



Supplement of

Implementation of a comprehensive ice crystal formation parameterization for cirrus and mixed-phase clouds in the EMAC model (based on MESSy 2.53)

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Figure S1. Annual zonal means of (grid-averaged) ice crystal number concentration (ICNC, $[L^{-1}]$) for the default simulation KL+LD and the absolute changes of BN+LD, KL+BN, and BN+BN with respect to it as functions of latitude and temperature. (*Last row*) Absolute changes of annual zonal means averaged along the latitude.



Figure S2. Seasonal (summer-*left* and winter-*right*) zonal means of (grid-averaged) ice crystal number concentration (*ICNC*, $[L^{-1}]$) for the default simulation KL+LD and the relative percentage changes of BN+LD, KL+BN, and BN+BN with respect to it (i.e. (*experiment* – DEF)/ $|DEF| \cdot 100$), computed where $ICNC^{DEF} \ge 1 L^{-1}$. The isotherms at 273 K and 238 K are seasonal means, the crossed pattern indicates areas with a significance level of 95%.



Figure S3. Annual means of vertically integrated ice crystal number concentration $(ICNC_{burden}, [10^8 \text{ m}^{-2}])$ for the default simulation and the relative percentage changes of BN+LD, KL+BN, and BN+BN with respect to it (i.e. $(experiment - DEF)/|DEF| \cdot 100$), computed where $ICNC_{burden}^{DEF} \ge 10^8 \text{ m}^{-2}$. The crossed pattern indicates areas with a significance level of 95%.



Figure S4. Relative percentage changes of annual means of (grid-averaged) ice water content (IWC, $[mg kg^{-1}]$) at 200 hPa (cirrus regime) and 600 hPa (mixed-phase regime) for BN+LD, KL+BN, and BN+BN with respect to the default simulation (i.e. (*experiment* – DEF)/ $|DEF| \cdot 100$), computed where $IWC^{DEF} \ge 0.1 \text{ mg kg}^{-1}$. The crossed pattern indicates areas with a significance level of 95%.

cloud_param	4	cloud scheme	Lohmann et al., 2010
ncdnc	3	CDNC scheme	UAF
nicnc	3	ICNC - cirrus regime	BN09
limm_BN09	Т	ICNC - mixed phase regime	BN09
lcover	F	cloud cover calculation	Sundqvist
I_cdnc_calc	Т	CDNC parameterisation calculations	
i_cdnc_calc	7	CDNC parameterisation calculation	UAF
i_cdnc_cpl	7	CDNC parameterisation feedback	UAF
aer_stream	'gmxe_gp'	aerosol model for cdnc coupling	GMXe

Table S1. Setup of cloud.nml for the simulation BN+BN. The first two columns show the parameter names and the corresponding values selected for BN+BN, respectively. The third column describes the meaning of the parameters. The forth column indicates the meaning of the values in the second column.



Figure S5. Annual means of shortwave, longwave, net cloud radiative effects (*SCRE*, *LCRE*, *NCRE*, $[W m^{-2}]$) for the default simulation KL+LD and the absolute changes of BN+LD, KL+BN, and BN+BN with respect to it. The crossed pattern indicates areas with a significance level of 95%.



Figure S6. Annual zonal means of vertically integrated number concentration of cloud droplets $(CDNC_{burden}, [10^{10} \text{ m}^{-2}])$ and ice crystals $(ICNC_{burden}, [10^{10} \text{ m}^{-2}])$, non-precipitable liquid water path $(LWP, [g \text{ m}^{-2}])$ and ice water path $(IWP, [g \text{ m}^{-2}])$ averaged over the whole grid-boxes, shortwave and longwave cloud radiative effects $(SCRE, LCRE, [W \text{ m}^{-2}])$, total cloud cover (TCC, [%]). Colored lines refer to the experiments: KL+LD (blue), BN+LD (green), KL+BN (light blue) and BN+BN (red), black lines refer to satellite observations, error bars are \pm one standard deviation. Observations are from ERBE 1985-1990 (https://www.esrl.noaa.gov/psd/data/gridded/cmip3-clouds-rad-precip/datasets.html), CERES-EBAF-L3B-Ed2.8 2000-2016 (https://ceres.larc.nasa.gov/products.php?product=EBAF-TOA), MODIS-TERRA-v6 2004-2008 (ftp://ladsweb.nascom.nasa.gov/allData/6/MOD08_M3/).