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The State of the Art and Science of Coastal Engineering

Long-term coastal evolution modelling of longshore bars

LUSO-AMERICAN DEVELOPMENT foundation

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

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OUTLINE

- Objectives
- Model description: theoretical developments
- Model calibration and validation at Duck, USA
- Model application at Cocoa Beach, USA
- Final remarks

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MOTIVATION

- Many coastal systems across the world include natural longshore multi-bar systems;

- Need of proper simulation of the bar-berm material exchange to realistically reproduce the seasonal behaviour of the beach profile;

- Improvement of the numerical capabilities of regional coastal evolution numerical models (shoreline evolution models).

OBJECTIVES

- Investigate the numerical approaches for simulating cross-shore sediment transport and long-term profile evolution;
- Develop a subaqueous sub-model for simulating the evolution of a two-bar system, as well as the response of feeder mounds to incident waves;
- Test the developed model against available data.

Theoretical Developments. One-bar systems

Bar-berm material exchange model (Larson *et al.*, 2013)

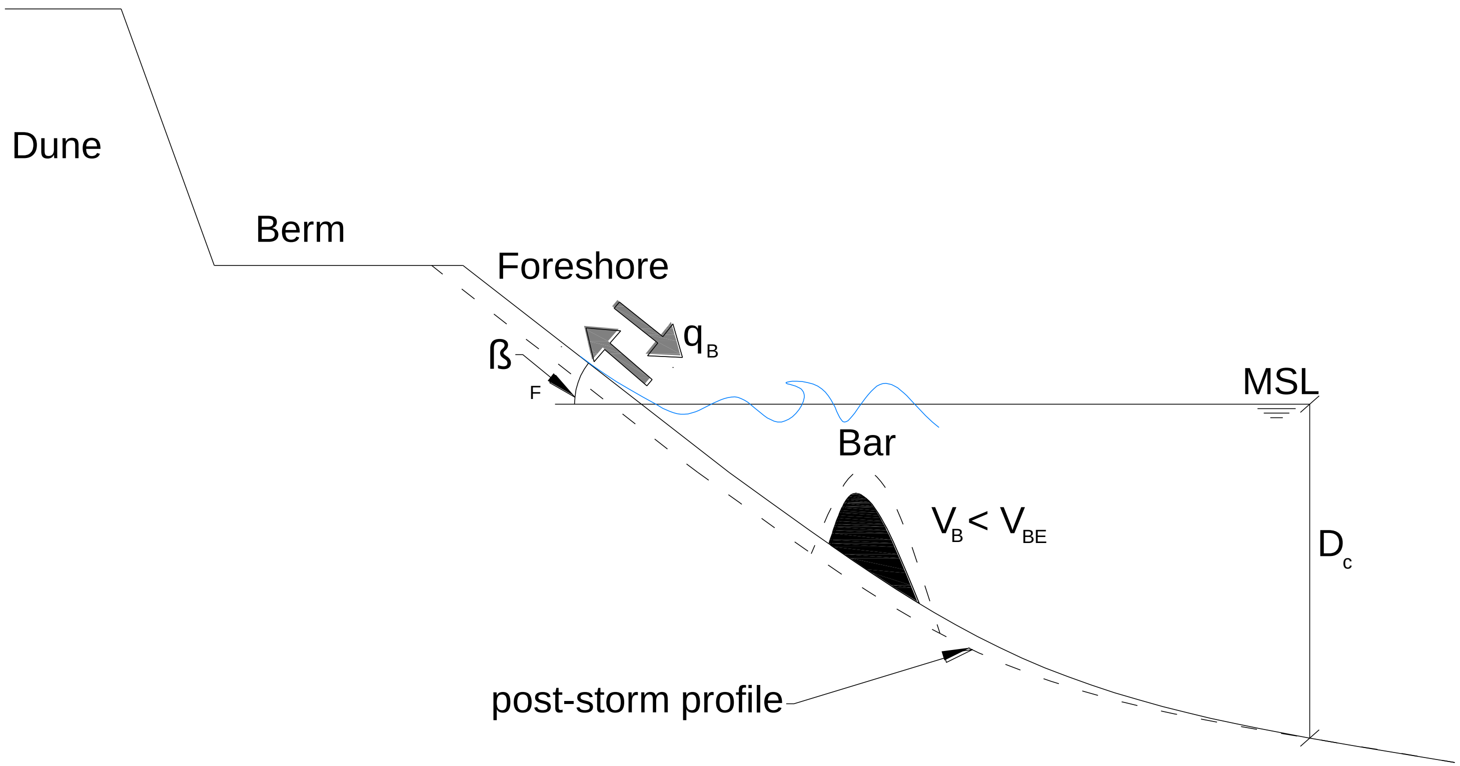
$$\frac{dV_B}{dt}=\lambda(V_{BE}-V_B)$$

$$\lambda=\lambda_0\left(\frac{H_0}{wT}\right)^m$$

$$\frac{V_{BE}}{L_0^2}=C_B\left(\frac{H_0}{wT}\right)^{4/3}\frac{H_0}{L_0}$$

$$V_B(t)=V_{BE}+(V_{B0}-V_{BE})e^{-\lambda t}$$

$$\Delta V_{B,i}=\left(V_{BE,i}-V_{B,i}\right)(1-e^{-\lambda_i\Delta t})$$



$V_{BE}<V_B$ the bar will **decay**
$V_{BE}>V_B$ the bar will **grow**

Theoretical Developments. Two-bars systems

Bar-berm material exchange model

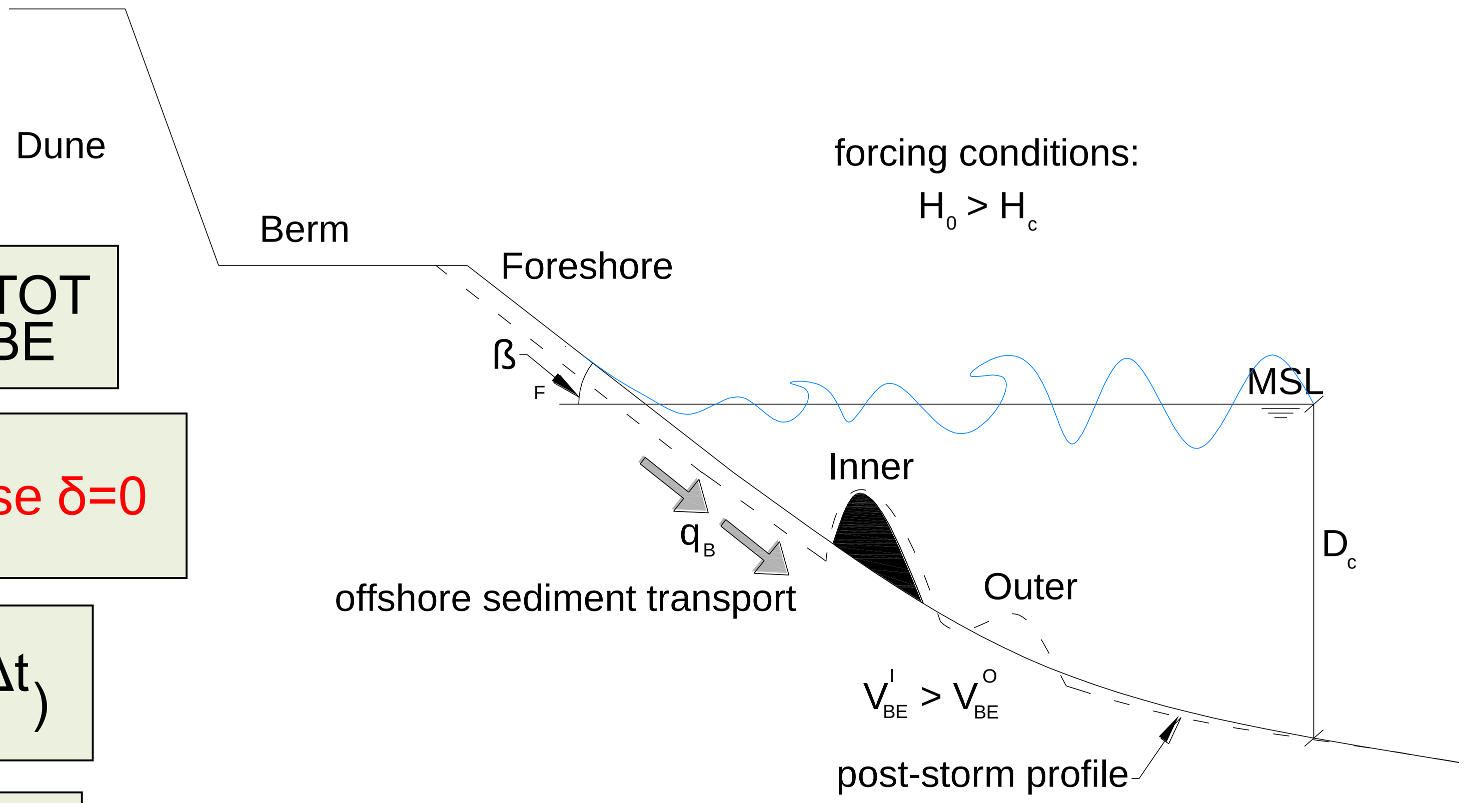
$$\frac{V_{BE}^{TOT}}{L_0^2} = \frac{V_{BE}^{I}}{L_0^2} + \frac{V_{BE}^{O}}{L_0^2}$$

$$V_{BE}^{I} = \frac{1}{1+\delta} V_{BE}^{TOT} \qquad V_{BE}^{O} = \frac{\delta}{1+\delta} V_{BE}^{TOT}$$

IF $H_0 > H_c$, $\delta = \delta_0 \left(\frac{H_0}{H_c} - 1 \right)$ otherwise $\delta = 0$

$$\Delta V_{B,i}^{I} = \left(V_{BE,i}^{I} - V_{B,i}^{I} \right) \left(1 - e^{-\lambda_i^{I} \Delta t} \right)$$

$$\Delta V_{B,i}^{O} = \left(V_{BE,i}^{O} - V_{B,i}^{O} \right) \left(1 - e^{-\lambda_i^{O} \Delta t} \right)$$



For 0<δ<1, the outer bar starts to form and grow.

Theoretical Developments. Two-bars systems

Bar-berm material exchange model

$$\frac{V_{BE}^{TOT}}{L_0^2} = \frac{V_{BE}^{I}}{L_0^2} + \frac{V_{BE}^{O}}{L_0^2}$$

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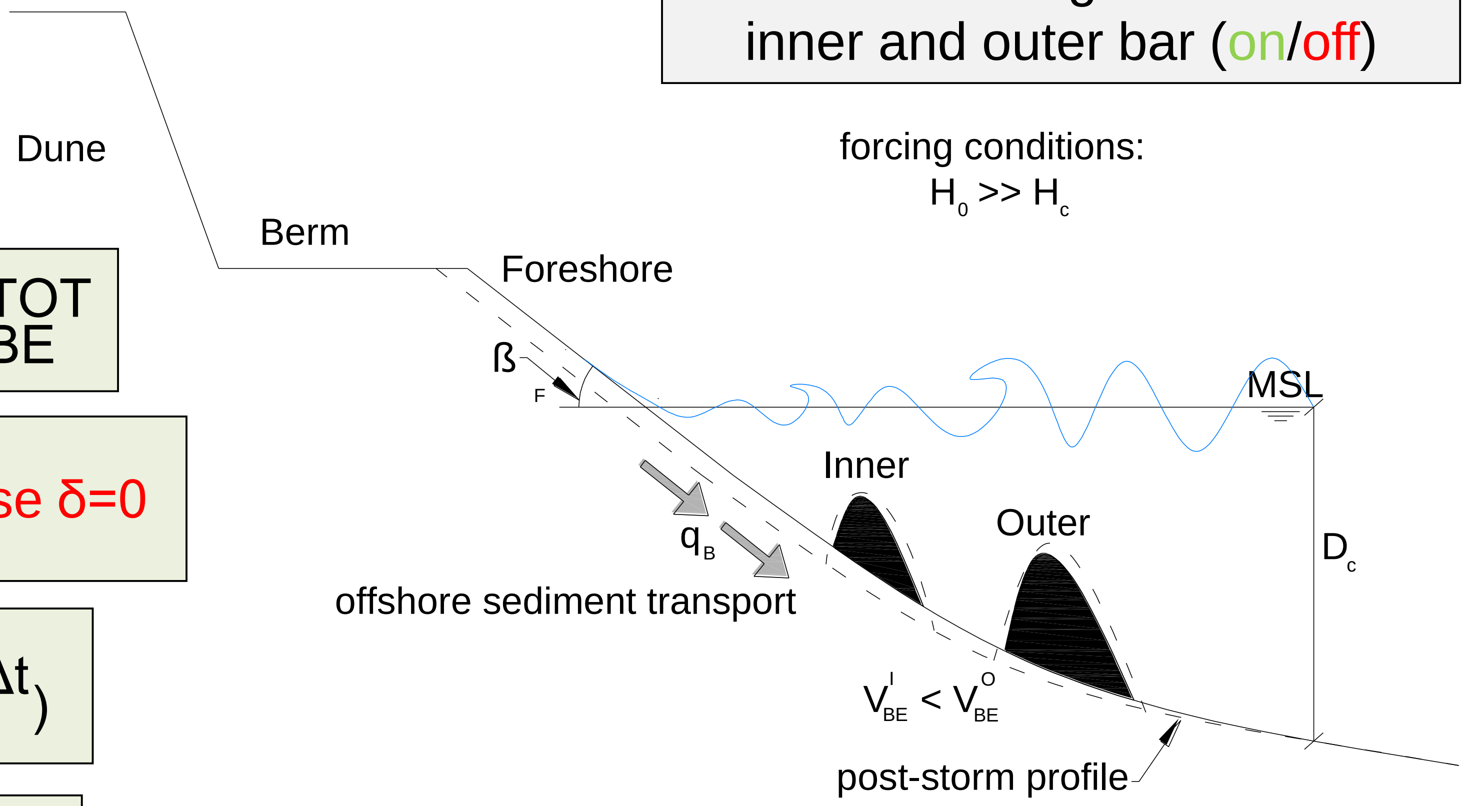
$$\Delta V_{B,i}^{I} = \left(V_{BE,i}^{I} - V_{B,i}^{I} \right) \left(1 - e^{-\lambda_i^{I} \Delta t} \right)$$

$$\Delta V_{B,i}^{O} = \left(V_{BE,i}^{O} - V_{B,i}^{O} \right) \left(1 - e^{-\lambda_i^{O} \Delta t} \right)$$

Material exchange between the inner and outer bar (on/off)



For δ>1, the outer bar grows relatively larger than the inner bar ($V_{BE}^{O} >> V_{BE}^{I}$)

Theoretical Developments. Two-bars systems

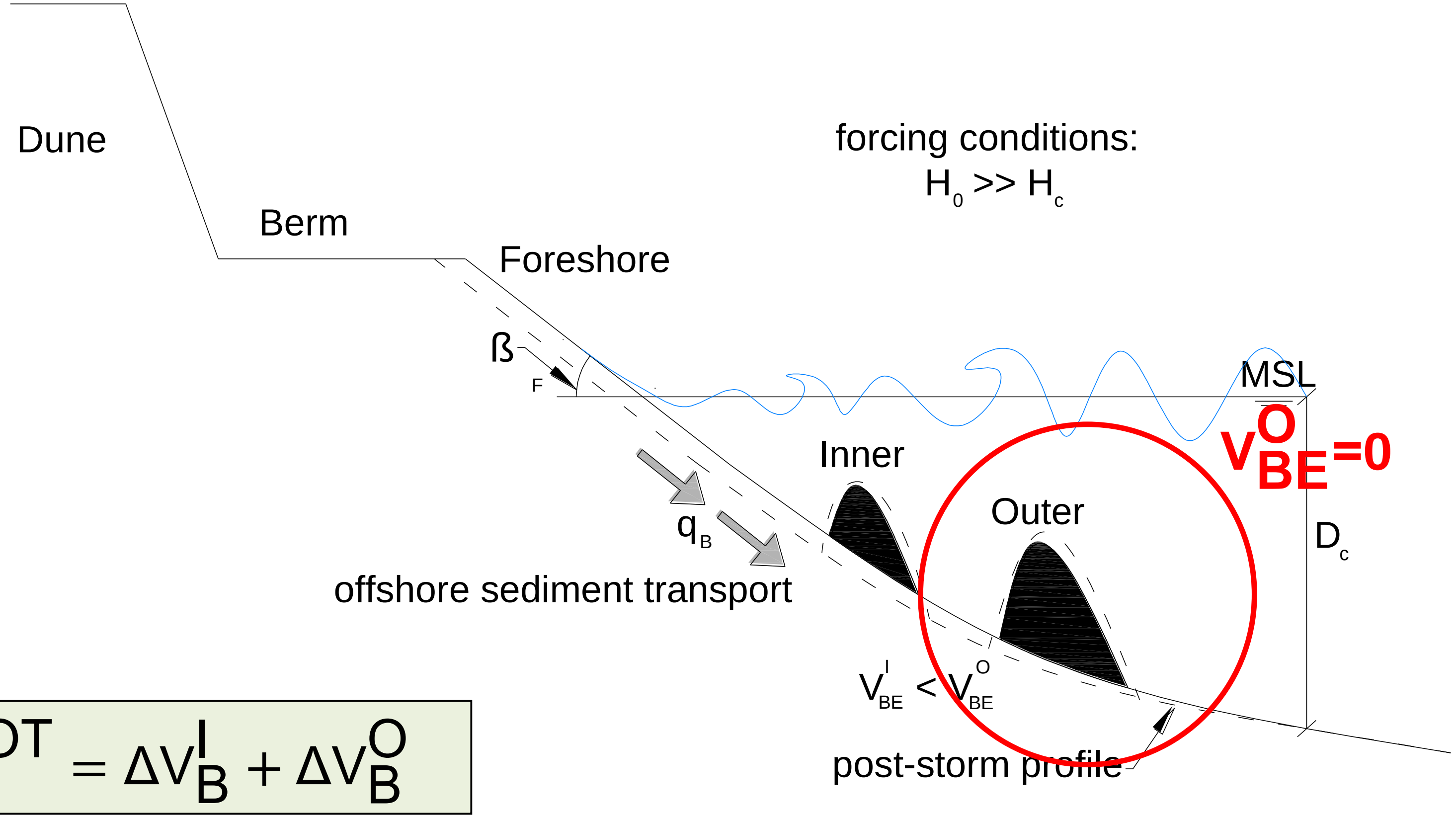
Hypothetical bar equation for nearshore placements

If $H_0 < H_b$ (non-breaking waves)

$$\Delta V^{O}_{B,i} = V^{O}_{B,i}\left(e^{-\lambda^{O}_{i}\Delta t} - 1\right)$$

Else $H_0 > H_b$ (breaking conditions)

$$\Delta V^{O}_{B} = 0$$



$$q_B(t) = \Delta V^{TOT}_{B} / \Delta T, \text{ where } \Delta V^{TOT}_{B} = \Delta V^{I}_{B} + \Delta V^{O}_{B}$$

Duck, N.C. case study. Data employed

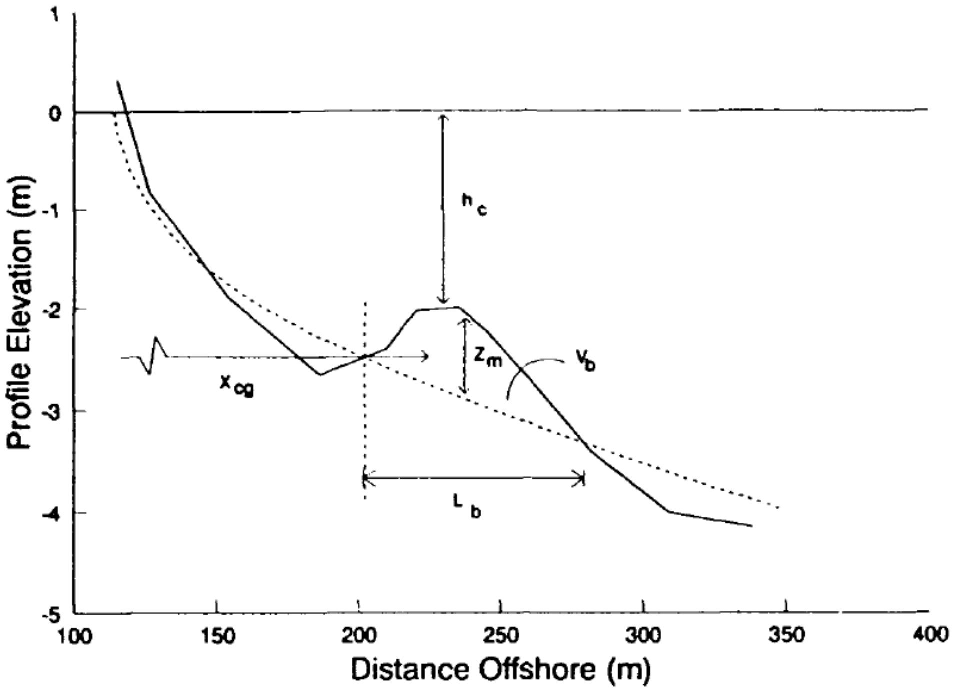
Beach profiles measurements:

Time series of a two-bars system
Duck, North Carolina

(Morphological properties of the inner and outer bar: volumes, depth, length, mass center etc.)

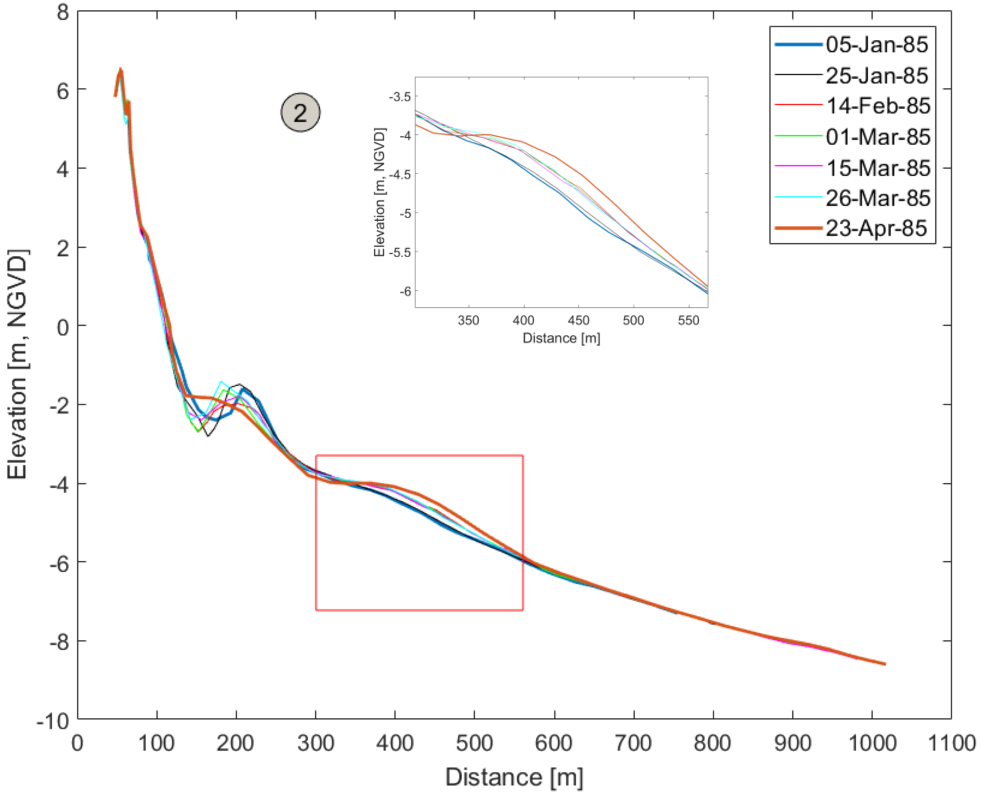
Frequency: 2-3 times/month by FRF

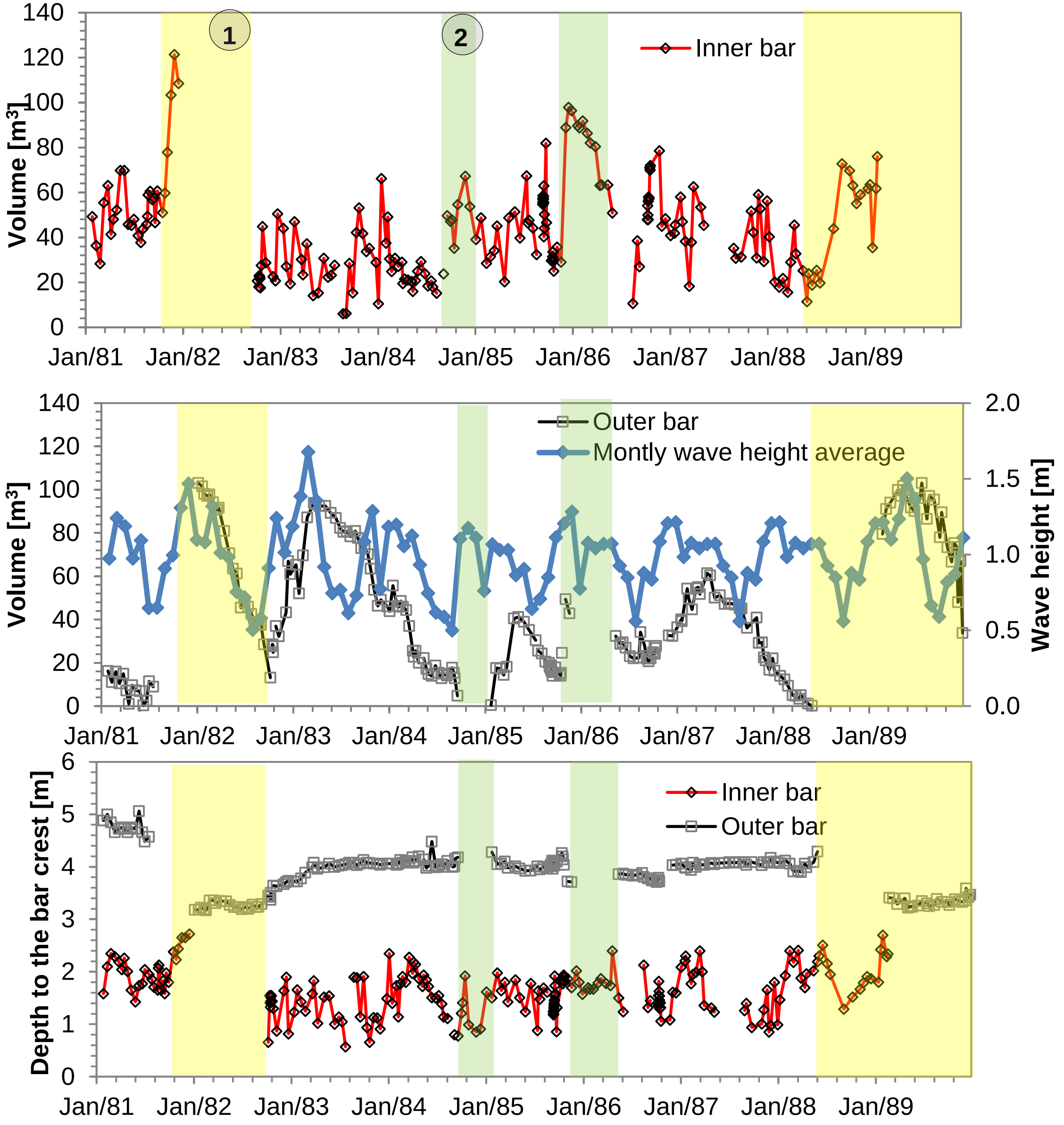
Monitoring period:
26-Jan-1981 to 09-Sep-1988 (inner)
26-Jan-1981 to 28-Dec-1989 (outer)



Duck, N.C. case study. Data employed

Beach profiles measurements:





- Wave data employed were recorded with a waverider buoy located in 18 m water depth, directly off the FRF research pier.

Duck, N.C. case study. Model calibration and validation

$\Delta t = 6$ h (time step)

Beach profile measurements divided into two main periods:

1981-1985: for model calibration of the site-specific parameters (m, C_B, λ_0, δ_0, H_c)

1985-1989: for model validation.

Two definitions were used to address the model performance:

$$\varepsilon = \left(\frac{\sum_{i=1}^{N} \left(V_B^{obs} - V_B^{cal} \right)^2}{\sum_{i=1}^{N} \left(V_B^{obs} \right)^2} \right)^{1/2}$$

$$NMSE = \frac{\sum_{i=1}^{N} \left(V_B^{obs} - V_B^{cal} \right)^2}{\overline{V_B^{obs}}\ \overline{V_B^{cal}}}$$

Duck, N.C. case study. Model calibration and validation

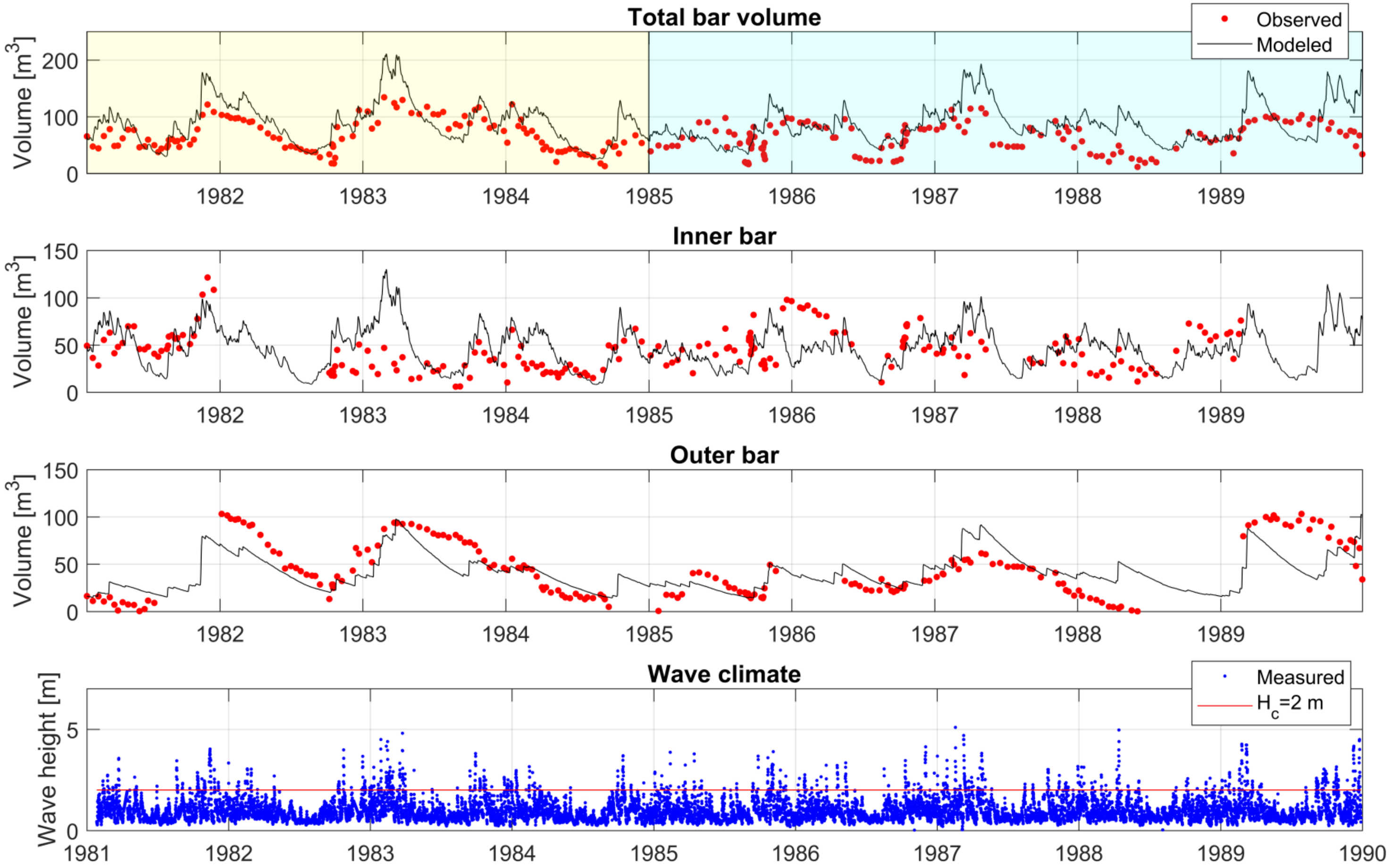
critical wave height, H_c=2 m

$V^{I}_{BE,\ initial}$= 49.2 m^3/m
$V^{O}_{BE,\ initial}$= 16.2 m^3/m

Water temperature= 15ºC

least-square error:

ε, total=0.51 (NMSE=0.24)
ε, inner=0.55 (NMSE=0.33)
ε, outer=0.39 (NMSE=0.24)



Without exchange between the inner and outer bar

Cocoa Beach, FL case study. Data employed

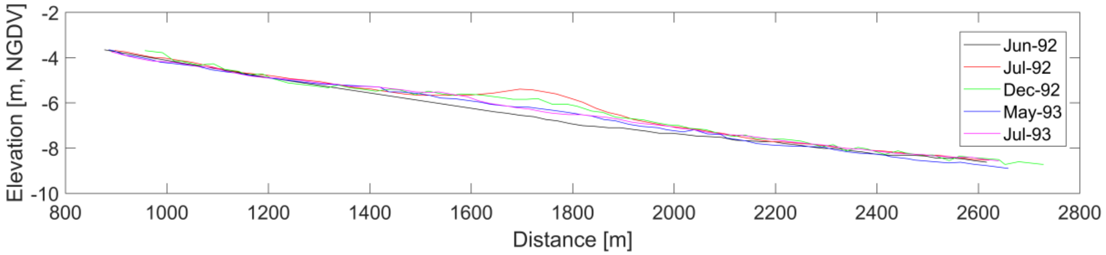
Fill volume: 121 000 m^3 of sand
Dates: from 6-Jun to 24-Jul 1992
Area: 2 895 x (200-245m)

$V^{I}_{B,\ initial} = 0\ m^3/m$
$V^{O}_{B,\ initial} = 0\ m^3/m$
(no natural bar was surveyed)

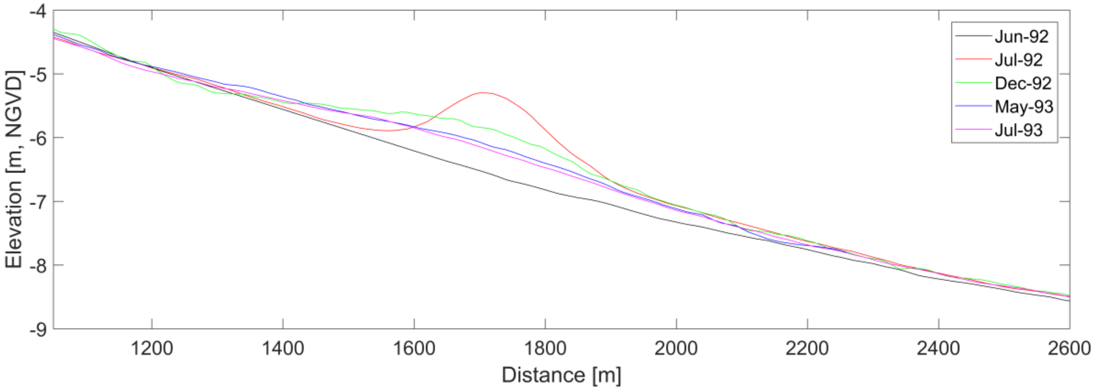
Fill volume = 47.3 m^3/m
(calculated based on surveys)

Wave hindcast with a 3-hour time step

Line located at 150 m, northern part:



Calculated average profile evolution:



Cocoa Beach, FL case study. Model calibration and results

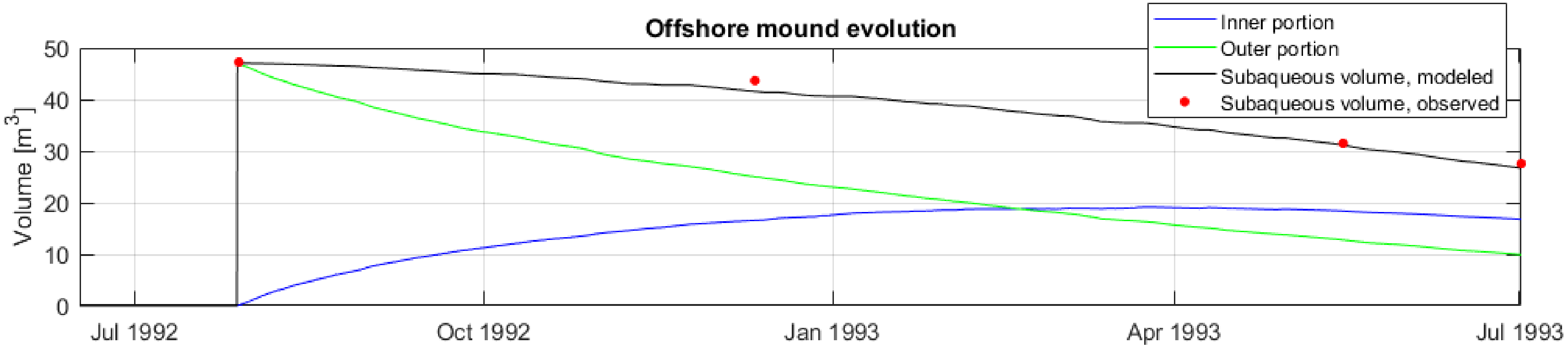
Hypothetical bar equation applied to reproduce the inshore portion (inner) and offshore mound (outer).

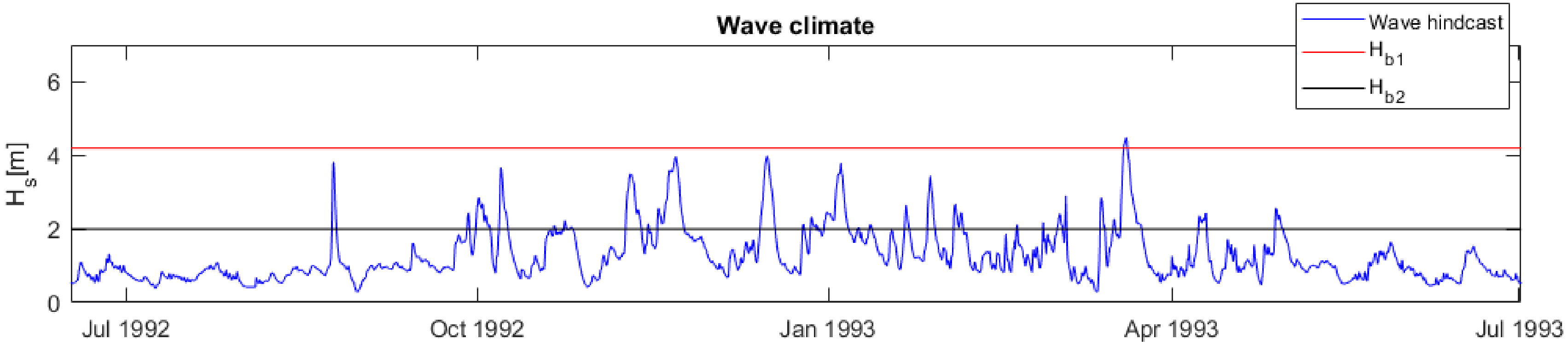
V^{I}_{BE}, V^{O}_{BE} = 0 m³/m

Wave heights thresholds:
H_{b1}= 4.2 m
H_{b2}= 2.0 m

Water temperature = 26ºC
d_{50}= 0.20 mm

least-square error: ε=0.03
NMSE=0.001





Final remarks. Conclusions

- An extended version of the heuristic model, first introduced by Larson *et al.* (2013), was here developed to reproduce the overall shift in material between the bar system and the berm of the profile by taking into account the long-term evolution of two-bar systems and the response of offshore mounds.

- The model was calibrated and validated in standalone mode at two field sites from the United States:
  1) Duck, NC, where two natural longshore bars (an inner and outer bar) typically form;
  2) Cocoa, FL, where an offshore mound was located in deep water, where no natural bar was found;

- Overall, equilibrium volumes and rate-of-change coefficients were related to non-dimensional wave and sediment properties, but during the calibration certain coefficient values had to be obtained through comparison with data and subsequently validated;

- Although the set of criteria presented should provide a first rough estimate of suitable values, parameters such us the H_c and H_b are expected to be site-specific and data are needed to apply the model with confidence at a particular site.

Final remarks. Conclusions

- The equilibrium model was skilled at predicting the time-varying volume of the outer bar, suggesting that this morphological feature is strongly influenced by offshore wave forcing in a predictable, equilibrium-forced manner.
- Model skill was lower when predicting the inner bar evolution due to the scatter of the observations. It is yet to be explored if the inner bars in a multi-bar sites display predictable, equilibrium driven cross-shore behavior, similar to outer bars and shorelines.
- The model prediction with focus on the evolution of nearshore mounds has been also successful through the simulation of hypothetical bars defined by $V_{BE}^{O} = 0$;
- The potential for using rather simple models to quantitatively reproduce the main trends in the subaqueous beach profile response in a long-term perspective through description of cross-shore volume changes in bars has been demonstrated.

Acknowledgments

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