EARLINET Internal Checkups

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Internal lidar checkup procedures

1 Introduction

The following measurements are part of the internal lidar system checkups. The telecover measurements are mandatory, while the calculation of deviations is not mandatory. I will do that.
The other tests should be performed and submitted as soon as possible. The dark measurements can be done with the telecover measurements and appended to this data file. The Rayleigh fit can be retrieved from a regular EARLINET measurement.
Details for each test are described below.
The preferred format for the submission of the data is described in chapter 6.

2 Telecover

The telecover checkup tool is described in more detail in EA-NA3-QA-Telecover-2.html.

A brief summary:

2.1 Nomencalture

Quadrant test: N,E,W,S,N2
Octant test : NO,EO,SO,WO,NO2 and NI,EI,SI,WI,NI2 looking from the sky into the telescope.
In-Out test : FO, FI
Dark measurement : D
FI is the inner ring, FO the outer ring, D is a dark measurement with the telescope fully covered.
The N2, NO2 or NI2 measurements are additional at the end of each cycle in order to estimate the influence of the atmospheric changes since the start of the measurements. This can be evaluated from N - N2. In case N2 is not possible, please measure something equivalent.

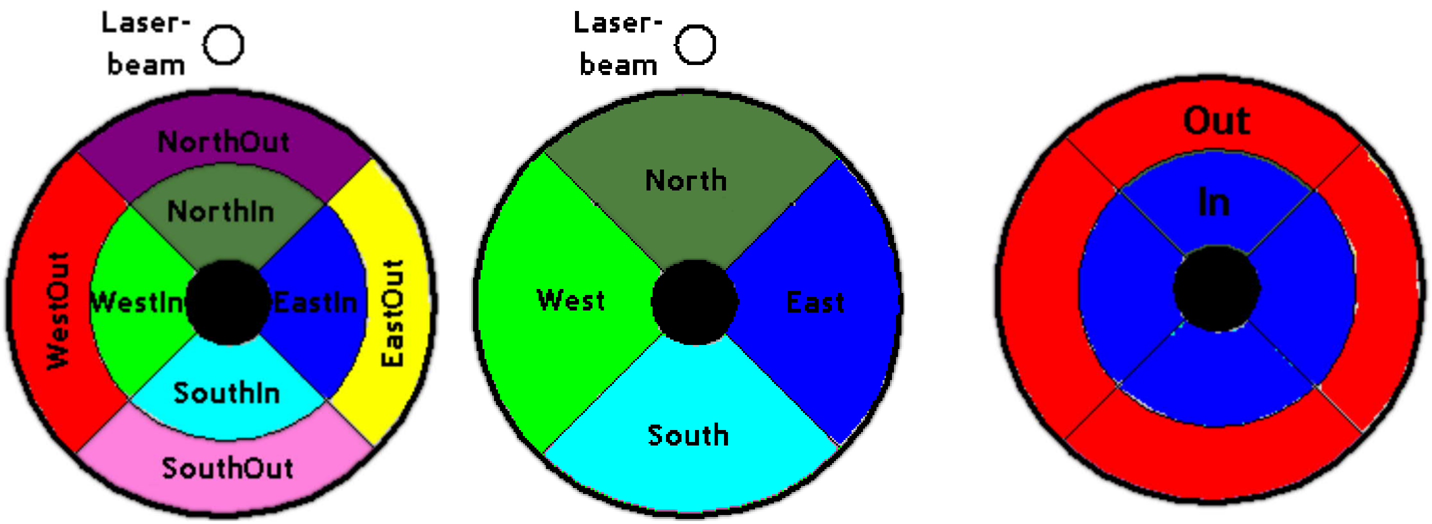

Figure 1

2.2 Required measurements

Biaxial systems: For the first attempt a quadrant test should be sufficient.
Monoaxial systems: In order to check laser tilt and other deviations, at least a quadrant and an In-Out test should be performed.

If necessary, the octant measurements can be performed for further investigations.

2.3 Calculation of deviations (not mandatory)

For the deviations I propose to calculate point by point

1. the mean of of all profiles: mean = (N + E + S + W) / 4 ...
2. the relative deviation of each profile (NDev, EDev,...) from the mean : NDev = (N - mean) / mean ....
3. the realtive RMS deviation of all profiles: AllDev = sqrt ((NDev^2 + EDev^2 + SDev^2 + WDev^2) / 4) ...
4. the atmospheric change (N - N2) / mean
   or the equivalent means and deviations (In, Out ....).

2.4 Smoothing and normalization

The measurements should be sufficiently smoothed over range or time in order to keep the deviations due to signal noise well below the limits.
According to my recent experience, the submission of non-normalized range corrected signals is preferred. This gives additional information about the relative intensity of the individual telescope sectors.

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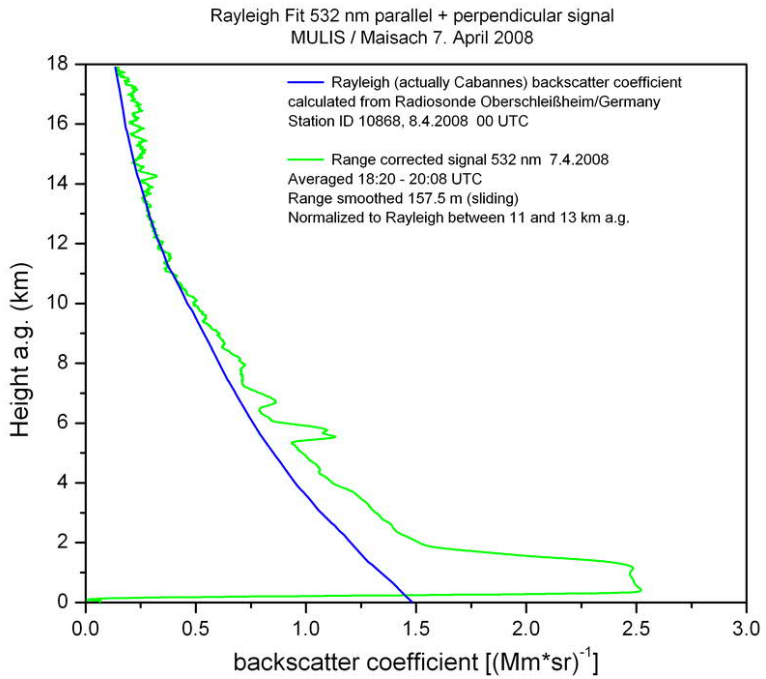
3 Rayleigh Fit

This checkup tells us the quality of the signals in the far range. Especially analog signals show distortions there. Additionally we gather information about the use of Radiosonde data at different sites.
Please provide for each channel a 30 min. averaged, range corrected signal (maybe from your records; please) together with the Rayleigh backscatter coefficient according to your standard calculation of the reference value for the Fernald/Klett/Raman retrievals. If you do this in another way, please write one or two sentences how you calibrate the signals.
Example:



Comments:

Actually the "Rayleigh Fit" is a normalization of the lidar signal to the calculated attenuated Rayleigh backscatter coefficient ($ß_R^{attn}$) in a range where we assume clean (Rayleigh) conditions and where the calculated signal fits the lidar signal sufficiently good.

A problem is that the reference value for the Fernald/Klett inversion has to be at a single rangebin, but the normalized lidar signal and the $ß_R^{attn}$ can be different over the whole fit range due to signal noise. That means the normalized lidar signal might not have any rangebin which can be used as a reference value for the inversion without introducing a noise error. There are probably several solutions for this problem.

My solution : I replace a value in the normalized lidar signal at the middle rangebin of the fitting range with the corresponding value of the calculated $ß_R^{attn}$.

I consider this as physically correct and exact solution. Comments are wellcome and can be published here.

My Rayleigh Fit procedure :

Let the lidar signal be:

$$P(r)r^2 \propto \left(\beta_R(r)+\beta_P(r)\right)\exp\left[-2\int_0^r\left(\alpha_R(r')+\alpha_P(r')\right)dr'\right]$$

1. Select a range in the lidar signal where clean air can be assumed (rmax, rmin).
2. Caclulate the ß $_R^{attn}$ using a "good" radiosonde, with attenuation starting at the middle rangebin (r_0 , reference range) of the selected range (rmin, rmax).

   $$\beta_R^{attn}(r,r_0)=\beta_R(r)\exp\left[-2\int_{r_0}^{r}\alpha_R(r')dr'\right]$$

   This means negative attenuation for r < r0 , and keeps the exact reference value at the reference range r0

   $$\beta_R^{attn}(r_0,r_0)=\beta_R(r_0)$$

3. Check whether the fit is sufficiently good. A general procedure to evaluate the "goodness of fit" is under development. Ideas are welcome.
4. If the fit is not good, repeat 1. to 3. until it is good.
5. Normalize the lidar signal to the ß $_R^{attn}$ using the means of the ß $_R^{attn}$ and of the lidar signal over the fit range. This avoids an additional error due to signal noise in the fit range.

   $$P^{norm}(r,r_0)r^2=P(r)r^2\frac{\int_{r\,\min}^{r\,\max}\beta_R^{attn}(r,r_0)dr}{\int_{r\,\min}^{r\,\max}P(r')r'^2\,dr}$$

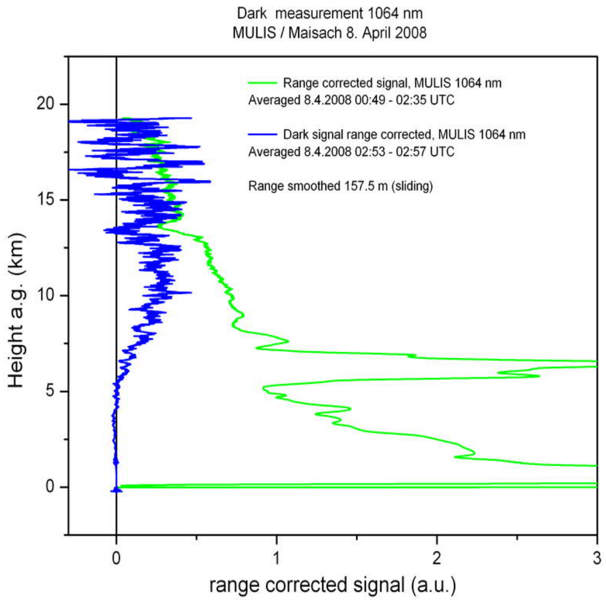
6. Replace the value of the lidar signal at the middle rangebin r0 with the value of the Rayleigh backscatter coefficient at this rangebin ß $_R$(r0). Note: this value should be the same as the one of the ß $_R^{attn}$ at this rangebin, i.e. the right reference value for Fernald/Klett.

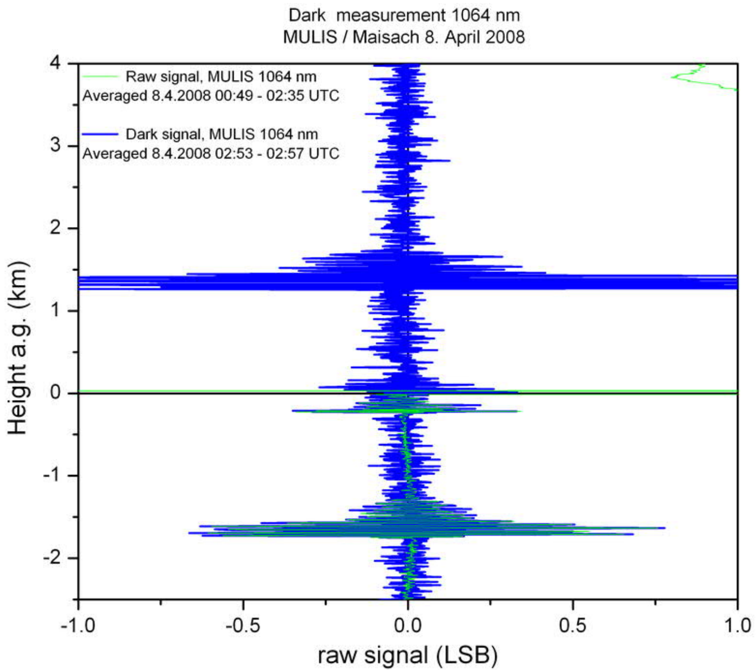
   $$P^{norm}(r_0,r_0)r^2=\beta_R^{attn}(r_0,r_0)=\beta_R(r_0)$$

7. Start the Fernald/Klett inversion from this rangebin.

4 Dark measurement

A dark mesurement is a normal measurement with sufficient time averaging, but with a fully covered telescope or with covered detectors. This signal shows all electronic stray pick-ups and signal distortions wich do not stem from the atmospheric backscatter, but from the lidar system itself; e.g. laser flash-lamp pulse pick-ups, or system trigger pick-ups. All system parameters, like e.g. detector HV, must be set in the same way as for a normal measurement.
Please make shure that no laser light reaches the detectors.
The dark measurement should be done and submitted with the telecover measurements (actually it is a telecover with fully covered telescope) and with the Rayleigh-fit in an addtional column marked as D .
Example:





The left picture shows range corrected signals: dark-measurement (blue) and a regular measurements (green) for comparison, while the right picture shows the same but raw signals zoomed-in intensity and towards the pretrigger regime. In the right picture the stray pick-up of the laser flash lamp and Q-switch triggers can be seen in the Dark signal as well as in the real signal before the Zero-bin. Under favourable circumstances, the dark signal can be subtracted from the real signal.
Whether this is possible or not must be investigated for each lidar channel and system setup separately.

Dark signals can change over short time when signal or trigger cables are touched, reconnected, or moved.
Hence the dark measurements should be performed immediatelly before or after the normal measurements without any system changes.

The dark signal subtraction can improve the signals - or the opposite, depending on the temporal stablility of the dark signal.
You have to decide for each channel what is the best.

Furthermore, the dark signal always adds some noise. Hence I propose to smooth the dark signal in the far range over long range periods corresponding to the bandwidth of the disturbance, and to not smooth it in the near range, where tirgger interspersions are at high frequencies.

In case of dark signal subtraction, you should do the background subtraction after the dark signal subtraction.
Please mention in the file header whether the signal is "dark signal subtracted".

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5 Zero-bin measurement

5.1 Theory

An error in the triggerdelay between the real laser output and the detection system start (system trigger, Zero-bin) can cause large errors in the near range signal up to about 1 km range. Especially the Raman signals can be distorted dramatically, because the signal slope in the near range changes very much when the trigger delay for the range correction is varied. Thus it is worth some effort to verify that the Zero-bin is really where we assume it to be.

The particle extiction coefficient $\alpha_p(r)$ can be calculated from Raman measurements according to:

$$\alpha_p(r) = \frac{\frac{d}{dr}\ln\alpha_m(r) - \frac{d}{dr}\ln\left[r^2 P(r)\right] - (1+f_m)\alpha_m(r)}{(1+f_p)}$$

with range r , subscripts p and m for particle and molecular components, the Raman lidar signal P (r) at the Raman wavelength, and f for the wavelength dependence terms

$$f_m = \left(\frac{\lambda_{Raman}}{\lambda_{Laser}} \right)^{4.085} \quad \text{and} \quad f_p = \left(\frac{\lambda_{Raman}}{\lambda_{Laser}} \right)^{k}$$

The uncertainty of the true Zero-Range r_0 can be accounted for by substitution of the range correction factor r^2 by $(r - r_0)^2$, and after separating this factor from the signal P , we get :

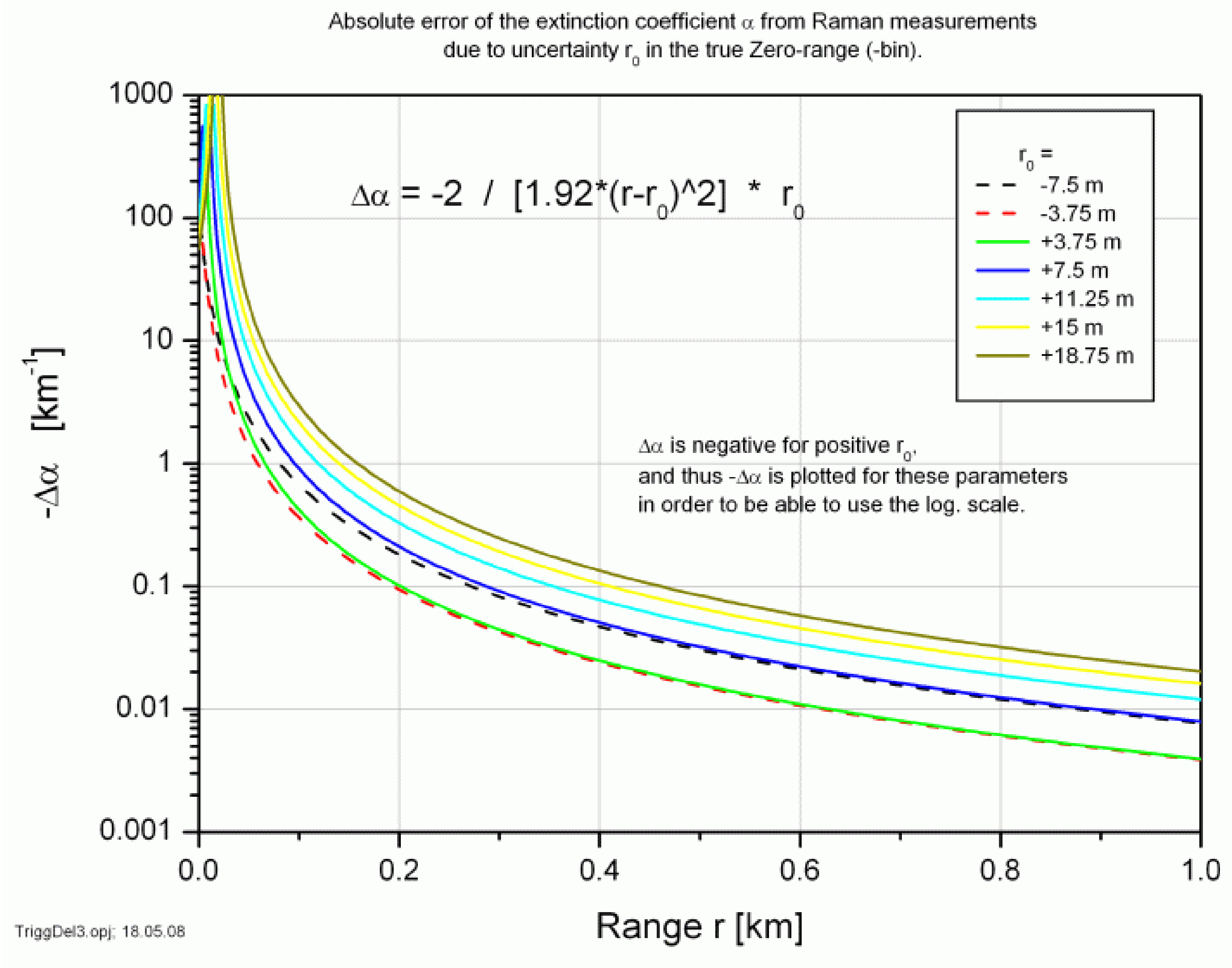
$$\alpha_p(r, r_0) = \frac{\frac{d}{dr} \ln \alpha_m(r) - \frac{d}{dr} \ln P(r) - \frac{d}{dr} \ln (r - r_0)^2 - (1 + f_m) \alpha_m(r)}{(1 + f_p)}$$

After differentiation with respect to r_0 etc. it follows that the absolute error of the particle extinction coefficient depends only on r_0 and f_p :

$$\boxed{\Delta \alpha_p(r, r_0) = \frac{2}{1 + f_p} * \frac{1}{(r - r_0)^2} * r_0}$$

For λ_{Laser} = 355 nm, λ_{Raman} = 387 nm and k = 1 follows f_p = 0.92.

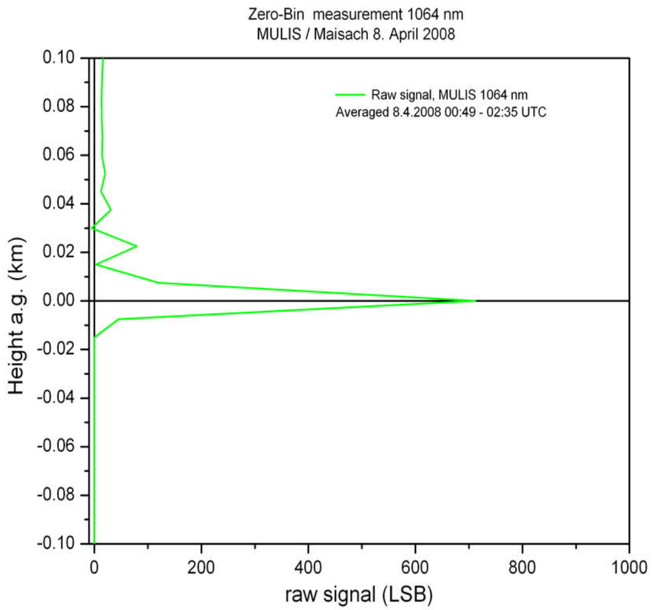
Although we can only measure the range in steps (range bin) according to the resolution of the transient recorder, i.e. 3.75 m or 7.5 m for the LICEL systems TR40 and TR20, respectively, the uncertainty r_0 can take any value, as it results from several trigger delays independent from the transient recorder. However, below some results for the error with Zero-range errors in fixed rangesteps:



5.2 How to measure

In case pretrigger samples are recorded, the Zero-bin can easily be detected due to the signal peak from stray-light reflected from the laboratory walls or similar, as can be seen in the picture below. In our case the roof-window side walls reflect enough diffuse laser light to

produce a pronounced Zero-bin peak.
This peak could be enhanced and discerned from other near range reflections by blocking the laser output with a diffuse reflecting material (like e.g. paperboard).



Zero-bin pulse of MULIS/Munich from diffuse reflections of the outgoing laser pulse from the roof window of the lidar lab.

In case no pretrigger samples are recorded:

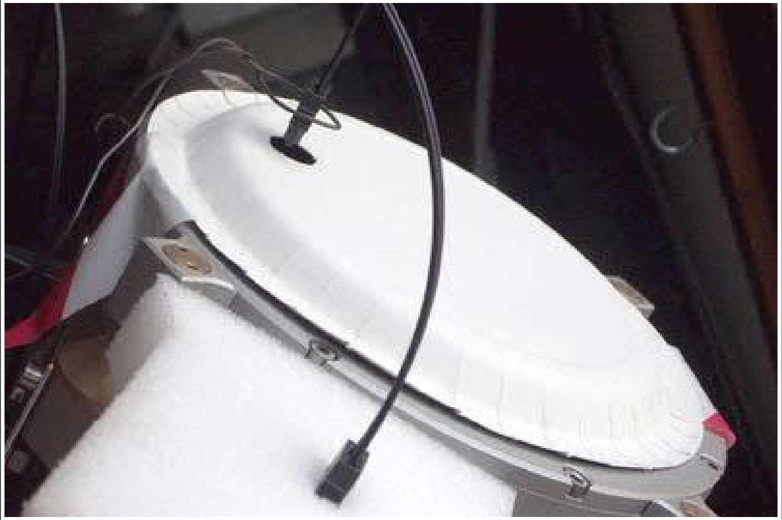
1. A <u>near range target</u> with a defined distance to the lidar could produce a signal peak for Zero-bin calibration.
For LICEL systems without trigger generator (and thus without pretrigger) a distance of one or two rangebins (7.5 to 15 m for TR20) could be sufficient.

2. <u>Optical fiber delay</u> : The outgoing laser pulse - sufficiently attenuated - can be fed into an optical fiber with sufficient length s , and the fiber output positioned at the aperture of the telescope. Thus a signal pulse would be measured with a delay dt = s / v = s / c * n to the outgoing laser pulse, with c = speed of light in vacuum, v = speed of light in the fiber with refractive index n . The delay in range bins dRB is then dRB = dt / t_{RB} , with t_{RB} = duration of one range bin in seconds.

Below are some images about how we realized that for POLIS with LICEL TR20 recorders.

A 15 m long optical fiber (full plastic, cheep, for optical communication) with about 1 mm core diameter and a core refractive index of about 1.5 is used to produce a laser pulse delay of 75 ns, which amounts to 1.5 range bins for a LICEL TR20 recorder.	
For the input of the laser pulse into the fiber we use a hard plastic foam typically used for packing, which serves as a good light diffusor.	

With the radial distance of the laser spot to the fiber, we can controle the signal pulse intensity. If the telescope can see the diffusely scattered light from the foam, we get an additional peak at the Zero-bin.	
In order to reduce the diffuse scattering and to remove the atmospheric lidar signal, the telescope is covered with cardboard, leaving a hole for the fiber input. Please don't forget to wear laser safety glasses!	

Having now a single pulse in the signals, also the trigger delay between different channels can be measured (e.g. analog - photon counting for LICEL systems).	

Please note:
1. There is a system immanent delay between the analog and photoncounting Zero-bin in LICEL systems described in the manual. This delay is different for different systems. This can be up to 7 rangebins (personal communication, Bernd Mielke, LICEL). Please contact LICEL to get information about this delay in your system.
2. There can be additional delays between the optical laser pulse and the time the electronic trigger pulse from the laser electronics reaches the trigger input of the data acquisition system due to delays in the laser electronics and the trigger cables etc. .

5.3 Information about available fibers

Barbara Lahnor got information (from MPI) about a cheap fiber made by AVAGO Technologies and ordered it from Farnell:

100 m cost about 120 Euro

```
HFBR EUS100Z
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http://no.farnell.com/avago-technologies/hfbr-eus100z/cable-optical-fibre-100m-poly/dp/1247698?Ntt=HFBR+EUS100z

```
Attenuation per Metre:0.19dB
Cladding Diameter:1000µm
Cladding Refractive Index:1.417
Core Diameter:1mm
Core Refractive Index:1.492
External Diameter:2.2mm
Length:100m
```

6 Submission data format

6.1 General Information

Dark measurements

In the past, the submission of the dark-measurements was meant to be sure that you are aware of possible problems and that you take the appropriate measures.
Recently it turned out that for some lidar systems the dark-signal subtraction is absolutely necessary in order to make the gluing of the analogue and photon-counting signals possible.
Therefore the QA must make sure and demonstrate that you are doing the right thing.
Since recently my software can subtract the dark-signals from the submitted Rayleigh-fit and telecover signals if they are appended in the D-column (<u>background subtracted, and range-corrected with the correct trigger-delay as the other signals</u>).
The dark-signals must be included in the Rayleigh-fit and/or telecover files, and the header must indicate whether you already subtracted them from the other signals, as indicated below.
For the polarisation calibration files I assume that you do the necessary and no D-column is needed.
If you submit only glued signals, I assume that you already subtracted the dark-signals if necessary, but to make sure that you are aware of the problem, please append a column with the dark-signals.
If you submit separate analogue and pc signals, you must append the dark-signals to the analogue signals and indicate in the header whether you already subtracted them.
Dark signals are only necessary and meaningful for analogue signals. In photon-counting files they will be ignored.

Data files

- Encoding: ASCII
- Columns must be separated by commas. Spaces are neglected.
- Decimal sign must be point.
- Provide at least 4 significant decimal digits over the whole range (scientific number format e.g. 1.234e-04 or 0.0001234)
- Line breaks: DOS/Windows (CR+LF). Please mention in the email if you cannot produce CR+LF line breaks and line breaks are UNIX (CR).

The data files must contain following header lines (descriptive, not for programmed reading):

1. lidar site (according HOI)

2. lidar system (system name)
3. signal/channel (analog or photoncounting), named according the HOI, dark-subtraction
4. date of the measurement, time (dd.mm.yyyy, hh - just to discern different measurements of the same day)
5. additional line/s
6. column names
7. ... data (please follow the format rules below!)

6.2 Data examples

6.2.1 Telecover (According to my recent experience, the submission must contain non-normalized , range corrected signals.)
Dark measurements must be appended in the analogue files marked as D . => NEW: best to submit with Rayleigh Fit signals (see below).
One file for each wavelength.
No columns/data other than quadrant, octant, In/Out, and D measurements.
Do not forget the second N2 etc. measurements!

Example:

```
station ID = MS (Maisach)
system = MULIS
signal = 532, parallel, analog, dark-subtracted / not-dark-subtracted
date, time = 28.03.2008, 15UTC
range, NI, EI, SI, WI, NI2, NO, EO, SO, WO, NO2, D
0.00375, 4.4902E-7, 5.1238E-7, 1.7329E-6, 1.2163E-6, 3.575E-7, 9.5749E-7, 4.031E-6, 2.5536E-6,
2.2719E-6, 1.1367E-6, 0
0.0075, -2.3213E-6, -4.0958E-6, -1.1091E-5, -1.6087E-5, -4.0408E-6, -9.5406E-6, -2.4612E-5,
-1.9998E-5, -2.2383E-5, -1.2518E-5, 0
0.01125, 1.8175E-5, 2.12E-5, 3.1289E-5, -1.7014E-6, 7.0487E-6, 1.1296E-4, 9.0652E-5, 1.146E-4,
5.4473E-5, 2.0361E-5, 0
0.0150, 1.5628E-3, 1.9424E-3, 4.007E-3, 1.6751E-3, 9.5026E-4, 8.0557E-3, 8.8403E-3, 1.1014E-2,
7.3912E-3, 3.438E-3, 0
0.01875, 1.228E-2, 1.4972E-2, 3.7926E-2, 2.0086E-2, 8.9909E-3, 5.5995E-2, 7.8451E-2, 1.0363E-1,
7.1994E-2, 3.4479E-2, 0
0.0225, 3.9465E-2, 4.8788E-2, 1.3362E-1, 7.2022E-2, 3.0372E-2, 1.6097E-1, 2.6914E-1, 3.5023E-1,
2.5453E-1, 1.1953E-1, 0
....
```

6.2.2 Rayleigh Fit

1. lidar site (according HOI)
2. lidar system (system name)
3. signal/channel (analog or photoncounting), named according the HOI, dark-subtraction
4. date, time, and duration of the measurement (dd.mm.yyyy, hh, ss - Rayleigh signal average time in seconds, default 1800 s)
5. used radiosonde (location, WMO station ID, date, time)
6. the used fit range (in km)
7. column names
8. … data

The submitted data (30 min. averaged), for each channel (wavelength) separate, should include the Rayleigh signal, i.e. the calculated attenuated Rayleigh or Cabannes backscatter coefficients (depending on the interference filter bandwidth; calculated from actual local radiosonde data with the software usally used for the signal inversion), and a range corrected lidar signal with a clean atmosphere in the fit range.

One file for each wavelength.
No columns/data other than attenuated_RayleighBSC, RangeCorrectedSignal, and optionally DarkMeasurement (only analog)

Dark measurement (only analog) column can optionally be appended marked as D. The dark measurement should be processed in the same way as the range corrected signal (background subtraction, range correction, etc).

Example:

```
station ID = MS (Maisach)
system = MULIS
signal = 532, parallel+perpendicular, analog, dark-subtracted / not-dark-subtracted
date of measurement, time, duration of measurement = 28.03.2008, 23UTC,   1800 s
location, WMO radiosonde station ID, date of radiosonde = Oberschleißheim, 10868, 29.03.08, 00UTC
lower and upper Rayleigh height limits = 11, 13
range, attnRayleighBSC, RangeCorrectedSignal,  D
0.0075, 1.483903E-6, 1.765201E-4, 0.00011
0.0150, 1.482827E-6, 1.763579E-4, 0.00013
...
```

6.2.3 ~~Dark measurement~~ (Not necessary any more. Append dark-signals to the Rayleigh-fit and telecover data files as described under 6.2.1 and 6.2.2)

1. lidar site (according HOI)
2. lidar system (system name)
3. signal/channel (analog or photoncounting), named according the HOI
4. date and time of the measurement (dd.mm.yyyy, hh)
5. column names
6. ... data

The submitted data should include a range corrected signal without dark measurement subtraction, and a dark measurement with sufficient temporal averaging.
The dark measurement should be processed (background subtraction, range correction etc.) like the range corrected signal in order to be comparable.
One file for each wavelength.

Example:

```
station ID = MS (Maisach)
system = MULIS
signal = 532, parallel, analog
date, time = 28.03.2008, 15UTC
range,     RangeCorrectedSignal,      D
0.0075,       1.765201E-4,            0.00011
0.0150,       1.763579E-4,            0.00013
```

6.2.4 Polarisation calibration measurements

1. lidar site (according HOI)
2. lidar system (system name)
3. signal/channel, analog or photoncounting or glued [default]) - named according the HOI
4. date and time of the calibration measurement (dd.mm.yyyy, hh)
5. date of the Rayleigh measurement (dd.mm.yyyy)
6. GR, GT, HR, HT, K, laser polarisation rotation, system rotation y
7. column names
8. ... data

Comments:
- Range corrected signals
- Dark signals subtracted if necessary
- GHK-parameters
according to http://www.atmos-meas-tech.net/9/4181/2016/
calculate them with https://bitbucket.org/iannis_b/atmospheric_lidar_ghk
see also "implementation_depol_SCC_10102016.pdf" in the EARLINET forum https://earlinetforum.imaa.cnr.it/viewtopic.php?f=30&t=210
- laser polarisation rotation: 0° (90°) if laser polarisation is parallel (perpendicular) to the incidence plane of the polarising beam splitter.
- system rotation y: in general = +1. Some Raymetrics systems, e.g., enable to rotate the polarising beam splitter cube and the attached detectors by 90° => y = -1.
- simple calculation
- only considering the polarising cube beam splitter (with laser polarisation rotation = 0°, neglecting emitter and receiver optics):

GR = 1
GT = 1
HR = y * (Rp - Rs) / (Rp + Rs)
HT = y * (Tp - Ts) / (Tp + Ts)
K = 1
laser polarisation rotation = 0
y = y

- only considering the polarising cube beam splitter and cleaning analysers with transmission Tparallel = 0.4, Tperpendicular = 0.0 behind the PBS in above example and y = +1 (cleaning analysers / pol-filters make life very easy!)

GR = 1
GT = 1
HR = -1
HT = +1
K = 1
laser polarisation rotation = 0
y = +1

Signals:
- ITplus45 : transmitted signal of PBS, i.e. usually the parallel (p) signal relative to PBS, with calibrator at +45° orientation
- IRplus45 : reflected signal of PBS, i.e. usually the perpendicular (s) signal relative to PBS, with calibrator at +45° orientation
- ITminus45 : transmitted signal of PBS, i.e. usually the parallel (p) signal relative to PBS, with calibrator at -45° orientation

- IRminus45 : reflected signal of PBS, i.e. usually the perpendicular (s) signal relative to PBS, with calibrator at -45° orientation
- ITRayleigh : transmitted signal of PBS, i.e. usually the parallel (p) signal relative to PBS, without calibrator or calibrator at 0° orientation
- IRRayleigh : reflected signal of PBS, i.e. usually the perpendicular (s) signal relative to PBS, without calibrator or calibrator at 0° orientation

The latter two "Rayleigh" signals are the same as the signals for the Rayleigh fit. In this context we use them to determine the Rayleigh (molecular) linear depolarisation ratio using the calibration constant of the first four signals. For these Rayleigh signals you can use the same measurements as for the Rayleigh fit, even if they are from another date - as long as the polarization calibration is still valid.

Example:

```
station ID = MS (Maisach)
system = MULIS
signal = 532,glued
date of the calibration, time = 28.03.2008, 15 UTC
date of the Rayleigh measurement = 29.03.2008
GR, GT, HR, HT, K, laser polarisation rotation, system rotation y = 1.000, 0.983, -0.014, -0.982,
1.051, 90, -1
range,ITplus45,IRplus45,ITminus45,IRminus45,ITRayleigh,IRRayleigh
0.00375, 4.4902E-7, 5.1238E-7, 1.7329E-6, 1.2163E-6, 3.575E-7, 9.5749E-7
0.0075, -2.3213E-6, -4.0958E-6, -1.1091E-5, -1.6087E-5, -4.0408E-6, -9.5406E-6
0.01125, 1.8175E-5, 2.12E-5, 3.1289E-5, -1.7014E-6, 7.0487E-6, 1.1296E-4
...
```

6.2.5 Trigger delay (bin shift) report

Please use following sheet for reporting the trigger delay measurements.
trigger_delay_report_example_mu_td_150828.doc

Volker Freudenthaler 2008 … 25. June 2018