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QUALITY INFORMATION DOCUMENT

North West European Shelf Production Centre NWSHELF_MULTIYEAR_BIO_004_011

Issue: 5.1

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CHANGE RECORD

When the quality of the products changes, the QuID is updated and a row is added to this table. The third column specifies which sections or sub-sections have been updated. The fourth column should mention the version of the product to which the change applies.

Issue	Date	§	Description of Change	Author	Validated By
1.0	January 2014	All	Creation of the document for V4.0	Sarah Wakelin	Ed Blockley
2.0	December 2014	All	Addition of biological product assessment (BIO_004_011)	Robert McEwan	Ed Blockley
2.1	February 2015	All	Revision after acceptance V5		Ed Blockley
2.2	13/03/2015	I.2, II	Warning remarks after evidence of 004_011 interannual nutrient drifts		Ed Blockley
2.3	May 1 2015	all	Change format to fit CMEMS graphical rules		L. Crosnier
3.0	21/01/2016	all	Update for V2 (time series extension to 2014 and addition of MLD)	Sarah Wakelin, Jon Tinker	Marina Tonani
3.0	01/04/2016	all	Revision after V2 AR	Marina Tonani	Marina Tonani
4.0	01/09/2018	all	New version for Copernicus V4 (BIO only)	Susan Kay, Robert McEwan, David Ford	Ina Lorkowski
4.1	17/01/2019	all	The reanalysis was extended to December 2017, with no changes in quality.	Susan Kay	Marina Tonani
4.2	19/04/2019	all	The reanalysis was extended to December 2018, with no changes in quality.	Susan Kay	Marina Tonani
5.0	10/09/2020		New version for Copernicus V5	Susan Kay, Robert McEwan, David Ford	Marina Tonani
5.1	15/02/2021	all	Add interim product INT and 2018/9 rerun with Jan-June 2020 extension	Susan Kay, Robert McEwan, David Ford	Marina Tonani

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I EXECUTIVE SUMMARY

I.1 Products covered by this document

NWSHELF_MULTIYEAR_BIO_004_011: The biogeochemical part of a North West European Shelf Reanalysis performed at ~7 km resolution, 1993-2019, with monthly interim updates.

I.2 Summary of the results

The quality of the NWS reanalysis simulation NWSHELF_MULTIYEAR_BIO_004_011 from 01/01/1998 to 31/12/2019 has been assessed by comparison with observations. With the exception of satellite estimates of chlorophyll from ocean colour observations, the observational data is unevenly distributed in time and space, and quantitative estimates of accuracy should be used with caution. Some information about the period 1993-1997 is also provided, but without quantitative estimates.

Chlorophyll: the reanalysis reproduces the spatial and temporal variation of surface chlorophyll seen by satellite, though values are lower in model outputs than in satellite (Figure 4), giving an overall median bias of -0.28 mg m^{-3} for the continental shelf (Table 3). Model-satellite correlation is above 0.55 for most regions. Comparison to in situ data, at all depths, has a similar correlation but larger bias (Table 4).

Nitrate: Comparison of surface nitrate to climatology shows that the seasonal cycle is well reproduced (Figure 12). The reanalysis shows a positive bias compared to in situ observations, largest in the Southern North Sea and English Channel (Table 6).

Phosphate: Comparison of surface phosphate to climatology and in situ observations shows that the seasonal cycle is well reproduced but modelled values are lower than observations, especially in the shelf region (Figure 15 and Table 7).

Oxygen: Compared to a climatology of surface observations, the reanalysis values are consistently low, but show the same temporal and spatial patterns (Figure 18). The model-observation correlation is 0.55 or higher in all areas except the English Channel (Table 8).

Surface pCO_2: The model reproduces observed spatial patterns and seasonal changes (Figure 21). The bias is variable in direction and size but is typically around 1 Pa and the median absolute difference between model and observation is around 3 Pa (Table 9).

pH: Fewer observations are available than for other variables, but on the evidence available the model shows some skill in all regions (Table 10).

Light attenuation: the model reproduces the observed spatial and temporal patterns of satellite Kd490, but gives values higher than observed (Figure 27).

I.3 Estimated Accuracy Numbers

Accuracy is provided for the period 1998-2019, where data assimilation is used. These estimates may not apply to the period 1993-1997.

Surface chlorophyll accuracy, based on the match to daily ocean colour satellite values:

Table 1 Estimated accuracy numbers for surface log10-chloropyll, chlorophyll units mg m-3

Region	**Mean bias** (model–observation mean)	**Root mean square difference**	**Median bias** (model–observation median)	**Median absolute difference**
Continental Shelf	-0.30	0.51	-0.27	0.29
Offshelf	-0.15	0.41	-0.14	0.22
Full domain	-0.19	0.44	-0.18	0.24

The ocean colour data is taken from the CMEMS catalogue, product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098, 1998-2019. The mean bias of the log-transformed data is 0.03 and the root mean square error 0.37 (from the product QUID).

The following table shows estimated median bias (model-observation) and median absolute difference for the on-shelf part of the model domain, based on match-ups to in situ observation. **The estimates should be used with caution**: the in situ measurements are not distributed evenly in time or space and their accuracy is not known. Users are advised to consult the tables in section IV for more information about accuracy within each region: there is considerable variation between regions.

Table 2 Estimated accuracy numbers based on comparison to in situ data for chlorophyll (all depths, actual concentration, not log), nitrate, phosphate, oxygen, surface pCO2 and pH, for the on-shelf part of the model domain.

Variable	**Median bias (model-observation)**	**Median absolute difference**	**Spearman correlation**
chlorophyll	-0.48 mg m^{-3}	0.69 mg m^{-3}	0.67
nitrate	3.8 mmol m^{-3}	4.6 mmol m^{-3}	0.41
phosphate	-0.10 mmol m^{-3}	0.20 mmol m^{-3}	0.51
oxygen	-15 mmol m^{-3}	19 mmol m^{-3}	0.64
Surface pCO_2	-0.65 Pa	3.2 Pa	0.29
pH	0.063	0.091	0.38

Note that the accuracy measures use robust statistics: median bias, median absolute difference and Spearman rank correlation. Robust statistics are independent of the distribution of the dataset, and so are more appropriate for biogeochemical variables, which often have a non-Gaussian distribution and contain outliers that can distort measures such as the mean. See section III for more information about the metrics used.

II PRODUCTION SYSTEM DESCRIPTION

Production centre name: Met Office, UK

Production system name: North West European Shelf Reanalysis biogeochemistry (CMEMS names: NWSHELF_MULTIYEAR_BIO_004_011)

Description

The North West shelf reanalysis was produced using the Forecasting Ocean Assimilation Model 7 km Atlantic Margin model (FOAM AMM7) which is comprised of version 3.6 of the Nucleus for European Modelling of the Ocean (NEMO) ocean model code (Madec et al., 2016) coupled to the European Regional Seas Ecosystem Model (ERSEM 19.04; Butenschön et al. 2016). Surface phytoplankton functional type chlorophyll values, estimated from satellite ocean colour measurements, were assimilated using the 3D-Var NEMOVAR scheme (Skákala et al., 2018; Waters et al., 2015) for the period from September 1997 onwards.

The model is located on the European North-West continental Shelf (NWS), from 40°N, 20°W to 65°N, 13°E (boundary region masked), on a regular lat-lon grid with 1/15° latitudinal resolution and 1/9° longitudinal resolution (approximately 7 km square). The model domain is shown in Figure 1, partitioned into shallow (on shelf) and deeper (off shelf) waters. Although the domain extends beyond the shelf to include some of the adjacent North-East Atlantic, the focus of this system is on the shelf itself and the deep water is primarily included to ensure there is appropriate cross-shelf exchange. Thus a hybrid s-sigma terrain following coordinate system (following Siddorn and Furner, 2013) with 51 levels is employed in order to retain vertical resolution on the shelf. However, in order to make analysis and visualization easier for users, the products are delivered on 24 geopotential (z-level) vertical levels based upon the ICES standard depths. Gridpoints near to the model boundaries are strongly affected by the model boundary conditions and so products are provided for the interior of the domain only. The outermost 10 gridpoints and points East of 10°E on the Baltic boundary are masked.

For full details of the physical modelling system, its forcing data and product quality please see the Quality Information Document for that system (CMEMS_NWS_QUID_MULTIYEAR_PHYS_004_009.pdf).

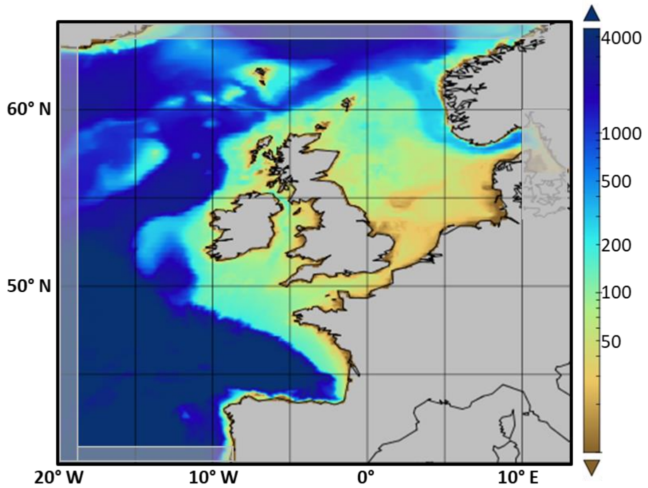


Figure 1 FOAM AMM7 bathymetry (m).

ERSEM (Figure 2) is a marine biogeochemistry model which simultaneously describes pelagic and benthic ecosystems in terms of phytoplankton, bacteria, zooplankton, zoobenthos and the biogeochemical cycling of C, N, P and Si. ERSEM uses a functional group approach to describe the ecosystem, whereby biota are grouped together according to their trophic level (subdivided according to first size, then trophic role and finally feeding method). Four functional groups of phytoplankton are included, three of zooplankton and one of bacteria. The dynamics of biological functional groups are described by both physiological (ingestion, respiration, excretion and egestion) and population processes (growth and mortality). The differences between the functional groups mainly lie in the rate constants, which are derived from the literature or from allometric considerations and in the food components on the uptake side. Production of the phytoplankton groups is driven by broadband photosynthetically active radiation (PAR), and underwater light field computed with the Beer-Lambert equation of light attenuation. The diffuse attenuation coefficient is computed by using broadband absorption and backscattering (i.e. the "Inherent Optical Properties") of the phytoplankton groups, of water, and of coloured detrital matter and other non-modelled material; the latter is nudged towards climatological satellite data. Suspended particulate matter is not explicitly included in the model. The model includes the carbonate system, enabling pCO_2 and pH to be included in the available products.

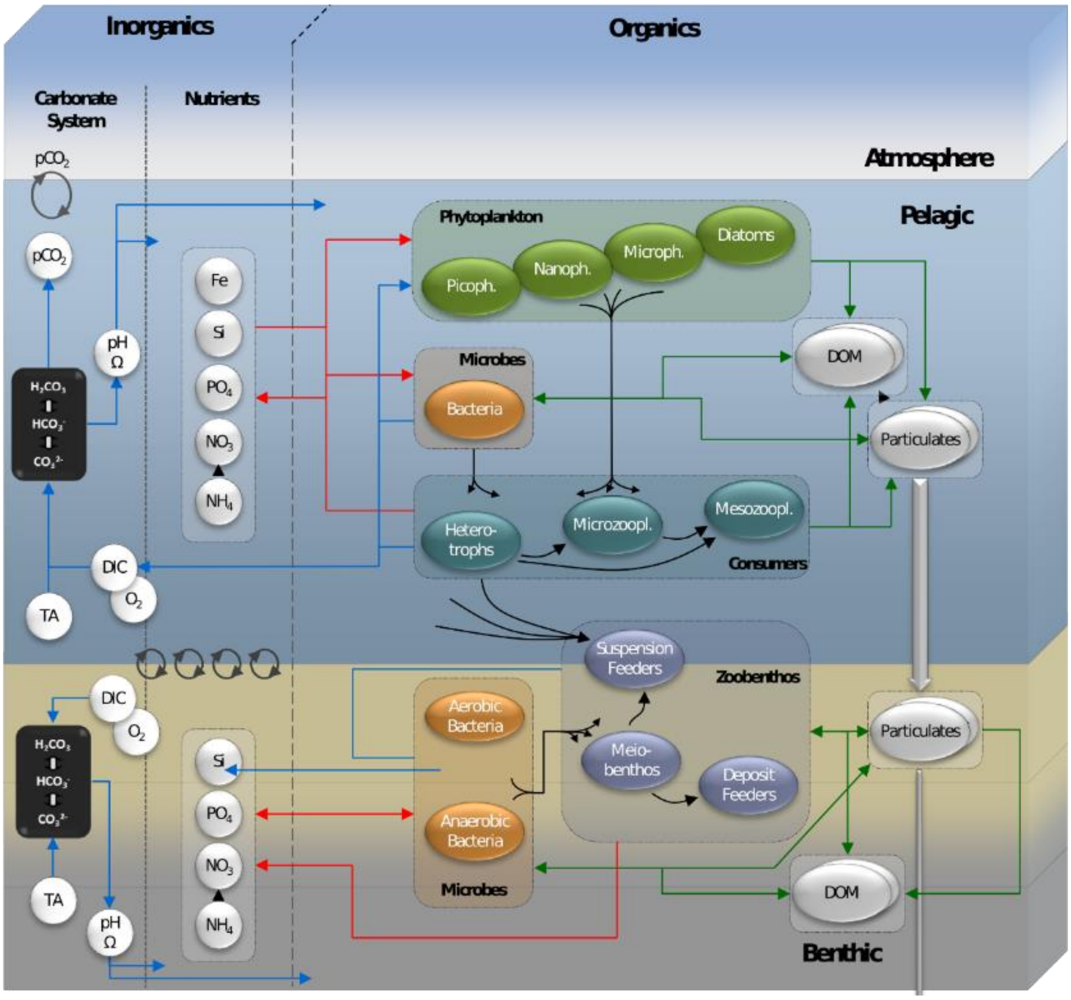


Figure 2 Schematic diagram of the ERSEM biogeochemical model.

Full information on ERSEM can be found in Butenschön et al. (2016) and references therein.

ERSEM is coupled to the NEMO physical model through the Framework for Aquatic Biogeochemical Models (FABM, Bruggeman and Bolding, 2014).

Remotely sensed ocean colour data are assimilated using the 3D-Var NEMOVAR scheme (Skákala et al., 2018; Waters et al., 2015), with four plankton functional types (PFTs) assimilated separately. Observations of chlorophyll-a concentration for the microphytoplankton, nanophytoplankton and picophytoplankton are taken from the European Space Agency Climate Change Initiative (ESA CCI) v3.1 daily merged product, CMEMS product OCEANCOLOUR_GLO_CHL_L3_REP_OBSERVATIONS_009_065. Microphytoplankton are split into diatoms and dinoflagellates (Brewin et al., 2017), and all four types are bias corrected following Ciavatta et al. (2016). NEMOVAR is used to calculate increments to the model surface PFT chlorophyll-a concentrations, and levels of C, N, P and Si within phytoplankton are updated so that the assimilation does not directly alter the phytoplankton stoichiometry. All increments are applied equally through the mixed layer using incremental analysis update (Bloom et al., 1996). Concentrations of dissolved nutrients are not updated but adjust in response to the changes to phytoplankton. The assimilation configuration is very similar to that described by Skákala et al. (2018), except for the use of two equally-weighted correlation length scales, one based on the Rossby radius and one set to 100 km, to provide short- and long-scale corrections respectively. The version of the ocean colour product used changed after 28/10/2018, from v3.1 to v5.0. The quality of the reanalysis for the period after 28/10/2018 is comparable to before, but users may notice some small differences.

Monthly interim updates assimilate just total chlorophyll, from the CMEMS near-real-time product OCEANCOLOUR_ATL_CHL_L3_NRT_OBSERVATIONS_009_036. The total chlorophyll increments were split into PFTs so as to maintain their existing background ratios in the model. This impacts the phytoplankton community structure, but any effect on total chlorophyll-a concentration, and other model variables, will be small. The near-real-time chlorophyll product has had fewer quality checks than the reprocessed product used in the main part of the reanalysis and is likely to contain more gaps. This means that the interim reanalysis is likely to show more variability than the main part of the reanalysis and it should be used with care.

The ecosystem model used climatologies for the boundary conditions: nitrate, phosphate, silicate and oxygen from World Ocean Atlas 2013v2 (WOA, Garcia et al., 2014a,b) and alkalinity and dissolved inorganic carbon from GLODAPv2 (Key et al., 2015, and Lauvset at al., 2016). Daily timeseries of river discharge, nutrient loads (nitrate, phosphate, silicate, ammonia), alkalinity (total alkalinity, bioalkalinity, dissolved organic carbon) and oxygen were produced from an updated version of the river dataset used in Lenhart et al. (2010) combined with climatology of daily discharge data from the Global River Discharge Data Base (Vörösmarty et al., 2000) and from data prepared by the Centre for Ecology and Hydrology as used by (Young and Holt, 2007). Nitrogen deposition at the surface used data from the EMEP project (http://www.emep.int); the last available year is 2017, so the 2017 values were repeated for 2018 and 2019. The ecosystem model is forced by the physical model via an online coupling and is run at the same time step as the physical model (300s).

The reanalysis covers the period 01/01/1993 to 31/12/2019. Assimilation of surface chlorophyll starts in September 1997 and this means that many variables have different average and range for 1993-1997 than for 1998-2019 – care should be taken when using the full period. See Section IV for more details.

The previous multiyear product, V4, assimilated total chlorophyll but no physical variables, while this product assimilated PFT chlorophyll and physical variables (sea surface temperature, temperature and salinity profiles). The assimilation of physical variables produces some degradation of the biogeochemical outputs in the offshelf region, but there is no effect on outputs for shelf region, which is the main target of this product. The change means that there is full consistency between the biogeochemical variables provided in this product and the physical variables provided in NWSHELF_MULTIYEAR_PHYS_004_009.

III VALIDATION FRAMEWORK

The products assessed are chlorophyll, nitrate, phosphate, oxygen, pCO_2 and pH. Light attenuation is included but without quantitative assessment.

Model surface chlorophyll is compared to daily satellite ocean colour measurements (CMEMS product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098) to give monthly maps for the whole domain and statistics for sub-regions. This is a different ocean colour product from that assimilated during the reanalysis.

Model nutrients and oxygen are compared to climatological fields from the North Sea Biogeochemical Climatology (Hinrichs et al., 2017) to give monthly maps.

Surface pCO2 is compared to seasonal averages of the SOCATv6 gridded coastal fields for 2000-2017, taken from CMEMS product INSITU_GLO_CARBON_REP_OBSERVATIONS_013_050.

Surface pH is compared to the annual average GLODAP gridded field, taken from CMEMS product INSITU_GLO_CARBON_REP_OBSERVATIONS_013_050.

Time series of surface chlorophyll and nitrate are compared to in situ measurements from the Western Channel Observatory (point L4; 50°15.0'N, 4°13.0'W, www.westernchannelobservatory.org.uk, Figure 3).

All assessed variables except pCO_2 are compared to in situ measurements from the database of the International Council for the Exploration of the Sea (ICES, 2014), to give statistics summarised in target diagrams. In situ data for surface pCO_2 data is taken from the SOCAT database version 2020 (Bakker et al., 2016) and the ICES data for pH is supplemented by additional data from GLODAPv2.2020 (Key et al., 2015, Lauvet et al., 2016, and Olsen et al., 2016).

The light attenuation coefficient is not fully assessed, but seasonal maps for light attenuation are compared to daily satellite ocean colour measurements of Kd490 (OCEANCOLOUR_GLO_OPTICS_L3_REP_OBSERVATIONS_009_086).

The quality of the interim monthly updates is compared to daily satellite ocean colour measurements (CMEMS product OCEANCOLOUR_ATL_CHL_L4_NRT_OBSERVATIONS_009_037). There were insufficient observations available to assess other variables, but a qualitative comparison to previous years has been made.

Robust statistics have been used in all analyses. These are independent of the distribution of the data and so avoid distortion by outliers. Metrics used are:

Number of matched observations (n) All metrics are based on the set of observations and a set of model outputs matched in time and space. In situ (ICES, SOCAT and GLODAPv2) observations were matched to the monthly mean model outputs: a match was considered valid if it was in the same grid cell, within 2 m vertically and 15 days of the observation. Daily ocean colour data was matched to the daily mean surface model outputs for all grid cells where satellite data was available. For the match to the in situ data, where observations are sparse in some areas, the number of matched points is shown in the tables in section IV.

Median Bias: the median difference between the model data and the observation (reference) data. This gives an indication of consistent differences between the model and observation, with positive bias meaning the model is higher than observation.

$$Bias = median\left(x_{model} - x_{reference}\right)$$

Median absolute difference (MAD): the median of the absolute difference between the model and observation values at each point. This indicates the average size of the difference between model and observation.

$$MAD = median(abs\left(x_{model} - x_{reference}\right))$$

Spearman rank correlation coefficient: this is the Pearson correlation coefficient between the ranked values of the model and observation data: if the model data increases when the observations do, they are positively correlated. It can be interpreted in the same way as the Pearson correlation, i.e. 1 shows perfect correlation and 0 shows no correlation.

Target diagrams: these show the MAD plotted against bias, with both normalised by the interquartile range (IQR) of the observation data, i.e. the difference between the 75th and 25th percentile, a robust measure of the spread of the data. The MAD is unbiased by subtracting the median at each data point for both model and observation dataset. The sign of the x-value is given by the difference between the IQR for the model and reference data. Thus the closer to (0,0) the better the match between model and observation; values to the left of the y-axis show that model has less spread (variability) than observation and negative y-values show that the model values are on average smaller than observations.

x-axis:

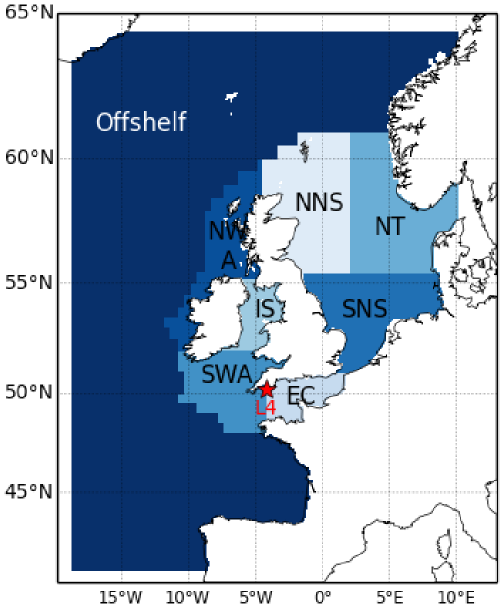
$$sign\left(IQR_{model} - IQR_{reference}\right) * \frac{median\left(abs\left(\left(x_{model} - median(x_{model})\right) - \left(x_{reference} - median\left(x_{reference}\right)\right)\right)\right)}{IQR_{reference}}$$

y-axis:

$$\frac{median(x_{model}) - median\left(x_{reference}\right)}{IQR_{reference}}$$

In the tables in section IV the bias and MAD are given without normalisation and have the same units as the model; the normalised values used in the target diagram are unitless.

Statistics have been calculated for the whole model domain and for various subregions – see Figure 3 for the location of these regions.



Regions:

EC: English Channel

IS: Irish Sea

NNS: Northern North Sea

NT: Norwegian Trench

NWA: North Western Approaches

SNS: Southern North Sea

SWA: South Western Approaches

The Continental Shelf regions includes all the above, i.e. all regions except Offshelf.

Observation stations:

L4: station L4 of the Western Channel Observatory

Figure 3 Regions and observing stations referred to in this document.

IV VALIDATION RESULTS

IV.1 Chlorophyll-a

Chlorophyll is produced by photosynthesising plankton when the conditions for growth are favourable: sufficient light for photosynthesis and nutrients for growth. Light, nitrate and phosphate can all act as limiting factors for chlorophyll, depending on the season and location. Chlorophyll concentration is related to phytoplankton biomass but plankton can vary their chlorophyll content depending on the light conditions so chlorophyll is not simply proportional to biomass.

Comparison of monthly mean surface chlorophyll from the reanalysis to ocean colour satellite values (Figure 4, Figure 5, Figure 6, Table 3 and Figure 7) shows that the model reproduces the spatial and temporal variation seen by satellite, though values are lower in model outputs than in satellite in the on-shelf region. This is reflected in the negative bias figures (Table 3).The model's peak chlorophyll values are higher than satellite in the period 1993-1997 but after chlorophyll data assimilation starts in September 1997 these high summer peaks are reduced (Figure 5); the comparisons in Figure 4, Figure 6, Table 3 and Figure 7 are for the period 1998-2019 only. The distribution of model chlorophyll values is similar to satellite (Figure 6), except that the model has more very low values, characteristic of the winter period.

For the subregions, the correlation is above 0.55 for most regions (Table 3), reflecting good ability to capture spatial and temporal patterns in these regions. The bias is negative for all regions, but well below the variability of the observations (Figure 7). Accuracy is relatively low (high MAD) in the Southern North Sea and Irish Sea, but the correlation is good for these areas and the MAD in relation to the variability of observations is similar to that of other regions.

It should be remembered that ocean colour data is less reliable for the winter months, when cloud obscures much of the imagery, and in areas strongly influenced by sediment, such as the southern North Sea. The QUID for the ocean colour product gives its bias as 0.03 and rmsd as 0.37 (using log-transformed values).

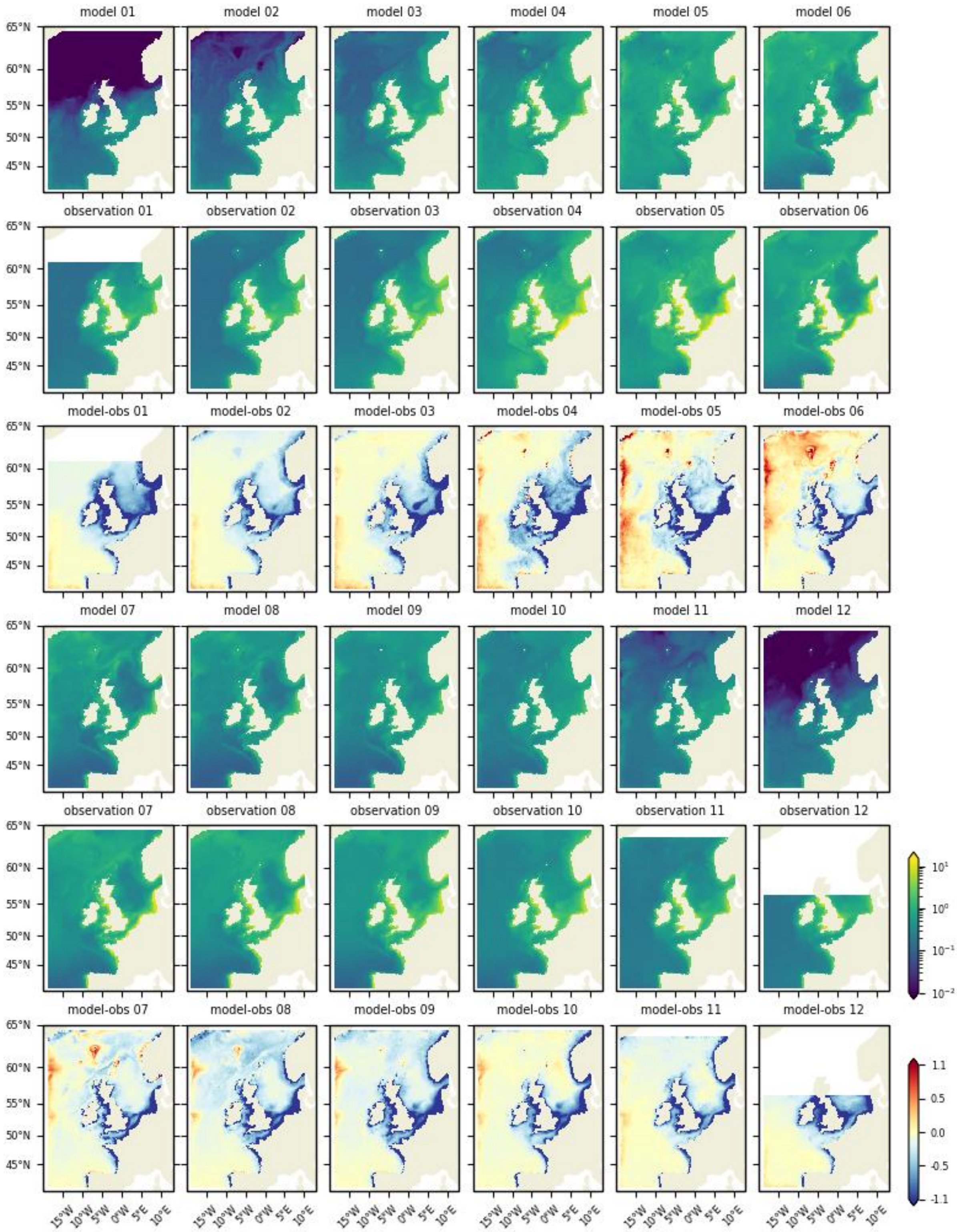


Figure 4 Mean monthly surface chlorophyll concentration (mg m-3) from the reanalysis (top row) and ocean color satellite (middle row) and the difference between the model and ocean colour values (bottom row). All plots show the mean for1998-2019. The ocean colour data comes from CMEMS product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098, daily values, regridded to match the model.

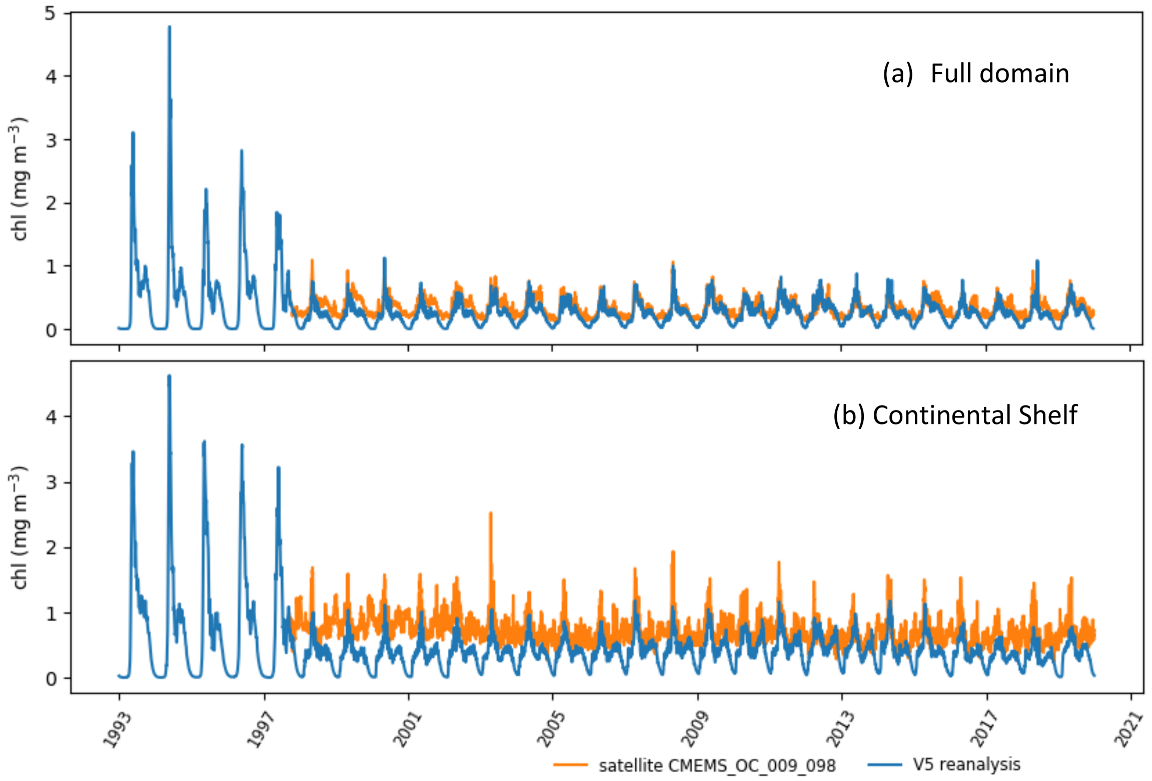


Figure 5 Time series of surface chlorophyll concentration from the model (blue) and ocean colour satellite (orange), daily median for (a) the whole domain and (b) the continental shelf. The ocean colour data comes from CMEMS product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098, daily values, regridded to match the model.

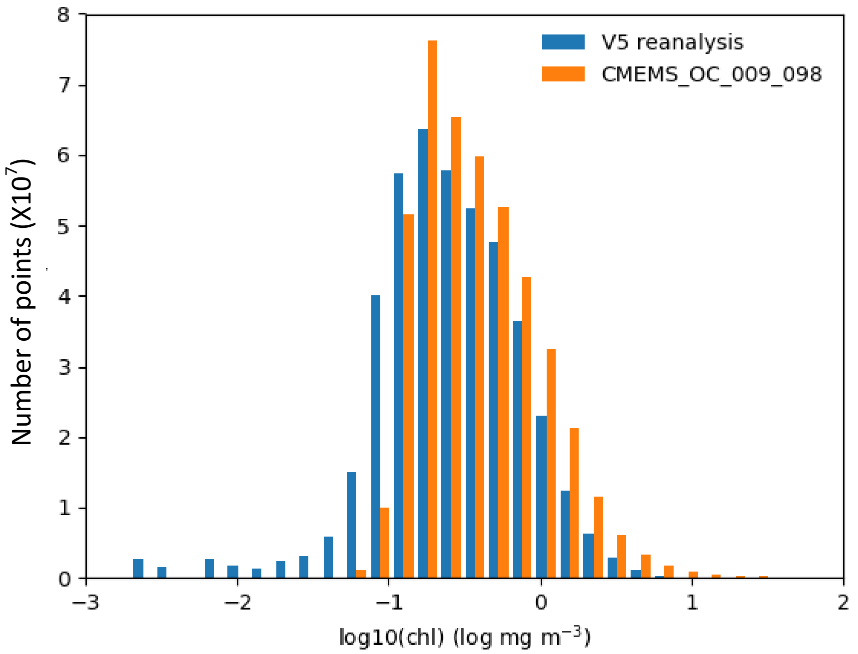


Figure 6 Histogram of surface log10-chlorophyll data from the model (blue) and ocean colour satellite (orange), daily median for the whole domain, 1998-2019. There is a grid point for each model cell each day, except where satellite data were unavailable due to cloud: these points were omitted from the model data. The ocean colour data comes from CMEMS product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098, daily values, regridded to match the model.

Table 3 Statistics for match-ups between daily model surface chlorophyll outputs and satellite ocean colour chlorophyll (CMEMS product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098), for the full domain and sub-regions, 1998-2019. See section III for information on the match-up process and statistics provided and the locations of the regions.

Region	Bias (mg m^{-3})	MAD (mg m^{-3})	Spearman correlation
Full Domain	-0.09	0.15	0.70
Continental shelf	-0.28	0.33	0.64
Offshelf	-0.06	0.11	0.68
Norwegian Trench	-0.20	0.28	0.58
Northern North Sea	-0.18	0.23	0.55
Southern North Sea	-0.69	0.71	0.64
English Channel	-0.42	0.43	0.66
Irish Sea	-0.71	0.73	0.43
South Western Approaches	-0.20	0.22	0.68
North Western Approaches	-0.19	0.27	0.55

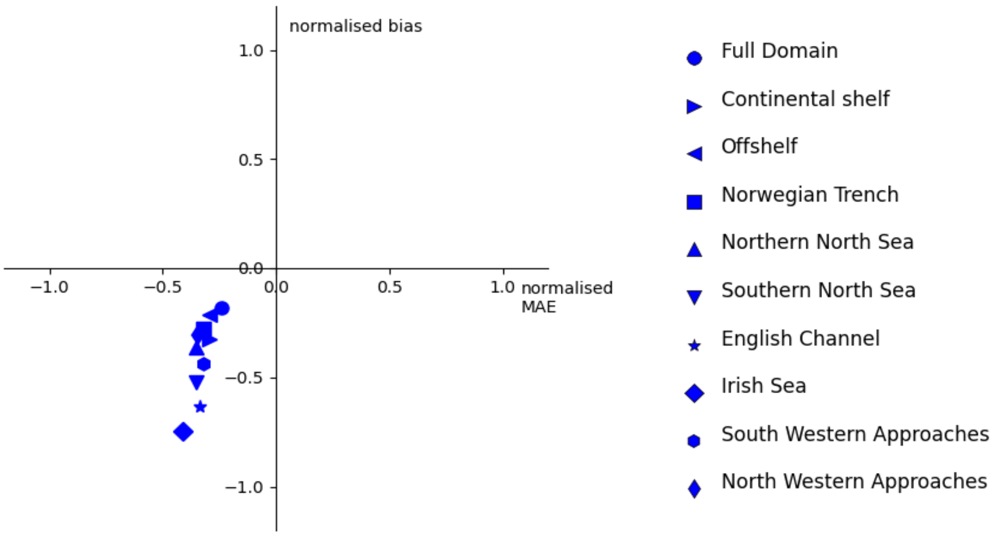


Figure 7 Target diagram for match-ups between daily model surface chlorophyll outputs and satellite ocean colour chlorophyll (CMEMS product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098), for the full domain and sub-regions. See section III for information on how the target diagram is defined.

Comparison to in situ data is shown in Figure 8 (time series at observing station L4, surface value, and Figure 9 and Table 4, various locations, all depths). As with the comparison to satellite data, modelled values tend to be lower than observation (negative bias). Modelled values at station L4 are generally in line with observations, but peak values are lower than observed. The timing of blooms is reproduced reasonably well, though noise in the observation data makes this difficult to check (Figure 8). The MAD for match-ups to observations is around 1 mg m^{-3} for most shallow water regions, lower for deep water areas and 0.69 mg m^{-3} for the shelf area as a whole. The negative x-values on the target diagram show that the model outputs have lower variability than observation, consistent with Figure 8.

Accuracy figures for the in situ comparison are not the same as those for the comparison to satellite ocean colour chlorophyll, for a number of reasons: the in situ data contains data from all depths, it is based on monthly rather than daily values and the in situ data is less regularly distributed in time and space (note the "n" column in Table 4, which shows the number of observations in each region over the whole time period 1998-2019). The in situ data has greater variability than the satellite, hence the normalised bias and MAD are smaller in Figure 7 than Figure 9. Users should assess which comparison is more appropriate for their application of the reanalysis.

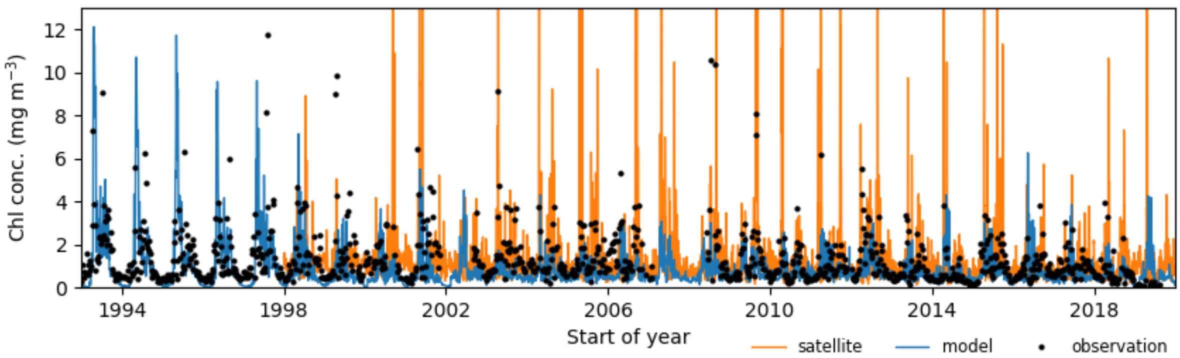


Figure 8 Surface chlorophyll concentration from the reanalysis (blue line), satellite ocean colour (orange line) and measurements at station L4 (black circles). See Figure 3 for location of L4; observation data is from https://www.westernchannelobservatory.org.uk/l4_chn.php); satellite data CMEMS product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098.

Table 4 Statistics for match-ups between monthly model chlorophyll outputs at all depths, 1998-2019, and in situ observations from the ICES database (ICES, 2014), for the full domain and sub-regions. See section III for information on the match-up process and statistics provided and the locations of the regions.

Region	n	Bias (mg m^{-3})	MAD (mg m^{-3})	Spearman correlation
Full Domain	49503	-0.37	0.60	0.69
Continental shelf	40179	-0.48	0.69	0.67
Offshelf	9324	-0.078	0.28	0.74
Norwegian Trench	16085	-0.30	0.50	0.64
Northern North Sea	4136	-0.14	0.22	0.73
Southern North Sea	12446	-1.30	1.40	0.66
English Channel	2165	-0.73	0.87	0.73
Irish Sea	2166	-0.74	0.98	0.41
South Western Approaches	1463	-0.50	0.72	0.42
North Western Approaches	1844	-0.54	0.80	0.29

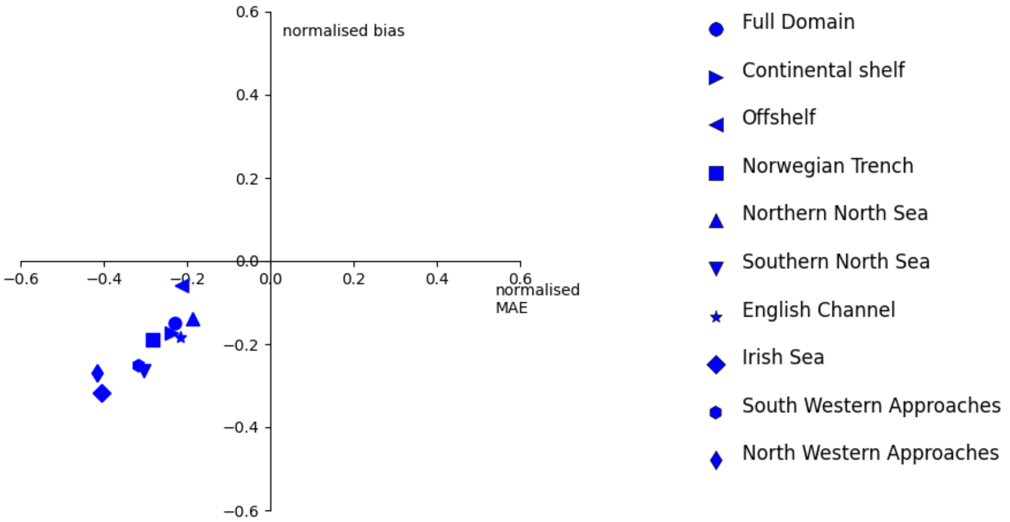


Figure 9 Target diagram for match-ups between monthly model chlorophyll outputs at all depths, 1998-2019 and in situ observations from the ICES database (ICES, 2014), for the full domain and sub-regions. See section III for information on how the target diagram is defined.

Chlorophyll for Interim updates

Surface chlorophyll from the interim run for 1 July 2020 to 31 December 2020 has been compared to near-real-time satellite product for the same periods (Table 5 and Figure 10**Erreur ! Source du renvoi introuvable.**). There were insufficient in situ observations available to assess the quality at other depths. The quality of the product in on-shelf and offshelf areas is broadly comparable to that of the main product. Biases are reduced for all regions and MAD is reduced for all shelf regions, however correlation is also reduced compared to the main product. It should be noted that this comparison is only for a 6-month period and does not include the spring bloom, so the values should be considered to be indicative, and should not be treated as Estimated Accuracy Numbers.

Table 5 Statistics for match-ups between interim run daily model surface chlorophyll outputs and satellite ocean colour chlorophyll (CMEMS product OCEANCOLOUR_ATL_CHL_L4_NRT_OBSERVATIONS_009_037), for the full domain and sub-regions, 2020-07-01 to 2020-12-31. The right hand columns show the statistics for the main run, copied from Table 3 , for comparison.

Region	**Interim, July-December 2020**			**Reanalysis 1998-2019, as table 3**		
	Bias ($mg\ m^{-3}$)	**MAD ($mg\ m^{-3}$)**	**Spearman correl.**	**Bias ($mg\ m^{-3}$)**	**MAD ($mg\ m^{-3}$)**	**Spearman correl.**
Full Domain	-0.07	0.18	0.60	-0.09	0.15	0.70
Continental shelf	-0.24	0.31	0.58	-0.28	0.33	0.64
Offshelf	-0.04	0.14	0.55	-0.06	0.11	0.68
Norwegian Trench	-0.12	0.23	0.57	-0.20	0.28	0.58
Northern North Sea	-0.16	0.25	0.40	-0.18	0.23	0.55
Southern North Sea	-0.60	0.61	0.59	-0.69	0.71	0.64
English Channel	-0.35	0.37	0.57	-0.42	0.43	0.66
Irish Sea	-0.62	0.67	0.27	-0.71	0.73	0.43
South Western Approaches	-0.15	0.21	0.60	-0.20	0.22	0.68
North Western Approaches	-0.12	0.27	0.36	-0.19	0.27	0.55

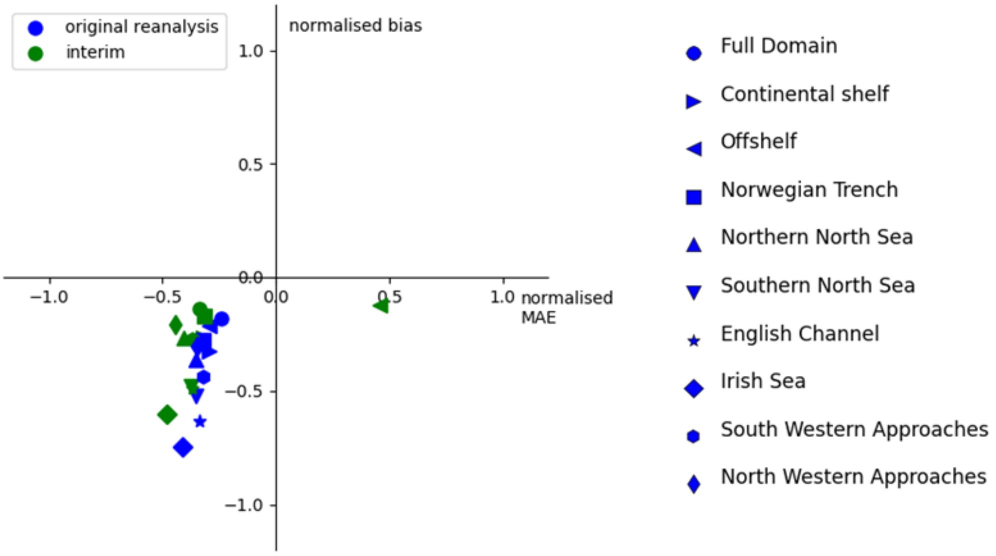


Figure 10 Target diagram for match-ups between interim daily model surface chlorophyll outputs and satellite ocean colour chlorophyll (CMEMS product OCEANCOLOUR_ATL_CHL_L4_NRT_OBSERVATIONS_009_037), for the full domain and sub-regions. The values from the original reanalysis, as in Figure 7, are shown for comparison.

IV.2 Nitrate

Nitrate is removed from the water during the growing season by phytoplankton and once the nitrate has been depleted plankton growth may slow or cease until levels are replenished. Sources of nitrate include excretion by plankton and bacteria, breakdown of particulate material and, particularly in winter, mixing from nutrient-rich waters below the surface layer. Nitrate, phosphate and light can all be limiting factors for phytoplankton growth, so the presence of nitrate does not automatically trigger growth.

Comparisons of model to in situ data are shown in Figure 11 (surface time series at observing station L4) and Figure 13 and Table 6 (match-ups to observations from all depths in the ICES database). The bias (model-observation median) is positive in the shelf areas and highest in the Southern North Sea. At station L4 the modelled values match observation in the winter but are higher than observed in the summer. The MAD is less than 5 mmol m^{-3} in most regions, but higher in the English Channel and Southern North Sea. Model-observation correlation is generally higher in deep water regions than shallower waters.

Figure 12 shows the monthly mean surface nitrate concentration compared to the climatology from the North Sea Biogeochemical Climatology (Hinrichs et al., 2017). The seasonal cycle is well reproduced, though with differences in variability: on the shelf the model is lower than observed in the winter and higher in the summer. The reverse is true for the offshelf region in the north west, but there are relatively few observations contributing to the climatology there. The positive bias is consistent with that seen in the comparison to in situ observations (Table 6), which are more frequently made in the summer.

The above assessments are for the period 1998-2019, when chlorophyll assimilation is in operation. For 1993-1997 nitrate values are higher in winter and lower in summer, especially in the on-shelf region (Figure 14).

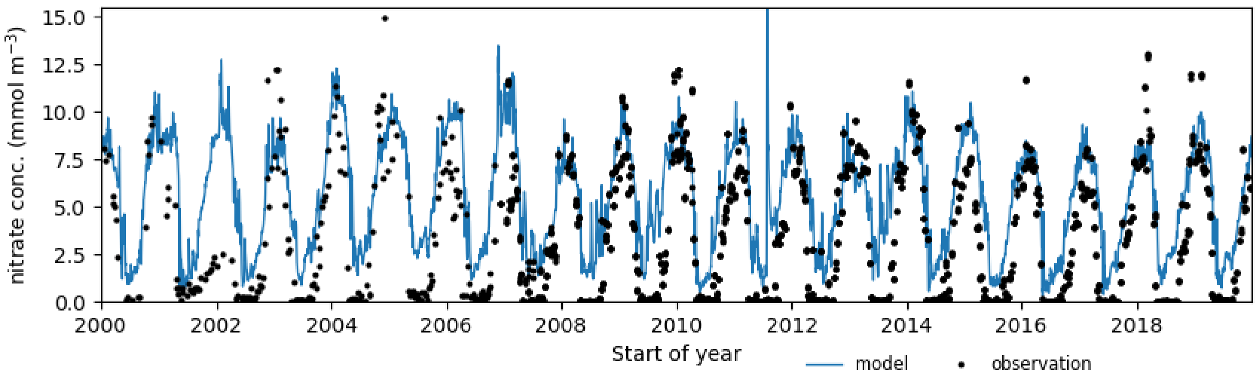


Figure 11 Surface nitrate concentration from the reanalysis (blue line) and measurements at station L4 (black circles). See Figure 3 for location of L4; observation data is from https://www.westernchannelobservatory.org.uk/l4_chn.php.

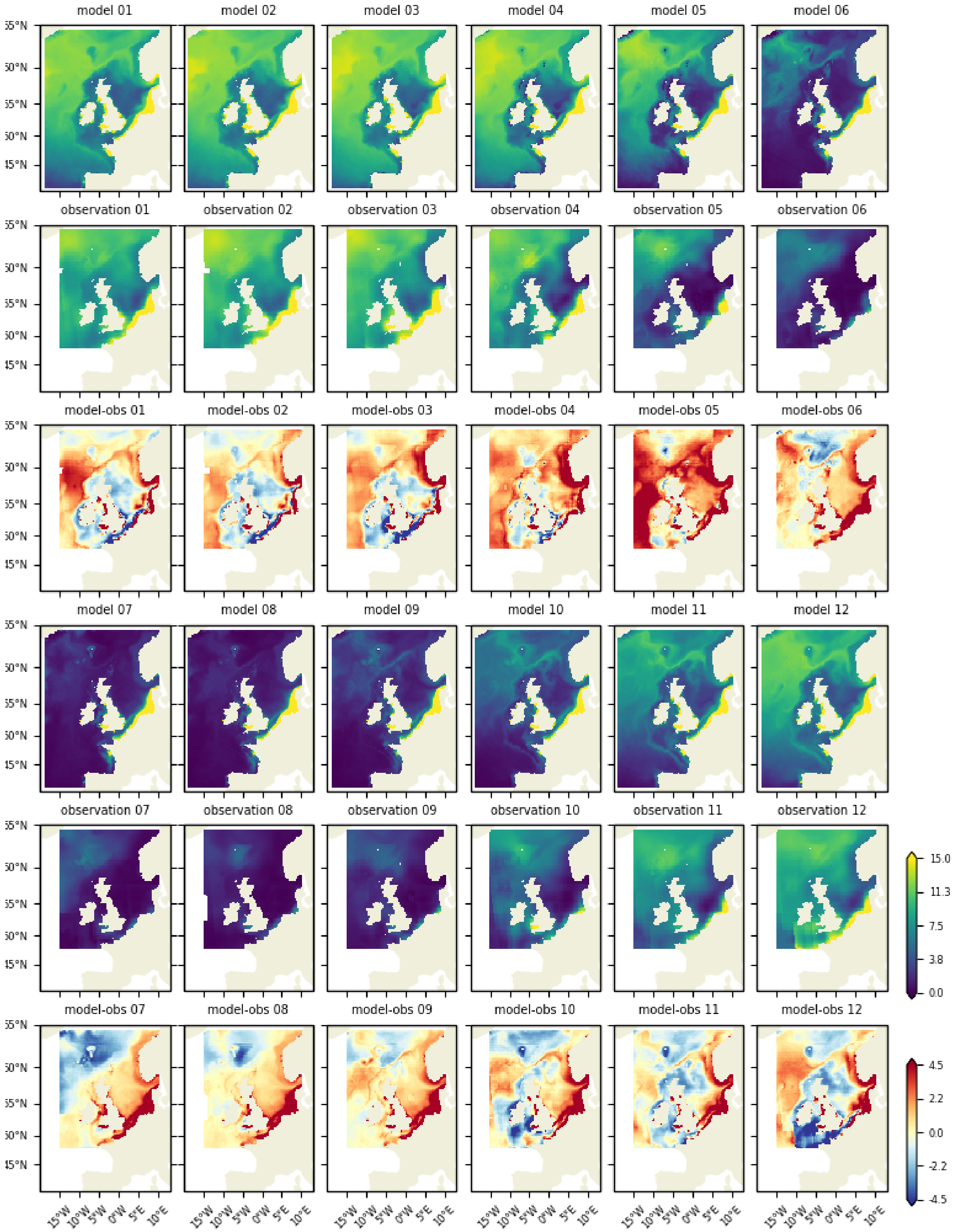


Figure 12 Median monthly surface nitrate concentration (mmol m-3) from the reanalysis 1998-2019 (top row) and the the North Sea Biogeochemical Climatology (middle row) and the difference between the model and the North Sea Biogeochemical Climatology values (bottom row).

Table 6 Statistics for match-ups between monthly model nitrate outputs at all depths and in situ observations from the ICES database (ICES, 2014), for the full domain and sub-regions. See section III for information on the match-up process and statistics provided and the locations of the regions.

Region	n	Bias (mmol m^{-3})	MAD (mmol m^{-3})	Corr
Full Domain	58140	2.74	3.64	0.43
Continental shelf	47910	3.84	4.55	0.41
Offshelf	10219	0.60	1.44	0.68
Norwegian Trench	20638	4.39	4.58	0.28
Northern North Sea	5576	0.06	1.58	0.57
Southern North Sea	13174	23.33	23.90	0.38
English Channel	1499	8.88	10.98	0.55
Irish Sea	3202	0.51	2.26	0.54
South Western Approaches	1477	0.42	1.65	0.71
North Western Approaches	2417	0.90	1.68	0.61

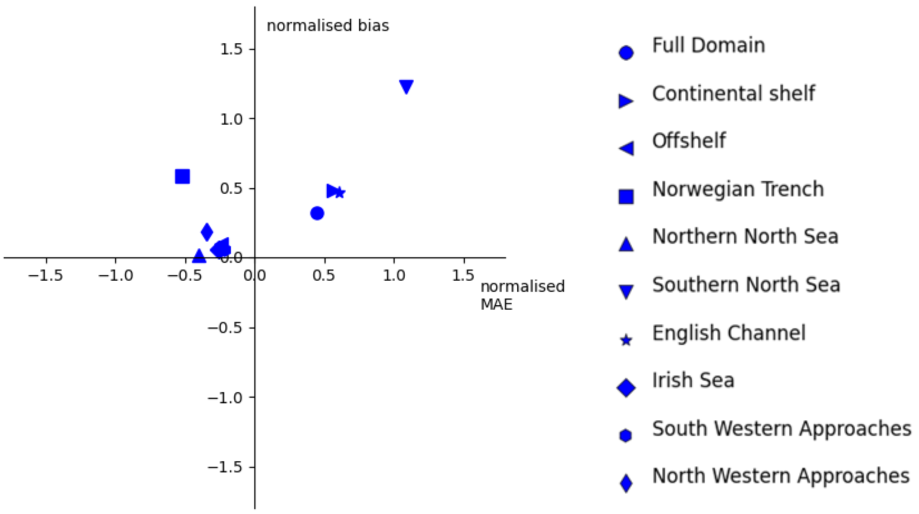


Figure 13 Target diagram for match-ups between monthly model nitrate outputs at all depths and in situ observations from the ICES database (ICES, 2014), for the full domain and sub-regions. See section III for information on how the target diagram is defined.

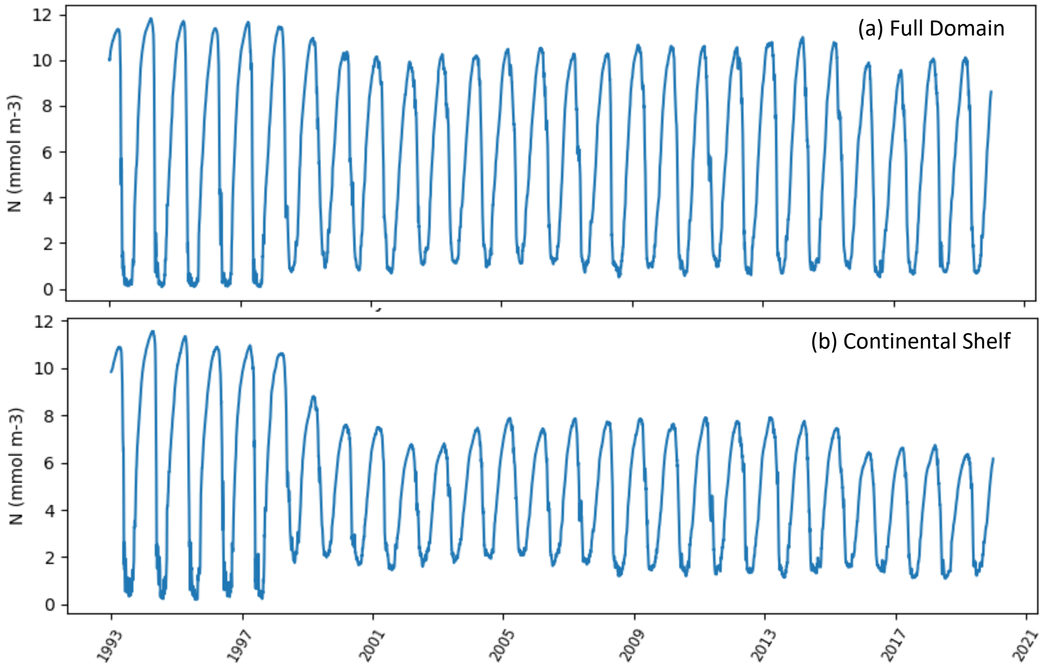


Figure 14 Time series of daily median surface nitrate concentration for (a) the whole model domain (b) the continental shelf.

Nitrate for Interim updates

There were insufficient observations available to assess the quality of interim nitrate. Values are similar to previous years except in the Irish Sea, English Channel and Southern North Sea which see large increases. Variability is greater, especially in shallow areas, and the quality should be assumed to be lower.

IV.3 Phosphate

Phosphate acts in the model in a similar way to nitrate. Phosphate is removed from the water during the growing season by phytoplankton and once the phosphate has been depleted plankton growth may slow or cease until levels are replenished. Sources of phosphate include excretion by plankton and bacteria, breakdown of particulate material and, particularly in winter, mixing from nutrient-rich waters below the surface layer. Nitrate, phosphate and light can all be limiting factors for phytoplankton growth, so the presence of phosphate does not automatically trigger growth.

Figure 15 shows the monthly mean surface phosphate concentration compared to the climatology from the North Sea Biogeochemical Climatology (NSBC, Hinrichs et al., 2017). The seasonal cycle is well reproduced, but values are lower in the model than NSBC observations across the continental shelf, except close to the coast. In the offshelf region model values are higher than observed in the winter and lower in the summer.

Comparison to matched in situ data at all depths from the ICES database (ICES 2014) is shown in Table 7 and Figure 16. In agreement with the NSBC comparison (Figure 15), this shows that the model values are lower than observation everywhere except the off-shelf area. The MAD is 0.1-0.3 mmol m^{-3} for most areas, higher in the Southern North Sea. The correlation is generally highest in the southern part of the domain and the off-shelf area.

The above assessments are for the period 1998-2019, when chlorophyll assimilation is in operation. For 1993-1997 the winter peaks of phosphate are much higher, especially in the on-shelf region (Figure 17).

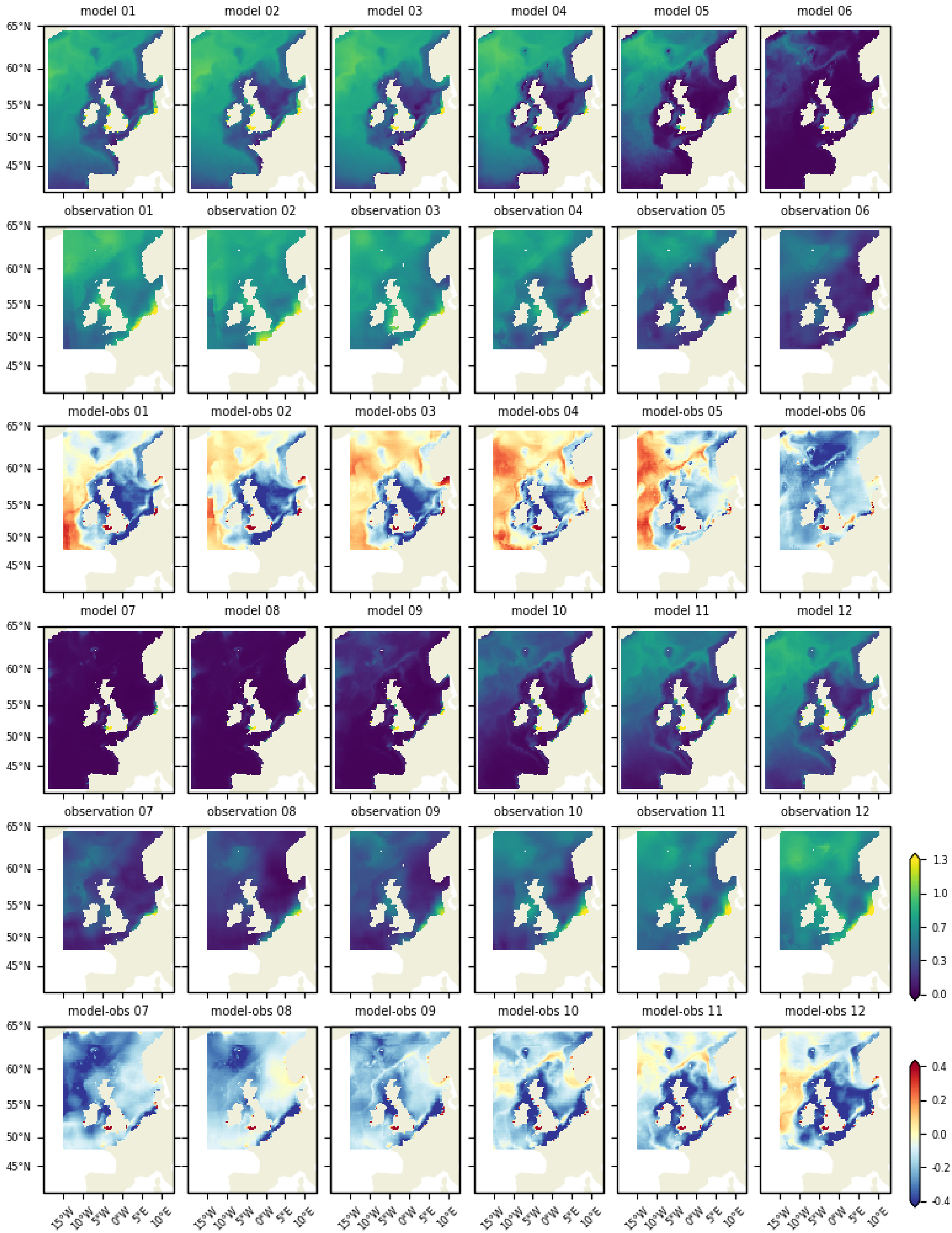


Figure 15 Median monthly surface phosphate concentration (mmol m-3) from the reanalysis (top row) and the North Sea Biogeochemical Climatology (middle row) and the difference between the model and North Sea Biogeochemical Climatology values (bottom row).

Table 7 Statistics for match-ups between monthly model phosphate outputs at all depths and in situ observations from the ICES database (ICES, 2014), for the full domain and sub-regions. See section III for information on the match-up process and statistics provided and the locations of the regions.

Region	n	Bias (mmol m^{-3})	MAD (mmol m^{-3})	Spearman correlation
Full Domain	61385	-0.063	0.179	0.57
Continental shelf	50868	-0.102	0.200	0.51
Offshelf	10506	0.033	0.103	0.79
Norwegian Trench	21239	-0.048	0.188	0.47
Northern North Sea	5577	-0.126	0.157	0.44
Southern North Sea	14816	-0.107	0.246	0.5
English Channel	1763	-0.233	0.297	0.65
Irish Sea	3409	-0.155	0.193	0.51
South Western Approaches	1772	-0.119	0.135	0.75
North Western Approaches	2365	-0.218	0.249	0.56

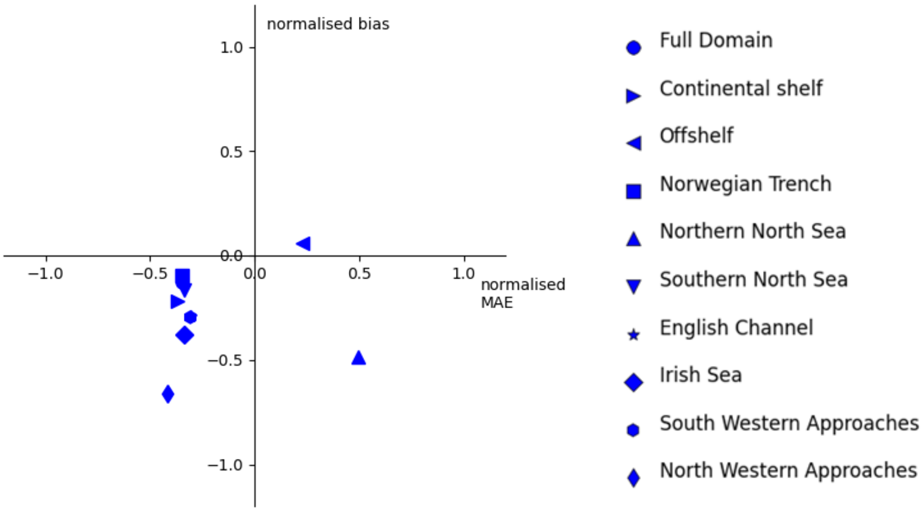


Figure 16 Target diagram for match-ups between monthly model phosphate outputs at all depths and in situ observations from the ICES database (ICES, 2014), for the full domain and sub-regions. See section III for information on how the target diagram is defined.

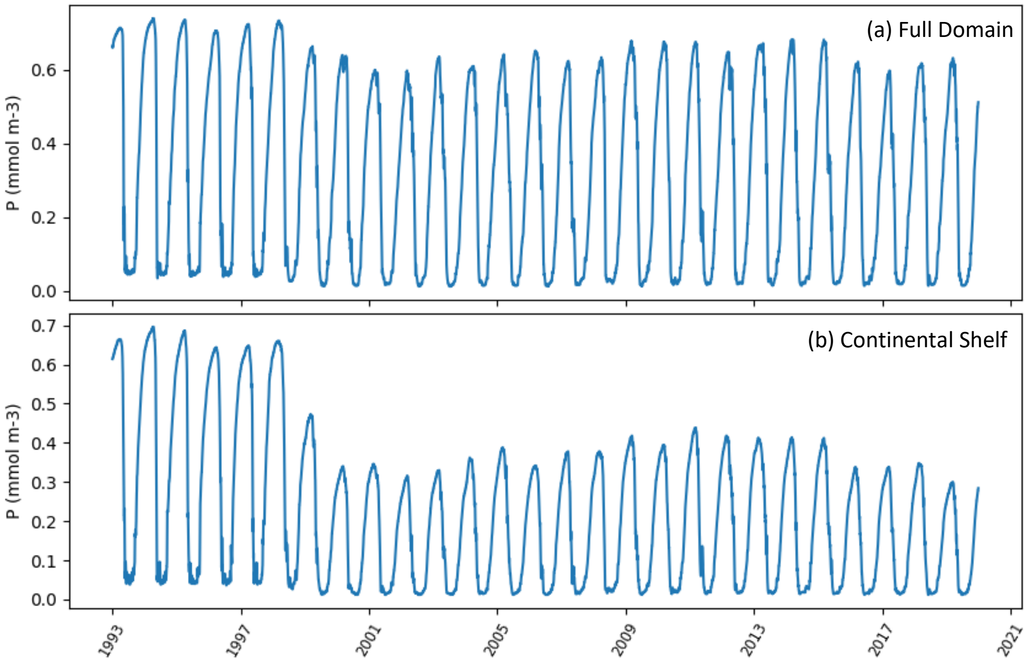


Figure 17 Time series of daily median surface phosphate concentration for (a) the whole model domain (b) the continental shelf.

Phosphate for Interim updates

There were insufficient observations available to assess the quality of interim phosphate. Values are similar to previous years except in the Irish Sea, English Channel and Southern North Sea which see large increases. Variability is greater, especially in shallow areas, and the quality should be assumed to be lower.

IV.4 Dissolved Oxygen

Oxygen is controlled by both physical and biological mechanisms. The solubility of oxygen varies with temperature and salinity, so warmer waters generally have lower oxygen levels. Oxygen concentration can increase due to photosynthesis by phytoplankton and decrease due to respiration by zooplankton and phytoplankton.

Figure 18 shows the monthly mean surface dissolved oxygen concentration compared to the climatology from the North Sea Biogeochemical Climatology (NSBC, Hinrichs et al., 2017). The model values are consistently below NSBC values by 30-50 mmol m^{-3}, but show the same temporal and spatial patterns.

Comparison to matched in situ data at all depths from the ICES database (ICES, 2014) is shown in Table 8 and Figure 19. This also shows the model has consistently lower values than observation, though by a smaller amount: 10-20 mmol m^{-3} on the continental shelf, higher in the off-shelf area. The MAD is 15-20 mmol m^{-3} for most areas, but 30 mmol m^{-3} in the off-shelf region. The model-observation correlation is around 0.6 in all areas except the English Channel. The off-shelf region is the only one where the model variability is higher than that of the observations (Figure 19).

The above assessments are for the period 1998-2019, when chlorophyll assimilation is in operation. For 1993-1997 the range of measurements is broadly the same, though with occasional unusually high values (Figure 20).

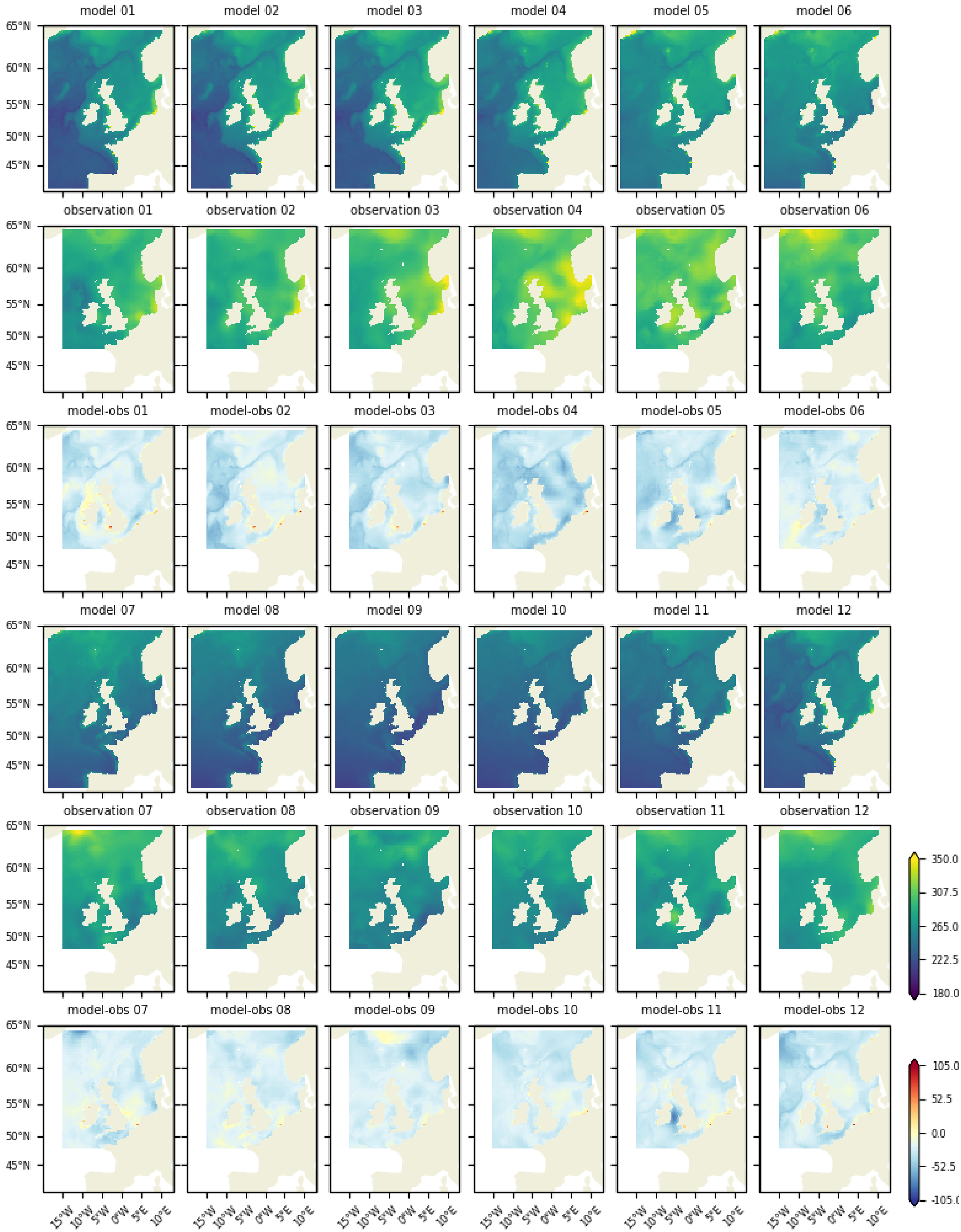


Figure 18 Mean monthly surface dissolved oxygen concentration from the reanalysis (top row) and the North Sea Biogeochemical Climatology (middle row) and the difference between the model and North Sea Biogeochemical Climatology values (bottom row).

Table 8 Statistics for match-ups between monthly model dissolved oxygen outputs at all depths and in situ observations from the ICES database (ICES, 2014), for the full domain and sub-regions. See section III for information on the match-up process and statistics provided and the locations of the regions.

Region	n	Bias (mmol m^{-3})	MAD (mmol m^{-3})	Spearman correlation
Full Domain	110140	-15.77	20.17	0.66
Continental shelf	90747	-14.55	18.74	0.64
Offshelf	19393	-26.87	30.75	0.64
Norwegian Trench	36417	-15.37	20.65	0.64
Northern North Sea	7673	-10.12	13.46	0.56
Southern North Sea	35821	-15.08	18.90	0.71
English Channel	3970	-18.51	19.21	-0.07
Irish Sea	2257	-14.60	16.75	0.62
South Western Approaches	3432	-19.15	22.12	0.55
North Western Approaches	1751	-10.31	16.13	0.59

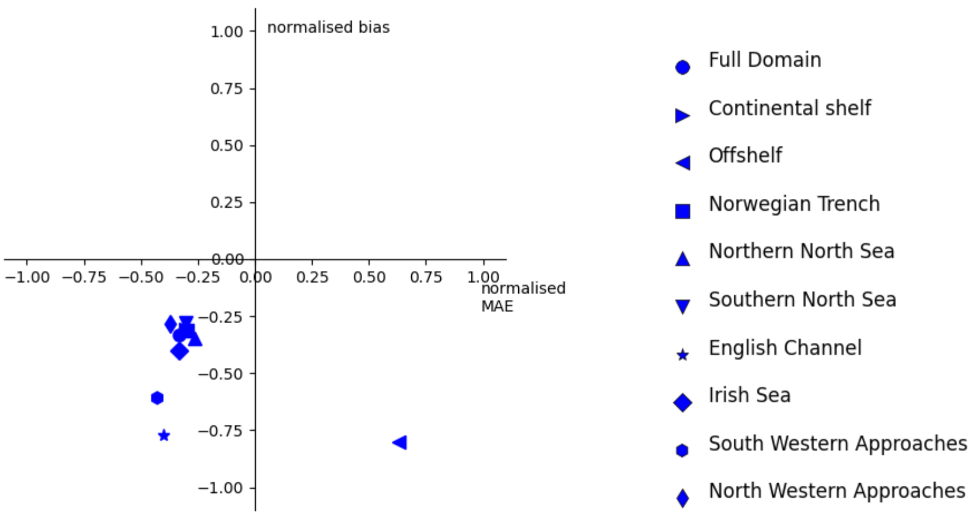


Figure 19 Target diagram for match-ups between monthly model oxygen outputs at all depths and in situ observations from the ICES database (ICES, 2014), for the full domain and sub-regions. See section III for information on how the target diagram is defined.

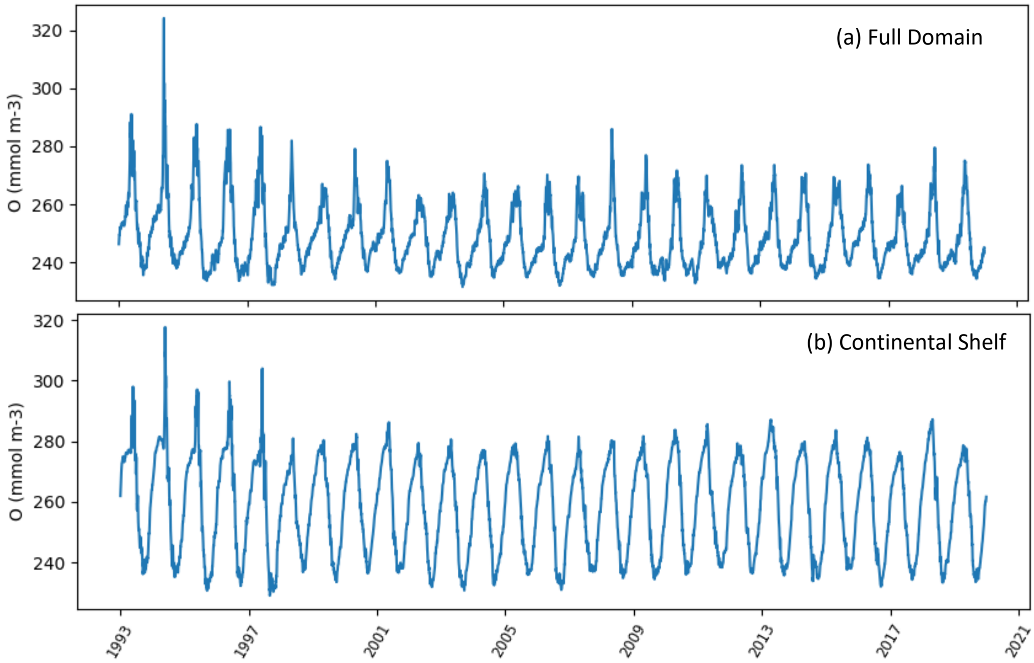


Figure 20 Time series of daily median surface dissolved oxygen concentration for (a) the whole model domain (b) the continental shelf.

Dissolved Oxygen for Interim updates

There were insufficient observations available to assess the quality of interim oxygen. Values are similar to previous years but the variability is greater, especially in shallow areas, and the quality should be assumed to be lower.

IV.5 Surface pCO_2

ERSEM's carbonate system calculates the levels of dissolved inorganic carbon (DIC) and total alkalinity (TA) based on processes of photosynthesis, respiration, calcification and nitrogen and phosphorus flows.
Gas exchange at the atmospheric surface also contributes to the DIC calculation, and temperature and salinity are used to estimate TA. The partial pressure of CO_2 and pH are then calculated from DIC and TA, but there is no feedback to the rest of the system.

Modelled values of the surface partial pressure of carbon dioxide (pCO_2) have been compared to values from the SOCAT database version 2020 (Bakker et al., 2016); maps comparing seasonal averages to gridded observations are shown in Figure 21 and statistics from matching model to observations are given in Table 9 and Figure 22. Spatial patterns broadly match those seen in the observations; agreement is poorest in the English Channel and Southern North Sea where the seasonal variation of modelled values is smaller than observed. The bias is variable in direction and size but is typically around 1 Pa. MAD is around 3 Pa; it is higher in the Irish Sea but based on relatively few observations. Model-observation correlation is low except in the deep water areas. The model has lower variability than observation in shallow areas, higher variability in deep water areas (Figure 22).

The SOCAT values are for fugacity of CO_2, but the difference between fugacity and partial pressure is small in the conditions of this region.

The above assessments are for the period 1998-2019, when chlorophyll assimilation is in operation. For 1993-1997 the variability in pCO_2 is larger, especially in the on-shelf region (Figure 23).

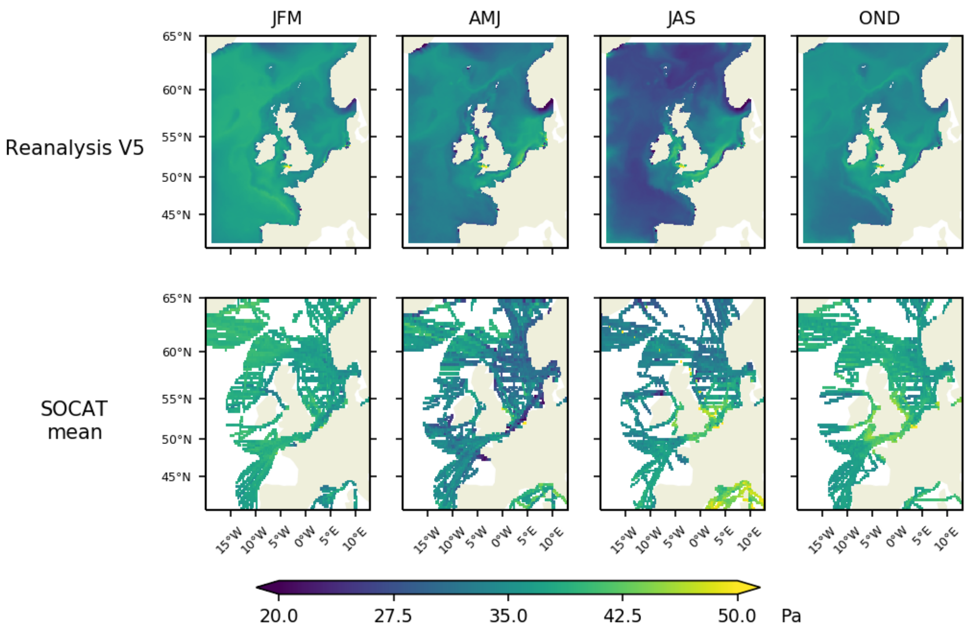


Figure 21 Seasonal average surface pCO2, from the model (top row) and in situ observations from the SOCAT database (bottom row). The SOCAT values are from the gridded coastal observation dataset, sourced from CMEMS product INSITU_GLO_CARBON_REP_OBSERVATIONS_013_050.

Table 9 Statistics for match-ups between monthly model surface pCO2 outputs and in situ observations from the SOCAT database v2020 (Bakker, 2016), for the full domain and sub-regions. See section III for information on the match-up process and statistics provided and the locations of the regions.

Region	n	Bias (Pa)	MAD (Pa)	Spearman correlation
Full Domain	729696	-1.01	3.15	0.39
Continental shelf	413979	-0.65	3.23	0.29
Offshelf	315717	-1.50	3.01	0.5
Norwegian Trench	171527	-0.96	3.12	0.35
Northern North Sea	50769	-1.59	2.94	0.43
Southern North Sea	132376	-0.19	3.84	-0.02
English Channel	29659	-0.23	3.28	0.02
Irish Sea	2962	2.72	5.04	0.1
South Western Approaches	32085	0.88	2.47	0.42
North Western Approaches	7493	-2.27	3.38	0.59

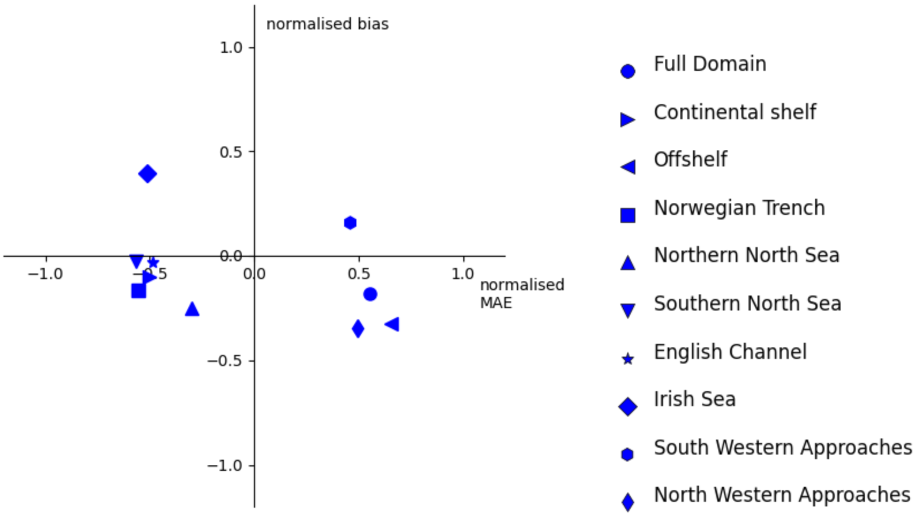


Figure 22 Target diagram for match-ups between monthly model surface pCO2 outputs and in situ observations from the SOCAT v2020 database (Bakker, 2016), for the full domain and sub-regions. See section III for information on how the target diagram is defined.

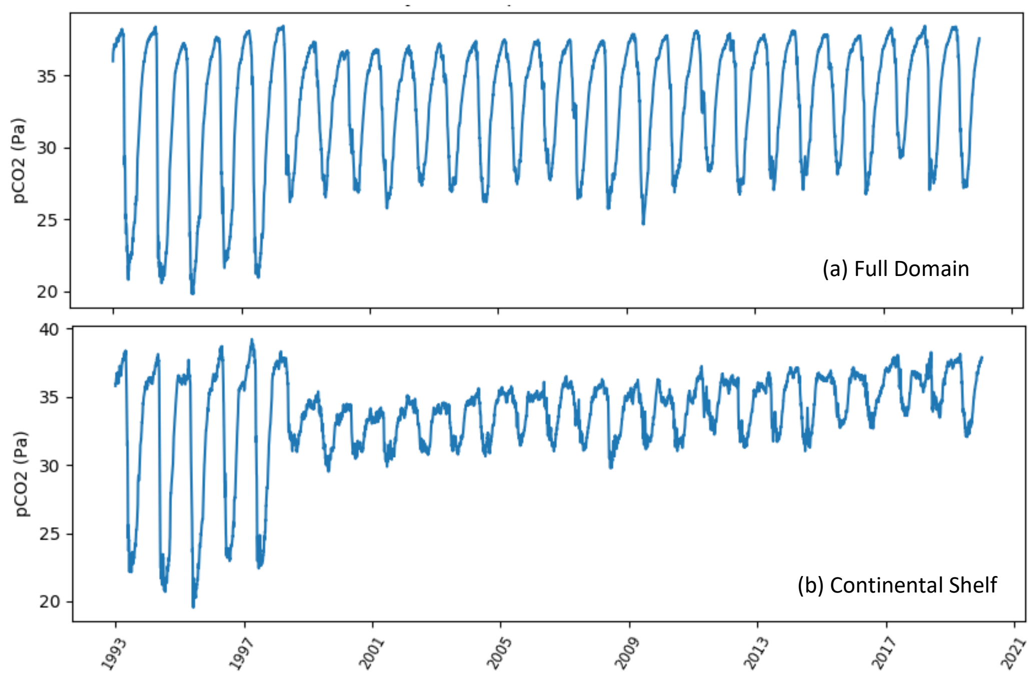


Figure 23 Time series of daily median surface pCO2 concentration for (a) the whole model domain (b) the continental shelf.

Surface pCO_2 for Interim updates

There were insufficient observations available to assess the quality of interim pCO_2. Values are similar to previous years except in the Irish Sea, English Channel and Southern North Sea which see large increases. Variability is greater, especially in shallow areas, and the quality should be assumed to be lower.

IV.6 pH

ERSEM's carbonate system calculates the levels of dissolved inorganic carbon (DIC) and total alkalinity (TA) based on processes of photosynthesis, respiration, calcification and nitrogen and phosphorus flows.
Gas exchange at the atmospheric surface also contributes to the DIC calculation, and temperature and salinity are used to estimate TA. The partial pressure of CO_2 and pH are then calculated from DIC and TA, but there is no feedback to the rest of the system.

Figure 24 shows annual mean surface fields from the model and the gridded GLODAP dataset, taken from CMEMS product INSITU_GLO_CARBON_REP_OBSERVATIONS_013_050. The spatial patterns and size of the modelled pH broadly matches GLODAP – for example, lower values in the southern North Sea – but the relatively low resolution of the GLODAP product limits the possible comparison.

Comparison to in situ data at all depths from the GLODAP and ICES databases is shown in Table 10 and Figure 25; note that there are fewer observations available than for other variables. There is a positive bias in all areas, ranging from 0.01 to 0.1. MAD is 0.06-0.1 in most areas. Model-observation correlation ranges from 0.3 to 0.7

The above assessments are for the period 1998-2019, when chlorophyll assimilation is in operation. For 1993-1997 the variability in pH is larger, especially in the on-shelf region (Figure 26).

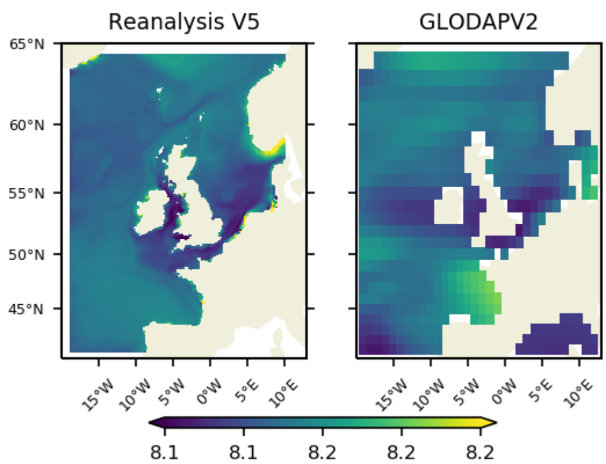


Figure 24 Annual mean surface pH from (left) the model and (right) the GLODAP gridded in situ dataset.

Table 10 Statistics for match-ups between monthly model pH outputs at all depths and in situ observations from the GLODAPv2.2020 (Key, 2015, and Olsen,2016) and ICES (ICES, 2014) databases, for the full domain and sub-regions. See section III for information on the match-up process and statistics provided and the locations of the regions.

Region	n	Bias	MAD	Spearman correlation
Full Domain	29667	0.058	0.092	0.35
Continental shelf	26652	0.063	0.091	0.38
Offshelf	3015	0.016	0.100	0.30
Norwegian Trench	1876	0.008	0.036	0.49
Northern North Sea	1228	0.025	0.034	0.70
Southern North Sea	17301	0.081	0.123	0.33
English Channel	2746	0.076	0.076	0.55
Irish Sea	1646	0.065	0.085	0.45
South Western Approaches	1086	0.039	0.062	0.48
North Western Approaches	863	0.122	0.124	0.42

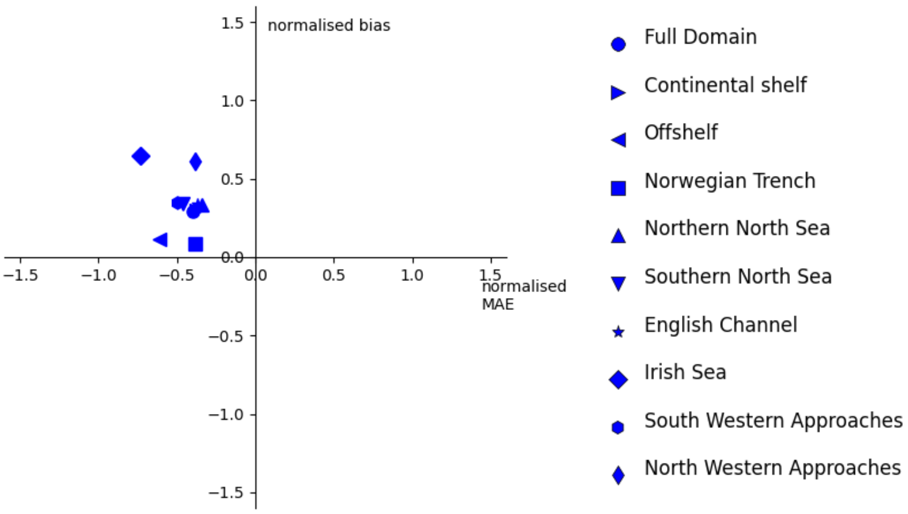


Figure 25 Target diagram for match-ups between monthly model pH outputs at all depths and in situ observations from the GLODAPv2.2020 (Key, 2015, and Olsen,2016) and ICES (ICES, 2014) databases, for the full domain and sub-regions. See section III for information on how the target diagram is defined.

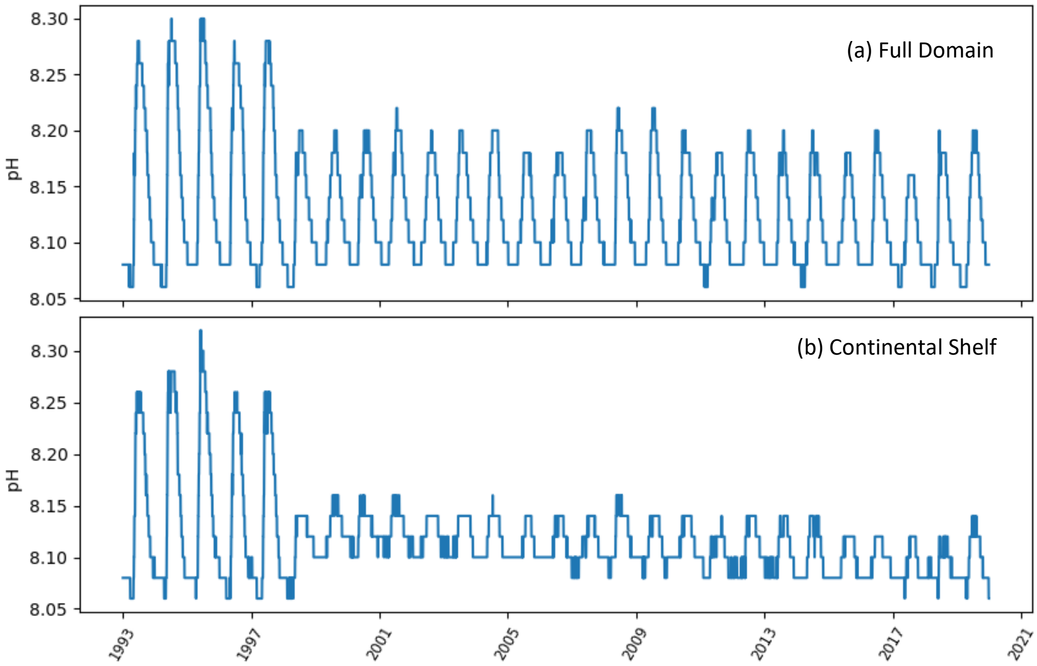


Figure 26 Time series of daily median surface pH concentration for (a) the whole model domain (b) the Continental Shelf.

pH for Interim updates

There were insufficient observations available to assess the quality of interim pH. Values are similar to previous years except in the Irish Sea, English Channel and Southern North Sea which see decreases. Variability is greater, especially in shallow areas, and the quality should be assumed to be lower.

IV.7 Light attenuation

Light attenuation is increased by particulate material in the water, including phytoplankton and zooplankton, so it tends to be higher in the spring and summer. It is also affected by the presence of non-modelled but optically active material in the water, which are advected by water currents and are nudged towards a climatology based on satellite values.

Figure 27 shows the seasonal average attenuation coefficient at the surface for the model and for satellite-derived values for Kd490. Kd490 is a comparable but not identical measure of attenuation, Kd490 refers to attenuation at 490 nm, while the model has no spectral dependence. The same spatial features and seasonal variation can be seen in the model and in satellite observations, though model values tend to be higher.

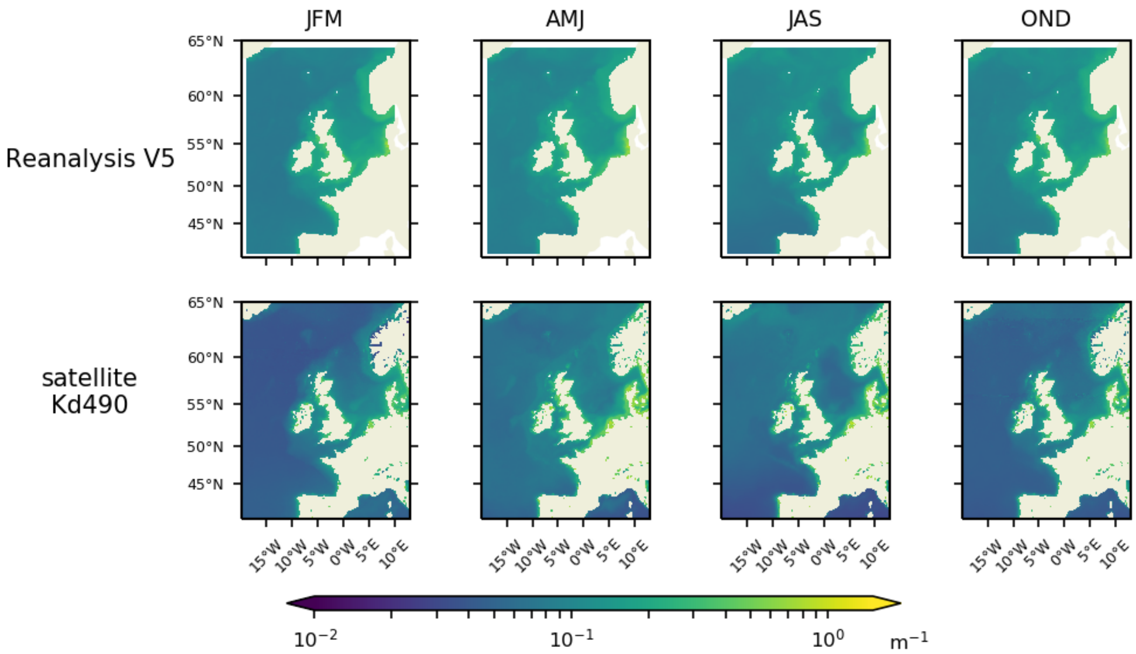


Figure 27 Seasonal average surface light attenuation coefficient: (top row) model values (bottom row) Kd490 derived from ocean colour satellite, CMEMS level 3 product 009_086; this is a comparable but not identical measure of attenuation.

The above plots are for the period 1998-2019, when chlorophyll assimilation is in operation. For 1993-1997 (Figure 28) the variability in attenuation is larger, with high summer values corresponding to higher chlorophyll values (Figure 5). In the shelf region the seasonal minima for attenuation are lower in 1998-2019 than 1993-1997.

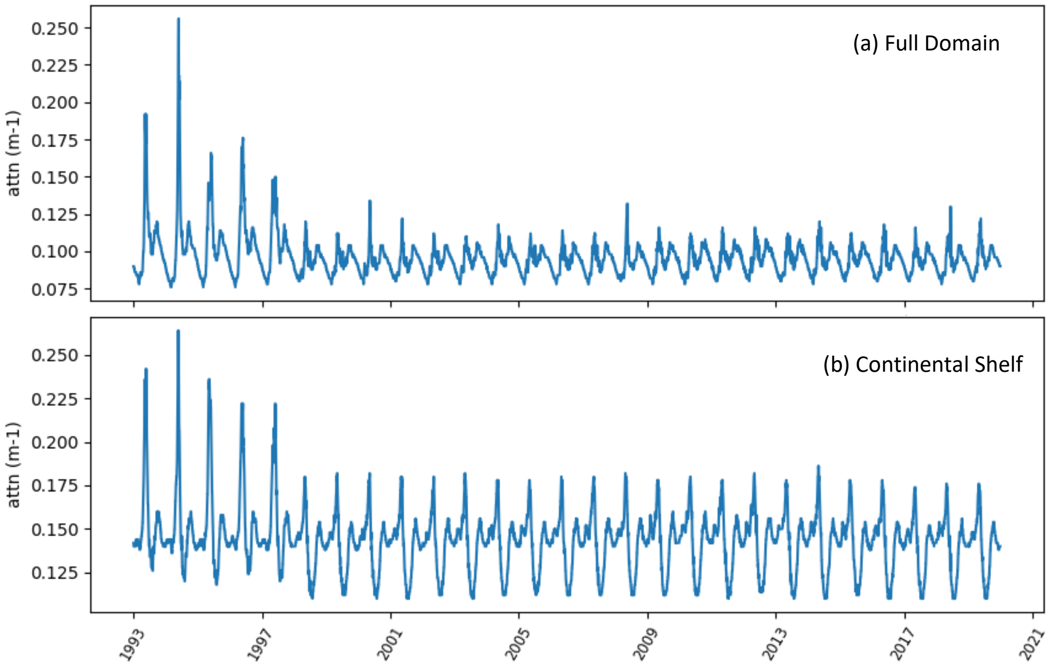


Figure 28 Time series of daily median surface light attenuation for (a) the whole model domain (b) the continental shelf.

Light attenuation for Interim updates

Values are similar to previous years but the variability is greater, especially in shallow areas, and the quality should be assumed to be lower.

V SYSTEM'S NOTICEABLE EVENTS, OUTAGES OR CHANGES

Date	Change/Event description	System version	other
September 2018	A completely new reanalysis was issued, using an updated biogeochemical model and assimilation of satellite ocean colour chlorophyll data. The model domain was unchanged, with the same resolution as the previous reanalysis.	4.0	
January 2019	At end of 2018, the reanalysis was extended to cover the year 2018. It will continue to be extended on a yearly or 6-monthly basis until it is superseded by a future version of the reanalysis. The quality of the 2017 reanalysis was assessed and was found to be similar to previous years. Further extensions will be assessed in the same way. The statistics in this document refer to the period 1993-2016 and this will only change if the quality of the reanalysis is found to change.	4.1	
April 2019	In April 2019, the reanalysis was extended to cover the year 2018. It will continue to be extended on a yearly or 6-monthly basis until it is superseded by a future version of the reanalysis. The quality of the 2018 reanalysis was assessed and was found to be similar to previous years. The ocean colour product was not continued after 28/10/2018, so for the remaining days of the run a comparable near-real-time product was used: OCEANCOLOUR_ATL_CHL_L3_NRT_OBSERVATIONS_009_036. This might produce a small discontinuity at the end of October 2018; however, this is the winter period, when biogeochemical activity is low, so the effect is minor and the estimated accuracy numbers are not affected. Further extensions will be assessed in the same way. The statistics in this document refer to the period 1993-2016 and this will only change if the quality of the reanalysis is found to change.	4.2	

Date	Change/Event description	System version	other
December 2020	A completely new reanalysis was issued, using assimilation of satellite ocean colour plankton functional type chlorophyll data. The model domain was unchanged, with the same resolution as the previous reanalysis.	5.0	
February 2021	Interim monthly updates were added, to extend the reanalysis more closely to real-time. The period October 2018 to December 2019 was rerun with Baltic boundary conditions from the Baltic reanalysis and with PFT Chlorophyll observations. Previously this period had used a Baltic climatology and total Chlorophyll observations as other data wasn't available. The reanalysis was also extended to June 2020. The quality of the reanalysis for the rerun period (Oct 2018 – Dec 2019) and for the extension (Jan-June 2020) was assessed and was found to be similar to previous years.	5.1	

VI QUALITY CHANGES SINCE PREVIOUS VERSION

The current reanalysis (V5) has similar quality to the previous version (V4), which assimilated total chlorophyll rather than plankton functional type chlorophyll. Summary statistics are given below for the comparison to satellite chlorophyll (Table 11) and in situ observations (Table 12). V5 has a slightly larger negative bias for chlorophyll than V4 but it has smaller bias and MAD for nitrate. Overall there is no systematic change in product quality.

In 2021 the reanalysis was extended to add January to June 2020. It will continue to be extended every 6 months. Further extensions will be assessed in the same way.

Table 11 Statistics for match-ups between daily model surface chlorophyll outputs (V5 and V4 reanalyses) and satellite ocean colour chlorophyll (CMEMS product OCEANCOLOUR_ATL_CHL_L4_REP_OBSERVATIONS_009_098), for the full domain and sub-regions.. See section III for information on the match-up process and statistics provided and the locations of the regions.

	V5 reanalysis, 1998-2019			***V4 reanalysis, 1998-2016***		
Region	**Median bias (mg m^{-3})**	**MAD (mg m^{-3})**	**Spearman correlation coefficient**	***Median bias (mg m^{-3})***	***MAD (mg m^{-3})***	***Spearman correlation coefficient***
Full Domain	-0.09	0.15	0.70	*-0.03*	*0.14*	*0.70*
Continental shelf	-0.28	0.33	0.64	*-0.12*	*0.24*	*0.67*
Offshelf	-0.06	0.11	0.68	*-0.01*	*0.11*	*0.66*
Norwegian Trench	-0.20	0.28	0.58	*-0.10*	*0.26*	*0.55*
Northern North Sea	-0.18	0.23	0.55	*-0.10*	*0.19*	*0.53*
Southern North Sea	-0.69	0.71	0.64	*-0.23*	*0.40*	*0.67*
English Channel	-0.42	0.43	0.66	*-0.13*	*0.24*	*0.67*
Irish Sea	-0.71	0.73	0.43	*-0.21*	*0.44*	*0.45*
SW Approaches	-0.20	0.22	0.68	*-0.08*	*0.14*	*0.73*
NW Approaches	-0.19	0.27	0.55	*-0.09*	*0.24*	*0.54*

Table 12 Statistics for comparison to in situ observations at all depths for the current reanalysis (V5) and the previous one (V4), for the whole model domain and the continental shelf. See sections III and IV for details of the observations used and the analysis methods.

Variable	**Region**	**V5 reanalysis, 1998-2019**			***V4 reanalysis, 1998-2016***		
		bias	**MAD**	**corr**	***bias***	***MAD***	***corr***
chlorophyll (mg m^{-3})	Full Domain	-0.37	0.60	0.69	*0.060*	*0.60*	*0.73*
	Shelf	-0.48	0.69	0.67	*-0.05*	*0.68*	*0.69*
nitrate (mmol m^{-3})	Full Domain	2.74	3.64	0.43	*3.61*	*4.15*	*0.42*
	Shelf	3.84	4.55	0.41	*4.02*	*5.27*	*0.39*
phosphate (mmol m^{-3})	Full Domain	-0.06	0.18	0.57	*-0.05*	*0.20*	*0.51*
	Shelf	-0.10	0.20	0.51	*-0.07*	*0.23*	*0.44*
oxygen (mmol m^{-3})	Full Domain	-15.77	20.17	0.66	*-13.22*	*18.82*	*0.7*
	Shelf	-14.55	18.74	0.64	*-15.65*	*20.42*	*0.68*
pCO_2 (Pa)	Full Domain	-1.01	3.15	0.39	*-0.89*	*4.67*	*0.39*
	Shelf	-0.65	3.30	0.29	*0.75*	*4.39*	*0.18*
pH	Full Domain	0.06	0.09	0.35	*0.002*	*0.053*	*0.23*
	Shelf	0.06	0.09	0.38	*0.001*	*0.055*	*0.20*

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