Water and Atmospheric Moisture

Physical Geography Lecture - GEOG B1

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Water

Water is the only common compound substance that occurs naturally in all three states of matter: **liquid**, solid, and vapor

When water changes from one state of matter to another, the heat energy absorbed or released helps power the general circulation of the atmosphere, which drives daily weather.

Water’s Unique Properties

One hydrogen and two oxygen atoms join to create the stable molecule of H_2O.
Water molecules attract each other.
Water dissolves many substances. *
Surface tension allows water molecules to hold together due to the hydrogen bonds.**

Phase Changes and Heat Exchange

Phase change - when water changes from one state to another. (**Fig. 7.2**)
>> heat energy must be added to it, or released from it
Melting & Freezing - describes phase changes between liquid and solid
Condensation - process where water vapor becomes liquid water
Evaporation - process where liquid water becomes water vapor
Vaporization - process of boiling water
Deposition - process where water vapor attaches directly to ice crystals (frost)
Sublimation - process where ice change directly to water vapor *

Ice - Solid Phase

Water expands as it freezes. *
Ice is less dense than liquid water, so it floats. **
Freezing water can crack rocks and pavement, and it can burst pipes.

Water - Liquid Phase

As a liquid, water is a non-compressible fluid, and it assumes the shape of its container.
For ice to change to water, heat energy must be applied to increase the motion of the water molecules enough to break the hydrogen bonds.
The heat energy of this phase change is **latent heat**: (**Fig. 7.5**)
>>80 calories of heat energy must be absorbed for a phase change of 1 gram (g) of ice melting into 1 g of water [+80 cal. = Latent heat of melting]
>>80 calories of heat energy must be released for a phase change of 1 g of water freezing to 1 g of ice [-80 cal. = Latent heat of freezing]

Water Vapor - Gas Phase

Water vapor is an invisible and compressible gas - each molecule moves independently of the others.

Latent heat of vaporization = +540 cal. for 1 g of water to become vapor

Latent heat of condensation = -540 cal. for vapor to condense to 1 g of water

Fig 7.5a

Latent Heat Transfer in Nature

In nature, water at normal temperatures (in lakes, streams, oceans, or soil) must absorb or release a great deal more heat energy to achieve evaporation or condensation.

Latent heat of evaporation is the dominant cooling process in Earth's energy budget - the water absorbs the heat energy.

Water Vapor

Fig 7.6 *

Water vapor is an important greenhouse gas.

Concentration of water vapor in atmosphere is tied to temperature.

As temperature rises, evaporation increases, which leads to more vapor in the atmosphere which strengthens the greenhouse effect, and the temperature rises.

This will lead to higher precipitation during the heaviest precipitation events (e.g. storms or mosoons).

Humidity

Humidity is the amount of water vapor in the air.
The capacity air has for water vapor is a function of the temperatures of both the air and the water vapor.
We spend billions to adjust the humidity of buildings with air conditioners* and with air humidifiers.**

Relative Humidity

Fig 7.7

Relative humidity - the ratio (expressed as a percentage) of the amount of water vapor that is actually in the air compared to the maximum water vapor possible in the air at a given temperature.

Relative humidity varies because of water vapor or temperature changes in the air.

Relative humidity is the most common measure of humidity in weather reports.

Saturation and Dew Point

Saturation - 100% relative humidity - the air can't take any more water vapor. When air reaches saturation, any addition of water vapor, or decrease in temperature, will result in condensation (clouds, for, or precipitation).
Dew-point temperature - the temperature at which air becomes saturated and condensation begins to form water droplets.
Fig 7.8 a *

Daily and Seasonal Relative Humidity Patterns

An inverse relation occurs during a typical day between air temperature and relative humidity: as temperatures rise, relative humidity falls.

Fig 7.9 *

The amount of water vapor in the air may stay the same, but the relative humidity changes because temperature and the rate of evaporation varies.

Seasonally, winter has higher relative humidity percent readings because air temperature is lower overall. The opposite happens in summer.

Atmosphere Stability

An air parcel is a volume of air with specific temperature and humidity characteristics. *

Stability - the tendency of an air parcel to either remain in place or to change its vertical position by ascending or descending

A parcel is **stable** if it resists displacement upward, or when disturbed, tends to return to its starting position.

A parcel is **unstable** if it continues to rise until it reaches an altitude where the surrounding air has a density and temperature similar to its own.

Fig 7.13 **

Adiabatic Process

An ascending air parcel cools by expansion in response to reduced pressure at a higher altitude. *
A descending air parcel heats with compression in response to increased pressure at a lower altitude. **
These methods of cooling and heating are adiabatic processes.
Adiabatic means occurring without a loss or gain of heat energy.
There is no heat exchange between the environment and the vertically moving air parcel - it's all about the air pressure.

Dry Adiabatic Rate

p. 178 - GIA 7

Dry adiabatic rate (**DAR**) - the rate at which “dry” air cools by expansion or warms by compression

Example: Dry air parcel at 27°C (81℉) rises to an altitude of 2,500 m (~8,000 ft). How much did the temperature change?

- (10 C°/1,000 m) x 2,500 m = 25 C° of total cooling *
- (5.5 F°/1,000 ft) x 8,000 ft = 44 F° of total cooling
- Subtract the 25 C° (44 F°) of adiabatic cooling from the starting temperature of 27°C (81℉), and the temperature in the air parcel is 2°C (36℉). **

Moist Adiabatic Rate

Moist adiabatic rate (**MAR**) - the rate at which "moist," or saturated, air cools by expansion or warms by compression

Use the same process as with the DAR, just substitute the MAR below…..

(6 C°/1,000 m)

(3.3 F°/1,000 ft)

Cloud Formation Processes

Cloud - a collection of tiny moisture droplets and ice crystals suspended in the air in a great enough volume and concentration to be seen. *

Cloud condensation in an air parcel also requires **cloud-condensation nuclei**, which are microscopic particles that are always present in the atmosphere. **

Cloud Types & Identification - I

Altitude and shape are key to cloud classification. *

- There are three forms: flat, puffy, and wispy
  - Stratiform - flat and layered clouds with horizontal development
  - Cumuliform - puffy and globular clouds with vertical development
  - Cirroform - wispy clouds - usuall at a higher altitude and made of ice crystals
- There are 4 altitudinal classes: low, middle, high, and clouds vertically developed through the troposphere.
- Combinations of shape and altitude result in ten basic cloud types.
- **p. 181 - Table 7.1   Fig. 7.17**

Cloud Types & Identification - II

Low clouds up to 2,000 m (6,500 ft) are stratus or cumulus.

- **Stratus** clouds - dull, grey and featureless
- **Nimbostratus** - stratus clouds yielding precipitation (*nimbo = stormy/rainy*)
- **Cumulus** clouds - right and puffy - do not have big vertical development
- **Stratocumulus** clouds - fill the sky in patch of lumpy, greyish, low-level clouds

Cloud Types & Identification - III

These clouds are made of water droplets mixed, when the temperature is cold enough, with ice crystals - around 2,000-6,000 m (6,500-20,000 ft) *

- **Altocumulus** clouds - broad category of looks, from patches of cotton balls, to arranged in rows or wave patterns, or lens shaped (lenticular)
- Above 6,000 m (20,000 ft), clouds are composed of ice crystals in thin concentrations.
- **Cirrus** clouds - wispy, feathery, look like brush strokes **
  - Cirrostratus - this veil high up
  - Cirrocumulus - puffy appearance

Cloud Types & Identification - IV

Cumulus clouds can develop into towering giants that fill the Troposphere.

- **Cumulonimbus** clouds* - also called thunderheads
  - Have huge vertical development where droplets turn into ice crystals
  - Usually involve wind gusts, updrafts, downdrafts, and heavy rain
  - Top of cloud usually sheared by high-altitude winds into the characteristic anvil shape
  - **Fig. 7.18 a** & **b**

Processes That Form Fog

Fog - a cloud layer on the ground where visibility is restricted to less than 1 km (3,300 ft)

The air temperature and dew-point temperature at ground level are almost identical, indicating saturated conditions.

A fog layer is usually capped by a temperature inversion layer (warmer temperatures above and cooler temperatures below).

Radiation Fog

Radiation fog - forms when radiative cooling of a surface chills the air layer directly above that surface to the dew-point, creating saturated conditions. Occurs only over moist ground, especially on or after a clear, cold night.
Fig. 7.19
Winter radiation fog is typical for the California Central Valley. *

Advection Fog

Forms when air in one place moves to another where conditions are right for saturation. * **Fig. 7.20**

Upslope Fog - moist air flows to higher elevations alog a hill or mountain
>>leads to adiabatic cooling as the air rises
>>results in a stratus cloud at the condensation level

Valley Fog - cooler mountain air settles into low-lying areas
>>produces a fog in the chilled, saturated air
>>**Fig. 7.21**

Evaporation Fog

Associated with advection and evaporation.
Evaporation fog - also known as steam fog
>>forms when cold air lies over the warm water of a lake, ocean surface, or swimming pool

>>wispy fog forms as the water molecules evaporate from the water surface into the cold air

>>humidifies the air to saturation and then condensation
Fig. 7.22

Fog as Hazard and Resource

Fig. 7.23 - Days with heavy fog in U.S. & Canada

Fog is a hazard to drivers, pilots, sailors, pedestrians, and cyclists, even though conditions of formation are very predictable.

Fog is an important moisture source for many organisms, including humans.

- Redwood trees of CA
- Sand beetles in Namib Desert of SW Africa
- 30 countries experience foggy conditions suitable for harvesting water. *