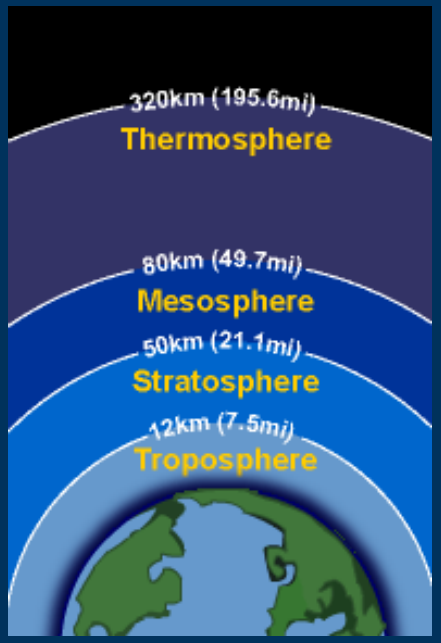
# CLIM-319/GGS-319
## Introduction

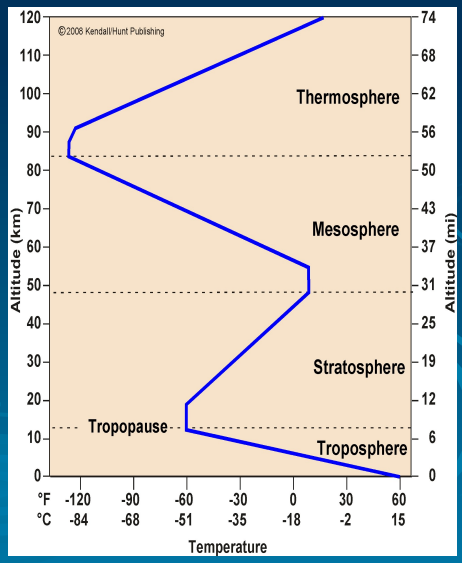
- ✓ The Atmosphere and its Layers
- ✓ Planetary Boundary Layer (PBL)



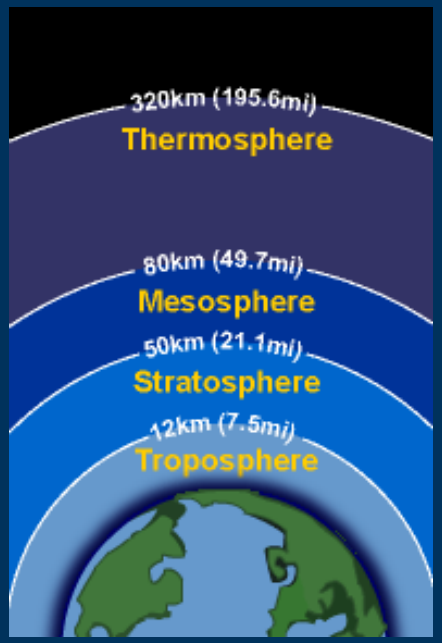
# Atmosphere

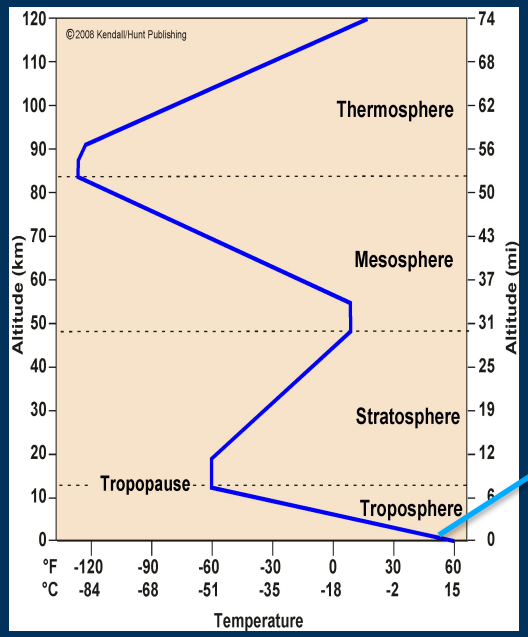
- Troposphere extends 9-16 km
  - Lapse rate 6.5 $^{0}$C/km
  - Well mixed
  - All weather formation
  - Pollutants and moisture confine in this layer
- Stratosphere extends to 50 km
  - Ozone formation
  - Absorption of SW radiation
  - Little mixing
  - No clouds and precipitation
  - Pollutants alter the radiation budget
- Mesosphere extends to 85 km
  - Temperature decreases
  - Coldest temperature occurrence
- Thermosphere
  - Conversion of solar energy into sensible heat

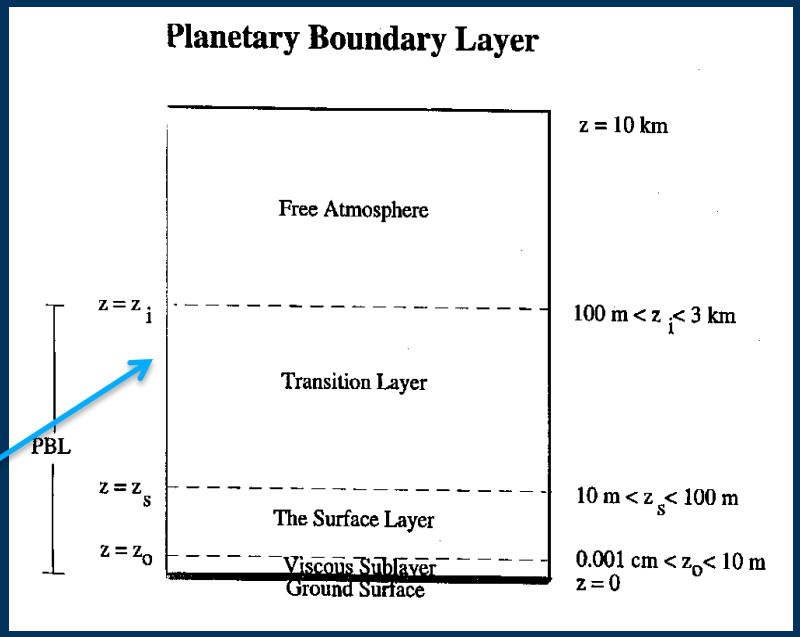


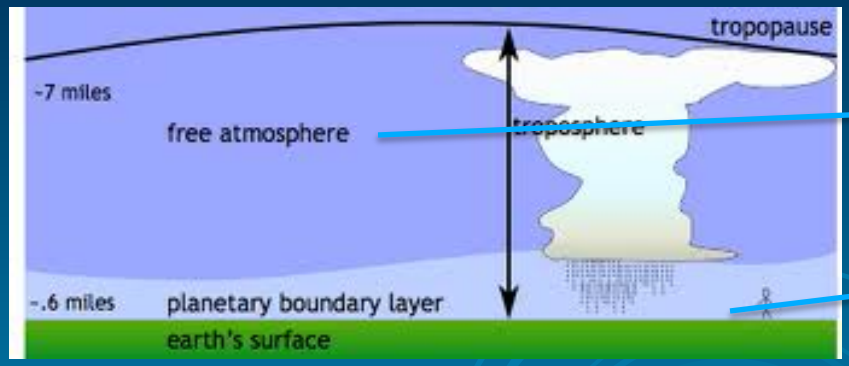



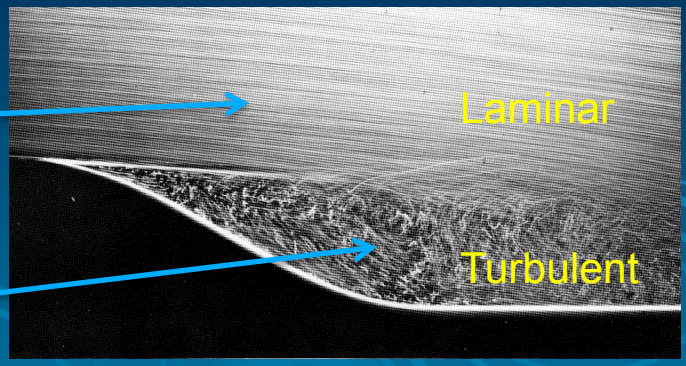
# Planetary Boundary Layer (PBL)



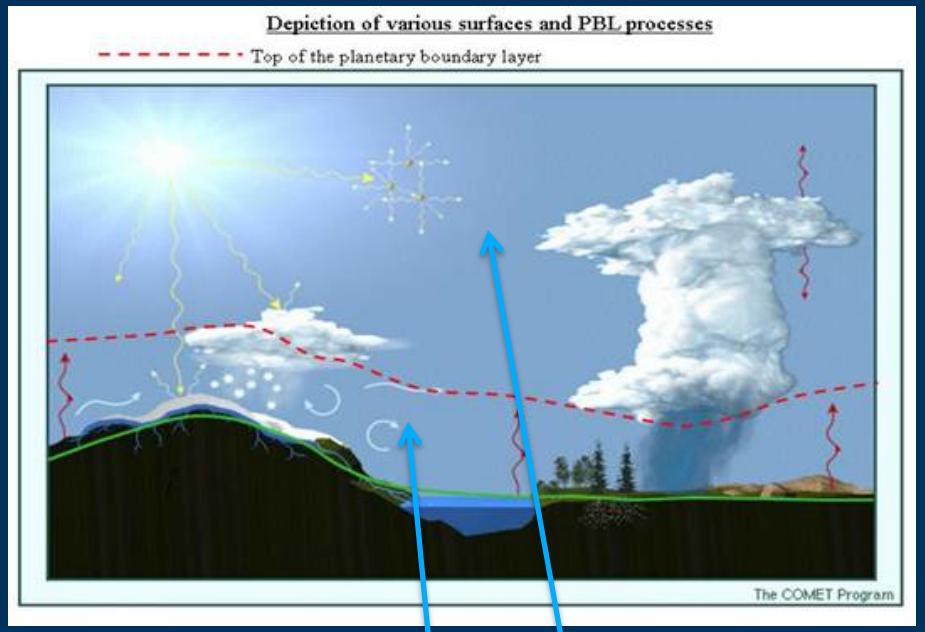



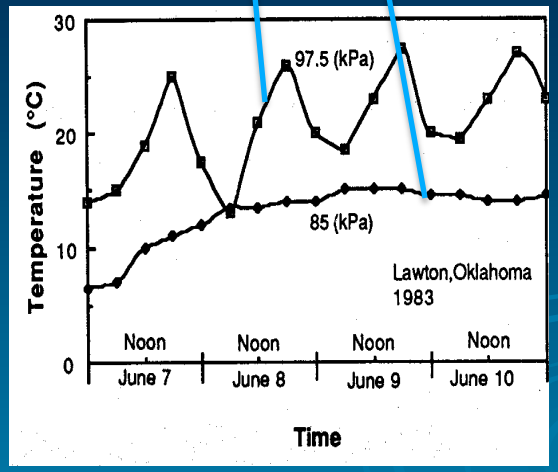



# Planetary Boundary Layer (PBL) Definition

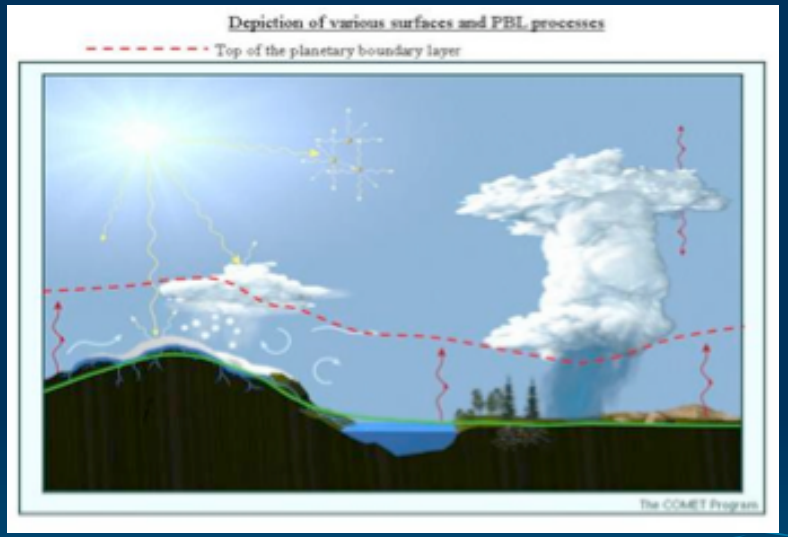


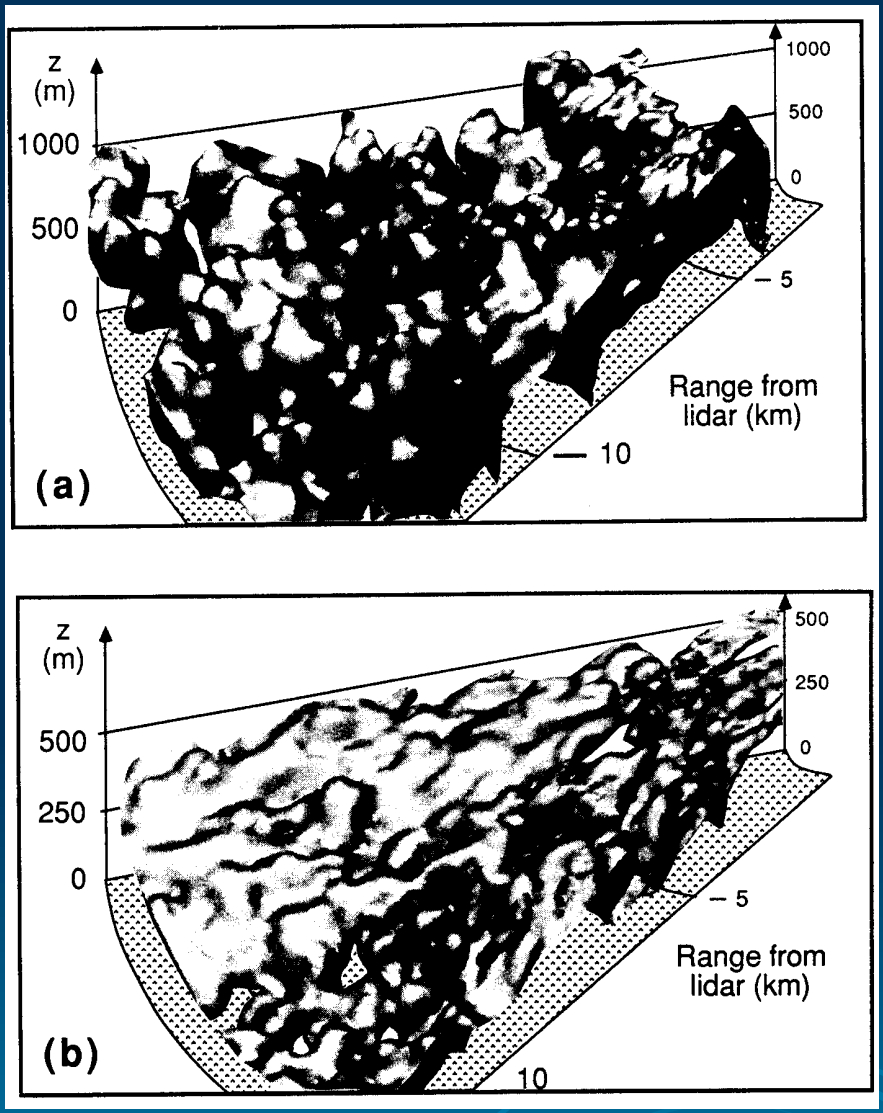




- We can define the boundary layer that part of troposphere that is directly influenced by the presence of the earth's surface, and response to surface forcings with a time scale of about an hour or less.

# Surface Forcings

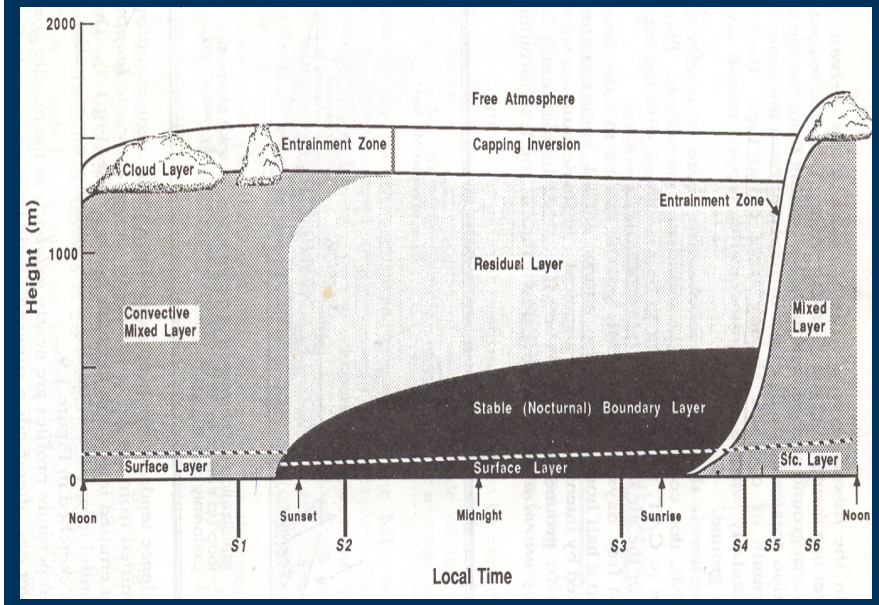
- The surface forcings
  - Frictional drag
  - Heat transfer
  - Evaporation and transpiration
  - Pollutant emission
  - Terrain induced flow modification
- It is ground that warms and cools in response to the radiation, which in turn forces changes in the PBL via transport processes
- Turbulence is one of the important transport processes

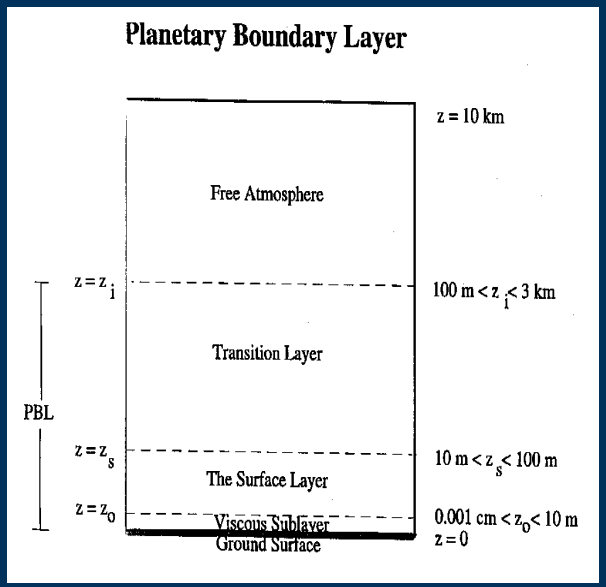


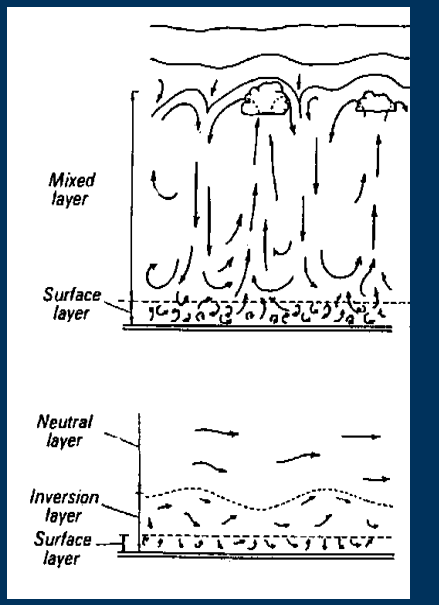



- Lidar image of the PBL aerosols
  - a) convective mixed layer observed 10:30 local time on July 1, 1987.
  - b) slightly stable PBL observed at 5:30 local time on July 7, 1987.

# PBL depth and structure




- Viscous sublayer (molecular dissipation dominant)
- Surface layer (small scale eddies dominant)
- Mixed layer (large scale eddies dominant)
- Residual layer is not considered within PBL concept

# PBL depth and structure

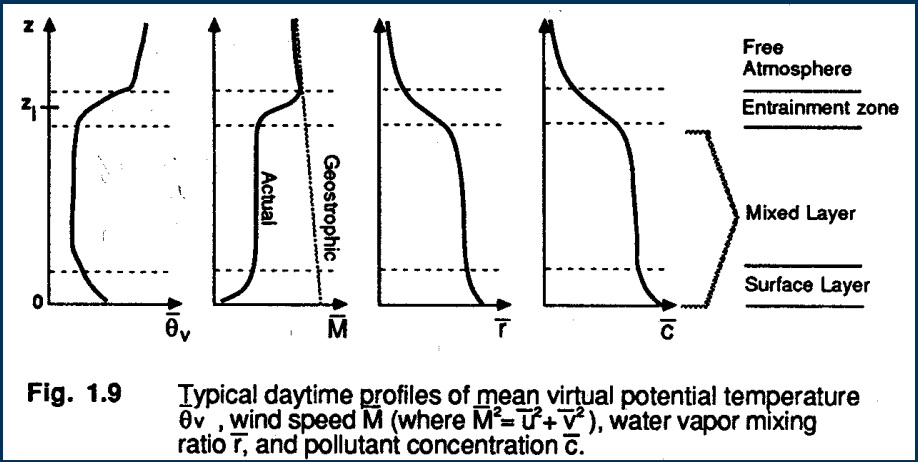
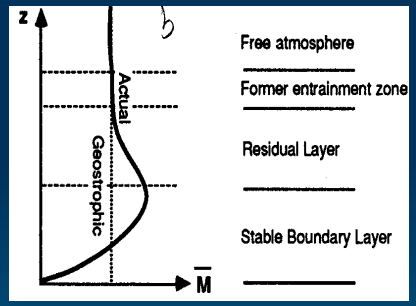



Fig. 1.9 Typical daytime profiles of mean virtual potential temperature $\bar{\theta}_v$, wind speed $\bar{M}$ (where $\bar{M}^2 = \bar{u}^2 + \bar{v}^2$), water vapor mixing ratio $\bar{r}$, and pollutant concentration $\bar{c}$.

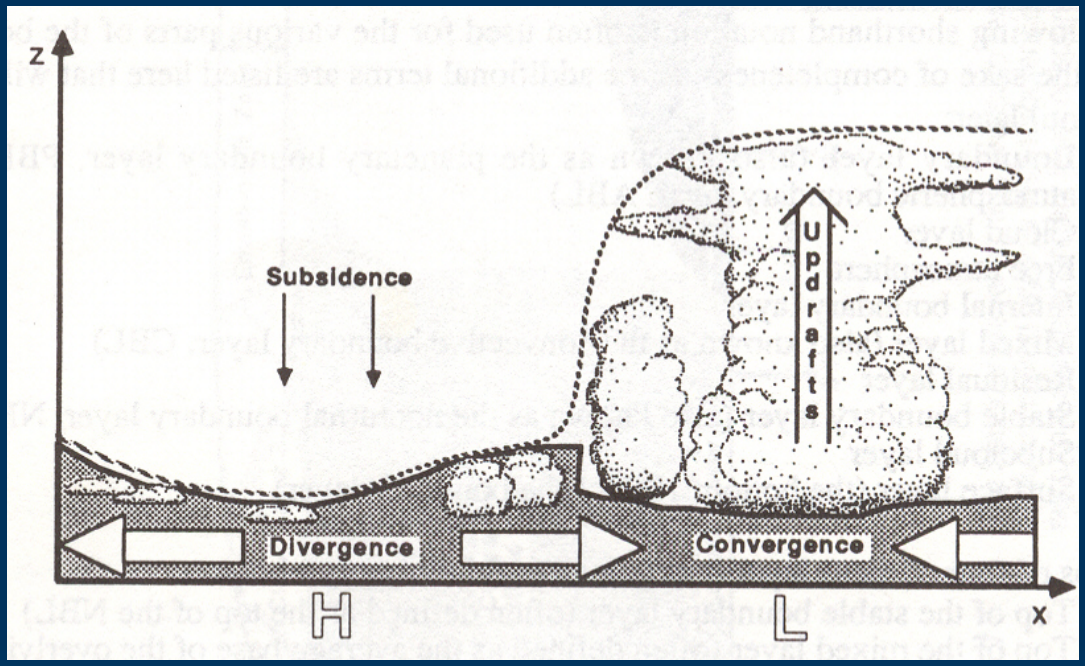
Daytime profiles




Nighttime wind profile

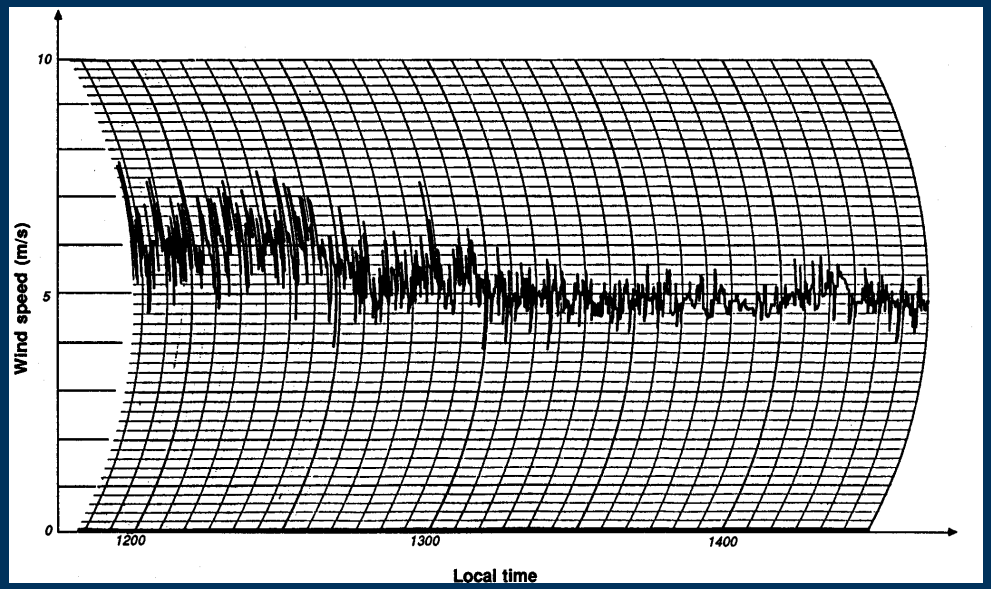
- Temperature is nearly **adiabatic** in the ML and **superadiabatic** in the SL.
- Wind speed is **subgeostrophic** in the ML and **logarithmic** in the SL
- Although the wind at ground level frequently becomes lighter at night, the winds aloft may accelerate to **supergeostrophic** speeds, 10-30 m/s (called **low-level jet** or **nocturnal jet**)

# PBL depth and structure

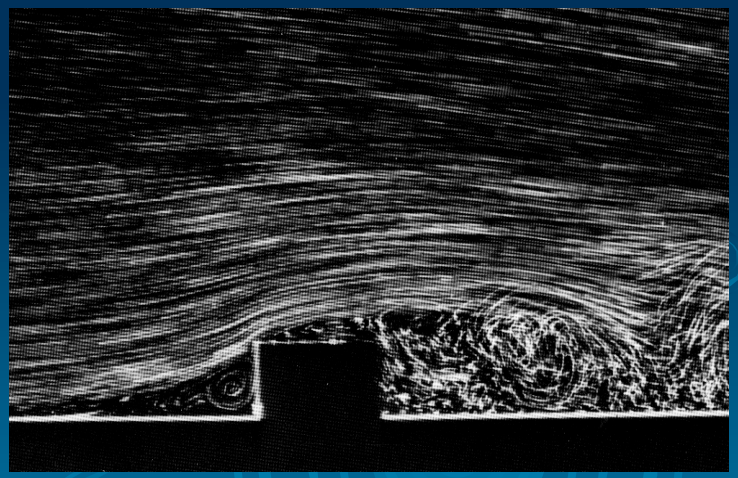



- Over oceans, the PBL depth varies relatively slowly in space and time
- The general nature of the PBL is to be thinner in HP regions than in LP regions

# Turbulent Nature of PBL





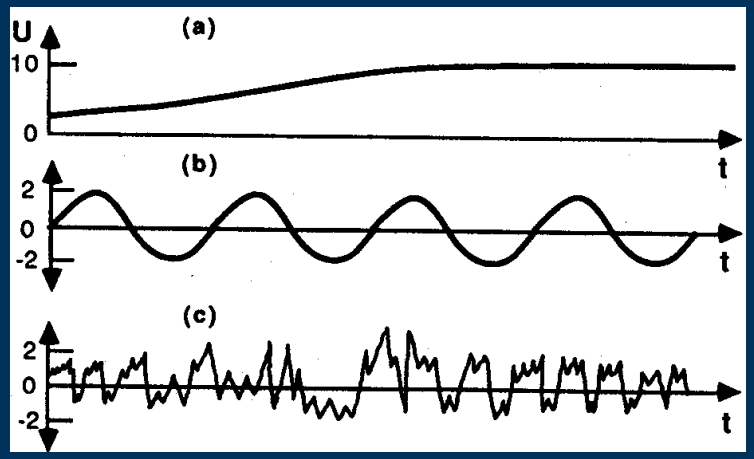



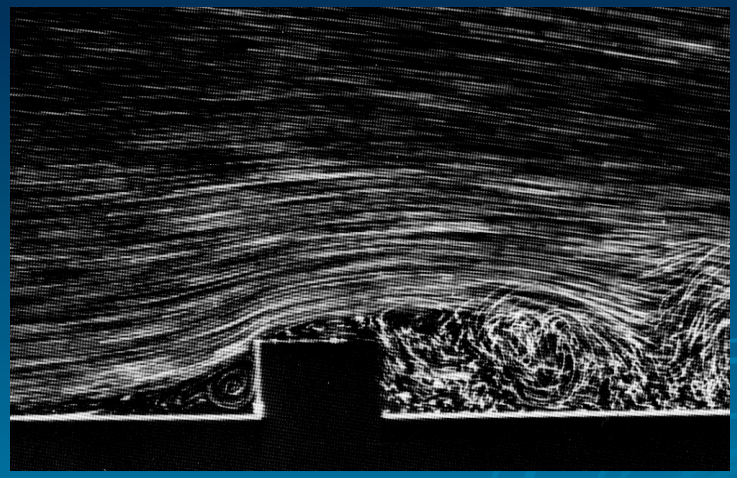
- The wind speed varies in an irregular pattern
- We can usually pick out a mean value (quasi-random)
- Wind speed vary over a limited range of speeds
- There appears to be a wide variety of time scales of wind variation superimposed on top of each other

# Transport by mean wind, waves and turbulence

- A common approach is to split variables such as temperature and wind into a mean part and a perturbation part.
- Mean part represents the effects of the mean temperature and mean wind .
- The perturbation part can represent either wave effect or the turbulence effect that is super imposed on the mean wind.

# Transport by mean wind, waves and turbulence



- Air flow = mean wind + waves + turbulence
- Each can exist separately, or in the presence of any of the others
- Transport quantities such as moisture, heat, momentum, and pollutants are transported by
  - Mean wind
  - Waves
  - Turbulence

# Transport by mean wind, waves and turbulence

- Mean wind
  - Responsible for horizontal transport, or **advection**.
  - **2** to **10 m/s** are common.
  - Friction causes the mean speed to be slowest near the ground.
  - Vertical mean winds are much smaller (on the order of **mm**)
- Waves
  - Frequently occur in the nighttime PBL
  - Generated locally by wind shear and obstacles
  - Effective at transporting momentum and energy
- Turbulence
  - Almost always exist in the PBL
  - This makes PBL different than the rest of the atmosphere
  - Outside of the PBL, CAT exist in convective clouds and jet stream

# Mean and turbulent part

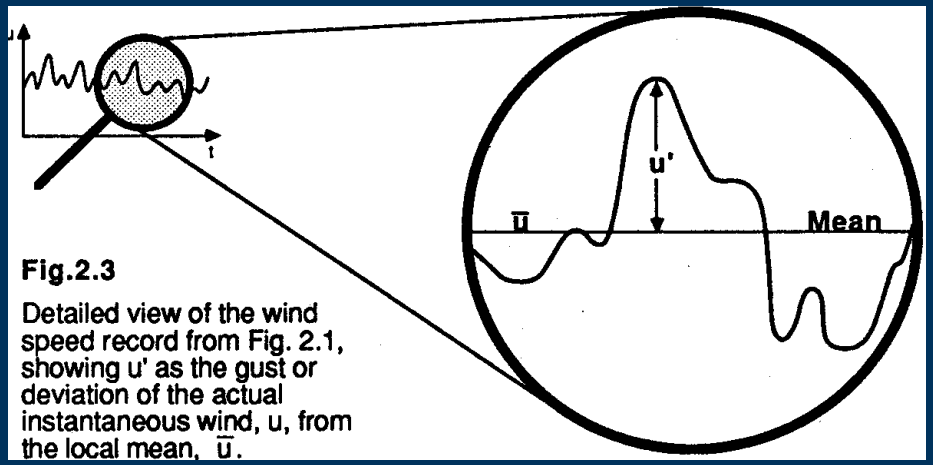
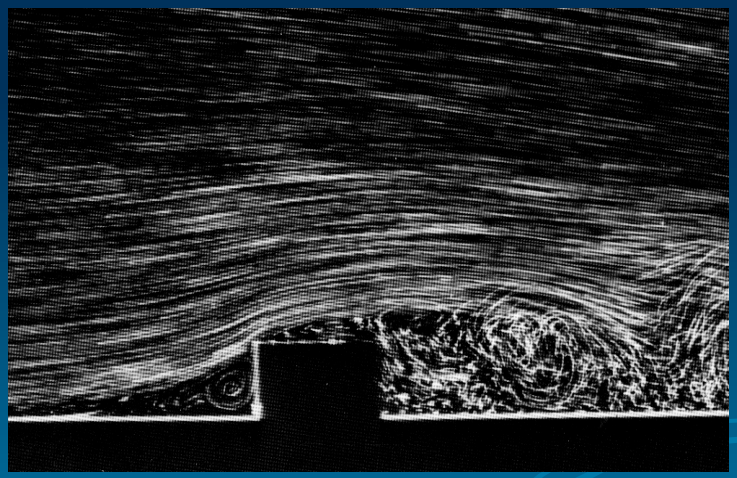



**Fig.2.3**

Detailed view of the wind speed record from Fig. 2.1, showing u' as the gust or deviation of the actual instantaneous wind, u, from the local mean, $\bar{u}$.



- We can isolate the large-scale variations from the turbulent ones
- By averaging out wind speed measurements over a period of 30 min to 1 hour, we can eliminate or average out the positive and negative deviations of the turbulent velocities about the mean
- Once we have the mean value, we can obtain the turbulent part
- The existence of a spectral gap allows us to partition the flow field in this manner

# The Spectral Gap

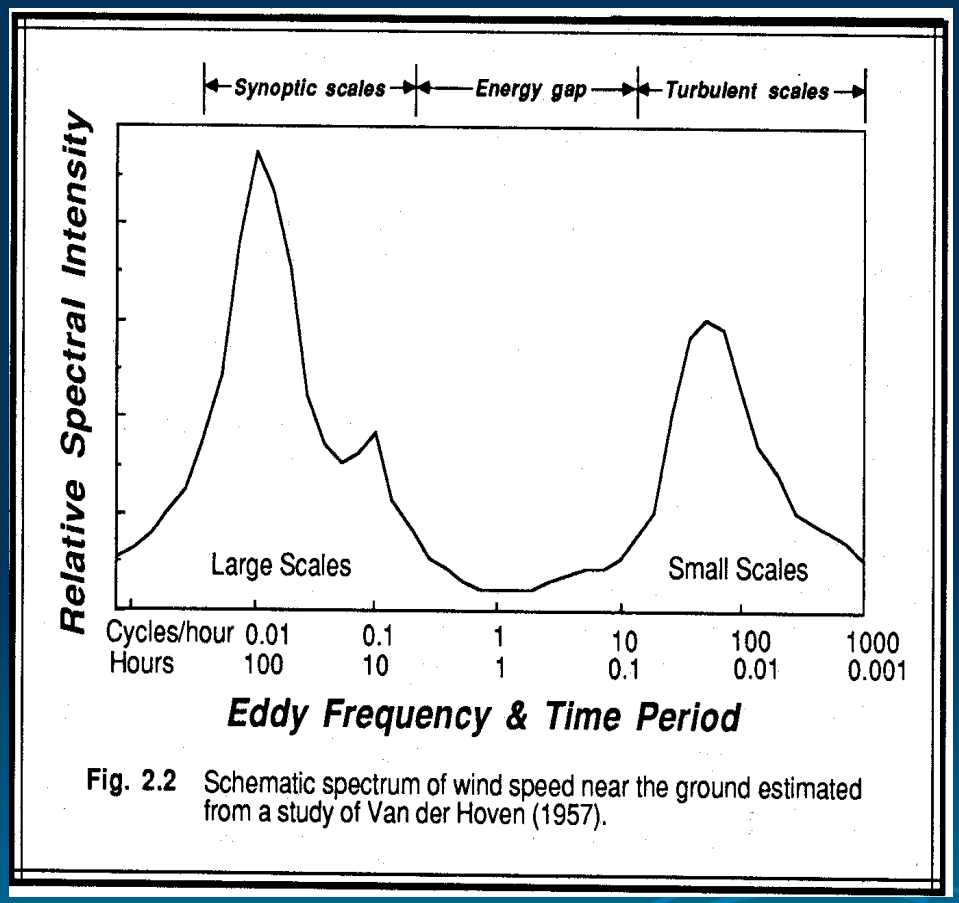



Fig. 2.2 Schematic spectrum of wind speed near the ground estimated from a study of Van der Hoven (1957).

- The eddies behave in a well-ordered manner when displayed in the form of a spectrum
- Peaks in the spectrum show which eddies contribute the most to the TKE
- Small eddies have shorter time periods than large eddies
- There are 3 peaks (large scale, 24 hours cycle, and microscale)
- Microscale eddies having durations of 10s to 10 min

# Mean and Turbulent Parts

$$U = \overline{U} + u'$$

$$V = \overline{V} + v'$$

$$W = \overline{W} + w'$$

$$\theta_v = \overline{\theta_v} + \theta_v'$$

$$q = \overline{q} + q'$$

$$c = \overline{c} + c'$$

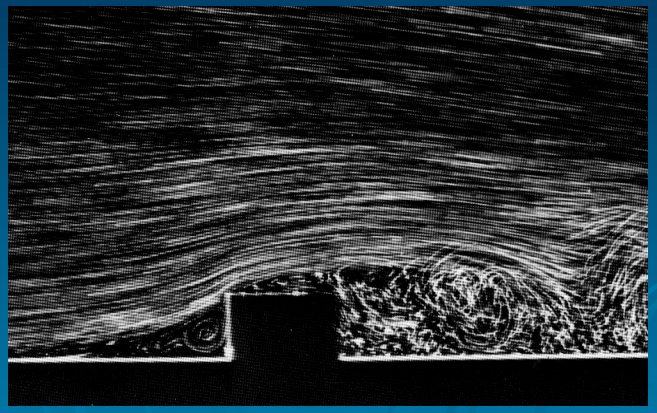
- Prime quantities represent the part of the flow that varies with periods shorter than about one hour
- The mean (or average) represents the part that varies with a period longer than about one hour

# Atmospheric Dispersion

- Atmospheric dispersion is the irreversible process by which a cloud of tracer or pollutant expands, mixes, and is diluted by atmospheric motions acting on the cloud
- It may be thought of as the result of two processes or components, *advection* and *diffusion*
- Dispersion = Transport (Advection) + Diffusion
  - Transport by “Mean Wind”
    - Whole body transport
    - Differential transport
  - Diffusion by “Turbulence”

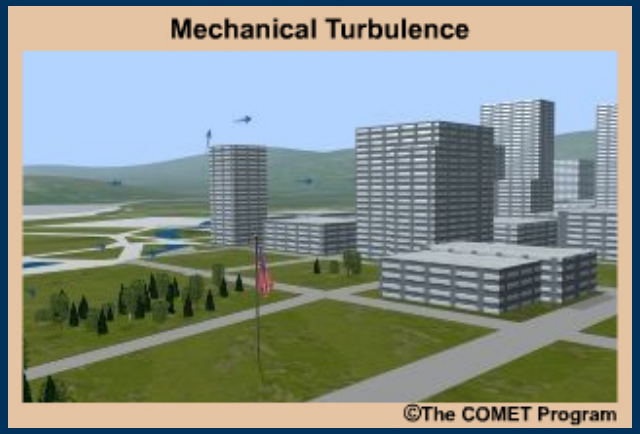
# Turbulent transport

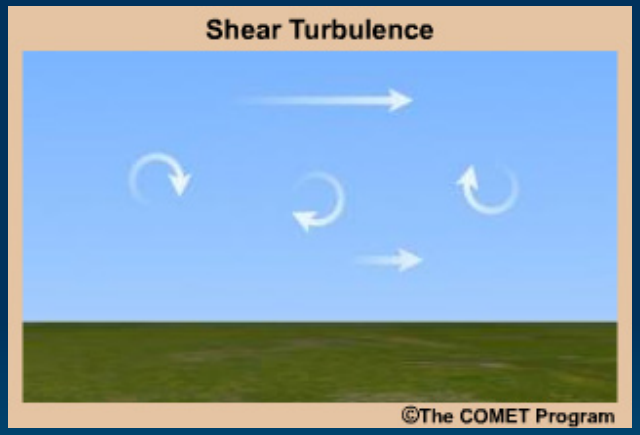
- Turbulence can be visualized as consisting of irregular swirls of motion called eddies.
- Turbulence consists of many different size eddies superimposed on each other.
- The relative strengths of these different scale eddies define the turbulence spectrum.
- PBL turbulence is generated by thermals, frictional drag, and obstacles
- The largest eddies scale to the depth of the PBL, that is 100 to 3000 m in diameter.

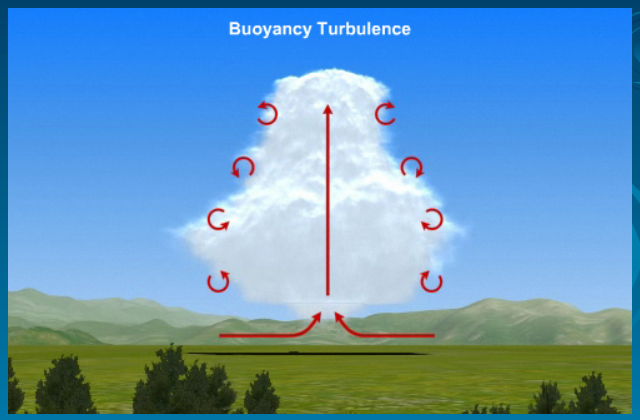


# Turbulent transport

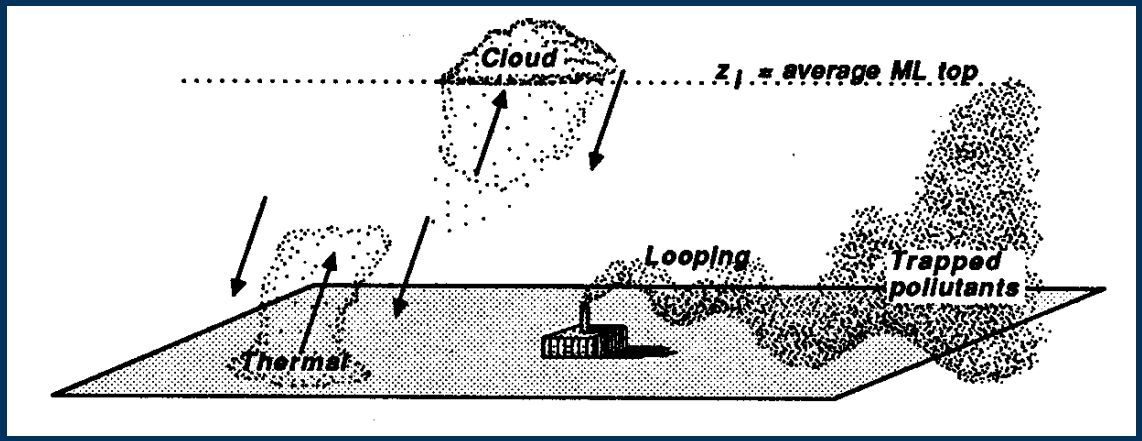
- 3 kinds of turbulence can act to disperse pollutants
  - Mechanical turbulence
  - Turbulence caused by wind shear
  - Turbulence caused by buoyancy due to heating



# Dispersion in the convective BL

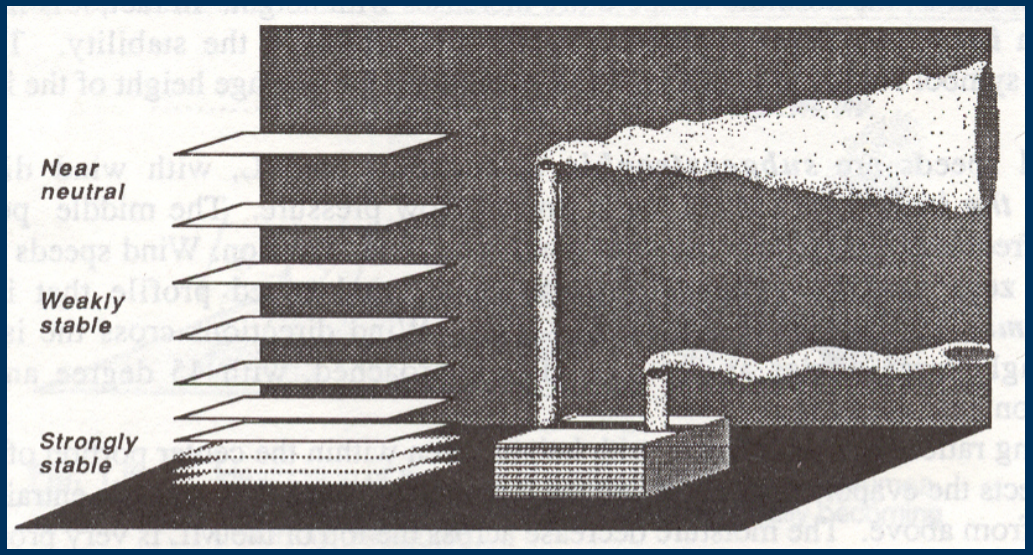







- The ML is characterized by intense mixing in an unstable situation where thermals of warm air rise from the ground
- The ML reaches its max depth in late afternoon and grows by entraining or mixing down into it.
- Pollutants exhibit a characteristic **looping** behavior

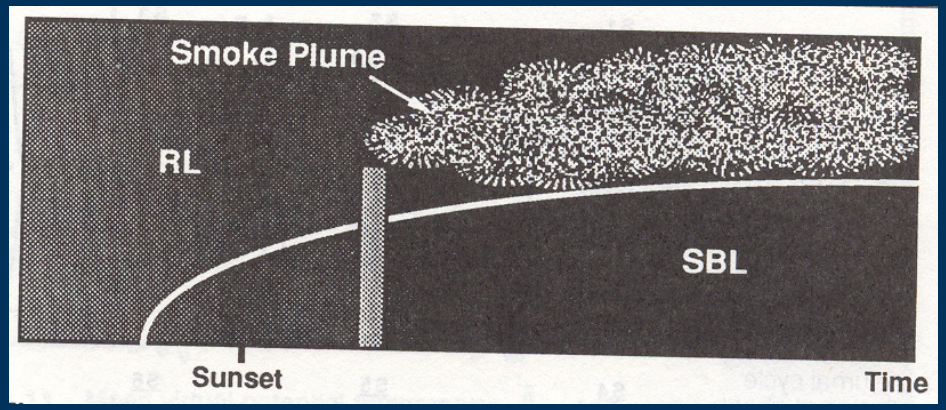
# Dispersion in the nocturnal BL






- Smoke emissions into the stable SL fan out (**fanning**) in the horizontal with little vertical dispersion other than wavelike oscillations
- Smoke emissions into the neutral RL spread with an almost equal rate in the vertical and horizontal, cone like shape (**conning**)

# Dispersion in the transitional zones

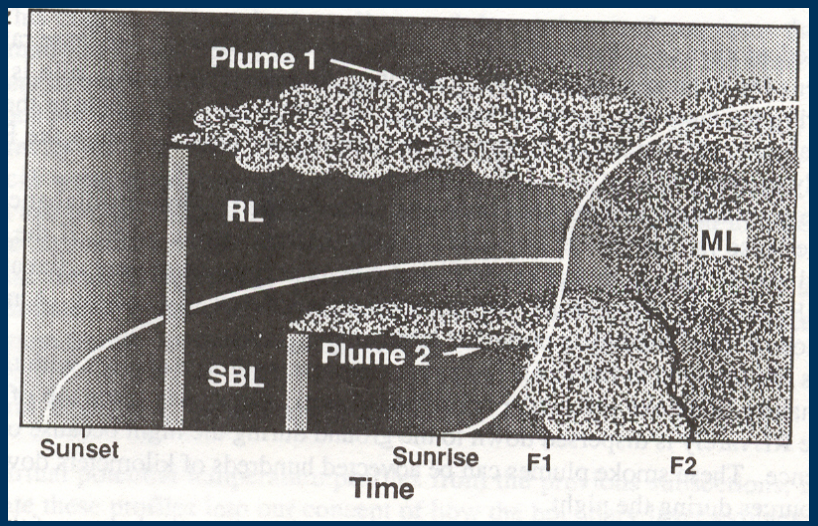






- Smoke plumes in the RL may disperse to the point where the bottom of the plume hits top of the SBL. The strong stability reduces downward mixing, (**lofting**)

# Dispersion in the transitional zones

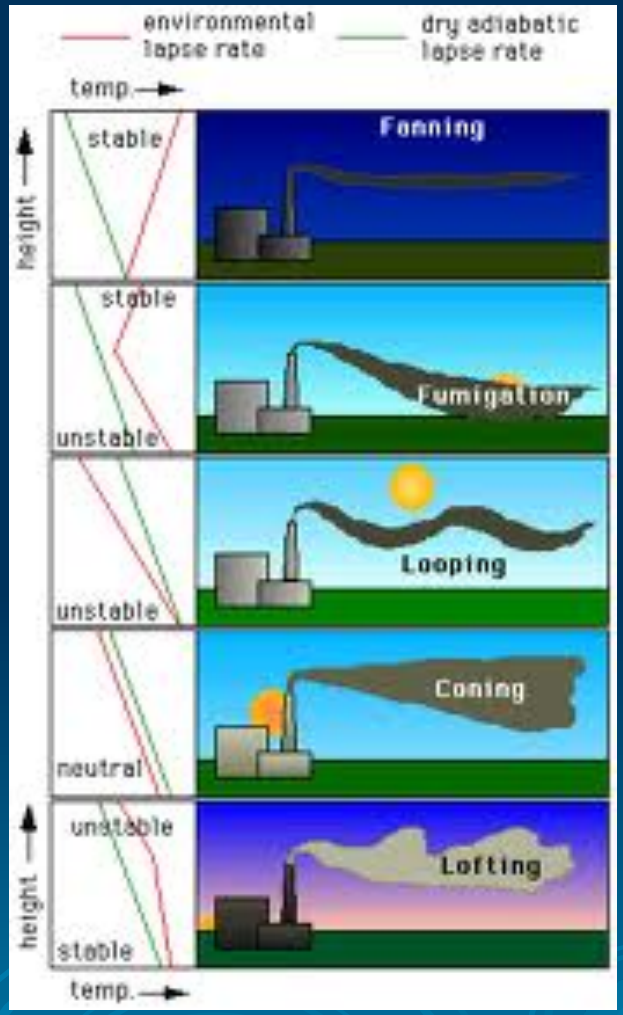






- After sunrise a new ML begins to grow, eventually reaching the height of the elevated plume from the previous night (**fumigation**)

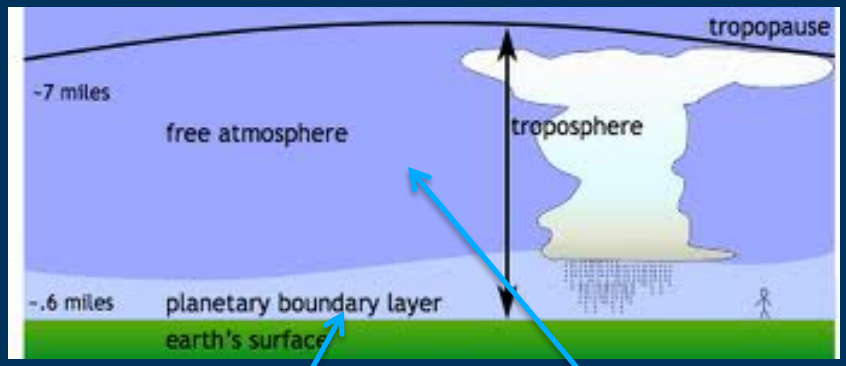
# Stability & Dispersion



# Significance of the boundary layer

- People spend most of their lives in the PBL
- Dew, frost and max min temperature forecasts are BL forecast
- Pollution is trapped in the BL
- Fog occurs within the BL
- Virtually most of the atmospheric moisture is in the BL
- Thunderstorm and hurricane evolution are tied to the inflow of moist BL air
- SL is the most important momentum sink in the atm.
- About 50% of the atmosphere's kinetic energy is dissipated in the BL
- About 90% of the net radiation absorbed by oceans causes evaporation. The latent heat stored in water vapor accounts for 80% of the fuel that drives atmospheric motions.
- Crops are grown in the BL.  Pollen distributed by BL circulations

# PBL vs. Free Atmosphere




| Property | Boundary Layer | Free Atmosphere |
|---|---|---|
| Turbulence | • Almost continuously turbulent over its whole depth. | • Turbulence in convective clouds, and sporadic CAT in thin layers of large horizontal extent. |
| Friction | • Strong drag against the earth's surface. Large energy dissipation. | • Small viscous dissipation. |
| Dispersion | • Rapid turbulent mixing in the vertical and horizontal. | • Small molecular diffusion. Often rapid horizontal transport by mean wind. |
| Winds | • Near logarithmic wind speed profile in the surface layer. Subgeostrophic, cross-isobaric flow common. | • Winds nearly geostrophic. |
| Vertical Transport | • Turbulence dominates. | • Mean wind and cumulus-scale dominate |
| Thickness | • Varies between 100 m to 3 km in time and space. Diurnal oscillations over land. | • Less variable. 8-18 km. Slow time variations. |