2019 IMEKO TC-19 International Workshop on
Metrology for the Sea
Genoa, Italy, October 3-5, 2019

Evaluation of HF-radar wave measures in the Gulf of Naples

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Abstract –

HF-radar systems are commonly employed for detecting the upper sea currents. Nevertheless, the signal of such systems can be further post-processed for characterizing as well the wave characteristics, though this is a recent application whose reliability has not been yet exhaustively investigated. In this work, we evaluate HF-radar measures of significant wave height, wave mean period and incident direction against the outcomes of two numerical models previously validated. The comparison is developed in the Gulf of Naples (hereinafter GoN), taking advantage of three antennas placed in the locations of Castellamare di Stabia, Portici and Sorrento. First, a wave hindcast defined on a regional scale is employed; then, wave data are downscaled through a local model defined over a finer resolution (local scale). The agreement between the systems is evaluated through statistical error indexes. Results show good consistency, leaving room for deepening the use of radars for wave data collection.

I. INTRODUCTION

Radar systems are probably nowadays the most diffused devices for land-based remote sensing of surface currents. The chance to couple such informations with those of the wave characteristics provides a challenging opportunity to track the main physical processes occurring in coastal areas [1, 2, 3]. Actually, the main advantages of radar systems is that they can sample wide areas in real-time, while the other devices commonly employed cannot. As an instance, wave buoys, often taken as sea truth data, provide punctual informations, while sat data just periodically refer to a particular area, being conditioned to the track of the satellite. Nevertheless, just recently the reliability of HF radar wave measures has started to be tested, therefore this kind of application is still under development [4, 5].

On the other hands, numerical modelling of sea states is is becoming a very diffuse practice, both for hindcasting of historical data and the forecast of wave features in the short-term period. Among the available models, two of the most commonly employed are Wavewatch III (hencefort WWIII) [6], and SWAN [7].

The present study compare HF-radar wave measures with the outcomes of the aforementioned models in the GoN. In particular, WWIII provides information at a regional scale, while SWAN is used to propagate the waves up to the shallow waters by taking into account the particular morphology of the coastline. First, both the models are validated with a buoy moored just outside the GoN in front of the island of Capri. Then, numerical results are compared with the radar measures over a period spanning from January 2010 to December 2010.

The paper is structured as follows. Section ii. presents the devices and data taken into account. Section iii. shows the error indexes used to quantify the consistency between radar measures and model outputs. Results are then presented and discussed in Section iv.. Finally, in Section v. results are summarized and future developments are presented.

II. DATA & METHODS

A. *HF-radar network*

Radar measurements have been collected from a 25 MHz SeaSonde HF-radar system by the Department of Science and Technology at the "Parthenope" University of Naples. The network is used both for measuring of surface current [8, 9] and wave fields [10, 11], and is operating in the sites of Portici (PORT) and Massa Lubrense (SORR) from 2004, whereas the antenna of Castellamare di Stabia (CAST) was activated in 2008. The system recorded and averaged single wave spectra along 1 km spaced range cells (RCs) centred on the antenna. For each RC the averaged wave parameters (significant wave height, centroid period and direction, say H_s^{HF}, T_c^{HF}, θ^{HF} respectively) were outputted every 10 minutes. For the following analysis we referred to the RC 5km far from the antenna, removing spikes and spurious data and filtering the wave heights lower than 0.5m according to the recommendations of [11].

B. *Wave buoy*

The buoy used to validate the numerical model is a SEAWATCH Wavescan Buoy manufactured by Fugro OCEANOR, managed by the Campania Region Department of Civil Protection. It is placed in front of the island of Capri, close to the west boundary of the area of interest at a depth of 754 m (crd lon/lat 14.189/40.535) see Fig. 1). As Figure 1 shows, a direct comparison between the buoy and radar measures was not feasible, since the devices are placed in location too far to obtain reliable outcomes. The buoy collected wave data every thirty minutes from August 2009 to mid-December 2010, and from mid-March to November 2012, providing information on significant wave height (H_s^{BUOY}), mean period (T_m^{BUOY}), peak period (T_p^{BUOY}) and directions (θ^{BUOY}) Data of H_s^{BUOY}, T_m^{BUOY} and θ^{BUOY} were used for the calibration of the regional and local numerical models.

Fig. 1. Map of GoN (Southeastern Tyrrhenian Sea) with the locations of the three HF radar sites and the PC wave buoy.

C. *Numerical models*

The regional hindcast was developed by the Department of Civil, Chemical and Environmental Engineering of the University of Genoa (DICCA,www.dicca.unige.it/meteocean/hindcast), with the WWIII numerical model. The outputs are hourly defined in the 1979-2018 period, over a the nodes of a computational grid with a 10km resolution both in longitude and latitude [12, 13]. Such a coarse resolution is needed in order to resolve the whole Mediterranean wave climate with a reasonable computational effort, but it may not allow to get the waves data in the near-shore areas: therefore, in order to evaluate the wave features at all the HF-radar RCs, the SWAN model has been used to downscale the informations provided by WWIII, employing a finer computational grid with a approximately 200 m of resolution, using a bathymetry of the area provided by the Hydrographic Institute of the Italian Navy.

III. VALIDATION OF NUMERICAL MODELS

The following indexes have been employed in order to validate the numerical models against the buoy data, and further used to compare the model outcomes with the radar measures:

- $\rho = \frac{1}{N}\frac{\sum_i^N (S_i-\bar{S})(O_i-\bar{O})}{\sigma_O\sigma_S}$
- $NRMSE = \sqrt{\frac{\sum_i^N (S_i-O_i)^2}{\sum O_i^2}}$
- $slope = S/O$
- $NBIAS = \frac{\bar{S}-\bar{O}}{\bar{O}}$
- $SI = \sqrt{\frac{\sum_i^N \left[(S_i-\bar{S})-(O_i-\bar{O})\right]^2}{\sum_i^N O_i^2}}$
- $HH = \sqrt{\frac{\sum_i^N (S_i-O_i)^2}{\sum S_i O_i}}$

where S_i and O_i are simulated and observed data, respectively; σ stands for the data standard deviation, whereas the overstanding bar indicates the average. In case of circular quantities, such as the wave directions, the directional indexes have to be modified as follows:

- $NRMSE_\theta = \sqrt{\frac{\sum_i^N \left[mod_{-\pi,\pi}(\theta_{S_i}-\theta_{O_i})\right]^2/N}{2\pi}}$
- $NBIAS_\theta = \frac{\sum_i^N mod_{-\pi,\pi}(\theta_{S_i}-\theta_{O_i})}{2\pi N}$

where the modulus operator $mod_{-\pi,\pi}$ implies to subtract a 2π angle if $\Delta\theta_i > \pi$, on the other hand, if $\Delta\theta_i < \pi$ a 2π angle is added to the difference.

In case of consistent datasets, ρ and $slope$ should attain values close-to-1, whereas the other indexes should be close to 0.

IV. RESULTS

Comparisons of significant wave heights and mean incident direction computed with WWIII and the buoy are shown in Figure 3 and 4. The panels show as well the values of the indexes explained in Section iii.. A very good match between the data can be appreciated, and this applies also for the mean wave periods; results are a bit more scattered for the wave directions which can be anyway considered consistent since almost all the divergences rely within the [-45°;45°] range. The same considerations hold for the local analysis (figures are not attached in order not to weight the paper down).

Having validated the numerical models against the buoy data, it has been possible to use them in order to test the reliability of the radar measures.

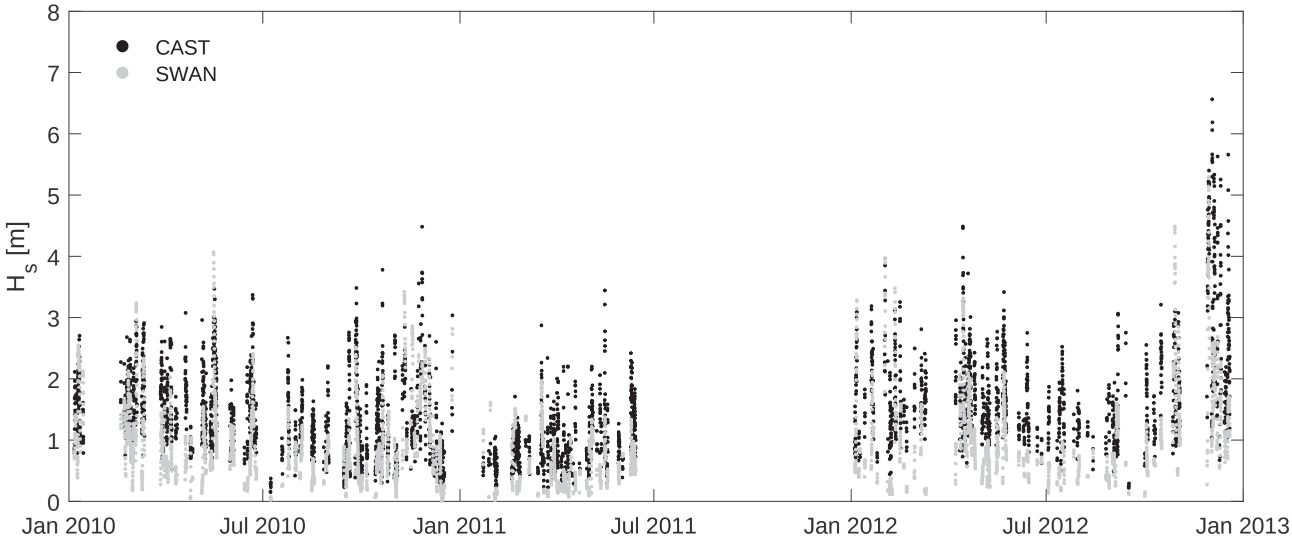

Fig. 2. Comparison of H_s series in Castellamare di Stabia.

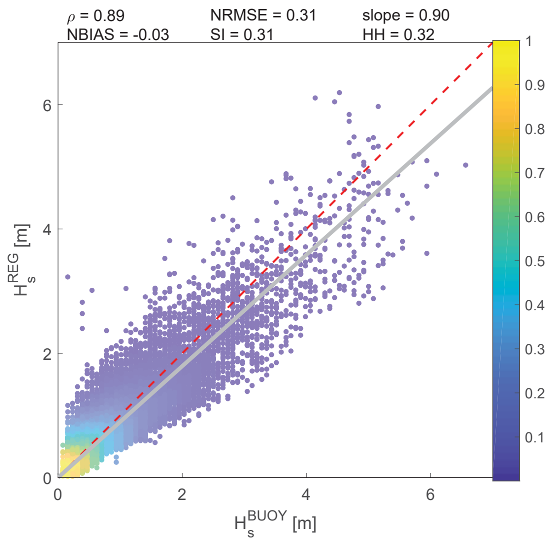

Fig. 3. H_s comparison between buoy data and regional model.

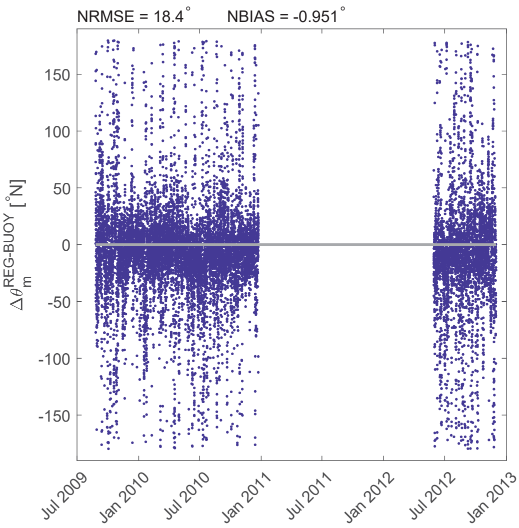

Fig. 4. θ_m comparison between buoy data and regional model.

Figure 2 shows an example of H_s series for the location of CAST computed with HF-radar (black dots) and SWAN (gray dots). Then, Table 1 summarizes the error indexes for all the locations and wave features. Then, Table 1 summarizes the error indexes due to the two models, for all the locations and wave features. Results reported in Table 1 show good consistency between the tested systems, and prove how HF-radars are able to provide reliable measures of H_s; similar results have been found also for the mean periods, whereas the analysis of wave directions requires again further investigations ($NRMSE_\theta$ and $NBIAS_\theta$ attain high values for the three locations under investigation).

The main divergences are most likely due to lower sea states, which are more difficult to be detected by the radar backscatter [14, 15]. Moreover, it is worth mentioning that the validation site of the numerical models is not affected by significant physical effects which may modify the wave characteristics (such as refraction and diffraction). On the contrary, the wave field behind the island of Capri may be more difficult to resolve, adding a source of uncertainty that should be therefore taken into account. Finally, it has to be pointed out that through the regional analysis it was not possible to carry out the wave characteristics in CAST due to the coarse resolution of the computational domain.

V. CONCLUSIONS

The results suggest the possibility to expand the wave monitoring network. However, it is necessary to implement new algorithms to broaden the range of wave parameters observed by HF radars and to improve the post-processing of their signals, especially as regards the incident wave directions.

Nevertheless, at the state of art, HF-radars may be already retained to retrieve wave information in coastal areas.

Table 1. Error indexes for H_s, T_m and θ_m, respectively

	PORT	CAST	SORR
ρ	0.73	-	0.65
$NRMSE$	0.31	-	0.83
$slope$	0.87	-	1.52
$NBIAS$	-0.05	-	0.72
SI	0.31	-	0.55
HH	0.34	-	0.67
ρ	0.64	-	0.53
$NRMSE$	0.29	-	0.36
$slope$	1.22	-	1.24
$NBIAS$	0.24	-	0.28
SI	0.17	-	0.23
HH	0.26	-	0.32
$NRMSE_\theta$	17.2	-	25.8
$NBIAS_\theta$	-3.7	-	5.15
ρ	0.74	0.60	0.71
$NRMSE$	0.38	0.59	0.70
$slope$	0.70	1.22	1.41
$NBIAS$	-0.22	0.38	0.60
SI	0.33	0.49	0.48
HH	0.45	0.54	0.59
ρ	0.65	0.75	0.57
$NRMSE$	0.24	0.18	0.33
$slope$	1.13	1.08	1.20
$NBIAS$	0.17	0.10	0.24
SI	0.18	0.14	0.23
HH	0.23	0.17	0.30
$NRMSE_\theta$	17.9	10.7	23.3
$NBIAS_\theta$	-5.26	3.52	5.05

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