# Assessing Coastal Erosion Risk in a GIS environment

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4as JORNADAS DE ENGENHARIA HIDROGRÁFICA

21, 22 E 23 DE JUNHO DE 2016

## BACKGROUND

- **Coasts are complex and dynamic**, often prone to erosion, presenting
  - **short-term changes**, e.g. after storm events, seasonal
  - **long-term trends**
    - **human interventions**, e.g. sediment depletion, man-made changes of morphology caused by dams and buildings, or local long-shore drift changes caused by groins, jetties or breakwaters
    - **natural processes**, such as climate change

## BACKGROUND

- **Coastal dynamics depends on**
  - **Local meteo and ocean climate**, e.g. wave and storm frequency and intensity, probability of hazards
  - **Vulnerability** – related to materials/sediments, human occupation, morphology and other factors affecting vulnerability and resilience
  - **Exposure**, which depends on the geographic setting, coastal orientation and on natural or man-made protective structures

  ⇒ Even neighbouring beach sectors may show contrasting behaviour because of their distinct features, which is challenging for coastal management



## GEOGRAPHIC INFORMATION SYSTEMS (GIS)

- **GIS** technologies are valuable tools for storage, management, analysis, and display of spatial information
  - **Storage of different types of data and information** in an **organised system** (georeferenced/spatial data, meta-information, tables, images, statistics, figures …)
  - **Editing** – selection, conversion, projection …
  - **Analysis** – statistics, overlays, algebra, profiles, budgets …
  - **Display** – maps, graphs, tables …

## OBJECTIVES

- Presentation of **GIS procedures for coastal characterisation and erosion risk assessment**
  - **Beach characterization**
  - **Beach segmentation**
  - **Quantification of beach dynamics and exposure** in a **GIS** environment
    - **Shore line migration**
    - **Δ Area**
    - **Δ Volume**
- **Case study**: Vila Nova de Gaia coast (Northern Portugal)



## STUDY AREA

- V. N. de Gaia coast
- Densely occupied, urbanised
- High-energy ocean climate
- Several sectors suffering erosion due to sediment depletion
- Rocky and sandy stretches
- Coastal interventions (detached breakwater, armouring, artificial beach nourishment)


## SURVEYS

- Survey airplane and digital camera; external orientation through direct georeferencing (GPS+INS)
- Dates: Nov. 2008
  April 2009
  Nov. 2009
  May 2010
- Non invasive
- Covers large areas, also those of difficult access



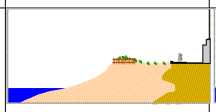
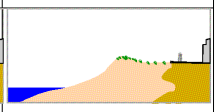
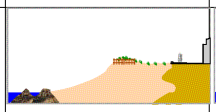
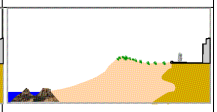
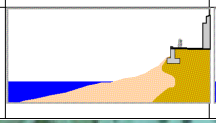
## DIGITAL ELEVATION MODELS (DEM)

- DEM were obtained through aerial photogrammetry (stereo-matching, using the BLUH software)
- Using high-resolution (7680×13824 pixels, 10 cm ground sampling distance) aerial photos
- Small dependence on ground control, due to GPS/INS


Flight plan with two rows of over-lapping photos ⇒ stereo imagery

# LOCAL FEATURES

## Beach type

| | | |
|---|---|---|
| **Tipo 1** | Totalmente constituída por rochas ☐ | Presença de afloramentos rochosos ☐ |
| Praias rochosas |  |  |
| **Tipo 2** | Perfil côncavo ☑ | Perfil convexo ☐ |
| Praia arenosa com afloramentos rochosos na face da praia |  |  |
| **Tipo 3** | Duna com paliçada ☑ | Duna sem paliçada ☐ |
| Praia arenosa com duna frontal |  |  |
| **Tipo 4** | Duna com paliçada ☐ | Duna sem paliçada ☐ |
| Praia arenosa com duna frontal e afloramentos rochosos |  |  |
| **Tipo 5** | Com obra de defesa ☐ | Com edificações na antepraia ☐ |
| Praia arenosa intervencionada |  |  |

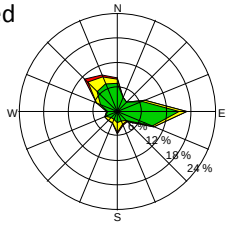


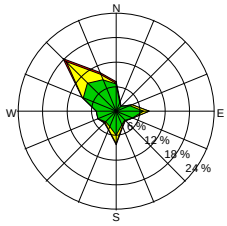
# LOCAL FEATURES: WIND, WAVES

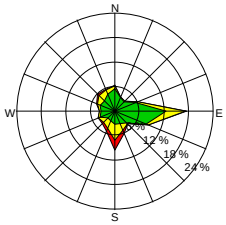
Nov.08-Apr.09 | Apr.09-Nov.09 | Nov.09-May 10

Mean wind speed

m/s
- <5
- 5–8
- ≥8

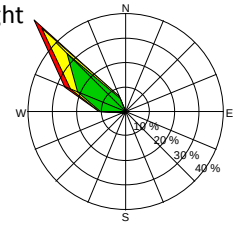


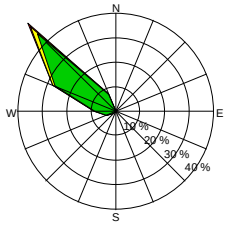



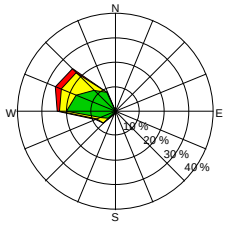




Sign. Wave height

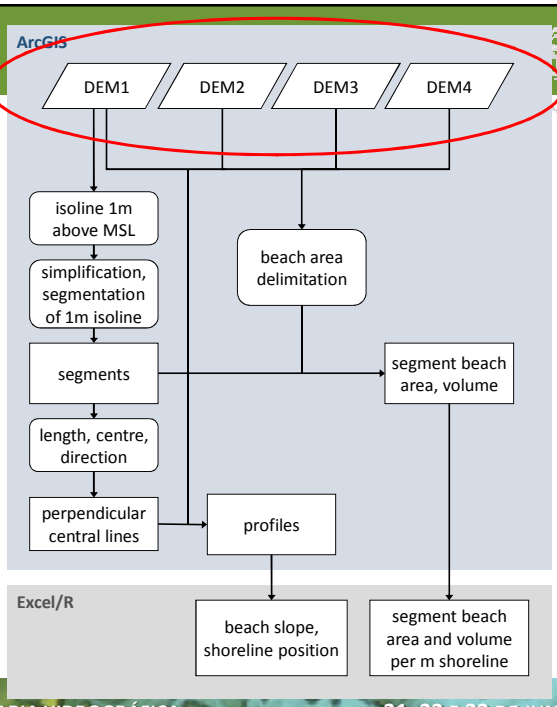
m
- <3
- 3–5
- ≥5



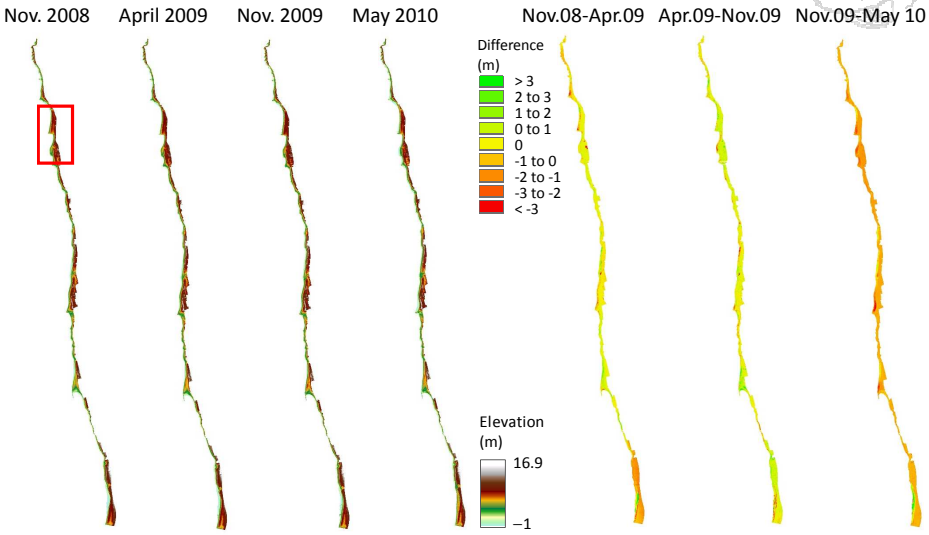



# METHODS

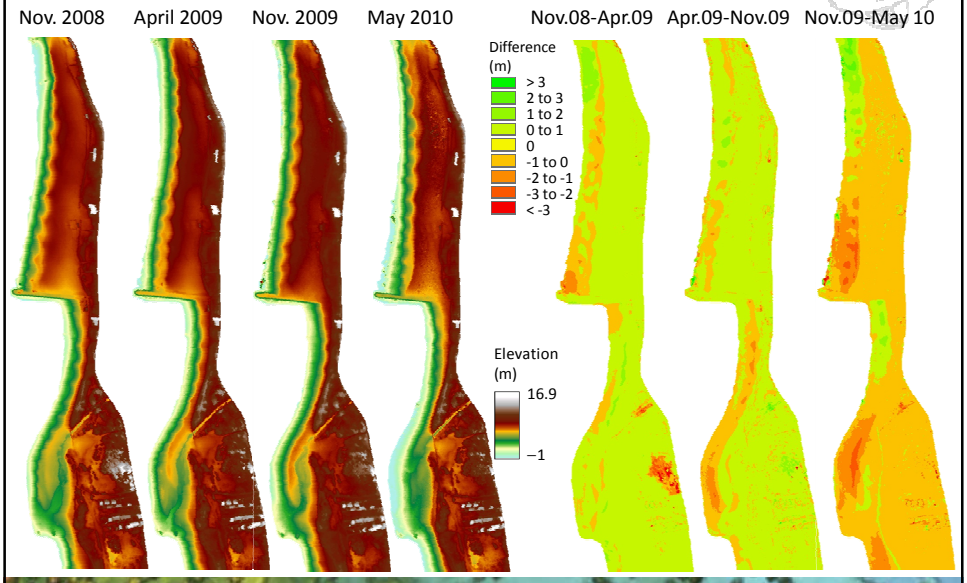





# GIS: DEM



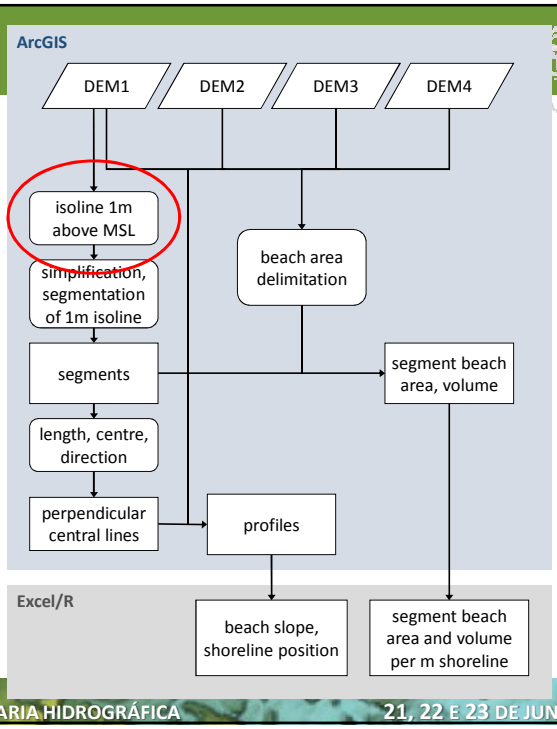
# GIS: DEM CANIDELO BEACH



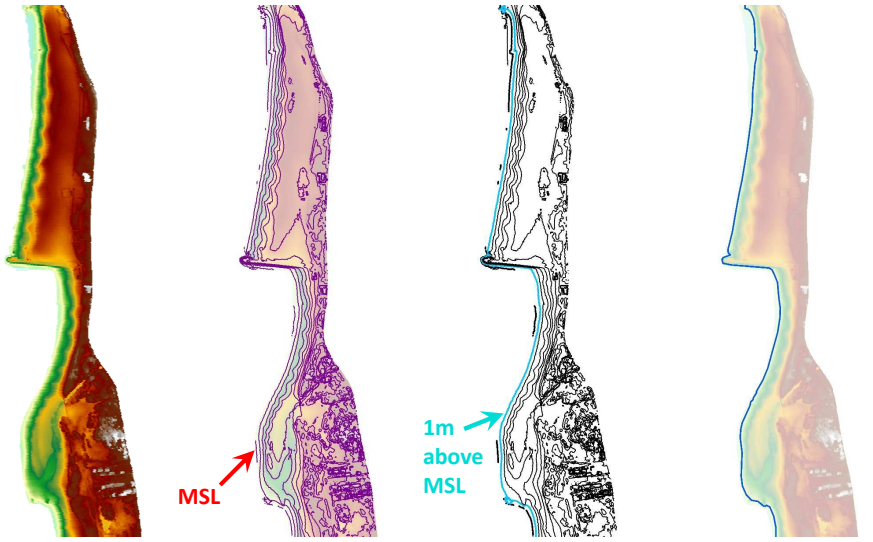



# METHODS

Shore line



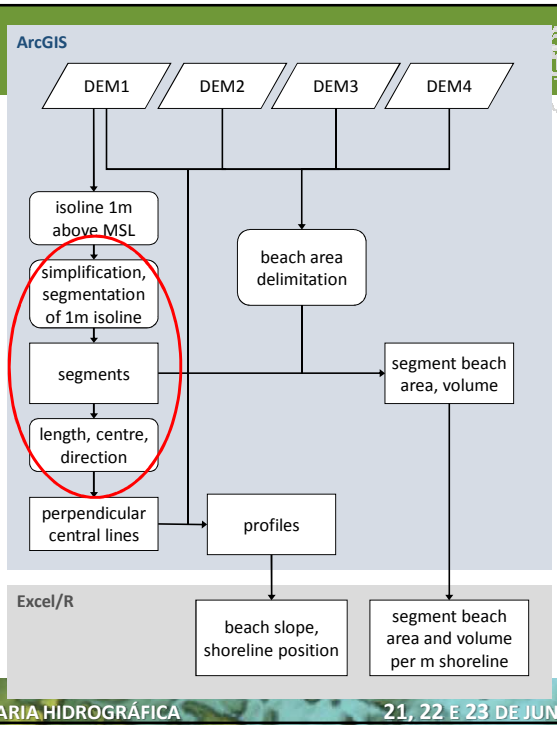
## GIS: SHORE LINE





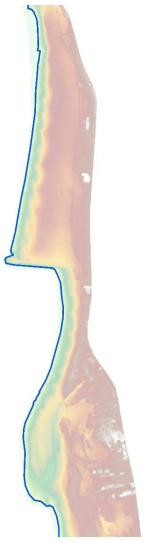

## METHODS

Segmentation

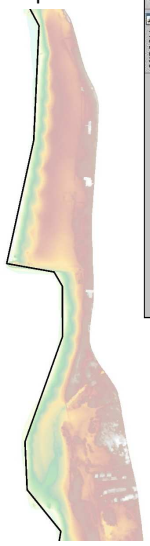


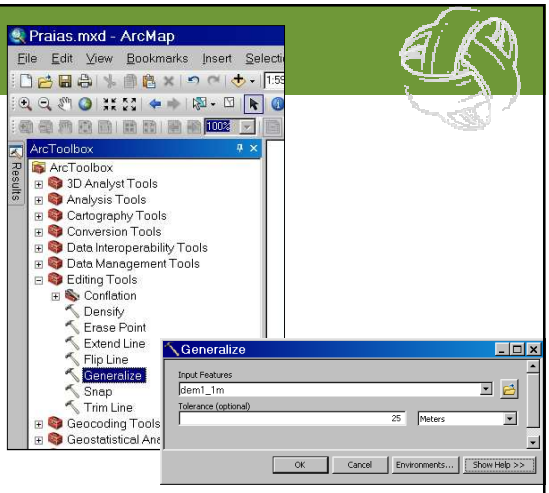
## GIS: SHORE LINE

1m above MSL



simplified



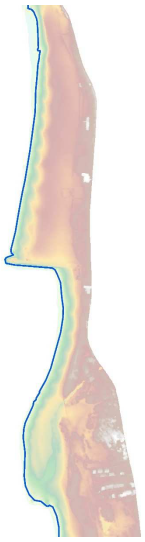



- Simplification
- *Editing tools > Generalize*
- Douglas-Peucker algorithm, maximum tolerance = 25 m

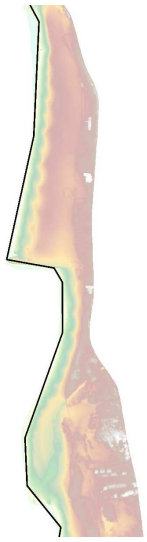


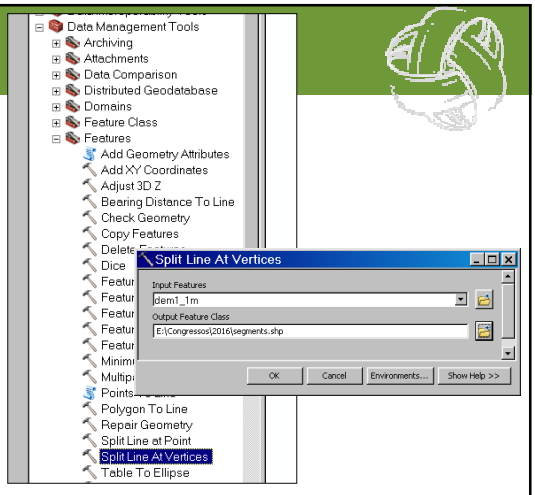
## GIS: SHORE LINE

1m above MSL



simplified

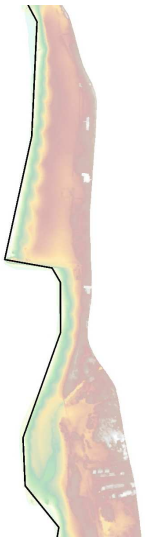




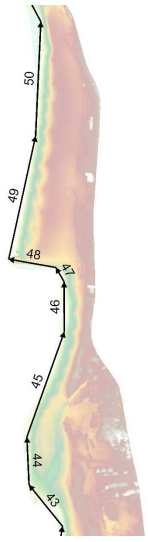

- Division of polyline into segments
- *Data Management tools > Features > Split Line at Vertices*

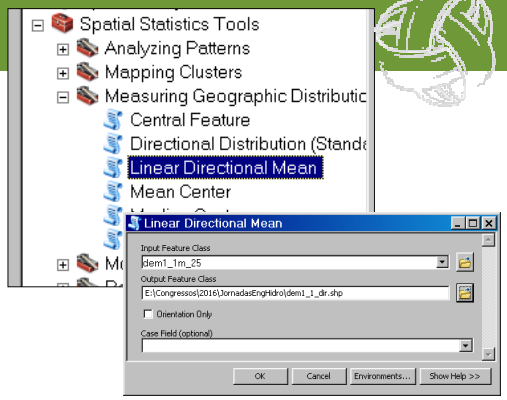
# GIS: SHORE LINE

1m above MSL



segments



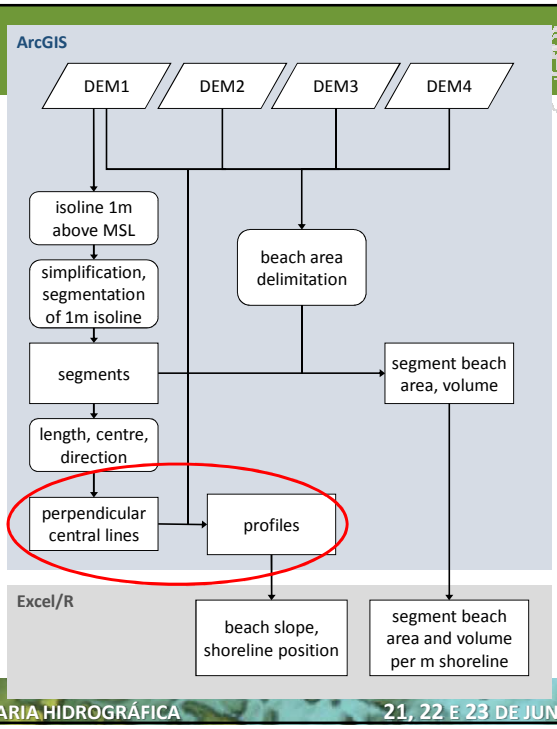




- Segment length, direction and centre
- *Spatial Statistics toolset > Measuring Geographic Distributions > Linear Directional Mean*

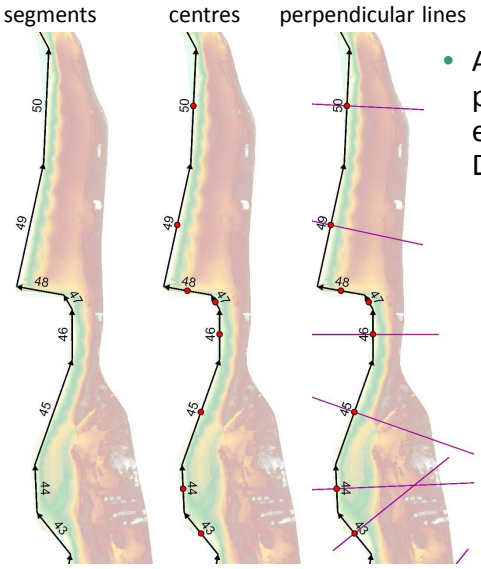


# METHODS

Profiles



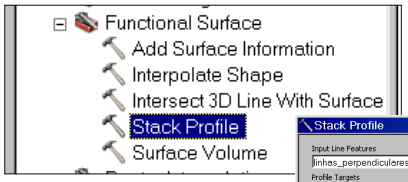
## GIS: SHORE LINE, PROFILE

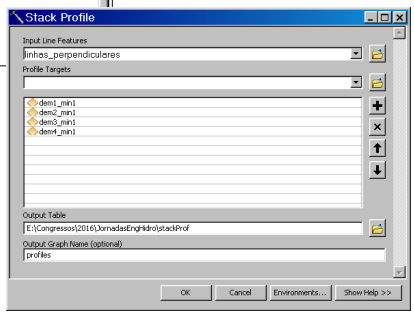



- At the centre of each segment, a perpendicular line was drawn to extract a beach profile for each DEM.



## GIS: SHORE LINE, PROFILE



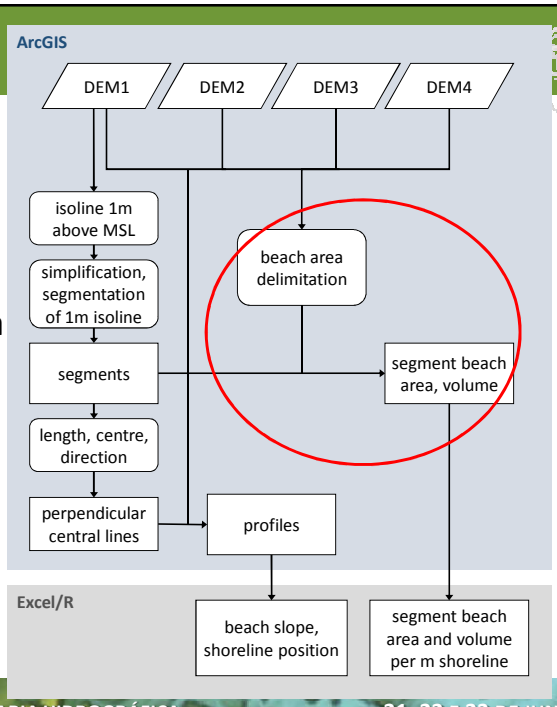




- Central profiles for all segments
- *3D Analyst Tools > Functional Surface > Stack Profile*

  ⇒ Profiles for all DEM along exactly the same lines, providing height values for exactly the same coordinates

# METHODS

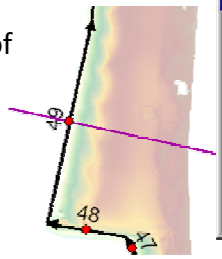
Beach volume & area

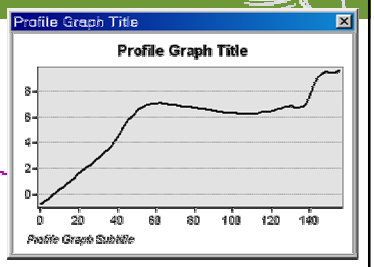


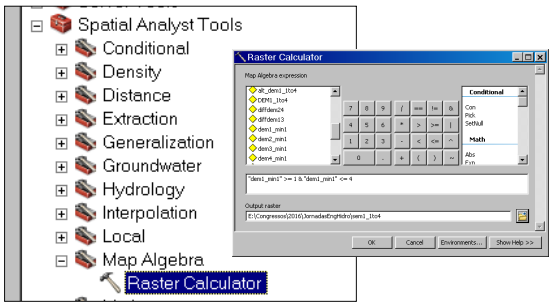



# GIS: BEACH AREA, VOLUME

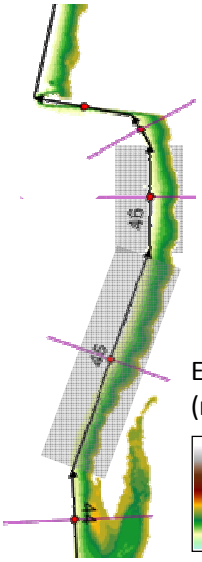
- To allow for comparison of morphodynamics we standardized approach
- Delimitation of "beach" = area with 1 m to 4 m elevation above MSL
- *Spatial Analyst Tools > Map Algebra > Raster Calculator*



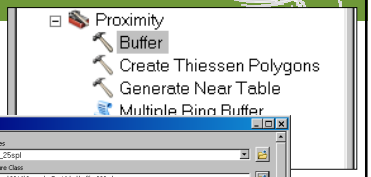
## GIS: BEACH AREA, VOLUME

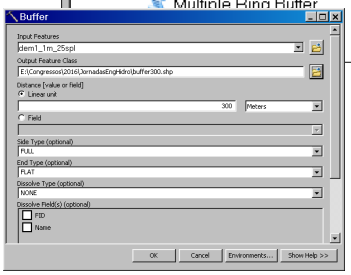


Elevation (m)

16.9

−1



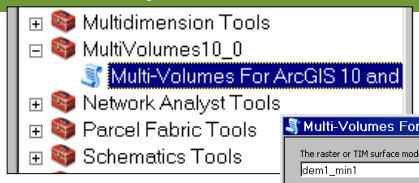



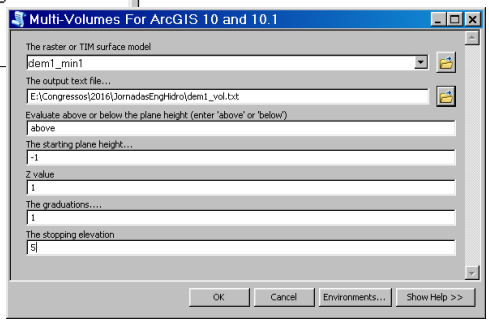

- Delimiting beach area per sector
- *Analysis Tools > Proximity > Buffer (End Type = flat, Dissolve Type = NONE)*

  ⇒ Changes can be evaluated per m of shore line



## GIS: BEACH AREA, VOLUME

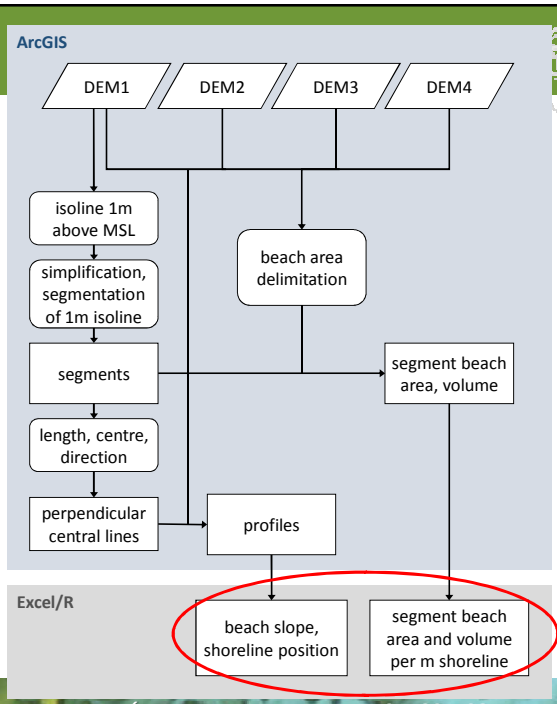



- 2D Area, 3D Area, Volume for different elevations

  ⇒ Areas and volumes per elevation layer
- *MultiVolumes 10_0 > Multi-Volumes For ArcGIS 10 and 10.1*

# METHODS

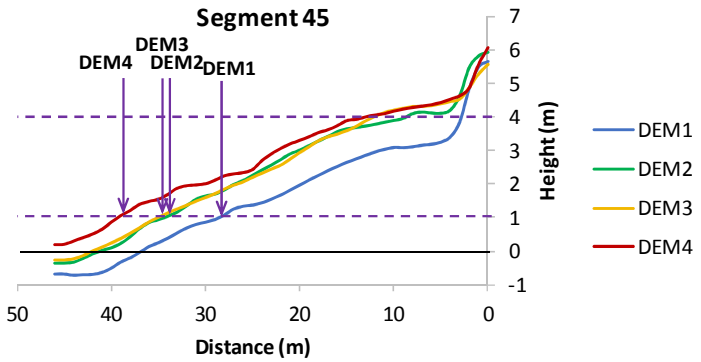



Morphodynamics



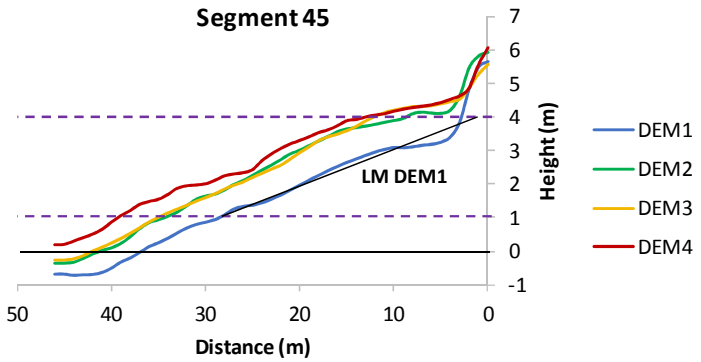
# MORPHODYNAMICS

- Beach between 1m and 4m above MSL
- Shore line at 1m above MSL (interpolated if necessary)



## MORPHODYNAMICS

- Beach slope between 1m and 4m above MSL
- Linear model slope






## MORPHODYNAMICS

ΔShoreline position (m)

Δ Area ($m^2$/m shore line)

Δ Volume ($m^3$/m shore line)

beach orientation "facing"

beach slope

beach type

# MORPHODYNAMICS

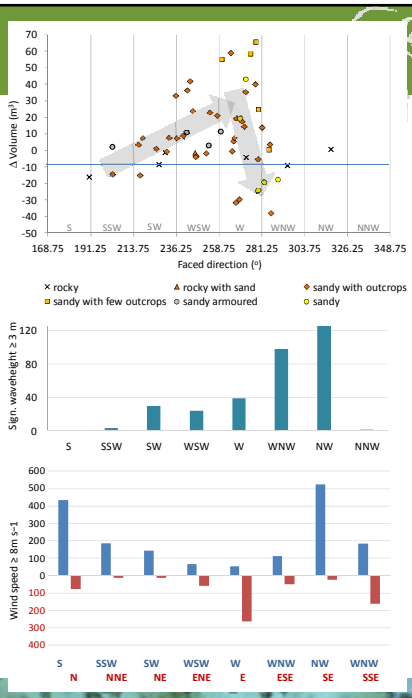
- Δ Shoreline position (m)
- Δ Area ($m^2$/m shore)
- Δ Volume ($m^3$/m shore)
  - ½ -yearly differences
  - Yearly differences
  - 1½ year differences

| Seg. | Orient. | Type | DEM1 to 2 | | | DEM2 to 3 | | | DEM3 to 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | L | A | V | L | A | V | L | A | V |
| 1 | 101 | 3 | 1 | 11 | 16 | 0 | -4 | -74 | 29 | 30 | 183 |
| 2 | 72 | 3 | -2 | -3 | 0 | -4 | 3 | 1 | 33 | 28 | 120 |
| 3 | 85 | 4 | -11 | -9 | -18 | 9 | 7 | 14 | 3 | 3 | 4 |
| 4 | 101 | 4 | -7 | -5 | -16 | 10 | 9 | 21 | 3 | 3 | 10 |
| 5 | 56 | 4 | 2 | 4 | 7 | 0 | -1 | 3 | -2 | 1 | -2 |
| 6 | 73 | 5 | -1 | 3 | 9 | 0 | -2 | -7 | 2 | 2 | 1 |
| 8 | 80 | 5 | 7 | 4 | 25 | 0 | 0 | -16 | 2 | 1 | 2 |
| 9 | 62 | 5 | 7 | 4 | 23 | 0 | 0 | -9 | 2 | 1 | -4 |
| 10 | 91 | 2 | 5 | 4 | 21 | -1 | 0 | -2 | 8 | 3 | -1 |
| 11 | 60 | 2 | 3 | 5 | 10 | 2 | 0 | -1 | -1 | 2 | 0 |
| 12 | 78 | 4 | 14 | 6 | 14 | 1 | 1 | 0 | 4 | 2 | 7 |
| 13 | 56 | 5 | 6 | 6 | 27 | 1 | 2 | -1 | 4 | 4 | 11 |
| 14 | 28 | 5 | 8 | 6 | 35 | 0 | 4 | 46 | 7 | 8 | 33 |
| 18 | 98 | 5 | 10 | 8 | 39 | 4 | 6 | 41 | -1 | -2 | 1 |
| 19 | 85 | 4 | 12 | 10 | 22 | -3 | -1 | 0 | 18 | 12 | 45 |
| 20 | 65 | 2 | 5 | 6 | 24 | -7 | -3 | -12 | 6 | 2 | 13 |
| 21 | 92 | 4 | 7 | 6 | 16 | -1 | 0 | -3 | 0 | -2 | 1 |
| 23 | 88 | 4 | 9 | 7 | 28 | -4 | 0 | -12 | 4 | -1 | 5 |
| 24 | 105 | 4 | 2 | 1 | 14 | -2 | -1 | -13 | -2 | 0 | 3 |
| 25 | 74 | 2 | 2 | 4 | 17 | 3 | 0 | 6 | 1 | 1 | 4 |
| 26 | 37 | 2 | 0 | 1 | 17 | 1 | -2 | -18 | -6 | -2 | -9 |
| 27 | 106 | 2 | -5 | -5 | -11 | -6 | -3 | -9 | -30 | -17 | -18 |
| 28 | 89 | 4 | 0 | 0 | -5 | 0 | 0 | 2 | -14 | -14 | -27 |
| 29 | 105 | 3 | 0 | 1 | -1 | -1 | -1 | 0 | 4 | 2 | 5 |
| 30 | 95 | 3 | 8 | 7 | 16 | 4 | 3 | 9 | 12 | 14 | 38 |
| 31 | 80 | 4 | 4 | 5 | 14 | 0 | -2 | -2 | 16 | 15 | 47 |
| 32 | 99 | 4 | 10 | 12 | 27 | -9 | -11 | -26 | 10 | 9 | 23 |
| 33 | 67 | 4 | -1 | 1 | 7 | 0 | -2 | -12 | -3 | 0 | 1 |
| 34 | 93 | 2 | 8 | 4 | 13 | 1 | 0 | -3 | 15 | 7 | 33 |
| 35 | 72 | 2 | 1 | 2 | 8 | 0 | 0 | -3 | 0 | -2 | -7 |
| 37 | 86 | 4 | 4 | 5 | 11 | 1 | 1 | 0 | -3 | -2 | -5 |
| 38 | 39 | 2 | 5 | 7 | 20 | 1 | 3 | 6 | -3 | -6 | -18 |
| 39 | 66 | 4 | 9 | 6 | 17 | -2 | 0 | -4 | -5 | -5 | -17 |
| 40 | 87 | 4 | 3 | 4 | 15 | 4 | 3 | 1 | -5 | -2 | -8 |
| 41 | 37 | 4 | 4 | 3 | 19 | 8 | 5 | 12 | -12 | -5 | -27 |
| 42 | 99 | 4 | -1 | 2 | -3 | 1 | 1 | -2 | -17 | -11 | -26 |
| 43 | 51 | 4 | 2 | 6 | 23 | 0 | -2 | 0 | -2 | -8 | -24 |
| 44 | 87 | 4 | 2 | 2 | 23 | -8 | -7 | -27 | -11 | -12 | -26 |
| 45 | 110 | 3 | -1 | 2 | 9 | -3 | -4 | -10 | -7 | -7 | -17 |
| 46 | 90 | 3 | 5 | 3 | 8 | 5 | 2 | -5 | -3 | 2 | 19 |
| 49 | 102 | 3 | -2 | -2 | -6 | -2 | 2 | 4 | -14 | -6 | -16 |
| 50 | 93 | 3 | 5 | 7 | 12 | 3 | 3 | 14 | 4 | 5 | 26 |
| 51 | 62 | 2 | 4 | 4 | 8 | 7 | 3 | 13 | 5 | 3 | 26 |
| 52 | 23 | 2 | 0 | -1 | -4 | -7 | -2 | -5 | -4 | -1 | -6 |
| 53 | 99 | 2 | 5 | -3 | -9 | 0 | 4 | 12 | 3 | -3 | -8 |
| 55 | 98 | 2 | 7 | 6 | 17 | -3 | -2 | -11 | 12 | 8 | 37 |
| 56 | 66 | 2 | 4 | 1 | -1 | 9 | -1 | -2 | 0 | 0 | 1 |
| 57 | 47 | 1 | -9 | -2 | -6 | -4 | -4 | -7 | 3 | 2 | 4 |
| 60 | 93 | 1 | 0 | -1 | -4 | 0 | -1 | -2 | 0 | 1 | 1 |
| 62 | 138 | 1 | 0 | 0 | 0 | 0 | -1 | -3 | 1 | 2 | 3 |



# MORPHODYNAMICS

- Dynamics depends on beach type; rocky more stable than sandy
- Dynamics depends on beach orientation; very noisy
- No clear pattern related to slope



## CONCLUDING REMARKS

- **GIS** allowed **analysis, comparison and mapping of the DEMs**
  - The study area was objectively divided into **beach segments**
  - Central segment beach **profiles** were obtained
  - **Areas** and **volumes** were quantified, both per segment and for the whole study area
  - Results could subsequently be exported and further analysed using statistical software, to assess beach dynamics and relate it to wave and wind time series



## CONCLUDING REMARKS

- Need for **regular, continued monitoring**; seasonal
- Need for a **municipal** or, even better, **regional coastal GIS** containing data and local information
- **Regional/national vision/investment** in coastal survey, defence, management
- The necessary **survey and GIS technologies are available** and affordable

## ACKNOWLEDGEMENTS

This research was supported by:

The Strategic Funding UID/Multi/04423/2013 through national funds provided by FCT – Foundation for Science and Technology and European Regional Development Fund (ERDF), in the framework of the programme PT2020.

The project INNOVMAR - Innovation and Sustainability in the Management and Exploitation of Marine Resources (reference NORTE-01-0145-FEDER-000035, within Research Line ECOSERVICES), supported by North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF)".

FCT Fundação para a Ciência e a Tecnologia

QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL PORTUGAL 2007.2013

UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional

NORTE2020 PROGRAMA OPERACIONAL REGIONAL DO NORTE

PORTUGAL 2020