KIPP & ZONEN
SINCE 1830

LAS & X-LAS

(Extra) Large Aperture Scintillometer

Instruction Manual

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IMPORTANT USER INFORMATION

Reading this entire manual is essential for full understanding of the proper use and safe operation of this product

Should you have any comments on this manual we will be pleased to receive them at:

Kipp & Zonen B.V.
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WARRANTY AND LIABILITY

Kipp & Zonen guarantees that the product delivered has been thoroughly tested to ensure that it meets its published specifications. The warranty included in the conditions of delivery is valid only if the product has been installed and used according to the instructions supplied by Kipp & Zonen.

Kipp & Zonen shall in no event be liable for incidental or consequential damages, including without limitation, lost profits, loss of income, loss of business opportunities, loss of use and other related exposures, however caused, arising from the faulty and incorrect use of the product. User made modifications can affect the validity of the CE declaration.

Manual version: **0307**

Throughout the manual symbols are used to indicate to the user important information. The meaning of these symbols is as follows:

The exclamation mark within an equilateral triangle is intended to alert the user to the presence of important operating, maintenance and safety information

DECLARATION OF CONFORMITY

1401/LASR/EMC

We,

Kipp & Zonen B.V.

(Supplier's name)

Röntgenweg 1
2624 BD Delft

(supplier's address)

declare under our sole responsibility that the product:

This declaration of Conformity is suitable to the European Standard EN 45014 *General Criteria for supplier's Declaration of Conformity*. The basis for the criteria has been found in international documentation, particularly in ISO/IEC, Guide 22, 1982, *Information on manufacturer's Declaration of Conformity with standards or other technical specifications*

LAS Receiver type LAS-R

Name, type or model, batch or serial number, possibly source and number of items.

to which this declaration relates in conformity with the following European, harmonized and published standards at date of this declaration:

EN 61326-1:2000

EN 61326-1:2000

Tile and or number and date of issue of the applied standard(s)

following the provisions of the Directives (if applicable):

EMC-directive : 89/336/EEC
Amendment to the above directive: 93/68/EEC

These conclusions are based on test reports:

1401/LASR/EMC
ce-test PO box 563 2600 AN Delft

test report number, date and name of test house

Delft,

Place and date of issue

BDiel

name of responsible for CE-marking

May 0305/27/03

We,

Kipp & Zonen B.V.

(Supplier's name)

Röntgenweg 1
2624 BD Delft

(supplier's address)

declare under our sole responsibility that the product:

This declaration of Conformity is suitable to the European Standard EN 45014 *General Criteria for supplier's Declaration of Conformity.* The basis for the criteria has been found in international documentation, particularly in ISO/IEC, Guide 22, 1982, *Information on manufacturer's Declaration of Conformity with standards or other technical specifications*

LAS Transmitter type LAS-T

Name, type or model, batch or serial number, possibly source and number of items.

to which this declaration relates in conformity with the following European, harmonized and published standards at date of this declaration:

EN 61326-1:2000

EN 61326-1:2000

Tile and or number and date of issue of the applied standard(s)

following the provisions of the Directives (if applicable):

EMC-directive : 89/336/EEC
Amendment to the above directive: 93/68/EEC

These conclusions are based on test reports:

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test report number, date and name of test house

Delft,

Place and date of issue

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May 0305/26/03

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

A_T	wavelength dependant constants [-]
A_Q	wavelength dependant constants [-]
c_p	heat capacity of air at constant pressure [~1005 J kg^{-1} K^{-1}]
C_n^2	structure parameter of the refractive index of air [m$^{-2/3}$] ($C_n^2 = 10^{(U_{CN2}-12)}$)
C_T^2	structure parameter of temperature [K^2 m$^{-2/3}$]
C_Q^2	structure parameter of humidity [kg^2 m^{-6} m$^{-2/3}$]
d	zero-displacement height [m]
D	aperture diameter of receiver and transmitter unit [m]
f_T	universal stability function [-]
g	gravitational acceleration [~9.81 m s^{-2}]
G_s	soil heat flux [W m^{-2}]
H	sensible heat flux [W m^{-2}]
I	signal strength or intensity [V] ($I = U_{DEMOD}$)
L	path length [m]
L_vE	latent heat flux (or evaporation) [W m^{-2}]
L_{MO}	Obukhov length [m]
Pot	potentiometer path length setting at ***Path length*** knob [-]
P	air pressure [Pa]
PU_{CN2}	scaled C_n^2 [m$^{-2/3}$] ($C_n^2 = PU_{CN2} \cdot 10^{-15}$)
Q	absolute humidity [kg m^{-3}]
Q^*	net radiation [W m^{-2}]
R_d	specific gas constant for dry air [~287 J K^{-1} kg^{-1}]
R_v	specific gas constant for water vapour [~461.5 J K^{-1} kg^{-1}]
T	absolute air temperature [K]
T_*	temperature scale [K]
u	wind speed [m s^{-1}]
u_*	friction velocity [m s^{-1}]
U_{CN2}	**log** C_n^2 signal [V] ($C_n^2 = 10^{(U_{CN2}-12)}$) [-5 V to 0 V]
U_{DEMOD}	demodulated signal [V] ($U_{DEMOD} = I$) [-1 V to 0 V]
U_{TH_R}	thermistor signal receiver unit [V] [0 V to 10 V]
U_{TH_T}	thermistor signal transmitter unit [V] [0 V to 10 V)]
z_{LAS}	(effective) height **LAS** or **XLAS** [m]
z_0	aerodynamic roughness length [m]
z_u	height wind speed measurements [m]
β	Bowen ratio [-] ($\beta = H/L_vE$)
κ_v	von Kármán constant (~0.40)
λ	wavelength of EM radiation (880 nm) [m]
ρ	density of air [kg m^{-3}] [~1.2 kg m^{-3} (at sea level !)]
σ^2	variance
$\sigma^2_{\ln I}$	of natural logarithm of intensity fluctuations (ln(I)) [-]
$\sigma^2_{U_{DEMOD}} = \sigma^2_I$	of U_{DEMOD} or intensity I [V^2]
$\sigma^2_{U_{CN2}}$	of U_{CN2} [V^2]
Ψ_m	integrated stability function for momentum [-]

ABBREVIATIONS

(X)LAS — (eXtra) Large Aperture Scintillometer

MOST — Monin-Obukhov Similarity Theory

A relationship describing the vertical behavior of non-dimensionalized mean flow and turbulence properties within the Surface Layer as a function of the Monin–Obukhov key parameters.

PBL — Planetary Boundary Layer

The PBL is the lowest region of the troposphere, which is directly affected by heating and cooling of the earth surface. In general the depth of the PBL varies between 100m to 2000m. The depth of the PBL increases during the day, when the surface is heated by the sun and decreases during the night.

RS — Roughness Sublayer

Lowest part of the SL, where the flow is influenced by individual roughness elements. Consequently, the SL can be divided into the Constant Flux Layer and the Roughness Sublayer. The height of the Roughness Sublayer strongly depends on the height (size and form) of the roughness elements, but also on the distribution. Usually, over tall vegetation 3 times the obstacle height is taken as the height of the Roughness Sublayer.

SL — Surface Layer

In general in the lowest 10% of the PBL the surface fluxes are constant with height, this part of the PBL is also known as the Constant Flux Layer of Surface Layer (SL). Therefore fluxes measured in the SL can be considered as being representative fluxes for the heat and mass exchange processes between the atmosphere and the surface. In general the SL begins at 3 times the vegetation height and has a typical depth of 20m (at night) to 100m (during daytime conditions).

1. GENERAL INFORMATION

1.1 INTRODUCTION TO THE LAS AND XLAS

The Large Aperture Scintillometer (**LAS**) and eXtra Large Aperture Scintillometer (**XLAS**) are instruments designed for measuring the path-averaged structure parameter of the refractive index of air (C_n^2) over horizontal path lengths from 250 m to 4.5 km[1] (**LAS**) and 1 km to 8 km[1] (**XLAS**). Structure parameter measurements obtained with the **LAS** or **XLAS** and standard meteorological observations (air temperature, wind speed and air pressure) can be used to derive the surface sensible heat flux (H).

The **LAS** and **XLAS** optically measure intensity fluctuations (known as scintillations) using a transmitter and receiver horizontally separated by several kilometers. The scintillations seen by the instrument can be expressed as the structure parameter of the refractive index of air (C_n^2). The light source of the **LAS** and **XLAS** transmitter operates at a near-infrared wavelength of 880 nm. At this wavelength the observed scintillations are primarily caused by turbulent temperature fluctuations. Therefore C_n^2 measurements obtained with the **LAS** or **XLAS** can be related the sensible heat flux.

Compared to traditional point measurements the **LAS** and **XLAS** operate at spatial scales comparable to the grid box size of numerical models and pixels of satellite images used in meteorology, hydrology and water-management studies. The **LAS** and **XLAS** have important applications in energy balance and also water balance studies, because the surface flux of sensible heat is linked to evaporation (L_vE).

Some key **LAS** and **XLAS** features are:

- Heated transmitter and receiver windows and internal temperature monitoring provide a mechanism to eliminate condensation problems.

- Simple construction using Fresnel lenses for collimation and collection of the light permits path lengths up to 4.5 km (**LAS**) and 8 km (**XLAS**) (depending on atmospheric conditions). Unlike mirror-based scintillometers the Fresnel lens avoids obstruction of the beam by the transmitting LED or the receiving detector.

- On-board calibration and reference signals at the receiver electronics allow rapid on-site confirmation of operation. Either the received carrier signal or the reference waveform can be monitored on the rear panel BNC output.

- Surge, over-voltage and lightning protection for both the transmitter and receiver units are standard.

- Eye-safe near-infrared light source.

- 12 Volt DC power for flexibility of use.

- Built-in pan and tilt adjuster for easier alignment.

[1] Depending on atmospheric conditions

1.2 MANUAL

The INSTRUCTION MANUAL is intended for customers who have purchased the **LAS** or **XLAS**. It includes all the information necessary to properly install and operate the **LAS**/**XLAS** and how to derive the sensible heat flux from the **LAS**/**XLAS** measurements. An appendix (appendix I) is added to the manual for users who are interested in the theoretical background on scintillometry and the derivation of the surface sensible heat flux (see also WINLAS help file) and references to scientific papers.

2. TECHNICAL DATA

Table 1: Specifications of LAS and XLAS Transmitter.

	LAS	**XLAS**
Operating temperature	-20 °C to +50 °C	-20 °C to +50 °C
Humidity	0 – 100% RH (≈ IP 66)	0 – 100% RH (≈ IP 66)
Voltage	12 VDC nominal (V_{min} = 10.5 V; V_{max} = 15 V)	12 VDC nominal (V_{min} = 10.5 V; V_{max} = 15 V)
Power	0.5 A maximum (path length dependant), ~ 3 A maximum with heater on	0.5 A maximum (path length dependant), ~ 1.7 A maximum with heater on
Window heater	yes, self-regulating at ~ 55 °C	yes, 14 W (non-regulating)
Surge protection	power (not heater)	power (not heater)
Optical wavelength of LED	880 nm (spectral bandwidth at 50% ~ 80 nm)	880 nm (spectral bandwidth at 50% ~ 80 nm)
Optical power output of LED	maximum 80 mW (I_F = 1 A, $\bar{I}_F$ = 500 mA, duty cycle 0.5)	maximum 80 mW (I_F = 1 A, $\bar{I}_F$ = 500 mA, duty cycle 0.5)
Modulation frequency	~ 7 kHz (duty cycle 0.5)	~ 7 kHz (duty cycle 0.5)
Beam width	~ 1 m at 100 m distance	~ 0.3 m at 100 m distance
Aperture diameter	0.152 m (6 inch)	0.328 m (12.9 inch)
Focal length Fresnel lens	0.152 m (6 inch)	0.610 m (24 inch)
Effective diameter	0.145 m	0.32 m
Typical signal 1 (U_{TH_T}, Thermistor)	0 V to 10 V	0 V to 10 V
Typical signal 2 (7 kHz oscillator)	7 kHz, 0.5 duty cycle, Amplitude = - 7.8 V	7 kHz, 0.5 duty cycle, Amplitude = - 7.8 V
Typical signal 3 (LED pulse, also on BNC)	7 kHz, 0.5 duty cycle, Amplitude = 0 V to 1 V	7 kHz, 0.5 duty cycle, Amplitude = 0 V to 1 V
Physical dimensions (including pan and tilt adjustment):		
Length	0.37 m*	1.07 m
Width	0.23 m*	0.43 m
Height	0.32 m*	0.58 m
Weight	13.5 kg	35 kg

Kipp & Zonen reserves the right to make changes to the specifications without prior notice. * Excluding sun cover **LAS**.

Table 2: Specifications of LAS and XLAS Receiver.

	LAS	**XLAS**
Operating temperature	-20 °C to +50 °C	-20 °C to +50 °C
Humidity	0 – 100% RH (≈ IP 66)	0 – 100% RH (≈ IP 66)
Voltage	12 VDC nominal (V_{min} = 11.3 V; V_{max} = 15 V)	12 VDC nominal (V_{min} = 11.3 V; V_{max} = 15 V)
Power	0.2 A nominal, ~3 A maximum with heater on	0.2 A nominal, ~ 1.4 A maximum with heater on
Window heater	yes, self-regulating at ~ 55 °C	yes, 14 W (non-regulating)
Surge protection	power (not heater)	power (not heater)
Responsivity of photodiode at 880 nm	0.6 A/W (spectral bandwidth at 50% ~ 60 nm)	0.6 A/W (spectral bandwidth at 50% ~ 60 nm)
Aperture diameter	0.152 m (6 inch)	0.328 m (12.9 inch)
Focal length Fresnel lens	0.152 m (6 inch)	0.610 m (24 inch)
Effective diameter	0.148 m	0.32 m
Scintillation signal bandwidth of electronics	0.2 Hz to 400 Hz	0.2 Hz to 400 Hz
Typical value signal 1 (U_{DEMOD} or signal strength I)	- 0.8 V to 0 V	- 0.8 V to 0 V
Typical value signal 2 (U_{CN2} or **log** C_n^2 signal)	- 5 V to 0 V	- 5 V to 0 V
Typical value signal 3 (7 kHz carrier)	~ 7 kHz, 0.5 duty cycle	~ 7 kHz, 0.5 duty cycle
Typical value signal 4 (U_{TH_R}, Thermistor)	0 V to 10 V	0 V to 10 V
C_n^2 turbulent range	10^{-12} to 10^{-17} $m^{-2/3}$	10^{-12} to 10^{-17} $m^{-2/3}$
Noise level of electronics (U_{DEMOD} = - 0.8 V; L_{LAS} = 1184 m; L_{XLAS} = 2152 m)	< 10^{-17} $m^{-2/3}$	< 10^{-17} $m^{-2/3}$
Physical dimensions (including pan and tilt adjustment):		
Length	0.37 m*	1.07 m
Width	0.23 m*	0.43 m
Height	0.32 m*	0.58 m
Weight	13.5 kg	35 kg

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Table 3: Operating Specifications of LAS and XLAS System.

	LAS	**XLAS**
Minimum path length	0.25 km	1 km
Maximum path length (depends on atmospheric conditions)	4.5 km	8 km
Minimum height	1.5 m (**Important**: read section 3.3, appendix II and III)	3 m (**Important**: read section 3.3, appendix II and III)
Maximum height for C_n^2 (or turbulence) measurements	no operational restriction	no operational restriction
Maximum height for flux (H) measurements	~ 100 m (in Constant Flux Layer, see section 3.3)	~ 100 m (in Constant Flux Layer, see section 3.3)

Kipp & Zonen reserve the right to make changes to the specifications without prior notice.

3. INSTALLATION

The following steps must be carefully taken for optimal performance of the instrument.

3.1 DELIVERY

Check the contents of the shipment for completeness (see below) and note whether any damage has occurred during transport. If there is damage, a claim should be filed with the carrier immediately. In this case, or if the contents are incomplete, the Kipp & Zonen Sales or Services organization should be notified in order to facilitate the repair or replacement of the instrument.

The **LAS/XLAS** scintillometer delivery will include the following items:

- (X)LAS transmitter (with pan and tilt adjuster)
- (X)LAS receiver (with pan and tilt adjuster)
- 2 × sun / weather cover
- 2 × sighting telescope with detachable mountings
- 2 × 0.1m diaphragms to adjust the LAS for short range applications (plus add. screws, washers and spacers)
- 2 × 5 m cable with 10 lead, fitted with a 10-way circular amphenol plug (male) at one end
- 4 spare bags of silica gel (5 gr. each)
- A CD containing WINLAS and a pdf-file of the LAS/XLAS manual

Any missing parts should be reported to your dealer, who will suggest appropriate action.

Unpacking

Keep the original packaging for later shipments!

Although the **LAS/XLAS** is weatherproof and suitable for rough ambient conditions, the transmitter and receiver do contain delicate optical and electronic parts. For this type of equipment, keep the original shipment packaging to safely transport the equipment to the measurement sites.

3.2 ORIENTATION PATH / SITE SELECTION

Avoid direct sunlight in both the receiver and transmitter windows to prevent overheating of the LED and permanent damage to the detector. It is recommended to select a path that is approximately parallel to the earth's surface (i.e. horizontal) and has a north-south orientation to avoid problems caused by low sun angles.

Important: *Exposure to direct sunlight can permanently damage the optical parts (LED and detector)*.

Important: *Verify that the optical path of the* **LAS** *or* ***X*****LAS** *is always free from obstacles (e.g. trees, buildings).*

3.3 HEIGHT – PATH LENGTH

To be certain that the C_n^2 measurements of the **LAS/XLAS** are reliable and fluxes (of sensible heat H and latent heat L_vE) can be derived from these measurements it is very important to follow the instructions/recommendations given in the following two sections.

3.3.1 Minimum height – Saturation

When the scintillation intensity rises above a certain limit the theory, on which the scintillation measurement method is based, is no longer valid. When this occurs the relationship between the measured amount of scintillations ($\sigma_{\ln I}^2$) and the structure parameter of the refractive index of air (C_n^2) fails. This phenomenon is known as **saturation**. In order to prevent saturation, C_n^2 must stay below a certain saturation criterion (S_{max}), i.e. the scintillometer can operate only under weakly scintillating conditions. The dependence of C_n^2 on the optical wavelength (λ), the aperture diameter (D), the measurement height (z_{LAS}) and the path length (L) can be written as follows

$$C_n^2(\lambda, D, z_{LAS}, L) \prec S_{\max} .$$

The path length and the measurement height are the only variables that can be adjusted in order to keep C_n^2 below the saturation criterion because the diameter and the wavelength of the **LAS** and ***X*****LAS** are constant. A scintillometer installed at a height close the earth's surface, will see more scintillations than a scintillometer installed high above the surface. As the path length increases more scintillations will be observed. This means that over long distances (~ several kilometres) the scintillometer must be placed high above the surface in order to prevent saturation. Over short distances (~ several hundred meters) the scintillometer can be installed close to the surface. Furthermore, the measured amount of scintillations depends on the surface conditions. Over dry areas the surface sensible heat flux is large, resulting in higher C_n^2 values than over wet surfaces where the sensible heat flux is small.

In figure 1a,b the minimum height of the **LAS** and ***X*****LAS** are given for different surface conditions as a function of the path length. The path length ranges between 250 m and 4.5 km for the **LAS** and 1 km and 8 km for the ***X*****LAS**, respectively. The surface conditions range from very dry (H ~ 400 W m^{-2}) to very wet (H ~ 50 W m^{-2}). The area above the curves in the figure is the so-called non-saturation zone. Below the curves saturation will occur. Based on the user's preferred path length, and the surface conditions of the area of interest, the user must install the **LAS** and ***X*****LAS** at a height that lies in the non-saturation zone.

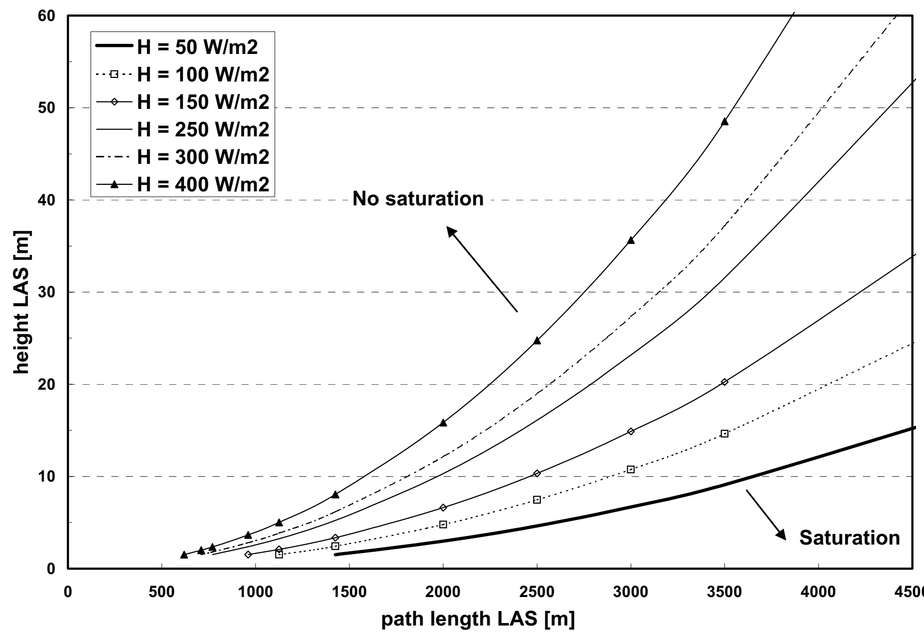

Figure 1a: The minimum installation height of the LAS as function of path length and for different surface conditions. The area above the curves is the non-saturation zone. Below the curves saturation of the signal occurs. In the presence of densely packed roughness elements add the zero-displacement height (see appendix III).

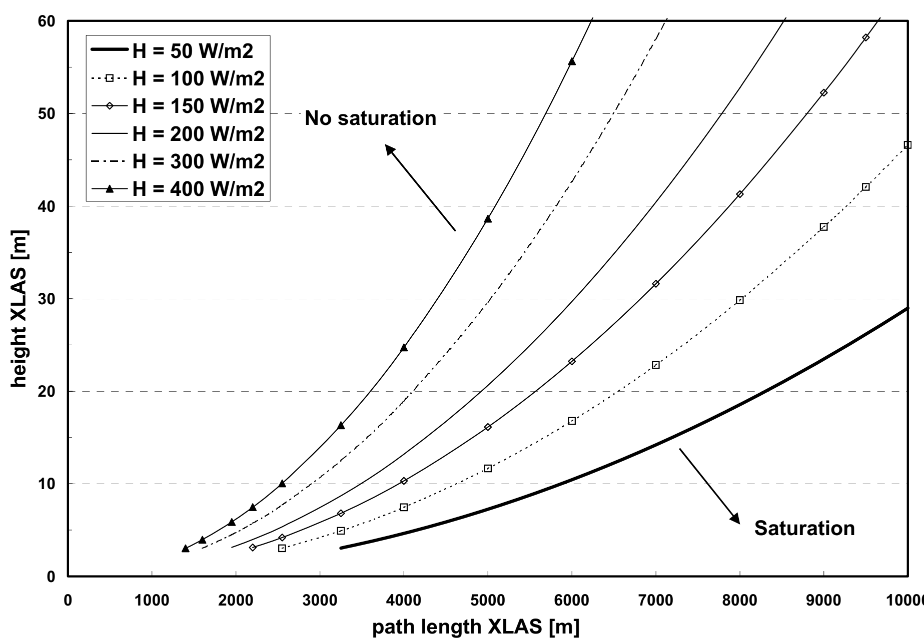

Figure 1b: The minimum installation height of the XLAS as function of path length and for different surface conditions. The area above the curves is the non-saturation zone. Below the curves saturation of the signal occurs. In the presence of densely packed roughness elements add the zero-displacement height (see appendix III).

For example a **LAS** installed over a relatively wet area (*H* ~ 100 W m^{-2}) and a path length of 3 km must be installed at a height of 10 - 12 meters or more, according to Figure 1a.

Important: *Verify that the* **LAS** *and* ***X*LAS** *are operating in the 'saturation free' zone.*

Important: *Determine the effective* ***height*** *of beam of the* **LAS/XLAS** *(z_{LAS}) along the path* ***precisely*** *as the sensible heat flux derived from the structure parameter data is very sensitive to the height (see appendix I)! When the area is relatively flat and the beam is parallel to the surface the effective height is easy to determine ($z_{transmitter}$ = $z_{receiver}$ = z_{LAS}). For situations that the area is NOT flat or slanted paths it is recommend measuring the height of the beam at several points along the path. By weighing the collected beam heights using the spatial weighting function of the* **LAS/XLAS** *(see appendix II) the effective beam height can be derived (see e.g. figure 16). In the presence of densely packed roughness elements (e.g. dense crop or forest) one has to account for the zero-displacement (d) height also (i.e. add d to the minimum height)!*

3.3.2 Minimum and maximum height – MOST

In order to derive the surface fluxes of sensible heat from the scintillometer measurements (i.e. C_n^2) we use the so-called Monin-Obukhov Similarity Theory (MOST) (see appendix I). MOST is widely used in the meteorology and is usually applied to the Surface Layer (SL) (and hence is sometimes called Surface Layer Similarity). The SL is roughly the lowest 10% of the Planetary Boundary Layer (PBL). The PBL is directly influenced by the earth's surface and its depth varies between roughly 100 m to 2 km. In general the PBL increases during the day, when the earth's surface is heated by the sun, and decreases again during the night. In the SL the variation of fluxes (such as the sensible heat flux *H* and latent heat flux L_vE) is negligible with respect to the magnitude of their value at the surface. Therefore, fluxes measured at a certain elevation in the SL can be considered as being representative for the exchange processes occurring between the earth surface and the atmosphere.

The SL can be divided again into the Roughness Sublayer (RS) influenced by the structure of the roughness elements (e.g. plants, trees, buildings etc) and the Constant Flux Layer where fluxes are assumed to be horizontally and vertically constant (due to turbulent mixing). This means that measurement techniques that apply MOST for estimating surface fluxes can be applied only in the Constant Flux Layer. Therefore the **LAS/XLAS** have to be installed at a height such that it is located above the Roughness Sublayer and is measuring within the Constant Flux Layer.

The depth of the SL roughly varies between 20 m to 100 m. The upper level strongly depends on the diurnal cycle of surface heating and cooling (and by the presence of clouds). Like the PBL, the SL increases during the day, as the surface is heated by the sun and is maximum at sun set (~100 m), before is decreases again due to cooling of the surface at night (~20 m). The height of the Roughness Sublayer (and thus lower level of the Constant Flux Layer) depends strongly on the size, form and distribution of the roughness elements. Usually, over tall vegetation, the height of the Roughness Sublayer is taken to be equal to three times the obstacle height (or roughness elements *h* (see also appendix III)). In case the estimated height of the Roughness Sublayer is smaller than the minimum height of the **LAS/XLAS** in table 3, take as minimum height the values shown in table 3!

Important: *Verify that the* **LAS** *and* ***X*LAS** *are measuring in the Constant Flux Layer.*

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3.4 THE MOUNTING SUPPORT

The **LAS** and ***X*LAS** can only function properly when the transmitter and receiver unit are precisely optically aligned. By mounting the scintillometer on a stable support, signal loss and regular re-alignment procedures will be avoided. In addition vibrations in the mounting structure must be prevented, which can lead to overestimated C_n^2 values.

Important: *Always place the* **LAS/XLAS** *units on a* ***STABLE*** *(vibration free) construction.*

3.5 MOUNTING THE LAS AND XLAS

The pan and tilt adjusters of the **LAS/*X*LAS** transmitter and receiver are supplied with a bottom flange, which provides simple mounting on the optional tripods (G-3M) using the M16 bolts and washers supplied. The bottom flange can also be fixed to the optional Kipp & Zonen tripod floor stands or to customer-supplied supports using 4× M10 bolts, nuts and washers (not supplied) for each of the transmitter and receiver.

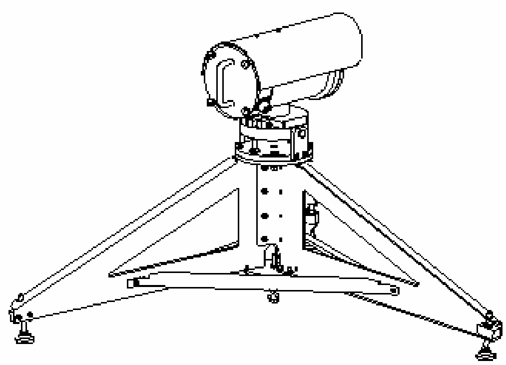


Figure 2: Example of LAS mounted on the optional tripod floor stand.

3.6 ELECTRICAL CONNECTION

3.6.1 Amphenol socket

The **LAS/*X*LAS** transmitter and receiver are each provided with a 5 m cable with 10 wires and a shield. At one end of each cable is a 10-way circular Amphenol plug is fitted. These plugs mate with the 10-way circular Amphenol sockets at the receiver and transmitter.

The **LAS/*X*LAS** can be connected to a computer or data logger. An analogue DC voltage input module with A to D (12 to 16 Bit) converter must be available.

Important: *Always measure* **log C_n^2** *(U_{CN2}) together with the demodulated signal (U_{DEMOD}). Although the demodulated carrier signal is not used in the calculations it is an important parameter for monitoring the quality of the C_n^2 measurements.*

Table 4: Transmitter cable color code.

Pin designation (amphenol plug)	Color code	Transmitter unit
A	Blue	Power GND
B	Violet	Power 12 VDC, 0.5 A
C	Red	Thermistor U_{TH_T} (Hi)
D	Orange	7 kHz oscillator (Hi)
E	Yellow	LED pulse (Hi)
F	Black	Not connected
G	White	Heater, 12 VDC
H	Grey	Heater
I	Green	Signals GND (Lo)
J	Brown	Not connected

Table 5: Receiver cable color code.

Pin designation (amphenol plug)	Color code	Receiver unit
A	Blue	Power GND
B	Violet	Power 12 VDC, 0.20 A
C	Red	Thermistor U_{TH_R} (Hi)
D	Orange	U_{CN2} (or **log C_n^2**) signal (Hi)
E	Yellow	Not connected
F	Black	7 kHz carrier (Hi)
G	White	Heater, 12 VDC
H	Grey	Heater
I	Green	Signals GND (Lo)
J	Brown	Demodulated carrier signal U_{DEMOD} (signal strength) (Hi)

The LAS receiver signals (C_n^2 and demod) can be connected to a Campbell or COMBILOG data logger as follows:

Campbell data logger:

C_n^2	Orange	→	High	Diff channel 1		(Optional with voltage divider)
	Green	→	Low	Diff channel 1	[1] ←	(Optional with voltage divider)
Demod	Brown	→	High	Diff channel 2		
	x		Low	Diff channel 2	[1] ←	

COMBILOG data logger:

C_n^2	Orange	→	In+	AIN1	
	Green	→	In-	AIN1	[1] ←
Demod	Brown	→	In+	AIN2	
	x		In-	AIN2	[1] ←

[1] Must be connected with small wire (Both signals have common signal ground)

3.6.2 BNC socket

The control panels of both the **LAS**/***X*LAS** receiver and transmitter can be accessed by removing the rear cover from the housing. BNC sockets allow the user to monitor various signals.

The BNC socket labeled ***LED pulse*** on the control panel of the **LAS** transmitter can be connected to an oscilloscope to monitor the magnitude of the 7 kHz carrier. This gives an indication of the transmitted waveform and the current being pulsed through the LED emitter. The pulse waveform is square-shaped and is scaled as 1 V equivalent to 1 A. The maximum permissible current is 1 A (when the ***Current adjust*** knob is set at maximum), which corresponds to an average current of 0.5 A (duty cycle of 0.5).

By connecting an oscilloscope to the BNC socket labeled ***Carrier*** on the control panel of the **LAS/*X*LAS** receiver the 7 kHz carrier can be monitored, provided that the switch labeled ***Mode*** is set at ***Signal***. The waveform should be sinusoidal. If the detector becomes saturated the shape of the wave is clipped and becomes saw-tooth like. When this occurs reduce the LED emitter current.

The BNC socket labeled ***log Cn²*** allows the user to monitor U_{CN2} using a standard DC Voltmeter, provided that the switch labeled ***Mode*** is set at ***Signal***. By applying equation 2 the structure parameter of the refractive index of air (C_n^2) can be derived.

3.6.3 Protection circuitry and fuse ratings

The 12 VDC power input to the electronic circuits of both the **LAS/*X*LAS** transmitter and receiver include protection circuitry consisting of a spark gap arrestor, in-line inductance and surge protection to guard against transients. A **2A quick blow fuse** protects the circuitry from current overload. To replace the fuse the control panels must be removed.

The control panels can be accessed by removing the rear cover of the **LAS/*X*LAS** receiver or transmitter unit. Proceed as follows: switch the power off, disconnect the internal plug and remove the 4 screws on the perimeter of the control panel, gently lift out the control panel and carefully disconnect the wiring harnesses linking the control panel to the printed circuit board behind. The power fuse can be identified and replaced (see figure 3).

Reassemble in the reverse order.

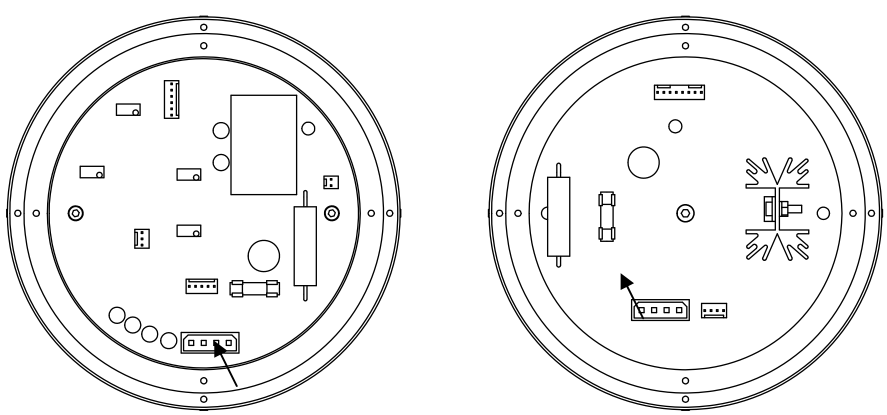


Figure 3: The location of the power fuse (identified by the arrow) on the receiver (left) and transmitter (right) printed circuit boards.

Important: *Always disconnect power before attempting to replace the fuse.*

3.7 OPTICAL ALIGNMENT

The alignment of the **LAS/*X*LAS** at the measurement site is an iterative process for establishing the optimum signal strength for horizontal line-of-sight transmission. The different steps are summarised below. We recommend practice of the alignment procedure at a short range (~ 150 m) first, before proceeding to longer distances. The transmitter and receiver can be rotated around both vertical and horizontal axes. The coarse adjustment of the horizontal alignment (pan) can be done before the bolt(s) that fixes the adjuster bottom flange to the supporting base/structure is (are) completely tightened. Fine pan adjustment can be done with the two horizontal screws with black knobs, which are located just below the case of transmitter or receiver, at the back of the adjuster. For the vertical alignment (tilt), two vertical adjustment bolts are provided, one at the front and one at the rear (see figure 4).

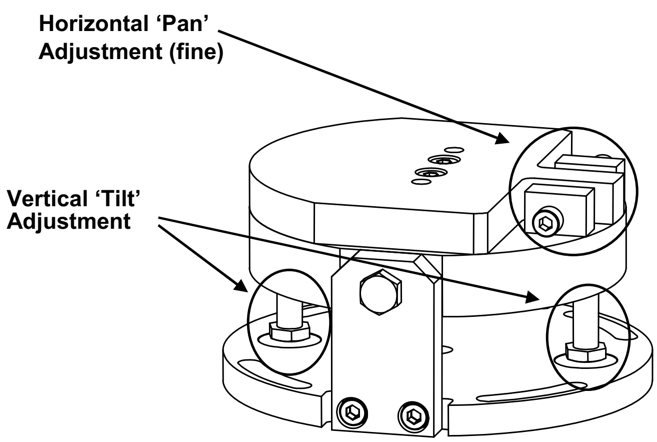


Figure 4: Diagram of pan and tilt adjuster.

Two people should carry out the alignment, one at the receiver and one at the transmitter site. They should be able to communicate either by radio, walkie-talkies or mobile telephones.

The transmitter and receiver are mounted at their respective positions. The bolts used to fix the pan and tilt adjusters of the **LAS/*X*LAS** to the supporting structures (either a tripod, or something else) are fastened by hand, so that the **LAS/*X*LAS** can still be turned around its vertical axis.

1. The telescopes are mounted to the rails on tops of the transmitter and receiver. Note that the telescopes are factory-aligned for each transmitter and receiver and are marked appropriately with either 'Transmitter' or 'Receiver'.
2. The transmitter is adjusted both horizontally (pan) and vertically (tilt) such that the crosshairs of the telescope are centered on the receiver. The same is done for the receiver, relative to the transmitter. Tighten the bolts fixing the pan and tilt adjusters of the **LAS/*X*LAS** to the supporting structures (further adjustments can be done with the pan fine adjustment screws).
3. Remove the rear covers of the transmitter and receiver, connect suitable power supplies to both units and switch on. The ***Power*** indicator on each control panel should illuminate. Set the switch labeled ***Mode*** at the receiver control panel to ***Signal***. At the transmitter side the current is adjusted to a reasonable value with the ***Current Adjust*** knob (the dial runs from 0 to 1000). Full scale is approximately 0.5 A (see table 6). For path lengths of about 1 km the current should lie approximately around 0.15 A, whereas for paths of 4.5 km 0.5 A is required. Note that the received signal strength depends on the visibility. If all is well, the analogue meter (***Signal Strength***) at the control panel of the receiver should give some signal already (to make the meter ten times as sensitive, it can be switched to ***long range***, rather than ***short range***).

Table 6: Power consumption LAS/XLAS transmitter as a function of *Current adjust* knob (window-heater not included).

Current adjust knob [-]	Power consumption Transmitter [A]
0	0.02
100	0.06
200	0.11
300	0.17
400	0.22
500	0.28
600	0.31
700	0.36
800	0.41
900	0.47
1000	0.52

Important: *During the alignment, the transmitter current should be kept constant at all time unless:*

- *If the analogue **Signal Strength** meter at the receiver goes over-range, decrease the transmitter current.*
- *If there is no reading on the analogue **Signal Strength** meter at the receiver, increase the transmitter current and try again.*

Otherwise the transmitter current should be kept constant, since when looking for a maximum signal strength, it only makes sense to compare readings at a given fixed transmitter power.

4. The following steps are intended to find the edges of the beam (use landmarks to locate these edges) at both the receiver and transmitter side and to get a good signal as indicated by the analogue meter on the rear of the receiver (see figure 5). It is very important to follow this procedure because the data is not reliable when the edges of the beam are too close to the receiver or transmitter aperture!
   a. The person at the receiver looks at the analogue ***Signal Strength*** meter and communicates the values he/she sees to the person at the transmitter.
   b. The person at the transmitter first turns the transmitter horizontally (**slowly**) left and right using the adjustment knobs until the optimal signal strength (as given by the person at the receiver) is reached by finding the center of the beam (midpoint between horizontal edges of beam).
   c. Then the transmitter needs to be adjusted vertically (using the two vertical adjustment bolts). The transmitter is turned up-wards and down-wards (**slowly**) until the optimum reading of the analogue ***Signal Strength*** meter at the receiver is reached (again find the midpoint between the vertical edges of beam). The vertical bolts are tightened smoothly by hand, taking care not to change the alignment.
   d. It is possible that the transmitter / receiver is not at the center of the crosshairs of the telescope compared with the center of the beam derived from the field alignment, due to a difference from the range at which they were factory adjusted. If necessary the crosshairs of the telescopes can be adjusted. Therefore never use the telescopes alone during the alignment procedure!

   Repeat steps b, c and d for the receiver, while the transmitter is kept at its position. The person at the receiver can turn the receiver both horizontally and vertically, while looking at the analogue ***Signal Strength*** meter, to obtain the optimum position (i.e. the center of the beam between the edges) and signal strength.

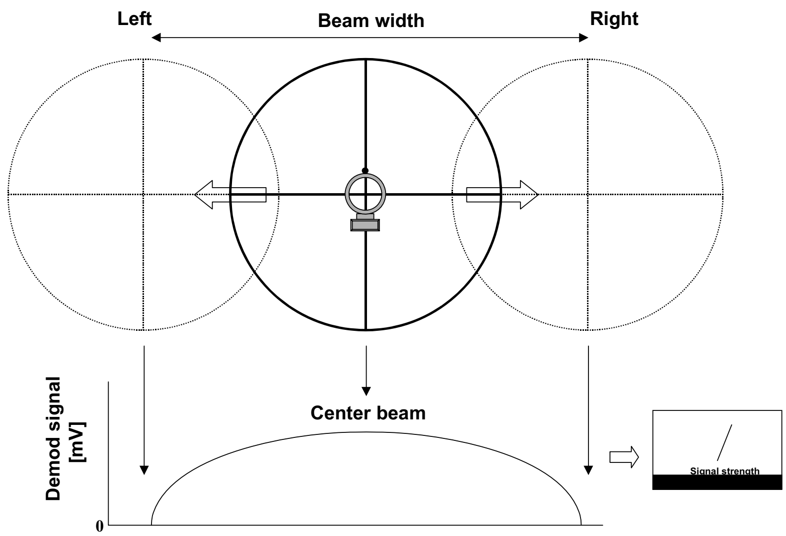


Figure 5: Behavior of the signal strength at the receiver when the receiver / transmitter is turned slowly from left to right (while looking through the telescope). The signal will behave similarly in the up-down direction.

5. The steps in 4 are repeated until the optimum alignment is reached. Tighten the two horizontal fine-adjustments bolts and the two vertical adjustment bolts at the transmitter and receiver with a spanner. Whilst fastening the bolts make sure that the alignment is not changed. This can be avoided by looking through the telescopes whilst tightening the bolts.
6. Finally, the current of the transmitter should be adjusted such that there is sufficient signal (U_{DEMOD}) at the receiver. At maximum distance (i.e. **LAS** over 4.5 km and ***X*LAS** over 8 km) the signal strength should be approximately –75 mV (transmitter at full power and clear atmospheric conditions). As a rule of thumb we advice to adjust the power of the transmitter such that the analogue meter reads approximately 50 (**LAS**: for distances longer than 2 km set switch to long range, for distances shorter than 2 km set switch to short range; ***X*LAS**: short range < 5 km and long range > 5 km). Typical values of LED current and signal strength for several path lengths are given in table 7.
7. Place the rear covers back on the transmitter and receiver and tighten the fixing screws, ensuring that the 'o'-rings are in their grooves and not distorted.
8. Remove the telescopes.
9. Install the protective heat shields on top of the transmitter and receiver unit and tighten the fixings.

⚠ **Important:** *Never (re-) align the* **LAS**/***X*LAS** *transmitter and receiver using the telescopes only.*

⚠ **Important:** *Never switch around the transmitter and receiver telescopes.*

⚠ **Important:** *Avoid signal saturation of the detector.*

Note: *When the receiver is positioned too close to the edge of the beam this will result in increased noise and incorrect C_n^2 measurements.*

Table 7: Typical values for LED current and signal strength as function of the path length (for clear atmospheric conditions!).

	Path length [m]	*Current adjust* knob [-]	U_{DEMOD} [mV]	*An. – meter* (short range)	*An. – meter* (long range)
LAS	250	< 10	> -600	80	×
LAS	1000	200	-450	60	×
LAS	4500	1000	-80	×	30
XLAS	8000	1000	-80	×	30

Table 8: Relation between the signal strength (U_{DEMOD}) and reading of the analogue *Signal Strength* meter for different signal strengths ($R_{detector}$ = 8M2 Ω; R_{meter1} = 560 Ω; R_{meter2} = 5k6 Ω; no optical filter).

An. – meter (short range)	*An. – meter* (long range)	U_{DEMOD} [DC-mV]	$U_{CARRIER}$ [AC-mV]
0	< 2	-8	0
10	30	-80	50
20	60	-160	90
30	90	-240	130
40	×	-300	175
50	×	-375	215
60	×	-445	250
70	×	-520	290
80	×	-600	335
90	×	-680	375
100	×	-770	415

3.8 SETTING PATH LENGTH POTENTIOMETER

Once the **LAS** has been installed and properly aligned the ***Path Length*** dial knob at the receiver control panel must be set for the correct distance between the transmitter and the receiver. The ***Path Length*** dial knob has 10 turns maximum with a vernier counter and a locking mechanism. These graduations are **NOT** in units of distance! The precise path length must first be converted to a dial knob setting (*Pot*) using the following relationship for the **LAS**

$$Pot_{LAS} = \left(\frac{5475.81}{\sqrt{(4.474 D^{\frac{7}{3}} L^{-3} 0.3314 \cdot 10^{12}) + 5.23}} \right) - 47, \qquad (1a)$$

and the ***XLAS***

$$Pot_{XLAS} = \left(\frac{2737.905}{\sqrt{(4.474 D^{\frac{7}{3}} L^{-3} 0.3314 \cdot 10^{12}) + 2.615}} \right) - 47, \qquad (1b)$$

where *D* is the aperture diameter (**LAS**: 0.152 m; ***XLAS***: 0.328 m) and *L* the distance between the transmitter and receiver (in meters). Calculated values of Pot_{LAS} and Pot_{XLAS} for different path lengths can be found in table 9. Note that because of the sensitivity of *Pot* to *L* and thus also C_n^2 to *L* the distance must be determined accurately. Also note that it is possible to recalculate incorrect C_n^2 data, due to an incorrect path length setting *Pot* (and thus *L*), afterwards in the WINLAS software (see section 5). However, this correction should be used for small corrections only!

⚠ **Important:** *Path length dial knob units are **NOT** in units of distance.*

⚠ **Important:** *Determine the path length precisely!*
(~ <1 %, e.g. 500 m (± 5 m) and 3 km (± 30 m))

Table 9: ***Path Length*** **(*Pot*) dial knob setting values for different path lengths between the (X)LAS transmitter and receiver.**

LAS		*XLAS*	
Path length [m]	Pot_{LAS} [-]	Path length [m]	Pot_{XLAS} [-]
250	91.9	1000	161.9
300	128.2	1250	223.5
350	164.6	1500	281.9
400	200.4	1750	336.2
450	235.3	2000	386.0
500	269.1	2250	431.4
550	301.5	2500	472.7
600	332.5	2750	510.1
650	362.0	3000	543.9
700	390.0	3250	574.5
750	416.5	3500	602.3
800	441.7	3750	627.5
850	465.4	4000	650.4
900	487.9	4500	690.2
950	509.1	5000	723.6
1000	529.1	5500	751.7
1184	593.5	6000	775.5
1200	598.5	6500	796.0
1400	654.0	7000	813.6
1600	698.8	7500	828.9
1800	735.2	8000	842.4
2000	765.2	8500	854.2
2500	820.6	9000	864.6
3000	857.7	9500	873.9
3500	883.8	10000	882.2
4000	902.9	×	×
4500	917.4	×	×
×	×	×	×

4. OPERATION

After completing the installation the **LAS/*X*LAS** (alignment, path length) will be ready for operation.

The C_n^2 values can simply be computed from the output signal (U_{CN2}) using the following equation

$$C_n^2 = 10^{(U_{CN2}-12)}. \qquad (2)$$

C_n^2	= structure parameter of the refractive index of air	[$m^{-2/3}$]
U_{CN2}	= *log* Cn^2 signal	[V]

For example if U_{CN2} = - 4.0 V, then $C_n^2 = 1 \cdot 10^{-16}$ $m^{-2/3}$.

Because of the non-linearity between C_n^2 and the output signal of the **LAS/*X*LAS** (U_{CN2}), an interval-averaged U_{CN2} (e.g. 10 minutes) will not yield the true interval-averaged C_n^2. Therefore we recommend one of the following two options:

1. Measure besides the interval averages of U_{CN2}, the variance of U_{CN2} ($\sigma^2_{U_{CN2}}$) and apply the following equation for deriving the correct interval-averaged C_n^2

   $$C_n^2 = 10^{\left(U_{CN2}-12+1.15\cdot\sigma^2_{U_{CN2}}\right)}. \qquad (3)$$

C_n^2	= structure parameter of the refractive index of air	[$m^{-2/3}$]
U_{CN2}	= *log* Cn^2 signal	[V]
$\sigma^2_{U_{CN2}}$	= variance of U_{CN2}	[V^2]

2. Calculate C_n^2 immediately after each measurement cycle (e.g. 1 Hz) and derive the interval-averaged C_n^2 (e.g. 10 minute averages) from the instantaneous C_n^2 values. Because C_n^2 values are too small to store in most conventional data acquisition systems (~ $1 \cdot 10^{-16}$) multiply the C_n^2 values by $1 \cdot 10^{15}$ (PU_{LAS}). Whether this option can be applied depends on the capability of the data acquisition systems to perform immediate calculations with the measured data. Afterwards the true C_n^2 values can be derived from PU_{CN2} as follows

   $$C_n^2 = PU_{CN2} \cdot 10^{-15}. \qquad (4)$$

In appendix IV and V examples are shown for Campbell Scientific (Model CR10X) and Theodor Friedrichs & Co data loggers (COMBILOG 1020).

5. WINLAS SOFTWARE

The following sections provide information about the **LAS**/***X*****LAS** software: WINLAS. WINLAS allows the **LAS**/***X*****LAS** user to derive the surface fluxes of sensible heat from collected LAS data and additional meteorological data, namely air temperature (T), air pressure (P), wind speed (u) and Bowen ratio (β) data. WINLAS calculates the fluxes according to the theory given in appendix I.

5.1 SYSTEM REQUIREMENTS

The minimum computer hardware requirements for WINLAS is a 100 MHz Pentium computer running Windows 95/98/NT/2000/XP/ME, 16 MB of Ram, 10 MB of free hard-disk space (excluding LAS data) and a mouse.

5.2 INSTALLATION

The WINLAS software consists of four files, namely an executable (WINLAS.exe), an initialization file (WINLAS.ini), a help file (WINLAS.chm) and a data-example file (EXAMPLE.txt), which are supplied on a CD. Once the files are copied to a (sub) directory on the PC, WINLAS can be started by double clicking on WINLAS.exe.

5.3 WINLAS OVERVIEW

Double clicking on WINLAS.exe with the Kipp & Zonen logo will open the software. The buttons in the Main Menu of the WINLAS software provide access to the various pages of WINLAS (see figure 6).

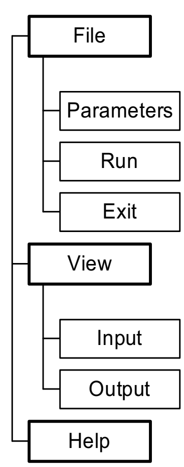


Figure 6: WINLAS menu options

File → Parameters

By selecting menu item Parameters in the File list a new window will appear (see figure 7). In this window named ***Input Parameters*** specific settings and data files used by WINLAS can set. In this window 6 categories can be seen. Under category ***Input file*** and ***Parameters*** the **LAS/XLAS** user is able to select input files and specify its format (header and separator) and the data columns sequence. In case the data file contains wind speed data the height of the anemometer and temperature sensor must be given. If no temperature and air pressure data is available constant values can be given. Under category ***Terrain*** the terrain characteristics (i.e. roughness length (z_o) and zero-displacement height (d)) where the LAS is installed can be set (see appendix III). Category **LAS/XLAS** is used to specify the path length that is set by the *Path length* dial knob at the back panel of the receiver, the real path length, the LAS type (either 0.1m-LAS, LAS or XLAS), and its effective beam height (for more information about the effective beam height see appendix II). Note that the path length correction should only be used for small corrections! In case no Bowen Ratio data is available a realistic constant value can be defined in category ***Bowen Ratio***. Finally, under category ***Minimum signal strength*** the minimum signal strength value is set. This value is used to check the validity of the **LAS** measurements. For situations the signal strength drops below this minimum value WINLAS will reject the C_n^2 data.

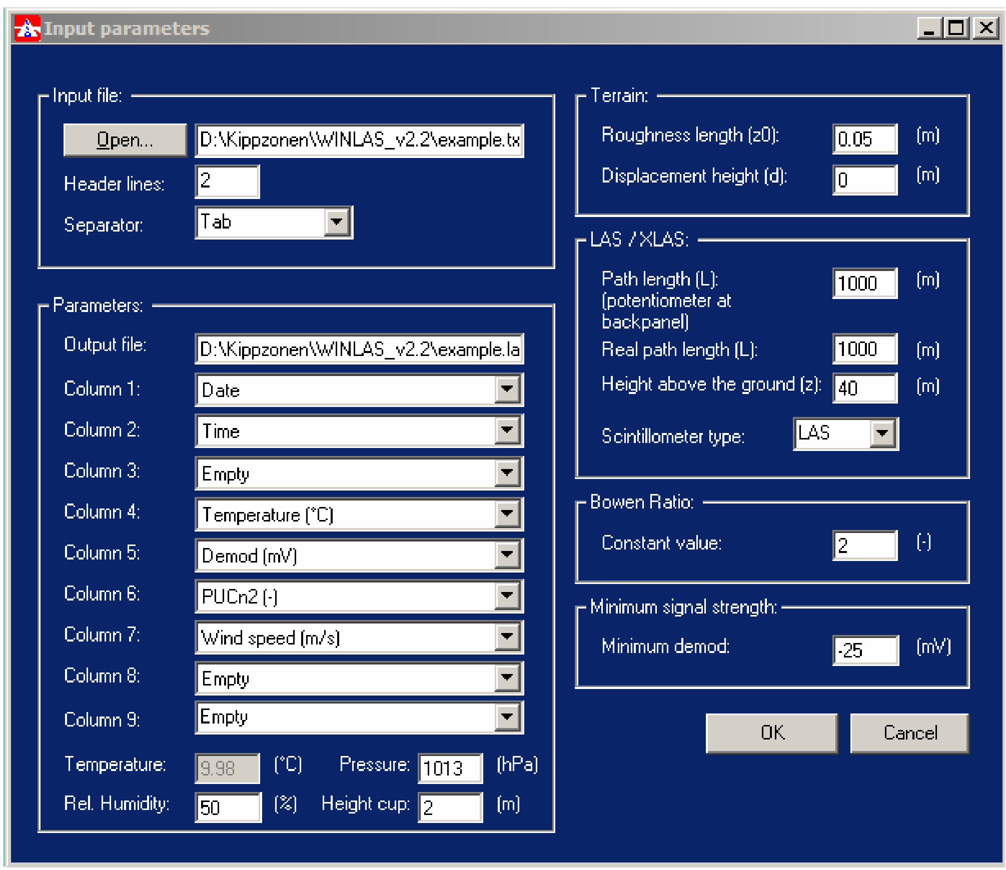


Figure 7: WINLAS Input parameters menu.

File → Run

Menu item Run will start the calculations and write the results to an output file. Before the calculations start the program will check whether the output file already exists. If so, the user is asked to either change the name or to press OK to overwrite the existing file.

File → Exit

The program WINLAS will be closed and its settings will be saved automatically in WINLAS.ini.

View → Input

Once an input file is selected in the Parameter menu, the menu item *Input* under View is enabled. Clicking this menu item will open the input file for viewing and editing.

View → Output

Once WINLAS has derived the fluxes from an input file the menu item *Output* is enabled. Clicking this menu item will open the output file for viewing and editing.

5.4 THE INPUT FILE

The data input file should be an ASCII file consisting of columns (with or without a header), which are separated by a comma, semicolon, a space or a tab. The first two data columns should always be a date stamp (or day number, DOY) and a time stamp, followed by **LAS**/***X*****LAS** data (C_n^2 and signal strength) and additional meteorological data (namely T, u, P and β). Header lines are the number of lines that will be skipped by the program before reading the actual data columns. If there is no header this value should be 0.

⚠ **Important:** *The maximum allowed number of data columns in the input file is* ***8****, including the Date/DOY and Time columns!*

The following **LAS** and additional meteorological data can be read by WINLAS:

- * C_n^2 [$m^{-2/3}$]
- * UCn2 [V] (i.e. U_{CN2} of the **LAS**/***X*****LAS**) preferably in combination with VarUCn2 [V^2] (i.e. the variance of U_{CN2}, namely $\sigma^2_{U_{CN2}}$) selected in the following data column. C_n^2 is calculated according to equation 3.
- * PUCn2 [-] (i.e. scaled C_n^2, which is stored by the CR10X Campbell program example shown in appendix IV). C_n^2 is calculated according to equation 4.
- Signal strength [mV] (i.e. U_{DEMOD} of the **LAS**/***X*****LAS**)
- Air temperature (T) [°C] (between -30 and +50 °C)
- Air pressure (P) [hPa] (between 950 and 1080 hPa)
- Wind speed (u) [m s^{-1}] (between 0 and 100 m s^{-1})
- Bowen ratio (β) [-] (between -10 and +10)
- Empty

* CHOOSE ONLY ONE OF THESE THREE OPTIONS!

⚠ **Important:** *In case of missing or invalid data the following* ***Dummy*** *value should be used in the input file:* ***-9999****. Other dummy values are not accepted by WINLAS.*

Doy	Time	U_{CN2}	Demod	Var_U_{CN2}	PU_{CN2}	*u*	*T*
[-]	[UTC]	[V]	[mV]	[V^2]	[-]	[m/s]	[°C]
11	600	-3.003	-102.4	0.009	1.0178	2.341	14.96
11	610	-3.144	-85	0.014	0.74559	1.869	15.09
11	620	-2.774	-46.46	0.038	1.8633	2.353	15.55
11	630	-1.612	-11.13	1.55	446.41	3.97	15.91
11	640	-2.45	-15.21	0.299	15.556	4.136	16.07
11	650	0.179	-1.806	0.028	1590.7	4.102	15.85
11	700	0.193	-1.823	0.001	1563.8	3.055	15.97
11	710	-0.095	-2.028	0.038	877.43	3.527	16.16
11	720	-0.997	-3.004	0.102	130.33	2.815	16.48
11	730	-2.362	-25.71	0.254	8.9348	3.117	16.54
11	740	-1.861	-6.99	0.001	13.809	2.674	16.72
11	750	-1.827	-6.582	0.002	14.989	2.553	17.18
11	800	-1.668	-5.105	0.001	21.535	3.214	17.23
11	810	-1.837	-7.09	0.061	16.85	2.939	17.61
11	820	-2.53	-27.05	0.05	3.409	2.407	17.47
11	830	-2.522	-66.5	0.045	3.4621	2.219	17.72
11	840	-2.895	-115.4	0.038	1.4077	2.764	18.1
11	850	-3.116	-159.3	0.01	0.78745	3.681	17.81
11	900	-3.224	-200.2	0.024	0.63656	2.513	16.78
11	910	-3.185	-220.2	0.019	0.68623	4.335	18.17
11	920	-3.265	-227.5	0.016	0.56941	3.687	17.86
11	930	-2.875	-229.7	0.037	1.4579	4.88	18.3
11	940	-2.651	-231.6	0.026	2.3807	4.309	18.15
11	950	-2.544	-233.9	0.02	3.0127	4.105	17.67
11	1000	-2.639	-232.3	0.009	2.351	3.067	17.54
11	1010	-2.504	-238.4	0.024	3.3331	3.882	18.24
11	1020	-2.398	-241	0.018	4.1807	4.878	18.23
11	1030	-2.438	-236.2	0.013	3.7704	5.279	18.83
11	1040	-2.286	-230.5	0.012	5.3446	4.522	18.14
11	1050	-2.372	-230.1	0.015	4.4093	4.278	18.9
11	1100	-2.319	-229.6	0.03	5.1836	4.205	18.42
11	1110	-2.367	-229.7	0.019	4.508	4.59	18.98
11	1120	-2.281	-229.7	0.016	5.4509	3.323	19.3
11	1130	-2.327	-227.2	0.013	4.877	3.858	19.19
11	1140	-2.323	-226.5	0.014	4.9236	3.239	19.06
11	1150	-2.153	-227.4	0.011	7.2483	2.932	18.61
11	1200	-2.306	-226.8	0.012	5.1062	3.009	18.43
11	1210	-2.285	-226.1	0.03	5.5913	2.958	18.85
11	1220	-2.145	-230.5	0.012	7.3962	3.717	18.53
11	1230	-2.255	-229.3	0.028	5.9785	4.161	18.93

Figure 8: example of an input file (contains 10-minute averages of LAS and additional data).

Note that the data file in figure 8 contains two columns with C_n^2 information, option1: column 3 combined with column 5 and option 2: column 6. In this case only one of these two options must selected in WINLAS and NOT both.

If temperature, air pressure and Bowen ratio data are selected in columns 3 to 8, the input boxes for constant values for temperature, air pressure and Bowen ratio will be disabled. In case no wind speed data is available WINLAS calculates the sensible heat flux using the free convection approach only.

5.5 THE OUTPUT FILE

Once an input file is selected, the output file is given the same name with extension .las. The output file is an ASCII file and contains the following data columns:

- Date or Day number (=DOY)
- Time
- C_n^2 [$m^{-2/3}$]
- Demod [mV]
- $H_{unstable}$ [W m^{-2}] (sensible heat flux, unstable (or day-time) solution)
- H_{stable} [W m^{-2}] (sensible heat flux, stable (or night-time) solution)
- $H_{free\ convection}$ [W m^{-2}] (sensible heat flux, free convection solution)
- Wind speed [m s^{-1}]
- $u_{*unstable}$ [m s^{-1}] (friction velocity, unstable solution)
- $u_{*stable}$ [m s^{-1}] (friction velocity, stable solution)
- $L_{MO\_unstable}$ [m] (Obukhov length, unstable solution)
- L_{MO_stable} [m] (Obukhov length, stable solution)
- Bowen ratio [-]
- Air temperature [^oC]
- Relative humidity [%]
- Air pressure [hPa]
- Air density [kg m^{-3}]
- Comment saturation (“no saturation”, “-“ or “possible saturation”)

6. MAINTENANCE

To be certain that the quality of the data is of high standard, care must be taken with the maintenance of the **LAS**/**XLAS**. Regular cleaning of the windows and checking the alignment (using telescopes) will prevent unnecessary signal attenuation and data loss. Also periodically check the condition of all cables and connectors.

Important: *Always keep power connected and switched on to the* **LAS**/**XLAS** *transmitter and receiver when they are placed outside to prevent condensation.*

Periodically check if there is **no** condensation inside the transmitter and receiver units (see humidity indictor or look at front window for condensation). Follow the instructions given by the humidity indicator, which is visible through the rear window of the back panel of both units. Depending on climate conditions and the number of times the units are opened, the silica gel bags have to be replaced once in a while. We recommend not opening the units unless necessary (e.g. during installation or re-alignment). The LED current of the transmitter, signal strength at the receiver and power indictor can be easily checked via the rear window during periodically checks, without removing the rear panel.

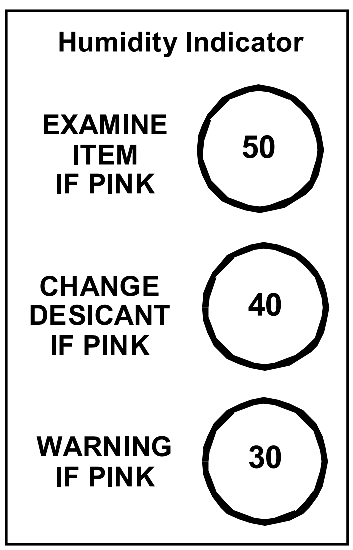


Figure 9: Humidity indicator (Type B2, 30% .. 40% .. 50%).

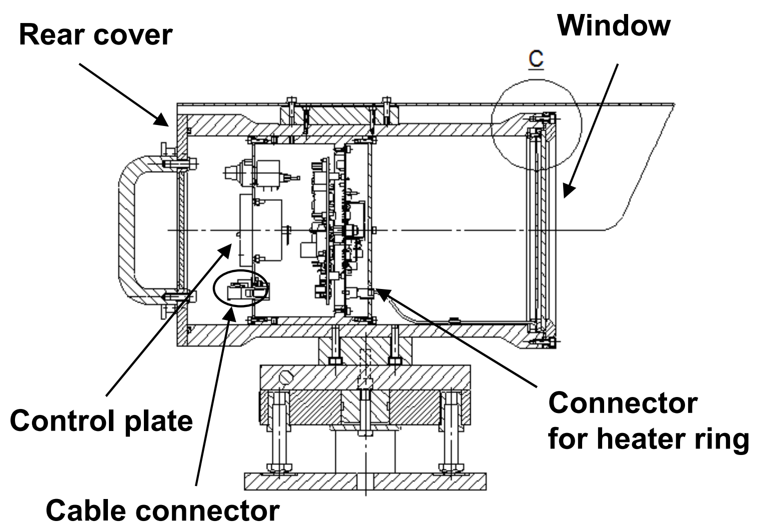
How to deal with internal condensation? First try to find the leak. Is it the amphenol connector or was the back panel not properly closed? Because the electronics of the **LAS**/**XLAS** don't dissipate enough power internally, one has to dry out the **LAS**/**XLAS** (Transmitter and/or receiver) as follows (see also figure 10):

1. Take the **LAS**/**XLAS** unit inside.
2. Remove the rear cover.
3. Disconnect the cable connector from the control plate.
4. Undo the 4 screws holding the control plate and carefully pull it out
5. Disconnect the cables that connect the control plate to the printed circuit board (pcb) behind

6. Remove the six screws at the front holding the window assembly to the housing. Be careful not to loose the screws and the rubber O-rings (6 small and 1 large). For details see figure 10.
7. Gently lift out the lens/heater ring assembly and disconnect the power cable from the heater to the bullet. Do NOT disassemble the housing any further because this might affect the optical alignment of the transmitting LED and/or receiving photo-diode!

Dry the inside of the housing as much as possible and clean off any surface corrosion. Clean the window and Fresnel lens using a dry tissue (and/or dust free blower). If the lens is still dirty then a mild soap solution can be used. **The Fresnel lens is a moulded plastic component - do NOT use solvents to clean it!**

Leave the housing open to dry for a couple of hours/days (depending on room temperature) and reassemble in the reverse order. Note that the Fresnel lens is mounted with the grooved surface facing outwards towards the window. Clean any hard grease off the o-ring seals and apply silicone grease before reassembly (if not available Vaseline will do). The front and rear covers screw down to make metal-to-metal contact with the housing when the o-rings are properly compressed.



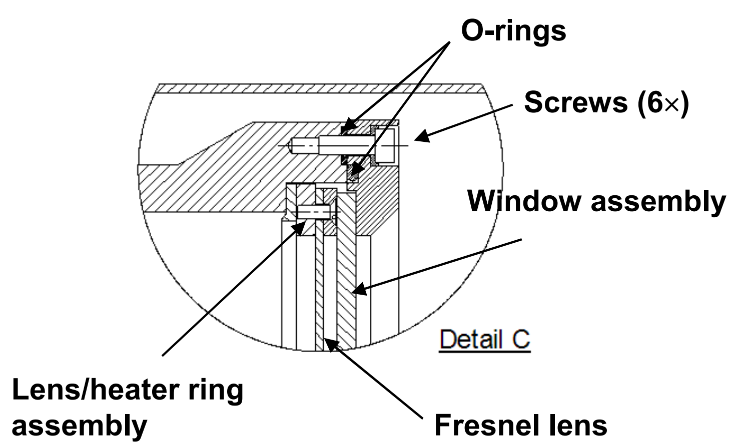


Figure 10: Window - Fresnel - Heating ring assembly.

7. CALIBRATION

7.1 ON-SITE CALIBRATION CHECK

The purpose of the electronics in the **LAS**/***X*****LAS** receiver unit is to provide real-time values for C_n^2 but scaled in voltage units, which can be recorded by data acquisition systems. The electronics perform the following steps: detection with feed-back circuit to remove slow ambient fluctuations; demodulation of the carrier signal; low-pass filtering at 400 Hz to remove high-frequency noise; producing the logarithm of the signal intensity; removing any offsets; path length correction (i.e. adjustment of Gain); filtering the scintillation bandwidth between 0.2 Hz and 400 Hz; calculation of the variance of the conditioned signal. In addition to the analogue pre-processing, calibration circuitry provides the user a quick on-site check of the performance of the real-time C_n^2 calculations.

By setting the receiver control panel switch labelled ***Mode*** to ***Calibration*** a reference signal of a known modulation and carrier frequency is sent through the analogue processing circuitry. This reference signal consists of a 7 kHz (± 0.7 kHz) square-wave carrier modulated by a 10 Hz (± 1 Hz) square-wave with a modulation depth of 50%. This reference signal can be monitored at the BNC socket labelled ***Carrier*** with an oscilloscope. Due to additional filters this reference signal is slightly distorted. However, the modulated signal is still recognisable.

By adjusting the ***Path Length*** dial knob of the **LAS** to a setting of **593.5** (equal to L = 1184 m) and for the ***X*****LAS** a setting of **414.1** (equal to L = 2152 m), zero volts should be measured at BNC socket ***log Cn²***. If the signal is not 0 V (± 15 mV) after 1 hour of warm-up time, the receiver electronics need to be recalibrated. In table 10 a range of output values are given for different ***Path Length*** dial knob settings when set in ***Calibration*** mode.

Important: *When performing a calibration check the* **LAS**/***X*****LAS** *receiver should be connected to a stable power supply and the environmental temperature must be constant at close to room temperature.*

Table 10: Output signal U_{CN2} at BNC socket (of LAS/XLAS) as a function of the *Path Length* dial knob setting (in *Calibration* mode) at constant room temperature.

LAS		XLAS	
***Pot*$_{LAS}$ [-]**	**U_{CN2} at BNC [mV]**	***Pot*$_{XLAS}$ [-]**	**U_{CN2} at BNC [mV]**
200	1415	200	813
300	1004	300	402
400	650	400	48
500	316	**414**	**0.0**
594	**0.0**	500	-286
700	-398	600	-626
800	-859	700	-1000
884	-1415	800	-1462

7.2 RECALIBRATION

The electronics of the **LAS**/***X*****LAS** receiver unit can change with time and with temperature. Therefore periodic checking of the electronic (see Section 6.1) is advised. If the signal is not within ± 15 mV of the values given in table 10 for different ***Path Length*** knob settings (check at least 5 different pot settings) the receiver electronics need to be recalibrated.

To return a **LAS**/***X*****LAS** to Kipp & Zonen for recalibration the use of the recalibration form at the end of this manual is strongly recommended.

7.3 CALIBRATION PROCEDURE AT KIPP & ZONEN

7.3.1 Calibration procedure RMS-circuits

The receiver electronics contain two RMS-circuits that operate in logarithmic mode. The purpose of the first RMS-circuit is to obtain the log of the received signal intensity. This circuit is calibrated for an arbitrary zero point (offset) and a fixed gain, using two reference voltages of 1.000 V and 0.100 V.

The purpose of the second RMS-circuit is to calculate the RMS of the amplified and filtered log intensity fluctuations (i.e. the conditioned signal). As the first RMS-circuit, the second circuit also requires calibration for offset and gain.

Because both RMS-circuits operate in log-mode an extra temperature-dependant resistor is added, which compensates for the temperature dependence of the (dB) output of the RMS IC’s. Therefore the electronics require **at least** 1-hour warm-up time.

7.3.2 Calibration path length

For the calibration of the *Path Length* dial knob setting an artificial signal is used with a carrier frequency of ~ 7 kHz, which is amplitude modulated with a block signal with a frequency of ~ 10 Hz and a modulation depth of 50%. This signal is directly fed to the demodulator unit (see also Paragraph 7.1).

8. SOLVING PROBLEMS

The **LAS**/***X*****LAS** is designed for both long and short periods of operation with little operator maintenance. However, if a problem occurs that cannot be corrected using the standard operating information supplied in the preceding sections of this manual, use the information in this chapter to identify and solve the problem.

If the problem cannot be corrected after reviewing the information in the following section, contact Kipp & Zonen. When contacting Kipp & Zonen with technical assistance questions, ensure that you have the following information readily available to aid the technician in solving your problem:

- The model number and serial number of the **LAS**/***X*****LAS**. This information is listed on the identification labels, located on the pan and tilt adjusters of the **LAS**/**XLAS** transmitter and receiver.

If you cannot solve the problem by the steps on the following pages, please contact Kipp & Zonen.

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8.1 PROBLEM CHECK-LIST

Check the items in the following list. If these do not help, see the following section on troubleshooting.

Check that:

- Power is supplied to both the **LAS**/***X*****LAS** transmitter and receiver unit.
- The data cables are correctly connected to the data logger or data acquisition unit.

8.2 TROUBLESHOOTING

Table 11: Troubleshooting.

Problem	Corrective action
LED indicator on back panel is off	Check the power fuse, see Paragraph 3.6.3 Check wires
The receiver has no signal	• Check power to transmitter and receiver units • Check if windows are clean (and lenses) and there is no internal condensation (see section 6 for instructions) • Check alignment (using telescopes) • Check for obstacles in the path of the beam • Check the performance of the transmitter electronics at the BNC socket labeled ***LED pulse*** • Check the performance of the real-time C_n^2 calculations of the receiver electronics by setting the receiver to ***Calibration*** mode

APPENDIX I – THEORY SCINTILLATION TECHNIQUE

When an electro-magnetic (EM) beam of radiation propagates through the atmosphere it is distorted by a number of processes. These processes remove energy from the beam and lead to attenuation of the signal. The most serious mechanism that influences the propagation of EM radiation is small fluctuations in the refractive index of the air (n). These refractive index fluctuations lead to intensity fluctuations, which are known as scintillations.

A scintillometer is an instrument that can measure the 'amount' of scintillations by emitting a beam of light over a horizontal path. The scintillations 'seen' by the instrument can be expressed as the structure parameter of the refractive index of air (C_n^2), which is a representation of the 'turbulent strength' of the atmosphere. The turbulent strength describes the ability of the atmosphere to transport scalars, such as heat, humidity and other species (dust particles, atmospheric gases). For a Large Aperture Scintillometer (**LAS**/***X*****LAS**) with equal transmitting and receiving apertures the relationship between the measured variance of the natural logarithm of intensity fluctuations ($\sigma_{\ln I}^2$) and the structure parameter is as follows (Wang et al., 1978)

$$C_n^2 = 1.12\sigma_{\ln I}^2 D^{7/3} L^{-3}, \qquad (5)$$

where D is the aperture diameter of the **LAS**/***X*****LAS** and L the distance between the transmitter and the receiver (i.e. the path length). The figure below shows an example of the diurnal cycle of the structure parameter of the refractive index of air derived from a **LAS** for a sunny day. Typical values of C_n^2 lie between 10^{-13} and 10^{-18} $m^{-2/3}$.

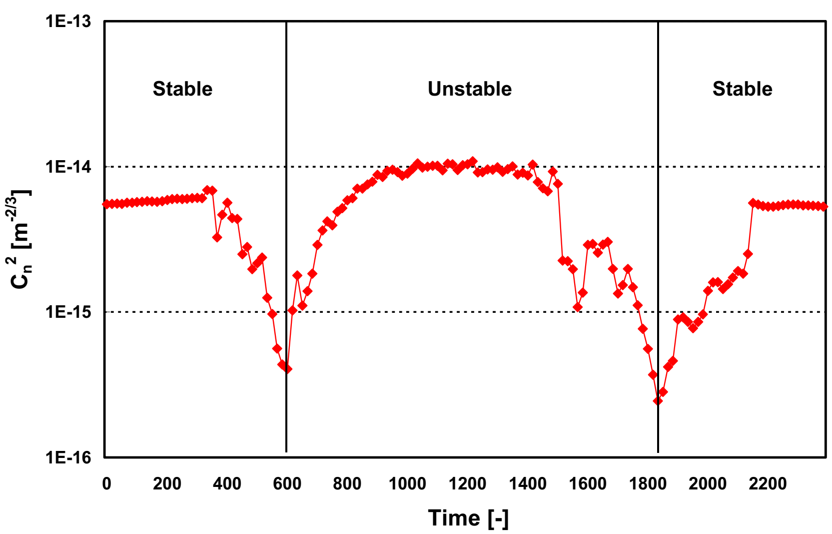

Figure 11: Example of diurnal cycle of C_n^2 obtained with a LAS for a sunny day. LAS setup: effective height roughly 40m and the path length 4.4 km.

In figure 11 the C_n^2 values show a distinct drop around 6:00 and 18:00, sunrise and sunset, respectively. Around sunrise the atmosphere changes from stable to unstable conditions and around sunset the atmosphere changes again from unstable to stable conditions.

In the atmosphere temperature (T), humidity (Q) and to a lesser extend pressure (P) fluctuations cause air density fluctuations and with it fluctuations in the refractive index of air (n). Therefore the structure parameter of the refractive index, C_n^2 can be decomposed into the structure parameters of temperature C_T^2, humidity C_Q^2 and the covariant term C_{TQ} as follows (neglecting pressure fluctuations) (Hill et al., 1980)

$$C_n^2 = \frac{A_T^2}{\overline{T}^2} C_T^2 + \frac{2 A_T A_Q}{\overline{T}\overline{Q}} C_{TQ} + \frac{A_Q^2}{\overline{Q}^2} C_Q^2 . \qquad (6)$$

A_T and A_Q are functions of the wavelength and the mean values of temperature, absolute humidity and atmospheric pressure and thus represent the relative contribution of each term to C_n^2. In the visible and near-infrared wavelength region of the EM spectrum A_T and A_Q are defined as follows (Andreas, 1988)

$$A_T = -0.78 \cdot 10^{-6} \left(\frac{P}{T} \right) + 0.126 \cdot 10^{-6} R_v Q , \qquad (7)$$

$$A_Q = -0.126 \cdot 10^{-6} R_v Q , \qquad (8)$$

where R_v is the specific gas constant for water vapour (461.5 J K^{-1} kg^{-1}). Typical values for A_T and A_Q, for 'normal atmospheric' conditions (P = 1·10^5 Pa, T = 288 K and Q = 0.012 kg m^{-3}), are –0.27·10^{-3} and –0.70·10^{-6}, respectively. Because A_T is much larger than A_Q the contribution of humidity related scintillations is much smaller than temperature related scintillations, i.e. the near-infrared **LAS**/***X*****LAS** is primarily sensitive to temperature related scintillations. Therefore a simplified expression can be derived, which makes it possible to derive C_T^2 from C_n^2 as follows (Wesely, 1976)

$$C_n^2 \approx \frac{A_T^2}{T^2} C_T^2 \left(1 + \frac{0.03}{\beta} \right)^2 \quad \text{or} \quad C_n^2 \approx \left(\frac{-0.78 \cdot 10^{-6} P}{T^2} \right)^2 C_T^2 \left(1 + \frac{0.03}{\beta} \right)^2 , \qquad (9)$$

where β is the Bowen ratio, which is a correction for term for humidity related scintillations. The Bowen ratio is defined as the ratio between the sensible heat (H) and latent heat flux (L_vE), i.e. $\beta = H/L_vE$. When the surface conditions are dry H is larger than L_vE, resulting in high β values (> 3). This means that the correction term in the latter equation is small. Over wet surfaces β is small (< 0.5), which means that a significant amount of scintillations are caused by humidity fluctuations, resulting in a large correction. Thus when the surface conditions are very dry, C_T^2 is directly proportional to C_n^2

$$C_n^2 \approx \frac{A_T^2}{T^2} C_T^2 \quad \text{or} \quad C_n^2 \approx \left(\frac{-0.78 \cdot 10^{-6} P}{T^2} \right)^2 C_T^2 . \qquad (10)$$

Once C_T^2 is known, the sensible heat flux (H) can be derived from similarity relationships that have been derived for C_T^2 which are based on the Monin-Obukhov Similarity Theory (MOST) (Wyngaard et al., 1971)

$$\frac{C_T^2 (z_{LAS} - d)^{2/3}}{T_*^2} = f_T \left(\frac{z_{LAS} - d}{L_{MO}} \right) \quad (L_{MO} < 0), \qquad (11)$$

where d is the zero-displacement height (see appendix III), z_{LAS} the effective height of the scintillometer beam above the surface (Hartogensis et al., 2003), T_* is a temperature scale defined as

$$T_* = \frac{-H}{\rho c_p u_*} , \qquad (12)$$

and L_{MO} is the Obukhov length

$$L_{MO} = \frac{u_*^2 T}{g k_v T_*}, \tag{13}$$

where ρ is the density of air (~ 1.2 kg m^{-3}), c_p the specific heat of air at constant pressure (~ 1005 J kg^{-1} K^{-1}), k_v the von Kármán constant (~ 0.40), g the gravitational acceleration (~ 9.81 m s^{-2}) and u_* the friction velocity. The universal stability function f_T is defined as follows for unstable (day-time, L_{MO} < 0)

$$f_T\left(\frac{z_{LAS}-d}{L_{MO}}\right) = c_{T1}\left(1 - c_{T2}\frac{z_{LAS}-d}{L_{MO}}\right)^{-2/3} \quad (L_{MO} < 0), \tag{14}$$

where c_{T1} = 4.9 and c_{T2} = 6.1 and for stable (night-time, L_{MO} > 0) conditions as

$$f_T\left(\frac{z_{LAS}-d}{L_{MO}}\right) = c_{T1}\left(1 + c_{T3}\left(\frac{z_{LAS}-d}{L_{MO}}\right)^{2/3}\right) \quad (L_{MO} > 0), \tag{15}$$

where c_{T3} = 2.2 (see Andreas, 1988; De Bruin et al., 1993; Wyngaard et al., 1971).

Important: There is no consensus about the stability function for stable (night-time) conditions!

In order to derive H from C_T^2, the friction velocity (u_*) is required. The friction velocity can be obtained from additional wind speed data (u) and an estimate of the surface roughness (z_0) (Panofsky and Dutton, 1984) (see appendix III)

$$u_* = \frac{k_v u}{\ln\left(\frac{z_u - d}{z_0}\right) - \Psi_m\left(\frac{z_u - d}{L_{OM}}\right) + \Psi_m\left(\frac{z_0}{L_{OM}}\right)}, \tag{16}$$

where z_u is the height at which the wind speed is measured and Ψ_m is the integrated stability function for momentum defined as (for unstable conditions (day-time))

$$\Psi_m\left(\frac{z}{L_{MO}}\right) = 2\ln\left[\frac{1+x}{2}\right] + \ln\left[\frac{1+x^2}{2}\right] - 2\arctan(x) + \frac{\pi}{2} \quad (L_{MO} < 0), \tag{17}$$

with

$$x = \left(1 - 16\frac{z}{L_{MO}}\right)^{1/4}, \tag{18}$$

or (stable conditions (night-time))

$$\Psi_m\left(\frac{z}{L_{MO}}\right) = -5\frac{z}{L_{MO}} \quad (L_{MO} > 0). \tag{19}$$

In summary, C_n^2 data together with additional wind speed, temperature data and an estimates of the surface roughness and the displacement height (see appendix III), the sensible heat flux can be determined from equations 11 to 19, which can be solved iteratively (see also figure 13).

For most day-time (unstable) conditions and when the **LAS** is installed relatively high above the surface (z_{LAS} > 20 m) the contribution of the friction velocity is relatively small. For these conditions the free convection method can be applied

$$H_{free} = \rho c_p b(z_{LAS} - d)\left(\frac{g}{T}\right)^{1/2}\left(C_T^{\,2}\right)^{3/4}, \tag{20}$$

where b is an empirical constant ($b = \sqrt{\left(\frac{1}{c_{T1}}\right)^{3/2} k_v c_{T2}} \cong 0.48$). The latter expression is also known as the free convection approach and provides a simple method to determine H directly from C_T^2 without knowing u_*. In practical applications the free convection approach can provide accurate fluxes when the scintillometer is installed relatively high above the surface (z_{LAS} > 20 m) (see figure 14).

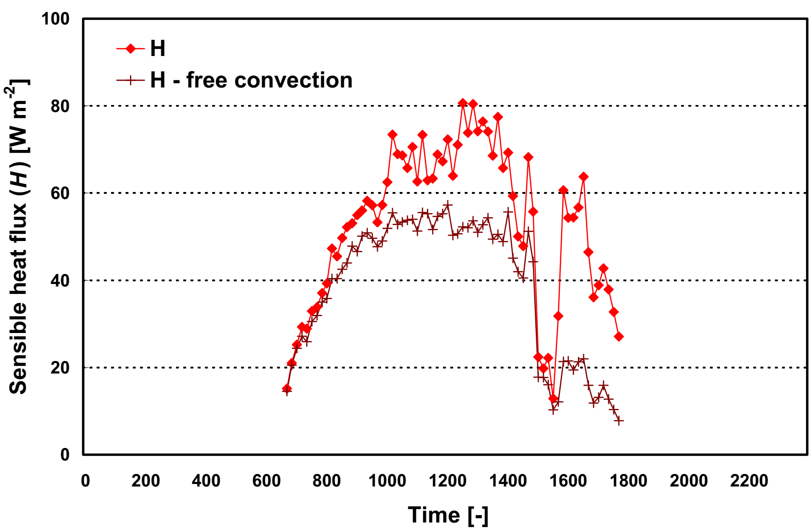

Figure 12: Example of H and H_{free} derived from a LAS (unstable period only).

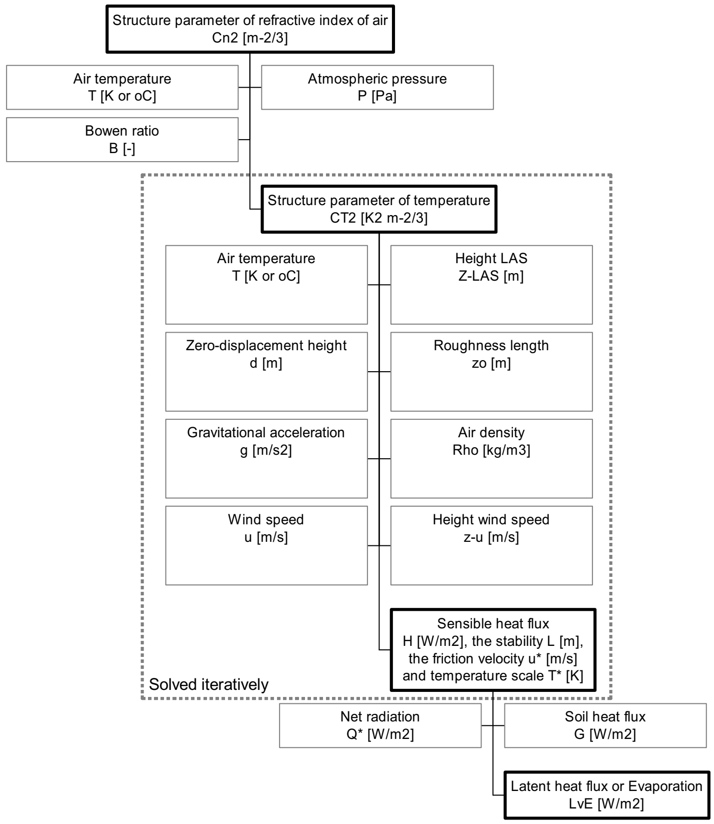

Figure 13: Summary of steps to derive H from LAS measurements.

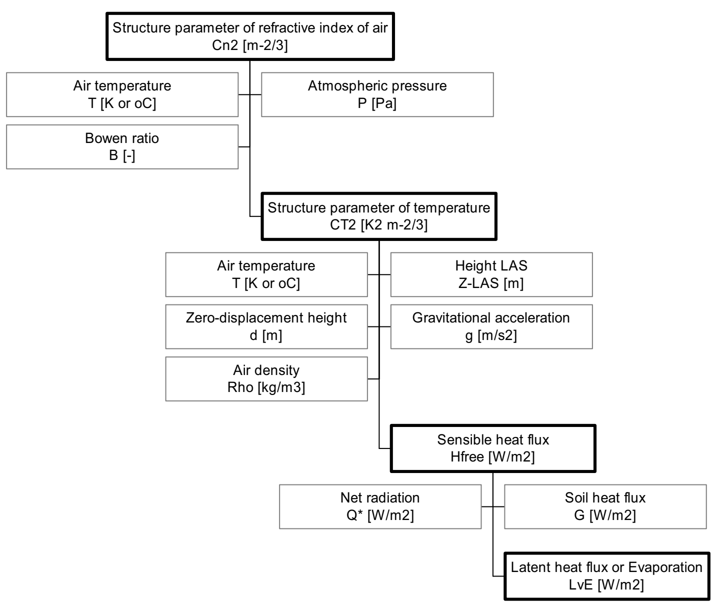

Figure 14: As figure 11 except for the free convection method.

Finally, when additional net radiation (Q^*) and soil heat flux (G_s) data are available, the latent heat flux L_vE (or actual evaporation) can be estimated applying the surface energy balance equation (see figure 15)

$$Q^* = H + L_v E + G_s \qquad (21)$$

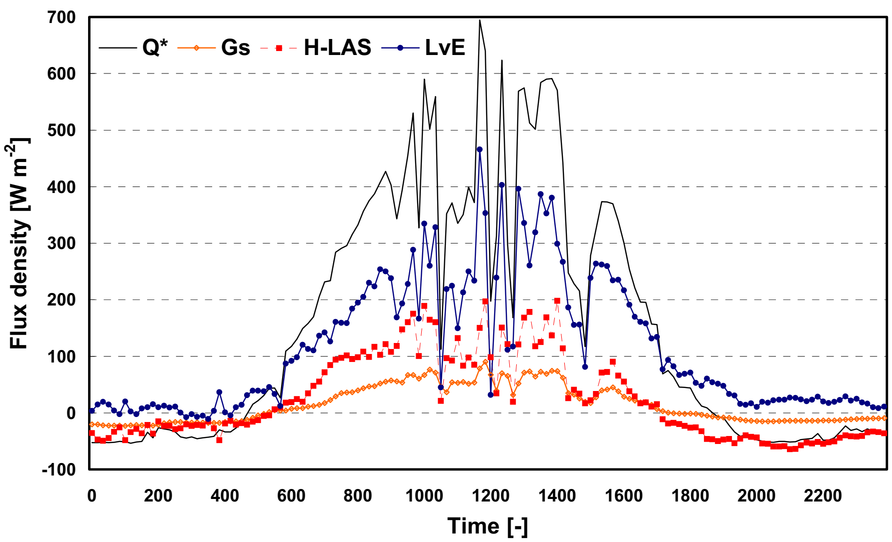

Figure 15: Example of time series of net radiation, soil heat flux, sensible heat flux and latent heat flux.

Complete list of required data/information for deriving sensible heat fluxes:

- **LAS**/**XLAS** – mean of C_n^2 (derived from U_{CN2})
- **LAS**/**XLAS** – mean of signal strength (or U_{demod})
- **LAS**/**XLAS** – variance of signal strength (or U_{demod})
- **LAS**/**XLAS** – path length (L)
- **LAS**/**XLAS** – average (effective) beam height (z_{LAS}) (see appendix II)
- Zero-displacement height (d) (see appendix III)
- Air pressure (P)
- Air temperature (T)
- Wind speed (u)
- Bowen ratio (β)
- Height(s) of cup anemometer(s) (z_u)
- Surface roughness (i.e. roughness length) of source area **LAS**/wind speed measurements (z_o) (see appendix III)

Other useful meteorological data:

- Radiation data (Global radiation, net radiation)
- Soil heat flux data
- Wind direction
- Rainfall

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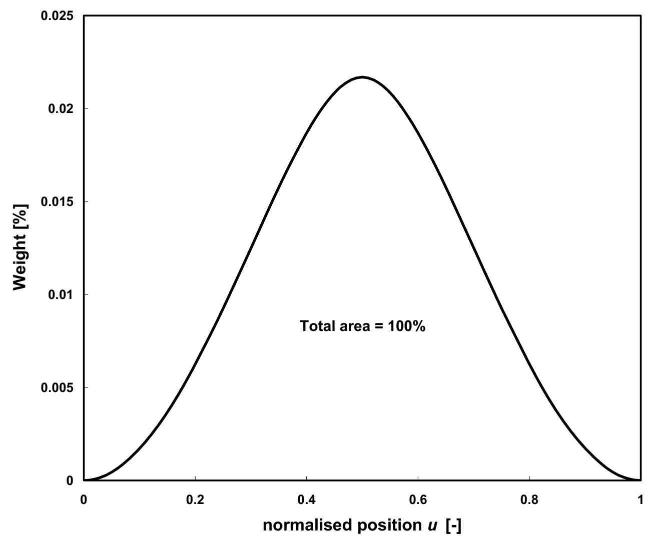
APPENDIX II – PATH-WEIGHTING FUNCTION LAS/XLAS

The **LAS**/***X*LAS** provides a measure of the structure parameter of the refractive index of air (C_n^2), weighted over the path length (*L*). For equal sized transmitter and receiver apertures this path-weighting function is symmetrical bell-shaped having a centre maximum and tapering to zero at the transmitter and receiver end (see figure 16). This means that the **LAS/*X*LAS** is most sensitive in the middle of its path. In figure 17 an example is shown how the weighting function has to be used in order to estimate the precise height of the beam of the **LAS**/***X*LAS** above the surface for non-flat areas. For further details the reader is referred to Hartogensis et al. (2003).



normalised position	weight
0	0.000
0.05	0.002
0.1	0.009
0.15	0.018
0.2	0.031
0.25	0.046
0.3	0.062
0.35	0.079
0.4	0.093
0.45	0.104
0.5	0.108
0.55	0.104
0.6	0.093
0.65	0.079
0.7	0.062
0.75	0.046
0.8	0.031
0.85	0.018
0.9	0.009
0.95	0.002
1	0.000

Figure 16: The path-weighting function of the (X)LAS.

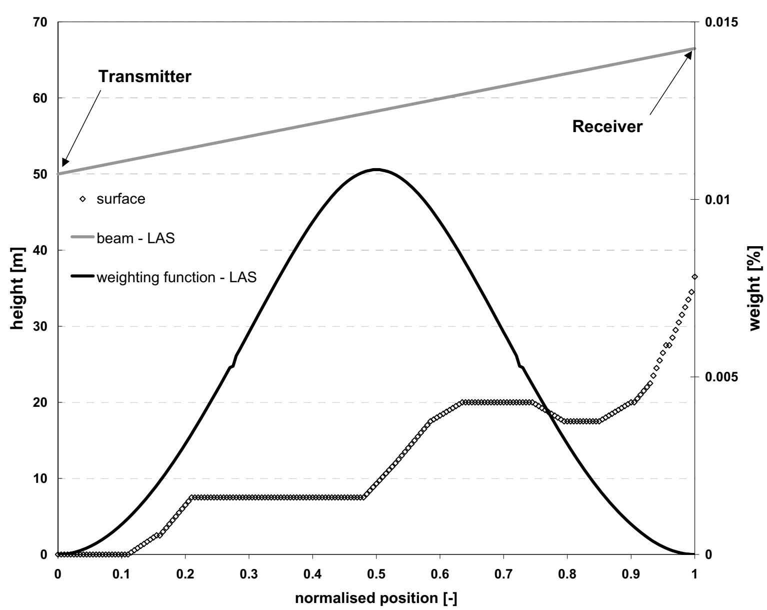


Figure 17: Example of a LAS setup over a non-flat area. Based on the elevation map and the path-weighting function an effective LAS height of 46 m was found.

APPENDIX III – ROUGHNESS LENGTH & DISPLACEMENT HEIGHT

The roughness length (z_0)

The aerodynamic roughness length or surface roughness (z_0) is an expression for the roughness of the earth's surface. It affects the intensity of mechanical turbulence and the fluxes of sensible heat (H), latent heat (L_vE) and momentum above the surface. The roughness length depends on the surface (or terrain) characteristics. For example a grassy plain has a smaller roughness length than an area with many trees and buildings. The surface roughness is loosely related to the typical height (h) of closely spaced surface obstacles, often called roughness elements (e.g. water waves, trees, buildings, blades of grass). It depends on the distribution as well as the height of roughness elements (h).

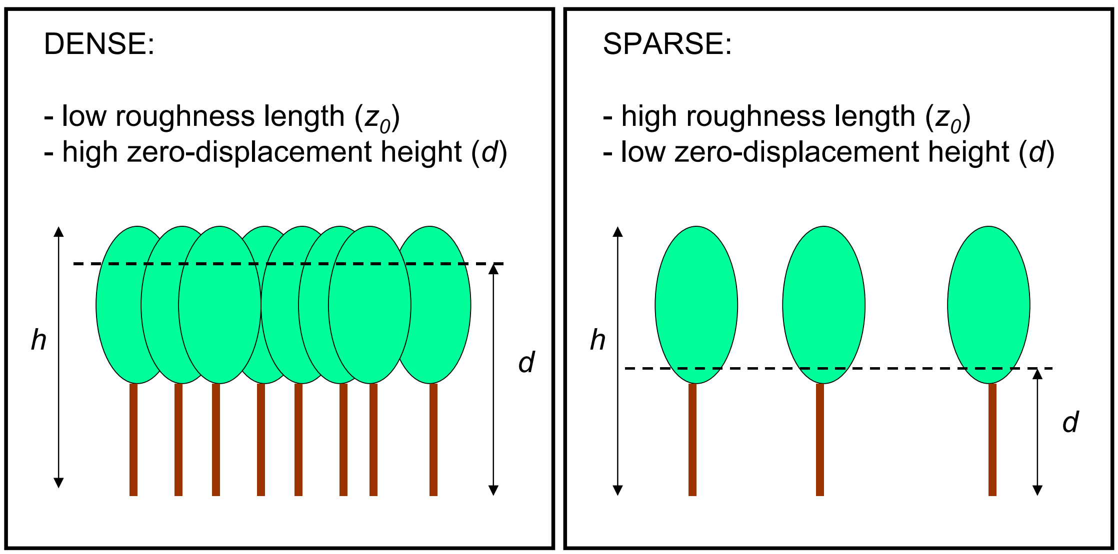


Figure 18: Dependence of the roughness length and zero-displacement height on height and density of roughness elements (e.g. trees).

In table 12 eight different terrain classifications are given plus their typical roughness length.

Table 12: Terrain classifications.

Classification		Roughness length [m]	Landscape features
No.	Name		
1	Sea	0.0002	Open water, tidal flat, snow with fetch above 3 km
2	Smooth	0.005	Featureless land, ice
3	Open	0.03	Flat terrain with grass or very low vegetation, airport runway
4	Roughly open	0.1	Cultivated area, low crops, obstacles of height h separated by at least 20h
5	Rough	0.25	Open landscape, scattered shelter belts, obstacles separated by 15h or so
6	Very rough	0.5	Landscape with bushes, young dense forest etc separated by 10h or so
7	Closed	1.0	Open spaces comparable with h, e.g. mature forest, low-rise built-up area
8	Chaotic	$>$ 2.0	Irregular distribution of large elements, e.g. city center, large forest with clearings

When the **LAS**/***X*****LAS** are installed over natural landscapes, which are mostly heterogeneous (and a path length of several kilometers) we recommend using table 12 for determining a representative roughness length, if necessary focus on the area in the middle of the path of the **LAS**/***X*****LAS** (most important area, see appendix II). In case the **LAS**/***X*****LAS** are installed over a relative homogeneous area (e.g. a (dense) agricultural field or (dense) forest) it is best to apply a simple rule of thumb:

$$z_0 = 0.1h \tag{22}$$

The zero-displacement height (*d*)

If the area surrounding the **LAS**/***X*****LAS** site consists of roughness elements that are packed very closely together like a dense forest or a dense crop, the top of those elements begin to act like a displaced surface, which is known as the zero-displacement height (*d*).

It is difficult to determine the zero-displacement height. The only proper way to derive the zero-displacement height is from wind profile data. There is simple rule of thumb to derive the displacement height from the crop height:

$$d = 0.7h \tag{23}$$

However, note that this rule of thumb is not accurate, especially when the crop/forest is **not** densely packed! In case the roughness elements are not closely packed (see figure 18 (left)) we recommend not using a zero-displacement height (i.e. $d = 0$).

Additional comments/suggestions

During daytime conditions with high solar insolation and when the **LAS**/***X*****LAS** are installed relatively high above the surface (> 20 m) the free convection method can be applied (see appendix I). Under those conditions the importance of the roughness length is small, meaning that the sensible heat flux (H) is not very sensitive to changes in z_0. However, during nighttime periods the roughness length becomes very important and can have large effects on the sensible heat flux (and also L_vE).

In case one has to apply a zero-displacement height it might be necessary to spatially weight d also using the weighting function of the **LAS**/***X*****LAS** (see appendix II).

In case the zero-displacement is difficult to determine (as roughness elements are not densely packed), one can minimize the (relative) effect of d on the sensible heat flux by installing the **LAS**/***X*****LAS** higher above the surface.

APPENDIX IV – HEATER AND THERMISTOR

Both the **LAS**/***X*****LAS** transmitter and the receiver units have an integral heater ring for keeping the Fresnel lens and window clear of dew/condensation/snow. The heater of the **LAS** is self-regulating working to maintain a constant 55 °C temperature the ring will initially draw more than 1A current when first switched on. At around 22 °C room temperature the heater resistance is 17 ohms. Power to the ring is independent of the other electronics and the user can decide whether this higher power demand mode is necessary, particularly if remote site operation is to be considered. The heater of the ***X*****LAS** is not self-regulating. Instead it constantly draws 1.2A current.

The heater ring is in thermal contact with the Fresnel lens and the front window but electrically insulated from the body of the **LAS**/***X*****LAS**. This assembly connects to the printed circuit boards mounted on the transmitter and receiver bullets. These connectors are 4-way providing an option for signal sensing a thermistor mounted on the heater ring assembly.

Ambient temperature inside the **LAS**/***X*****LAS** receiver and transmitter units are monitored by NTC thermistors connected to the printed circuit boards and in thermal contact with the bullet. This thermistor forms half of a voltage divider and a scaled voltage output is available at the internal and external bulkhead sockets. The calibration formulae for the transmitter and receiver units are as follows

LAS transmitter:

$$T = 71.54 - 20.39U_{TH\_T} + 1.21U_{TH\_T}^{2} \tag{24}$$

LAS receiver:

$$T = 71.54 - 10.87U_{TH\_R} + 0.35U_{TH\_R}^{2} \tag{25}$$

For example if the receiver output voltage, U_{TH_R} = 5.0 V then from the above equation the ambient temperature is about 26 °C inside the receiver unit. The rubber sealing O-ring between the front cap and the main tube provides a degree of thermal insulation and as the heater ring temperature stabilises a thermal difference is generated across the ring. The ambient temperature inside the tube will be observed to increase preventing the onset of condensation on the optics. Important to note is that he heater power consumption is > 12 Watt. The user can decide by themselves whether to use the heater or not, since the power supply of the heater is independent of the receiver/transmitter electronics (see table 4 and 5).

APPENIDX V – CR10X CAMPBELL PROGRAM

Comments program:

Data logger:	CR10X (Campbell Scientific)
Differential channel 1:	**log** Cn2 signal **LAS**/***X*****LAS** (i.e. U_{CN2}) (including voltage divider)
Differential channel 2:	demod signal (U_{DEMOD}) or signal strength (I)
Sampling rate:	1 Hz
Averaging time:	10 minutes

Because the output signal of the **LAS**/***X*****LAS** (U_{LAS}) has a range between –5 V and 0 V, a voltage divider is used to rescale this output signal to –2.5 V and 0 V that can be measured by the CR10X data logger. The program will start measuring when a full 10-minute interval is reached. This means that when the data logger is switched on it will wait until exactly 0, 10, 20, 30, 40 or 50 minutes (and 0 seconds) after a hour before collecting data. After a 10-minute interval the mean values of U_{CN2}, U_{DEMOD} and PU_{CN2}, the variances of U_{CN2} and U_{DEMOD}, and a counter N (should be 600) are stored. To avoid overflow problems in the data logger memory when using processing instruction **P62** (for calculating variances) that can be caused by large numbers, the first measurement values of each 10-minute interval are subtracted from the following measurements.

```
;{CR10X}
;
*Table 1 Program
        01: 1       Execution Interval (seconds)

; Start measurements at a full 10-minute interval

1:  If time is (P92)
        1: 0        Minutes (Seconds --) into a
        2: 10       Interval (same units as above)
        3: 12       Set Flag 2 High

2:  If Flag/Port (P91)
        1: 22       Do if Flag 2 is Low
        2: 30       Then Do

        3:  Beginning of Loop (P87)
                1: 0        Delay
                2: 12       Loop Count

        4:  Z=F (P30)
                1: 0        F
                2: 0        Exponent of 10
                3: 1        -- Z Loc [ UCN2     ]

        5:  Z=F (P30)
                1: 0        F
                2: 0        Exponent of 10
                3: 6        Z Loc [ N        ]

        6:  End (P95)

7:  End (P95)

8:  If Flag/Port (P91)
        1: 22       Do if Flag 2 is Low
        2: 0        Go to end of Program Table

; Do measurements of CN2 signal LAS in Volts
```

```
9:  Volt (Diff) (P2)
          1: 1        Reps
          2: 35       2500 mV 50 Hz Rejection Range (for countries with 60 Hz power grid, use 25)
          3: 1        DIFF Channel
          4: 1        Loc [ UCN2      ]
          5: 0.002 Mult  (conversion mV → V and correction for voltage divider)
          6: 0        Offset

;Do measurements of demod (or signal strength) signal LAS

10:  Volt (Diff) (P2)
          1: 1        Reps
          2: 35       2500 mV 50 Hz Rejection Range (for countries with 60 Hz power grid, use 25)
          3: 2        DIFF Channel
          4: 2        Loc [ demod     ]
          5: 1        Mult
          6: 0        Offset

; At the beginning of each measurement interval the first measurements
; are stored. The initial values are used to subtract the following
; measurements resulting in signals that fluctuate close to zero. These
; small values prevent overflow problems of the data logger.

11:  If Flag/Port (P91)
          1: 23       Do if Flag 3 is Low
          2: 1        Call Subroutine 1

; Calculate 10^(UCN2)

12:  Z=F (P30)
          1: 10       F
          2: 0        Exponent of 10
          3: 3        Z Loc [ Ten       ]

13:  Z=X^Y (P47)
          1: 3        X Loc [ Ten       ]
          2: 1        Y Loc [ UCN2      ]
          3: 4        Z Loc [ PowerUCN2 ]

; Calculate 10^(UCN2)*1000

14:  Z=X*F (P37)
          1: 4        X Loc [ PowerUCN2 ]
          2: 1000  F
          3: 5        Z Loc [ PUCN21000 ]

; Counter

15:  Z=X+F (P34)
          1: 6        X Loc [ N         ]
          2: 1        F
          3: 6        Z Loc [ N         ]


; Subtract initial values from measurement signals

16:  Z=X-Y (P35)
          1: 1        X Loc [ UCN2      ]
          2: 7        Y Loc [ UCN2_c    ]
          3: 9        Z Loc [ UCN2_P62  ]

17:  Z=X-Y (P35)
```

```
          1: 2        X Loc [ demod     ]
          2: 8        Y Loc [ demod_c   ]
          3: 10       Z Loc [ demod_P62 ]

; After 10-minutes write data to final storage.

18:  If time is (P92)
          1: 0        Minutes (Seconds --) into a
          2: 10       Interval (same units as above)
          3: 10       Set Output Flag High (Flag 0)

19:  Covariance/Correlation (P62)
          1: 2        No. of Input Locations
          2: 00       No. of Means
          3: 2        No. of Variances
          4: 00       No. of Std. Dev.
          5: 00       No. of Covariance
          6: 00       No. of Correlations
          7: 600      Samples per Average
          8: 9        First Source Loc [ UCN2_P62  ]
          9: 11       First Destination Loc [ Var_UCN2  ]
(Instruction 82 can also be used to calculate the standard deviation)

20:  Real Time (P77)
          1: 110      Day,Hour/Minute (midnight = 0000)

21:  Average (P71)
          1: 2        Reps
          2: 1        Loc [ UCN2      ]

22:  Sample (P70)
          1: 2        Reps
          2: 11       Loc [ Var_UCN2  ]

23:  Resolution (P78)
          1: 1        High Resolution

24:  Average (P71)
          1: 1        Reps
          2: 5        Loc [ PUCN21000 ]

25:  Resolution (P78)
          1: 0        Low Resolution

26:  Sample (P70)
          1: 1        Reps
          2: 6        Loc [ N         ]

; Set Flag 3 low to store new first values for next interval.

27:  If time is (P92)
          1: 0        Minutes (Seconds --) into a
          2: 10       Interval (same units as above)
          3: 30       Then Do

          28:  Do (P86)
                    1: 23     Set Flag 3 Low

          29:  Z=F (P30)
                    1: 0      F
                    2: 0      Exponent of 10
                    3: 6      Z Loc [ N         ]
```

30: End (P95)

*Table 2 Program
    02: 0.0000   Execution Interval (seconds)

*Table 3 Subroutines;

1: Beginning of Subroutine (P85)
    1: 1   Subroutine 1

2: Do (P86)
    1: 13   Set Flag 3 High

    3: Block Move (P54)
        1: 2   No. of Values
        2: 1   First Source Loc [UCN2   ]
        3: 1   Source Step
        4: 7   First Destination Loc [UCN2_c   ]
        5: 1   Destination Step

4: End (P95)

End Program

Input Locations CR10X:

1. UCN2 (= U_{CN2})
2. demod (or signal strength) (= U_{DEMOD})
3. Ten
4. PowerUCN2
5. PUCN21000 (= PU_{CN2})
6. N (counter, N = 600)
7. UCN2_c
8. demod_c
9. UCN2_P62
10. demod_P62
11. Var_UCN2 (= $\sigma^2_{U_{CN2}}$)
12. Var_demod (= $\sigma^2_{U_{DEMOD}}$)

Format output file, downloaded from CR10X memory:

Dummy, Doy, Time(HH:MM), UCN2, demod, var_UCN2, var_demod, PUCN21000 (= PUCn2), N

C_n^2 can be calculated as follows (two options, see paragraph 4):

$$C_n^2 = 10^{\left(U_{CN2} - 12 + 1.15 \cdot \sigma^2_{U_{CN2}}\right)}$$

$$C_n^2 = PU_{CN2} \cdot 10^{-15}$$

Note: Additional measurement instructions and sensors can added to program, such as a temperature sensor, cup anemometer, pressure sensor, net radiometer and soil heat flux plates (e.g. a small micrometeorological station). Of course additional meteorological data can be taken from other nearby field stations.

Note: the data file provided by the CR10X contains two Cn2 ‘formats’, which both can be read by the WINLAS software (namely, 1: U_{CN2} combined with Var_U_{CN2} , 2: PU_{CN2}).

APPENDIX VI – COMBILOG PROGRAM

Comments program:

Data logger:	COMBILOG (Theodor FRIEDRICHS & Co)
Differential channel 1:	**log** Cn2 signal **LAS**/***X*LAS** (i.e. U_{CN2})
Differential channel 2:	demod signal (U_{DEMOD}) or signal strength (I)
Sampling rate:	1 Hz
Averaging time:	10 minutes

COMBILOG

Location:	Undefined
Filename:	LAS_COMBILOG.PRO

Common Data	
User Name:	LAS
Answer Delay:	1 Char Times
Timeout:	0 s
Filter Freq.:	50 Hz
Config. Date:	26/09/2003 14:55
Auto Off:	Disabled
LED:	Disabled
Language:	English

Serial Interface Funct.	
RS485	
Baudrate:	19200
Format:	8e1
Module Timeout:	100 ms
RS232	
Connection type:	Line modem
Modem initialization:	
Alarm settings:	
Alarm 1	
Condition:	
Type:	Off
Alarm 2	
Condition:	
Type:	Off
Alarm 3	
Condition:	
Type:	Off
Alarm 4	
Condition:	
Type:	Off

Logger Funct.	
Sample Interval:	1 s
Mode:	Continuous
Logging Interval:	10 min
Variables to Log:	
Internal (Var#):	01,02,03,07,08,09
External (Addr/Var#):	None

Special Data

Block 0:	---
Block 1:	---
Block 2:	---
Block 3:	---
Block 4:	---
Block 5:	---
Block 6:	---
Block 7:	---

Configuration Data

Variable 1

Type:	Analogue Input	
Variable Name:	UCn2	
Sensor:	Voltage	
Type of Measurement:	Differential	
Unit:	V	
Field Length:	8	
Precision:	1	
Conversion Parameter:	Input Units [V]:	Engineering Units [V]:
0%:	-5	-5
100%:	0	0
Data Type:	Real	
Data Direction:	Input	
Min. Value [V]:	-5	
Max. Value [V]:	0	
On Sensor Failure:	Corresponding Limit	
Zero Calibration:	None	
Averaging:	Arithm. Averaging	
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes	

Variable 2

Type:	Analogue Input	
Variable Name:	Demod	
Sensor:	Voltage	
Type of Measurement:	Differential	
Unit:	mV	
Field Length:	8	
Precision:	1	
Conversion Parameter:	Input Units [V]:	Engineering Units [mV]:
0%:	-1	-1000
100%:	0	0
Data Type:	Real	
Data Direction:	Input	
Min. Value [mV]:	-1000	
Max. Value [mV]:	0	
On Sensor Failure:	Corresponding Limit	
Zero Calibration:	None	
Averaging:	Arithm. Averaging	
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes	

Variable 3

Type:	Arithmetic
Variable Name:	PUCn21000
Unit:	
Field Length:	8

Precision:	1
Data Type:	Real
Data Direction:	Input
Reset:	None
Formula:	1000*power(10;V1)
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 4	
Type:	Arithmetic
Variable Name:	Std_Cn2
Unit:	
Field Length:	8
Precision:	1
Data Type:	Real
Data Direction:	Input
Reset:	None
Formula:	SDev(V1)
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 5	
Type:	Arithmetic
Variable Name:	Std_Demod
Unit:	
Field Length:	8
Precision:	1
Data Type:	Real
Data Direction:	Input
Reset:	None
Formula:	SDev(V2)
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 6	
Type:	Arithmetic
Variable Name:	Std_PUCn21000
Unit:	
Field Length:	8
Precision:	1
Data Type:	Real
Data Direction:	Input
Reset:	None
Formula:	SDev(V3)
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 7	
Type:	Arithmetic
Variable Name:	Var_Cn2
Unit:	
Field Length:	8
Precision:	1
Data Type:	Real
Data Direction:	Input
Reset:	None
Formula:	power(V4;2)
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 8	
Type:	Arithmetic
Variable Name:	Var_Demod
Unit:	
Field Length:	8
Precision:	1
Data Type:	Real
Data Direction:	Input
Reset:	None
Formula:	power(V5,2)
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 9	
Type:	Arithmetic
Variable Name:	Var_PUCn21000
Unit:	
Field Length:	8
Precision:	1
Data Type:	Real
Data Direction:	Input
Reset:	None
Formula:	power(V6,2)
DP Real Config. Data:	93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Format output file, downloaded from COMBILOG memory:

Unit, Date, Time(HH:MM:SS), UCN2, Demod, PUCN21000, Var_UCN2, Var_Demod, Var_PUCN21000, N

C_n^2 can be calculated as follows (two options, see paragraph 4):

$$C_n^2 = 10^{\left(U_{CN2} - 12 + 1.15 \cdot \sigma_{U_{CN2}}^2\right)}$$

$$C_n^2 = PU_{CN2} \cdot 10^{-15}$$

Note: Additional measurement instructions and sensors can added to program, such as a temperature sensor, cup anemometer, pressure sensor, net radiometer and soil heat flux plates (e.g. a small micrometeorological station). Of course additional meteorological data can be taken from other nearby field stations.

Note: the data file provided by the CR10X contains two Cn2 'formats', which both can be read by the WINLAS software (namely, 1: U_{CN2} combined with Var_U_{CN2} , 2: PU_{CN2}).

APPENDIX VII – DIAPHRAGMS FOR SHORT RANGE APPLICATIONS

In case the LAS is required to operate over very short distances (i.e. at field-scale) the aperture diameter of the LAS can be reduced to 0.1 m using the supplied diaphragms. The LAS equipped with the 0.1m diaphragms (further denoted as **0.1m-LAS**) can be used over path lengths of 100 m to 1 km. The 0.1m diaphragms are placed in front of the LAS transmitter **and** receiver by removing 3 of the 6 retaining screws (see Figure 19). Figure 20 shows the minimum LAS height as function of path length and surface conditions. A typical installation height for such path lengths is 2.5 m.

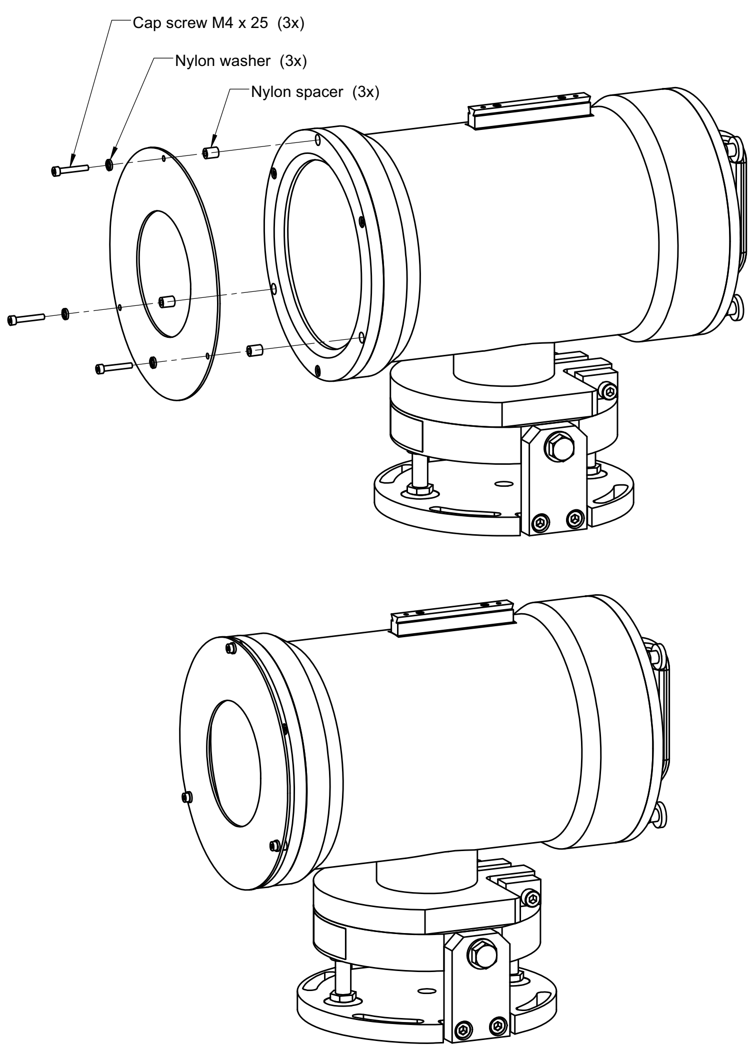


Figure 19: Diaphragm assembly on the LAS receiver and transmitter.

Table 13: Operating Specifications of 0.1m-LAS.

	0.1m - LAS
Minimum path length	0.1 km
Maximum path length (depends on atmospheric conditions)	1 km
Minimum height	1.5 m (see also figure 19)
Maximum height for C_n^2 (or turbulence) measurements	no operational restriction
Maximum height for flux (*H*) measurements	~ 100 m

Kipp & Zonen reserve the right to make changes to the specifications without prior notice.

Important: As the beam diameter becomes smaller so does the beam divergence. This means that the alignment of the 0.1m-LAS is more critical than for the standard LAS. It is recommended to use very stable mounting constructions.

Once the **0.1m-LAS** has been installed and properly aligned, the ***Path Length*** dial knob at the receiver control panel must be set for the correct distance between the transmitter and the receiver. Note that the ***Path Length*** dial knob setting for the **0.1m-LAS** is different from the standard LAS. For the **0.1m-LAS** the following relationship must be used

$$Pot_{0.1m-LAS} = \left(\frac{5475.81}{\sqrt{(4.474 D^{\frac{7}{3}} L^{-3} 0.3314 \cdot 10^{12})} + 5.23} \right) - 47 ,$$

where *D* is the aperture diameter (i.e. here 0.1 m must be taken instead of 0.152 m) and *L* the distance between the transmitter and receiver (in meters). Calculated values of $Pot_{0.1m\text{-}LAS}$ for different path lengths can be found in table 14. Note that because of the sensitivity of *Pot* to *L* and thus also C_n^2 to *L* the distance must be measured accurately and the potentiometer must be set precisely!

Table 14: *Path Length* (*Pot*) dial knob setting values of the 0.1m-LAS for a range of path lengths.

0.1m-LAS			
Path length [m]	**Pot_{LAS} [-]**	**Path length [m]**	**Pot_{LAS} [-]**
100	15.1	550	422.6
150	61.7	600	456.5
200	111.4	650	488.0
250	161.9	700	517.0
300	211.4	750	543.8
350	258.9	800	568.5
400	304.1	850	591.4
450	346.4	855	593.6
500	385.9	900	612.5
550	422.6	950	632.1
600	456.5	1000	650.3

Important: Data processing of the **0.1m-LAS** requires WINLAS version 2.2 or higher as older versions do not support the **0.1m-LAS**.

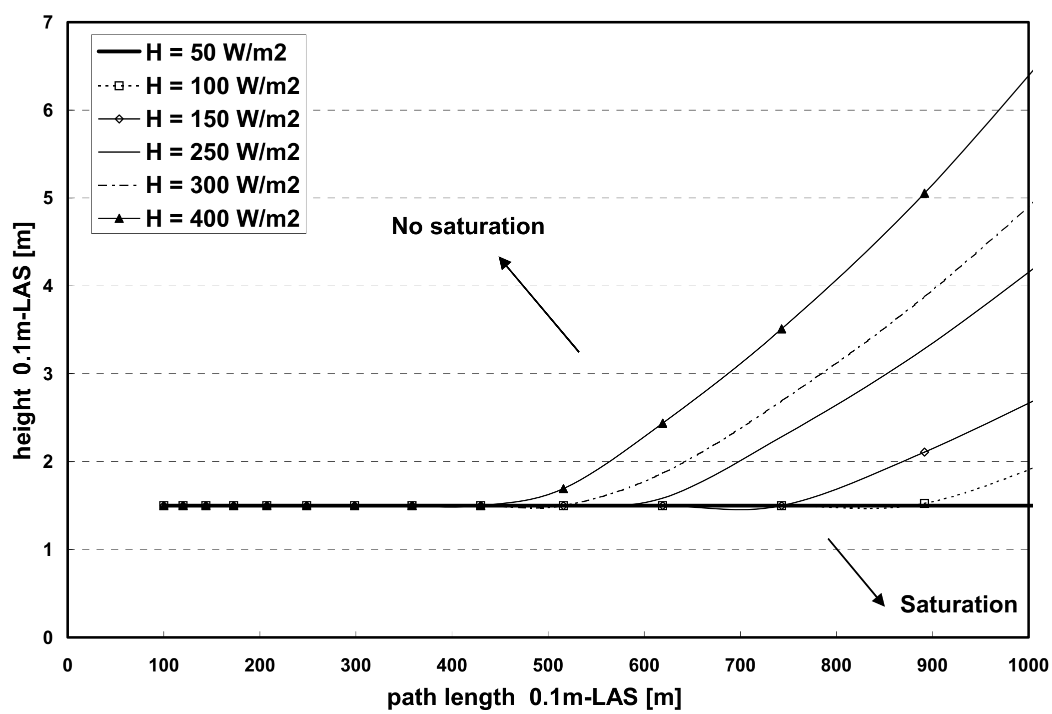


Figure 20: The minimum installation height of the 0.1m-LAS as function of path length and for different surface conditions. The area above the curves is the non-saturation zone. Below the curves saturation of the signal occurs. In the presence of densely packed roughness elements add the zero-displacement height (see appendix III).

APPENDIX VIII – RECALIBRATION SERVICE

In order to maintain the specific performance of the **LAS/*X*LAS** instrument, Kipp & Zonen recommends calibrating the **LAS/*X*LAS** instrument when it fails the on-site calibration check (see section 7.1 and 7.2). This can be done at the Kipp & Zonen factory (see section 7.3 for a description of the procedure). Here the calibration procedure can be performed at low cost and can usually be performed within several weeks. If required, urgent calibration can be accomplished in three weeks or less (subject to scheduling restrictions). Kipp & Zonen will confirm the duration of recalibration at all times. Note that special quantity recalibration discounts are available.

NAME	:
COMPANY/INSTITUTE	:
ADDRESS	:
POSTCODE + CITY	:
COUNTRY	:
PHONE	:
FAX	:

☐ I would like to receive a price list for recalibration
☐ I would like to submit my LAS instrument(s) for recalibration

Type/Model:	Qty:	Requested delivery time:
		I intend to send the instrument(s) to Kipp & Zonen on: ..../........./.........
		I would like to receive the instrument(s) back on: ..../........./.........

Confirmation by Kipp & Zonen
Yes, the dates are acceptable to us. No, unfortunately the dates do not fit into our calibration schedule. We suggest the following data: ..../........./......... ..../........./........./

Fax +31-15-2620351

or mail to:

Kipp & Zonen B.V.
P.O. Box 507
2600 AM Delft
The Netherland

Notes:

Our customer support remains at your disposal for any maintenance or repair, calibration, supplies and spares.

Für Servicearbeiten und Kalibrierung, Verbrauchsmaterial und Ersatzteile steht Ihnen unsere Customer Support Abteilung zur Verfügung.

Notre service 'Support Clientèle' reste à votre entière disposition pour tout problème de maintenance, réparation ou d'étalonnage ainsi que pour les accessoires et pièces de rechange.

Nuestro apoyo del cliente se queda a su disposición para cualquier mantenimiento o la reparación, la calibración, los suministros y reserva.

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