Ensemble prediction of storm surge for the city of Venice

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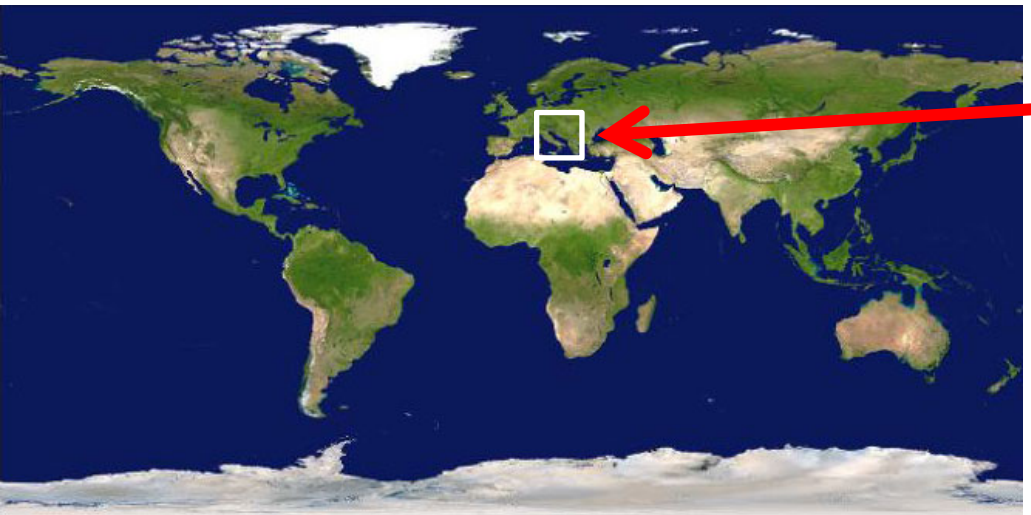
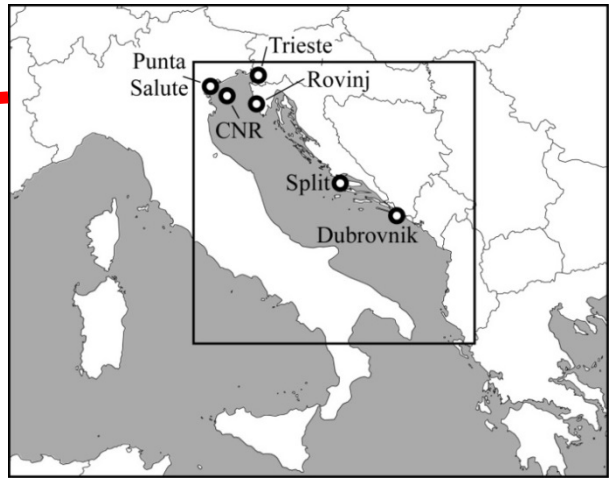
MOTIVATIONS

An accurate and fully informative prediction of sea level in the time range from few hours to several days is an essential tool for the management of Venice, in particular for operating efficiently the movable dams that the Italian government is presently building. Operational requirements impose that the decision of closing has to be taken about 5-8 hours before the Sea Level reaches a reference threshold (about 1 meter above mean sea level)

Objects of this research:

- To implement an EPS (Ensemble Prediction System) for storm surges in the Adriatic Sea to be used for a probabilistic prediction of SL (Sea Level)
- To analyse the reliability of EPS for storm surge forecasts in the Adriatic Sea
- To describe the uncertainty of the predictions of relatively large storm surges
- To put the premise for operational use of EPS (more to follow)

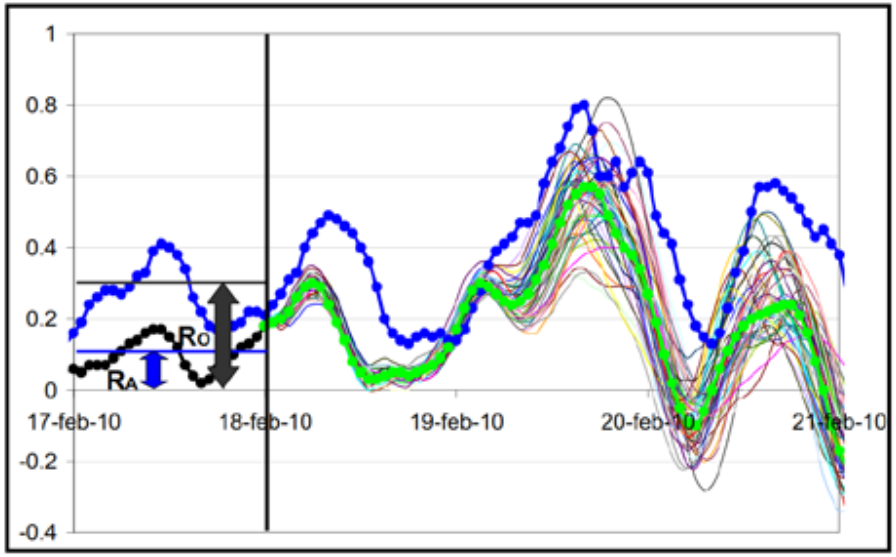




DATA AND METHODS

The SL (Sea Level) simulations are carried out using HYPSE (a standard single-layer nonlinear shallow water model based on the depth averaged momentum equations). The 3-hourly ECMWF wind and MSLP fields are used as forcing of the HYPSE model.

The ECMWF EPS produces 50 different forecasts, which are used for producing a corresponding SL-EPS. Ten relatively high storm surge (all in 2010) have been simulated and forecast ranges from1 to 5 days are considered.



The high resolution ECMWF meteorological forecast is used for a corresponding SL deterministic prediction (Deterministic Forecast, DF) with the same version of the HYPSE model.

The individual member of the EPS are used for a probabilistic prediction. T he EMF ensemble mean forecast shows the mean behaviour of the EPS

The actually computed variable is the SL residual (storm surge + seiches), which is what is left of the sea level after subtracting astronomical tide and long term (> several days) variability.

In order to facilitate comparison among the ten different events, SL values are reduced to a dimensionless index.

Analysis is focused on peak values

CONCLUSIONS

The EMF has an accuracy similar to that of the single DF for predicting the peak SL values, though it uses forcing fields at a much lower resolution. The SL prediction of EMF is more robust than that of DF, meaning that hourly predictions have a slightly lower mean absolute and maximum errors.

The EPS spread is correlated with the error of the EMF, meaning that events with large EPS spread are more likely to produce large errors in the EMF (and in the DF as well).

The SL forecast uncertainty increases linearly with time, but it has a peak at the time of the storm surge maximum level

SL Uncertainty is proportional to the spread of the forcing meteorological fields.

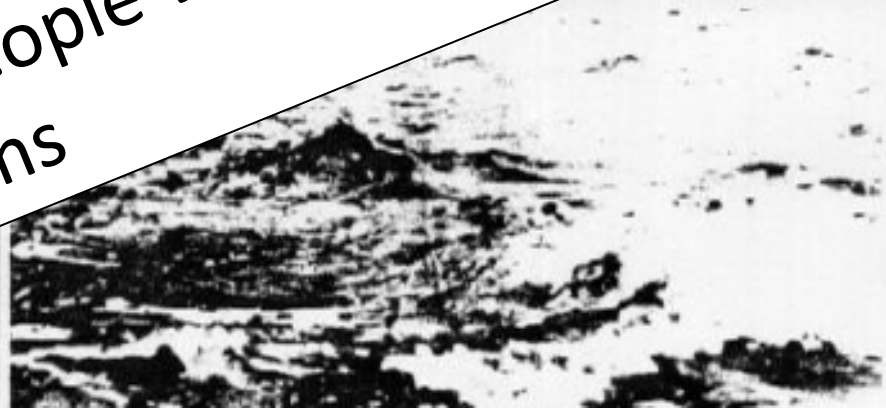
More info in Mel· R. and P. Lionello "**STORM SURGE ENSEMBLE PREDICTION FOR THE CITY OF VENICE"** (submitted)

The problem: the storm surge

Quel giorno si infransero le regole che regolavano il rapporto tra laguna e mare: Adriatico forza otto raffiche a cento km orari - Sedicimila persone persero ogni avere, danni per quattro miliardi di allora

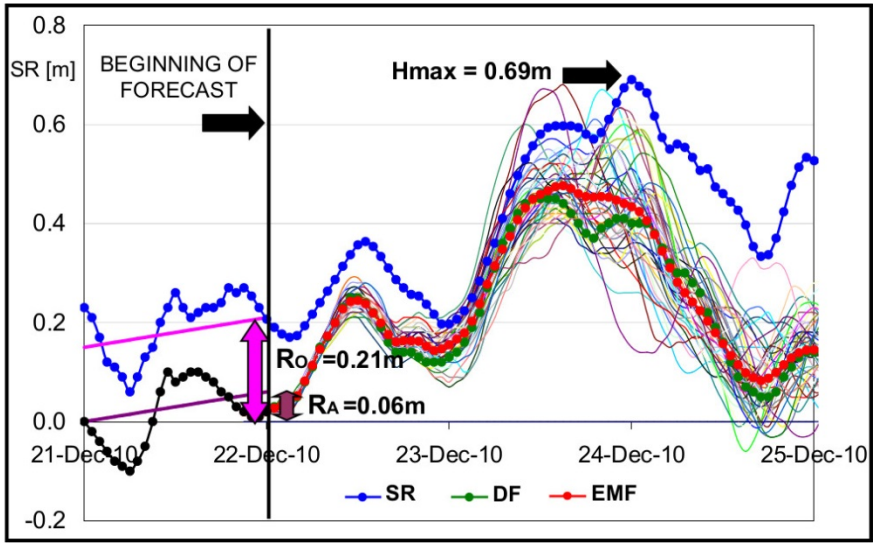
Incredibile: marea a quasi 2 metri

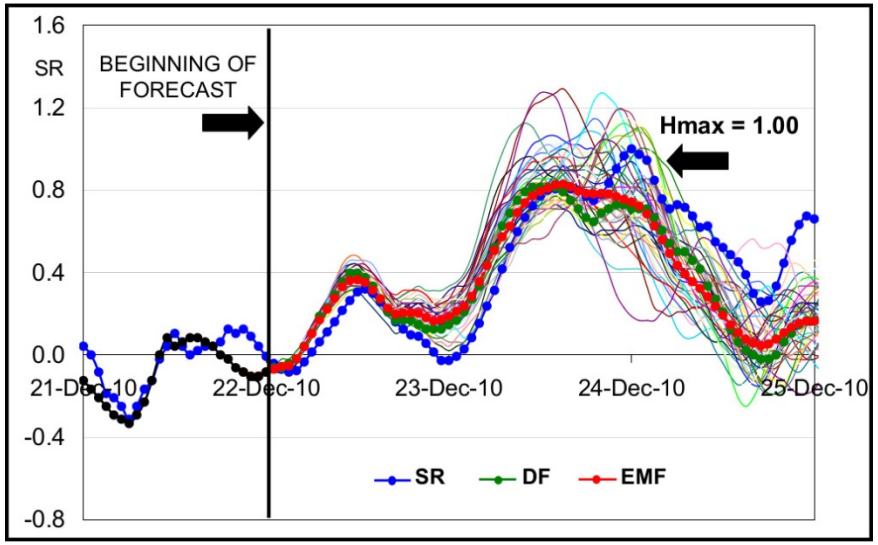
Fuga in barca per quattromila, onde mai viste su Burano e Sant'Erasmo, litorale s... so



- 4th nov. 1966 (De Zolt et al. 2006):
- damages for 400 million present-day Euros
- 4000 people were evacuated from coastal villages
- 3 victims

The procedure for producing a set of dimensionless time series





ISMAR-CNR platform, event n10 on 24.12.2010, 48 hour forecast.

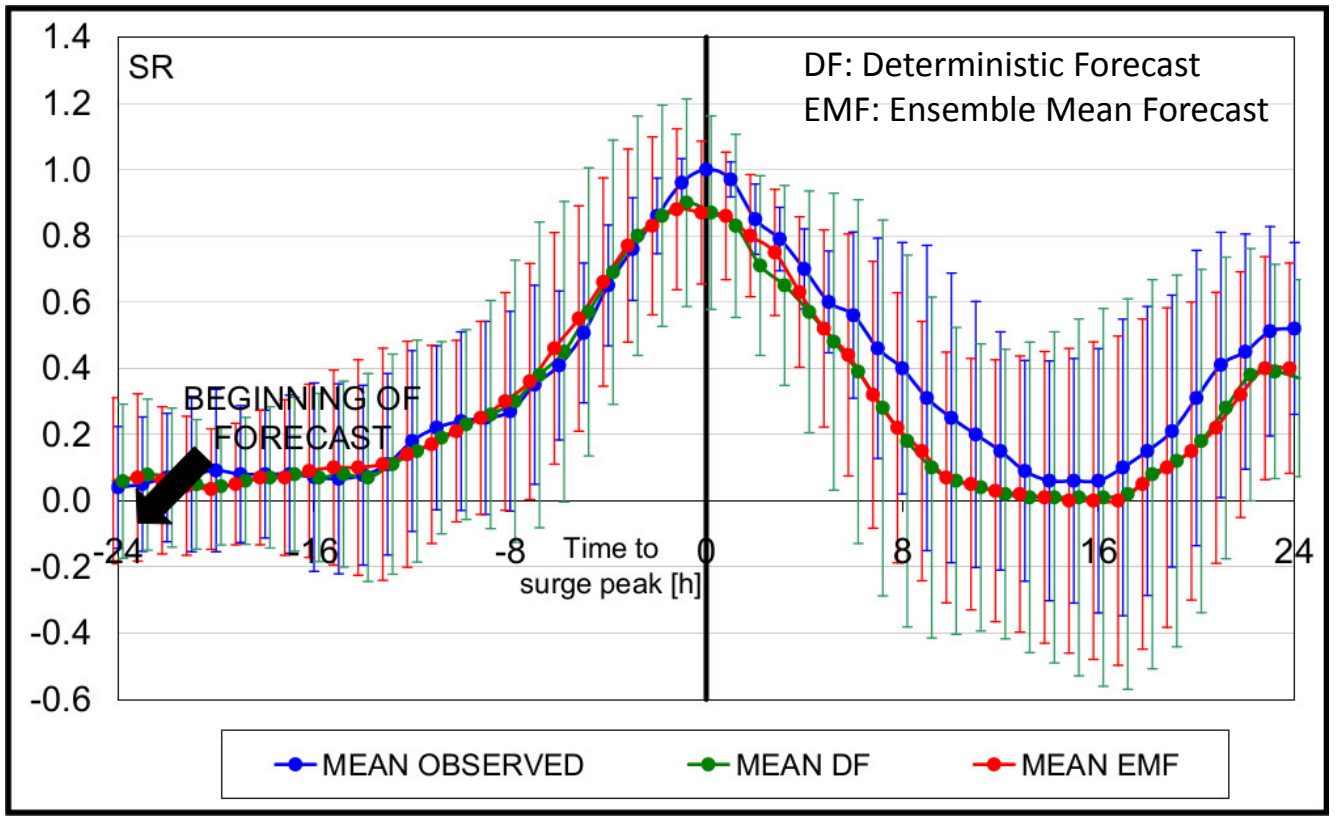
Top panel: original SL values (in m) showing the **observed time series**, the **DF**, the **EMF** (thick blue, **green** and **red** lines with dots) and the 50 EPS members (thin coloured lines). The value of R_O, R_A and of H_{max} (see formula below) are reported in this figure.

Bottom panel : the same information after the application of the normalization procedure as described in the following equation

$$\tilde{H}_i = \frac{H_i - R_x}{H_{max} - R_O}$$

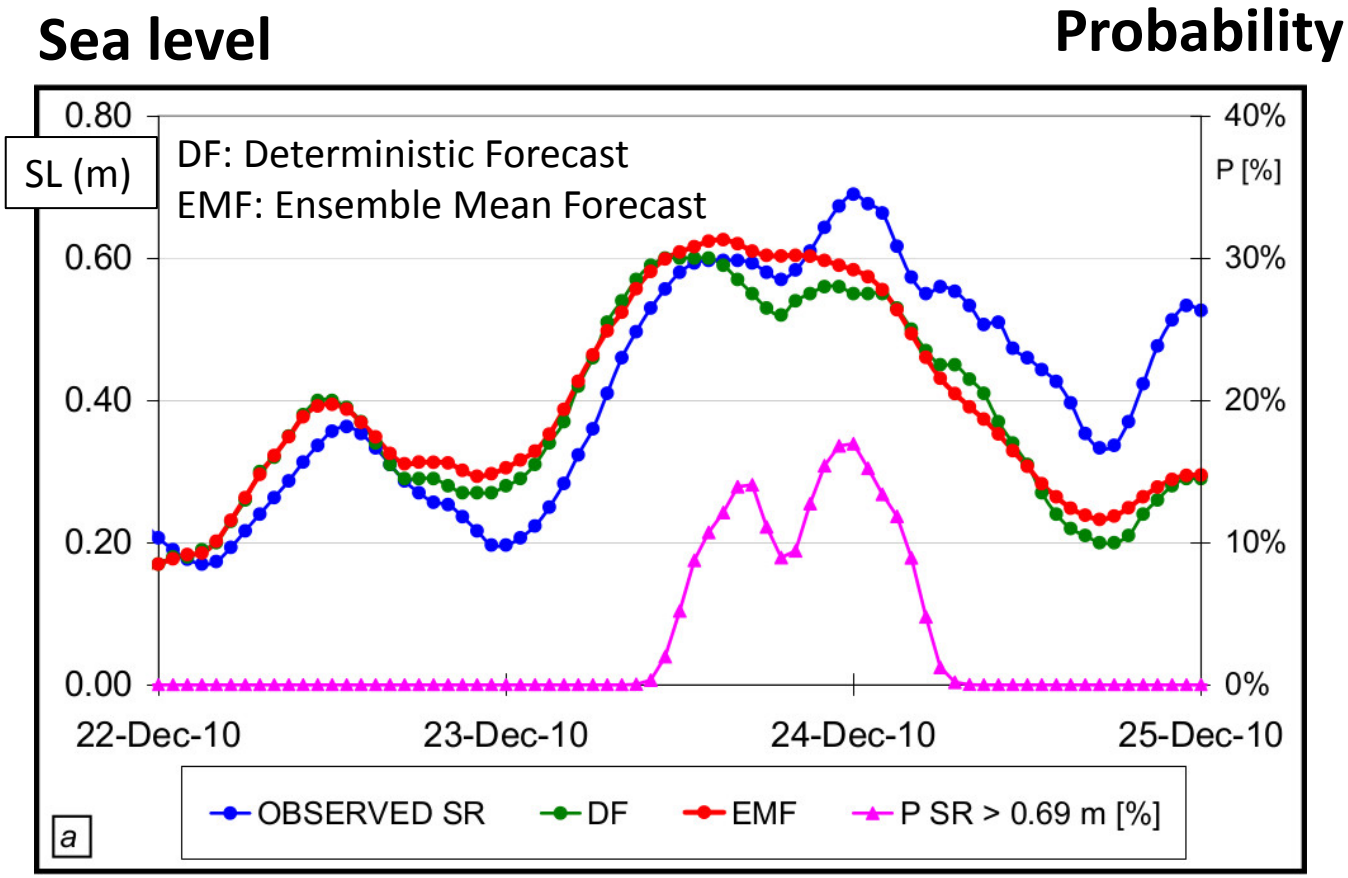
DF: Deterministic Forecast
EMF: Ensemble Mean Forecast

Mean "idealized" evolution of a storm surge in Venice



Mean evolution of the normalized time series of the ten events in the time range from -24 to +24 hours respect to the observed peak. The observed SL at the CNR platform (blue line), the EMF (red line) and the DF (green line) are shown considering the simulations that started approximately 24 hours before the observed peak.

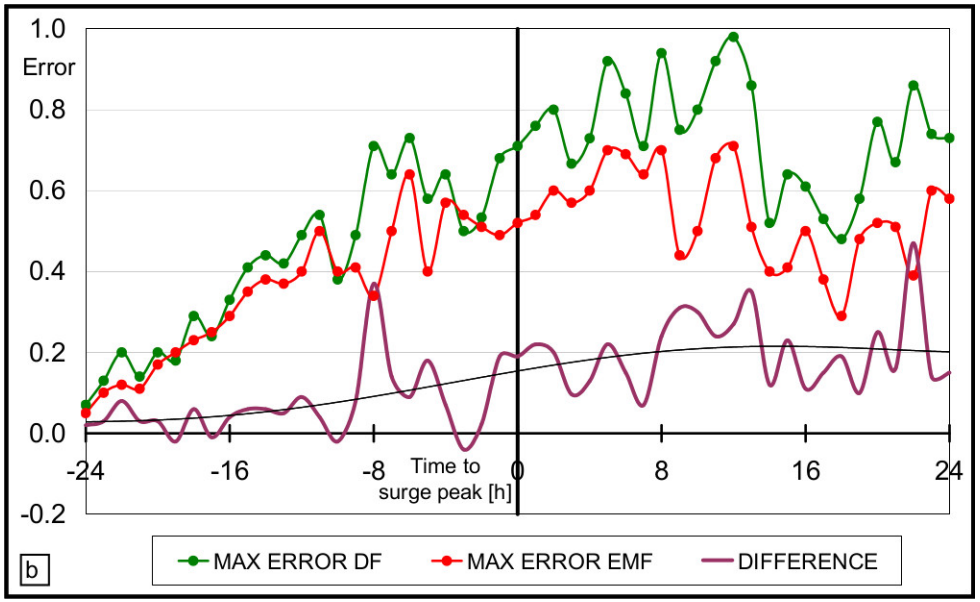
An example of probabilistic forecast



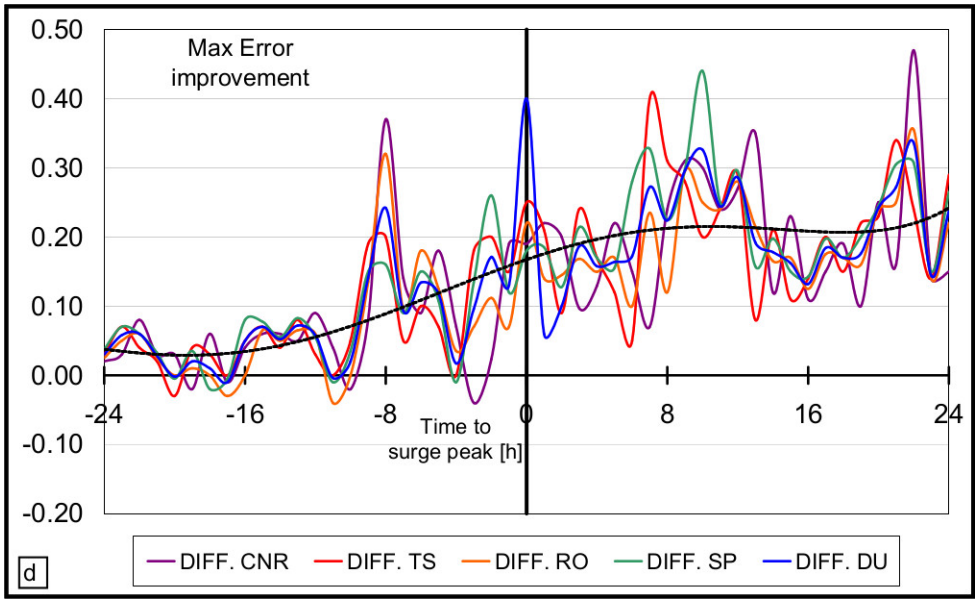
Event n.10, 48 hour forecast at the ISMAR-CNR platform. SL (left y axis, m) of 48 hour DF (green line), EMF (red line), observed level (blue line) and probability (violet line, right y-axis , %) of exceeding the observed peak level (69 cm). The panel reports also the actual values of the deterministic forecast (green bullet), EMF (red bullet) and the observed value (blue bullet).

The prediction of EMF is more robust than that of DF ….

MAX ABS ERROR



MAX ABS ERROR IMPROVEMENT



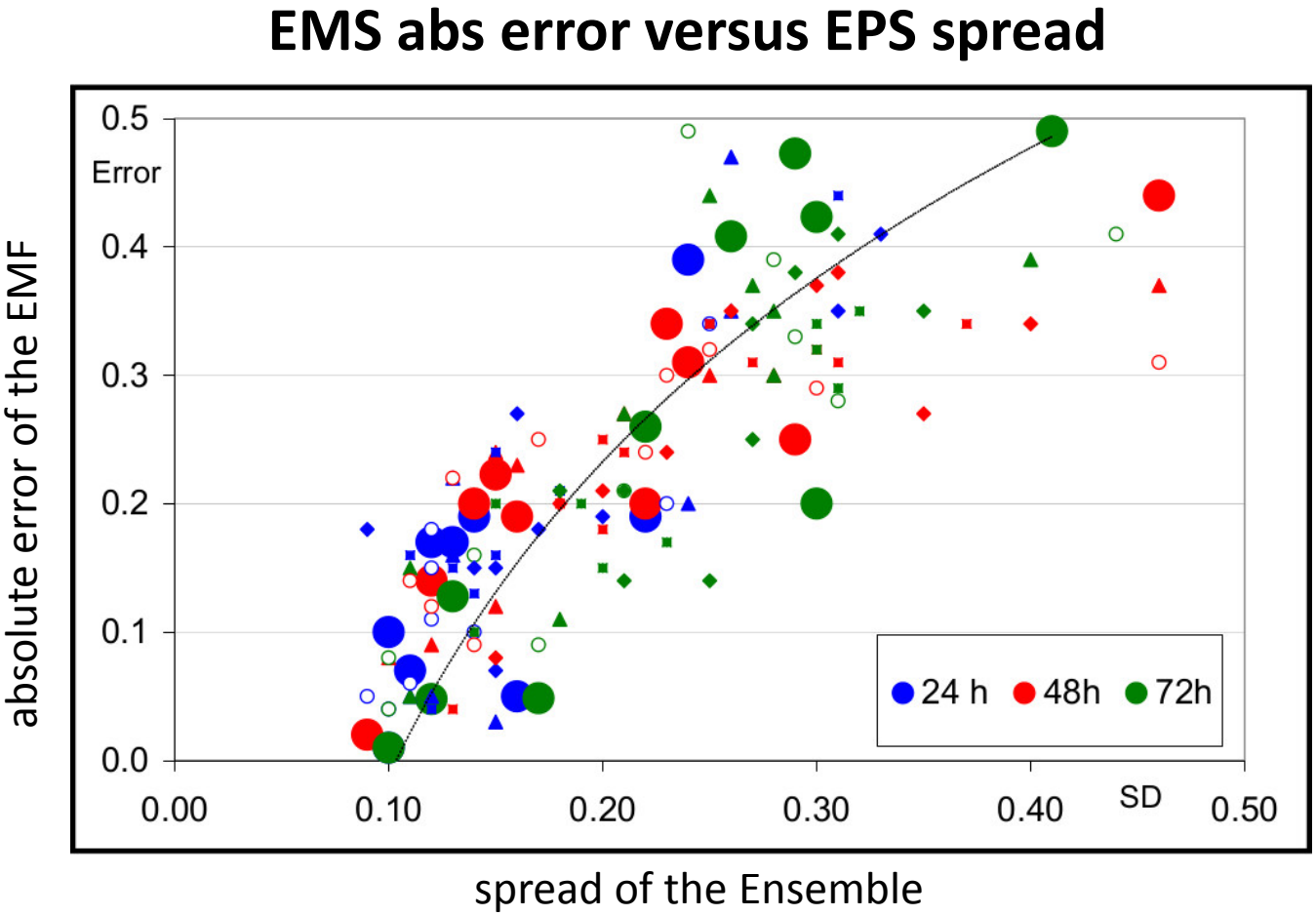
Top panel: maximum absolute error of the ten normalized events for the 24hour forecast at the ISMAR-CNR platform. The lines refer to the EMF (red), the DF (green) and to their difference (error of DF minus error of EMF, violet line). The time 0 refers to the time of the observed SL peak.

Bottom panel difference (DF minus EMF)between EMF and DF for the maximum absolute error at the five stations considered in this study.

In all panels the thin black line represents an interpolation of the error differences.

DF: Deterministic Forecast
EMF: Ensemble Mean Forecast

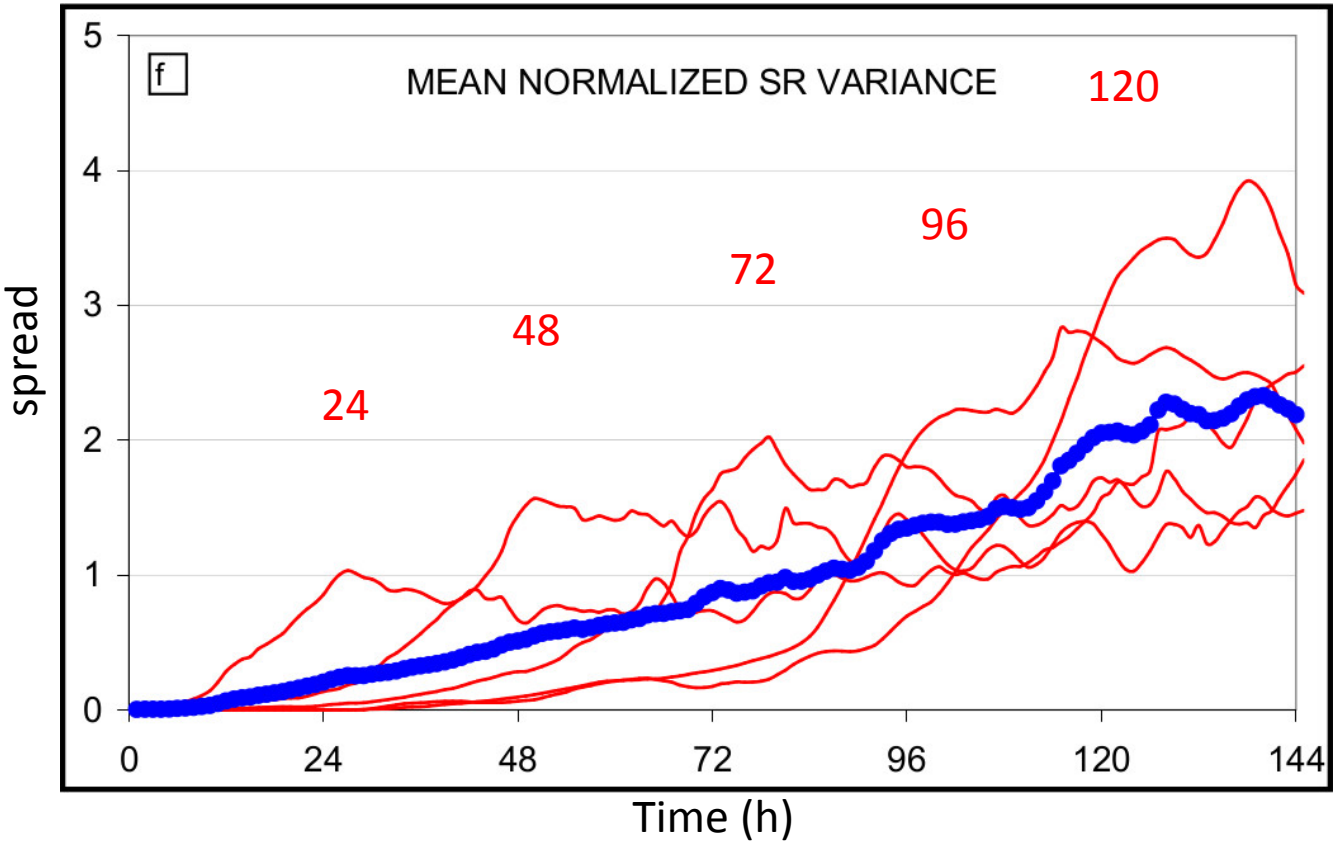
The EPS spread is correlated with the error of the EMF…



Scatter plot of the absolute error of the EMF (Ensemble Mean Forecast) y-axis) versus the spread of the Ensemble (x-axis) the 24 (red), 48 (green) and 72hours (blue) for CNR platform (large dots), Trieste (triangles), Rovinj (small circles), Split (squares) and Dubrovnik (diamonds). All values refer to the normalized peak indexes.

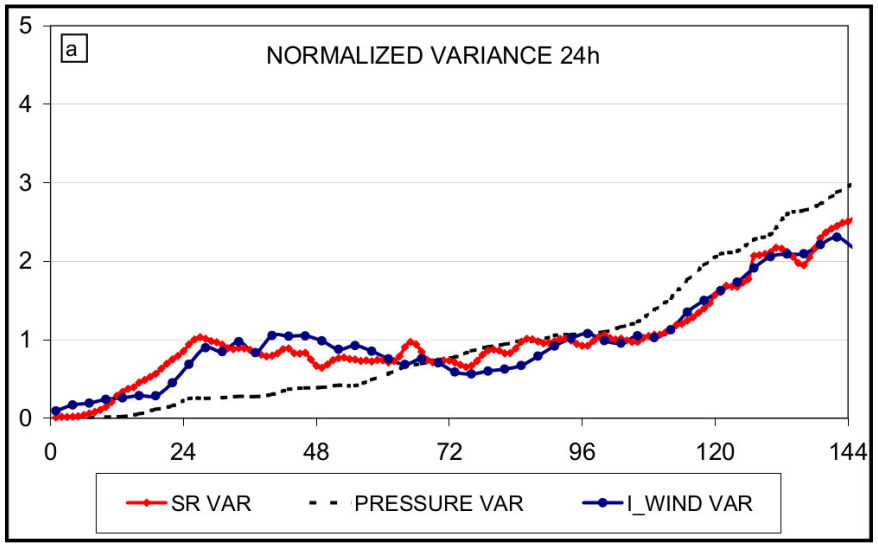
The SL forecast uncertainty increases linearly with time, but it has a peak at the time of the storm surge maximum level…

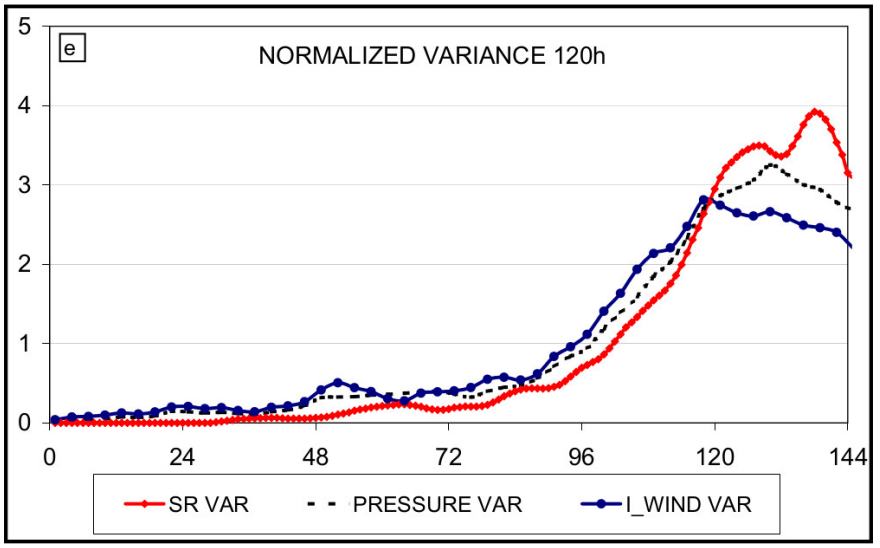
Time evolution of uncertainty and its dependence of the lead time

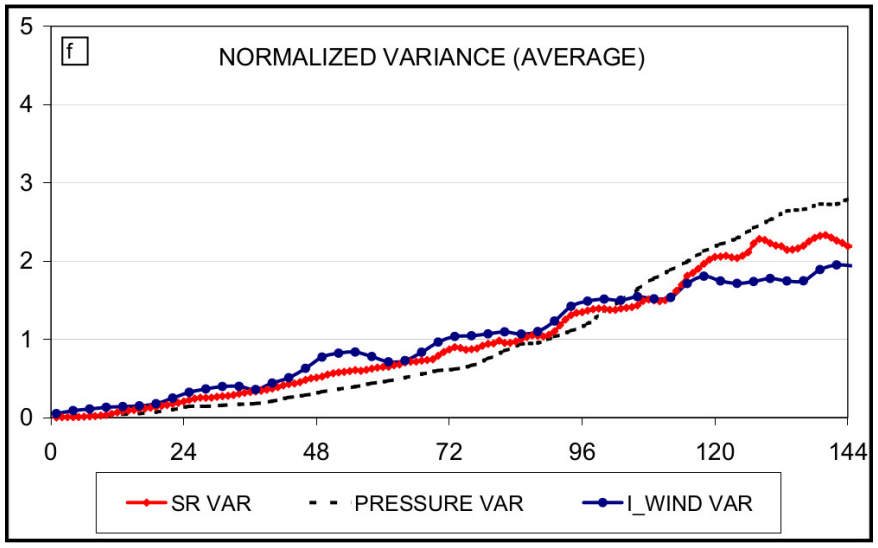


evolution in time of the normalized spread with time range. Each red line describes a forecast with different lead time with respect to the peak, so that the peak is reached at 24, 48, 72, 96, 120 hours. Colour lines represent the spread during each case, the red line their mean value. The blue line shows the mean of all red lines.

SL uncertainty is proportional to the spread of the forcing meteorological fields…



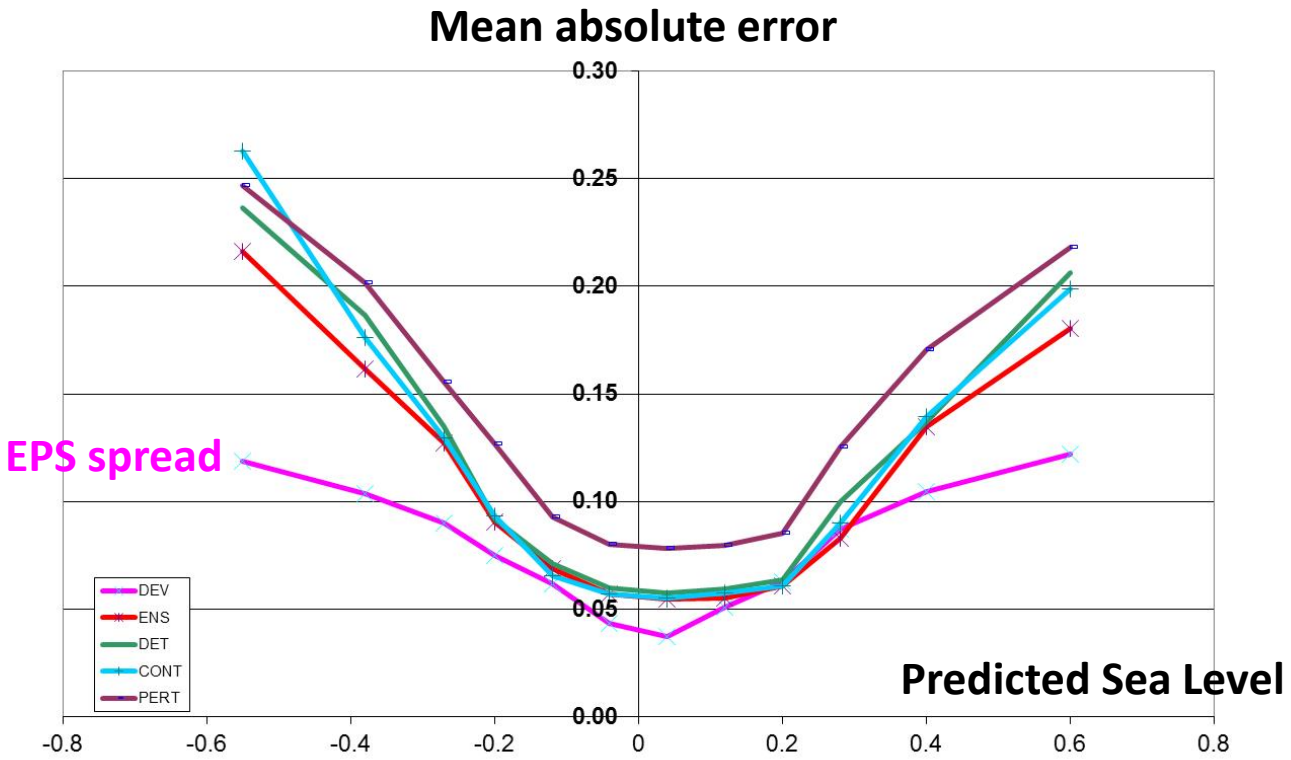




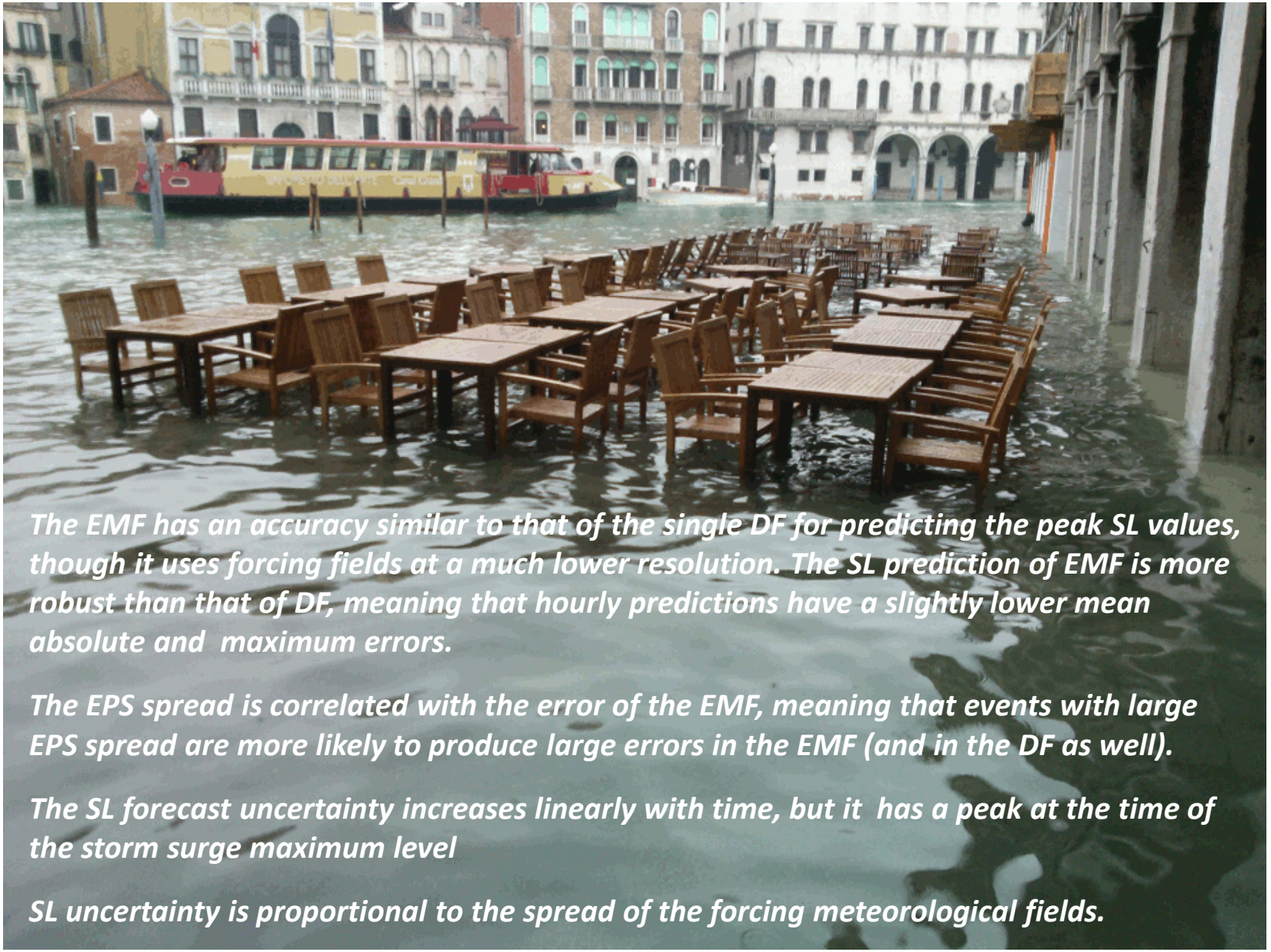
comparison of the evolution in time of spread for different variables: SL (red line), wind(solid blue line with dots), MSLP (dashed black line) at the ISMAR-CNR platform.
Panel f reports the mean of time series for all lead times

More work is in progress…

Simulating the operationalpractice for a 3-month long period, with EPS launched every 12 hours. Figure shows mean absolute error as function of the predicted sea level



CONCLUSIONS



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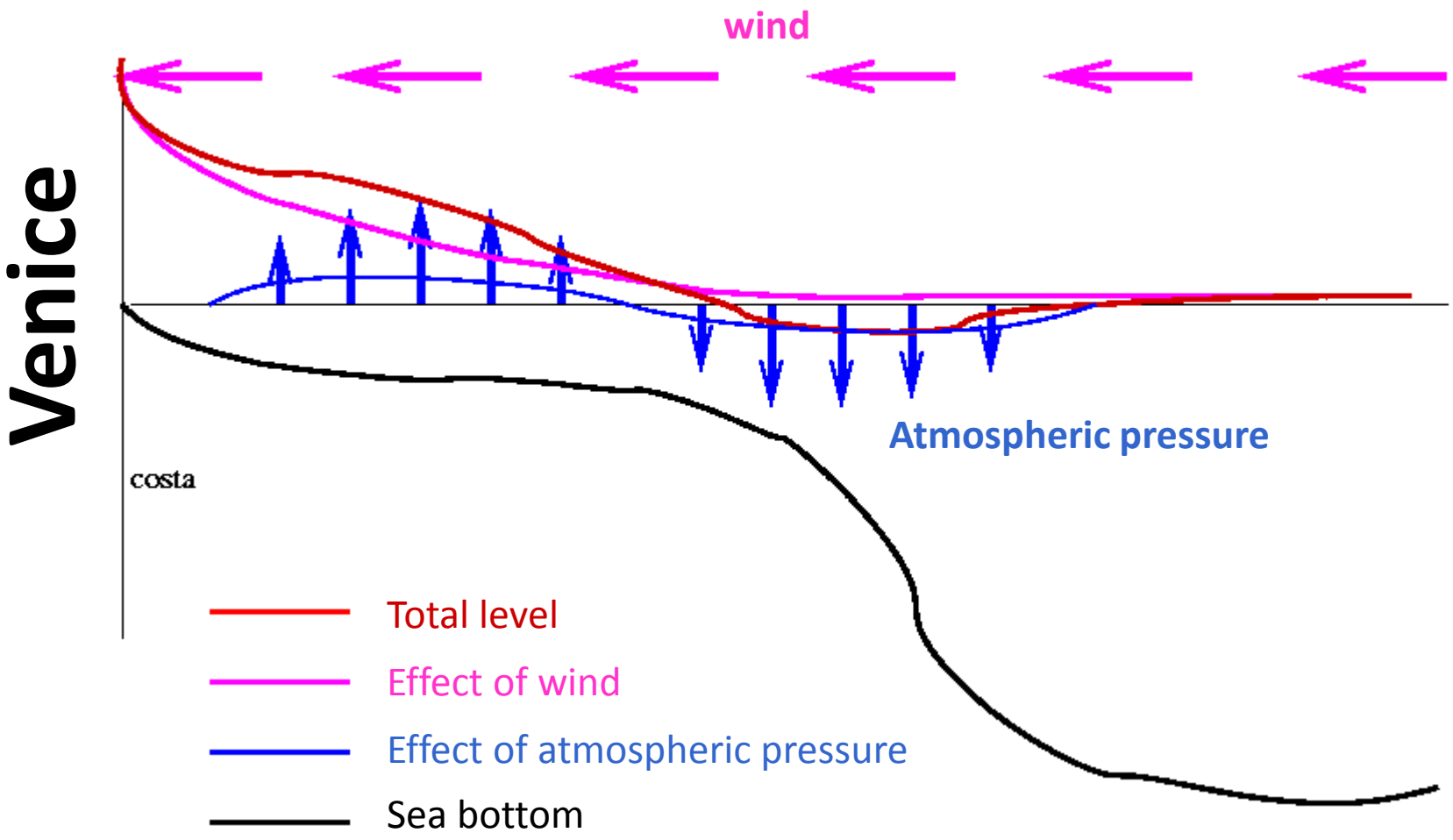
SL uncertainty is proportional to the spread of the forcing meteorological fields.

Storm surge dynamics in the Adriatic Sea



INFO on existing operational prediction tools

The forecast centre of the Venice municipality (I.C.P.S.M. - Istituzione Centro Previsione e Segnalazione Maree, Centre for tide prediction and warning) operates a set of models for SL prediction:

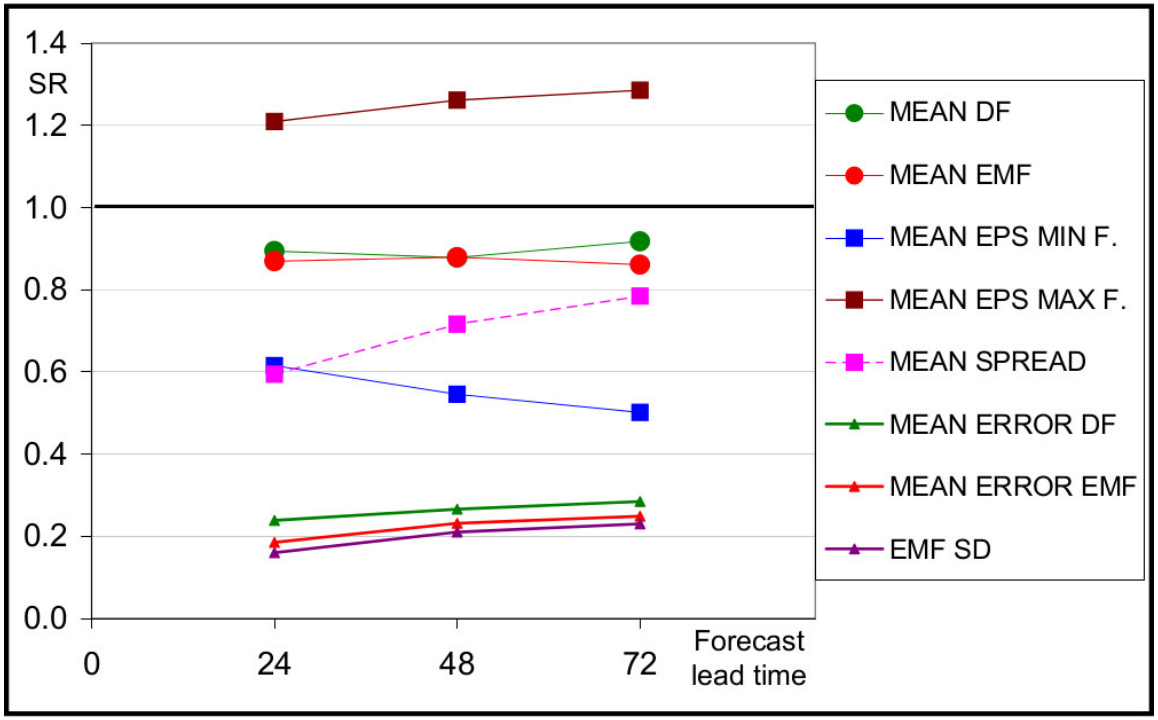
- BIGSUMDP (Tomasin, 1972, Canestrelli and Pastore, 2000), a linear statistical autoregressive model
- SHYFEM (Shallow Water Hydrodynamic Finite Element. Model, Umgiesser et al., 2004), based on the finite element method
- HYPSE-AM (HYdrostatic Padua Sea Elevation and Adjoint Model, Lionello et al., 2006), a finite difference model with data assimilation
- ENSEMBLE PREDICTION?

events analysed

Event n.	Peak date	SR (CNR)	SR (TS)	SR (RO)	SR (SP)	SR (DU)	Observed sea level (VENICE-PS)	SR (PS)
1	06.02.2010	0.45 m	0.26 m	0.41 m	0.24 m	0.23 m	h 01.55 0.84 m (1%)	0.44 m
2	20.02.2010	0.82 m	0.63 m	0.75 m	0.58 m	0.53 m	h 00.50 1.24 m (36%)	0.80 m
3	25.10.2010	0.46 m	0.20 m	0.43 m	0.31 m	0.31 m	h 10.50 1.02 m (7%)	0.48 m
4	01.11.2010	0.49 m	0.38 m	0.51 m	0.14 m	0.13 m	h 06.40 1.02 m (7%)	0.51 m
5	09.11.2010	0.56 m	0.48 m	0.65 m	0.43 m	0.42 m	h 11.45 1.06 m (9%)	0.57 m
6	16.11.2010	0.51 m	0.38 m	0.48 m	0.32 m	0.29 m	h 07.35 0.94 m (3%)	0.52 m
7	22.11.2010	0.73 m	0.68 m	0.73 m	0.59 m	0.55 m	h 00.10 1.22 m (32%)	0.72 m
8	26.11.2010	0.69 m	0.55 m	0.69 m	0.48 m	0.46 m	h 11.40 1.11 m (13%)	0.62 m
9	03.12.2010	0.70 m	0.54 m	0.93 m	0.70 m	0.51 m	h 08.55 1.36 m (53%)	0.67 m
10	24.12.2010	0.69m	0.73 m	0.86 m	0.63 m	0.53 m	h. 01.00 1.44 m (64%)	0.82 m

List of the 10 events analysed in this study: date, SR maxima at the five Adriatic gauges considered for the analysis: ISMAR-CNR (CNR), Trieste (TS), Rovinj (RO), Split (SP), Dubrovnik (DU). Last four columns show time and value of observed maximum SL with percentage of Venice flooded (between brackets), and maximum SR at the Punta Salute gauge (Venice city centre, PS).

Overall statistics



Mean (average values over the 10 normalized events) results for 24, 48 and 72 hours forecasts.
mean peak values of the

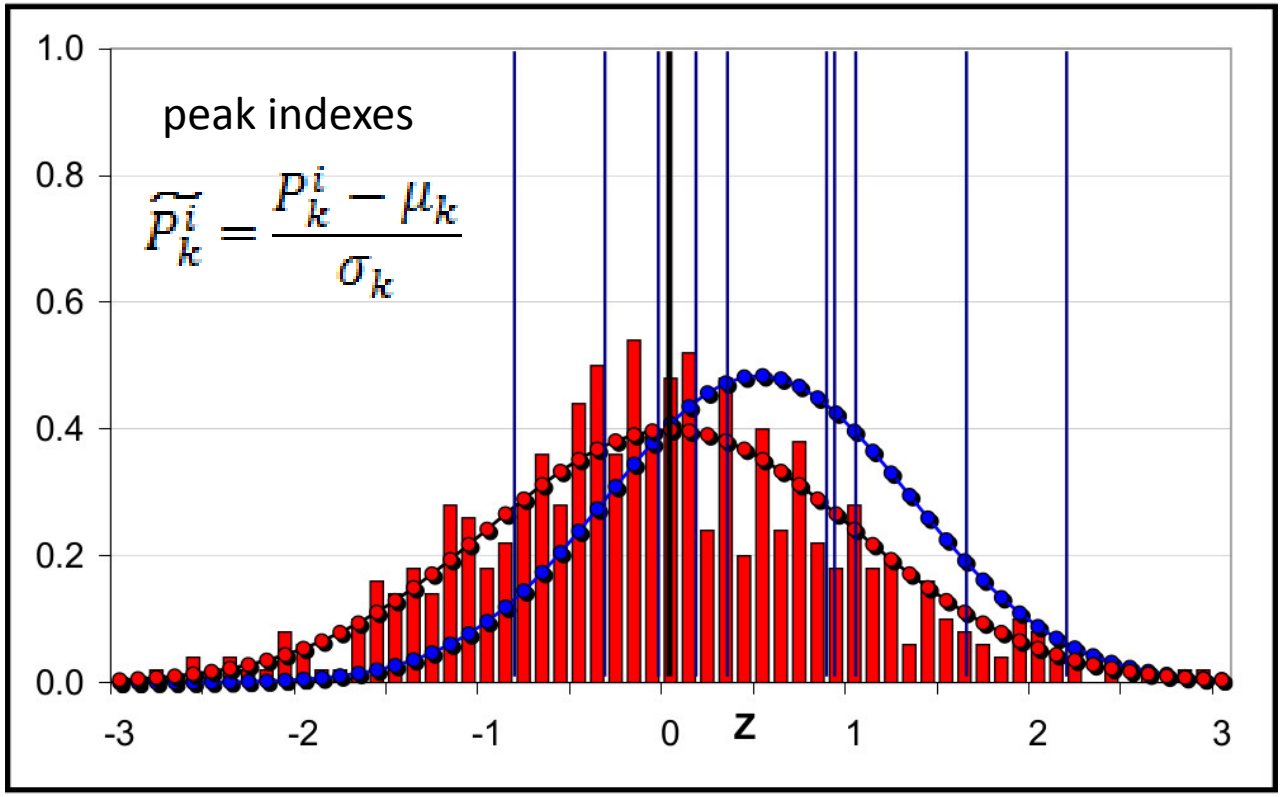
DF (Deterministic Forecast, green line with dots), of the
EMF (Ensemble Mean Forecast, red line with dots), of the
highest (brown line with squares) and lowest (blue line with squares) member of the EPS (Ensemble Prediction System) and their difference (EPS range, fuchsia line with squares),

mean absolute error (MABS) of the

DF (green line with triangles), EMF (red line with triangles),

standard deviation of the EPS (Ensemble Prediction System) members peak values (violet line with triangles).

Probability of storm surge peak values
EPS versus observations



Probability distribution of the peak indexes (red bars) with the respective Gaussian normalized distribution (**line with red dots) for the EPS** (Ensemble Prediction System) 24 hours forecast. **The blue bars show the observed peak indexes. The blue dotted line** shows the Gaussian with same mean value and standard deviation as the observations.