The impacts of secondary ice production on tropical deep convective clouds in a Hector Thunderstorm

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Background/Aims

- For decades, the concentrations of ice particles in convective clouds are frequently observed to be orders of magnitude higher than those produced directly from ice-nucleating particles.
- This reveals the existence of secondary ice production (SIP) in addition to the primary ice nucleation. The ice particle enhancement may have significant effects on the cloud dynamics, precipitation rate, and cloud radiative properties, impacting the surface energy budget and hydrological cycle.
- Several possible mechanisms of SIPs have been proposed based on laboratory and theoretical studies, e.g. rime splintering, fragmentation of freezing drops, and ice–ice collisional breakup.
- Rime splintering has been widely implemented in models, but recently microphysical parameterizations have started to consider additional SIP mechanisms. The effects of different SIPs on tropical deep convective clouds remains largely uncertain.

Aims:

- **Introducing SIP processes (rime splintering, ice–ice collisional breakup, and droplet shattering during rain freezing) into the Cloud-AeroSol Interacting Microphysics (CASIM) module.**
- **Investigating the effects of different SIPs on the microphysics and dynamics of a simulated Hector thunderstorm.**

Methods

Model description

- The Met Office Unified Model (UM) was used in this study. Cloud microphysics is described by the CASIM, which is a 2-mom scheme. CASIM considers homogeneous freezing of cloud droplets, heterogeneous freezing, aggregation of ice crystals, sedimentation of ice-phase hydrometeors, and the rime splintering.

Table 1. List of experiments

	Type of Secondary ice production	References
RS	Rime splintering	Hallett & Mossop (1974)
all-SIP	Rime splintering Ice–ice collisional breakup Droplet shattering during rain freezing (mode 1/2 included, regarding collisions with less/ more massive ice particles)	Hallett & Mossop (1974) Phillips et al. (2017) Phillips et al. (2018)
no-CB	Same as all-SIP but no ice-ice collisional breakup	
no-M1	Same as all-SIP but no mode 1	
no-M2	Same as all-SIP but no mode 2	
no-SIP	Same as RS but no RS process	

Model configuration and simulation experiments

- A pre-monsoon deep convective storm known as Hector (30 Nov 2005) was simulated. The initial and boundary conditions were from the 6-hourly ECMWF reanalysis data. The simulations had a horizontal grid spacing of 1.5 km (900×900), centering over Darwin region (12.4S,130.8E). There were 90 vertical levels stretched to 40 km. The simulations began at 00UTC on 30 Nov and integrated for 36 hr. The spin-up period was ~3 hr and the time step was 75 s.

References

1. Hallett, J. & Mossop, S. C. (1974). Production of secondary ice particles during the riming process, *Nature*, 249, 26–28.
2. Phillips, V. T. J., Yano, J.-I., & Khain, A.(2017). Ice Multiplication by Breakup in Ice–Ice Collisions. Part I: Theoretical Formulation, *J. Atmos. Sci*., 74, 1705–1719.
3. Phillips, V. T., Patade, S., Gutierrez, J., & Bansemer, A. (2018). Secondary Ice Production by Fragmentation of Freezing Drops: Formulation and Theory, *J. Atmos. Sci.*, 3031–3070.

Results

Comparison with observations

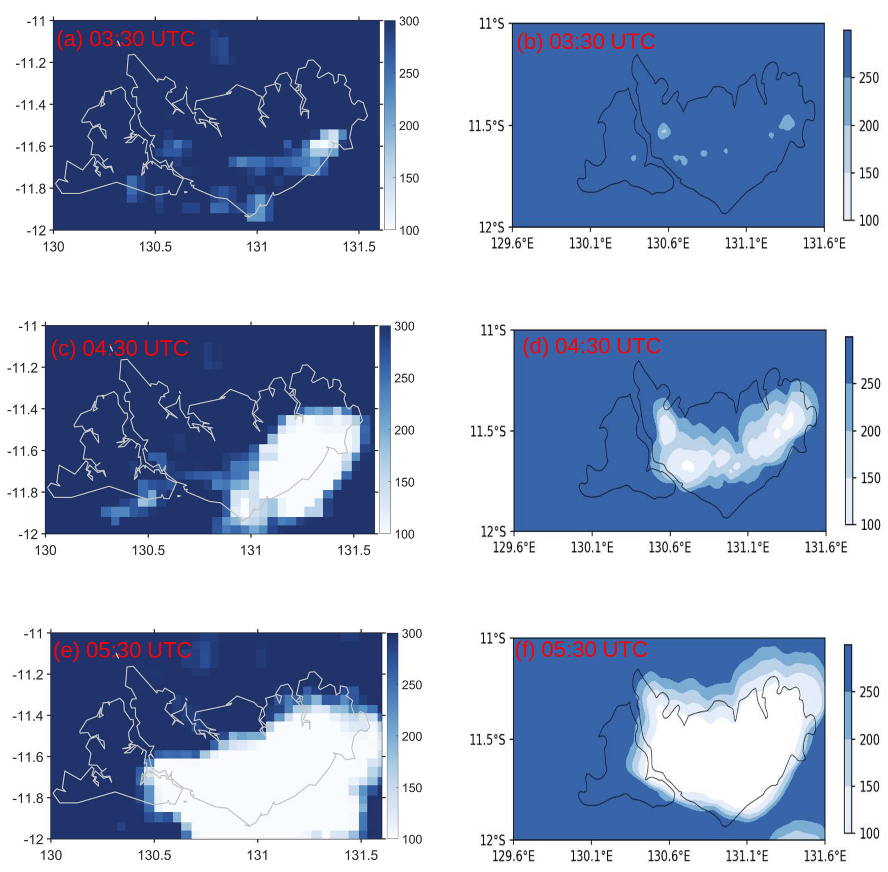

Figure 1: MTSAT visible channel images (a, c, e) and simulated outgoing longwave radiation (OLR) from the RS case (b, d, f) at 0330 UTC, 0430 UTC, and 0530 UTC.

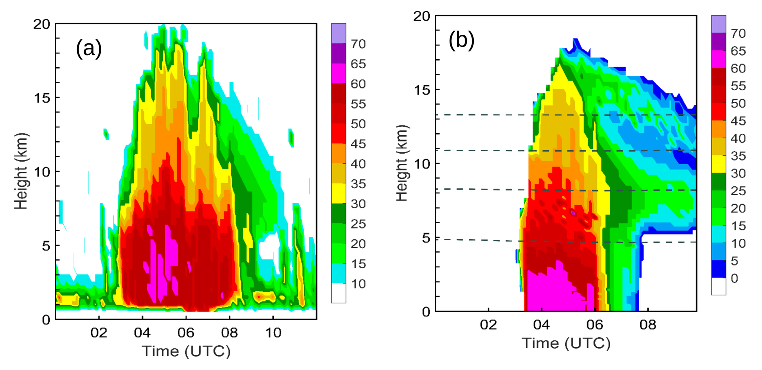

Figure2: Comparison of time–height plots of maximum radar reflectivity (dBZ) between (a) observation, and (b) RS simulation.

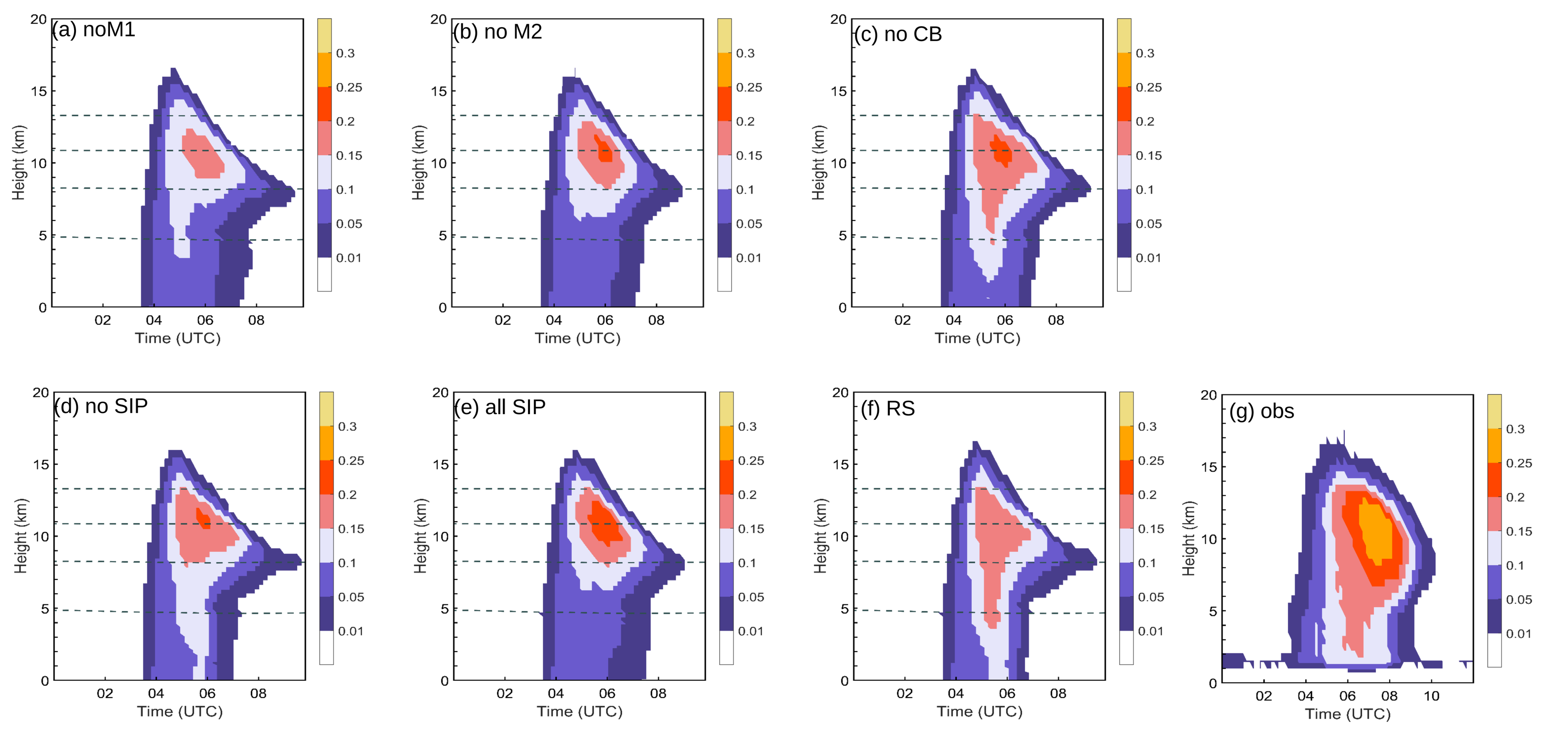

Figure 3: Comparison of time–height plots of CFADs (fraction of radar reflectivity >=10dBZ) between observation and simulations. (a) no M1, (b) no M2, (c) no CB, (d) no SIP, (e) all SIP, (f) RS, and (g) observation.

Impacts of SIP on microphysical properties

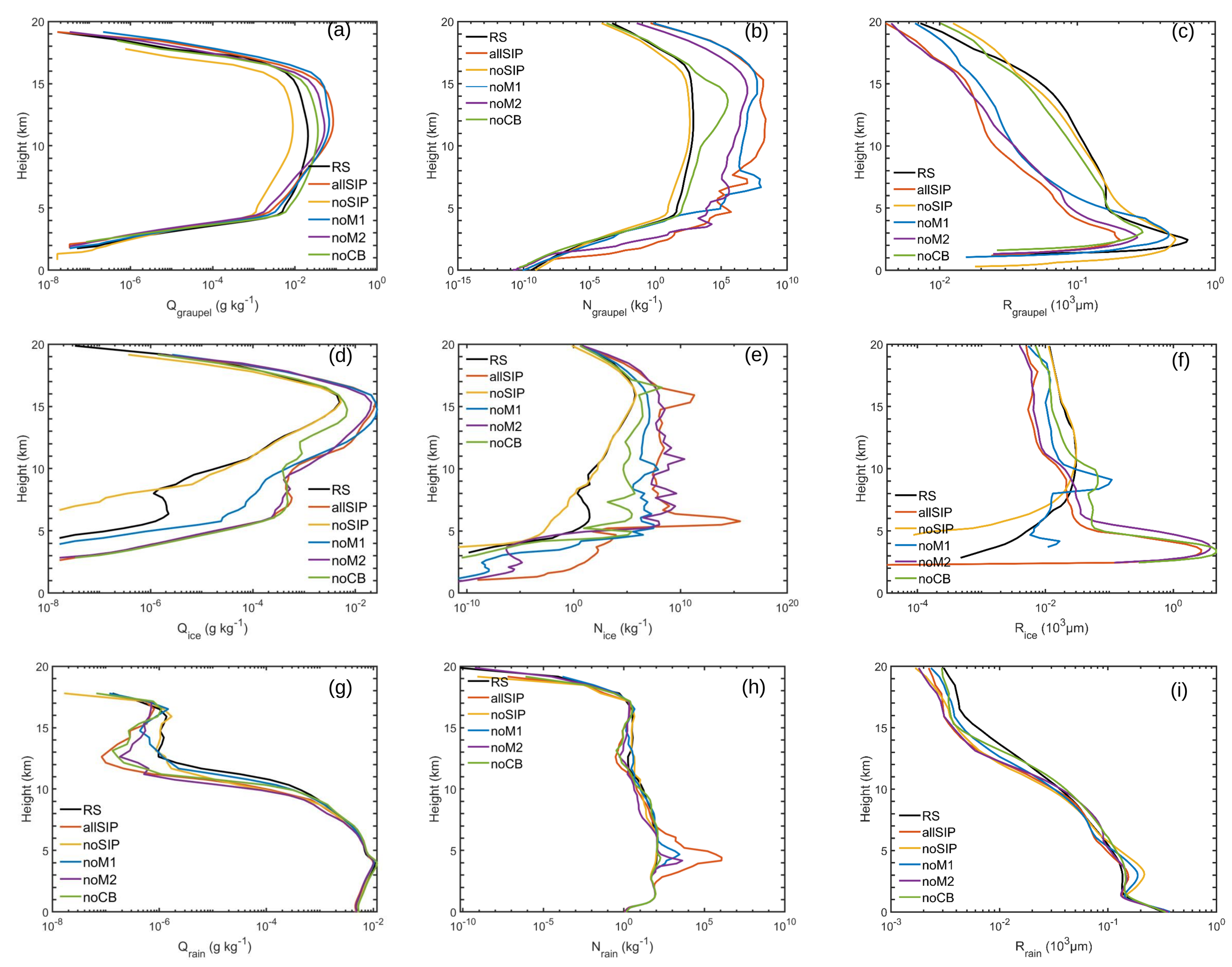

Figure 4: Vertical profiles of the mass mixing ratio (a, d, g), number concentration (b, e, h), and mean-mass radius (c, f, i) of graupel (a–c), ice crystals (d–f), and rain drops (g–i) during 03:00-10:00 UTC for different simulations.

Future work

- **More sensitivity studies** will be conducted to examine whether the current SIP schemes produce too much ice or the conversion of ice crystals between categories leads to this phenomenon.
- **Determine the best representation of the SIP process(es) and rates.** The impacts of SIPs on the dynamics, precipitation, and radiation in tropical convection will also be assessed.

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