Secondary ice production in NorESM2 climate model: quantifying the impact on Arctic clouds

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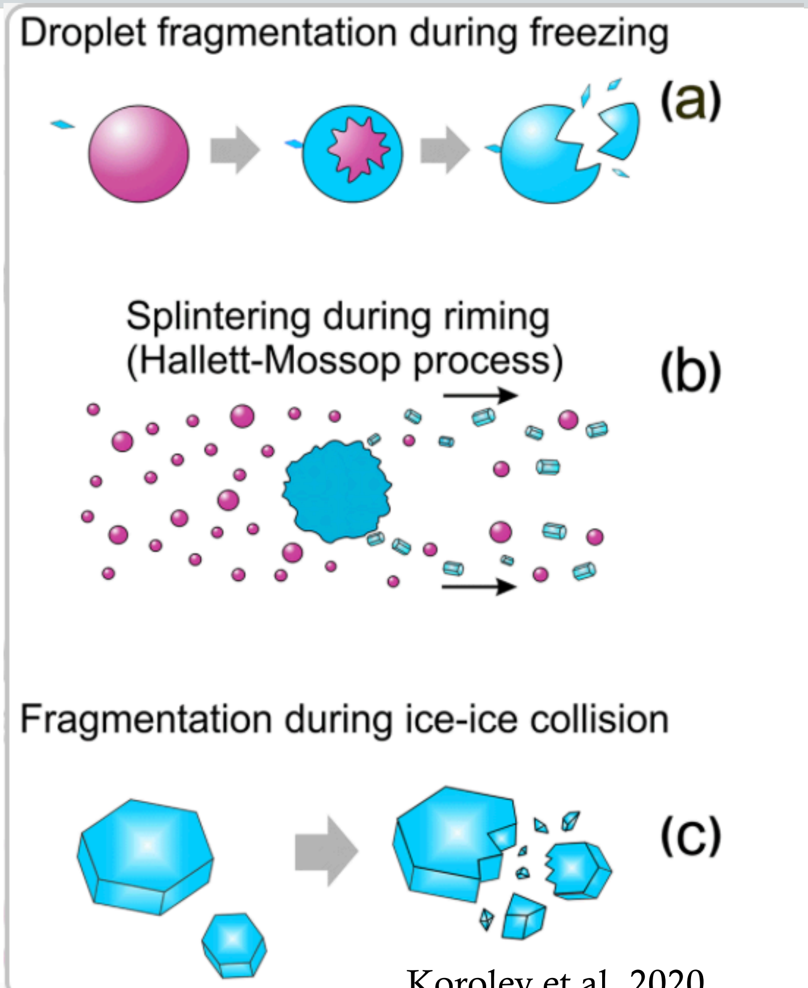
Well-known Secondary Ice Production (SIP) Mechanisms



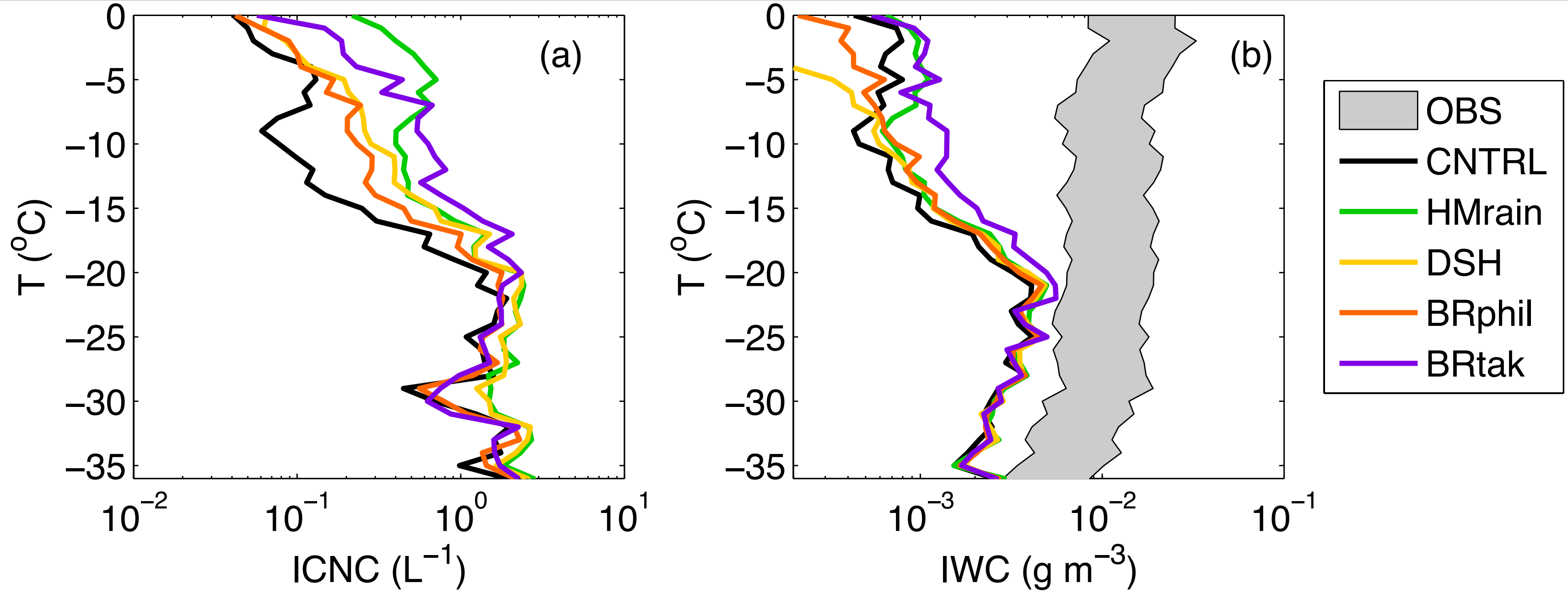
Korolev et al. 2020

- Climate models include only one SIP mechanism: the Hallet-Mossop process (active only between -8^{o}C and -3^{o}C
- In NorESM2, rime-splintering (Hallet-Mossop) occurs only after collisions of cloud droplets with snow (contribution from raindrops is not accounted)

Implementation of missing SIP processes in NorESM2

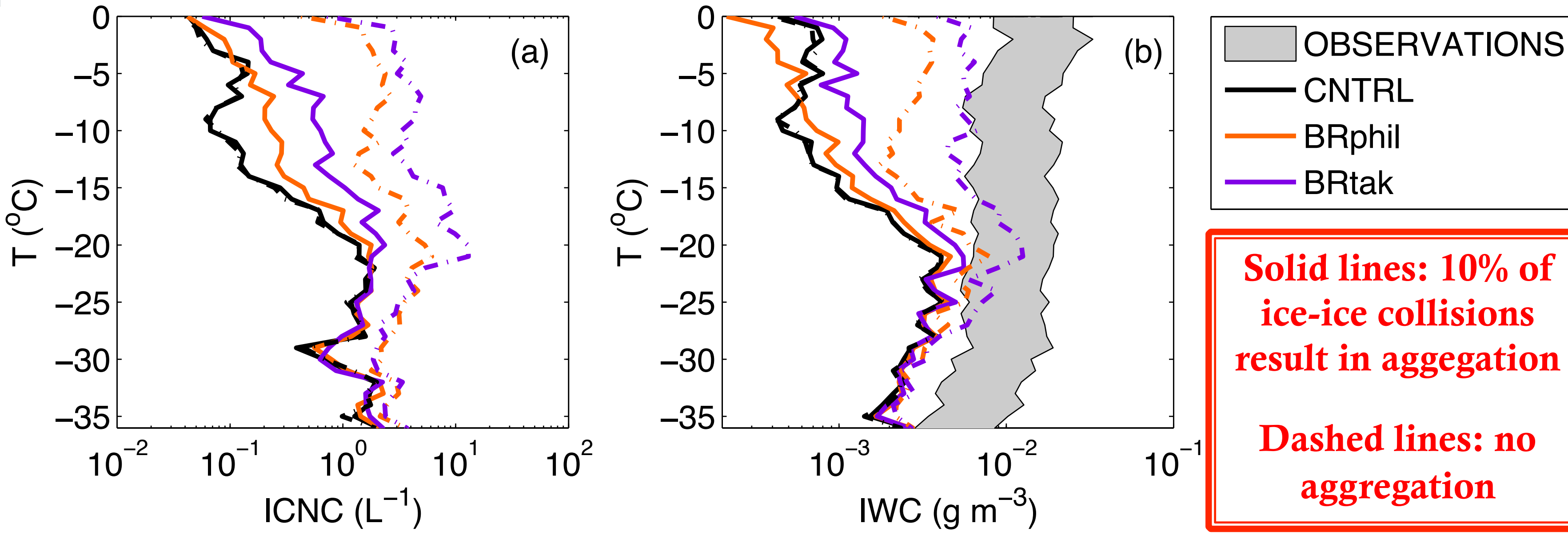
Sensitivity simulation	Set-up
CNTRL	Standard NorESM2 (SIP only through Hallet-Mossop & after cloud drop – snow collisions)
HMrain	Hallet-Mossop is also activated after raindrop-snow collisions
DSH	Drop-Shattering is the only active SIP mechanism. It occurs after rain – snow & rain – cloud ice collisions, & after immersion freezing. Description follows *Phillips et al. 2018*
BRphil	Collisional break-up is the only active SIP mechanism. It occurs after cloud ice – snow and snow – snow collisions. Description follows *Phillips et al. 2017*
BRtak	Collisional break-up the only active SIP mechanism. Description follows *Takahashi et al. 1995*, but scaled for size as *in Sotiropoulou et al. 2021*

Simulations of Arctic clouds observed at Ny-Alesund (06/2016-12/2017)



- Ice multiplication is most pronounced in HMrain and BRtak at temperatures above -20°C, increasing median ICNCs (ice crystal number concentrations) by a factor of ~5
- IWC enhancement is very weak; IWC (ice water content) remains substantially underestimated in all simulations

Impact of aggregation on collisional break-up efficiency

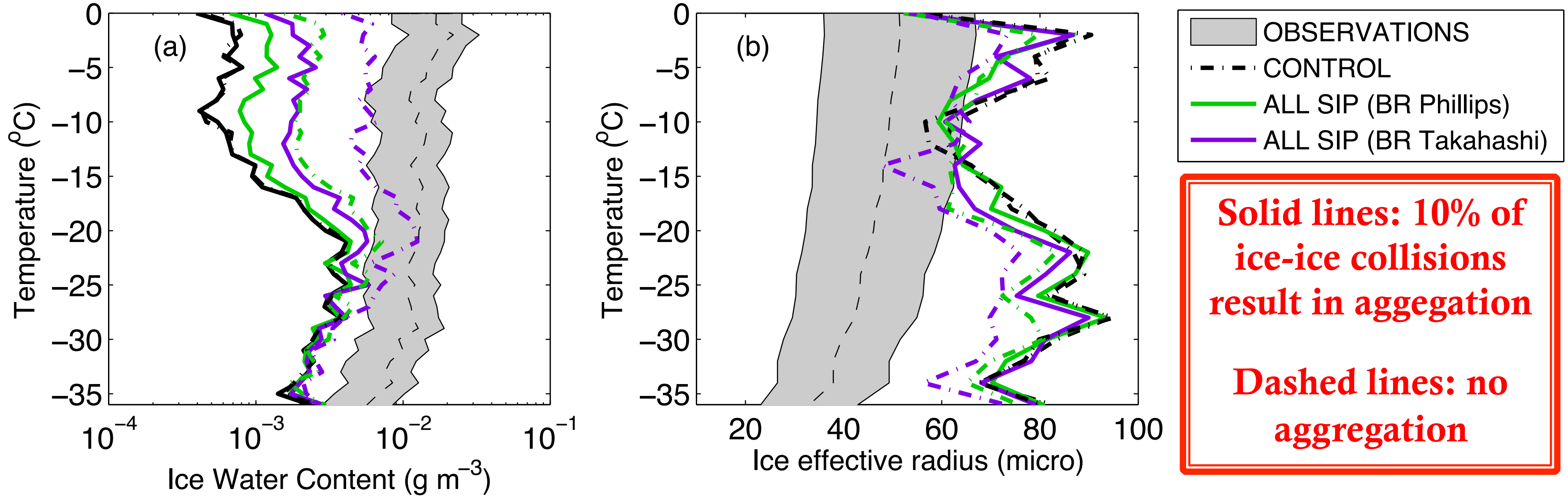


Solid lines: 10% of ice-ice collisions result in aggegation

Dashed lines: no aggregation

- Ice aggegation has no impact when collisional break-up is deactivated
- Ice aggregation limits the efficiency of collisional break-up
- BRtak without ice aggregation is the only simulation that reproduces observed IWC; it produces 50 times larger median ICNCs at temperatures below -20°C

Activation of all SIP mechanisms simultaneously

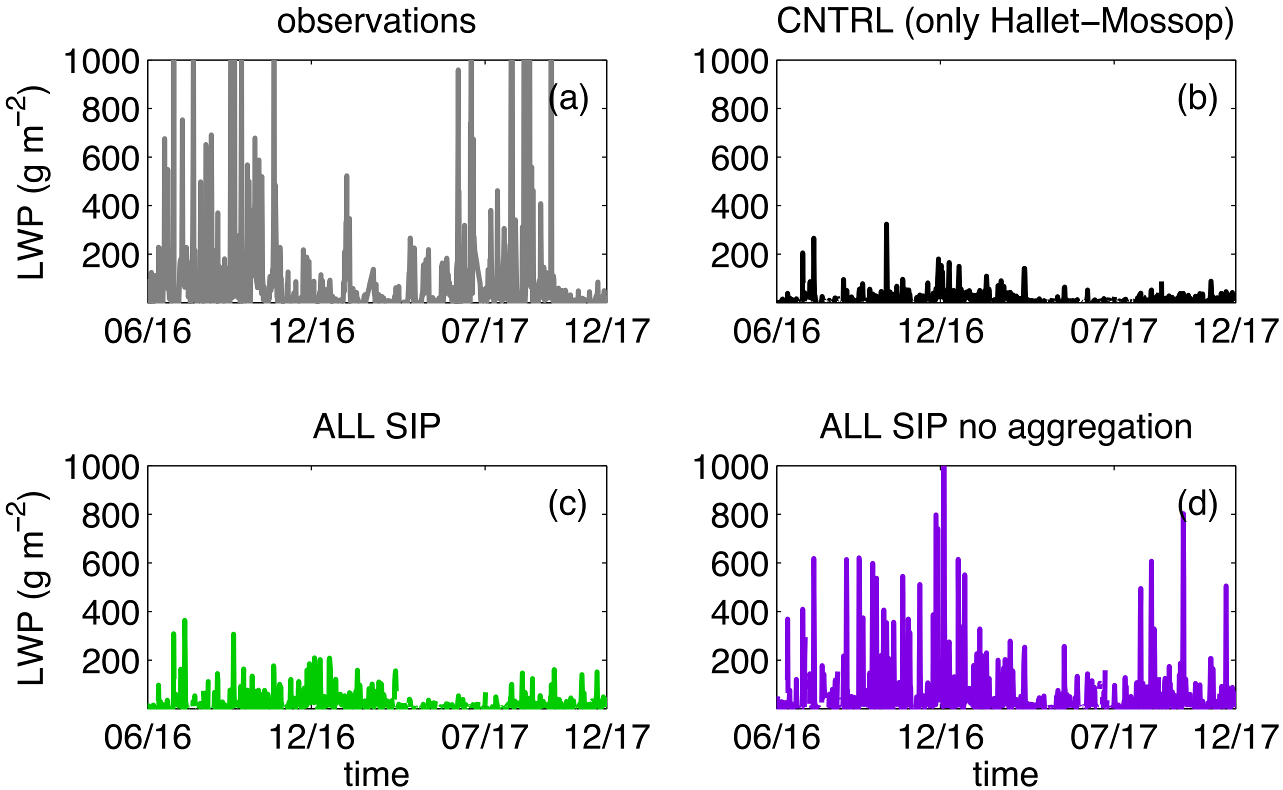


Solid lines: 10% of ice-ice collisions result in aggegation

Dashed lines: no aggregation

- Only the simulation with BR following Takahashi et al. (1995) (but scaled) and deactivated aggregation compares relatively well to observations. This gives very similar results to BRtak (suggesting negligible contribution from other mechanisms)

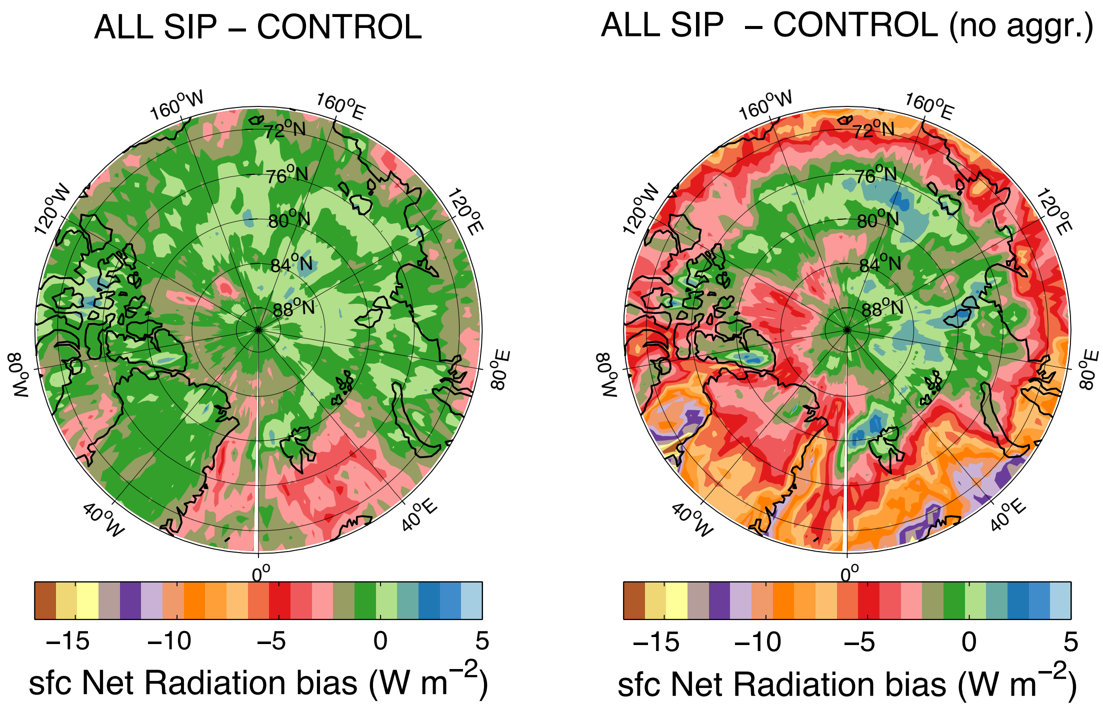
Ice multiplication effects on Liquid Water Path (LWP)



**** ALL SIP simulations are performed with Takahashi et al. 1995 scaled BR parameterization**

- The simulation (panel d) with more realistic IWC and ice effective radius also gives more realistic LWP
- Simulations with larger ICNCs also produce larger LWP (likely due to enhanced sublimation of the smaller precipitation particles)

Ice multiplication effects on surface net radiation



- Activating all SIP mechanisms in NorESM2 has hardly any impact on surface radiation (panel a), due to the fact that the 5-fold enhancement in ICNCs has little effect on ice and liquid macro-physical properties

- Activation of SIP in combination with deactivated aggregation (panel b) can alter the net radiation budget by up -5 – -10 Wm^{-2} in several Arctic regions. This is the simulation that best conforms with observations.

Conclusions:

- Activation of all SIP mechanisms in NorESM2 results in a ~5-fold ICNC enhancement at temprature above -20^{o}C, compared to CNTRL. This has a weak enhancing impact on IWC and LWP, and thus hardly ay impact on surface radiation.
- Deactivation of ice-ice aggregation enhances the efficiency of collisional break-up (BR) by almost a factor of 10 at warm subzero temperatures, thus this process eventually dominates ice multiplication.
- The simulation with Takahashi et al. (1995) scaled BR parameterization and deactivated aggregation results in best agreement with IWC and LWP observations. This set-up enhances median ICNCs by a factor of 50 compared to CNTRL at Temp>-20^{o}C, and alters surface net radiation budget by ~ -10 to -5 W m^{-2} in several Arctic regions.

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