Organization of SIP mechanisms among basic cloud types

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Background

- **High concentrations** of ice particles observed in precipitating ice clouds are often significantly **higher than** those of **active ice nuclei.**
- SIP is crucial for predicting ice concentrations realistically in observed clouds.
- Cloud models in the scientific community **typically under-predict** the high concentrations of ice observed when validation is done.

SIP mechanisms: HM process of rime splintering, Collisional fragmentation, Raindrop-freezing fragmentation (Phillips *et al.* 2018), Sublimation breakup (Deshmukh *et al.* 2022)

Methodology

The four basic cloud types are defined as: (1) warm-based convective and stratiform clouds; and (2) cold-based convective and stratiform clouds.

Aerosol-Cloud model (AC) is used. AC includes the four mechanisms of secondary ice production as follows: ice-ice collisional breakup, raindrop freezing fragmentation, Hallett-Mossop (HM) process and sublimational breakup. The intent is to generalize the contribution of each SIP mechanism among basic cloud types.

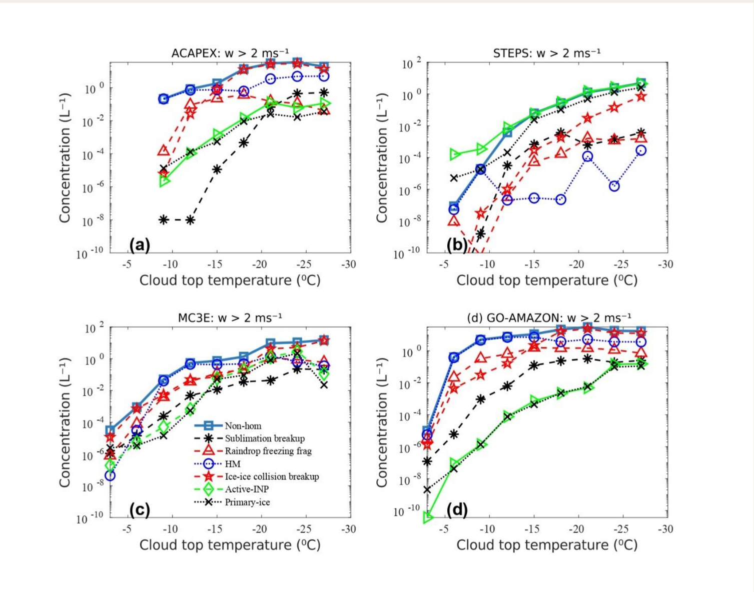

Figure 1. Ice particle concentrations for different basic cloud types are represented for various cloud top temperatures are shown. The particle concentration of non-homogeneous ice (right-pointing triangle), sublimational breakup (asterisk), raindrop-freezing fragmentation (upward-pointing triangle), HM process (circle), ice-ice collisional breakup, active INP's (diamond) and primary ice (cross) are displayed here for (a) ACAPEX, (b)STEPS, (c) MC3E, and (d) GO-Amazon.

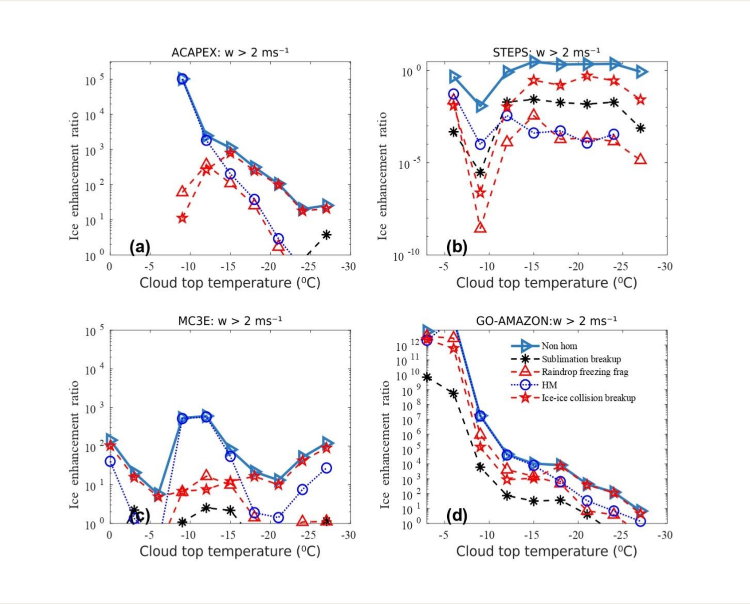

Figure 2. Ice enhancement ratio is shown with respect to cloud top temperatures (algorithm described by Waman *et al.* 2022). IE ratio for non-homogeneous ice (right-pointing triangle), sublimational breakup (asterisk), raindrop-freezing fragmentation (upward-pointing triangle), HM process (circle) and ice-ice collisional breakup is represented for (a) ACAPEX, (b)STEPS, (c) MC3E, and (d) GO-Amazon.

Results

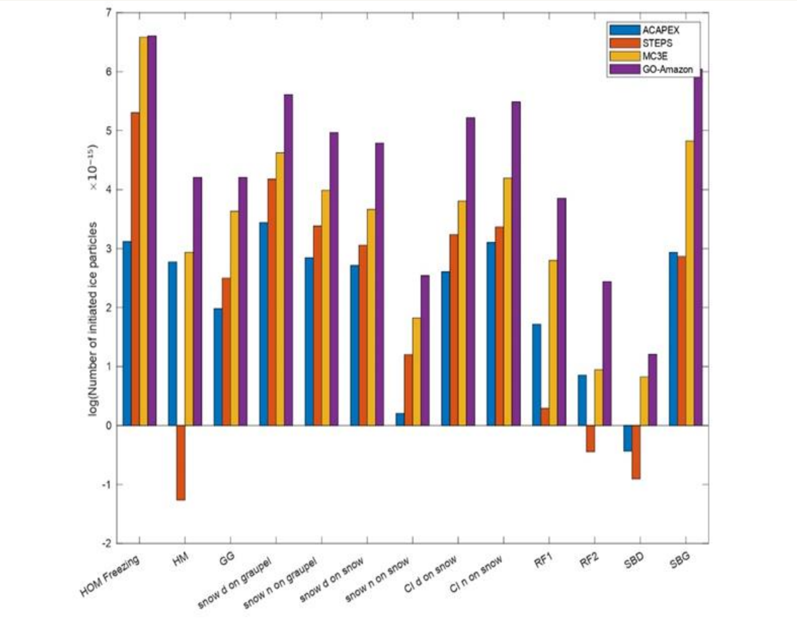

Figure 3. Bar chart for entire storm budgets of the number of secondary ice crystals initiated in the basic cloud simulation of the AC. Here, ACAPEX (blue), STEPS (orange), MC3E (yellow) and GO-Amazon (purple) simulations.

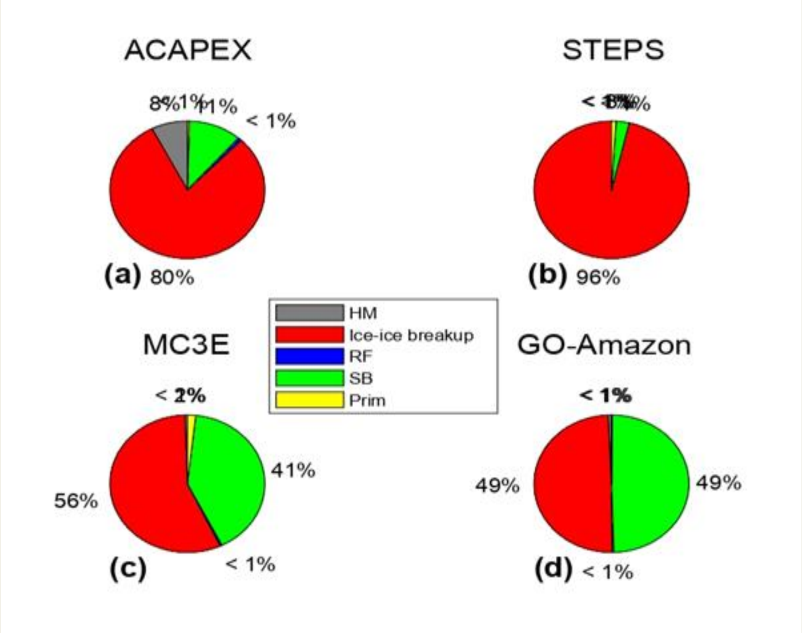

Figure 4. Pie chart for the ice contribution of primary ice(yellow), and secondary ice components (HM process (grey), breakup in ice-ice collision (red), raindrop-freezing fragmentation (blue) and sublimational breakup (green)) is displayed here. The basic cloud simulation of the AC for (a) ACAPEX, (b) STEPS, (c) MC3E and (d) GO-Amazon simulations are shown.

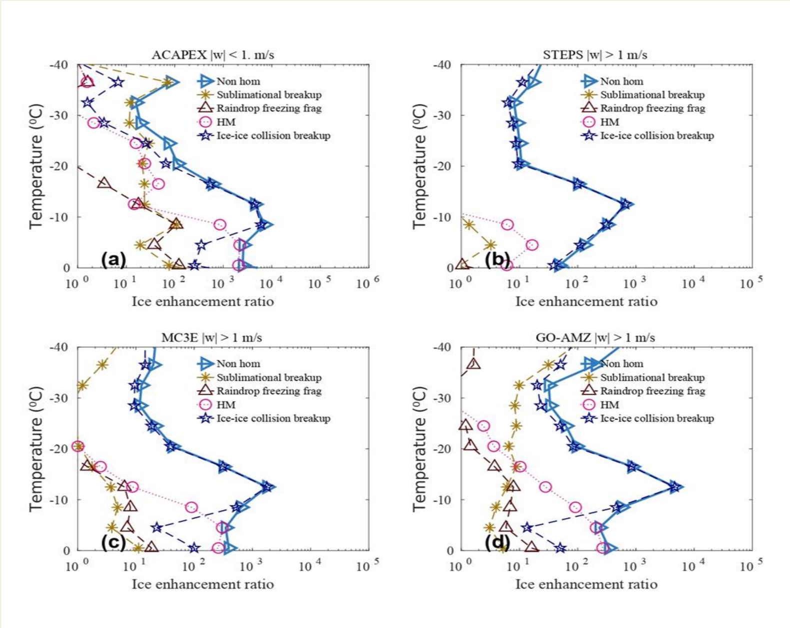

Figure 5. The IE ratio from non-homogeneous ice (right-pointing triangle), sublimational breakup (asterisk), raindrop-freezing fragmentation (upward-pointing triangle), HM process of rime splintering (circle), ice-ice collisional breakup (star) shown for(a) ACAPEX, (b)STEPS, (c) MC3E, and (d) GO-Amazon.

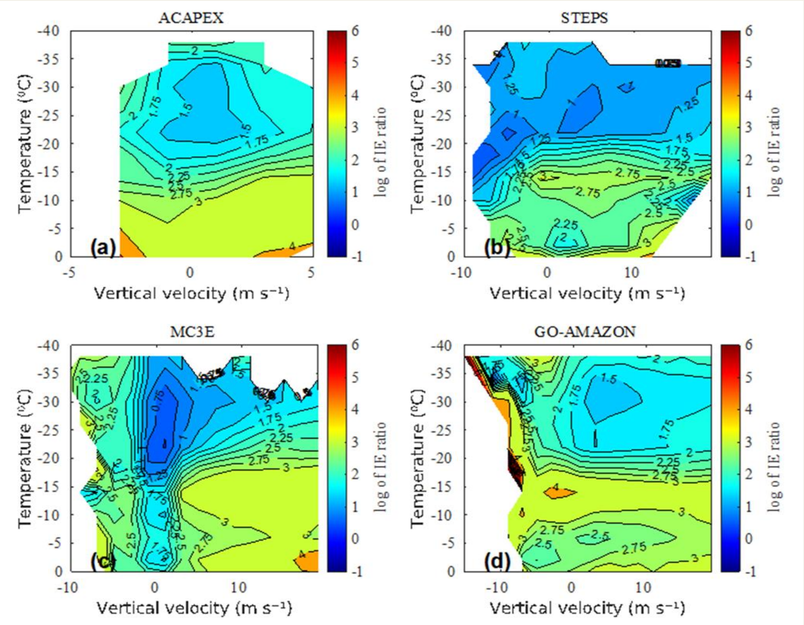

Figure 6. *w-T* map of total IE ratio for (a) ACAPEX, (b) STEPS, (c) MC3E and (d) GO-Amazon

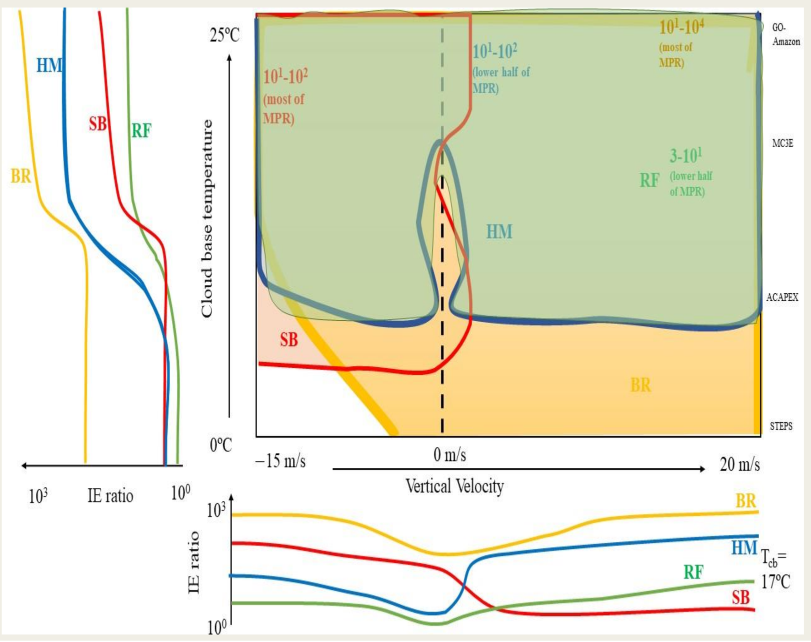

Figure 7. The schematic of SIP mechanisms and their dependence on cloud base temperature and vertical velocities is displayed. Here, the HM process ('HM', blue line), breakup in ice-ice collisions ('BR', yellow line), rain-drop freezing fragmentation ('RF', green line) and sublimational breakup ('SB', red line) are shown. Also, mixed-phase region is denoted by 'MPR'.

Conclusions

- Warm-based or very warm-based convective clouds display higher ice enhancement from breakup in ice-ice collisions compared to cold-based convective clouds.
- As the ascent increases from 2 to 20 m/s, the IE ratio from the HM process deepens from 10^2 to 10^3 in the lower half of mixed-phase region of cloud.
- The ice enhancement by the HM process increases as the cloud-base temperature increases from cold to very warm.
- Warm and very warm-based convective clouds, the contribution from sublimational breakup to the IE ratio (~10^2) strengthens with increasing cloud-base temperature. This contribution is small in the cold-based convective clouds. Based on different cloud types, the sublimational breakup is not the most prevalent mechanism but it is also non-negligible.
- Raindrop freezing fragmentation displays no ice enhancement in the cold-based convective clouds, due to the deficiency of a warm rain process, and shows only a little ice enhancement in the warm-based convective clouds.

References

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