GROUND TRUTH MEASURMENTS FOR THE VALIDATION OF MOS DATA AND ATMOSPHERIC CORRECTION ALGORITHMS

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ABSTRACT

Ground truth measurements performed synchronous to overflights of imaging spectrometer MOS deliver more or less complete sets of parameters for characterisation of the radiation field of the atmosphere/ocean system. TOA- radiances computed using complete sets of ground-truth parameters for input are compared with radiances measured by the MOS sensor. A good coincidence was found for all examples after fitting the computed spectrum to the measured varying the wind speed. Calibration uncertainties of some spectral channels already known from other investigations could be confirmed. Ground-truth data are also used for validation of atmospheric correction algorithms.

1 INTRODUCTION

Imaging spectrometer MOS was launched in 1996 onboard the Indian Remote Sensing Satellite IRS/P3. The spectrometer works fine since this time and MOS data are used successfully for many tasks. Validation of MOS data and vicarious calibration in the spectral channels can be done with the help of complete sets of ground truth measurements. These include measurements of direct solar radiation, sky brightness distribution in the almucantar, spectral downward flux at the earth‘s surface, upward radiance just above the water surface and meteorological data such as air pressure, wind speed, temperature, relative humidity, cloud conditions and columnar ozone content. The ground-truth data are also useful for experimental validation of atmospheric correction algorithms.

2 GROUND TRUTH APPROACH FOR VALIDATION

The validation scheme for MOS-data is illustrated in figure 1. Ground-truth measurements are performed synchronous to satellite overpasses for characterisation of the meteorological situation and the properties of ocean water and atmosphere. Whereas measurements for ocean water properties and the water leaving reflectance are performed onboard a ship, atmospheric measurements are better done at a nearby coastal location. Own meteorological measurements of wind speed, wind direction, air pressure and relative humidity are supplemented by standard measurements of meteorological services at coastal stations and ships.

Spectral optical thickness of aerosol and other atmospheric constituents can be determined from measurements of direct solar radiation. Measurements of sky brightness in the almucantar at low sun elevations together with data of spectral optical thickness are input data for the CIRATRA method (Wendisch & von Hoyningen-Huene, 1994; von Hoyningen-Huene & Posse, 1997) and allow retrieval of further aerosol properties including columnar aerosol size distribution, real part of refractive index, aerosol phase function, asymmetry parameter and information about the particle shape. The spectral downward flux gives the possibility to check the atmospheric parameters. Together with the upward radiance above the water surface the water leaving reflectance can be calculated. Model atmospheres are used to add parameters not available from realised measurements. Such complete ground truth data sets measured synchronously with overflights of the imaging spectrometer MOS deliver input values for radiative transfer calculations. Computed upward radiances can then be compared with measured values from the MOS sensor to complete the ground truth closure. Direct comparison of ground-truth parameters with results estimated from satellite data allows experimental validation of atmospheric correction algorithms.

The spectrometers used for atmospheric ground-truth observations are characterised in table 1 (Zimmermann, 1998, von Hoyningen-Huene et.al., 1991). HiRES-A and HiRES-B are grating spectrometers with different spectral resolution and different spectral range. The two spectrometers measure direct solar irradiance, which allows computation of columnar aerosol optical thickness spectra. Both spectrometers are also capable to measure sky-brightness within solar

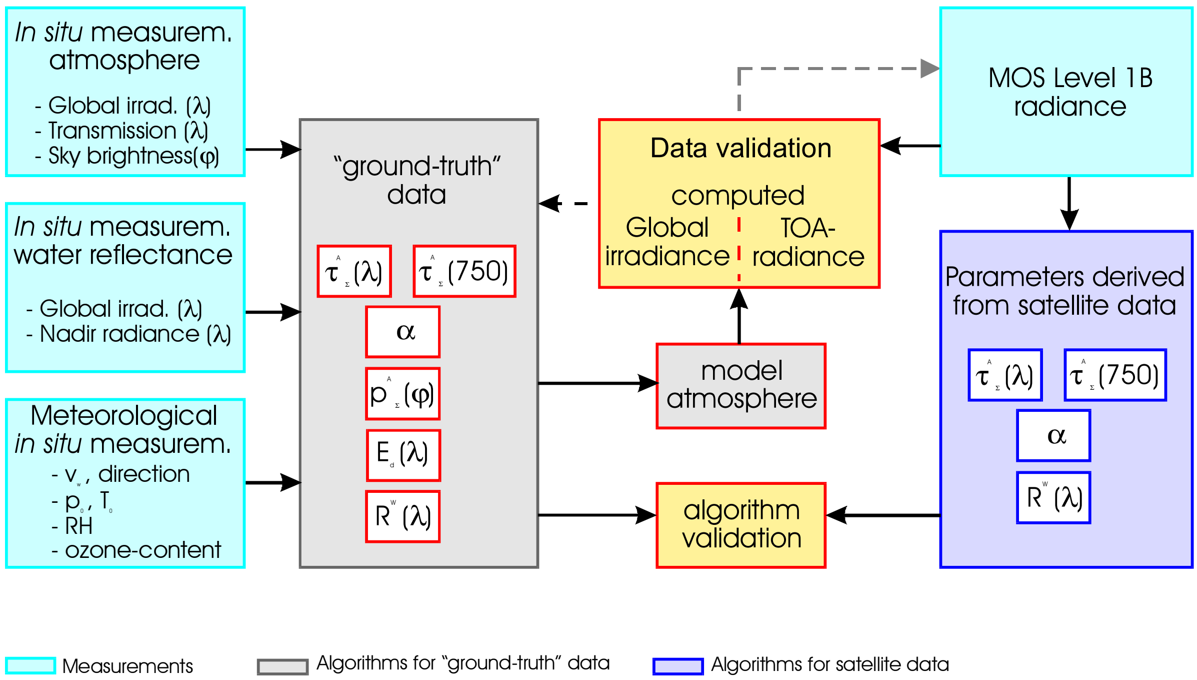

Fig.1: Validation scheme for MOS-data

almucantar. Mostly HiRES-A is used for almu-measurements during the experiments, because the small sky-brightness signals outside the solar aureole can be better measured with larger halfwidth. Additionally, inversion of aerosol size distribution from combined almu- and optical thickness spectra measurements works more stable using the larger spectral range of HiRES-A. ASP-3 is a filter spectrometer developed from v.Hoyningen-Huene [von Hoyningen-Huene et.al., 1991], which also has been used for direct solar irradiance and almu-measurements during ground-truth campaigns. Spectrometers HiRES-ES, MCS and MMS-3 measure the incident global radiation and the upward nadir radiance reflected by the ocean surface.

Table 1: Spectrometers used for atmospheric ground-truth observations

Spectrometer	wavelength range	halfwidth	No. of channels	observation modes
HiRES-A ASP-3 HiRES-B	400-800 nm 350-1100 nm 650-780 nm	1.2 – 1,6 nm 8-15 nm 0.3 – 0,6 nm	512 80 512	Transmission (λ) Sky brightness (φ)within solar almucantar
HiRES-ES	400-800 nm	1.2 – 3,8 nm	512	Downward global irrad. Ed (λ) Upward radiance Lu(λ)
MMS-3	310-1130 nm	12 nm	256	Downward global irrad. Ed (λ) Upward global irrad. Eu (λ) Upward radiance Lu(λ)
MCS	190-1020 nm	3 – 7 nm	1024	Downward global irrad. Ed (λ) Upward radiance Lu(λ)

The reliability and accuracy of ground truth data is of great importance for successful validation. Therefore great efforts have been done for quality insurance. Radiometer intercomparisons with the well established ASP radiometers of the working group from von Hoyningen-Huene (Posse et. al., 1997) at the Baltic coast and at Helgoland island led to improvements of the HiRES spectrometers as well as for the algorithms of ground truth derivation. Repeated laboratory measurements checked the device properties. The calibration of sun-radiometers was done with the Langley-Plot method at the Teide observatory (Tenerife) once every year. In this context we want to acknowledge particularly the kind support we have got from the Instituto de Astrofisica de Canarias, Tenerife, for these calibration measurements. Table 2 shows the very good stability of spectrometer calibration over three years fulfilling the accuracy requirement in order of 1%.

Table 2: Calibration factors for HiRES-A spectrometer resulting from Langley-Plot measurements at Teide observatory *(selected example wavelengths)*

Wavelength	Calibration factor resulting from measurements at 13.8.1997	17.6.1999	20.6.1999	$\frac{\Delta_{max}}{\bar{x}}$
415.2 nm	12.479	12.506	12.495	$2.1\cdot10^{-3}$
485.2 nm	13.483	13.489	13.468	$1.6\cdot10^{-3}$
615.3 nm	13.523	13.524	13.500	$1.8\cdot10^{-3}$
778.0 nm	13.013	13.036	13.014	$1.7\cdot10^{-3}$

3 EXPERIMENTAL RESULTS

During last four years several measuring campaigns were prepared and performed synchronous to satellite overpasses of IRS/P3. Complete ground truth data sets could be measured in different geographical regions and at different seasons, so that data sets are available for very different water types and atmospherically conditions as well as for various geometry conditions and signal levels for the satellite image data.

Figure 2 illustrates one example of aerosol properties retrieved out of the experimental data of direct solar radiation and sky brightness distribution by the CIRATRA method. The measurements were performed with HiRES-A spectrometer at Maspalomas on Gran Canary island. This situation with normal aerosol conditions is characterised by lower aerosol optical thickness of about 0.1 and mixed aerosol components. The Angstrom exponent around 1.2 and the real part of the refractive index 1.375 indicate, that the origin of aerosol particles is not pure maritime. That corresponds with north wind direction from land to sea at Maspalomas. Aerosol phase function for nonspherical particles gives slightly better result than aerosol phase function computed using Mie-theory showing effects of nonspherical particles.

4 MODELLING OF TOA-RADIANCES

Complete ground truth measurements performed synchronously with overflights of the imaging spectrometer MOS deliver input values for radiative transfer calculations corresponding to the scheme in figure 1. Computed upward radiances can then be compared with measured values from the MOS sensor. This comparison helps to study calibration accuracy of the MOS-sensor and can give a contribution to reduce uncertainties within some spectral channels.

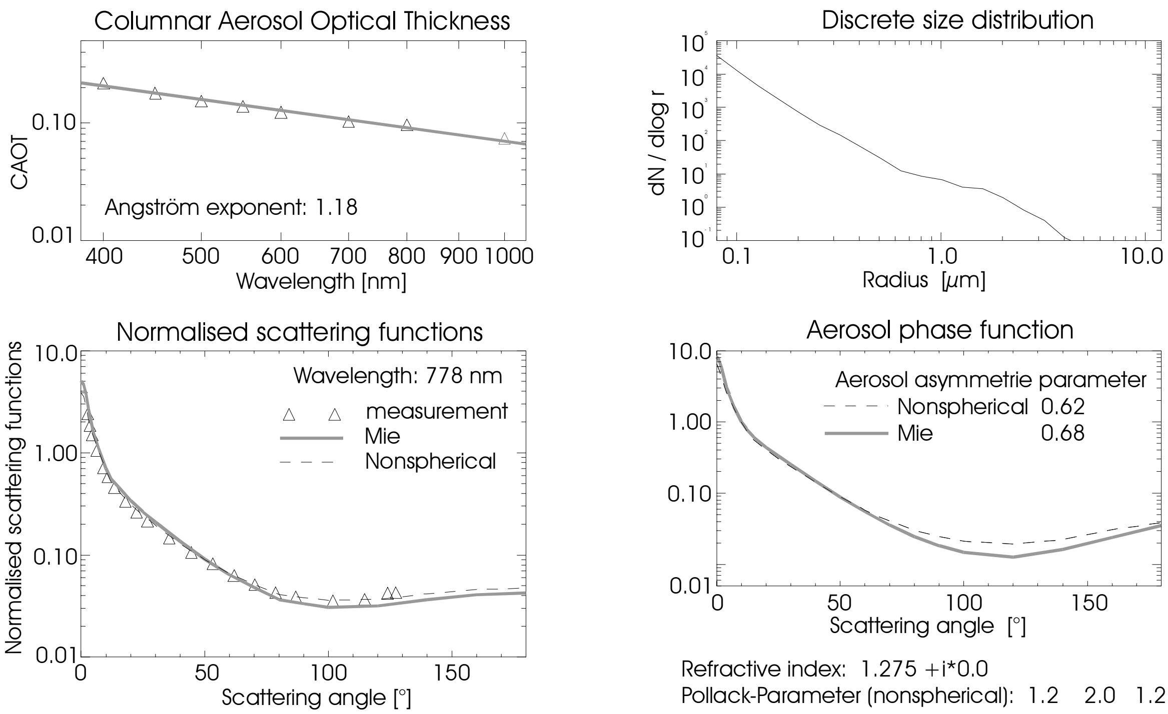

Figure 2: Atmospheric ground-truth results calculated using CIRATRA inversion scheme.
Measurements: HiRES-A: August 27, 1997, 8:45 UTC, Maspalomas / Gran Canaria

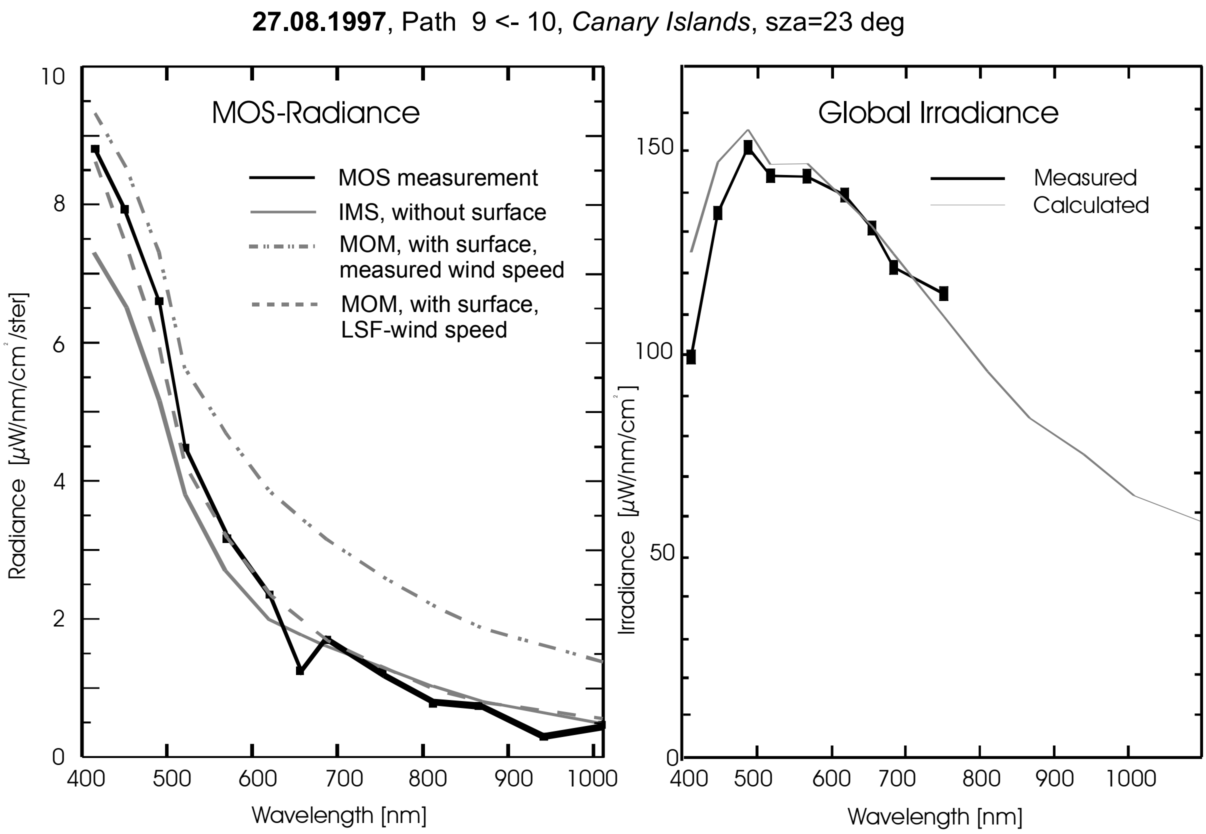

Figure 3: Comparison of modelled and measured MOS-spectra and global irradiance for August 27, 1997
IMS: Radiative transfer program of Nakajima&Tanaka (1988), without consideration of ocean surface reflection
MOM: Radiative transfer program of Härtel (1983), with consideration of ocean surface reflection
Calculations were performed using the wind speed measured by the next meteorological station and using the wind speed best fitting the modelled spectrum to the measured (LSF-fit).

Simultaneously, the radiative transfer calculations helps validating the ground truth data itself.

The first attempt modelling MOS-radiances was made with the IMS (intensity corrected multiple scattering) radiative transfer programme by Nakajima & Tanaka (1988) which is also a component within the CIRATRA package. This program uses an albedo value for the underlying surface and cannot consider the bi-directional reflectance function of ocean surface. The resulting radiance spectra are smaller than MOS-measurements, especially for some overflight situations in the Canary Islands region with its high sun elevations (Figure 3). Therefore the Matrix-Operator radiative transfer program MOM by Härtel (1983) was employed simultaneously considering an albedo value as well as a given wind speed to consider the rough ocean surface (Cox & Munk, 1956). Using the wind speed measured by the next meteorological station in many situations leads to modelled spectra much larger than the measured. A sensitivity study performed for discussion of the differences showed, that variations of aerosol optical thickness, refractive index and aerosol size distribution result in significant changes of computed spectra. However, the deviations found can not be explained by realistic variations of these aerosol parameters. Furthermore, the coincidence between modelled and measured global irradiance confirms the ground-truth aerosol parameters. The reason for the differences between measured and calculated TOA radiances consequently should be attributed to uncertainties of the ocean surface reflection. The wind speed measured by the next meteorological station very probably deviates from the actual wind speed because of large distances in space and time between ground-truth location and satellite overpass time from location and time of the meteorological measurement. Therefore, the wind speed best fitting the modelled spectrum to the measured one was determined (LSF-fit) and used for final discussion. Then the measured signal is good reproduced by the computed (Figure 3). Deviations at 814 nm and 942 nm can be explained by water vapour absorption within these spectral channels, which is not included into the radiative transfer computation. The channel at 650 nm is distorted since the launch of the spectrometer. Figure 3 shows, that the measured signal is slightly too low within the NIR-region of the spectrum. That confirms other investigations (Walzel, 1998). The differences for the spectral channels in the blue part of spectrum are not systematically. They occur only for some situations.

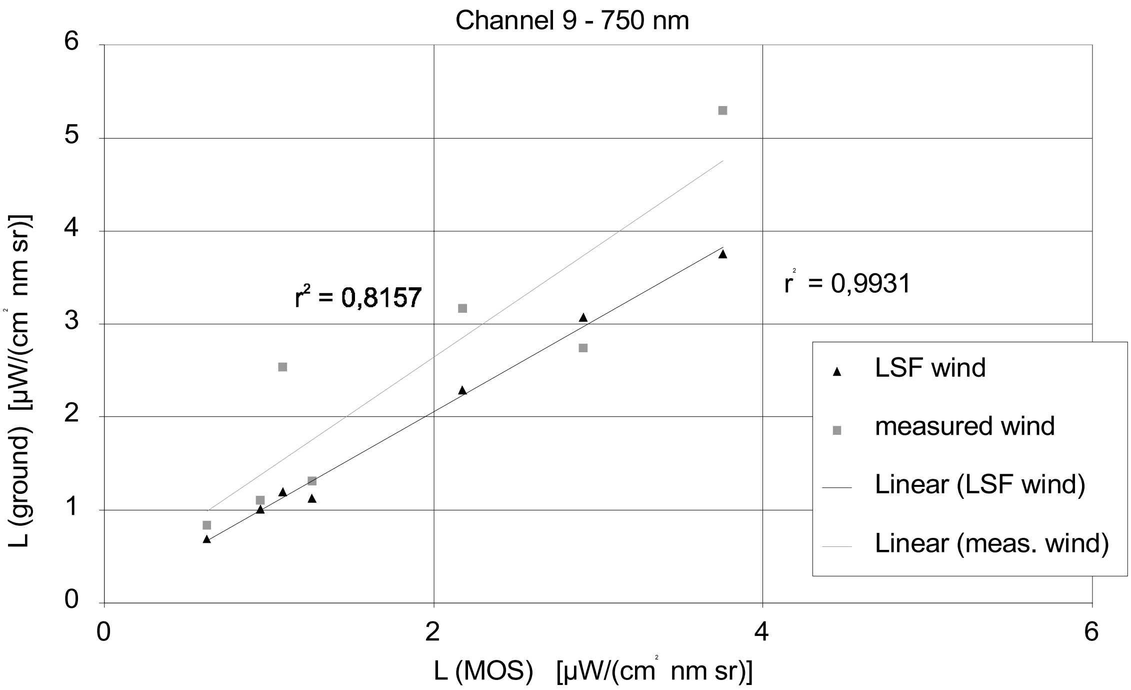

Figure 4: Comparison of modelled and measured MOS-radiance for channel 9 (750 nm).

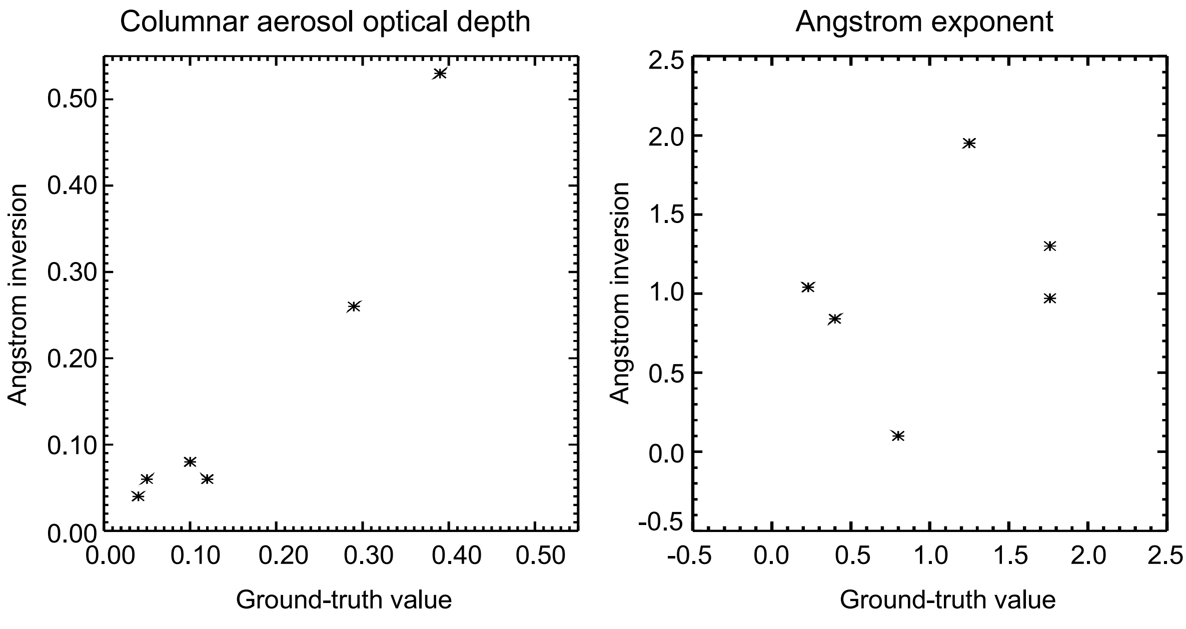

Fig. 5: Comparison of Angstrom inversion results with ground truth data.

Figure 4 demonstrates, that in nearly all cases a significantly better coincidence could be achieved between measured and modelled TOA radiances using LSF-fit wind speed. However, before using present results to find trustworthy conclusions for vicarious calibration of some MOS-channels, much more examples are required. That requires much more measurements at cloudless conditions.

VALIDATION OF ATMOSPHERIC CORRECTION ALGORITHMS

Algorithms for atmospheric correction of ocean colour measurements must estimate aerosol parameters from satellite data. Direct comparison of ground-truth aerosol parameters with results estimated from satellite data therefore allows experimental validation of atmospheric correction algorithms. This will be short demonstrated on example of the Angstrom Inversion algorithm (Krawczyk et.al., 1998), which estimates columnar aerosol optical thickness and Angstrom exponent for atmospheric correction.

Figure 5 shows a good agreement for aerosol optical thickness results except for one situation, where the Angstrom inversion algorithm overestimates aerosol optical thickness. This situation is the only one from Canary Islands region included into comparison at present time. Sun elevation is high at Canary Islands region and therefore ocean surface reflection significantly contributes to MOS-radiances. Present version of the Angstrom inversion algorithm only considers reflection of the flat ocean surface. Neglecting reflections of the rough ocean surface will lead to overestimated optical thickness values. Probably, the agreement between optical thickness estimated from satellite data and from ground-truth values will become still better for all situations, if the Angstrom inversion algorithm take into account reflection of the rough ocean surface. Angstrom exponent estimation using satellite data strongly depends on noise level. Numerical experiments have shown, that the retrieved Angstrom exponent varies by about ±0.5, if the noise level of data is of order 2%. Assuming this noise level for MOS-B data, Angstrom exponents estimated by the Angstrom inversion algorithm agree with ground truth values. Probably, estimation of Angstrom exponent from satellite data gets more stable, if more than 2 spectrometer channels are used. This assumption will be a topic of further investigations.

SUMMARY

Ground-truth results have been used to compute MOS-radiances for comparison with measured data. For all examples a fairly good coincidence between calculated radiances and MOS data can be seen and so the measurements are validated. Remaining differences exist in the NIR region of the spectrum where the measured signal in these MOS channels is too low. This confirms earlier investigations. Also a tendency for slightly high measured values in the first channels between 400 and 500 nm can be seen. However, many examples are still required until these results can assist other efforts in further reducing calibration uncertainties of the MOS sensor.

The ground-truth data are also used for validation of atmospheric correction algorithms. The agreement between aerosol optical thickness and Angstrom-exponent estimated from satellite data and ground-truth values confirms expectations.

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