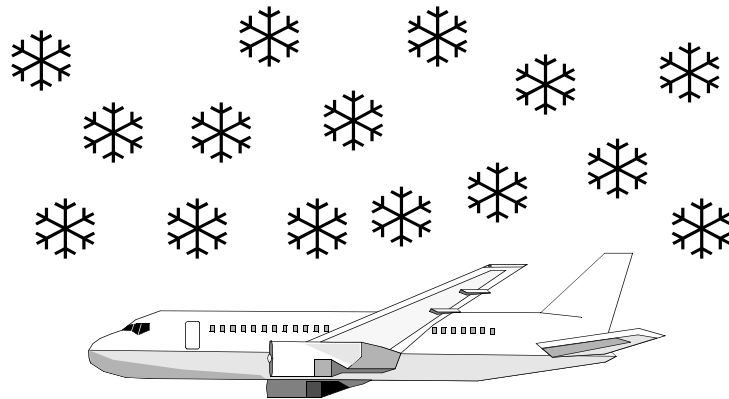


How Snow Can Fool Pilots

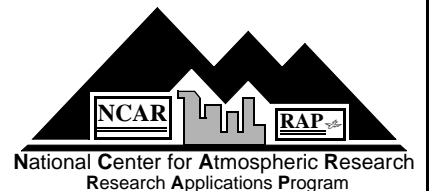


Dr. Roy Rasmussen & Jeffrey A. Cole

National Center for Atmospheric Research*

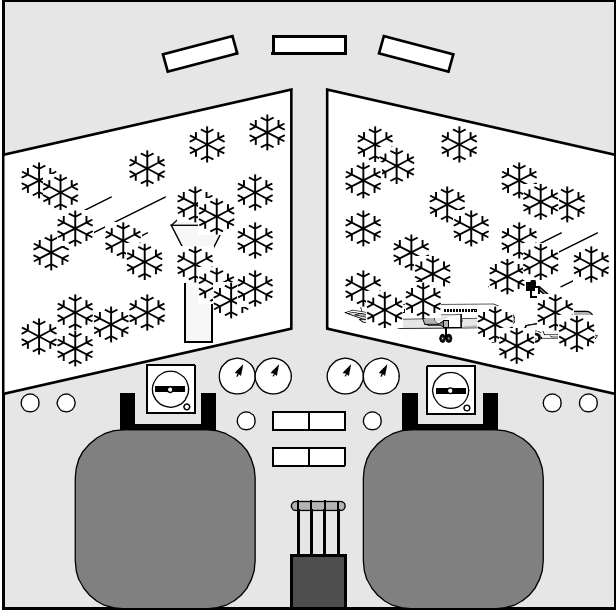
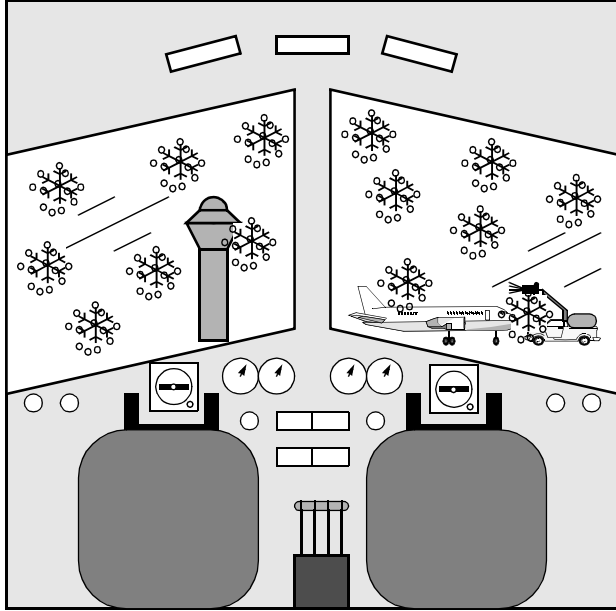
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Which Case Causes the Greatest Aircraft Ground-Icing Threat?

Case #1	Case #2
	
Visibility = 1/4 mile (0.4 km) NWS Snowfall Rate = Heavy (S+) Note: based on visibility Liquid Precip Rate = 0.10 in/hr (2.5 mm/hr) Snow Crystals: 3-5 mm Dendrites Crystal Riming: None - Light ❄️ Aggregates: 5-25 mm ❄️❄️	Visibility = 3/4 mile (1.2 km) NWS Snowfall Rate = Light (S-) Note: based on visibility Liquid Precip Rate = 0.10 in/hr (2.5 mm/hr) Snow Crystals: 1-3 mm Dendrites & Plates Crystal Riming: Heavy ❄️❄️❄️ Aggregates: None ❄️❄️❄️

Answer: Both

Why Visibility Can Be Misleading

In both cases there is an equal threat of ground-icing due to similar amounts of liquid-equivalent snow accumulation on the aircraft, despite the higher visibility in Case #2. Research and an analysis of the meteorological conditions associated with previous accidents has shown that visibility can vary widely for the same snowfall rate. Since the NWS snowfall intensity scale is based on visibility, the currently reported snow intensities of Light (SN-), Moderate (SN), and Heavy (SN+) can be misleading. The visibilities in the above cases range from Light (SN-) to Heavy (SN+) snowfall intensity, whereas the actual precipitation rates are both considered Heavy liquid equiv snowfall (see table below). The snow crystals in Case #1 consisted of larger, less dense crystals with aggregation (more than one crystal clumped together), whereas the snow crystals in Case #2 were individual, small, densely-rimed (adhesion of super-cooled cloud droplets) crystals. The crystal variation accounts for the similar water content and the difference in visibility. Another dangerous case occurs in wet snow conditions with an OAT near freezing, which results in misleadingly high visibilities at high snowfall rates. Visibility is inversely related to the diameter-squared of the snow crystal, not necessarily the liquid water content, therefore if the crystals are larger or crystal aggregation is occurring then visibility will decrease. An analysis of previous aircraft accidents on the following page shows the variation in visibility for the same snowfall rate in each case.

NWS Snow Intensity	Visibility	SAE/NCAR Snowfall Rate (liq equiv)
Light (SN-)	5/8 mi or more	< 1 mm/hr (10 gr/dm ² /hr)
Moderate (SN)	<5/8 to 5/16 mi	1 mm/hr to 2.5 mm/hr (10 to 25 gr/dm ² /hr)
Heavy (SN+)	<5/16 mi	> 2.5 mm/hr (> 25 gr/dm ² /hr)

$$\text{Visibility} = \frac{k}{N_T D^2}$$

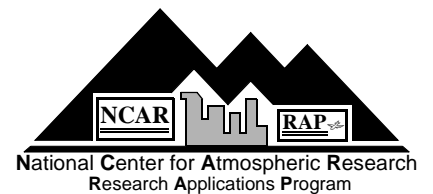
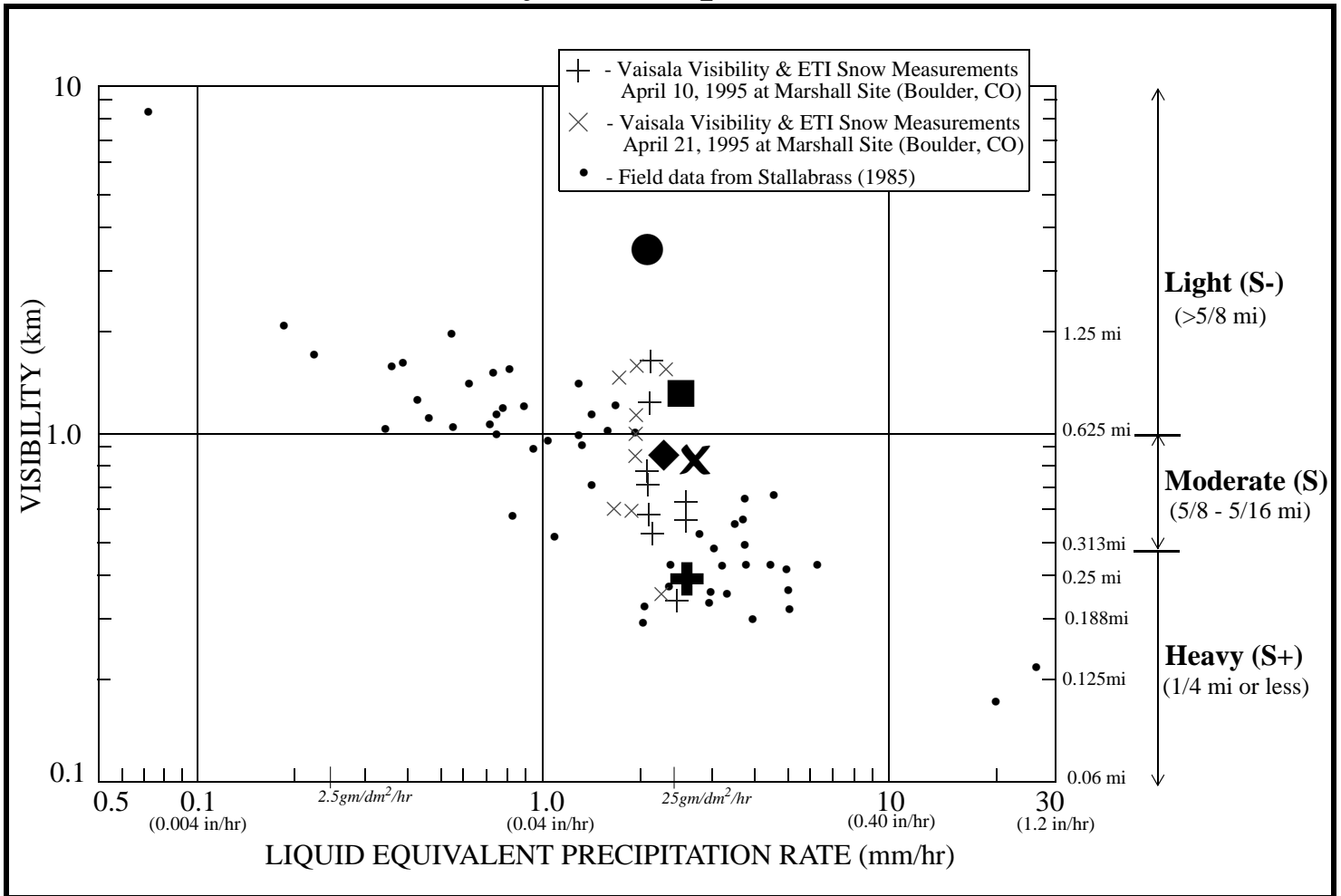
k = constant
 N_T = # particles
 D = diameter of particle

U.S. Jet Transport Takeoff Icing Accidents in Snow Conditions

Accident Location	Date	Accident Time(Z)	Type of Aircraft	Aircraft Deicing	Time between Deicing & TO	Fluid Type	Precip Rate Obs Period	Liq Equiv Precip Type	Visibility	Wspd(kts) Wdir(deg)	Temp
✕ Newark, NJ (Newark Int'l)	11/27/78	1650Z	DC-9	No	-----	-----	0.095in/hr (1600-1700Z)	Snow/Fog	0.50 mi (@1600Z)	8 kts 30°	27°F (-3.9°C)
● Boston, MA (Logan Int'l)	2/18./80	1908Z	BB-253F	Yes	45-60 min*	Type I	0.08in/hr (1800-1900Z)	Light Snow & Fog	2.0 mi (@1854Z)	11 kts 330°	30°F (-1.1°C)
✚ Washington, DC (National)	1/13/82	2100Z	B-737	Yes	50 min*	Type I	0.09in/hr (2000-2100Z)	Snow	0.25 mi (@2000Z)	10 kts 10°	25°F (-3.9°C)
◆ Denver, CO (Stapleton)	11/15/87	2115Z	DC-9	Yes	27 min*	Type I	0.10in/hr (2100-2200Z)	Snow	0.5 mi (@2100Z)	10 kts 30°	26°F (-3.3°C)
■ Flushing, NY (LaGuardia)	3/23/92	0235Z	F-28	Yes	35 min*	Type I	0.10in/hr (0200-0240Z)	Snow	0.75 mi (@0200Z)	13 kts 70°	31°F (-0.6°C)

*Exceeds present SAEAMS4737 holdover time guidelines for Type I Fluids

Visibility vs Precipitation Rate



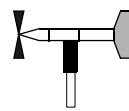
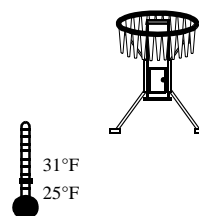
Snowfall and Visibility Conclusions

- **Visibility can give a false sense of security to pilots and ground operations, who often rely on visual estimates of snowfall rate in absence of other data.**
- **NTSB report from LaGuardia accident quotes first officer of the aircraft as describing the snowfall as “not heavy, no large flakes.” Weather observer described snowfall as “wet”, consistent with small, dense snowflakes.**
- **Previous aircraft ground-icing accidents had common values of:**

a. **Precipitation rate: 0.08-0.1 in/hr (2.0 to 2.5 mm/hr)**

b. **Temperature: 25° to 31°F (-0.5 to -3.5°C)**

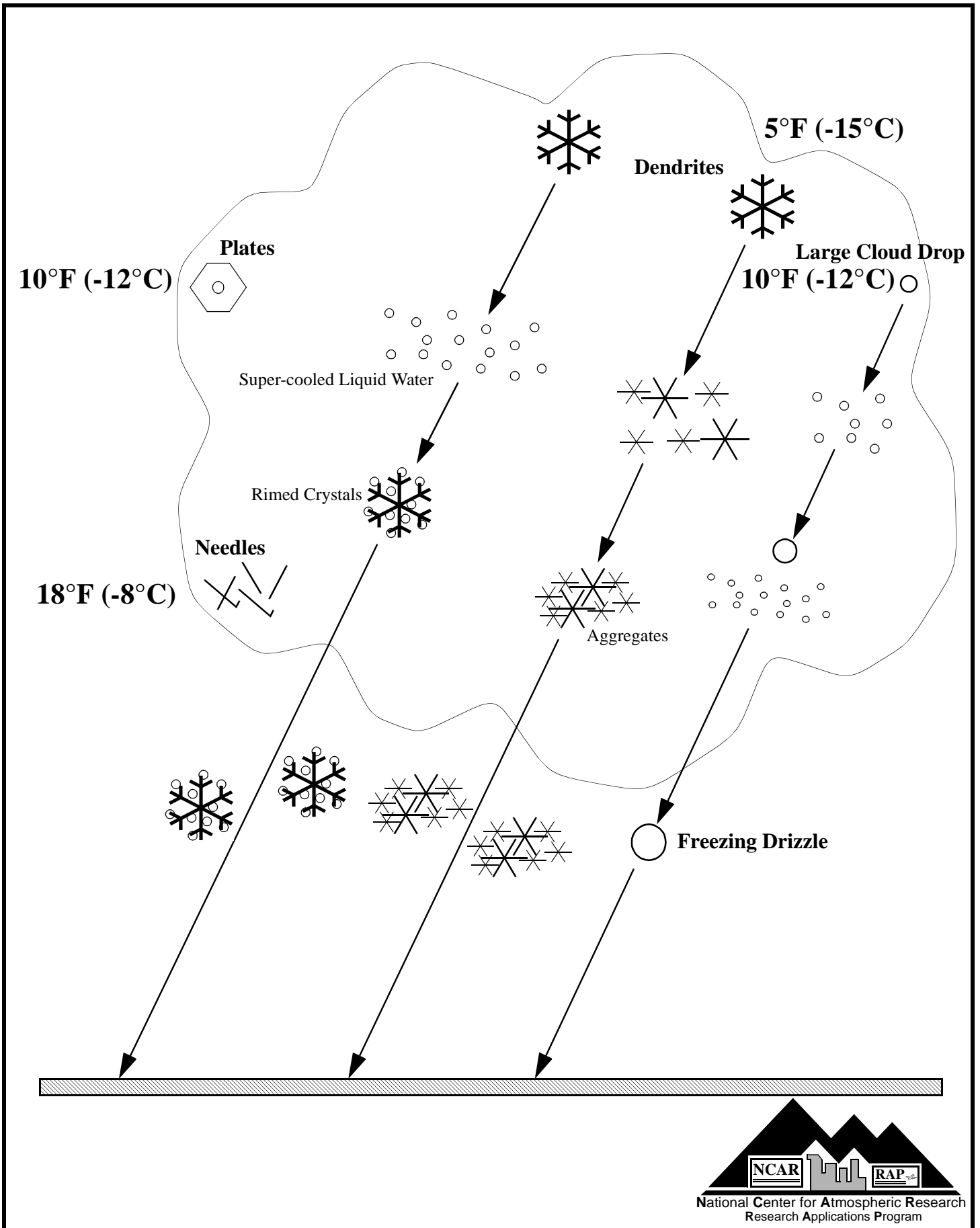
c. **Wind Speed: 8 to 13 knots (4 to 6.5 m/s)**



Note: These meteorological conditions are conducive to cases of “good visibility” but dangerously high liquid-equivalent snowfall rates.

- **Visibility varied considerably from 0.25 to 2.0 miles; suggesting that visibility is a poor surrogate to use for snowfall rate.**
- **Accurate, real-time measurements of liquid-equivalent snowfall rates need to be made and reported to pilots and ground operations personnel, not just visibility measurements.**
- **Snow crystal formation and characteristics are not necessarily based upon surface conditions. Upper-level cloud temperature and structure are more important.**
(See diagram on next page)

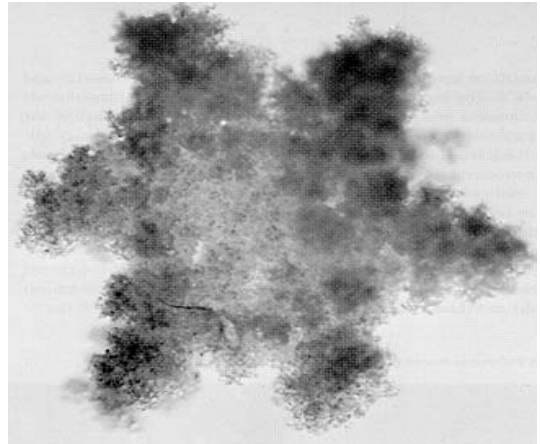
Formation of Snow and Freezing Drizzle



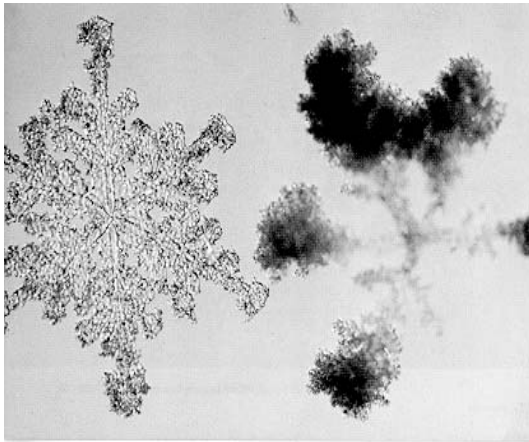
Example Snow Crystals



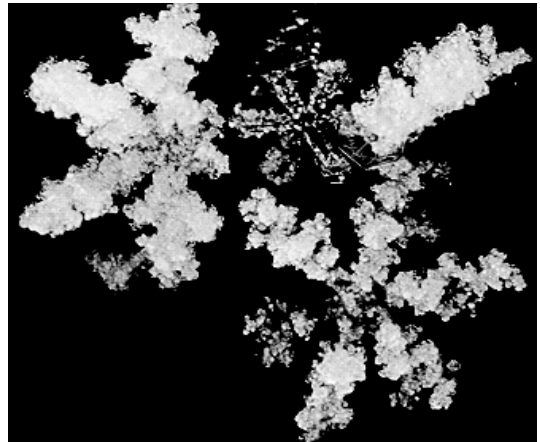
Stellar Crystal with no riming



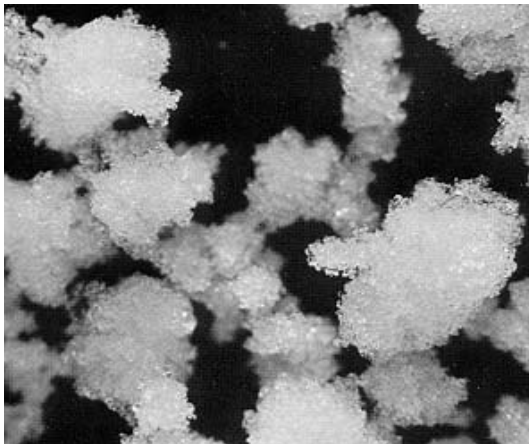
Stellar Crystal with heavy riming



Differences in riming on large stellar crystals



Various degrees of riming on stellar/plate crystals



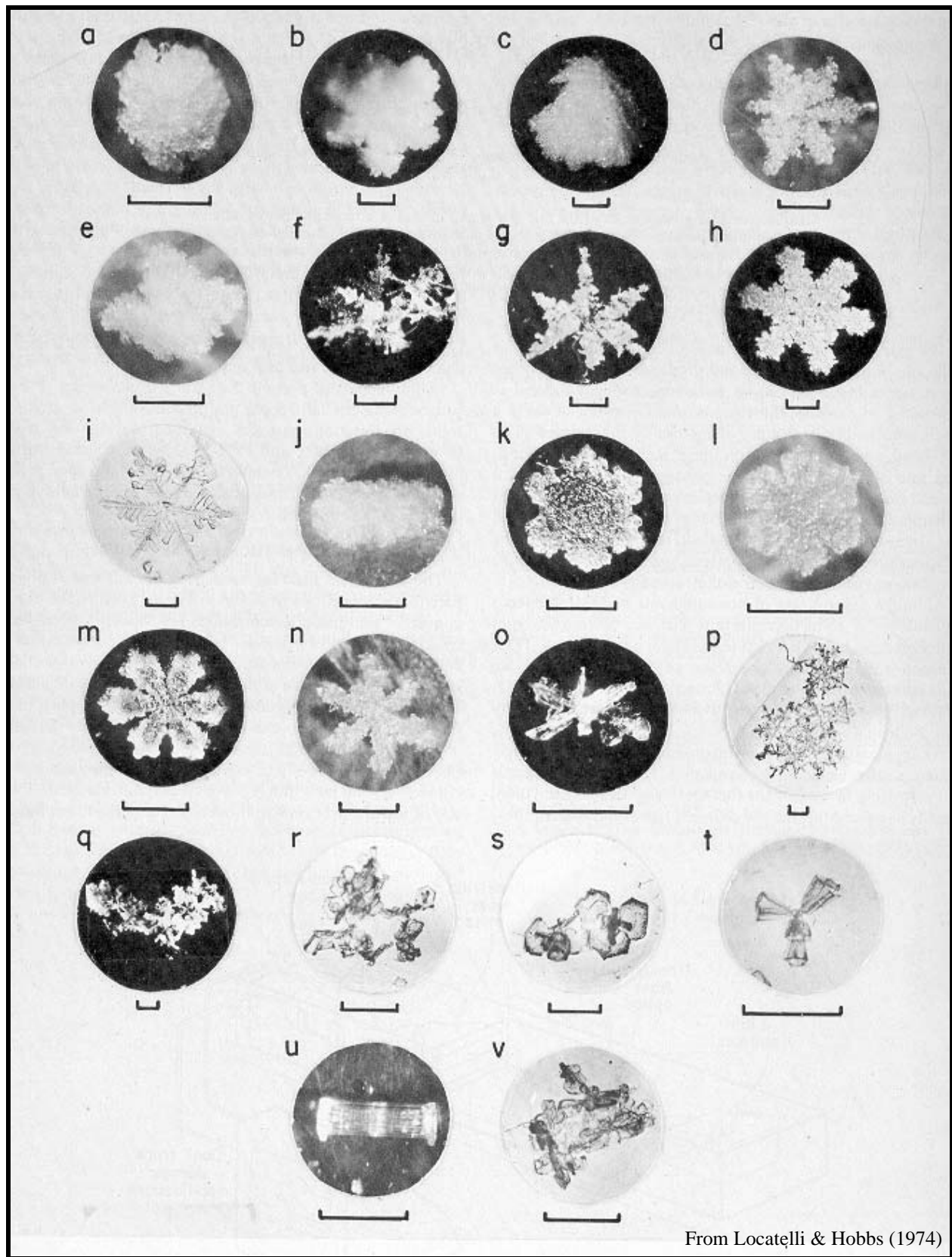
Graupel or pellet snow



Lightly rimed needle crystals

Crystal photos by Edward R. LaChapelle

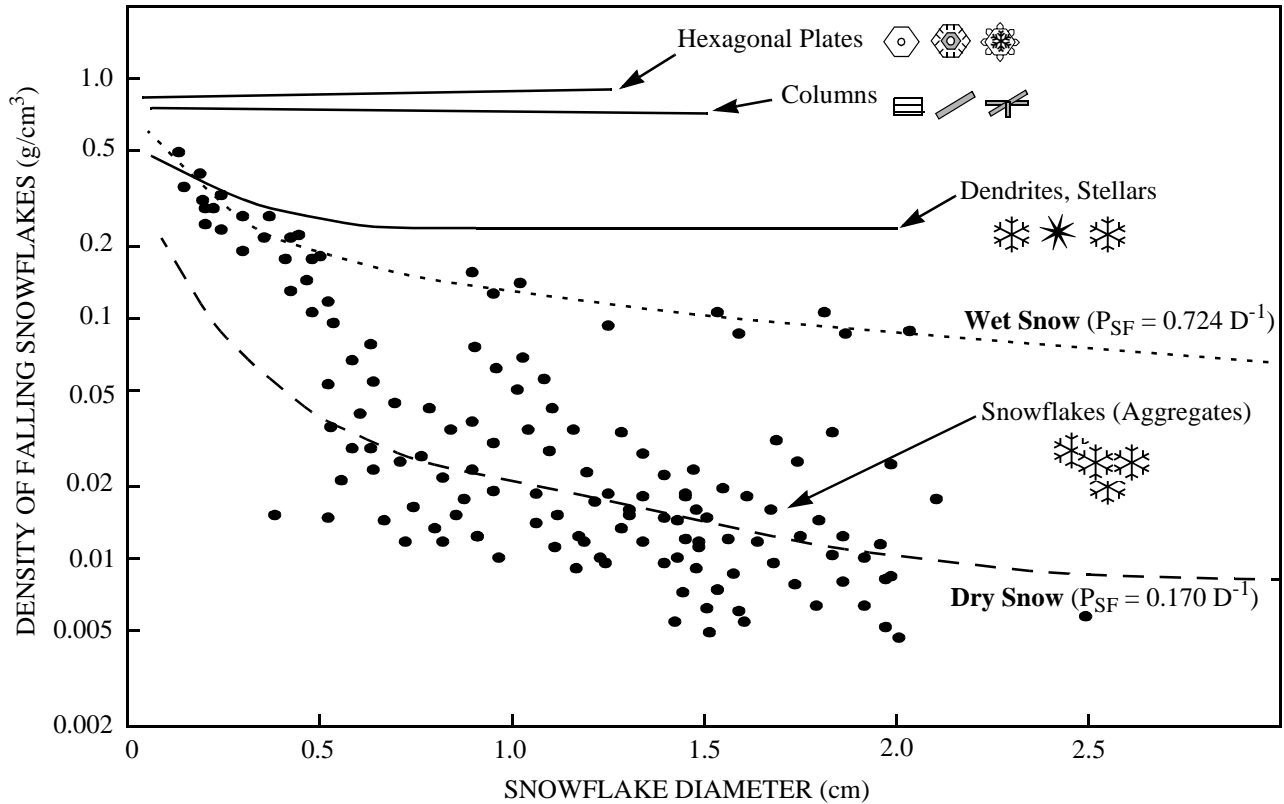
Example Snow Crystals



From Locatelli & Hobbs (1974)

Type of solid precipitation particles. (a) Lump graupel, (b) hexagonal graupel, (c) conical graupel, (d) graupel-like snow of hexagonal type, (e) graupel-like snow of lump type, (f) unrimed radiating assemblage of dendrites, (g) densely rimed radiating assemblage of dendrites, (h) densely rimed dendrite, (i) unrimed dendrite, (j) densely rimed column, (k) densely rimed plate with simple extensions, (l) densely rimed crystal with sector-like branches, (m) densely rimed crystal with broad branches, (n) densely rimed stellar, (o) unrimed side plane, (p) lightly rimed aggregate of dendrites, (q) densely rimed aggregate of radiating assemblages of dendrites, (r) unrimed aggregate of bullets, columns, assemblages of plates, and side planes, (s) lightly rimed assemblage of plates, (t) unrimed bullets, (u) unrimed column, and (v) unrimed aggregate of side planes. The scale line below each photograph represents 1 mm.

Snow Density, Diameter & Crystal Type



Snowfall Equations

$$Visibility = \frac{k}{N_T D^2}$$

k = constant
N_T = # particles
D = diameter of particle
Ps(D) = Snow Density as func of Diameter

$$Snowfall\ Rate = \frac{k}{Vis}$$

if

$$Snow\ Density\ [P_s(D)] = \frac{k}{D}$$

Note: The constant k in the snowfall rate equation depends on the type of ice crystal, the degree of riming, the degree of aggregation of crystals, and whether dry or wet snow. Wet and/or rimed snow has a factor of 4x higher value of k leading to high visibility, high snowfall rate conditions, which can be misleading to pilots.

Modified Visibility Criteria for Snow Intensity* (based on Temperature and Day or Night)

Condition	Temperature		Horizontal Visibility (Statute Miles)					
	°C	°F	1/4	1/2	3/4	1	1-1/4	> 1-1/4
Snow (SN)	< -1°C	< 30°F	Heavy	Moderate	Light			
Daytime (Light > 3 ft candles)	≥ -1°C	≥ 30°F	Heavy		Moderate	Light		
Snow (SN)	< -1°C	< 30°F	Heavy		Moderate	Light		
Nighttime (Light < 0.5 ft candles)	≥ -1°C	≥ 30°F	Heavy			Moderate		Light

*Chart compiled by NCAR and Transport Canada.

Weather Phenomenon*

Definition*

Intensity Criteria**

FROST (No METAR code) Note: No Intensity is assigned to FROST.	Ice crystals that form from ice-saturated air at temperatures below 0°C (32°F) by direct sublimation on the ground or other exposed objects.
FREEZING FOG (FZFG) Note: No Intensity is assigned to FRZ FOG.	A suspension of numerous minute water droplets which freezes upon impact with ground or other exposed objects, generally reducing the horizontal
SNOW (SN)	Precipitation of ice crystals, most of which are branched, star-shaped, or mixed with unbranched crystals. At temperatures higher than about -5°C
FRZING DRIZZLE (FZDZ)	Fairly uniform precipitation composed exclusively of fine drops [diameter less than 0.5 mm (0.02 in.)] very close together which freezes upon impact with
FREEZING RAIN (FZRA)	Precipitation of liquid water particles which freezes upon impact with the ground or other exposed objects, either in the form of drops of more than 0.5
RAIN (RA)	Precipitation of liquid water particles either in the form of drops of more than 0.5 mm (0.02 in.) diameter or of smaller widely scattered drops.
SNOW PELLETS (GS) and/or SMALL HAIL	Precipitation of white and opaque grains of ice. These grains are spherical or sometimes conical; their diameter
SNOW GRAINS (SG)	Precipitation of very small white and opaque grains of ice. These grains are fairly flat or elongated; their diameter is
HAIL (GR)	Precipitation of small balls or pieces of ice with a diame-
ICE PELLETS (PE)	Precipitation of transparent (sleet or grains of ice), or translucent (small hail) pellets of ice, which are spherical or irregular, and which have a diameter of 5 mm (0.2 in.)

	Snow(SN),Pellets(GS),Grains(SG)		Ice Pellets (PE)
Estimated Intensity	Horizontal Visibility (statute mile)	Liquid Equivalent Snow (SN) Intensity***	Definition and Horizontal Visibility
Light (-)	If visibility is: ≥ 5/8 mi (≥ 1.0 km)	Trace to 0.05 in/hr (≤ 1.0 mm/hr or 10 gr/dm ² /hr)	Scattered pellets on the ground. Visibility <u>not</u> affected.
Moderate	If visibility is: < 5/8 to 5/16 mi (< 1.0 to 0.5 km)	> 0.05 to 0.10 in/hr (> 1.0 to 2.5 mm/hr) (> 10.0 to 25.0 gr/dm ² /hr)	Slow accumulation on the ground. Visibility reduced to less than 7 mi.
Heavy (+)	If visibility is: < 5/16 mi (< 0.5 km)	More than 0.10 in/hr (> 2.5 mm/hr or 25 gr/dm ² /hr)	Rapid accumulation on the ground. Visibility reduced to less than 3 mi.
Note: Horizontal visibility is only an <u>estimation</u> of snow and freezing drizzle intensity. Measurements and observations have			

	Drizzle Intensity (FZDZ)
Light(-)	Trace to 0.01 in/hr (0.254 mm/hr or 2.54 gr/dm ² /hr)
Moderate	From 0.01 to 0.02 in/hr (2.54 to 5.08 gr/dm ² /hr)
Heavy(+)	More than 0.02 in/hr (> 5.08 gr/dm ² /hr) Note: Drizzle > 0.04 in/hr is usually in the form of rain.

	Rain (RA), Freezing Rain (FZRA), Ice Pellets (PE)
Measured Intensity	Up to 0.10 in/hr (2.5 mm/hr or 25 gr/dm ² /hr) Maximum 0.01 inch in 6 minutes
Light (-) Estimated Intensity	From scattered drops that, regardless of duration, do not completely wet an
Measured Intensity	0.11 in to 0.30 in/hr (7.6 mm/hr or 76 gr/dm ² /hr) More than 0.01 to 0.03 inch in 6 minutes
Moderate Estimated Intensity	Individual drops are not clearly identifiable; spray is observable just above
Measured Intensity	More than 0.30 in/hr (7.6 mm/hr or 76 gr/dm ² /hr) More than 0.03 inch in 6 minutes
Heavy (+) Estimated Intensity	Rain seemingly falls in sheets; individual drops are not identifiable; heavy

* From World Meteorological Organization Guide to Meteorological Instruments and Methods of Observation (1983)
 ** From American Meteorological Society, Glossary of Meteorology WSOH #7 MANOBS (3/94)
 *** NCAR/SAE Proposed Definition for Liquid Equivalent Snowfall Intensity

1) gm/dm² = 0.01 cm = 0.1 mm = 0.0039 in
 2) in = 2.54 cm = 25.4 mm = 254 gm/dm²

Compiled by Jeff Cole and Roy Rasmussen of NCAR/RAP Sept 8, 1999
 (Updated for METAR codes)