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

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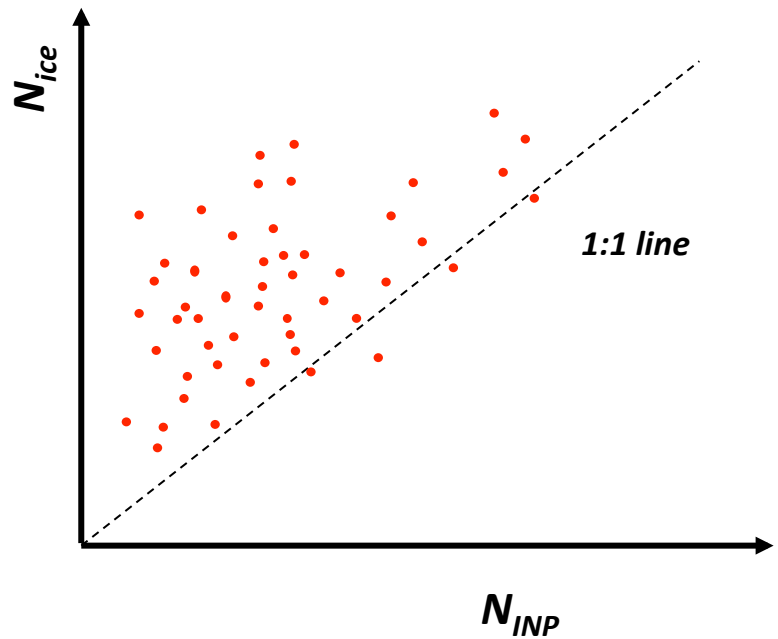
# Antarctica is a remote and very clean environment, where INPs *( aerosols that can act as Ice Nucleating Particles)* are sparse

Grosvenor et al. 2012

Lachlan-Cope & Listowski 2016




O'Shea et al. 2017

Young et al. 2019

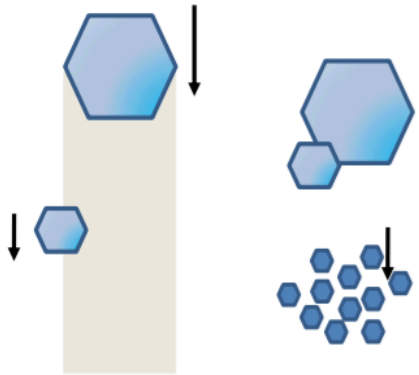
- **In-situ campaigns have revealed that Ice Crystal Number Concentrations (ICNCs) in Antarctic clouds are much higher than the available INPs**

***How do these numerous ice crystals arise at temperatures <-38°C?***

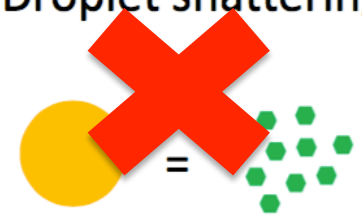
# Could Secondary Ice Production (SIP*) explain the enhanced ice crystal concentrations in Antarctica ?

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

✓ ice-ice collisions:

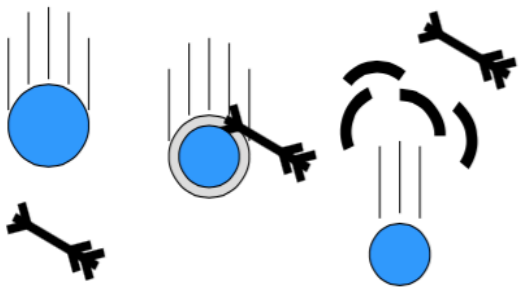


✓ Droplet shattering:



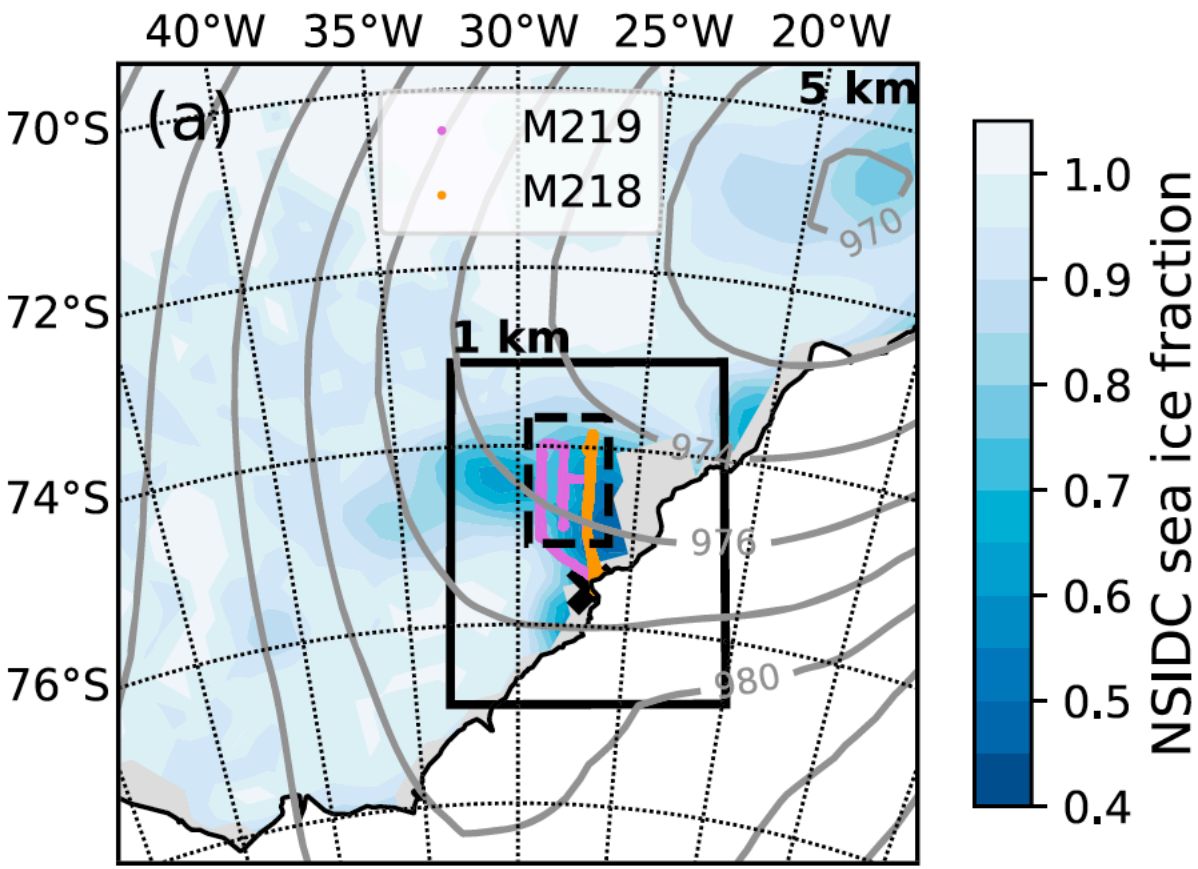
*Not efficient in the Arctic (Fu et al 2019; Sotiropoulou et al. 2019)*

✓ 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"**

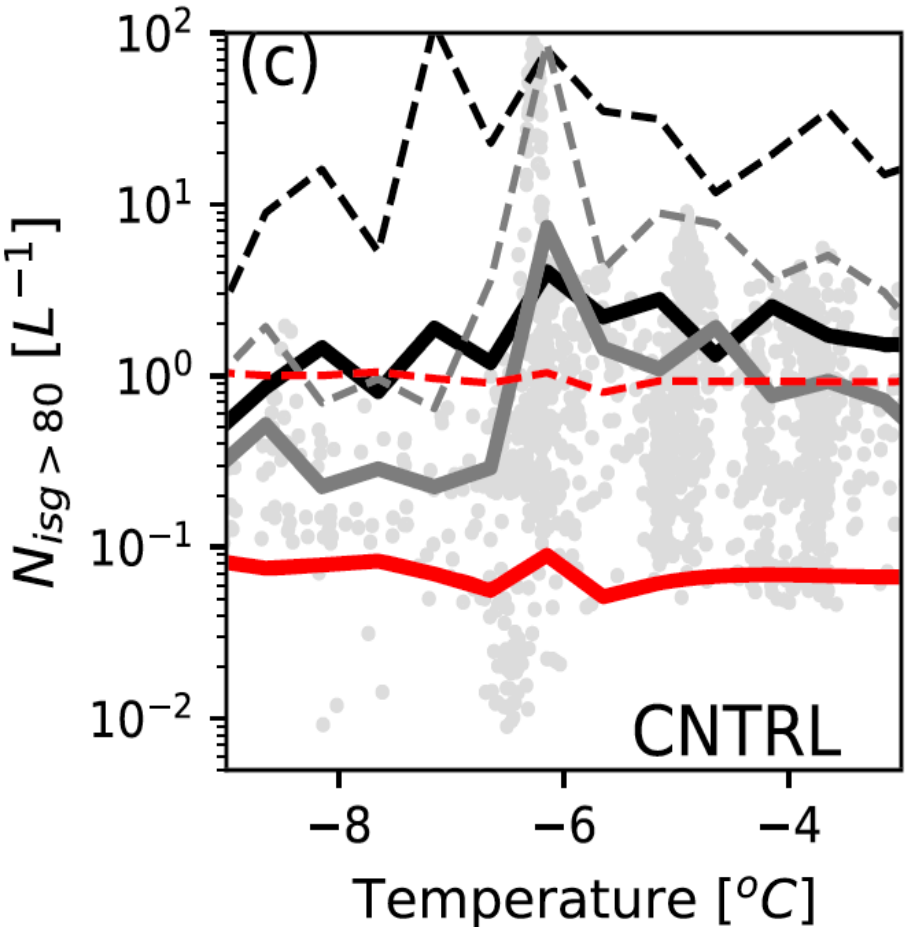
**27 November 2015:**

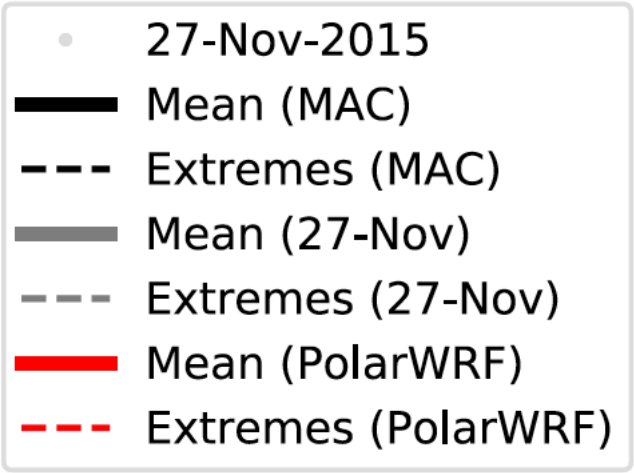
**Flight M218**

**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:**

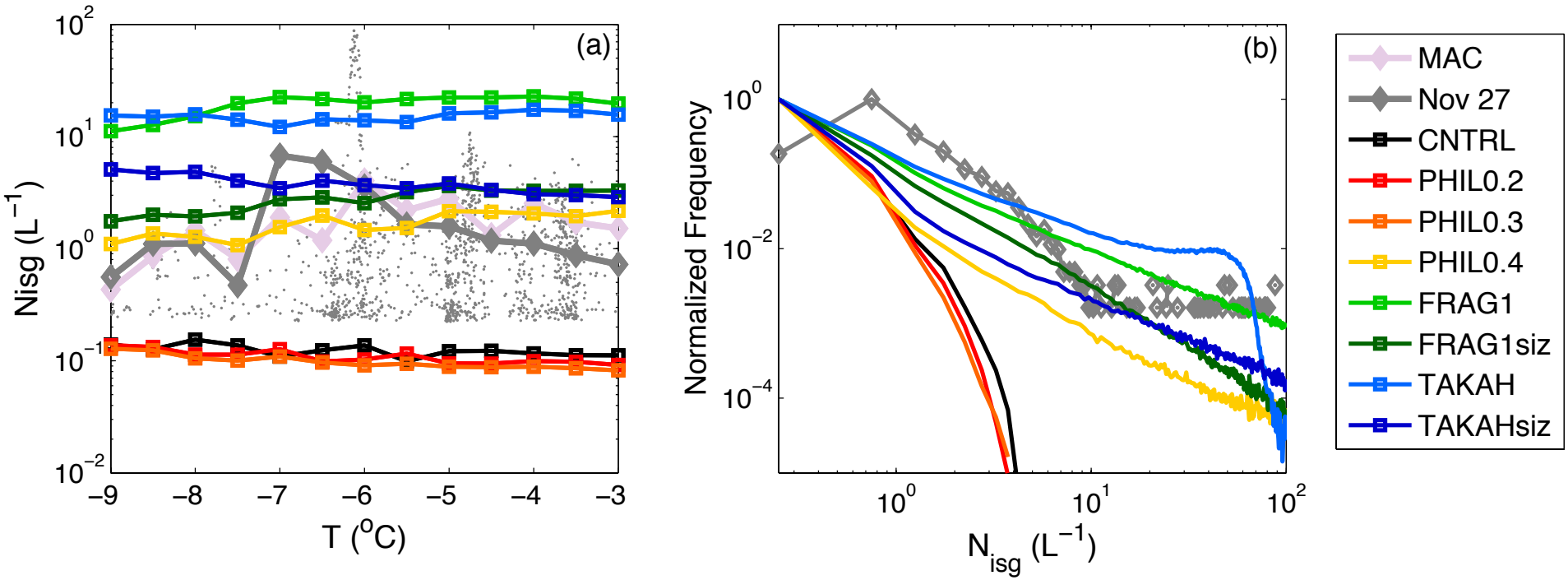
- PHIL0.2: Phillips parameterization (2017) with an assumed rimed fraction ~0.2 for the collided particle (*lightly rimed*)
- PHIL0.3: rimed fraction ~ 0.3 (*moderately rimed*)
- PHIL0.4: rimed fraction ~ 0.4 (*heavily rimed*)

- 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

*Total ice crystal number concentrations : $N_{isg}$*




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

**Grey line**: mean observations for the case study

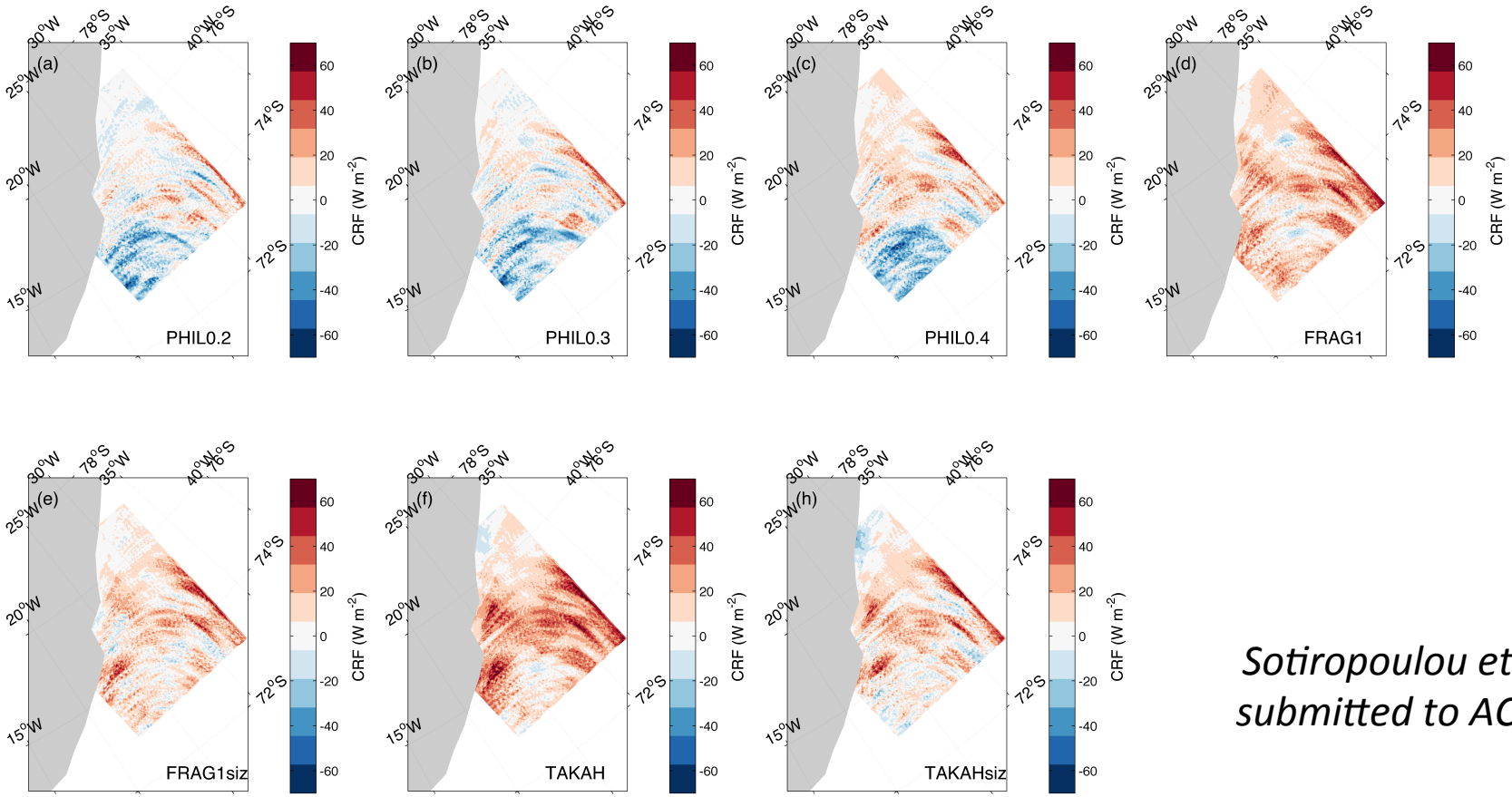
**Pink line**: mean observations for the whole MAC campaign

**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!

# 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