The AUGER Raman LIDAR

CRLF

PIERRE AUGER OBSERVATORY

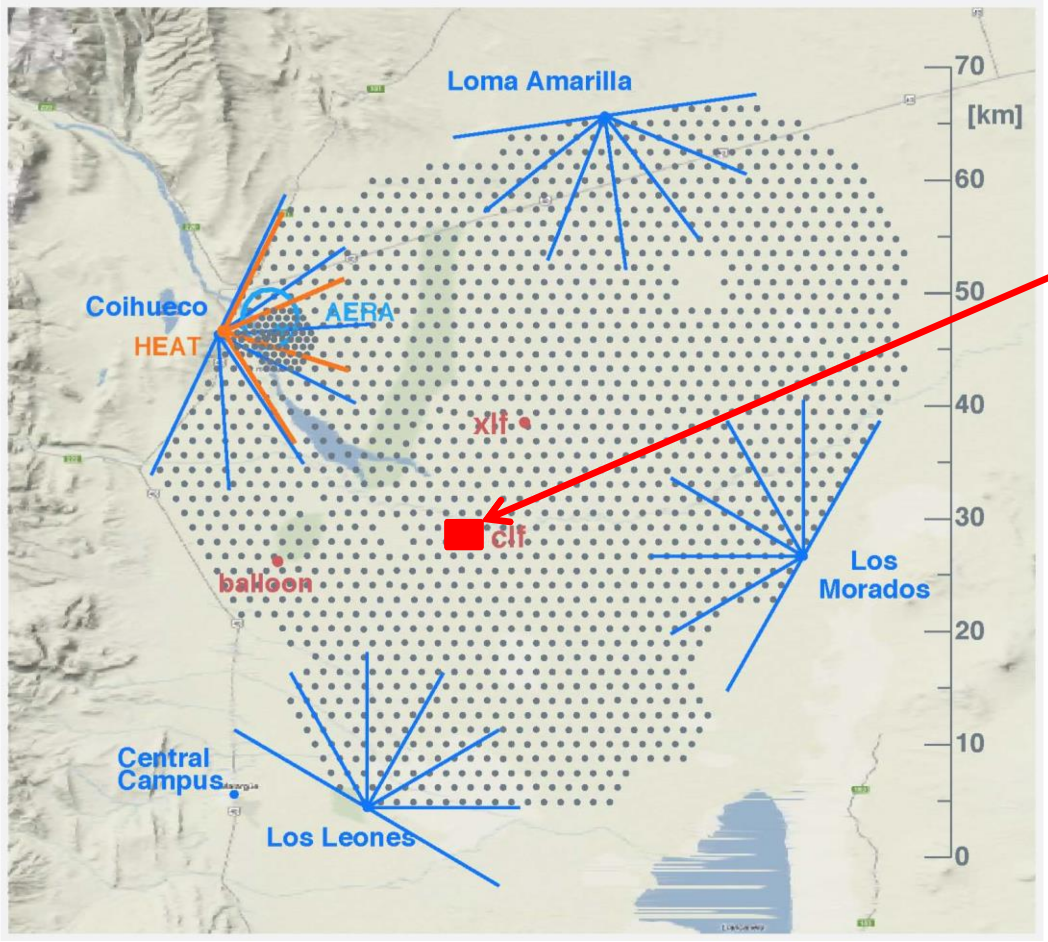
INFN Istituto Nazionale di Fisica Nucleare

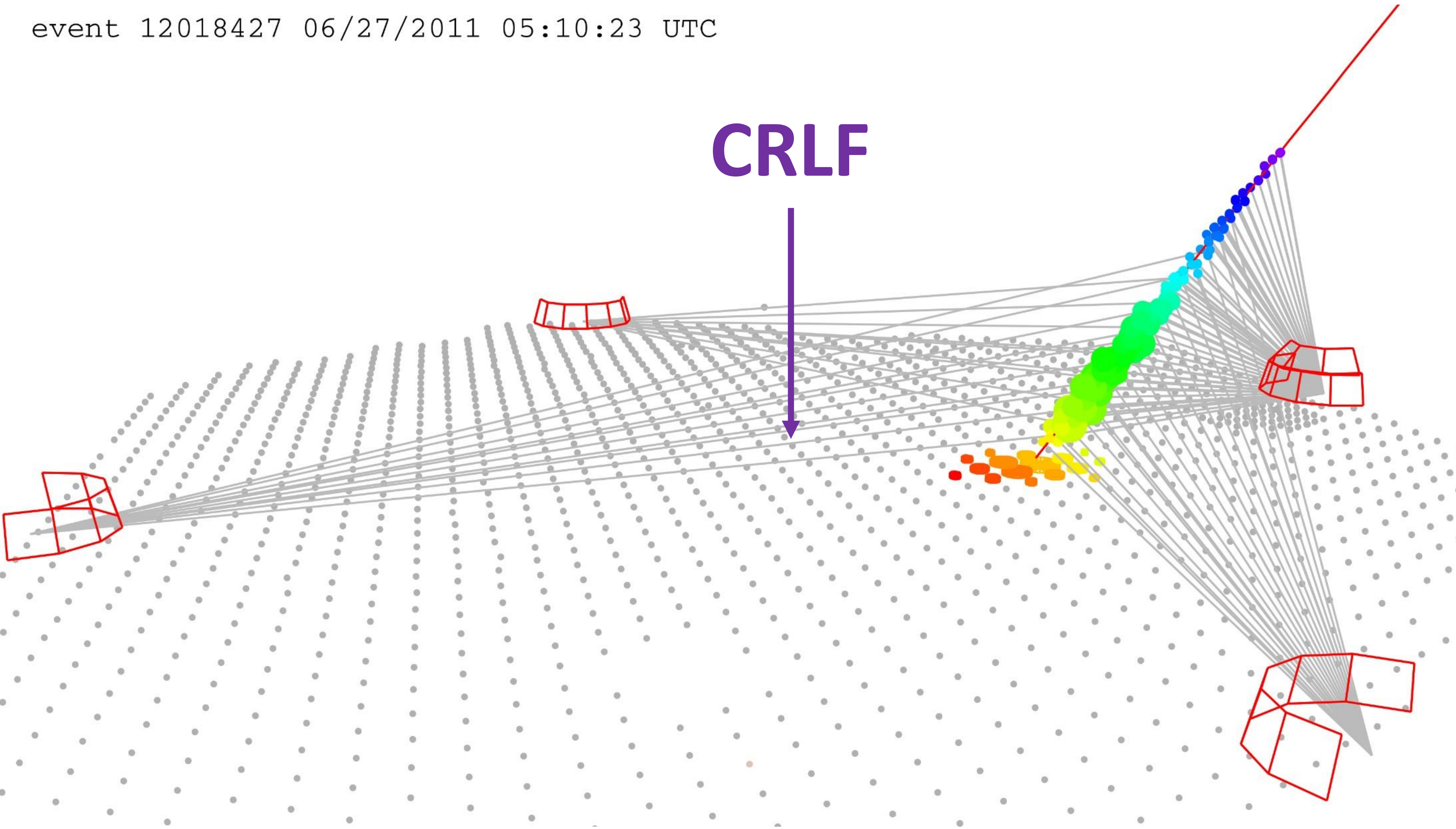
SCHOOL OF MINES 1874 COLORADO

Vincenzo Rizi, INFN & CETEMPS/DSFC/UNIVAQ, L'Aquila Italy

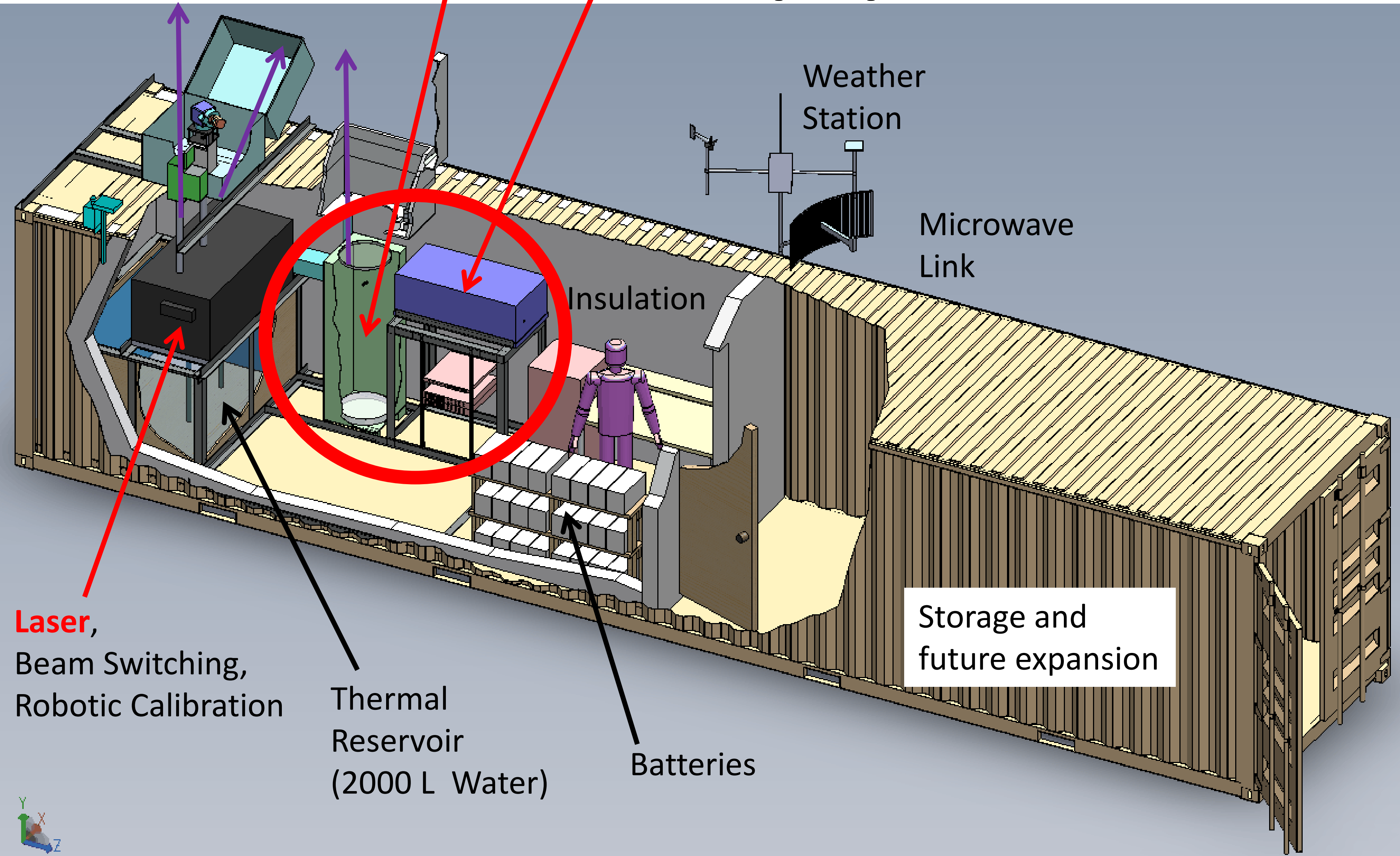
Raman LIDAR (RL)

The RL system samples vertically the part of the atmosphere **above the CRLF site**, and the retrieved VAOD profiles have a **representativeness** of the aerosol optical transmission in the atmosphere over the Observatory.

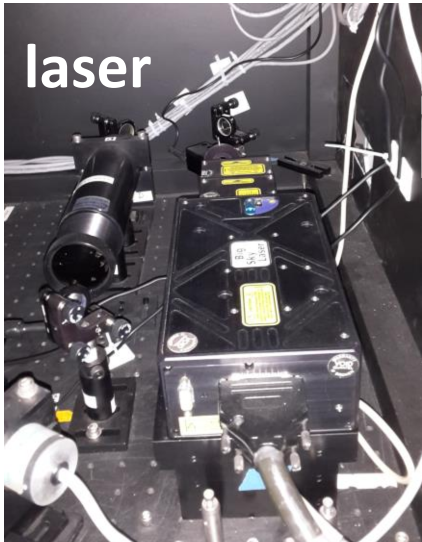


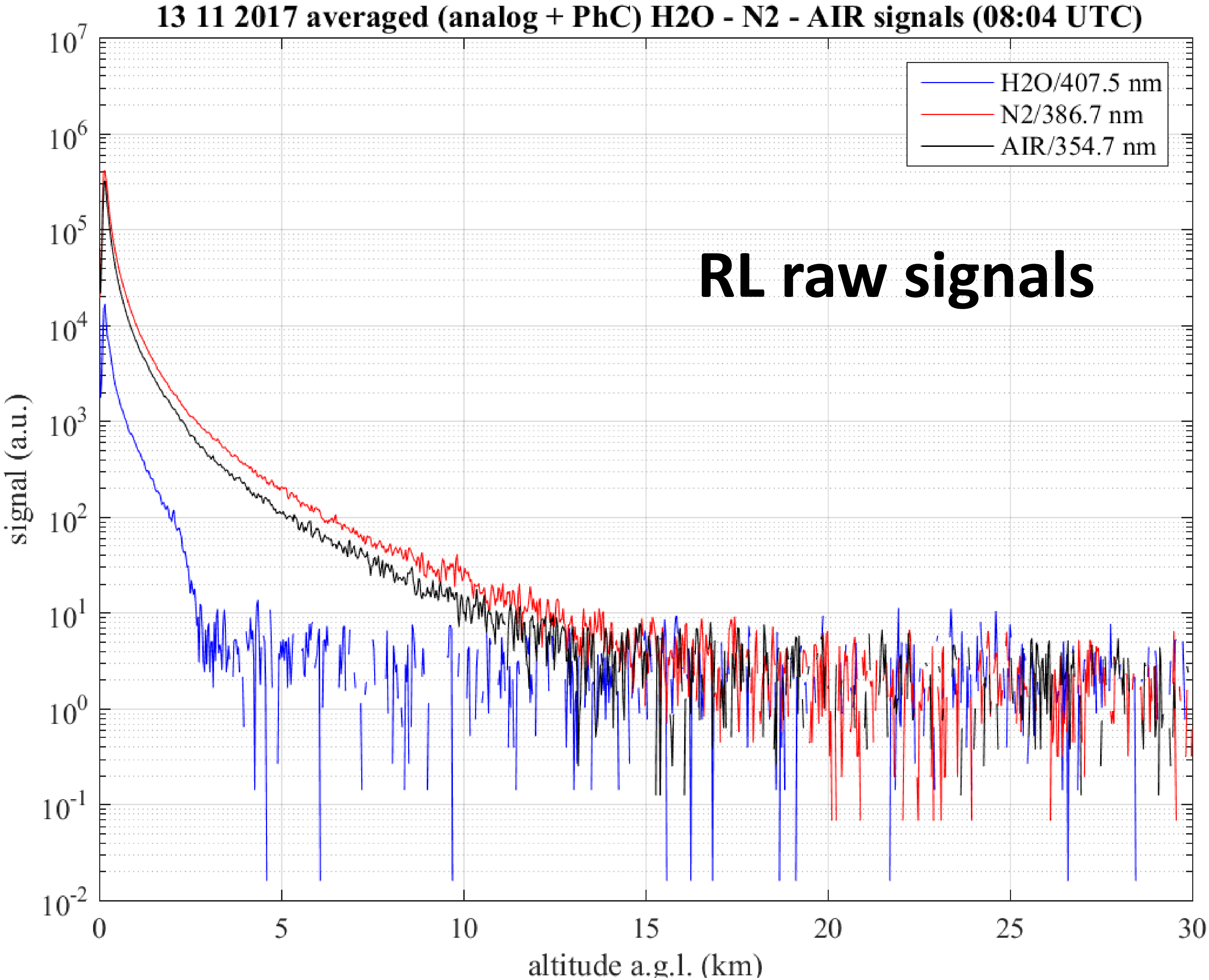

event 12018427 06/27/2011 05:10:23 UTC
CRLF

Raman LIDAR (RL)



Raman LIDAR (RL)




13 11 2017 averaged (analog + PhC) H2O - N2 - AIR signals (08:04 UTC)
H2O/407.5 nm
N2/386.7 nm
AIR/354.7 nm
RL raw signals
signal (a.u.)
altitude a.g.l. (km)
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
0
5
10
15
20
25
30

Outline:

Performance
Cost
Maintenance
Data
Technical documentation
Science
Some considerations & Summary

Interesting contents in the backup slides …

Performance

The system is **automatic** and it is run at Central Raman Laser Facility (**CRLF**) during the **FD shift periods** in 3 time windows of about 15 minutes **before, during** and **after** (**BDA**) the daily FD shift.

- RAMAN shots: Next bays need to be close from 1:30 to 1:50 local time:
  - Los Leones: Bay 4
  - Los Morados: Bay 4
  - Loma Amarilla: Bay 3
  - Coihueco: Bay 3

[...] [...]

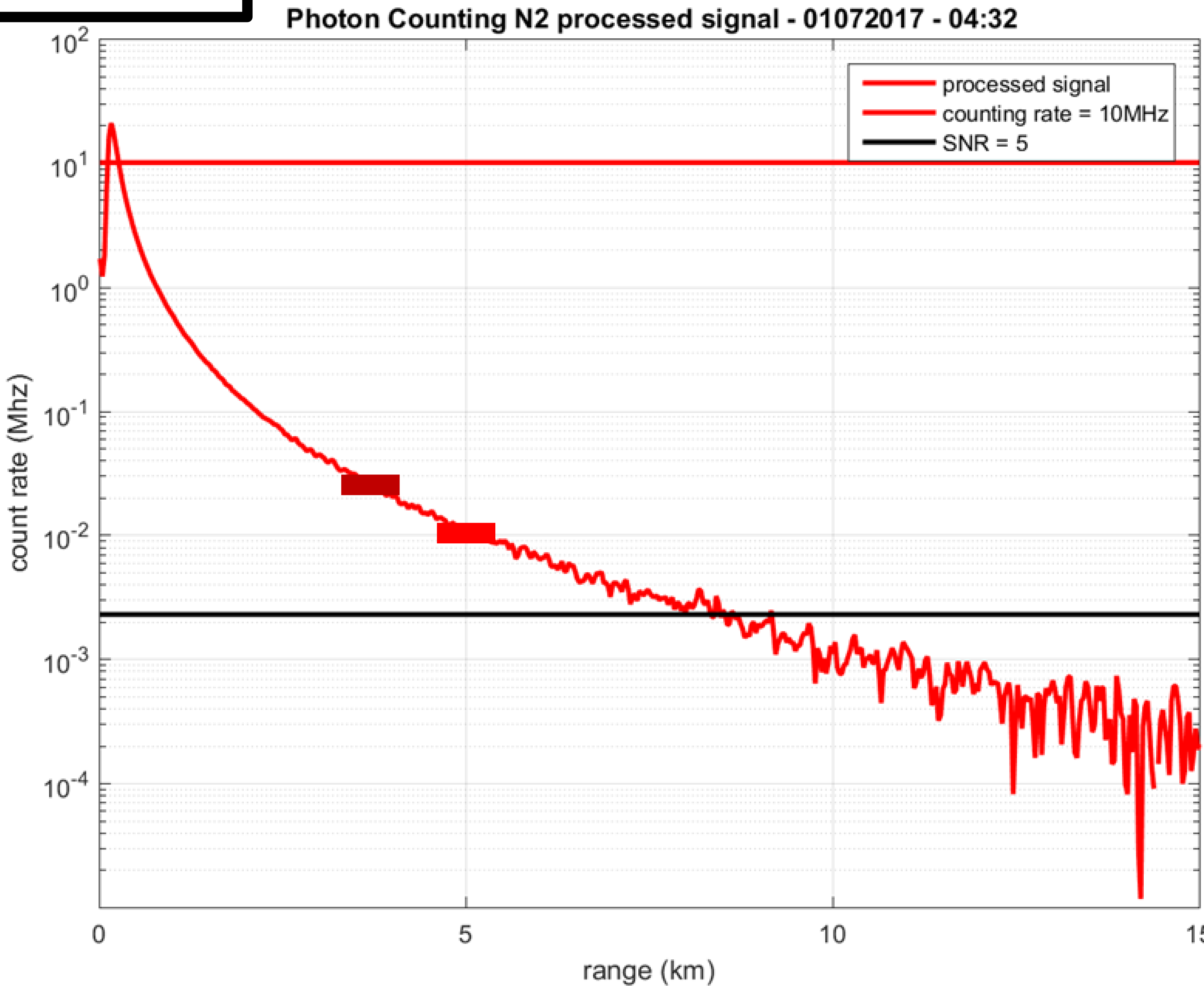
The programmed measurements have been regularly taken. The **RL database** cover a period between **September 2013** to **present:**
2013-2017
- 2601 measurements of vertical aerosol optical depth profile;
- **2488 measurements of the vertical aerosol volume backscatter profile**;
- 1804 measurements of the vertical water vapour mixing ratio profile;

and the current BDA schedule of the observations has started since **October 2014**.

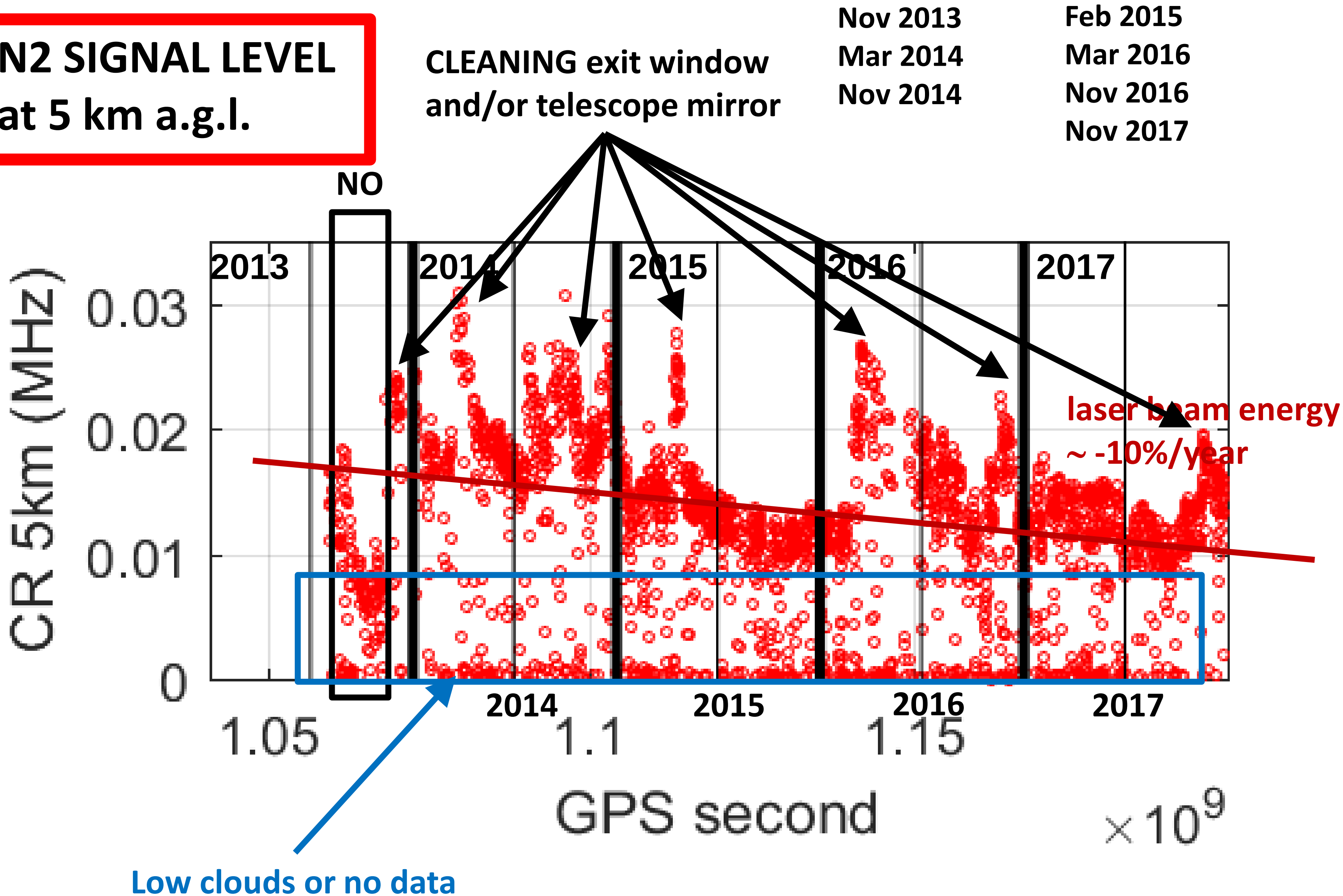
some "metrics" to assess the RL long term performances
September 2013 December 2017

Performance

RL N2 SIGNAL



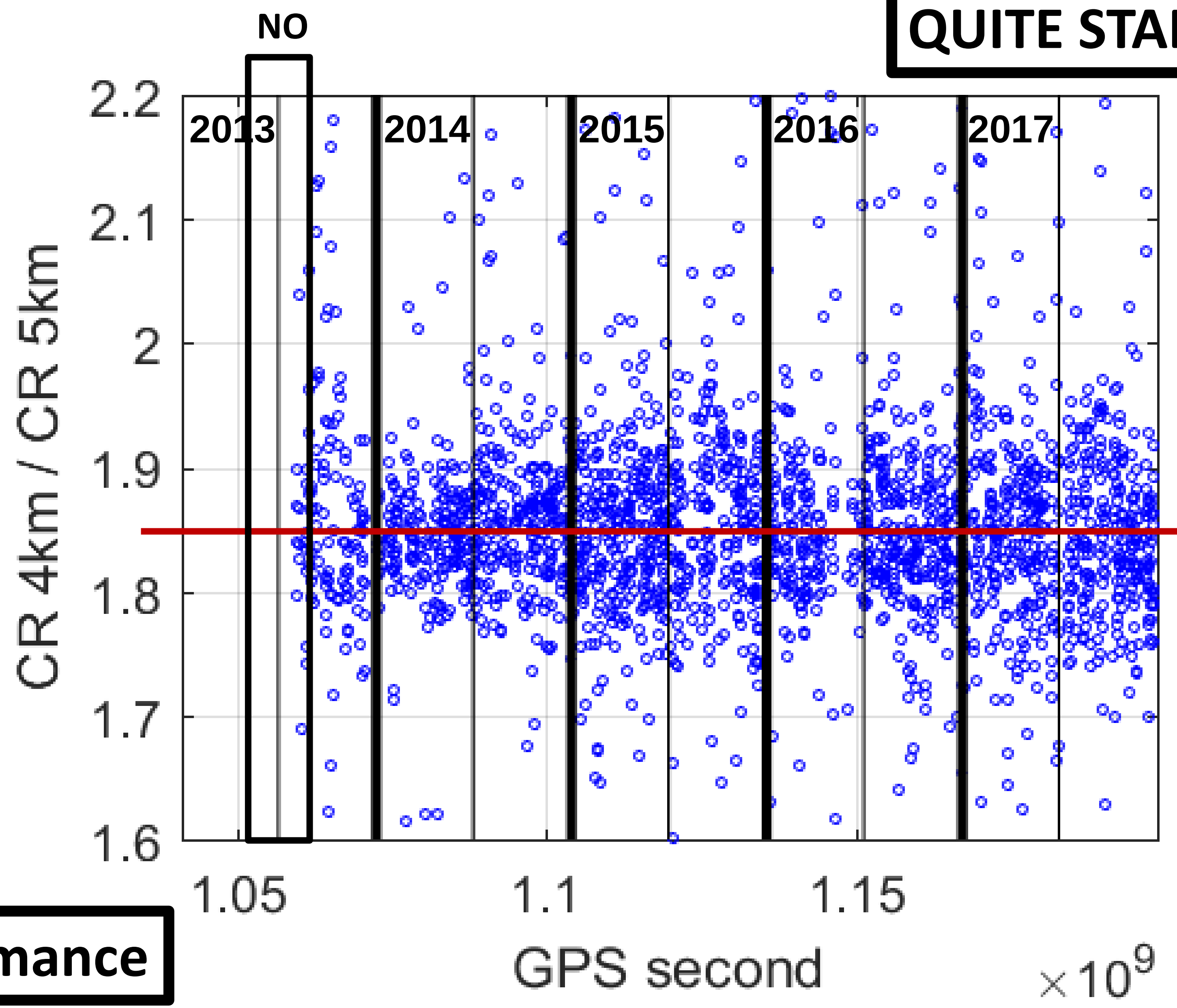
N2 SIGNAL LEVEL at 5 km a.g.l.



Performance

RATIO OF N2 SIGNAL LEVELS at 4 km a.g.l. and 5 km a.g.l.

QUITE STABLE



Performance

Cost

[redacted]

Maintenance

Once a month, the local staff is taking care of the regular maintenance at CRLF, […].

[…], 2 times per year, scientists travel to RL site to support **special** activities on RL system and sub-systems (i.e., the **optical alignments of the laser transmitter and of the receiver bench, and the status of the detectors**).

Data

INFN/L'Aquila is also responsible of the analysis of the RL data.

RAW DATA (real-time)

the N2 RL signals are in:

http://cetemps.aquila.infn.it/osservatorio/CLRF_raman_lidar/RL_data/N2_signals/

they are used (usable) to estimate the VAOD profiles

Filenames: **L_N2_DDMMYYYY_hhmm.dat** or **L_N2_GPSsecond.dat (**in **…/GPS_second/)**

Format**: [altitude agl (km)] [pre-processed signal a.u.]**

raw vertical resolution: **30 m**

Data period: **2013, 2014, 2015, 2016 and 2017**

The next release of RL data and software …

Raw signals, codes (C++) and documentations.
with the help of several collegues

Technical documentation

RL system description in paper:

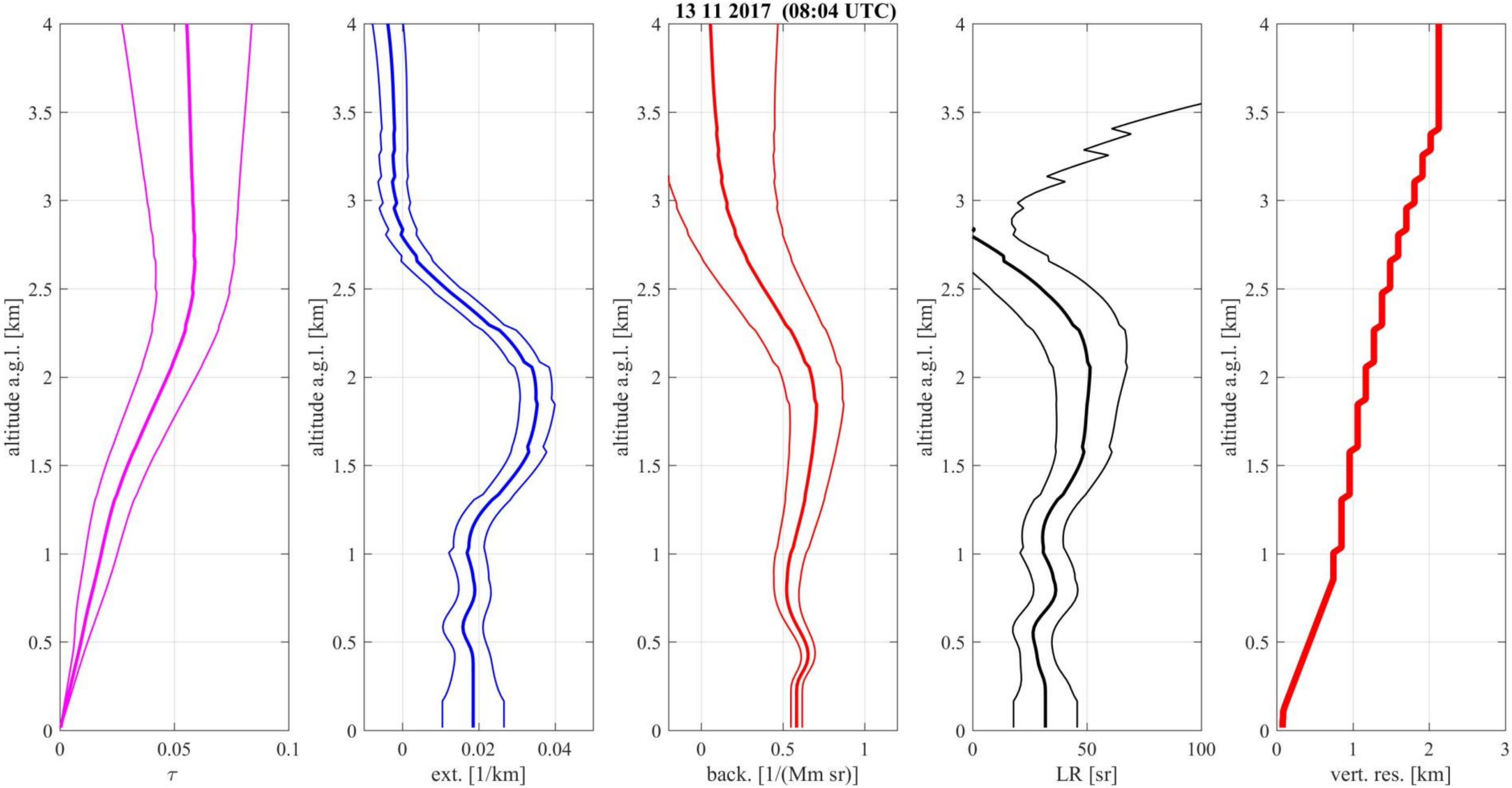
Joint Elastic Side-Scattering Lidar and Raman Lidar Measurements of Aerosol Optical Properties in South East Colorado, Journal of Instrumentation 12(03):P03008, March 2017, DOI: 10.1088/1748-0221/12/03/P03008

Drawings and users' manuals.

Science

12 min run during FD shift

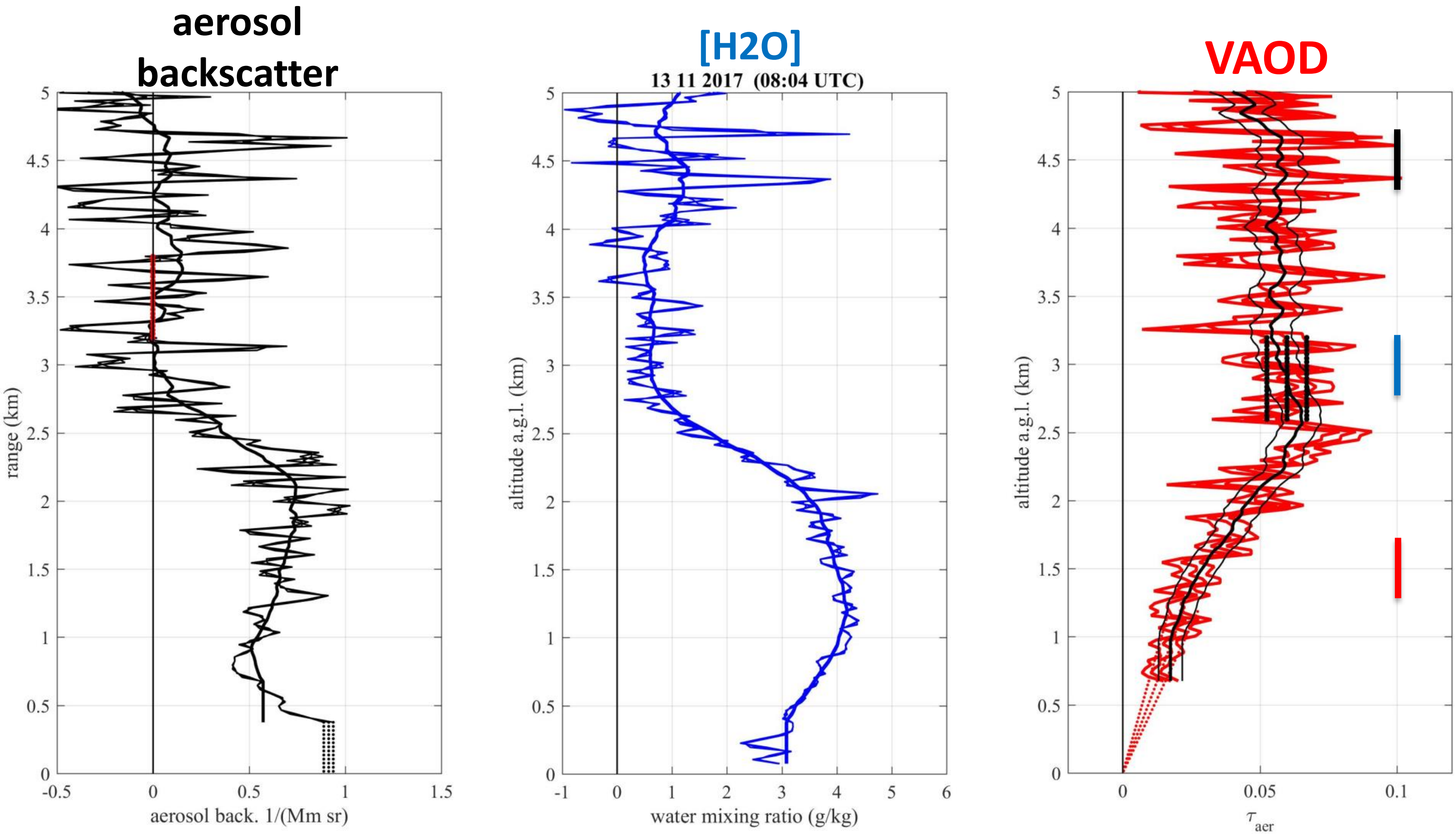
VAOD | aerosol extinction | aerosol backscatter | lidar ratio | vertical resolution



13/11/2017 08:04 – 08:16 UTC

Science

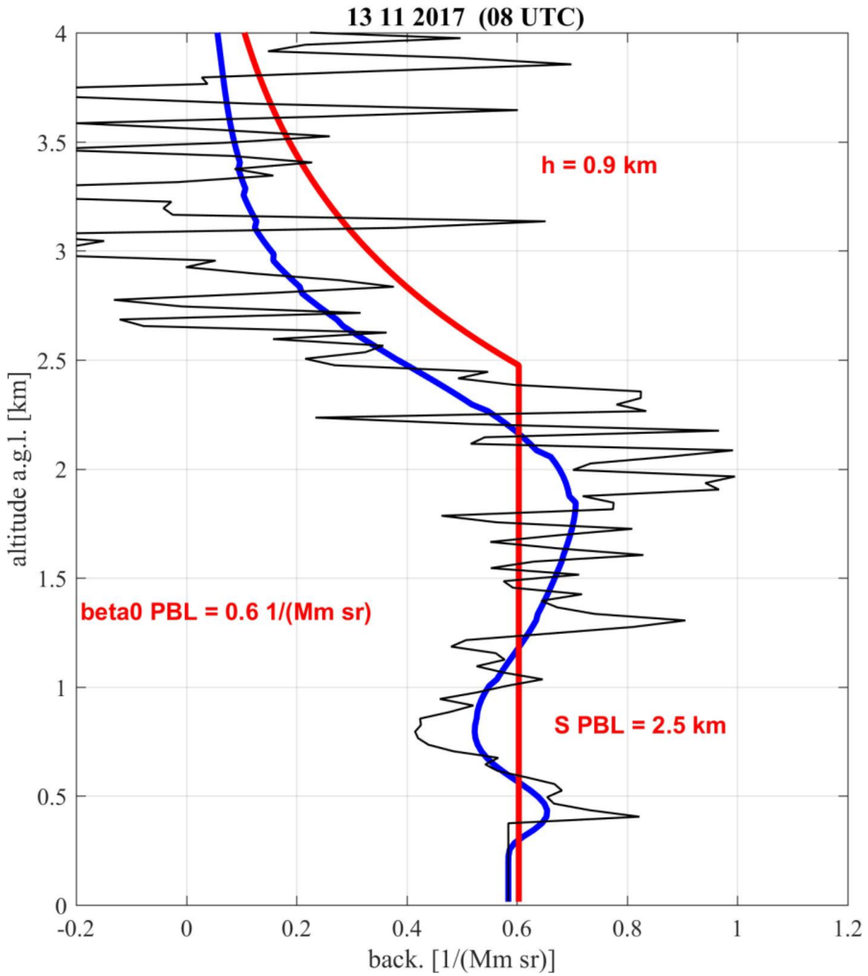
12 min run during FD shift



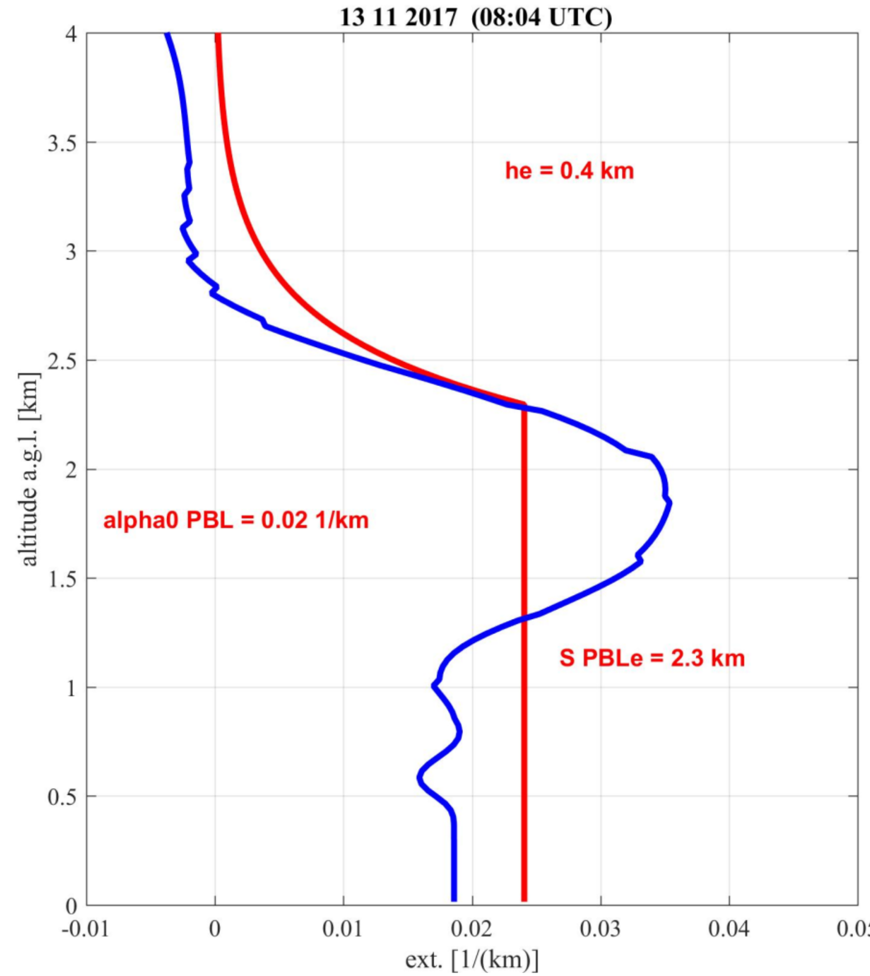
13/11/2017 08:04 – 08:16 UTC

Science

13/11/2017 08:04 – 08:16 UTC



aerosol backscatter



aerosol extinction

aerosol model …

PBL height and transition zone to free troposphere

data NOV2013-DEC2017

VAOD data selection:

simple criteria

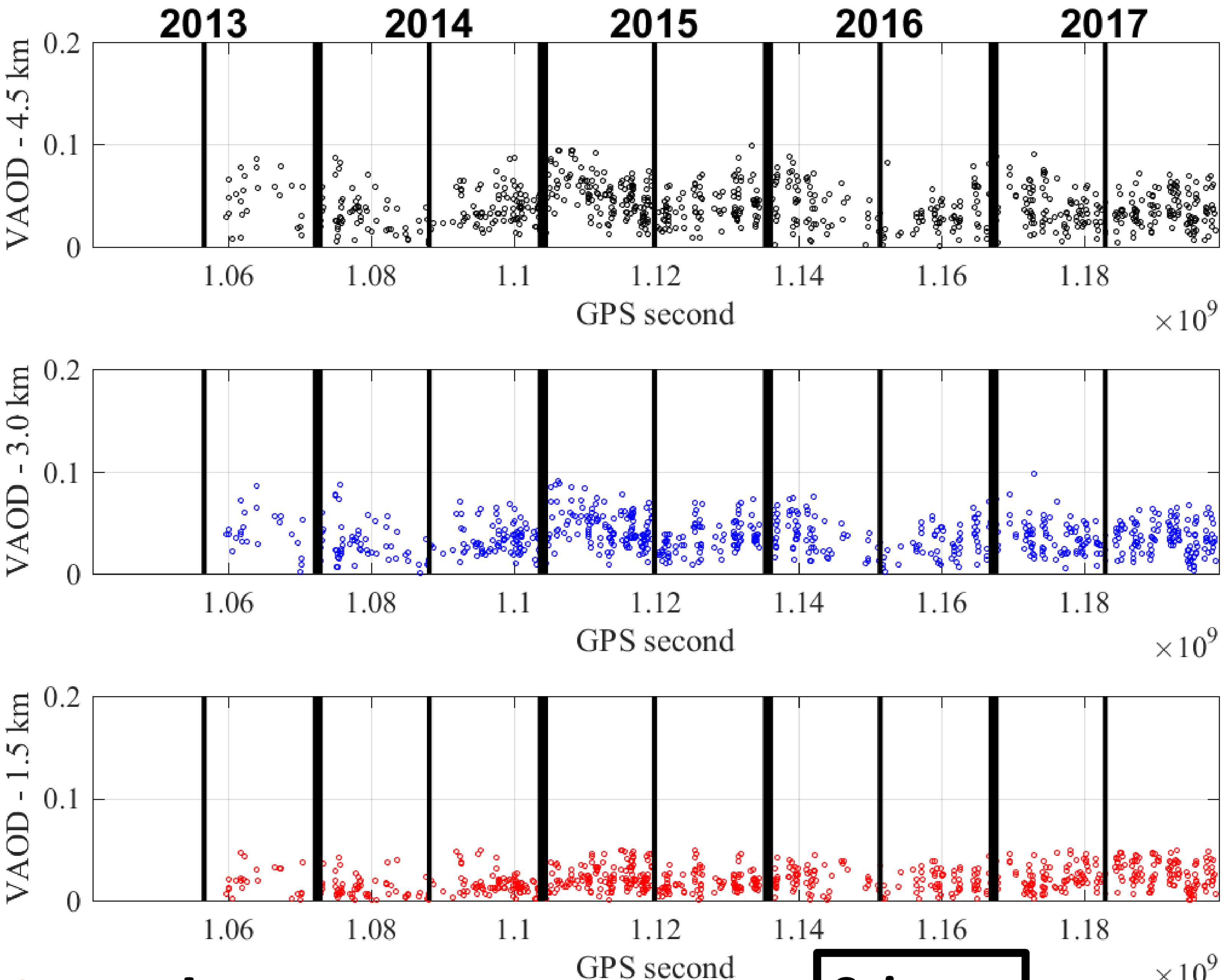
0 < VAODvalue@1.5km < 0.05

0 < VAODvalue@3.0km < 0.10

0 < VAODvalue@4.5km < 0.10

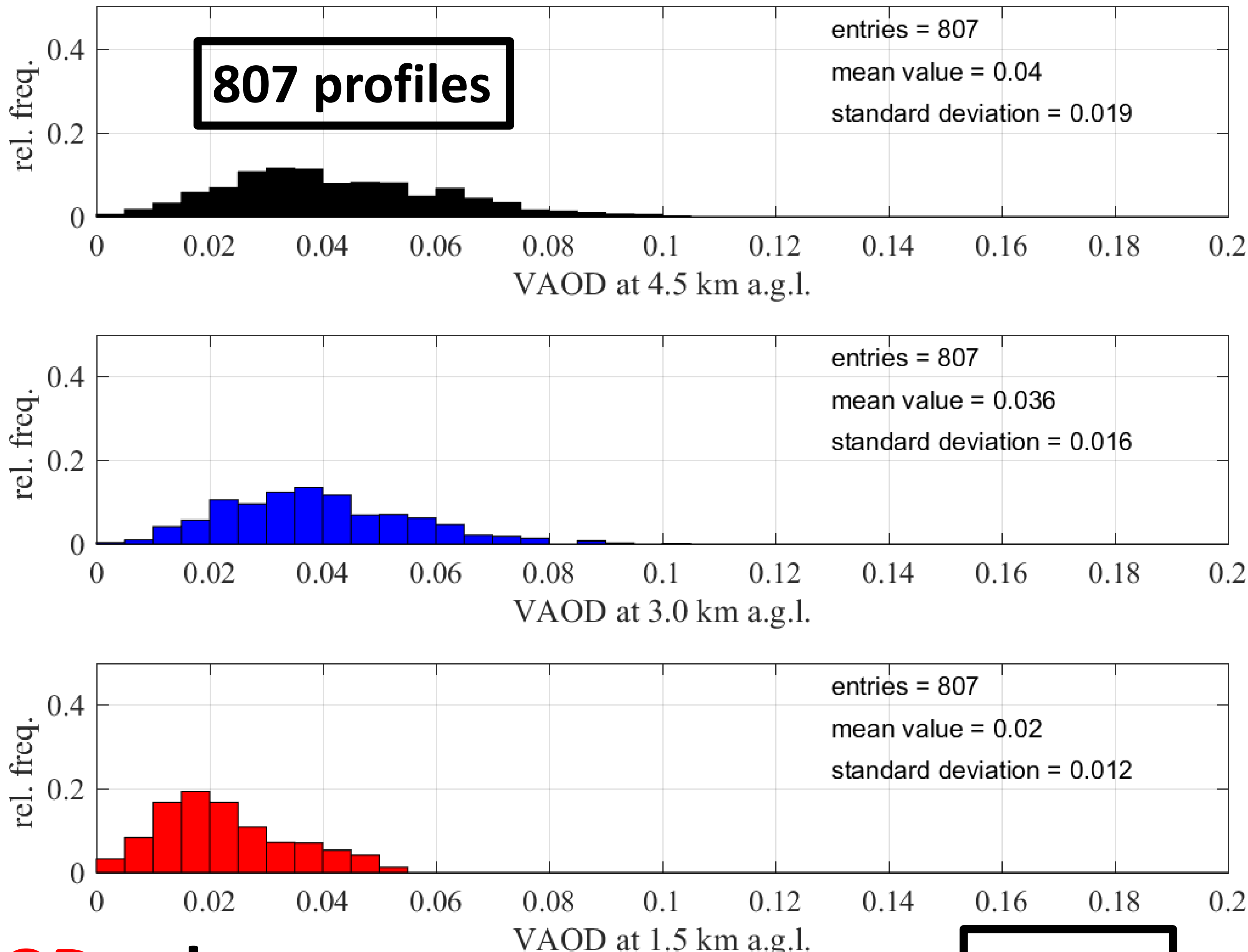
Quality cuts and cloud masking.

VAOD values



VAOD values

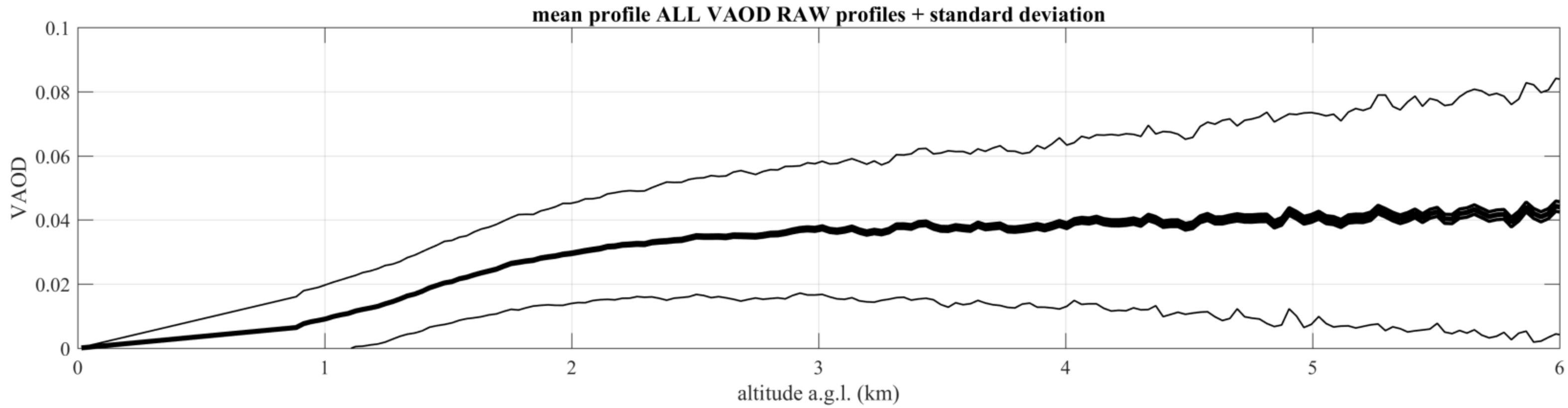
Science

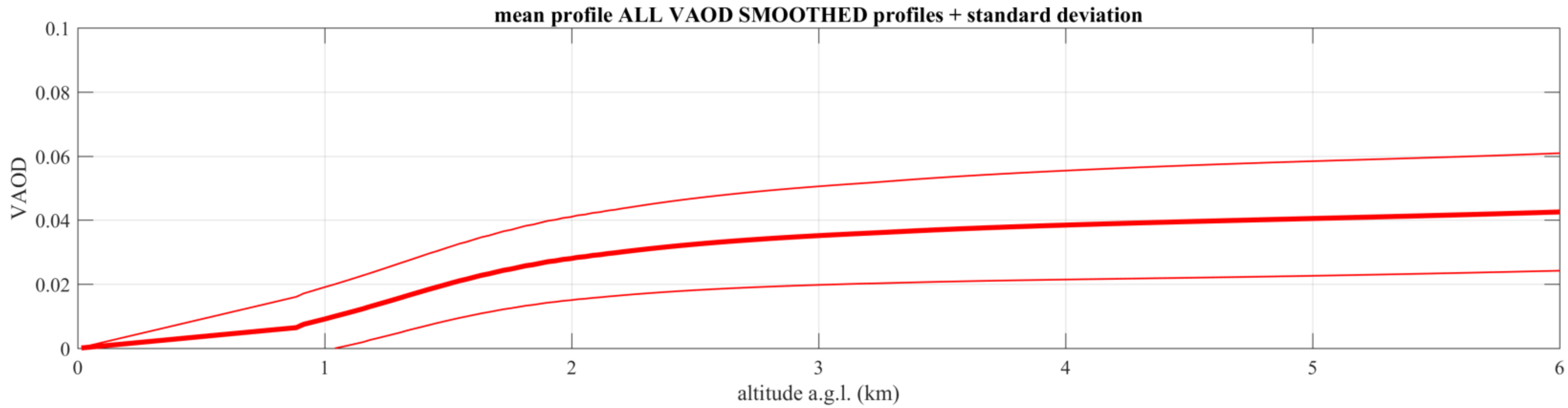


VAOD values

Science

Mean profiles <u>all NOV2013-DEC2017</u>

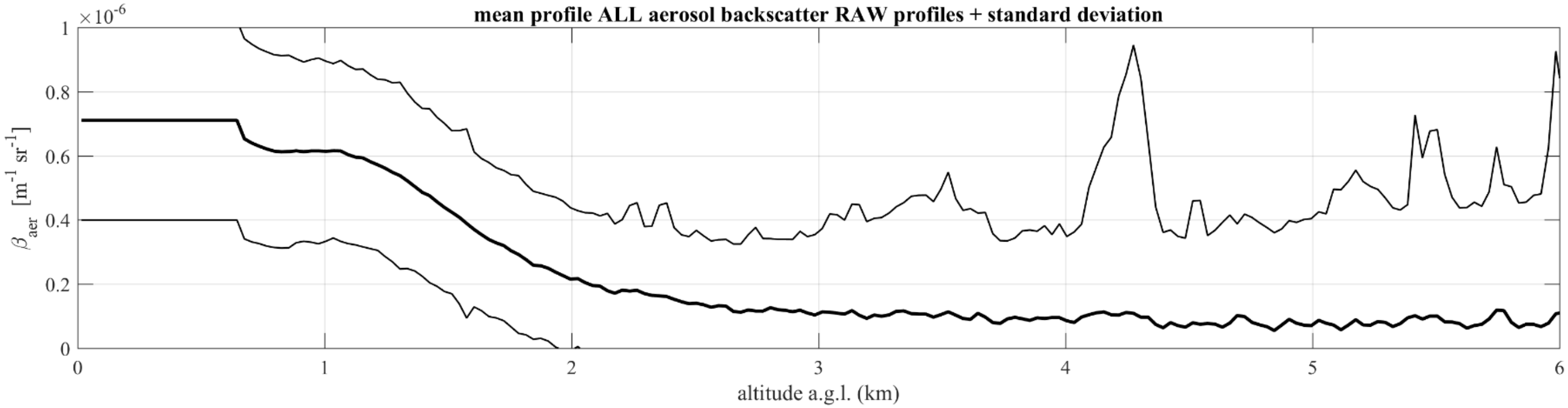


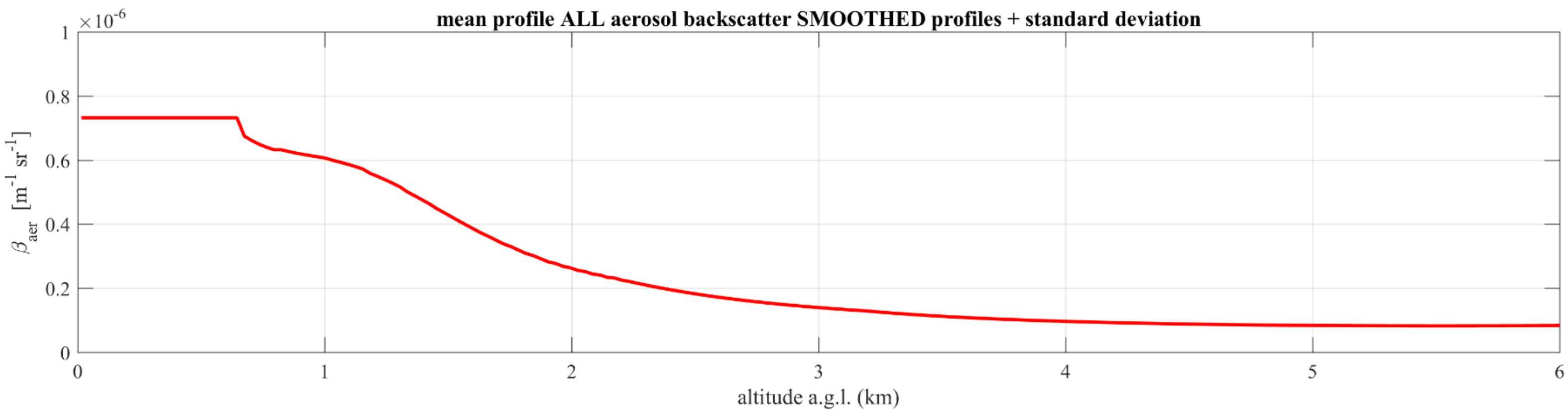


VAOD

Science

Mean profiles all NOV2013-DEC2017



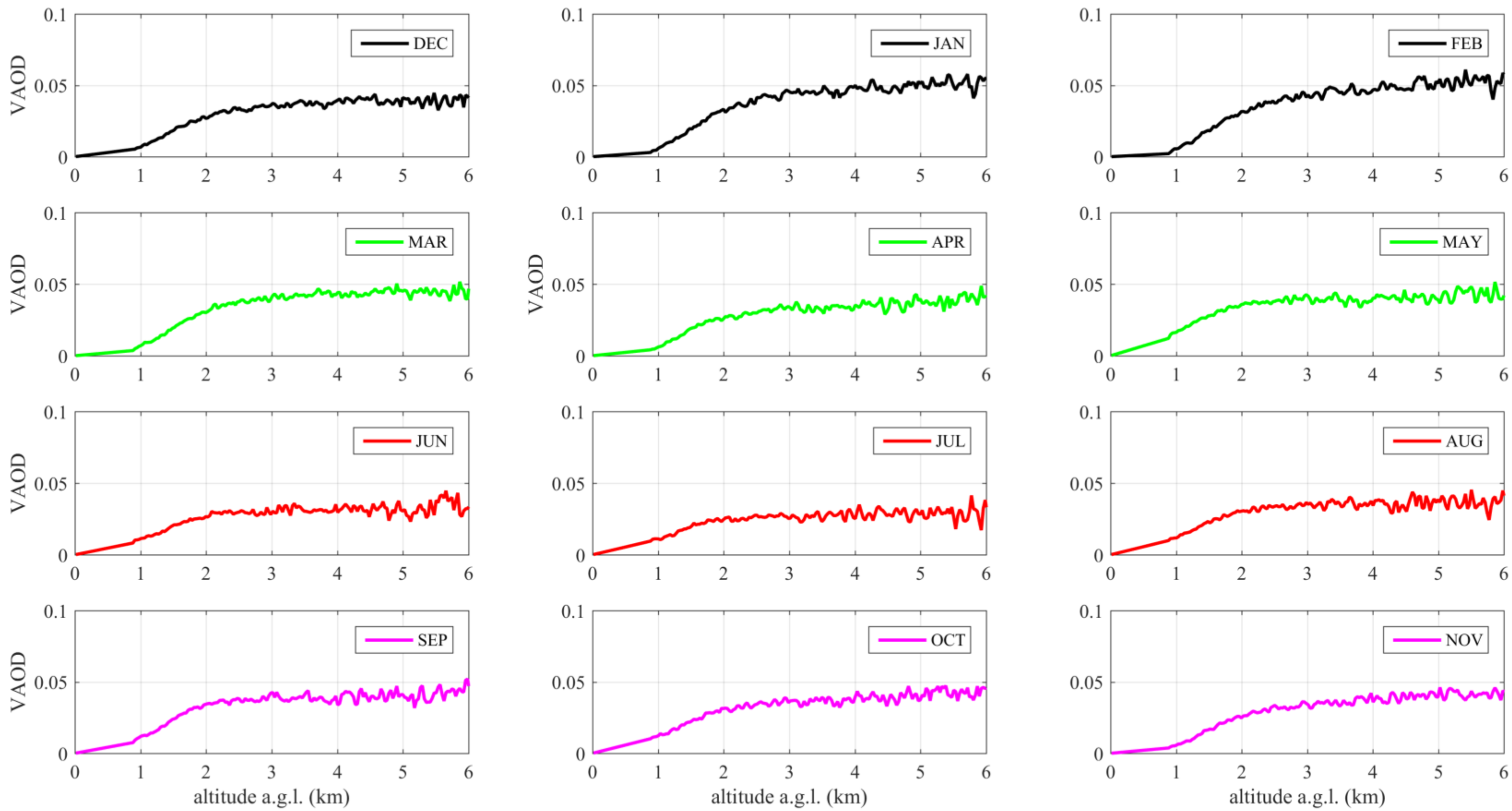


aerosol backscatter

760 profiles

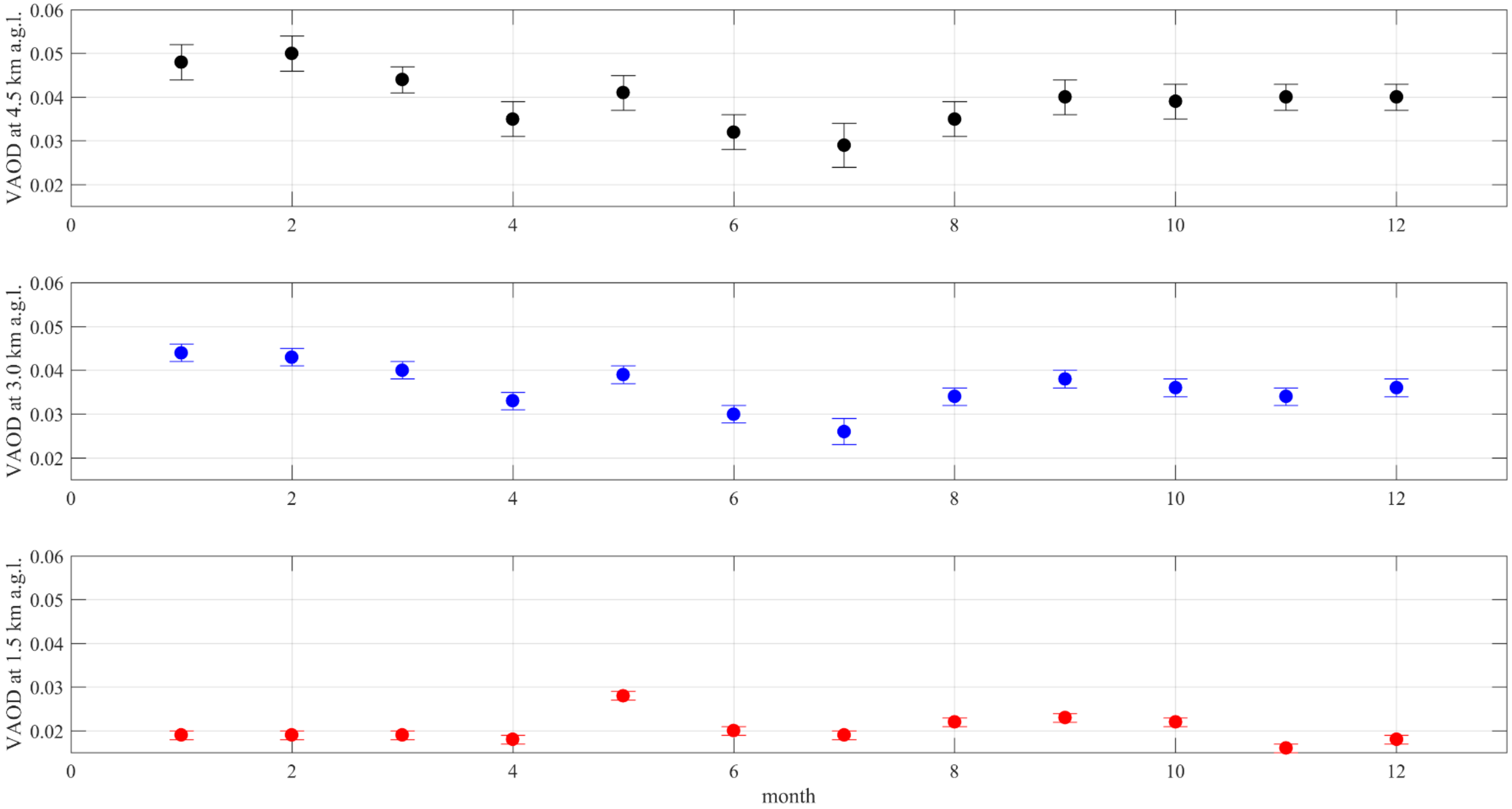
Monthly mean profiles - VAOD

Science



all NOV2013-DEC2017

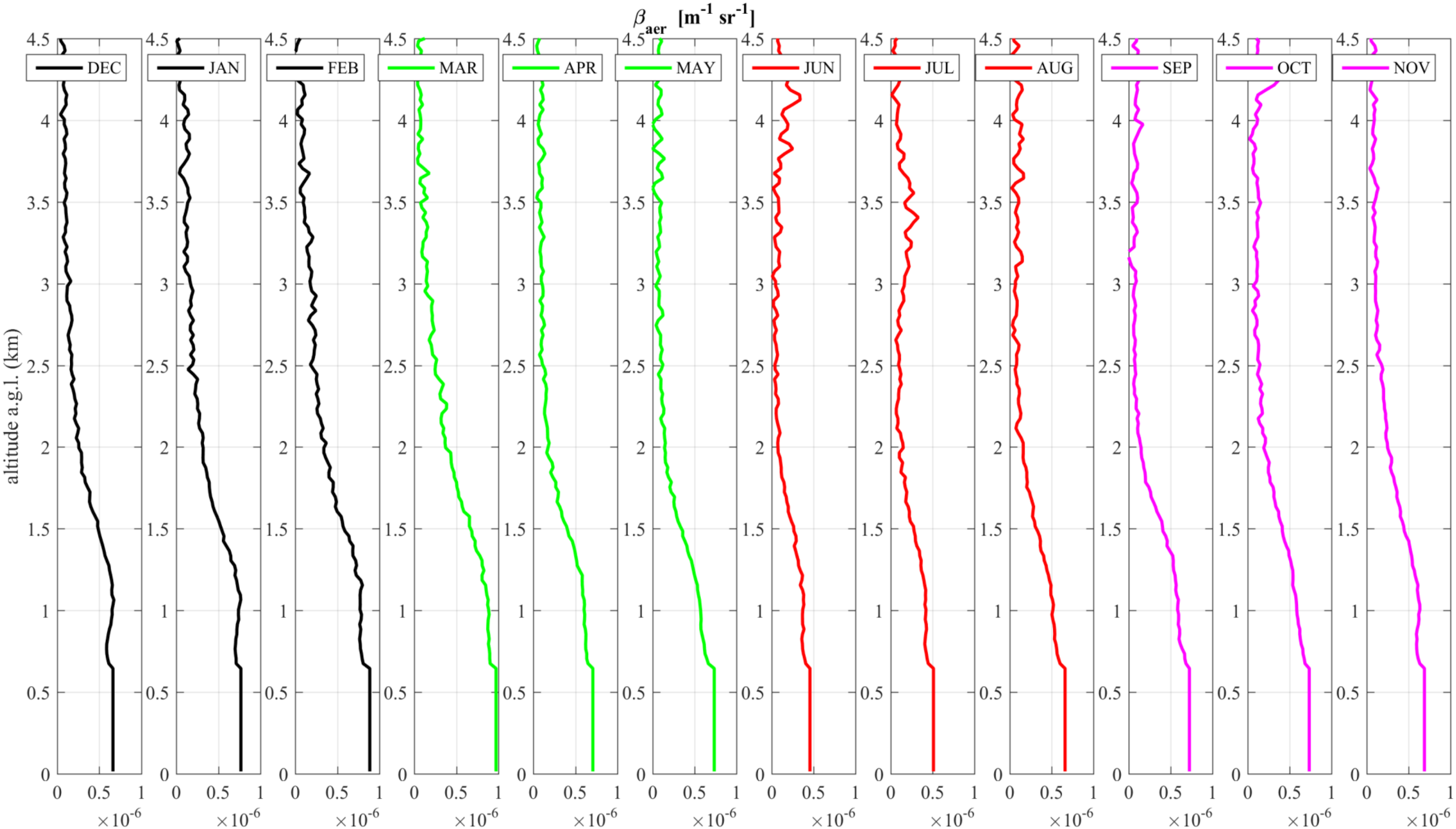
Monthly mean values – VAOD values



Science

all NOV2013-DEC2017

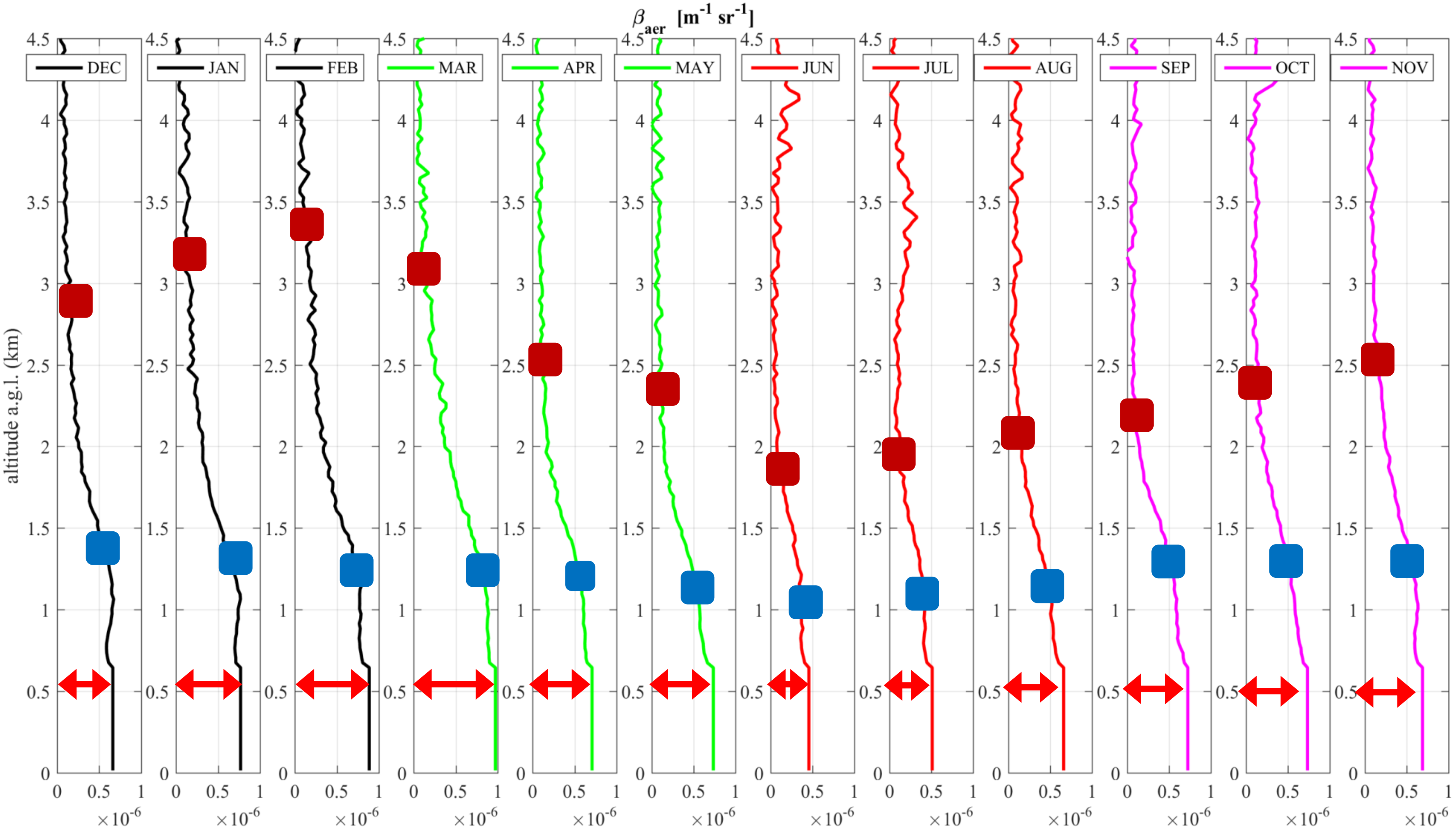
Monthly mean profiles - backscatter



Science

all NOV2013-DEC2017

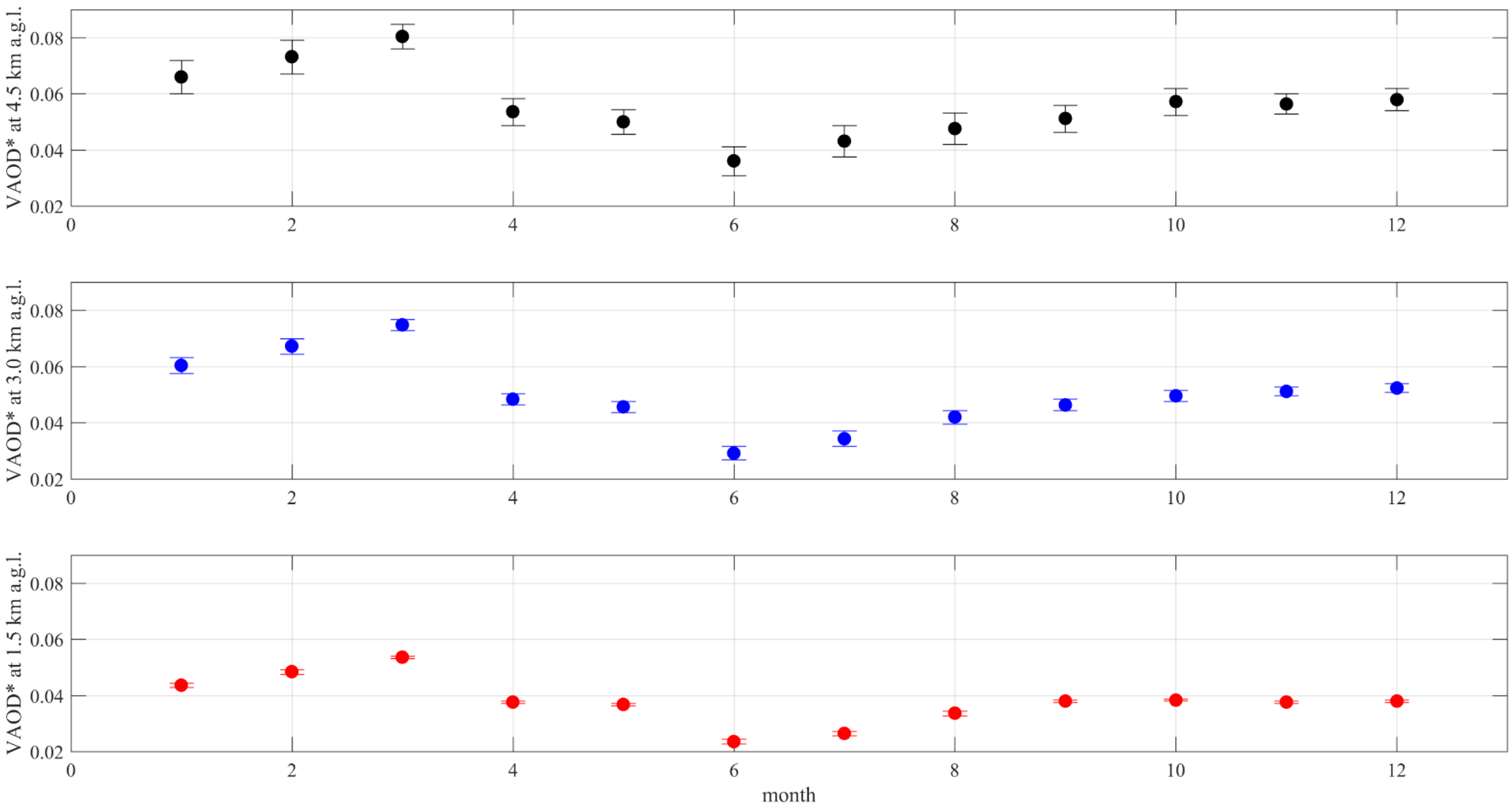
Monthly mean profiles - backscatter



Science

all NOV2013-DEC2017

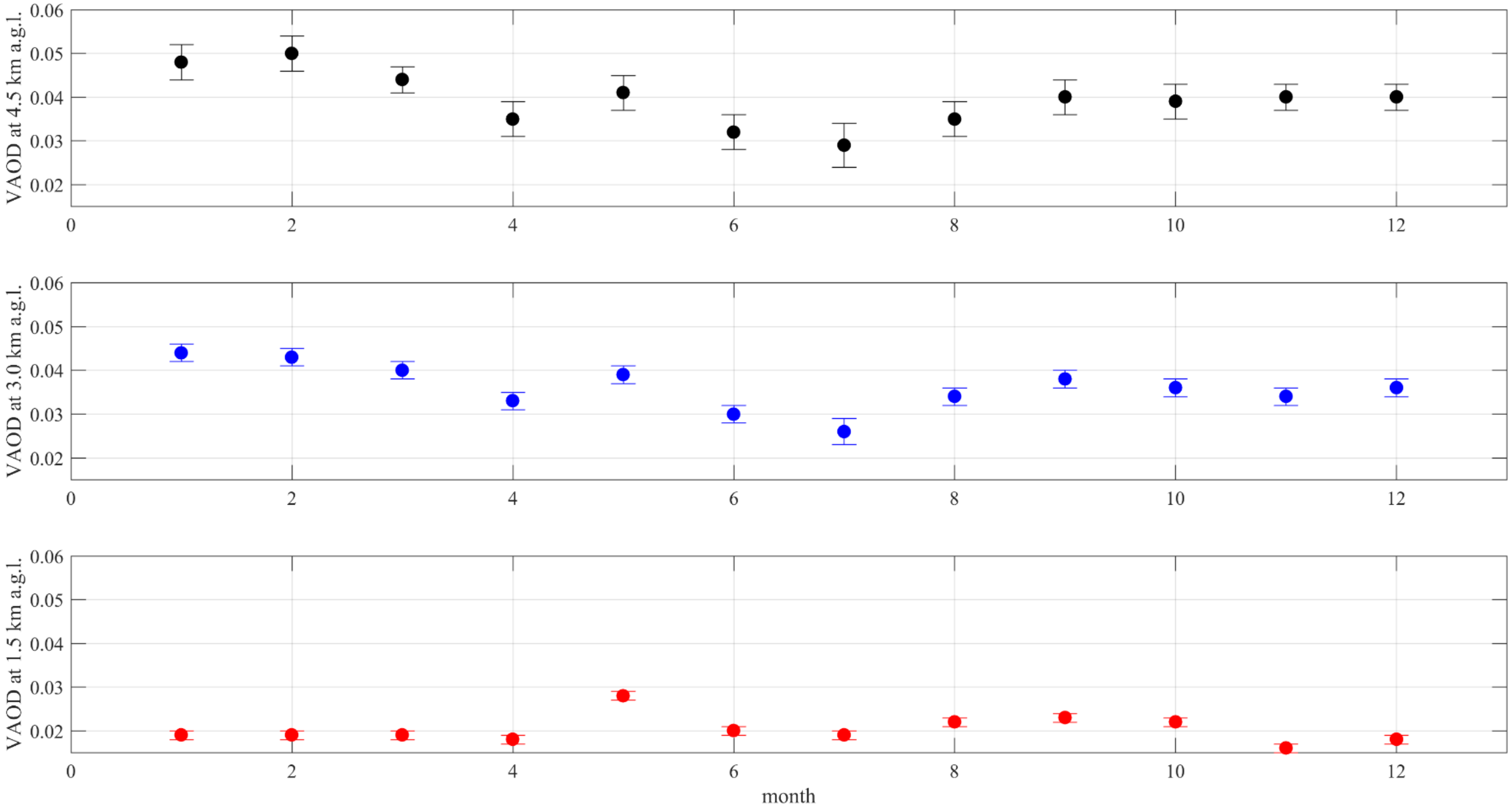
Monthly mean values – VAOD* values Using int. backscsatter x lidar ratio (40 sr)



Science

all NOV2013-DEC2017

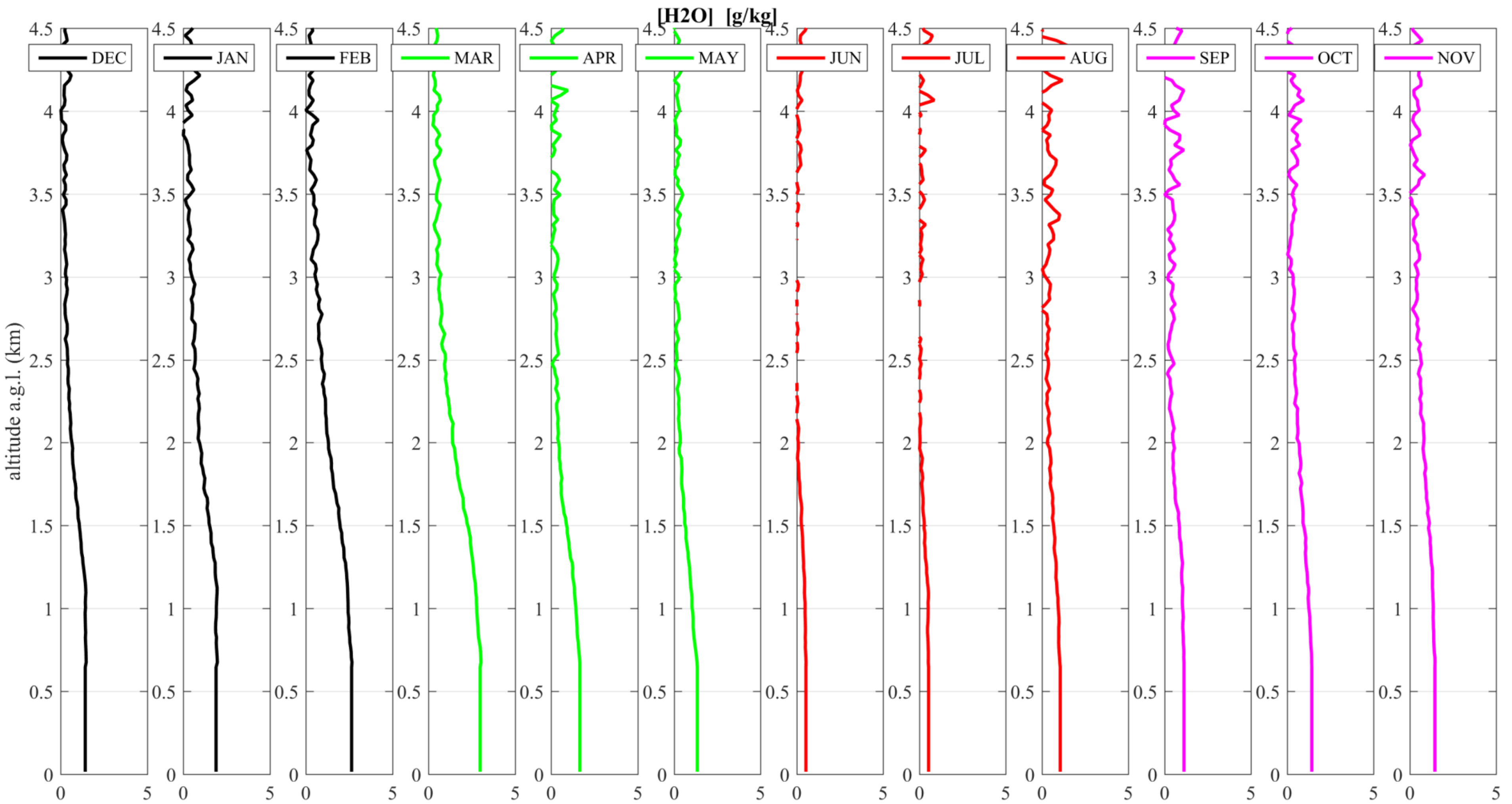
Monthly mean values – VAOD values



Science

<u>**all NOV2013-DEC2017**</u>

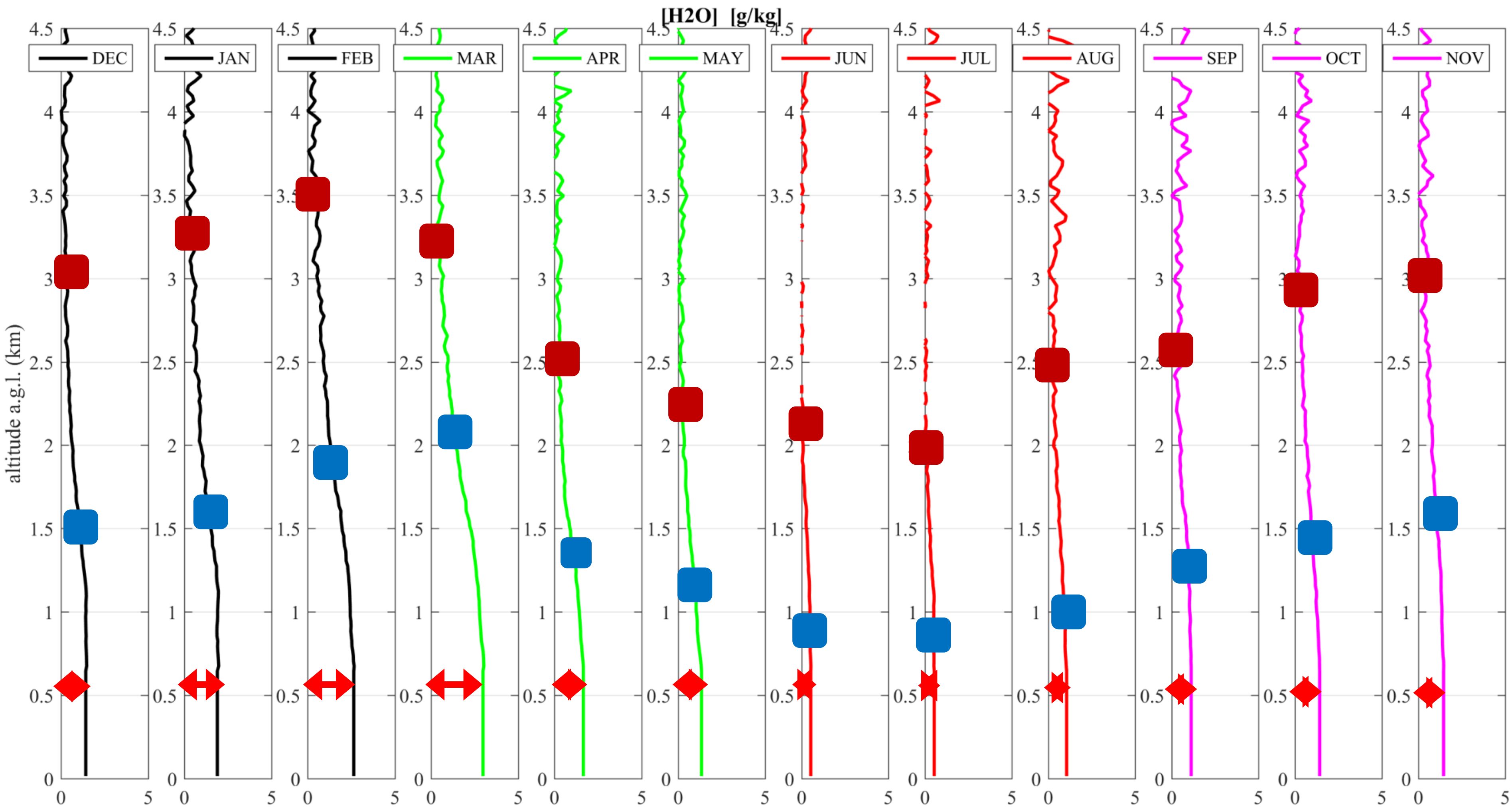
Monthly mean profiles – water vapour



Science

all NOV2013-DEC2017

Monthly mean profiles – water vapour



Science

all NOV2013-DEC2017

Considerations & SUMMARY

The AUGER RL can continue to run in the present mode, its impact on FD data taking seems negligible.

Other strategies of measurements can easily implemented.

Improvements in RL optics

Laser lifetime

Considerations & SUMMARY

RL VAOD database

gpstime
max_quota_db
min_quota_cloud
altitude (a.s.l.)
alfa
alfa_min_uncorrelated
alfa_max_uncorrelated
alfa_min_correlated
alfa_max_correlated
vaod
vaod_min_uncorr
vaod_max_uncorr
vaod_min_corr
vaod_max_corr

data at a resolution of 200 m, up to **max_quota_db**.
alfa = aerosol extinction coefficient
correlated = systematic
uncorrelated = statistical

Considerations & SUMMARY

- RL is measuring the aerosol optical properties at 355 nm since November 2013;

- the RL data analysis is documented and reproducible;

- the shape of the measured vertical profiles of the aerosol backscatter and extinction suggest a simple model of the aerosol vertical distribution;

- the measured vertical profiles of the aerosol backscatter and extinction show, as expected, a seasonal dependence;

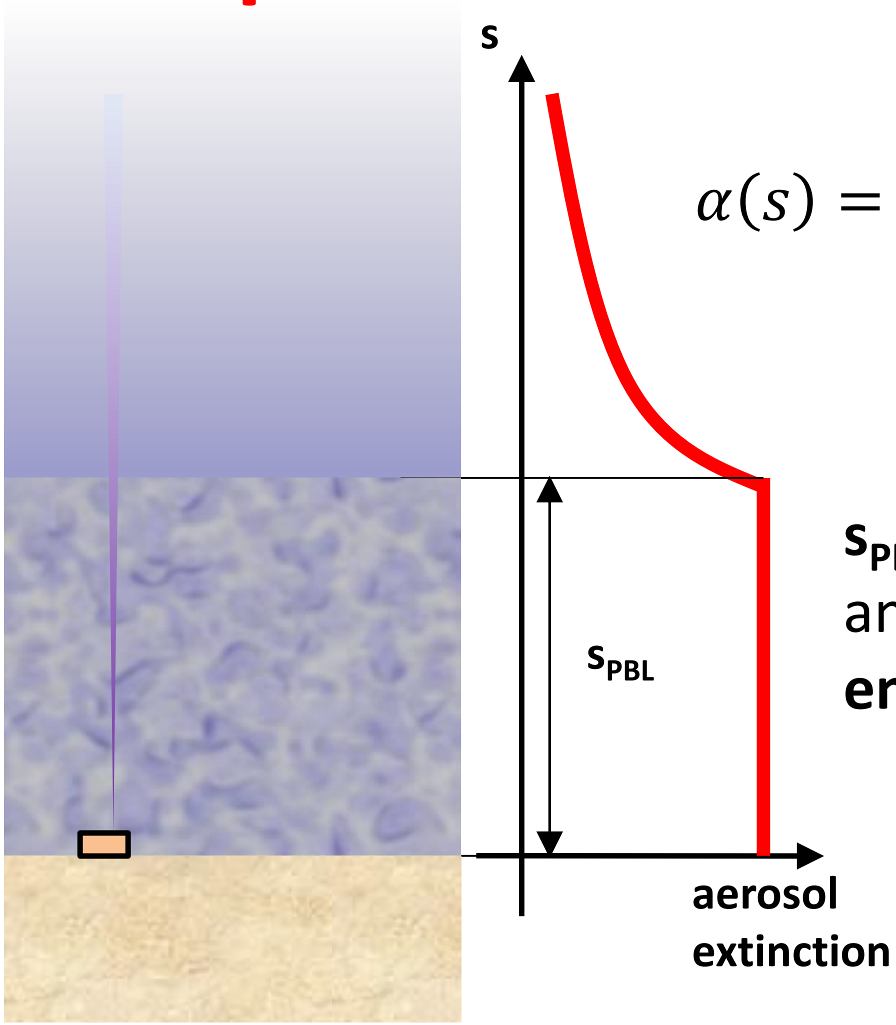
- the database of the raw RL signals, and RL vertical profiles of the aerosol backscatter, VAOD, (and water vapour) will be made available with all the documentations and analysis programs;

- maybe it is time for a paper describing RL data;

- […] comparison with other techniques;

BACKUP slides #1

3 parameters aerosol model

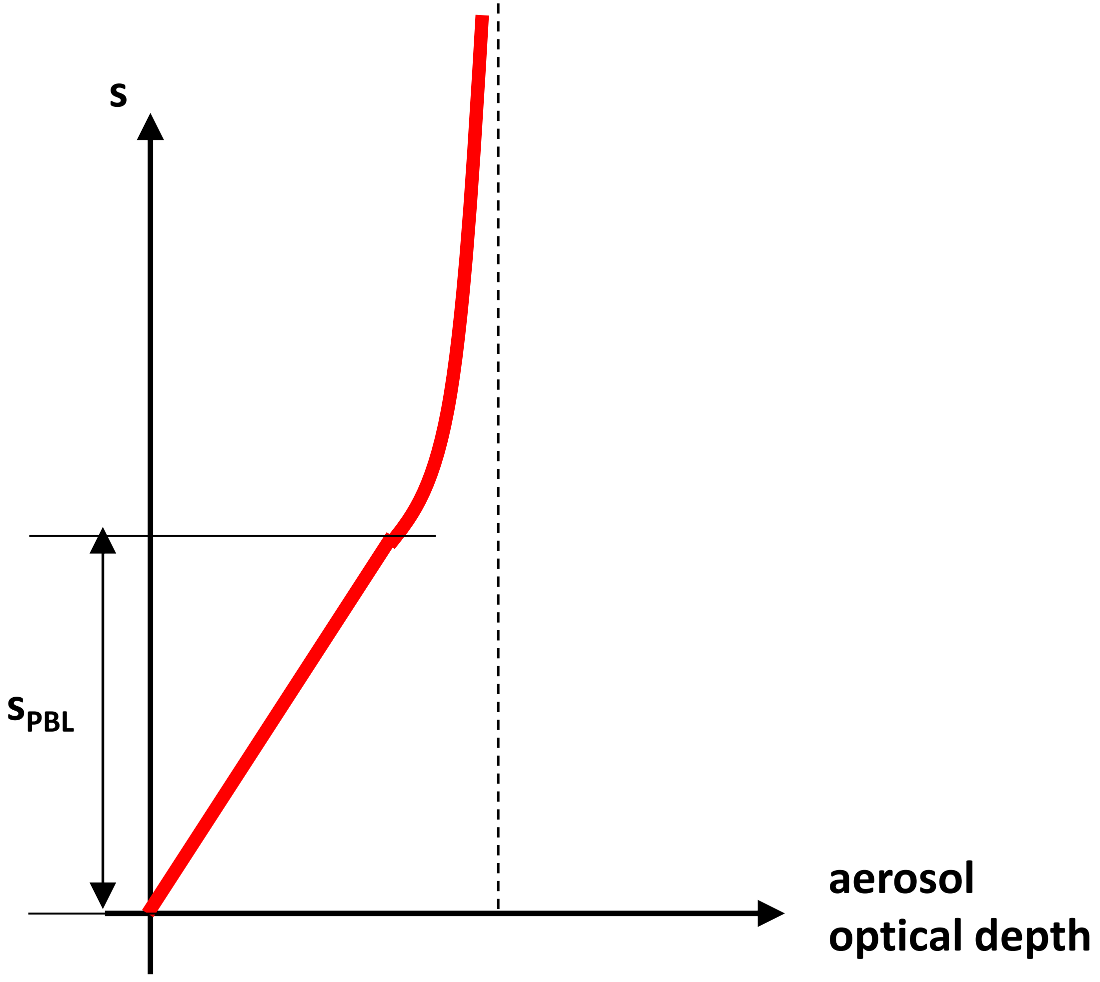


$$\alpha(s) = \begin{cases} \alpha_o & s \leq s_{PBL} \\ \alpha_o \cdot e^{-\left(\frac{s - s_{PBL}}{h}\right)} & s \geq s_{PBL} \end{cases}$$

s_{PBL} and ***h*** depict the **PBL height**, and an estimation of the **entrainment zone** thickness.

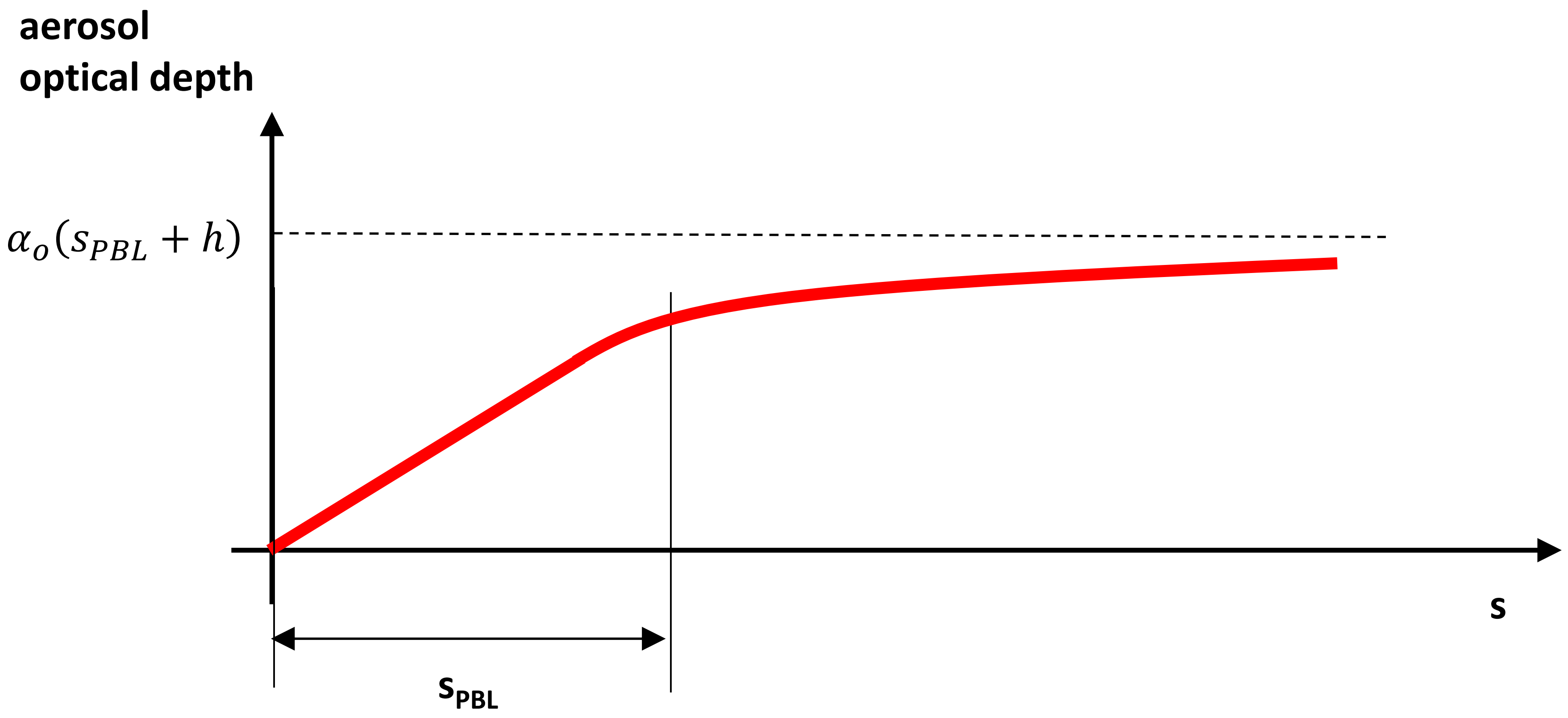
3 parameters aerosol model

$$\tau(s) = \begin{cases} \alpha_o s & s \leq s_{PBL} \\ \alpha_o (s_{PBL} + h) - \alpha_o h \cdot e^{-\left(\frac{s - s_{PBL}}{h}\right)} & s \geq s_{PBL} \end{cases}$$



3 parameters aerosol model

$$\tau(s) = \begin{cases} \alpha_o s & s \le s_{PBL} \\ \alpha_o (s_{PBL} + h) - \alpha_o h \cdot e^{-\left(\frac{s - s_{PBL}}{h}\right)} & s \ge s_{PBL} \end{cases}$$



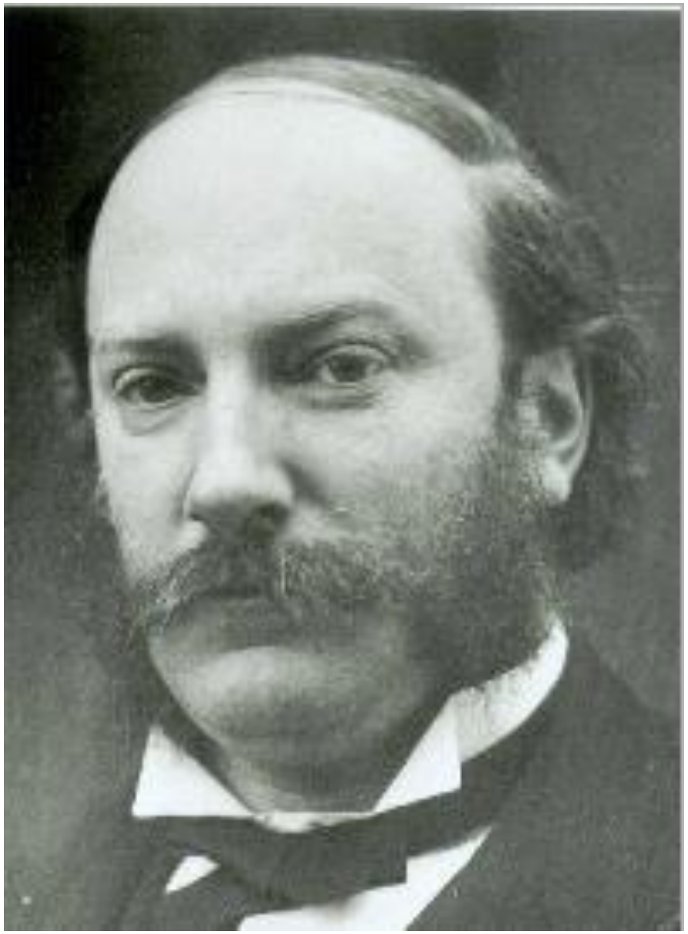
BACKUP slides #2

Raman LIDAR sensitivity

Raman LIDAR sensitivity:
minimum measurable VAOD at 355 nm
~ 0.005

Raman LIDAR sensitivity

Rayleigh night is the night without aerosols!

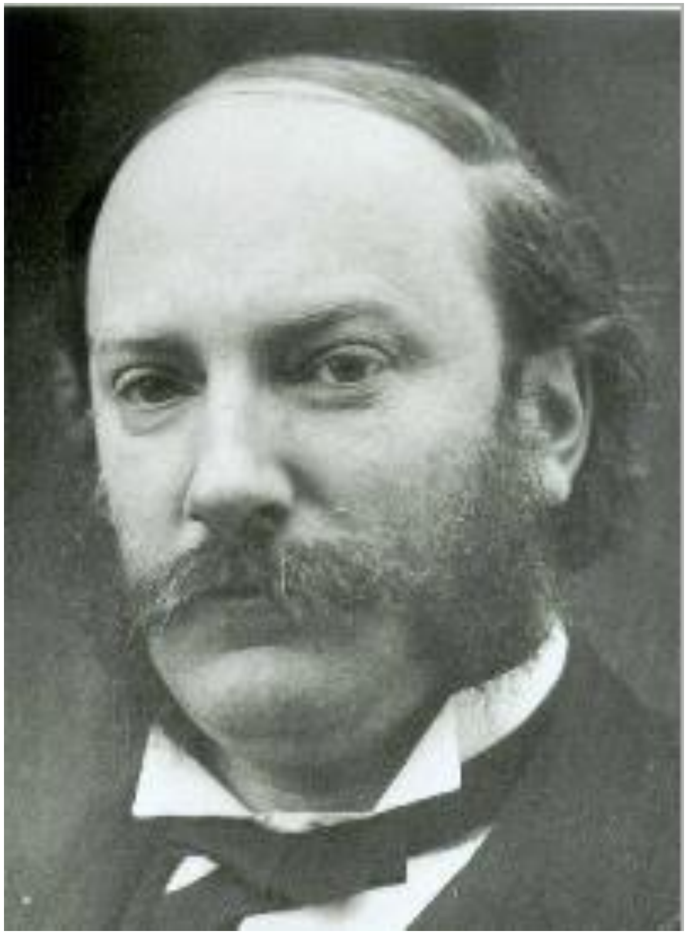


Lord Rayleigh

Raman LIDAR sensitivity

VAOD ~ 0.005

T = exp(-VAOD)

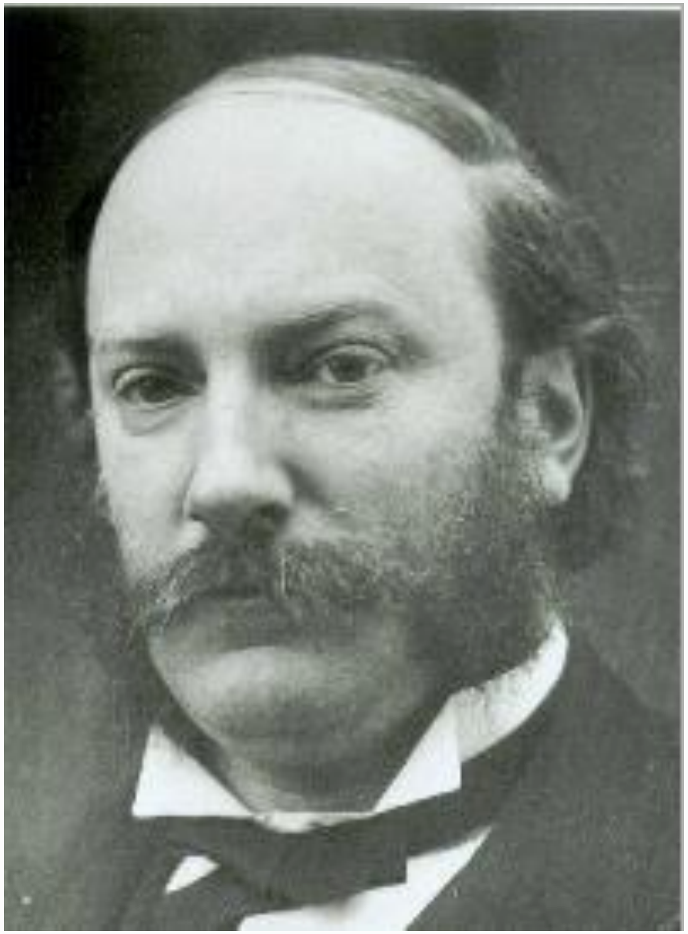


Lord Rayleigh

Raman LIDAR sensitivity

VAOD ~ 0.01

T = exp(-VAOD)

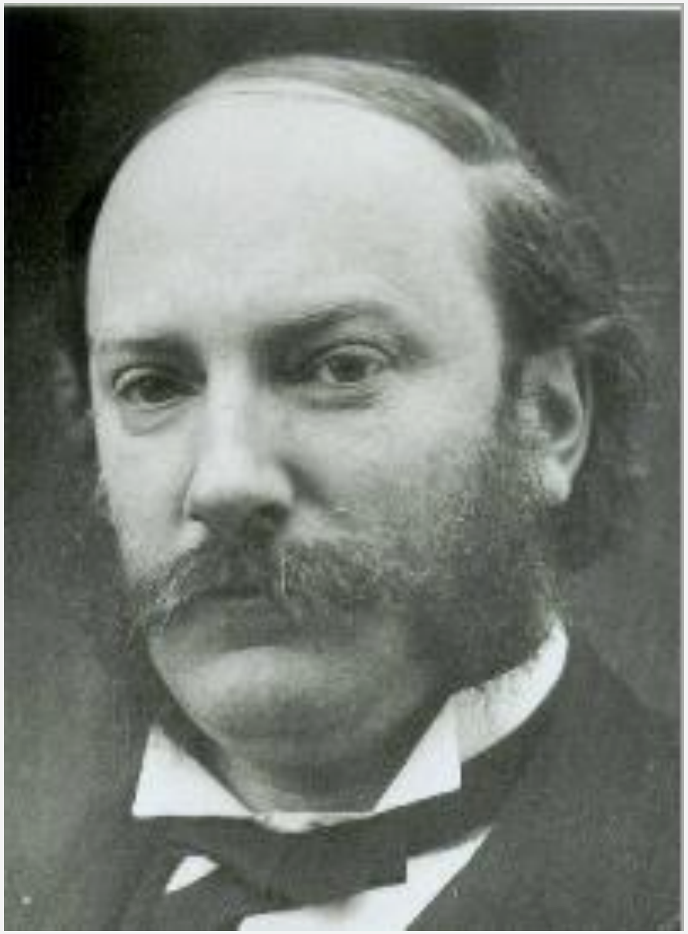


Lord Rayleigh

Raman LIDAR sensitivity

VAOD ~ 0.05

T = exp(-VAOD)

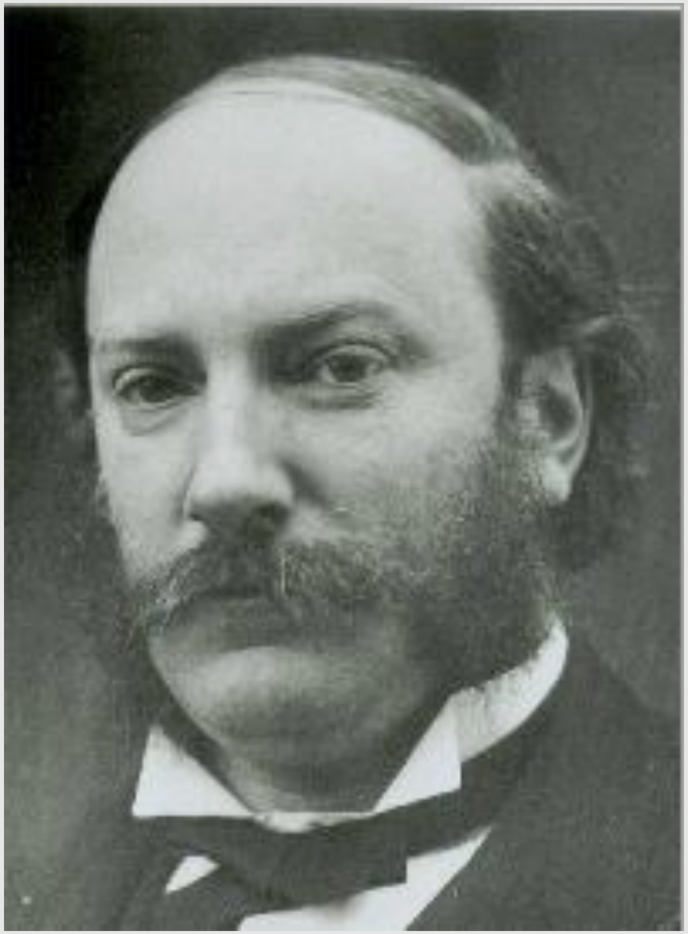


Lord Rayleigh

Raman LIDAR sensitivity

VAOD ~ 0.1

T = exp(-VAOD)



Lord Rayleigh

Raman LIDAR sensitivity

VAOD ~ 0.2

T = exp(-VAOD)

Lord Rayleigh

Raman LIDAR sensitivity

VAOD ~ 0.5

T = exp(-VAOD)

Lord Rayleigh

BACKUP slides #3

Raman LIDAR
Vertical Aerosol Optical Depth $\tau_{aer}(s)$ sources of errors

constant

range scale

N_2 Raman backscatter

$$\tau_{aer}(s) = -\frac{log\left(\frac{C \cdot s^2 L_R(s)}{T_{mol}(s) \cdot T_{mol}^R(s) \cdot n_{mol}(s)}\right)}{1 + \left(\frac{\lambda_o}{\lambda_R}\right)^k}$$

optical properties of molecular atmosphere

Angstrom exponent

RANDOM/STATISTICAL

SYSTEMATIC

ALL HAVE BEEN ESTIMATED

Raman LIDAR
Vertical Aerosol Optical Depth $\tau_{aer}(s)$
estimations of the errors

12 min standard acquisition: $N_{laser}\ shots \sim 24000;\ \Delta t_{bin} = 200\ ns$

RANDOM/STATISTICAL

$$\Delta\boldsymbol{\tau}_{\boldsymbol{aer}}(\boldsymbol{s})\Big|_{\boldsymbol{L}_{\boldsymbol{R}}(\boldsymbol{s})} \leq \pm\, 0.01\ (s\ \leq 3\ km)$$

$$\Delta\boldsymbol{\tau}_{\boldsymbol{aer}}(\boldsymbol{s})\Big|_{\boldsymbol{B}} \leq \pm\, 0.003\ (s\ \leq 3\ km)$$

$$\Delta\boldsymbol{\tau}_{\boldsymbol{aer}}(\boldsymbol{s})\Big|_{\boldsymbol{calib}} \leq \pm\, 0.004$$

Raman LIDAR
Vertical Aerosol Optical Depth $\tau_{aer}(s)$

estimations of the errors

12 min standard acquisition: $N_{laser}\ shots \sim 24000;\ \Delta t_{bin} = 200\ ns$

IMPORTANT SYSTEMATICS

t_o is the delay between the reference trigger pulse and the output of laser pulse.

$\Delta\tau_{aer}(s)|_{t_o}$ *it can be important. It has been measured. To be checked periodically;*

(laser output jitter) $\Delta\tau_{aer}(s)|_{t_o} \leq \pm 0.001$

Assuming that GDAS is representing well the atmosphere over PAO.
The seasonal and hour to hour variations of the molecular number density is generally larger than its indetermination. We are ready to use the GDAS hourly profiles.

$$\Delta\tau_{aer}(s)\Big|_{mol} \leq \pm 0.005$$

Raman LIDAR

Vertical Aerosol Optical Depth $\boldsymbol{\tau_{aer}(s)}$

estimations of the errors

12 min standard acquisition: $N_{laser}\ shots \sim 24000;\ \Delta t_{bin} = 200\ ns$

$$\Delta\boldsymbol{\tau_{aer}(s)}\Big|_{\boldsymbol{L_R(s)}} \leq \pm\, 0.01\ (s\ \leq 3\ km)$$

$$\Delta\boldsymbol{\tau_{aer}(s)}\Big|_{\boldsymbol{B}} \leq \pm\, 0.003\ (s\ \leq 3\ km)$$

$$\Delta\boldsymbol{\tau_{aer}(s)}\Big|_{\boldsymbol{calib}} \leq \pm\, 0.004$$

$$\Delta\tau_{aer}(s)\Big|_{t_o} \leq \pm 0.001$$

$$\Delta\tau_{aer}(s)\Big|_{k} \leq \pm\, 0.02 \cdot \tau_{aer}(s)$$

$$\Delta\tau_{aer}(s)\Big|_{mol} \leq \pm 0.005$$

$$\Delta\boldsymbol{\tau_{aer}(s)}\Big|_{\boldsymbol{tot}} \leq \pm\, \mathbf{0.012}$$

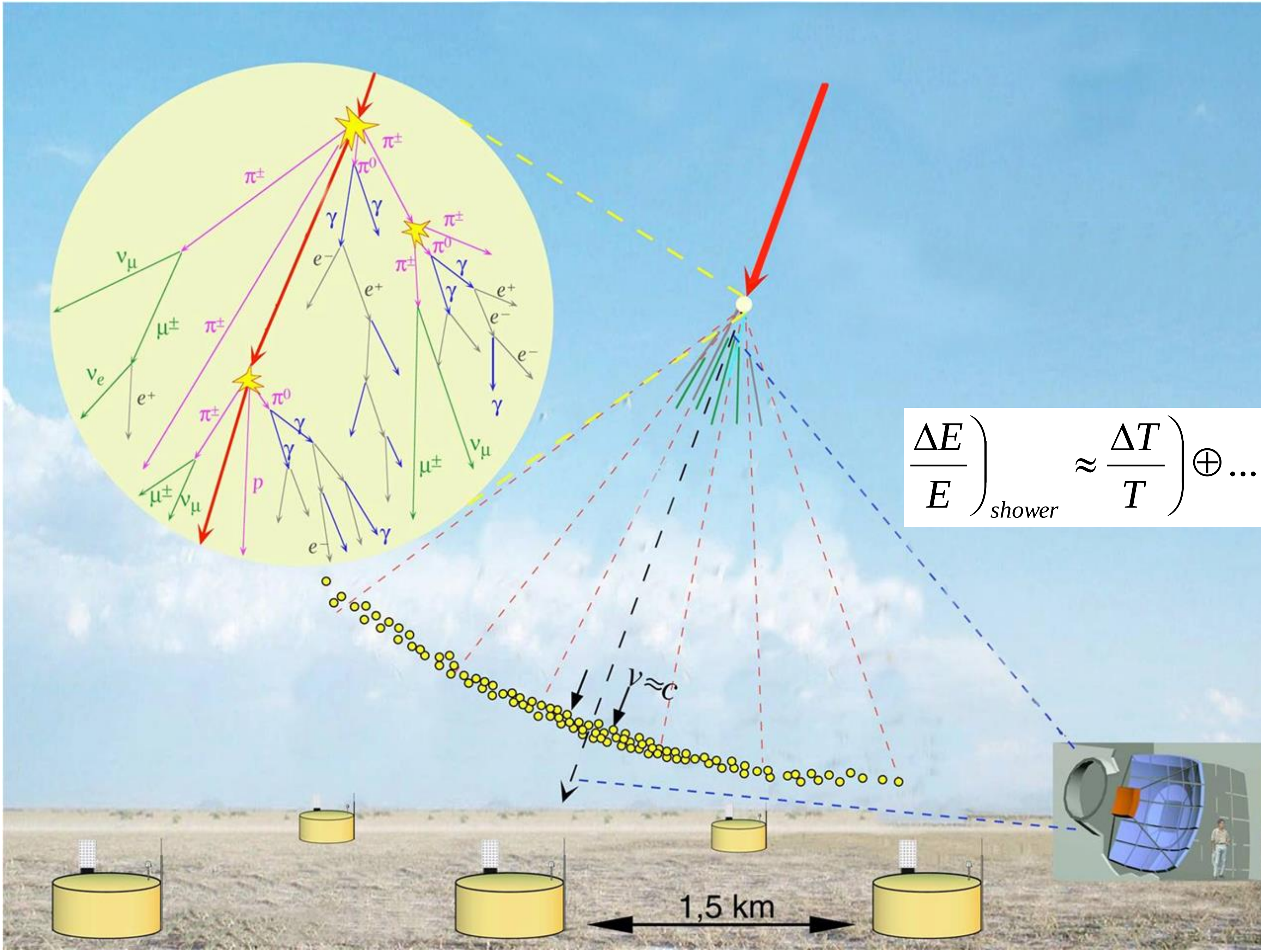
bin to bin

$s\ \leq 3\ km$

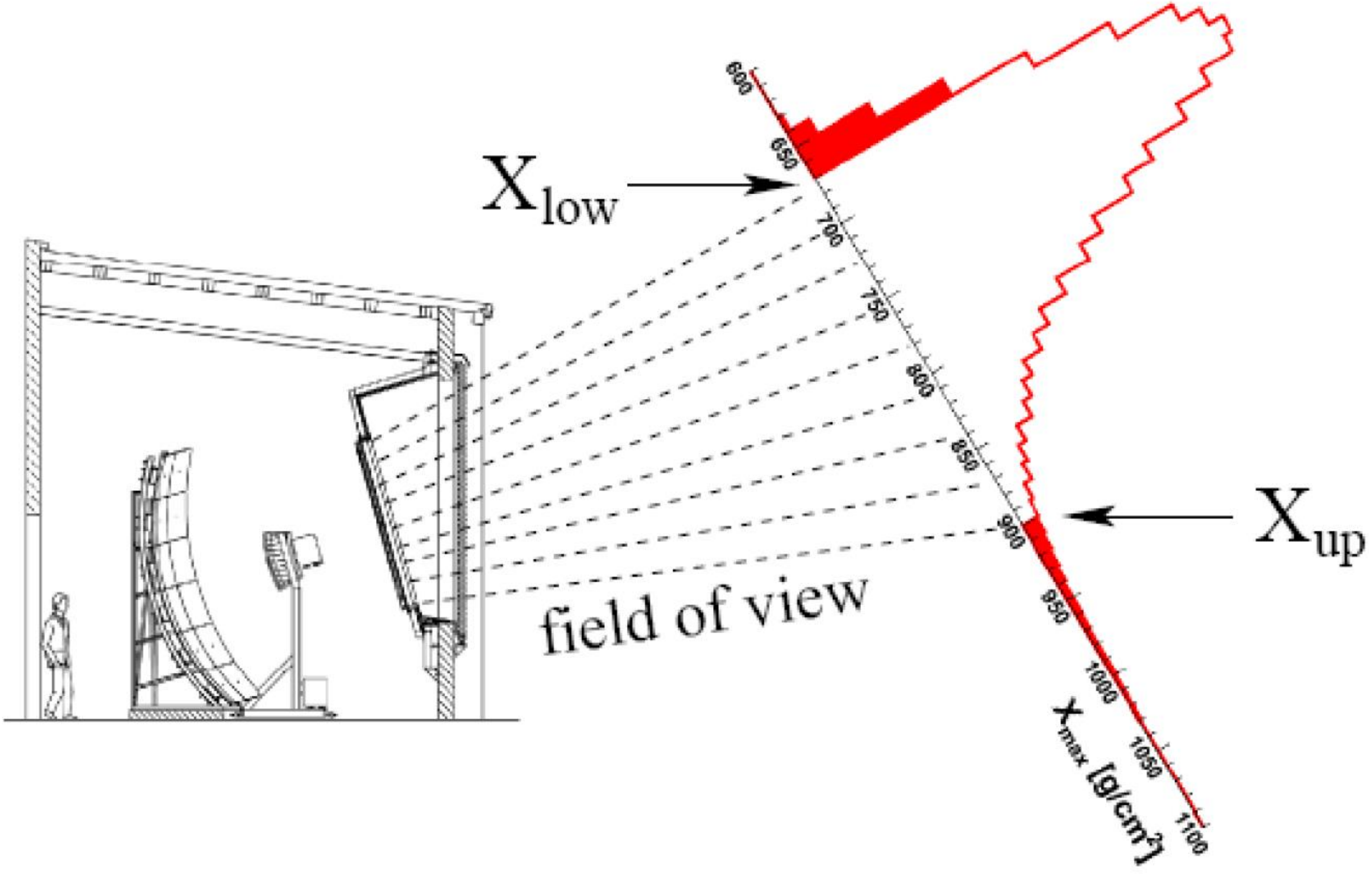
$\tau_{aer}(s) \sim 0.05$

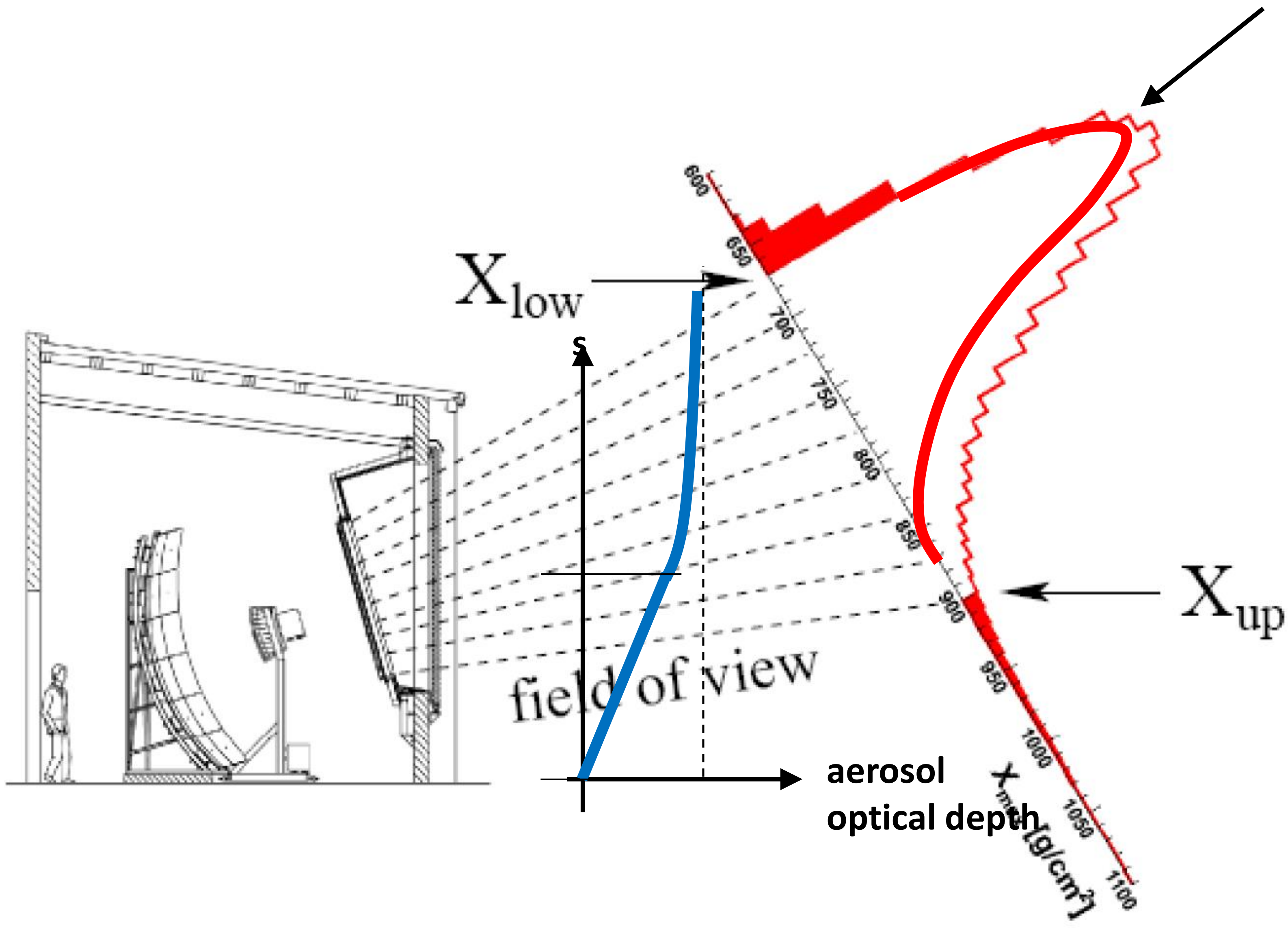
It can be lower if a model of VAOD is fitted to the data.

BACKUP slides #4

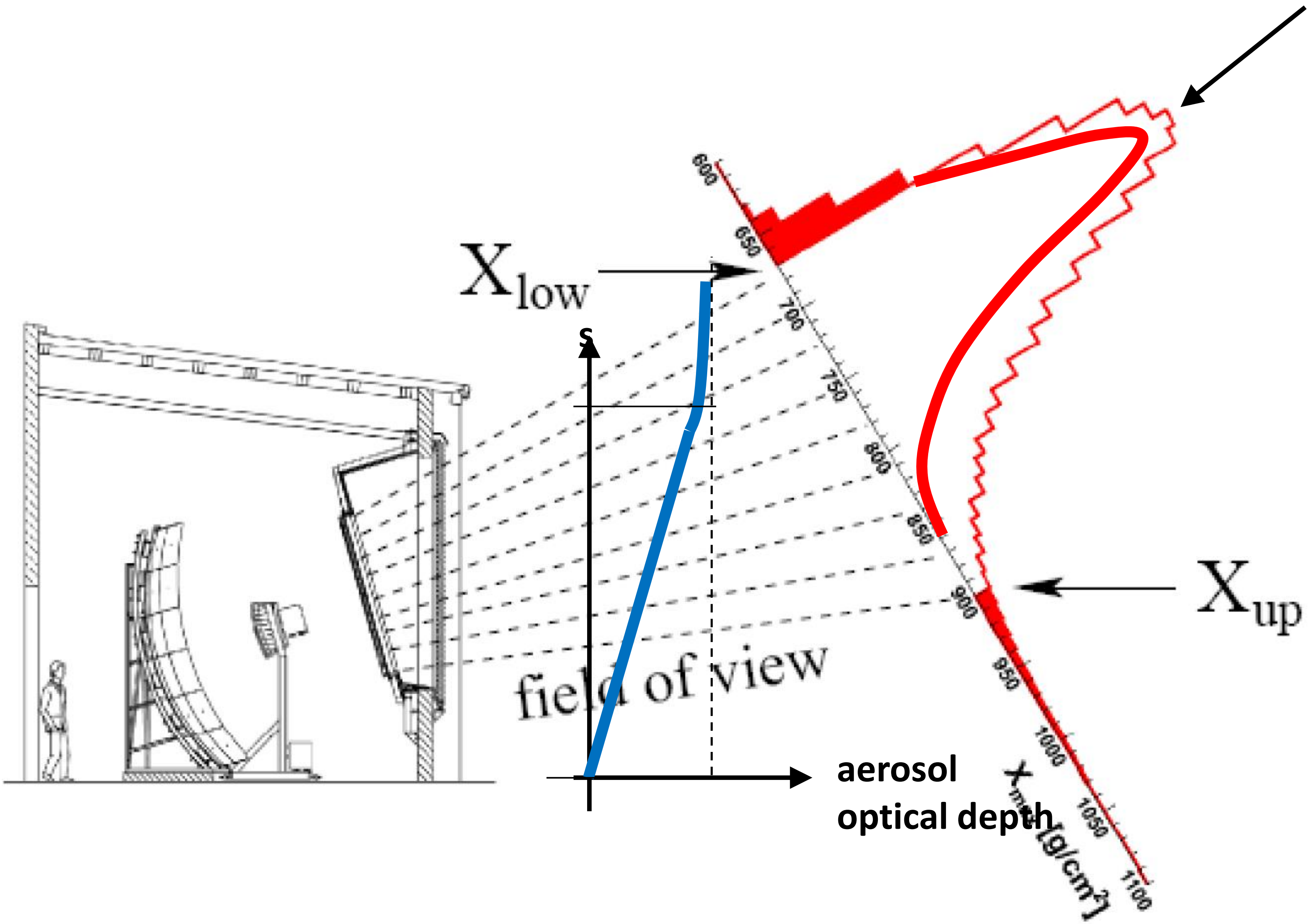


$$\left.\frac{\Delta E}{E}\right)_{shower} \approx \left.\frac{\Delta T}{T}\right) \oplus \ldots$$


X_low
X_up
field of view
600
650
700
750
800
850
900
950
1000
1050
1100
X_max [g/cm²]



X_low
s
field of view
aerosol
optical depth
X_up
600
650
700
750
800
850
900
950
1000
1050
1100
X_max [g/cm²]



X_low
X_up
s
field of view
aerosol
optical depth
X_max [g/cm^2]
600
650
700
750
800
850
900
950
1000
1050
1100