CIVE 3331 - ENVIRONMENTAL ENGINEERING
Spring 2003

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Purpose: Lecture #14 CIVE3331

Meterology and Air Pollution

Stability

Stable air – tends to remain at one elevation.

Unstable air – tends to rise/fall relative to surrounding air because of density differences.

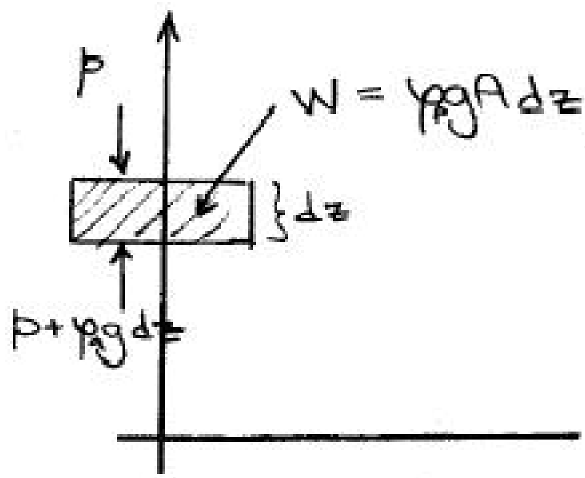


Figure 1. Air Parcel Definition Sketch

Force balance for air parcel

$$\Sigma F_z = -pA + (p + \rho_a g\, dz)A - \rho_p g A\, dz$$

$$= (\rho_a g\, dz - \rho_p g\, dz)A$$

If $\rho_p=\rho_a$ then parcel will remain in position

If $\rho_p<\rho_a$ then parcel will rise

If $\rho_p>\rho_a$ then parcel will sink

From thermodynamics recall that $\Delta H = C_p\, \Delta T - V\, \Delta p$. For constant enthalpy (and or zero heat transfer) we can write

$$\frac{\Delta T}{\Delta p} = \frac{V}{C_p}$$

Now using a hydrostatic pressure distribution as an approximation of the atmosphere we can relate elevation to pressure and temperature.

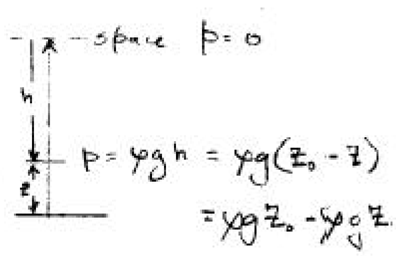


Figure 2. Atmosphere model

Hydrostatic pressure model:

$$p(z) = \rho g z_0 - \rho g z$$

Pressure variation as function of depth (derivative of hydrostatic model)

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

Zero-heat transfer pressure volume relationship, substitute pressure variation where indicated.

$$\frac{\Delta T}{\Delta p} = \frac{\Delta T}{-\rho g \Delta z} = \frac{V}{C_p}$$

Rearrange and cancel like terms

$$\frac{\Delta T}{\Delta z} = -\frac{\rho g V}{C_p} = -\frac{g}{C_p}$$

The term on the right is called the adiabatic lapse rate and it indicates the temperature change of the atmosphere as the elevation changes. Numerically the typical values are:

$$\frac{\Delta T}{\Delta z} = -0.00976\,K/m = -9.76^{\circ}C/km = -5.4^{\circ}F/1000\,ft \quad (\text{Dry rate})$$

These values assume dry air – when water vapor is present (as is always the case) the rate is a function of relative humidity. If there is enough water vapor so that condensation occurs (phase change – latent heat of vaporization) then we use the saturated lapse rate. The average value for saturated air is about 6°C/km, or 3°F/1000 feet.

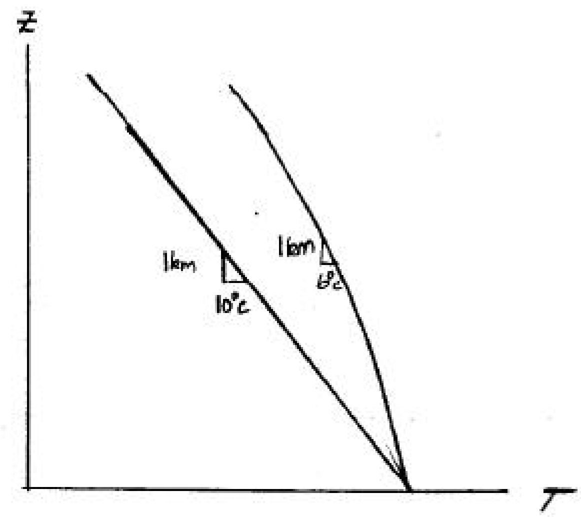


Figure 3. Dry and Saturated Temperature Profiles

Lapse rates are used to understand atmospheric stability. The idea is to take a conceptual air parcel, move it up or down and determine from the lapse rate its stability.

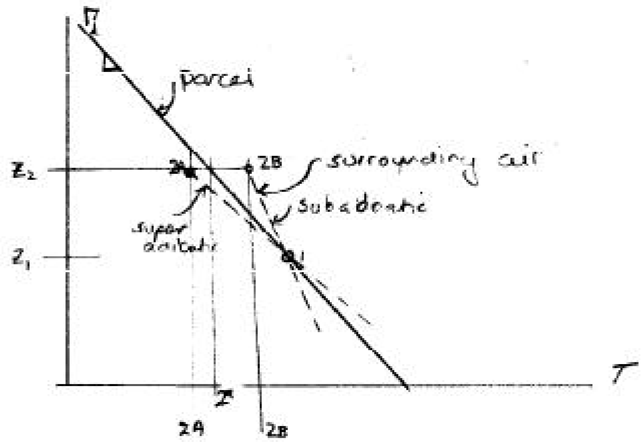


Figure 4. Stability Diagram

For example, start parcel at position 1 on Figure 4. Then “move” it to position (elevation) 2 along the “solid” profile (i.e. this is the equilibrium for the parcel). If the surrounding air follows the subadibatic lapse line, then the parcel will cooler than the surrounding air, and will tend to sink back to its starting position (stable). If the surrounding air follows the superadibatic lapse line then the parcel will be warmer than the surrounding air and it will tend to continue to rise (unstable).

One consequence of stability is that pollutants can concentrate. Unstable atmospheres mix pollutants (dilution) and are desirable. Neutral stability concentration can occur, but usually the conditions change enough to create unstable or stable conditions.

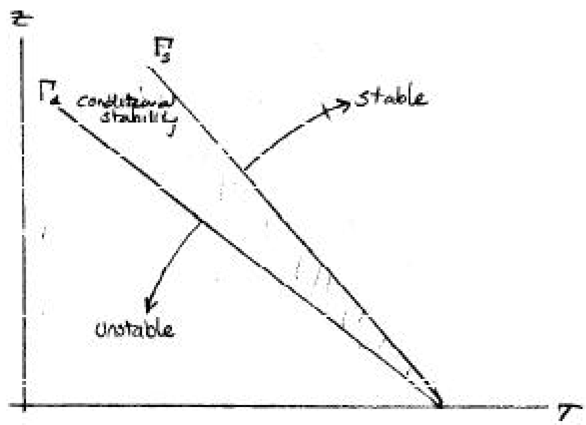


Figure 5. Relative stability relationships

<u>Temperature inversion</u>

A temperature inversion is an extreme case of stability, where the temperature profile develops a "kink" that similar to the thermocline in a lake restricts movement through the "kink"

Radiation inversion

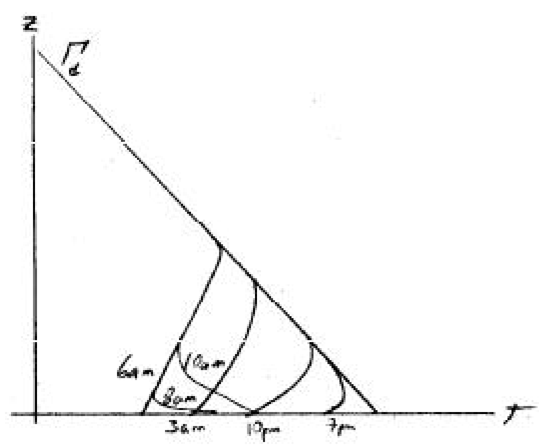


Figure 6. Radiation inversion (time profiles)

On a clear night, the earth radiates heat outward and cools air near surface. In morning sun reheats surface faster than the heat can transfer to the upper layers of air and creates the temperature kink.

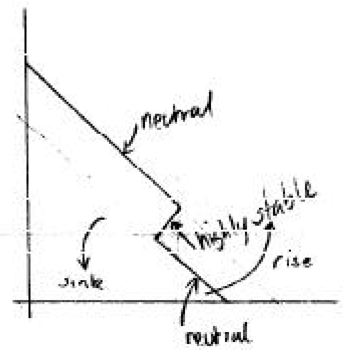


Figure 7. Radiation inversion stability

During the morning before the profile erodes, pollutants concentrate in the neutral zone below the inversion (highly stable) layer. When erosion does occur a fumigation effect is observed as the stable layer sinks as the near surface air rises. Usually there is no PC-smog, but CO and toxics are significant.

Subsidence inversion

High pressure anticyclones (a weather pattern) that can last for weeks cause subsidence inversions.

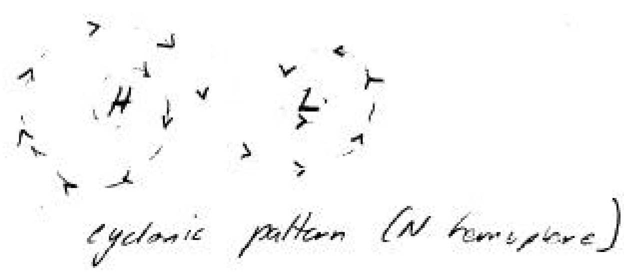


Figure 8. Cyclonic pattern (plan view)

PC smog is significant. Anti cyclone cells are expected at Equator, 30^o,60^o and 90^o

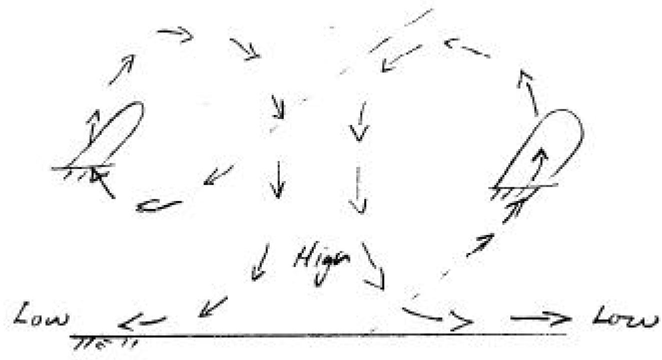


Figure 9 Cyclonic Pattern (Elevation view)

At other latitudes rotation driven currents tend to prevent set-up.

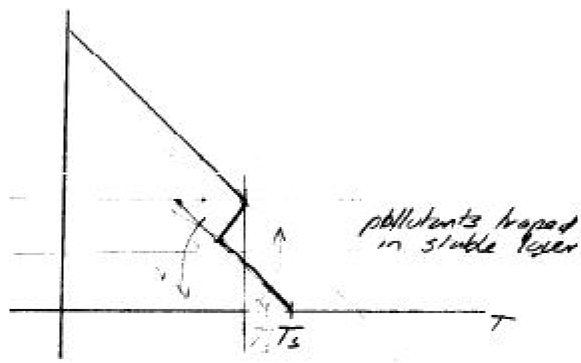


Figure 10. Subsidence inversion profile

<u>Stability and Mixing Depth</u>

Stability and mixing concepts are used to estimate vertical dilution of pollution. Temperature profiles and stability play a big role in discharge location (how high to make a stack).

Ventilation coefficient is a calculation used to estimate dilution.

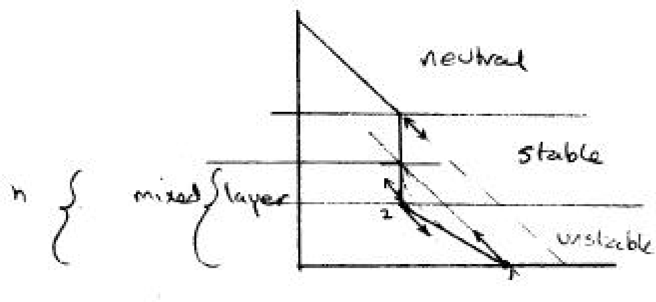


Figure 11. Mixing depth model

VC = u*h

h= mixing depth; u = average windspeed

if VC < 6000 m2/sec then there is a high air pollution potential.

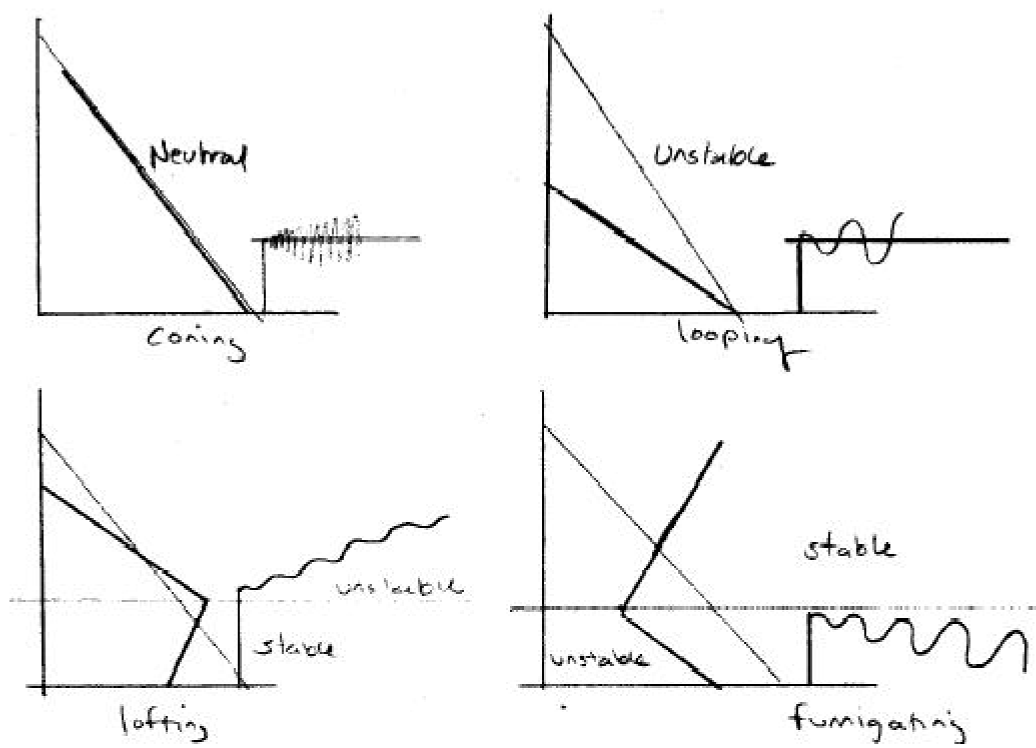
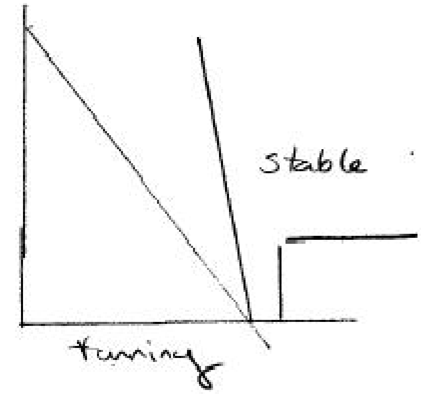


Figure 12. Plume shapes and stability



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