Consiglio Nazionale delle Ricerche

The Single Calculus Chain of EARLINET for the automatic processing of aerosol lidar data: an overview

Giuseppe D'Amico
giuseppe.damico@imaa.cnr.it

GRUAN – ICM7 26th February 2015

Outline

- Background
  - EARLINET-ASOS
  - ACTRIS
- SCC description
  - Goal
  - Structure
  - Aerosol products (extinction, backscatter)
- New products implementation
  - Particle linear depolarization ratio
  - Automatic aerosol layer detection
  - Cloud mask

Background

✓ Since 2000

✓ 27 lidar stations

✓ Not homogeneous lidar systems

- Single backscatter lidars
- Raman lidars
- Multi-wavelength Raman lidars
- Single and multiple telescope lidars
- Different analog and/or photoncounting acquisition systems
- Lidars operating with scanning capabilities

Different instruments require different way of data processing: system dependent corrections should be applied before to retrieve the aerosol optical properties

On the other hand...

Background

The aerosol products, released by a network, should be:

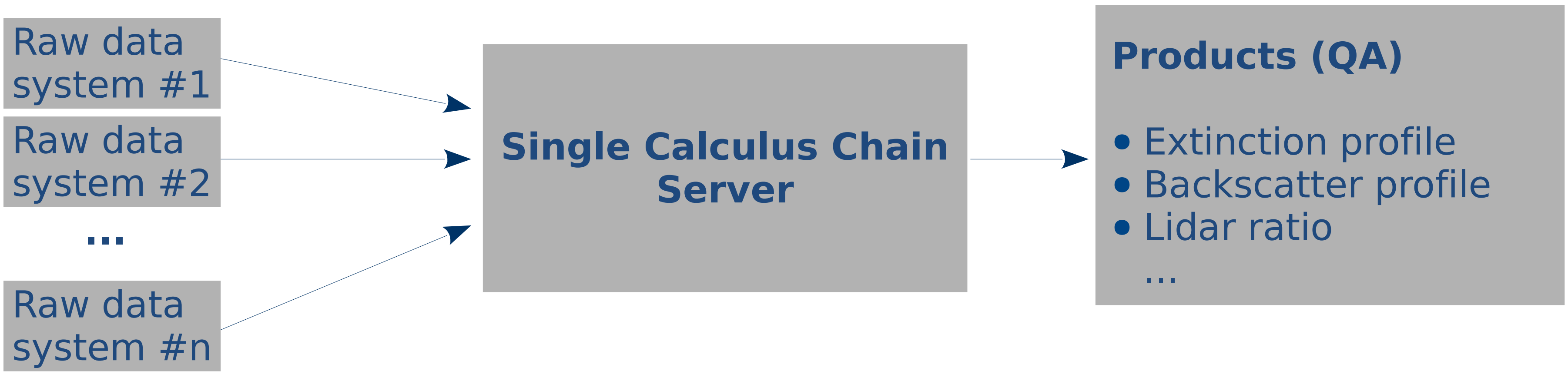
- Homogeneous and standardized along all the network
- High quality certified (instrumentals and algorithms)
- Released in near real time

↓

2006 ↓ 2011	EARLINET-ASOS NA5: Optimization of data processing
2011 ↓ 2015	ACTRIS Task 2.3: Improvement of lidar techniques and data analysis for aerosol characterization

The main objective is the implementation of a Single Calculus Chain (SCC) to meet all the above requirements at network level

SCC



Benefits:

- Provides all the EARLINET partners with the possibility to use a common processing chain for the evaluation of their data, from raw signals to final products
- The algorithms implemented are fully tested and so provide final products that are quality checked from algorithm point of view
- Operates only on the raw signals from lidar systems that have passed all the instrumental quality checks defined within EARLINET
- Operates automatically and so final results could be released in near real time without a large time consuming user activity

SCC server (hosted by CNR-IMAA)

Collects all the input parameters required to retrieve aerosol optical products from lidar signals:

- experimental ones to correct instrumental effects (dead time, trigger delay...)
- configuration ones to define how to calculate a particular product

To each measurement is assigned an unique measurement ID starting from which it is possible to get all the corresponding parameters.

SCC database

SCC server (hosted by CNR-IMAA)

ELPP
Earlinet Lidar PreProcessor

Implements all the corrections to be applied to the raw signals before they can be used to derive optical properties.

According to the specific lidar system different operations can be applied:

- dead-time correction
- trigger-delay correction
- overlap correction
- background subtraction
- automatic gluing
- vertical interpolation
- molecular profile calculation
- time averaging
- statistical uncertainty propagation

SCC database

SCC server (hosted by CNR-IMAA)

ELPP
Earlinet Lidar PreProcessor

ELDA
Earlinet Lidar Data Analyzer

Applies to pre-processed signals the algorithms for the retrievals of aerosol optical parameters.

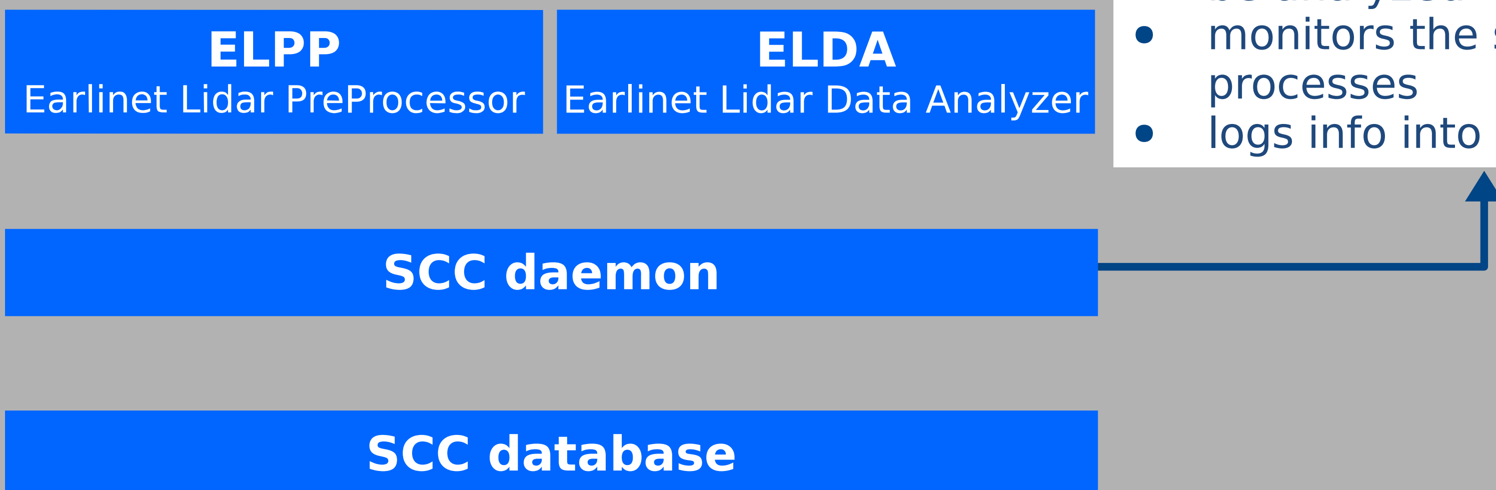
Implemented procedure are:

- elastic backscatter (Klett, iterative)
- extinction profile retrieval
- Raman backscatter retrieval
- automatic vertical-smoothing
- automatic time-averaging

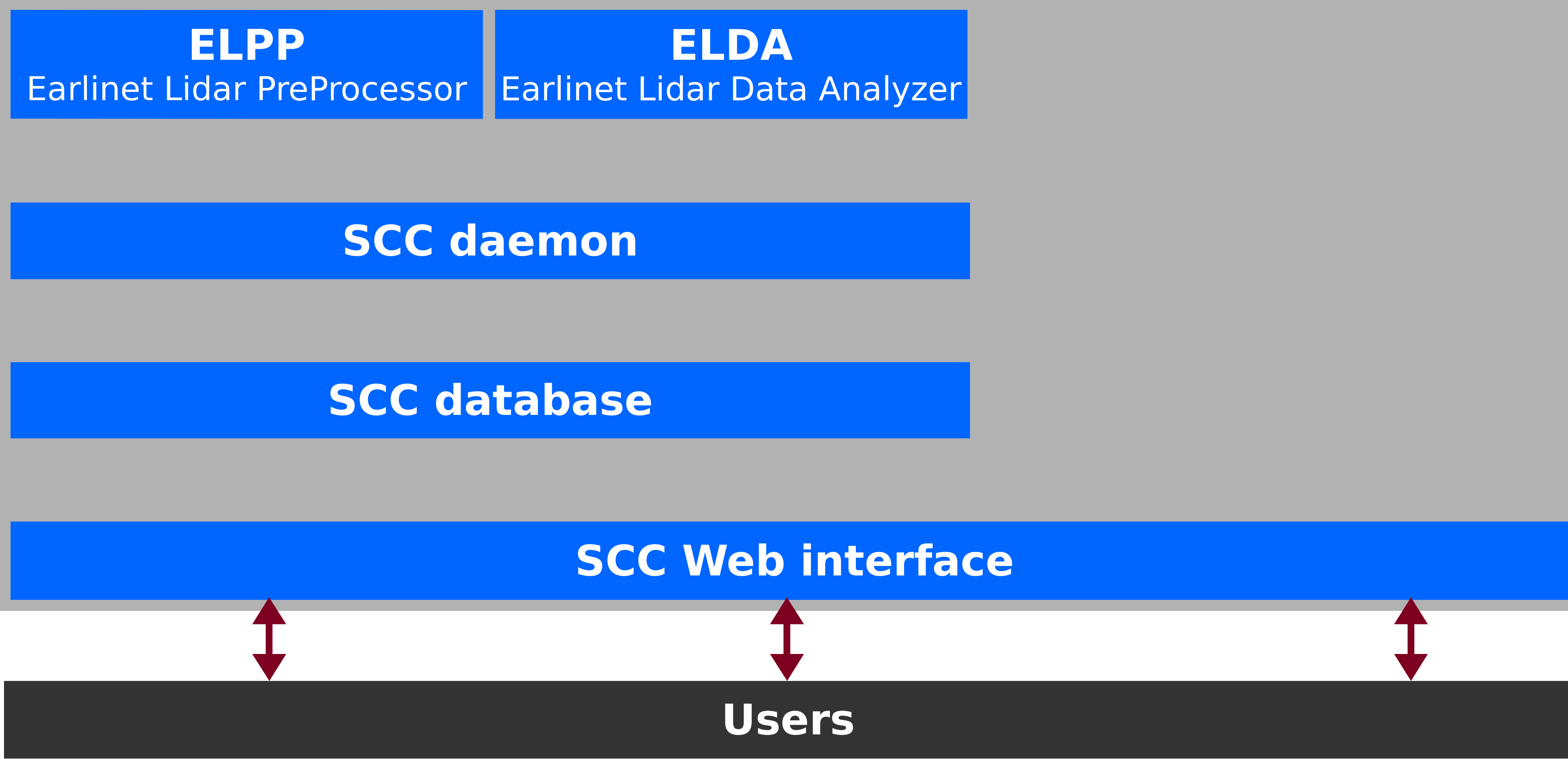
SCC database

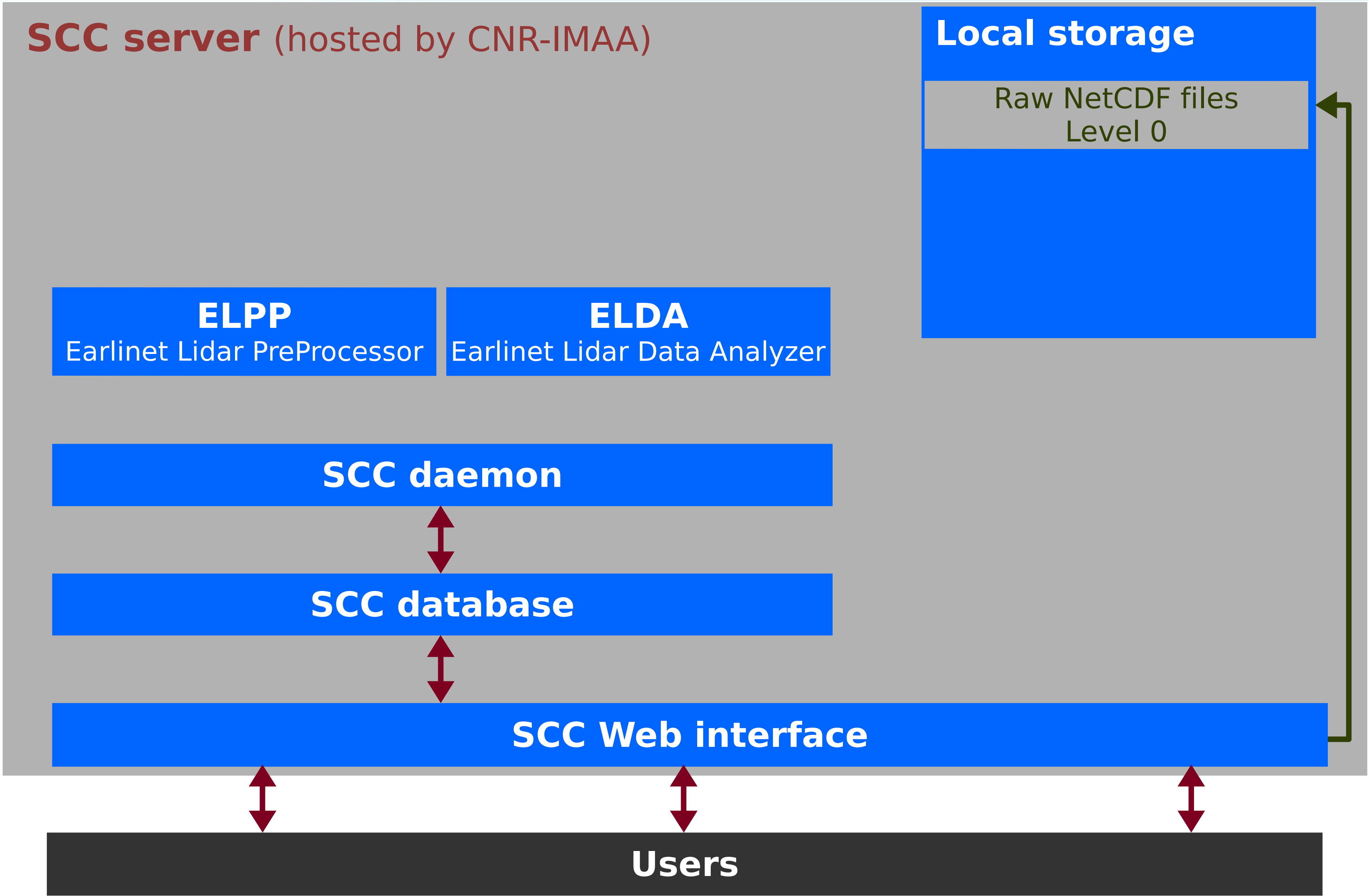
SCC server (hosted by CNR-IMAA)

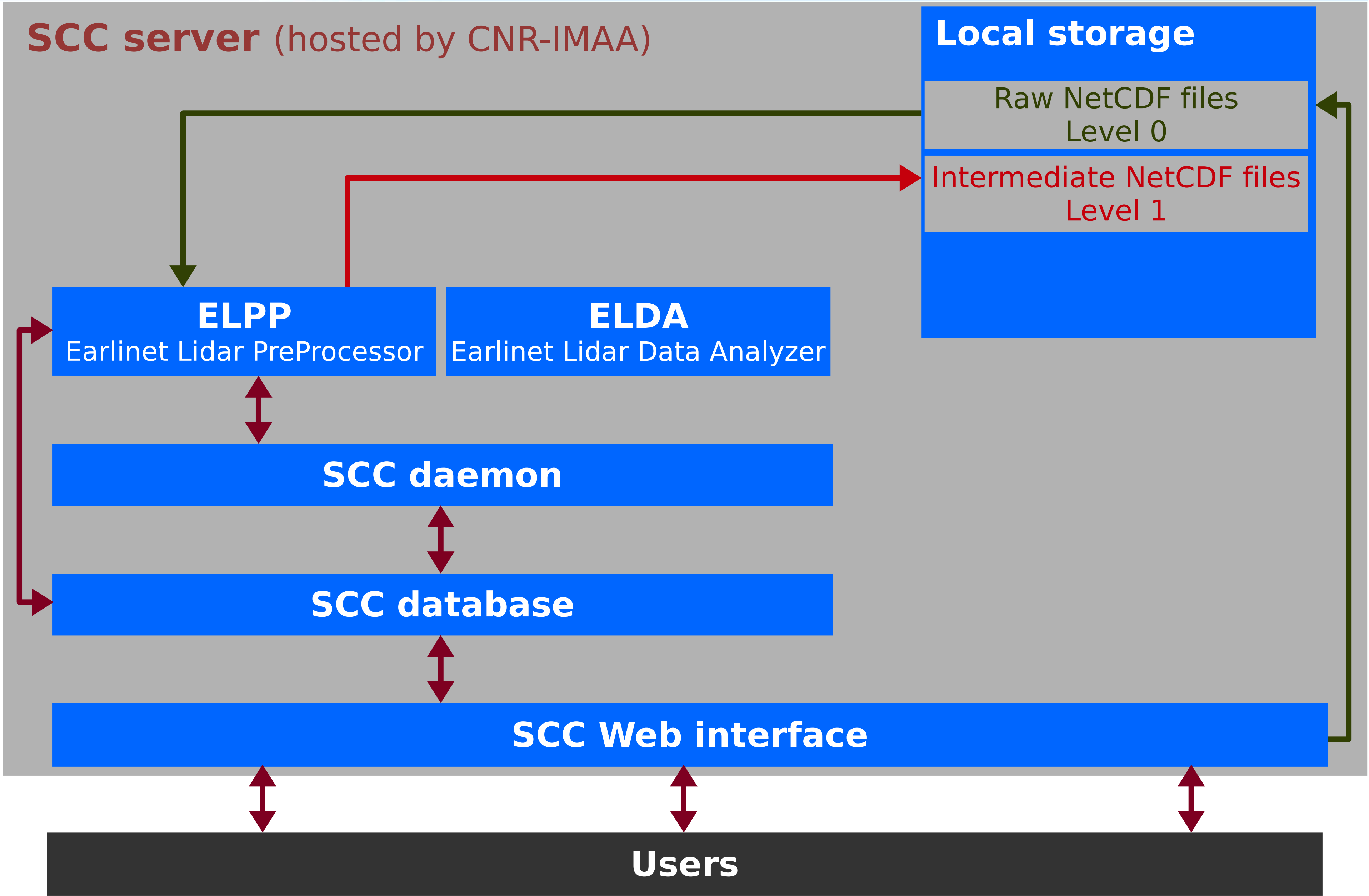
- starts ELPP when there are raw files ready to be pre-processed
- starts ELDA when there are pre-processed files ready to be analyzed
- monitors the started processes
- logs info into database

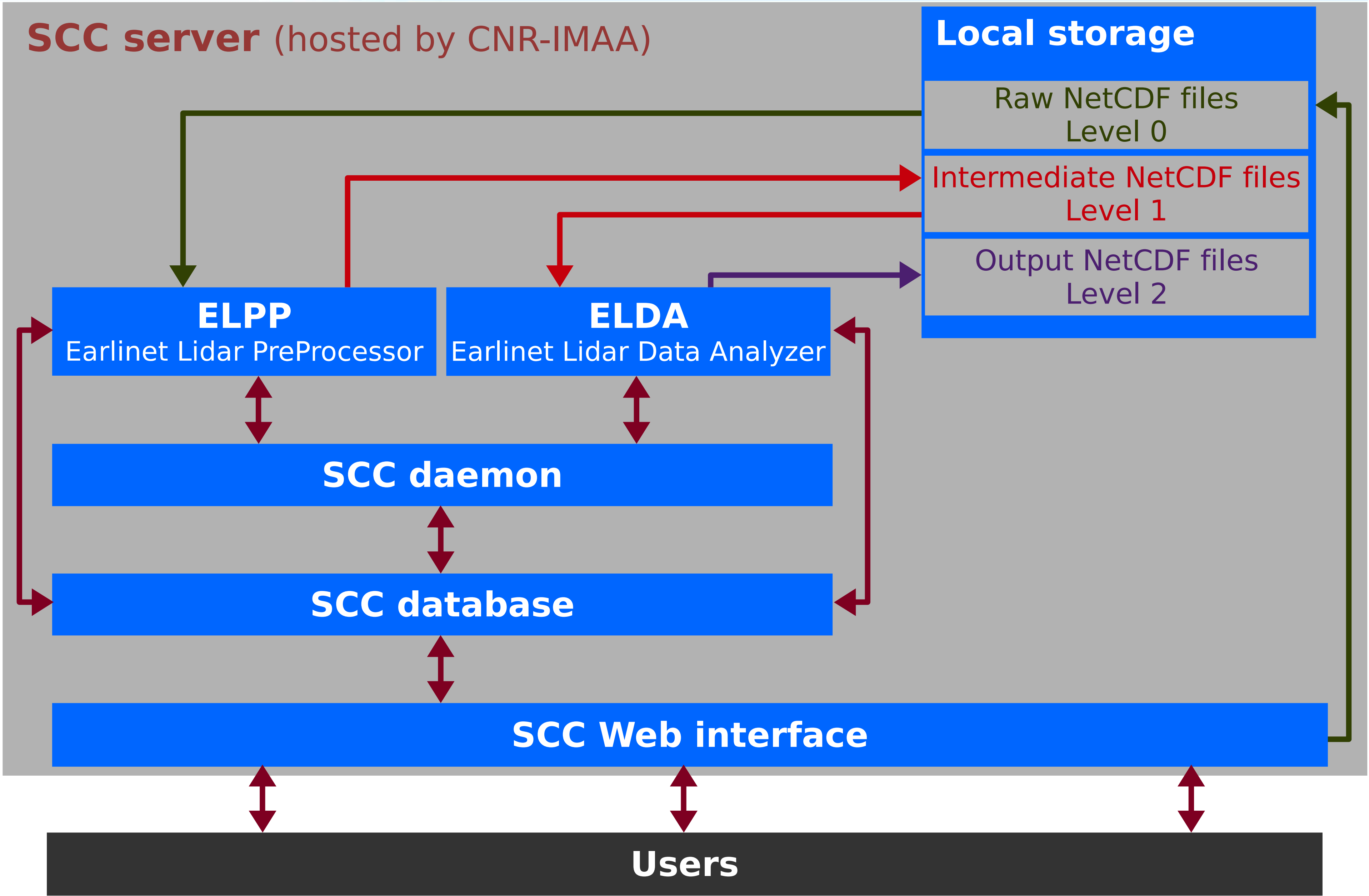


SCC server (hosted by CNR-IMAA)




SCC server (hosted by CNR-IMAA)
Local storage
Raw NetCDF files
Level 0
ELPP
Earlinet Lidar PreProcessor
ELDA
Earlinet Lidar Data Analyzer
SCC daemon
SCC database
SCC Web interface
Users


SCC server (hosted by CNR-IMAA)
Local storage
Raw NetCDF files
Level 0
Intermediate NetCDF files
Level 1
ELPP
Earlinet Lidar PreProcessor
ELDA
Earlinet Lidar Data Analyzer
SCC daemon
SCC database
SCC Web interface
Users


SCC server (hosted by CNR-IMAA)
Local storage
Raw NetCDF files
Level 0
Intermediate NetCDF files
Level 1
Output NetCDF files
Level 2
ELPP
Earlinet Lidar PreProcessor
ELDA
Earlinet Lidar Data Analyzer
SCC daemon
SCC database
SCC Web interface
Users

SCC

The SCC has been developed taking into account:

- Flexibility

  Processing of the raw data measured by all different EARLINET systems.

  Depending on experimental configuration, it can be decided the way in which the lidar data will be processed among a quite large set of pre-defined options (usecases).

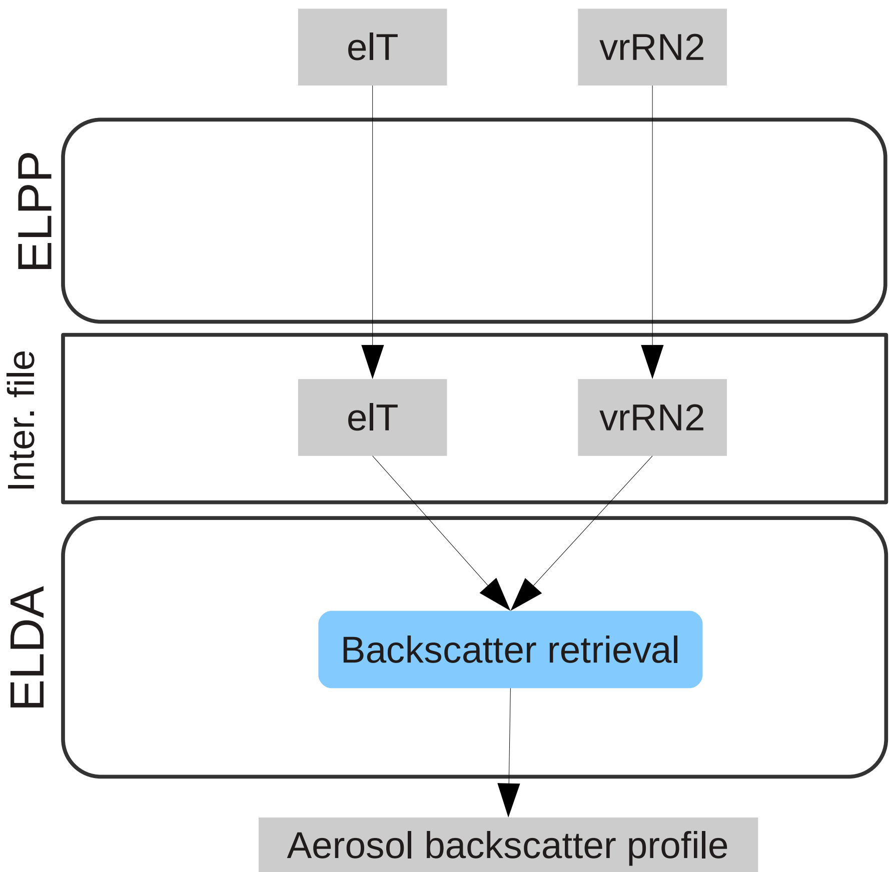
- Expandability

  Relatively easy to add a new usecase for a new lidar system that does not fit with the ones already defined.

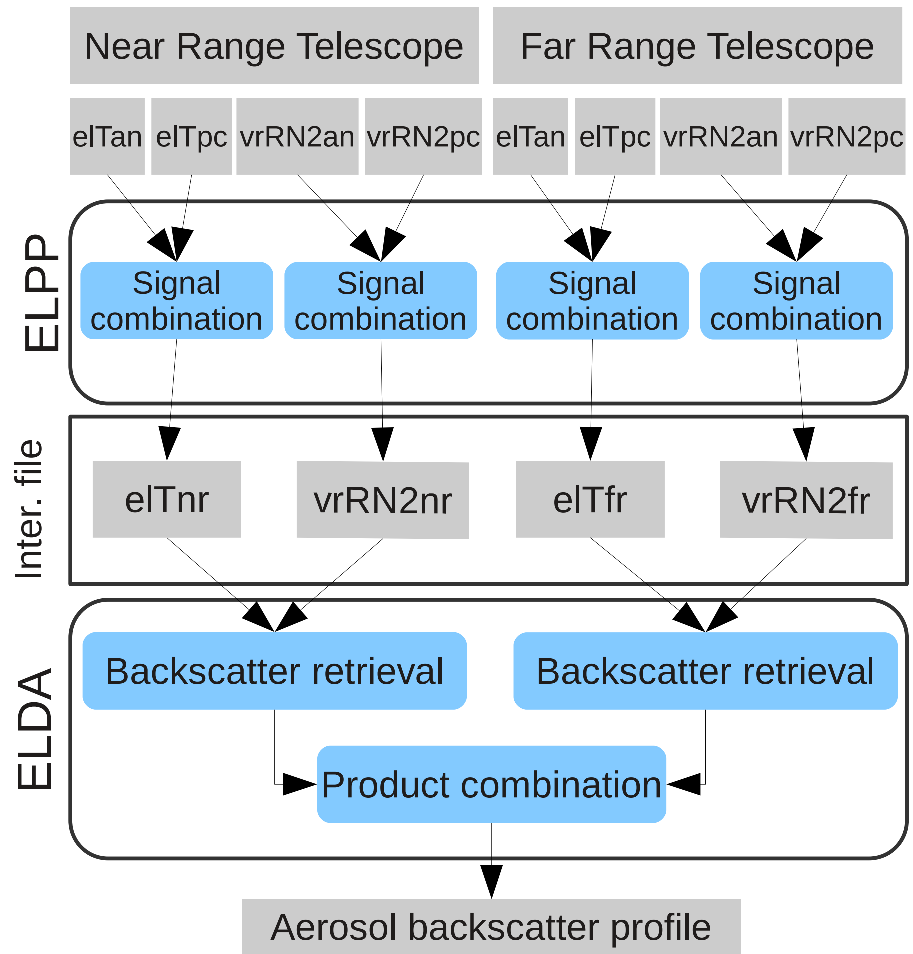
  This makes possible to use of the SCC also outside EARLINET.

SCC Usecase

Raman Backscatter Calculation: Usecase 0



Raman Backscatter Calculation: Usecase 13



Implemented usecases:

Raman backscatter: 19

Elastic backscatter: 9

Raman extinction: 6

SCC Web interface

Single Calculus Chain | Data processing | Handbook of Instruments | Station Admin | Logout

Welcome to Earlinet's SCC v2

Process your lidar data in near-real time

HOME

This web graphic interface was designed to improve the user-friendliness of EARLINET's Single Calculus Chain (SCC) and to manage the set of experimental parameters needed to perform lidar analysis.

Feel free to browse through the menu and discover it's functionatity. You can also start by reading the documentation.

Scc info

- Version: 3.0
- Pre processing ver.: 5.13
- Elda ver.: 1.2
- Deamon ver.: 3.2
- Database ver.: 3.11
- Web interface ver.: 2.0
- Release: 2014-03-18 18:00

Funded by the ACTRIS and ITaRS projects.

EARLINET

ACTRIS

SEVENTH FRAMEWORK PROGRAMME

Data Processing

Single Calculus Chain | Data processing | Handbook of Instruments | Station Admin | Logout

Data processing

HOME / DATA PROCESSING

Explore

Search Measurements

Ancillary files

Actions

Quick Upload

Upload Ancillary

Data processing overview

In the data processing section you can upload lidar measurements to be processed, monitor the processing procedure, and download the output products. Use the links in the "*Explore*" section of the menu to search for already processed measurements and browse the related ancillary files. Use the links in the "*Actions*" section to upload new measurements and ancillary files. Before using these options be sure to set-up your system and product parameters in the Admin section.

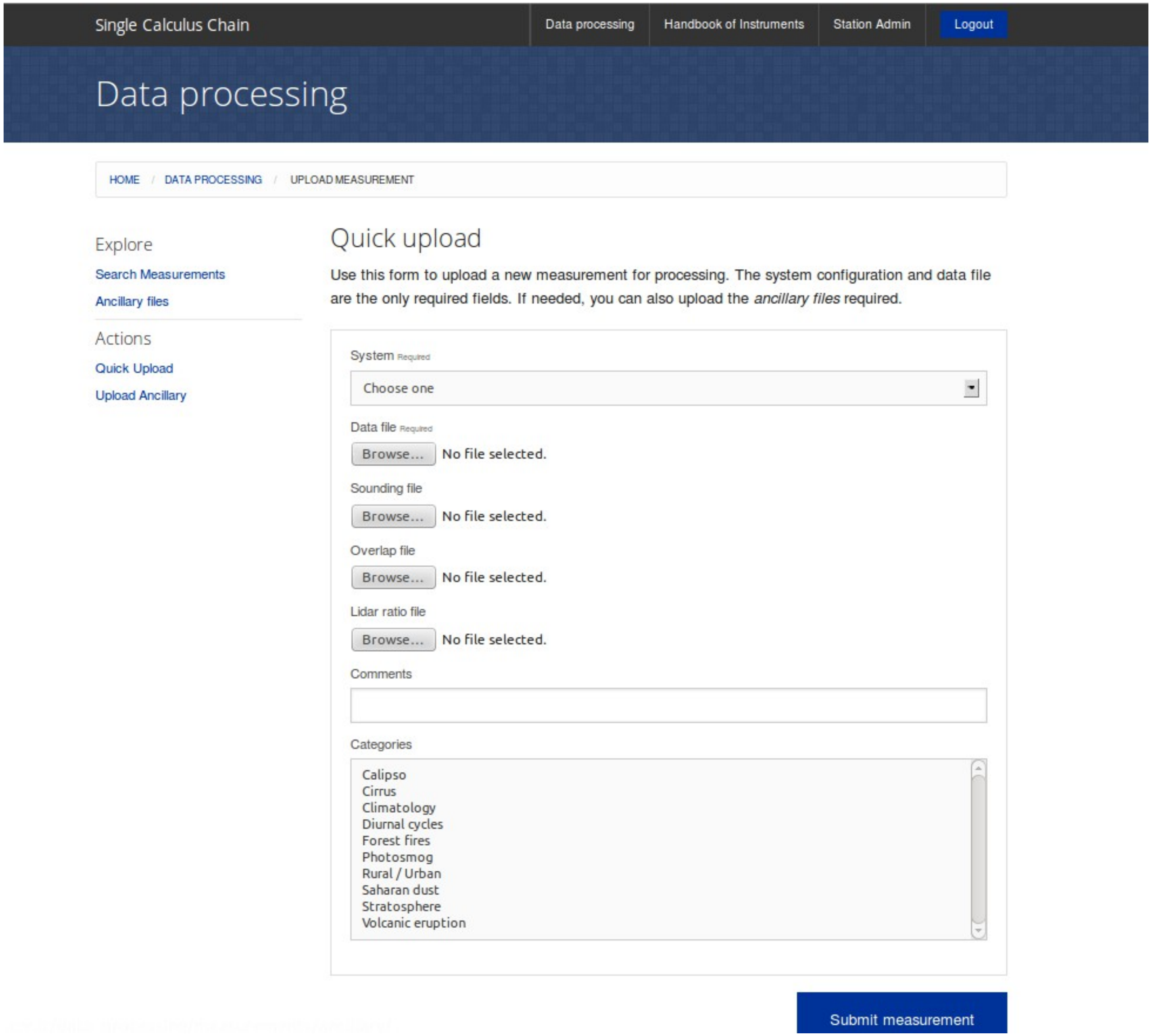
Recently updated measurements

Id	Uploaded on	Last update	Status
20140403bu06	2014-04-07 06:03 UTC	6 hours, 9 minutes ago	
20140402bu03	2014-04-04 13:19 UTC	2 days, 22 hours ago	
20140403bu05	2014-04-04 13:12 UTC	2 days, 23 hours ago	
20140403bu04	2014-04-04 13:07 UTC	2 days, 23 hours ago	
20140403bu03	2014-04-04 12:46 UTC	2 days, 23 hours ago	

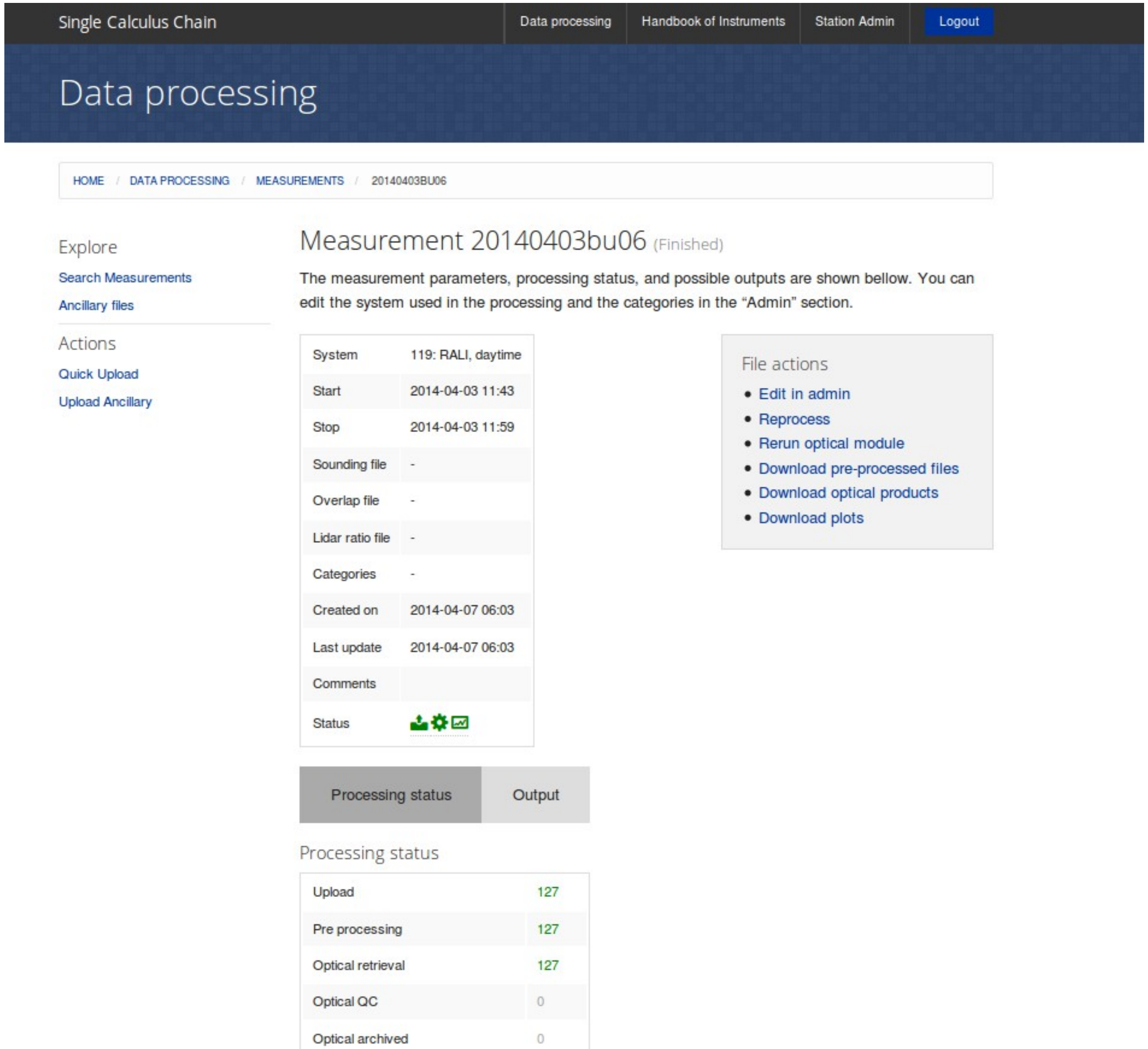
Recently uploaded ancillary files

File	Station	Submission	Status
rs_20090101in00.nc	in	2014-03-14 14:05	Ok
rs_20090101in01.nc	in	2014-03-14 14:03	Ok
rs_20120714ev03.nc	ev	2014-03-14 13:23	Ok
rs_20120425ev03.nc	ev	2014-03-14 13:23	Ok
rs_20120806ev15.nc	ev	2014-03-14 13:23	Ok

Submit new measurement



Measurement status



Single Calculus Chain

Data processing | Handbook of Instruments | Station Admin | Logout

Data processing

HOME / DATA PROCESSING / MEASUREMENTS / 20140403BU06

Explore

Search Measurements

Ancillary files

Actions

Quick Upload

Upload Ancillary

Measurement 20140403bu06 (Finished)

The measurement parameters, processing status, and possible outputs are shown bellow. You can edit the system used in the processing and the categories in the "Admin" section.

System	119: RALI, daytime
Start	2014-04-03 11:43
Stop	2014-04-03 11:59
Sounding file	-
Overlap file	-
Lidar ratio file	-
Categories	-
Created on	2014-04-07 06:03
Last update	2014-04-07 06:03
Comments	
Status	

File actions

- Edit in admin
- Reprocess
- Rerun optical module
- Download pre-processed files
- Download optical products
- Download plots

Processing status | Output

Processing status

Upload	127
Pre processing	127
Optical retrieval	127
Optical QC	0
Optical archived	0

Consiglio Nazionale delle Ricerche

Output product : plots

Single Calculus Chain | Data processing | Handbook of Instruments | Station Admin | Logout

Data processing

HOME / DATA PROCESSING / MEASUREMENTS / 20100605PO64 / PO1006050059.B1064

Explore

- Search Measurements
- Ancillary files

Actions

- Quick Upload
- Upload Ancillary

Products po1006050059.b1064

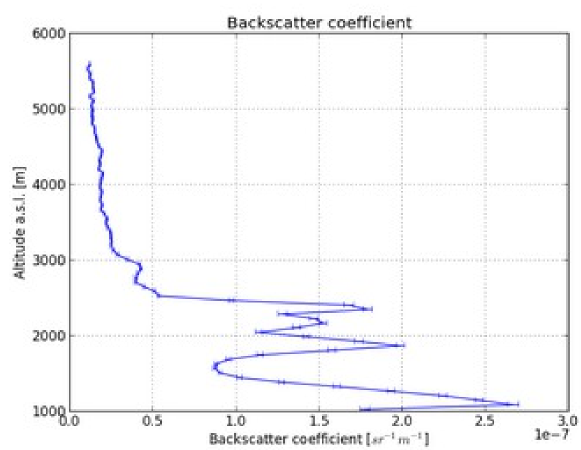
General info

Database id	10993
File name	po1006050059.b1064
Product	ID: 294 | elast. backscatter (usecase: 0) at 1064.0 nm
Calculation date	2014-08-06 10:53

Product actions

- Replot data

Variable plots



Consiglio Nazionale delle Ricerche

Station Admin

SCC station management Back to the site

Home

Site administration

Systems settings

General settings about stations, systems and their varius components.

HOI stations	+ Add	☰ Change
HOI systems	+ Add	☰ Change
HOI telescopes	+ Add	☰ Change
HOI lasers	+ Add	☰ Change
HOI channels	+ Add	☰ Change
Laser emission lines	+ Add	☰ Change
System photos	+ Add	☰ Change

Product settings

Settings about the optical products that will be calculated.

Products	+ Add	☰ Change

Measurements and files

Advanced controls for the already uploaded measurements and files.

Measurements	+ Add	☰ Change
Sounding files	+ Add	☰ Change
Lidar ratio files	+ Add	☰ Change
Overlap files	+ Add	☰ Change

Support

↗ SCC documentation

↗ Forum

Recent Actions

☰ ID: 130 | elast. backscatter (usecase: 0) at 355.0 nm
Product

☰ ID: 132 | elast. backscatter (usecase: 0) at 532.0 nm
Product

☰ ID: 253 | lidar ratio and extinction (usecase: 0) at 532.0 nm
Product

☰ ID: 252 | lidar ratio and extinction (usecase: 0) at 355.0 nm
Product

☰ ID: 127 | extinction only (usecase: 0) at 355.0 nm
Product

ModelList: Administration

Groups	+ Add	☰ Change
Sites	+ Add	☰ Change
Users	+ Add	☰ Change

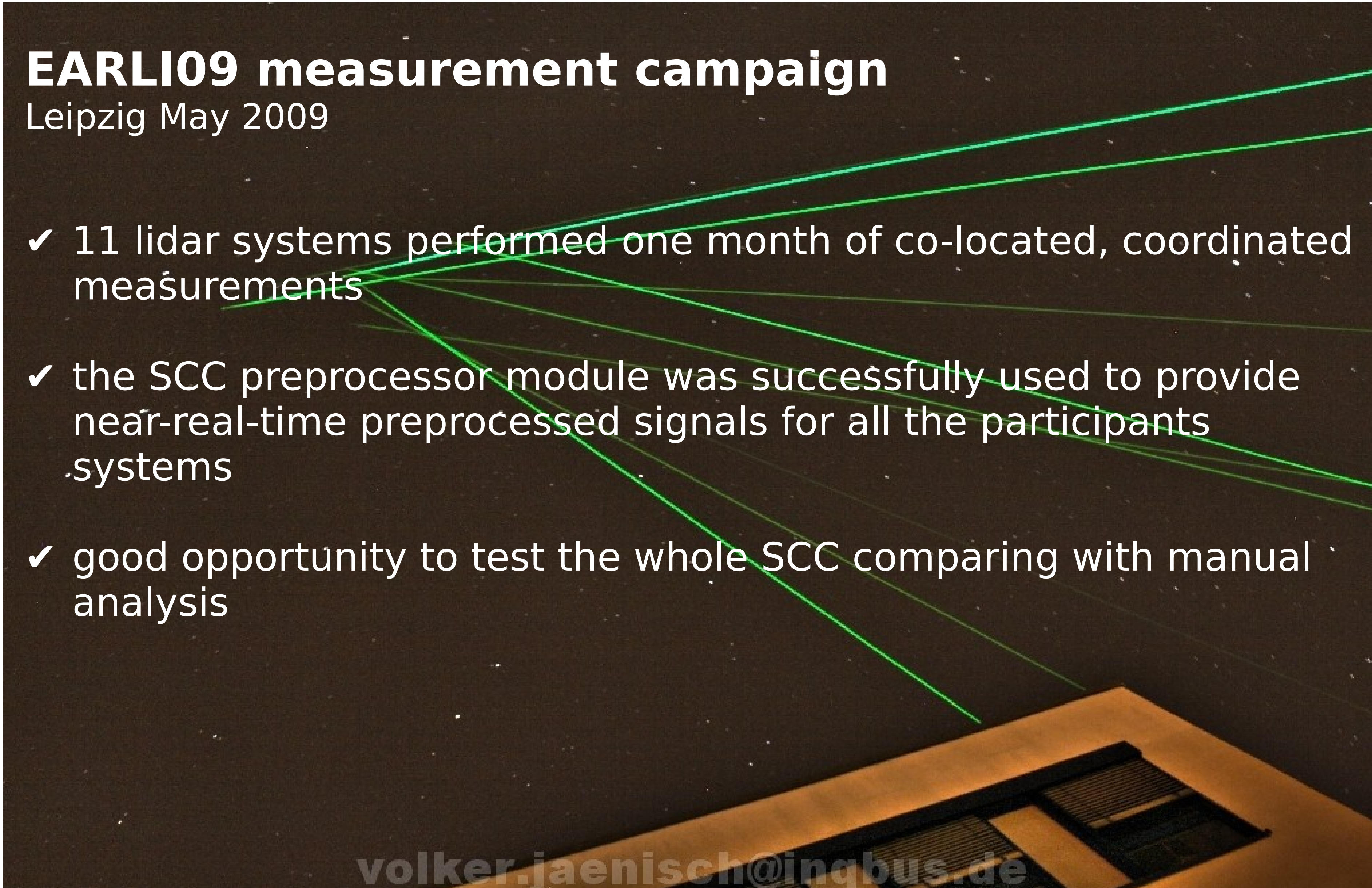
SCC Usage Summary (23.02.2015)

Total measurements	1594	
Pre-processed successfully	1403 (88%)	~50% glueing 50% incorrect format
Optical processed successfully	879 (63%)	~50% calib. 50% iterative bck
Pre-processed files	5198	
Optical processed files	3512	
System configurations	59	
Registered channels	430	
Registered products	400	
Users	45	

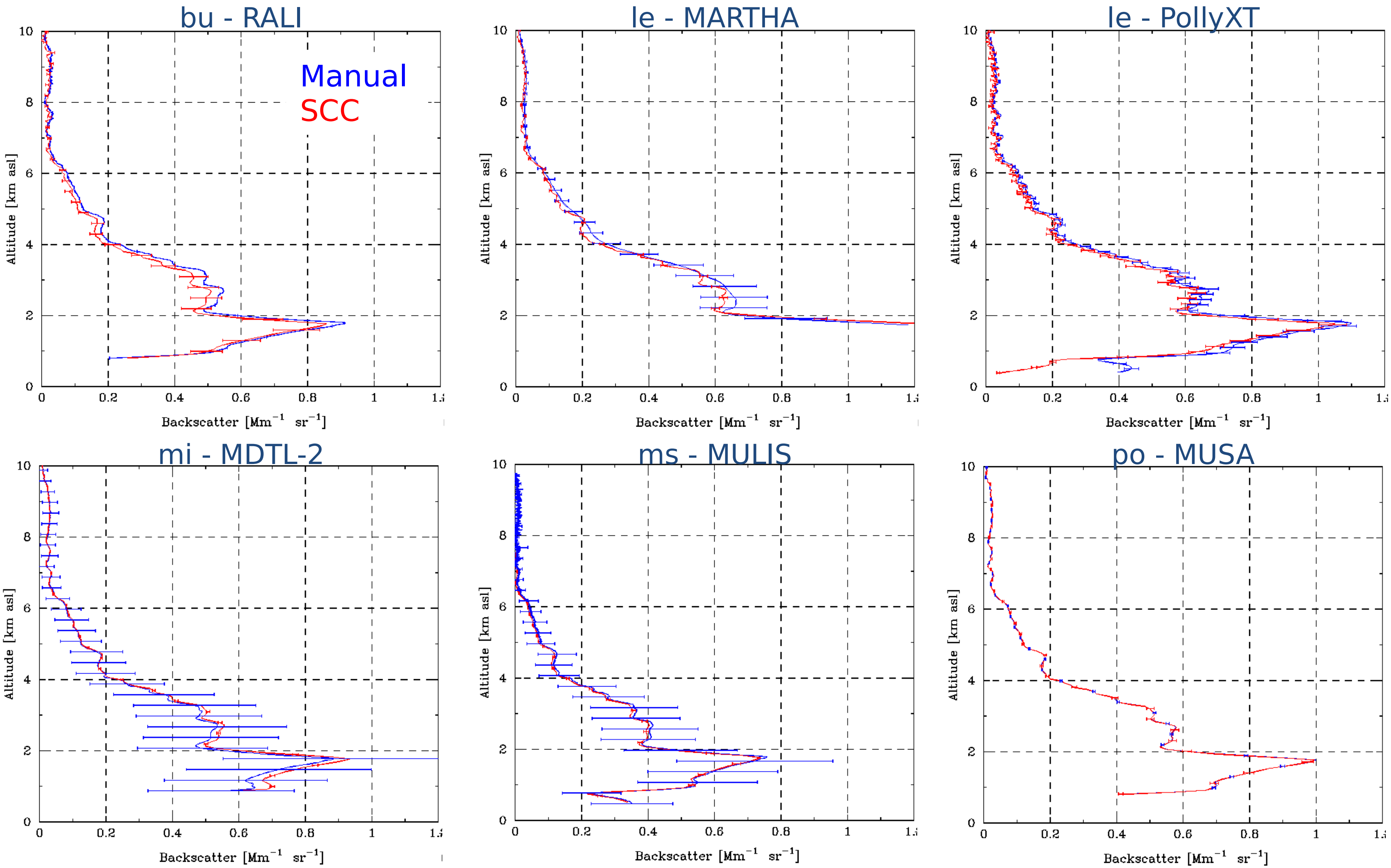
EARLI09 measurement campaign

Leipzig May 2009

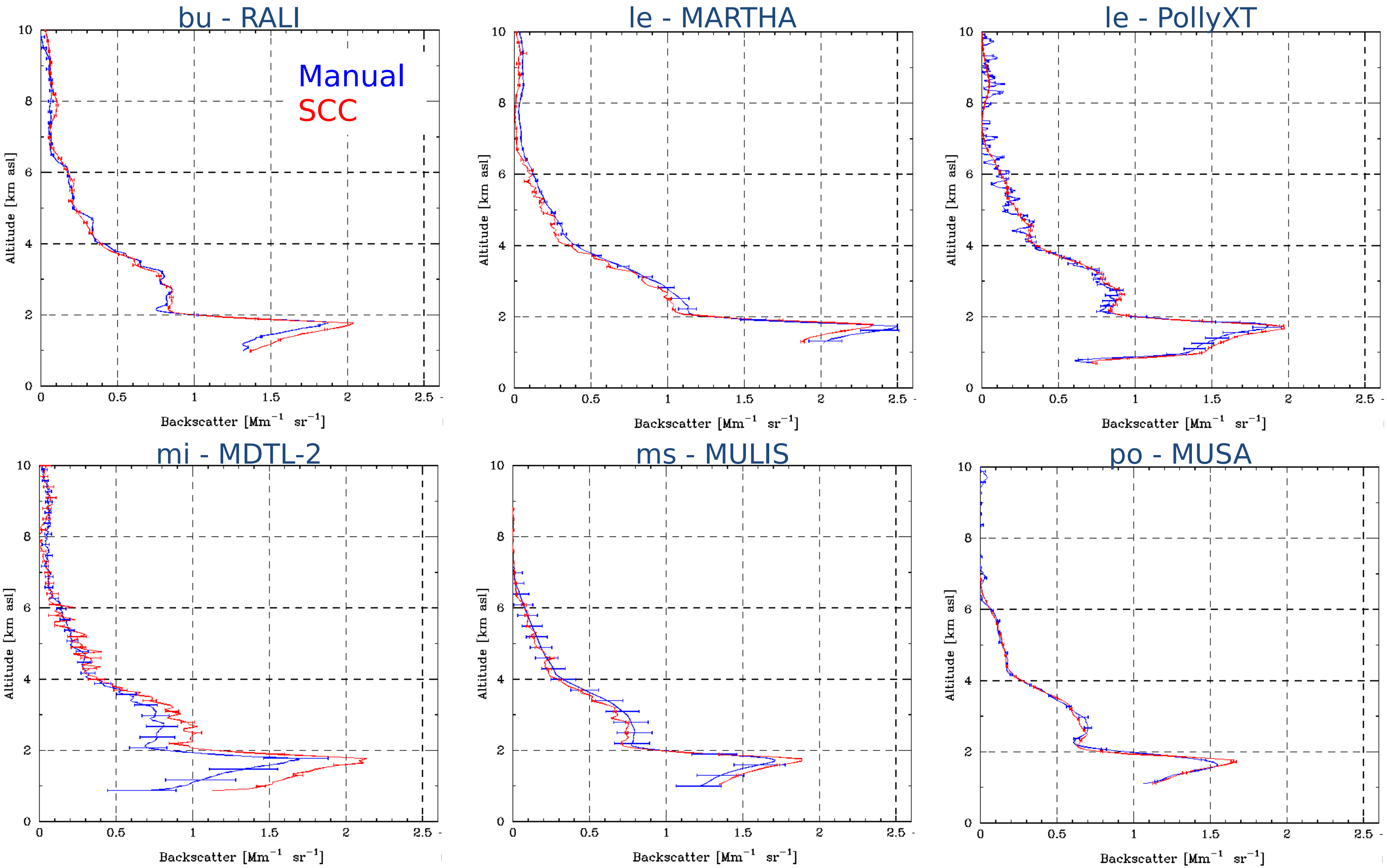
- ✔ 11 lidar systems performed one month of co-located, coordinated measurements
- ✔ the SCC preprocessor module was successfully used to provide near-real-time preprocessed signals for all the participants systems
- ✔ good opportunity to test the whole SCC comparing with manual analysis



EARLI09 – 25052009 session 4 - b1064

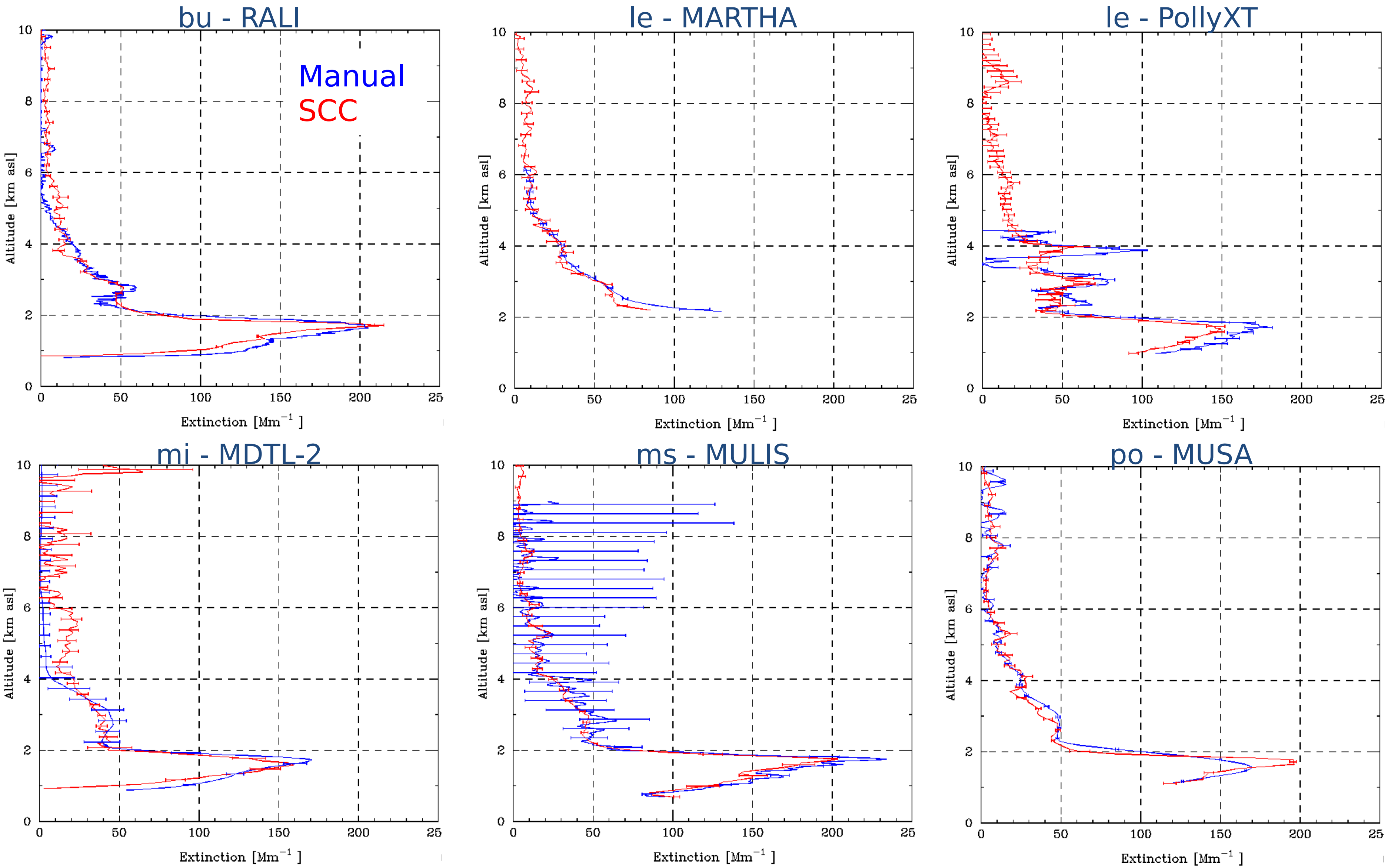


EARLI09 – 25052009 session 4 - b532



Consiglio Nazionale delle Ricerche

EARLI09 – 25052009 session 4 - e355

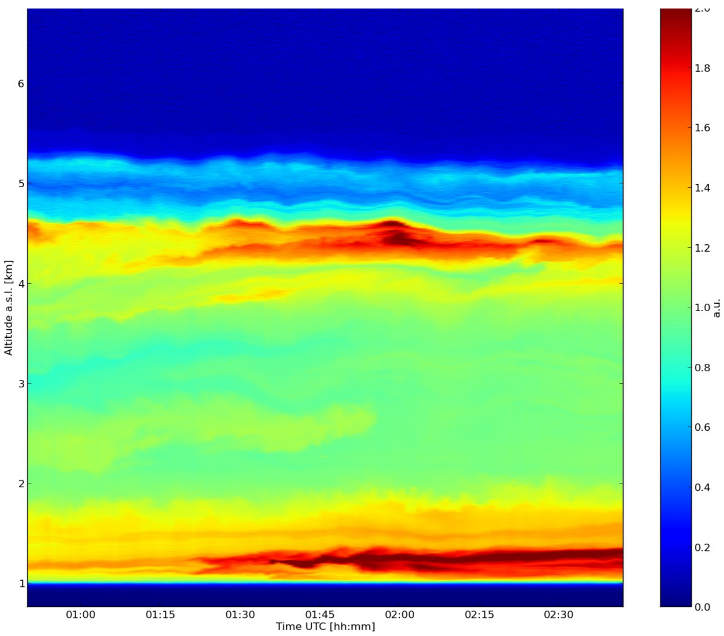


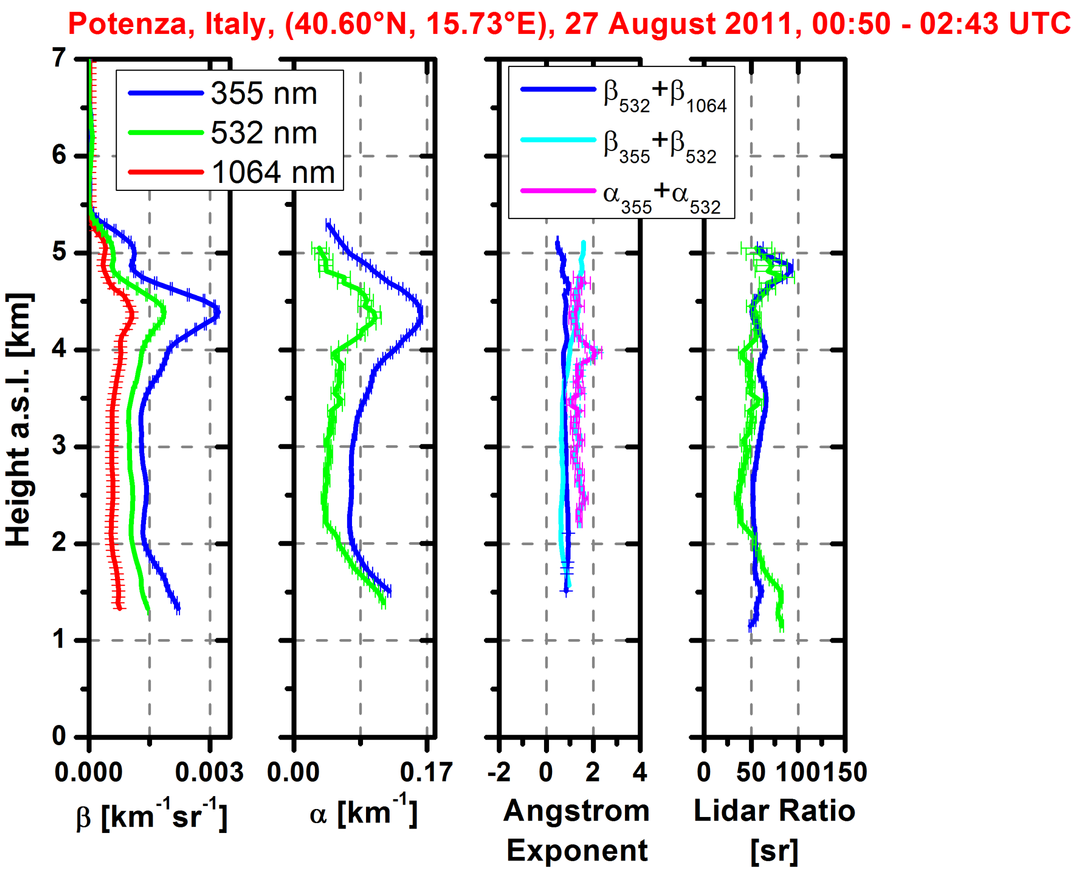
New products implementation

Main goals:

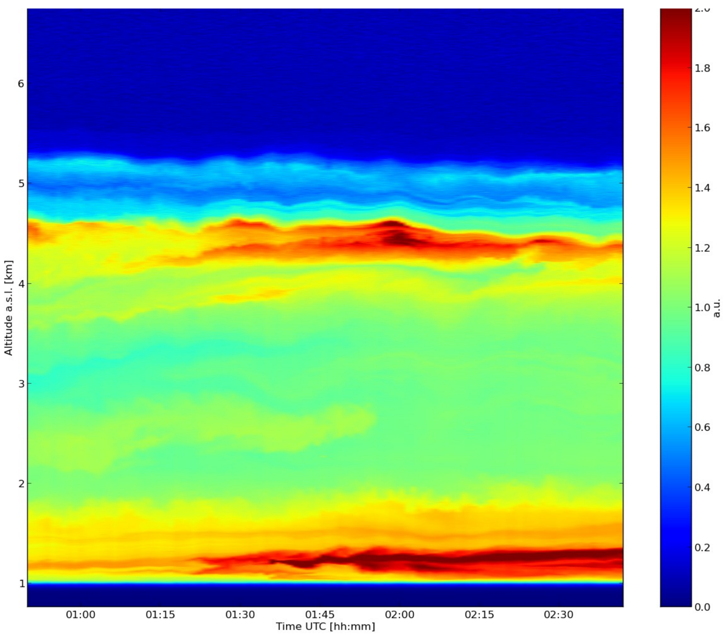
- extend the set of optical products already provided by the SCC with the following new products (better aerosol characterization):
  - particle linear depolarization ratio
  - automatic aerosol layer detection
  - automatic cloud masking

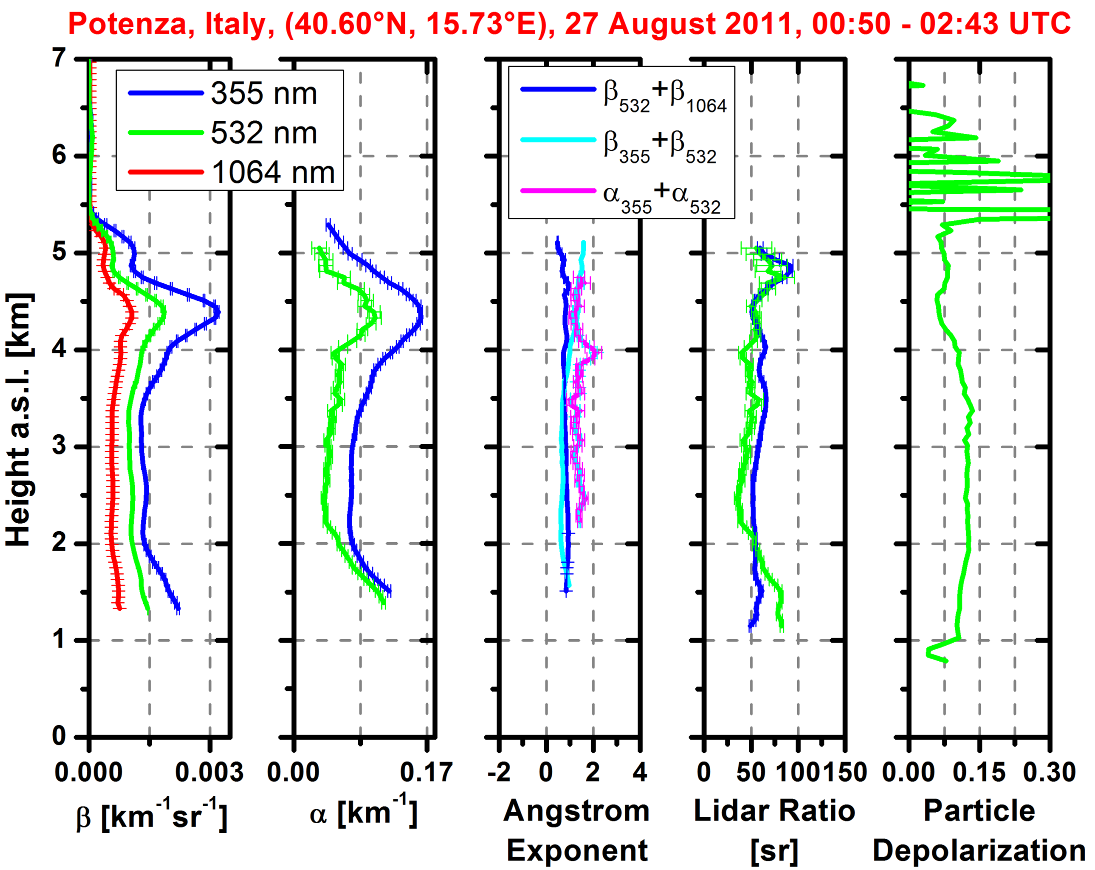
Particle linear depolarization



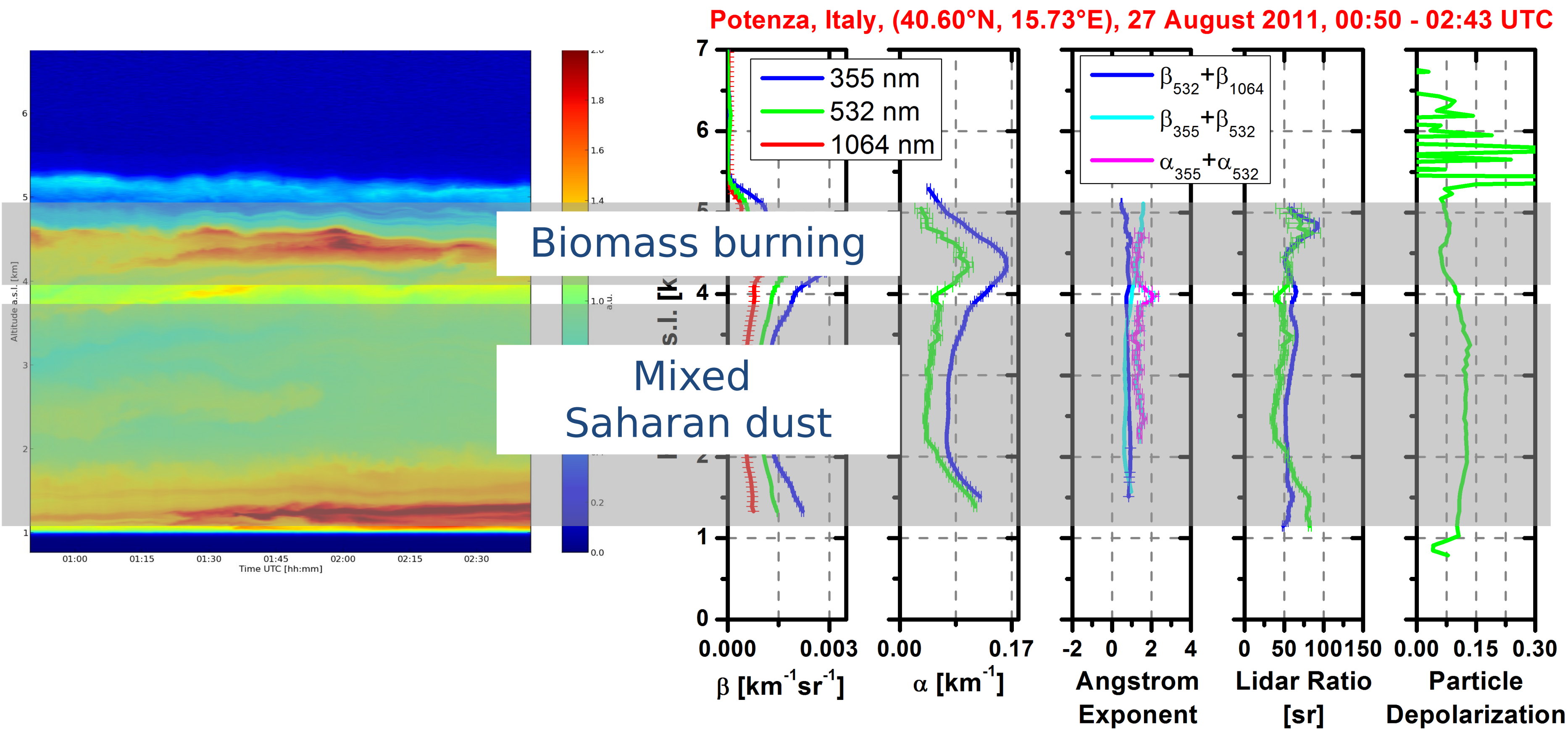


Particle linear depolarization

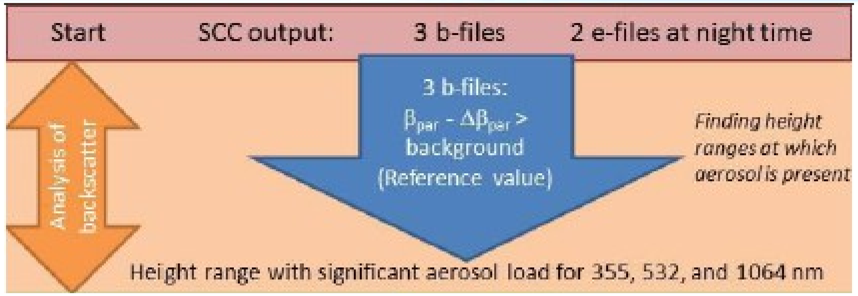




Particle linear depolarization

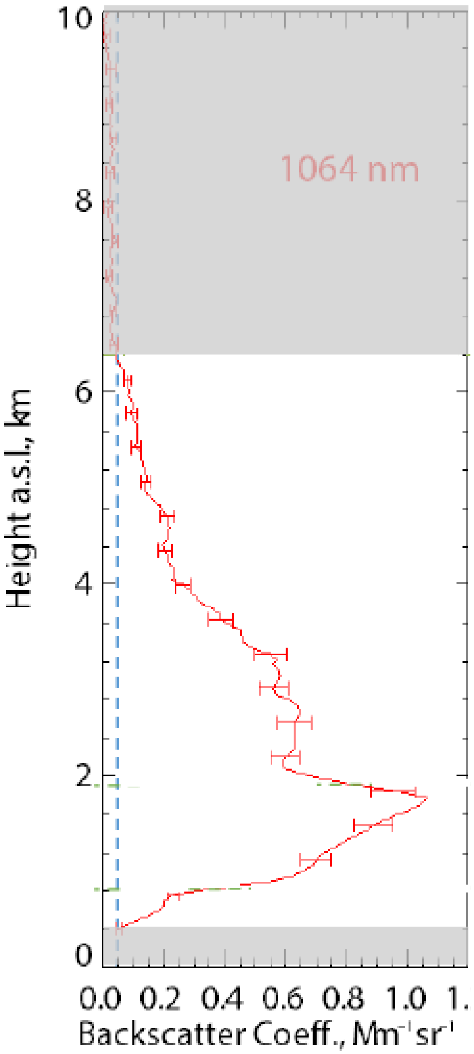


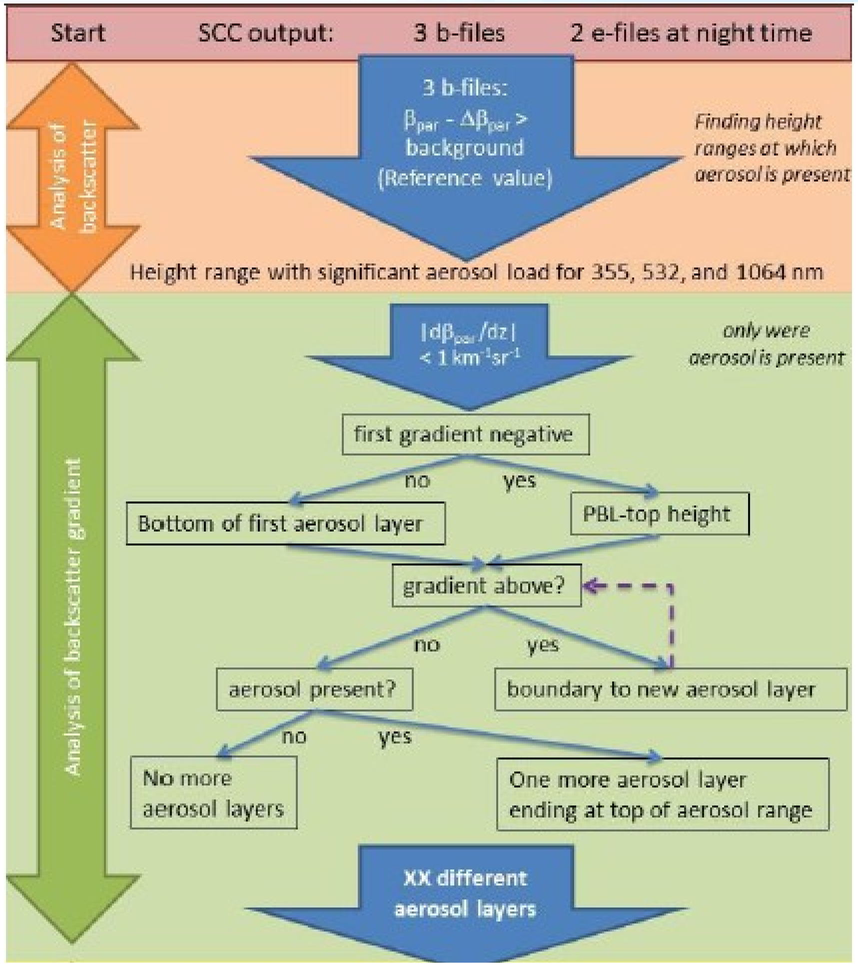
Implementation of PLDR in the SCC → improvements of aerosol characterization!



Layer identification procedure

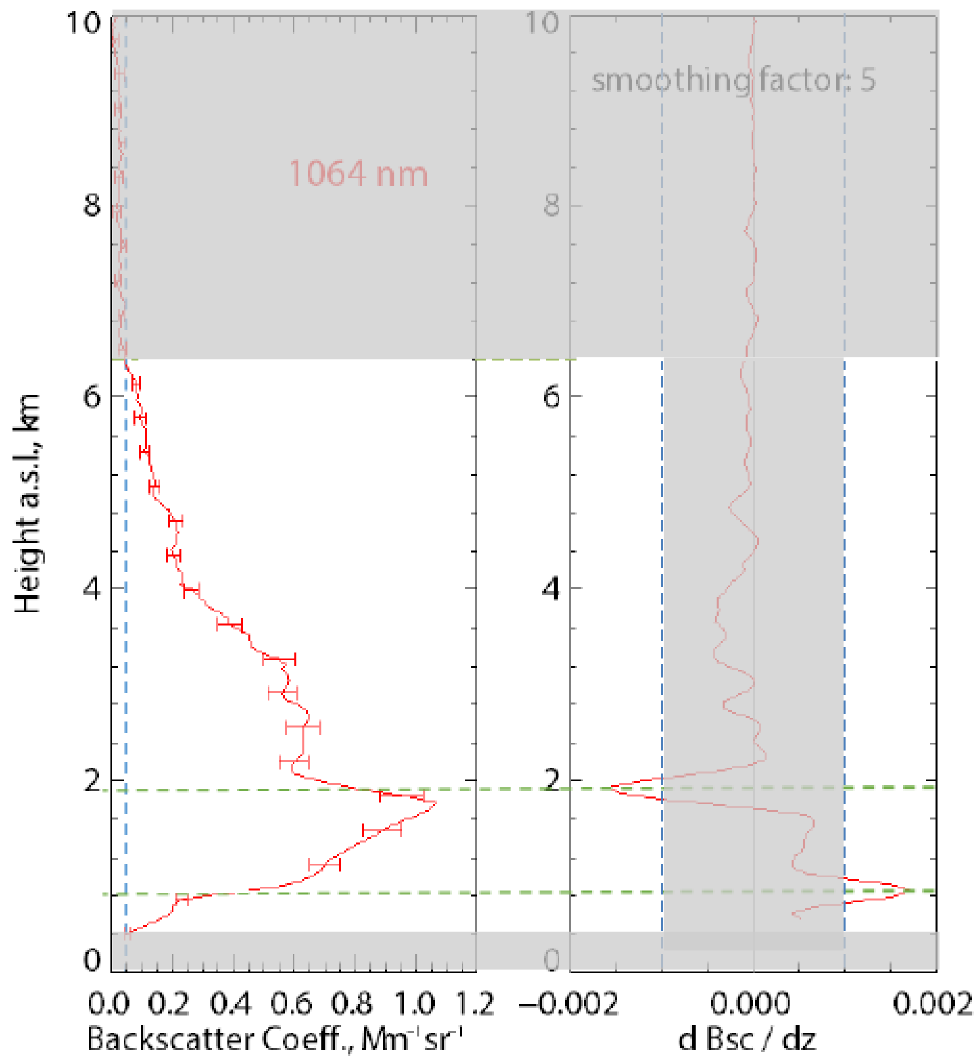
Step 1: Aerosol presence $\beta_p - \Delta\beta_p > \beta_{bck}$





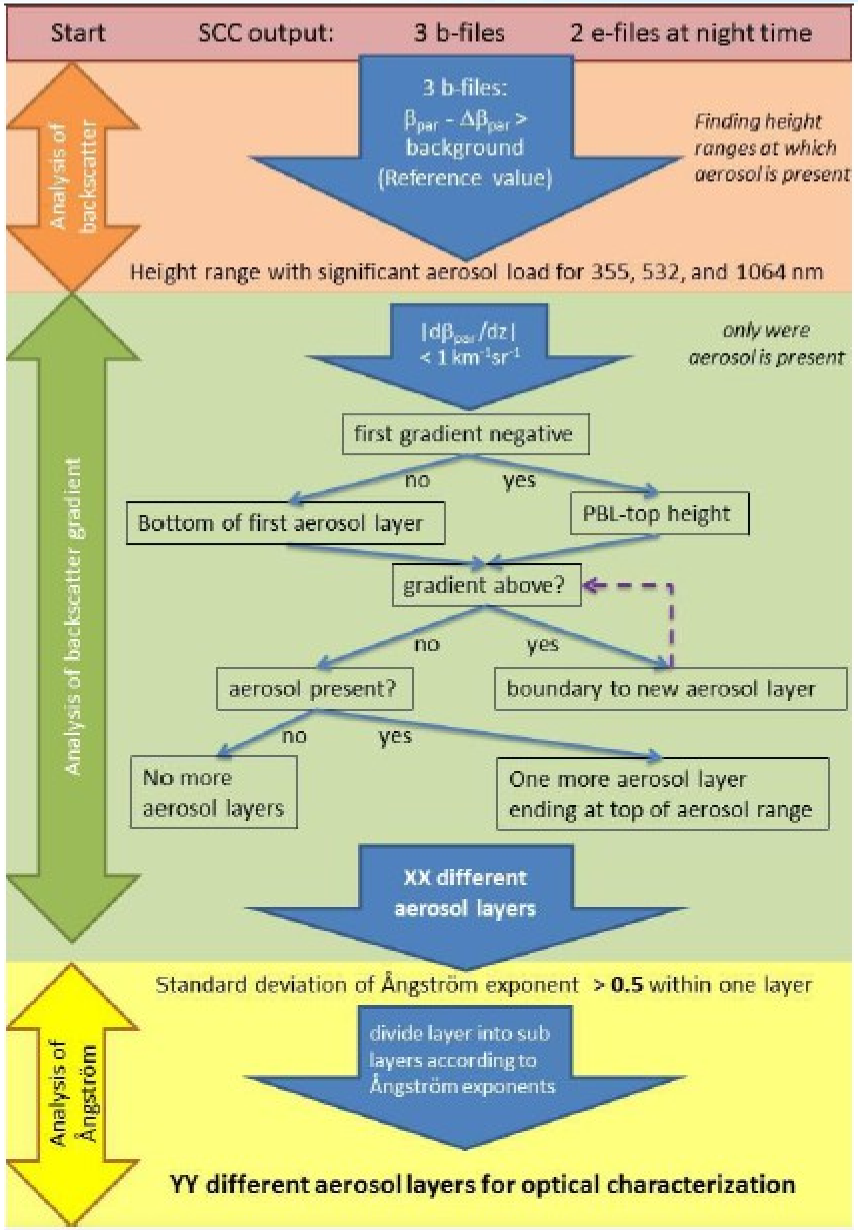
Layer identification procedure

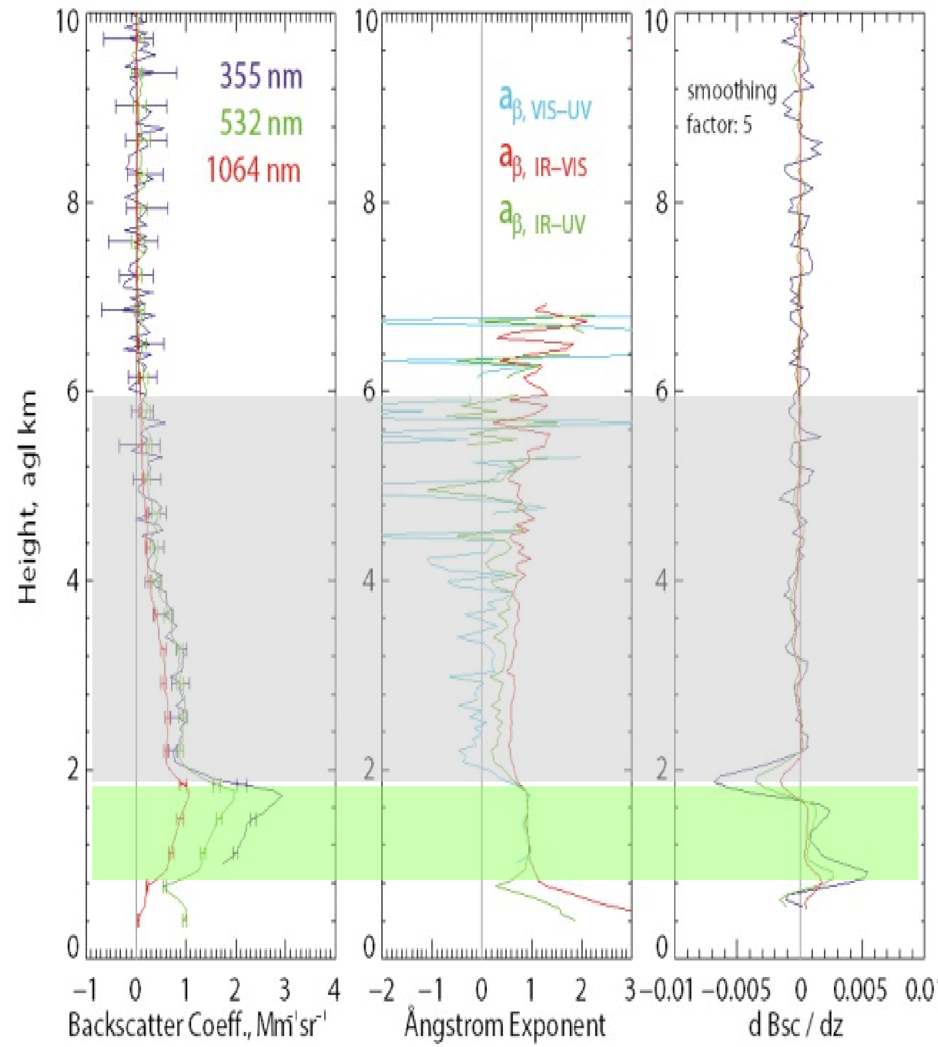
Step 2: Check for grad. $|d\beta_p/dz| > th$



Layer identification procedure

Step 3: Quality Check



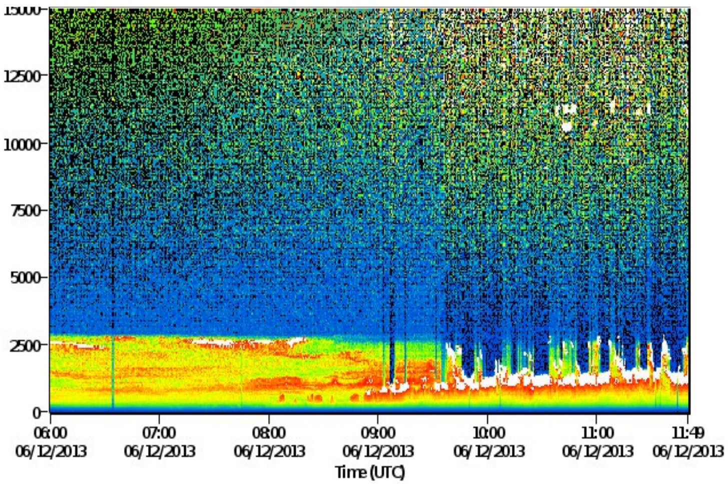


Automatic cloud mask

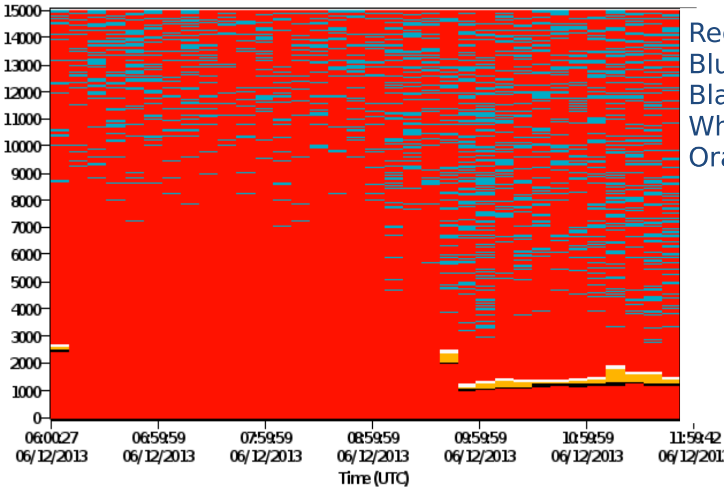
- Critical point for a correct lidar data analysis
- Still an open issue!
- Three possible approaches:
  - Wavelet Covariance Transform (WCT) techniques
  - Physically meaningful thresholds
  - K-nearest neighbors (KNN) algorithm

Automatic cloud mask (WCT)

Range corrected signal 1064nm

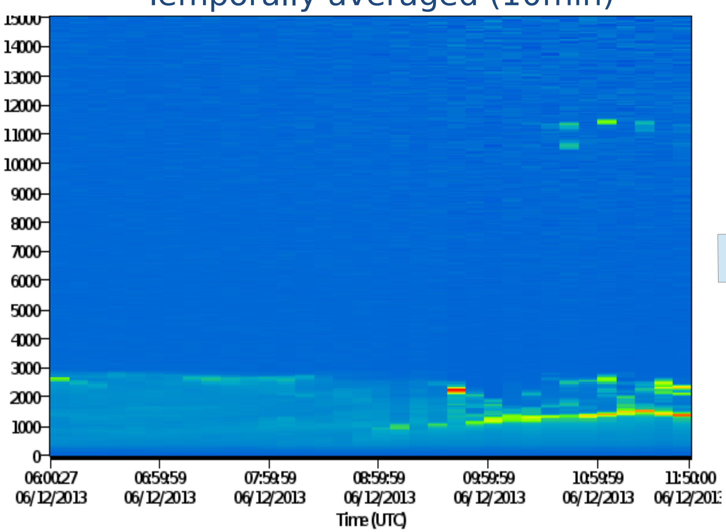


Flagged data



Red: valid signal (SNR > 2)
Blue: noise
Black: cloud base
White: could top
Orange: could

Temporally averaged (10min)



$$W_R(a,b,\lambda)=\frac{1}{a}\int_{z_b}^{z_t} R(z,\lambda)\,H\left(\frac{z-b}{a}\right)dz$$

→ Haar function

Cloud base detection

$$\begin{cases} W_R(a,b,\lambda)=W_{th}=-0.5 \\ SNR\geqslant 2 \end{cases}$$

Cloud top detection

$$\begin{cases} z>z_{base} \\ R(z,\lambda)=R(z_{base},\lambda) \\ SNR\geqslant 2 \end{cases}$$

Automatic cloud mask
Physically meaningful thresholds

Basic idea: detect clouds defining physical thresholds directly on optical aerosol products provided by lidar measurements

Low clouds

- there are no aerosol layers so dense to compete in backscatter coefficient with low clouds (assumption)
- identification can be done using a proper threshold on backscatter coefficient

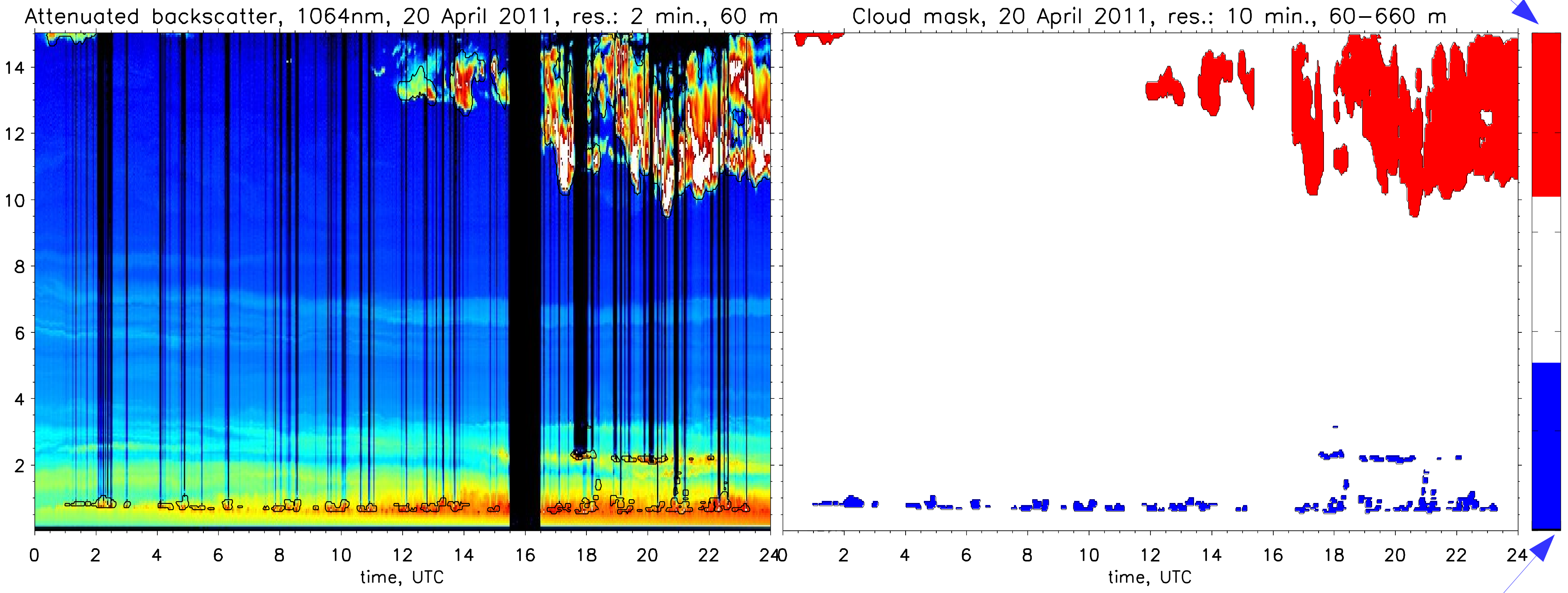
Cirrus clouds

- raw screening is done just defining the altitude range where they are allowed to be (using atmospheric temperature profile)
- more detailed identification is performed putting a threshold on depolarisation ratio (usually the cirrus clouds are strongly depolarising scatters).

Consiglio Nazionale delle Ricerche

Automatic cloud mask
Physically meaningful thresholds

threshold on particle/volume depol. ratio

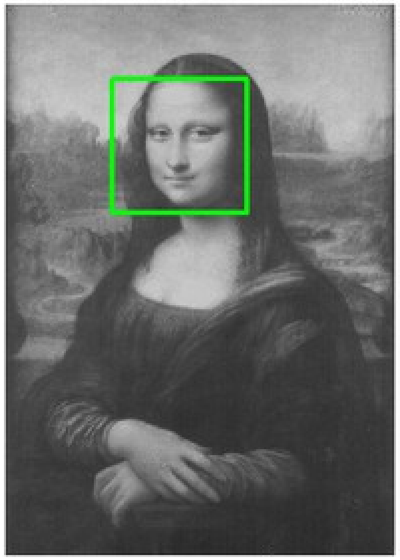


threshold on particle backscatter coeff.

Automatic cloud mask (KNN) (still in experimental phase!)

Basic idea:

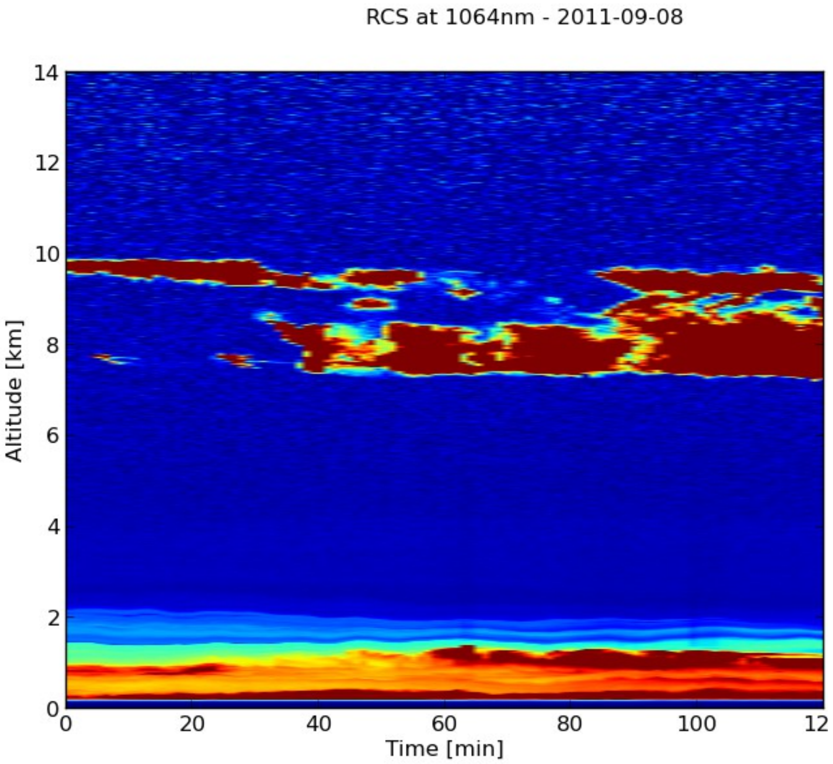
- aerosols and clouds exhibit different vertical and temporal variability
- apply pattern recognition algorithms to range-corrected timeseries to detect cloud features (the same algorithms used for example for the face detection)

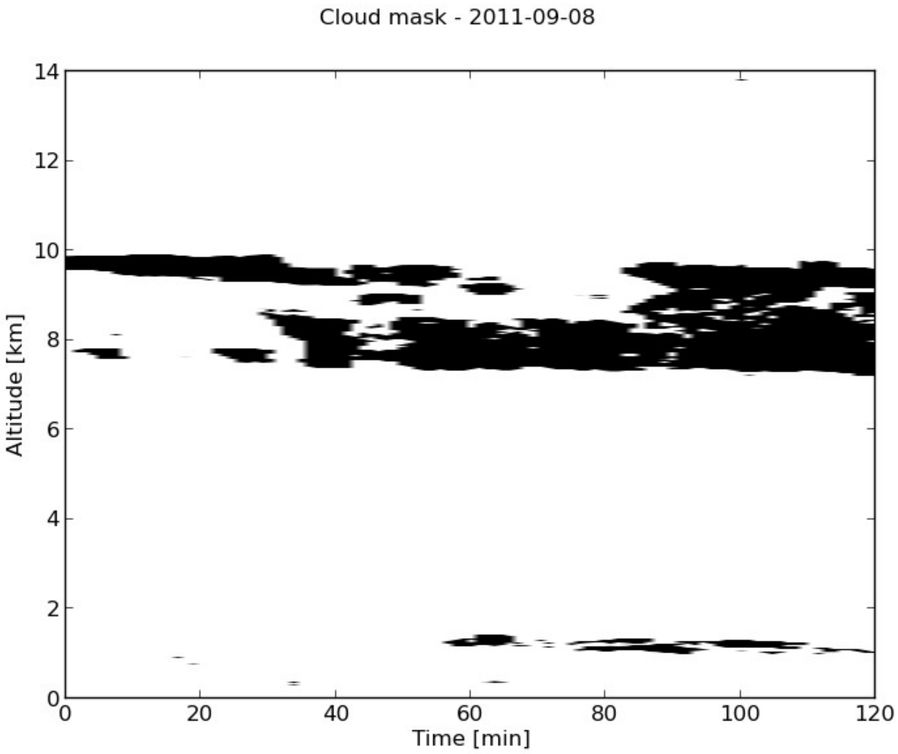


Duda, Richard O., Peter E Hart, and David G. Strok, Pattern Classification. New York: Wiley 2001

Automatic cloud mask (KNN) (still in experimental phase!)

How to apply to extend to cloud detection?





Summary

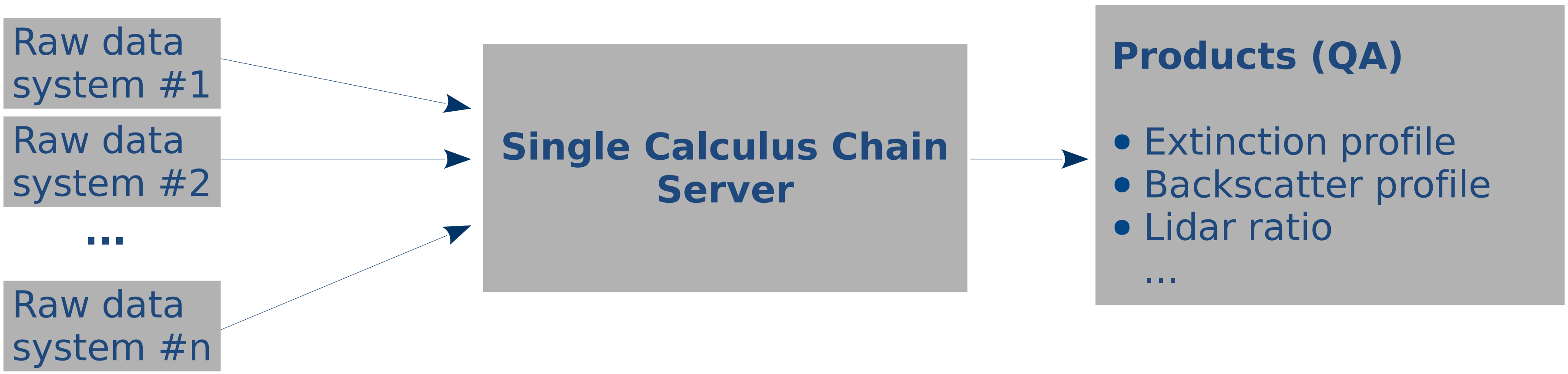
- SCC: automatic tool for the retrieval of EARLINET quality assured aerosol optical products:
  - aerosol extinction
  - aerosol backscatter
  - particle linear depolarization ratio
  - automatic aerosol layers
  - cloud mask

  } Next SCC release (particle linear depolarization ratio, automatic aerosol layers, cloud mask)

- User friendly Web interface
- SCC is the standard tool for automatic analysis of EARLINET data
- Usage of SCC can be extended to different lidar networks (GALION)

THANK YOU !

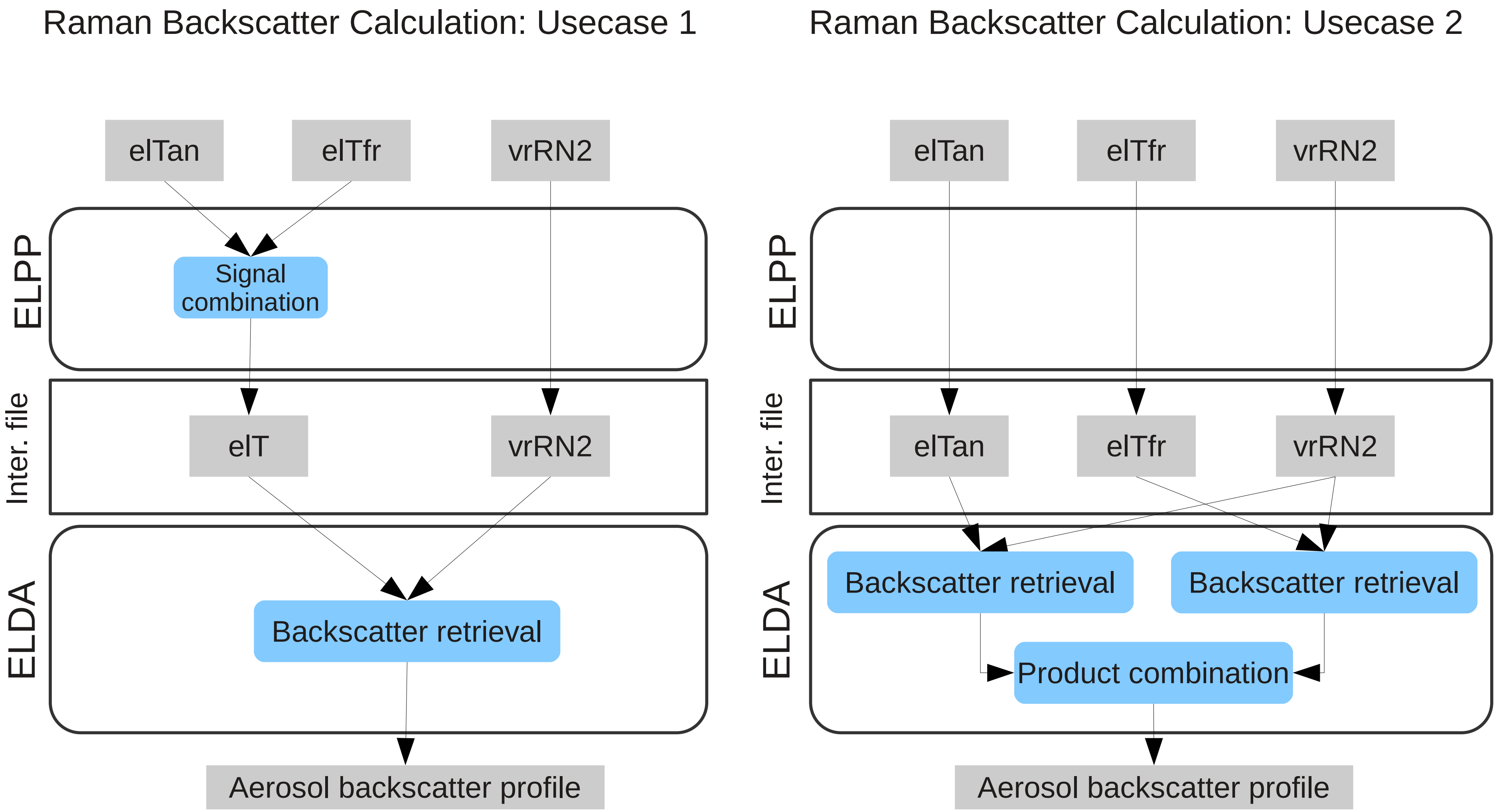
SCC



Main difficulties:

- Implementation of full and robust automatic procedures
- Handling raw data of lidar systems with different hardware set up

SCC Usecase



Implemented usecases:

Raman backscatter: 19

Elastic backscatter: 9

Raman extinction: 6

SCC file format (NetCDF)

Raw NetCDF files (Level 0)

Contents:

- Raw lidar data timeseries
- Parameters needed for instrumental corrections

Generator: user

Usage: mainly internal

Intermediate NetCDF files (Level 1)

Contents:

- pre-processed lidar data (range corrected signals)
- molecular extinction and transmissivity

Generator: ELPP module (SCC)

Usage: lidar intercomparison campaign, model assimilation, quicklooks

Output NetCDF files (Level 2)

Contents:

- particle extinction and backscatter coefficient

Generator: ELDA module (SCC)

Usage: model assimilation/validation, input for advanced aerosol study, satellite validation, monitor critical events,....

Consiglio Nazionale delle Ricerche

imaa

3 main sections

Single Calculus Chain | Data processing | Handbook of Instruments | Station Admin | Logout

Welcome to Earlinet's SCC v2

Process your lidar data in near-real time

HOME

This web graphic interface was designed to improve the user-friendliness of EARLINET's Single Calculus Chain (SCC) and to manage the set of experimental parameters needed to perform lidar analysis.

Feel free to browse through the menu and discover it's functionatity. You can also start by reading the documentation.

Scc info

- Version: 3.0
- Pre processing ver.: 5.13
- Elda ver.: 1.2
- Deamon ver.: 3.2
- Database ver.: 3.11
- Web interface ver.: 2.0
- Release: 2014-03-18 18:00

Funded by the ACTRIS and ITaRS projects.

EARLINET

ACTRIS

SEVENTH FRAMEWORK PROGRAMME

Station Admin : Channel settings

SCC station management Back to the site

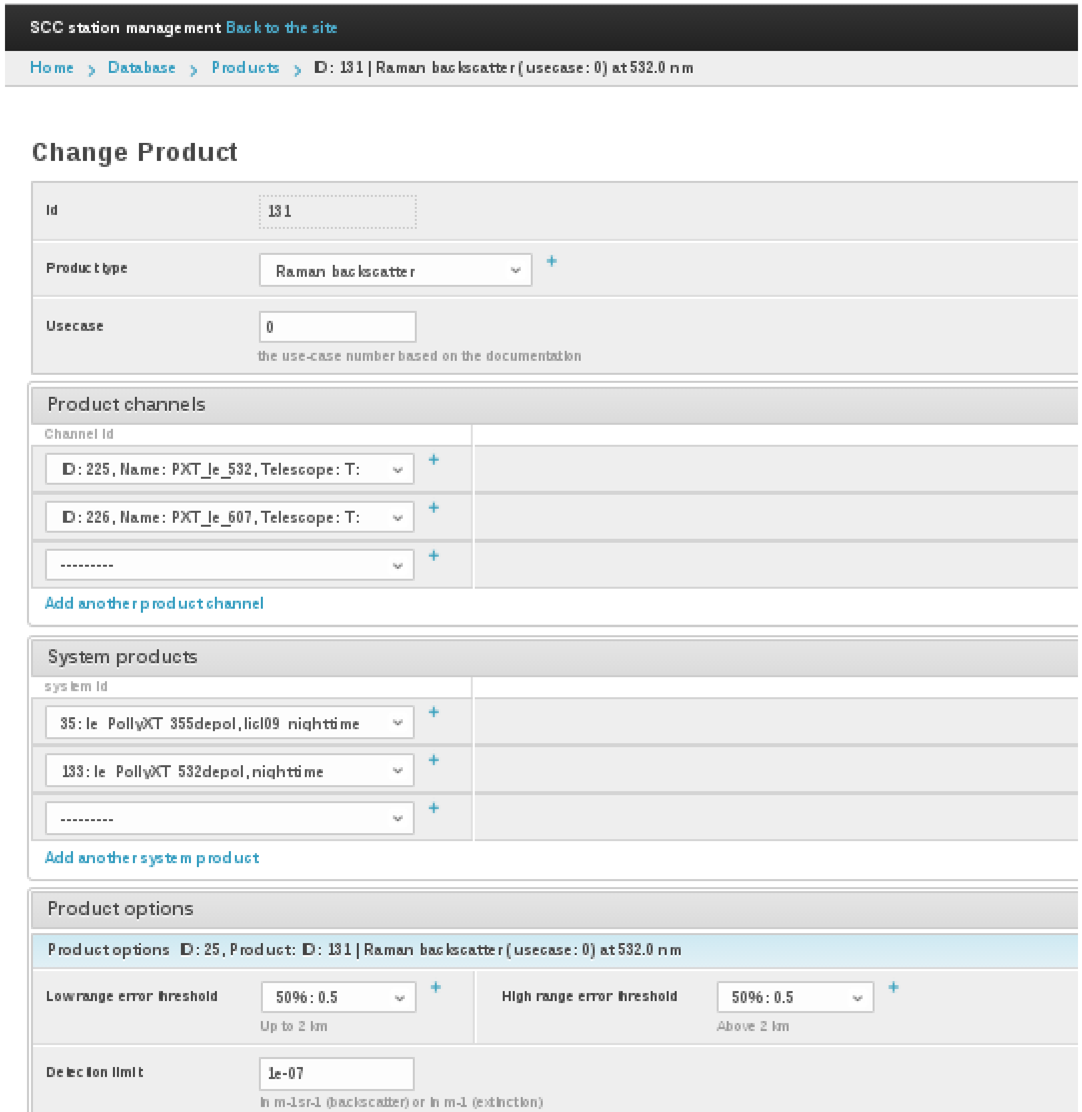
Home › Database › HOI channels › ID: 255, Name: 607 nr pc BH, Telescope: T: Newton, D: 150.0, F: 420.0, Laser: Continuum: PowerLite Precision ...

Change HOI channel

Name	607 nr pc BH
Telescope	T: Newton, D: 150.0, F: 420.0
Laser	Continuum: PowerLite Precision II 9030
Scattering mechanism	vibrational rotational Raman at nitrogen molecules
Interference filter center	607.0 in nm
Interference filter FWHM	1.0 in nm
Emission wavelength	532.0 in nm
Field of view	1.3 in mrad
Raw range resolution	7.5 in m
Dead time correction type	Not-Paralyzable channel
Dead time	3.7 in ns
Trigger delay	0.0 in ns
Trigger delay interpolation type	Linear Interpolation

Consiglio Nazionale delle Ricerche

Station Admin : Product settings



Consiglio Nazionale delle Ricerche

Handbook of Instruments

Single Calculus Chain | Data processing | Handbook of Instruments | Station Admin | Logout

Handbook of instruments

HOME / HANDBOOK OF INSTRUMENTS / GR

Explore
- Stations
- About

Station Centro Andaluz de Medio Ambiente (CEAMA) - Universidad de Granada (gr)

Institute:	**Centro Andaluz de Medio Ambiente (CEAMA) - Universidad de Granada**
PI:	**L. Alados Arboledas**
Latitude:	**37.164**
Longitude:	**-3.605**
Altitude:	**680.0 a.s.l.**
Number of systems:	**2**
Number of measurements:	**71**

Systems

Raymetrics LR321-D400

Channels	**10**
Different configurations	**3**
PIs	**L. Alados Arboledas**

Raymetrics LR111-ESS-D200

Channels	**5**
Different configurations	**3**
PIs	**L. Alados Arboledas**

Funded by the ACTRIS and ITaRS

HOI – System details

Beam expansion factor:	
Beam divergance after exp.:	

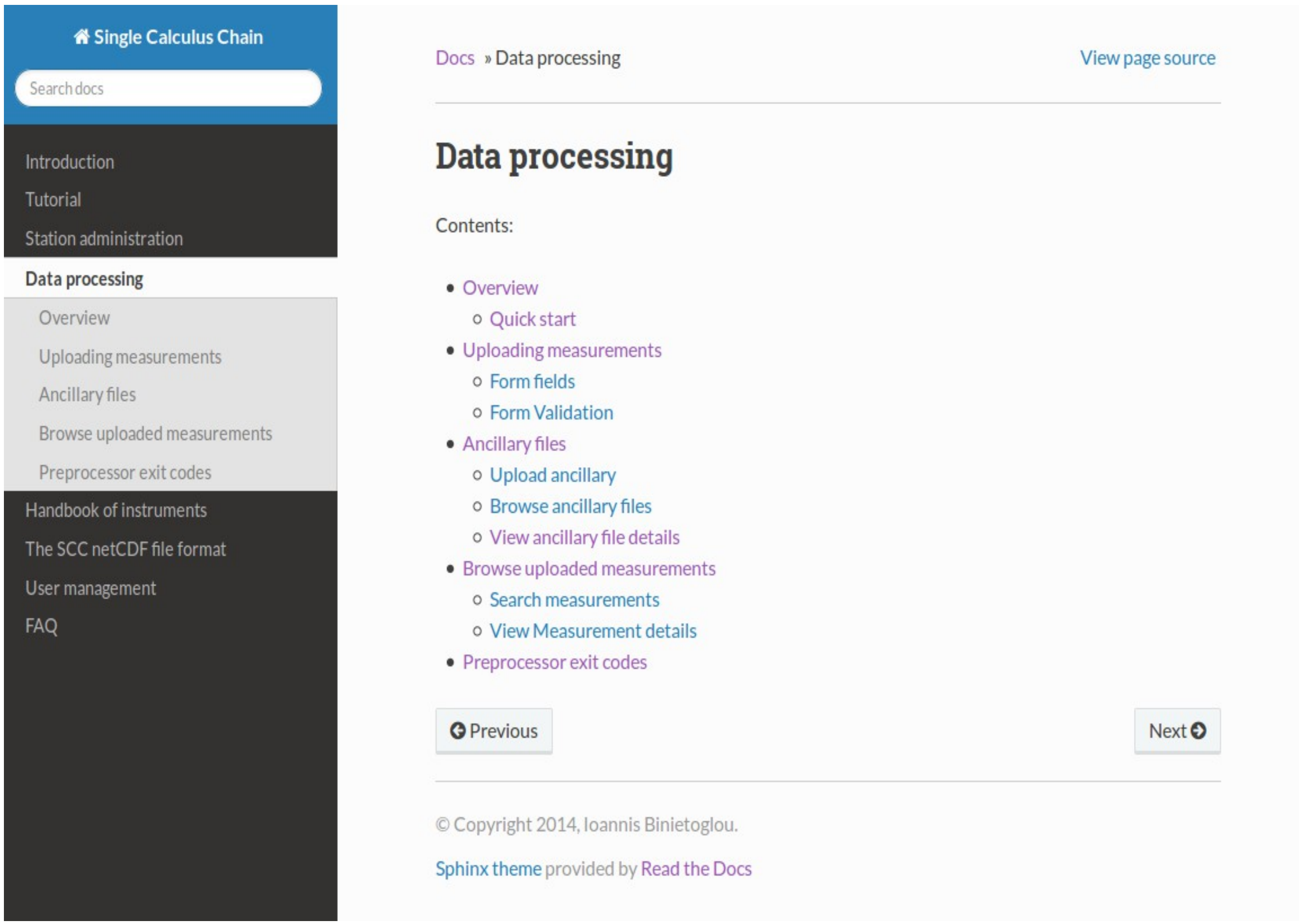
Telescope 1

Type	**Cassegrain - Raymetrics D400**
Manufacturer	-
Model	-
Aperture diameter	**400.0 m**
Obscuration diameter	-
Focal length	**3998.0 m**
Field of view	-
Fieldstop type	-
Fieldstop size	-
Optical fiber Numerical Aperture	-
Optical fiber manufacturer	-
Optical fiber type	-
Collimation system type	-
Collimation system model	-
Collimation focal length	-

	355 an	355 pc	387	407	532 c an	532 c pc	532 p an	532 p pc	607	1064
Scattering mechanism:	elastically, total signal	elastically, total signal	vibrational rotational Raman at nitrogen molecules	vibrational rotational Raman at water vapor molecules	elastically, cross polarized component	elastically, cross polarized component	elastically, parallel polarized component	elastically, parallel polarized component	vibrational rotational Raman at nitrogen molecules	elastically, total signal
Wavelength separation:		-	-	-		-		-	-	-
Beam telescope distance:	-	-	-	-	-	-	-	-	-	-
Separation Passband bandwidth:	-	-	-	-	-	-	-	-	-	-

Documentation

http://scc-documentation.readthedocs.org/



Documentation - FAQ

http://scc-documentation.readthedocs.org/en/latest/faq.html

Single Calculus Chain

Search docs

Docs » FAQ   View page source

FAQ

- Frequently asked questions
  - Using an ancillary file
  - Reusing an ancillary file
  - Deleting an ancillary file
  - Clouds in the data
  - High/low range channels
  - Variable depolarization factor
  - Extra netcdf parameters
  - Netcdf version
  - Lidar ratio
  - Calculation of Raman and elastic backscatter
  - Filename conventions
  - Photocounting values should be integers
  - Preprocessing failed but no Exit code is provided
  - Optical processing (ELDA) failed but no Exit code is provided

Previous   Next

ELPP err.	Description	N
20	Found mismatch among usecase, product type and given channels	2
22	Found wrong value(s) for variable 'Dead_Time_Corr_Type' in NetCDF file or in SCC_DB	5
23	Found negative number of counts in lidar data!	3
32	Too few lidar profiles or integration time too mutch small	2
33	Cannot calculate the errors after time integration	1
36	Error: Gluing between analog and pc signal not possible. No suitable overlap region can found	33
39	Error: Gluing between analog and pc signal not possible. Slope test not passed	26
40	Error: Gluing between pc signals not possible. No suitable overlap region can found	12
46	Found wrong value(s) for range type id	10
47	Too few lidar points to calculate atmospheric background	2
49	Too few lidar profiles or integration time too mutch small	25
51	Cannot apply dead time correction. Please check the dead time value and your photoncouning raw data	16
77	Found error(s) in SCC_DB for the submitted Measurement_ID	1
104	Dimension 'nb_of_time_scales' not found in Raw Data NetCDF input file	1
107	Incorrect definition of global attribute 'Measurement_ID' in Raw Data NetCDF input file	1
113	Missing one or more channels in NetCDF input file	21
126	Variable 'Pressure_at_Lidar_Station' not found and/or not defined correctly in the Raw Data NetCDF input file	7
130	Found invalid value(s) for Variable 'LR_Input'	3
139	Sounding NetCDF input file not found	1
156	Variable 'Overlap_Function' not found and/or not defined correctly in the Overlap NetCDF input file	5
166	Found negative or not defined value in 'Laser_Shots' array	5
169	Cannot find variable 'Depolarization_Factor' within NetCDF input file.	1
170	Wrong or undefined value for variable 'Depolarization_Factor' within NetCDF input file.	2
174	Sounding file error: 'Altitude' array should contain altitudes in ascendent order	4
178	Dimension 'time' cannot be zero	2

ELDA error code	Description	N
7	Use case not yet implemented	3
13	No valid data points for calibration	227
14	Cannot create merged signal	24
17	Some of the needed options for product calculation were not found in the db. Please check in the products page that all needed values were defined correctly (e.g. product options, monte carlo options, ...).	4
20	Iterative bsc calculation does not converge	36
22	Unknown runtime exception	229
255	Timeout	1

SCC licence

"European Union Public Licence" (EUPL v1.1)

Key points:

- created by European Commission
- designed to be compatible with the law of all the Member States
- has identical value in 22 linguistic versions (all EU languages)
- is an F/OSS licence (Free/Libre/Open Soource Software)
- ensures downstream compatibility issues with the most relevant other licences (including General Public Licence GPL)
- ensures to the author(s) the full ownership of the software with a guarantee that his copyright is publicly known and that his software will never been appropriated by a third party

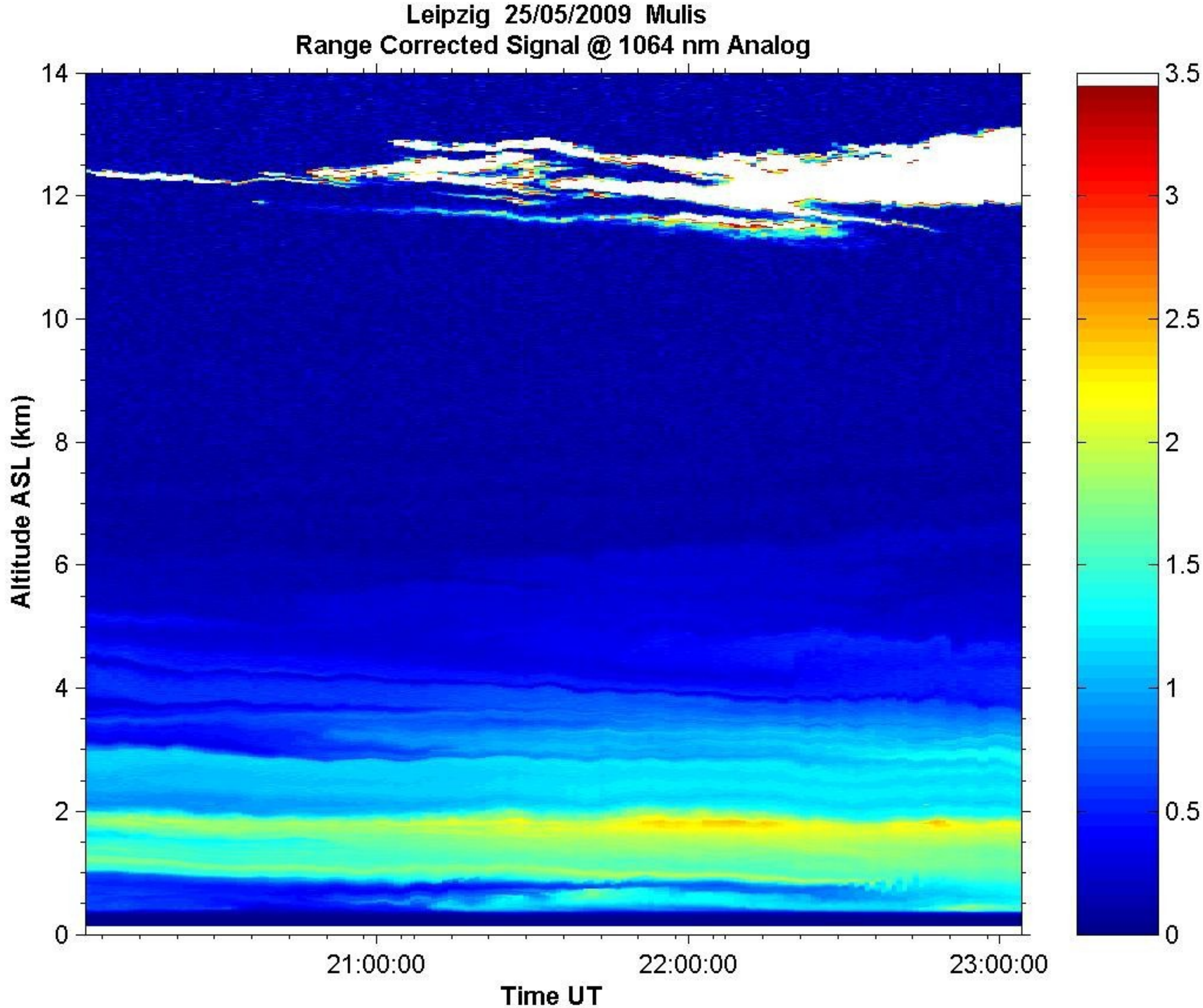
Official information:
https://ioinup.ec.europe.eu/software/page/eupl

SCC licence

"European Union Public Licence" (EUPL v1.1)

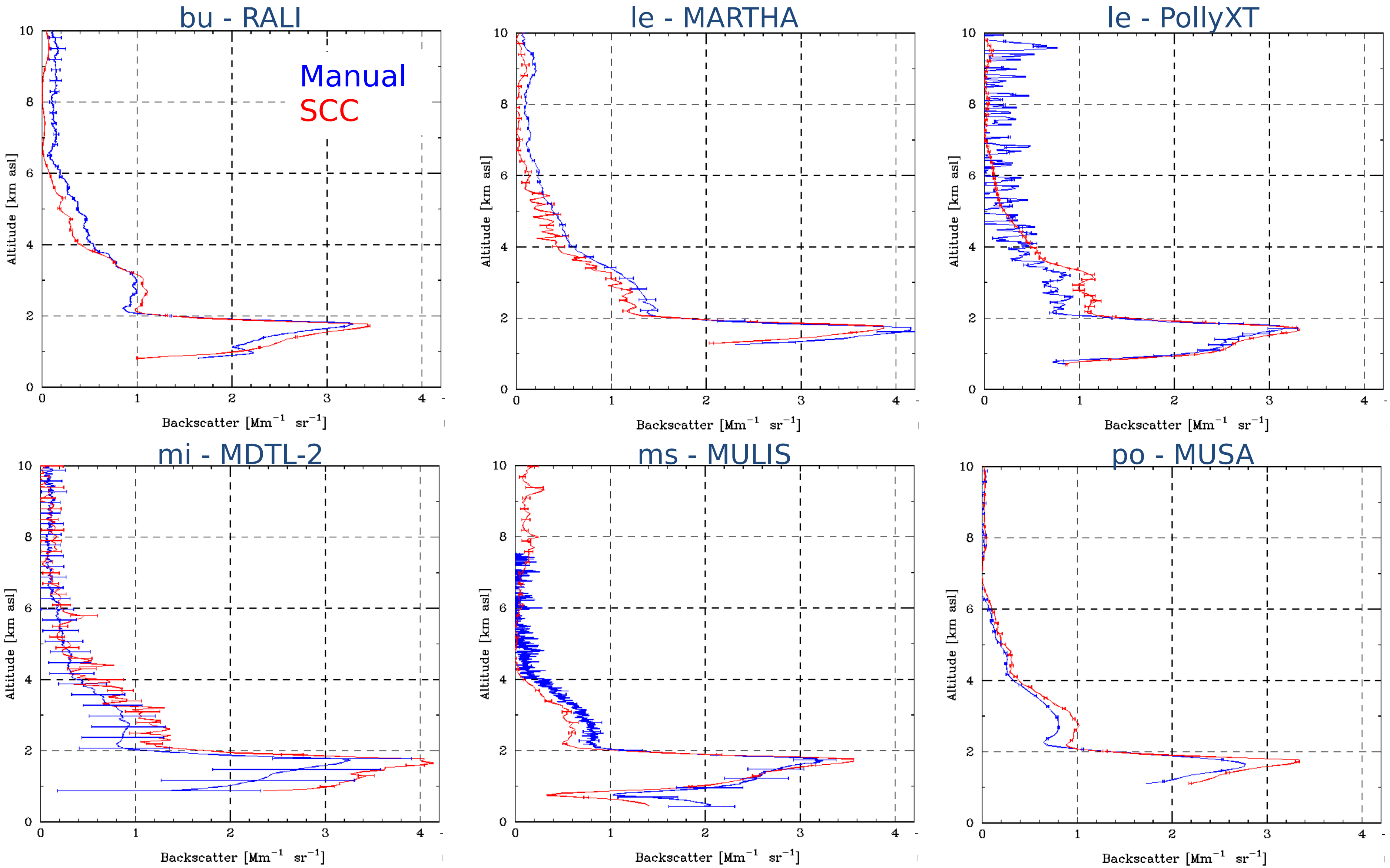
Rights for the subsequent users:

- obtain the source code of the software from a free access repository
- use the software in any circumstance and for all usage
- reproduce (copy, duplicate) the software
- modify the original software and/or make derivative works out of it
- communicate the software to the public
- distribute the software or copies thereof to other users
- if redistribute the software, ensure that it is done under the EUPL licence (or under a compatible licence)


Leipzig 25/05/2009 Mulis
Range Corrected Signal @ 1064 nm Analog
Altitude ASL (km)
Time UT
21:00:00
22:00:00
23:00:00
0
2
4
6
8
10
12
14
0.5
1
1.5
2
2.5
3
3.5

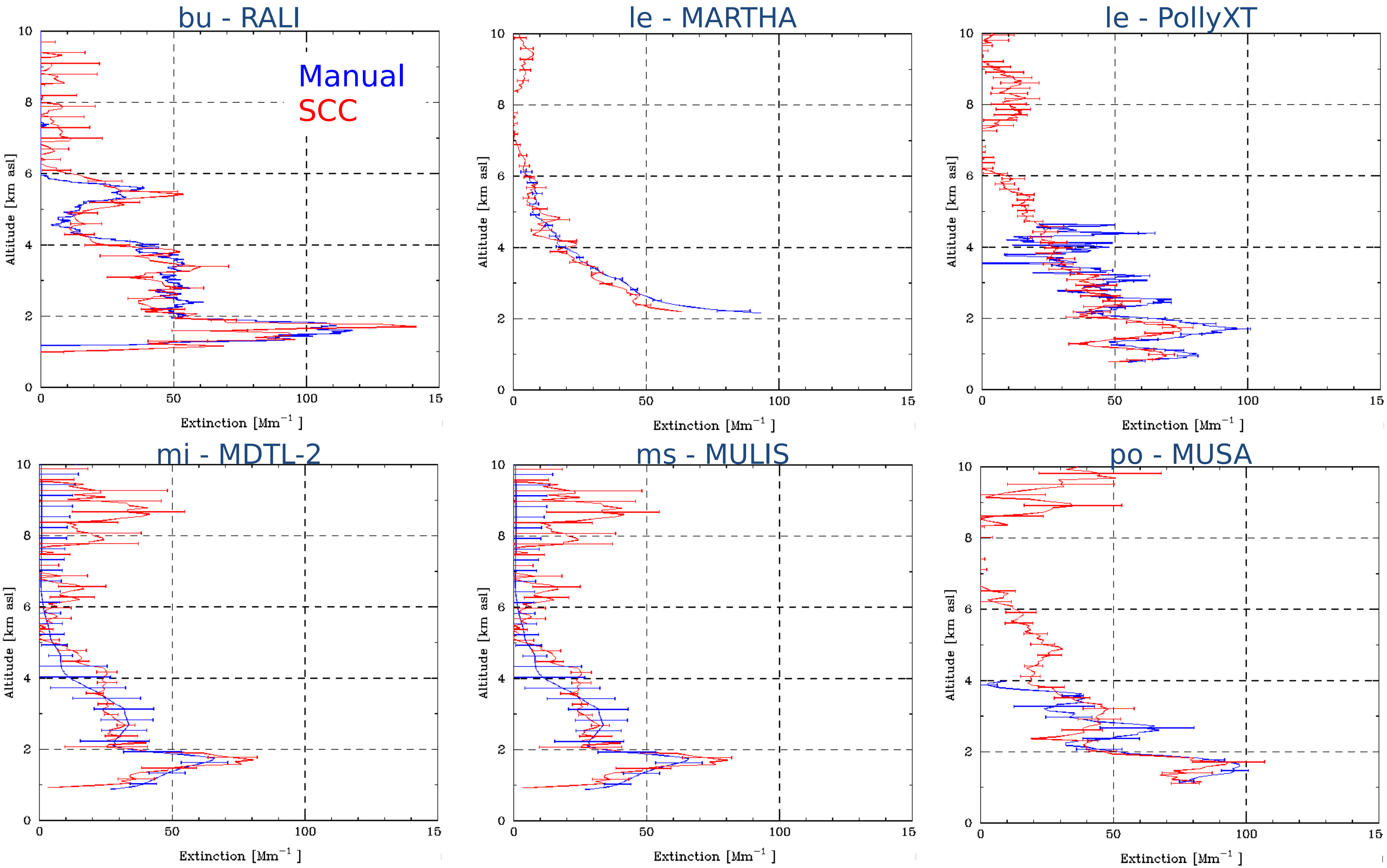
Consiglio Nazionale delle Ricerche

EARLI09 – 25052009 session 4 - b355



Consiglio Nazionale delle Ricerche

EARLI09 – 25052009 session 4 - e532



Mean profile comparisons (po data)

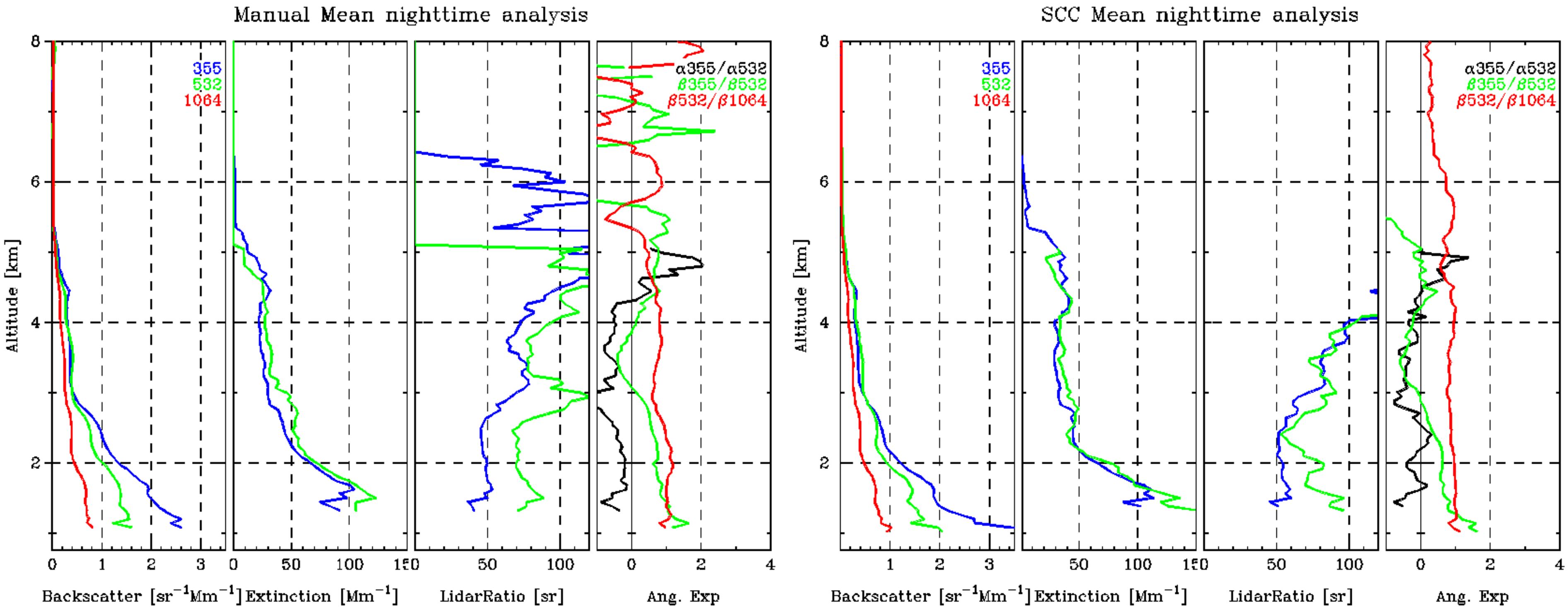
Measurements compared: CALIPSO overpasses uploaded on EARLINET database

Period: from March 2010 up to November 2011

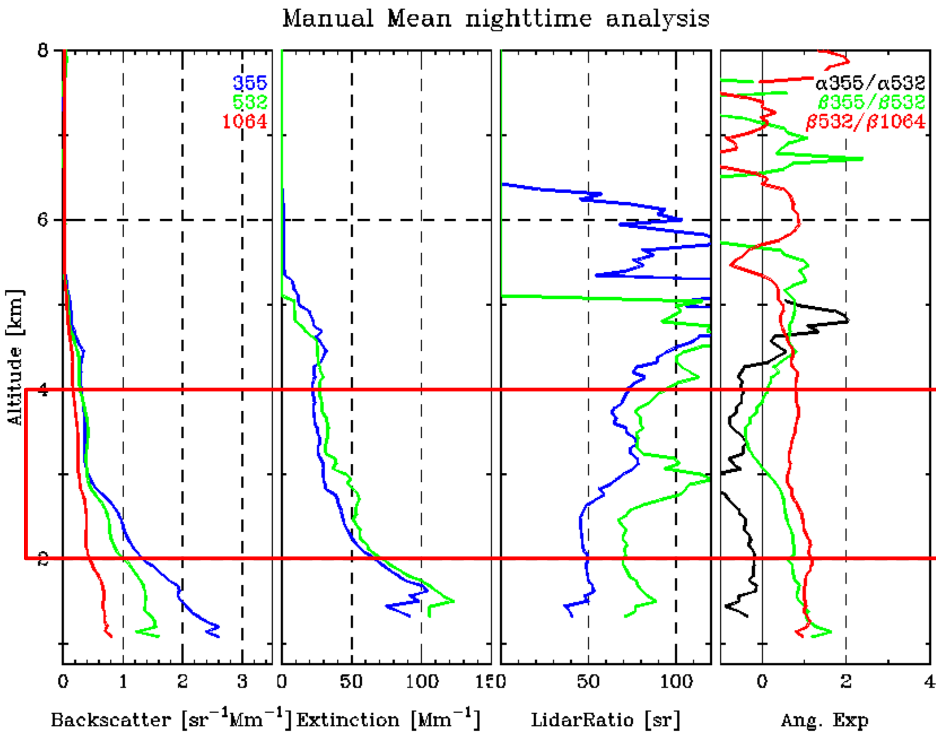
Number of profiles compared:

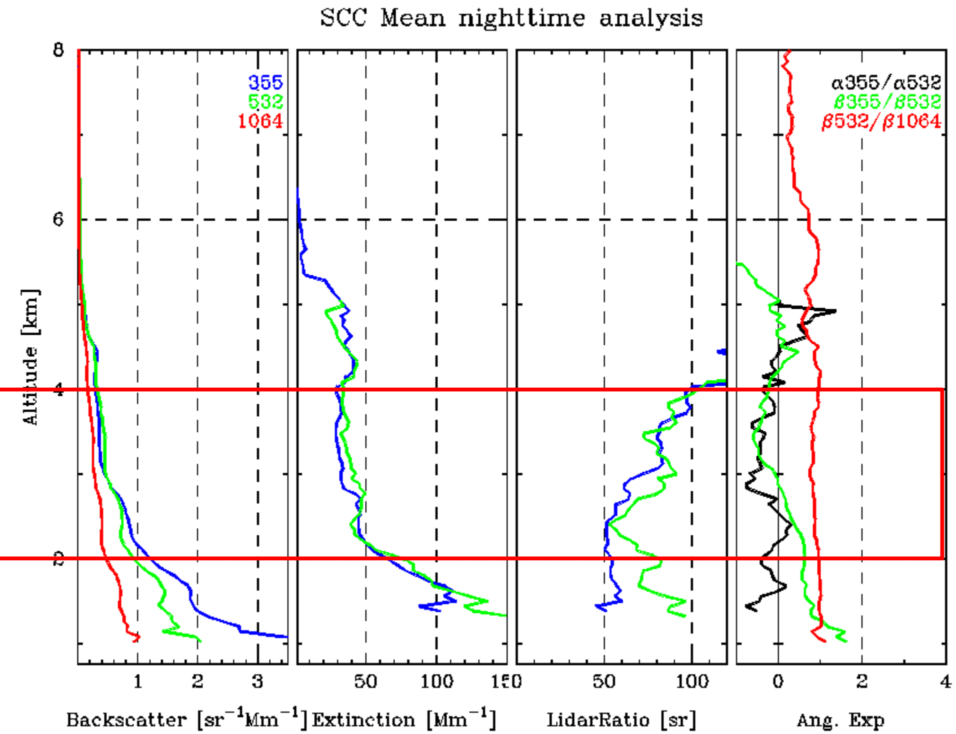
	Nighttime	Daytime
b1064	23	12
b532	20	12
b355	24	10
e532	16	-
e355	14	-

Mean profile comparisons (po data)



Mean profile comparisons (po data)

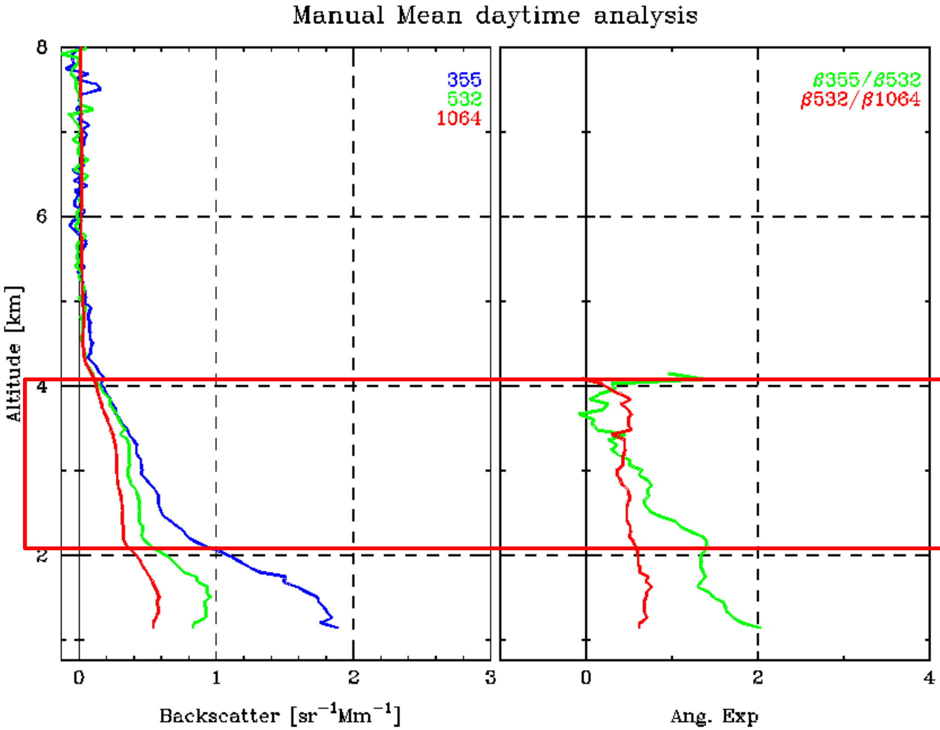


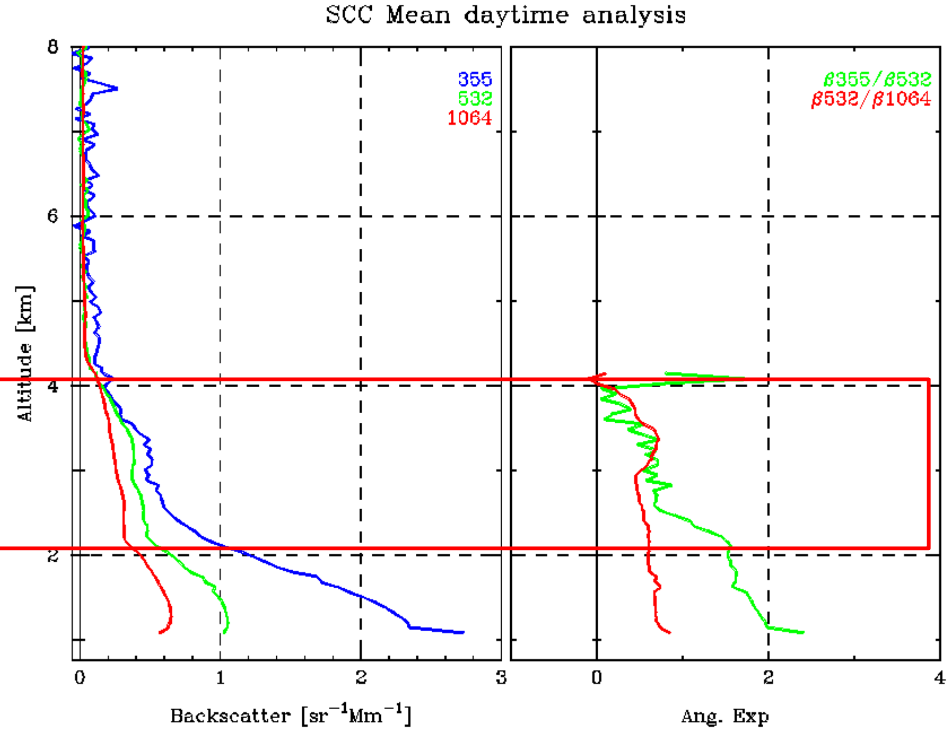


λ [nm]	β [$sr^{-1}Mm^{-1}$]	α [Mm^{-1}]	*LR* [sr]
355	0.60	35.74	60.0
532	0.54	43.81	81.1
1064	0.29	-	-

λ [nm]	β [$sr^{-1}Mm^{-1}$]	α [Mm^{-1}]	*LR* [sr]
355	0.58	37.86	65.2
532	0.56	41.73	74.5
1064	0.31	-	-

Mean profile comparisons (po data)



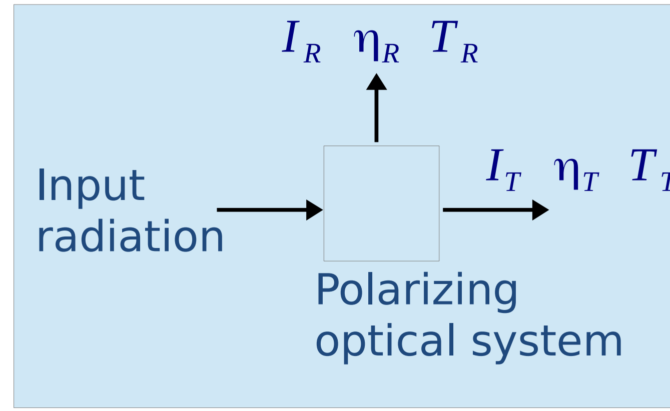


λ [nm]	β [sr^{-1}Mm^{-1}]
355	0.52
532	0.37
1064	0.25

λ [nm]	β [sr^{-1}Mm^{-1}]
355	0.54
532	0.39
1064	0.26

General procedure to get PLDR

Experimantal set-up



- Get the polarization channel gain factor from calibration measurements

$$\eta = \frac{\eta_T T_T}{\eta_R T_R}$$

- Calculate the quantity:

$$\delta^* = \frac{1}{\eta} \frac{I_T}{I_R}$$

if I_T=cross channel, I_R=parallel channel → δ^* = "apparent" VLDR

- Get the VLDR and the total intensity correcting for systematic effects due to not perfect optics and alignment (cross-talk, diattenuation):

$$\delta_V = \frac{\delta^*(G_R + H_R) - (G_T + H_T)}{(G_T - H_T) - \delta^*(G_R - H_R)}$$

$$I_{total} \propto \frac{1}{\eta} H_R I_T - H_T I_R$$

G_T H_T = pol. cross-talk correction parameters for transmitted channel

G_R H_R = pol. cross-talk correction parameters for reflected channel

- Get PLDR from VLDR and backscatter coefficient

Particle linear depol. implementation

Some definitions:

Linear Molecular Depolarization Ratio

$$\delta_m = \frac{\beta_\perp^m}{\beta_\parallel^m}$$

Volume Linear Depolarization Ratio

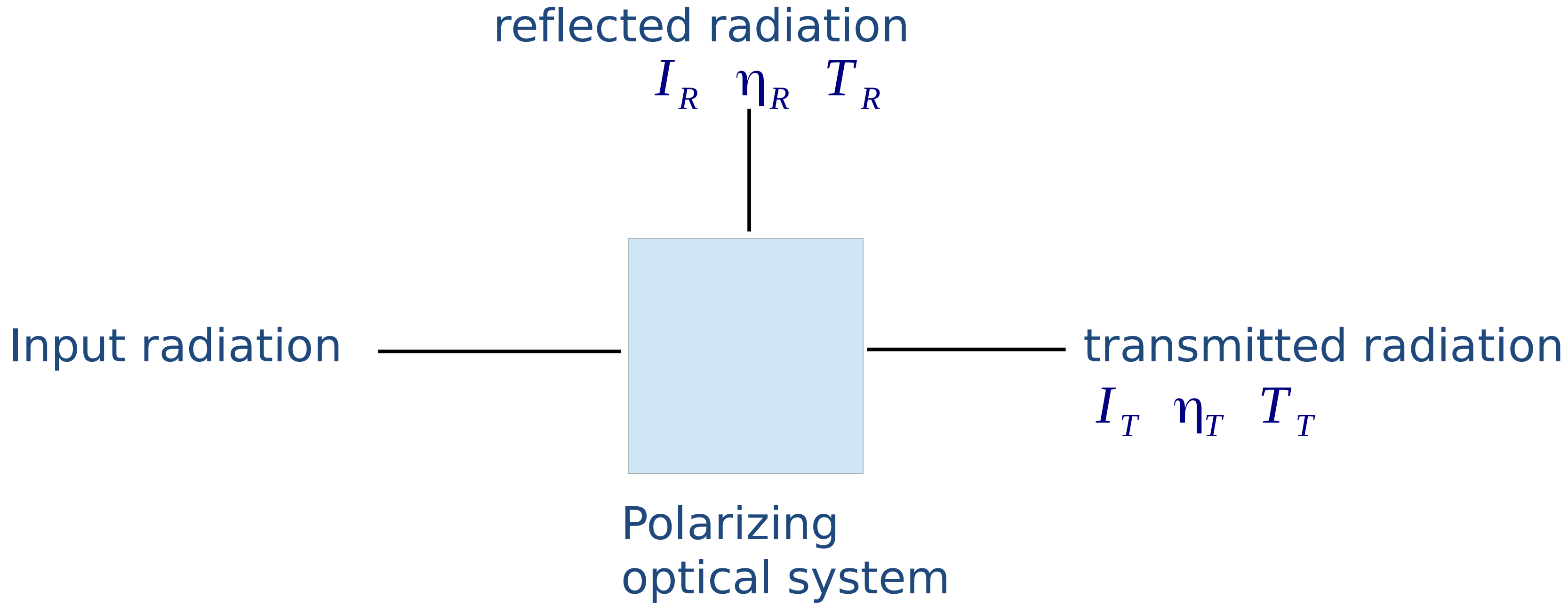
$$\delta_v = \frac{\beta_\perp^m + \beta_\perp^p}{\beta_\parallel^m + \beta_\parallel^p}$$

Particle Linear Depolarization Ratio

$$\delta_a = \frac{\beta_\perp^p}{\beta_\parallel^p} = \frac{(1+\delta_m)\delta_v R - (1+\delta_v)\delta_m}{(1+\delta_m)R - (1+\delta_v)}$$

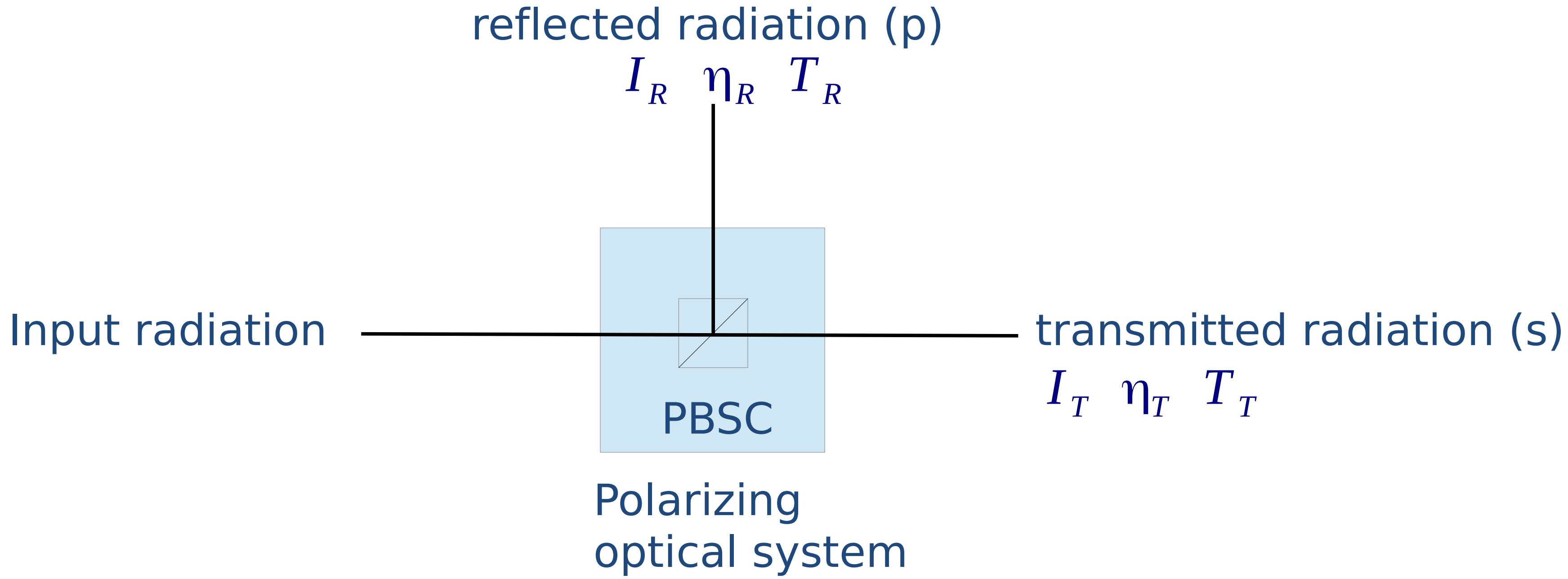
Particle linear depol. implementation

General polarization sensitive lidar channels setup



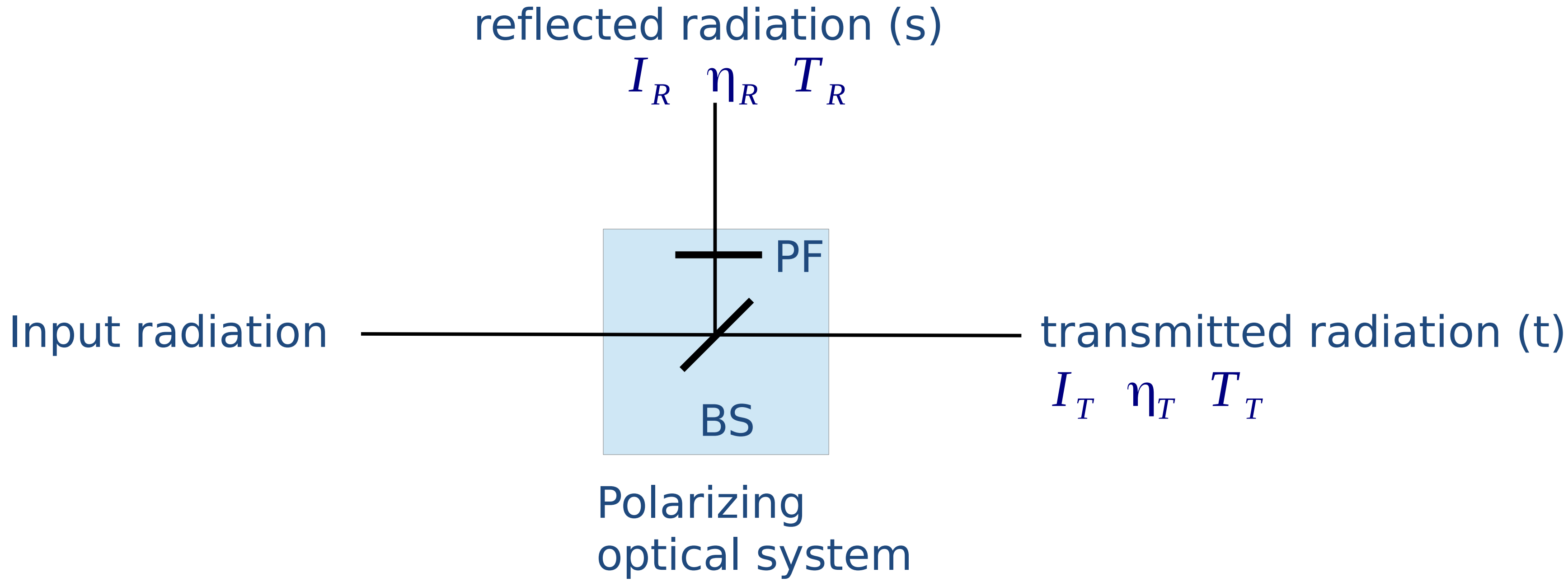
Particle linear depol. implementation

General polarization sensitive lidar channels setup



Particle linear depol. implementation

General polarization sensitive lidar channels setup



Calibration of Pol. Sensitive lidar channels

Commonly calibration procedures:

- Rayleigh calibration
- +45 calibration method or $\Delta 90$ calibration method (made by +45 and -45 measurements)
- 3 signals method (total, cross and parallel)

It is well known that Rayleigh calibration could produce easily large errors on PLDR which cannot be controlled.

Only the methods b) and c) can be used to provide reliable polarization calibrations

Calibration of Pol. Sensitive lidar channels

+45 calibration method or $\Delta 90$ calibration method:

Make measurements with the polarization rotated of +45 or -45 degree with respect to the “zero” position (usually by means of waveplate)

$$\eta^*(\pm 45) = \frac{I_T(\pm 45)}{I_R(\pm 45)}$$

+45 calibration method

$$\eta = \eta^*(+45)$$

$\Delta 90$ calibration method

$$\eta = \sqrt{\eta^*(+45)\,\eta^*(-45)}$$

Consiglio Nazionale delle Ricerche

Calibration of Pol. Sensitive lidar channels

The 3 signals method consists in solving the equation:

$$a_s I_s + a_p I_p = I_t$$

in two type of atmospheric layers with considerably different VLDR.

To calibrate in this way it is necessary to detect the total, cross and parallel polarization components.

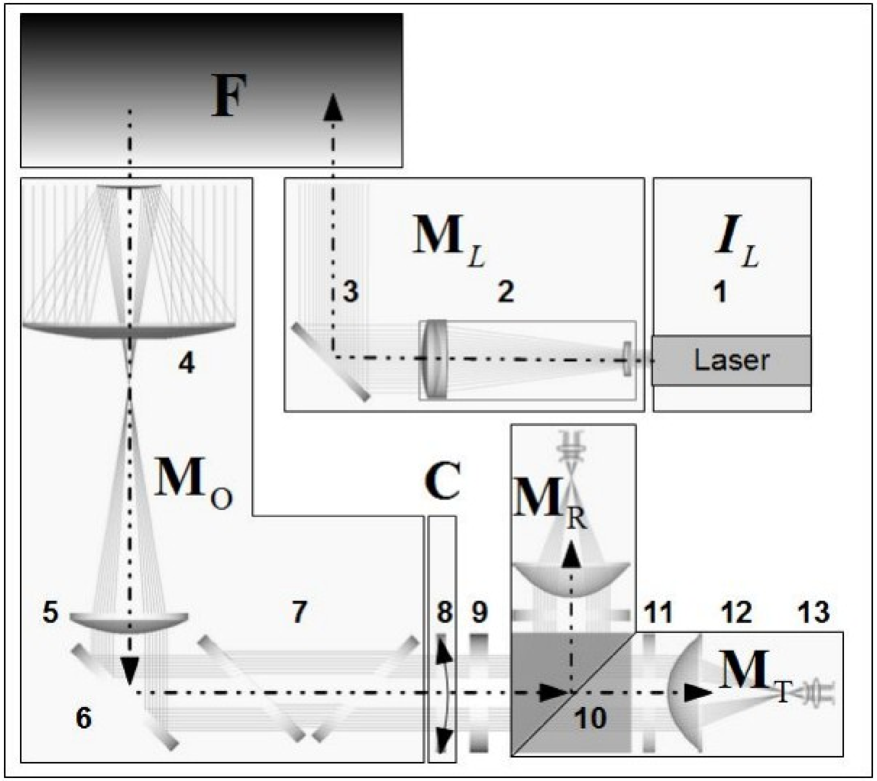
Configuration not so common; tests are ongoing

At moment this calibration method is not yet implemented in the SCC

Only the +45 and $\Delta 90$ calibration methods are implemented

Polarization cross-talk correction parameters

General lidar system setup



$$I_{T,R} = \eta_{T,R} \mathbf{M}_{T,R} \mathbf{C} \mathbf{M}_O \mathbf{F} \mathbf{M}_L I_L$$

$\eta_{T,R} \Rightarrow \eta_S$ electronic gains and optical attenuation (non polarised)

Polarization cross-talk correction parameters

$$\delta' = \frac{\delta^*(G_R + H_R) - (G_T + H_T)}{(G_T - H_T) - \delta^*(G_R - H_R)}$$

$$\delta' = \frac{\delta_V + \delta_L}{1 + \delta_V \delta_L} \quad if \quad \delta_L \ll \delta_V \quad \delta' \approx \delta_V + \delta_L$$

$$I_{total} \propto \frac{1}{\eta} H_R I_T - H_T I_R$$

To get the parameters *G* and *T* we need to perform specific measurements on lidar setup to find:

- diattenuation of all the optics
- misalignments due to unwanted rotation of polarization axis
- cross-talk factors

Polarization cross-talk correction parameters

$$\delta' = \frac{\delta^*(G_R + H_R) - (G_T + H_T)}{(G_T - H_T) - \delta^*(G_R - H_R)} \qquad I_{total} \propto \frac{1}{\eta} H_R I_T - H_T I_R \qquad \delta^* = \frac{1}{\eta} \frac{I_T}{I_R}$$

Ideal systems:

Laser polarization	Detected in lidar channel			
	Transmitted		Reflected	
	G_T	H_T	G_R	H_R
total	1	0	1	0
parallel	1	1	1	1
cross	1	-1	1	-1

Examples:

transmitted=cross
reflected=parallel

$$\delta_V = \delta' = \delta^* = \frac{1}{\eta} \frac{I_T}{I_R} \qquad I_{total} \propto \frac{1}{\eta} I_T + I_R$$

transmitted=cross
reflected=total

$$\delta_V = \delta' = \frac{\delta^*}{2 - \delta^*} \qquad I_{total} \propto I_R$$

SCC implementation of PLDR

SCC_DB

Calibration configuration:

channels: ±45elPT, ±45elPR

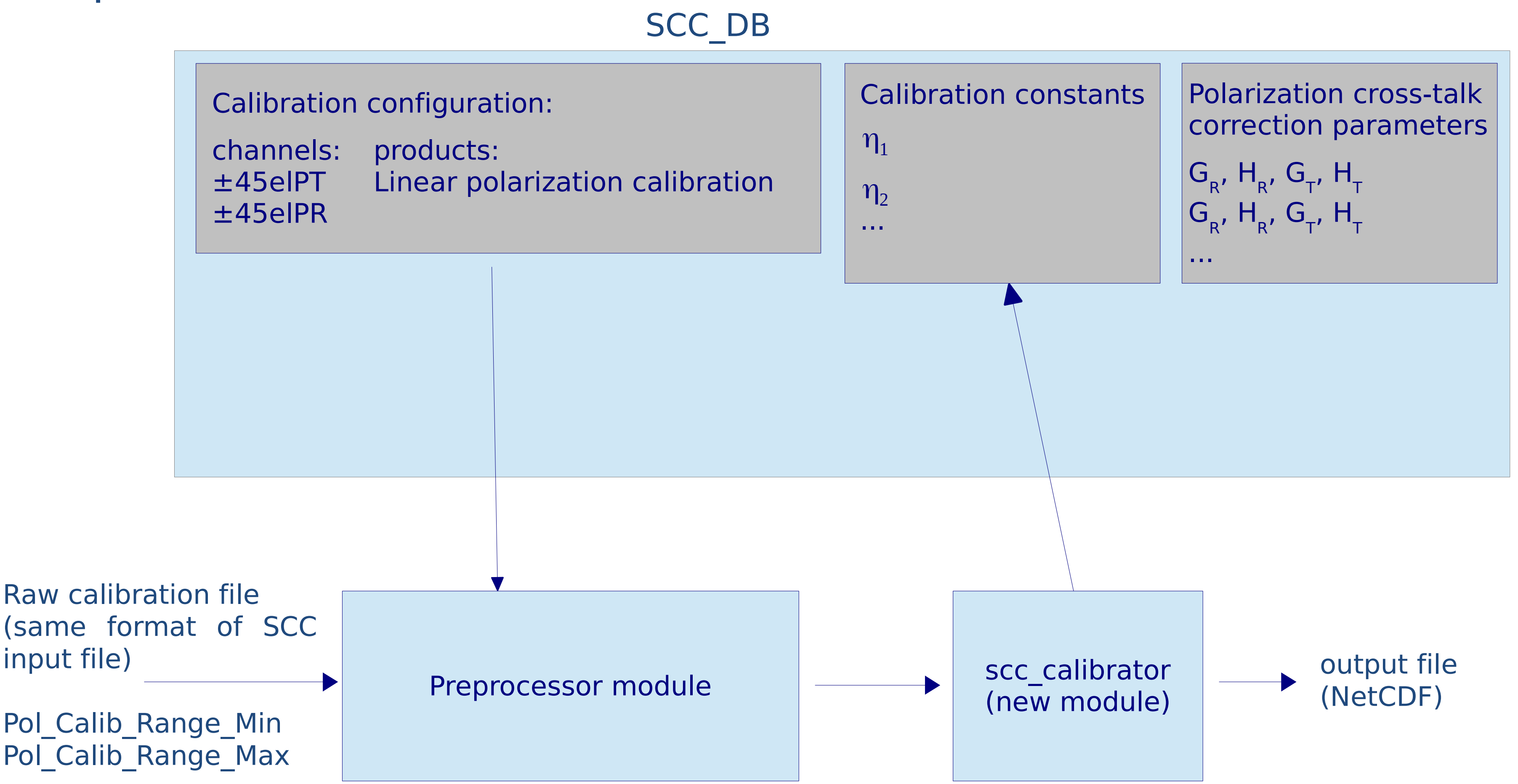
products: Linear polarization calibration

Polarization cross-talk correction parameters

G_R, H_R, G_T, H_T
G_R, H_R, G_T, H_T
...

SCC implementation of PLDR

Step 1: Calibration



SCC implementation of PLDR

Step 2: PLDR Calculation

SCC_DB

Calibration configuration:

channels:	products:
±45elPT	Linear polarization calibration
±45elPR	

Measurement configuration:

channels:	products:
elPT	Raman bck and PLDR
elPR	
vrRN2	

Calibration constants

η_1

η_2

...

Polarization cross-talk correction parameters

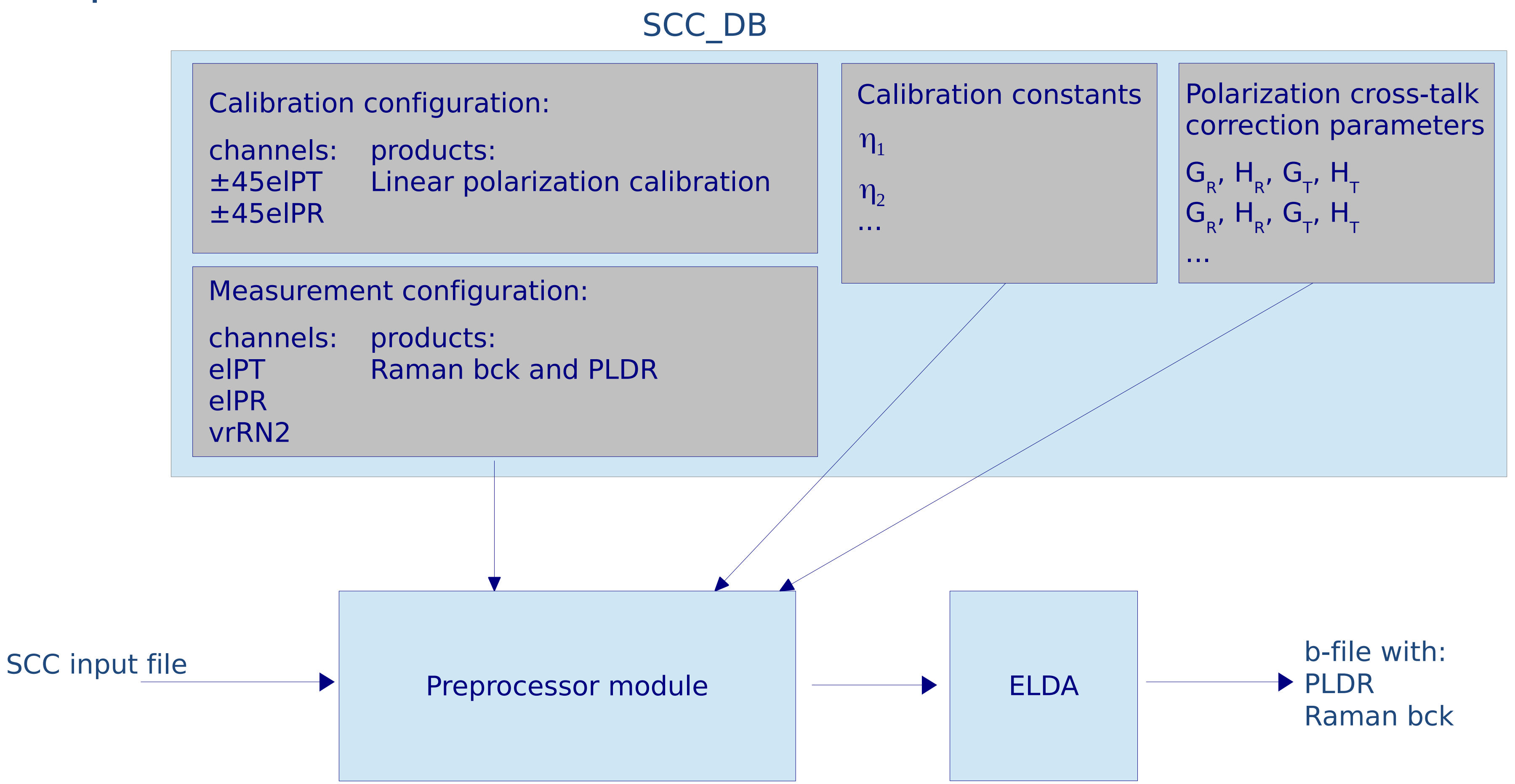
G_R, H_R, G_T, H_T

G_R, H_R, G_T, H_T

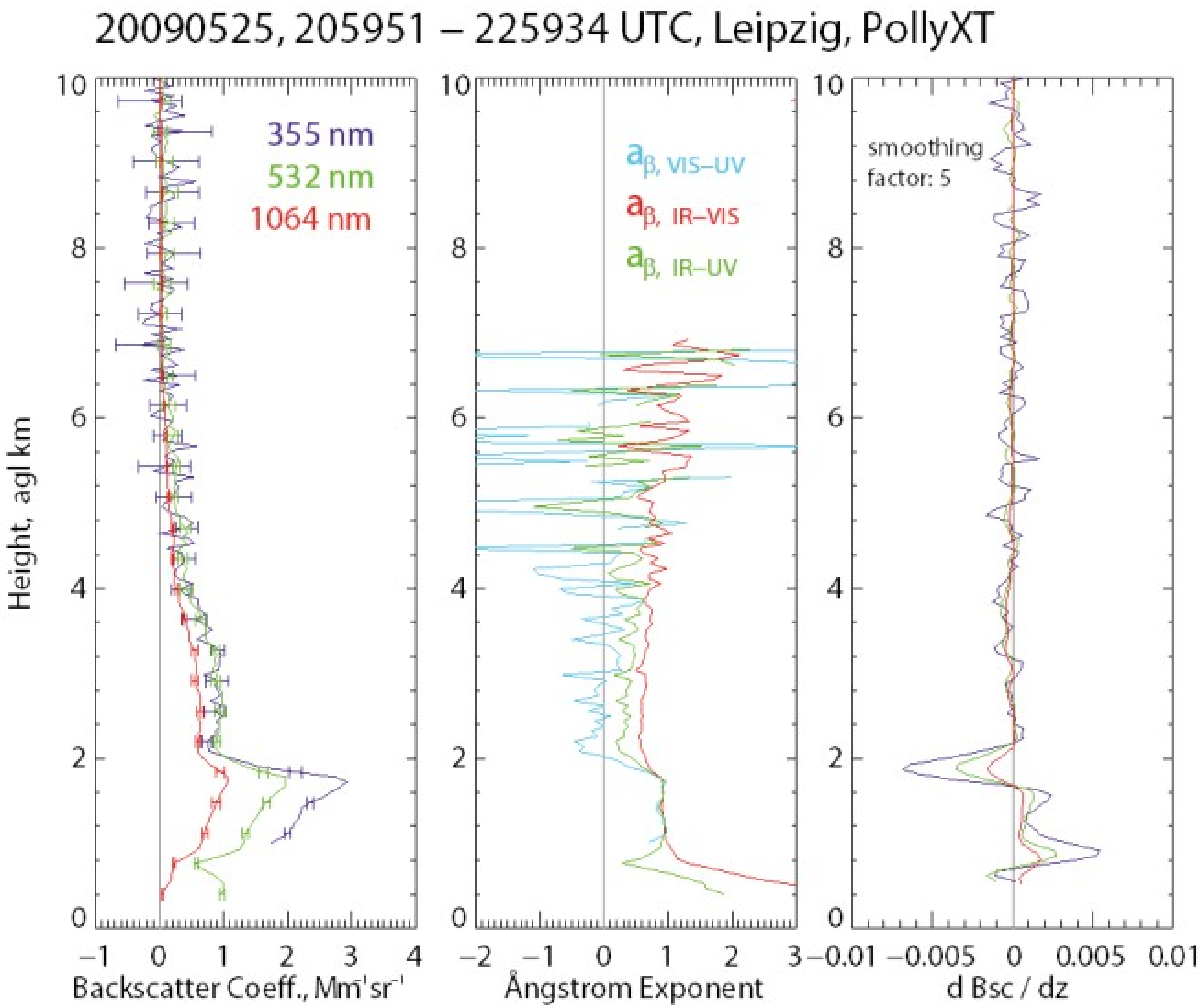
...

SCC implementation of PLDR

Step 2: PLDR Calculation



Automatic layer detection



Automatic cloud mask (WCT)

Basic idea:

- decomposition of the range-corrected elastic signal using wavelets
- determination of cloud base and top by putting thresholds in the wavelet space

$$R(z,\lambda)=P(z,\lambda)z^2=P_0 O(z) C_s(\lambda)\beta(z,\lambda)\exp\left[-2\int_0^z \alpha(r,\lambda)dr\right]$$

Wavelet transform

$$W_R(a,b,\lambda)=\frac{1}{a}\int_{z_b}^{z_t} R(z,\lambda)H\left(\frac{z-b}{a}\right)dz$$

Automatic cloud mask (WCT)

$$W_R(a,b,\lambda)=\frac{1}{a}\int_{z_b}^{z_t} R(z,\lambda)\,H\left(\frac{z-b}{a}\right)dz$$

$$H\left(\frac{z-b}{a}\right)=\begin{cases}+1 & b-\frac{a}{2}\leqslant z\leqslant b\\ -1 & b\leqslant z\leqslant b+\frac{a}{2}\\ 0 & otherwise\end{cases}$$

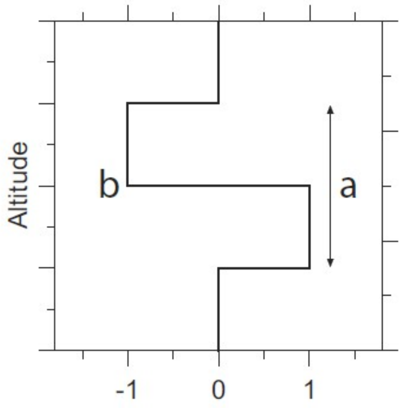


Figure 4.1: Shape of the Haar function.

$$W_R(a,b,\lambda)=\frac{1}{n}\left(\sum_{b-\frac{a}{2}}^{b} R(z,\lambda)-\sum_{b}^{b+\frac{a}{2}} R(z,\lambda)\right)$$

dilatation a → fixed (180m)

translation b → height above lidar

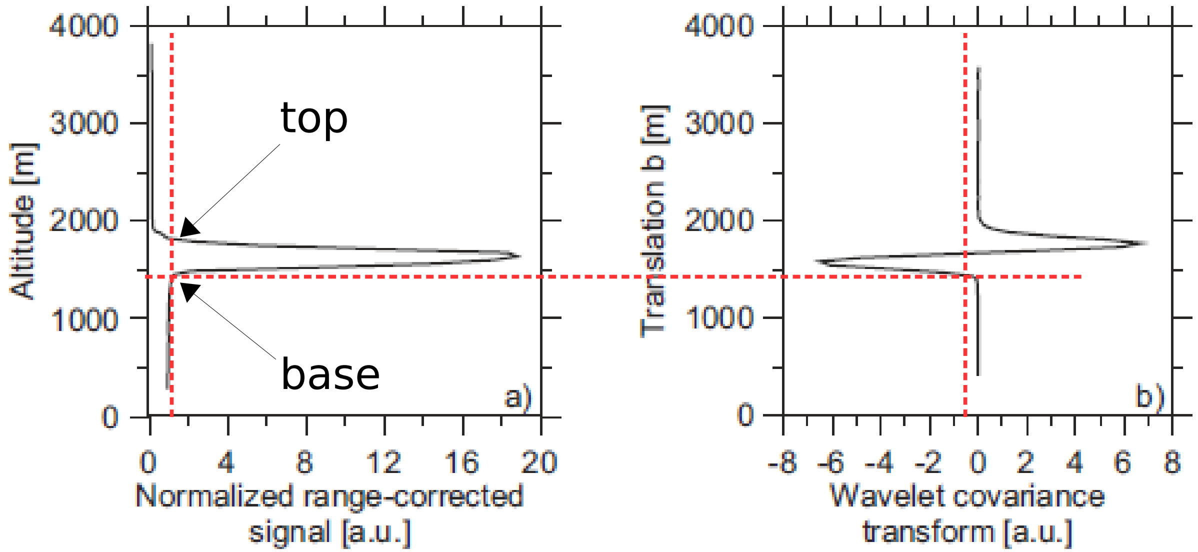
Automatic cloud mask (WCT)

Cloud base detection

$$\begin{cases} W_R(a,b,\lambda)=W_{th}=-0.5 \\ SNR \geqslant 2 \end{cases}$$

Cloud top detection

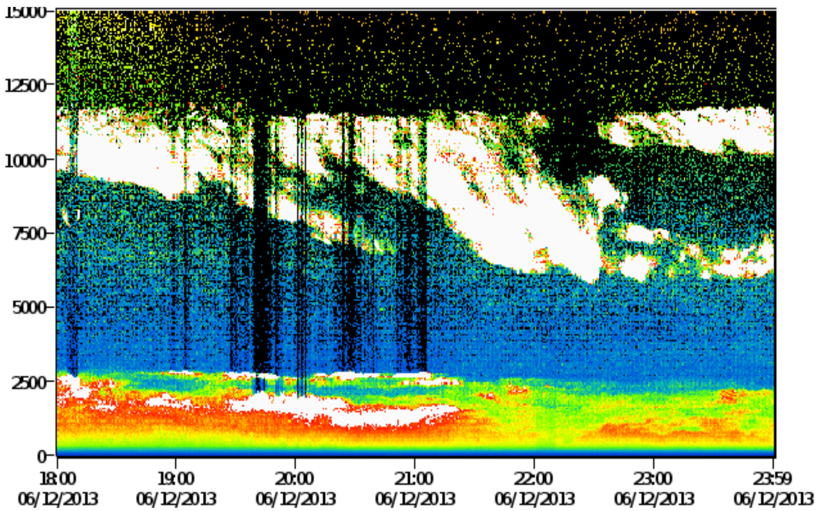
$$\begin{cases} z > z_{base} \\ R(z,\lambda)=R(z_{base},\lambda) \\ SNR \geqslant 2 \end{cases}$$



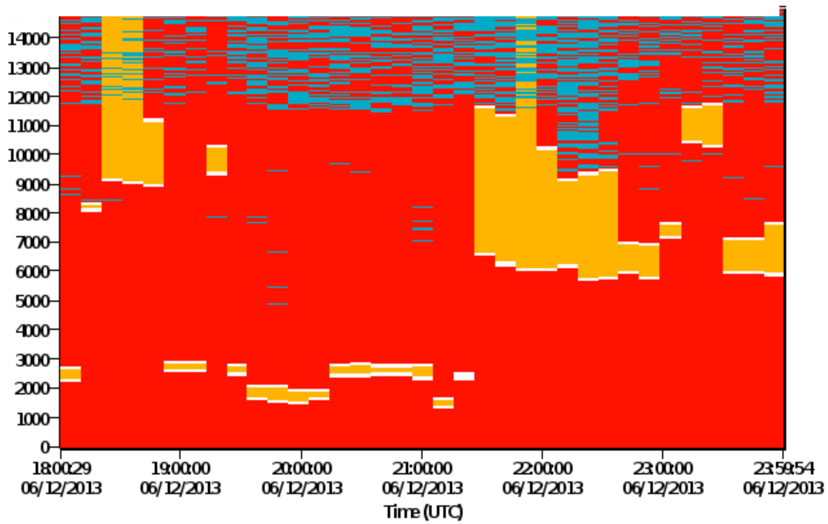
Consiglio Nazionale delle Ricerche

Automatic cloud mask (WCT)

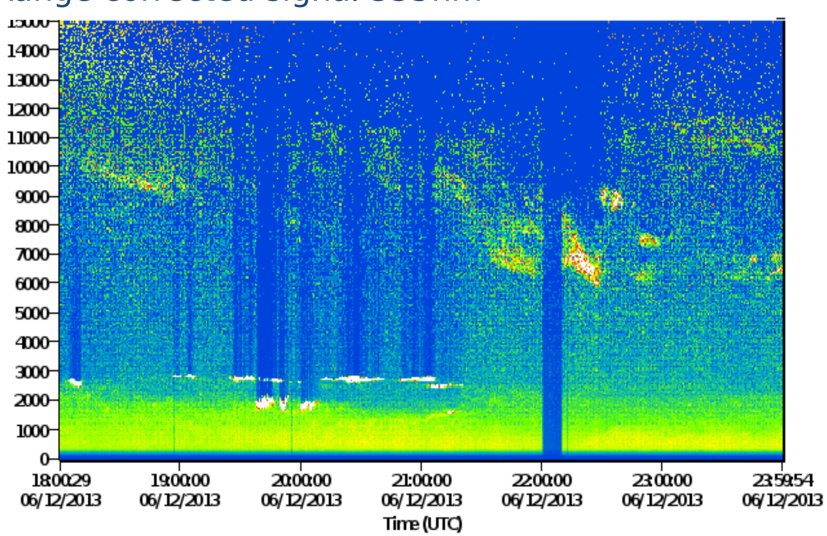
Range corrected signal 1064nm

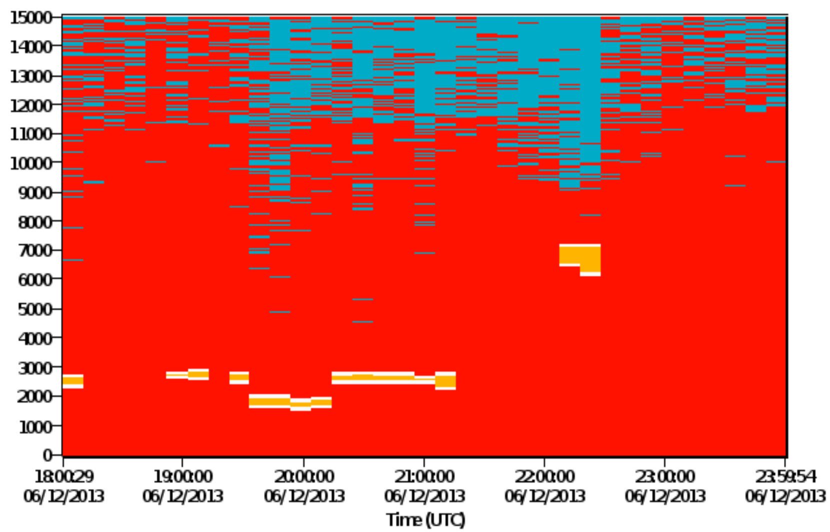


Red: valid signal (SNR > 2), Blue: noise
Black: cloud base, White: could top , Orange: could



Range corrected signal 355nm





Automatic cloud mask (WCT)

Critical points:

- No physically meaningful thresholds
- Fail detection may occur in case of strong separated aerosol layers
- Non-detection may happen in case of very low clouds, i.e., when the cloud starts below the valid lidar profile but is existent also in the lowermost lidar profile. Then of course, no gradient can be observed…

Automatic cloud mask
Physically meaningful thresholds

Critical points:

- High temporal resolution aerosol optical parameters are needed (mainly particle backscatter and volume or particle linear depolarisation ratio)

Automatic cloud mask (KNN) (still in experimental phase!)

How the KNN algorithm works?

- it's the simplest procedure belonging to the class of techniques know as supervised machine learning algorithms
- definition of a set of parameters (classifiers) from the dataset forming a vector $x_1, x_2, \ldots, x_n$
- Feature space: space in which the vectors x_i belong

- **Step1: Training the algorithm**
  define a set of training vectors in the features space assigning to each of them a class label

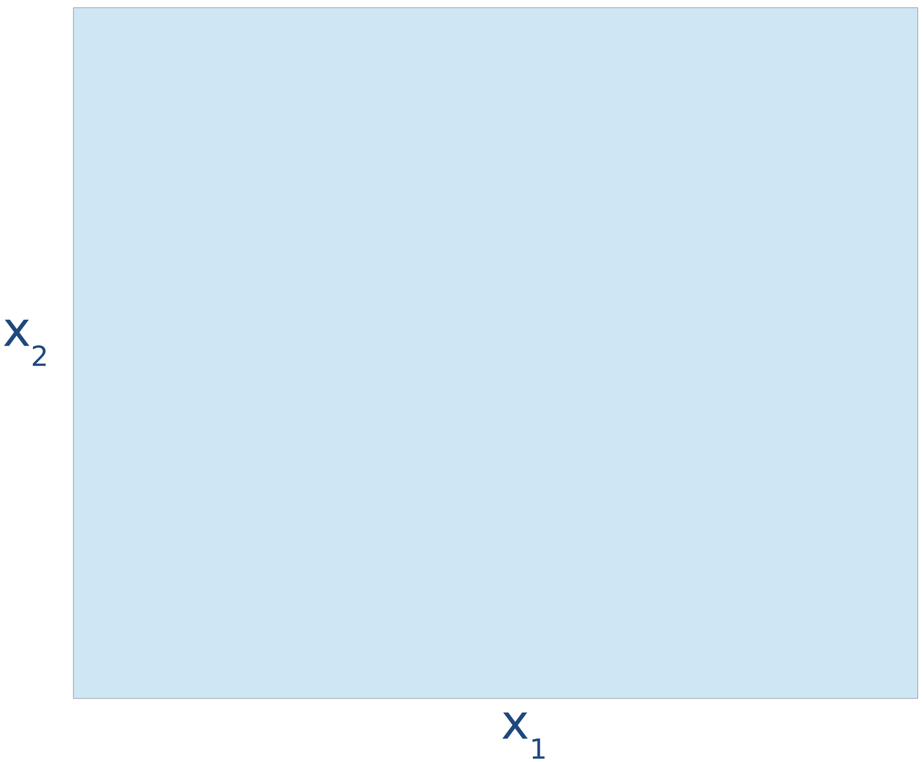
- **Step2: Classification**
  an unlabelled vector is classified by assigning the label which is most frequent among k nearest neighbors training vectors (k is an user-defined constant)

Duda, Richard O., Peter E Hart, and David G. Strok, Pattern Classification. New York: Wiley 2001

KNN algorithm

Very basic example

2-dimensional feature space



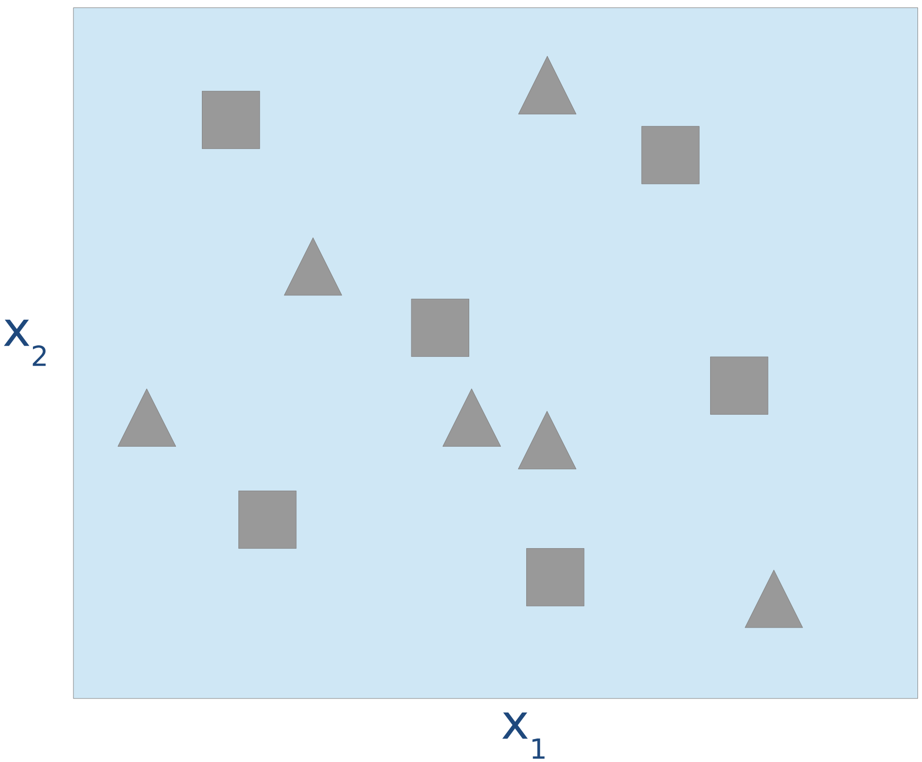
2-classes: squares, triangles

Final goal:
Points (x_1,x_2) have to be labelled as square or as triangles on the base of their position in the feature space

KNN algorithm

Very basic example

2-dimensional feature space



2-classes: squares, triangles

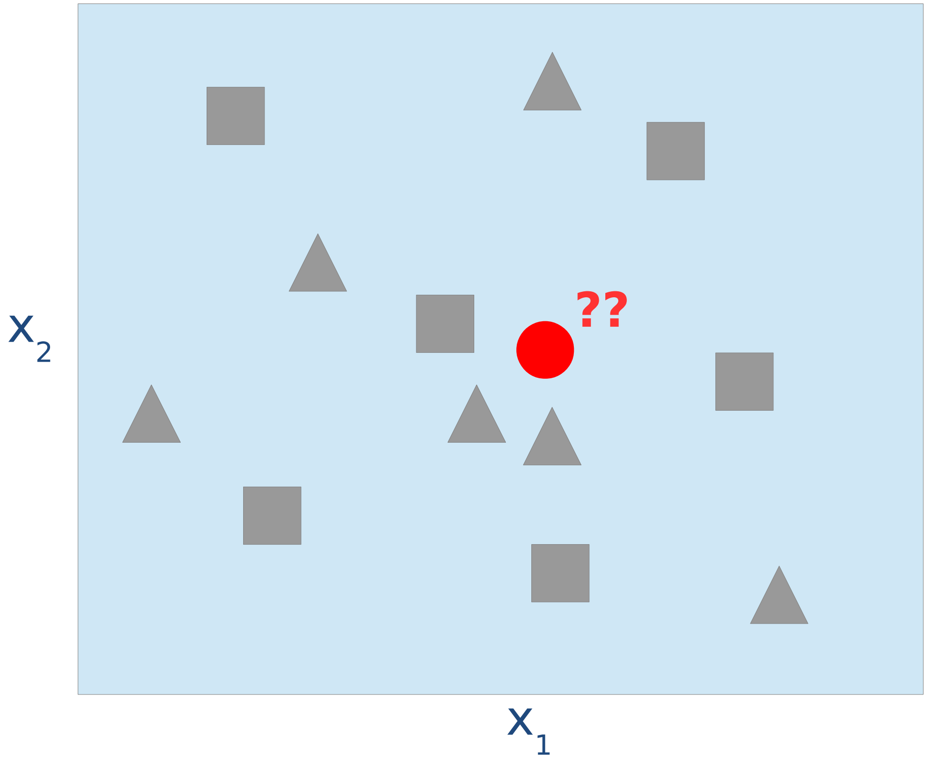
Final goal:
Points (x_1,x_2) have to be labelled as square or as triangles on the base of their position in the feature space

Training: define training vectors (points we know a-priori the class)

KNN algorithm

Very basic example

2-dimensional feature space



2-classes: squares, triangles

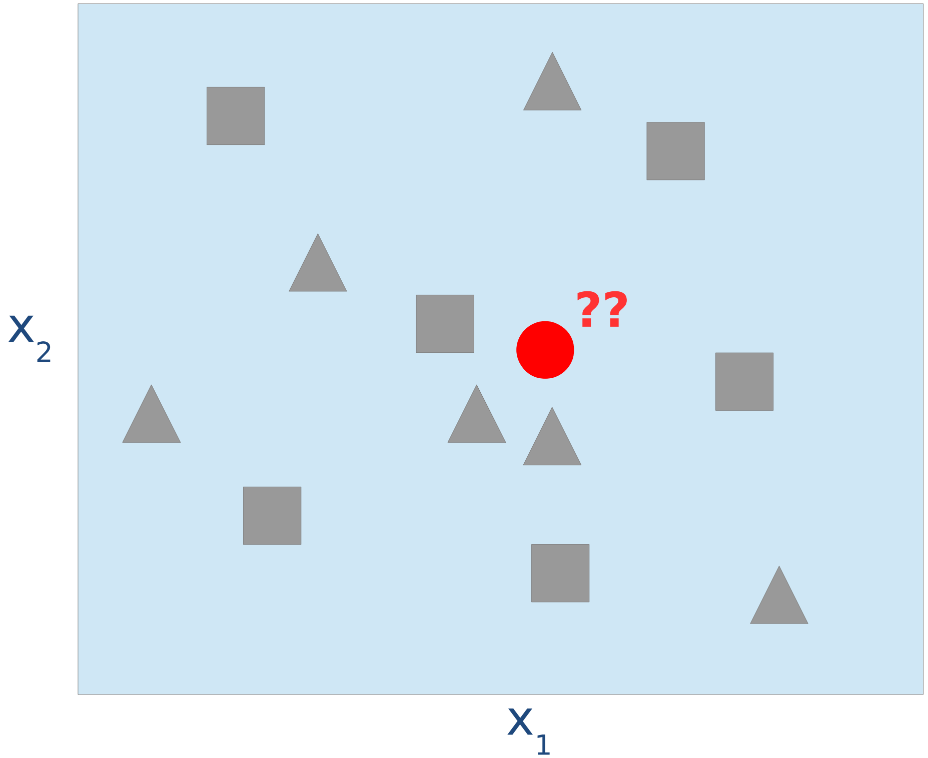
Final goal:
Points (x_1,x_2) have to be labelled as square or as triangles on the base of their position in the feature space

Which is the class to assign to new point?

KNN algorithm

Very basic example

2-dimensional feature space



2-classes: squares, triangles

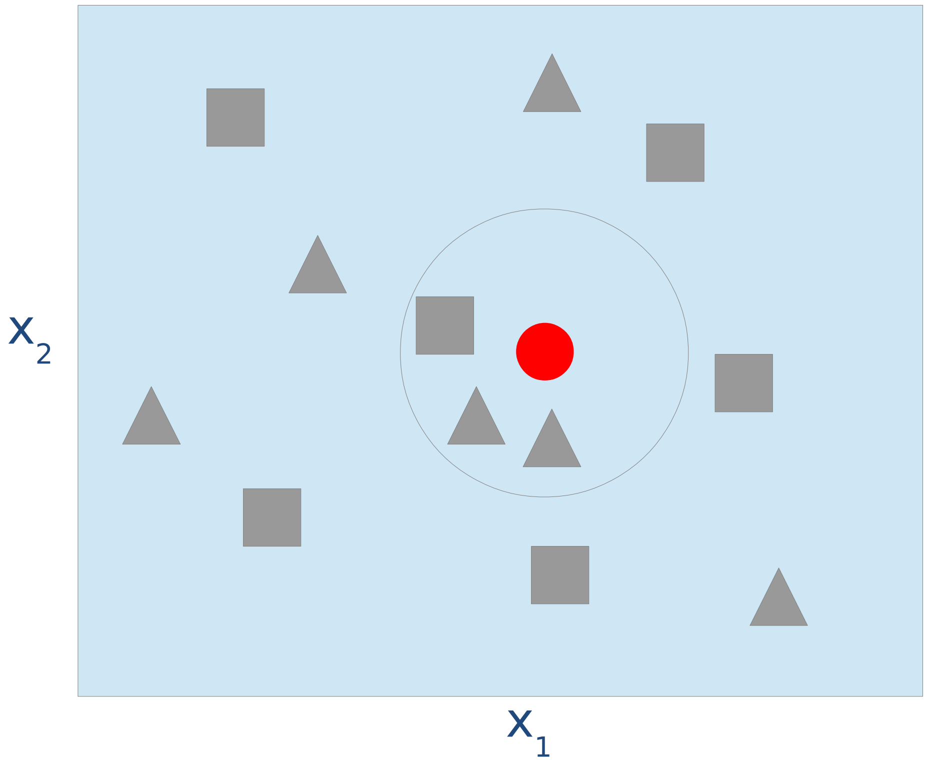
Final goal:
Points (x_1,x_2) have to be labelled as square or as triangles on the base of their position in the feature space

Which is the class to assign to new point?

KNN algorithm

Very basic example

2-dimensional feature space



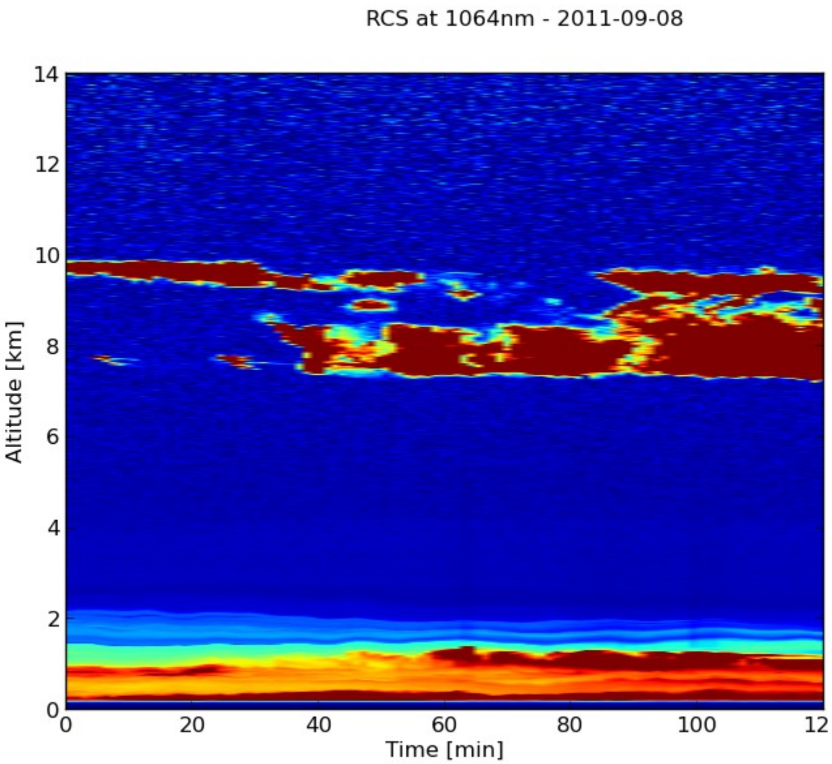
2-classes: squares, triangles

Final goal:
Points (x_1,x_2) have to be labelled as square or as triangles on the base of their position in the feature space

Classification: most frequent among k nearest neighbors training vectors (k=3) → triangle

Automatic cloud mask (KNN)
(still in experimental phase!)

How to apply to extend to cloud detection?



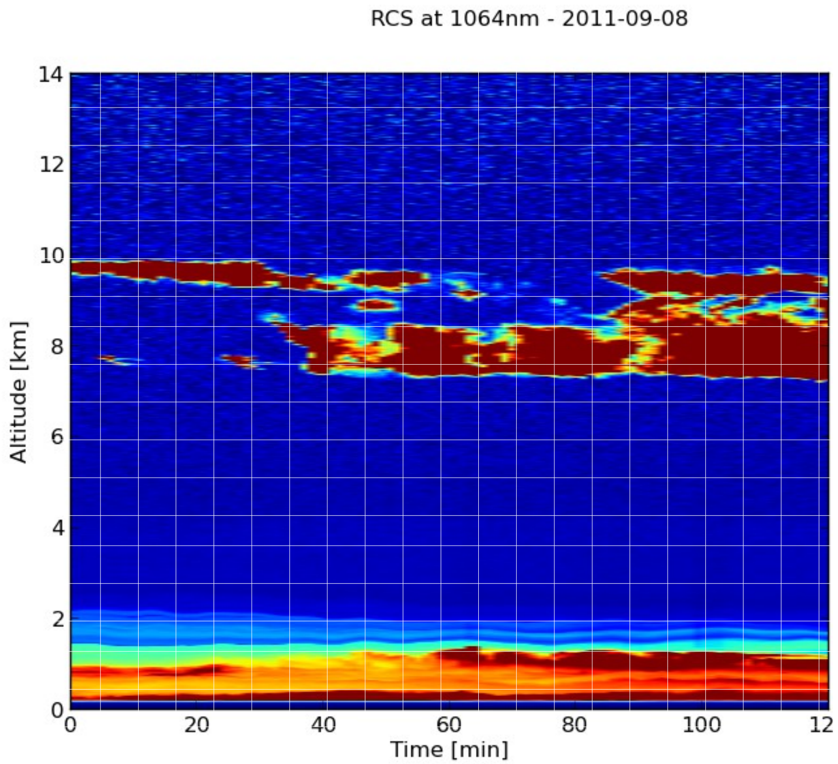
Classes: cloud,no-cloud

Classifiers:

- SNR at each point of the map

Automatic cloud mask (KNN) (still in experimental phase!)

How to apply to extend to cloud detection?



Classes: cloud,no-cloud

Classifiers:

- SNR at each point of the map
- SNR for a grid 5x 5
- max_{grid} - min_{grid}
- time variability within the grid (calculated as standard deviation)
- vertical variability within the grid
- ratio of the horizontal variability to the total variability within the grid

Feature space dim. = 6

Automatic cloud mask (KNN)
(still in experimental phase!)

Critical points:

- not all the classifiers are system independent.
  In particular the ones depending on SNR can depend strongly from the lidar system and make the whole method less general and robust. However some tests are in progress to try to find the best trade off between system independency and classification accuracy

- full assessment of the applicability of the approach to cloud detection is needed