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.

- 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 $<-38^\circ C$?
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
WRF cannot reproduce the observed ice crystal concentrations!!!

NOTE: WRF includes only the Hallet-Mossop process
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

2) cloud ice – snow collisions

3) snow – graupel collisions

4) graupel – graupel collisions

5) snow – snow collisions
Modeling MAC cases (Young et al. 2019) with the updated WRF model

**Sensitivity Simulations:**

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

- **FRAG1:** constant fragmentation number \(\sim 1\) frag ejected per every collision
- **FRAGsiz:** constant fragmentation number with size restrictions \(\sim 1\) frag ejected after break-up of particles \(> 300\mu m\) (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: $N_{\text{isg}}$

### (a)

- **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

### (b)

- **MAC**
- **Nov 27**
- **CNTRL**
- **PHIL0.2**
- **PHIL0.3**
- **PHIL0.4**
- **FRAG1**
- **FRAG1siz**
- **TAKAH**
- **TAKAHsiz**

*Sotiropoulou et al., submitted to ACP*
WRF simulations of MAC case study

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

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.