Advancement of the AMSSP for Ground-Based Measurements of the Complete Stokes Vector

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1 Introduction

Aerosol scattering changes the state of sun light in terms of spectral intensity and polarization. Thus, polarization can be used to retrieve aerosol properties such as optical properties (AOT, refractive index,...), particle number concentration and other aerosol related parameters. The knowledge of aerosol parameters helps to examine and understand the effects of aerosols on the climate.
One way to describe polarization of light is the Stokes vector. The multispectral polarimeter AMSSP (airborne multispectral sunphotometer and polarimeter) measures four intensities with different sets of polarizing components simultaneously. Those intensities and a proper characterization of the components of the instrument are needed to calculate the complete Stokes vector. All angles and further parameters of the polarization sensitive optical components were determined during laboratory calibrations. On the basis of experimental experiences, the measurement setup of the AMSSP will be improved to get more stable polarization information.

2 AMSSP and measurement principle

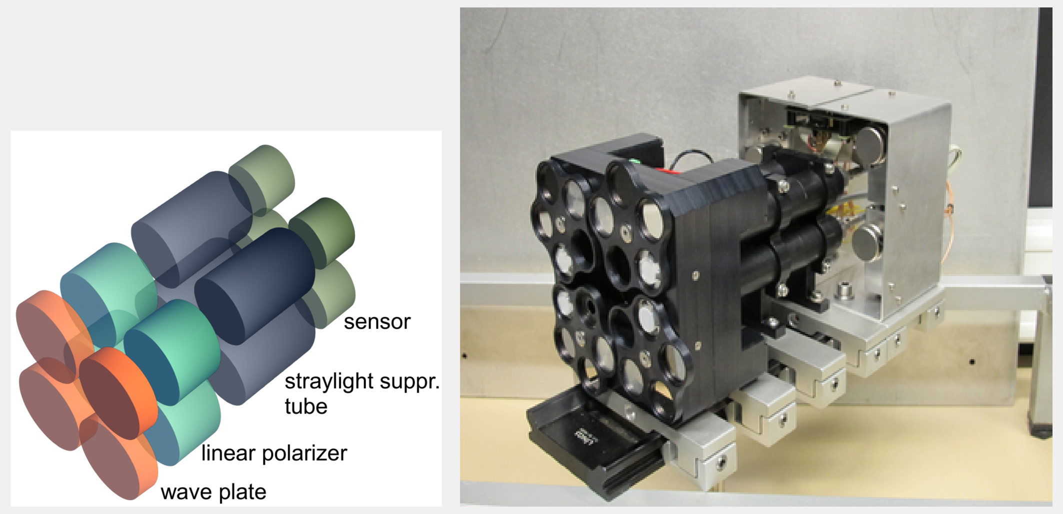


Fig. 1: Setup of AMSSP

- On four paths through the instrument, the light is changed by one polarizer and one wave plate
- Stokes vector $\vec{S} = [I, Q, U, V]$ of the light in front of the instrument is calculated by: $\vec{S} = A^{-1}\vec{I}$ with $\vec{I}$ the measured intensities and A the matrix which characterizes the effect of the optical components of the instrument on the light [1]
- Matrix A depends on angles of the polarizer ϕ_p, angles of the wave plates ϕ_w and the retardation δ_w

3 Laboratory calibration

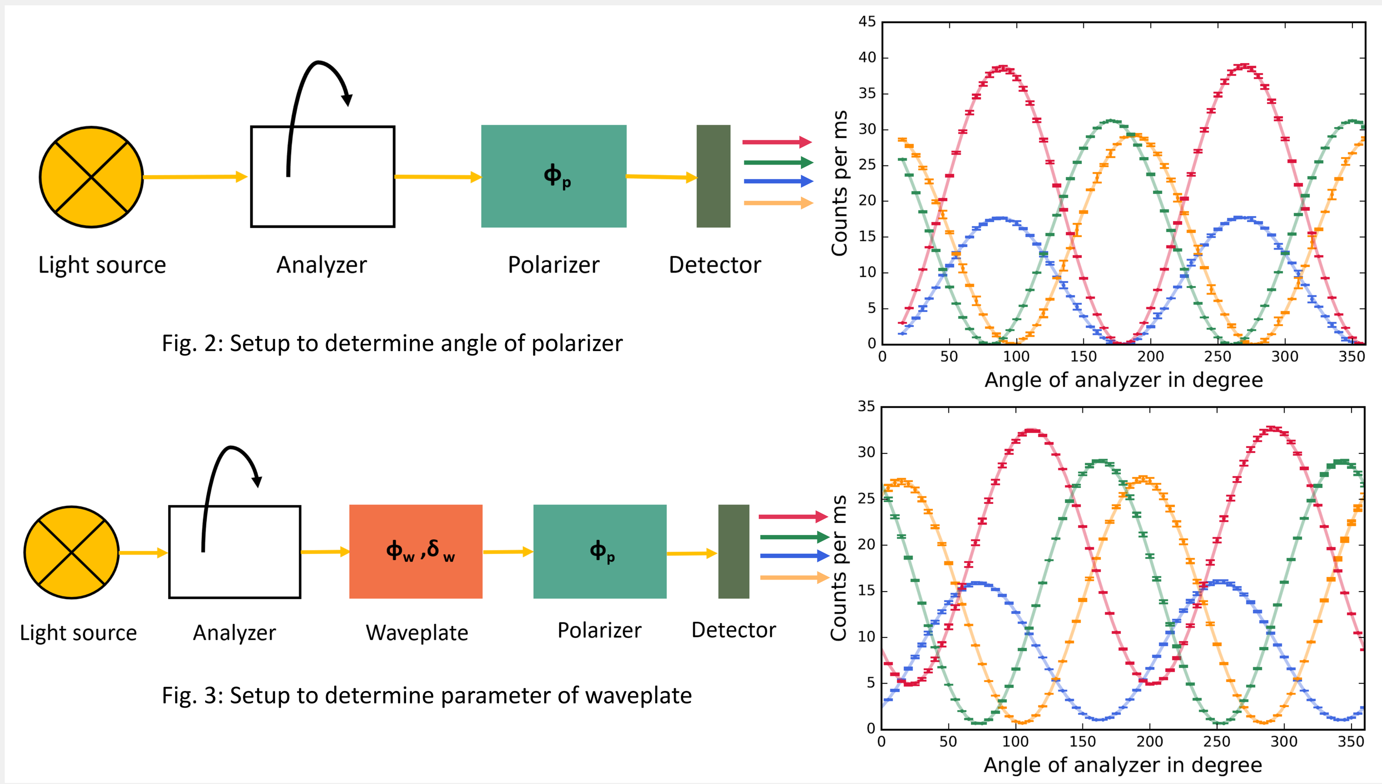


Fig. 2: Setup to determine angle of polarizer

Fig. 3: Setup to determine parameter of waveplate

Fit function to find angle of polarizer:

$$I = \vec{S}[0] = (M_p(\phi_p)M_p(\phi_{analyzer})\vec{S}_0)[0]$$

Fit function to find parameter of waveplate:

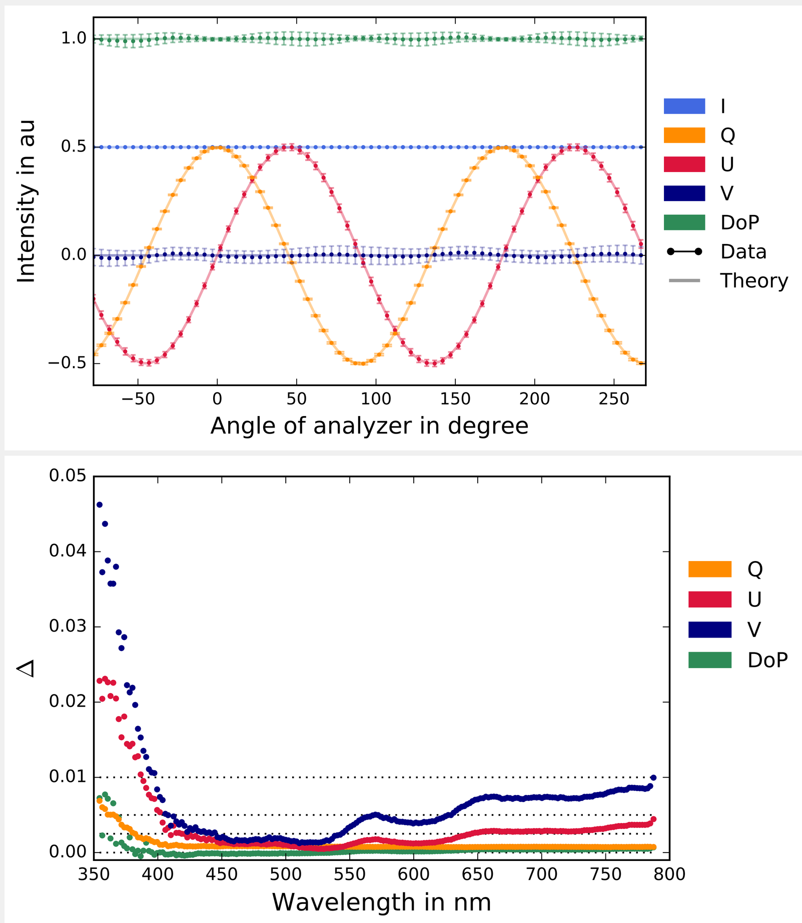
$$I = \vec{S}[0] = (M_w(\phi_w,\delta_w)M_p(\phi_p)M_p(\phi_{analyzer})\vec{S}_0)[0]$$

Data processing

- Working fit only with very good alignment of setup and accurate rotational stage of analyzer (rotating polarizer)
- Pre-processing: offset correction, averaging, wavelength calibration, time normalization
- Fit measured intensity with theoretical intensity derived using Mueller matrices of polarizer (M_p) and wave plates (M_w) [2] and an input Stokes vector ($\vec{S}_0 = [1,0,0,0]$) of unpolarized light

Results

- Angles and retardations of optical elements determined with fit
- Additional fit parameter: amplitude factor, used for relative calibration
- Matrix A and A^{-1} calculated to determine Stokes vector
- Complete polarized Stokes vector could be calculated using $\vec{S} = A^{-1}\vec{I}$ shown in upper plot for 633 nm
- Absolute difference (Δ) between calculated Stokes parameter and theoretical values for each wavelength as mean over all analyzer angles in lower plot



4 Uncertainty estimation and consitency

Uncertainty estimation

$$\left(\Delta\frac{S_i}{S_0}\right)^2 = \sum_{j=0}^{3}\left(\frac{\partial\frac{S_i}{S_0}}{\partial A^{-1}_{ij}}\Delta A^{-1}_{ij}\right)^2 + \left(\frac{\partial\frac{S_i}{S_0}}{\partial A^{-1}_{0j}}\Delta A^{-1}_{0j}\right)^2 + \left(\frac{\partial\frac{S_i}{S_0}}{\partial I_j}\Delta I_j\right)^2$$

with ΔA^{-1} calculated using difference quotients:

$$\Delta A^{-1} = \sqrt{\left(\frac{\partial A^{-1}}{\partial\phi_{w0}}\Delta\phi_{w0}\right)^2 + \ldots + \left(\frac{\partial A^{-1}}{\partial\delta_0}\Delta\delta_0\right)^2 + \ldots + \left(\frac{\partial A^{-1}}{\partial\phi_{p3}}\Delta\phi_{p3}\right)^2}$$

and uncertainty of measured intensities

$$\Delta I_j = \sqrt{\Delta I^2_{dc} + \Delta I^2_{lin.Regr.} + \Delta I^2_{\Delta 180^o}}.$$

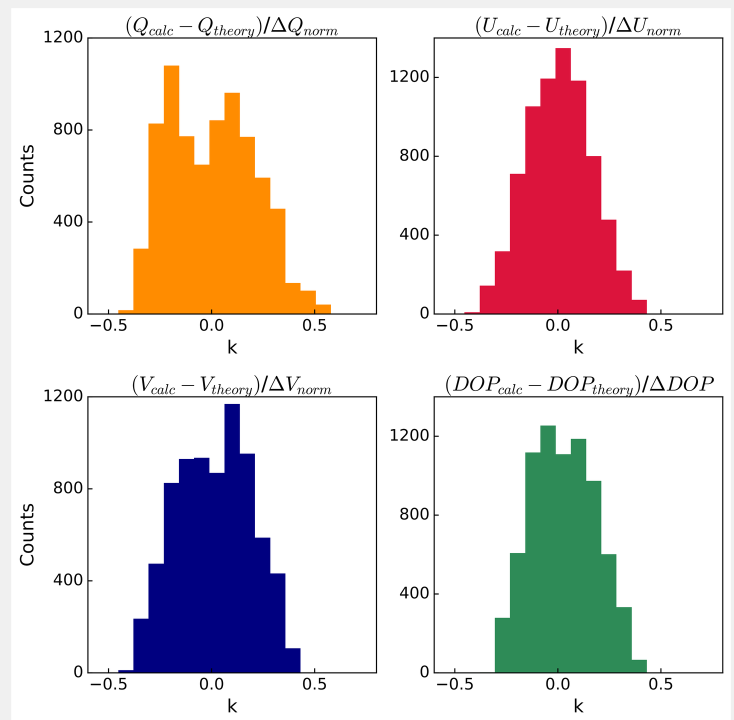
with uncertainties originating from the data processing: dark current correction (ΔI_{dc}), averaging ($\Delta I_{lin.Regr.}$) and from fluctuations of setup ($\Delta I_{\Delta 180^o}$).

Consistency

- Consitency check as shown by Immler et al. [3]:

$$\|m_1 - m_2\| > k\sqrt{u_1^2 + u_2^2}.$$

- k-value for all estimated Stokes parameters at the different angles of the analyzer:



5 Advancement

- New operating platform:
  - rotation of complete instrument towards desired viewing direction
  - no mirrors needed which could change polarization properties of light indistinct
  - direct sun measurements for adjustment and measurement of AOT
  - simultaneous measurements of atmospheric trace gases with Pandora-2S
- Adjustable entrance optics to ensure same viewing direction of four spectrometer
- New waveplates with less wavelength dependence to make calibration routine more robust

Fig. 2: Operating platform before installation of instruments.

6 References

[1] André Hollstein et al. "Optimization of system parameters for a complete multispectral polarimeter". In: *Applied optics* 48.24 (2009), pp. 4767–4773.

[2] Russell A Chipman, Wai Sze Tiffany Lam, and Garam Young. *Polarized Light and Optical Systems*. CRC Press, 2018, pp. 169,175.

[3] FJ Immler et al. "Reference quality upper-air measurements: Guidance for developing GRUAN data products". In: *Atmospheric Measurement Techniques* 3.5 (2010), pp. 1217–1231.