Ground based measurements of aerosol properties using Microtops instruments

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Abstract. The contribution of aerosols to the signals at top of the atmosphere must be accounted for remote sensing of the ocean and land surface, which is known as atmospheric correction. Validation of atmospheric correction procedures require ground based measurements of aerosol properties. Ground based measurements of aerosol properties give also a basis for validation of the aerosol models used by atmospheric correction algorithms.

Ground based measurements of aerosol properties have been performed in the coastal area of the southern Baltic Sea and near Berlin with a Microtops II Sunphotometer and a Microtops II ozone monitor, both onboard a ship and on the land surface. The present paper gives examples of atmospheric parameters which can be obtained from Microtops measurements and reports some experience how to perform and analyze these measurements. Then application of these results is demonstrated with 2 examples. Validation of atmospheric correction algorithms is demonstrated with a comparison of aerosol optical thickness resulting from satellite data with total column aerosol optical thickness from ground based measurements at time of satellite overpass. The agreement is better than 0.03 at 750 nm. Another example uses the aerosol properties found from ground based measurements as input to radiative transfer modeling of the signals received at satellite. The agreement between modeled and measured signals is fine within the expectable uncertainty.

Keywords: Ground based measurements, Microtops instruments, aerosols, total column ozone content, precipitable water vapour
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INTRODUCTION

Variations of aerosol properties in time and space are the dominating source of the variability of remote sensing signals in the optical spectral range. Consequently, the contribution of aerosols to the signals at top of the atmosphere must be accounted for remote sensing of the ocean and land surface, which is known as atmospheric correction. Ground based measurements of aerosol properties give a basis for validation of atmospheric correction procedures. They are also useful for validation of the aerosol models used by atmospheric correction algorithms. More, measurements of aerosol properties are useful for climate studies because aerosol particles have an impact on the radiation balance of the earth due to its influence on the radiation field.

Microtops are small, portable instruments and therefore they are very useful for ground based measurements at changing locations. They can give total column aerosol optical thickness spectra together with total column ozone content and precipitable water vapor within the atmosphere. However, even if they seem to be operated very simple, measurements must be performed and analyzed very carefully to get reliable results. Some experience how doing this is reported in the present paper. This is supplemented by examples of the obtained parameters and examples of their use for validation of atmospheric correction procedures and of satellite data.

INSTRUMENTS

Ground based measurements have been performed with a Microtops II Sunphotometer and a Microtops II ozone monitor produced by Solar Light Co., Inc., USA. Microtops are small, easy to operate instruments with a sun target pointing assembly. They are designed for hand-held operation and very suitable for mobile use. The field of view of each of the optical channels is 2.5 deg with the sun target assembly laser-aligned to within 0.1 deg from the optical axis of the block. Each instrument has 5 spectral channels with a narrow-band interference filter. Center wavelengths of the ozone monitor are at (305.5, 312.5, 320, 936, 1020) nm and of the sunphotometer at (380, 440, 500, 675, 870) nm. Signals are first amplified and then converted to digital signal by a high resolution A/D-converter. Signals from the individual detectors are processed in series with 20 conversions per second. Thus results can be treated as if the photodiodes were read simultaneously. Microtops save only 1 value for each scan of each optical channel, which is the average of the top ranking samples out of a total number of samples (scan length). Both the scan length and the total number of top selected records can be configured. A scan with 32 rapid samples takes approximately 10 seconds.

RESULTS

Ground based measurements of aerosol properties have been performed over several years in the coastal area of the southern Baltic Sea and near Berlin with a Microtops II Sunphotometer and a Microtops II ozone monitor. Sunphotometer measurements over several years require a large effort to maintain accurate radiometric calibration of the instruments. Sensor calibration was found to be very stable. Sensor degradation per year is less than 0.1% over a period of 10 years with exception of the 1020 nm channel, where it is about 1% per year.

The data set at the Baltic Sea includes 7 observation periods at 4 different locations, both onboard a research vessel and on the land surface. The dataset near Berlin starts in December 2010 and continues on separated, single days over the entire year 2011. Measurements at May 30, 2003 onboard a research vessel on the Southern Baltic Sea have been selected for an example presenting typical results obtained from Microtops. This example is shown in figure 1. It represents an example day with cloudiness changing between 0/8 and 1/8 and waves corresponding to wind speed of 4-7 m/s. Total column aerosol optical thickness spectra at wavelengths (380, 440, 500, 675, 870, 1020) nm, total column ozone content and precipitable water vapour content of the atmosphere are derived directly from the Microtops signals.

Computation of total column ozone content was realized following the description of Morys et al. [1]. Ozone content is expressed in terms of cmSTP which corresponds to Dobson units divided by 1000. There are obtained two ozone values out of the 3 channels for ozone measurements. Ozone12 is derived from the channels at 305 nm and 312 nm and ozone23 from the channels at 312 nm and 320 nm. Ozone12 gives the more reliable results than ozone23 and should be used at low airmass. With decreasing sun height the signal in the channel at 305 nm becomes too small for using ozone12. Then using ozone23 extends the airmass range usuable for ozone retrieval.

Computation of total column aerosol optical thickness spectra is performed by application of the Lambert-Bougier extinction law.

$$\tau_X^A = \frac{1}{am} \cdot \left(LnCs0_X - LnCs_X \right)$$
$$LnCs_X = \ln\left(V_X \cdot SD_{corr}\right) + am \cdot \tau_X^R \cdot p / p_0 + amo3 \cdot \left(\frac{o3cont}{0.3316} \cdot \tau_X^{O3} + \tau_X^{no2} \right) \tag{1}$$

Here *X* stands for the optical channel, LnCs0 for the extraterrestrial signal, V for the voltage measured by the instrument and the factor SD_{corr} accounts for the actual sun-earth distance on the day of measurements. The airmasses am and amo3 are calculated by the formula of Kasten [2] and following Komhyr [3,4]. Optical thickness for Rayleigh scattering τ^R is computed with the formula of Bucholtz [5] for the midlatitude summer atmosphere and scaled to the actual air pressure p with p_0=1013.25 hPa. Molecular absorption optical thickness of ozone and nitrogen dioxide comes from model calculations for standard conditions. The ozone absorption is scaled with the actual ozone amount *o3cont* obtained from the ozone monitor measurements.

Total column aerosol optical thickness spectra are fitted to the Ångstrœm-power law $\tau^A(\lambda)=\beta\cdot\lambda^{-\alpha}$. The parameter α is the so called Ångstrœm-exponent depending on the size of aerosol particles. The Ångstrœm-exponent lies typically between 0 and 2. The smaller the Ångstrœm-exponent is, the larger are the aerosol particles. The Ångstrœm-exponent can be transformed to the effective mean radius of the aerosol particles with the assumption of a Junge-power law for the size distribution of aerosol particles.

Computation of precipitable water vapour again follows the description of Morys et al. [1] with the exception, that the Ångstrœm-exponent is used for the slope of the aerosol optical thickness spectra between 1020 nm and 936 nm instead of the fixed relation used by Morys [1]. Water vapour content of the atmosphere is expressed in terms of cm precipitable water column.

The whole dataset for the coastal environment at the Baltic Sea and for the urban environment near Berlin includes very clear and very turbid conditions. Situations with dominating large aerosol particles have been observed as well as situations with dominating small aerosol particles. Aerosol optical thickness at 550 nm varies from 0.04 to 0.7 and the Angstroem-exponent ranges from 0.25 to 1.8. Variations of the observed optical aerosol parameters in the coastal area show no clear relation to the related wind and humidity conditions. Probably the dataset is still too small for this kind of analysis.

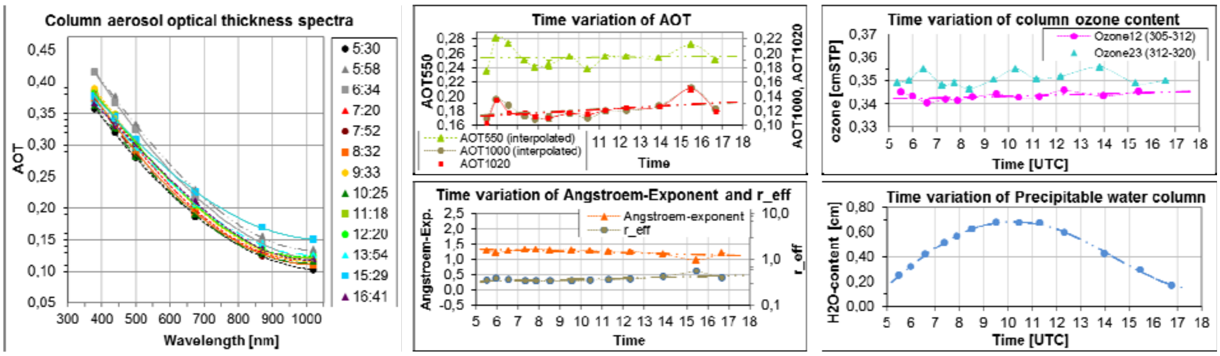

FIGURE 1. Typical results obtained from Microtops II Sunphotometer and Microtops II ozone monitor measurements. (a) Aerosol optical thickness spectra (AOT), (b) Time variation of aerosol optical thickness (AOT), (c) Time variation of aerosol size (Ångstrœm-exponent and effective particle radius r_eff), (d) Total column ozone content, (e) Precipitable water vapour

Experience on using Microtops instruments

Data analysis makes combined use of both the data of the Ozone monitor and of the Sun-photometer. Results obtained from the internal algorithm of the instruments have the disadvantage that default values of ozone content are used for computation of aerosol optical thickness and a fixed value for the spectral variation of aerosol optical thickness between 1020 nm and 936 nm is used for the calculation of precipitable water vapout content. Therefore, results of the internal algorithm can have large errors if the actual conditions differ from the used default values. However, results of the internal algorithm are displayed on the LCD of the instruments and thus they are a nice quick look.

Measurements included into the final data computation must be selected very carefully. Sun pointing errors are contained in the data stored by the instrument, most of all on a sea sawing ship (Figure 2a). The only way to get reliable results in this situation is to perform enough scans. This gives the opportunity to dismiss scans with sun pointing errors during data analysis. The number of scans per time can be configured depending on the sea state using the instrument setup. The more the sea surface is rough, the more the number of scans stored into the instruments should be increased by decreasing both the scan length and the number of the best ranking samples. Even at the stable land surface it is recommended performing groups of at least 10 scans with each instrument for each time step required for the final data analysis.

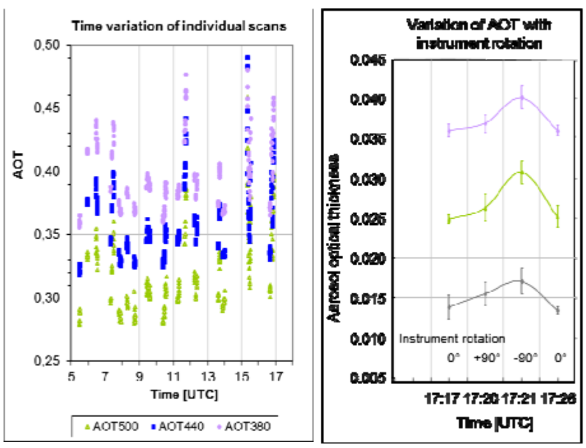

FIGURE 2. Measurement errors using Microtops
(a) Sun pointing errors within groups of Microtops scans onboard a ship. These data are the basis for the results shown in figure 1.
(b) Effect of rotating the Microtops around its main axis

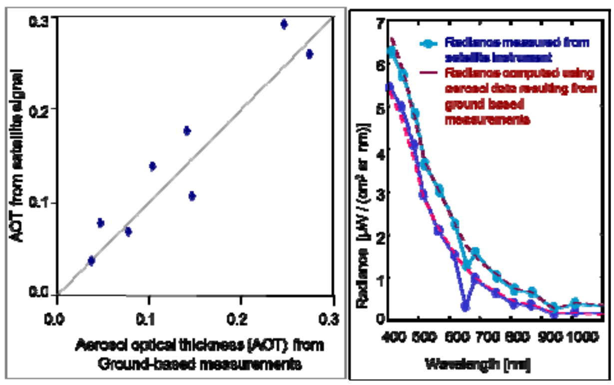

FIGURE 3. Application of ground based aerosol data for
(a) validation of atmospheric correction and
(b) validation of satellite signals

A good indicator of measurement quality is comparison of AOT1000 with AOT1020 (Figure 1b). Both values result from different instruments. They should be identical for measurements performed at the same time and follow the same variations over time. AOT1000 results from fitting the spectra resulting from the sunphotometer to the Ångstrœm-law and AOT1020 is computed directly from the Ozone-Monitor measurements. If both values do not follow the same variations over time, this indicates sun pointing errors.

The instruments have to switch off after each group of measurements as outlined already in the Microtops user's Guide [6], because the dark signal is determined by the instrument at each initialization after switching on the instrument. Dark signals are not saved by the Microtops and are subtracted from the signals by the interior signal processing algorithm. There is no chance for later corrections! More, it is recommendable keeping the temperature of the optical block inside the instrument as constant as possible. Avoid putting the instrument into the sun between groups of measurements.

The instruments must be operated always in horizontal orientation. Rotating the instrument around its main axis leads to significant errors (Figure 2b). Of course, an accurate calibration is required for computing reliable data. Instruments have to be recalibrated regularly and the front window of the instruments must keep clean.

Using ground based aerosol data

Application examples of using ground based aerosol data are shown in figure 3. Validation of atmospheric correction algorithms is demonstrated with a comparison of total column aerosol optical thickness resulting from satellite data with aerosol optical thickness from ground based measurements at time of satellite overpass. The agreement is better than 0.03 at 750 nm. Another example uses the aerosol properties found from ground based measurements as input to radiative transfer modeling of the signals received at satellite. The agreement between modeled and measured signals is fine within the expectable uncertainty.

CONCLUSIONS

Microtops instruments yield reasonable aerosol spectra and vertical column absorber amounts of O3 and H2O, if exists a valid radiometric calibration and if they are correctly operated. Parameters characterising the vertical column aerosol amount and aerosol type can be computed on basis of the aerosol spectra. Microtops instruments can be used both on the land surface and onboard a ship. Resulting atmospheric parameters are very useful for validation of atmospheric correction algorithms and of satellite signals.

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