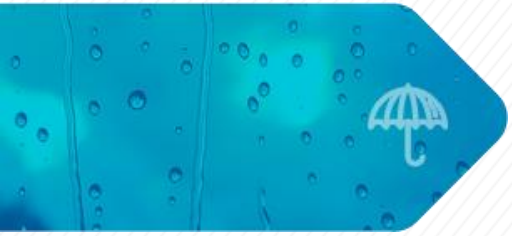
# Introduction to Meteorology

## 09 Fog

## Introduction

There are several ways to change unsaturated air into saturated air. Air can be saturated by adding water vapor, cooling air down to dew-point temperature, mixing ~~of~~ cold air with warm and humid air, and cooling air via adiabatic expansion. Fog is formed when air is saturated by such processes.

## Contents



1. Formation of fog
2. Types of fog
3. Dew and frost

## Learning objectives

1. Explain the formation of fog.
2. Describe the type of fog.
3. Understand the difference between dew and frost.

# Learning Activities

## 1. Formation of fog

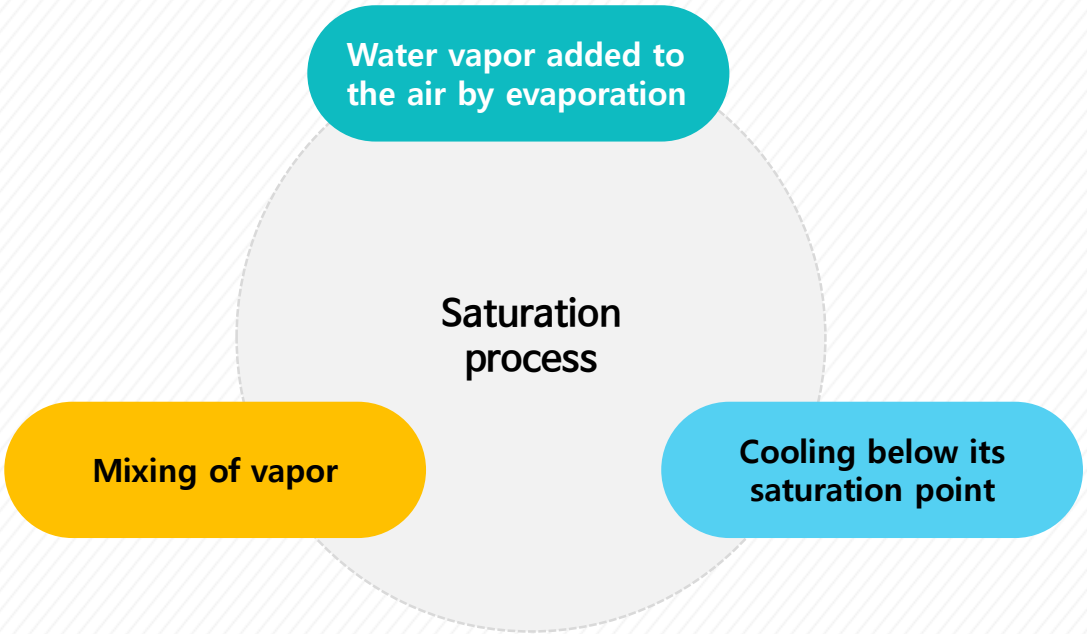
A fog can be defined as a cloud whose bottom is very close to the ground. In fact, there is no fundamental difference between fog and cloud. The most important difference is how and where it is formed. Clouds occur when the air rises and adiabatically cools, whereas fog occurs when the air is cooled or when a sufficient amount of water vapor is contained in the air and saturates.

For fog to occur, it must contain a lot of water vapor in the atmosphere, the temperature should drop below the dew-point to saturate the air, and the water vapor must condense into water droplets. Therefore, fog forms either when warm and humid air meets cold air near the surface or when the humidity is high due to the large amount of water vapor in the vicinity. Also, if there exist enough condensation nuclei which promote condensation, fog can develop even at relatively low humidity. In industrial area, the condensation nuclei such as dust are abundant, although humidity is only 80%, fog can form easily. Once fog is formed, new fog droplets are constantly formed from the condensation nuclei. It means that air has to maintain a certain level of saturation through continuous cooling or evaporation and mixing of vapor into the air.

# Learning Activities

## 1. Formation of fog

In order for the fog to form continuously, the wind must be weaker than 2~3m/s, and the air around the surface must be stabilized. A typical example is a surface inversion layer resulted from rapid cooling of the air above the ground during the night. Fog usually forms in three ways: by cooling, by evaporation, and by mixing.



# Learning Activities

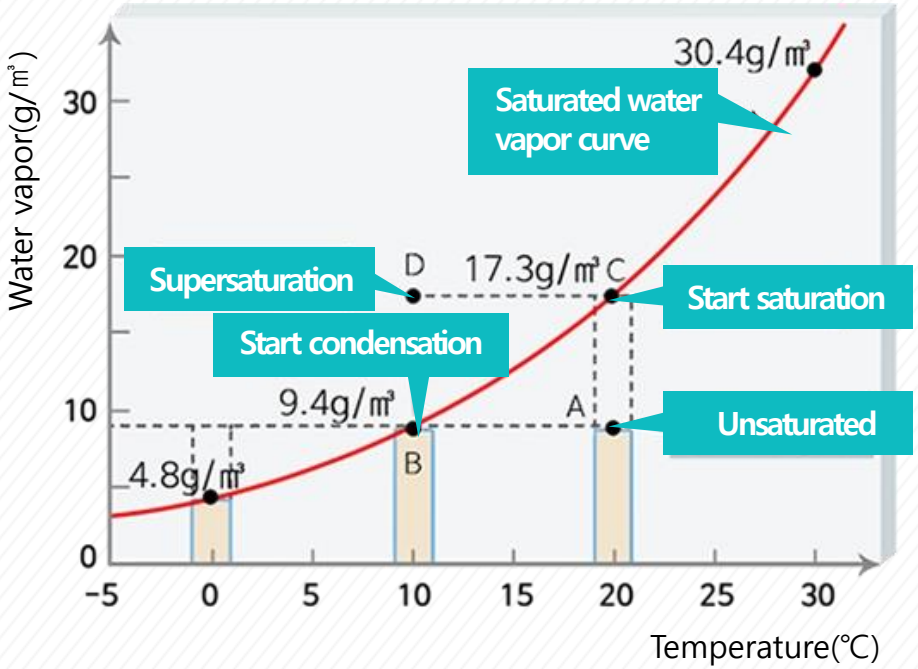
## 1. Formation of fog

### 1) Saturation by evaporation

First, let's look at saturation by the addition of water vapor.

This graph shows the saturation process of unsaturated air. In the graph, the solid curve is the saturation water vapor pressure curve, the upper part of the curve shows the supersaturation state, and the lower part shows the unsaturated state. How do we saturate the unsaturated air at point A, which has 20˚C? At point A, because it is unsaturated, it is possible to add water vapor with the same temperature of 20˚C so that it becomes saturated.

For example, when you take a shower, the temperature of the air in the bathroom differs from the temperature of the water, but the warm water evaporates into the air in the bathroom, which causes the air to reach saturation. When the supersaturation of the water vapor in the bathroom occurs, condensation of water vapor can take place on the mirror and the wall of the bathroom. The evaporation of raindrops can saturate air near the surface, and form a fog.




〈Saturation process〉

※ Source: http://study.zum.com/book/15316

# Learning Activities

## 1. Formation of fog

### 2) Saturation by cooling

Formation of dew and fog on the surface is a phenomenon caused by condensation of water vapor due to the decrease in air temperature within a constant air pressure. During isobaric process, keeping the water vapor constant and lowering the temperature cause saturation. In this case, the saturation occurs when the temperature changes from A to B. The corresponding temperature at B is called the dew-point temperature, which is 10˚C in this case. Physically, the dew-point temperature is defined as the temperature at which the current water vapor pressure changes to saturation water vapor pressure by cooling during isobaric process.

When the temperature drops below 0 ℃, a frost occurs and the temperature is called frost point. Frost point is the temperature at which the unsaturated air is cooled and saturated with ice during isobaric process. Frost is formed not by freezing of water but by deposition of water vapor on the surface of the object at temperature below 0 ℃. Fog has the following difference from dew and frost:

| Fog | VS | Dew and frost |
|---|---|---|
| Saturation of water vapor in the atmosphere | | Condensation and deposition of water vapor on the surface of an object |

# Learning Activities

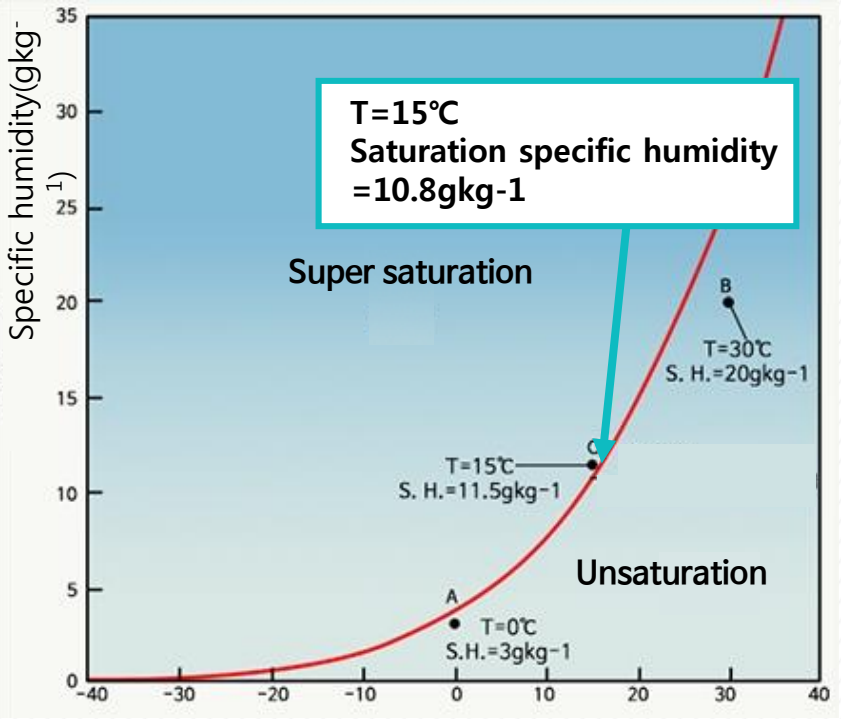
## 1. Formation of fog

### 3) Saturation by mixture of two different types of air

Saturation can take place by mixing of cold air with warm and humid air.

Consider ~~the~~ two unsaturated air parcels, in which the temperature at A is 0℃ and specific humidity is 3 g kg $^{-1}$, and the temperature of the air at B is 30℃ and specific humidity is 20 g kg $^{-1}$. When mixing the two air parcels, the average temperature will change to 15℃, the specific humidity will be 11.5 g kg $^{-1}$. Note that the saturation specific humidity at 15℃ is 10.8 g kg $^{-1}$, which is less than the specific humidity of the mixed air. The 0.7 g will be condensed in the mixed air, and such air is supersaturated.

When we exhale in a cold day, warm moisture that we breathe out will turn into tiny droplets of water, which is an example of saturation caused by a mixture of two different air parcels.




〈Supersaturation by mixture of two air parcels with different temperature and specific humidity〉

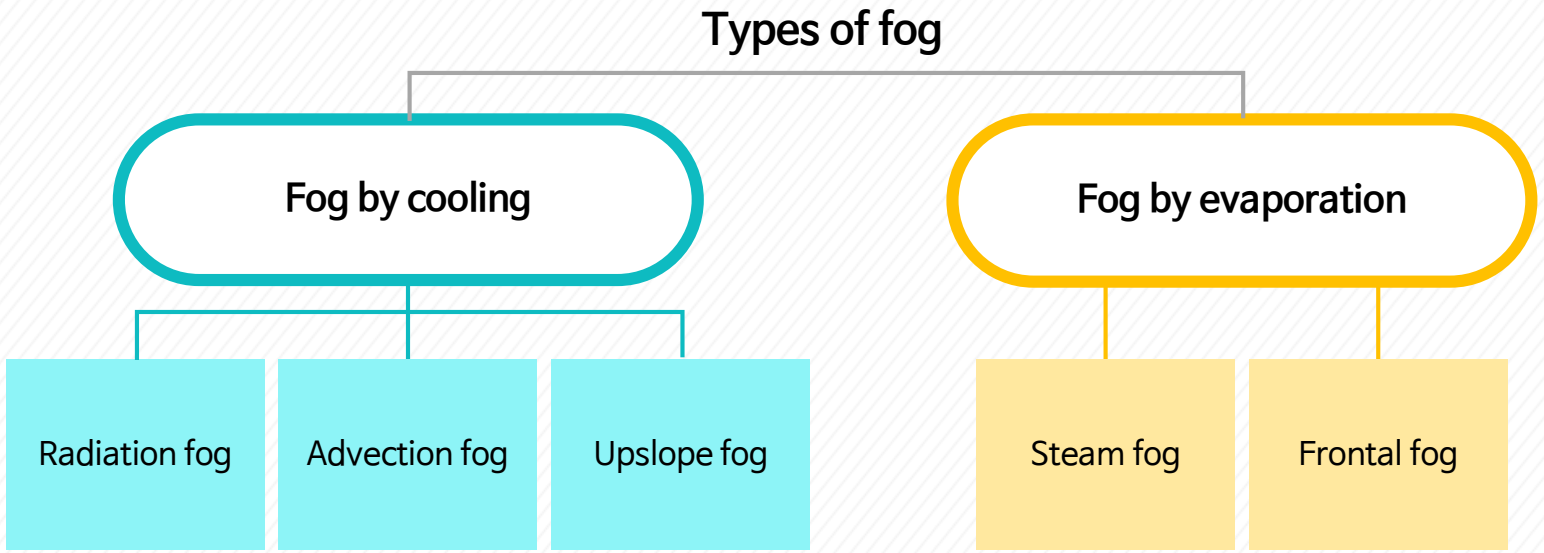
※ Source: Environmental Atmospheric Sciences 3rd edition (Kyung-Eak et al., Donghwa Technology) p80

# Learning Activities

## 2. Types of fog

### 1) Fog by cooling

Fogs usually form in one of two ways: by cooling or by evaporation. Fogs by cooling include radiation fog, advection fog, and upslope fog. Fogs by evaporation consist of steam fog and frontal fog.



# Learning Activities

## 2. Types of fog

The radiation fog occurs when the temperature of the atmosphere near the ground cooled by longwave radiation at night falls to the dew point. As the surface cools, the air just above it cools and temperature inversion develops. The moist lower-atmosphere is rapidly saturated and forms a fog. The radiation fog is formed by diabatic cooling process. Radiation fog forms well at night under a clear sky with high pressure. Radiation fog is therefore likely to form when longwave radiation from the surface more easily escapes into the atmosphere. The longer the night, the longer the cooling time and the more the fog occurs. During the winter, when a high pressure becomes stagnant over an area, radiation fog may form on consecutive days. Radiation fog is, therefore, commonly observed from late fall to winter over the inland.

Another factor promoting the formation of radiation fog is a light breeze. Fog is better formed under weak wind than under a calm air. Slight air movement brings more of the moist air in direct contact with the cold ground and, the transfer of heat takes place more quickly. The strong wind mixes the air near the surface with the drier air in the upper layer, reducing the likelihood of radiation fog formation. In calm air, fog will form unevenly to a depth of less than 1m. Therefore, in order to increase the vertical range of the radiation fog, a slight breeze is needed. Light breeze generates sufficient turbulence, raising the fog 10~30m without dispersion.

The radiation fog usually starts to dissipate within a few hours after sunrise. The sunlight passing through the fog heats the ground, which causes the temperature of the air above ground to rise. As the temperature increases, particles of the fog evaporate gradually. Due to the fast evaporation from bottom, the fog looks as if it is rising although they do not actually move vertically. When radiation fog is well developed, much of the incoming solar radiation is scattered into the atmosphere, reducing the amount of energy reaching the surface. This can cause the nighttime fog to persist for days, especially during the winter months when the day is short and the sun's altitude is low.

# Learning Activities

## 2. Types of fog

The following is a satellite image of a deep fog from the San Joaquin Valley, California. The air containing fog is relatively cold and dense, therefore it falls along the slope. As a result, radiation fog forms in the valley, which called the valley fog. The cold air and high moisture content in river valleys make them susceptible to radiation fog. Since radiation fog forms in lowlands, hills can be clear all day long, while adjacent valleys are fogged in.

〈Fog in San Joaquin Valley, California (2002.11.20)〉

※ Source: Atmospheric Science 10th Edition (Ahn, Joong Bae, et al., Sigma Press) p165

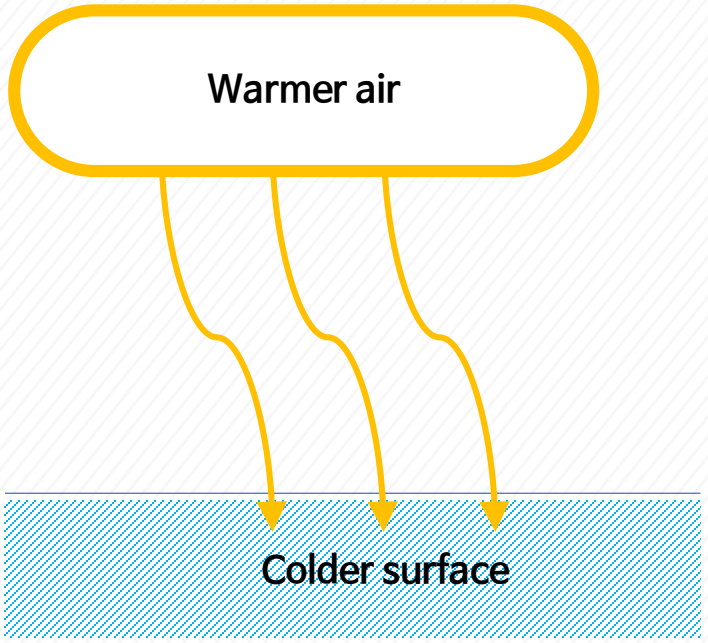
# Learning Activities

## 2. Types of fog

Advection fog forms when warm and humid air moves over a sufficiently colder surface. The fog in the ocean is formed when warm moist air from the ocean is advected by wind over the cold coastal waters.

Warm air moves over the cold surface, the bottom of the air cools to its saturation point and forms fog. Such fog is formed by diabatic cooling process and can travel a considerable distance (about 0.5 km), and lasts for a long time on the downwind side of the area. For the advection fog to develop, a certain amount of turbulence (winds between 10 and 30 km/hr) is necessary. The advection fog is thicker and has a longer duration than the radiation fog.

The upslope fog is formed by adiabatic cooling process. As the relatively moist air rises along a slope, the air expands and adiabatically cools down. Once it reaches the dew-point, a large fog layer forms.

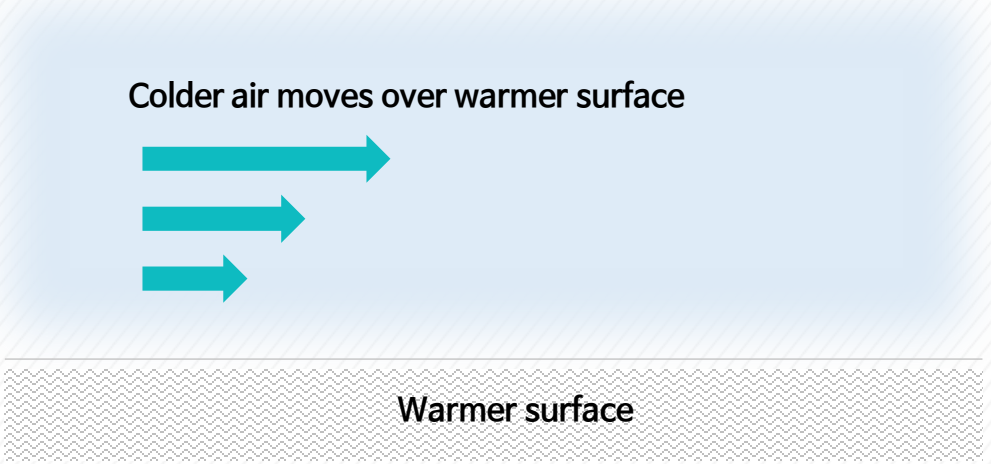


# Learning Activities

## 2. Types of fog

### 2) Fog by evaporation

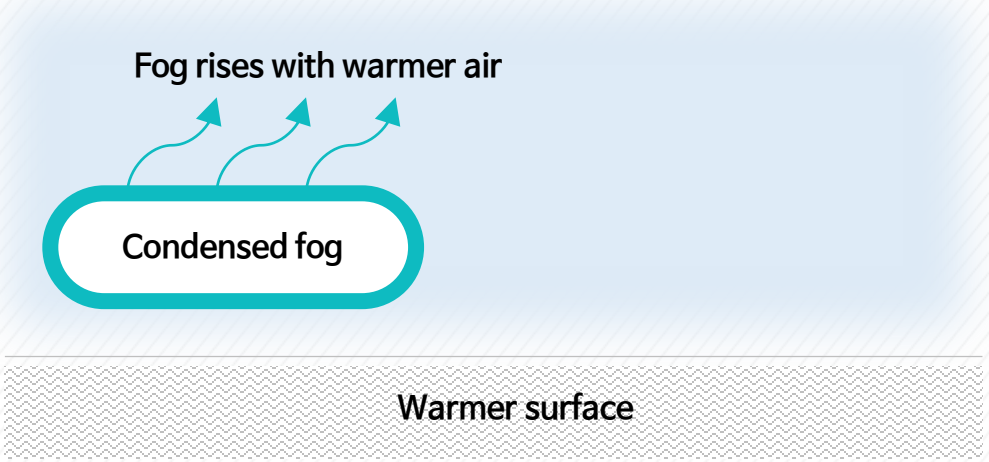
Evaporation fog forms when evaporation occurs by air moving over warmer water. It is also known as a mixing fog, because the evaporation increases the atmospheric water vapor when two unsaturated masses of air are mixed.




Steam fog forms when the cold air over the warm water is saturated and a sufficient amount of water vapor evaporated from the water saturates the overlying air.

# Learning Activities

## 2. Types of fog




The condensed fog rising along with warm air below appears to steam which looks similar to steam rising from hot coffee. In fact, it is more appropriate to call the fog an evaporation-mixing fog because air containing water vapor is actually mixed and saturated with the cold air as it is rising upward.

# Learning Activities

## 2. Types of fog

Steam fog often appears on riverside or lakeside on clear, cool autumn morning, because rivers and lakes are relatively warm, while the air is rather cold. In the Arctic ocean, the cold Arctic air meets a relatively warm ocean. Temperature difference between the warm ocean and cold air is known to exceed 30 ℃. As a result, the water vapor increases and saturates to form a huge fog layer.

A warm rain falling through a layer of cold and moist air can produce fog. As a warm raindrop falls into a cold layer of air, part of the rain water evaporates into the air. This process of which the air saturates and mixing takes places forms fogs. Such fog usually develops in the shallow layer of cold air ahead of a warm front or behind a cold front. This type of fog is called frontal fog or precipitation fog.

# Learning Activities

## 3. Dew and frost

### 1) Dew

On a clear and calm night, objects near the Earth's surface cool rapidly by emitting longwave radiation. The ground and objects contacting the cold surface often become colder than the surrounding air. The atmosphere in contact with such cold surfaces cools by conduction and eventually cools down to the dew point.

〈Dew on leaves〉

When tree branches, leaves, grass leaves, etc. are cooled below the dew point, the water vapor starts to condense on it and becomes a droplet, that is, dew.

# Learning Activities

## 3. Dew and frost

Because objects emit longwave radiation at different rates, dew may be only on some object surface. For example, a car can be covered with dew just after sunset, while concrete roads beneath the car may not go through condensation overnight. Dew is common in lawns early in the morning. The grass is often covered with dew even when no dew is formed on other objects nearby. This is because the evaporation of water vapor by the leaves raises the relative humidity to a higher level. Therefore, it can be seen that saturation and condensation start when only moderate cooling occurs.

A frozen dew occurs when the temperature drops below freezing. Since the lowest temperature air is near the surface, dew is better formed on the grass leaves nearer the ground than on higher objects.

# Learning Activities

## 3. Dew and frost

### 2) Frost

A white frost forms on cold, clear, calm morning when the dew-point temperature falls below 0°C. Water vapor turns into ice without becoming a liquid. This process is called deposition. Frost is made up of white ice crystals and is shaped like a treelike branch that easily distinguishes itself from frozen dew.

〈Frozen dew〉

〈Frost〉

Freeze and black frost form in a very dry weather when air drops below freezing without ever reaching the frost point and without a visible frost.

# Learning Activities

## 3. Dew and frost

### 3) Haze

Haze occurs as the relative humidity increases with cooling of a deep layer of atmosphere at night. When the relative humidity of the atmosphere reaches about 75%, water vapor starts to condense on the small particles floating in the air. Because the moisture sticks to the condensation nuclei, the condensation nuclei grow. Although these condensation nuclei are still small, they are large enough to scatter visible light in all directions. This forms a layer of particles dispersed through a portion of the atmosphere. As the relative humidity gradually approaches 100%, haze particles grow larger and condensation begins on the less-active nuclei. Water is now condensing onto a large fraction of the nuclei, causing the droplets to grow even bigger, until they become visible to the naked eye.
The increasing size of droplets restricts visibility. When the visibility is less than 1km, the haze becomes a cloud resting near the ground, which we call fog.

# Summary

## 1. Formation of fog

- For fog to occur, it must contain a lot of water vapor in the atmosphere, the temperature should drop below the dew-point to saturate the air, and the water vapor must condense into water droplets.
- Fog usually forms in three ways: by cooling, by evaporation, and by mixing.

# Summary

## 2. Types of fog

- Fog by cooling

| | |
|---|---|
| Radiation fog | The radiation fog occurs when the temperature of the atmosphere near the ground is cooled by longwave radiation at night and falls to the dew point. |
| Advection fog | Advection fog forms when warm and humid air moves horizontally over a sufficiently colder surface. |
| Upslope fog | The upslope fog is formed by adiabatic cooling process |

# Summary

## 2. Types of fog

- Fog by evaporation

| | |
|---|---|
| Steam fog | Steam fog forms when the cold air over the warm water is saturated, and a sufficient amount of water vapor evaporated from the water saturates the air above it. |
| Frontal fog | A warm rain falling through a layer of cold and moist air can produce frontal fog. |

# Summary

## 3. Dew and frost

- On a clear and calm night, objects near the Earth's surface cool rapidly by emitting longwave radiation.
- The atmosphere in contact with cold surfaces cools to the dew point.
- A white frost forms when the dew-point temperature falls below 0˚C in the cold, clear and calm morning.