Organization of secondary ice production mechanisms among basic cloud-types

Vaughan Phillips[1]; Akash Deshmukh[1]; Deepak Waman[1]; Arti Jadav[1]; Martanda Gautam[1]; Sachin Patade[1]; Aaron Bansemer[2]; Paul Connolly[3] ; Paul DeMott[4]; Greg McFarquhar[5] | [1]Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden; [2]National Center for Atmospheric Research, Boulder, Colorado, USA; [3]Department of Physics, University of Manchester, UK; [4]Colorado State University, USA; [5]School of Meteorology, University of Oklahoma, USA.

ASR Atmospheric System Research

Overview

BACKGROUND

It was appreciated decades ago that solid aerosol material in the air initiates the first ice, while actual ice concentrations are much higher than the first ice. This has led to the realisation that 'secondary ice' is formed somehow from pre-existing primary ice from this aerosol material. Various types of fragmentation of pre-existing precipitation explain this secondary ice.

OUTLINE OF PROJECT

An ASR project (2018-2023) has elucidated how various mechanisms of fragmentation of ice are organized among basic cloud-types:

- Rime-splintering (the Hallett-Mossop [HM] process);
- Breakup in ice-ice collisions ('BR');
- Fragmentation during freezing of rain and drizzle ('RF') by Modes 1 and 2;
- Sublimational breakup of dendritic crystals/snow and graupel ('SB').

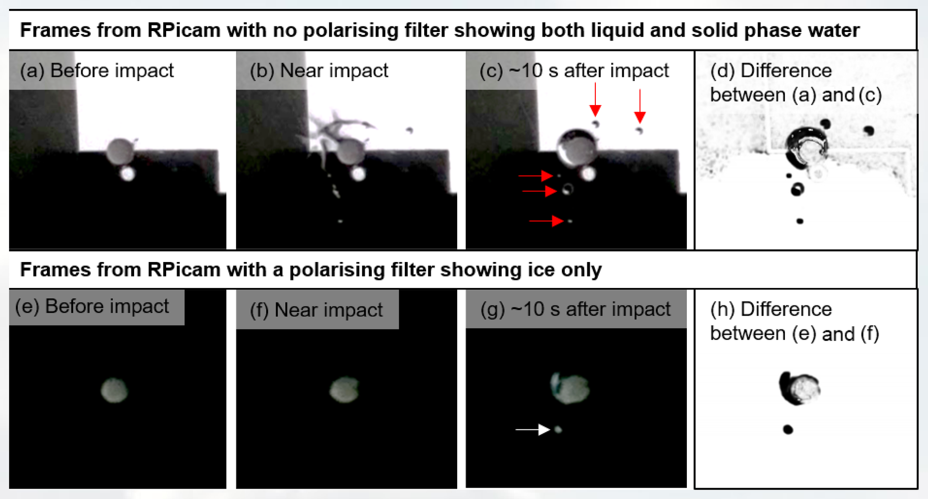

Figure 1: Drop (5 mm= on impact with secondary drops (red arrows). Some freeze (white arrow). From James et al. (2021)

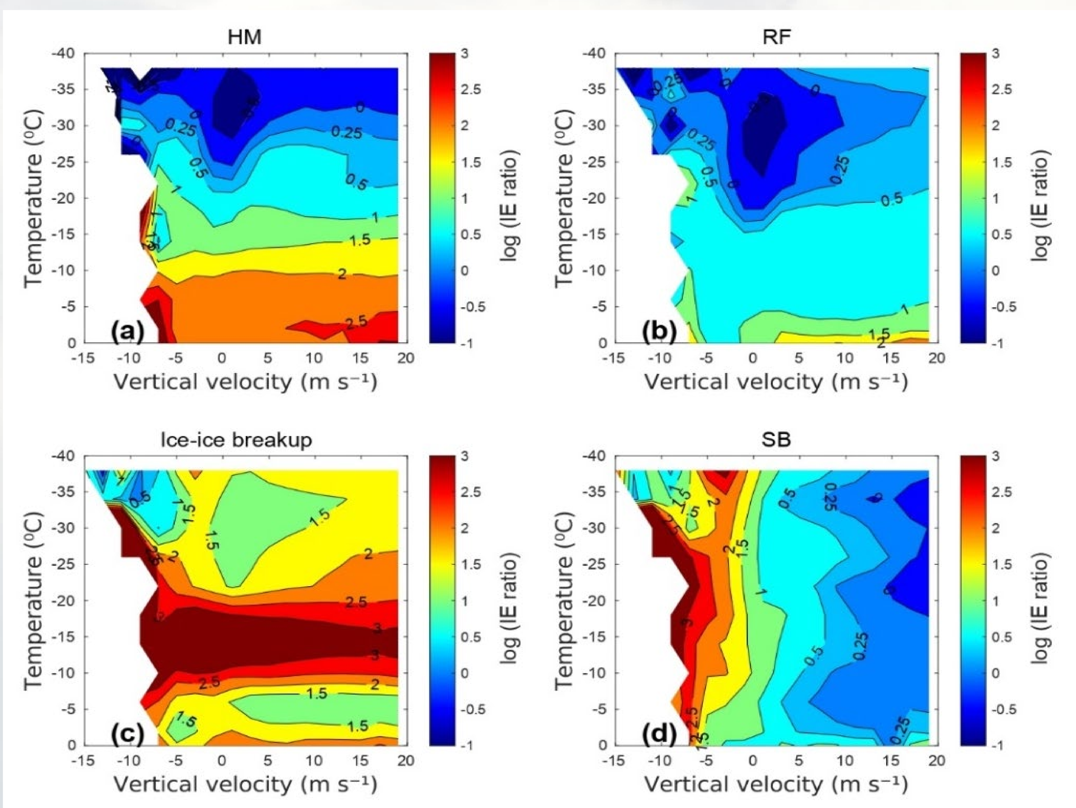

Figure 2: Ice enhancement (IE) ratios averaged over entire simulation of a very warm-based case of deep convection from Manaus, Brazil (Go-Amazon) with 4 SIP mechanisms: (a) HM; (b) RF; (c) BR; and (d) SB.

> *"Like a heavy fragrance*
> *Snowflakes settle:*
> *Lilies on rocks"*
>
> *Matsuo Basho, 17th century, Japan*

Method

NUMERICAL MODELING

With the Aerosol-Cloud model (AC; Phillips et al. 2017, 2020), simulations of four contrasting cases of clouds were validated for ice concentrations and other cloud properties from aircraft and ground-based observations:

- stratiform cloud with a slightly cold base ('ACAPEX');
- convective clouds with cold ('STEPS'), warm ('MC3E') and very warm ('GoAMAZON') bases.

Tagged ice concentrations are for each SIP source.

LAB OBSERVATIONS DISCOVERING NEW SIP MECHANISM

James et al. (2021) observed raindrops falling on fixed ice particles (a few mm). 30% of secondary droplets (e.g. from a splash) froze (Fig. 1). This confirmed existence of 'Mode 2' of RF (Phillips et al. 2018).

INNOVATION OF SUBLIMATION BREAKUP SCHEME

The scheme was derived theoretically and fitted to published lab data (E.g. Oraltay and Hallett 1989). For dendritic snow of size, d, fragment emission during sublimation for a relative humidity with respect to ice (%), Rh_i, is (Deshmukh et al. 2022):

$$\frac{dN}{dt} \approx \beta d^{\gamma+1}\,(100 - RH_i) f_v\, \Xi\, \nu$$

Results from Cloud Simulations

Figures 2 and 3 show w-T maps of ratio of concentrations of total ice to primary ice, from the very warm- and cold-based cases of deep convection (STEPS and Go-AMAZON).

Figure 4 shows how the precipitation mechanism (warm rain vs ice crystal process) is controlled by cloud-base temperature. There are ramifications for graupel and SIP.

Figure 5 is a budget for SIP.

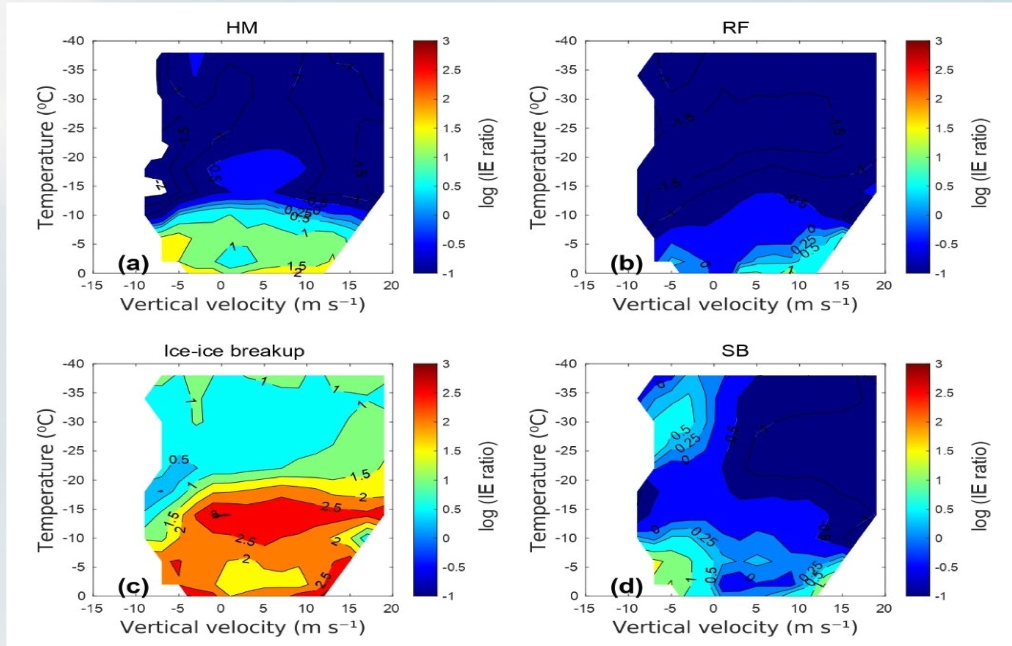

Figure 3: IE ratios of SIP mechanisms for a cold-based case of deep convection (STEPS), plotted as in Fig. 2.

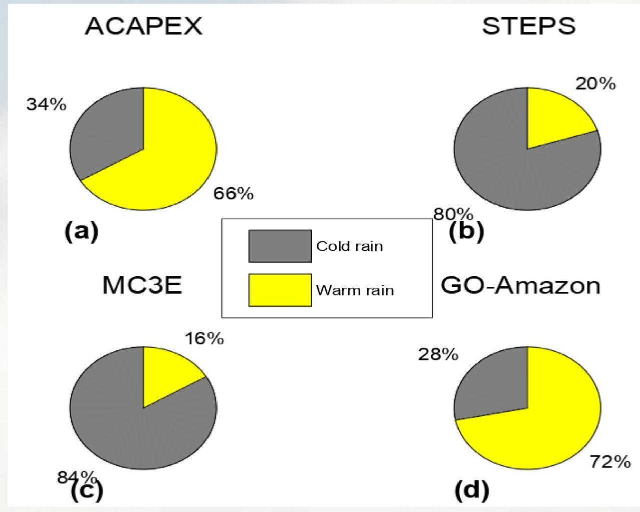

Figure 4: Surface precipitation accumulation.

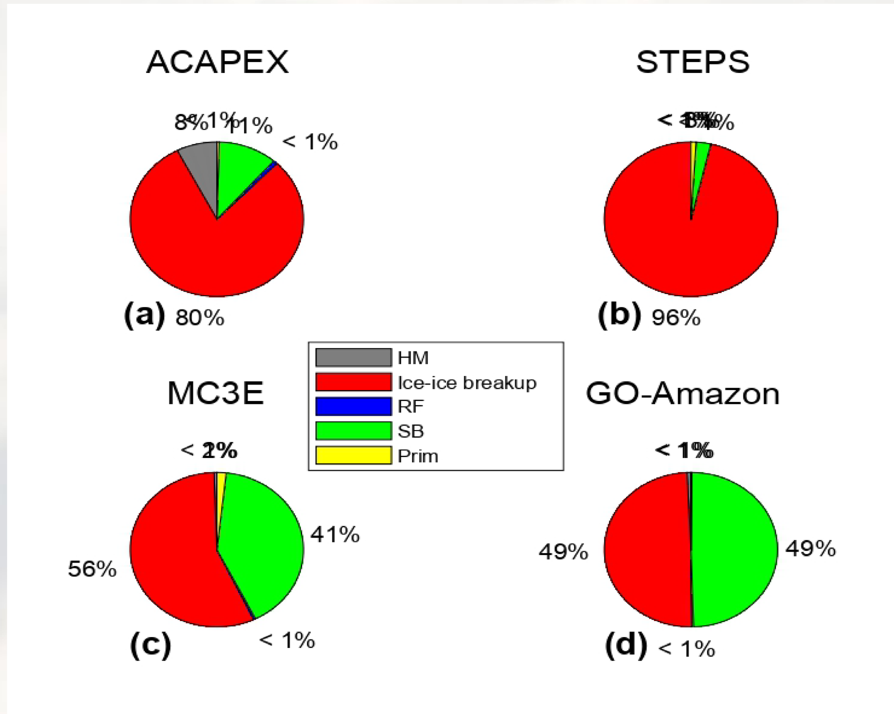

Figure 5: Budget from entire simulations of total numbers of ice particles initiated by SIP processes for the four cases, (a)-(d). For sublimational breakup, only splinters that survive are shown.

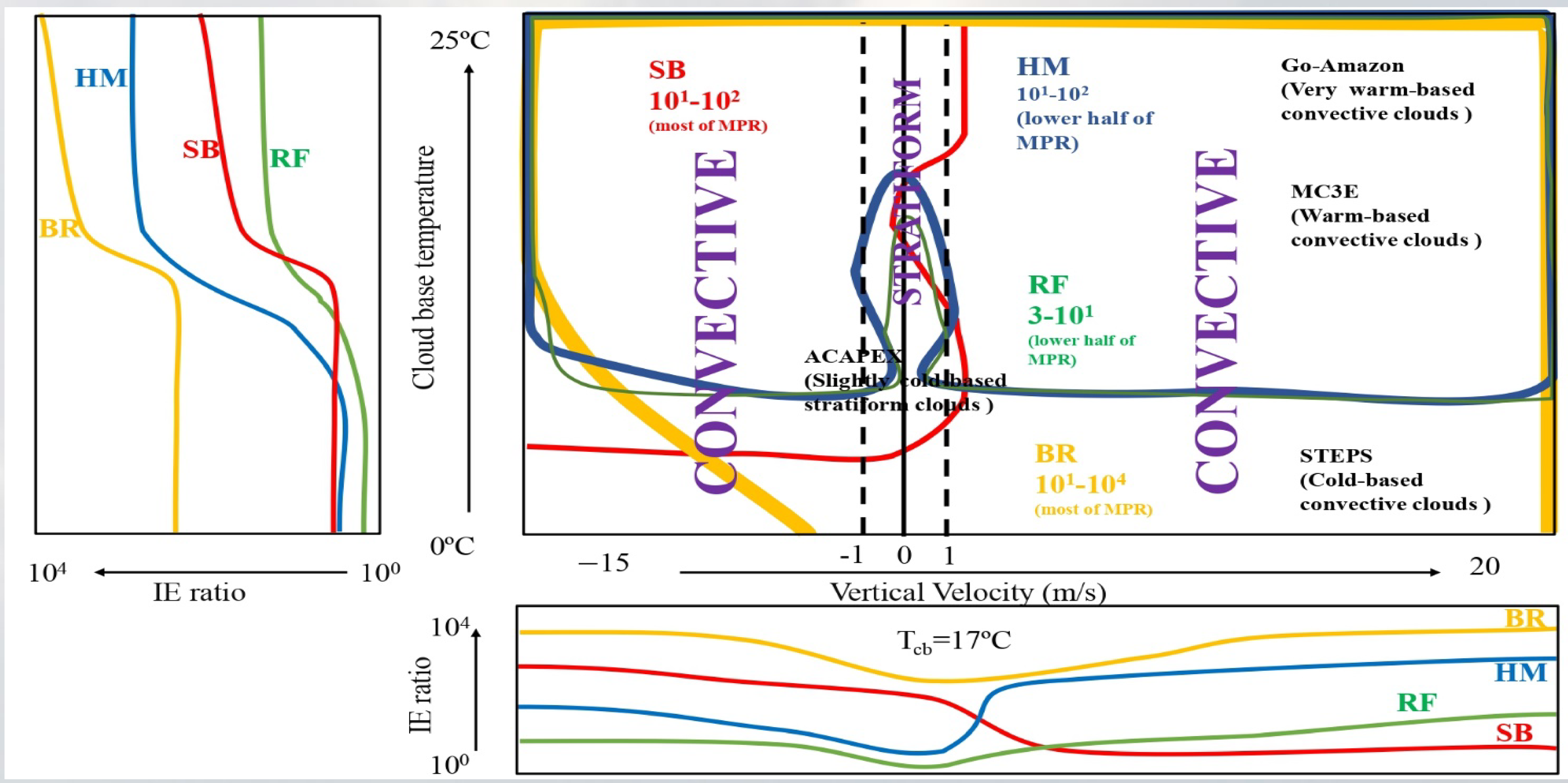

Fig 6. Conceptual picture of where in the phase-space of cloud-types the various SIP mechanisms are active.

Conclusions

- HM process and raindrop-freezing fragmentation initiate less ice overall;
- Breakup in ice-ice collisions shows the most fragment generation overall,
  - dendritic snow hitting graupel prevails;
- Sublimational breakup is influential;
- Cooling of cloud-base slows breakup in ice-ice collisions slightly but almost completely suppresses the other SIP mechanisms;
- Conceptual picture of organization among cloud-types in Fig. 6.

References

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Contact Information

- Vaughan.Phillips@nateko.lu.se

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