Chapter 6
Clouds

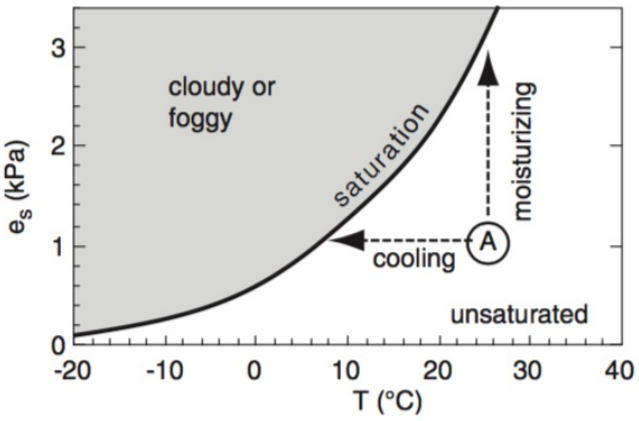
Chapter overview

- Processes causing saturation
  - Cooling, moisturizing, mixing
- Cloud identification and classification
- Cloud Observations
- Fog

Why do we care about clouds in the atmosphere?

Cloud Development

Clouds form when air becomes saturated.



How can unsaturated air become saturated?

- Cooling
- Adding moisture
- Mixing

Cooling and moisturizing

The amount of cooling needed for air to become saturated is given by $\Delta T = T_d - T$

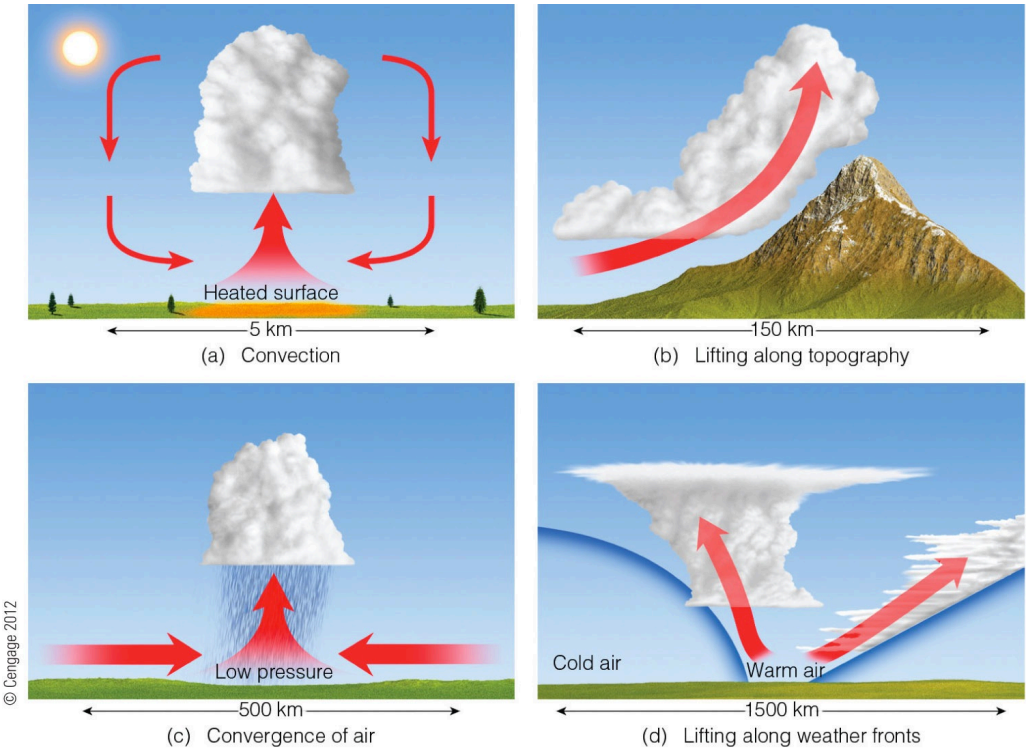
The amount of additional moisture needed for air to become saturated is given by $\Delta r = r_s - r$

The change in temperature (ΔT) or the change in moisture (Δr) can be determined by evaluating the heat or moisture budget of an air parcel.

Most clouds form as a result of rising air.

How does the temperature and relative humidity of an air parcel change as it rises adiabatically?

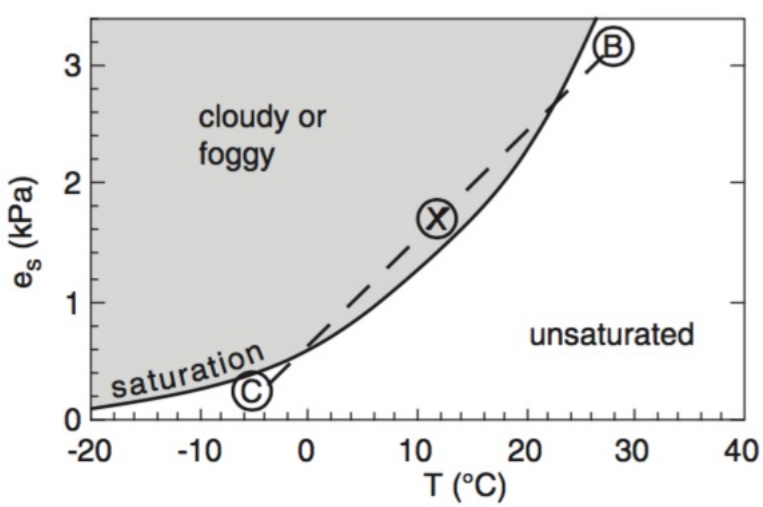
What processes are responsible for causing air to rise?



Cumuliform clouds form in air that rises due to its buoyancy.

Stratiform clouds form in are that is forced to rise.

Mixing



Mixing of two unsaturated air parcels can result in a saturated mixture.

Why can the mixing of unsaturated air result in air becoming saturated?

What are some examples of air becoming saturated in this way?

The temperature and mixing ratio of the mixture can be calculated using:

$$m_x = m_B + m_C$$

$$T_x = \frac{m_B T_B + m_C T_C}{m_x}$$

$$r_x = \frac{m_B r_B + m_C r_C}{m_x}$$

Where the *m* is the mass of the air parcel, subscripts *B* and *C* indicate the two original air parcels, and subscript *X* indicates the mixture.

Vapor pressure or specific humidity can be used in place in mixing ratio.

Cloud Identification

Cloud: A visible aggregate of tiny water droplets or ice crystals suspended in the air.

TABLE 5.2 The Four Major Cloud Groups and Their Types

1. HIGH CLOUDS	3. LOW CLOUDS
Cirrus (Ci)	Stratus (St)
Cirrostratus (Cs)	Stratocumulus (Sc)
Cirrocumulus (Cc)	Nimbostratus (Ns)
2. MIDDLE CLOUDS	**4. CLOUDS WITH VERTICAL DEVELOPMENT**
Altostratus (As)	Cumulus (Cu)
Altocumulus (Ac)	Cumulonimbus (Cb)

Clouds are divided into four major groups and ten types as shown in the table to the left.

The four major cloud groups are defined based on cloud base height (low, middle, and high) and on clouds that have more vertical than horizontal development.

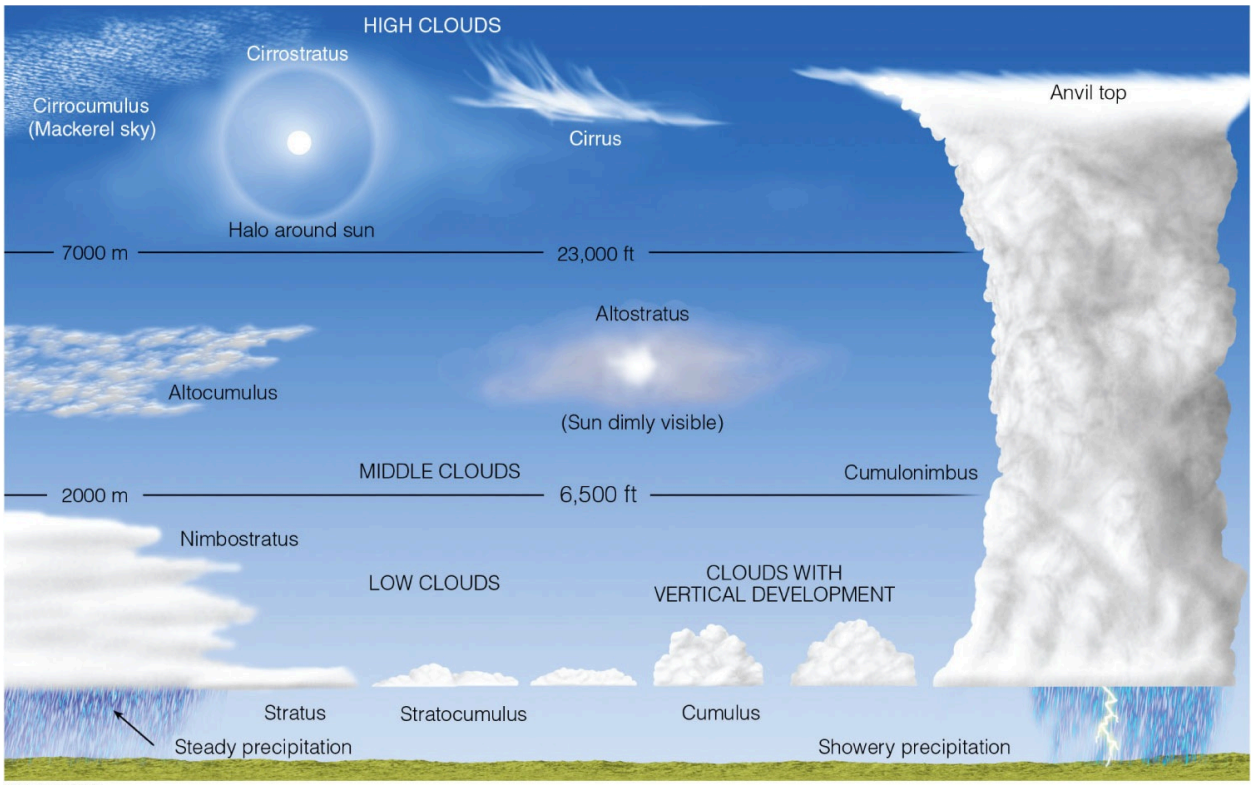
High clouds (above 6000 m): Tend to be composed almost exclusively of ice crystals and are usually thin. High cloud names have cirro or cirrus as a prefix.

Middle clouds (2000 to 7000 m): Composed of water drops and some ice crystals. Middle cloud names have alto as a prefix.

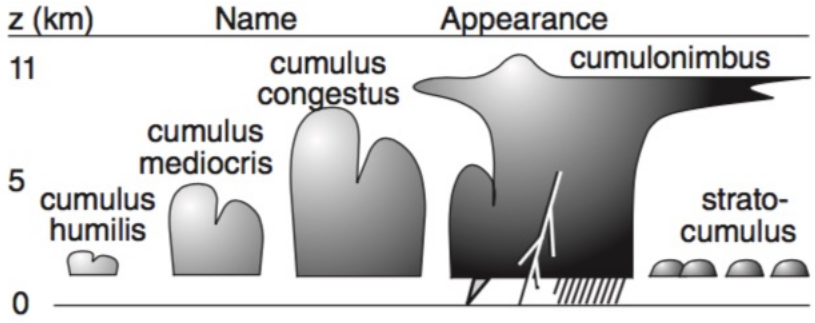
Low clouds (below 2000 m): Are almost always composed of water droplets, but may contain ice crystals in cold weather.

Within each group individual cloud types are based on the appearance of the cloud.

Cirrus - wispy appearance
Cumulus (cumuliform) - heaped, puffy, or lumpy appearance
Stratus (stratiform) - layered appearance
Nimbus - precipitating cloud



Cumuliform clouds



Cumuliform clouds form in strong updrafts.

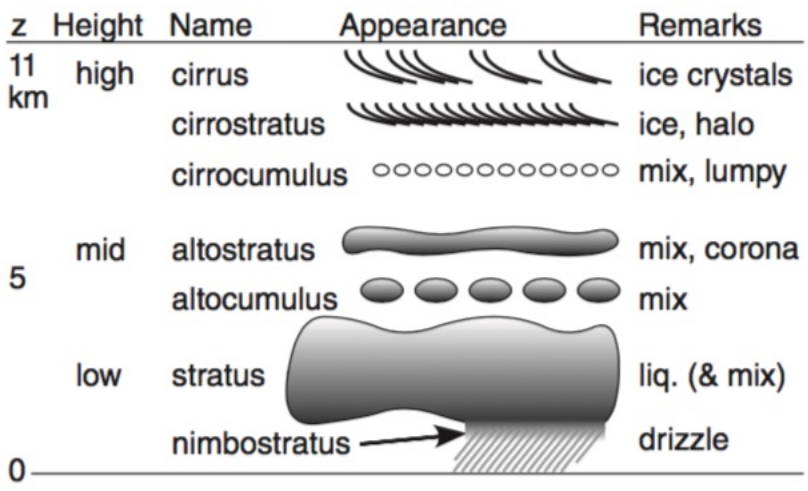
These clouds often have a depth that is similar to their width (aspect ratio near 1).

Cumuliform clouds develop when air near the surface is warm and/or when the air aloft is cold.

What are some situations that would favor the development of cumuliform clouds?

In chapter 5 we will use thermodynamic diagrams to illustrate the development of cumuliform clouds.

Stratiform Clouds



Stratiform clouds are horizontal cloud layers that cover large areas.

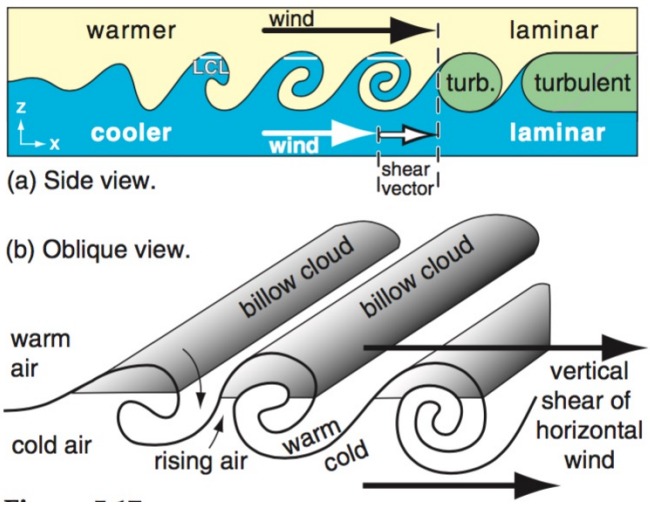
Their appearance is similar to a blanket or sheet.

Most stratiform clouds form due to horizontal advection of relatively moist air which is gradually lifted until it becomes saturated.

How does the mechanism by which air is lifted to form stratiform clouds differ from the lifting mechanism that creates cumuliform clouds?

If observed temperature and dew point temperature profiles are plotted on a thermodynamic diagram cloud layers can be identified as areas where the temperature and dew point temperature are equal (or nearly equal).

Unusual cloud types



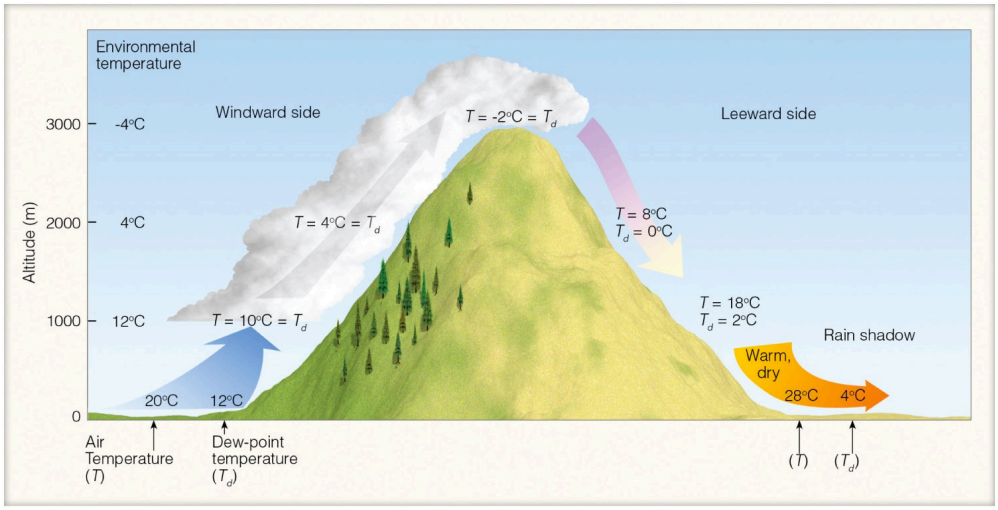
Billow clouds: Parallel, horizontal lines of clouds that form in a shallow layer.

Billow clouds form as a result of vertical wind shear which causes Kelvin-Helmholtz (KH) waves to develop. The billow clouds form in the crest of the KH waves.

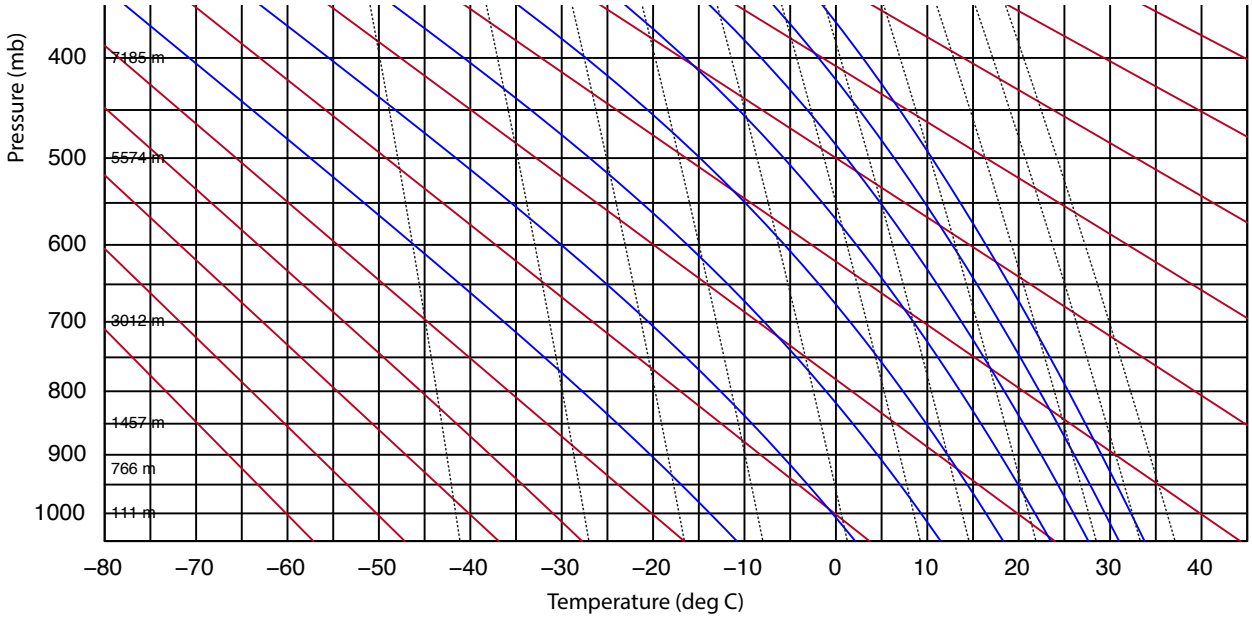
Topography and Clouds

Orographic uplift: Forced lifting of air as it encounters a topographic barrier.

Orographic clouds: Clouds formed by orographic uplift.

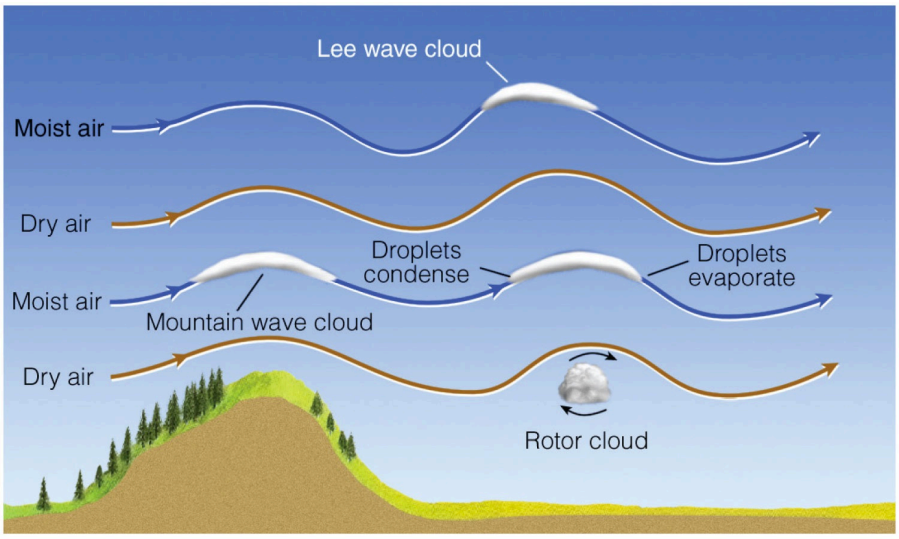


Example: Use the thermodynamic diagram below to illustrate the changes in air parcel temperature and moisture as air flows over a mountain.



Why does the temperature and dew point temperature differ on the upwind and downwind side of a mountain when orographic clouds form?

Rain shadow: An area with noticeably less precipitation on the leeward (downwind) side of a mountain range.



Lenticular cloud: Smooth, wavy clouds that form as air flows over a mountain.

Other names for lenticular clouds include mountain wave clouds and lee wave clouds. They may also be called a cap cloud if they form directly over a mountain peak or ridge.

Billow and lenticular clouds form in a statically stable atmosphere where wave like motions are supported. (Static stability is discussed in Chapter 5).

Other unusual cloud types

Mammatus cloud: Rounded clouds extending below the base of a flat cloud layer. These clouds form in sinking rather than rising air.

How can mammatus clouds form in sinking air?

Contrail: Clouds that form from the exhaust of jet aircraft.

The name contrail is a contraction of “condensation trail”.

Polar stratospheric clouds (nacreous clouds): Pearly looking clouds that form in the polar stratosphere at altitudes of 20 to 30 km.

Cloud Observations

Table 6-7. Sky cover. Oktas= eighths of sky covered.

Sky Cover (oktas)	Sym-bol	Name	Abbr.	Sky Cover (tenths)
0	○	Sky **Clear**	SKC	0
1	◴	**Few*** Clouds	FEW*	1
2	◔			2 to 3
3	◑	**Scattered**	SCT	4
4	◑			5
5	◒	**Broken**	BKN	6
6	◕			7 to 8
7	◕			9
8	●	**Overcast**	OVC	10
un-known	⊗	Sky **Obscured**	**	un-known

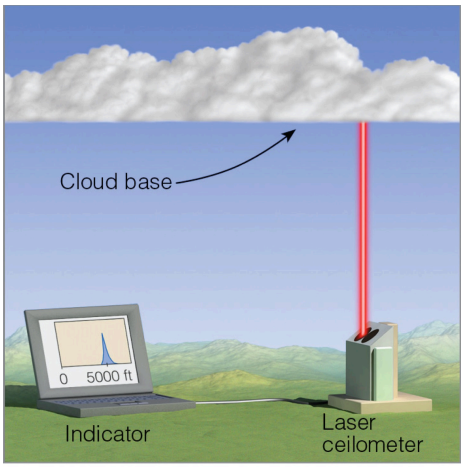
** "Few" is used for (0 oktas) < coverage ≤ (2 oktas).*

*** See text body for a list of abbreviations of various obscuring phenomena.*

Sky cover, cloud cover, or cloud amount: The fraction of the sky covered by clouds and measured in eights (oktas)

Obscured sky conditions are reported when clouds cannot be observed from the ground.

What features could obscure clouds?



Ceiling: The height of the lowest layer of more than 5/8 cloud cover (broken or overcast).

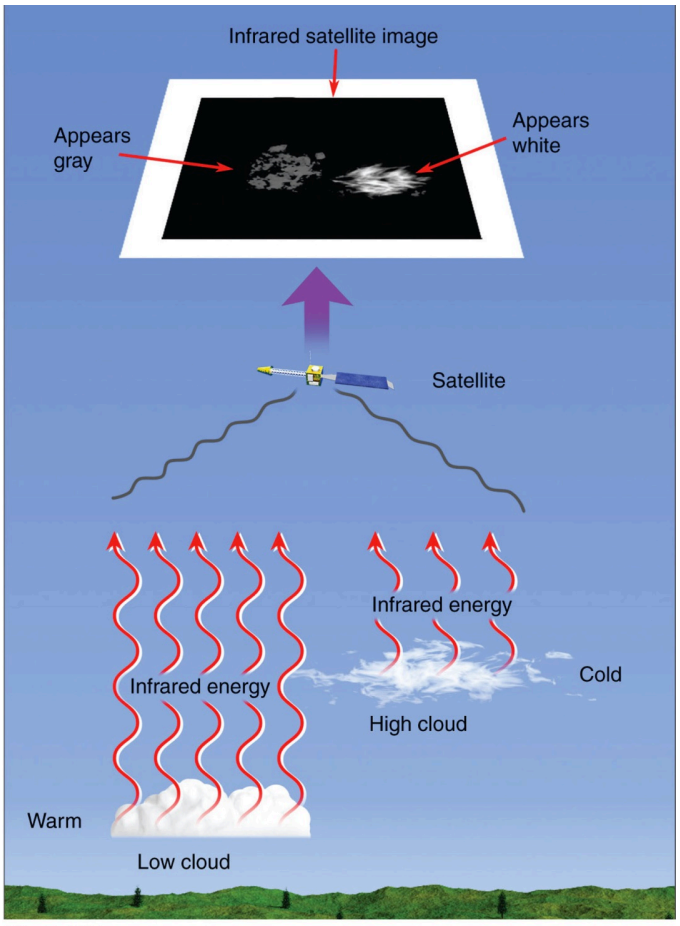
Satellite Observations of Clouds

Interpreting Satellite Imagery

	Visible	Infrared	Water Vapor
Satellite measures	reflected solar radiation	emitted infrared (temperature)	infrared radiation emitted by water vapor only
Brightest regions	thick clouds, snow	coldest clouds or surfaces	moist air
Darkest regions	ocean, forests	warmest clouds or surfaces	dry air

Weather satellites typically measure both visible and infrared radiation.

Information about temperature and water vapor can be determined based on the types of infrared radiation measured by the satellite.



How do different height clouds appear on visible and infrared satellite images?

What causes this difference in appearance?

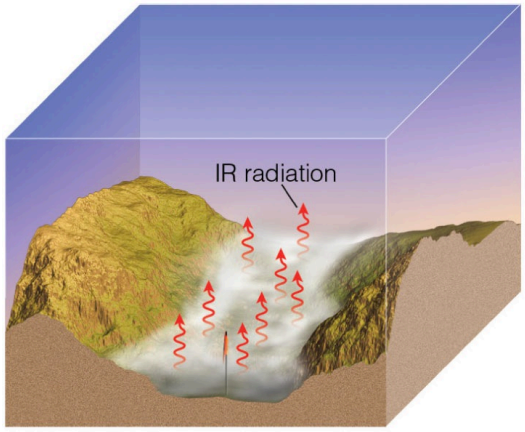
In addition to indicating moist or dry locations in the atmosphere what other meteorological information can be determined from water vapor satellite images?

Fog

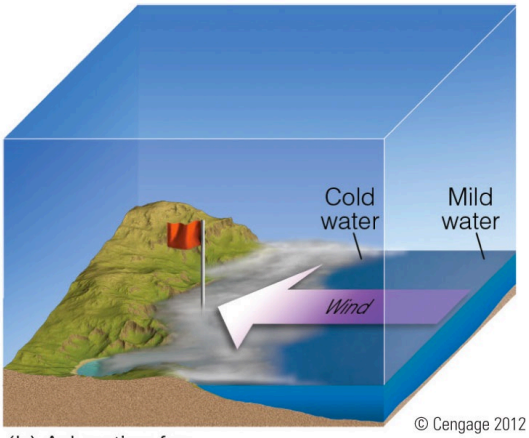
Fog is a cloud that touches the ground.

There are five types of fog:

- Radiation
- Advection
- Upslope
- Steam
- Precipitation or frontal



(a) Radiation fog



(b) Advection fog

Radiation fog

Radiation fog: Fog that forms as air near the ground cools and the relative humidity increases to 100%.

What conditions favor radiation fog formation?

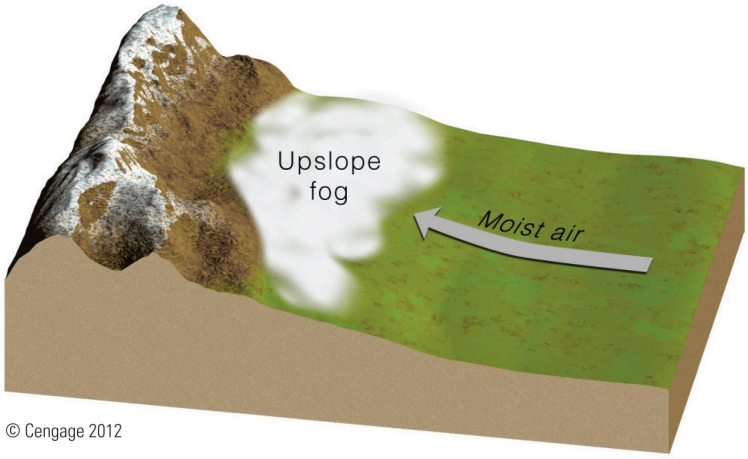
Advection fog

Advection fog: Fog that forms as warm, moist air moves over a colder surface and is cooled to its dew point temperature.

What are some examples of locations / conditions where advection fog may form?

Upslope fog

Upslope fog: Fog that forms as moist air flows uphill and cools adiabatically.



What conditions favor upslope fog formation in Boulder?

Steam fog

Steam fog: Forms as cold air overlies a warm, wet surface.

Evaporation from the warm, wet surface increases the amount of moisture in the air while turbulence mixes this warm, moist air with the cooler air above. This mixture becomes saturated to form steam fog.

What are some examples of conditions when steam fog would form?

Precipitation (or frontal) fog

Precipitation (or frontal) fog: Fog that forms as rain falling into a cold layer of air evaporates and increases the amount of moisture in the cold layer until it becomes saturated.

What processes cause a fog layer to dissipate?