

North Sea Trophic transfer modelling

Progress report



North Sea Trophic transfer modelling

Progress report

Author(s)

Tineke Troost
Jelle Rienstra
Lisa Schneider
Lauriane Vilmin
Sonia Heye

North Sea Trophic transfer modelling

Progress report

Client	Rijkswaterstaat Water, Verkeer en Leefomgeving
Contact	Edwin Verduin
Project reference	SITO-PS IenW 2025 WBK09
Keywords	Wozep, North Sea, ecosystem model, trophic transfer, phytoplankton, zooplankton

Document control

Version	1.0
Date	09-03-2026
Project nr.	11211547-002
Document ID	11211547-002-ZKS-0001
Pages	41
Classification	
Status	Final

Author(s)

	Tineke Troost Jelle Rienstra Lisa Schneider Lauriane Vilmin Sonia Heye	

Summary

Offshore wind (OWF)-driven (and other) changes in primary production can propagate through the marine food web. Proper modelling of the primary producers and their primary consumers is essential to understand and predict impacts on organisms at higher trophic levels. This task is focused on attaining realistic temporal and spatial patterns of modelled algae and zooplankton using the 3D DCSM-FM model.

Current 3D DCSM-FM model versions are not able to sustain a zooplankton population over the winter, probably because the modelled algal winter-concentrations are too low. To find the underlying causes, we took a stepwise approach. First, we checked the zooplankton module for bugs. Next, we compared the 3D DCSM-FM model results to those of previous model versions and validated the algal-growth and light-climate related constituents of the model against data. Finally, we performed several runs to test our findings and to solve the issue.

No bugs were found in the zooplankton module. Cross-comparing results of different model versions turned out to be challenging but showed that the algal growth issue was already (partially) present in previous model versions. In spite of the limited data availability (especially in winter), which made it hard to draw absolute conclusions, results from the validation analysis suggest that there is not one clear and specific cause for the low algal winter concentrations, but we found several factors may contribute to it. These include specific algal parameter settings and the choice for an inorganic matter field (IM).

In the various test runs it was found that resetting several recalibrated algal parameters to their default values and reducing the algal mortality rates are indeed (partial) solutions enabling the zooplankton to survive winter. Interestingly, even when some changes in IM seemed less visible in terms of the algal winter concentrations, it was found that they could still be important for the growth and survival of zooplankton. Also, when including zooplankton into the run, this resulted in a shorter winter periods without algae. Apparently, including zooplankton can itself be part of the solution for the algal winter issue. At the same time, however, it also leads to earlier algal blooms in spring, which increases the mismatch with measurements. This may require some more finetuning of parameters.

Finally, we provide a list of general and concrete recommendations in order to improve both OSPAR and Wozep versions of 3D DCSM-FM with water quality.

Contents

	Summary	4
	Contents	5
1	Introduction	6
2	Materials and methods	7
2.1	3D DCSM-FM water quality model versions	7
2.2	Approach	7
2.2.1	First checks on functioning of grazer module	7
2.2.2	Consequent checks with respect to the algal modelling	7
2.2.3	Specific checks and tasks	8
3	Results	9
3.1	DEBGRZ functioning (Checks in 2024)	9
3.2	Algal concentrations in the 3D DSCM-FM water quality model	10
3.3	Model comparison	11
3.4	Hydrodynamical model validation	15
3.4.1	Temperature	15
3.4.2	Vertical mixing	16
3.5	Water quality model validation	16
3.5.1	Nutrients versus light limitation	16
3.5.2	Incoming light	21
3.5.3	Total extinction rate	21
3.5.4	DOC	23
3.5.5	Inorganic matter (IM)	24
3.5.6	Light extinction coefficients	29
3.5.7	Algal growth-related parameters	29
3.6	Test runs with zooplankton	31
3.6.1	DCSM-Wozep with various rates of algal mortality	31
3.6.2	DCSM-OSPAR with various IM fields	32
4	Discussion and recommendations	34
4.1	Algal winter issue	35
4.2	Zooplankton survival	35
4.3	Recommendations	36
4.3.1	General recommendations	36
4.3.2	Concrete actions	37
5	References	38
A	Effects of zero phytoplankton in the winter period	40

1 Introduction

Long term objective:

Offshore wind (OWF)-driven (and other) changes in primary production can propagate through the marine food web. Proper modelling of the primary producers and their primary consumers is essential to understand and predict impacts on organisms at higher trophic levels. This task is focused on attaining realistic temporal and spatial patterns of modelled algae and zooplankton using the 3D DCSM-FM model.

Problem statement:

Zooplankton biomass has been modelled using the so called 'DEBGRZ' module in earlier North Sea model versions (GENO, ZUNO-coarse), the model configurations of which were used as a starting point for modelling zooplankton in 3D DCSM-FM. Although the earlier zooplankton models did lead to acceptable results regarding zooplankton biomass (e.g. Maar et al., 2018; Troost et al., 2018), the biomass modelled using the 3D DCSM-FM model turned out substantially lower than in the previous model applications as well as lower than observed in CPR Survey data, and could not sustain the zooplankton population over winter.

Objectives:

- Finding the cause of the low zooplankton biomass in the 3D DCSM-FM model
- Exploring solutions to overcome this issue, resulting in more realistic modelled zooplankton biomasses.

Note to the reader:

Please note that this is a technical report relating to underlying processes and the way they are parameterised in the modelling suite. The report is intended for those with some background in marine ecosystem modelling.

2 Materials and methods

2.1 3D DCSM-FM water quality model versions

Currently, two versions of the 3D DCSM-FM water quality model exist, which were set up in overlapping but slightly different contexts and projects: Wozep and OSPAR, which have been run for the years 2007 and 2012-2017 respectively. Both versions show similar issues with respect to the modelled zooplankton population.

In order to avoid confusion further on in the report, here we list the differences between these two model versions. Their main difference lies with the inorganic matter field. In Wozep, the dynamics of fine inorganic sediment are simulated together with water quality and ecology processes (online coupled). In OSPAR, a forcing was used for inorganic matter, which was based on a smooth cosine function of which the amplitude and offset were based on a multi-annual time series of RS-data. Other differences are the river loads which are based on EHYPE results in Wozep and on the ICG-EMO/RID database in OSPAR to comply with international standards. Finally, also the vertical resolutions in deeper areas are different, with Wozep using a sigma-approach, while OSPAR is using a z-sigma approach (with additional layers in areas deeper than 100 m). The “DCSM-Wozep” model comes in two different resolutions (coarse and fine); in this report we mainly focus on the DCSM-Wozep coarse version.

2.2 Approach

2.2.1 First checks on functioning of grazer module

At the end of 2024 we first looked for issues in the DEBGRZ module and its implementation which could be causing the change in outcomes. Note that in this step we made a direct comparison between the DCSM-Wozep model and the ZUNO-coarse model which produced acceptable zooplankton results. Several checks were carried out in 2024 and included:

- the new parameterization of the DEBGRZ module,
- the used version of the code,
- its functioning,
- boundary conditions,
- and the D-Water Quality model configuration.

Since these checks did not reveal any essential changes affecting the grazer results, it was hypothesized that the modelled environmental conditions (temperature and food availability) might be causing the problem rather than the zooplankton module itself. The CMEMS validation results were indeed in line with this hypothesis, leading to consequent checks with respect to the algal modelling (i.e. food availability).

2.2.2 Consequent checks with respect to the algal modelling

To find the cause of the low algae winter-concentrations, we first carried out a model comparison between current and previous model versions.

Second, we discussed the issue and the approach with a selection of our most experienced water quality modelling experts. We considered a range of potential causes (model version, model code, model grid, vertical mixing, light (extinction), algal module set up) and singled out the most probable candidate causing the absence of algae in the winter to be light extinction.

As a result, we decided to focus on validating the modelled light extinction and all related parameters. If the validation would show clear mismatches indeed, we would tune the relevant extinction coefficients or related processes to improve the underwater light climate. If the validation would not show mismatches, we would also investigate changing the algal model and/or its parameterisation. The selection of parameters that we validated, and their dependencies, is shown in Figure 1.

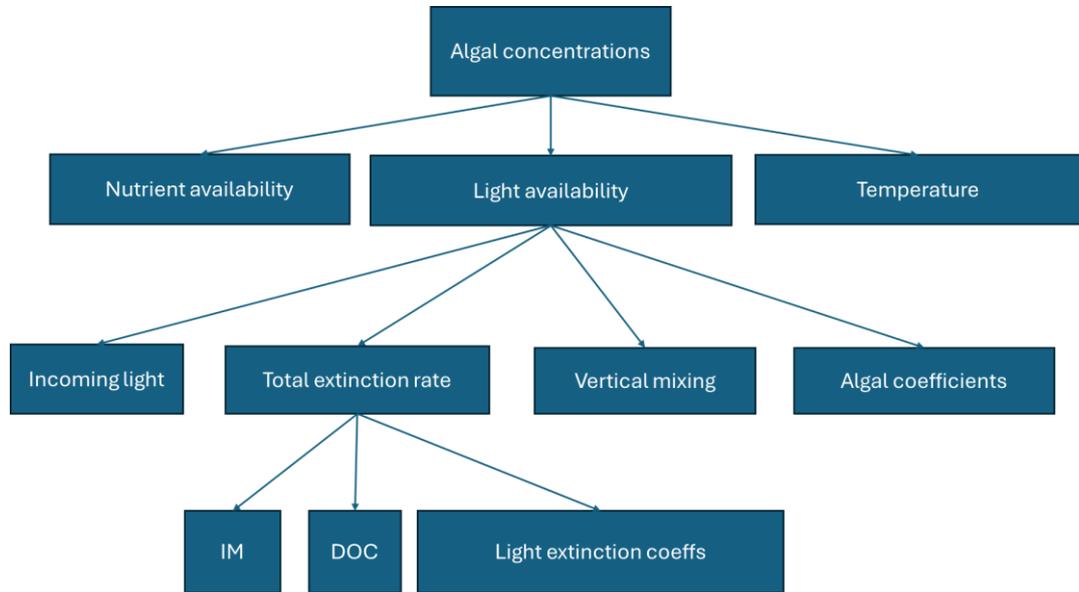


Figure 1 Schematic representation of the dependencies between algal concentrations and other variables or parameters, which was used to find the cause of the low algal winter concentrations.

2.2.3 Specific checks and tasks

- Documenting our reasons to focus on light extinction and related parameters to find the cause for the low algal concentrations in winter/fall.
- Confirming that the algae are light limited and not nutrient limited during their winter-absence.
- Validating the model with respect to the incoming light, the total light extinction rate, as well as its constituents (inorganic matter, algae, detritus, DOC).
- Depending on the outcomes of the previous step, taking steps to improve the performance of the model with respect to the light climate.
- If still necessary, we may also change the algal model and/or its parameterization. For this, we will start by carrying out several sensitivity tests.

3 Results

3.1 DEBGRZ functioning (Checks in 2024)

These checks consisted of a direct comparison between DCSM-Wozep (as described in section 2.1) and ZUNO-coarse (as published in Maar et al., 2018):

- 1 DEBGRZ code/equations and its implementation within DELWAQ/D-Water Quality**

Originally, the ZUNO model was executed using DELWAQ Version 5.08.00.63393M, Mar 08 2019, 19:43:33). To test whether the code version was causing the issue, the ZUNO model was run using the code version (DELWAQ-executable version) with which the 3D DCSM-FM model was run within Wozep (DELWAQ Version 6.2.763e41f8aab9deef87d7306cd7b88b6182b2d5d9, Jan 29 2024, 11:14:06). While this resulted in small differences within the ZUNO model, the overall behaviour and survival outcomes remained similar.

It was however found that DCSM-Wozep was run using a DELWAQ version which does not allow for a density dependent mortality rate of grazers. The density-dependent mortality of zooplankton is a feature that is typically included in Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD)-models. It is needed because the zooplankton mortality is a closure term, which needs compensation for the absence of its predators (and the resulting predator-prey dynamics) in the model. This feature was added in a previous model version (but was not yet included in the main code), based on discussions in the ICES workgroup on Integrated Physical and Ecological Modelling (WGIPEM) in which we compared various North Sea NPZD models (Maar et al., 2018). When using a calibrated value of $Z_ddmfk = 0.005 \text{ mgC/l}$ for the for the density-dependency half-saturation constant, the predicted zooplankton biomasses were higher and more in line with the other models when including the density dependent mortality. So it would be a no regret action to include this feature in the main code and employ it in the 3D DCSM-FM water quality model too.

- 2 DEBGRZ parameters**

The parameter values of the zooplankton were fully identical between the two model versions (ZUNO-coarse and DCSM-Wozep).

- 3 Water quality model configuration**

The substances, processes and parameter values that were applied within the models were compared between ZUNO-coarse and DCSM-Wozep. The two model versions differed in all these aspects (state variables, processes and parameters), as well as in their formatting (online vs offline), which complicated the comparison. Notable differences in substances include absence/presence of particulate and dissolved organic nutrients, and the forcing of inorganic matter. Differences in process parameterisation involve (among others): denitrification, vertical diffusion, mineralization, and algal settling rates. But none of these differences were expected to impact zooplankton negatively in the DCSM-Wozep model, as was based on theoretical considerations involving the direction of change of the involved substances and their relations with zooplankton.

4 DEBGRZ Food intake and metabolism.

The functioning of the DEBGRZ module was studied in more detail using a simplified column model simulating conditions on the FINO1 location, of which the boundary conditions were derived from the DCSM-Wozep model. Mass balances of this model showed that the DEBGRZ model processes are activated and functioning: algae are being eaten by the zooplankton in both models (ingestion rate is positive), but the energy intake is not enough to cover somatic maintenance. Apart from DEBGRZ-parameter values, these terms depend on food availability and temperature.

Based on the above checks and findings we hypothesized that temperature and/or food availability were causing the negative energy intake and low zooplankton biomass in the DSCM-Wozep model.

3.2 Algal concentrations in the 3D DSCM-FM water quality model

The recent CMEMS report (Meszaros 2025) in which the “DCSM-OSPAR” model was compared against in situ observation and RS data, showed that modelled algal concentrations were indeed very low during a long period in fall and winter (see Figure 2). This clearly contrasts with the measured concentrations which are year-round non-zero.

Though the modelled algal concentrations vary with location, and more algae are present in coastal stations, spatial maps of chlorophyll concentrations show that the chlorophyll-concentrations are close to zero in large areas of the North Sea during October and November (Figure 3.) This finding is in line with our hypothesis that low food concentrations are causing the death of the zooplankton in the model. How this finding affects results from previous modelling studies is discussed in 5A.

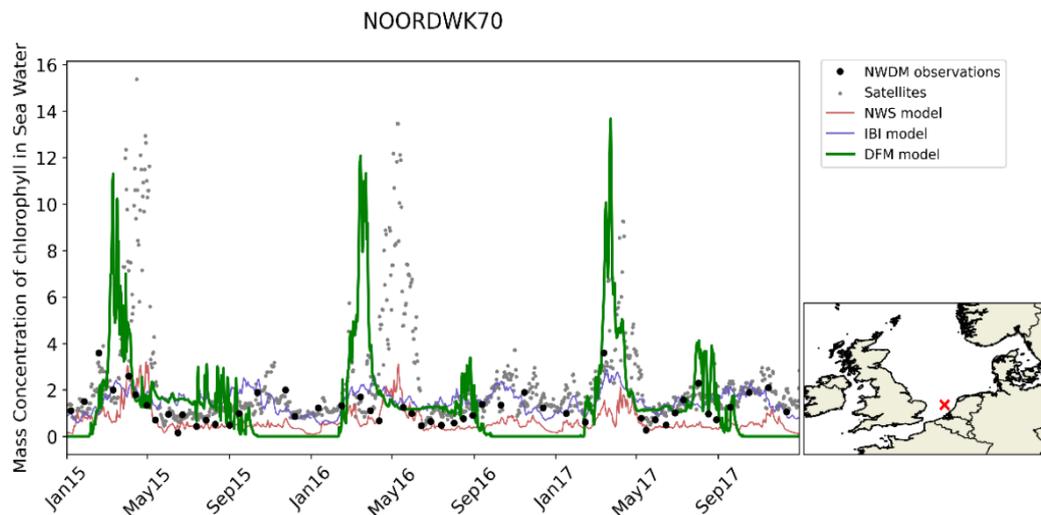


Figure 2 Chlorophyll concentrations (ug/l) measured and modelled at Noordwijk 70. Source: Meszaros et al 2025.

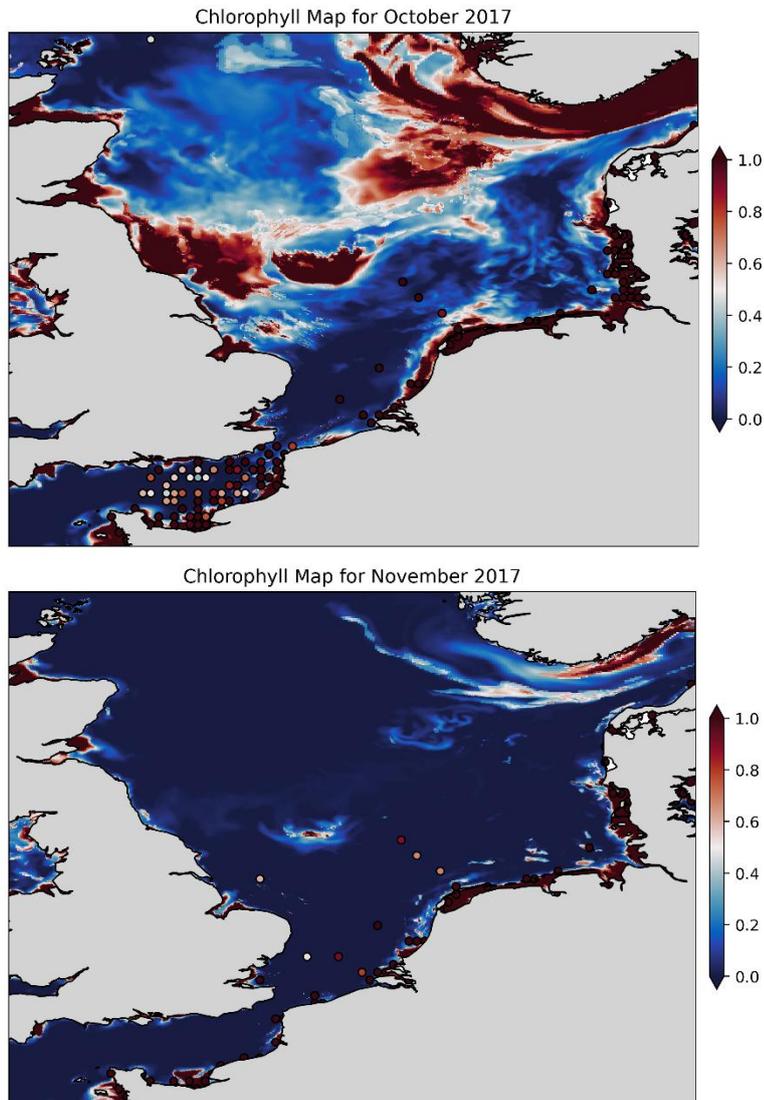


Figure 3 Average chlorophyll concentrations ($\mu\text{g/l}$) in October (upper frame) and November (lower frame) 2017 as modelled by the DCSM-OSPAR model.

3.3 Model comparison

To identify factors causing low algal growth in the 3D DCSM-FM water quality model we compared algae winter concentrations with those of previous model versions (including ZUNO-DD and ZUNO-coarse). These model versions differ with respect to several factors. Most of these are of a technical/numerical nature and are not supposed to affect the outcomes (e.g. spatial domain, grid type/design, spatial and temporal resolution, integration method). Factors that could however make a difference are the inorganic matter field (discussed in section 3.5.5) and the hydrodynamic model determining the vertical mixing (section 3.4.1) and the temperature (section 3.4.1).

The model comparison turned out to be complicated due to several factors:

- **Modelled period** The model versions cover different (periods of) years. This made it difficult to distinguish differences caused by the model versions from inter-annual differences (such as for instance were present in temperature).
- **Output data** The model versions differ with respect to output variables, model domain, and monitoring locations/areas. Notably, in the 3D DCSM-FM model the number of output variables is limited in order to reduce file sizes. Although this is not a fundamental issue, it typically takes a lot of effort and requires rerunning the model to get the extra, desired output.
- **Output format** The model versions differ in terms of output file formats, which makes it difficult to combine data into one plot. This applies both to the time-series outputs and the mass balance information. Also, the format/order of the DELWAQ process file (a.k.a. lsp-file) depends on the executables with which the model has been run. The lsp-file provides an overview of which DELWAQ species, processes and parameters or forcings are used during the computations, which allows for inspecting that the model is representing the processes as the user expected. To enable direct comparison of the lsp-files of different model versions, we had to rerun older model versions with the more recent DELWAQ version that was used in 3D DCSM-FM.
- **Number and thickness of vertical layers** When comparing vertical mixing between two models, the so-called 'FRACTIME' output variables as produced by the VTRANS process may seem suitable candidates. These are tracers that are released every BLOOM timestep to determine the vertical distribution of the algae per location, which are used by the BLOOM module to determine the algal light experience and the resulting algal growth rates. However, the relative nature of the FRACTIMES and their corresponding dependency on the number and thickness of the vertical layers obstruct a direct comparison between two models which differ in this respect.
- **Multiple changes** Since each model version involved several changes (grid, domain, spatial and temporal resolution, hydrodynamic model, executable, substance list, parameter values, forcings) it is hard to pinpoint the source of the resulting differences.

Because of these complexities, we compared the modelled chlorophyll concentrations of these model versions at only one location (Noordwijk70) and used the model results for the available (i.e. different) years (see Figure 4-Figure 8). This comparison showed that the length of the period with low algal concentrations differed per model version, and that long zero-algal periods were not exclusive to 3D DCSM-FM, but already present in e.g. ZUNO-DD (Table 1). The fact that there is no clear trend or trend break in these model versions, makes it unlikely that the cause of the algal issue is related to the technical/numerical differences in the models, but we cannot be sure of this conclusion.

What does stand out is that the ZUNO-coarse model clearly features the shortest period without algae. Also, the Wozep coarse model shows a shorter period without algae than most of the other model versions.

Interestingly, the Wozep fine and coarse grid do show a difference, suggesting an influence of grid resolution after all. Also, both ZUNO-DD model versions differ, but since they use the same grids, the effect on the winter issue is probably due to the different silt fields they use. These differences clearly show that the issue is affected by multiple factors.

Finally, we also compared a run in which the algal BLOOM module (using linear optimization) was replaced by PROTIST. This is a newly developed module calculating primary production using more traditional growth equations (Schneider, 2021). Although PROTIST has not yet been calibrated well, and its simulated timing of the bloom is not in line with the measurements, it does predict a similar duration of the bloom, as well as a similar duration of

the period without algae. This suggests that the low algal winter concentrations are not a BLOOM-specific issue .

Table 1 Overview of previous model versions and their results regarding the algal winter concentrations.

Model version	year(s) looked at in this study	Grid	silt model	no algae in NW70*	Duration of algal absence (months)	Reference/ validation report
DCSM-Wozep (coarse)	2007	FM/sigma	modelled	Nov-Dec/Jan	2.5	Silt: Minns et al 2022 Temperature: Zijl et al 2021 WAQ: Zijl et al 2023
DCSM-Wozep (fine)	2007	FM/sigma	modelled	Oct-Nov+Jan	3	
DCSM-OSPAR	2015-2017	FM/sigma/z	smooth cos	Oct-Jan	4	Meszaros et al 2025
DCSM-OSPAR + PROTIST	2013-2014	FM/sigma/z	smooth cos	Dec-Mar	4	Pers comm Lisa Schneider
ZUNO-DD (MERZW 2011)	2007	Curvilinear-domain-decomposition	Hybrid (cos+random variation off shore and modelled in Dutch	Sep-Feb/ Mar	5.5	ZUNO-DD-slib kalibratie: MV2 (Cronin and Blaas 2015) en MER-zandwinning (Arentz et al 2012); Silt correction for waq: Harezlak et al 2012a en 2012b.
ZUNO-DD (MERZW 2017)	2007	Curvilinear-domain-decomposition	Hybrid (cos+random variation off shore and modelled in Dutch coastal areas)	Sep/Oct-Feb	4.5	Van der Kaaij et al 2018
ZUNO coarse including zooplankton	2008	Curvilinear	cos+random variation	Jan	1	Maar et al., 2018; Troost et al., 2018 v.d. Wolfshaar et al 2021

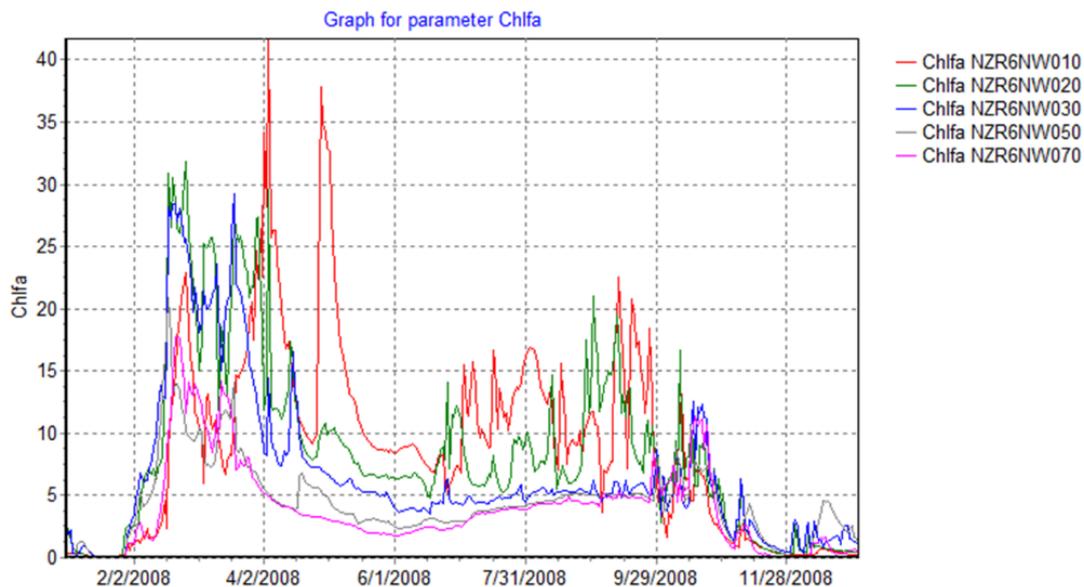


Figure 4 Chlorophyll concentrations (ug/l) as modelled by the ZUNO-coarse model (with zooplankton) at various stations along the Noordwijk transect for the year 2008.

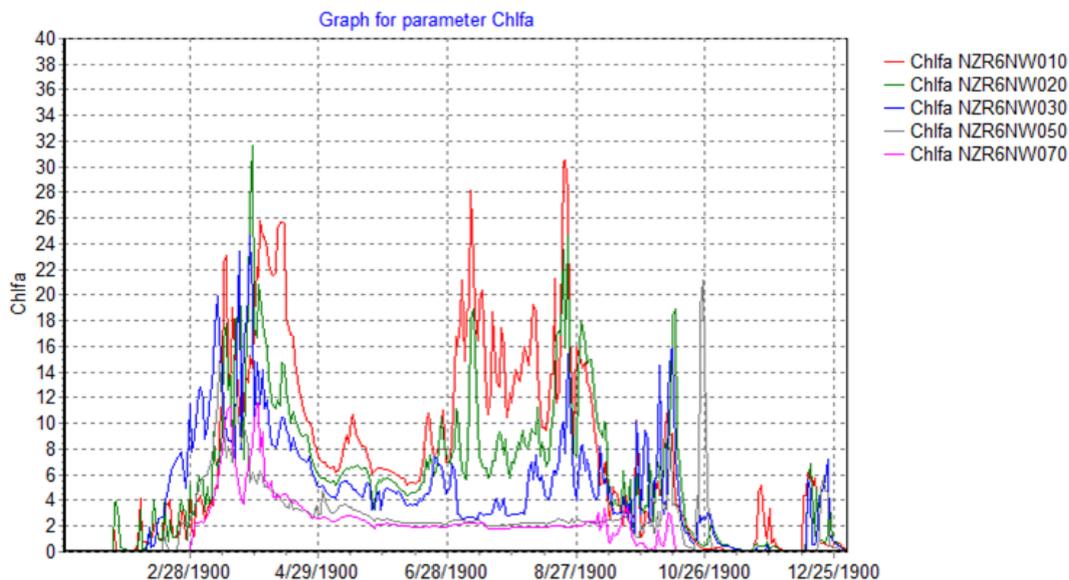


Figure 5 Chlorophyll concentrations (ug/l) as modelled by the ZUNO-DD model (MER 2017) at various stations along the Noordwijk transect for the year 2007 (Note that the timestamp on the x-axis refers to the wrong year, which is inherent to the old model set-up).

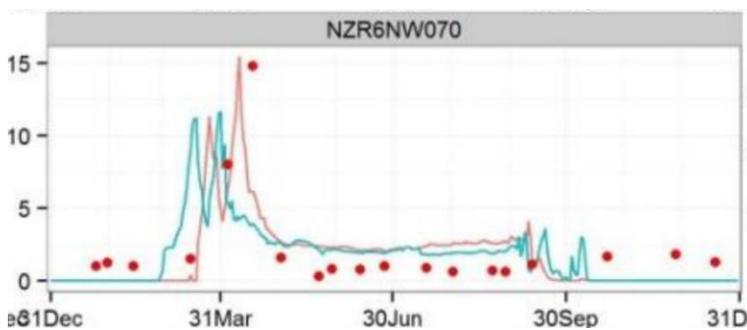


Figure 6 Chlorophyll concentrations (ug/l) as modelled by two versions of the ZUNO-DD model at Noordwijk 70 for the year 2007 (MER2011: red line, and MER2017: blue line). Source: Van der Kaaij 2018.

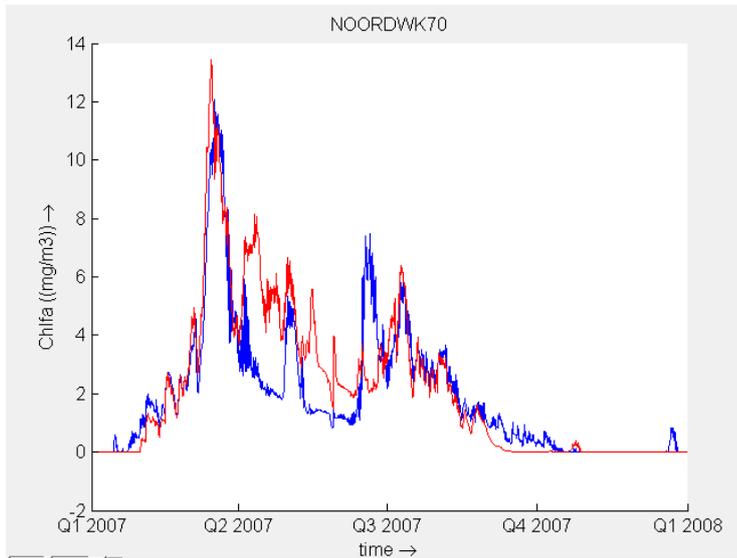


Figure 7 Chlorophyll concentrations (ug/l) as modelled by two versions of the DCSM-Wozep model at Noordwijk 70 for the year 2007 (DCSM-Fine: blue line, and DCSM-coarse: red line).

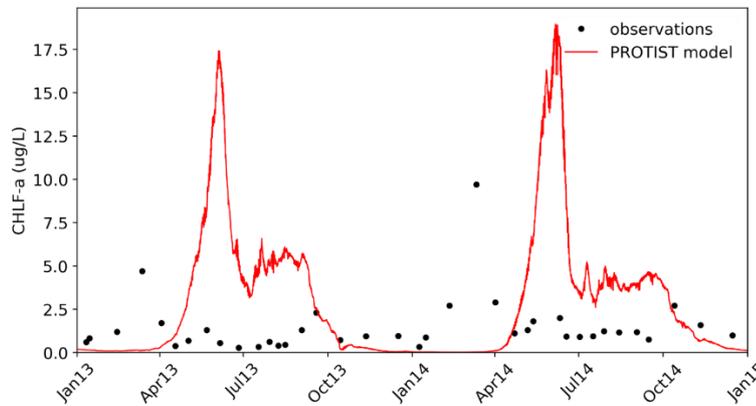


Figure 8 Chlorophyll concentrations (ug/l) as modelled using the PROTIST primary producer module for the years 2013-2014 (red line) using the DCSM-OSPAR set-up.

3.4 Hydrodynamical model validation

3.4.1 Temperature

Temperature is one of the hydrodynamic variables that can be captured with high accuracy by 3D DCSM-FM. In fact, modelled sea surface temperatures match the observed ones well, with an average RMSE of around 0.4 – 0.5 °C in the southern North Sea (Zijl et al 2021). From this we conclude that the algal growth issue is not caused by mismatches in modelled temperatures.

It should be noted though that intra-annual variability in temperatures may still play a role in the growth of the algae and in the survival of the zooplankton in the various model versions, because they model different periods. For example, in 2017, surface water temperatures were significantly lower in winter and spring than in 2007, and higher in the summer period. At most observation stations, the simulated spring bloom overall starts slightly later than in 2007 and coincides with the timing of observed chlorophyll-a peaks (Minns et al 2022). This

may be a partial explanation of why the algae and zooplankton in the DCSM-OSPAR model show a larger period without algae than in DCSM-Wozep.

3.4.2 Vertical mixing

The hydrodynamic model determines the vertical mixing, which may affect the vertical distribution of algae in the water column. This, in turn, may affect the amount of light that the algae experience, and may thus influence their growth.

However, the vertical algal profiles vary over time and space and are difficult to validate due to limited data. Hence, here we fall back on existing information about stratification and vertical silt profiles.

3D DCSM-FM shows a good representation of inter-annual variation in seasonal temperature stratification (Zijl et al 2021). In addition, the vertical profiles of modelled IM seem acceptable and not significantly different from those in previous model versions (pers. comm Thijs van Kessel). Also, the 3D DCSM-FM model generally shows a smaller diffusivity than previous model versions, which positively affects the algal light experience.

To double check our hypothesis that vertical mixing is not the main cause of the algal issue, we tested the sensitivity of the algae growth to their vertical distribution by setting their sedimentation to zero. As expected, this run did not result in algal presence during winter nor allowed the zooplankton to survive.

These findings suggests that the vertical mixing is not the (main) cause of the problem. Remaining factors affecting algal growth are temperature, light and nutrients.

3.5 Water quality model validation

3.5.1 Nutrients versus light limitation

To check whether light or nutrients were limiting algal growth in winter, we looked at the 'growth-limiting factor'. The growth-limiting factor stems from Liebig's Law which states that algae growth is constrained not by total resources, but by the scarcest (limiting) nutrient. Increasing other nutrients will not boost growth until the limiting factor is added. The growth-limiting factor is standard output of the BLOOM module, in which a value of 1 corresponds to limitation and a value of 0 corresponds to non-limitation. When considering a community (instead of an individual), multiple resources can be limiting simultaneously (because a community consists of multiple species, each experiencing a different limiting factor). Environmental conditions (e.g., nutrient availability) can vary spatially and temporally, which also means that the growth-limiting factor can vary in space and time. When averaging the results across multiple locations or over a period of time, the value of the limiting factor may fall between 0 and 1.

Plots showed that light is the only limiting factor during the winter at the NOORDWK70 location (Figure 9), as well is in the entire North Sea (Figure 10, Figure 11, Figure 12). This means that nutrients are amply available for growth of algae and that the modelled algal concentrations are independent of them. This is why we focus the validation on the light-related parameters, and not on the modelled nutrient concentrations.

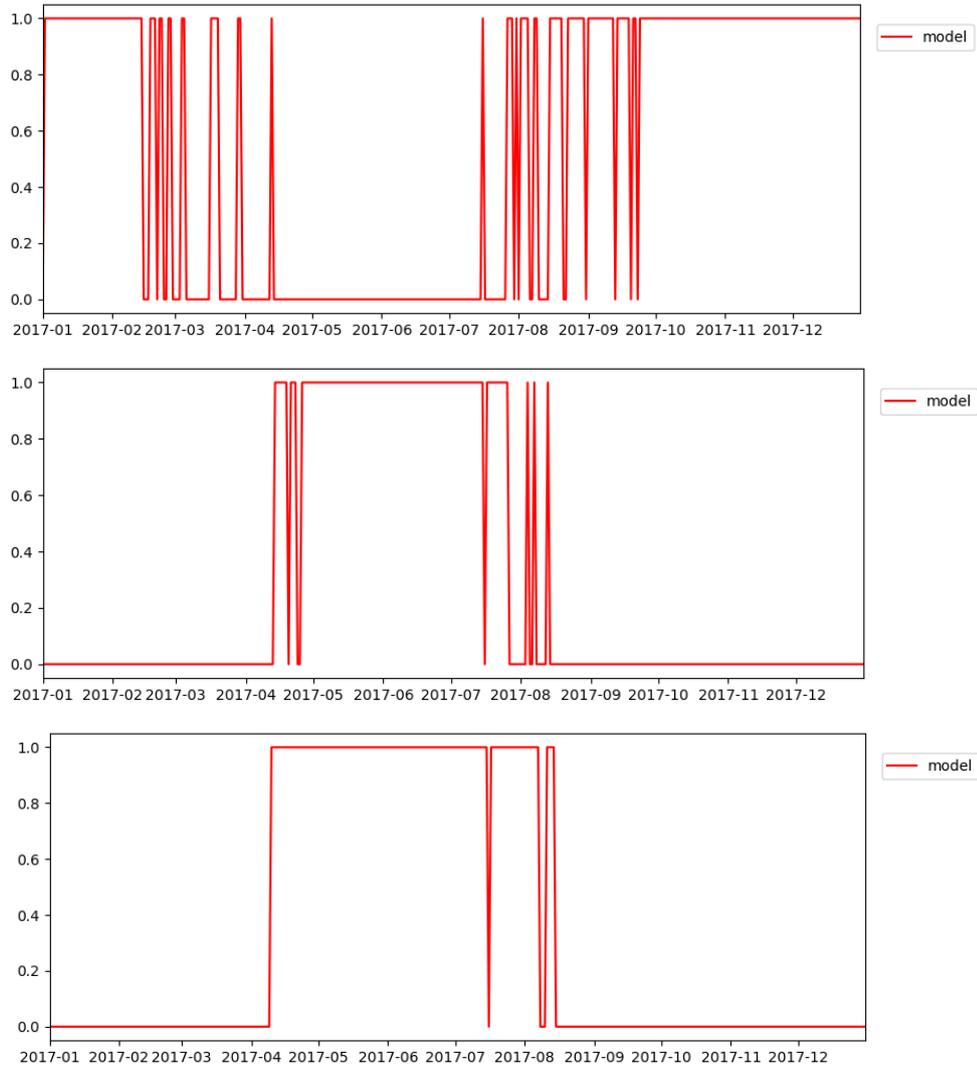
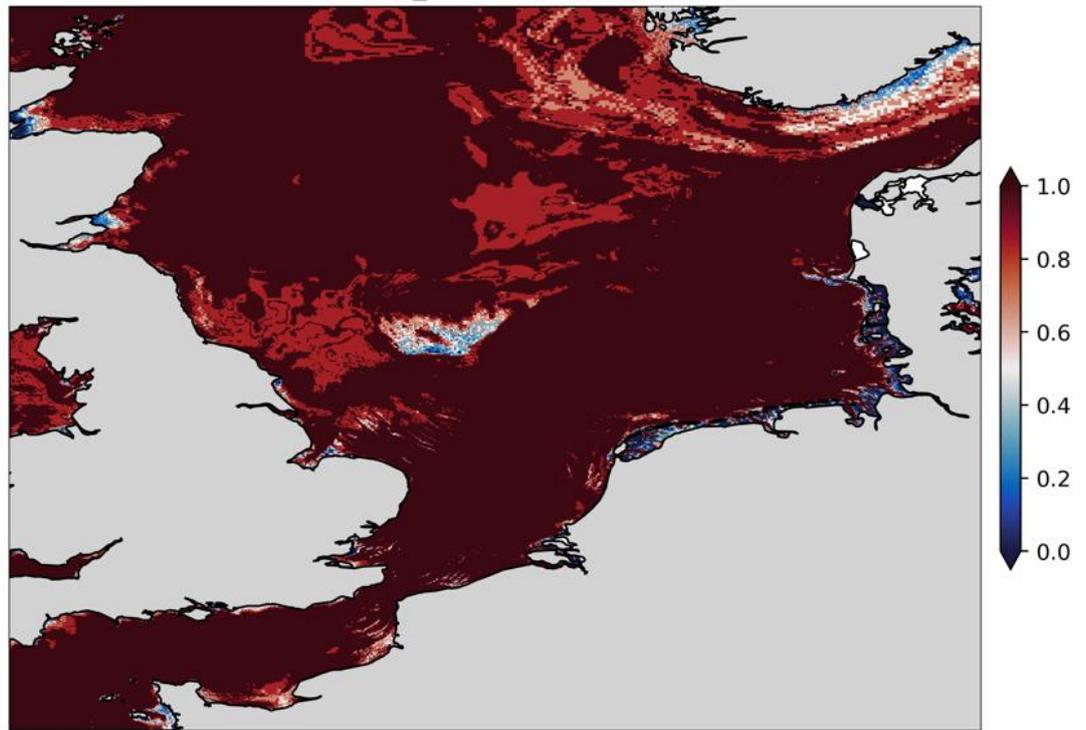


Figure 9 Limitation of light (upper), nitrogen (middle) and phosphorus (lower) at NOORDWK70. A value of 1 indicates that the algae are limited by a certain factor, a value of 0 indicates that they are not limited.

Surface limit_e map for October 2017



Surface limit_e map for November 2017

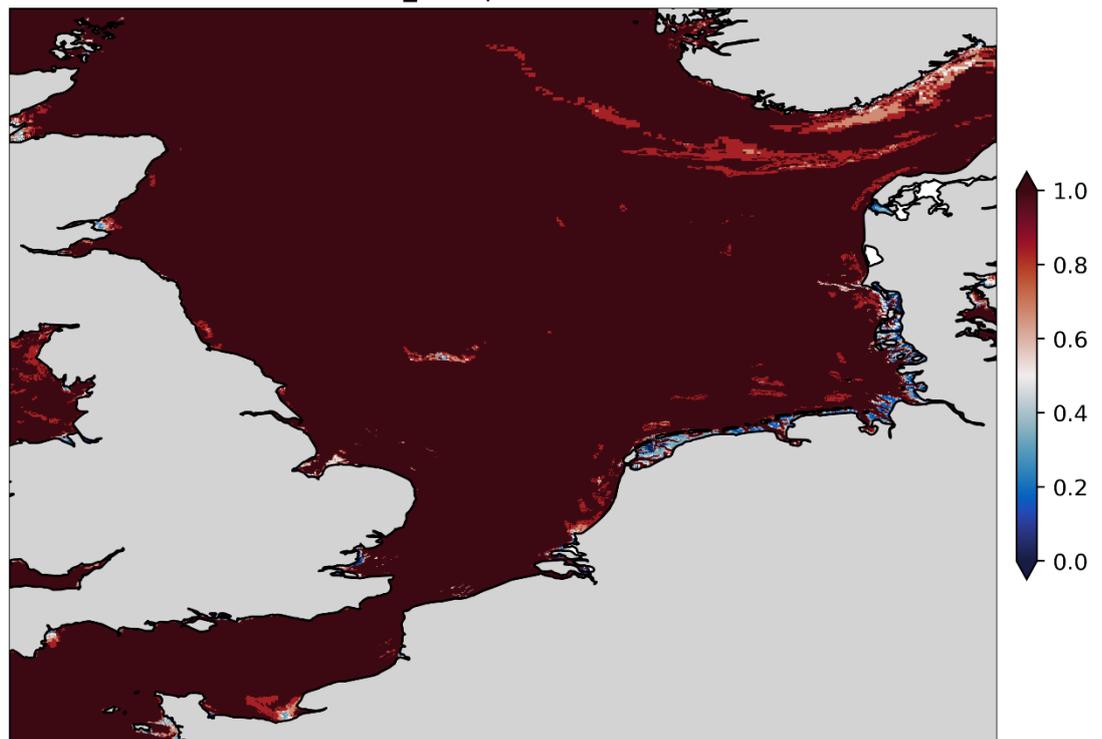
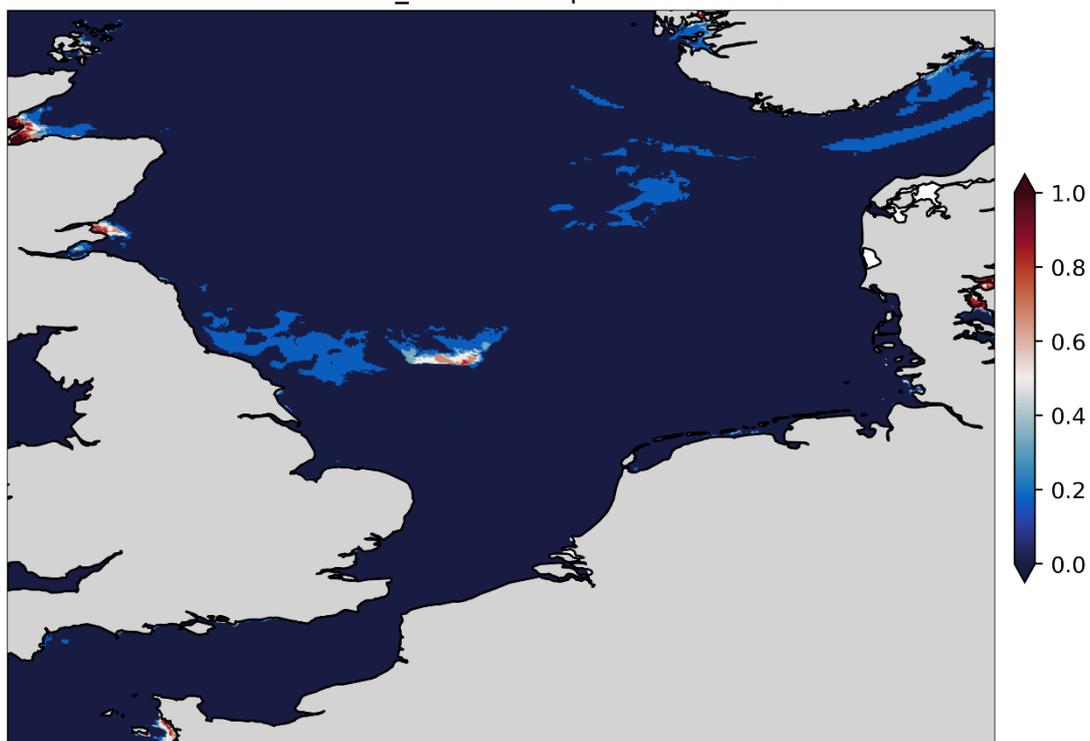


Figure 10. Average light limitation as modelled with DCSM-OSPAR in October 2017 (upper) and November 2017 (lower). An average value of 1 indicates always limited, a value of 0 indicates never limited.

Surface mesh2d_Limit nit map for October 2017



Surface mesh2d_Limit nit map for November 2017



Figure 11 Average nitrogen limitation as modelled with DCSM-OSPAR in October 2017 (upper) and November 2017 (lower). An average value of 1 indicates always limited, a value of 0 indicates never limited.

Surface mesh2d_Limit pho map for October 2017



Surface mesh2d_Limit pho map for November 2017



Figure 12 Average phosphorus limitation as modelled with DCSM-OSPAR in October 2017 (upper) and November 2017 (lower). An average value of 1 indicates always limited, a value of 0 indicates never limited.

3.5.2 Incoming light

The incoming light is driving the light climate in the water column and is included in the model as a forcing function (Figure 13). We confirmed that the incoming radiation (RadSurf) in 3D DCSM-FM was expressed in the correct units (daily averaged W/m^2). A further comparison with the incoming radiation as used in the ZUNO-coarse model version show that both assume the incoming light to be the *total* incoming irradiance, and both multiply it with the same fraction (0.45) to derive the photosynthetic active radiation (PARRAD). Also, both take into account reflection that is calculated on basis of latitude.

Although the exact forcings of incoming light differ due to year and temporal resolution, the incoming radiation does not show a structural difference that would negatively affect the algal growth in the 3D DCSM-FM model. The only difference is that the latitude of the ZUNO-coarse model is provided as one (more or less average) value (which makes the incoming light spatially constant), whereas that of 3D DCSM-FM is spatially varying. The impact of this difference is expected to be relatively small, since the total domain of ZUNO-coarse is much smaller than that of 3D DCSM-FM, and the corresponding latitude-related variation in incoming light is not very large.

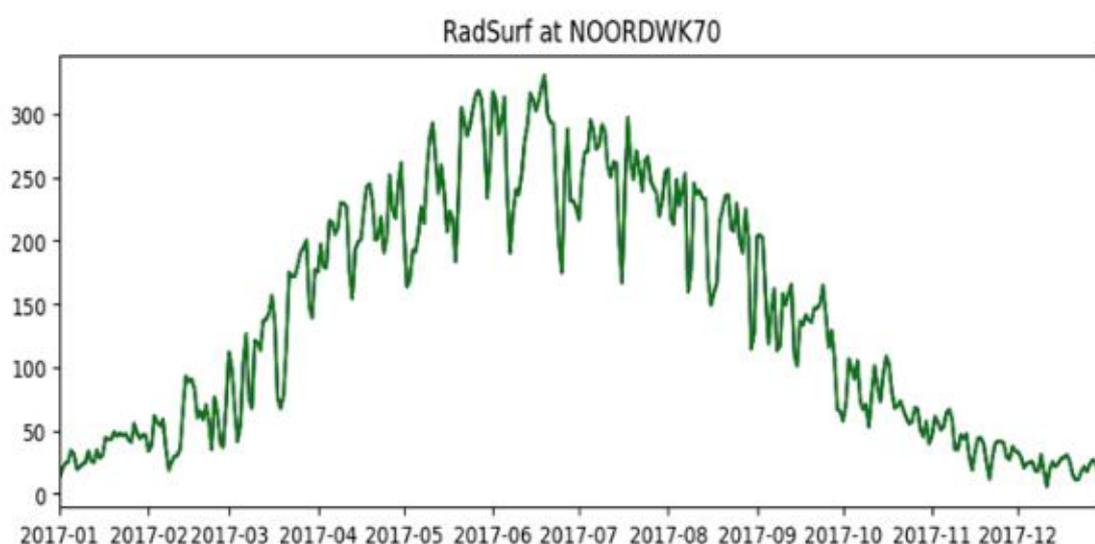


Figure 13. Total incoming radiation (W/m^2) as used by the DCSM-OSPAR water quality model. The figure shows only the Noordwijk 70 location.

3.5.3 Total extinction rate

The data availability on light extinction is rather limited, especially during winter. This makes it difficult to validate the model results on total extinction and draw absolute conclusions. For near-shore locations, somewhat more data points seem to be available.

Comparison of the modelled extinction rate with the observed values in Noordwijk70 suggests a reasonable match (Figure 14). On average, the modelled values lie within the observed ranges, although they do lack variability. In nearshore locations the modelled light extinctions seem slightly underestimated. At first sight, this may suggest that the modelled total light extinction is not causing the algal growth issue, but the mismatch in variability (especially in winter) still may be an essential factor (also see section 3.5.5).

In view of the limited data availability for total extinction, we also looked at the underlying constituents contributing to it. Biggest contributors are DOC and inorganic matter (Figure 15), which are discussed in following sections. Further, it should be noted that including zooplankton in the model will affect the phytoplankton biomass, which in turn will affect the total light extinction; calibration or validation should thus preferably be done on a model version including zooplankton.

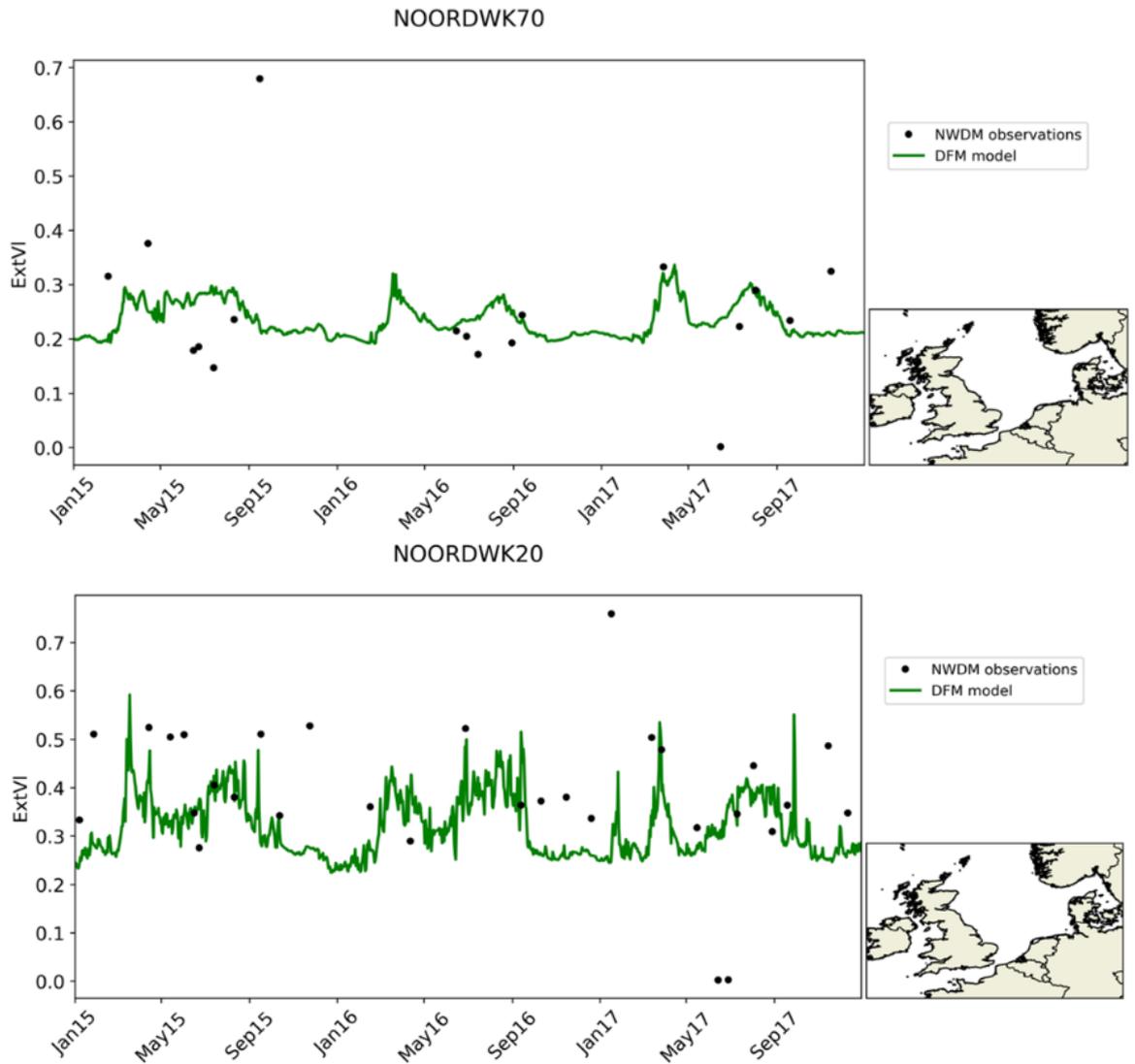


Figure 14. Total extinction (1/m) measured and modelled by the DCSM-OSPAR model at Noordwijk 70 (upper frame) and Noordwijk 20 (lower frame).

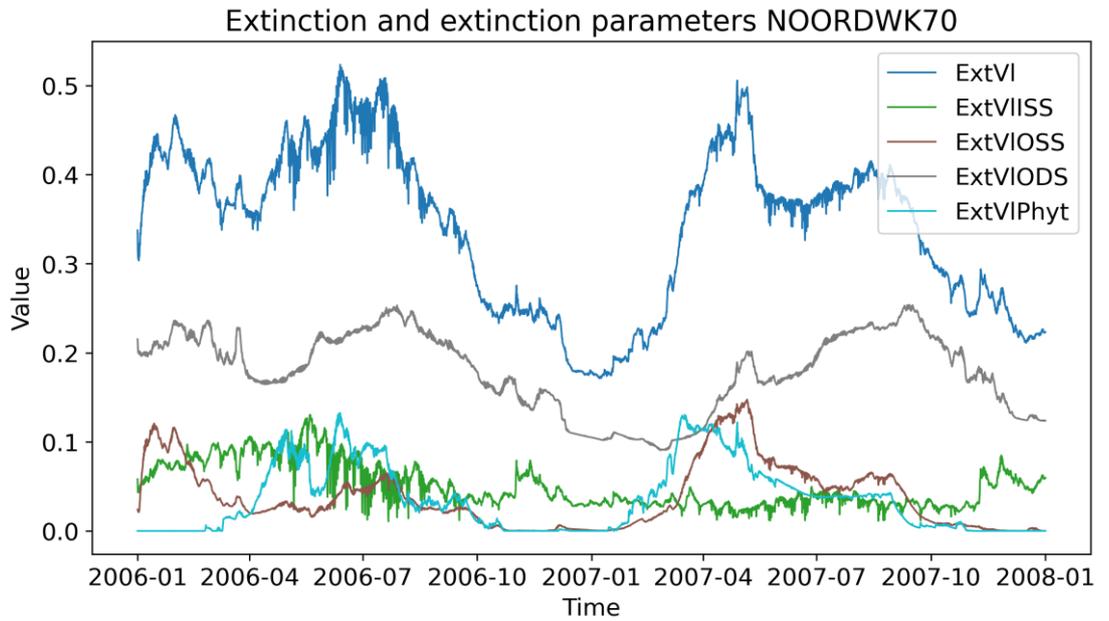
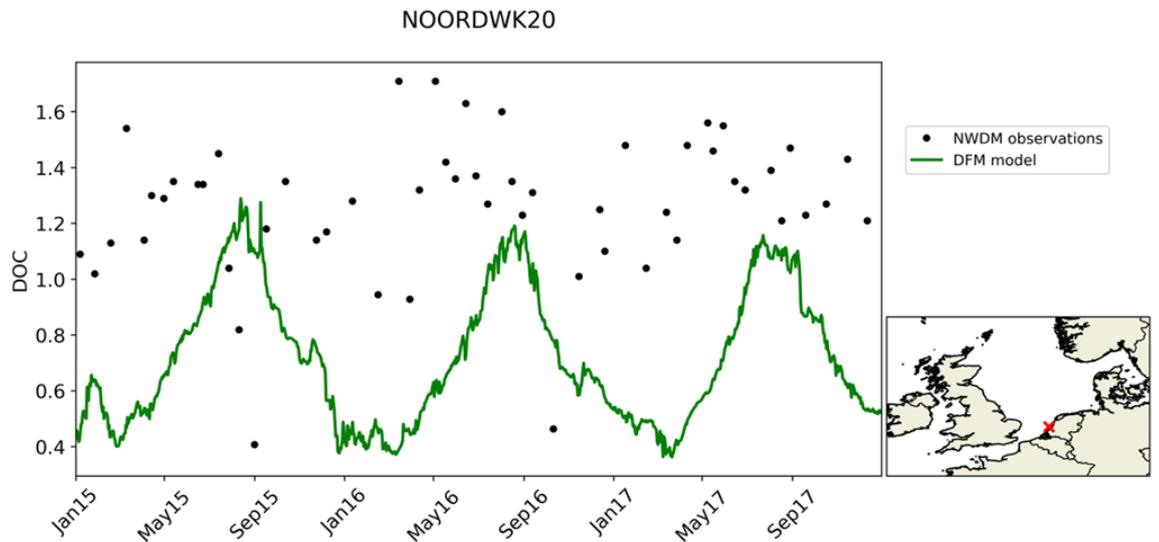


Figure 15. The various fractions contributing to the total extinction ($1/m$) as modelled by the DCSM-Wozep coarse model (including zooplankton) at Noordwijk 70.

3.5.4

DOC

For DOC no observation data were available for Noordwijk70. However, looking at other locations, the modelled DOC seemed to clearly underestimate the observations (Figure 16). Hence, there is no reason to assume that DOC causes the algal growth issue.



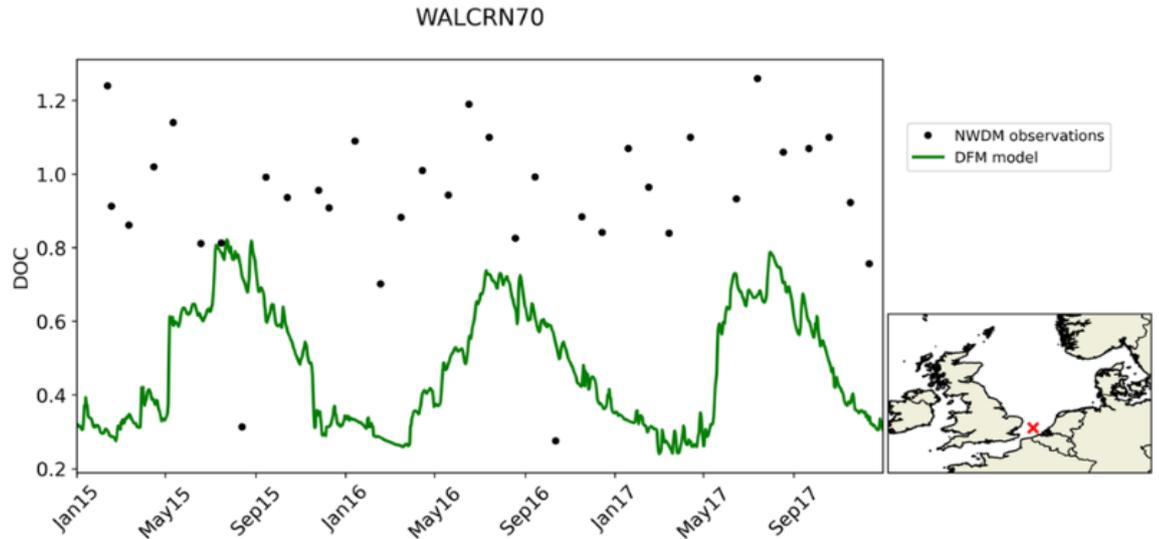


Figure 16. DOC concentrations (mgC/l) as measured and modelled by the DCSM-OSPAR model at Noordwijk 70 (upper frame) and Walcheren 70 (lower frame).

3.5.5 Inorganic matter (IM)

IM has been included in water quality models in various ways that have changed over time and with model version (Table 1). In the two 3D DCSM-FM water quality model versions (Wozep and OSPAR) different IM forcings have been used, both of which are discussed below. For comparison, also the IM forcing as used in the ZUNO-coarse model is discussed, as well as a newly developed inorganic matter field based on RS-data that has become available only recently.

IM in DCSM Wozep

Wozep was the first project where the fully online-coupled 3D DCSM-FM model, incorporating both fine sediment and water quality and ecology processes was developed and applied. Validation was carried out against measured suspended sediment concentrations (SSC, Figure 17). The comparison shows a quite good match especially in the locations closer to the shore. However, in the further offshore located stations, the IM concentrations seem to be rather underestimated. Initially, when this IM field was first implemented in the 3D DCSM-FM model in an earlier phases of the Wozep project, this resulted in a large overestimation of algal growth. To solve this issue, DOC was added to the model and several algal parameters were recalibrated (see section 3.5.7 and Zijl et al., 2023).

Note that also differences exist between the coarse and fine grid model versions. The coarser version of the model tends to underestimate sediment concentrations along the coast.

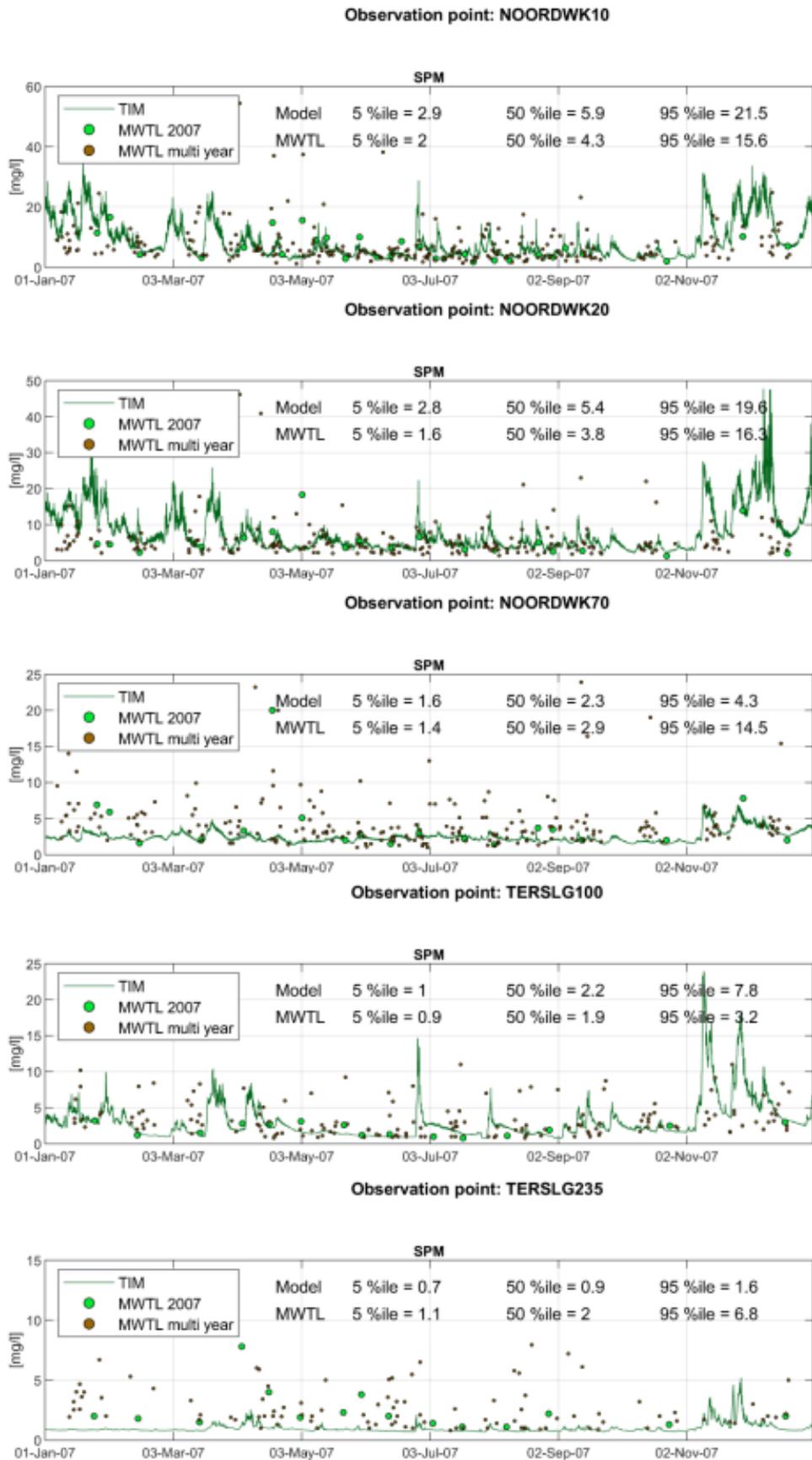
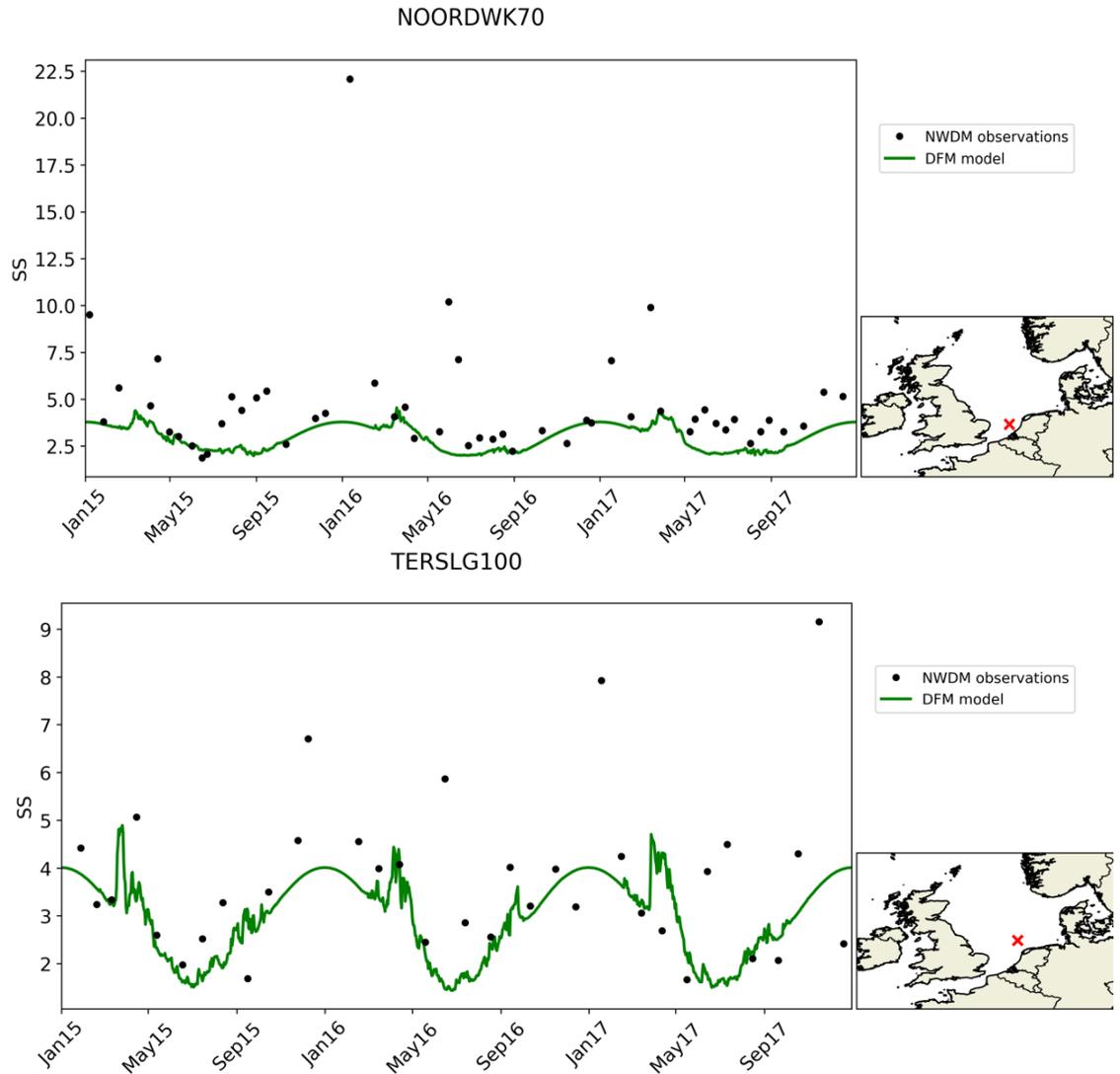


Figure 17. Surface sediment concentrations (SSC, mg/l) as measured and modelled by the DCSM-Wozep model at various station. Source: Minns et al 2022.

IM in DCSM OSPAR

Within the OSPAR context, IM is forced using a smooth cosine calibrated on basis of RS-data from MERIS (Nechad et al 2010).

This IM forcing was validated by comparing modelled against observed suspended solids (SS Figure 18). Note that SS also includes other substances than IM, such as (living or dead) algae, which can be seen from the modelled SPM curves which do not always follow a smooth cosine function. However, these deviations occur not often (mainly during the spring bloom) and are not very large. Results show that on average the modelled SS fall well within the observed ranges, but that it does not capture the large variability that is present in the observations.



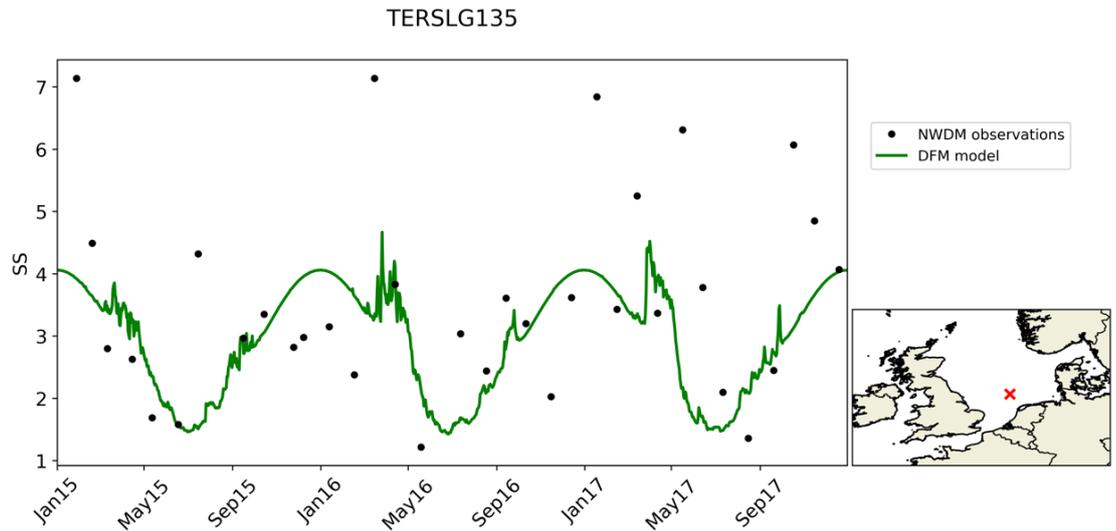


Figure 18. Suspended sediment concentrations (mg/l) as measured and modelled by the DCSM-OSPAR model at various locations.

IM in ZUNO-coarse and ZUNO-DD

In the old ZUNO-coarse model where zooplankton were surviving and algae were present during winter, IM was forced in the model using a similar cosine as in the DCSM-OSPAR version. However, temporal variability was added to the forcing function based on wind speed and a random generator. The resulting temporal variation in IM seems quite relevant for the modelled algae, since small winter blooms occur exactly on the moments of low IM (Figure 19).

The ZUNO-DD model version was the first to use a modelled silt field as input for the water quality model. In Arentz et al. (2012) the results are compared to those when using the random cosine forcing. This was the first time that modelled silt forcing led to reasonable chlorophyll concentrations. However, the near-shore results were clearly better than those offshore, where the bloom season started later and was shorter, resulting in a longer period without algae. In their report, Arentz et al. discuss the complexity of calibrating the water quality model and emphasizes that it is only useful to calibrate the water quality model after the silt model has been calibrated for the full North Sea domain. The extinction coefficient of suspended matter is suggested as a good candidate to calibrate the water quality model.

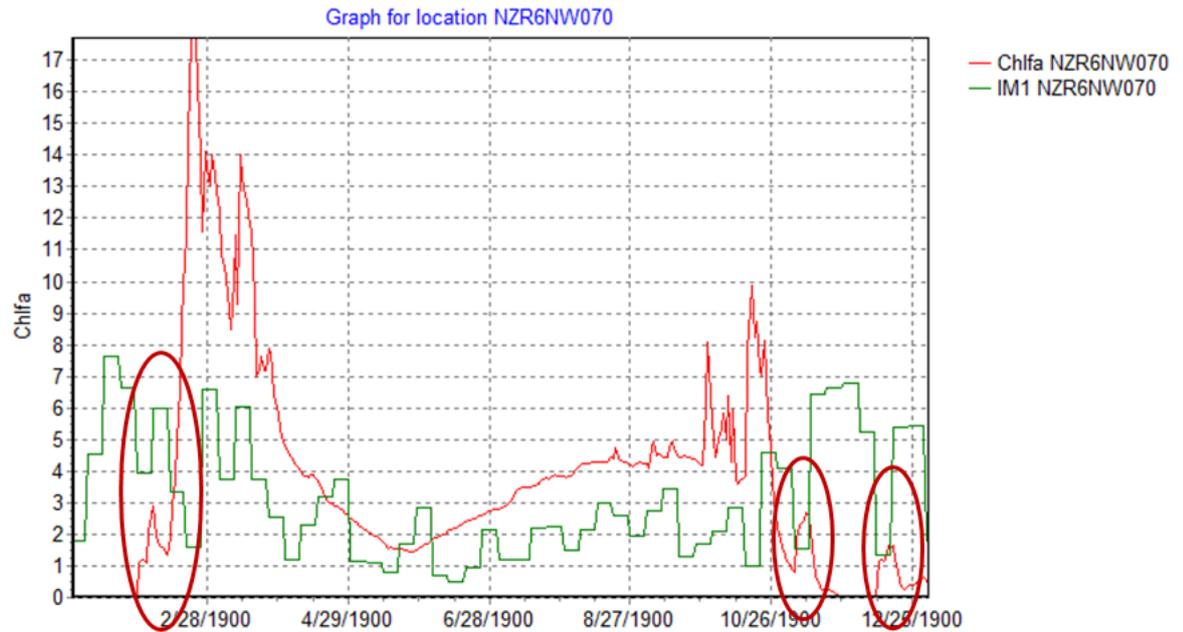


Figure 19. Chlorophyll concentrations in ug/l (red line) as modelled by the ZUNO-coarse model (with zooplankton) at Noordwijk 70 and the forced inorganic matter field based on a cosine function and wind-based variations (green line).

Newly developed RS-based IM field

Recently, a new inorganic matter field has been developed on basis of RS-data by Lotta Beyaard (Deltares, for the Horizon Europe FOCCUS project). Because it closely follows the local measurements, this field is better at representing both the observed amplitude and variability across all regions of the North Sea than the IM field that is currently used in DCSM-OSPAR (Figure 20). Note that the RS data used by Lotta are from different satellite products (focussing more on offshore/clear waters) than those on which the smooth cosine field used in the DCSM-OSPAR version was based (focussing more on coastal/turbid waters), which suggests some room for improvement might still be possible.

Surprisingly, this IM field only has a small effect on the algal results; the spring bloom starts slightly earlier, and algae are sustained slightly longer in fall/winter than the base run using the smooth cosine IM field (Figure 21). This could indicate that the inorganic matter field plays a smaller role in the algal winter concentrations than we were originally thinking.

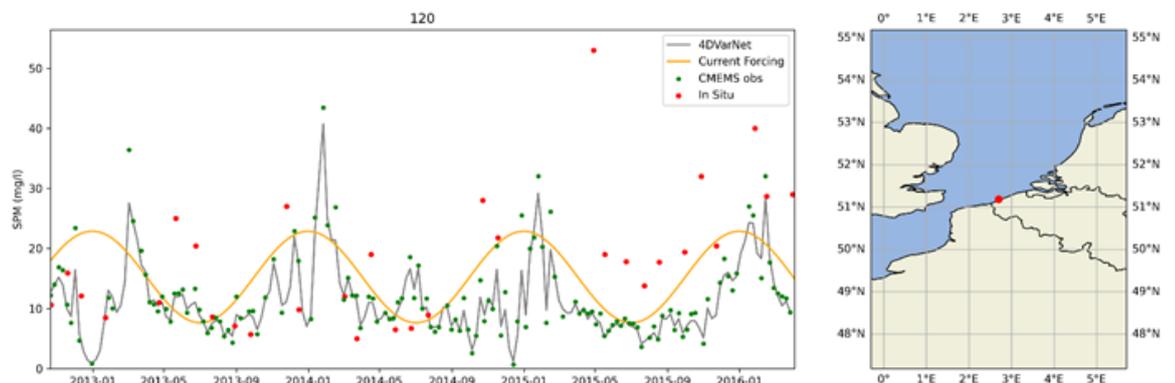


Figure 20. The newly developed RS-data based IM field in mg/l (grey lines) as compared to those of DCSM-OSPAR (yellow line) and measurements. Source: pers. comm Lotta Beyaard.

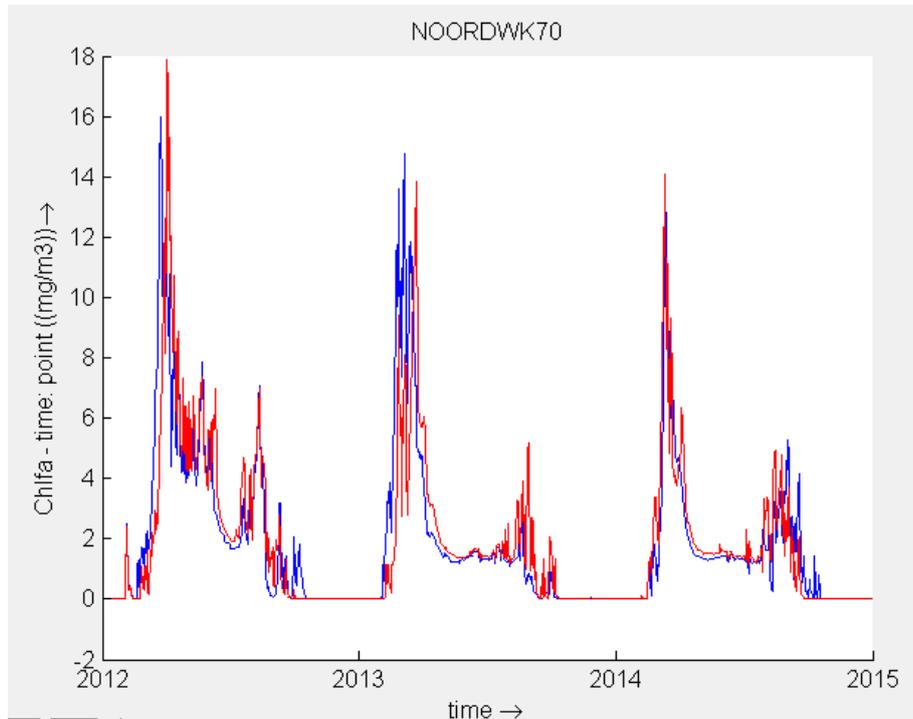


Figure 21. Chlorophyll concentrations (ug/l) as modelled by DCSM-OSPAR using the newly developed IM field based on RS-data (blue line) as compared to those using the IM field based on a smooth cosine (red line).

3.5.6 Light extinction coefficients

The light extinction coefficients of the DCSM model have changed in comparison to previous model versions (Table 2), which was necessary because -in contrast to previous model versions- several IM fractions were taken into account and DOC was added to the model. Since these extinction coefficients mainly affect the average light extinction (which seems to fall within the observed ranges, see 3.5.3), and not its variability, there is no direct need to again change these extinction coefficients.

Table 2 Light extinction coefficients.

	DCSM-Wozep	ZUNO-coarse
IM1	0.03	0.025
IM2	0.01	-
IM3	0.01	-
POC1	0.2	0.1
DOC	0.16	-
Background	0.04	0.08

3.5.7 Algal growth-related parameters

Algal parameter values in the 3D DCSM-FM model versions were largely identical to those in the ZUNO-coarse model version in which zooplankton was able to survive the winter. Some differences showed up though.

BLOOM Timestep

BLOOM is typically/ideally calculated once per day. If the hydrodynamic timestep is smaller than a day, this is taken care of by multiplying it with a fixed value (TimMultBL). In the DCSM-Wozep model, the value of TimMultBL was set to a fairly small value, resulting in BLOOM being calculated multiple times per day. This however only affects the outcomes if the environmental conditions (light and nutrients) change substantially between these time steps. In reasonably steady environments (such as in the offshore North Sea), the effect is expected not to be very large, which was confirmed in a test run (Figure 22). Still it is better to correct the TimMultBL, if only to reduce computational time. Also note that the output time step of the water quality model should be the same as the BLOOM time step, to avoid numerical variability in the output.

Additionally, in the 3D DCSM-FM model, the timestep of the hydrodynamics may vary if D-Flow FM considers it necessary, depending on flow velocity and the size of the grid cell. This variability in time step is however not dealt with properly by TimMultBL, which just has a constant value. As a result, in 3D DCSM-FM models in which the water quality is online coupled, and the time step of the water quality processes is the same as the hydrodynamic time step, such as in DCSM-Wozep, the BLOOM time step may also vary over time, which is in itself undesirable and makes it impossible to synchronize the output time step with the BLOOM time step. To correct this issue, a technical adjustment of the code is needed¹. Note that for model versions without online coupled inorganic matter an easy work around exists by separating the time stepping of the water quality processes (including BLOOM) from the hydrodynamic processes and calculate them with a fixed interval (by setting the option DtProcesses to a non-negative value).

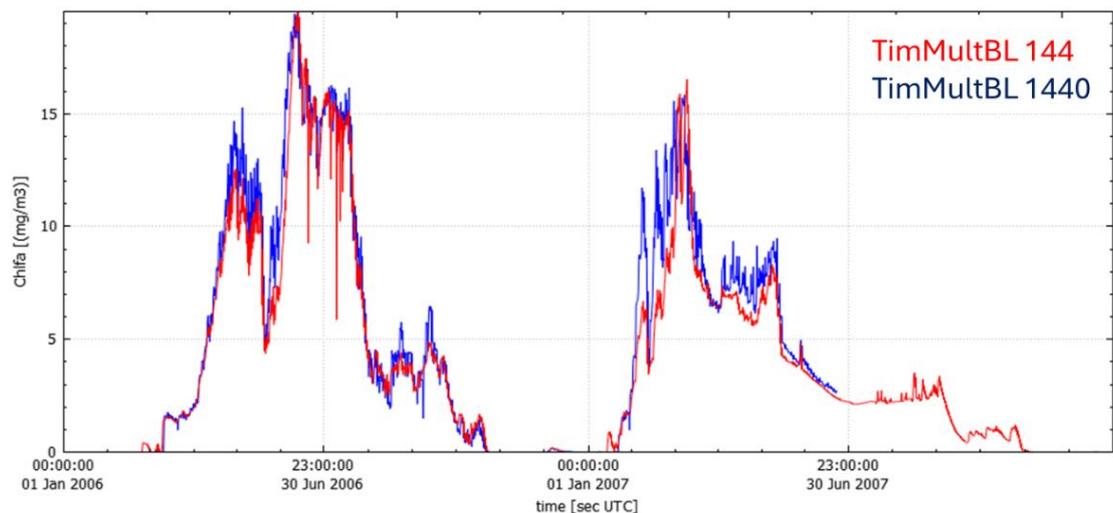


Figure 22. Chlorophyll concentrations (ug/l) as modelled by the DCSM-Wozep model (with zooplankton) at Noordwijk 70 using different parameter values for TimMultBL.

Recalibrated parameters

In earlier phases of the DCSM-Wozep model development, some phytoplankton parameter values were recalibrated in order to improve model performance (Zijl et al., 2023). The first change they made involved the temperature-dependency of the growth rate. In BLOOM, the temperature dependency for primary production uses a linear function, parameterized by its slope and the temperature at which primary production is equal to zero (TcPMx parameter).

¹ This correction has been recently added to the DELWAQ code.

At the monitoring stations, the simulated spring bloom is mainly composed of marine diatoms, marine flagellates and *Phaeocystis*. Dinoflagellates occur later in the growing season. Therefore, as described in Zijl et al. (2023), the TcPMx parameter for diatoms, flagellates and *Phaeocystis* ecotypes was shifted by +2°C. Although this modification improved the model performance for chlorophyll-a representation, by delaying and lowering the algal blooms, it may also be a partial explanation for the absence of algae in winter.

The second change made in the recalibration described in Zijl et al. (2023) involved the algal stoichiometry. Algal stoichiometry was changed to improve the model performance for the representation of inorganic nutrients in the growing season. To this end, the P:C ratios of all phytoplankton species in the model were reduced by 10% and their N:C ratios were increased by 10%. Although this modification led to a reduction in the overall biases for simulated DIN and PO₄ concentrations, it also makes the algae less nutritious for zooplankton by increasing the differences between algal and zooplankton stoichiometry. Hence this will negatively affect their growth – and therefore their survival in winter.

3.6 Test runs with zooplankton

At first, when zooplankton were included in DCSM Wozep, they did not survive. Along with our above findings focussing on the algal winter concentrations, we carried out several runs to test the effects on the survival of zooplankton. Below we discuss the most relevant ones, in which the zooplankton were able to survive.

3.6.1 DCSM-Wozep with various rates of algal mortality

In BLOOM, the default mortality rates vary per algal species (Blauw et al., 2009). These values have been based on experiments, semi-auto calibration and manual fine-tuning based on model applications in many water systems around the world. Yet, the mortality rate remains a difficult parameter to parameterize (also see section 4.3.1).

In model versions without an explicit zooplankton compartment, zooplankton grazing is included implicitly in the mortality rates of the algae. When introducing zooplankton into the DCSM-Wozep model, the mortality rates of the algae has to be reduced, in order to not include zooplankton grazing twice (implicitly and explicitly). However, the size of the reduction is debatable. Conceptually, it depends on how large the zooplankton grazing is in comparison to other mortality factors (grazing by other organisms, viruses, mechanical damage by shear stress, etc). Although it is unclear which part of the mortality is due to grazing, in ZUNO-coarse we reduced the mortality rate of the algae by 50%, which was enough to sustain a zooplankton population. Later on, it was derived that zooplankton grazing could constitute a larger part (at least ~60%) of the algal mortality (Calbet and Landry, 2004).

Hence, several DCSM-Wozep test runs were performed with an increased reduction of the algal mortalities to test the survival of the zooplankton. As an indicator for zooplankton survival, we do not look at the zooplankton biomass in winter, because we do not know exactly how big this should be to ensure survival. Instead, we look at the peak zooplankton biomass in summer, and at whether it is sustained across various years. With a 60% reduction of the algal mortality rates, the zooplankton population showed a distinct reduction in the second year, which suggests that it is not able to survive another year (Figure 23, pink line). However, with an 80% reduction the zooplankton biomass in the second year is very close to that of the first year (not shown), which suggests it could survive fine. When resetting the recalibrated algal parameters to their default values, the zooplankton could again survive with a 60% reduction of the algal mortalities (Figure 23, green line).

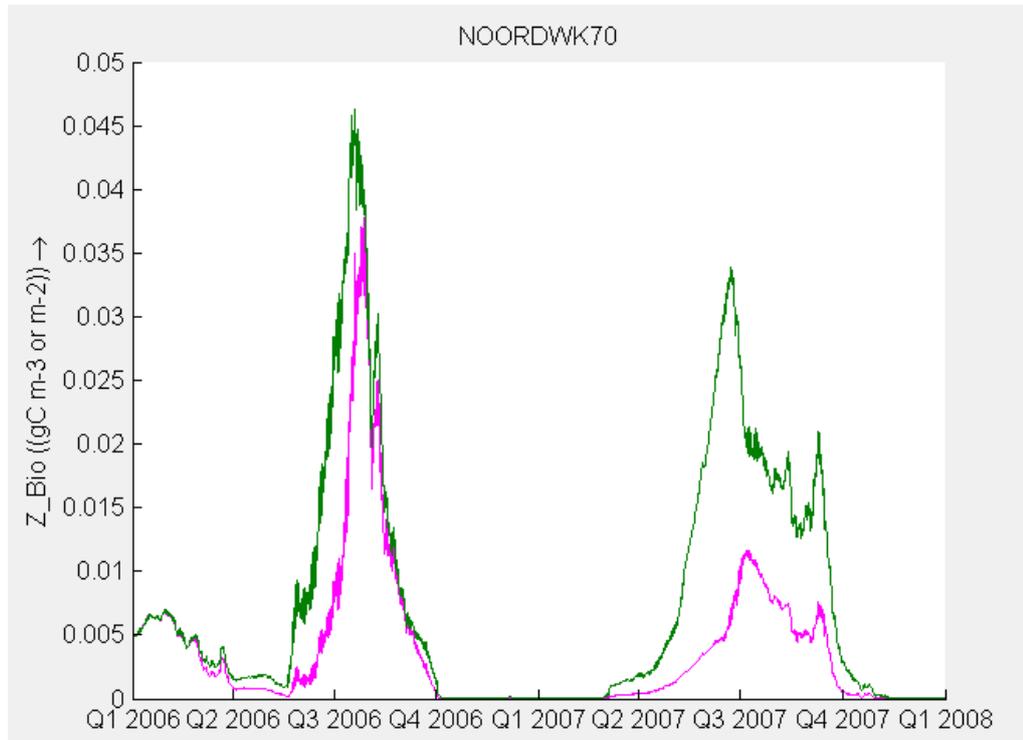


Figure 23. Zooplankton biomass (mgC/l) by DCSM-Wozep with the recalibrated algal parameter values (pink line) and with those parameters set back to their original values (green line), both runs with a 60% reduction of the algal background mortality.

3.6.2 DCSM-OSPAR with various IM fields

Like for DCSM-Wozep, it was found that DCSM-OSPAR could also sustain a zooplankton population when reducing the algal mortalities by 60% (Figure 24, red line). Interestingly, when including zooplankton into the run, this resulted in a shorter period without algae (Figure 25, red line). At the same time, however, it also leads to an earlier algal bloom, which increases the mismatch with measurements. Both phenomena can be explained by the fact that the total algal mortality (background mortality + grazing) is relatively low in periods in which the zooplankton population is small (i.e. during winter, early spring, and late summer).

We also tested the effect of the newly developed RS-based IM field on the zooplankton. Although this IM field only led to minor changes of the algal concentrations (when run without zooplankton, see Figure 21), it led to substantially higher zooplankton biomasses than those in the run with the original “smooth-cosine” IM field (Figure 24); differences range up to twice the original value.

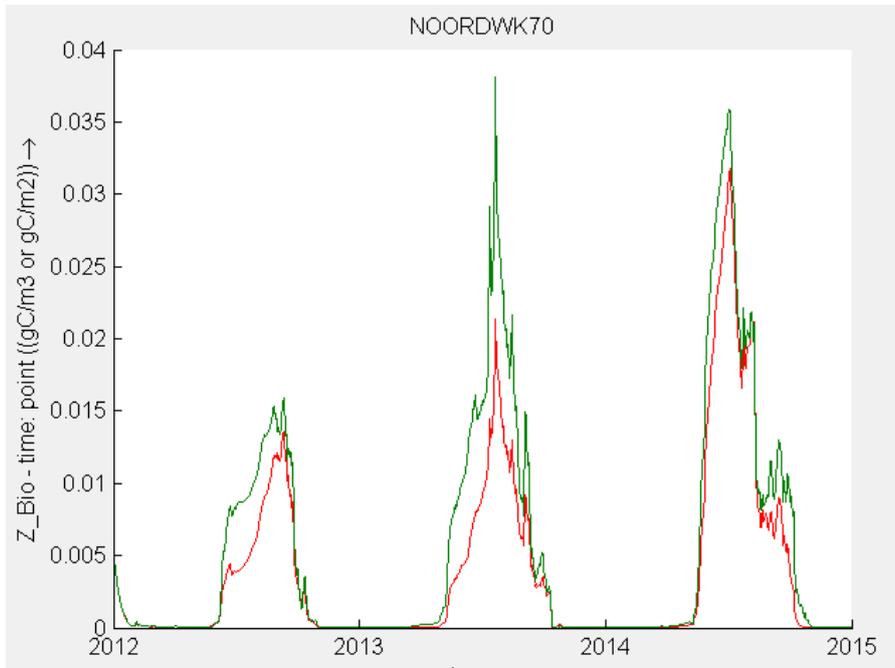


Figure 24. Zooplankton biomass (mgC/l) by DCSM-OSPAR using the original IM field (red line) and the newly developed IM field based on RS-data (green line), both runs with a 60% reduction of the algal background mortality.

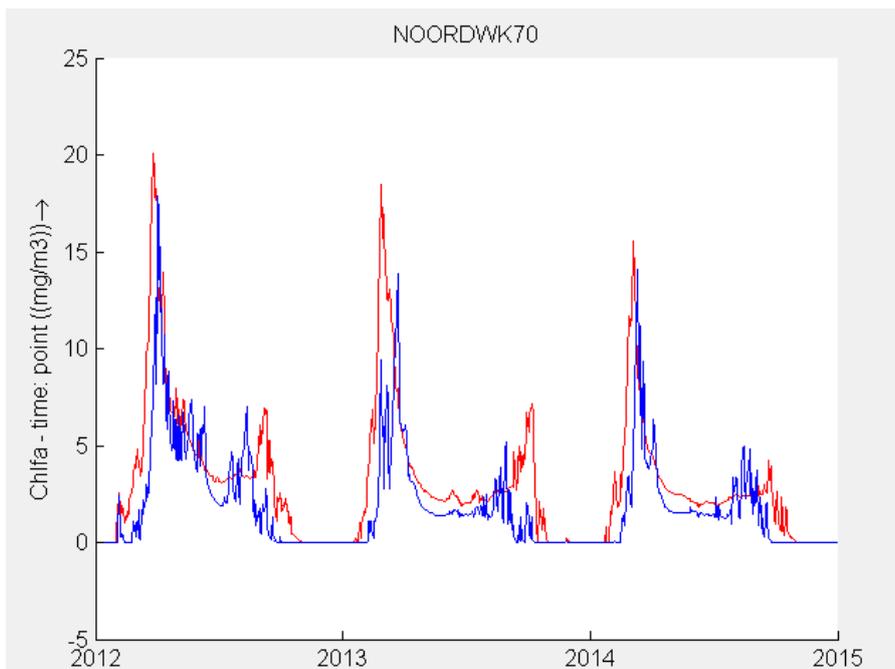


Figure 25 Chlorophyll concentrations (ug/l) as modelled by DCSM-OSPAR with zooplankton and a 60% reduction in the algal background mortality (red line) as compared to those without zooplankton and the default algal background mortalities (blue line). Both runs are using the original IM field.

4 Discussion and recommendations

In this task we tried to find out why the modelled algal winter-concentrations in the DCSM model are too small to sustain a modelled zooplankton population. To this end, we compared the model results to those of previous model versions and validated the algal-growth and light-climate related constituents of the model against data. Cross-comparing results of different model versions turned out to be challenging, due to a range of factors. Yet, the comparison showed that the algal growth issue was already (partially) present in previous model versions with a different grid, inorganic matter field, and/or algal module, which did not point to a clear cause. Hence, we based our conclusions more on model validation than on model comparison. The main complication in model validation was the limited data availability (especially in winter), which made it hard to draw absolute conclusions.

Our findings suggests that there is no clear and specific cause for the low algal concentrations, but we did find several factors that may contribute to it: the IM field and various specific algal parameter settings. Figure 26 presents a summary of our findings regarding light climate and algal coefficients, which are discussed in more detail in section 4.1.

Along with our findings regarding the modelled light climate, we also carried out various runs in which we tested their effect on zooplankton survival, which are discussed in section 4.2. Recommendations are provided in section 4.3. In 5A we discuss whether the modelled low algal winter concentrations impact the results and conclusions of previous projects.

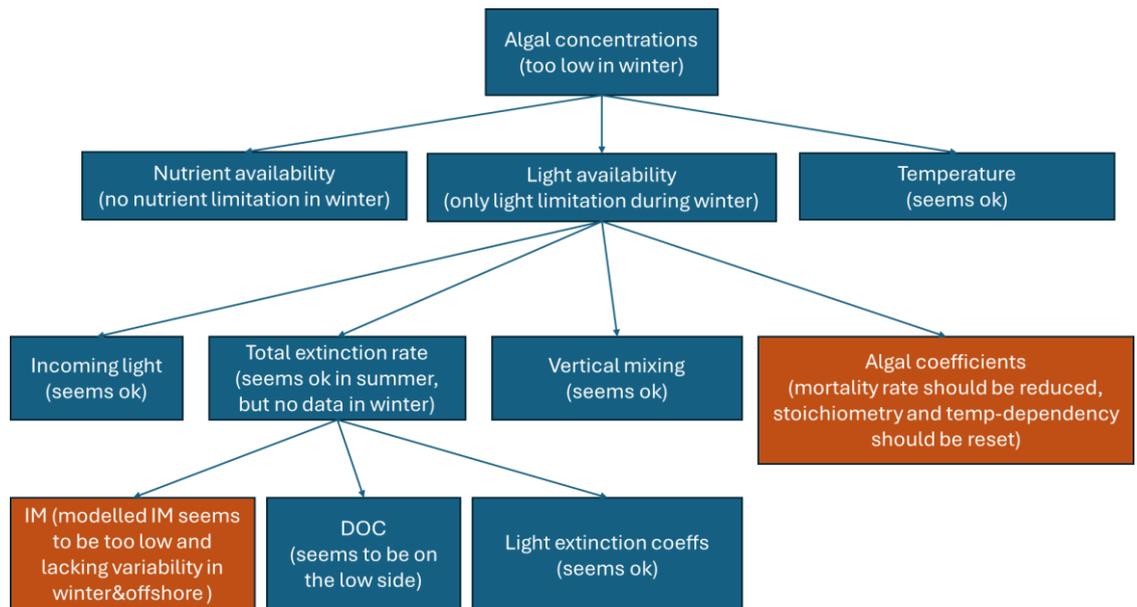


Figure 26 Summary of our findings combined in a schematic representation of the dependencies between algal concentrations and other variables/parameters.

4.1 Algal winter issue

Since the algae were only light-limited in winter, we focussed our search on light-related aspects and did not look any further into nutrient-related aspects. The model validation suggested that the hydrodynamic component (vertical mixing) of 3D DCSM-FM is not causing the problem. Neither did we find any mismatches in the incoming radiation nor with the modelled temperatures (apart from the fact that the surface water temperatures were significantly lower in winter and spring of 2017 than those in 2007, which may have emphasized the algal winter issue in the DCSM-OSPAR version). The modelled total extinction rate seemed rather too low than too high, suggesting that it probably is not causing the low algae concentrations either.

Yet, a more detailed look into the factors contributing to the total extinction, showed that the **inorganic matter (IM) field** could be improved, both in terms of amplitude (for Wozep) and variability (both in OSPAR and Wozep water quality model versions). In DCSM-Wozep, the IM winter concentrations (especially offshore) seem too low, leading to too early and high bloom peaks. Regarding the variability, both the empirically based IM forcing in DCSM-OSPAR IM and the modelled IM concentrations in DCSM-Wozep do not capture the full short term (i.e. daily/weekly) variability as observed in measured IM concentrations.

In the ZUNO model version in which zooplankton were able to survive, the variability in the IM field seemed to be essential for algal growth in winter. However, a test run with a new RS-based IM field that captured the correct amplitudes as well as the full variability of the measured IM concentrations, showed that this only slightly changed the algal concentrations, and hardly affected the length of the period without algae in winter. This could indicate that the inorganic matter field plays a smaller role in the algal winter concentrations than we were originally thinking. Yet, it does seem to affect the zooplankton biomass (see next section).

Another finding was that in DCSM-Wozep, some algal parameters were recalibrated to compensate for too low IM concentrations offshore. These parameters included the **temperature-dependency of the growth rate** (which negatively affects especially the algal winter concentrations) and the **stoichiometry of the algae** (which negatively affects especially the zooplankton growth).

4.2 Zooplankton survival

In the various test runs focussing on the survival of zooplankton, it was found that resetting the recalibrated algal parameters to their default values and reducing the algal mortality rates are indeed (partial) solutions that enable the zooplankton to survive winter.

Interestingly, when including zooplankton into the run, the period in winter without algae was shortened due to earlier spring blooms and a longer lasting bloom in fall. These phenomena can be explained by the fact that both in spring and in fall the zooplankton population is relatively small, which reduced the grazing mortality. As a result of this reduced grazing, in combination with the reduced background mortality rates of the algae, in these periods the total algal mortality is lower than in the run without the zooplankton. Apparently, including zooplankton can itself be a partial solution for the algal winter issue. However, its leading to earlier algal blooms in spring is undesirable and increases the mismatch with measurements. This may require some more finetuning of parameters (especially the algal mortality rates).

We also tested the effect of an updated RS-based IM field (accounting for inter-annual variabilities) on the zooplankton. Although this IM field only led to minor changes of the algal concentrations (when run without zooplankton) this field did lead to substantially higher zooplankton biomasses than those in the run with the smooth IM field. This finding shows that inorganic matter, although its effect is maybe less visible in terms of the algal winter concentrations, may still be important for the growth and survival of zooplankton.

4.3 Recommendations

4.3.1 General recommendations

First of all, it is recommended to thoroughly validate any new model version when it is created, and to carry out a close comparison of the modelled water quality variables with those of the previous model version. In view of the grazer populations, it is necessary not only to look at model behaviour during summer, but also during winter.

Secondly, it is recommended to be cautious with calibrating the algal parameters. Often, the cause of a mismatch in modelled chlorophyll does not lie in the algal model, but in their modelled environment. Only as a last resort, algal parameter values should be changed in order to compensate for other model issues. Also, most algal parameters have been based on experimental data, in combination with well weighted adjustments in the course of many years and projects. Yet, in some cases changing the algal parameter values (such as growth rates, PE-curves or chlorophyll: nutrient ratios) can help fine-tune the timing of spring blooms or better describe summer average chlorophyll concentrations. But note that these calibration options are only useful when the chlorophyll concentrations are reasonably well described; otherwise, the algal dynamics will be distorted. Of the algal parameters that could be adjusted, the most suitable candidate is the algal mortality rate. This parameter directly affects the algal productivity by scaling the first-order reduction of the algal biomass. Also, mortalities are knowingly difficult to measure and may vary with time and location. Hence, grazing pressures from the past may no longer be representative for the present. Moreover, when the model includes explicit grazers, the first-order mortality rate only represents the remaining (or 'background') mortality, of which it is quite unclear how small or large this exactly is. All in all, this makes algal mortality an acceptable calibration parameter. In case there is need for a calibration parameter that more specifically affects algae during the winter period, the algal PE-curves and/or the corresponding temperature reference might pose an interesting candidate too.

In view of the above arguments, and since the inorganic matter field still seems to be one of the important factors for zooplankton growth and survival, it is recommended to validate and calibrate the algal and grazer behaviour in a model version with the best inorganic matter field that is available. This will avoid making changes in the algal parameters to compensate for (un)known issues in the inorganic matter field. Although the modelled inorganic matter field has been improving over time and with model version, the modelled inorganic matter field in DCSM-Wozep is still not matching the measured amplitude and variability in all regions of the North Sea. A new version of this modelled inorganic matter field is currently being developed and will hopefully meet these expectations. In the meantime, it is recommended to use the newly developed inorganic matter field based on RS data to pursue the phytoplankton/zooplankton calibration and validation.

Finally, it is recommended to always include zooplankton, as it was found to affect the algal concentrations, both with respect to the timing of the bloom and to the concentrations during winter.

4.3.2 Concrete actions

Inorganic Matter

- In DCSM-Wozep: recalibrate the IM model to better match the higher winter concentrations observed in offshore locations, and to better capture the high variability.
- In DCSM-OSPAR: Preferably, use the updated RS-based inorganic matter field instead of the smooth cosine field. The RS-based IM field could potentially be further improved (especially for the coastal waters) by basing it on the satellite product that was used to derive the smooth cosine in OSPAR.

Algal parameters

- TimMultBL: use the latest DELWAQ code in order to make sure that it can cope with the variable time stepping of FM. Also, make sure that the output time step is equal to the BLOOM time step.
- In DCSM-Wozep, reset the temperature dependency of the algal growth rate and the algal stoichiometries to their default values.
- Calibrate the background mortality rates of the algae, and maybe some other parameters with which it is possible to more specifically target the algal winter behaviour, like the PE-curves and/or the corresponding reference temperature. To evaluate the calibration, keep an eye both on the zooplankton survival as well as on the timing and amplitude of the bloom.

Grazer functioning

- Incorporate explicit grazers in all model runs.
- Incorporate density dependent mortality of the grazers. This feature has been added to the DELWAQ and is available from version 26.01 onwards. Hence, test runs should make sure to use a recent enough version.

5 References

- L. Arentz, v. Harezlak, T. van Kessel, & T. van der Kaaij. (2012). *Kalibratie slibtransport-en GEM-model*. Deltares report 1205620-000-ZKS-0014
- Calbet, A., & Landry, M. R. (2004). Phytoplankton growth, microzooplankton grazing, and carbon cycling in marine systems. *Limnology and Oceanography*, 49(1), 51-57.
- Cronin, K., & Blaas, M. (2013). *MoS2-II Deterministic Model Calibration; Updates of the ZUNO-DD Hydrodynamic and SPM model*. Deltares report 1204561-000-ZKS-0025
- Cronin, K. and M. Blaas. 2015. Maasvlakte 2 and fine sediment fluxes towards the Wadden Sea. 1210059, Deltares, Delft.
- Harezlak, V., A. van Rooijen, Y. Friocourt, T. van Kessel, H. Los (2012a): "Winning suppletiezand Noordzee. Scenariostudies m.b.t. slibtransport, nutriënttransport en primaire productie voor de periode 2013-2017". Deltares rapport 1204963-ZKS-0040.
- Harezlak, V., A. van Rooijen, Y. Friocourt, T. van Kessel, H. Los (2012b): "Winning suppletiezand voor herstel zwakke schakels Noord-Holland. Scenariostudies m.b.t. slibtransport, nutriënttransport en primaire productie voor de periode 2013-2017". Deltares rapport 1204963-ZKS-0036
- Lorinc Meszaros, Anouk Blauw, & Sonia Heye. (2025). *COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE North West European Shelf Biogeochemical Multi-year Products IBI_MULTIYEAR_BGC_005_003 NWSHELF_MULTIYEAR_BIO_004_011 Scientific Validation Plan North West European Shelf*. 23167-COP-NWS NG VAL GREEN RELAUNCH-5600
- Maar, M., Butenschön, M., Daewel, U., Eggert, A., Fan, W., Hjøllø, S. S., Hufnagl, M., Huret, M., Ji, R., Lacroix, G., Peck, M. A., Radtke, H., Saille, S., Sinerchia, M., Skogen, M. D., Travers-Trolet, M., Troost, T. A., & van de Wolfshaar, K. (2018). Responses of summer phytoplankton biomass to changes in top-down forcing: Insights from comparative modelling. *Ecological Modelling*, 376, 54–67. <https://doi.org/10.1016/j.ecolmodel.2018.03.003>
- Minns, T., Thijs van Kessel, Vincent van Zelst, Jill Hanssen, Lauriane Vilmin, & Luca van Duren. (2022). Environmental effects of large-scale implementation of offshore wind farms; Further analyses. 11208071-001-ZKS-0006, 2 June 2022, draft
- Nechad, B., Ruddick, K. G., & Park, Y. (2010). Calibration and validation of a generic multisensor algorithm for mapping of total suspended matter in turbid waters. *Remote Sensing of Environment*, 114(4), 854–866. <https://doi.org/10.1016/j.rse.2009.11.022>
- Schneider, L. K. (2021). Coastal water management under the mixoplankton paradigm. Thesis Université libre de Bruxelles.
- Theo van der Kaaij, Thijs van Kessel, Tineke Troost, Peter Herman, Luca van Duren, & Nicky Villars. (2018). *Modelondersteuning MER winning suppletie- en ophoogzand Noordzee 2018 – 2027; modelvalidatie*. Deltares rapport 1230888-002

Troost, T. A., Desclaux, T., Leslie, H. A., van der Meulen, M. D., & Vethaak, A. D. (2018). Do microplastics affect marine ecosystem productivity? *Marine Pollution Bulletin*, 135, 17–29. <https://doi.org/10.1016/j.marpolbul.2018.05.067>

F.Zijl, Laan, S. C., Emmanouil, A., Kessel, T. van, Zelst, V. T. M. van, Vilmin, L. M., & Duren, L. A. van. (2021). Potential ecosystem effects of large upscaling of offshore wind in the North Sea; Bottom-up approach. Deltares report 11203731-004-ZKS-0015, Version 1.1

Zijl, F., Laan, S., Leummens, L., Zijlker, T., van Kessel, T., van Zelst, V., Jaksic, L., Vilmin, L., Schneider, L., & van Duren, L. (2023). Scenario studies on potential ecosystem effects in future offshore wind farms in the North Sea. Deltares report 11208071-001-ZKS-0001

A Effects of zero phytoplankton in the winter period

In this annex we discuss how or to what extent the low phytoplankton in winter may have affected the model results from previous projects. This text is closely based on the memo dd 11 March 2025, with the topic 'Trophic transfer task & need for re-calibration of the WOZEP model'.

Do we see in spring a biomass limitation in the growth?

In BLOOM, the concentration of phytoplankton depends on the available light and nutrients, temperature and algal biomass. When surplus nutrients and light are available, such as during the initial phase of the spring bloom, growth is determined solely by the initial biomass and the algal growth rate. This will lead to the typical exponential curve after which this 'exponential growth phase' was named. This phase is thus dependent on the initial algal biomass, and low biomasses could potentially delay the bloom peak. (The height of the peak is a determined by nutrient availability and thus not dependent on initial biomass). However, BLOOM makes use of a *minimum* amount of initial biomass. In other words: if the calculated concentration of phytoplankton drops too low, BLOOM uses a small threshold biomass instead of the actual calculated concentration for the phytoplankton, from which it may start to grow back. The rationale for this approach is that phytoplankton are very widespread, and spores or cysts may be present in the sediment or might travel via air. This ensures that the modelled phytoplankton can appear everywhere, even if they are absent in winter (i.e. zero initial biomass), and it will also limit the delay of the bloom peak. Hence, this approach makes the BLOOM algae less sensitive to low or zero algal concentrations such as after winter.

How does the low winter concentration impact the reproduction of phytoplankton dynamics - do we accurately reproduce spring bloom peaks in peak timing and also in the steepness of peaks?

For the reasons mentioned above, the low winter concentrations are expected not to have a large impact on the simulated peak/concentrations once the conditions are favourable for phytoplankton to grow. In addition, the previous model versions were calibrated and validated on time-series model-observation comparisons at MWTL stations, where attention was paid to the timing and intensity of the bloom and to simulated chlorophyll a values in the growing season (spring/summer) and on maps of near-surface growing-season chlorophyll a. As a result, the potential small delay in the timing of the bloom that may still have resulted from the low initial biomass might have been (partly) compensated for by other parameter settings. Furthermore, statistical indicators such as the yearly averages of chlorophyll concentrations are not impacted by the small winter concentrations either. This is because observed chlorophyll concentrations outside of the blooming period are orders of magnitudes smaller than the summer concentrations.

Therefore, we expect that our previous results focussing on nutrients and algae in spring and summer will not have been affected much by the zero or low winter concentrations. Also, we consider the conclusions that were based on those results not be sensitive to this issue either.

Deltares is an independent institute for applied research in the field of water and subsurface. Throughout the world, we work on smart solutions for people, environment and society.

Deltares

www.deltares.nl