

DISCLAIMER

This report was prepared as an account of work sponsored by the U.S. Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

Vaisala Ceilometer (VCEIL) Handbook

VR Morris

March 2012

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Contents

1.0	General Overview.....	1
2.0	Contacts	1
2.1	Mentor	1
3.0	Deployment Locations and History	1
4.0	Near-Real-Time Data Plots	4
5.0	Data Description and Examples	4
5.1	Data File Contents.....	4
5.1.1	Primary Variables and Expected Uncertainty	4
5.1.2	Secondary / Underlying Variables	6
5.1.3	Diagnostic Variables	6
5.1.4	Data Quality Flags.....	6
5.1.5	Dimension Variables	8
5.2	Annotated Examples	8
5.3	User Notes and Known Problems	8
5.4	Frequently Asked Questions	9
6.0	Data Quality.....	9
6.1	Data Quality Health and Status	9
6.2	Data Reviews by Instrument Mentor.....	10
6.3	Data Assessments by Site Scientist / Data Quality Office	10
6.4	Value-Added Procedures and Quality Measurement Experiments	10
7.0	Instrument Details.....	11
7.1	Detailed Description.....	11
7.1.1	List of Components	11
7.1.2	System Configuration and Measurement Methods	12
7.1.3	Specifications	13
7.2	Theory of Operation.....	13
7.3	Calibration.....	16
7.3.1	Theory	16
7.3.2	Procedures	16
7.3.3	History	16
7.4	Operation and Maintenance	16
7.4.1	User Manual	16
7.4.2	Routine and Corrective Maintenance Documentation	16
7.4.3	Software Documentation.....	16
7.4.4	Additional Documentation	16

7.5 Glossary..... 16
7.6 Acronyms 16
7.7 Citable References..... 17

Figures

1 CL-View cloud intensity graph..... 4
2 Backscatter density in $10^{-9} \text{ m}^{-1} \text{ sr}^{-1}$ with mixing-layer-height in m from Vaisala CT25K and CL31 Ceilometers on 06/23/08 at SGP. 5
3 Typical measurement signal 14

Tables

1 History of Deployment Locations..... 2
2 Primary Variables 5
3 Secondary Variables 6
4 Diagnostic Variables..... 6
5 Data Quality Flags 7
6 Data Quality Thresholds 7
7 Time Quality Flags 8
8 Dimension Variables..... 8
9 Vaisala CL31 Main Parts 11
10 Vaisala CL31 Configuration Settings 12
11 Specifications of CL31 Ceilometer, as operated at ARM sites..... 13

1.0 General Overview

The Vaisala Ceilometer (VCEIL) is a self-contained, ground-based, active, remote sensing device designed to measure cloud-base height, vertical visibility, and potential backscatter signals by aerosols. It detects up to three cloud layers simultaneously. Model CL31 has a maximum vertical range of 7700 m. The laser ceilometer transmits near-infrared pulses of light, and the receiver detects the light scattered back by clouds and precipitation.

2.0 Contacts

2.1 Mentor

Victor Morris
Pacific Northwest National Laboratory
P.O. Box 999, MS K9-24
Richland, WA 99352
Phone: 509-372-6144
Fax: 509-375-6448
E-mail: vic.morris@arm.gov

3.0 Deployment Locations and History

The U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility currently operates a total of seven laser ceilometers at its fixed sites (in Oklahoma, Alaska, Australia, Papua New Guinea, and the Republic of Nauru) and its mobile facilities. Initially, a [Belfort 7013C Laser Ceilometer](#) was deployed at the ARM Climate Research Facility Southern Great Plains site in 1994 and was replaced with a Vaisala CT25K Ceilometer in 2000. Meanwhile, additional VCEILs were gradually deployed at all other ARM sites between 1996 and 2004. Through the American Recovery and Reinvestment Act, six of the ceilometers were replaced in 2010 with the Vaisala CL31 that provides greater spatial and temporal resolution, improved algorithms for cloud amount and mixing layer height, and better detection of aerosol layers.

Table 1. History of Deployment Locations.Current status = **operational**, **spare**, **failure**, or **decommissioned**

Model number	Serial number	Site	Start date	End date
CL31	F1040006	SBS/M1	09/24/2010	present
CL31	F1040005	GRW/M1	07/15/2010	present
CL31	F1040004	TWP/C3	08/16/2010	present
CL31	F1040003	TWP/C1	08/26/2010	present
CL31	F1040002	NSA/C1	06/16/2010	present
CL31	F1040001	SGP/C1	04/16/2010	present
CT25K	Z11201	PYE/M1	02/01/2005	09/15/2005
CT25K	Z11201	NIM/M1	11/23/2005	01/08/2007
CT25K	Z11201	FKB/M1	03/12/2007	01/18/2008
CT25K	Z11201	HFE/M1	05/01/2008	12/30/2008
CT25K	Z11201	GRW/M1	05/16/2009	07/15/2010
CT25K	Z11201	ALTOS	10/01/2010	present
CT25K	V45106	TWP/C3	02/27/2002	12/09/2002
CT25K	V45106	NIES	02/08/2003	07/01/2003
CT25K	V45106	TWP/C2	04/17/2007	present
CT25K	V45105	NIES	12/22/2001	02/08/2003
CT25K	V45105	Vaisala	03/25/2003	10/20/2003
CT25K	V45105	TWP/C1	12/06/2003	08/26/2010
CT25K	V36301	HFE/S1	07/29/2008	12/15/2008
CT25K	U06301	SGP/B6	01/05/2001	08/31/2007
CT25K	T24501	TWP/C1	01/13/2000	06/24/2001
CT25K	T24501	Vaisala	07/20/2001	12/03/2001
CT25K	T24501	TWP/C1	01/18/2002	12/06/2003
CT25K	T24501	TWP/C2	04/01/2005	02/04/2007
CT25K	T24501	Vaisala	04/26/2007	07/30/2007
CT25K	T24501	SGP/B6	08/31/2007	01/13/2010
CT25K	S17102	NSA/C1	12/12/1997	12/03/2009
CT25K	R0850006	SGP/B4	09/20/1999	07/23/2002
CT25K	R0850006	TWP/C3	12/09/2002	12/12/2005
CT25K	R0850006	Vaisala	03/06/2006	04/27/2006
CT25K	R0850006	TWP/C3	05/18/2006	12/20/2006
CT25K	R0850006	TWP/C3	01/12/2007	01/16/2007
CT25K	R0850006	TWP/C3	01/19/2007	07/11/2007

Model number	Serial number	Site	Start date	End date
CT25K	R0850006	Vaisala	09/10/2007	10/18/2007
CT25K	R0850006	SGP/B5	10/23/2007	11/07/2007
CT25K	R0850006	SGP/B5	02/27/2008	01/17/2009
CT25K	R0850006	NSA/C1	12/03/2009	06/15/2010
CT25K	R0850004	SGP/B5	09/21/1999	04/26/2001
CT25K	R0850004	SGP/B4	07/23/2002	01/07/2003
CT25K	R0850004	SGP/B4	05/10/2004	02/17/2010
CT25K	R0850003	SGP/B6	09/21/1999	08/24/2000
CT25K	R0850003	SGP/B1	11/24/2000	10/20/2009
CT25K	R0850003	ICECAPS	04/01/2010	present
CT25K	R0850002	SGP/B1	09/20/1999	08/29/2000
CT25K	R0850002	SGP/B5	04/26/2001	07/14/2005
CT25K	R0850002	SGP/C1	04/19/2006	04/16/2010
CT25K	R0450013	NSA/C2	08/22/1999	01/17/2011
CT25K	P2710016	SGP/C1	05/22/2000	12/06/2004
CT25K	P2710016	SGP/B5	07/14/2005	10/23/2007
CT25K	P2710016	SGP/B5	11/08/2007	02/27/2008
CT25K	P2710016	GRW/M1	04/20/2009	05/16/2009
CT25K	P2710016	Vaisala	07/30/2009	present
CT25K	P2710015	TWP/C2	12/22/1995	09/23/2002
CT25K	P2710015	Vaisala	10/28/2002	01/03/2003
CT25K	P2710015	SGP/B4	01/07/2003	05/10/2004
CT25K	P2710015	SGP/C1	12/06/2004	04/19/2006
CT25K	P2710015	TWP/C3	01/16/2007	01/19/2007
CT25K	P2710015	TWP/C2	02/05/2007	04/17/2007
CT25K	P2710015	Vaisala	05/21/2007	07/30/2007
CT25K	P0110009	TWP/C1	12/11/1995	01/13/2000
CT25K	P0110009	Vaisala	02/23/2000	04/25/2000
CT25K	P0110009	SGP/B6	08/24/2000	01/05/2001
CT25K	P0110009	TWP/C1	06/24/2001	01/18/2002
CT25K	P0110009	TWP/C2	09/23/2002	04/01/2005
CT25K	P0110009	TWP/C3	12/12/2005	05/18/2006
CT25K	P0110009	Vaisala	07/17/2006	09/15/2006
CT25K	P0110009	TWP/C3	12/20/2006	01/12/2007
CT25K	P0110009	Vaisala	05/04/2007	06/13/2007
CT25K	P0110009	TWP/C3	07/11/2007	08/16/2010

4.0 Near-Real-Time Data Plots

Available [data plots and other data products](#).

5.0 Data Description and Examples

The figure below shows an example of the independent data collection, storage, and presentation program available for the Vaisala Ceilometers (CL-VIEW). This particular example shows a cloud intensity graph of backscattering data collected at the Southern Great Plains site on 04/16/2010 during acceptance testing of the CL31.

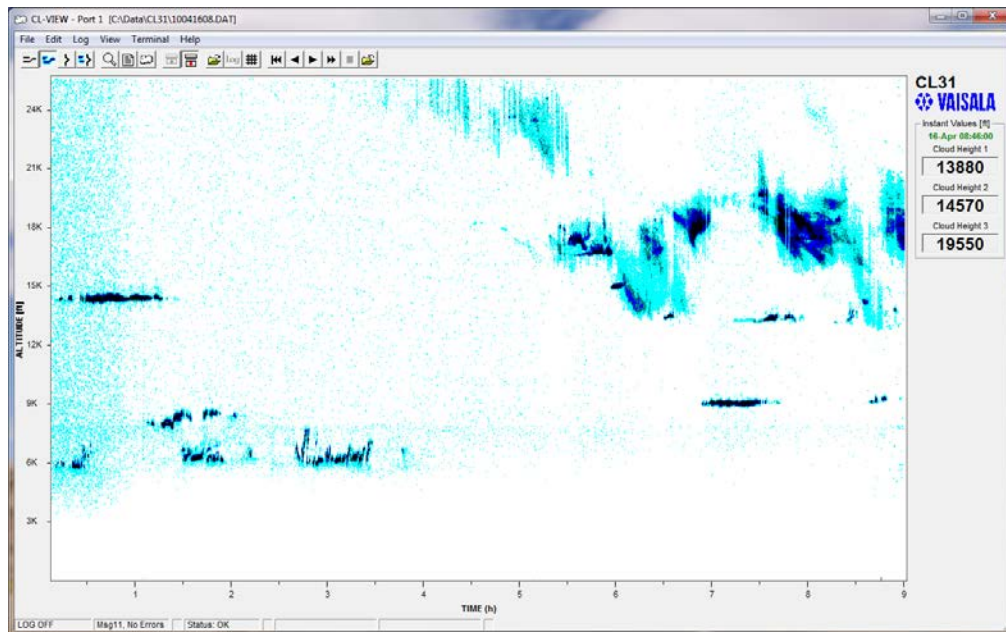


Figure 1. CL-View cloud intensity graph.

5.1 Data File Contents

The VCEIL produces datastream [vceil25k](#), available from the [ARM Archive](#), containing cloud base heights below 7700 m with 10-m resolution.

5.1.1 Primary Variables and Expected Uncertainty

The Vaisala ceilometers measure the backscattered light intensity from a pulsed InGaAs diode laser (910 nm) as a function of distance. These measurements are used to produce derived products that are recorded.

Table 2. Primary Variables

Variable Name	Quantity Measured	Unit
backscatter	Backscatter	1/(srad*km*10000)
first_cbh	Lowest cloud base height detected	m
second_cbh	Second lowest cloud base height	m
third_cbh	Third cloud base height	m
vertical_visibility	Vertical visibility	m

5.1.1.1 Definition of Uncertainty

The calibration of the VCEIL laser transmitter is checked every year to ensure a range resolution of 10 m. The instrument-derived product of cloud-ceiling height may drift with time if the relative sensitivity of the instrument degrades considerably. In the worst case, this change would not be observed until differences with the micropulse lidar (MPL) are observed. This would lead to an uncertainty equal to the range resolution of the MPL, or 75 m.

A comparison was performed between the Vaisala CT25K and CL31 at the Southern Great Plains (SGP) site in summer 2008. This comparison showed a similar shape to cloud features observed by the two systems, with the CL31 indicating a better vertical resolution, yielding better estimates of mixing-layer height. Figure 2 is an example of the comparison of the backscatter of lowest cloud heights from the two instruments on one of the 31 days.

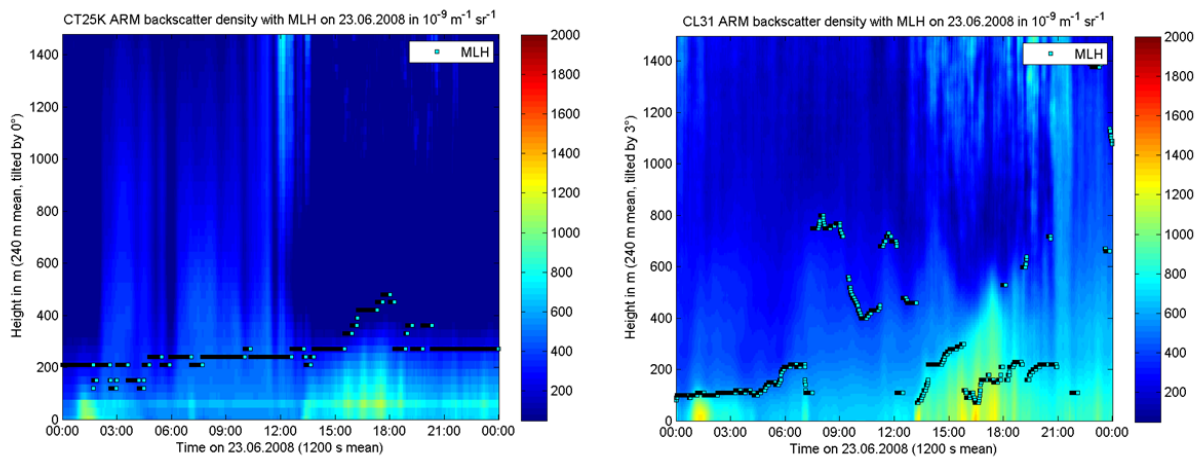


Figure 2. Backscatter density in $10^{-9} \text{ m}^{-1} \text{ sr}^{-1}$ with mixing-layer-height in m from Vaisala CT25K and CL31 Ceilometers on 06/23/08 at SGP.

5.1.2 Secondary / Underlying Variables

Table 3. Secondary Variables

Variable Name	Quantity Measured	Unit
time	Time offset from midnight	seconds
range	Distance to the center of the corresponding range bin	m
alt_highest_signal	Altitude of highest signal	m
sum_backscatter	Sum of detected and normalized backscatter	1/srad

5.1.3 Diagnostic Variables

Table 4. Diagnostic Variables

Variable Name	Quantity Measured	Unit
time_offset	Time offset from base_time	seconds
laser_pulse_energy	Laser pulse energy	%
laser_temperature	Laser temperature	C
window_transmission	Window transmission estimate	%
tilt_angle	Tilt angle	degree
background_light	Background light	mV
status_string	Warning, alarm, and internal status information	unitless
detection_status	Detection status	unitless
status_flag	Ceilometer status indicator	unitless
measurement_parameters	Instrument measurement parameters	unitless

5.1.4 Data Quality Flags

Most fields contain a corresponding, sample-by-sample, automated quality check field in the b1 level datastreams. These flags are named **qc_<fieldname>**. For example, the **first_cbh** field also has a companion **qc_first_cbh** field. Possible values for each sample of the **qc_<fieldname>** are shown in the table below.

Table 5. Data Quality Flags

Value	Definition
0	All QC checks passed
1	Sample contained 'missing data' value
2	Sample was less than prescribed minimum value
3	Sample failed both 'missing data' and minimum value checks
4	Sample greater than prescribed maximum value
5	Sample failed both minimum and maximum value checks (highly unlikely)
7	Sample failed minimum, maximum, and missing value checks (highly unlikely)
8	Sample failed delta check (change between this sample and previous sample exceeds a prescribed value)
9	Sample failed delta and missing data checks
10	Sample failed minimum and delta checks
11	Sample failed minimum, delta, and missing value checks
12	Sample failed maximum and delta checks
14	Sample failed minimum, maximum, and delta checks
15	Sample failed minimum, maximum, delta, and missing value checks

The minimum and maximum thresholds are currently defined as follows for datastream **vceil25k**:

Table 6. Data Quality Thresholds

Field Name	Units	Min	Max	Delta
first_cbh	m	0	7700	--
second_cbh	m	0	7700	--
third_cbh	m	0	7700	--
vertical_visibility	m	0	7700	--
alt_highest_signal	m	0	7700	--
laser_pulse_energy	%	10	110	100
laser_temperature	C	-10	60	5
tilt_angle	degree	0	4	1

In addition to the above data quality checks, the **qc_time** field is also supplied. The purpose of this field is to help detect duplicate samples, missing samples, or other sample time problems. The qc_time field contains a value for each sample time. It has a lower limit of 14 s and an upper limit of 16 s. Refer to the table below for details.

Table 7. Time Quality Flags

Value	Description
0	Dt is within specified range
1	Dt is 0, duplicate sample
2	Dt is less than specified lower limit
4	Dt is greater than specified upper limit

Additional information is found at the ARM netCDF file header description of the [vcei125k Data Object Design](#).

5.1.5 Dimension Variables

Table 8. Dimension Variables

Variable Name	Quantity Measured	Unit
base_time	base time in Epoch	seconds
lat	north latitude	degrees
lon	east longitude	degrees
alt	altitude	meters above Mean Sea Level

5.2 Annotated Examples

This section is not applicable to this instrument.

5.3 User Notes and Known Problems

The status_flag field is briefly set to “Alarm” during daily preventative maintenance due to water and/or alcohol used to clean the window.

The VCEILs at the ARM sites are normally operated in vertical orientation. The tilt angle of the CL31 is measured by a thermal sensor on the transmitter board. A diurnal oscillation of the measured tilt angle from 0 to 3 degrees has been observed that is attributed only to solar heating of the ceilometer, not due to an actual change in the tilt angle. The detected cloud-base height is automatically compensated for the tilt angle.

The Vaisala CT25K ceilometers were replaced with model CL31 in 2010 (BCR-1647).

5.4 Frequently Asked Questions

What is the difference between cloud height determination algorithms using the ceilometer and the micropulse lidar (MPL)?

The MPL uses a threshold variation to identify the cloud bottom, and the ceilometers use a calculated vertical visibility threshold of 100 m. This means that the ceilometer will not classify thin cloud regions that the MPL would identify and usually give a slightly higher cloud bottom height.

Can direct sun damage the optics and detection systems of a ceilometer?

No. Optical filters provide solar protection of the transmitter and receiver diodes of the CL31 so there is no need for additional protection of the window. However, direct solar radiation exposure may cause alarms and temporarily invalidate the data.

Are the ceilometers eye-safe?

Yes. However, the outgoing beam must never be viewed through magnifying optics such as binoculars or a camera.

Can the ceilometer returns be used to detect aerosol mixed-layer depths in the absence of clouds?

Yes, to some extent. At the ARM sites, the CL31 measurement algorithms have been optimized for performance in aerosol and mixing-layer applications.

How does the VCEIL compare with other ceilometers during low cloud conditions such as are often observed in the Arctic?

The VCEIL uses overlapping transmitting and receiving optics so that beam overlap occurs at shorter distances, so that detection of thin clouds at only about 10 m above the ceilometer is improved.

Are the cloud heights provided by the VCEIL measured above sea level or above ground level?

The cloud height values are measured above the optics assembly and are not adjusted for altitude.

6.0 Data Quality

6.1 Data Quality Health and Status

The following links go to current data quality health and status results.

- [DQ Explorer](#)
- [NCVweb](#) for interactive data plotting using.

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

On a weekly basis, the instrument mentor inspects plots of the data from the VCEILs at the SGP, Tropical Western Pacific (TWP), North Slope of Alaska (NSA), and ARM Mobile Facility (AMF) sites. Time series plots are inspected to compare backscatter density and cloud heights measured by the VCEIL and MPL.

The MPL uses photon counting, rather than photocurrent detection, and defines a cloud by identifying a sudden increase in backscatter, rather than cloud droplet scattering that reduces visibility to less than 100 m. The increased sensitivity and looser definition of a cloud causes the MPL to often report clouds that are not reported by the VCEIL. However, both instruments should normally report clouds and cloud bases that correspond closely.

The data are also examined for internal consistency, specifically whether clouds are observed at heights up to the limit of the system (7.7 km), the backscatter plots show expected variability, data gaps are minimal, and warning flags for window contamination are minimal.

Data Quality Reports (DQRs) are submitted when needed, and an [Instrument Mentor Monthly Summary](#) of data quality is sent monthly to the Instrument Team manager and the DQ Office.

6.3 Data Assessments by Site Scientist / Data Quality Office

All DQ Office and most Site Scientist techniques for checking have been incorporated within [DQ Explorer](#) and can be viewed there.

6.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the ARM Climate Research Facility are met through the analysis and processing of existing data products into "value-added" products, or VAPs. Despite extensive instrumentation deployed at the ARM sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the program. Conversely, ARM produces some VAPs not in order to fill unmet measurement needs, but instead to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces "best estimate" VAPs. A special class of VAP called a Quality Measurement Experiment (QME) does not output geophysical parameters of scientific interest. Rather, a QME adds value to the input datastreams by providing for continuous assessment of the quality of the input data based on internal consistency checks, comparisons between independent similar measurements, or comparisons between measurement with modeled results, and so forth. For more information see [VAPs and QMEs](#).

The most useful quality measurement experiment for the ceilometer is comparison of cloud heights detected with a micropulse lidar (MPL) and the VCEIL. However, it must be kept in mind that the MPL can detect backscatter from thin clouds that are not discernible from the processed VCEIL backscatter. One reason for this includes the fact that the VCEIL is designed to detect clouds that obscure pilot visibilities to less than 100 m and is just not as sensitive as the MPL (photon counting versus photo-

current detection, respectively). Also, there is a change in daytime/nighttime sensitivity in the data. When there are both MPL and VCEIL data, the most sensitivity to thin clouds will always come from the MPL. The combination of the MPL and the VCEIL is still valuable not only in maintaining a continuous data stream, but also the higher resolution of the VCEIL is useful for lower level cloud detection and possibly cloud-free mixing-depth estimates under some circumstances.

Another quality measurement experiment can be performed by comparing the VCEIL cloud base height and the calculated lifting condensation level from surface humidity and temperature measurements. The lifting condensation level temperature can be calculated as $T_l = 1 / [(1/(T_k - 55)) - \ln(U/100)/2840]$ where T_k is the absolute surface temperature (K) and U is the surface relative humidity (%). The height associated with the lifting condensation level can be calculated from an adiabatic lapse rate assumption.

7.0 Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The system components consist primarily of the Measurement Unit and Shield, which include the following replaceable parts:

Table 9. Vaisala CL31 Main Parts

Component	Part Code
Receiver	CLR321
Transmitter	CLT321
Optics Unit	CLO321
Engine Board	CLE321
Laser Monitor Board	CLM311
Window Assembly	CLW311
Window Blower	CLB311
Internal Heater	CLH311
AC Power	CLP311
Battery	226116
Power Cable	CT35324
Data Cable	CT3838
Termination Box	TERMBOX-1200

Presently, the spare parts supply includes one each transmitter, receiver, and heater. The optional parts supply includes a maintenance cable, QMZ101, and an optical termination hood, CLTERMHOOD, for diagnostics and calibration

7.1.2 System Configuration and Measurement Methods

The VCEIL measures cloud-bottom heights and vertical visibilities. These instruments employ pulsed diode laser lidar (light detection and ranging) technology, where short, powerful laser pulses are sent out in a vertical or slant direction. The directly backscattered light caused by haze, fog, mist, virga, precipitation, and clouds is measured as the laser pulses traverse the sky. This is an elastic backscatter system, and the return signal is measured at the same wavelength as the transmitted beam. The ceilometer backscatter profile (i.e., signal strength versus height) is stored, and the cloud bases are detected. Knowing the speed of light, the time delay between the launch of the laser pulse, and the detection of the backscatter signal gives the cloud-base height (see Theory of Operation, Section 7.2).

The VCEIL is able to detect three cloud layers simultaneously. Besides cloud layers, it can detect whether there is precipitation or other obstructions to vision. The embedded software includes several service and maintenance functions and gives continuous status information from internal monitoring.

To optimize performance for measuring aerosol and boundary-layer structure, the CL31 ceilometers have been configured with the following user command assignments:

Table 10. Vaisala CL31 Configuration Settings

Command	Parameter	Description
set unit_id	<character assigned to unit SN>	set unit ID
set message type	msg1_10x770	set message format to type 1 with 10m x 7700m profile
set message interval	16	set message delivery interval to 16 s
set message port	data	set message delivery into data port
set message units	meters	set reported heights unit to m
set message angle_corr	off	set heights correction for tilt angle to off
set message profile noise_h2	on	set range gate normalization to on
set factory algo_sensit general	1	set algorithm parameter to 1
set factory algo_sensit second_layer	4	set algorithm parameter to 4
set factory algo_sensit cloud	3	set algorithm parameter to 3
set factory algo_sensit high_cloud	5	set algorithm parameter to 5

The instruments are placed on a foundation. The foundation should be a concrete pad at least 200 mm thick (the hole depth for the mounting bolts is 160 mm). The width should be 500 mm or larger (the

whole spacing is a square pattern 283 mm on a side). The orientation of the pad ordinarily is made so that the one side of the pad points in a north-south direction. The ceilometer is delivered with the measurement unit attached to the shield. It is recommended that the measurement unit is first removed, the shield mounted onto the foundation so that the door faces north in the northern hemisphere and south in the southern hemisphere, and then the measurement unit installed into the shield.

7.1.3 Specifications

Table 11. Specifications of CL31 Ceilometer, as operated at ARM sites

Property	Value
Range	0–7.5 km
Vertical resolution	10 m
Accuracy (against reflector)	±1% or ±5m
Measurement interval	2 s
Reporting interval	16 s
Wavelength	910 nm at 25°C
Transmitter	Indium Gallium Arsenide pulsed diode laser
Receiver	Silicon Avalanche Photodiode
Field of view divergence	±0.83 mrad
Dimensions	1190 x 335 x 324 mm
Weight	32 kg
Power	115 VAC, 310 W max.

7.2 Theory of Operation

Basic Principle of Operation

The operating principle of the ceilometer is based on measurement of the time needed for a short pulse of light to traverse the atmosphere from the transmitter of the ceilometer to a backscattering cloud base and back to the receiver of the ceilometer. The general expression connecting time delay (t) and backscattering height (h) is $h = ct/2$, where c is the speed of light. With $c = 2.9929 \times 10^8$ m/s, a reflection from 7620 m will be seen by the receiver after $t = 50.9 \mu\text{s}$.

Practical Measurement Signal

Generally, particles at all heights backscatter light, and so the actual return signal may look like that shown in the figure below.

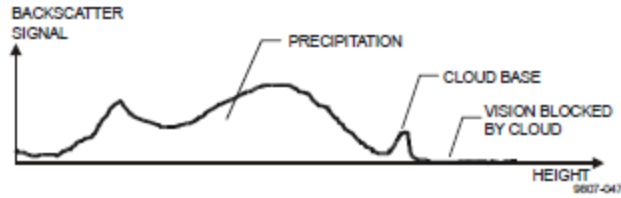


Figure 3. Typical measurement signal

The instantaneous magnitude of the return signal will provide information on the backscatter properties of the atmosphere at a certain height. From the return signal, information about fog and precipitation, as well as cloud, can be derived. Since fog and precipitation attenuate the light pulse, the cloud base signal will appear lower in magnitude in the return echo. However, the fog and precipitation information also provides data for estimating this attenuation and computing the necessary compensation, up to a limit. In its normal full-range operation, the ceilometer digitally samples the return signal every 67 ns from 0 to 50 μ s, providing a spatial resolution of 10 m from ground to 7700 m distance. This resolution is adequate for measuring the atmosphere, since visibility in the densest clouds is of the same order.

Noise Cancellation

For safety and economic reasons, the laser power used is so low that the noise of the ambient light exceeds the backscattered signal. To overcome this, a large number of laser pulses are used, and the return signals are summed. The desired signal will be multiplied by the number of pulses, whereas the noise, being random, will partially cancel itself. The degree of cancellation for white (Gaussian) noise equals the square root of the number of samples; thus, the resulting signal to noise ratio improvement will be equal to the square root of the number of samples. However, this processing gain cannot be extended endlessly since the environment changes, and, for example, clouds move.

Height Normalization

Assuming a clear atmosphere, it can be seen that the power is inversely proportional to the square of the distance or height (i.e., the strength of a signal from 10,000 ft is generally one hundredth of that from 1,000 ft). The height square dependence is eliminated by multiplying the value measured with the square of the height (height normalization). However, noise, being height independent from a measurement point of view, will then be correspondingly accentuated with increasing height.

The Backscatter Coefficient

The volume backscatter coefficient, $\beta(z)$, represents the portion of light that is reflected back towards the ceilometer from a distance z (e.g., by water droplets). It is obvious that the denser a cloud is, the stronger the reflection will be. The relationship can be expressed as: $\beta(z) = k \cdot \sigma(z)$

where

k = "constant" of proportionality and

σ = is the extinction coefficient (i.e., the attenuation factor in a forward direction).

The extinction coefficient relates to visibility in a straightforward manner. If visibility is defined according to a 5% contrast threshold (World Meteorological Organization definition for Meteorological Optical Range (MOR), equals daylight horizontal visibility), then $\sigma = 3 / V$

where

$V = \text{MOR visibility (5\% contrast)}$

The "constant" of proportionality, k , also called the Lidar Ratio, has been subjected to a lot of research. Although the Lidar Equation can be solved without knowing its value, it must remain constant with height if accurate estimates of the extinction (or visibility) profile are to be made.

It has been found that in many cases, k can be assumed to equal 0.03, tending to be lower in high humidities, to 0.02; and higher in low humidities, to 0.05. However, in precipitation of various kinds, k will have a wider range of values. Assuming a value 0.03 (srad^{-1}) for k and visibility in clouds being in the range 15–150 m, gives the range of value for β :

$$\beta = 0.0006 - 0.006 \text{ m}^{-1}\text{srad}^{-1} = 0.6 - 6 \text{ km}^{-1}\text{srad}^{-1}$$

Extinction Normalization and Vertical Visibility

Any fog, precipitation, or similar obstruction to vision between ground and cloud base may attenuate the cloud base signal and produce backscatter peaks that far exceed that from the cloud. Virtually any backscatter height profile is possible, up to some physical limits. To distinguish a significant cloud return signal, the attenuation of fog, precipitation, etc., has to be taken into account by normalizing with regard to extinction. The profile thus obtained is proportional to the extinction coefficient at various heights and enables the use of fairly straightforward threshold criteria to determine what is cloud and what is not.

By assuming a linear relationship between backscatter and extinction coefficient according to the previous formula and that the ratio, k , is constant over the range observed, it is possible to obtain an extinction coefficient profile through a mathematical computation. This is also called inverting the backscatter profile to obtain the extinction coefficient profile and answers the question, "What kind of extinction coefficient profile would produce the backscatter profile measured?"

No assumption as to the absolute value of the ratio, k , needs to be made if k is constant with height. The assumptions that have to be made are fairly truthful, and in any case, accurate enough for the purpose of cloud detection. Likewise, the inversion is also independent of several instrumental uncertainties including transmitted power and receiver sensitivity.

An estimate of vertical visibility can easily be calculated from the extinction coefficient profile because of the straightforward extinction coefficient to visibility relationship, provided that a constant contrast threshold is assumed. Visibility will simply be that height where the integral of the extinction coefficient profile, starting from ground, equals the natural logarithm of the contrast threshold, sign disregarded.

Tests and research have, however, shown that the 5% contrast threshold widely used for horizontal measurement is unsuitable for vertical measurement if values close to those estimated by a ground-based observer are to be obtained. The ceilometer uses a contrast threshold value that, through many tests, has been found to give vertical visibility values closest to those reported by ground-based human observers. A

wide safety margin is obtained with regard to pilots looking down in the same conditions since the contrast objects, especially runway lights, are much more distinct on the ground.

7.3 Calibration

7.3.1 Theory

This section is not applicable to this instrument.

7.3.2 Procedures

This section is not applicable to this instrument.

7.3.3 History

This section is not applicable to this instrument.

7.4 Operation and Maintenance

7.4.1 User Manual

See [Vaisala CL31 Ceilometer documentation](#).

7.4.2 Routine and Corrective Maintenance Documentation

See [TWP/AMF Operations Manual](#).

7.4.3 Software Documentation

See [Vaisala CL-View documentation](#).

7.4.4 Additional Documentation

None.

7.5 Glossary

See the [ARM Glossary](#).

7.6 Acronyms

See the [ARM Acronyms](#).

7.7 Citable References

Emeis, S, et al. 2004. “Atmospheric boundary-layer structure from simultaneous SODAR, RASS, and ceilometer measurements.” *Atmospheric Environment* 38: 273–286.

Emeis, S, K Schäfer, and C Münkel. 2009. “Observation of the structure of the urban boundary layer with different ceilometers and validation by RASS data.” *Meteorologische Zeitschrift* 18: 149–154.

Münkel, C. 2007. “Mixing height determination with lidar ceilometers - results from Helsinki Testbed.” *Meteorologische Zeitschrift* 16: 451–459.

Münkel, C. 2006. “Retrieval of mixing height and dust concentration with lidar ceilometer.” *Boundary-Layer Meteorology*: doi:10.1007/s10546-006-9103-3.



U.S. DEPARTMENT OF
ENERGY

Office of Science