Supplement material

This supplementary material to the main paper is designed to help users who want to configure their systems following the Met Office global (GS512L4EUK) and regionals (AMM15SL2) wave systems framework. Interested researchers are strongly encouraged to contact the corresponding author who will be able to provide access to a mirror of the trialling rose suites (described in Table S4) via external repository.

WAVEWATCH III model compilation switches and configuration namelist

The variance of the sea surface for irregular wind waves can be described through the two-dimensional- variance density spectra $F(k,\theta)$ that is a function of the wavenumber k and the direction θ. Furthermore, wave propagation is described by

$$\frac{DN(k,\theta)}{Dt} = \frac{S(k,\theta)}{\sigma} \quad (1)$$

where D/Dt is the total derivative, $N(k,\theta)$ is the model wave action density spectrum or native WWIII wavenumber-direction spectrum ($\equiv F(k,\theta)/\sigma$), $S(k,\theta)$ represents the net effect of sources and sinks for the spectrum $F(k,\theta)$, and σ is the intrinsic (radian) frequency. The total source term S can be defined as the combination of different physical processes that in deep water can be simplified to the wind--wave interaction term S_{in}, a nonlinear wave---wave interaction term S_{nl} and a dissipation term S_{ds}. Additionally, a linear input term for initial wave growth S_{ln} and the additional processes for shallow water (wave--bottom interactions S_{bot} and depth-induced breaking S_{db}) are included:

$$S = S_{in} + S_{nl} + S_{ds} + S_{ln} + S_{bot} + S_{db} \quad (2)$$

Table A1 include the compilation switches used in all the Met Office operational wave systems. S_{in} and S_{ds} use the Ardhuin et al. (2010) (ST4 package) to parameterize wind–wave interaction, whitecapping dissipation and swell dissipation. This includes minor tuning adjustments for compatibility with Met Office wind forecast data (refer to Table A2). An important tuning parameter is BETAMAX, which provides an overall control on the input wind stress. This was revised to 1.39 in PS45 for compatibility with Met Office Global Unified Model wind data and implemented commonly across both global and regional wave models. The wave model also uses the surf breaking parameterisation (S_{db}) proposed by Battjes and Janssen (1978) and JONSWAP bottom friction formulation (S_{bot}; Hasselmann et al., 1973) to represent shallow water wave energy dissipation. Nonlinear wave–wave interactions (S_{nl}) are resolved using the Discrete Interaction Approximation (DIA) package (Hasselmann et al., 1985). Conversion from wind speed to momentum stress flux computations are included in the source term (FLX0 switch). Additionally, a switch with linear wave growth (LN1; Cavaleri and Rizzoli, 1981) for lower winds is also implemented (S_{ln}).

Table S1. Summary of WAVEWATCH III compilation switches used in the MO operational modelling systems.

Switch	Comment
ST4	Ardhuin et al. (2010) source term package for wave growth and dissipation
FLX0	No routine used for flux computation; computation included in source terms
LN1	Linear wave growth for low wind speeds as per Cavaleri and Rizzoli (1981)
NL1	Discrete interaction approximation (DIA; Hasselmann et al., 1985)
BT1	JONSWAP bottom friction formulation (Hasselmann et al., 1973)
DB1	Depth-induced breaking of as per Battjes and Janssen (1978)
TR0	No triad interactions used
BS0	No bottom scattering used
IC0	No damping by sea ice
IS0	No scattering by sea ice
REF0	No reflection
WNT1	Linear interpolation of wind over time
WNX1	Approximately linear speed interpolation of wind over space
RWND	Correct wind speed for current velocity
CRT1	Linear interpolation of current over time
CRX1	Approximately linear speed interpolation of current over space
RTD	Rotated grid option
SMC	Activate SMC grid
NOGRB	No GRIB package included
SHRD	Shared memory model
PR2	Higher-order schemes dispersion correction with the classical GSE alleviation method (Booij and Holthuijsen, 1987)
UNO	Second-order (UNO) propagation scheme
CRT0*	No interpolation of current over time. Should substitute CRT1 switch.
COU*	Activates the calculation of variables required for coupling
OASIS*	Initializes OASIS Coupler
OASOCM*	OASIS oceanic model coupling fields

*Extra switches for AMM15 ocean-wave coupled.

WAVEWATCH III model configuration namelist

Table S2. Source code values relevant for the MO global and regional configurations (ST4 and SDB1 switches). Non default values are highlighted in bold.

Switch	Variable in code	GS512L4EUK	AS512L4EUK	AMM15SL2	AMM15 coupled
ST4	BETAMAX	**1.39**	**1.39**	**1.39**	**1.48**
ST4	TAUWSHELTER	0.3	0.3	0.3	0.3
ST4	SWELLF	0.66	0.66	0.66	0.66
ST4	SWELLF3	0.022	0.022	0.022	0.022
ST4	SWELLF4	1.5E5	1.5E5	1.5E5	1.5E5
ST4	SWELLF7	360000	360000	360000	360000
SDB1	BJALFA	1.0	1.0	1.0	1.0

Code adaptations

Table S3 summarizes the relevant branches in order to build the Met Office wave operational systems with WAVEWATCH III version 7.12. This version also includes all the code adaptations implemented for inclusion within the Met Office coupled systems (Lewis et al., 2019). All the repositories including suites and configuration files used in the trials is presented in Table S4.

Table S3. Summary of the GitHub branches used by the Met Office wave operational systems.

	Code	Branch name
WAVEWATCH III version 7.12 repository	https://github.com/NOAA-EMC/WW3.git	develop
WAVEWATCH III Met Office configuration	https://github.com/ukmo-waves/WW3.git	ukmo_ps45-1.hotfixes

Suite repositories

Table S4. Summary of the FCM repositories used by the Met Office wave operational systems.

	FCM repository URL
Analysis suite	svn://fcm1/roses_mi_svn/a/z/9/0/8/ST4FLX0@155130 (Last access: 01 July 2022)
Forecast suite	svn://fcm1/roses_mi_svn/b/c/6/1/5/trunk@155253 (Last access: 01 July 2022)
WW3 grid and configuration files	svn://fcm3/WW3_svn/WW3CONFIG/trunk@2839 (Last access: 06 October 2022)

Description on the observational datasets for wave models evaluation

The global in-situ measurements JCOMM-WFVS for open waters include floating buoys and fixed marine platforms which measure H_s, T_{02}, U_{10} and U_{10} dir. Over 400 measurement sites are registered in the system, although these are predominantly based in the northern hemisphere and within several hundred kilometres of the coasts of North America and Europe. Observations are sampled on a 6-hourly basis (temporal sample of 12 hours from January 2020) and quality controlled each month under the World Meteorological Organisation - International Oceanographic Commission (WMO-IOC) JCOMM's operational Wave Forecast Verification Scheme (Bidlot et al., 2007). Data is averaged over a 4-hour period (+/-2 hours) around the validity time as explained by Bidlot and Holt (2006). This can be directly compared to the standard observation scale that represents a 20–30-minute sample of the wave field at the location.

Daily Ship Synop Observations SHPYNS include H_s, T_{02}, U_{10} and U_{10} dir from around 110 in-situ locations across the NW shelf (approx. 46N-63N, 19W-8E). These comprise data from a variety of buoys, lightvessels and fixed platforms. In-situ observations are available to the Met Office from the Global Telecommunications System (GTS). These are sampled on an hourly basis, collated and quality controlled, and no time-averaging is performed due to the potential high frequency variability introduced by tidal effects. Little or no metadata are available to confirm certain aspects of the data such as platform type or height of the measured wind which might affect the quality of the dataset. Hence, model comparison against this dataset is always complemented with the other observational datasets.

WAVENET dataset is comprised by wave measurements taken by Waverider buoys at coastal waters. Measurements of wave statistics include H_s, T_{02} and Dir among others. These measurements are sourced from a number of UK coastal observatory programs, in particular the National Network of Regional Coastal Monitoring Programmes (https://coastalmonitoring.org/) and the Cefas Wavenet (https://www.cefas.co.uk/cefas-data-hub/wavenet/) network of buoys. Observations used in the model evaluation are sampled on an hourly basis with no time-averaging performed in order to be able to capture the potential high frequency variability introduced by tidal effects. Whilst this ensures that the observed data are not aliased and that tidal signals are not removed, some degradation of the resulting averaged metrics such as periods might be expected as this will exacerbate the double penalty effect.

MA_SUP03 global dataset include wave bulk parameters extracted from the sea state CCi L3 product (Piolle et al., 2020) and wind speed across open waters taken from satellite altimeter missions with scatterometers. Satellite observations cover mostly up to a max 81.5° latitude, with best coverage up to 66° latitude. This dataset includes edited merged daily products retaining only quality-checked measurements from all altimeters over one day (one daily file), with simplified content (only a few key wave parameters) from the JASON-2, CryoSat and SARAL-AltiKa missions. Standard 1 Hz altimeter observations of H_s are subject to a high degree of sampling noise. At 1 Hz the altimeter 'looks' over a smaller sample of individual waves than would be measured by the in-situ sensors. Therefore, satellite altimeter data are 'super-observed' to a 3 Hz sample in order to smooth the observations and achieve a representative sampling scale closer to that of the in-situ data. In addition, prior to super-observation, two quality control measures recommended by Meteo France are used to remove small measured significant wave heights (less than 0.1 m) and measurements where the 1 Hz sample standard deviation is large (greater than approximately 1.25 m). Refer to Piolle et al. (2020) for detailed information.

Metrics and wave parameters for model evaluation

Simulated values x of wave and wind bulk parameters are compared against observations x_o in order to provide standard metrics for model evaluation. Basic metrics include $bias = n^{-1}\sum(x - x_o)$; root mean square deviation $RMSD = \sqrt{n^{-1}\sum(x - x_o)^2}$; observations standard deviation $SDobs = \sqrt{n^{-1}\sum(x_o - \overline{x_o})^2}$; model standard deviation $SDmodel = \sqrt{n^{-1}\sum(\mathrm{x} - \bar{x})^2}$; and Pearson correlation coefficient $r = \sum(x - \bar{x})\,(x_o - \overline{x_o})/\sqrt{\sum(x - \bar{x})^2}\sqrt{\sum(x_o - \overline{x_o})^2}$, where $\bar{x} = n^{-1}\sum x$, $\overline{x_o} = n^{-1}\sum x_o$ and n is the number of available observations. We define the error as the difference between the model and the observations $error = x - x_o$, the standard deviation of the error is also computed as $StdE = \sqrt{n^{-1}\sum(error - \overline{error})^2}$. Variance is then calculated as $Var = StdE^2$.

Extreme verification and extra metrics for model evaluation were also provided. Following the metrics used by the World Meteorological Organisation (WMO), Scatter Index (*SI*) and Symmetric Slope (*SS*) between the model and the observations are also included. *SI* describes a comparison between model-observation difference, *SD* and an observed background value that is defined as the standard deviation of the observations instead of the observations mean ($\overline{x_o}$); $SI = StdE/SDobs$. The *SS* is described as the ratio of model variance to observations variance being $SS = (SDmodel/SDobs)^2$. Evaluation of the systems performance replicating the extremes was conducted using those observations and model data exceeding the 90th percentile in both. Computation of relative changes in absolute *bias* and *RMSD* as well as difference in model capability replicating the observations (Cov/r, Var and mean square deviation; *MSE*) is also presented in order to assess differences in performance between the different configurations and/or model trials.

Extra forcing evaluation: currents

The quality of AMM15 FOAM products has been extensively demonstrated (refer to Tonani et al., 2019 for more detailed information). In order to verify the validity of the surface currents used in the trialling period presented here, some extra evaluation is shown. Intensity and direction of modelled surface currents used as forcing in AMM15SL2 based trials is compared against observations of HF radar during the months of January and February 2020 (Fig. S1). There were very few measurements of velocity in the model domain during the trialling period, and those correspond with the HF radar in the German Bight (COSYNA products; Gurgel et al., 2011) and in the W coast of The Netherlands (HFR-MATROOS System; refer to http://dspace.azti.es/handle/24689/903 for quality control details on the data). A low-pass filter was used in both model and observations to separate the tidal and residual component of the total velocity. Bias and RMSD (in ms^{-1}) were estimated on the velocity vector magnitudes of the tidal currents; whilst veering is computed as the angle of the complex correlation with positive (negative) veering representing a clockwise (anti-clockwise) angle of AMM15 FOAM with respect to the HF radar vectors.

Surface currents are in good agreement with observations overall (Fig. S1). It is noted that although the two areas evaluated here have a strong tidal signal, other processes such as topographic effects (very shallow areas, depth <30m) may dominate. Whilst *bias* for the tidal signal across the German Bight variates between positive and negative ($\pm 0.15 ms^{-1}$; Fig. S1a), the residual currents are overall overestimated ($0.1 ms^{-1}$; not shown) and *RMSD* values are of the *O*.$0.25 ms^{-1}$ (Fig. S1b). Tidal (residual) currents are consistently underestimated (overestimated; not shown) across the W coast of the Netherlands (Fig. S1d) with values of *RMSD*=$0.15 ms^{-1}$ (Fig. S1e). Regarding the veering between observed and modelled currents, a negative veering angle is present in the two locations for both tidal (Fig. S1c,f) and residual currents (not shown). If the veering is also interpreted as a temporal phase of the tidal signal, a negative veering means that the observations tidal velocities lead the model velocities.

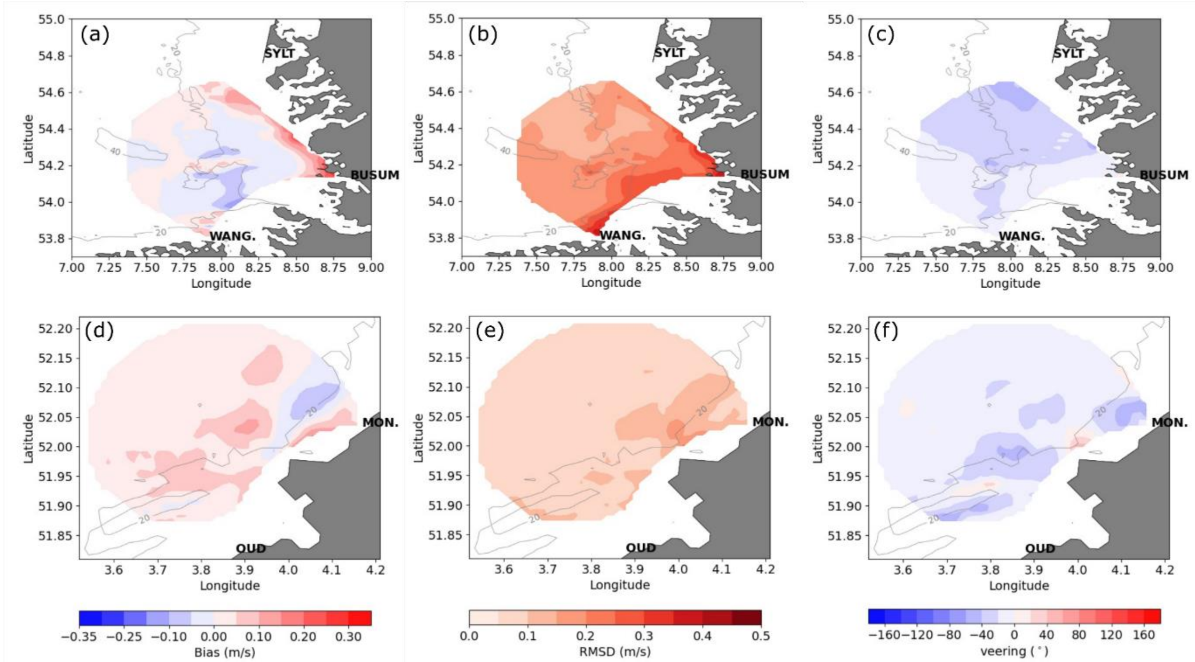

Figure S1. Surface current statistics estimated using HF radar observations versus AMM15 FOAM model outputs over Jan-Feb 2020. (a,d) *Bias*, (b,e) root mean square deviation (*RMSD*) and (c,f) phase or veering are computed for the German Bight (a-c) and the W coast of the Netherlands (d-f). Positive (negative) veering represents a clockwise (anti-clockwise) angle of AMM15 vectors with respect to the HF radar vectors. HF radar data for the German Bight corresponds to COSYNA (Gurgel et al., 2011) and the SW coast of the Netherlands to the MATROOS (http://dspace.azti.es/handle/24689/903) HF radar systems. SYLT, WANG, and BUSUM show the locations of the three COSYNA WERA HF radars on the islands of Sylt, Wangerooge and Büsum. MON and OUD show the locations of the two WERA radars at Ouddorp and Monster.