Investigating the Relative Contributions of Secondary Ice Formation Processes to Ice Crystal Number Concentrations within Mixed-Phase Clouds

Georgia Institute of Technology

Sylvia C. Sullivan (ssullivan37@gatech.edu)[1], Athanasios Nenes[1,2]

1. School of Chemical and Biomolecular Engineering and 2. School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA,

Funding from NESSF (NNX13AN74H), DOE EaSM

AGU American Geophysical Union

MOTIVATION

- Observed atmospheric ice number concentrations, n_i, can be orders of magnitude higher than the ice nuclei number concentrations. This multiplication can be explained by *secondary ice processes*.
  → Limited effort has gone into modelling several of these processes simultaneously.

- Many associated parameters, e.g. number of fragments produced upon collision or collision efficiency, are uncertain.
  → Parcel model simulations can be used to estimate the effect of these uncertain parameters on n_i.

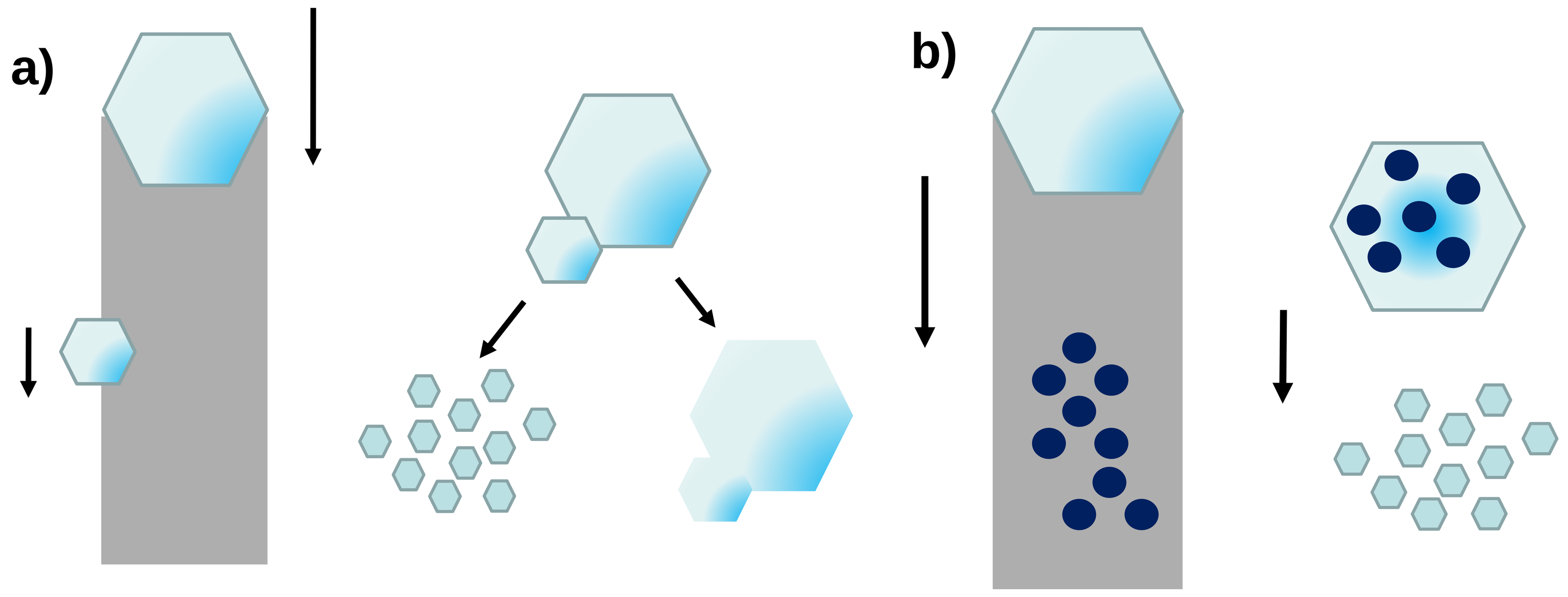


FIGURE 1
a) Ice-ice collision results in splintering or aggregation.
b) Rime-splintering, when a falling crystal collides with droplets, may also generate additional crystals.

MODEL DEVELOPMENT

(2) Parcel supersaturation evolution: modified from *Korolev and Mazin 2003* to include aspect ratio as in *Chen and Lamb 1994* and *Jensen and Harrington 2015*

$$\frac{dP}{dt} \quad \frac{dT}{dt} \quad \frac{ds_w}{dt} \quad \frac{dq_v}{dt} \quad \frac{dq_w}{dt} \quad \frac{dq_i}{dt} \quad \frac{dr_w}{dt} \quad \frac{dr_i}{dt} \quad \frac{da_g}{dt} \quad \frac{da_G}{dt}$$

$$\frac{d(\ln c)}{d(\ln a)} = \Gamma(T)$$

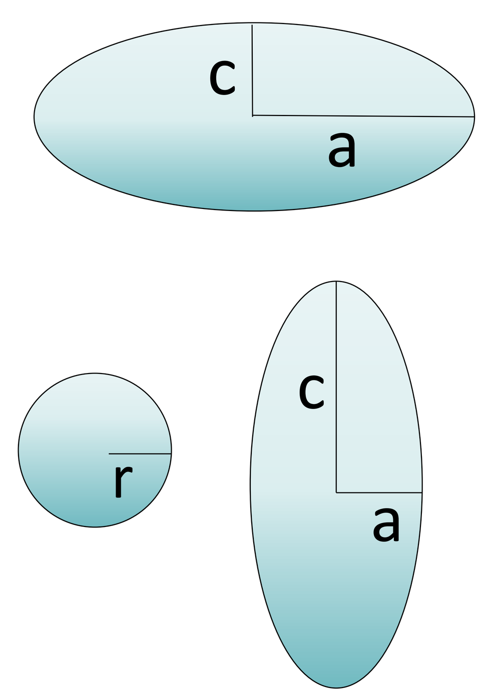
(1) Ice crystal and graupel number evolution in three bins

$$\frac{dn_c}{dt} \quad \frac{dn_g}{dt} \quad \frac{dn_G}{dt}$$

$$\left(\frac{dn}{dt}\right)_{agg} = f(\eta_{agg}, K_{agg})$$

$$\left(\frac{dn}{dt}\right)_{coll} = f(\eta_{coll}, N_{frag}, K_{coll})$$

$$\left(\frac{dn}{dt}\right)_{HM} = f(\eta_{HM}, N_{frag}, LWC, K_{HM})$$



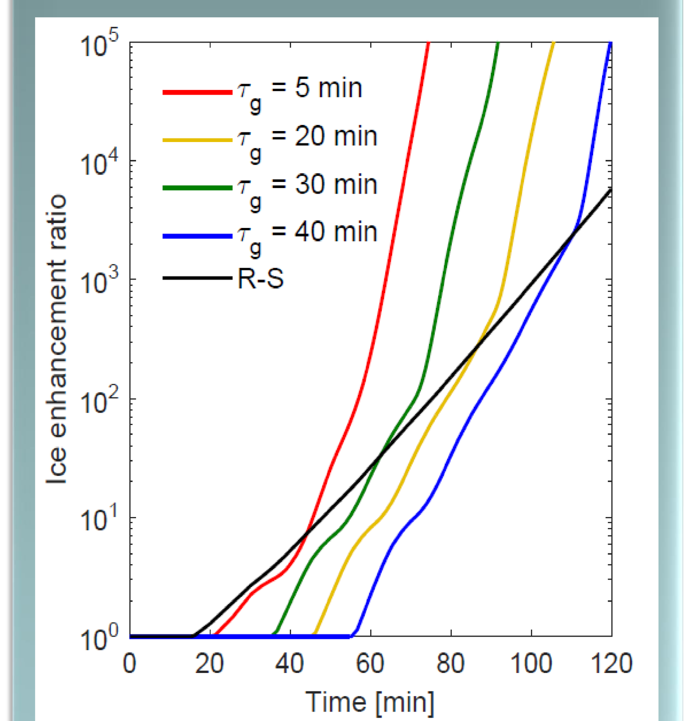


FIGURE 2
Ice enhancement ratio, i.e. ice number normalized by nucleated crystal number, for different time delays; reproduced from Yano and Phillips

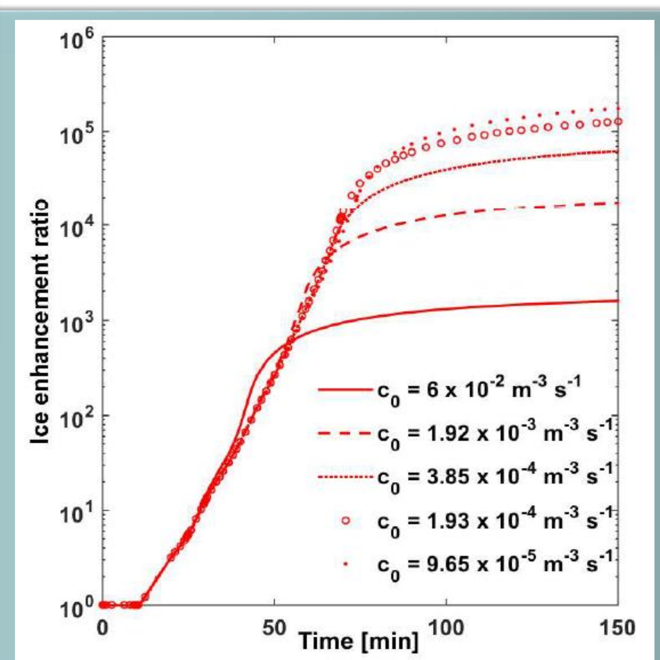


FIGURE 3
Ice enhancement after coupling number evolution to supersaturation in the parcel

(1) Ice crystal and graupel number evolution: modified from the time-delay formulation of *Yano and Phillips 2011*

(2) Parcel supersaturation evolution

PERTURBED PHYSICS ENSEMBLE

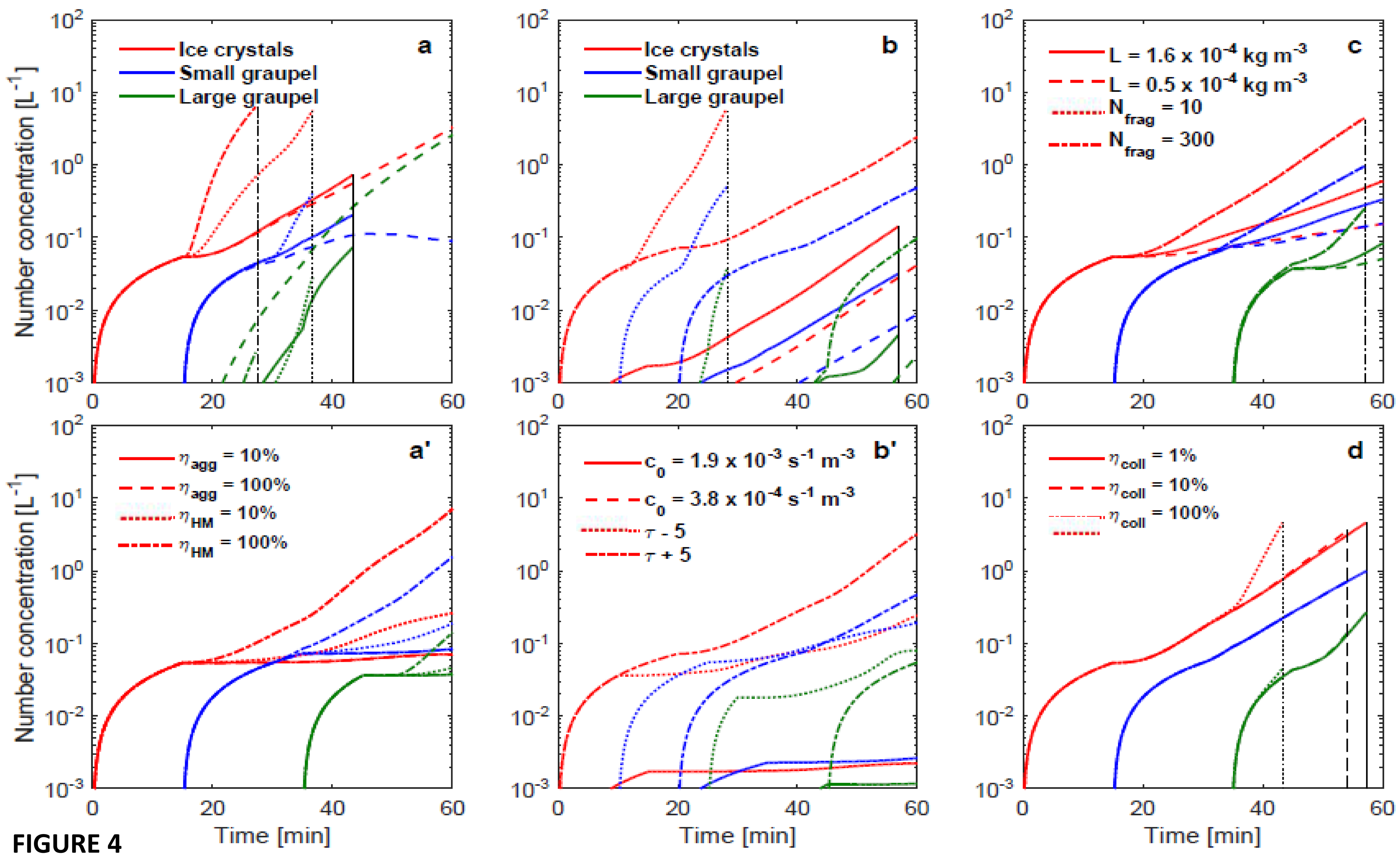


FIGURE 4
Ice crystal and graupel number concentrations over time in a mixed-phase parcel, changing five parameters as in Table 1.

a) SET 2 and spheroidal graupel: higher aggregation efficiency, η_{agg} → longer-lived cloud with lower n_i; higher rime-splintering efficiency, η_{HM} → shorter-lived cloud with higher n_i.
a') SET 2 and spherical graupel: higher η_{HM} → higher n_i; η_{agg} has almost no impact on n_i.
b) SET 4 and spheroidal graupel: lower production rates of primary ice, c_0 → significantly lower n_i. Shorter time delays, τ → significantly shorter-lived cloud.
b') SET 4 and spherical graupel: Shorter τ → higher n_i; Below a certain value, c_0 has little impact.
c) SET 3 and spheroidal graupel: Lower LWC → lower n_i; N_{frag} has a limited impact.
d) SET 1 and spheroidal graupel: Higher η_{coll} → shorter-lived cloud with higher n_i.

Table 1	SET 1	SET 2	SET 3	SET 4
η_{agg} η_{HM} η_{coll}	1% 1% 1, 10, 100%	10, 100% 10, 100% 1%	1% 1% 1%	1% 1% 1%
c_0	60 L^{-1} s^{-1}	60 L^{-1} s^{-1}	60 L^{-1} s^{-1}	1.9, 0.38 L^{-1} s^{-1}
LWC	0.5 g m^{-3}	0.5 g m^{-3}	0.14, 0.05 g m^{-3}	0.5 g m^{-3}
N_{frag}	100	100	10, 300	100
τ	15, 20, 10 min	15, 20, 10 min	15, 20, 10 min	10, 15, 5 min 20, 25, 15 min

CONCLUSIONS

- When graupel is assumed to be spheroidal, rime-splintering parameters, production of primary ice, and depositional growth times are the most influential parameters.
  → LWC and c_0 primarily affect ice number concentration. η_{HM} and τ primarily affect glaciation time.

- When graupel is assumed to be spherical, depositional growth times and rime-splintering efficiency are the most influential parameters.
  → τ primarily affects glaciation time. η_{HM} primary affects ice number concentration.

REFERENCES

[1] Chen and Lamb. *J. Atmos. Sci.* 51 (9), 1994. **[2]** Jensen and Harrington. *J. Atmos. Sci.* **72** (7) 2015. **[3]** Korolev and Mazin. *J. Atmos. Sci.* **60** (24) 2003. **[4]** Yano and Phillips. *J. Atmos. Sci.* **68** (2) 2011.