sea level pressure p_0 of 1.01×10^5 Pa, a molar fraction for oxygen of 21%, a mean molecular mass $\overline{m}$ for air of 29 kg/kmole, gravitational acceleration $g = 9.81$ m/s^2, and Avogadro's constant $N_A = 6.02 \times 10^{26}$ kmole^{-1}, compute (a) the mass per unit area of the atmospheric column assuming hydrostatic balance, (b) the number of oxygen molecules per unit area in the column, and (c) the optical thickness and vertical transmittance due to molecular oxygen at 0.24 μm.

Throughout most of the visible band (0.4 μm$<\lambda<$0.7 μm), the atmosphere is quite transparent, apart from a few weak and narrow absorption bands due to oxygen or ozone.

In the near IR band (0.7 μm$<\lambda<$4 μm) things start to get more interesting. Over this relatively narrow range of wavelength, the atmosphere swings several times between being almost perfectly transparent to being almost perfectly opaque. Most of the absorption is due to water vapor; however there are also important contributions from CO_2, CH_4, and N_2O.

As already mentioned, water vapor is a highly variable component of the atmosphere. The plot appearing in Fig. 7.6 was derived for the typical atmospheric conditions of a station in the middle latitudes during summertime. In a colder, drier environment, the total amount of water vapor present in the column will be drastically smaller, so that the atmosphere may be substantially more transparent in some spectral bands than indicated in this plot. In a moist tropical environment, of course, the reverse is true.

Through the thermal IR band (4 μm$<\lambda<$50 μm) there are broad bands of near-total absorption due to CO_2 (near 4 μm), water vapor (from 5–8 μm), ozone (near 9.6 μm), and again CO_2 ($\lambda>$13 μm). However, there is also a wide band within which the atmosphere is rather transparent from 8–13 μm, terminated only by the ozone band and increasing absorption by water vapor beyond 12 μm.

The far IR band (50 μm$<\lambda<$1 mm) is not terribly important in the calculation of radiative fluxes in the atmosphere, nor is it used much for remote sensing. For both reasons, it is hard to find plots of atmospheric transmission in this band. As a rule of thumb, however, it can be said that water vapor is the dominant absorber throughout most of this band.

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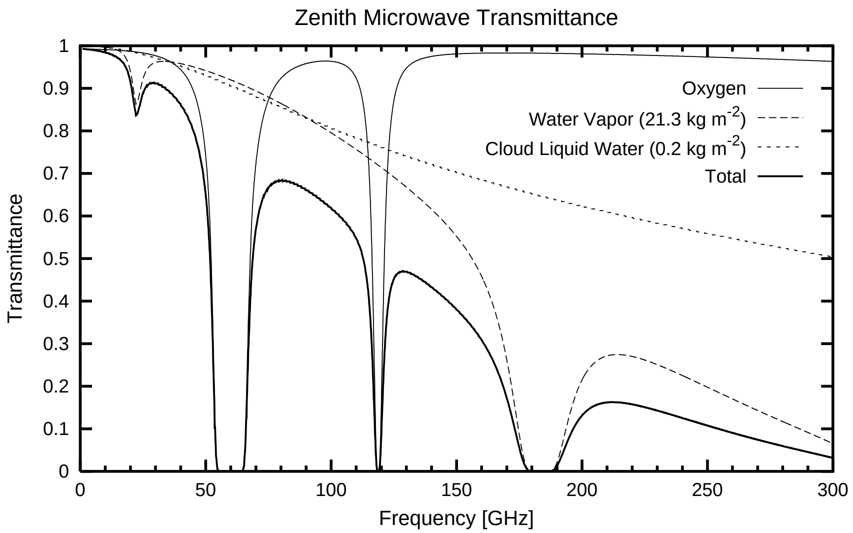

Fig. 7.7: Zenith atmospheric opacity in the microwave band under typical midlatitude conditions, including the effects of a moderately thick nonprecipitating cloud layer.

The microwave band is of interest primarily for remote sensing, mainly below 300 GHz. Fig. 7.7 depicts the principal features of the absorption spectrum in this band. There is a strong absorption band due to oxygen centered on 60 GHz; this band plays an important role in satellite retrievals of atmospheric temperature. A second, somewhat narrower oxygen band is also present at 118 GHz. There is a very strong water vapor band centered on 183.3 GHz; this band is used in microwave retrievals of atmospheric humidity profiles.

All three of the microwave absorption bands just mentioned are strong enough to render the atmosphere completely opaque at the centers of the bands. A difference between the oxygen bands and the water vapor bands, however, is that the latter is only present to the degree that water vapor is present. In an extremely dry arctic atmosphere, the 183.3 GHz band is substantially weaker than shown in Fig. 7.7.

Last but not least, there is a weak water vapor absorption line located near 22 GHz. Despite its weakness (indeed, partly *because* of its weakness), microwave observations made at this frequency have long been crucial for retrieving the total (vertically integrated) water vapor content of the atmosphere.

Apart from the major absorption bands just mentioned, Fig. 7.7 reveals a strong tendency for the atmosphere to become more opaque with increasing frequency, with the standard midlatitude atmosphere becoming nearly opaque by 300 GHz. This tendency is due to the so-called *continuum absorption* by water vapor; that is, absorption that is not concentrated in a few discrete lines or bands. It is partly because of the increasing dominance of water vapor continuum absorption that frequencies higher than 300 GHz are not terribly useful for remote sensing, except perhaps for observing cirrus clouds that lie well above the majority of water vapor in the troposphere.

Throughout every major band just discussed, there exist spectral *windows* for which the cloud-free atmosphere is relatively transparent. For example, the entire visible band is a spectral window, as is the 8–13 μm region in the thermal IR band and the 80–100 GHz and 0–40 GHz regions in the microwave band. If no clouds are present, then a satellite observing upwelling radiation within a window region has a more or less unobstructed view of the earth's surface. Also, radiation emitted by the earth's surface at wavelengths falling within one of the windows in the thermal IR band readily escapes to space, so that these window regions play an important role in surface cooling.

In many spectral windows, the atmosphere is not perfectly transparent but has a moderate component of absorption due to water vapor or some other constituent. Such regions of the spectrum are often referred to as "dirty windows," because radiation originating from the surface remains observable from space but significant corrections for atmospheric absorption and emission must be applied, especially when the atmosphere is humid.

One final important comment concerning the gaseous absorption features we have been discussing: The plots above give a somewhat simplified depiction of the actual dependence of transmittance on wavelength. If you were to "zoom in" on any one of the absorption bands discussed above, you would find that it represents a complex aggregate of many very closely spaced "lines" of absorption. There may be hundreds of such lines in a very narrow wavelength band. In the gaps between individual lines, the at-

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