Bringing Lidar Data Online as a GRUAN Data Product

Thierry Leblanc…

Jet Propulsion Laboratory, California Institute of Technology, Wrightwood, CA USA

… and the GRUAN Task Team on Ancillary Measurements (TT5)

Foreword

Lidars can measure many species.
This presentation cannot cover all aspects of all lidar measurements for GRUAN.
In other words, there is not one answer, but many, to addressing topics such as:

- *Lidar Measurement Scheduling*
- *Lidar Measurement Uncertainty*
- *Lidar Data Processing*
- *Lidar Product Quality and Relevance*
- *Lidar Data and Product Archiving*

This presentation will only cover a limited number of lidar applications, targeting three of the ECV1/2:

- *Water Vapor (0-20 km)*
- *Ozone (0-50 km)*
- *Temperature (0-90 km)*

Outline

Lidar technique refresher	*4 slides*
Application 1: Backscatter temperature	*3 slides*
Application 2: DIAL ozone	*4 slides*
Application 3: Raman water vapor	*3 slides*
Application 4: Rot-Raman temperature	*2 slides*
Lidar Measurement Uncertainties Overview	*1 slide*
Photon Counting Noise and resulting uncertainty	*1 slide*
Lidar-specific corrections and resulting uncertainties	*7 slides*
Mimimizing Uncertainty	*1 slide*
Pathway towards implementation	*10 slides*

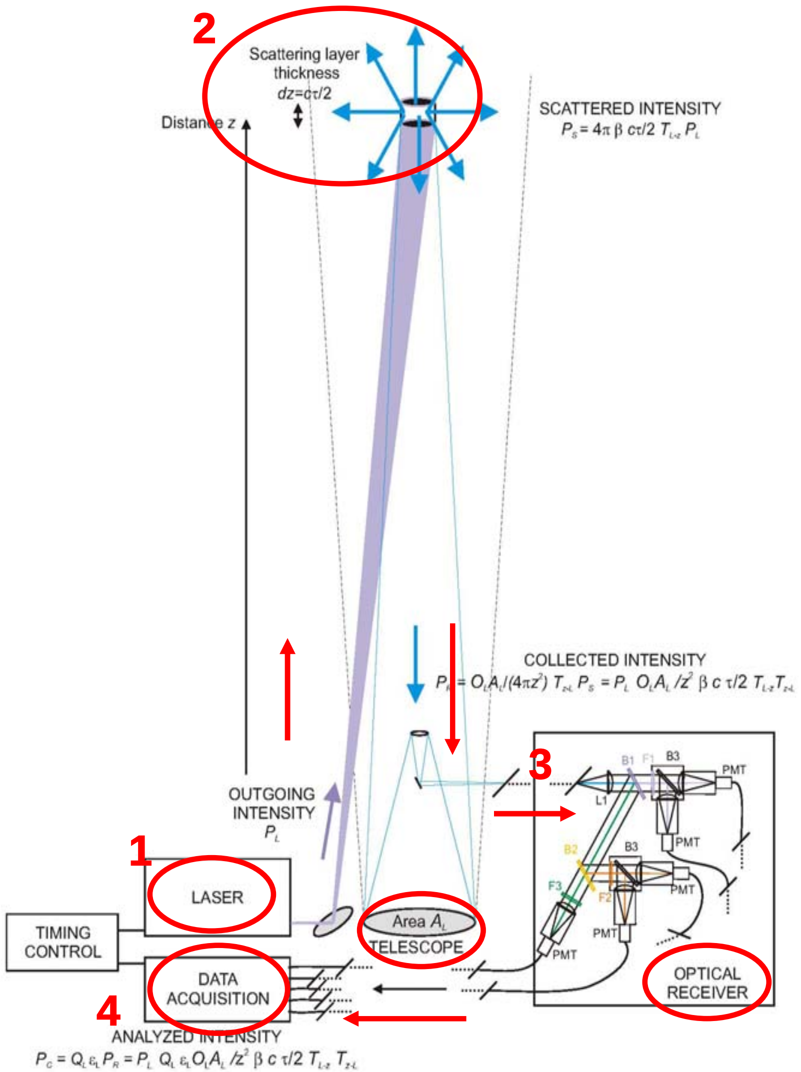
Lidar Principle

1. *Laser beam sent in the atmosphere*

2. *Light backscattered by molecules and particles*

3. *Light collected in optical channels*

4. *Signals sampled as a function of time (i.e., altitude)*



Understanding Lidar Specificity

1. Active remote sensing:

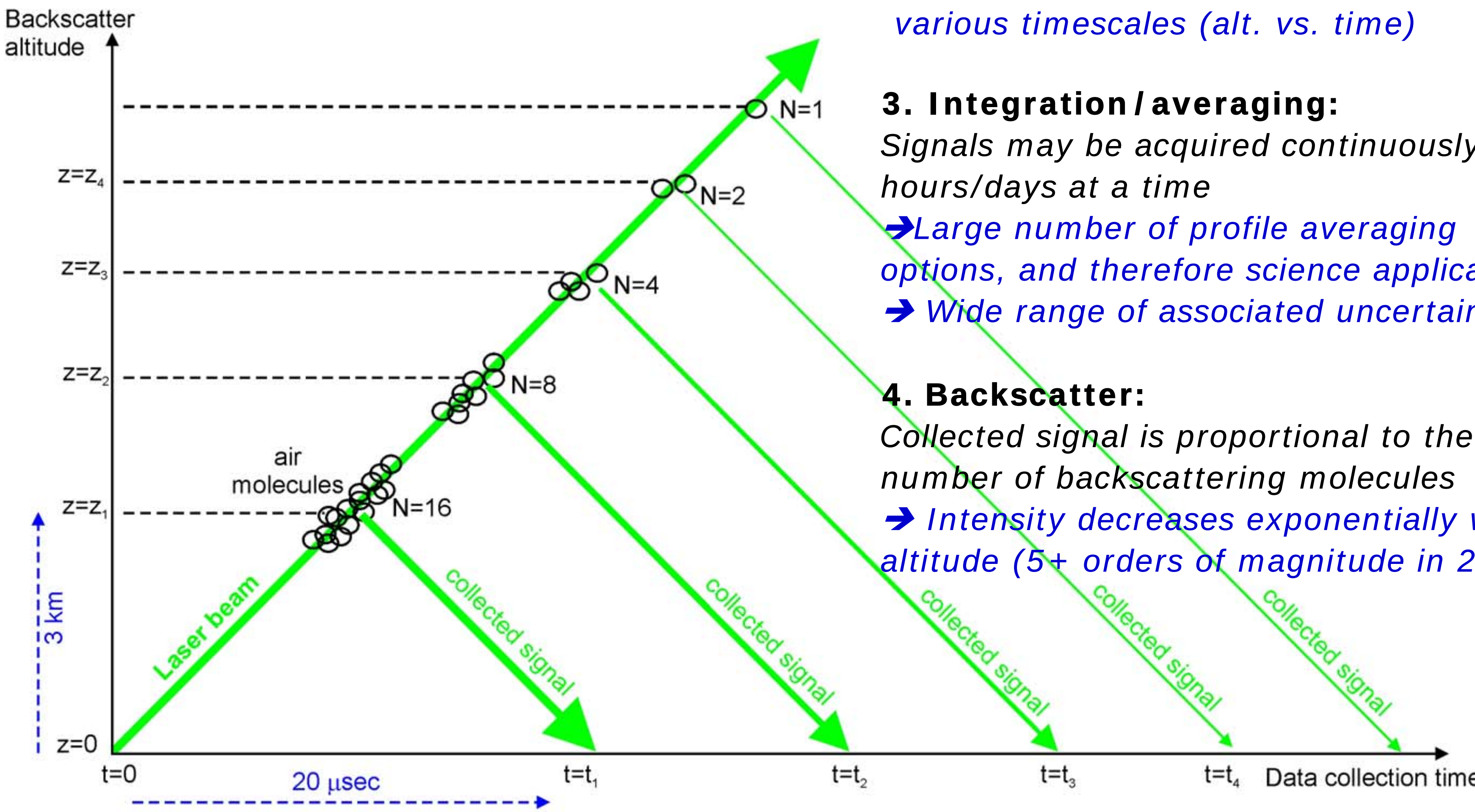
Signals sampled as a function of time, i.e., geometric altitude

➔ High vertical resolution (~meters)

2. Eulerian measurement:

Signals reflect the temporal evolution of the atmosphere at a fixed location

➔ Potential for "2D curtain plots" at various timescales (alt. vs. time)



3. Integration / averaging:

Signals may be acquired continuously for hours/days at a time

➔Large number of profile averaging options, and therefore science applications

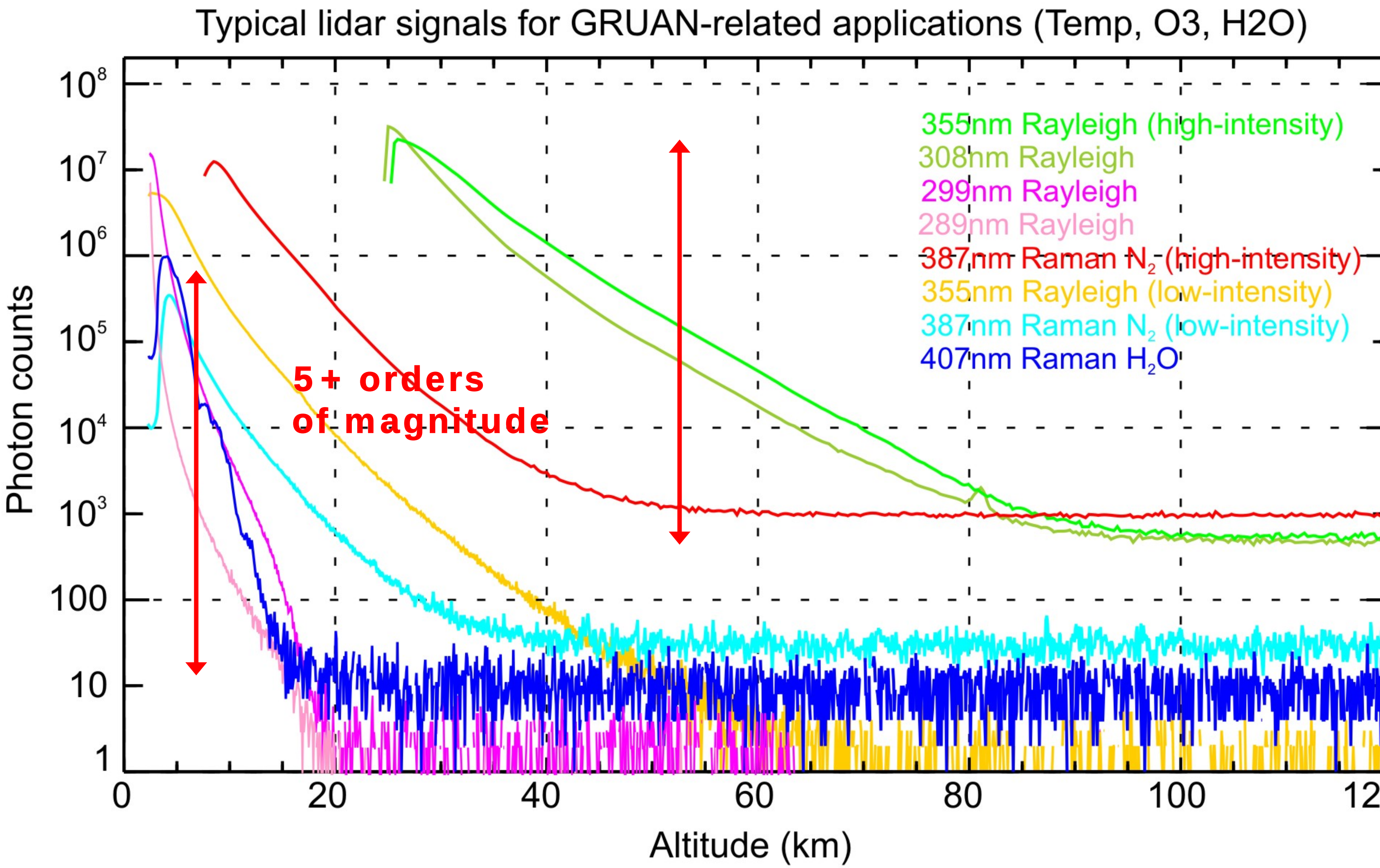
➔ Wide range of associated uncertainties

4. Backscatter:

Collected signal is proportional to the number of backscattering molecules

➔ Intensity decreases exponentially with altitude (5+ orders of magnitude in 20 km)

Sample Raw Signals



Starting point: Basic Lidar Equation

$$P_E(r,\lambda_E)\exp\left[-\int_0^r \alpha(r',\lambda_E)dr'\right]\sigma_M(r,\lambda_E \rightarrow \lambda_D)N_M(r)\exp\left[-\int_0^r \alpha(r',\lambda_D dr'\right]\frac{O_L(r)A_L\delta r}{r^2}\kappa_L(\lambda_D) = P_D(r,\lambda_D)$$

Photon counts emitted by laser

Laser beam extinction on the way up

Backscatter intensity

Laser beam extinction on the way back

Lidar receiver efficiency terms and viewing geometry

Photon counts detected

r	= *range*
δr	= *sampling resolution*
subscript E	= *emitted*
subscript D	= *detected*
subscript L	= *lidar*
subscript M	= *molecule*

The idea behind the lidar technique:

Build receiver channels at specific wavelengths and spectral widths to target specific types of scattering or extinction process

Application 1: Backscatter temperature (12-90 km)

Use the backscatter part of the lidar equation, more specifically: its variation with height

$$P_E(r,\lambda_E)\exp\left[-\int_0^r \alpha(r',\lambda_E)dr'\right]\sigma_M(r,\lambda_E \rightarrow \lambda_D)N_M(r)\exp\left[-\int_0^r \alpha(r',\lambda_D dr'\right]\frac{O_L(r)A_L\delta r}{r^2}\kappa_L(\lambda_D) = P_D(r,\lambda_D)$$

The signal is proportional to atmospheric number density

The Lidar Equation is reverted to access N_{Air}: P_D ➔ $(P_D)^{-1}$

$$N_{air}(r) = k_L P_D(r,\lambda_D)$$

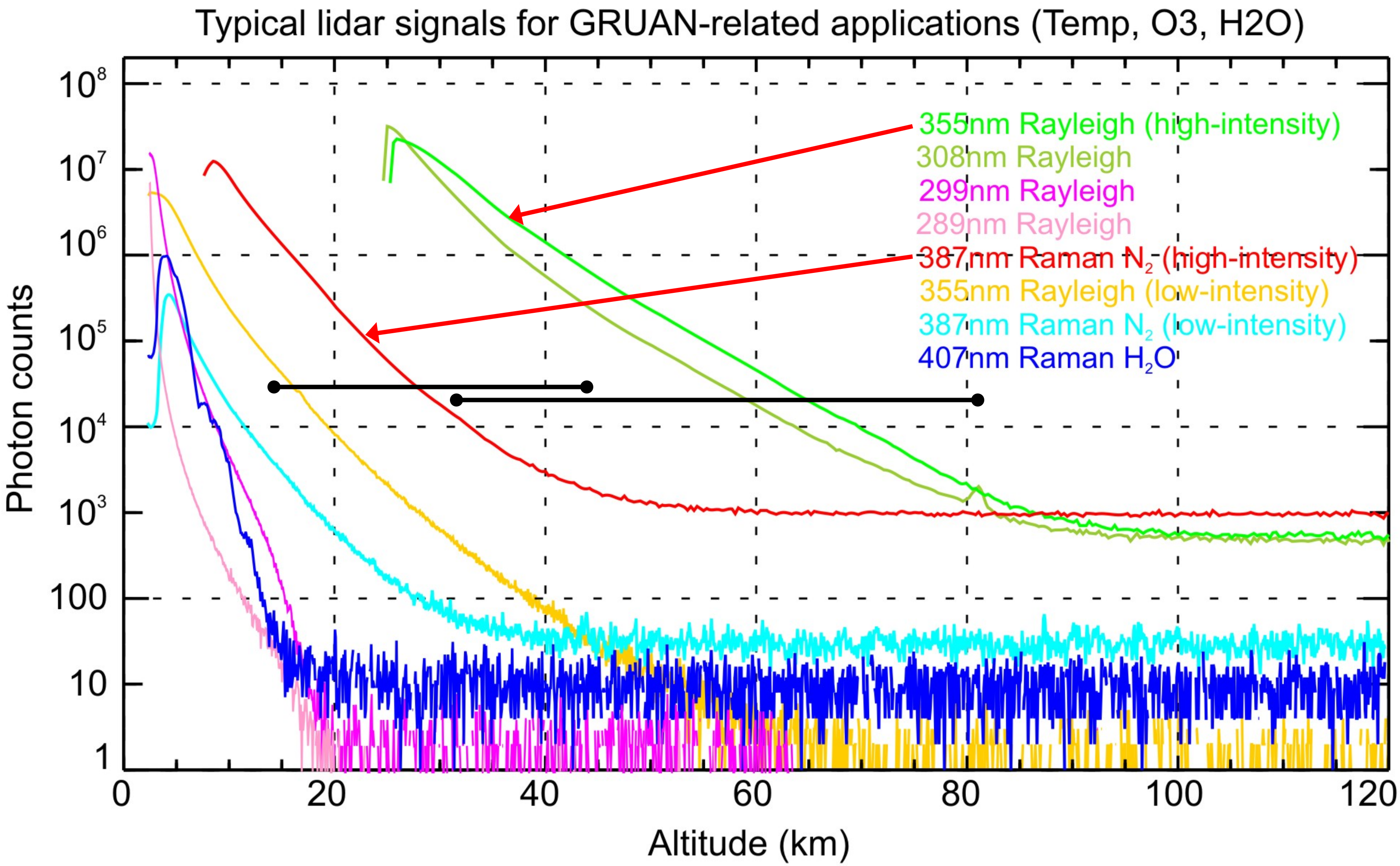
The number density is calibrated using (p-T) values from radiosonde or a model, then temperature is retrieved by downward integration of the ideal gas law and hydrostatic equation:

$$T(r-\delta r) = \frac{N_{air}(r)}{N_{air}(r-\delta r)}T(r) + \frac{M_{air}g(r-\delta r/2)N_{air}(r-\delta r/2)}{k_B N_{air}(r-\delta r)}\delta r$$

with: $T(r_{TOP}) = T_{apriori}$

This method requires a one-time tie-on to a single "a priori" temperature value at the top of the profile (e.g., MSISE model)

Application 1: Backscatter temperature (2 of 3)



Application 1: Backscatter temperature (3 of 3)

Strengths:

- *Very easy to implement (minimal laser/receiver implementation requirements)*
- *Large fraction of the atmosphere covered if dynamic range taken care of (multiple channels and receivers, use of Rayleigh and Vib-Raman scattering)*

Caveats:

- *Rayleigh channels sensitive to atmospheric opacity (clouds, aerosols)*
- *Cannot be used in lower atmosphere (never below 10-15 km, rarely below 20-25 km)*

Applications for GRUAN:

Nighttime only (standard equipment):

- *15-75 km: validation of satellite temperature measurements*
- *15-75 km: process studies at timescale longer than a few hours (e.g., long-term)*
- *15-60 km: process studies at timescale shorter than a few hours (e.g., tides)*

Daytime (with proper upgraded equipment):

- *All of the above over a reduced range (e.g., 15-40 km)*

Application 2: DIAL ozone (0-50 km)

Use the extinction part of the lidar equation, more specifically: the absorption by ozone

$$P_E(r,\lambda_E)\exp\left[-\int_0^r \alpha(r',\lambda_E)dr'\right]\sigma_M(r,\lambda_E \to \lambda_D)N_M(r)\exp\left[-\int_0^r \alpha(r',\lambda_D dr'\right]\frac{O_L(r)A_L\delta r}{r^2}\kappa_L(\lambda_D) = P_D(r,\lambda_D)$$

$$\alpha_{O3}(r,\lambda) = \sigma_{O3}(r,\lambda)N_{O3}(r)$$

Laser beam is partially absorbed along the laser beam path

Intensity of absorption depends on wavelength

➔ Use 2 wavelengths λ_1 and λ_2 with different absorptions

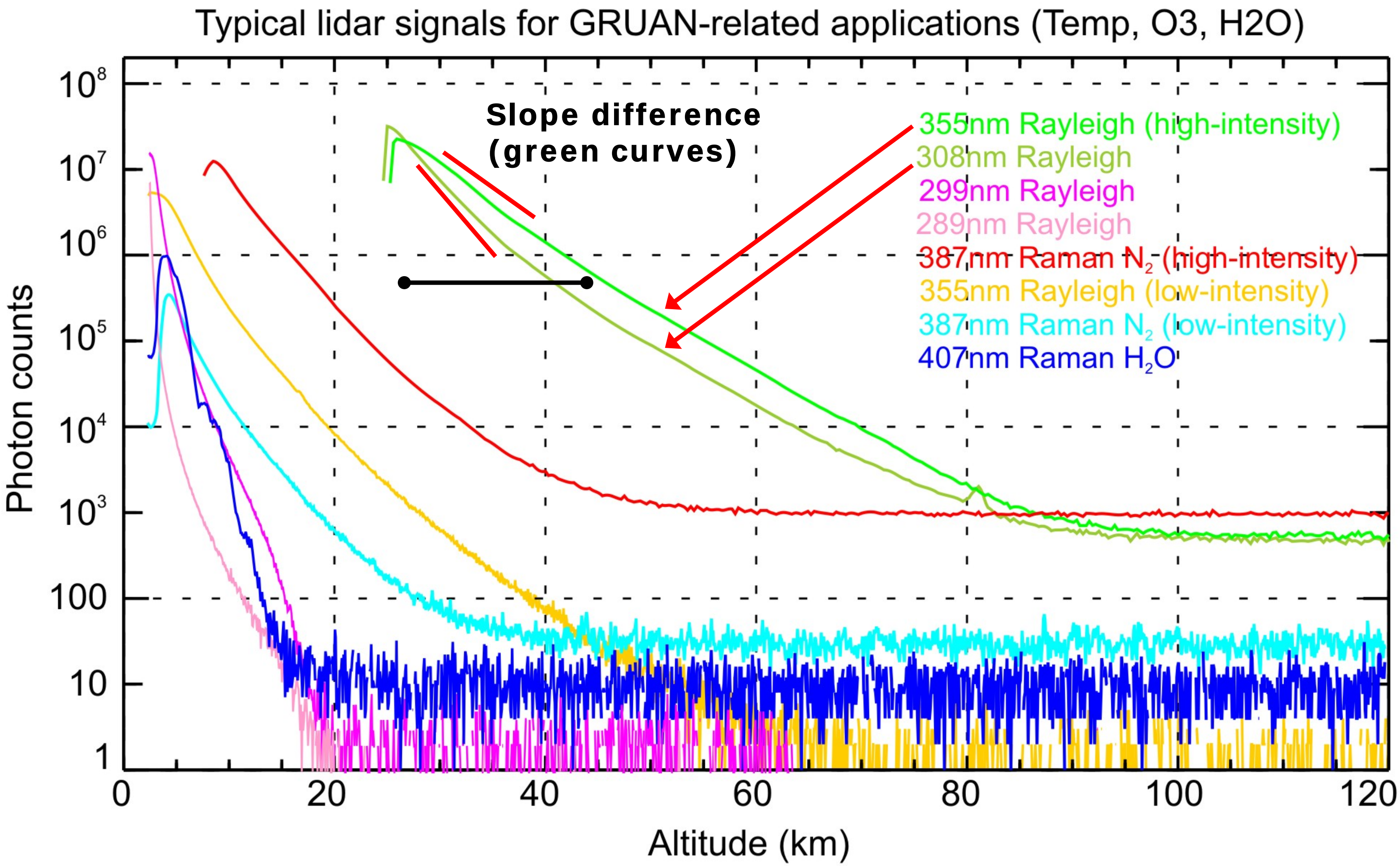
The Lidar equation is reverted to access N_{O3}: P_D ➔ $d/(\log(P_D))/dz$

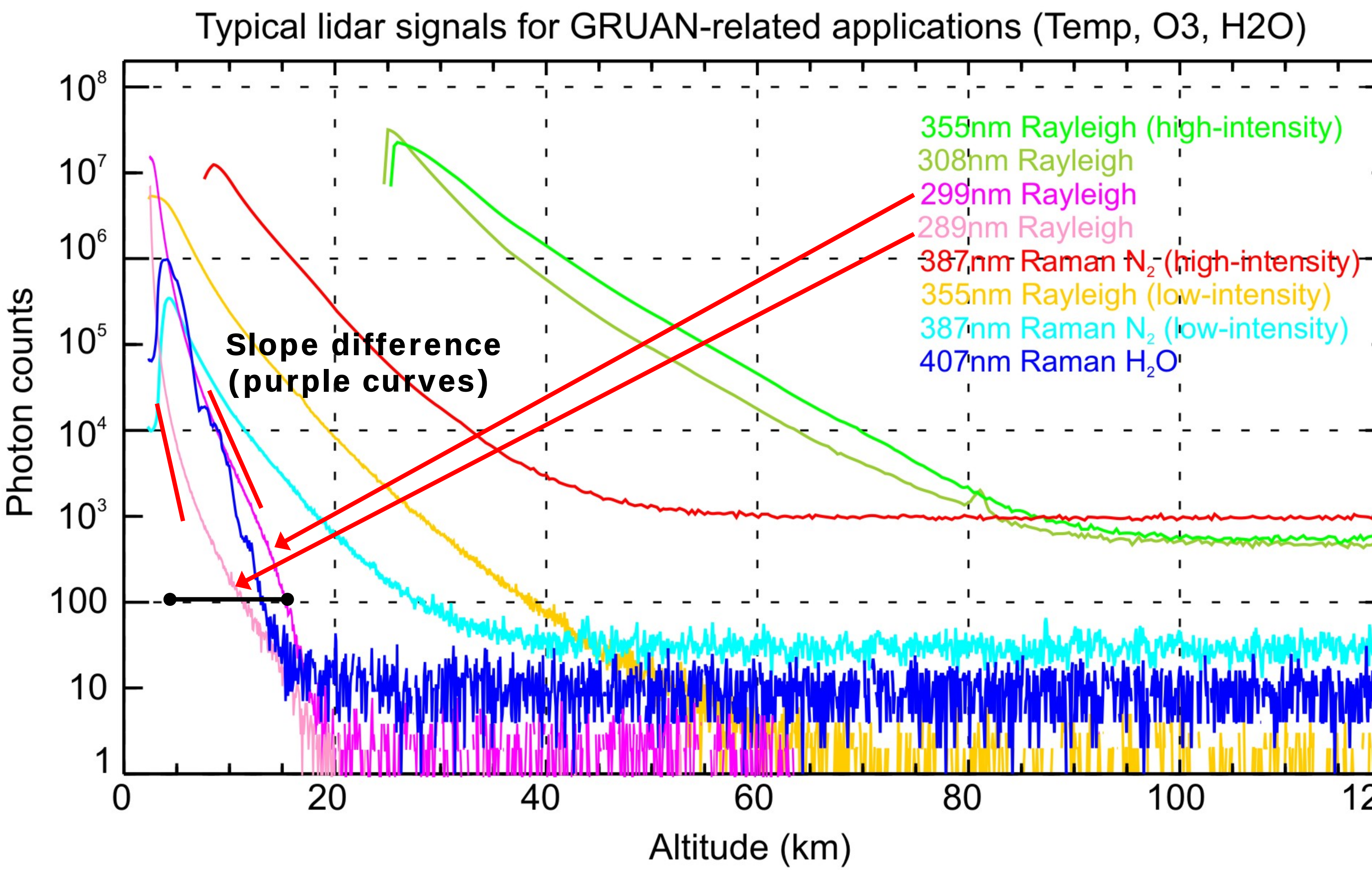
$$\frac{d}{dr}\left[ln\left(\frac{P_D(r,\lambda_1)}{P_D(r,\lambda_2)}\right)\right] = -\left(\sigma_{O3\uparrow}(r,\lambda_1)+\sigma_{O3\downarrow}(r,\lambda_1)-\sigma_{O3\uparrow}(r,\lambda_2)-\sigma_{O3\downarrow}(r,\lambda_2)\right)N_{O3}(r)$$

$$N_{O3}(r) = \frac{1}{\Delta\sigma_{O3\uparrow}(r)+\Delta\sigma_{O3\downarrow}(r)}\frac{d}{dr}\left[ln\left(\frac{P_D(r,\lambda_1)}{P_D(r,\lambda_2)}\right)\right]$$

Self calibrating method:
No need for calibration

Application 2: Stratospheric Ozone DIAL (2 of 4)




Typical lidar signals for GRUAN-related applications (Temp, O3, H2O)
Photon counts
Altitude (km)
355nm Rayleigh (high-intensity)
308nm Rayleigh
299nm Rayleigh
289nm Rayleigh
387nm Raman N2 (high-intensity)
355nm Rayleigh (low-intensity)
387nm Raman N2 (low-intensity)
407nm Raman H2O
Slope difference
(purple curves)

Application 2: DIAL ozone (4 of 4)

Strengths:

- *Mature technique (already several decades of data available)*
- *Does not require any calibration procedures*
- *Large range covered (0-50 km) if tropospheric and stratospheric setup available*

Caveats:

- *Accuracy limited by current knowledge of the temperature dependence of the ozone absorption cross-sections*
- *Requires non-basic laser equipment for stratospheric ozone (e.g., Excimers)*

Applications for GRUAN:

Nighttime only (standard equipment):

- *0-50 km: validation of satellite ozone measurements*
- *0-50 km: process studies at timescale longer than a few hours (e.g., long-term)*
- *0-15 km: tropospheric process studies at timescale shorter than a few hours (e.g., air quality)*
- *15-30 km: stratospheric process studies at timescale shorter than a few hours (e.g., UTLS)*

Daytime (with proper upgraded equipment):

- *All of the above over a reduced range (15-30 km for stratosphere, 0-8 km for troposphere)*

Application 3: Raman Water Vapor (0-20 km)

Use the backscatter part of the lidar equation, more specifically: the ratio of this backscatter by two molecules

$$P_E(r,\lambda_E)\exp\left[-\int_0^r \alpha(r',\lambda_E)dr'\right]\sigma_M(r,\lambda_E\to\lambda_D)N_M(r)\exp\left[-\int_0^r \alpha(r',\lambda_D dr'\right]\frac{O_L(r)A_L\delta r}{r^2}\kappa_L(\lambda_D)=P_D(r,\lambda_D)$$

The signal is proportional to number density of the target molecules. Taking H_2O and N_2 as target molecules, the ratio of the signals collected at each Raman wavelength is:

$$R(r)=\frac{\overline{P}_{H2O}(r)}{\overline{P}_{N2}(r)}=\frac{\kappa_{H2O}}{\kappa_{N2}}\frac{O_{H2O}(r)A_{H2O}}{O_{N2}(r)A_{N2}}\frac{\sigma_{H2O}(r)}{\sigma_{N2}(r)}\frac{N_{H2O}(r)}{N_{N2}(r)}\exp\left[-\int_0^r\left(\alpha_{H2O}(r')-\alpha_{N2}(r')\right)dr'\right]$$

The Lidar equation is reverted in a way to access the mixing ratio $q \sim N_{H2O}/N_{N2}$, P_D ➔ $(P_{H2O}/P_{N2})^{-1}$

$$R(r)=\kappa_{eff}\kappa_\sigma(r)\kappa_O(r)\kappa_\alpha(r)q(r)$$

Ratio of receiver efficiency

Ratio of cross-sections

Ratio of overlap

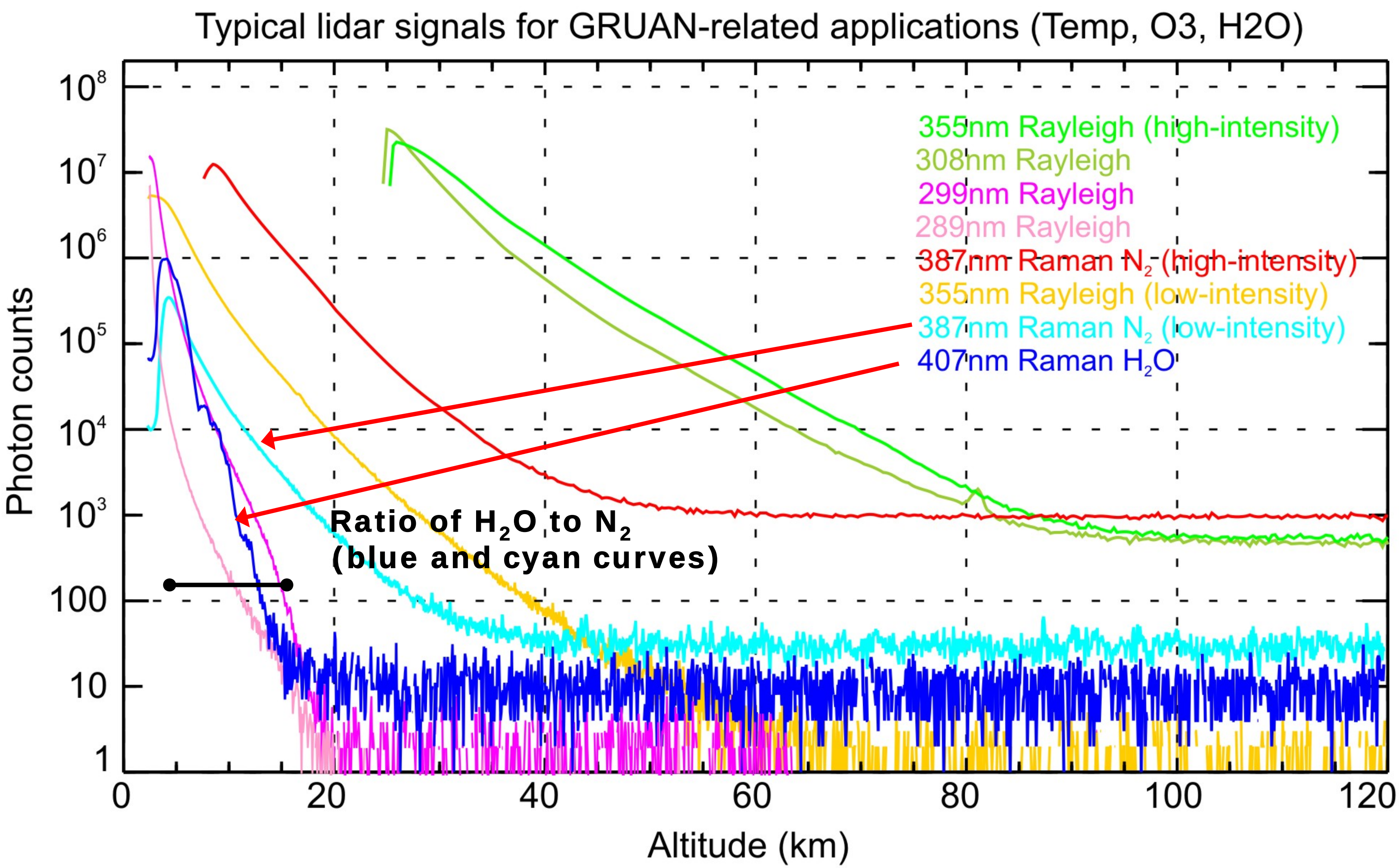
Ratio of extinction

This method requires calibration for e.g., to m.r. measured from radiosonde in the lower troposphere, or to IPW measured from GPS

Determination of altitude dependence of κ_s, κ_O, κ_a may be seen as "corrections"

Estimation of κ_{eff} or of the overall product $\kappa_{eff}.\kappa_s.\kappa_O.\kappa_a$ may be seen as "calibration"

Application 3: Raman Water vapor (2 of 3)



Application 3: Raman Water Vapor (3 of 3)

Strengths:

- *Easy to implement (minimal laser/receiver implementation requirements)*
- *Can reach UTLS if upgraded equipment is used (e.g., higher laser power, narrower filters)*

Caveats:

- *Requires calibration ("first principle" calibration still not a standard option)*
- *Range limited by the strong/fast decrease of H2O m.r. with altitude*
- *Sensitive to tropospheric opacity, especially in the LT (clouds, tropospheric aerosols)*

Applications for GRUAN:

Nighttime only (standard equipment):

- *0-10 km: validation of satellite water vapor measurements*
- *0-10 km: process studies at timescale longer than a few hours (e.g., long-term)*
- *0-7 km: process studies at timescale shorter than a few hours (e.g., fronts)*

Nighttime only (upgraded equipment):

- *All of the above with a 5-10 km extended range*

Daytime (upgraded equipment):

- *All of the above over a reduced range (e.g., 0-5 km)*

Application 4: Rot-Raman Temperature (0-30 km)

Use the scattering cross-section part of the lidar equation, more specifically: the temperature dependence of this cross-section in two well-selected Raman-rotation lines

$$P_E(r,\lambda_E)\exp\left[-\int_0^r \alpha(r',\lambda_E)dr'\right]\sigma_M(r,\lambda_E \to \lambda_D)N_M(r)\exp\left[-\int_0^r \alpha(r',\lambda_D dr'\right]\frac{O_L(r)A_L\delta r}{r^2}\kappa_L(\lambda_D)=P_D(r,\lambda_D)$$

The backscatter intensity of the molecules' RR lines is temperature dependent. Taking two well-selected RR lines, each with a "well-known" temperature dependence, the ratio of the signals collected at each set of RR lines is:

$$R(T(r))=\frac{P_{RR1}(r)}{P_{RR2}(r)}=\frac{\kappa_{RR1}}{\kappa_{RR2}}\frac{\sigma_M(T(r),\lambda_{RR1})}{\sigma_M(T(r),\lambda_{RR2})}$$

The Lidar Equation is reverted to fit the ratio of the temperature-dependent cross-sections to an assumed model P_D ➔ $(P_{RR2}/P_{RR1})^{-1}$

$$T(r)=F(R(r))^{-1}\approx\frac{b}{a-\ln(R(r))}+c\left(\frac{b}{a-\ln(R(r))}\right)^2+d$$

Note: the fitting model may differ, only one example is given here

This method requires calibration to a measured temperature (e.g., from radiosonde in the lower troposphere

Application 4: Rot-Raman temperature (2 of 2)

Strengths:

- *Insensitive to tropospheric opacity (unlike backscatter temperature lidar technique)*
- *A good complement to backscatter temperature lidar technique for lower atmosphere*

Caveats:

- *Requires calibration*
- *Requires upgraded equipment (narrow-band filters and laser)*
- *Requires line stabilization*
- *Not a mature technique (only a handful of operational systems worldwide)*

Applications for GRUAN:

Nighttime only (standard equipment):

- *0-30 km: validation of satellite temperature measurements*
- *0-30 km: process studies at timescale longer than a few hours (e.g., long-term)*
- *0-10 km: process studies at timescale shorter than a few hours (e.g., fronts)*

Daytime (upgraded equipment only):

- *All of the above over a reduced range (e.g., 0-5 km)*

Uncertainty in Lidar Measurements: Overview

Overall Measurement Uncertainty Depends on:

- *Target Species*
- *Signal strength and quality, which itself depends on:*
  - *Site elevation*
  - *Instrumental Setup*
  - *Atmospheric Conditions*

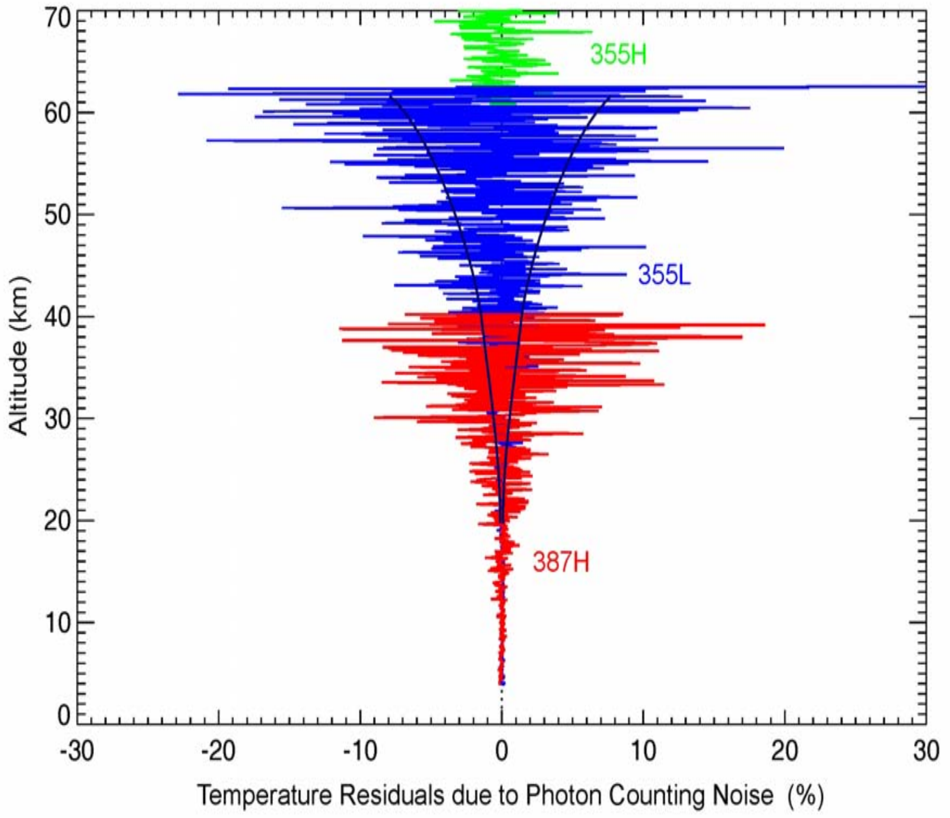
Main Sources of Uncertainty, All Species:

- *Photon Counting, random noise (impacts top of measurement range)*
- *Background Noise, incl. daylight (impacts top of measurement range)*
- *Signal saturation (impacts bottom of measurement range)*
- *Laser beam/telescope misalignment (impacts bottom of measurement range)*
- *Particles: Clouds and/or aerosols (impacts where particles present, sometimes above)*

Main Sources of Uncertainty, Species-Dependent:

- *H_2O and Tropospheric Temperature: Calibration (LT)*
- *Stratospheric Temperature: A priori Tie-on (top of measurement range)*
- *Ozone: Absorption Cross-sections*
- *H_2O: Fluorescence (UTLS)*

Photon Counting Noise and Resulting Uncertainty



Photon Counting Noise:

- *Becomes sigificant at low count rates i.e., at the top of the signal range*
- *Caused by loss of sensitivity in remote and/or rarefied atmosphere*

Associated Uncertainty:

Exact quantification very easy

Directly derives from the Poisson Statistics, i.e., equals square-root of photons counted:

$$\Delta S(r) = \sqrt{S(r)}$$

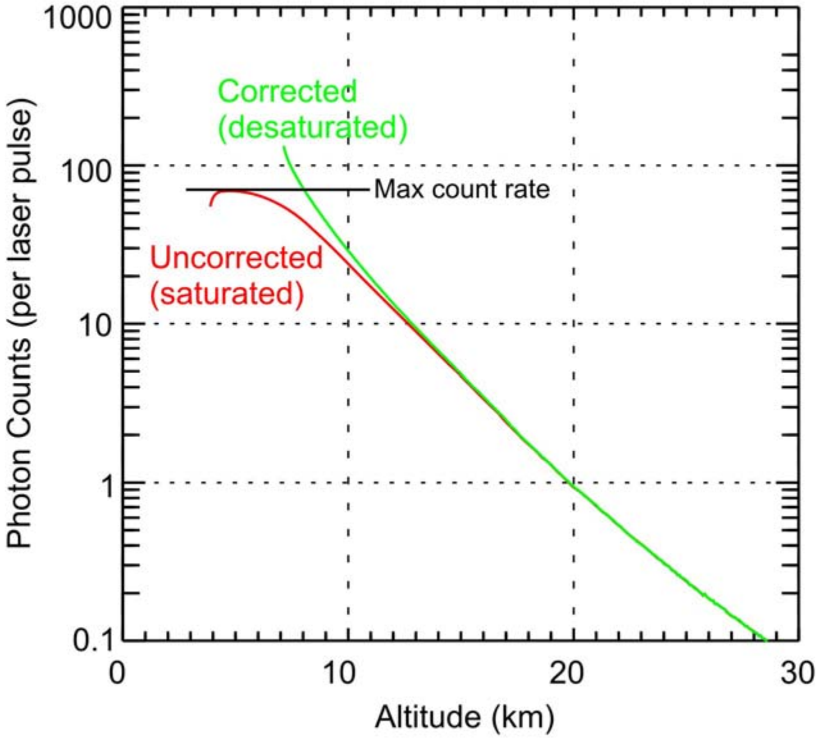
Impact on all Products:

Uncertainty exponentially increasing with altitude (growth rate depends on product)

Resulting Product Uncertainty depends on many factors:

- *Instrumental: Laser Power, collecting surface, receiver efficiency, spectral width*
- *Atmospheric: Opacity (the cleaner the sky, the better)*
- *Raw Data acquisition/averaging Time (often referred to as “integration time”)*
- *Raw Data vertical smoothing*

Lidar-Specific Corrections and Resulting Uncertainties (1 of 6)



Saturation ("pile-up") correction:

- *Occurs at high count rates i.e., at the bottom of the signal range*
- *Caused by non-linearity of the opto-electronic response of the detectors*
- *Correction is applied to "de-saturate" the signal*

Associated Uncertainty:

Exact quantification very difficult

- *Depends on how well detector specs are known*
- *Depends on de-saturation equation used*
- *Depends on channel intensity*

Impact on Product:

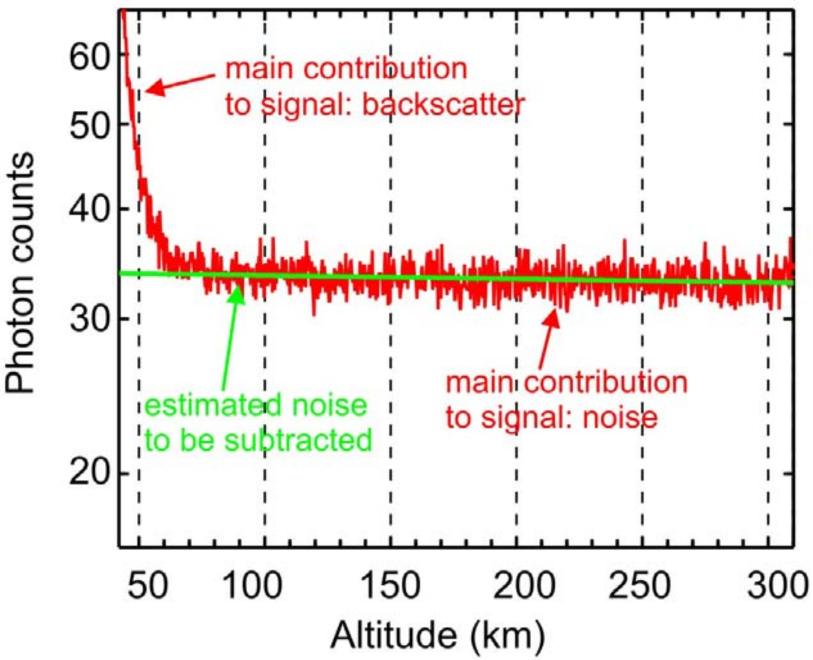
From <u>first</u> to <u>second</u> order effect on all products.
Uncertainty decreasing with altitude

Resulting Product Uncertainty can exceed 2% in the following cases:

- *Backscatter temperature, low-intensity range: below 12 km*
- *Stratospheric DIAL ozone , low-intensity range: below 18 km*
- *Tropospheric DIAL ozone , low-intensity range: below 6 km*
- *Raman water vapor, low-intensity range: below 3 km*

Actual examples available, ask Thierry to see them

Lidar-Specific Corrections and Resulting Uncertainties (2 of 6)



Background Noise:

- Occurs at upper end of the signal range
- Caused by residual noise from sky and detector
- Correction is applied to remove the noise

Associated Uncertainty:

Quantification possible from fitting function
- Small for "flat noise" (fit a constant)
- Small for gentle linear slopes
- Large for steep linear and non-linear fits

Impact on Product:

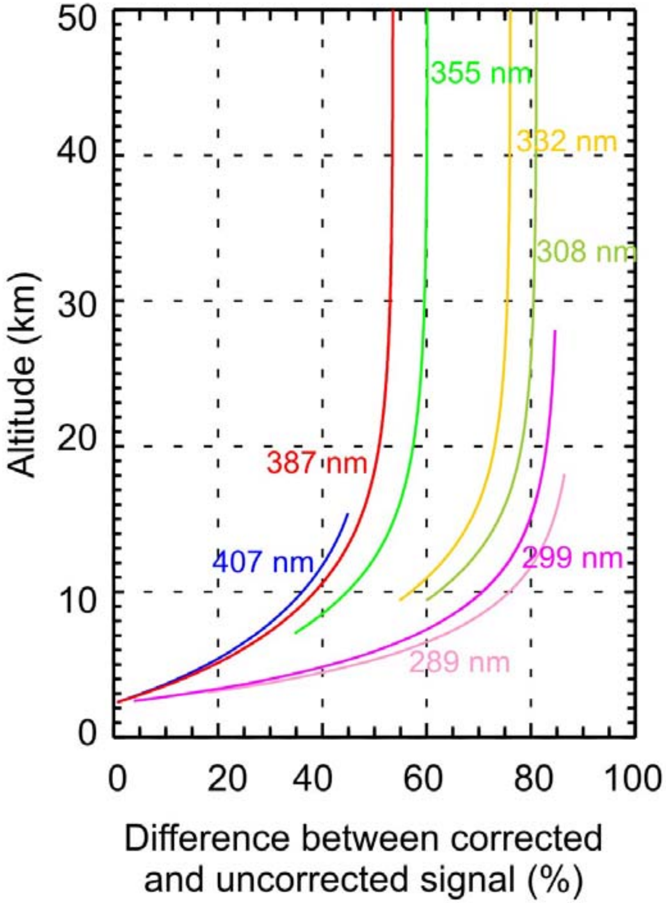
From first to second order effect on all products.
Uncertainty increasing with altitude

Resulting Product Uncertainty can exceed 2% in the following cases:

- Backscatter temperature, high-intensity range: above 60 km
- Stratospheric DIAL ozone , high-intensity range: above 40 km
- Tropospheric DIAL ozone , high-intensity range: above 17 km
- Raman water vapor, high-intensity range: above 10 km

Actual examples available, ask Thierry to see them

Lidar-Specific Corrections and Resulting Uncertainties (3 of 6)



Molecular Extinction:

- *Occurs mostly below 20 km*
- *Caused by absorption/scattering along beam path*
- *Correction uses a priori N_{air} from radiosonde or model, and laboratory-measured cross-sections*

Associated Uncertainty:

Quantification possible using uncertainty associated with the a priori

- *Rayleigh cross-sections: <2%*
- *a priori: 3% in T and/or p*

Impact on Product:

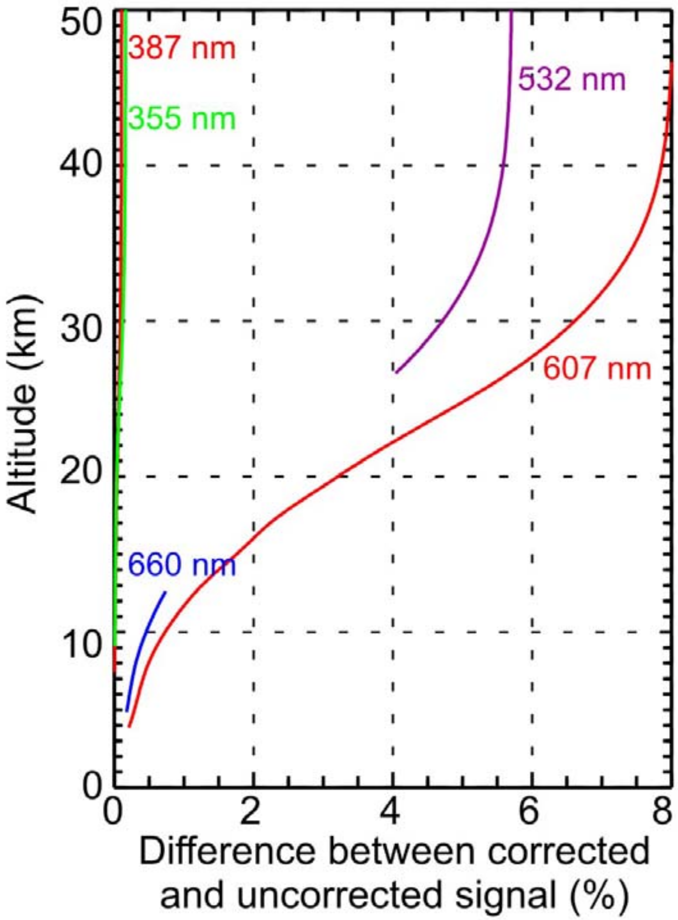
Mostly <u>second</u> order effect, depending on product and altitude

Resulting Product Uncertainty can exceed 1% in the following cases:

- *Backscatter temperature: below 20 km*
- *Stratospheric DIAL ozone: below 20 km (differential)*
- *Tropospheric DIAL ozone: below 4 km (differential)*
- *Raman water vapor: below 4 km (differential)*

Actual examples available, ask Thierry to see them

Lidar-Specific Corrections and Resulting Uncertainties (4 of 6)



Absorption by constituents (O3):

- *Occurs mostly by ozone in ozone layer (10-30 km) (may occur in highly-polluted BL, by O_3 and NOx)*
- *Caused by absorption along beam path*
- *Correction uses measured or climatological N_M and laboratory-measured cross-sections*

Associated Uncertainty:

Quantification possible using uncertainty associated with the a priori

- *Absorption cross-sections: <2%*
- *a priori: 5% in N_{O3}, highly variable for other molecules*

Impact on Products:

Second order effect for stratospheric temperature using 532 nm or 607 nm, and for UTLS water vapor using 607 nm and 660 nm

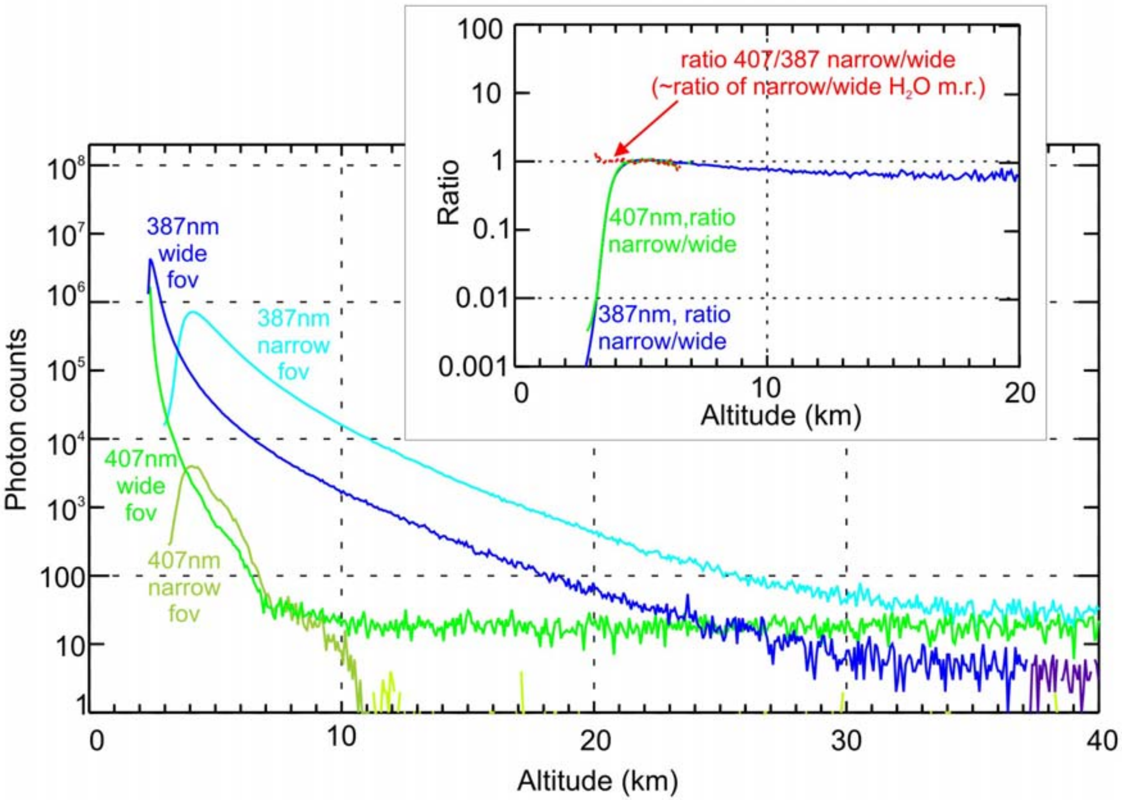
Negligible effect for all other products (exception for highly-polluted BL)

Resulting Product Uncertainty might exceed 0.2% in the following cases:

- *Backscatter temperature at 607 nm in ozone layer*
- *Raman water vapor at 660/607 nm in LS*

Actual examples available, ask Thierry to see them

Lidar-Specific Corrections and Resulting Uncertainties (5 of 6)



Partial Overlap:

- *Occurs when using narrow field-of view receivers*
- *Caused by incomplete overlap of laser beam image and field-of-view*
- *Correction uses either empirical or measured fit of narrow-to-wide f.o.v.*

Associated Uncertainty:

Quantification difficult

- *Depends on instrumental setup*
- *Can be unstable from night to night*

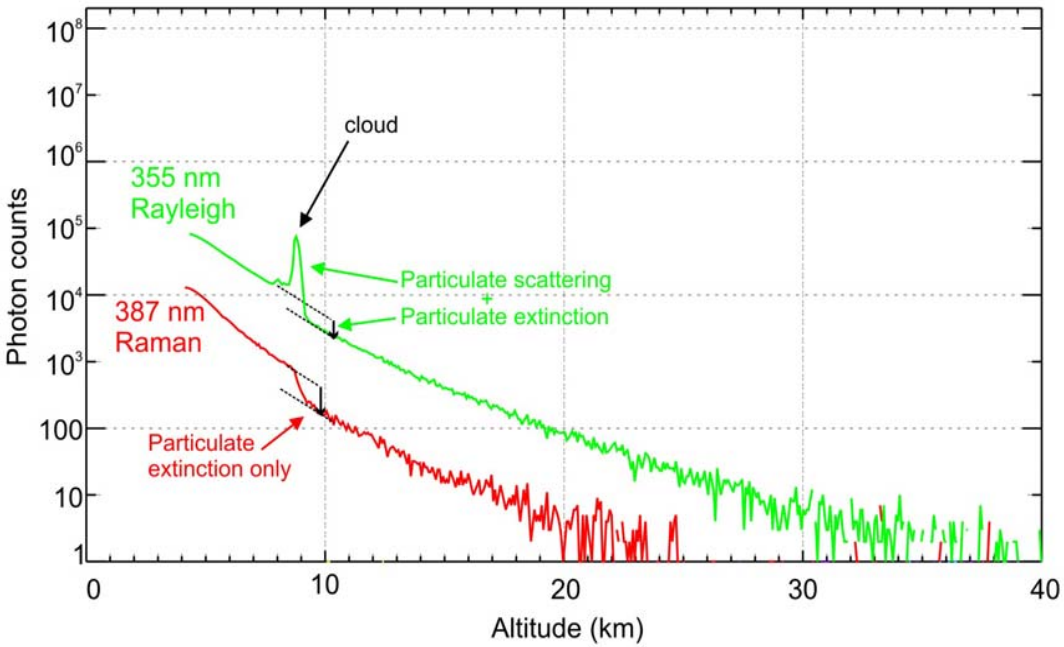
Impact on Products:

First to second order effect, depending on product, altitude, and instrument design

Resulting Product Uncertainty can exceed 5% in the following cases:

- *At the bottom end of the profile retrieved from any very-narrow-fov channel*
- *At the bottom end of the profile retrieved from any narrow or wide fov channel, if misaligned*

Lidar-Specific Corrections and Resulting Uncertainties (6 of 6)



Particulate backscatter and extinction:

- Occurs if clouds or aerosols are present
- Caused by absorption and scattering by particles along beam path
- Correction uses assumptions on the properties of the scattering layer (size, density, and type of particles)

Associated Uncertainty:

Quantification difficult

- *Depends on a priori assumptions*
- *Sensitive to multiple scattering*

Impact on Products:

First to second order effect, depending on product, on optical depth, and on the properties of the scattering layer

Resulting Product Uncertainty can exceed 5% in the following cases:

- *Within clouds of moderate optical thickness*
- *In the boundary layer at any time*

Beyond Corrections:
Remedies for Minimization of Uncertainty

Before applying corrections, there are ways to minimize uncertainty!

Ways to minimize uncertainty, all species:

- *Site elevation: Pick higher elevation site if BL measurements are not required*
- *Atmos. conditions: Pick "dry" and "clean" site if all-weather sampling is not required*
- *Instrumental setup: Design/<u>modify</u> instrument setup to minimize overlap ($$)*
- *Photon counting: Use high power laser ($$$)*
- *Background noise, nighttime: Use mechanical chopper to avoid SIN ($$)*
- *Background noise, daytime: Use UV wavelengths and/or narrowband filters ($$)*
- *Signal saturation: Use chopper, gating, AD channels, and/or multiple telescopes sizes ($$)*
- *Misalignment: Use multiple telescopes sizes, with wide f.o.v., re-align frequently ($)*
- *Particles: Pick "clean air" site, pick a clear-sky measurement schedule, and/or use aerosols channels to estimate cloud/aerosol properties before correcting data ($)*

Ways to minimize uncertainty, species-dependent:

- *Calibration (H2O, tropo-T): Pick a site with strong potential for multiple, co-located <u>and</u> simultaneous calibration sources (e.g., radiosonde, GPS)*
- *Absorption Cross-sections (O3): Stay "wired" of latest lab. studies and dedicated WGs such as the WMO SAG*
- *A priori Tie-on (T): Exclude top 10-km of profile (usually in the mesosphere)*
- *H2O: Fluorescence (UTLS): Design "fluo-free" receiver*

Pathway Towards GRUAN Lidar Products

January 2012:
GRUAN Lidar Guidelines first draft

Current document applies to water vapor Raman lidar

Extending to all other species is straightforward because water vapor is the most "problematic" measurement

QUICK REFERENCE GUIDE

3 requirements: Quality, Consistency, Traceability
3 tools: IGLIMP, LidarRunClient, GLASS

IGLIMP: Individual GRUAN Lidar Measurement Protocol

A document written <u>and updated</u> by each GRUAN lidar PI in which a complete description of the lidar program is reported, in ALL its aspects: instrumental setup, changes with time, standard operating procedures, and measurement schedules

LidarRunClient:

An interface utility to record the <u>complete</u> set of metadata of <u>every</u> measurement contributing to the GRUAN Lidar Data Archive Center. The information conveyed by LidarRunClient must be fully consistent with that provided in the IGLIMP, and ready to be used by the GLASS

GLASS: GRUAN Lidar data Analysis Software Suite

A centralized Data Analysis Software maximizing the consistency of the data processing among all GRUAN lidars, and complying with all GRUAN standards. The input parameters must be fully consistent with information reported in the IGLIMP and transmitted through the LidarRunClient utility. The output products may be of multiple nature, i.e., adapted to the science application they may be used for (e.g., process studies vs. long-term, etc.)

Purpose of Lidars within GRUAN

1) to provide redundant measurements at GRUAN sites, therefore complementing the water vapor profiles from radiosondes and frost-point hygrometers, and the total column water measurements from GPS

2) to sample time-altitude cross-sections over time periods ranging from a few minutes to several days, thus providing an additional, flexible contribution to instrument validation and process studies

GRUAN Lidar Programme Certification

Need to distinguish between "GRUAN site" and "GRUAN lidar Programme"

A lidar deployed at a certified GRUAN Site does not acquire the status of GRUAN Lidar. The lidar instrument is still required to follow the GRUAN Lidar Certification Process before it becomes "GRUAN lidar"

Lidar Certification Process aligned to that described in GRUAN Guide for sites

Iterative Process between Lidar Programme Rep, Lead Center, and WG-ARO

1) Candidate: contact GRUAN Lead Centre to notify them of their interest to contribute to GRUAN

2) LC: follow the procedures in place for the selection of a specific measurement programme, in particular provide candidate all the necessary GRUAN governing docs

3) Candidate: read, understand and <u>approve</u> all GRUAN governing documents, including GRUAN Manual, and GRUAN Lidar Programme Guidelines

4) Candidate: Provide technical document including information pertaining to instrument, personel, SOP, etc. proposed to be performed as part of their GRUAN Programme

5) Based on documentaiton, LC and WG-ARO work on certificaiton approval and notify candidate of their final decision

Proposed GRUAN Lidars Measurement Scheduling

1) A minimum of 6 hours per week spread over 2 to 4 nights of operation may be suitable to most applications

2) If logistical/financial support allows it, GRUAN lidar instruments having a 24/7 capability should adopt the 24/7 schedule as their default schedule

3) when logistical/financial support does not allow 24/7 operations, default schedules must be chosen to address one or several of the following questions: long-term variability studies, process studies, satellite validation, and GRUAN measurement redundancy

4) Raw data should be acquired at temporal resolutions shorter than 5 minutes in order to capture shorter scales of variability.

5) In order to increase precision, those 5 minutes resolution data may be averaged over several hours for applications such as long-term variability studies

Proposed GRUAN H2O Lidars Measurement Redundancy Plan

1) For sites performing at least daily radiosonde flights:

The lidar does not need to be operated every night, but when operated, its running time should be coincident with the first night-time flight of the day. The first half-hour of the radiosonde flight must fully encompass the lidar data acquisition period, i.e., must be included between lidar start and end times

2) For sites performing weekly or monthly radiosonde flights:

The lidar must be operated at least on the nights (days) of the radiosonde flights. The first half-hour of the radiosonde flight must fully encompass the lidar data acquisition period, i.e., must be included between lidar start and end time

3) For sites performing Frost-point hygrometer (FPH) flights:

The lidar must be operating at least on the nights (days) of the FPH flights. Extended hours of lidar operation (e.g. all night or at least 4-5 hours) are recommended to extend and/or optimize the profiles in the UT/LS. The first full hour of the FP flight must fully encompass the lidar data acquisition period, i.e., must be included between lidar start and end times

All of the above weather-permitting obviously

Proposed GRUAN H2O Lidars Calibration Approach (1)

1) Calibration using an external source of measurement is the default approach
In this approach, the calibration is performed at a late stage of the data processing (GLASS), not during or before measurement.

2) A simultaneous and colocated external source of measurement is required
In order to reduce the impact of atmospheric variability, an average of several calibration runs is preferred to single calibration runs

3) Multiple external sources of measurement is strongly recommended
All available calibration constants should be reported in the final GRUAN lidar product file, though only one of them should apply to the reported lidar profile (i.e., no merging of the calibration constants)

4) First Principle calibration *(i.e., not requiring an external source of measurement) is difficult to achieve on a routine basis with a suitable accuracy. The performance of this approach, however, must be reviewed regularly in the future for a possible "standard implementation" within GRUAN.*

Proposed GRUAN H2O Lidars Calibration Approach (2)

5) Acceptable external calibration sources:

Corrected radiosondes, Frost-point Hygrometers, GPS, microwave instruments and water vapor DIALs, all of which must have been validated prior to use

6) Unacceptable calibration sources:

Any measurement that does not include Uncertainty Estimates inferred following GRUAN's recommendations

7) Monitoring Calibration Stability:

A Laboratory Lamp to *monitor calibration stability with time is strongly recommended. The lamp may be fixed or scanning, but its position(s) with respect to the receiver must remained unchanged during the monitoring period (i.e., between 2 external calibration runs)*

8) Managing Change:

Going beyond all previously defined GRUAN requirements ☺ ...

Use radiosondes from identical manufacturing batches during the same calibration periods at multiple sites (requires robust cross-network-sites logistical support)

Proposed GRUAN Lidar Data Archiving Levels

(naming convention to be synched to new Manual)

Level 0 (L0): "Original raw data"

The raw data slices acquired by the data acquisition electronics. They must be kept indefinitely at the GRUAN lidar programme site and mirrored at the GRUAN lidar data host facility

Level 1 (L1): "Converted raw data" (now CRD)

The raw data slices converted to a common format. They must be kept indefinitely at the GRUAN lidar data host facility

Level 2 (L2): "Standard GRUAN Lidar Product"

Does not require incorporation of an independent source of measurements. The standard lidar product output from the GLASS

Level 3 (L3): "Composite GRUAN Product"

An integrated product that does require incorporation of independent measurements, i.e., the standard lidar product output from the GLASS combined with measurements from other instruments

Proposed GRUAN Lidar Level 2 Data Products

The selection of integration time is made at the GLASS level, i.e., the raw data input to the GLASS always have a 5-min time resolution or less (level 1)

Products output from the GLASS (level 2) may include profiles processed using different averaging times, depending on measurement schedule and science app.

Level 2L: Specific to Long-Term Studies

Longer integration times (at least several hours) are preferred to increase precision. Traceability and stability of this product over long periods of time are essential

Level 2P: Specific to Process Studies.

Shorter integration times are preferred to facilitate short temporal variability studies. Traceability and stability of this product over long periods is less critical, though highly desired.

Level 2V: Specific to Validation Studies.

Integration times may vary, based on the temporal variability of the measured species, and on the spatio-temporal configuration of the coincident/correlative measurements to be validated

Pathway Towards GRUAN Lidar Products (10 of 10)

Timeline and Supporting Tools and Documents

January 2012:

First draft of GRUAN Lidar Guidelines document circulated to TT5 members and all GRUAN TT co-chairs

March-April 2012:

Re-synchronization of the revised GRUAN Manual and GRUAN Lidar Guidelines.

September 2012:

Revised GRUAN Lidar Guidelines document, near official "version 1"
(will include all species, not just water vapor)

2012/2013:

Build-up and synchronization of the IGLIMP, LidarRunClient and GLASS
(multiple iterations required)

2013:

First official GRUAN lidar Product

Thank You