LB100-ESS-D200
Backscatter Scanning LIDAR

DOC 0201

September 2013

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PREFACE

This User's Manual contains the technical information needed to properly operate and maintain RAYMETRICS Backscatter Scanning LIDAR system. It provides instructions for set operation, service and preventive maintenance, and a troubleshooting (fault-isolation) guide.

The Lidar system consists of four major sub-assemblies: (1) the Lidar receiver (including optical telescope and detection unit), (2) the transmitter (including the laser head, the power supply and cooler unit), (3) the Transient recorder unit and (4) the PC, which includes all the software modules for data acquisition, analysis and visualization.

Caution and warning labels, in accordance with CDRH and CE requirements, are prominently displayed on the Laser Head and power supply of the laser unit, as well as in the front and rear panel of the Lidar telescope. For safety, the maximum ratings indicated on the system labels are in excess of the normal operating parameters.

The laser system produces laser radiation, which is hazardous to eyes and skin, can cause burning and fires and can vaporize substances. The laser safety chapter in the User's Manual contains essential information and user guidance about these hazards.
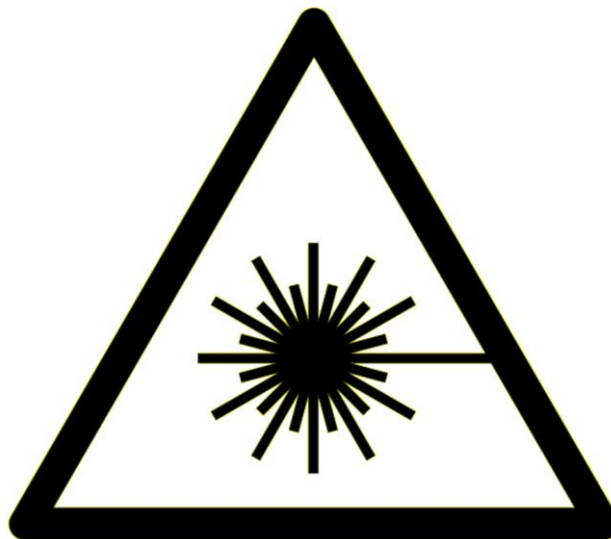
QUALITY CONTROL

FINAL TEST DATA SHEET

Model: LB100-ESS-D200

S/N: 200-01-13

Test Date: 19/04/2013

Telescope Calibration:	✓
Laser Beam Calibration:	✓
Lidar Alignment :	✓
Lidar signals 355 nm:	✓
Polarization Calibration:	✓
Laser Security Interlocks:	✓

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TABLE OF ABBREVIATIONS

ABREVIATION	EXPLANATION
A/D ADC	Analog to Digital Conversion
AN	Analog
APD	Avalanche PhotoDiode
AR	Anti Reflection
ASCII	American Standard Code for Information Interchange
BG	Background
CGU	Coolant Group Unit
CNC	Computer Numerical Control
DAQ	Data Acquisition
DB	Database
EXT	External
FOV	Filed Of View
GL	Glued
HR	High Reflecting
HT	High Transmitting
HV	High Voltage
HVAC	Heating Ventilation and Air Cooling
IFF	Interference Filter
INT	Internal
IP	Internet Protocol
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
Lidar	Laser Interferometry Detection and Ranging
LR	Lidar Ratio
LSB	Least Significant Bit
ND	Neutral Density
OU	Optical Unit
PBC	Polarizing Beamsplitter Cube
PC	Photon counting

PCC	Power supply Cooling unit Cabinet
PMT	Photo Multiplier Tube
PSU	Power Supply Unit
QS	Q-Switch
RAM	Random Access Memory
RCS	Range Corrected Signal
RDP	Remote Desktop
SAU	Signal Acquisition Unit
SHG	Second Harmonic Generator
SNR	Signal To Noise Ratio
TCP	Transmission Control Protocol
THG	Third Harmonic Generator
TR	Transient Recorder
TTL	Transistor–Transistor logic
WOL	Wake On Lan
WSU	Wavelegth Saparation Unit

TABLE OF CONTENTS

1. LASER SAFETY

DANGER

VISIBLE AND/OR INVISIBLE LASER RADIATION

The Model LB100-ESS-D200 Lidar System carries a Class IV laser. Its output beam is, by definition, a safety and fire hazard. Precautions must be taken to prevent accidental exposure to both direct and reflected beams. Raymetrics S.A. shall not be held responsible for accidents to the user or to third parties caused by non-compliant use of the equipment.

The warning symbols below will be used throughout this document and on equipment to warn the user of important instructions which, if not followed, could lead to potential danger.

WARNING - LASER RADIATION, avoid exposure of eyes or skin to direct or diffused rays. Permanent ocular lesions may occur.

WARNING - HIGH VOLTAGE, electric shocks and burns from capacitor discharge or power circuits could lead to serious injury or even death.

Class IV laser systems may produce lesions both by the direct beam or its spectacular reflections and by diffuse reflections. These systems must only be implemented by personnel with sufficient experience with their operation; these personnel must be approved by the laser safety officer. The safety rules explained below must be read and followed by everyone who uses the laser.

1. Always wear protective eyewear
2. Never look at the direct beam from the laser or from a hand piece or one of its reflections.

3. Avoid exposing any part of the body to the beam. Limit access to the work area to the required personnel only. Evacuate all objects with a reflecting or shiny surface from the work area, as well as all inflammable materials.

4. The laser beam emission area must be lit correctly in order that the eye pupils of the people present open as little as possible, which limits the amount of light which penetrates into the eye and reduces the risks of lesions.

5. Only use the laser in supervised areas, which are clearly marked and have supervised access. It is recommended that access ways to work areas be equipped with contactors connected with the external safety loop of the laser. The sign supports must be appropriate and clearly visible.

6. During normal operation, a warning area limited by barriers is necessary to warn all people of the potential risk that lies within the laser area.

7. Only qualified people may operate the lasers. When not in use, the Lidar must be completely inoperable and it must be made impossible for unauthorized people to operate them, for example, by removing the door key or the laser key.

8. Using laser radiation to aim at individuals, vehicles, aircraft or any other flying object is formally prohibited.

9. Due to the risk of electric shock, the power supplies must be switched off and the power supplies must be disconnected from the flashlamp prior to any maintenance operation. Electric shocks or burns resulting from the power supply of the network or from condenser discharges may cause serious wounds and traumas. They may be fatal.

Precautions for Safe Operation of Class IV Lasers

10. Keep the protective covers on the Laser Head as much as possible. Do not operate the laser with the covers removed for any reason.

11. Avoid looking at the laser output beam.

12. Do not wear reflective jewelry while using the laser, as it might cause inadvertent hazardous reflections.

13. Use protective eyewear at all times

14. Operate the laser at the lowest possible beam intensity, given the requirements of the intended application.

15. Increase the beam diameter wherever possible to reduce beam intensity and thus reduce the hazard.

16. Avoid blocking the laser beam with any part of the body.

17. Establish a controlled access area for laser operation. Limit access to those trained in the principles of laser safety.

18. Maintain a high ambient light level in the laser operation area so the eye pupil remains constricted, thus reducing the possibility of hazardous exposure.

19. Post prominent warning signs near the laser operation area.

20. Provide enclosures for the beam path whenever possible.

21. Set up an energy absorber to capture the laser beam, preventing unnecessary reflections or scattering.

WARNING: Use of controls or adjustments, or performance of procedures other than those specified in this User's Manual may result in hazardous radiation exposure.
Follow the instructions within this manual carefully to ensure the safe operation of your laser.

2. INTRODUCTION TO THE LIDAR TECHNIQUE

The atmospheric laser remote sensing implies the so-called Light Detection And Ranging (LIDAR) technique, to probe the atmosphere up to altitudes as high as ~120 km. The development of matured pulsed laser sources has enabled the range-resolved measurements of the principal atmospheric gases[1] and atmospheric/meteorological parameters, in a manner somewhat analogous to the radar technique. In this mode of operation a short laser light pulse is transmitted to the atmosphere in one or more wavelengths (Fig. 2.1).

Fig. 2.1: The principle of operation of the Lidar technique.
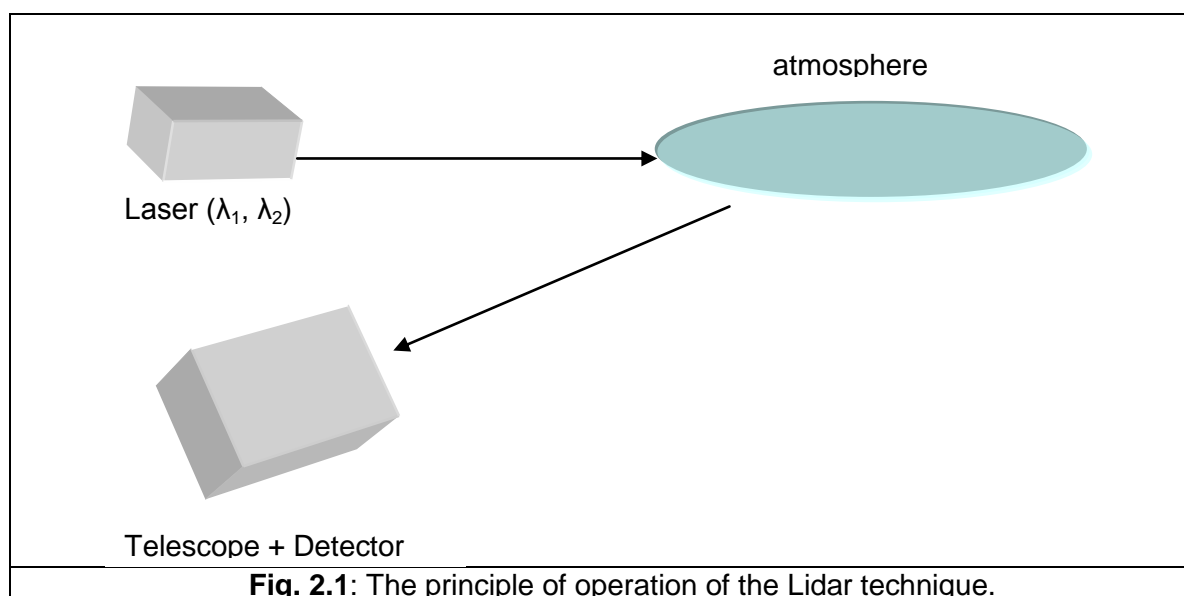
The time between the transmission of the laser pulse and the arrival of the backscattered return signal is directly related to the range at which the scattering occurred. The most common processes related to laser pulse scattering by the suspended aerosol particles include the *elastic* Mie and Rayleigh scattering and the *inelastic* Raman scattering[2].

The atmospheric volume being probed backscatters the laser radiation and a receiving telescope is used to collect all the backscattered laser light occurring through elastic and inelastic processes. Wavelength-separation units are used to spectrally separate the Lidar signals at various wavelengths and to reject the atmospheric background radiation. The Lidar signals are then fed to fast detectors (photomultiplier tubes: PMTs). The PMT output signals after amplification and digitization are sent to a central computer machine for further processing and storage.

The Lidar observations of suspended aerosol particles can be made remotely with high spatial and temporal resolution using the Lidar technique. The Lidar systems can be operated from ground or mobile platforms, such as aircrafts, helicopters or satellites.

The basic Lidar equation is given below:

$$P(z) = P_o \frac{c\tau}{2} \beta(z) A_{tel} O(z) \frac{1}{z^2} \exp\left[-2\int_0^z a(z^*)dz^* \right] \qquad (1)$$

where, P(z) is the power incident on the receiving optics from distance z, P_o is the laser output power, τ is the duration of the laser pulse, c is the velocity of light, $\beta(z)$ is the volume backscattering coefficient, $a(z)$ is the extinction coefficient of the atmosphere and A_{tel} is the receiving telescope aperture. $O(z)$ is the so-called geometrical form factor (or overlap factor). This factor represents the probability of radiation in the target plane at range z reaching the detector, based on geometrical considerations. The $1/z^2$ dependence leads in many applications to a signal-amplitude dynamic range that extends over several decades. Therefore, two detection modes are used: the analog detection mode and the photon counting operation mode (paragraph 3.3.2).

The detection of the suspended aerosol particles can be performed by an elastic Lidar system (single or two-wavelengths) or by an inelastic (Raman) Lidar system. The elastic backscattered Lidar signals can be inverted using the Klett's inversion algorithm[3], while the inelastically backscattered Lidar signals can be inverted using the Raman inversion technique, as presented by Ansmann et al. (1992)[4].

3. LIDAR SYSTEM HARDWARE COMPONENTS

A typical LIDAR contains a transmitter, a receiver, a data acquisition system (DAQ) and a computer that controls the transmitter and receiver and also stores the acquired data. A power distribution unit is used to protect and power the various systems. To make things more operational everything is contained in an industrial enclosure.

In addition this lidar is a scanning lidar which means that the lidar head (transmitter – telescope) are separated from the enclosure and placed on a positioner. All these are mounted on a tripod base.

At the image below a typical Lidar with its main components is illustrated.
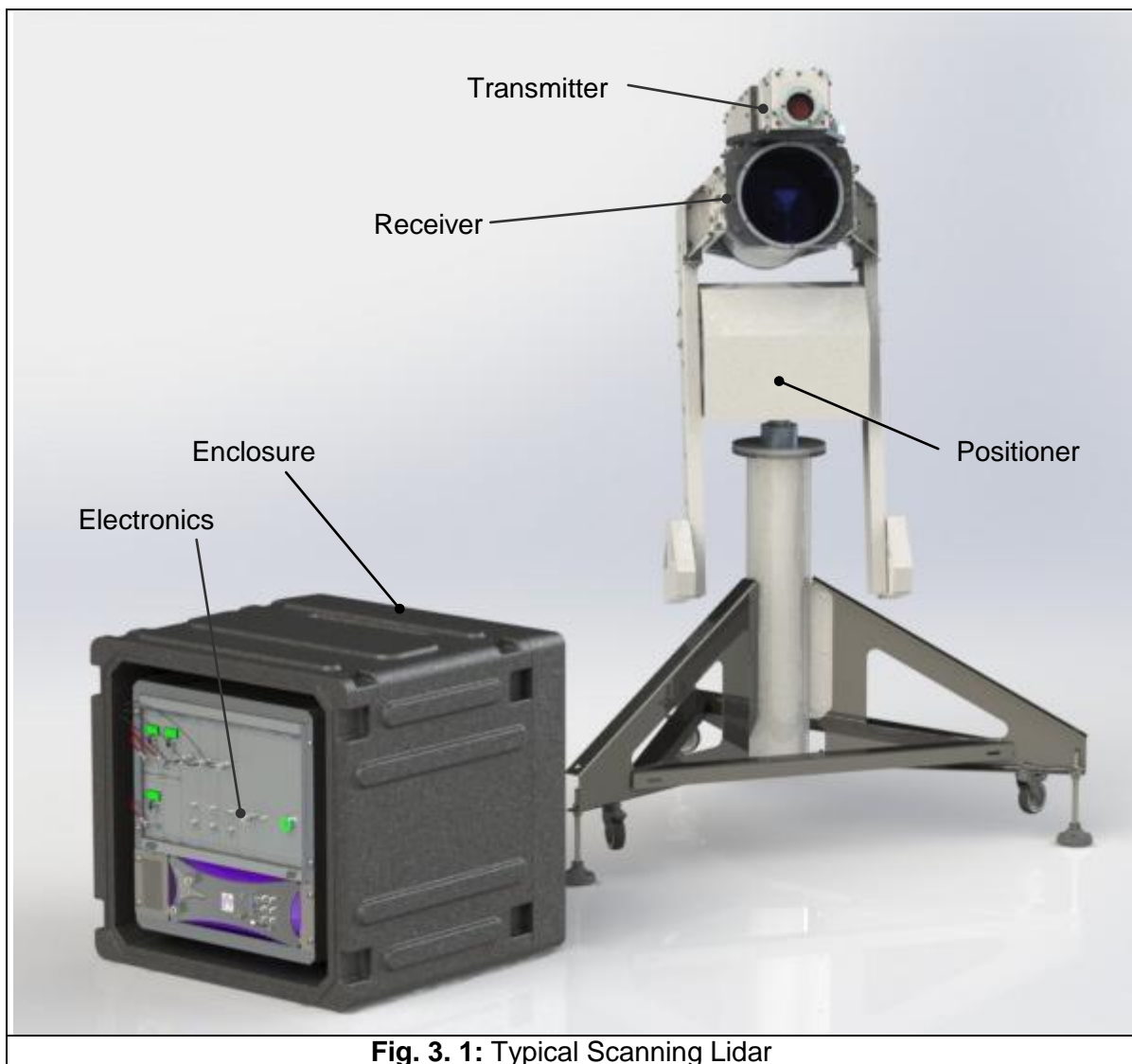
Fig. 3. 1: Typical Scanning Lidar

All these components are described in detail below.

3.1. TRANSMITTER

The Lidar transmitter consists of five sub-units: a laser, a beam splitter, a Beam expander, a beam trap and a high reflective mirror.

The transmitter along with the light path is enclosed in a case that protects the user from direct contract with the laser beam and also prevents light to enter the receiver. The special high energy laser glass (window) with antireflection coating and λ/10 surface ensures that no dust or humidity enters the emitter enclosure and its high specifications minimize the emission losses.

Beam Splitter

Beam Expander

Laser

High Transmission Window

Fig. 3. 2: Lidar Transmitter Layout
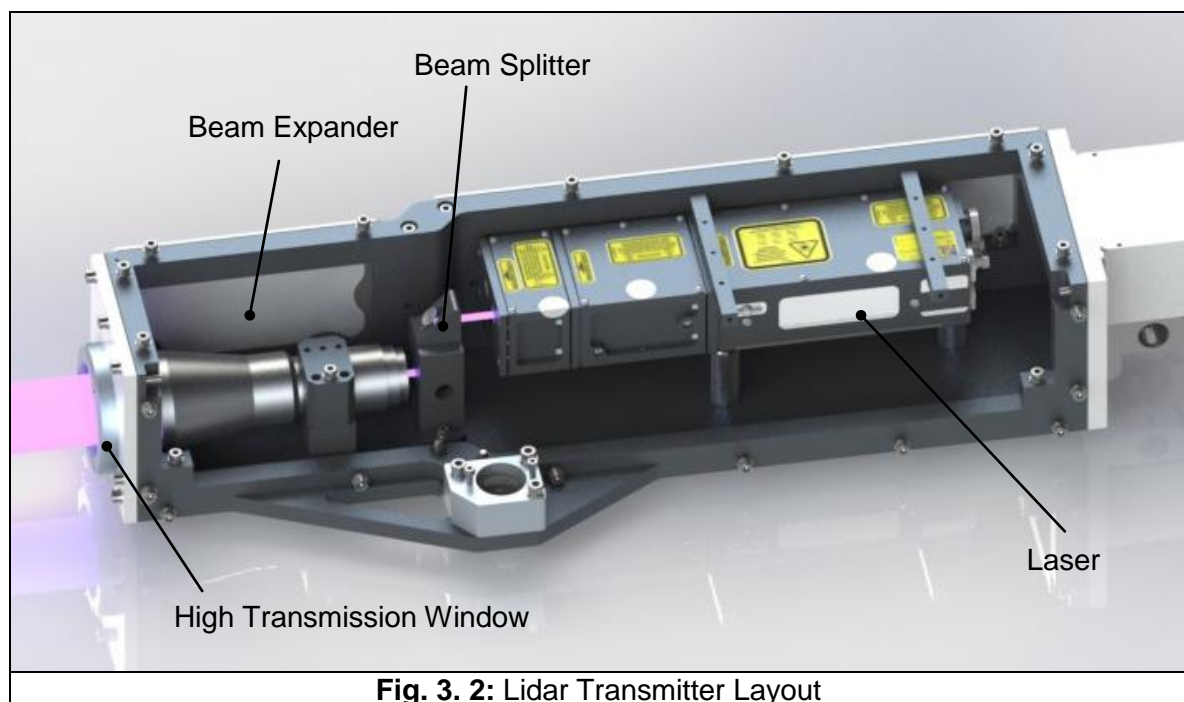
3.1.1. Laser

The laser source used is a water cooled pulsed Nd:YAG laser transmitting short pulses at 1064nm. The pulse repetition rate is typically 20Hz. The pulse duration is of the order of 6-9 ns. Trough the Second Harmonic Generation (SHG) 532nm wavelength is produced and through the Third Harmonic Generation (THG) 355nm wavelength is produced. This specific laser 355nm and rejects the rest. The laser is factory preset for maximum energy output at its third (THG) frequency (355). Therefore, the user should not change, remove or alter any of the laser parts or sub-units. The laser consists of two major components: the optical head and the power supply unit (PSU). They are connected together by power and signal cables and water hoses for cooling the head. The laser model is a ULTRA100 by Quantel which includes the PSU model ICE450 standard version.

A detailed description of the characteristics, specifications and operation mode of the laser source is given in the laser's instruction manual DOC00040.pdf.

Safety Instructions

- The user is requested to wear the laser protective eyewear during the laser operation. Do not stare into the laser beam even when using your laser protective eyewear goggles. It may be too dangerous for your eyes!

- Do not place any obstacle or reflective object in the transmitted laser beam. Primary or secondary reflections may damage your eyes or reflected back to the laser causing damage!

- Before you turn off the laser, you should leave the water circulation pump in the ON position for at least 10-15 min. to cool down the laser optical head.

- Always respect the instructions of the laser manufacturer regarding the minimum number of laser shots requiring the replacement of the laser head flash lamps (see laser's instruction manual DOC00040.pdf).

- Always respect the instructions of the laser manufacturer regarding the replacement of the de-ionizing filter/unit of the laser system (see laser's instruction manual DOC00040.pdf).
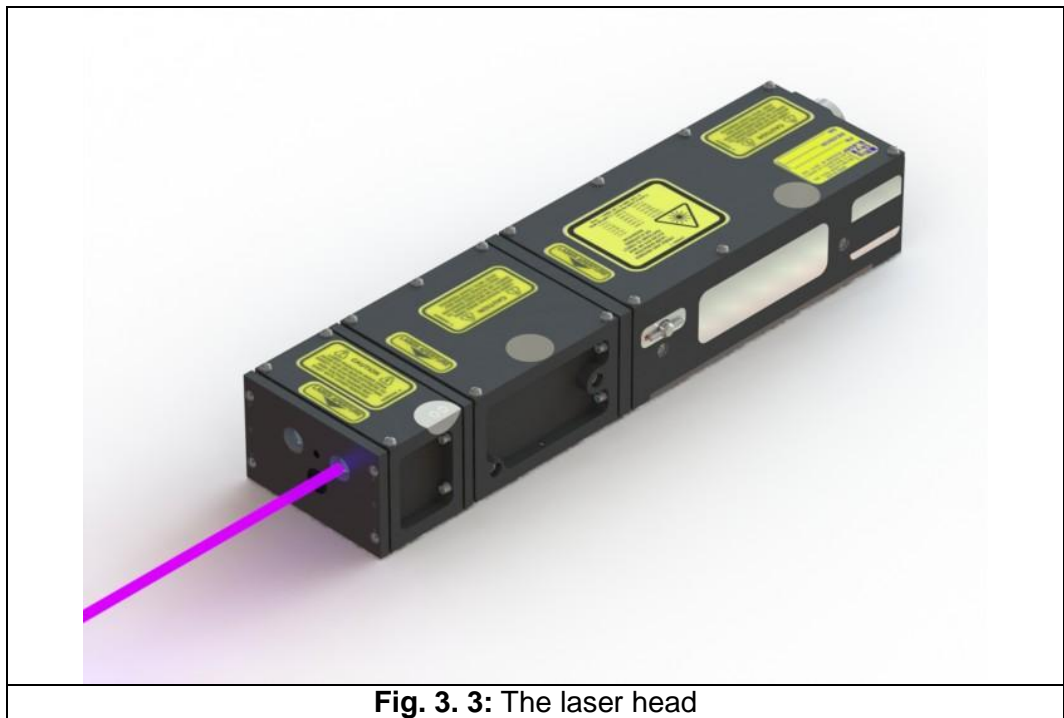
Fig. 3. 3: The laser head

Attention!

- Do not stare into the laser beams, even when using your laser protective eyewear goggles. It may be too dangerous for your eyes!

- Do not touch the optical components of the Lidar system (laser mirrors, laser windows, protective windows, etc.). It may lead to a complete destruction of their optical coatings and to a misalignment of the Lidar optics.

3.1.2. Beam Splitter

As previously noted the laser transmits 355nm and rejects the rest. However there are still some residuals from the rejected 532nm and 1064nm. In order to comply with the laser eye safety regulations these residuals must be rejected and for this we use the beam splitter. The beam splitter is a pair of HR reflective mirrors at 355nm and HT at 532 and 1064. They are mounted at a 45°deg angle on a CNC machined mirror mount. This also ensures that no reflections return into the laser that could cause permanent damage and mainly it ensures that only primary wavelength 355nm is transmitted.

The high reflective mirrors (HR) of the Lidar system are conceived to provide a high reflection (>98%) at the reflected wavelength (355nm) and high transmission at 355nm and 1064nm due to the special coating on the front side suitable for high laser energy. At the back side there is antireflection coating to ensure that no back reflection will be transmitted.

Attention!

The reflective mirrors are aligned during the construction of the Lidar system. This system is designed so that the mirrors don't need any alignment. For that reason be very cautious not to move the HR mirrors, as it may lead on total misalignment of the system.

Fig. 3. 4: The beam splitter
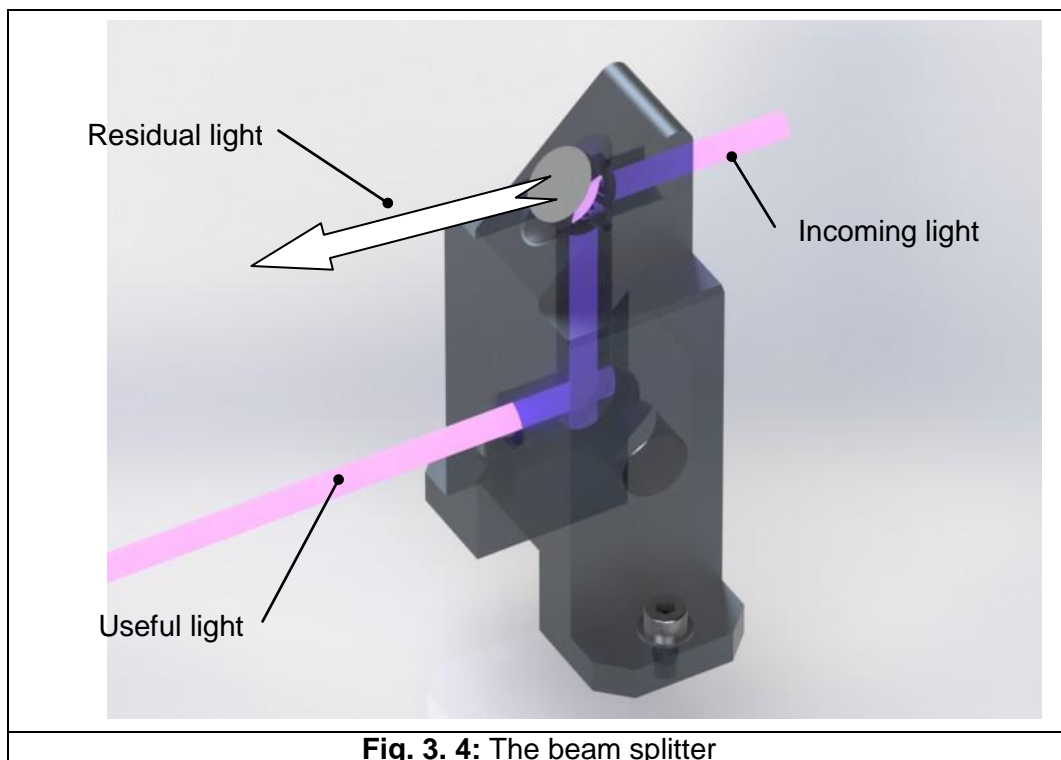
3.1.3. Beam Expander

The beam expander serves tow main purposes; it reduces the light's divergence and reduces the energy concentration.

As the name indicates it expands the beam's diameter by 10 times. With this way the energy per square centimeter is reduced while the total power remains the same. This is a smart way to make an eye-safe lidar without reducing its power.

Moreover the beam expander improves the divergence of the laser beam. This means that it makes the beam as parallel as possible and eventually it improves the maximum range and the precision of the system.
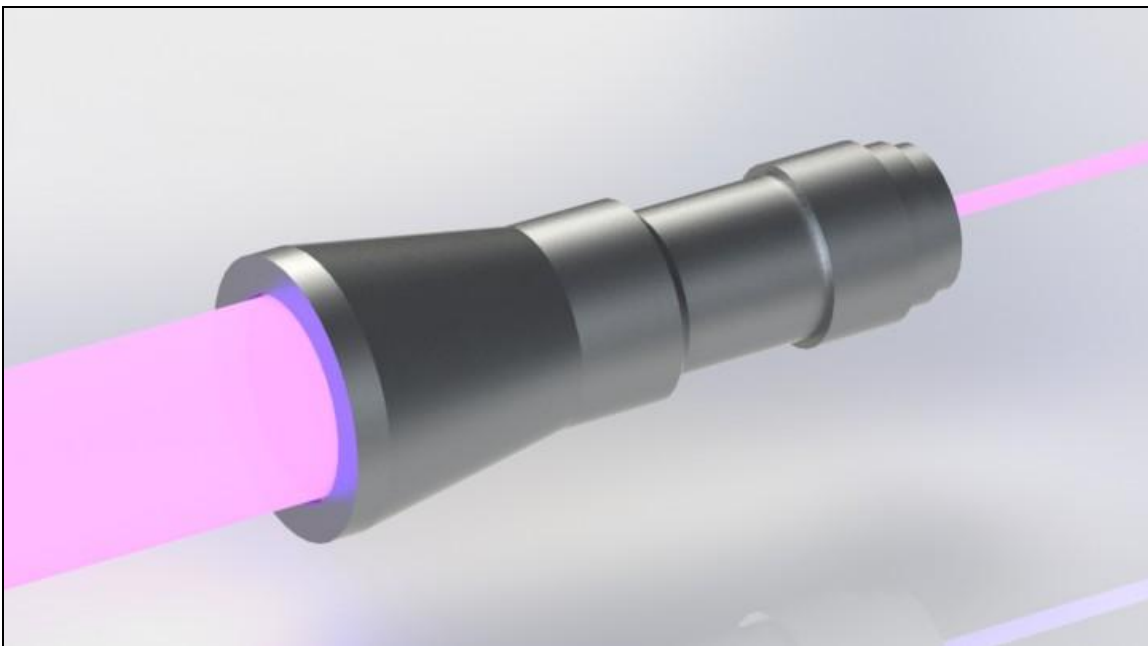
Fig. 3. 5: Beam expander

3.2. RECEIVING SYSTEM

The receiving system consists of two sub-units: a receiving telescope (T) and a wavelength separation unit (WSU) (Fig. 3.6).
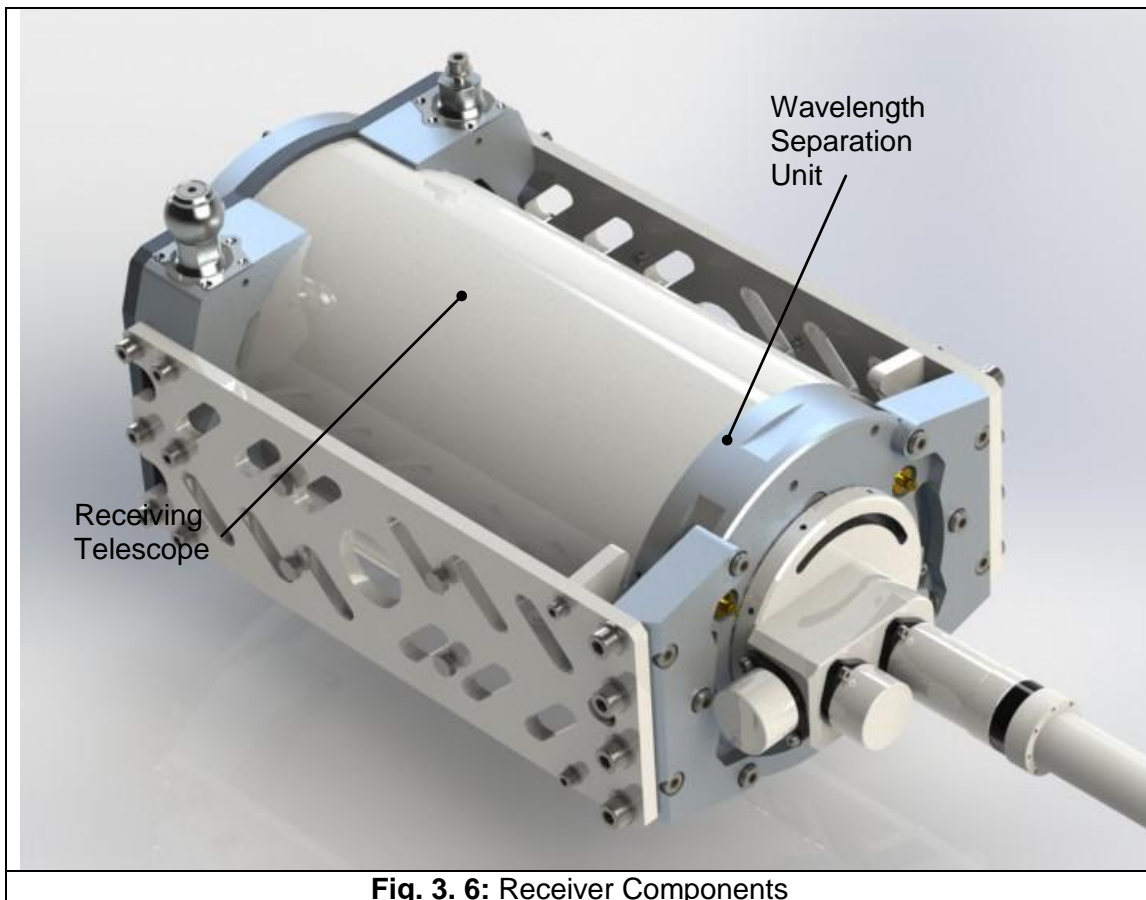
Fig. 3. 6: Receiver Components

3.2.1. Telescope

The signal that returns in terms of light is very weak and the only way to amplify it is by collecting as much light as possible with a telescope. In this LIDAR a powerful 200mm diameter Cassegrain telescope is used. The primary reflective mirror has a diameter of 200mm and is coated with a durable high reflective coating suitable for the 350-1100 nm spectral region. The optical material selected shows a very low thermal expansion coefficient, similar to that of *Zerodur®* optical properties.

The secondary reflective mirror has a diameter of 48mm and is coated similarly to the primary mirror. The received Lidar beams are then collected and focused on an Optical Unit (OU) placed on the telescope's focal point. At the exit of the OU the Lidar beams are then collimated by using an achromat technique

Primary mirror

Focal Point

Secondary mirror

Optical Unit

Fig. 3. 7 Telescope main components
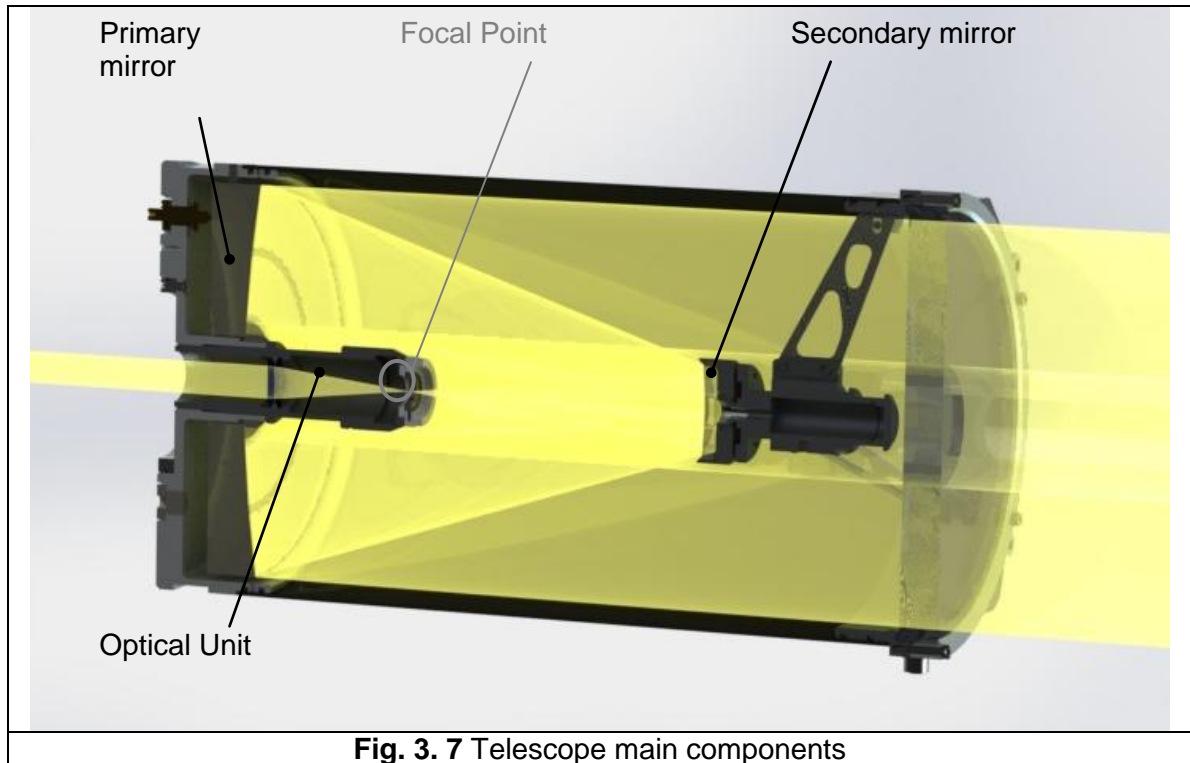
Each telescope is thoroughly designed and simulated at Zemax. Each distance is very critical. A small change can alter the focus of the telescope.

- Telescope
  - Type: Cassegrain
  - F4
  - Focal Length: 800mm

- Primary **D**iam.: 200mm
- Secondary Diam.: 48mm

Fig. 3. 8: Telescope Characteristics

SURFACE 8: TELE FOCUS
FULL FIELD SPOT DIAGRAM

- Green : Far Field (25 Km),
- Blue : Near Field (0.5 Km)

Fig. 3. 9: Typical Light simulation from far and near field at the field stop
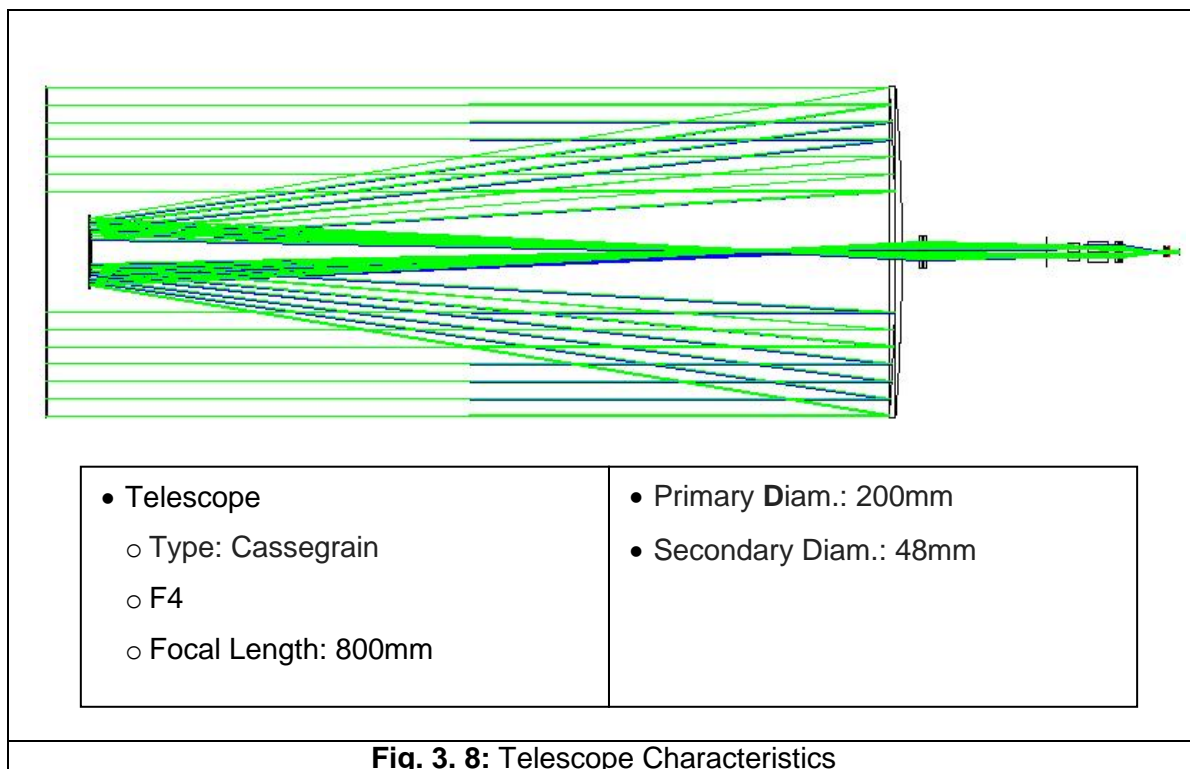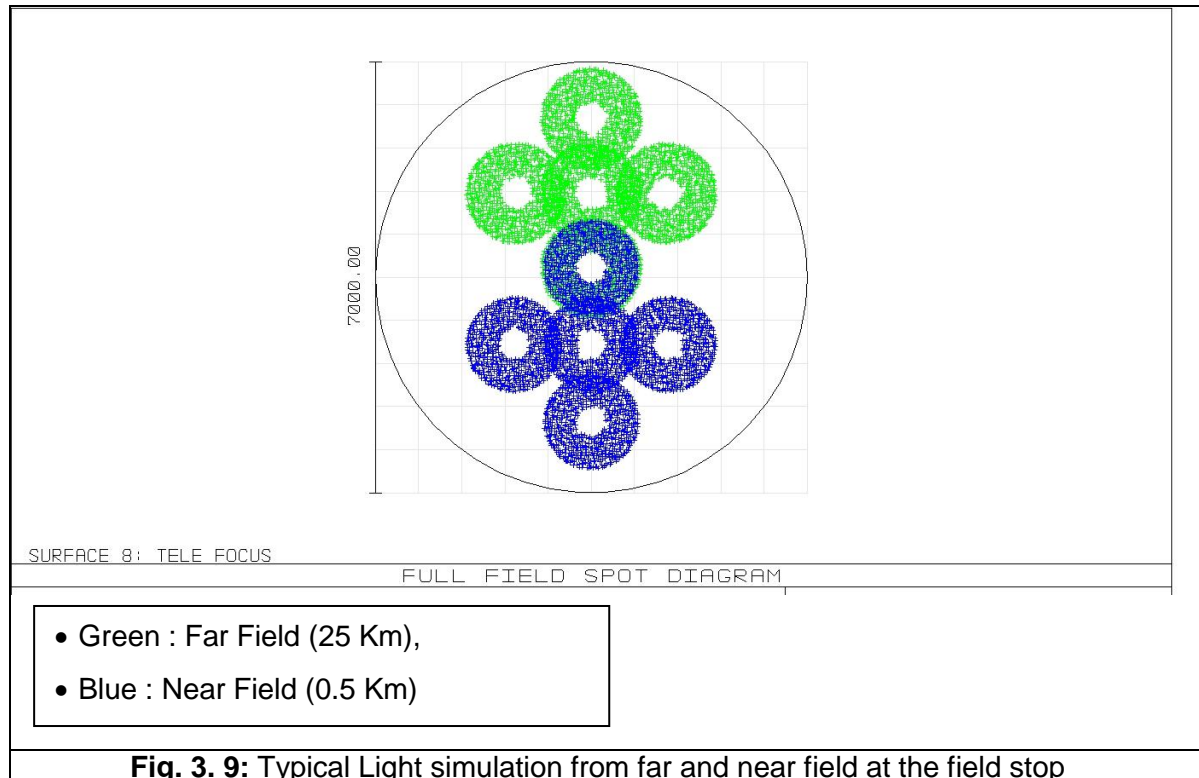
The special Telescope glass (window) with antireflection coating and λ/10 surface, ensures that no dust or humidity will enter the telescope while with its high performance the Lidar signal remains intact.

3.2.2. Wavelength separation unit

At the entrance of the Wavelength Separation Unit (WSU) of the Lidar system the received Lidar beams are collimated to one parallel beam. A series of factory preset custom-made dichroic reflective mirrors and one polarization cube perform the wavelength separation at the various wavelengths and polarizations received [355P, 355S, 387nm].

At each wavelength exit specially designed interference filters (IFF) are used to select the Lidar wavelengths and to reject the atmospheric background radiation during daytime and nighttime operation. The current configuration detects only 355nm but the WSU can accommodate all three channels (355nmP&S and/or 387nm).

Fig. 3. 10: WSU
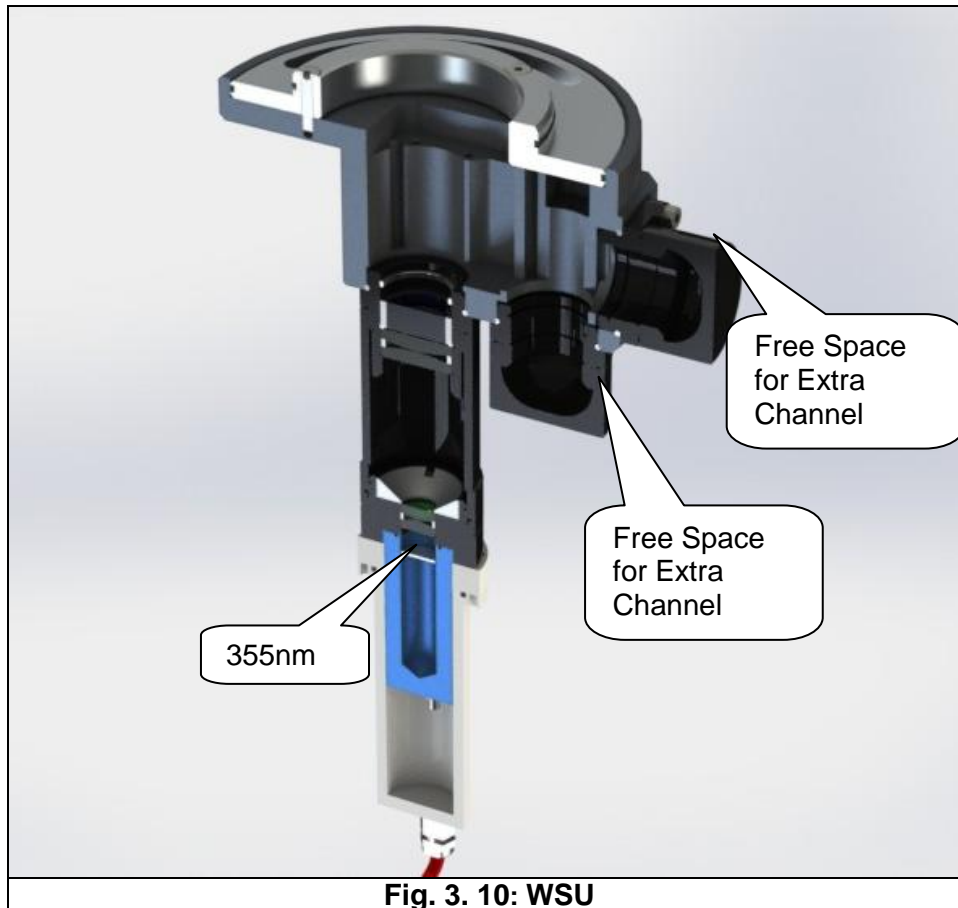
3.2.3. Depolarization Technique

The laser transmits a narrow, fully polarized beam of light in which light waves all oscillate in the same plane. The receiver measures the polarization of light scattered in the backward direction. For a cloud of spherical water droplets, the backscattered light is fully polarized in the same direction as the transmitted beam; i.e., it has only a "co-polarized" or parallel component. However, for a cloud composed of non-spherical ice crystals, the backscattered light can be partially depolarized; i.e., it can have a "cross-polarized" component which vibrates perpendicularly to the transmitted polarization.

This system has the ability to measure simultaneously both the parallel (P) and the cross-polarized (S) component at the backscatter wavelength which is at 355nm. This is achieved by separating the parallel and the cross-polarized components, with a depolarization cube, and each component measured by a PMT. From the combination of these two signals the user can extract the depolarization ratio. The depolarization ratio can show the existence of non-spherical particles.

Fig. 3. 11: Depolarization Module
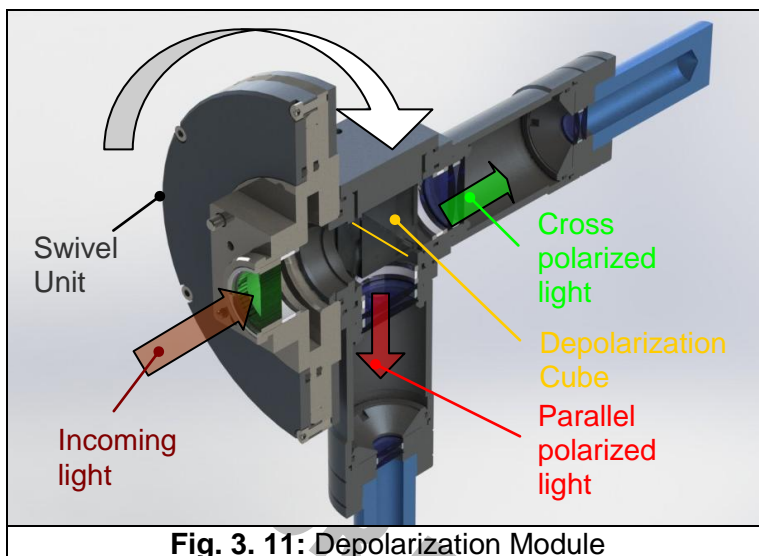
In order to calculate the depolarization ratio the user has to calculate the depolarization calibration constant. This constant depends on various things such as the atmosphere the temperature and the system itself, thus it is impossible to calculate this analytically. More specifically this is measured by comparing measurements taken with the depolarization module turned at ±45° degrees around the normal position. When the depolarization module is turned the parallel signal is decreased and the cross is increased.

The swivel unit is machined in CNC mills from one part so that the best precision is achieved even when it is turned. Moreover the sophisticated design makes this procedure as easy as possible. The procedure can be outlined in three steps.

1. Pull the pins A and B shown in the image below.
2. Turn the depolarization module slightly, release the pins and turn at 45 degrees until you hear a clicking sound from the pin.
3. Now you can start the measurement.

If the rotation is not very easy you may have to loosen the screws located at the other side of the swivel unit.

| +45° deg | 0° deg | -45° deg |

Fig. 3. 12: WSU ±45° polarization calibration procedure
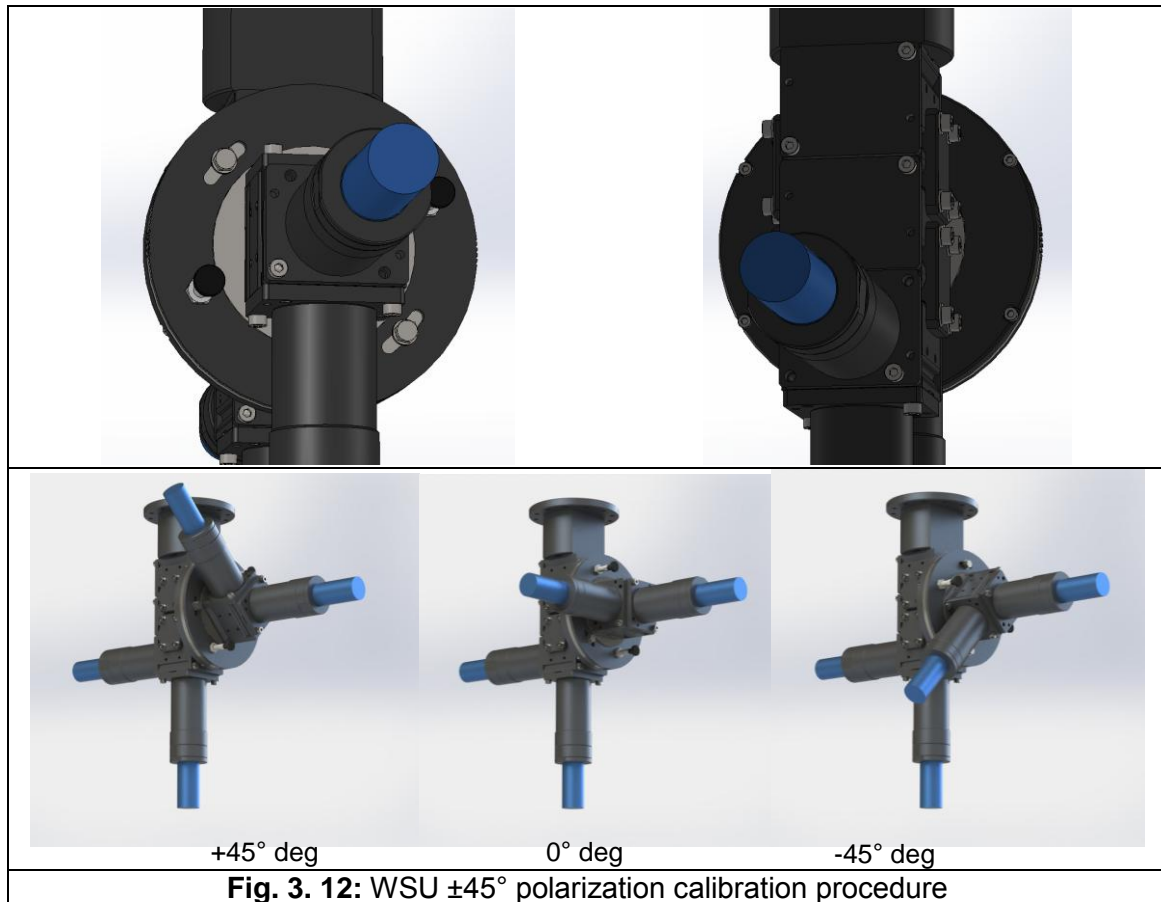
3.2.4. Light Detectors

The light is detected from the photomultiplier tubes (PMT) and converted into a signal that goes to the detection electronics. The electronics are synchronized with the laser control and the signal is recorded in relation to the time. The electronics communicate via Ethernet with the PC where the data are saved. The detection electronics are presented at paragraph 3.3.2. The detectors along with the electronics are called Signal Acquisition Unit (SAU).

Detector

Fig. 3. 13: WSU and PhotoMultiplier Tubes (PMT).

8000.00

SURFACE IMA: DETEKTOR
FULL FIELD SPOT DIAGRAM
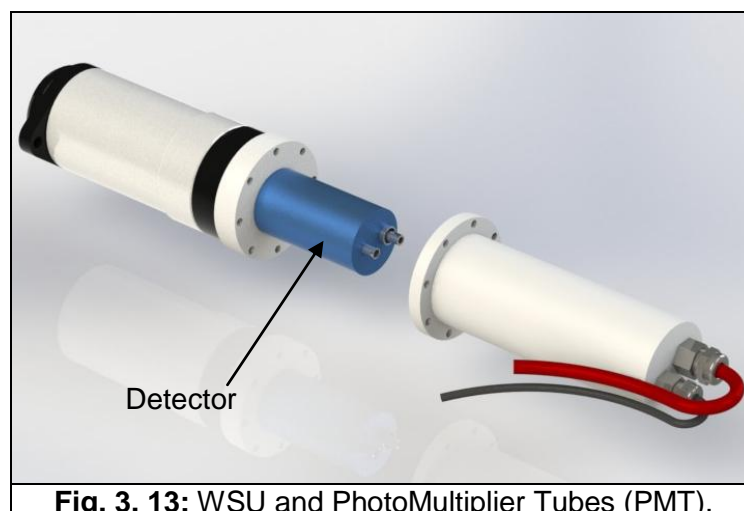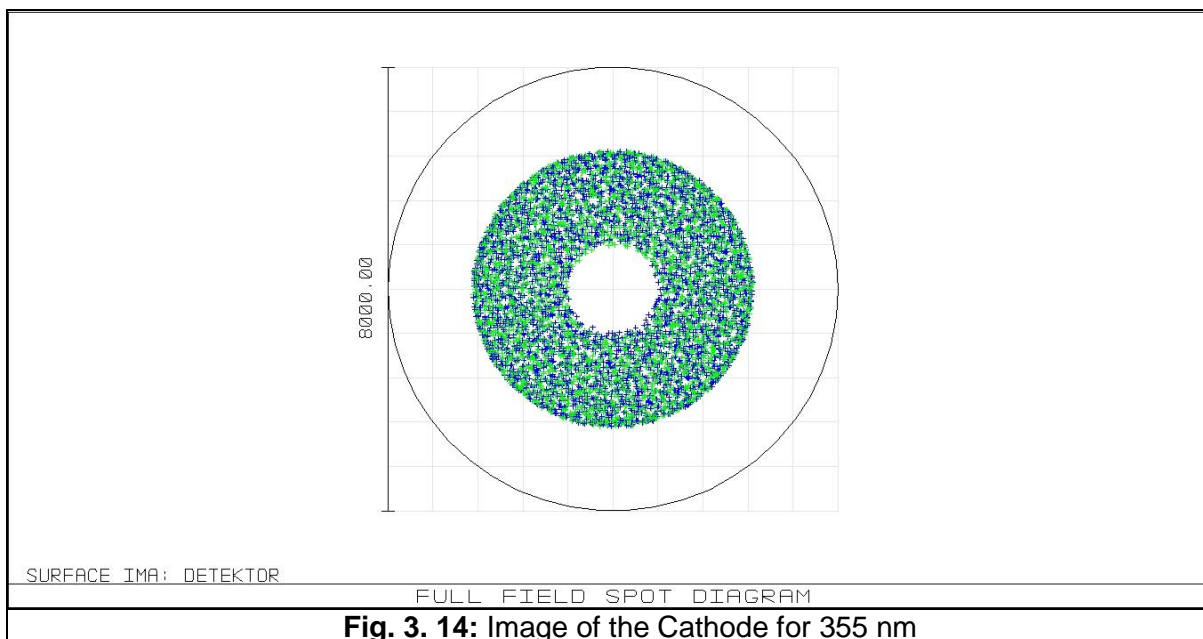
Fig. 3. 14: Image of the Cathode for 355 nm

+ 0.3550

OBJ: 0.00, 7505.00 MM

0.10

IMA: 0.000, 0.000

OBJ: 0.00, 0.00 MM

IMA: 0.000, 0.000

OBJ: 0.00, -7505.00 MM

IMA: 0.000, 0.000

OBJ: 7505.00, 0.00 MM

IMA: 0.000, 0.000

OBJ: -7505.00, 0.00 MM

IMA: 0.000, 0.000

SURFACE 19: F-IFF
SPOT DIAGRAM: COSINE SPACE
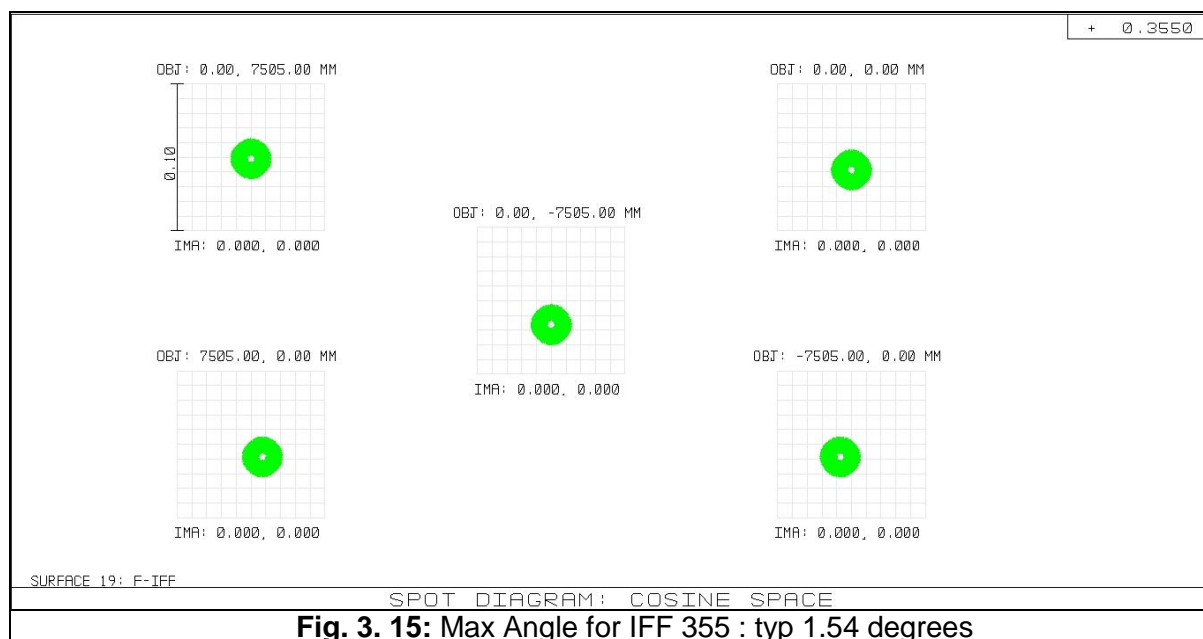
Fig. 3. 15: Max Angle for IFF 355 : typ 1.54 degrees

The spectrally resolved Lidar signals inside the WSU are detected by photomultiplier tubes (PMTs) directly mounted at the respective exits of the WSU. The PMTs used are selected to be compact and to provide optimum operation in the spectral range 355-532 nm. The PMTs work in the pulse mode regime and are characterized by a short rise time constant.

The PMTs have been tested prior to shipment. The PMTs optimum working voltage (for linear operation) is between 750-900V, depending on the amplitude of the received signal and the atmospheric conditions (background skylight conditions during daytime or nighttime conditions and/or cloud presence). Usually, during daytime conditions the PMT working voltage is slightly lower than during nighttime operation.

Technical Specs

Part Number	R9880U-110	
PM Type	Hamamatsu	
PM High Voltage (V)	0-1000	
Supply Voltages (V)	+15	
Current Limit (mA)	200	
Resistance Anode-GND (Mohm)	1.0	
Output Connector	BNC (50 Ohm)	

All the details for your PMTs are inside Licel printed manual.

Attention!

- For optimum operation the temperature and humidity conditions should be kept unchanged during field operation.

- Operation at HV higher than 900 V should lead to PMT saturation, thus to a *non linear* operation and/or possibly to PMT permanent failure.

- Reed carefully below the environmental conditions of the PMTs.

Humidity: Operation in a very damp atmosphere may lead to insulation problems, because of the high voltages (HV) used. Condensation gives rise to leakage currents which in turn increase the PMTs dark current. Therefore, the PMTs should be operated under the environmental conditions given in Licel's user manual.

Light conditions: The PMTs are highly sensitive to ambient light conditions; therefore never expose the PMTs to ambient light, even when no HV is applied. If high voltage is applied to the PMTs which are exposed to ambient light, the PMTs are permanently destroyed.

Mechanical stress: Like all electronic devices, PMTs should be protected against mechanical and thermal stress. Vibration or shock transmitted to the PMT dynodes can modulate the PMTs gain.

Magnetic fields: Never expose the PMTs to magnetic fields, even as weak as the earth's one. They may affect the PMT's performances. Strong fields may permanently magnetize some parts of the PMTs, thus affecting their performance.

3.3 CONTROL UNIT

The control unit consists of four main components; the laser control and power supply (ICE450 standard version), the transient recorders and PMT power supply, the PC and the electrical cabinet.

3.3.1 Laser control and power supply

This device controls all the functions of the laser and supplies the laser head with power and deionised water.

Fig. 3.16: Laser power supply and controller

3.3.1.1. Control

Through the control the user can operate the laser and check its status. The operation mainly is the flashlamp/Q-switch start and stop and the Q-switch delay (that reduces the laser beam energy). Regarding the status the user can obtain various information about the laserhead such as the counted number of shots, the temperature, the flow of the pump etc. All interlocks appear at the control with a short explanation.

The device has two interfaces; one remote control box and a RS232 that is connected to the PC. That means that user can control the laser either from the control box or the PC.

Fig. 3.17: Control Box

Note that in order to control the laser from the PC the user has to switch manually from the control box the serial link. In order to do that navigate with ▼▲ choose "System Info" and validate with↵. Choose serial link and with the ➕ button change the status from "off"

to "on". Each time the user presses a button on the control box the serial link automatically turns to "off".

3.3.1.2. Power and water Supply

The laser apart from the power supply needs water supply as well since the head is water cooled. This is achieved from an individual unit inside the ICE450 called Coolant Group Unit (CGU). The CGU cools the flashlamp(s) and the laser rod with a closed loop of de-ionized coolant. This temperature regulated coolant also provides thermal stabilization of the oscillator's structure.

A thermostatic electronic circuit, which regulates the fan's speed and airflow rate through the exchanger, provides thermal stabilization of the coolant. The temperature stabilization is within ± 1 °C. The ambient air temperature can range from 15 °C to 28 °C with no effect on laser operation.

The CGU includes a de-ionizing system that, with proper maintenance, can maintain the conductivity of the coolant at less than 1.0 µS⋅cm-1 (resistivity ≥ 1.0 MΩ⋅cm). The CGU has coolant level, flow, and heat-sensing switches to interlock with the Power Supply Unit to prevent damage to the laser head in the event of a cooling system failure.

The CGU requires approximately 1.5 liters (0.4 US gal.) of coolant for standard systems incorporating three-meter coolant lines. **Use only distilled water with 1MΩ-cm to 5MΩ-cm resistivity.** The water is transferred to the laserhead though two hoses which are along with the power and signal cords components of the umbilical cord. Even though the CGU contain a powerful pump, if the umbilical cord is bended above a certain level then an interlock will appear and the laser will not operate. For further information refer to laser's manual.

Fig. 3. 18: Control Unit With coolant hoses, power and signals cables.
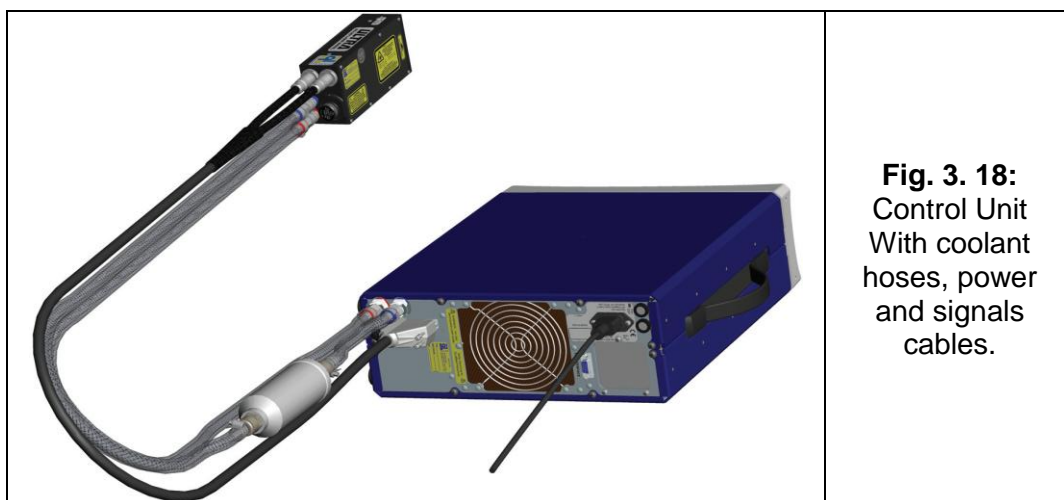
3.3.2 Detection electronics

The detection electronics receive a analogue signal from the PMTs and transform it to a Lidar signal. This device is designed to work in two modes: the analog detection mode and the photon counting detection mode.

3.3.2.1. Concept

The Licel transient recorder is a powerful data acquisition system, especially designed for remote sensing applications. To meet the demanding requirements of optical signal detection, a new concept was developed to reach the best dynamic range together with high temporal resolution at fast signal repetition rates.
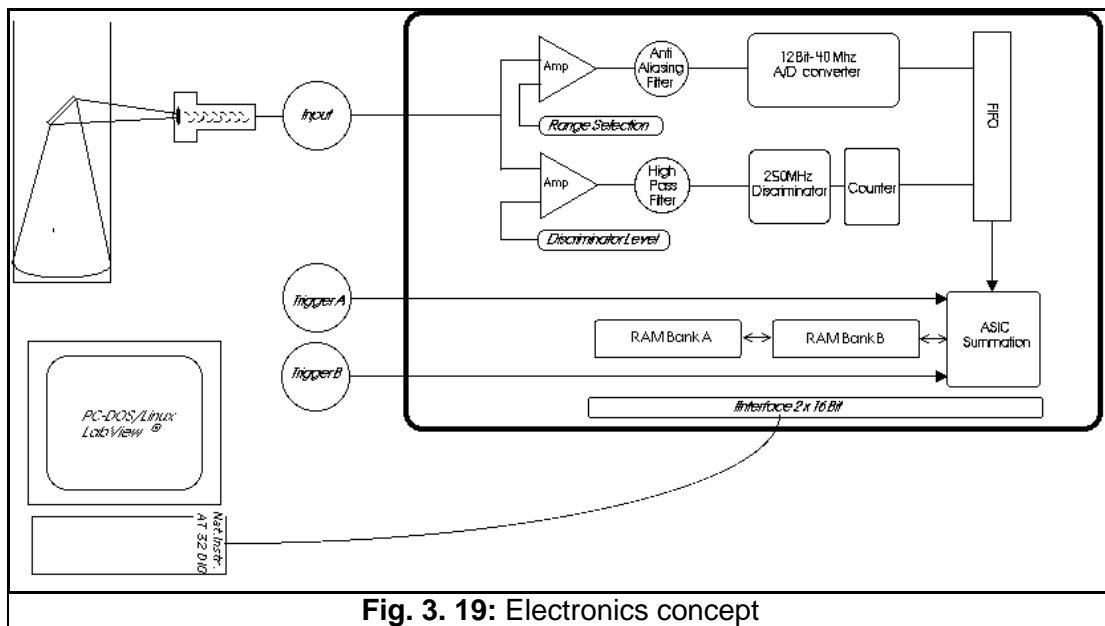
Fig. 3. 19: Electronics concept

For the first time analog detection of the photomultiplier current and single photon counting is combined in one acquisition system. The combination of a powerful A/D converter (12 Bit at 40 MHz) with a 250 MHz fast photon counting system increases the dynamic range of the acquired signal substantially compared to conventional systems. Signal averaging is performed by specially designed ASIC's which outperform any CISC- or RISC-processor based solution. A high speed data interface to the host computer allows readout of the acquired signal even between two laser shots. At figure 22 the connectivity of the transient recorder is explained. The implementation of this concept makes the Licel transient recorder the state of the art solution for all applications where fast and accurate detection of photomultiplier, photodiode or other electrical signals is required at high repetition rates.

3.3.2.2. Principle of operation

The Licel transient recorder is comprised of a fast transient digitizer with on board signal averaging, a discriminator for single photon detection and a multichannel scaler combined with preamplifiers for both systems. For analog detection the signal is amplified according to the input range selected and digitized by a 12-Bit-20/40 MHz A/D converter. A hardware adder is used to write the summed signal into a 24-Bit wide RAM. Depending on whether trigger A or B is used, the signal is added to RAM A or B, which allows acquisitions of two repetitive channels if these signals can be measured sequentially.

At the same time the signal part in the high frequency domain is amplified and a 250 MHz fast discriminator detects single photon events above the selected threshold voltage. 64 different discriminator levels and two different settings of the preamplifier can be selected by using the acquisition software supplied. The photon counting signal is written to a 16-Bit wide summation RAM which allows averaging of up to 4094 acquisition cycles.

3.3.2.3. Analog detection

The analog detection mode is used to detect intense Lidar signals coming from relatively short distances (typically less than 8-10 km). A transient recorder operating in the analog detection mode is based on an analog-to-digital converter (ADC), which samples and digitizes the Lidar signals with a sampling rate of 20-40 MHz (depending on the type of the transient recorder used) with a 12-bit resolution. A memory length up to 8192 or 16000 time bins (Tr-xx-80 or Tr-xx-160) depending on the transient recorder type) can be selected. Each time bin corresponds to a spatial resolution of 3.75 or 7.5 m (depending on the sampling rate of the transient recorder used, Tr-20-yy or Tr-40-yy). For instance the 20 MHz sampling rate corresponds to a 7.5 m spatial resolution.

Fig. 3. 20: Typical Lidar signal acquired in the analog mode.
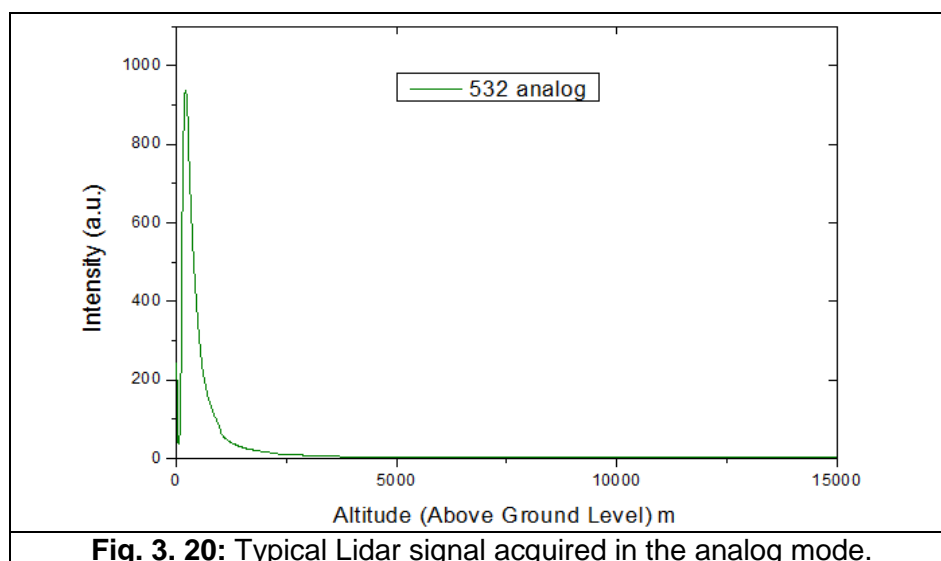
3.3.2.4. Photon counting detection

The photon counting detection mode is used to detect very low intensity Lidar signals coming from relatively large distances (typically higher than 8-10 km). Thus, the PMT is operated under *single electron* conditions. Flux levels as low as a few tens of photons per second can be measured. In the photon counting mode the level of the incident flux is such that the cathode transmits only single electrons. The individual anode charges due to single photons are integrated to produce proportional voltage pulses, which are passed by a discriminator to a pulse counter, whose output over a pre-set time period is a measure of the incident flux.

Because of statistical fluctuations in the electron multiplication, the amplitude of the single-electron pulses is distributed according to the Poisson statistics. To obtain a satisfactory signal-to-noise ratio (SNR) of the Lidar signal in the photon counting mode, a sufficiently large number of laser shots should be obtained (normally more than 1000). If the received Lidar signal is higher than 60-100 MHz the PMT output signal should be corrected to take into account the dead-time effect. If the dead-time of the counter (τ_d) is comparable to the mean interval separating two successive pulses, the counting error may be appreciable. If a dead-time correction has to be applied, then if the N_{obs} is the observed count rate, then the true count rate (N_{true}) corrected for the dead-time effect is given by:

$$N_{true} = \frac{N_{obs}}{1 - N_{obs} \times \tau_d} \qquad (2)$$

Note: The value of τ_d depends on the type of the PMT module used (i.e. $\tau_d = 4$ ns).

Specific environmental effects may increase or decrease the count rate. For instance, background radioactivity increases it.
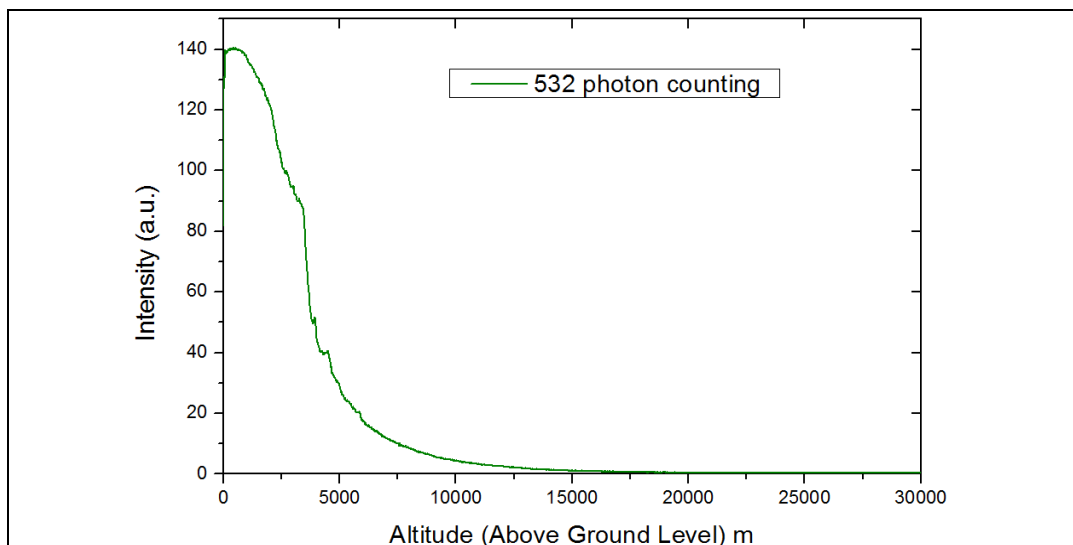

Fig. 3. 21: Typical Lidar signal acquired in the photon counting mode.

3.3.2.5. Signal processing

The Lidar data processing is fulfilled in two steps: (i) *Lidar data pre-processing* and (ii) *Lidar inversion algorithm,* which are explained hereafter.

Step I- Lidar data pre-processing

The Lidar data pre-processing is performed on the raw Lidar signals. Each Lidar data file (containing the average of a certain number of backscattered Lidar signals S(z) coming from a distance z) is corrected for the background noise contribution (BG) due to atmospheric skylight and electronic noise of the instrumentation used. A distance square-law correction (z^2) is applied to each data point (time bin) to compensate for range-related attenuation from the atmosphere. Then, the natural logarithm of the resulting quantity is calculated. On the resulting *log range-corrected* signal SLOG where $\mathrm{SLOG} = \ln\left[(S(z) - BG)z^2\right]$, a running low-pass derivative digital filter, with variable path is applied. The smoothing method is a running least-square fit of the dataset to the second-order polynomial, which represents a good fit for the vertically decreasing atmospheric scale height (Ancellet al., 1989)[1]. The spatial resolution of the measurement is related to the number 2n+1 of data points fitted to the second-order polynomial.

Step II- Lidar inversion algorithm

To retrieve the vertical profile of the aerosol backscatter coefficient (b_{aer}) at 532 nm the improved Klett inversion technique is used. This technique is based on a far-end backward iterative technique, taking into account also the atmospheric molecular contribution as described by Klett (1985)[3]. The uncertainties associated with this technique have been discussed in detail by Chazette et al.(1995)[5] and by Boesenberg et al. (1997)[6], while the limitations of this technique arise from an ill-posed mathematical problem (one set of signals measured with two sets of parameters to be retrieved: the aerosol extinction and backscatter coefficients) in conjunction with the a priori assumptions made for the Lidar inversion, such as the fixing of the 'reference height' (where the atmosphere is purely molecular), and of the so called aerosol *'Lidar ratio' LR where* $LR(sr) = \dfrac{a_{aer}\left(km^{-1}\right)}{\beta_{aer}\left(km^{-1}sr^{-1}\right)}$.

At 355 nm the inelastically backscattered Lidar signals can be inverted using the Raman inversion technique, as presented by Ansmann et al. (1992)[4]. This technique is applicable mostly under low light conditions (during early evening and nighttime) since the Raman Lidar signal is sensitive to the presence of daytime background skylight.
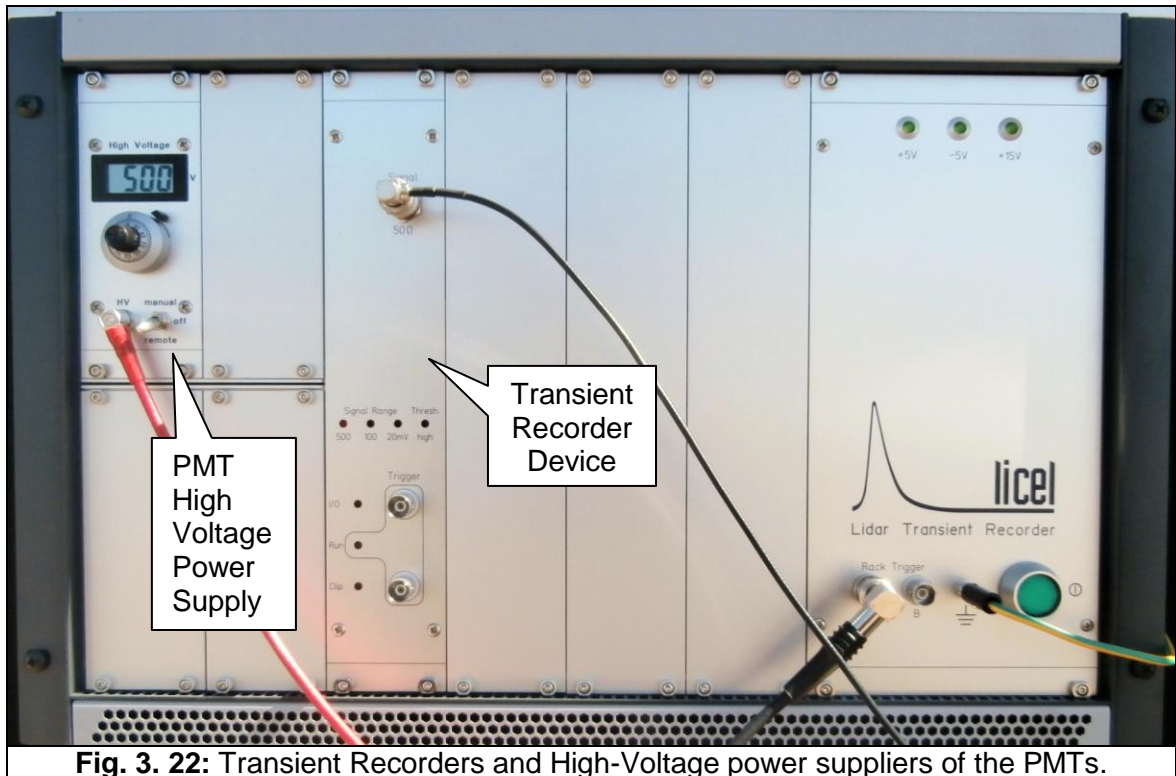
Fig. 3. 22: Transient Recorders and High-Voltage power suppliers of the PMTs.

3.3.3 Industrial Computer

The LIDAR system uses an industrial touch panel computer as a Controlling Unit, which features industrial grade robust mechanical design and reliability. All LIDAR subcomponents (LASER, DAQ) can be controlled from this Unit. Controlling Unit also acts as storage unit and as a communication interface as well.

Features

The ARK3360L Embedded Box Industrial Computers are state-of-the-art Human Machine Interfaces with Intel Atom processors 500 Series with Intel 82801HM I/O Controller and the following key features:

- **Fanless**

By using a low-power processor, the system does not have to rely on fans, which often are unreliable and causes dust to circulate inside the equipment.

- **Windows CE Support**

In addition to the OS support of Windows XP, Advantech offers platform support for WES7 and Windows XP embedded. The optional Windows CE operating system, specifically for Industrial Touch Panel Computers is also available.

- **Energy Star Certified**

Fig. 3. 23: Advantech Industrial Computer

3.3.4 Electrical Cabinet

The electrical cabinet is separated from the Lidar head and provides protection for the electronics. It contains the laser power supply the Licel electronics and the industrial computer. Furthermore it communicates with the Lidar head through an umbilical cord which can be separated for the transportation.

Having two doors one in front and another on back, the electrical cabinet provides easy access to every component.

The cabinet is made from molded plastic that makes it robust and lightweight. It is also shock and water resistant. The side latches hold the lids firmly and are very easy to release. Finally with the build-in wheels, the low profile pull handle and the side handles the enclosure is very easy to lift and transport.

Fig. 3. 24: Electrical Cabinet

3.3.4.1 Features

- Weather protection
- Internal heater
- Fans for air circulation
- Easy access to all components
- Castors and handles for easy transportation
- Door locks
- Robust and lightweight
- Connectors and plugs for quick connection
- Energy box with circuit breakers for every part
- Embedded industrial Ethernet switch

3.3.4.2 Connections

The Licel transient recorder communicates with the PC VIA an Ethernet network with the PC and to an external host. By default the network IP is set as shown in figure below. The user can easily connect to the Lidar and control remotely the instrument simply by using windows remote desktop. As illustrated below the internal computer has two Ethernet ports. One is used from the Lidar Local Network while the other is connected to the external Ethernet socket. This gives the option to connect in a local network (LAN) or directly to another computer with a cross link cable. If the local network gives access to this computer through the firewall, then it can be reached from anywhere in the word.

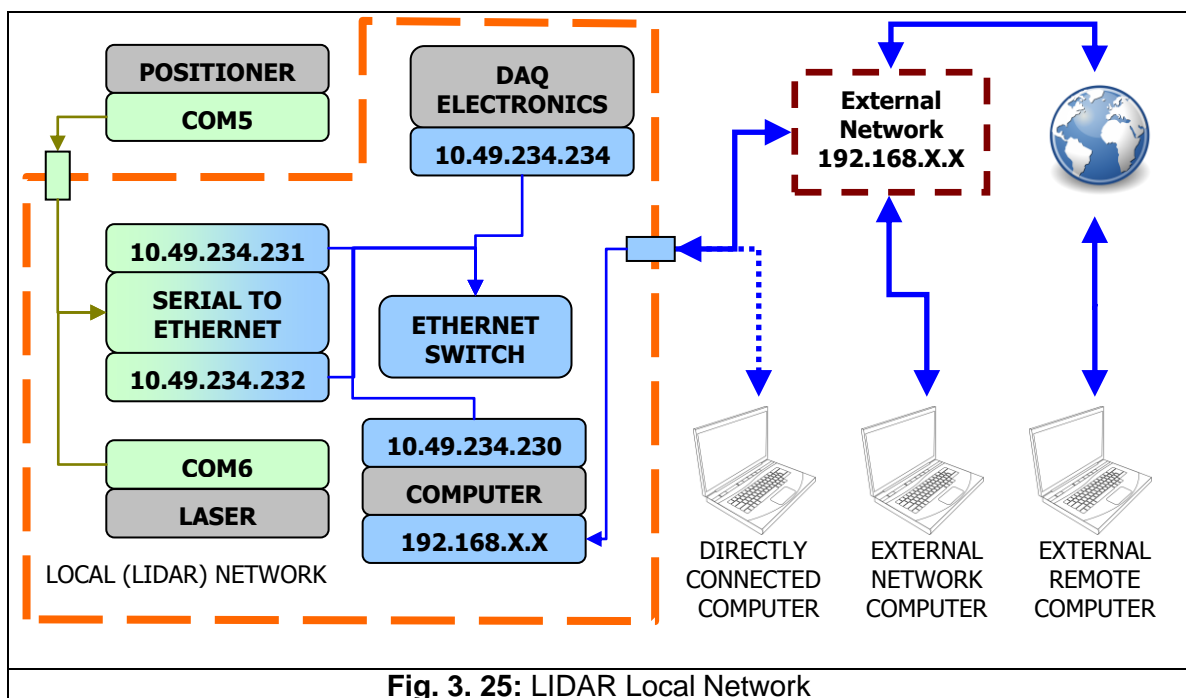At the image below the connections between all components are shown.

Fig. 3. 25: LIDAR Local Network

The transient recorders are externally triggered from the ICE450 through a BNC cable. The laser creates TTL pulse to trigger the flashlamp for every shot. In order to achieve the maximum energy the Q-switch needs to have a small delay with the Flashlamp which is

factory preset for optimum energy, however the user can increase the delay to reduce the energy. For this reason another TTL pulse is produced to trigger the Q-Switch with the required delay. The transient recorders need to be triggered from the Q-Switch TTL pulse, so that the laser emission is synchronized with the acquisition start time.

As shown in the image below default connection is at memory A on Transient recorder and at "QS OUT" on the laser.
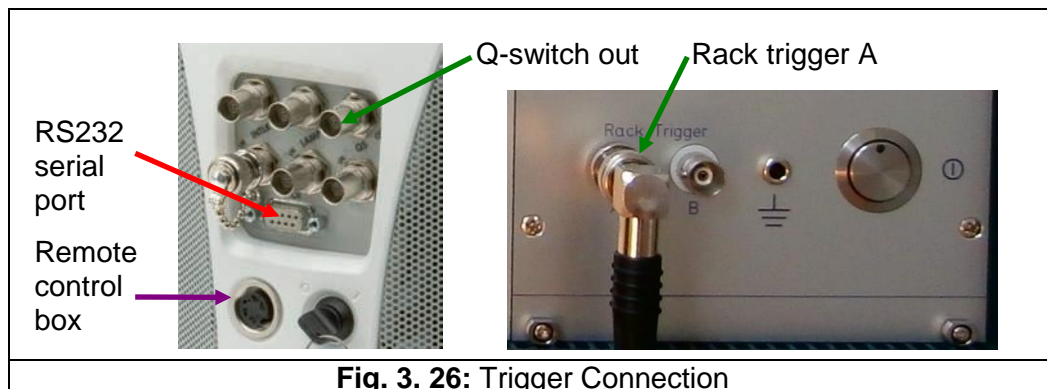
Fig. 3. 26: Trigger Connection

There are also two trigger inputs for the Transient recorder and there are several outputs and inputs for the laser. These are for triggering externally or using the flashlamp TTL pulse to trigger something. How to use these features is explained in A1 HOW TO CONTROL THE LASER

3.3.4.3 Electrical drawing

The electrical cabinet has a power distribution unit which contains the switches for the components of the control unit. Furthermore inside there is the thermostat which is covered for protection but the user can remove the cover strip in order to set the temperature of the thermostat.

1. "Main" Switch. This gives power to the rest of the components.
2. Circuit protection breaker 30mA. In case of a short circuit this will automatically shut down the mains.
3. "Laser". Switch for the laser.
4. "TR" Switch for the Transient recorder and PMT power Supply
5. "Tracker" Switch for the positioner.
6. "HVAC". Switches on the Ventilation Fans or the Heater.
7. "LAN". Switch for the power supply [11] of the industrial Ethernet switch.
8. "PC". Switches the power supply [12] of the panel computer.
9. PSU for the Industrial Ethernet switch
10. PSU for the Industrial Panel Computer
11. Thermostat (Beneath Cover)
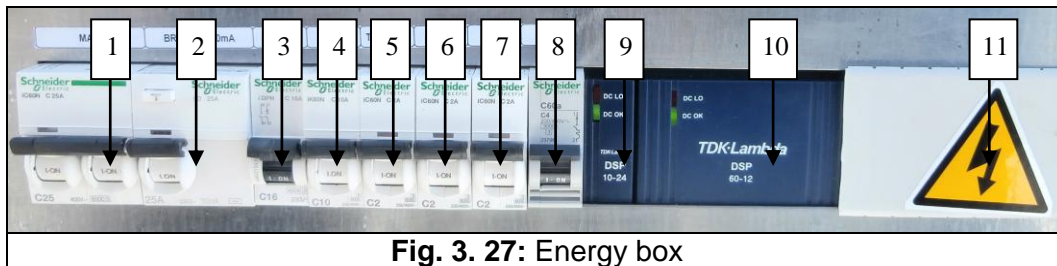
Fig. 3. 27: Energy box

> **WARNING – HIGH VOLTAGE:** Do not operate the Lidar without the protective cover. Keep away from liquids. Electric shocks could lead to serious injury or even death.

To set the desired temperature on the thermostat unplug the instrument and remove the plastic cover next to item 10 in Fig. 3. 27.

At the figure below is shown a simplified electrical drawing of the power distribution unit. Note that this is only for reference. Do not apply any changes before consulting us.
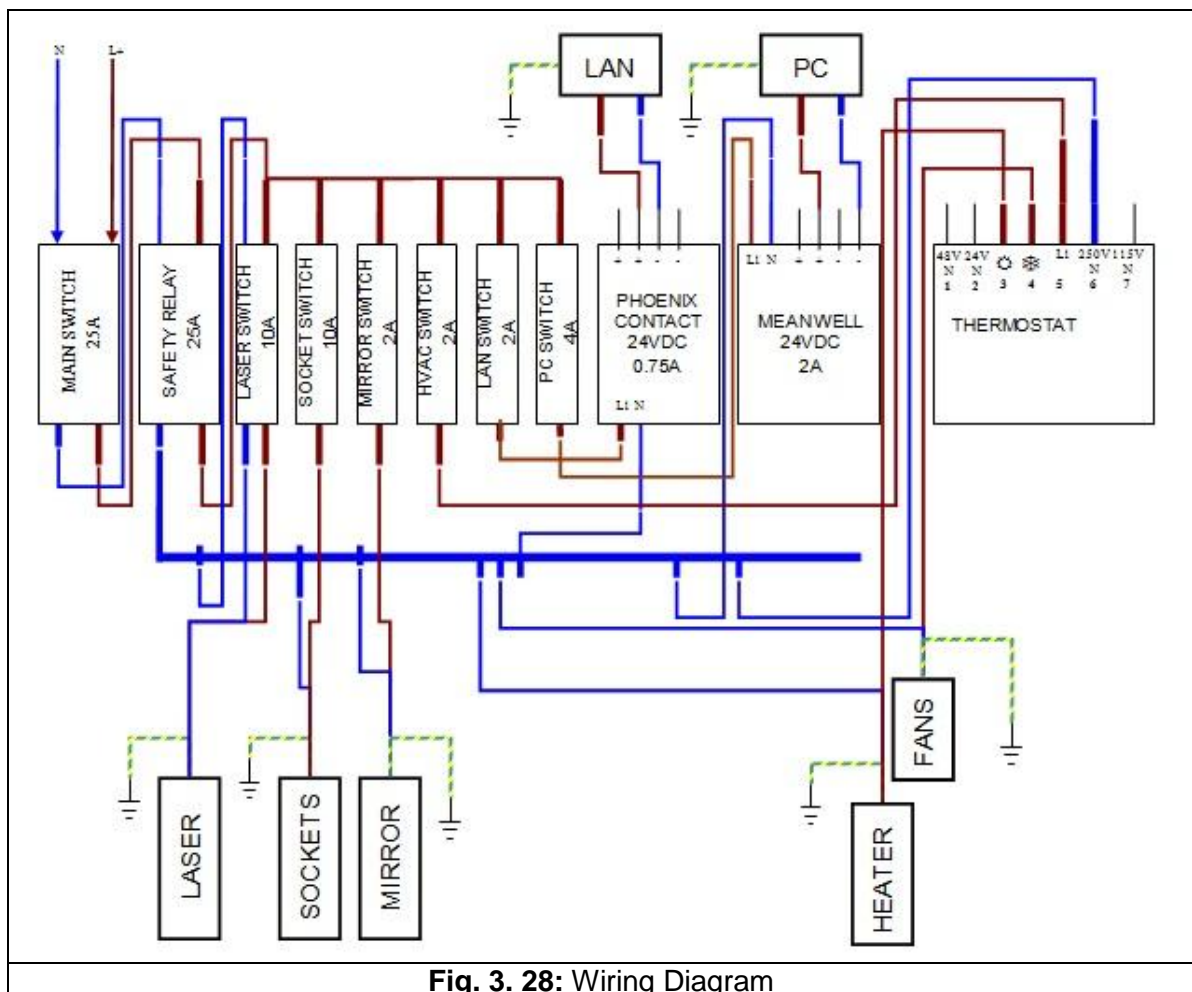
Fig. 3. 28: Wiring Diagram

4. LIDAR SYSTEM SOFTWARE

The Lidar comes with a series of software programs. These can be grouped in three main categories; Operating, post processing, tools. Operational software are used to acquire the Lidar raw data, the post processing is used to analyze the raw data and the tools are used for maintaining the Lidar in it's peak performance, customization and diagnostics.

Below is a diagram with some of the basic software modules.

Fig. 4.1: Software Modules
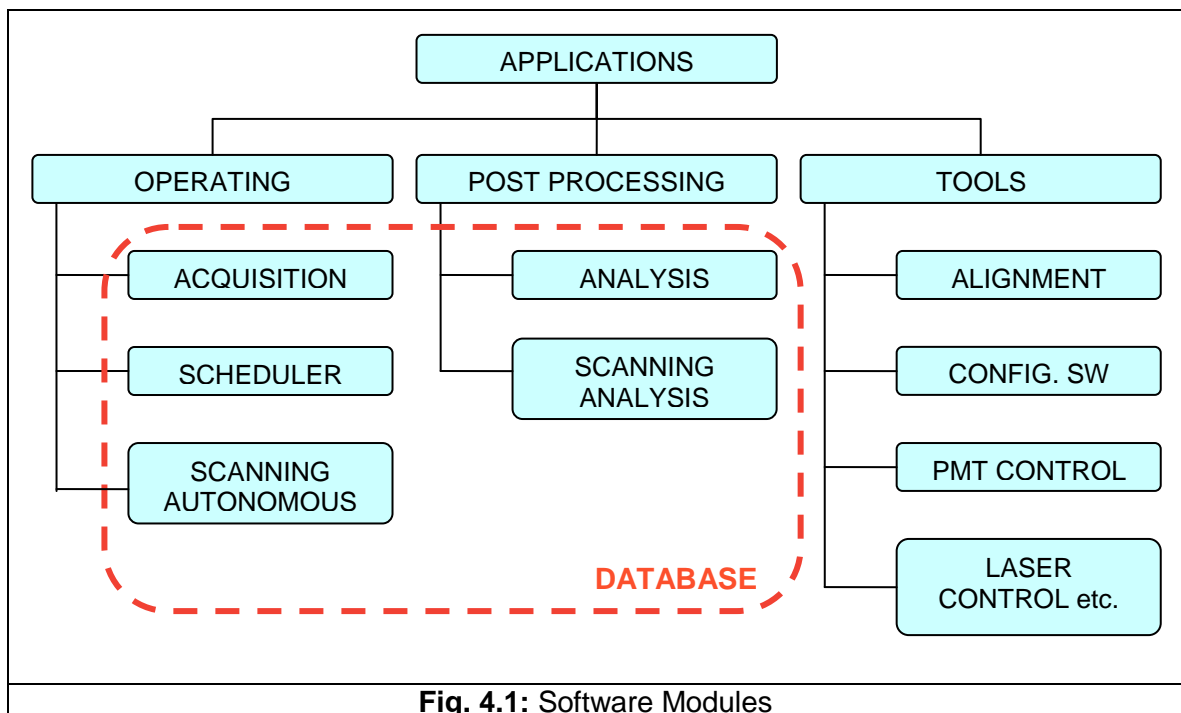
The data from the measurements (raw data) are saved in a database. This database is shared with the analysis software which can also edit it. It is important to understand how this database works so that the measurements are registered normally. You can create more that one databases but keep in mind that the data are bulky and not easy to handle. All raw data in one database are saved in one folder with a unique datalog file which contains all information for the records (measurements).

In the next paragraphs are presented the main software modules. Use this only as a reference, some features may not be available in you system. Refer to the applications user manual for further information.

4.1. OPERATION SOFTWARE

As previously noted the operation software is used to acquire the Lidar data. In other words this program will start, stop and save a measurement. This means that the software controls the devices that are used for the measurement and data logs the output of the measurement. Raymetrics has combined all different software from each device in a single program to make the process of measurement as easy as possible.

The acquisition software simultaneously does the following:

- Transient recorders control

- PMTs control

- Laser control

- Data logging

While the scheduler gives the user the ability to schedule a series of weekly measurements.

4.1.1 Acquisition

The acquisition program is the most important program for the Lidar. Knowing how to acquire good Lidar data is more important than analysing the data, as the operator will not miss any data. Below is the interface of "Lidar Acquisition.exe".
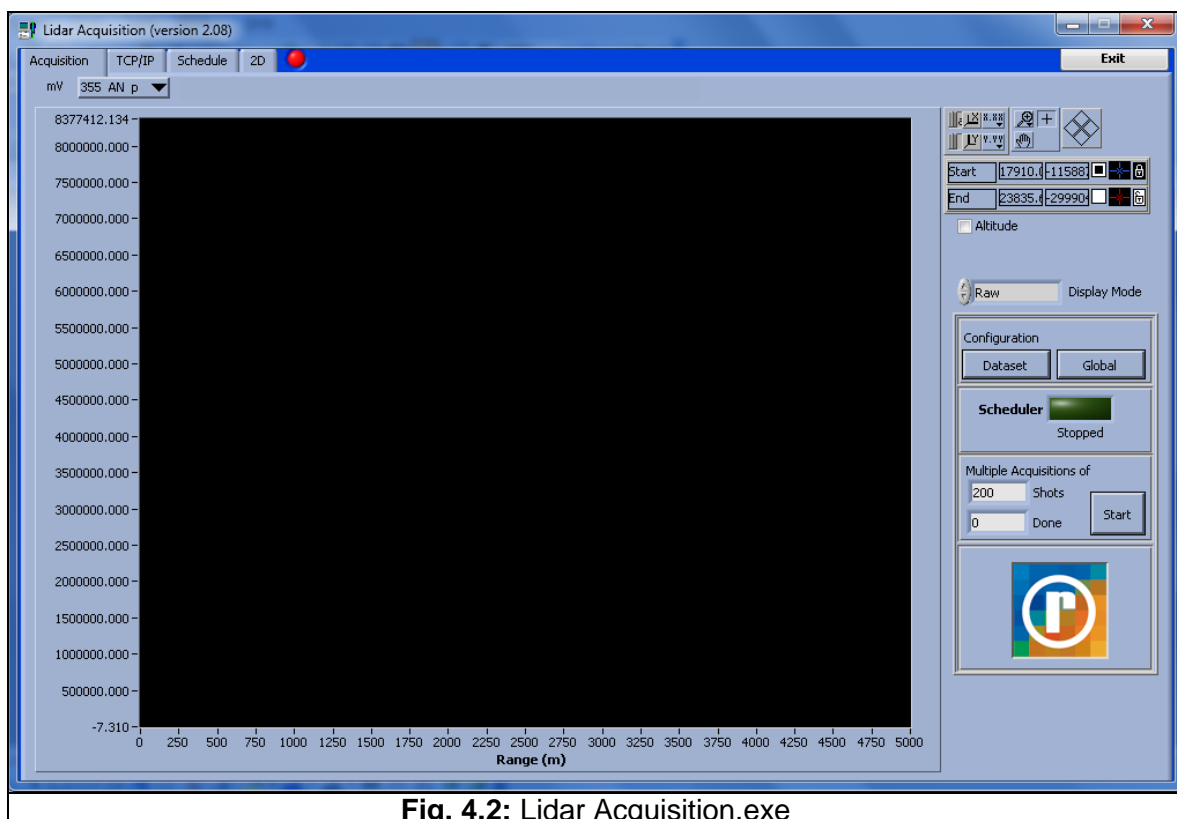
Fig. 4.2: Lidar Acquisition.exe

The GUI contains three main tabs. The Acquisition tab the TCP/IP tab and the 2D Tab. Here only the Acquisition tab is presented which is the main one. The TPC/IP is used only for the configuration of the connection with the transient recorder while the 2D tab shows a 2D graph of the time evolution of the acquired measurements.

The main features in the Acquisition tab are:

- a graph that displays in real time the acquired profiles

- various controls for the graph

- two configuration buttons "Dataset" and "Global"

- and a Star/Stop button

The dataset button opens a new window that allows you to set the parameters for each channel. Below is presented the interface and the main parameters.
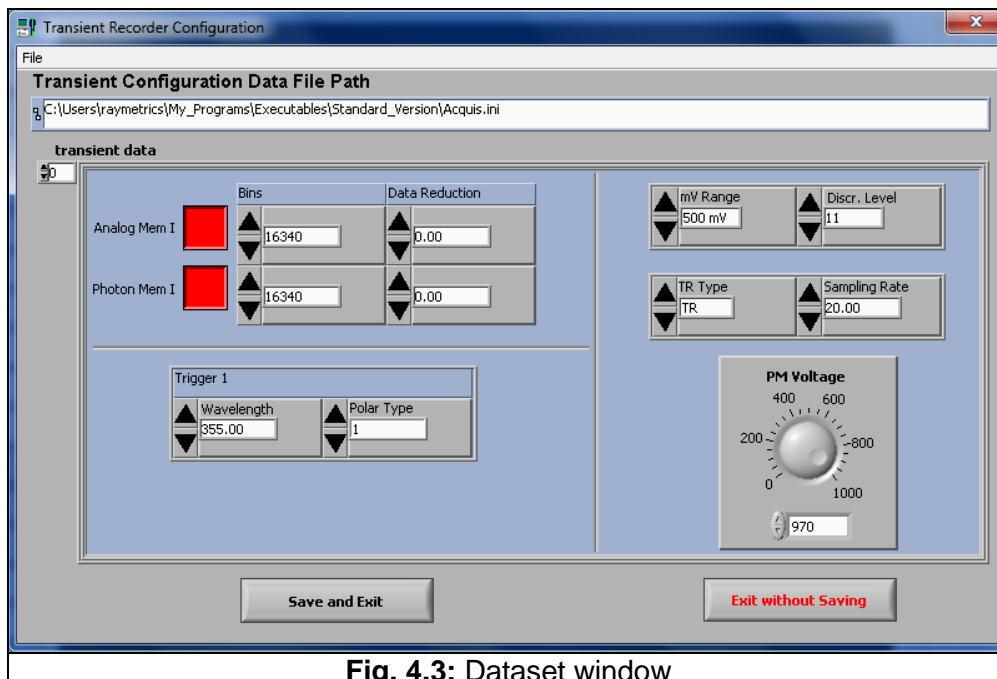
Fig. 4.3: Dataset window

On the menu under File there is the option to load and save a configuration file. Below the selected file is shown. Next to the Transient Data frame there is a numeric control that indicates the selected device

The parameters and settings here are:

- Memory selection button and measurement size for Analog and Photon counting separately.

- TR parameters such as mV range, TR type and sampling rate.

- PMT high voltage setting. This not only sets the header file but also sets the desired voltage to be used for the specific PMT throughout the measurement.

The Global button opens a dialog to set general settings regarding the measurent. As shown below the user can set:

- the location parameters (Name, Altitude, Longitude and Latitude)

- The ambient temperature and pressure

- The laser's information (wavelengths and frequency)

- And the most important the number of shots for each profile.
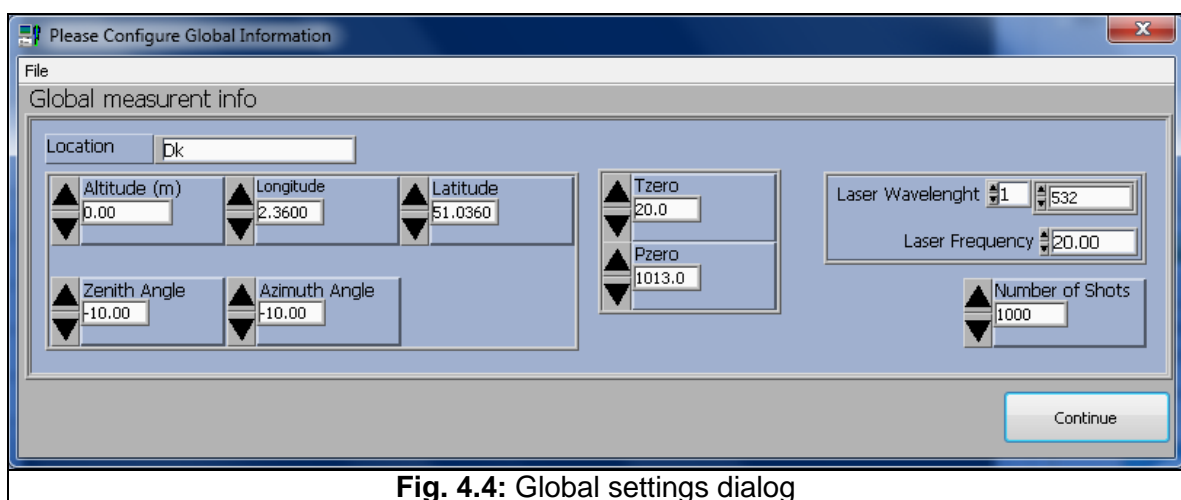
Fig. 4.4: Global settings dialog

4.1.2 Scheduler

The Time scheduler.exe allows you to program the Lidar to perform scheduled measurements. This is quite useful when the instrument is at a remote location without a fast internet connection. The user sets a daily plan of measurements and selects which days of the week will use this plan.

The concept of this software is to use the Lidar in a fully automated mode. There is no actual need for an operator since the Lidar will start and stop and save all the data automatically. Furthermore if a mobile phone is installed the software can produce text messages that will prompt the user in case of an emergency or a failure. All these features combined make a fully remotely controlled Lidar.

Here is only presented the main interface of the program for more information please refer to paragraph 6.4. MEASUREMENT SCHEDULING.
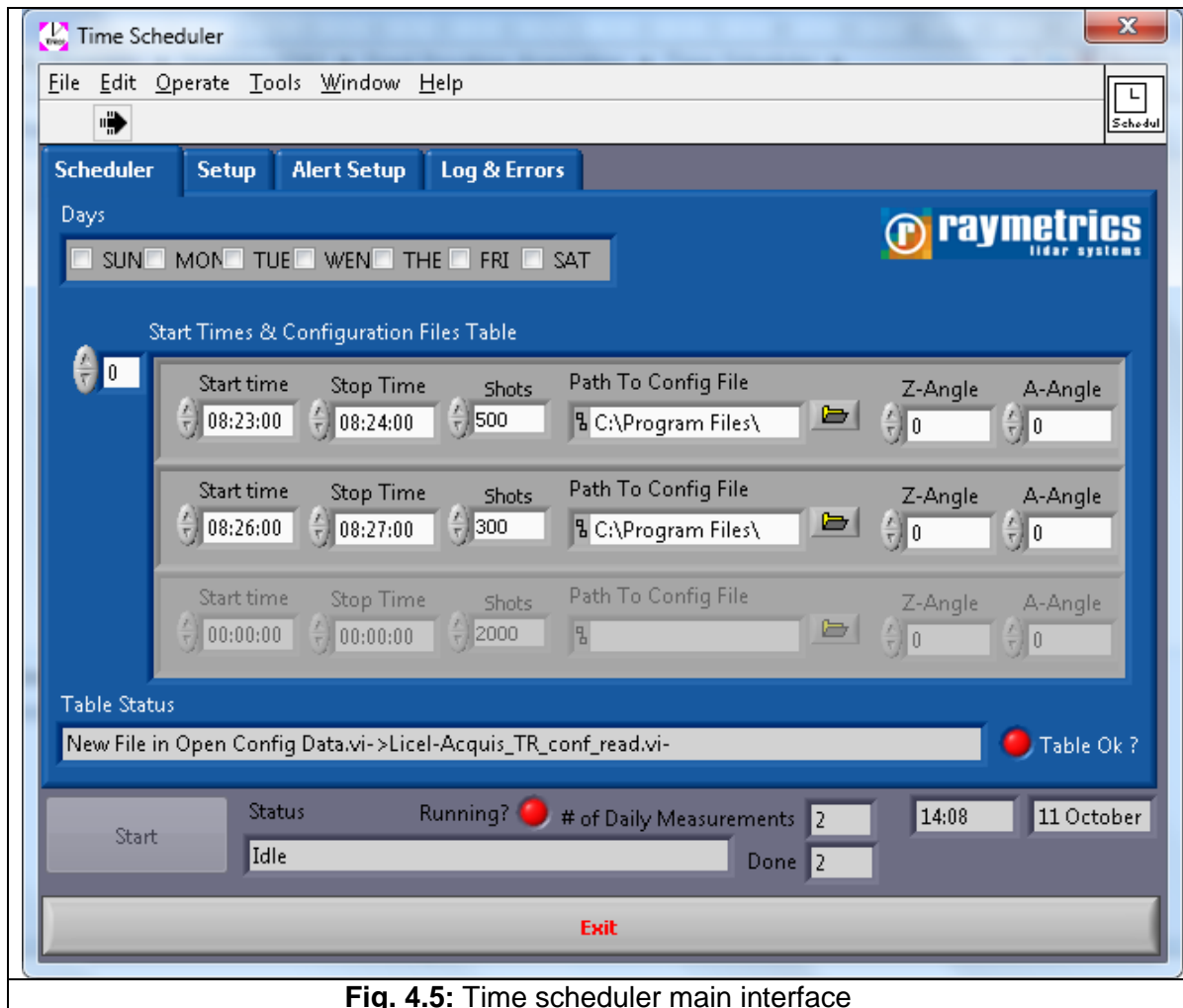
Fig. 4.5: Time scheduler main interface

4.1.3 Scanning autonomous and Time scheduler

For a scanning lidar there is the ability to scan an area or even schedule to scan multiple areas. There are two main programs available; scanning autonomous and Time Scheduler Scanning. Both programs use configuration files as the fixed point time scheduler but these files contain geometrical information regarding the scan. To create such a file there is an extra tool called acquisition configurator. This set of programs make a full scanning lidar operation software pack which gives the user all the possible options one could ask. To make this software complete there the equivalent data processing program for scanning measurements. This is totally necessary while the volume of data when scanning is vast.

Below are only presented the main interfaces of the configurator and the scanning autonomous. The Time Scheduler Scanning differs very little from the one presenteted above and thus is skipped. You can find more information fro these programs in paragraph 6.5. SCANNING OPERATION.
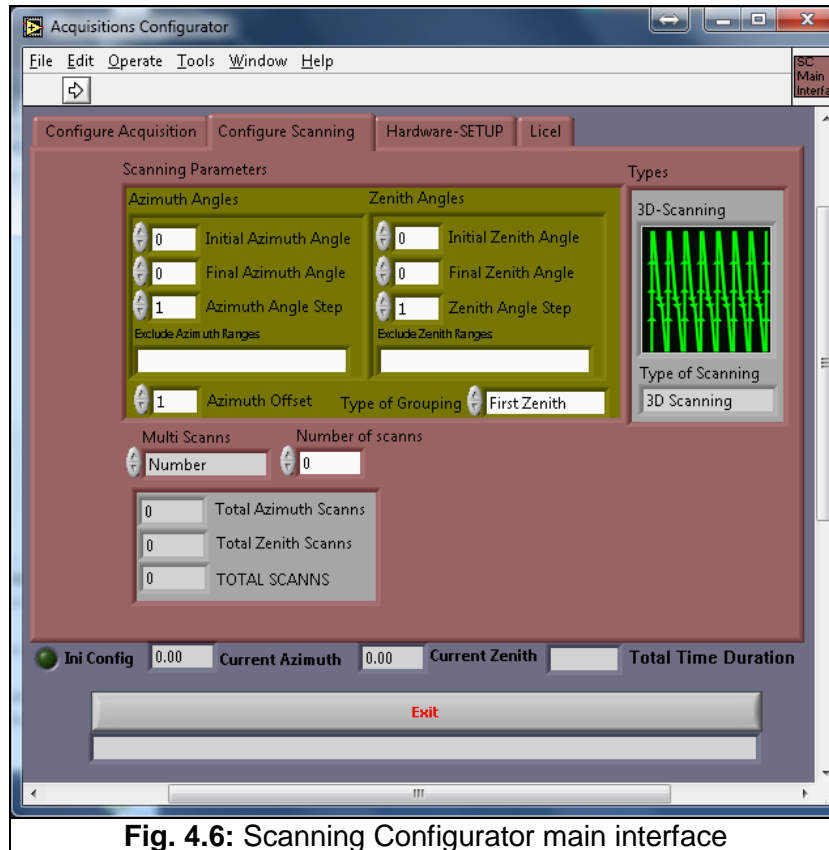
Fig. 4.6: Scanning Configurator main interface
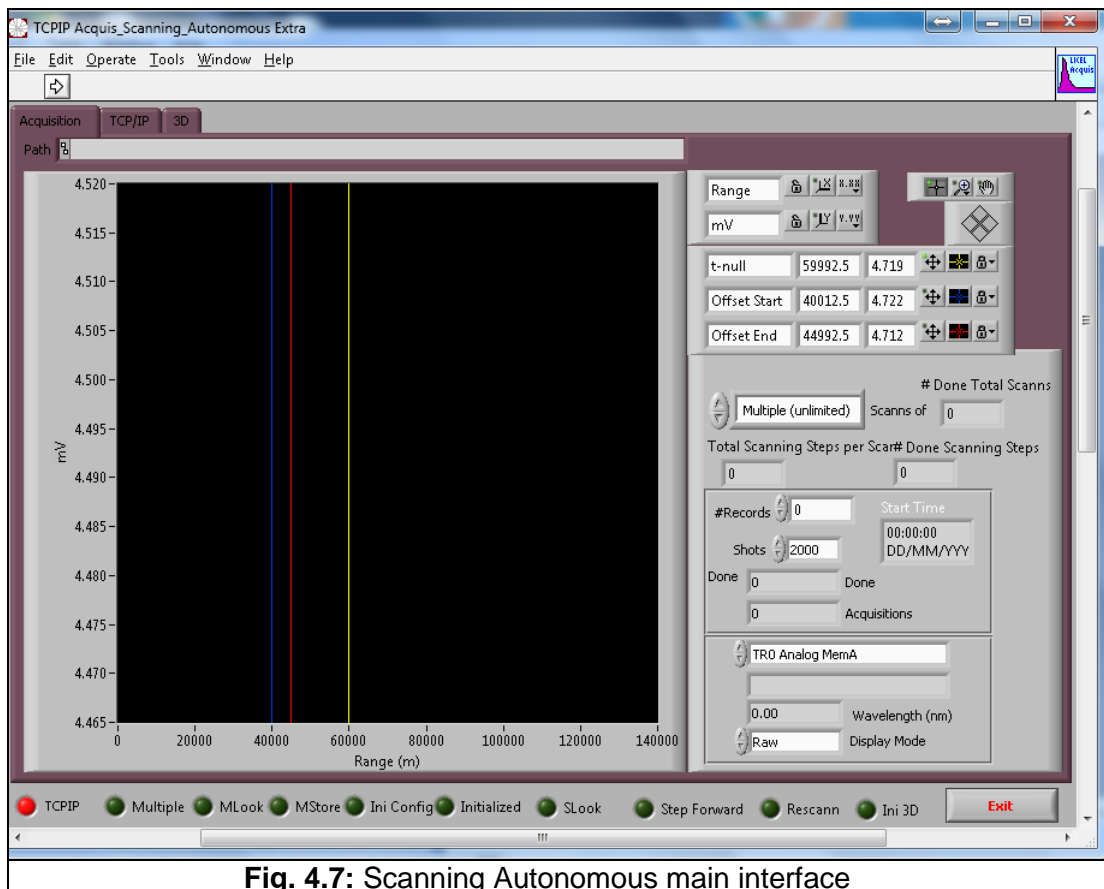
Fig. 4.7: Scanning Autonomous main interface

4.1.4 Database and Working Directory

The measurement produces a series of binary files with the raw data. The volume of data is normally enormous which makes it absolutely necessary to use a program that will arrange the data in databases.

As previously explained all raw data files are saved in one working directory (one single folder) which forms along with the datalog file one unique database. At first site this looks not very easy to handle since one folder can contain thousands of data files. However these files are not comprehensive for the user since they are in a binary form and there is no actual need to go through this folder anyway. These files are already organized well in the database, don't alter the folder and keep a regular backup of your data.

You can create a new database by changing the working directory with a new one. You may make as many databases as you wish but keep in mind that you won't be able to have an overview of the measurements.

4.2. POST PROCESSING SOFTWARE

Now is obvious the need to use a program that can organize the database and will at the same time process and plot the data. The Lidar computer has preinstalled a powerful program, named Lidar Data Preview and Analysis for post processing the Lidar raw data. Many users prefer to use another computer for the data analysis. For this reason, this software is open source code software and can be easily installed in any other computer. The software was compiled in Labview and thus you will need to install the Labview runtime engine which is supplied for free from the National Instruments website.

However there are some users that use their own software to post process the data. In this case we provide the tool to translate the data from binary to ASCII and also the encoding method to use directly the binary files.

The **Data preview and analysis software** was created based on the needs of the Lidar users. Through the years this software was developed so much that today the users can find many features embedded. However in this paragraph it is only presented. To use the analysis software please refer to paragraphs

7.2. DATA PREVIEW for using the database and for the data analysis. With this software the user can:

- Preview and edit a database
- Analyse the raw data and extract various information such as the range corrected signal the backscatter coefficient the beta molecular, the water vapour and many other
- Use a worksheet to perform additional calculations which may not be included in the main analysis.
- Use advanced Lidar techniques such as data Gluing
- Present the data in 2D, surface (time evolution) and 3D plots.
- Use this software as a health diagnostic tool for the system i.e. Lidar Alignment state.
- Convert data to ASCII form binary files
- The program also supports radiosonde data import, or background noise files.

Raymetrics also provides the methods that the software uses for the analysis, so that the user can be aware of the theory that lies beneath.

The software contains an extra module for the Lidar analysis. Each time the user selects to perform a plot or a process of the raw data a series of widows appear to select the data set that will be used for the analysis, then another window where the user has to select what will be the output of the analysis and finally the main analysis window appears. In this window there are many, user or automatically selected parameters, that provide a totally precise analysis.
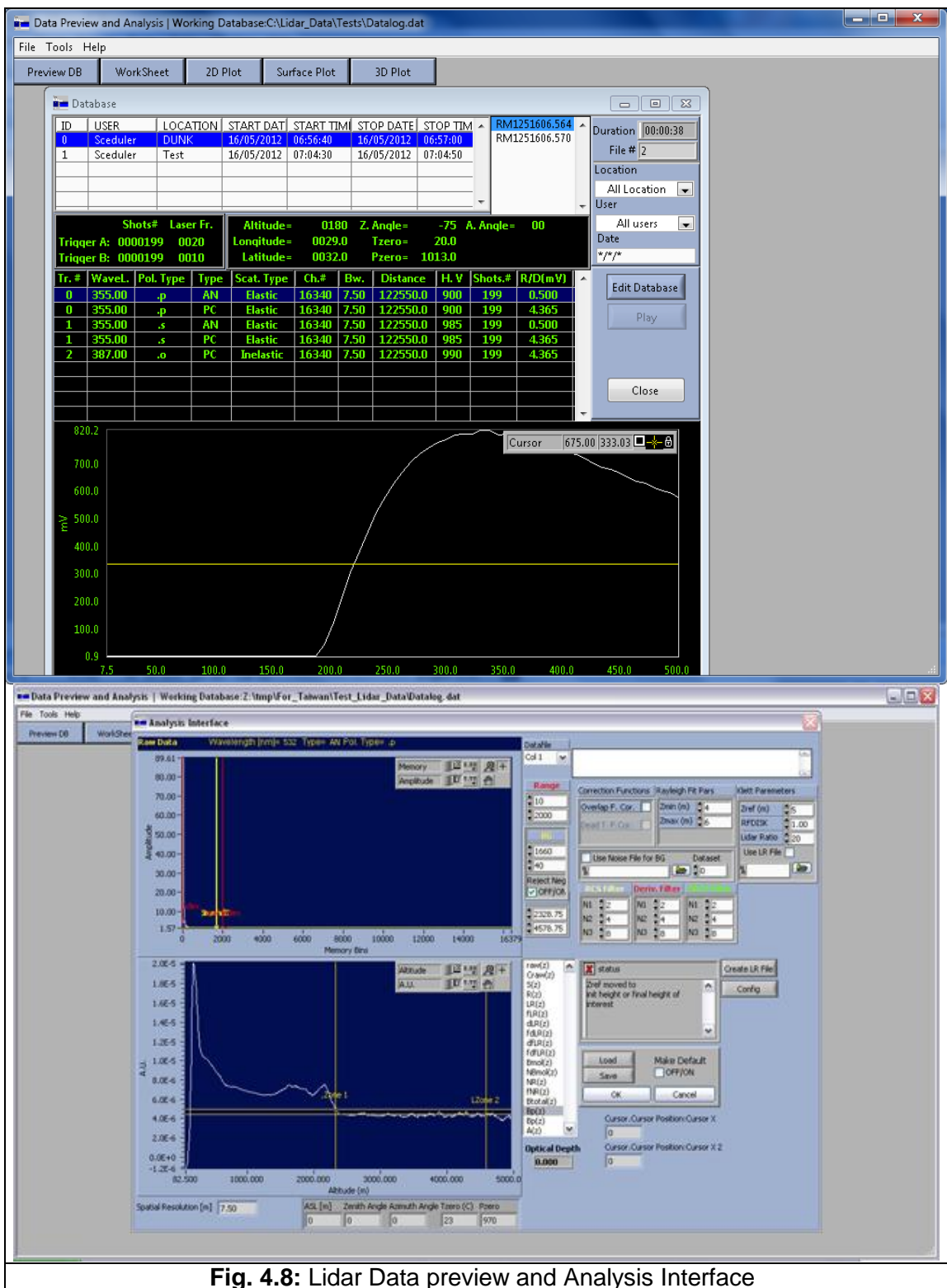
Fig. 4.8: Lidar Data preview and Analysis Interface

Another useful tool is the Advanced Viwer Extra which is specially designed to handle scanning data. With this program the user can group scanning data analyse plot save and many more. This software also cooperates with Google SketchUp to create 3D

representations of scanning data in Google Earth. You can reed more in paragraph 7.4. SCANNING DATA ANALYSIS.
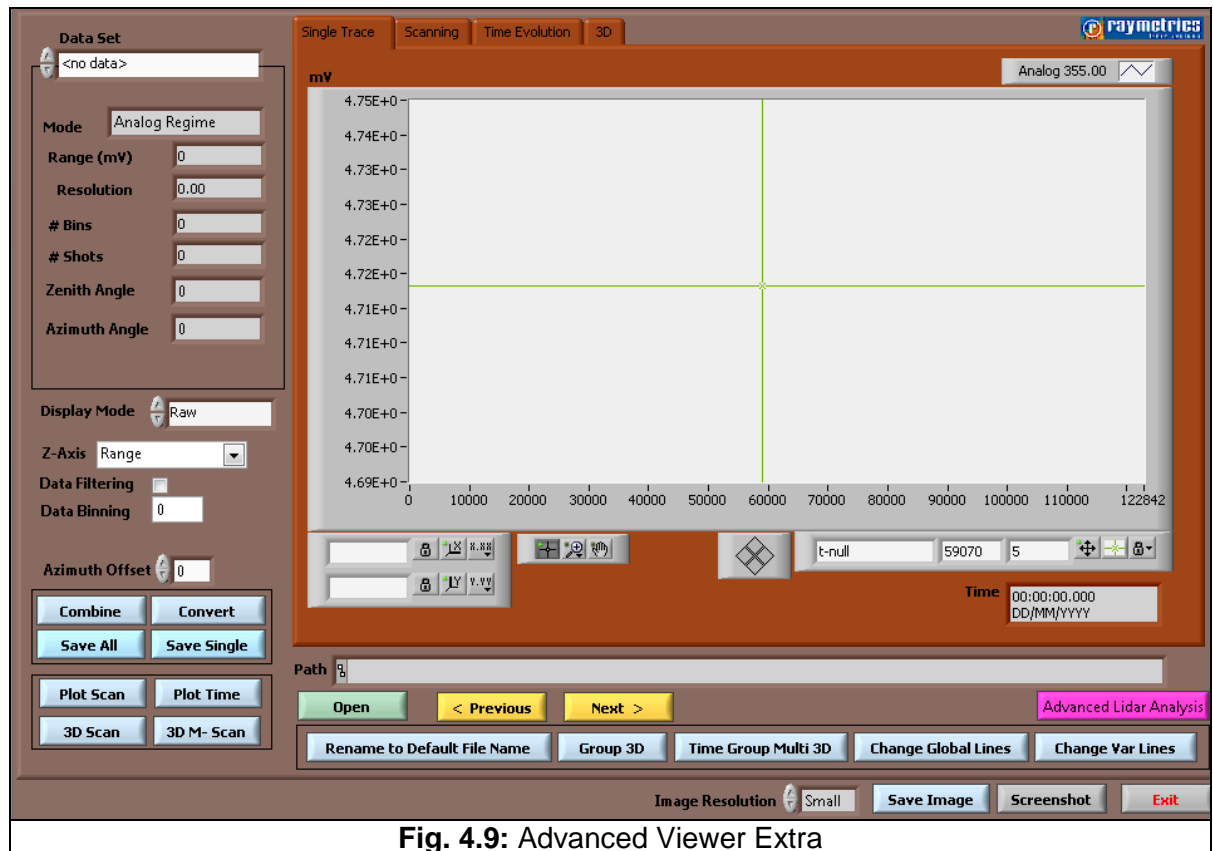
Fig. 4.9: Advanced Viewer Extra
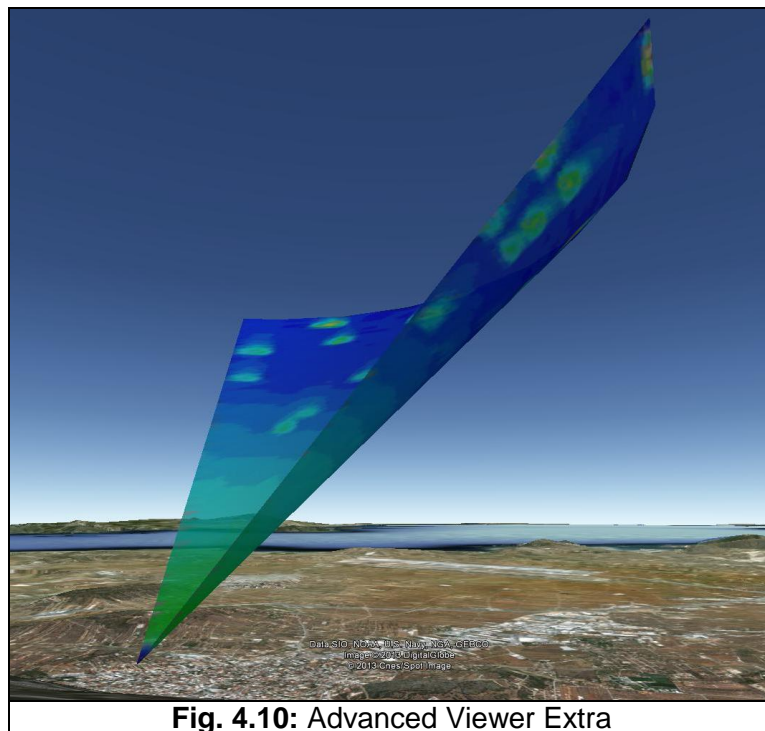
Fig. 4.10: Advanced Viewer Extra

4.3. SOFTWARE TOOLS

There are some software tools that will become very useful to the Lidar operator. To begin with a very useful tool is Lidar alignment, used to align the Lidar. Then there are a series of software modules to control different devices individually, and finally there are some software used for diagnostics and for the configuration of the Lidar's components.

4.3.1 Lidar Alignment Software

This software is a real-time acquisition software that doesn't save any raw data files but is only for viewing the signal. It is suggested to check the signal regularly to make sure that the data you acquire are the best possible. Reed more about the alignment in paragraph 6.2 LIDAR ALIGNMENT.
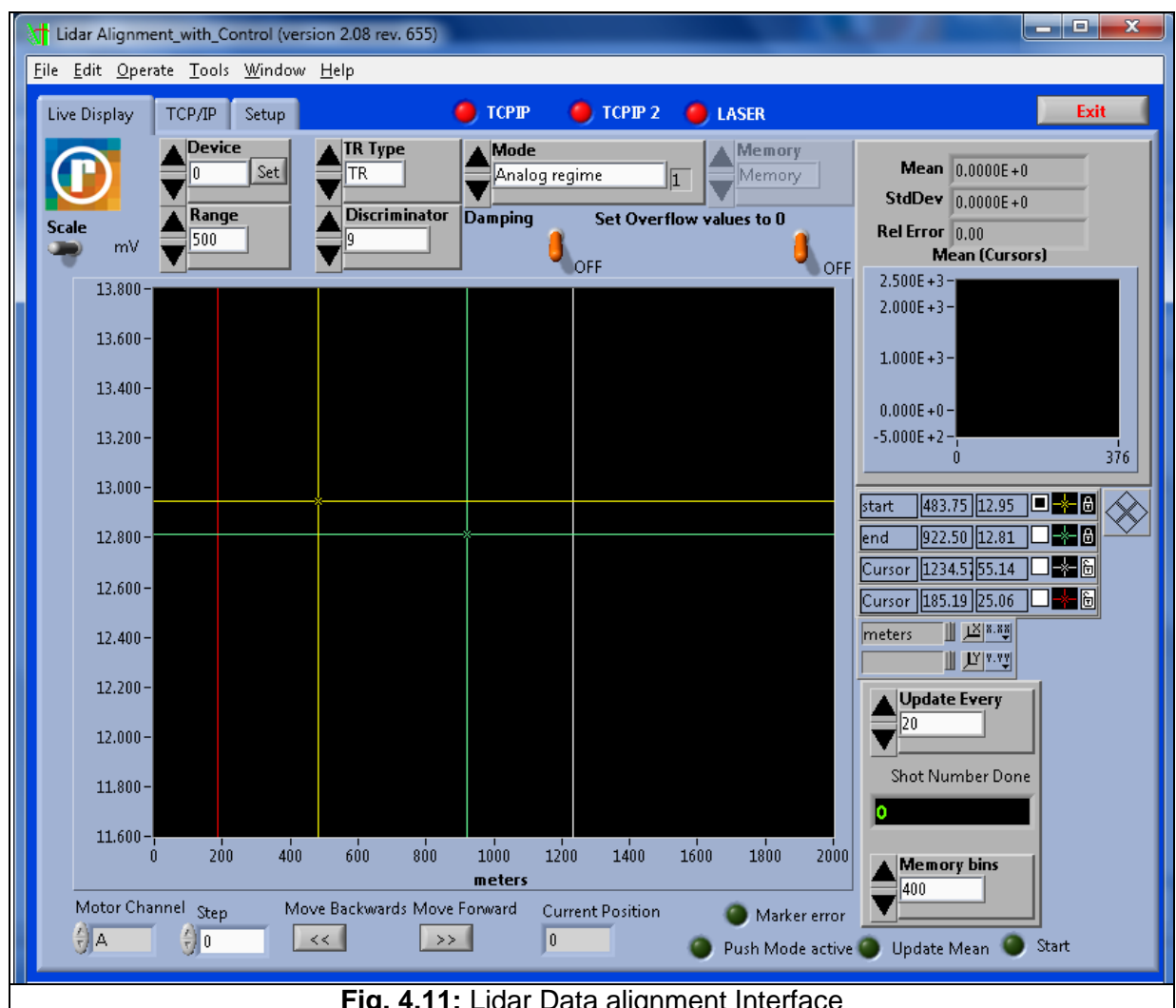
Fig. 4.11: Lidar Data alignment Interface

The interface looks alike with the Lidar Acquisition program. However there are some important differences which make this alignment tool unique. Starting with the common

features there is a graph with its controls and also four cursors instead of two that the acquisition program has. There are also the same numeric inputs all together in the same interface and these are the shot number, the memory bins, the discriminator, the range, TR Type, the mode and the device. The device has also a set button which allows the user to set the PMT high Voltage value. Another extra is a small graph on the right side and above this a series of numeric outputs. These objects are used to verify the process of the alignment.

4.3.2 Configure other hardware

One configuration tool is the "configure other hardware.exe". With this program the user can select what devices will be controlled automatically from the acquisition software and also to change the communication port for the device.
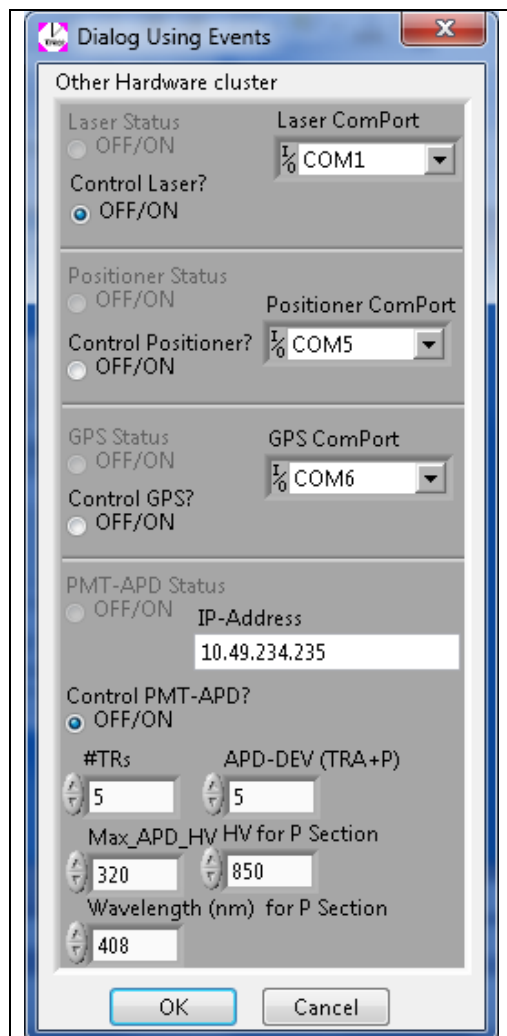
Fig. 4.12: Configure Other hardware

For example in Fig. 4.12 it is selected to control the laser via COM1 and the PMT-HV device through the IP address 10.49.234.235.

4.3.3 Laser Control Interface

This software module is used in case that the user may need to control the laser individually. Furthermore it provides plenty information about the laser state (flashlamp shots, water level and flow etc).
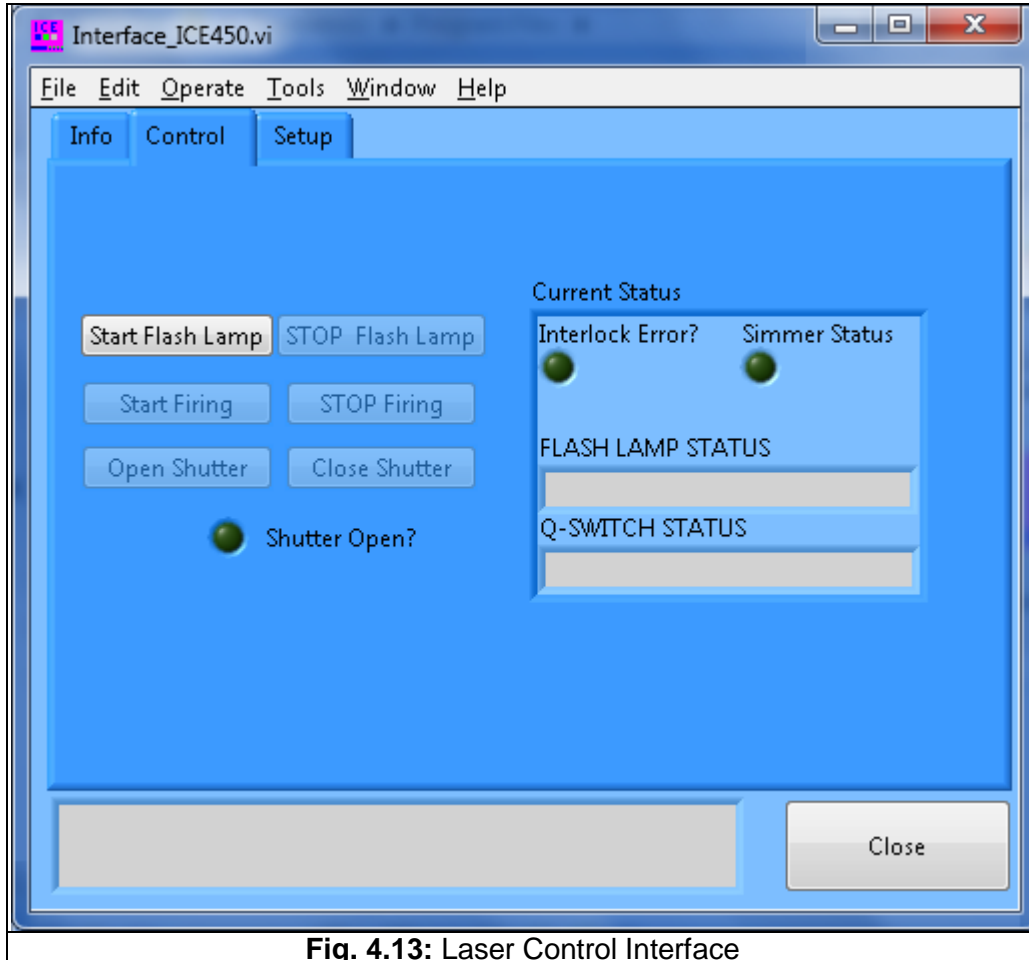
Fig. 4.13: Laser Control Interface

4.3.4 Licel Software

Apart from Raymetrics software there is also installed Licel's software which can be used alternatively to control the Transient recorder the PMTs HV device and also some other devices such as the trigger generator. It also provides some diagnostics tools like the "Track.exe" or the "search controllers.exe".

With this set of programs an advanced Lidar user has the ability to control separately the devices and also perform advanced Lidar measurements. Since these programs have their own documentation, here are only presented just the most commonly used.

4.3.4.1. Control PMT APD program
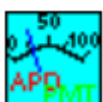
In order to run a non-automated but remote measurement the user also needs to control the PMTs High voltage. Licel provides among other a program to control

the PMTs. The interface is close to the device's interface, the only thing the user has to set is the number of the PMT's - APD's and the IP address of the device.

4.3.4.2. Search Controllers program

This tool is useful when the user has a communication issue and wants to debug. If for some reason the computer doesn't communicate with the Transient recorder or the PMT HV device then when the user runs the acquisition or the alignment software it will show an error message and the TCP/IP led will turn red. This problem may be caused from a bad cable or an Ethernet card overflow. The "search controllers.exe" searches for Licel devices that are in the same network and gives information about their status and the IP address.

4.3.4.3. Control Timing program

The Lidar is equipped with a trigger generator which is used to trigger the laser and the electronics individually. This option is handy when a special study needs to be performed where there must be a time delay in between the laser pulse and the recorder. When using this option the acquisition becomes a non-automated procedure and the user has to use all control programs separately.

4.3.4.4. TCPIP Set Fixed IP Address program

For users with advanced network knowledge it may be needed to change the IP addresses of Licel devices. In this case you can use the "TCPIP Set Fixed IP Address.exe" to set a new fixed IP address for each device. Note here that the external trigger is a different device and has a unique IP address.

5. UNPACKING AND INSTALLATION

5.1. UNPACKING THE LIDAR SYSTEM

The Lidar system has been carefully packaged to assure its secure delivery to the customer.

Inspection after shipment

Check carefully the crate for damage before uncrating the Lidar system. Take notes of all visible external damage. **If you notice any damage caused during the transportation please advice Raymetrics before sign the delivery note.**

Unpacking

The Lidar system should be unpacked only by the authorized personnel of Raymetrics S.A. during the Lidar installation on site. Any damage caused by the user in an attempt to unpack and install the Lidar is not covered by the warranty.

If you have permission to unpack the Lidar system, remove the external film, and open the crate by removing all screws. Remove the straps. Some systems are shipped without the wheels to reduce space. The wheels are usually inside the crate or inside the Lidar enclosure. There is a key usually above the Lidar. In case that there are no wheels pull one corner of the enclosure each time out of the crate and place all wheels. If the Lidar is shipped with the wheels on then lift from the base of the enclosure with a forklift and place it gently on the ground.

IMPORTANT: Make sure that the Lidar is always safe from falling by tilting; avoid at any time and impacts sudden movements.

5.2 INSTALLATION OF THE LIDAR SYSTEM

Site:

For proper operation of the Lidar system the ambient temperature should range between 18 and 28°C.

It is preferable that the Lidar system is positioned and secured on a solid horizontal surface. When choosing a place for your Lidar system other than an open-air site, make sure that the housing has an opening (hatch) over the Lidar, with an area 15-20% larger

than the total area of the transmitting/receiving windows of the Lidar system. The housing must have an air condition.

Keep always in mind:

- Access should be available from all sides of the Lidar system, especially in the front where the control unit is,
- Choose a location for the laser and power supply and cooling unit, cabinet (PCC), such that each side of the cabinet is not less than 25-30 cm away from a wall or obstacle. Front and rear panels of the instrument should be placed at least 50 cm away from a wall or other obstacle, to allow efficient cooling of the instrument.

- Power:

Power is to be 110 V (50/60 Hz) with available operation current up to 6.7A and a peak current capacity up to 13.4A. Make sure that the power is stable and no large motors are on the same line. If for any reason the power has large peaks the laser will not function. If there are often power failures it is strongly suggested to install an external on-line UPS for safe shut down of the instrument. The on-line UPS stabilizes the power as well. **For the installation make sure that there is a socket rated for at least 13.4A and the appropriate plug to fit this socket and to the power cable (Fig. 5.8). The power cable type is 3x2,5mm^2.**

- Water services:

The laser cooling unit is a water/air heat exchanger and does not require any external water service. However the user must make sure that there is **distilled water with 1MΩ-cm to 5MΩ-cm resistivity** always available at any time and especially during the installation.

The on-site installation and Lidar system alignment will be totally assured by the Raymetrics S.A. personnel.

Attention!

No attempt should be made by the user to install the Lidar system. Damage occurring due to the non-respect of the previously mentioned instructions will not be covered under our warranty.

5.2.1 Assembly

The lidar before shipment is packed carefully in components. The control unit has the umbilical cord attached. The positioner is placed separately with the Lidarhead while the tripod base is dismantled to reduce space.

Start by assembling the tripod base. Place the main tube horizontally in the ground and mount the legs. Then place the support bars and hold them together with the supplied screws.
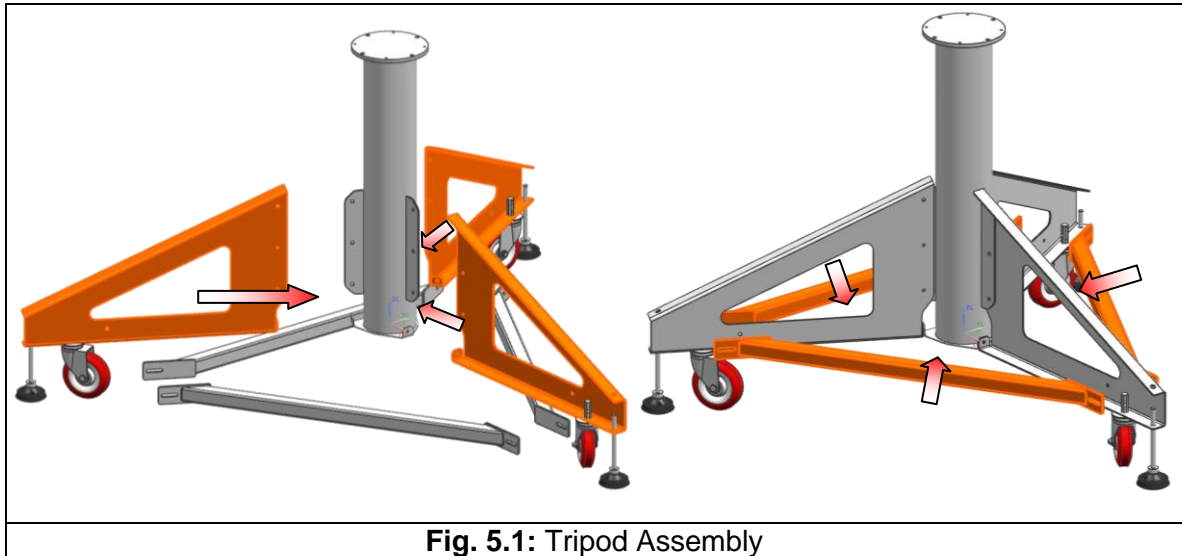
Fig. 5.1: Tripod Assembly

Next install the positioner on the base and place the counterweight side brackets on the positioner shaft. Don't tight the connex screws yet because you will have to move the brackets in order to fit the Lidarhead.
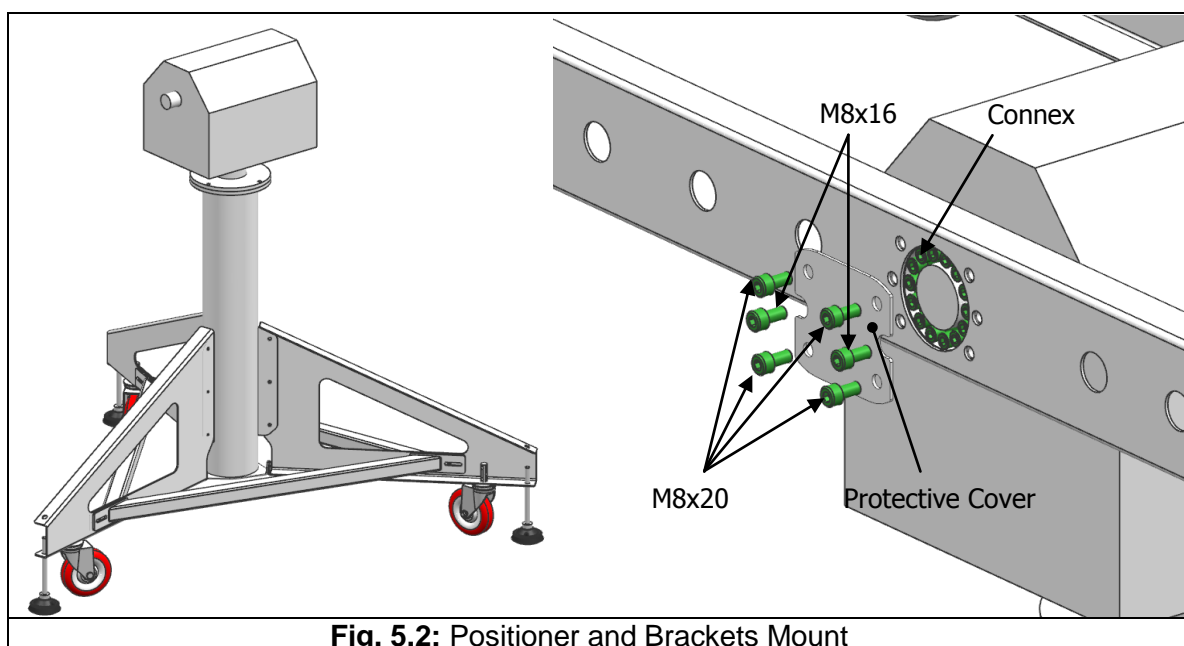
Fig. 5.2: Positioner and Brackets Mount

Now place the lidar head to the side brackets carefully. Before the placing Lidarhead you should indicate which one is the correct side. On the positioner there is a small round window where the bubble level is. This side must face the side of the telescope as shown in fig.36. It is more convenient to turn the brackets at vertical position and then fit the Lidarhead's mounts on them.

Fig. 5.3: Lidarhead Installation
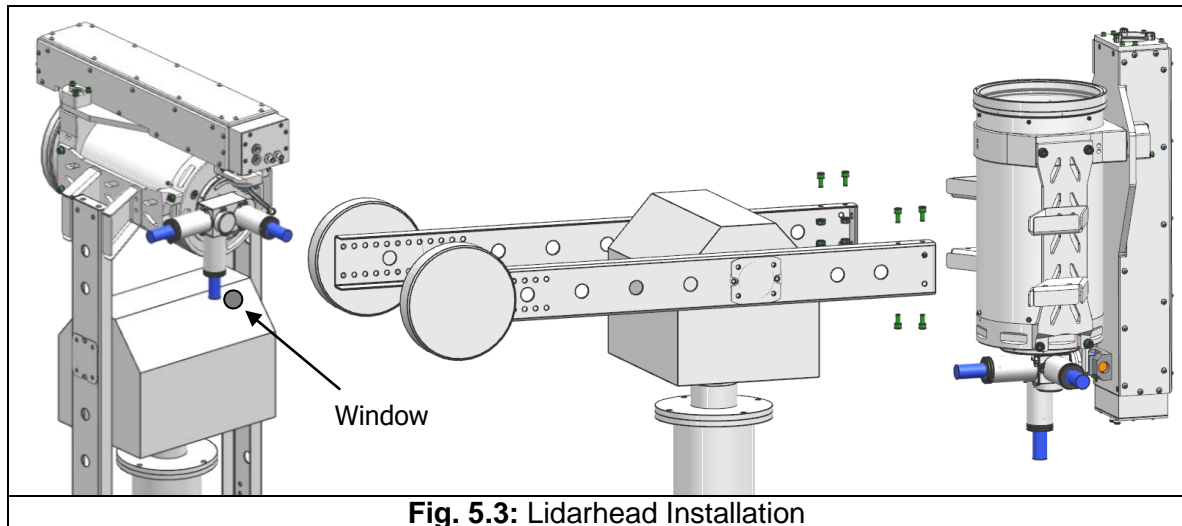
CAUTION! When installing the LIDAR head one must hold the brackets which should be free to rotate and translate on the positioner's shaft. After the head is installed fix the screws of the Connex to secure the brackets in a horizontal position.

For extra precaution the WSU should be separated from the Lidarhead during transportation. Place the WSU underneath the telescope and press it to fit into the telescope's hole. Place the hexagon screws, screw them first by hand and tight them with a no.10 spanner.

Fig. 5.4: WSU Installation
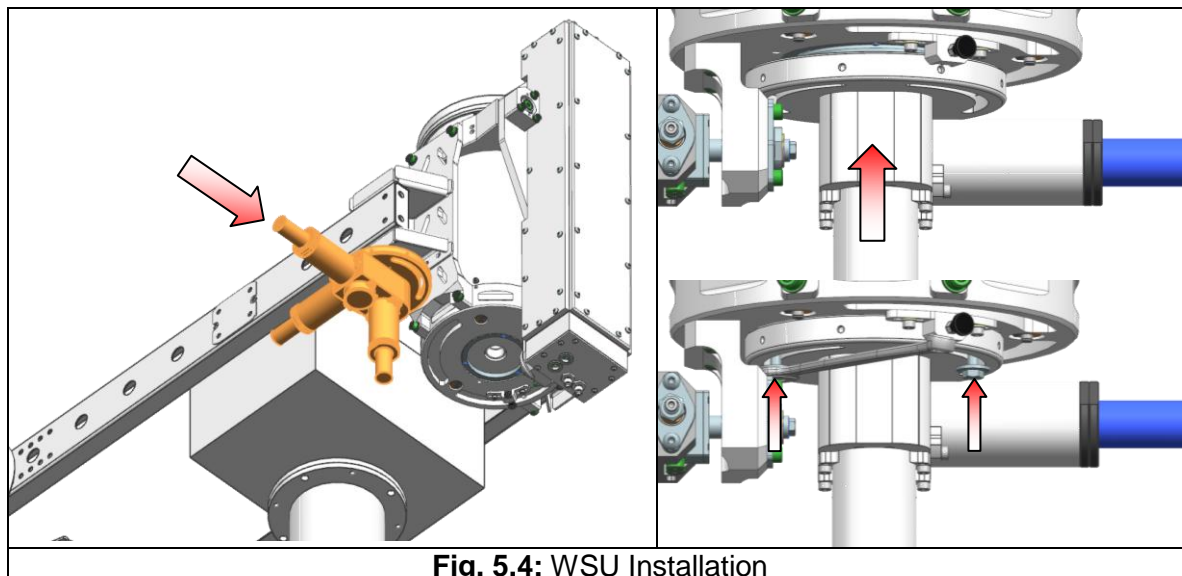
NOTE: The WSU unit needs also extra caution when handling and it is very important for the optical not to be dirtied. It is strongly recommended to use sterile gloves in this phase.

5.2.2 Cable Connections

5.2.2.1 Umbilical Cord

The Lidarhead umbilical is fed into the cabinet through cable conduit and thus it is attached to it while the other end has connectors that mate at the back of the Laser head. To have access to the laser head remove the top cover of the transmitter.

Find which connector goes to which receptacle; one cable has a 19pin connector and the other has a 2+2pin connector. Then locate the red spot on the connector and on the receptacle. This spot indicates the orientation of the connector.

The water hoses have quick coupling fittings. The red is for the warm and the blue is for cold. On one of the hoses is written "cold" the other is for warm.

Fig. 5.5: Laser Umbilical Connection
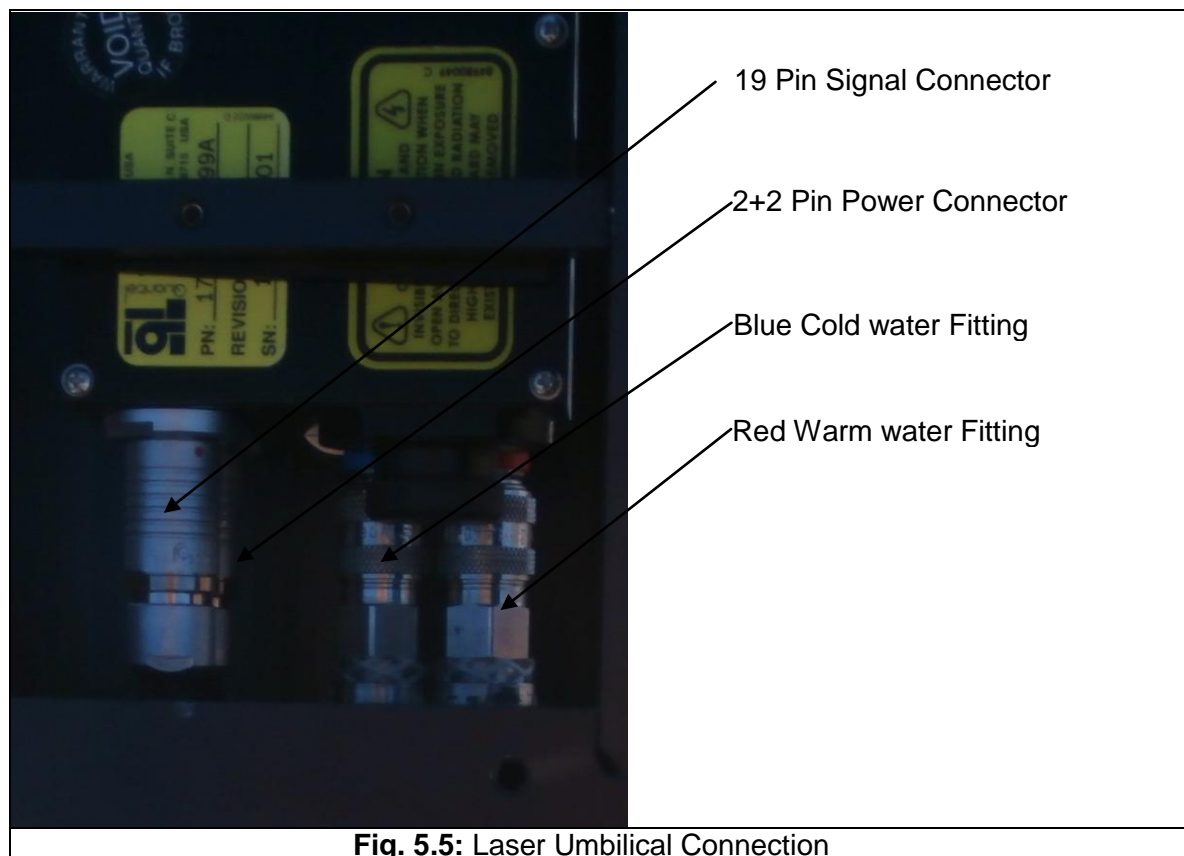
Once the cables are in place back the cover and tight the screws of the conduit end cap.

Fig. 5.6: PMT Connection

Next connect the cables on the back of the PMT and mount the protective cap. Make sure that you place each cable set to the corresponding PMT and that the cables are not stretched.

Finally with some cable ties fix the umbilical on the side of the telescope's bracket. Make sure that the cable has enough length to move along with the positioner and that it is does not interfere with the tripod. When joining the umbilical place the laser umbilical in between the red and the black cables of the WSU. The red cables are for the high voltage of the PMTs and the red are for the signal. If these two are very close it is likely that the signal will be affected.

Fig. 5.7: Umbilical Tie Down

5.2.2.2 Other Connections

In addition connect the positioner's power supply and signal cable, the laser's remote control box, the external Ethernet cable and the system's power supply to the cabinet.
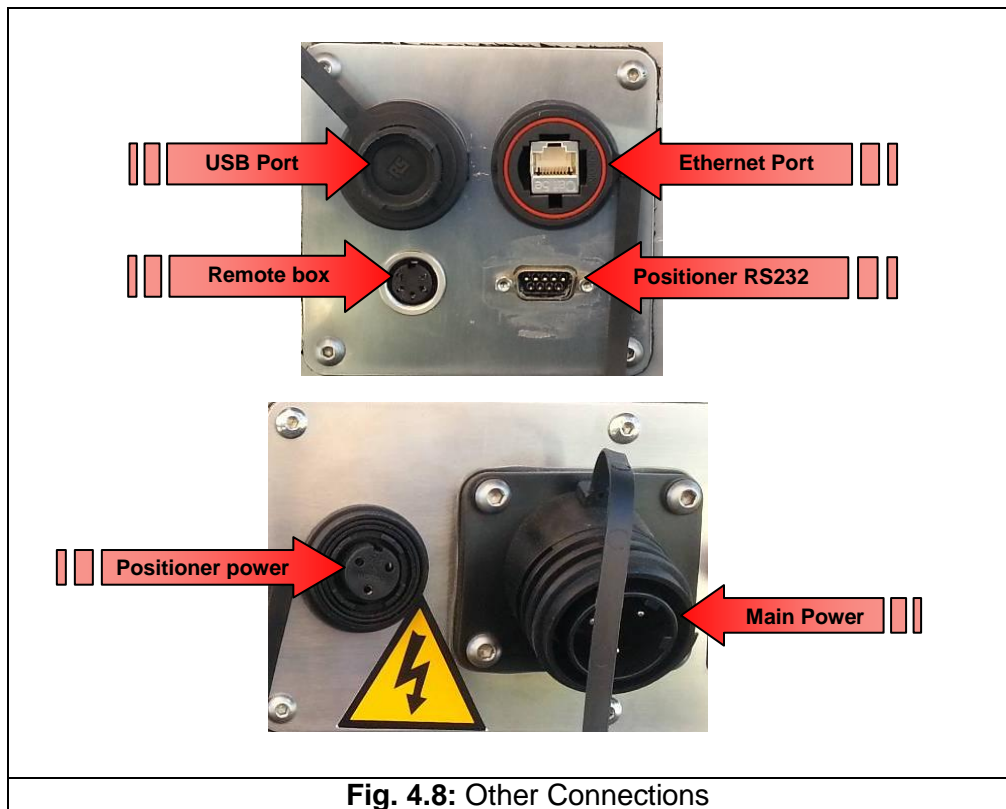
Fig. 4.8: Other Connections

Finally assemble the plug on the power cable (Fig. 5.8) which fits the socket of the installation site. Make sure that the plug and socket meets the requirements of the Lidar power consumption
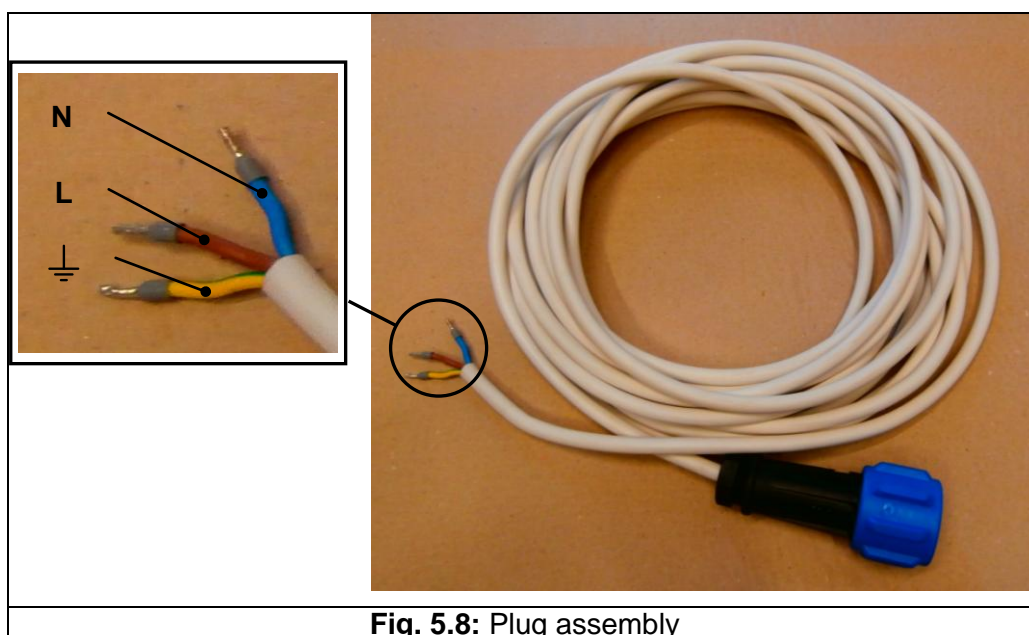
Fig. 5.8: Plug assembly

Note: The cables colours are explained below:

████ **Brown cable goes to "L" (Live)**

████ **Blue cable goes to "N" (Neutral)**

▨▨▨ **Yellow-Green cable goes to "⏚" or "G" or "E" (Ground or Earth)**

Connect the power cable to the Lidar's socket. You may also use the other ports the Ethernet port to connect the Lidar with a network or the USB port to connect a USB device.

5.2.3 Water Filling

For shipping the Lidar, a Raymetrics' technician drained the coolant from the coolant reservoir of the laser. Before use, the customer must fill the coolant reservoir with about **1,5 litres of distilled water with 1MΩ-cm to 5MΩ-cm resistivity**.

1. Turn on the red main switch at the side of the electrical cabinet.

Fig. 5.9: Main Switch

2. Open the front and back lid of the cabin.
3. Switch on all the switches at the energy box at the back of the cabin.
4. Please follow the instruction that you can find at page 11 of the User's Manual Quantel.

IMPORTANT: Each time the Lidar is transported by plane the coolant **must** be drained off the reservoir and especially off the Laserhead to avoid freezing that will destroy the Laser.

5.2.4 Software Installation

Raymetric's Lidar systems are supplied with a computer system which has already installed all the necessary software for apparatus alignment, data acquisition and data preview and analysis.

At any time you can install the executables files that will come with the instrument.

5.2.4.1 Configuration Utility for your Lidar

For manually run configuration utility just open <installation path\Registry Tools\Config Application.vi>

This is an autorun vi.
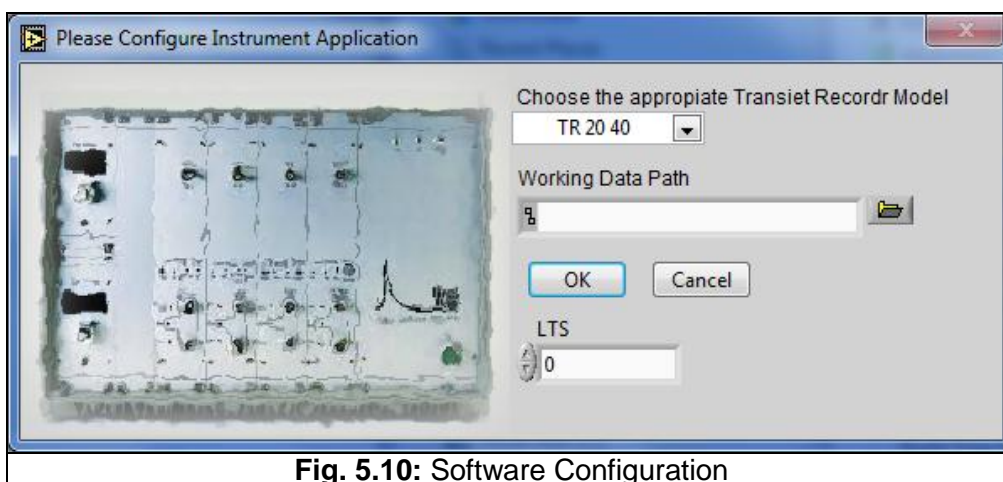
Fig. 5.10: Software Configuration

Select type of Transient Recorder Tr-xx-yy

xx: Sample rate

20 MHz (7.5 range resolution)

40 MHz (3.75 range resolution)

yy: FIFO memory Length

160 (16384 databins)

80 (8192 databins)

Select default location (folder) for saving raw data during data acquisition

Select default location (folder) for ASCII data when converting raw files to ASCII format

Select default location (folder) for backup raw data.

Press Ok to confirm or cancel to quit.

Caution: For proper use of the supplied VI's uncheck "Use localized decimal Point" option

Step by step procedure:

1. Open Labview
2. Select new vi

3. Go to Tools menu

4. Select options

5. Go to front panel section

6. Uncheck (if checked) "Use localized decimal Point" option

5.3 STORAGE AND SERVICE

Storage

- Turn all the electrical units OFF.

- Disconnect the power cord from the Lidar system.

- Even if you don't use the Lidar turn on the laser's ICE450 every month for 30minutes.

- If you plan to store your Lidar for an extended period of time, protect it against intense rain and humidity. Place it indoors or cover it up with a waterproof material.

	WARNING: Follow the instruction for every unit on your instrument

	CAUTION: If you are planning to ship your Lidar by air or install it in a cold environment, your laser system must be completely drained before transporting, since the coolant could freeze. Follow very carefully the instruction at laser manuals.

Service

If returning your Lidar to Raymetrics, please carefully pack the Lidar using the original package material that came with the unit.

6. LIDAR OPERATION

6.1. START-UP

There are two ways to use the Lidar; manually and automatically through the software. The user can choose which one is more convenient to use however here are presented both. The next steps will guide you through the safe operation. The first steps are common for either manual or automated operation.

1. Plug in the power cord (**Error! Reference source not found.**), and turn on the main switch (**Fig. 5.9**) on the side panel. Turn on the switches of the power distribution unit

2. Turn the "**Power Key Switch**" on the front panel of the PCC to the ON ("I") position (**Fig. 6.1**). The "power" and the "interlock" indicators on the Remote Box will illuminate. If not, check for interlock fault messages on the Remote Control Box LCD Display.

Fig. 6.1: Laser Power Up

3. Wait approximately 10-15 minutes, depending on the environmental conditions and amount of coolant in the system (coolant line length), until the coolant temperature reaches the preset value for flashlamp operation.

4. The computer whenever you power up the Lidar turns on automatically. In case it is turned off switch off the power switch on the power distribution unit, wait for 10secons and switch it back on.

5. Power up the Licel electronics (TR, PMT).
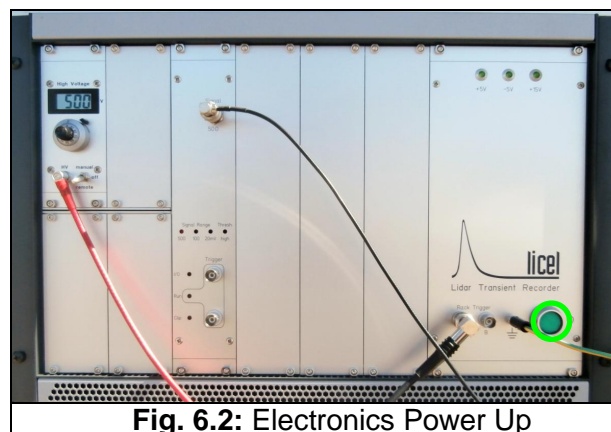
Fig. 6.2: Electronics Power Up

6. Select the desired control mode for all PMTs High Voltage. To do so lift the switch and then turn. Set to manual for manual operation or remote for automated operation.

Fig. 6.3: Control Mode selection
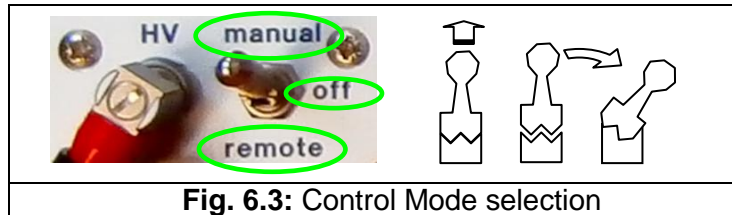
6.1.1 Manual Operation

7. Set the switch on each PMT HV to manual. Adjust the applied high voltage to the PMTs. Check signal, HV and trigger cables if they are at the right position. Turn on the HV by switching the HV switch to the manual position for each HV power supply you are willing to work with. (For remote operation through software, switch to the remote position). Turn the HV potentiometer counter clockwise up to the desired value. (High voltages values should be 750-900V, linear range of operation)

Fig. 6.4: PMT High Voltage Adjustment

8. Press the "**Flashlamp Ready**" button on the Remote Control Box. The corresponding "ready" LED and "LASER ON" indicators illuminate. Wait for a couple of seconds and if no interlock appears press the "**Flashlamp Start**" button on the Remote Box. The corresponding flashlamp "start" LED will blink and (in internal mode) the flashlamp will start flashing.

9. The PCC requires a safety delay of up to 8 seconds after the flashlamp starts before it enables Q-Switch operation. This stands for both Internal and External Q-Switch operation modes.

WARNING: The following steps result in laser light emission from the output aperture of the laser head. Do NOT look directly the laser beam. Before you press the Q-Switch make sure that nothing is blocking the light path.

10. Press the "Q-Switch Start" button to activate the Q-Switch. Verify that the corresponding Q-Switch "start" LED blinks and the "Laser ON" sign illuminates.

Power	Interlock LED
Transmitting indicator	LCD Display
Navigation Buttons	Set Buttons
	Enter Button
Flashlamp Ready Button	Flashlamp Stop Button
Q-Switch Start Button	Flashlamp Start Button
Q-Switch Single Shot Button	Q-Switch Stop Button

Fig. 6.5: Remote Control Box Indications
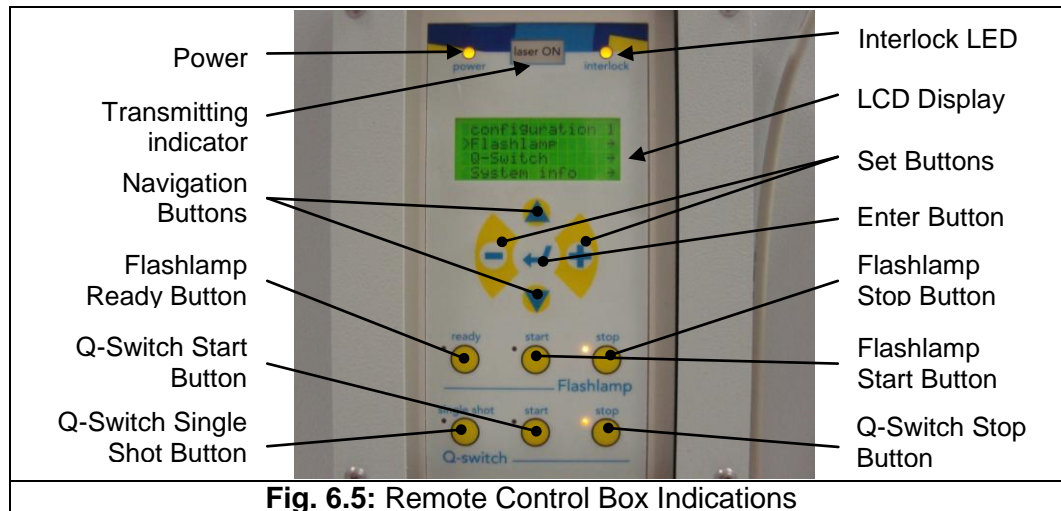
11. Run the Lidar Alignment.exe (Live display from Licel)

12. Watch the signal and fine align if necessary (see paragraph 6.2 LIDAR ALIGNMENT)

13. Run the Lidar Acquisition executable

14. To stop laser emission, press the "Q-Switch Stop" button. Verify that the Q-Switch "start" LED turns off. To stop the flashlamp, press the "Flashlamp Stop" button. Verify that the flashlamp "start" and "ready" LEDs turn off.

6.1.2 Automated Operation

7. Set the switch on each PMT HV to remote.

8. **Whenever the user presses any button on the remote control of the laser the serial communication with the computer is lost**. To set the serial communication navigate through the menu using the ▼▲ buttons, choose "System Info" and validate with the ↵ button. Go to serial link and with the ➕ button change the status from "off" to "on".

WARNING: The following steps result in laser light emission from the output aperture of the laser head. Do NOT look directly the laser beam. Before you press the Q-Switch make sure that nothing is blocking the light path.

9. Run the Lidar alignment executable to check the signals and align if necessary, or directly run the Acquisition.exe to perform a single measurement or the scheduler to program a series of daily measurements. When you wish to stop the measurement press the "stop" button to stop the laser and PMTs as well.

6.2 LIDAR ALIGNMENT

In order to acquire the best possible Lidar signal the user has to align the laser beam to the telescopes field of view. Measurements acquired with a misaligned Lidar can lead to fault results. Normally the Lidar is aligned as illustrated in **Fig. 6.6**. You can see that the signal starts to rise when the light of the laser beam inserts into the telescope's Field Of View (FOV) (point A) and reaches its peak value when the entire beam is inside the field of view (point B). After that point the signal starts to decrease because the light is attenuated easily when in low range.

Fig. 6.6: Aligned Lidar
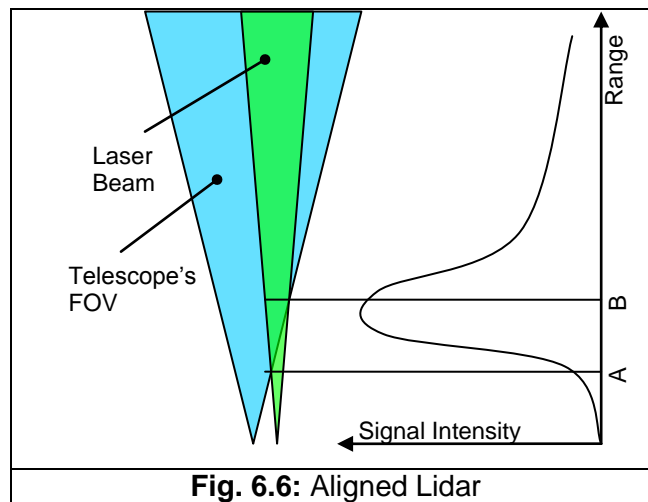
There are two cases of misalignment. Both are shown in **Fig. 6.7**. In the first case the laser beam is tilted at the opposite direction and there is no Lidar signal. However there is still some noise from the electronics and the background. In the second case the laser beam enters the telescope's FOV (point A-B) but exits after a certain point (point C-D). The second case is more difficult to distinct as the signal looks like a normal Lidar signal. However there are techniques to perfectly align the Lidar such as the telecover test.

Fig. 6.7: Misaligned Lidar
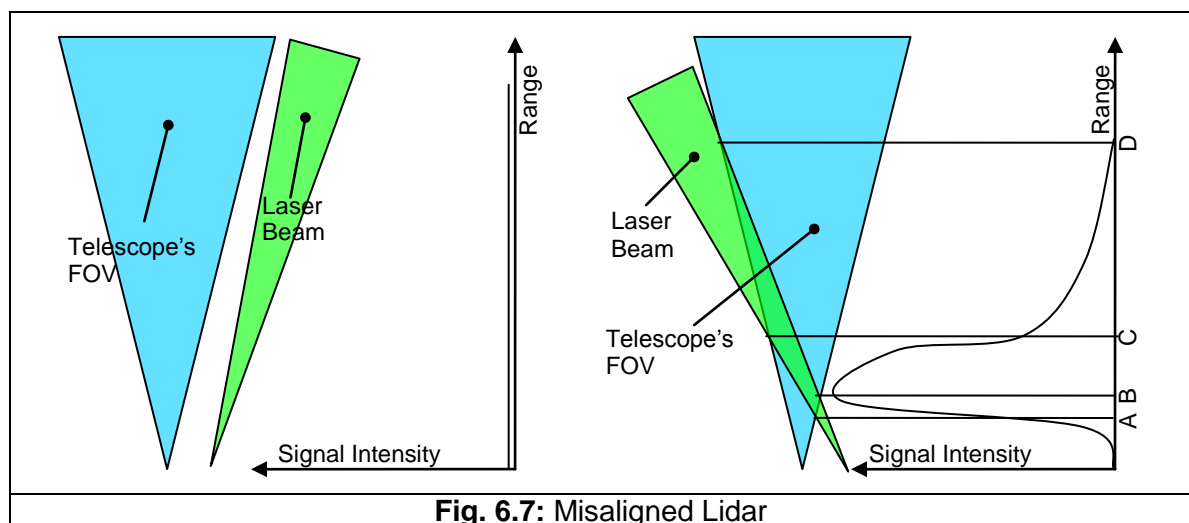
In the next figure you can see how the real Lidar signals for these cases. Black curve corresponds to a good aligned Lidar setup, while the Red and Green curves (same alignment but reduced signal intensity) correspond to a case similar to Fig. 6.7b.

Fig. 6.8: Alignment Example Real Signals
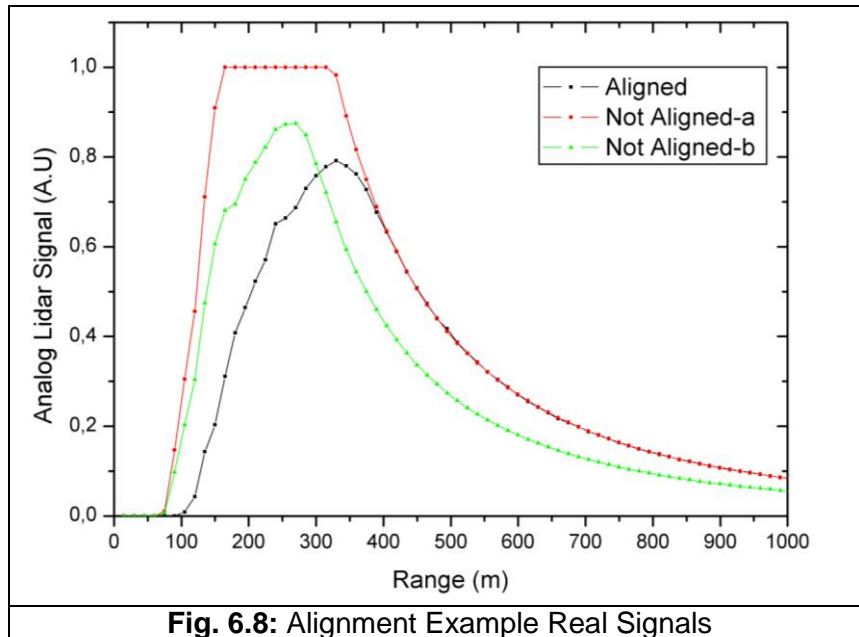
In many cases an inexperienced user will consider the red curve as a very good aligned signal since this signal is very strong (even has saturation between 150 and 350 meters). However if we reduce the signal intensity (see *6.2.4 Signal Intensity Reduction*) in order to get rid the saturation, we get the signal of the green curve and we can see that at the far field the black curve has almost double value compared to greed curve.

Fig. 6.9: Alignment Example Real Signals far filed
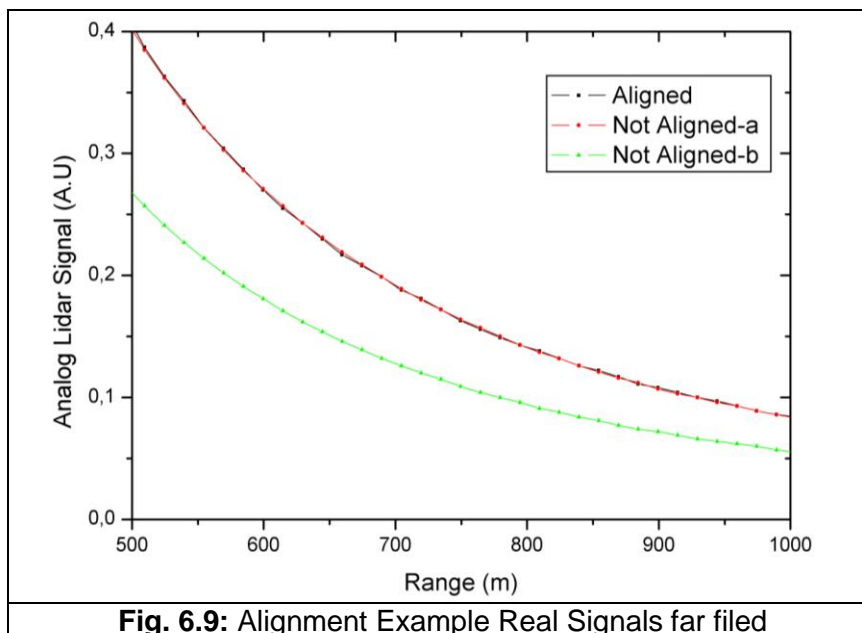
6.2.1 Laser Beam Kinematic

The Lidar alignment is done by moving the transmitter. Using two actuators the laser beam steers to meet the axis of the telescope's FOV. To choose which actuator should move is not always easily understood so here is presented the effect of each actuator. These two will be conventionally named "A" and "B"
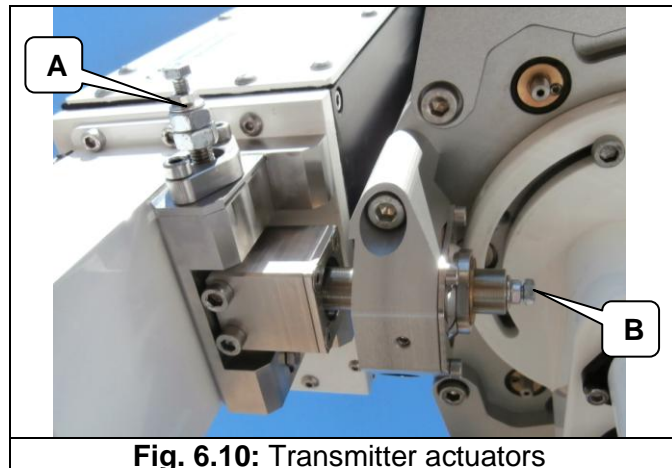
Fig. 6.10: Transmitter actuators

Because of the small allowable angle the actuators have a very small resolution so that the movement is also small and the Lidar signal is not very sensitive to the actuator movement. This give the user the ability to micro align the Lidar.

In the next figure is shown the effect of actuator A and B on the laser's beam direction.
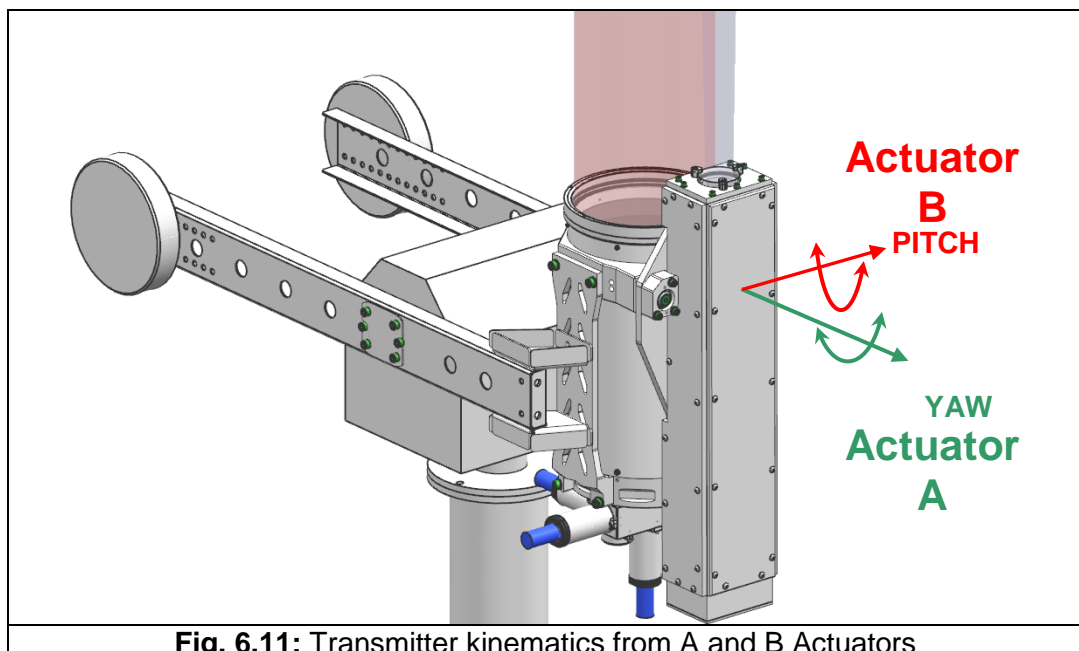
Fig. 6.11: Transmitter kinematics from A and B Actuators

Below is a schematic representation of the laser beam movement caused by each actuator in relation to the telescope. To sum up actuator "B" a moves the beam in a vertical way while actuator "A" moves the beam in a horizontal way.
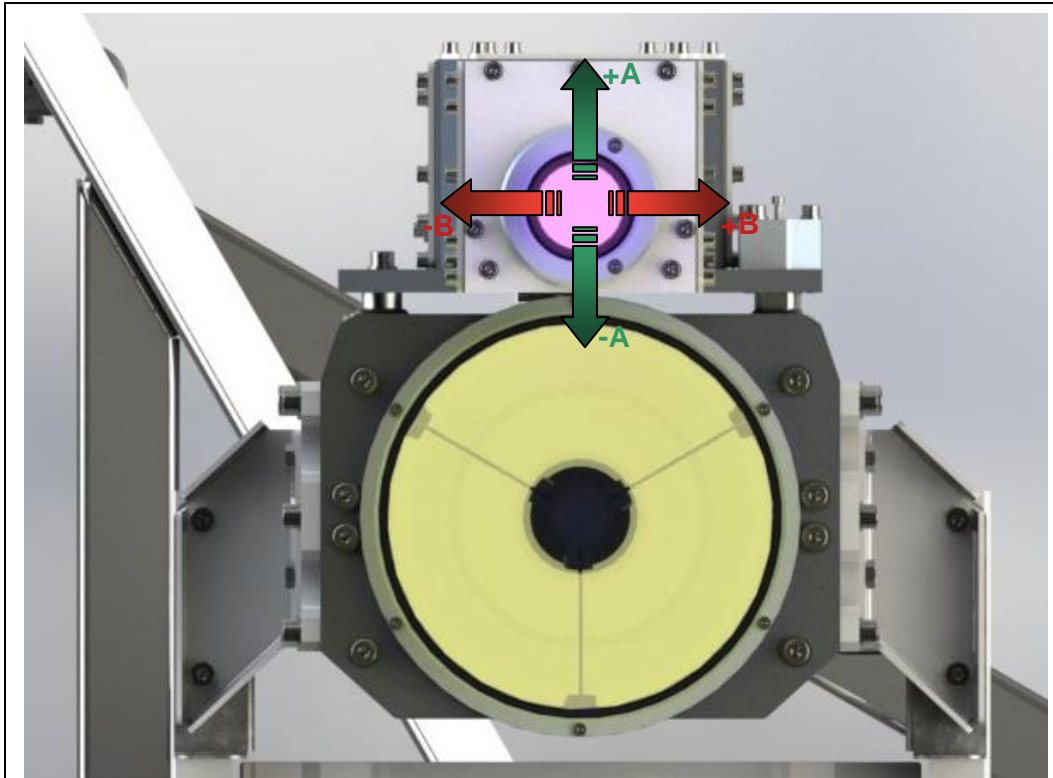
Fig. 6.12: Laser Beam kinematics

6.2.2 Lidar Alignment Procedure

The Lidar alignment is achieved in two steps. During the first step (coarse alignment), the far-range signal is monitored and the optical axes are fixed in a position where that signal is maximum. The second step (fine alignment) can be done in two different ways. One is by increasing the intensity of the signal in far range and the other is by performing a fast telecover test. To verify also the alignment the user can perform a comparison with a pure molecular atmosphere model in the analysis software. For more information see paragraph *7.3.4 How to Check Lidar Alignment*.

6.2.2.1 Intensity Maximization at far range
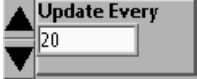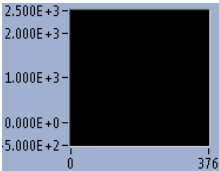
When the intensity of the signal increases in general it means that more light enters the FOV of the telescope. It is very easy to increase the signal in the near range but it is also easy to misalign the Lidar as shown in case II in Fig. 6.7. When the intensity of the signal is maximized in the far range then it means that as far the telescope can see there is a laser beam.

The alignment procedure is quite simple; the user selects an area on the slope as far as possible and tries to maximize the mean value of this area by using the actuators. Once the mean value reaches its peak, another area further that the initial is selected and the process is repeated with a smaller actuator step. When the value doesn't change for the selected step size it means that the Lidar is aligned. In more detail the procedure can be described in these steps:

1. Run Lidar Alignment.exe. If you run in automated mode the laser will start the emission and prompt for the HV value of the selected PMT. On top there are three red LEDs these should turn green. If not there is a communication problem.

2. Notice on the right the controls for the cursors . Click the and select bring to center. Click the and select lock to plot if not selected.

3. Place the yellow cursor (start) on the graph somewhere before the end of the graphs slope.

4. Next do the same with the green cursor (end) and place it closer to the edge of the graphs slope.

5. You can also zoom to the area by using the axes scale controls . The scale is either automatically adjusted to the maximum value or it can be fixed in a specific range. Click on the switch to toggle between these two states. When the axes are fixed set the lowest and highest values close to where the selected area is.

6. You can set the shots number for each profile to the right in the "Update Every" input. Set the number so that the image is good and is refreshed in less than 5 seconds.

7. Once everything is set click on the small graph on the right and select clear graph. This will empty all previous values. Remember to do so each time you change the selected area. Wait for a couple of profiles to be taken so that you will have a starting view.

8. Select one actuator A or B. It doesn't matter which one you select since this is a try and error procedure. As for the step size begin with a rather big step and gradually reduce it when close.

Fig. 6.13: Intensity Maximization Alignment method
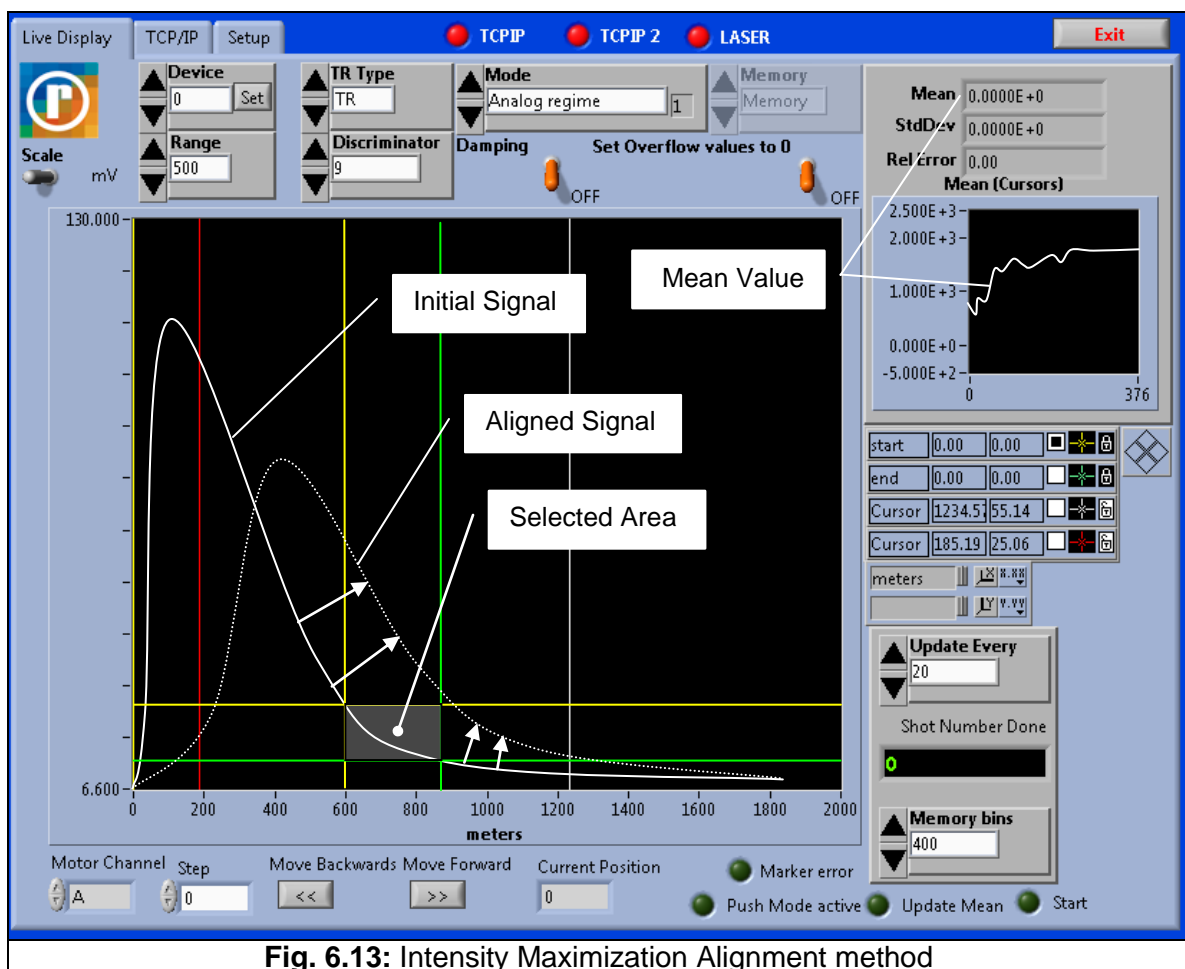
9. Move forward and backwards the actuator. You will notice the changes in the signal. Wait for the signal to be stabilized for one or two profiles and notice the change in the small graph. If the mean value is getting higher then continue to move this actuator at the same direction. If the mean value is reduced then go to the opposite direction and check if the value gets better.

10. After repeating this process the mean value will reach a point that moving the actuator in both directions will only be reduced or remain the same. At this point change the selected actuator to the other one.

11. Continue with the same procedure as described with the other actuator.

12. You may have to swift between the actuators a coupe of times until you will reach a point that no is improvement of the mean value. At this point select an area even further than the current, clear the graph, reduce the step size and continue with the same logic used above.

6.2.2.2 Telecover Test

With this test you simply isolate the critical areas of the telescope and check at each area the signal. For this reason we divide the telescope at four quarters. Each quarter is named after the cardinal points for unification reasons. The north is always looking at the laser beam. At an aligned Lidar the west and the east quarter should have identical signal shapes while the one that is at the south gives the full overlap.

Fig. 6.14: Telecover Signals
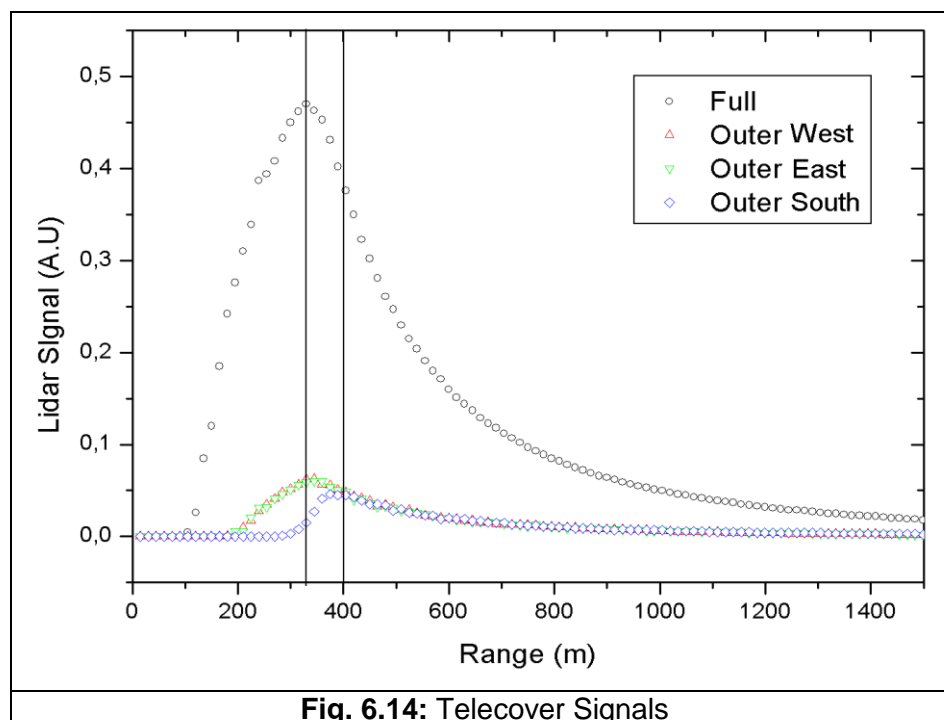
In **Fig. 6.14** you can see an example of Telecover test for D400 Lidar. Although the peak signal for the full telescope is appeared around 320 meters the real overall is around 400 meters at it can be seen from the Outer South part test. In addition we can see that the OW and OE signals are almost identical.

The east and west parts in theory are identical but in reality these two can never be identical because of the inhomogeneity of the optics and the PMT cathode. Most typical reason of inhomogeneity is dirt on the windows or in the telescope. This means that the signal intensity cannot be used as a criterion for the comparison but the overlap on the other hand is absolute.
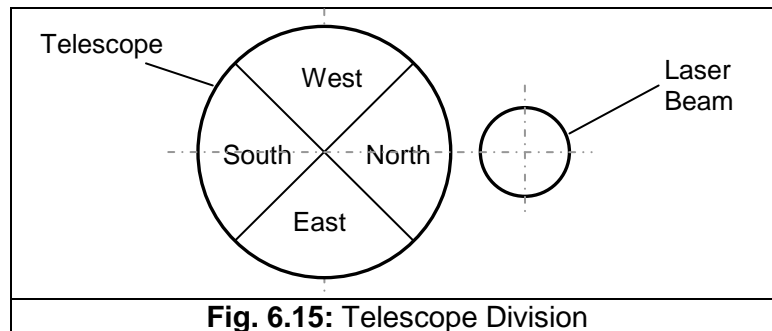
Fig. 6.15: Telescope Division

Normally we would expect that the part that gives the overlap should be the one that is close to the laser beam (inner quarter). This is true but the image at the cathode is reversed. The light focuses at the field stop and defocuses resulting to an upside down and mirrored image. This will help us to understand why moving the laser beam towards the obvious desired direction has the opposite effect on the signal.
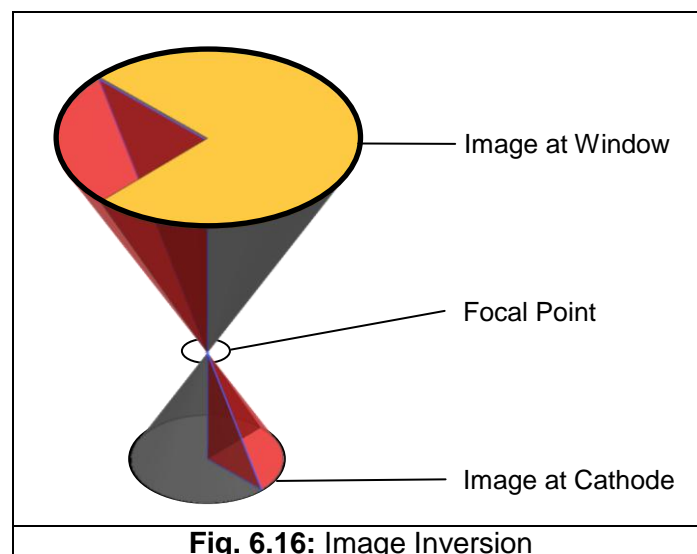
Fig. 6.16: Image Inversion

To make this telecover even more precise we can divide each quarter to two equal areas; inner and outer. To do so we need to take into account the blind spot of the telescope created from the secondary mirror. We symbolize these parts with two letters: the first letter is ether O for outer and I for inner, while the second letter can be W, E, S and N that stand for West, East, South and North respectively. Now imagine an axis from the center of the telescope to the center of the laser beam. This axis is not always

horizontal or vertical. So when placing the telecover you have to align the center of the clear area with the imaginary axis.

Fig. 6.17: Detailed Telescope Division
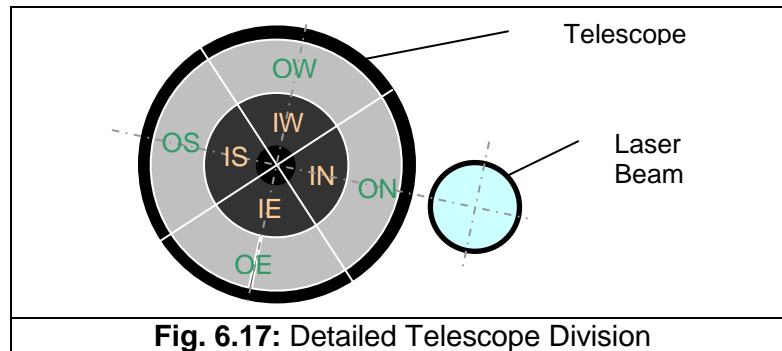
The fine alignment procedure with this method is described below.

1. Open the "Lidar alignment" program.
2. Place the cover on the telescope's window letting the light only from the south side.
   NOTE THAT THE LASER IS NOW TRANSMITTING, FOLLOW CAREFULLY THE SAFETY INSTRUCTIONS.
3. Using the actuators shift the peak of the curve at live display to reach the desired full overlap. This systems full overlap is at 200meters.

Fig. 6.18: Full Overlap Alignment
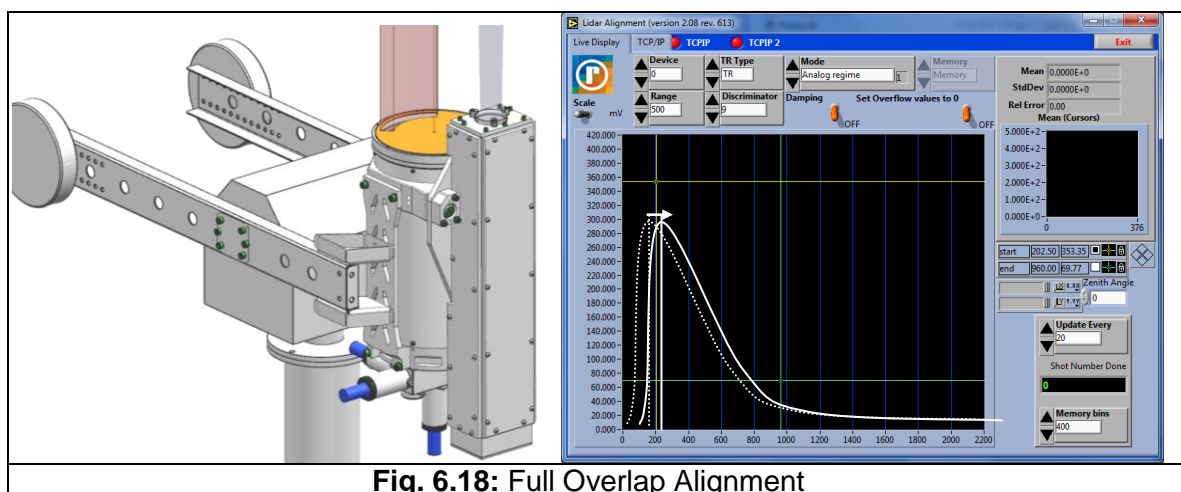
4. Turn the cover letting the light only from the east side and place a cursor on the peak of the curve at the graph but make sure that the cursor is unlocked.
5. Flip the cover to the opposite side (west side).
6. Using the actuators try to reach the same overlap as the cursor placed before on the curve. Once you are close place another cursor there.
7. Turn the cover to the opposite side (east side) and repeat the last steps until the two curves have the same overlap. This means that the telescope is symmetrical to the laser beam.
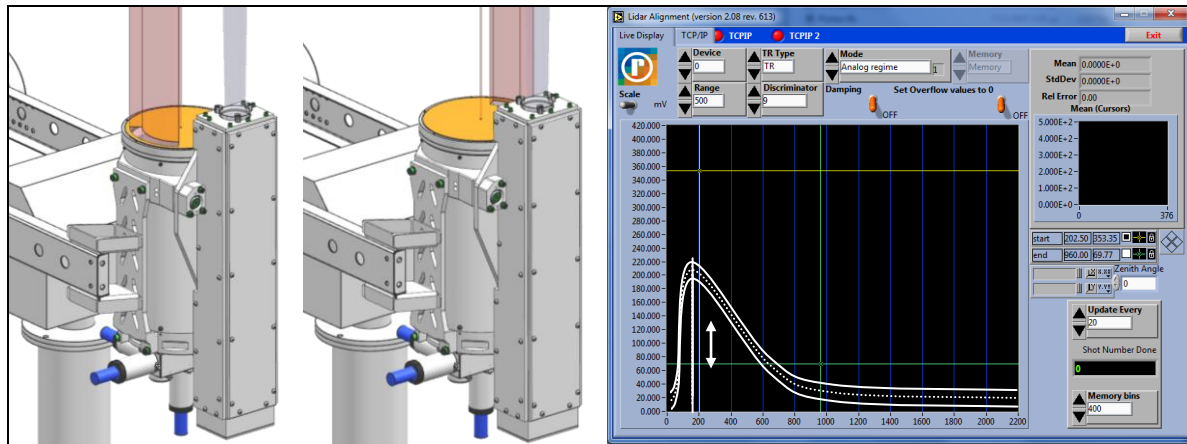
Fig. 6.19: Symmetry Alignment

A fast way to find out if the alignment is roughly good or not, is to make a telecover test with the OS part. If we do so we are going to see Lidar signals as the image below
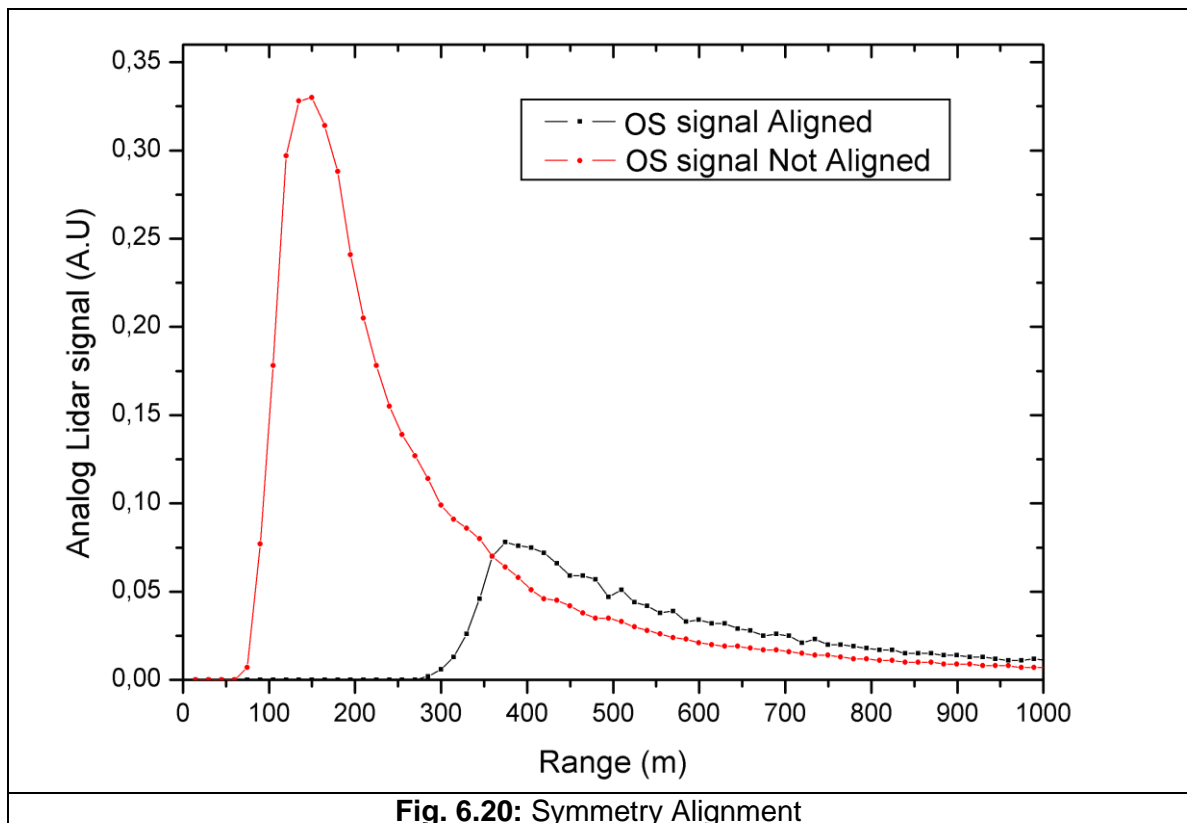
Fig. 6.20: Symmetry Alignment

The OS (outer south) part of the not aligned signal gives an overlap at around 180 meters while the good aligned signal gives an overlap around meters 380 which is the value that we expect

For this specific Lidar configuration the overlap is close to 200meters.

6.2.3 Using the Alignment Software

In paragraph *4.3.1 Lidar Alignment* the Lidar alignment software was introduced. Here lies a complete guide how to use the software.

To open the alignment software, click the "Lidar alignment" shortcut. When the program starts it tries to communicate with all devices. In this case there are four devices to communicate with:

1. Transient recorder
2. PMT High voltage device
3. Laser

When the Licel devices and the laser communicate with the computer then the LEDs on the top of the window turn to green. If for any reason they remain red consult the trouble shooting section communication errors.

The last tab named Setup refers to the motorized mirror mount, if the Lidar is equipped with one. The parameters here are for the communication port etc and for the speed and acceleration of the mirror mount. Don't change these parameters unless you are an experienced user.

At the TCP/IP tab you can select the communication port but the IP address has to be changed from Licel's "TCPIP Set Fixed IP Address" program.
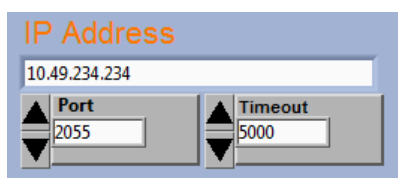
After the connection has been established with all devices the program asks the user to start firing the laser. Verify by pressing "OK" but if for any reason you don't want to start the laser press "Cancel".

Next another dialog appears where the user is prompted to input the high voltage value for the selected PMT. By default device 0 is selected. After closing this dialog the "Live Display" tab appears by default.
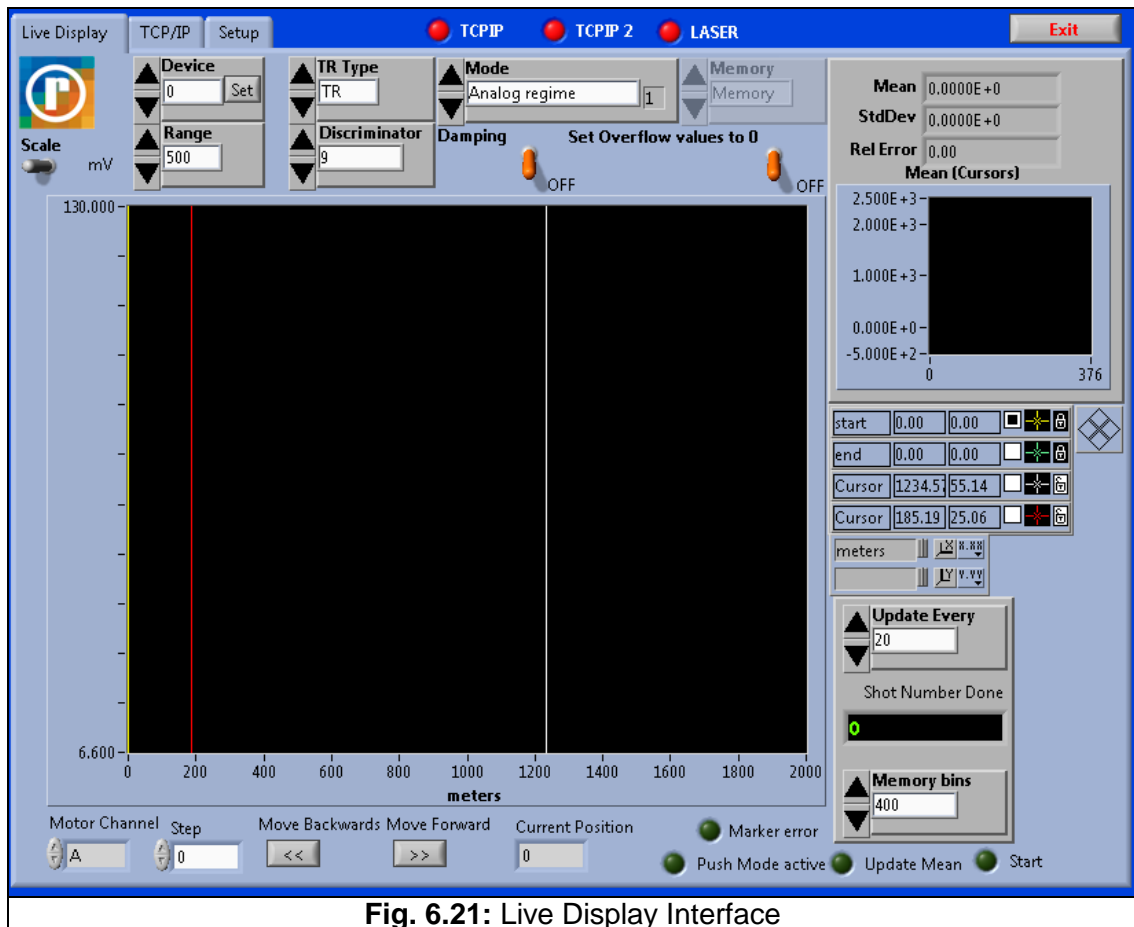
Fig. 6.21: Live Display Interface

The laser needs a small delay time to start the q-switch for self protection. You may have to wait until it starts and then the "Shot Number Done" indicator will increase for every trigger pulse transient recorder receives (or a laser pulse if the recorder is triggered from the laser source).
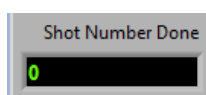
Set the desired value on the "Update Every" indicator. Setting this number to high will result in a very slow response to the changes graph, but if the number is too low the graph will be affected strongly by the laser's energy oscillations resulting to a bad quality image. Suggested value is close to the laser repletion rate (20Hz).
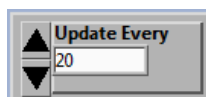
When "Shot Number Done" is equal to "Update Every" value the data are read from the recorder, are displayed at the graph and the procedure starts over until the exit button is pressed.

The "Strob Number" indicator stands for the number of bins to be transferred from the transient recorder and to be displayed.
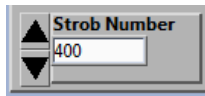
The dataset which is displayed to the graph depends on the selections you make. Select device, TR type, and mode. If you want to change the High voltage value for the selected PMT (device) click in "Set", located next to the device setting.
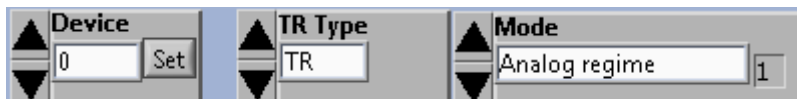
Set discriminator level, and the analog input range of the preamplifier (Range). The signal starts at 0 and extends to -20, -100, or -500mV. Turn on the overflow switch, to display all bins with overflow as 0. According to the EARLINET suggestions the range has to be twice the peak signal. When the signal is too strong there is saturation in the signal and the range must be increased, otherwise the PMT will be damaged. If the maximum range is selected and the signal remains saturated refer to *6.2.4 Signal Intensity Reduction* paragraph to solve this issue.

The small graph at the right corner of the interface shows the average of the region of interest on the waveform graph that is selected by using the cursors. The cursors at the right of the waveform graph allow for the selection of a region to average over. The average of the region selected is displayed in small graph at the right upper corner.
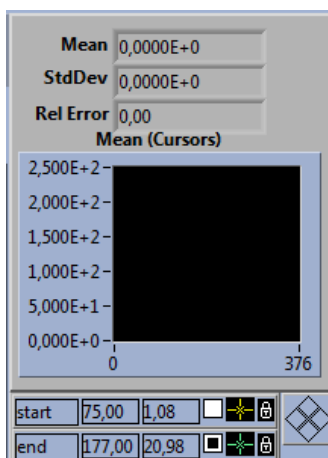
The x and y controls at the left allow the user to autoscale the x or y axis. By clicking these buttons the scale is automatically adjusted to the highest value. The slide next to it

changes from autoscale mode to fix. On autoscale mode the scale is adjusted to the highest value each time it is changed. On fix mode the scale remains constant unless the user presses the x or y controls (Autoscale Button). Defaults are autoscale for the y axis and fix values for the x axis. The x.xx and y.yy controls allow for the specification of the format precision and mapping modes of the x and y axis.
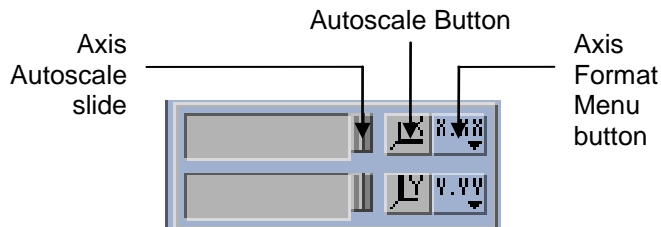
For more information about wave-graph refer to Labview manual.

WARNING:

NEVER BLOCK THE TRANSMITTED LASER BEAM, WHILE THE PHOTOMULTIPLIERS ARE SWITCHED ON. THE REFLECTIONS FROM THE BLOCKING OBJECT WILL DAMAGE THE PMTs. IF YOU WANT TO BLOCK THE LASER BEAM (e.g. for screening purposes during alignment) ALWAYS SWITCH OFF THE POWER SUPPLY OF THE PMT's AND APD AND COVER THE TELESCOPE (with a piece of soft black cloth) IN ORDER TO PREVENT THE ENTRANCE OF REFLECTIONS INSIDE THE TELESCOPE.

6.2.4 Signal Intensity Reduction

Having a strong signal may seem ideal but in fact it can damage the PMT. The high voltage setting must be in compliance with the average maximum anode current of the PMT. This average current for Raymetrics Lidar systems are 100 µA which means 5 mV. So, the value of 5 mV should not be exceeded for more than 30 seconds.

However the peak signal can significantly exceed the background average level as long as the integral current is below 100 µA. The analog signal should fit into the input range of the preamplifier and the ADC. Due to the fluctuations of the Lidar signal the following rule of thumb will keep the signal inside the ADC range.

The analog backscatter signal should be about half (+/-10%) of the preamplifier full range. Check this after fully align the Lidar.

For a 20 mV range this corresponds to 10 mV, for a 100mV input range this corresponds to 50mV and for 500mV input range 250 mV.

Peak signals should not exceed 500 mV for more than 10 µs (i.e. 3000 meters or 400 memory bins) or 100 mV for more than 50 µs (i.e. 15000 meters or 1200 memory bins)

The signal input range is user selectable by using the software. Before concluding that the signal is too strong, make sure that the range is properly selected. By default the range is up to 100mV not allowing voltages above that and thus it will look as if the signal is saturated. In this case turn the knob to 500mV.
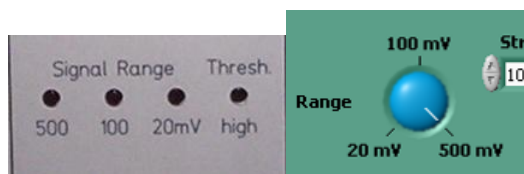
The max. cathode voltage of 1000V (High Voltage HV) should not be applied for more than 30 seconds.

Too high background signals and peak signals introduce artefacts and decrease the life of time of the PMTs. There are four ways to reduce the signal intensity:

- Laser energy reduction

- Field stop diameter reduction

- PMT HV reduction

- Use of filters in the eyepiece

The two first are not the best solutions because they affect all detected wavelengths and also the Raman signals which are by nature weak. If how ever you only have backscatter signals then this is the easiest solution. Reducing the field stop will increase the overlap and minimize the Lidar effective range.

Reducing the applied HV can help on the first glance but is not the optimal solution as a long term solution. The PMT cathode can provide a limited amount of photons over its lifetime, exposing the tube to a constant DC light will shorten this lifetime. This concludes that the best way is by placing neutral density filters (or a color filter) in front of the PMT or by using a narrower interference filter (costly solution).

Below are presented all solutions as the most effective depends on the Lidar type and also on the user.

1. Decreasing the Laser Output Energy

Operation at a decreased energy level is useful when starting an experimental setup or testing equipment and you detect extensive saturation at your Lidar signal. A simple way to decrease the energy is to increase the flashlamp to Q-Switch delay to a value that is higher than the optimum (highest power) delay using the Remote Box.

WARNING: Laser manufacturer advises NOT to decrease the high voltage of the flashlamp(s) to reduce the output energy. Decreasing the high voltage of the flashlamp(s) will cause a change in beam characteristics. Divergence and position of the focal points alter may cause damage to the laser's internal optics.

To adjust the output energy:

1. Select Q-Switch from the Main menu on the Remote Box.

2. Press the "Enter Menu" button.

3. Select Flashlamp / Q-Switch delay (FLQS Dly) from the Q-Switch menu.

4. Press the "Increase Value" and "Decrease Value" buttons on the Remote Box to adjust the output energy to the desired value.

WARNING: Do not attempt to modify the pumping power by increasing the flashlamp energy with the Remote Box of the PCC. This energy has been factory-set for optimal laser performance. Adjust the flashlamp energy with the Remote Box only if the flashlamp efficiency decreases. Please contact Quantel Customer Service Department to ascertain the origin of the efficiency decrease.

2. Field stop diameter reduction.

This is only suggested to users who have advanced Lidar knowledge as reducing the field stop will affect the range and the overlap. In this case you may affect the Lidar's performance for which Raymetrics has no responsibility.

As shown in **Fig. 3. 7** Telescope main components on top of the optical unit lies the focal plane. There you will find an adjustable calibrated iris. Use an Allen key to unlock and turn the external ring to reduce or increase the diameter. Be careful not to turn the Optical unit as this will result to telescope defocus.

Fig. 6.22: Optical Unit with Iris

3. Decrease the HV power supply of the PMTs.

This is a good solution when you are close to the signal intensity that you desire. You can scientifically increase or decrease the signal by changing the HV but in order to have a linear behaviour of the PMTs the minimum value should not be lower than the suggested range (750-900V) for every detected channel.

4. Use colour or ND filters

Absorptive ND filters are the suggested solution, although reflective ND is good as well. Another good solution is to use colour filters. Interference filters can also be used which will decrease the OD as well but in this case it is a costly solution. Please contact Raymetrics for the best suggestions. However before contacting us, send raw datafiles.

1. Unplug both cables from the PMT.

2. Remove the Detection Module from the Wavelength Separation Unit.

3. Place carefully the colour filter at the appropriate position

4. Place back the Detection Module to its position.
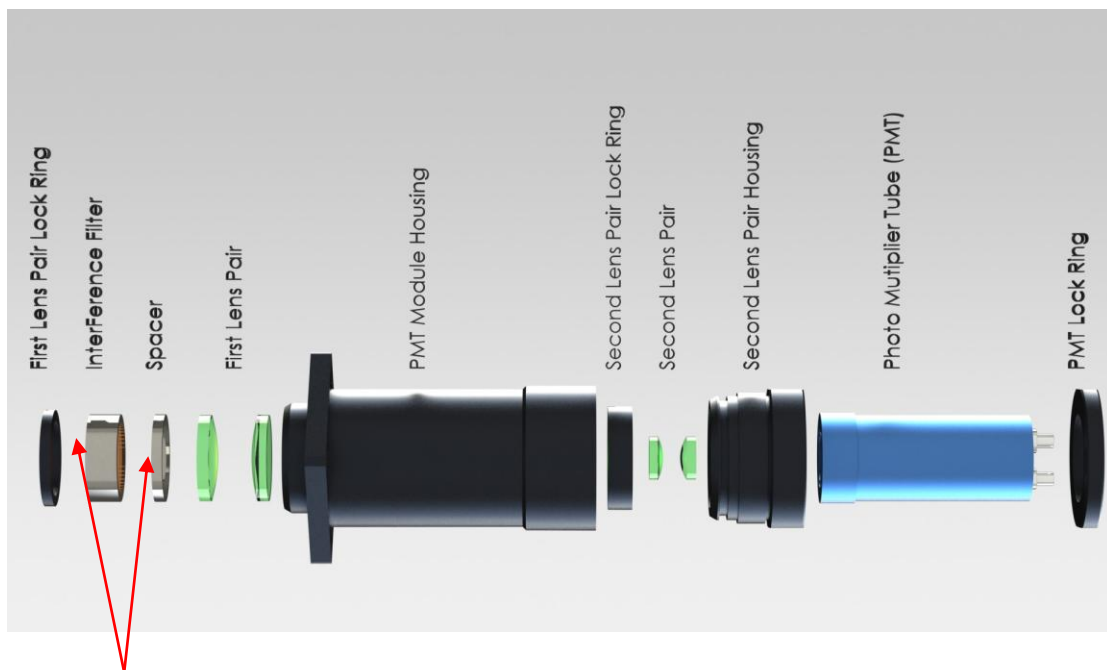
Place where you can install a ND filter.

Attention: It is recommended that photomultipliers are protected from excessive light during installation of the colour filters. After illumination the dark current will be temporarily increased

Do not remove the interference filter which is located just in front of the PMT.

Note: Final optimization of you system will be done in-situ from Raymetrics engineers during installation and training period.

6.3. DATA ACQUISITION

6.3.1 Introduction to the Acquisition Interface

Exit the alignment program click on Lidar Acquisition icon. Keep in mind that:

- This interface is for multiple measurements.

- Before starting a measurement all parameters have to be configured (see below).

- By default the system is set to automated mode. **This means that once you press the Start button the laser will start firing without any notice. Follow the safety rules.**

- **Exiting program without previously stop a running multiple acquisition, may cause unpredictable entries into the main database.**

Below the main features of the "Acquisition" tab are presented.

Fig. 6.23: Lidar Acquisition Interface
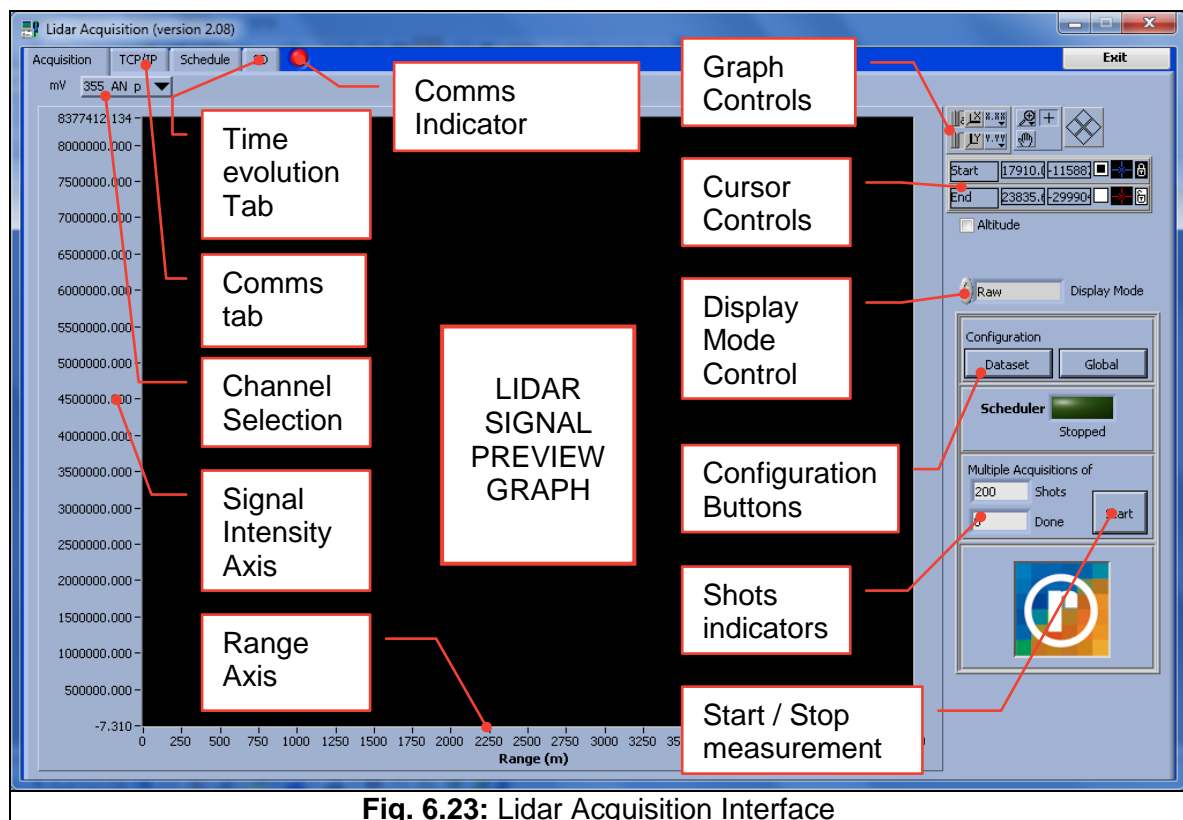
6.3.2 Configure Measurements

You can set the parameters needed with the Dataset and Global buttons. The dataset parameters are actually those which are related to the channels that you wish to use. The global parameters are more general and not very likely to be changed. The global parameters are saved by default while the dataset can be saved as a configuration file which can also be loaded. Usually the operators make a couple of different datasets (for

example day time and night time) which are loaded each time to save time and avoid mistakes.

Configure Transient Recorder

Start with the dataset. Click the dataset button and a new window will appear. On top there is the menu item file that contains four sub-items that the user can choose from. If you would like to edit an existing file, choose "Load transient information" and select a file. After you have edited the data, you can save the information by choosing "Save transient information as..." and either you choose the same file name, which overwrites the old file, or give a new name. If you have edited the data and have made a mistake, you can reload the original information by pressing Reset Information. The current configuration file is shown at the display below the menu. If you select "Exit without saving" the dataset used will be the original one that was selected initially.

Below this there is a numeric control. ⬆0⬇ This selects the device that you currently set. Pressing the up and down arrow will navigate though the devices. For instance here device 0 is selected.
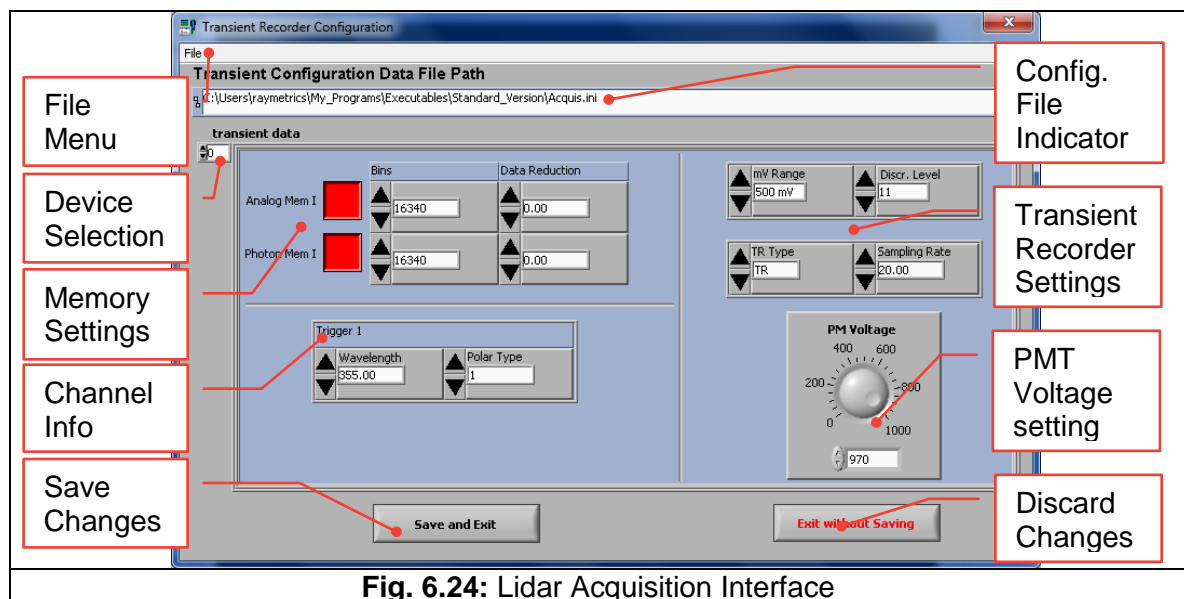
Fig. 6.24: Lidar Acquisition Interface

In the Transient data frame there are several inputs and controls. The values set here have to be different for each device, as each device measures a unique wavelength.

The memory settings are those which send the command to write on the memory or not. When the button is red ▮ the memory is activated and when grey deactivated. Here you can choose separately which memory you want photon or analog. For the elastic backscatter channels you need both in Raman you may need only photon if the signal is weak. If you don't want to use a channel uncheck (gray) both buttons. This may be useful

for a Raman channel during day time that you don't want to use to save data space. You may also save space by reducing the memory bins. As already explained the memory bins are related to the range. The spatial resolution of the recorder depends on the sampling rate or in other words the recoding frequency. This system has a 20MHz recorder which means that every 0.050μs writes a memory bin. When a laser pulse is transmitted the recorder starts the time counter. The first photons will that arrive back are recorded after 0.050μs but this time was spent for the photon to reach the target and reflect back. So actually the time that the photon needed to reach the target was 0.0250μs. The speed of light on the other hand is approximately $3x10^8$ m/s so we calculate that the distance is 300 x 0.0250 = **7.50m**. This is the minimum distance that the recorder can record, known as the spatial resolution. The memory limit of the 12bit TR is 16384bins. This gives a total of 16384 x 7.50 = **122880m** which in most of the cases is not needed.

Another way to reduce the data size is by using the data reduction function. This function groups bins together to make a superbin. One level of reduction in value reduces the height resolution by 1/2 and doubles the number of bins that are combined together. A data reduction level of 0, 1 and 2 corresponds to 1, 2, and 4 bins per data point respectively. In this way the spatial resolution increased but the maximum range is the same. This also means that the maximum number of bins is reduced.

0 Data reduction	Bins	1	2	3	4	…	16381	16382	16383	16384
	meters	7.50	7.50	7.50	7.50	…				7.50
1 Data reduction	Bins	1		2		…	8191		8192	
	meters	15.00		15.00		…	15.00		15.00	
2 Data reduction	Bins	1				…	4096			
	meters	30.00				…	30.00			

Set the data reduction and the Bins number to read out from the memory bank keeping in mind that the maximum number of bins is given by 32168 / (2^data reduction).

Below the memory setting there is the channel info. Here you have to specify the detected wavelength and the polarization type. The polarization types are:

0 .... No Polarization

1 .... Parallel Polarization

2 .... Cross Polarization

Move on to the transient recorder settings. Here you have to set the range values of the transient recorder, the discriminator level, the TR type and the sampling rate. The ranges values are 0-20mV, 0-100mV and 0-500mV. These are selected based on the signal intensity that you have noticed in the Lidar Alignment software. According to EARLINET the range has to be twice the signal peak. For example if the signal peak is close to 50mV you select 0-100nV range, or if close to 250mV select 0-500mV. **Setting the wrong range may result to signal saturation and eventually to PMT damage.**

There are 64 discriminator levels (values 0-63) which correspond to either a range of 0-24mV without gain reduction or 0-96mV with gain reduction.

Based on the model that you have the transient recording devices can be of different type. You will have to set for each device the correct type TR (analog and photon) or PR (only Photon) and also the sampling rate for each. You may find this information at section 10. LIDAR SYSTEM TECHNICAL SPECIFICATIONS.

The final setting that you have to set is the PMT Voltage that will be applied to the PMT during the measurement. The allowable range of linear behavior is 750-900V. This similarly to the range is set based on the signals intensity that you have noticed in the Lidar Alignment software.
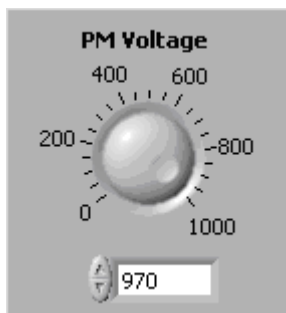
After finishing configuration of the transient recorder units, you can exit the configuration program by either pressing the Save and Exit button, if you would like to save the information to the actual file path as shown, or, alternatively, you can press Exit without Saving if you would like to exit without saving your changes. Please note that when you exit the program without saving, any unsaved data is lost! Thus if you have configured the data and wish to keep it, you need to either choose Save and Exit or choose File->Save transient information as... from the pull down menu before you exit the program. If you want the current transient recorder configuration to be used as the default transient recorder information, you must save this data as Acquis.ini in the installation path.

Configure Global Parameters

Next setting is the global parameters. These are more general here you can set:

- the Location information of the measurement site (8 characters length), longitude, latitude and altitude (in meters),

- The ground temperature (in Celsius) and ground pressure (in mhA)

- The transmitted wavelengths and frequency from laser source

- Finally the number of shots for each profile. Here you set in other words how many profiles will be averaged to create a single one. The higher you set the best Lidar data you get but slowly evolving. The number of shots should be set high enough so that data files are not written more quickly than every ten seconds (i.e. 100 shots at 10Hz, 200 shots at 20Hz, etc.). This is due to a limitation of the naming convention. The maximum allowable value is 4094 due to transient recorder ram limitations.
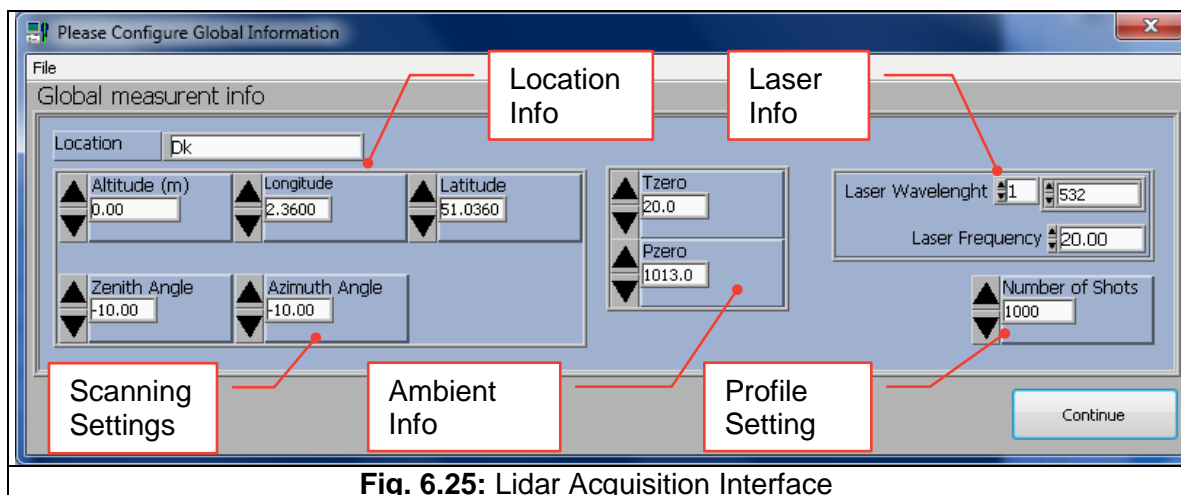
Fig. 6.25: Lidar Acquisition Interface

Every parameter is now set. Note there two types of parameters; those who are for information purpose and those who configure actually the measurement. All informational parameters are stored as a header in the data files, so that the user can see what parameters were used to take the data. The information entered in these fields has no affect whatsoever upon the data acquisition. It is used purely to store information about the experimental setup in the data files.

6.3.2 Configure the Working Directory

The working directory is the default directory where the data are saved. If you want to set or change the working directory you just have to run the program: **Config Lidar Acquis.exe.**

As displayed at **Fig. 6.26** it is a very simple program that changes the most basic information for the Acquisition. That is the TR Model and the working directory.
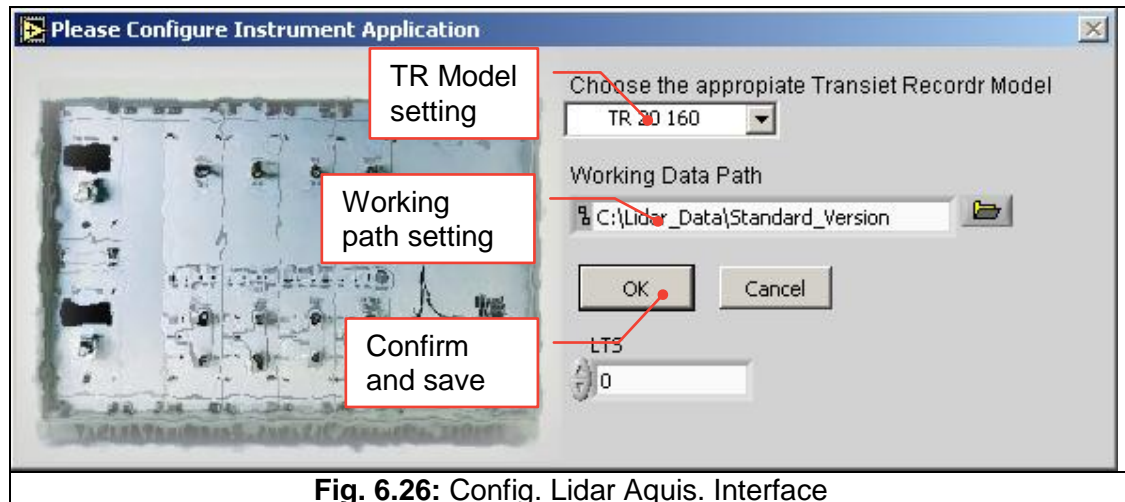
Fig. 6.26: Config. Lidar Aquis. Interface

Choose the TR 20 12bit and then select a working data path.

If the working data path that you will select already exists and contains a datalog.dat file then the software will ask you if you like to overwrite this file. If you choose yes then a new "empty" datalog.dat will be created. **Make sure that the path doesn't contain spaces; you can replace them with underscores.**

6.3.3 Lidar Measurements

After configuration press start button to start the measurement.

The start time field is automatically updated with the current date and time.

The transient recorders, in which you have activated data sets, should now acquire data. If the acquisition has been started successfully, the number of shots done in the shots indicator group should start increasing. When this number reaches the number above, a new profile is shown in the graph area and a new unique file is save with the raw data. The naming convention is explained in paragraph 7.1 DATA FILES HANDLING. The waveform graph is refreshed with the newly saved data and starts a new measurement.

Select the desired dataset from the drop down list to be displayed. You may also select at the display mode to see the raw signal (raw), the offset corrected signal or the range corrected signal (Pr2).

You can change the axis scale and place cursors on the graph by using the controls on right.

Press stop button to stop data acquisition. The waveform graph will be refreshed and will display the dataset that the user has specified. Save acquired data to a unique file for further analysis. By pressing the stop button a new record into the database will be added with the same values into the start and stop time fields. **If you exit the program without stopping the measurement the database will not be updated, and the data will not be available in the Analysis software.** This doesn't mean that the data are lost but they need to be manually inserted at the database which is a time consuming process.

Finally you can have an overview of the data in the 2D tab which shows the time evolution of the acquired profiles. Here the vertical axis is the height and the horizontal is the time. The signal intensity s represented with a color scale which you can also alter.
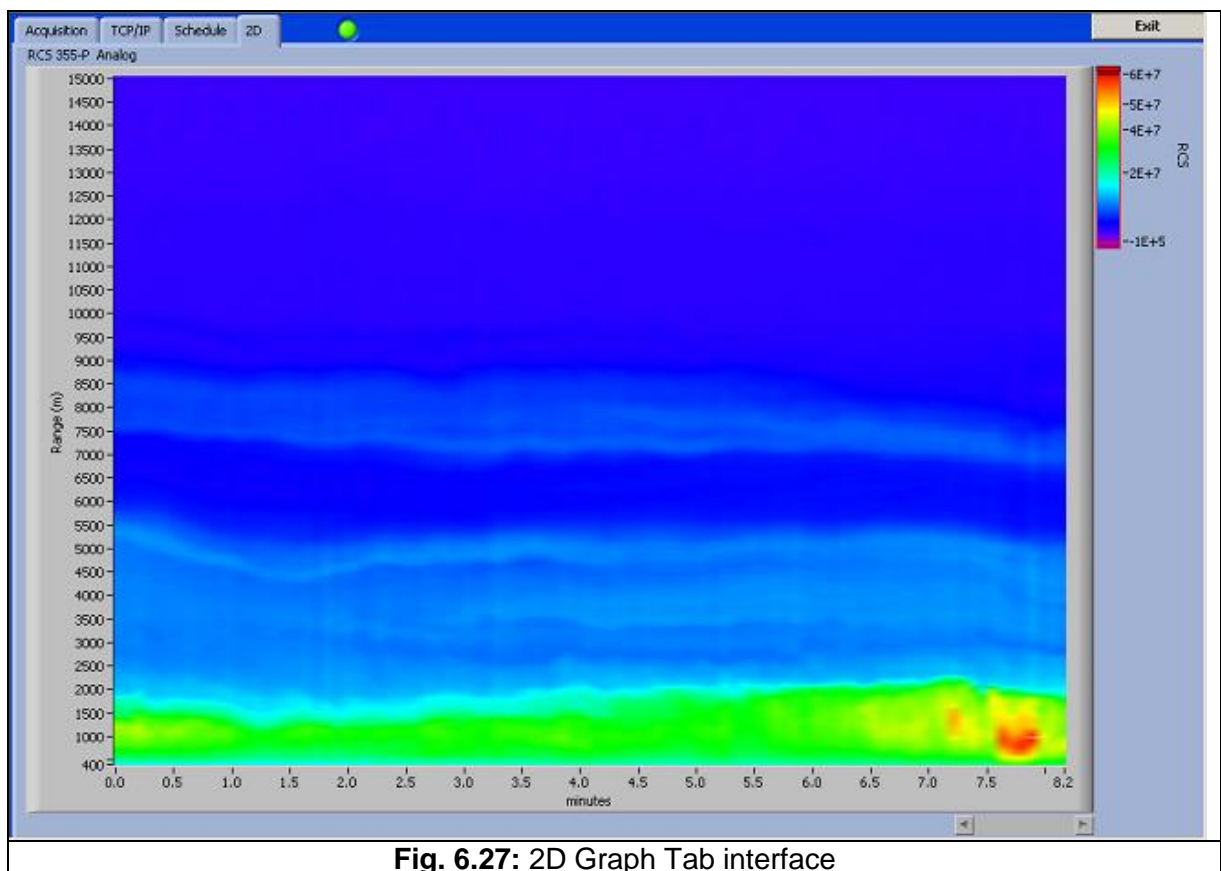
Fig. 6.27: 2D Graph Tab interface

6.4. MEASUREMENT SCHEDULING

A very useful tool is the Lidar Scheduler. With this software you can set a series of programmed measurements on a daily basis. The main purpose of this tool is to perform Lidar measurements without the need of an operator. This in combination to the remote setting and alert setup makes a fully remotely operated Lidar. The software shares the same acquisition module and thus the configuration parameters are already known.

The interface has four Tabs. The main tab is the "Scheduler" Tab. This contains the time table and the scheduler status information.
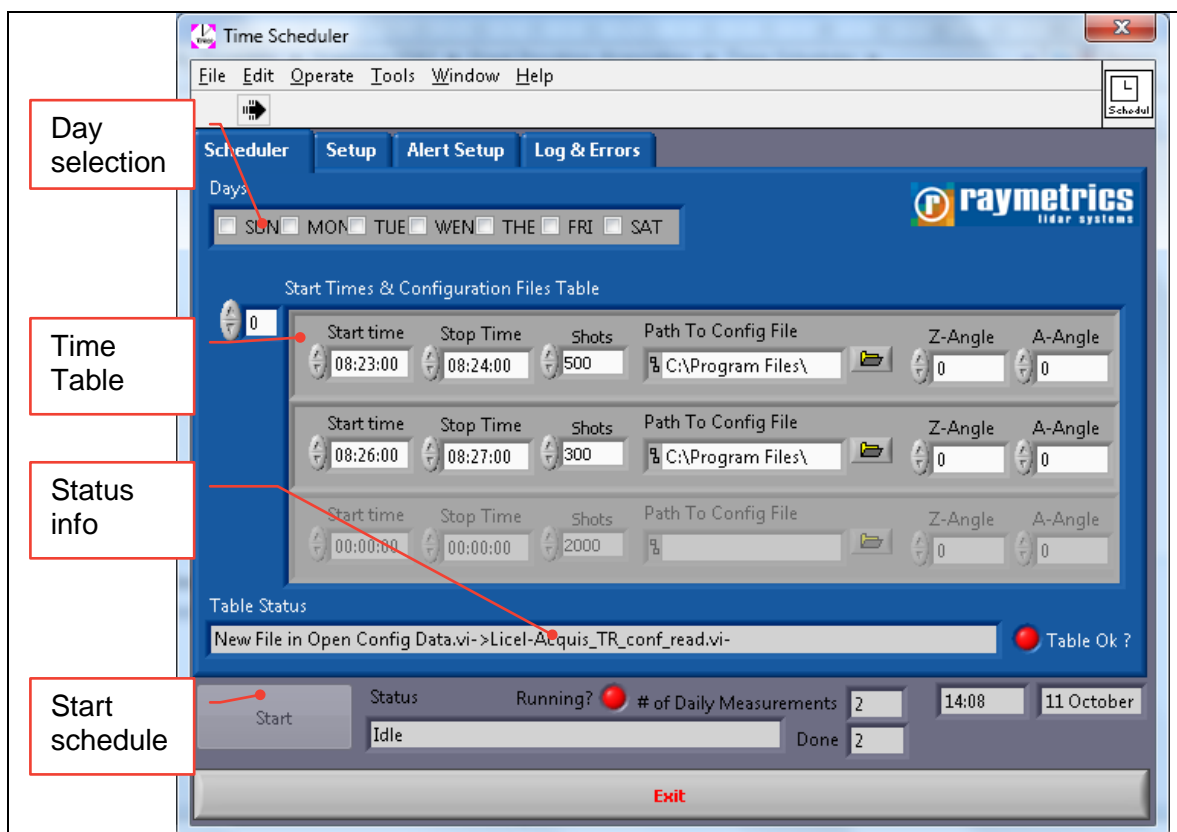
Fig. 6.28: Time scheduler main interface

On top there is the day selection area. Select here which day of the week you will run the programmed schedule below.

The Timetable is an array of inputs. You may add as many as you wish. To navigate though the table use the control on the side.

Each measurement needs six main parameters:

- Start time

- Stop time

- Number of shots for each profile

- Configuration (Dataset) file to be used

- Zenith angle (Z-Angle)

- Azimuth angle (A-Angle)
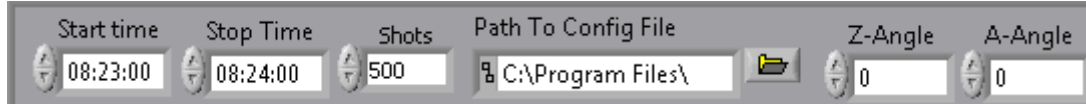
To make a correct table you have to keep in mind some simple rules.

- The start time has to be earlier than the stop time.

- The number of shots divided by the laser repetition must not exceed the run time of the measurement.

- The configuration file and path have to be valid.

The Start time of the next measurement has to be later than the stop time of the previous one.

For example at the table in Fig. 6.28 the stop time of the first measurement is bigger by two minutes or 120 seconds, which is okay, and also the shots are only 200 which divided by the laser's frequency 20Hz gives 10 seconds for each profile, which is enough to acquire 12 profiles. If however the shots where set more than 2400 the table would show an error and the green led "Table Ok?" will turn red. The same will happen if you set the start time of the next measurement earlier than the last or if the configuration file is not correct.

The user can create a configuration file on the setup tab. The scheduler starts when the user presses the start button.

You can check the status of the scheduler on the bottom of the tab where information about errors and the measurements done is available.
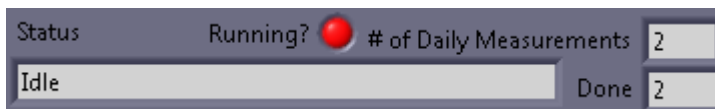
At the setup tab you can find all the global settings like the acquisition software except from the shots number, as previously explained.
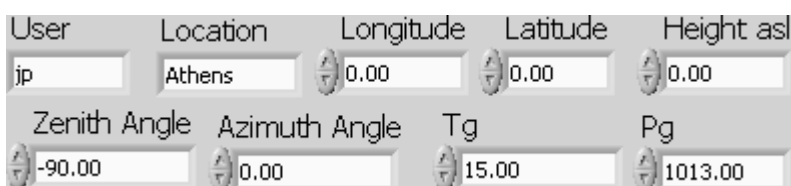
Below this you will find the working directory setting, which is actually the selection where the data will be saved. To select a folder click on the folder icon to open a windows dialog, and select the directory by pressing the "select current Dir.". **Make sure that the path doesn't contain spaces; you can replace them with underscores.**
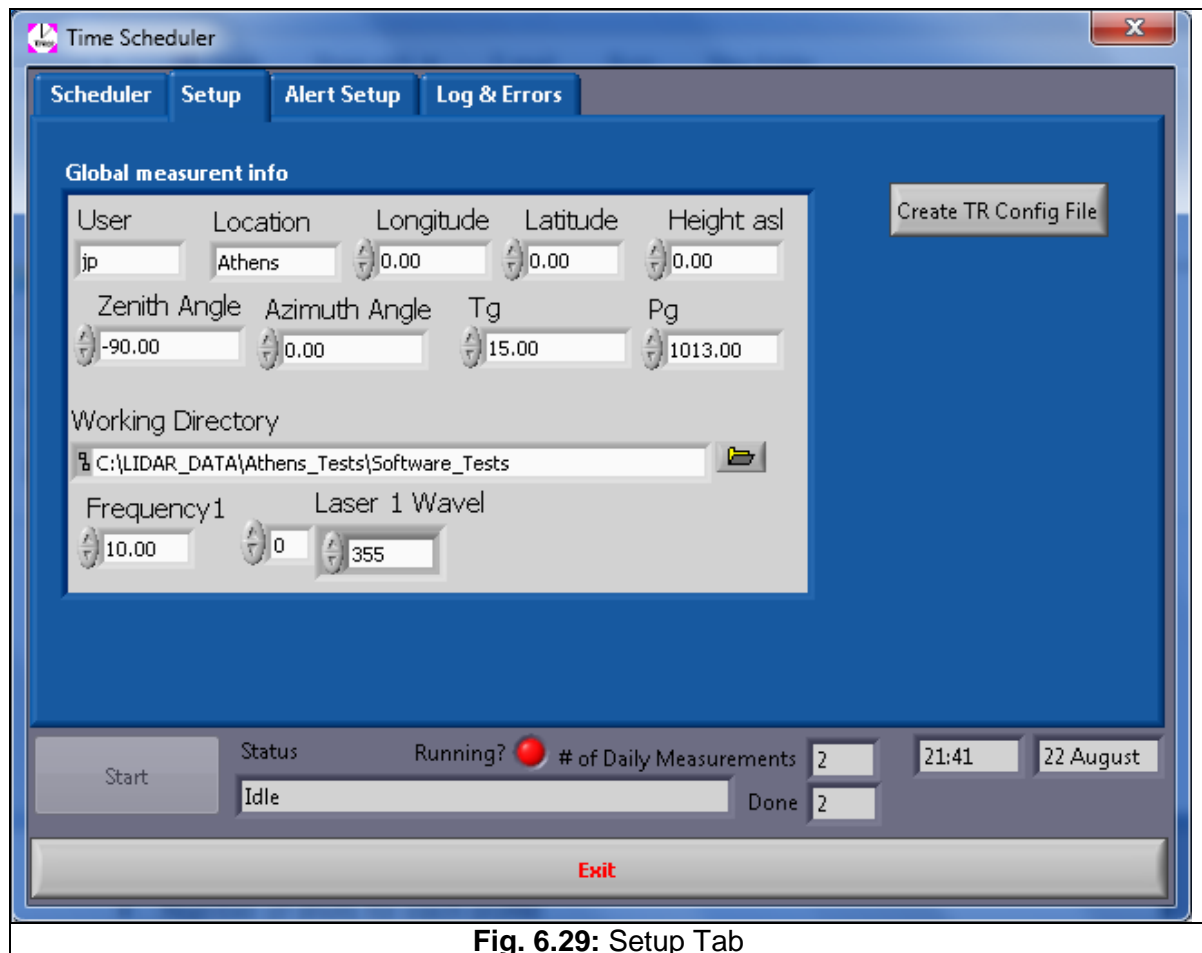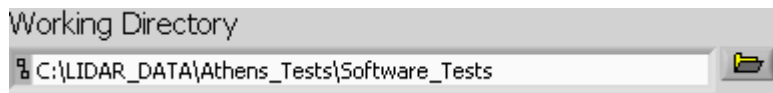
Fig. 6.29: Setup Tab

On the left there is a button "Create TR Config file", which is creates the configuration Dataset file. When this button is pressed two windows open sequentially. The first window, "config other hardware" is used to select the devices to be controlled by the software along with their communication ports and some parameters which have to be set for the system. This software module is presented in the tools section in Fig. 4.12. Once the user presses OK another window opens that is very similar to the Dataset window (see Fig. 4.3). The main difference is the communication port which has to be set there. By default the port is 2055. For the IP address refer to the connections paragraph at **Fig. 3. 25:** LIDAR Local Network.

6.5. SCANNING OPERATION

Until now all programs presented are used to acquire data in a fixed position. Here is presented a set of program to use the lidar in scanning mode. The set contains three programs fro the acquisition. The idea remains the same as previously noted; the user has to make a configuration file to specify the type of measurement(s) that will be performed. Here this file contains also geometrical and kinematic information about the scan. Once the file is created it is loaded either at the scanning autonomous or the Time scheduler Scanning program.

6.5.1 Creating a Configuration File

To make things easier there is a software module that guides the user to create the configuration file. This runs alone as an executable or is called through the scanning autonomous and time Scheduler programs.

At the image below is the main interface of the acquisition configuration tab. This is more or less similar to the setup window from acquisition program.
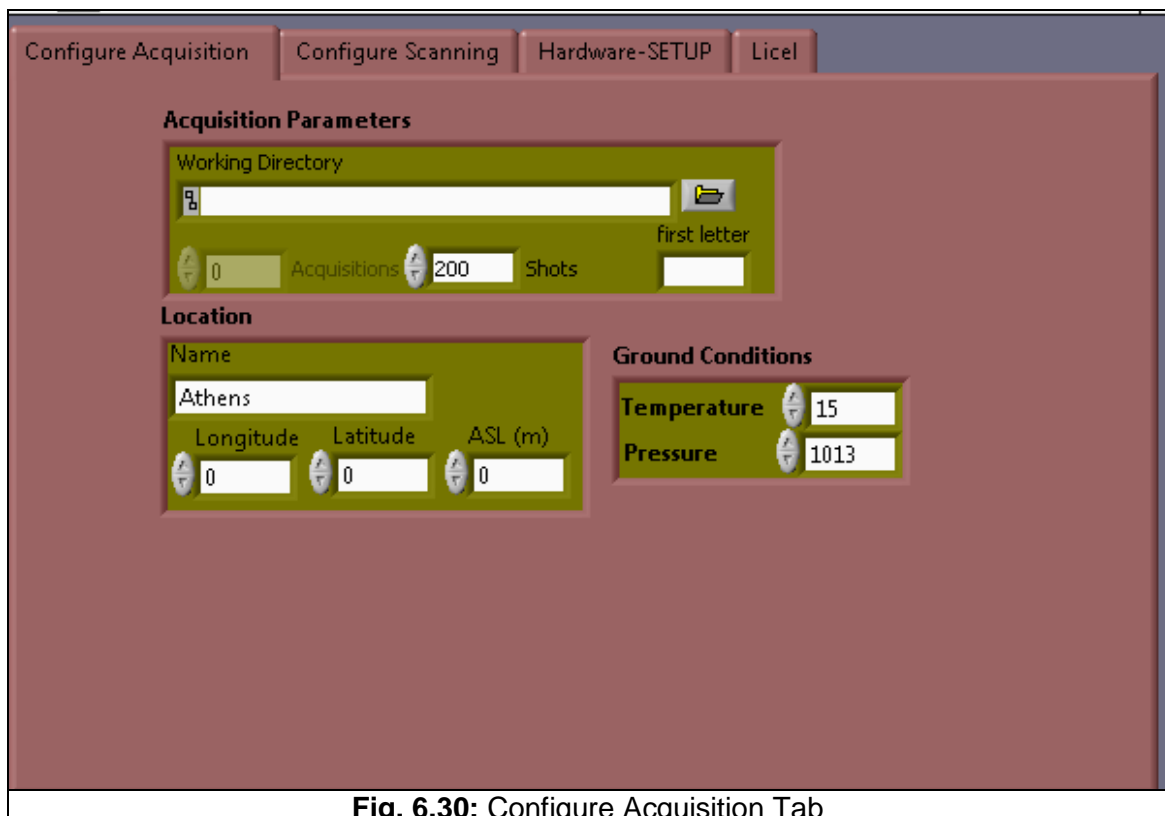
Fig. 6.30: Configure Acquisition Tab

Next to this is the scanning configuration tab. Here the user sets all the parameter that will be used for the scanning.

Starting with the scanning parameters the user has to set the angles that define a scan. For example setting the initial azimuth angle to 0 and the final to 90 degrees the lidar will perform an azimuth scan in horizontal position (0deg at zenith) which practically is a quarter of a circular scan. The step angle is the resolution of the scan. Setting this too low will increase the resolution but degrease the speed of the scan. Similarly to this example the user can set only the angles for a zenith scan but also can set the limits angles for both zenith and azimuth to perform a 3D scan. Furthermore in a 3D scan there are options of how the positioner will move from point to point. The options are four; Zenith or Azimuth first (zigzag type of scan) and Snake zenith or azimuth (snake type of scan).

There is also the option to set an offset for the azimuth orientation. If for example the instrument is not directed to the east at the home position but has an offset , you can set this number here.

Finally the scan that you set here can run as many times you wish. At the text boxes below you can see the summarize of the azimuth and zenith scans.
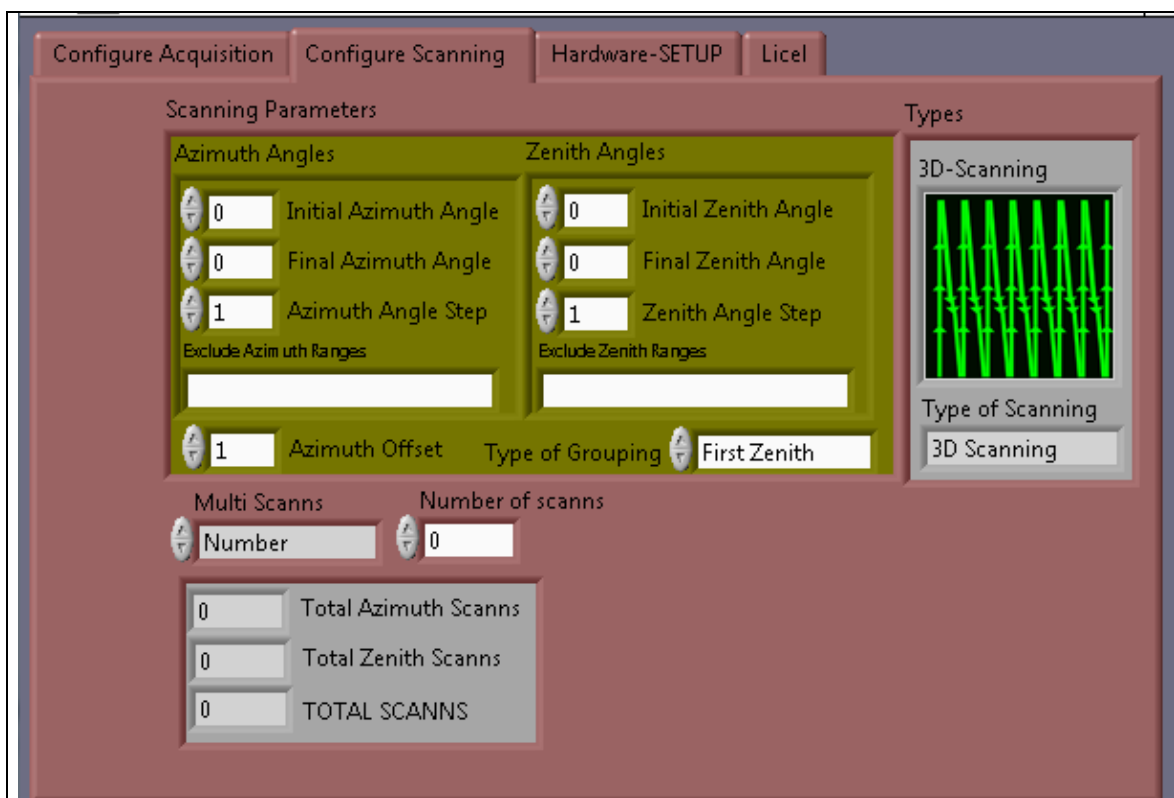
Fig. 6.31: Configure Scanning Tab

Next tab sets the hardware control, i.e. if the laser is controlled from the software, or the positioner (2AP) etc.
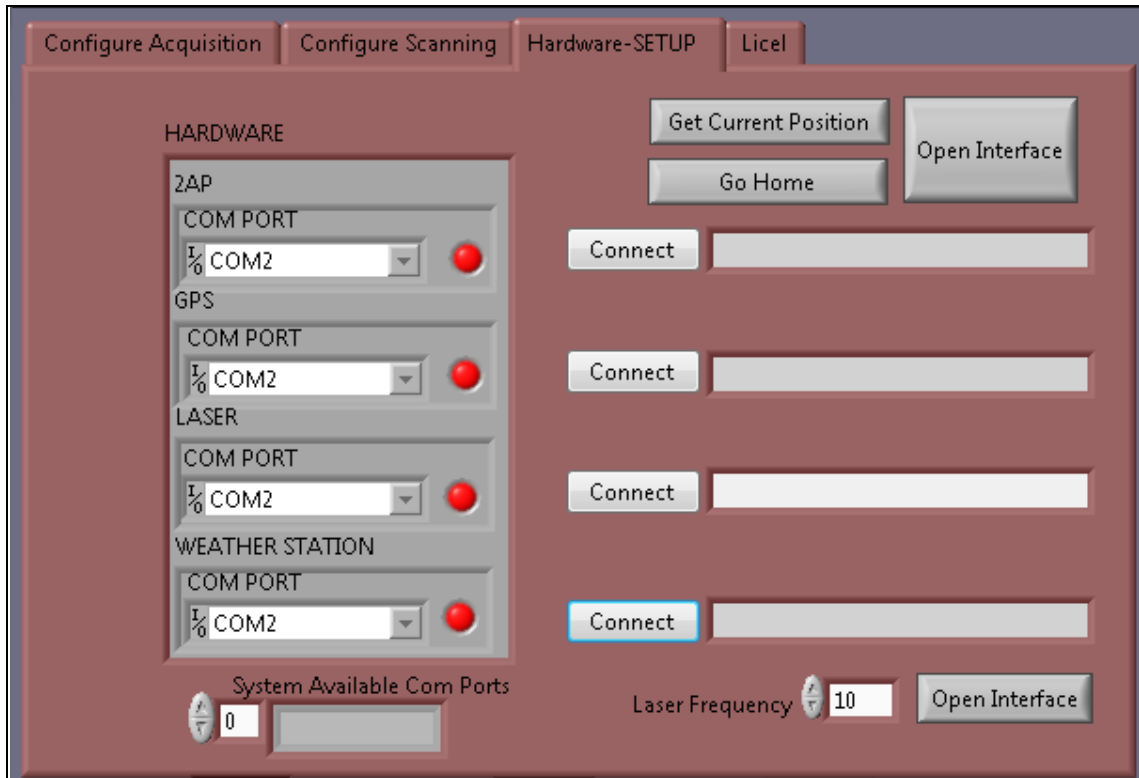
Fig. 6.32: Configure Hardware Tab

Finally the last tab contains all information for the dataset which is already explained.
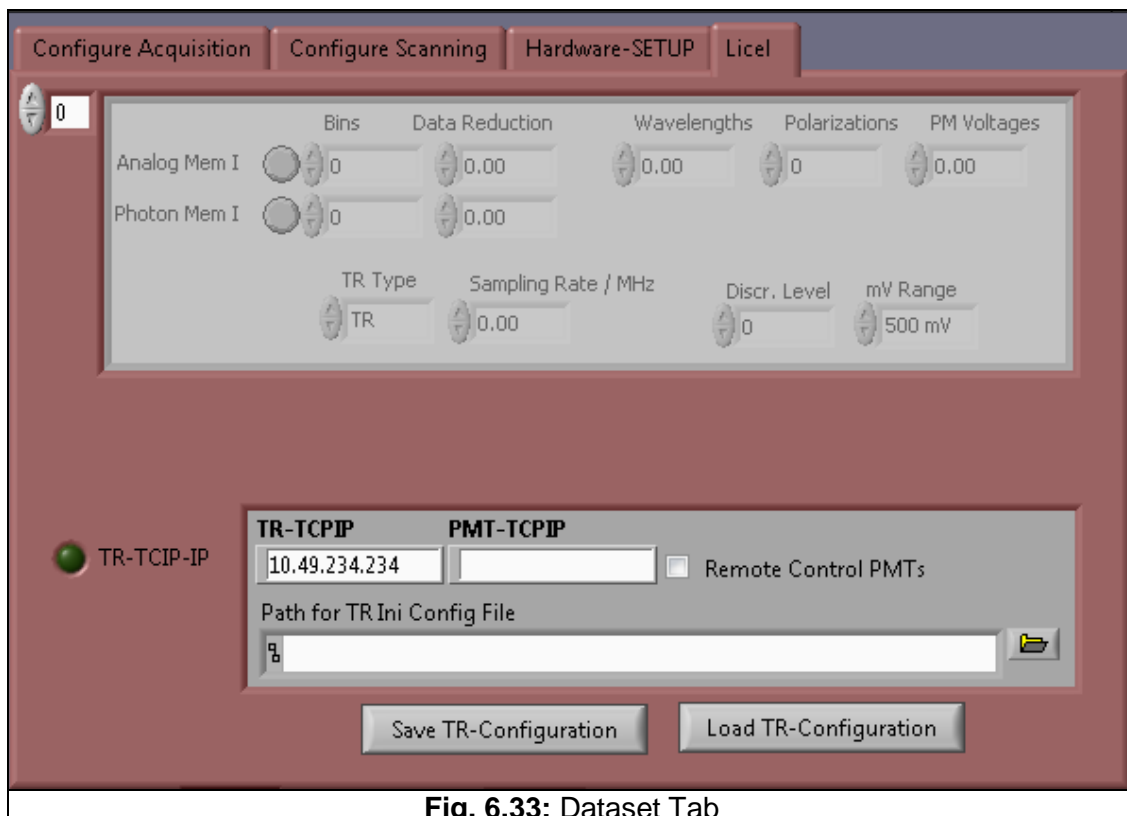
Fig. 6.33: Dataset Tab

Once all necessary parameters are set the bar on the bottom shows information about the estimated duration and also you can see the current position.
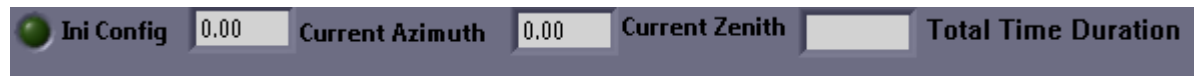
6.5.2 Scanning Autonomous

With this program the user can acquire scanning data with the lidar. The interface is very similar to the fixed point acquisition program.

When the program starts it prompts to load a configuration file. Select the file that you created with the configurator and click ok to load.
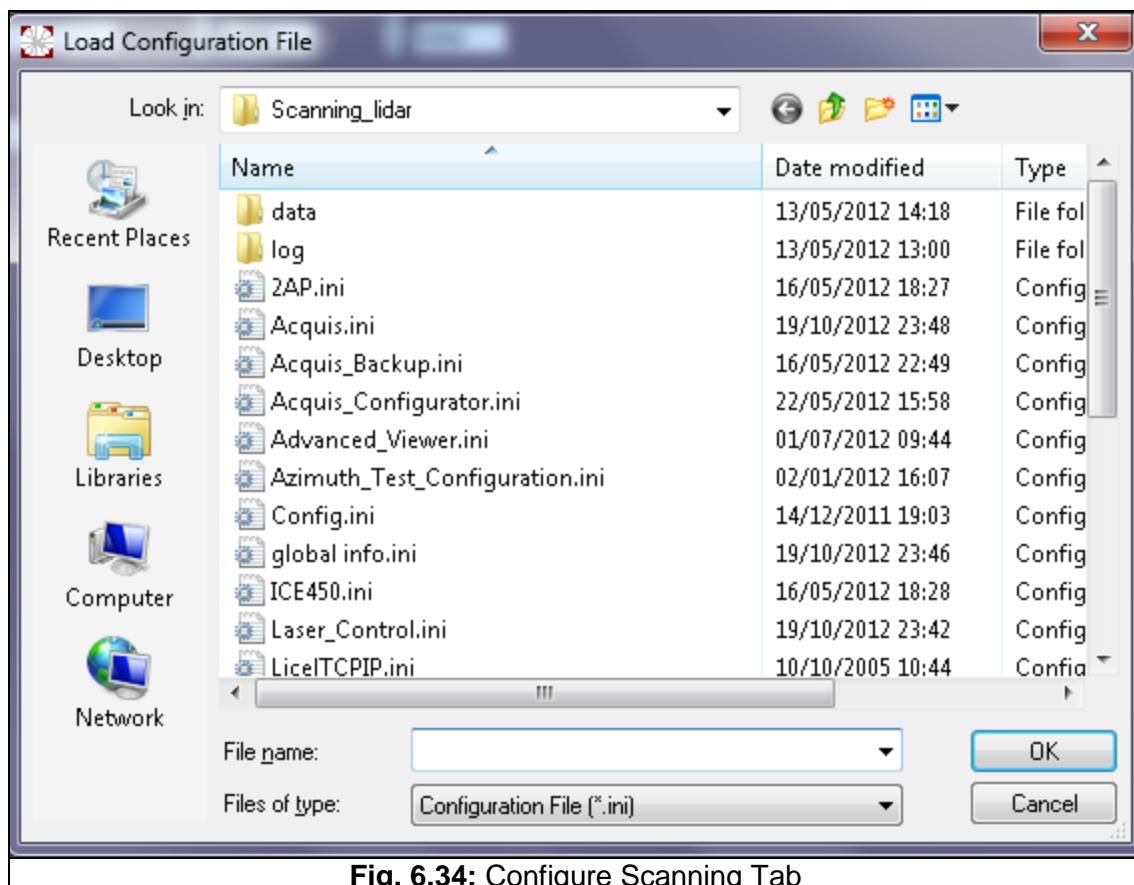
Fig. 6.34: Configure Scanning Tab

The main interface is very similar to the acquisition interface the main difference here are the indicators on the bottom that shows some information regarding the type of the scan to be performed. Note that you have the option here to set to run the same scan scenario continuously until the user press the stop button. The counter nex to this option indicates how many scans have already performed and the counters below shows the number of scan steps per scan and those that are currently done.

At the 3D tab the user can have a quick look of the scan as this was acquired in a 3D graph.
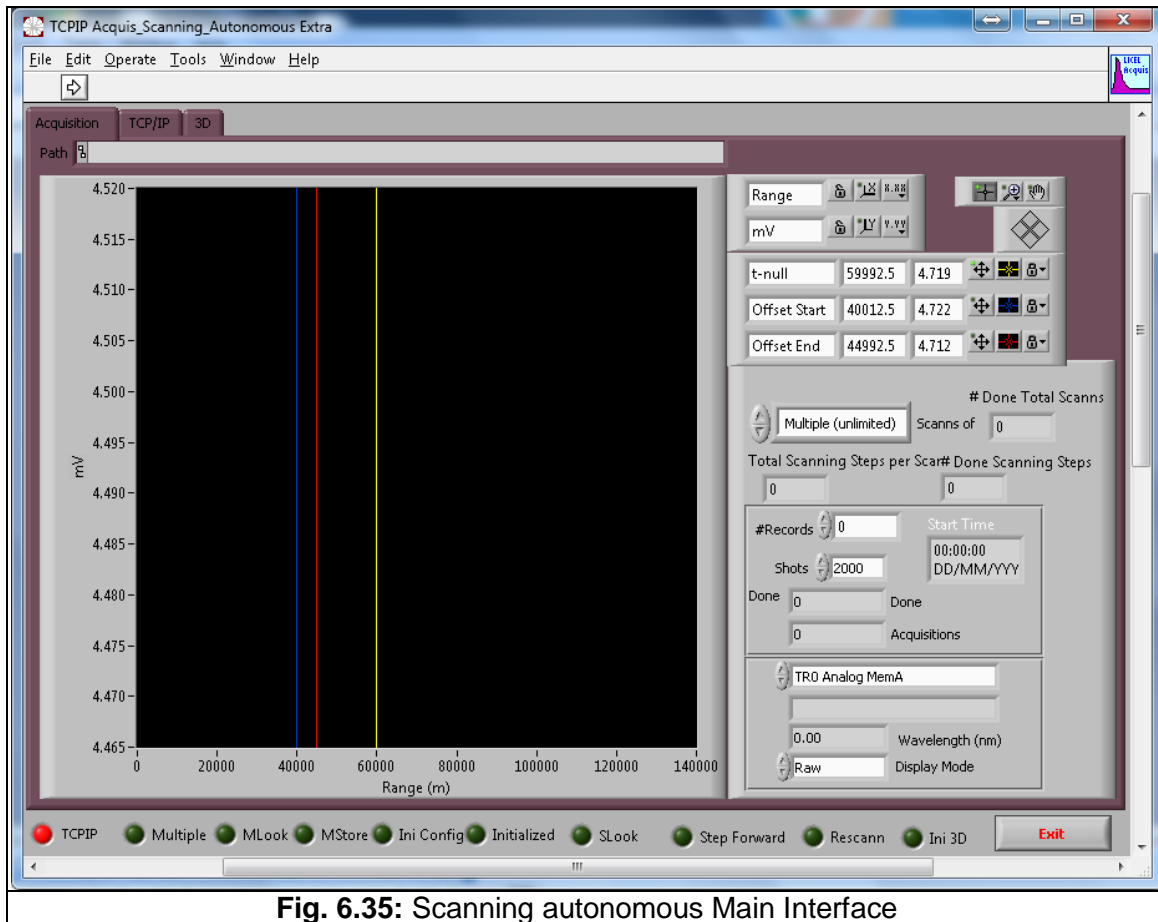
Fig. 6.35: Scanning autonomous Main Interface

6.5.3 Time scheduler for Scanning

This program as already explained is used to make a schedule of measurements. The difference with the fixed point time scheduler is that this can run scanning acquisitions instead of fixed pointed ones. The same logic is used whit the scanning autonomous you can use the configurator to create a scanning configuration file or you can call this program by clicking on create TR config file at the set up tab.

Once you have the configurations files that you will use, go to the scheduler tab and select the days of the week to run or none to run only once, below that set the start time and the configuration file, press the start button and the scheduler will start measuring the scheduled measurements. Notice that there is no stop time here as this is estimated from the configuration file. Make sure that the next measurement will not overlap with the previous. If this happens the Table Ok LED remains red and the Start button grayed out.
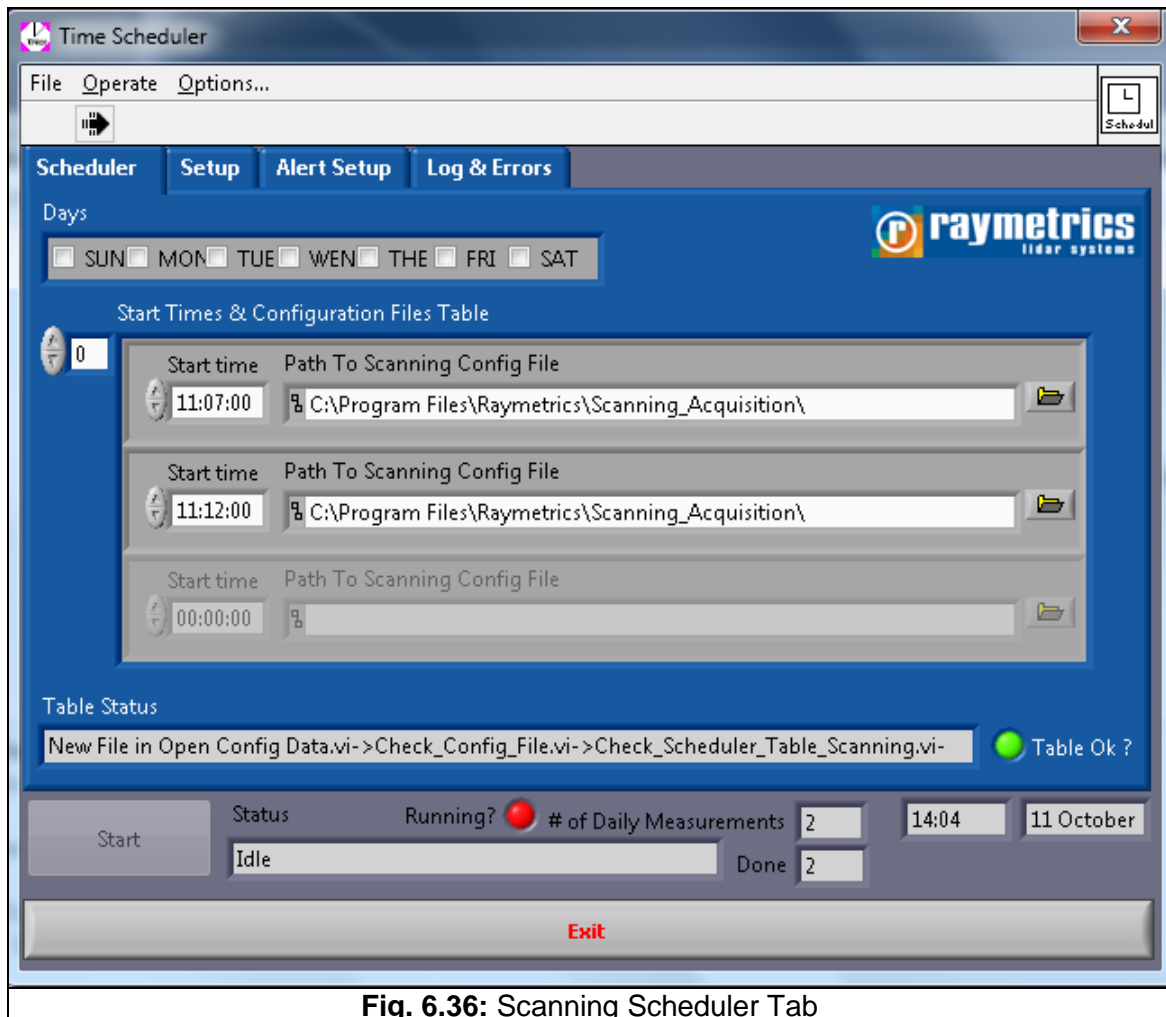
Fig. 6.36: Scanning Scheduler Tab

At the setup tab you get all different options on how to save the data. This is very useful while the scanning data are too many to be saved in a single folder. This way you can group the data in folders by date or/and scan and have a much more organized data base. Finally there is an option to save data in ASCII format if the user intends to use a non Raymetrics program for the data analysis.
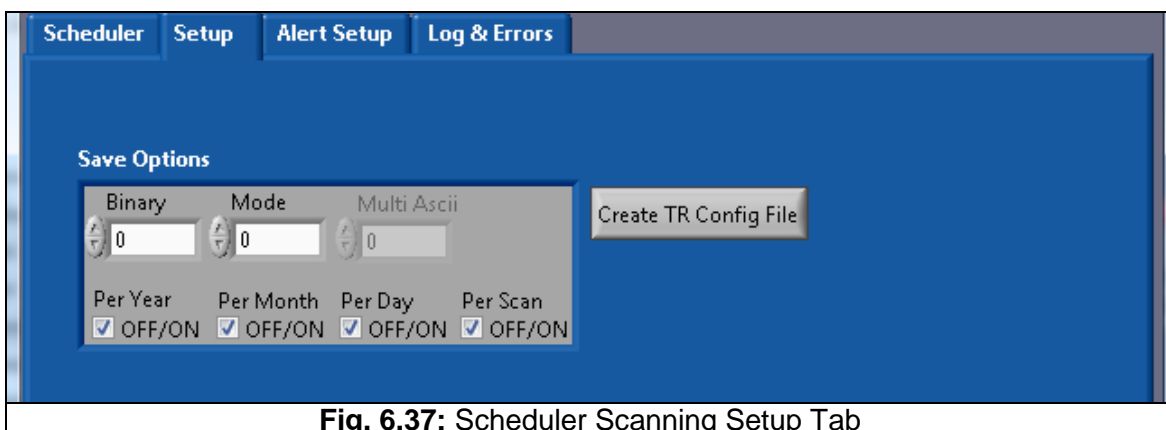
Fig. 6.37: Scheduler Scanning Setup Tab

6.6. REMOTE LIDAR

The Lidar can be fully remotely controlled. When it is plugged to a network it automatically acquires an IP address. Any user in the same network should be able to connect to the Lidar's computer. If this network also has internet access with the appropriate permission from the network administrator you can connect externally to the Lidar from anywhere in the world. In this paragraph there are some practical guides how to connect and operate the computer remotely.

6.6.1 Establishing a connection

Once the Lidar is connected to an external network, you can use the windows remote desktop to control the Lidar's computer. Follow the steps below to establish a connection from a windows 7 operating system.

1. Open the network to browse all computers connected to your network.
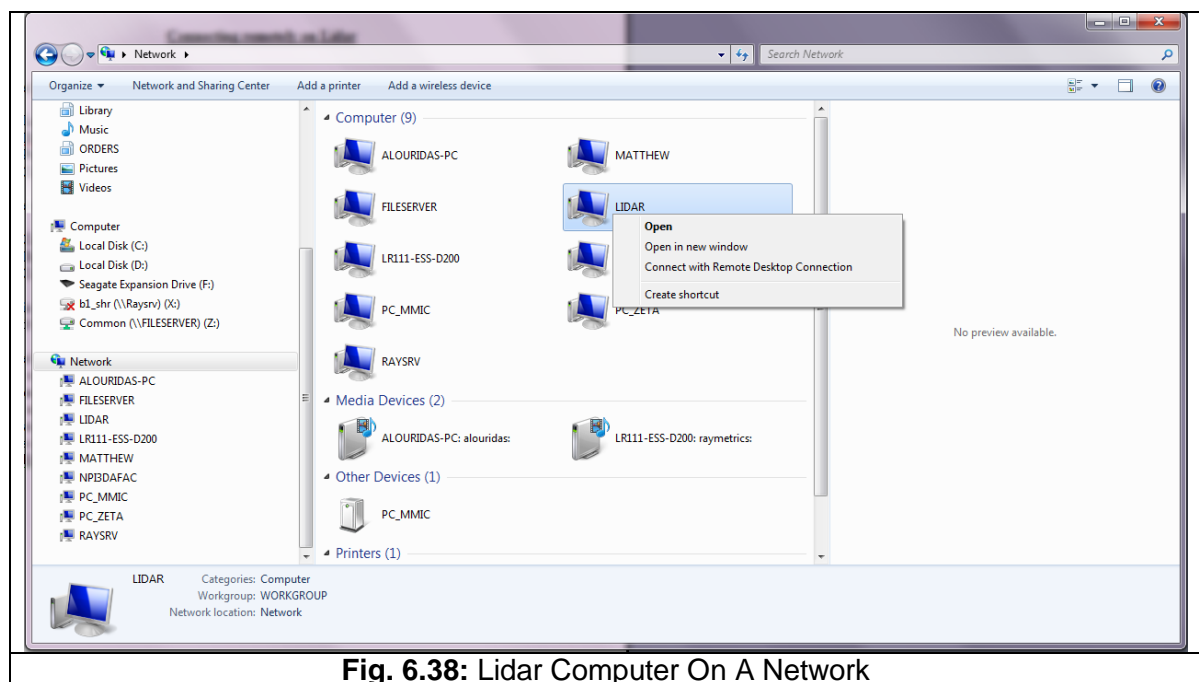
Fig. 6.38: Lidar Computer On A Network

2. Locate the computer named "LIDAR" and right click. "LIDAR" Is a generic name you can see in the computer properties the computer name.

3. In case you cannot find the Lidar computer, make sure that the Lidar is powered on, and that the connection cable is well placed at the Lidar and at the wall. If this doesn't fix the problem use another cable or another wall socket.

4. Select "Connect with Remote Desktop Connection" (RDP).

5. When you click the window below appears.
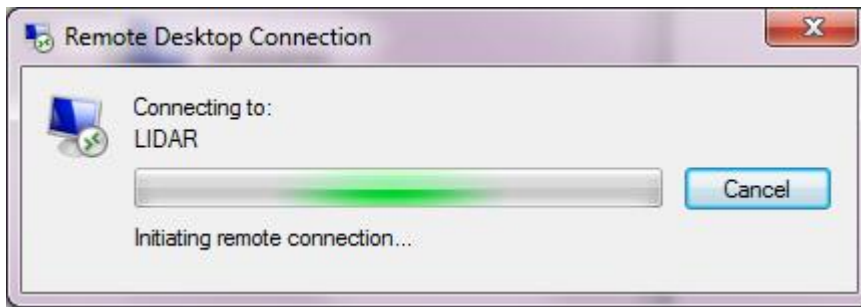
6. Normally you will have to wait for a couple of seconds. If it takes longer that one minute then probably the connection cannot be established and the window below appears.
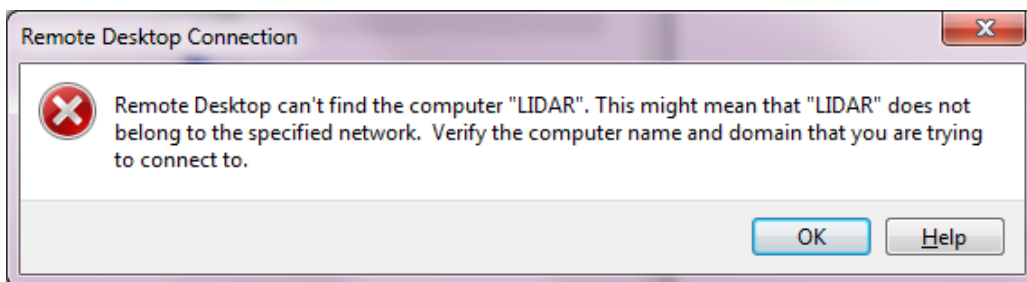
7. The most common reason for this is that the computer is turned off. You can see how to remotely wake up the computer at "*6.6.2 Shut down and WOL*" paragraph. If the problem is still there refer to the "*6.6.3 Remote Connection*" paragraph.

8. Key in the user name and password when prompted and check "Remember my Credentials".

   By default the account used has the credentials below:

   Username: **User**

   Password: **Lidar**

9. A new window will open showing the Lidar's desktop. Use the mouse and keyboard and control the Lidar.

   Note that this is a window which you can resize, minimize and close like all windows. When you resize keep in mind that you don't view the whole screen. There might be icons missing or the taskbar which you can view by using the scroll bars.

   Also keep in mind that when you close the window you don't close the Lidar computer but only the connection. The computer logs off and remains turned on. If you want to shut down the computer refer to "*6.6.2 Shut down and WOL*" paragraph
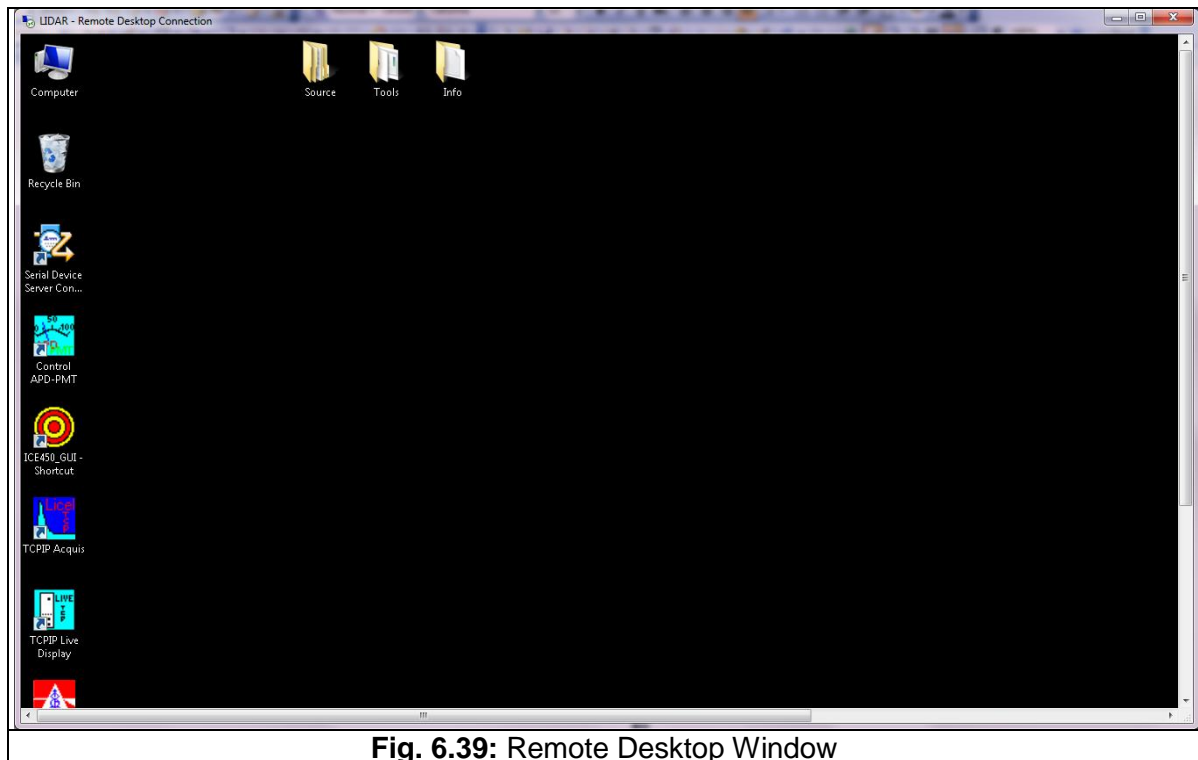
Fig. 6.39: Remote Desktop Window

6.6.2 Shut down and WOL

Once connected, you will notice that the options in "Start" are limited to "Disconnect" and "Lock".
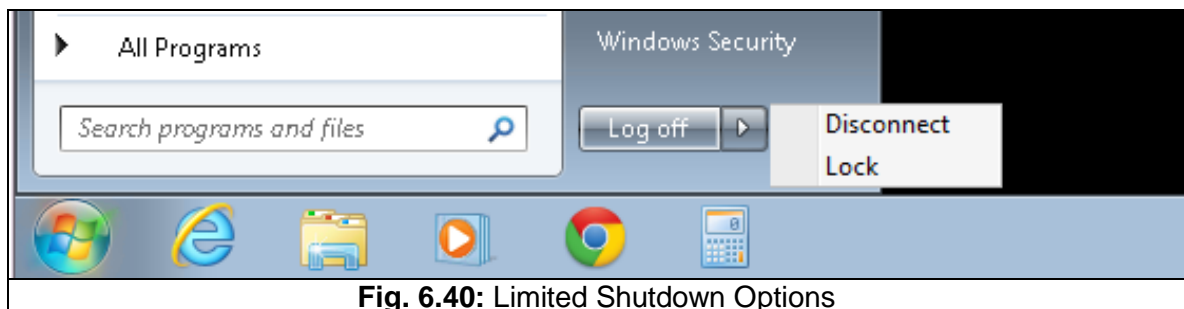
Fig. 6.40: Limited Shutdown Options

In order to shut down the computer, click "Windows Security" right above the "Log off" button. This will show you a new screen which is shown when you press "Alt+Ctrl+Delete" in windows 7. From there you can select to shut down safely the Lidar computer.

Note that if you try with the key shortcut "Alt+Ctrl+Delete" the screen that is shown refers to your computer and not the Lidar's computer. There is however the option to use this shortcut also in the remote connection. Please refer to the "*6.6.3 Remote Connection*" paragraph.
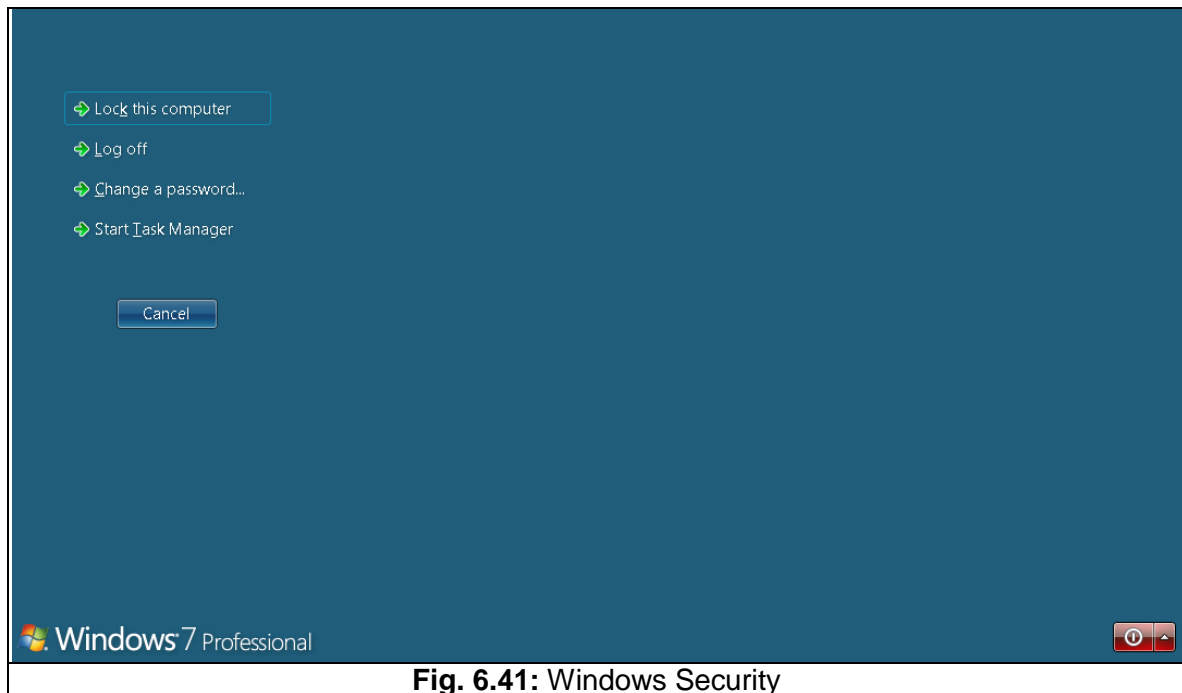
Fig. 6.41: Windows Security

The next thing now is to turn the computer on remotely through the LAN. This procedure is called "Wake on LAN" and it is an event that wakes up the computer using the local network or even the internet. To do this a packet of codes must be send from your computer to the Lidar's computer, which is called "Magic Packet". This packet is produced and sent with very simple software which is called in general "Magic Packet Sender". You can find many free programs over the internet. All of these programs need the Lidar's IP and MAC address to work however some require more information.

Many of these programs can scan the network and find all computers which are currently turned on and acquire automatically the Name, IP and MAC address. Below is an example of such a program.
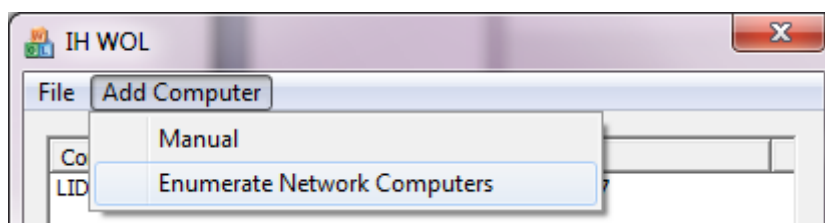
Note: The program will not find the computer if it turned off. If you want for the first time to scan to find the Lidar computer, turn it on and then you can save the information needed to the program so that you can use the next time.

Note: You have to give permission from windows to scan the network. If you are prompted for security issues for this operation check the option to allow the program to perform the scan.

Once you have the computer's information you simply have to select the correct name and turn it on.
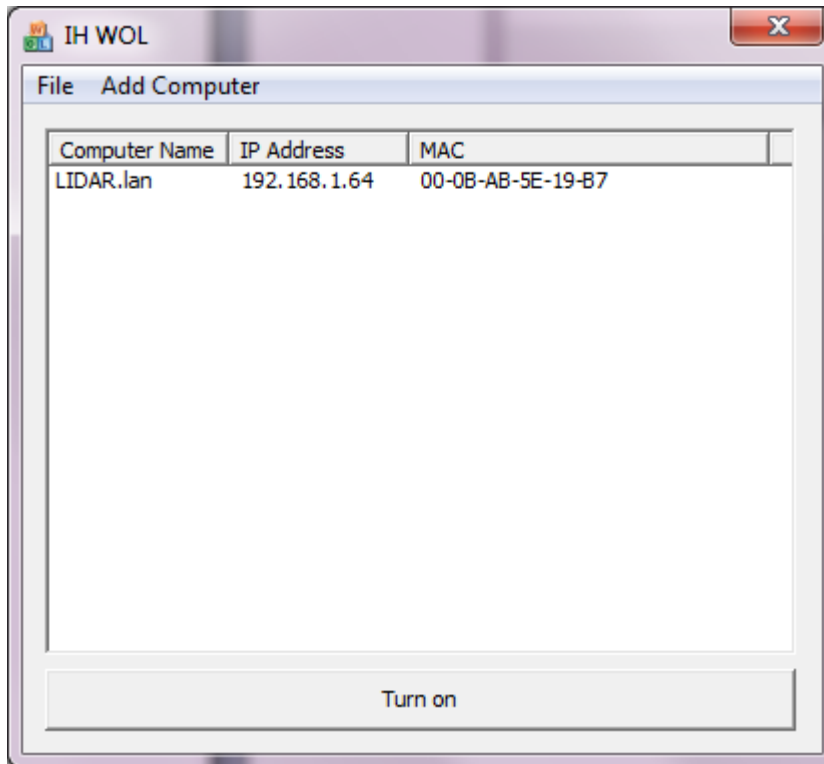
Note: You will have to wait for a moment to let the computer start windows, before you can connect to it.

There is also the option to perform this from this task from a distant computer over the internet but in this case you will need to set a static external IP address for the Lidar at the network router's options and also to set an access port at the firewall options. **Please consult your IT department before performing such a task.**

6.6.3 Remote Connection

The procedure described in the paragraph "Establishing a connection" is the fast way to connect. However you don't get all the options with this way. You can see more options if you go to "Start -> All Programs -> Accessories -> Remote Desktop Connection" or simply if you type at Start "Remote".
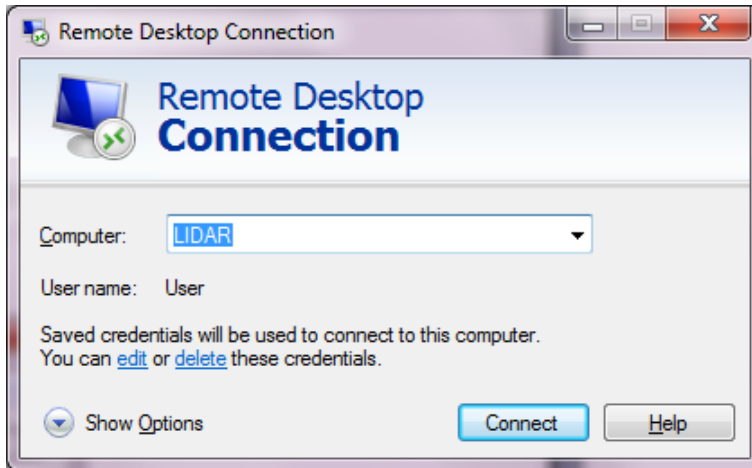
Click at "Show Options" to view the options tabs. Here you can do many things such as save the connection setting, select the quality of the connection, set the local resources options and set more advanced options.
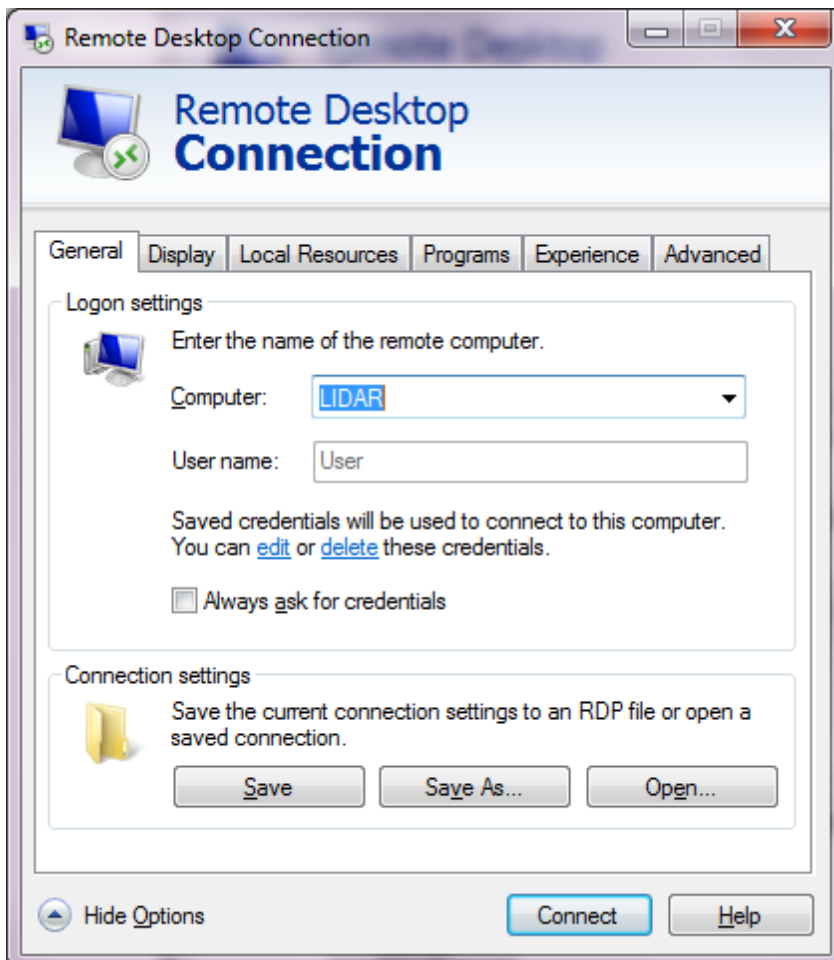
On the local resources tab you can choose how the key combinations behave such as the "Alt+Ctrl+Delete". If you press the "More" button you can select to share a drive while connected, which come in hand when transferring data.
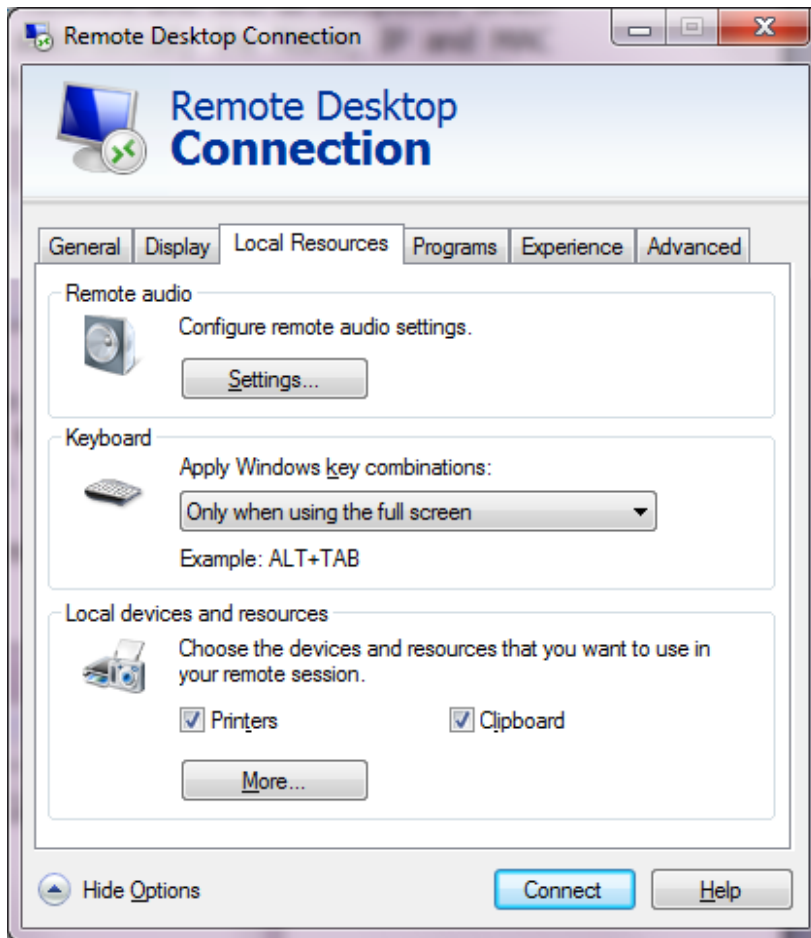
At the experience tab you can select the performance depending on you connection.

Note if you face connection problems check at the advanced tab the settings for the "Connect from Anywhere Option". When you use a local network select the "Automatically detect RD Gateway server Settings". In some cases this might change on its own and cause a connection problem.
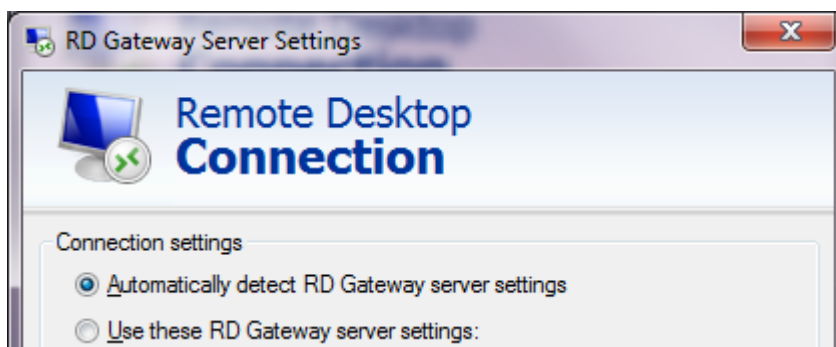
The interface has four Tabs. The main tab is the "Scheduler" Tab. This contains the time table and the scheduler status information.

7. LIDAR DATA PROCESSING

The data processing is not always an easy task. Here is first explained the form of the data and also it is provided a guide how to work and edit the database and also to perform a basic analysis using the Data preview and analysis software. Performing a really precise Lidar analysis lies on the verge of art since the user has to select through many parameters that eventually alter the final result. Experience in combination with the capabilities of the analysis software can create exceptional Lidar results.

The first paragraph refers to the data file format which is useful when the Lidar analyst wants to use another program for the analysis. The data are saved in binary form to reduce space. Even though the format is given there is also an extra tool embedded in the Data preview and analysis software that converts the binary files to ASCII.

However you decide to work make sure that the database is not affected and always keep a back up of Lidar data. Remember that raw data are irreplaceable.

7.1 DATA FILES HANDLING

The data files are saved in the folder set by the user. Apart from the data files there is also saved a datalog file which contains the main information of each data file. This is automatically saved whenever the user presses the Stop button. If the user presses the Exit button while measuring the file is not created and thus the data need to be manually selected.

The name of the data files is given by the acquisition software automatically using the date and time of the measurement. The general format is RMyyMddhh.mms and is explained below.
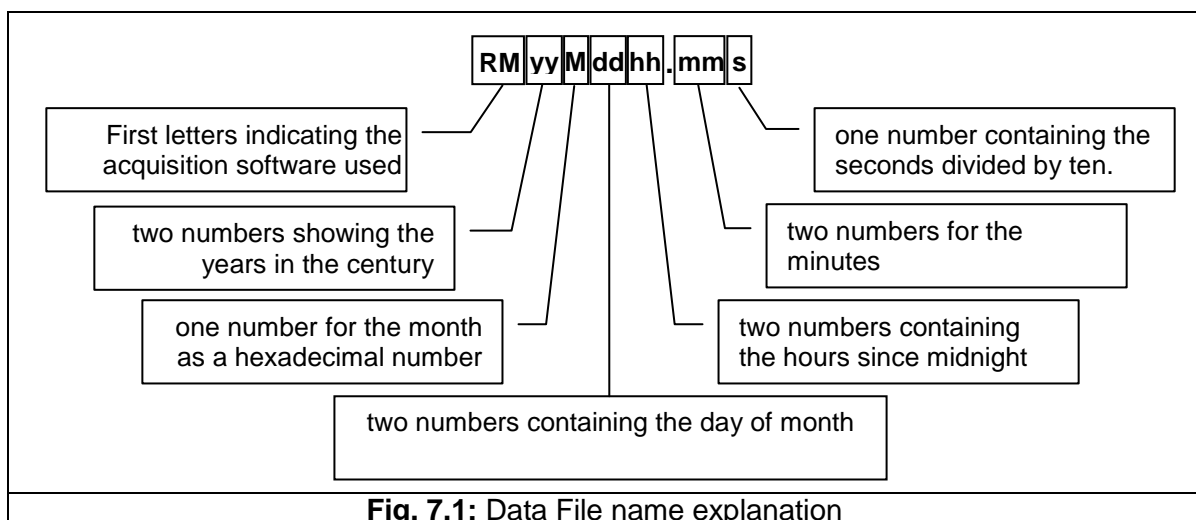
Fig. 7.1: Data File name explanation

For example the file RM12C2815.572 is created by Raymetrics software (RM), in year 2012 (12), month December (C), day 28th (28) at 15:57 (15.57) past 20 seconds (2).

The file format is a mixed ASCII-binary format where the first lines describe the measurement situation, below follow the dataset description and then raw data as 32-bit integer values itself.

RM12C2815.572
ATHENS 28/12/2012 15:57:02 28/12/2012 15:57:22 0180 0029.0 0032.0 -90 00 20.0 1013.0
0000200 0010 0000200 0010 08
1 0 1 16380 1 0850 7.50 00355.p 0 0 00 000 12 000200 0.500 BT0
1 1 1 16380 1 0850 7.50 00355.p 0 0 00 000 00 000200 4.3651 BC0
1 0 1 16380 1 0850 7.50 00355.s 0 0 00 000 12 000200 0.500 BT1
1 1 1 16380 1 0850 7.50 00355.s 0 0 00 000 00 000200 4.3651 BC1
1 0 2 16380 1 0850 7.50 00387.o 0 0 00 000 12 000200 0.500 BT2
1 1 2 16380 1 0850 7.50 00387.o 0 0 00 000 00 000200 4.3651 BC2
1 0 2 16380 1 0850 7.50 00408.o 0 0 00 000 12 000200 0.500 BT3
1 1 2 16380 1 0850 7.50 00408.o 0 0 00 000 00 000200 4.3651 BC3

Fig. 7.2: Sample file header

The first line contains the measurement's name which is exactly the same with the File name, as explained above.

The second line contains more information about the location, start and stop time and the extrenal conditions.

- Location String with 8 Letters
- Start Time dd/mm/yyyy hh:mm:ss
- Stop Time dd/mm/yyyy hh:mm:ss
- Height asl. four digits (meter)
- Longitude four digits (including - sign). One digit for decimal grades.
- Latitude four digits (including - sign). One digit for decimal grades.
- Zenith angle two digits in degrees
- Azimuth angle two digits in degrees
- Ground Temperature (Celsius)
- Ground Pressure (hPa)

The third line contains information for the laser.

- Laser 1 Number of shots integer 7 digits (how many laser shots were averaged in one profile)
- Pulse repetition frequency for Laser 1 integer 4 digits (Usually 10 or 20)*
- Laser 2 Number of shots integer 7 digits
- Pulse repetition frequency for Laser 2 integer 4 digits
- number of datasets in the file integer 2 digits

The next lines that are in ASCII format are the dataset description. The parameters are divided by space.

- 1 digit integer: 1 if dataset is present, 0 otherwise
- 1 digit integer: 0 for Analog / Photon counting, 1 for Photon counting
- 1 digit integer: 1 for Laser source 1, 2 for Laser source 2.
- 5 digits integer: Number of bins (example 16380 x 7.5m each bin = 122.850m)
- 1 digit integer: N/A
- 4 digits integer: PMT high voltage in Volt
- 2 digit real with 2 decimal: Bin width in meters
- String with 5 digits: Laser wavelength in nm
- dot and letter: Polarisation, o _ no polarisation, s _ perpendicular, p _ parallel
- 0 0 00 000 backward compatibility
- 2 digits integer: number of ADC bits in case of an analogue dataset, otherwise 0
- 6 digits integer: number of shots
- 1 digit real with 3 decimal: input range in mVolt in case of analog dataset, discriminator level in case of photon counting.
- String with 2 letters: Dataset descriptor BT=analog dataset, BC=photon counting
- And one hexadecimal number: the transient recorder number.

The data set description is followed by an extra CRLF. The datasets are 32bit integer values. Datasets are separated by CRLF. The last dataset is followed by a CRLF. These CRLF are used as markers and can be used as check points for file integrity.

Using the analysis software presented below the user can translate all binary files to ASCII so that any program can be used for the data analysis.

7.2. DATA PREVIEW

Once you open the Data preview and analysis software you see the main interface. The window consists of a menu bar and a toolbar

Click the preview DB to open the Main DB interface.

Preview DB

With Preview DB you can have a quick look of the database and through the DB interface you can edit the database. Furthermore under tools in the main menu you can convert automatically database files to an ASCII format to use them with other programs.

7.2.1 Database Interface

The Database Interface is consisted of:

- the measurements table on top which shows all measurements in this database,
- a list on the right with the data files that there were written during this measurement,
- an information field below the measurements table, that contains the global information of the measurement,
- another table with the recovered channels right above the measurement table
- on the right of the window there are two dropdown lists and a text box which are used as filters,
- below this the edit database, the play and the close buttons
- and at the bottom a graph to preview the raw data of each selected channel

At the measurement table, every record represents a set of measurements. Each record has the following fields:

- User Name: is the username that is entered when someone call data acquisition interface.
- Location: Is the Location which is entered during global information configuration procedure.
- Start, Stop Time and Date

Whenever a measurement is finished, a new record is added to the main table with the start date and time from the first filename of the measurements' set and stop date and time fields from the last saved file.
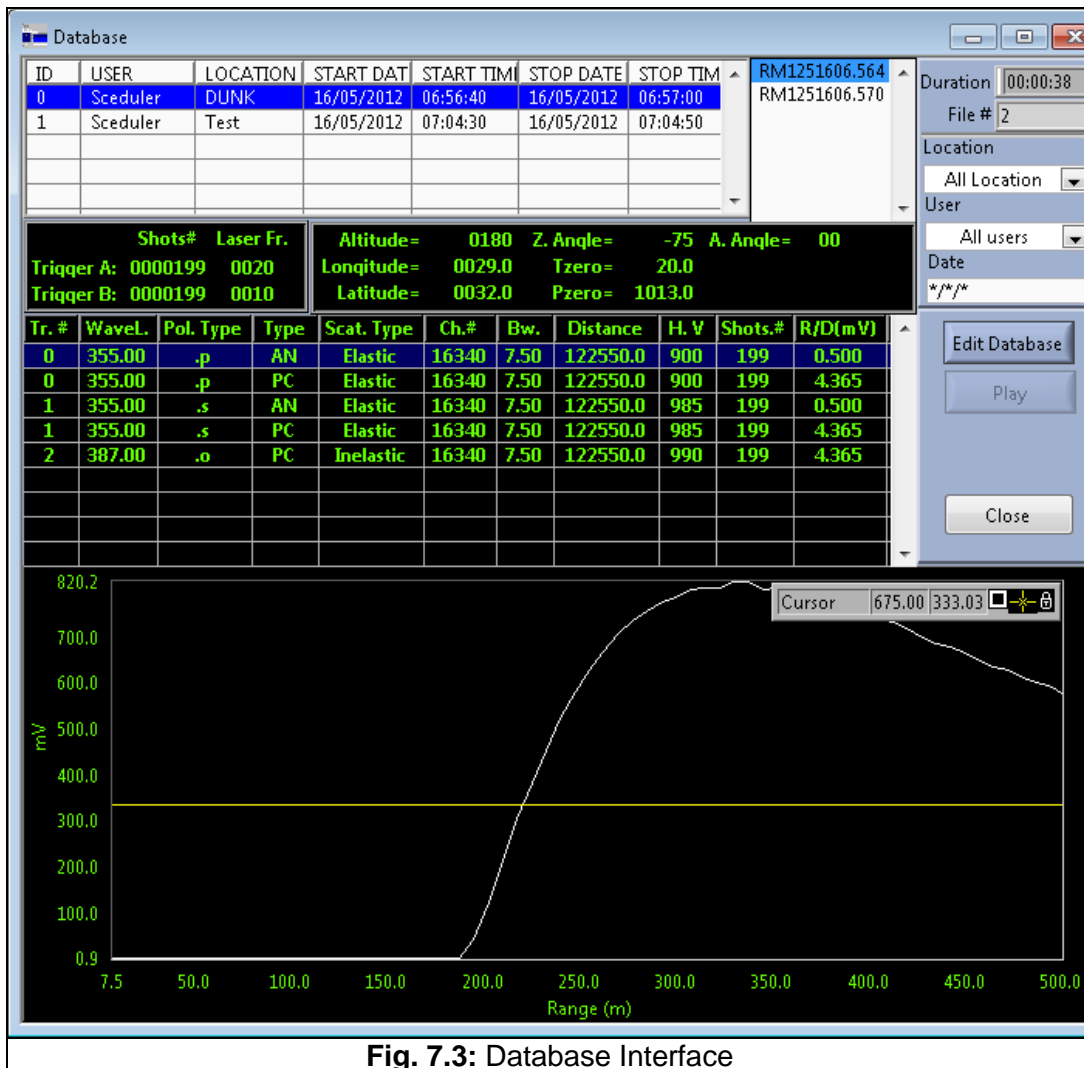
Fig. 7.3: Database Interface

Choose the file on the right that you want to preview and see below at the table the dataset description of the selected file, or in other words which channels where recorded during each measurement. Select a row to view corresponding plot. Every row consists of eleven shells that are:

- Tr.: Transient recorder device

- Wave L.: Detected wavelength

- Polarization Type: p-parallel, s – cross, o – no polarization

- Type: AN-analog, PC – photon counting

- Scat. Type: scattering type, elastic (transmitted wavelength equal to detected wavelength) inelastic (transmitted wavelength not equal to detected wavelength)

- Ch#: Number of channels recorded

- Bw.: Bin width = 2 ^ (reduction number) * resolution (in meters)

- Distance: maximum distance in meters

- H. V: PMT High voltage (V)

- Shots#: Number of shots

- R/D: For analog: input range (mV), for photon counting discriminator level.

In the next paragraphs there are step by step tutorials on how to edit the database.

- How to copy raw data files to create a new datalog file.

- How to work with a different database

- How To Create Manually A New Record At The Datalog.Dat

- Exporting and converting data from a data base

For context help just click <Control>+H

For getting help for the active window click <Control>+<Shift>+H

7.2.2 How to copy raw data files to create a new datalog file

Open the "Preview DB" window and click on the "Edit Database" Button on the right.
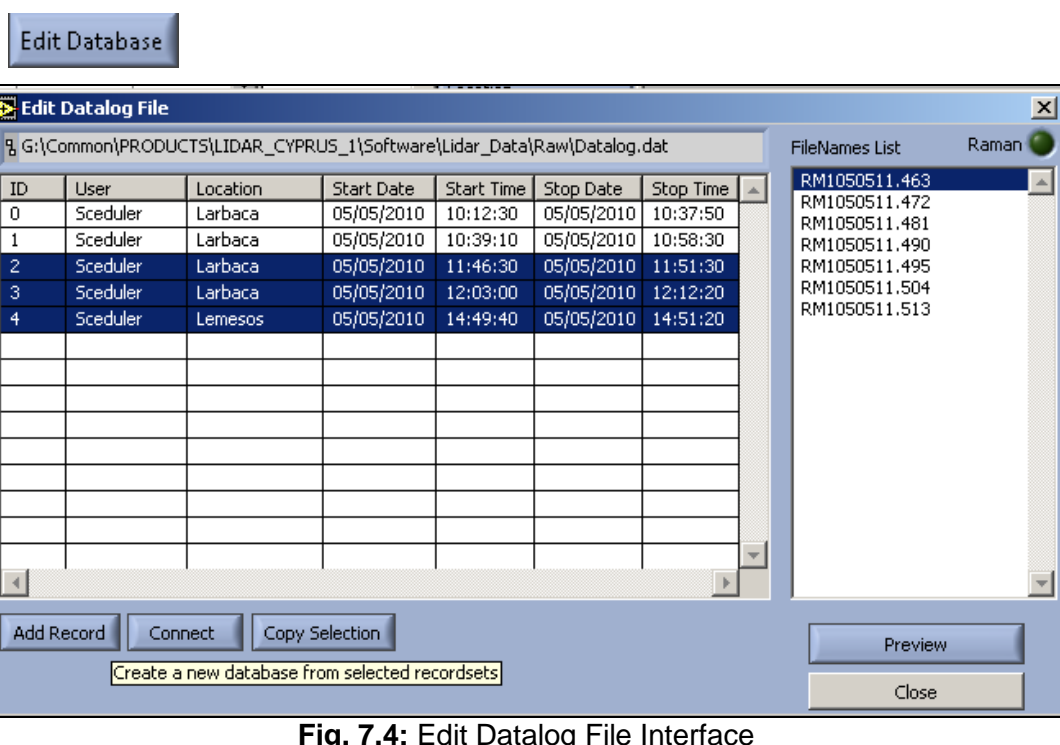
Fig. 7.4: Edit Datalog File Interface

In order to create a new datalog file with part of your database (for example to distribute it to your partners) you have first to select one or more (by keeping pressed the "left Shift" button at your keyboard) records and then press the "Copy Selection" button at the "Edit Datalog File" interface. A "Save As" common explorer interface appears. Choose an empty directory (or create a new one where ever you like).
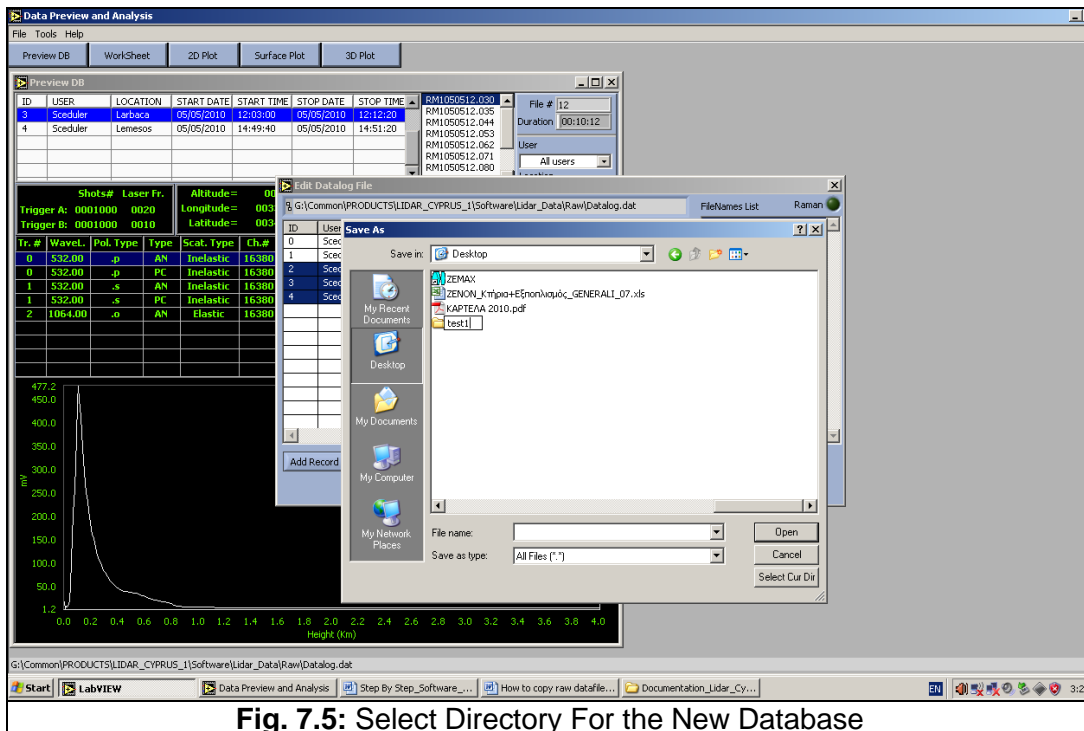
Fig. 7.5: Select Directory For the New Database

Double click on the icon of this directory (in order to get into it) and then click on "Select Cur Dir" button.

Then a new datalog.dat file will be created with only the previously selected records and all the associated raw datafiles will be copied inside this newly created folder (directory).

7.2.3 How to Create Manually a New Record at the Datalog.Dat

Many times users forget to click on "Stop" button before they exit the acquisition program (or in case of a power failure). In that case, although all the acquired raw data files have been saved to the default location, software failures to add a new record at the datalog.dat file that describes the measurement that user just did.

So user has to add manually this new record by following the procedure below.

Note: It is suggested to make a backup of your datalog.dat file before you proceed.

Open Preview DB window and click on the "Edit Database button as in paragraph *7.2.2 How to copy raw data files to create a new datalog file*.

Click the "Add Record" button as you see in Fig. 7.4 [Add Record]

Click the folder icon [icon] to open a windows selection dialog.
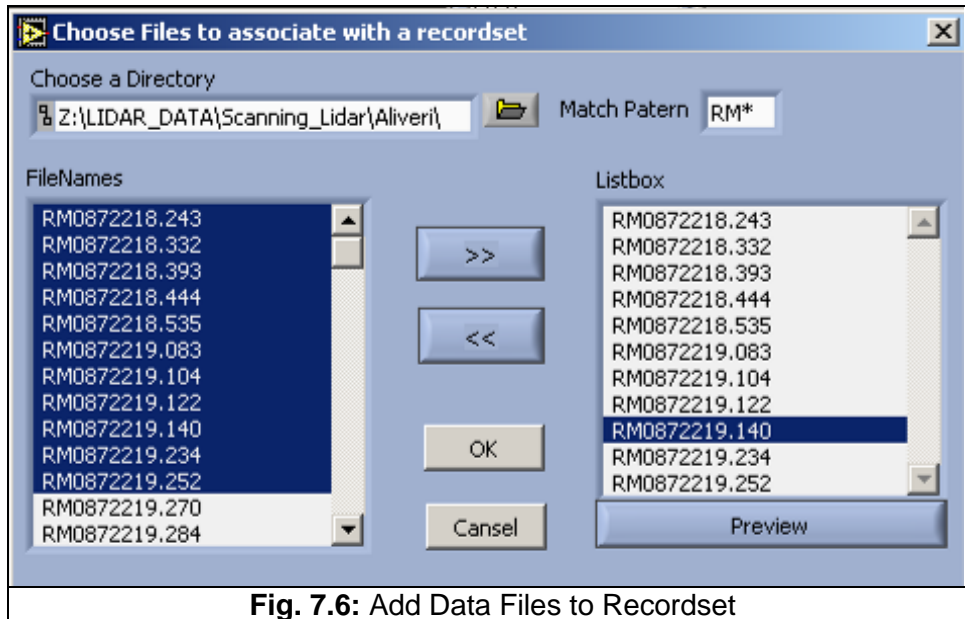
Fig. 7.6: Add Data Files to Recordset

Choose the directory that your raw data files are located (For example C:\lidar_data\Raw\), step into it and click on "Select Cur Dir" button.
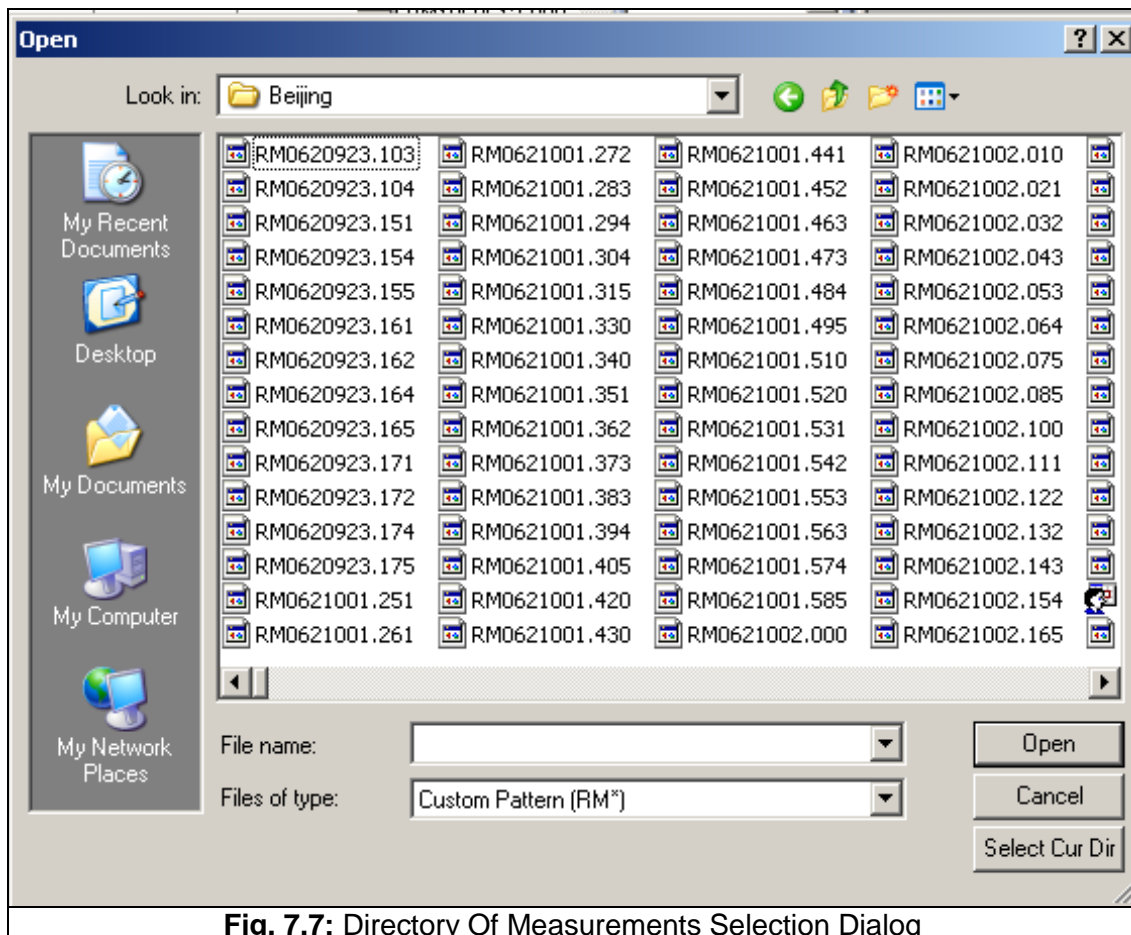
Fig. 7.7: Directory Of Measurements Selection Dialog

All the RM files will be displayed at the list box on the left.

Select all the files you want (be sure that they are sequential and belong to the same measurement)

Click the >> button to transfer them at the right list and click Ok

Then software asks to type a User and a Location. Type whatever you like but keep it less than 10 characters without spaces and click ok.

Fig. 7.8: Add Data Files to Recordset
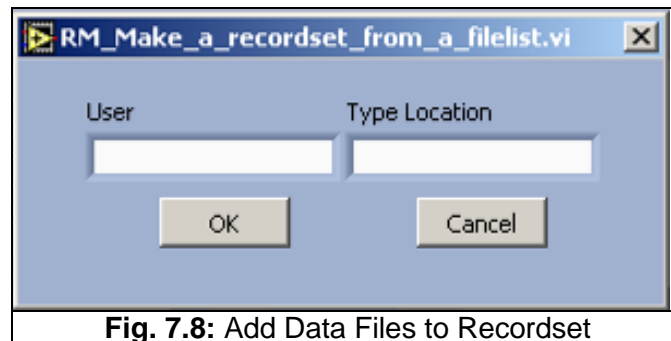
Click once more the OK button at the "Edit Datalog File" interface (Fig. 7.4)

If you now reopen the Preview DB window the new record will also appear.

7.2.4 How to Select a Different Database

When you have multiple databases saved in different folders you can work with any you wish at a time. Go through these steps to select another database to wok with.

Close the "Preview DB" window if it is open and go to Menu Bar and click Tools->Configure DB
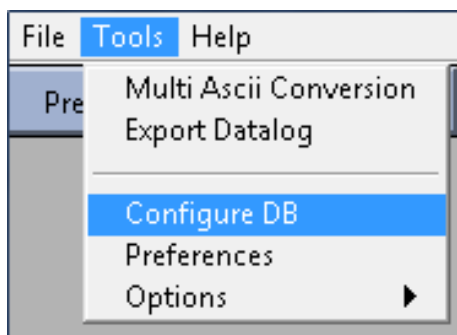
A dialog opens that prompts you to configure the Preview Application.

Click the Folder Icon (right up corner) of the Working Data Path text box. A normal windows selection dialog opens and asks to select the directory.
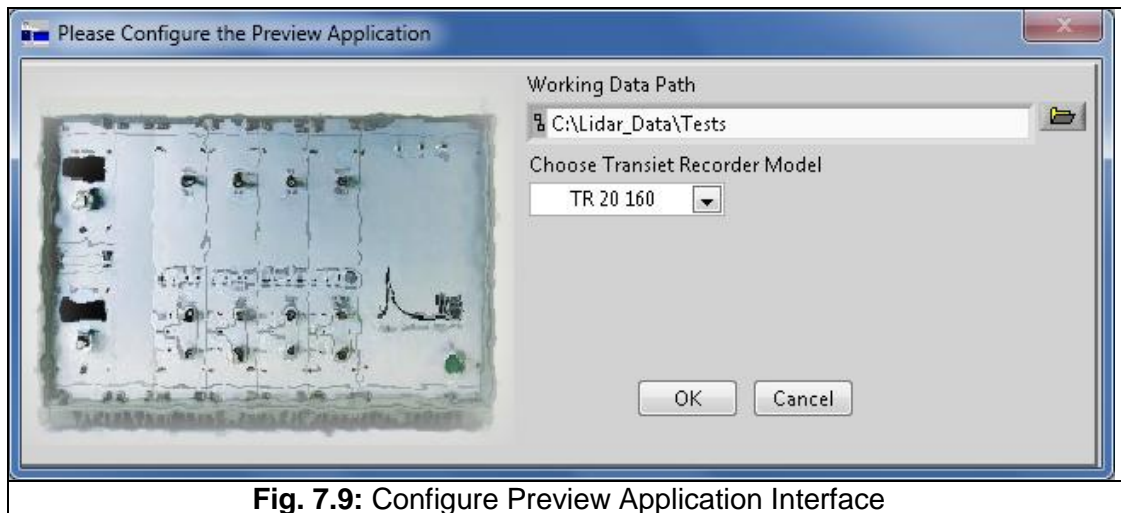
Fig. 7.9: Configure Preview Application Interface

Locate the directory where another datalog.dat file (with all the raw data files) exists. Note that by default there is a filter and you can only see the .dat files.
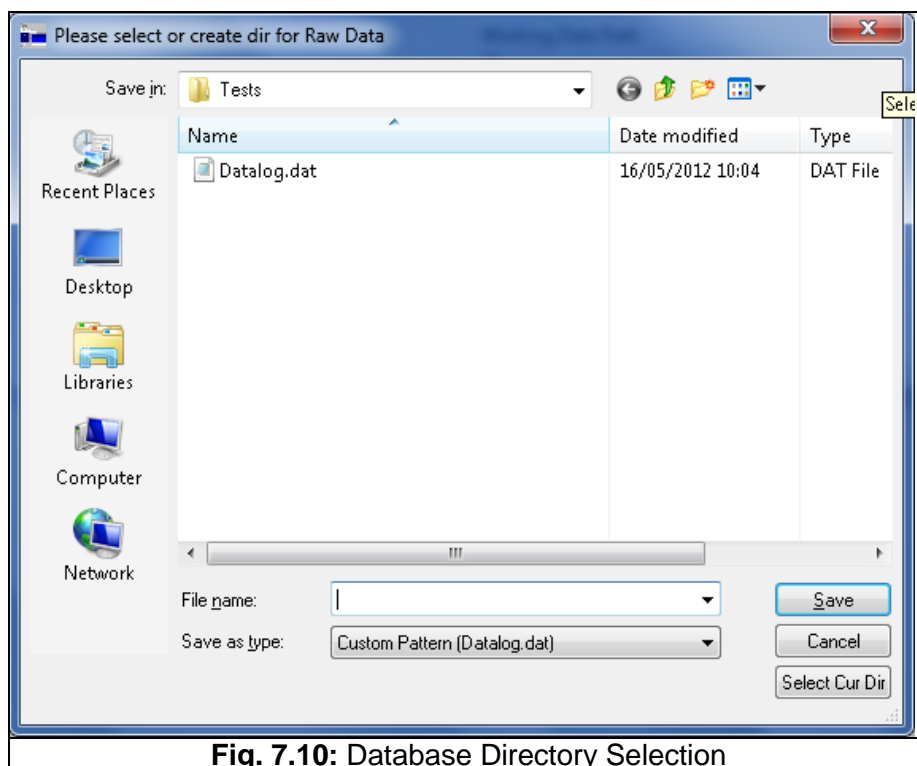
Fig. 7.10: Database Directory Selection

Double click the icon of that folder in order to get into it and click the "Select Cur Dir" Button.

Note: Please do not forget to choose the right type of your transient recorder

7.2.5 Converting Binary Files to ASCII

The software provides a function to convert all files of a record (measurement) from binary to ASCII format. This is useful when you want to read the files with software.

Click first the Preview DB button to open the database. On top select at the measurement table which record you want to convert.

Next go to "Menu" -> "Tools" -> "Multi ASCII Conversion".
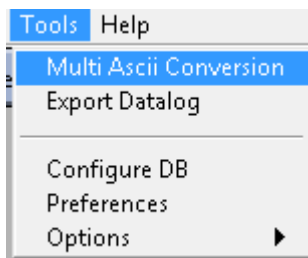
A window opens that prompt's you to select the folder where the converted data will be stored. Select a folder and click "select Current Dir."
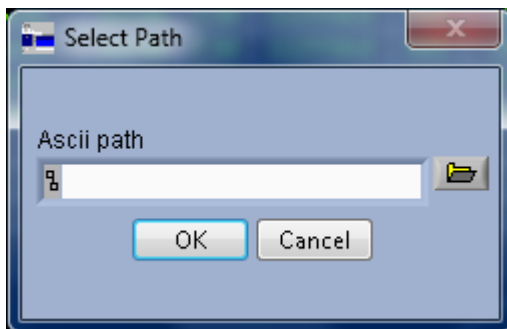
Wait until the status bar reaches the end and the data are now saved in an ASCII format. You can verify if they are written correctly if you choose to open one file with notepad. These files have actually no extension so they don't belong to any program. Because there is a dot before the last three digits on the filename windows recognize the last three digits as the type of the file.

You may also save as a text file the datalog file to use it with the converted files if you go to "Menu" -> "Tools" -> "Export Datalog"

7.3. DATA ANALYSIS

As already explained the analysis software is what analyst use to extract all the useful information from their Lidar data. Even though it provides a lot of information and functions the user has to first understand the theory that lies beneath the software so to understand the way things are calculated.

WorkSheet	2D Plot	Surface Plot	3D Plot

With the series of button shown above the user can:

- Use worksheet interface to insert data from external files or database into a worksheet.
- Plot directly database data or from external files using 2D Plot interface.
- Create surface graphs from acquired data using Surface Graph Interface
- With 3D Plot you can plot the temporal data in a 3D graph.

For more information about worksheet and plots refer to electronic form of Raymetrics user manuals.

Here in the next paragraphs there is a series of tutorials on:

- How to Plot Data
- How to Calculate Backscatter Coefficient
- How to Calculate Aerosol Extinction Coefficient
- How to Check Lidar Alignment
- How to Calculate Water Vapor Profiles
- How to subtract the Background
- How to Glue Analog and Photon Counting signals
- How to make a 3D Graph
- How to use soundings from global model data

With these 9 tutorial lessons the user will understand fully how to use the program. As deeper the analyst goes in the software's capabilities the biggest the theory background is required. In some lessons the basic theory required is given as introduction, but the analyst should look into the references and build a stronger Lidar knowledge.

7.3.1 How to Plot Data

Here is shown the way to plot your data. There are three ways to represent the data. One is a single 2D graph which can be data from a single file or a summation of multiple files. Another way is to plot the data on a surface that shows actually multiple files one next to the other as they evolve by time. The last is a 3D plot which also shows multiple files but in a 3D graph.

In this paragraph you will learn how to make a surface plot. Once you understand this you can easily also plot a 2D graph.

1. Click "Surface Plot".
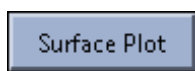
2. Click "Import Data".
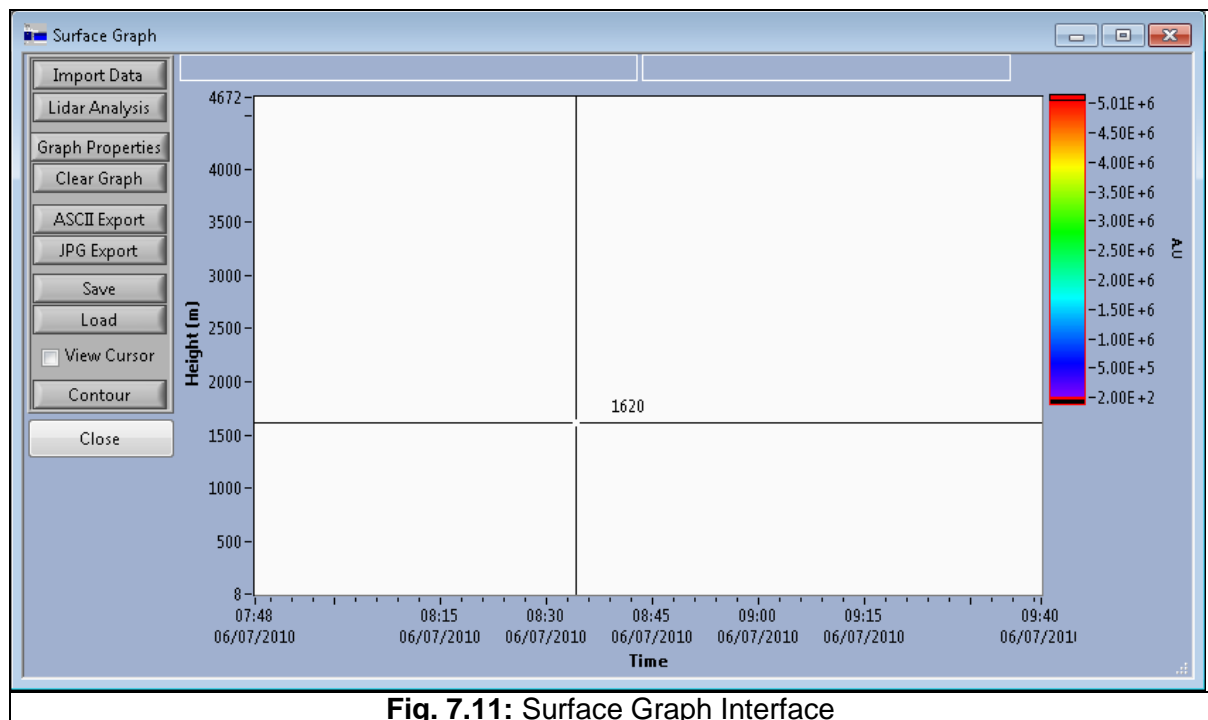
Fig. 7.11: Surface Graph Interface

3. Scroll up in the table if you do not see your data. Select the data in the table you wish to plot. In the right-hand column, hold the shift key to select the measurements you wish to plot. Click "Next".
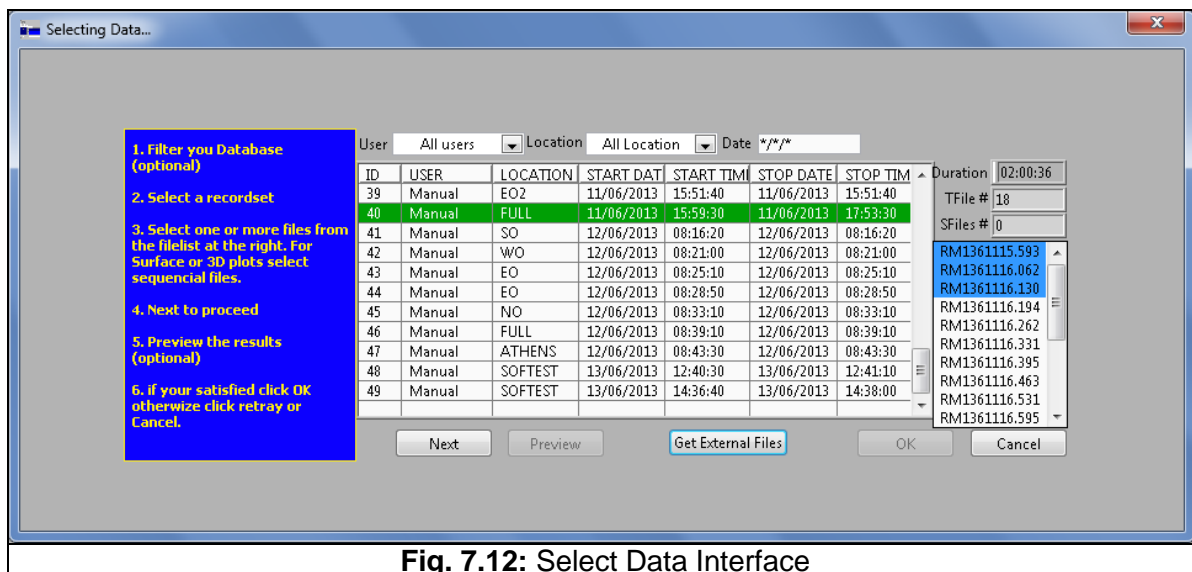
Fig. 7.12: Select Data Interface

4. Click "Basic Analysis" option.
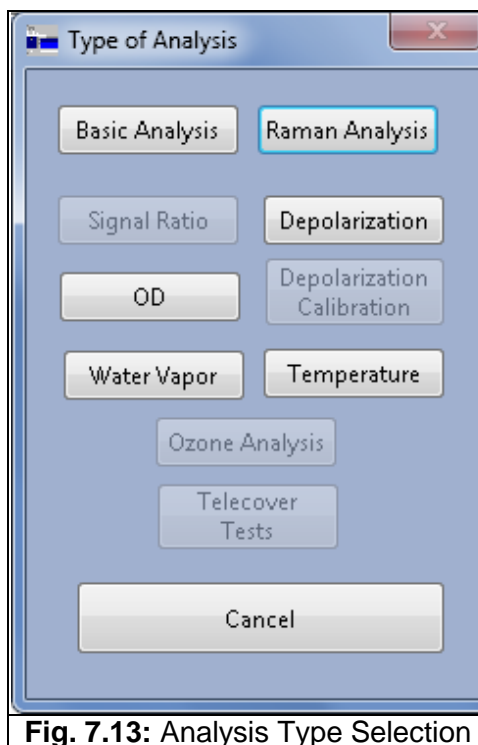
Fig. 7.13: Analysis Type Selection

5. Select the data type you wish to plot. For example "355.00.p.AN" from the list on the left. From the list on the right, select "RCS".

Note: "532.00.p.AN" – 532.00 = wavelength in nm, p = primary (as opposed to secondary - depolarization), AN = analogue (as opposed to Photon Counting or Glued – PC and GL). Other options include calibrated signal for depolarization (b). RCS = Range Corrected Signal.

Note: Hold down the "Ctrl" key and press "h" for help.
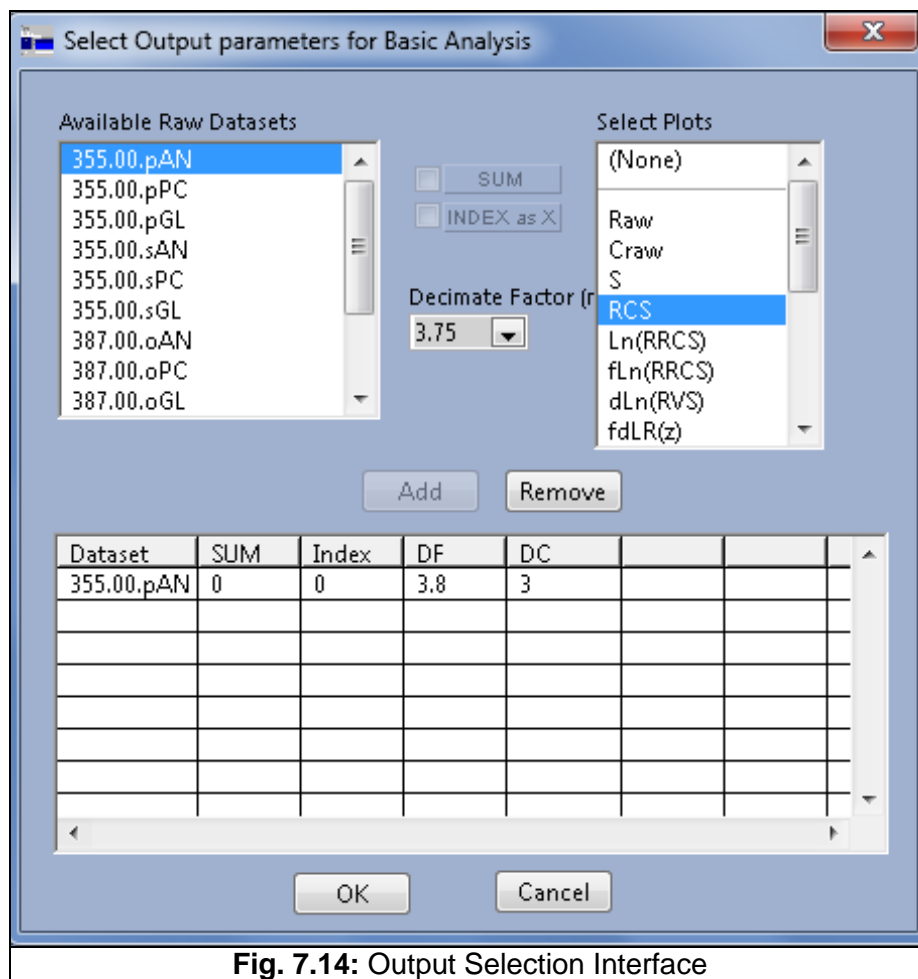
Fig. 7.14: Output Selection Interface

6. Click the "Add" button. Your selection will now appear in the small data table.

7. Click "OK" button. The software will now load your requested data.
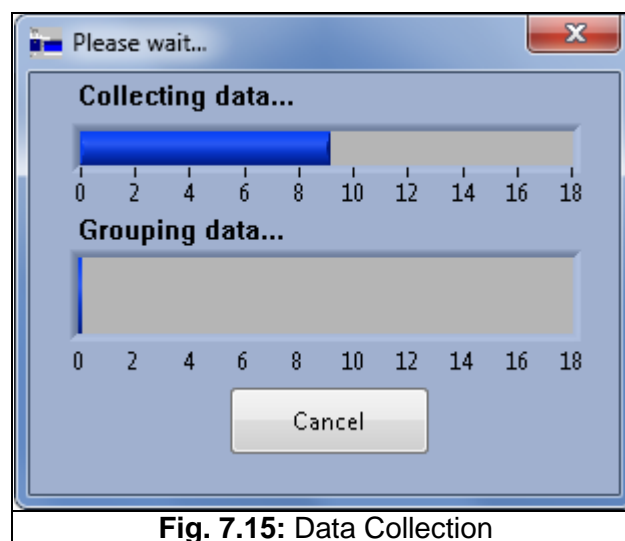
Fig. 7.15: Data Collection

8. After a few seconds, you will see the following blank graph.
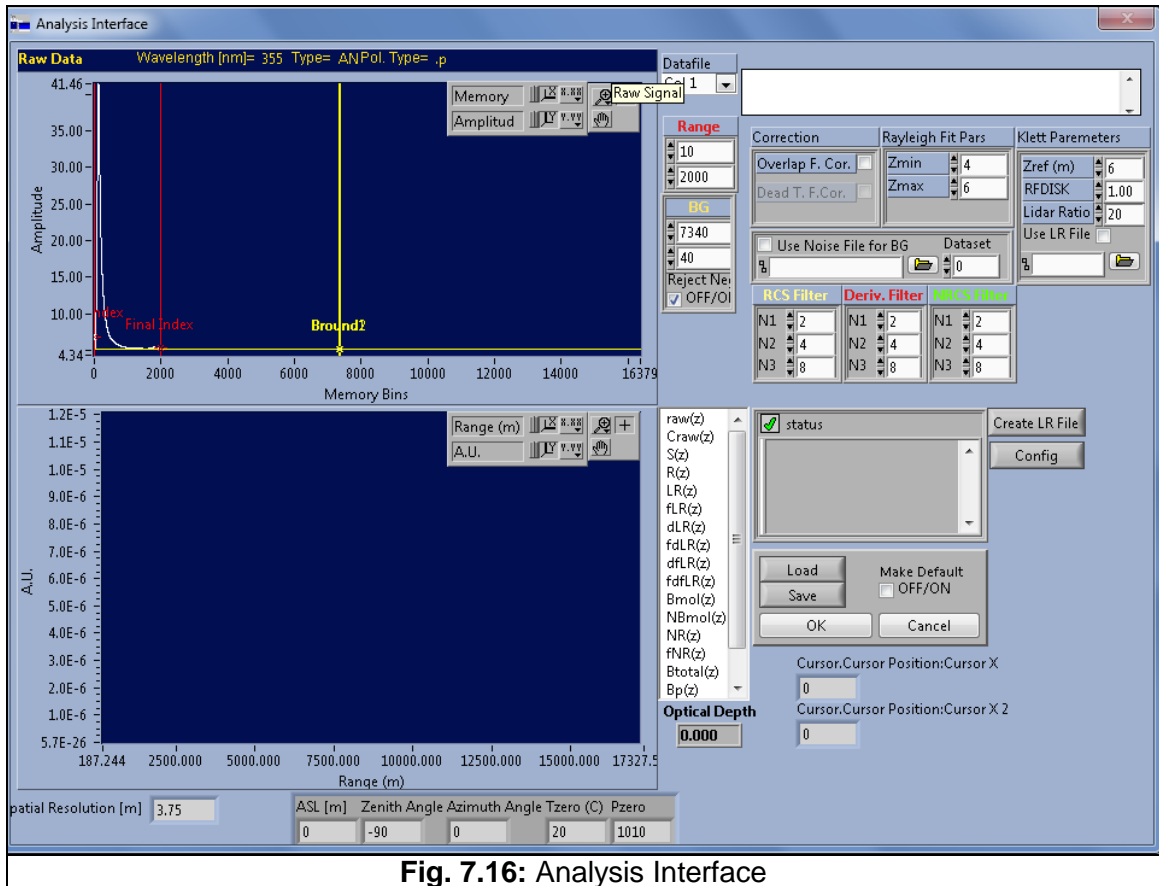
Fig. 7.16: Analysis Interface

9. In order to see the results, select a parameter from the parameter list to the right of the bottom graph (e.g. R(z) – range corrected signal).
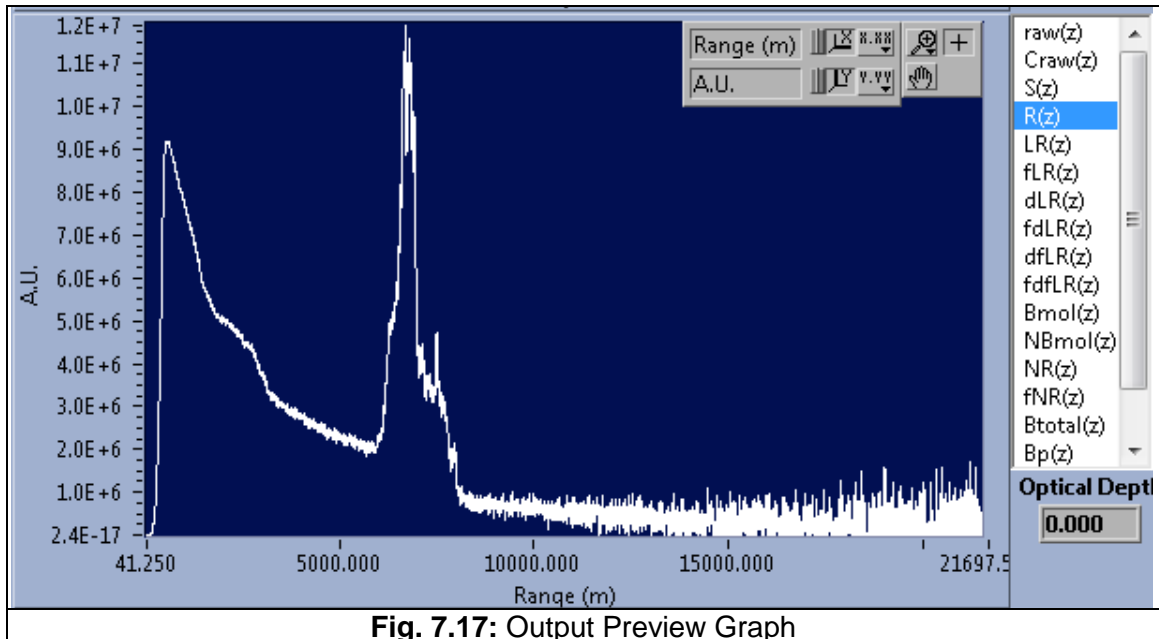
Fig. 7.17: Output Preview Graph

10. Click on the two red bars on the top graph and drag them to define the range (height) of interest. As you drag the bars, you will see the data change on the

bottom graph. You can also change the scales of the graph by simply clicking on any value on the x or y axis and typing a new value. The graph will then re-scale automatically
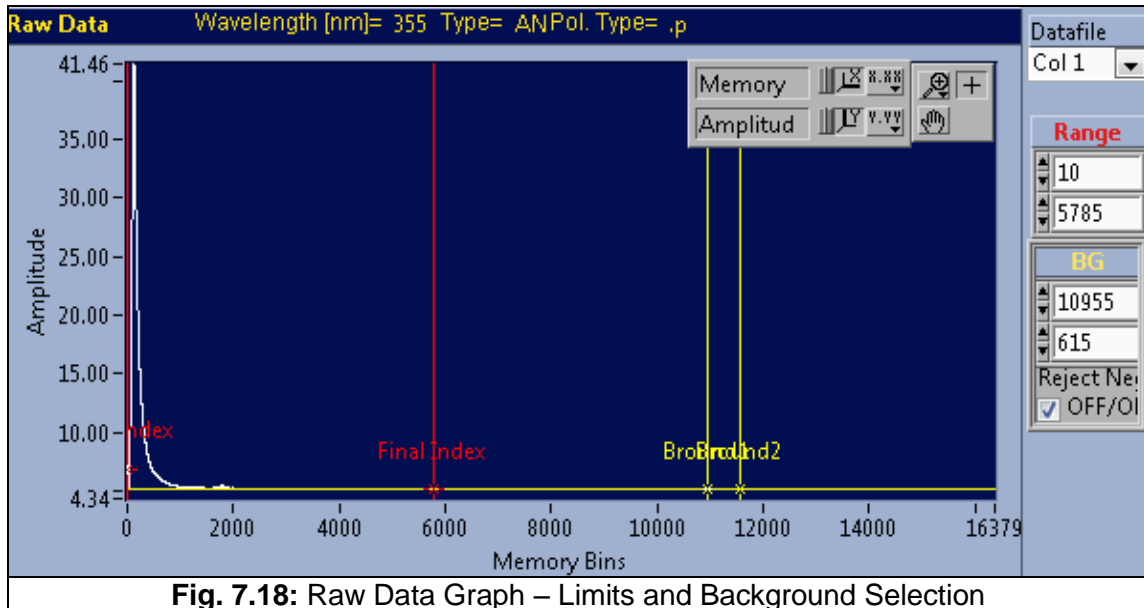
Fig. 7.18: Raw Data Graph – Limits and Background Selection

11. When you have the range desired, click the "OK" button. The previous window "Selecting Data…" (See Fig. 7.12) will appear back. Click the "OK" button again.

12. The selected data and parameters will now be displayed on a graph. Time is on the x axis, range on the y axis, with color values showing the intensity of the signal.
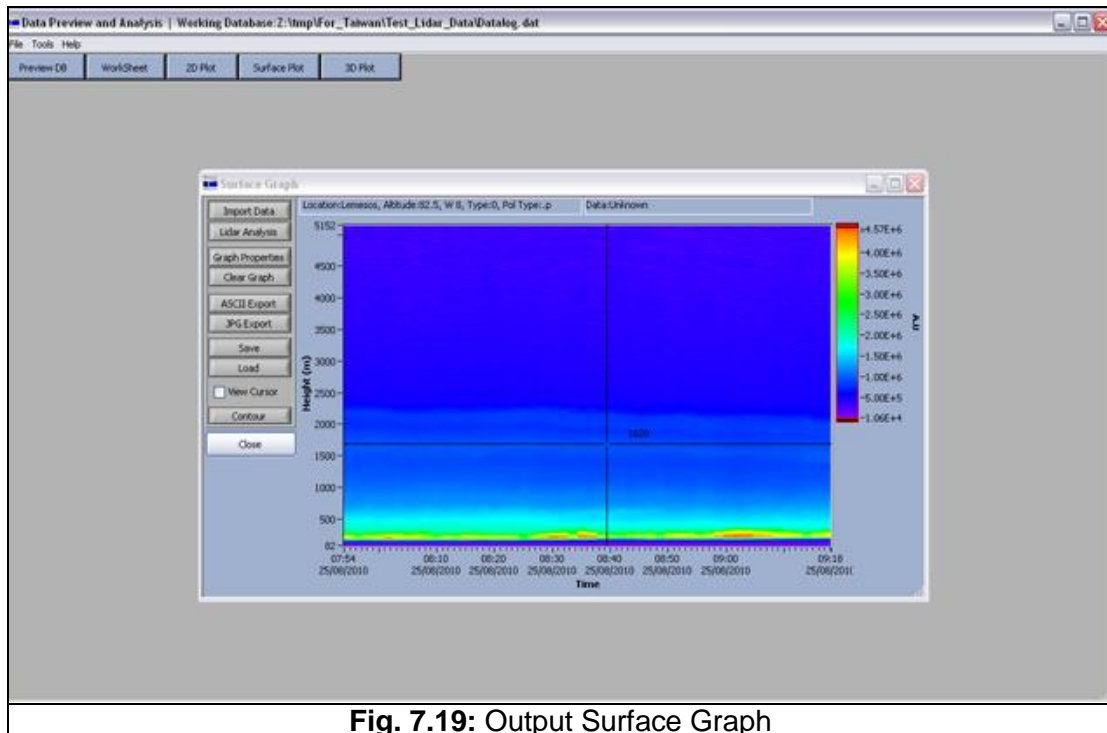
Fig. 7.19: Output Surface Graph

13. The image on the screen can be re-scaled by dragging on the bottom right corner of the window.
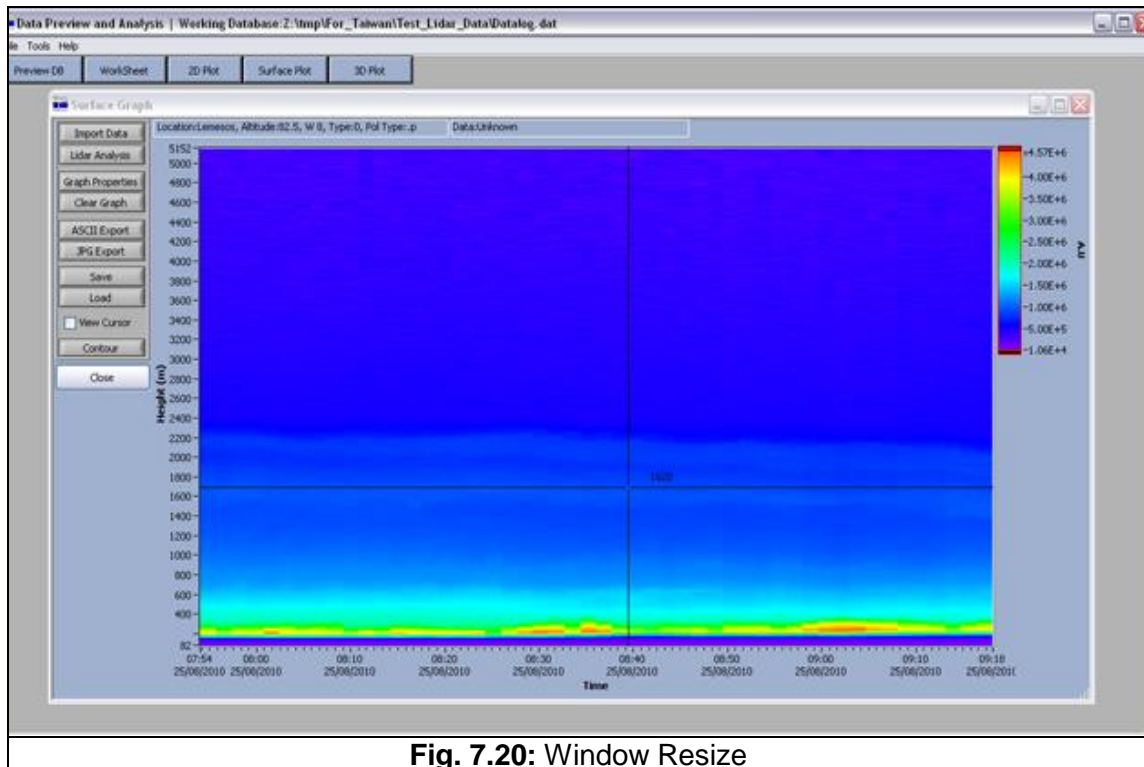
Fig. 7.20: Window Resize

14. Adjust the color scale of the graph by clicking on "Graph Properties" on the left and selecting the tab "Z-sc" (z scale).
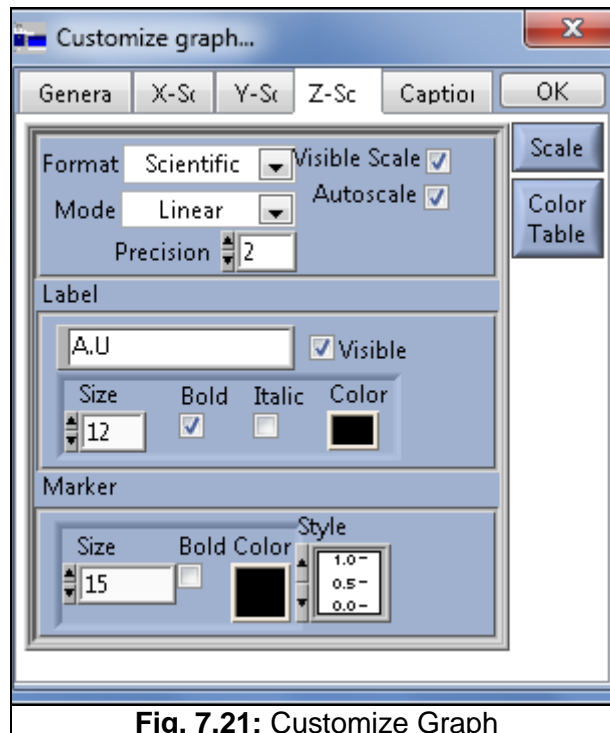
Fig. 7.21: Customize Graph

15. Click on the "Color Table" button on the right. At the top of the window, click "Choose C. Table". Select a new color scheme (if desired) from the options (e.g. "fire" or "rainbow"). Click "OK" and "OK" again.
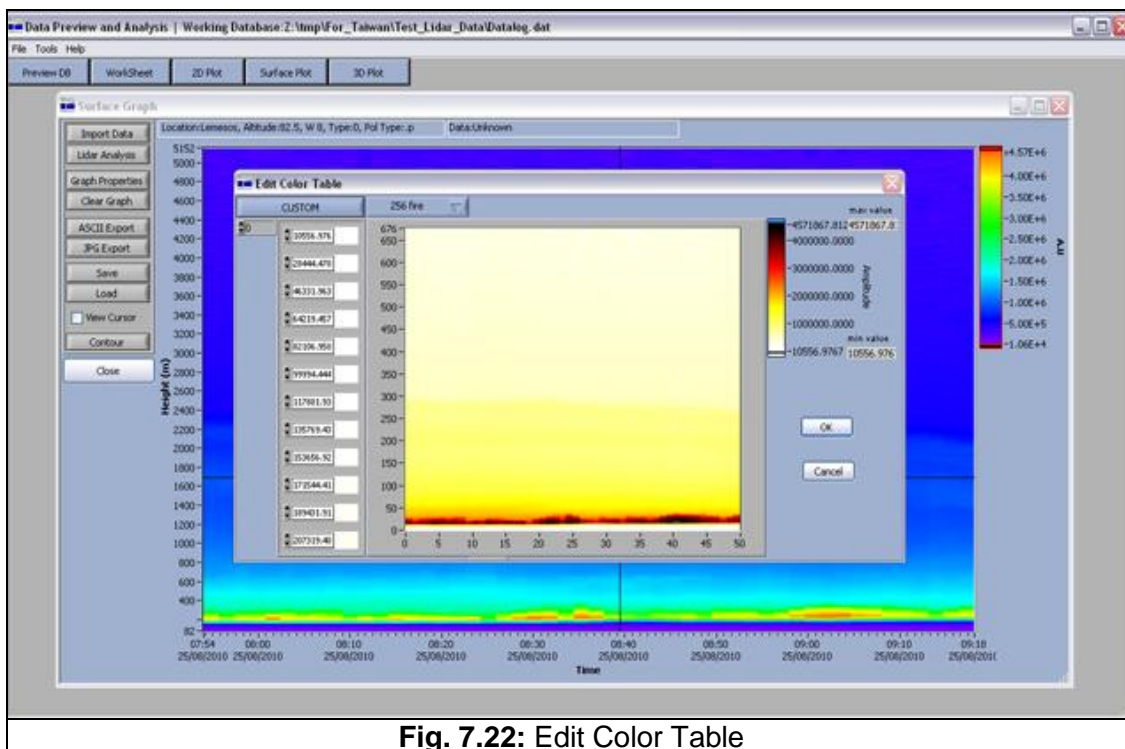
Fig. 7.22: Edit Color Table

16. If required, manually change values of range and signal intensity by clicking on the values on the graph axes and/or on the z scale to the right of the graph.
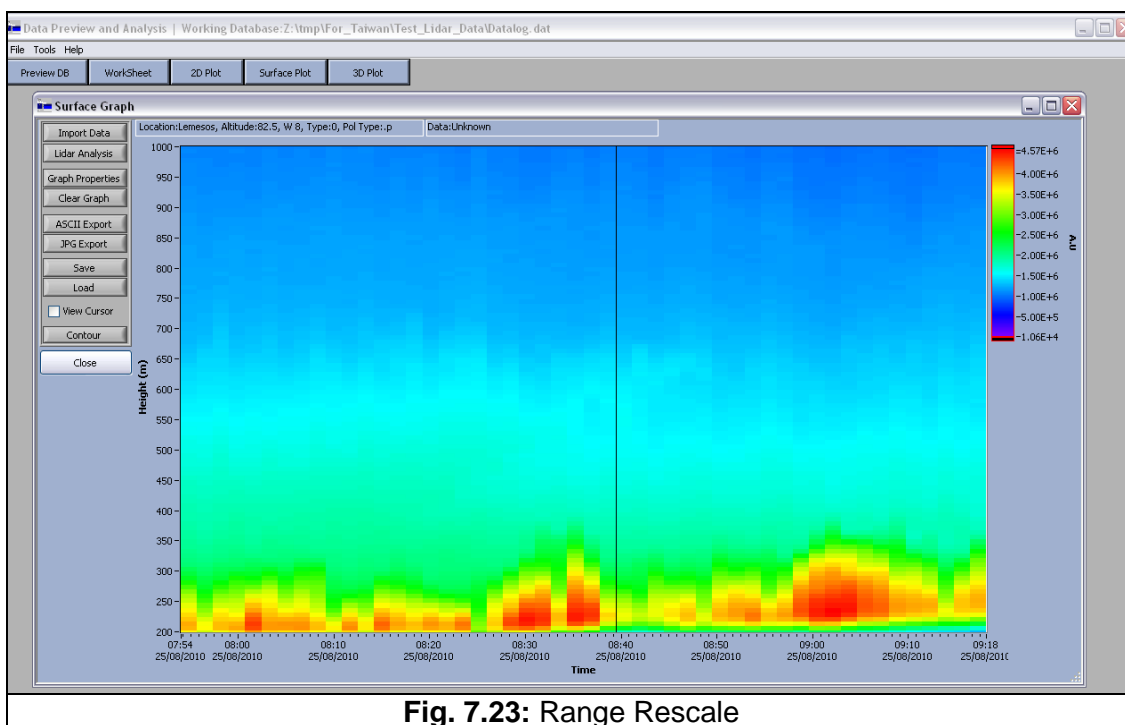
Fig. 7.23: Range Rescale

7.3.2 How to Calculate Backscatter Coefficient

10. Click "2D Plot".
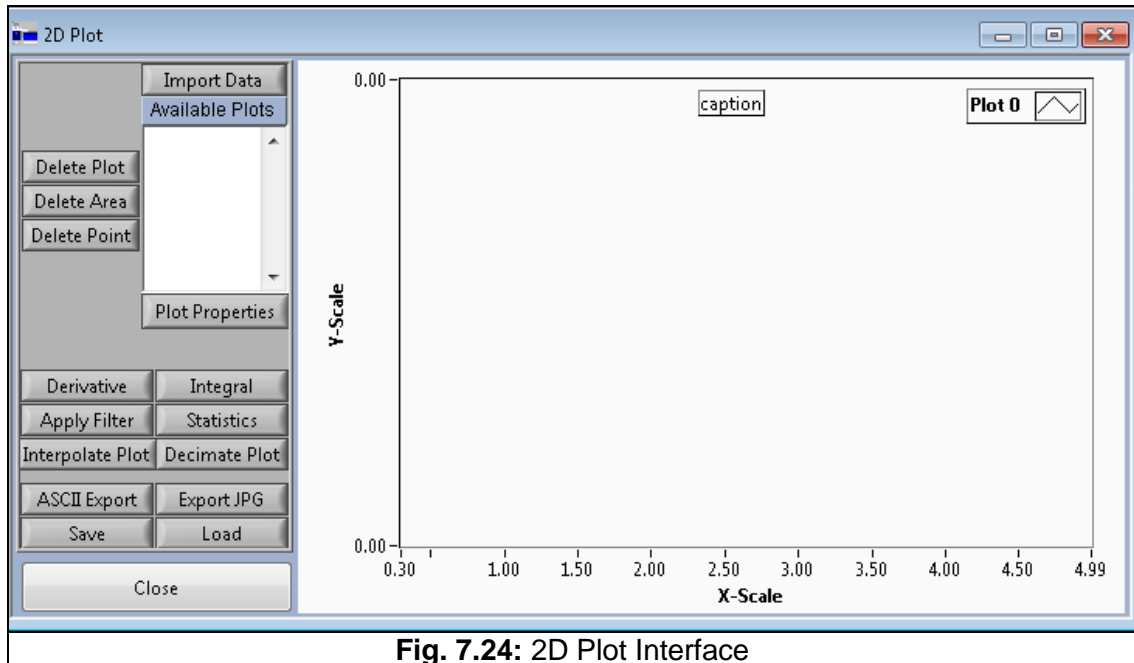
Fig. 7.24: 2D Plot Interface

11. Click "Import Data" and ensure Data Source is set to "From DB" in the drop-down list. Click "OK".
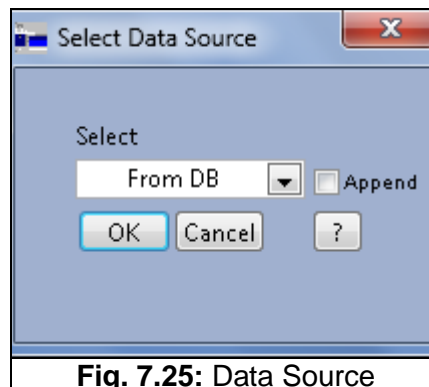
Fig. 7.25: Data Source

12. Select the record and the data you want to calculate aerosol backscatter coef for (as in previous tutorial Fig. 7.12). Make sure that the data files that you select are free of clouds. By holding the shift key you can select multiple files which are going to be averaged if you select it in the next step. Click "Next" and select "Basic Analysis" option (as in previous tutorial Fig. 7.13).

13. Select "355.00.p.AN" dataset. Click "Sum" check box (if you need the average over time). Select "Baer>0" (backscatter aerosols – positive values only) from the light on the right. Click "Add" button and then "OK" button.
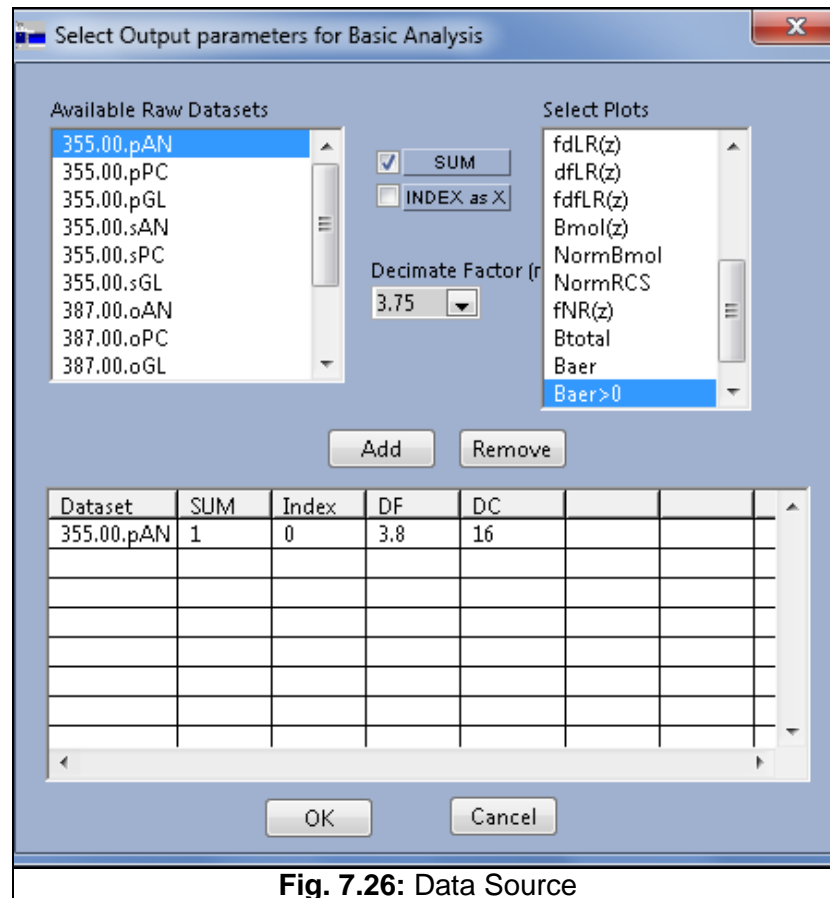
Fig. 7.26: Data Source

14. Define the range of interest with the two red cursors from the top graph (as in previous tutorial Fig. 7.18).

15. Insert the maximum range (altitude in kilometers) for calculating Aerosol Backscatter coef in the Zref (km) box in the top right corner of the window.
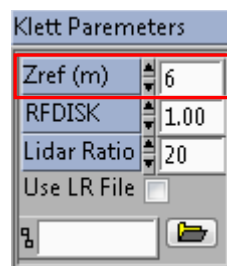
16. Select Bp(z) from the list in order to preview the Backscatter coef on the bottom graph. (Re-scale the graph if required by clicking on any value and typing a new value.)
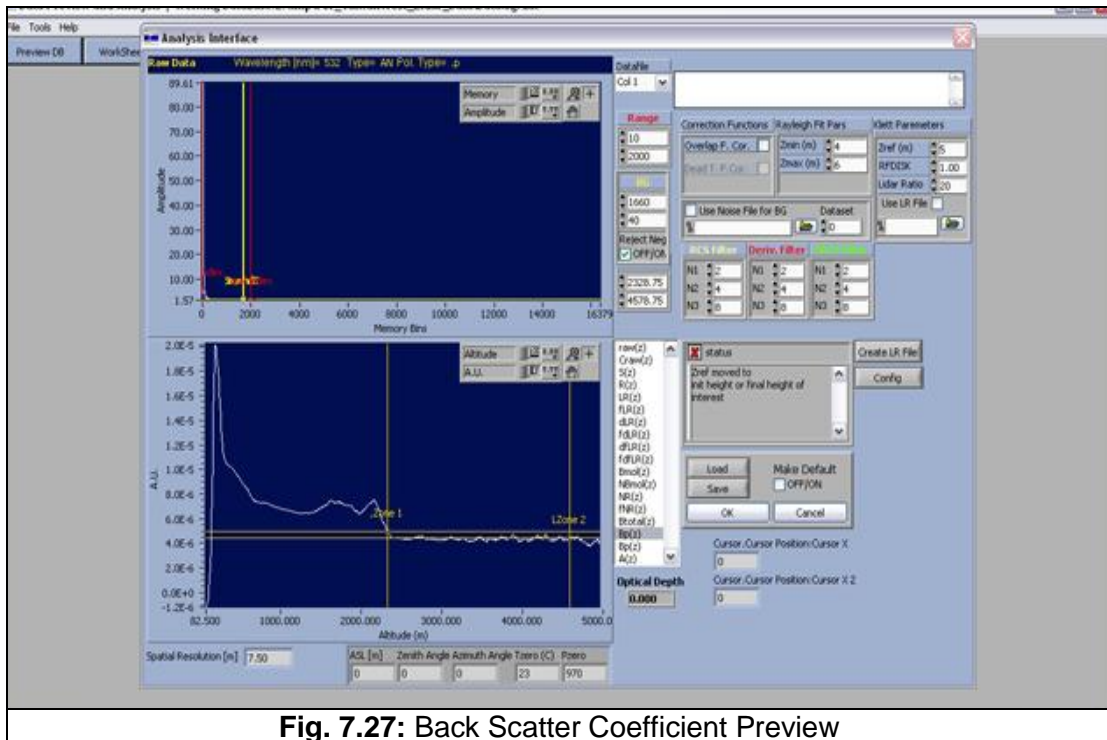
Fig. 7.27: Back Scatter Coefficient Preview

17. In order to check the maximum altitude to which Backscatter coef. can be calculated without errors, click the LR(z) from the list.
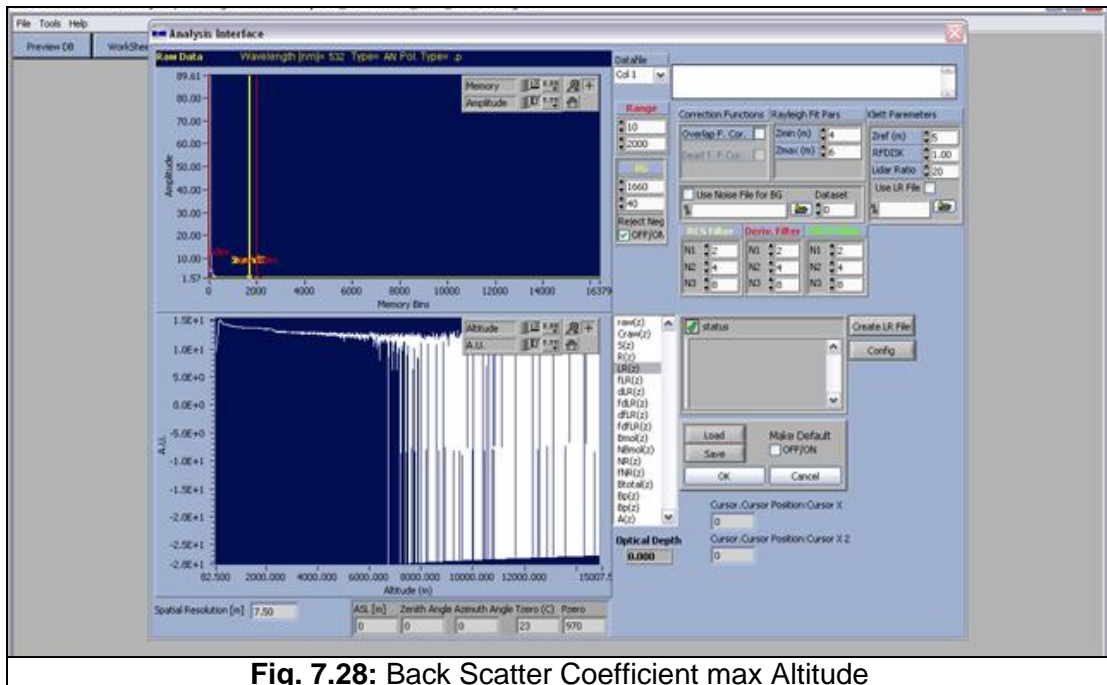
Fig. 7.28: Back Scatter Coefficient max Altitude

18. Locate the altitude where the first negative values appear (for example close to 7 km at Fig. 7.28). **This is the maximum altitude to which you can calculate backscatter coef. without errors for the selected data.**

7.3.3 How to Calculate Aerosol Extinction Coefficient

1. The procedure is the same in the above tutorial *7.3.2 How to Calculate Backscatter Coefficient* until point 16. At this stage, instead of selecting Bp(z) the user has to select A(z).
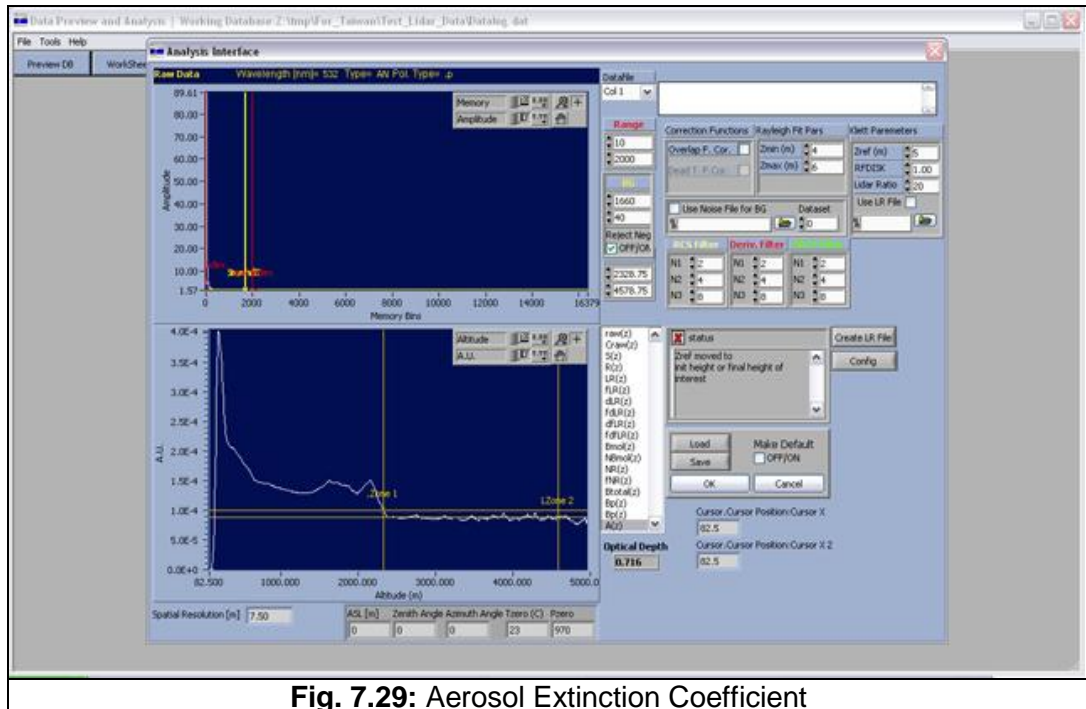
Fig. 7.29: Aerosol Extinction Coefficient

2. Please notice that A(z) depends strongly on the assumption of the Lidar ratio.
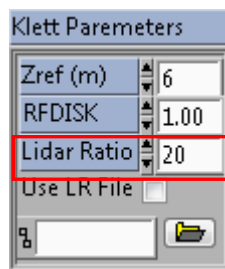
3. Continue with the rest of the procedure as described at the previous tutorials.

7.3.4 How to Check Lidar Alignment

For the fine alignment, the range-corrected Lidar signal (RCS) $P_{cor} = P(z) \times z^2$ is compared to the range corrected exponentially attenuated Rayleigh backscattered coefficient $\beta_{cor} = \beta_{Ray} \times z^2 \times \exp\left(-\int a_{Ray} dz\right)$, at a range interval, which is considered free of any aerosol loading (pure molecular atmosphere). The molecular backscatter and extinction coefficients (β_{Ray} and a_{Ray}, respectively) can be calculated either from a Standard Atmosphere (U.S.S.A 1976)[7] or more accurately from available local radiosonde data. The advantages of this method are that it does not require any extra equipment; it can be performed during daytime or night-time measurements and is very accurate.

Note: clear sky without clouds is important, since in that case the Lidar signal extinct very fast and is not possible to calculate the molecular signal from experimental results.

In Fig. 7.30 a typical Lidar aligned signal 'matching' the pure molecular atmosphere.

Range corrected signal and Rayleigh fit for the evaluation of the optical alignment

Fig. 7.30: Lidar signal 'matching' the pure molecular atmosphere.
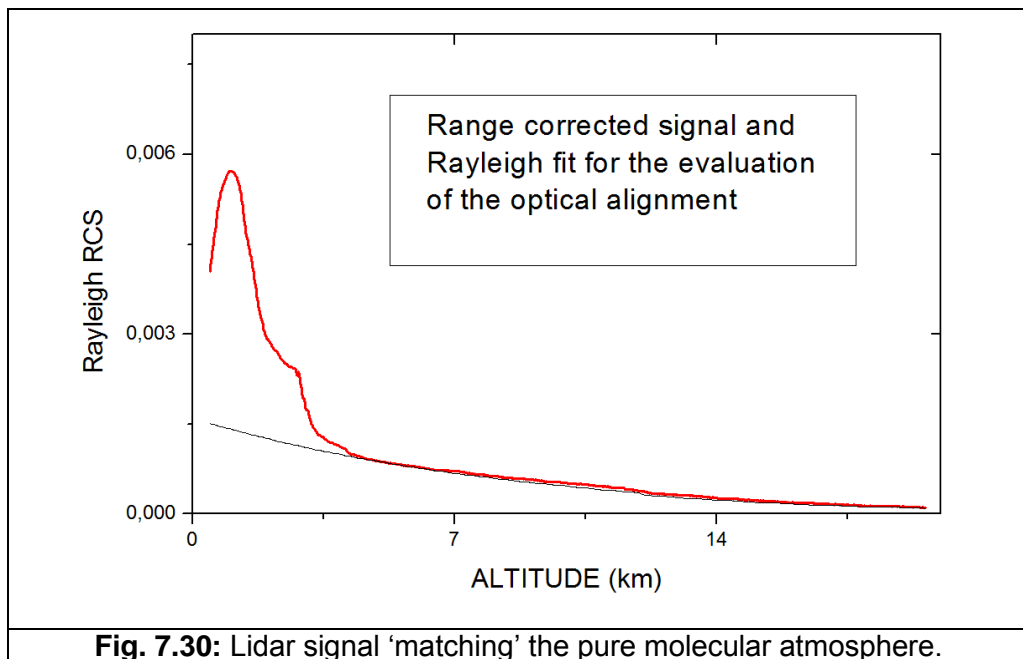
Now in the software NBr(z) is actually the β_{cor} from the equation above and NR(z) is the normalized Range Corrected Signal. RCS(z) is the range-corrected Lidar signal P_{cor}.

$$NR(z) = RCS(z) * \frac{\sum\limits_{Z1}^{Z2} RCS(z) \Big/ Z_2 - Z_1}{\sum\limits_{Z1}^{Z2} \beta_{cor}(z) \Big/ Z_2 - Z_1}$$

Where Z_2 and Z_1 define a range clear of aerosols (From Rayleigh Parameters Section: MinR(km), MaxR(km))

To check the alignment of the Lidar, follow the steps below.

1. Follow the same steps in tutorial *7.3.2 How to Calculate Backscatter Coefficient* until point 13. Then select 355.pPC (Photon Counting Data at 355nm). Select NBmol and fNr(z) parameters to plot (by holding <Ctrl> to select multiple options).

2. Define a range in atmosphere where you assume it is free of aerosols (for example 10 to 14 km at the above image-example).
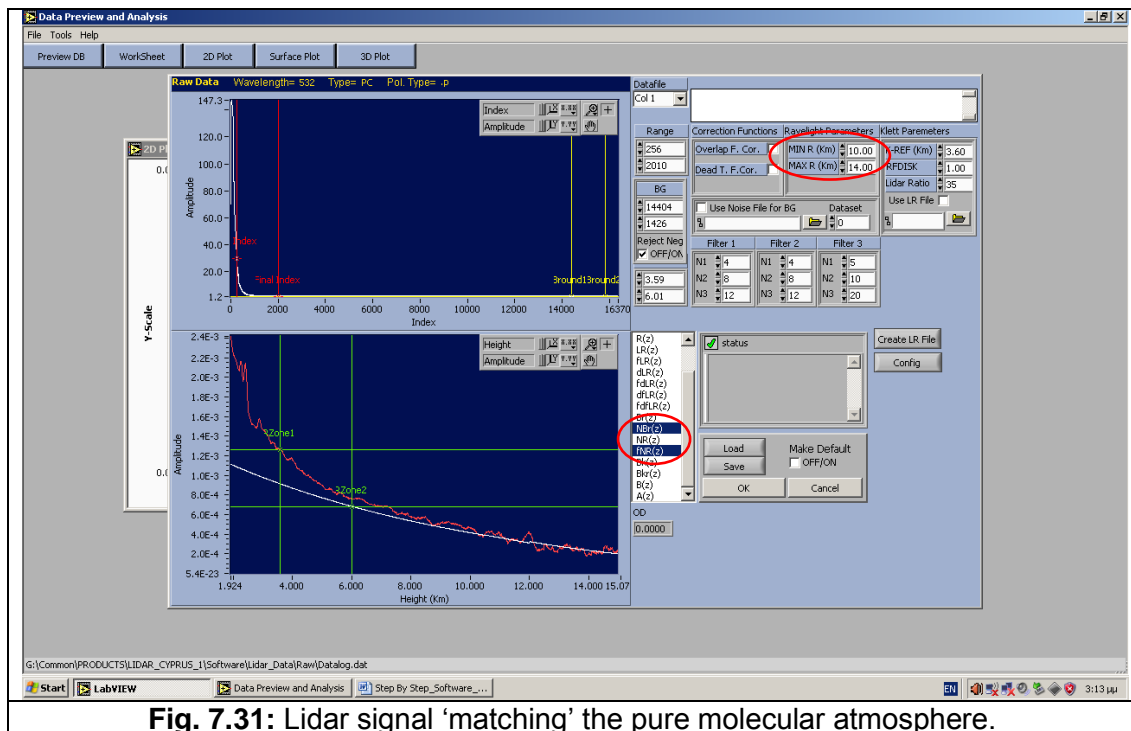
Fig. 7.31: Lidar signal 'matching' the pure molecular atmosphere.

A. You can notice that the Lidar signal fits the molecular atmosphere up to 15 km

B. All the signal bellow 10 km is higher than the molecular atmosphere.

7.3.5 How to Calculate Water Vapor Profiles

Before you go through this document make sure that your system can measure water vapor. To measure water vapor your Lidar should measure 408nm and 387nm Raman backscatter wavelengths.

Intro:

Water vapour profile is calculated by using the following equation:

$$m(z) = \frac{P_{\lambda,H_2O}(z)}{P_{\lambda,N_2}(z)} K = \frac{P_{\lambda,408}(z)}{P_{\lambda,387}(z)} K$$

eq.1

Where K is the overall system calibration constant, and P(z) is the range corrected signals.

The overall system calibration constant (K) can in principle be deduced from the known Raman cross sections and the measured properties of the spectrometer used, but in practice it is determined from the comparison of the Lidar measurement with critically evaluated data from a radiosonde ascent. In the calculation of the transmission ratio, there is an effect of the particle extinction which can be negligible on the mixing ratio determination under clear air conditions but must be taking into account if an optically dense medium like a water cloud is present.

A new and easier way for the calculation of water vapor profile have been developed, which is embedded in the software. Here is shown a tutorial how to plot a 2D graph. If you want to display the temporal evolution of water vapor profile, open a surface graph, or if you wish to analyze and do additional calculation open a worksheet.

1. Follow the same steps in tutorial *7.3.2 How to Calculate Backscatter Coefficient* until point 12. tutorial, **but** select water vapor Analysis in the "Type of Analysis" dialog shown in Fig. 7.13. If the record set you selected doesn't contain any Water Vapor info (channel 408nm) the "water vapor analysis" button will not be available.

2. Then select 355.pPC (Photon Counting Data at 355nm). Select NBmol and fNr(z) parameters to plot (by holding <Ctrl> to select multiple options).

3. A new interface appears. Using this interface is straight forward and easy. Depending on the detected channels and the type of detection several options can appear at the Data Type list box at the top left corner of the window. For example if your system detects only Photon Counting signals for 408nm channel and only Photon Counting signals for 387nm channel. Then you have only one option to

calculate water vapor profile by using only Photon Counting signals. If for example your system detects Analog and Photon Counting signals for 387 nm then you have two options to calculate the water vapor profile. One by using only the photon counting signals for both channels and one by using Photon Counting for 408 nm channel and Glue data for 387nm (about Gluing please take a look at Licel manual and at paragraph *7.3.7 How to Glue Analog and Photon Counting signals*).
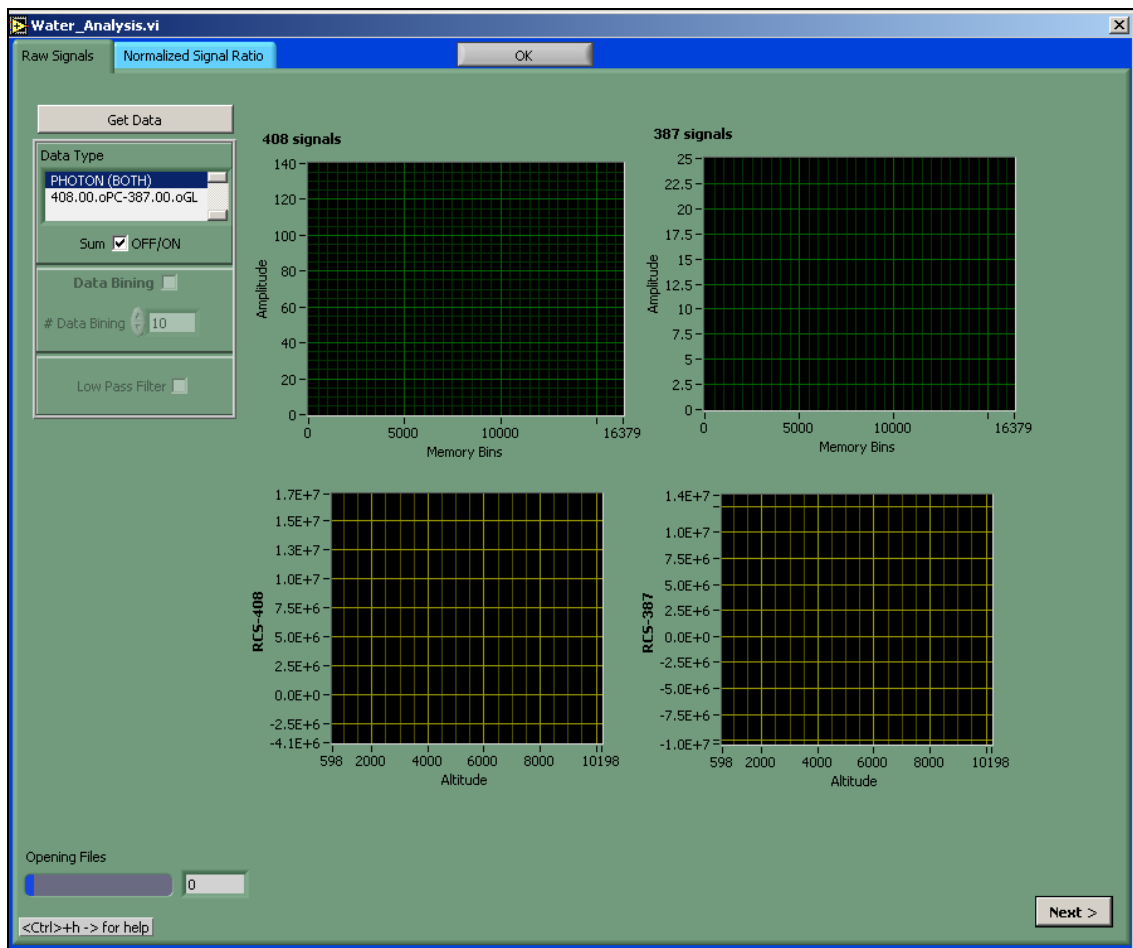
Fig. 7.32: Water Vapour Analysis Interface – "Raw Signal" Tab

4. Click on the "Sum" check box to average all the selected datafiles. In that case the temporal resolution decreases but the signal to noise ratio is getting much better so the effective range of the profile will be increased.

Note: For surface plot (temporal evolution) this options is deactivated.

5. After that click on the 'Get Data" button and a new interface will appear (Data Pre-process) where you can subtract the background and select the range of interest (by using the two red cursor from the top graph). This process will be done twice. One for 387nm and one for 408. After that the range corrected signal will be calculated for both channels.

Note: Take into consideration that both Range Corrected signal is calculated at the same range of interest. An easy way to do that is to click on the "Make Default" check box and then on the Save button. The next time that this interface will appear will have the same range of interest.
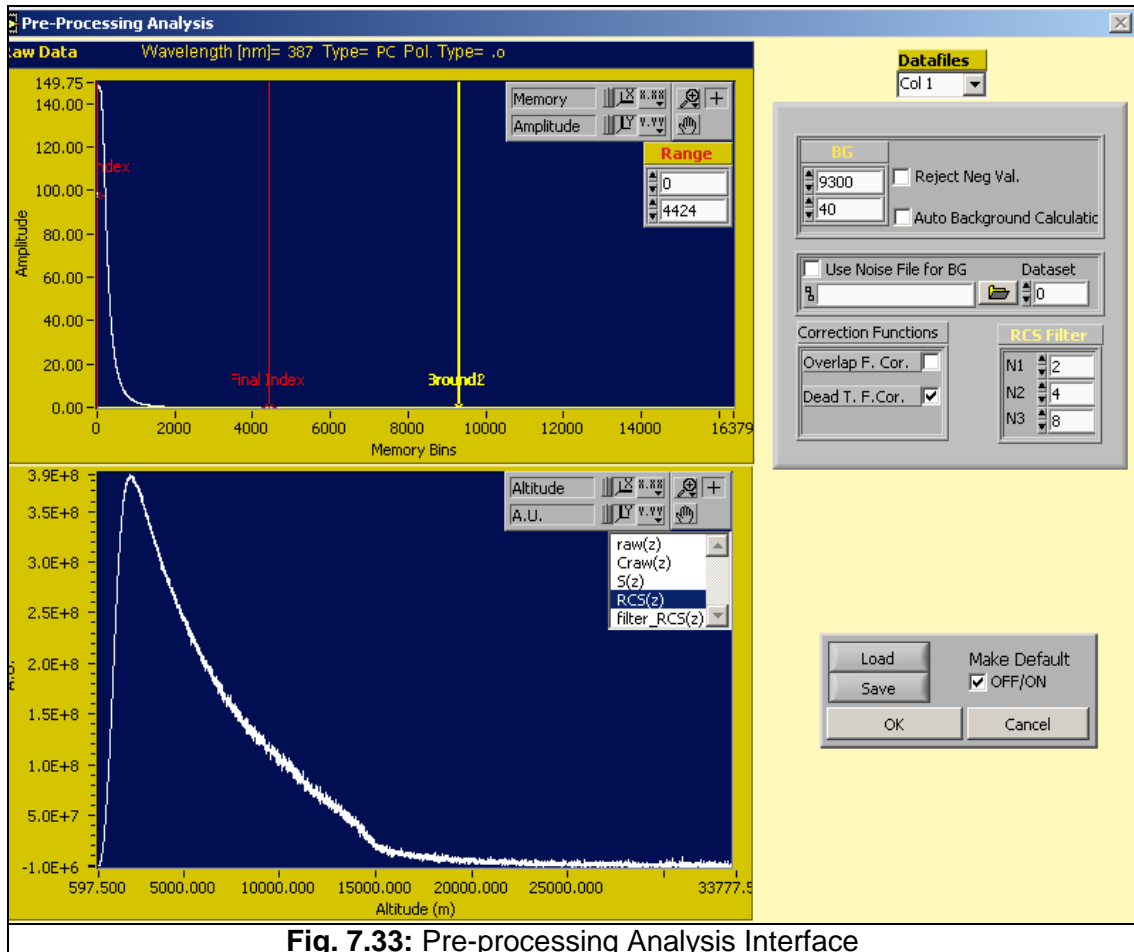
Fig. 7.33: Pre-processing Analysis Interface

6. When both of range corrected signals have been calculated the Pre-processing Analysis Interface closes and the program returns to the main interface. The graphs are updated and you can preview all in one the 387nm and 408nm - Raw and RCS signals. Click on the "Next" button or just the Normalized Signal Ratio Tab.

7. There are two graphs at this Tab. The top one shows the signal ratio while the second one shows the calculated water vapor profile. Use the two yellow cursors from the top graph in order to zoom in the range where you ratio profile is strong enough to calculate the water vapor profile.

Fig. 7.34: Water Vapour Analysis Interface – "Norm Signal Ratio" Tab
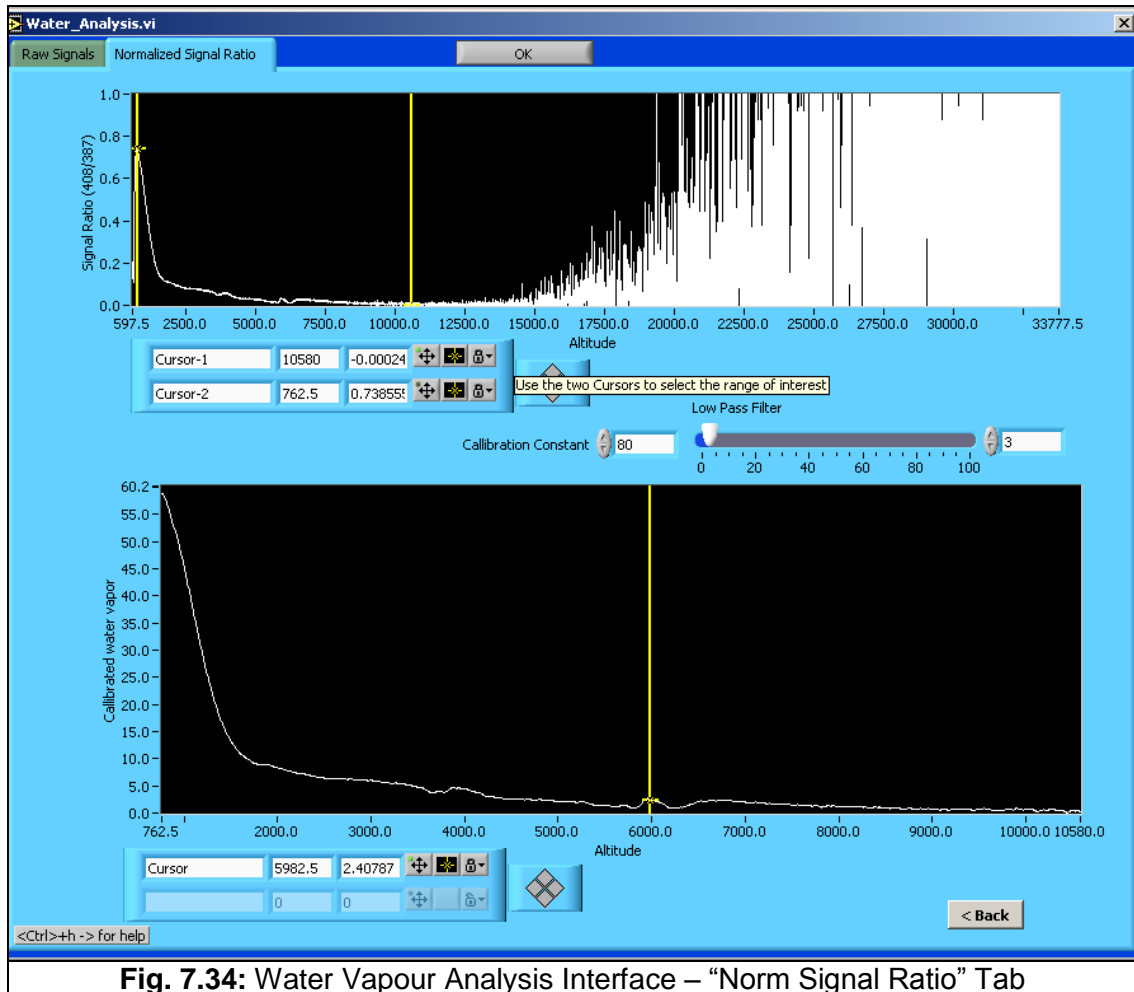
8. At this Tab you can adjust the calibration constant or even to apply a low pass filter at the final product (zero means no filter). Finally click on the OK button located at the top of this interface.

Note: In cases that the signal to noise ratio is to low you can try improving it by data binning of raw signals or even to apply a low pass filter. You can do that at the "Raw Data" tab.

How data binning works:
Every value of the input signals corresponds to 7.5 metes (one bin) by calculated the average signal of a number of sequential bins (number of data binning) then the resulting signal has a special resolution of 7.5*(number of data binning).

7.3.6 How to subtract the Background

Intro:

Background noise is due to atmosphere (solar or lunar background light) and due to electronic noise.

There several methods for removing the background signal from a Lidar signal. The most common method is to locate a range that there is no Lidar signal and calculate the mean value at that range. Then this value is subtracted from the Lidar signal. Usually this range is at the far range (very high altitude) or at the very first meters if you Lidar supports pre-triggering.

However using always very high altitudes is not the best practise. Experience shows that some times when the signal (analog) is two weak or decreases very fast (after a cloud) suffers from no linearity. In that case for calculating the background is better to select a range where the signal is quite stable and the mean value at that range is minimum.

Of course in that case the effective range of the signal is restricted until that range.
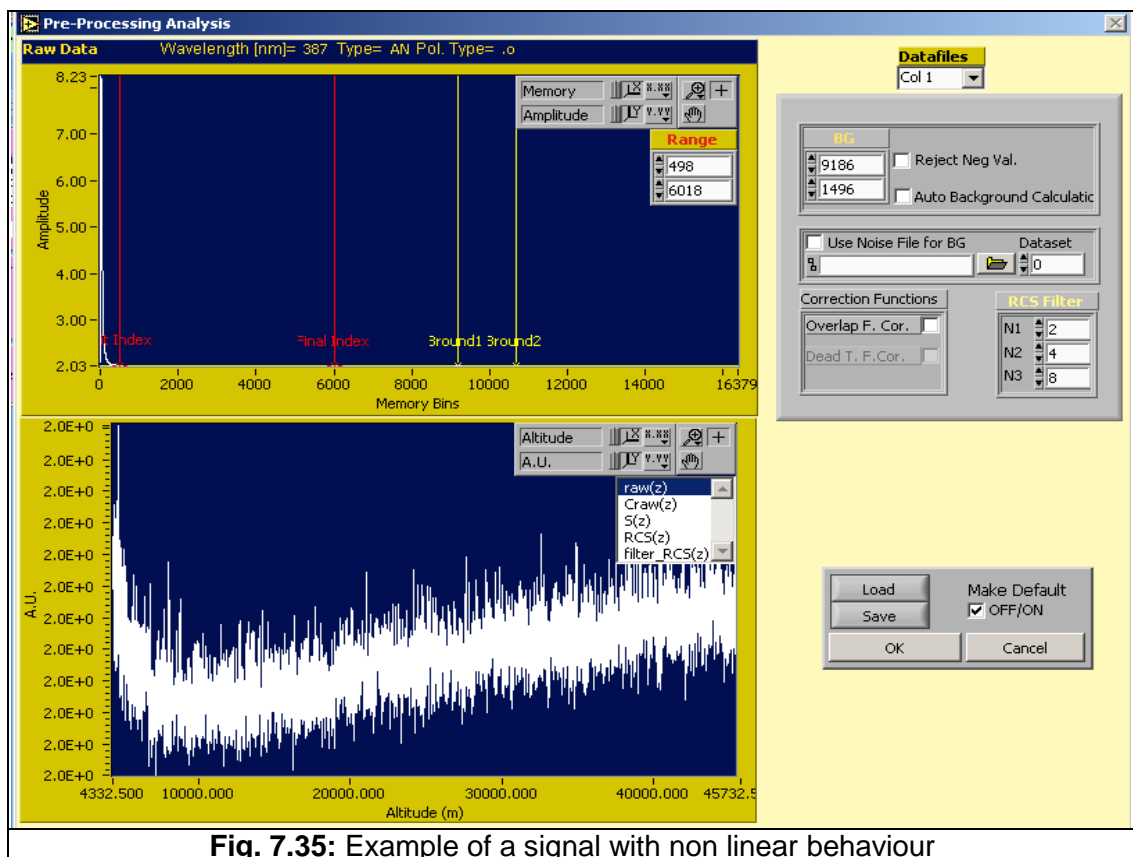
Fig. 7.35: Example of a signal with non linear behaviour

In the case it is suggested to locate a range where the signal is minimum and to calculate the background mean value at that range (you can do that easily by using the two red cursors to zoom.
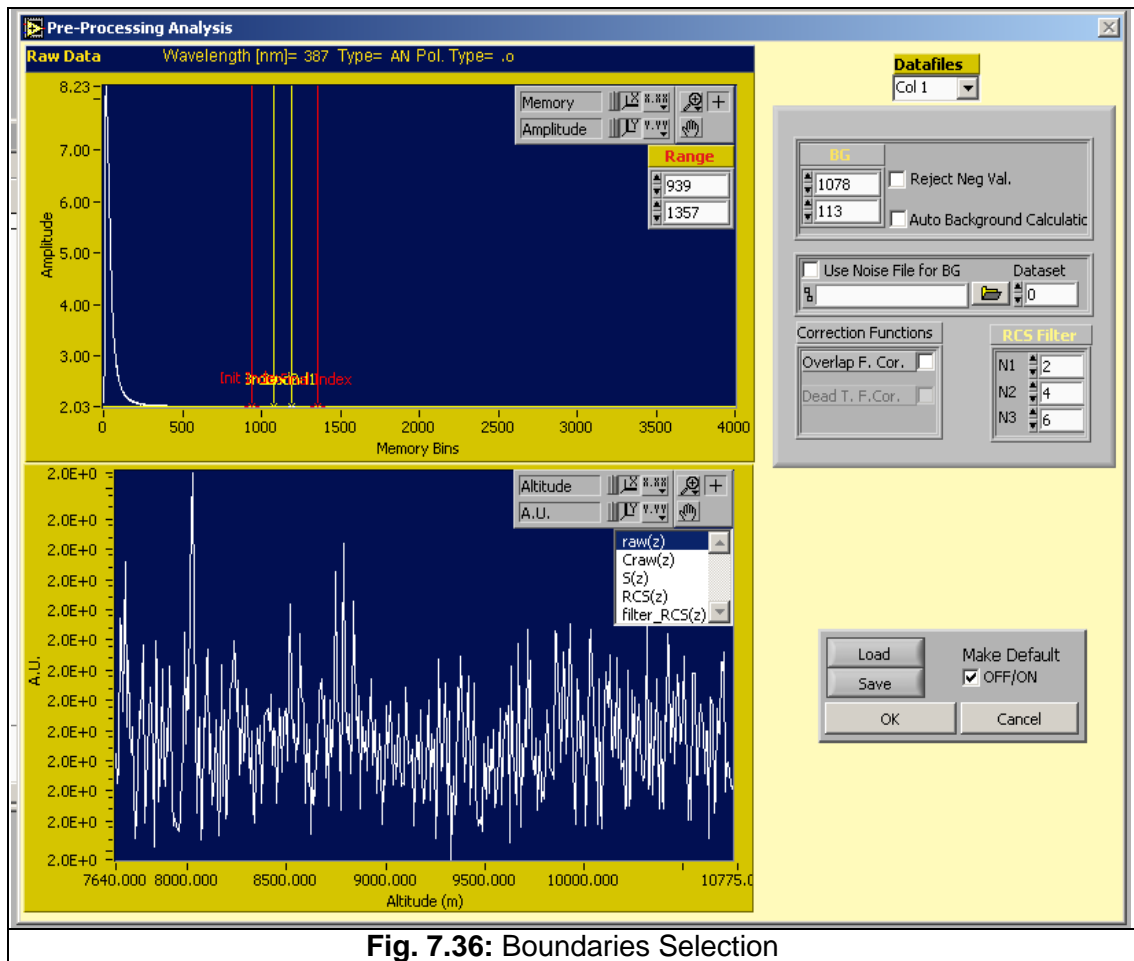
Fig. 7.36: Boundaries Selection

Then place the two yellow cursors somewhere in between (as shown in Fig. 7.36) in order to calculate the mean value.

For analog measurements it is suggested to use a background profile to avoid ADC slopes or electromagnetic interference taken as real atmosphere response. A background profile can be taken by covering the telescope and starting a normal measurement. If no light enters through the telescope the only thing that is measured is the noise from the electronics. Alternatively you can use an external trigger to initiate a measurement without using the laser at all. In this case you measure the electronics' noise and the sun's radiation.

Make sure that you know which measurement it is so that you can select it afterwards at the software interface in order to subtract the background profile (Is called noise file) from the signals that you want to work.
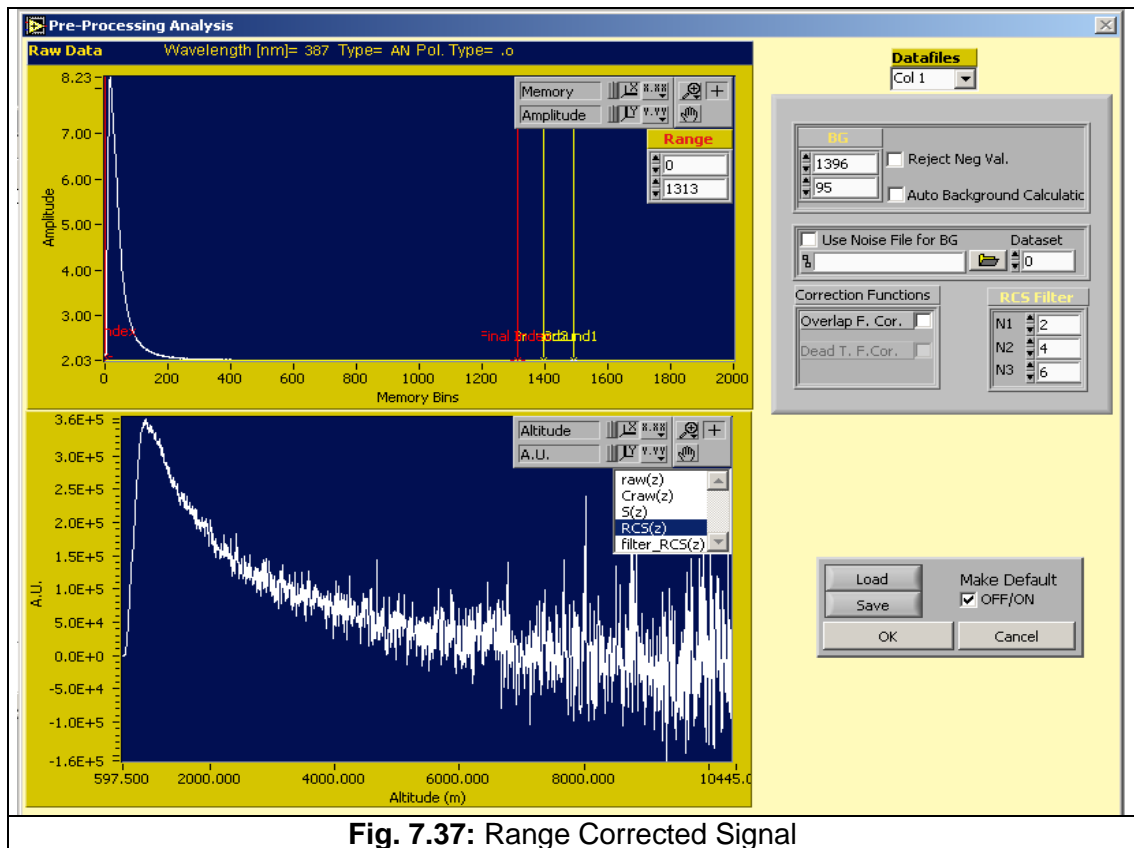
Fig. 7.37: Range Corrected Signal

You can see how the range corrected signal (RCS) looks in Fig. 7.37.

7.3.7 How to Glue Analog and Photon Counting signals

Intro:

Depending on your Lidar configuration many detected signals are recorded simultaneously by two methods; Analog and Photon Counting method.

The combination of both signals allows using the high linearity of the analog signals for strong signals (near fields) and the high sensitivity of the photon counting for weak signals (far fields). The idea is to combine the signals, at a region where both signals (analog and photon) are valid and have a good signal to noise ratio. For a typical case this region extends from 0.5 to 20 Hz in photon counting mode.

Before we glue signals the photon counting data should be dead time corrected (Raymetrics software does that). There are two typical dead-time scenarios, while the Licel photon counter can be best described as nonparalyzable.

In that case the dead time corrected photon counting signal is given by the following equation:

$$S = \frac{N}{1 - N * \tau_d}$$

Where S is the corrected counties, N is the observed count rate and τ_d is the system dead time. Raymetrics software uses a value of 260 MHz for τ_d

For detailed discussion of the theory of photon counting dead time correction please see the following paper: D. P. Donovan, et.al. "Appl. Opt. 32, 6742-6753 (1993).

The gluing

In the region where both signals are valid (between the lower toggle frequency – typical 0.5 MHz and the upper toggle frequency – typical 20 MHz) one seeks the linear regression coefficient to transfer the analog data into photon counting data.

After transferring analog to photon the scaled analog signal is used above the upper toggle frequency and the photon counting signal

When gluing is possible:

The peak value of the dead time corrected photon counting signal is above the maximum toggle frequency (save values for maximum toggle frequency is between 10 MHz and 70 MHz for the dead time corrected signal) and the background of the dead time corrected photon signal is below the minimum toggle frequency.

If the signal is too weak (maximum peak of photon counting signal less than 20 Hz) use only photon (gluing is not useful)

If the signal is too strong (background of the dead time corrected signal more than 20 MHz)

Raymetrics software

The first step is to figure out until what range the analog signal has good signal to noise ratio. A suggested way is to remove the background noise and then to figure out until what point the signal is 2 to 5 times more than LSB. The value of LSB (The minimum change in voltage required to guarantee a change in the output code level is called the least significant bit (LSB) voltage. The resolution Q of the ADC is equal to the LSB voltage and depends on the full range of the pre-amplifier that you have select during the measurements. There are three possible values for the full range, 500, 100 and 20 mV and the LSB is $500/2^{12}$=122 mV, $100/2^{12}$=24.4 mV, $20/2^{12}$=4.8 mV.

Let assume that the maximum memory bin that the signal is 5 times the LSB is Xa.

In addition let assume that the Photon Counting signal has a value of 50 MHz at memory bin Xp. If Xp < Xa then gluing is possible. If not then gluing is not suggested.
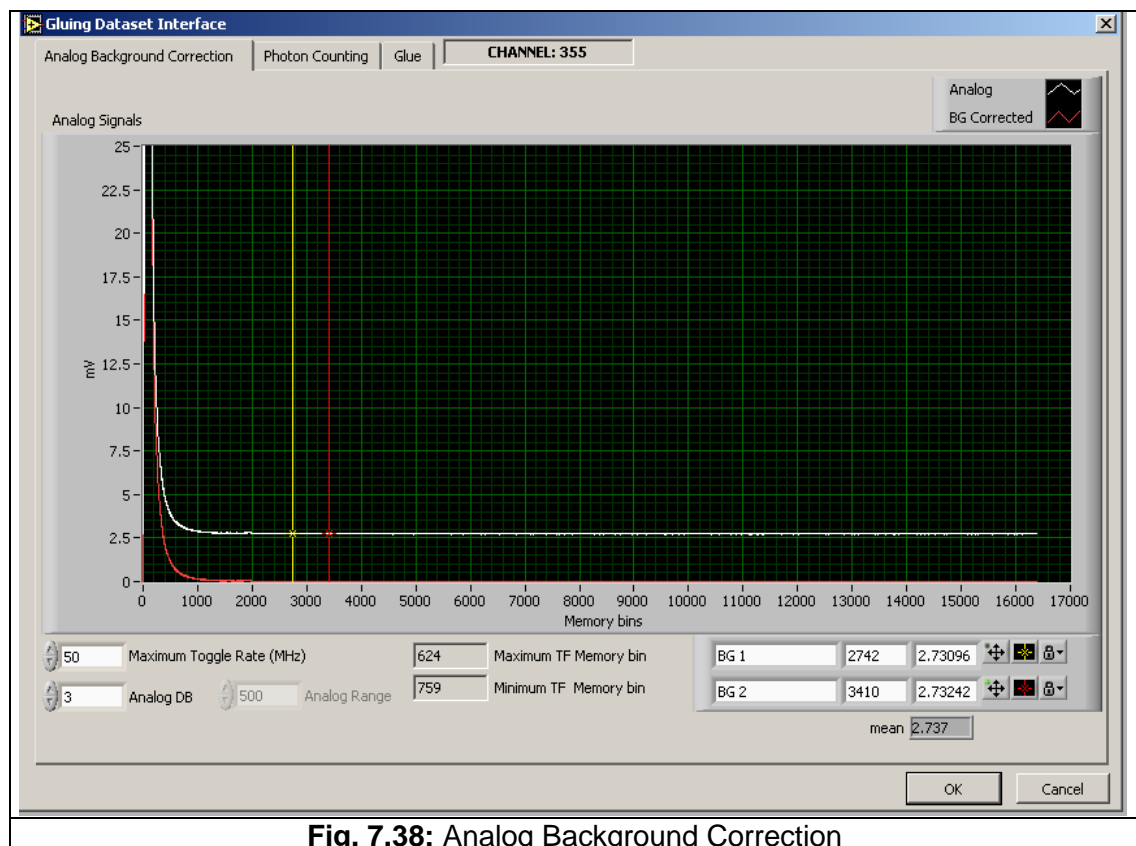
Fig. 7.38: Analog Background Correction

Fig. 7.39: Photon Counting and Dead time photon counting

Fig. 7.40: Glued Signal
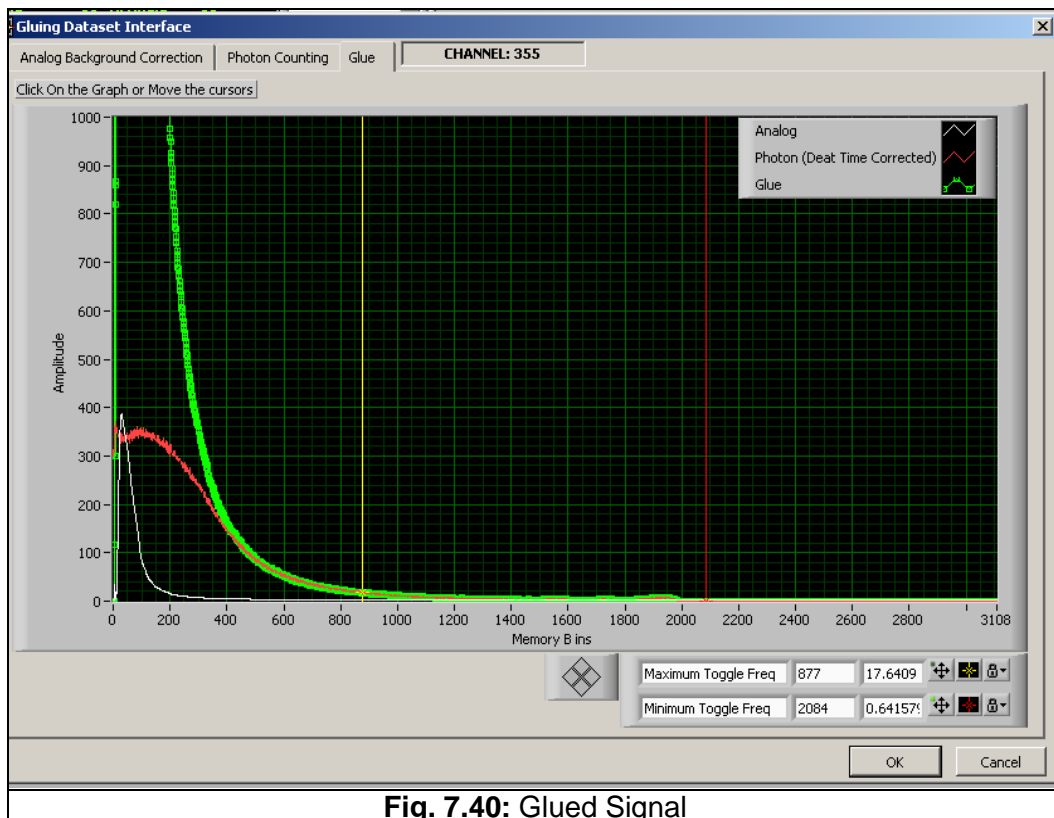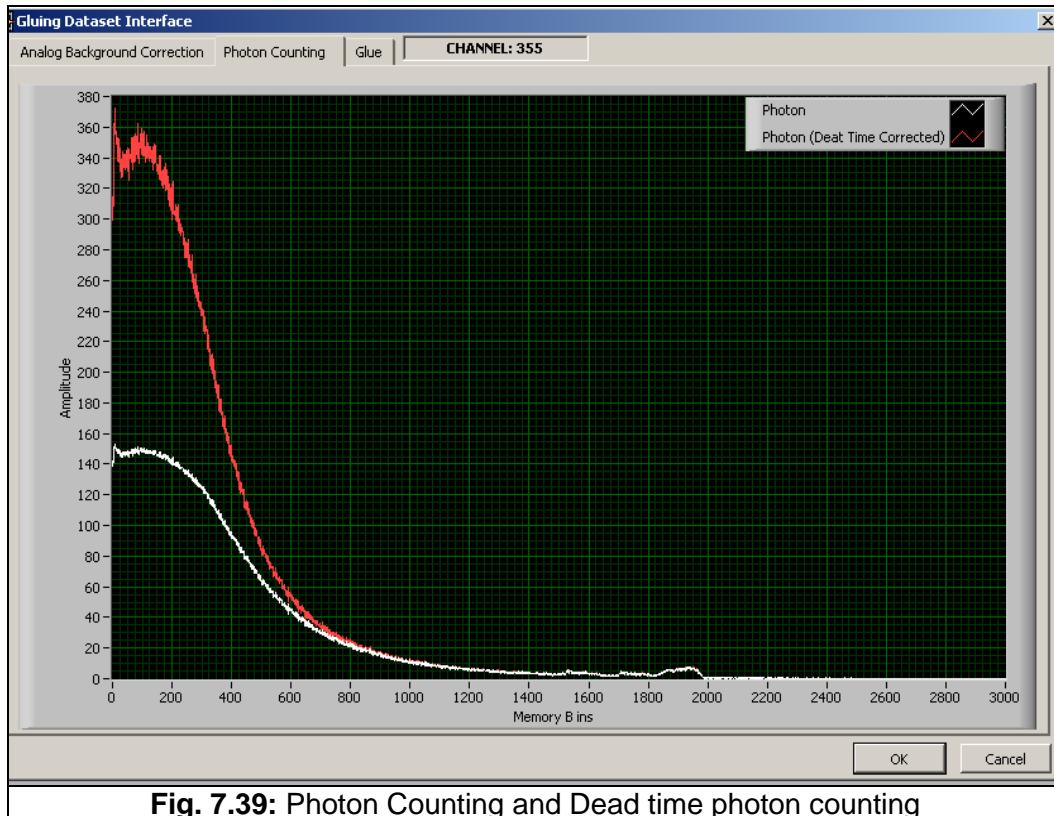
Use the two cursor to change Maximum or/and Minimum Toggle Frequency (if you want), or just click on the graph and then OK button.

7.3.8 How to make a 3D Graph

In many studies analysts are interested in structures that usually come from clouds. In most of the cases these are represented in a surface plot that shows the time evolution of the phenomenon. There is another way to illustrate the measurement by plotting the data in a 3D graph which can be rotated, panned and zoomed. This may give a better understanding of the structures. This tutorial will teach you how you can make such a plot.

1. Preview the database and find a record that has interesting cloud structures. Close the Preview and click the "3D Plot" Button.

3D Plot

2. A new interface appears with an empty 3D Graph. Click on the *Insert Data from DB* button (as you can see in Fig. 7.41)
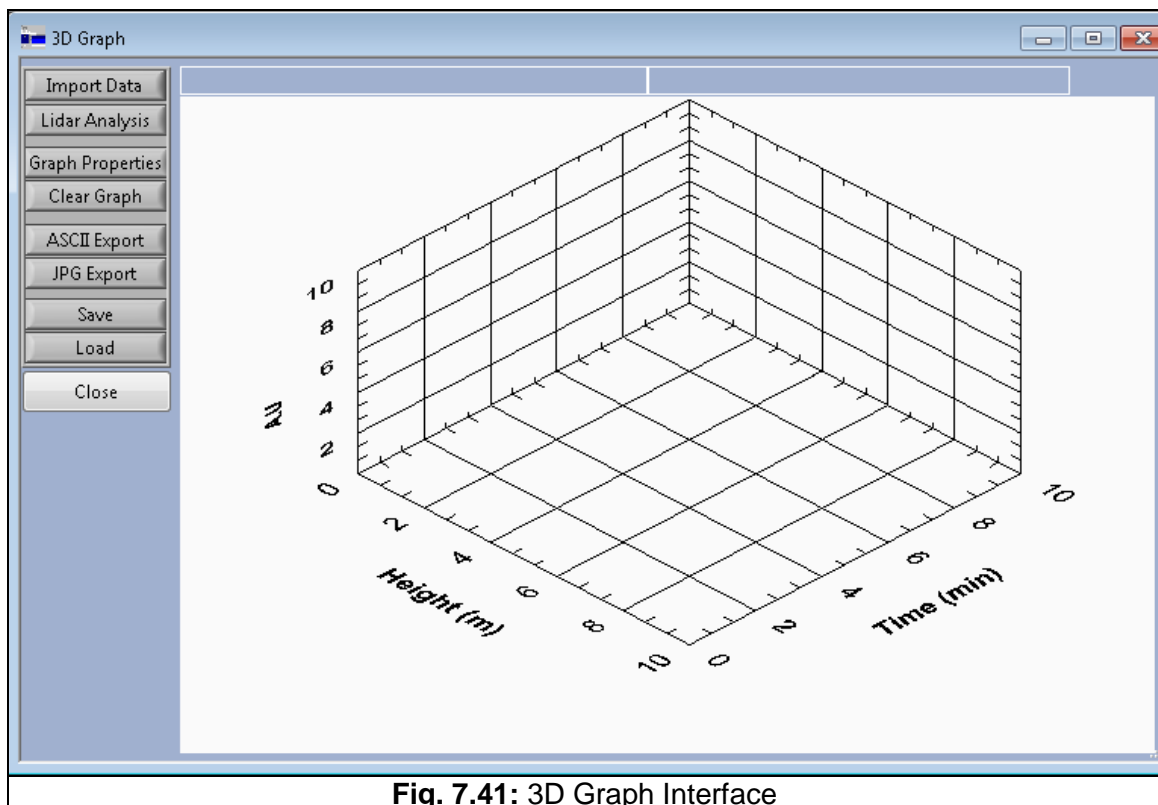
Fig. 7.41: 3D Graph Interface

3. Follow the same procedure explained earlier in paragraph *7.3.1 How to Plot Data* to make the analysis and plot. Keep in mind that since you are interested in the area where the structures are you can select with the red cursors the boundaries of the graph from the beginning. This way the plot is going to be focused where you want.

Note: In the analysis interface you can see all the files that are selected for plotting if you select the data file in the list box right next to the raw signal graph.

Datafile
Col 1
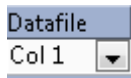
4. Once you complete the analysis you can have an image that looks like the one in Fig. 7.42

Fig. 7.42: 3D Plot
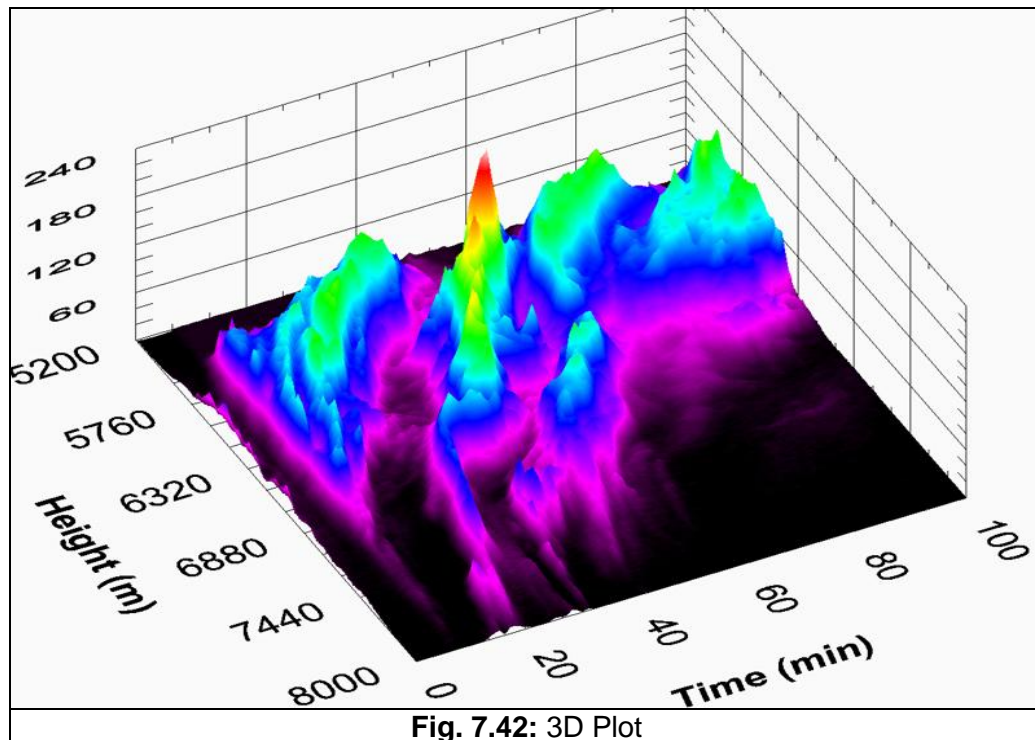
5. Hold the mouse left button down and drag to rotate the graph.

6. Hold "Alt" key with Left Mouse and drag to resize.

7. Hold "Shift" key with Left Mouse and drag to pan.

You can modify the properties of the graph at "Graph Properties" or save the graph as an image at "JPG Export".

7.3.9 How to use soundings from global model data

Accurate radiosonde data from model analyses (and forecasted data), are much better than data calculated with standard atmospheres. You can find this information for free at the internet. Here is presented where you can find and how you can use the data.

1. Load the website: http://rucsoundings.noaa.gov/, to get model data for every location on earth on a 0.5° grid.
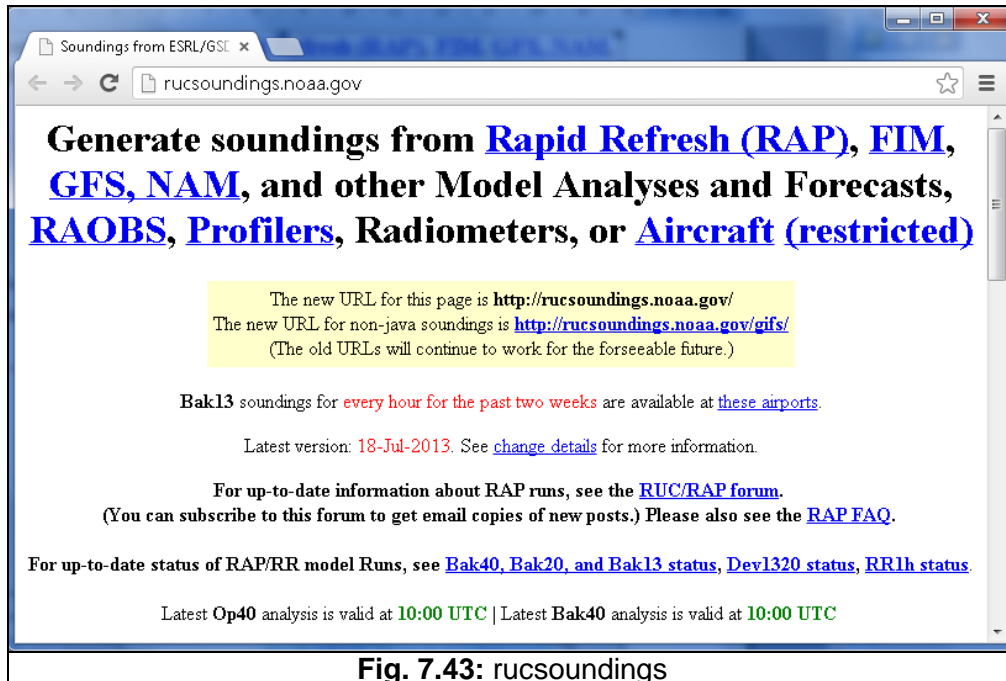
Fig. 7.43: rucsoundings

2. Select, FIM, 24, 12 or 8 for No. of Hours, your lat and lon (like: 34.7, 33.07)

Fig. 7.44: rucsoundings

3. Click on the ASCII Format (GSD).

4. At the new page that will appear use your mouse to select the data that you want like below

```
FIM analysis valid for grid point 12.5 nm / 196 deg from 34.7,33.07:
FIM       0      1     Apr    2011
   CAPE      0    CIN      0  Helic     0      PW      0
      1   23062  99999  34.50 -33.00  99999  99999
      2   99999  99999  99999     68  99999  99999
      3          34.7,33.07                12      kt
      9   10061     88    201     71     45     13
      5   10019    123    205     57     46     14
      5    9946    186    207     35     48     15
      5    9846    271    211     10     52     16
      5    9735    367    212    -10     55     16
      5    9614    472    210    -29     58     17
      5    9485    586    204    -44     61     17
      5    9350    708    197    -61     64     16
      5    9210    836    191    -77     67     15
      5    9066    969    184    -93     69     14
      5    8921   1106    176   -108     71     13
      5    8775   1245    166   -123     72     12
      5    8631   1385    157   -134     72     10
      5    8489   1525    150   -139     72      9
      5    8349   1663    141   -139     73      8
      5    8212   1802    131   -136     77      7
      5    8078   1939    121   -131     82      6
      5    7946   2077    111   -129     90      5
      5    7816   2213    100   -129    103      4
      5    7688   2350     89   -129    118      4
      5    7561   2486     77   -130    137      4
      5    7437   2626     66   -130    157      4
      5    7163   2900     41   -127    187      5
      5    6537   3621    -10   -131    230     11
      5    5811   4621    -85   -179    245     19
      5    5087   5696   -168   -267    252     19
      5    4327   6862   -267   -359    249     27
      5    3571   8197   -382   -426    244     35
      5    2910   9487   -499   -548    245     40
      5    2588  10218   -560   -615    246     47
      5    2464  10554   -579   -647    247     49
      5    2352  10852   -594   -677    249     52
      5    2251  11133   -607   -697    251     54
      5    2153  11421   -615   -705    253     55
      5    2055  11719   -619   -712    254     56
      5    1954  12034   -617   -718    255     58
      5    1851  12373   -612   -722    255     62
      5    1747  12730   -604   -727    255     66
      5    1640  13125   -595   -733    256     68
      5    1510  13648   -592   -735    257     67
      5    1354  14347   -602   -746    256     63
      5    1196  15135   -617   -790    255     57
```

Fig. 7.45: Results page

5. Copy the data (Select and right click to copy)

6. Open a text editor and past the data. Save the file with a name that you want (like Road_Data.txt). The columns that we are interesting for are the column 2 (pressure in tenths of milibars), column 3 (altitude in meters) and the column 2 (temperature in tenths of Celsius). Raymetrics software needs to read an ASCII file with three columns separated by tab.

a. First Column: Altitude in meters

b. Second Column: Temperature in K

c. Third Column: Pressure in hPa.

7. Now we need to convert the Road_Data.txt file to another ASCII formatted file suitable to be read by Raymetrics software. To do so locate the Rm_Utils.llb and run the **ROAD_GSD_to_Ascii_Format.vi**.

8. Select the file that you want to convert e.g. Road_Data.txt.

9. The software will ask to save the formatted data to another file. Then give another filename for the formatted file eq. Road_Data_formated.txt (if you like you can overwrite the original one).
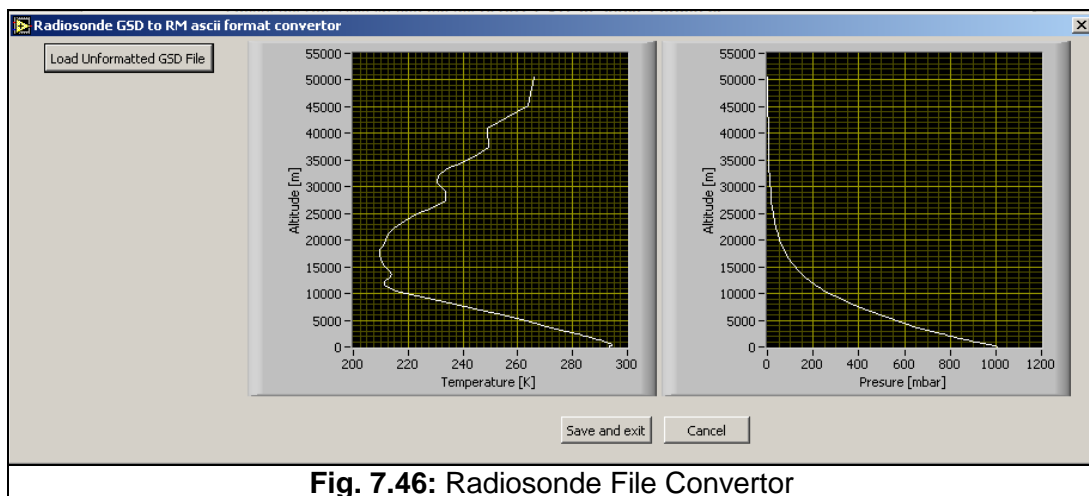
Fig. 7.46: Radiosonde File Convertor

10. Now at the analysis interface you can click on the Config button
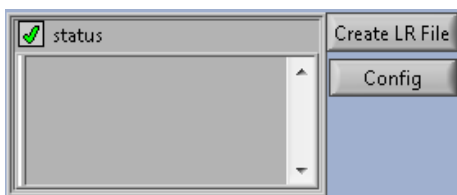
11. Then click on the Use Radiosonde Check box and then load the formatted ASCII file by clicking on the folders icon. Then Click ok.
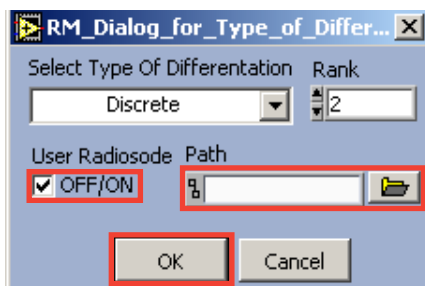
7.4. SCANNING DATA ANALYSIS

As previously noted the scanning data are usually too many to handle in a traditional way. For this the user needs software that will automatically recognize the type of the scan, the angles and then manipulate them to make different types of analysis.

Furthermore the representation of scanning data is also very important to be in a comprehensive form. Through a series of freeware and in combination of scripts written from Raymetrics, the user ca easily extract the data to Google Earth files.

7.4.1 How to use the Advanced Viewer Extra

The advanced viewer extra is a program used for the analysis of scanning data. Below is a short tutorial on how you can use this program.
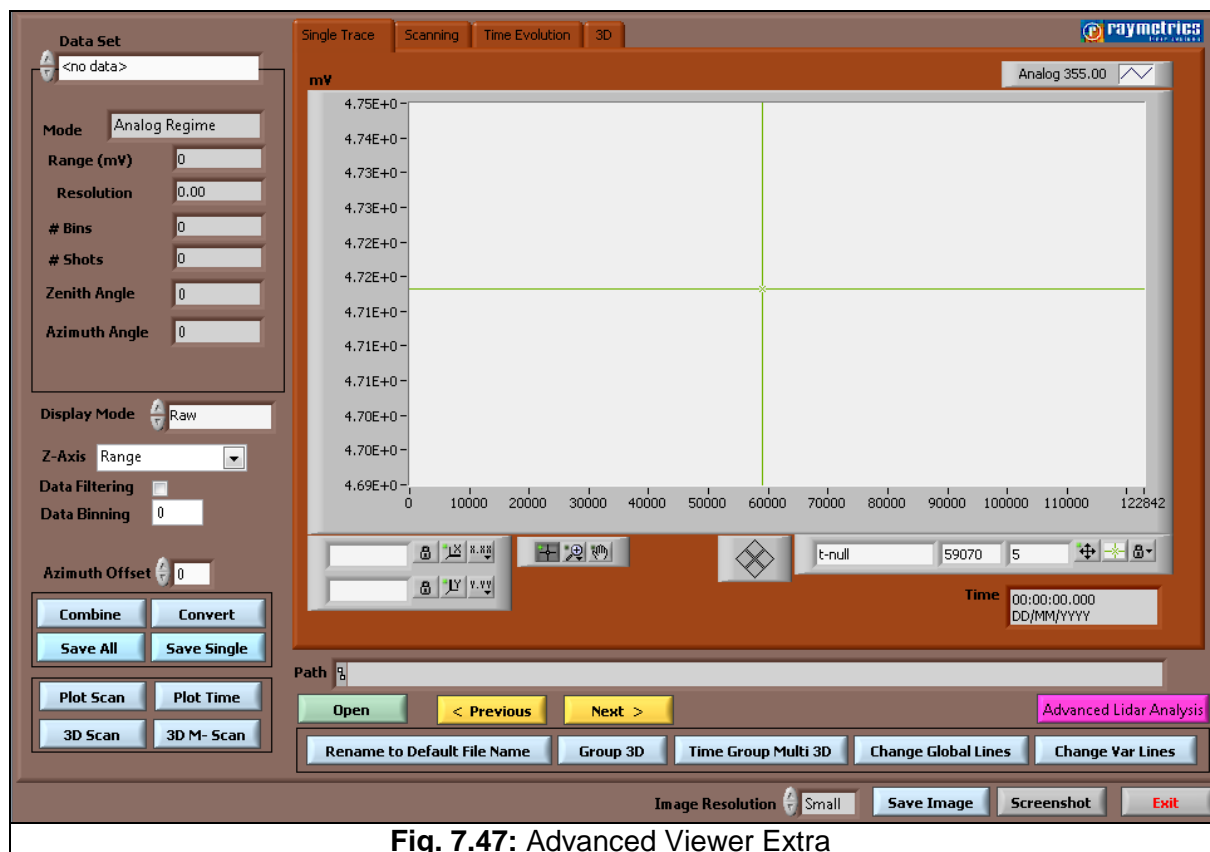
Fig. 7.47: Advanced Viewer Extra

When the program starts it prompts to load the data. Select the first file of the data in the folder where you scanning data are saved and press ok to select the last file of your data set.

If you skip this step or if you want to load different data, you can open by pressing the open button. Once they are loaded you can preview the records at the single trace tab, one by one by pressing the < and > buttons.

Next you can see all information regarding the acquisition as in the mode, range resolution, Number of bins Number of shots zenith and azimuth angle. All tehese change according to the selected file that is currently previewed.

Below this you can chose how you wish to view the chosen data file. For example raw or range corrected signal or range and altitude etc.
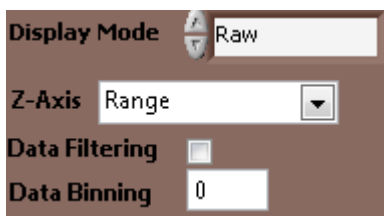
Here you can set the azimuth offset to compensate the direction offset during the installation of the lidar with the east. If you choose to correct then the data will not correspond to the actual orientation.

Below this you have multiple operations for the database manipulation. You can either save one or all files convert them or even combine them to a single one.

And finally you have the options of what to do with these data. You can plot them either in a scan plot or as a time evolution plot. You can also plot a 3D scan which basically

means that the data of the 3D scan will be grouped either in set of azimuth or zenith scans. Finally in multiple 3D scans you also get the option of time evolution of the same scans.

One useful tool is below the open button. Here are a set of button that can change things in your data. You can rename the files, group them in a 3D scan, group them as time evolution 3D scans, change the global information or the variables of the files

On the bottom of the interface there are options to save the image of the 3d graph or just a screenshot and of course the exit button. When the user saves an image a text file is also saved that contains all the information of the plotted scan. This file is used from the Sketchup script to create the geometry of the scan.

Finally what makes this program even more powerful is the option to run the advanced analysis as this was explained in the previous paragraph.

7.4.1 How to Display Scans in Google Earth

This is a guide how to use both the advanced viewer to make a scan plot and also how to use the Raymetrics script that runs on Google Sketchup. These two programs in combination can easily produce impressive representation of your data in Google Earth.

Start by running the Advanced Viewer extra and select the data to be analyzed.

Click on the Plot Scan button. Select the first file of the scan you want to plot and then the last file of the scan you want to plot.

Then select the ray data set and the parameter you want to plot.
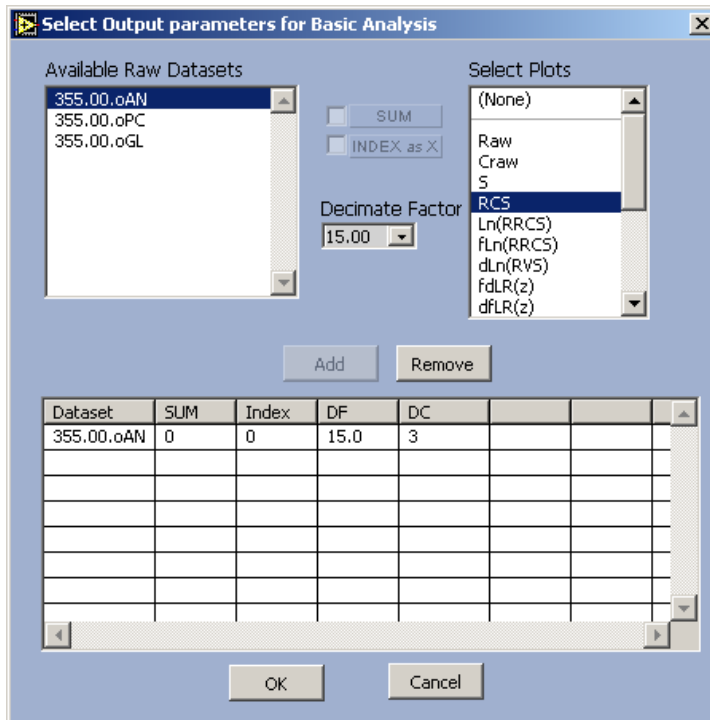
Define the range of interest make the analysis and click the ok button (make a note about the range that you have selected eg: 5000 meters
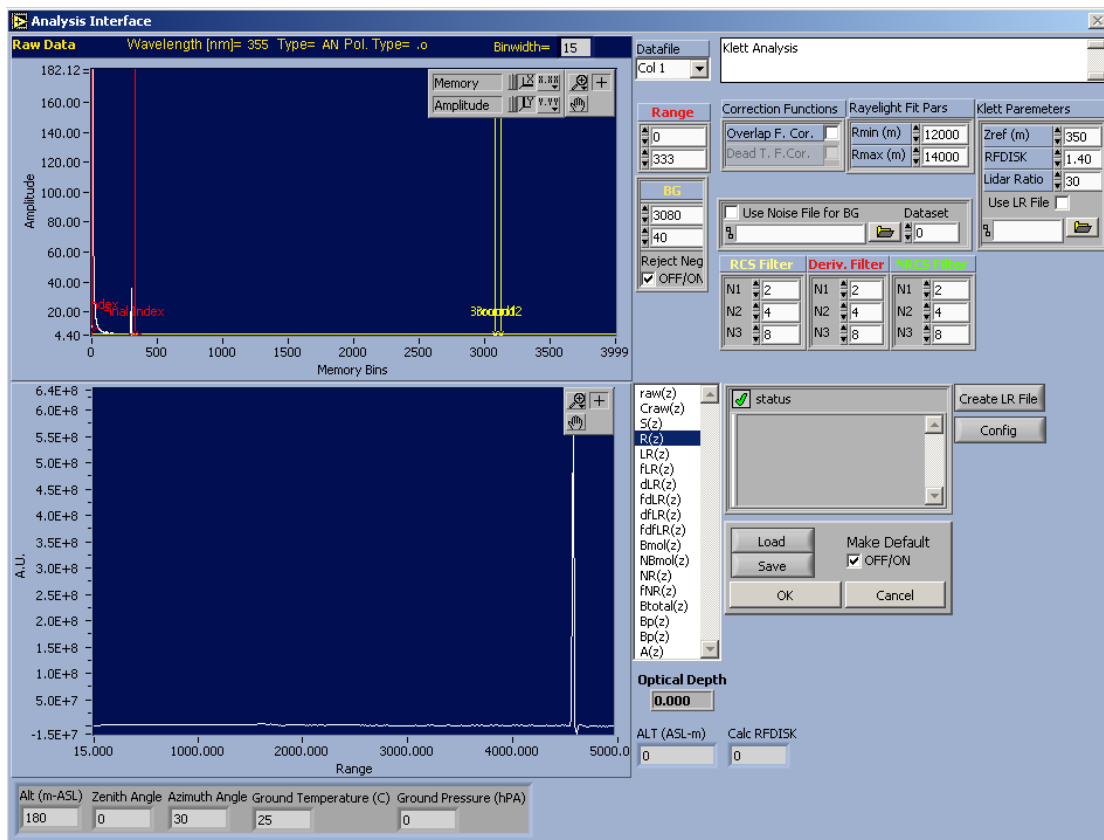
Now the analysis is done and the program returns to the main interface. If you go to the 3D tab you can see the plotted data in a 3D graph.
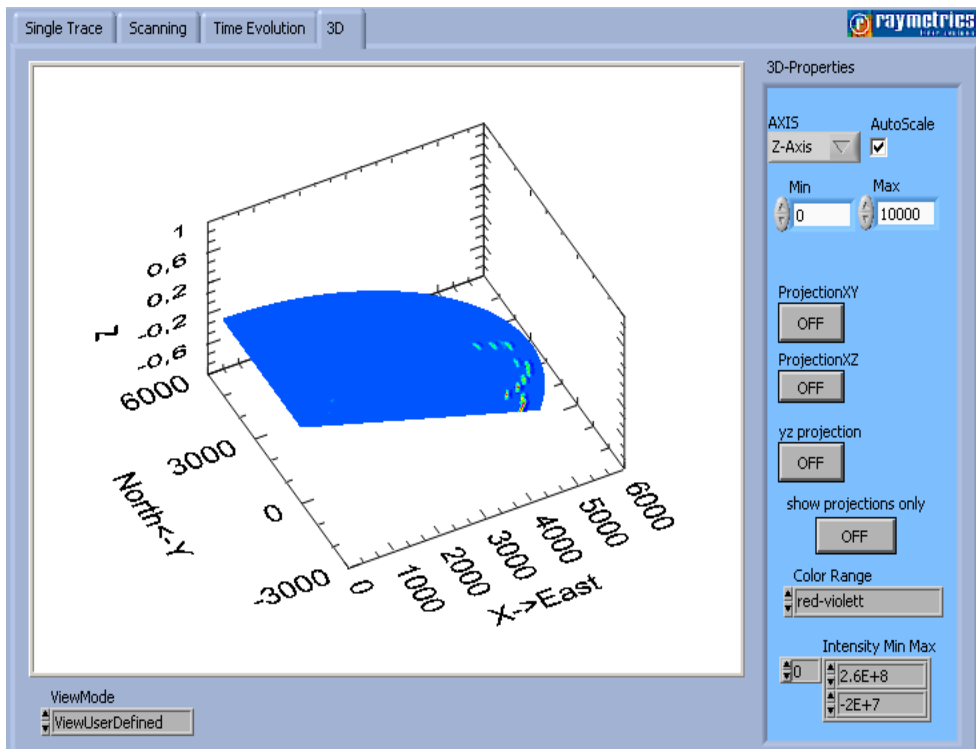
To make this image compatible with the Sketchup script you need to view the XY-plane. At the 3D-properties pane press the ProjectionXY button.
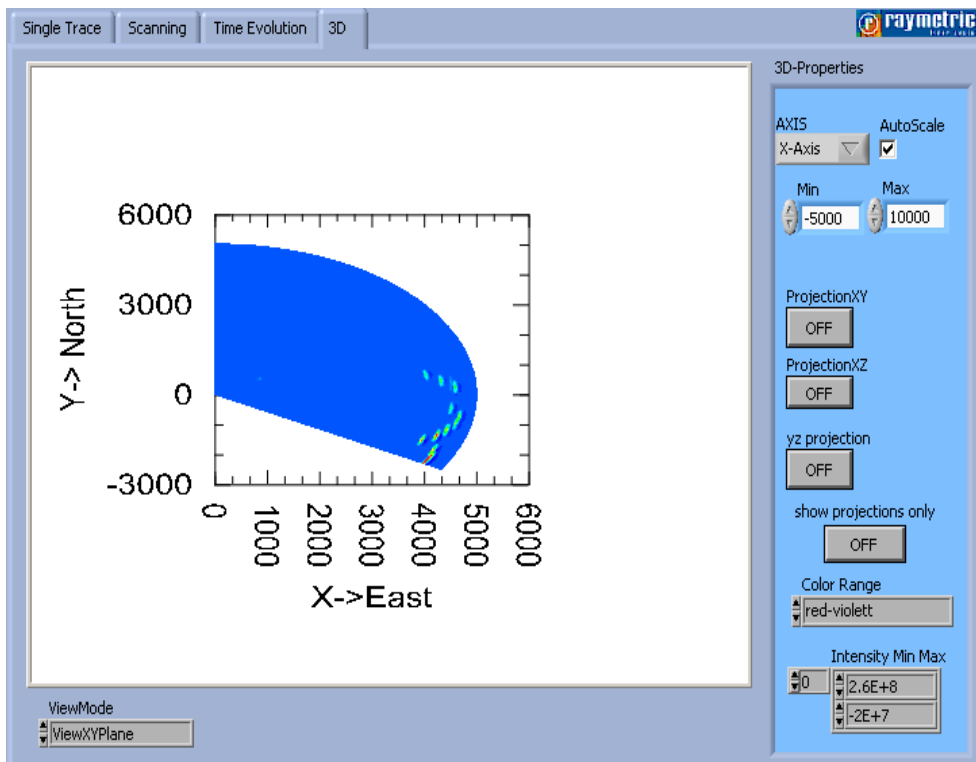
Press the Define the scales for X and Y axis to have the same length and equally spaced. For example select the x-axis and set the min to -5000 and max to 5000m, then select the Y-axis and set the same values (do not forget to uncheck AutoScale)

Now the image should be in the middle. Make sure that the plot is not cropped but it also no too small.

Then select Min Max values for color scale. If you intend to represent several scans make a note of the color scale so that you the images can be comparable.

Then use the Alt+Click and move your mouse to Zoom – UnZoom and Shift+Click and move your mouse to move the graph.

Then select High Resolution Option and Click on the Save Image.
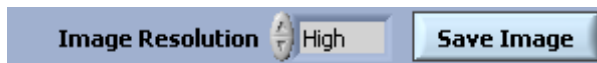
At the pop-up window select 3D and click Ok. At the pop-up dialog set the information for the geo-coding and the azimuth offset.
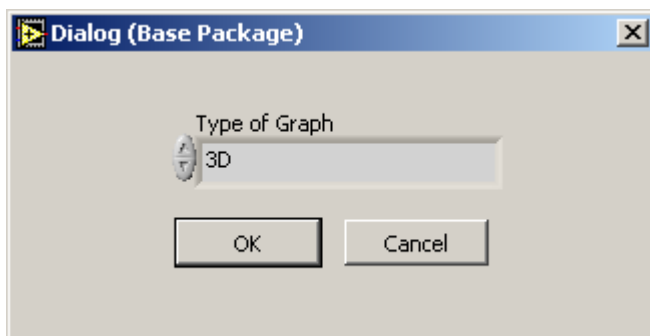
Now the saved image should look like this.
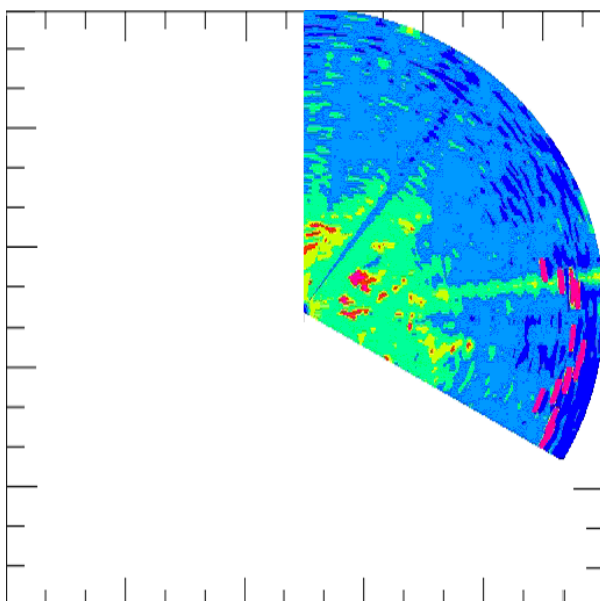
Next open Google Sketch-up with the installed script and click on the toolbar the draw scan icon . The script promots the user to load the info file. Select the txt file that has the same name with the image that you have saved. Once you click ok the program automatically creates a 3D model with the scan.
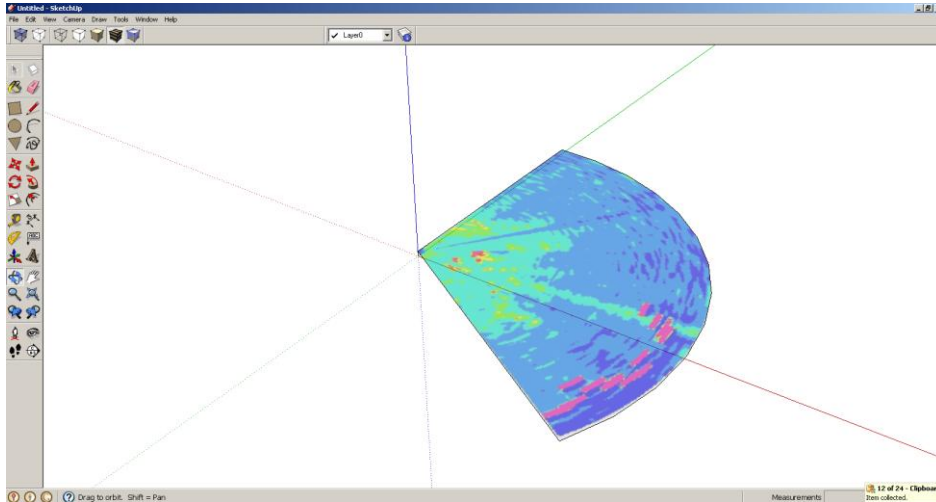
If you choose not to use the geo location information you can set them manually by clicking on the icon at the bottom of the window.
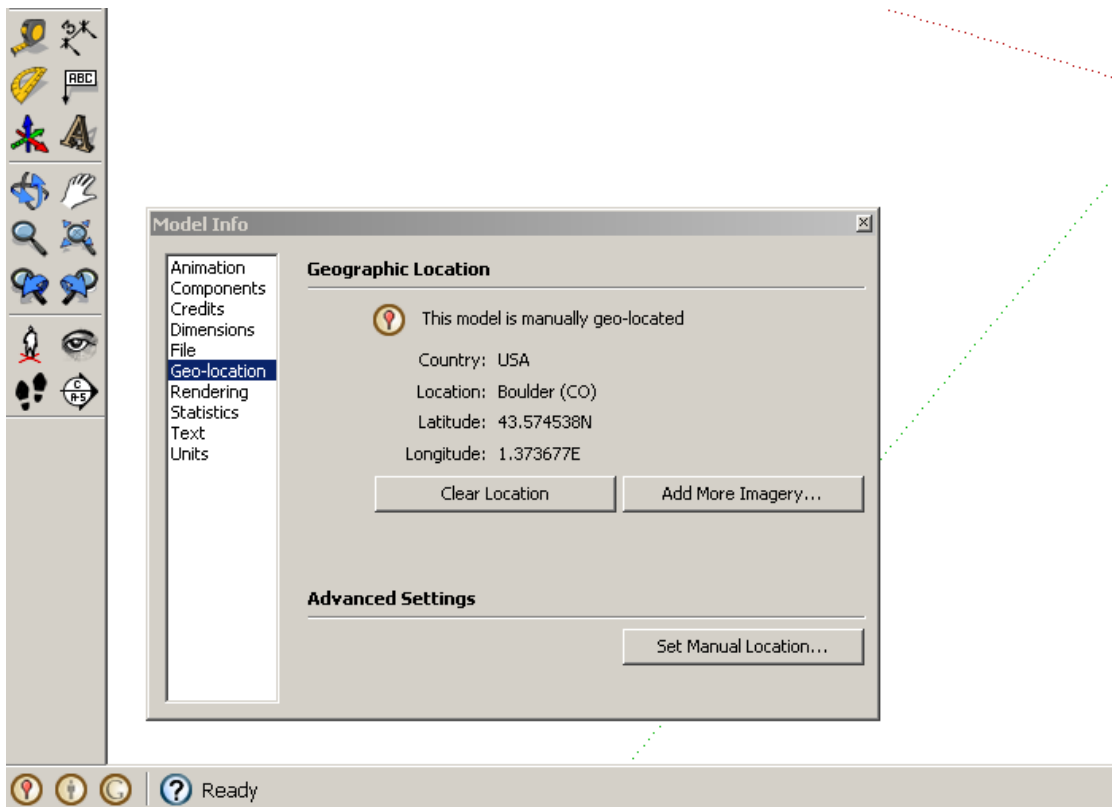
Select Geo-Location and click on the Set Manual Location. Give Long and Lat. Now your sketch is geocoded and you can save it as a kmz file either by pressing the button on the Raymetrics toolbar or go to menu File->Export->3D Model.

If you want you can change the opacity of the model or select to draw a geometry without using an info file at the options button.

For more information about the script click the help button.

If you exported the image by using the toolbar a kmz file is created in the same folder with the image and with the same name with the image. Open the exported file and Google earth will take you to the location set from Sketchup and show the measurement as a 3D model. (For the last actions you have to have internet access).
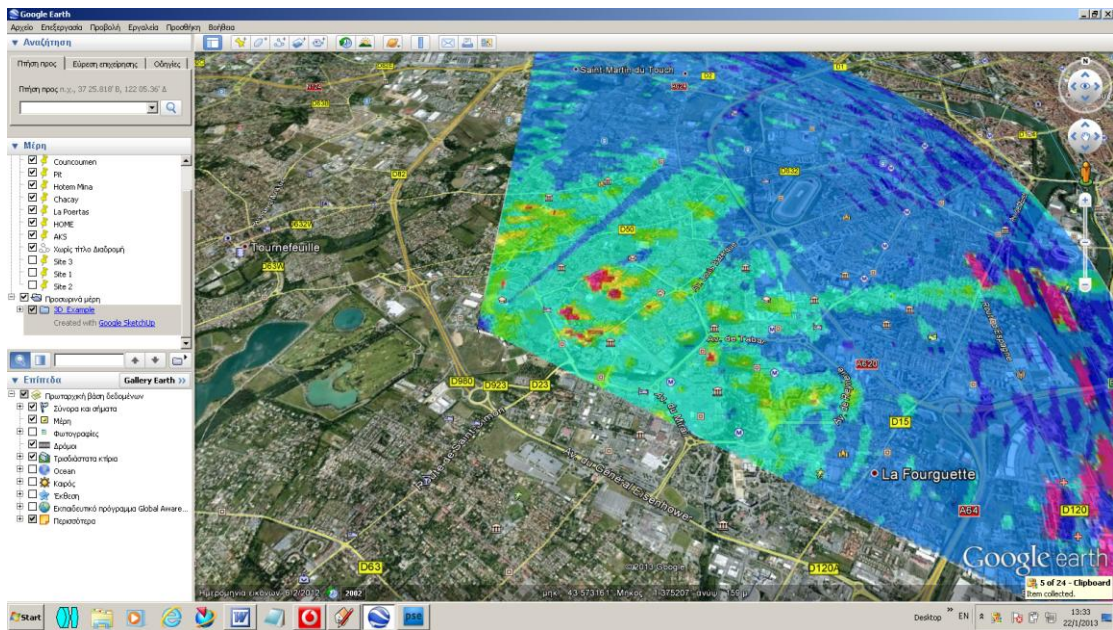
You can draw as many scans as you want in the same SketchUp file, but note that in this case you may need to name the kmz file in a name of your choice.

Follow the same steps and refer to the help file to make a zenith scan model.

8. LIDAR SYSTEM MAINTENANCE

8.1. LASER SYSTEM

The laser system requires minimal maintenance, if it is operated in a standard laboratory environment with specified power line and ambient temperature conditions (see 10. LIDAR SYSTEM TECHNICAL SPECIFICATIONS. Please, refer to the Laser's INSTRUCTION MANUAL for a detailed description of the laser's maintenance procedure (alignment verification, flash lamps replacement, cooling group unit, etc.).

8.2. REFLECTIVE MIRRORS

Although the closed Lidar structure provides a dust-free operation for optical components, the Lidar should never be operated without the protective housing. In case the reflecting mirrors become dusty, they should be cleaned with *absolute ethanol* using flint-free optical paper. If this is done by non-specialized personnel, serious damage may occur on the optical components and the warranty will not be further valid. Therefore, it is strongly recommended that you sign an after sales Servicing Contract with Raymetrics S.A. for a trouble-free maintenance of your Lidar system.

8.3. TELESCOPE

Although the Lidar structure provides a dust-free operation for optical components, it is preferable that in open air the Lidar system should be operated with the protective housing on. In case the telescope becomes dusty, it should be cleaned with *absolute ethanol* using flint-free optical paper. If this is done by non-specialized personnel, serious damage may occur on the optical components and the warranty will not be further valid.

8.4 CLEANING OF OPTICAL COMPONENTS

All optical elements are delicate and should be handled as carefully as possible. The glass and antireflective (AR) coated surfaces will be damaged by any contact, especially if abrasive particles have come into contact with the surface. In most cases, it is best to leave minor debris on the surface.

Use of oil-free dry air or nitrogen under moderate pressure is the best tool for removing excessive debris from an optical surface. In the case that the contamination is not dislodged by the flow of gas, please use the following protocol for cleaning the part:

1. Clean the part using an absorbent towel such as Kimwipes™, not lens paper. Use enough towelling so that solvents do not dissolve oils from your hands which can make their way through the towelling onto the coated surface.

2. Wet the towel with an anhydrous reagent grade ethanol.

3. The use of powder-free gloves will help to keep fingerprints off the part while cleaning.

4. Drag the trailing edge of the ethanol soaked Kim wipe across the surface of the component, moving in a single direction. A minimal amount of pressure can be applied while wiping. However, too much pressure will damage the component.

5. If the surface requires additional cleaning, always switch to a new Kimwipes before repeating the process.

The purpose of the solvent is only to dissolve any adhesive contamination that is holding the debris on the surface. The towel needs to absorb both the excessive solvent and entrap the debris so that it can be removed from the surface. Surface coatings on interference filters and dichroics are typically less hard than the substrate. It is reasonable to expect that any cleaning will degrade the surface at an atomic level. Consideration should be given as to whether the contamination in question is more significant to the application than the damage that may result from cleaning the surface.

In many cases, the AR coatings that are provided to give maximum light transmission amplify the appearance of contamination on the surface.

8.5 POSITIONER

The positioner's model is 2AP sun tracker and is made by Kipp & Zoenen. You can find the full documentation of this device in the Lidar's computer for a proper operation. In short the positioner needs greasing once per six months depending on the usage. To do so you will have to turn vertically the lidar to remove the cover.

9. TROUBLESHOOTING

This chapter addresses some of the problems you might encounter while running your Lidar system and indicates ways how to solve these problems.

9.1 EMISSION

PROBLEM	POSSIBLE CAUSES	CORRECTIVE ACTION
Dead (no power)	AC mains	Check power source. Inspect power cord
	Blown fuse(s)	Check fuses on back panel T10A/250V, QTY 2 and replace if necessary.
NO Simmer, NO Interlocks Three audible clicks from ICE450	Faulty laser I/O cable	Verify laser I/O cable connectors are fully inserted and thumbscrews are tightened. Visually inspect high current contacts on both ends of the laser I/O cable for carbon film or pits caused by poor connector insertion and arcing.
The control unit starts and after a few seconds turns off.	Low coolant level	If the reservoir is not filled a flow interlock appears in the LCD screen. Add coolant to the reservoir.
Flashlamp does not lamp.	Flashlamp is not enabled	Verify that both the "flashlamp ready" light and the "flashlamp start" light on the Remote Box are illuminated.
	Simmer Problem	Either ionized, or contaminated coolant, or a degraded flashlamp may be the cause. Coolant should indicate a resistivity of 100kΩ-cm to 5MΩ-cm for proper operation. If coolant resistivity is less than 100kΩ-cm, replace the coolant. If the lamp still does not simmer replace the flashlamp.
	Charger Latch-up	If the ICE450 makes a squealing or hissing sound when the high voltage is enabled, and the simmer LED is illuminated but the flashlamp does not flash, **disable the high voltage immediately**. A component inside the ICE450 has most likely failed and the high voltage charger is attempting to charge into a short circuit. If the ICE450 is operated in this mode for longer than a few seconds additional electronics damage may occur.
Flashlamp does not fire. NO Interlocks	Flashlamp is not in Internal Mode	Verify that Internal sync is selected in the flashlamp menu.
	Flashlamp is broken	If, after pressing the "Flashlamp Ready" button, the "ready" light does not light, nor is there a visible flashlamp flash, the flashlamp may need to be replaced.
Flashlamp does not fire. Interlock **"emergency stop button pushed"**	The red button on Remote Box is pushed in.	Pull the button out. If that does not work, there may be an open circuit in the Remote Box, cable, or internal harness.
Flashlamp does not fire. Interlock **"BNC Intlk in on ICE450 front panel"**	The "INTLK In" connector on the front panel is open.	Connect a shorting plug, to the "Interlock In" BNC on the front panel. If that does not work, there may be a problem with the shorting plug.
Flashlamp does not fire. Interlock **"thermal sensor on Laser Head"**	The thermostat in the Laser Head is open.	Allow the head to cool down. If that does not work, there may be an open circuit in the Laser Head or in the Laser Head I/O cable
Flashlamp does not fire. Interlock **"flashlamp disabled time out delay**	The flashlamp timeout has expired.	Either disable timeouts or change the flashlamp timeout to 00:00.

expired"		
Flashlamp does not fire. Interlock **"heater over temp"**	The coolant heater is too hot.	Turn off power to the ICE450 and allow it to cool down. If that does not work, contact Raymetrics.
Flashlamp does not fire. Interlock **"charger/simmer over temp"**	The Charger inductor is too hot.	Turn off power to the ICE450 and allow it to cool down. Verify that air flow is not obstructed at the front or back of the ICE450 and correct if necessary. If that does not work, contact Raymetrics.
Flashlamp does not fire. Interlock **"low coolant temperature"**	The coolant is not warm enough for proper operation.	Give the ICE450 time to warm the coolant. If that doesn't work increase the temperature of the cabinet's thermostat.
Flashlamp does not fire. Interlock **"high coolant temperature"**	The coolant is too warm for proper operation.	Turn off the ICE450 and allow it to cool down and decrease the temperature of the cabinet's thermostat.
Flashlamp does not fire. Interlock **"low coolant flow"**	The coolant is not flowing properly.	There may be an obstruction in the coolant lines. Examine the lines and make sure they are not kinked or otherwise obstructed.
Q-Switch doesn't start. Interlock **"Q-S disabled Please wait for 8 seconds"**	There is no problem. This is normal.	Wait until the 8 second timeout expires, then activate the Q-Switch.
Q-Switch doesn't start. Interlock **"Q-S disabled coolant temperature under limit"**	The coolant temperature is below the minimum Q-Switch operating temperature.	Allow the coolant to warm up.
Q-Switch doesn't start. Interlock **"Q-S disabled time out delay expired"**	The user-set timeout period expired.	Disable timeouts or set the Q-Switch timeout to 00:00.
Energy is low	Cold Flashlamp	This is normal wait for 10 minutes to reach the desired energy.
	Flashlamp Degradation	If output energy is slightly below normal level, it may suggest gradual lamp degradation. If significant lamp degradation is suspected, replace the flashlamp.
	Coolant Degradation	Inspect the coolant for clarity.
	Incorrect Q-Switch Delay	Check that the Q-Switch delay is set to 135µs with respect to the flashlamp.
	Resonator Misaligned	If beam quality has degraded, it may suggest that the resonator needs realignment. Contact Quantel USA for more details.
Coolant leak	DI Cartridge installation	Verify that DI cartridge is locked in place and fittings are fully inserted.
	Laser Head o-rings	Inspect o-rings on coolant line connectors at Laser Head for damage and replace if necessary.
RS232 port does not operate: no communications.	Serial port disabled	For safety reasons, the serial port is disabled when any button is pressed on the Remote Box. In the "system" menu, turn serial port ON.
	Baud rate incorrect.	See ICE450 User's manual Chapter 5, Serial Protocol Description for correct baud rate setting.

For further information on laser troubleshooting please refer to the laser's instruction manual for a relevant troubleshooting list for any problems you may encounter when using your solid state Nd:YAG laser.

9.2 DETECTION

PROBLEM	POSSIBLE CAUSES	CORRECTIVE ACTION
Dead (no power)	AC mains	Check power source. Inspect power cord
	Blown fuse(s)	Check fuses on back panel and replace if necessary.
No signal at all channels	HV Power supply off.	Turn on the PMT power supply and apply the specified voltage.
	No connection.	Check that all connectors are in place.
	Laser is not transmitting.	Turn on the laser (flashlamp – Q-switch)
	Lidar is misaligned.	**Reduce the energy** of the laser so that the light can be hardly seen when placing a white paper in above the widow of the emission unit. Raise the paper and tilt it in a way so that the light is reflected directly into the telescope. If the Lidar is misaligned then you should see the signal changing. Realign the Lidar (see paragraph 6.2 LIDAR ALIGNMENT) **CAUTION! If the energy is high the PMTs will be destroyed.**
No signal at one of the channels.	Broken connector or cable.	To verify which cable is fault, connect the HV and signal cable (one at a time) to another working device.
	HV power supply broken.	If the cables are okay connect the HV cable of a working channel to the HV power supply that is not working. If there is no signal at the working channel then the HV power supply is broken.
	TR Device broken.	If the cables are okay connect the signal cable of a working channel to the TR device that is not working. If there is no signal at the non-working channel then the TR is broken.
	The PMT is burned.	If the cables, the HV power supply and the TR device are okay then the PMT is burned probably due to excess of light exposure.
No acquisition in one of the channels	Wrong dataset configuration.	Verify that the button is red next to "analog or photon Mem I" at the corresponding device in the dataset at the acquisition program.
Cannot change high voltage	HV power supply switch.	Switch to manual position for manual HV application or to remote for application VIA the computer
High voltage is unstable	Bad connection.	If the variation is higher that 5 volts **switch off immediately the HV power supplies**. The connector is broken.
No TCP/IP connection	Ethernet switch off.	Turn on the "LAN" switch on the energy box. Make sure that the green light at the Power supply illuminates
	Communication crash	Run Licel's "Search Controllers.exe. If all devices are detected the buffer is full. Restart all the devices.
	Wrong IP address.	Run Licel's "Search Controllers.exe. If the devices are not detected make sure that the computer's IP address belongs to the same network of the Licel's and change the computer's IP if necessary.
	Broken connector or cable.	Check that the lights illuminate at the Ethernet switch, make sure that the cable clicks when it is placed on the switch, if not change the cable.

For further information on Licel electronics please refer to Licel's instruction manual for a relevant troubleshooting list for any problems you may encounter when using your detection electronics unit (digitization and detection of Lidar signals).

10. LIDAR SYSTEM TECHNICAL SPECIFICATIONS

Transmitter	
Pulsed Laser Source	Nd:YAG (Quantel ULTRA100 Series)
Laser Class	IV
Primary Wavelength	355 nm
Energy / Pulse	32.5 mJ
Repetition Rate	20Hz
Near Field Beam Diameter	3.37mm
Beam Expansion	X10
Laser Beam Divergence	<0.4 mrad
Motorized Alignment	No

Receiver		
Telescope Type	Cassegrain	
Primary Diameter	200mm	
Secondary Diameter	48mm	
F Num	F4	
Focal Length	800mm	
Transmitter–Receiver Distance	152 mm	
Default Field Of View	1,75 mrad (adjustable from 0.5 to 3mrad)	
Overlap	200m	
Detected Elastic Backscatter Wavelengths	355nm	Analog + Photon Counting
Detected Raman Wavelengths	N/A	
Interference Filter Bandwidth	IFF355	CWL 354,7nm / BW 0,9 nm / **OD<1**

PMT Characteristics

SERIAL	TYPE	CATHODE LUMINOUS SEN (µA/lm)	ANODE LUM. SENS A/lm	ANODE DARK C (nA)	CATHODE BLUE SEND INDEX	REC. OPERATING VOLTAGE Volts
BAC0220	R9880U-110	125	246	0.09	13.0	750-900V

Control Unit		
Transient recorder	Manufacturer	Licel
	Type	20-12bit
	Raw Spatial Resolution	7.50m
Computer	Manufacturer	Advantech
	Model	ARK3360L
	CPU:	Intel® Atom™ D525 1.8GHz
	VGA:	Integrated in ICH8M

	Ethernet:	10/100/1000Base-T
	Storage:	SATA HDD 360Gb
	RAM:	4Gb
	Safety:	FCC Class A CE certificated The front bezel is compliant with NEMA 4 and IP65
Software	OS:	MS Windows 7 Professional
	Backup:	Software for data backup
	Alignment:	Lidar System Checking and Alignment
	Acquisition:	Data Acquisition (with real time data display)
	Analysis:	Data Analysis
	Control SW	Laser Control, Scheduler, PMT HV Control
Enclosure	Manufacturer:	SKB CASES
	Material:	High stiffness roto molded
	Ethernet:	Advantech EKI-2525 5-port Industrial Switch
	Main Plug:	Bulgin IP68 panel mount industrial plug 32A
	Main Switch:	Schneider electric IP66 industrial emergency switch
	External USB	Bulgin IP68 panel mount USB A Type
	Ext. Ethernet	Bulgin IP68 panel mount RJ45
General	IP protection:	IP56 to EN 60 529/10.91
	Dimensions:	500mm x 500mm x 620mm WxHxD
	Weight:	55 kg
	Voltage	110VAC 50/60Hz
	Power	740 Watt (Nominal) 1500Watt (Peak)
	Temperature	Operating: +5 to 45°C Storage: +5 to 50°C
	Humidity	Operating: 10 to 80% non condensing (+5 to 28°C) Storage: 10 to 90% non condensing (+5 to 28°C)

LIDAR Performance

Lidar type	Biaxial
Depolarization Calibration (+/- 45 degrees)	Mechanical
Depolarization offset correction	Mechanical
Upgradable	YES Depolarization and 3787nm Ready
Scanning 3D	Yes
Max Backscatter Effective range*	8-12Km

*Depending on the atmosphere's conditions and integration time.

11. LIMITED GUARANTEE

NOTICE

Raymetrics SA reserves the right to make improvements of the products described in this Manual at any time and without notice. Thus, all specifications of this Lidar system or sub-systems are subject to change at any time and without notice.

Raymetrics SA shall not be liable for errors contained in this Manual or for incidental or consequential damages in connection with the furnishing, performance or use of this material.

WARRANTIES

Raymetrics SA, as well as the Lidar-components providers (laser source, acquisition electronics, photo-multiplier tube (PMT), personal computer, Digital acquisition PC-card and cables) warrant the products or sub-systems of this Lidar system to be free from defects in materials and faulty workmanship under normal use for a period of 12 months after the date of the original purchase and following the delivery to the FOB site (for details see the Instruction Manuals of the Lidar sub-systems providers and comments therein). Laser flash lamps are guaranteed for 25 millions shots or 1 year whichever comes first.

This warranty does not cover:

- equipments or components where the original identification markings have been altered or removed or if any parts have been replaced by other components
- equipment or components that have become defective due to mishandling, erroneous use, accidental alteration, improper operation, or any other cause, without the prior written agreement of Raymetrics SA.

The cost and terms of non-warranty service are fixed by Raymetrics SA and the Lidar sub-systems providers and are subject to change.

RETURNS, ADJUSTMENTS AND SERVICE

If warranty, service or general repair of a Raymetrics SA Lidar system is requested by the customer that leads to the product's return to Raymetrics SA, the terms of such return include the following:

a) Freight and insurance (CIF) charges are pre-paid by the customer, who also takes all the risks of loss, damage or delay in shipment,

b) The Lidar system must be packed in the original containers provided by Raymetrics SA. All water must have been drained from the laser head according to the laser manufacturer rules, prior to packing.

c) Prior to sending the product back to Raymetrics SA the customer must obtain a written authorization for the product return for service.

d) After the product receipt Raymetrics SA reserves the right to fully inspect the Lidar system and determine the cause of failure and warranty status. The same is valid for the laser provider. If the product has suffered damage during the shipment Raymetrics SA has no obligation to perform a warranty repair.

e) If the warranty of the product has expired the customer will be advised of the cost of such repair and a written purchase order for the repair and service work will be required before the performance of the work.

f) If the product is still under warranty status it will be repaired or replaced free of charge in accordance with the terms of the Raymetrics SA and Lidar components providers. Finally, the warranty period for a replaced or repaired component will be only the period remaining on the original product, thus no extra warranty is provided by such repair.

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APPENDIX A

A1 HOW TO CONTROL THE LASER

Intro

Basically there are three major ways to control laser. First to use the Remote Box, second way is to use LaserControl.exe from Raymetrics the third is to use the external trigger. Here is mainly presented the second and the third option. For more info about the Remote Box please read the Laser Manuals that have been supplied to you.

Note: For optimum laser energy
1. The resulting Q-Switch Delay should be 135µs.
2. Do not change the frequency. For GRM laser should be 20Hz.

Communication

The primary communications and control is via the RS-232 port located on the ICE450 front panel (Rack ICE450 back panel). The ICE can be set to lock out ront panel key control and avoid conflict with RS-232 communications.

The serial communications configuration is:

- 9600 baud

- 8 data bits

- no parity

- 1 stop bit

- no flow control

- The Ultra uses only Tx and Rx for its communications.

- No hardware handshaking is utilized.

Important Note: Usually ICE450 is connected physically (through RS-232) to the Lidar computer. In that case you have to use remote desktop to connect to lidar's computer and then use the LaserControl.exe (or the CE450_GUE.exe). In some cases Laser is connected to a Serial To Ethernet Server. If this is the case you have to create a virtual com port to your computer (by using Serial Device Server Configuration Utility) and run the

LaserControl.exe program from your computer. In most of the cases the Laser is connected to Port 2 of the Serial to Ethernet Server Device with IP address 10.49.234.232.

A1.1 Manual Laser Operation Mode

Use Manual Mode for the normal operation of the Power Supply and flashlamp. Press the "ready" button on the Remote Box to initiate simmer current in the flashlamp. The PCC generates a flashlamp discharge as part of establishing simmer. Verify that the LASER ON indicator is illuminated on the front panel of the PCC. Please be advised not to perform laser emission (Q-switching) in this mode.

1. Press the Flashlamp Start button.

2. The PCC generates flashlamp pulses at the rate specified by the "frequency" setting in the Flashlamp menu. This setting is adjustable.

3. For Gaussian Resonator (GRM) type Laser Heads, the frequency is set at Big Sky Laser Technologies. **Please do not adjust the frequency setting for GRM heads.**

4. Wait for 2 Seconds

5. Press the Q-switch Start button (Figure 5, [7]).

6. The PCC starts generating Q-switch pulses internally. They occur after the flashlamp pulse at a time specified by the "FLQS delay" setting in the Q-switch menu.

Adjusting this delay is one method of adjusting the optical energy of a laser pulse.

Note: For this mode the only necessary physical connection between the PCC and the transient recorder is a BNC 50-Ohm cable from Q-Switch out to Rack Trigger input of the Transient Recorder

Note: Q-Switch Out: This BNC Connector allows synchronization to the laser Q-Switch trigger. The Q-Switch trigger corresponds to the rising edge of this positive signal (5V, 50 mA max, and > 10 µS pulse width).

A1.2 Laser Control Program

Laser control Program provides a user friendly GUI for every day operation and control of the laser. The program actually does not need any installation to your computer. Just copy exe and ini file to your computer and run it.

Note: if your pc does not have installed labview runtime library (LVRunTimeEng.exe) version 7 or later you have to install it. You can downloawd this file from www.ni.com or you can find usually into Laser folder that Raymetrics supplies to users.

In addition, If user's pc does not have installed visa301 runtime library (visa301runtime.exe) you have to install it. You can down lowed this file from www.ni.com or you can find usually into Laser folder that Raymetrics supplies to users.

When program start first it is trying to find the laser at the serial port that it saved in the ini file. In our example COM8

Example of Laser_Control.ini

[Laser_Control]
prefDlgTestData=1234
useLocaleDecimalPt=False
postScriptLevel2=False
[Communication]
Com Port=ASRL8::INSTR

If successfully connected, the program starts and you get the version of the laser and its status.
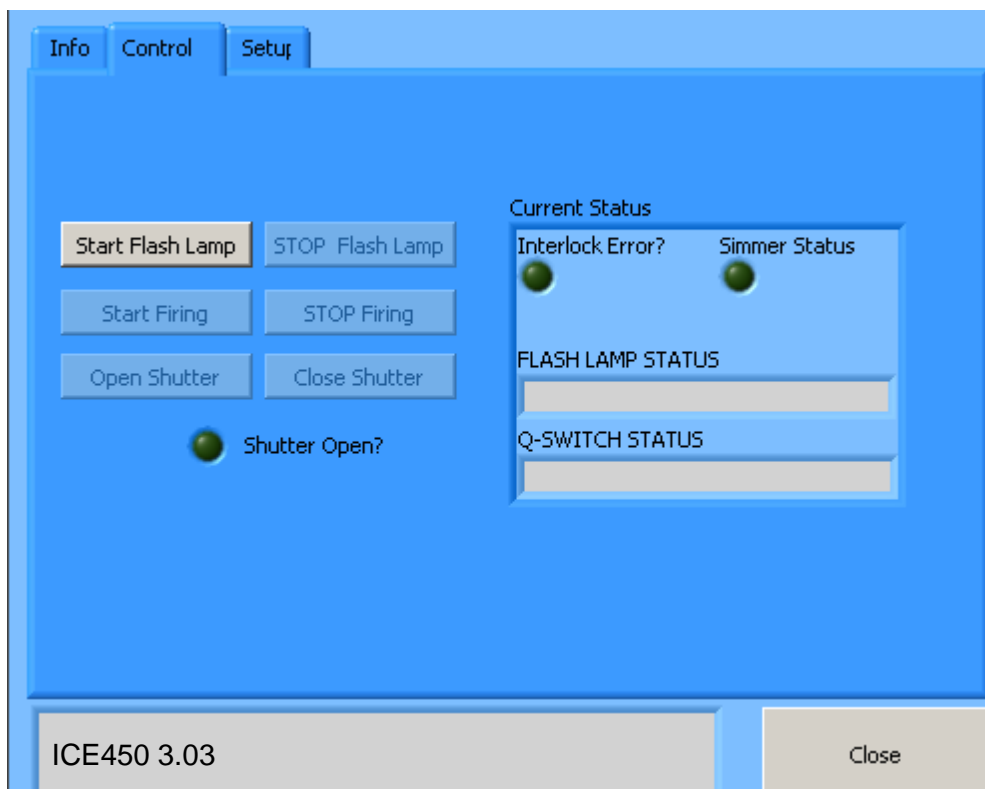
Then you can just click "Start Flash Lamp" button to start the flash lamp. Wait until Simmer Status Led is getting green. Wait a couple of seconds more and then click on the activated "Start Firing" button to start emission of laser pulses. To stop the laser follow the opposite direction. In case that your laser is equipped with an automated shutter just not forget to click on the "Open Shutter" button in order to start emission.

However if the program fails to connect with the laser then another window appears giving user the option to try a different COM port.
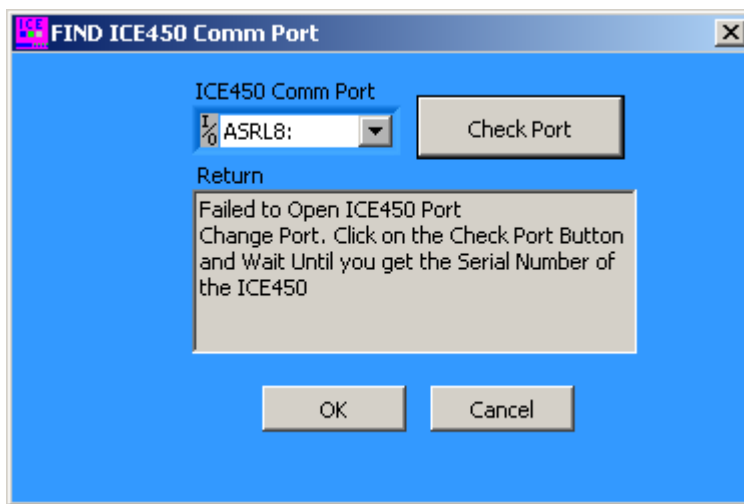
Select an available COM port from the drop down list and click the "Check Port" button. If successfully connected (Return message should be like CE450 x.xx) click the OK button. If not successfully connected try a different COM port.

For more info about INFO and Setup TABS please read the Laser manual.

Troubleshooting

1. The software fails to start

   - Make sure that you computer has installed the appropriate Labview runtime engine.

2. The software starts successfully but can not communicate with the laser.

   - Make sure that your laser is powered on.

   - Make sure that you have assign the right COM port

   - Make sure that laser serial cable is correctly attached to the lidar's computer or to the serial to Ethernet server device or finally to your computer.

3. Software runs and communicates successfully but I can not start firing (Or you get an interlock error message)

    - In these cases please try to control your laser manually (by using the remote box or the software provided by laser manufacturer). Consult Laser user manual.

Before contactng Raymetrics please try to indentify the problem and send screen shot and a detailed description of the message that you can on the LCD display of the Lasers Remote Box.

A1.3 Flashlamp in Internal Mode and Q-switch in External Mode

In this configuration, the PCC generates the flashlamp pulse signals and an external source (Trigger Generator) generates the Q-switch trigger signals. This may be useful when you:

a. Require better resolution for the Q-switch delay than is available using the PCC since the Lamp Out signal is a copy of the actual flashlamp trigger.

b. Require pretrigger function of your Lidar.

To use this mode, select internal flashlamp sync and external Q-switch sync as follows:

1. From the main menu, go into the Flashlamp menu and select flash sync "INT".

2. Return to the main menu.

3. Enter into the Q-switch menu and select QS Sync "EXT".

4. Open Control Timing exe (from Licel menu)

5. Click on the Acquisition Timing Tap.

6. Switch Master Trigger to External (up Position)

For optimum laser energy the resulting Q-Switch Delay should be 135µs. For example if you need 20 µs of pretriggering then Lamp to Acquisition should be 115µs + 20µs Acquisition to Q-Switch. If no pretrigger is required then put Lamp to Acquisition at 135µs and Acquisition to Q-Switch at 0 µs.
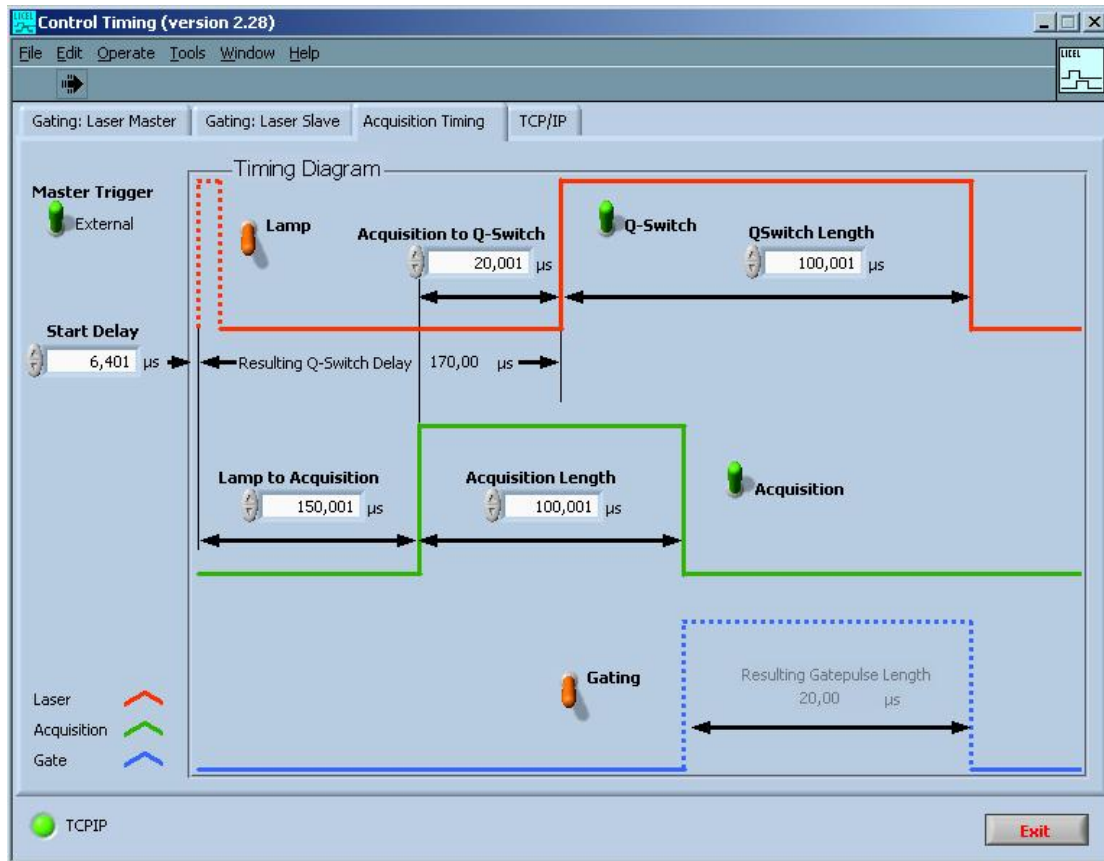
Now you can switch on and off the laser by switching the Q-Switch numb.

A1.4 Flashlamp and Q-switch in External Mode Mode

In this configuration, an external source (Trigger Generator) generates both the flashlamp trigger and the Q-switch trigger.

To use this mode, select external flashlamp sync and external Q-switch sync as follows:

1. From the main menu, go into the Flashlamp menu, and select flash sync "EXT".

2. Return to the main menu.

3. Enter into the Q-switch menu and select QS Sync "EXT".

4. Open Control Timing exe (from Licel menu)

5. Click on the Acquisition Timing Tap.

6. Switch Master Trigger to Internal (up Position)

For example if you need 20μs pretriggering then Lamp to Acquisition should be 615μs + 20μs Acquisition to Q-Switch. If no pretrigger is required then put Lamp to Acquisition at 635μs and Acquisition to Q-Switch at 0μs. **Note:** There is a processing delay of 500μsec between the external flashlamp trigger input and the actual flashlamp activation.
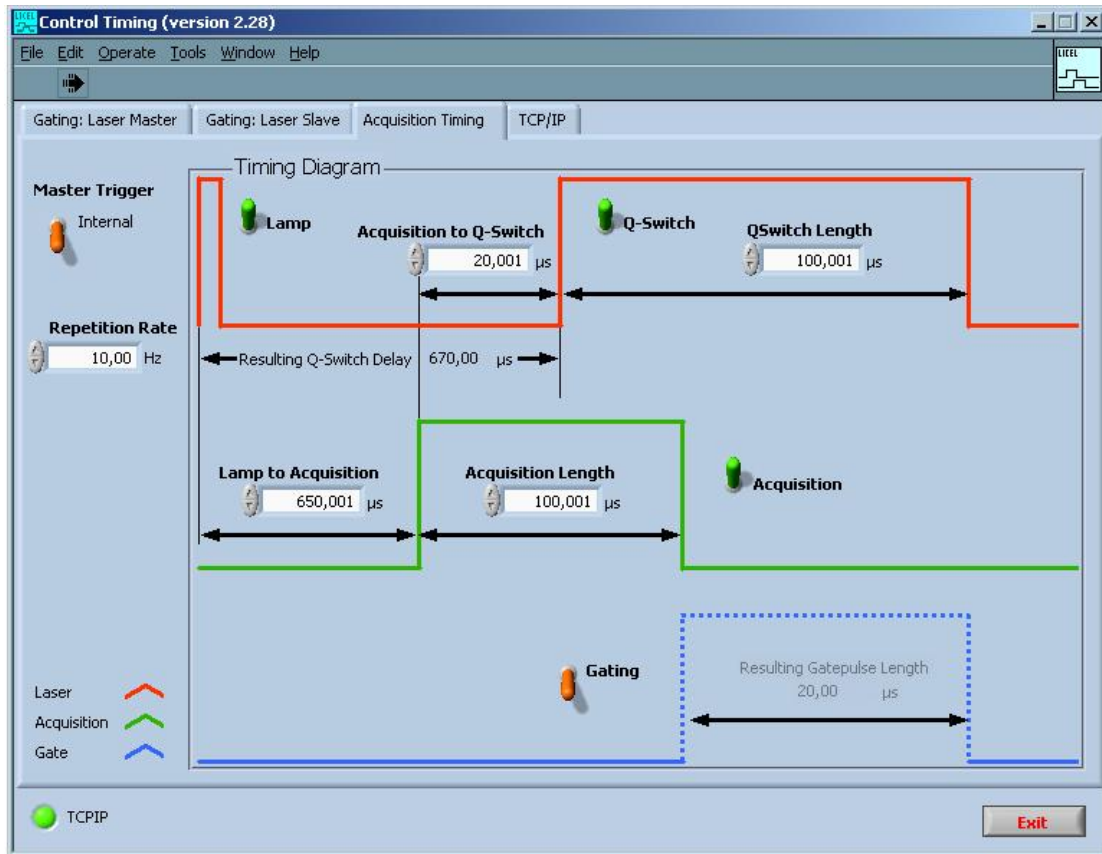
Note: Please always switch off the Q-Switch knob before you switch off the Lamp knob.

A2 HOW TO USE ANOTHER COMPUTER

If for any reason you want to use another computer you have to setup the communications and install the programs for the Lidar. You can use any computer that you want that has Windows XP OS and later.

Communications Setup

The communications are with the Licel's controllers, the Laser and positioner (tracker) if your system is equipped.

Licel has a LAN based communication. Lidar's TR IP address is by default: 10.49.234.234. So user's pc should belong to the same subnet class:

10.49.234. xxx

Where xxx any number for 0 to 254.

Note: Make sure that you do not use numbers for xxx from 230 up to 237. These ranges are reserved for Lidar hardware.

To change users or Lidar's PC TCP IP address, read windows documentation or consult your system administrator

To change Transient Recorder TCP IP address, run the program TCPIP Set Fixed IP Address.exe

Usually located at C:\Program Files\Licel\Configure\ TCPIP Set Fixed IP Address.exe
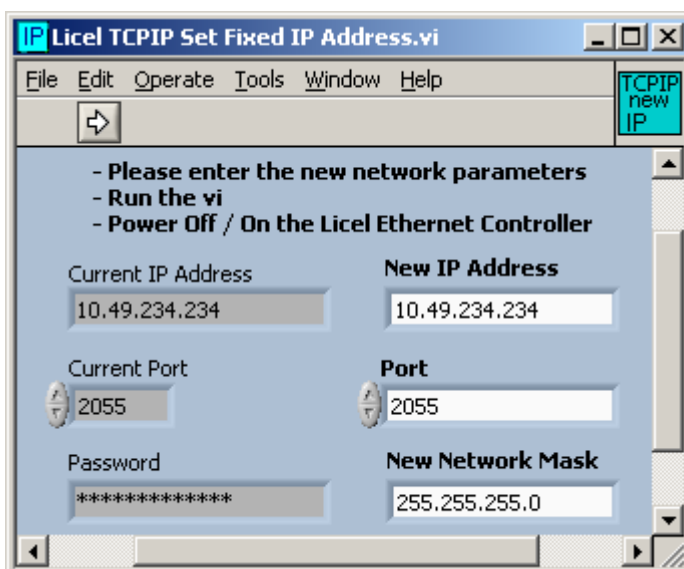
For more info please read carefully Licel Documentation

The laser and tracker have an RS232 communication so they require serial ports unless there is installed in your system an RS232 to Ethernet converter. This device needs separate installation but gives you the option to connect all devices on an Ethernet switch to which you also connect your computer. This makes the connection very easy, other wise you have to use the external USB port with an RS232 to USB adaptor to connect to your computers USB port. If there are more than one devices with RS232 port use a hub and separate RS232 to USB adaptors for each device.

Lidar software installation

First install Licel software (this step is not necessary but it is suggested)

If user's pc does not have installed Labview runtime library (LVRunTimeEng.exe) version 7 or later you have to install it. You can download this file from www.ni.com or you can find usually into Laser folder that Raymetrics supplies to users.

If user's pc does not have installed visa301runtime library (visa301runtime.exe) you have to install it. You can download this file from www.ni.com or you can find usually into Laser folder that Raymetrics supplies to users.

If your Lidar comes with a positioner (tracker) then install Win2AP software. Unzip the KippZonen_Win2AP-V3R2.zip file and then run setup.

Make a copy from the Lidar's pc the win2ap.ini file

Copy this file to the same folder where you just installed the Win2AP software

APPENDIX B

SUMMARY OF LIDAR THEORY

CONTENTS

INTRODUCTION

About Backscatter coefficient β(R,λ)

About extinction coefficient, α(R,λ)

The Lidar equation

SUMMARY OF LIDAR PROBLEM SOLUTIONS

1. The slope method.

2. Inver Klett-Fernard method (Raymetrics Software)

AN INTRODUCTION TO RAMAN LIDAR

Molecular backscatter coefficient

Other Lidar equation solution

Solutions for one component atmospheres

Solutions for Two component atmospheres

SIGNAL TO NOISE RATIO

CALIBRATION METHODS

POLARIZATION LIDAR BASICS

B1 INTRODUCTION

In the simplest from, the detected Lidar signal can be written as

$$P(R) = KG(R)\beta(R)T(R)$$ eq. 1

The power P received from a distance R is made up of four factors.

1. The first factor, K , summarizes the performance of the Lidar system

2. The second, G(R), describes the range-dependent measurement geometry

   Note: These two first factors are completely determined by the Lidar setup and can thus be controlled by the experimentalist. The information on the atmosphere, and thus all the measurable quantities, are contained in the last two factors.

3. The term β (R) is the backscatter coefficient at distance R.

4. The term T (R) is the transmission term and describes how much light gets lost on the way from the Lidar to distance R and back.
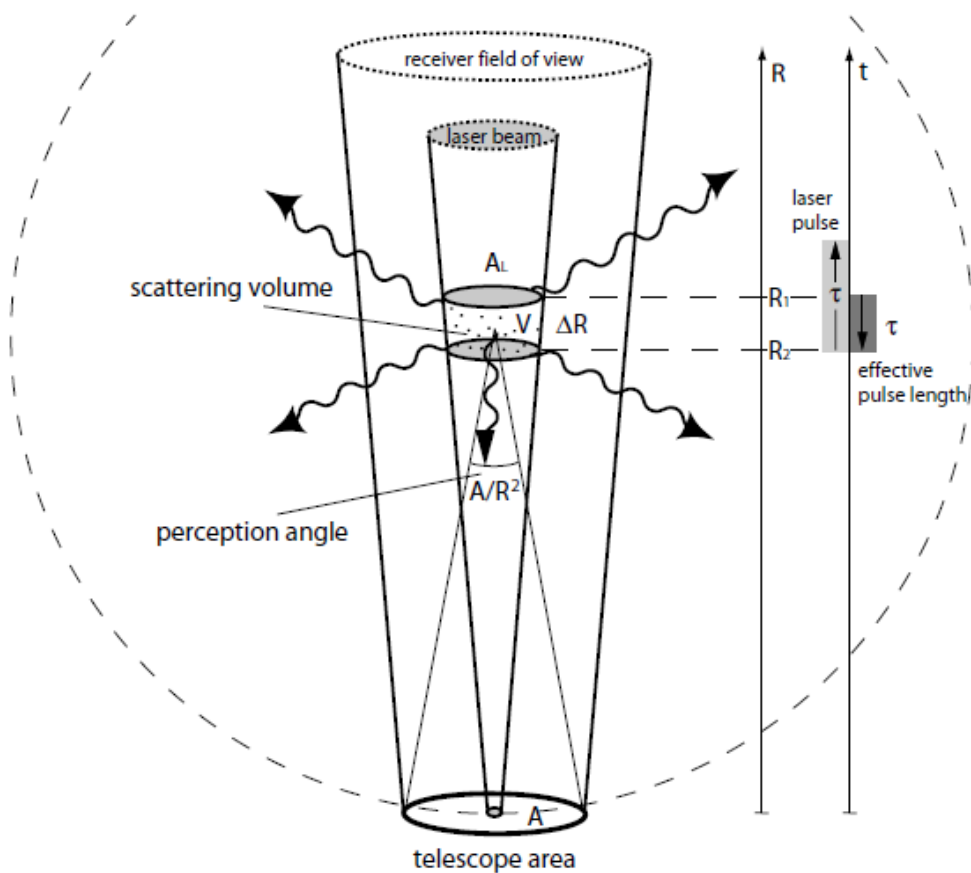
Fig. B1

In a more analytic form the term K is given by the following equation

$$K = P_0 \frac{c\tau}{2} An$$

eq. 2

P_o is the average power of a single laser pulse and τ is the temporal pulse length.

Hence $E_o = P_o * \tau$, is the pulse energy and c*τα is the length of the volume illuminated by the laser pulse at a fixed time. The factor ½ appears because of an apparent "folding" of the laser pulse through the backscatter process. A is the area of the primary receiver optics responsible for the collection of backscattered light (usually the primary mirror of a telescope) and n is the overall system efficiency which includes the optical efficiency of all the elements that transmit and receive light.

The geometric factor G(R) can be given from the following equation:

$$G(R) = \frac{O(R)}{R^2}$$

eq. 3

and includes the laser-beam receiver-field-of-view overlap function O(R) described before and the term R^{-2}. The quadratic decrease $1/R^2$ of the signal intensity with distance is due to the fact that the receiver telescope area makes up a part of a sphere's surface with radius R that encloses the scattering volume. If we imagine an isotropic scattered at distance R, the telescope area A will collect the fraction I_C:

$$\frac{I_C}{I_S} = \frac{A}{4\pi R^2}$$

eq. 4

of the overall intensity I_S scattered into the solid angle 4π . In other words, the solid angle A/R^2 is the perception angle of the Lidar for light scattered at distance R. The factor 4π does not appear explicitly in the Lidar equation because it cancels out by the definition of the backscatter coefficient β as we will see below. It is primarily the $1/R^2$ dependence that is responsible for the large dynamic range of the Lidar signal. If we start detecting a signal with O(R)=1 at a distance of 10 m, the signal will be 6 orders of magnitude lower at 10 km distance just because of the geometry effect. To what extent Lidar is a *range-resolving and remote* measurement technique depends on our ability to compensate for this effect.
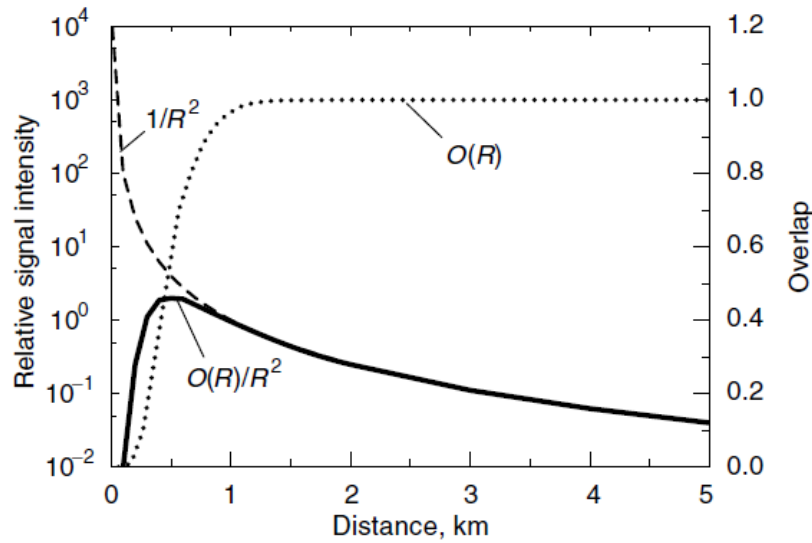
Graph 1: Influence of overlap function O(R), at Lidar signal

B1.1 About Backscatter Coefficient β(R,λ)

The backscatter coefficient β(R, λ) is the primary atmospheric parameter that determines the strength of the Lidar signal. It describes how much light is scattered into the backward direction, i.e., towards the Lidar receiver. In the atmosphere, the laser light is scattered by air molecules and particulate matter, i.e., β (R, λ) can be written as

$$\beta(R,\lambda) = \beta_{mol}(R,\lambda) + \beta_{aer}(R,\lambda) \quad \text{eq.5}$$

Molecular scattering (index mol), mainly occurring from nitrogen and oxygen molecules, primarily depends on air density and thus decreases with height, i.e., backscattering decreases with distance if the observation is made from the ground. Particulate scattering (index aer for aerosol particles) is highly variable in the atmosphere on all spatial and temporal scales. Particles represent a great variety of scatterers: tiny liquid and solid air-pollution particles consisting of, e.g., sulfates, soot and organic compounds, larger mineral-dust and sea-salt particles, pollen and other biogenic material, as well as comparably large hydrometeors such as cloud and rain droplets, ice crystals, hail.

B1.2 About Extinction Coefficient, α(R,λ)

The last term in the Lidar equation, we have to consider the fraction of light that gets lost on the way from the Lidar to the scattering volume and back. The transmission term T(R) can take values between 0 and 1 and is given by

$$T(R,\lambda) = \exp\left[-2\int_0^R a(r,\lambda)dr\right]$$ eq. 6

This term results from the specific form of the Lambert–Beer–Bouguer law for Lidar. The integral considers the path from the Lidar to distance R. The factor 2 stands for the two-way transmission path. The sum of all transmission losses is called light extinction, and α(R,λ) is the extinction coefficient. Extinction can occur because of scattering and absorption of light by molecules and particles.

B1.3 The Lidar Equation

Below is the extensive form of the well known Lidar equitation

$$P(R,\lambda) = P_0 \frac{c\tau}{2} An \frac{O(R)}{R^2} \beta(R,\lambda)\exp\left[-2\int_0^R a(r,\lambda)dr\right]$$

eq. 7.1

Or

$$P(R) = \frac{n \times P_o \times A \times O(R) \times [\beta_{mol}(R) + \beta_{aer}(R)] \times \exp[-2\int_0^R [a_{mol}(r) + a_{aer}(r)]dr}{R^2} + P_{bgr}$$

eq. 7.2

In equation 7.2 wavelength dependence λ have been omitted for simplicity. In addition a new term P_{bgr} is the background noise that comes from atmospheric defused light (daytime) and the electronic noise.

In any form of the eq. 7 has two unknown quantities (β and α). So this is an intrinsic problem of an elastic backscatter Lidar. One has to measure two quantities with only one equation. Several solutions (depending on different assumptions) have been proposed in literature in order to solve the Lidar equation.

Note: Raymetrics Software uses the Inver Klett-Fernard method (Far-end solution)

B2 SUMMARY OF LIDAR PROBLEM SOLUTIONS

There are three basic inversion methods commonly used to find extinction coefficient. These methods are:

B2.1 The Slope Method.

This method is useful for homogeneous atmospheres. In many cases, atmospheric horizontal homogeneity is a reasonable assumption. With the slope method, a mean value of the extinction coefficient over the examined range in a homogeneous atmosphere is obtained.

One can reform the eq. 7.1 at the following form:

$$P(R) = C_0 T_0 \frac{\beta(R,\lambda)}{R^2} \exp\left[-2\int_{R_0}^{R} a(r,\lambda)dr\right] \quad \textbf{eq. 8}$$

C_0 is the system constant and T_0 is an unknown, two-way transmission term from ground to R_0 (R_0 is where the overlap function O(R)=1).

$$T_0(R) = \exp\left[-2\int_{0}^{R_0} a(r,\lambda)dr\right]$$

In a homogeneous atmosphere we can assume that

α(r)=α=constant and β(r)=β=constant

In that case we get

$$P(R) = C_0 T_0 \frac{\beta(R,\lambda)}{R^2} \exp\left[-2(R-R_0)a\right]$$

Then we define the Range Corrected Signal as:

$$RCS(R) \equiv P(R)R^2 = C_0 \beta e^{-2aR},$$

Taking the natural logarithm we get the following (singe β and α are assumed range independed for homogeneous atmospheres:

$$Z(R) = B - 2\alpha R \quad \textbf{eq. 9}$$

Where

$$B \equiv \ln(C_0 \beta)$$

The linear dependence of Z(R) on range R, is a key factor when seeking the simplest solution to the Lidar equation. It allows determination of the α by linear square fit. In addition the estimate of the standard deviation of the linear fit for Z(R) can be used to estimate the degree to which the assumption of atmospheric homogeneity is valid.

Note: As always before you apply such a solution you have first to subtract background noise from the Lidar signals

B2.2 Inver Klett-Fernard method (Raymetrics Software)

$$\beta(R) = \frac{RCS(R) * \exp\left(2*(L-L_{mol})* \int\limits_{R}^{R_{ref}} \beta_{mol}(r)dr\right)}{\dfrac{RCS(R_{ref})}{C*\beta_{mol}(R_{ref})} + 2*L* \int\limits_{R}^{R_{ref}} RCS(R')*\exp\left(2*(L-L_{mol})* \int\limits_{R'}^{R_{ref}} \beta_{mol}(R'')dR''\right)dR'}$$

eq.10

Where

$$C = \frac{\beta_{mol}(R_{ref}) + \beta_{aer}(R_{ref})}{\beta_{mol}(r)}$$ **eq.11**

if the reference point R_{ref} is in a clean atmosphere (for example free troposphere without aerosols) then it is safe to assume that $\beta_{aer}(R_{ref})=0$ so C=1

$$L_{mol}(r) = \frac{a_{mol}(r)}{\beta_{mol}(r)} = \frac{8\pi}{3}$$ **eq.12**

and

$$L(R) = \frac{a_{aer}(R)}{\beta_{aer}(R)} = const$$ **eq.13**

L(R) is the aerosol Lidar ratio and depends on particle size distribution, complex refractive index, the shape of aerosols, relative humidity height and wavelength.

B3 AN INTRODUCTION TO RAMAN LIDAR

As we saw above by measuring only the elastically backscattered signal we have to make an assumption for the Lidar ratio in order to solve the Lidar equation. This introduces errors since we know that the Lidar ratio in not constant and depends on height relative humidity (which varies strongly by height) and other microphysical parameters.

However by measuring simultaneously the inelastically (Raman) backscattered signal by Nitrogen we get two equations with two unknowns. So the problem now can be solved. The determination of the particle extinction coefficient from molecular backscatter signal is rather straightforward and there is no need for Lidar-Ratio assumptions. However it should be pointing out that Raman signals can be 1000 times weaker than elastic signals so the background noise reduce significantly the range of measurements of such signals. Practically Raman signals can detect only at night time.

As we show previously the power received from the distance R for an elastic channel is given by the equation:

$$P(R) = \frac{n \times P_o \times A \times O(R) \times [\beta_{mol}(R) + \beta_{aer}(R)] \times \exp[-2\int_0^R [a_{mol}(r) + a_{aer}(r)]dr}{R^2} + P_{bgr} \quad 7.2$$

For simplicity we rewrite the equation in the following form (for the $R>R_0$ where $O(R)=1$)

$$P(R,\lambda_L) = \frac{C \times [\beta_{mol}(R,\lambda_L) + \beta_{aer}(R,\lambda_L)] \times \exp[-2\int_{R_0}^R [a_{mol}(r,\lambda_L) + a_{aer}(r,\lambda_L)]dr}{R^2} \quad \textbf{eq. 14}$$

where λ_L is the laser emitted wavelength.

The power received from distance R from a Raman channel is given from the following equation:

$$P(R,\lambda_R) = \frac{C \times \beta(R,\lambda_L,\lambda_R)}{R^2} \exp\left[-\int_0^R [a(\lambda_L,r) + a(\lambda_R,r)]dr\right] \quad \textbf{eq. 15}$$

$$\beta(R,\lambda_L,\lambda_R) = N_R(R)\frac{d\sigma(\lambda_L,\lambda_R,\pi)}{d\Omega} \quad \textbf{eq. 16}$$

Where λ_R is the Raman shifted wavelength from the Raman-active gas (usually nitrogen at 387 nm)

The eq.15 has two main differences from eq. 14. First there is not the -2 factor since the extinction in that case happens only one way (backwards to the Lidar receiver). The Raman backscatter coefficient (eq.16) is given by the molecular number density N(R) of the Raman-active gas (usually nitrogen at 387 nm) and the differential Raman cross section for the backward direction.

By using the above three equation we can get:

$$a_p(\lambda_L,R) = \frac{\dfrac{d}{dr}\left[\ln\dfrac{N_R(R)}{R^2 P(R)}\right] - a_{mol}(\lambda_L,R) - a_{mol}(\lambda_L,R)}{1 + \left(\dfrac{\lambda_L}{\lambda_R}\right)^k}$$

eq. 17

The above equation is valid for $R>R_o$ in other worlds where O(R) = 1

In addition:

$$a(\lambda_L,R) = a_{aer}(\lambda_L,R) + a_{mol}(\lambda_L,R) \quad \text{and} \quad a(\lambda_R,R) = a_{aer}(\lambda_R,R) + a_{mol}(\lambda_R,R)$$

and

$$\frac{a_{aer}(\lambda_L,R)}{a_{aer}(\lambda_R,R)} = \left(\frac{\lambda_R}{\lambda_L}\right)^k$$

The aerosol backscatter coefficient is given from the following equation:

$$\beta_{aer}(\lambda_L,R) = -\beta_{mol}(\lambda_L,R) + \left[\beta_{aer}(\lambda_L,R_{ref}) + \beta_{mol}(\lambda_L,R_{ref})\right] \times \frac{P(\lambda_R,R_{ref})P(\lambda_L,R)N_R(R)}{P(\lambda_L,R_{ref})P(\lambda_R,R)N_R(R_{ref})} \times$$

$$\frac{\exp\left\{-\int_{R_{ref}}^{R}\left[a_{aer}(\lambda_R,r) + a_{mol}(\lambda_R,r)\right]dr\right\}}{\exp\left\{-\int_{R_{ref}}^{R}\left[a_{aer}(\lambda_L,r) + a_{mol}(\lambda_L,r)\right]dr\right\}}$$

Eq.18

Once more usually at R_{ref} $\quad \beta_p(\lambda_L,R_{ref}) + \beta_{mol}(\lambda_L,R_{ref}) \cong \beta_{mol}(\lambda_L,R_{ref})$

B3.1 Molecular backscatter coefficient

In any case (elastic or Raman backscatter liars) one has to calculate the molecular backscatter coefficient.

$$a_m(R) = N(R)\sigma = N(R)\frac{24\pi^3}{\lambda^4 N_s^2}\frac{\left(n_s^2(\lambda)-1\right)^2}{\left(n_s^2(\lambda)+2\right)^2}F_k$$

Since

$$L_{mol} = \frac{a_m}{\beta_m} = \frac{8\pi}{3}$$

Then

$$\beta_m(R) = N(R)\frac{9\pi^2}{\lambda^4 N_s^2}\frac{\left(n_s^2(\lambda)-1\right)^2}{\left(n_s^2(\lambda)+2\right)^2}F_k \quad \textbf{Eq.19}$$

The values for n_s and F_k can be taken from the table below

Λ	ns-1	Fk	ns	(ns^2-1)^2/(ns^2+2)^2
nm	x1E-8			
266		1,06	1,000294650	3,85823E-08
289		1,057	1,000291880	3,78603E-08
299		1,056	1,000290860	3,75961E-08
308	29047,7	1,05575	1,000290513	3,75065E-08
316		1,0551	1,000289140	3,71528E-08
351	28602,7	1,05308	1,000285983	3,63460E-08
354,814	28572,4	1,0529	1,000285745	3,62854E-08
355	28570,2	1,05289	1,000285745	3,62854E-08
386,8	28350,2	1,05166	1,000283480	3,57125E-08
400	28275,2	1,05126	1,000282764	3,55325E-08
407,663	28235,1	1,05105	1,000282407	3,54427E-08
510,6	27869,4	1,04922	1,000278711	3,45212E-08
532	27819,9	1,04899	1,000278235	3,44032E-08
532,221	27819,4	1,04899	1,000278235	3,44032E-08
607,6	27686,3	1,04839	1,000276804	3,40504E-08
710	27570,4	1,0479	1,000275731	3,37870E-08
800	27503,8	1,04763	1,000275016	3,36119E-08
1064	27397,5	1,04721	1,000273943	3,33502E-08
1064,442	27397,4	1,04721	1,000273943	3,33502E-08

N(R) is the atmospheric number density and can be easily calculated by using several atmospheric models or by using Radiosonde measurements.

$$N(R) = N_s \frac{T_o}{P_o} \frac{P(R)}{T(R)}$$

N_s molecular number density for standard atmospheric conditions at ground lever. $N_s = 2.5477 \times 10^{19} \text{cm}^{-3}$, $P_o = 1013.25$ hPa and $T_o = 15\ ^\circ\text{C}$

B3.2 Other Lidar Equation Solution

B3.2.1 Solutions for one component atmospheres:

In a more generic form the equation 8 can be written as below:

$$P(R) = C_0 T_0 \frac{\beta_{aer}(R) + \beta_{mol}(R)}{R^2} \exp\left[-2 \int_{R_0}^{R} [a_{aer}(r) + a_{mol}(r)] dr \right] \quad \textbf{Eq. 20}$$

Now we define two new quantities

$$\overline{L}(R) = \frac{\beta_{aer}(R)}{a_{aer}(R)}$$

Where

$$\beta_{aer}(R) \equiv \beta_{aer}(R, \theta = \pi)$$

backscatter coefficient (θ=π) and

$$a_{aer}(R) = \beta_{aer}(R, \theta) + \alpha_{aer}^{A}(R)\ .$$

So we can write

$$\overline{L}(R) = \frac{\beta_{aer}(R)}{\beta_{aer}(R, \theta) + a_{aer}^{A}(R)}$$

Here the extinction is split to scattering at all direction and to extinction because the absorption processes. In the same way we define

$$\overline{L}_{mol}(R) = \frac{\beta_{mol}(R)}{\beta_{mol}(R, \theta) + a_{mol}^{A}(R)}$$

In the case of one component atmosphere with no absorption. The solution of the Lidar equation can be written as

$$a_{aer}(R) = \frac{RCS(R)}{C' - 2\int\limits_{R_0}^{R} RCS(r)dr}$$

eq.21

Where

$$C' = C_0 T_0 \overline{L}_{aer}$$ eq. 22

for a single component atmosphere well mixed $\overline{L}_{aer}$ does not depend on range (R).

To find aerosol extinction coefficient from eq. 21 we need to know C' (which called sometimes Lidar calibration constant). This is not an easy task. Even if we know C_0 the other two parameters can be determined only during measurements. However in order to calculate α_{aer} we need two know only the product which means only the C' and not the individual components of eq. 22. The simplest way to determine the C' is to establish a boundary condition of the equation at some point of the Lidar measurement range. This makes possible to find the constant C' and then to use it to determine α_{aer} over the total measurement range.

If we know the value of α_{aer} at a specific point R_{ref} which is inside the measuring range then

$$C' = \frac{RCS(R_{ref})}{a_{aer}(R_{ref})\exp\left[-2\int\limits_{R_0}^{R_{ref}} RCS(r)dr\right]}$$

we remind here that R_0 is the range where O(R)=1

by replacing C' into the eq. 21 we get finally

$$a_{aer}(R) = \frac{RCS(R)}{\dfrac{RCS(R_{ref})}{a_{aer}(R_{ref})} + 2\int\limits_{R}^{R_{ref}} RCS(r)dr}$$

Far range solution $R_{ref} > R$

$$a_{aer}(R) = \frac{RCS(R)}{\dfrac{RCS(R_{ref})}{a_{aer}(R_{ref})} - 2\int\limits_{Rref}^{R} RCS(r)dr}$$

Near range solution $R_{ref} < R$ (and close to R_0)

Eq. 23

The most stable solution for α_{aer} is the far range solution. Such solution is given by Klett).

Optical Depth Solution

Another way to solve the problem is to use total path transmittance over the Lidar operating range as a boundary solution. Once more this solution applied with the assumption that the Lidar ratio is constant (one component atmosphere). We define the upper Lidar measuring limit R_{max} which is usually taken as the range at which the signal-to-noise ratio reaches a certain threshold value. In this solution the two way transmittance T_{max} is used as a boundary solution.

$$T_{max} = \exp\left[-2\int\limits_{R_0}^{R_{max}} \alpha_{aer}(r)dr \right]$$ **eq. 24**

$$a_{aer}(R) = \frac{1}{2} \frac{RCS(R)}{\dfrac{I_{max}}{1-T_{max}} - \int\limits_{R_0}^{R} RCS(r)dr}$$ **eq. 25**

$$I_{max} = \int\limits_{R_0}^{R_{max}} RCS(r)dr$$ **eq. 26**

If we define the aerosol optical depth as

$$AOD = \int\limits_{R_0}^{R_{max}} \alpha_{aer}(r)dr$$ **eq.27**

Then we get $T_{max} = \exp(-2AOD)$

T_{max} is the quantity we need to know in order to calculate α_{aer}. For real atmospheric conditions is a finite positive value ($0 < T_{max} < 1$).

B3.2.2 Solutions for Two component atmospheres:

$$P(R) = C_0 T_0 \frac{\overline{L}_{aer}(R) * a_{aer}(R) + \overline{L}_{mol}(R) * a_{mol}(R)}{R^2} \exp\left[-2\int_{R_0}^{R}[a_{aer}(r) + a_{mol}(r)]dr\right]$$

Far-end boundary point solution

$$a(R) = \frac{RCS(R)}{\dfrac{RCS(R_{ref})}{a(R_{ref})} + 2\int_{R}^{R_{ref}}RCS(r)dr} \qquad \textbf{eq.28}$$

where

$$a_{aer}(R) = a(R) - L(R)\beta_m(R) \quad \textbf{eq.29}$$

In case that Rref is in free troposphere (atmosphere without aerosols) then

$$a_{aer}(R_{ref}) = 0 \quad \text{and} \quad a(R_{ref}) = L(R_{ref})\beta_m(R_{ref})$$

Optical Depth Solution:

$$a_{aer}(R) = \frac{1}{2}\frac{RCS(R)}{\dfrac{I_{max}}{1 - V_{max}^2} - \int_{R_0}^{R}RCS(r)dr}$$

Where once more the Imax is given from eq.26 and

$$V_{max} = T_{max}\exp\left[-(\frac{L(R)}{L_m} - 1)\int_{R_0}^{R_{max}}a_m(r)dr\right]$$

$$T_{max} = \exp\left[-\int_{R_0}^{R_{max}}a(r)dr\right] \quad \text{if we know the Optical Depth}$$

$$OD = \int_{R_0}^{R_{max}}a(r)dr$$

Then we can calculate T$_{max}$ and V$_{max}$

B4 SIGNAL TO NOISE RATIO

Theory

The SNR of the echo Lidar signal is obtained by the following equation:

$$S/N = \frac{Ips}{\sqrt{2eFB(Ips + Ipb + Id)}}$$

Where Id is the PMT's anode dark current (with typical values of about 1nA), I_{pb} is the anode current due to background radiation signal, I_{ps} is the anode average output current of the echo Lidar signal, B is the bandwidth of the system, e is the electric charge and F is the noise component (noise figure) produced in the multiplication process in the PMT. F indicates how much the signal to noise ratio will degrade between the input and the output of the PMT.

Usually $F = \frac{\delta}{\delta + 1}$ where δ is the secondary emission ratio and is a function of the interstate voltage of dynodes. Typical values for δ are between 3 and 7.

The output current at the anode $I_p = \mu * I_c$ where μ is the gain and changes in relation to the supply voltage V to the PMT. Typical values are around 2×10^6.

I_c is the photocurrent produced at the photocathode of the PMT and is calculated from the following equation.

$$I_c = S_c P \quad \text{(A)},$$

Where P is the incident radiant flux (W) and S_c is the cathode radiant sensitivity (A/W). Typical values for S_c are around 120 mA/W

The radiation power (W) arising from natural sources (background radiation) accepted by the receiver optics can be expressed in the form:

$$P_b = \chi A \Omega S_b(\lambda) K_0(\lambda)$$

χ is overall optical system efficiency, A is the area of primary receiver optics responsible for the collection of backscattering light (m^2), Ω is its acceptance solid angle, and $K_0(\lambda)$ is termed the filter function of the receiver system.

$$K_0(\lambda) \equiv \int_{\Delta\lambda} \xi(\lambda')d\lambda'$$

The S_b represents the spectral radiance of the sky background ($Wm^{-2}sr^{-1}nm^{-1}$).

At wavelengths within the visible range, a typical value for S_b is about 0.1 (Pratt, 1969) at sea level for a zenith angle of 45 degrees, with excellent visibility (for moonlight its value is approximately $1x10^{-12}$). For 355nm it is about $1x10^{-4}$.

The power of the echo Lidar signal corresponding to a distance R for a Raman channel can be written as:

$$P_{N2}(R) = \frac{\chi E_0 AQ(R)cN_{N2} \times \frac{d\sigma}{d\Omega}\Big|_{N2}}{R^2} \exp\left[-\int_{R_0}^{R}\left[a_{aer}(x,\lambda_L)+a_{mol}(x,\lambda_L)+a_{aer}(x,\lambda_{N2})+a_{mol}(x,\lambda_{N2})\right]dx\right]$$

E_0 is the energy of a single laser pulse (J), c is the velocity of light (m/s). The term Q(R) is the laser beam receiver field of view overlap function, describing the range-dependent measurement geometry, and can take values from 0 to 1. N is the atmospheric number density of Nitrogen (for simulation we use the USSA76 standard atmospheric model) and dσ/dΩ is the Raman backscatter cross section (1000 times smaller than elastic backscatter cross section).

$α_{mol}(R,λ)$ is the extinction coefficient for laser and Raman wavelengths and is estimated from USS76 standard atmospheric models.

Extinction at the Raman wavelength is estimated from the following equation.

$$a_{aer}(R,\lambda_{N_2}) = \frac{a_{aer}(R,\lambda_L)}{\left(\dfrac{\lambda_{N_2}}{\lambda_L}\right)^{\gamma}}$$

For the simulation the following equation was used for calculating the backscatter coefficient:

$$\beta_{aer} = \left\{ 2.47 \times 10^{-6} \exp\left(\frac{-R}{2000}\right) + 5.13 \times 10^{-9} \exp\left(-\frac{\left(\frac{R}{1000} - 20\right)^2}{36} \right) \right\} \left(\frac{532}{\lambda}\right)$$

(Horst Jager, et. al., Appl. Opt., 30(1), pp. 127-136, 1991)

In the next step we introduced the particle extinction to backscatter ratio (Lidar Ratio):

$$L_{aer}(\lambda, R) = \frac{\alpha_{aer}(\lambda, R)}{\beta_{aer}(\lambda, R)}$$ in analogy to molecular Lidar ratio

$$L_{mol}(\lambda) = \frac{\alpha_{mol}(\lambda)}{\beta_{mol}(\lambda)} = \frac{8\pi}{3} sr$$

In contrast to the molecular Lidar ratio, the particle Lidar ratio in general is range dependent because it depends on the size distribution, shape and chemical composition of the particles. For our simulation we used a constant value of 35 sr.

For horizontal measurement simulation we used the following equation:

$$a_{aer} = 2 \times 10^{-4} \left(\frac{532}{\lambda}\right)$$ for λ=355 nm

This gives a value of:

$\alpha_{aer}=3 \times 10^{-4}$ (1/m) and $\beta_{aer}=8.5 \times 10^{-6}$ [1/(m*sr)]

B5 CALIBRATION METHODS

A Lidar system can be divided in two main functional units: the opto-mechanical transmitter-receiver unit, and the electronic data acquisition, each of which needs special tools for testing. The main problem of the transmitter-receiver unit is the a priori unknown range-dependent transmission, which enters as a factor into the Lidar equation. Usually only the incomplete overlap between the fields of view of the transmitter and the receiver is considered by the so-called overlap function, but in reality several other opto-mechanical features potentially have an influence, e.g. the incident angle dependence of the transmission of optical coatings of beam splitters and interference filters, vignetting of the light beam by mechanical apertures, and the spatial inhomogeneity of the sensitivity of the light detectors.

Methods that Raymetrics follows to calibrate and test its instruments:

Rayleigh fit / Matching method

The transmitter-receiver overlap has its main impact in the near range of the signal, but if the transmitter is not well aligned, the far range of the signal might also be affected. A well known check for the latter problem is a fit of the far range Lidar signal, assuming clear air in the upper troposphere, to the calculated clear air Rayleigh signal, the so called "Rayleigh fit" or "matching method". Raymetrics provides software tools for easy Rayleigh fit calibration. This calibration procedure can be done in the field very easily and takes less than one minute.

Telecover Checkup tool

Before the shipment of any of our Lidar systems, extensive performance tests and calibration procedures are performed. One of the tools that Raymetrics uses for checking Lidar instrumentation is the newly developed "telecover test", which is strongly suggested by EARLINET.

Raymetrics in addition provides all of the hardware and software required for such tests with all of our Lidar systems.

Electronic data acquisition

Light measurement is done in two ways in Lidar systems: in analogue mode, measuring the electron current from a detector after sufficient amplification with preamplifiers, and/or by means of counting amplified pulses of individual photons (photon counting method). Raymetrics uses special pulse generator techniques to calibrate and adjust analogue and photon counting measurements. It is well known, especially in analogue detection mode, that the main problem is various signals inducing signal distortions. If these distortions are neglected, errors of the Lidar signal inversion on the order of magnitude of 100% can result, although the distortion might be very small compared to the maximum signal. The Lidar signal should only be used over ranges where these errors are acceptable. This can be tested with a specially designed pulse generator.

Calibrating the "ranging"

In Lidar technologies two errors commonly occur if special attention is not paid:

There is always a delay between the emitted pulse and the data acquisition process, especially for analogue mode due to delays at the pre-amplification process. But this is true as well in Photon Counting mode, although the phenomenon is not so pronounced. These delays reduce the accuracy of ranging of a Lidar.

Raymetrics uses special optical triggering that eliminates any delay in photon counting mode. In addition we use a near range target with a defined distance to the Lidar that produces a signal peak for Zero-bin calibration in analogue and photon counting modes. If such a target is not available we use a special procedure with an optical fibre to calibrate the "ranging" of our systems.

Calibration method for depolarization Lidar

For calibration of the linear depolarization channels there are several methods, such as:

1. Rayleigh method (0°)

2. 45° method

3. +/- 45° method

4. Multi-rotation-angle fit method

5. Three signal method

6. Unpolarized light source

1) Rayleigh method (0°)

This method is based on knowledge of the molecular linear depolarization ratio in an aerosol-free calibration range. However, since we can never be sure that the aerosol free region that we have assumed really is free, this method introduces many errors. It has been proved that this can give errors up to 260%. In addition this method cannot provide a range dependent calibration factor.

2) 45° method

With this method a 45° angle is produced between the laser polarization plane and the PBC. Rotation can be achieved mechanically, by using a half-wave plate or by the rotating of a polarizing sheet filter. This method is fast and has relatively few errors. However it gives large errors when there is a small angle difference between the laser polarization plane and the PBC at the default position (0°).

3) +/- 45° method

With this method the polarization plane of the PBC is turned +45 and -45 degrees from the default position (0 ^{o}). This method is fast accurate and it is 100 times less sensitive to errors produced by a small angle γ from the default position (0 ^{o}) compared to the 45° method.

4) Multi-rotation-angle fit method

With this method the PBC is rotated to several angles. It is a good method but it is time consuming and sensitive to atmospheric changes during the calibration procedure. In addition it exhibits low accuracy of the calibration constant.

5) Three signal method (detection of the total, cross and parallel signals separately)

With this method the Lidar detects a fraction of incoming light and the rest is beam-split by a Polarizing Beam Splitter. However such a set-up increases the cost of the instrument significantly (three deferred detected channels instead of two) and depends on large differences in δ(R).

6) Unpolarized light source

The beam path of rays from an unpolarized light source through the receiver optics is used. This method has many disadvantages and introduces errors.

Summary of theory for depolarization calibration

The total backscattering power P(r) is given by the Lidar equation:

$$P(R) = \frac{\chi E_0 A Q(R) c \beta(R,\lambda) T(R,\lambda)}{2R^2}$$

For simplicity we form the equation in the following way:

$$P(r) = C \frac{\beta(r)T(r)}{r^2}$$

The backscatter power **before the PBC** can be written as:

$$P(r) = C_{II} \frac{\left(\beta_{II}^{aer} + \beta_{II}^{mol}\right)T(r)}{r^2} + C_\perp \frac{\left(\beta_\perp^{aer} + \beta_\perp^{mol}\right)T(r)}{r^2}$$

The linear volume depolarization ratio δ^v is given by:

$$\delta^v(r) = \frac{\beta_\perp(r)}{\beta_{II}(r)} = \frac{P_\perp(r)}{P_{II}(r)}$$

However the measured signal ratio δ^* is given by:

$$\delta^*(r) = \frac{P_R(r)}{P_T(r)}$$

Where P_R and P_T are the reflected and transmitted signals from the PBC and are the ones which are recorded.

$$P_R(\phi) = \left[P_p(\phi)R_p + P_s(\phi)R_s\right]V_R \text{ and } P_T(\phi) = \left[P_p(\phi)T_p + P_s(\phi)T_s\right]V_T$$

Where V_R and V_T include the optical transmittances of the receiver and the electronic amplification in each channel.

In addition the power components with respect to the incident plane of the PCB are:

$$P_s(\phi) = P_{II} \sin^2(\phi) + P_\perp \cos^2(\phi) \quad \text{and} \quad P_p(\phi) = P_{II} \cos^2(\phi) + P_\perp \sin^2(\phi)$$

Φ is the angle between the plane of polarization of the laser and the incident plane of the PCB.

Combining the above equations we get:

$$\delta^*(\phi) = V^* \frac{\left[1 + \delta^\nu \tan^2(\phi)\right] R_p + \left[\delta^\nu + \tan^2(\phi)\right] R_s}{\left[1 + \delta^\nu \tan^2(\phi)\right] T_p + \left[\delta^\nu + \tan^2(\phi)\right] T_s}$$

Where $V^* = V_R/V_T$ and R, T are the transmittance and reflectance of the PBC.

In order to retrieve the total backscatter power P and δ^ν from the measurements we need to know the V^* which is the calibration constant and we can get it through several methods.

For φ=0 we get:

$$V^* = \frac{T_p + \delta^\nu T_s}{(R_p + \delta^\nu R_s)} \delta^*(0^0)$$

If we know δ^ν for some range of the Lidar signal, we can determine V* (for example by using the linear depolarization ratio of air molecules). However a very low amount of strong depolarization aerosols, in the assumed clean range, causes very big errors on δ^ν and thus of V*. So this method cannot be used for reliable data.

Another method is to turn 45 degrees (45-calibration method). φ=45 in that case:

$$V^* = \frac{T_p + T_s}{R_p + R_s} \delta^*(45)$$

As can be seen, the calibration constant does not depend on δ^v. However it is very difficult and practically impossible to measure exactly the angle between the laser and the PBC. An error γ of the order of 1 degree causes a large error in V*.

With the proposed method we calculate V* from two subsequent measurements at exactly 90 degrees (φ=45+γ and φ=-45+γ) in that case:

$$V^* = \frac{T_p + T_s}{R_p + R_s} \sqrt{\delta*(45) + \delta*(-45)}$$

With this method (+/- 45 calibration method) it can be shown that the errors γ compensate each either over a large range of γ.

Retrieving of the linear depolarization ratio δ^v and linear aerosol depolarization ratio δ^p

If we know the calibration constant then:

$$\delta^v(r) = \frac{P_\perp(r)}{P_{\mathrm{II}}(r)} = \frac{P_s(r)}{P_p(r)} = \frac{\dfrac{\delta^*(r)}{V^*(r)}T_p - R_p}{R_s - \dfrac{\delta^*(r)}{V^*(r)}T_s}$$

The total echo power is given by:

P(r)=V*(r)P$_T$(r)+P$_R$(r)

$$\delta^{aer} = \frac{(1+\delta^m)\delta^v R - (1+\delta^v)\delta^m}{(1+\delta^m)R - (1+\delta^v)}$$

δ^m can be determined with high accuracy from radiosonde data (or by using a model).

$$R = \frac{\beta^m + \beta^{aer}}{\beta^m}$$

Where β^{aer} is retrieved from the total signal P using the Fernald/Klett inversion with a reference value $\beta^{aer}(r_{ref})$ at a reference range and known range dependent Lidar ratio L(r) (retrieved by an additional measurement with a Raman Channel).

Theory and the Inversion Problem of Lidar technique

The power of the echo Lidar signal corresponding to a distance R can be written as

$$P(R) = \frac{\chi E_0 A Q(R) c \beta(R,\lambda) T(R,\lambda)}{2R^2}$$

eq. 1

E_0 is the energy of a single laser pulse (J), c is the velocity of light, m/s. The term Q(R) is the laser beam receiver field of view overlap function, describing the range-dependent measurement geometry and can take values from 0 to 1. The β(R,λ) is the backscatter coefficient (1/(m*sr)) and it stands for the ability of the atmosphere to scatter light backwards. T(R) is the transmission term and describes how much light gets lost on the way from the Lidar to distance R and back.

$$T(R,\lambda) = \exp\left[-2\int_0^R \alpha(R',\lambda)dR' \right]$$ The factor 2 stands for the two-way transmission path.

β(R,λ) = β$_{mol}$(R,λ)+β$_{aer}$(R,λ) and α(R,λ) = α$_{mol}$(R,λ)+α$_{aer}$(R,λ)

α(R,λ) is the extinction coefficient.

Here we can rewrite the Lidar equation as

$$P(R) = C_0 \frac{\beta_\pi(R,\lambda)}{R^2} \exp\left[-2\int_0^R a(R,x)dx \right]$$

The factor C_0 is the Lidar system constant. One of the limitations of this equation is that includes more than one unknowns. Therefore, it is considered to be mathematically ill posed and thus indeterminate. Such an equation cannot be solved without either a priori assumption about atmospheric properties along the Lidar range or the use of independent measurements of the unknown atmospheric parameters. Usually the use of a priori assumptions is the most common method.

Generally, the extinction coef. profile is the parameter of primary interest. A potential way to overcome this problem might be to make independent measurements of backscattering by the use of a combined Raman-elastic backscatter Lidar method (This method is used at our Raman Lidar Systems).

In order to extract a α(R) profile the calibration factor C_0 must be known and in addition, the relationship between backscatter and total extinction must in some way be established (Raman Lidar) or assumed (Klett solution)

$$P(R) = C_0 T_o^{\ 2} \frac{\beta_\pi(R,\lambda)}{R^2} \exp\left[-2\int_{R_0}^{R} a(R,x)dx\right]$$ eq. 2

Where

$$T_o = \exp\left[-\int_{0}^{R_0} a(R,x)dx\right]$$

Methods-Solution for the inversion of Lidar equation and Lidar calibration

Intro

The simplest method is based on an absolute calibration of the Lidar system can use only Co, whereas the other factors in the Lidar equation remains unknown (for example the two way atmospheric transmittance over the incomplete overlap zone). All self-sufficient elastic Lidar signal inversion methods developed to date require the use of one or more a priori assumptions that are chosen according to the particular optical situation. There are three basic inversion methods that Raymetrics uses depending an the Lidar type and the applications:

1. Slope method: This method is used for homogeneous atmospheres. In many of the cases, horizontal homogeneity is a reasonable assumption. With the slope method a mean value of α over the examined range in a homogeneous atmosphere is obtained.

2. The boundary point solution: This requires knowledge of or an a priori estimate of α at some point within the measurement range.

3. The optical depth solution: Here the total optical depth or transmittance over the Lidar measurement range should be known or assumed. In case of a clear and moderately turbid atmosphere the total α (or optical depth) is found be a solar radiometer.

In case of a two component atmosphere (with is the most usual case especially for vertical pointing systems)

The Lidar equation can be written as:

$$P(R) = C_0 T_o^2 \frac{\beta_{aer}(R) + \beta_{mol}(R)}{R^2} \exp\left[-2\int_{R_0}^{R}[a_{aer}(x) + a_{mol}(x)]dx\right]$$

In that case the backscatter coefficient can be found from the following equation:

$$\beta_{aer}(R) = -\beta_{mol}(R) + \frac{RCS(R)\exp\left\{2\int_{R}^{Rref}\left[L_{aer}(R) - \frac{8\pi}{3}\right]\beta_{mol}(x)dx\right\}}{C + 2\int_{R}^{Rref}\left[L_{aer}(x)RCS(x)\exp\left(\int_{x}^{Rref}\left[L_{aer}(z) - \frac{8\pi}{3}\right]\beta_{mol}(z)dz\right)\right]dx}$$

This equation is solved iteratively downwards and gives the calibration constant of the instrument

$$C = \frac{RCS(R_{ref})}{\beta_{aer}(R_{ref}) + \beta_{mol}(R_{ref})}$$

Calibration at height R_{ref} gives the system constant C.

Hardware solution to the inversion problem

Use of Nitrogen Raman scattering for extinction measurements

Similar to an elastic Lidar, a Raman channel detects the inelastic backscatter Raman shifted radiation. Atmospheric gases like nitrogen and oxygen interact with the emitted radiation via the Raman Scattering process, causing light of longer wavelengths to be scattered. Thus in addition to elastically backscattered signal an extra backscattered wave-shifted component is detected. Because of the small value for the cross-sections of Raman scattering (so the small backscatter coefficient) the number of photons returning to the Lidar is small. **Because the probability of Raman scattering is proportional to λ^{-4} the use of short wavelengths increases the magnitude of signal.**

In addition the discrimination of Raman Photons from the background light is a problem. So operating at UV where the background radiation is smaller, it is strongly suggested. Since deep UV is strongly absorbed by Ozone and because the molecular scattering is reduced at longer wavelengths the optimum solution is around 350 nm. However discriminating Raman scattered photons from solar background is still an issue and requiring special measures. If the system is expected to operate during the day, the use of extremely narrow field of view in the receiving optics is required. For biaxial system this is almost impossible since the overlap is getting too high. In addition the system is

getting susceptible to misalignments which are not good for an operational Lidar that have to be moved.

$$P_{N2}(R) = C_{N2} \frac{Q(R)N_{N2} \times \frac{d\sigma}{d\Omega}\Big|_{N2}}{R^2} \exp\left[-2\int_{R_0}^{R}\left[a_{aer}(x,\lambda_L)+a_{mol}(x,\lambda_L)+a_{aer}(x,\lambda_{N2})+a_{mol}(x,\lambda_{N2})\right]dx\right]$$

Finally we can get

$$a_{aer}(R,\lambda_L) = \frac{\frac{d}{dR}\left[\ln\left(\frac{N_{N2}}{RCS_{N2}(R)}\right)\right]-a_{mol}(x,\lambda_L)-a_{mol}(x,\lambda_{N2})}{1+\left(\frac{\lambda_L}{\lambda_{N2}}\right)^{\gamma}}$$

α_{mol} are well known and can be found from Rayleigh scattering theory. The dominator corrects for the small difference in particulate attenuation between the laser and Raman scattered wavelengths. In horizontal direction for visibility from 3 to 20 km it is close to 1.3.

Finally when the Raman technique is used, the aerosol backscatter coef can be determined by reference to the signal at some height. The conventional assumption is made of the existence of a aerosol free area somewhere within Lidar measurements range $\beta_{aer}(R_{ref})=0$.

$$\beta_{aer}(R,\lambda_L) = -\beta_{mol}(R,\lambda_L)+\left[\beta_{aer}(R_{ref},\lambda_L)+\beta_{mol}(R_{ref},\lambda_L)\right]\frac{P(R_{ref},\lambda_{N2})P(R,\lambda_L)N_{N2}(R)}{P(R_{ref},\lambda_L)P(R,\lambda_{N2})N_{N2}(R_{ref})}\exp\left[-\int_{R}^{R_{ref}}\left[a_{total}(x,\lambda_L)-a_{total}(x,\lambda_{N2})\right]dx\right]$$

Usually at R_{ref} $\beta_{aer}(R_{ref},\lambda_L)+\beta_{mol}(R_{ref},\lambda_L) \cong \beta_{mol}(R_{ref},\lambda_L)$

B6 POLARIZATION LIDAR BASICS

B6.1 Introduction

B6.1.1 Aerosols' Properties And Depolarization

Shape, size distribution and composition of aerosol particles influence their scattering characteristics and thus the radiative impact. **The polarization Lidar technique** (Sassen, 1991; Sassen, 2005) is a well-established method to distinguish ice clouds from water clouds and to identify layers with ice crystals in mixed–phase clouds. Freudenthaler et al. (1996) applied a scanning polarization Lidar to study the evolution of contrails. The technique has been used to identify the type of polar stratospheric clouds (Sassen, 2005) and volcanic ash in the troposphere and stratosphere (Sassen et al., 2007). The polarization Lidar is also well suited for aerosol profiling and allows us to unambiguously discriminate desert dust from other aerosols. Based on model calculations, it has been demonstrated that the spectral dependence of the dust linear depolarization ratio is sensitive to the size distribution of the nonspherical scatterers. Thus, observations of the linear depolarization ratio at several wavelengths may be used in retrieval schemes (Dubovik et al., 2006) to improve the estimation of the microphysical properties of dust from optical measurements (Wiegner et al., 2008). First dual-wavelength aerosol polarization Lidar measurements were presented by Sugimoto et al. (2002).

B6.1.2 Overview of Lidar Linear Depolarization

Lidar often uses polarized laser beams for sounding the atmosphere, and depolarization measurements have long been used in lidar investigation. **The main application of depolarization measurements is the discrimination and the extent of liquid and solid phase clouds and aerosols**. Lidar signal is the superposition of scattering that is due to molecules and scattering that is due to particles that are greater than the typical dimensions of atmospheric molecules. Molecular backscattering follows Rayleigh theory, in which case changes in polarization are due only to the polarizability of molecules: The contribution to the orthogonal polarization is ;1%.2 Scattering processes on aerosols must be treated by means of Mie theory if particles are spherical or with

Stokes matrix if particles are non-spherical. From Mie theory the polarization of incident light is conserved after backscattering, whereas backscattering on solid particles can change the polarization direction. If a laser beam is emitted with a definite polarization, the presence of polarized light in the perpendicular component denotes the presence of backscattering from nonspherical particles. Hence polarized backscattering, parallel to the laser polarization is considered, and depolarization is used to refer to the perpendicular component of polarized backscattered light. **Three points** must be taken into account during treatment with depolarization studies: 1. multiple scattering processes induce depolarized backscattering even in the presence of spherical scatterers, 2. particles with small dimensions compared with the lidar wavelength do not show depolarization even if they are not spherical and 3. emitted light polarization must remain stable throughout the measurement.

B6.1.3 Polarization Method Applied To Modern Lidar Systems: Theory and Methodology

Measurements of the **linear depolarization ratio δ** with lidars are often performed with the aim to just discern between the dry, the liquid and the ice phase of aerosols and clouds in the profiles of one lidar system, which requires only a relative measure of *δ* with a low accuracy of the absolute values. The total backscattered power *P*(*r*) with their dependence on the distance *r* from the lidar is described by the lidar equation

$$P = \frac{\eta \beta(r) \tau^2(r)}{r^2}$$

(1)

where *η* is the system constant, *β* the backscatter coefficient and the factor r^2 accounts for the atmospheric transmittance on the way from the lidar to the scattering volume, and back. For the determination of *δ* the lidars used in this study measure the atmospheric backscatter signals in two receiver channels, parallel- and cross-polarized with respect to the plane of the linear polarized output of the laser beam. The two polarization components are separated in the receiver by means of **polarizing beam splitter cubes (PBC).** But this separation is not perfect. Furthermore the polarizing beam splitter might be misaligned with respect to the plane of polarization of the emitted laser beam, and additionally, a rotation of the polarization plane is used for the relative calibration of the two

receiver channels. Therefore, we show the necessary equations of the angle ϕ between the plane of polarization of the laser and the incident plane of the polarizing beam splitter cube, according to Fig. B2.
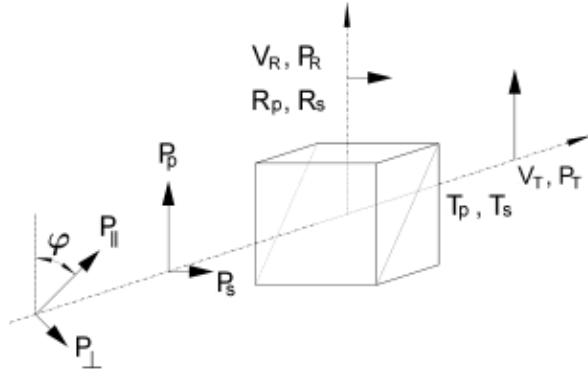

Fig. B2. **Signal power components in a receiver of a depolarization lidar with a polarizing beam splitter cube with reflectivity R_p and R_s and transmittances T_p and T_s for linearly polarized light parallel (p) and perpendicular (s) to the incident plane of the polarizing beam splitter. P_R and P_T are the measured quantities in the reflected and transmitted path, respectively, and V_R and V_T are the corresponding amplification factors including the optical transmittances.**

The backscatter powers before the PBC are (skipping the range dependence in the following for convenience)

$$P_\perp = \frac{\eta_\perp \left(\beta_\perp^p + \beta_\perp^m\right) \tau^2}{r^2},$$
$$P_\parallel = \frac{\eta_\parallel \left(\beta_\parallel^p + \beta_\parallel^m\right) \tau^2}{r^2}, \qquad (2)$$

with the system constants $\eta_\parallel$ and $\eta_\perp$ including here only the laser power and the telescope aperture, assuming negligible diattenuation of the optics before the PBC, for example, a telescope or dichroic beam splitters. The backscatter coefficient β is split up in the parallel- ($\beta_\parallel$) and cross-polarized ($\beta_\perp$) components of the backscatter from particles (β^p) and from molecules (β^m). The total backscatter power P and the total backscatter coefficient β are the sum of both polarized components:

$$P = P_\parallel + P_\perp. \qquad (3)$$

The ratio of the total backscatter coefficient to the molecular component is called the backscatter ratio **R**

R = *βm* + *βp βm* , (4)

and the ratio of the total cross- to the total parallel-polarized backscatter coefficient is called the linear volume depolarization ratio δ^{v}:

$$\delta^{\mathrm{v}} = \frac{\beta_\perp}{\beta_\parallel} = \frac{P_\perp}{P_\parallel}.$$

(5)

The power components with respect to the incident plane of the PBC are

$$P_s(\varphi) = P_\parallel \sin^2(\varphi) + P_\perp \cos^2(\varphi),$$
$$P_p(\varphi) = P_\parallel \cos^2(\varphi) + P_\perp \sin^2(\varphi).$$

(6)

The subscripts p and s denote the planes parallel and perpendicular to the incident plane of the PBC (see Fig. 1), respectively, and ϕ is the angle between the plane of polarization of the laser and the incident plane of the PBC. Depending on this angle, the cross polarized signal $P\perp$ can be measured in the reflected (for $\phi = 0\circ$) or in the transmitted path ($\phi = 90\circ$). Hence, we denote the power measured in the reflected and transmitted paths with the subscripts R and T, respectively. Behind the PBC the total reflected (P_R) and transmitted (P_T) power components are

$$P_R(\varphi) = [P_p(\varphi) R_p + P_s(\varphi) R_s] V_R,$$
$$P_T(\varphi) = [P_p(\varphi) T_p + P_s(\varphi) T_s] V_T.$$

(7)

The amplification factors V_R and V_T include the optical transmittances of the receiver and the electronic amplification in each channel. *P*R and *P*T are the quantities we actually record with the data acquisition. For the following it is convenient to introduce a relative amplification factor $V*$ and the measured signal ratio $\delta*$

$$\delta^*(\varphi) = \frac{P_R(\varphi)}{P_T(\varphi)}, \quad V^* = \frac{V_R}{V_T}.$$

(8)

With eqs. (6)–(8), we achieve

$$\delta^*(\varphi) = V^* \frac{[1 + \delta^{\mathrm{v}} \tan^2(\varphi)] R_p + [\tan^2(\varphi) + \delta^{\mathrm{v}}] R_s}{[1 + \delta^{\mathrm{v}} \tan^2(\varphi)] T_p + [\tan^2(\varphi) + \delta^{\mathrm{v}}] T_s}.$$

(9)

B6.1.4 Retrieval of the Linear Volume Depolarization Ratio δ^v

Once $V*$ is known, we get δ^v with eqs. (5) and (6), for a regular measurements at $\phi = 0\circ$:

$$\delta^v = \frac{P_\perp}{P_\parallel} = \frac{P_s}{P_p}, \quad \varphi = 0°.$$

(10)

As for commercial PBCs, Rs is usually much closer to 1 than Tp, the noise and error caused by the cross-talk from the strong parallel-polarized signal to the weaker cross-polarized signal are reduced if the parallel polarized signal is detected in the reflected s-branch of the PBC. For this setup $\phi = 90\circ$, and we get

$$\delta^v = \frac{P_\perp}{P_\parallel} = \frac{P_p}{P_s}, \quad \varphi = 90°.$$

(11)

From eqs. (5)–(8) follows

$$\frac{P_s}{P_p} = \frac{\frac{\delta^*}{V^*}T_p - R_p}{R_s - \frac{\delta^*}{V^*}T_s}$$

(12)

And

$$P = P_p + P_s = \frac{V^*\left(R_s - R_p\right)P_T + \left(T_p - T_s\right)P_R}{V_R\left(T_pR_s - R_pT_s\right)}.$$

(13)

The knowledge of V_R is not necessary, as we only need a relative signal for the lidar signal inversion with the Fernald/Klett retrieval (Klett, 1985; Fernald, 1984), and thus we can set it to VR = 1. In case the parameters of the polarizing beamsplitter cube are

Ts = 1 − Rs, Rp = 1 − Tp, (14)

B6.1.5 Retrieval of the Linear Particle Depolarization Ratio δ^P

The δ^p can be calculated from eqs. (2)–(5) using

$$\delta^p = \frac{\beta_\perp^p}{\beta_\parallel^p} = \frac{(1+\delta^m)\,\delta^v R - (1+\delta^v)\delta^m}{(1+\delta^m)R - (1+\delta^v)} \qquad (15)$$

with the height in dependent linear depolarization ratio of air molecules:

$$\delta^p = \frac{\beta_\perp^p}{\beta_\parallel^p} = \frac{(1+\delta^m)\,\delta^v R - (1+\delta^v)\delta^m}{(1+\delta^m)R - (1+\delta^v)} \qquad (16)$$

which can be determined with high accuracy (Behrendt and Nakamura, 2002). The backscatter ratio **R** can be retrieved from the total signal *P* using, for example, the Fernald/Klett inversion with a reference value βp(r0) at a reference range r0 and known range-dependent lidar ratios *S*

$$S = \frac{\beta^P}{\alpha^p}, \qquad (17)$$

where α^p is the particle extinction coefficient. *S*(r) must be retrieved by an additional measurement, for example, with a Raman channel. The values of δ^v and R are subject to systematic and statistical (noise) errors.

B6.2 Experiments And Results (From Samum Field Campaign) [11]

B6.2.1 Results and Comparison

During Saharan Mineral Dust Experiment (SAMUM), it was attempted to measure a possible wavelength dependence of the dust particle linear depolarization ratio δ^p, with four different lidar systems at four wavelengths as inputs for model calculations of δ^p regarding the particles shapes and size distribution. Thus, the uncertainty of the absolute values must be known and should be small compared with the expected natural variance. The paper presents linear particle depolarization ratio δ^p measurements at four wavelengths. However, MULIS (532 nm) and the airborne DLR-HSRL (532 and 1064 nm) provided the most accurate measurements of the linear depolarization ratio. These lidar measurements represent the backbone of the entire SAMUM polarization lidar activity. First, we compare the height resolved profiles of δ^p of all lidars at four dates with coincident measurements in Fig. B3. The lidar ratios S used for the depolarization retrieval of MULIS at 532 nm were adopted from the coincident DLR-HSRL measurements (displayed in Fig. 6 as broken lines) with errors in the range of ±5 sr. For non-coincident measurements S is assumed to be 50 sr ± 10 sr.
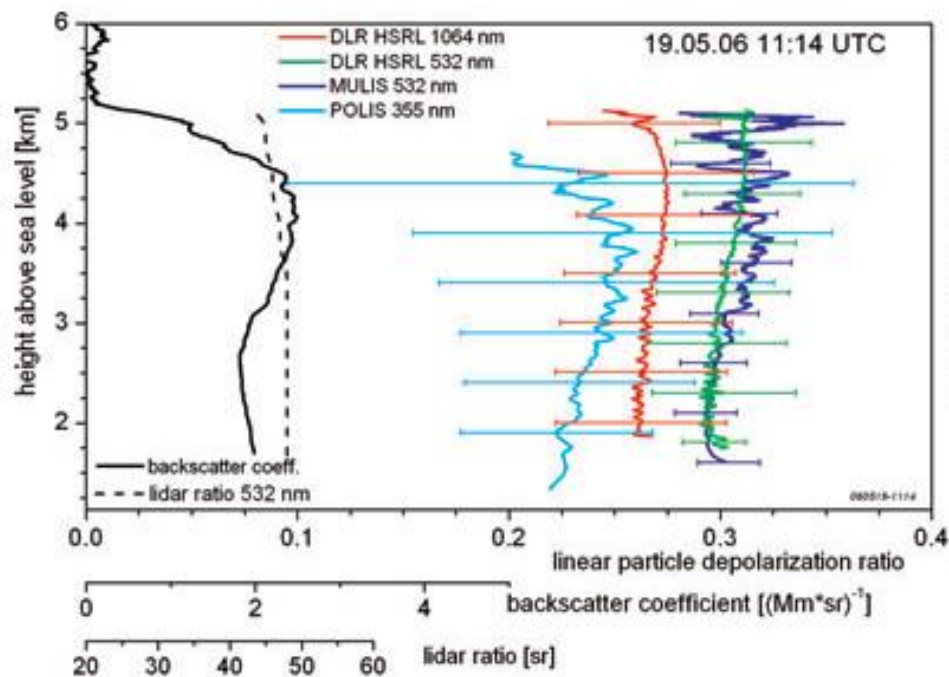

Fig. B3. Particle linear depolarization ratio profiles on 19 June 2006 at several wavelengths. The error bars indicate the systematic uncertainties
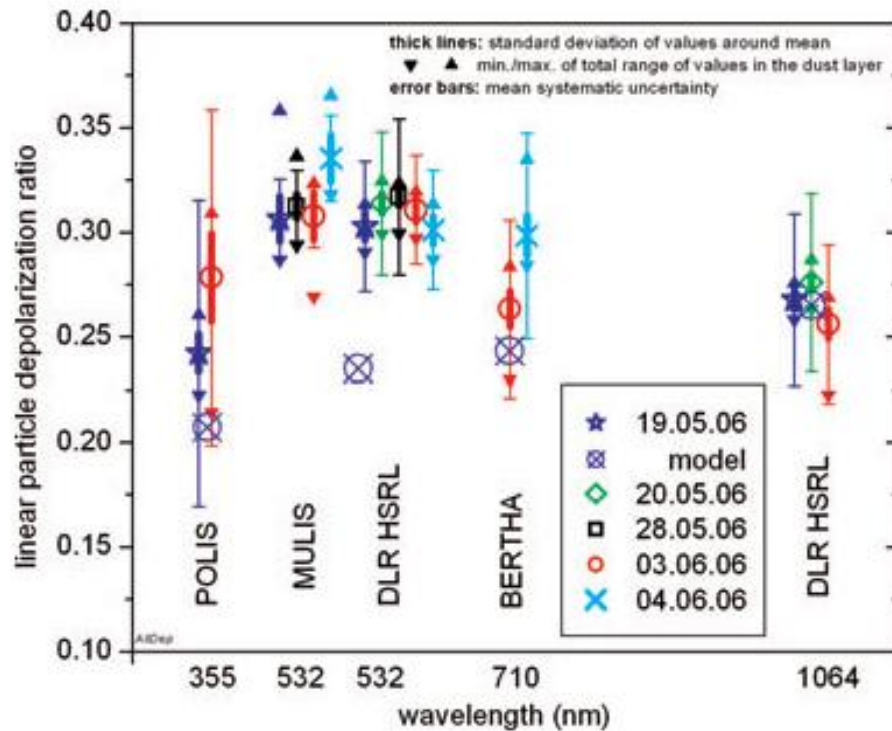
Fig. B4. Mean linear depolarization ratio of particles in the dust layer over the wavelength of the four lidar systems at four different dates during SAMUM 2006 and results of model calculations for the reference case 19 May 2006 (Wiegner et al., 2008).

The linear depolarization ratio was measured with MULIS continuously during SAMUM. Retrievals of the linear particle depolarization ratio δp at selected dates, together with error bars and statistical information are displayed in Fig. B5 and listed in Table 2, together with the measurements from the other lidars

from Fig. B4. The full ranges of the δp values are often asymmetric to the mean towards smaller δp. These smaller values mostly stem from the dust layer top caused by temporal averaging of the lidar measurements with changing dust layer top height.
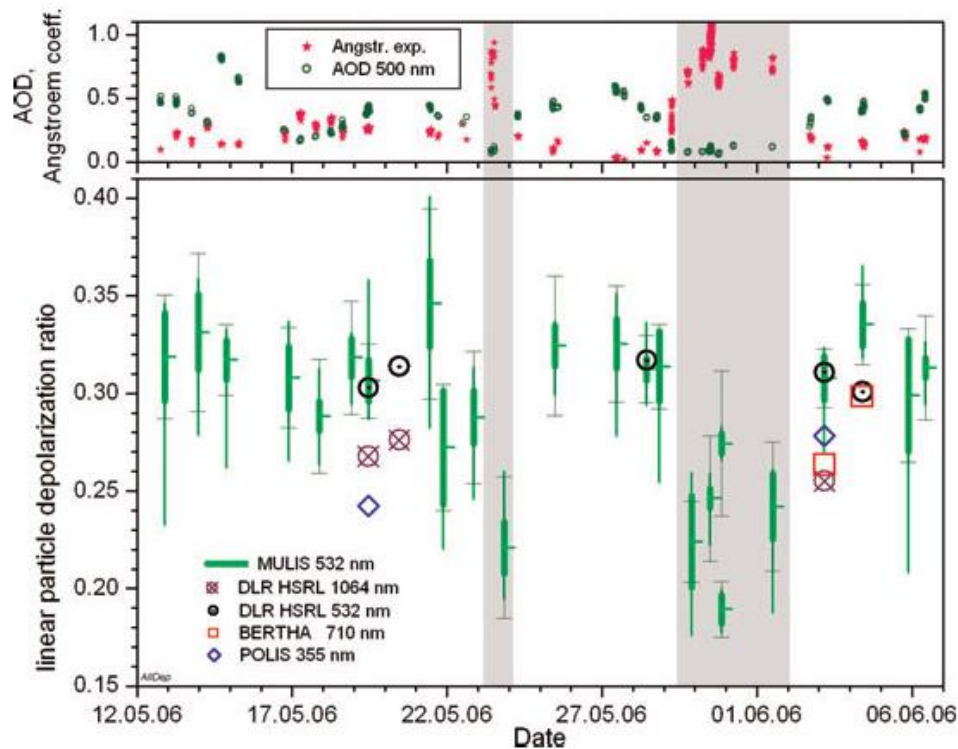
Fig. B5. Mean linear particle depolarization ratio δp in the dust layer over Quarzazate during the SAMUM 2006 period for selected dates (lower plot) and aerosol optical thickness at 500 nm and Ångström exponent (440–870 nm) from SSARA sun photometer at Quarzazate (upper plot).

The AOD at 500 nm and the AE (440–870 nm) derived from the SSARA measurements temporally closest to the MULIS measurements are displayed on top of Fig. B5. For night time, when no sun photometer data were available, the AE values were interpolated and the AE errors show the slope. Comparing the time-series in Fig. B5 we see low δp and high AE in the shaded time periods, and high δp and low AE else, whereas there is no evidence for a correlation between δp and AOD, as expected.

More details and information about this field campaign can be found at [11].

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Summary of equations for backscatter coef. calculation

Invert Klett Technique (Far – end solution)

$$\beta(r) = \frac{RCS(r)*\exp\left(2*(LR - LR_{mol})*\int\limits_{r}^{r_{ref}}\beta_{mol}(r')dr'\right)}{\dfrac{RCS(r_{ref})}{C*\beta_{mol}(r_{ref})} + 2*LR*\int\limits_{r}^{r_{ref}}RCS(r')*\exp\left(2*(LR - LR_{mol})*\int\limits_{r'}^{r_{ref}}\beta_{mol}(r'')dr''\right)r'}$$

$$\beta(r) = \beta_{mol}(r) + \beta_{p}(r)$$

Where

p is for particles (aerosols) and mol for molecular (Rayleigh)

$$LR_{mol}(r) = \frac{a_{mol}(r)}{\beta_{mol}(r)} = \frac{8\pi}{3} \quad LR(r) = \frac{a_p(r)}{\beta_p(r)} = const = LR$$

,

$$RCS(r) = P_c(r) * r^2$$

This is the range corrected signal.

$$P_c(r)$$

is the background corrected lidar signal.

$$C = \frac{\beta_p(r_{ref}) + \beta_{mol}(r_{ref})}{\beta_{mol}(r_{ref})}$$

Usually at r_{ref} we assume that $\beta_p(r_{ref}) = 0$ so C=1.

In any other case you can try different values for C.

How you can calculate the $\beta_{mol}(r)$

$$\alpha_{mol}(r) = \frac{8\pi^3}{3} \cdot \frac{\left(m_{air}^2 - 1\right)^2}{\lambda^4 N_S^2} \cdot \frac{6+3\delta}{6-7\delta} \cdot N_S(r) \cdot \frac{T_0}{p_0} \cdot \frac{p(r)}{T(r)}$$

$$\beta_{mol}(r) = \frac{\alpha_{mol}(r)}{LR_{mol}} = \frac{3}{8\pi} \cdot \alpha_{mol}(r)$$

$T_0 = 288.15 \text{ K}$

$p_0 = 1013 \text{ hPa}$

$$m_{air}^2 - 1 = \begin{vmatrix} 5.7148 \cdot 10^{-4} \rightarrow 355 \\ 5.5647 \cdot 10^{-4} \rightarrow 532 \\ 5.48 \cdot 10^{-4} \rightarrow 1064 \end{vmatrix}$$

$$\delta = \begin{vmatrix} 0.0301 \rightarrow 355 \\ 0.0284 \rightarrow 532 \\ 0.0273 \rightarrow 1064 \end{vmatrix}$$

$$N_S(r) = N_{S0} \cdot \frac{p_g}{T_g} \cdot \frac{T_0}{p_0} \cdot \exp\left(-\frac{r}{10200}\right)$$

$N_{S0} = 2.547 \ 10^{25}$ molecule/m^3

in troposfera (0 → 12000 m):

$$T(r) = T_g - \gamma \cdot r$$

$\gamma = 0.0065$ K/km

$$p(r) = p_g \cdot \left[1 - \frac{T(r)}{T_g} \right]^{\frac{M \cdot g}{\gamma \cdot R}}$$

unde: M = 0.0289644 kg/mol

g = 9.81 m/s^2

R = 8.31432 J/K

Tropopause (12000 → 15000 m)

$$T(r) = T(r = r_{troposhere} = const)$$

$$p(r) = p(r = r_{troposhere}) \cdot \exp \left\{ -\frac{M \cdot g}{T(r = r_{troposhere}) \cdot R} \cdot (r - r_{troposhere}) \right\}$$