Air pollution

Lecture 12

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Meteorology of Air Pollution

هواشناسی آلودگی هوا

بادها

نیروها

گردش کلی جو

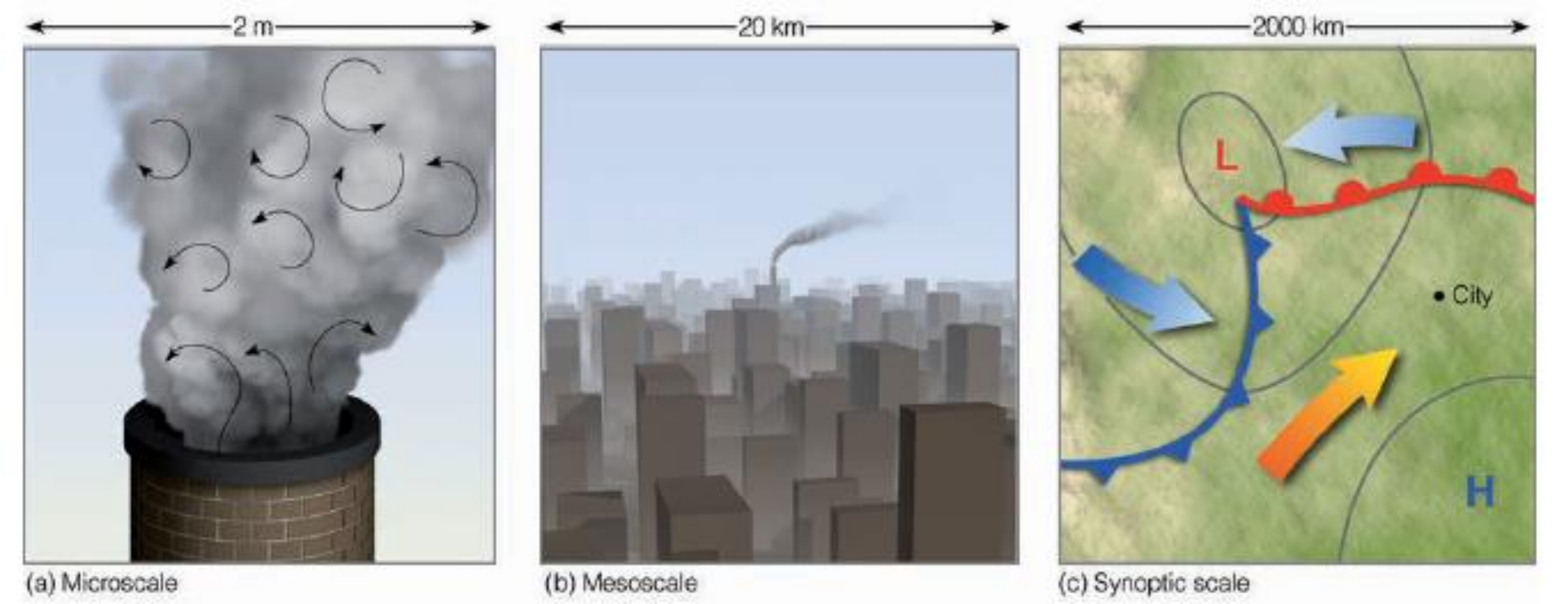
پایداری

مشخصه مقیاس های فضایی پدیده های شیمیایی مختلف در جو

Scales of atmospheric motion.

The tiny microscale motions constitute a part of the larger mesoscale motions, which, in turn, are part of the much larger synoptic scale.

Notice that as the scale becomes larger, motions observed at the smaller scale are no longer visible.



پایداری قائم جو

اگر بخواهیم پدیده های مهم جوی مانند آشفتگی و آلودگی هوا را درک و پیش بینی کنیم باید برای پایداری حرکت قائم هوا ضابطه برقرار کنیم.

بنابراین به بررسی جوی که در ترازمندی هیدروستاتیکی است می پردازیم و نیروهایی را که به هنگام حرکت قائم وارد می شوند مطالعه می کنیم.

Structure of the Static Atmosphere

جو ایستا: در صورتی که در جو هیچگونه ناپایداری وجود نداشته باشد یعنی همه جو در حال سکون باشد جو را ایستا گویند.

حالت ترمودینامیکی جو در هر نقطه با مقادیر فشار، دما و چگالی (حجم ویژه) در آن نقطه تعیین می شود رابطه ای که ارتباط این کمیت‌ها را با هم نشان می دهد معادله حالت نامیده می شود.

We can express the equation of state for dry air as:

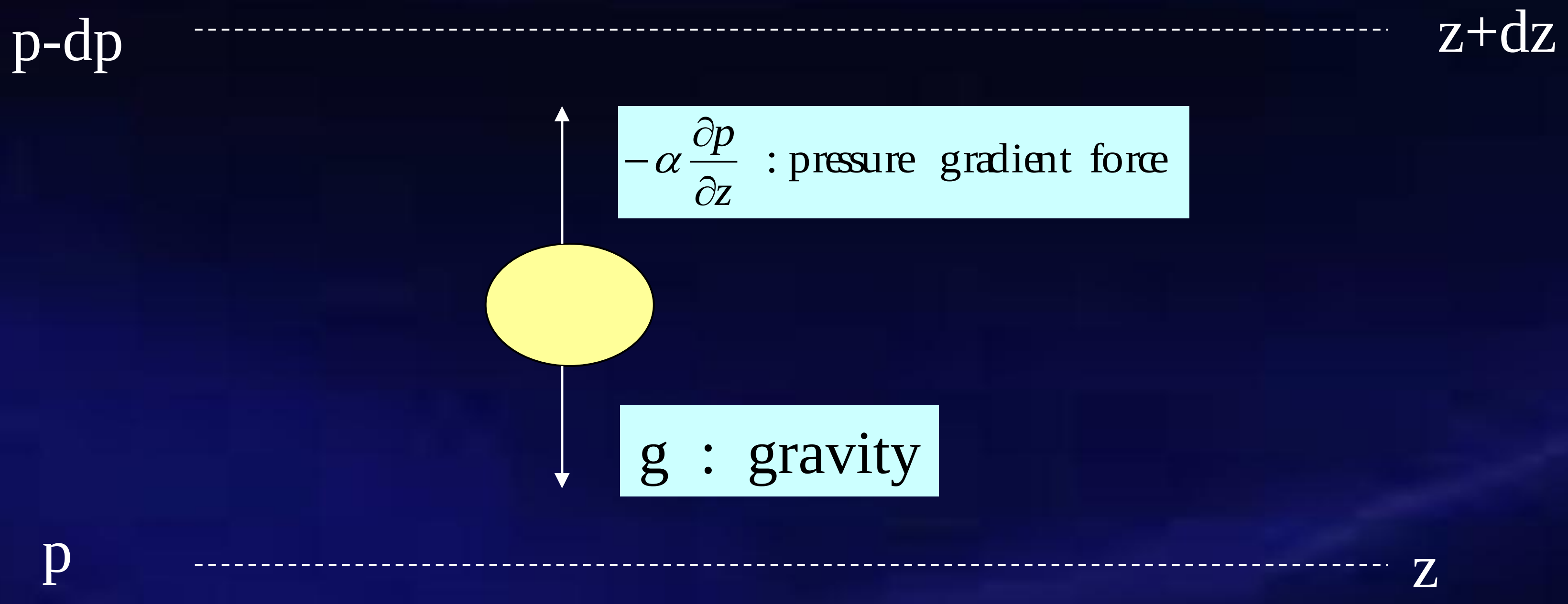
$$P\alpha = RT$$

$$P = \rho RT$$

Where R is the gas constant for dry air ($R=287\ Jkg^{-1}K^{-1}$)

The Hydrostatic Equilibrium

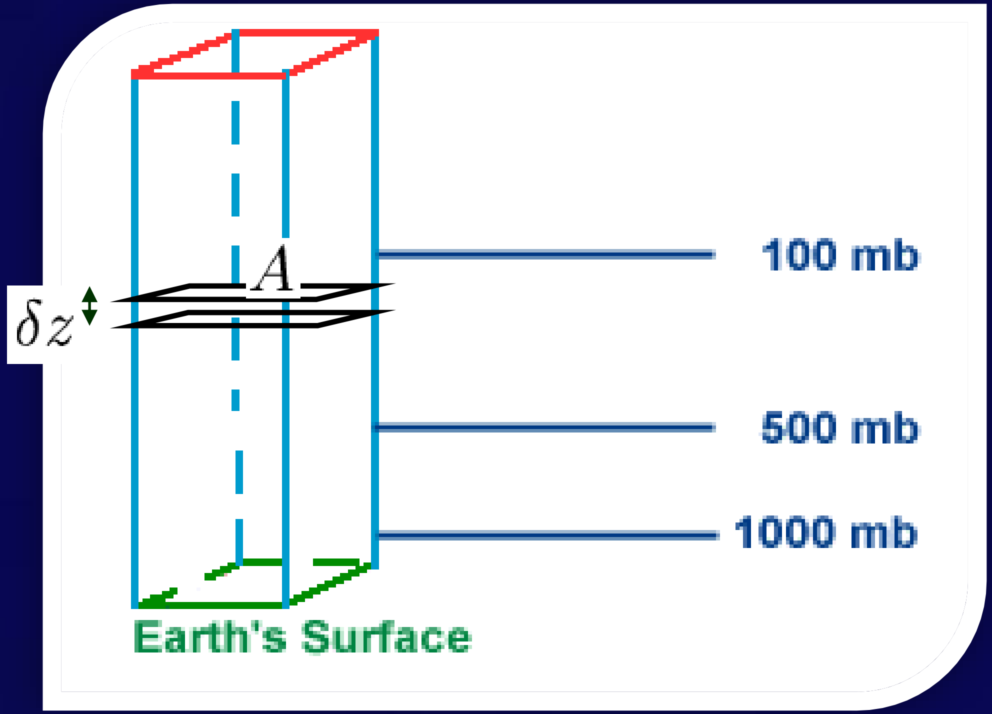
In the absence of atmospheric motions the gravity force must be exactly balanced by the vertical component of the pressure gradient force.



$$-\alpha \frac{dp}{dz} = g \qquad \frac{dp}{dz} = -\rho g$$

(one of the best approximations in meteorology)

Hydrostatic Approximation



Mass = density x Volume

$$\delta m = \rho\,\delta V = \rho\, A\, \delta z$$

Newton's Second Law

$$\delta F = \delta m\, a = -\rho\, A\, \delta z\, g$$

pressure = force per unit area

$$\delta p = \delta F / A = -\rho\, \delta z\, g$$

Rearrange last equation to yield hydrostatic approximation

$$\frac{\delta p}{\delta z} = -\rho\, g$$

$$\frac{dp}{dz} = -\rho g$$

$$dp = -\rho g\, dz$$

$$p(z) = \int_z^{\infty} \rho g\, dz$$

Pressure at any point is the weight per square meter of the atmospheric column overlying that point.

For average conditions,

$$p(0) = \int_0^{\infty} \rho g\, dz = 101.325\, kPa$$

This is the mean sea-level pressure

Thermodynamics of Dry Air

Dry Air

The First Law of Thermodynamics states that a small amount of heat, dQ, added to unit mass of a system (which here is a small parcel of air) can be used to change the internal energy, dU, and to do work, dW, against the surroundings.

$$dQ = dU + dW$$

Where the work done by the viscous forces can be neglected, the work is communicated only by the pressure force $pd\alpha_{parcel}$.

we can write $dW = pd\alpha$, which is the work done by expansion, and α is the specific volume. For dry air $dU = C_v dT$. Thus, the first law can be written:

$$dQ = C_v\, dT + p\, d\alpha \qquad [\text{dry air}(1)]$$

Hence, heat added to the system may cause a change in volume of the gas, or it may result in a change in temperature of the gas, or both.

Air behaves nearly like a perfect gas, so we may use the perfect gas equation

$$p\alpha = RT \qquad R = C_p - C_v$$

and write the first law in the form

$$\mathrm{d}Q = C_p\,\mathrm{d}T - (1/\rho)\,\mathrm{d}p \qquad \text{[dry air (2)]}$$

An adiabatic process is one in which no heat enters or leaves the system, thus

$$\mathrm{d}Q = 0$$

$$C_v \, \mathrm{d}T = -p \, \mathrm{d}\alpha$$

$$C_p \, \mathrm{d}T = \alpha \, \mathrm{d}p$$

Hence, an expansion ($d\alpha > 0$) will cause a reduction in the internal energy of the gas and therefore a decrease in temperature ($dT < 0$).

Alternatively we see that an decrease in temperature results in a decrease in pressure ($dp < 0$).

Dry Adiabatic Lapse Rate (DALR)

آهنگ کاهش دمای بی دررو خشک

In atmospheric flow, we have a significant built-in vertical variation in the pressure, the air density, and the temperature.

A baseline for this variation is the adiabatic change with respect to height.
Density changes over short height differences are small.

Thus using a constant density approximation, we can calculate the vertical adiabatic temperature change as a function of the pressure change.

This temperature profile is called the dry adiabatic lapse rate.

$$C_p \, \mathrm{d} T = \alpha \, \mathrm{d} \, p \qquad \qquad \alpha \frac{dp}{dz} = -g$$

Assuming ρ = const, we obtain

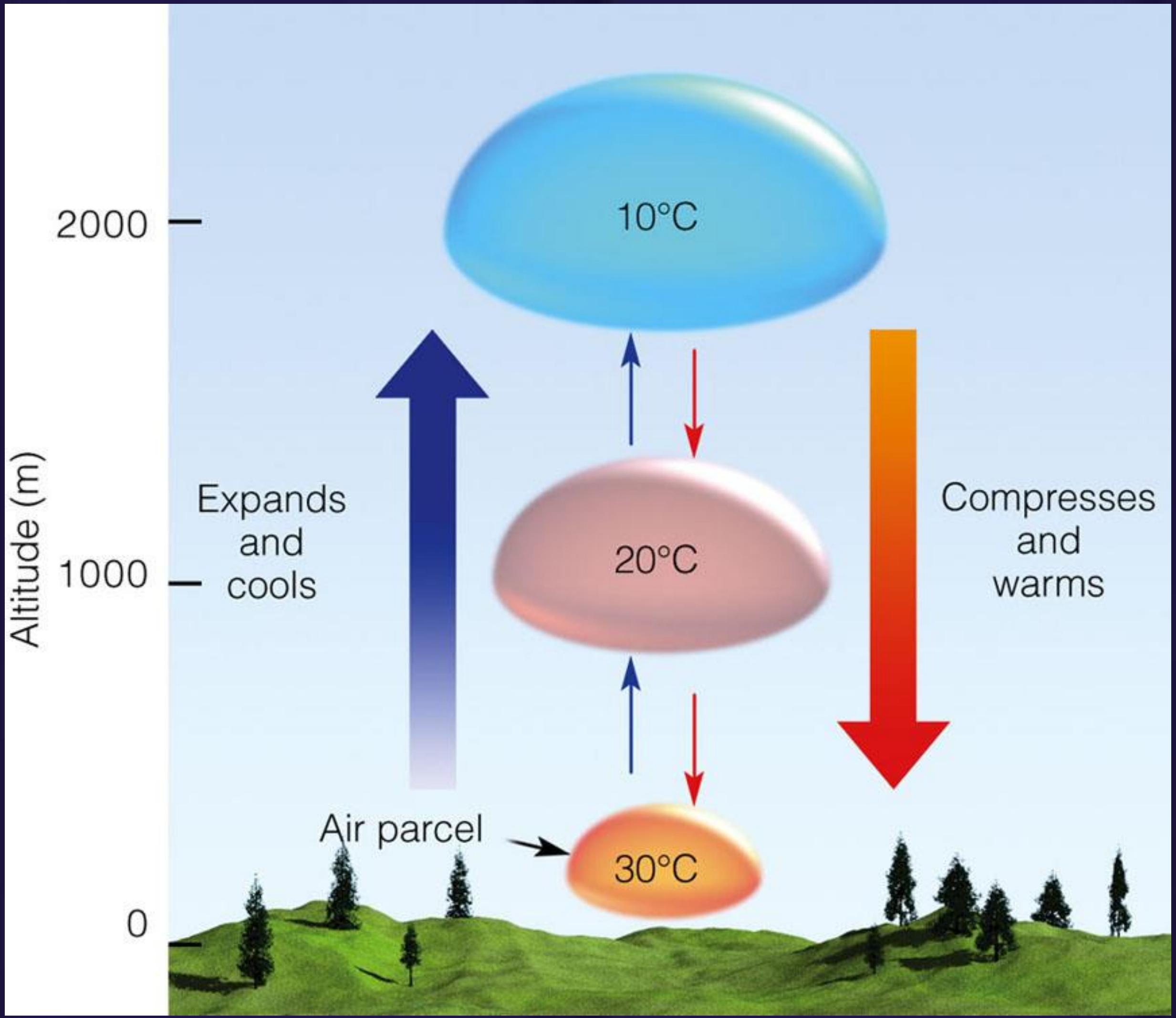
$$-\left(\frac{\partial T}{\partial z}\right)_{DALR} = \frac{g}{C_p}$$

We denote $(\partial T/\partial z)_{DALR}$ by Γ_d and call it the dry adiabatic lapse rate (DALR):

$$-\left(\frac{\partial T}{\partial z}\right)_{DALR} \equiv \Gamma_d$$

Dry adiabatic lapse rate = 10 °C/1000m

Temperature changes that occur without a change in heat content.



Or, no exchange of energy between the air parcel and the surroundings.

Adiabatic temperature changes