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Supplement of

Offline Fennel: a high-performance and computationally efficient biogeochemical model within the Regional Ocean Modeling System (ROMS)

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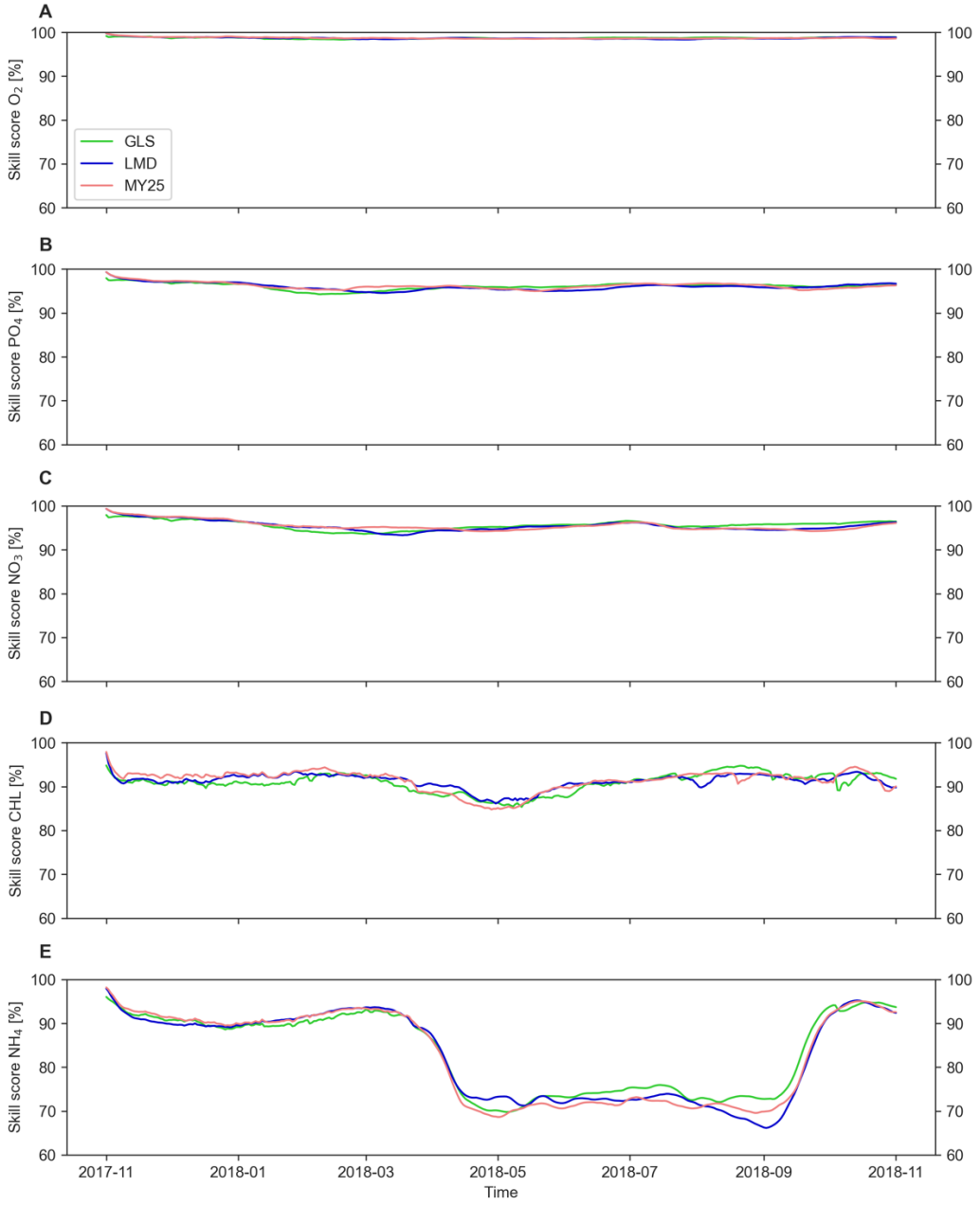
Table S1: Computational time for online and offline simulations across different mixing schemes: Generic Length Scale (GLS), Large–McWilliams–Doney (LMD), and Mellor-Yamada 2.5 (MY25). The table lists the computational times for each simulation type, with columns representing the time taken for online (coupled) simulations and offline simulations multiples of various time step configurations: x1, x3, x5, x10, and x15.

Mixing scheme	Online (coupled)	Offline (x1)	Offline (x3)	Offline (x5)	Offline (x10)	Offline (x15)
GLS	5h 17’	3h 32’	1h 14’	55’	27’	19’
LMD	4h 36’	3h 29’	1h 12’	47’	25’	17’
MY25	5h 52’	3h 36’	1h 15’	52’	31’	20’



10 **Fig. S1: Time series of skill scores (SSs) [%] for key biogeochemical tracers for the x1 time-step simulation, comparing offline and online runs using the Generic Length Scale (GLS), Mellor–Yamada 2.5 (MY25), and Large–McWilliams–Doney (LMD) mixing schemes.** Panels show (A) dissolved oxygen (O_2), (B) phosphate (PO_4), (C) nitrate (NO_3), (D) chlorophyll (CHL), and (E) ammonium (NH_4). Green, blue, and coral lines correspond to GLS, LMD, and MY25 simulations, respectively.

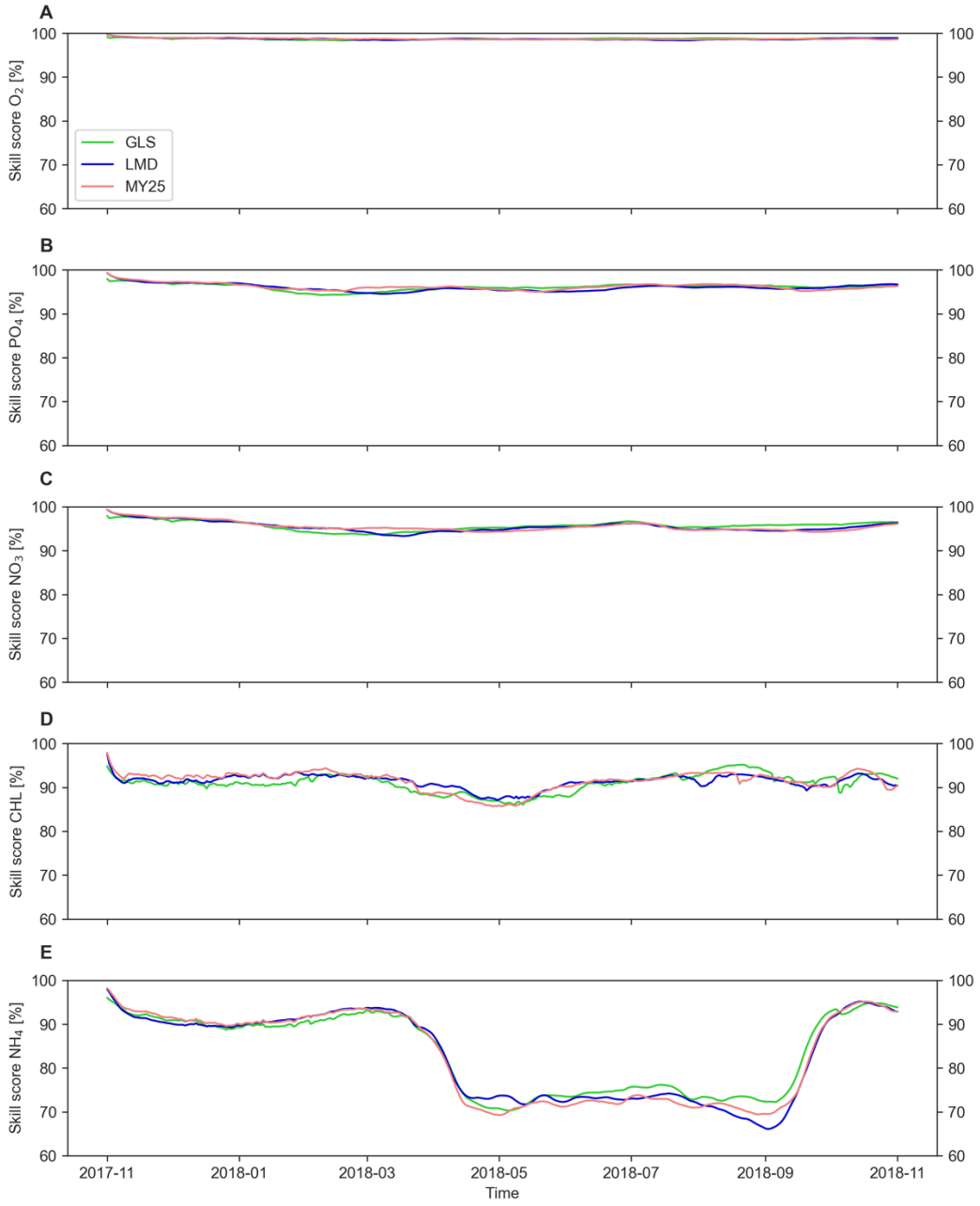


Fig. S2: Time series of skill scores (SSs) [%] for key biogeochemical tracers for the x3 time-step simulation, comparing offline and online runs using the Generic Length Scale (GLS), Mellor–Yamada 2.5 (MY25), and Large–McWilliams–Doney (LMD) mixing schemes. Panels show (A) dissolved oxygen (O_2), (B) phosphate (PO_4), (C) nitrate (NO_3), (D) chlorophyll (CHL), and (E) ammonium (NH_4). Green, blue, and coral lines correspond to GLS, LMD, and MY25 simulations, respectively.

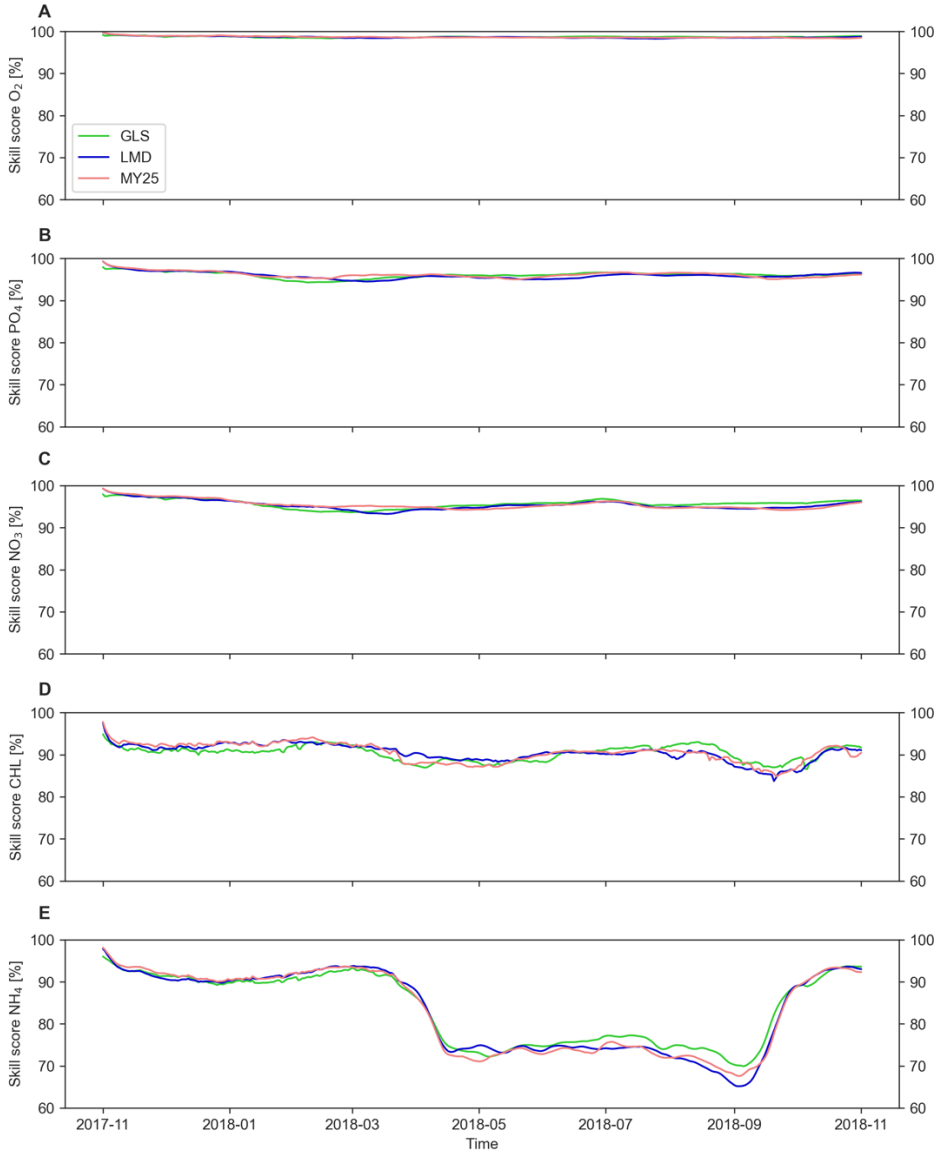


Fig. S3: Time series of skill scores (SSs) [%] for key biogeochemical tracers for the x10 time-step simulation, comparing offline and online runs using the Generic Length Scale (GLS), Mellor–Yamada 2.5 (MY25), and Large–McWilliams–Doney (LMD) mixing schemes. Panels show (A) dissolved oxygen (O_2), (B) phosphate (PO_4), (C) nitrate (NO_3), (D) chlorophyll (CHL), and (E) ammonium (NH_4). Green, blue, and coral lines correspond to GLS, LMD, and MY25 simulations, respectively.

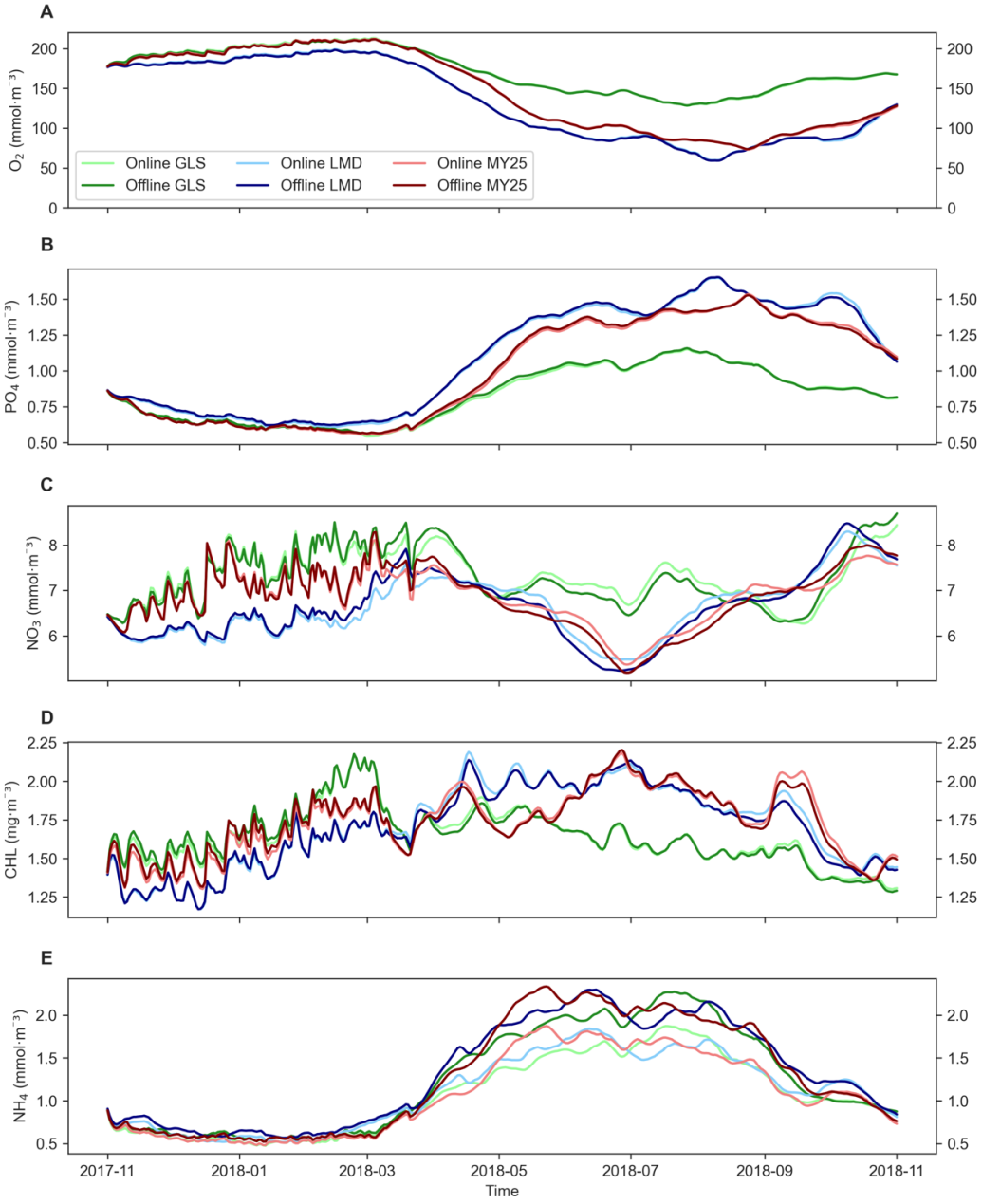


Fig. S4: Area-averaged time series of biogeochemical variables at the bottom layer for x5 time-step online and offline simulations using different mixing schemes. Panels show (A) dissolved oxygen (O_2), (B) phosphate (PO_4), (C) nitrate (NO_3), (D) chlorophyll (CHL), and (E) ammonium (NH_4). Light and dark green, light and dark blue, and light and dark red represent online and offline simulations that used Generic Length Scale (GLS), Mellor–Yamada 2.5 (MY25), and Large–McWilliams–Doney (LMD) mixing schemes, respectively.

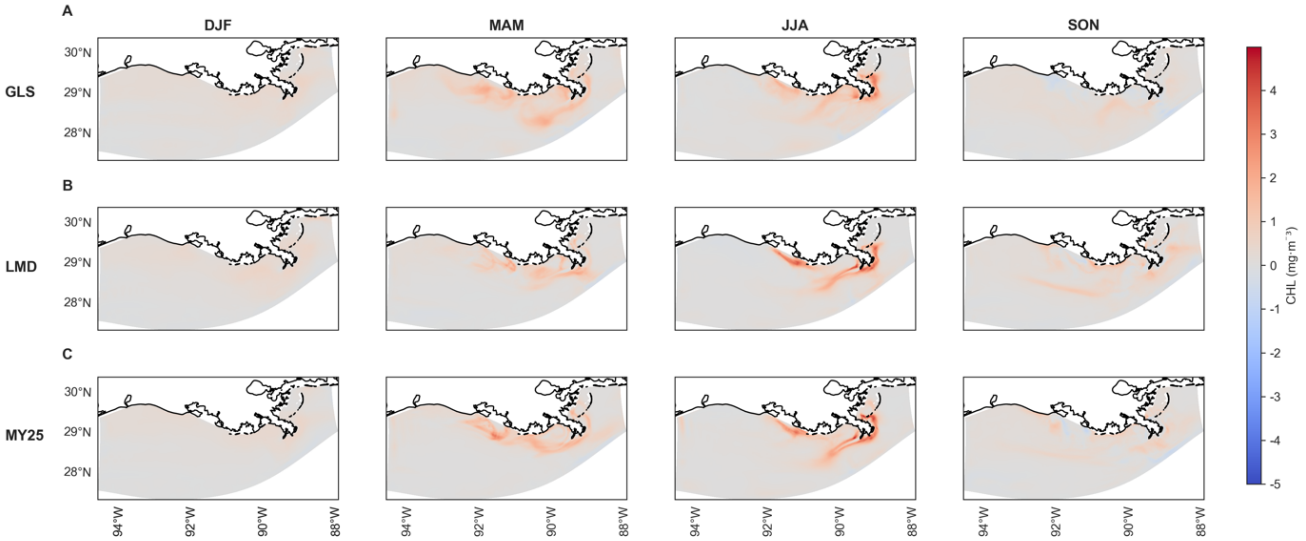


Fig. S5: Mean seasonal differences in chlorophyll concentrations (CHL) at the surface layer. The panels illustrate the differences between offline (x5 DT) and online simulations for each mixing scheme: (A) Generic Length Scale (GLS), (B) Mellor–Yamada 2.5 (MY25), and (C) Large–McWilliams–Doney (LMD). The coolwarm color scale on the right indicates the magnitude of the differences. Seasonal designations are as follows: DJF (December-January-February, winter), MAM (March-April-May, spring), JJA (June-July-August, summer), and SON (September-October-November, fall). This figure highlights the variability in CHL concentrations across different mixing schemes and seasons, providing insight into the performance of the offline simulations relative to the online model.

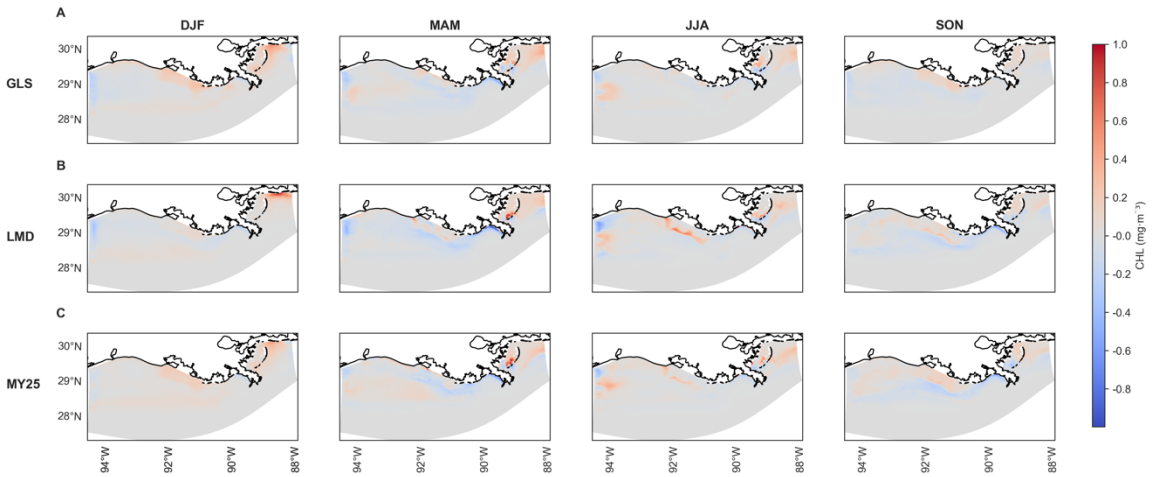


Fig. S6: Mean seasonal differences in chlorophyll concentrations (CHL) at the bottom layer. The panels illustrate the differences between offline (x5 DT) and online simulations for each mixing scheme: (A) Generic Length Scale (GLS), (B) Mellor–Yamada 2.5 (MY25), and (C) Large–McWilliams–Doney (LMD). The coolwarm color scale on the right indicates the magnitude of the differences. Seasonal designations are as follows: DJF (December-January-February, winter), MAM (March-April-May, spring), JJA (June-July-August, summer), and SON (September-October-November, fall). This figure highlights the variability in CHL concentrations across different mixing schemes and seasons, providing insight into the performance of the offline simulations relative to the online model.

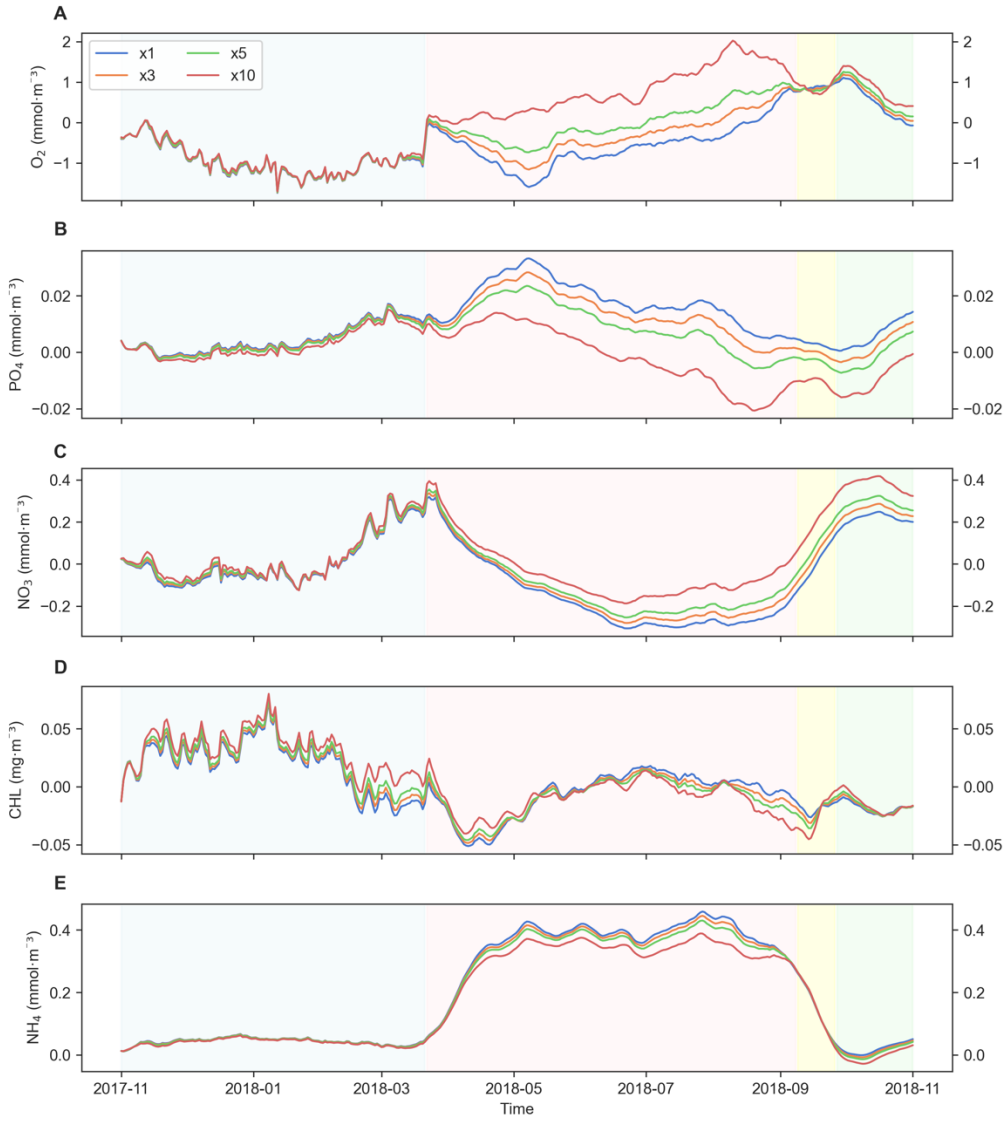


Fig. S7: Differences in simulation results at the bottom layer across time steps (DTs) used in simulations with the Generic Length Scale (GLS) mixing scheme. Panels show the following variables: (A) dissolved oxygen (O_2), (B) phosphate (PO_4), (C) nitrate (NO_3), (D) chlorophyll (CHL), and (E) ammonium (NH_4). The blue, orange, green, and red lines represent offline simulations with DT multiples of x1, x3, x5, and x10, respectively. The blue shaded area indicates the spin-up period where all simulations show high variability but converge to similar values. The pink shaded region marks the stabilization phase, with variables showing reduced variability and the emergence of differences between DT simulations. The yellow shaded region highlights a potential computational artifact or response to forcing, characterized by divergence in PO_4 and convergence in O_2. The green shaded region suggests seasonal dynamics, with a distinct change in behavior for the simulated variables.