Air Pollution: Introduction

Meteorology,

Topographical Influences,

& the Atmosphere

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Meteorology and the Atmosphere

- **Meteorology:** is the science of the atmosphere.

- **The atmosphere:** is the media into which all air pollution is emitted. Atmospheric processes such as the movement of air (wind) and the exchange of heat (convection and radiation for example) dictate the fate of pollutants as they go through the stages of transport, dispersion, transformation and removal.

- **Air pollution meteorology** is the study of how these atmospheric processes affect the fate of air pollutants.

Composition of the Atmosphere

Table 1-1. Chemical composition of dry atmospheric air

Substance	Concentration (ppm)[1]
Nitrogen	780,900
Oxygen	209,400
Argon	9,300
Carbon dioxide	315
Neon	18
Helium	5.2
Methane	2.3
Krypton	0.5
Hydrogen	0.5
Xenon	0.08
Nitrogen dioxide	0.02
Ozone	0.01-0.04

1. ppm is an abbreviation for parts per million. To convert from a concentration expressed as ppm to a concentration expressed as a percent of a total, divide the ppm concentration by 10,000.

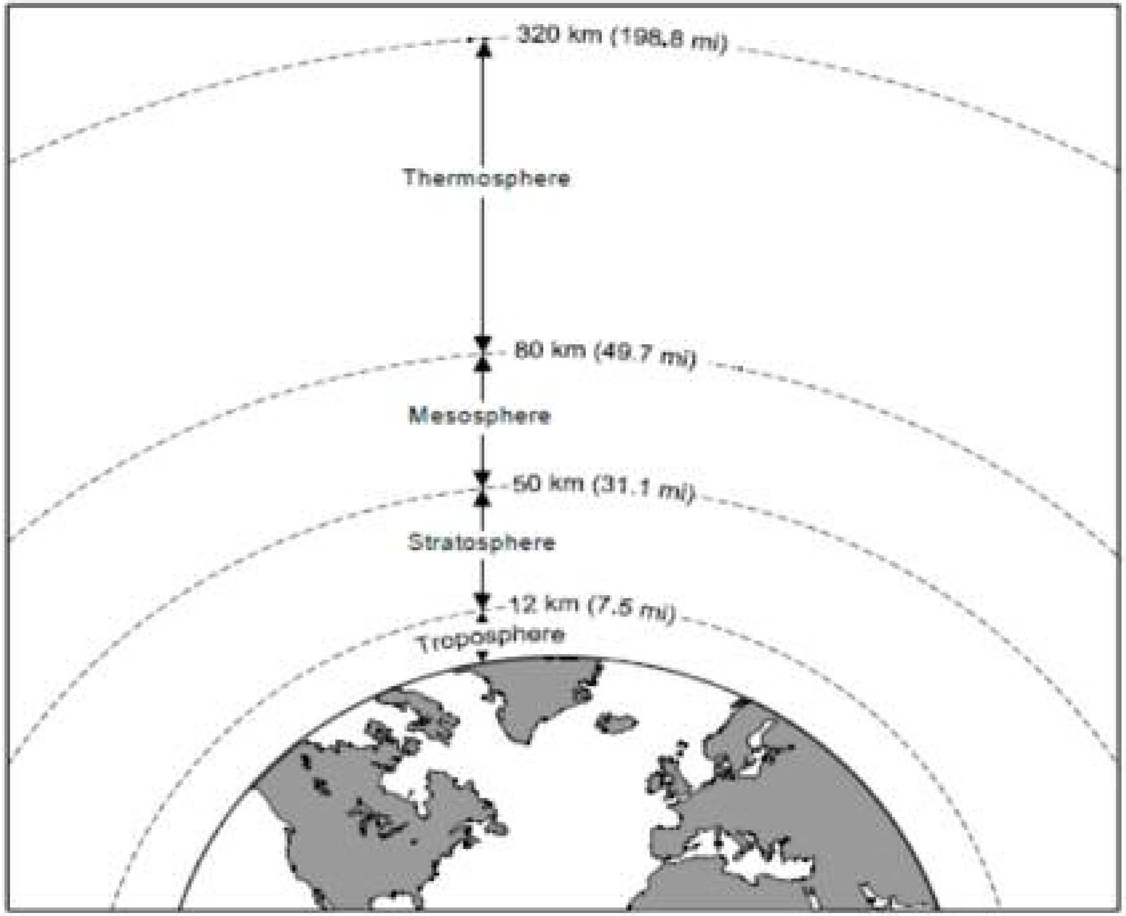
Source: *Handbook of Air Pollution* 1968.

Although the **water vapor** content of the air is fairly small, it absorbs six times more radiation than any other atmospheric constituent and is therefore a very important component of the atmosphere.

Layers of the Atmosphere

Troposphere

- 75–80% of the earth's air mass
- contains nearly all of the water associated with the atmosphere (vapor, clouds and precipitation).
- Close to the earth's surface
- Chemical composition of air
- Rising and falling air currents: weather and climate
- Involved in chemical cycling

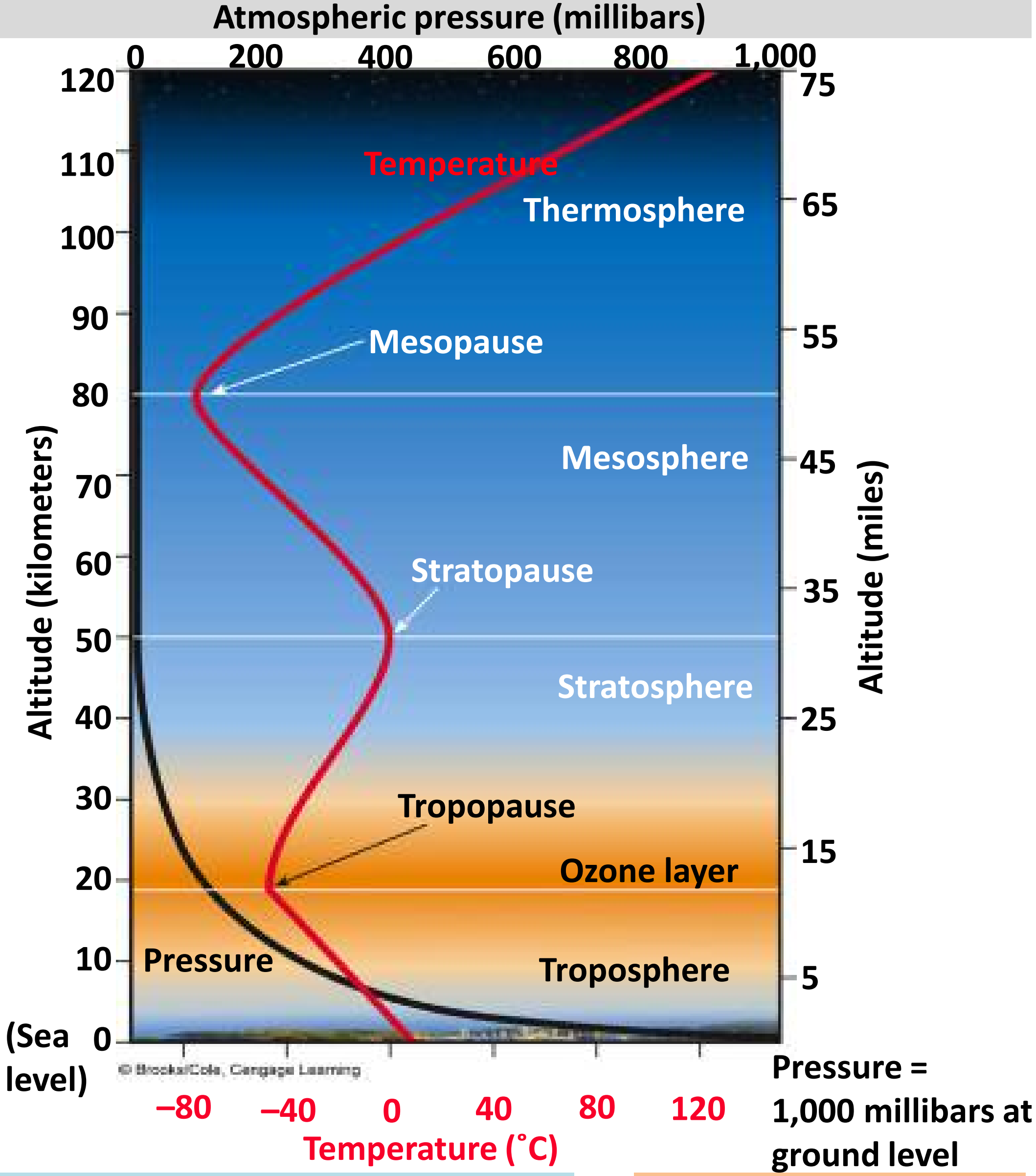


- The depth of the troposphere changes constantly due to changes in atmospheric temperature

Earth's atmosphere

❑ Stratosphere

- Similar composition to the troposphere, with 2 exceptions
  - ➢ Much less water
  - ➢ O_3, **ozone layer,** filters UV



- Virtually all air pollution is emitted within the troposphere. Air pollution transport is governed by the speed and direction of the winds.

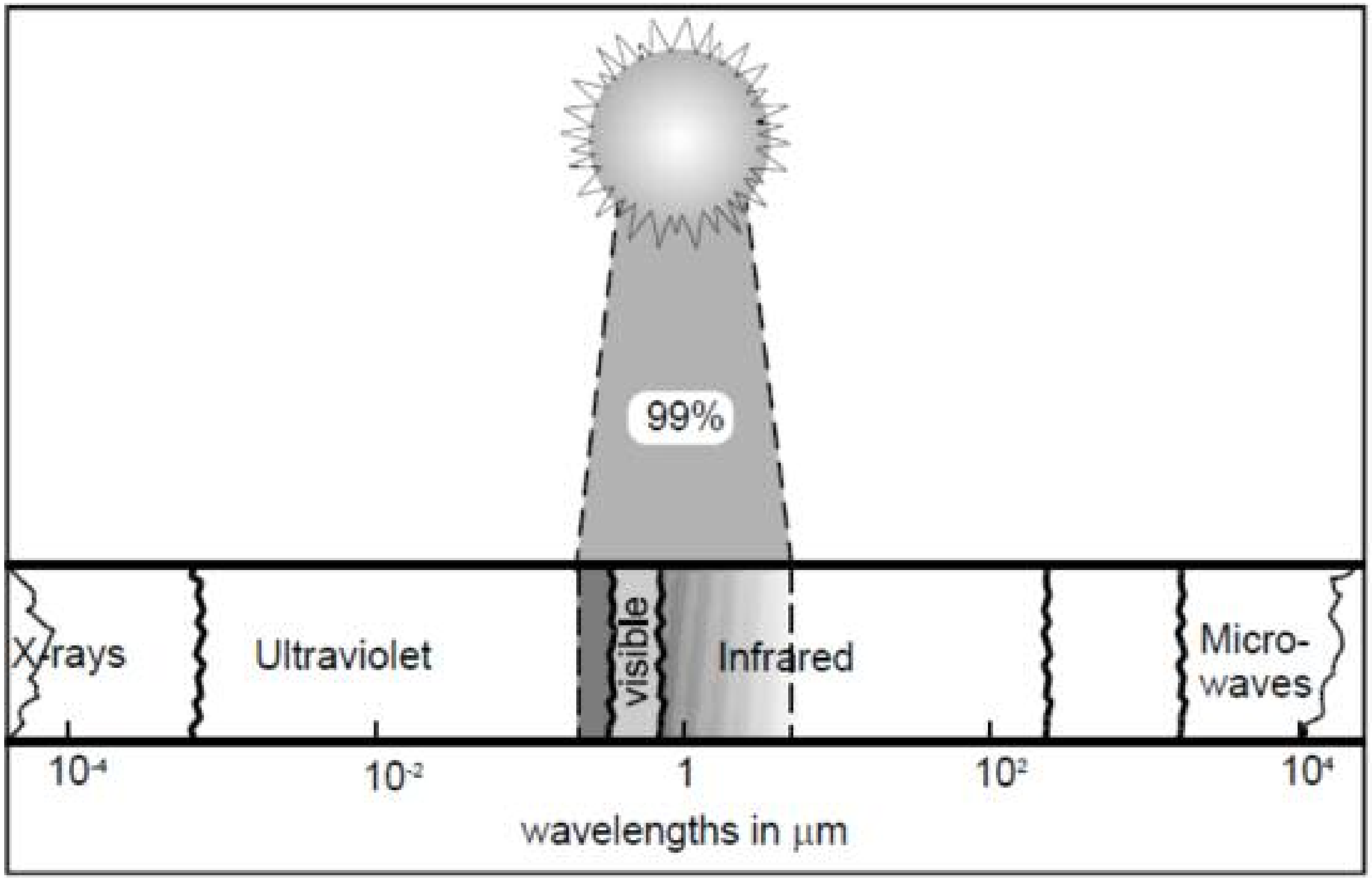
- The rate of dispersion is influenced by the thermal structure of the atmosphere as well as by mechanical agitation of the air as it moves over the different surface features of the earth.

- Transformation of the emitted air pollutants is impacted by exposure to solar radiation and moisture as well as other constituents in the atmosphere.

- The removal of pollutants depends not only on the pollutants' characteristics but also on weather phenomena such as rain, snow and fog.

Heat Balance of the Atmosphere

- The sun energy is transferred by radiation of heat in the form of electromagnetic waves.
- The radiation from the sun has its peak energy transmission in the visible wavelength range [0.38 to 0.78 micrometers (μm)] of the electromagnetic spectrum.
- The sun also releases considerable energy in the ultraviolet and infrared regions.
- Ninety-nine percent of the sun's energy is emitted in wavelengths between 0.15 to 40 μm.
- solar radiation striking the earth generally has a wavelength between 0.29 and 2.5 μm.



Source for data: Moran and Morgan 1994.

The amount of **<u>in</u>**coming **<u>sol</u>**ar radi**<u>ation</u>** received at a particular time and location in the earth-atmosphere system is called ***<u>insolation</u>***.

Insolation is governed by four factors:

- Solar constant
- Transparency of the atmosphere
- Daily sunlight duration
- Angle at which the sun's rays strike the earth

Values for Solar Constant

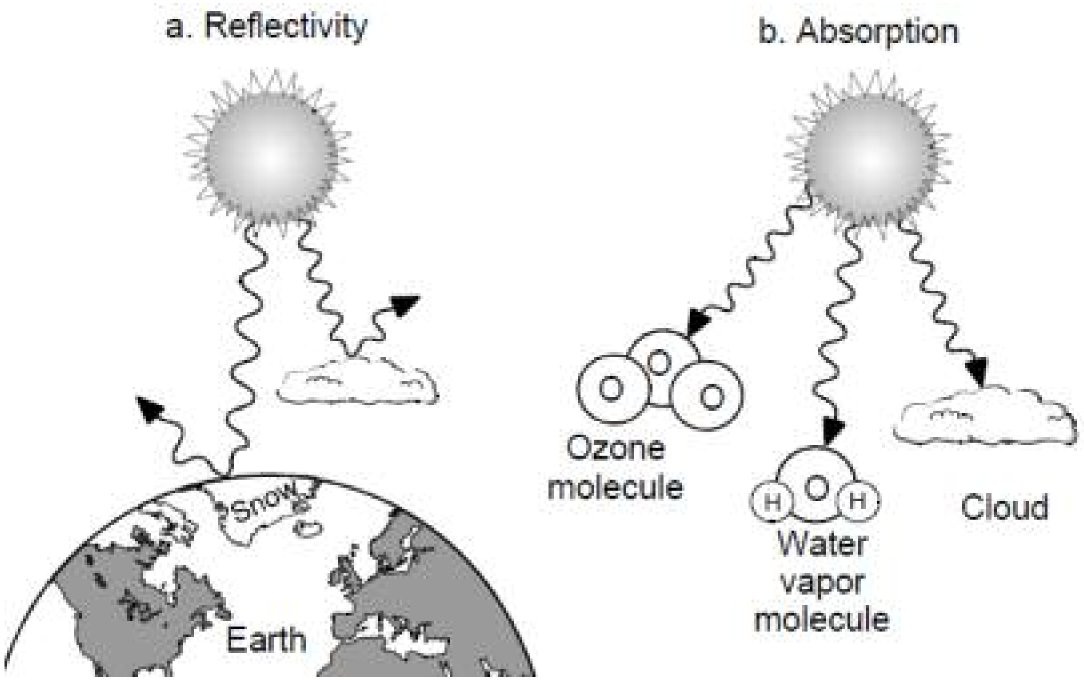
Solar constant =	1.94 cal/cm^2 min
	1,353 W/m^2
	428 Btu/ft^2 hr
	4,871 kJ/m^2 hr

Transparency

- Transparency of the atmosphere refers to how much radiation penetrates the atmosphere and reaches the earth's surface without being depleted.

- The emitted radiation is depleted as its passes through the atmosphere. Different atmospheric constituents absorb or reflect energy in different ways and in varying amounts.

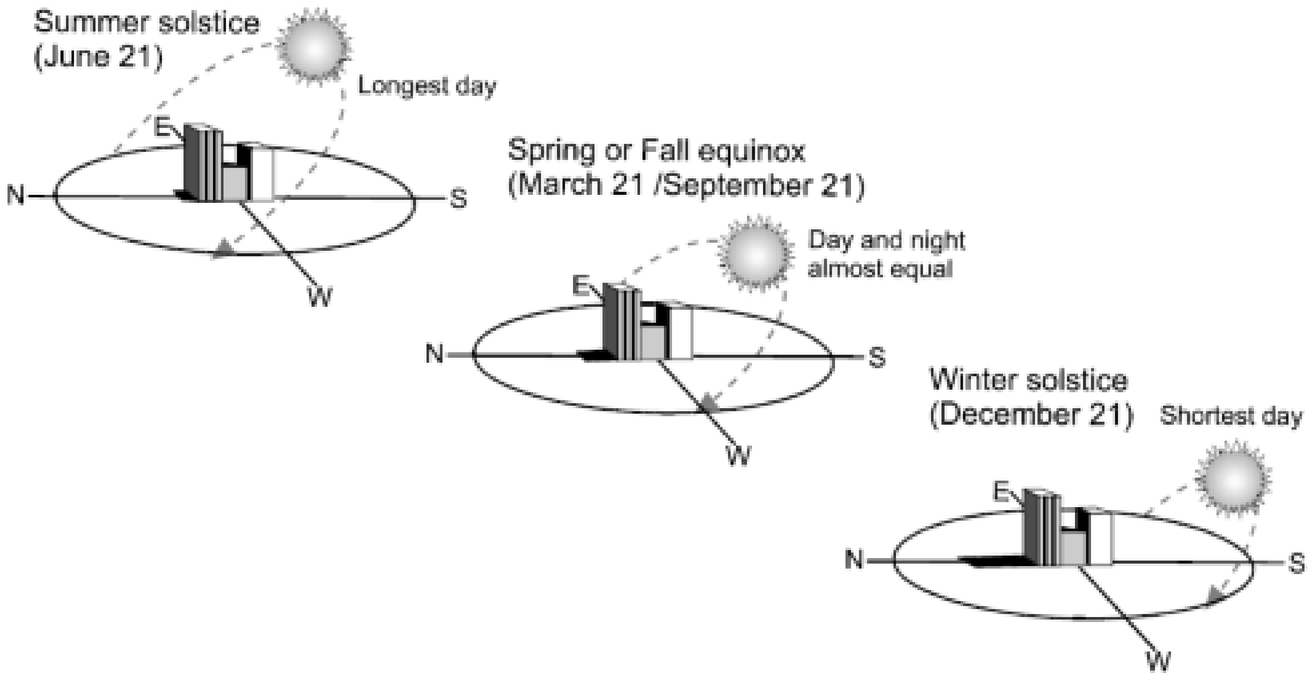
- some of the radiation received by the atmosphere is reflected from the tops of clouds and from the earth's surface and some is absorbed by molecules and clouds.



Daylight Duration

- The duration of daylight also affects the amount of insolation received: the longer the period of sunlight, the greater the total possible insolation.

- Daylight duration varies with latitude and the seasons. At the equator, day and night are always equal. In the polar regions, the daylight period reaches a maximum of twenty-four hours in summer and a minimum of zero hours in winter.



Angle of Rays

- A relatively flat surface perpendicular to an incoming vertical sun ray receives the largest amount of insolation.

- At solar noon, the intensity of insolation is greatest. In the morning and evening hours, when the sun is at a low angle, the amount of insolation is small.

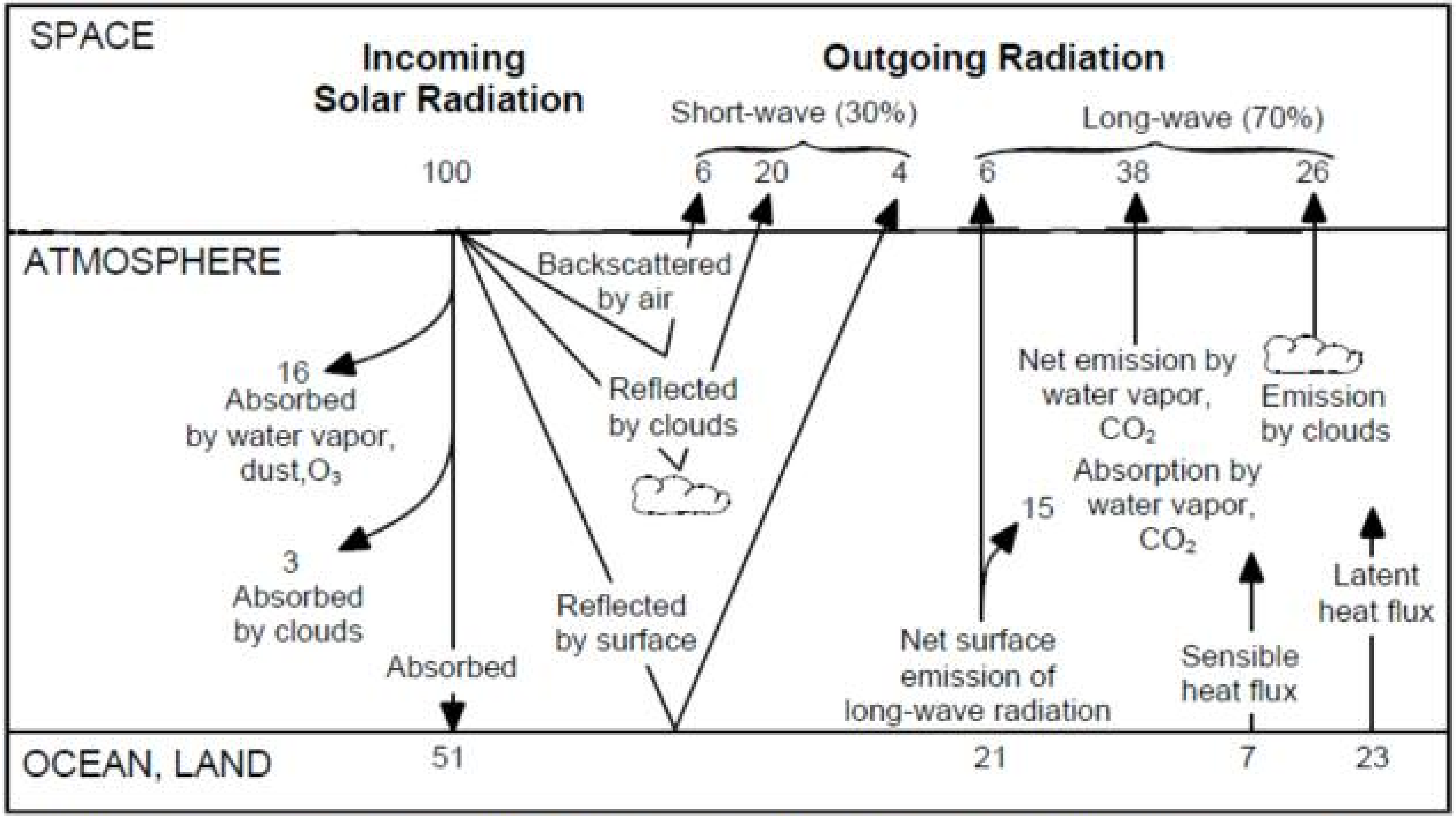
Heat Balance

- The earth absorbs short-wave solar radiation and emits longer wavelength **terrestrial radiation**.

- This phenomenon explains the reason air temperatures are usually warmer on nights with cloud cover than on clear nights.

- Since energy from the sun is always entering the atmosphere, the earth would overheat if all this energy were stored in the earth-atmosphere system. So, energy must eventually be released back into space. On the whole, this is what happens. Incoming radiation eventually goes back out as terrestrial radiation, and a heat balance, called the **radiational balance** results.

- For every 100 units of energy that enters the atmosphere, 51 units are absorbed by the earth, 19 units are absorbed in the atmosphere and 30 units are reflected back to space. The 70 units that are absorbed by the earth-atmosphere system (51 units +19 units) are eventually reradiated to space as long wave radiation.



The mean annual radiation and heat balance of the atmosphere relative to 100 units of incoming solar radiation

Source: National Academy of Sciences 1975, p. 18.

- Air moves in an attempt to equalize the air pressure imbalances that develop as a result of variations in insolation and differential heating.

- Differential heating is the main cause of atmospheric motion on the earth

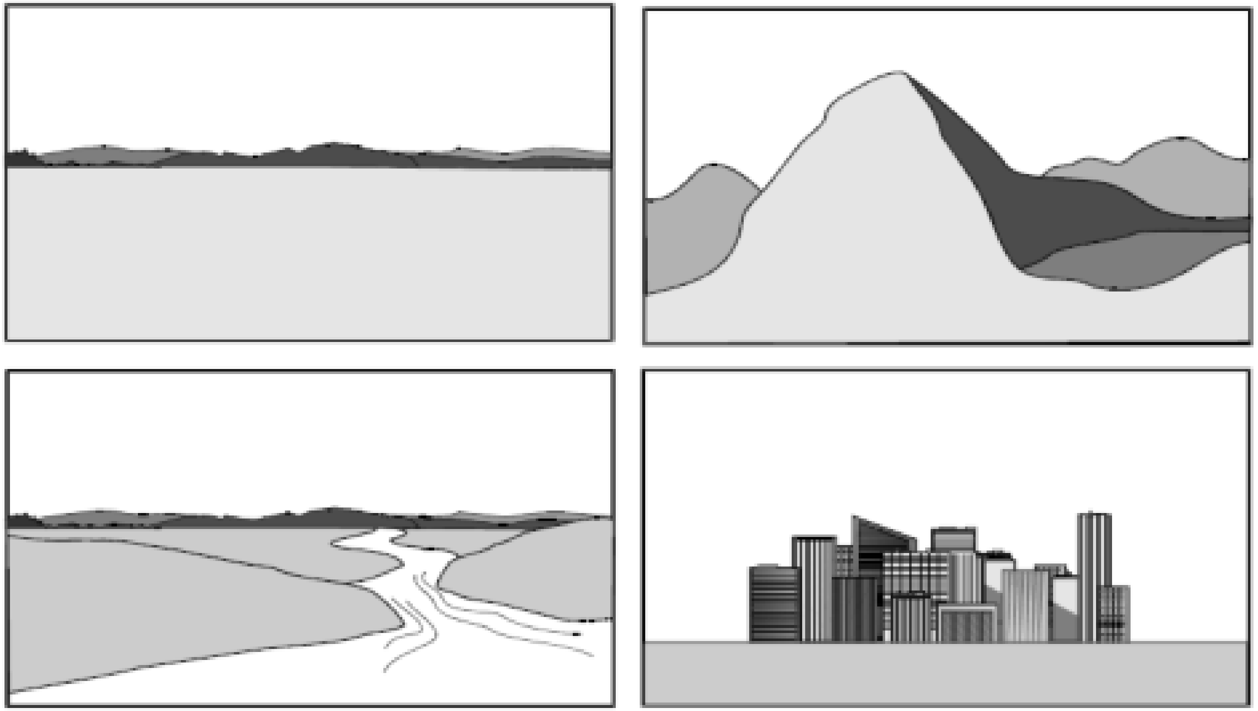
- Air pressure is a function of the number of air molecules in a given volume and the speed at which they are moving.

- When air is confined within a certain boundary, heating the air increases its pressure and cooling the air decreases its pressure.

Topographical Influences

Terrain features or topography: The physical characteristics of the earth's surface.

- Topographical features not only influence the way the earth and its surrounding air heat up, but they predominantly affect air flow relatively close to the earth's surface.

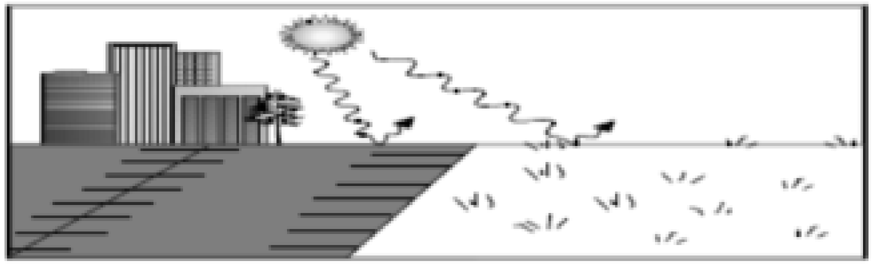


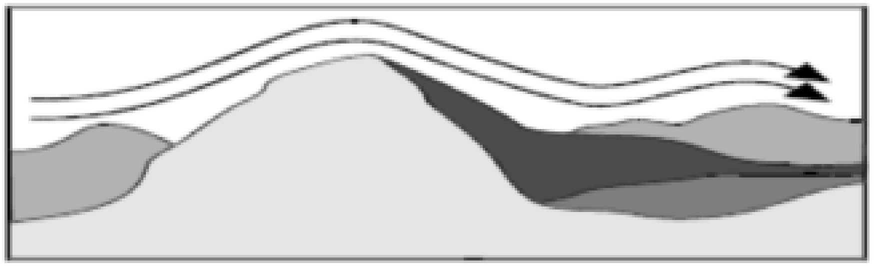
Topographical features affect the atmosphere in two ways:

- Thermally (through heating); and
- geometrically (also known as mechanically).

- The thermal turbulence is caused by **differential heating**. Different objects give off heat at different rates. For example, a grassy area will not absorb and subsequently release as much heat as an asphalt parking lot.

- Mechanical turbulence is caused by the wind flowing over different sizes and shapes of objects. For example, a building affects the wind flowing around it differently than a corn field would affect it.

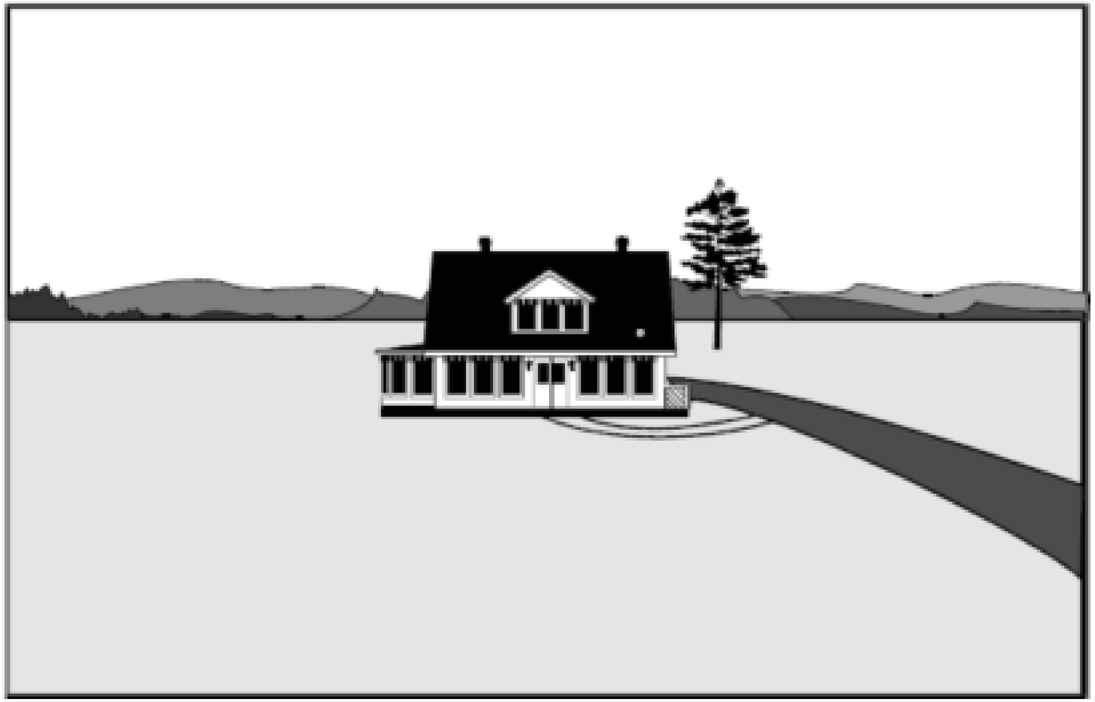


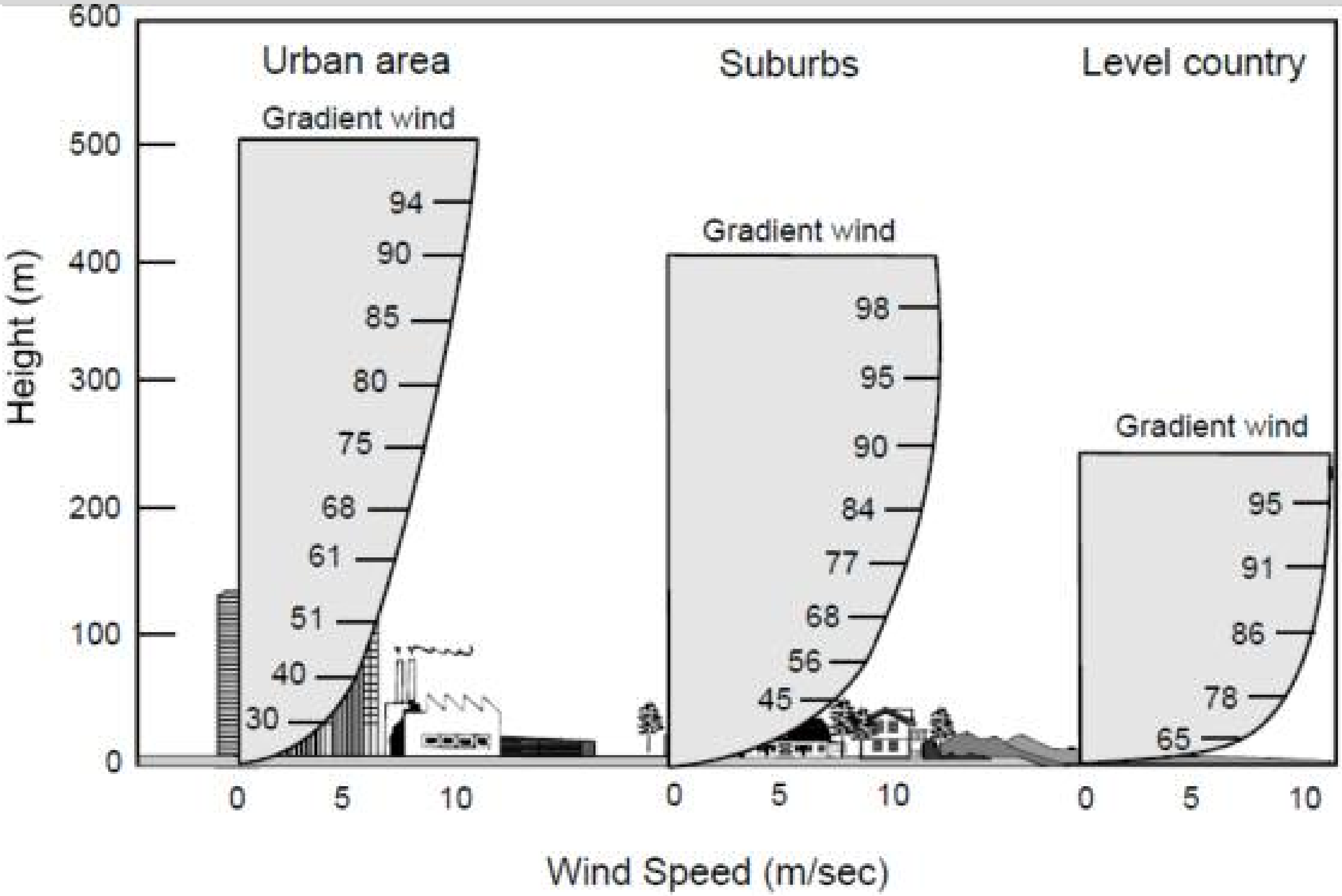


Flat Terrain

Although very little of the earth's surface is completely flat, some terrain is called **flat** for topographical purposes. Included in this category are oceans, even though they have a surface texture; and gently rolling features on land

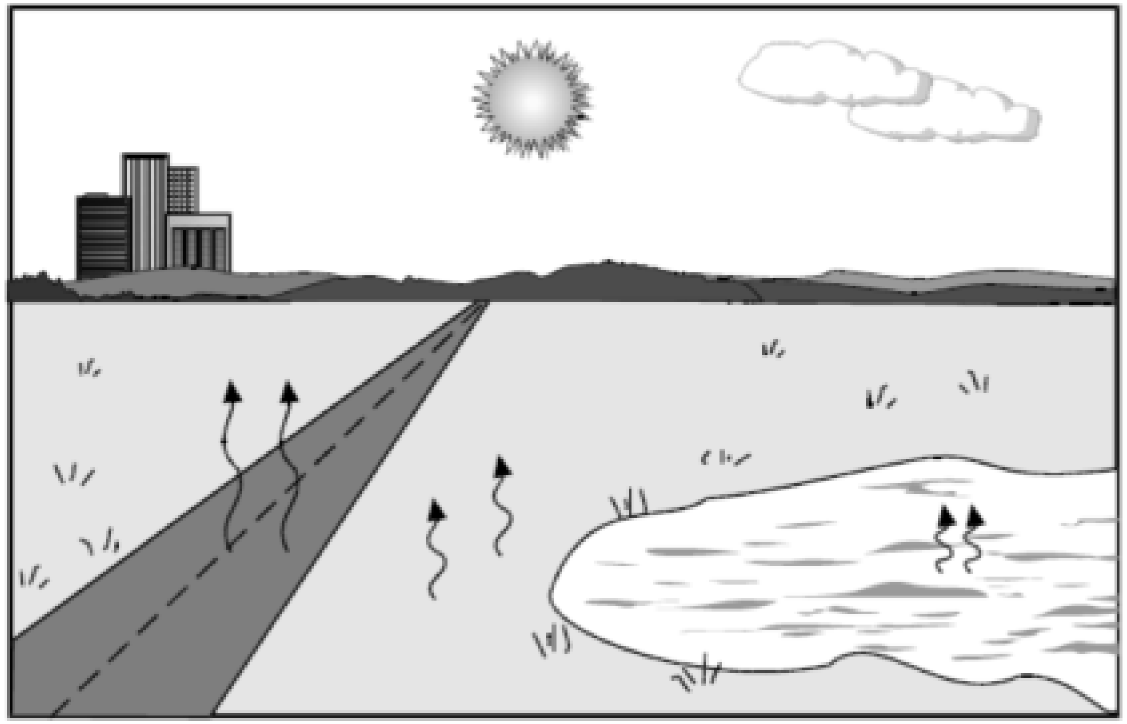
- Turbulence in the wind over flat terrain is limited to the amount of roughness of either natural or manmade features that are on the ground.
- These features induce a frictional effect on the wind speed and result in the well known wind profile with height.





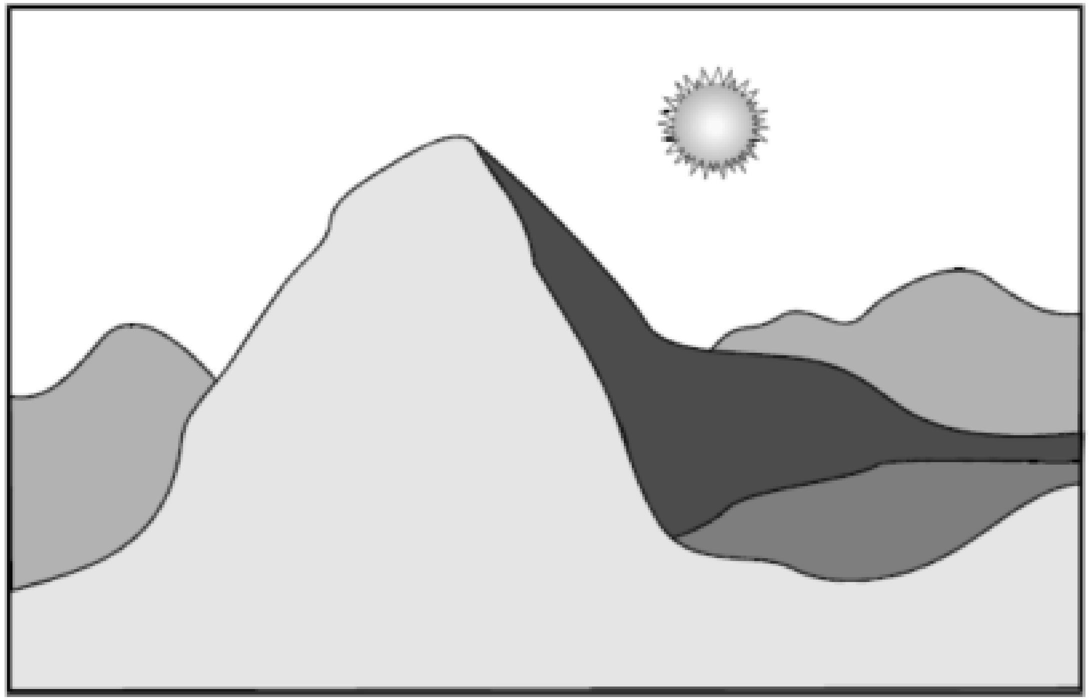
Examples of variation of wind with height over different surface roughness elements (Figures are percentages of gradient wind.) **Source: Turner 1970.**

Thermal turbulence over flat terrain is due to natural or manmade features.



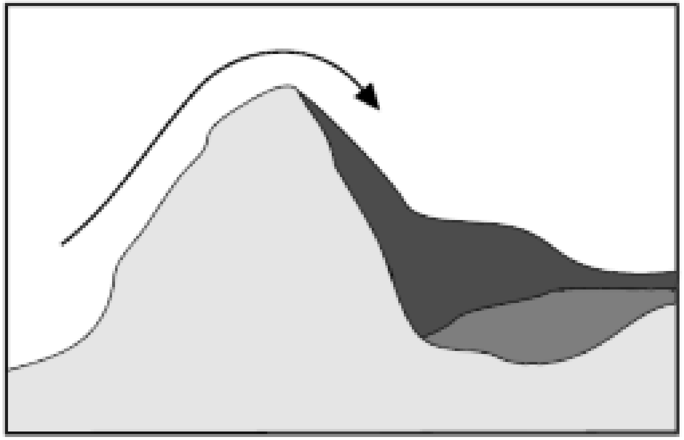
Air rises over heated objects in varying amounts (convection)

Mountain/ Valley: complex terrain.

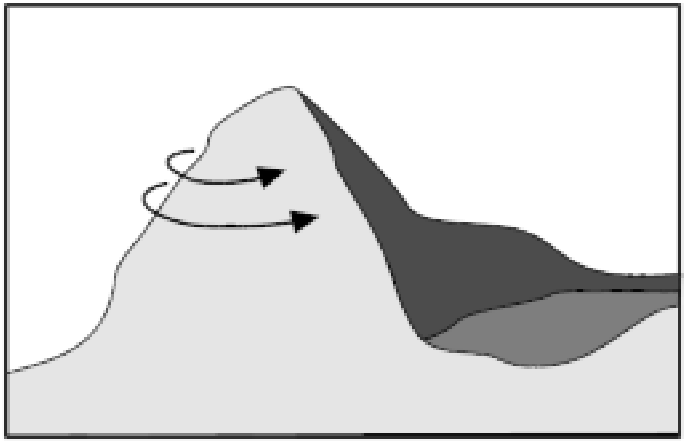


All air pollution investigators agree that atmospheric dispersion in complex terrain areas can be very different from, and much more complicated than, that over flat ground.

Mechanical turbulence over mountain/valley terrain is invariably connected to the size, shape, and orientation of the features.



The numerous combinations of mountain/valley arrangements include a single mountain on flat terrain, a deep valley between mountains, a valley in flat terrain, or a mountain range. However, air tends to flow up and over an obstacle in its path with some air trying to find its way around the sides.

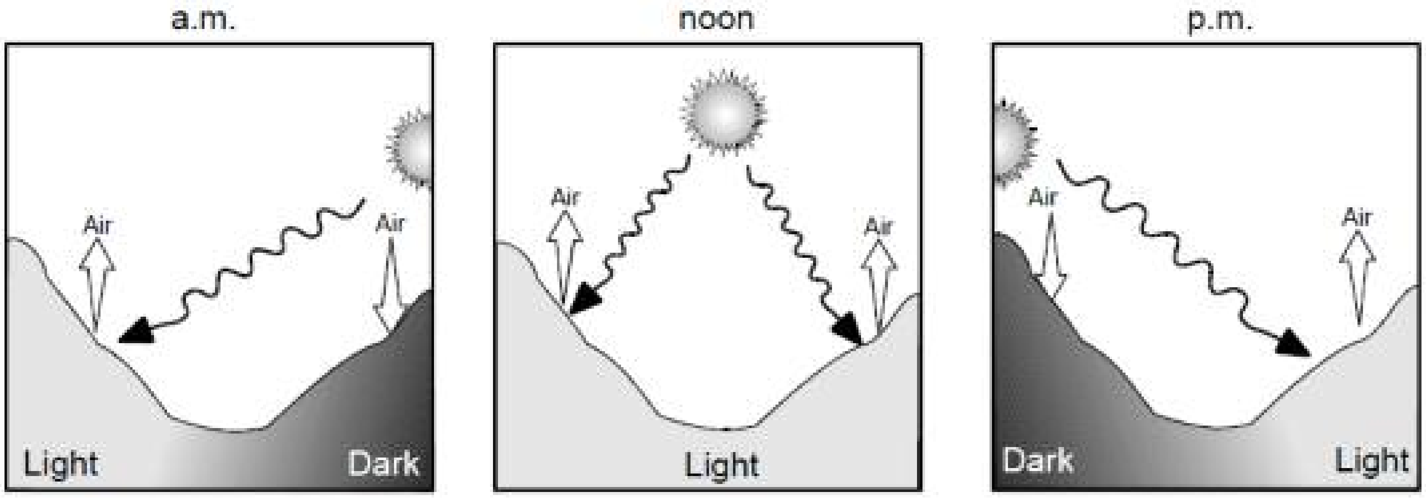


If an elevated temperature inversion (warm air overlying cooler air) caps the higher elevation, then the air must try to find its way around the sides of the mountain. If the air flow is blocked, then trapping or recirculation of the air occurs. At night, hills and mountains induce downslope wind flow because the air is cooler at higher elevations.

Thermal turbulence in mountain/valley terrain is also connected to the size, shape, and orientation of the features.

- Mountain/valleys heat unevenly because of the sun's motion across the sky:

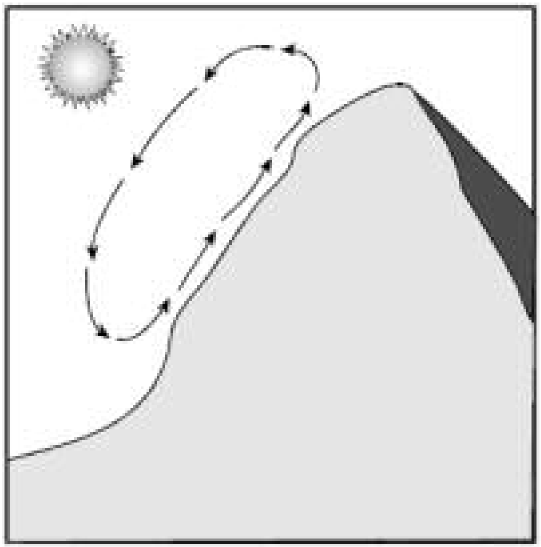
- In the morning, one side of a mountain or valley is lit and heated by the sun. The other side is still dark and cool. Air rises on the lighted side and descends on the dark side.
- At midday both sides are "seen" by the sun and are heated.
- The late afternoon situation is similar to the morning. After dark, as the air cools due to radiational cooling, the air drains down into the valley from all higher slopes.



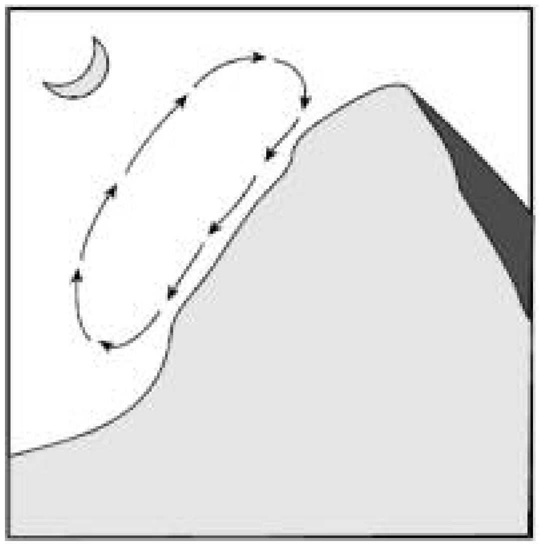
The upslope and downslope winds occur during the day and night respectively. In a true valley situation, downslope winds can occur on opposite slopes of the valley causing cool, dense air to accumulate or pool on the valley floor.

This cooler air can move down the valley resulting in air movement due to cold air drainage. Also, since the cooler air drains to the valley floor the air aloft is warmer.

This results in a temperature inversion which restricts vertical transport of air pollutants



Upslope wind



Downslope wind

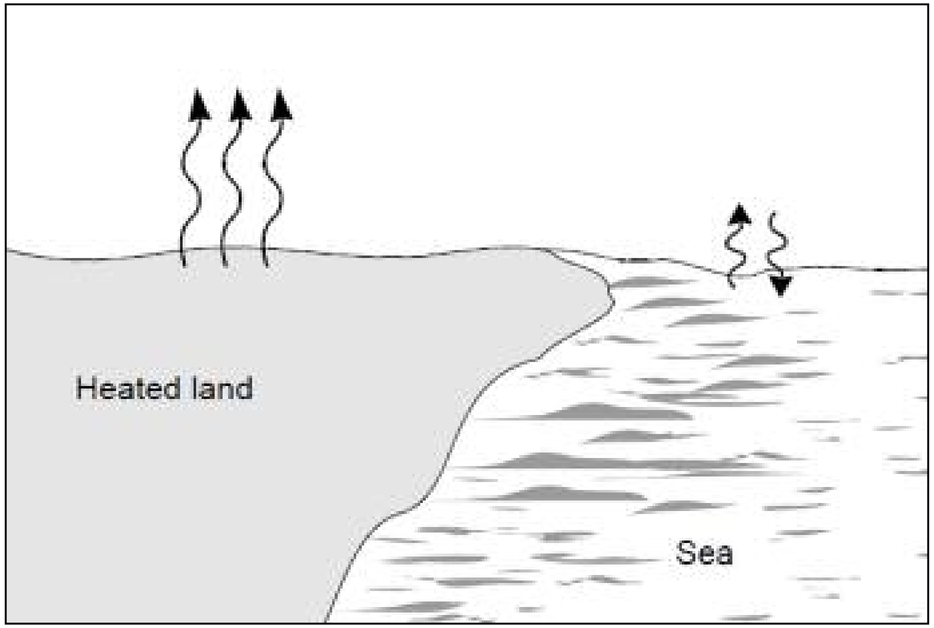
Land/Water interface

The land and water not only exhibit different roughness characteristics but different heating properties. The air flow and thus plume dispersion and transport can be very difficult to predict.

Land and objects on it will heat and cool relatively quickly. However, water heats and cools relatively slowly.

Water temperatures do not vary much from day-to-day or from week-to week.

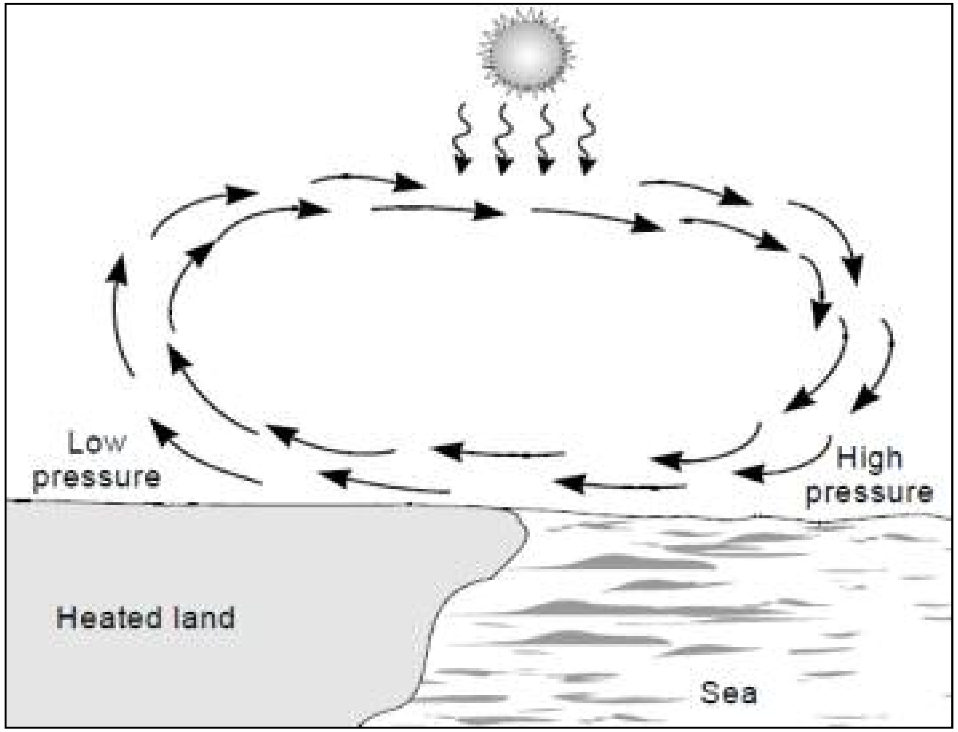
Water temperatures follow the seasonal changes, being delayed by as much as 60 days.



For example, the warmest ocean temperatures are in late summer to early fall, and the coolest ocean temperatures are in late winter to early spring.

Sea breeze due to differential heating

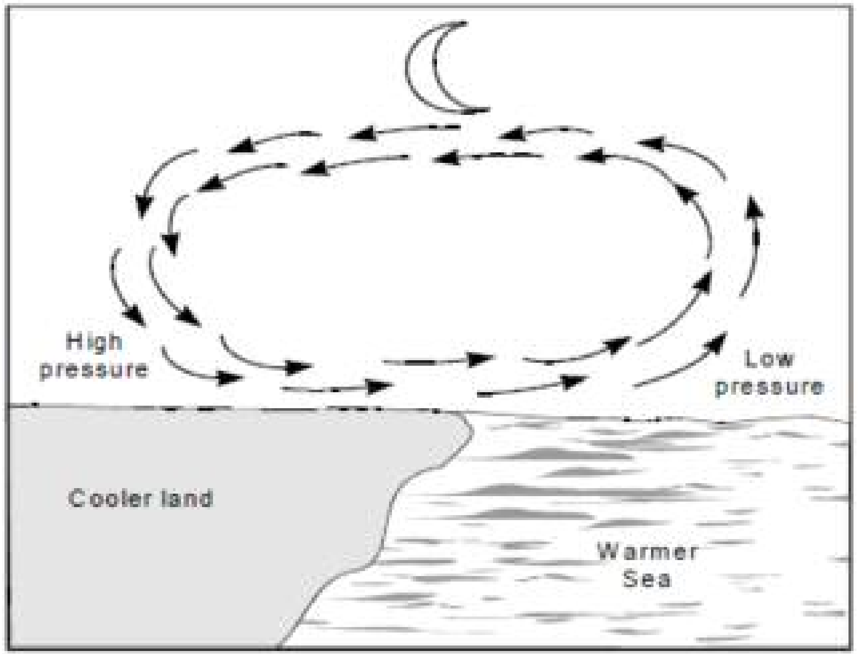
As the sun shines down on the land/water interface, solar radiation will penetrate several feet through the water. On the other hand solar radiation striking land will only heat the first few inches. Also, as the sun shines on the water surface, evaporation and some warming take place.



The thin layer of water next to the air cools due to evaporation and mixes downward, overturning with the small surface layer that has warmed. This mixing of the water layer close to the surface keeps the water temperature relatively constant. On the other hand, land surfaces warm quickly, causing the adjacent air to heat up, become less dense, and rise. The cooler air over the water is drawn inland and becomes the well-known **sea breeze**

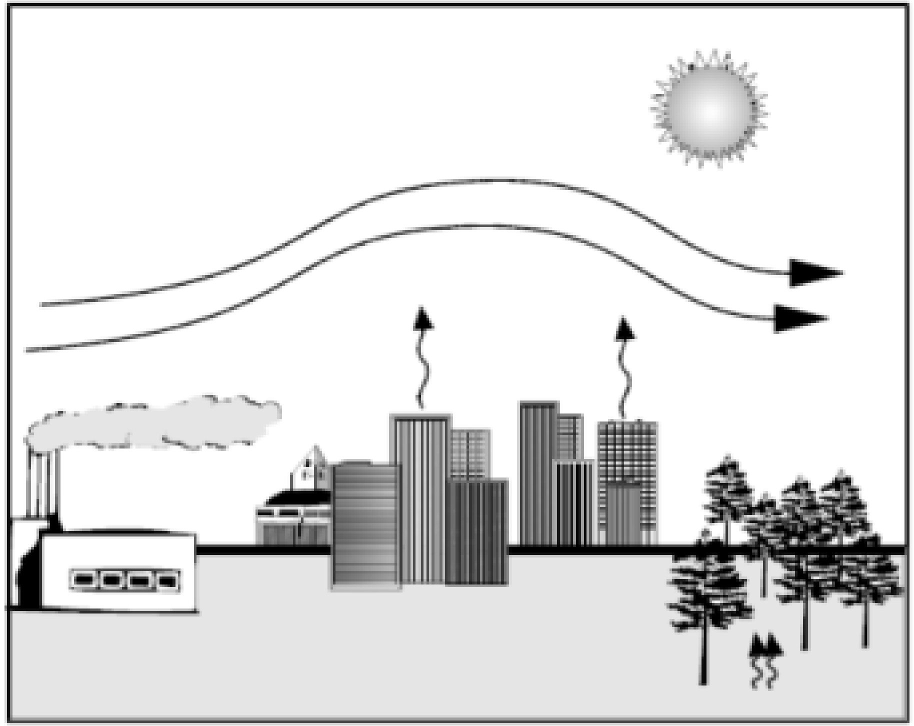
At night, the air over the land cools rapidly due to radiational cooling, which causes the land temperature to fall faster than that of the adjacent water body.

This creates a return flow called the **land breeze**



Urban

- Urban areas have added roughness features and different thermal characteristics due to the presence of man-made elements.
- The thermal influence dominates the influence of the frictional components.
- Building materials such as brick and concrete absorb and hold heat more efficiently than soil and vegetation found in rural areas. After the sun sets, the urban area continues to radiate heat from buildings, paved surfaces, etc. Air warmed by this urban complex rises to create a dome over the city. It is called **the heat island effect**.



The city emits heat all night. Just when the urban area begins to cool, the sun rises and begins to heat the urban complex again. Generally, city areas never revert to stable conditions because of the continual heating that occurs.