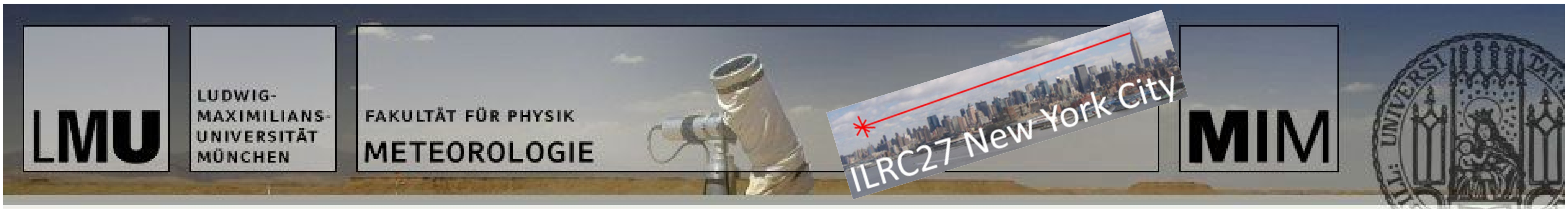

Accuracy of linear depolaristion ratios in clear air ranges measured with POLIS-6 at 355 and 532 nm

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Introduction

The POLIS-6 lidar system (specs. see Tab. 1) has been designed for high accurate linear depolarization ratio (LDR) measurements at two wavelengths (355 and 532 nm). An inadequate calibration technique and the neglect of important systematic influences, like diattenuation of the optics, can lead to large errors in the linear depolarization ratio measured with lidar systems. Here we show how the high accuracy is achieved with POLIS-6 and how accurate it really is by comparing measurements during SALTRACE with the theoretical values of the molecular LDR.

Table Specifications of POLIS-6

Laser	Nd:YAG Litron LG-250-10
Emitted wavelengths [nm]	355, pol. vertical / 532, pol. horiz.
SHG/THG	KTP II / BBO
Emitted pulse energy	50 / 27 mJ*
Repetition rate	10 Hz
Puls length	4 - 6 ns
Pointing stability	< 70 µrad fw
Beam divergence	<0.5 mrad**
Telescope	Dall-Kirkham
Effective diameter	175 mm
Focal length	1200 mm
Field of view [mrad]	variable, typ. ±2.5
Detection channels	355s, 355p, 387, 532s, 532p, 607
Filter bandwidths: CWL, BW fwhm [nm]	354.6 s&p, 1.1 386.7, 0.52 532.04 s&p, 0.97 607.54, 1.38
Additional polarization-filters: WL (nm), type, extinction ratio	ITOS: 355, XP-38R, 6.4e-4 532, XP-40HT, 2e-4
Data acquisition	6x Licel TR 40-160
Range resolution	3.75 m

* with internal attenuation
** full width (fw) at 90% of output energy

Lidar setup (like design of POLIS-6)

– Avoid production of elliptical polarization between the laser and the polarizing beam splitter.
– Do not use inclined emitter optics (no beam-steering)!
– Because the orientation of the plane of polarisation of the laser is usually not known => include the possibility to rotate the laser polarization (laser rotation, ε). POLIS-6: included in the Δ90°-calibration setup (see [2])
– Avoid any rotational misaligment around the optical axis of inclined optics (beamsplitters).
– Include an accurate polarization calibration in the design. POLIS-6: mechanical Δ90°-calibration (see [2])
– Suppress cross talk of the polarizing beam splitter with additional polarization filters (see table)
– Use only optics with well known and / or low diattenuation D_O => is sometimes correctable / or negligible
POLIS-6: very small, in total $D_O = 0.002$ @355 nm and 0.032 @532 nm

$$D_O = \frac{T_p - T_s}{T_p + T_s}$$

Figure 1: POLIS-6 with the receiving optics rotated at ±45° (left, right) for the **Δ90°-calibration**, and at 0° (middle) for atmospheric measurements.

Theoretical molecular linear depolarization ratio

Interference filter bandwidth is very small (0.2 – 3 nm typ.) => exact shape and center wavelength must be considered (Fig. 3); Avoid temperature dependence!
Rotational Raman line LDR is 0.75 (wings) in contrast to ~0.004 of the central line at the laser wavelength => calculate RRL intensities (Fig. 3) [8] and resulting LDR (Fig. 6) considering
- **laser wavelength:** unkown on the order of 0.1 nm due to unknown rod temp. (Fig. 4) [5, 6]
- **air temperature:** variable with height range where clean air was found

Results: expected molecular LDR with POLIS-6 under local conditions (Fig. 6):
LDRmol = 0.00785 ± 0.00024 at 355 nm and 0.00444 ± 0.00008 at 532 nm

Measurements

– Sufficient temporal averaging, stable atmospheric conditions => decrease random errors. Here: favorable measurement conditions during SALTRACE (Barbados) stable atmosphere; low clean air range.
– Determine (Fig. 5) and correct the laser rotation (ε) and correct for diattenuation D_O (Eq. 1, theroy see [2]). δ^* is the uncorrected and δ the corrected LDR.
– Calculate errors from known systematic uncertainties (Fig. 6): i.e. calibration error, laser rotation error (Eq. 2, theroy see [2]) .
– Determine the weighted mean and deviation over all measurements (Fig. 6)
LDRmeas = 0.00824 ± 0.00021 at 355 nm and 0.00546 ± 0.00031 at 532 nm

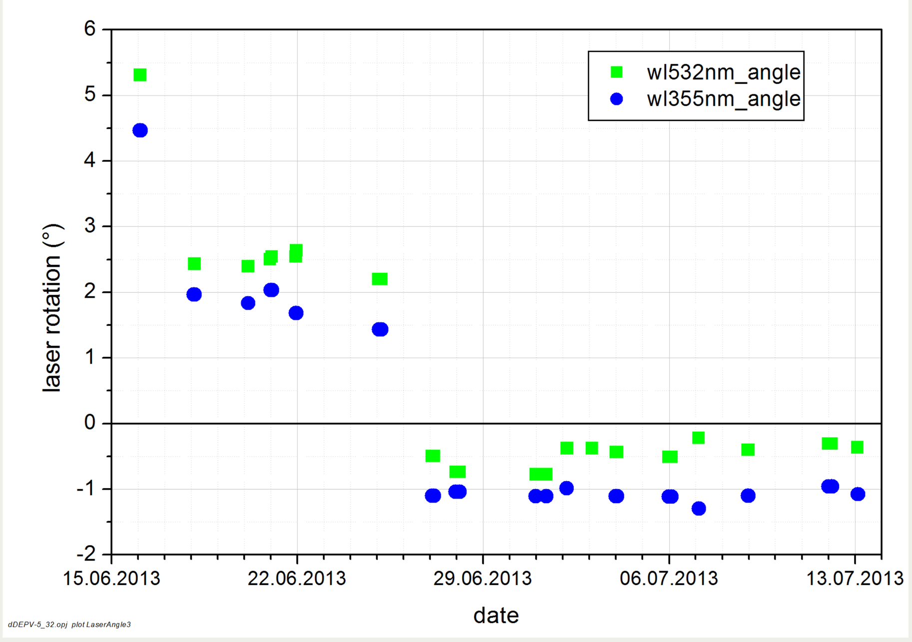

Figure 5: Rotation ε between the plane of polarization of the laser beam and the incidence plane of the receiving optics (**laser rotation**) determined with the Δ90°-calibration.

$$\delta = \frac{1 + D_O}{1 - D_O} \frac{\delta^* - \tan^2 \varepsilon}{1 - \delta^* \tan^2 \varepsilon} \quad \text{Eq. (1)}$$

$$|\Delta\delta| \approx \frac{1 + D_O}{1 - D_O}\left(|\Delta\delta^*| + |2\varepsilon\Delta\varepsilon|\right) \quad \text{Eq. (2)}$$

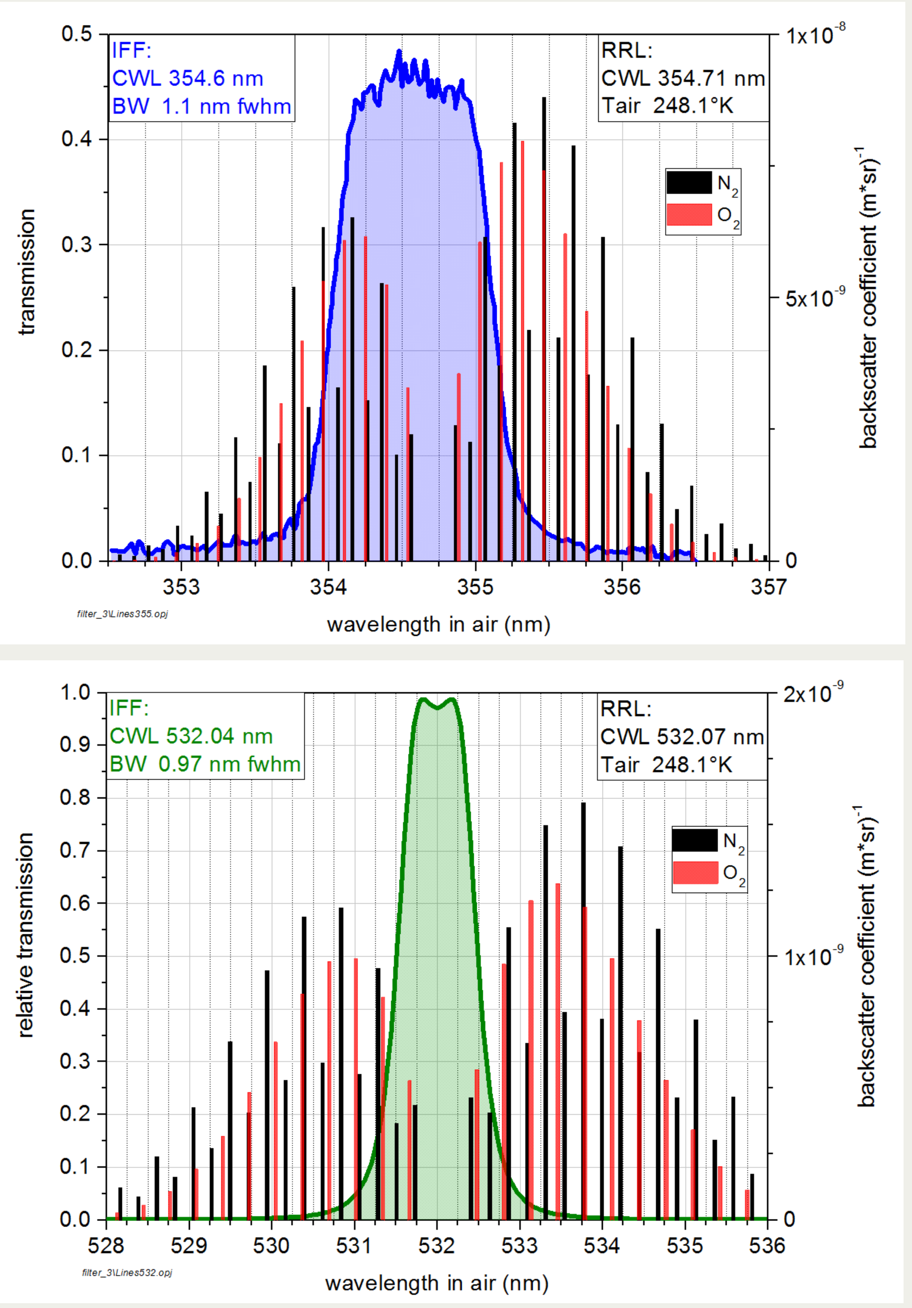

Figure 3: Rotational Raman lines (RRL, backscatter coefficient, right scale) of N_2 and O_2 at 248 K air temperature (central line omitted) and the transmission of the used interference filters (IFF) (see Table for BW and CWL).

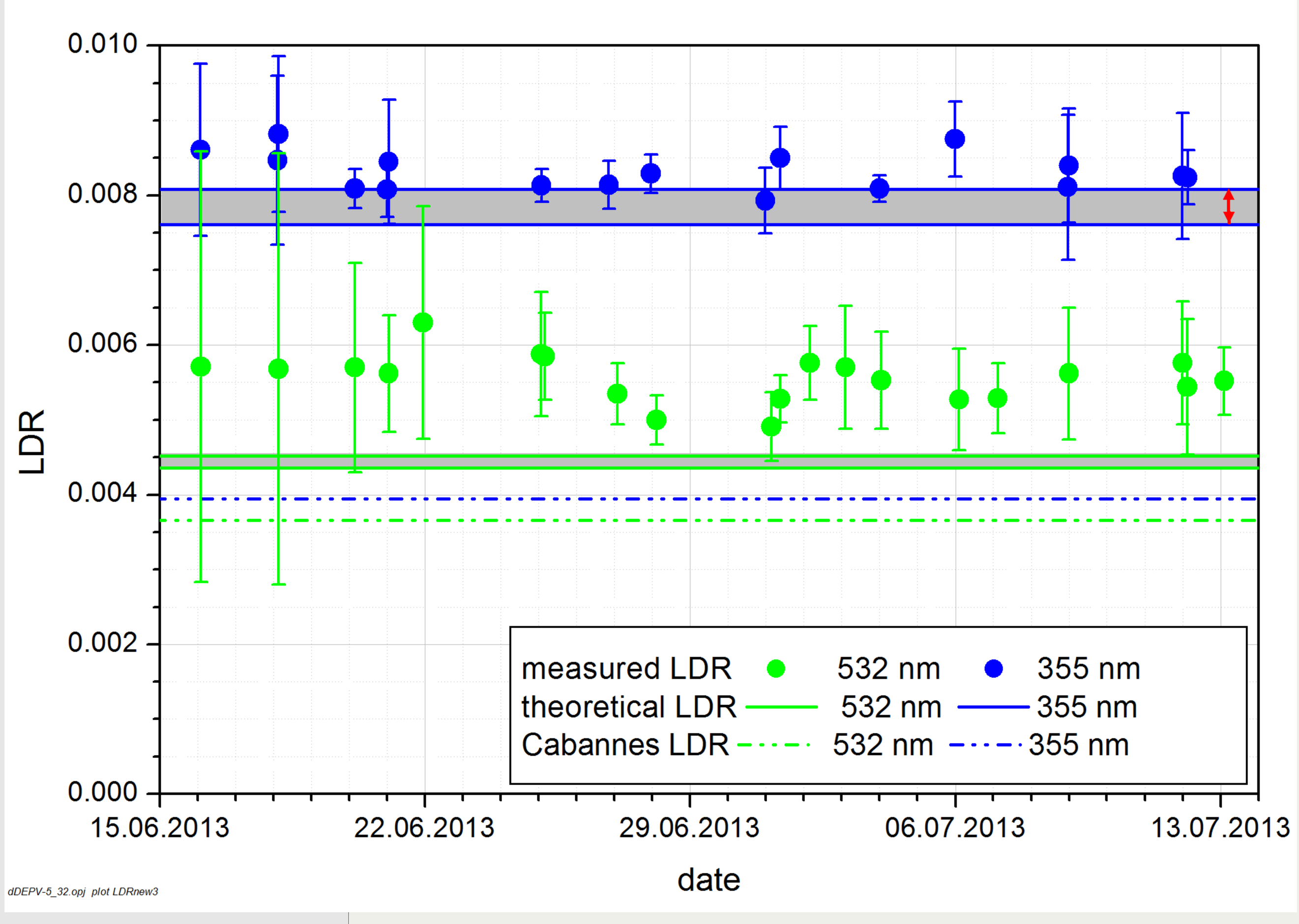

Figure 6: Linear depolarization ratios (LDR) of presumable clean air ranges **measured** during SALTRACE with POLIS-6 at 355 and 532 nm (dots with systematic error bars). The dash-dotted lines show the theoretical LDR if only the central Cabannes line passes the IFF, and the gray areas between solid lines show the theoretical ranges of LDRmol from Fig. 4.

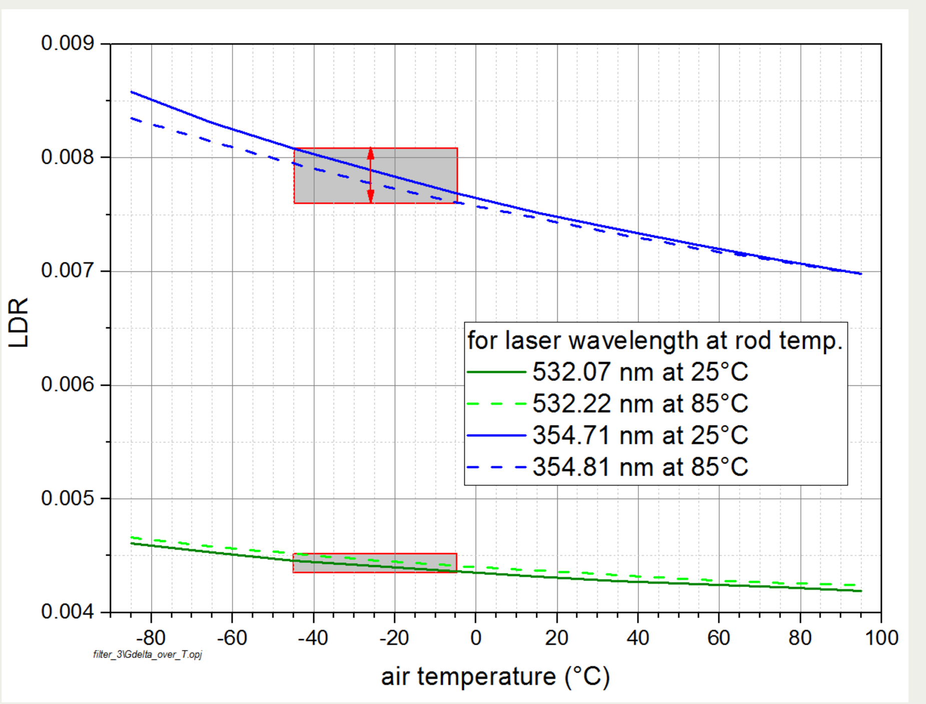

Figure 4: Theoretical LDRmol of clean air (with 385 ppmv CO_2 and 0% RH) over air temperature including the rotational Raman lines of O_2 and N_2 within the used IFF bandwidths and considering laser wavelength ranges for rod temperatures between 25°C and 85°C. The red rectangles show the considered variability of air temperature and laser wavelength, and the red arrow the resulting uncertainty of the theoretical LDR.

Conclusion

While the measured LDR at 355 nm agree with the theoretical LDRmol values within the error bars (mean difference ~0.0004), the difference at 532 nm is larger (mean difference ~0.001) and significant considering the error bars; the source of that is unknown, but certainly an offset and not the calibration factor with a relative error always less than ±2% due to the accurate Δ90°-calibration. This is important, because an error of ~0.001/0.0055 would mean a relative meas. error of ~18% for all other LDR values of aerosol like Saharan dust or cirrus clouds.

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