The use of QuikSCAT wind fields in water level modeling of the Adriatic Sea

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Abstract

A finite element hydrodynamic model for the Mediterranean Sea has been used to reproduce the sea surface elevation in the Northern Adriatic Sea. Particular attention has been devoted to the simulation of the storm surge events that cause the flooding of Venice. A crucial problem in the hydrodynamic modeling is the quality of the wind fields forcing the circulation model. In this paper an attempt to use wind fields derived from satellite observations is described. A set of hindcast simulations has been realized, forcing the hydrodynamic model with these new wind fields over the Adriatic Sea, merged with ECMWF fields on the rest of the Mediterranean Sea. The simulated sea level shows good agreement with the observed values in the Northern Adriatic Sea; the correlation and the reproduction of storm surge peaks are better than those obtained forcing the circulation model with only ECMWF wind fields.

1 Introduction

Storm surge events periodically occur in the Adriatic Sea: they are responsible for sea level rising along the coasts and, under severe weather conditions, also for the flooding of the city of Venice. These extreme meteorological events are studied through numerical models. In the last two years a new operational system for the sea level forecast in the city of Venice has been set-up at the Centro Previsioni e Segnalazioni Maree of the Venice Municipality: it is built up of a hydrodynamic finite element model of the Mediterranean Sea, developed at the Istituto per le Scienze Marine ISMAR-CNR of Venice, forced by the meteorological fields (pressure and wind) of the European Centre for Medium-Range Weather Forecasts (ECMWF). The hydrodynamic model calculates the currents and the sea level in a grid, made out of variable size triangular elements, representing the whole Mediterranean basin: the grid is particularly fine in the region of interest, the northern Adriatic Sea, especially near the Venice Lagoon. The output of this operational model, today still in a preliminary and experimental version, is expected to be of great importance in the forecast of the periodical flooding of the city of Venice. During the first phase of study and implementation of the model, some hindcast simulations were realized. The results were compared with observations, showing

an underestimate of the modeled sea level in the platform "Acqua Alta" situated in the Northern Adriatic Sea, near the Venice Lagoon. The role of the meteorological input fields appears crucial: in fact, while the pressure at sea level seems to be well represented, the wind velocity at the same station shows a systematic underestimate of the peaks.
The difficulty to describe the local features of the wind field, so important in the geographical context of the Adriatic Sea (semi-enclosed basin, surrounded by mountain chains) has to be attributed especially to the grid size of the ECMWF fields (0.5°), too coarse with respect to the basin's scale and orography.
This inadequacy leads to search for an alternative meteorological input fields to drive the hydrodynamic model: a real possibility, for analysis and preconditioning purposes, is to use satellite wind observations, which are essential to describe the spatial meso-scale variability of the Mediterranean Sea winds [6], [7]. At the Istituto di Scienze dell'Atmosfera e del Clima ISAC-CNR of Padua, wind data from the QuikSCAT [2] scatterometer are preprocessed and elaborated to be used in the modeling activity, together with the ECMWF wind fields. Several hindcast simulations have been realized, attempting to find a better way to merge the satellite data (QuikSCAT) with data from the atmospheric model.
In section 2 the hydrodynamic model for the Mediterranean Sea is described. The wind field characteristics from ECMWF atmospheric model and from QuikSCAT scatterometer, used as input of the hydrodynamic model, are treated in section 3. In section 4 the simulations and the results are presented. Some final considerations are reported in section 5.

2 The hydrodynamic model

A 2-dimensional hydrodynamic model of the Mediterranean Sea, based on the finite element method, has been used: it solves the well known shallow water equations on a grid that represents the whole Mediterranean Sea. The grid, represented in Fig. is made out of 18626 triangular elements, variable in size and dimension; in regions with a complex bathymetry, as the Adriatic coasts, the elements are very small, while the spatial resolution is kept lower in the other regions.
The model uses finite elements for spatial integration and a semi-implicit algorithm for integration in time. The terms treated implicitly are the water levels gradient, the Coriolis and the friction term in the momentum equation and the divergence term in the continuity equation, all other terms are treated explicitly. The model solves the vertically integrated shallow water equations in their formulations with levels and transports:

$$\frac{\partial U}{\partial t} - fV + gH\frac{\partial \zeta}{\partial x} + RU + X = 0 \tag{1}$$

$$\frac{\partial V}{\partial t} + fU + gH\frac{\partial \zeta}{\partial y} + RV + Y = 0 \tag{2}$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \tag{3}$$

where ζ is the water level, U and V the vertically-integrated velocities (total or barotropic transports), g is the gravitational acceleration, $H = h + \zeta$ the total water depth, h the undisturbed water depth, t the time, R the friction term and f the variable Coriolis parameter. The terms X and Y contain all other terms like the wind stress, the nonlinear advective terms and the variable Coriolis parameter f. The wind stress is computed in the quadratic formulation:

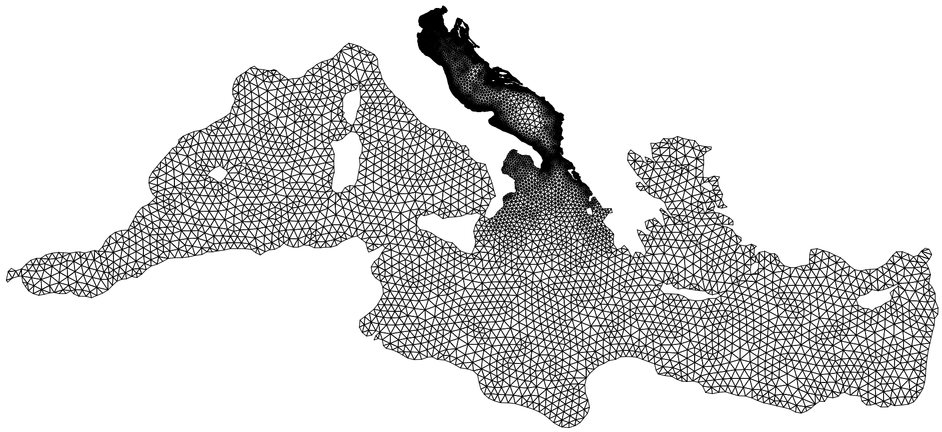

Figure 1: Grid of the hydrodynamic finite element model for the Mediterranean Sea

$$\tau_{x,y} = \frac{\rho_a}{\rho_0} C_D |u| u_{x,y} \tag{4}$$

where ρ_a, ρ_0 are the density of air and water respectively, $|u|$ the wind speed and $u_{x,y}$ the wind components along x and y axis. In this formula C_D is a dimensionless drag coefficient that has to be considered constant over the whole domain:

$$C_D = 2.5 \cdot 10^{-3} \tag{5}$$

The wind speed is directly specified for each element of the domain as the horizontal components of the wind velocity.
At the closed boundaries only the normal velocity is set to zero and the tangential velocity is a free parameter. This correspond to a full slip condition.

3 Input wind fields

3.1 ECMWF fields

A commonly used meteorological input for the circulation models are the wind fields produced at ECMWF. They are calculated by a global atmospheric model, based on the primitive equations. The model represents the atmosphere divided by 31 vertical layers, with higher resolution in the planetary boundary layer; in the horizontal dimension it uses a spectral representation, with a horizontal resolution of about $0.5°$. The ECMWF assimilates observational data (also QuikSCAT data) producing "forecast" and "analysis" fields.
In this work, only analysis fields have been used. These are wind fields at 10 m, interpolated on a longitude-latitude grid with spacing $0.5°$. The temporal interval between two following fields is 6 hours: fields of hours 00, 06, 12, 18 UTC are available for every day. An example of ECMWF wind field over the Mediterranean Sea can be seen in Fig.2.

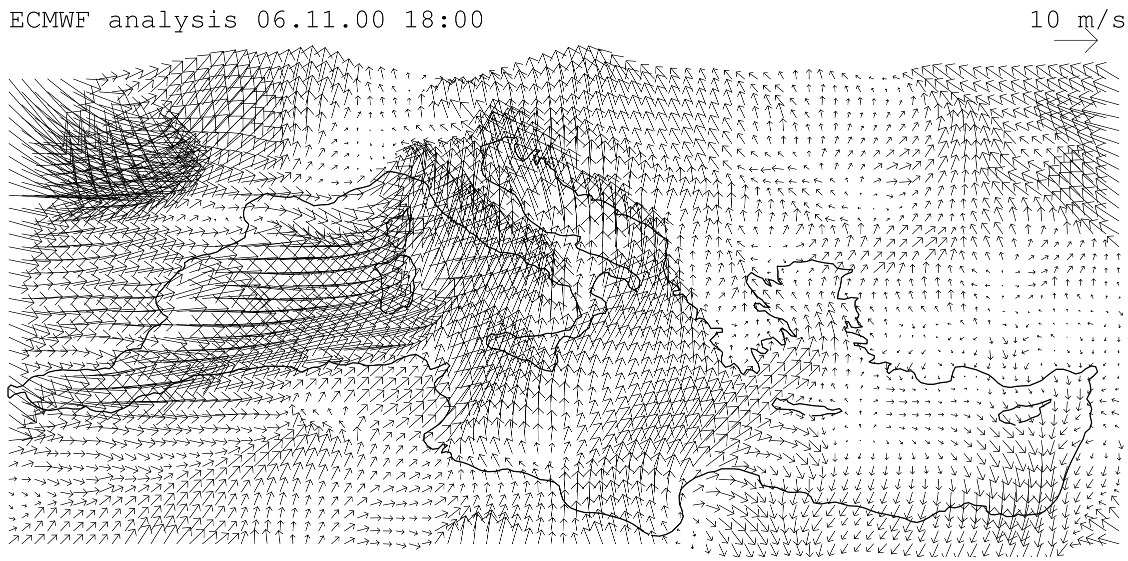

Figure 2: ECMWF wind field at 10 m, over the Mediterranean Sea, on 6 November 2000 at 18:00 UTC.

3.2 QuikSCAT fields

QuikSCAT is a scatterometer hosted on-board the SeaWinds satellite, launched on 19 June 1999. Its periodicity is 4 days and the spatial coverage reaches 90% of the global ocean surface every day. The scatterometer is still operative at this moment.

Wind data from QuikSCAT have a better spatial resolution (25 km $\times$ 0.25 km) than ECMWF wind fields: they can be very useful as forcing in the hydrodynamic modeling of the Northern Adriatic Sea, where the meso-scale wind patterns are important. Nevertheless the spatial coverage of QuikSCAT is not sufficient to cover the whole Mediterranean Sea and, until today, the temporal coverage is lower than ECMWF fields (the Adriatic Sea, region of interest in this study, is covered on average two times in a day). Moreover, QuikSCAT data are taken at times changing inside the periodicity interval, which makes them quite difficult to manage in the modeling activity.

An example of QuikSCAT wind field is shown in Fig.3. To be used in the modeling activity, QuikSCAT wind fields have been preprocessed: only data over the Adriatic and the Ionian Sea have been kept; these data have been interpolated over a regular $0.25°$ grid and extrapolated, if necessary, over a fixed grid which covers the whole Adriatic Sea. Fig.4 shows an original QuikSCAT wind field over the Adriatic Sea and the extrapolated field using in the model simulations.

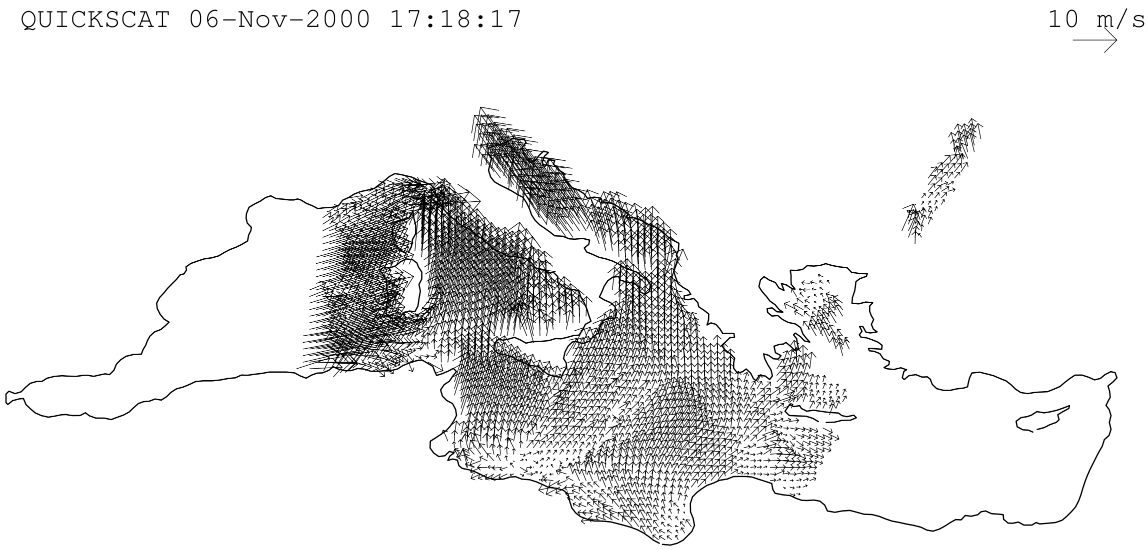

Figure 3: QuikSCAT wind field at 10 m, over the Mediterranean Sea, on 6 November 2000 at 17:18 UTC.

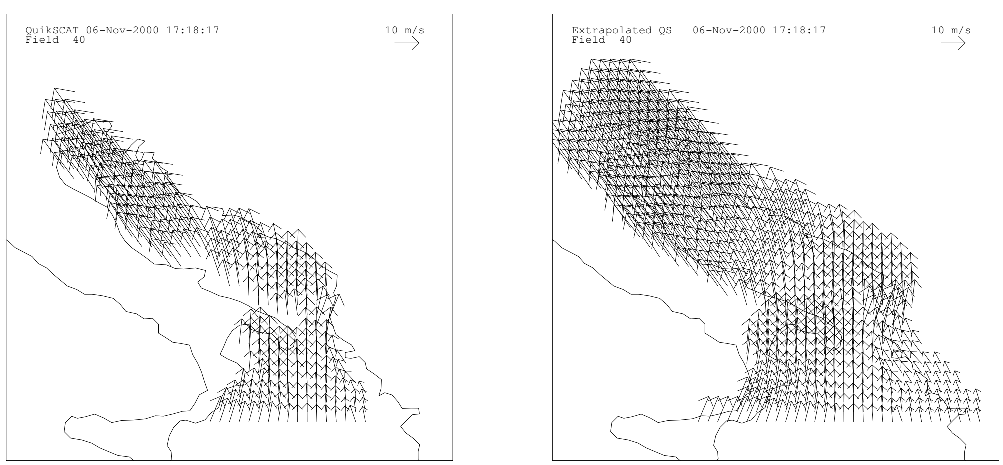

Figure 4: QuikSCAT wind field at 10 m, over the Adriatic Sea, on 6 November 2000 at 17:18. Left panel: original wind field; right panel: extrapolated wind field.

4 Simulations and results

November 2000 was characterized by a very strong storm surge event, occurred the 6th, when a strong southern wind blew for 12 hours along the Adriatic Sea, and an intense local pressure drop was observed. In Fig.5 the residual sea surface elevation time series can be seen, during November 2000, measured in the platform "Acqua Alta" of the CNR, situated in the Northern Adriatic Sea, 16 km offshore the Venice Lagoon coast. The residual sea level is obtained subtracting the tidal component from the measured sea surface elevation. In the same figure is reported also the residual sea level computed in a hindcast simulation (called in the following "Run E") realized using ECMWF wind fields as forcing. This result is already reported in [1] being part of the first experimental phase of the operative model setting. The modeled sea level is not very satisfactory, showing a strong underestimation of the peak on November, 6. In effect also the ECMWF wind *in situ* was underestimated, with respect to the observed values, as can be seen in Fig.6.

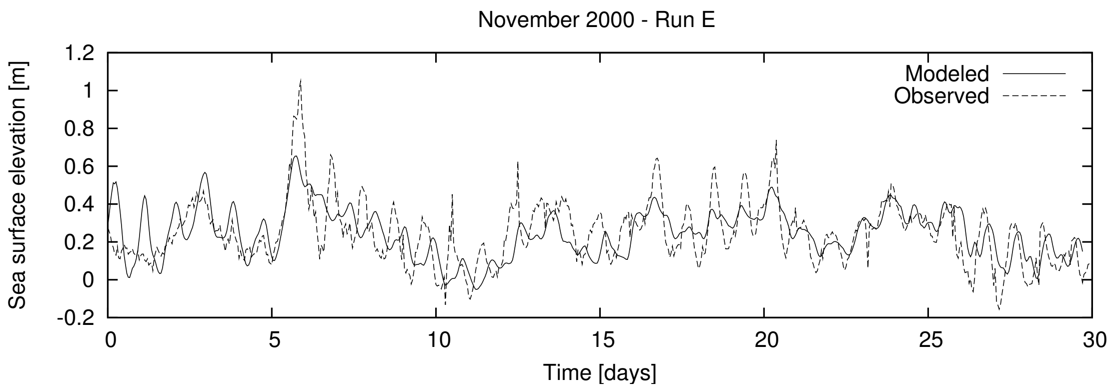

Figure 5: Time series of residual sea surface elevation at CNR platform, November 2000: modeled values in the E simulation and *in situ* values.

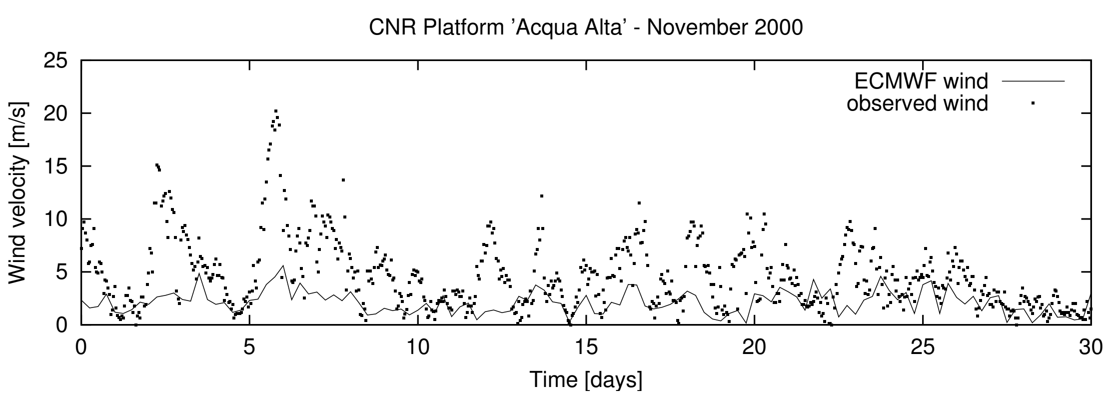

Figure 6: Time series of wind velocity at CNR platform, November 2000: ECMWF wind and *in situ* values.

For the same month, three other hindcast simulations, called in the following Q1, Q2, Q3, have been realized with the hydrodynamic model, forced by QuikSCAT data in the Adriatic Sea. The

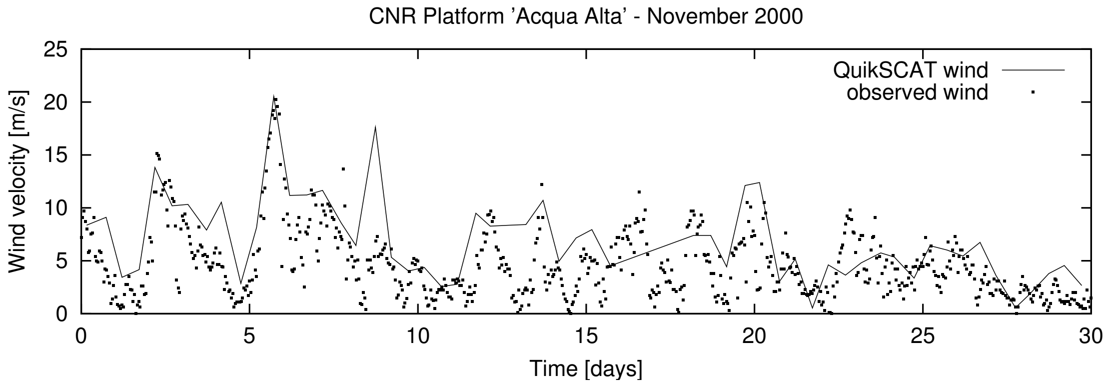

Figure 7: Time series of wind velocity at CNR platform, November 2000: QuikSCAT wind and *in situ* values.

QuikSCAT wind at the CNR platform site is represented in Fig.7 along with the *in situ* wind: the agreement between the two time series is much better than in the case of ECMWF wind.
The QuikSCAT data has been used in three different ways, to build up a complete input file for the hydrodynamic model. In all cases, ECMWF wind has been imposed over the Mediterranean Sea, except over the Adriatic and the Northern Ionian Seas. In this region, shown in Fig.4, the forcing wind is different in every simulation:

- Q1 QuikSCAT wind when it exists; ECMWF wind otherwise (at hours 00, 06, 12, 18 UTC).
- Q2 QuikSCAT wind when it exists.
- Q3 QuikSCAT wind when it exists; QuikSCAT wind, linearly interpolated in time, otherwise (at hours 00, 06, 12, 18 UTC).

Fig.8 shows the temporal distribution of the input wind fields over the Adriatic Sea, in a typical day of simulation: it has been supposed that QuikSCAT fields are available at hours 4 and 17 UTC; ECMWF fields are every day available at hours 00, 06, 12, 18 UTC. Simulation Q2 has two input wind files, on average, in a day, depending on the QuikSCAT data availability. Q1 and Q3 simulations have six wind fields in a typical day; Q3 has time interpolated QuikSCAT wind at hours 00, 06, 12, 18, while Q1 has ECMWF wind.
Fig.9 shows the time series of wind speed, at CNR platform, imposed as input in Q1, Q2, Q3 simulations.
Fig.10 reports the time series of residual sea surface elevation computed by the hydrodynamic model at CNR platform, in Q1, Q2, Q3 simulations, and the measured values.
Run Q1 is a first attempt to include the scatterometer data in the hydrodynamic simulation: ECMWF data were kept as basis to construct the input wind file; QuikSCAT data were simply substituted when available. Due to the big difference between QuikSCAT and ECMWF data, this procedure which alternates the two kind of data, produces an oscillating and not realistic wind. However the results of the simulation are good, showing a more accurate reproduction of the sea level at the observation point: the signal results in phase with the experimental data and the sea level peak of 6 November is quite well reproduced. The quality of the results of Run Q1 appear evident especially if compared with the results of Run E, in Fig.5.

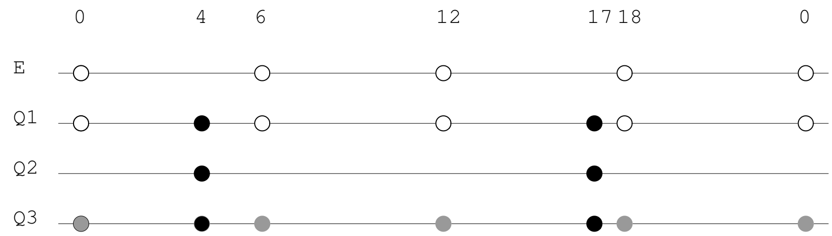

Figure 8: Temporal distribution of input wind fields over the Adriatic Sea, in a typical day of simulation: white circles indicate ECMWF fields, black circles QuikSCAT fields, grey circles QuikSCAT fields interpolated in time.

The input wind fields over the Adriatic Sea of Run Q2 and Run Q3 are slowly variable in time, with new information two times every day on average. The difference between the two simulations is the frequency of variation of the wind fields over the Mediterranean Sea, greater in Run Q3. The results are promising, showing a right estimate of sea level peak of 6 November. The time series of sea level modeled in Run Q2 and Q3, seem very similar, indicating the poor influence of the Mediterranean Sea in the simulated circulation of the Adriatic Sea.

5 Conclusions

This paper describes a first approach to the use of satellite data in the hydrodynamic modeling of the Adriatic Sea. It shows that it is possible to manage such data, in spite of their not always regular distribution in space and in time.
Satellite data over the Adriatic Sea have been preprocessed and integrated with ECMWF data over the Mediterranean Sea. The greater resolution of satellite data permits a better reproduction of the sea level in the Northern Adriatic Sea, with respect to those obtained using only ECMWF data.
The comparison between obtained results suggests that the Mediterranean Sea contribution to the circulation of the Adriatic Sea can be neglected, for what concern the storm surge events simulation.
The high quality of the results in the sea level simulation invites to use satellite data also in an operational context: certainly they can contribute to improve the spin-up of an operative model, generating an optimal initial condition on which run a forecast simulation.

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The authors are listed in alphabetical order.

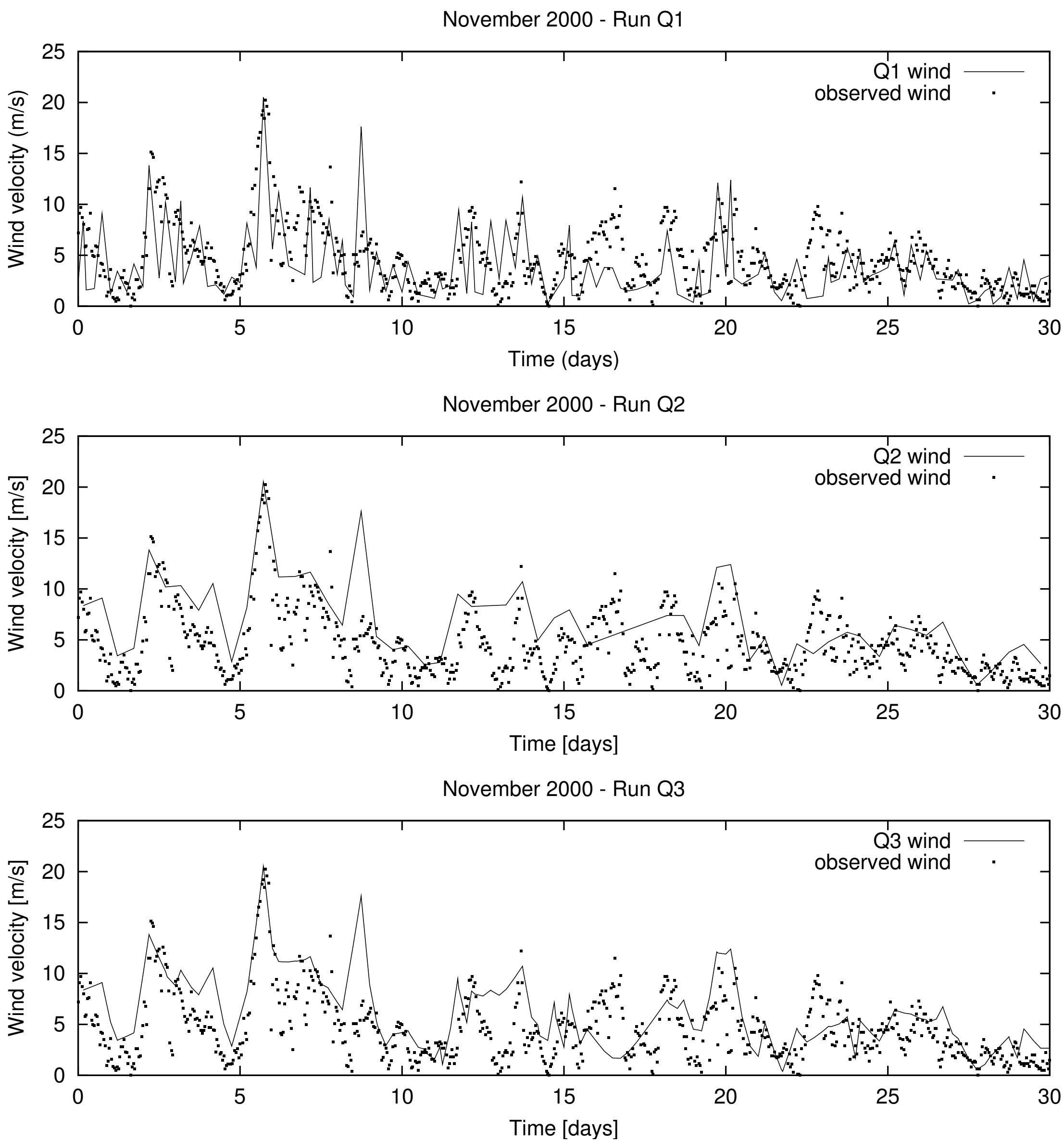

Figure 9: Time series of wind speed at CNR platform, November 2000: input wind in the Q1, Q2, Q3 simulations and *in situ* values.

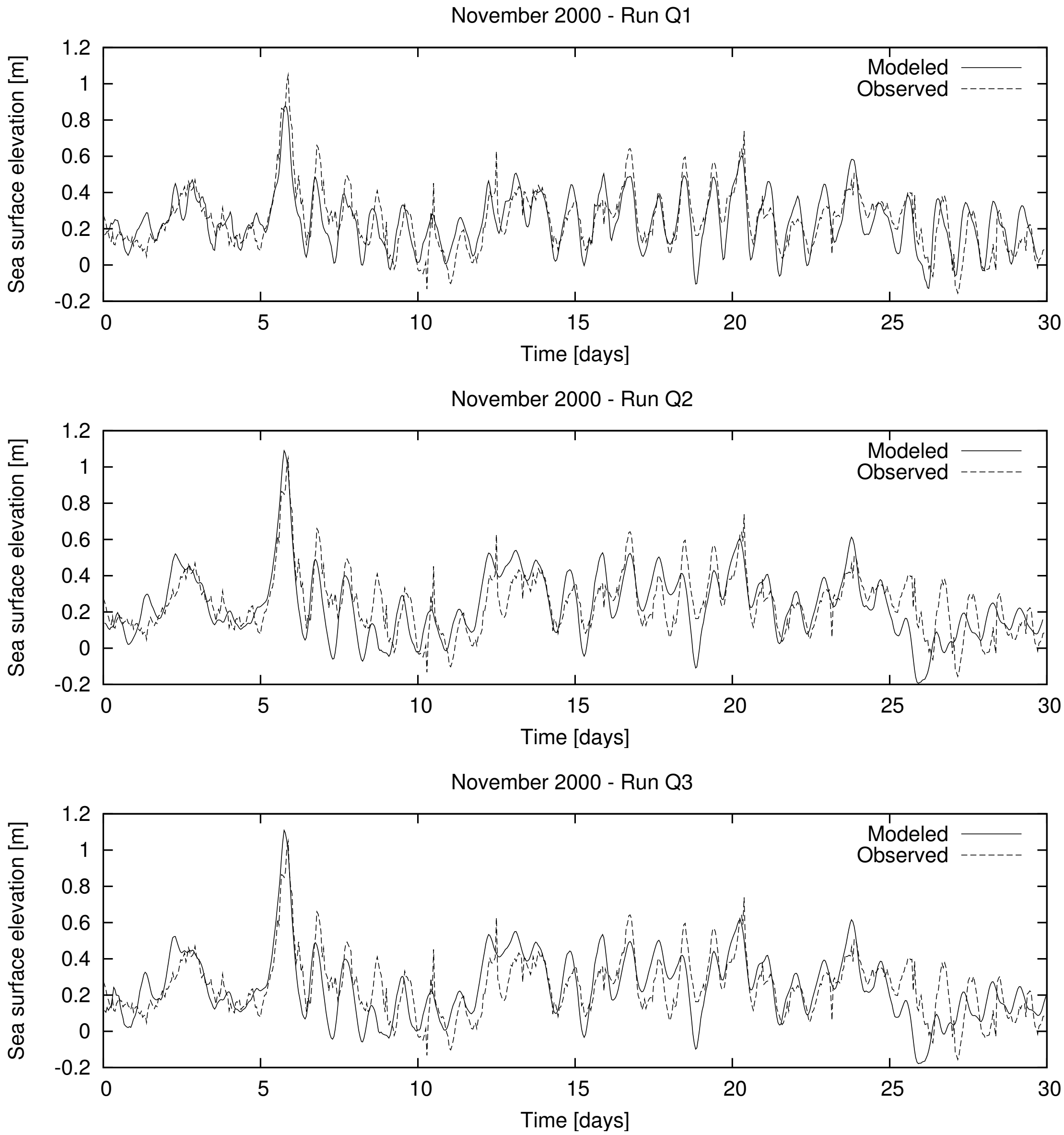

Figure 10: Time series of residual sea surface elevation at CNR platform, November 2000: modeled values in the Q1, Q2, Q3 simulations and *in situ* values.

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