Climate, Climate Change Nuclear Power and the Alternatives

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PHYC 40050

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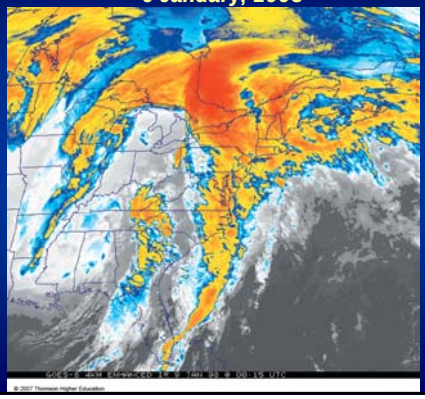
Lecture 3

Water in the Atmosphere

MOISTURE

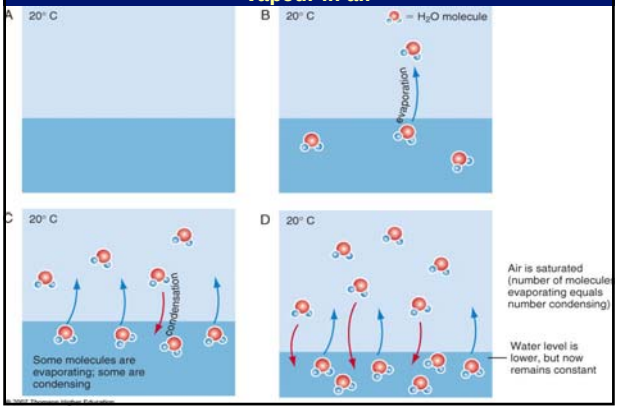
- Water vapor constitutes only a small fraction of the atmosphere.
- Varies from 0% to about 4%
- Water is probably the most important gas in the atmosphere for understanding atmospheric processes.
- The source of atmospheric water is evaporation

Satellite picture of clouds over North America, 9 January, 1998

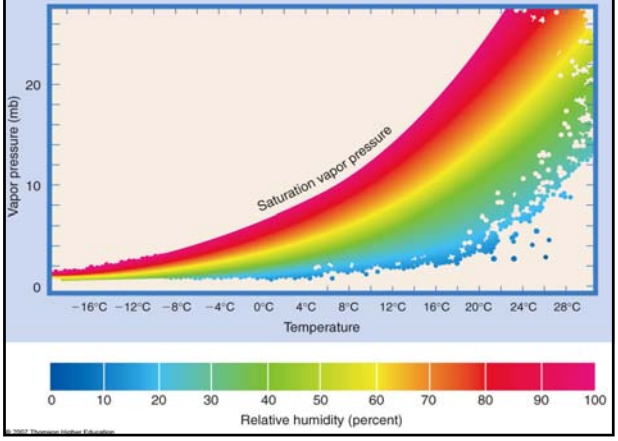


Crumpled steel electrical transmission towers – Canada, January, 1998

Sequence of events leading to saturation of water vapour in air



OBSERVATIONS OF VAPOUR PRESSURE AS A FUNCTION OF TEMPERATURE

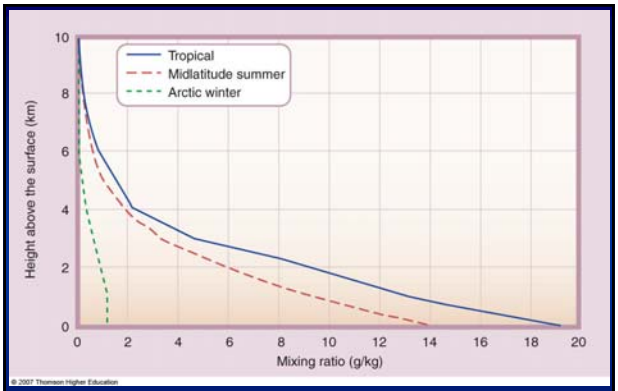


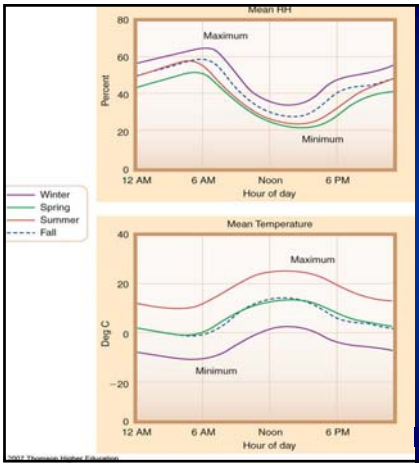
HUMIDITY

- Humidity describes the amount of water vapor in the air.
- Humidity is described quantitatively as vapour pressure, absolute humidity, mixing ratio and relative humidity.
- Saturation is achieved when the number of water vapor molecules leaving a water surface is equal to the number returning from the atmosphere to the water surface.

HUMIDITY

- Saturation vapour pressure is the pressure exerted by the water vapour at saturation.
- Absolute humidity is the mass of water per unit volume . Units are usually grams per cubic meter.
- Mixing ratio is the mass of water vapor in an unit mass of air. Usually in grams per kilogram.
- Relative humidity is the actual amount of water vapour in the air over the amount of water vapour required for saturation.





Climatology of hourly temperature and relative humidity

When the temperature of the air around this web cooled to the dew point temperature, dew formed, making the web more visible

RELATIVE HUMIDITY

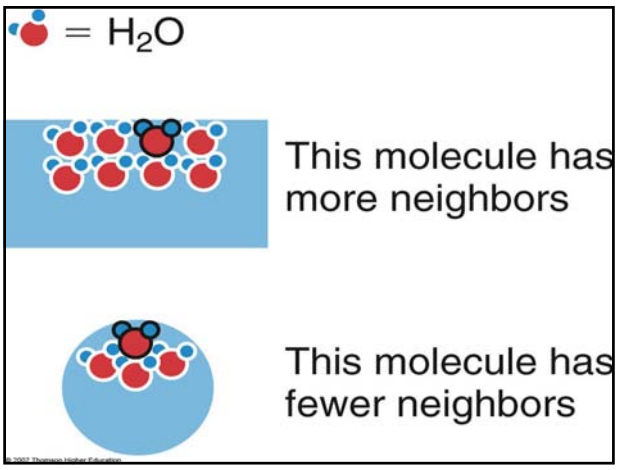
- Relative humidity changes as daily temperature changes.
- It changes from one location to another.
- It changes when air moves vertically in the atmosphere.
- Daily variation of temperature and relative humidity
- However the water vapour content of the air can stay the same.
- Dew point is the temperature at which water vapour will condense out of the atmosphere – frost point.

Temperature (°C)	-10	-10	20	20
Relative Humidity	25	75	25	75
Mixing Ratio (g/kg)	0.45	1.35	3.67	11.15
Vapor Pressure (mb)	0.72	2.16	5.87	17.60
Sat. vapor pressure (mb)	2.88	2.88	23.47	23.47
Dew point Temp. (°C)	-26.2	-13.5	-0.5	15.6
Dew point depression (°C)	16.2	3.5	20.5	4.4

Heat index table

Relative humidity (%)	Air temperature (°F)										
	70	75	80	85	90	95	100	105	110	115	120
0	64	69	73	78	83	87	91	95	99	103	107
10	65	70	75	80	85	90	95	100	105	111	116
20	66	72	77	82	87	93	99	105	112	120	130
30	67	73	78	84	90	96	104	113	123	135	148
40	68	74	79	86	93	101	110	123	137	151	
50	69	75	81	88	96	107	120	135	150		
60	70	76	82	90	100	114	132	149			
70	70	77	85	93	106	124	144				
80	71	78	86	97	113	136					
90	71	79	88	102	122						
100	72	80	91	108							

Great risk to health, heatstroke imminent.
Risk of heatstroke.
Prolonged exposure and physical activity could lead to heatstroke.
Prolonged exposure and physical activity may lead to fatigue.



CONDENSATION AND DEPOSITION

- Curvature effect – even if air is saturated over a flat surface, it may not be for a curved surface.
- Supersaturation – relative humidity can be above 100% without condensation
- Nucleation – droplets usually form around particles – condensation nuclei.
- Condensation nuclei can be hydroscopic or hydrophobic.
- Ice nuclei.

ADVECTION FOG

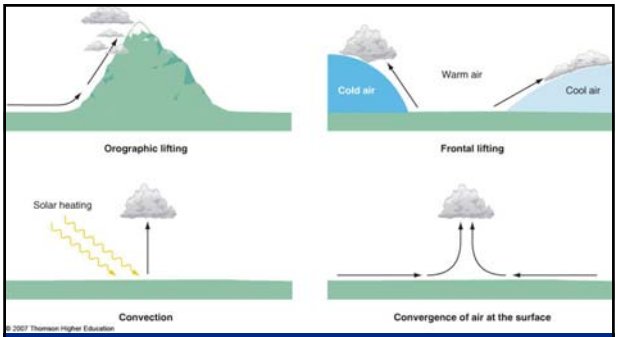
STEAM FOG

FOG FORMATION

- Fog defined as a cloud with its base at or near the ground.
- Fogs result when air is cooled or by the addition of water vapour to cause saturation.
- Radiation fog – cooling of surface by emission of thermal radiation.

FOG FORMATION

- Advection fog – warm and moist air blown over a cool surface. Needs turbulence at the surface.
- Evaporation/steam fog – air picks up additional water over water surfaces.
- Upslope fog – air is cooled as it flows up a slope.



Four mechanisms that cause air to ascend

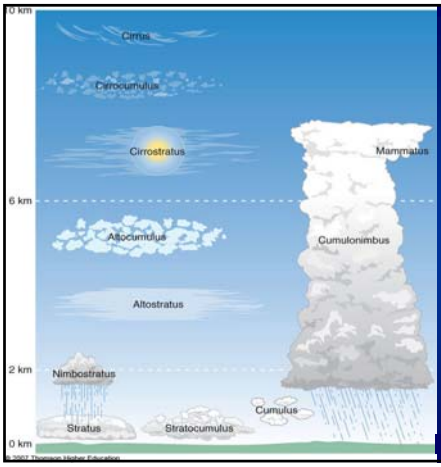
Lifting Mechanisms that form Clouds

Air raised to the Lifting Condensation Level (LCL) becomes saturated.

- Orographic lifting
- Frontal lifting
- Convection
- Convergence

"The Cloud" – Percy Bysshe Shelley

I am the daughter of Earth and Water,
And the nursling of the sky
I pass through the pores of the ocean and shores;
I change but I cannot die.
For after the rain when with never a stain
The pavilion of Heaven is bare,
And the winds and sunbeams with their convex gleams
Build up the blue dome of air,
I silently laugh at my own cenotaph,
And out of the caverns of rain,
Like a child from the womb, like a ghost from the tomb,
I arise and unbuild it again.

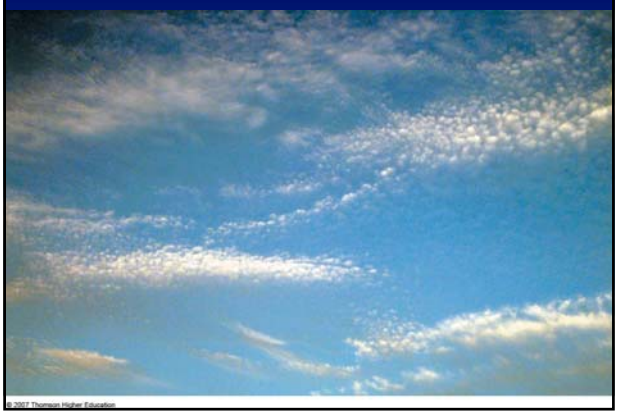


Major cloud types arranged by altitude.

Cirrus Clouds

Cirrostratus clouds showing halo around the sun

Cirrocumulus clouds



HIGH CLOUDS

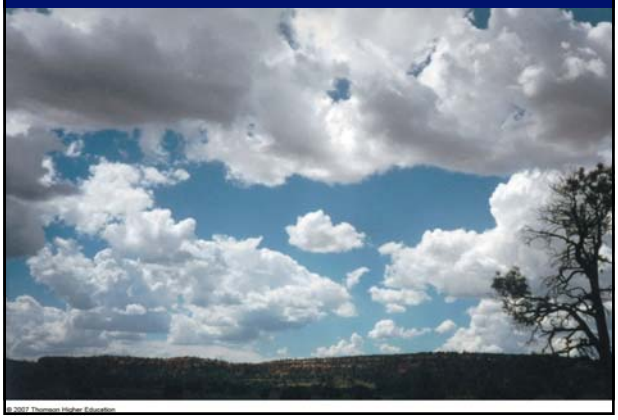
- Above 6000 meters
- Three main types
  - Cirrus - detached clouds composed of delicate icy filaments, have some vertical extent (mares' tails)
  - Cirrostratus - transparent cloud veil - produces a halo around the sun or moon.
  - Cirrocumulus - very small cells or ripples - mackerel sky
- High clouds can be a portend of stormy weather
- Mackerel scales and mares' tails make tall ships carry low sails

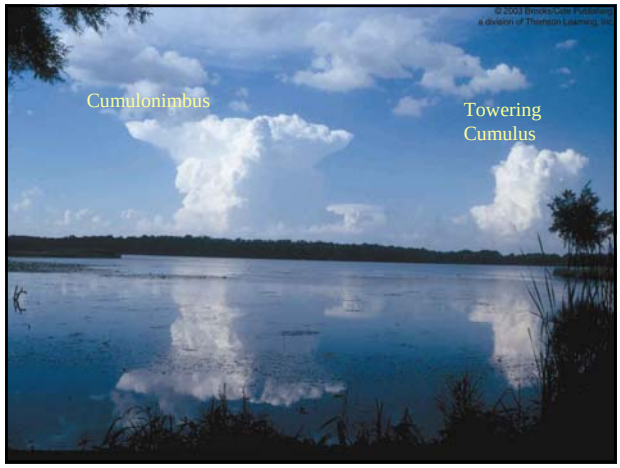
Altocumulus clouds

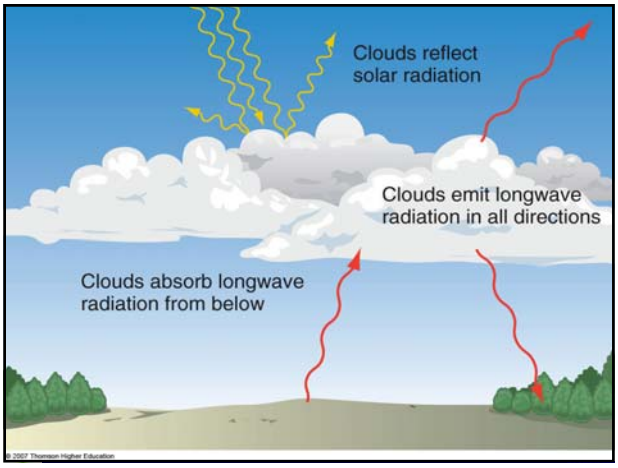
MIDDLE CLOUDS

- 2000 to 6000 meters.
- Composed of water droplets
- **Altocumulus** - large patches composed of rounded masses or rolls.
- **Altostratus** - formless layer of grayish clouds covering all or a large portion of the sky

Cumulus clouds





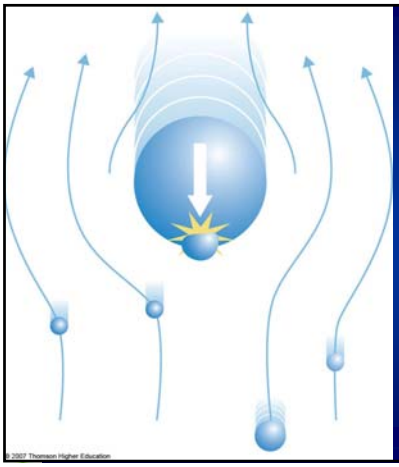


SEPARATOR.

PRECIP follows.

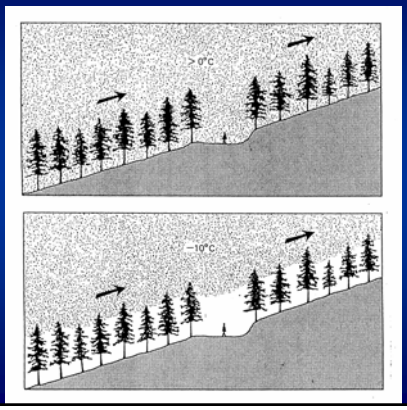
PRECIPITATION GROWTH

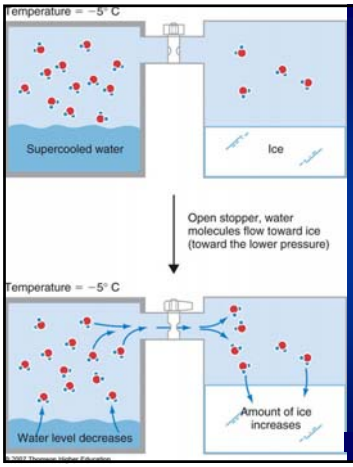
- Cloud droplets are typically 10 microns in size. Small raindrops are typically 1000 microns (~almost one million droplets)
- Raindrops grow by two processes
  - (1) Collision-coalescence – warm clouds.
  - (2) Bergeron process – cold clouds.
- In the Bergeron process snow / ice crystals are formed – mid-latitude clouds
- Rain at mid-latitudes is the result of the melting of the snow / ice as it descends to temperatures above zero



Collision-coalescence process

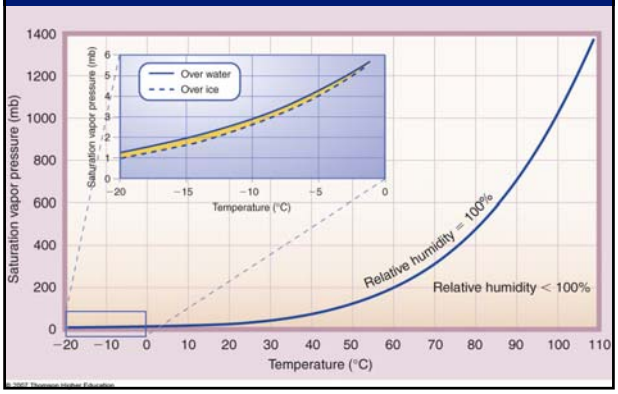
Bergeron walk

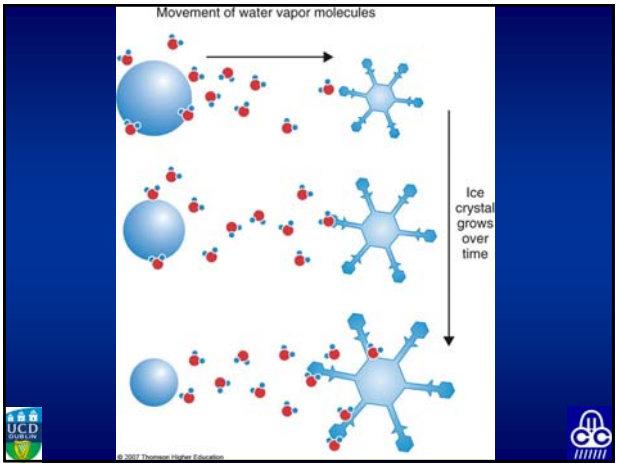




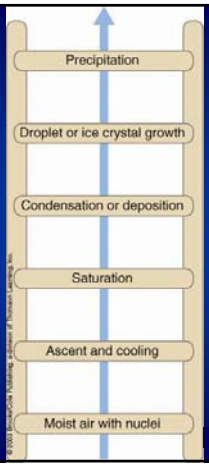
Attraction of water vapour to ice *versus* water

Saturation vapour pressure over ice and water



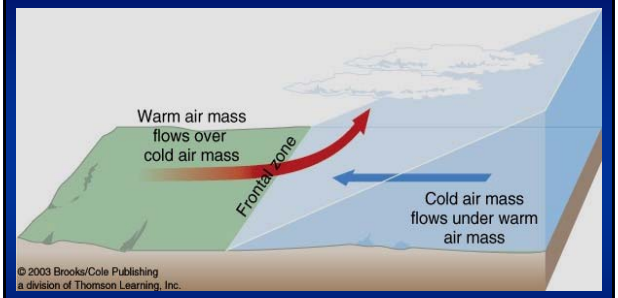


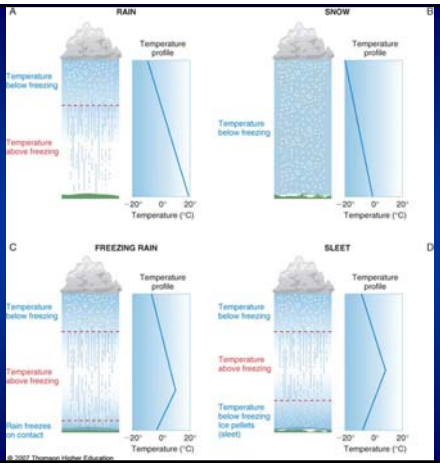
Process of aggregation



Steps in the formation of the precipitation types

WARM FRONT





FORMS OF PRECIPITATION

- **Rain** - droplets of water greater than 0.5 mm in diameter. Droplets smaller than 0.5 mm called **drizzle**.
- Much rain starts out aloft as ice crystals.
- **Snow** - ice crystals. If air is cold (low humidity), we get light and fluffy snow (powder). If air is warm than about -5°C, then we get wet snow (good for snowballs).
- **Sleet** - small particles of ice. Raindrops encounter freezing air on descent. If freezing not complete - freezing rain.
- **Hail** - layers of ice form as the hailstorm travels up and down in a strong convective cloud.
- **Rime** - formed by freezing of supercooled fog on objects.

THE EFFECTS OF AIRFLOW OVER A MOUNTAIN

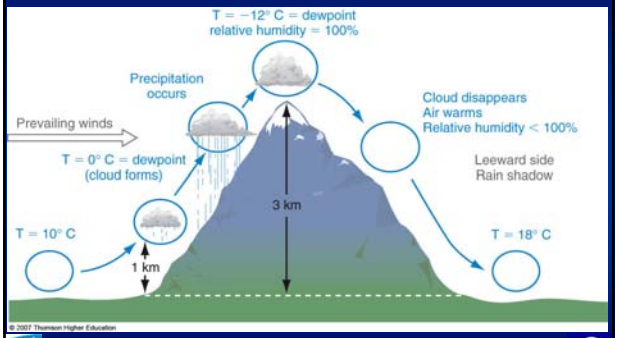


TABLE 4.4 Difference in Temperature, Cloud Cover, and Precipitation on the Windward and Leeward Sides of the Cascade Mountains in Washington State

	Windward (West) Side (Seattle–Tacoma)	*Leeward (East) Side (Yakima)*
Mean winter temperature	41° F	32° F
Mean summer temperature	64° F	68° F
Mean annual temperature range (warmest month's average minus the coldest month's average)	25° F	40° F
Number of mostly cloudy days per year	226	164
Average annual precipitation	37.2 inches	8.0 inches

Adiabatic Cooling and Warming

Effects of Moisture

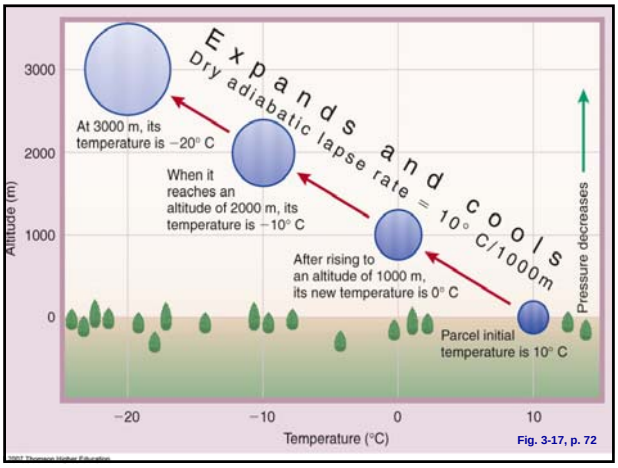


Fig. 3-17, p. 72

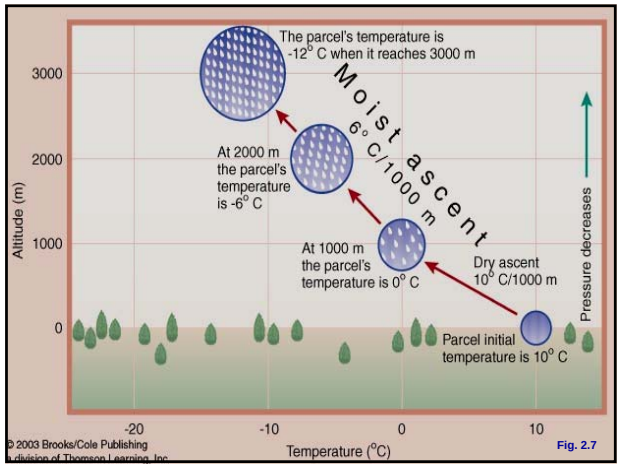


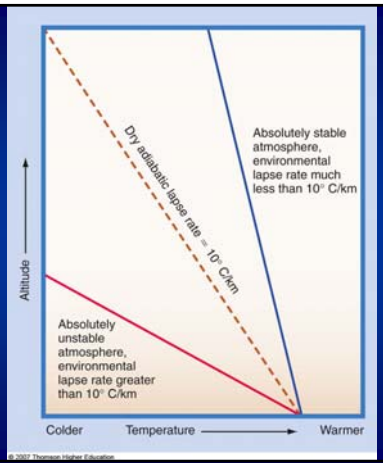
Fig. 2.7

Adiabatic Cooling and Warming

- A rising parcel of air always expands
- As the parcel expands it will cool
- Adiabatic process - no heat energy is gained or lost by the parcel
- The rate of cooling with altitude due to this process is called the dry adiabatic lapse rate

Adiabatic Cooling and Warming

- Usually the air contains water vapour.
- As the parcel rises an altitude will be reached when the water vapour condenses.
- But this releases latent heat of condensation to the air parcel.
- Thereafter, the temperaure of the parcel will not fall as much as for dry air.
- Moist adiabatic lapse rate.



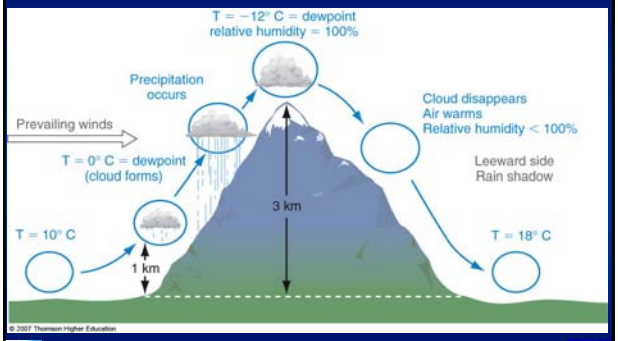
Clouds and Precipitation near Mountains

- As air ascends mountain it cools adiabatically, clouds form, and precipitation occurs.
- Above this altitude the relative humidity stays at 100%
- At the peak of the mountain the absolute humidity is determined by the saturation vapour pressure at -12C.
- As the air descends its absolute humidity remains the same as at the peak

Clouds and Precipitation near Mountains

- As the air descends it is compressed, so it warms
- Hence the saturation vapour pressure will increase, and the relative humidity will decrease
- The net effect of the air ascending and descending the mountain is that the air becomes drier and warmer.
- On the island of Hawaii, the west side of the coast (westerly winds) has rain forests, the eastern side has deserts.

THE EFFECTS OF AIRFLOW OVER A MOUNTAIN



PREVIEW

The *EdGCM* Climate Model

End of Lecture 3