AOSC400-2015
October 15, Lecture # 12

Back to Beer Law

o Absorption by ozone

o Absorption by water vapor

o Solving Test Problems

In Lecture # 9 we have discussed how to account for molecular (Rayleigh) Scattering in the Beer's equation:

Other information one can derive from the solar direct beam

Solar direct beam:

$$I = \int\limits_{0}^{\infty} I_{o\lambda} \exp\left(-\tau_{e\lambda} \sec\theta\right) d\lambda$$

$\sec\theta \approx m_r$ (relative optical mass)

$\tau_{e\lambda}$ = sum of extinctions due to scatter and absorption

$$I = \int\limits^{\infty} I_{o\lambda} \exp\left[-\left(\tau_{R\lambda} + \tau_{oz\lambda} + \tau_{wv\lambda} + \tau_{D\lambda}\right)m_r\right] d\lambda$$

For the whole atmosphere
the vertical optical depth $\tau_{R\lambda}$, is given by:

$$\tau_{R\lambda} = \int_0^\infty \kappa_{R\lambda}\rho \, dz = \int_0^\infty \beta_{R\lambda} \, dz$$

where
$\kappa_{R\lambda}$ = Rayleigh mass scattering coefficient

$\beta_{R\lambda}$ = volume scattering coefficient

$$\kappa_{R\lambda}\rho = \beta_{R\lambda}$$

To a good approximation:

$$\tau_{R\lambda} = 0.00888 \, \lambda^{-4.05}$$

Table 6.1

m_r	$\bar{\tau}_R(m_r)$	I (mW cm^{-2})
0.5	0.105	128.6
1.0	0.099	122.8
1.5	0.094	117.7
2.0	0.089	113.5
3.0	0.082	106.0
4.0	0.076	100.0
6.0	0.067	90.7
8.0	0.060	83.9
10.0	0.055	78.2

Rayleigh scatter "mean optical depth" and corresponding direct beam irradiance as a function of relative air mass

The two remaining issues are ozone and water vapor. Once we know how to accont for these two it s possible to learn on the effect of aerosols on the extinction of the solar beam.
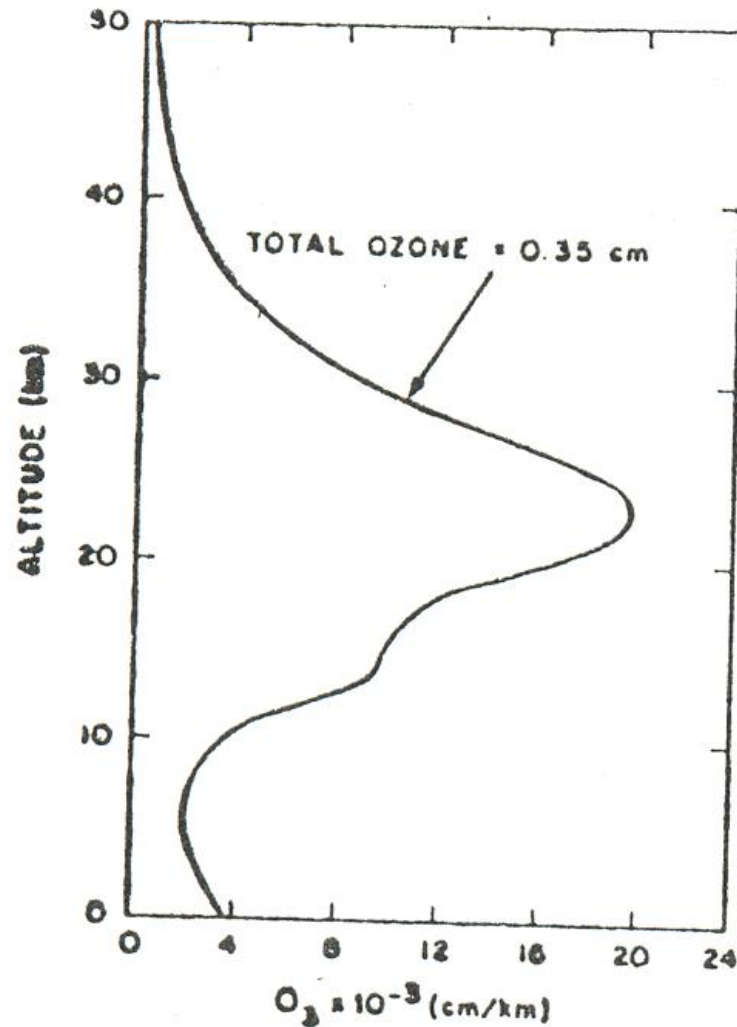
The ozone in the stratosphere filters about 99% UV from the sun. Figure shows the vertical distribution of ozone.

Total ozone is defined as: All the ozone in a column of air condensed at standard temperature and pressure (NTP/STP). It has a thickness of about 3.5 cm.

Variation of ozone concentration with altitude. This figure represents average conditions at mid-altitudes.

Ozone absorption in the visible and UV

Ozone has *2 absorption bands*, one in the visible region (*Chapuis band)* and the other in the UV region (*Hartley-Huggins).*

Next Figure shows the percent of total solar flux absorbed as a function of ozone amount in each of these bands.

Because the ozone concentration in the atmosphere is low (total ozone ~ 3.5cm), therefore, the *UV region* is used in instruments to measure the amount of ozone in the atmosphere. In the UV region, the sensitivity is much higher.
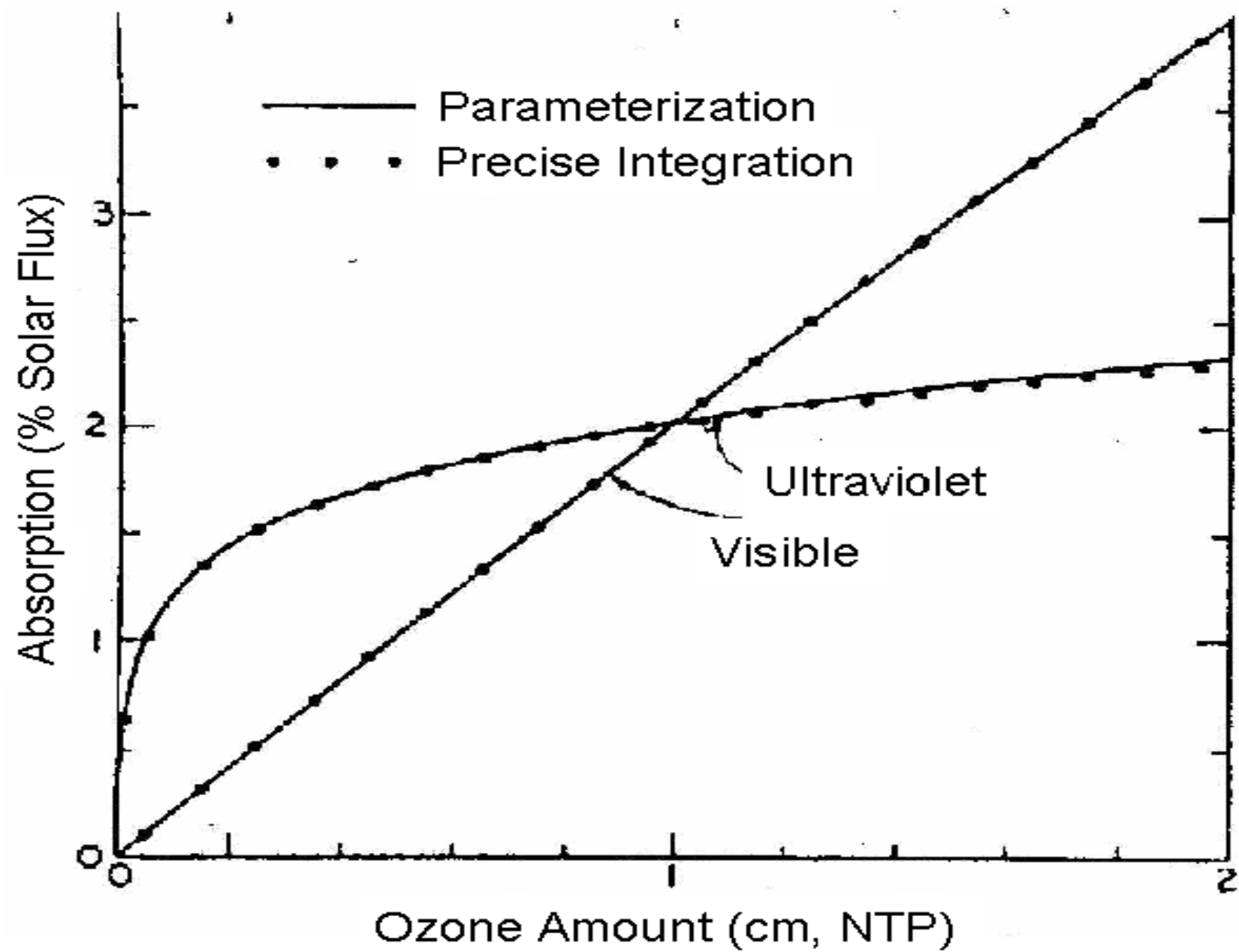
Percent of total solar flux absorbed as a function of ozone absorption coefficients of Howard et al. (1961) . The dotted curves are the results of integrations over wavelength using the wavelengths at which Howard et al. tabulate the absorption coefficient. The parameterization refers to equations from Lacis and Hansen (1974).

Hartley-Huggins ozone absorption band

Hartley bands are the strongest ozone bands in the solar spectrum region due to electronic transitions, and cover the region from 200~300 nm and are centered at 255.3nm.

The solar flux absorption in these bands takes place primarily in the upper stratosphere and in the mesosphere. Huggins bands are weak absorption bands and reside between 300 and 360 nm. The weaker absorption bands in the *visible* and near-IR regions **(Chappuis bands)** are in the spectral intervals from about 440 nm to 1180 nm.

The solid curves of the figure are best-fit relations for absorptions (referred to the complete solar spectrum) as a function of ozone path x in centimeters:

$$a_{oz}^{vis}(x) = \frac{0.02118x}{1 + 0.042x + 0.000323x^2} \quad (1)$$

and:

$$a_{oz}^{uv}(x) = \frac{1.082x}{(1 + 138.6x)^{0.805}} + \frac{0.0658x}{1 + (103.6x)^3} \quad (2)$$

Sum of eqs. 1 and 2

The total absorptance is the simple

What is a Dobson Unit?

The Dobson Unit is the most common unit for measuring ozone concentration. One Dobson Unit is the number of molecules of ozone required to create a layer of pure ozone 0.01 mm at a temperature of 0^0 C and a pressure of 1 atmos. A column of air with an ozone concentration of 1 Dobson Unit would contain about 2.69x1016 ozone molecules for every square centimeter of area at the base of the column. Over the Earth's surface, the ozone layer's average thickness is about 300 Dobson Units or a layer that is 3 millimeters thick.

December 31, 2006
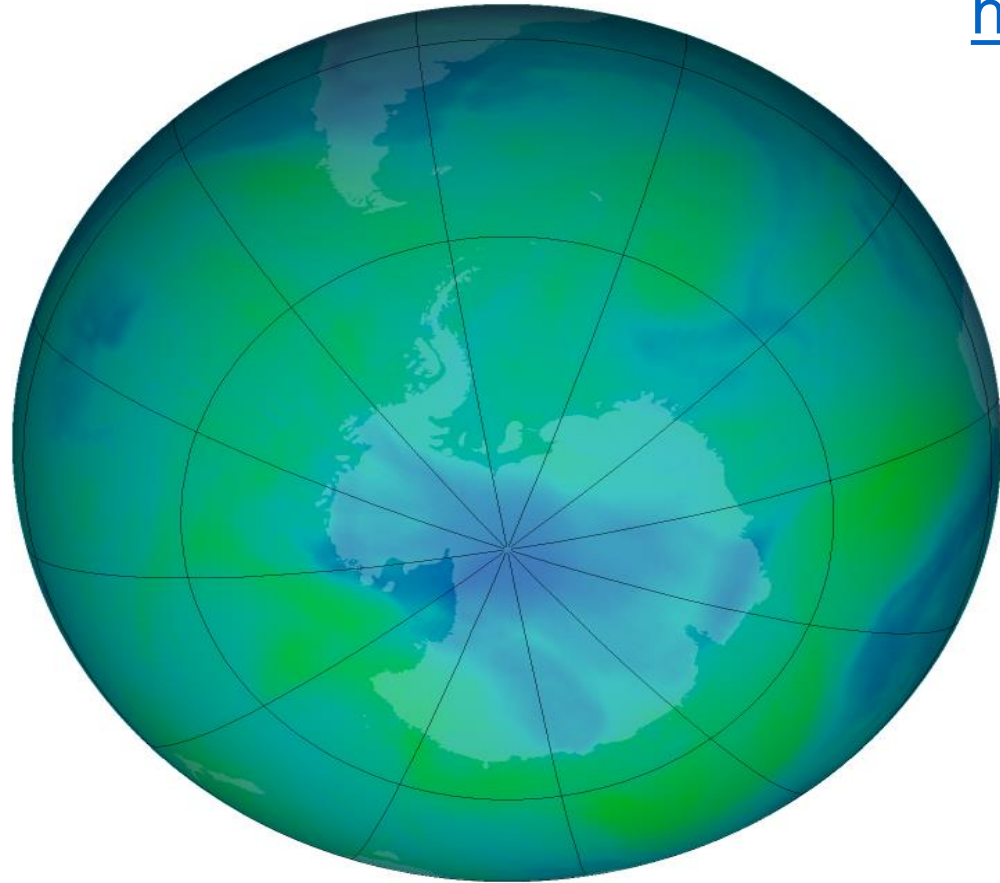
Gives
latest status of the ozone layer
over the South Pole.

Satellite instruments that
monitor the ozone layer:

OMI
TOMS
GOME
NOAA SBUV/2
MLS
Balloon Sondes

Total Ozone (Dobson Units)

110   220   330   440   550
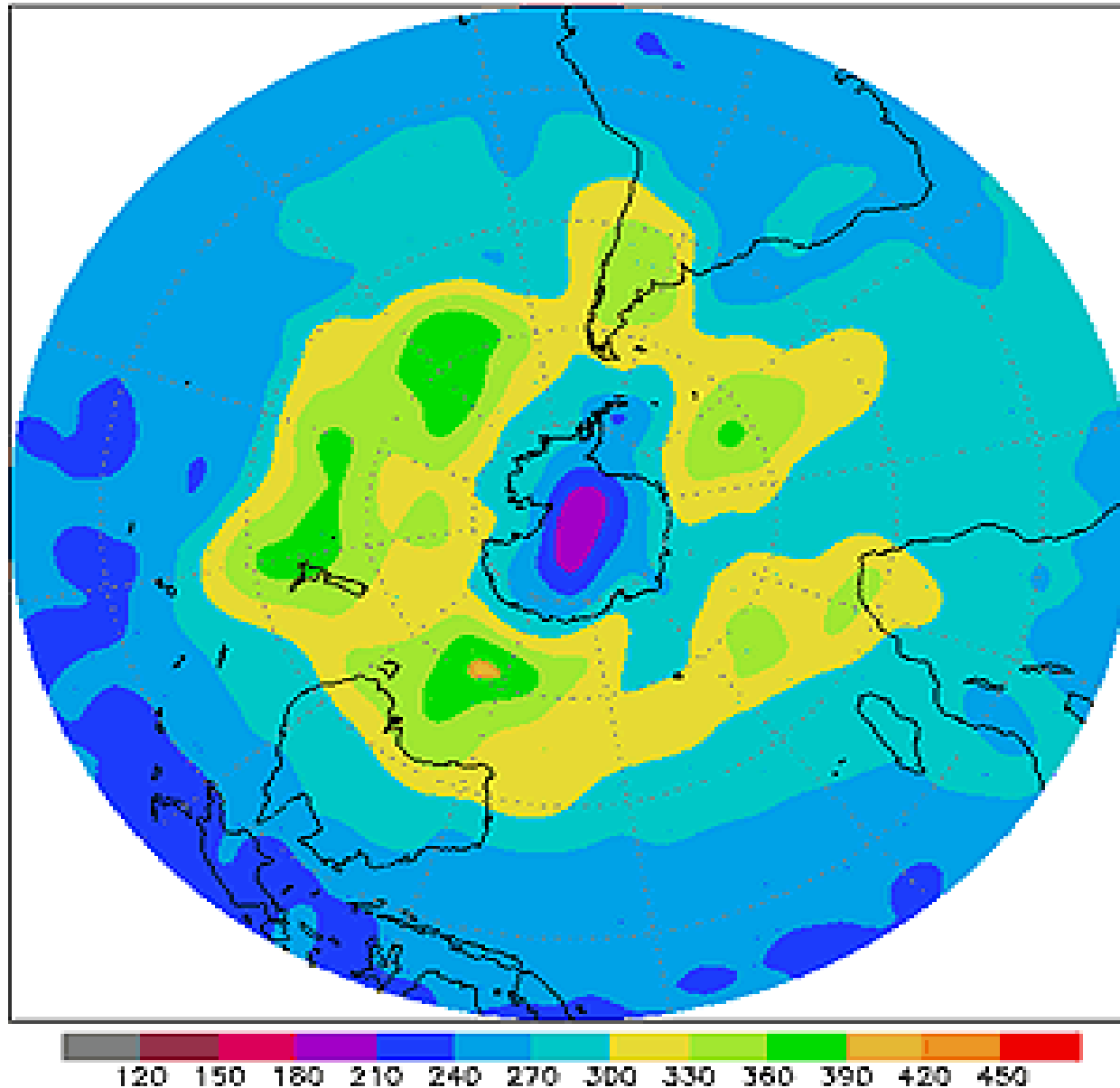
What is the Ozone Hole?

The ozone hole is a region of exceptionally depleted ozone in the stratosphere over the Antarctic that happens at the beginning of Southern Hemisphere Spring (August–October). It results in the destruction of up to 70% of the ozone normally found over Antarctica.

The average concentration of ozone in the atmosphere is about 300 Dobson Units; any area where the concentration drops below 220 Dobson Units is considered part of the ozone hole.

TOVS Total Ozone Analysis (Dobson Units)
Climate Prediction Center/NCEP/NWS/NOAA
08/05/03

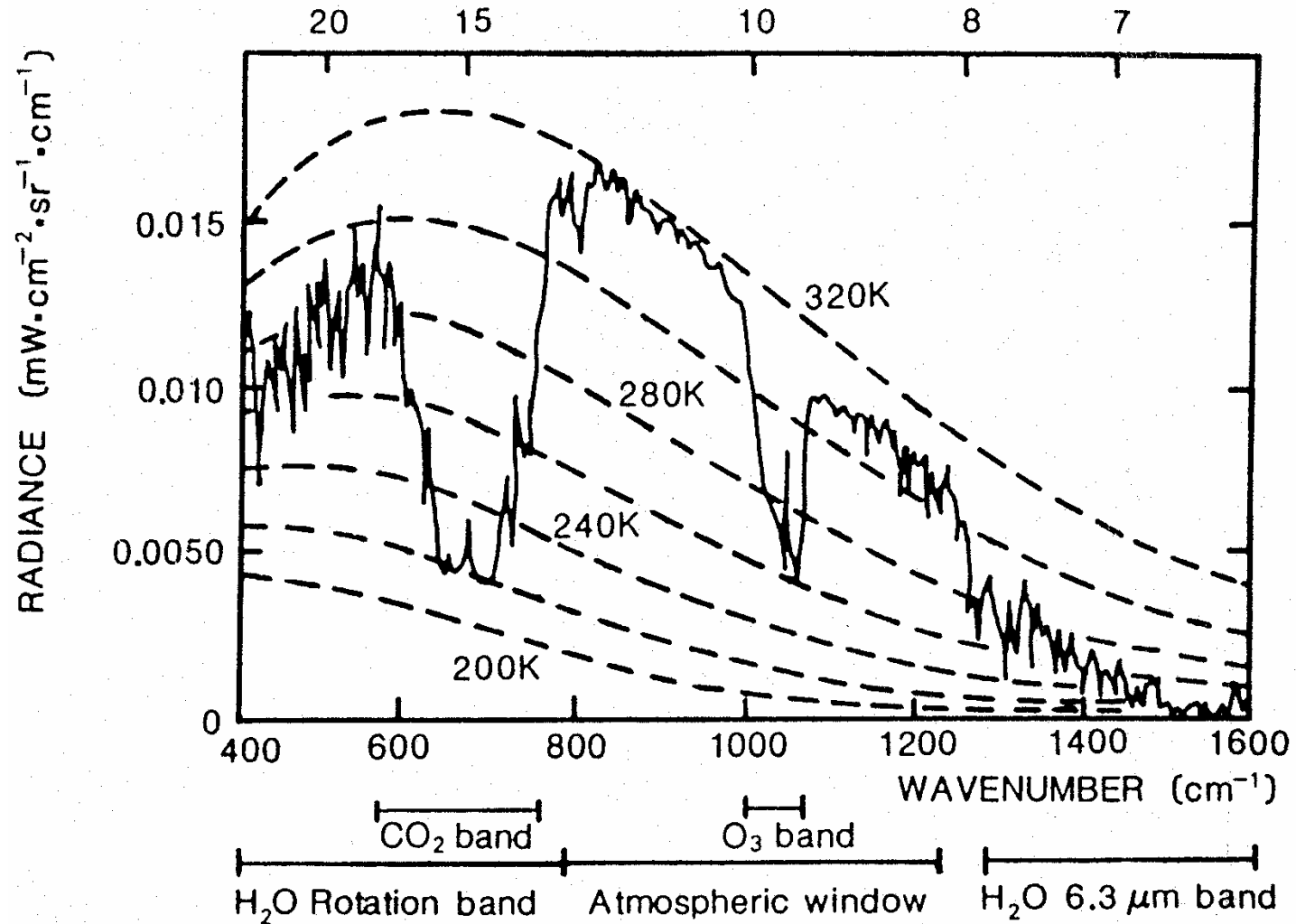120 150 180 210 240 270 300 330 360 390 420 450

The ozone hole is defined as the area having less than 220 Dobson units of ozone in the overhead column between ground and space.

Antarctic ozone minimum (60–90 S)

Absorption by water vapor

In the visible, we use the unit μm for wavelength; in IR, we use wave number; and in microwave-GH.

Absorption by water vapor

Absorption by major water vapor bands has been measured at low spectral resolution by Howard et al., (1956). Yamamoto (1962) weighted these absorptivites with the solar flux and summed them, including estimates for weak absorption bands near 0.7 and 0.8 μm which were not measured by Howard et al., to obtain the total absorption as a function of water vapor amount y (centimeters of precipitable water vapor). The formula:

$$A_{wv}(y) = \frac{2.9y}{(1 + 145.5y)^{0.635} + 5.925y} \quad (1)$$

fits Yamamoto's absorption curve within < 1 % for $10^{-2} \leq y \leq 10$ cm.

The water vapor absorptivity given by (1) is compared in Fig. 1 with the absorptivities of Fowle (1956) and Korb et al. (1956). The formula based on Fowle's old laboratory data ,

$$A_{wv}(y) = 0.0946y^{0.303} \qquad\qquad (2)$$

includes a modification of ~ 10% introducing by Manabe and Moler (1961) to account for the bands at 0.7 and 0.8 μm; weak bands contribute significant absorption because of the large solar flux in that region.

The formula of Korb et al.:

$$\log_{10}[2A_{wv}(y)] = -0.74 + 0.347\log_{10}y \qquad (3)$$

$$-0.056\log_{10}^{2}y - 0.006\log_{10}^{3}y$$

uses the Curtis-Godson approximation and is also based on Howard et al. absorption data, but it does not include the weak near-infrared bands at 0.7 and 0.8 μm. While the three curves in Fig. 1 are qualitatively similar, their differences are significant, particularly for small water vapor amounts. Moreover, the

uncertainty in their absolute value is as great as the differences among the three curves.

The absorptivities (1) – (3) apply for the standard pressure and temperature (P_o = 1013 mb and T_o = 273 K). We make a common approximate correction for the pressure and temperature dependence of the absorption by using an effective water vapor amount,

$$y^{eff} = y(P/P_o)^n(T_o/T)^{1/2} \qquad (4)$$

There is little theoretical justification for using (4) for the entire spectrum of water vapor bands (Goody, 1964); but it id probably better than applying no pressure and temperature correction at all.
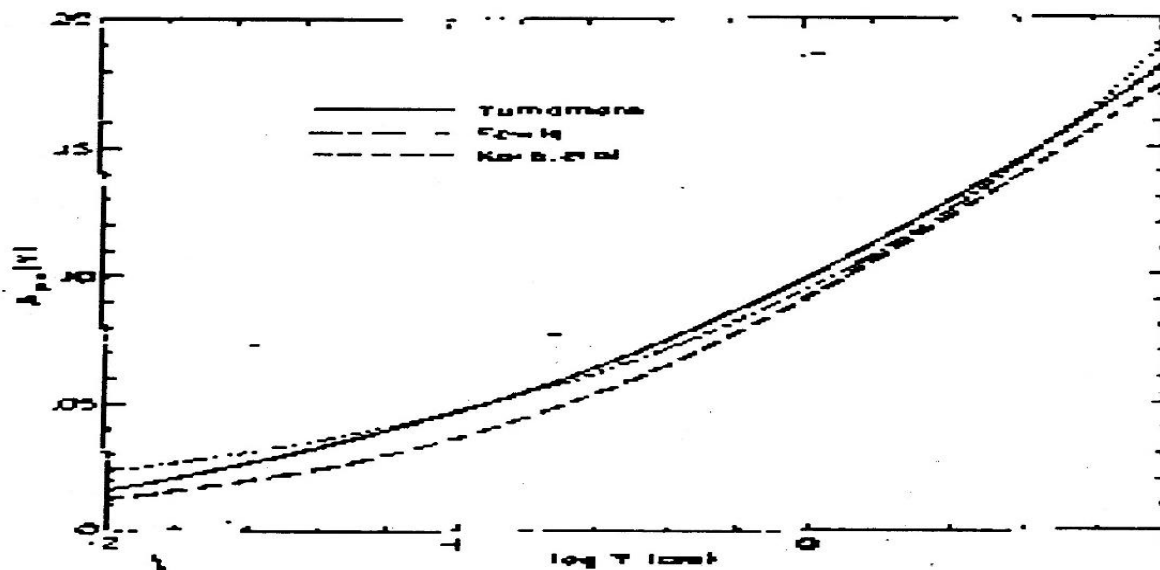

Fig. 1 Absorptivity vs. water vapor amount in precipitable centimeters where aborptivity = 1 - transmission, and refers to the entire solar spectrum. The three curves are given by (1) - (3) and refers to standard pressure ad temperature.
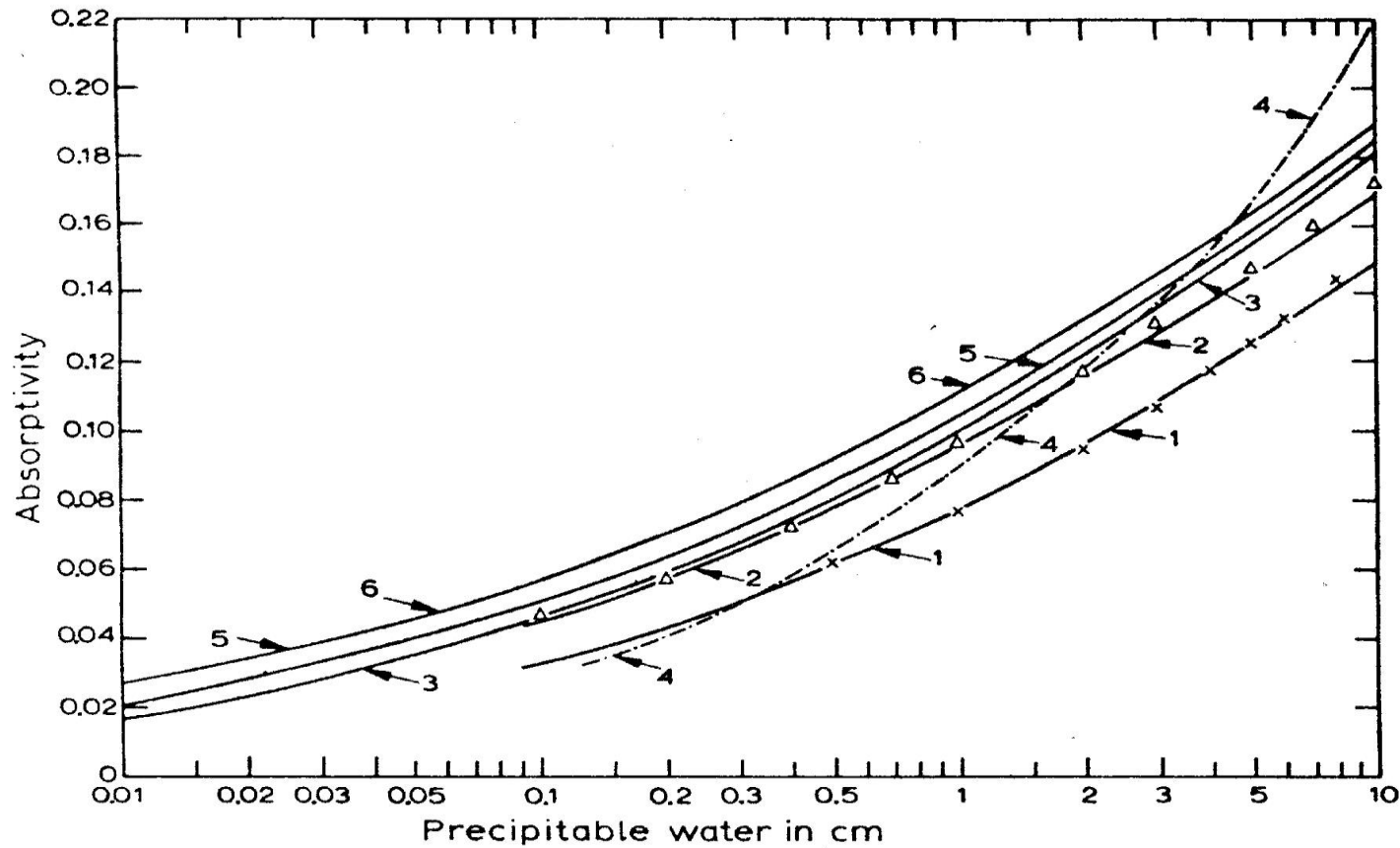
Fig. 5.5. Absorptances of the near-infrared bands. Curve *1* = absorptance summed over the 0.72-, 0.8-, 0.94-, 1.1-, 1.38-, 1.87-μm H_2O bands ($\times$ = absorptances estimated by McDonald (1960) over the same bands). Curve *2* = absorptances over the 0.94-, 1.1-, 1.38-, 1.87-, 2.7-, 3.2- and 6.3-μm H_2O bands ($\triangle$ = absorptances estimated by Möller (1957) over the same bands). Curve *3* = absorptances over all the H_2O bands considered. Curve *4* = absorptances estimated by Houghton (1954). Curve *5* = absorptances over the H_2O and CO_2 bands. Curve *6* = absorptances over the H_2O, CO_2 and O_2 bands. (From Yamamoto, 1962.)

Assuming 3 out of the 4 terms responsible for extinction , namely:

$$\left(\tau_{R\lambda} + \tau_{oz\lambda} + \tau_{wv\lambda} + \tau_{D\lambda} \right)$$

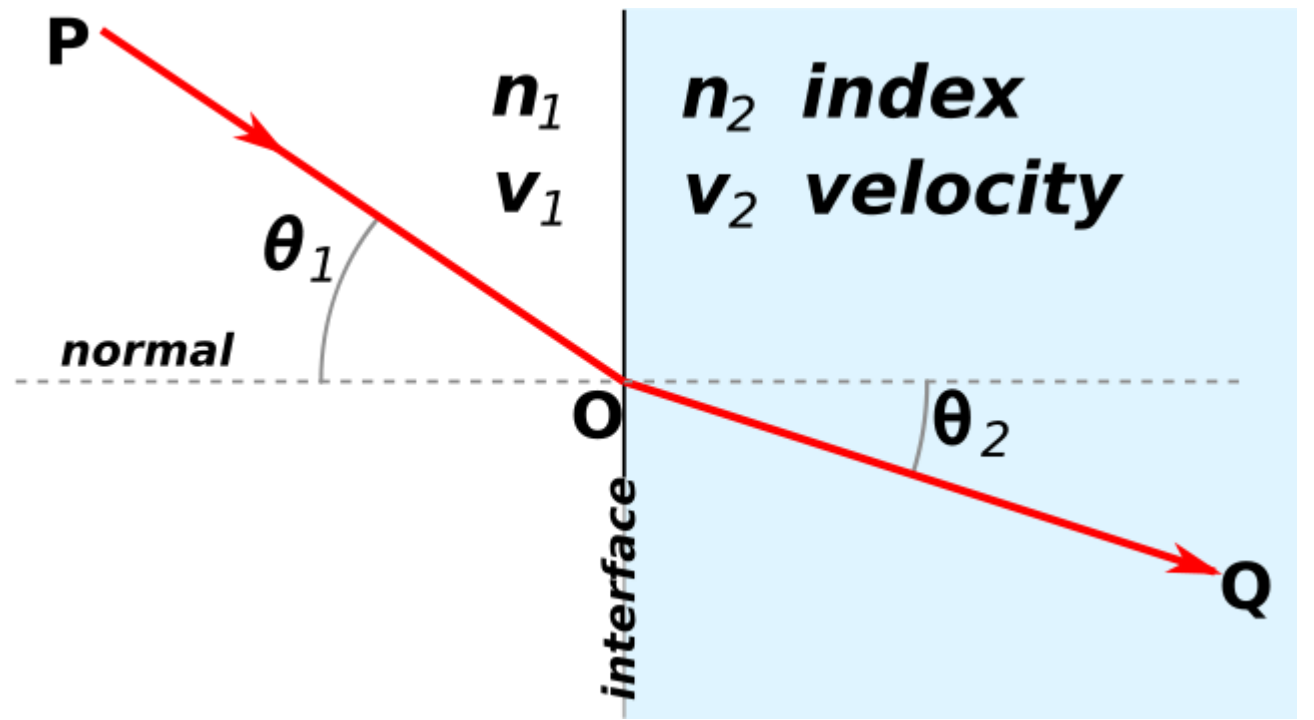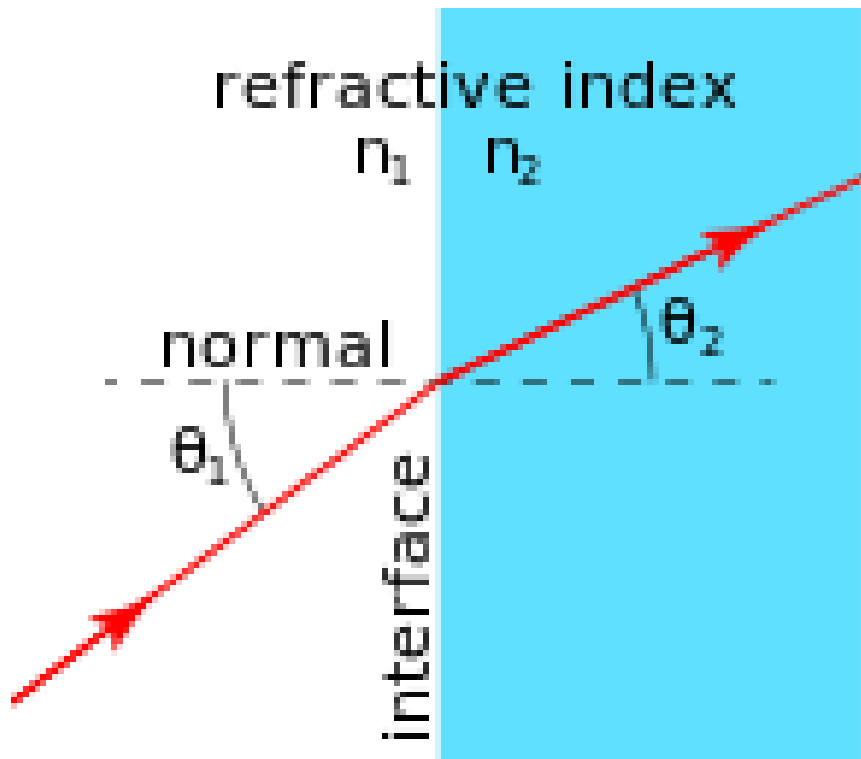are known, the 4ᵗʰ can be estimated.

where:

$\tau_{R\lambda}$ is due to Rayleigh scattering

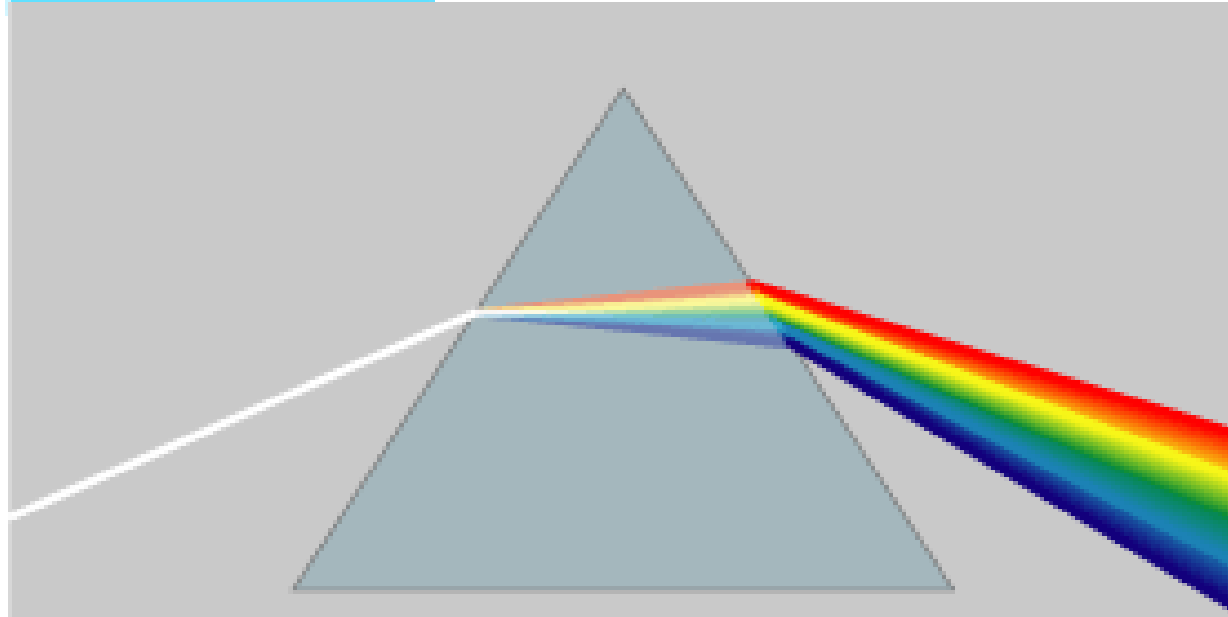$\tau_{oz\lambda}$ is due to ozone absorption

$\tau_{wv\lambda}$ is due to water vapor absorption

$\tau_{D\lambda}$ is due to aerosol extinction

Review of selected Test Questions:

refractive index

n_1 n_2

normal

θ_2

interface

θ_1

P

n_1 n_2 *index*

v_1 v_2 *velocity*

θ_1

normal

O

interface

θ_2

Q

Reminder of what discussed in class:

Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2.$$

Problem # 9:

Calculate the angle of refraction of the ray in   figure provided given:

$\vartheta_1 = 50^0$

$N_{water} = 1.33$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2.$$

- $\vartheta_1 = 50^0$
- $n_{water} = 1.33$

Assume n_1 air is about 1 and plug in above equation to solve for ϑ_1

Problem # 6 : Compute the air mass for a zenith angle of 30^0.
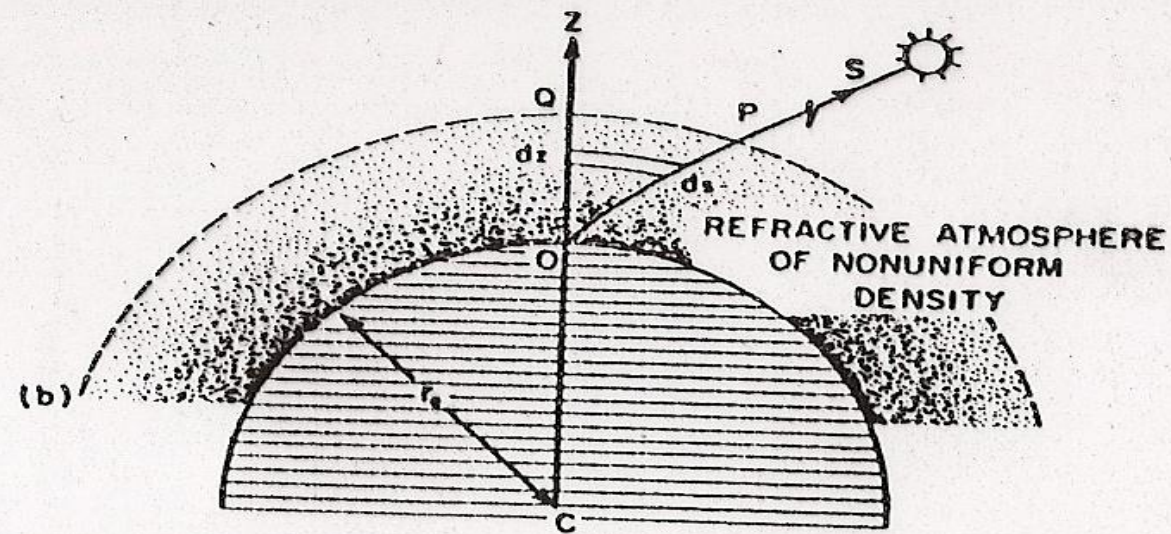As was given in class, in the figure use eq. (5.6.4).

Figure 5.6.1   The trajectory of a solar ray through the earth's atmosphere. (a) Nonrefractive plane parallel atmosphere of uniform density. (b) Refractive spherical atmosphere of variable density.

Ignoring the earth's curvature and assuming that the atmosphere is nonrefractive and completely homogeneous (Fig. 5.6.1a), it can be seen that the relative optical mass applied to all the atmospheric constituents is

$$m_r' = \sec \theta_z.$$

(5.6.4)

Problem # 8:

Use:

Solar time = standard time + E + 4 (L_{st} – L_{loc})

Solar time = 10:00+ (-3.14)+4(75^0-77^0)

Solar time = 10:00-3.14-8=9:49