Determination of Thresholds for Storm Impacts

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Scope

To determine thresholds responsible for beach erosion and associated damage as a tool for coastal planning and management

Outline

Introduction
Study Area
Thresholds for Coastal Erosion
Thresholds for Overwash Occurrence
Thresholds for Coastal Damage
Conclusions
Determination of Thresholds for Storm Impacts

Introduction
The Role of Storms

- Induce rapid and dramatic changes in beach morphology (without damages)
The Role of Storms

- Cause important erosion
  - Punctual when beach and dune recovery is possible.
  - Permanent when induces shoreline retreat at places with sedimentary deficit.
The Role of Storms

- Promote overwashes and dune destruction (reducing the protective role of dunes)
The Role of Storms

- Promote destruction and loss of property
Determination of Thresholds for Storm Impacts - Introduction

The Need to Forecast - Modelling

Involved variables (storm)
- Wave parameters (height; period; direction)
- Storm duration
- Sea level (tidal level and storm surge)

Involved variables (morphology)
- Beach parameters (berm width; beach face slope; grain size)
- Bathymetry
- Dune elevation

Complex task performed by models
High degree of uncertainty
Frequently not used (or difficult to be used or understood) by coastal managers
The Need to Forecast - Determining thresholds

Why?
Simpler approach (less variables)
Forecast (wave/surge) allow to determine if a threshold (erosion; overwash; destruction) is reached or not at a given coastal area
Provide coastal managers with an easy tool/result to allow interventions with some (2-3) days in advance
Permits 2-3 days to take actions (beach nourishment/population warning/evacuate the population in extreme cases)
Determinination of Thresholds for Storm Impacts - Introduction

The Need to Forecast - Determining thresholds

Method

Select the most important variables (storm and morphology)

Determines how and when storms promote an event (erosion; overwash; damage) for a given coastal area - based on measurements or observations

Advantage

Smaller degree of uncertainty

Easier to be understood and applied by coastal managers

Allows quick and urgent interventions when needed

Disadvantage

Do not predict the degree of consequence (destruction/erosion) but only the occurrence

Site specific (based on the existing morphology; different from site to site)

Thresholds to be presented (this presentation)

Coastal erosion (major beach morphology changes)

Overwash occurrence

Coastal damage
Determination of Thresholds for Storm Impacts

Study Area
Determination of Thresholds for Storm Impacts - Study Area

Study Area

Application example – Ancão Peninsula, Algarve, Portugal

WAVES
- Moderate energy (~1m)
- Storm Hs > 3m
- W/SW: 71%
- SE/E: 23%
- Longshore drift towards SE

TIDES/SURGE
- Mesotidal (~2.2 m)
- Semi-diurnal
- Max. range: 3.5m
- Max. level: 3.8m
- Storm surge up to 75 cm

Morphology
- Beach with reflective behaviour; berm + beach face + low tide terrace (not always)
- Barrier island width: 50 – 250 m
- Dune height: 6-8 m above MSL
Study Area

Application example – Ancão Peninsula, Algarve, Portugal

Coastal evolution

Western area with shoreline retreat (average -0.8m/year, max of -1.4 m/year)

Central area without shoreline retreat but facing overwash

Eastern part under accretion (up to +0.4 m/year)
Determination of Thresholds for Storm Impacts - Study Area

Study Area

Application example - Ancão Peninsula, Algarve, Portugal

Human Occupation

Central part (and some of the western) heavily urbanised

Eastern and western tips almost without occupation or at no risk
Determination of Thresholds for Storm Impacts

Study Area

Ancão Peninsula, Algarve, Portugal

Large dataset available:
- Beach monitoring since 1995 (5 profiles)
- Wave data since 1996 (hindcast for ~40 years)
- Damage observation since 1995 (with detail) and before that (not so rigorous - media and reports)
Study Area

Application example - Ancão Peninsula, Algarve, Portugal

Large dataset available:
- Beach monitoring since 1995 (see profiles)
- Damage observation since 1995 (with detail) and before that (not so rigorous, see photos)
Determination of Thresholds for Storm Impacts

Coastal Erosion (vertical variability)
Method

Establish a wave height (Hs) threshold for important morphological changes (vertical variability) across the beach profile.

Four steps:

- Definition of the profile active zone
- Establishment of cross-shore sectors
- Determination of vertical variability
- Definition of thresholds of morphological change (relating Hs with profile vertical variability)
Method

1st Step: Definition of the profile active zone (2 years of data)

Topographic data:
- 6 Topo-bathymetric beach profiles;
- Dune Crest until 17m depth;
- 20m lateral spacing;
- 20 surveys (2 Summers and 2 Winters);

Wave data:
- From a directional wave rider buoy (Portuguese Hydrographical Institute);
- 3h acquisition frequency with higher frequency when $H_s > 3m$;
Method

1st Step: Definition of the profile active zone

Overlaying all elevation data (standard deviation) between surveys

Beach’s upper and lower limits defined when $sd < 20$ cm (includes errors from equipment and operation)
Determination of Thresholds for Storm Impacts - Coastal Erosion

**Method**

2nd Step: Establishment of cross-shore sectors

Profile divided in sectors defining the main active zones based on the obtained standard deviations

Low standard deviation correspond to minor morphological changes

High standard deviation correspond to beach features (berm; bar) with the most important morphological changes
3rd Step: Determination of vertical variability

The maximum vertical variation (MVV) is determined for each sector between consecutive surveys. The threshold for important vertical variations is established per sector being at least: i) MVV > survey technical error (~20 cm); ii) MVV > average of the observed variations for each sector (e.g. MVV = 40 cm for sector A).
Determination of Thresholds for Storm Impacts - Coastal Erosion

Method

4rd Step: Determination of thresholds of morphological change (Hs versus vertical variability)

Hs99 (99th percentile) used as a proxy to maximum wave energy between surveys

Fit equations between Hs99 and MVV - definition of thresholds for important morphological changes (each sector)

Maximum vertical difference (MVV) between consecutive surveys, for all sectors and defined threshold limits

Percentile 99 of Significant wave Height (Hs99) between surveys
Method

4th Step: Determination of thresholds of morphological change (Hs versus vertical variability)

Hs99 (99th percentile) used as a proxy to maximum wave energy between surveys

Fit equations between Hs99 and MVV - definition of thresholds for important morphological changes (each sector)

Maximum vertical variation (MVV) versus Hs99 for sectors A to D with the best fit represented.
Results

At Ancão Peninsula wave heights ranging from 2.3 m (sector A - berm and intertidal area) to 4.1 m (sector D - nearshore) are needed to induce important morphological changes at the profile.
Determination of Thresholds for Storm Impacts

Overwash Occurrence
Determination of Thresholds for Storm Impacts - Overwash Occurrence

**Method**

Based on the storm impact scale (Sallenger, 2000)

Relates RHIGH (extreme runup level) and the dune morphology/elevation (DLOW - dune base; DHIGH - dune crest)

\[ RHIGH = R_2 + SL \]

\[ R_2 = 2\% \text{ exceedence level of runup (e.g. Stockdon et al., 2006 equation)} \]

\[ SL = \text{tidal level} + \text{storm surge} \]

\[ R_2 = 1.1 \left( 0.35 \beta_f (H_s L)^{\frac{1}{2}} + \frac{H_s L (0.563 \beta_f^2 + 0.004)^{\frac{1}{2}}}{2} \right) \]
Determination of Thresholds for Storm Impacts - Overwash Occurrence

**Method**

Based on the storm impact scale (Sallenger, 2000)

- **Collision regime** - When $D_{HIGH} > R_{HIGH} > D_{LOW}$
- **Overwash regime** - When $R_{HIGH} > D_{HIGH}$
- **Inundation regime** - When $R_{LOW} > D_{HIGH}$ (Not considered in this study)
Determination of Thresholds for Storm Impacts

Method

Based on the storm impact scale (Sallenger, 2000)

- **Collision regime** - When $D_{HIGH} > R_{HIGH} > D_{LOW}$
- **Overwash regime** - When $R_{HIGH} > D_{HIGH}$
- **Inundation regime** - When $R_{LOW} > D_{HIGH}$ (Not considered in this study)
Method

To assess vulnerability and to make the hazard map Ancão Peninsula was divided in different sectors with different characteristics (e.g. beach slope)
Determination of Thresholds for Storm Impacts - Overwash Occurrence

Results

Dune features (DLOW and DHIGH) are compared with calculated RHIGH values (for given return periods; e.g. 5, 10 and 25 years)

Where the dunebase/crest is lower than the storm runup the area is categorised as vulnerable to collision/overwash (for a given return period)

Ancão Peninsula - Collision regime is a constant hazard; Overwash hazard varies spacialy and with time (return period)
Results

To assess the vulnerability to collision and overwash regimes a map was designed. Vulnerable areas are represented using a GIS for different storm scenarios.

Ancão P. is largely overwashed by a storm with 25 yr return period; a 5 yr return period storm only causes overwashes at particular sites; collision affects the area almost entirely even for a 5 yr return period.

The central area is the most affected (reflective beach slope + lowering and destruction of dunes by human intervention).
Determination of Thresholds for Storm Impacts - Overwash Occurrence

Results

Thresholds for storm impact regimes calculated for each profile using different Hs, T, for mean high tide conditions. Black area represents the overwash regime, grey the collision regime, and white the swash regime.
Determination of Thresholds for Storm Impacts

Coastal Damage
Determination of Thresholds for Storm Impacts - Coastal damage

Method

Analysis of the hydrodynamic conditions associated to historical storm impacts with relevant consequences (damage to infrastructures).

Qualitative assessment of storm’s impacts on the coast (last decades): quantitative and qualitative information (newspapers, reports, beach monitoring, aerial photographs).

Definition of the hydrodynamic conditions for each event with consequences (number of storms, duration, power, Hs, direction, tide and surge levels).
Method

Examples of storms with hazards

1969: Report - important overwashes over the houses and inlet opening in front of the camping park

1989: Photos - important overwashes, strong erosion with scarp formation, shoreline retreat, destruction of walls and houses

1996: Photos and field survey - overwashes over the parking and road

1997: Photos and field survey: overwashes over walls
Method

Hs and S time-series used for the identification of 15 extreme events for which damage was reported along Faro beach.
Determination of Thresholds for Storm Impacts - Coastal damage

Method

Identification of associated hydrodynamic conditions (storms or groups of storms associated to damage) Observed and reported characteristics and consequences of extreme events at Faro beach

<table>
<thead>
<tr>
<th>Event number</th>
<th>Date (day(s)/month/year)</th>
<th>N° of storms</th>
<th>Duration (days)</th>
<th>Max. Hs (m)</th>
<th>Direction</th>
<th>Max. Tide elevation (m)</th>
<th>Max. S (m)</th>
<th>Power (J/m)</th>
<th>Description of consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>03-12/01/1969</td>
<td>2</td>
<td>2/3</td>
<td>3.2/4.3 **</td>
<td>SW</td>
<td>-</td>
<td>0.18</td>
<td>0.29**</td>
<td>4.00x10^{10} Major overwash of houses; opening of an inlet; shoreline retreat</td>
</tr>
<tr>
<td>2</td>
<td>13-18-24-27/11/1989</td>
<td>4</td>
<td>2/4/2/1</td>
<td>3.4/7/3.8/3.6 *</td>
<td>SW</td>
<td>1.5/1/0.75*</td>
<td>0.2/0.57/0.24/0.22*</td>
<td>1.1082x10^{11} Major overwash; destruction of walls and some houses; shoreline retreat</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>05/03/1990</td>
<td>1</td>
<td>2</td>
<td>6 **</td>
<td>SE</td>
<td>0.6*</td>
<td>0.46*</td>
<td>2.2796x10^{10} Shoreline retreat; destruction of the road and some houses</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>02-12/12/1994</td>
<td>2</td>
<td>2/1</td>
<td>3.9/3.5 **</td>
<td>SW</td>
<td>1.4/0.6*</td>
<td>0.25/0.21*</td>
<td>2.6980x10^{10} Overwash of infrastructure and dunes</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>10-16-19/01/1995</td>
<td>3</td>
<td>1/3/1</td>
<td>3/4/3/3 **</td>
<td>SW</td>
<td>0.44/1/1.16/1.32*</td>
<td>0.15/0.3/0.15*</td>
<td>3.9252x10^{10} Overwash of infrastructures and dunes; shoreline retreat</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>23/01/1996</td>
<td>1</td>
<td>4</td>
<td>6.5 ♦</td>
<td>SW</td>
<td>1.8*</td>
<td>0.51*</td>
<td>3.0865x10^{10} Overwash of car park; shoreline retreat</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>18/12/1997</td>
<td>1</td>
<td>5</td>
<td>5 ♦</td>
<td>SW</td>
<td>1.4*</td>
<td>0.36*</td>
<td>4.5193x10^{10} Overwash of wall close to main road</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>02-04-08/02/1998</td>
<td>3</td>
<td>4/2/1</td>
<td>5.6/3.3/3.2 ♦</td>
<td>SW</td>
<td>1.31/0.84/1.1*</td>
<td>0.43/0.25/0.16*</td>
<td>4.5195x10^{10} Major overwash of houses; shoreline retreat</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>03-08-13/04/2000</td>
<td>3</td>
<td>2/3/1</td>
<td>4/4/2/3.2 ♦</td>
<td>SE</td>
<td>1.25/1.36/0.72*</td>
<td>0.20/0.31/0.22*</td>
<td>3.8169x10^{10} Overwash of infrastructures and dunes; shoreline retreat</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>18/12/2001</td>
<td>1</td>
<td>1</td>
<td>4.9 #</td>
<td>SW</td>
<td>1.2*</td>
<td>0.23*</td>
<td>1.6722x10^{10} Major morphological changes to beach profile</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>02-06/01/2002</td>
<td>2</td>
<td>2/2</td>
<td>4.1/3 ♦</td>
<td>SE</td>
<td>1.47/1</td>
<td>0.26/0.10*</td>
<td>2.9403x10^{10} Some overwashes</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>02/03/2002</td>
<td>1</td>
<td>1</td>
<td>3.7 #</td>
<td>SW</td>
<td>1.4*</td>
<td>0.27*</td>
<td>1.1875x10^{10} Major morphological changes to beach profile</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>13-17-23/02/2008</td>
<td>3</td>
<td>1/1/1</td>
<td>3.9/4/3.4/3.3 ♦</td>
<td>SE</td>
<td>1/0.76/1.5*</td>
<td>0.23/0.25/0.20*</td>
<td>2.5178x10^{10} Overwash of infrastructure and dunes</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>05/02/2009</td>
<td>1</td>
<td>2</td>
<td>4.7 ♦</td>
<td>SW</td>
<td>0.9*</td>
<td>0.30*</td>
<td>2.2851x10^{10} Overwash of car park and dunes</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>23-31/12/2009</td>
<td>2</td>
<td>4/3</td>
<td>5.8/4.4 ♦</td>
<td>SW</td>
<td>0.84/1.33</td>
<td>0.44/0.3*</td>
<td>8.6198x10^{10} Big overwashes over the car park; swash colliding with dune base</td>
<td></td>
</tr>
</tbody>
</table>

Legend: ♦ Faro buoy data; ** HIPOCAS data; * Data retrieved from reports; ● data obtained from WXtide32; ▲ data retrieved from the tide tables from I.H.; + data obtained from Equation Hs vs SS,* data retrieved from Huelva tide gauge.
Results

Thresholds were defined for 2 main wave directions (W-SW and E-SE), for storm groups and for individual storms, for the last 4 decades, at Ancão Peninsula based on P (power).

Selected events near the threshold of damage were also used to help identifying the threshold values.
Determination of Thresholds for Storm Impacts - Coastal damage

Results

P was translated to the associated Hs and storm duration to have simpler (easier to use) thresholds

- Individual Storm; Max. Hso > 4.7m; Duration >= 2 Day; SW
- Individual Storm; Max. Hso > 6 m; Duration >= 2 Day; SE

Overwashes over infrastructures \ dunes;

23 000 000 J/m.s
Results

P was translated to the associated Hs and storm duration to have simpler (easier to use) thresholds.

- Overwashes over infrastructures \ dunes;
- Destruction of walls and houses;

- Overwashes over infrastructures \ dunes:
  - >= 3 Storms; Storms with Max. Hso > 3.9m; Duration >= 1 Day; SE
  - >= 2 Storms; Storms with Max. Hso > 3.5m; Duration >= 2 Day; SW

\[ 27\,000\,000 \, J/m.s \]
Determination of Thresholds for Storm Impacts - Coastal damage

Results

Return period (Pr) and annual probability (Po) for the threshold conditions able to trigger damage in the study area.

<table>
<thead>
<tr>
<th>Event number</th>
<th>Storm type</th>
<th>Direction</th>
<th>Pr (years)</th>
<th>Po</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Individual</td>
<td>SE</td>
<td>40</td>
<td>0.025</td>
</tr>
<tr>
<td>14</td>
<td>Individual</td>
<td>SW</td>
<td>3.1</td>
<td>0.32</td>
</tr>
<tr>
<td>13</td>
<td>Group</td>
<td>SE</td>
<td>40</td>
<td>0.025</td>
</tr>
<tr>
<td>4</td>
<td>Group</td>
<td>SW</td>
<td>1.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Conclusions

Methods to determine thresholds associated:
- Morphological changes (coastal erosion)
- Overwash occurrence
- Coastal damage

Based on simple approaches

Applicable to all coastal areas with:
- Recent beach morphology surveys
- Information on waves and sea level data (years to decades - including several storms)
- Records of damage

Methods easily adapted to specific beach conditions → useful for wide range of exposed beaches

Direct application on coastal management plans, useful for:
- Human occupation strategies
- Dune recovery and beach nourishment design

Possible to be implemented in early warning systems (future improvement)
Thank You
Gràcies
Gracias