Marine Heatwaves in the Mediterranean Sea: A Convolutional Neural Network study for extreme event prediction

Response to Reviewers

We thank the reviewers for their thoughtful and constructive feedback. Below, we provide detailed responses to their final comments, highlighted in blue, while retaining the reviewers' original text in black for reference. The line numbers mentioned correspond to the revised manuscript (clean version, without track changes)

Editor comments:

Line 53, abbreviation “DL” should not be used, because it is used only 3 time in the manuscript.

Thank you for this suggestion. We have now changed it to "Deep Learning" throughout.

Line 164, it seems that local winds have not been considered as an input variable. This may partially account for the relatively poor ML model performance in the coastal ocean areas, such as the Aegean Sea and the Adriatic Sea. It is mentioned later in the paper that air temperature has been tested as an input variable, but not much improvement in MHW forecast. Have you tested winds as an input?

Thank you for raising this point. Following a correlation analysis of SST and mixed layer heat budget terms (not shown), we adopted an approach similar to Sun et al. (2023) selecting a minimal set of SST-correlated variables to maintain strong predictive performance and enhance replicability. Wind data was not included in the training phase. We now acknowledge its potential value for future work in lines (547-556). However, we would like to note here, that Bonino et al. (2023) found SST to have a week dependence on wind speed in a similar study for the Mediterranean Sea, demonstrating that the amount of information that can be gained from one variable by observing the other is low. We now discuss these, in added lines (545-557), that read:

“This is also observed in Bonino et al. (2023a), where the authors also report a reduced forecast ability of their neural network model around the Adriatic Sea, Balearic islands, the Alboran and Aegean Sea. Given that ocean circulation along the coast is primarily driven by local winds and can be influenced by offshore currents near complex topographic features, the exclusion of winds as an input dataset may have further reduced the forecast accuracy of our ML model in shallow coastal areas, where SST variations become more complicated (Berthou et al., 2024; Liu et al., 2025). However, Bonino et al. (2023a) found a weak dependence of the SST on wind speed across all the Mediterranean sub-basins they considered, by calculating the Mutual Information index prior to applying the ML method. While incorporating atmospheric variables into the training process could thus potentially enhance the model's ability to capture broader climatic influences on MHW occurrence, ultimately, we selected a limited set of training variables, in order to enhance the model's simplicity and replicability across both the training and prediction phases, following Sun et al. (2023).”

Line 220, should “NN” be ‘CNN” o r a new acronym?

It was implied to be the neural network from the CNN acronym, because the overfitting that is commented is a challenge in general in neural networks. It is amended for readers’ clarity and spelled out entirely.

Line 559 – 569, another possible reason could be the excluding of winds as an input the ML model. This is because coastal ocean circulation is mostly driven by local winds. Also, ocean circulation may be influenced by offshore currents forcing at the locations of complicated topographic features. These may not be properly represented in the ML model. Thus, temperature changes (and MHW changes) become more complicated in shallow coastal oceans (e.g., Berthou et al., 2024; Liu et al., 2025). It would be good to include these in the discussion.

References:

Berthou, S., Renshaw, R., Smyth, T., Tinker, J., Grist, J. P., Wihsgott, J. U., et al.: Exceptional atmospheric conditions in June 2023 generated a northwest European marine heatwave which contributed to breaking land temperature records, *Communications Earth & Environment*, 5(1), 287. https://doi.org/10.1038/s43247-024-01413-8, 2024.

Liu, Y., Weisberg, R.H., Sorinas, L., Law, J.A., Nickerson, A.K.: Rapid intensification of Hurricane Ian in relation to anomalously warm subsurface water on the wide continental shelf, *Geophysical Research Letters*, 52, e2024GL113192, https://doi.org/10.1029/2024GL113192, 2025.

We appreciate the Editor's suggestion on the potential impact of excluding wind as an input variable. Indeed, coastal ocean circulation is predominantly driven by local winds and offshore currents may influence circulation at locations with complex topographic features. We now acknowledge that these dynamics may not be fully captured by our model, potentially contributing to discrepancies in coastal regions such as the Aegean and Adriatic Seas. While our study followed an approach similar to Sun et al. (2023), where the number of input variables was kept minimal for model efficiency and replicability, we acknowledge that incorporating wind data could be investigated as part of a future research work. Although the study of Bonino et al. (2023) has shown that SST exhibits a low dependence on wind speed. Added discussion can be found in lines (545-557), that read:

"This is also observed in Bonino et al. (2023a), where the authors also report a reduced forecast ability of their neural network model around the Adriatic Sea, Balearic islands, the Alboran and Aegean Sea. Given that ocean circulation along the coast is primarily driven by local winds and can be influenced by offshore currents near complex topographic features, the exclusion of winds as an input dataset may have further reduced the forecast accuracy of our ML model in shallow coastal areas, where SST variations become more complicated (Berthou et al., 2024; Liu et al., 2025). However, Bonino et al. (2023a) found a low correlation between the wind speed and SST in all the Mediterranean sub-basins they considered. To do that, prior to the ML method, the authors calculated the Mutual Information index using SST and several variables of interest, indicating that the amount of information that can be gained from one variable by observing the other is low. While incorporating atmospheric variables into the training process could thus potentially enhance the model's ability to capture broader climatic influences on MHW occurrence, ultimately, we selected a limited set of training variables, in order to enhance the model's simplicity and replicability across both the training and prediction phases, following Sun et al. (2023). "

References:

Bonino, G., Galimberti, G., Masina, S., McAdam, R., and Clementi, E.: Machine learning methods to predict Sea Surface Temperature and Marine Heatwave occurrence: a case study of the Mediterranean Sea, EGUsphere, 2023, 1-22, 10.5194/egusphere-2023-1847, 2023.

Sun, W., Zhou, S., Yang, J., Gao, X., Ji, J., and Dong, C.: Artificial Intelligence Forecasting of Marine Heatwaves in the South China Sea Using a Combined U-Net and ConvLSTM System, 15, 4068, 2023.