Applications of ELCIRC at LNEC
stratification in the Guadiana estuary
tidal propagation in the Óbidos lagoon

Lígia Pinto
Anabela Oliveira
André B. Fortunato
Outline

- **Stratification in the Guadiana estuary**
  - The Guadiana estuary
  - Objectives
  - Field data review
  - Model set-up and validation
  - Stratification analysis
  - Summary and conclusions

- **Tidal propagation in the Óbidos lagoon**
The Guadiana estuary

- River flow:

<table>
<thead>
<tr>
<th>Year</th>
<th>Monthly-averaged river flow (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
</tr>
<tr>
<td>Dry</td>
<td>2.5</td>
</tr>
<tr>
<td>Wet</td>
<td>13</td>
</tr>
<tr>
<td>Very wet</td>
<td>15</td>
</tr>
</tbody>
</table>

- Semi-diurnal tides: 0.6 - 3.5 m

- Old stratification analysis (empirical criteria)
  - well-mixed: Q < 10 m³/s
  - stratified: Q > 100 m³/s
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Objectives

- Analyze the conditions for stratification in the Guadiana estuary
- Characterize the salinity field under stratified conditions

Combination of field data analysis and numerical modeling
### 2001 Data campaigns

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>River flow (m³/s)</th>
<th>Tides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb. 2</td>
<td>V.R.S.António</td>
<td>384</td>
<td>neap tide</td>
</tr>
<tr>
<td>Feb. 10</td>
<td>Odeleite</td>
<td>2005</td>
<td>spring tide</td>
</tr>
<tr>
<td>Sept. 11</td>
<td>Odeleite</td>
<td>4</td>
<td>neap tide</td>
</tr>
<tr>
<td>Sept 18</td>
<td>V.R.S.António</td>
<td>4</td>
<td>spring tide</td>
</tr>
<tr>
<td>May 23</td>
<td>2.01</td>
<td>70</td>
<td>spring tide</td>
</tr>
<tr>
<td>May 29</td>
<td>2.01</td>
<td>35</td>
<td>neap tide</td>
</tr>
<tr>
<td>Oct. 18</td>
<td>2.02</td>
<td>20</td>
<td>spring tide</td>
</tr>
<tr>
<td>Oct. 24</td>
<td>2.02</td>
<td>249</td>
<td>neap tide</td>
</tr>
</tbody>
</table>

- 14 h vertical profiles, 1 m spacing in the vertical
- ADCP at station 2.01 for February and September campaigns
Model set-up

Version 4.01 (triangular elements)

Domain discretization
- **Horizontal**: 12000 nodes, spacing 9-3600 m
- **Vertical**: 32 levels, spacing 0.75-200 m
- Extent defined through satellite images

Time step specification
- Sensitivity analysis: 5, 3, 2, 1.5 min

Horizontal diffusion: Set to zero

Level 2.5 Mellor-Yamada
- Estuary minimum mixing length: 0.15 m
- Sea minimum mixing length: 1 m

Boundary conditions
- Ocean: regional tidal model
- Upstream: daily averaged river flow & elevation
  - No elevation data
  - Run ADCIRC
  - Z0 function of river flow (linear function)
Model validation: Downstream station

Comparison for homogeneous conditions (Q ~ 4 m³/s):
- good representation of the magnitude and vertical structure of salinities
- errors below 2-6 ppt

Comparison for stratified conditions (Q ~ 400 m³/s):
- worse representation of the magnitude of salinities (errors ~ 10 ppt)
- decreasing the estuary minimum mixing length to 5 cm did not improve

Incorrect plume behavior in the continental shelf?
Model validation: Upstream station

Upstream station Odeleite, $Q = 4 \, \text{m}^3/\text{s}$:

- reasonable representation of the magnitude of salinities (errors below 6-10 ppt)
- reasonable representation of the maximum salinity propagation
**Model validation: ADCP data**

**Velocity: Comparison with ADCP data**

- Reasonable representation of magnitude, vertical structure
- Good representation of flow inversion
- Near-bottom velocity is under-predicted
  → Insufficient vertical resolution?
Analysis of stratification

Using model ELCIRC

- **Simulations set-up**
  - Constant river flow: 2, 10, 50, 100, 200 m³/s
  - 30 day run, with 15 days warm-up ⇒ spring and neap tides
  - 45 km transect through the main channel

- **Main findings**
  - Stratification increases: larger river flow, smaller tidal amplitudes and during ebb
  - Saline front is less stratified than the downstream regions at flood slack
  - Ebb slack: retention of saltier water in the deep points

![Diagram showing stratification analysis with river flows of 200 m³/s and depth profiles with flood and ebb slack stages for spring and neap tides.]
Analysis of stratification

Stratification criterion (adapted from Prandle, 1985)

- **Quantify stratification:** $\delta S / \bar{S}$ criterion
  - $\delta S / \bar{S} < 0.15$ **well mixed**
  - $\delta S / \bar{S} > 0.32$ **stratified**

Using the stratification criterion with model results: variability in space and time

- **Main conclusions:**
  - $Q = 2$ m$^3$/s: Well-mixed
  - $Q = 10$ m$^3$/s - transition: Well-mixed for spring tides, except ebb slack; Stratified/partially mixed for ebb; stratified in part of domain, well mixed upstream for flood
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Analysis of stratification

- Main conclusions:
  - $Q \geq 50 \text{ m}^3/\text{s}$: stratified even for spring tides
  - $X$ empirical criteria; $✓$ data
  - Tidal amplitude is dominant relative to river flow:
    - $Q = 50 \rightarrow 200 \text{ m}^3/\text{s}$, stratification $✓$
    - Spring $\rightarrow$ Neap, stratification $✓$ $✓$ $✓$
Conclusions

- **Analysis of stratification**
  - Stronger stratification for high river flows and small tidal amplitude.
  - Stratification occurs for river flows of 10 m³/s (empirical criteria overestimates limits).
  - Tidal amplitude is dominant relative to river flow in the strength of stratification
    - Contrast with frequently used empirical criteria, agrees with field data
  - Saline front is less stratified than the downstream regions

- **Application of model ELCIRC**
  - Excellent results of stability, efficiency
  - Adequate comparison with field data
  - Problems:
    - Need to specify both flux and elevation at inflow boundaries
    - Simulations with horizontal diffusion are unstable
Tidal propagation in the Óbidos lagoon

- The Óbidos lagoon
- Model set-up
- Field data review
- Model calibration: ADCIRC
- Model calibration and validation: ELCIRC
- Impact of dredging on tidal propagation
- Summary
The Óbidos lagoon

Semi-diurnal tides: 1.5 m

Goal:

- Simulate barotropic tides for several bathymetric configurations
- Reproduce well the flood dominance
- Reproduce well the wetting and drying
The Óbidos lagoon: bathymetry

June 2000

November 2000

July 2001

November 2001

April 2002

October 2002
Model set-up

Domain discretization
- **Horizontal**: 20000 nodes, spacing 5-1300 m

Boundary conditions
- **Ocean**: regional tidal model

Bathymetry
- **November 2000, July 2001 and October 2002**

Model: ADCIRC
- Time step: 0.6 s
- Horizontal diffusion: 1 m²/s

Model: ELCIRC
- Time step: 90 s
- **Model adaptations**
  - harmonic analysis of elevations and depth-integrated velocities
  - **Friction using Manning formulation**
Field data review

2000-2002 water level measurements

- Strong variation of tidal characteristics with bathymetry changes

Evolution of M2 amplitudes
Model calibration: ADCIRC

- Mass errors: Up to 50% differences between ebb and flood tidal prisms
- ADCIRC simulations lead to ebb-dominated instead of flood-dominated system
Model calibration and validation: ELCIRC

Downstream station

Calibration: July 2001

- Mass errors:
  4% differences between ebb and flood tidal prisms
- RMSE: 12 cm
- Errors in the flood and ebb durations: 1%
- CPU time is 1/7 of ADCIRC CPU time

Validation: October 2002

- RMSE: 18 cm
- Errors in the flood and ebb durations: 13%
Impact of dredging on tidal propagation

M2 amplitudes

- Dredging increases tidal amplitude and tidal prism in the lagoon
- Dredging effects are still important 15 months later (October 2002)

Tidal prism (% of November 2000 value)

<table>
<thead>
<tr>
<th>Simulation</th>
<th>July 2001</th>
<th>October 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neap</td>
<td>150</td>
<td>135</td>
</tr>
<tr>
<td>Spring</td>
<td>198</td>
<td>145</td>
</tr>
</tbody>
</table>

Dredging increases tidal amplitude and tidal prism in the lagoon

Dredging effects are still important 15 months later (October 2002)
Applications of ELCIRC at LNEC

Summary

- Calibration/validation of a system with a fast bathymetric evolution is difficult
- ADCIRC: mass conservation problems
- ELCIRC simulations:
  - stable
  - efficient
  - compared well with field data
  - Outputs in the frequency domain reduced storage requirements and can be used in morphodynamic simulations
Summary

- Problem:
  - Very large velocity gradients in drying areas can lead to problems in morphodynamic and residence time calculations.

![Diagram showing velocity gradients using Chézy friction]