Name of research institute or organization:

Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
Kipp & Zonen B.V., Delft, The Netherlands

Title of project:

Sunphotometry at the High Altitude Research Station Jungfraujoch

Project leader and team

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Project description:

Introduction

The aerosol optical thickness (AOT), which is directly related to the atmospheric aerosol load, is the principal variable describing the effect of aerosols on radiative transfer in the Earth's atmosphere. The level of understanding of this effect is rather low, which is one of the reasons why the current state of the climate is not well understood and why predictions of future climate are uncertain. Traditionally, the AOT is derived from direct solar irradiance measurements with a sunphotometer. The aims of the project described here are testing and calibration of two different types of sunphotometers: the SPUV-6 (manufacturer: Yankee Environmental Systems, Inc) operated by KNMI and the POM-01L (manufactured by PREDE Co., Ltd) operated by Kipp & Zonen B.V. The project was performed at the High Altitude Research Station Jungfraujoch during the period August–November 2003.

Instrumentation

The SPUV-6 is a six-channel sunphotometer which is normally operational at the Cabauw Experimental Site for Atmospheric Research (CESAR) in the Netherlands. The main product of the instrument, AOT, is used for process studies (interaction between radiation and aerosols) and for the construction of an AOT climatology for the centre of the Netherlands. So far, the instrument has been operational sice 1997. The central wavelengths of the SPUV-6 are: 368, 501, 675, 780, 871, and 940 nm. All channels (except the 940 nm channel, which is located in a water-vapour absorption band) are used for the retrieval of AO. The instrument is mounted on a Kipp & Zonen 2AP sun tracker.

The sunphotometer POM-01L is designed for routine measurements of direct and diffuse solar radiation at seven wavelengths (315, 400, 500, 675, 870, 940, and 1020 nm). The SKYRAD.pack code developed by Nakajima et al. (1996; *Appl. Opt.*, 35, 2672–2686) provides dedicated algorithms for the retrieval of various columnar aerosol properties such as AOT, volume size distribution, average values for the real and imaginary aerosol refractive index, as well as ground albedo. When data of both direct and diffuse solar radiation are used, the detectable radius interval for aerosol particles is approximately from 0.03 to 10 µm. These aerosol optical properties allow to calculate several secondary data products, such as the extinction parameter and the asymmetry factor. An integrated sun sensor provides active solar tracking. Figure 1 shows the SPUV-6 and POM-01L as mounted on the upper terras of the Sphynx.

Figure 1: The POM-01 (left) and the SPUV-6 (right) installed on the upper terrace of the Sphynx.

Langley calibration

The principle of calibration of a sunphotometer is based on Bouguer's law, which states that $I = I_0\, e^{-\tau m}$, where I is the signal of the sunphotometer as measured on the ground (in e.g. μA or mV), I_0 the top-of-atmosphere signal, τ the total atmospheric optical thickness, and m the relative airmass. The latter is related to the photon path length through the atmosphere and can be written as a function of the solar zenith angle. The equation implies that when the sunphotometer signal is plotted on a logarithmic scale as a function of the relative airmass (the plot is referred to as Langley plot), a straight-line fit is produced. The interception with the *y*-axis ($m = 0$) gives the Extraterrestrial Constant I_0, which is unique for each sunphotometer and channel. One of the aims of the project described here is to derive values of I_0 for all channels of both the SPUV-6 and POM-01L, i.e. to calibrate the instruments.

Results

Because of the many cloudless days during the summer and autumn of 2003, a large number of Langley plots could be constructed. As a representative example, measurements made with both sunphotometers are shown for 20 September 2003 (Figure 2). The left panels of Figure 2 show measurements of the direct irradiance, and the right panels show the corresponding Langley plots together with the residuals (differences between the measurements and the fit, relative to the instrument signal). The irradiance curves are extremely smooth, indicating the stability of the atmospheric composition during the measurements. The only large irregularity, at around 6 AM, is caused by the presence of the Trugberg, which casts its shadow over the Sphynx in the morning. The Langley plots are of excellent quality for both the SPUV-6 and the POM-01: the residuals are almost all within ±0.1% of the instrument signal, which corresponds to ±1 instrument count. This implies that the deviation of Bouguer's law is of the order of the instrument's resolution.

The period August–November 2003 gave at least 18 clear mornings for which the quality of the measurements was comparable to that of the example shown in Figure 2. The Extraterrestrial Constants for all aerosol channels of the SPUV-6 as obtained from the 18 clear mornings are shown in the left panel of Figure 3. The results for the POM-01L are shown in the right panel of the same figure. Note that the time series for the POM-01L is shorter; this is because the instrument was removed from the Joch on 23 September. For the SPUV-6, the standard deviation of the mean varies from 0.3% for the 500 nm channel to less than 0.1% for the other channels. This is an excellent result, which will be the basis for accurate retrievals of the AOT in the Netherlands. Similar results are obtained for the POM-01L: 0.5% for the 400 nm channel and less than 0.3% for the other channels. It is important to note that the variability in the Extraterrestrial Constants is comparable for both instruments and correlated.

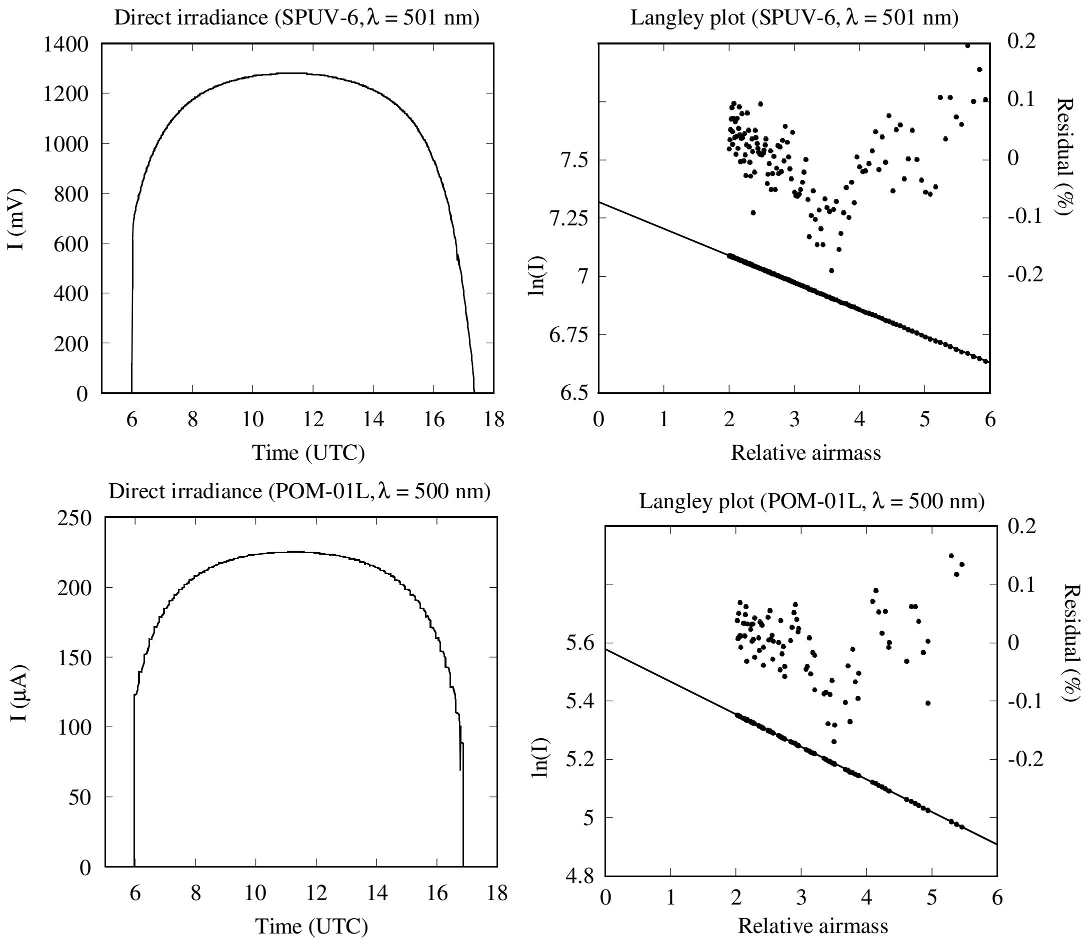

Figure 2: Direct irradiance measurements and Langley plots for the SPUV-6 (KNMI) and POM-01L (Kipp & Zonen) for 20 September 2003. The wavelength is 500 nm. The scattered points indicate the differences between the measurements and the fit, relative to the instrument signal.

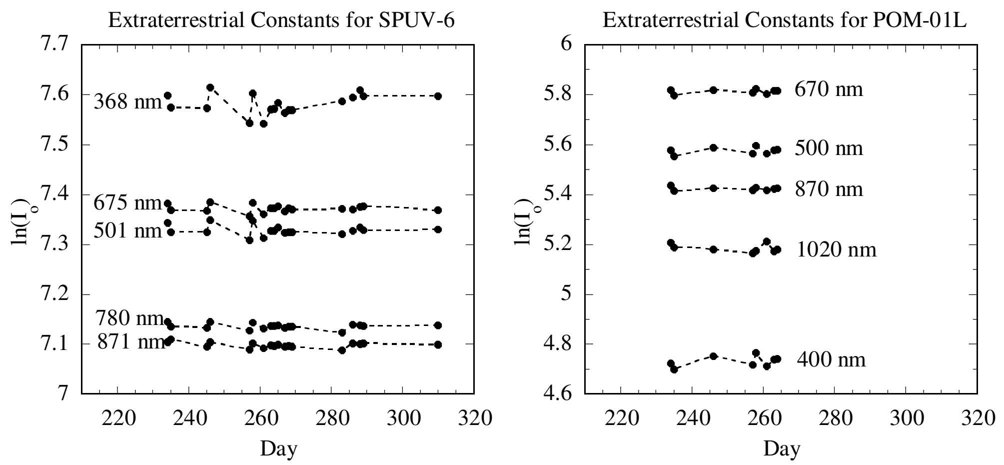

Figure 3: Extraterrestrial Constants for the aerosol channels of the SPUV-6 (left panel) and POM-01L (right panel) for the measurement period. For both data sets the first point corresponds to 22 August 2003. For the SPUV-6 the last point was taken on 6 November 2003, for the POM-01L this was 21 September 2003. The standard deviation of the mean varies between <0.1% and 0.5 %, depending on the channel and the instrument.

POM-01L measurements of direct and diffuse solar radiation, made in a cloudless atmosphere, can be used to derive not only the aerosol optical thickness, but also the aerosol single-scattering phase function, size distribution, and complex refractive index. This is done by means of a radiative transfer code and linear and nonlinear inversion schemes, brought together in the SKYRAD.pack code. The basic radiometric quantity required by the algorithm is the ratio between the diffuse and the direct irradiance. Figure 4 shows two SKYRAD.pack data products: the volume size distribution and the single scattering phase function, for 20 September 2003 at 12 UTC. Further investigations of the measurements are intended to compare the calibrations of the instruments and the retrieval methods and to compare the aerosol optical properties with in situ measurements for measurements obtained during clear and stable atmospheric conditions. Note that the SKYRAD.pack code does allow to retrieve AOT without absolute calibration of the POM-01L. One of the objectives of the present investigation is therefore to compare the AOT as obtained by the SKYRAD.pack code and the AOT derived from the Langley calibration.

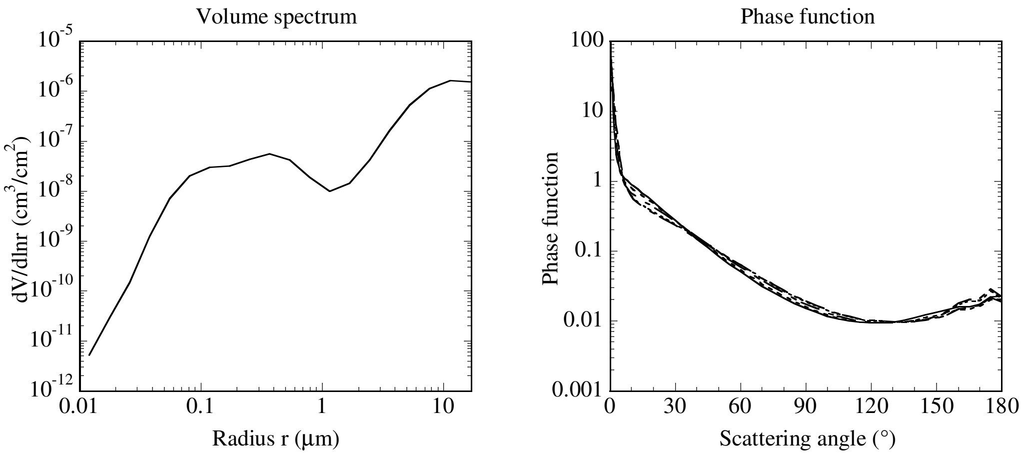

Figure 4: Volume spectrum (left) and phase function (right) of the columnar aerosol on 20 September 2003 1200 UTC as obtained with the POM-01L and the SKYRAD.pack code.

Concluding remarks

The preliminary results shown in this report demonstrate the unique possibilities of performing sunphotometry at a high-altitude site. The Extraterrestrial Constants can only be determined with high precision if both the slope and the scatter of the Langley regression are small. This is only accomplished if the optical thickness is small (small slope) and invariable (little scatter). Precisely these conditions are met at the High Altitude Research Station Jungfraujoch, in particular when the site is situated in the free troposphere and only background aerosol concentrations are found. Compared to Langley calibrations for the SPUV-6, performed at sea level, the results obtained at Jungfraujoch indicate that the calibration of the instrument is significantly more accurate and precise. This will allow us to continue the AOT monitoring efforts of KNMI in The Netherlands with higher accuracy.

The instruments that are present at the Jungfraujoch, in particular the Precision Filter Radiometers of the CHARM network and the aerosol in-situ instruments for the GAW Aerosol Programme, provide a wealth of data for comparisons of AOT and aerosol optical properties. Such comparisons, that are planned for the near-future, are valuable for the evaluation of retrieval methods, such as provided by the SKYRAD.pack code for the POM-01L, but also for obtaining insight in the performance of our sunphotometers. The frequently clear and stable conditions at the Jungfraujoch allow us to perform evaluations of methods and instruments in a more effective way than is possible at sea level.

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Key words:

Aerosol optical thickness, Langley calibration, sunphotometer

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