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Micro- to mesoscale evolution of beaches in response to climatic shift: observation and conceptual modelling (Brittany, France)

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Abstract

In the framework of the European project 'Climate change and coastal evolution in Europe', the microscale (< 1 year) morphological evolution of beaches in Brittany (W France) has been monitored for some years and linked to immediate forcings, the first one being tides (with a 13-m tidal range), and the second storm intensity. For the same sites, a mesoscale (decades) evolution was reconstructed from air photographs and historical data. The evolution is forced first of all by human activities, and secondly by climatic shift: wind direction changes and average wind velocity evolution. These results were used to build and calibrate a model of coastal behaviour. The model is based on a simple sediment cell (input – transit – output) and simulates the movements of volumes of sands under successive morphodynamic processes. Each of these processes is modelled (in terms of volume exchanges) and parameterized by the relevant atmospheric element. Thus, the model is not deterministic but simulates different probabilities for atmospheric events and morphological response. The model runs for one year and produces realistic sediment accumulation values and coastal retreat rates. When run for half a century, results are also quite comparable to the field data. Storm frequency changes appear to be an important element for the evolution, but the main and first forcing is the availability of sediment.

Introduction

The evolution of coastal sandy landforms under climatic change is the object of some concern on the coast of Brittany (W France). In most of the sites no great risk is involved for more than some isolated buildings or polders. However, the erosion of beaches and barriers, and the retreat of dune systems, may strongly affect the touristic basis of the local economy. For example, some archaeological coastal sites, fervently visited by tourists, may disappear.

These factors led local authorities to ask for funding from European institutions to support the study of the present-day evolution of these coastal landforms, in order to predict their behaviour over the next years. This time scale reflects microscale (< 1 year) evolution, according to the terminology used by the European contract 'Climate change and coastal evolution in Europe' (De Groot & Orford this issue).

Although beach monitoring is accurate and useful, it is difficult to separate new (allogenic) change from natural variation. The present movement of the coastline is forced by present atmospheric conditions, especially storms, and the present inertia of sand bodies. This might produce a highly unstable system with a stochastic behaviour. To avoid these difficulties, we have postulated that this stochastic behaviour is scale-dependent and we have chosen beaches from 5 to 0.4 km wide, to filter all high-frequency spatial stochastic activity. The analysis of mesoscale evolution (some decades) has been undertaken to allow for comparisons, and eventually for the determination of trends in the evolution of the coast. Atmospheric elements acting at microscale level are here called

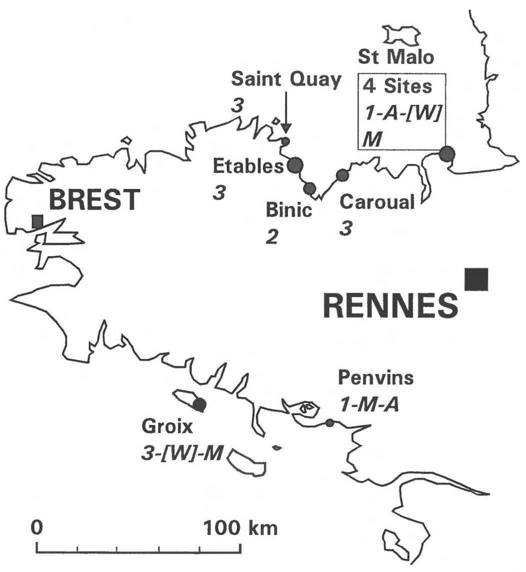

Figure 1. Location of the sites. *1*: site monitored every two weeks for two years; *2*: site monitored every month and a half for three years; *3*: site monitored every two months for six years; *A*: archaeological and historical artefacts; *[W]*: local wind measurements; *M*: Metéorologie Nationale or Marine Nationale weather station. The four sites close to St Malo are Du Guesclin, Petit Port, Le Verger and La Saussaye.

'meteorological agents' whereas those which act at a mesoscale level are here called 'climatic agents'.

The collected data (Regnauld et al. 1996) were used to build a semi-quantitative behaviour-oriented model, that could be calibrated at both the micro- and the mesoscale. The aim of the modelling process was to test the sensitivity of the sedimentary cell to strong meteorological events such as storms. Storms have a significant impact on the beach and dune morphology especially since storm frequency and strong-wind direction have been observed to change significantly during the last 30 years. The sensitivity of the sediment cell to these (30 years) climatic shifts could be a way to approach coastal evolution under actual climatic change, if the 30 years are extended to 50 or more in the model. A longer extrapolation in time would probably meet with some unpredictable changes. The up-scaling of microscale meteorological parameters to mesoscale climatic forcing was the main problem to solve.

Methods and field work results: the microscale

At the microscale level, beach monitoring was undertaken through survey by theodolite while beach sediment was obtained by coring. For two years five beaches on the northern coast of Brittany (English Channel), and two on the southern one (Bay of Biscay) were levelled at varying time intervals (2 weeks – 2 months). The surrounding cliffs, the erosion of which provides most of the sediment, were also surveyed. The sites are shown on Figure 1.

At every site a core was drilled through the beach, until it reached either a peat or rock basement. Each peat layer was dated (Regnauld et al. 1996). Grain-size analysis was undertaken on sediment taken at regular intervals across the beach. At the same time, local meteorological conditions were observed. The beaches were chosen to be very close (1 km) to a Marine Nationale or Météo Nationale weather station, furnishing observations on the wind (direction and speed), air pressure, temperature, precipitation and wave climate. On the beaches themselves, a light set of weather stations was installed for some time, especially during storms in 1994 and 1995.

Microscale evolution of these beaches is partly as follows. Their thickness (measured between the basement and the top of the sand layer, on three reference points across the beach) varies first of all in relation to tidal amplitude, when no strong storm occurs. The sand-thickness variation is correlated with a monthly tidal cycle of two spring tides (sand is brought to the beach) and two neap tides (sand is taken from the beach). The beach profile remains plane, with a slight inflexion at the neap-tide high-water mark. As the tidal range is between 8 (neap tide) and 13 m (spring tide), this is not totally surprising. High-water marks of the neap tides occur more or less at the level where deposition takes place during spring-tides high-water, and the sediment brought by neap tides is then spread across the beach face. The complete mechanism is not fully understood but the regularity of this cycle is quite remarkable.

Beaches vary also according to a longer cycle. They accumulate sand during the summer months and they lose sediment during winter. Although the details of this behaviour are not so clear, accumulation starts during late spring (April) and lasts until December. Occasionally, in October and/or November some losses may happen, but they are compensated by the end of December. In late January, February, and early March, most of the depletion takes place, linked to a series of strong storm events (of which one in 1996 was extreme). In this case the beach profile becomes concave.

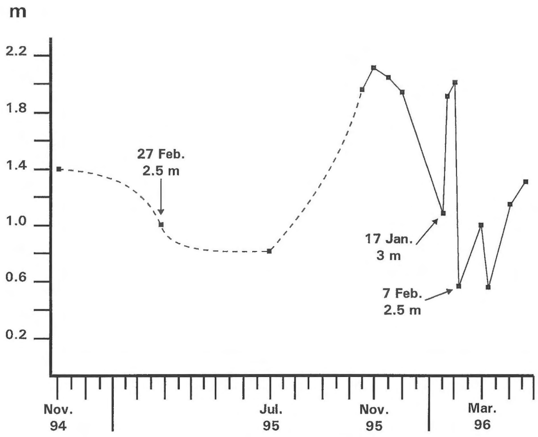

Figure 2. Site of Petit Port: variation of beach-sand thickness in 1995–1996 and occurrence of storms (arrows). Wave height during storms is indicated. Annual average height in this place is 0.8 m. Dashed line indicates part of curve which may have overlooked short episodes (days) of sand input or depletion.

Table 1. Retreat of the periglacial cover on the coastal cliffs in m/yr.

Location		1993/94	1994/95	1995/96	1948/93
St Brieuc:	Binic	1.2	?	1.4	0.1
St Brieuc:	Plouha	1.6	?	1.3	0.1
St Malo:	Cancale 1	0.8 to 1.5	0.6 to 1.6	0.2 to 1.5	0.8 to1
St Malo:	Cancale 2	0.3	0.5	0.4	0.1? to 0.4

Figure 2 shows the evolution of beach-sand thickness and the occurrence of storms during 1995–1996. In as far as the same seasons can be compared, the sand thickness does not vary significantly. Our time series, however, is still a bit short.

If the accumulation and depletion processes on the beaches appear to be seasonal, the input of sediment to the system is quite different. As some sand contains shells of the gastropod *Crepidula fornicata*, it must come from the open sea (5 to 15 m deep), but most of it comes from the winnowing of the collapsed Pleistocene periglacial cover of the surrounding cliffs. The nature of this sediment has been described by Regnauld & Kuzucuoglu (1992) and Loyer et al. (1995). The height of these cliffs varies between 5 and 25 m, with an average of 8 m in the studied sites, while the periglacial cover never exceeds 4 m (average thickness c. 1 m). The cliff-retreat rate varies considerably from one place to the other (Table 1), and is probably related to the stratigraphy of the periglacial deposits, the nature of the substrate, and the intensity of the touristic use of the sites. The rhythm and time scales of the erosion are unclear. Most of the biggest erosional events occur in winter after heavy rains (January 1995 especially), forming flows deposited in conical and lobate features on top of the beach. The scattering and destruction of these lobes is linked some days after to very high spring tides, and not to ordinary waves. During summer, most of the erosional events are block falls triggered by drought-induced fractures. From one year to the other, the volume of this input varies from c. 1 to 10 m^3, for a 100-m length of shore. At each site, two to five cliff sections were measured. The 1996 data are limited to winter and spring.

The output of the system is represented by beach-sediment loss to the sand banks in the open sea (Augris et al. 1996) and to dune accretion. Some coupled wind-speed and sand-movement measurements have been run in sites as Groix and Hoedic (small island, SW of Penvins). Unfortunately, they cannot be extrapolated easily in space, due to the changes in grain size and beach (and air) moisture. To avoid this problem of spatial discontinuity (Sherman & Bauer 1993a, b), dune accretion has been estimated through levelling assuming that sediment came from the beach.

Methods and field work results: the mesoscale

Mesoscale evolution was reconstructed based on aerial photographs and a historical analysis of human occupation. The upper parts of some cores (radiocarbon dates of 150 BP to 1900 BP, Regnauld et al. 1995) have also been used if they provided information on human activities and ancient 'management' of the dunes.

The last 2000 years were characterized by a constant retreat of the dunes landward. Fresh-water peats (1900 ± 70 BP) are found 10 m seaward of the present dunes in La Saussaye. In Le Verger and Du Guesclin, Celtic pottery and tools are found below the present dunes, intercalated in fresh-water muds (Cocaign 1993, 1994). On the southern site of Penvins, mediaeval ditches draining a former back-barrier salt marsh are located below the contemporary tidal beach.

The first maps of the 17th century are not always accurate enough to allow the exact calculation of retreat rates, but they clearly establish that at that time the dunes were seaward of their present position. Aerial photographs since 1943 are available and allow retreat rates to be calculated. Our results are very comparable to those of Meur (1993) and Yoni (1995) who worked farther west in Finistère, and to those of Costa (1995) who studied Normandy retreat rates.

A regional view of microscale evolution is given on Figure 3, that shows the measured rates of retreat

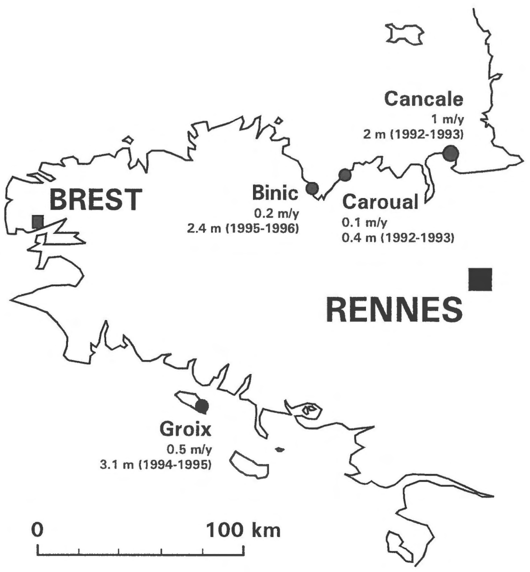

Figure 3. Rates of retreat of dune systems. Annual mean rate from aerial photographs between 1943 and 1996. Extreme annual retreats (averaged over two years) for two exceptional years are shown. Sites are exposed to wind direction changes shown in Figure 4.

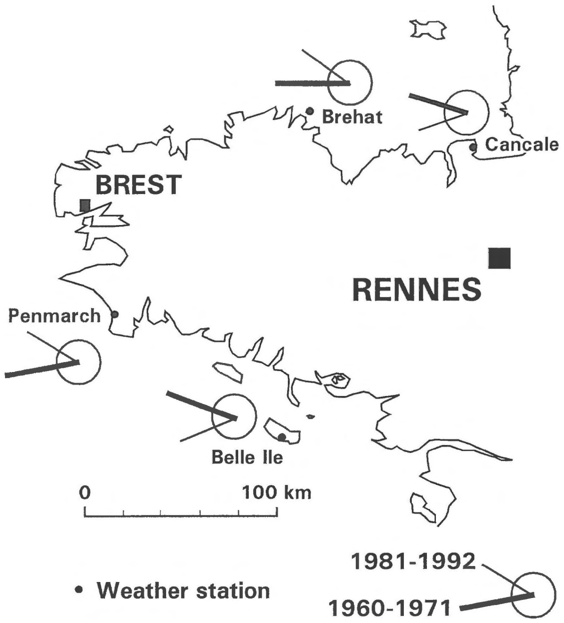

Figure 4. Storm wind (> 18 m/s) direction changes between 1960 and 1992.

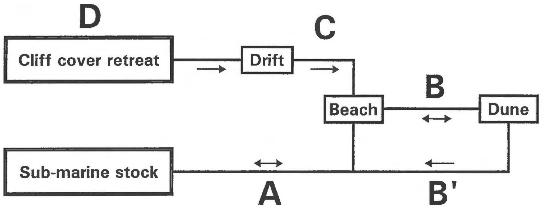

Figure 5. Schematic model of the sediment cell. See text 'A conceptual model' for explanation of links A to D.

(field work) in our sites in Brittany. Annual retreats for two recent years are compared with average rates during approximately the last 45 years derived from aerial photographs.

Retreat rates at the mesoscale are linked to two main forcing factors. The first and more important is the human impact related to extraction of sands during the 1942–1980 period when some dune fields were totally destroyed. Since 1980 (1985 in some sites) extractions are banned and dunes protected (or even rebuilt). But these protections resulted in an unexpected behaviour: the dunes were building-up and retreating at the same time. Vertical accumulation rates vary between 0.01 and 0.25 m/yr and retreat rates (measured on the crest) are below 0.1 m/yr. Variations are important from one site to another, but accumulation rates do not vary much from one year to the next at the same site.

The second main factor is climatic shift. The higher retreat rates are always associated with places where local storm-wind directions have significantly shifted during the last 30 years. Storm waves have also changed accordingly. Most of the coastal features that were adapted to an ancient direction of wave action have been eroded and they are hoped to adapt themselves to the new wave direction. The wind evolution and its effects on erosion have been described in Devoy (1995) and in Tabeaud (1996). During the 1960–1993 period, the average wind speed in the region has been increasing by 10 to 15%. Two periods of high increase were identified: before 1969, and between 1977 and 1982. The beginning of the 90s is probably a new period of wind speed increase. The form of this increase is unique: the calms periods are slightly decreasing in length; the very strong storms are not more common, but the relaxation time between ordinary storms is shortening. At the same time, the direction of storm winds has changed: from west to northwest at Penmarch and Brehat, from northwest to southwest at Belle Ile and Cancale (Figure 4).

A conceptual model: from microscale meteorological forcing to mesoscale climatic evolution

The results have been used to interpret more precisely other site studies (Regnauld et al. 1995, Guilcher & Hallegouet 1991). They have also been compared with the evolution of other sites where similar features are found, though the environment is different (Orford et al. 1995, Bray et al. 1995). A conceptual model of the sediment cell was produced based on a number of links that relate to sediment volume changes (Figure 5).

Link A represents the landward and seaward transport, and is varying at a microscale rhythm (annual variability) but the year-to-year beach volume remains more or less constant.

Link B represents a very regular vertical accumulation rate while B’ shows a very irregular horizontal retreat rate. Both are very sensitive to human management. In case of very strong storms the dune is eroded and sediment goes back to the submarine stock.

Link C represents the movement of the sand from the cliffs to the beaches but only in a quantitative, volumetric fashion. Directions of longshore drift (and their changes along with wind direction shifts) are known from field data. Volumes of sand have to be estimated on the basis of year to year comparisons. The rhythm of the movement remains unknown at a microscale level. From Ile de Groix we know that cliff material reaches the beach after 3 to 4 months, whereas in St Brieuc bay it is after 2 to 3 days.

Link D represents a beginning or end state and not a link per se. It is well documented in terms of volume and cause but not of frequency.

This simple model has to be parameterized. From our field work we know that microscale behaviour is linked to local meteorological forcing whereas mesoscale evolution depends on regional climatic characteristics. Two levels of atmospheric forcing are effective, but they do affect different elements of the coastal system. Two possible types of models were considered (Figure 6). The first type uses a deterministic approach: climate shift is modelled and then applied to the sediment budget system, directly forcing the volume of sediment. The second type is far less deterministic. Each morphological process is allowed to adapt itself to new atmospheric forcings and then to moving sediment. Two processes may react in different ways (higher waves bring more sediment onto the beach, but remove also more sand from the foredune). This type of model allows for more climatic variability (Dubreuil 1992) because it is quite often based on simulation and series of data, and not only on synoptic meteorological mechanisms.

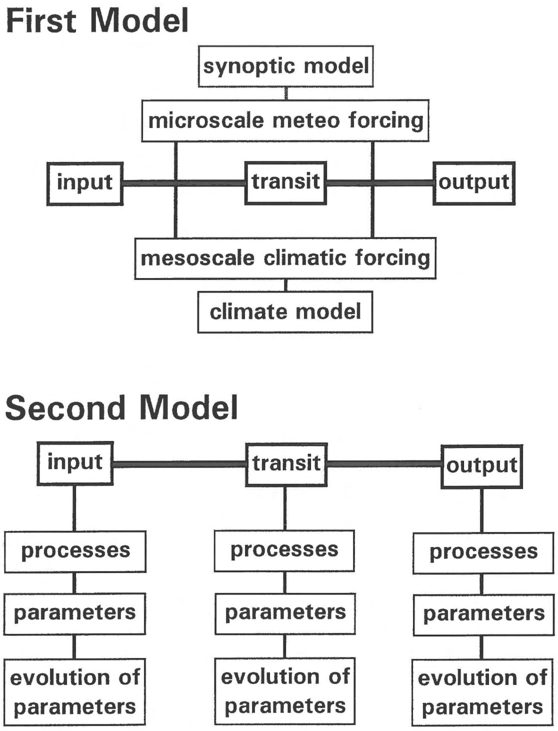

Figure 6. Two possible models describing the influence of climate on the coastline. The first one takes climatic (mesoscale) and meteorological (microscale) models as two different forcings and applies them to a sediment cell budget. The second considers a step-by-step approach and searches out how each process depends on a precise atmospheric element independent of its scale. In the first type of model, morphological behaviour is a deterministic result of climatic change. In the second, morphological processes follow their own way after they have adapted themselves to atmospheric change.

The second type of model was chosen because the aim of this modelling was to simulate the behaviour of the system and to appreciate the sensitivity of the response to the frequency of storms.

A first set of atmosphere-related parameters was built to describe the input part of the system. It includes sea-level change as well as high rainfall occurrences, and their impacts on periglacial cliff-cover retreat. A second set of parameters was applied to the output part of the system including wind speed, wind direction, and their changes. These sets were then associated with the human use of the coastal system.

The main part of the model concerns the central part of the system. Many observations and detailed studies have demonstrated that this part, the movement

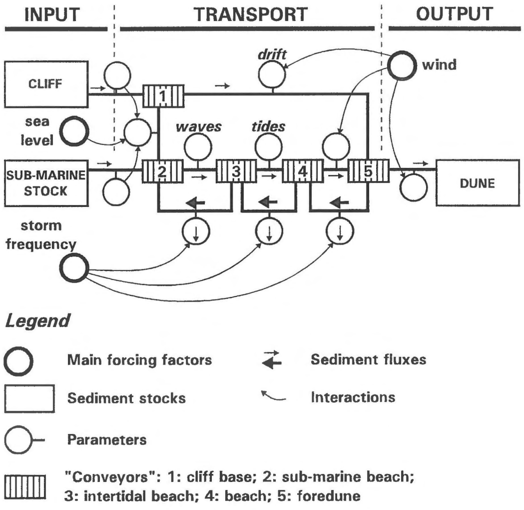

Figure 7. Logical structure of the model (Stella software). Interactions are modelled by equations and series of data. See text 'Semi-quantitative model'.

of sand from the subtidal beach to the highest part of the foredune, is linked to a complicated combination of tide, wave, wind and storm microscale effects, of which no model is available. It was therefore decided to proceed step by step. The process mechanism varies according to the type of 'cyclic' or 'probabilistic' variation that was observed in the atmospheric forcing, which is introduced in the model as a set of data. Transfer from the submarine stock offshore to the subtidal beach is mainly forced by the wave climate, whereas the transfer from this subtidal beach to the tidal beach is forced by local waves. The beach profile varies according to the tides and the tidal beach feeds the upper beach, then the foredune. However, storms will remove sand from any of these places to any of the offshore ones. Finally the interactions between these three sets of processes are taken into account.

Numerical relations between the different components of the model belong to several types. Some meteorological events are described by a probability of frequencies while others are described by intensity. The latter is for instance the case of the wind which determines longshore drift. Tides and ordinary waves on the other hand, are described by trigonometric functions of which the period is chosen to fit the time step of the simulation. Climatic evolution (inducing sea-level change) is approached through linear ramp functions. The effect of these atmospheric elements on processes is simulated by empirical equations, relating input and output of sediment volumes.

Semi-quantitative model: calibration and results

Figure 7 shows the model built with the Stella software in the way recommended by Hannon & Ruth (1994). This software asks for 'n' input values, 'm' output values, and 'steps' in between. These steps may act as 'black boxes' (white rectangles) or as 'conveyors' (rectangles with vertical bars inside). When they act as black boxes, the equation has to be written in such a way as to calculate the output according to the input and the possible parameters (circles). When they act as conveyors, a capacity (input per unit of time), a duration for the process (such a quantity will stay in for so long), as well as two ways for the output have to be assigned. The bulk of the output goes farther 'downstream' while a smaller part 'leaks' (leakage fraction has to be declared) allowing for feedback effects.

In the entire model as shown in Figure 7, straight arrows represent the movement of sediment, while curved arrows represent numerical relations. The landward movement is to the right and the seaward one is to the left. Thus, the movement landward is from one conveyor to the next and is parameterized by thin arrows and white circles. The movement seaward is from one conveyor to the previous one and is parameterized by white circles with a down-pointing arrow inside. Each step in the central part of the model (between the conveyors cliff base and foredune) may be considered as some successive feedback-regulated system (Cowell & Thom 1993): the amount of sediment which is locked-in for each time step has a great variability; the output modifies the input but the average value over long time periods does not change if parameters are fixed. In this respect, the feedback mechanism acts against sediment transport to the dune and is responsible for some sort of equilibrium of the beach.

The retreat rate is a relation between the amount of erosion (mainly due to storms) and the accumulation in the dunes. This implies that no erosion takes place in the dunes when no storms happen. If human activities extract sand from the system, some new element should be added. From the above, it should be noted that this model is more a numerical behaviour simulation than a deterministic model.

The model was first run at a daily time step for one year, then at a weekly time step for the same length of time. Tides, waves, wind, and sea-level changes (and associated functions) have to be changed from daily values to weekly values (the tides are simulated by a sinus function). Results are given in Figure 8. The

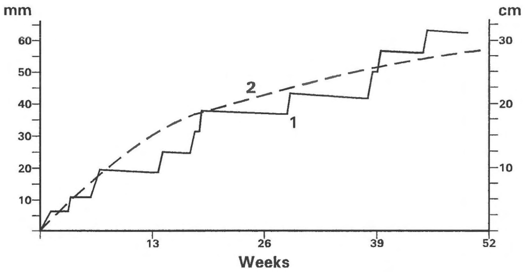

Figure 8. Simulation for one year at a weekly time step. Left Y axis is cumulated cliff retreat (mm); right Y axis is cumulated vertical dune accretion (cm). Results are quite realistic, with c. 62 mm retreat (line 1) and c. 27 cm accretion (line 2). The average duration between two erosional events (retreat) is 8 weeks, which is a good simulation of the actual observed rhythm. Between two events, the retreat is interrupted. No extreme storm was modelled during this simulation.

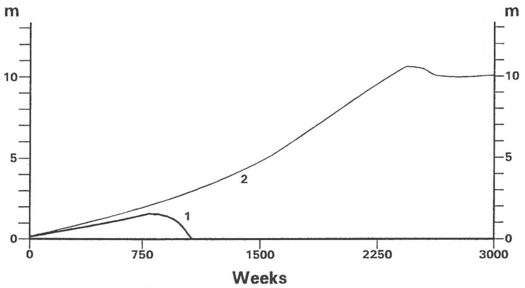

Figure 9. Simulation for 57 years. Y axis: retreat and acccretion, respectively. In this case retreat is a series of yearly values whereas accretion is a cumulated value over the whole period. Retreat (line 1) reaches a maximum at c. 15 years, then slows down as the dune system has grown high enough to withstand the biggest storms. Accretion (line 2) goes down after 2300 weeks (44 years) because the cliff material is totally removed: the sediment input is not sufficient any more and erosion resumes.

model assumes a 100 × 100 m area. The part of coast which is simulated is a 100-m-long beach, with a dune area extending 100 m inward from the high-water line. The input comes from a 100-m-long and 100-m-wide part of a cliff uniformly covered by periglacial drift. The distance between the beach and the cliff is shorter than 0.5 km and the cliff is supposed to be adjacent to the beach with no headland in between.

A calibration test was run by simulating a year-long evolution. Results given by the model were compared to field data (retreat below 0.1 m/yr and accumulation below 0.25 m/yr). The simulation of a year-long evolution is clearly quite satisfactory as it produces both reasonable figures and acceptable behaviour. At the end of the year, the simulated retreat is c. 6.2 cm and the simulated accumulation on the dune is c. 27 cm which is realistic. The curve (number 1 on Figure 8) represents the variation of the retreat. It shows successive steps, since the retreat is high under some bad weather conditions, and successive platforms develop when no retreat takes place and some accumulation partly compensates it. The retreat events are separated from each other by periods of 6 to 8 weeks. This simulation describes reasonably well the inter-annual variability of the dune response to atmospheric changes. At this one-year-scale level, no climatic shift is visible although sea level has risen by 0.5 mm. This comparison between a year-long simulation and field data was considered as a good calibration.

The model has also been run for longer time periods (from 19 to 57 years or 1000 to 3000 weeks). As the time step is one week, the number of steps is expressed in weeks and does not necessarily give a full number of years. The results are always comparable to those of Figure 9 which represent a 57-years simulation. Sea level rises in a linear way (1 mm/yr). The dune (line 2) first accumulates sand, then remains almost stable. The retreat reaches a maximum after 800 weeks, then slows down to very low values, though it never really stops. This can be explained in the following way.

In this model the amount of energy available for erosion is limited. It corresponds to the biggest possible storm with the highest tide and strongest wind, both considered as one extreme event. For this simulation, values have been taken from the three big storms of 1987, 1990 and 1996. Such an extreme event can remove a limited, though important, amount of sediment. When the dune system is small, this quantity may represent a large part of it. When the dune system has accumulated more sand, and is large, this same quantity may be relatively small and the retreat is not important. As this model does not allow a variation in the maximum-strength storm during one single simulation, the results are always showing a high retreat at the beginning when storms are removing high percentages of the previously accumulated sand, then a stabilisation when the dune is big enough to withstand strong storms, and finally a decrease of the retreat when accumulation is so high that retreat becomes almost negligible. This is considered to be a 'stabilisation time' needed by the dune to withdraw landward and to grow up high enough to withstand strong storms. The size of the dune at the moment when the retreat rate begins to slow is called 'equilibrium volume'. The changes in this volume could probably be called 'variability' as they occur later without affecting the dune's ability to withstand storms. Though discussion of these terms should describe their exact meanings in relation to mesoscale evolution, this might be a specific example of what has been described by Carter & Woodroffe (1993) as an 'evolution' of the coast 'towards an organised morphodynamic system' being able to 'control its own environment. It may well move from a less stable to a more stable one, capable of absorbing a far greater range of energy, sediment or information input'.

After a long period (2250 weeks or 43 years), accumulation slows down because the input from the cliff is all spent. No more material is available. We have not run the simulation long enough to see what would happen afterwards, and whether the retreat rate would rise again. It is not sure that the model would be useful over a longer period, as some sediment might be lost and chaotic events might occur. Still, this simulation over half a century is quite acceptable if compared to our field data: the maximum retreat rate would be 1.2 m/yr and the dune would reach a relative altitude of 11 m. These figures are quite realistic.

The model simulates reasonably well the possible evolution of the dune systems on a mesoscale and on a microscale basis.

Discussion and conclusion

The local applicability of this model may allow its use for simulations involving other parameters. At the same time, this applicability must not hide some important limits that have to be corrected in the future.

A set of simulations was undertaken with different values for storm frequency. Our field data and statistical analysis tend to give a strong importance to the effects of storms on erosion. The model translates this into the 'leakage fraction' of the conveyors. This aspect of the simulation may be affected by any change in the storminess pattern. For each simulation, three different patterns of storminess were chosen. The first pattern simulates the present frequency of storms, the second has a lower, and the third a higher frequency. The diagrams present some of the most interesting results (Figures 10A–C). In any of these cases the model always assumes a net transfer of sediment into the dunes and the sediment which temporarily goes offshore is always able to go back to the coast. No structural seaward losses will occur.

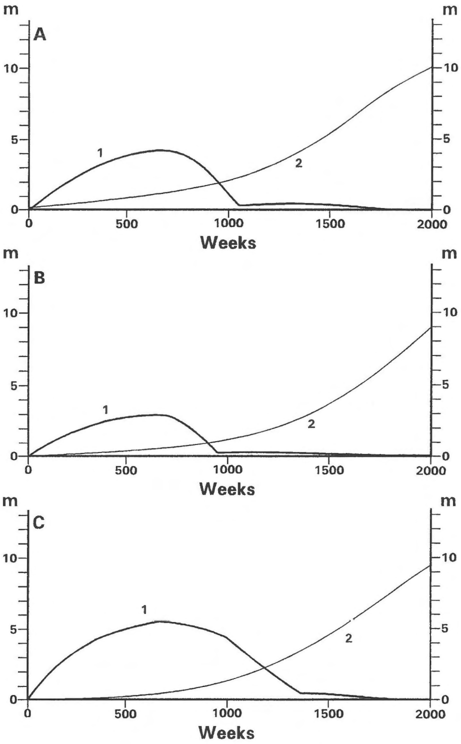

Figure 10. Simulation results for different storm frequencies. Same Y axis as on Figure 9. Time steps are one week, duration is 38 years and 3 months (2000 weeks) and sea-level is supposed to rise by 0.5 mm/yr. In A, the storm frequency is similar to present, with a very big storm every 7 years. In B, big storms occur every 10 years, and in C, every 5 years. In the three cases, the amount of moved sediment is more or less the same (vertical accretion is c. 9.8 m, line 2) but the maximum annual retreat (line 1) varies between 2.6 and 5.7 m.

Storm frequency is the easiest way we have to simulate climatic evolution. No changes in wind direction were introduced in the model at this stage. Within these limits, the diagrams establish that storm frequency is important, but that the main factor is the total amount of available sediment. In all different situations (storm frequency, sea-level change, and their combination) the final result in accumulation is linked to the input of sediment. Erosion of sediment from the cliff cover and its subsequent transport onto the beaches by longshore drift are the first forcing agents. As long as the system is fed, it will withstand sea-level rise and climatic change. These simulations show that in the end, the volume of the dune is more or less the same in all the cases and its height is always around 9 m. This result is acceptable because 10 m is the average height of artificially reconstructed dunes in the St Malo area (Rotheneuf and La Touesse for instance) and is considered to be an optimum for management and protection against surges.

The simulations also show that this height is reached in different situations. The maximum retreat rates calculated for each situation vary from 2.6 to 5.7 m/yr. In no way these values are average rates. They are maximum rates associated to very stormy years occurring exactly when the dune is just beginning to reach its 'equilibrium volume'. Higher rates are associated with the highest frequencies and longest 'stabilisation periods'. This seems to emphasize the importance of local conditions, exposure to storm waves especially, as wind direction might change again. These scenarios of climatic shift are obviously presenting very serious challenges to managers and planners. They also expose the main limits of our model.

Several important physical elements have not been included: grain size for instance. In our sites grain size is not an important problem, as it varies considerably from one tidal condition to the other and from one beach to the next. The most reasonable way to simulate a general situation is to postulate a very rough average grain-size value. Any detailed data would (probably) simulate one specific beach better, and offer bad results for the others.

The absence of morphological data is a much more difficult problem. The retreat of a barrier system as sea level rises is known to depend strongly on the substrate slope (Hesp & Thom 1990, Cowell et al. 1992, Roy et al. 1995). Our sites are situated in small bays with a metamorphic or granitic substrate of which the topography is irregular as it has been shaped by periglacial processes, at least during oxygen-isotope stage 2 when sea-level was some 110 m lower than today. We do not have a precise palaeo-topography of the substrate in each site, but this type of data should be included in our next simulations. Our model must be considered as a base for further developments, based on more precise field work and new data rather than on new types of equations.

Although this model lacks some precision it is an interesting tool to begin to simulate the effects of climatic shift on beach and dune evolution. In western France climatic shift appears to look like a series of events following one another (storm surges, summer temperature increases, thunder storm frequencies, strong winds ...) with ever shortening intervals. Climatic shift does not appear exactly as a trend, but as a new input of high-energy events with a short relaxation time between them. As far as their impact on shore processes is concerned the question is to know whether coastal features are able to withstand this new frequency of events. Today, they cannot resist and they retreat. The model tends to establish that an important stock of sediment is needed to strengthen them so they can cope with an increasing frequency of high-energy events.

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