GRUAN Lidar Data Stream:
Progress Status

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with contributions from:
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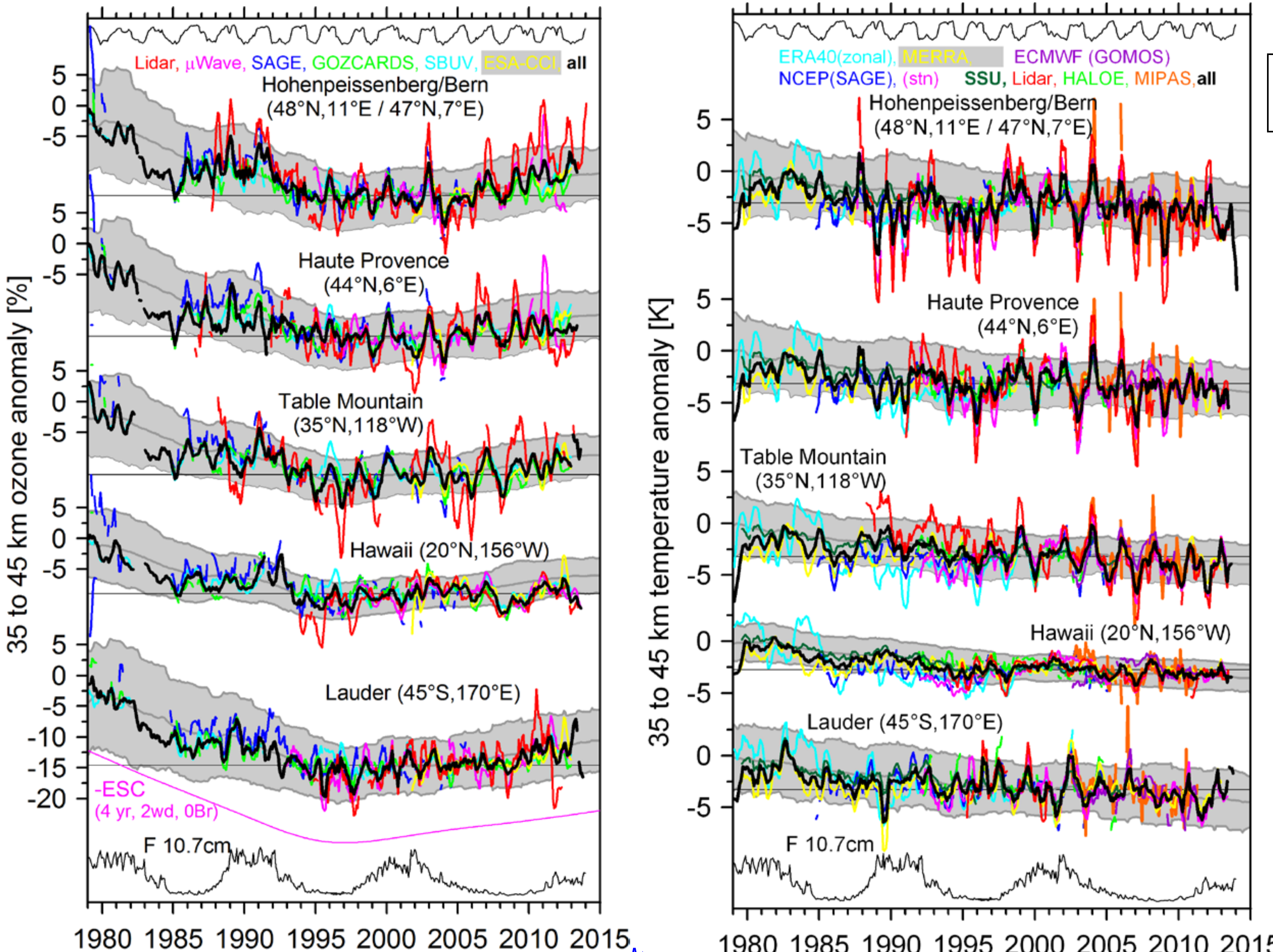
5 NDACC time-series with GB lidar
ECVs: O3 and T



From
W. Steinbrecht

Definition

The overall infrastructure underlying the lidar measurement and the subsequent production of a GRUAN lidar product, from data acquisition to data product management.

Domains of application

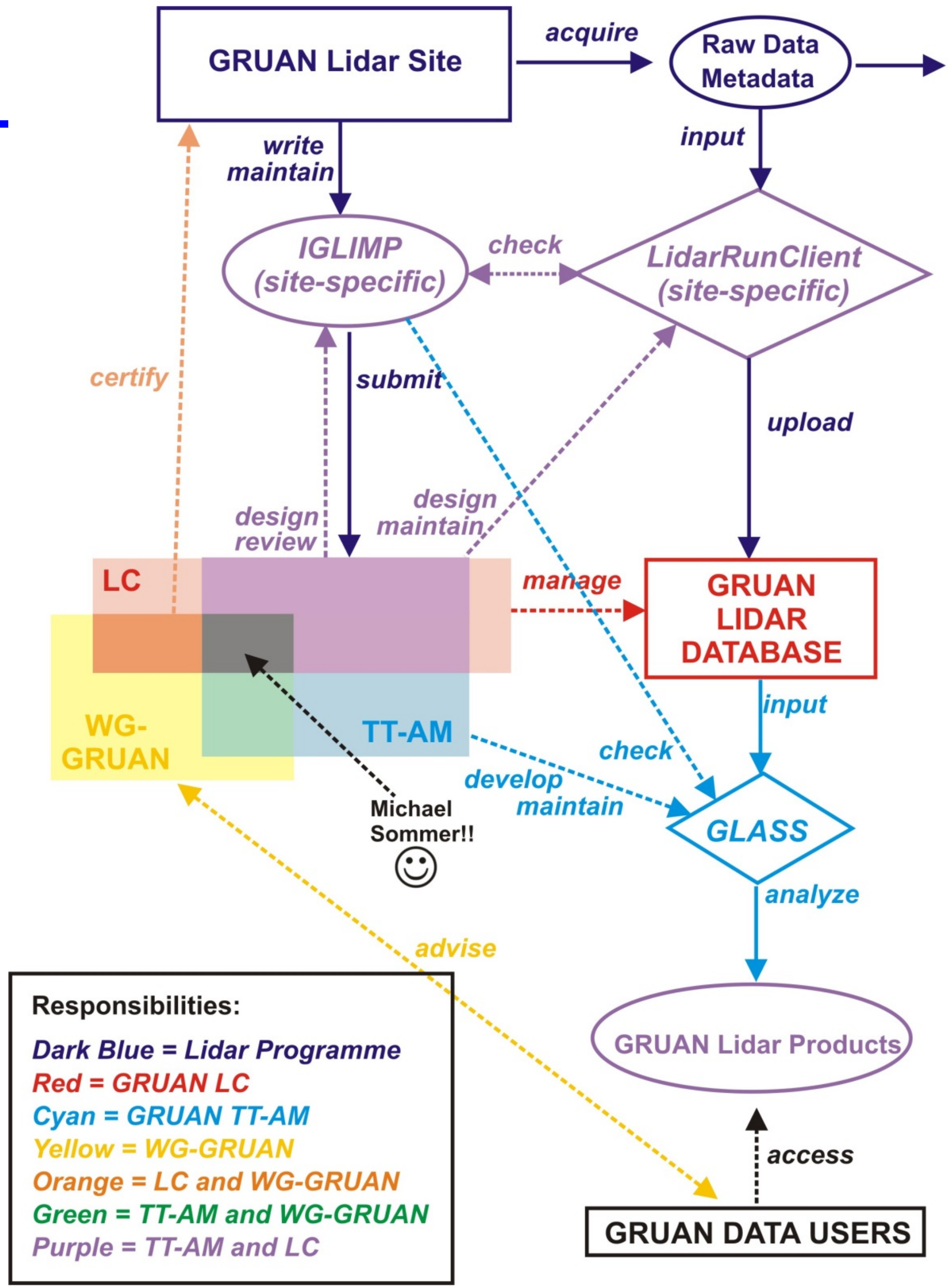
Setup, modification and maintenance of the instrumentation, the standard operating procedures for the acquisition of the raw data and the lidar calibration, and the complete and homogenized upload of the raw data and meta-data onto the GRUAN lidar data handling center for subsequent centralized processing

Mandatory components

- *The **GRUAN Lidar Guide** defining the complete framework of the Programme, from instrumentation to retrieval*
- *A lidar instrument* ☺
- *Dedicated and motivated staff* ☺
- *An Individual GRUAN Lidar Instrumentation and Measurement Protocol (**IGLIMP**)*
- *The **LidarRunClient** utility for traceable data and meta data recording and upload*
- *The centralized GRUAN Lidar Analysis Software Suite (**GLASS**) for consistent data processing*

GRUAN

Lidar Programme Modus Operandi



Why a GLASS?

In-house lidar data processing softwares exist for all sites, so what is the deal, really?...

Something traceable

A comprehensive uncertainty budget

Something “standardized” across the network

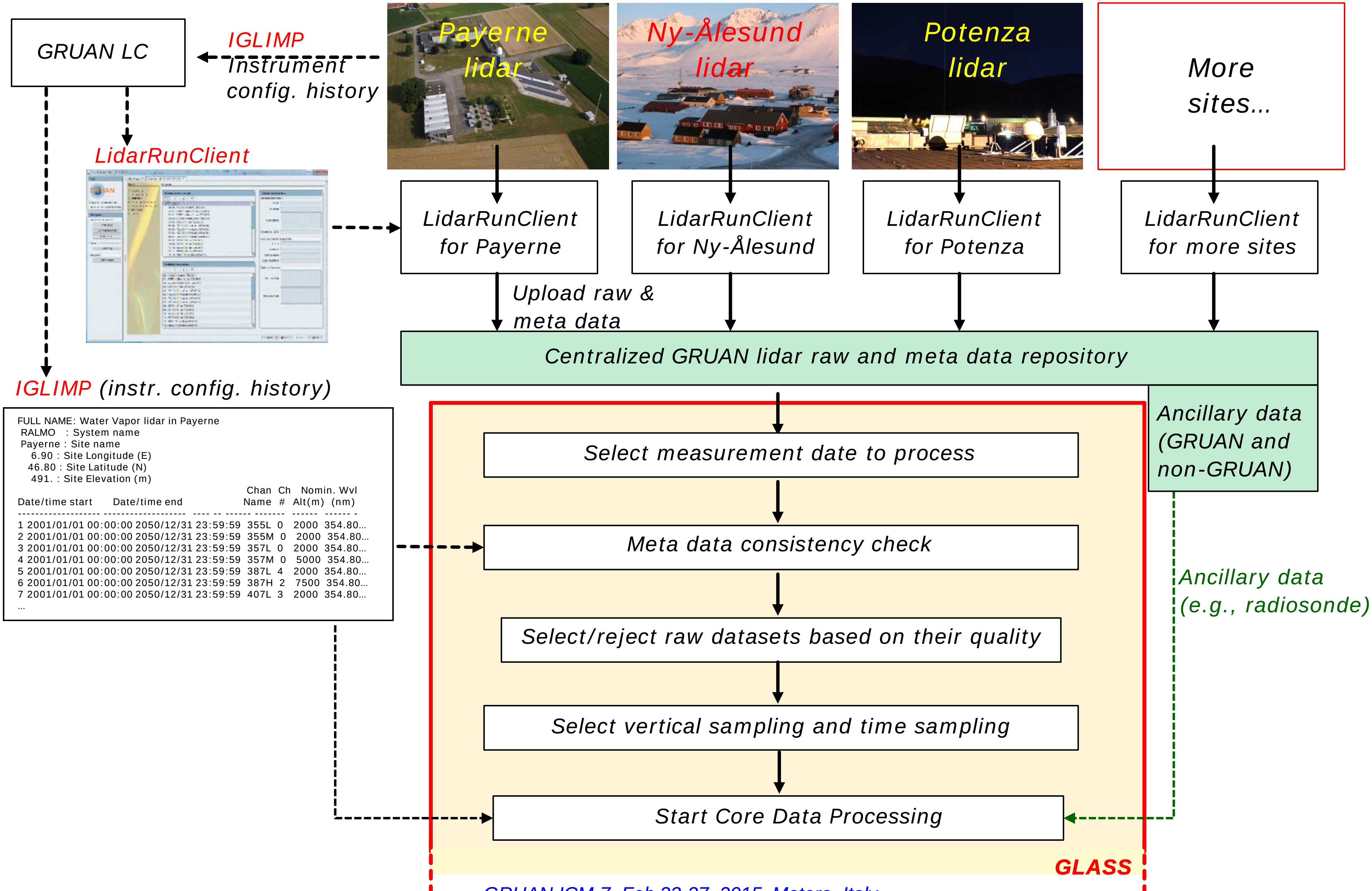
Ability to re-analyze the raw data whenever needed

Something flexible and tailored to the user needs

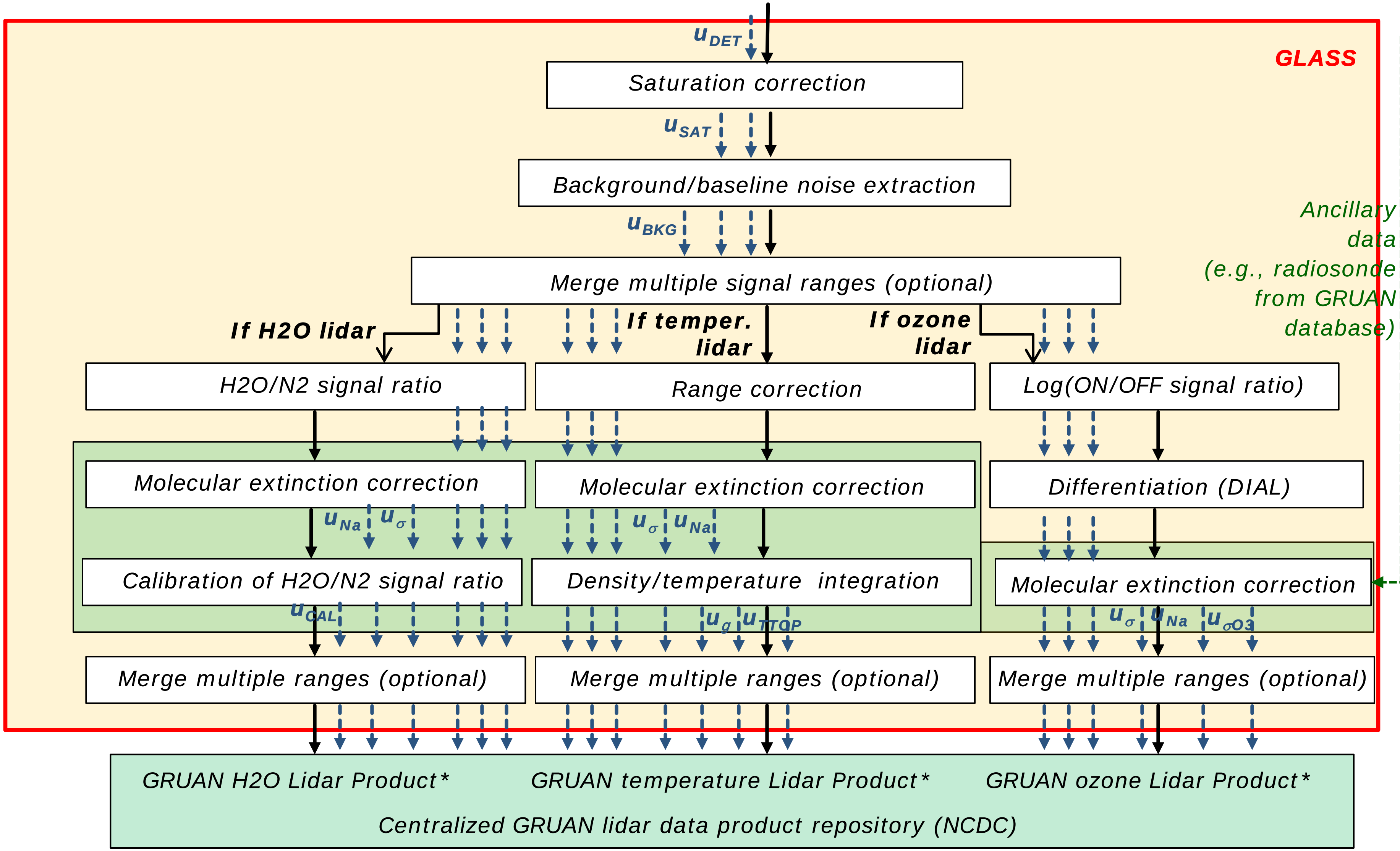
Something well-documented ➔ *transparent*

➔ **We need a GLASS (GRUAN Lidar Analysis Software Suite), a centralized lidar data processing software that can address all the above requirements**

Raw data quality check and ingestion procedure (traceability)



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

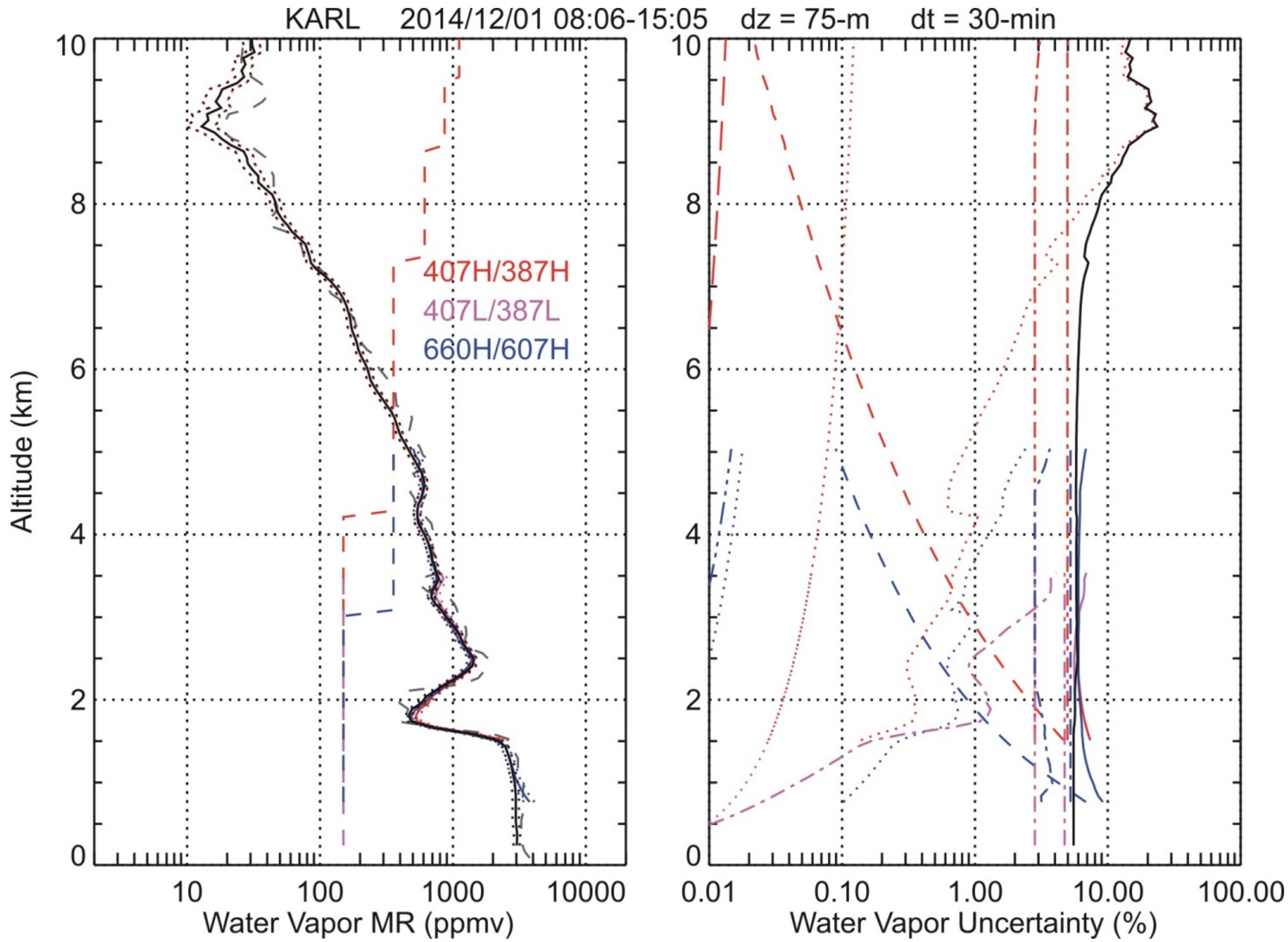
Red , purple and blue dashed lines: lidar, vertical resolution, in meters (NDACC-standardized)

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)

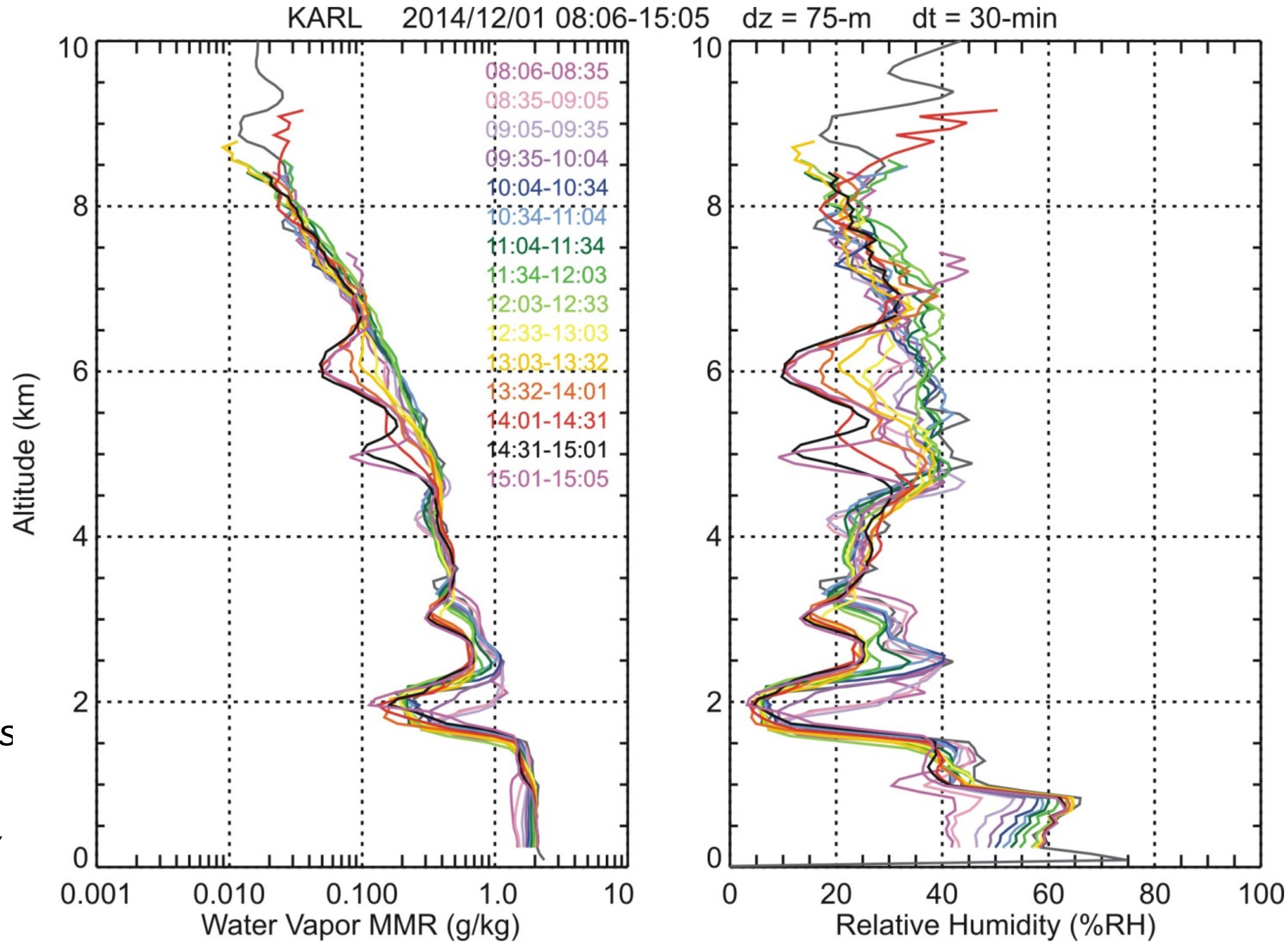
Right plot: RH (%)

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

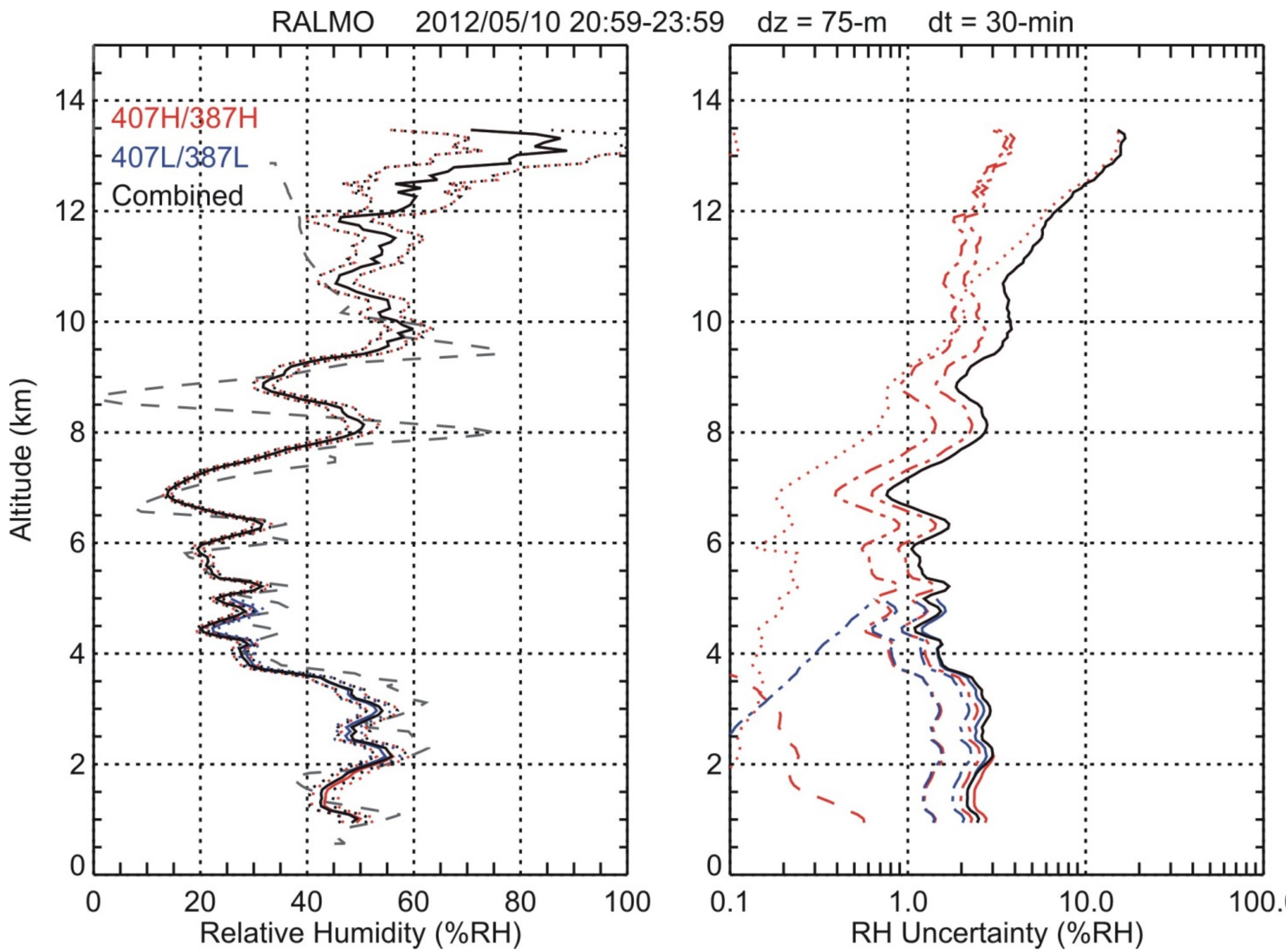
Red , purple and blue dashed lines: lidar, vertical resolution, in meters (NDACC-standardized)

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

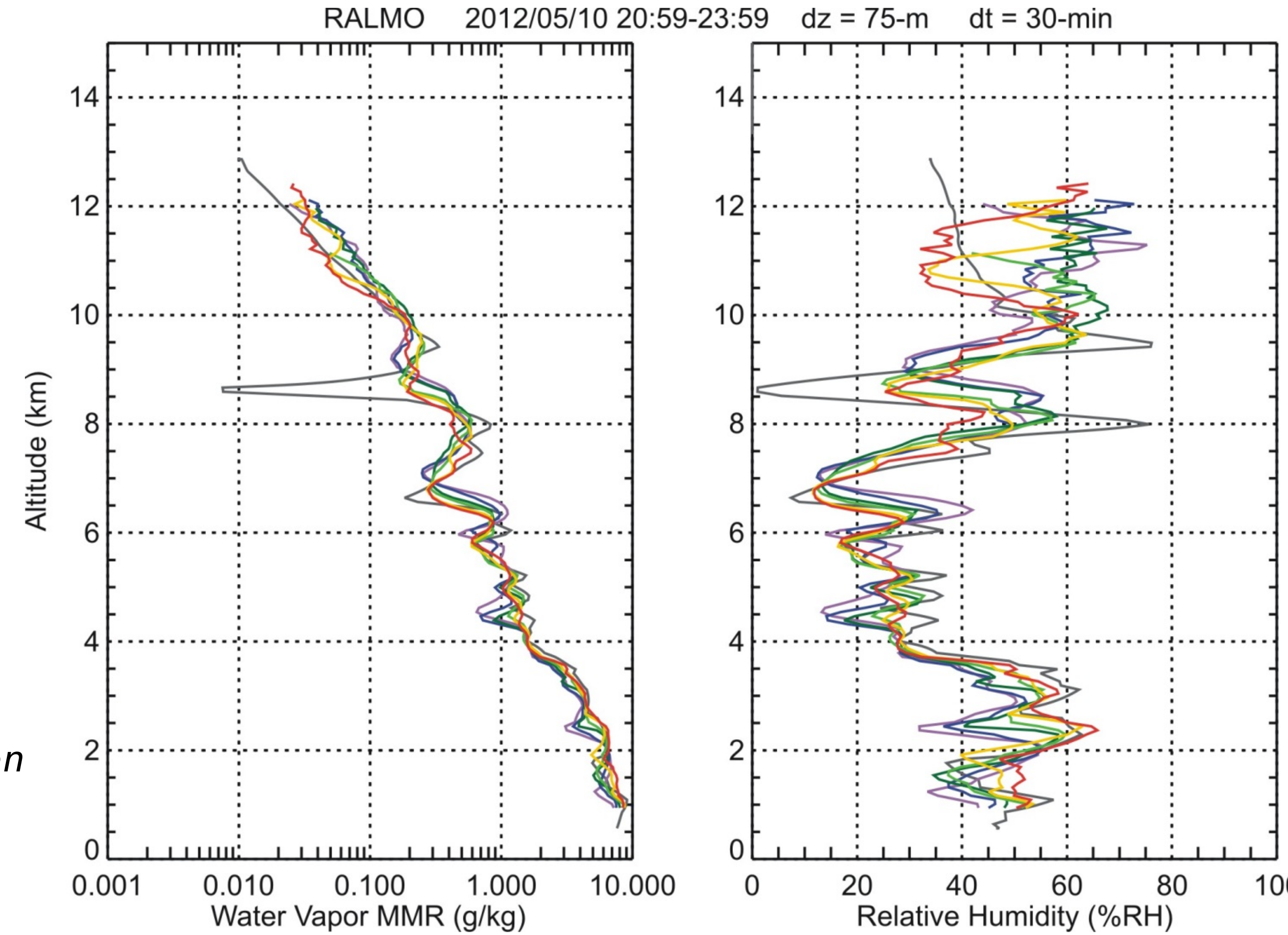
➔**Example of suitable GRUAN product for climatology and trends**

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)

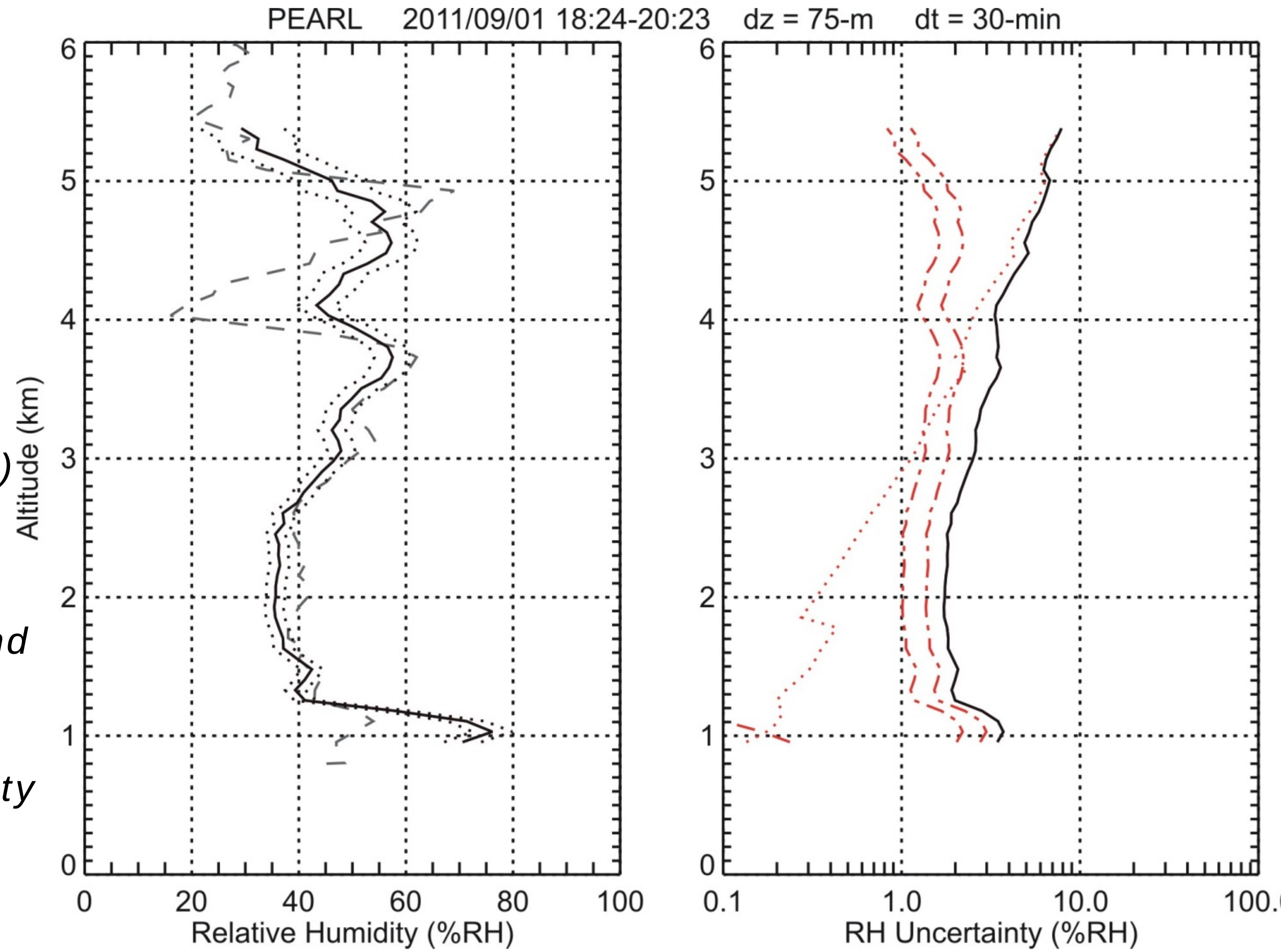
2-hour average (nighttime)

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 every instrument yields different answer 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

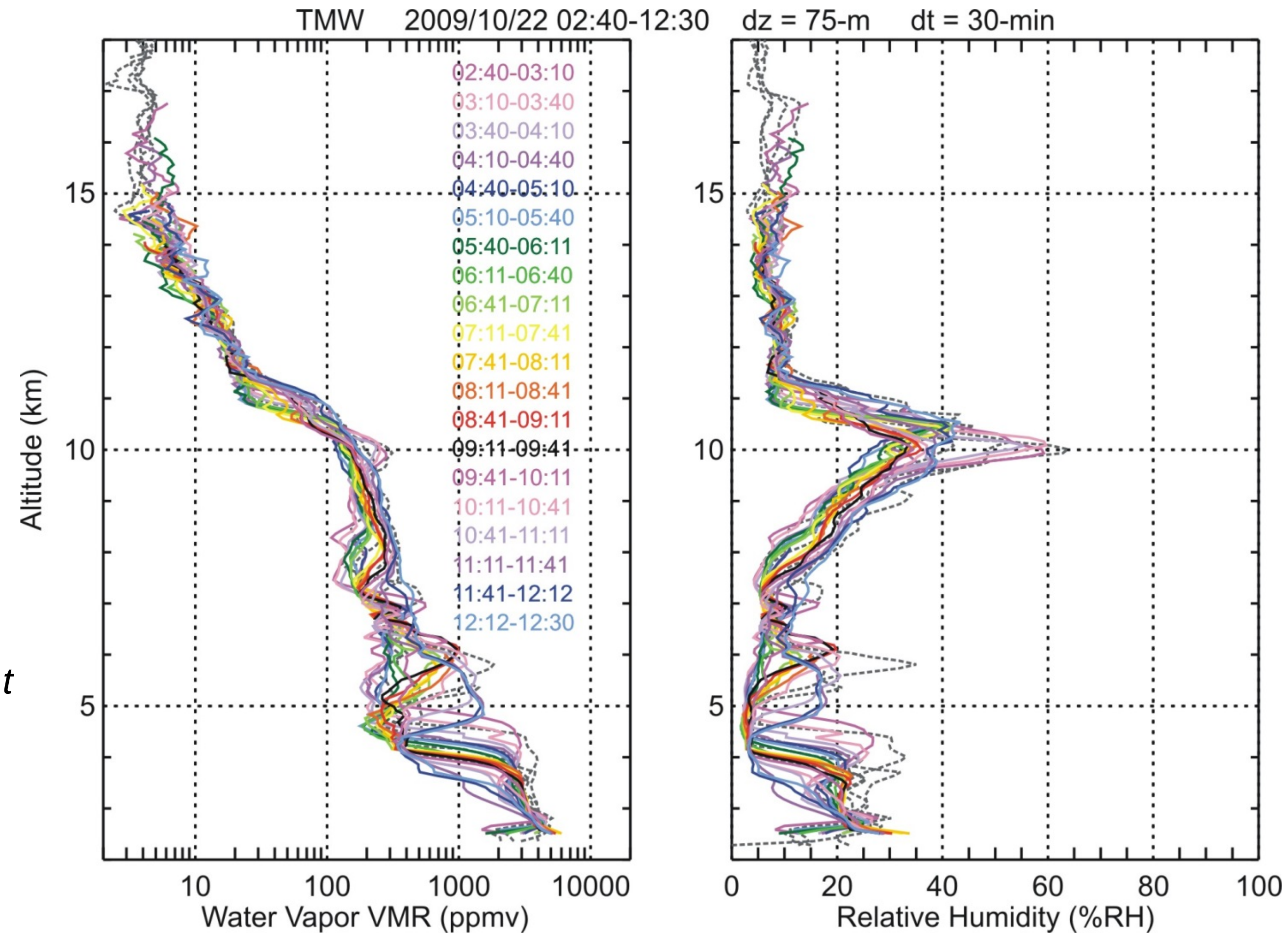
30-min slices (nighttime)

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

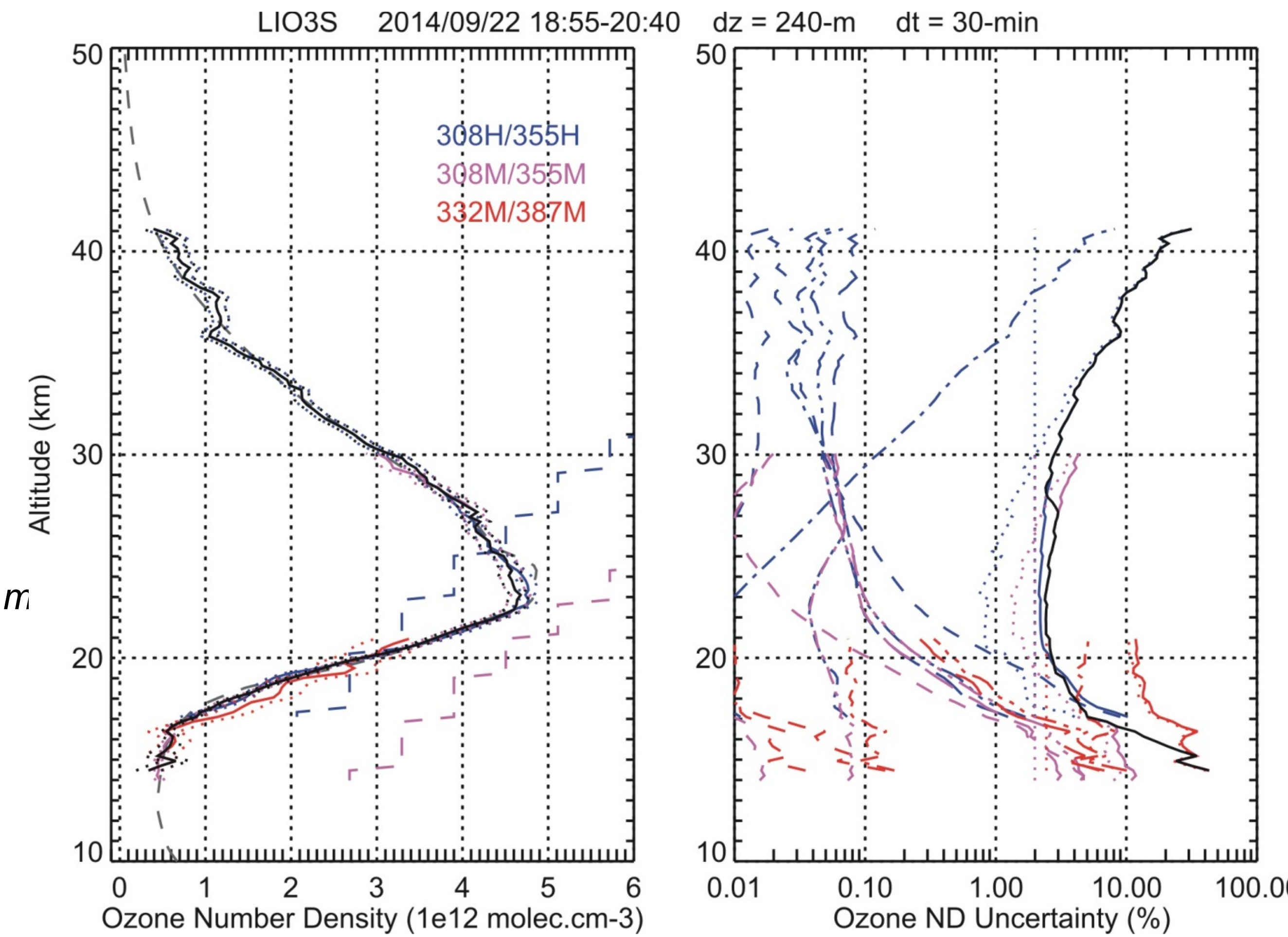
2-hour average (nighttime)

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)

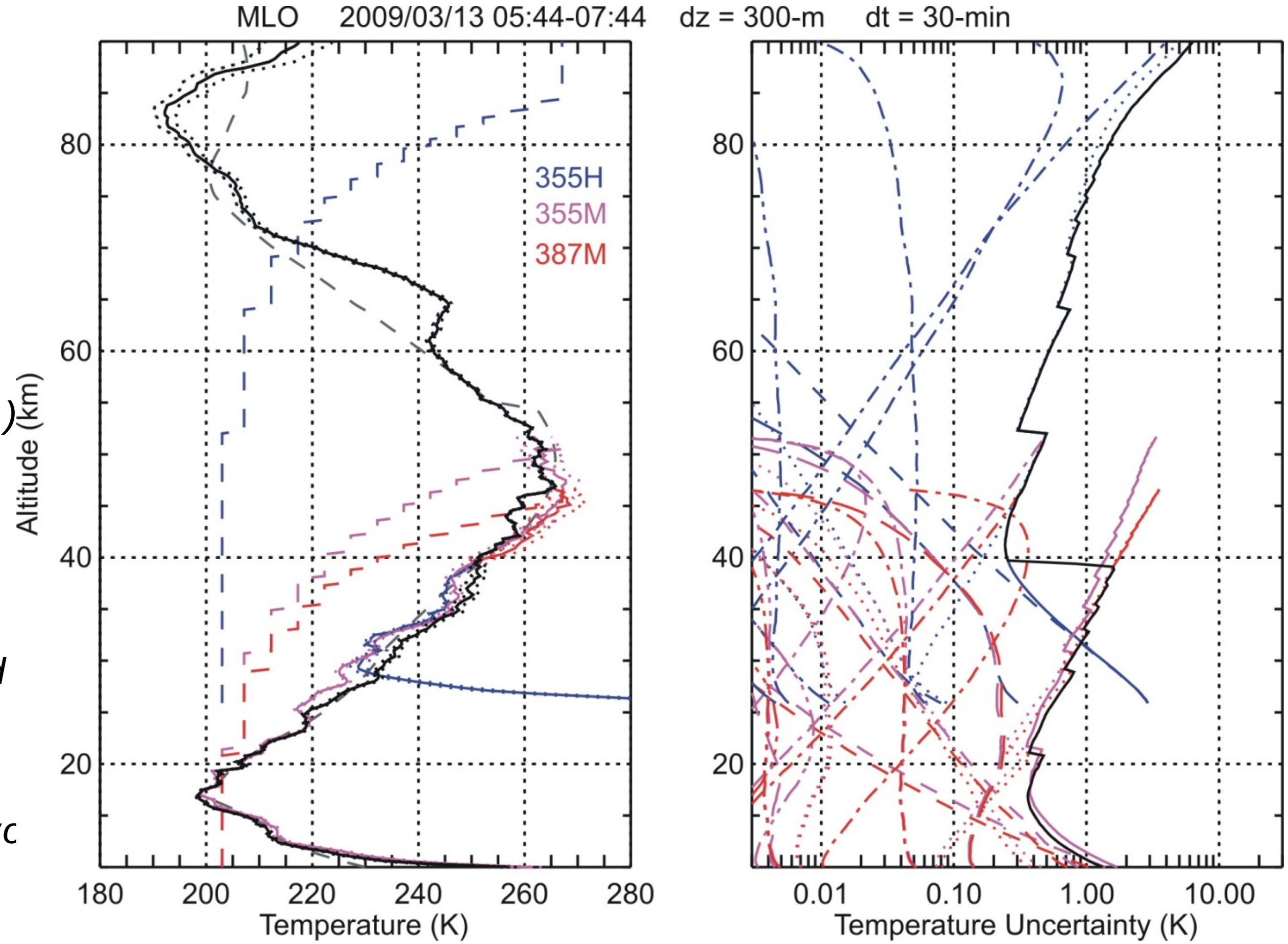
2-hour average (nighttime)

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

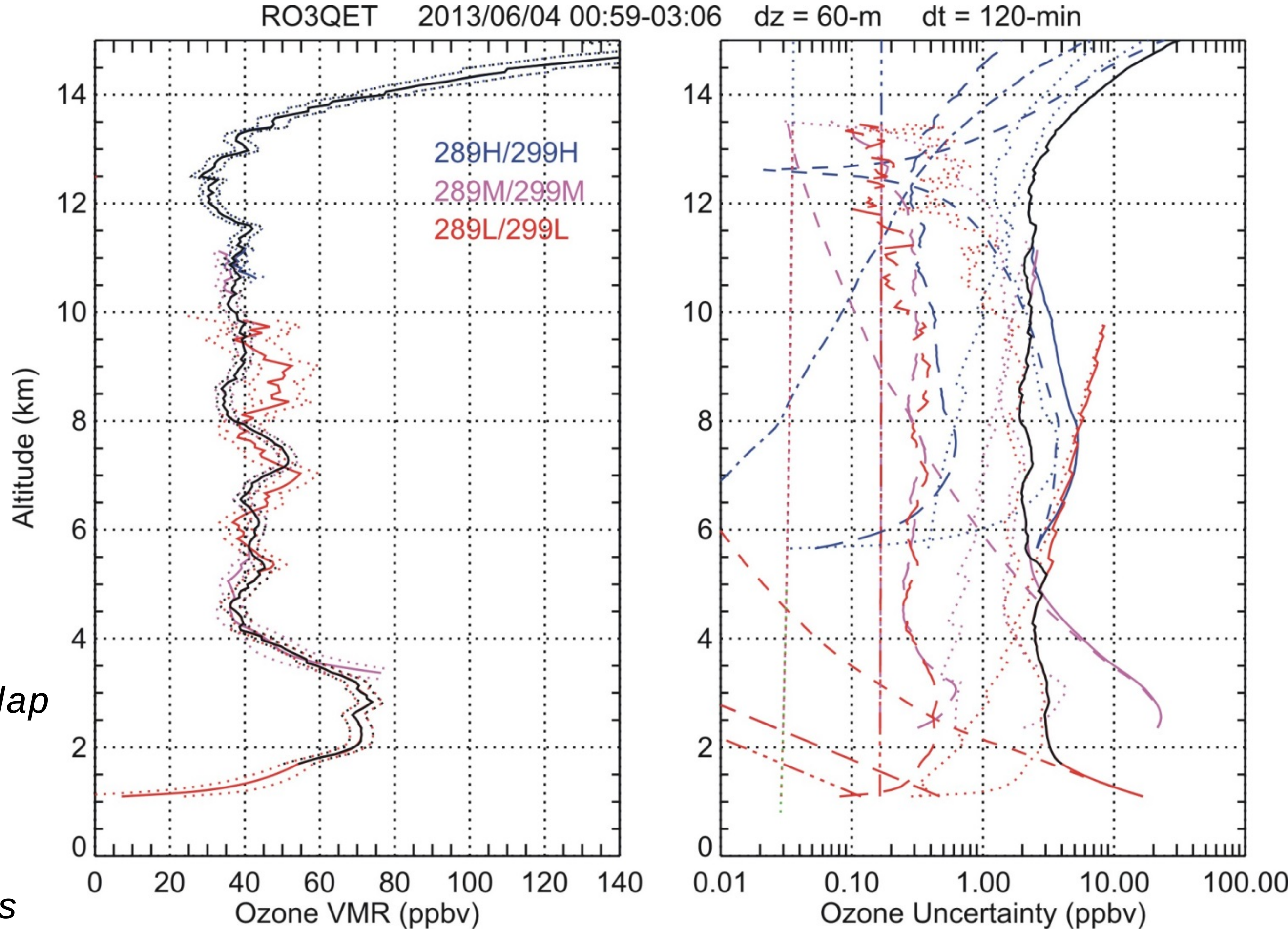
Many NDACC lidars measuring temperature could be added to GRUAN

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"

Looking forward...

Next steps (short / mid-term)

Finish up LidarRunClient

Connect the puzzle pieces together

Analyze multiple years of raw data

Incorporate more lidars (Beltsville?, Cabaw?, SGP?)

Validate products using the multiple years analyzed

Refine algorithm, add alternate calibration methods, etc.

Thank You

Backup slides

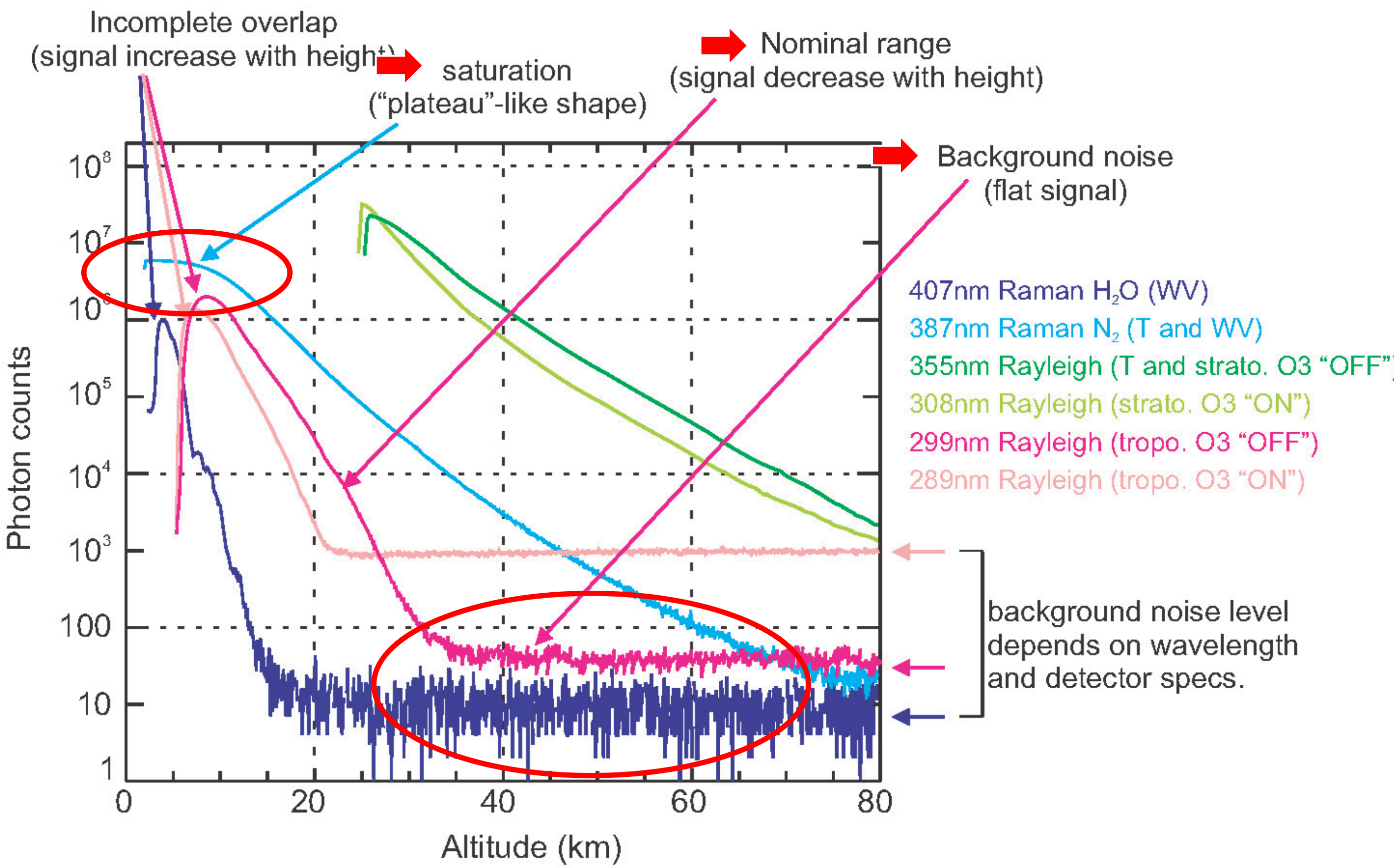
Sources of Measurement and Retrieval Uncertainty

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)*

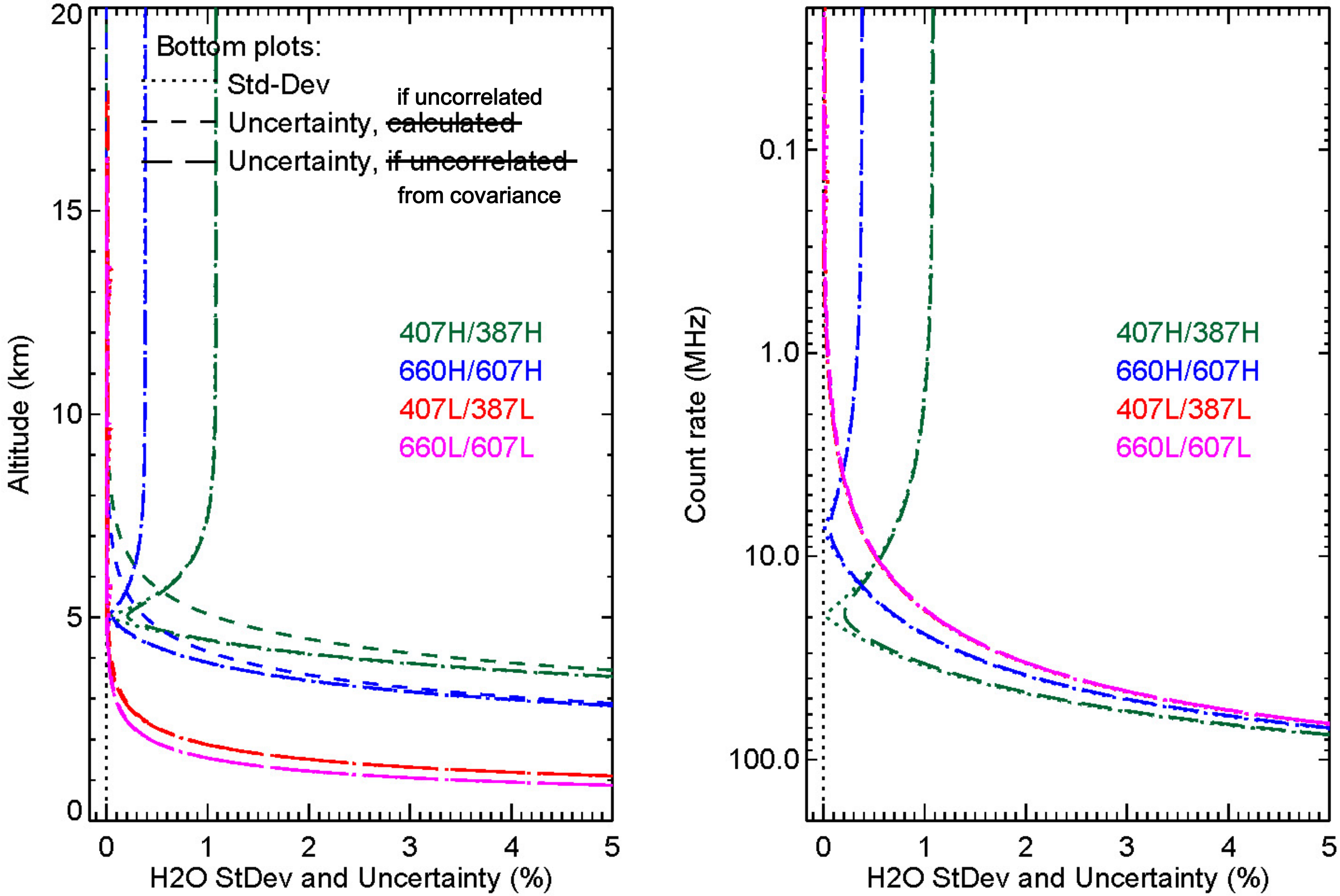
Propagating Uncertainty with Correlated Terms

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!