

Here S_{Target} is the trace gas concentration integrated between the instrument and the target, and S_{Atm} is the trace gas concentration integrated between the target and top of the atmosphere. For many trace gases such as NO_2 , BrO , or O_3 , a substantial or major fraction of the total atmospheric column is located in the stratosphere; for such trace gases, S_{Atm} will be independent from the MAX-DOAS viewing direction because the absorption paths through the stratosphere are determined by the solar zenith angle. Even for trace gases located in the free or upper troposphere this assumption is valid with only small restrictions.

It should be noted that the sensitivity of the measurement for the trace gases between the instrument and the target strongly depends on the brightness of the target and the atmospheric conditions. Only for white targets is the measured SCD almost similar to the true SCD S_{Target} (see Subsection 2.C.1).

Since we are interested in S_{Target} , we have to remove S_{Atm} from the total signal. This can be easily achieved and will be explained in Subsection 2.B. Another fundamental question is to determine the sensitivity of the measurement for the trace gas between the instrument and the target, in particular the dependence of the sensitivity as a function of the distance from the instrument. For an ideal measurement the sensitivity would be constant along the light path between the instrument and the target as, for example, for traditional long-path DOAS observations. We will show below that for many cases the sensitivity can be expressed as a simple functional expression of the distance from the instrument. For bright targets, for example, the sensitivity becomes similar to that for long-path DOAS observations. Nevertheless, in general, this sensitivity decreases with the distance from the detector because additional sunlight is scattered into the line of sight of the instrument (see Fig. 1). For the correct interpretation of the measurement, this sensitivity has to be characterized (see Subsection 2.C) and corrected. If no simple correction is possible, radiative transfer modeling has to be applied (see Subsection 2.D).

B. Removal of the Signal From the Region Between the Target and Top of the Atmosphere (S_{Atm})

The correction of the partial SCD between the target and the top of the atmosphere (S_{Atm}) can be easily (and quasi automatically) achieved by two procedures. The main aspect of both methods is that for the DOAS analysis of scattered sunlight, a so-called Fraunhofer spectrum has to be included for the correction of the strong solar Fraunhofer lines.^{8,9,11,23} For this purpose, usually a measurement taken with the same instrument but under different measurement conditions (e.g., at a low solar zenith angle) is used. Since this Fraunhofer spectrum contains not only the solar Fraunhofer lines but also atmospheric absorptions, the result of the spectral DOAS analysis is the difference between the SCDs of the measurement and the Fraunhofer spectrum. The trick for the correction of signal from between the target and the top of the

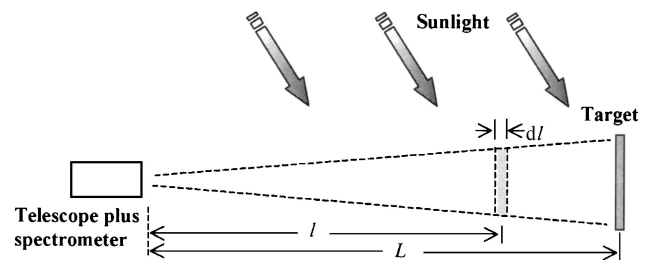


Fig. 2. Composition of the light received by the telescope: sunlight can be reflected by the target or scattered by molecules and aerosols between the target and the instrument.

atmosphere (S_{Atm}) is to select a Fraunhofer spectrum that contains only S_{Atm} . This can easily be achieved by two simple approaches. The first approach is to point the telescope of the instrument toward the zenith. It then receives photons that have traversed almost similar paths as those between the target and the top of the atmosphere. Especially for trace gases that (in addition to the boundary layer) are located only in the stratosphere, a zenith-scattered spectrum is already sufficient for the correction of S_{Atm} . If trace gases are also located in the free troposphere it might be better, however, to choose a refined approach. For the measurement of the Fraunhofer spectrum the telescope should then be directed to a target close to the instrument, which has similar properties compared to the real targets. Particularly the orientation (the angle of the reflecting surface with respect to the instrument and the Sun) and the reflectivity (the albedo) of the nearby target should be similar to the target at far distance. This procedure ensures that the photon paths in the lower free troposphere (and thus the S_{Atm}) of both the actual measurement and the Fraunhofer spectrum are almost identical.

In some cases it might be sufficient to use a measurement from one (far) target (e.g., measurement D in Fig. 1) as the Fraunhofer spectrum for the analysis of a measurement from another (far) target that is placed in the same direction but at a different distance (e.g., measurement C in Fig. 1). Then the resulting S_{Target} is the integrated trace gas concentration along the path between both targets.

C. Sensitivity of the Measurement for Trace Gases Between the Instrument and the Target

For the correct interpretation of the trace gas absorption determined by the DOAS analysis the sensitivity of the MAX-DOAS observation for the trace gas between the instrument and the target (e.g., as a function of the distance from the instrument) has to be known. We show in Subsections 2.C.1–2.C.3 that for many cases simple functional expressions for this dependence can be found. The light received by the telescope $I(\lambda, L)$ contains two parts (see Fig. 2):

$$I(\lambda, L) = I_{\text{Atmos}}(\lambda, L) + I_{\text{Target}}(\lambda, L), \quad (3)$$

where $I_{\text{Target}}(\lambda, L)$ is the measured radiance caused by the reflected sunlight by the target, and $I_{\text{Atmos}}(\lambda, L)$ is