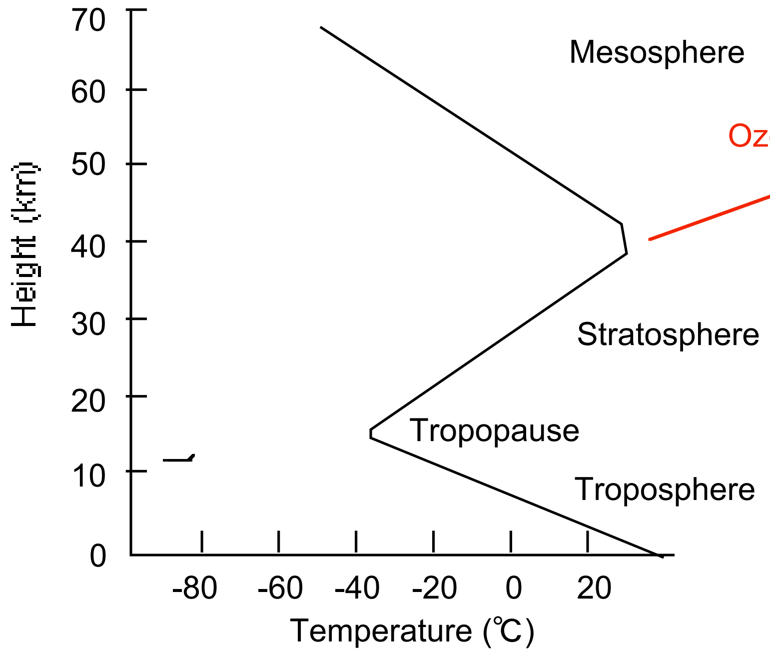
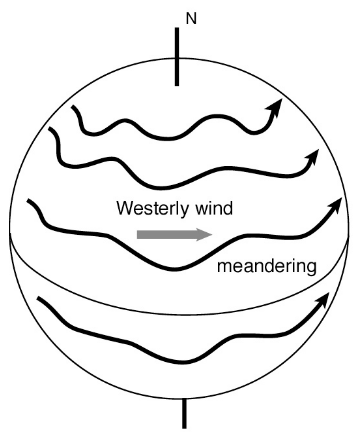
1. Atmospheric Structure of the Earth

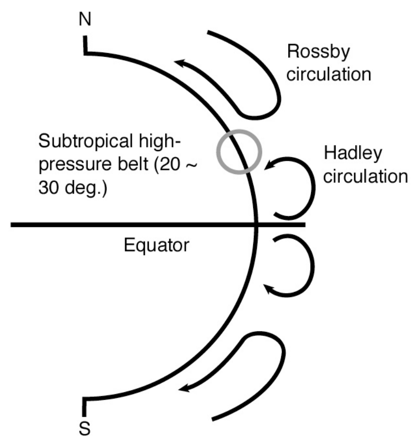
From the surface to the altitude of about 10 km, the atmospheric motion is active and the layer is called as the **troposphere**, or the troposphere is defined as the layer in which the effects of the surface heated by the insolation are reached. Above the troposphere, there is the thermally stable layer named **stratosphere** because the temperature increases with altitude. The boundary of the troposphere and the stratosphere is named tropopause.

- Most **local or regional air pollution** occurs in the troposphere
- In the troposphere, the **temperature decreases with altitude** (0.65 degrees C / 100 m).



Model Temperature Profile and the Atmospheric Layers





Meridional Circulation

note: The ozone causes the increasing temperature in the stratosphere. Ozone is concentrated around an altitude of 25 kilometers. The ozone molecules absorb the ultraviolet part of the insolation, which heats the air around them.

2. Boundary Layer

In the troposphere, the atmospheric motion is affected by the mechanical stress caused by the **surface friction** which is introduced by the texture of earth surface such as composed of weeds, forest, buildings, topographies, etc (**surface roughness**). This effect reaches to the altitude of 1000 ~ 1500 m, and is named **planetary boundary layer**. The wind speed increases with altitude in this layer. Sometimes the **power law** is used to represent the wind speed profile in this layer as:

$U/ U_i= (z/ z_i)^p$,

where, U_i is wind speed at the altitude z_i , and p is nearly equal to 1/7 in rural area and to 1/4 ~ 1/2 in urban area when the atmospheric stability is neutral in each case (p become larger value when stability is stable, and become smaller value when unstable).

In the planetary boundary layer, the lowest layer (surface to altitude of 50 ~ 100 m) is strongly affected by the surface condition, and named **surface boundary layer**. The layer, above the surface boundary, to the top of the planetary boundary layer is called as **ekman layer**.

3. Atmospheric Stability (Temperature Sturucture of the Atmosphere near Surface)

The atmospheric stability deeply relates to the behavior of the pollutants, and the historical air pollution incidents occurred in the presence of stable inversion layer.

a. Inversion Layer

The vertical distribution of temperature in the troposphere shows generally a profile of decreasing with height, however, the profile sometimes shows a inversed one which is called "inversion layer." In the night of fine weather, the **infrared radiation** of earth surface to the sky removes the heat of surface and introduces the decreasing of temperature near the surface (**radiative cooling**). This process makes a **radiative inversion layer**. The radiative inversion layer develops to the maximum at the dawn, and the height of the layer sometimes reaches to 300 m.
The inversion layers are formed also in the case of high pressure **descending air current**, and found in the **transition layer of the front** (warm/ cold) where the warm air mass is over the cold one.

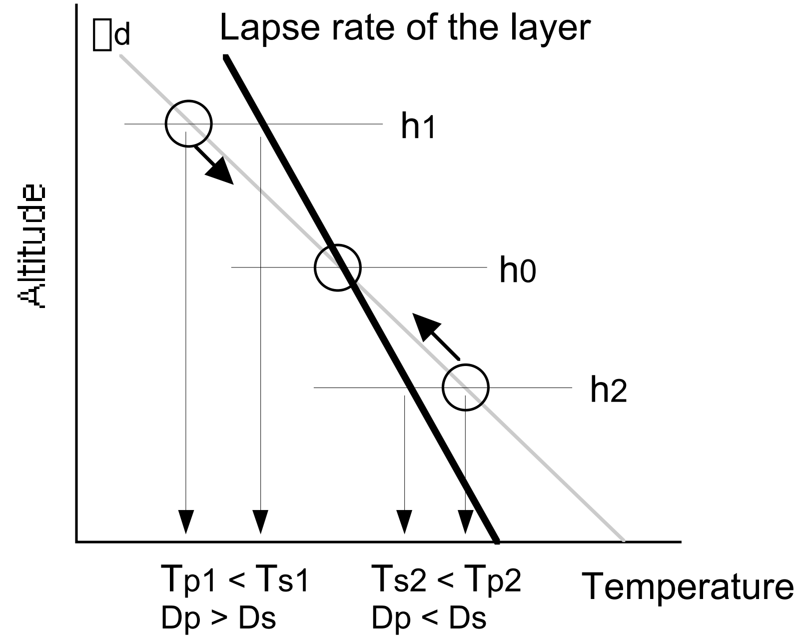
b. Adiabatic lapse rate

When rising a parcel of dry air adiabatically, the temperature of the parcel decreases with height, and this decreasing rate of **0.98 degrees C / 100 m** is called as **dry adiabatic lapse rate** (**□d**). As shown in previously, the actual lapse rate in the troposphere is 0.65 degrees C/ 100 m causing the effect of latent heat of water vapor in the atmosphere.

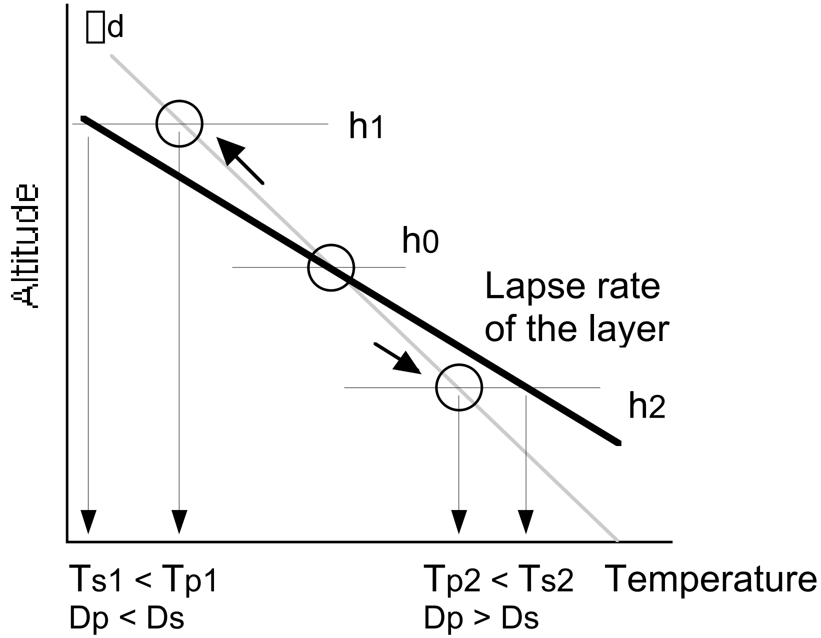
NOTE: adiabatic; Of, relating to, or denoting a reversible thermodynamic process executed at constant entropy and occurring without gain or loss of heat.

c. Air motion and the lapse rate

The motion of an air parcel including pollutants is relating to the lapse rate of surrounding atmosphere, then considering the air motion, the atmospheric thermal conditions are categorized with the **atmospheric stability**. Lower-left figure shows the relation between the air parcel motion and atmospheric **stable condition**: when an air parcel positioned at the altitude h_0 ascends to h_1, the temperature of the parcel becomes to T_{p1}, however, the surrounding air temperature is T_{s1}. Because $T_{p1} < T_{s1}$, the air parcel density Dp is larger than the surrounding air density Ds, introduces the buoyancy force to move the parcel back to the original position h_0. The same process occurs for the descending of parcel. These processes make the whole layer to **stable**, and **suppress the diffusion of the smoke**. On the contrary, unstable condition makes the layer **unstable**. The **neutral** condition is the case when the lapse rate is equal to the **dry adiabatic lapse rate**. The atmosphere is very stable in the **inversion layer** also.



Stable condition



Unstable condition

d. Index of the stability

The real atmosphere is filled with the turbulences generated by the wind shear (inclination of the mean wind vertical profile) and the thermally caused air buoyancy, so, the atmospheric stability is defined not only by the thermal conditions but by the wind shear.

•Richardson number

Richardson (1926) introduces a nondimensional number represents the relation between the energy generated wind shear and the effect of the thermal buoyancy as,

$$Ri = \frac{(g/T_0)(\Gamma_d + \partial T/\partial z)}{\left(\partial U/\partial z\right)^2} = \frac{(g/\theta_0)(\partial \theta/\partial z)}{\left(\partial U/\partial z\right)^2}$$,

where, g is gravitational acceleration [m/s^2], T is temperature [℃], U is mean wind speed [m/s], z is height [m], Γ_d is dry adiabatic lapse rate [℃/m], θ is potential temperature [℃], and the suffix 0 represents mean value. The potential temperature is the temperature when moved the considering parcel to 1000 hPa level.

The Richardson number can be used as a index of the stability. When Ri=0, the stability is stable, then Ri >0 when stable, and Ri <0 when unstable.

NOTE: In the neutral condition, the potential temperature gradient $d\theta/dz$ becomes 0.

•Pasquill's atmospheric stability

Pasquill (1961) proposed a practical stability categories using **windspeed** and **insolation** in daytime, and windspeed and **cloud amount** for nighttime. Because the observation of cloud amount in nighttime accompanies some difficulty, in the Atmospheric Environmental Standard, modified Paquill stability category table is used. For this table, observation of the **net radiation budget** is used instead of the cloud amount.

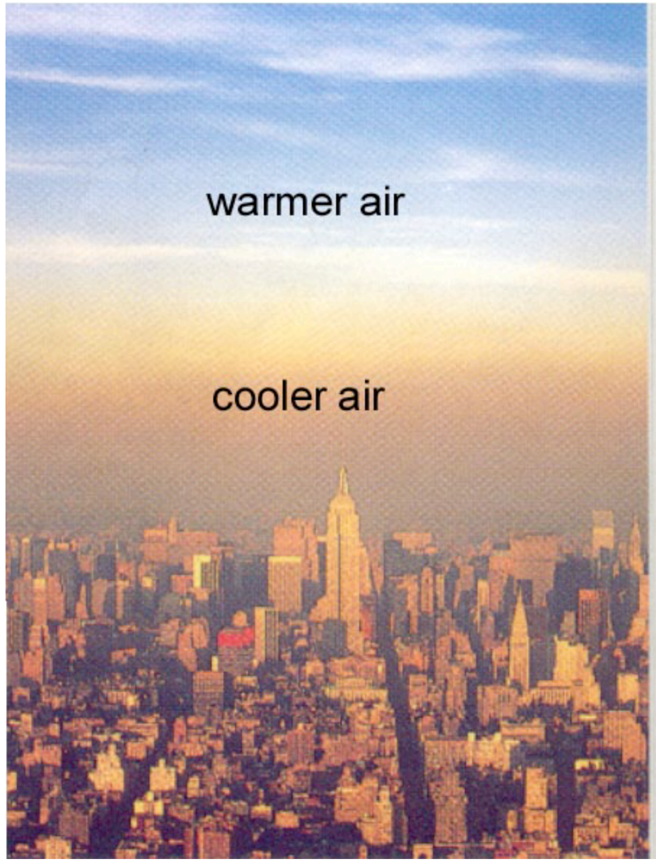
	Insolation T [kW/m2]				Net radiation budget Q [kW/m2]		
Windspeed U [m/s]	T >= 0.60	0.60 > T >= 0.30	0.30 >T >= 0.15	0.15 > T	Q >= -0.020	-0.020 > Q >= -0.040	-0.040 > Q
U < 2	A	A-B	B	D	D	G	G
2=< U < 3	A-B	B	C	D	D	E	F
3=< U < 4	B	B-C	C	D	D	D	E
4=< U < 6	C	C-D	D	D	D	D	D
6=< U	C	D	D	D	D	D	D

In the table, D shows the stability neutral, C, B, and A are unstable (A represents the most unstable case), E, F, and G are stable conditions (G: most stable).

4. Mixing Layer and Air Pollution

•Mixing layer

When the insolation begins, heated surface boundary layer produces the **convection**. The convected layer is **well mixed** and this layer is called as **mixing layer**. The height of mixing layer increase by the time and defined with the nighttime temperature profile and the total insolation. The **mixing layer depth** (height) reaches to maximum in daytime, and sometimes becomes from some hundred meter to 2000 m.



•Lid of the mixing layer (Occasionally)

In the mixing layer, the pollutants are **well mixed**. Occasionally, there is the inversion layer on the top of the mixing layer, and suppresses the further diffusion of the pollutants. The suppressing inversion layer is called **lid**.