Atmospheric Aerosol
- A Special Topic in Environmental Physics -

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- PART 4 -

1. Sun Photometer Measurements

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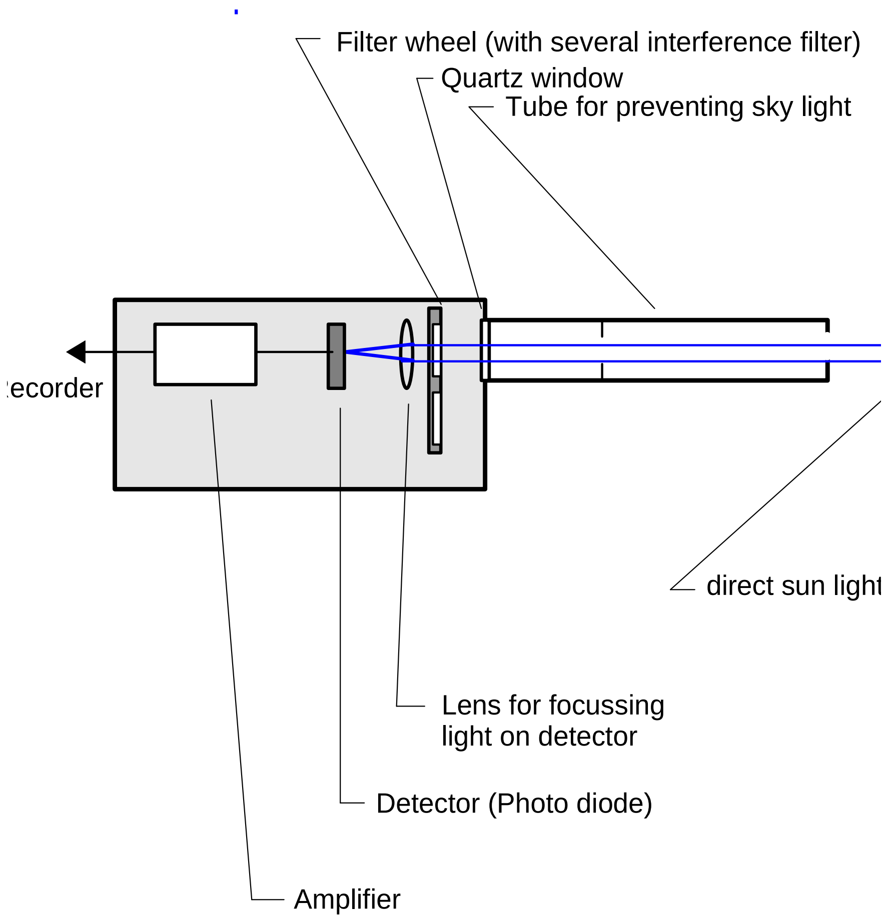
2. Lambert Beer Law and optical parameters

3. Determination of aerosol optical thickness

Sun Photometer

A sun photometer is an optical instrument for the measurement of the spectral direct solar radiation. The spectral resolution depends on the number of channels. The range of wavelength is most between 0.35 - 1.05 μm. Form the measured direct solar radiation at first the total optical thickness of the atmosphere can be determined.
A principle scheme of a sun photometer is shown in the figure below.



A diaphragma tube determines the viewing angle of the instrument, which is slightly larger than the angle of the sun disk (0.5 deg). Most instruments use 1.0 deg.

A quartz window protects the interior of the instrument.

A rotating filter wheel enables the selection of the different wavelength channels.

CIMEL instruments have 8 channels: 0.340, 0.380, 0.440, 0.500, 0.670, 0.870, 0.936, 1.020 μm. Except the channel of 0.936 μm all channels serve the determination of the aerosol optical thickness, because they are out of strong bands of absorbing gases. For 0.500 and 0.670 μm ozone absorption of the Chappius band takes place and has to be corrected.

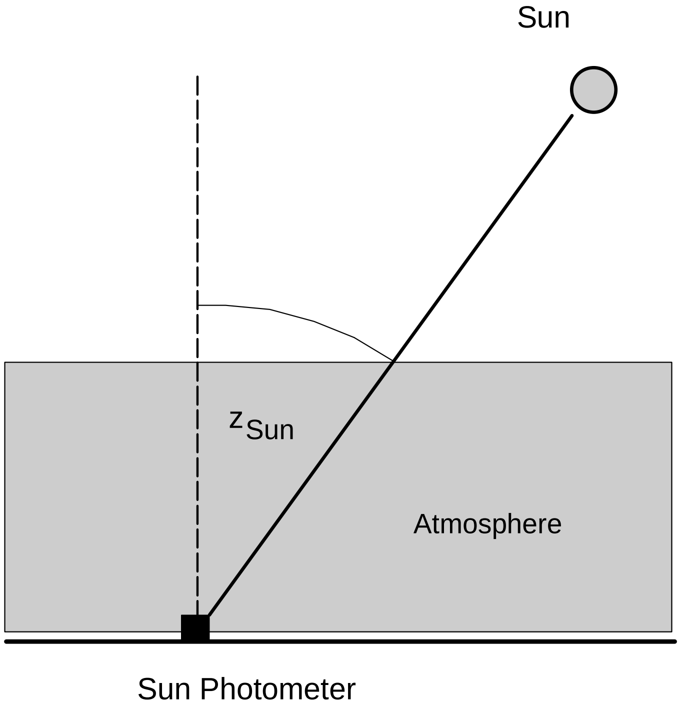
After the rotation filter wheel a lens is focussing the light onto the detector, a photodiode, transforming the light into a photo current. The photo current is proportional to the incoming radiance.

$$i\lambda = f \cdot L\lambda = f \cdot \frac{E}{\Omega_{Tube}}$$

The following amplifier is a current correct amplifier, giving a proportional signal to the incoming radiance.
The signal will be digitized and recorded for further use.

Lambert Beer Law and Optical Parameters

The measurement principle is shown in the figure below:



In a plane parallel atmosphere the Lanbert-Beer law describes for monochromatic light the radiance of the sun after passing the atmosphere:

$$E(\lambda) = E_0(\lambda)e^{-\delta(\lambda)\cdot M(z_{Sun})}$$

E	-	direct solar radiation (flux) at the earth surface
E_0	-	extraterrestrial solar radiation
δ	-	optical thickness (total turbidity of atmosphere on a vertical path through the atmosphere)
M	-	relative optical air mass or air mass factor
z_{Sun}	-	solar zenith distance

A real atmosphere is curved and not plane parallel. The density of atmosphere decreases from bottom to the top of atmosphere. Therefore the light beam self is curved by the refraction. Both effects increase with increasing solar zenith distance. Therefore the air mass factor deviates from $M = 1/cos(z_{Sun})$ for zenith distances > 30 deg.

For a determination of optical thickness the Lambert-Beer law is solved for the δ:

$$\delta(\lambda) = \frac{1}{M} \ln(\frac{E_0(\lambda)}{E(\lambda)} = \frac{1}{M} \ln(\frac{i_0(\lambda)}{i(\lambda)})$$

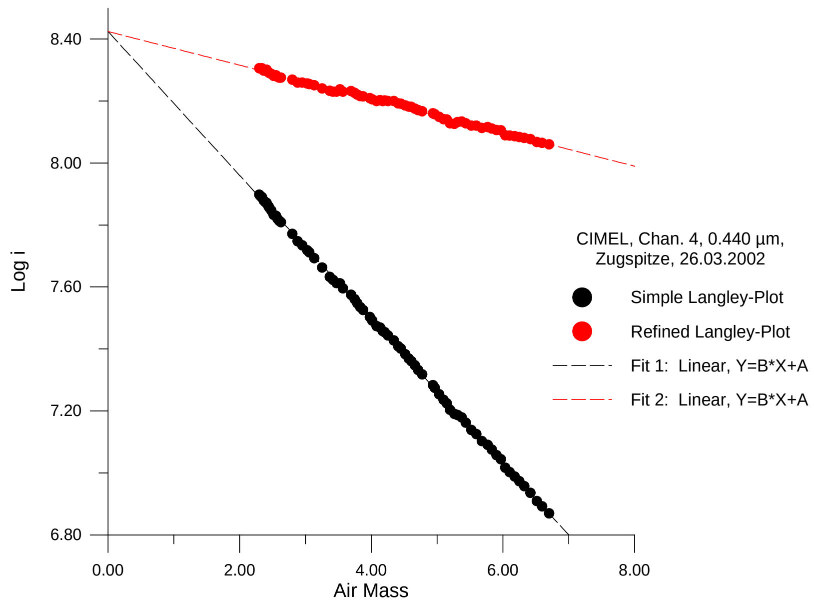
Since $i(\lambda)$ is measured by the instrument, for the determination of an optical thickness $i_0(\lambda)$ and the airmass factor M is required.
$i_0(\lambda)$ will be obtained by the calibration of the instrument by a Langley-plot.
M is a function of z_{Sun}.

Calibration by Langley-Plot

The calibration by the Langley-plot technique makes use of the Lambert-Beer law:

$$\ln i(\lambda) = \ln i_0(\lambda) - \delta(\lambda) \cdot M$$

Using the logarithms of i and i_0 transforms the Lambert-Beer law into a linear equation. If the optical thickness $\delta(\lambda)$ for one channel is constant, the extraterrestrial signal of the instrument can be obtained, if measurements with different air mass factors are performed. Then i_0 is obtained, if i will be extrapolated to the air mass $M = 0$.



The refined Langley-plot is the same, corrected for the Rayleigh scattering, e.g. divided by the transmission for the Rayleigh scattering.

Both curves should meet for $M = 0$ at the same point, at i_0 (or E_0 or if the field of view of the instrument $\Omega_{Instrument}$ is known, L_0).

If i_0 for each channel is known, the optical thickness of the atmosphere can be determined.

Air Mass Factor

The relativ optical air mass or air mass factor is defined as ratio of the slant column optical path to the vertical column optical path.
The relative optical air mass for the US standard atmosphere is parameterized by Kasten, 1989.

$$M(z) = \frac{1}{cosz + a(b - z)^{-c}}$$

The coefficients are:

$$\begin{aligned} \text{a} &= 0.50572 \\ \text{b} &= 6.07995 \\ \text{c} &= 1.6364 \end{aligned}$$

This includes for the US standard atmosphere curvature and refraction of atmosphere for zenith distances 0 ... 85 deg. For larger zenith distances more accurate calculations are required. However for the most sun photometer applications this relationship is sufficient.
For zenith distances smaller than 30 deg the simple relation $M = 1/cosz$ can be used.

Aerosol Optical Thickness

For the determination of the aerosol optical thickness, the optical thickness of atmosphere must be corrected for gaseous absorption and Rayleigh scattering.

$$\delta_{Aer}(\lambda) = \delta(\lambda) - \delta_{Gas}(\lambda) - \delta_{Ray}(\lambda)$$

δ_{Aer}	-	aerosol optical thickness
δ	-	optical thickness of atmosphere, measured by the instrument
δ_{Ray}	-	optical thickness of Rayleigh scattering
δ_{Gas}	-	optical thickness of gaseous absorbers

Mostly channels for a sun photometer are selected, that they are outside of bands of gaseous absorbers. Only ozone absorption must be considered.
Optical thickness of Rayleigh scattering can be determined by the following parameterization:

$$\delta_{Ray}(\lambda) = 0.008735 \cdot \lambda^{-4.08}$$

With this corrections the aerosol optical thickness can be obtained, see figures in the previous section.