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Supplement of

The importance of turbulent ocean–sea ice nutrient exchanges for simulation of ice algal biomass and production with CICE6.1 and Icepack 1.2

Pedro Duarte et al.

Correspondence to: Pedro Duarte (pedro.duarte@npolar.no)

Introduction

This supporting information contains information on model forcing, parameters and initial conditions (Text S1 and Tables S1 – S3) and, supplementary figures (Figures S1 – S16).

Model forcing is shown in Figure 2 of Duarte et al. (2017). All datasets used for model forcing and definition of initial conditions are publicly available following the DOIs of the following datasets (see paper references): Hudson et al. (2015) for wind speed, air temperature, precipitation and specific humidity; Hudson et al., (2016) for incident surface short and longwave radiation; Gerland et al. (2017) for ice temperature and salinity sea ice data; Peterson et al. (2016) for sea surface current velocity, temperature, salinity, and heat fluxes from a turbulence instrument cluster (TIC); Assmy et al. (2016) for sea surface nutrient concentrations and Assmy et al. (2017) for sea-ice biogeochemistry.

The drift of the ice floes SYI and refrozen leads simulated in this study is shown in Figure 1 of Duarte et al. (2017).

Text S1

Model parameters and initial conditions

Model parameters for thermodynamics and biogeochemistry are listed in Tables S1 and S2, respectively. Most of these parameters may be changed in the CICE input file (ice_in) without the need to recompile the software. Other parameters are hard-coded and treated as constants and any changes require recompiling the software. Table S2 contains the full biogeochemical parameter set used by the CICE model (Jeffery et al., 2016), including parameters not used in the present simulations such as those related with iron and dimethyl sulphite (DMS). The parameter values used in this study are the default ones, except for those changed under one or more simulations and referred to in the paper: *R_snw* (Sigma coefficient for snow grain size) (Table S1), K_{SiO3} (Silica half saturation constant) and $R_{si:n}$ (Algal Si to N ratio) (Table S2). There are two biogeochemical parameters that are not part of the model input file but instead hard-coded: the ocean background concentration of ammonia (amm) and ice algae (algalN): 0.23 and 0.011 mM N. The former value was obtained from the average ammonia concentration observed during the N-ICE2015 expedition (Granskog et al., 2018), during the period corresponding to the simulations. The latter value was the default one in CICE. When three values are indicated for biogeochemical parameters, it means that they depend on a specific algal group: diatoms, small phytoplankton or *Phaeocystis* sp., respectively, (Jeffery et al., 2016). In the present study only diatoms were considered.

The initial conditions are for second year ice (SYI) simulations only (listed in Table 1 of the paper) that begin from a restart file containing the data shown in Table S3. Simulations for the refrozen lead begin with zero ice and, therefore, do not require initial conditions. When ice starts to build up its chemical and biological initial conditions are defined by the water properties and model forcing functions.

Table S1. Los Alamos Sea Ice (CICE) Model thermodynamic parameters and their values listed in a way similar to that used in Table 2 of Urrego-Blanco et al. (2015), with parameters grouped in broad categories indicating the model physics more directly affected by them.

Parameters	Description	Value	Units
rhos	Snow density	330	kg m^{-3}
rhoi	Ice density	917	
	Radiation, using the Delta-Eddington radiative scheme		
rsnw_fresh	Fresh snow grain size	100	µm
rsnw_mlt	Max. melting snow grain size	1500	
rsnw_nonmelt	Nonmelting snow grain size	500	
rsnw_sig	Sigma of snow grain size	250	
dT_mlt	Melt/no-melt snow grain Δtemperature	1.5	K
hi_ssl	Ice scattering layer	0.050	m
hs_ssl	Snow scattering layer	0.040	
hp0	Pond depth for transition to bare ice	0.200	
R_ice	Sigma coefficient for albedo of bare ice	0	dimensionless
R_pnd	Sigma coefficient for ponded ice albedo	0	
R_snw	Sigma coefficient for snow grain	1.5 for Refrozen lead simulations and 0.8 for Second Year Ice simulations, following Duarte et al. (2017)	
fr_min	Overcast factor for snow grain	0.80	
	Mushy thermodynamics		
kb	Thermal conductivity of brine	0.5375	W m^{-1} K^{-1}
kappal	Thermal diffusivity of brine	$8.824.10^{-8}$	m^{-2} s^{-1}
ksno	Thermal conductivity of snow	0.30	W m^{-1} K^{-1}
cp_ice	Sea-ice heat capacity	2.106	J kg^{-1} K^{-1}
phi_i_mushy	Solid fraction at lower interface	0.85	dimensionless
a_rapid_mode	Brine channel diameter	$0.5.10^{-3}$	m

Rac_rapid_mode	Critical Rayleigh number	10.0	dimensionless
dSdt_slow_mode	Slow drainage strength	$-5.0.10^{-8}$	$m\ s^{-1}\ K^{-1}$
phi_c_slow_mode	Liquid fraction porosity cutoff for slow mode drainage	0.05	
phic	Liquid fraction for impermeability	0.05	dimensionless
advection_limit	Max. fraction of brine advection	0.005	
lambda_pond	Drainage time scale of ponds	$1.16.10^{-6}$	s^{-1}
viscosity_dyn	Brine dynamic viscosity	$1.79.\ 10^{-3}$	$kg\ m^{-1}\ s^{-1}$

Table S2. Los Alamos Sea Ice (CICE) Model biogeochemical parameters. When three values are indicated, parameters depend on the algal group (diatoms, small phytoplankton or *Phaeocystis* sp., respectively) (Hunke et al., 2016). In the present study only diatoms were considered.

Parameters	Description	Value	units
f_{graze}	Fraction of growth grazed	0,0.1,0.1	
f_{res}	Fraction of growth respired	0.05	
l_{max}	Maximum tracer loss fraction	0.9	
m_{pre}	Maximum mortality rate	0.007,0.007,0.007	day^{-1}
m_T	Mortality temperature decay	0.03,0.03,0.03	$^oC^{-1}$
T_{max}	Maximum brine temperature	0	^oC
k_{nitr}	Nitrification rate	0	day^{-1}
f_{ng}	Fraction of grazing excreted	0.5	
f_{gs}	Fraction of grazing spilled	0.5	
f_{nm}	Fraction of mortality to NH_4	0.5	
f_{dg}	Frac. spilled grazing to DON	0.6	
k_{nb}	Bacterial degredation of DON	0.03	day^{-1}
f_{cg}	Fraction of mortality to DOC	0.4,0.4,0.2	
$R^C_{C:N}$	Algal carbon to nitrogen ratio	7.0,7.0,7.0	mol mol^{-1}
k_{cb}	Bacterial degradation of DOC	0.03,0.03,0.03	day^{-1}
τ_{fe}	Conversion time pFe↔dFe	3065	day
$r^{mx}_{fed:doc}$	Max ratio of dFe to saccharids	0.2	nM Fe/µMC
ffa	Fraction of remin. N to dFe	0.3	
$R_{fe:n}$	Algal Fe to N ratio	0.023, 0.023,0.7	mmol mol^{-1}
$R_{s:n}$	Algal S to N ratio	0.03,0.03,0.03	mol mol^{-1}
f_{sr}	Resp. Loss as DMSPd	0.75	
τ_{dmsp}	Stefels rate	3	day
τ_{dms}	DMS oxidation rate	10	day
y_{dms}	Yield for DMS conversion	0.5	
K_{NO3}	NO_3 half saturation constant	1,1,1	mmol m^{-3}
K_{NH4}	NH_4 half saturation constant	0.3,0.3,0.3	mmol m^{-3}
K_{SiO3}	Silica half saturation constant	4.0 or 2.2 [see Table 1 and Duarte et al. (2017)],0,0	mmol m^{-3}
K_{fed}	Iron half saturation constant	1.0,0.2,0.1	µmol/m-3
op_{min}	Boundary for light attenuation (optical depth)	0.1	
chlabs	Light absorption length per chla conc.	0.03,0.01,0.05	m^{-1} (mg/m^3)
α	Light limitation factor	0.30,0.20,0.67	m^2 W^{-1}
β	Light inhibition factor	0.002,0.001,0.01	m^2 W^{-1}
μ_{max}	Maximum algal growth rate	0.81,0.41,0.851	day^{-1}
μ_T	Temperature growth factor	0.06,0.06,0.06	day^{-1}
f_{sal}	Salinity growth factor	1	
$R_{si:n}$	Algal Si to N ratio	1.0 [following Duarte et al. (2017)],0,0	mol mol^{-1}
amm	Background concentration of ammonia	0.23	mmol m^{-3}
algalN	Background concentration of ice algae	0.0011,0.002,0.002	mmol m^{-3}

Table S3. Model initial conditions for second year ice (SYI) simulations (see Table 1 in the paper for details on model simulations). The model uses one snow layer and 15 ice layers (presented below from the snow-ice interface to the ice-ocean interface). There is a physical grid for thermodynamics and a biogrid for biogeochemistry. The latter also has 15 layers, but values are evaluated at the top and at the bottom of each layer, reason why there are 16 initial values for biogeochemical variables presented below and two more values (not shown) for the snow layer which were assumed zero for all biogeochemical variables. Variables include the abbreviations used in the restart CICE file and the respective dimensions.

Bulk snow and ice properties			
Snow thickness (vsnon, m)	0.4	Ice concentration or fractional area (aicen, dimensionless)	1.0
Snow enthalpy (qsno, J m^{-3})	-1.21×10^{8}	Ice thickness (vicen, m)	1.4
Skin temperature (Tsfcn, ˚C)	-17.66	Fraction of level ice (alvl, dimensionless)	1.0

Layer ice properties

Layers	Ice enthalpy (qice, 10^8 J m^{-3})	Ice salinity (sice, ppt)	Nitrate (bgc_Nit, mmol m^{-3})	Ammonia (bgc_Am, mmol m^{-3})	Silicic acid (bgc_Sil, mmol m^{-3})	Ice algae (bgc_N, mmol m^{-3})
1	-3.20	1.1	1.21	0	0.7	0.17
2	-3.18	0.1	1.64	0	0.7	0.31
3	-3.17	0.2	0.71	0	0.7	0.47
4	-3.15	2.5	1.11	0	0.7	0.80
5	-3.14	2.6	0.58	0	0.7	1.12
6	-3.12	2.2	0.40	0	0.7	1.08
7	-3.11	3.3	0.42	0	0.7	0.72
8	-3.09	4.8	0.44	0	0.7	0.38
9	-3.08	3.4	0.57	0	0.7	0.47
10	-3.06	3.3	1.79	0	0.7	0.56
11	-3.04	3.1	0.69	0	0.7	0.51
12	-3.01	4.0	0.40	0	0.7	0.35
13	-2.96	4.0	0.40	0	0.7	0.21
14	-2.81	3.8	0.44	0	0.7	0.17
15	-2.18	4.9	3.12	0	0.7	0.15
			16.8	0	0.7	0.17

Figures S1 – S19

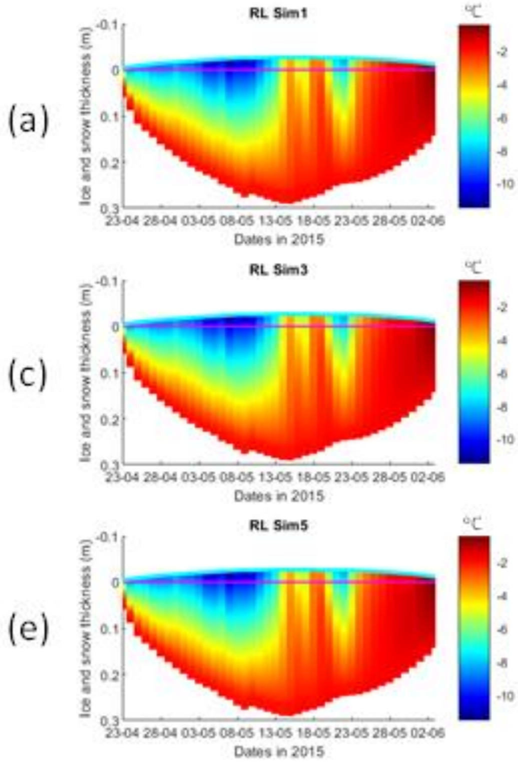

Figure S1. Daily averaged results for the refrozen lead (RL) simulations 1 - 5: Simulated evolution of sea-ice temperature, as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The magenta line represents sea level. Refer to Table 1 for details about model simulations.

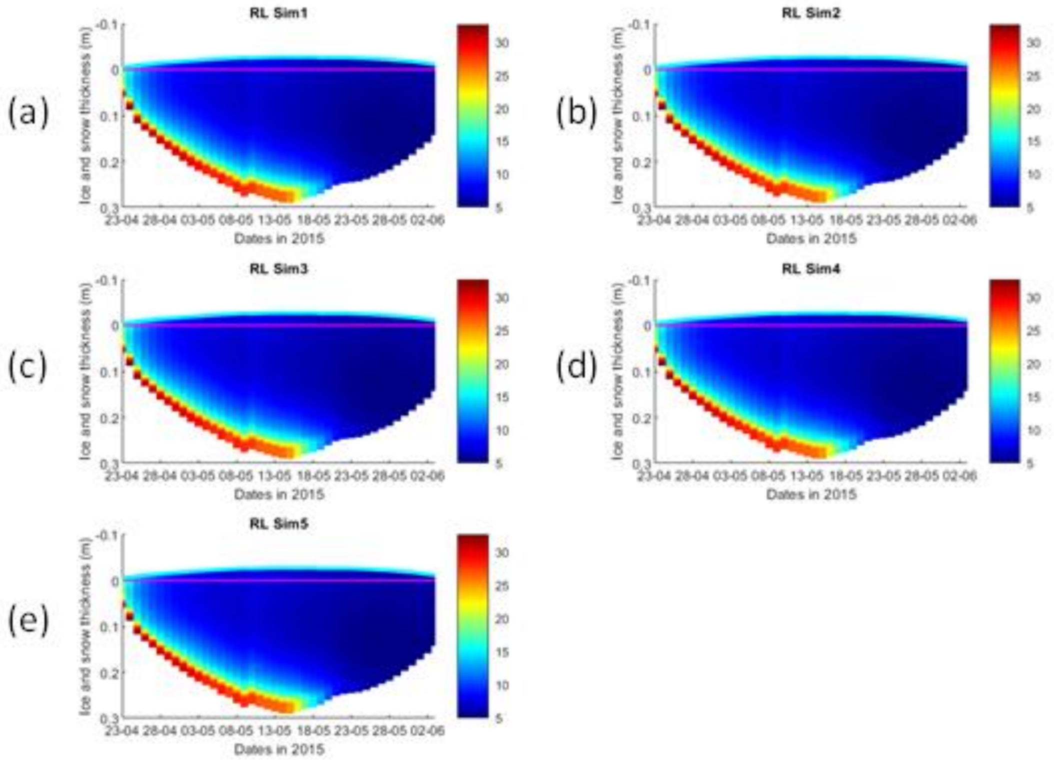

Figure S2. Daily averaged results for the refrozen lead (RL) simulations 1 - 5: Simulated evolution of sea-ice bulk salinity, as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The magenta line represents sea level. Refer to Table 1 for details about model simulations.

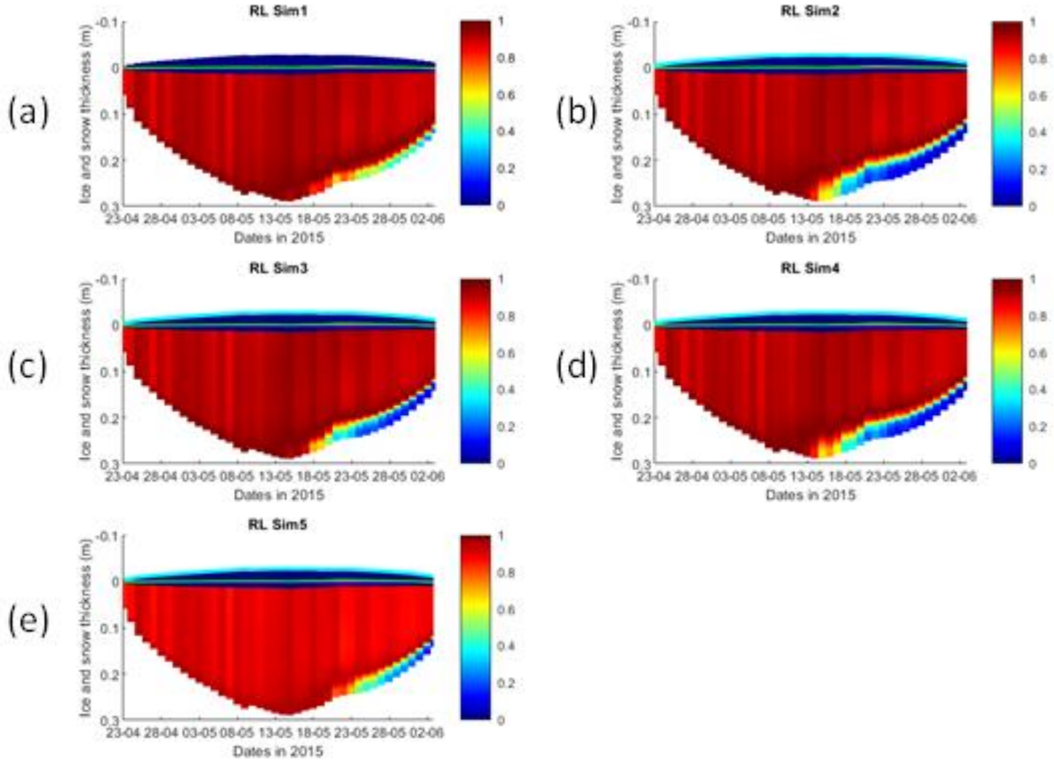

Figure S3. Daily averaged results for the refrozen lead (RL) simulations 1 - 5: Simulated evolution of light limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line, partly covered by the green line, represents sea level. Refer to Table 1 for details about model simulations.

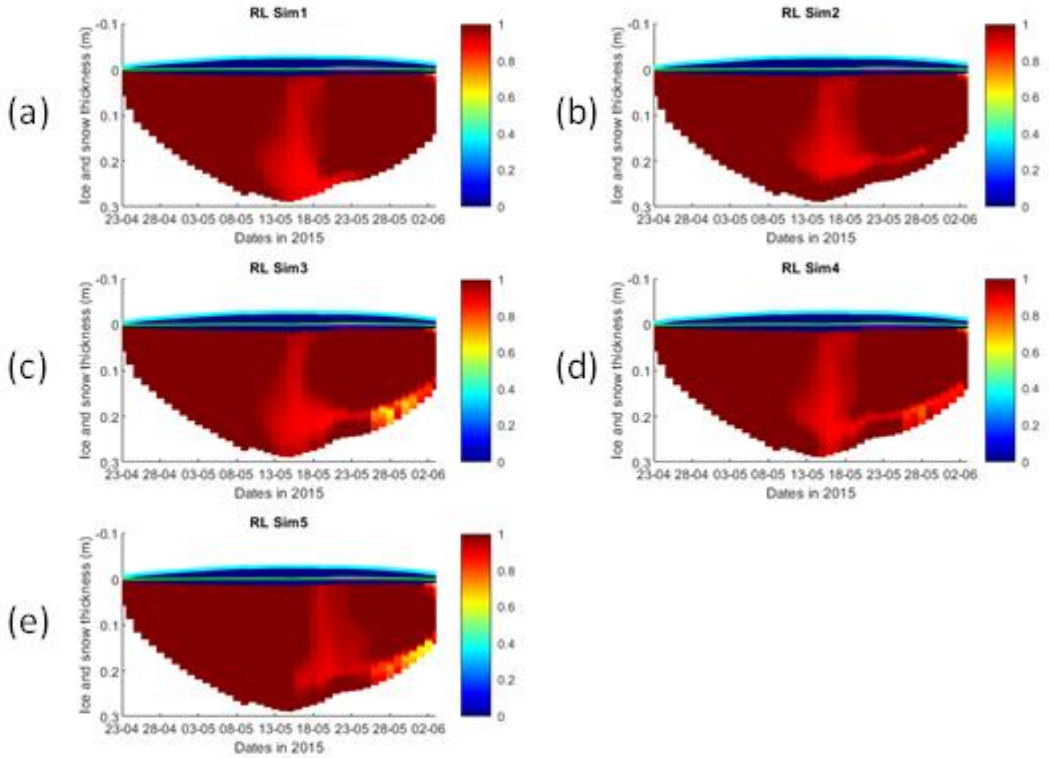

Figure S4. Daily averaged results for the refrozen lead (RL) simulations 1 - 5: Simulated evolution of nitrogen limitation (one means no limitation and zero is maximal limitation), , as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line, partly covered by the green line, represents sea level. Refer to Table 1 for details about model simulations.

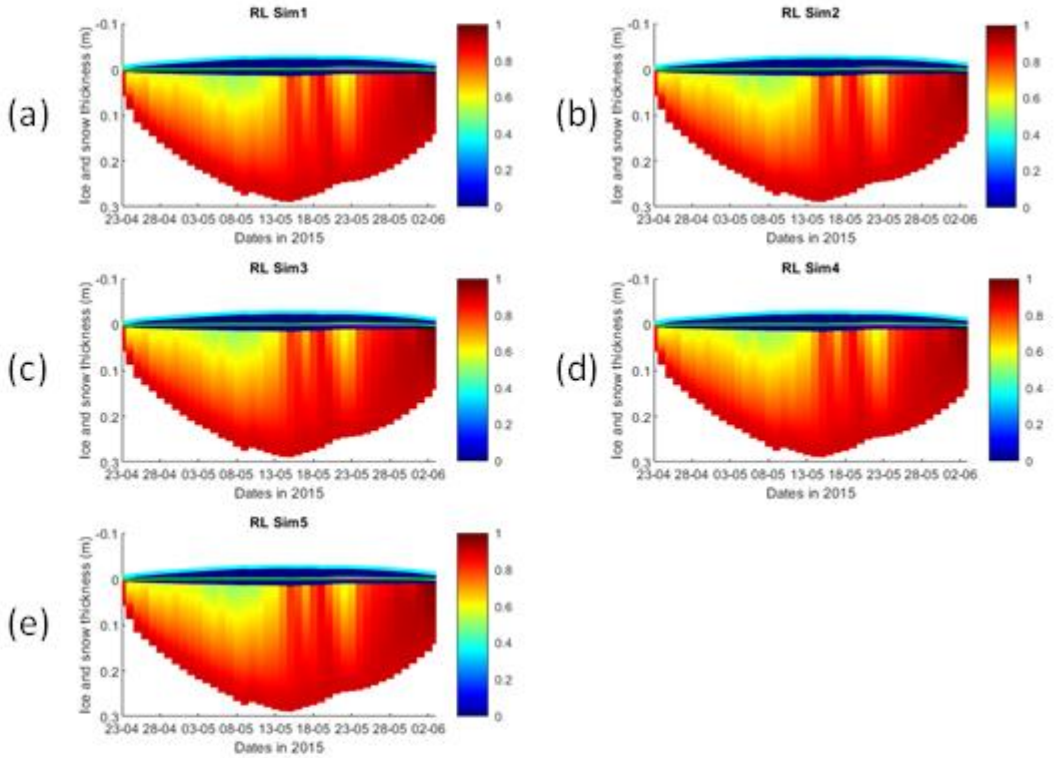

Figure S5. Daily averaged results for the refrozen lead (RL) simulations 1 - 5: Simulated evolution of temperature limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line, partly covered by the green line, represents sea level. Refer to Table 1 for details about model simulations.

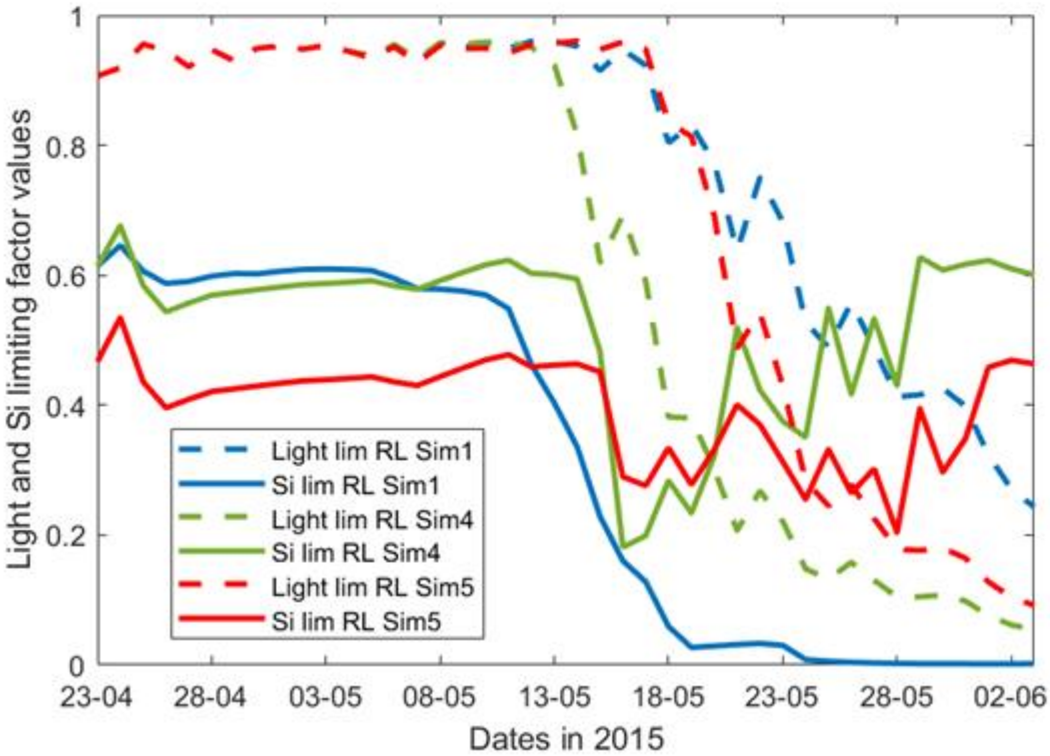

Figure S6. Daily averaged results for the refrozen lead (RL) simulations 1, 4 and 5: Simulated evolution of light (dashed lines) and silica (continuous lines) limitation (one means no limitation and zero is maximal limitation), , as a function of time at the ice bottom layer (one means no limitation). Refer to Table 1 for details about model simulations.

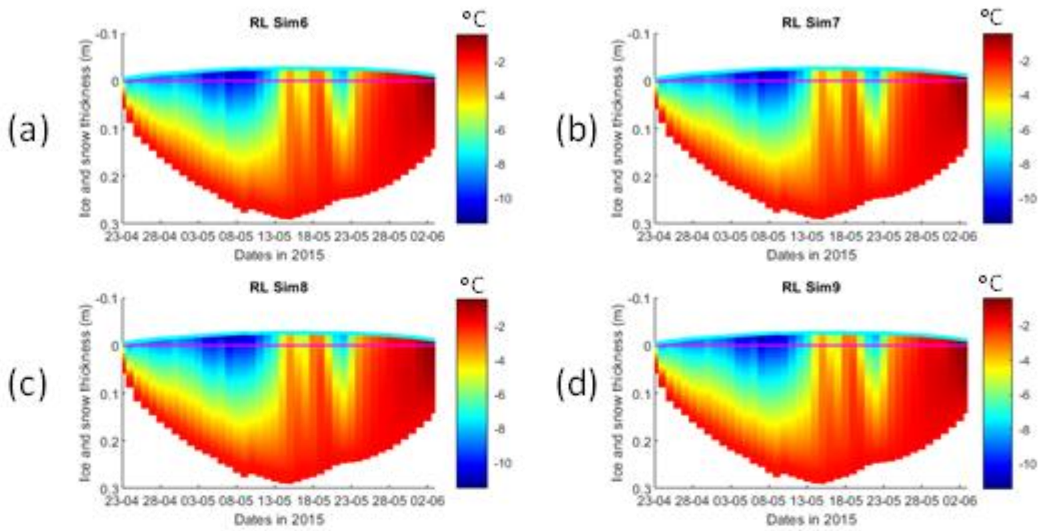

Figure S7. Daily averaged results for the refrozen lead (RL) simulations 6 - 9: Simulated evolution of sea-ice temperature, as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The magenta line represents sea level. Refer to Table 1 for details about model simulations.

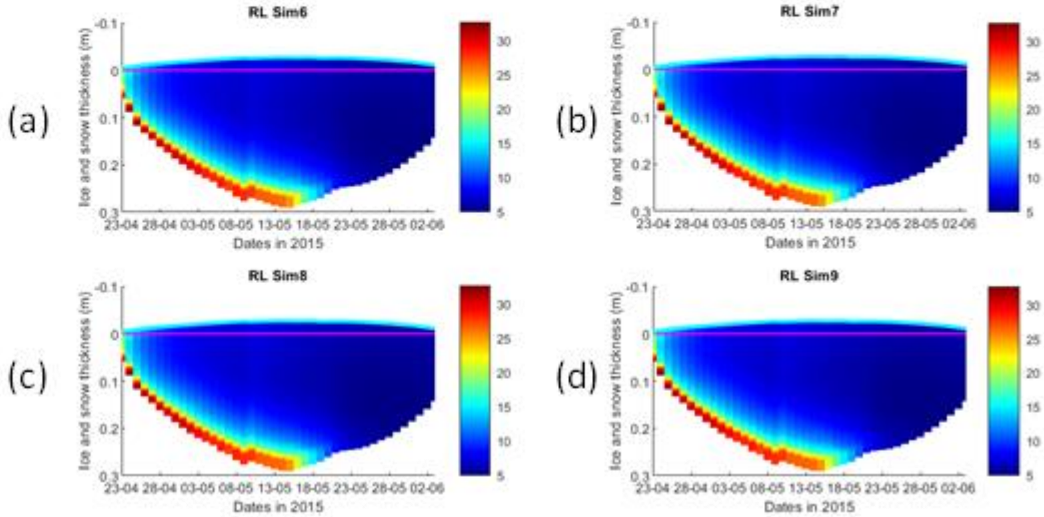

Figure S8. Daily averaged results for the refrozen lead (RL) simulations 6 - 9: Simulated evolution of sea-ice bulk salinity, as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The magenta line represents sea level. Refer to Table 2 for details about model simulations.

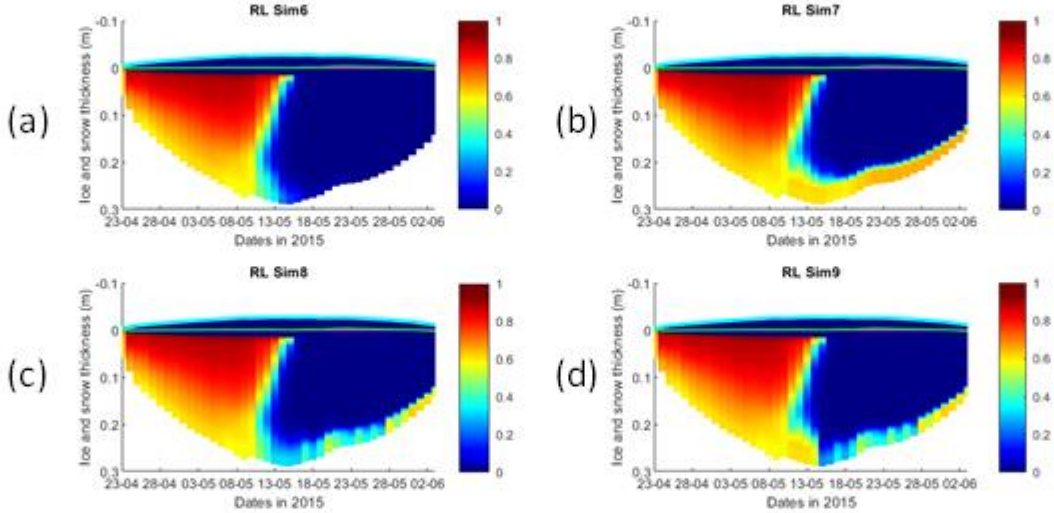

Figure S9. Daily averaged results for the refrozen lead (RL) simulations 6 - 9: Simulated evolution of silica limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line, partly covered by the green line, represents sea level. Refer to Table 1 for details about model simulations.

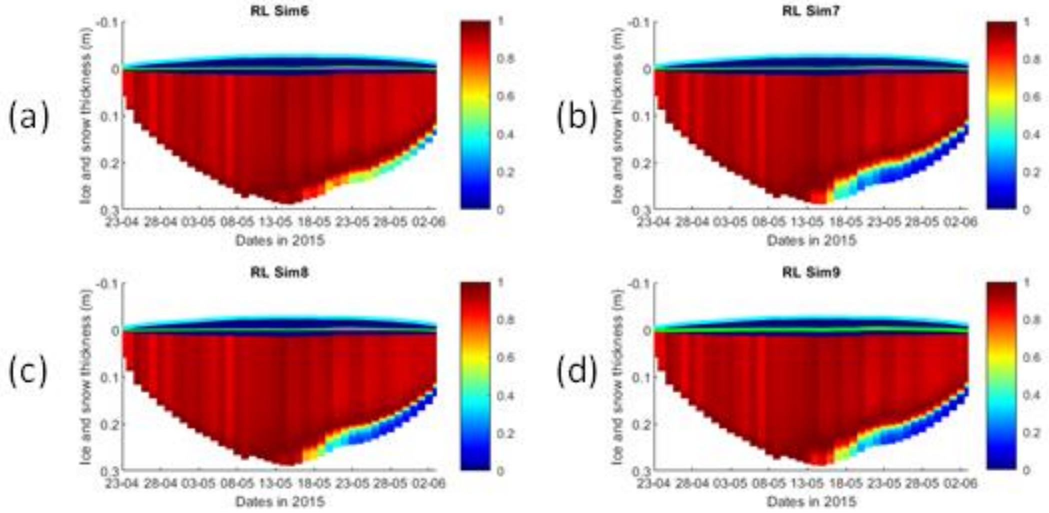

Figure S10. Daily averaged results for the refrozen lead (RL) simulations 6 - 9: Simulated evolution of light limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line, partly covered by the green line, represents sea level. Refer to Table 1 for details about model simulations.

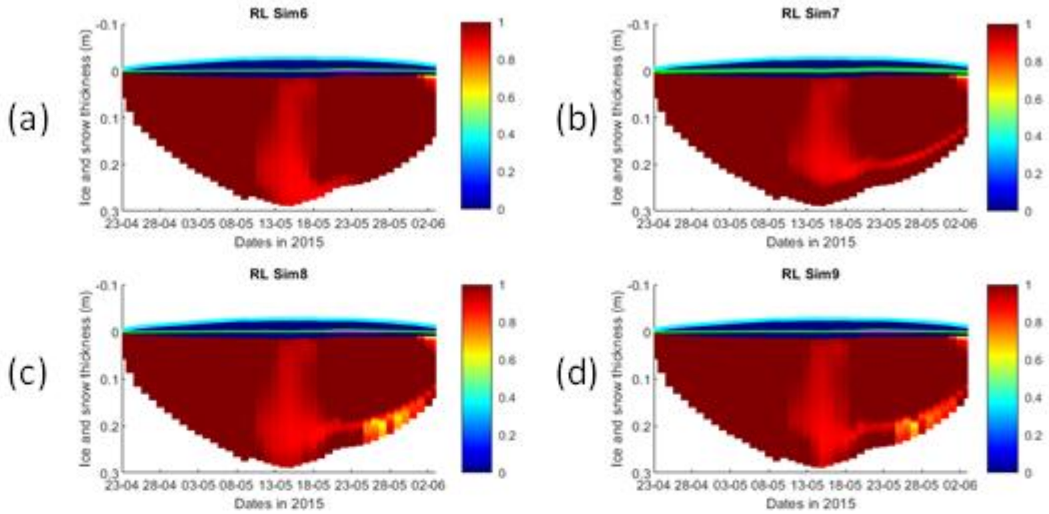

Figure S11. Daily averaged results for the refrozen lead (RL) simulations 6 - 9: Simulated evolution of nitrogen limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line, partly covered by the green line, represents sea level. Refer to Table 1 for details about model simulations.

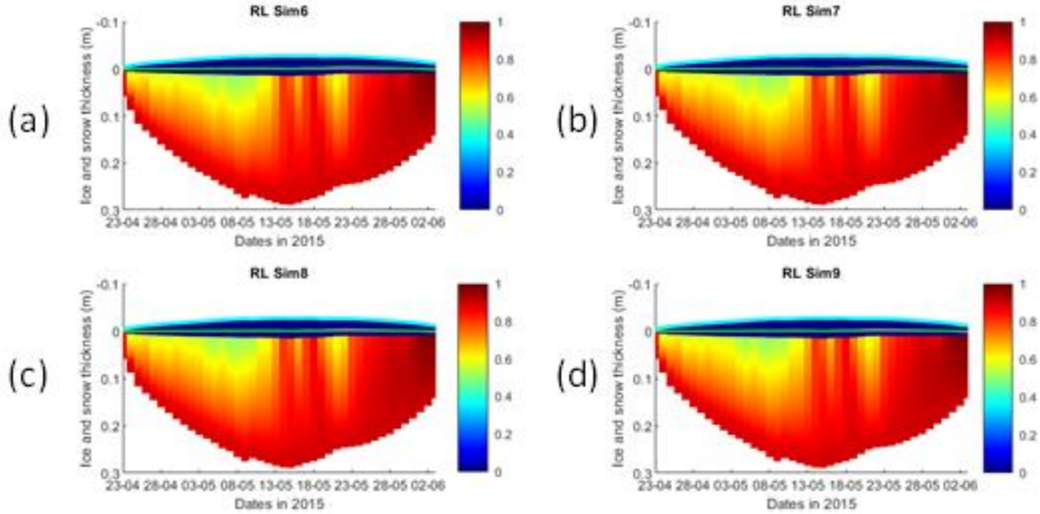

Figure S12. Daily averaged results for the refrozen lead (RL) simulations 6 - 9: Simulated evolution of temperature limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line, partly covered by the green line, represents sea level. Refer to Table 1 for details about model simulations.

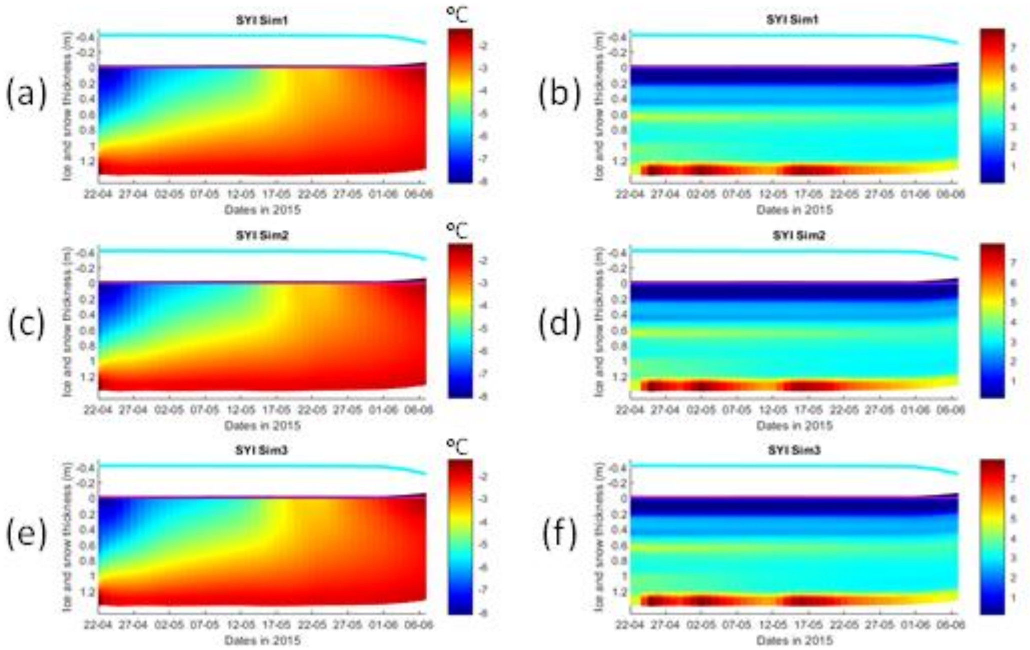

Figure S13. Daily averaged results for second year ice (SYI) simulations 1 - 3: Simulated evolution of sea-ice temperature (left panels) and salinity (right panels) as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. . The magenta line, partly covered by the green line, represents sea level and the cyan line represents the top of the snow layer. Refer to Table 1 for details about model simulations.

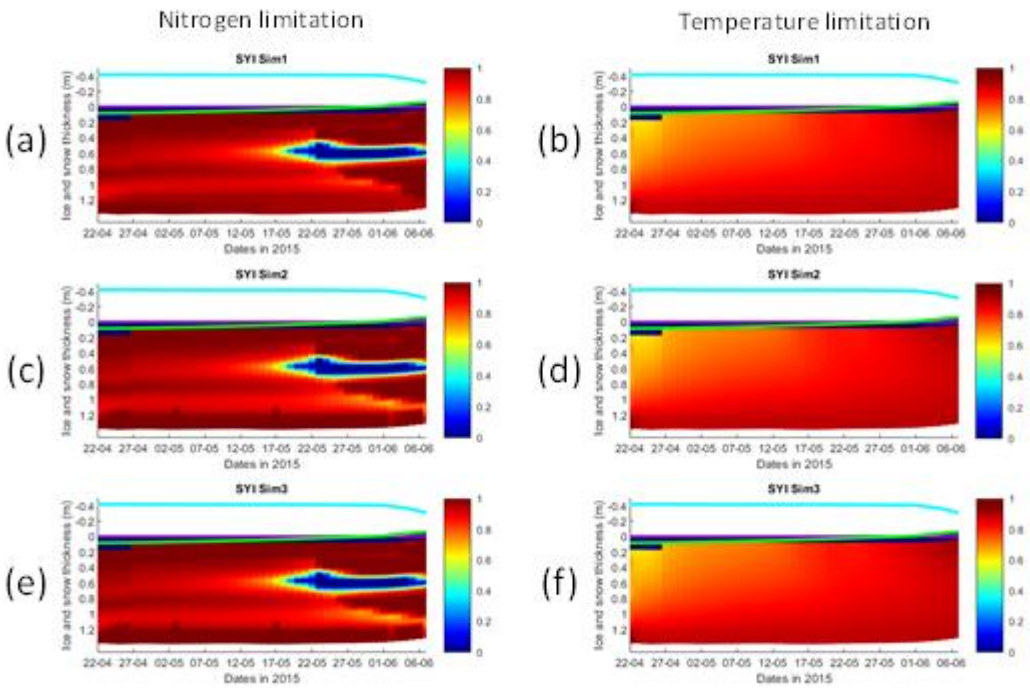

Figure S14. Daily averaged results for second year ice (SYI) simulations 1 - 3: Simulated evolution of nitrogen (left panels) and temperature (right panels) limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line represents sea level and the cyan line represents the top of the snow layer. Refer to Table 1 for details about model simulations.

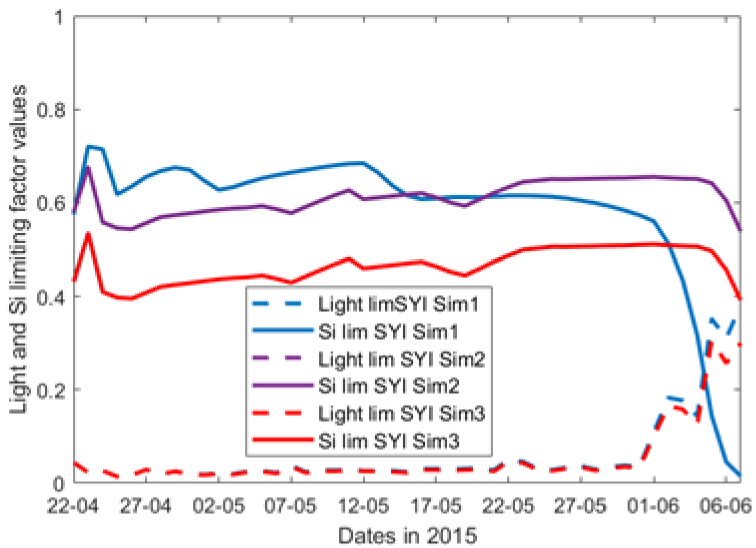

Figure S15. Daily averaged results for the second year ice (SYI) simulations 1, 2 and 3: Simulated evolution of light (dashed lines) and silica (continuous lines) limitation (one means no limitation and zero is maximal limitation), as a function of time at the ice bottom layer (one means no limitation). Refer to Table 1 for details about model simulations.

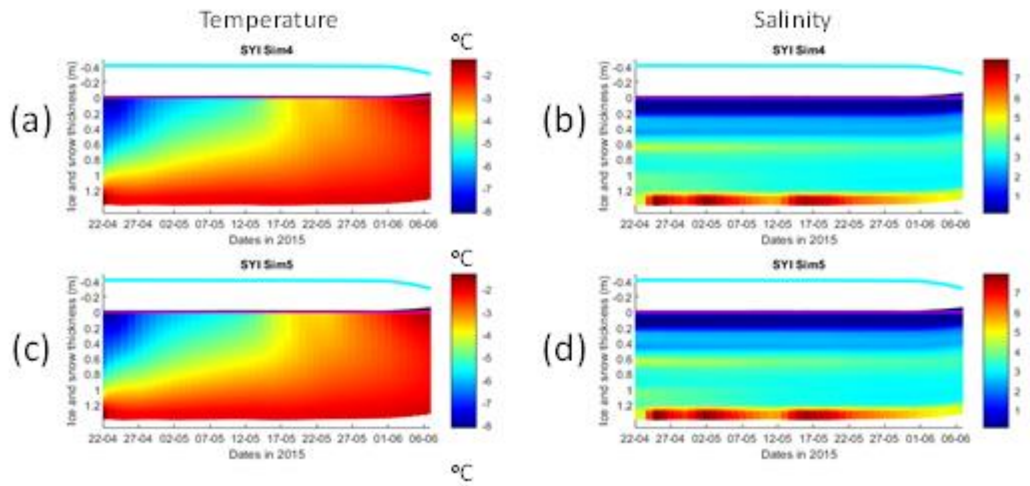

Figure S16. Daily averaged results for second year ice (SYI) simulations 4 and 5: Simulated evolution of sea-ice temperature (left panels) and salinity (right panels) as a function of time and depth in the ice. Ice thickness is given by the distance between the upper and the lower limits of the maps. . The magenta line represents sea level and the cyan line represents the top of the snow layer. Refer to Table 1 for details about model simulations.

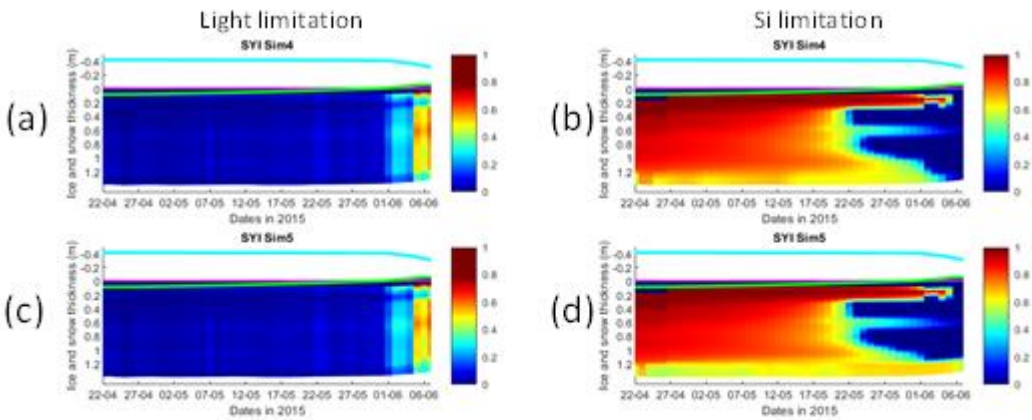

Figure S17. Daily averaged results for second year ice (SYI) simulations 4 and 5: Simulated evolution of light (left panels) and silica (right panels) limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line represents sea level and the cyan line represents the top of the snow layer. Refer to Table 1 for details about model simulations.

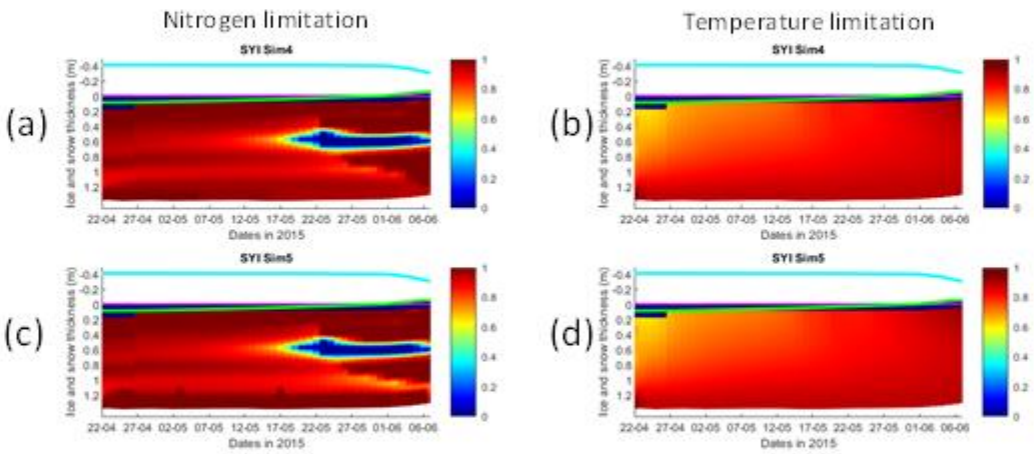

Figure S18. Daily averaged results for second year ice (SYI) simulations 4 - 6: Simulated evolution of nitrogen (left panels) and temperature (right panels) limitation (one means no limitation and zero is maximal limitation), as a function of time and depth in the ice. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line represents sea level and the cyan line represents the top of the snow layer. Refer to Table 1 for details about model simulations.

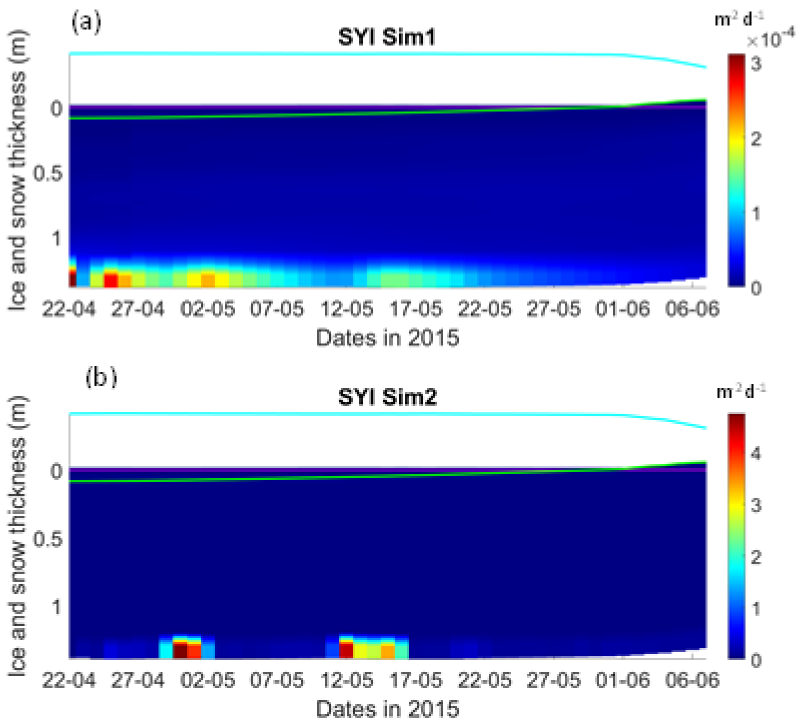

Figure S19. Daily averaged results for the second year ice (SYI) simulations 1 and 2: Simulated evolution of interface diffusivity as a function of time and depth in the ice (note the color scale differences between the various panels). Ice thickness is given by the distance between the upper and the lower limits of the maps. The upper regions of the graphs, above the green line with zero values, are above the CICE biogrid and have no brine network. The magenta line represents sea level and the cyan line represents the top of the snow layer. Refer to Table 1 for details about model simulations.