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Secondary ice production in summer clouds over the Antarctic coast: an underappreciated process in atmospheric models

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Section S1: Additional ICNC statistics

While mean statistics and maximum values are discussed in the main text in detail, additional statistical metrics are presented in Fig. S1: median ICNCs and the 25th, 75th and 95th percentiles are shown as a function of temperature. FRAG1 is in closest agreement with median observations, while TAKAH substantially overestimates median values; all the other simulations result in substantial underestimates (Fig. S1a). However, all simulations underestimate the 25th percentiles (Fig. S1b), while TAKAH agrees with observations. In Fig. S1c, TAKAH overestimates the observed 75th percentiles, while the rest of the simulations underestimate measurements with FRAG1 performing slightly better. Finally, the 95th percentile in FRAG1, TAKAH and TAKAHsc is generally higher than in observations, while all the other simulations underestimate results with PHIL0.4 being closer to observations (Fig. S1d).

While mean and median ICNC observations are of similar magnitude, suggesting that this parameter follows a normal distribution, in all simulations except CNTRL, PHIL0.2 and PHIL0.3, mean and median results can differ by order of magnitude, suggesting positively skewed distributions.

Section S2: Cloud Radiative Forcing

The surface cloud radiative forcing (CRF) is calculated as in Young et al (2019), who used the methodology of Ramanathan et al. (1998) along with the modifications of Vavrus (2006) to exclude the influence of the high surface albedo at high latitudes. The difference between all-sky (as), thus with clouds, and clear-sky (cs) net longwave (LW) and shortwave (SW) radiation is used to calculate the net radiative effect at the surface:

$$CRF_{LW} = LWD_{as} - LWU_{as} - LWD_{cs} + LWU_{cs}$$
$$CRF_{SW} = SWD_{as} - SWU_{cs}$$
$$CRF = CRF_{LW} + CRF_{SW}$$

The sum of CRF_{LW} and CRF_{SW} anomalies for all sensitivity simulations, presented in Fig. S1, is calculated by considering the differences between each simulation and CNTRL. Red (blue) color indicates that more (less) SW radiation reaches the surface than in CNTRL, suggesting the presence of less (more) liquid-dominated clouds. Activating BR and thus enhancing ICNCs can result in significant CRF biases over the ocean surface, in agreement with Young et al. (2019). Considering the maximum/minimum CRF biases in simulations PHIL0.4 (-68/64 Wm^{-2}), FRAG1 (-46/75 Wm^{-2}) and TAKAHsc (-52/87 Wm^{-2}) which improve the representation of the observed ICNCs, our results indicate that including a BR description in climate models can have a significant impact in the projections of the future climate.

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Figures:

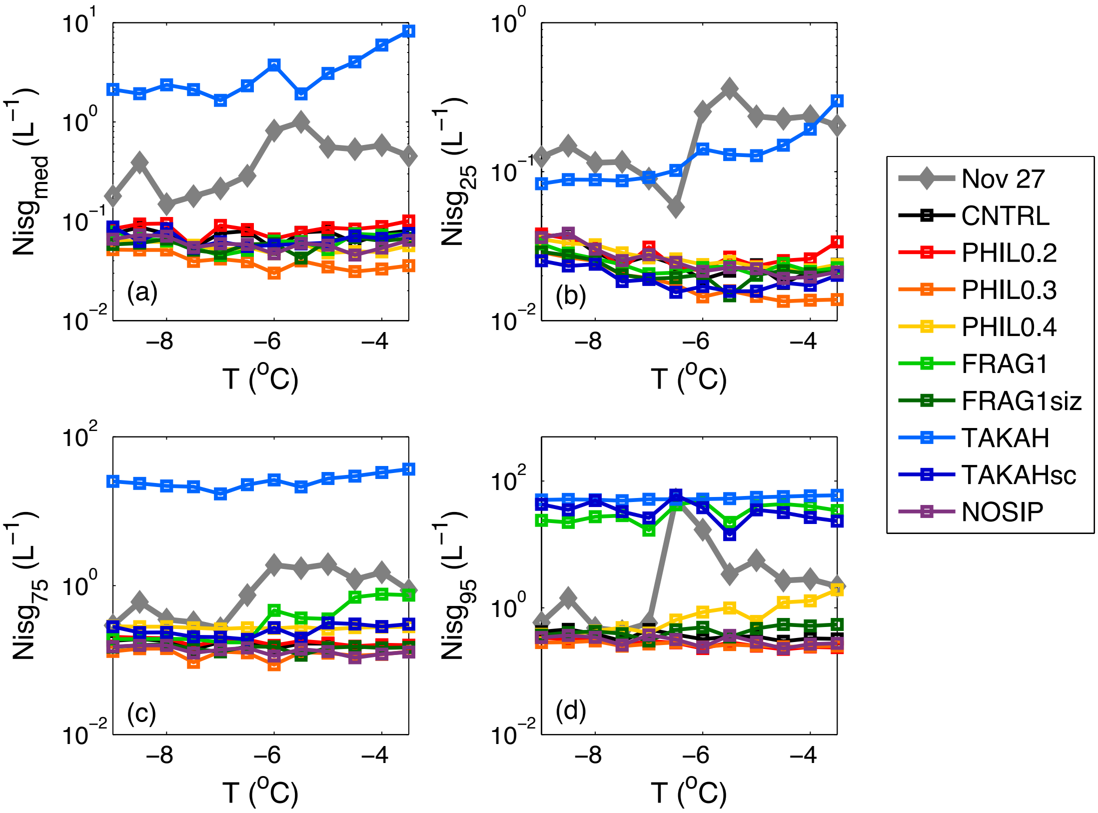

Figure S1: Total ice number concentrations (ice+snow+graupel, N_{isg}) as a function of temperature for the case study (grey) and the nine model simulations. Median values, the 25th, 75th and 95th percentile are shown in panels (a), (b), (c) and (d), respectively (see Section S1). Modeled ice properties are calculated for particles > 80 µm and for N_{isg} > 0.005 L^{-1} within the lowest 1.5 km a.s.l. Limits of y-axes differ between all panels.

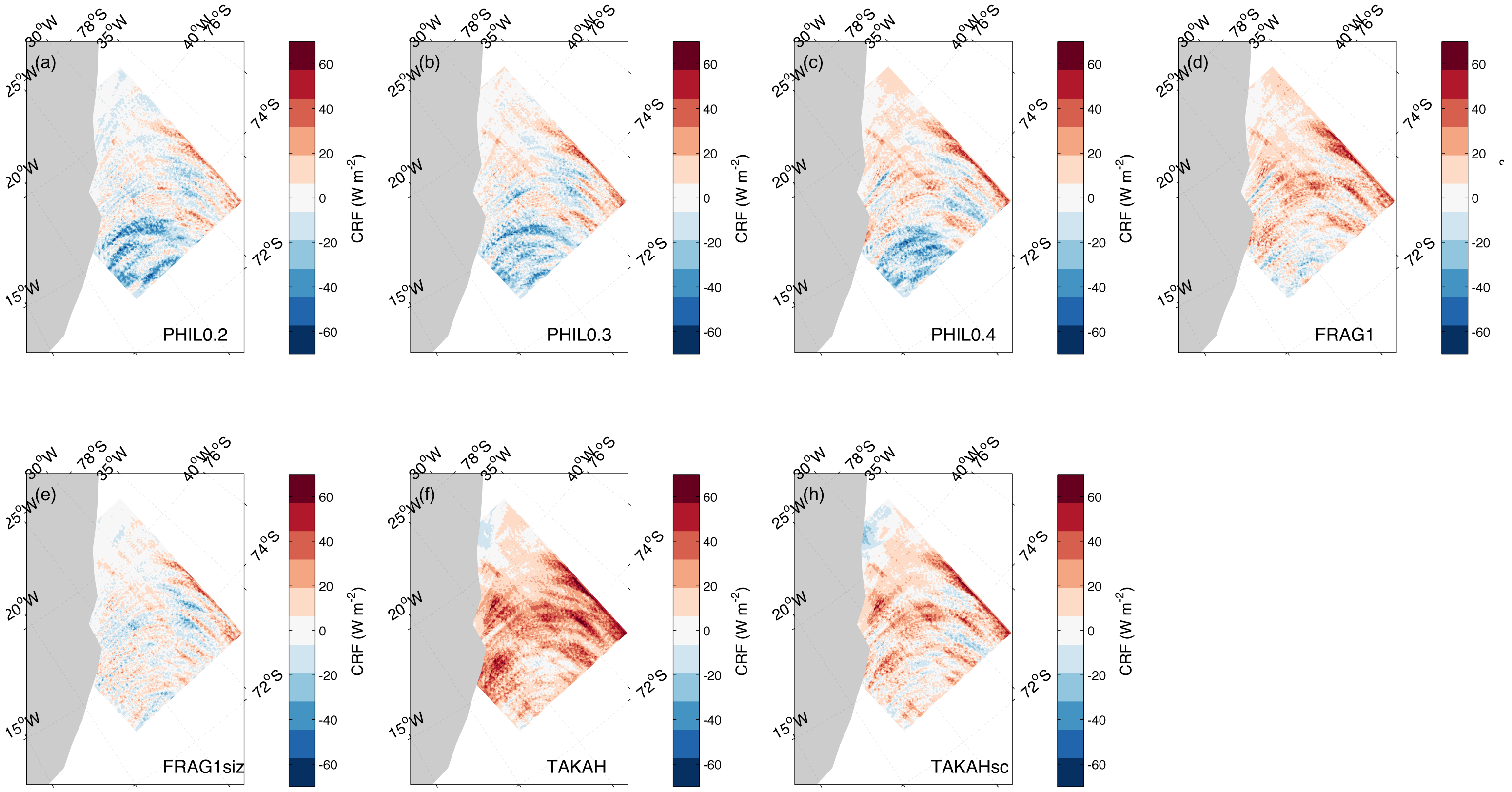

Figure S2: Map of daily mean Cloud Radiative Forcing (CRF) anomalies at the surface averaged over the 1-km domain for the seven sensitivity simulations presented in the main text (see Section S2).