THE HIGH RESOLUTION BATHYMETRY OF THE LAGOON OF VENICE: A BASE MAP FOR INTERDISCIPLINARY RESEARCH


Gebco Science Day 2013
Venice.
The lagoon of Venice is the biggest lagoon in the Mediterranean area with a surface of about 550 km$^2$.

It communicates with the Adriatic Sea through three inlets.

It has an average depth of about 0.8 m.

The typical morphological features are:

- navigation canals (20 m deep at the inlets up to 2 m deep)
- natural tidal channels and creeks (few m to few dm deep)
- tidal flats (often less than 1 m deep)
- intertidal areas
- salt marshes
THE LAGOON OF VENICE IS IN RAPID EVOLUTION:

- salt marsh areas decreased by more than 50% in the last century
- deepening trend in some parts of the lagoon was observed with a net sediment flux exiting from the inlets.
- Major engineering interventions ongoing at the inlets
- impact of large ships

THE NEED OF MONITORING:

- Transitional environments undergo strong natural and human induced action.
- The changes can be assessed by repeated bathymetric surveys
- Extremely shallow environments are a challenge for acoustic bathymetric surveys

BATHYMETRY IS ONE OF THE MAIN FACTOR IN MULTIDISCIPLINARY STUDIES

- Habitat mapping
- Sediment budgets
- Geo-archaeology
- Hydrodynamic modelling
THE CHALLENGE OF BATHYMETRY IN THE LAGOON OF VENICE

- Extremely shallow water (~1 m) – Multipath effect and reverberation
- High turbidity – no transparent water

- High tide excursion (about 1m) – operational problems and need for tide correction

- Current speed (about 1 ms\(^{-1}\) in the Lido inlet and 0.2 ms\(^{-1}\) in the Scanello channel, Northern Lagoon)
- Sound velocity profile variations (variation in salinity and temperature)

Scanello channel \(svp\) vs time

From Dese to Torcello \(svp\) vs space
Current and tide data from the hydrodynamic model of the Venice Lagoon in the day of the survey

(data courtesy of Dr M. Bajo - ISMAR Venice)

Average currents ranging from 0.17 to 0.2 m/s
THE CHALLENGE OF BATHYMETRY IN THE LAGOON OF VENICE
Investigate all channels key areas in the shallowest water

STARTING WITH 6 MONTHS OF SURVEY FOR 8 HOURS A DAY

More than 20 people and 5 different groups involved
BATHYMETRY IN THE LAGOON OF VENICE: EQUIPEMENT

Multibeam System **Kongsberg EM 2040D-C**

Positioning system **Kongsberg Seapath 300**

Motion sensor **Kongsberg Seatex MRU 5**

Valeport Mini SVS and AML Oceanographic SV Profiler
SURVEY AREAS – THE CITY OF VENICE

San Marco Square
SURVEY AREAS – San Marco square (DTM 0.2m V.E:5X)
SURVEY AREAS – The city of Venice

San Marco Square

-0.73 m
-23.5 m
SURVEY AREAS – The city of Venice
BIG CRUISE SHIPS AND HIGH WATER
SURVEY AREAS – The city of Venice
BIG CRUISE SHIPS AND HIGH WATER
SURVEY AREAS - DIFFERENT ENVIRONMENTS
MOSE CONSTRUCTION

-0.73 m
-23.5 m
Resolution
0.5 M

V.E. 5X
LIDO INLET
Treporti channel

DTM 0.2 m
v.E 5 x
RESULTS: SURVEY AREAS DIFFERENT ENVIRONMENTS

- Scanello channel
- San Marco basin
- Venice Arsenal
- River Dese
- Lido inlet

-0.73 m
-23.5 m
Case study of the Scanello Channel: ideal laboratory for a multidisciplinary approach

- Bathymetry – geomorphometry (roughness, ...)
- Sediment sampling (grain size, ...)
- Benthos sampling (habitat, ...)
- Current measurements (ADCP)
- High spatial resolution modelling of the hydrodynamics
SCANELLO Channel, geomorphometry

Grid 0.5m

V.E = 5

Grid 0.5m

V.E = 5

60m
After computation of the 2D FFT of partially overlapping 20mx20m windows of the bathymetry we obtained average orientation and wavelength for each dune field.

For example for the dune field 2:

- Average orientation $\alpha = 88^\circ$
- Average wavelength $\lambda=10$ m
Extraction of bedform wavelengths and orientations from the 2D FFT (dune field 2)

- Average orientation angle: 88 degrees
- Average wavelength of
  - $\lambda = 8.8$ m
  - $\lambda = 13.8$ m
  - $\lambda = 32$ m

Bathymetric profile dune field 2

Periodogram of dune field 2

Bathymetry and orientations of bedforms extracted with the 2D FFT

- L=32 m
- L=13.8 m
- =8.8 m
Approximating the dune with a triangle, we can define the dune height $H$, wavelength $L$, asymmetry index $L_1/L_2$ and steepness $L/H$. 

**Figure 1.** Definition of the morphologic parameters wavelength and height and characteristic morphologic points of bed forms, the crest point, $C$; trough point, $T$; inflection point of the lee side, $i$; brink point, $b$; and toe point, $t$. (modified from Van Dijk et al. 2008)
## Dune field parameters

<table>
<thead>
<tr>
<th>Type of subacqueous dunes</th>
<th>Medium dunes</th>
<th>Small dunes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dune field</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Wavelength L (mean)</td>
<td>9.18 m</td>
<td>5 m</td>
</tr>
<tr>
<td></td>
<td>9.43 m</td>
<td>5.08 m</td>
</tr>
<tr>
<td>Wavelength L (range)</td>
<td>2.49-13.97 m</td>
<td>2.99- 7.96 m</td>
</tr>
<tr>
<td></td>
<td>4.49-16.46 m</td>
<td></td>
</tr>
<tr>
<td>Height H (mean)</td>
<td>0.45 m</td>
<td>0.19 m</td>
</tr>
<tr>
<td></td>
<td>0.37 m</td>
<td>0.26 m</td>
</tr>
<tr>
<td>Height H (range)</td>
<td>0.04-0.84 m</td>
<td>0.01- 0.52 m</td>
</tr>
<tr>
<td>Asymmetry index L₁/L₂ (mean)</td>
<td>1.32</td>
<td>1.99</td>
</tr>
<tr>
<td>Asymmetry index L₁/L₂ (range)</td>
<td>0.33-4.02</td>
<td>0.14-5.06</td>
</tr>
<tr>
<td>Steepness H/L (mean)</td>
<td>0.044</td>
<td>0.035</td>
</tr>
<tr>
<td>Steepness H/L (range)</td>
<td>0.01-0.08</td>
<td>0.065- 0.006</td>
</tr>
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Dune field parameters

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<th>Type of subaqueous dunes</th>
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<tr>
<td>Dune field</td>
<td>1 2 3 5</td>
<td>4 6</td>
</tr>
<tr>
<td>Wavelength L (mean)</td>
<td>9.18 m 9.43 m 6.389 m 7.06 m</td>
<td>5 m 5.08 m</td>
</tr>
<tr>
<td>Wavelength L (range)</td>
<td>2.49-13.97 m 4.49-16.46 m 3.49-9.47 m 4.48-9.95 m</td>
<td>2-8.5 m 2.99-7.96 m</td>
</tr>
<tr>
<td>Height H (mean)</td>
<td>0.45 m 0.37 m 0.32 m 0.36 m</td>
<td>0.19 m 0.26 m</td>
</tr>
<tr>
<td>Height H (range)</td>
<td>0.04-0.84 m 0.06-0.74 m 0.06-0.7 m 0.16-0.67 m</td>
<td>0.01-0.52 m 0.11-0.54 m</td>
</tr>
<tr>
<td>Asymmetry index L1/L2 (mean)</td>
<td>1.32 1.79 1.32 1.26</td>
<td>1.99 1.04</td>
</tr>
<tr>
<td>Asymmetry index L1/L2 (range)</td>
<td>0.33-4.02 0.25-5.1 0.12-5.1 0.5-2.5</td>
<td>0.14-5.06 0.39-2.03</td>
</tr>
<tr>
<td>Steepness H/L (mean)</td>
<td>0.044 0.037 0.047 0.039</td>
<td>0.035 0.043</td>
</tr>
<tr>
<td>Steepness H/L (range)</td>
<td>0.01-0.08 0.051-0.013 0.076-0.014 0.068-0.006</td>
<td>0.065-0.006 0.090-0.006</td>
</tr>
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</table>

• From the wavelength $L$ and the height $H$ one can estimate the roughness length
• From the asymmetry index $L_1/L_2$ one can determine the dominant dune direction
Roughness estimation

\[ u(z) = \frac{u^*}{K} \ln \frac{z}{z_0} \]

\( z_0 \) is the roughness length, i.e. the height where the current velocity tends to zero.

- If the bottom is flat it is related to the drag of the single grains (grain roughness)
- If the bottom has beforms it is also related to the bedform friction (bedform roughness)
- It is used to estimate the bed shear stress which is an essential parameter in boundary layer dynamics, hydrodynamics, and sediment transport calculations and modeling

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Table 1  Some bedform roughness predictors

<table>
<thead>
<tr>
<th>Authors</th>
<th>Validity</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swart (1976)</td>
<td>Wave-formed ripples</td>
<td>( z_0 = 0.83 \frac{H^2}{L} )</td>
</tr>
<tr>
<td>Grant and Madsen (1982)</td>
<td>Wave-formed ripples under oscillatory flow or combined waves and currents</td>
<td>( z_0 = 0.92 \frac{H^2}{L} )</td>
</tr>
<tr>
<td>Nielsen (1992)</td>
<td>Roughness of rippled bed under waves</td>
<td>( z_0 = 0.27 \frac{H^2}{L} )</td>
</tr>
<tr>
<td>Soulsby (1997)</td>
<td>Generalization of previous equations</td>
<td>( z_0 = a_b \frac{H^2}{L} ) and ( a_b = 1 )</td>
</tr>
<tr>
<td>Van Rijn (1984)</td>
<td>Ripples, dunes and large dunes 0.01 &lt; ( H/L &lt; 0.2 )</td>
<td>( z_0 = 0.04H \left( 1 - e^{-25H/L} \right) )</td>
</tr>
<tr>
<td>Bartholdy et al. (2010)</td>
<td>Dunes under currents</td>
<td>( z_0 = 0.019H )</td>
</tr>
</tbody>
</table>

(from Lefebvre et al. 2011)
## Bedform roughness estimation

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<tr>
<td>Dune field</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Wavelength $L$ (mean)</td>
<td>9.18</td>
<td>9.43</td>
<td>6.39</td>
</tr>
<tr>
<td>Height $H$ (mean)</td>
<td>0.45</td>
<td>0.37</td>
<td>0.32</td>
</tr>
<tr>
<td>Roughness $z_0$ (cm) (Soulsby 1997)</td>
<td>2.206</td>
<td>1.452</td>
<td>1.603</td>
</tr>
<tr>
<td>Roughness $z_0$ (cm) (Van Rijin 1984)</td>
<td>1.271</td>
<td>0.925</td>
<td>0.914</td>
</tr>
<tr>
<td>Roughness $z_0$ (cm) (Bertholdy et al. 1997)</td>
<td>0.855</td>
<td>0.703</td>
<td>0.608</td>
</tr>
</tbody>
</table>

The roughness associated with the bedforms ranges from 0.36 to 2.2 cm.
One year-long simulation was carried out forcing the model with real wind and water level data. The residual current distribution, computed averaging model results over the whole investigated period, displayed a circulation pattern with inflow into the Scanello channel system. The residual currents, which highlight the influence of the wind and tides as non-linear and topographic induced effects, give the net water movement and they determine the predominant spreading of a dissolved or particulate substance inside the lagoon.

www.ismar.cnr.it/shyfem
Model results- residual currents:

The bed-form orientation generally follows the direction of the residual currents.
Backscatter data
Backscatter intensity and sediment sampling
The grain roughness $z_0 = d_{50}/12$ (Engelund and Hansen, 1967) ranges from 0.003 to 0.026 mm (2 order of magnitude smaller than the bedform roughness).
Acoustic images of the seafloor will show variations in grey levels.
Some of the more subtle variations can only be detected numerically (using second-order statistics) Grey-Level Co-occurrence Matrices (GLCMs) calculate the number of times particular grey-levels occur together.
GLCMs can be described with statistical parameters (e.g. entropy, homogeneity).
These parameters describe the textures. From these, one can (hopefully) characterise the type of seafloor.
Sediment classification with TexAN analysis and sediment samples

Manual supervised classification

Automatic supervised classification with TexAN

Backscatter classification
- coarse silt with shell and oyster fragments
- very coarse silt without shells
- very coarse silt with shell fragments
- very coarse silt with fine shell fragments
- very coarse silt with oyster and shell fragments
- very coarse silt and fine sand with small shell and oyster fragments
- very fine sand with oyster and shell fragments

Classification by Philippe Blondel
Conclusions

- ISMAR has a new TEAM able to collect and processes High resolution bathymetric data
- Snapshot of the lagoon morphology to assess the long term changes induced by engineering works and ship traffic
- Starting from bathymetry we carried out a multidisciplinary experiment in order to:
  1. Develop a methodology to quantitatively describe the lagoon geomorphology for future comparisons
  2. Compare the hydrodynamic model with high resolution bathymetry
  3. Develop a methodology to automate bottom sediment classification for habitat mapping
THANKS FOR YOUR ATTENTION

QUESTIONS?
SAN MARCO SQUARE - The Third Column legend or reality?
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