A wave ensemble prediction system for the Mediterranean Sea

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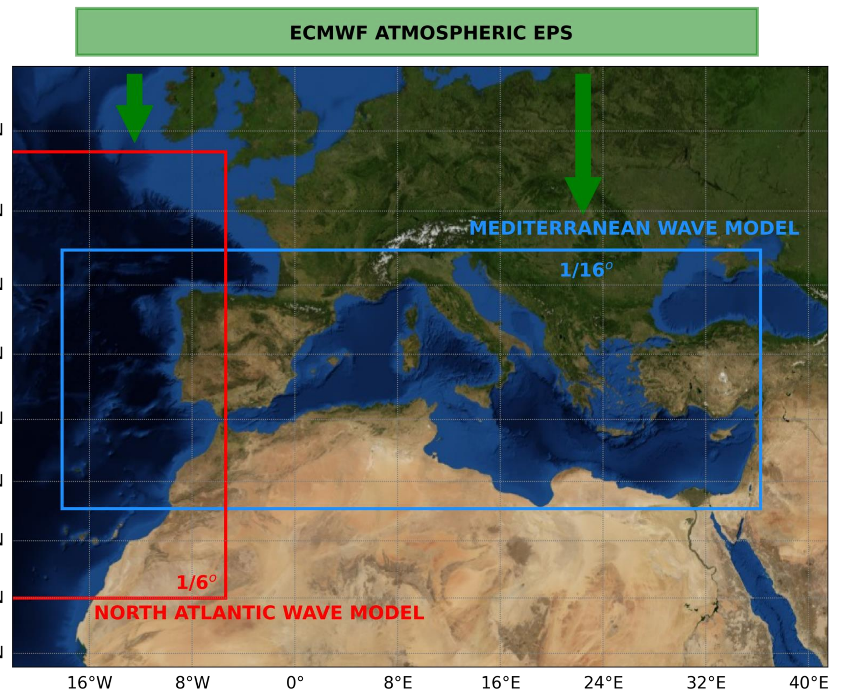
A. Introduction

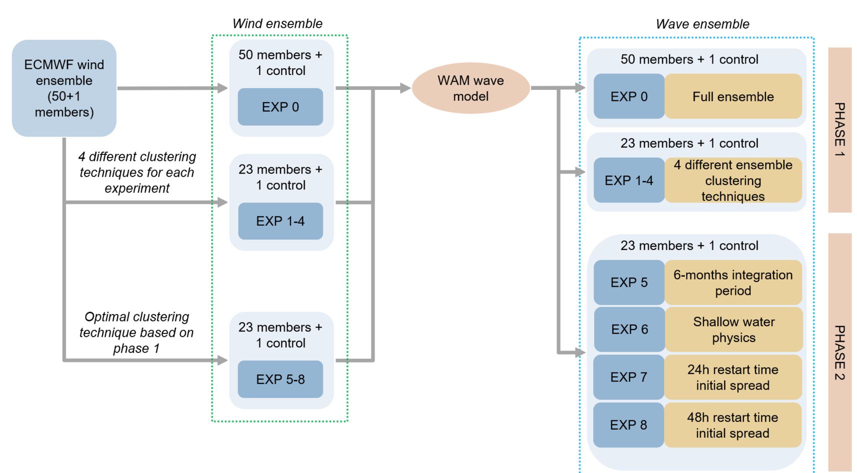


- The core of the Med-waves EPS is the WAM Cycle 6 wave model implemented over the Mediterranean basin at 1/16° horizontal resolution (CMEMS Med-Physics EAS1 system) with open boundaries in the Atlantic where OBCs are provided by a 1/6° North Atlantic model. Each day, the system produces Mediterranean waves ensemble forecasts for 10 days ahead.
- To force the Med-waves EPS, a subset of 10m ensemble winds are selected from the ECMWF atmospheric EPS (50+1 members) using clustering techniques (K-means methodology applied at the 5th forecast day of the ECMWF ensemble). For each forecast cycle, all 23 ensemble members are initialized from the control run (the run that is driven with ECMWF control 10m winds).
- At this stage of development, no perturbations are introduced to the wave ensemble members (e.g. stochastic perturbations to the initial conditions or the WAM model physics). Thus, immediately after initialization, Med-waves ensemble spread is zero and the uncertainty evolution is controlled by the ensemble of 10m winds corresponding to the ECMWF atmospheric EPS.

B. Methods

The Med-waves EPS has been validated for a period up to 6 months (Jan 2022 – Jun 2022), where the system has been run for one cycle per day (12:00 UTC) with a forecast horizon of up to 10 days. A variety of metrics, both deterministic and probabilistic were used, in order to assess as many forecast quality attributes as possible and to best determine the performance of the Med-waves EPS. The wave ensemble was verified against available satellite and in situ SWH observations, as well as reference forecasts like those produced by the Med-waves NRT system and the ECMWF wave EPS.

- PHASE 1 (EXP0-4): (a) Provide an initial assessment of the Med-waves EPS, using the full 50+1 ECMWF atmospheric EPS wind forcing (EXP0), and (b) investigate the optimal method for the reduction of the atmospheric ensemble to a total of 23+1 members, with the use of various clustering techniques (EXP1-4).
- PHASE 2 (EXP5-8): (a) Continue the overall assessment of the reduced Med-waves EPS of 23+1 members, for a longer forecasting and validation period (EXP5), (b) examine the effects of shallow water physics in the model parameterization (EXP6), and (c) examine different strategies for the potential increase of the initial ensemble spread by initializing the ensemble members with the restart output produced at T+24 (EXP7) or T+48 (EXP8).
- The model was integrated for 1-month for EXP0-4 (March 2022) and EXP6-8 (January 2022), and a 6-months period for EXP5 (January – June 2022), with forecast horizons of 6 and 10 days for Phases 1 and 2 respectively.



C. Results

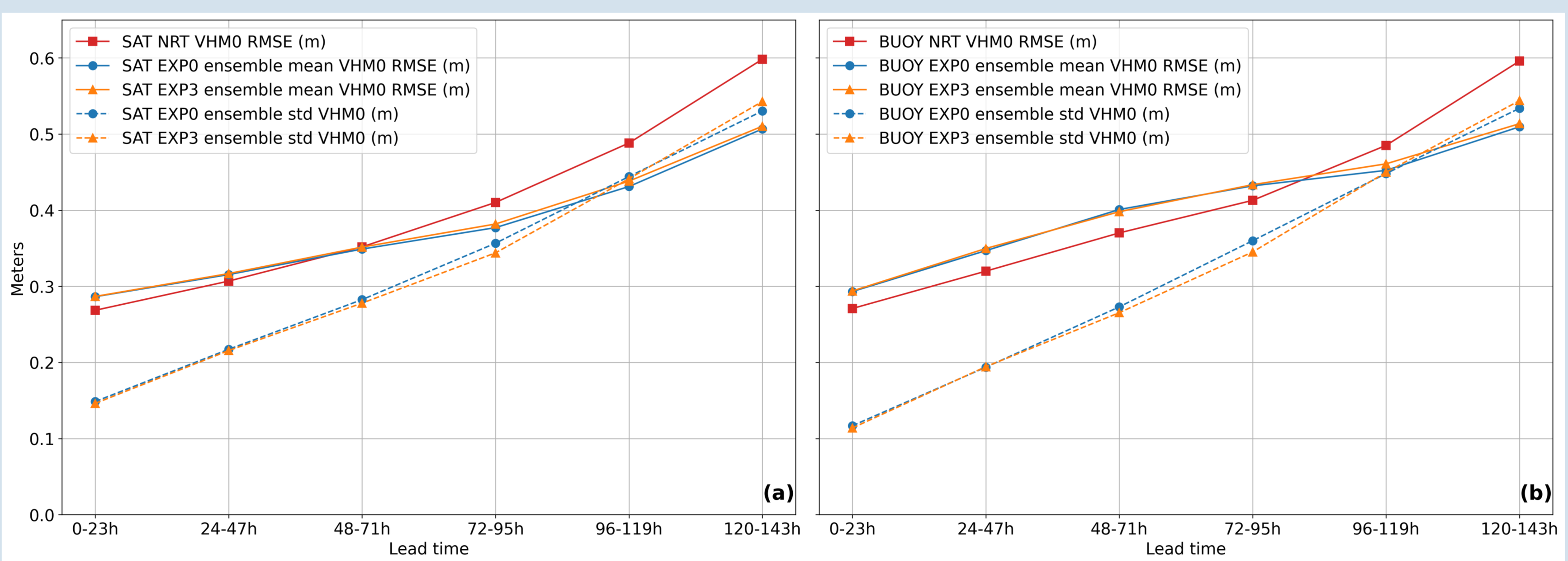


Figure 1: RMSE score for the Med-waves EXP0 (50+1 members) & EXP3 (23+1 members) ensemble mean and NRT (deterministic) forecasts, and standard deviation (std) of the EXP0 & EXP3 ensembles. The performance metrics were produced based on (a) satellite and (b) buoy collocated observations.

Objectives

The development and validation of a wave ensemble prediction system for the Mediterranean Sea (Med-waves EPS), based on an implementation of the WAM Cycle 6 wave model for the basin.

Key findings

1. Multiple quality attributes (i.e. accuracy, reliability, etc.) were investigated and denoted a good performance for the Med-waves EPS forecasts.
2. Ensemble reduction methods were applied successfully, without diminishing the skill of the EPS.
3. The wave EPS becomes more "skillful" than the deterministic system after the first 48 (satellites) and 72 (buoys) hours of forecast.
4. The spread of the ensemble, encompasses "perfectly" the forecast error at the 5th - 6th day approximately.
5. Initializing the ensemble members with the restart output generated during the previous forecast cycles (24 or 48 hours before), has a positive impact in increasing the initial ensemble spread.

Further info

Sharing is encouraged

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C. Results

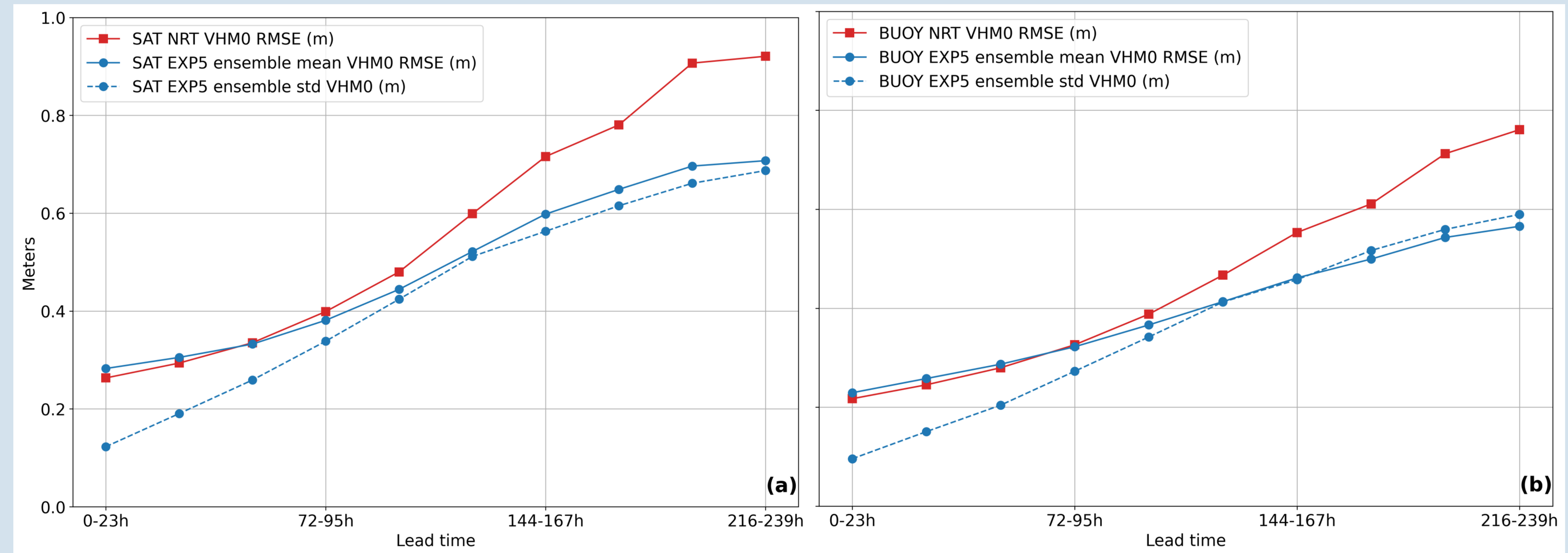

Figure 2: RMSE score for the Med-waves EXP5 ensemble mean (23+1 members – same clustering technique as EXP3) and NRT (deterministic) forecasts, and standard deviation (std) of the EXP5 ensemble. The model integration period is increased to 6-months and the forecast horizon to 10 days. The performance metrics were produced based on (a) satellite and (b) buoy collocated observations.

- EXP0 & EXP3 perform similarly to one another (Fig. 1a,b), denoting a successful ensemble reduction, in which the spread of the reduced ensemble of 23+1 members (EXP3) can encompass the forecast error like the full ensemble of 50+1 members (EXP0), and thus not diminish the reliability of the forecast.
- Intercomparison between the RMSE of the Med-waves EPS and the forecast produced by the Med-waves NRT (deterministic) system, shows that the EPS has a better skill after the first 48 hours of forecast based on the satellite observations (Figs. 1a, 2a) and 72 hours based on the buoy observations (Figs. 1b, 2b).
- The spread of the ensemble, starts from a low initial value for the first 24h and increases thereafter, achieving briefly an ideal value that encompasses "perfectly" the forecast error at the 5th - 6th day approximately.

- The system shows a good reliability which increases with lead time and for higher thresholds, as indicated by the proximity to the diagonal (Fig. 3).
- The reliability curves lie mainly above the diagonal, indicating an under-forecasting bias for the model.
- The distribution of the population in the lower and higher ends of the histogram, indicates a sharp forecast. Sharpness decreases with lead time.
- Most points are in the shaded area and contribute positively to the Brier skill score.

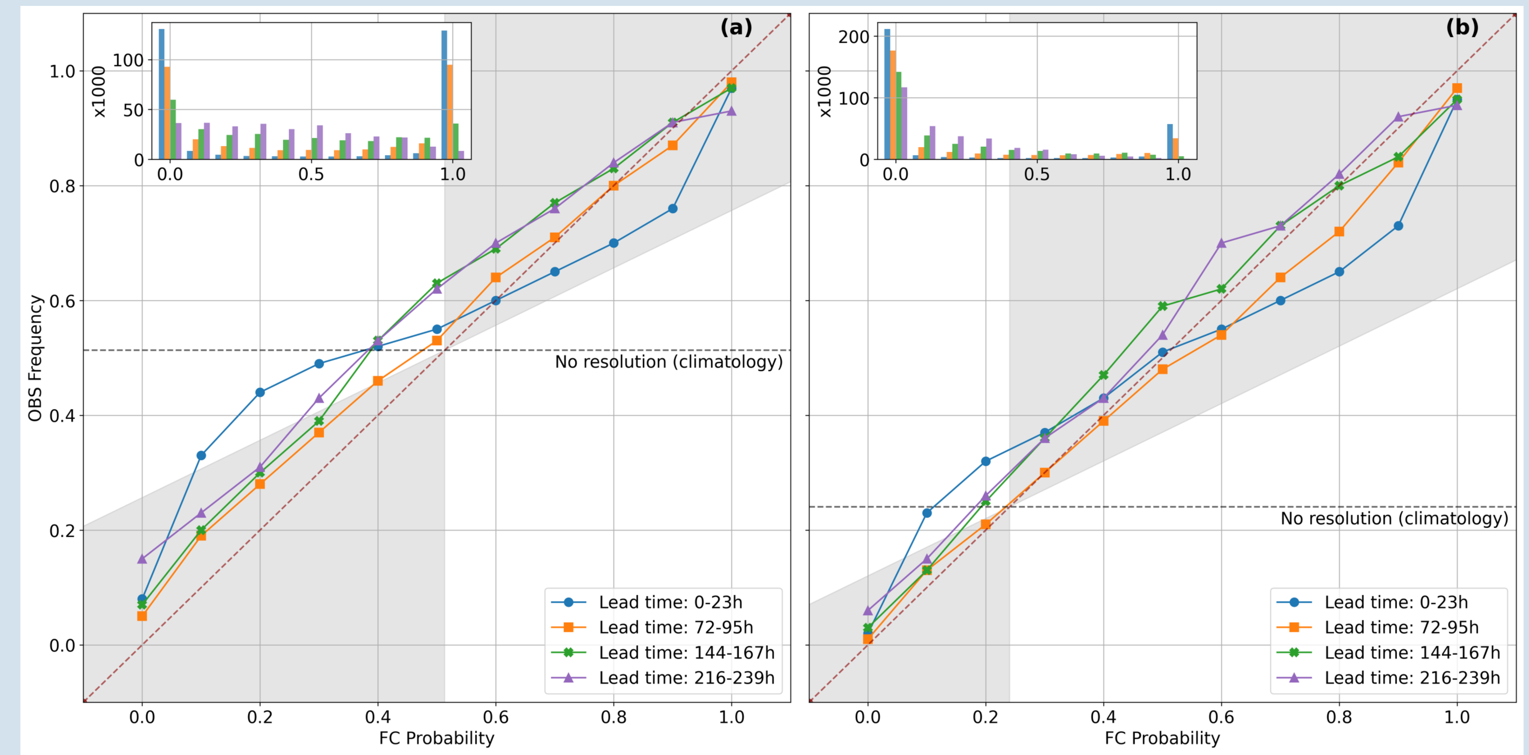

Figure 3: EXP5 reliability (attributes) diagrams of the Med-waves EPS for forecast probabilities of significant wave height exceeding the (a) 1.1m and (b) 1.8m thresholds. The supplementary histogram presents the population of forecasted values in each probability category, and denotes the sharpness of the forecast. The source of the observations is the satellite collocated dataset.

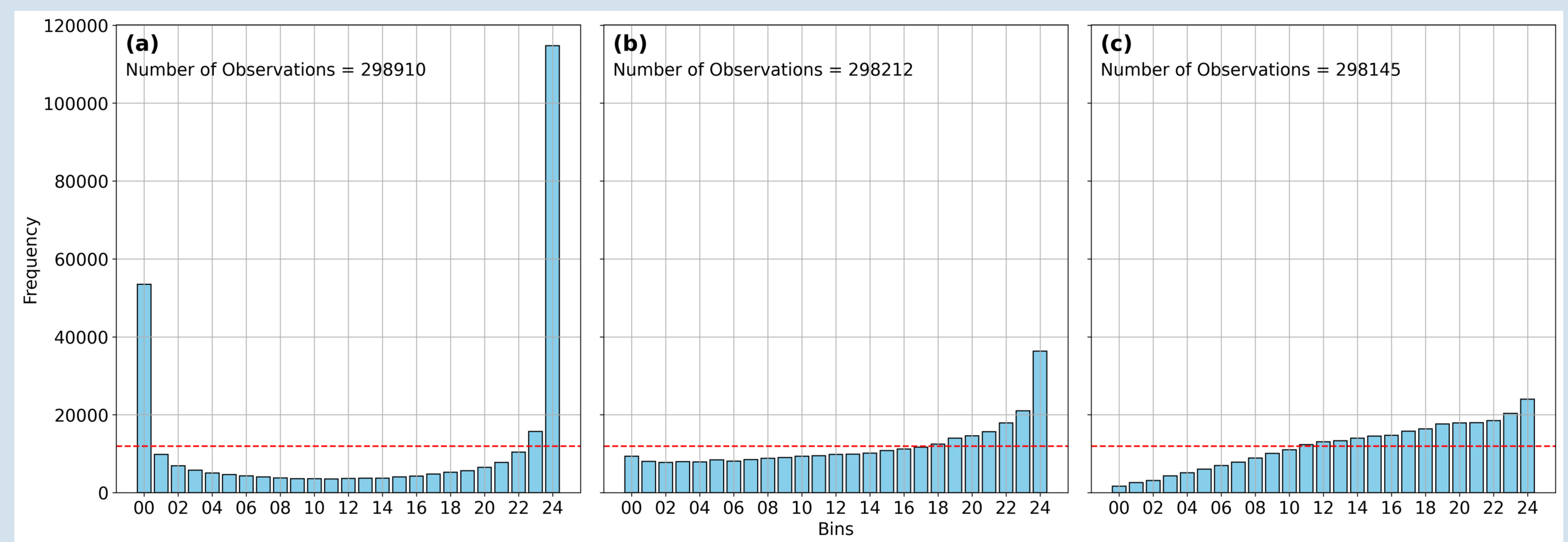

Figure 4: Rank Histograms (Talagrand Diagrams) for EXP5 of the Med-waves EPS for lead times: (a) 0-23h, (b) 96-119h and (c) 216-239h. The red dashed line, represents the perfectly equal distribution of the observations in all bins (flat histogram). The source of the observations is the satellite collocated dataset.

- During the first 24h of the forecast (Fig. 4a), in which the spread is at the lowest, many observations fall outside the lowest and highest SWH values predicted by the members of the ensemble.
- During day 5 (Fig. 4b), observations approach a nearly equal distribution among all bins (red dashed line), denoting that the ensemble nears an ideal spread.
- The "triangle" shape during day 10 (Fig. 4c) is an indication of the negative systematic bias of the ensemble.