GRUAN Lidar
Technical Document and Data Stream
Progress Status

Thierry Leblanc

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

What is the GRUAN Lidar Technical Document going to address?

2012-2013:
Definition and Design of GRUAN Lidar Programmes

➔ "***GRUAN Lidar Guide***" *first draft, presented to WG-GRUAN, ICM-5 (2013)*

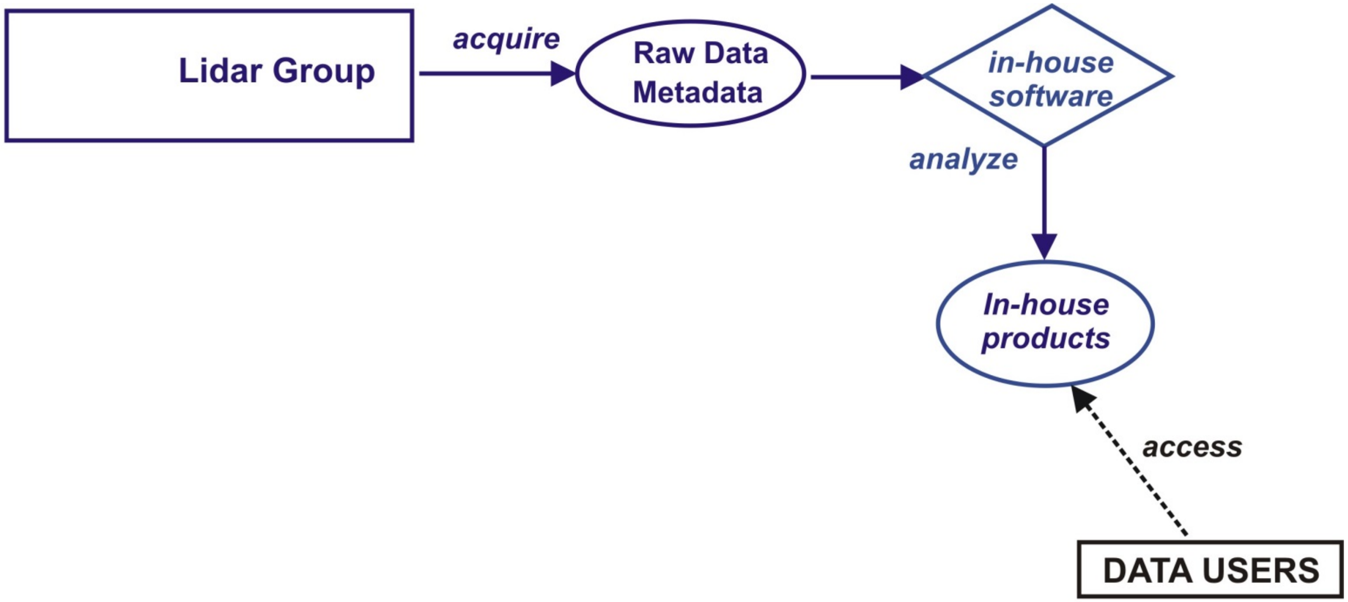
1- Define responsibilities

Responsibilities:

- *Red = GRUAN LC*
- *Cyan = GRUAN TT-AM*
- *Yellow = WG-GRUAN*
- *Orange = LC and WG-GRUAN*
- *Green = TT-AM and WG-GRUAN*
- *Purple = TT-AM and LC*

First: Define responsibilities (LC, WG-GRUAN, TT-AM)

2- Identify instrument



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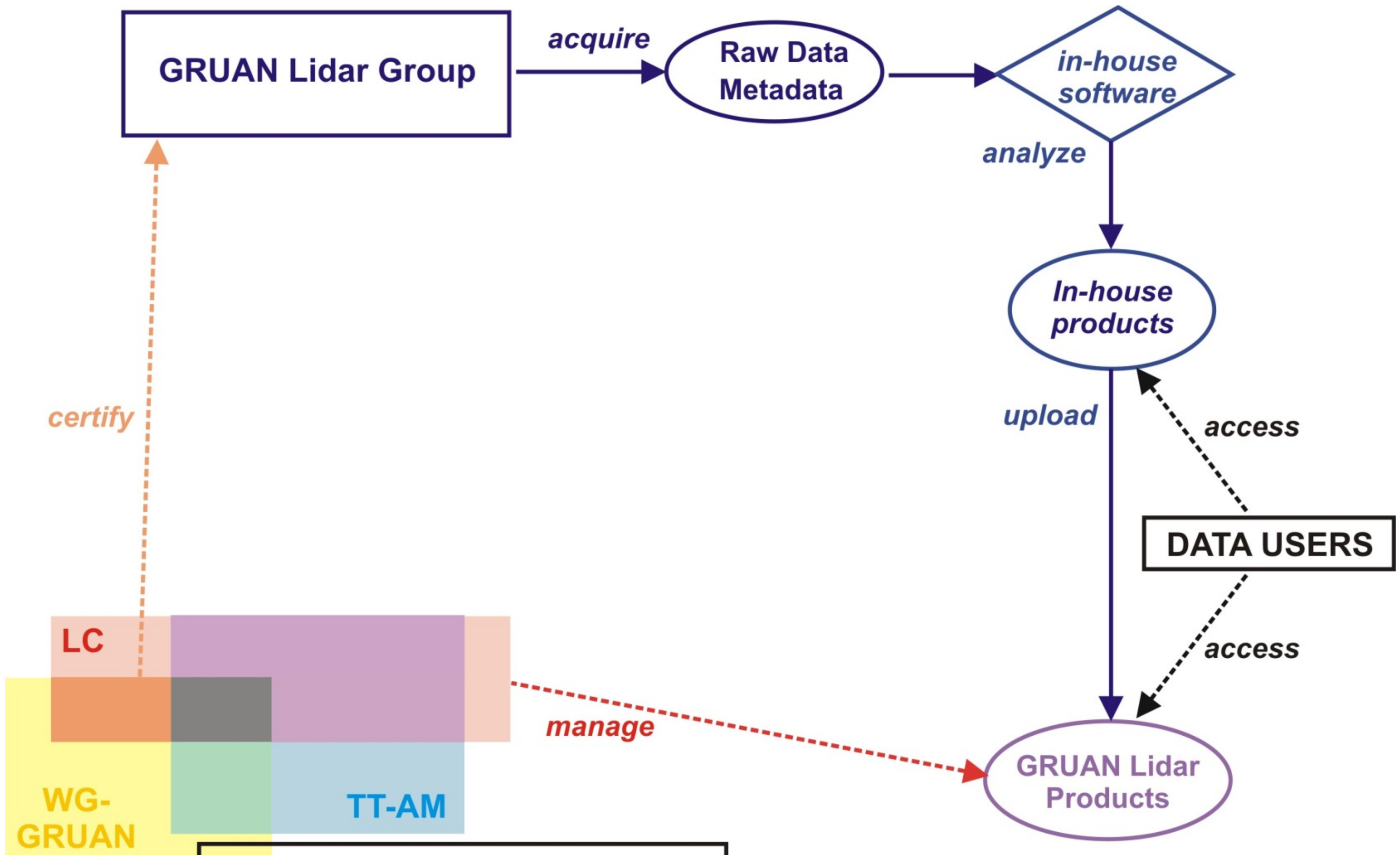
- Orange = LC and WG-GRUAN
- Green = TT-AM and WG-GRUAN
- Purple = TT-AM and LC
- Dark Blue = Lidar group

Then, identify a candidate instrument…

3- Instrument enrollment… NDACC-style ?



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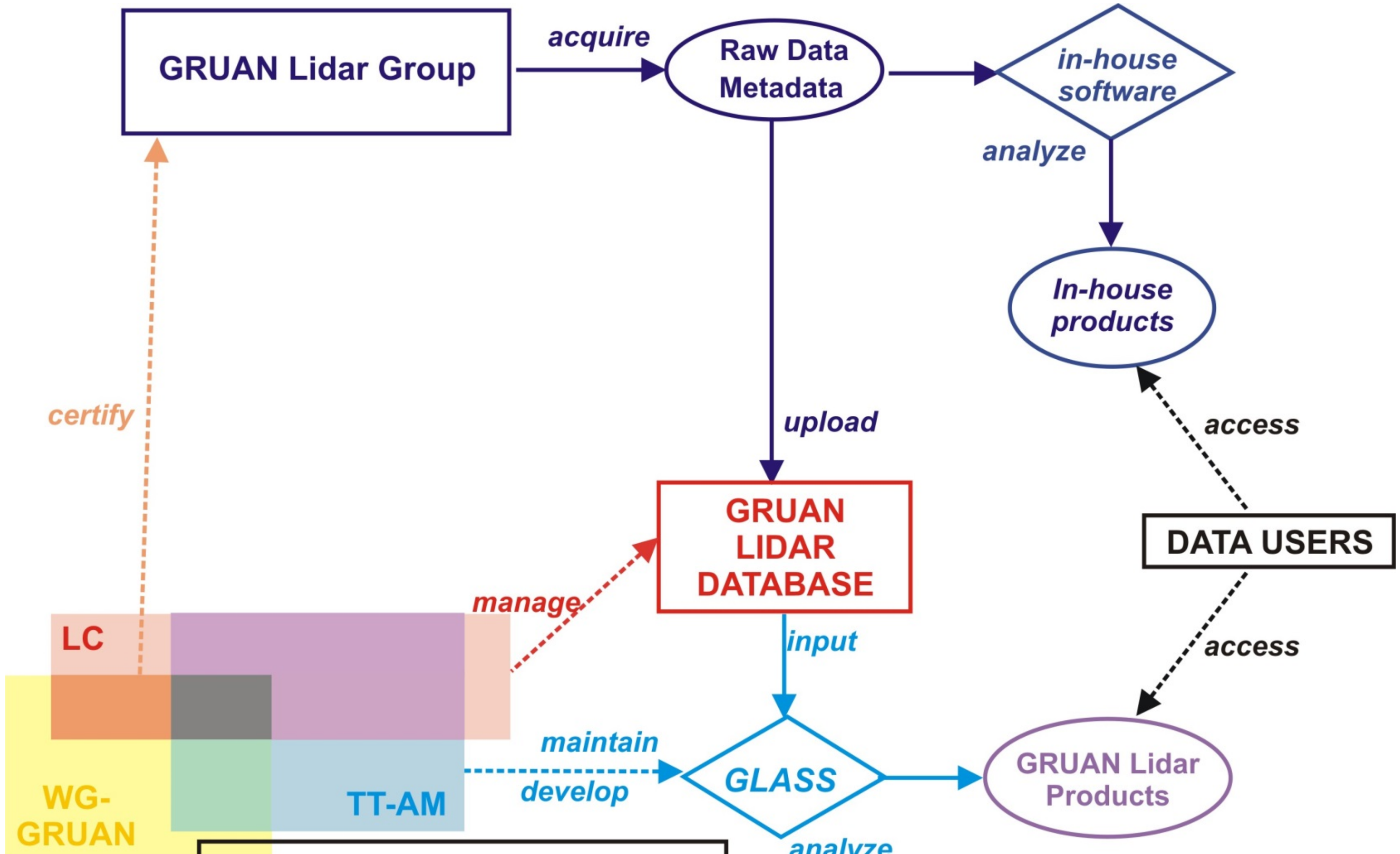
NDACC-style:

1- In-house processing

2- In-house products centrally archived

4- Instrument enrollment… GRUAN-style (basic)



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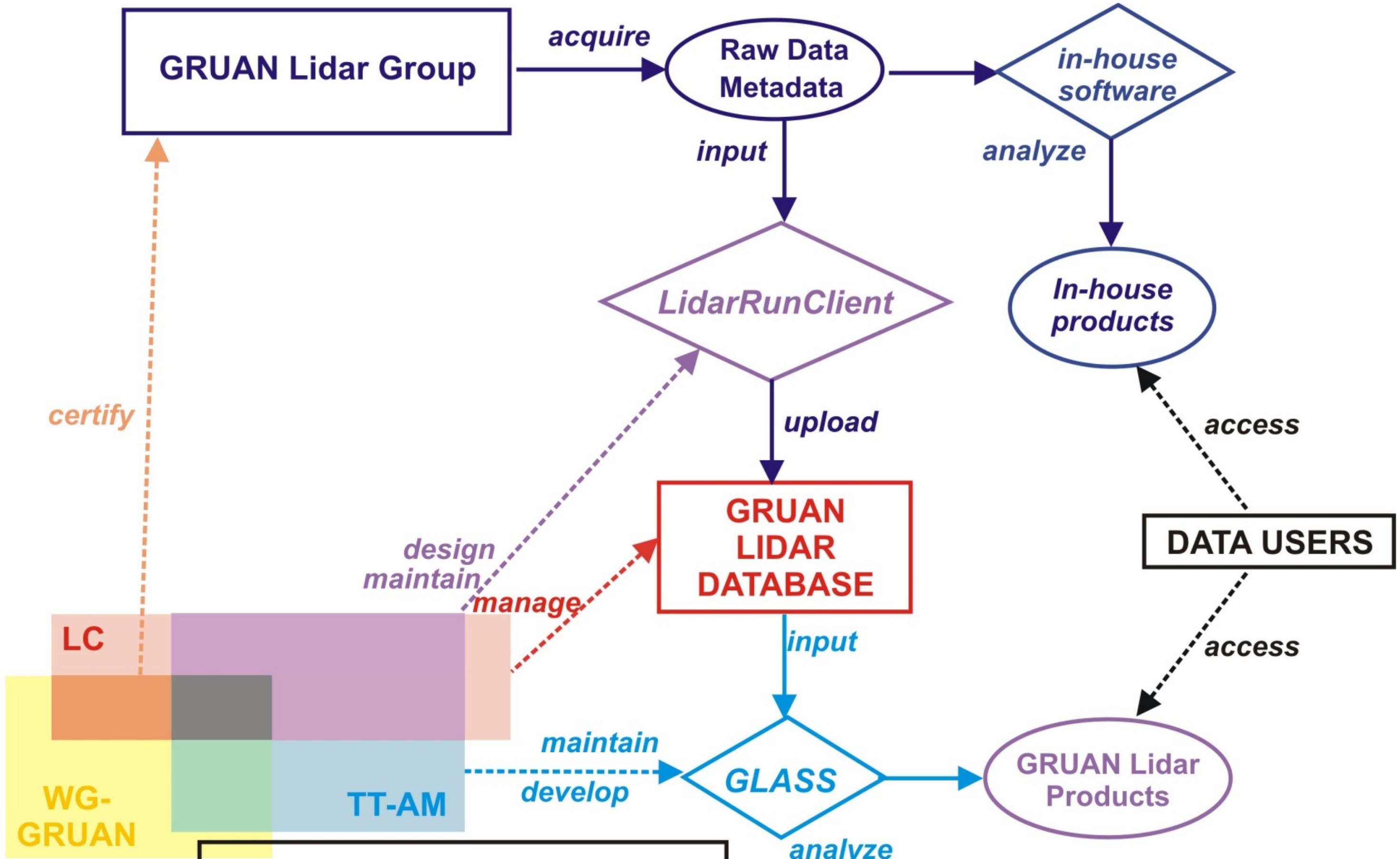
Purple = TT-AM and LC
Dark Blue = Lidar group

GRUAN-style, basic:

1- Centralized processing and archival
2- No infrastructure for follow up on meta data

5- Instrument enrollment… GRUAN-style (enhanced)



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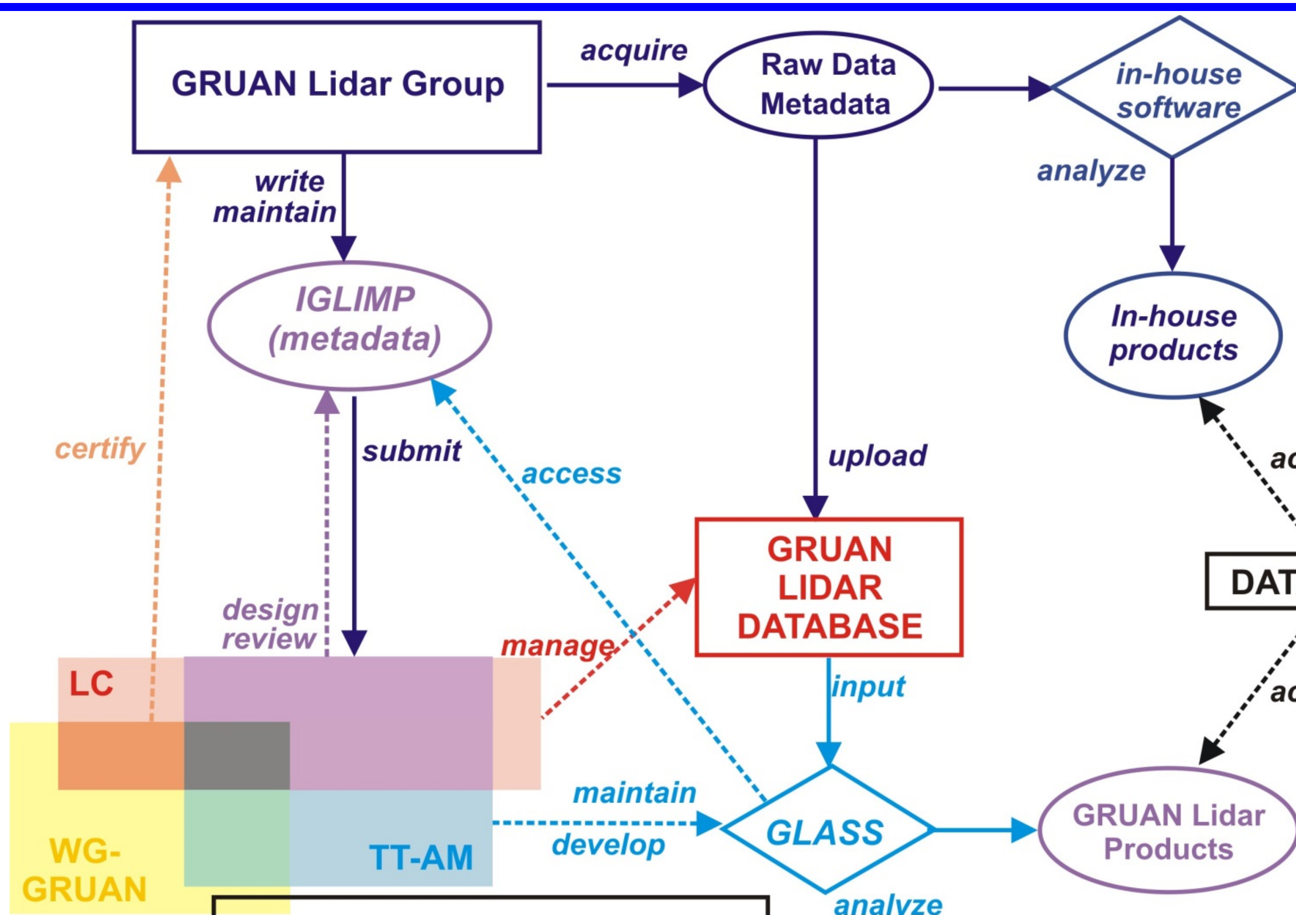
- *Purple = TT-AM and LC*
- *Dark Blue = Lidar group*

GRUAN lidar Programme (v1):

1- Centralized processing and archival

*2- **LidarRunClient** for standardized upload of raw data and meta data*

6- Instrument enrollment… GRUAN-style (enhanced v2)



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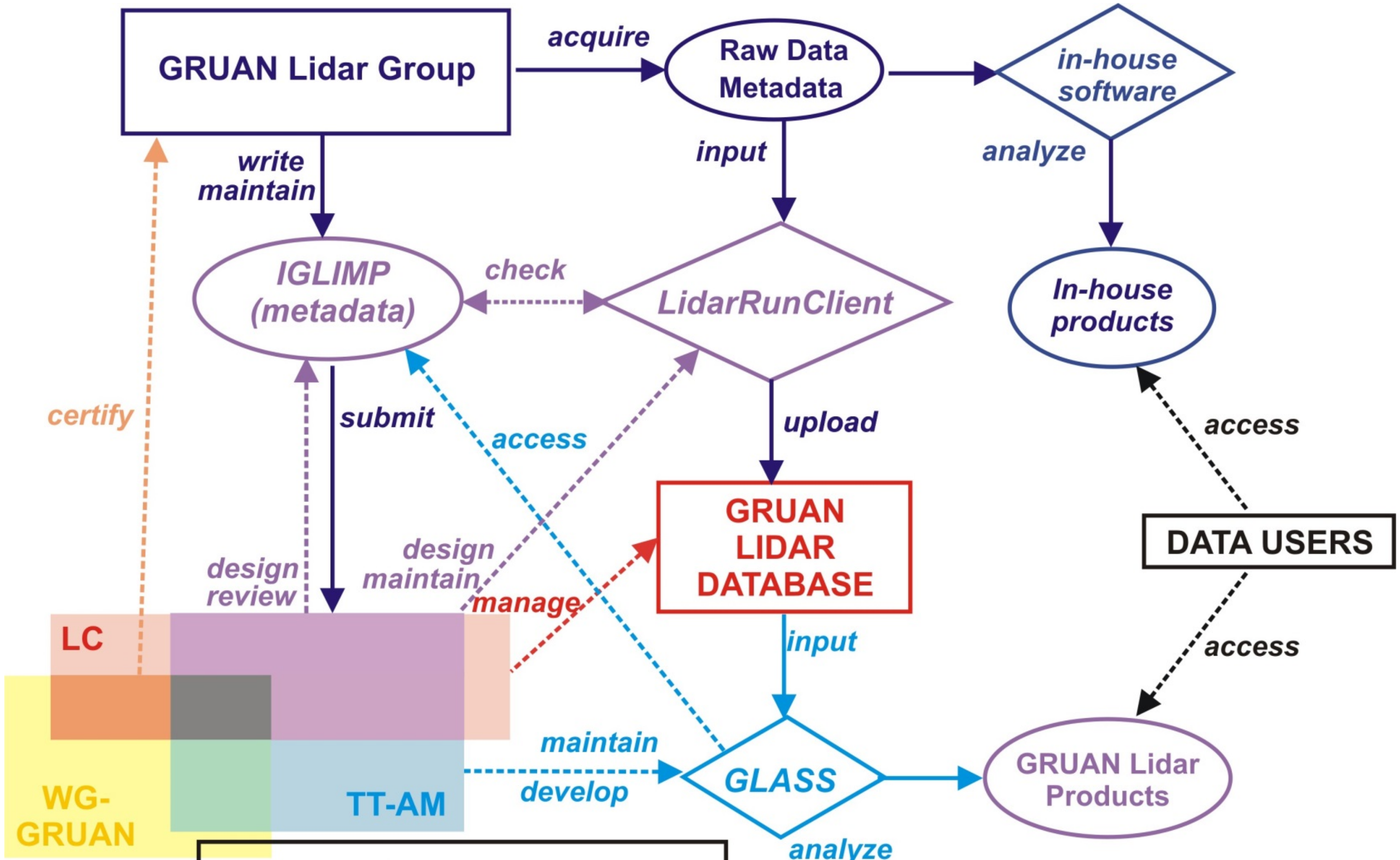
GRUAN lidar Programme, version 2:

1- Centralized processing and archival

*2- **IGLIMP** meta data file for full traceability of meta data*

7- Enrollment, GRUAN-style (optimal)….



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- *Green = TT-AM and WG-GRUAN*
- *Purple = TT-AM and LC*
- *Dark Blue = Lidar group*

GRUAN lidar Programme, optimal:

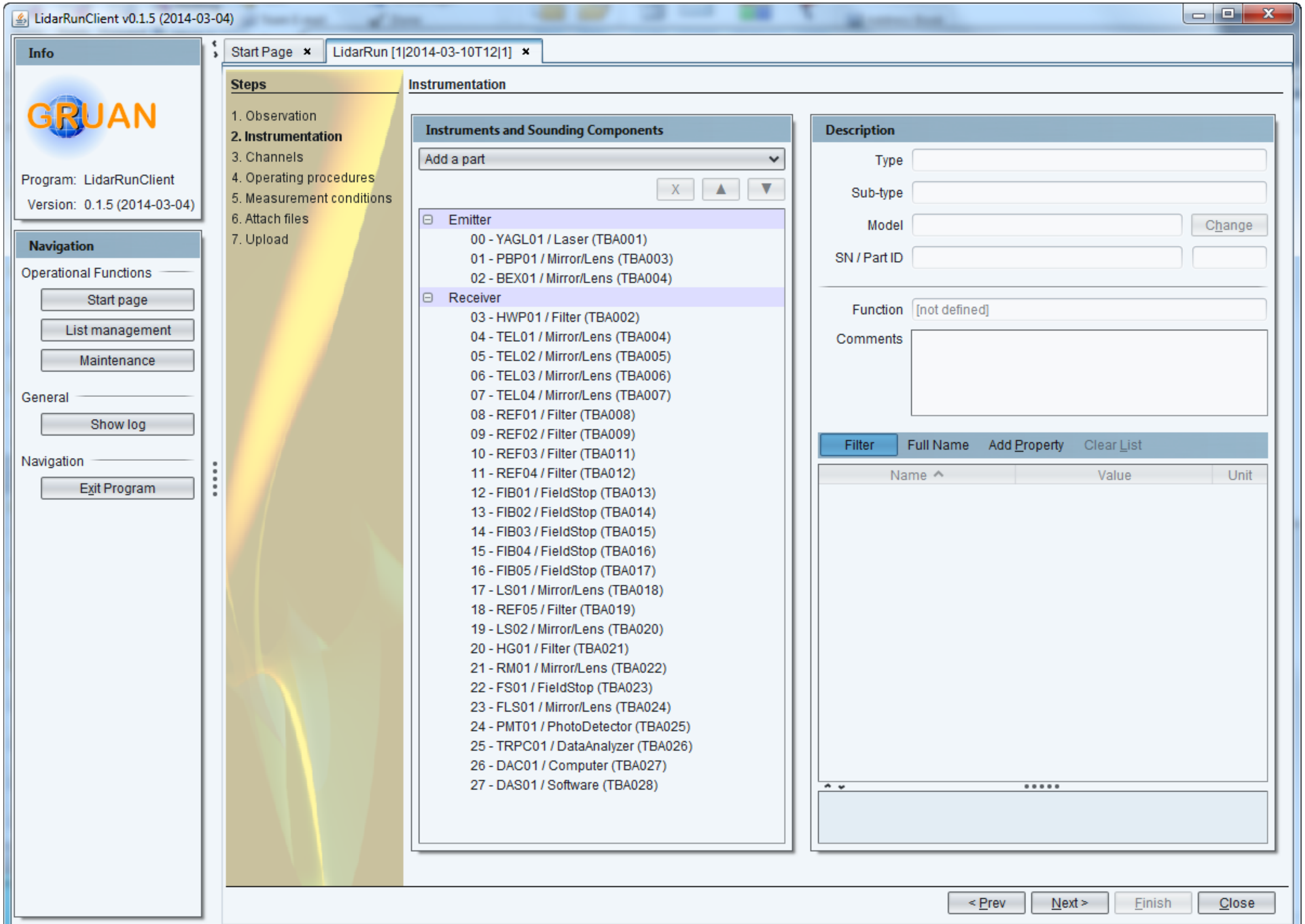
1- Centralized processing and archival

*2- **LidarRunClient** interface*

*3- **IGLIMP** meta data file*

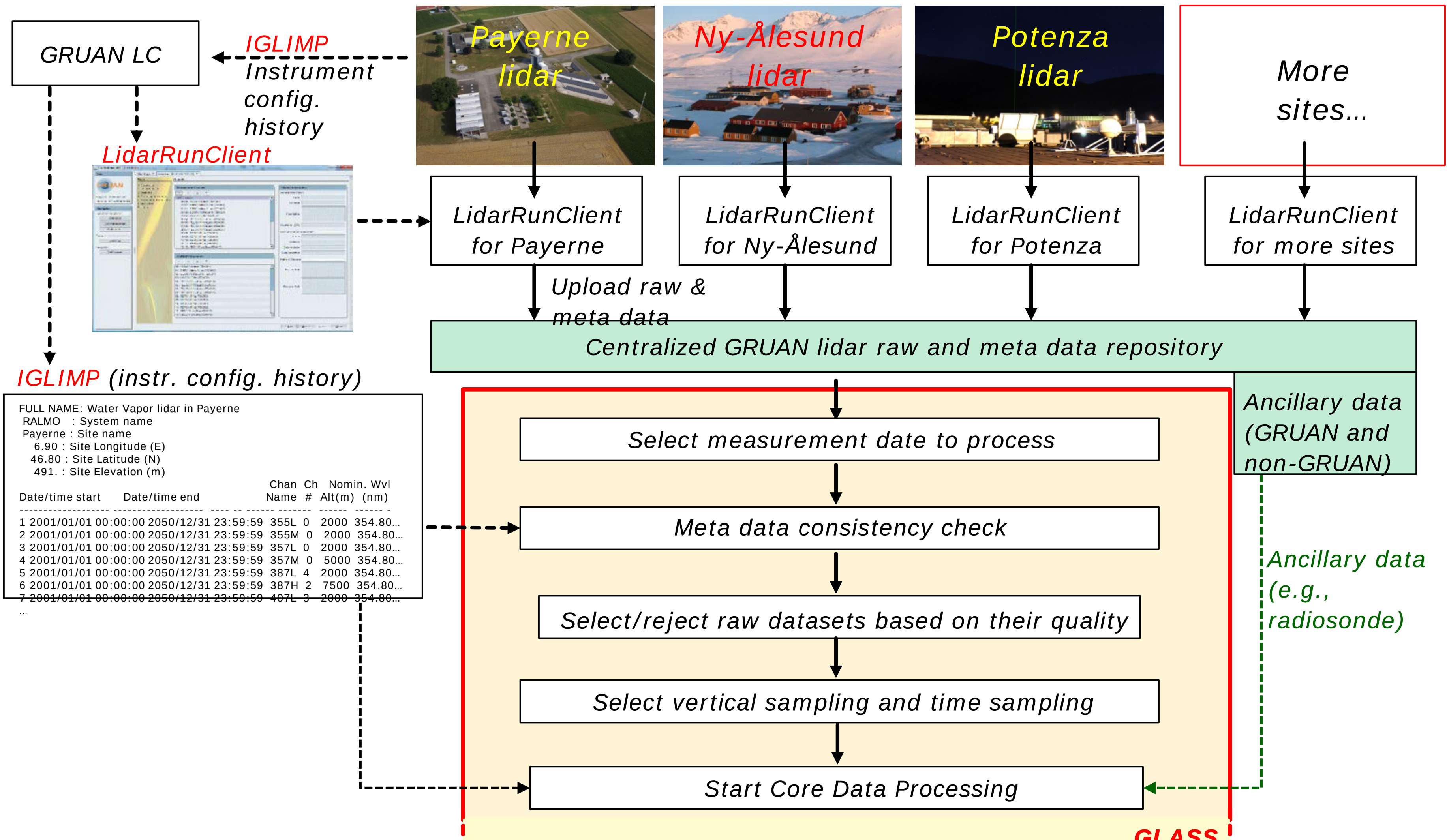
2013-2014: Definition and Design of the LidarRunClient

➔ *"**LidarRunClient**" first prototype, presented to WG-GRUAN, ICM-6 (2014)*



2014-2015: Development of the Centralized Data Processing

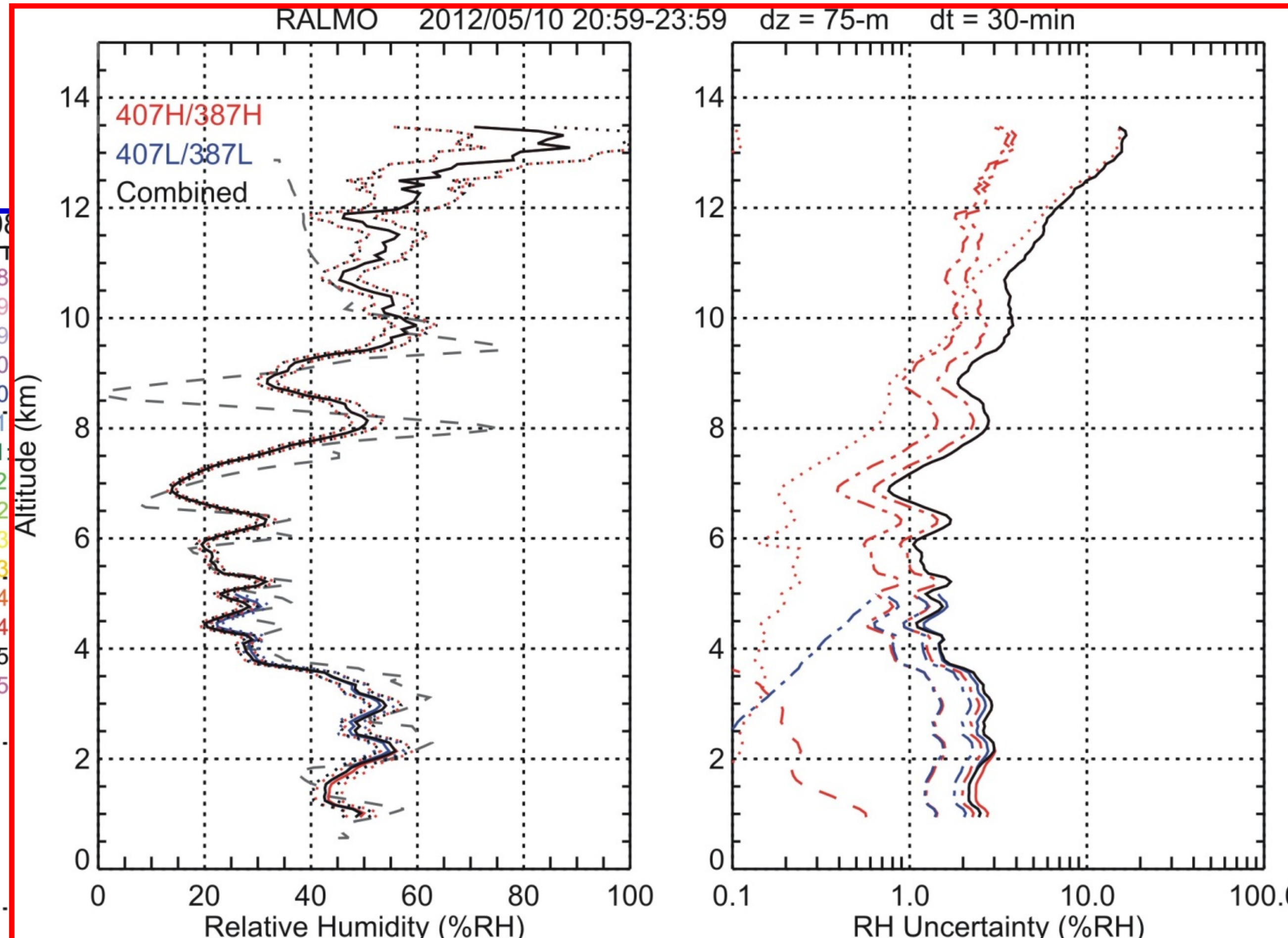
➔ “**GLASS**” *first prototype, presented to WG-GRUAN, ICM-7 (2015)*



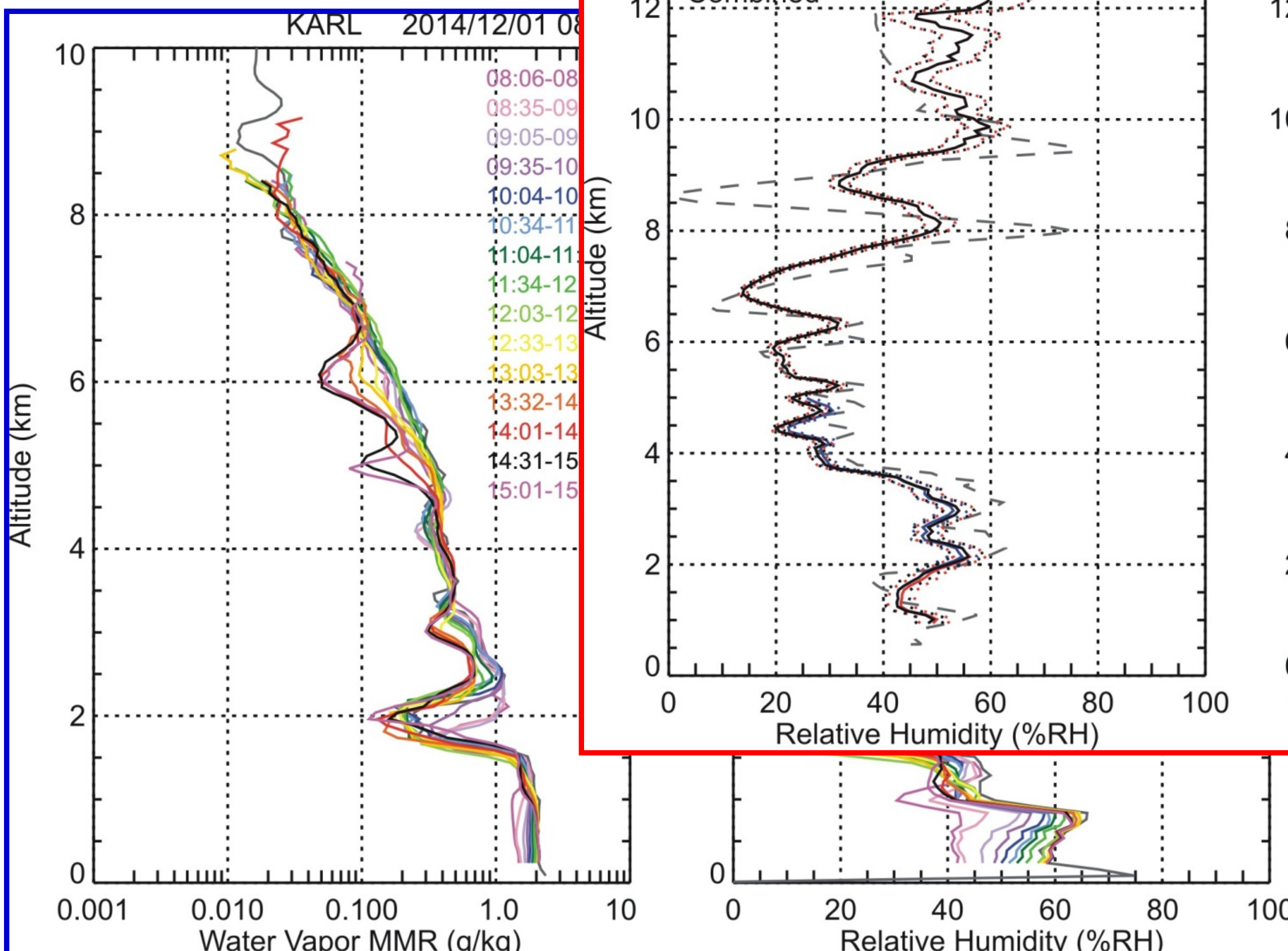
2014-2015: Development of the Centralized Data Processing

➔ "**GLASS**" first prototype, presented to WG-GRUAN, ICM-7 (2015)

Payerne



Ny-Ålesund



What was planned next after ICM-7?

➔ Put the puzzle pieces together

1- Finalize IGLIMP meta data definition
2- Finalize LidarRunCLient
3- Embed IGLIMP and LidarRunCLient into GLASS
4- Expand/improve GLASS
5- Resume/finalize GRUAN Lidar Guide based on all of the above

How much of the above has been done?

➔ Very little! ☹ but….

1- Uncertainty budget for lidar raw signals, ozone and temperature is now published (AMTD NDACC Special Issue) and was implemented into GLASS

2- Will work on LidarRunClient and IGLIMP as early as NEXT WEEK

3- The new "GRUAN Lidar Technical Document" is a straightforward adaptation of the old "GRUAN Lidar Guide"

GRUAN Lidar Technical Document

Technical document structure

1 Introduction

1.1 Instrument heritage – explain something of the histo
ments. What have been the scientific uses for the data
extent does this measurement system fulfil the WMO
is the state-of-the art capability of this system?

1.2 The role of the instrument in GRUAN and the data products it will provide. What GRUAN data products does this instrument serve (connect to **Section 7.8**)? Which essential climate variables does this measurement programme target? Which GRUAN Task Team(s) will oversee the operation of this instrument?

1.3 Organisation and design concepts of the GRUAN measurement programme. Define the descriptive terms used in the document (terminology), and who is responsible for what. (The content included here should focus more on 'operational' aspects than 1.2 above.)

1.4 Implementation of the measurement programme. How do the various components of the network-wide measurement programme interact? (E.g. in terms of instruments being operated at multiple sites, raw data and meta-data flowing to centralised data processing, dissemination of the resultant data products, QA/QC across the programme, oversight that the protocols outlined in this document are adhered to, etc.)

1.5 Use in partner networks – in what other networks is this instrument used and where else can GRUAN call on expertise?

1.6 Use of this instrument in serving GRUAN's key user communities (satellite validation, monitoring changes in climate, numerical weather prediction, process studies) – how has this instrument been used to meet the needs of these groups and how might it be used in these roles in the context of GRUAN?

1.7 Finances – provide a rough indication of the estimated capital costs for the instrumentation as well as on-going operational costs. It is recognized that this information will date, but potential users of this instrument will want some indication of these values. If the instrument relies on other instruments for the generation of data products (see Section 6.2) those costs should be included in the estimate.

From "old" GRUAN Lidar Guide

To be added (there was no financial considerations in the old Lidar Guide)

GRUAN Lidar Technical Document (cont.)

From “old” GRUAN Lidar Guide

Moved to section 3 “Uncertainty Budget”

2 Instrumentation

2.1 Terminology[1] – defines how the terms measurement accuracy, measurement uncertainty, measurement error, random error, random uncertainty, systematic error stability, correction lifetime are used in the context of this measurement system.

2.2 Theoretical basis – provides the technical details on how the measurement is made.

2.3 Justification for instrument selection – why should this instrument be considered over other similar instrument types for use in GRUAN?

2.4 Instrument redundancy – what other measurement systems might provide the redundant measurements required to validate the measurements and their uncertainties?

2.5 Instrument co-location – what are the key considerations for assessing the location of this measurement system in the context of related measurement systems?

2.6 Calibration, validation and maintenance – what procedures need to be implemented to ensure that the calibration, validation and instrument maintenance procedures are fit for GRUAN?

Now: 2.1 Measurement technique
2.2 Instrumentation

Moved to section 4 “Reference Measurements”

From “old” GRUAN Lidar Guide

GRUAN Lidar Technical Document (cont.)

Moved down to Section 4 ("Uncertainty" is now Section 3)

To be added (there was no focused material on this in the old Lidar Guide)

3 Reference measurements

3.1 Making reference measurements – what are the processes that need to be in place to make reference measurements with this measurement system? (Connect to Section 4.2 for standard operating procedures)

3.2 Managing change – what sort of changes might need to be managed and how will that management occur? What are the key steps in managing change events for this measurement system? (This describes the process of 'managing' the changes at different sites rather than 'mandating' how sites quantify the effects of changes. Align with content of GRUAN *Guide to Operations*.)

From "old" GRUAN Lidar Guide

GRUAN Lidar Technical Document (cont.)

Moved up to Section 3

4 *Measurement uncertainty*

4.1 Evaluating measurement uncertainty – how is this done for this measurement system? Ideally papers in the peer reviewed literature would be cited here.

4.2 Reporting measurement uncertainty – how will the measurement uncertainty be reported to users of the data?

4.3 Reducing measurement uncertainty – what is the way forward for reducing measurement uncertainty for this measurement system?

4.4 Reducing operational uncertainty – how might uncertainties related to instrument set-up, sampling rates and the application of algorithms for data analysis be reduced?

4.5 Validating measurements – what is the process for validating the measurements and the measurement uncertainties?

From "old" GRUAN Lidar Guide

Grouped

From ISSI Team on NDACC lidar algorithms

Leblanc, T., et al.: Proposed standardized definitions for vertical resolution and uncertainty in the NDACC lidar ozone and temperature algorithms - Part 1: Vertical resolution, Atmos. Meas. Tech. Discuss., 2016, 1-40, 10.5194/amt-2016-119, 2016.

Leblanc, T., et al.: Proposed standardized definitions for vertical resolution and uncertainty in the NDACC lidar ozone and temperature algorithms - Part 2: Ozone DIAL uncertainty budget, Atmos. Meas. Tech. Discuss., 2016, 1-55, 10.5194/amt-2016-121, 2016.

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GRUAN Lidar Technical Document (cont.)

From "old" GRUAN Lidar Guide

5 Measurement scheduling

5.1 Guiding principles – what are the key considerations for deciding measurement scheduling for this instrument?

5.2 Factors affecting measurement scheduling – likely references here to the peer reviewed literature to justify measurement scheduling needs.

5.3 Interplay of science goals and scheduling frequency – discuss how different requirements on measurement scheduling across different user groups might be balanced.

5.4 Measurement schedule – what is the GRUAN recommended measurement schedule for this instrument? There are likely to be a number of different schedules tailored for sites at different stages of development e.g. entry-level sites and fully equipped sites.

GRUAN Lidar Technical Document (cont.)

6 Data management

6.1 Overview of data flow – describe the differen
Describe if and how these data might be requi
if so, the processing required for NRT data deli

6.2 Inter-instrument dependence – does the creati
pend on measurements made by other instrume

6.3 Software/analysis packages – describe the diffe
to facilitate the collation and processing of the data streams, as well as, to the extent possible, how it is to be implemented and by whom.

6.4 Centralized data processing – describe how the centralized data processing for this instrument will occur. If a centralized data processing facility for this GRUAN product has been identified, this can be documented here, including details of its operation.

6.5 Data policy – discuss any constraints on the provision of these data to users via the GRUAN data base.

6.6 Collation of metadata – provide an in-depth description of the metadata that need to be collated for this measurement system to meet the goals of GRUAN.

6.7 Data format – describe the format(s) in which the data will be provided to users.

6.8 Data submission – how will the data be distributed to use

6.9 Data archiving – which data (including metadata) need
archiving occur?

6.10 Creation of the GRUAN data product – how will the d
create GRUAN data products? It may be that it will be us
ments. Of particular interest is the use of the data in Integ

From "old" GRUAN Lidar Guide

GRUAN Lidar Technical Document (cont.)

7 Post-processing analysis and feedback

What processes will be implemented to allow users to provide feedback on the quality and utility of the data being produced by this measurement system?

8 Quality management

What processes will be implemented for quality assurance/quality control for this instrument system?

From "old" GRUAN Lidar Guide

GRUAN Lidar Technical Document (cont.)

From "old" GRUAN Lidar Guide

9 *Site assessment and certification*

9.1 Criteria – against what criteria should this measurement programme be assessed at the time of GRUAN site assessment and certification? (I.e.: What are the minimum requirements for that programme to be certified.)

9.2 Standard operating procedures – what is the GRUAN recommended standard operating procedure for this instrument? Which aspects of the standard operating procedure are mandatory?

9.3 Criteria for assessing added value – when a site using this measurement system applies for GRUAN certification, how should the added value that this measurement system brings to the network be assessed in the context of existing similar measurement systems?

9.4 Auditing – what specific aspects of the measurement system must be considered at the time of site auditing (noting that audits will occur some years after the certification or previous audit)?

GRUAN Lidar Technical Document (cont.)

10 Appendices

All material that would be too detailed for the main body text should go here. This might include, for example, instructions on using the data collation/analysis tools (including screen shots), list of acronyms, etc.

- ✓ *Appendix A: Acronyms*
- ✓ *Appendix B: Water Vapor Lidar (Raman)*
- ✓ *Appendix C: Temperature Lidar (backscatter)*
- ✓ *Appendix D: Temperature Lidar (rot-Raman)*
- ✓ *Appendix E: Ozone DIAL*
- ✓ *Appendix F: Aerosol lidars*
- ✓ *Appendix G: IGLIMP Meta data file example*
- ✓ *Appendix H: LidarRunClient Manual*

All appendices on specific target species include the following:

- technique-specific measurement principle (details of retrieval)
- technique-specific calibration requirements
- technique-specific uncertainty budget
- technique-specific certification and measurement scheduling
- technique-specific SOP, meta-data inventory, and LidarRunClient specifics
- technique-specific data management
- technique-specific post-processing

CONCLUSION

PLEASE BE PATIENT!

Yes, this year's conclusion is just the same as last year's:

Putting the puzzle pieces together…

GRUAN Lidar Products from a Centralized data processing are coming up, slowly, but surely…

THANK YOU

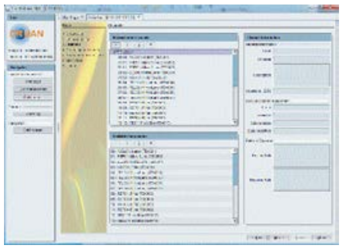
Backup slides

Raw data quality check and ingestion procedure (traceability)

GRUAN LC

IGLIMP
Instrument config. history

LidarRunClient



More sites...

LidarRunClient for Payerne

LidarRunClient for Ny-Ålesund

LidarRunClient for Potenza

LidarRunClient for more sites

Upload raw & meta data

Centralized GRUAN lidar raw and meta data repository

Ancillary data (GRUAN and non-GRUAN)

IGLIMP (instr. config. history)

```
FULL NAME: Water Vapor lidar in Payerne
 RALMO   : System name
 Payerne : Site name
    6.90 : Site Longitude (E)
   46.80 : Site Latitude (N)
    491. : Site Elevation (m)
                                          Chan  Ch  Nomin. Wvl
Date/time start     Date/time end         Name  #   Alt(m)  (nm)
------------------- ------------------- ---- -- ----- -------  ------  ------ -
1 2001/01/01 00:00:00 2050/12/31 23:59:59 355L 0  2000 354.80...
2 2001/01/01 00:00:00 2050/12/31 23:59:59 355M 0  2000 354.80...
3 2001/01/01 00:00:00 2050/12/31 23:59:59 357L 0  2000 354.80...
4 2001/01/01 00:00:00 2050/12/31 23:59:59 357M 0  5000 354.80...
5 2001/01/01 00:00:00 2050/12/31 23:59:59 387L 4  2000 354.80...
6 2001/01/01 00:00:00 2050/12/31 23:59:59 387H 2  7500 354.80...
7 2001/01/01 00:00:00 2050/12/31 23:59:59 407L 3  2000 354.80...
...
```

Select measurement date to process

Meta data consistency check

Select/reject raw datasets based on their quality

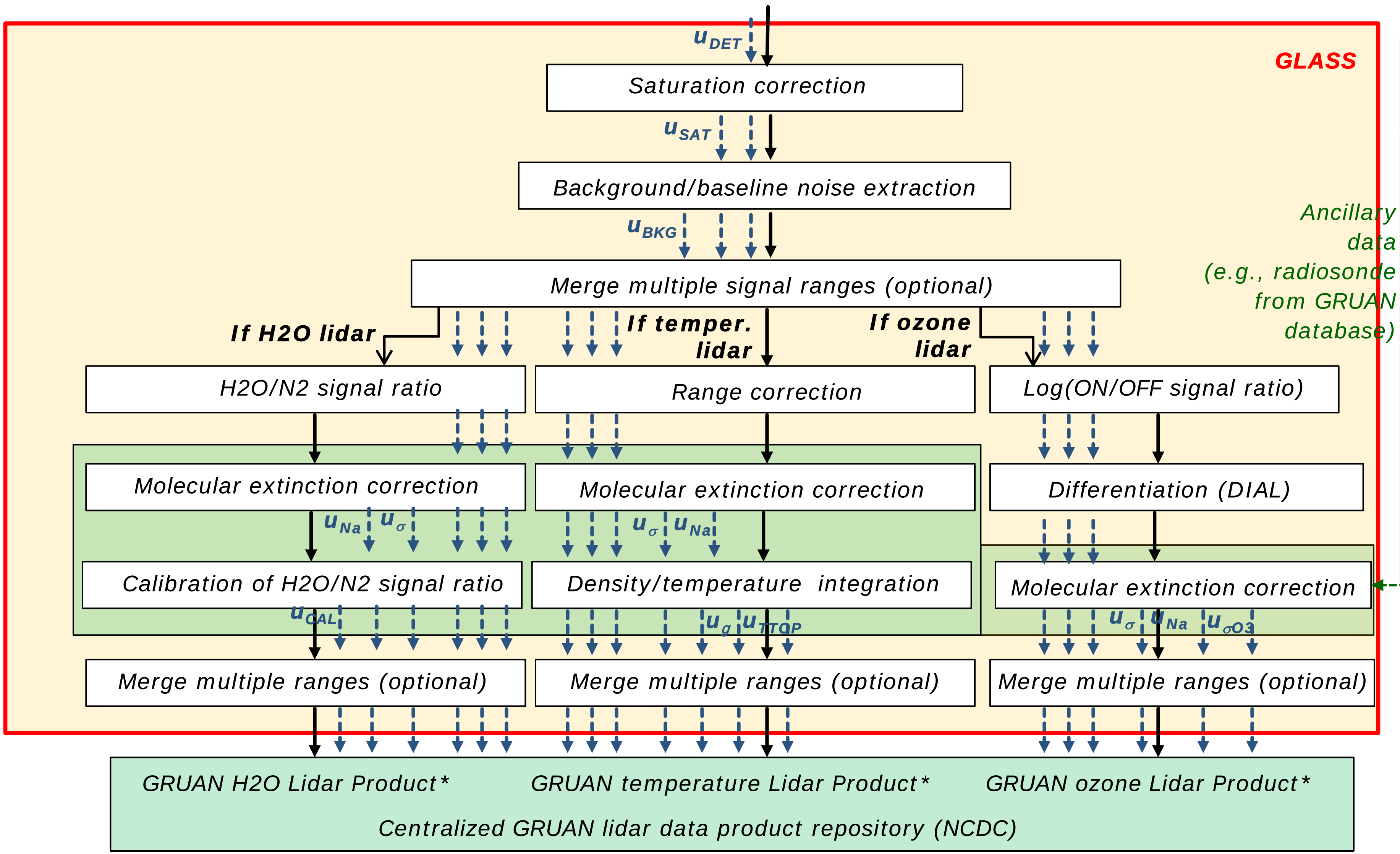
Select vertical sampling and time sampling

Start Core Data Processing

Ancillary data (e.g., radiosonde)

GLASS

Core data processing



* Product is tailored to user need and/or science application (determined by time and vertical sampling options)

GRUAN lidar data products

List of measured and derived products, available today through the GLASS:

1. Water vapor (covering troposphere up to 6-18 km depending on instrument):
- Volume Mixing Ratio
- Mass Mixing Ratio
- Relative Humidity (derived from MR using Hyland/Wexler w.r.t. water)

2. Ozone (covering both troposphere and stratosphere up to 50 km):
- Ozone Number Density
- Ozone Mixing Ratio (derived from ND using best available ancil. p-T profile)

3. Temperature (stratosphere and mesosphere covering 12-90 km):
- Temperature
- Air Density and Pressure (derived using lidar and best available ancil. p-T)

GRUAN lidar data products (cont.)

Four "pools" of GRUAN lidar data products, each pool dedicated to a specific user needs and / or science application:

1. Climatology and trends:
- *time average: optimized for low noise (i.e., hours rather than minutes)*
- *vertical resolution: optimized for low noise (i.e., km rather than m)*

2. Process studies:
- *time average: optimized for target science application (minutes to hours)*
- *vertical resolution: optimized for target science application (m to km)*

3. Redundancy and validation:
- *time average: optimized to best match coincident measurement*
- *vertical resolution: optimized to best match coincident measurement*

4. Operational and assimilation:
- *time average: optimized to best match assimilation scheme*
- *vertical resolution: optimized to best match assimilation scheme*

One instrument can produce GRUAN data products of one or several pools

Example 1: Ny-Ålesund, water vapor

7-hour average (daytime, winter)

Left plot:

Red, purple and blue solid lines: lidar, individual ranges

Black solid line: lidar, combined ranges

Black dotted line: lidar, total uncertainty

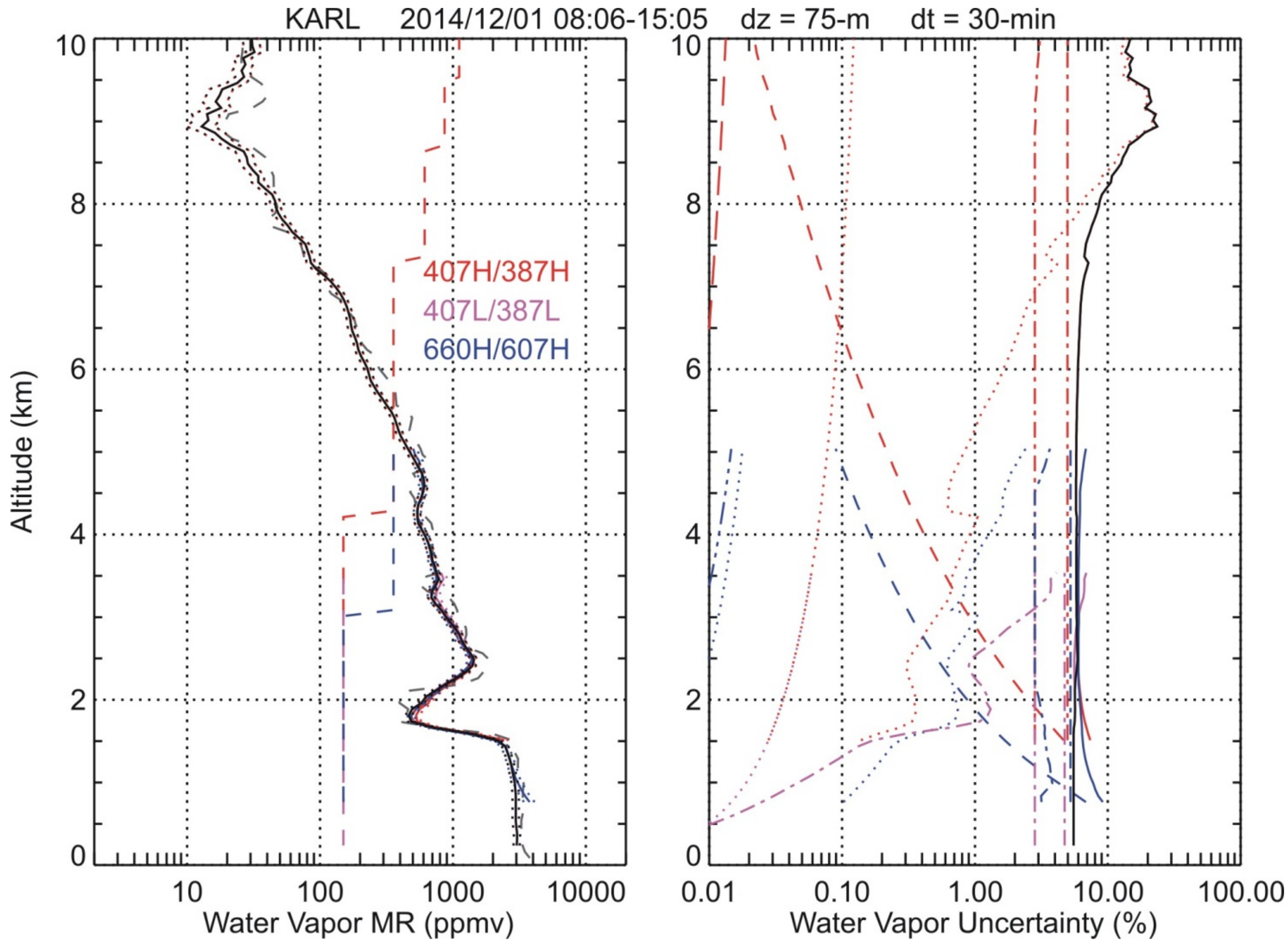
Red , purple and blue dashed lines: lidar, vertical resolution, in meters (NDACC-standardized)

Grey dashed line: co-located radiosonde

Right plot:

Solid lines: Combined Uncertainty

Dotted, dashed, dash-dotted, etc. lines: Individual uncertainty components



Raw lidar data provided by Christoph Ritter, AWI, Potsdam

➔ Example of suitable GRUAN product for climatology and trends

Example 2: Ny-Ålesund, water vapor

30-minute slices (daytime, winter)

Left plot: MMR (g/kg)

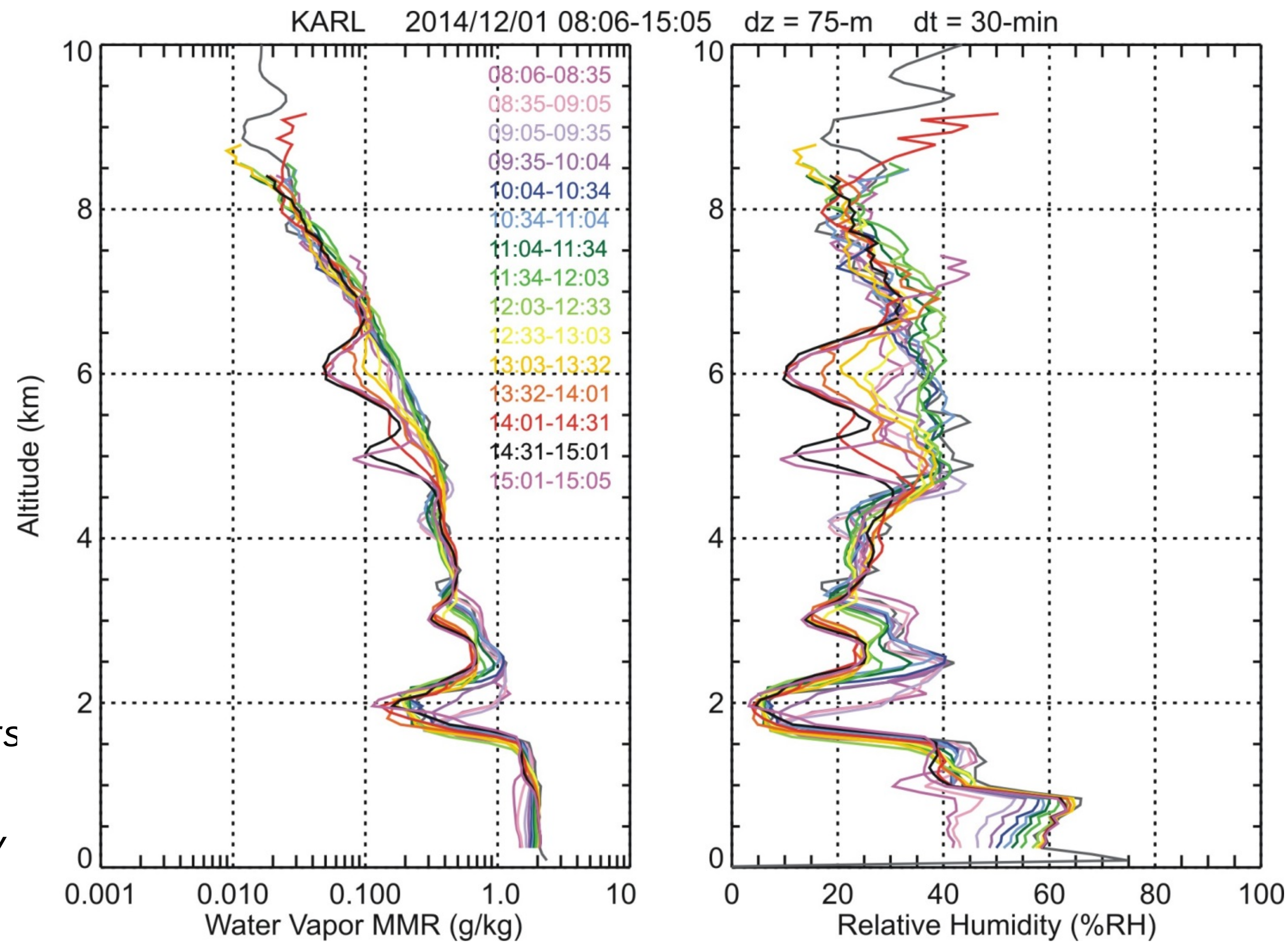
Right plot: RH (%)

Colored lines:
lidar, combined ranges,
30-min slices

Grey line:
Radiosonde

Note:

- *Moving dry and moist layers as time goes*
- *Calibration reflects late day radiosonde coincidence*



Raw lidar data provided by Christoph Ritter, AWI, Potsdam

➔ **Example of suitable GRUAN product for process studies**

Example 3: Payerne, water vapor

3-hour average (nighttime)

Left plot:

Red, purple and blue solid lines:
lidar, individual ranges

Black solid line:
lidar, combined ranges

Black dotted line:
lidar, total uncertainty

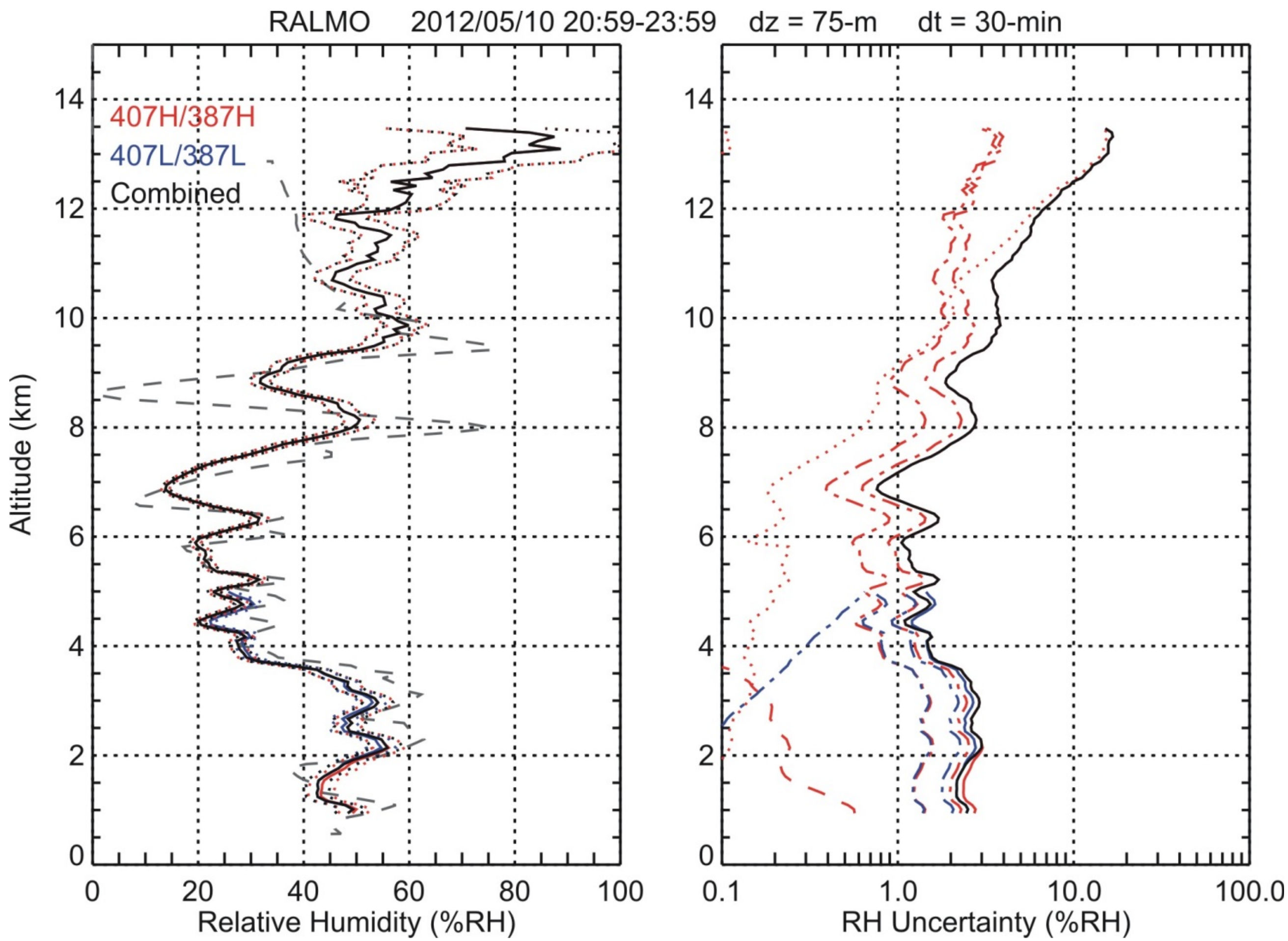
Red , purple and blue dashed lines:
lidar, vertical resolution, in meters (NDACC-standardized)

Grey dashed line:
co-located radiosonde

Right plot:

Solid lines:
Combined Uncertainty

Dotted, dashed, dash-dotted, etc. lines:
Individual uncertainty components



Raw lidar data provided by Gianni Martucci, Meteoswiss, Payerne

➔Example of suitable GRUAN product for climatology and trends

Example 4: Payerne, water vapor

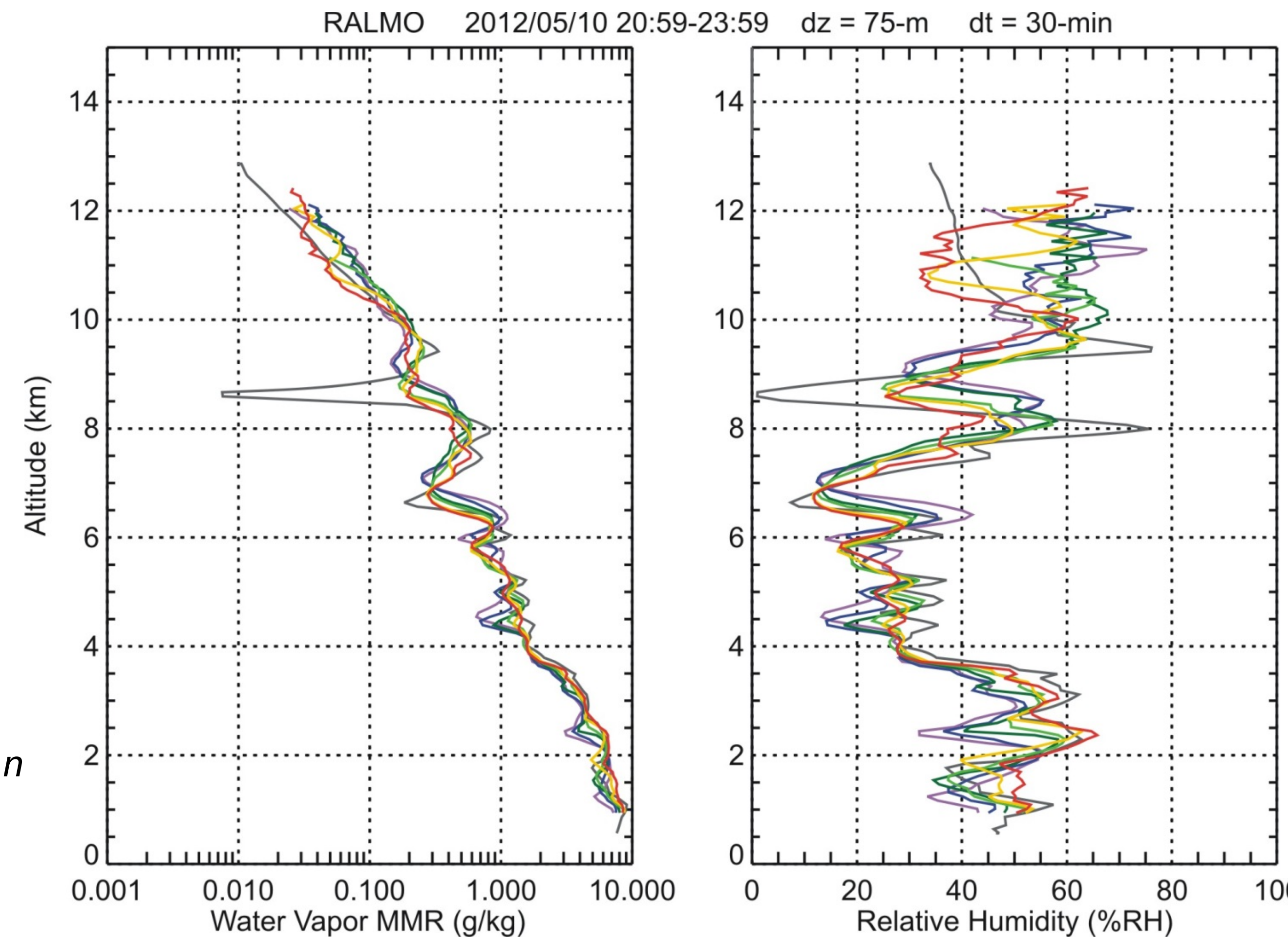
30-min time slices (nighttime)

Left and right plots:

Curves and colors same as before

Note:

- *Moist lidar bias above 10 km needs investigation*



Raw lidar data provided by Gianni Martucci, Meteoswiss, Payerne

➔ Example of suitable GRUAN product for process studies

Example 5: Potenza, water vapor (CIAO lidar)

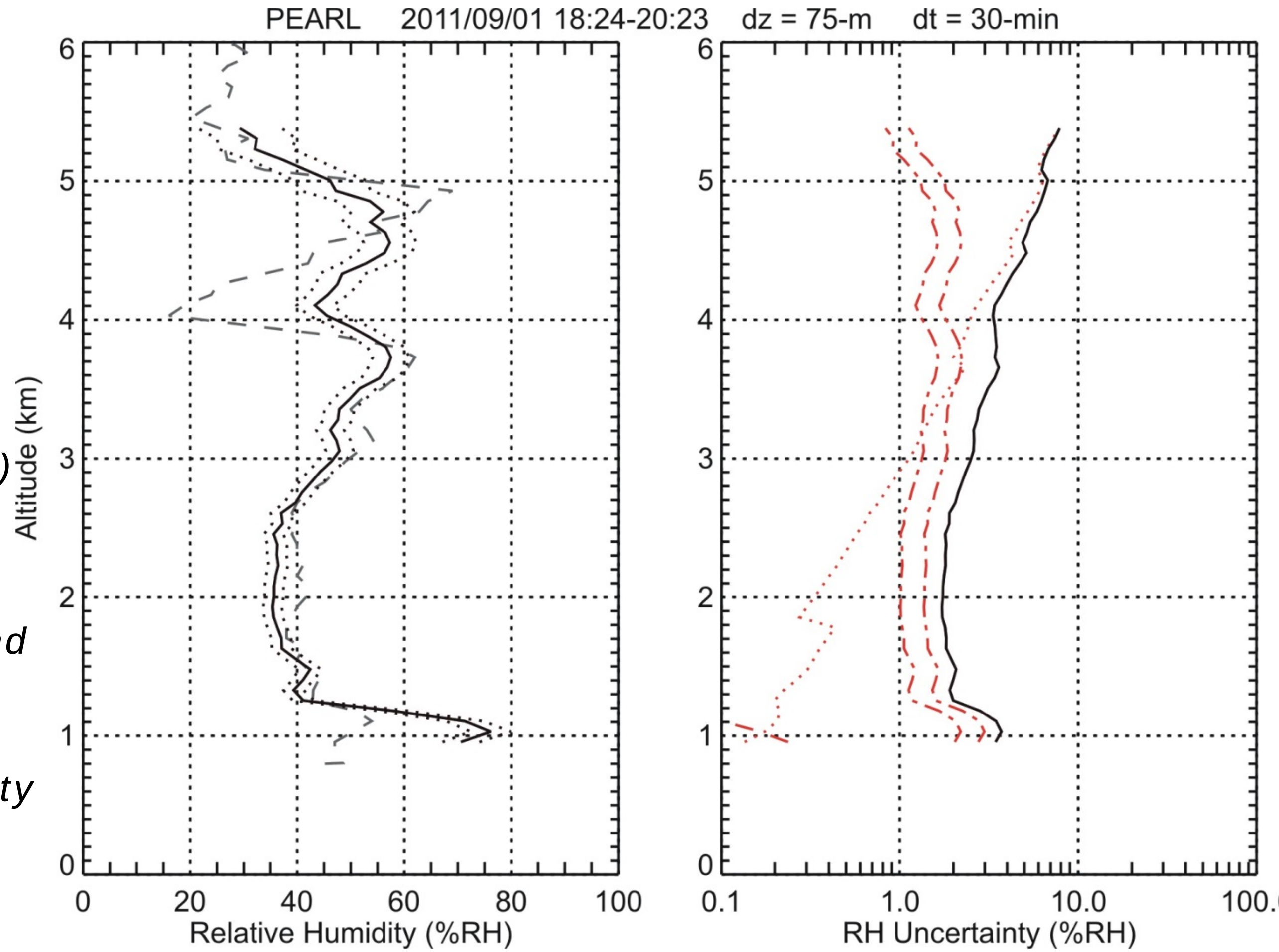
2-hour average (nighttime)

Left and right plots:

Curves and colors same as before

Note:

- *Only 1 range here (red curves, no blue curves)*
- *Easier to look at individual uncertainty components*
- *Comparison with RALMO and KARL shows that <u>every instrument yields different answer</u> regarding uncertainty (e.g., saturation)*



➔ **Standardization concept holds at "definition" and "approach" levels but breaks down at the quantitative estimates level**

Raw lidar data provided by Fabio Madonna, CIAO, Potenza

Example 6: JPL Table Mountain, CA, water vapor

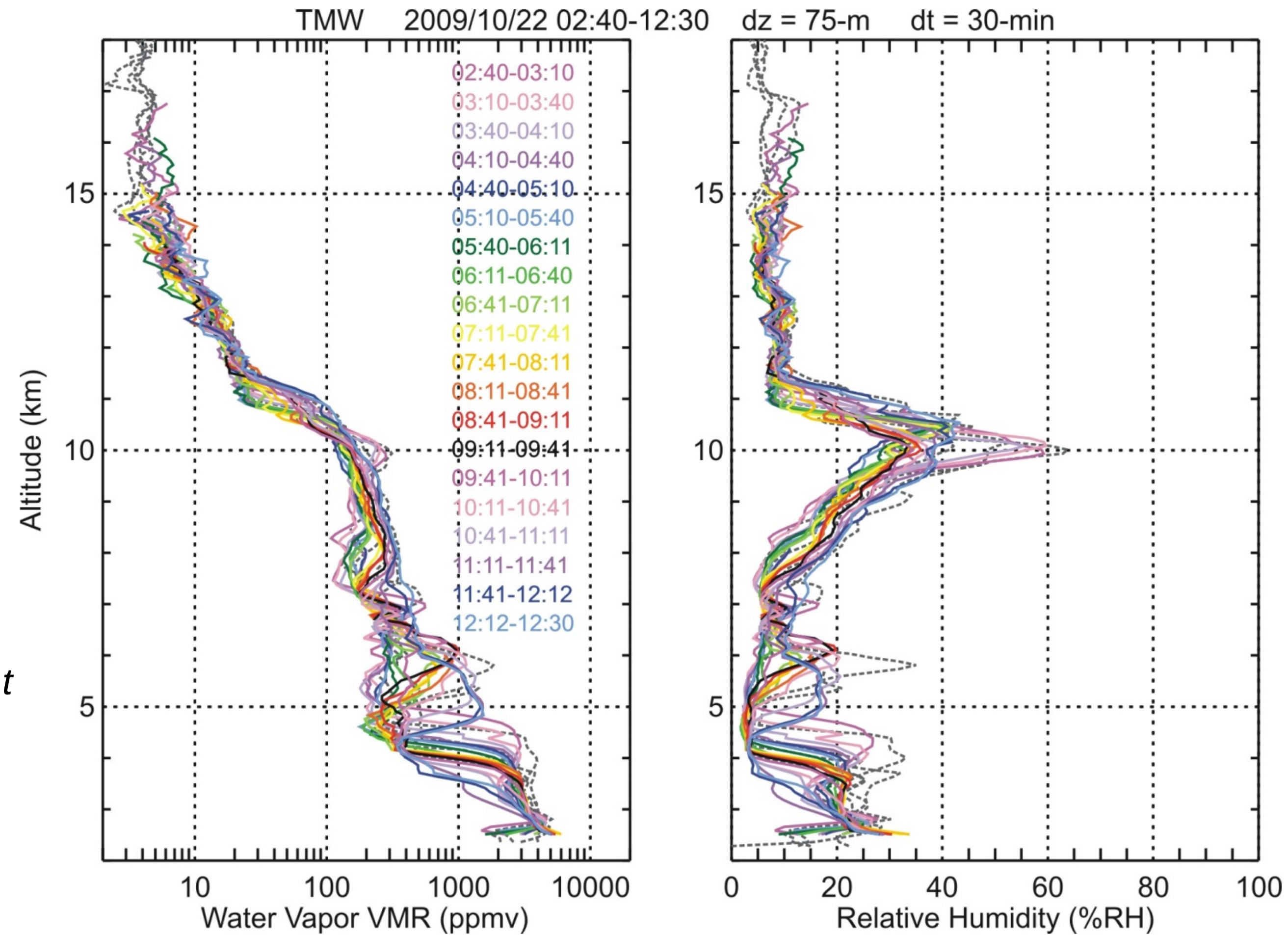
30-min slices (nighttime)

Left and right plots:

Curves and colors same as before

Note:

- *MOHAVE-2009 night*
- *4 radiosonde launches in one night*
- *Optimized calibration: GLASS computes one single calibration constant using all flights*



Many NDACC (and non-NDACC) lidars measuring water vapor could be added to GRUAN

Example 7: Maïdo, Reunion Is., stratospheric ozone

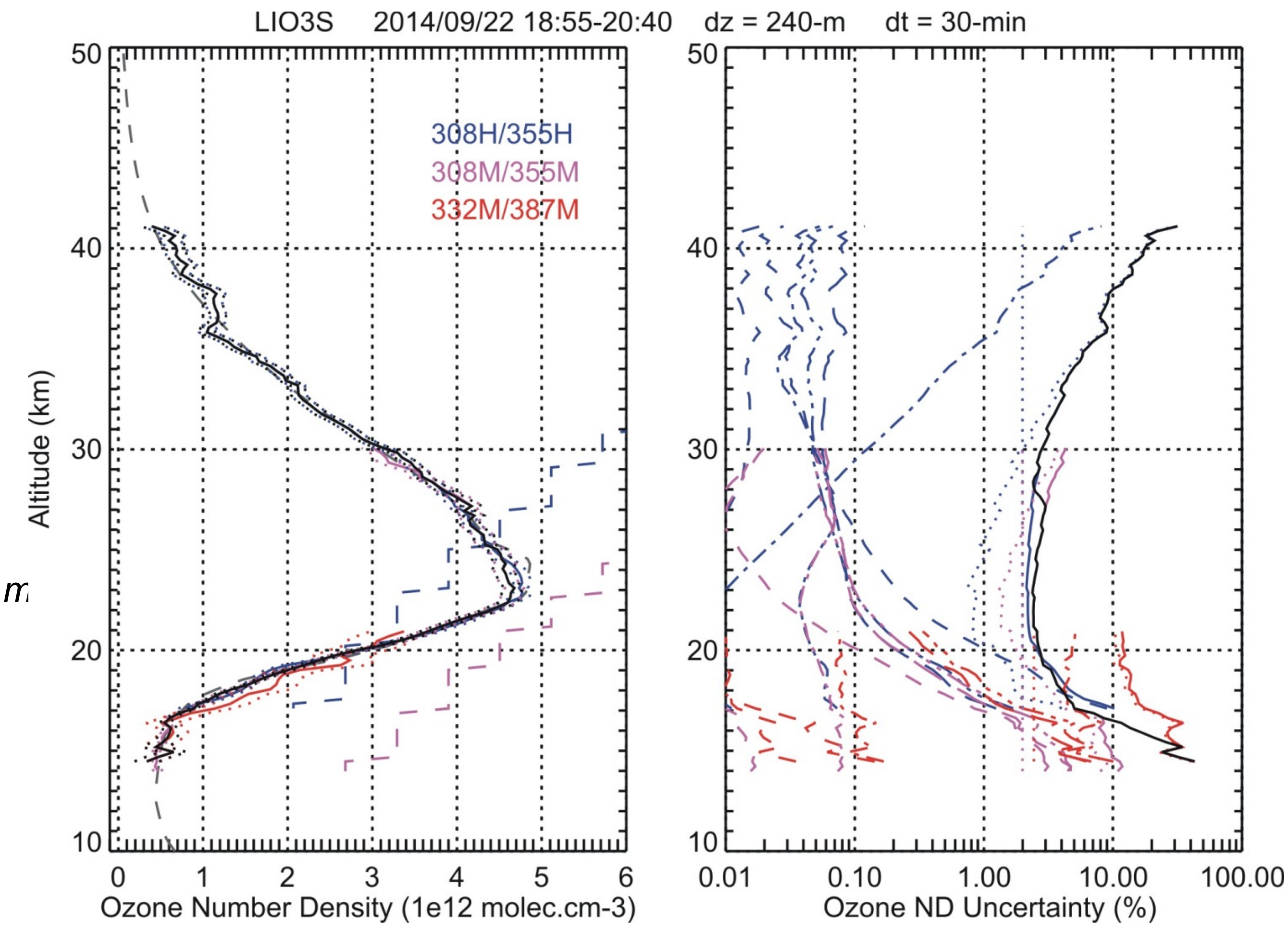
2-hour average (nighttime)

Left and right plots:

Curves and colors same as before

Note:

- *Instrument still waiting for NDACC validation*
- *Typical expected maximum range is 50 km*



Many NDACC lidars measuring stratospheric ozone could be added to GRUAN

Raw lidar data provided by Thierry Portafaix, LACy, U. Reunion

Example 8: Mauna Loa, temperature (JPL lidar)

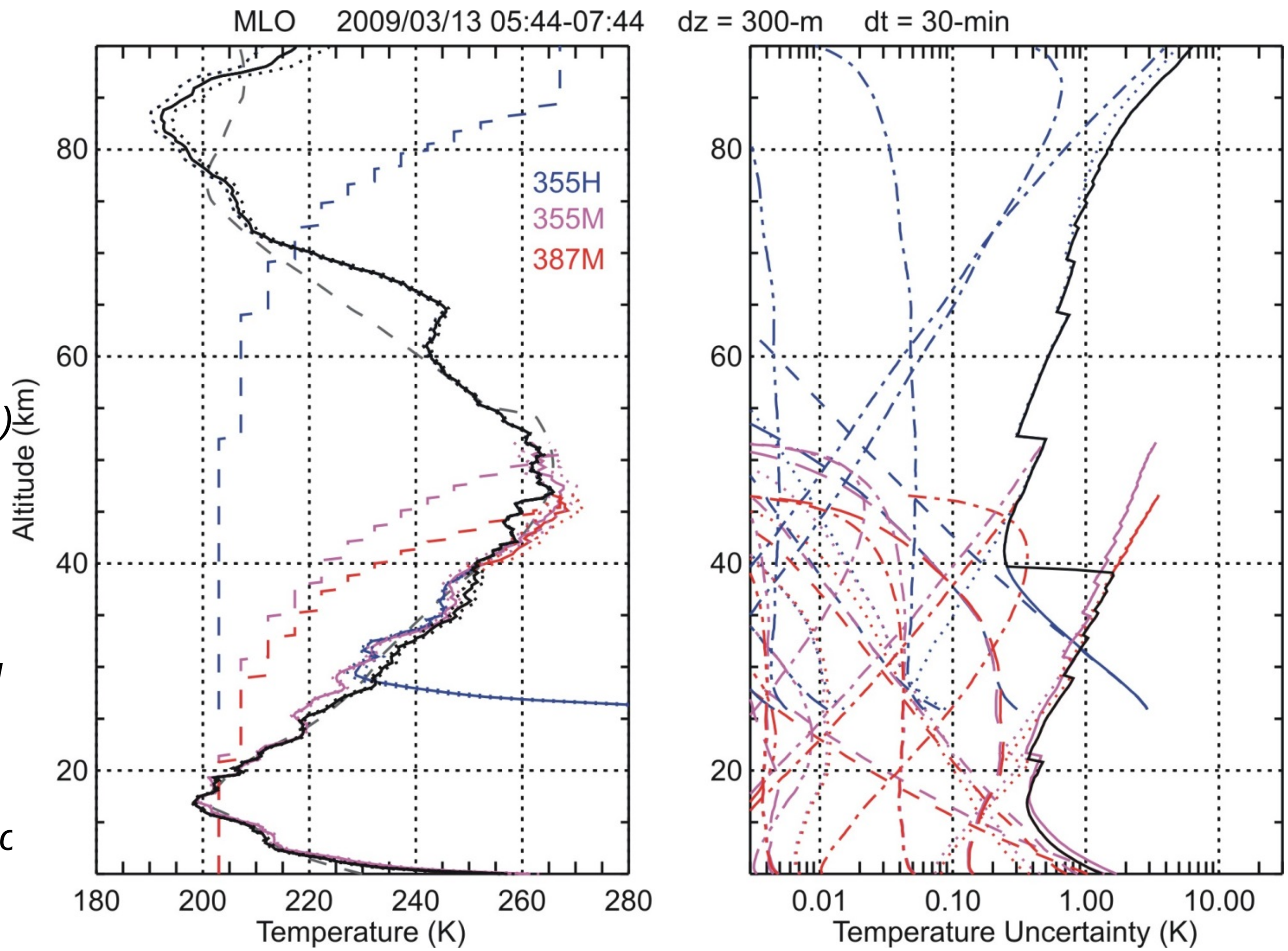
2-hour average (nighttime)

Left and right plots:

Curves and colors same as before

Note:

- *355H and 355M (Rayleigh) too cold below 39 km because of stratospheric aerosols, which is why we have 387M (Raman)*
- *387M and 355H combined automatically at 39 km*
- *Procedure uses minimum difference between the two ranges, and minimization of the total uncertainties*



Raw lidar data from JPL-Lidar

Many NDACC lidars measuring temperature could be added to GRUAN

Example 9: Huntsville, tropospheric ozone

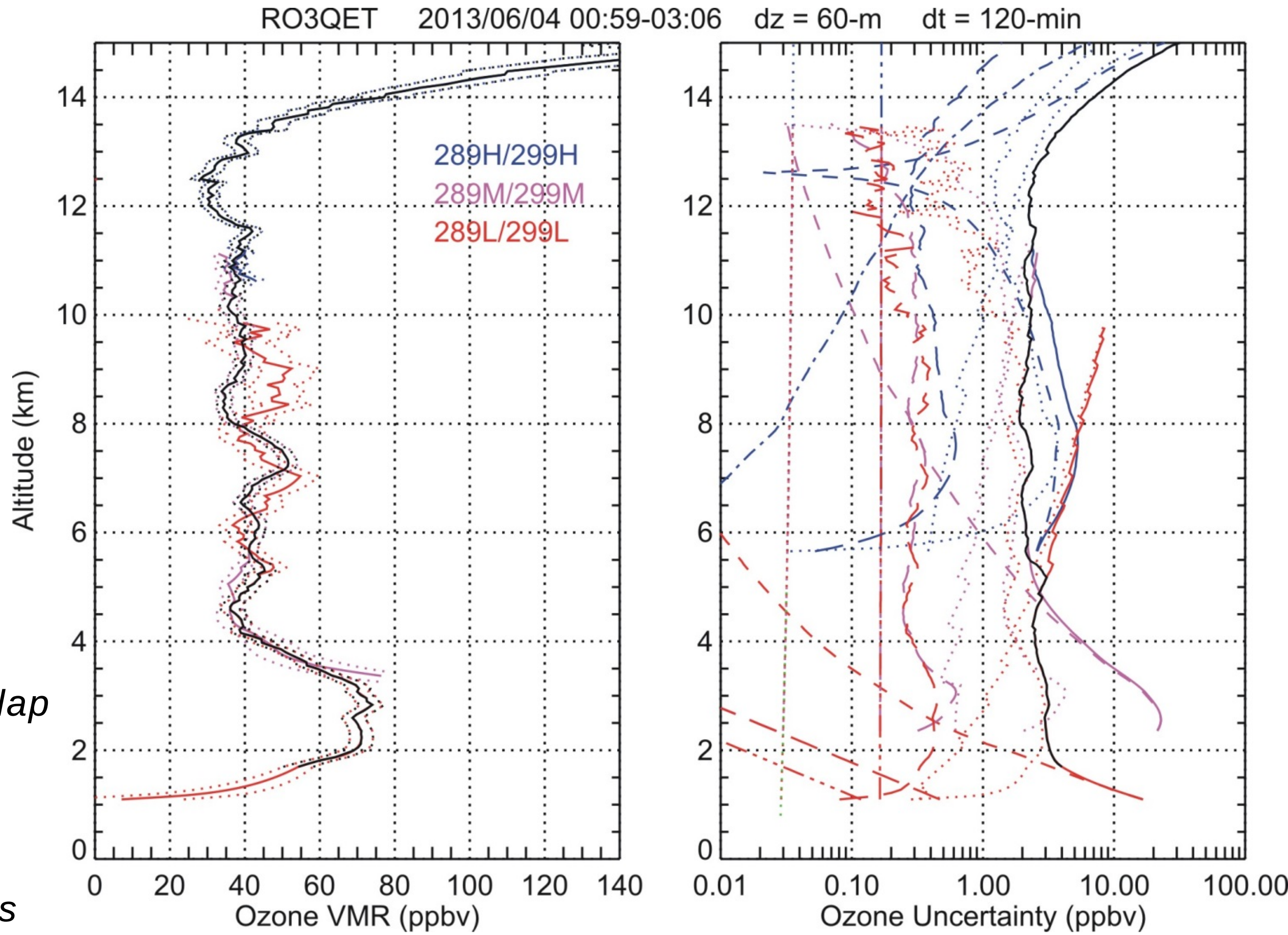
2-hour average (daytime)

Left and right plots:

Curves and colors same as before

Note:

- *Combined profile cut-off at bottom to avoid wrong measurements below 1.5 km*
- *This error at bottom is typical of lidar as it is related to incomplete overlap of the beam and telescope field of view*
- *An "empirical" correction is possible but very dangerous due to its lack of traceability and potential resulting misinterpretation*



Raw lidar data provided by Mike Newchurch, U. Alabama, Huntsville

Several tropospheric ozone lidars (NDACC and non-NDACC) could be added to GRUAN

Other sites/stations/lidars....

√√√ *Mauna Loa, JPL and NOAA lidars:*
- Water vapor, Stratospheric ozone, Temperature

√√√√ *JPL- Table Mountain Facility, CA:*
- Water vapor, Tropospheric ozone, Stratospheric ozone, Temperature

√√√√ *NASA-GSFC Mobile lidars, NDACC and TOLNet (PI: McGee):*
- Water vapor, Tropospheric ozone, Stratospheric ozone, Temperature

√ *NASA-Langley Mobile lidar, TOLNet (PI: DeYoung):*
- Tropospheric ozone (TOLNet)

√√√√ *Observatoire de Haute-Provence, NDACC (PI: Godin-Beekmann, Keckhut, etc.):*
- Water vapor, Tropospheric ozone, Stratospheric ozone, Temperature

√√√√ *Reunion Island, NDACC (PI: Portafaix, Duflot, etc.):*
- Water vapor, Tropospheric ozone, Stratospheric ozone, Temperature

√ *Lauder, NDACC (PI: Swart):*
- Stratospheric ozone, Temperature

√√ *Rio Gallegos, NDACC (PI: Quel):*
- Stratospheric ozone, Temperature

√√√√ *Many more NDACC...*
(Eureka, Univ. W. Ontario, Hohenpeissenberg, Zugspitze, etc.)

GLASS: the Good, the Bad and the Ugly….

The Good:

1) High degree of flexibility:

- *time sampling*
- *vertical sampling and vertical resolution*
- *multiple options for range-merging optimization*
- *multiple options for profile cut-off optimization*

2) Comprehensive and "standardized" uncertainty budget (ISSI Team Report):

- *~10 independent uncertainty sources for each product*
- *Each uncertainty source propagated "in parallel" and <u>traceable all the way to the archived product</u>*

The Bad:

1) Progress in 2014 has been slow due to lack of time availability

2) Potential issue on where/when/how raw lidar data will be archived and analyzed

The Ugly:

What's awaiting ahead of us…

- *Linking together the pieces of the puzzle (LidarRunClient+GLASS+IGLIMP)*
- *Automating data processing for "mass-production"*

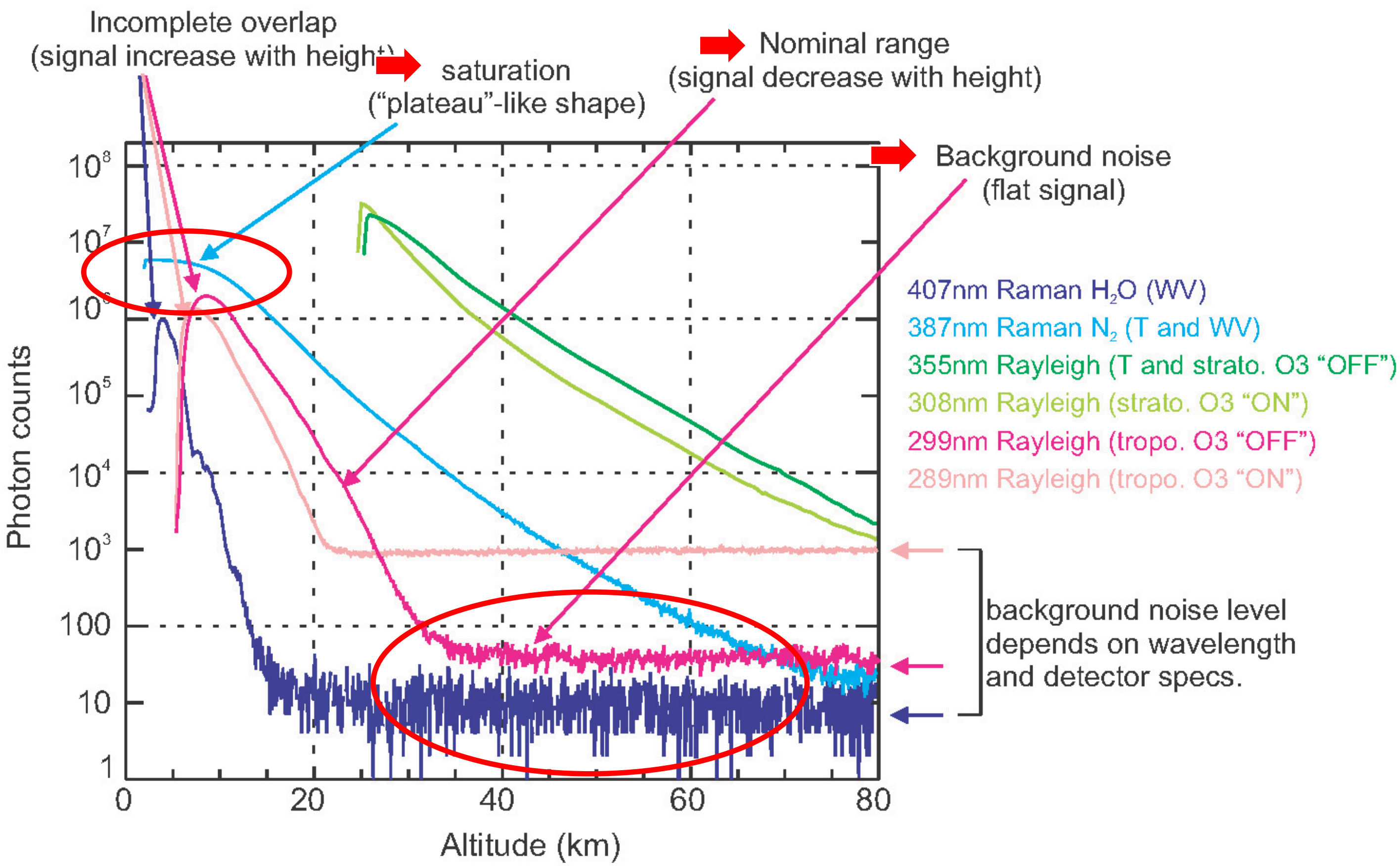
Sources of Measurement and Retrieval Uncertainty

Addressed by ISSI Team and included in GLASS:

1. *Photon Counting statistical noise*
2. *Saturation (pile-up): dead-time τ*
3. *Background correction: Fitting coefficients b_j*
4. *Molecular extinction: cross-sections values σ_{Ray}*
5. *A priori air density $N_a(z)$ for molecular extinction correction*
6. *Absorption cross-sections $\sigma_A(T(z))$ for $O3$, $NO2$, $O2$, $SO2$*
7. *A priori Number Density of interfering gases $N_{IG}(z)$ for $O3$, $NO2$, $SO2$*
8. *Gravity g(z,lat) for temperature integration*
9. *A priori (tie-on) air density or pressure $T_a(z)$, $N_a(z)$, $p_a(z)$*
10. *Raman backscatter cross-section temperature dependence $\sigma_{Ram}(T(z))$*
11. *Water Vapor Calibration (including uncertainty in a priori source)*

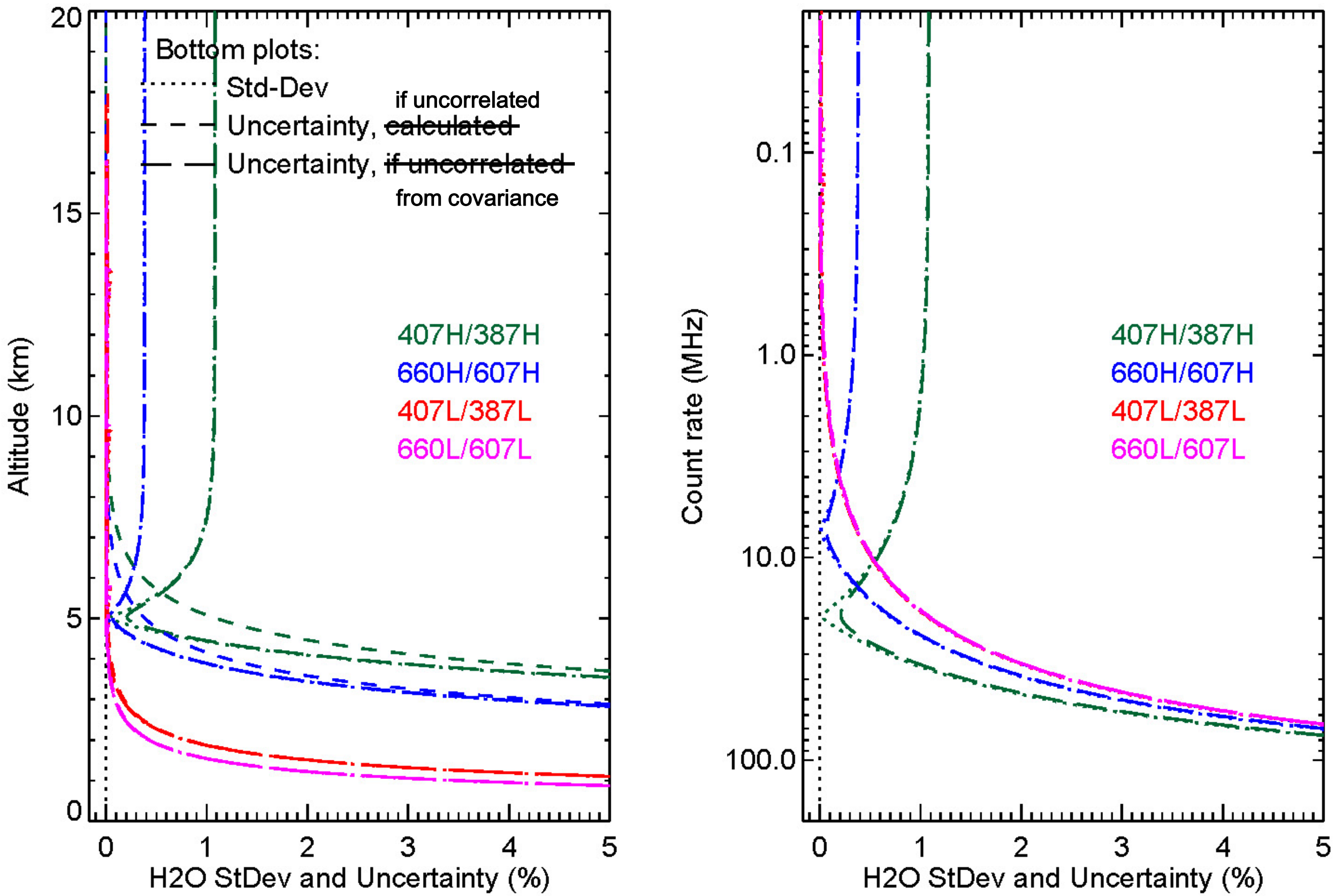
Propagating Uncertainty with Correlated Terms

Uncertainty owed to background noise and saturation corrections cannot be propagated assuming the corrected signals are uncorrelated in altitude!



➔ ***Monte Carlo Simulations are required to compute covariance matrix and estimate the resulting impact of correlated terms on uncertainty***

Quantifying saturation correction uncertainty on water vapor (example using simulated signals)



Uncertainty due to saturation is either overestimated or underestimated if assumed uncorrelated!