AN OPERATIONAL SYSTEM FOR THE STORM SURGE FORECAST IN THE ADRIATIC SEA (ITALY): RESULTS AND EVALUATIONS

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ABSTRACT

A new storm surge forecasting system for the Mediterranean Sea is running operationally since 2011 at the Venice branch of the Italian Institute for Environmental Protection and Research (ISPRA) in the framework of the Sistema Idro-Meteo-Mare (SIMM). The forecasting system focuses on the Northern Adriatic Sea and the Venice Lagoon, areas which are frequently subject to severe storm surge events. In this study, the forecast performance of the hydrodynamic model forced by two atmospheric models – namely ECMWF and BOLAM – has been evaluated. The results refer to one year of simulations (statistical assessment) and the analysis of an exceptional storm surge event.

METHOD: HYDRODYNAMIC MODEL AND METEOROLOGICAL FORCINGS

This operational forecasting system is based on a finite element hydrodynamic model, named SHYFEM (www.ismar.cnr.it/shyfem), developed at the Institute of Marine Sciences (ISMAR). The model is applied in a simplified 2D formulation computing the barotropic transports and the water level.

The system runs daily (fig. 1) and it is forced by two different meteorological fields over the Mediterranean area: wind and mean sea-level pressure forecast fields provided by either the ECMWF Integrated Forecasting System (IFS) or the BOlogna Limited Area Model (BOLAM) provided by the Rome branch of ISPRA (http://www.isprambiente.gov.it/pre_meteo/).

ECMWF: spatial res. 0.5°; time frequency 00, 06, 12, 18 UTC; forecast range 96 hrs

BOLAM: spatial res. 0.1°; time frequency 1 hour; forecast range 84 hrs

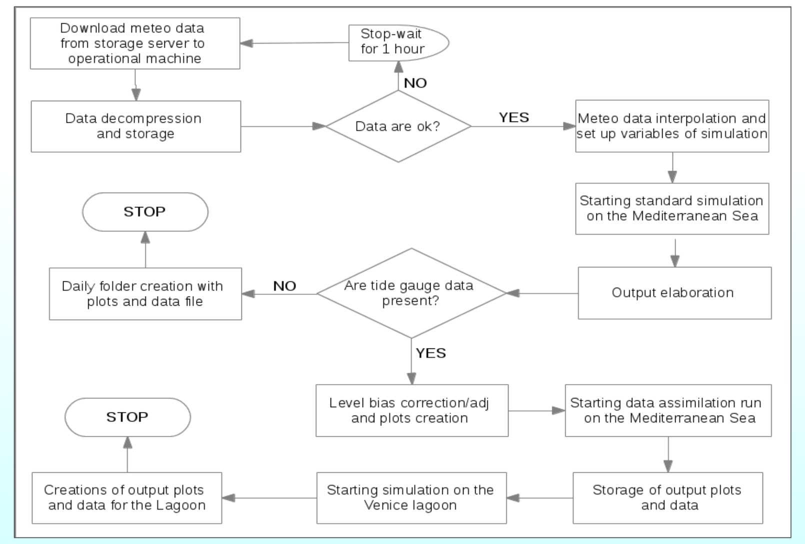

Fig.1 – Flowchart of the operational forecasting system.

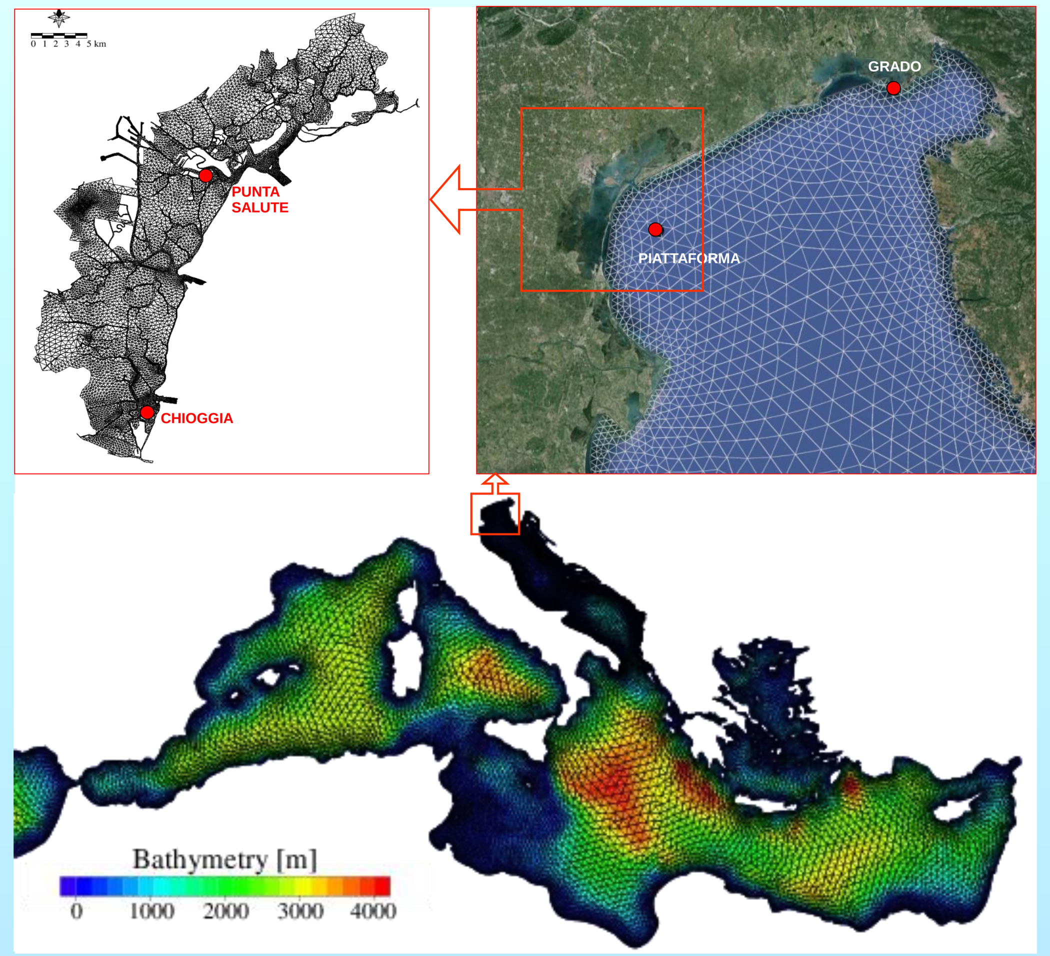

Fig.2 - Mediterranean grid and Venice Lagoon grid used by the hydrodynamic model. Red points show the selected four stations.

From 2012 a data assimilation (DA) system, based on the dual 4D-Var technique, has been developed and implemented: the latest 24 hours residual levels measured at 9 stations are assimilated.

The SHYFEM-based system produces a first run over the Mediterranean domain to forecast the storm surge, then it adds the predicted storm surge to the astronomical tide at Piattaforma (fig. 2). The resulting total sea level is imposed at the three inlets in order to forecast the total water level in the Venice lagoon.

The results are referred to the 4 stations shown in figure 2: Piattaforma (oceanographic tower) and Grado in the Adriatic Sea; Punta Salute and Chioggia inside the Venice Lagoon.

CONCLUSION

The SHYFEM model is able to well reproduce the tide behavior in the study area. The analysis performed by considering two different meteorological forcings shows that **BOLAM** provides the **better accuracy** in predicting the severe storm surge events. In additions, this work points out the importance of adopting different meteorological models in order to provide a sort of "multi-model ensemble" defining an **uncertainty strip** for the storm surge forecasts.

RESULTS: ONE YEAR SIMULATIONS

A statistical analysis of one year (Oct 2012 – Oct 2013) compares the predicted sea levels with the measured data at four different tide gauges (fig. 2): Punta Salute and Chioggia (in the Venice Lagoon), Piattaforma and Grado in the Northern Adriatic Sea. The analysis examines both the whole year forecast data (fig. 3) and the data related only to the maximum peaks observed during the selected year (fig. 4). The results show the different model performances obtained with and without DA scheme and with different meteorological forcings.

Statistical analysis:

In the fig. 3 the mean error and the accuracy index (*AI*) for Punta Salute are shown:

- $\overline{E}$ model mean error expressed as the difference between modelled and observed sea level at different forecast time (96 hrs for ECMWF, 72 hrs for BOLAM);
- *AI* accuracy index as the mean error ± twice the standard deviation (σ) for each forecast (*f*)

$$AI_f = \overline{E_f} \pm 2\sigma_f$$

In the first 24 hours, the assimilated run show best accuracy index values (narrower range around mean error). It is worth noting that even if the lead time increases, the accuracy values do not worse and they are within ± 20 cm for assimilated runs at max lead time.
In most of the cases the ECMWF runs show the best performance.

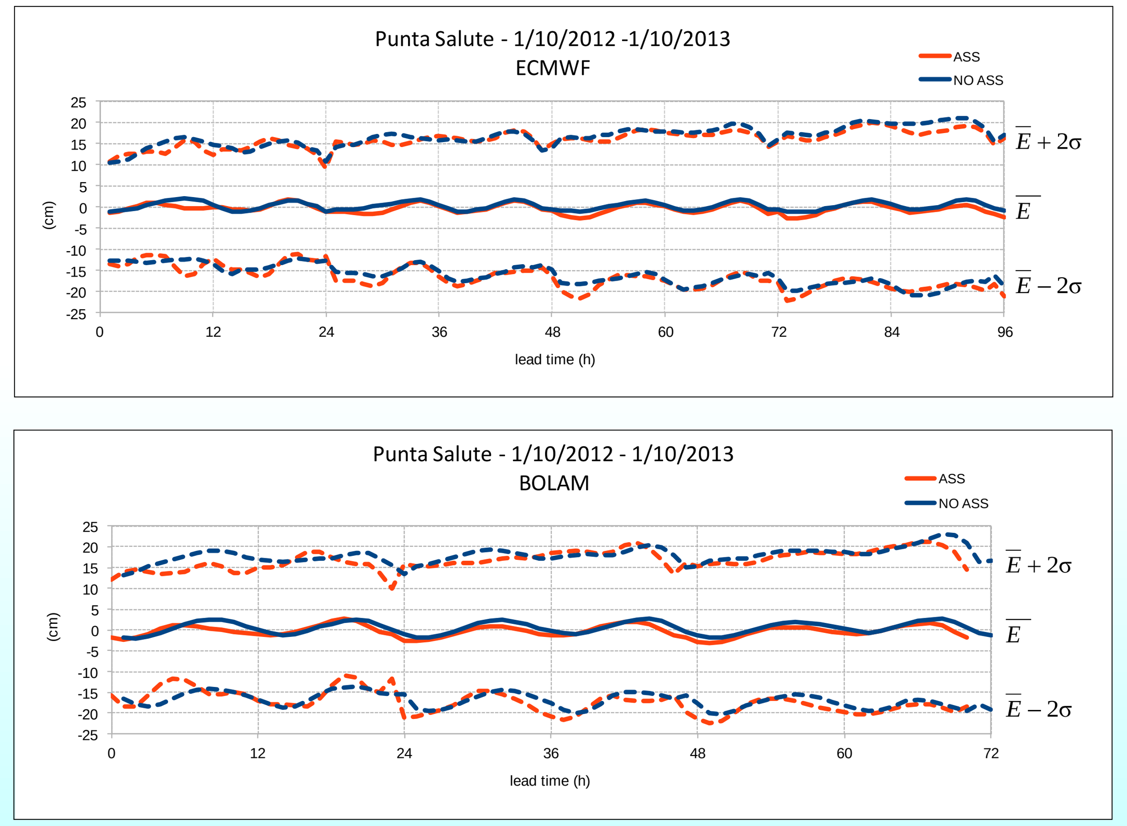

Fig.3 - Mean error (solid lines) and Accuracy Index (dashed lines) calculated at Punta Salute for simulations forced by ECMWF (upper) and BOLAM fields (lower).

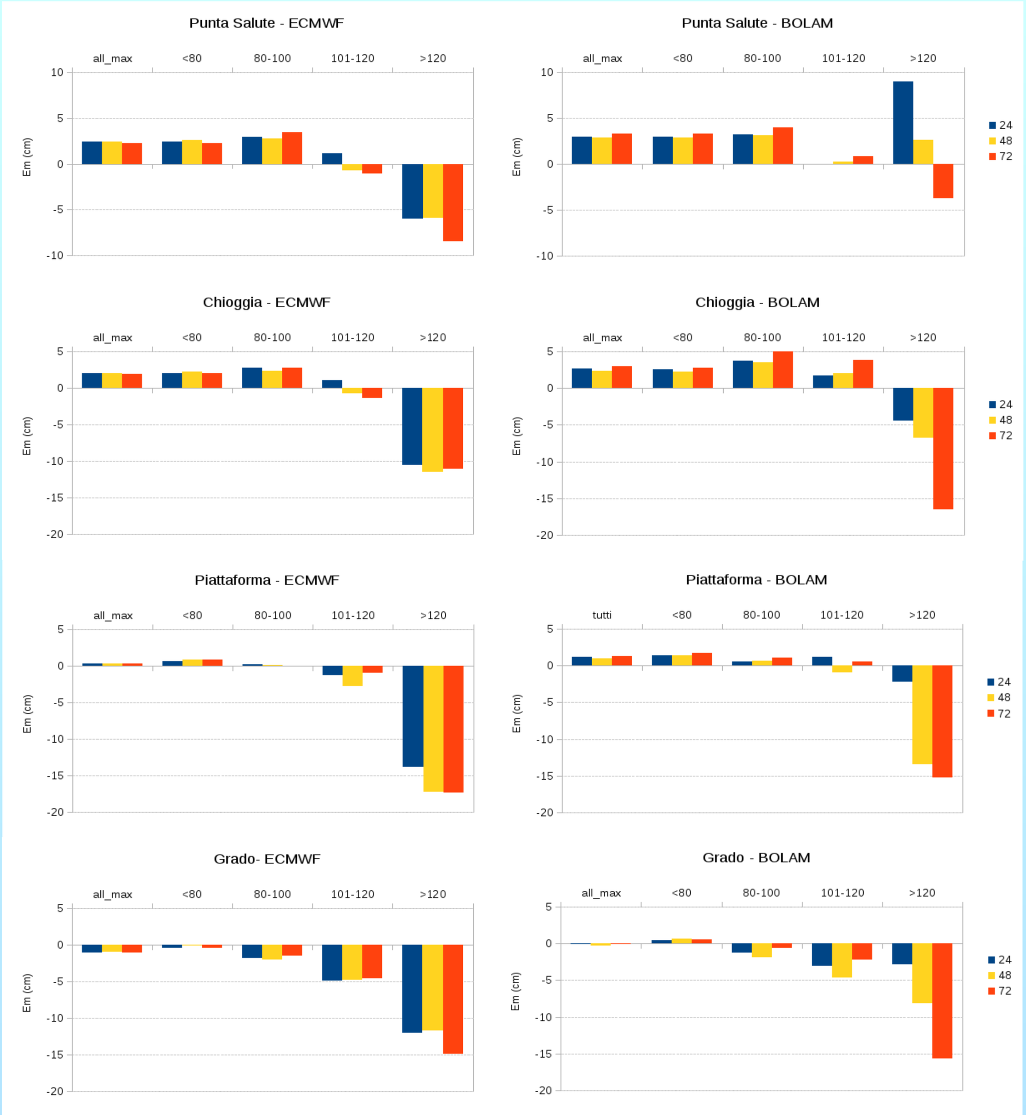

Fig.4 - Mean error calculated for the maximun peaks at the 4 stations. Run forced by ECMWF (left) and BOLAM fields (right) without DA.

Mean errors of the **maximum peaks** are shown in figure 4. The errors are evaluated taking into account both all the peaks (~ 600) and the observed sea levels **higher than 80, 100, 120 cm**. Moreover, for each class 3 different lead time - 24, 48 and 72 hours before the maximum – are considered in order to observe the effect of the forecast anticipation on the mean error.
<u>Left</u> : forecasts forced by ECMWF, no data assimilation.
<u>Right</u> : forecasts forced by BOLAM, no data assimilation.

Good model performance: no significant differences between the ECMWF and BOLAM for peaks lower than 100 cm, in general **overestimation** (**errors <+3 cm** in the sea and errors <+5 cm in the lagoon).
For peaks >100 cm the **ECMWF** runs show a majority of underestimated forecasts, obtaining errors up to **10-17 cm**; **BOLAM** fields allow to obtain **better performances**, particularly in the highest class where the mean **error decreases greatly** (more than 10 cm) reducing the forecast anticipation. Bolam runs show overestimated forecasts in the extreme events.

EXTREME EVENT: 31 OCTOBER 2012

A sudden pressure drop along the whole Adriatic Sea triggered a Scirocco wind on the southern-central portion, whereas on the northern Adriatic a strong local Bora wind (NNE) arose on the 31 October, with a maximum intensity of 18.6 m/s at Piattaforma in the evening (Fig. 7).

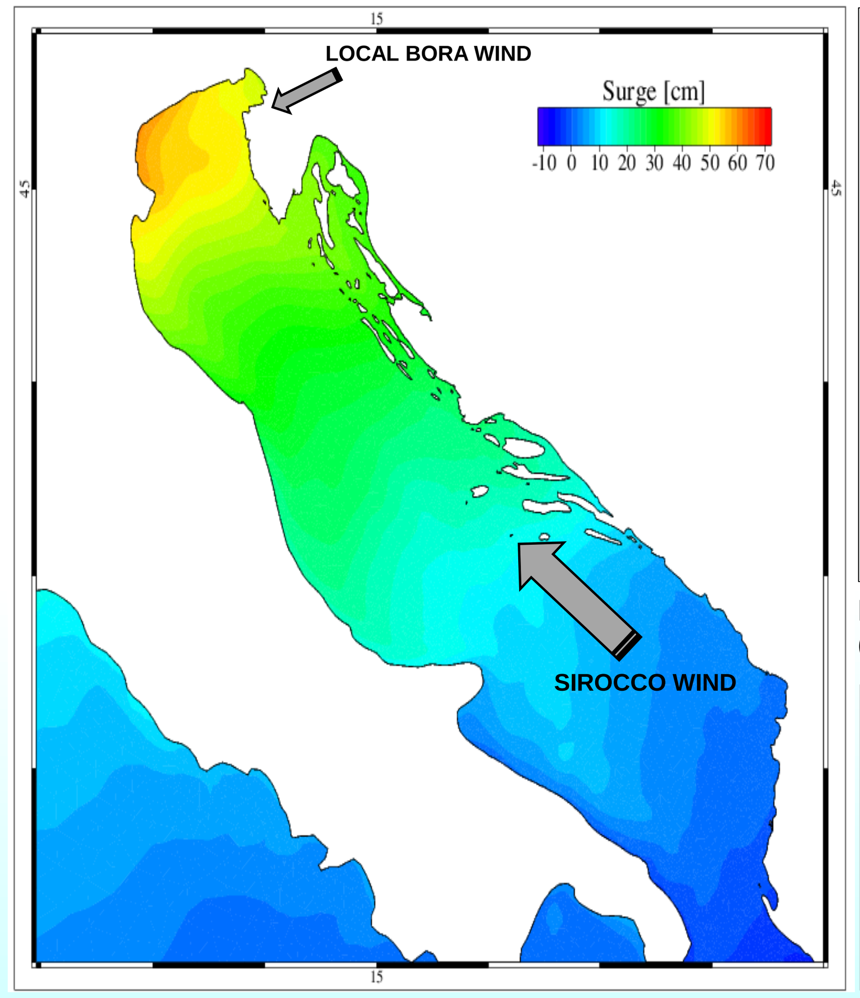

Fig.5 - Storm surge values modelled by ECMWF on 31th October : the map shows the situation at 23 UTC (23hrs of lead time) during the maximum of high tide.

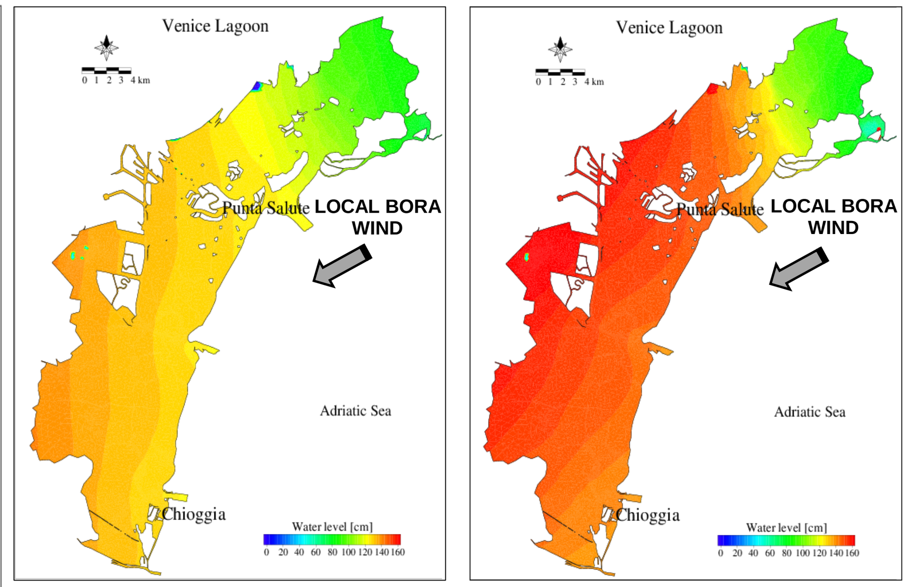

Fig.6 - Total water levels forecasted on 31/10: ECMWF (left) and BOLAM (right). The maps show the situation during the maximum of high tide.

Effect on the Adriatic coast (fig. 5) and on the Venice Lagoon (fig. 6): wind pushed the water southwards, increasing surge level southwards.
P. Salute = 143 cm
Chioggia = 164 cm

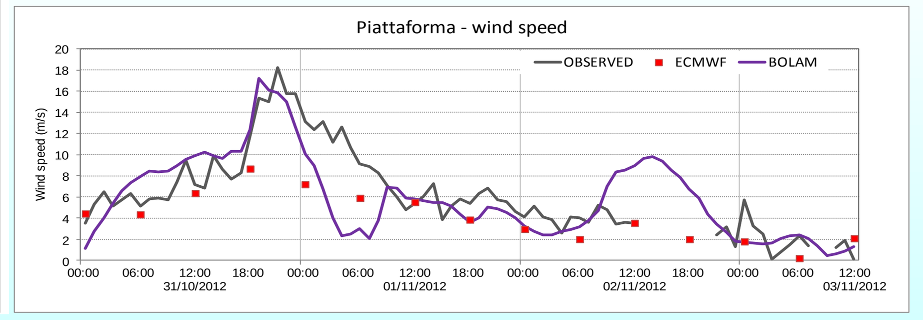

Fig.7 - Wind speed at Piattaforma: observations against forecasts predicted by ECMWF and BOLAM on 31th October.

The BOLAM fields produce a storm surge peak close to the observed one and higher (+ 25 cm) than that obtained using the ECMWF fields (fig. 8).

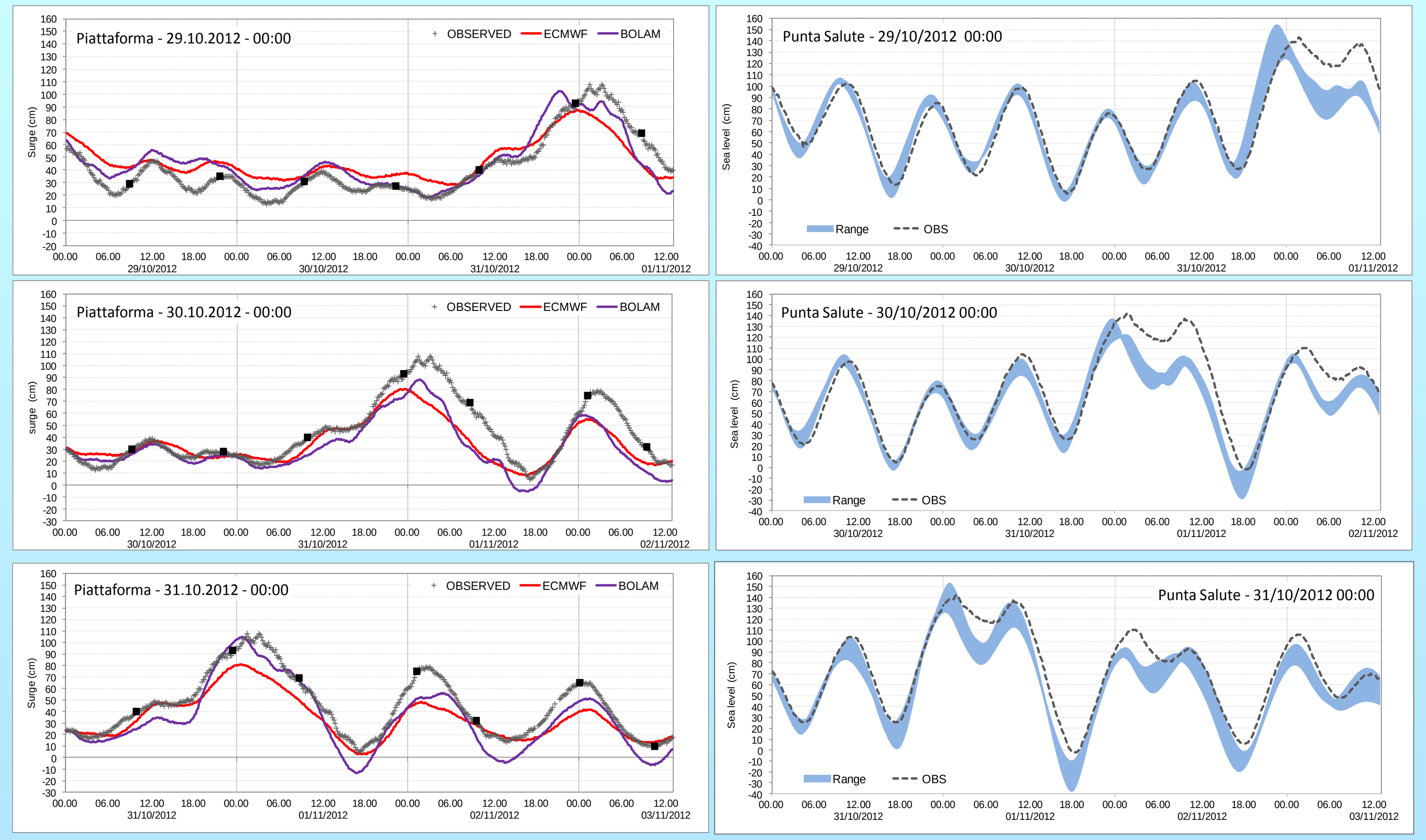

Fig.8 - Residual levels at Piattaforma (left) and total water levels at Punta Salute (right), observed and predicted at different lead time.

Left panels: Piattaforma **residual** level measured and forecasted at 3 different lead time: 72, 48, 24 hrs. The storm surge signal is well estimated by the model; the BOLAM runs show the best accuracy.

Right panels: Punta Salute **total** water level, observed vs. forecasted values. The range is the max-min values calculated using all the running model versions. Two different meteorological forcings and the data assimilation scheme offer an uncertainty strip for the storm surge forecasts. A wider strip corresponds to a bigger uncertainty in the forecast.