E-PROFILE:

Glossary of lidar and ceilometer variables

compiled by:
I. Mattis and F. Wagner

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1 Introduction

E-PROFILE is one of the observation programms in the framework of EUMETNET. Its goal is to operationally provide vertical profiles of wind measurements and of the aerosol distribution from European networks of radar wind profilers, weather radars, automated lidars, and ceilometers. Whereas the network for wind observations has been already established in the former programme E-WINPROF, the network of automated lidars and ceilometers (ALC) has to be setup in the framework of E-PROFILE.

This document shall provide a glossary with definitions of terms and formulas that are used in the ALC community in order to allow all participants (including lidar experts, operators, and end users) to speak a common language.

This report is organized as follows: Chapter 2 provides the basic equation (lidar equation) and the glossary itself, including formulas and units. Chapter 3 is a collection of definitions used in the raw data of widely used ceilometers.

2 Glossary

To our knowledge, there are no generally certified definitions in the global lidar community. The definitions in this glossary are equivalent to formulations that are widely used in the lidar community, especially in EARLINET. Nevertheless, there might be publications or frameworks that use some terms of this glossary with different definitions.

This glossary is only for elastic-backscatter lidars and depolarization lidars, not for Raman or HSRL lidars. For further details, the lidar textbook by *Weitkamp* [2005] is recommended.

Some terms are labeled with an *. Those are short terms that could be used for oral communication or a better readability of texts. The correct and complete formulations (full term) are provided in the corresponding descriptions.

Theoretical background

The **lidar equation** is the basic equation for the analysis of lidar signals. It describes the power of the measured signals:

$$^{\mathrm{p}}P_\lambda(t,r) = \frac{\overline{^{\mathrm{p}}P_{0}}_\lambda(t)\,\tau_\lambda\,c\,A_T}{2}\,\frac{^{\mathrm{p}}\eta_\lambda(t,r)\,O(r)}{r^2}\,{}^{\mathrm{p}}\beta_\lambda(t,r)\,T_\lambda(t,r) + {}^{\mathrm{p}}P_\lambda^{bg}(t,r). \tag{2.1}$$

The symbols mean:

$^{\mathrm{p}}P_\lambda$	power of the measured raw signal,
r	range,
t	time
Index λ	wavelength,
Index p	polarization state of the backscattered light with respect to the polarization of the emitted laser light,
$\overline{^{\mathrm{p}}P_{0}}_\lambda$	mean laser power per pulse,
τ_λ	temporal length of a laser pulse,
c	speed of light,
A_T	area of the receiver telescope,
$^{\mathrm{p}}\eta_\lambda$	system efficieny,
O	overlap function,
$^{\mathrm{p}}\beta_\lambda$	total volume backscatter coefficient,
T_λ	two-way atmospheric transmission, and
$^{\mathrm{p}}P_\lambda^{bg}$	background signal.

Glossary

- **altitude of complete overlap:** Beyond a certain distance r_{ovl} from the lidar receiver, the overlap between laser beam and receiver field of view is complete and the overlap function is defined to be $O(r) = 1$.
  Unit: [m]
- **arbitrarily normalized signal that was corrected for background, range and incomplete overlap:** see normalized signal
- **atmospheric background signal:** ${}^{\mathrm{p}}P_\lambda^{bga}$ is the range independent component of the raw signal, caused by atmospheric background. It is measured as average over several range bins in large altitudes where the term $\frac{{}^{\mathrm{p}}\beta_\lambda(r)}{r^2}\,T_\lambda(t,r)$ is assumed to be negligible (far field) or before the laser emits light into the atmosphere (pre-trigger).
  Unit: Same as the corresponding raw signal
- **atmospheric transmission*:** $T_\lambda(t,r)$ is the attenuation of the emitted laser light and of the backscattered light on the way from the ALC emitter to the scattering volume at distance r and back to the ALC receiver. The atmospheric transmission depends on the vertical profile of the extinction coefficient $\alpha_\lambda(t,\zeta)$.
  $$T_\lambda(t,r) = \exp\left(-2\int_0^r \alpha_\lambda(t,\zeta)\mathrm{d}\zeta\right) \tag{2.2}$$
  Unit: unitless
  full term: ‘two-way atmospheric transmission’.
- **attenuated backscatter:** ${}^{\mathrm{p}}\beta_\lambda^{att}(t,r)$ is the volume backscatter coefficient that is affected by the atmospheric transmission of the layers between lidar and altitude r. The attenuated backscatter corresponds to an overlap corrected signal or a range corrected signal that was calibrated by the lidar constant C_λ in case of $r < r_{\mathrm{ovl}}$ or $r \geq r_{\mathrm{ovl}}$, respectively.
  $${}^{\mathrm{p}}\beta_\lambda^{att}(t,r) = \frac{\widetilde{{}^{\mathrm{p}}P_\lambda^{oc}}(t,r)}{C_\lambda} = {}^{\mathrm{p}}\beta_\lambda(t,r)\,T_\lambda(t,r). \tag{2.3}$$
  This quantity is reported in the CALIPSO lidar level 1B profile products *Hostetler et al.* [2006].
  This quantity should be used with caution. Even if two aerosol layers would have the same backscatter coefficient, the attenuated backscatter might be completely different if they are observed, e.g., one on top of a clean and the other one on top of a polluted planetary boundary layer.
  Unit: [$\mathrm{m}^{-1}\mathrm{sr}^{-1}$]
  full term: ‘calibrated signal that was corrected for background, range and incomplete overlap’.
- **background, range, and overlap corrected signal:** see overlap corrected signal
- **background and range corrected signal:** = range corrected signal

- **background corrected signal:** The measured raw signal, corrected for atmospheric background and electronic background

$$\widehat{{}^{\mathrm{p}}P_\lambda}(t,r) = {}^{\mathrm{p}}P_\lambda(t,r) - {}^{\mathrm{p}}P_\lambda^{bga}(t) - {}^{\mathrm{p}}P_\lambda^{bge}(t,r). \tag{2.4}$$

  Unit: Same as corresponding raw signal

- **background signal:** The sum of atmospheric background and electronic background

$${}^{\mathrm{p}}P_\lambda^{bg}(t) = {}^{\mathrm{p}}P_\lambda^{bga}(t) + {}^{\mathrm{p}}P_\lambda^{bge}(t,r). \tag{2.5}$$

  Unit: Same as corresponding raw signal

- **backscatter coefficient*:** $\beta_\lambda^{\mathrm{par}}(t,r)$ is the backscatter coefficient of the particles in the scattering volume. There are two different methods to calculate the paerticle backscatter coefficient from elastic signals only: The iterative method is described e.g., by *Di Girolamo et al.* [1999] and *Masci* [1999]. The Klett-Fernald solution can be found in *Klett* [1981] and in *Fernald* [1984]. The sources of uncertainties in the retrieval of the backscatter coefficient are the same for both methods:
  - uncertainties caused by the calibration,
  - uncertaity due to the assumption of a particle lidar ratio (profile); this error can easily exceed 20% [*Sasano et al.*, 1985],
  - uncertainty in the lowest part of the profile (below r_{ovl}) due to the incomplete overlap between laser beam and receiver field of view.

  Unit: [$\mathrm{m}^{-1}\mathrm{sr}^{-1}$]
  full term: 'total particle backscatter coefficient'.

- **backscatter ratio:** The backscatter ratio $R_\beta^\lambda(t,r)$ is the ratio between volume backscatter coefficient and molecular backscatter coefficient

$$R_\beta^\lambda(t,r) = \frac{\beta_\lambda^{\mathrm{mol}}(t,r) + \beta_\lambda^{\mathrm{par}}(t,r)}{\beta_\lambda^{\mathrm{mol}}(t,r)}. \tag{2.6}$$

- **calibrated signal*:** see attenuated backscatter

- **deattenuation:** The deattenuation $\widetilde{{}^{\mathrm{p}}\eta_\lambda}(r)$ describes the dependency of the transmissivity of the optical elements in the ALC system on the polarization status of the emitted or received light. it is an altitude and time dependent component of the system efficiency . It is neglected in this document ($\widetilde{{}^{\mathrm{p}}\eta_\lambda}(r) \equiv 1$), even if it can cause large and not quantifiable, highly variable systematic errors under unfavorable conditions.

- **electronic background signal:** ${}^{\mathrm{p}}P_\lambda^{bge}(r)$ is a component of the raw signal that can be caused by various effects of the device's electronic. This signal depends on range, but typically not on time. It can be measured, e.g., with the lidar telescope closed.
  Unit: Same as corresponding raw signal

- **extinction coefficient*:** $\alpha_\lambda^{\mathrm{par}}(t,r)$ is the extinction coefficient of the particles in the scattering volume. It is the sum of the particle scattering coefficient and the particle absorption coefficient: $\alpha_\lambda^{\mathrm{par}}(t,r) = \alpha_\lambda^{\mathrm{s,par}}(t,r) + \alpha_\lambda^{\mathrm{a,par}}(t,r)$.
  Unit: m^{-1}
  full term: particle extinction coefficient

- **lidar constant:** The range-independent parameters of the lidar equation can be combined into a lidar constant

$$C_\lambda(t) = \frac{\tau_\lambda \, c \, A_T}{2} \left[{}^{\mathrm{p}}\overline{P_0}_\lambda(t) \, {}^{\mathrm{p}}\eta_\lambda(t) \right] . \tag{2.7}$$

  Laser power and system efficiency can be time dependent. There might be shot-to-shot variations as well as long-term trends.

  The lidar constant can be derived under favourable atmospheric conditions from the lidar measurement itself. Rayleigh calibration can be performed if there is an altitude region without aerosol particles or clouds and a sufficiently high signal-to-noise ratio.The CLOUDNET algorithm can be applied in the presence of midlevel stratiform clouds [*O'Connor et al.*, 2004]. In general, those $C_\lambda(t)$ values are valid only during the individual measurement situation when the calibration has been applied. Only in case of ALC systems with laser power and system efficiency that remain stable over long time periods or if those quantities are predictable from ancillary parameters, the lidar calibration factor can be applied to all measurements, independent on atmospheric conditions. A method for such an 'absolute calibration' is described e.g. in *Wiegner and Geiß* [2012] for Jenoptik CHM15kx ceilometers.

- **lidar ratio*:** The lidar ratio S^{par} is the ratio between extinction coefficient and backscatter coefficient. The lidar ratio is highly variable in time, location and altitude. It strongly depends on size and refractive index of the particles in the scattering volume.
  Unit: [sr]
  full term: 'particle lidar ratio'.

- **molecular backscatter coefficient*:** $\beta_\lambda^{\mathrm{mol}}(t,r)$ is the backscatter coefficient of the molecules in the scattering volume.
  It can be calculated from the number density of the molecules, their scattering cross-section, and the phase function for the scattering angle in backward direction. Number density can be obtained from radio soundings or standard atmosphere profiles.
  Unit: $[\mathrm{m}^{-1}\mathrm{sr}^{-1}]$
  full term: 'total molecular backscatter coefficient'.

- **molecular depolarization ratio*:** The molecular depolarization ratio $\delta_\lambda^{\mathrm{mol}}$ is the ratio between cross polarized and parallel polarized molecular backscatter coefficients.
  Unit: %
  full term: 'molecular linear depolarization ratio'.

- **molecular extinction coefficient:** $\alpha_\lambda^{\mathrm{mol}}(t,r)$ is the extinction coefficient of the molecules in the scattering volume. Absorption due to molecules $\alpha_\lambda^{\mathrm{a,mol}}(r)$ is neglected for the usual wavelengths of aerosol lidars (355, 532, and 1064 nm), thus $\alpha_\lambda^{\mathrm{mol}}(t,r) = \alpha_\lambda^{\mathrm{s,mol}}(t,r)$. It can be calculated from air pressure and temperature profiles taken from radiosonde launches, from atmospheric models (e.g. US standard atmosphere), or analysis data sets of numerical weather prediction models.
  Unit: m^{-1}
- **molecular lidar ratio:** The molecular lidar ratio S^{mol} is the ratio between molecular extinction coefficient and molecular backscatter coefficient. It has the constant value of $\frac{8}{3}\pi$ sr.
  Unit: [sr]

- **molecular linear depolarization ratio:** molecular depolarization ratio
- **normalized signal*:** overlap corrected signal or a range corrected signal that is normalized for temporal variations and trends of the the lidar constant $C_\lambda(t)$ in case of $r < r_{\mathrm{ovl}}$ or $r \geq r_{\mathrm{ovl}}$, respectively .

  $$ {}^{\mathrm{p}}\widetilde{P_\lambda^{norm}}(t,r) = {}^{\mathrm{p}}\widetilde{P_\lambda^{oc}}(t,r)\, F_{norm}(t) \tag{2.8} $$

  The normalization factor $F_{norm}(t)$ can be derived, e.g.,
  - as ratio between temporal average and current value of the signal at a certain altitude, where the aerosol concentration is assumed to be time-independent (r_{norm}).
  - from an internal calibration signal as, e.g., in case of the Jenopik CHM 15k instruments.

  Unit: [counts m^2] or [V m^2]; often provided as [arbitrary units (a.u.)]
  full term: ‘arbitrarily normalized signal that was corrected for background, range and incomplete overlap’.
- **overlap corrected signal*:** The range corrected signal, additionally corrected for the incomplete overlap between laser beam and telescope field of view

  $$ {}^{\mathrm{p}}\widetilde{P_\lambda^{oc}}(t,r) = \frac{{}^{\mathrm{p}}\widetilde{P_\lambda}(t,r)}{O(r)} = C_\lambda\, {}^{\mathrm{p}}\beta_\lambda(t,r)\, T_\lambda(t,r). \tag{2.9} $$

  In case of $r \geq r_{\mathrm{ovl}}$, the overlap corrected signal is the same as the range corrected signal.
  Unit: [counts m^2] or [V m^2]; often provided as [arbitrary units (a.u.)]
  full term: ‘background, range, and overlap corrected signal’.
- **overlap function** The overlap function $O(r)$ describes the incomplete overlap between the emitted laser beam and the receiver field of view along the laser line-of-sight. The values of the overlap function usually ranges from 0 (close to the ALC system) to 1 (for $r \geq r_{\mathrm{ovl}}$).
  Unit: unitless

- **particle backscatter coefficient:** see backscatter coefficient
- **particle depolarization ratio*:** The particle depolarization ratio $\delta_\lambda^{\mathrm{par}}$ is the ratio between cross polarized and parallel polarized particle backscatter coefficients.
  Unit: %
  full term: 'particle linear depolarization ratio'.
- **particle extinction coefficient:** extinction coefficient
- **particle lidar ratio:** lidar ratio
- **particle linear depolarization ratio:** particle depolarization ratio
- **prefix 'cross polarized' :** This prefix describes signals that measure only the component of the backscattered light that is cross polarized with respect to the polarization of the emitted linearly polarized laser light as well as backscatter coefficients that are derived from those signals. The upper left index of these quantities is usually p $=\perp$. The prefix can be attributed to:
  - ∼ raw signal ${}^{\perp}P_\lambda(r)$
  - ∼ background signal ${}^{\perp}P_\lambda^{bg}$
  - ∼ atmospheric background signal ${}^{\perp}P_\lambda^{bga}(r)$
  - ∼ electronic background signal ${}^{\perp}P_\lambda^{bge}(r)$
  - ∼ background corrected signal $\widehat{{}^{\perp}P_\lambda}(r)$
  - ∼ range corrected signal $\widetilde{{}^{\perp}P_\lambda}(r)$
  - ∼ overlap corrected signal $\widetilde{{}^{\perp}P_\lambda^{oc}}(r)$
  - ∼ normalized signal ${}^{\perp}\widetilde{P_\lambda^{norm}}(t,r)$
  - ∼ attenuated backscatter ${}^{\mathrm{p}}\beta_\lambda^{att}(t,r)$
  - ∼ backscatter coefficients of volume ${}^{\perp}\beta_\lambda(t,r)$, molecules ${}^{\perp}\beta_\lambda^{\mathrm{mol}}(t,r)$, and particles ${}^{\perp}\beta_\lambda^{\mathrm{par}}(t,r)$
- **prefix 'parallel polarized' :** This prefix describes signals that measure only the component of the backscattered light that is parallel polarized with respect to the polarization of the emitted linearly polarized laser light as well as backscatter coefficients that are derived from those signals. The upper left index of these quantities is usually p $=\parallel$. The prefix can be attributed to:
  - ∼ raw signal ${}^{\parallel}P_\lambda(r)$
  - ∼ background signal ${}^{\parallel}P_\lambda^{bg}$
  - ∼ atmospheric background signal ${}^{\parallel}P_\lambda^{bga}(r)$
  - ∼ electronic background signal ${}^{\parallel}P_\lambda^{bge}(r)$
  - ∼ background corrected signal $\widehat{{}^{\parallel}P_\lambda}(r)$

- $\sim$ range corrected signal $^{\parallel}\widetilde{P_\lambda}(r)$
- $\sim$ overlap corrected signal $^{\parallel}\widetilde{P_\lambda^{oc}}(r)$
- $\sim$ normalized signal $^{\parallel}\widetilde{P_\lambda^{norm}}(t,r)$
- $\sim$ attenuated backscatter $^{\mathrm{p}}\beta_\lambda^{att}(t,r)$
- $\sim$ backscatter coefficients of volume $^{\parallel}\beta_\lambda(t,r)$, molecules $^{\parallel}\beta_\lambda^{\mathrm{mol}}(t,r)$, and particles $^{\parallel}\beta_\lambda^{\mathrm{par}}(t,r)$

- **prefix 'total' :** This prefix describes signals that contain both polarization components (parallel plus cross polarized) as well as backscatter coefficients that are derived from those signals. Total signals could be either directly measured without polarization separation or can be the sum of two separately obtained signals or backscatter coefficients. The upper left index p is usually left empty for these quantities. The prefix can be attributed to:
  - $\sim$ raw signal $P_\lambda(r)$
  - $\sim$ background signal P_λ^{bg}
  - $\sim$ atmospheric background signal $P_\lambda^{bga}(r)$
  - $\sim$ electronic background signal $P_\lambda^{bge}(r)$
  - $\sim$ background corrected signal $\widehat{P_\lambda}(r)$
  - $\sim$ range corrected signal $\widetilde{P_\lambda}(r)$
  - $\sim$ overlap corrected signal $\widetilde{P_\lambda^{oc}}(r)$
  - $\sim$ normalized signal $\widetilde{P_\lambda^{norm}}(t,r)$
  - $\sim$ attenuated backscatter $\widetilde{\beta_\lambda}(t,r)$
  - $\sim$ backscatter coefficients of volume $\beta_\lambda(t,r)$, molecules $\beta_\lambda^{\mathrm{mol}}(t,r)$, and particles $\beta_\lambda^{\mathrm{par}}(t,r)$

- **range corrected signal*:** The background corrected signal, additionally corrected for the $1/r^2$ dependency

$$^{\mathrm{p}}\widetilde{P_\lambda}(t,r) = {}^{\mathrm{p}}\widehat{P_\lambda}(t,r)\, r^2. \tag{2.10}$$

  Unit: [counts m^2] or [V m^2]; often provided as [arbitrary units (a.u.)]
  full term: 'background and range corrected signal'
  abbreviation: RCS .

- **raw signal:** $^{\mathrm{p}}P_\lambda(r)$ is the value that is measured by the lidar detector (see lidar equation).
  Unit: [photon counts] or [Volts]

- **RCS:** abbreviation of range corrected signal

- **scattering volume:** The volume, that is illuminated by the laser pulse at range r. It has a cylindrical shape with a base area that is identical to the cross section of the laser beam at range r. The length of the scattering volume is $\frac{1}{2}\tau_\lambda\, c$.

- **system efficiency:** The overall system efficiency is the product of the optical transmissivity of the emitter and receiver units of the ALC system and the detector efficiency. It can be split into an altitude-independent part ${}^{\mathrm{p}}\eta_\lambda(t)$ and the deattenuation term $\widetilde{{}^{\mathrm{p}}\eta_\lambda}(t,r)$

$$ {}^{\mathrm{p}}\eta_\lambda(t,r) = {}^{\mathrm{p}}\eta_\lambda(t)\, \widetilde{{}^{\mathrm{p}}\eta_\lambda}(t,r). \tag{2.11} $$

  Unit: unitless

- **total linear depolarization ratio:** volume depolarization ratio
- **total molecular backscatter coefficient:** see molecular backscatter coefficient
- **total particle backscatter coefficient:** see backscatter coefficient
- **total volume backscatter coefficient:** see volume backscatter coefficient
- **two-way atmospheric transmission:** atmospheric transmission
- **two-way attenuated backscatter coefficient:** see attenuated backscatter
- **volume backscatter coefficient*:** $\beta_\lambda(t,r)$ is the sum of the backscatter coefficients of all particles and molecules in the scattering volume. $\beta_\lambda(t,r) = \beta_\lambda^{\mathrm{mol}}(t,r) + \beta_\lambda^{\mathrm{par}}(t,r)$
  Unit: $[\mathrm{m}^{-1}\mathrm{sr}^{-1}]$
  full term: 'total volume backscatter coefficient'.
- **volume depolarization ratio*:** The volume depolarization ratio δ_λ is ratio between cross polarized and parallel polarized volume backscatter coefficients caused by molecules and particles.
  Unit: %
  full term: 'volume linear depolarization ratio'.
- **volume extinction coefficient:** The extinction coefficient $\alpha_\lambda(r)$ is a combination of the scattering coefficients $\alpha_\lambda^{\mathrm{s}}$ and the absorption coefficients $\alpha_\lambda^{\mathrm{a}}$ of molecules (mol) and aerosol particles (par) in the scattering volume:

$$ \alpha_\lambda(t,r) = \alpha_\lambda^{\mathrm{mol}}(t,r) + \alpha_\lambda^{\mathrm{par}}(t,r) = \alpha_\lambda^{\mathrm{s,mol}}(t,r) + \alpha_\lambda^{\mathrm{a,mol}}(t,r) + \alpha_\lambda^{\mathrm{s,par}}(t,r) + \alpha_\lambda^{\mathrm{a,par}}(t,r). \tag{2.12} $$

  Unit: m^{-1}

- **volume linear depolarization ratio:** volume depolarization ratio

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3 Example ALC raw data formats

This chapter provides the definition of raw data formats of some widely used ALC systems and its relations to the definitions of the glossary.

3.1 Jenoptik CHM15k

Raw data of Jenoptik CHM15k instruments are stored in NetCDF format. Raw signals are detected in photon counting mode, thus their unit is [counts]. The netCDF files report all variables as temporal averages with variable resolution, e.g. 15 seconds. You can find the settings of your instrument in the variable *average_time*.

The following list provides units and descriptions (in quotes) as provided in the manufacturers NetCDF format. For some items the description was extended with additional explanations. Further, for the main NetCDF variables this list provides links to the related items of the glossary and detailed formulas that describe these relations.

- **altitude_axis**: is not a NetCDF variable!
  - unit: [m]
  - formula: $altitude = \cos(zenith) \times range$
- **base:**
  - description: 'daylight correction factor' = average number of photon counts measured in the last few bins of the profile, normalized with the number of laser pulses during the average_time.
  - unit: [photons per shot]
  - related to: background signal ${}^{\mathrm{P}}P_{\lambda}^{bg}$
  - formula: ${}^{\mathrm{P}}P_{\lambda}^{bg} = base \times laser\_pulses$
- **beta_raw (algorithm version $<$ 0.702)**
  - description: 'lidar backscatter raw data, which are offset corrected and normalized by laser shot number and noise (standard deviation)'.
  - unit: [snr]
  - related to: raw signal
  - formula: ${}^{\mathrm{P}}P_{\lambda} = (beta\_raw \times stddev + base) \times laser\_pulses$
- **beta_raw (algorithm version $\geq$ 0.702)**

description ‘normalized range corrected signal
(signal_raw / lp - b) /(c * o(r) * p_cal) * r * r)’
unit [none]
related to raw signal [sum of photons in the range bin]
formula ${}^{\mathrm{p}}P_{\lambda} = (beta\_raw/range^2 \times overlap \times p\_calc \times scaling + base) \times laser\_pulses \times range\_scale$
related to normalized signal
formula ${}^{\mathrm{p}}P_{\lambda}^{norm} = beta\_raw$

- **beta_raw_hr (algorithm version $\geq$ 0.702)**
  description ‘normalized range corrected signal
  (signal_raw / lp - b) /(c * o(r) * p_cal) * r * r)’ with high resolution
  unit [none]
  related to raw signal
  formula ${}^{\mathrm{p}}P_{\lambda} = (beta\_raw\_hr/range\_hr^2 \times overlap \times p\_calc \times scaling + base) \times laser\_pulses$
  related to normalized signal
  formula ${}^{\mathrm{p}}P_{\lambda}^{norm} = beta\_raw\_hr$
- **laser_pulses:**
  description ‘the number of laser pulses averaged over the average_time’.
  unit [unitless]
- **overlap** : is not a NetCDF variable!
  description overlap function that could be provided by the manufacturer for each individual ceilometer system
  related to overlap function
- **p_calc (algorithm version $\geq$ 0.702)**
  description ‘calibration pulse in photons per shot’
  unit [photons per shot]
  scale_factor 1E-5
- **range**
  description ‘distance from lidar’
  unit [m]
- **range_hr**
  description ‘high resolution distance from lidar’
  unit [m]
- **range_scale** : is not a NetCDF variable!
  description if i is the number of an altitude bin, range_scale is the ratio between range resolution and high-resolution range resolution
  formula $(range[i] - range[i-1]) \ / \ (range\_hr[i] - range\_hr[i-1])$
- **scaling (algorithm version $\geq$ 0.702)**

description ‘scaling factor (c)’
unit [unitless]

- **stddev:**
  description ‘standard deviation raw signal’ = standard deviation (along the altitude axis), calculated in the same altitude range as base, normalized with the number of laser pulses during the average_time.
  unit [photons per shot]
- **zenith:**
  description ‘laser direction of site’ = zenith angle = deviation from vertical
  unit [degree]

3.2 Vaisala CL51

Raw data of the Vaisala CL51 instrument are ASCII files with a 20-bit HEX code. The following quantities are reported in the manual [*Vaisala Oyj*, 2010]:

- **altitude_axis**: not in the file!
  description altitude of any bin n, starting with $n = 1$.
  unit [m]
  formula $altitude(n) = \cos(tilt\_angle) \times profile\_resolution \times n$
- **profile_resolution**
  description vertical resolution of the profile
  unit [m]
- **profile_length**
  description number of vertical bins in the profile
  unit [unitless]
- **scale**
  description scaling factor of two-way_attenuated_backscatter
  unit [%]
- **tilt_angle**
  description ‘the built-in sensor detects the tilt angle, that is, the deviation from vertical’ = zenith angle
  unit [degrees from vertical]

- **two-way_attenuated_backscatter**

description	'two-way attenuated backscatter profile with sensitivity normalized units unless otherwise scaled with the SCALE parameter'. Raw signals are not available and cannot be deduced from the raw data file. The lidar constant and the applied calibration method are not provided.
unit	$[(100000\,\mathrm{sr\,km})^{-1}]$
related to	attenuated backscatter
formula	${}^{\mathrm{p}}\beta_{\lambda}^{att}(t,r) = scale \times two{-}way\_attenuated\_backscatter(t,r)$

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