Aerosol effect on clouds III

Immediate feedbacks of changes in the droplet size distribution in the cloud scale:

(1) Cloud's optical properties
(2) Droplet collection processes
(3) Droplets Mobility
(4) Diffusion processes efficiency
(5) Twilight – mixing – entrainment

All of the above link cloud microphysics to dynamics

Cloud Core and Margins

Cloud Core and Margins

Cloud Core and Margins

By 3 measures

$$RH$$

$$B = g \cdot \left(\frac{\theta'}{\theta_o} + 0.61 q_v' - LWC\right) \qquad (1),$$

$$\frac{dS}{dt} = Q_1 w - Q_2 \frac{dLWC}{dt} \qquad (2),$$

Heiblum et al, 2019

Cloud Core and Margins

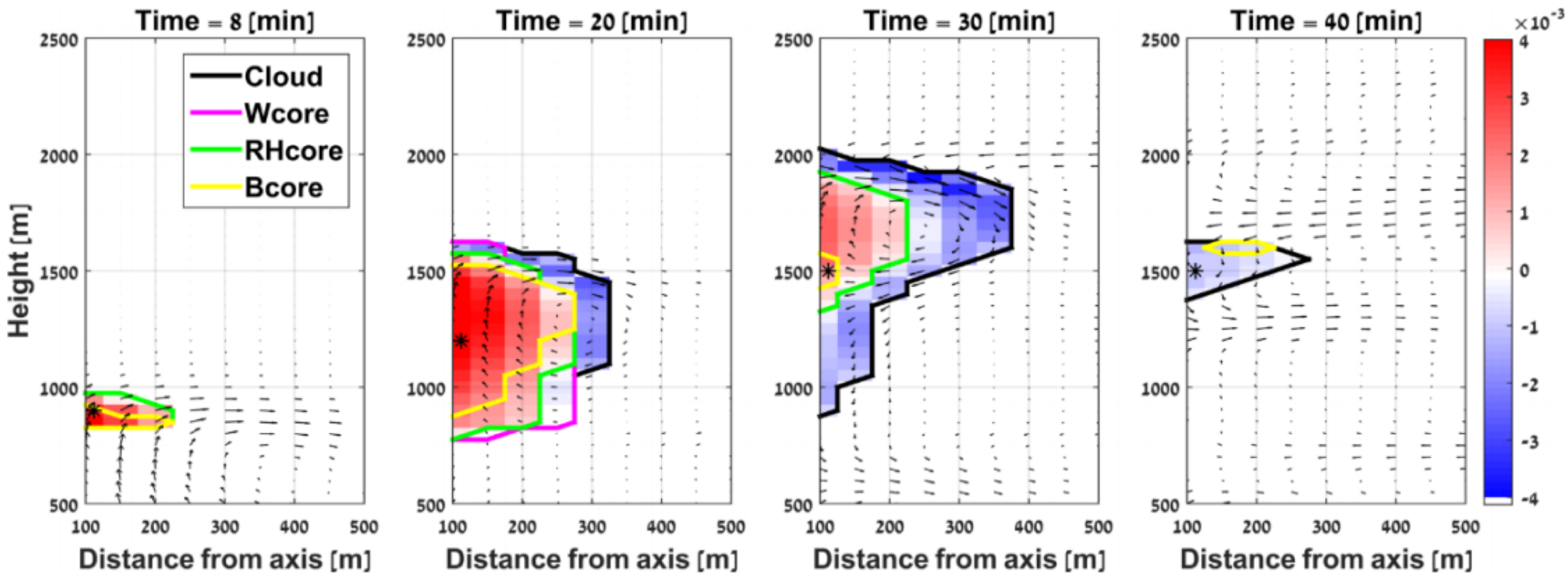

Figure 2. Four vertical cross-sections (at t=10, 20, 30, 40 minutes) during the single cloud simulation. Y-axis represents height [m] and X-axis represents the distance from the axis [m]. The black, magenta, green and yellow lines represent the cloud, W_{core}, RH_{core} and B_{core}, respectively. The black arrows represent the wind, the background represents the condensation (red) and evaporation rate (blue) [g kg^{-1} s^{-1}], and the black asterisks indicate the vertical location of the cloud centroid. Note that in some cases the lines indicating core boundaries overlap (mainly seen for RH and W cores).

Heiblum et al, 2019

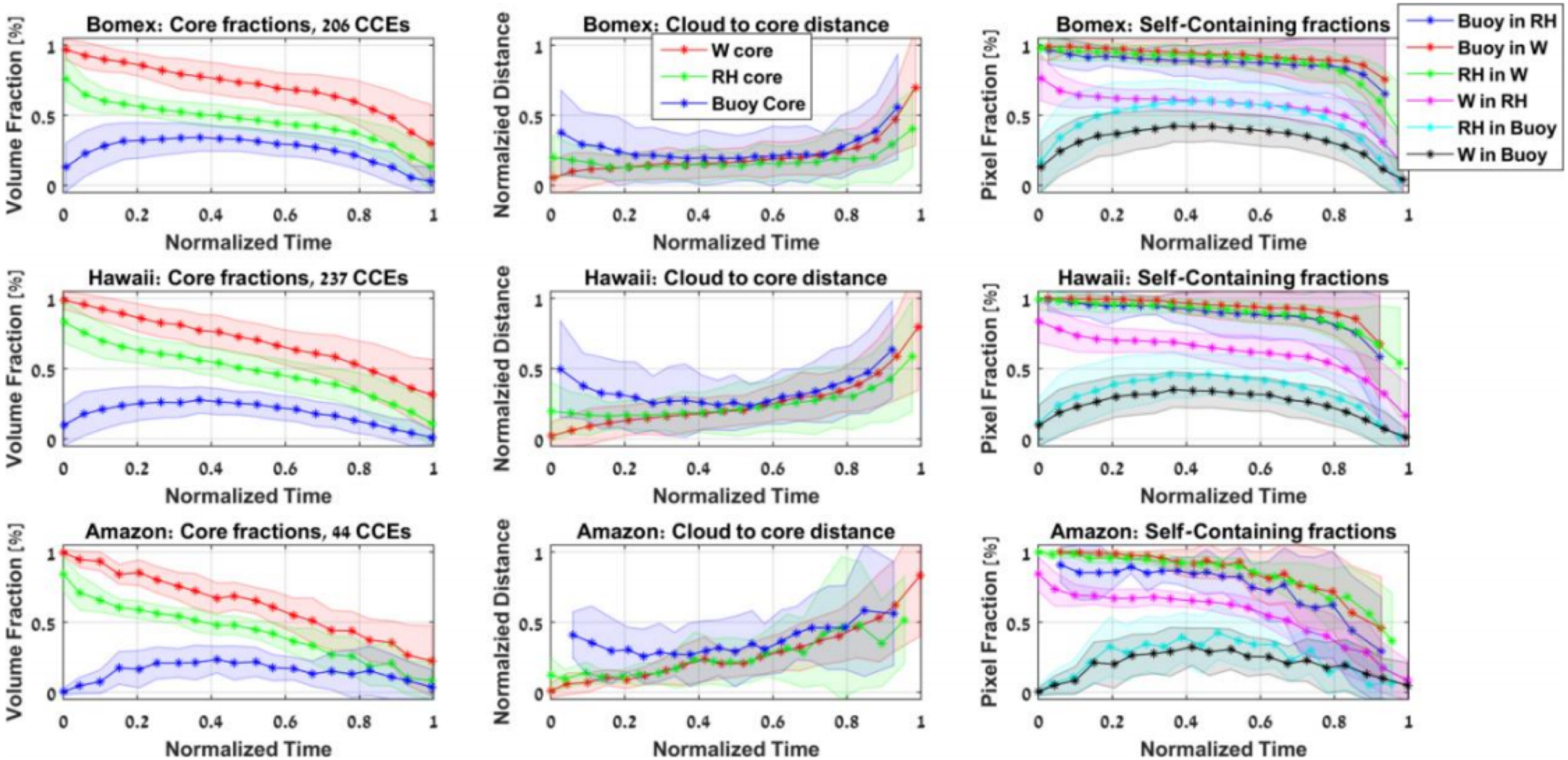

Figure 7. Normalized time (τ) series of CCE averaged core fractions for the BOMEX (upper row), Hawaii (middle row), and Amazon (bottom row) simulations. Both core volume fractions (left column), normalized distances between cloud and core centroid

Heiblum et al, 2019

How will aerosol concentration affect such partition?

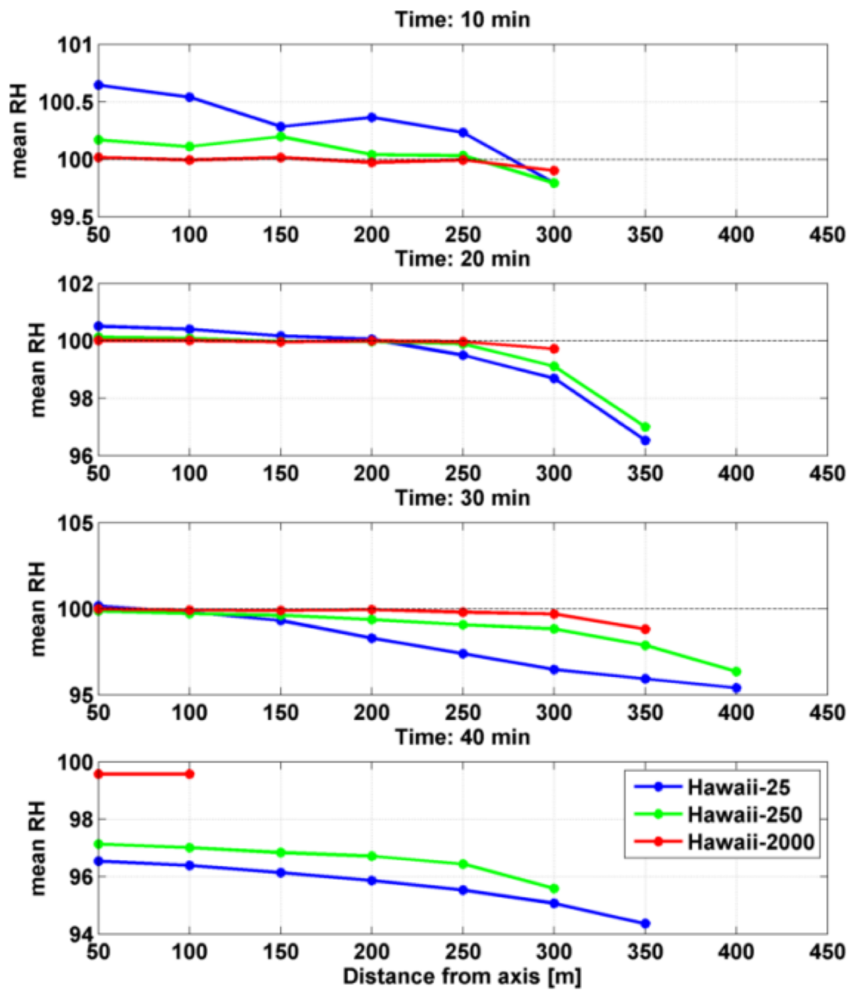

Figure 4. Four temporal snapshots (see panel titles for times) of RH [%] horizontal cross-sections. Panels include the results of different aerosol concentrations (see legend). Cross-sections are obtained by taking the mean RH of all vertical levels for each horizontal distance from the cloud center axis.

How will aerosol concentration affect such partition?

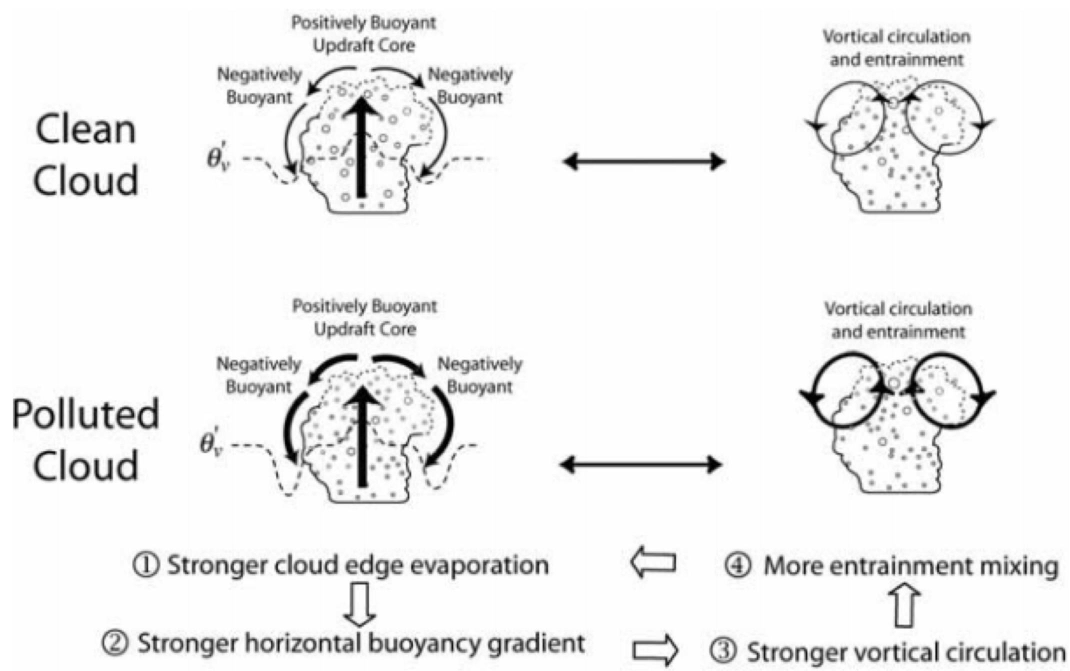

Figure 1. Schematic of the evaporation-entrainment feedback mechanism. (top) Clean and (bottom) polluted clouds are represented. The basic circulation features of small cumulus clouds are shown, indicating positively buoyant updrafts in the core of clouds and a shell of negatively buoyant air at cloud edges. θ_v', a measure of buoyancy, is represented by the dashed curves. At the edges of polluted clouds, evaporation is more rapid than in clean clouds, resulting in larger negative θ_v' and hence stronger horizontal buoyancy gradients. This in turn results in stronger vortical circulation in polluted clouds which leads to higher entrainment rates, thereby increasing evaporation and thus completing the feedback mechanism. We note that other positive and negative feedbacks within the cloud may dampen or amplify the feedback depicted here.

So if most of the cloud is sub-saturated, what is a cloud?
What is the cloud boundary?
What is the cloud fraction?

On sequence of:

Core -> Margins -> Entrainment and mixing -> Twilight

A short intermezzo on mixed and cold microphysics

So far we talked about warm (phase) clouds.

When ice and water hydrometeors coexist -> mixed phase cloud

Ice only -> cold clouds (cirrus, anvils, polar)

A short intermezzo on mixed and cold microphysics

But the level of complexity is much higher; and so our level of understanding is inversely proportion to the complexity.

Why mixed on cold clouds processes are more complex?

(I) It has more thermodynamic pathways:

- vapor to/from liquid - condensation and evaporation
- liquid to/from ice - freezing and melting
- vapor to/from ice - deposition and sublimation

Ice saturation vapor is lower than water.

This imply preferable diffusion toward ice particles

It allows conditions supersaturation over ice when it is subsaturation over water

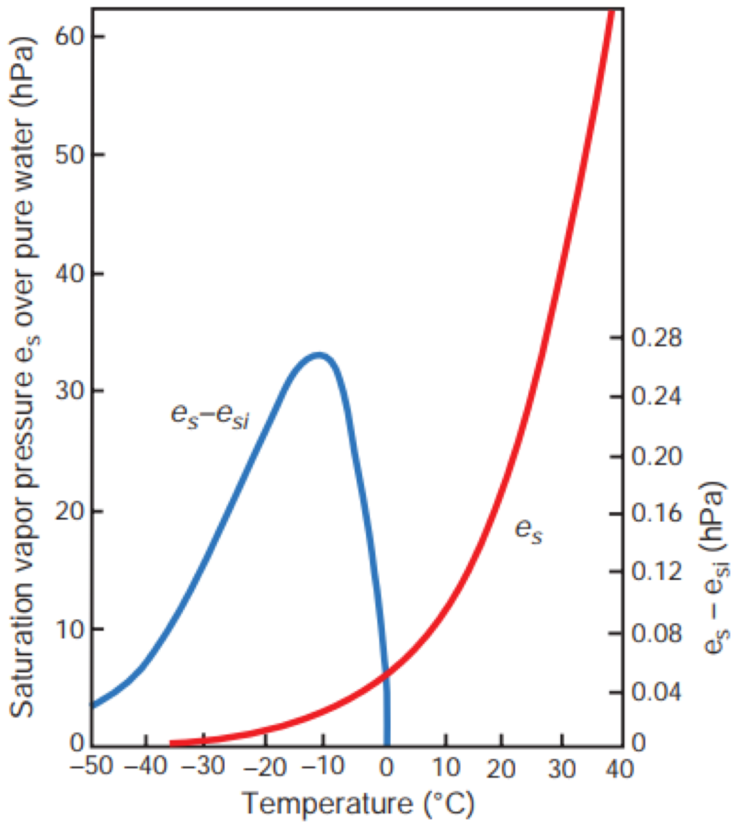

Fig. 3.9 Variations with temperature of the saturation (i.e., equilibrium) vapor pressure e_s over a plane surface of pure water (red line, scale at left) and the difference between e_s and the saturation vapor pressure over a plane surface of ice e_{si} (blue line, scale at right).

Wallace and Hobbs

Ice saturation vapor is lower than water.

This imply preferable diffusion toward ice particles

It allows conditions supersaturation over ice when it is subsaturation over water

It also allows for cases for which ice consume the ambient S such that it goes below the critical S for water. In such case ice will grow on the expense of water.

Wegener-Bergeron-Findeizen (WBF)

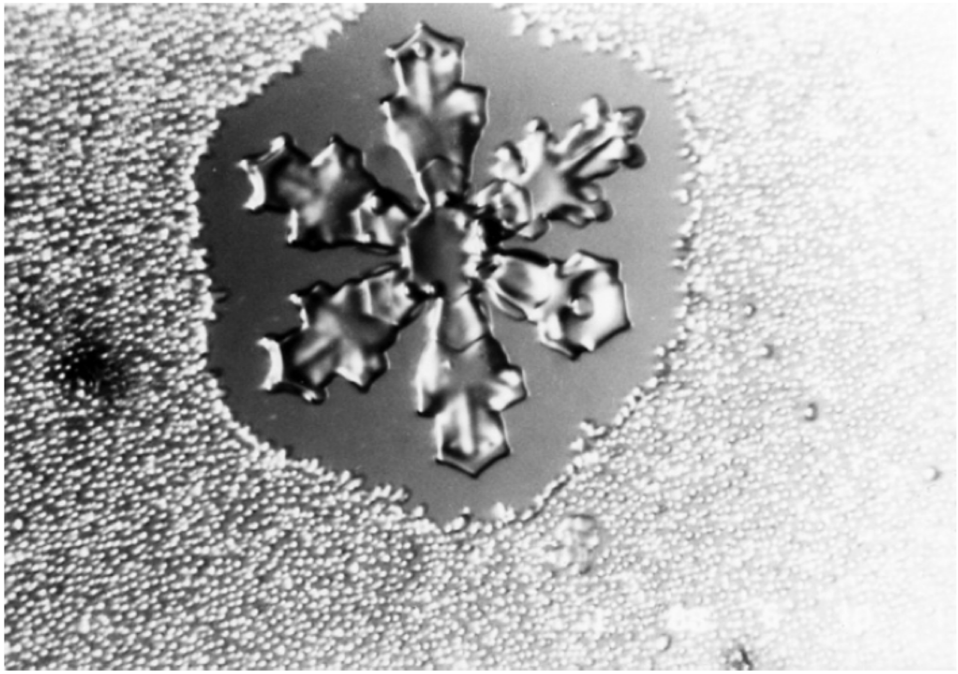

Fig. 6.36 Laboratory demonstration of the growth of an ice crystal at the expense of surrounding supercooled water drops. [Photograph courtesy of Richard L. Pitter.]

Wallace and Hobbs

A short intermezzo on mixed and cold microphysics

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(II) Many types of ice formation mechanisms

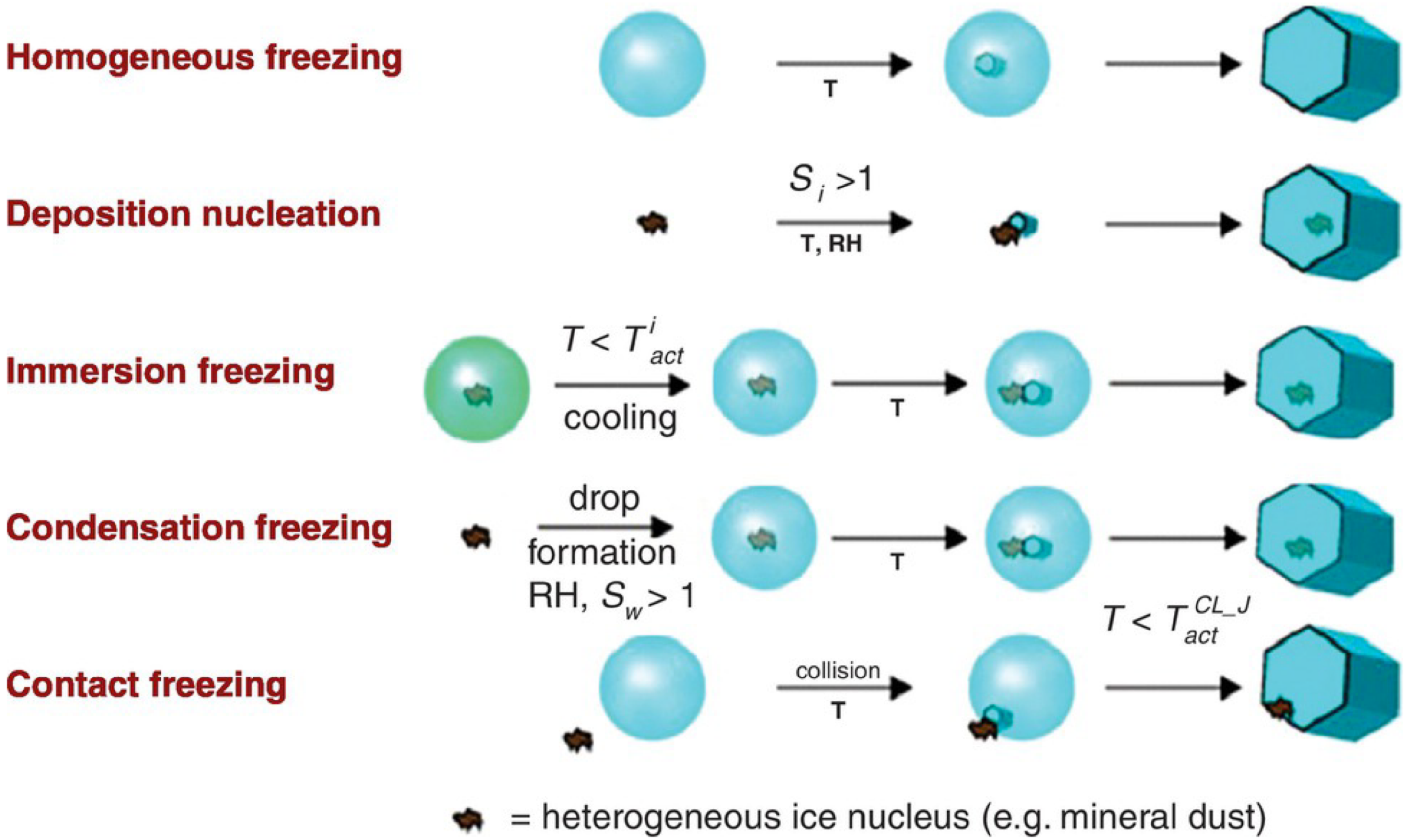
A short intermezzo on mixed and cold microphysics

When passing the T=0 ℃ -> supercooled droplets

Similarly to the gas to water transition, homogenous nucleation will require much lower temperatures ~ -35 to -40 ℃ (depends also on the droplet size)
-> Homogenous nucleation occurs high in the atmosphere.

Heterogeneous nucleation -> freezing in much higher temperatures. Depends heavily on the Ice Nuclei (IN) properties.

Khain, A., & Pinsky, M. (2018). Microphysical Processes in Ice and Mixed-Phase Clouds. From Vali, 1999, with changes.



Deposition nucleation takes place during condensation of water vapor molecules onto the surface of IN. It is difficult to distinguish deposition nucleation from condensational freezing, so these modes are often considered in parameterization schemes as a single process.

Condensation freezing takes place when water vapor condenses on the surface of a particle that serves as IN, when the particle is already covered with some water film. This mode is efficient when there is supersaturation with respect to water. Freezing of haze particles, condensational freezing, and immersion freezing, which are thermodynamically undistinguishable, belong to the *deliquescent-heterogeneous* freezing (DHF) mode (Khvorostyanov and Curry, 2005a).

Contact freezing takes place when drops contact IN due to collisions. Drop freezing by contact nucleation can take place at temperatures substantially higher than those in the deposition-nucleation mode.

Ice multiplication – Secondary ice processes

Secondary ice fragments will serve as ideal IN. If they are small we can call them IN. Larger can be viewed as ice particle that can collect or being collected …

Eventually most of the freezing can be secondary – by contact.

In mixed phase clouds the transition to stochastic processes is likely to be faster.

MENU
nature
International journal of science

Letter | Published: 03 May 1974

Production of secondary ice particles during the riming process

J. HALLETT & S. C. MOSSOP

Nature **249**, 26–28 (1974) | Download Citation

Abstract

ICE crystals play a vital part in the formation of precipitation, particularly outside the tropics, so it is important to know the concentrations of ice particles in natural clouds and to attempt to predict them from measurements made, for example in laboratory cloud chambers, at the same temperature.

secondary ice production (SIP)

Secondary Ice Production: Current State of the Science and Recommendations for the Future

P. R. FIELD,[a,b] R. P. LAWSON,[c] P. R. A. BROWN,[a] G. LLOYD,[d] C. WESTBROOK,[e] D. MOISSEEV,[f]
A. MILTENBERGER,[b] A. NENES,[g] A. BLYTH,[b] T. CHOULARTON,[d] P. CONNOLLY,[d] J. BUEHL,[h] J. CROSIER,[d]
Z. CUI,[b] C. DEARDEN,[d] P. DEMOTT,[i] A. FLOSSMANN,[j] A. HEYMSFIELD,[k] Y. HUANG,[b] H. KALESSE,[h]
Z. A. KANJI,[l] A. KOROLEV,[m] A. KIRCHGAESSNER,[n] S. LASHER-TRAPP,[o] T. LEISNER, G. MCFARQUHAR,[o]
V. PHILLIPS,[p] J. STITH,[q] AND S. SULLIVAN[r]

ABSTRACT

Measured ice crystal concentrations in natural clouds at modest supercooling (temperature ~>−10°C) are often orders of magnitude greater than the number concentration of primary ice nucleating particles. Therefore, it has long been proposed that a secondary ice production process must exist that is able to rapidly enhance the number concentration of the ice population following initial primary ice nucleation events. Secondary ice production is important for the prediction of ice crystal concentration and the subsequent evolution of some types of clouds, but the physical basis of the process is not understood and the production rates are not well constrained. In November 2015 an international workshop was held to discuss the current state of the science and future work to constrain and improve our understanding of secondary ice production processes. Examples and recommendations for in situ observations, remote sensing, laboratory investigations, and modeling approaches are presented.

secondary ice production (SIP)

Secondary Ice Production: Current State of the Science and Recommendations for the Future

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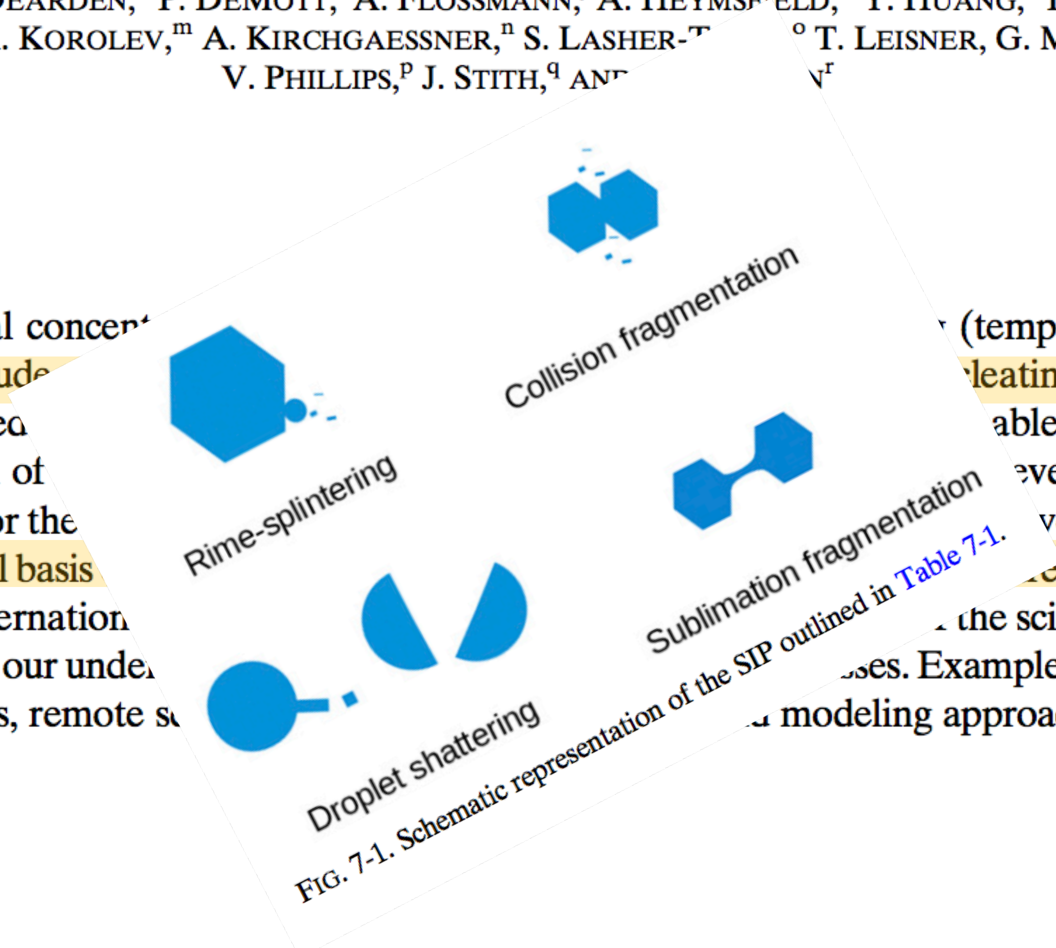

FIG. 7-1. Schematic representation of the SIP outlined in Table 7-1.

Measured ice crystal concen… (temperature ~>−10°C) are often orders of magnitude … …leating particles. Therefore, it has long been proposed … able to rapidly enhance the number concentration of … events. Secondary ice production is important for the … volution of some types of clouds, but the physical basis … not well constrained. In November 2015 an internation… the science and future work to constrain and improve our unde… …ses. Examples and recommendations for in situ observations, remote s… modeling approaches are presented.

A short intermezzo on mixed and cold microphysics

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(I) It has more thermodynamic pathways:

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- vapor to/from ice - deposition and sublimation

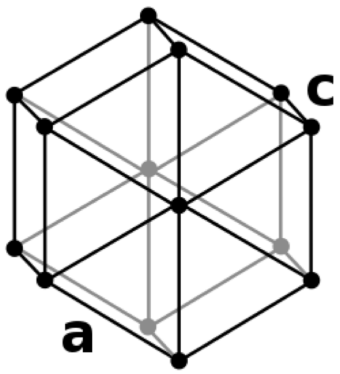
(II) Many types of ice formation mechanisms

(III) Many types of ice crystal shapes -> verity of ETV functions

What makes a particle good IN?

Geometry [edit]

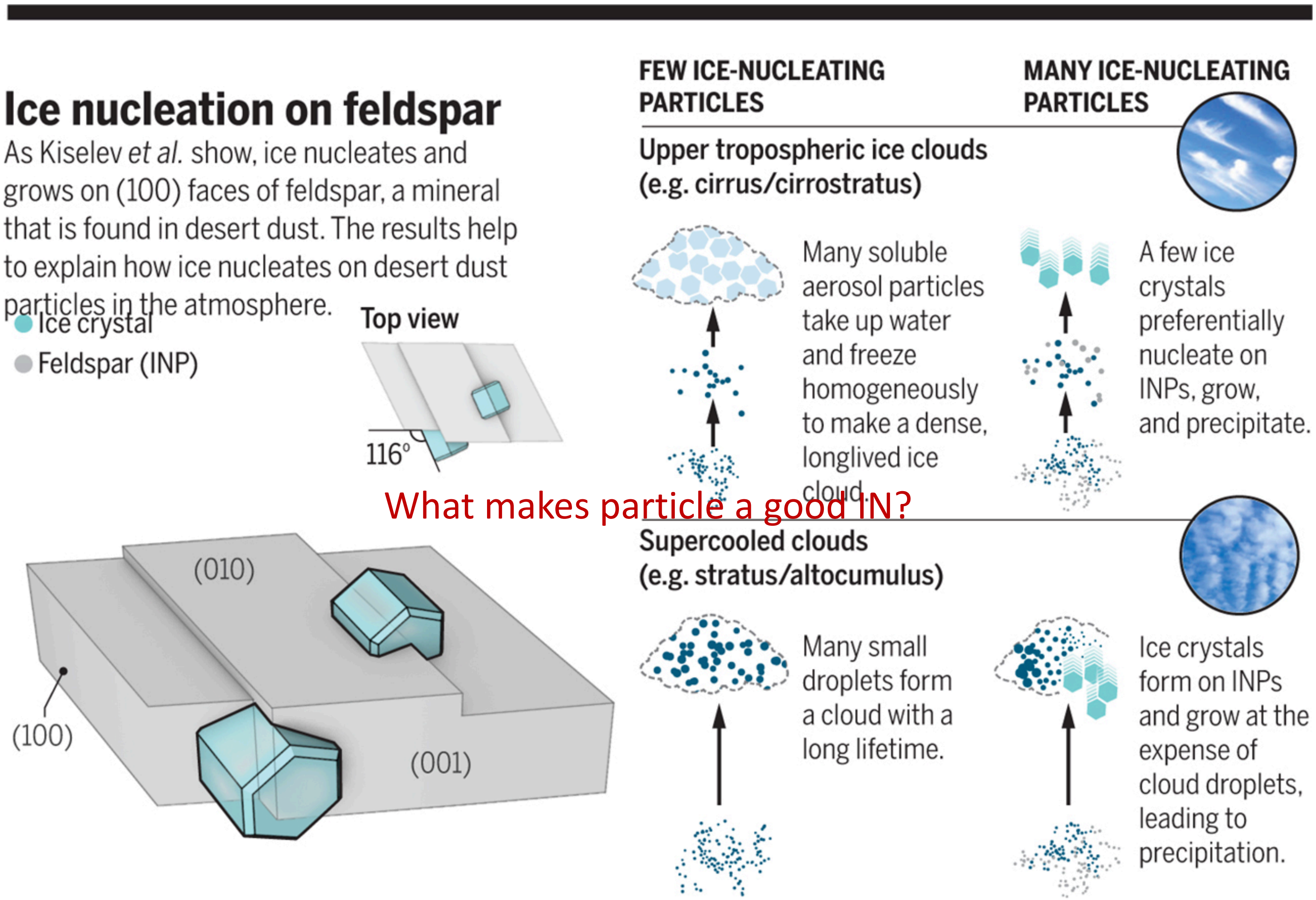
At ambient temperature and pressure, water molecules have a V shape. The two hydrogen atoms bond to the oxygen atom at a 105° angle.[3]



Common ice crystals are symmetrical and have a hexagonal pattern.

https://en.wikipedia.org/wiki/Ice_crystals

What makes particle a good IN?



What makes particle a good IN?

Ice nucleation on feldspar

As Kiselev *et al.* show, ice nucleates and grows on (100) faces of feldspar, a mineral that is found in desert dust. The results help to explain how ice nucleates on desert dust particles in the atmosphere.

CREDITS: (GRAPHIC) V. ALTOUNIAN/*SCIENCE*; (INSET PHOTOS, TOP TO BOTTOM) FIR0002/WIKIMEDIA COMMONS; JIMMY TAN/FLICKR

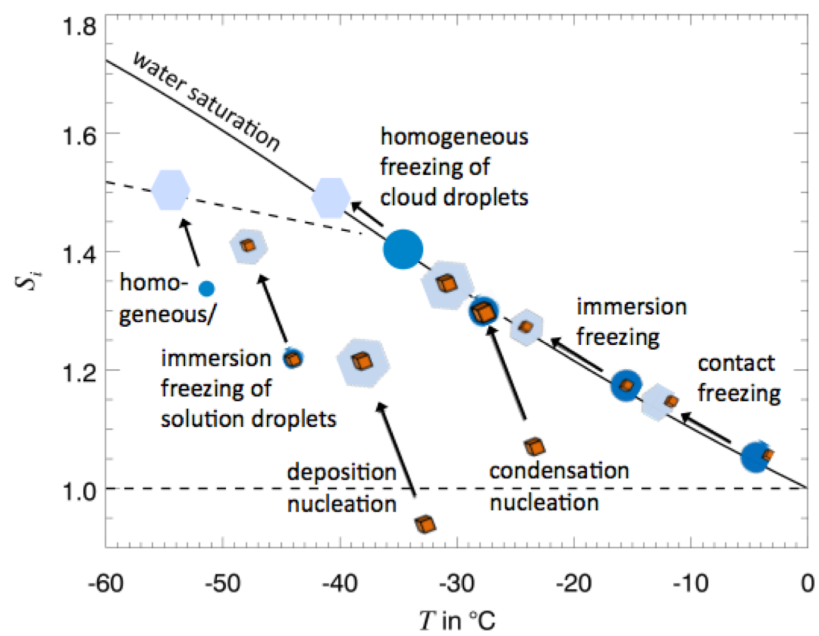


Fig. 1. Schematic representation of the different nucleation modes.

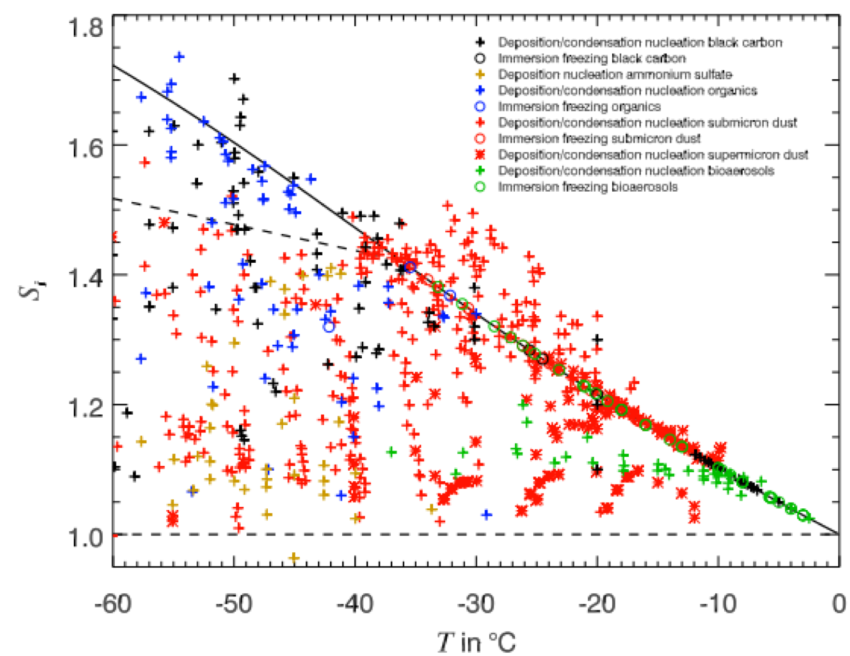
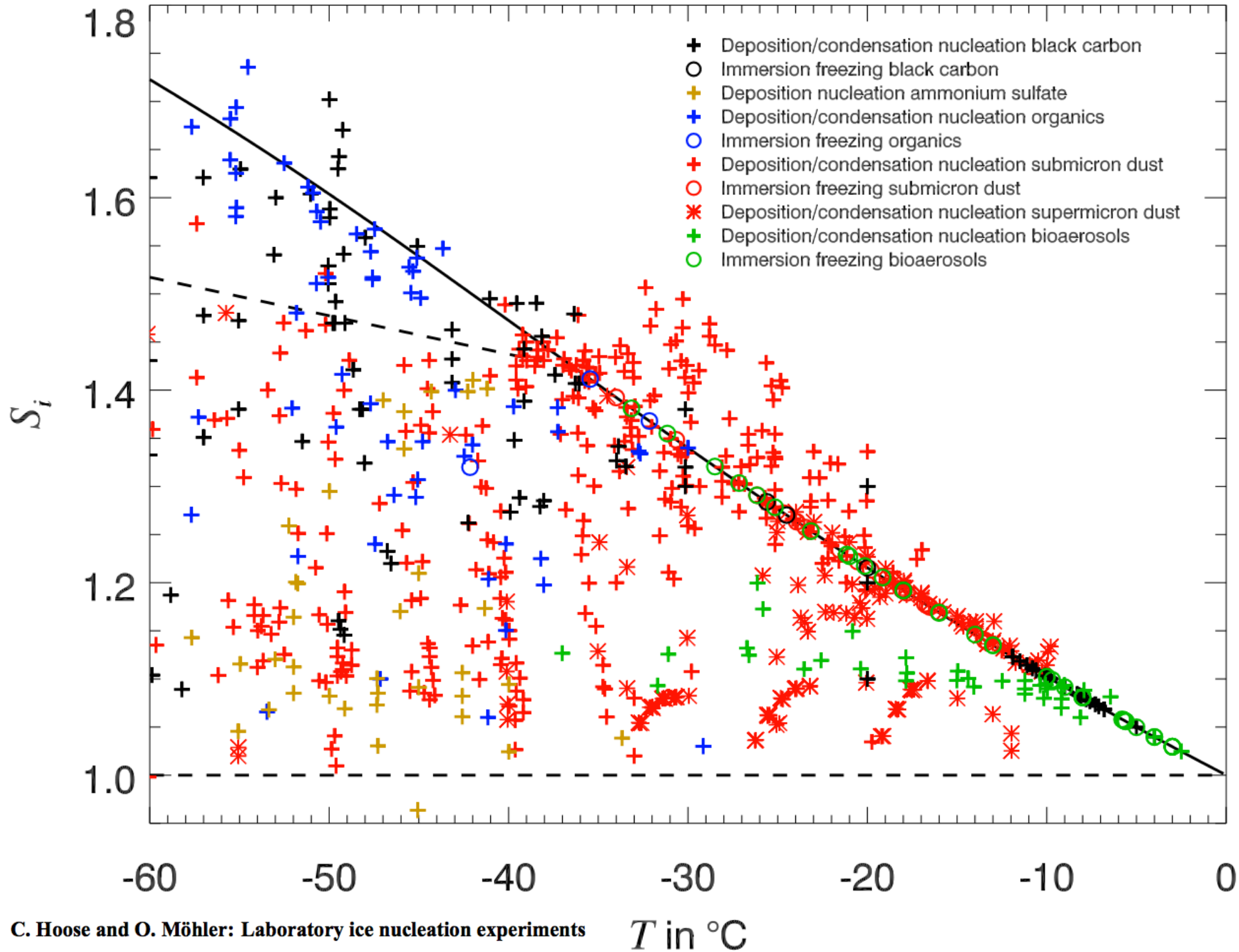
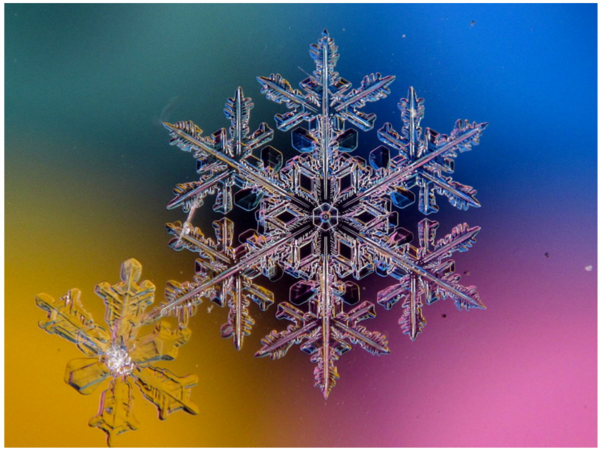


Fig. 2. Overview of ice nucleation onset temperatures and saturation ratios. Data sources are listed in the following figures.


1.8
1.6
1.4
1.2
1.0
S_i
-60
-50
-40
-30
-20
-10
0
T in °C
Deposition/condensation nucleation black carbon
Immersion freezing black carbon
Deposition nucleation ammonium sulfate
Deposition/condensation nucleation organics
Immersion freezing organics
Deposition/condensation nucleation submicron dust
Immersion freezing submicron dust
Deposition/condensation nucleation supermicron dust
Deposition/condensation nucleation bioaerosols
Immersion freezing bioaerosols

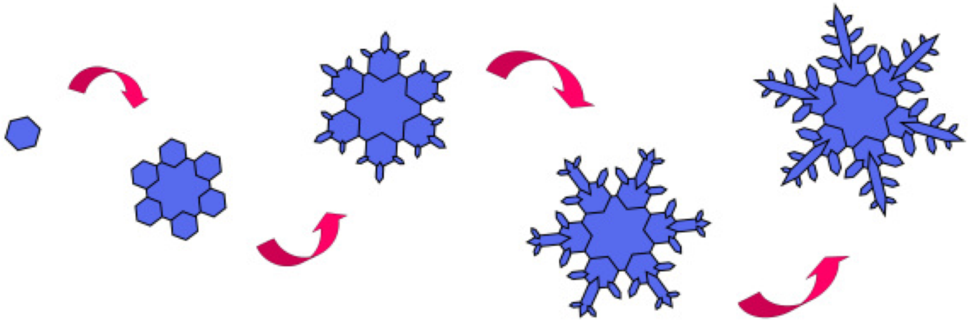
Slow to fast freezing -> deposition to contact freezing



By Rubelson - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=45347722

By Brocken Inaglory - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=5792113

Why such complex, symmetrical shapes? And why are no two alike?

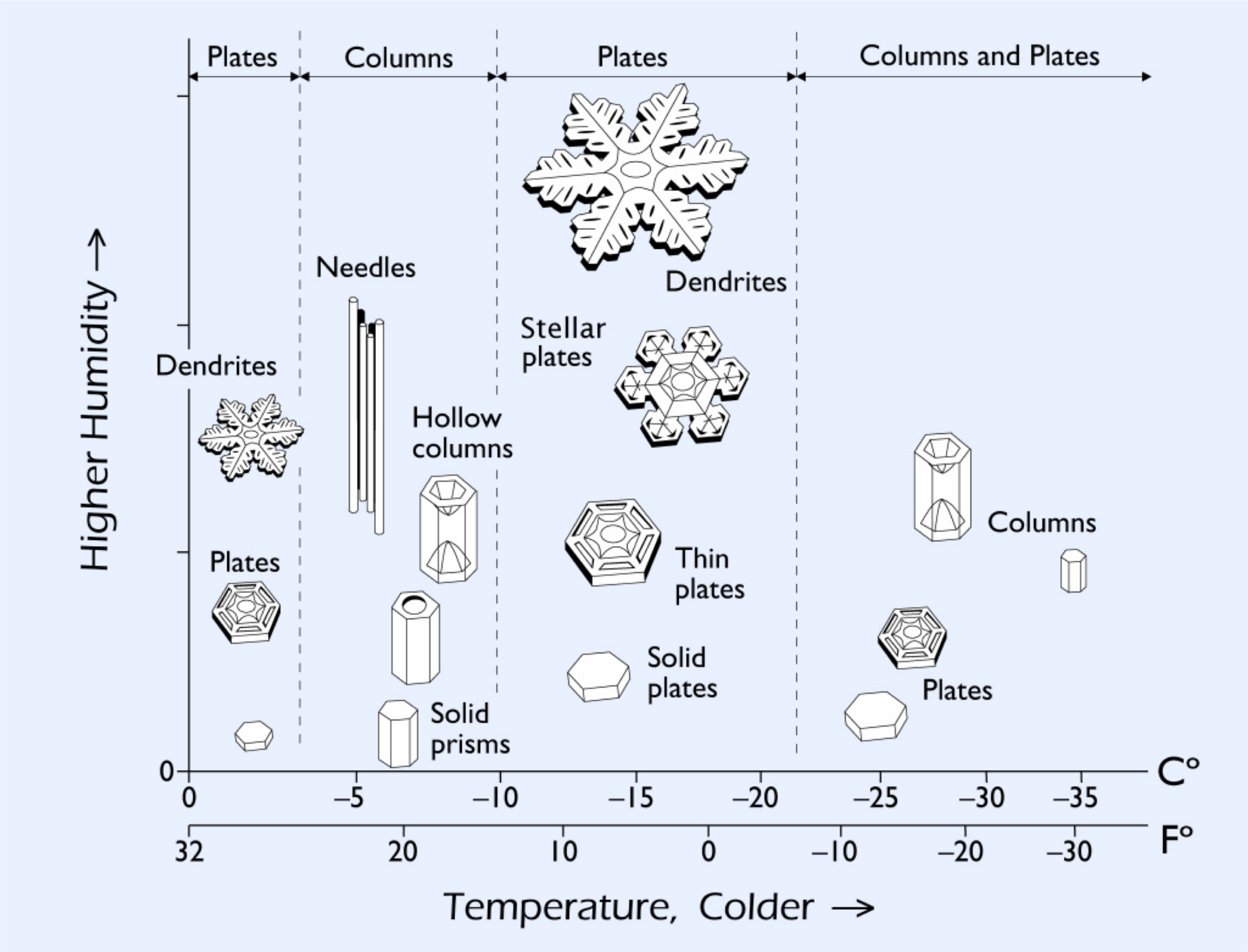


A stellar snow crystal begins with the formation of a small hexagonal plate, and branches sprout from the six corners when the crystal grows larger. As it tumbles through the clouds, the crystal experiences ever changing temperatures and humidities, and each change makes the arms grow a bit differently.

The exact shape of the final snow crystal is determined by the precise path it took through the clouds. But the six arms all took the same path, and so each experienced the same changes at the same times. Thus the six arms grow in synchrony, yielding a complex, yet symmetrical shape. And since no two snow crystals follow the exact same path through the clouds as they fall, no two look exactly alike.

We have made "identical-twin" snowflakes by exposing a pair of tiny seed crystals to nearly identical varying conditions as a function of time. This shows essentially what would happen if two snow crystals traveled side-by-side as they fell from the clouds.

http://www.snowcrystals.com/science/science.html



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(II) Many types of ice formation mechanisms

(III) Many types of ice crystal shapes -> verity of ETV functions

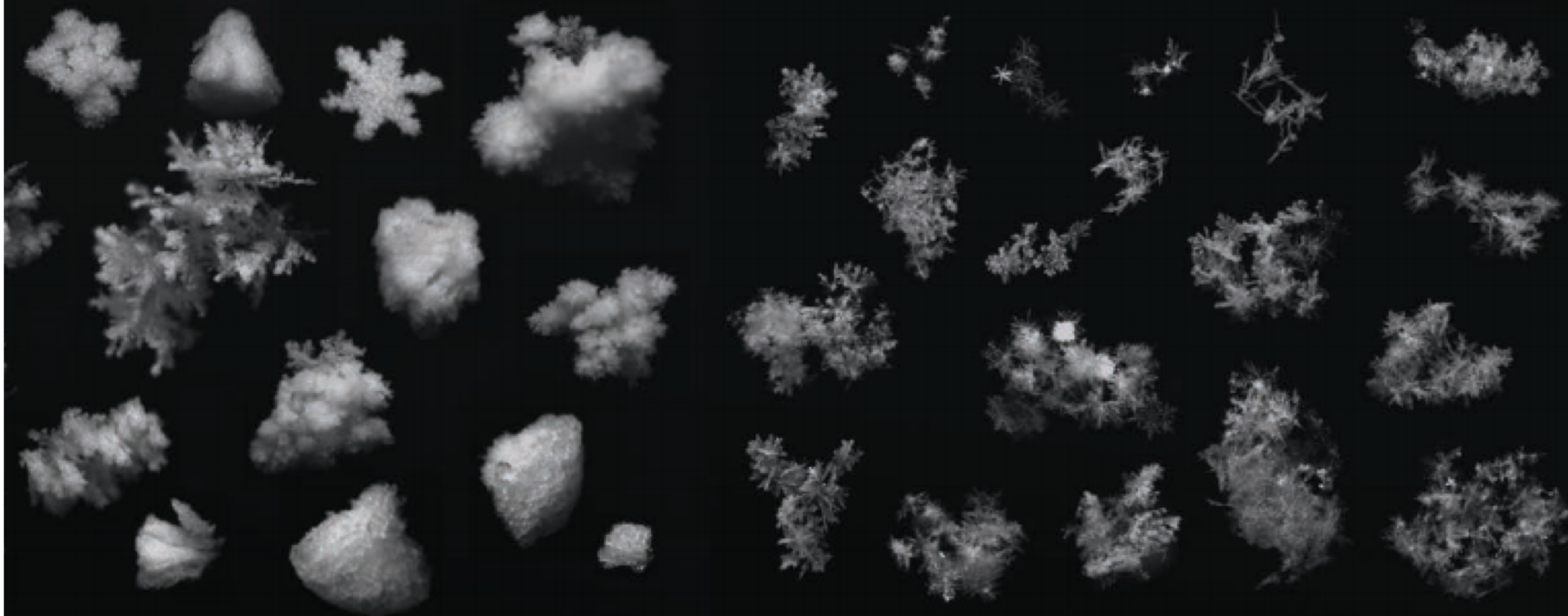
(IV) Many types of ice and water clusters/aggregates

(V) Interaction with EM radiation and therefore RS is much more complex by Kevin Hammonds

CRYSTALLIZING OPINION

Ultra-high-speed cameras are being used to study snowflake formation

Numerical weather models misdiagnose the huge variety of frozen hydrometeors that fall, but scientists from the University of Utah have developed a way to accurately predict where and how snow will fall



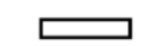
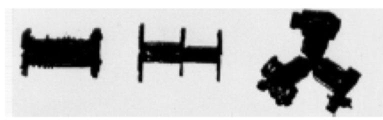
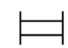
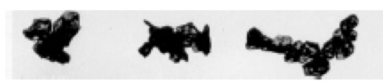
The many types of snowflake, from large aggregate to rimed and graupel, photographed using the MASC

USAIR FLIGHT 405, MARCH 22, 1992

On the tarmac at New York's LaGuardia Airport, the First Officer of a USAir Fokker F28 described the snowfall as "not heavy, no large flakes". The airplane spent half an hour with no further de-icing. Then at take-off, with 51 passengers on board, the airplane failed to gain any more than a few meters of clearance from the ground. After striking several obstacles, the aircraft skidded off the runway into Flushing Bay. Twenty-seven died in the tragedy.

Failure to undergo proper de-icing procedures at LaGuardia was what doomed the aircraft. But a 1990s study led by Roy Rasmussen of the National Center for Atmospheric Research suggested that the root cause was a hazard termed 'high visibility, high snowfall rate conditions'. Wet and rimed snow falls very quickly. But even if the snowfall rate is high, the hydrometeors are compact and they do not impede visibility nearly as efficiently as would large and fluffy aggregated flakes. Under these conditions, high snowfall and rapid icing conditions can be missed where visibility alone is used to assess snowfall rates, as had happened at LaGuardia. The results highlighted the importance of determining hydrometeor form for helping to avoid aircraft icing in winter.

Table 6.2 A classification of solid precipitation[a,b,c]

Typical forms	Symbol	Graphic symbol
	F1	
	F2	
	F3	
	F4	
	F5	
	F6	
	F7	
	F8	
	F9	
	F10	

[a] Suggested by the International Association of Hydrology's commission of snow and ice in 1951. [Photograph courtesy of V. Schaefer.]

[b] Additional characteristics: *p*, broken crystals; *r*, rime-coated particles not sufficiently coated to be classed as graupel; *f*, clusters, such as compound snowflakes, composed of several individual snow crystals; *w*, wet or partly melted particles.

[c] Size of particle is indicated by the general symbol D. The size of a crystal or particle is its greatest extension measured in millimeters. When many particles are involved (e.g., a compound snowflake), it refers to the average size of the individual particles.

Wallace and Hobbs