A Process Study of Mixed Phase Arctic Stratus and Associated Aerosol Eeffects

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with many thanks to the ISDAC team

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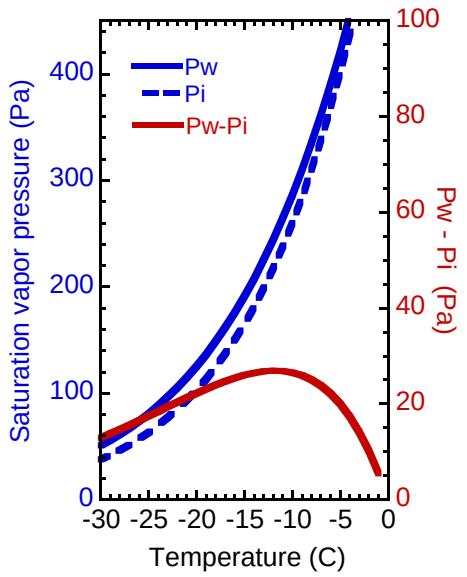
Liquid, ice, and vapor mixture is unstable:

Processes we know:

- Difference in saturation vapor pressure over ice and liquid

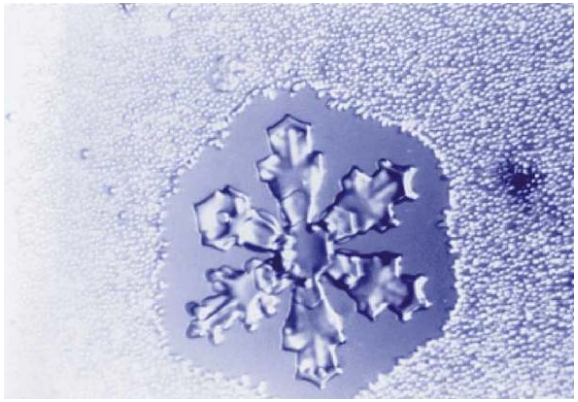


- Growth rate depends on saturation ratio (*S*) and particle concentration (N) and size (*r*)

$$\frac{dq_w}{dt} \sim (S_w - 1) \cdot \overline{N_w r_w} < 0 \quad \text{(liquid)}$$

$$\frac{dq_i}{dt} \sim (S_i - 1) \cdot \overline{N_i r_i} > 0 \quad \text{(ice)}$$

if $S_i < S < S_w$



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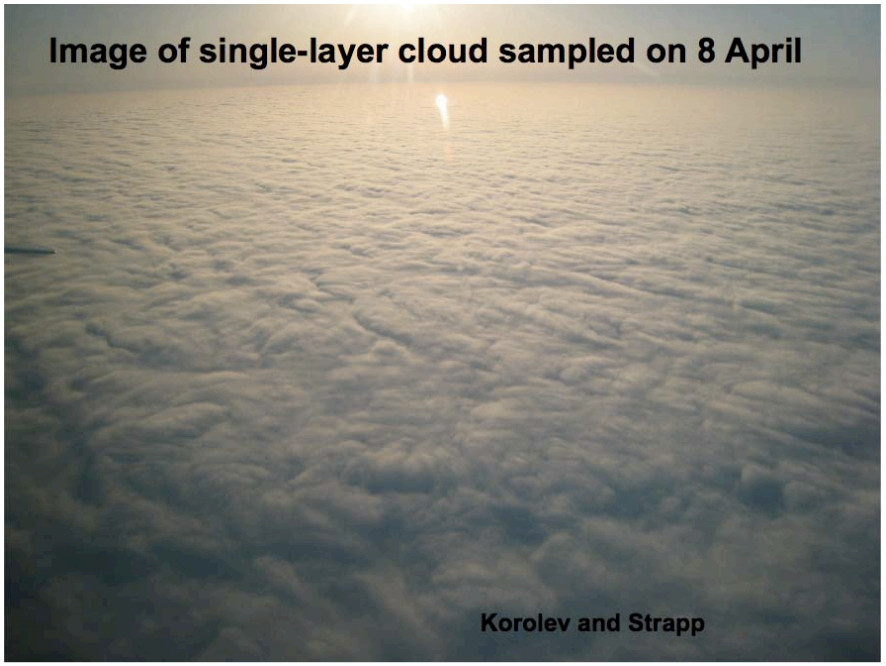
Wegener–Bergeron–Findeisen (WBF)

- Wegener (1911): “The vapour tension will adjust itself to a value in between the saturation values over ice and over water. The effect of this must then be, that condensation continuously will take place on the ice, whereas at the same time liquid water evaporates, and this process must go on until the liquid phase is entirely consumed.”

- “... within an admixture of these (ice and liquid) particles, and provided that the total water content were sufficiently high, the ice crystals would gain mass by vapor deposition at the expense of the liquid drops that would lose their mass by evaporation.”

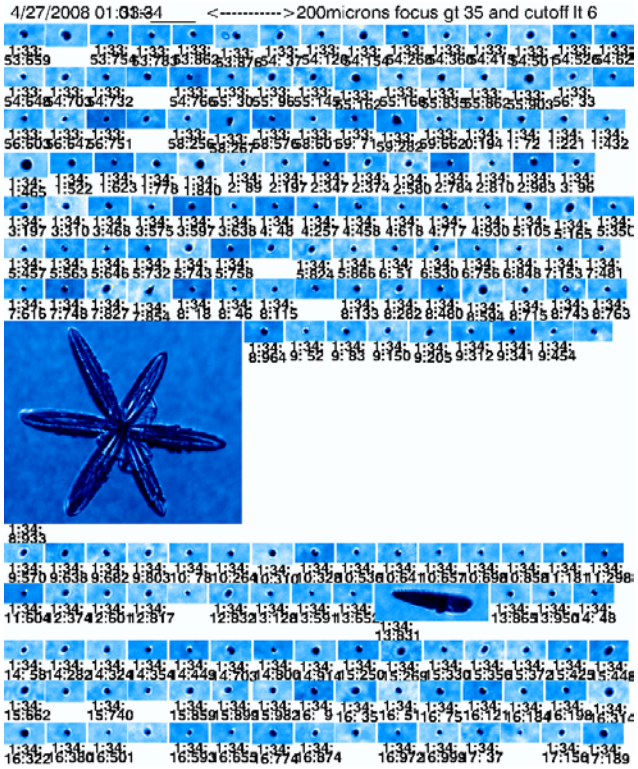
Glossary of Meteorology, 2nd ed. AMS, Glickman, T., Ed., 2000.

… and yet



- with both liquid and ice particles are clearly present

- Clouds extend for 100's of miles and persist for hours and days



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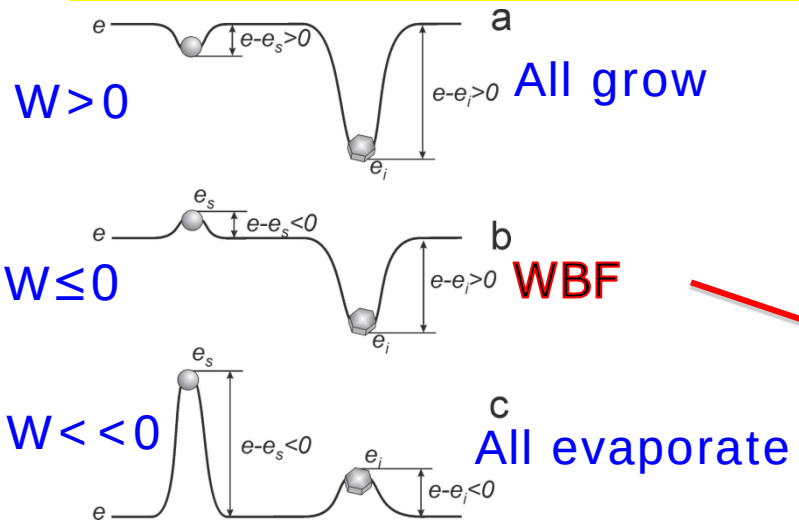
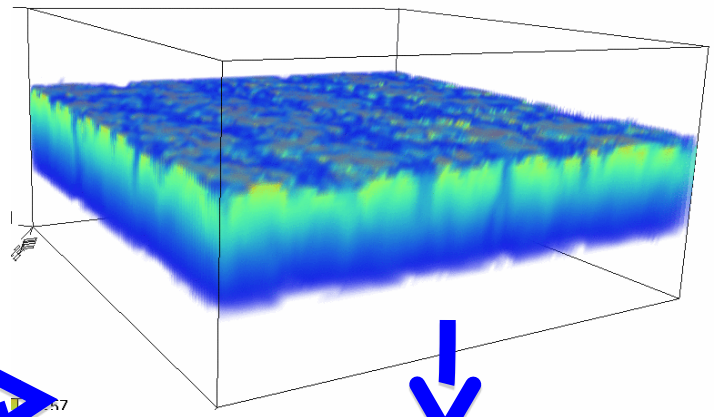
Dynamics is important

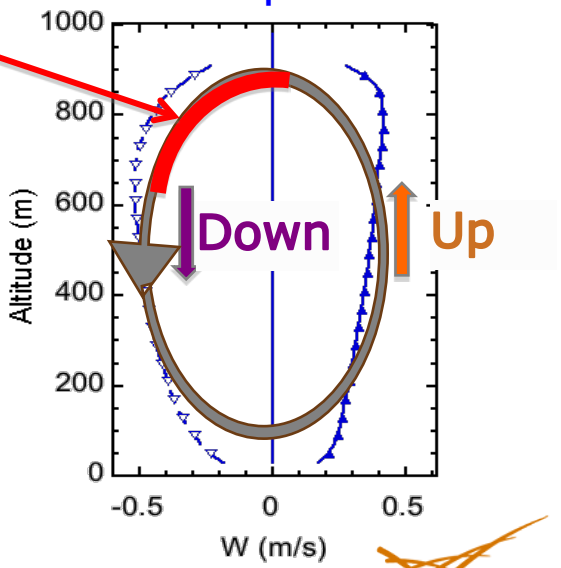
WBF does not operate everywhere



Korolev (2007)



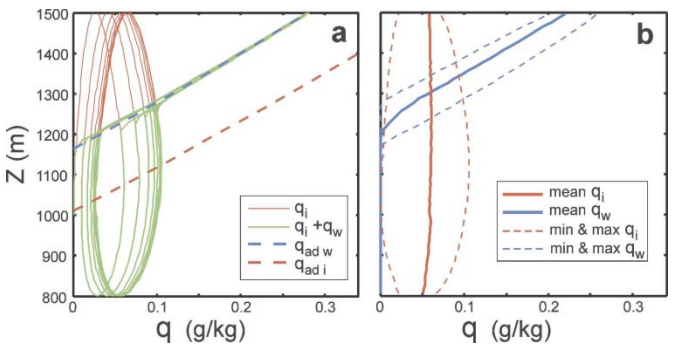
Mean profiles



Persistent mixed-phase cloud in a box model:

Prescribed motions

No sedimentation



Korolev & Field (2008)

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What is the role of WBF process ?

Do we need to resolve the updraft - downdraft difference

in diffusional growth of ice?

(*More troubles for global models ?!*)

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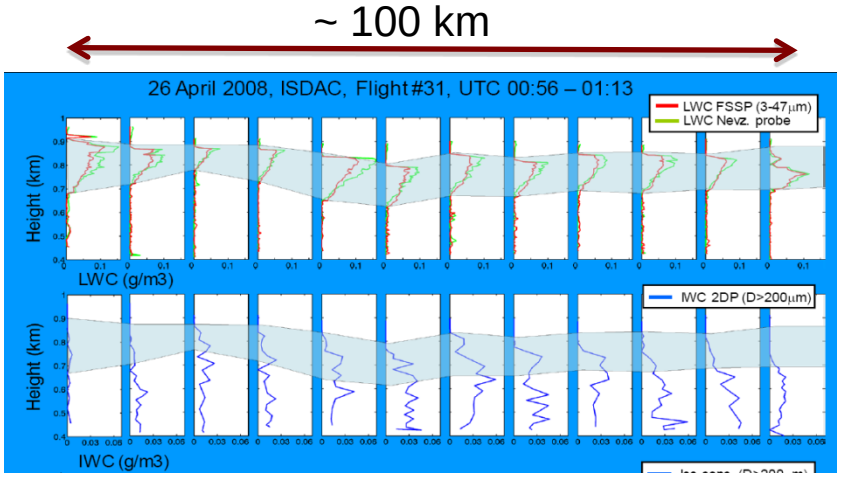
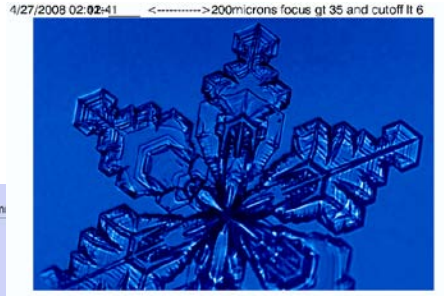
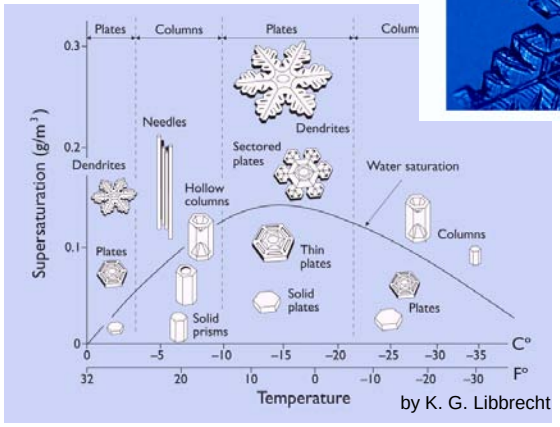
ISDAC Flight 31 – A modeler's dream case

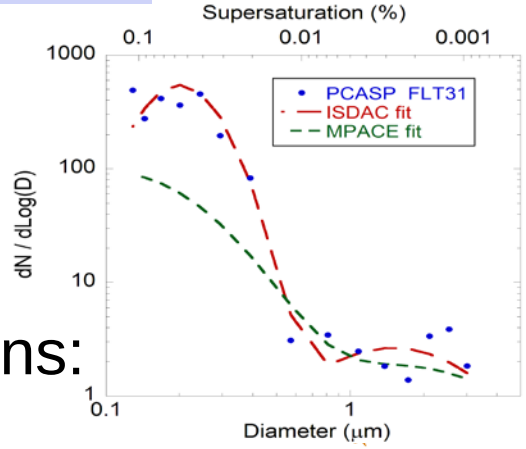
- Steady state cloud







- Dominant diffusional growth, little collision/coalescence, aggregation, or riming
- Dendrites, dendrites, dendrites
- Uniform droplet and ice particle concentrations:
  - nearly all CCN activate
  - ... and ice nuclei ? … Constrain ice nucleation for now.



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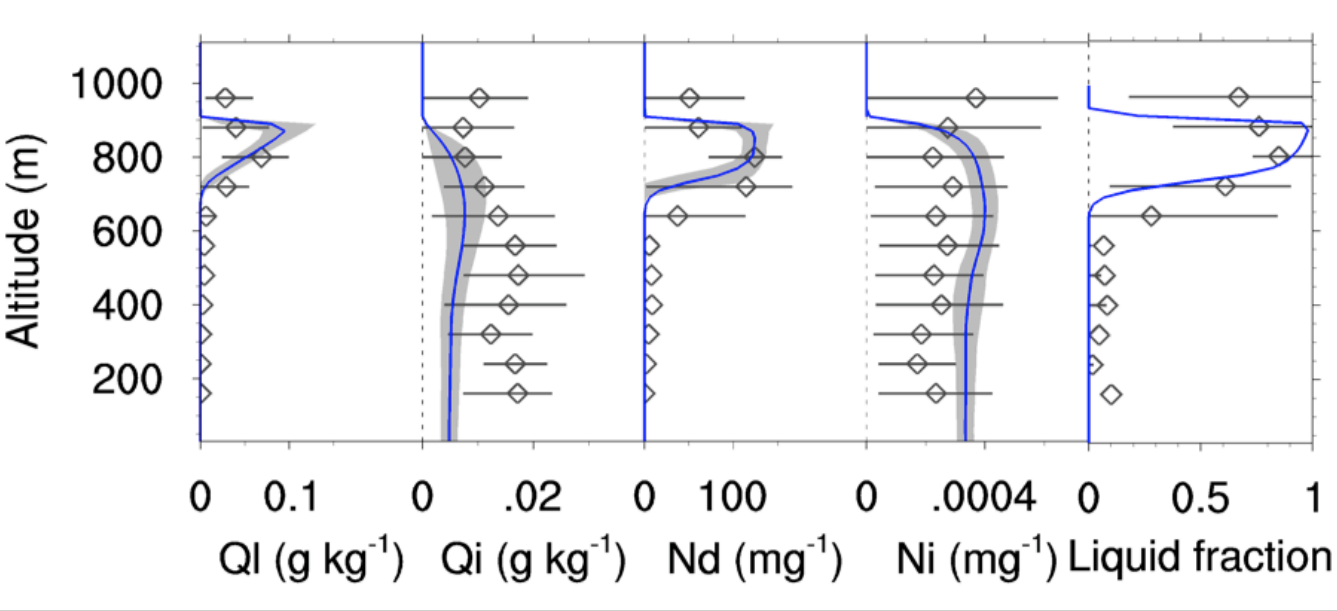
Observed and simulated cloud profiles

Quasi steady state mixed-phase cloud is simulated with a structure similar to the observed one



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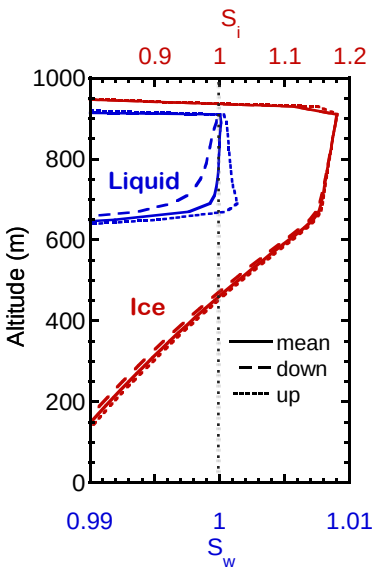
Diffusional growth of liquid and ice

$$\frac{dq_w}{dt} \sim (S_w - 1) \cdot \overline{N_w r_w}$$

$$\frac{dq_i}{dt} \sim (S_i - 1) \cdot \overline{N_i r_i}$$



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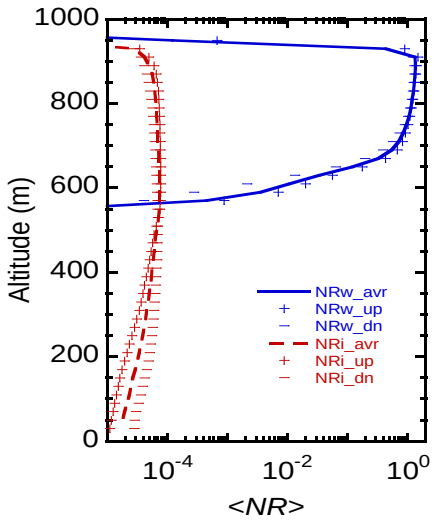

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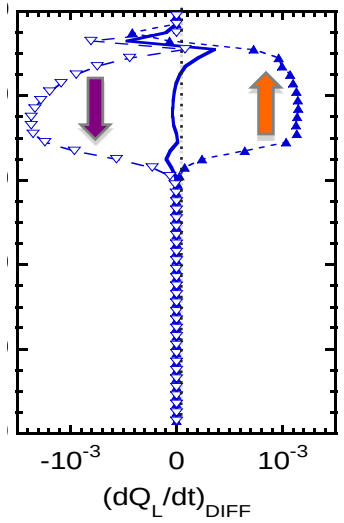
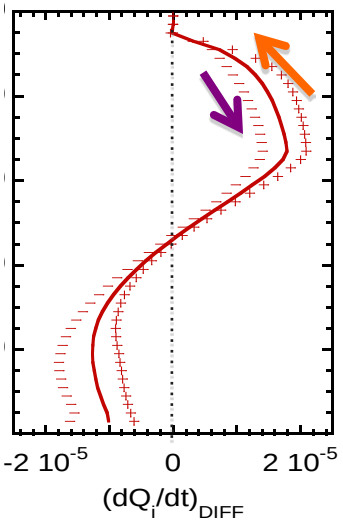
Liquid



Ice



Growth rates

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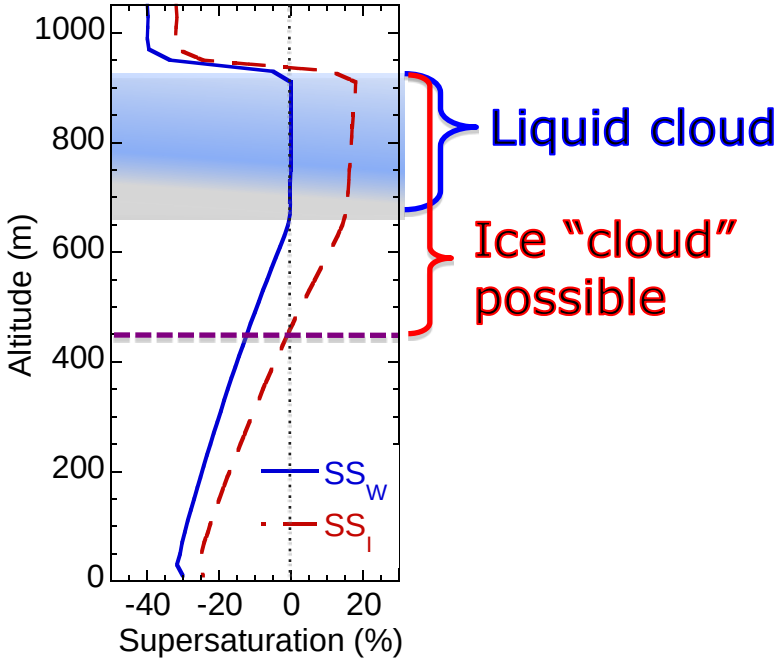
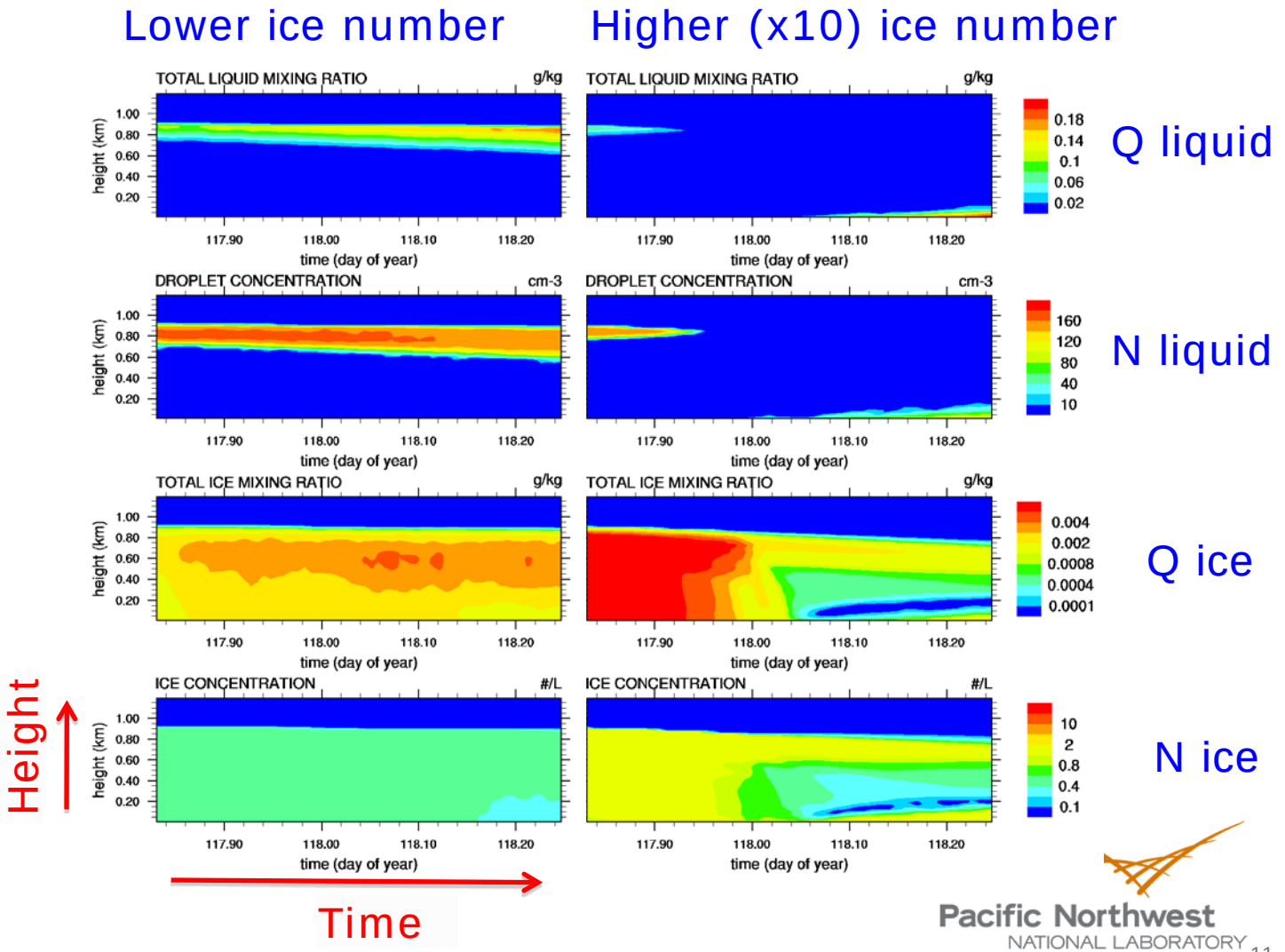
Do ice and liquid "feel" each other through the vapor interaction?

In this shallow stable mixed-phase cloud

- Ice presence has insignificant effect on liquid
- Ice growth is slowed by liquid because of $RH_w \approx 100\%$ limit



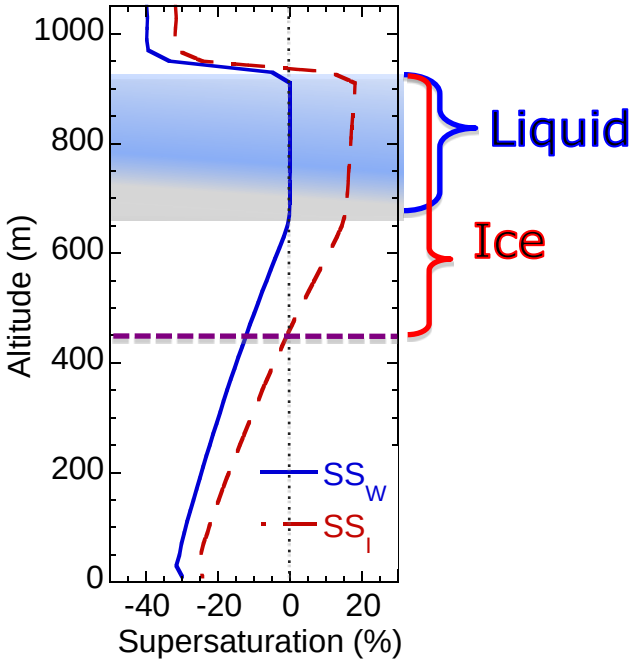
Cloud structure is very sensitive to ice concentration



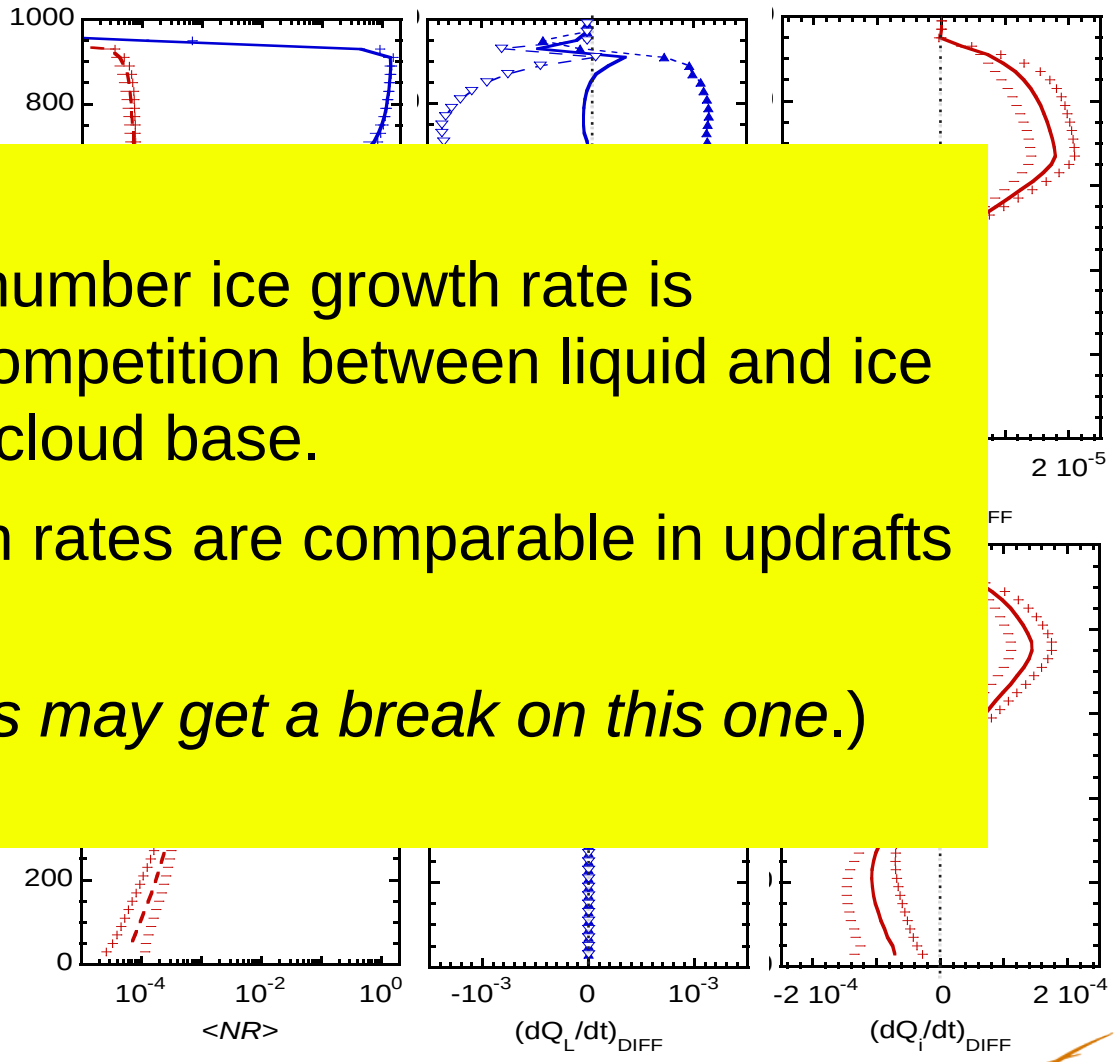
“Aerosol” effects

- Why sensitivity to ice number can be greater than to droplet number ?

Liquid cloud	Ice cloud
Growth is vapor limited	Growth is ice surface limited
Droplet number ↑ ↓	Ice number ↑ ↓
Water content (liquid) ≈ Particle size ↓	Water content (ice) ↑ Particle size ≈



Is WBF destroying the cloud ?



With higher ice number ice growth rate is increased and competition between liquid and ice begins near the cloud base.

… but ice growth rates are comparable in updrafts and downdrafts.

(*Global modelers may get a break on this one*.)

Conclusion

Do we need to resolve the updraft - downdraft difference in diffusional growth of ice?

Not necessarily

Cloud Physics

Not all questions about nucleation, growth, and precipitation of water particles are yet answered.

Henry G. Houghton

6 Feb 1959