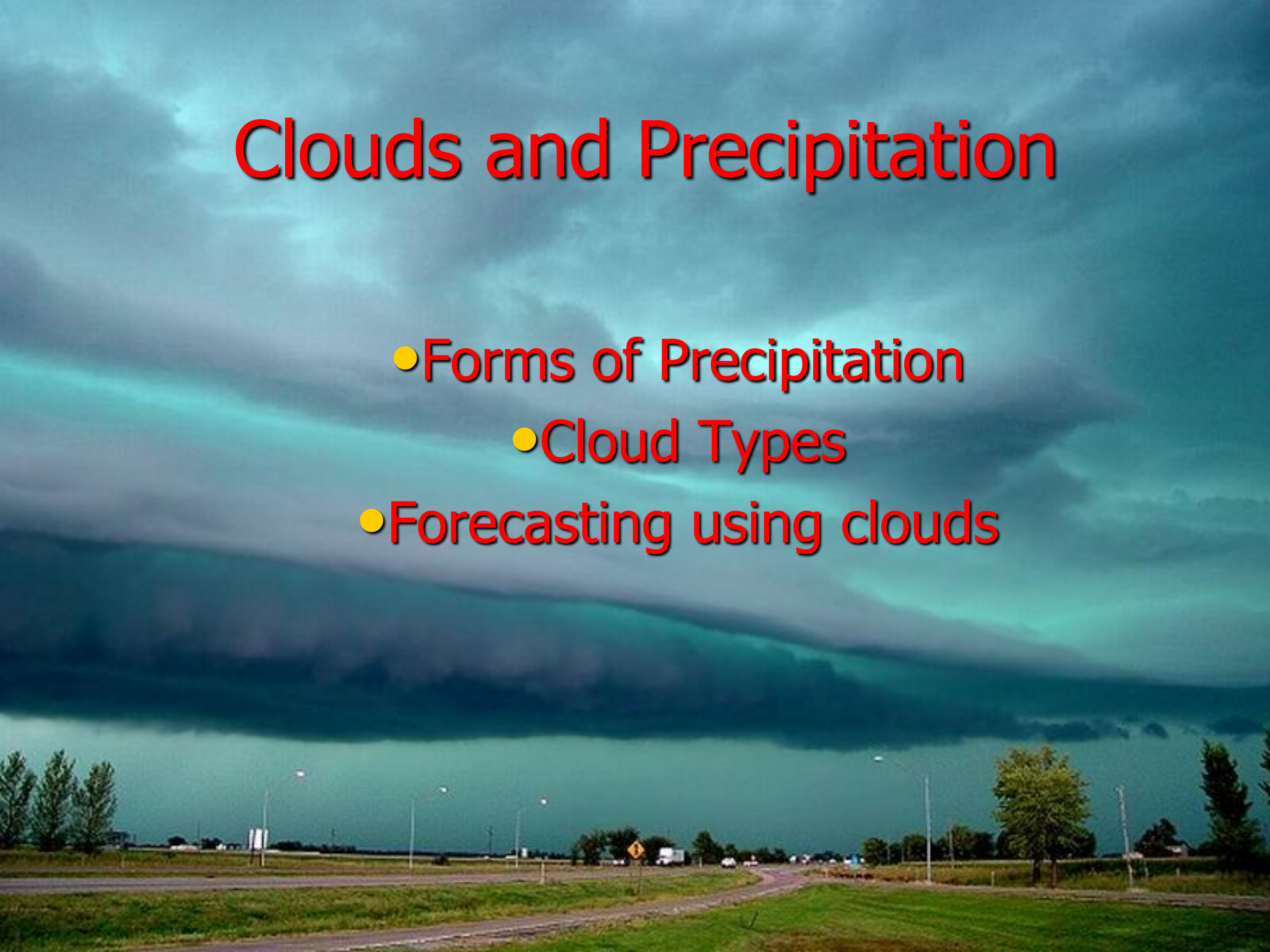
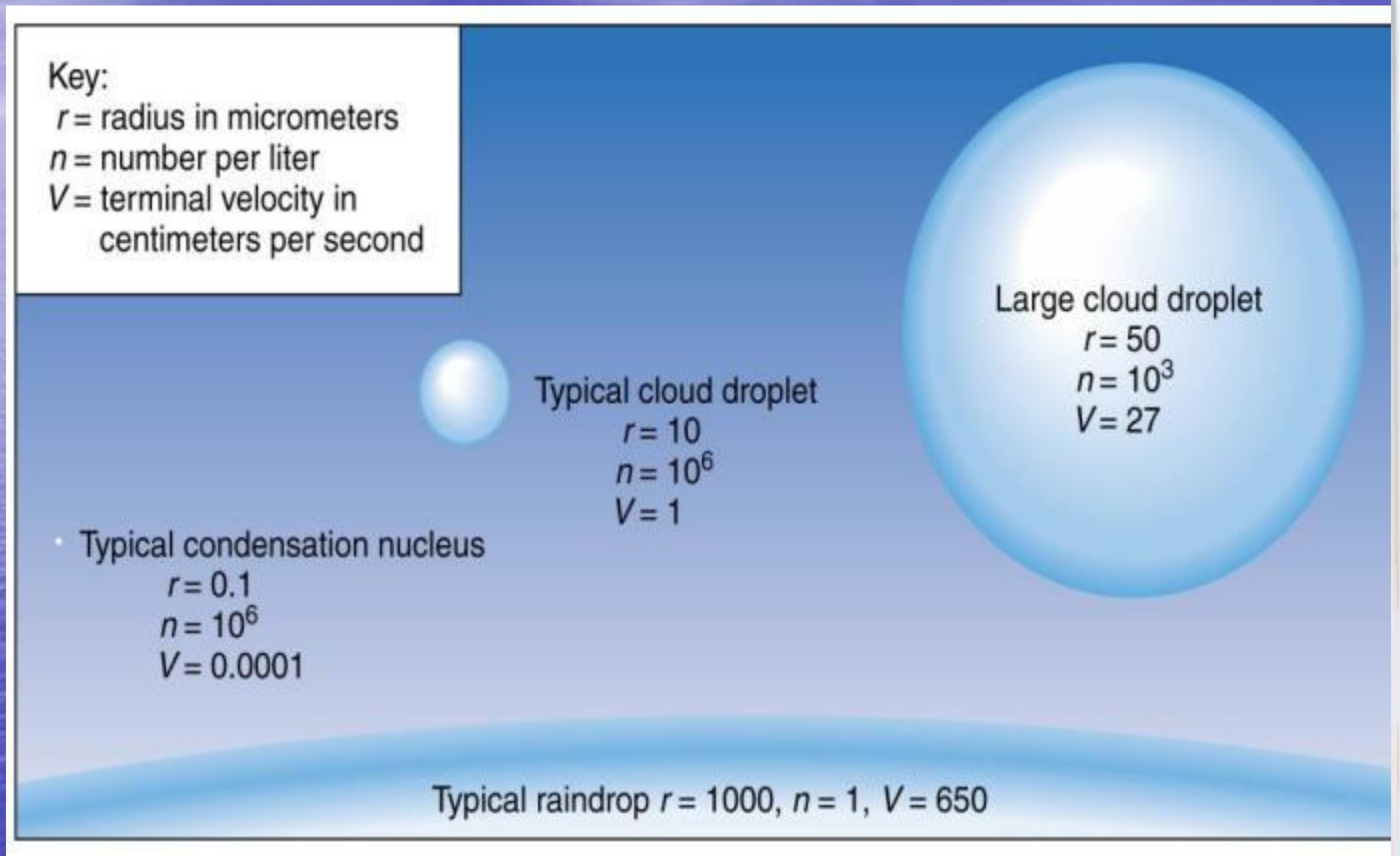
Clouds and Precipitation

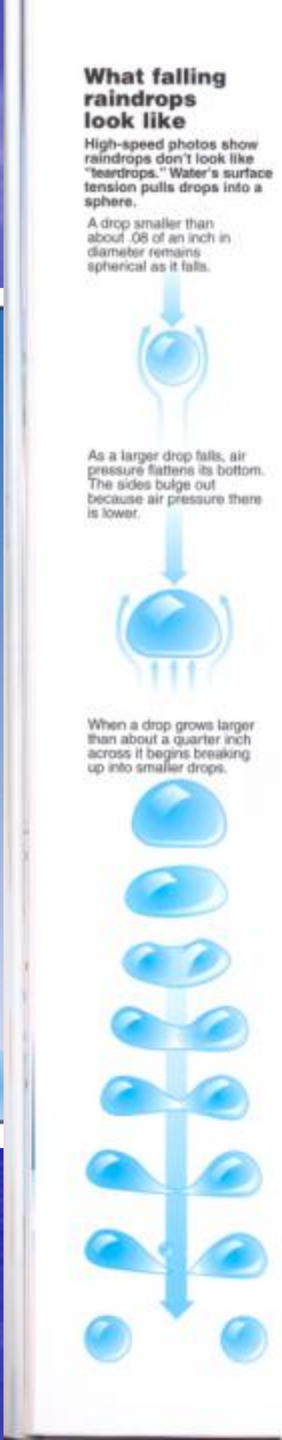
- Forms of Precipitation
- Cloud Types
- Forecasting using clouds



Gravity Vs. Friction

- Not all clouds produce precipitation
  - Size vs. Terminal velocity (TV)
- Cloud Droplets extremely low TV
- Rapid cloud drop growth rates are required for precipitation to form
  - Weak updrafts maintain even small particles
  - Size of rain droplet = 100 * cloud droplet size (Volume = 1,000,000)


Key:
r = radius in micrometers
n = number per liter
V = terminal velocity in centimeters per second
Large cloud droplet
$r = 50$
$n = 10^3$
$V = 27$
Typical cloud droplet
$r = 10$
$n = 10^6$
$V = 1$
Typical condensation nucleus
$r = 0.1$
$n = 10^6$
$V = 0.0001$
Typical raindrop $r = 1000$, $n = 1$, $V = 650$

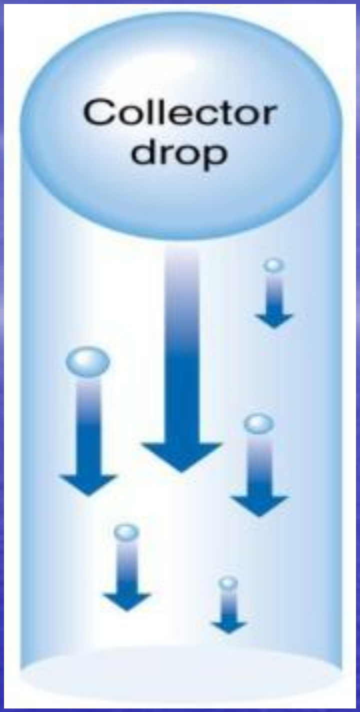

What falling raindrops look like
High-speed photos show raindrops don't look like "teardrops." Water's surface tension pulls drops into a sphere.
A drop smaller than about .08 of an inch in diameter remains spherical as it falls.
As a larger drop falls, air pressure flattens its bottom. The sides bulge out because air pressure there is lower.
When a drop grows larger than about a quarter inch across it begins breaking up into smaller drops.

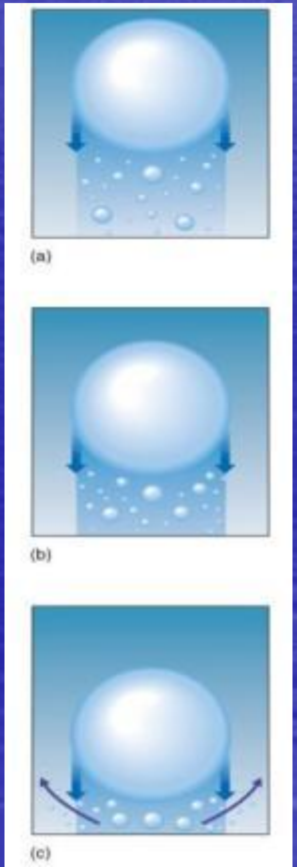
How do clouds precipitate?

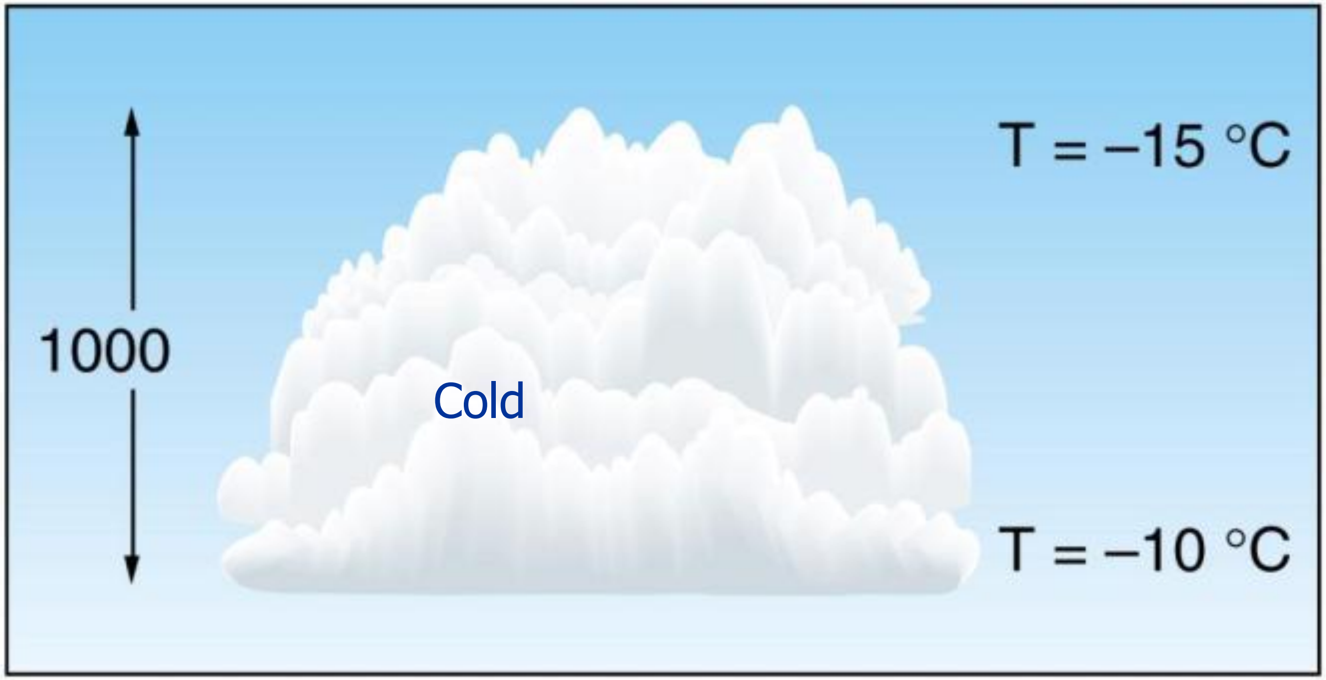
- Growth by Condensation
  - Condensation about condensation nuclei initially forms most cloud drops
  - Only a valid form of growth until the drop achieves a radius of about 20 μm due to overall low amounts of water vapor available
  - Insufficient process to generate precipitation
  - Two other processes necessary……

- Growth in Warm Clouds
  - Clouds with temperatures above freezing dominate tropics and mid-latitudes during the warm season
  - ***Collision-coalescence*** generates precipitation
  - Process begins with large collector drops which have high terminal velocities

- Collision
  - Collector drops collide with smaller drops
  - Due to compressed air beneath falling drop, there is an inverse relationship between collector drop size and collision efficiency
  - Collisions typically occur between a collector and fairly large cloud drops
  - Smaller drops are pushed aside
- Coalescence
  - When collisions occur, drops either bounce apart or coalesce into one larger drop
  - Coalescence efficiency is very high indicating that most collisions result in coalescence



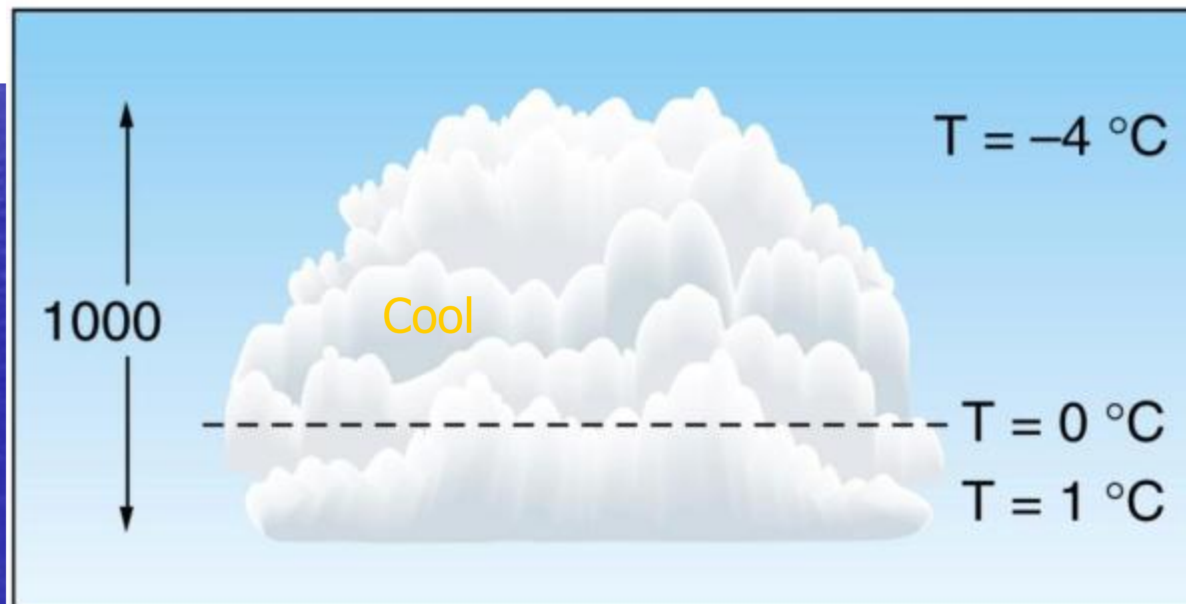




Cold Clouds

(a)

Cool Clouds



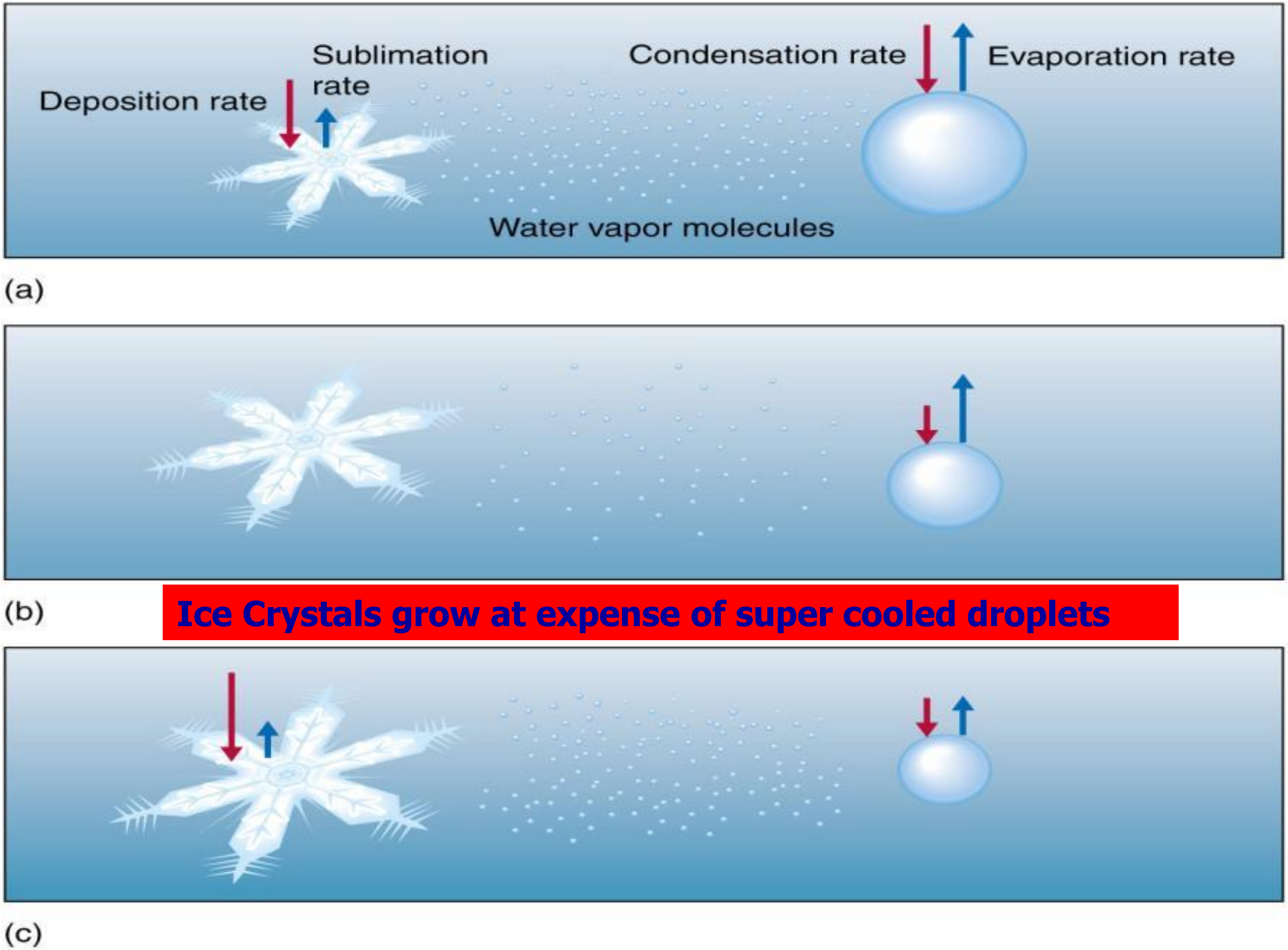
(b)

Big storm clouds contain:
•ice
•liquid drops
•mix of ice and liquid

Growth in Cool/Cold Clouds

- Cool month mid-latitude and high latitude clouds are classified as cool clouds as average temperatures are usually below freezing in portions
- Clouds may be composed of
  - Liquid water
  - Supercooled water
  - and/or Ice
- Coexistence of ice and supercooled water is critical to the creation of cool cloud precipitation - the ***Bergeron Process***

The Bergeron Process



Ice Crystals grow at expense of super cooled droplets

Review of Bergeron

- Saturation vapor pressure of ice is less than that of supercooled water and water vapor
- During coexistence, water will sublimate directly onto ice
- Ice crystals grow rapidly at the expense of supercooled drops
- Bergeron not enough……

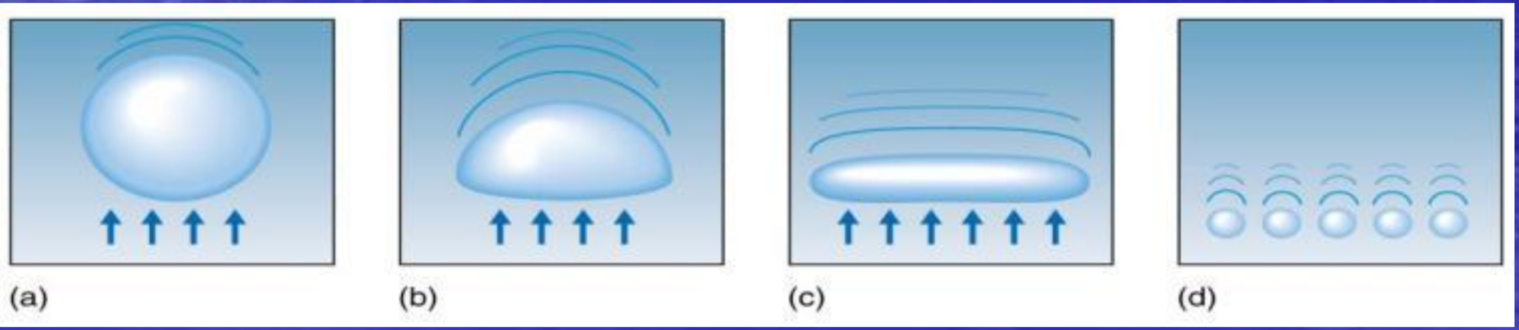
- *Riming* = liquid water freezing onto ice crystals producing rapid growth
- *Aggregation* = the joining of multiple ice crystals through the bonding of surface water builds ice crystals to the point of overcoming updrafts
  - Likely when temps not much above 0C
- Collision combined with riming and aggregation allow formation of precipitation within 1/2 hour of initial formation

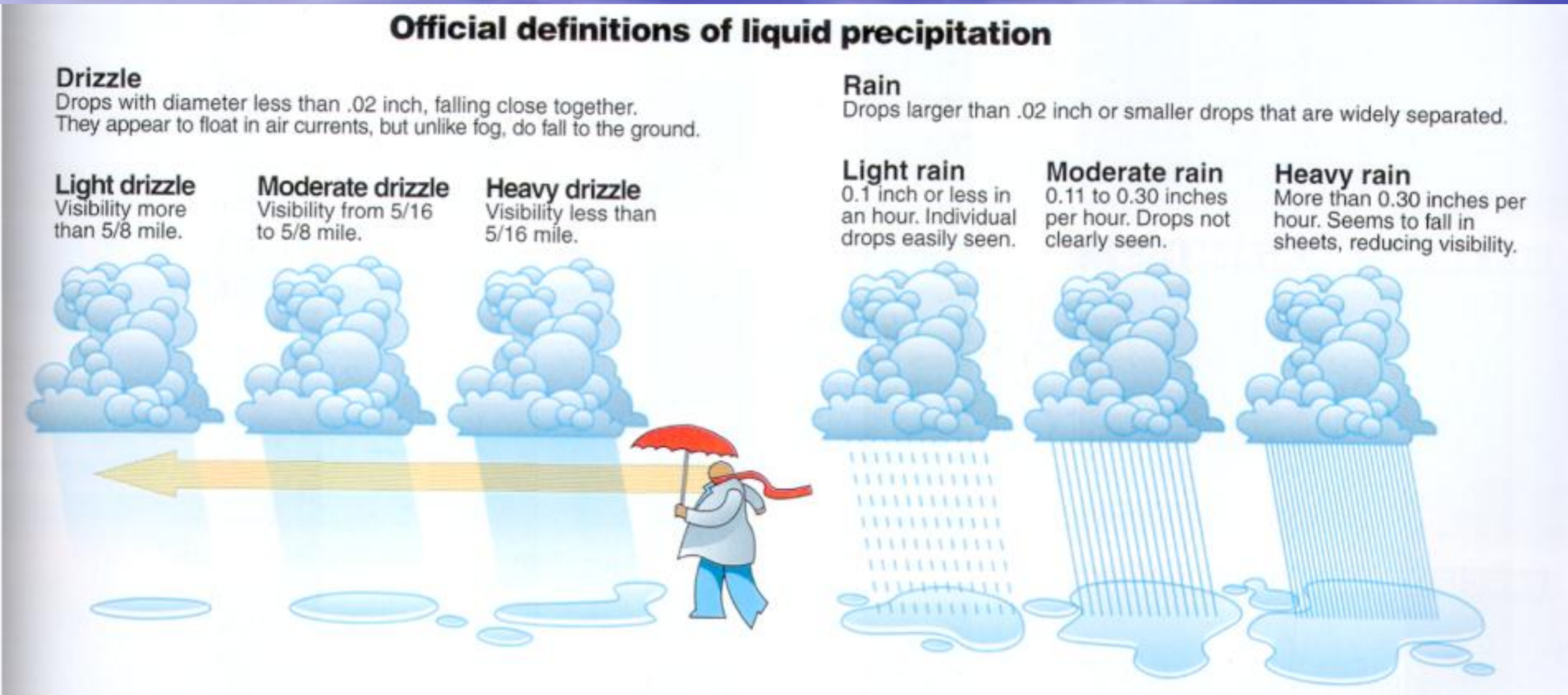
- Warm snow vs. Cold snow

Forms of Precipitation

- Rain
- Snow
- Graupel
- Hail
- Sleet
- Freezing Rain

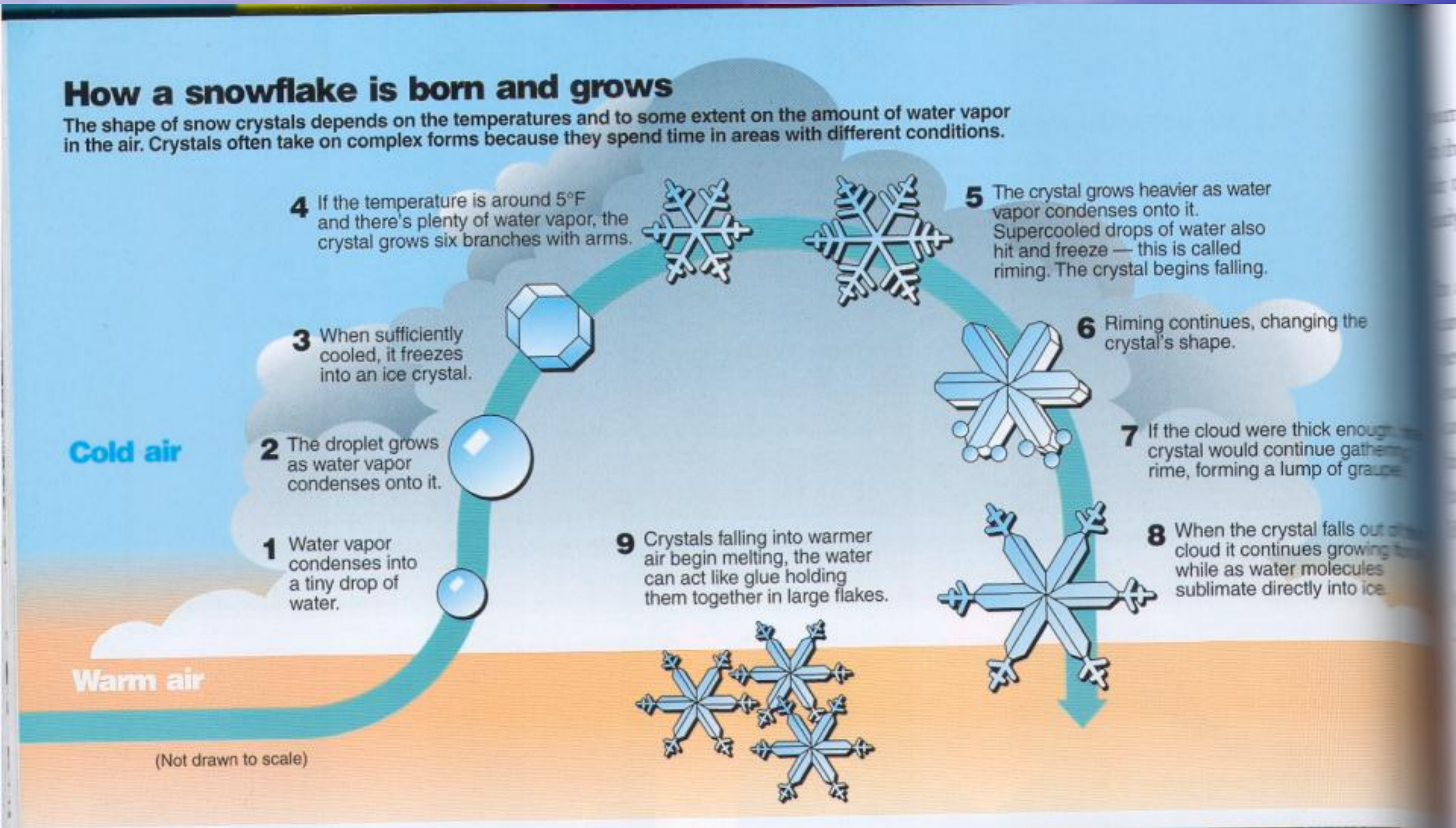
- *Rain* is associated with warm clouds exclusively and cool clouds when surface temperatures are above freezing
- ***Rainshowers*** are episodic precipitation events associated with convective activity and cumulus clouds
  - Drops tend to be large and widely spaced to begin, then smaller drops become more prolific
- ***Raindrop Shape*** begins as spherical
  - As frictional drag increases, changes to a mushroom shape
  - Drops eventually flatten
  - Drops split when frictional drag overcomes the surface tension of water
  - Splitting ensures a maximum drop size of about 5 mm and the continuation of the collision-coalescence process




Official definitions of liquid precipitation
Drizzle
Drops with diameter less than .02 inch, falling close together. They appear to float in air currents, but unlike fog, do fall to the ground.
Light drizzle
Visibility more than 5/8 mile.
Moderate drizzle
Visibility from 5/16 to 5/8 mile.
Heavy drizzle
Visibility less than 5/16 mile.
Rain
Drops larger than .02 inch or smaller drops that are widely separated.
Light rain
0.1 inch or less in an hour. Individual drops easily seen.
Moderate rain
0.11 to 0.30 inches per hour. Drops not clearly seen.
Heavy rain
More than 0.30 inches per hour. Seems to fall in sheets, reducing visibility.

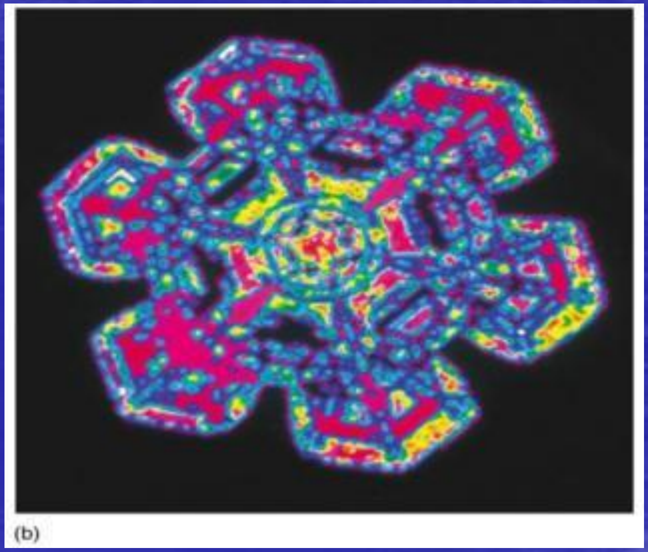
Snow

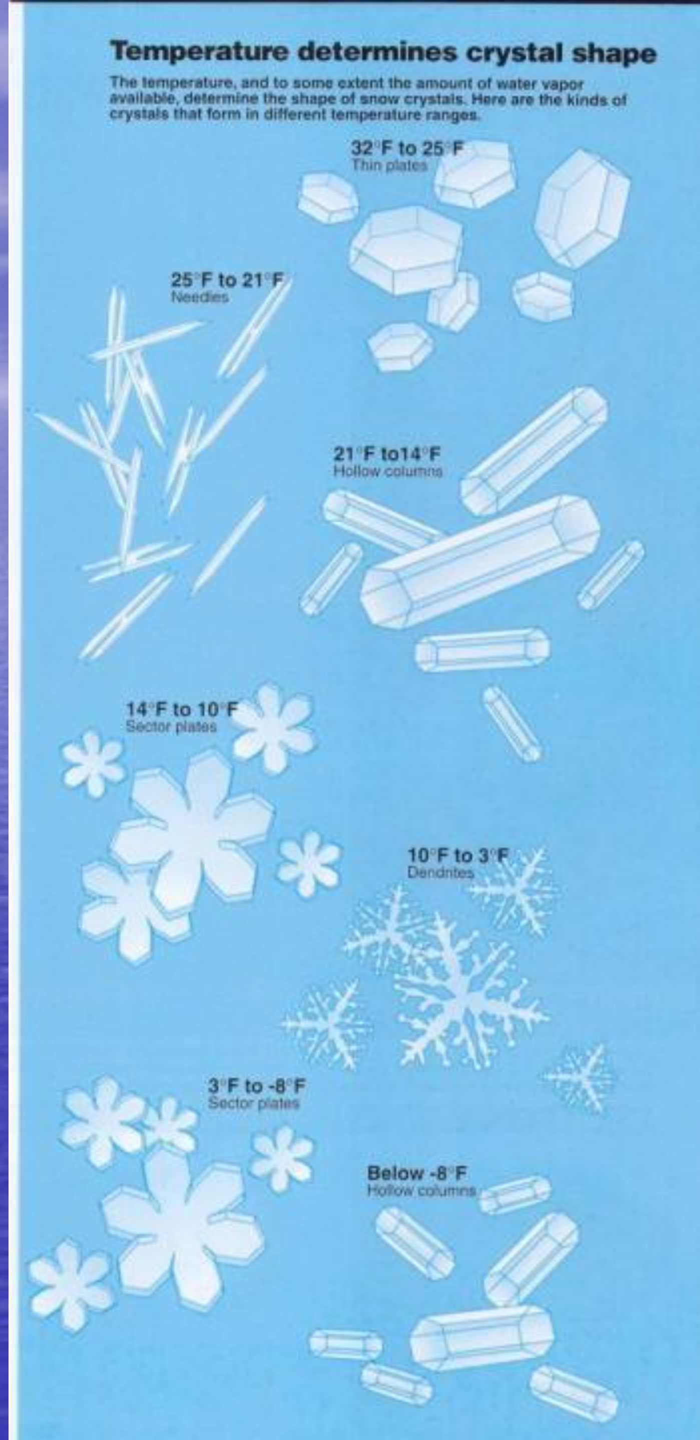
- *Snow* results from the Bergeron process, riming, and aggregation
- Snowflakes have a wide assortment of shapes and sizes depending on moisture content and temperature of the air
- Snowfall distribution in North America is related to north-south alignment of mountain ranges and the presence of the Great Lakes
- Lake effect snows develop as the warm lake waters evaporate into cold air
  - More on this later
- Topographic features aid downwind snow development


How a snowflake is born and grows
The shape of snow crystals depends on the temperatures and to some extent on the amount of water vapor in the air. Crystals often take on complex forms because they spend time in areas with different conditions.
1 Water vapor condenses into a tiny drop of water.
2 The droplet grows as water vapor condenses onto it.
3 When sufficiently cooled, it freezes into an ice crystal.
4 If the temperature is around 5°F and there's plenty of water vapor, the crystal grows six branches with arms.
5 The crystal grows heavier as water vapor condenses onto it. Supercooled drops of water also hit and freeze — this is called riming. The crystal begins falling.
6 Riming continues, changing the crystal's shape.
7 If the cloud were thick enou crystal would continue gath rime, forming a lump of gra
8 When the crystal falls ou cloud it continues growin while as water molecules sublimate directly into ice
9 Crystals falling into warmer air begin melting, the water can act like glue holding them together in large flakes.
Cold air
Warm air
(Not drawn to scale)

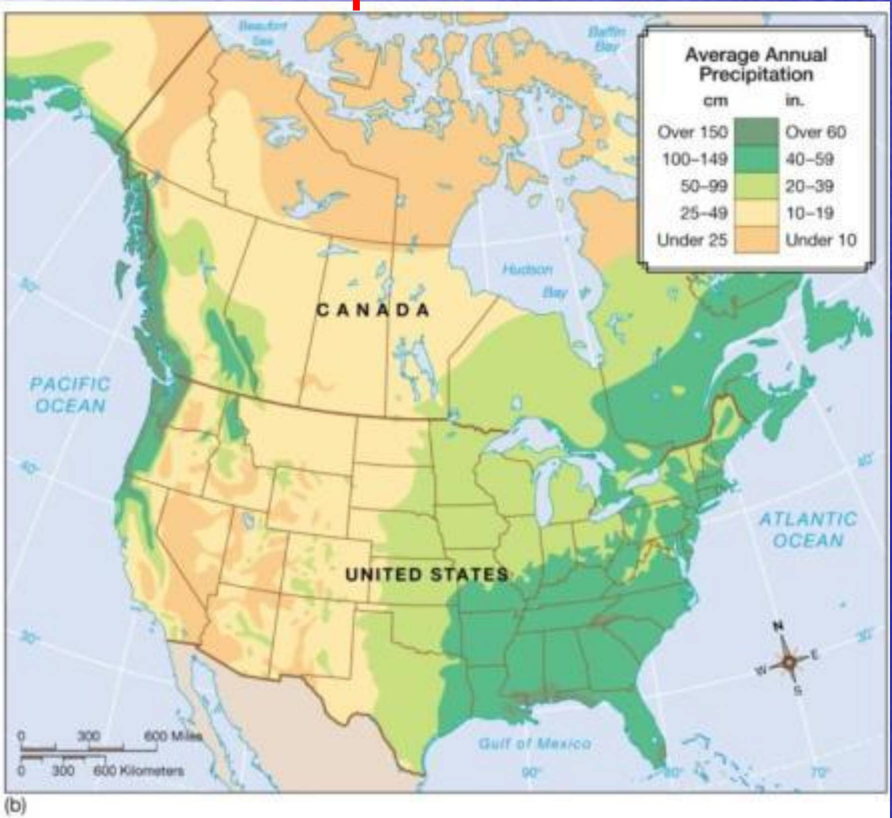
Dendrite ice crystals

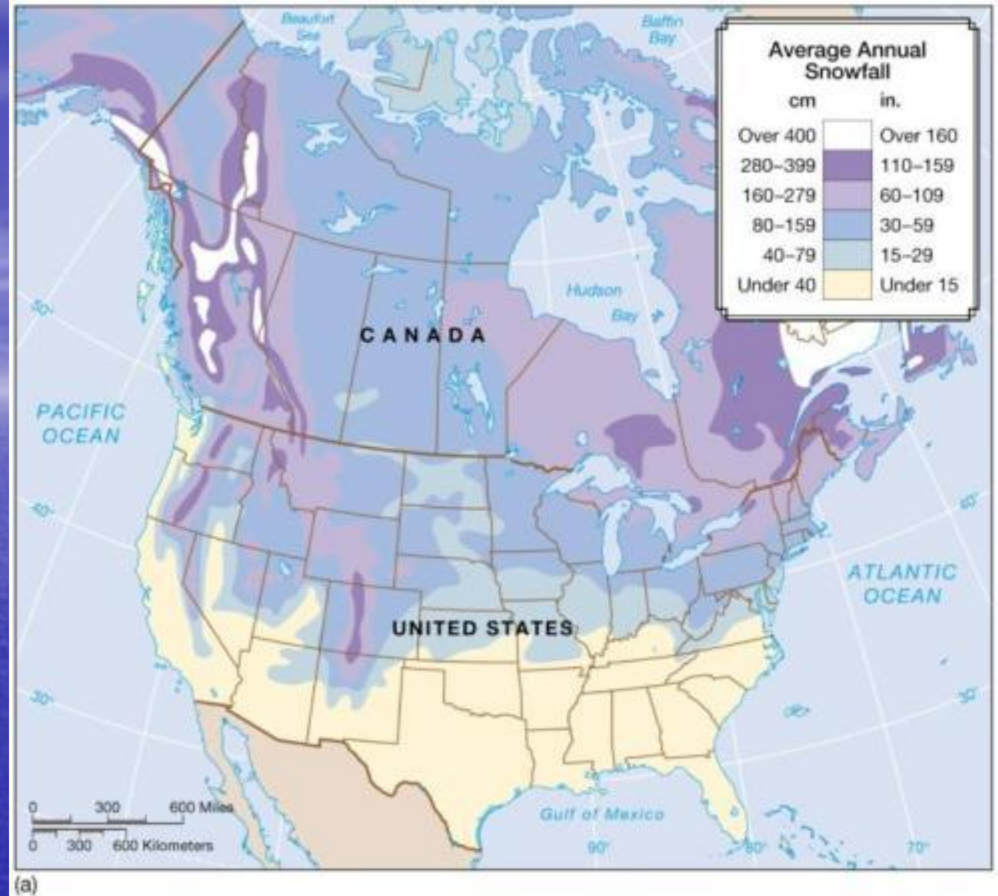
Plate ice crystal




Temperature determines crystal shape
The temperature, and to some extent the amount of water vapor available, determine the shape of snow crystals. Here are the kinds of crystals that form in different temperature ranges.
32°F to 25°F
Thin plates
25°F to 21°F
Needles
21°F to14°F
Hollow columns
14°F to 10°F
Sector plates
10°F to 3°F
Dendrites
3°F to -8°F
Sector plates
Below -8°F
Hollow columns

Precipitation





Snowfall

- *Graupel* are ice crystals that undergo extensive riming
  - Lose six sided shape and smooth out
  - Either falls to the ground or provides a nucleus for hail
- *Hail* forms as concentric layers of ice build around graupel
  - Formed as graupel is carried aloft in updrafts
  - At high altitudes, water accreting to graupel freezes, forming a layer
  - Hail falls but is eventually carried aloft again by an updraft where the process repeats
  - Hailstones are very heavy as the process ensures a composition high in water and low in air
  - Capable of tremendous amounts of damage
  - Great Plains = highest frequency of hail events

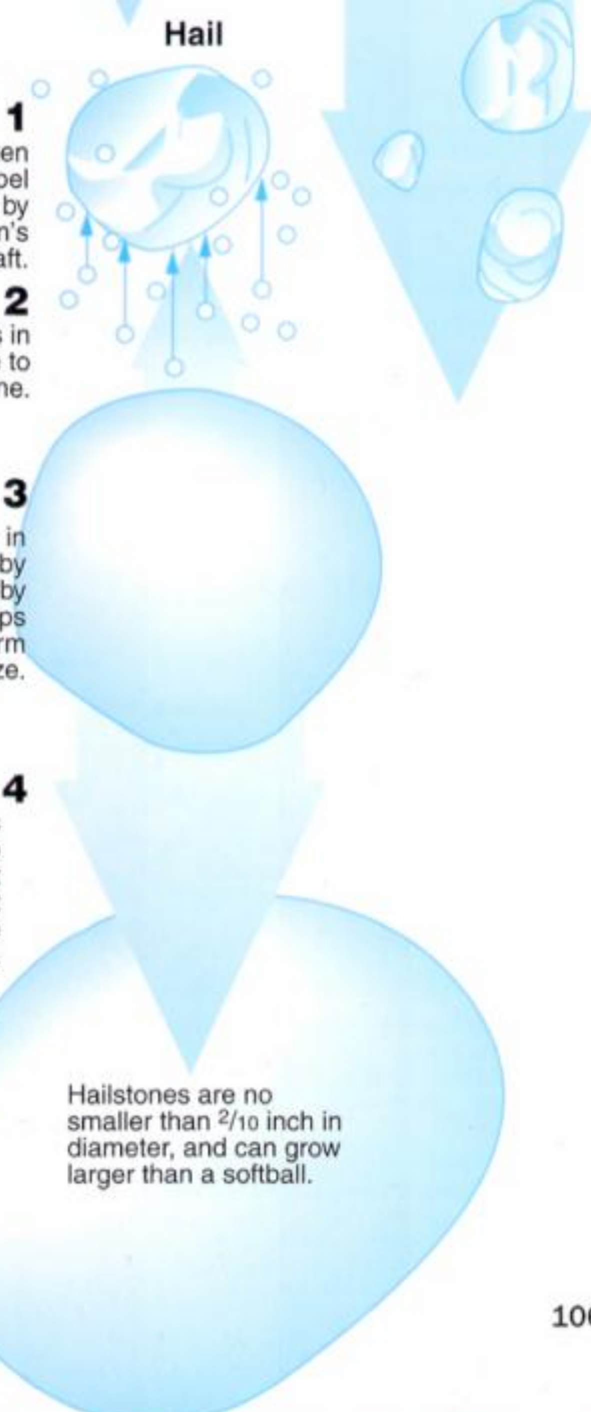
Graupel

1
Ice crystals — they can be snow — fall through supercooled cloud droplets.

2
Supercooled droplets that hit the crystal freeze to it.

3
Eventually the frozen droplets can hide the original shape.

Hail



1
Hail begins as a frozen raindrop or graupel that's kept from falling by a thunderstorm's updraft.

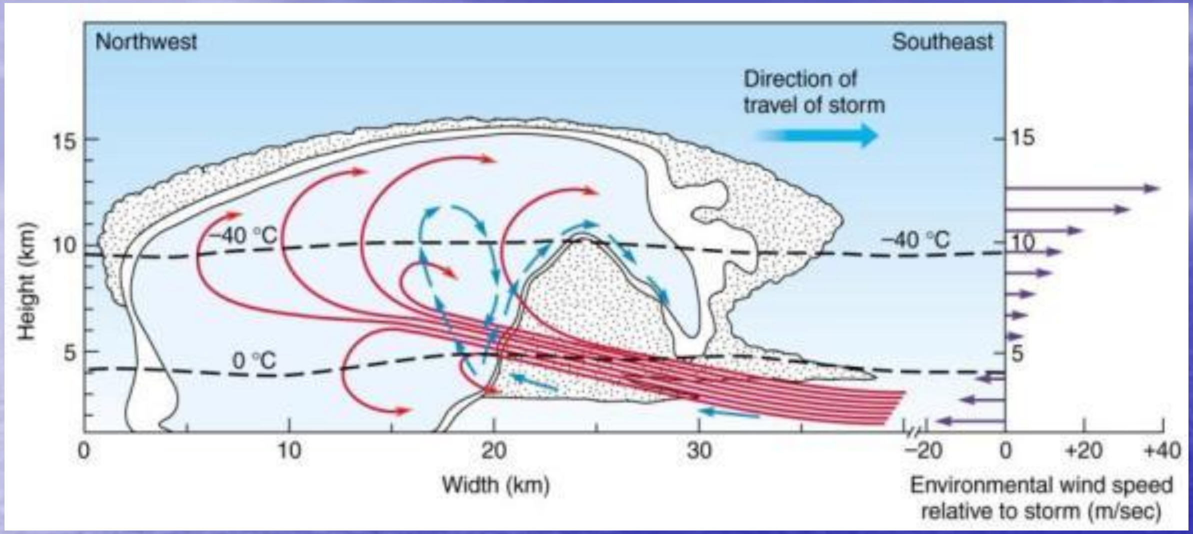
2
Supercooled drops in the updraft freeze to the growing hailstone.

3
Hailstones often grow in layers, sometimes by riming and sometimes by supercooled drops spreading out to form glaze.

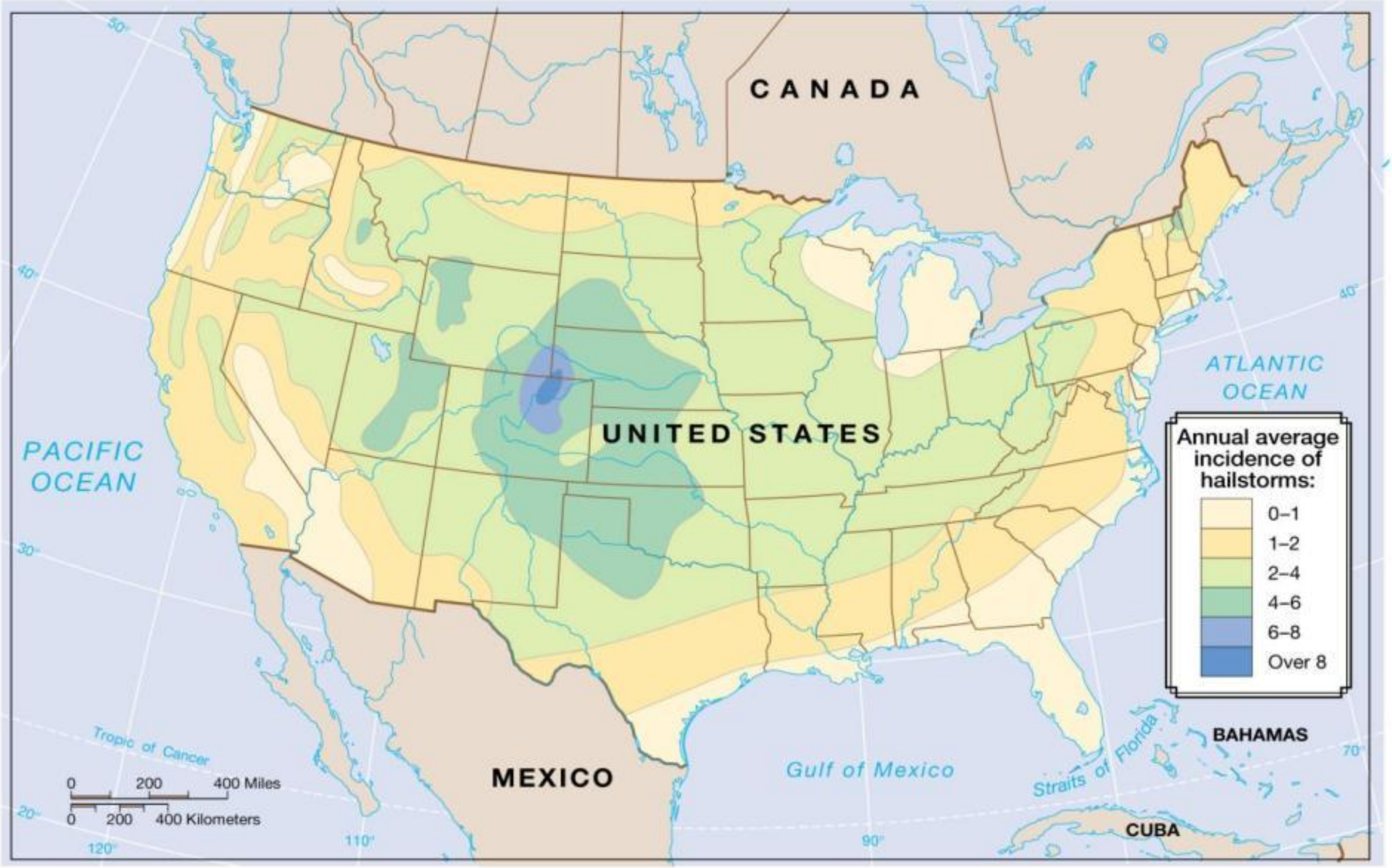
4
The hailstone falls when it grows too heavy for the updraft to continue holding it up, or when the updraft weakens.

Hailstones are no smaller than 2/10 inch in diameter, and can grow larger than a softball.

Hail Formation



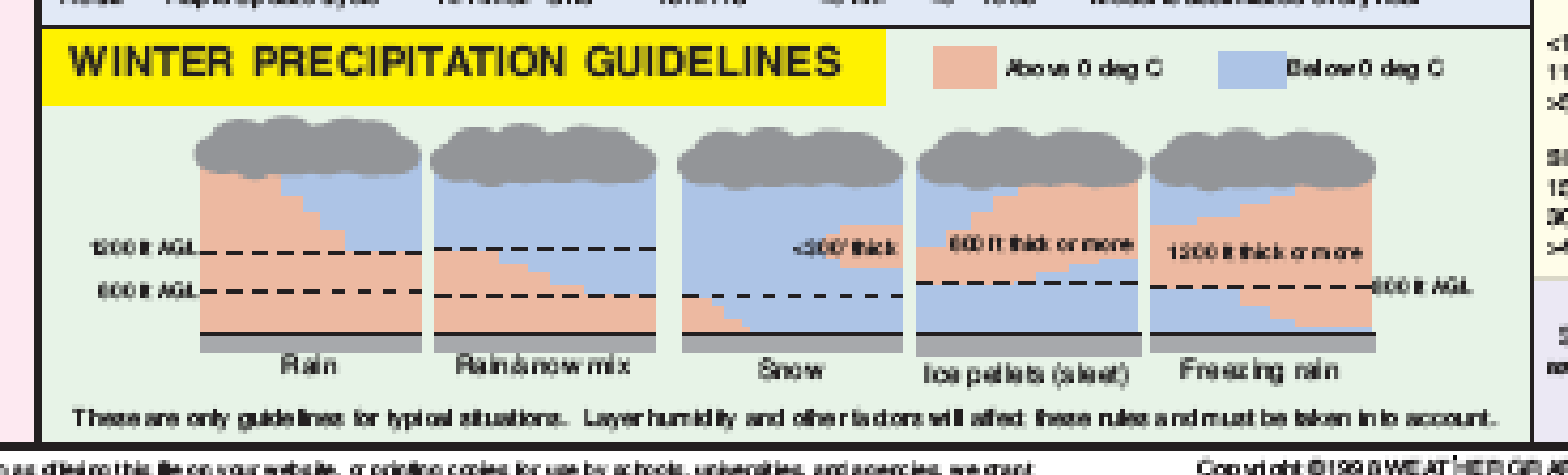
Concentric layers of ice in hail indicate the cyclical hailstone formation process



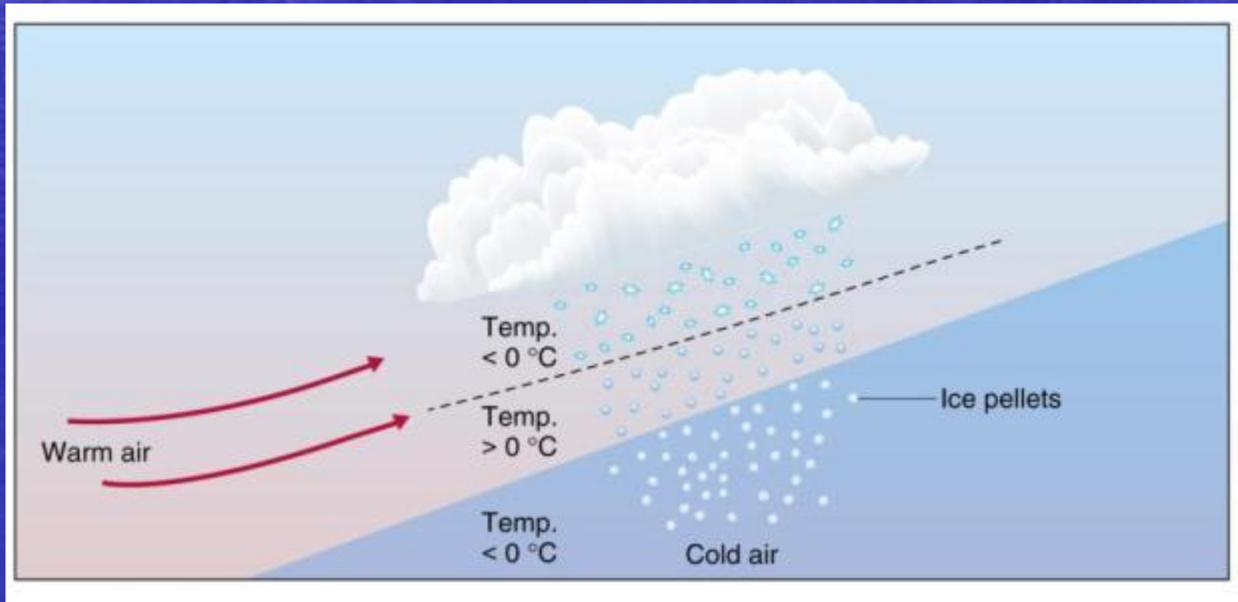
CANADA
UNITED STATES
MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
Straits of Florida
BAHAMAS
CUBA
Tropic of Cancer
Annual average incidence of hailstorms:
0–1
1–2
2–4
4–6
6–8
Over 8
0 200 400 Miles
0 200 400 Kilometers
50°
40°
30°
20°
120°
110°
90°
70°

Sleet begins as ice crystals which melt into rain through a mid-level inversion before solidifying in colder near surface air

Freezing Rain forms similarly to sleet, however, the drop does not completely solidify before striking the surface

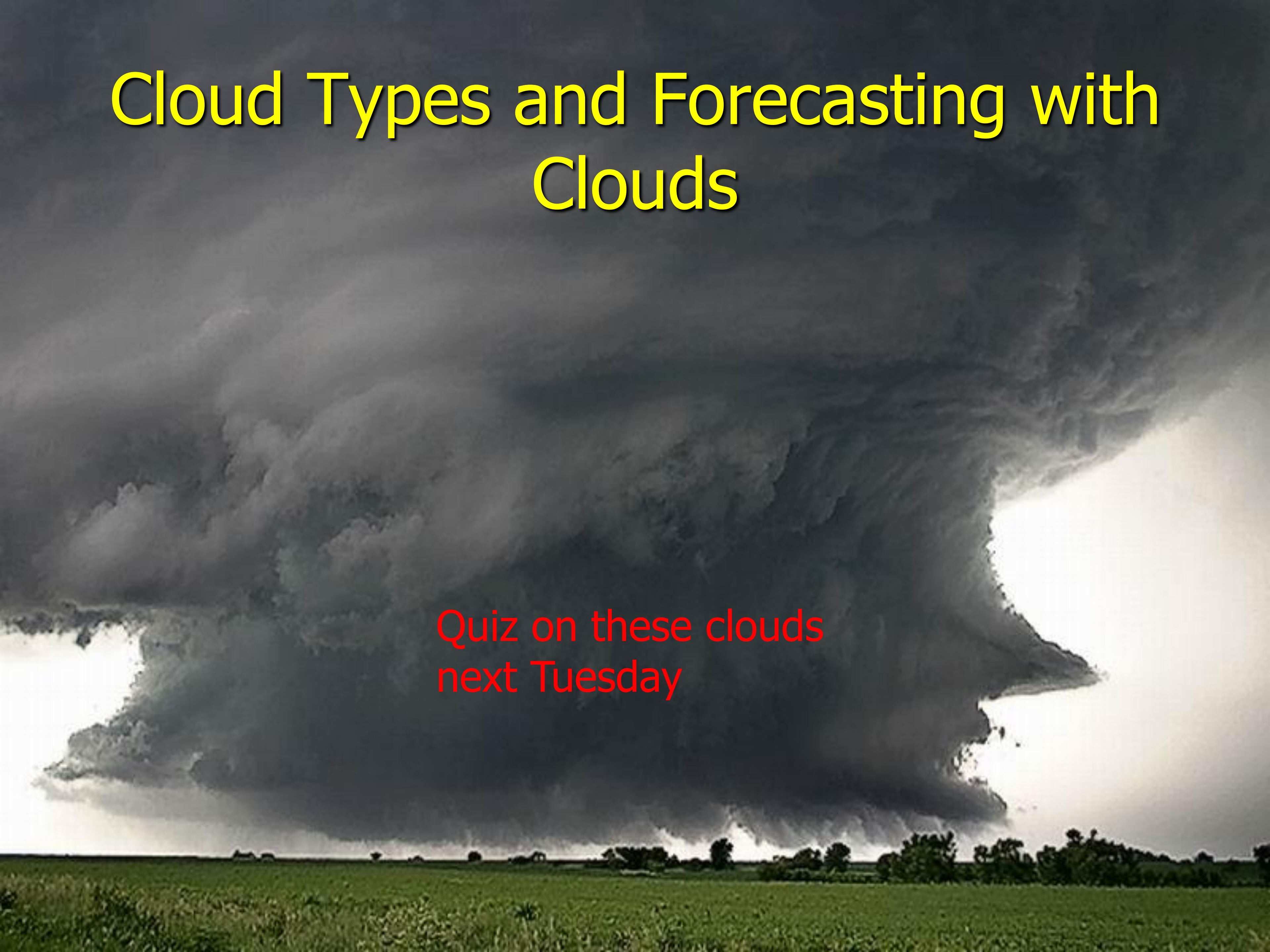


Sleet formation involves a mid-level inversion




40

Cloud Types and Forecasting with Clouds



Quiz on these clouds
next Tuesday

Forms of Condensation

- Dew
- Frozen Dew
- Frost
  - Hoar Frost
  - Rime Frost
- Fog
- Clouds

(a)

- Dew

- Liquid condensation on surface objects

- Diabatic cooling of surface air typically takes place through terrestrial radiation loss on calm, cool, clear nights

- Surface air becomes saturated and condensation forms on objects acting as condensation nuclei

Frozen Dew

- Occurs when normal dew formation processes occur followed by a drop in temperature to below freezing
- Ensures a tight bond between ice and the surface
- Causes “black ice” on roadways

(b)

- Frost

  Similar to dew except that it forms when surface temperatures are below freezing

  - <u>Hoar Frost</u> – Water Vapor to Ice

  - <u>Rime Frost</u> – Super cooled water freezing to surface

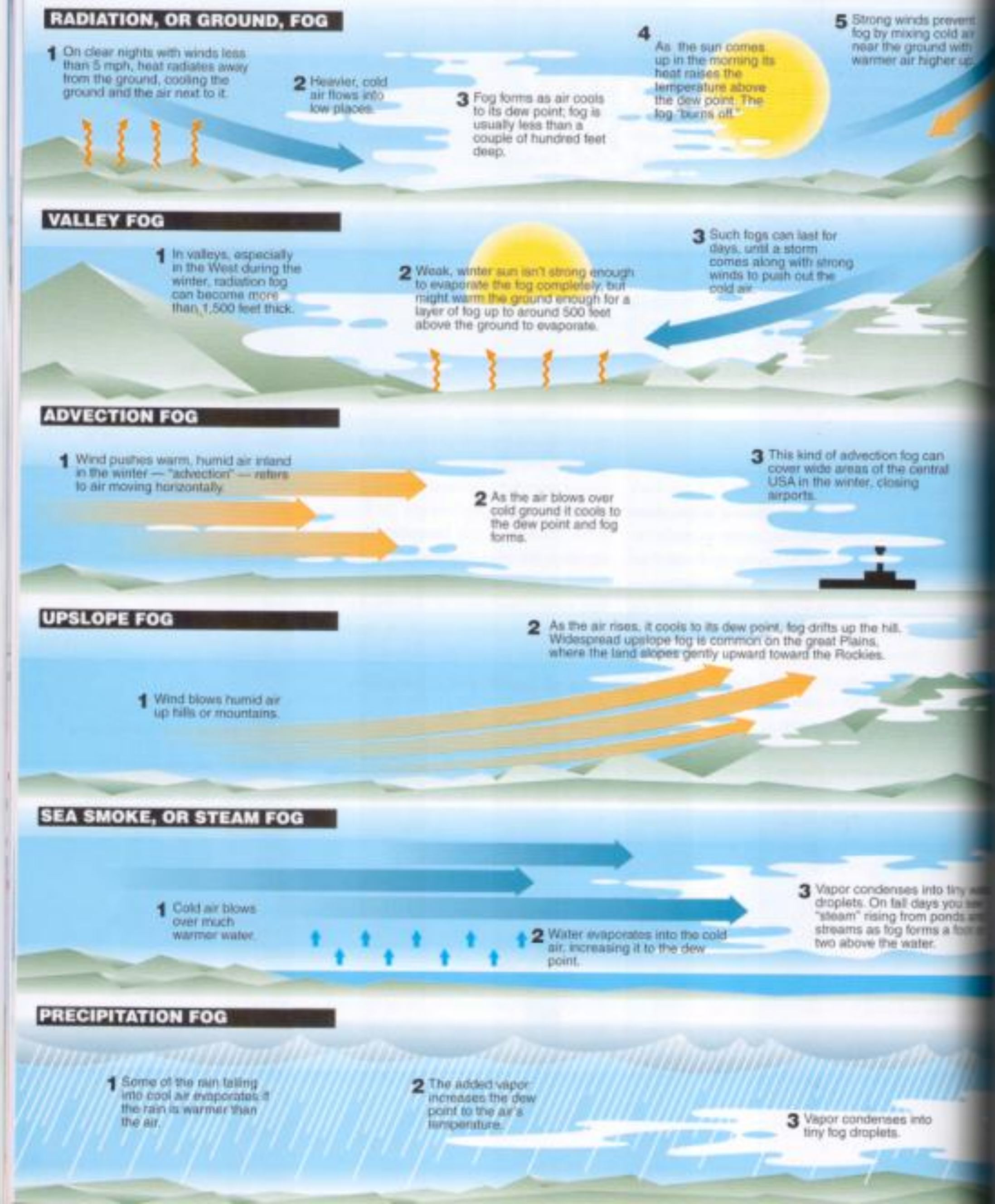

Rime Ice

Fog

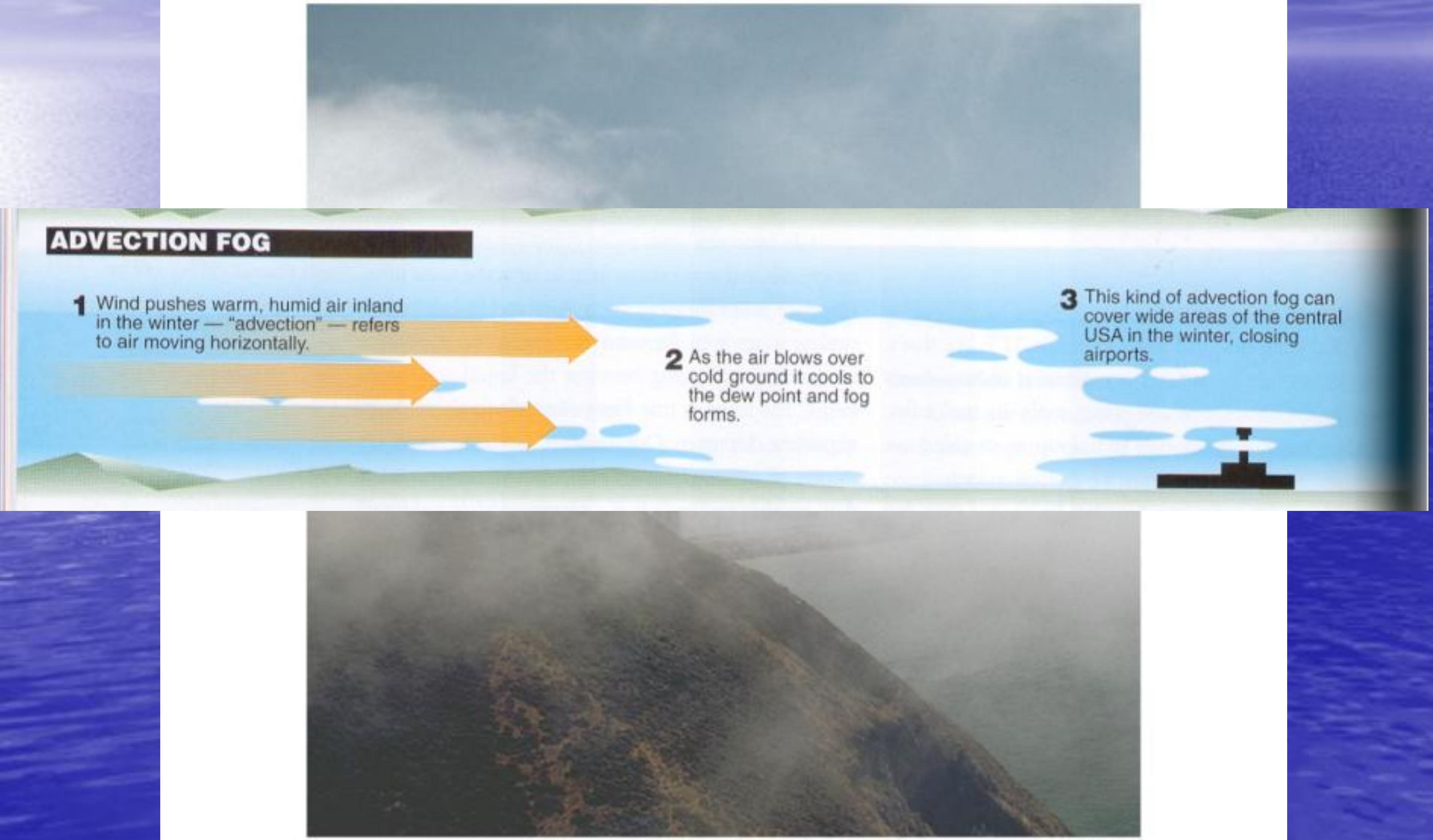
- Advection fog
- Evaporation fog
- Upslope fog
- Valley fog
- Radiation fog

How fog forms

Fog is a cloud on the ground. The most common kinds of fog form when humid air is cooled to its dew point, causing water vapor to begin condensing into tiny drops. Sometimes fog forms when extra water evaporates into the air, increasing the dew point enough to match the temperature.



Advection Fog




Break'n Waves
SEA•DOO
PRIVATE BEACH
STATE PARK

Evaporation Fog

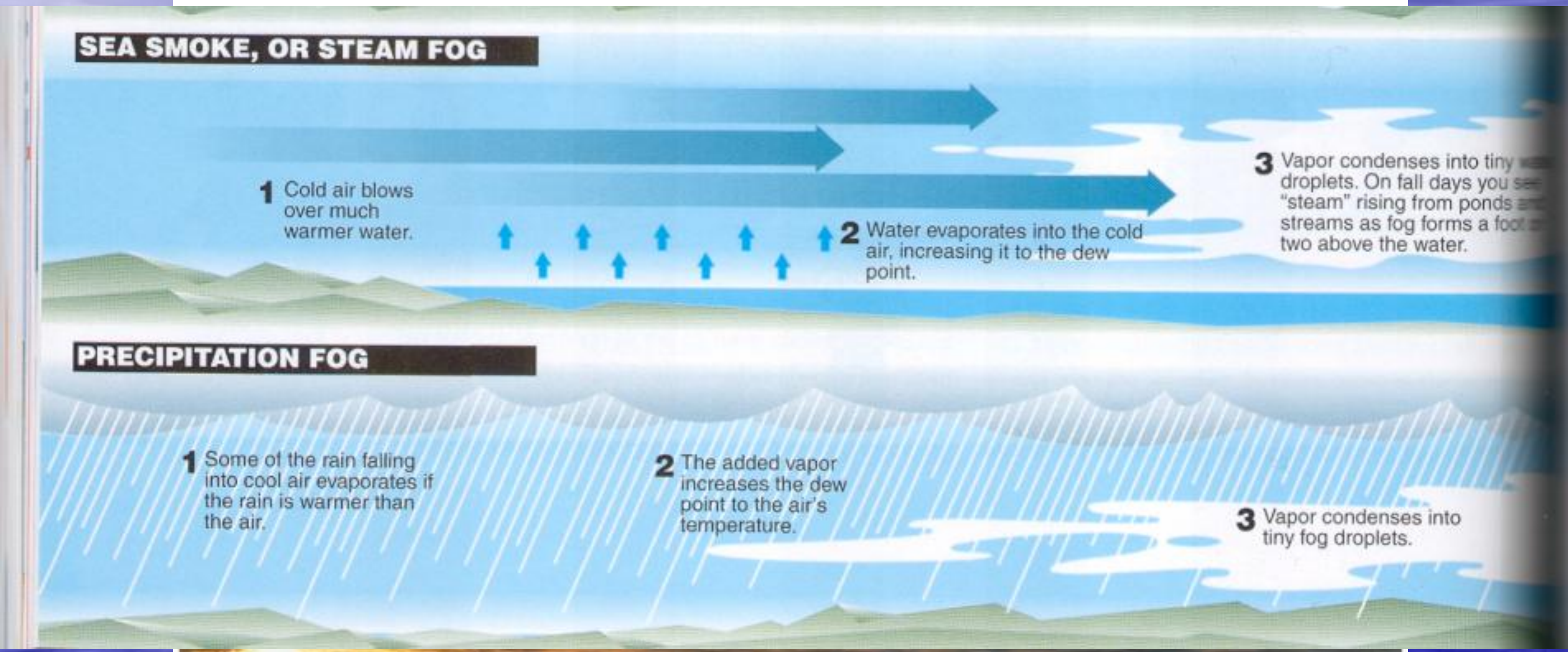


Figure 5.2 Figure 5.25

Valley Fog

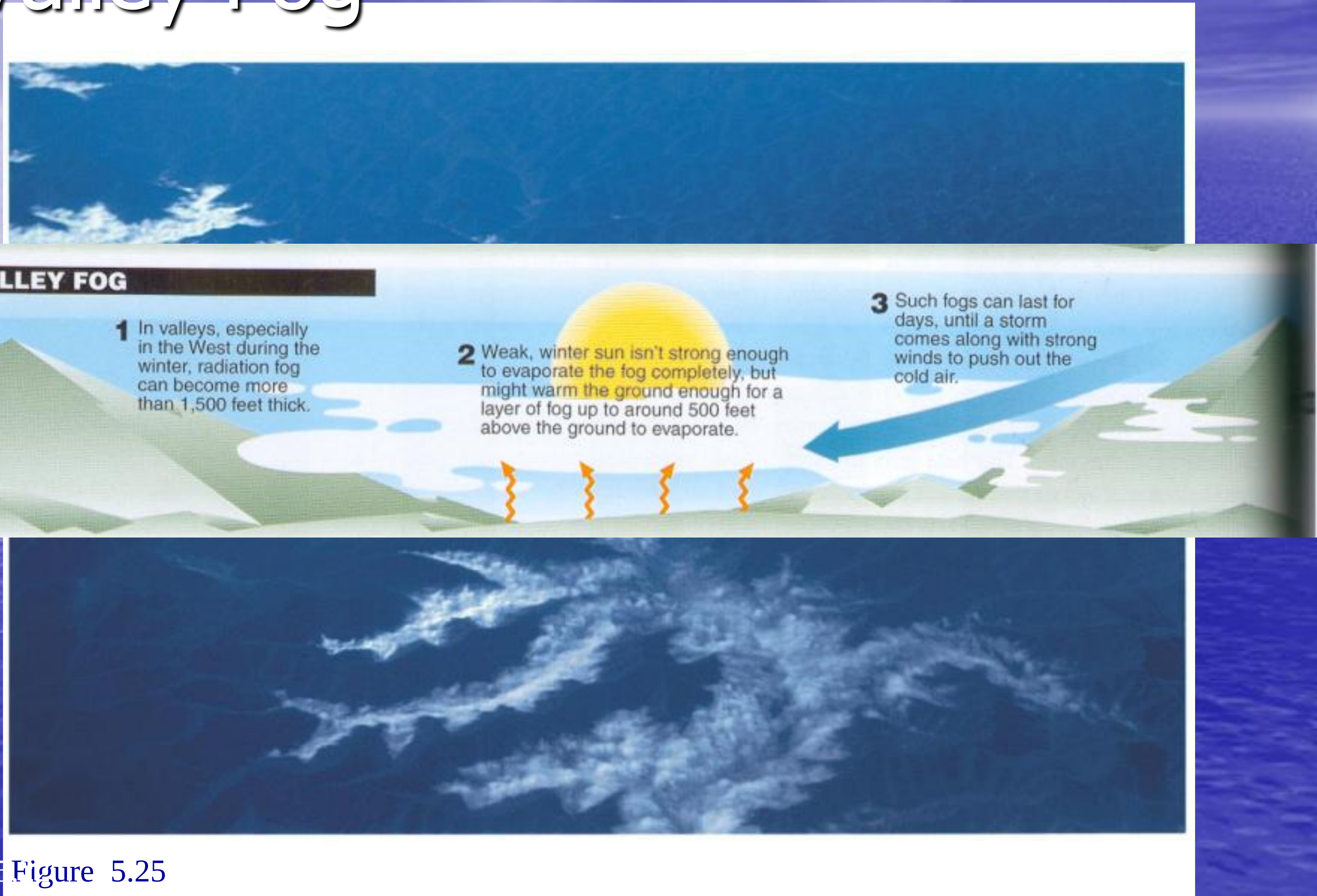


Figure 5.25

Radiation Fog

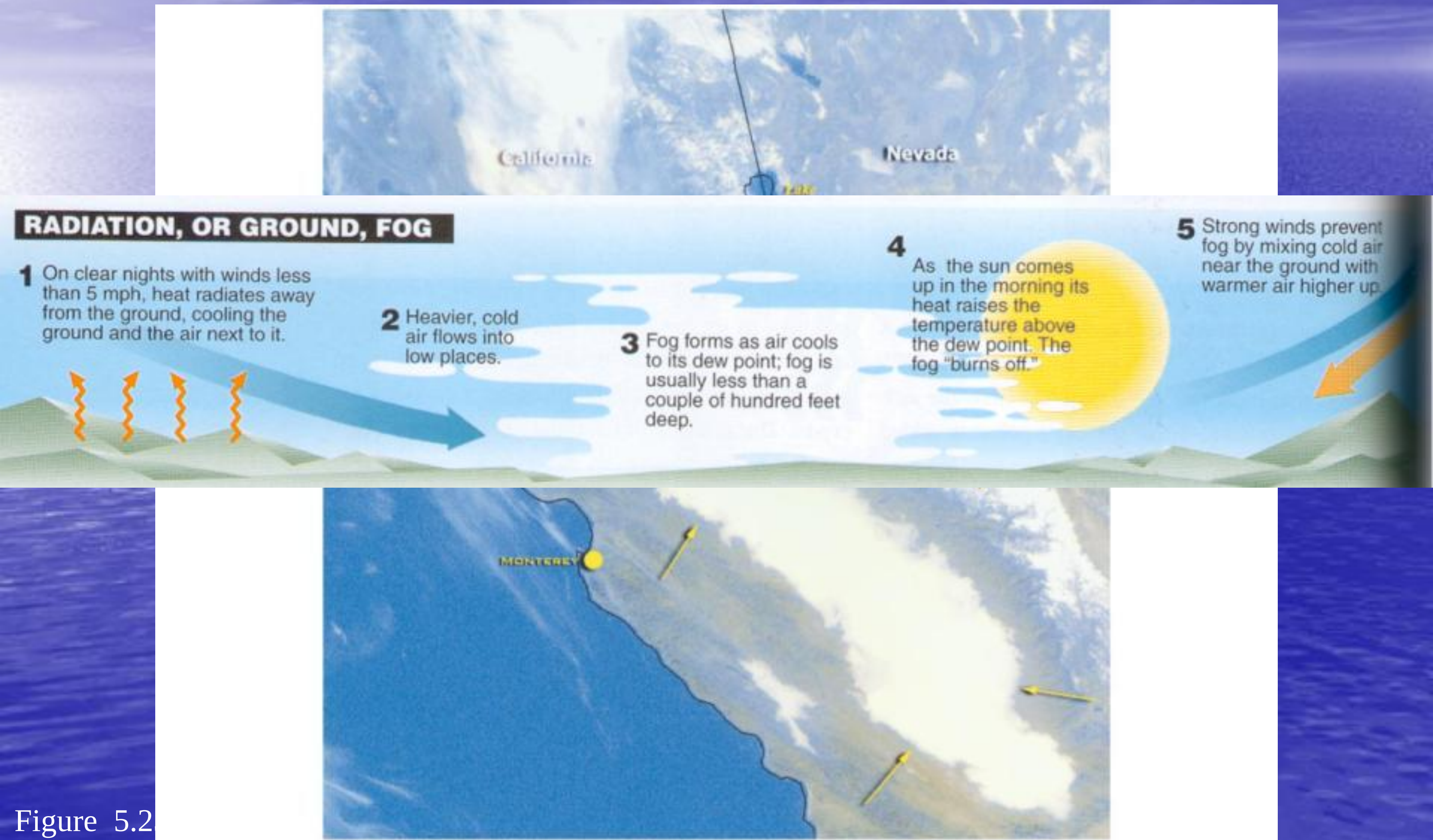


Figure 5.2

Different types of fog found throughout the U.S.

Clouds and Weather Watching

- Watch for patterns/series of clouds
- Three Rules:
  - Sequence of Clouds
  - Direction of Movement
  - Surface Winds

Cloud Categories

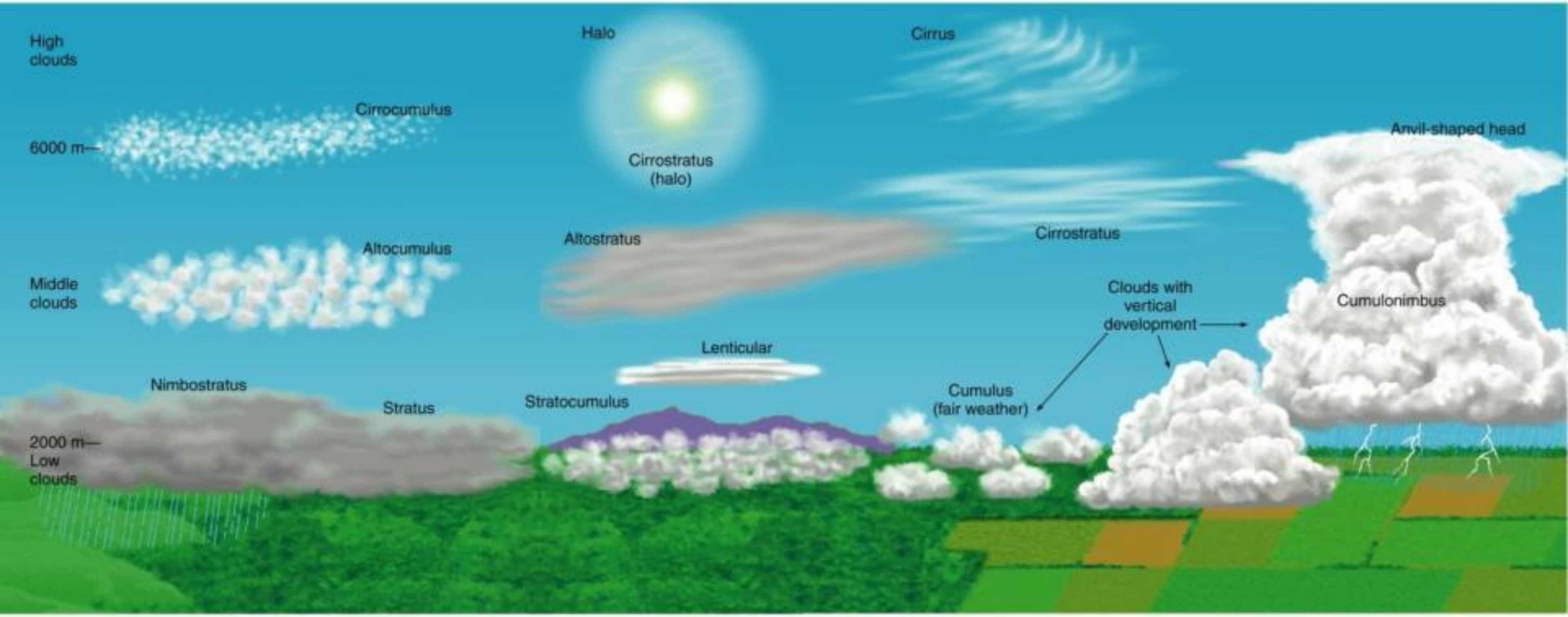
- Main Types
  - Cirrus
  - Stratus
  - Cumulus
  - Nimbus

Table 6–1 • Ten Principal Cloud Types

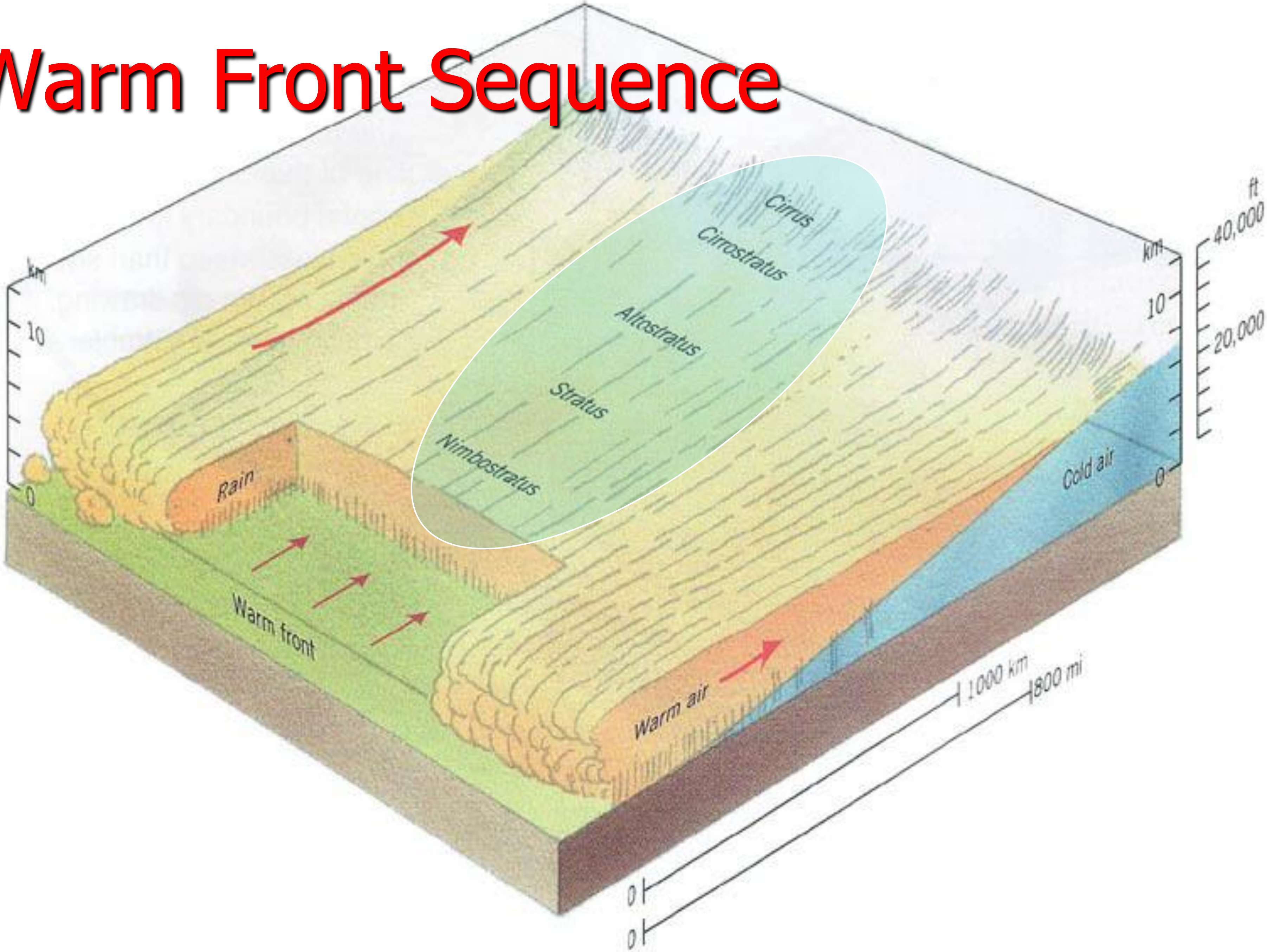
High Clouds (heights greater than 6000 m, or 19,000 ft)	
Cirrus (Ci)	(Figure 6–16)
Cirrostratus (Cs)	(Figure 6–19)
Cirrocumulus (Cc)	(Figure 6–20)
Medium Clouds (heights between 2,000 m and 6000 m, or 6000 to 19,000 ft)	
Altostratus (As)	(Figure 6–21)
Altocumulus (Ac)	(Figure 6–22)
Low Clouds (below 2000 m, or 6000 ft)	
Stratus (St)	(Figure 6–23)
Nimbostratus (Ns)	(Figure 6–24)
Stratocumulus (Sc)	(Figure 6–25)
Clouds with Vertical Development (may extend through much of atmosphere)	
Cumulus (Cu)	(Figures 6–26 and 6–28)
Cumulonimbus (Cb)	(Figure 6–29)

- Cloud Coverage
  - When clouds comprise more than 9/10th of the sky = ***overcast***
  - When coverage is between 6/10th and 9/10th = ***broken***
  - When coverage is between 1/10th and 6/10th = ***scattered***
  - Cloud coverage less than 1/10th = ***clear***

Cloud Types and Identification



Warm Front Sequence

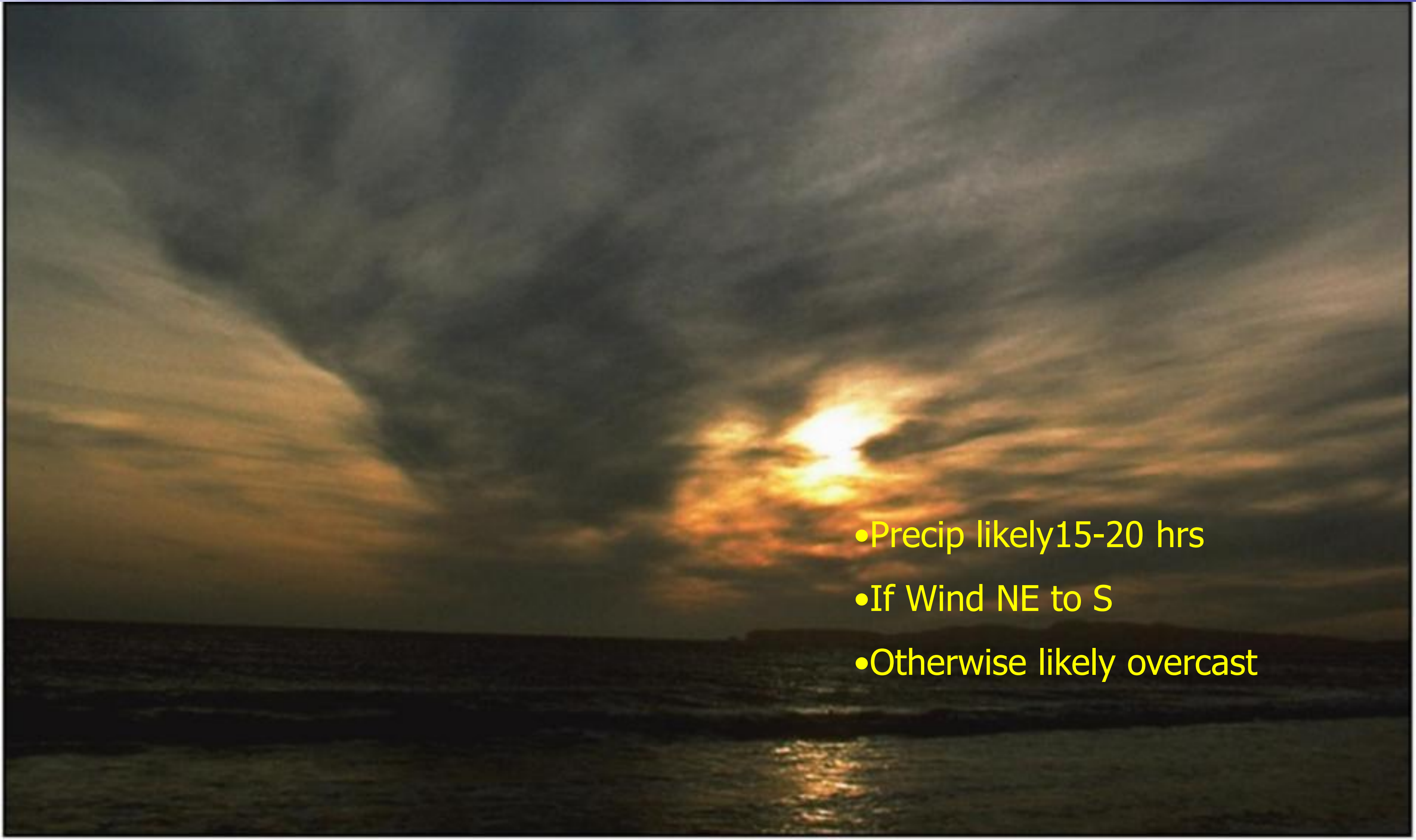


Cirrus

- Good weather if wind W to NW
- Rain (20-30 hrs) if E to SE


Foretells of Good Weather

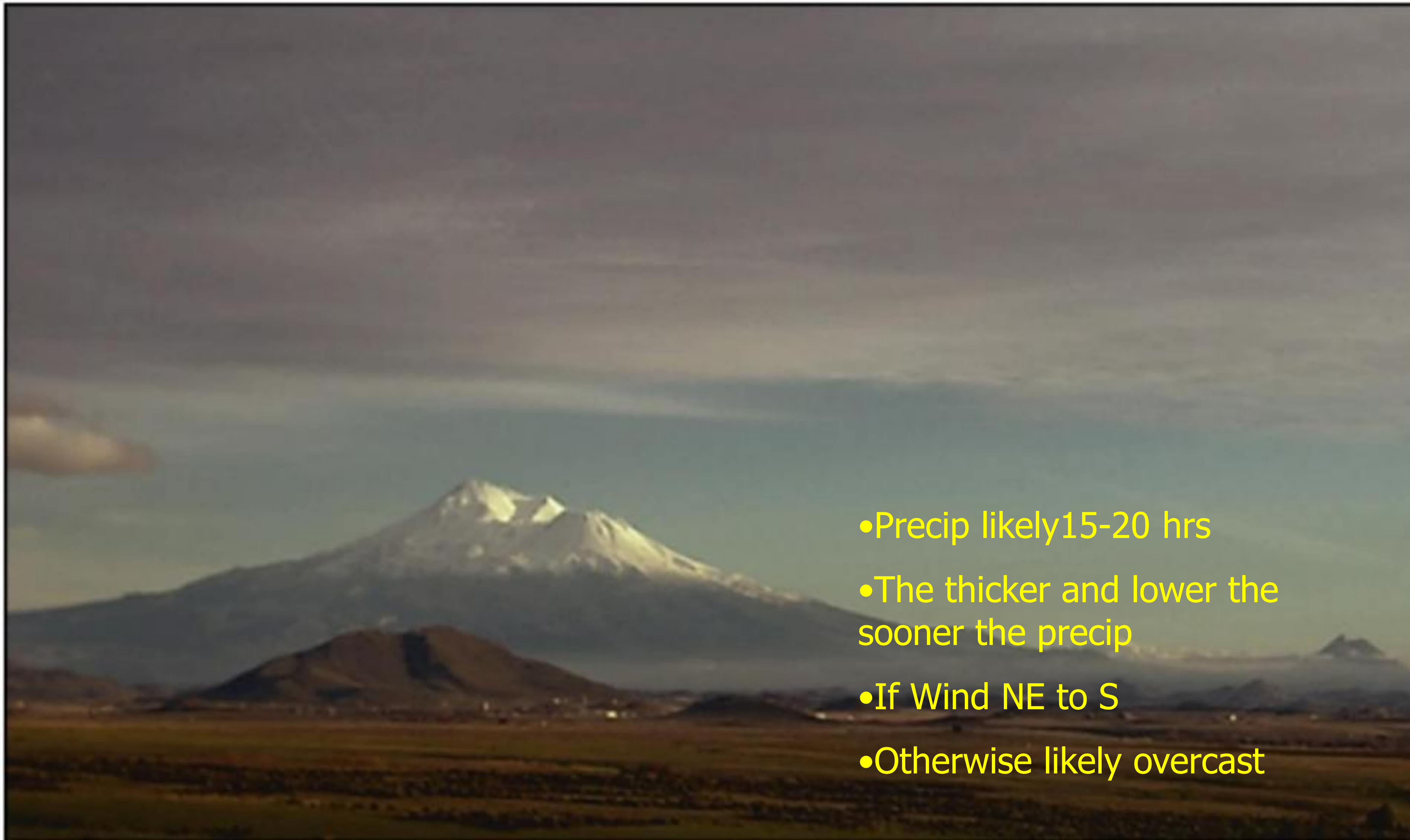
Cirrostratus



Altocumulus

- Some precip likely15-20 hrs
- If Wind NE to S
- Otherwise likely overcast

Altostratus



Stratus

- If Wind NE to S Heavy precip soon
- Otherwise likely light drizzle or overcast

Nimbostratus

Cumulus

- Watch for Vertical Development
- Watch Wind Direction
- Strong SW and vertical means strong storms possible


Doesn't Look Good

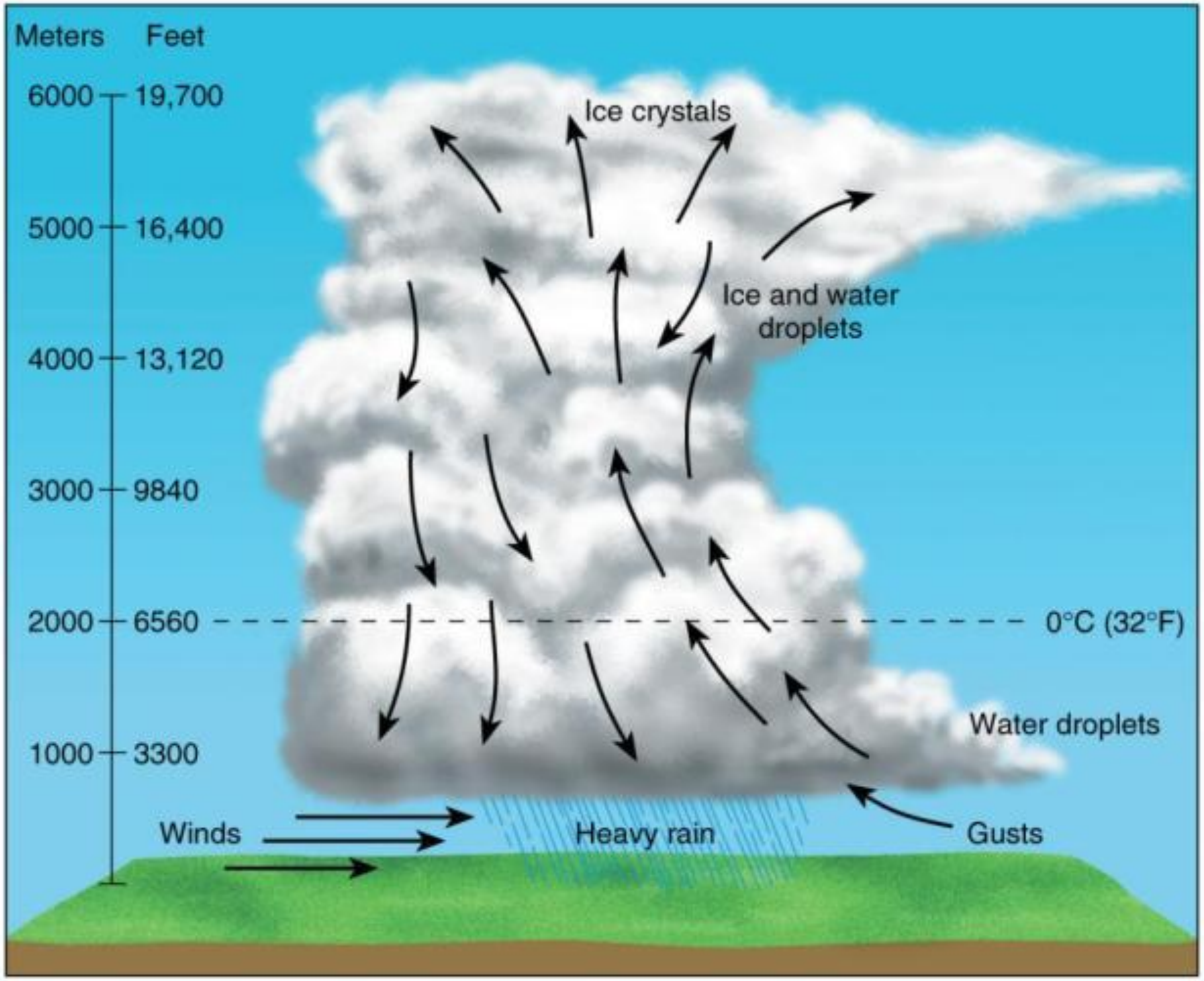
Cumulus congestus


Cumulus Fractostratus

Cumulonimbus


WTF

Cumulonimbus Development



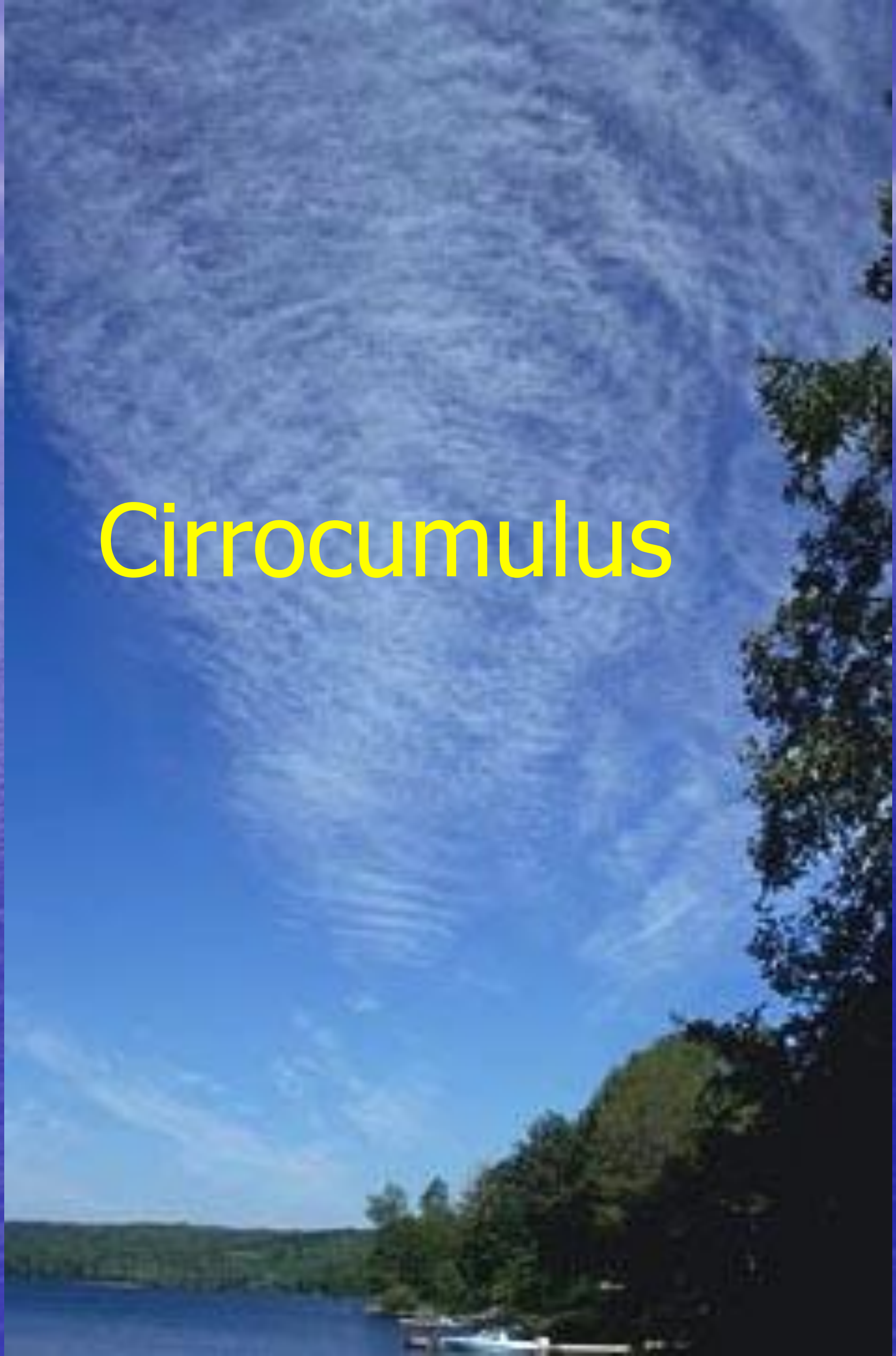
(a)

(b)


Cirrus Fibratus


Cirrus unicus
(mares tails)


Cirrus unicus
(mares tails)

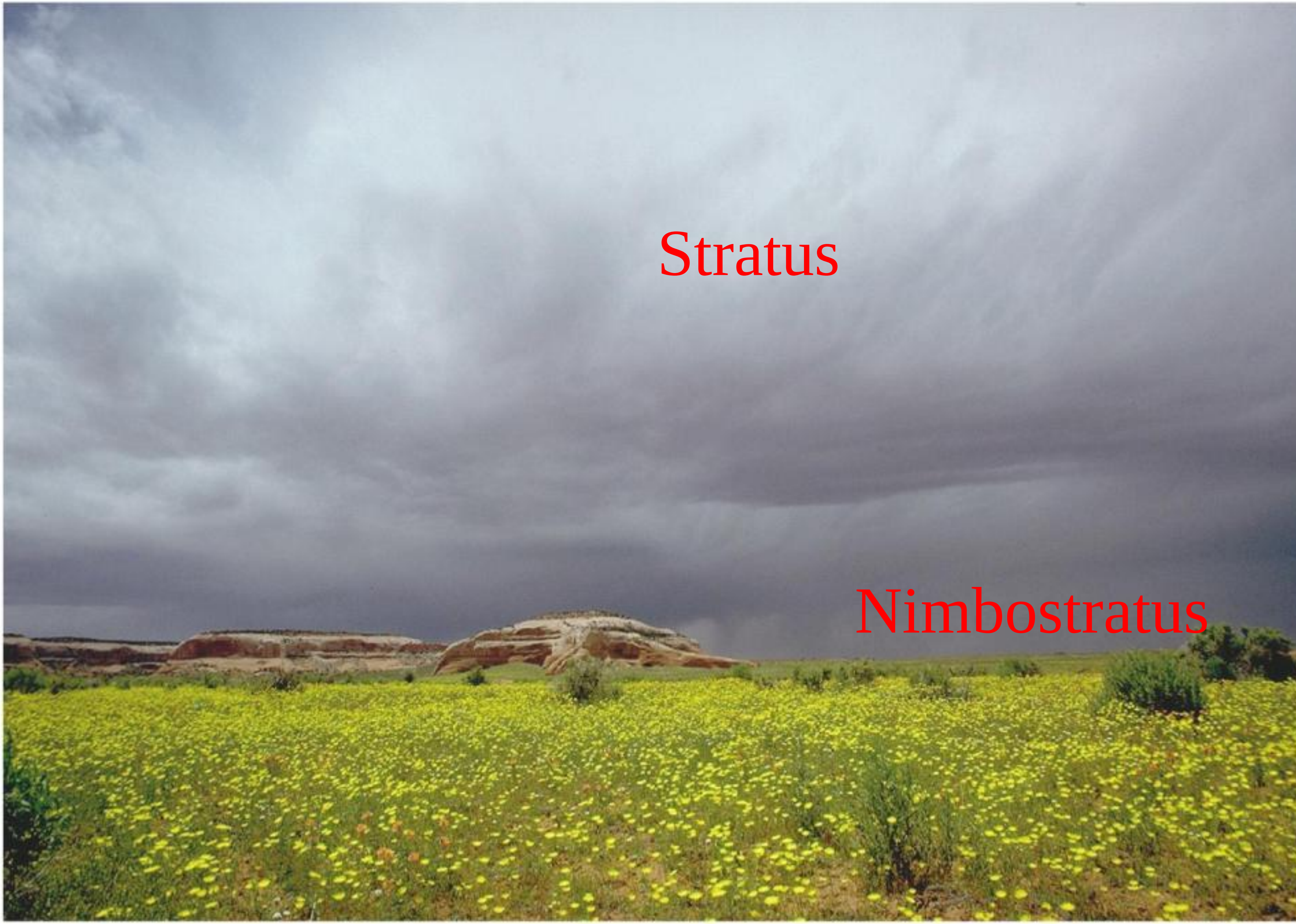

Cirrocumulus


Cirrocumulus

"Mare's tails and mackerel scales make tall ships take in their sails."


Cirrostratus

Cirrostratus


Stratus
Nimbostratus


Stratus

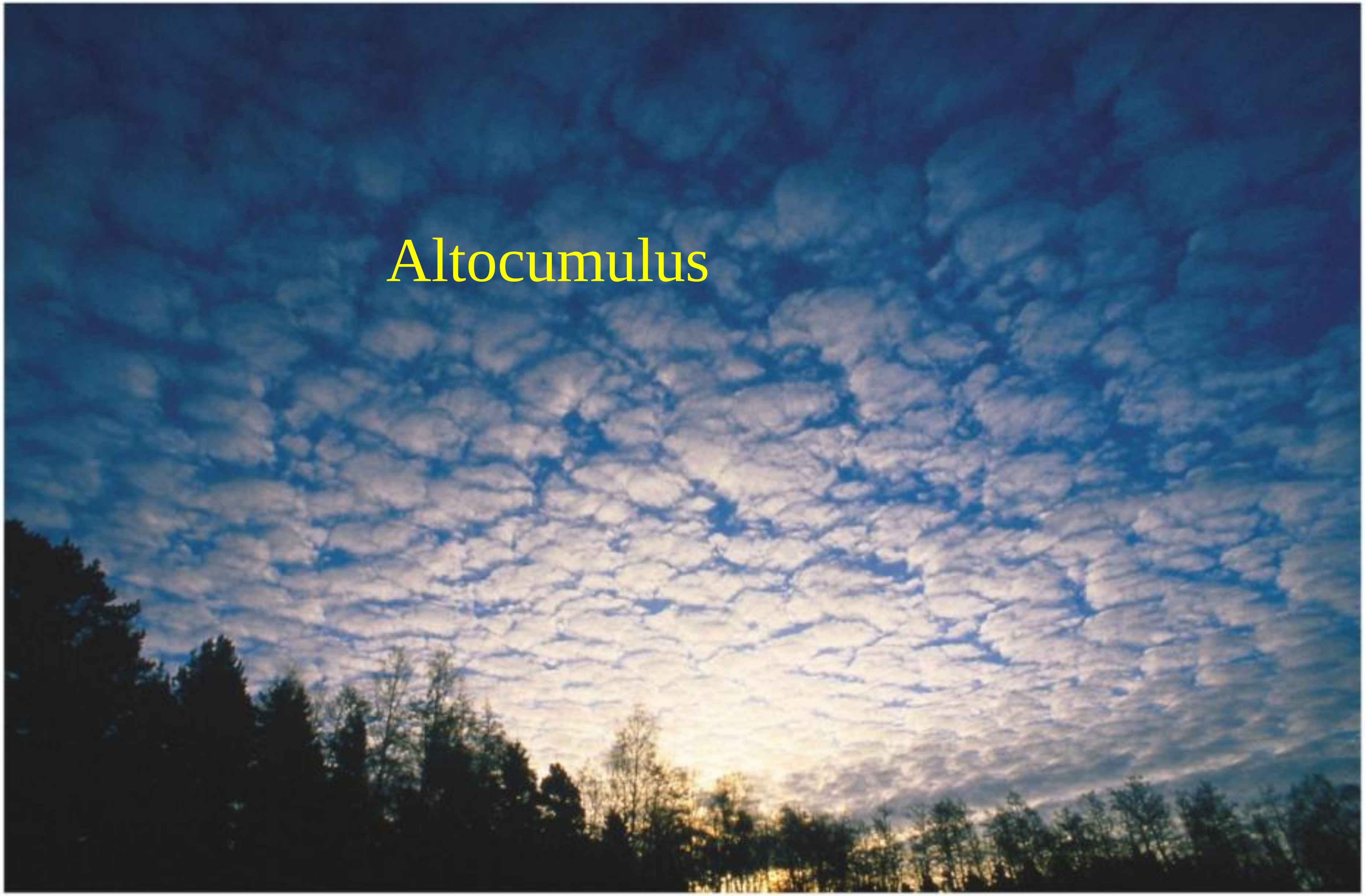

Altostratus


Cumulus humilis

Cumulus humiliated-is


Cumulus Mediocris

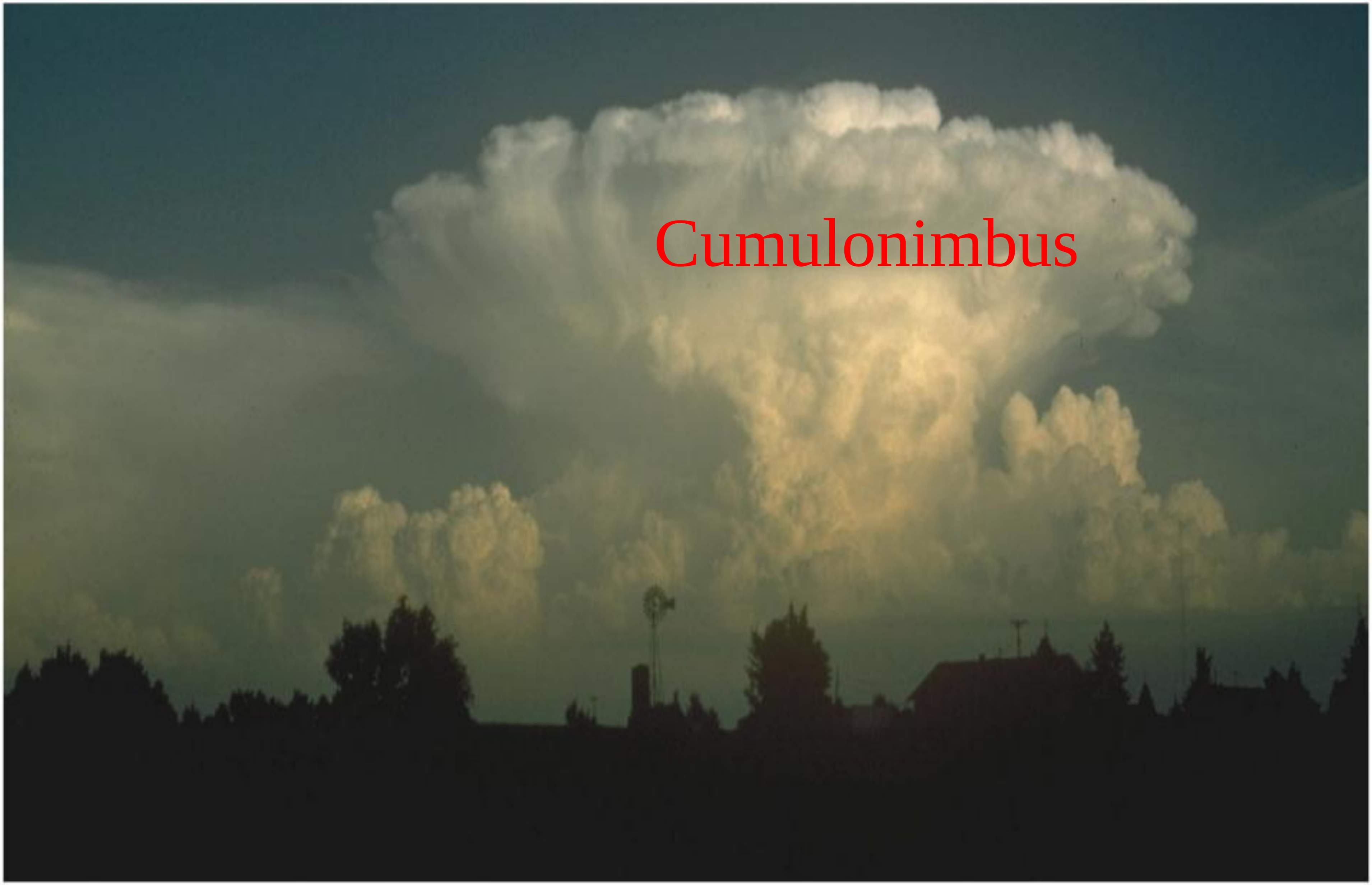

Cumulus congestus


Altocumulus

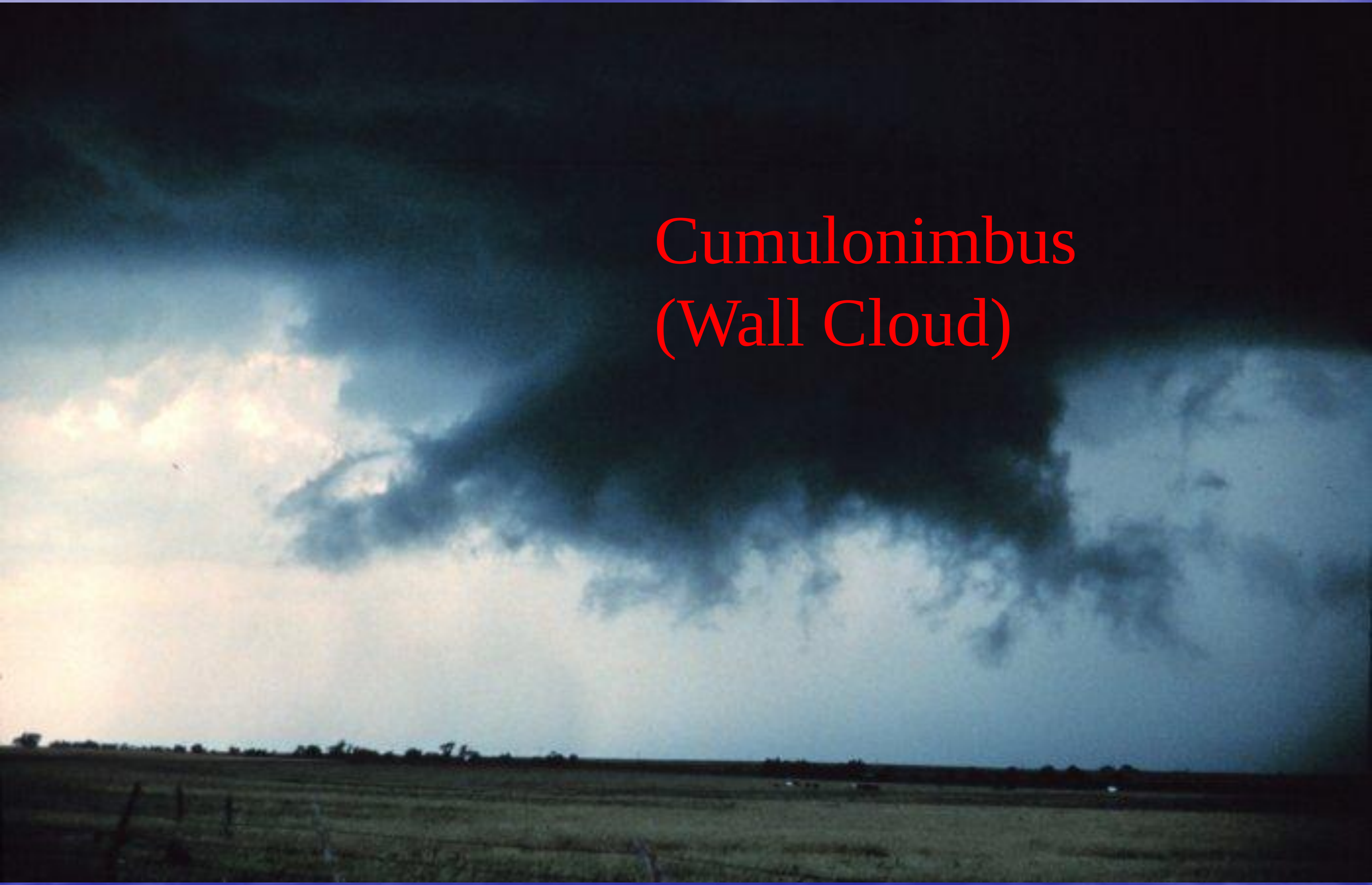

Altocumulus


Altocumulus
(Mackeral Sky)

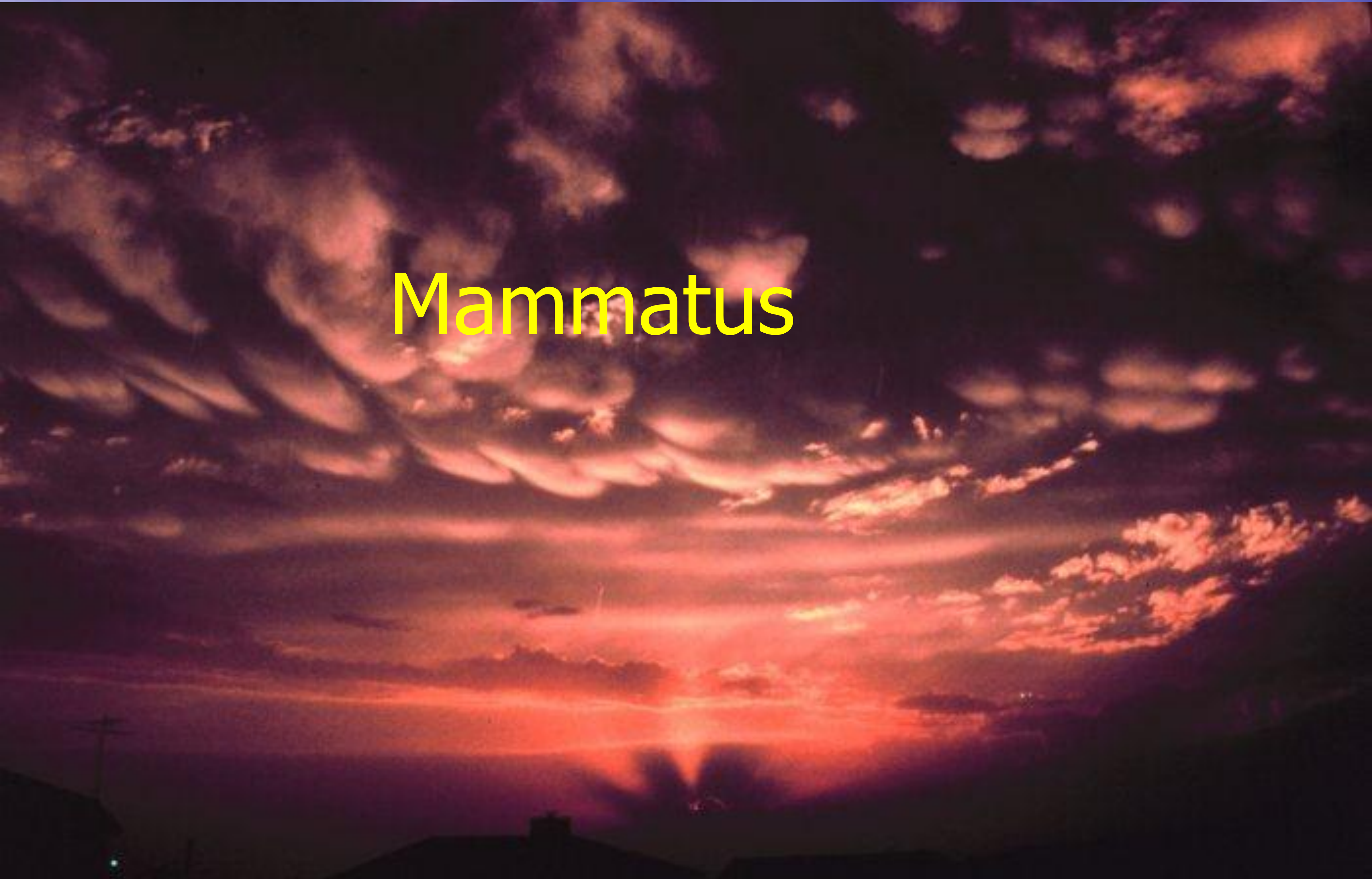

Stratocumulus

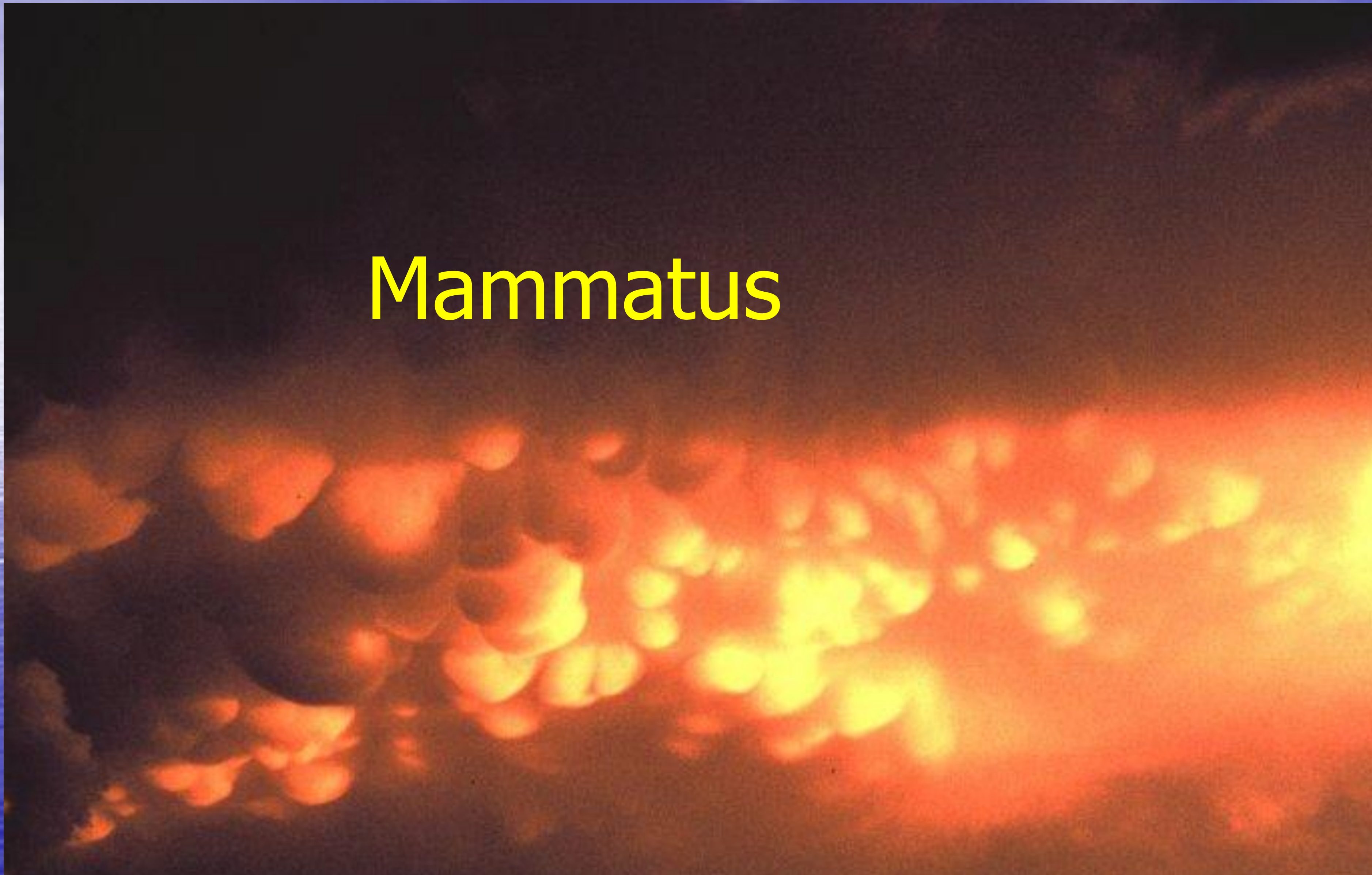

Cumulonimbus

Cumulonimbus
(Super Cell)


Cumulonimbus
(Wall Cloud)

Mammatus




Mammatus

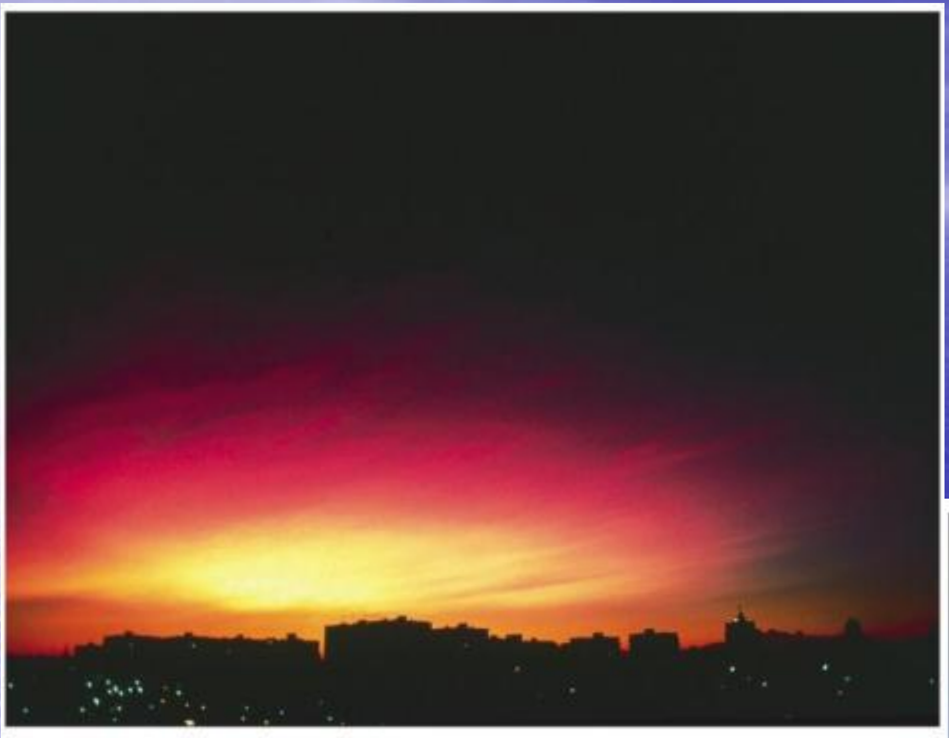

Mixed Sky


Mixed Sky

Lenticular

Banner cloud


Sun Dog near Ironwood MI



Nacreous

Noctilucent