Long lifetime ice particles in mixed-phase stratiform clouds

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1. Background

- Our previous study shows that a uniform volume source of ice nucleation in a mixed-phase stratiform cloud will lead to a 2.5 power law relationship between ice water content and ice number concentration.[1,2]
- However, our minimalist model can't explain the existence of large ice particles, which are found in both large eddy simulation and observational results.[3,4]

    Possible explanations:
    1) Ice particles grow faster than we expected. Shape factor? Density effect?
    2) Ice particles stay longer than we expected. Quasi-steady growth? Recycling?[5]

2. Method

Continuous seeding

- 81920 ice particles with 10 μm initial radius are seeded uniformly within the liquid cloud layer between 600 m and 800 m every 8 s, with 50 m horizontal separation and 10 m vertical separation.
- The growth and trajectory of each ice particle are calculated within time-dependent field from a LES cloud model.

Result: Total number of ice particles in the cloud monotonically increases over the full 1.5 simulated hours. (no steady state reached)

Seeding at beginning

- If we seed ice particles uniformly within the cloud only at the beginning of the simulation, how does the fraction of those ice particles in the mixed-phase cloud decay with time?

3. Long-lifetime ice particles in a 3-D Time-Dependent Field

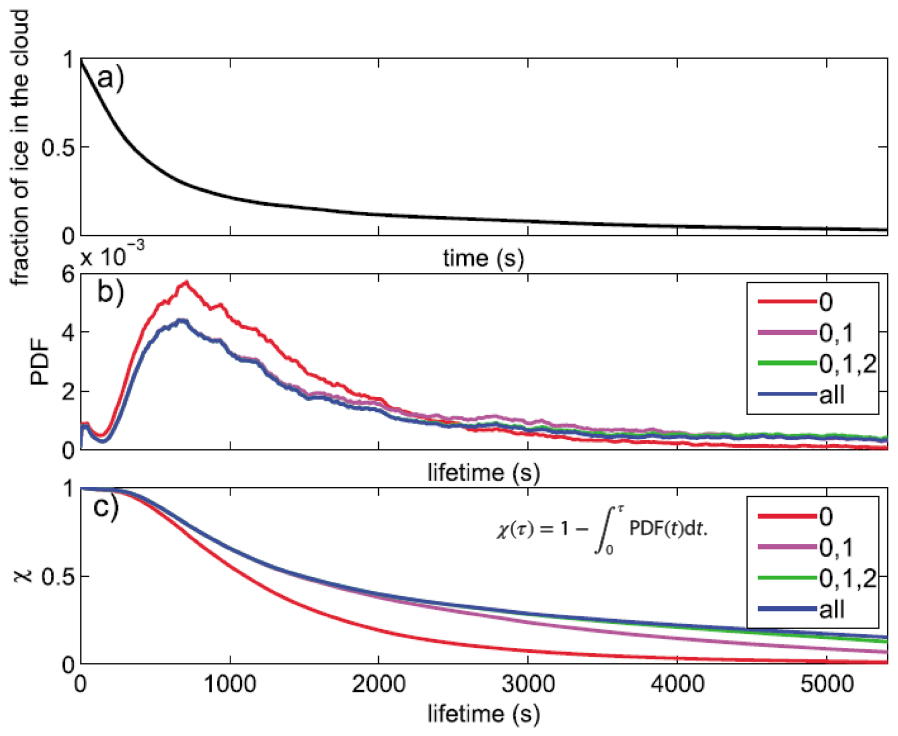

Fig.1. a) Fraction of ice particles remaining in the mixed-phase cloud (600–800 m layer). b) PDF of ice particle lifetimes. c) Ice particle survival fraction in the whole boundary layer (0–800 m) after a specific lifetime.

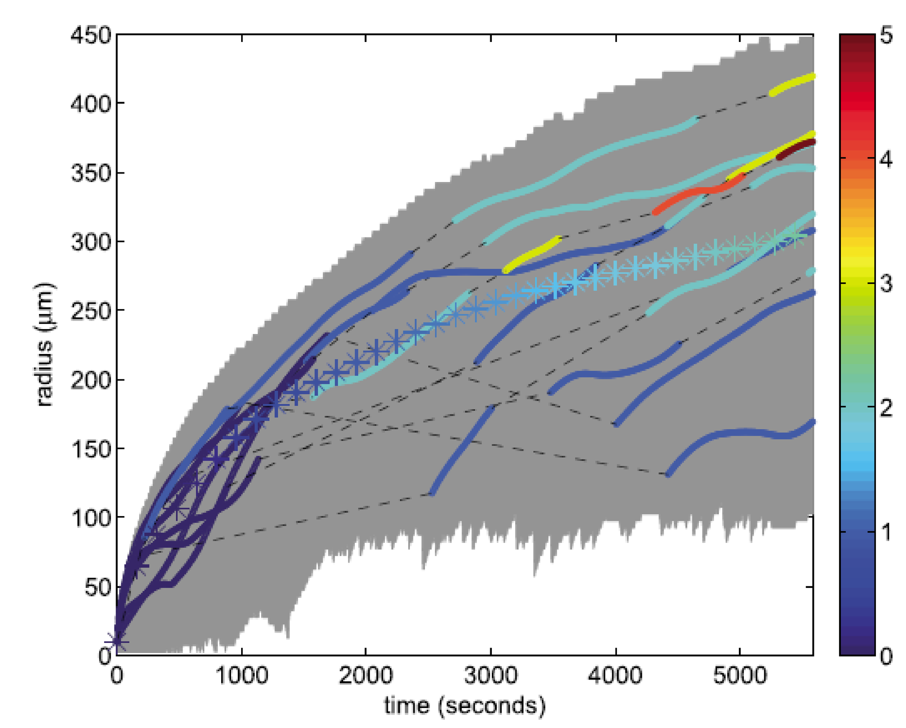

Fig.2. Radius versus time for 10 long-lifetime ice particles in the mixed-phase cloud (600-800m layer). The large star symbols represent the average ice particle radius over the whole mixed-phase cloud region, and its color represents the average recycling number at that time. The gray shading indicates full range of ice particle size distribution at each time.

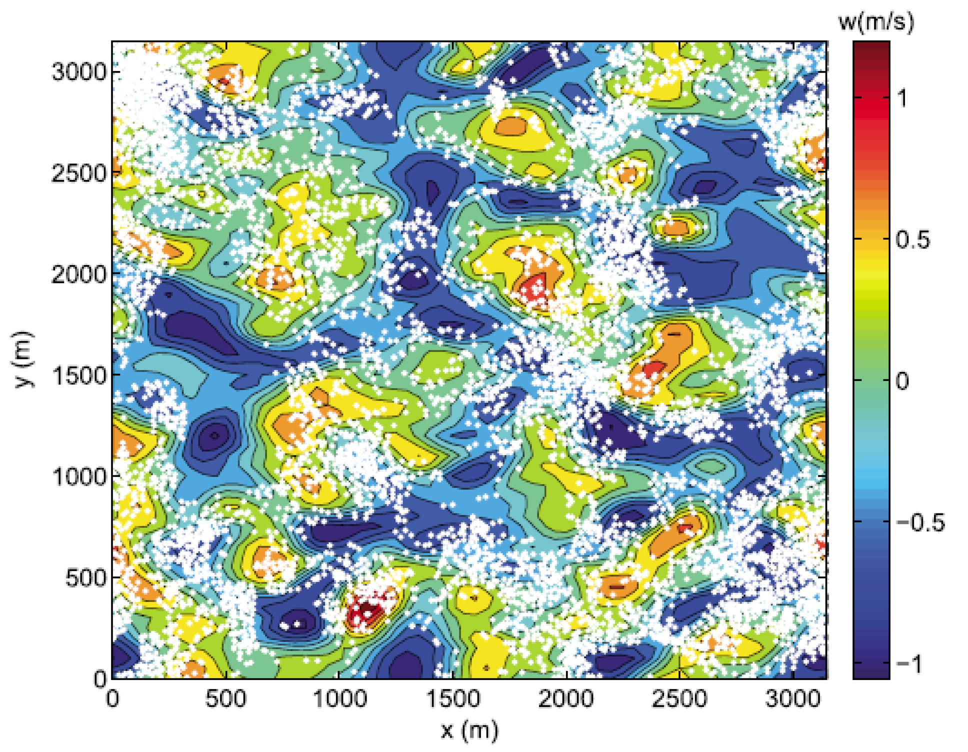

Fig.3. The vertical velocity at the time of seeding for long-lifetime ice particles. Background color represents the initial air vertical velocity. Note that seeding locations are clustered with a length scale similar to the large eddy length.

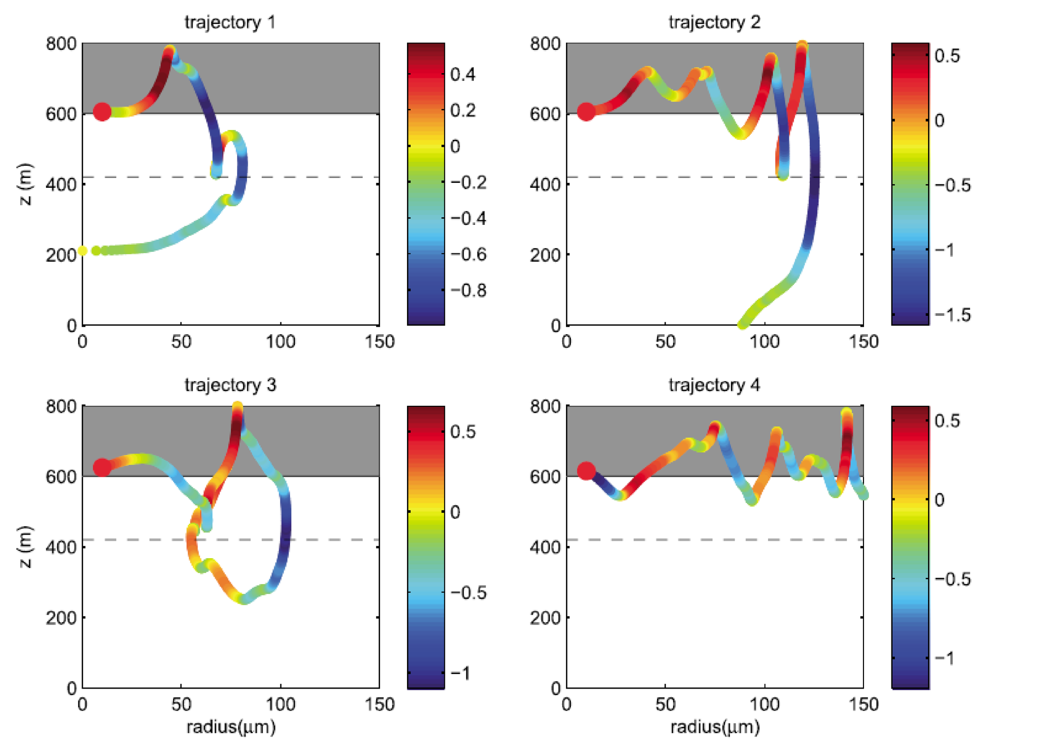

Fig.4. Height versus radius for four specific ice particles in the 3-D time-dependent field. Gray shading indicates the mixed-phase cloud region, and the colorbar represents the vertical velocity (in m s^{-1}). Red dots represent the initial seeding locations. Recycling events are observed.

4. Long-lifetime ice particles in a 2-D idealized velocity field

To investigate the origins of the long-lifetime ice particles, we seed ice particles in an idealized 2-D velocity field.

Coupled field

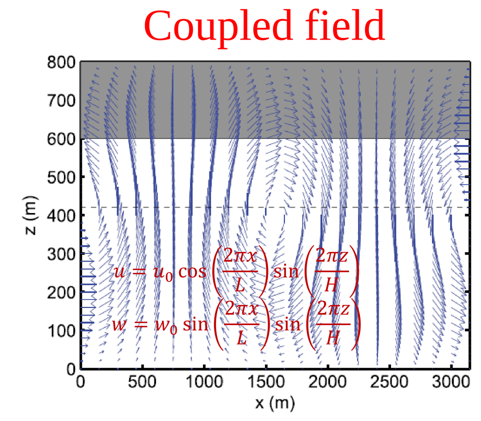

Fig.5. Velocity field in the idealized field with v_{max} = 2 m s^{-1}. The black dashed line (at 420 m) represents the level above which the environment is supersaturated with respect to ice, the shaded area denotes the mixed-phase region.

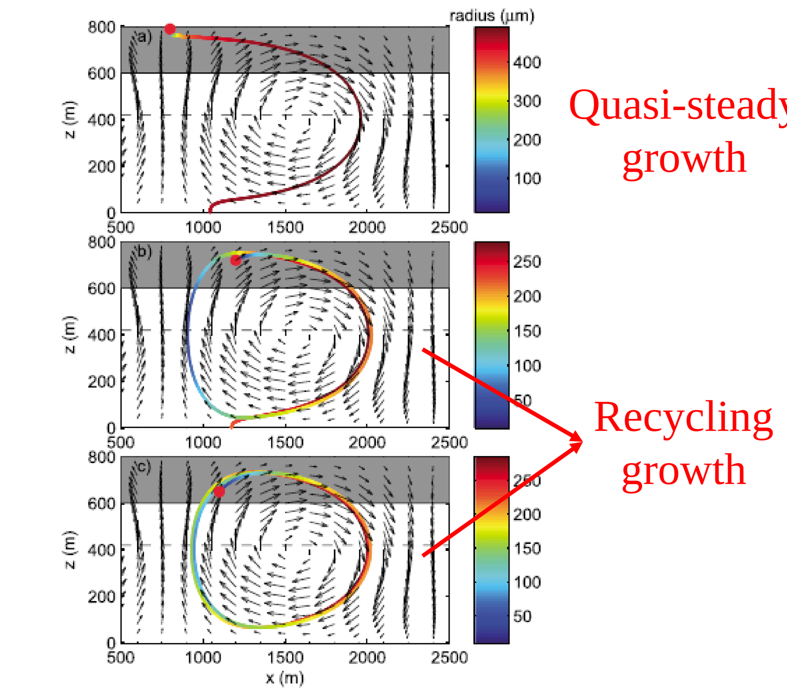

Fig.6. Trajectories of three different ice particles in an analytical velocity field with v_{max} = 2.0 m s^{-1}

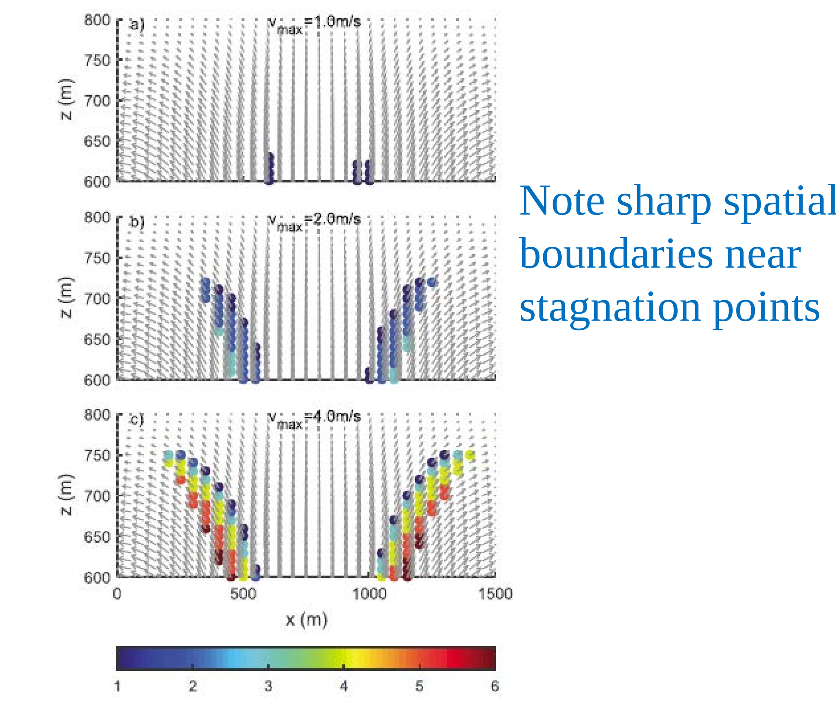

Fig.7. Seeding locations of the recycled particles when for three different v_{max} Color represents the recycling number.

5. Coupled versus decoupled boundary layer

Decoupled field

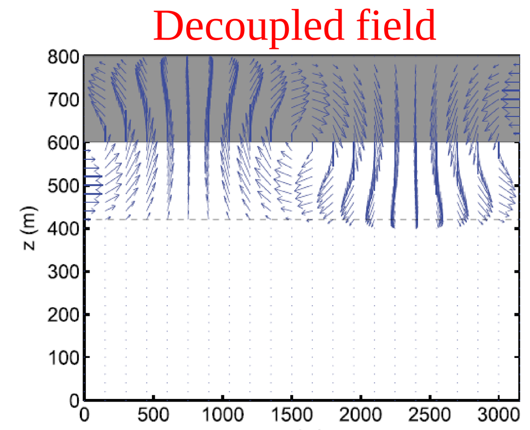

Fig.8. Velocity field when the eddy is decoupled from the surface.

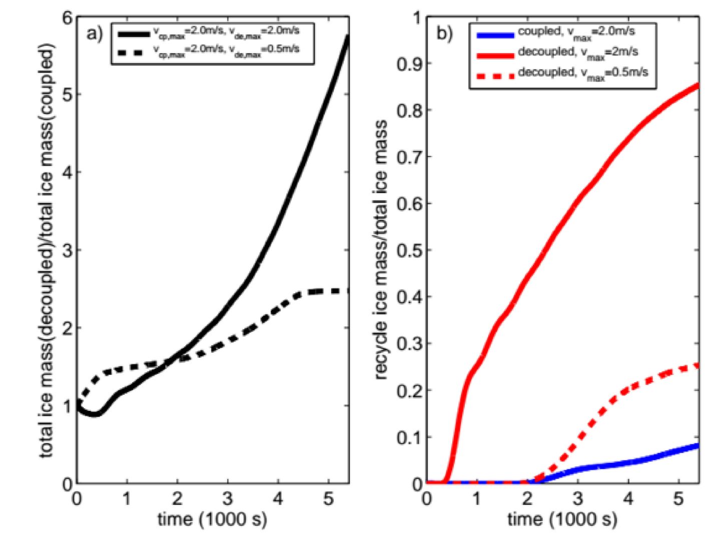

Fig.9. (a) Variation of total ice water mass ratio in the mixed-phase cloud (between 600 m and 800 m) over the 1.5 h simulation time for two cases with respect to the base case: coupled field with v_{max} = 2.0 ms^{-1}. (b) The mass fraction of recycling ice particles in the mixed-phase cloud for the coupled field with v_{max} = 2.0 ms^{-1}, the decoupled field with v_{max} = 2.0 ms^{-1} and decoupled field with v_{max} = 0.5 ms^{-1}. Larger ice water content in the decoupled field than that in the coupled field.

6. Take home message

1. Lagrangian ice particle tracking in mixed-phase clouds shows that more than 10% of ice particles have lifetimes longer than 1.5 h, much longer than the large eddy turnover time or the time for an ice crystal in still air to grow and fall out of the cloud layer.
2. Results form a 2-D idealized field show that there are two types of long-lifetime ice particles: quasi-steady and recycled growth.
    - For quasi-steady growth, ice particles are suspended in the updraft velocity region for a long time.
    - For recycled growth, ice particles are trapped in the large eddy structures, and whether ice particles grow or sublimate depends on the ice relative humidity profile within the boundary layer.
3. The relative contribution of the long-lifetime ice particles to the cloud mean ice water content depends on both the dynamic and thermodynamic properties of the mixing layer.

References

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Acknowledgments

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Ref.[2]

Ref.[5]