Supporting Information for "Impact of an isolated open water storm on sea ice and ocean conditions in the Arctic Ocean"

Emma Bent[1], Camille Lique[1], Peter Sutherland[1]

[1]Univ. Brest, CNRS, Ifremer, IRD, Laboratoire d'Océanographie Physique et Spatiale (LOPS), IUEM, F29280 Plouzané, France

Sensitivity analysis to model numerics and parametrizations

In order to examine how sensitive our results are to the chosen numerics and parametrizations of our 1D configuration, we conduct a number of runs for which we vary several key numerical parameters related to wave-induced turbulence. We choose the run from sections 3 to 6 with a 4-day storm at 15 m/s on August 15, that is initialized with the temperature and salinity profiles of the 1D ensemble (Figure 1b,c), and vary these parameters one by one.

The first parameter we test is for the Langmuir circulation parametrization (Axell, 2002). We vary the constant parameter c_{LC} (section 2.1) which must be chosen between 0.15 and 0.54 according to Axell (2002). Following Couvelard et al. (2020) we have used 0.30 in order to better represent the mixed layer depth. We therefore test the sensitivity of the run to two other values of this constant: 0.15 and 0.54.

The second parameter we test is also for the Langmuir circulation parametrization which contains the surface Stokes drift, defined as a percentage of the 10-m wind speed:

$\alpha_{\mathrm{SD}} = u_{\mathrm{SD}_0}/U_{10} = 1.6\%$ (Li & Garrett, 1993, section 2.1). Results obtained with a global wave model suggest that the global annual mean of this percentage varies between 0.8 to 1.5% (Rascle et al., 2008). We test the sensitivity of the run to two other values of this percentage, $\alpha_{\mathrm{SD}} = 0.8\%$ and 1.2%, in order to cover this range of values.

The third parameter we test is for the wave breaking parametrization (Craig & Banner, 1994; Mellor & Blumberg, 2004): we vary the Craig and Banner (1994) constant of proportionality α_{CB} which depends on the "wage age". According to Mellor and Blumberg (2004) this constant varies between 57 for mature waves to 146 for younger waves. Here we have used a constant equal to 100 following their suggestion. We therefore test how sensitive the run is to two other values of this constant: 57 and 146.

The fourth parameter we test is for the attenuation of the Langmuir circulation in the presence of ice. The effect of the Langmuir circulation is weighted by the sea ice concentration between 0 and 25% and cut off for sea ice concentration values greater than 25% (section 2.1). We test how sensitive the run is to an attenuation weighted by the sea ice concentration between 0 and 10%, and to no attenuation as well.

The fifth test we do is for the penetration of TKE below the mixed layer (Rodgers et al., 2014) which we turn on or off ($e_\tau = 1$ or 0, respectively). This parametrization relies on the choice of many parameters that are poorly constrained. The runs in this study are conducted without it to avoid having a redistribution of TKE, meaning that the relative effect of the storm is more important than with the parametrization turned on.

Results for the sensitivity analysis are given in Figure S1. The red cross corresponds to the case study run presented in sections 3 to 6 (referred to here as the 'experiment run'). The values of the parametrizations for this run are: $c_{\mathrm{LC}} = 0.30$, $\alpha_{\mathrm{SD}} = 1.6\%$, $\alpha_{CB} = 100$, 25% for the sea ice concentration cut off of the effect of the Langmuir circulation, and $e_\tau = 0$. The colored dots represent the runs from the sensitivity analysis. For each run we change only one parameter from the experiment run.

The sensitivity runs are very close to the experiment run, except for the runs with $e_\tau = 1$ and with $c_{\mathrm{LC}} = 0.54$ (Figure S1). For the runs close to the experiment run, the ice formation dates and the sea ice thicknesses maximum do not vary much when the parametrizations are modified (on the order of hours and millimeters respectively). When compared to the ranges of results that we have found (section 3: 2 weeks and 10 cm respectively) these results suggest low sensitivity to the choice of parametrizations. The runs with $e_\tau = 1$ and with $c_{\mathrm{LC}} = 0.54$ are significantly different in mixed layer depth and temperature evolution, especially after the storm (differences of 5-20 m for the mixed layer depth and on the order of 10^{-1} °C for the mixed layer temperature). This leads to differences in ice formation date and sea ice thickness maximum on the order of days and centimeters respectively. This can be explained by the fact that these parametrization lead to increased TKE production or redistribution, resulting in deeper mixed layer depths, thereby accentuating the findings discussed in sections 3 and 7. Therefore we opted for $e_\tau = 0$ and $c_{\mathrm{LC}} = 0.30$ in our study to enhance the relative impact of storms on both the ocean and sea ice.

References

Axell, L. B. (2002). Wind-driven internal waves and Langmuir circulations in a numerical ocean model of the southern Baltic Sea. *Journal of Geophysical Research*, *107*(C11), 3204. doi: https://doi.org/10.1029/2001JC000922

Couvelard, X., Lemarié, F., Samson, G., Redelsperger, J.-L., Ardhuin, F., Benshila, R., &

Madec, G. (2020). Development of a two-way-coupled ocean–wave model: assessment on a global NEMO(v3.6)–WW3(v6.02) coupled configuration. *Geoscientific Model Development*, *13*(7), 3067–3090. doi: https://doi.org/10.5194/gmd-13-3067-2020

Craig, P. D., & Banner, M. L. (1994). Modeling wave-enhanced turbulence in the ocean surface layer. *Journal of Physical Oceanography*, *24*(12), 2546 - 2559. doi: https://doi.org/10.1175/1520-0485(1994)024⟨2546:MWETIT⟩2.0.CO;2

Li, M., & Garrett, C. (1993). Cell merging and the jet/downwelling ratio in Langmuir circulation. *Journal of Marine Research*, *51*(4), 737–769.

Mellor, G., & Blumberg, A. (2004). Wave breaking and ocean surface layer thermal response. *Journal of Physical Oceanography*, *34*(3), 693 - 698. doi: https://doi.org/10.1175/2517.1

Rascle, N., Ardhuin, F., Queffeulou, P., & Croizé-Fillon, D. (2008). A global wave parameter database for geophysical applications. part 1: Wave-current–turbulence interaction parameters for the open ocean based on traditional parameterizations. *Ocean Modelling*, *25*(3), 154-171. doi: https://doi.org/10.1016/j.ocemod.2008.07.006

Rodgers, K. B., Aumont, O., Mikaloff Fletcher, S. E., Plancherel, Y., Bopp, L., de Boyer Montégut, C., . . . Wanninkhof, R. (2014, August). Strong sensitivity of Southern Ocean carbon uptake and nutrient cycling to wind stirring. *Biogeosciences*, *11*(15), 4077–4098. doi: https://doi.org/10.5194/bg-11-4077-2014

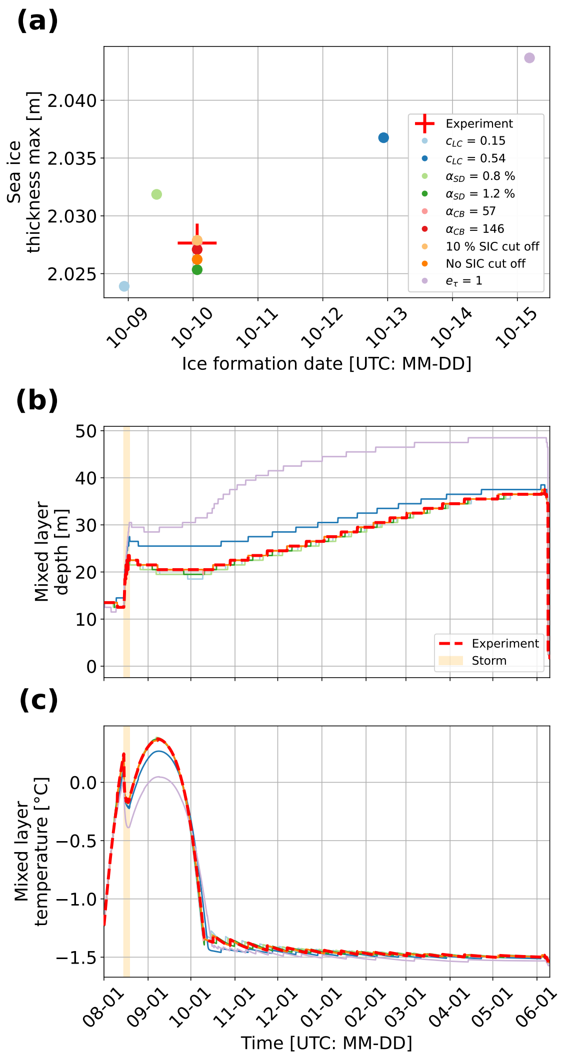

Figure S1. (a) Sea ice thickness maximum as a function of ice formation date. Colours indicate the parameter or parametrization that is tested: Langmuir circulation (blue dots), Stokes drift (green dots), and wave breaking parametrizations (red dots), sea ice concentration cut off of the LC (orange dots), parametrization of redistribution of TKE in the mixed layer (purple dot). The experiment run from our study is represented with the red cross. The constants of the parametrizations for this run are: $c_{\mathrm{LC}} = 0.30$, $\alpha_{\mathrm{SD}} = 1.6\%$, $\alpha_{\mathrm{CB}} = 100$, 25% for the sea ice concentration cut off of the Langmuir circulation, and $e_\tau = 0$. (b) Time series of mixed layers depths and (c) mixed layer temperatures. Colours are the same as panel (a). Time series for the experiment run are dotted red. The orange shading represents the storm duration.