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HNMS Marine Forecasts in Cases of Weather Warnings: Verification against Satellite Measurements †

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Abstract: The Hellenic National Meteorological Service (HNMS) issues marine weather bulletins for the Mediterranean and the Black Seas as part of the Global Maritime Distress and Safety System, with wind forecasts being of high importance. This study evaluates the accuracy of HNMS marine forecasts during Wind Warning (WW) events when weather warnings were also issued for Greece. The analysis focuses on events that occurred over the Ionian and the Aegean Seas from September 2019 to February 2023. Remote sensing data are used to objectively verify the forecasted wind speed and sea state. An evaluation of the accuracy of numerical weather prediction products against satellite data during the weather system 'Barbara' (February 2023), that was also a WW event, is included.

Keywords: marine warnings; Ionian and Aegean Seas; gale winds; significant wave height; ASCAT; altimeter data; ECMWF; ICON

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1. Introduction

Marine weather forecasting is crucial for ensuring the safety of seafarers and the effective management of marine resources. Countries with coastlines issue weather bulletins for shipping, which include forecasts and warnings for winds exceeding a specific threshold. These bulletins aim to provide concise descriptions of the anticipated conditions of wind, sea state, visibility and significant weather at every location within fixed geographical areas over a certain forecast period. Due to their broadcast through various means at specific time intervals, they need to be brief. These bulletins are currently produced by marine forecasters, but an automated system may be implemented in the future if it proves to be at least as accurate as the manual version after verification [1].

Greece, in particular the Hellenic National Meteorological Service, is responsible for issuing marine weather bulletins for the METAREA-3 (Mediterranean and Black Seas) within the framework of the Global Maritime Distress and Safety System under the auspices of the International Convention for Safety Of Life At Sea. These bulletins namely are: Meteorological Warnings for anticipated winds $\geq$ 8 Beaufort (Bf) and Forecasts; HNMS forecasters prepare the relevant forecasts for 36 sub-regions times per day. The Hellenic Coastguard Legislation categorizes all passenger vessels into categories according to their length; Port Authorities suspend voyages for each category with respect to forecasted wind force. Voyages for all ships are suspended when forecasted wind force exceeds 8 Bf. Therefore, it's obvious that the forecasted wind is of highest importance and a big challenge for HNMS forecasters.

Verification against satellite measurements is a paramount aspect of meteorological research and forecasting, particularly for extreme events. Remote sensing has enabled wide field high accuracy data collection that is employed in verification techniques [2,3] as well as in nowcasting processes. In addition, according to the World Meteorological Organization, National Meteorological Services must be aware of their performance [4]. Verifications of hand written forecasts and numerical models focusing on cases of extreme events are scarce but of the highest significance for the forecasters.

This study attempts to objectively evaluate marine warnings and forecasts issued for the Hellenic Seas (Figure 1) for the period September 2019 to February 2023. It refers to challenging meteorological cases of Wind Warning (WW) events when a weather warning for Greece was also issued. The verification is performed based on remote sensing products derived from scatterometry and altimetry, takes into account only the cases of forecasted winds exceeding 8 Bf and refers to wind speed and sea state (significant wave height SWH). The weather system 'Barbara' (February 2023) that induced winds of 9 Bf and very rough seas is also examined as a WW event, including a verification of the operationally available numerical weather products. The results of this study provide insights for future improvements in marine weather forecasting; the method and the results are currently being examined for possible improvements related to forecasters' needs and for automation.

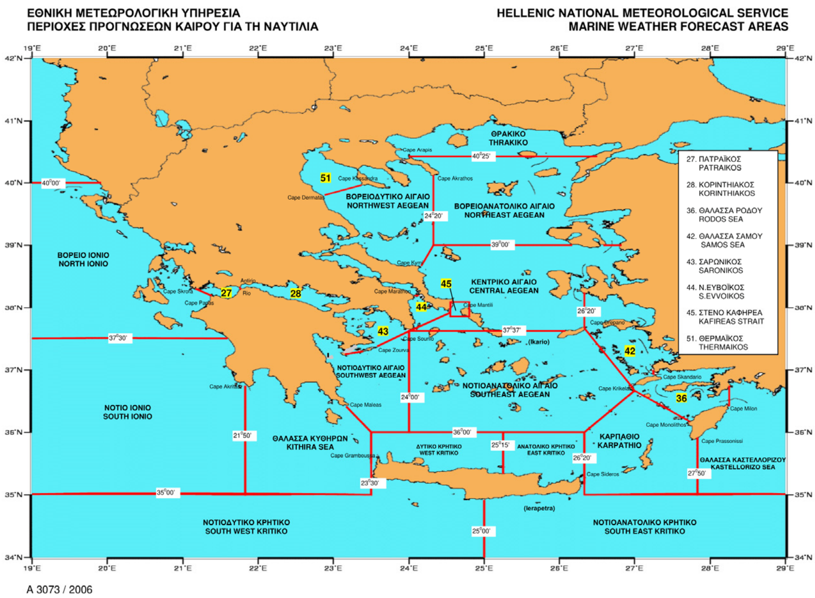

Figure 1. The study area where the 17 sub-regions of verification are shown.

2. Data and Methodology

The verification of HMNS marine warnings and forecasts in respect to wind speed and sea state (SWH) was conducted for the period September 2019–February 2023, including the WW event of 5–7 February 2023 'Barbara' (Figure 2). For the latter, the performance of the numerical weather products for wind and SWH available to the forecasters at HNMS Forecasting Center was also evaluated. The area of evaluation was the 'Hellenic Seas' as shown in Figure 1. Specifically, 17 out of the 23 sub-regions of forecast were checked (Saronikos, Korinthiakos, Partaikos and Thermaikos gulfs plus South Evvoikos and Kafireas straight were excluded). During the study period, 57 WW events were registered that referred to 81 days. Each sub-region forecast for a time period ≤ 6 h that coincided with the availability of relevant satellite data was considered 'a case'. Forecasted winds ≥ 8 Bf and SWH ≥ 2.5 m were only considered.

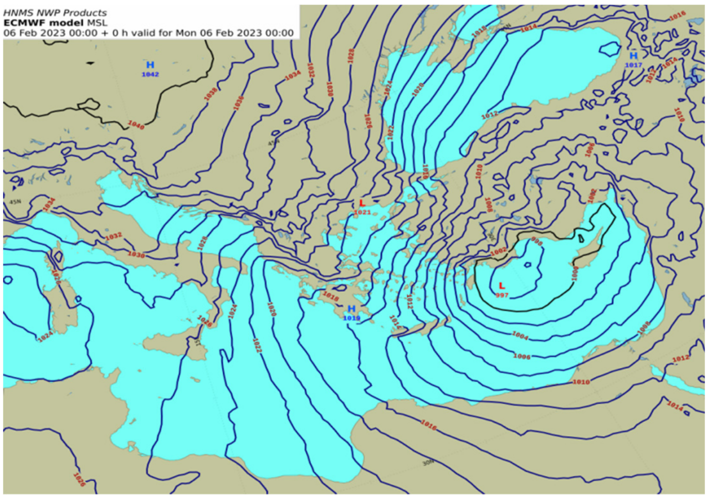

Figure 2. A snapshot of the barometric system 'Barbara' according to ECMWF analysis.

The satellite data used for the evaluation of the marine forecasts and warnings were acquired through the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) data center. Satellite scatterometer winds are deemed the most appropriate for the validation of numerical products due to their extensive spatial and temporal availability; here, they were also used for validating the forecasters' performance. In particular, the ASCAT (Advanced Scatterometer) wind measurements obtained from the METOP-A (until November 2021), METOP-B (for the entire study period) and METOP-C (starting from February 2019) satellites were utilized for the wind speed verification process. These data are currently available at a resolution of 12.5 km and their accuracy is approximately 1 m/s or better. Altimetry data from the satellites S3A, Altika and Jason-3 with a spatial resolution of 0.3–2 km and a vertical accuracy of about 3.5 cm were used to evaluate the sea state (SWH) forecasts. It is a well-established fact that the verification outcomes are heavily influenced by the observational data used in each case and satellite scatterometer and altimeter data are considered of the most suitable. The only disadvantage of all the above satellite observations is that they refer to an instantaneous measurement, while HNMS warnings and forecasts refer to a time period (usually 6 h).

The numerical weather products for wind and SWH, of which the performance was also evaluated for the WW event 'Barbara', come from: the European Centre for Medium-Range Weather Forecasts Integrated Forecasting System (ECMWF IFS) at the high resolution of 9 km and the regional model ICON (ICOsahedral Nonhydrostatic) at 2.5 km resolution.

The main part of this study was the extraction of the satellite wind speed and wave height data and pairing the forecasted (or numerical model) values with observations. The process involved cataloguing the date and time of the issued warnings and forecasts, their duration and the forecasted wind and sea state for each of the 17 sub-regions. The availability of scatterometer wind and altimeter SWH measurements was verified and listed, including the date-time of the remote sensing observation and the maximum wind force and SWH recorded for each sub-region; this process involved using Python code. By matching date, time and sub-region, 591 forecast cases for wind and 477 for SWH were identified during the study period September 2019–February 2023.

The forecasted wind force was expressed as a decimal number when 2 Bf scale levels were involved (9 to 10 Bf was registered as 9.5 Bf). The sea state was categorized from 0 to 6 according to the Douglas scale (smooth = 0 to very high = 6), with each number representing a specific range of SWH. The latest issued warnings and forecasts were utilized.

The verification approach was straightforward: the difference between satellite wind measurements and the corresponding forecasted values (Forecast-Observation) was used to evaluate the forecast quality. This was accomplished by classifying the results into three categories (successful, less successful and not successful) based on Tables 1 and 2. At the end, the total percentage of every single category was computed. It is worth noting that a difference of −1 Bf was deemed not successful, as not predicting higher winds could pose a safety risk. The wide range of wind forecasts classified as less successful was designed to balance the instantaneous nature of satellite data with the time interval of a forecast, ensuring fairness for the forecaster in the verification process.

Table 1. Grades of wind forecast quality.

Wind Difference (Bf) Forecast-Observation	Forecast Quality
From −0.5 to 0.5	Successful
1 or 1.5	Less successful
Other value	Unsuccessful

Table 2. Grades of sea state forecast quality.

Sea State Difference Forecast-Observation	Forecast Quality
0	Successful
1	Less successful
Other value	Unsuccessful

In the case of the weather system 'Barbara', the same method was applied for testing the performance of the relevant numerical model data of the latest run available to the forecasters. The closest forecast time step coinciding better with the satellite measurements was taken into account.

3. Results and Discussion

The data analysis of the whole study period showed for the forecasted wind speed a very high percentage of successful forecasts and a percentage below 2.5% for the not successful ones. It should be noted that one not successful forecast refers to one sub-region for a time period ≤ 6 h. Since ship voyages in Greece are suspended only according to the forecasted wind, there are cases of high waves after the winds' attenuation where the forecasters extend the wind warnings based on the anticipated sea state. For the case study of the 'Barbara' event, the hand written forecasts were successful by 92.5% and the not successful ones were about 3%. The successful numerical models' forecasts ranged from 73.2% for ECMWF at 1000 hPa and 69.1% for ICON at 10 m to 60% for ECMWF at 10 m. The not successful ones were 7% for ICON at 10 m, 17% for ECMWF at 1000 hPa and 39% for ECMWF at 10 m (Table 3). It is noted that surface pressure during the event was close to 1000 hPa.

Table 3. Summarizing the results of the various numerical models regarding the wind speed.

Forecast Numerical Model	Percentage of Successful Wind Forecasts	Percentage of Unsuccessful Wind Forecasts
ECMWF at 1000 hPa	73.2%	17%
ECMWF at 10 m	60%	39%
ICON at 10 m	69.1%	7%

For the whole verification period, HNMS marine forecasters presented high skill in describing the expected wind conditions at sea during WW events; they also performed better than numerical models in the case of the weather system 'Barbara'. The models lower than the human performance observed during 'Barbara' is anticipated by the forecasters. In cases of extreme events and strong depressions, models are expected to deviate; in addition, for stronger winds model biases increase and the ageostrophic wind departure should be taken into account. In such rare cases, the true state is better represented by higher level winds and an approach could be a 5–10% increase of the 10 m winds [5]. The above highlight the necessity for the continuous improvement of numerical forecasting models. On the other hand, an operational forecaster can combine numerical products, adjust forecasts based on real-time data when model deviations are observed and perform better than models.

Regarding the sea state, the results for the whole study period showed a relatively lower percentage of successful hand written forecasts compared to the considerably high percentage of successful wind forecasts. HNMS marine forecasters have already been informed about these deviations and corrective actions have been taken. During 'Barbara', forecasters and numerical products (ECMWF and ICON) performed almost equally.

4. Conclusions

For a marine forecaster, it is crucial to accurately predict both the wind and the sea state. Relevant verifications provide useful information for the performance of both forecasters and numerical models that are essential for their improvement. The conducted verification revealed that HNMS marine forecasts exhibit a high success rate. In cases of WW events, there are evidences that, at least till now and as far as the wind is concerned, forecasters do better than models, highlighting the indispensable role of human intervention and expertise.

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