Monitoring of recent morphological changes of the dune of Vougot Beach (Brittany, France) using Differential GPS

By

Serge Suanez, Jean-Marie Cariolet, and Bernard Fichaut
GEOMER – UMR 6554 CNRS LETG, Université de Bretagne Occidentale
Institut Universitaire Européen de la Mer, Technopôle Brest-Iroise,
Place Nicolas Copernic, 29280 Plouzané, France
serge.suanez@univ-brest.fr

ABSTRACT

The dune of Vougot beach is a massive drifting sand body approximately 250 to 400 m wide and 2 km long. It is located in the municipality of Guissény, on the north coast of Finistère (Brittany). This dune, with a southwest to northeast position, protects a vast polder area which was disconnected from the sea by a dike construction in 1834. For several decades the eastern part of this dune experienced erosion mainly due to the construction of an artificial jetty in 1974 (Curnic jetty), which entirely modified the hydrodynamics and sedimentation processes. In order to determine the actual trend of evolution, the advance rate, and the resultant sand drift that is occurring, a survey of the dune was achieved between 2004 and 2009. Shoreline changes were monitored on a yearly basis; in addition, two detailed topography surveys (2005 and 2009) were carried out. Topography surveys were made using a Trimble DGPS respectively with 5 cm and 1.5 cm of horizontal and vertical accuracy. ArcView GIS was used to process the data and display the results. Shoreline change rates were determined using Digital Shoreline Analysis (DSA) ArcView tools to measure erosion and accretion transects. 3D surface analysis was based on Digital Elevation Model (DEM) calculations using Surfer software. Foredune changes showed that dune evolution since 2004 is in accordance with the trend observed during the last decades. However, the speed of dune retreat has increased from 0.6 m/yr to 1.5 m/yr. The comparison between DEMs obtained from the 2005 and 2009 surveys confirmed this evolution. A volume of eroded sand from the dune amounting to -10,677 ± 110 m^3 with an erosion of the foreshore beach of -10,933 ± 1,396 m^3 was determined. These results confirm the fact that the Curnic jetty is constantly interrupting the sand drift inducing an increase in sediment loss from the Vougot beach/dune system.

ADDITIONAL KEYWORDS: DGPS, monitoring; dune erosion; sand drift.

Manuscript submitted 14 May 2009, revised and accepted 4 November 2009.

Coastal monitoring is considered as a major challenge in anticipating the response to coastal hazards (Ruggiero *et al.* 2000; Rieb and Walker 2001). It provides useful help in terms of management decisions regarding coastal defense, land use and planning (Hamm *et al.* 2002; Meur-Férec *et al.* 2008). Furthermore, Integrated Coastal Management (ICM) plans, to be successful, must explicitly incorporate a realistic range of coastal processes and responses based on an understanding of the physical environment by means of surveys (Solomon and Forbes 1999). For instance, along the U.S. east coast, historical shoreline monitoring and trend analysis provide the requisite data for projection of future shoreline positions for many coastal management programs, and in the future may be incorporated into the Federal Emergency Management Administration's (FEMA) flood insurance mapping program (Leatherman 2003). Identification of erosion hazard zones could potentially represent a significant advancement toward fulfilling the intent of the National Flood Insurance Program (NFIP). Another example concerns the JARKUS database of the Dutch Department of Public Works (Rijkswaterstaat), which consists of 30 years of annual profiles spaced every 250 metres along the Dutch coast. It also led to advances in understanding temporal profile evolution and the spatial variability in morphologic behavior (Louisse and van der Meulen 1991). This survey led to changes in national policy, due to which the dynamic preservation of the 1990 coastline using beach nourishment now has legal authority (Koster and Hillen 1995).

This study presents the results of the follow-up of morphological changes in the dune of Vougot beach over the 2004-2009 period (Figure 1). It was based on DGPS measurements which were described as sophisticated technology providing the means to perform high-quality data collection in terms of spatial and temporal resolution (Morton *et al.* 1993; Huang *et al.* 2002; O'Reagan 1996). Moreover DGPS surveying techniques for beach monitoring activities are commonly used (Wamsley and Edge 2001; Rebêlo *et al.* 2002). The aim of this work was to quantify the sediment budget of the dune; in addition, observations were also made on the tidal beach. The characterization of changes in morphology contributed to a better understanding of morphosedimentary processes. It also provided useful data to enable decision-making in terms of possible coastal protection strategies.

GEOGRAPHIC SETTING AND PURPOSE

The study area covers the Vougot beach located in the municipality of Guissény; it is situated on the north coast of Finistère in Brittany (Figure 1). This coastal area comprises a large rocky outcrop corresponding to the submerged part of the Léon plateau. Contact between the coastal platform and the continental

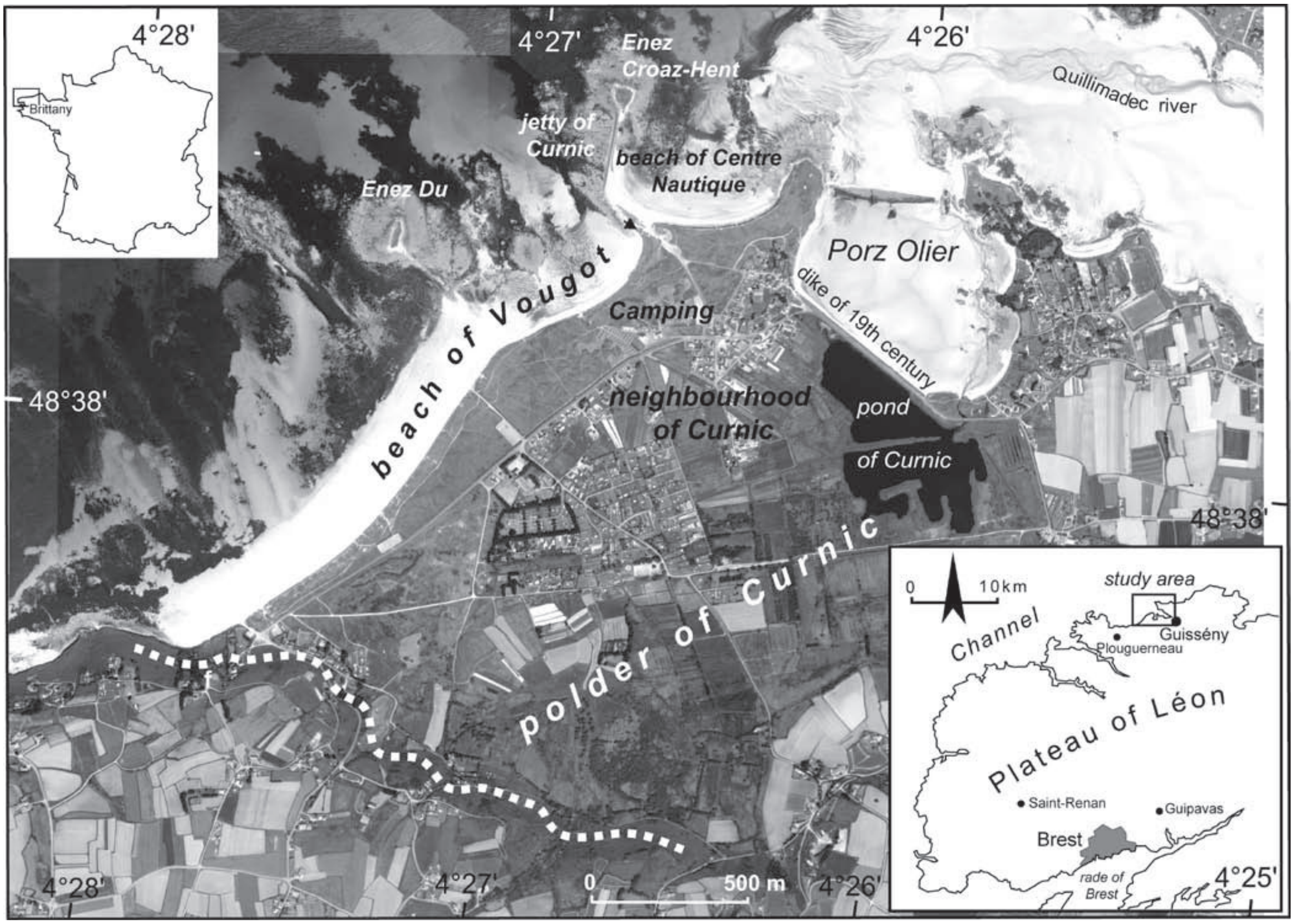

Figure 1. Location of the study area.

part of the plateau consists of a partly tectonic scarp with 30 m to 50 m height variation. In the Vougot beach area, the scarp is disconnected from the sea due to the existence of a dune which was formed during the Holocene (Guilcher and Hallégouët 1991). This dune stretches over about 2 km from the abandoned Zorn cliff, following a southwest to northeast direction. It culminates at 13 m NGF in altitude (i.e. above sea level – a.s.l.). (The altimetric reference NGF – *Nivellement Général Français* – refers to the French topographic datum. In our case this reference is situated 3.5 m above the spring-tide low-water level.). It corresponds to a massive dune complex 250 m to 400 m wide (Figure 2). Until the 19th century, this vast sand body bordered wetlands which were connected to the sea in the Porz Olier sector located in the northeast. In 1834, a dike was built in order to isolate the area from the sea, and wetlands were drained to make them farmable. Today, this polder area, partly occupied by the Curnic pond, stands near or below sea level. This low-lying land is also protected from the sea by the dune, which acts as a natural defense. This element is all the more important since this area has been inhabited over a period of time (camping, Curnic neighbourhood, farming, etc.).

In the last decades, the dune of Vougot beach has experienced erosion (Suanez *et al.* 2007). A historical shoreline change analysis based on a series of aerial photographs from 1952 to 2000 showed that retreat of the dune principally affected the eastern part of Vougot beach (Sparfel and Suanez 2007). Erosion was caused by the construction of the Enez Croas Hent jetty in 1974, which completely modified the hydrodynamics and sediment circulation in this area (Figure 3). Before the construction of the jetty, sediment circulated from the Centre Nautique beach to the Vougot beach (inducing foredune progradation) within a general east-to-west sediment transport cell. After the building of the jetty, sediment became trapped in the western part of the Centre Nautique beach, inducing rapid accretion (Figure 4); while the Vougot beach, which was no longer supplied, started experiencing erosion. Calculation of erosion rates over the 1978-2000 period (following the building of the jetty in 1974) showed that the maximum retreat of the dune reached values ranging from 0.5 to 0.7 m/yr (see profiles P03 to P06 in Figure 5). However, erosion speeds decreased moving further west (profiles P06 to P10) where the dune experienced progradation from profiles P10 to P15 (Sparfel and Suanez 2007; Suanez *et al.* 2007).

Table 1.

Margins of error (in meters) for (x, y, z) DGPS measurements calculated using standard deviation.

	X	Y	Z
CP01	0,043	0,042	0,009
CP02	0,059	0,051	0,009
CP03	0,035	0,033	0,011
CP04	0,078	0,026	0,012
CP05	0,031	0,034	0,011
mean	0,049	0,037	0,010

The aim of this study is to analyze the current evolution of the dune in order to determine whether the morphosedimentary processes measured on a historical

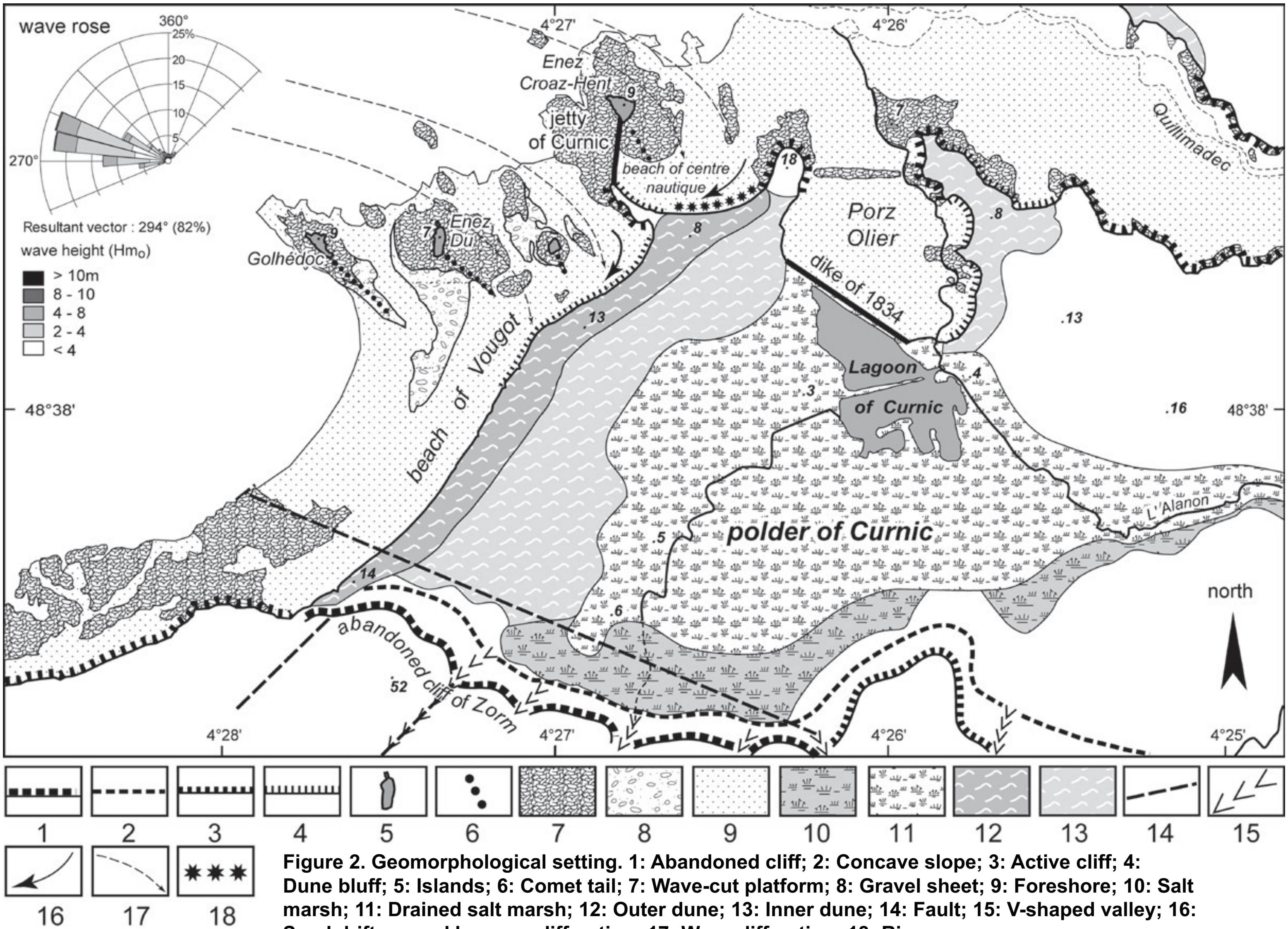

Figure 2. Geomorphological setting. 1: Abandoned cliff; 2: Concave slope; 3: Active cliff; 4: Dune bluff; 5: Islands; 6: Comet tail; 7: Wave-cut platform; 8: Gravel sheet; 9: Foreshore; 10: Salt marsh; 11: Drained salt marsh; 12: Outer dune; 13: Inner dune; 14: Fault; 15: V-shaped valley; 16: Sand drift caused by wave diffraction; 17: Wave diffraction; 18: Riprap.

scale still act in the same way, and to the same extent. To this end, topomorphological survey based on DGPS measurements was carried out since 2004. Three types of data were measured: beach/dune profile along three radials on a monthly basis, foredune position on a yearly basis, and beach/dune topography on a pluriannual basis. Within the framework of this article, results presented only refer to the two last types of observation. The foredune position measured from 2004 to 2009 allows representing the dune front kinematics over a recent period. These data were compared with those obtained from photo interpretation since the 1950s. Simultaneously, two surfacic measurements from the Vougot and Centre Nautique beaches were made in 2005 and 2009 to quantify the evolution of the sediment budget of both beaches, and to evaluate the medium term impact of the Curnic jetty on the morphosedimentary functioning of the entire area. The goal as regards to this last point is again to determine whether the environment's current evolution confirms observations made on the historical scale. Finally, these results allow suggesting forecasting scenarios in terms of management and defense strategies against erosion.

METHOD AND DATA ANALYSIS

A Trimble 5700/5880 Differential GPS was used to collect data points in Real Time Kinematics (RTK) mode. Each GPS measurement represents a 3D location and is described by three coordinate values (x, y, z) for each point. Each DGPS measurement was calibrated using the geodesic marker from the French datum and the geodesic network provided by the IGN (*Institut Géographique National*) located about 2 km from the study area. Five control points were installed in the field to evaluate the accuracy of the surveys (Figures 6A-7A). Since the survey started, 72 field campaigns were achieved. For each of them, the position of the control points was measured and the margin of error for the three dimensions (x, y, and z) was calculated using standard deviation (Table 1). The result shows an x, y, z accuracy reaching respectively 4-5 cm and 1 cm. These values were used to calculate margin of error associated with the sediment budget calculation.

The first survey consisted of annual measurements of foredune changes using the edge of the dune as the erosion reference feature (ERF). This limit is highly relevant because it corresponds to the top of the bluff cut by erosion processes, which clearly demarcates the dune vegetation from the loose sand of the backshore (Crowell *et al.* 1991; Zuzeck *et al.* 2003). Foredune change rates were then performed using Digital Shoreline Analysis (DSA) ArcView GIS tools to measure erosion and accretion transects (Moore 2000). The process automates the drawing of a baseline and the

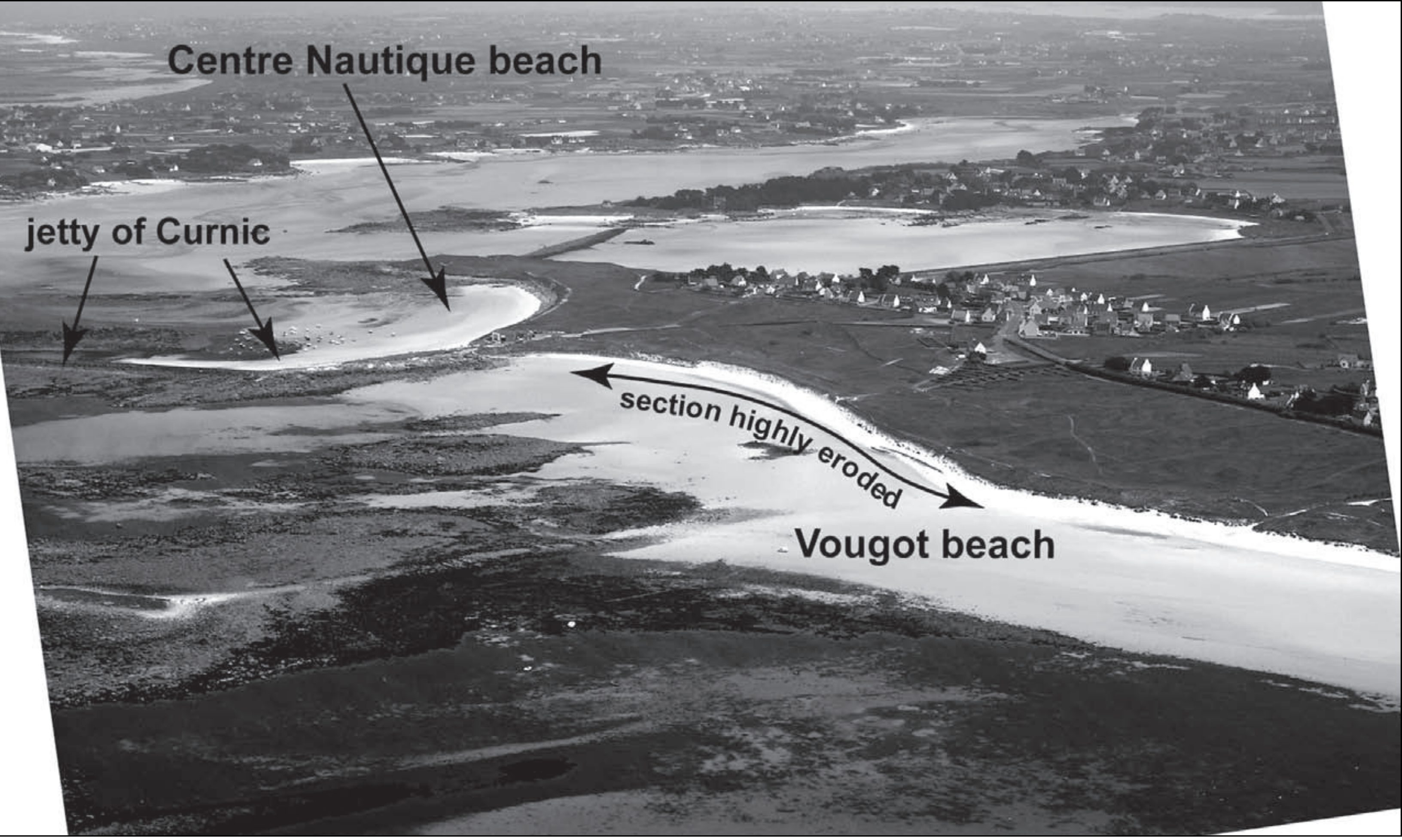

Figure 3. Curnic jetty separating Centre Nautique and Vougot beaches.

corresponding perpendicular transects with a constant 50 m spacing (Figure 8B). The determination of long- and medium-term foredune erosion rates was achieved using the least squares method (Figure 8A), provided that the shape of data points allowed calculating the "best fit" using linear regression (Fenster *et al.* 1993; Crowell *et al.* 1997; Douglas *et al.* 1998; Zuzeck *et al.* 2003).

In addition to foredune changes monitoring, two detailed surveys —one in 2005 and the other in 2009 — were carried out. The monitored site covered a surface area of about 60 ha including the Vougot and Centre Nautique tidal beaches, skerries and small islands, the Curnic jetty, and part of the vegetated dunes (Figures 6A-7A). The 2005 survey was planned in two phases. The first phase was oriented toward monitoring both the Vougot and Centre Nautique beaches and the unvegetated dune area in the shortest possible period. It took place during October 2005. The second phase was oriented toward monitoring the vegetated dune area and took place during the rest of the year. A total of 20,236 (x, y, z) points were measured during the 2005 survey (Figure 6A). The 2009 survey took place from October to November. It was carried out only on the tidal beaches and the loose sand close to the dune bluff contact. Vegetated dunes, skerries, and small islands, showing no changes, were not monitored any further. These area points from the first 2005 survey were used. Overall, 21,080 (x, y, z) points were measured in 2009 (Figure 6A). Compared to the 2005 survey, the 844-point difference is mainly due to two components. Firstly, the space between measurements in 2009 was considerably increased in zones where erosion occurred, because the topography was rougher (e.g. the dune bluff). This is also due to the fact that, for the Centre Nautique beach, the 2009 survey was extended further to the low-tide terrace whereas the 2005 one was not.

In each survey, the space between measurements was not rigid but dependent on topography. An approximately 10 m to 20 m interval was used in flat smooth topography, such as a tidal beach with a gentle slope. The interval was reduced by less than 0.5 m to 0.2 m where the topography was very rough. Surfer 8.0 software was used to import and process the (x, y, z) data. Interpolation was applied to convert data point observations into continuous fields, generating grids (altitude matrices). The whole study area contour lines and 3D visualization were generated from a 0.5 m grid (Figures 6-7). The kriging interpolation model supporting breaklines was used to generate all grids. In order to map the changes that occurred, and calculate the volumetric difference between two surfaces, a 2005 and 2009 grid subtraction was achieved. From the resulting grid, contour maps were drawn (Figure 9).

RESULTS

Shoreline changes

The results show that the foredune retreat speeds calculated over the last decade (2000-2009) increased everywhere in relation to those obtained over the 1978-2000 period (as illustrated in the case of profile P05, retreat went from 0.6 to 0.9 m/yr; see Figure 8A). Moreover, these speeds increase from east to west; they double between the jetty and profile P07 (Figure 8B). Beyond profile P08, although the foredune was stable or undergoing accretion over the 1978-2000 period, its retreat reached 1.5 m/yr locally after 2000.

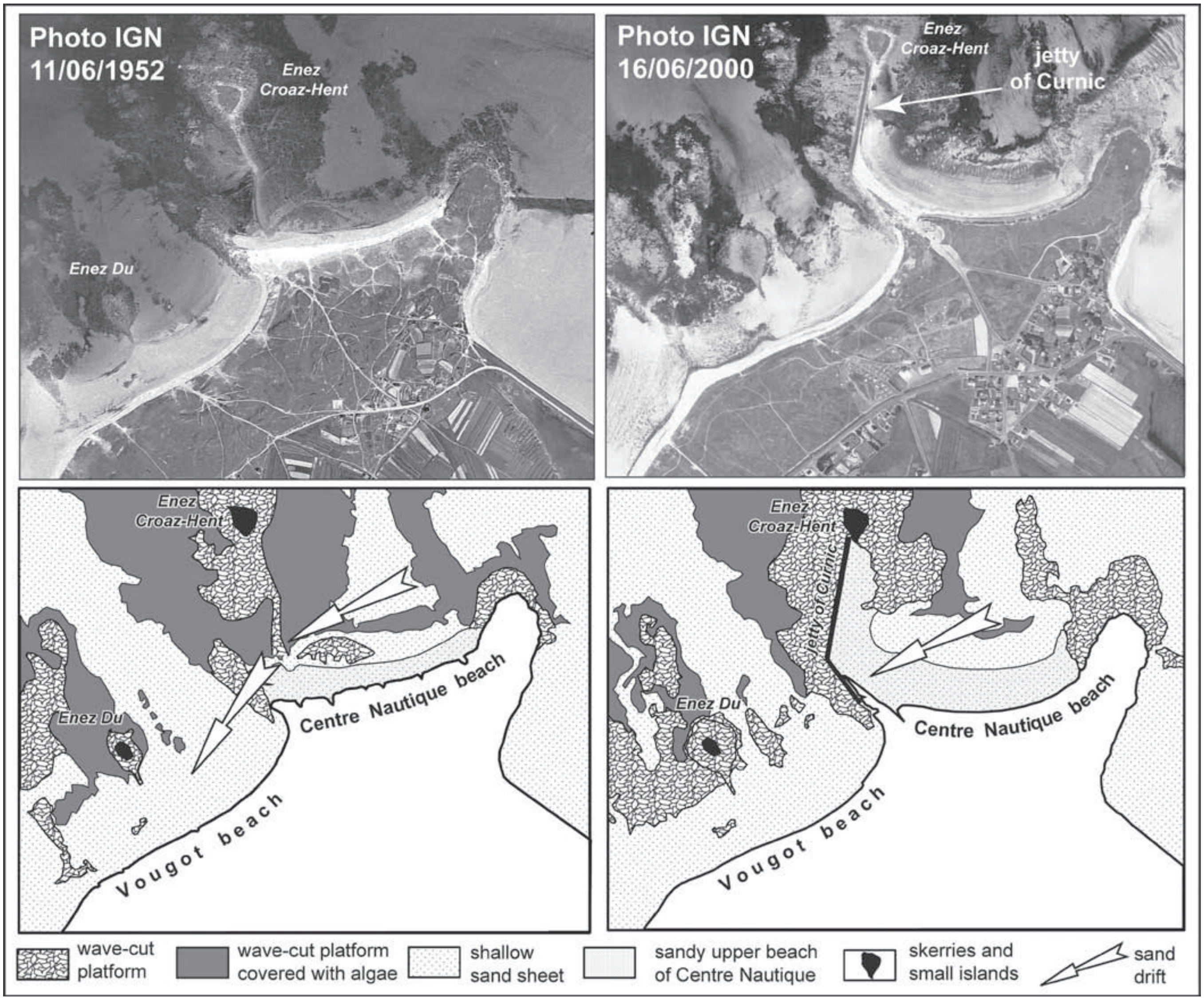

Figure 4. Comparison of 1952 and 2000 aerial photographs illustrating the accretion of the Centre Nautique beach due to the building of the Curnic jetty in 1974. The east-to-west sand drift is generated by wave diffraction around Enez Croaz-Hent island (modified from Sparfel and Suanez 2007).

Sediment budget changes

The sediment budget study was carried out by dividing the study area into several cells named "boxes" (Figure 9, Table 2). They facilitate the reconstruction of sediment transport according to the "box model" principle. Between 2005 and 2009, the dune of Vougot beach (box 1) lost 10,677 ± 72 m^3. Part of this material seems to have accumulated on the upper beach and particularly in the eastern section (box 2: +5,391 ± 192 m^3). However, if the foreshore budget in deficit is taken into consideration (boxes 2 + 3 + 4), the entire eastern part of the intertidal beach lost 4,637 ± 1,396 m^3. Most of this material contributed to building up the western section of the Vougot beach, which gained 4,505 ± 489 m^3 (box 5). The data obtained for the Centre Nautique beach show that the dune ridge had also eroded (box 6); the lost volume amounts to -374 ± 5 m^3. By contrast, the entire intertidal beach significantly built up (box 7 and 8: +20,054 ± 837 m^3), from sediment removed by the swell in the close sublittoral zone.

DISCUSSION

Erosion of the Vougot beach dune ridge provides a perfect example of the negative effects of anthropization on the coastal sediment budget. Since 1974, the Curnic jetty structure completely altered the hydrosedimentary functioning of the entire area of study, interrupting the longshore sediment transport from the Centre Nautique beach to the Vougot beach. Yet, as highlighted by various authors, longshore sediment transport is one of the most important parameters contributing to the balance of the sediment budget of the beaches (Clayton 1980; Shuisky and Schwartz 1983; Komar 1996). It allows supplying areas "in deficit" from sediment-providing areas, and is structured in cells and/or sub-cells dividing the coastline into compartments linked to each other. Thus the concept of coastal cells created by Inman and Frautschy (1966) in the 1960s is inseparable from that of sediment budget. The development of coastal structures likely to interrupt sediment transport within a cell therefore necessarily requires that a scientific assessment be previously carried out in order to evaluate the risks incurred in terms of erosion. This approach, in which geomorphologists play an essential part, is crucial to all consistent management and planning policies (Evans 1992; French 2001).

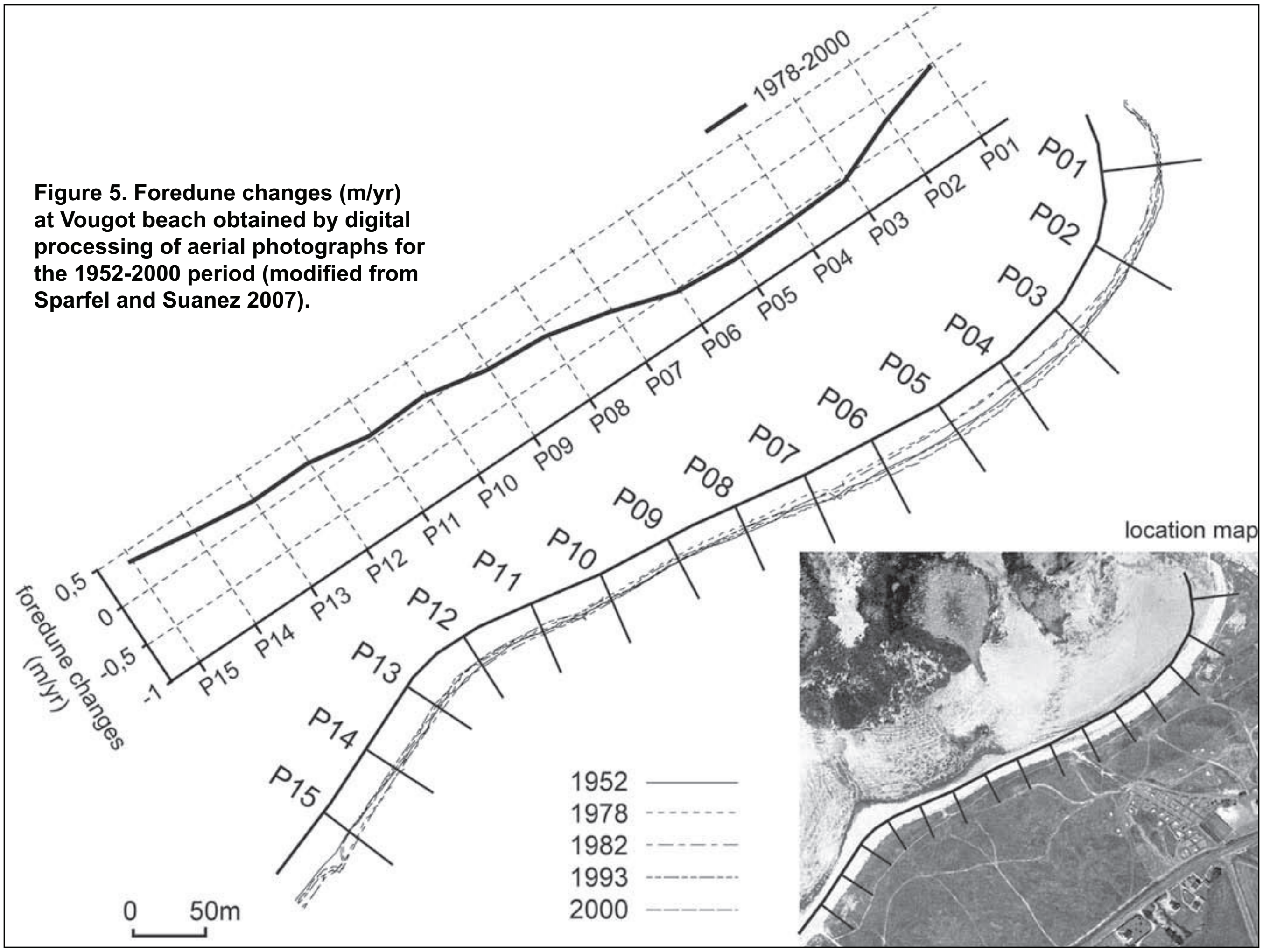

Figure 5. Foredune changes (m/yr) at Vougot beach obtained by digital processing of aerial photographs for the 1952-2000 period (modified from Sparfel and Suanez 2007).

The analysis of morphosedimentary changes shows that the trends measured for three decades have accelerated in recent years. The increase in retreat speeds for the Vougot dune is related to the increasingly significant deepening of the intertidal beach that is eroding. As demonstrated by many authors, this phenomenon favors, through feedback, the increasingly frequent erosion of the foot of the dune caused by the swell in storms (Carter and Stone 1989). It also shows that strategies for the protection of the foredune can only be considered by taking into account the morphosedimentary functioning of the dune/beach system since, as demonstrated by various authors, sediment exchanges between these two environments contribute to the balance of the sediment budget of the entire system (Sherman and Bauer 1993). Differences in behavior observed between past decades and the current period illustrate the difficulties in measuring the most representative trend evolution for the whole observation period (Fenster *et al.* 1993; Crowell *et al.* 1997; Douglas *et al.* 1998; Zuzeck *et al.* 2003). Yet this element is a determining point in establishing the most consistent coastal protection policies both from an economic and environmental point of view (Leatherman 2003; Meur-Férec *et al.* 2008).

Sediment retention on the Centre Nautique beach currently represents a sizeable sediment stock. As shown in Figure 10, the altitudinal difference between the Vougot and the Centre Nautique beaches amounts to 3 m in height. This sand stock could be used to replenish the Vougot beach if a bypass system was developed between both beaches. On this base, it was considered that the Curnic jetty could be made permeable by installing nozzles or partially rebuilding on stilts, in order to allow for sediment transport to resume from east to west. This solution would appear as the most ecological (French 2001), and would avoid resorting to a "hard" engineering solution, such as riprap or geotube.

CONCLUSIONS

The use of DGPS to monitor the recent morphological changes of the dune of Vougot beach proved to be effective. This technique provides very accurate topo-morphological data within the framework of long-term survey. The scientific assessment carried out within the framework of this study showed that uncombined planning policies could produce particularly detrimental effects affecting geosystem functioning "irreversibly." Elected representatives and coastal populations settled behind the dune are concerned with the acceleration of the Vougot beach dune ridge retreat. The issue of coastal protection is now being raised, even though maximum retreat speeds measured (1.5 m/yr) remain relatively low compared to dune width (250-400 m). The most ecological solution would be to facilitate sediment transport resumption by making the Curnic jetty permeable. Sediment retained on the Centre Nautique beach could thereby supply the Vougot beach again and favour its elevation. This pro-

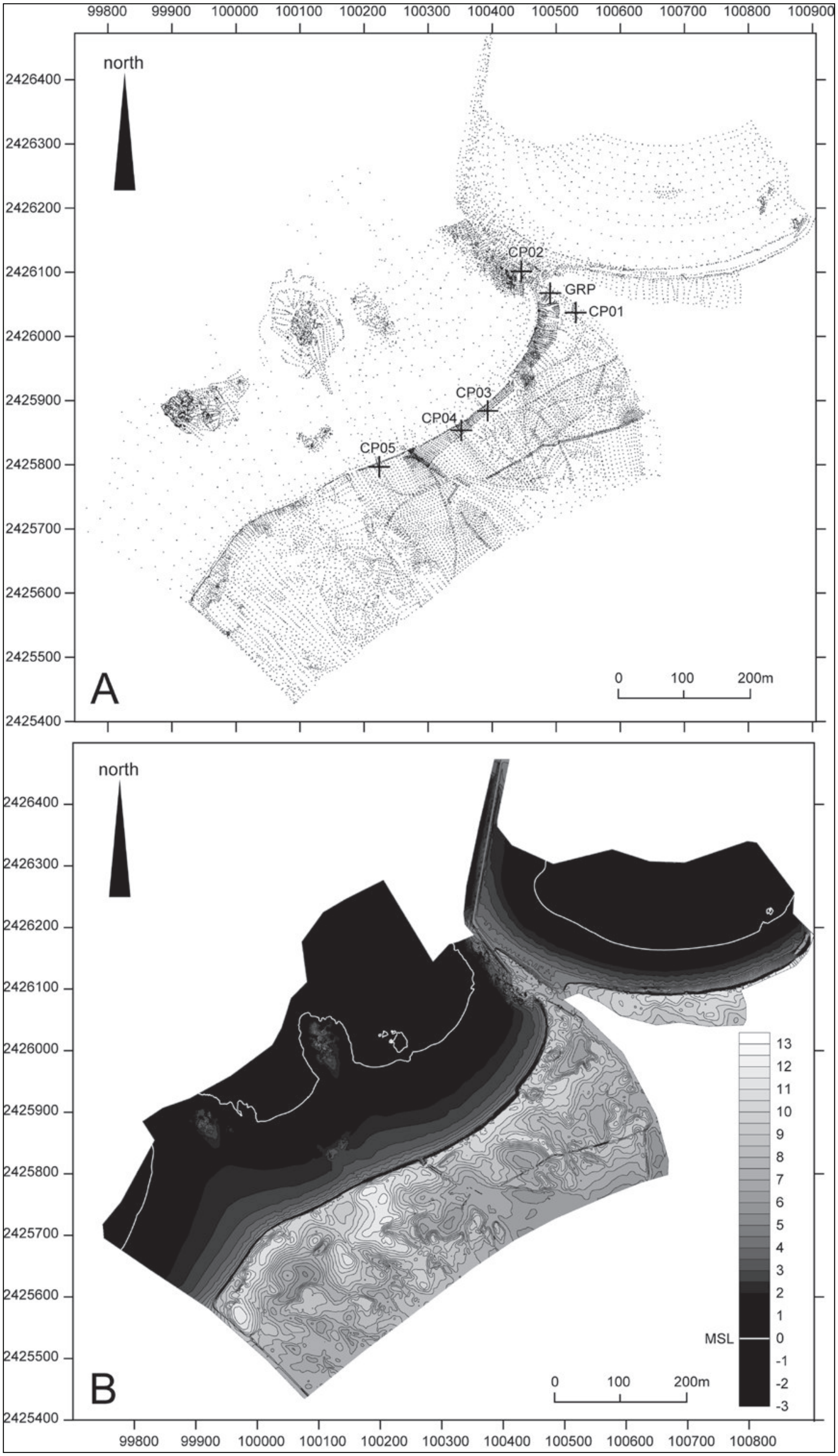

Figure 6. 2005 survey (A) data points (x, y, z) set (B) Digital Elevation Model. Altimetry in meters.

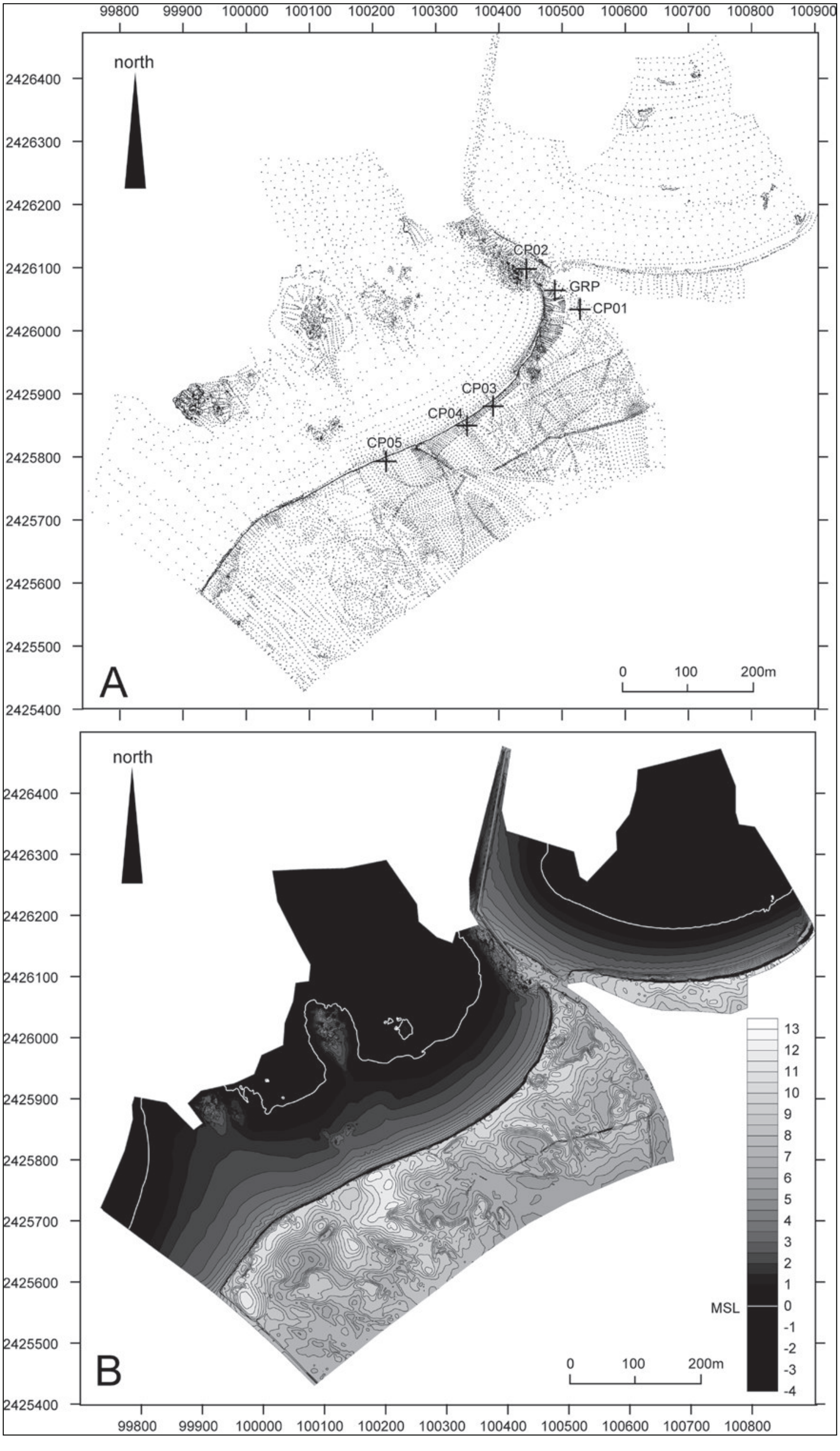

Figure 7. 2009 survey (A) data points (x, y, z) set (B) Digital Elevation Model. Altimetry in meters.

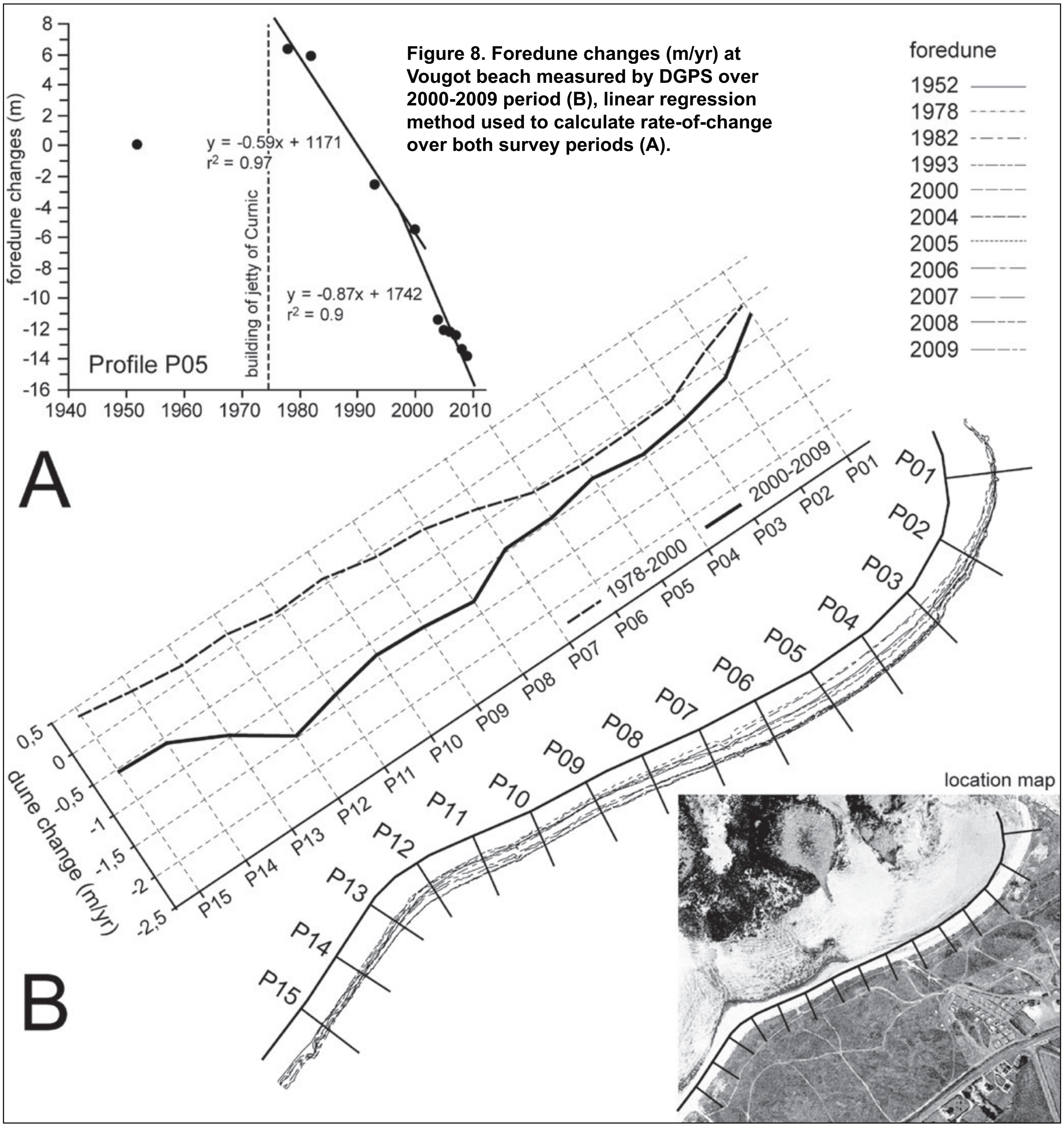

Figure 8. Foredune changes (m/yr) at Vougot beach measured by DGPS over 2000-2009 period (B), linear regression method used to calculate rate-of-change over both survey periods (A).

cess would eventually enable building up the dune and protecting it against marine damage. To this effect, propositions were made to the elected representatives.

REFERENCES

Carter, R.W.G., and G.W. Stone 1989. "Mechanisms associated with the erosion of sand dune cliffs, Magilligan, Northern Ireland," *Earth Surface Processes and Landforms,* 14(1), 1-10.

Clayton, K.M., 1980. "Beach sediment budgets and coastal modification," *Progress in Physical Geography*, 4(4), 471-486.

Crowell, M., S.P. Leatherman, and M.K. Buckley 1991. "Historical shoreline change: error analysis and mapping accuracy," *J. Coastal Res.,* 7(3), 839-852.

Crowell, M., B.C. Douglas, and S.P. Leatherman 1997. "On forecasting future U.S. shoreline positions: a test of algorithms," *J. Coastal Res.*, 13(4), 1245-1255.

Douglas, B.C., M. Crowell, and S.P. Leatherman 1998. "Considerations for shoreline position prediction," *J. Coastal Res.,* 14(3), 1025-1033.

Evans, A.W., 1992. "The application of geomorphology in coastal management studies," *Ocean and Coastal Man.*, 17(1), 47-55.

Fenster, M., R. Dolan, and J.F. Elder 1993. "A new method for predicting shoreline positions from historical data," *J. Coastal Res.*, 9(1), 147-171.

French, P.W., 2001. *Coastal defences: processes, problems and solutions.* Routledge, London, 366p.

Guilcher, A., and B. Hallégouët 1991. "Coastal dunes in Brittany and their management," *J. Coastal Res.*, 7(2), 517-533.

Hamm, L., M. Capobianco, H.H. Dette, A. Lechuga,

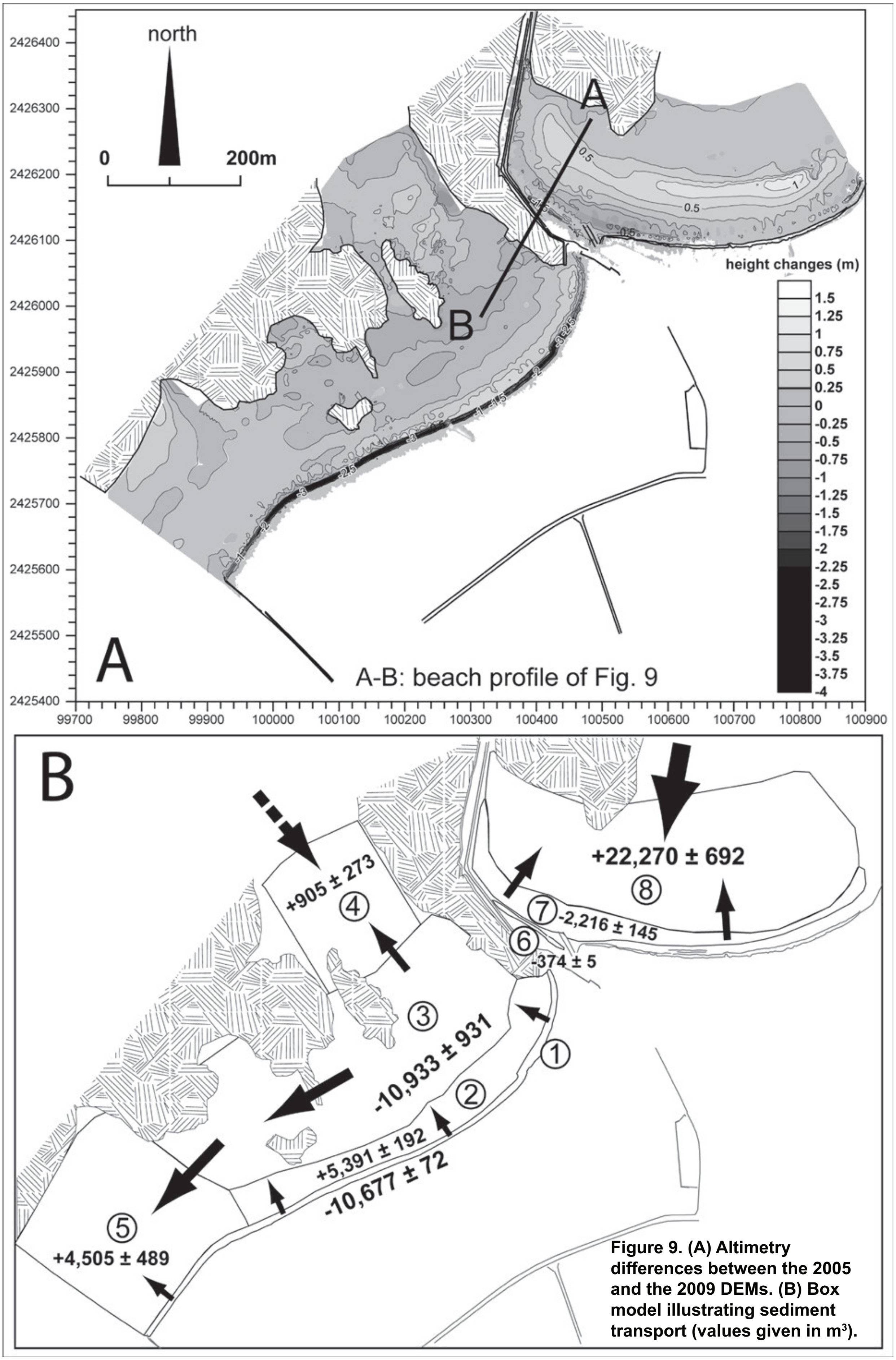

Figure 9. (A) Altimetry differences between the 2005 and the 2009 DEMs. (B) Box model illustrating sediment transport (values given in m³).

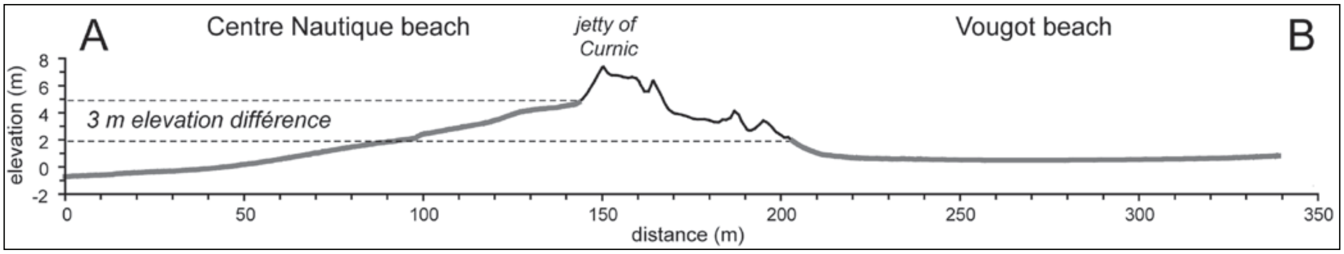

Figure 10. Elevation difference between Vougot and Centre Nautique beaches (see location of profile in Figure 9A).

R. Spanhoff, and M.J.F. Stive 2002. "A summary of European experience with shore nourishment," *Coastal Eng.*, 47(2), 237-264.

Huang, J., D.W.T. Jackson, and J.A.G. Cooper 2002. "Morphological monitoring of a high energy beach system using GPS and total station techniques, Runkerry, Co.Antrium, Northern Ireland," *J. Coastal Res.*, 36(SI), 390-398.

Inman, D.L., and J.D. Frautschy 1966. "Littoral processes and the development of shorelines." *Proc. Coastal Eng. Speciality Conf.*, Santa Barbara, CA: *Amer. Soc. Civil Engrs.,* 511-536.

Komar, P.D., 1996. "The budget of littoral sediments. Concepts and applications," *Shore & Beach*, 64(3), 18-26.

Koster, M.J., and R. Hillen 1995. "Combat erosion by law: coastal defence policy for The Netherlands," *J. Coastal Res.*, 11(4), 1221-1228.

Leatherman, S.P., 2003. "Shoreline change mapping and management along the U.S. East Coast," *J. Coastal Res.*, 38(SI), 5-13.

Louisse, C.J., and F. van der Meulen 1991. "Future coastal defence in the Netherland: Strategies for protection and sustainable development," *J. Coastal Res.,* 7(4), 1027-1041.

Meur-Férec. C., P. Deboudt, and V. Morel 2008. "Coastal risks in France: An integrated method for evaluating vulnerability," *J. Coastal Res.*, 24(2B), 178-189.

Moore, L.J., 2000. "Shoreline mapping techniques," *J. Coastal Res.,* 16(1), 111-124.

Morton, R.A., M.P. Leach, J.G. Paine, and M.A. Cardoza 1993. "Monitoring beach changes using GPS surveying techniques," *J. Coastal Res.*, 9(3), 702-720.

O'Regan, P.R., 1996. "The use of contemporary information technologies for coastal research and management—a review," *J. Coastal Res.*, 12(1), 192-204.

Rebêlo, L.P., P.O. Brito, and J.H. Monteiro 2002. "Monitoring the Cresmina dune evolution (Portugal) using differential GPS," *J. Coastal Res.*, 36(SI), 591-604.

Rieb, G., and P. Walker 2001. "Suivi morphologique du littoral," *Géologues*, 129, 75-79.

Ruggiero, P., B. Voigt, and G. Kaminsky 2000. *Beach monitoring for enhanced decision-making*, Coastal Society 17th Conf., Coasts at the Millennium, 9-12 July 2000, Portland, Oregon, n.p.

Sherman, D.J., and B.O. Bauer 1993. "Dynamics of beach-dune systems," *Progress in Physical Geography,* 17(4), 413-447.

Shuisky, Y.D., and M.L. Schwartz 1983. "Basic principles of sediment budget study in the coastal zone," *Shore & Beach,* 51(1), 34- 40.

Solomon, S.M., and D.L. Forbes 1999. "Coastal hazards and associated management issues on South Pacific Islands," *Ocean and Coastal Man.*, 42(6-7), 523-554.

Sparfel, L., and S. Suanez 2007. "Le vougot à l'épreuve des flots," *Penn ar Bed*, 199/200, 39-49.

Suanez, S., B. Fichaut, and L. Sparfel 2007. "Méthode d évaluation du risque de submersion des côtes basses appliquée à la plage du Vougot, Guissény (Bretagne)," *Géomorphologie : Relief, Processus et Environnement,* 1, 15-32.

Wamsley, T., and B.L. Edge 2001. " Shoreline monitoring program on the Texas coast by real-time kinematic differential global positioning system," *Shore & Beach*, 69(4), 25-31.

Zuzeck, P.J., R.B. Nairn, and S.J. Thieme 2003. "Spatial and temporal considerations for calculating shoreline change rates in the Great Lakes Basin," *J. Coastal Res.*, 38(SI), 125-146.

Table 2.

Sediment budget calculated for coastal cells of Vougot and Centre Nautique beaches (see Figure 9B).

#	Dune of Vougot Beach 1	Eastern Vougot Beach 2	3	4	Western Vougot Beach 5	Dune of Centre Nautique beach 6	Centre Nautique beach 7	8
		Upper beach face	Beach face	Low tide terrace			Upper beach face	Beach face
Surface area	7,200	19,270	93,100	27,330	48,900	500	14,470	69,250
Sediment budget (m3)	-10,677 ± 72	+5,391 ± 192	-10,933 ± 931	905 ± 273	+4,505 ± 489	-374 ± 5	-2,216 ± 145	+22,270 ± 692
		-4,637 ± 1,396					20,054 ± 837	