Earth Observation in Storm Surge Forecasting: the Lesson Learnt from the eSurge-Venice Project, and the Transition to Operational Forecasting in Venice (Adriatic Sea)

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INTRODUCTION

Coastal areas are subject to flooding caused by storm surges. One of the most exposed region of the Mediterranean Sea is the Gulf of Venice, in the Adriatic Sea. The Tide Forecast and Early Warning Center (Centro Previsioni e Segnalazioni Maree - CPSM) of the Venice Municipality runs operational storm surge models to predict the surge and mitigate the impact of the floods. The output of atmospheric models (sea surface wind and pressure) is used to force the storm surge models. The performance of the atmospheric model output in coastal areas is generally lower than in open-ocean: in the Adriatic Sea the surface wind forecasts are often underestimated *[Zecchetto and Accadia, 2014]*. ***eSurge-Venice***, a project funded by the Data User Element (DUE) Programme of the European Space Agency (ESA), has demonstrated the improvement of the storm surge forecasting with the use of earth observation data, focusing on the Gulf of Venice. ***The main outcome of eSurge-Venice has been the development of a methodology (wind bias mitigation) to reduce the bias between the sea surface wind observed by the scatterometers and that supplied by numerical weather prediction (NWP) models, for storm surge forecasting applications.*** This methodology is now being implemented in the pre-operational storm surge forecast chain of the CPSM.

THE SCATTEROMETER-MODEL WIND BIAS

Fig. 1 right shows the spatial pattern of the relative bias ($\Delta w_s/w_{sc}$) for scatterometer-model data for two years (Jan 2008 - Nov 2009) in the Adriatic Sea: it ranges from -5% to +20% of the scatterometer wind. A bias is found also in the wind direction: it will not be considered here. Left: distributions of wind speed and direction for scatt and model, in the same two years.

- *Scatterometer observations from QuikSCAT and ASCAT*
- *NWP model data from the ECMWF deterministic model*

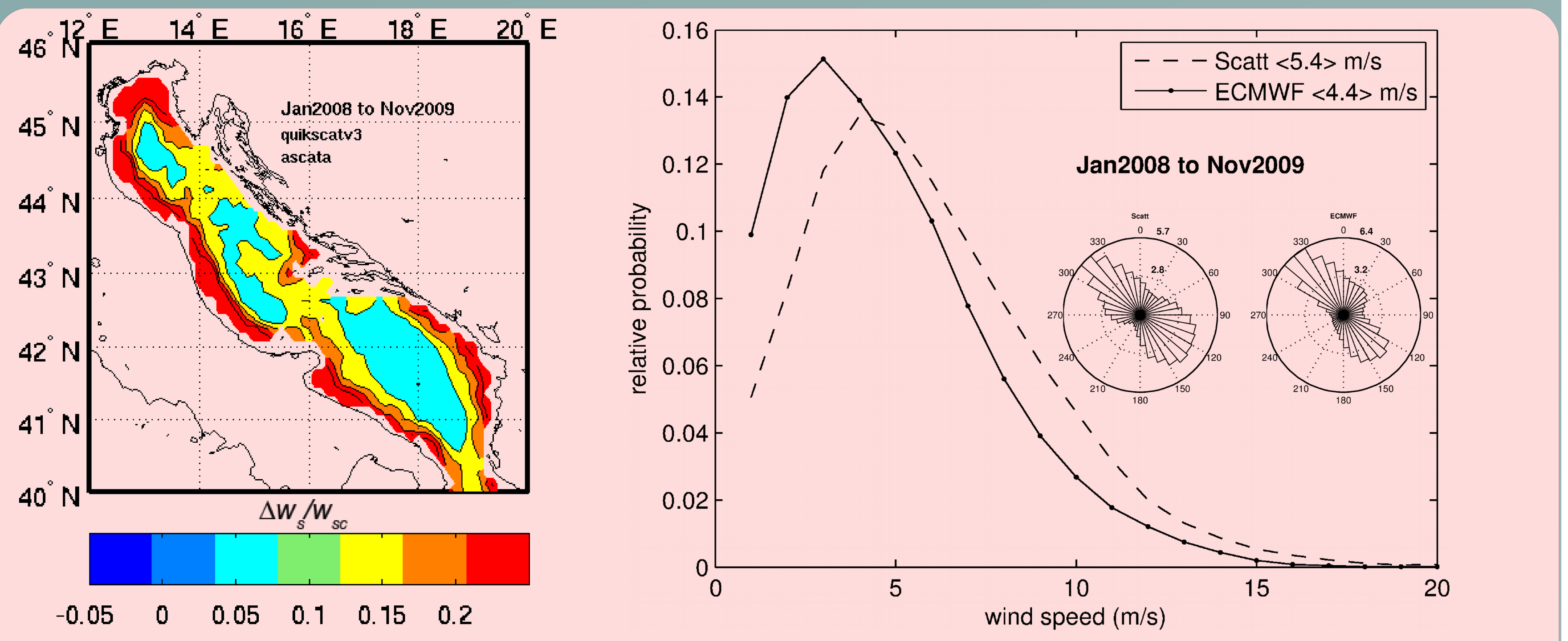

Fig. 1 - Left: SCATT-ECMWF bias spatial pattern Jan 2008 - Nov 2009 (relative wind speed bias). Right: distributions of wind speed and direction frequencies for scatterometer and ECMWF model (Jan 2008 – Nov 2009): ECMWF wind speeds are generally lower than scatterometer observations (bias ≈ 1 m/s). ECMWF has a narrower N-S direction distribution.

WIND BIAS MITIGATION: HOW IT WORKS

Atmospheric model winds are scaled by a spatial factor (1+α) before being fed into the storm surge model. α is derived from the statistics of the scatterometer-model bias of the three days before, and thus varies in space and time [Zecchetto et al., 2015]. Eight different mathematical formulations of α have been tested, originating from four mathematical approaches:

1. Euristic (original formulation in [Zecchetto et al., 2015]);
2. Euristic alternatives (variations of the above);
3. Analytical solution;
4. Least square regression (LSR).

For the latter, four different cost functions have been considered:

- Linear LSR (**LLSR**): the cost function depends on the differences of the scatt and model wind speeds;
- Linear LSR (**LLSR$_E$**): the cost function depends on the differences of the scatt and model ***squared*** wind speeds;
- Relative LSR (**RLSR**): the cost function depends on the ratio of the scatt-model wind speeds and of the scatt wind speed;
- Relative LSR (**RLSR$_E$**): the cost function depends on the ratio of the squared scatt and model wind speed diffrences and of the scatt wind speed.

ROADMAP:

- Model wind bias mitigation pre-operational chain ready in Jan 2019.
- Introduction of corrective factor for the wind direction mid 2019.
- Wind speed and wind direction biases are completely independent, but they should be regressed simoultaneously, using a linear least square regression approach. The starting point is to write a cost function (CF) to be minimized, where the optimal values of the two parameters α and β are determined at the same time, constrained by the condition on the wind speed (the factor of the Lagrange multiplier λ):

$$CF=\sum_{i=1}^{N}\left(u_i^{scatt}-(1+\alpha)\cdot u_i^{model}\right)^2+\sum_{i=1}^{N}\left(v_i^{scatt}-(1+\beta)\cdot v_i^{model}\right)^2-\lambda\cdot\sum_{i=1}^{N}\left(\sqrt{\left(u_i^{scatt}\right)^2+\left(v_i^{scatt}\right)^2}-\sqrt{\left((1+\alpha)\cdot u_i^{model}\right)^2+\left((1+\beta)\cdot v_i^{model}\right)^2}\right)^2$$

VERIFICATION: SCATT-MODEL WIND BIAS

Four sets of scatterometer and model winds corresponding to storm surge events in the Gulf of Venice (448 wind events): among them, the 7 surge events worst predicted in 2012-2016 by CPSM.
Results: the model wind standard forecast and the mitigated forecast, compared to scatterometer observations:

- Have similar centered RMS difference (scatt – model)
- Have comparable Pearson's correlation
- Have similar standard deviation

Moreover:

- The mitigated forecasts have always a lower bias than the standard forecast
- The mitigated forecasts perform better than the standard forecast in about 70 % of the cases (**Table 1 & Fig. 2**)

Dataset	LLSR	RLSR	OF	AF1	AF2	AS	LLSR$_E$	RLSR$_E$
D1 (#29)	79	72	72	76	76	76	79	76
D2 (#48)	79	73	73	71	75	75	81	75
D3 (#364)	71	71	73	71	73	73	73	70
D4 (#7)	86	71	86	57	86	86	100	86

Table 1 - Percentage of success of the hindcast experiment: percentage of times that the RMS difference of the mitigated and scatterometer winds scored better than the RMS difference of the standard and scatterometer winds. POS are shown for four datsets and the eight mitigation types. **The best scores are obtained by the LLSR$_E$ WBM approach.**

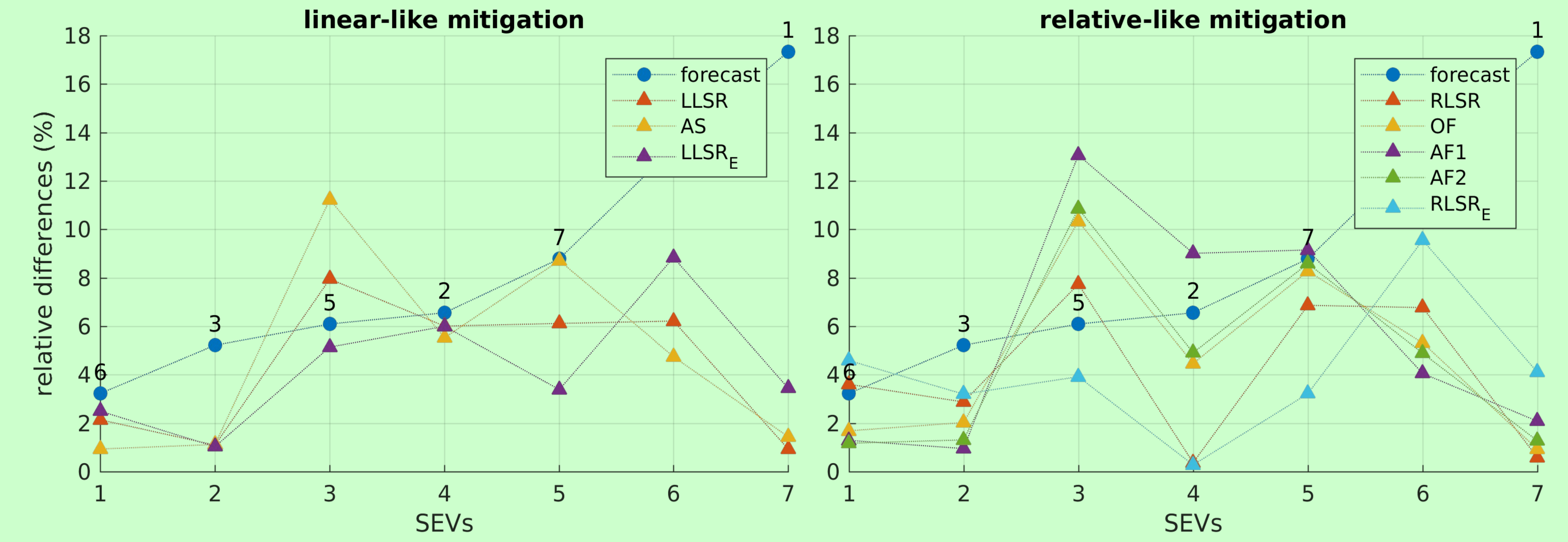

Figure 2 - Percentage of success for the 7 worst cases (CPSM). Left: comparison of the scores of the linear-like formulations of the wind bias mitigation. Right: scores of the relative-like formulations.

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