Storm surge forecast in Venice through an hydrodynamic model

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Abstract

Since the end of 2002 a finite element hydrodynamic model, called SHYFEM, is operational at the Office for the tidal forecast of the Venice municipality (ICPSM). It solves the 2D shallow water equations in a computational grid of the Mediterranean Sea. Wind and atmospheric pressure fields, provided by the ECMWF Centre, are used as forcing. Since December 2007 a routine of local data assimilation based on an Artificial Neural Network (ANN) is operational. The network input is composed by surge forecasts, observations and model errors. The output is the corrected storm surge forecast. Database of 2003, 2004, 2005 have been used to train the ANN. The testing phase was made with data of 2006 and the validation with data of 2007. Results of the assimilation procedure show a double of the accuracy for short term forecast (~1 day), and good improvements also the next days.

Model description

The SHYFEM model solves the vertically integrated shallow-water equations in their linearised formulation with levels and transports.

$$\frac{\partial U}{\partial t} - fV + gH\frac{\partial \zeta}{\partial x} + \frac{1}{\rho_w}\left(\tau_{xb} - \tau_{xw}\right) = 0$$

$$\frac{\partial V}{\partial t} + fU + gH\frac{\partial \zeta}{\partial y} + \frac{1}{\rho_w}\left(\tau_{yb} - \tau_{yw}\right) = 0$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0$$

It uses finite elements for spatial integration and a semi-implicit algorithm for integration in time. The terms treated implicitly are the water level gradients, the Coriolis term and the bottom friction term in the momentum equations and the divergence term in the continuity equation. All other terms are treated explicitly.

The wind speed and the atmospheric pressure are directly specified for each element of the domain and are provided by the ECMWF forecast fields (model T799).

At the closed boundaries only the normal velocity is set to zero and the tangential velocity is a free parameter. This corresponds to a full slip condition [5, 6].

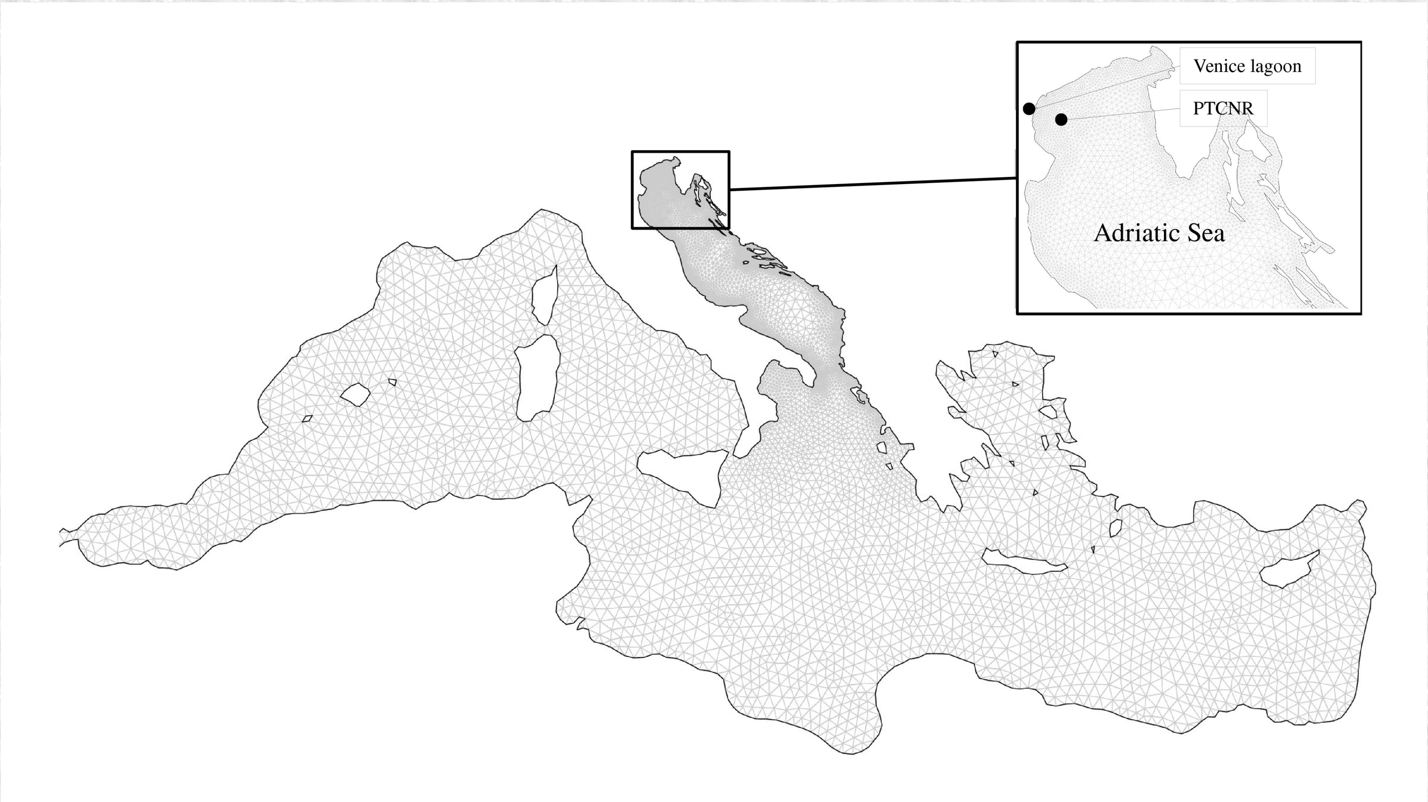

Fig 1: Computational grid of the Mediterranean Sea.

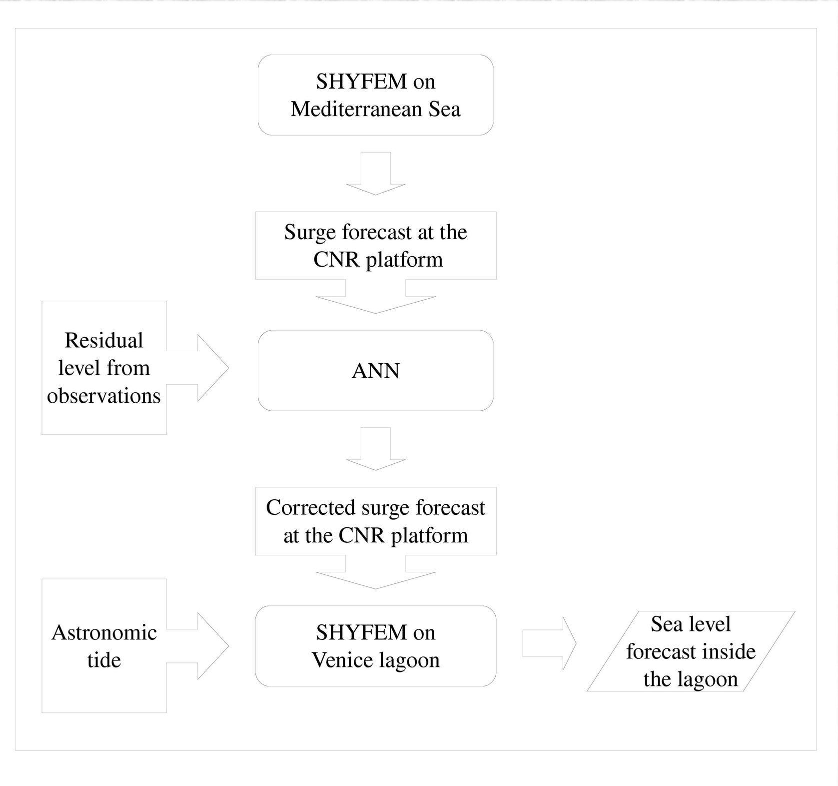

Fig 2: Scheme of the operational system.

The shallow-water equations are solved on a finite element grid of the Mediterranean Sea, made out of 18,626 elements (Fig. 1). Then the forecast storm surge is extracted near Venice and added to the astronomic tide, predicted by mean of the harmonic constants in order to provide the total sea level for five days and half in advance [1]. *The ANN routine provide a second estimate of the sea level near Venice.*

To obtain the sea level inside the lagoon, the sea level computed outside is applied at the three inlets of a grid of the lagoon with 7,842 elements.

After the simulation the sea level is extracted in three locations: Burano, Chioggia and Punta Salute, in the centre of Venice (see Fig. 2). Also maps of the whole lagoon are provided both for the current and for the level (Figs. 3, 4 and 5).

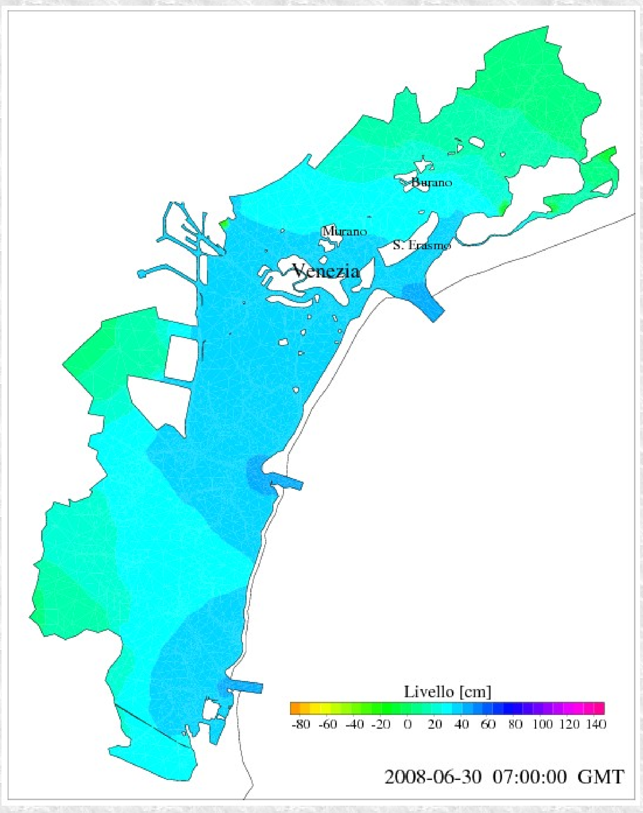

Fig 3: Forecast of the level inside the Venice lagoon.

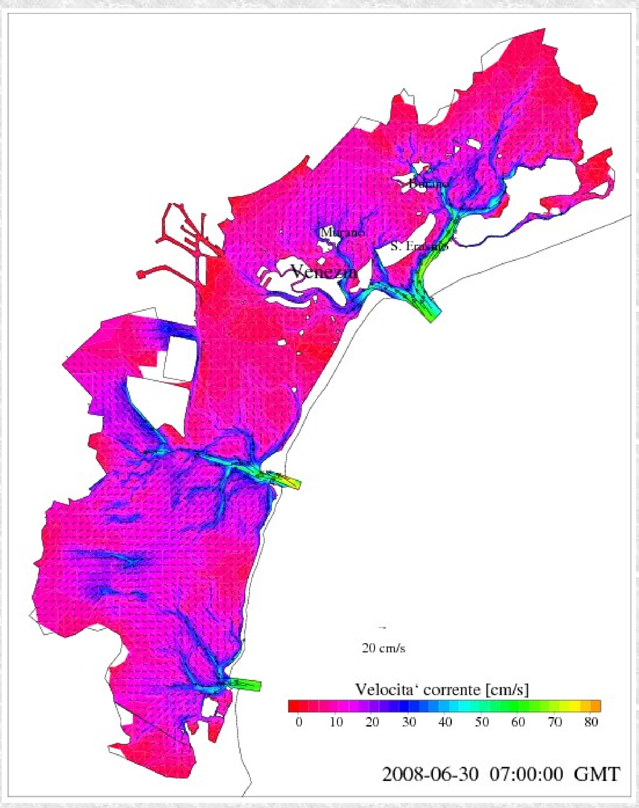

Fig 4: Forecast of the currents inside the Venice lagoon.

Data assimilation routine based on neural networks

The ANN library used in this work is named FANN (Fast Artificial Neural Network) [4]. The code is open source and freely downloadable at the web-page: *http://leenissen.dk/fann/*.

Creation of databases and ANN training

Each daily run of the hydrodynamic simulation has 133 forecast hours, for each one different databases were created.

Each database contains observations and model results used as input and observations used as desired output (see [3] for a description of the post-processing methods).

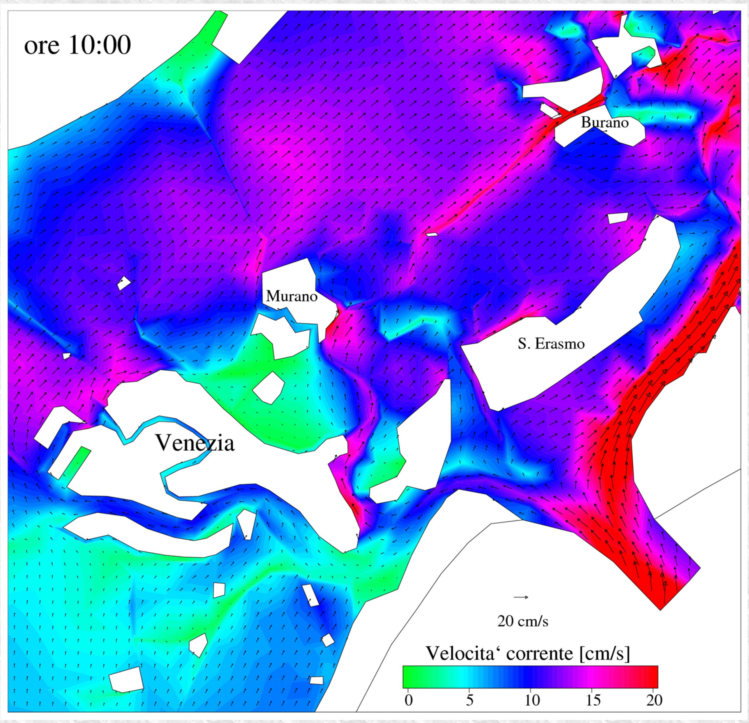

Fig 5: A particular of a current forecast inside the Venice lagoon.

Results

In order to test the performance of the network the databases of 2006 was used for testing during the calibration procedure, while the results of 2007 for the validation [2]. In Tab. 1 the standard deviation and the mean of the differences between modeled and observed levels are reported for the normal results (Mod) and the post-processed results (Fann) at different forecast lags. The last two columns reported the correlation coefficients.

Forecast day	Std dev		Media		Correlazione	
	Mod	Fann	Mod	Fann	Mod	Fann
1-day	0.094	0.047	0.023	0.002	0.71	0.90
2-day	0.094	0.062	0.023	0.004	0.71	0.82
3-day	0.095	0.071	0.018	0.003	0.68	0.76
4-day	0.105	0.080	0.016	0.002	0.63	0.68
5-day	0.115	0.089	0.012	0.000	0.55	0.59

Tab 1: Daily statistic of the model performances.

In Fig. 6 hourly values of mean and standard deviation are reported for modeled results (Mod) and after the ANN correction (Fann).

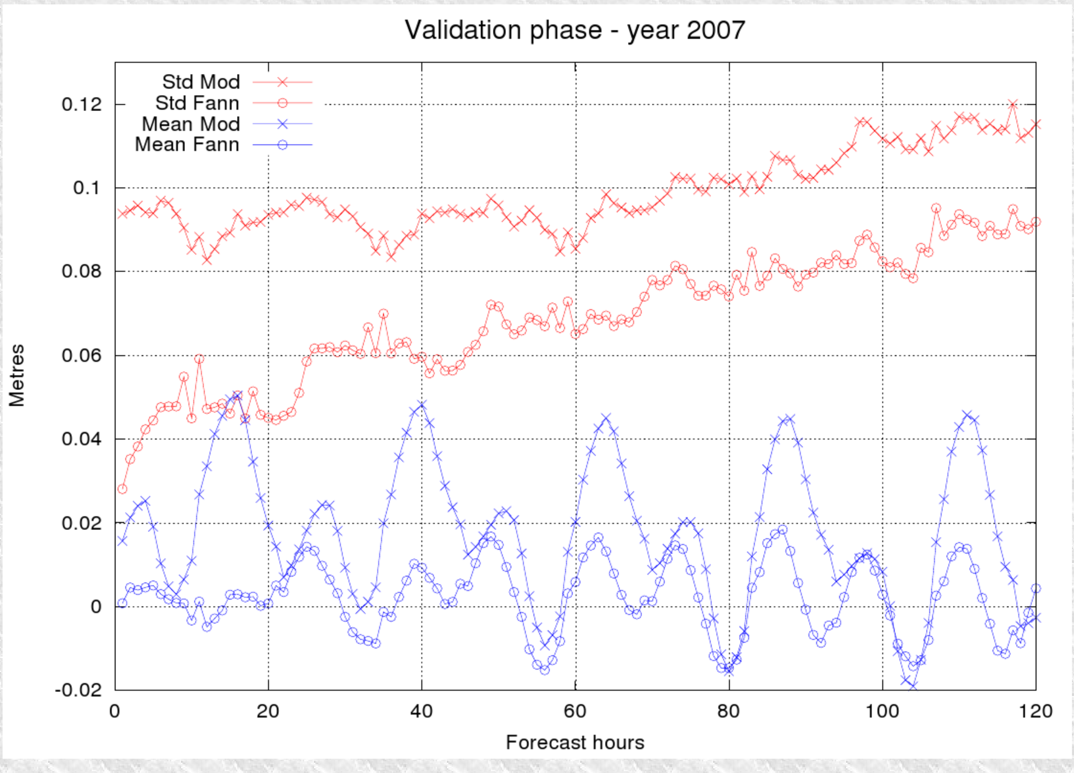

Fig 6: Mean and standard deviation (in metres) of the differences between modeled and observed surge plotted against the forecast hour.

In Tab. 2 a comparison with other operational models of the ICPSM Centre is reported. SHYFEM model with the ANN correction reaches the best performances.

Model	6-hour forc.	12-hour forc.	24-hour forc.	48-hour forc.	72-hour forc.
SHYFEM	(0.6±18.3)	(2.2±17.0)	(0.5±17.1)	(0.4±17.1)	(0±18.4)
SHYFEM nn	*(0.2±10.3)*	*(-0.7±9.3)*	*(0.8±10.3)*	*(1.1±13.4)*	*(1.2±15.3)*
Statistical m. "Semplificato"	(0±13)	(0±14.2)	(0±17)	--	--
Statistical m. "Completo"	(0±12.2)	(0±14)	(0±17.6)	--	--
Statistical m. "Esteso meteo"	(-0.1±13.2)	(-0.2±13.6)	(0±14.6)	--	--

Tab 2: Accuracy indexes (mean ± 2*stdev) of some forecast hours of the model (SHYFEM), of the model with neural correction (*SHYFEM nn*) and of three statistical models that are operational at the ICPSM Centre: Semplificato, Completo and Esteso Meteo (the statistical values of these models were found in the web-page: http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/3073).

Conclusions

As shown in Tab. 2 a hydrodynamic model generally does not reach the accuracy of a statistical model on short forecasts. This problem can be bypassed using a post-processing method, as the one presented in this work. The final system will take advantage from both the approaches.

References

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