Project: **1541**

Project title: **Oceanic Extremes in the North Sea and European Northwest Shelf (OXtreme-NWS)**

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Report period: **2025-11-01 to 2026-10-31**

1. Wave Modelling in the European Northwest Shelf (NWS)

We have successfully conducted wave modelling of the European Northwest Shelf for the period from 1980 to 2025, using the WAM (NWS-WAM) model. This model incorporates several significant physical processes, including wave-current interaction and data assimilation. It also uses accurate wave spectra at the open boundaries from the North Atlantic (NA-WAM) model. High-resolution bathymetry was obtained from the EMODnet dataset. The wave model is driven by reanalysis winds (ERA5) from the ECMWF. All available radar altimeter measurements from the CFOSAT, CryoSat-2, Envisat, Jason-1, Jason-2, Jason-3, Saral/AltiKa, HaiYang-2B, HaiYang-2C, Sentinel-3A, Sentinel-3B and Sentinel-6A missions have been assimilated for the NWS-WAM model.

The NWS-WAM model has been validated against satellite and buoy observations. Figure 1 shows the scatter plots of significant wave height (VHM0) obtained from NWS-WAM model compared to all observations from all satellites and buoys covering the full simulation period 1980-2025 and across all the NWS regions. We employed several statistical indices and skill metrics to evaluate the model performance, including bias, root-mean-square-difference (RMSD), scatter index (SI), Hanna-Heinold index (HH), skill score (SKILL), and correlation coefficient (CORR). The validation shows that the NWS-WAM model reproduced very well observations. Using satellite data assimilation, bias and RMSD are relatively small, approximately 6.57 cm and 17.70 cm, respectively. SI and HH indices are minor while SKILL and CORR are almost perfect, particularly for CORR. For buoy data, the observations are independent and not used for assimilation, resulting in slightly higher bias, RMSD, SI, HH, and lower SKILL and CORR compared to the validation results against satellite data. However, this validation indicates that NWS-WAM model produced accurate wave parameter in the NWS. We are continuing to analyse the model output in order to investigate extreme events in the NWS region.

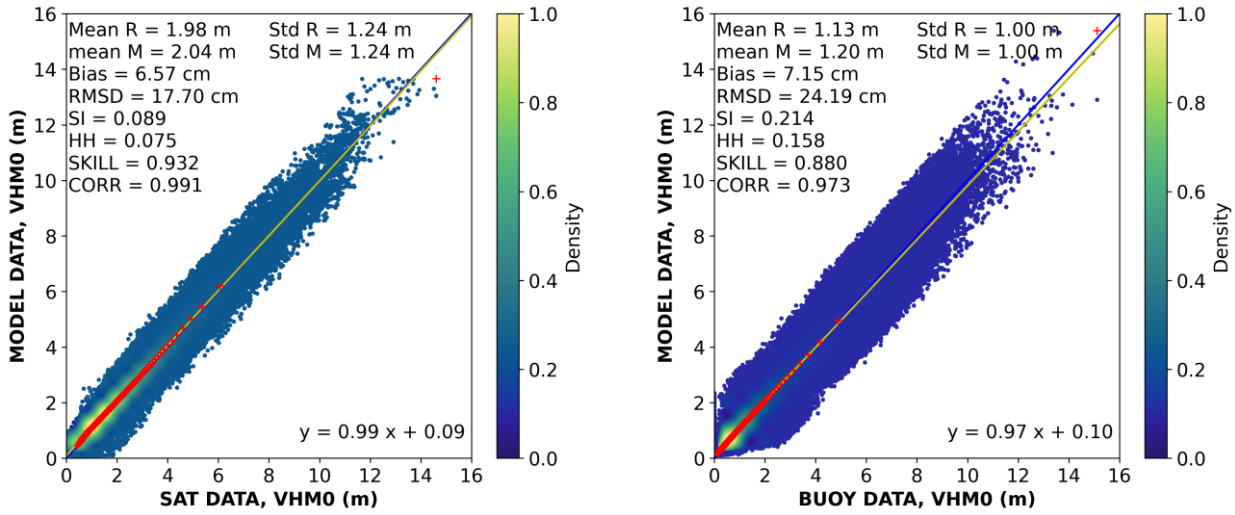


Fig. 1. Scatter plots of VHM0 of all available satillites and wave buoys vs. model covering the full simulation period 1980-2025. Also shown are the estimated bivariate probability density (colours), the least squares linear fit of modelled vs observed wave heights (yellow line), specific quantiles taken from the empirical cumulative density function (red crosses), and the 45° diagonal (blue line). Summary statistics and skill scores are included. R: reference (sattellite/buoy) data, M: model data.

2. Coastal Hydrodynamics in the North Sea

We also run experiments on coastal hydrodynamics in the North Sea for several years using the coupled WAM-NEMO models. The model is forced by the atmospheric conditions by the reanalysis ERA5. At the open boundaries, the temperature and salinity from AMM15, the tidal elevation derived from TPXOv8, and wave spectra from NA-WAM model are employed. In addition, daily freshwater discharge data from the Mesoscale Hydrologic Model are used.

Figure 2 shows the comparison between anomalies of sea surface temperature (SST) averaged over two years 2011 and 2018 obtained from uncoupled model (only NEMO, EXP0), coupled model (WAM-NEMO, EXP1) and satellite observations. The reference is the mean SST calculated based on 43-year data from the Copernicus Marine Service. Overall, the anomalies from the coupled model are higher than those from the uncouple model in the southern North Sea. The obtained computed results are slightly overestimated observations

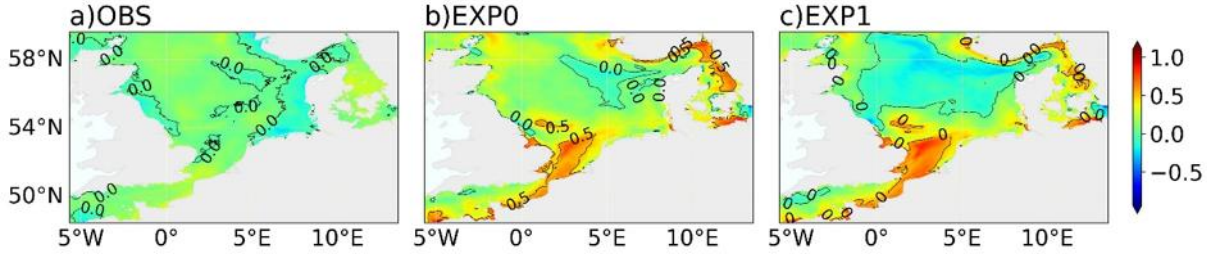


Fig. 2. Map of SST anomalies averaged over two years 2011 and 2018 for the North Sea: (a) observations, (b) NEMO only model, and (c) WAM - NEMO coupled model.

We are currently evaluating the model performance, detecting the marine heatwave characteristics, and investigating the development of brown shrimp and their distribution in the southern North Sea.

3. Application of 4DVarNet deep learning to sea level in the North Sea

We used one-year sea surface height (SSH) data from the NS-NEMO-WAM model in 2018 to train the 4DVarNet model. We then tested the model's ability to reconstruct SSH in 2016. Figure 3 shows a map of the Observing System Simulation Experiments (OSSE) on 15 November 2016, using synthetic data to learn system dynamics, alongside the original NS-NEMO-WAM data and the reconstructed data. The 4DVarNet model reproduced well the SSH from the OSSE, and the discrepancies between the reconstruction and original data are minor.

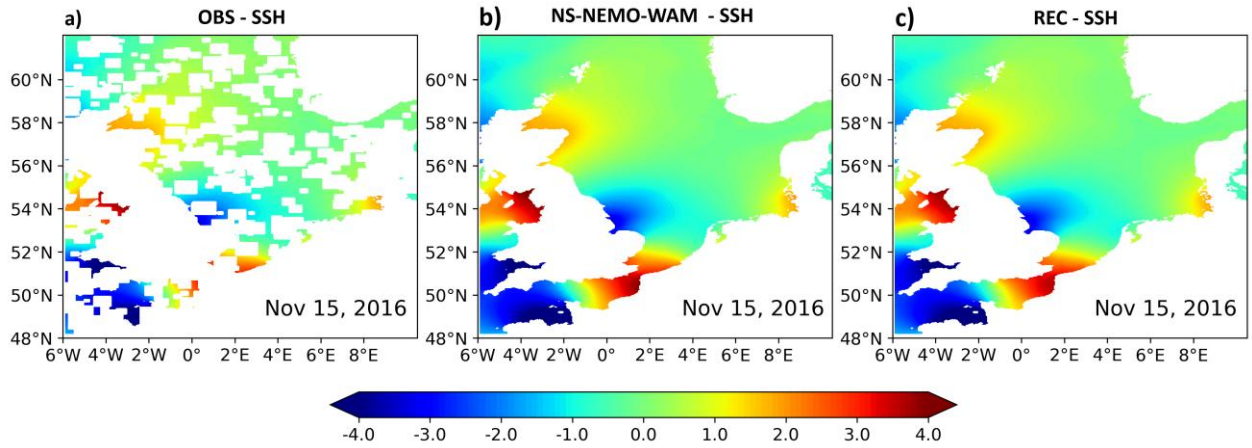


Fig.3. Artificial observations of SSH from OSSE (a), NS-NEMO-WAM-SSH (b), and reconstructed SSH by 4DVarNet (c).

In addition, we used computational resources from the project bg1541 to run experiments on the sediment plume in the Black Sea following the breach of the Kakhovka dam. These significant results have recently been published in the Marine Pollution Bulletin, doi: 10.1016/j.marpolbul.2026.120439.

We are continuing to work on the wave climate in the NWS, coastal hydrodynamics in the NS with a focus on extreme events. We will publish significant results in high-impact factor journals in the near future.