Secondary Ice Production in Antarctic clouds: a process neglected in large-scale models

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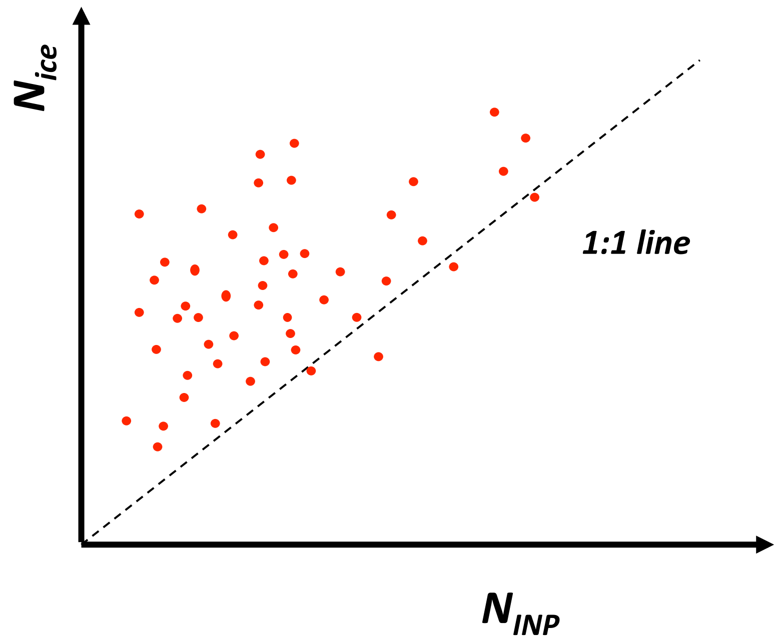
Antarctica is a remote and very clean environment, where INPs *(aerosols that can act as Ice Nucleating Particles)* are sparse

Grosvenor et al. 2012

Lachlan-Cope & Listowski 2016



O'Shea et al. 2017

Young et al. 2019

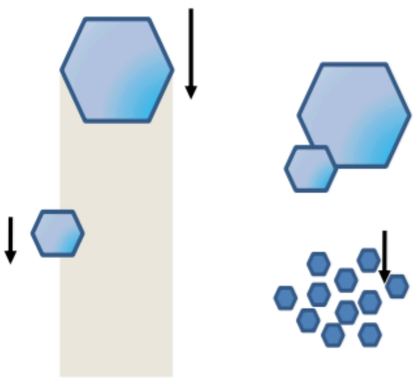
In-situ campaigns have revealed that Ice Crystal Number Concentrations (ICNCs) in Antarctic clouds are much higher than the available INPs

How do these numerous ice crystals arise at temperatures <$-38^{o}C$?

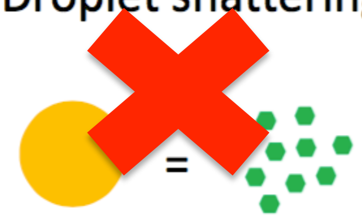
Could Secondary Ice Production (SIP*) explain the enhanced ice crystal concentrations in Antarctica ?

SIP* = ***multiplication of the few primary ice crystals in the absence of additional INPs***

✓ ice-ice collisions:

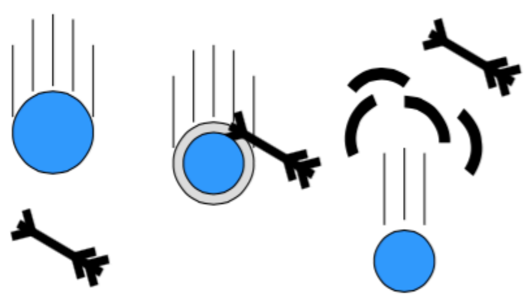


✓ Droplet shattering:



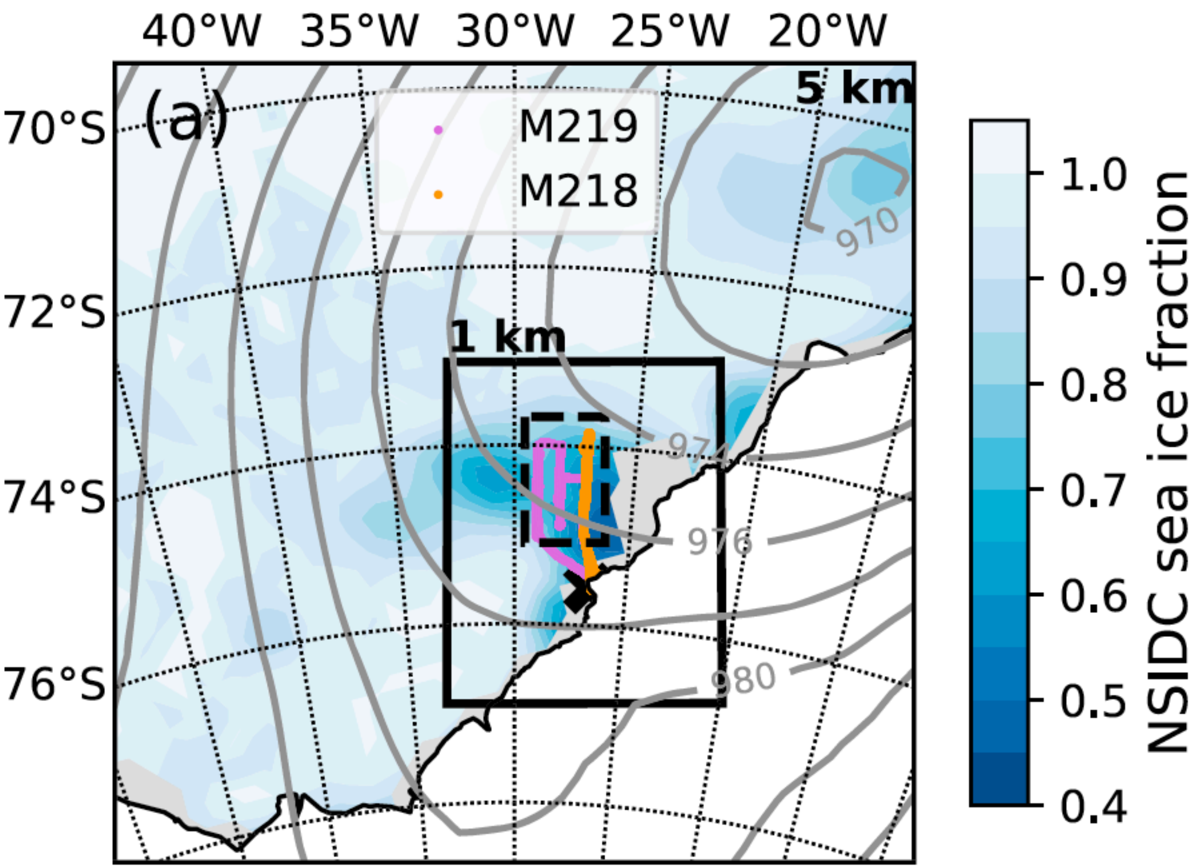
Not efficient in the Arctic (Fu et al 2019; Sotiropoulou et al. 2019)

✓ Ice fragments from riming: **(Hallet-Mossop)**



The only SIP mechanism extensively implemented in models

Modeling Secondary Ice Production in Antarctic Stratocumulus with WRF:



MAC campaign: "Microphysics of Antarctic clouds"

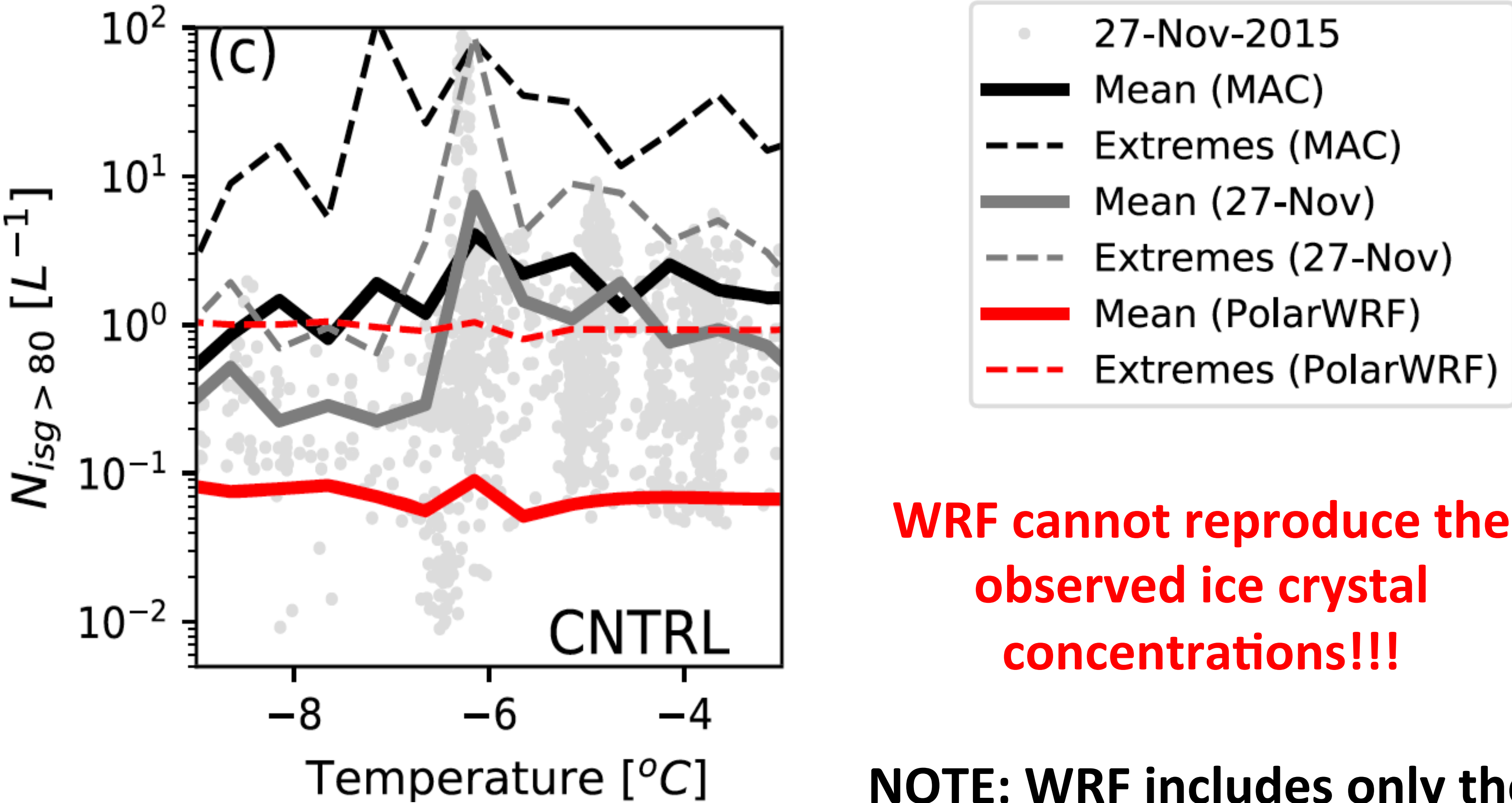
27 November 2015:

Flight M218

Flight M219

Young et al. 2019

Modeling Secondary Ice Production in Antarctic Stratocumulus with WRF:



WRF cannot reproduce the observed ice crystal concentrations!!!

NOTE: WRF includes only the Hallet-Mossop process

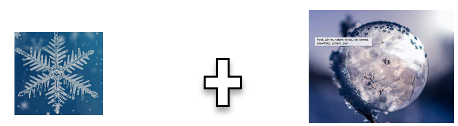
Young et al. 2019

Implementation of Collisional Break-up in Morrison microphysics scheme (WRF V4.1)

Morrison: 2-moment bulk microphysics scheme with 5 hydrometeor species (cloud drops, rain drops, cloud ice, graupel, snow)

Fragmentation is assumed to occur after:

1) cloud ice – graupel collisions



fragmentation of ice

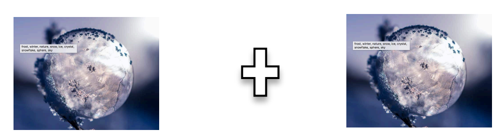
2) cloud ice – snow collisions

fragmentation of ice

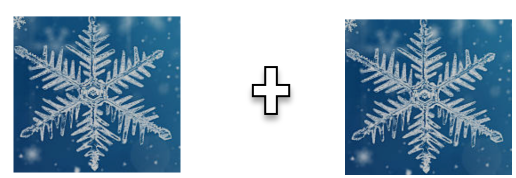
3) snow – graupel collisions

fragmentation of snow

4) graupel – graupel collisions



5) snow – snow collisions



Fragments added to cloud ice category

Modeling MAC cases (Young et al. 2019) with the updated WRF model

Sensitivity Simulations:

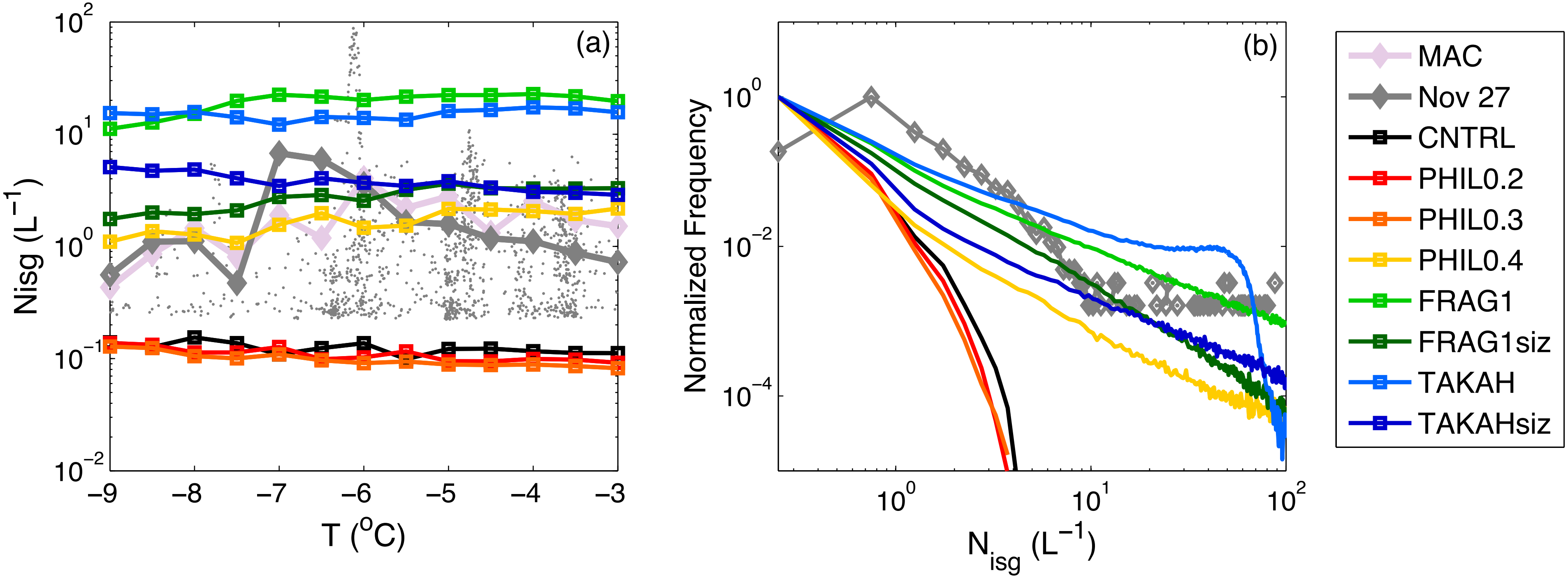
- PHIL0.2: Phillips parameterization (2017) with an assumed rimed fraction ~0.2 for the collided particle (*lightly rimed*)
- PHIL0.3: rimed fraction ~ 0.3 (*moderately rimed*)
- PHIL0.4: rimed fraction ~ 0.4 (*heavily rimed*)

- FRAG1: constant fragmentation number ~ 1 frag ejected per every collision
- FRAGsiz: constant fragmentation number with size restrictions ~ 1 frag ejected after break-up of particles > 300µm (Schwarzenboeck et al., 2009)

- TAKAH: fragmentation number estimated using the temperature dependent Takahashi formula (Takahashi et al. 1995; Sullivan et al. 2018)
- TAKAHsiz: Takahashi formula scaled with size

WRF simulations of MAC case study

Mean total ice crystal number concentrations : N_{isg}



Black line : default Morrison scheme (only Hallet-Mossop)

Grey line: mean observations for the case study

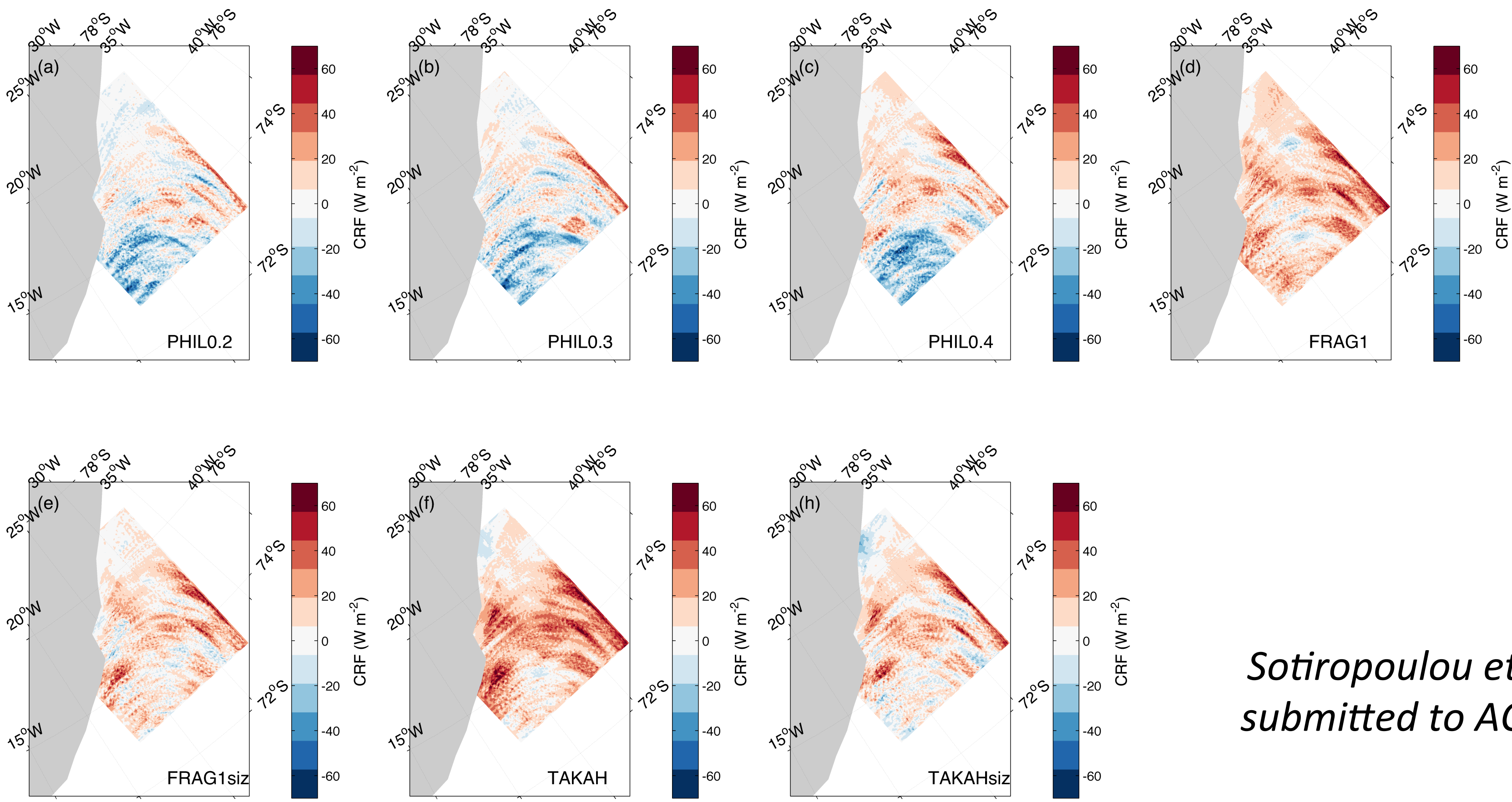
Pink line: mean observations for the whole MAC campaign

Other colors: different parameterizations for collisional break –up

Sotiropoulou et al., submitted to ACP

WRF simulations of MAC case study

Surface Cloud Radiative Forcing (CRF) Biases : CNTRL- Sensitivity test

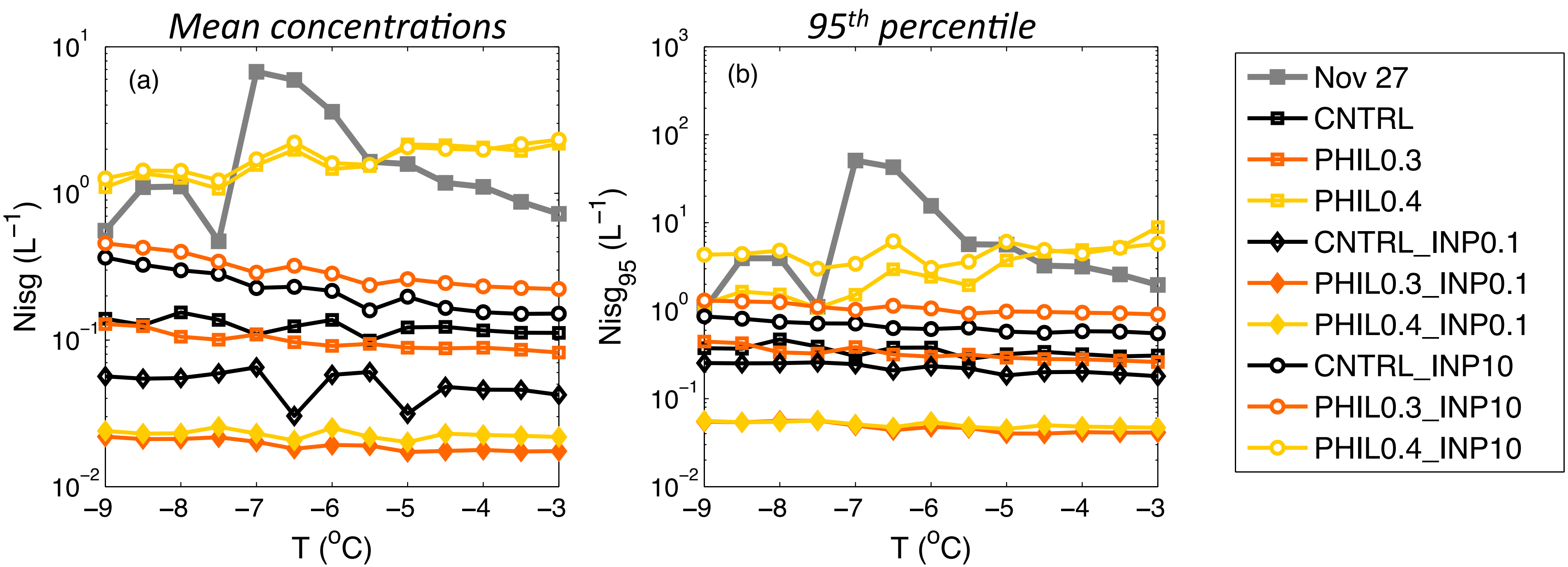


Sotiropoulou et al., submitted to ACP

Significant changes in surface cloud radiative forcing when a parameterization for collisional break-up is included in WRF!

WRF simulations of MAC case study

Sensitivity of collisional break-up to uncertainties in primary ice production



- **INP x 0.1:** PHIL0.3_INP0.1 and PHIL0.4_INP0.1 do not produce secondary ice due to lack of enough primary ice crystals to initiate collisional break-up
- **INP x 10:** Small differences between PHIL0.3 – PHIL0.3_INP10 and PHIL0.4 –PHIL0.4_INP10

Conclusions:

- Break-up from ice–ice collisions can explain the enhanced ice crystal number concentrations observed in Antarctic clouds
- Phillips parameterization for break-up (Phillips et al. 2017) performs well only if a high rimed fraction is assumed for the particles that undergo fragmentation
- Improved performance by parameterizations that account for the influence of the collided particle's size (e.g. PHIL0.4, FRAG1siz, TAKAHsiz)
- Implementing collisional break-up in atmospheric models can substantially impact the representation of the surface radiation budget
- Little sensitivity of collisional break-up to uncertainties in primary ice production, as long as there are enough primary ice crystals to initiate the process

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