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# Turbulence-driven nutrient supply sustains ice-algal growth in the Arctic: a modeling approach with CICE 6.1 coupled to Icepack 1.2, and with SIMBA 2.0

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# Supplementary Material

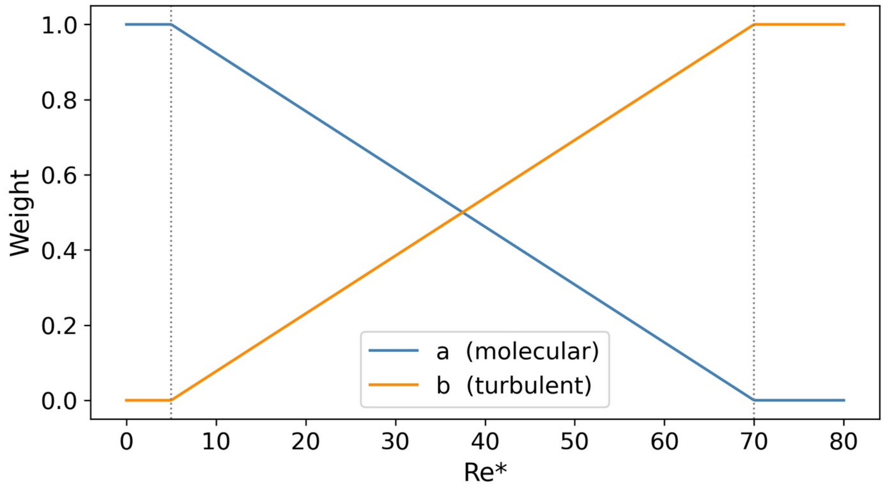


**Figure S1:** representation of the two weighting factors, *a* and *b*, as a function of the Reynolds number (*Re**) as described in equations (5) and (6)

**Tuning**

The timing of algal bloom in the case of MOSAiC is poorly represented by CICE + Icepack with the initial set of parameters because the model accumulates too much snow compared to observations. In order to first test this hypothesis and then to overcome this issue, we proceeded as follows: we first ran SIMBAv2.0 with interpolated snow observations instead of snow thickness produced by CICE + Icepack. In this case the initial growth represented by SIMBAv2.0 is in much better agreement with observed chl *a* than in the case when we force the model with CICE + Icepack output for snow thickness, also supporting our initial hypothesis (Figure S2, we took the case of $h_s$ = 0.0025 m). We then tuned the PI parameter α (the initial slope of the Production-Light function) in SIMBAv2.0 to be able to reproduce the same onset of growth even with the snow simulated by CICE + Icepack. This is shown in Figure S3 (for the case of $h_s$ = 0.0025 m). We did not change how CICE + Icepack calculates snow thickness based on precipitation because, as mentioned in the manuscript, other processes responsible for snow redistribution may have impacted the snow depth values measured at the coring site, rather than thermodynamic processes.

We used the tuned set of parameters from SIMBAv2.0 to infer the corresponding parameters for CICE + Icepack. However, there is no direct correspondence between the way SIMBAv2.0 and CICE + Icepack calculate light limitation: SIMBAv2.0 utilizes a Jassby-Platt formulation (Jassby and Platt, 1976), whereas CICE + Icepack uses the Platt et al. (1980) formulation with photoinhibition. Even if α represents in both models the initial slope of the PI curve, the formulations and the units of α are different. We thus tuned the values of α in Icepack so that they match the PI curve in SIMBAv2.0 (Figure S4). The simulations for the MOSAiC case are then carried out with the tuned parameters for CICE + Icepack.

Values for the exchange coefficients $\alpha_s$ from observations vary between $8.6 \times 10^{-5}$ and 0.006 (McPhee et al., 2008). During the tuning procedure we tested different values in both CICE + Icepack and SIMBAv2.0. The final results presented in the revised manuscript are obtained with the same value of $\alpha_s$ for both Icepack and SIMBAv2.0 for the MOSAiC case. However, for the NICE and Resolute case the values are different between the models. Moreover, we account for the effect of stratification during melting by reducing the $\alpha_s$ coefficient by ~1 order of magnitude. This approach follows McPhee, (2008) and is based on the ratio between the two extreme values that were observed: 0.006 and $8.5 \times 10^{-5}$. With this approach, we most likely introduce an underestimation of the turbulence in the case of MOSAiC that already uses a small value for the $\alpha_s$ coefficient, making our conclusions more conservative.

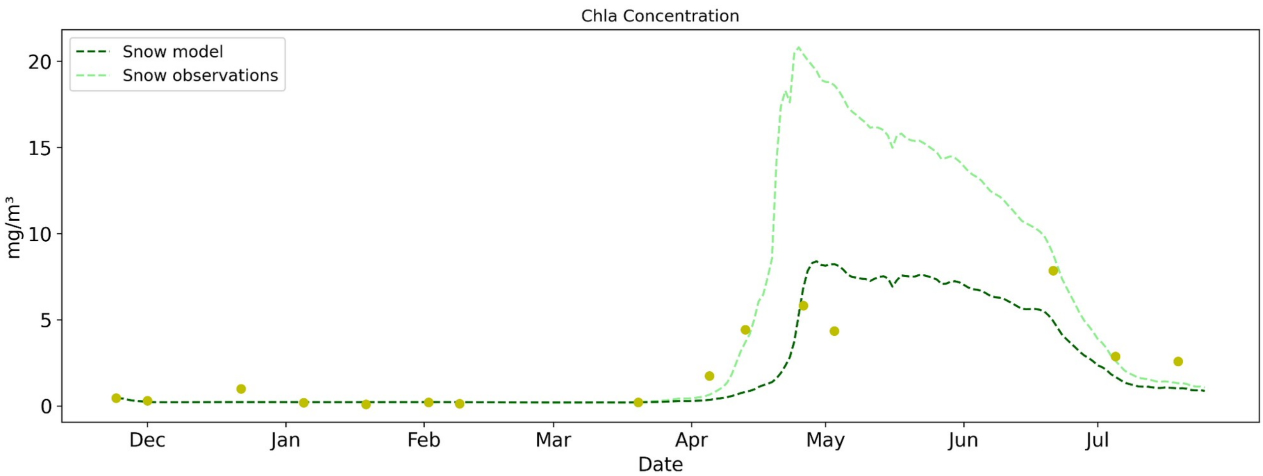


**Figure S2:** Algal growth simulated by SIMBAv2.0 in the case of hs=0.0025 comparing the case when the model is forced by observations (light green line) and when the model is forced by the snow thickness computed by CICE + Icepack (dark green line). Dots represent observations.

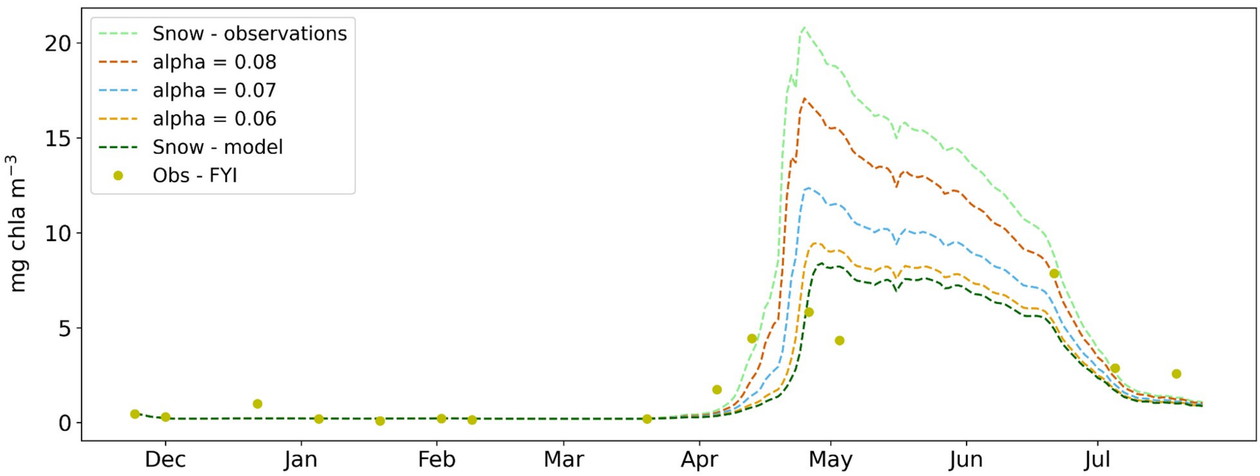


**Figure S3:** Chl a concentration in the bottom 10cm of the ice as simulated by SIMBAv2.0 for different values of the photosyntetic efficiency parameter α. The light green line represents the simulation carried with snow height from observations, all other simulation are carried out with snow thickness calculated by CICE + Icepack. Dots represent observations.

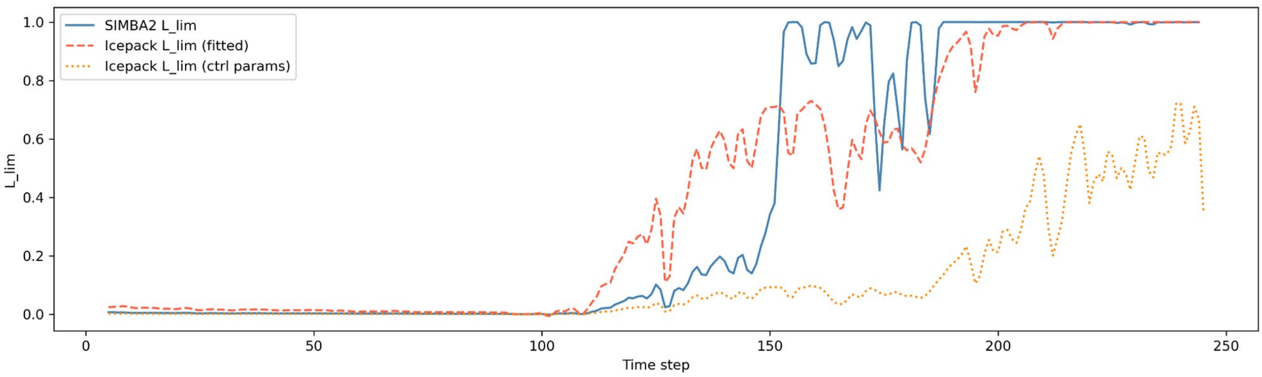


**Figure S4:** Fitting of the two formulations for light limitation from Icepack and SIMBAv2.0. For Icepack the yellow curve is obtained when using the control values of the parameters, the orange line is obtained with the fitted parameters.

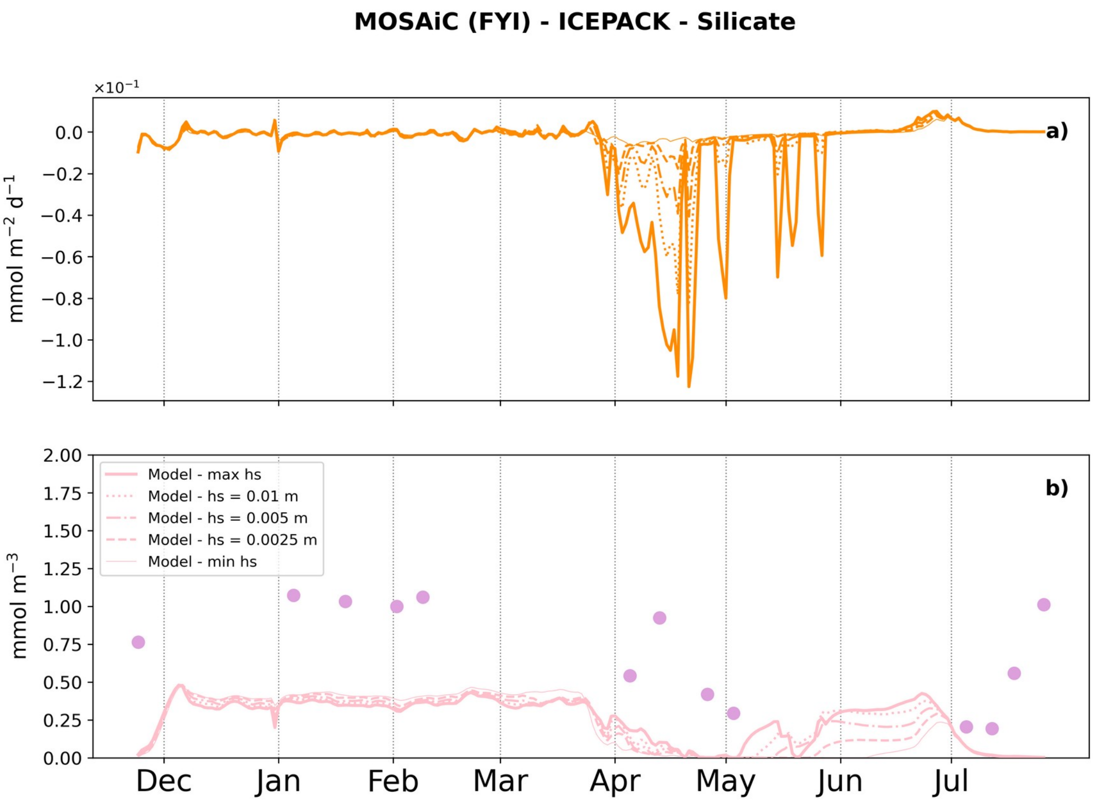


**Figure S5**: Same as Figure 4 for the MOSAiC case study, but for a) silicic acid fluxes and b) silicic acid concentration in the bottom 10 cm of ice.

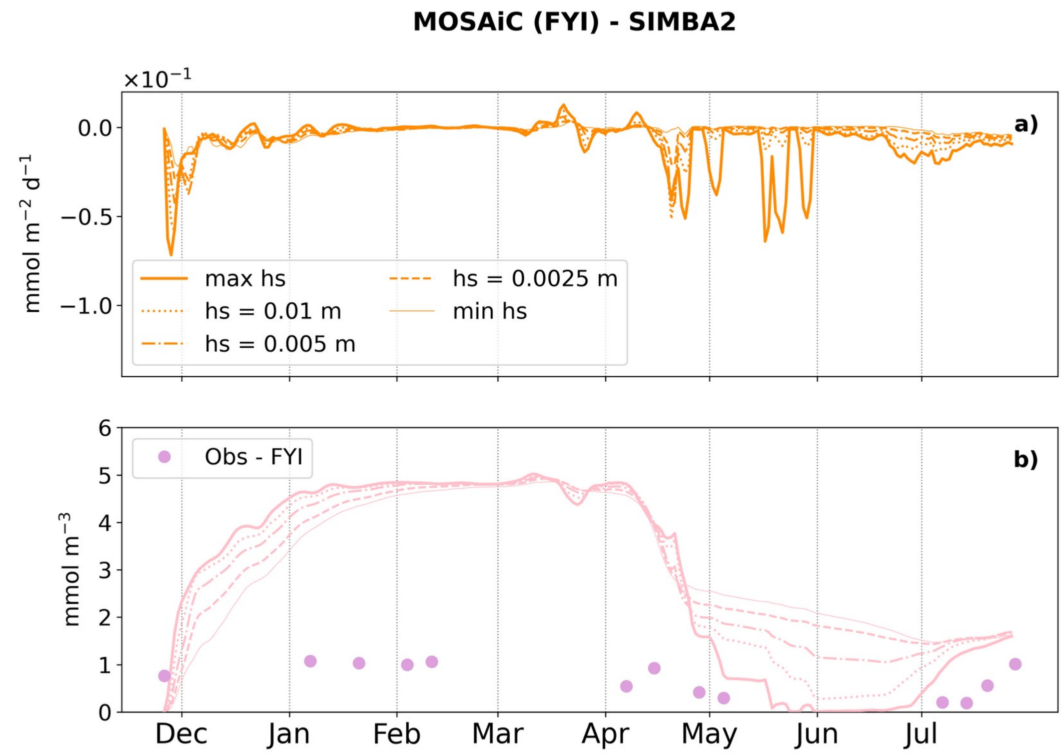


**Figure S6**: Same as Figure 5 for the MOSAiC case study, but for a) silicic acid fluxes and b) silicic acid concentration in the bottom 10 cm of ice.

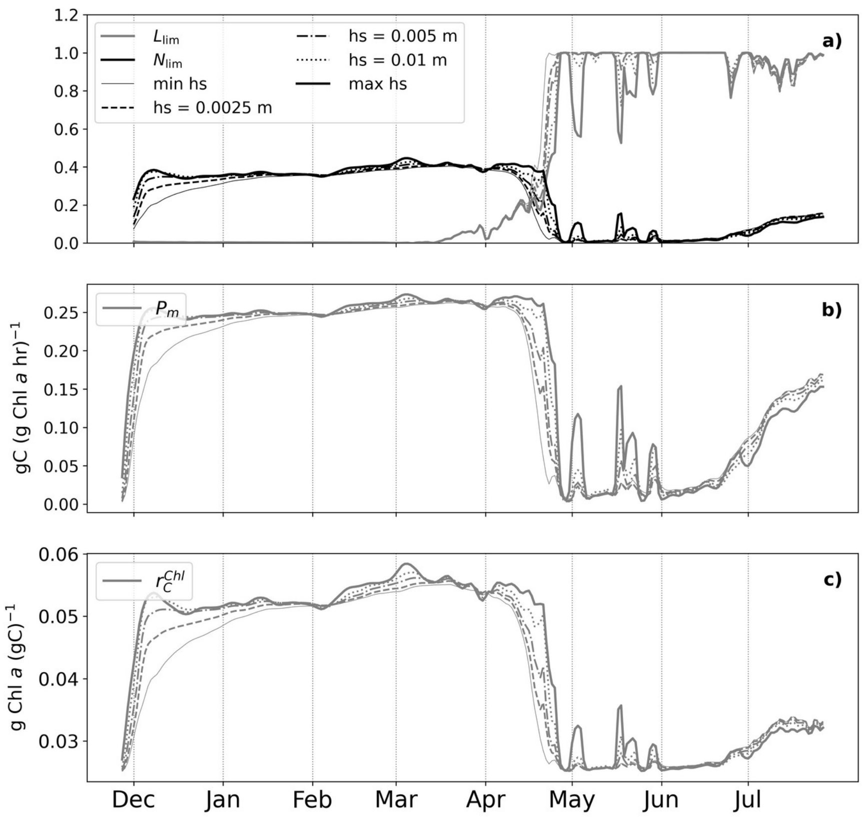


**Figure S7**: SIMBAv2.0 results for the MOSAiC case study showing a) nutrients and light limitation; b) Maximum photosynthetic efficiency $P_m$ and c) chla:C ratio. Note that in the legend in panel a) the colour of the line shows whether the limitation source is light (grey) or nutrients (black), whereas the line style represents the runs with different value of surface roughness.

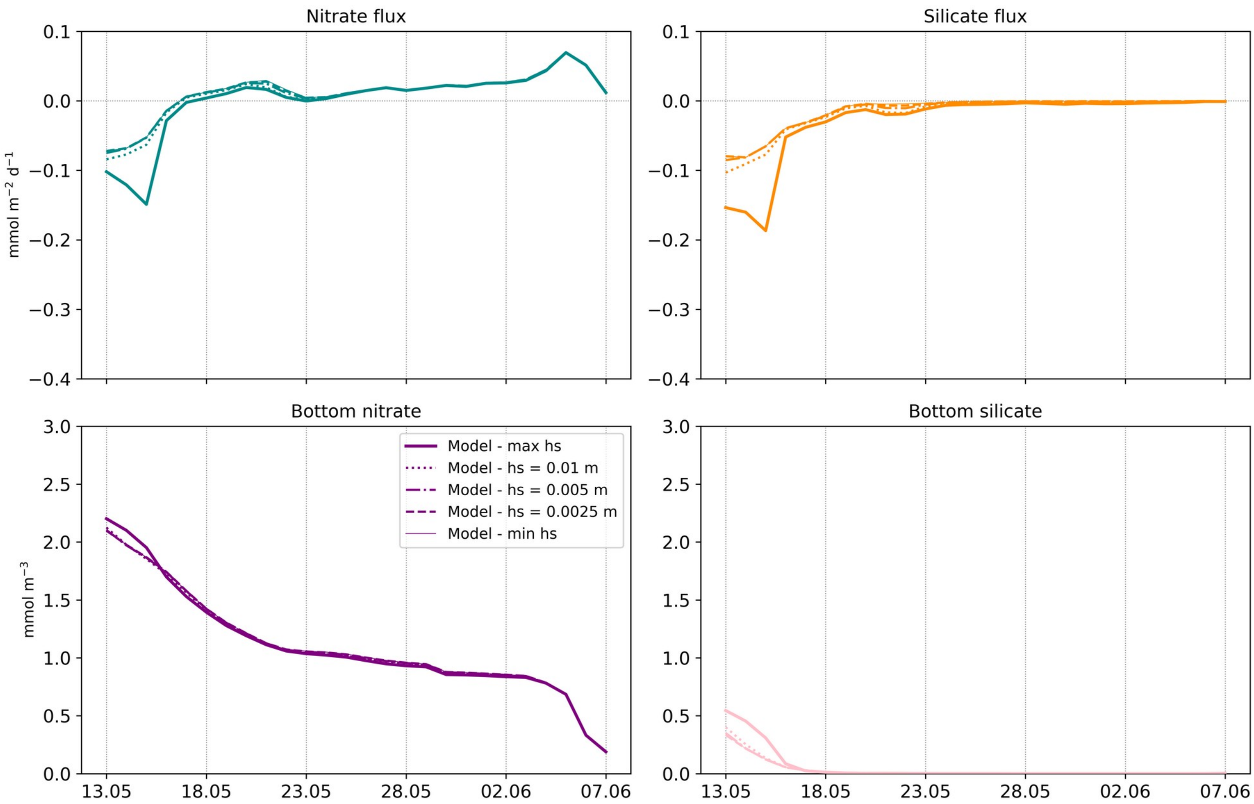


**Figure S8:** Fluxes (top row) and concentrations in the bottom of the ice (lower row) of nitrate and silicic acid for the N-ICE2015 case study, simulated with CICE+Icepack.

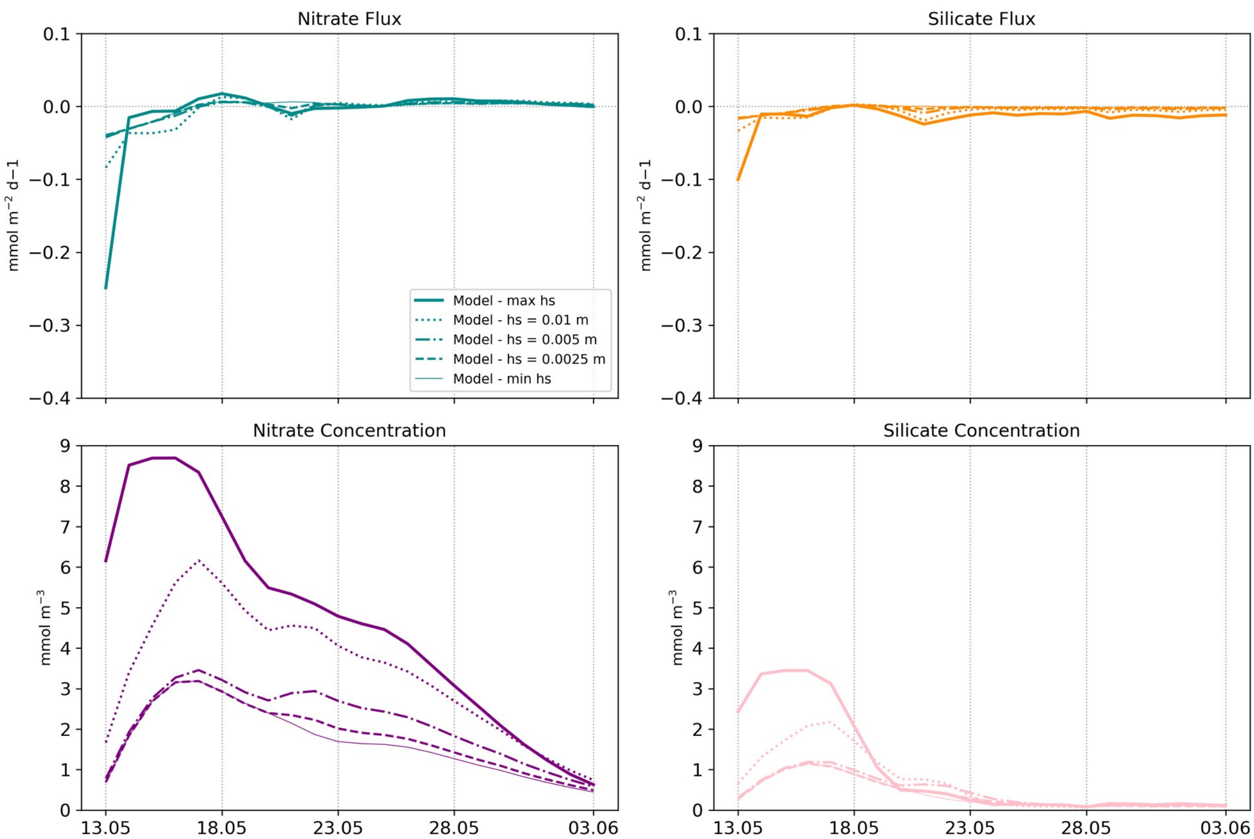


**Figure S9:** Same as Figure S4 but simulated with SIMBA

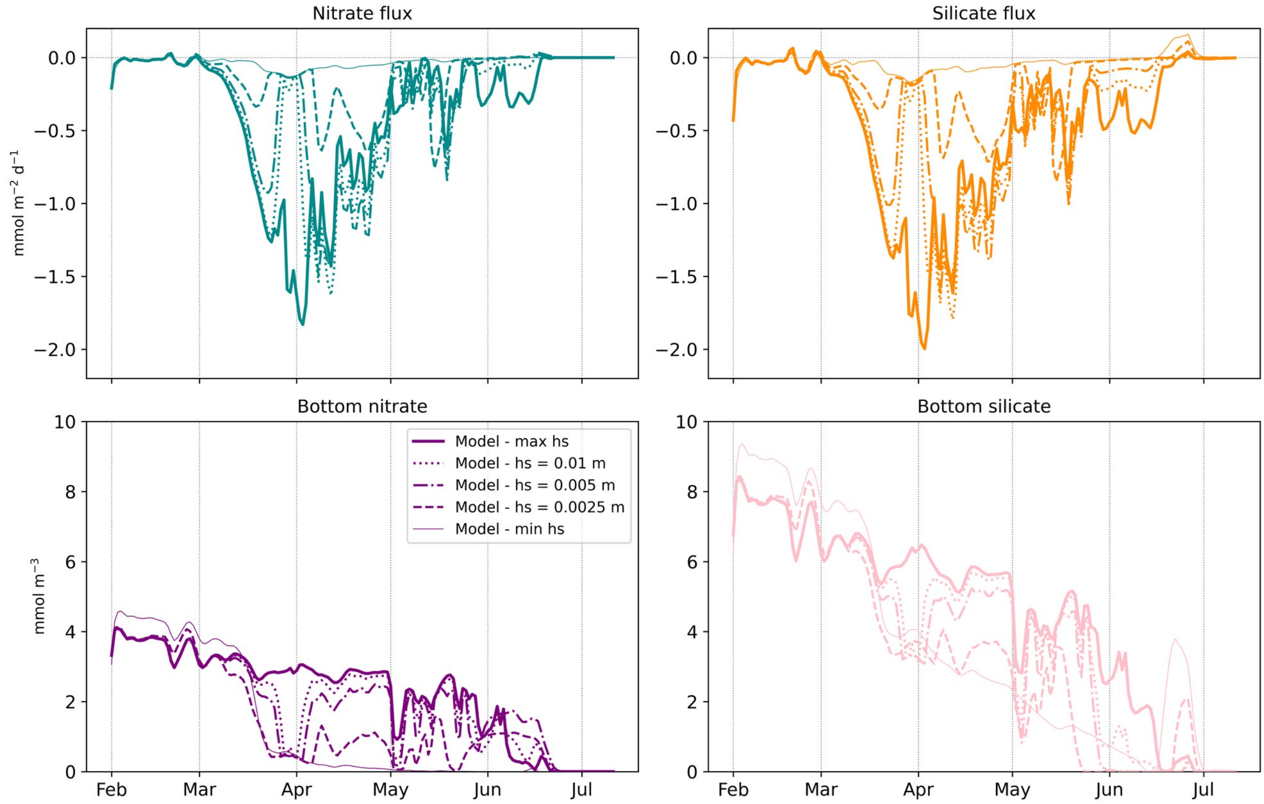


**Figure S10:** Fluxes (top row) and concentrations in the bottom of the ice (lower row) of nitrate and silicic acid for the Resolute case study, simulated with CICE+Icepack.

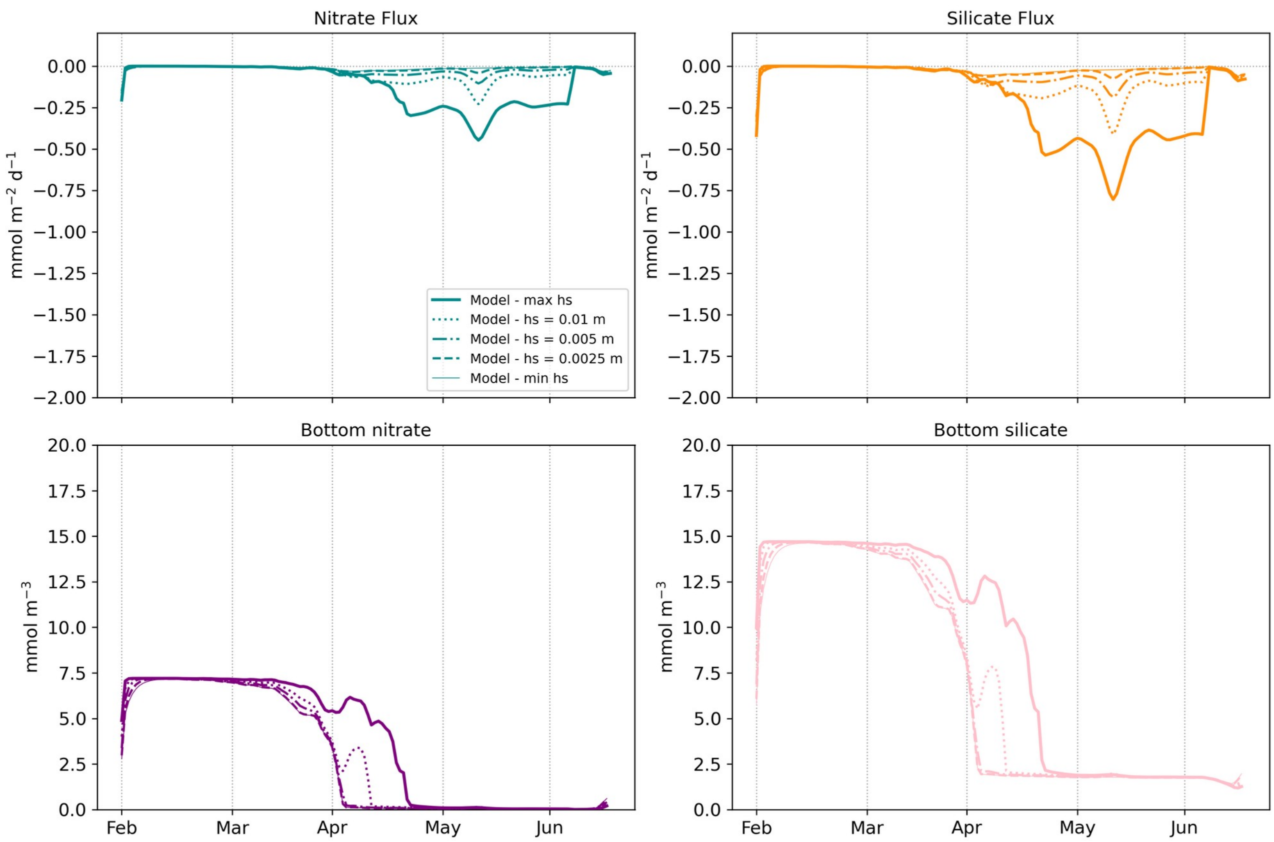


**Figure S11:** same as Figure S6 but simulated with SIMBAv2.0

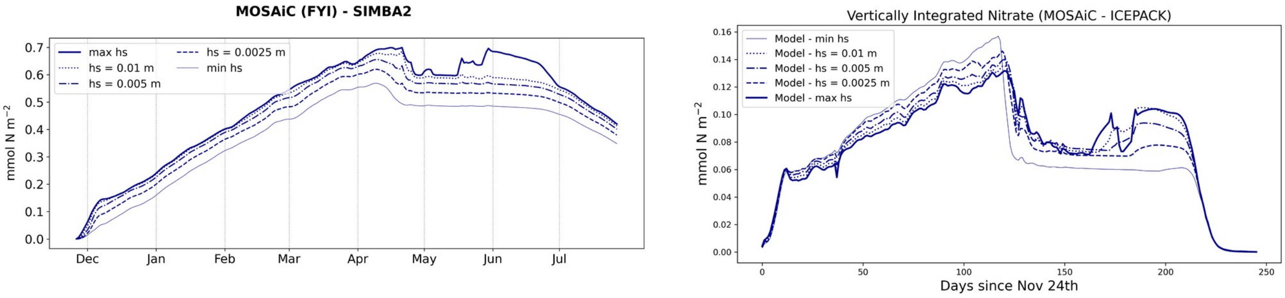


**Figure S12:** Vertically integrated nitrate concentrations in SIMBAv2.0 (left panel) and in CICE + Icepack (right panel).

## References

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