

clouds

Lecture 9

Fog

1. *Fog is* a cloud with its base at or very near the ground
2. Fogs can be formed by:
 - I. cooling the air, or
 - II. by adding water vapor

Fogs caused by Cooling the Air

Condensation produces fog when the temperature of the layer of air in contact with the ground falls below its dew point

1. *Radiation fog* –

- results from radiation cooling of ground & adjacent air
- Radiation fog occurs at night under clear skies
- Radiation fog is thickest in valleys (cold air), burns off 1 to 3 hours after sunrise

Fogs caused by Cooling contd.....

2. *Advection fog* :

- caused when warm moist air passes over a cold surface
- Advection fogs are frequently very thick

3. *Upslope Fog*:

- created when relatively humid air moves up a gradually sloping plain, or steep slopes of mountains



Radiation Fog

Advection Fog

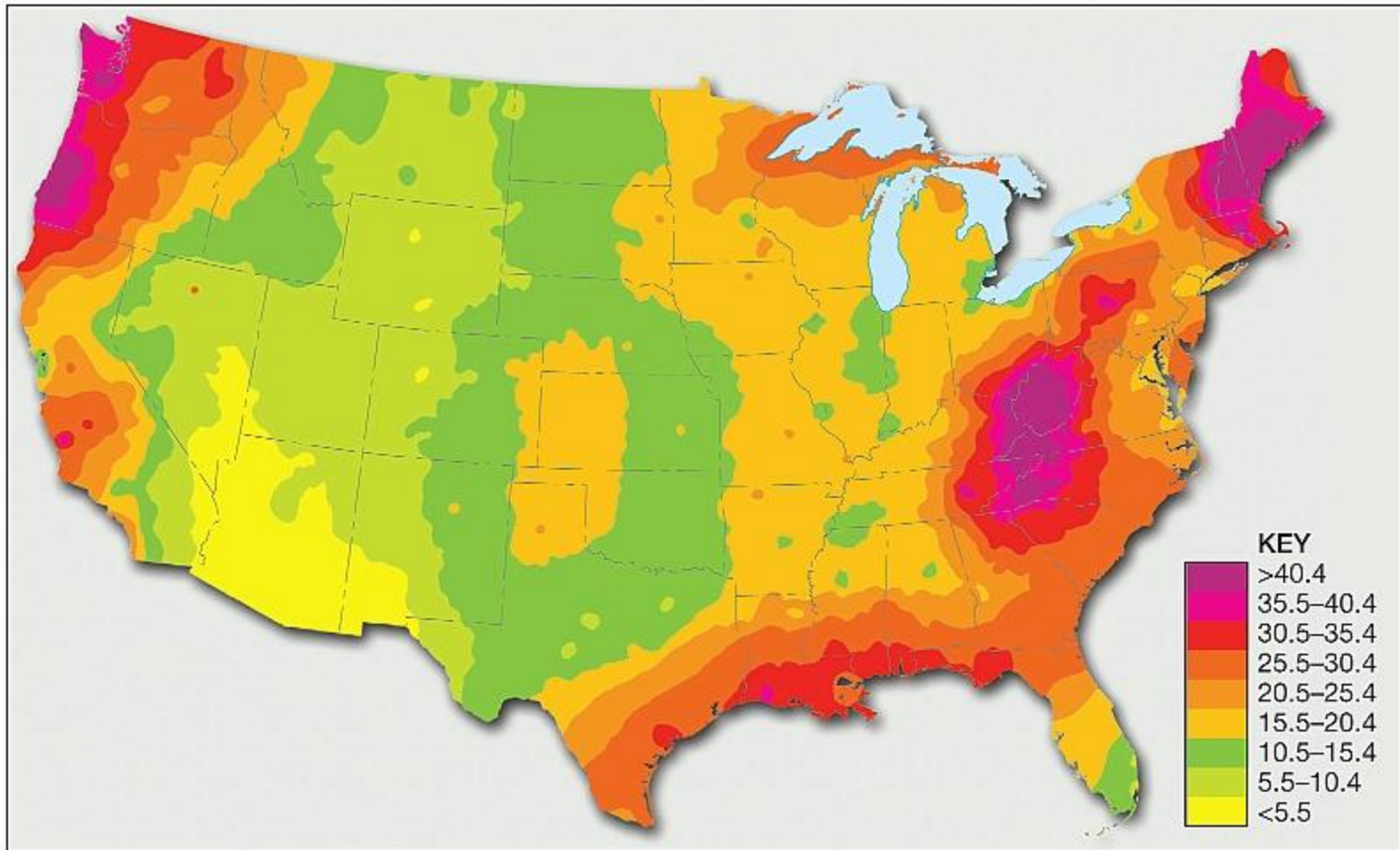


Copyright © 2007 Pearson Prentice Hall, Inc.

Occurrence of Fog

- Fig 5-12 shows average number of days per year with fog.
- Pacific Northwest, California, New England
- Cold ocean climates lower the temperature of the air, increasing the RH to 100%, so water vapor condenses out

Heavy fog days/year



Copyright © 2010 Pearson Education, Inc.

Fogs formed by Evaporation

- **Evaporation fogs** are caused by the addition of water vapor
- Two types:
 - steam fog &
 - frontal (precipitation) fog

1. **steam fog** :

- If cool air moves over warm water, enough water may evaporate to saturate the air immediately above. As the rising vapor meets the cold air, it condenses - **steam fog**

Fogs ... by Evaporation - 2

- Steam fog is common over lakes & rivers when the water is warm and the air is cold

2. frontal or precipitation fog:

- When frontal wedging occurs, warm air is lifted over cold air. If the resulting clouds yield rain, and the cold air below it is near the dew point, enough rain can evaporate to produce ***frontal or precipitation fog***

Steam Fog

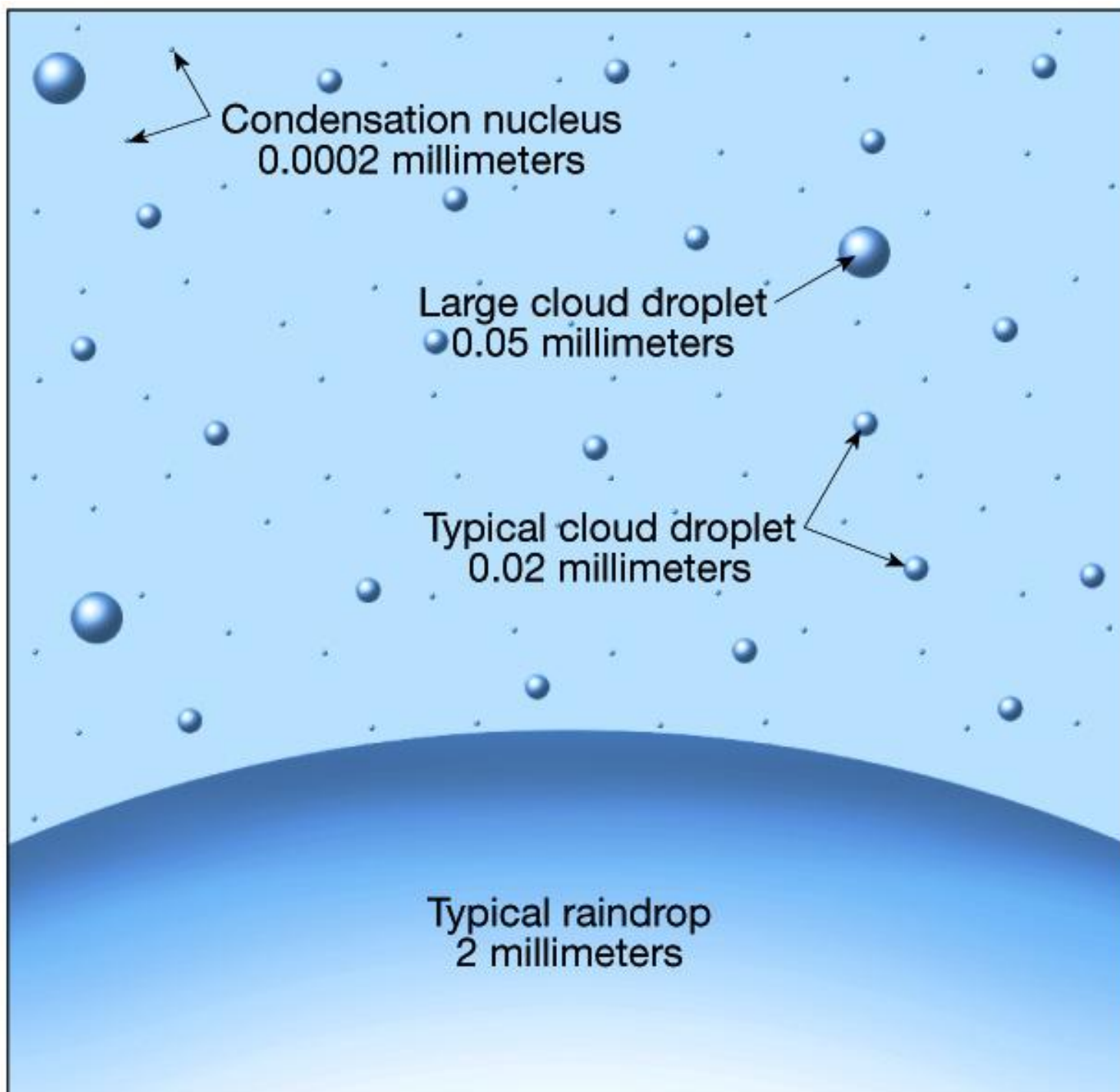


Dew & Frost

- 1. *Dew is*** water vapor condensed on objects that have radiated enough energy to drop their temperature below the dew point of the air
- 2. *White frost*** forms when the dew point of the air is below freezing

How Precipitation Forms

1. Cloud droplets are very small - 20 μm .
Numerous condensation nuclei share the available water vapor
2. Because they are small, cloud droplets fall very slowly. Probably evaporate.
3. Raindrops have diameters around 2000 μm (2 mm)



How Precipitation Forms - 2

1. To form a raindrop, cloud droplets must increase by a million times to produce "massive" rain drops
2. "Massive" rain drops are formed by the **Bergeron process** and by **collision-coalescence**

TABLE 5-A Maximum Fall Distance Before Evaporation

Drop diameter (μm)	Maximum fall distance (m)
2500	280,000
1000	42,000
100	150
10	0.033
0	0.0000033

TABLE 5–3 Fall Velocity of Water Drops

Types	Diameter (millimeters)	Fall velocity	
		(km/hr)	(mi/hr)
Small cloud droplets	0.01	0.01	0.006
Typical cloud droplets	0.02	0.04	0.03
Large cloud droplets	0.05	0.3	0.2
Drizzle drops	0.5	7	4
Typical rain drops	2.0	23	14
Large rain drops	5.0	33	20
Data from Smithsonian Meteorological Tables.			

The Bergeron Process

1. The *Bergeron process* is the process by which ice crystals attract water droplets, thereby becoming large enough to produce rain.

Bergeron Process - 2

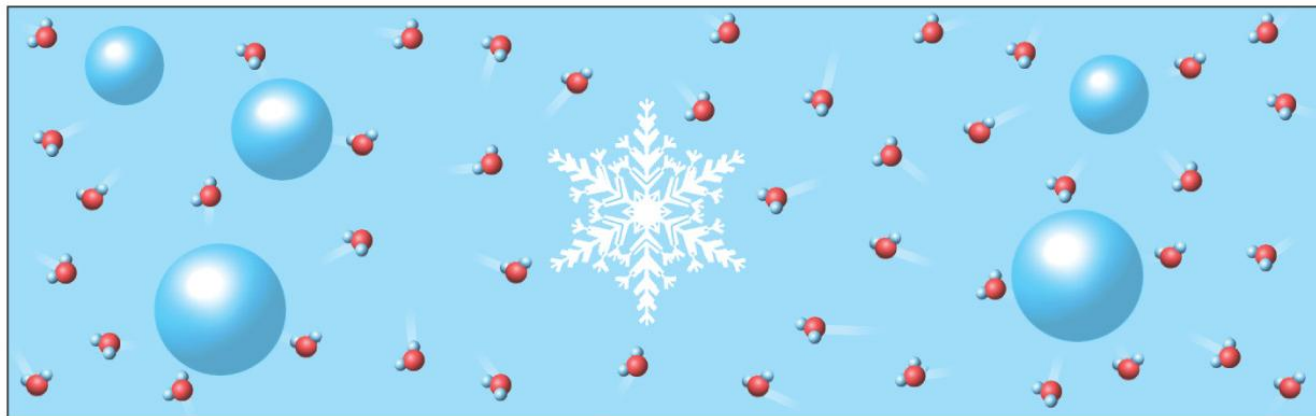
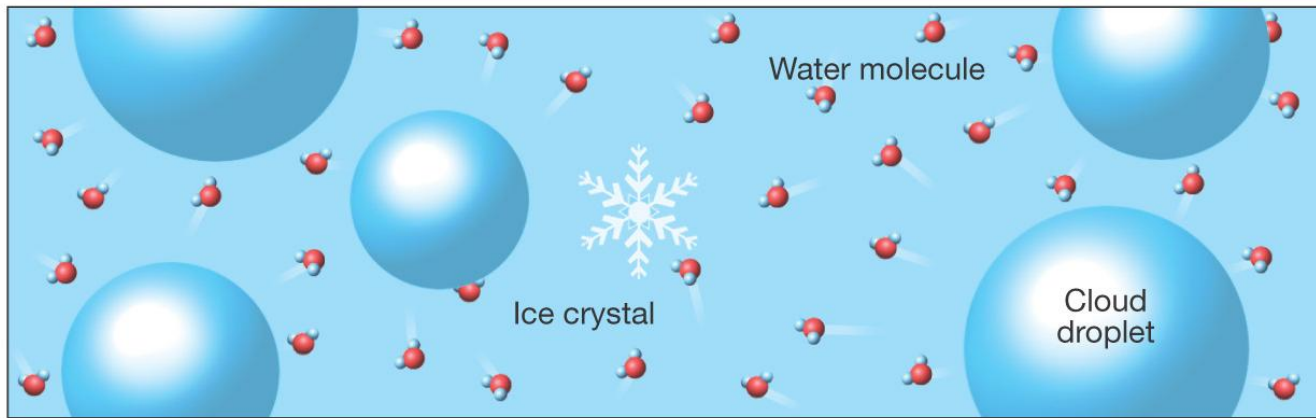
- **Process relies on two properties of water**
 - 1. One** - Pure water suspended in air does not freeze until the temperature drops to -40°C . **However**, supercooled water droplets will freeze on contact with particles that have a form closely resembling that of ice
 - 2. Two** - The saturated vapor pressure above ice crystals is somewhat lower than above supercooled liquid droplets (basically because ice is solid), **so** ice crystals attract more water vapor than the liquid droplets, and grow faster

Bergeron Process - 3

1. Water in the liquid state at temperatures below 0C is called *supercooled*.
2. Supercooled water droplets condense on what are called *freezing nuclei*.
3. Freezing nuclei are much less numerous than condensation nuclei.
4. Second important property of water - the SVP above ice crystals is somewhat lower than above supercooled liquid droplets (because ice is solid)

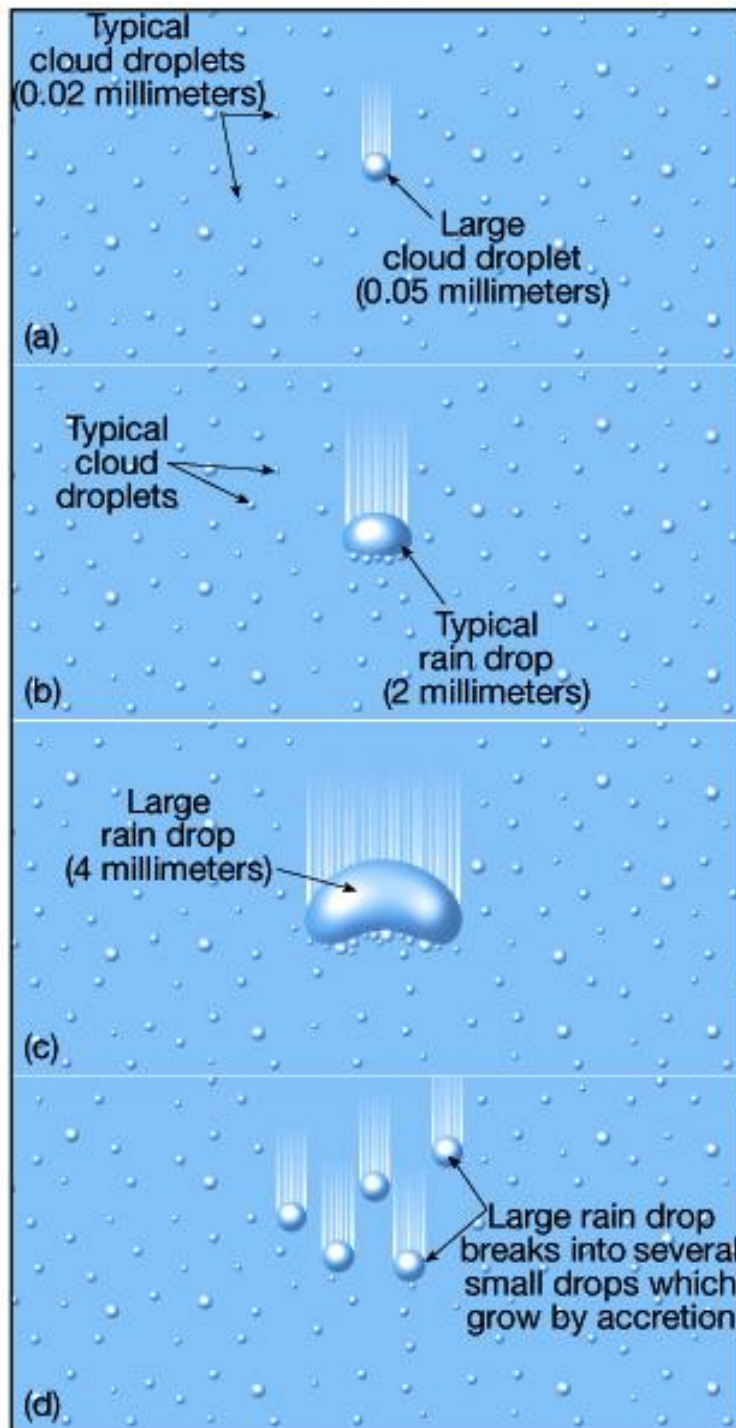
Bergeron Process - 4

1. Thus when air is saturated wrt liquid droplets, it is supersaturated
2. Ice crystals therefore collect more water molecules than they lose by sublimation, and grow bigger - and so we get precipitation
3. For the Bergeron process to work, at least the upper portions of clouds must be cold enough to produce ice crystals. **Mostly occurs at mid-latitudes**



Precipitation from Warm Clouds Collision-Coalescence

1. Large droplets(>20 μm) formed when "giant" condensation nuclei (such as sea salt) are present, or when hygroscopic particles exist.
2. Large droplets fall faster than small droplets, and add to their size as they fall by colliding and coalescing with the small droplets. Because they get larger, they fall faster, etc.



Precipitation from Warm Clouds Collision-Coalescence - 2

1. If the drops get too big, they are broken up because of air resistance, and the smaller drops start the process over again.
2. Process is most efficient over the tropical oceans. There are fewer condensation nuclei, so each drop can pick up more of the smaller droplets, and thus grow larger.

Forms of Precipitation - 1

1. *Cloudbursts* - unusually heavy rainfall
2. *Drizzle* - fine uniform drops of water with a diameter less than 0.5 mm
3. *Mist* - precipitation containing the very smallest droplets able to reach the ground
4. *Virga* - Rain evaporates before it hits the ground

Forms of Precipitation - 2

1. Rain, snow, sleet, glaze, hail
2. ***Rain*** - drops of water that fall from a cloud and have a diameter of at least 0.5 mm.
3. Maximum size of rain drops is about 5 mm

Forms of Precipitation - 3

- 1. *Snow*** - is precipitation in the form of ice crystals or aggregates of ice crystals
- 2. *Sleet*** - small particles of ice that are clear to translucent. Snowflakes melt, then refreeze before hitting the ground.
- 3. *Hail*** - precipitation in the form of hard rounded pellets or irregular lumps of ice. Hailstones build up successive layers as they move up and down in a strong convective cloud.

Forms of Precipitation - 4

1. Hail is produced only in cumulonimbus clouds where updrafts reach 160 km/h. Needs an abundant supply of supercooled water.
2. **Rime** - deposit of ice crystals formed by the freezing of supercooled fog or cloud droplets on objects with surface temperatures below freezing.
3. **Freezing rain** - rain falling in liquid form through a shallow sub-freezing layer of air. The rain freezes on impact with the ground.

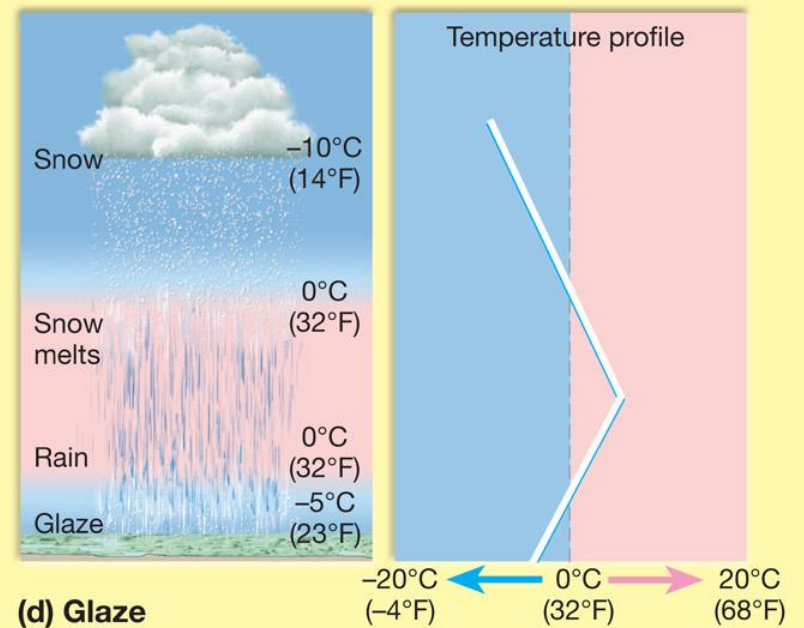
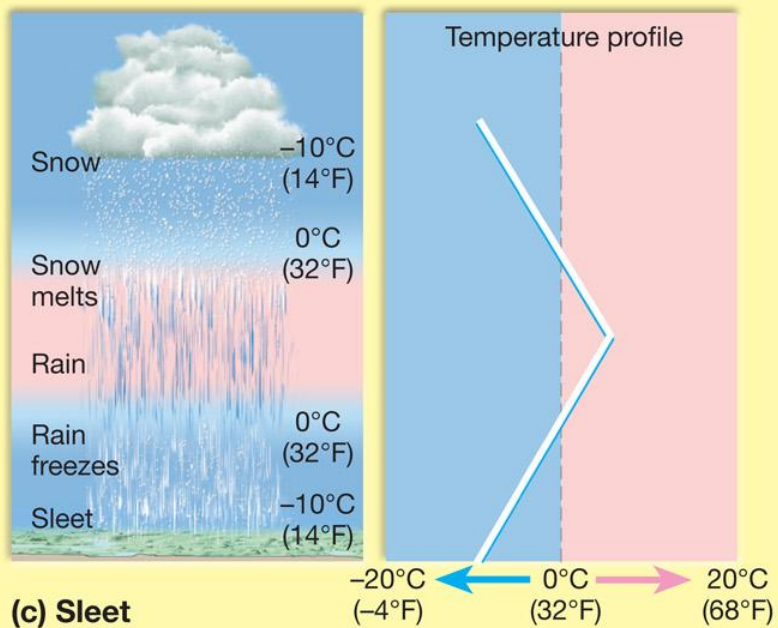
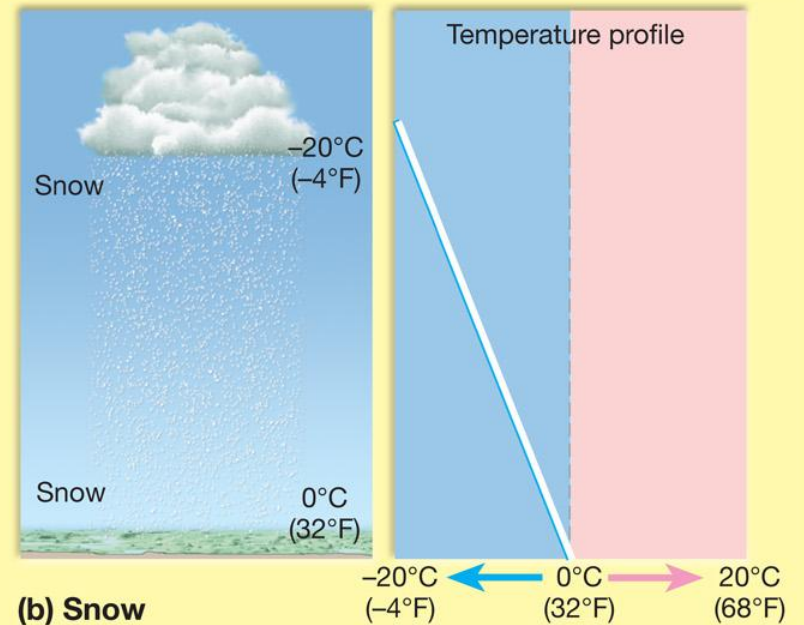
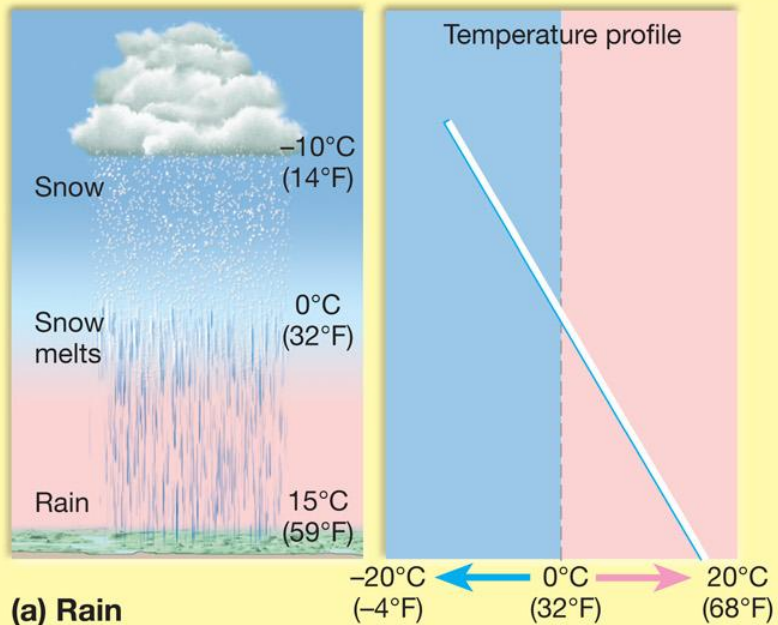
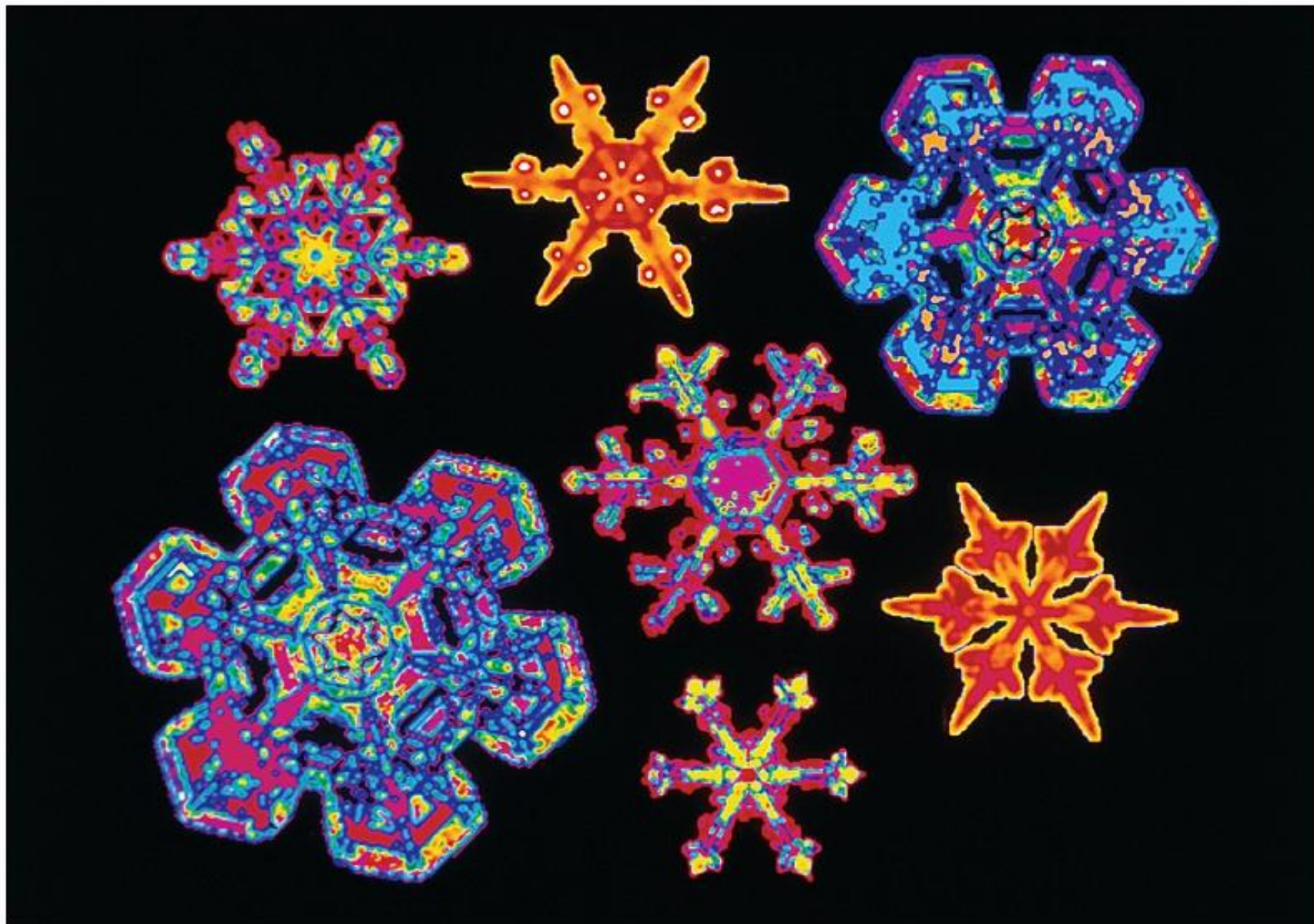


TABLE 5-4 Types of Precipitation

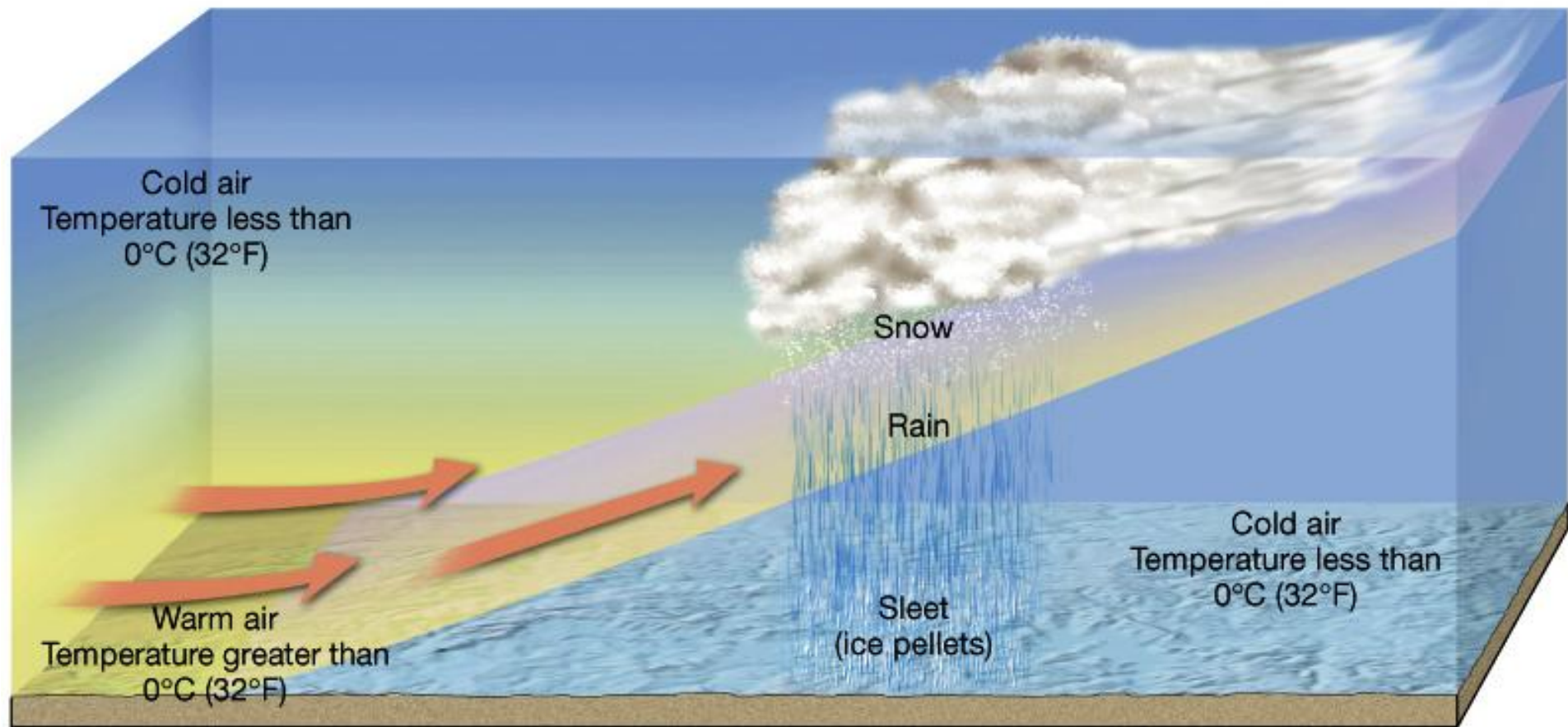
Type	Approximate size	State of water	Description
Mist	0.005 to 0.05 mm	Liquid	Droplets large enough to be felt on the face when air is moving 1 meter/second. Associated with stratus clouds.
Drizzle	Less than 0.5 mm	Liquid	Small uniform drops that fall from stratus clouds, generally for several hours.
Rain	0.5 to 5 mm	Liquid	Generally produced by nimbostratus or cumulonimbus clouds. When heavy, size can be highly variable from one place to another.
Sleet	0.5 to 5 mm	Solid	Small, spherical to lumpy ice particles that form when raindrops freeze while falling through a layer of subfreezing air. Because the ice particles are small, any damage is generally minor. Sleet can make travel hazardous.
Glaze	Layers 1 mm to 2 cm thick	Solid	Produced when supercooled raindrops freeze on contact with solid objects. Glaze can form a thick coating of ice having sufficient weight to seriously damage trees and power lines.
Rime	Variable accumulations	Solid	Deposits usually consisting of ice feathers that point into the wind. These delicate frostlike accumulations form as supercooled cloud or fog droplets encounter objects and freeze on contact.
Snow	1 mm to 2 cm	Solid	The crystalline nature of snow allows it to assume many shapes, including six sided crystals, plates, and needles. Produced in supercooled clouds where water vapor is deposited as ice crystals that remain frozen during their descent.
Hail	5 mm to 10 cm or larger	Solid	Precipitation in the form of hard, rounded pellets or irregular lumps of ice. Produced in large convective, cumulonimbus clouds, where frozen ice particles and supercooled water coexist.
Graupel	2 mm to 5 mm	Solid	Sometimes called "soft hail," graupel forms as rime collects on snow crystals to produce irregular masses of "soft" ice. Because these particles are softer than hailstones, they normally flatten out upon impact.

Virga (streak)



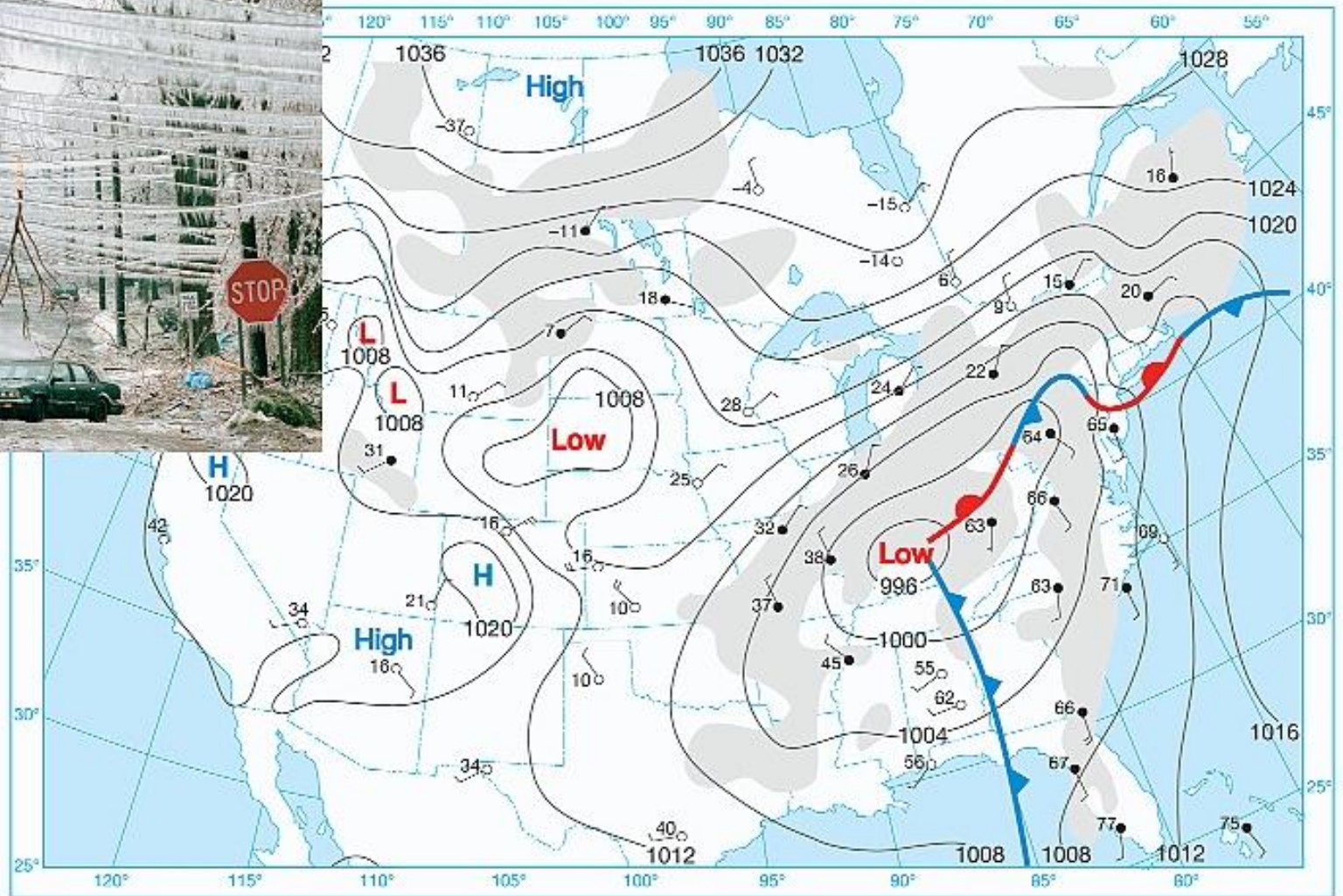


Copyright © 2010 Pearson Education, Inc.





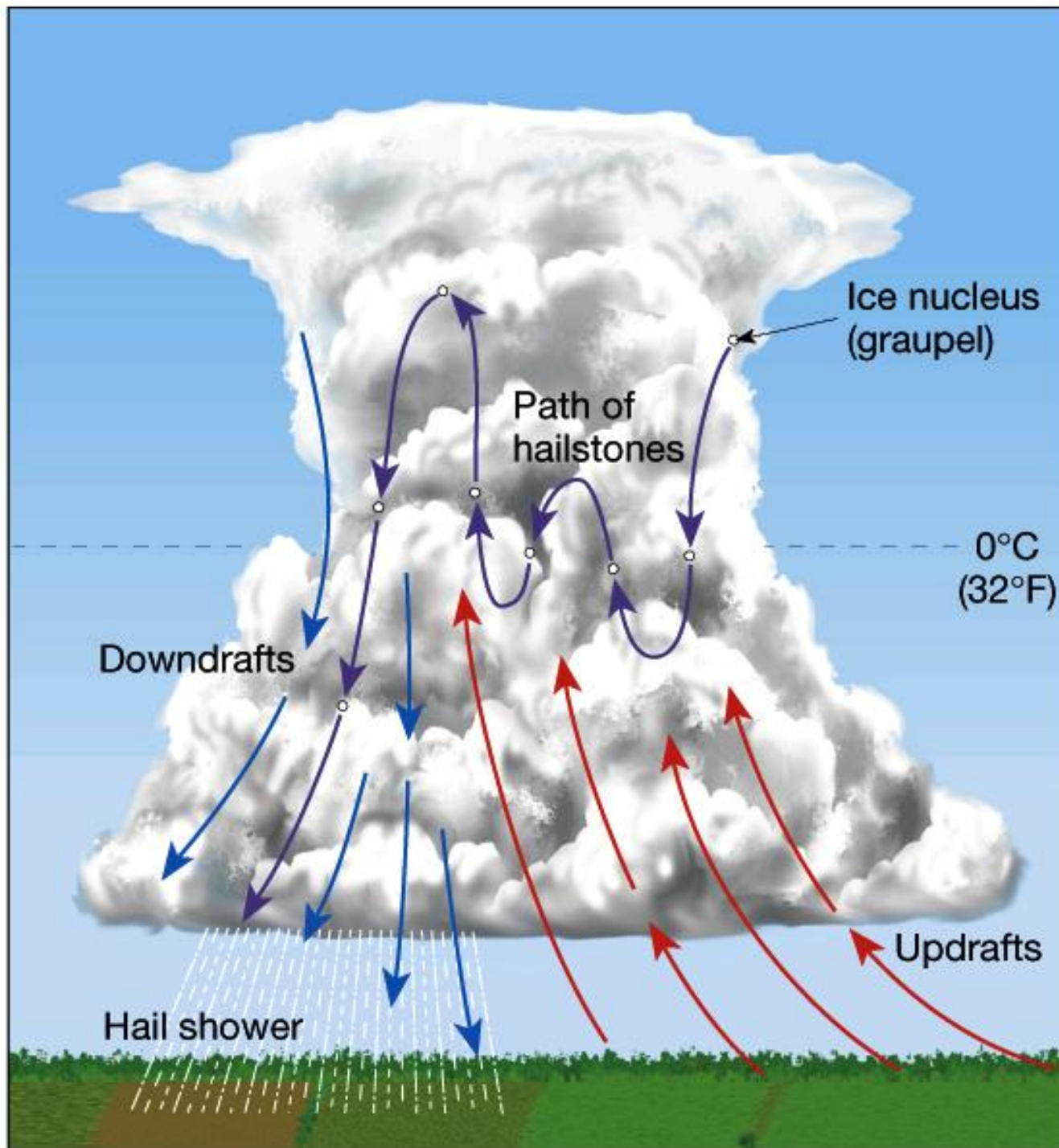
(a)



(b)







Rime

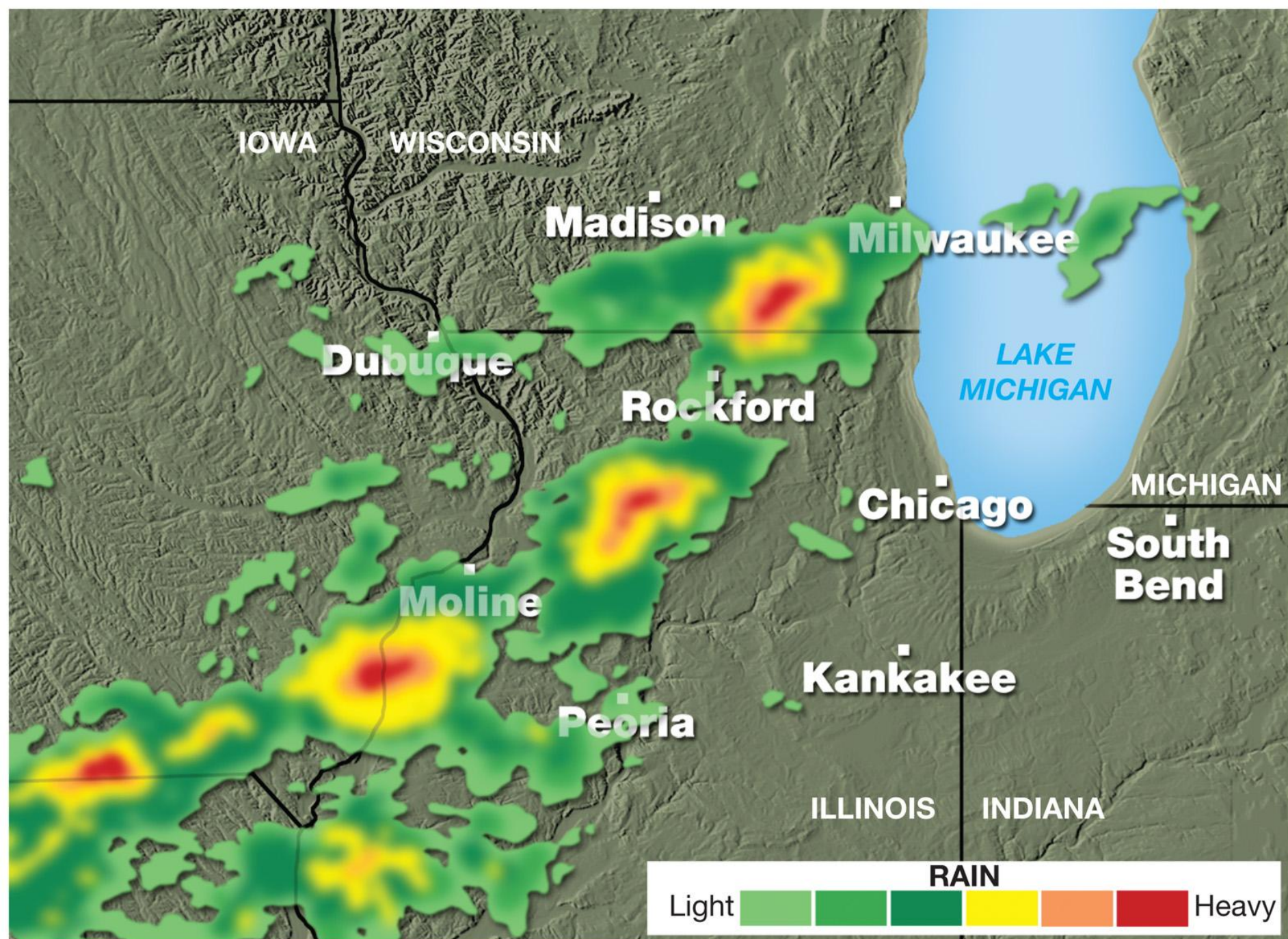


Worst Winter Weather

- Snow flurries
- Blowing Snow
- Drifting Snow
- Blizzard
- Severe Blizzard
- Heavy Snow Warning

Worst Winter Weather - 2

- Freezing Rain
- Sleet
- Traveler's Advisory
- Cold Wave
- Windchill (Box 3-5)



Intentional Weather Modification

Three broad categories:

- Use energy, mainly heat
- Modify land and water surfaces to change the albedo
- Provide extra condensation nuclei

Weather Modification

1. **Cloud seeding** - silver iodide crystals. The cloud must be supercooled.
2. Researchers are confident that winter precipitation can be enhanced by seeding supercooled orographic clouds.
3. Using large hygroscopic particles to seed warm convective clouds might work.
4. Economic viability uncertain. Also political ramifications (stealing someone else's rain)





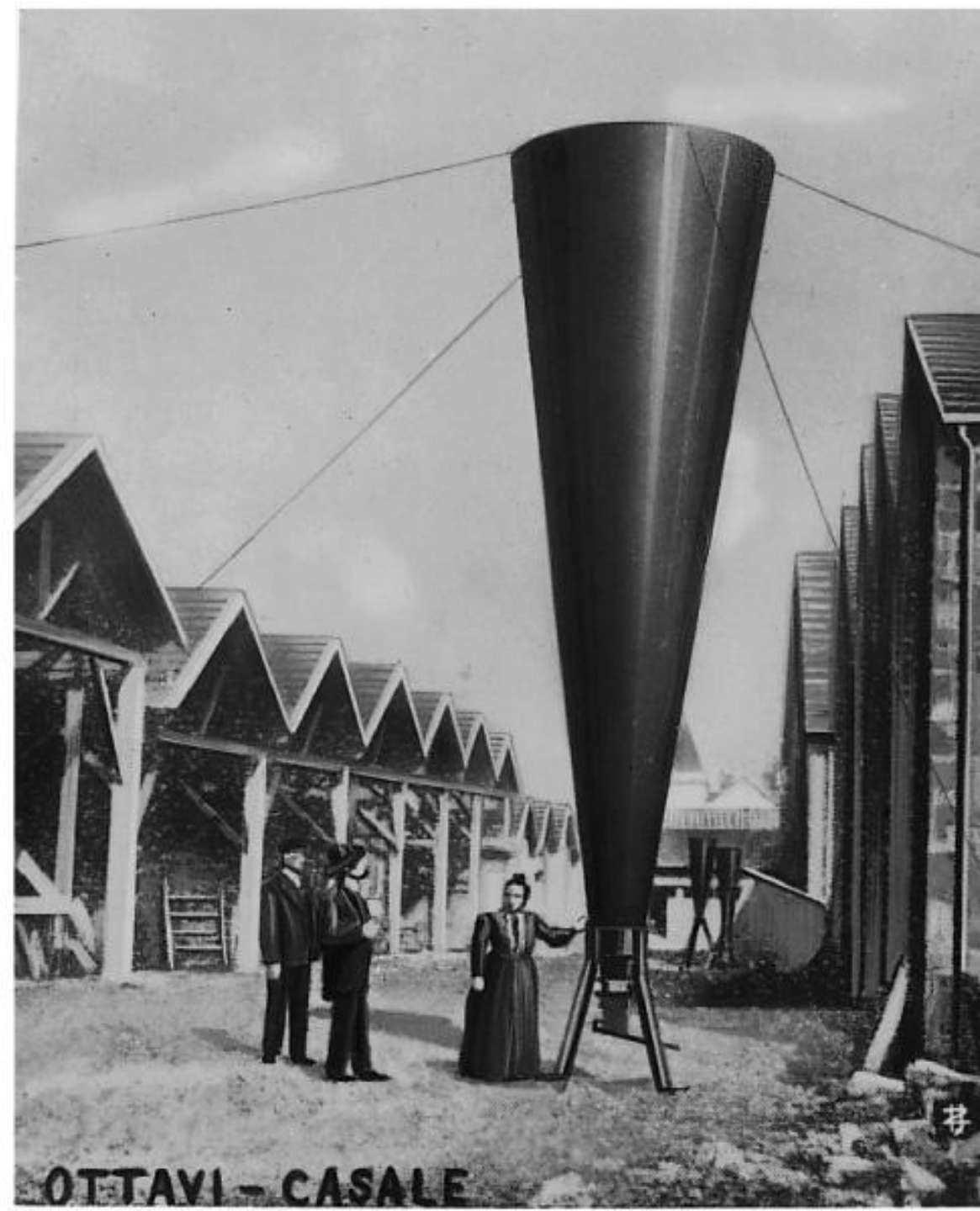
Weather Modification - 2

- 1. *Fog & Cloud Dispersal*** - can spread particles of dry ice (solid carbon dioxide) into layer of supercooled fog or stratus clouds disperses them. Light snow may result.
- 2. *Hail suppression*** - use silver iodide crystals - no real effect

Hail Damage



Hail Cannon



Weather Modification - 3

1. ***Frost prevention*** - frost induced by radiation cooling is easy to combat
2. Methods either conserve heat, or provide heat
3. Insulation (e.g., paper) conserves heat.
4. Water can be used to keep the crops warm. Spray the crops with water (before the frost forms) and rely on the latent heat released when the water freezes.
5. ***Best results*** come from orchard heaters, but these are expensive.

Sprinklers



(a)

Wind machines



(b)

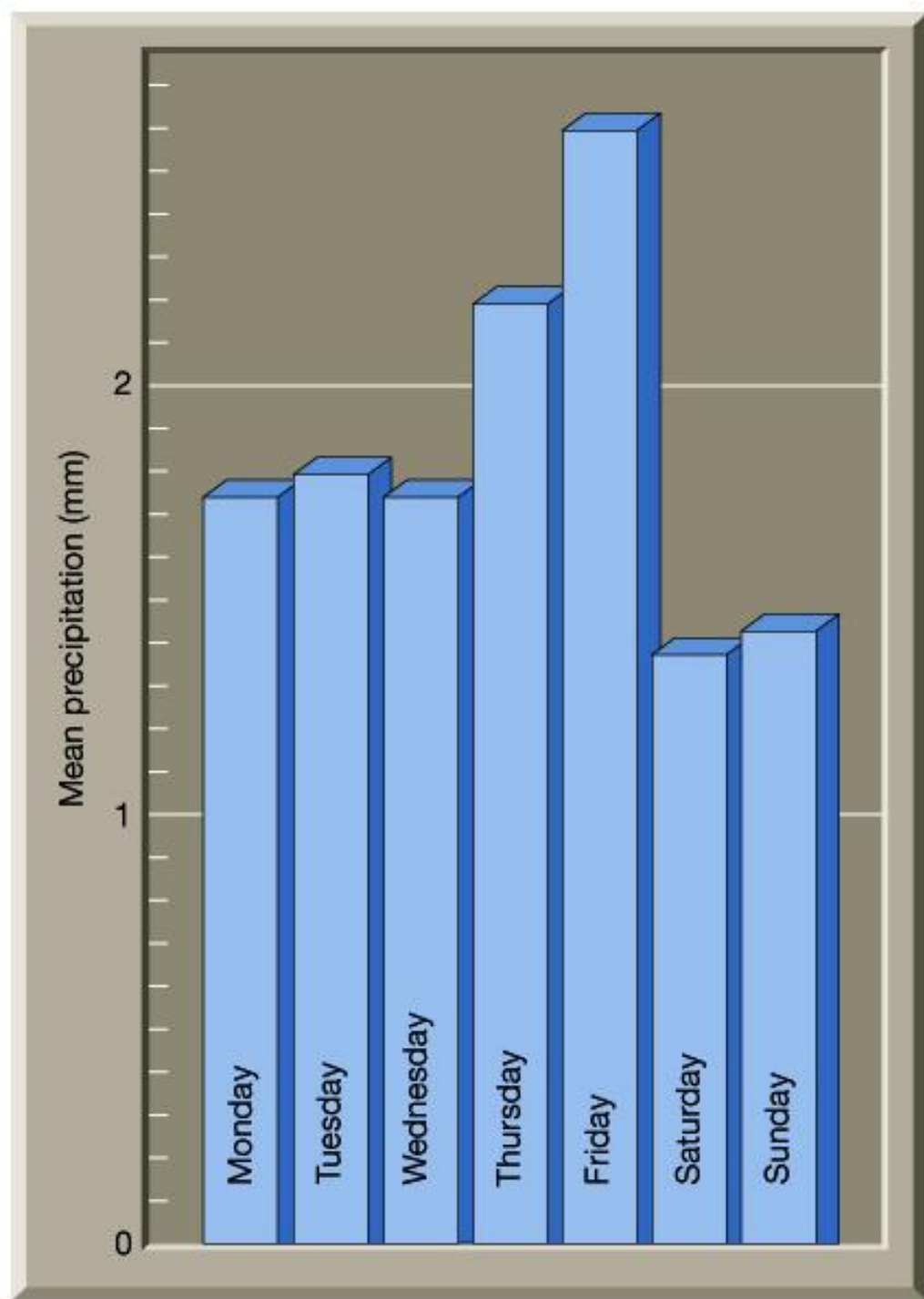
Orchard Heaters



Inadvertent Weather Modification

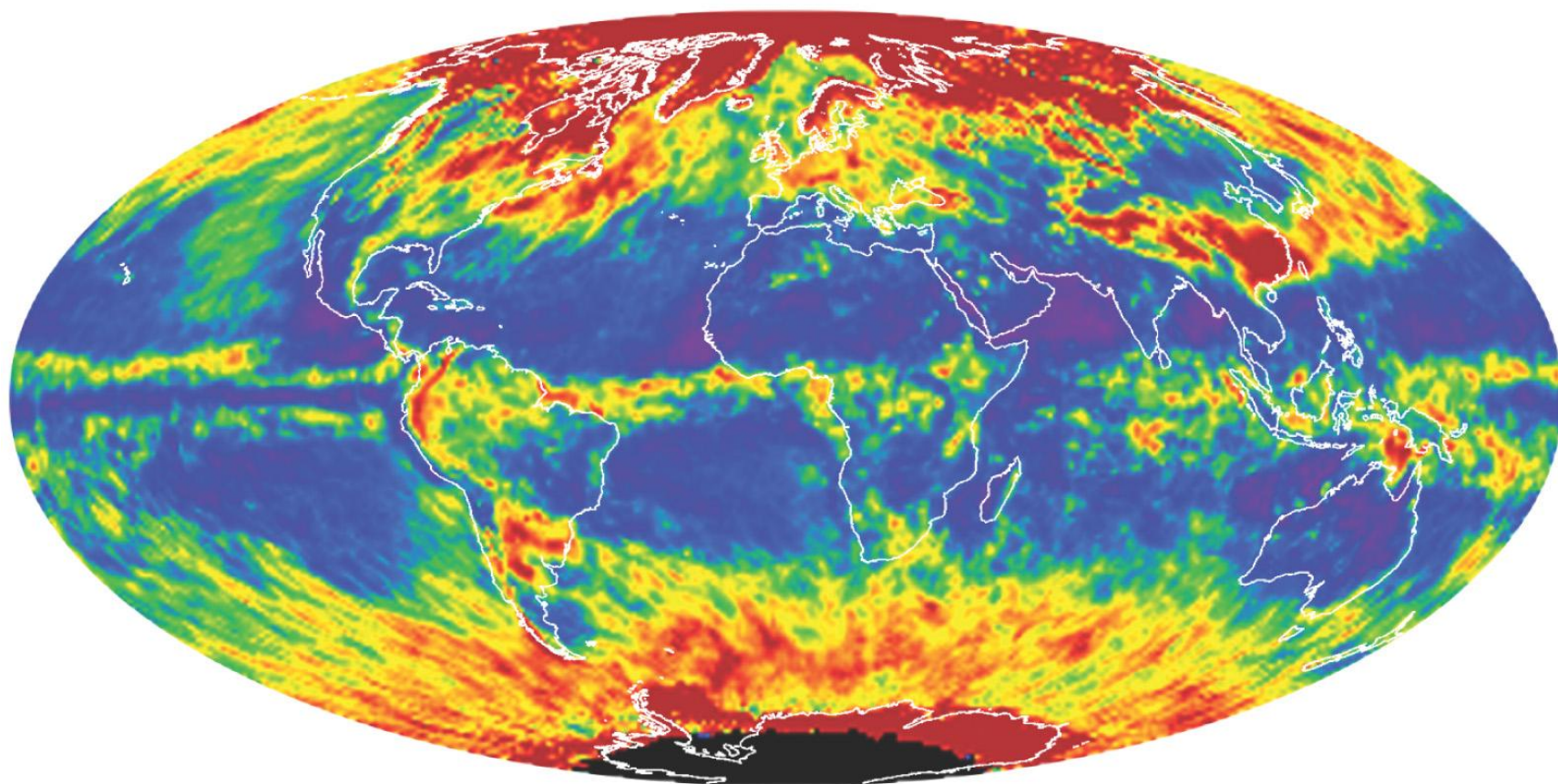
1. Cities modify weather. Get about 10% more rain than country. Effect also occurs downwind.
2. Particulate matter emitted by cities include hygroscopic particles and freezing nuclei.
3. Cities are warmer than the countryside. Surface heating of air tends to increase the environmental lapse rate, thus enhancing instability.
4. Large buildings of cities cause convergence, and enhance the upward flow of air.

Rainfall by day of week



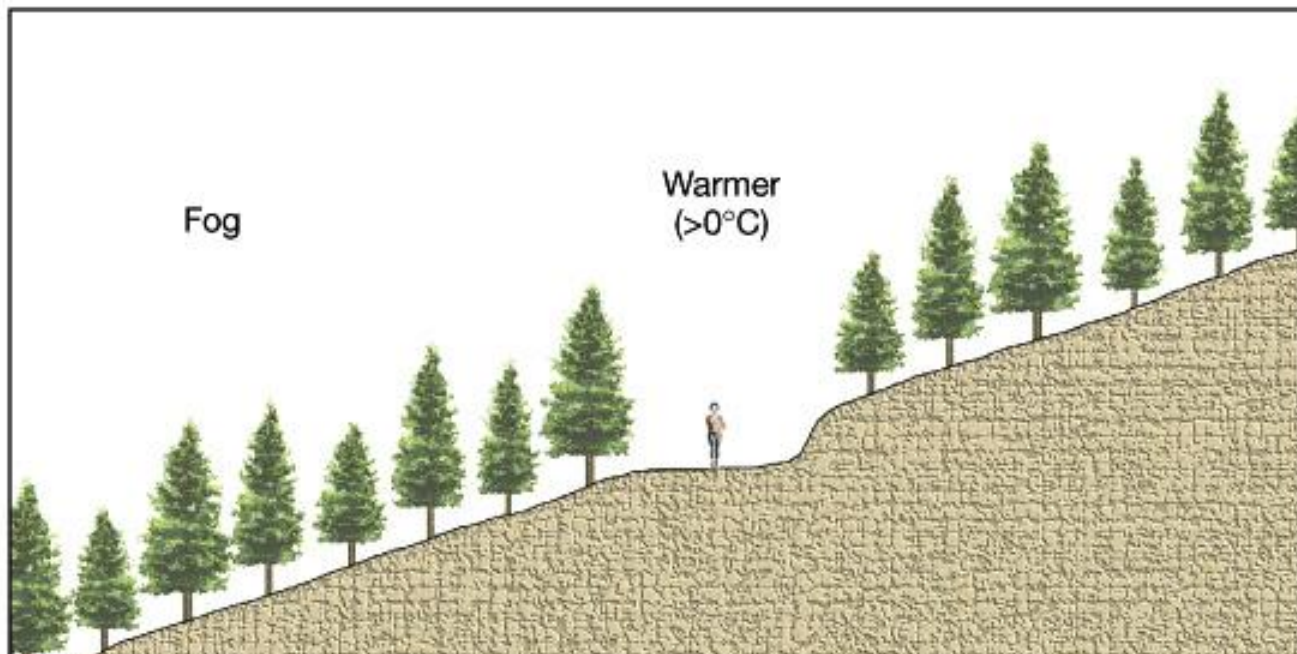
Clouds & Climate

- Moderate resolution Imaging Spectroradiometer (MODIS)
- False-color average for a month of optical thickness
- How much solar radiation can penetrate the atmosphere
- Blue- no cloud; red & yellow – very cloudy; green – in between



Cloud Optical Thickness





Science & Serendipity

