

Supplement to:
 Tuning ocean biogeochemistry for an Earth system model: approaches, challenges and impact on model performance
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Table S1. Parametric statistics RMSE, bias B and correlation coefficient R of biogeochemical model tracers for FOCI-CC, FOCI-HG, ECCO-U and ECCO-I. The the unbiased RMSE (RMSE’), correlation coefficient and bias (as percent of observed mean) are shown in Fig. S7.

Experiment	Phy	Zoo	POP	DOP	PO ₄	NO ₃	O ₂	DIC
RMSE								
FOCI-CC / pictrl	0.013	0.010	0.044	0.413	0.260	5.119	37.091	39.211
FOCI-HG / pictrl	0.012	0.010	0.046	0.224	0.286	5.241	34.636	43.937
FOCI-CC / hist	0.013	0.010	0.044	0.416	0.259	5.059	37.738	39.545
FOCI-HG / hist	0.012	0.010	0.046	0.224	0.284	5.165	34.381	44.762
ECCO-U	0.013	0.010	0.045	0.221	0.295	4.790	30.943	51.647
ECCO-I	0.013	0.010	0.045	0.228	0.265	4.762	31.624	54.472
Bias								
FOCI-CC / pictrl	0.004	0.002	-0.013	0.349	-0.117	-3.527	-13.377	-20.444
FOCI-HG / pictrl	0.003	-0.001	-0.015	0.059	-0.126	-3.515	-6.506	-25.902
FOCI-HG / hist	0.004	0.002	-0.013	0.353	-0.112	-3.406	-15.818	-22.889
FOCI-HG / hist	0.003	-0.001	-0.016	0.061	-0.121	-3.393	-8.796	-28.312
ECCO-U	0.003	-0.000	-0.014	0.066	-0.176	-3.085	-10.680	-48.614
ECCO-I	0.004	0.000	-0.013	0.085	-0.139	-3.106	-9.854	-51.702
R								
FOCI-CC / pictrl	0.345	0.095	0.413	0.075	0.973	0.954	0.924	0.965
FOCI-HG / pictrl	0.322	0.095	0.373	0.016	0.968	0.948	0.942	0.960
FOCI-CC / hist	0.348	0.097	0.417	0.073	0.973	0.954	0.922	0.952
FOCI-HG / hist	0.334	0.099	0.375	0.016	0.968	0.948	0.941	0.946
ECCO-U	0.347	0.115	0.398	0.032	0.970	0.959	0.939	0.970
ECCO-I	0.339	0.111	0.398	0.024	0.974	0.958	0.935	0.969

Table S2. Parametric statistics IQD, HD and BD calculated from KDEs of biogeochemical model tracers for FOCI-CC, FOCI-HG, ECCO-U and ECCO-I. See also section 2.4.3 for calculation.

Experiment	Phy	Zoo	POP	DOP	PO ₄	NO ₃	O ₂	DIC
IQD								
FOCI-CC / pictrl	1.886	0.773	1.449	258.100	0.005	0.140	0.238	1.781
FOCI-HG / pictrl	0.988	0.131	2.374	28.760	0.005	0.107	0.310	1.854
FOCI-CC / hist	1.833	0.714	1.459	264.200	0.005	0.128	0.276	2.615
FOCI-HG / hist	0.927	0.131	2.393	31.340	0.004	0.097	0.183	2.793
ECCO-U	0.793	0.657	1.704	38.710	0.013	0.116	0.072	3.417
ECCO-I	1.104	0.671	1.318	50.760	0.007	0.087	0.091	4.200
HD								
FOCI-CC / pictrl	0.509	0.312	0.259	0.829	0.138	0.168	0.127	0.124
FOCI-HG / pictrl	0.386	0.179	0.270	0.475	0.151	0.153	0.139	0.123
FOCI-CC / hist	0.519	0.301	0.255	0.835	0.145	0.165	0.116	0.155
FOCI-HG / hist	0.389	0.172	0.268	0.492	0.154	0.149	0.124	0.156
ECCO-U	0.278	0.260	0.247	0.568	0.168	0.110	0.081	0.180
ECCO-I	0.313	0.270	0.233	0.614	0.147	0.120	0.088	0.193
BD								
FOCI-CC / pictrl	0.300	0.102	0.069	1.165	0.019	0.029	0.016	0.016
FOCI-HG / pictrl	0.161	0.033	0.075	0.256	0.023	0.024	0.019	0.015
FOCI-HG / hist	0.314	0.095	0.067	1.195	0.021	0.028	0.014	0.024
FOCI-HG / hist	0.164	0.030	0.075	0.277	0.024	0.022	0.015	0.025
ECCO-U	0.081	0.070	0.063	0.389	0.029	0.012	0.007	0.033
ECCO-I	0.103	0.076	0.056	0.474	0.022	0.015	0.008	0.038

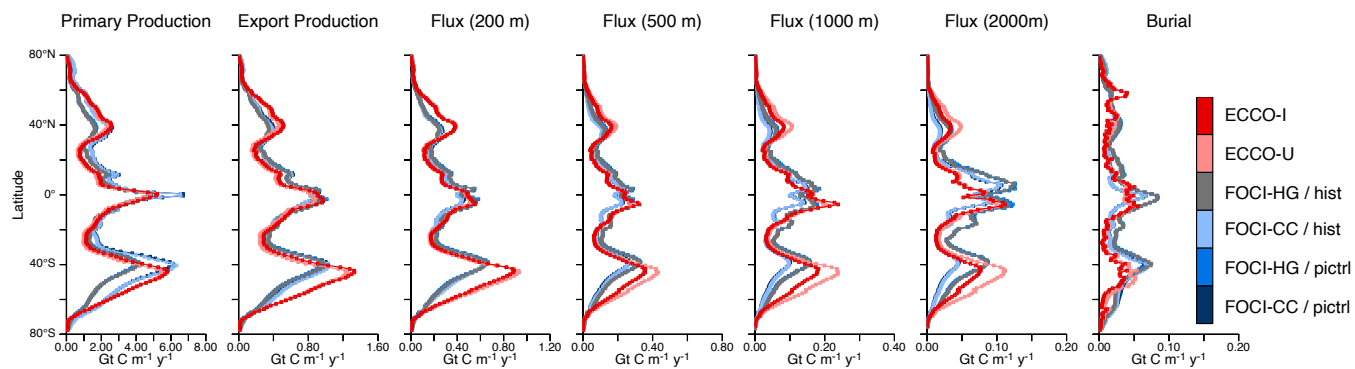


Figure S1. Zonally integrated annual fluxes of different model experiments.

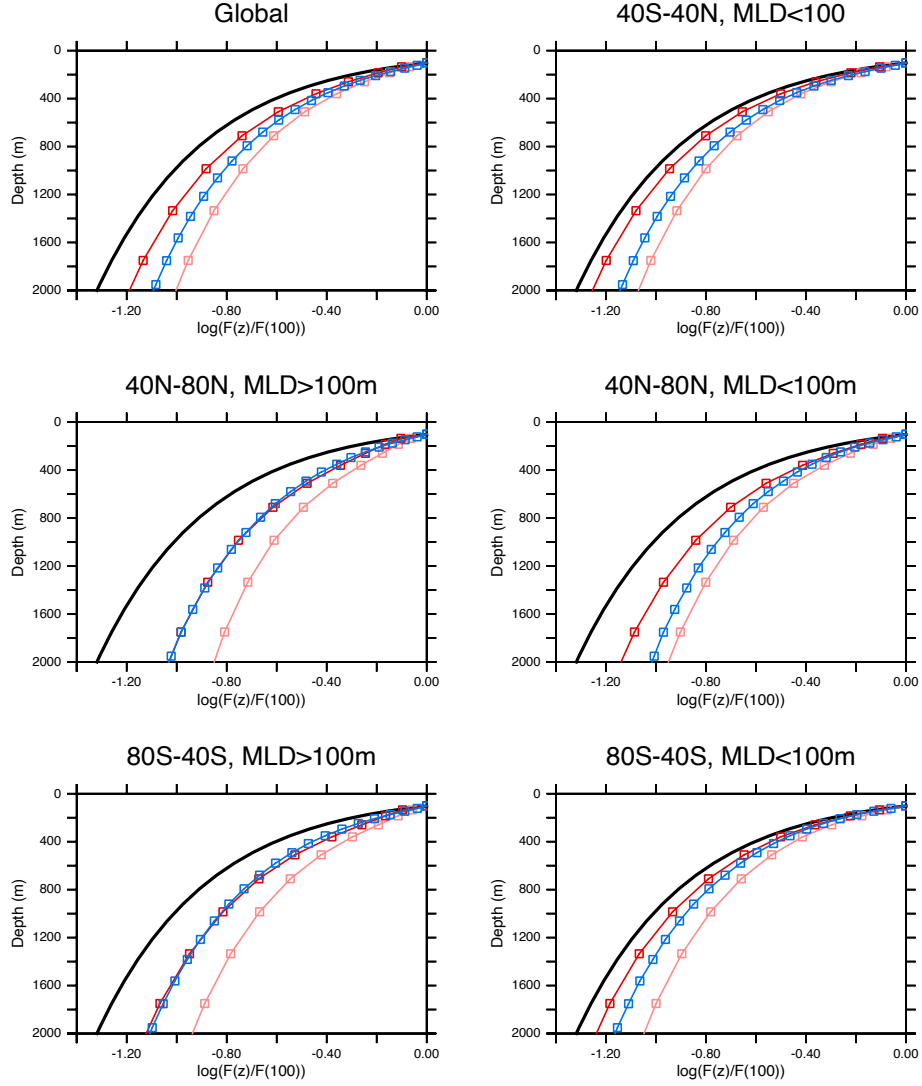


Figure S2. Global mean particle flux, normalised by export flux at ≈ 100 m for model simulation FOCI-HG/pictrl (blue), ECCO-U/pictrl (light red) and ECCO-I/pictrl (dark red). To avoid any limitation of decay rates in oxygen-deficient zones, evaluation of model flux has been restricted to regions with $\sigma_t > 10$ mmol m $^{-3}$. The thick black line indicates the hypothetical (prescribed) flux profile calculated from $F(z)/F(100) = (z/100)^{-b}$, where $b = 1.022589$ is the prescribed particle flux exponent. The different panels show normalised particle flux for different areas of maximum mixed layer depth (see text for its evaluation).

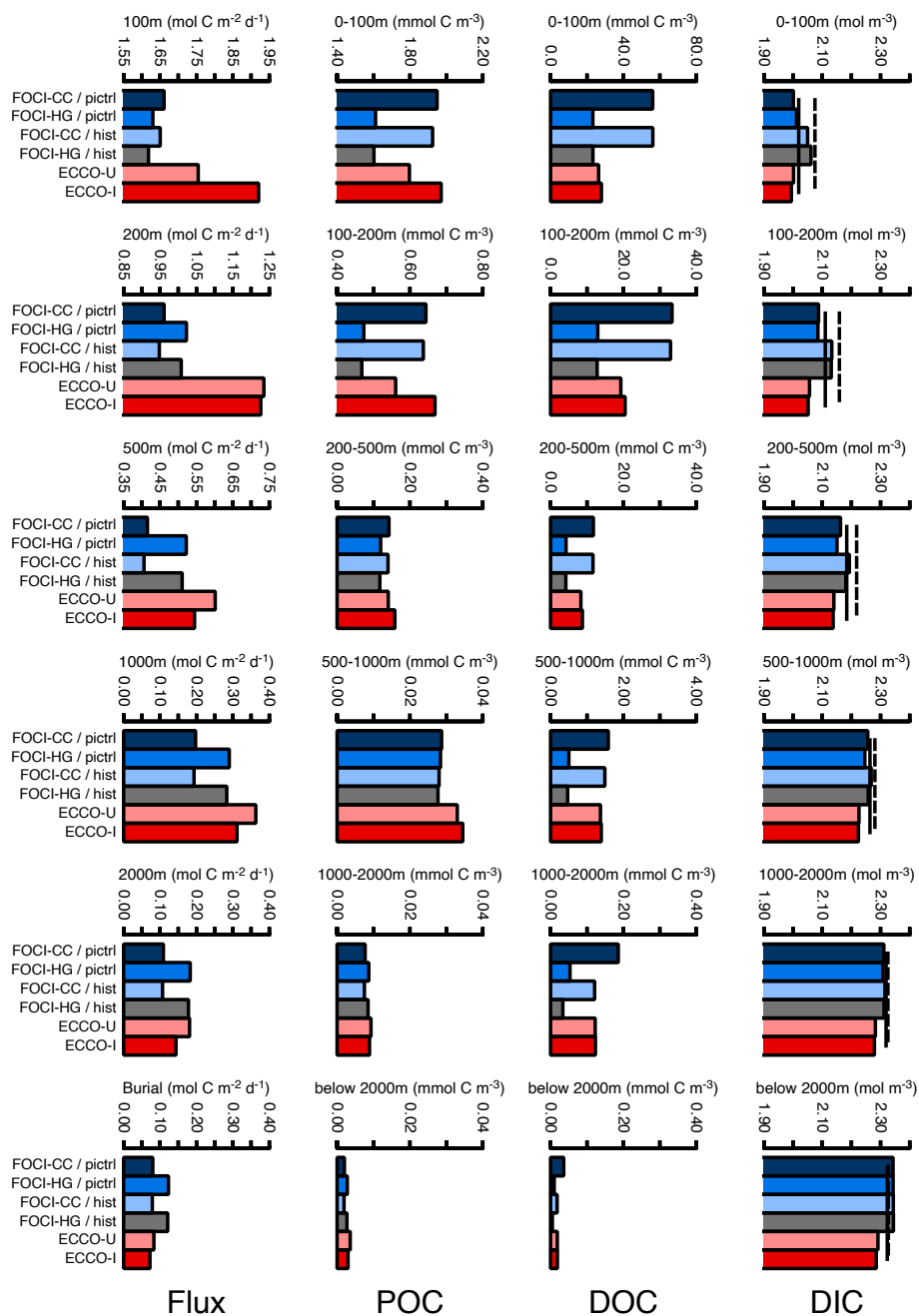


Figure S3. Simulated global mean fluxes and carbon tracers in different vertical domains. Note that the scales differ between different tracers and vertical domains. The straight (broken) vertical lines in the panels for DIC denote observed pre-anthropogenic (contemporary) DIC.

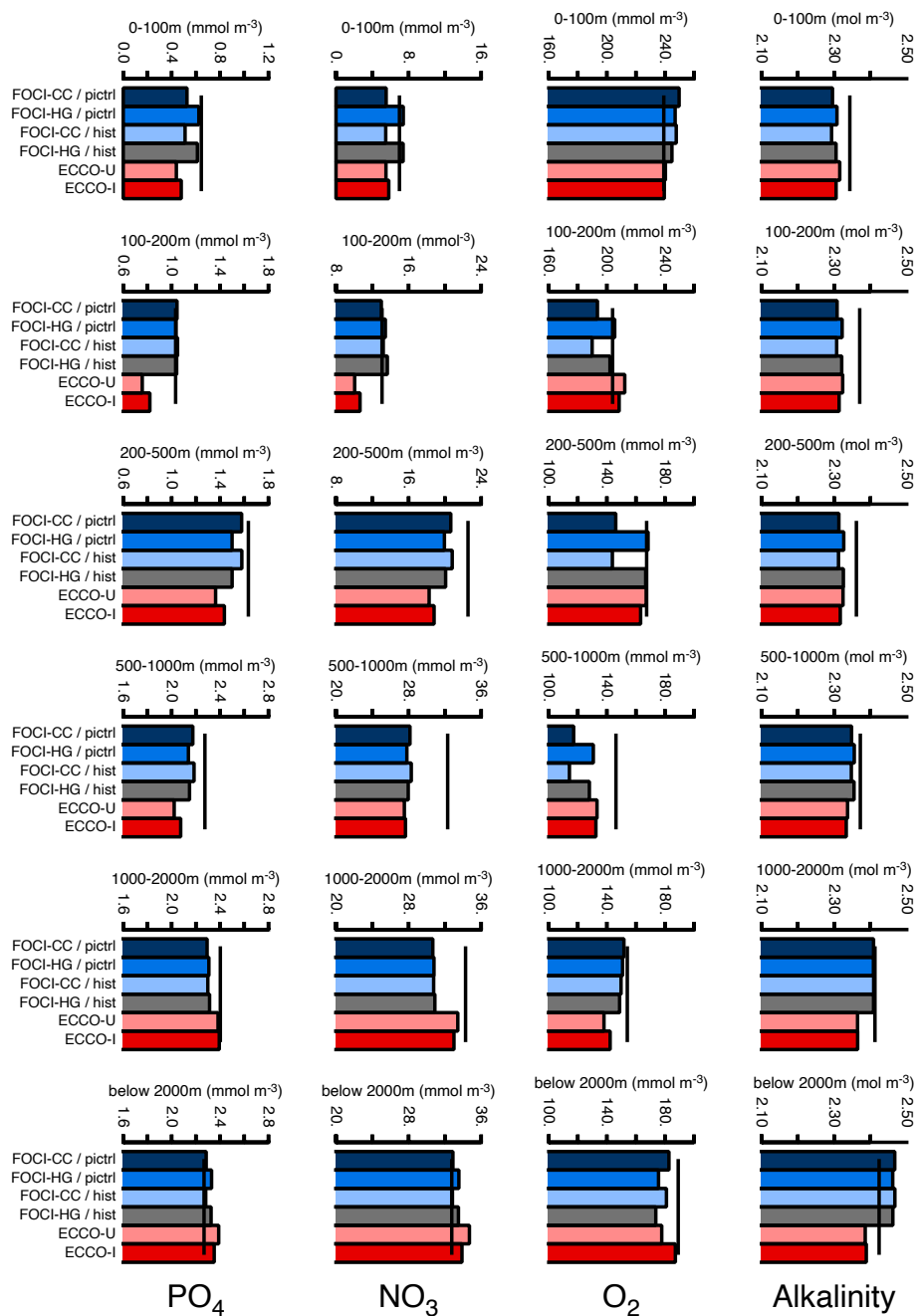


Figure S4. Simulated global mean inorganic tracers in different vertical domains. Vertical bars indicate mean of observations. Note that the scales differ between different tracers and vertical domains. The straight lines denote observed tracers.

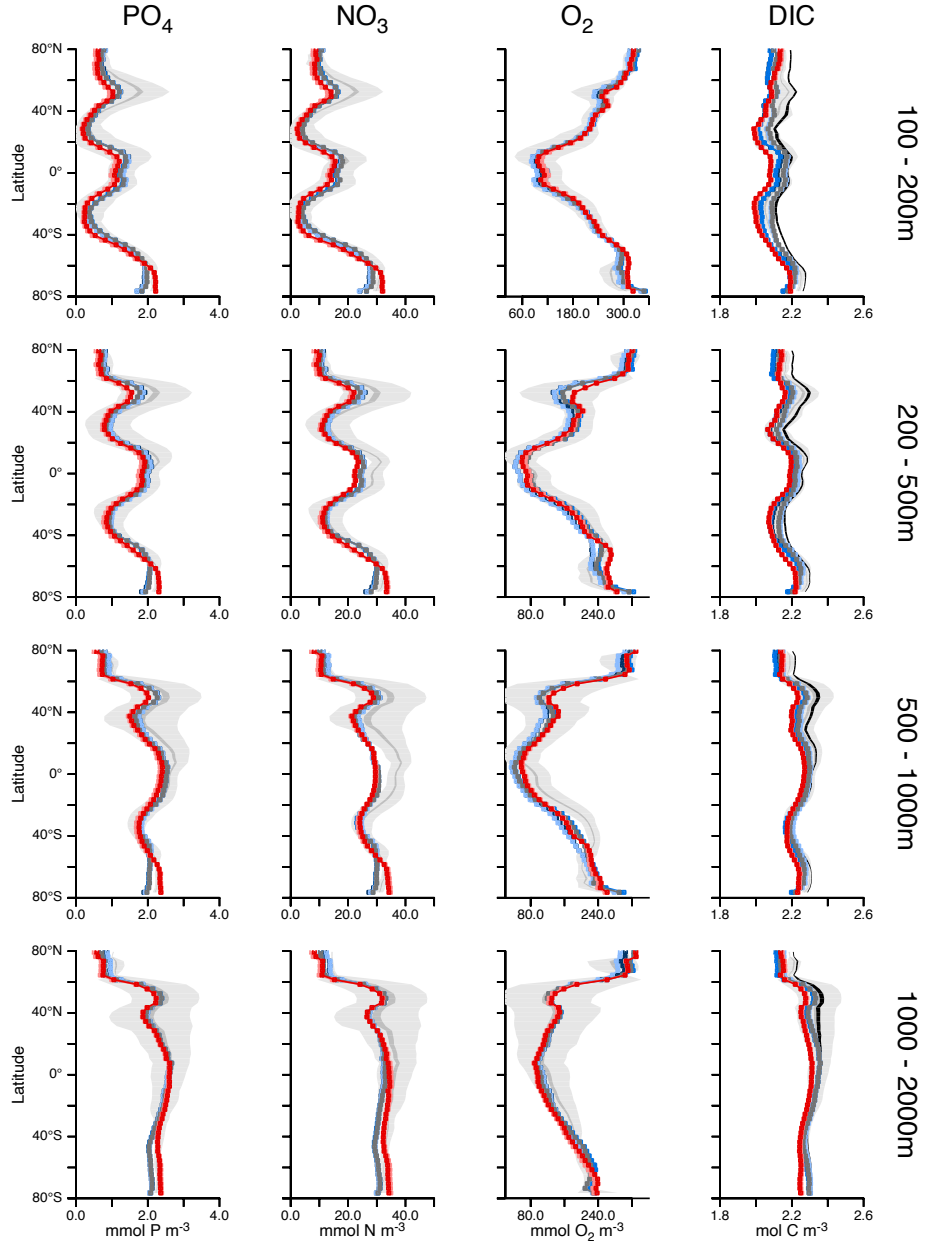


Figure S5. Zonal averages of inorganic tracers averaged over different vertical domains. Dark shaded areas: mean of observations ± 0.1 standard deviations. Light shaded areas: mean $\pm$ one standard deviation. The light and dark grey area in the panel for DIC denotes observed pre-anthropogenic DIC, the black area contemporary DIC. Coloured lines with symbols: model means, with the models sampled at locations of observations.

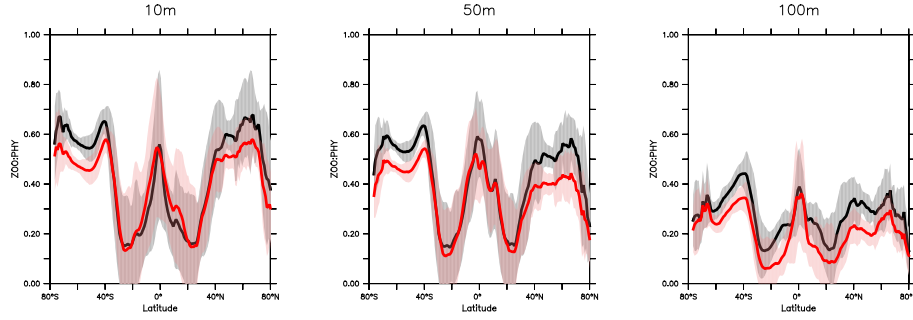


Figure S6. Zonal averages of the average ratio between zooplankton and phytoplankton in FOCI-CC/pictrl (black line) and FOCI-HG/pictrl (red line) for different vertical domains. Shaded areas depict the mean $\pm$ one standard deviation.

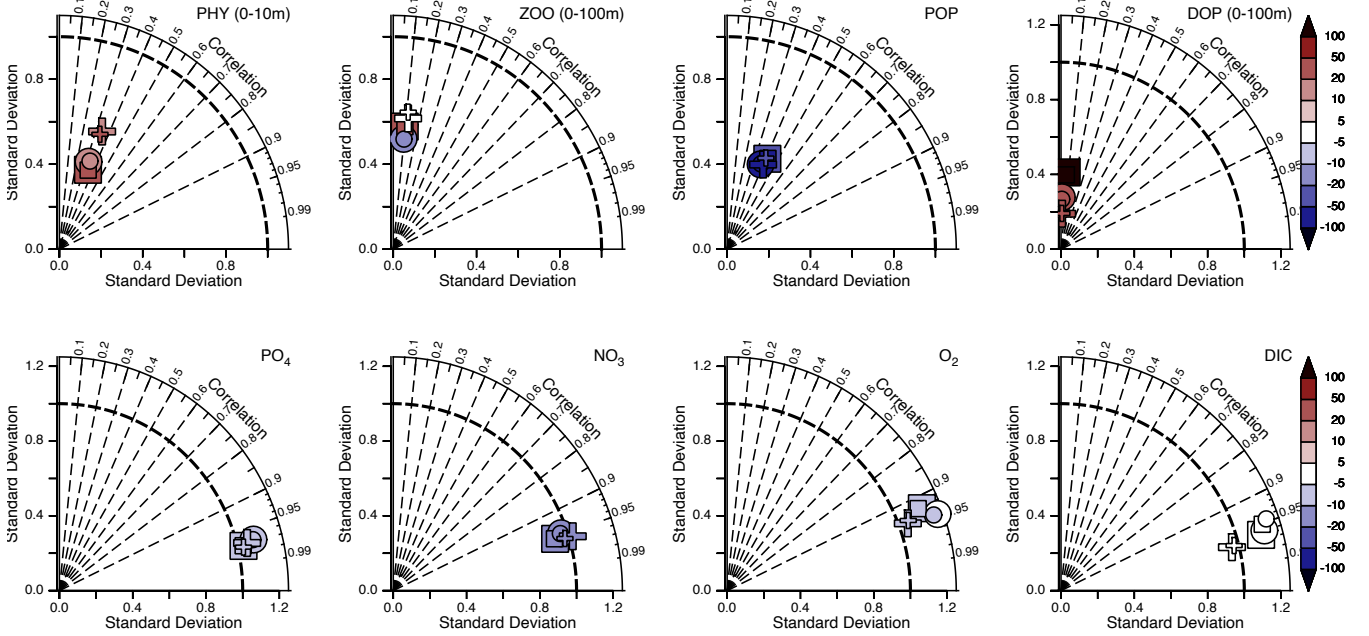


Figure S7. Taylor plot showing model performance of different model experiments with respect to observed phytoplankton (0-10m), zooplankton (0-100m), POP (0-200m), DOP (0-100m), nutrients (0-2000m), oxygen (0-2000m) and DIC (0-2000m). Colour indicates the relative bias (model minus observation) as percent of observed mean. Symbols indicate model experiments. Large square: FOCI-CC/pictrl; large circle: FOCI-HG/pictrl; small square: FOCI-CC/hist; small circle: FOCI-HG/hist; large plus: ECCO-U/pictrl; small plus: ECCO-I/pictrl. The non-normalised bias and RMSE associated in with this plot are listed in Table S1, together with the numerical values of the correlation coefficient.

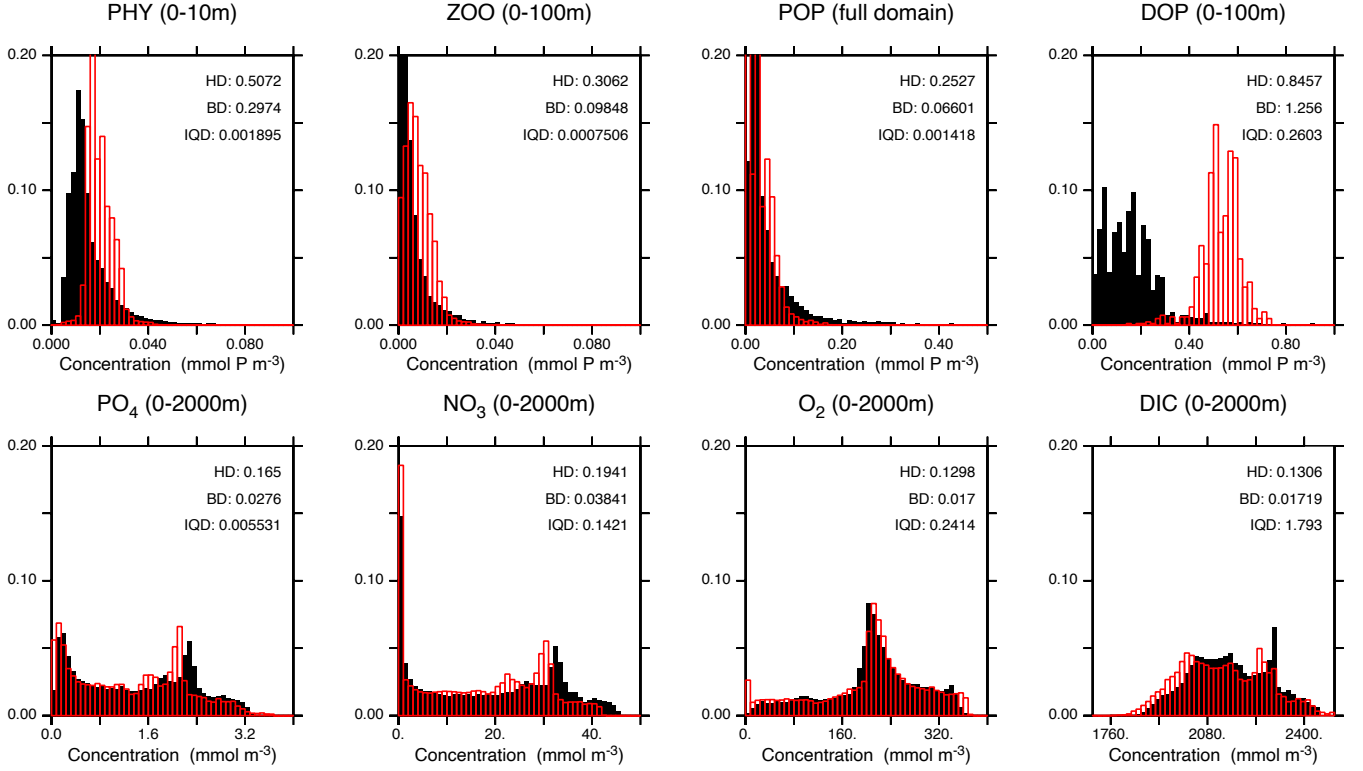


Figure S8. Histograms (PDF) of tracer concentrations from observations (black) and simulation FOCI-CC/pictrl. Tracer concentrations of tracer X have been binned into $N = 50$ concentration classes over the indicated range, and their frequency has been calculated for the model and observations. Numbers in the upper right of each panel show the L1-metric, the Hellinger distance (HD) and the Bhattacharyya distance (BD), evaluated as explained in section 2.4.2. Note that vertical domains over which the metrics have been calculated differ for the different tracers, and are the same as in Figure S7.

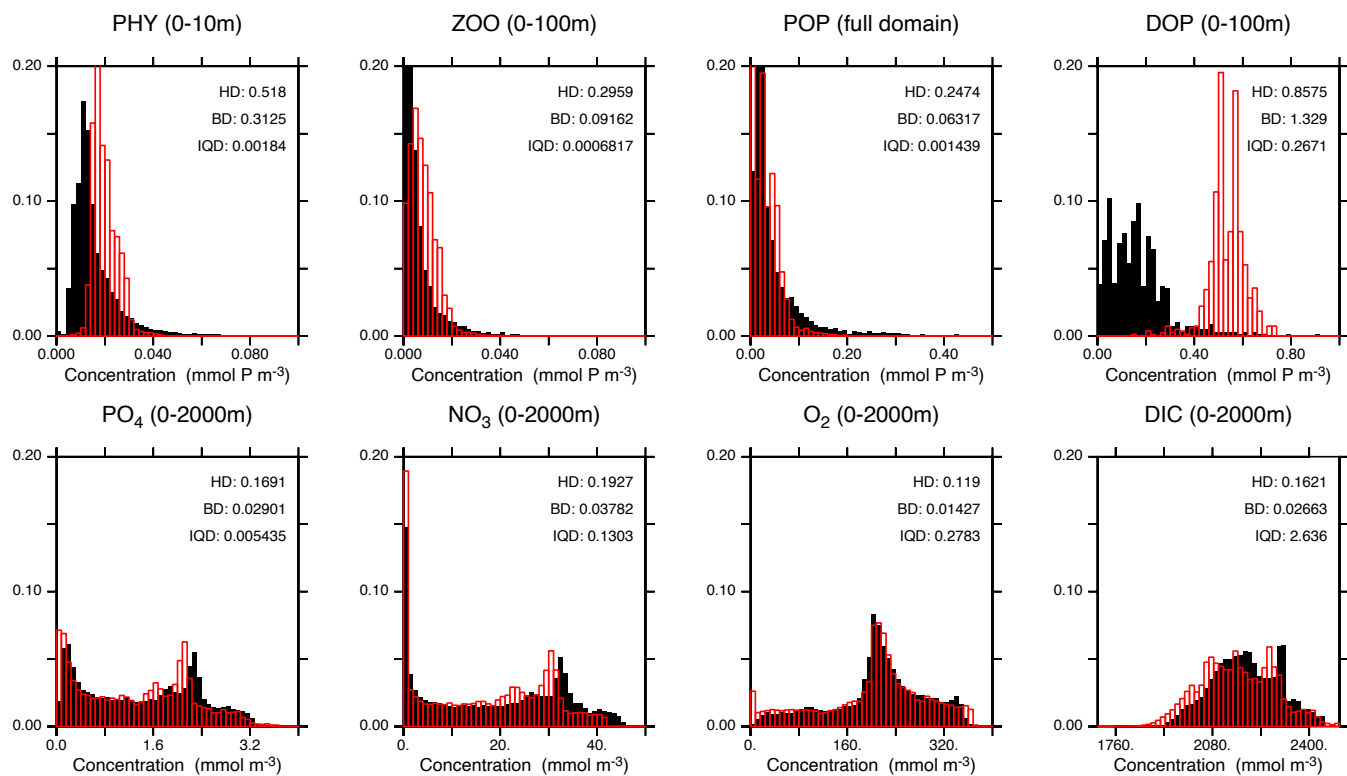


Figure S9. As Figure S8, but for FOCI-CC/hist.

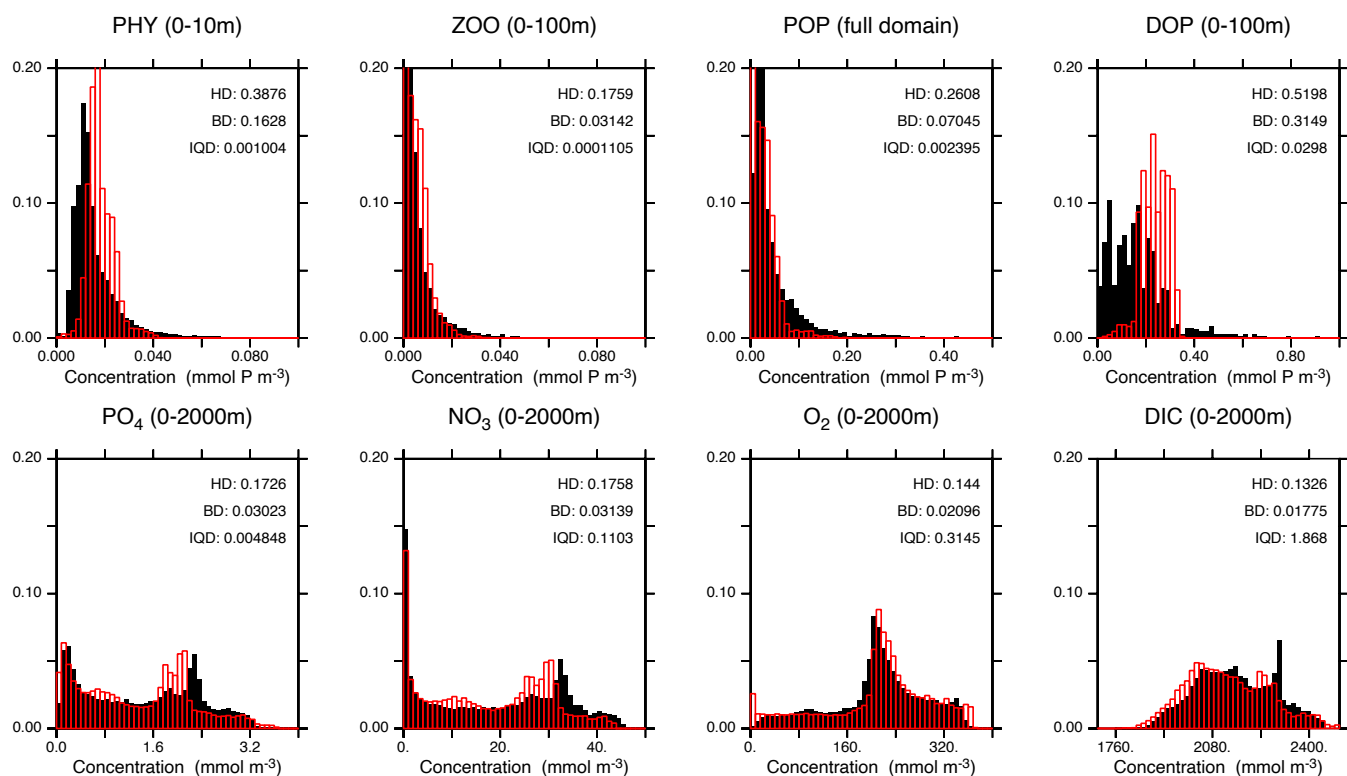


Figure S10. As Figure S8, but for FOCI-HG/pictrl.

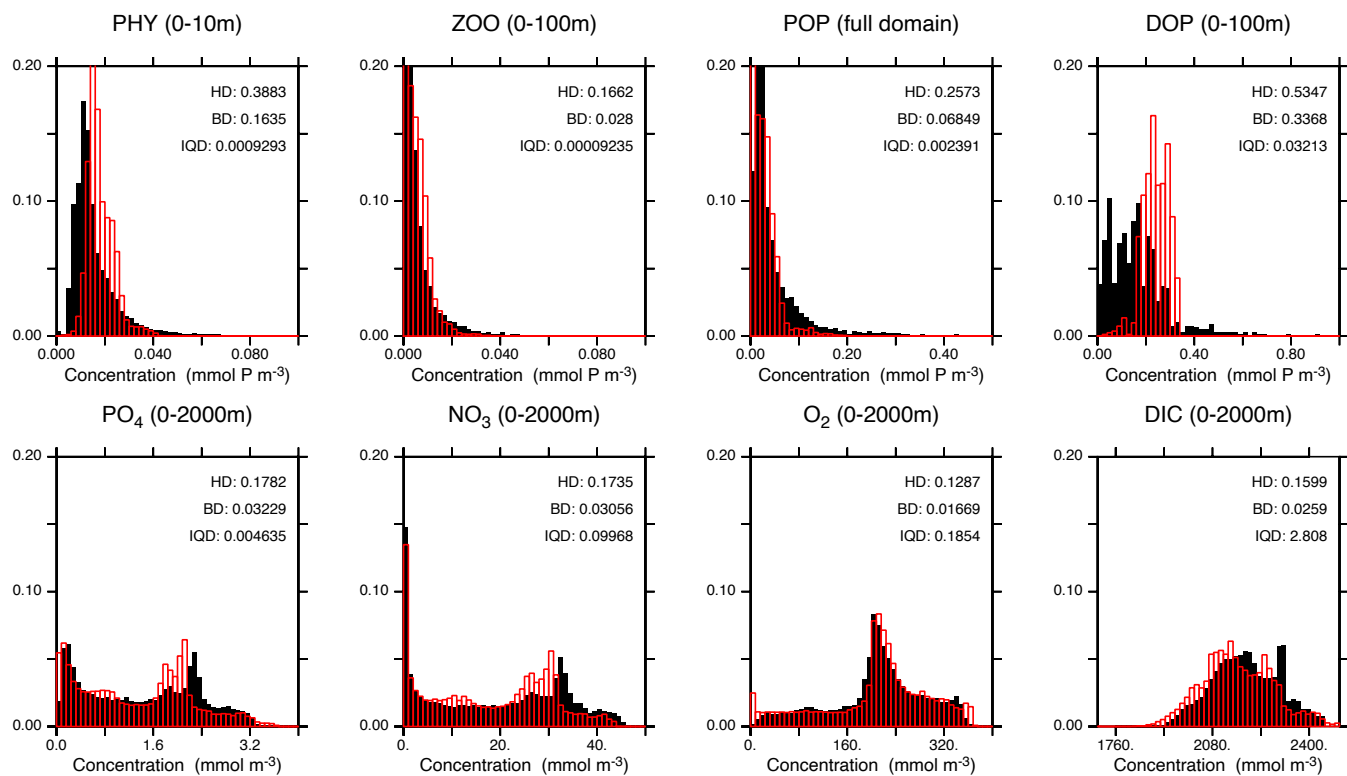


Figure S11. As Figure S8, but for FOCI-HG/hist.

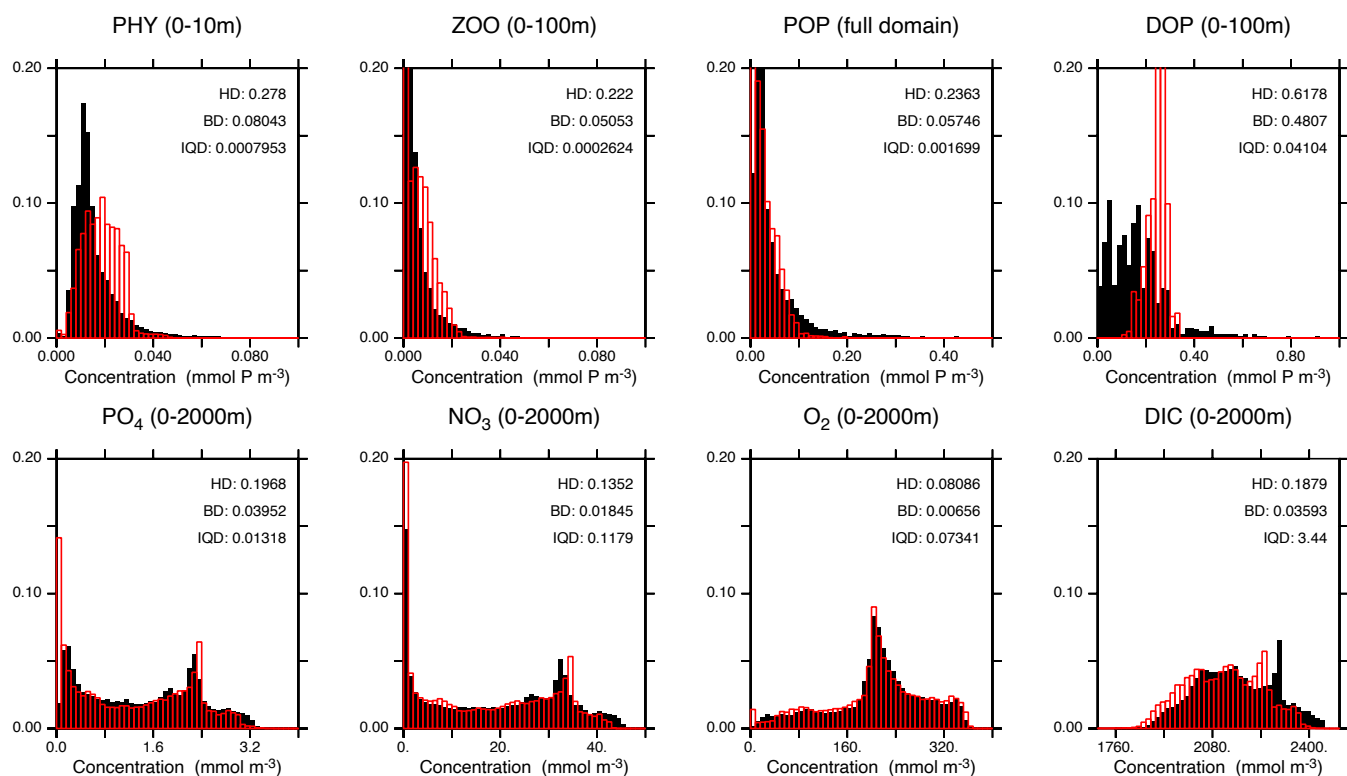


Figure S12. As Figure S8, but for ECCO-U.

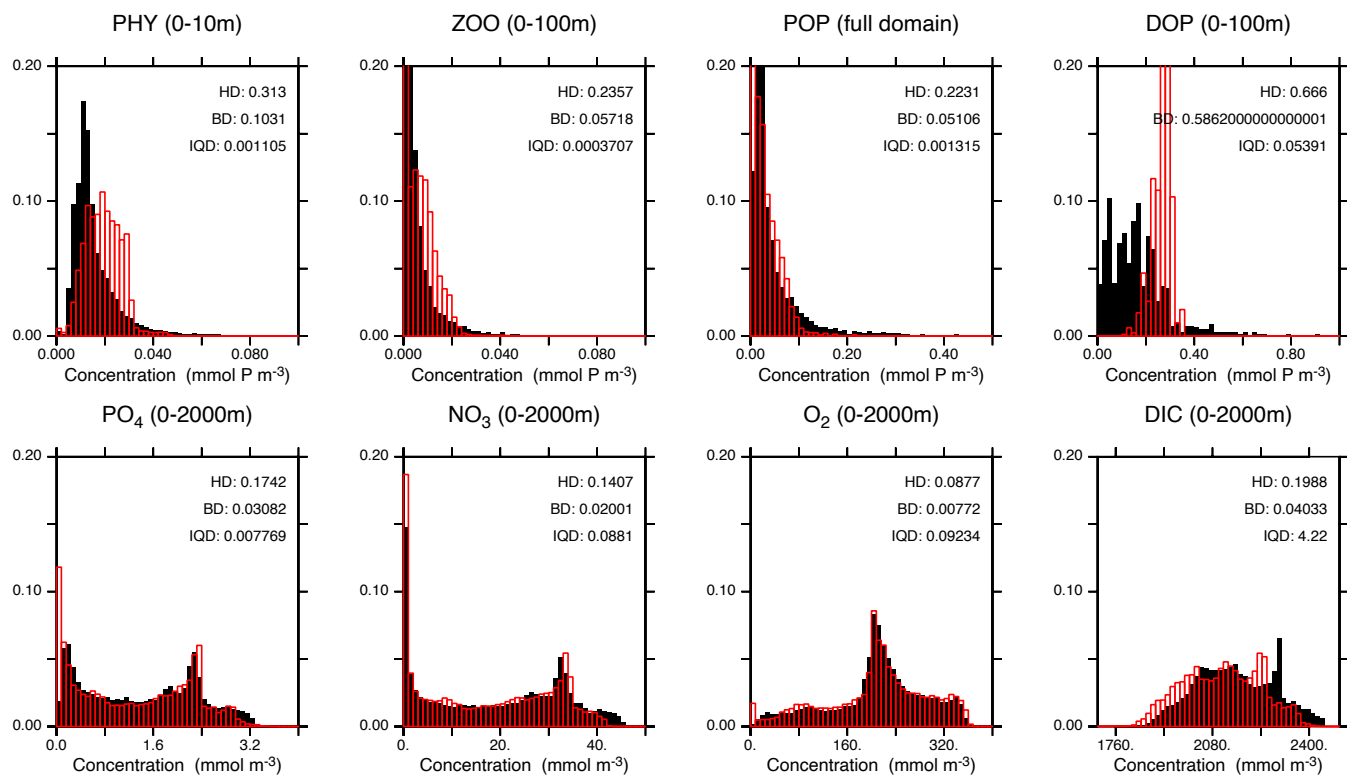


Figure S13. As Figure S8, but for ECCO-I.

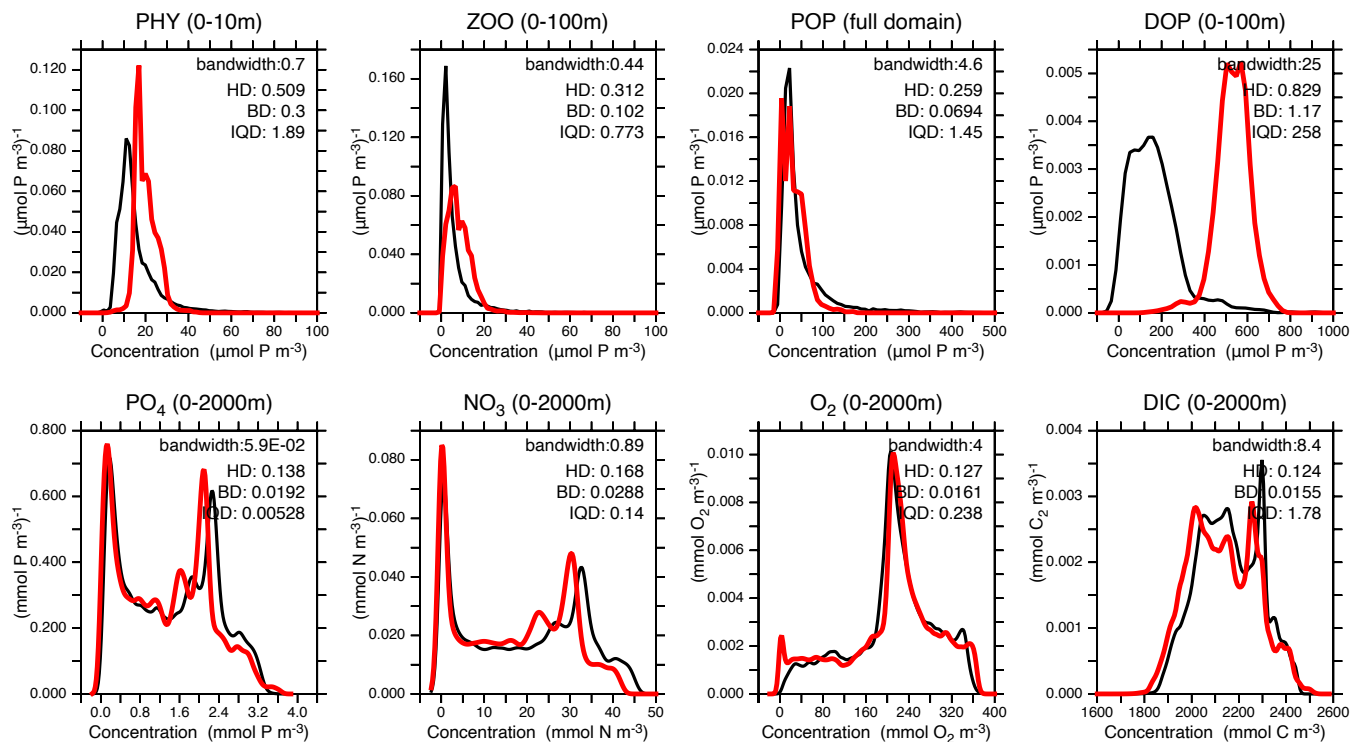


Figure S14. Kernel density estimates (KDE) of tracer concentrations from observations (black) and simulation FOCI-CC/pictrl. KDEs of simulated and observed tracer concentrations have been calculated as explained in section 2.4.3. Numbers in the upper right of each panel show the L1-metric, the Hellinger distance (HD) and the Bhattacharyya distance (BD), evaluated as explained in section 2.4.2. Note that vertical domains over which the metrics have been calculated differ for the different tracers, and are the same as in Figure S7.

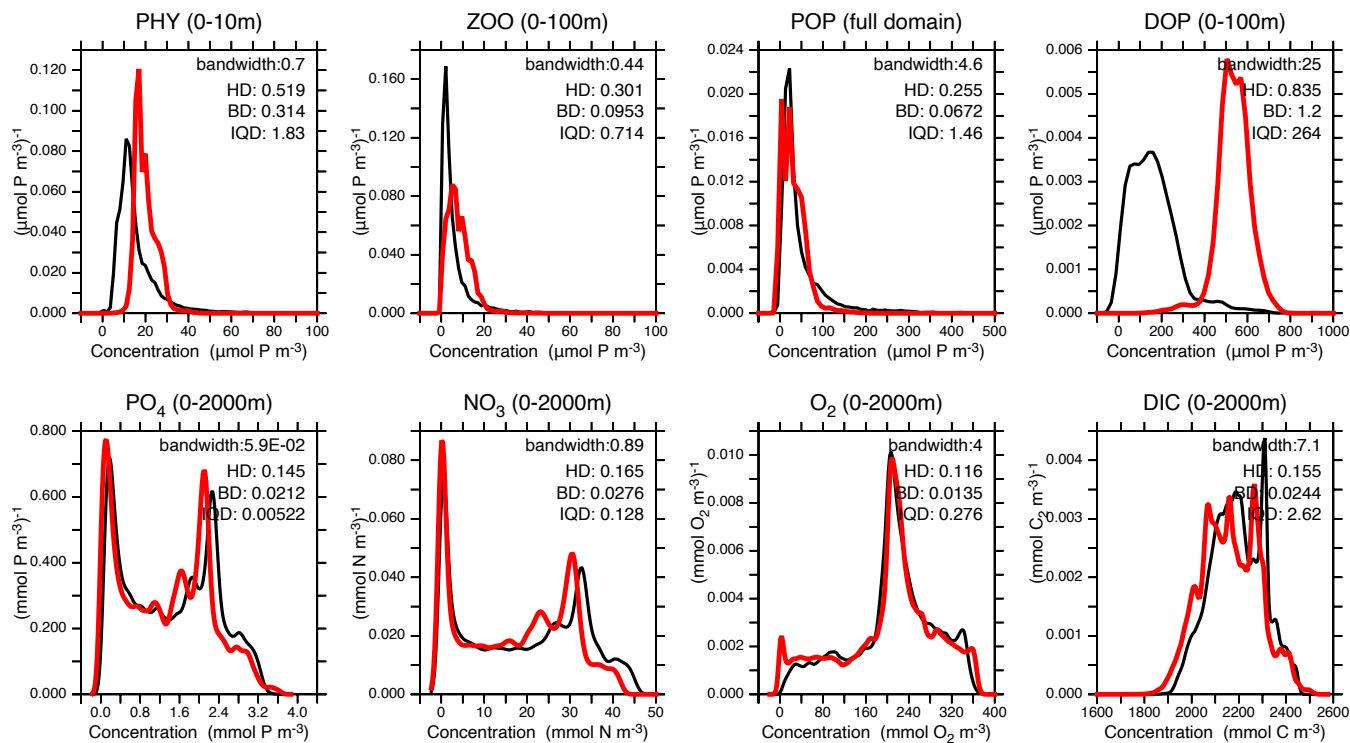


Figure S15. As Figure S14, but for FOCI-CC/hist.

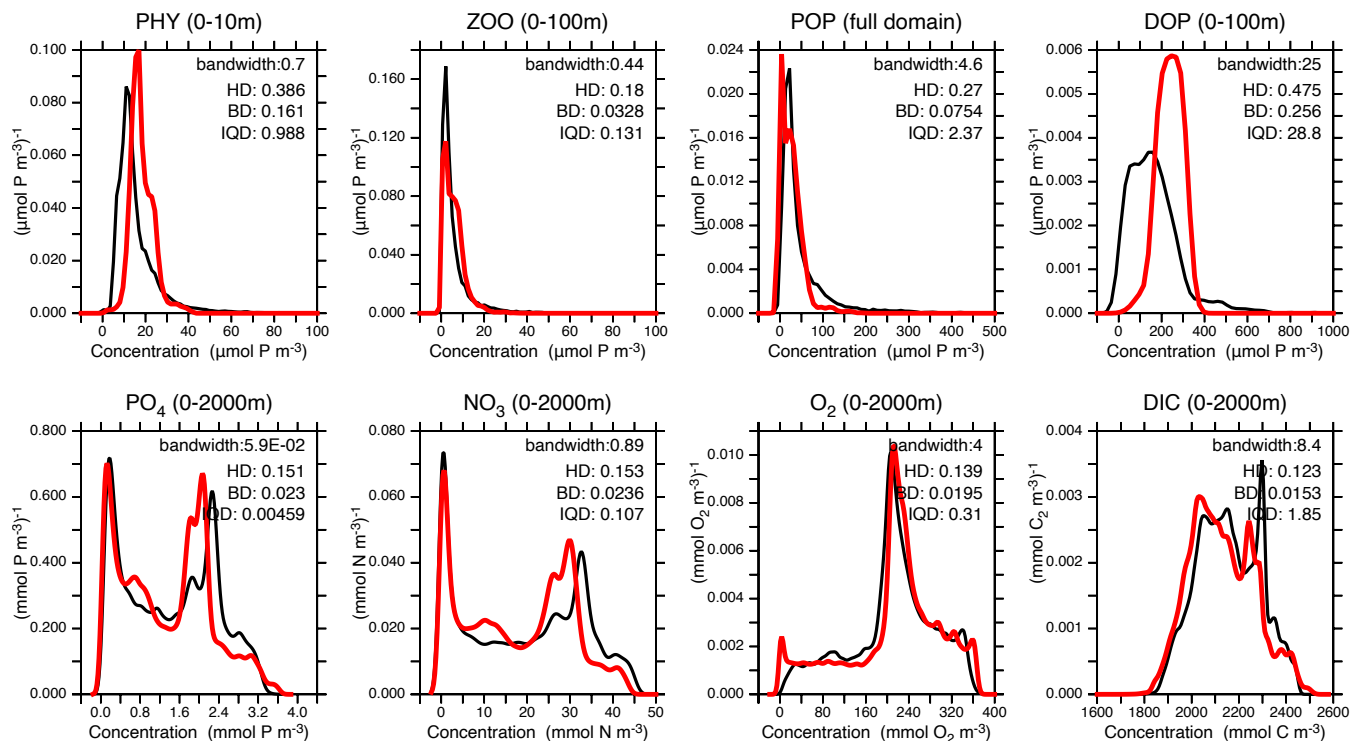


Figure S16. As Figure S14, but for FOCI-HG/pictrl.

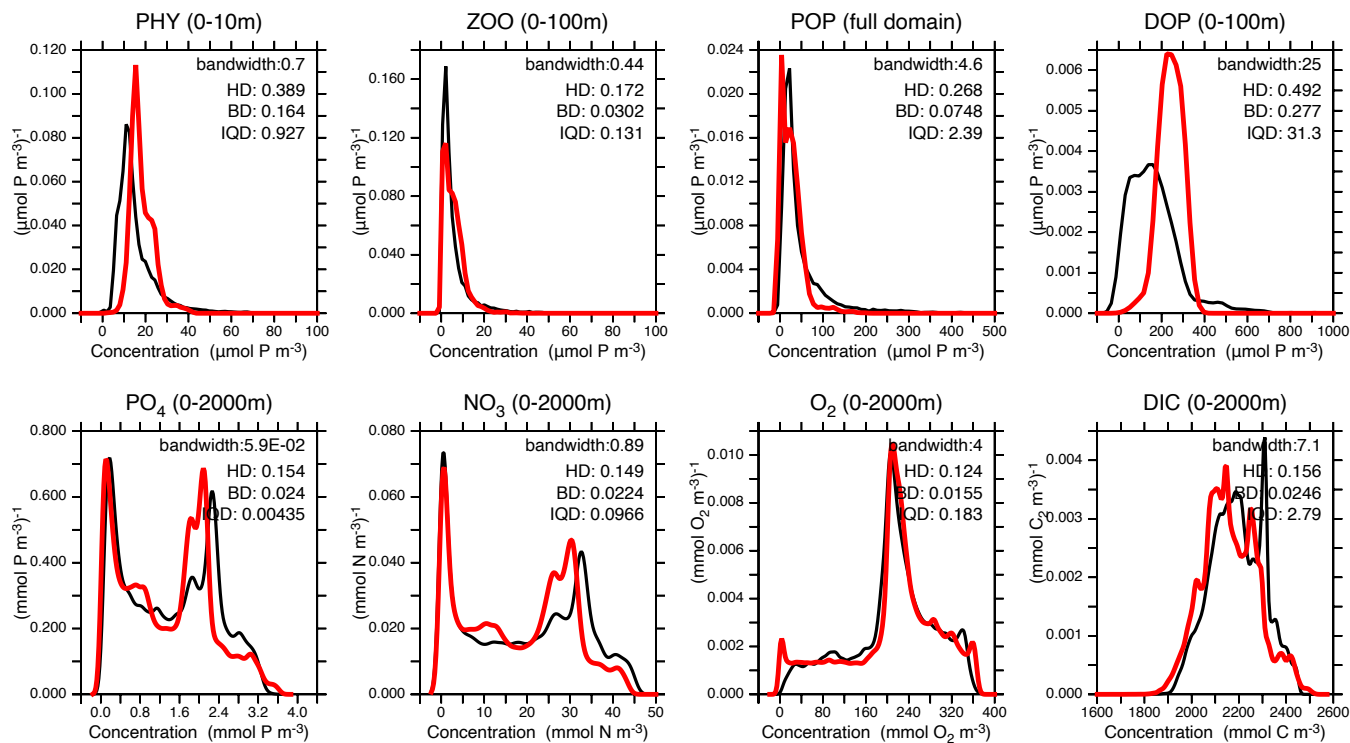


Figure S17. As Figure S14, but for FOCI-HG/hist.

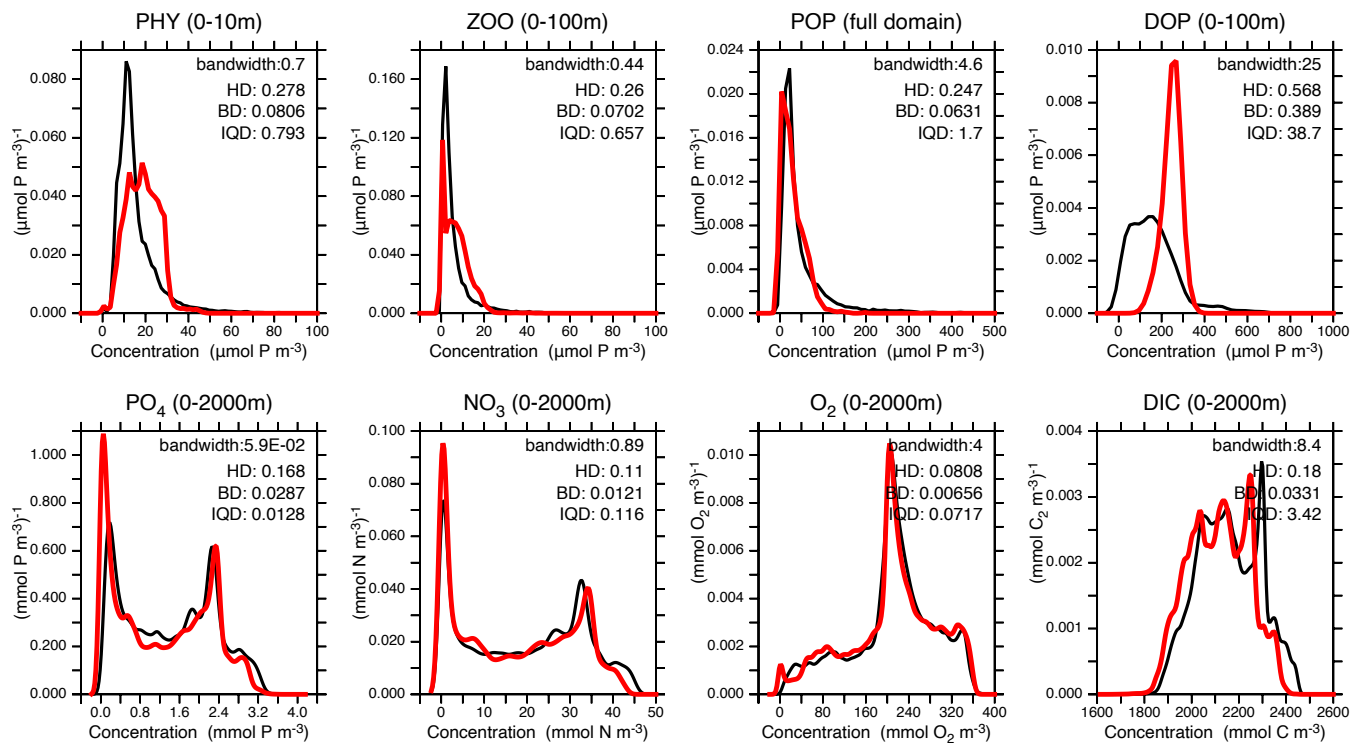


Figure S18. As Figure S14, but for ECCO-U.

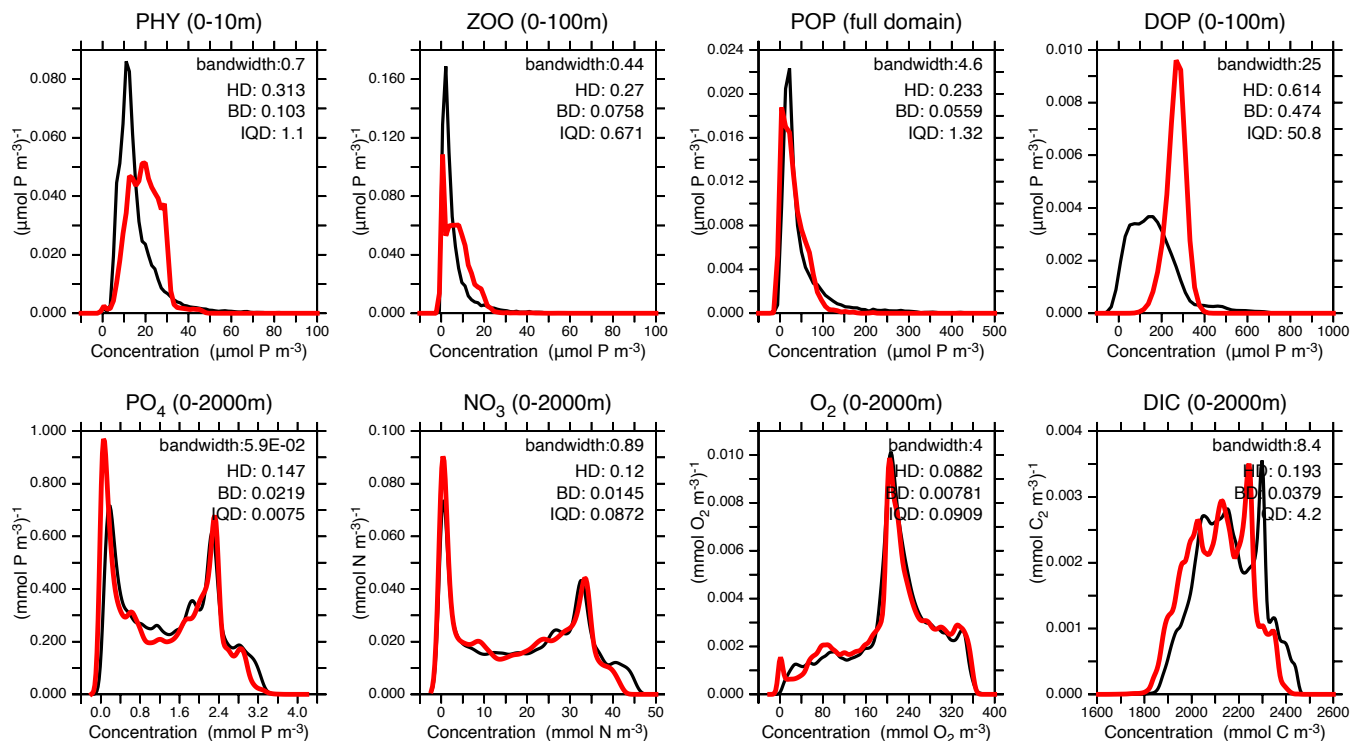


Figure S19. As Figure S14, but for ECCO-I.

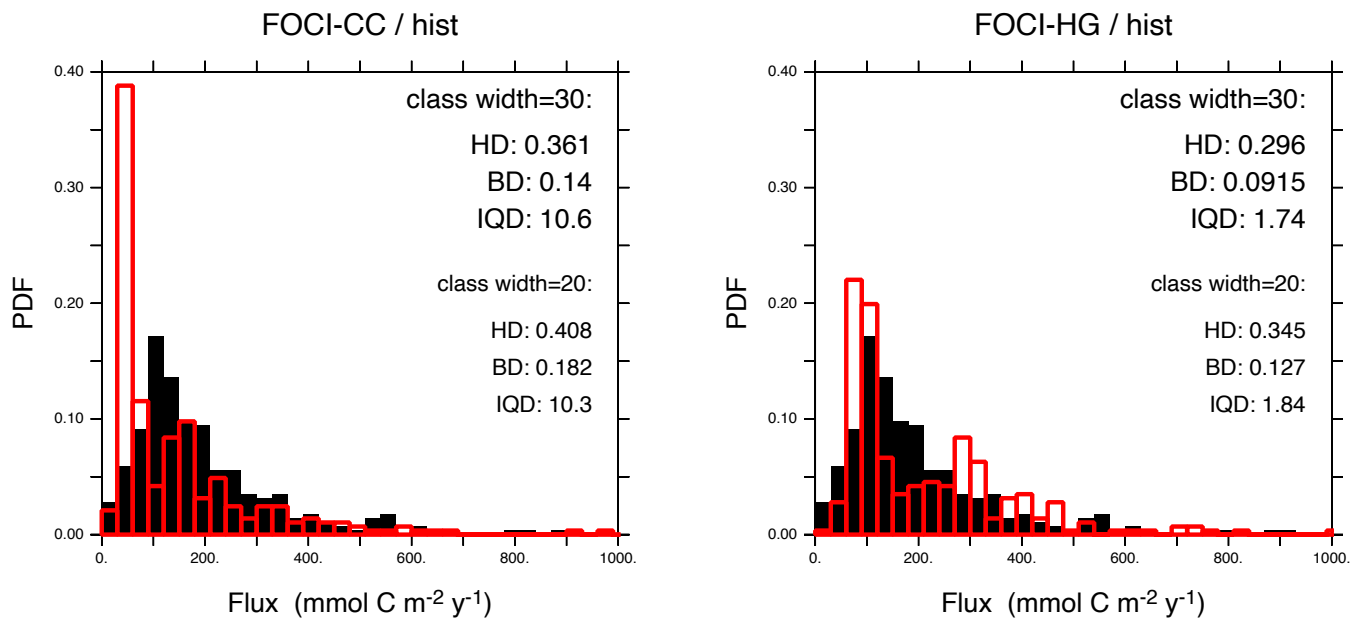


Figure S20. Histograms (PDF) of particle flux from observations (black) and simulation FOCI-CC/hist and FOCI-HG/hist (red). Particle flux has been binned into $N = 34$ flux classes with a width of $30 \text{ mmol C m}^{-2} \text{ y}^{-1}$ over the indicated range, and the frequency has been calculated for the model and observations. Numbers in the upper right of each panel show the L1-metric, the Hellinger distance (HD) and the Bhattacharyya distance (BD), evaluated as explained in section 2.4.2. Small letter and numbers list the metrics for $N = 20$ classes with a width of $50 \text{ mmol C m}^{-2} \text{ y}^{-1}$.