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2.5. Transmission of optical radiation in atmosphere

The interaction of emitted optical radiation with atmosphere is a complex process. This subchapter discusses only the essential theories and experimental data needed to explain the influence of the atmosphere on thermal radiation on its way from the source to the detector. Earth's atmosphere is a mixture of many gases. The gaseous contents in atmosphere vary with altitude, time and space. However, the gaseous contents shown in Tab. 2.7 can be considered as typical for clear atmosphere [13]. The major components of the atmosphere are molecules of N_2 and O_2. Next is argon of much less concentration. Other constituents have very low concentration in atmosphere. However, two of them are important as they mostly decide about atmosphere transmittance.

Water vapor have concentration of about 10^{-5} % to about 10^{-2} % of the volume. The concentration of the water vapor depends significantly on altitude, season, geographic location, time of day, meteorological conditions and is subject to large fluctuations.

Carbon dioxide is more uniformly distributed, with concentration of approximately about 3×10^{-2} % of the volume. There is higher concentration of carbon dioxide over industrial centers and vegetation areas than over oceans and deserts.

Tab. 2.7. Composition of atmospheric constituent gases

Constituent gas	Content (% by volume)
N_2	78.084
O_2	20.9476
Ar	0.934
CO_2	3×10^{-2}
H_2O	10^{-5} - 10^{-2}
Ne	$1.81\ 10^{-3}$
He	$5.2\ 10^{-4}$
CH_4	$2\ 10^{-4}$
Kr	$1.14\ 10^{-4}$
H_2	$5\ 10^{-5}$
N_{2O}	$\approx 5\ 10^{-5}$
CO	$\approx 7\ 10^{-6}$
O_3	0 to $7\ 10^{-6}$
NO	0 to $2\ 10^{-6}$

Optical properties of atmosphere

Thermal radiation emitted by objects carries information about radiance distribution on the surfaces of these objects. Atmosphere can significantly distort this information because of four phenomena: absorption, scattering, emission and turbulence.

The first two phenomena cause attenuation of propagating optical radiation; the third one adds additional radiation, and the fourth one causes distortion of the image of the emitting objects.

There are distinguished two kinds of absorption: molecular absorption and aerosol absorption. However, because of several minor components of the atmosphere, the molecular absorption is a much more significant source of attenuation of propagating radiation than the aerosol absorption is.

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Scattering phenomenon causes redistribution of the incident flux into all direction of propagation and diminishes the flux propagation in the original direction. There are distinguished two kinds of atmospheric scattering: molecular (Rayleigh) scattering and aerosol (Mie) scattering. The aerosol scattering affects atmospheric transmittance much more stronger than the molecular scattering does. Generally, the scattering effect diminishes when wavelength of the propagating radiation increases. Therefore, transmittance of haze is much higher in the infrared than in the visible.

It was shown in Section 2.4.2 that the directional spectral emissivity $\varepsilon_{\lambda,\varphi}$ is equal to the directional spectral absorptance $\alpha_{\lambda,\varphi}$. It means that atmospheric absorptance equals its emissivity. As atmospheric absorptance is always higher than null and atmosphere temperature is also always higher than absolute null it means that the atmosphere must emits its own radiation. However, for short-distance conditions during typical non-contact temperature measurements the atmosphere emissivity is usually very low. Temperature of the atmosphere during most measurement is also lower than the temperature of the tested object. Therefore, the phenomenon of atmosphere emission can be treated as negligible in most temperature measurement applications.

Atmospheric turbulence phenomenon is caused by random irregular air movements. It arises when air molecules of slightly different temperatures are mixed by wind and convection. From optical point of view such random irregular air movements means random fluctuation of refractive index of the atmosphere. When optical radiation propagate through atmosphere, the refractive index varies through the medium and that smears the image generated by the optical system. This effect is evident for distances object-system of at least a few hundredth meters and only for thermal cameras of high quality of the image. Therefore, this phenomenon can significantly degrade performance of military thermal or TV cameras. However, non-contact temperature measurements are rarely made at the distances over 50 m and image quality of typical measurement thermal cameras is not very good. Therefore, the influence of atmospheric turbulence on results of temperature measurement with non-contact thermometers can be almost always treated as negligible.

Numerical calculations

Because of large number of parameters the atmospheric transmittance depends on, it is necessary to employ numerical models to predict with a high degree of accuracy the transmittance through atmosphere for a given path, meteorological conditions and wavelength.

It seems, that there are three most popular numerical models that enable calculation of atmospheric transmittance: LOWTRAN, MODTRAN and HITRAN. All three models were developed in the Air Force Geophysics Laboratory (AFGL).

LOWTRAN is a computer code that calculates atmospheric transmittance with low spectral resolution over a wide spectral range. It enables calculation of atmospheric transmittance within spectral range from 0.25 μm to 28.5 μm with a spectral resolution of 0.002 λ that is sufficient for most applications.

MODTRAN is a higher resolution version of LOWTRAN.

HITRAN is actually not a transmission model but a molecular data compilation to be used with line-by-line transmittance codes. Its spectral resolution is about 0.00005 λ that makes it especially suitable for laser transmittance calculations.

All three models are continuously updated as new measurements become available and better understanding of transmission process are reached. Currently, LOWTRAN 7 version is available.

Almost all non-contact thermometers are relatively broadband systems in comparison to spectral resolution offered by the LOWTRAN. Therefore, this model or other low-resolution models are used to calculate and correct the influence of the atmosphere on propagating thermal radiation on its way to non-contact thermometers. It happens also, as for typical short-distance measurements the influence of the atmosphere on temperature measurement is often small, that some manufactures of relatively modern systems do not use any transmittance models to correct effect of attenuation of propagating radiation by the atmosphere. As spectral bands of non-contact thermometers are usually located within so called "atmospheric transmittance windows" this practice is quite justified for a short distance measurements [Fig. 2.9-Fig. 2.11], especially when the thermometer spectral band is located within the 8-14 μm window.

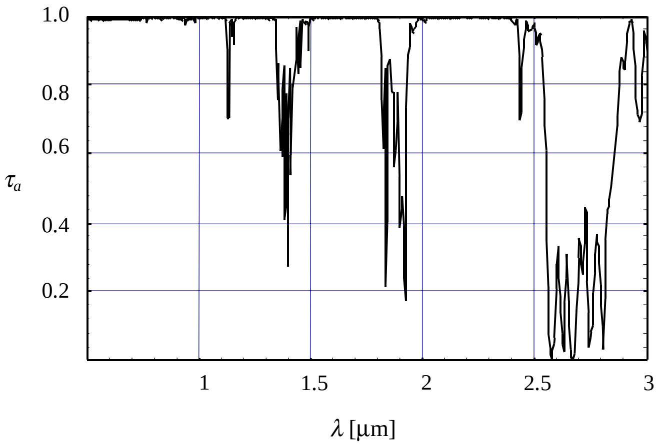

Fig. 2.9. Atmospheric transmittance for 10 m distance in spectral range 1-3 μm

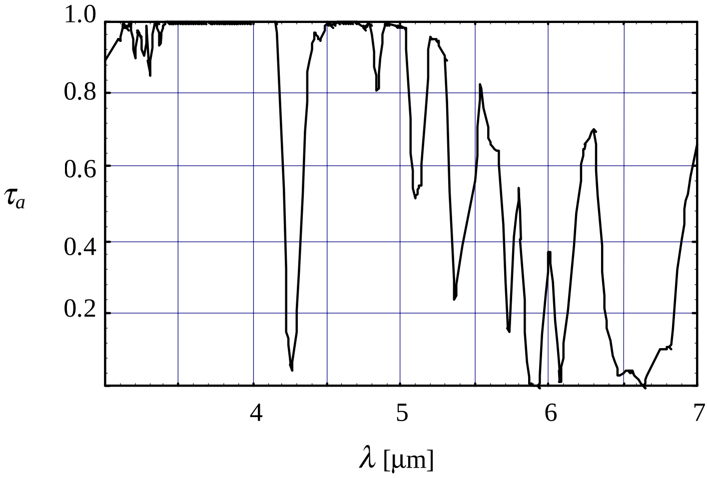

Fig. 2.10. Atmospheric transmittance for 10 m distance in spectral range 3-7 μm

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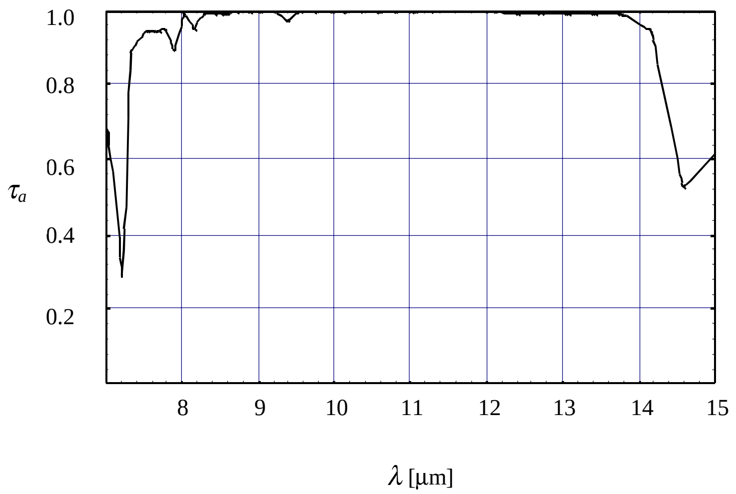

Fig. 2.11. Atmospheric transmittance for 10 m distance in spectral range 7-14 µm