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“Climate Change Impacts and Adaptation for Coastal Transport Infrastructure in Caribbean SIDS”

Method to estimate touristic beach erosion

By

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Method to estimate touristic beach erosion

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Synopsis

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3. Analytical models
4. Numerical models
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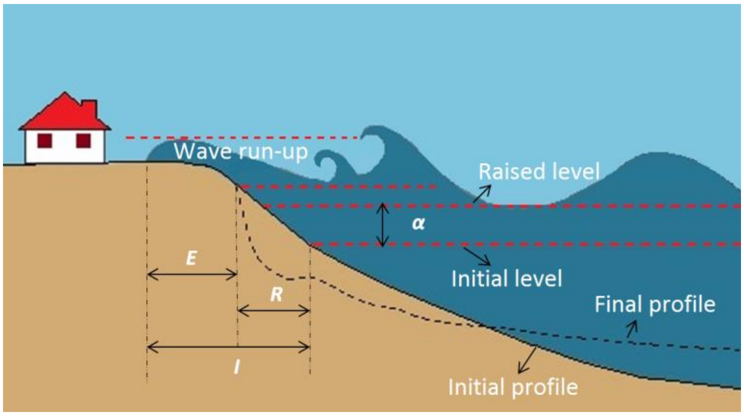
The nexus Transport/Tourism – Importance of touristic beaches

The tourist industry in St Lucia is based on the “3S” model (Sea, Sand and Sun). A most critical component of 3S tourism is the availability of beaches that are environmentally and aesthetically sound and retain adequate carrying capacity

Carrying capacity is defined as the “maximum number of people that may visit a tourism destination at the same time, without causing destruction of the physical, economic and socio-cultural environment and an unacceptable decrease in the quality of the visitor’ satisfaction”

Beach erosion due to e.g. sea level rise might reduce significantly the carrying capacity and the quality of the beaches as environments of leisure and consequently the attractiveness of the country to tourism and travel, <u>resulting to significant international travel expenditure loss.</u>

Beach response to sea level rise



Sketch showing beach response to sea level rise. If the sea level rises by α, beach face sediments are eroded and transported offshore to be deposited at the seabed, resulting to a shoreline retreat of R.

Beach response to sea level rise

Long- and short-term beach erosion

Beach erosion due to the sea level rise can be differentiated into

- Long-term erosion i.e the irreversible shoreline retreat (and/or drowning) due to the long-term sea level rise
- Short term erosion caused by storms/storm surges (may or may not result in permanent shoreline retreats)

Beach response to sea level rise

Diagnosis/prediction of beach response to (wave forcing) and sea level changes

Basic principle: when the sea level and/or the wave forcing changes the beach profile is forced to change to a new profile

Beach erosion/retreat models can be differentiated into

- Analytical/parametric models
- Numerical/dynamic models

Analytical models

The analytical (static) models can estimate beach retreat due to long-term sea level rise.

beach erosion/retreat is assessed through the solving of one or of a system of equations

Advantage: simplicity

Disadvantage: they can not successfully describe beach changes due to high frequency events and/or longshore sediment transport

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Analytical models: Procedure

Estimation of beach (shoreline) retreat under sea level rise

Data → Parameters → Results

Data

Offshore wave height H_0 and period T_0

Initial bathymetry or beach slope

Parameters

B_h, berm height above the sea level

h_c, closure depth

l, the cross-shore distance to closure depth

h_b, wave breaking depth

W_b, surf zone width (distance from wave breaking to shoreline)

Analytical models

Results

Estimation of beach retreat s under sea level rise α

Numerical models

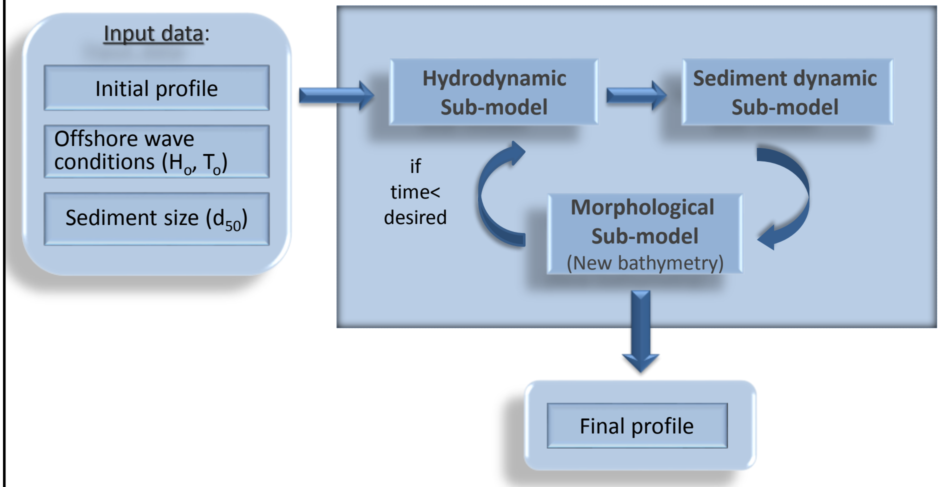
The numerical (dynamic) models can estimate beach retreat due to short-term sea level rise (e.g. storm surges).

They compute at different locations of the cross-shore profile and they simulate beach morphology evolution in each time step

They contain the following modules

- Hydrodynamic module
- Sediment dynamic module
- Morphological module

Numerical models

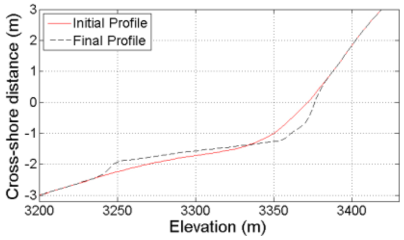


Numerical model flow diagram

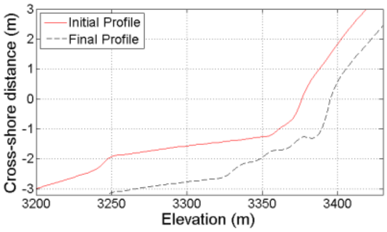
Numerical models

Beach retreat predictions under storm surges

Ho = 2.8 m, T = 8 s, sediment size (d50) = 0.28 mm.
Beach retreat of 4.8 m after 5-hour simulation



Same wave conditions
Short-term SL increase high tide + storm surge = 1.2 m
Beach retreat 19.8 m



Methodology

Digitization
Web/GIS

Record/ Analysis of spatial characteristics (e.g. max. Width, density of backshore assets)

Comparison of max. width with model ensemble projections

Impacts on 'dry' beach width (carrying capacity) and on backshore infrastructure/assets

Methodology

Collection of input data

Data	Source	Publicly Available	Expertise Needed	Required Software or Other Resources
Beach location and width	Manually digitized from Google Earth	Yes	None	Google Earth Pro, Arc GIS
Beach slope	Plausible range of beach slopes	No	None	None
Wave conditions	Plausible wave condition range based on ERA-INTERIM wave data (1979-2015)	Yes	Manipulation of NetCDF Data	Software for Manipulating or Displaying NetCDF Data
Median sediment size D_{50}	Optical information (Google Earth and other available information)/collated from scientific literature/reports	Yes	None	None
Mean Sea Level Rise Projections	Integrated Climate Data Center - ICDC	Yes	None	None
Episodic extreme sea Level Projections	Joint Research Centre (JRC)	Yes	Manipulation of NetCDF Data	Software for Manipulating/ Displaying NetCDF Data

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Methodology

Ensemble modeling

(i) Seven cross-shore (1-D) morphodynamic models used to create 2 ensembles:
  - A long-term, consisting of 3 analytical models (Edelman, Bruun, Dean) and
  - A short-term (storm surge), consisting of 4 numerical models (Leont'yev, SBEACH, Xbeach and Boussinesq)

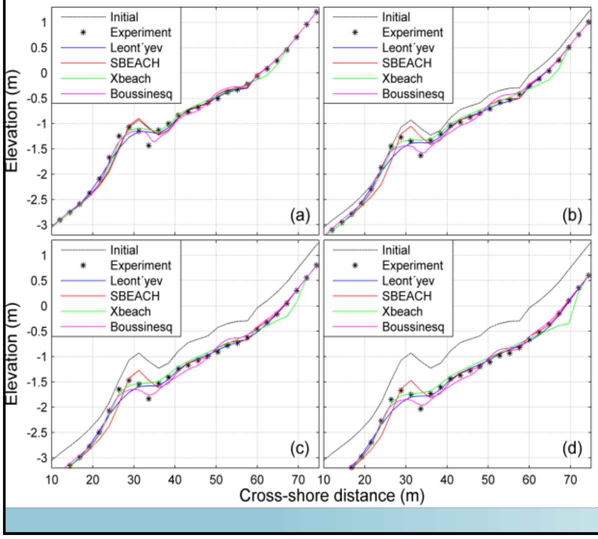
(ii) All models were applied using linear profiles. Experiments were carried out for:
  - different profile slopes (1/10-1/30)
  - for varying offshore wave conditions (H=1 – 4 m, T=4 – 8 sec)
  - sediment texture (d_{50}=0.2 -5 mm)

For each set of environmental conditions 11 SLR scenarios (up to 2 m) were tested (Totally 5500 experiments).

Methodology

Ensemble modeling

Validation of the models



Profiles by numerical models plotted against results from physical experiments at the GWK wave flume (Hanover): (a) initial/present water level; (b) water level rise of 0.2 m; (c) rise of 0.4 m; and (d) rise of 0.6 m. Both numerical and physical experiments were set up for the same initial (non-linear) profile. (Monioudi et al., 2017, NHESS)

Methodology

Outputs of the approach

Final “outputs” of this approach are:

(i) potential ranges of beach retreat/erosion and temporary inundation/flooding,

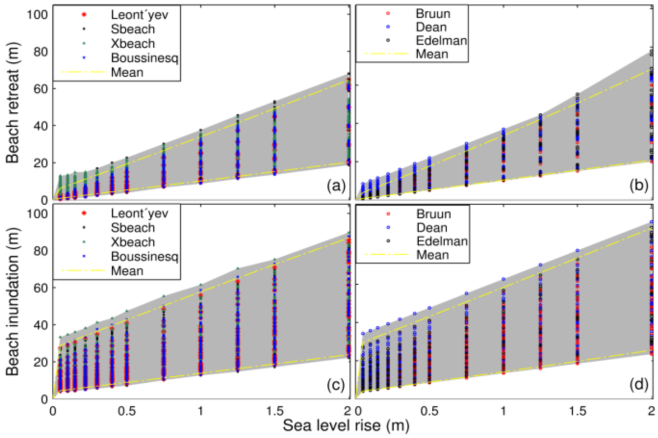
(ii) ranges of decreases in 'dry' beach widths projected through the comparison between the ranges of beach retreat/erosion (*S*) and the maximum widths of the Saint Lucia beaches,

(iii) ranges in beach temporary inundation/flooding, estimated by the comparison between the ranges of combined beach retreat and wave run-up excursions (*S(i)*) and the beach maximum widths and

(iv) numbers (N) and percentages of beaches where backshore infrastructure/assets are projected to be affected by beach retreat/erosion and flooding.

Methodology

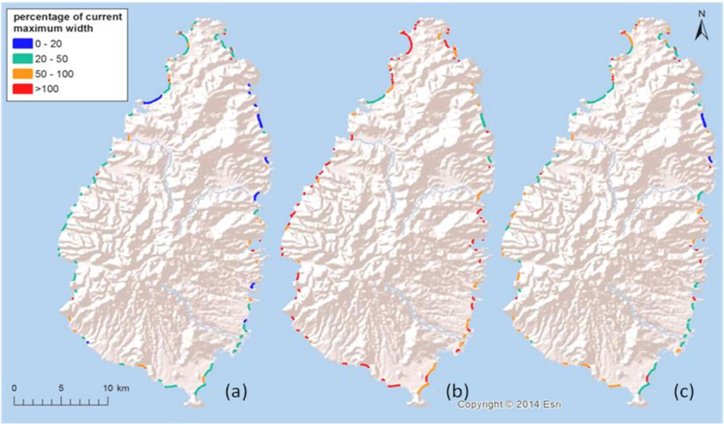
Outputs of the approach



Projections of beach retreat/erosion (a and b) and temporary inundation/flooding (c and d) due to short-term (a and c) and long-term (b and d) SLR. Projections are for different beach slopes, sediment sizes and wave conditions. The means of the highest and lowest projections of all models in the ensembles are shown as yellow stippled lines.

Methodology

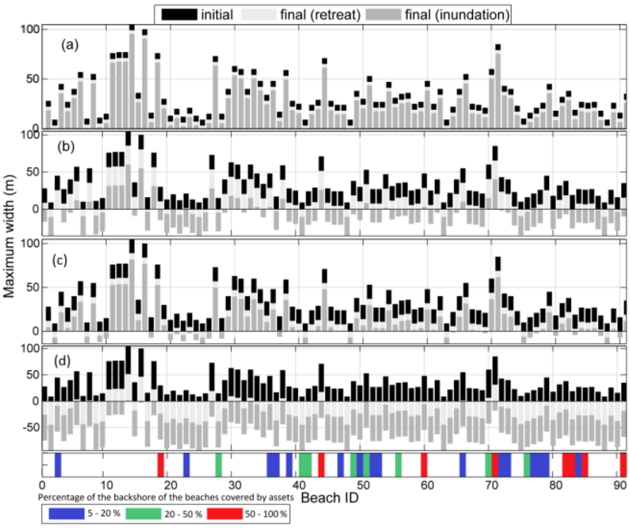
Outputs of the approach



Projections of (a) and (b) minimum and maximum beach retreat under a combined SLR of 1.2 m (for the year 2040) and (c) minimum beach retreat under a combined SLR of 1.8 m (for the year 2100), showing beaches projected to retreat by distances equal to different percentages of their initial maximum widths

Methodology

Outputs of the approach



Minimum and maximum retreat and flooding of Saint Lucia beaches for different SLR scenarios on the basis of the low and high means respectively of the ensemble projections. a) and b) Minimum and maximum retreat and flooding under a MSLR of 0.56 m. c) and d) Minimum and maximum retreat and flooding under a combined lon- and short-term SLR of 1.56 m (see text). Final widths < 0 show beaches lost or shifted landward or flooded by their entire maximum width.

Bars show currently existing infrastructure/assets fronted by beaches.

Methodology

Advantages of the approach

The approach estimates sea level induced-changes in the dry beach width.

The approach is fast, easy, flexible, does not require particular expertise and enables rapid assessments of beach erosion.

It provides predictions at large spatial scale (e.g. island-scale, basin-scale)

Results can be used to forecast beach exposure to sea level rise if the results are compared with beach spatial characteristics (e.g. dry beach width)

Methodology

Constraints of the approach

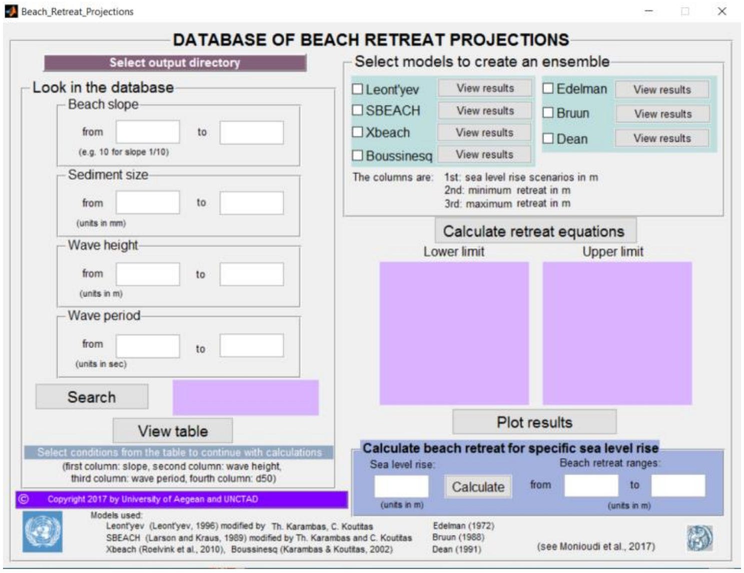
It is assumed that beaches comprise an inexhaustible sediment reservoir. For detailed studies, 2-D and/or 3-D morphodynamic modeling is required.

The approach is not designed to account for other erosion factors (e.g. beach sedimentary budgets, the presence of beach protection schemes)

Therefore, results may underestimate beach retreat/erosion and inundation exposure for individual beaches

The aim of the approach is not to replace detailed beach modeling studies, but to provide a science-based, user-friendly facility for the rapid assessment of potential beach retreats. Detailed research is still essential.

Application with Guide User Interface (GUI)



(first column: slope, second column: wave height, third column: wave period, fourth column: d50)

The columns are: 1st: sea level rise scenarios in m
2nd: minimum retreat in m
3rd: maximum retreat in m

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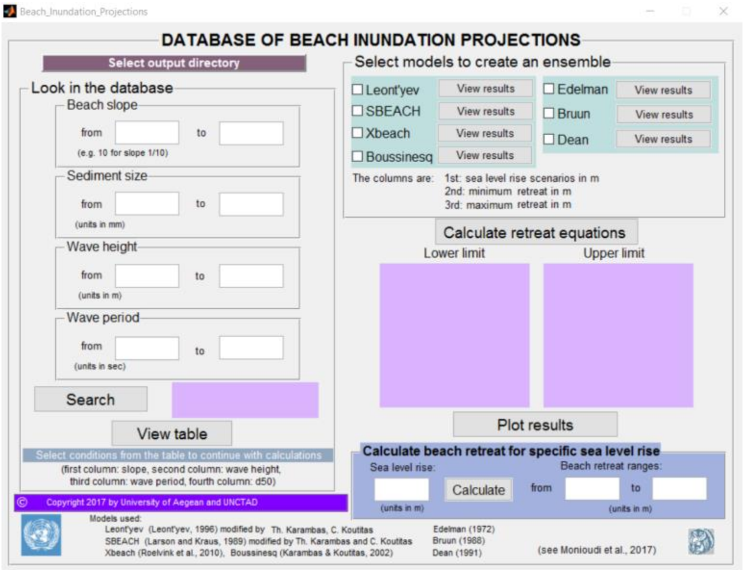
Models used:
Leont'yev (Leont'yev, 1996) modified by Th. Karambas, C. Koutitas
SBEACH (Larson and Kraus, 1989) modified by Th. Karambas and C. Koutitas
Xbeach (Roelvink et al., 2010), Boussinesq (Karambas & Koutitas, 2002)
Edelman (1972)
Bruun (1988)
Dean (1991)
(see Monioudi et al., 2017)

Application with Guide User Interface (GUI)



DATABASE OF BEACH INUNDATION PROJECTIONS

(e.g. 10 for slope 1/10)

(units in mm)

(units in m)

(units in sec)

Select conditions from the table to continue with calculations
(first column: slope, second column: wave height,
third column: wave period, fourth column: d50)

The columns are: 1st: sea level rise scenarios in m
2nd: minimum retreat in m
3rd: maximum retreat in m

Calculate beach retreat for specific sea level rise

(units in m)

(units in m)

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