Operational storm surge modelling in Venice: the ICPSM activity

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ESA Storm Surge Project - UCM meeting
Venice 17-18 September 2009
Aim of ICPSM (Venice Municipality): to forecast the sea level in Venice and alert the population to a prompt alarm, which allows to minimize discomfort and to reduce economical damage.
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The Adriatic Sea is an elongated (800x200 km), semi-enclosed basin, surrounded by mountain chains, deeper in the South (as to 1200 m) and shallower in the North.

The tidal wave propagates from the Adriatic Sea, through the three inlets, into the Venice Lagoon and reaches the city of Venice.
Storm surges are characterized by:

- low pressure
- strong Sirocco wind along the Adriatic

Circulation scheme likely to induce high tide in the Venice Lagoon

In these cases a strong meteorological residual (surge) is generated and produces floodings in coastal areas “high water” in Venice

(image from NASA, www.visibleearth.nasa.gov)
Principal problem:

to compute the meteorological residual (= surge)

numerical models

Statistical models
Hydrodynamic finite element model
    SHYFEM
Hydrodynamic finite difference model
    HYPSE

a critical point is the quality of the meteorological input
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Statistical models

\[ \Delta h_{(t+\tau)} = \sum \left( a_i^{(r)} \cdot \Delta h_{(t-i)} + b_i^{(r)} \cdot p_{(t-i)} + c_i^{(r)} \cdot \Delta p_{x(t-i)} \right) \]

- **Semplificato model**
  - Forecast 36 hours
  - Input: \( p \) (synop)

- **Completo model**
  - Forecast 36 hours
  - Input: \( p \) (synop)

- **Esteso Meteo model**
  - Forecast 144 hours
  - Input: \( p \) (ECMWF)

- **Esperto model**
  - Forecast 144 hours
  - Input: \( p \) (ECMWF)

Splitting Database

- 3 criteria
- Multiple sets of coefficients

- Seasonality
- Air pressure differences in Adriatic
- Time of registration level/air pressure
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Finite element model SHYFEM

\[
\begin{align*}
\frac{\partial U}{\partial t} - fV + gH \frac{\partial}{\partial x} \left( \zeta + \frac{p}{\rho_0 g} \right) - A_H \left( \frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} \right) - \frac{1}{\rho_0} \tau_{x} = \tau_{bx} = 0 \\
\frac{\partial V}{\partial t} + fU + gH \frac{\partial}{\partial y} \left( \zeta + \frac{p}{\rho_0 g} \right) - A_H \left( \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} \right) - \frac{1}{\rho_0} \tau_{y} = \tau_{by} = 0 \\
\frac{\partial \zeta}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0
\end{align*}
\]

Atmospheric forcing: pressure, wind stress

ISMAR-CNR Venice

CNR platform

Punta Salute

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Finite difference model HYPSE

Shallow water equations.

**Finite difference grid** of the Adriatic Sea with curvilinear coordinate system.

Forcing: ECMWF pressure and wind fields.

Data assimilation for the level (adjoint model).

Operational since 2003.

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Meteorological forcing: ECMWF fields

ECMWF global atmospheric model

- Pressure at mean sea level
- Wind at 10 m
- $\Delta x = \Delta y = 0.25^\circ$  $\Delta t = 3$ hours

Analysis forecast (to +144 hours)
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Meteorological forcing: high resolution fields

Limited area model LAMI
ARPA-SIM Italy
boundary condition from the global model of DWD

pressure at mean sea level
wind at 10 m
Δx = Δy ~ 7 km  Δt = 3 hours
forecast (to +72 hours)

Limited area model ALADIN
DHZ Croatia
boundary condition from the ARPEGE global model (Meteo-France)

pressure at mean sea level
wind at 10 m
Δx = 0.12°
Δy = 0.08°  Δt = 3 hours
forecast (to +72 hours)

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The operational sea level forecasting

The ICPSM technical staff:

- control and interpret the model results
- integrate them with observed data (ICPSM monitoring network, METEOSAT images,…)
- formulate the sea level forecast for the next two days and circulate it throughout the city

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Satellite data: QuikSCAT and ASCAT winds

Satellite wind data (from QuikSCAT and ASCAT) are received in near-real time at ICPSM.

Wind over the open sea is now available.

A comparison with ECMWF wind fields is done.

Satellite winds can help in:
• formulating the subjective sea level forecasting
• evaluating the reliability of meteorological fields used as forcing of sea level models.
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A case study: the event of 1 December 2008
Operational storm surge modelling in Venice: the ICPSM activity

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ΔP ~ 20 hPa
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Forecast of 29 November 2008
Forecast lag + 2 days
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observed data

forecast of 30 December
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A case study: the event of 27 April 2009

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Event of 27 April 2009 - Punta Sottomarina

Event of 27 February 2009 - Punta Sottomarina

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Conclusions and future developments

The sea level forecasting in Venice is obtained through numerical models and subjective evaluation by the technical staff.

A key problem is the quality of the forcing meteorological fields from atmospheric models.

Satellite wind data can help in:
- formulating the subjective sea level forecasting
- evaluating the reliability of forcing meteorological fields
- individuating the most reliable sea level model (= forced by the most reliable atmospheric input) in each particular situation

In the future, if suitable tools will be developed, satellite data could be assimilated in the forcing input fields.

[Zampato et al: “Storm surge in the Adriatic Sea…” Advances in Geosciences 7, 2006]
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Acknowledgements

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- ECMWF (Reading UK)
- University of Padua
- ISMAR-CNR Venezia
- ISAC-CNR Padua
- Italian Air Force
- ARPA-SIM (Emilia Romagna, Italy)
- ISPRA
- CO.RI.LA.

Thank you for your attention!
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Operational storm surge modelling in Venice: the ICPSM activity
The water level in Venice can be described as sum of two terms:

\[
\text{level} = \text{astronomical tide} + \text{meteorological residual}
\]
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Seiches

they are free oscillations of the Adriatic Sea, due to its peculiar geometry and started by the meteorological forcing.

Periods:

\[ T_1 \sim 22 \text{ hours} \]
\[ T_2 \sim 11 \text{ hours} \]

Seiches persist for some days after their generation. They are progressively attenuated by bottom friction or energy loss through the Strait of Otranto.

6-10 Novembre 2000: Piattaforma CNR

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## Errors of numerical models

### Statistical model (ESPERTO)

<table>
<thead>
<tr>
<th></th>
<th>6 h</th>
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<th>18 h</th>
<th>24 h</th>
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<tbody>
<tr>
<td>(E) (cm)</td>
<td>-0.4</td>
<td>-0.1</td>
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<td>0.3</td>
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### Finite element model SHYFEM

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