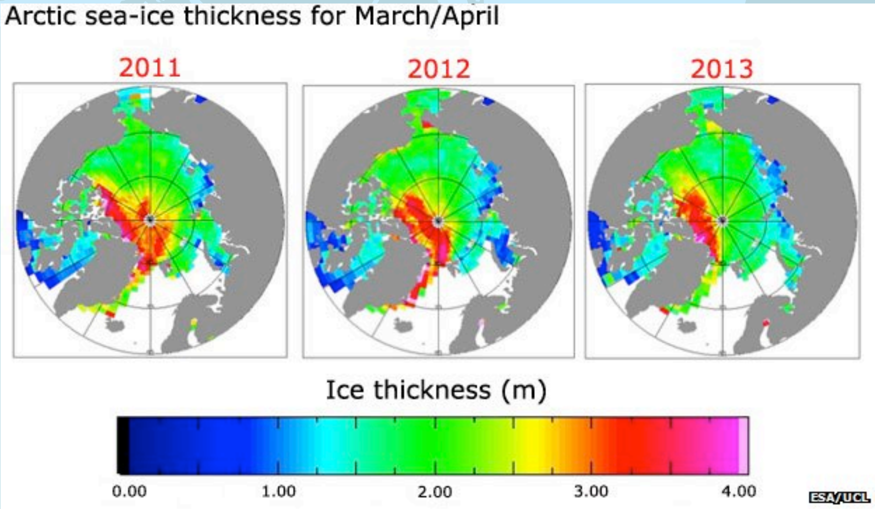
MET 200 Lecture 6
Clouds and Cloud Formation

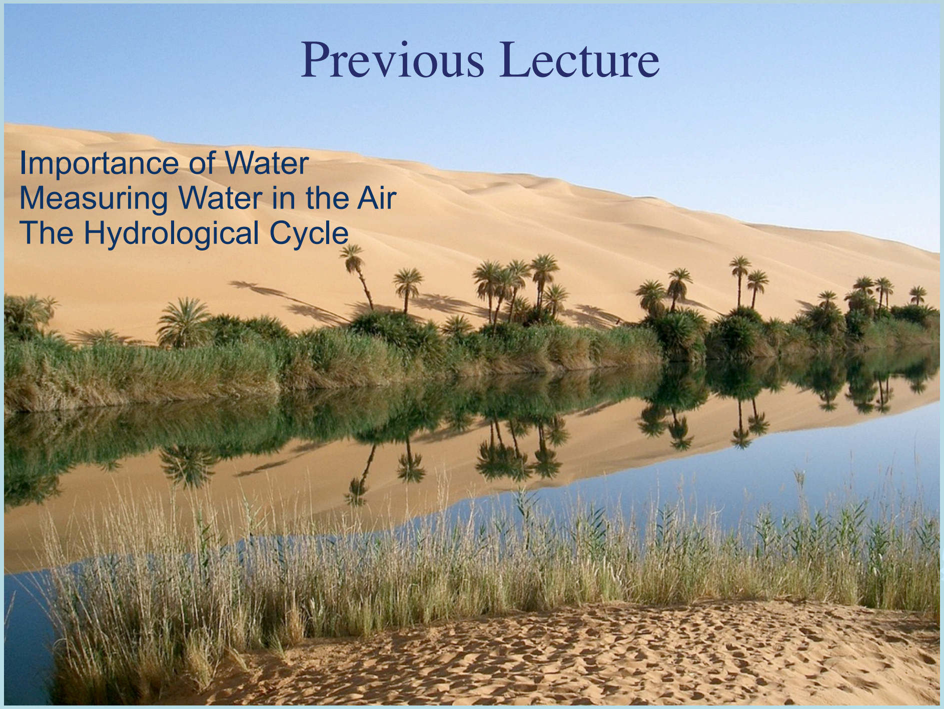
Arctic Ice Volume



Clouds and Cloud Formation

Observations by Last Year's Class

Previous Lecture



Importance of Water
Measuring Water in the Air
The Hydrological Cycle

Cloud Formation

Outline

- Condensation and the formation of clouds
- Fog

Clouds

Clouds impact the environment in many ways –
Radiation balance, water cycle, pollution processing, earth-atmosphere charge balance, etc…

And they can be very beautiful.

Cloud Formation

All clouds require 3 things

1. Water vapor
2. Cloud Condensation nuclei (CCN)
3. Cooling - heat transfer out of air parcel or work done by air molecules in parcel.

Sources of Water Vapor

- Evaporation from the subtropical oceans
- Evapotranspiration from plants.
- Evaporation from Lakes and Rivers
- Sublimation from snow and ice.

Surface Turbulent Fluxes

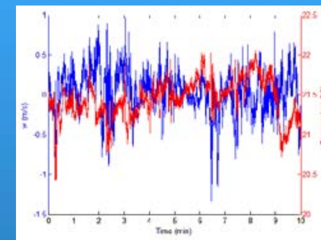
Sensible Heat Flux

$\rho C_p \overline{w'T'}$

ϱ =density of the air

$T' = \overline{T} - T$

C_p =specific heat at constant pressure



Latent Heat Flux

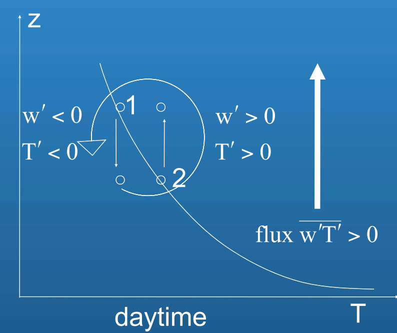
$\rho L_v \overline{w'r'}$

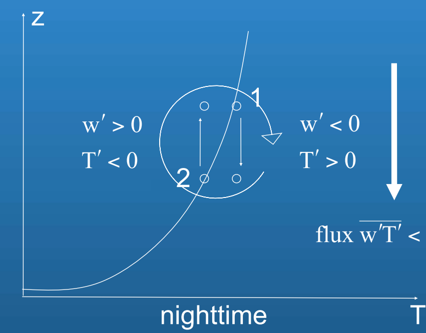
Specific latent heat of vaporization,

$L_v = 2.5 \times 10^6 \text{ J kg}^{-1}$

r = mixing ratio

ϱ =density of the air



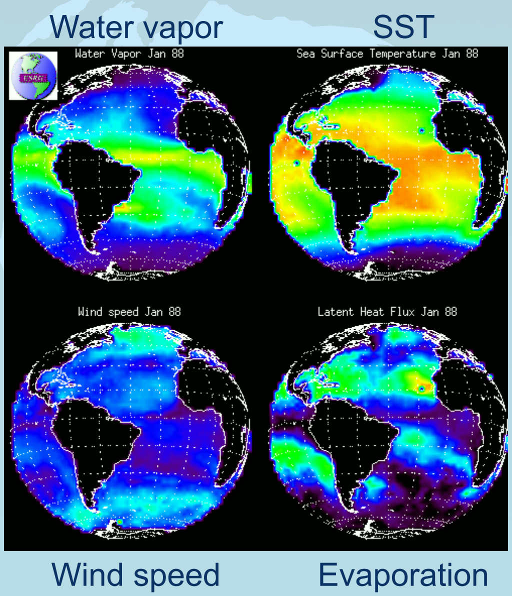


Sources of Atmospheric Water

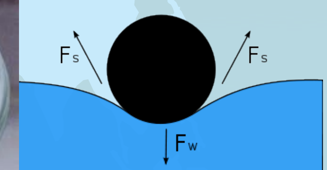
- Water vapor is concentrated in the tropics.
- Evaporation from the sea surface depends on SST, wind, and RH.
- The greatest source of water vapor is in the subtropics.

$$F_{LE} = L_v \rho C_d U_{10} (T_0 - T_{10})$$

F_{LE} = latent heat flux
L_v = specific heat of evaporation
ρ = density of air
C_D = drag coefficient
U_{10} = wind speed at 10 m
T_0 = temperature at surface
T_{10} = temperature at 10 m



Impact of Surface Tension



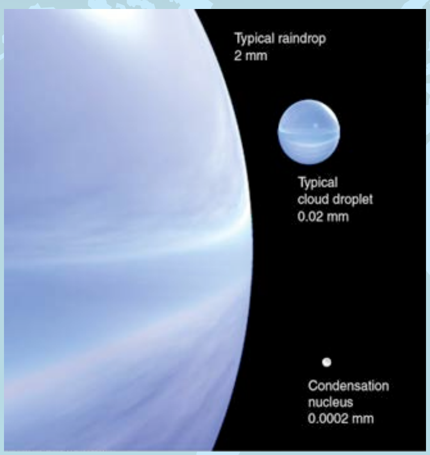
Surface Tension caused by cohesion of similar molecules, makes it hard for water molecules to enter droplets, just as this pin is having trouble.

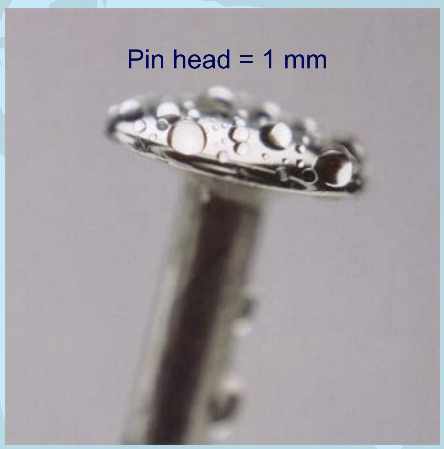
Impact of Surface Tension

Impact of Surface Tension

Surface Tension pulls drops into spherical shape.

Typical sizes





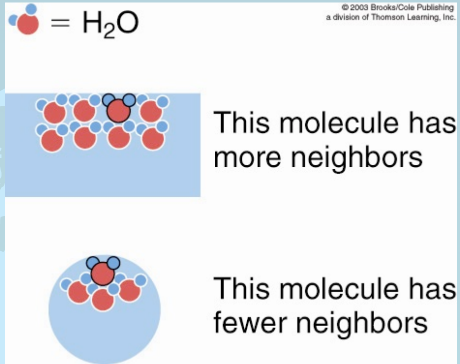
The smaller the droplet the harder it is for water the enter the drop so that it can grow.

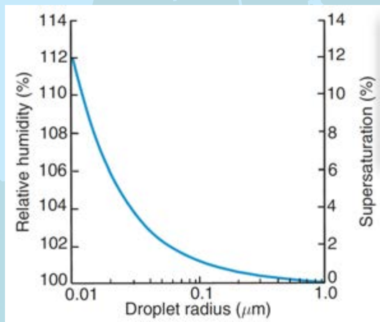
Cloud Condensation Nuclei

- If the air temperature cools below the dew point (RH > 100%), water vapor will tend to condense and form cloud drops.
- Drop formation occurs on particles known as cloud condensation nuclei (CCN).
- The most effective CCN are water soluble.
- Without CCN clouds would not form in the atmosphere, because a RH of several hundred percent is required for pure water drop formation. Why?

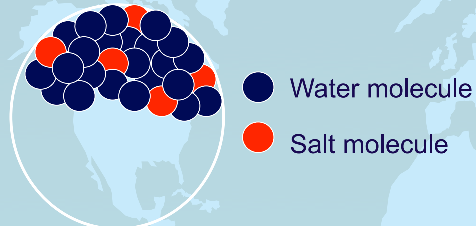
Very Small Drops Tend to Evaporate!

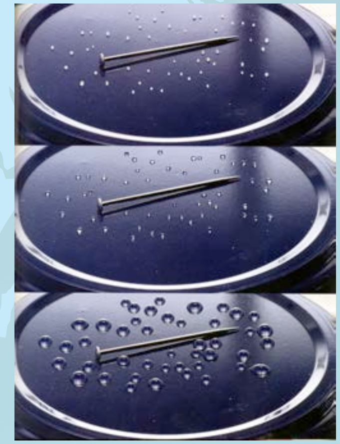
- Small drops have large curvature
- Large curvature gives a high saturation vapor pressure because of effect of surface tension.
- Very high RH required for equilibrium over very small drops
  - ~300% RH for "clean" air without CCN.





CCN that Dissolve in Water





Water soluble CCN act to reduce the saturation vapor pressure over the droplet surface by taking up spaces on the surface, by reducing the curvature, and by reducing the cohesion with neighbor water molecules.

CCN are Aerosols

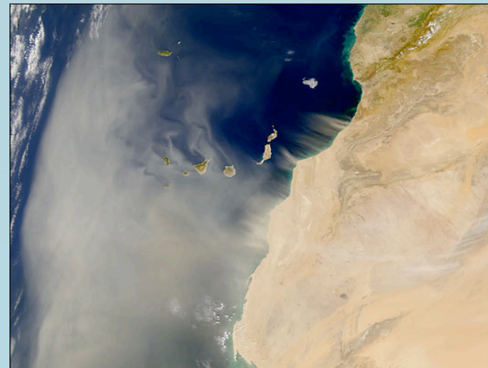
Sources of Aerosols and CCN

Smoke from natural and man-made fires.

Sources of Aerosols and CCN

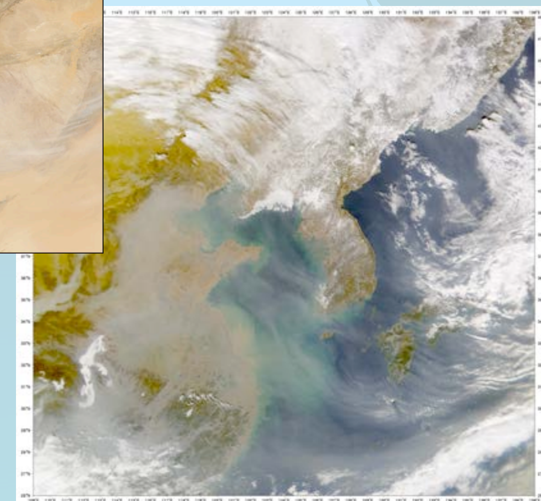
Aerosols from Volcanoes

CCN are Aerosols



African Dust

Industrial Pollution from China



More Sources of CCN

Sulfate aerosol

$SO_2 \rightarrow H_2SO_4$

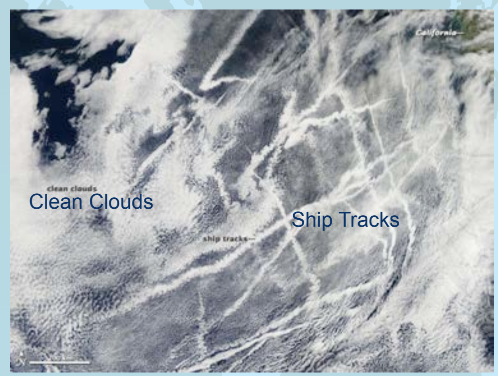
sulfuric acid

SO_2

Clouds even contribute to CCN production

- Clouds ingest sulfur dioxide (SO_2)
- Chemical reactions in the cloud drops convert dissolved SO_2 to soluble forms of sulfate, such as sulfuric acid - H_2SO_4.
- When the cloud drops evaporate, soluble sulfate particles are left behind.
- SO_2 is emitted by volcanoes and by phytoplankton in the ocean.

More about CCN



Ship Tracks

CCN concentrations vary in time and space

- Typically 100-1000 per cubic centimeter.
- Higher in polluted environments
- Higher CCN concentrations give rise to greater cloud-drop concentrations.
- Climate impacts of these more reflective clouds? They have a higher albedo and rain out much more slowly.

CCN Summary

- Natural CCN
  - Sea salt particles (NaCl)
  - Forest fire smoke, volcanic aerosols.
  - Dust and pollen blown into the air.
- CCN from human activity
  - Pollutants from fossil fuel combustion form acids and salts.
  - Smoke
- Not all atmospheric particles are cloud condensation nuclei (CCN).
- Good CCN attract water (hydroscopic).
- Clouds produce some CCN and leave them behind if the cloud evaporates.

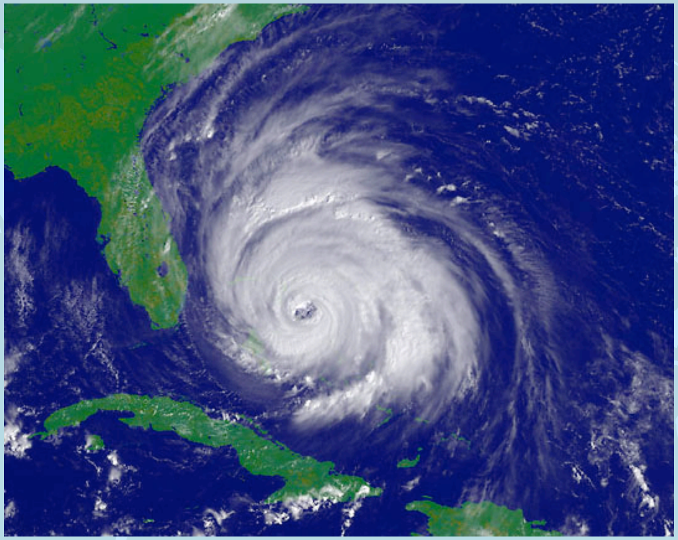
Mechanisms for Cooling the Air

1) Lifting – most clouds form when air is lifted.
   a) Convergence – low press center – stratus
   b) Mountains – lifting by terrain
   c) Fronts – lifting over denser air.
   d) Warm air relative to surroundings
      i) Fires, volcanoes – cumulus
      ii) Latent heat
2) Mixing – seeing your breath on cold day
3) Contact – with cold surface – advection fog
4) Radiation – ground fog

Lifting

Most clouds form when air is lifted.
a) Convergence of air into a low pressure center.
b) Mountains – lifting by terrain
c) Fronts – lifting over denser air.
d) Warm air relative to surroundings
i) Fires, volcanoes – cumulus
ii) Latent heat

Lifting

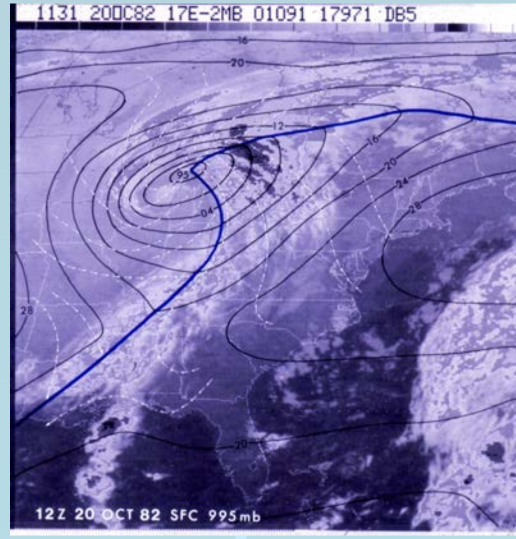


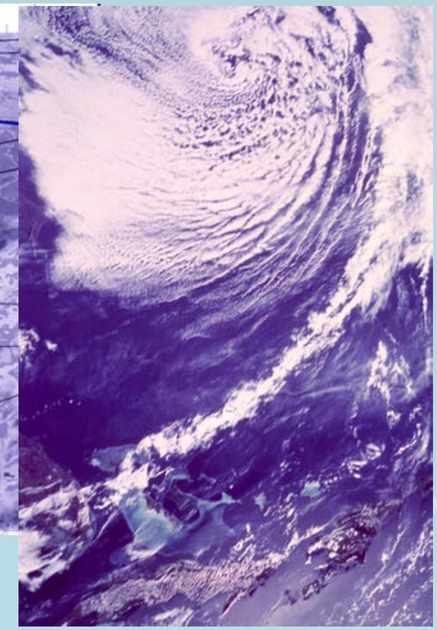
Convergence into a Low

Lifting

Lifting by terrain

Lifting



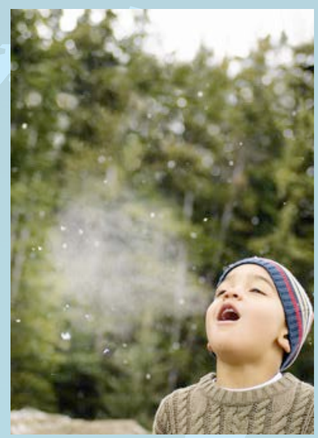


Lifting by Fronts

Lifting

Warm Air Relative to Surroundings

Mixing

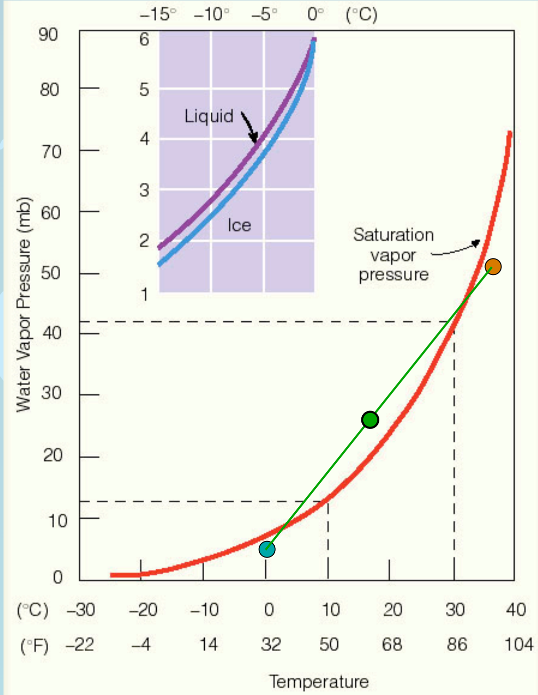


Seeing your breath on a cloudy day

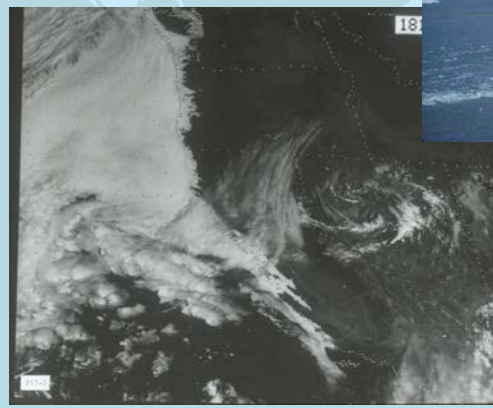
Fog in cold air over warm water

Mixing fog

- Your breath in winter because of mixing with cold air.
- It does not fog in summer because of the small temperature difference.



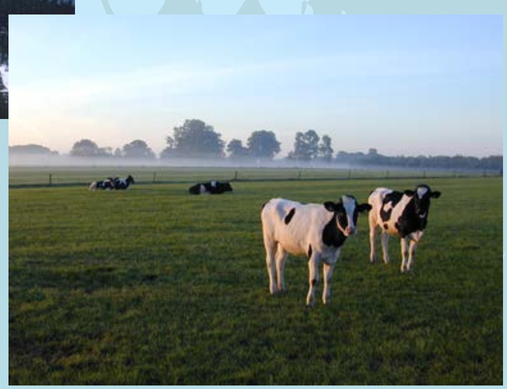
Contact with a Cold Surface



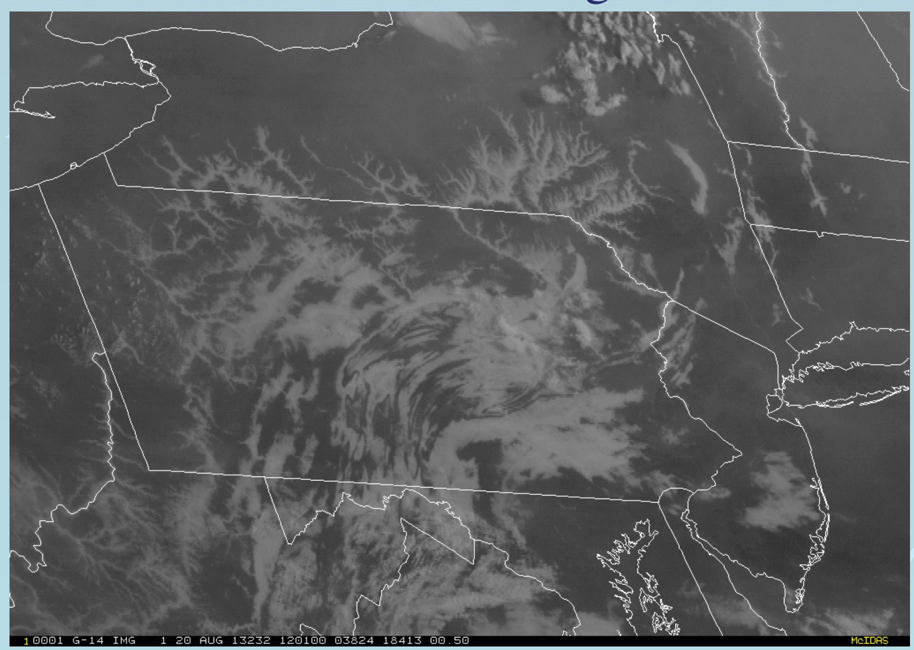
Advection Fog

Radiation

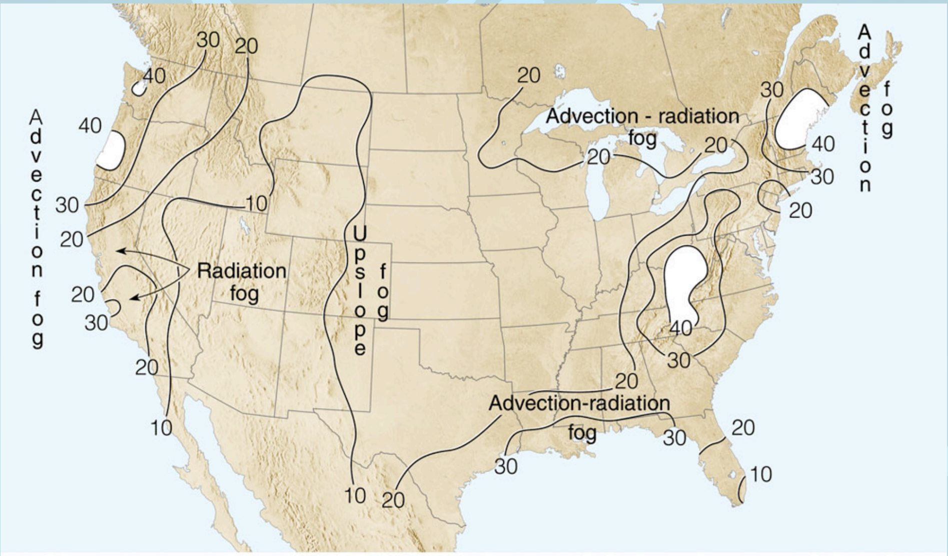
Ground Fog or Radiation Fog



Radiation Fog



Annual days of dense fog (visibility < 0.25 miles)

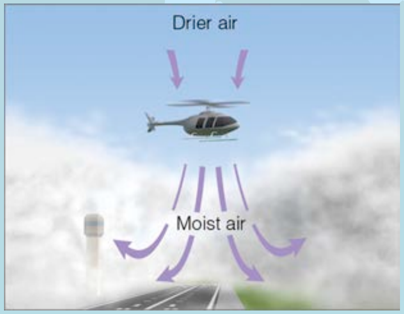


Fog Summary

- Fogs are clouds in contact with the ground
- Several types of fogs commonly form
  - Radiation fog
  - Advection fog
  - Upslope fog
  - Evaporation (mixing) fog

Fogs and visibility

- Light scattering by fog drops (geometric scatterers) degrades visibility, leading to
  - Traffic fatalities
  - Airport accidents and closures
- Remedies
  - Fog monitoring and warning (optical sensors)
  - Fog dispersal (expensive and of limited utility)



Dew

- Surfaces cool strongly at night by radiative cooling
  - Strongest on clear, calm nights
- The dew point is the temperature at which the air is saturated with water vapor.
- If a surface cools below the dew point, water condenses on the surface and dew drops are formed.

Frost

- If the temperature is below freezing, the dew point is called the frost point
- If the surface temperature falls below the frost point, water vapor is deposited directly as ice crystals
  - deposition
- The resulting crystals are known as frost, hoarfrost, or white frost

Haze

Small droplets that form at RH > 60% on hygroscopic nuclei (salt, sulfuric and nitric acid)

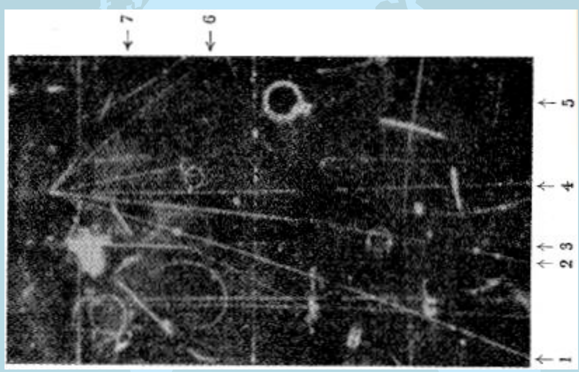
Also obscuring by smoke, dust, pollen, etc.

Becomes visible by scattering light.

Wilson's cloud chamber

a sealed environment containing a supercooled, supersaturated water vapor. When an alpha particle or beta particle interacts with the mixture, it ionizes it. The resulting ions act as condensation nuclei, around which a mist forms.

Brocken Spectre (Glory)



Charles Thomson Rees Wilson (1869-1959), a Scottish physicist, is credited with inventing the cloud chamber. Inspired by sightings of the Brocken spectre while working on the summit of Ben Nevis in 1894, he began to develop expansion chambers for studying cloud formation and optical phenomena in moist air. Very rapidly he discovered that ions could act as centers for water droplet formation in such chambers. He pursued the application of this discovery and perfected the first cloud chamber in 1911.

Questions?