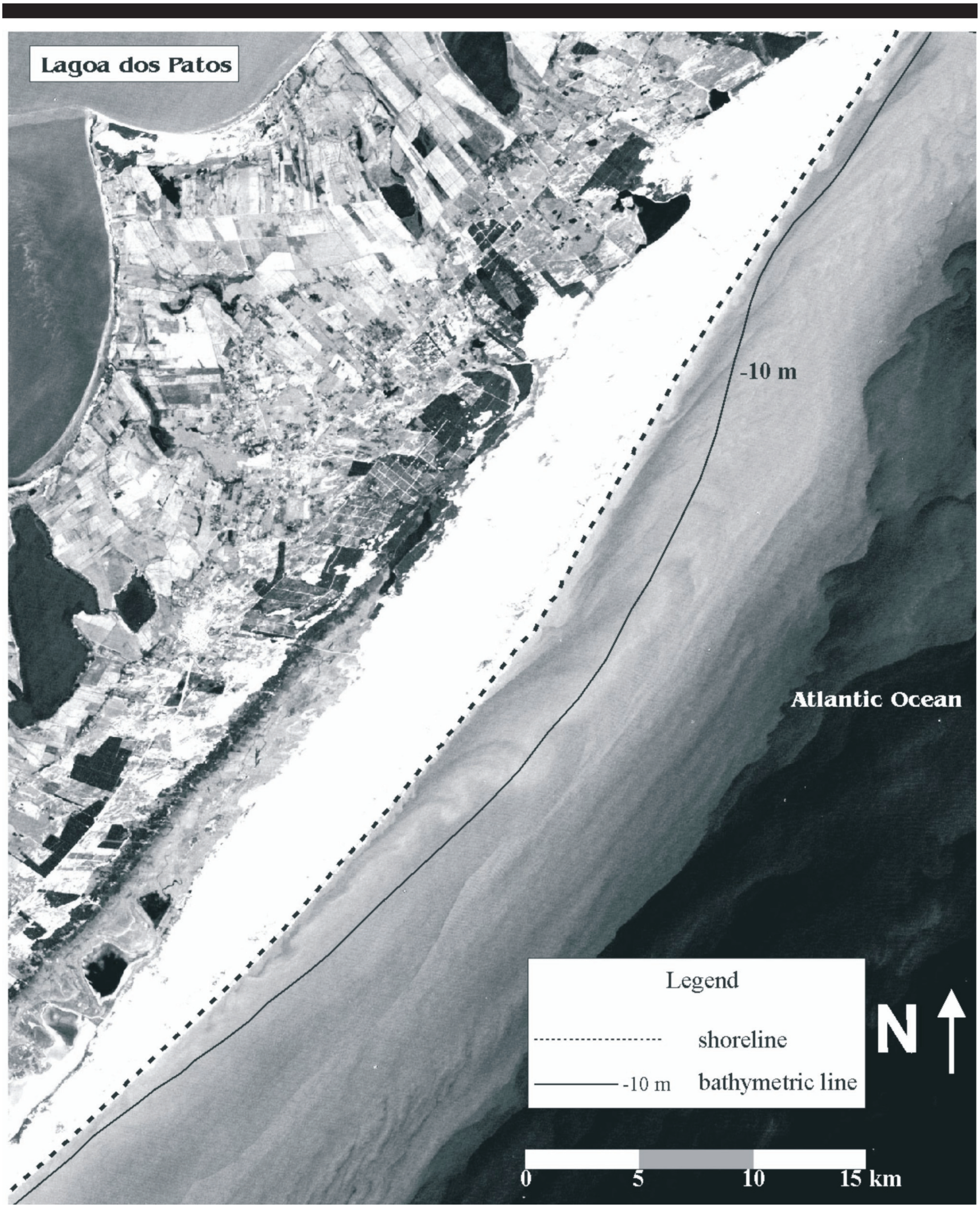

Figure 4. Satellite image showed changes in the shoreline alignment between coastal stretches 44-2 and 44-3 (Mostardas beach), the presence of coastal f jet, the coastal dunes and shoreface accretion (Toldo *et al*., 2003).

nearshore zone that are non-depositional in the long-term (years or decades). Large episodic events characterized by a strong coastal current, like the event in May 20th 2000, resuspend and transport the sediment from these temporary sinks to more permanent sinks. A fraction of the suspended load is incorporated by the shoreface every year, developing a large sand bank as can be seen in the 10-m bathymetric contour (Figure 4). These sand bank complexes have been termed shoal-retreat massifs (SWIFT and SEARS, 1974, In: DYER and HUNTLEY, 1999).

Also, the physical process that control the formation and evolution of the coastal jet have not been fully explored, but good agreement was found between the shoreface accretion area, for more than 2 km offshore, and the extension of the coastal jet over this area, as observed in the satellite image (Figure 4).

Variability of Coastal Dunes Field Width

In an paper published in 2000 TOMAZELLI *et al.,* describe the oceanic beach deposits associated with barrier-lagoon system IV, the most recent barrier of Rio Grande do Sul coastal plain, that was formed during the Holocene. The long barrier that separates the Lagoa dos Patos (Figure 1), from the ocean is composite and includes both a Holocene barrier (System IV) and a Pleistocene barrier (System III). The Holocene coastal dune fields are mainly barchanoid ridges and are well developed over the barrier-lagoon-system IV, principally on the protruding stretches of the coast with a variable width of 2 to 8 km (DILLENBURG *et al*., 2000).

The shoreface and coastal dune field width change in the same way along of central coast: the wider dune field are associated to those beaches where shoreface is also wider. Both width are pronounced from quantitative measures, the mean coastal dune fields width changes from less than 1 km to more than 6 km along the 31 and 35 km for Dunas Altas and for Mostardas beach, respectively.

Due to large longshore sand transport volume along of central coast and the sediment jam provide by changes on shoreline alignment on Dunas Altas and Mostardas beach, the sand accumulation are important sediment source for both coastal dune fields and shoreface areas.

In response to the strong and prevailing northeastern winds the aeolian sand transport is active and the san dunes transgress the hinterland in a SW direction (TOMAZELLI *et al*., 2000), developing wide dune fields principally on Dunas Altas and Mostardas beach (Figure 1).

CONCLUSIONS

The estimated potential of sediment transport predicts a substantial variation of the energy flux into the surf zone, due to little changes in shoreline alignments.

The reduction in the sediment flux due to changes in the shoreline alignment produce a jam in the longshore transport. Part of the sediment arriving from the upstream stretch may be deposited or diverted offshore (DETTE, 2001).

The sediment jam provide by changes on shoreline alignment on Dunas Altas and Mostardas beach are important sediment source for development of both large coastal dune fields and shoreface areas, in a sandy coast with 276.9-km characterized by extensive shore retreat.

ACKNOWLEDGEMENTS

This work is the result of research sponsored by CNPq and OEA-CECO/IG/UFRGS Project. We are grateful to Tec. Laurindo Guasselli, Cesar D. C. Gonçalves, Luiz G. Raupp and José C. Nunes, for their technical support.

LITERATURE CITED

ALMEIDA, L.E.S.B.; ROSAURO, N.M.L. and TOLDO JR., E.E., 1997. Análise Preliminar das Marés na Barra do Rio Tramandaí, RS. *Anais do XII Simpósio Brasileiro de Recursos Hídricos* (Vitória, ES., Brasil ABRH), Resumos, pp. 560-566.

ALMEIDA, L.E.S.B.; ROSAURO, N.L.; TOLDO JR., E.E. and GRUBER, N.L.S., 1999. Avaliação da profundidade de fechamento para o litoral norte do Rio Grande do Sul. *Anais do XIII Simpósio Brasileiro de Recursos Hídricos* (Belo Horizonte, MG., Brasil, ABRH), CD, 8 p.

CALLIARI, L.J. and KLEIN, A.H.F., 1993. Características morfodinâmicas e sedimentológicas das Praias Oceânicas entre Rio Grande e Chuí, RS. *Pesquisas*, (UFRGS, Brasil), 20(1), 48-56.

DAVIS, Jr., R.A., 1997. Regional Coastal Morphodynamics Along the United States Gulf of Mexico. *Journal of Coastal Research,* 13(3), 595-604.

DYER, K.R. and HUNTLEY, D.A., 1999. The origin, classification and modeliing of sand banks and ridges. *Continental Shelf Research*, 19, 1285-1330.

DETTE, H.H., 2001. Influence of shoreline alignment on offshore sediment transport. *Proceedings of Coastal Dynamics'91*, (Lund, Sweden, ASCE), pp. 938-947.

DILLENBURG, S.R.; ROY, P.S.; COWELL, P.J. and TOMAZELLI, L.J., 2000. Influence of antecedent topography on coastal evolution as tested by the shoreface translation-barrier model (STM). *Journal of Coastal Research*, 16(1), 71-81.

EADIE, B.; EDGINGTON, D.; LESHT, B.; KLUMP, V.; NEALSON, K.; ROBBINS, J. and TONNER, B., 1996. *The Impact of Episodic Events on Nearshore-Offshore Transport in the Great Lakes: Sediment Resuspension and Transport.* http://www.glerl.noaa.gov/eegle.

ESTEVES, L.S.; TOLDO JR., E.E.; DILLENBURG, S.R. and TOMAZZELLI, L.J., 2002. Long and short-term coastal erosion in southern Brazil. *Journal of Coastal Research, Proccendigs of the 7th International Coastal Symposium,* (Northern Ireland), SI 36: 273-282.

GRUBER, N.L.S., 2002. A antepraia na região de Tramandaí , RS. Porto Alegre, RS., Brasil. Universidade Federal do Rio Grande do Sul. 221 p. Ph.D. thesis, 221p.

LIMA, S.F.; ALMEIDA, L.E.S.B. and TOLDO JR., E.E., 2001. Estimate of longshore sediments transport from waves data to the Rio Grande do Sul coast. *Pesquisas* (UFRGS, Brasil), 28 (2), 99-107.

MARTINS, L.R. 1967. Aspectos texturais e deposicionais dos sedimentos praiais e eólicos da Planície Costeira do Rio Grande do Sul. *Publicação Especial n] 13*. (UFRGS, Brasil) 100 p.

MARTINS, L.R. and CORRÊA, I.C., 1996. *Morphology and Sedimentology of Southwest Atlantic Coastal Zone and Continental Shelf from Cabo Frio (Brazil) to Peninsula Valdes (Argentina).* Porto Alegre, RS., Brasil. IOCUNESCO / MCT / CPRM Publication, 20 maps and glossary, 74p.

NICOLODI, J.L.; SIEGLE, E.; RECHDEN F°., R. and CORRÊA, I.C.S., 2002. Análise sedimentológica do pós-praia no Rio Grande do Sul. *In*: Martins, L.R., Toldo Jr., E.E., Dillenburg, S.R (eds). *Erosão Costeira: Causas, análise de risco e sua relação com a gênese de depósitos minerai*s Porto Alegre. RS.,Brasil. Editora CECO-IG-UFRGS, 3p.

TOLDO JR, E.E.; ALMEIDA, L.E.S.; BARROS, C. and MARTINS, L.R., 1999. Retreat of the Rio Grande do Sul coastal zone, Brazil. *In:* Martins, L.R. and Santana, C.I. (eds.). *Non Living Resources of the Southern Brazilian Coastal Zone and Continental Margin*. Porto Alegre, RS., Brazil: Editora CECO-IG-UFRGS, pp. 62-68.

TOLDO JR, E.E.; DILLENBURG, S.R.; CORRÊA, I.C.S. and ALMEIDA, L.E.S.B., 2000. Holocene Sedimentation in Lagoa dos Patos Lagoon, Rio Grande do Sul, Brazil. *Journal of Coastal Research*, 16 (3), 816-822.

TOLDO JR, E. E. and DILLENBURG, S. R., 2000. Swash bar migration at the inlet of the Lagoa dos Patos Lagoon, Brazil. *Journal of Coastal Research. Proccendigs of the 6th International Coastal Symposium,* (New Zealand) SI 34: 489-492.

TOLDO JR, E.E.; ALMEIDA, L.E.S.B.; ESTEVES, L. S. and NICOLODI, J. L., 2003. Shoreface Width as a Function of Longshore Transport. *Proceedings of the 5th International Symposium on Coastal Engineering and Science of Coastal Sediment Process,* (Clearwater Beach, Florida, ASCE), CD, 8p.

TOLDO JR, and ALMEIDA, L.E.S.B., 2003. A linha d' água como indicadora da posição da linha de praia. *Anais do IX Congresso da Associação Brasileira de Estudos doQuaternário,* (Recife, PE., Brasil, ABEQUA), CD, 3p.

TOMAZZELLI, L.J. and VILLWOCK, J.A., 1992. Considerações sobre o ambiente praial e a deriva litorânea de sedimentos ao longo do litoral norte do Rio Grande do Sul, Brasil. *Pesquisas*, (UFRGS, Brasil), 19, 3-12.

TOMAZZELLI, L. J.; DILLENBURG, S.R. And VILLWOCK, J. A., 2000. Late quaternary geological history of Rio Grande do Sul coastal plain, Southerm Brazil. *Revista Brasileira de Geociências*, 30(3), 474-476.

U.S. ARMY COASTAL ENGINEERING RESEARCH CENTER / CERC, 1984. Shore Protection Manual. 4ed., Vol (1). Waterways Experiment Station, Corps of Engeneers. USA. 208 p.