along the path. To at least first order, these properties are embodied in the volume extinction coefficient β_e and the single scatter albedo $\tilde{\omega}$, both of which are generally functions of position (in three dimensions) and wavelength λ. Recall that if you know β_e and $\tilde{\omega}$, you can easily obtain β_s and β_a, and vice versa, so there is no single "correct" way to describe the radiative properties of the atmosphere. Also, there are times when it is more convenient to work with the mass-normalized or particle-normalized quantities k_e, σ_e, etc., but it is straightforward to convert between these and β_e, etc., if the amount (mass density ρ or particle concentration N) of the relevant constituents is known.

We are now ready to undertake a survey of the observed transmission characteristics of the atmosphere at various wavelengths. For now, we only want to answer the following basic questions:

- At which wavelengths is the cloud-free atmosphere reasonably transparent?
- At which wavelengths is the cloud-free atmosphere strongly absorbing, and which constituents are responsible for the absorption?
- How do the extinction and scattering properties of clouds vary with wavelength?

In later chapters, we will revisit all of the above questions in a much more detailed way.

Absorption by Atmospheric Gases

Except at short visible and UV wavelengths (where scattering by air molecules can be important), the overall transmittance of the cloud-free atmosphere is controlled primarily by absorption due to various constituent gases. Where absorption is strong, the transmittance is small; where absorption is weak or absent, the transmittance is close to 100%. Table 7.1 lists a number of radiatively important constituents and their approximate abundances. Two points are worth highlighting right away:

- Some constituents make up a large fraction of the total mass of the atmosphere. In fact, nitrogen (N_2) and oxygen (O_2) alone

Table 7.1: Key constituents of air in the troposphere and stratosphere.

Constituent	Fraction by volume in (or relative to) dry air	Significant absorption bands	Remarks
N_2	78.1%	—	
O_2	20.9%	UV-C, MW near 60 and 118 GHz, weak bands in VIS and IR	
H_2O	(0–2%)	numerous strong bands throughout IR; also in MW, especially near 183 GHz	highly variable in time and space
Ar and other inert gases	0.936%	—	monoatomic
CO_2	370 ppm	near 2.8, 4.3, and 15 μm	concentration as of 2001; increasing 1.6 ppm per year
CH_4	1.7 ppm	near 3.3 and 7.8 μm	increasing due to human activities
N_2O	0.35 ppm	4.5, 7.8, and 17 μm	
CO	0.07 ppm	4.7 μm (weak)	
O_3	$\sim10^{-8}$	UV-B, 9.6 μm	highly variable concentration; high in stratosphere and in polluted air
$CFCl_3$,CF_2Cl_2, etc.	$\sim10^{-10}$	IR	industrial origin

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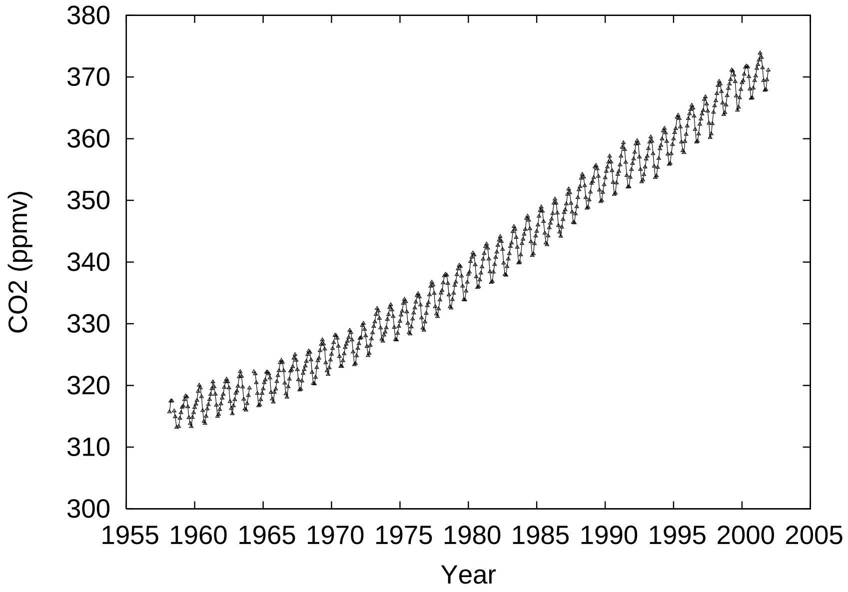

Fig. 7.5: Measurements of atmospheric carbon dioxide concentration at Mauna Loa Observatory, Hawaii. (Source: C.D. Keeling and T.P. Whorf, Scripps Institute of Oceanography, University of California.)

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