Solid earth

Figure 13. Eruption of Mount Pinatubo in the Phillipines in 1991. This type of explosive eruption injects large amounts of material into the stratosphere to altitudes of greater than 30 km.

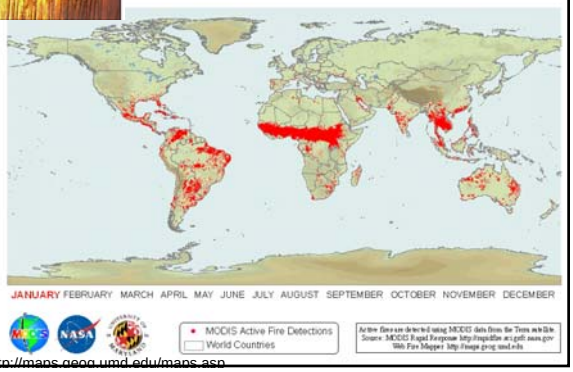
- Volcanoes: sulfur compounds (SO_2, H_2S, COS), particles, H_2O, CO_2, HCl…
- Rocks (radiogenic): Helium (decay of uranium and thorium), Argon (decay potassium-40), radon (decay of uranium-238)

Biological sources

- e.g.: Biological source of CH_4: swamps, rice paddies, termites, ruminants

Fires

MODIS Rapid Response Fire Detections for 2005



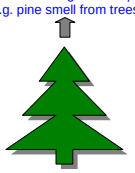
http://maps.geog.umd.edu/maps.asp

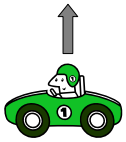
Anthropogenic

http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4333

Chemical

VOC = volatile organic compound (e.g. pine smell from trees) + NO_x = nitrogen oxides (e.g. from cars) → O_3 = photochemical smog





"Trees cause more pollution than automobiles do." Ronald Reagan 1981

Also requires emissions from cars/industry!

Size of Sources

Point Source: very localized source
for example: +Smoke stacks,
+Industrial facility
+single tail pipe

Distributed (area) Source:
sources cover a wider area
for example:
+cluster of point sources (cars in city)
+rice paddies emitting methane

Examples

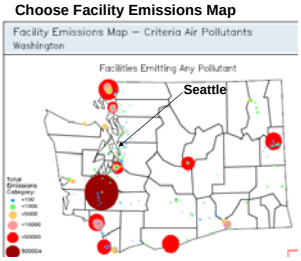
Point source

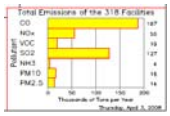
Distributed source

Sources of pollution in the US

EPA web site: http://www.epa.gov/air/data/geosel.html

Choose Facility Emissions Map





How close are you willing to live to a freeway?

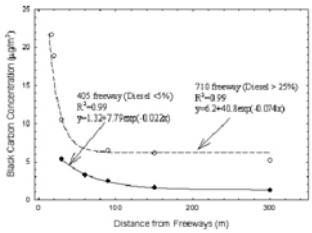
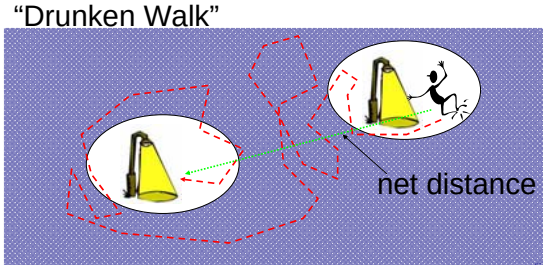


Figure from: The East Bay Children's Respiratory Health Study of Traffic-Related Air Pollution Near Busy Roads

http://www.arb.ca.gov/research/eb-kids/bc-dist.jpg

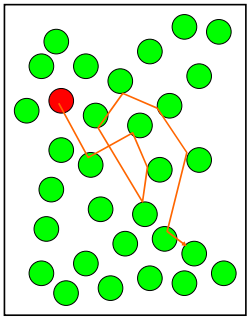
Random Walk

"Drunken Walk"



Man diffuses from one light to the other

Brownian Motion / Random Walk

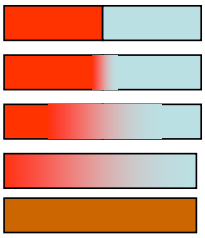


Gas molecules are always in motion and collide with each other (Brownian motion)
→ ~ 1 billion collision per second

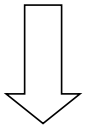
⇒ They can reach a certain place in a random walk. They **diffuse** to that place.

(Molecular) Diffusion

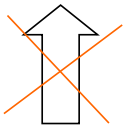
Gas molecules move randomly in all directions
These movements lead to mixing until all gases are equally distributed



2 separated gases



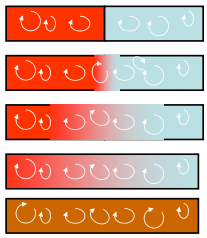
gas mixture



This never happens

Turbulence

Swirls lead to a mixing until all gases are equally distributed (turbulent diffusion). Turbulence is much more efficient (faster) than molecular diffusion



2 separated gases

gas mixture

This never happens

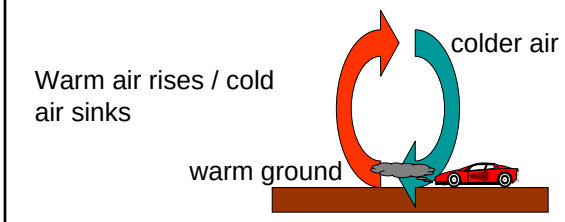
Transport of smoke aerosols from fires in Southern California to Great Lakes region

SeaWiFS: October 30, 2003 - http://earthobservatory.nasa.gov/NaturalHazards

Haze from industrial NE US blowing off to the Atlantic May 4, 2001

http://visibleearth.nasa.gov/view_rec.php?id=1727

Convection / Vertical Transport

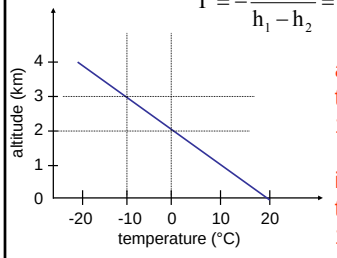


- Lofts pollutants from surface away from people
- Precipitation often forms → rain out soluble pollutants
- If escape rain, pollutants enter heights with stronger winds → transported over long distances

Dry adiabatic lapse rate

Γ: decrease of temperature with altitude

$$\Gamma = -\frac{T_1 - T_2}{h_1 - h_2} = -\frac{-10^\circ C - 0^\circ C}{3km - 2km} = 10^\circ C/km$$

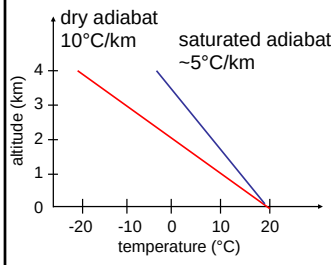


a dry air parcel lifted in the atmosphere cools 10°C per km of altitude

in a dry atmosphere the temperature drops 10°C per km of altitude

Saturated adiabatic lapse rate

Γ_s ~ 5 °C/km

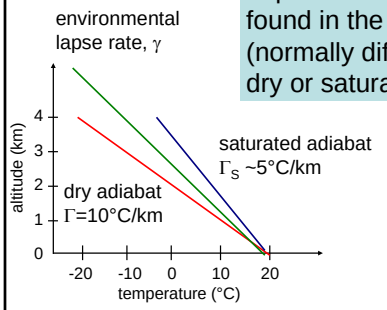


An air parcel with a relative humidity of 100% lifted in the atmosphere cools 5°C per km of altitude.

In an atmosphere with a rel. humidity of 100% the temperature drops 5°C per km of altitude.

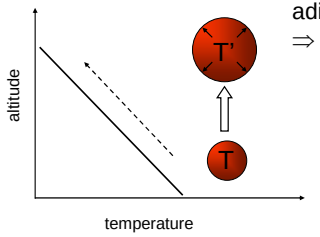
Environmental lapse rate, γ

Lapse rate that is found in the real atmosphere (normally different than dry or saturated lapse rate)



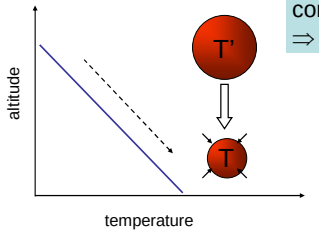
Rising air parcel in the atmosphere

rising air parcel expands adiabatically
⇒ cools

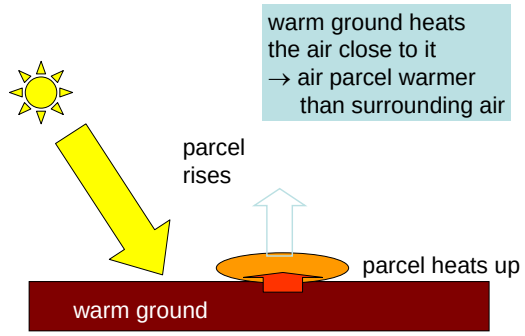


Sinking air parcel in the atmosphere

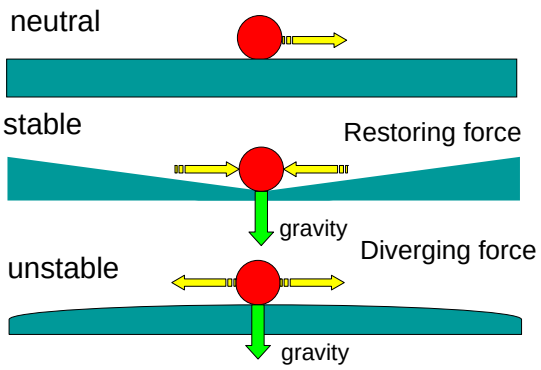
sinking air parcel gets compressed adiabatically
⇒ warms



How does an air parcel leave the ground?



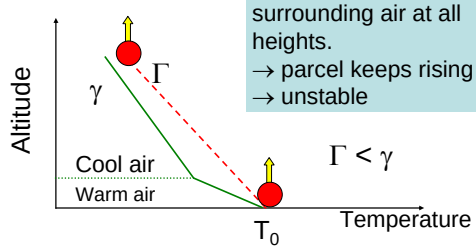
Stability



Atmospheric Stability

Unstable case:

Temp. of rising air parcel has higher temp. than surrounding air at all heights.
→ parcel keeps rising
→ unstable



Example: Hot Air Ballon

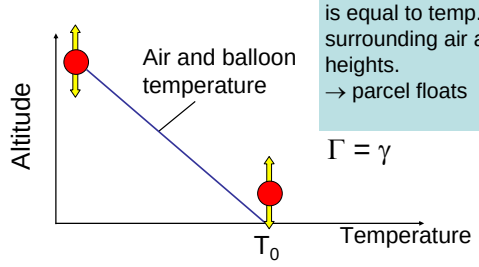
Density of air decrease (increases)
with increasing (decreasing) temperature

In the balloon air temp.
is much higher than outside
→ air in balloon has lower density than outside
→ balloon will rise (additional weight keeps it floating)

Atmospheric Stability

Neutrally stable case:

Temp. of air parcel is equal to temp. of surrounding air at all heights.
→ parcel floats

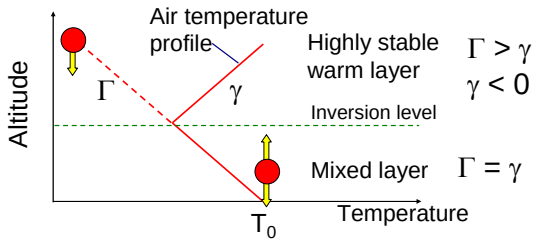


$\Gamma = \gamma$

Atmospheric Stability

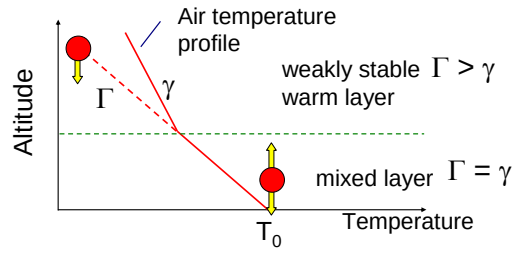
Stable case:

Rising air parcel above inversion is always colder than surrounding air
→ parcel will not rise and be pushed back to its original altitude.

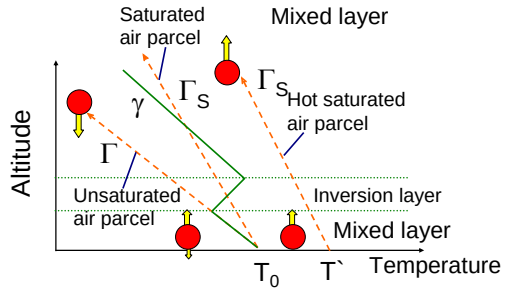


Atmospheric Stability

Stable case:



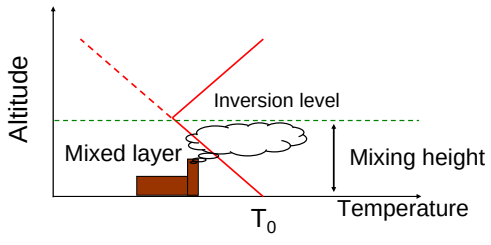
Inversion



Inversion height, influence on pollution

The inversion limits the volume into which pollutants are emitted ("lid on a pot")

small mixing height → small volume



Inversion layer, Los Angeles, Dec. 19, 2000

Mark Z. Jacobson

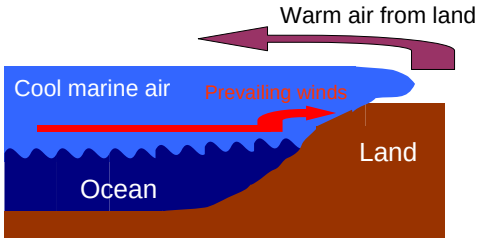
Seattle on a smoggy day – inversion (July 22 2006)

Visibility web cam: http://www.pscleanair.org/airq/visibility/default.aspx

Smoke Trapped in Inversion After Fire Menlo Park, California (June, 2001)

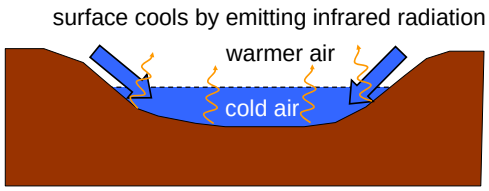
Mark Z. Jacobson

Marine Inversion



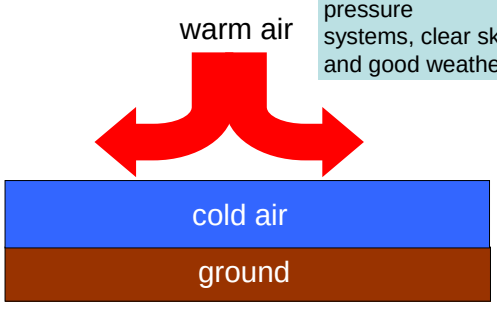
Radiation Inversions

occur at night when the ground cools down



Subsidence Inversions

associated with high pressure systems, clear skies, and good weather



Regional Subsidence Inversion