Storm surges forecast in the Adriatic Sea with the use of data assimilation (EnKF)

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Summary

Storm surges and seiches are common phenomena in the Adriatic, causing floods in the northernmost part of the basin. Since seiches can persist several days, they can overlap to new storm surges. Therefore a correct reproduction of these events is very important also for forecast purposes. In this study we have analysed a couple of storm-surge events, preceded by seiche oscillations. The events were reproduced by means of the finite element hydrodynamic model applied to the whole Mediterranean, and results were evaluated using measurements from twelve stations located along the entire Adriatic coastline. Extensive sea-level dataset allowed a very detailed description of the selected episodes. The goal of this study is find the best configuration of the model and to assess the impact of sea level data assimilation. We found that the data assimilation improves the forecast of both the considered events. This improvement is big in the first day forecast, but lasts for several days due to the correction of the seiche oscillation.

The hydrodynamic model

The hydrodynamic model used in this work is named SHYFEM (Shallow water HYdrodynamic Finite Element Model) and solves the shallow water equations using a finite element numerical method. The model is written in Fortran 90 and is freely available on the web at: https://github.com/SHYFEM-model/shyfem. The time discretisation uses a semi-implicit scheme, in order to obtain an unconditional stability in the reproduction of gravity waves. The water levels are solved semi-implicitly, while the transports can be computed afterwards explicitly, thus obtaining a much smaller linear system than in the case of a fully implicit scheme. In order to avoid mass loss a staggered grid is used. Water level is prescribed in the nodes and water transport in the elements. Wind stress is specified with the Large and Pond formulation, while several formulations have been used for bottom friction. The wind and the atmospheric pressure fields are provided by ECMWF, from the deterministic operational model at 0.25 degree of horizontal resolution. A description of SHYFEM and of the importance of an accurate wind in storm surge forecasting is given in *Bajo et al. (2017).*

Data assimilation

Observations from twelve coastal sea level stations are assimilated hourly for four days before the forecast. The assimilation is sequential by means of an Ensemble Kalman Filter. The ensemble is composed by 60 members which are obtained by varying the wind forcing. An ensemble of perturbed wind is created using random gaussian perturbations correlated in space and time, with a mean near to the deterministiic run and a relative standard deviation that can be prescribed. These perturbations made a dynamical consistent spread of the hydrodynamic variables. The EnKF uses also a inflation algorithm (RTPS), while local analysis is going to be tested. For more details see Bajo et al. (2019).

References

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Sea level analysis

Period and decay time of modelled seiches were determined using residual sea levels at the twelve tide-gauge locations. Period of the first mode was computed calculating spectra with frequency resolution of 0.0024 cph. Decay time was determined by the following procedure. First, seiche activity was extracted by applying the band-pass filter (around 22 hours) to detided residuals. Then, seiche envelopes were calculated and fitted with exponential functions.

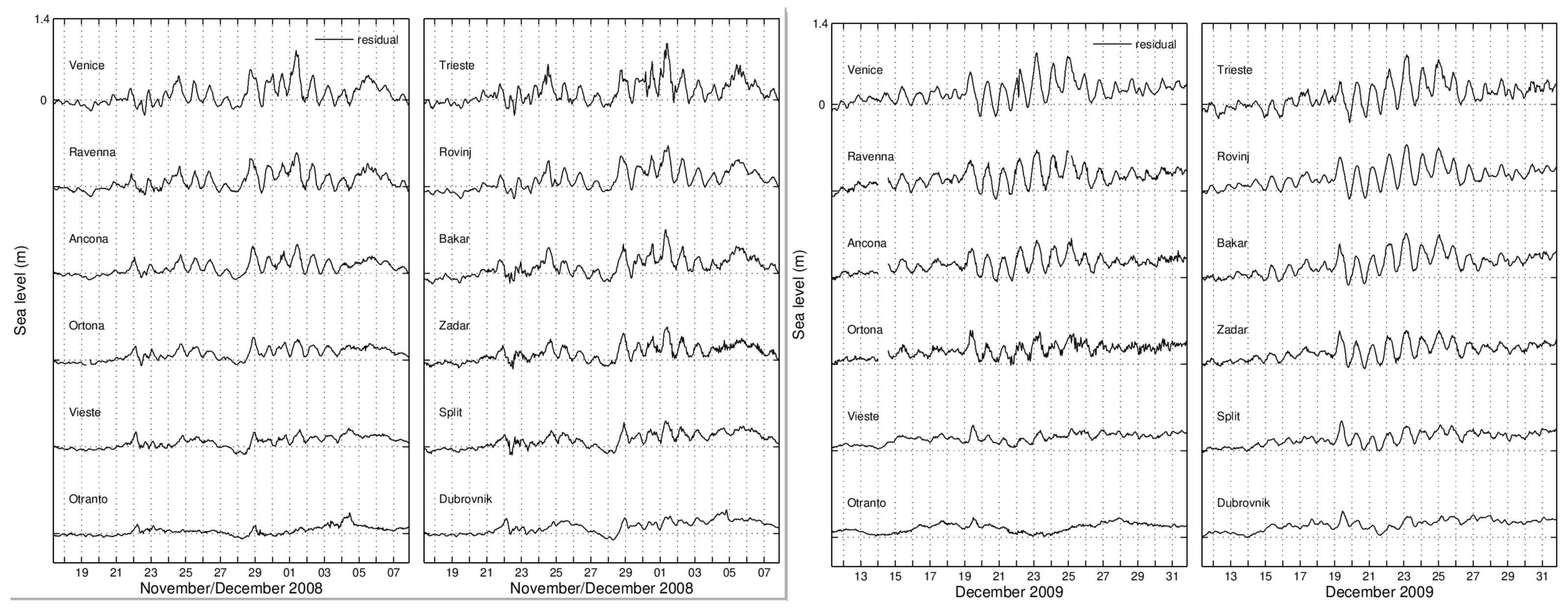
Sea level observations

Sea level observations are collected at twelve stations in the Adriatic Sea, along both the Italian and the Croatian coasts. These stations are located in the towns of Trieste, Venezia, Ravenna, Ancona, Ortona, Vieste, Otranto, Rovinj, Bakar, Zadar, Split and Dubrovnik. The sea level is debiased and detided and the residual level is used for comparison with the modelled surge level.

The study area and case studies

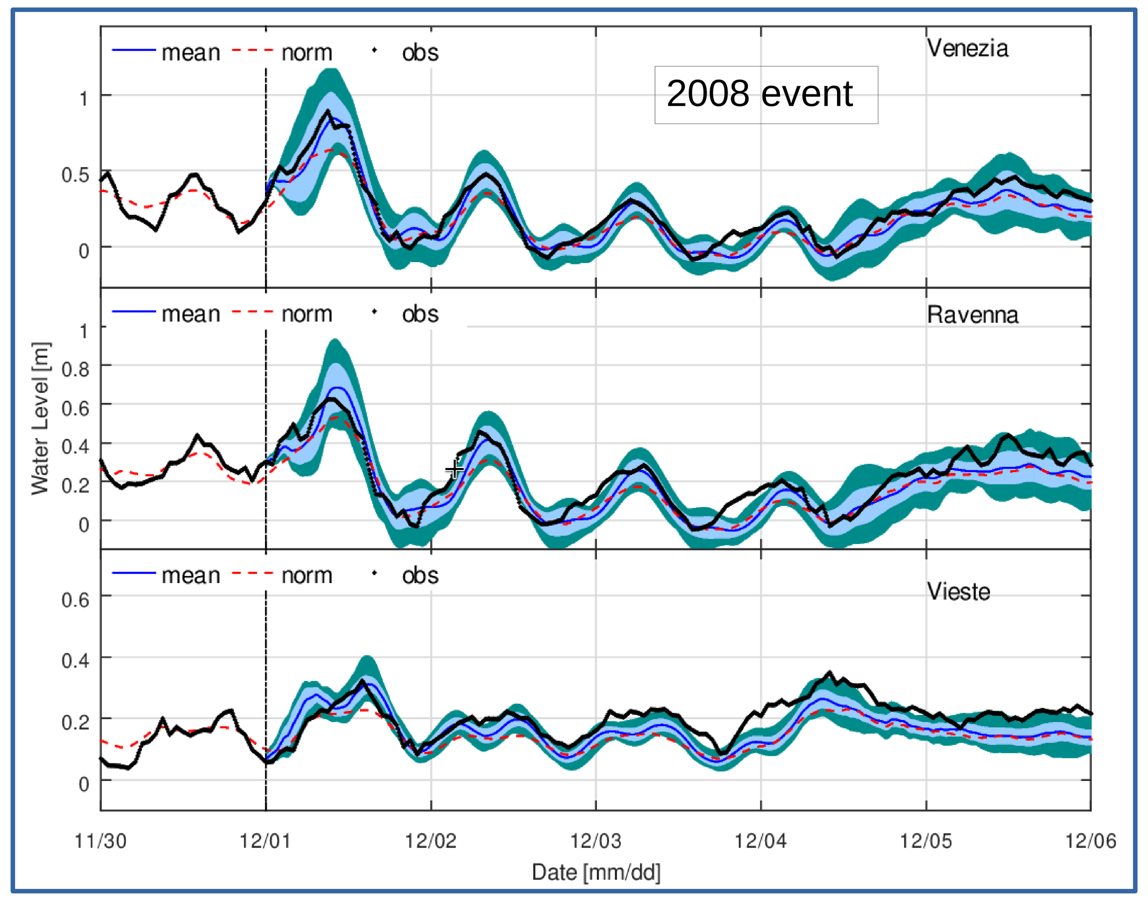
The Adriatic Sea is an elongated basin enclosed between the Italian peninsula and the Balkan countries, about 800km long and 200km wide. Its shape, the bordering orography and the frequent sirocco (south-east) wind combine with the shallow bathymetry in the north to lead to frequent storm surges. Since the southern end of the sea, in the Otranto Strait, is quite narrow, storm surges can trigger the oscillation modes of the basin. The first mode has a period of about 21.2 hours and a decay time of 3.2 days (*Cerovečki et al., 1997)*. The sea is subject to a microtidal regime and the largest amplitude of tides is about one metre in the northern end.

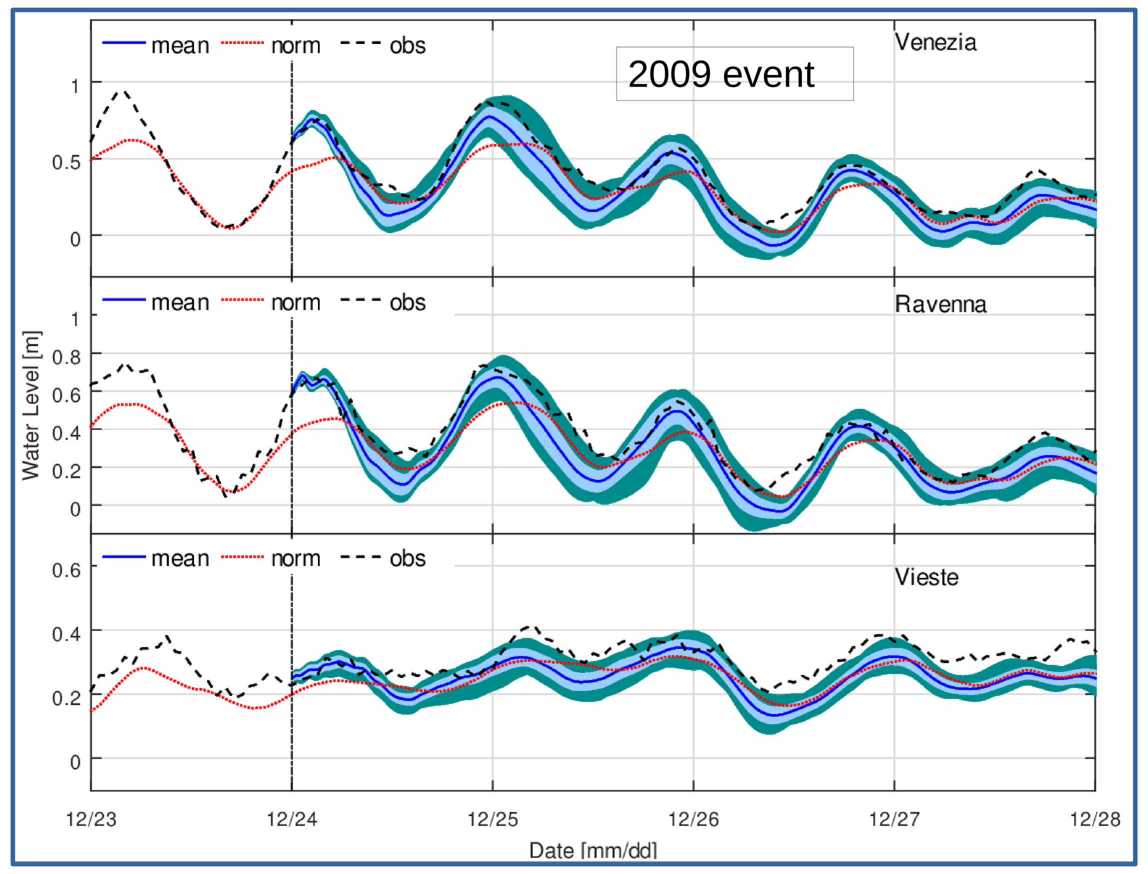
Two storm surge cases were selected and studied in the present work. The first event happened on December 1, 2008 (*Međugorac et al., 2015)*, while the second on December 25, 2009. Both events were extremely strong and preceded by a seiche.



Results

Here we show the forecast of the residual level in three stations in the Adriatic Sea (Venezia, Ravenna, Vieste). Light shades are the standard deviation of the ensembles, while the dark shades are the maximum and minimum widths. Seiches are more evident in the northern part of the basin, as well as the improvement of the data assimilation. Data assimilation corrects the initial state at the begin of the forecast and this correction propagates forward (mean), while the run without data assimilation (norm) keeps rather far from the observations.





Conclusions

A correct reproduction of seiche oscillations is extremely important in storm surge forecasting since the strongest events are often influenced by pre-existing seiches. Such events would be well reproduced with an accurate wind forcing, but this is not the case most of the times. We found that sea level data assimilation in the Adriatic Sea improves consistently the storm surge forecasting. Unfortunately, sea level data from many of the stations used are not available in real time, thus avoiding the chance to use them in an operational model.