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Air quality — Test methods for snow depth sensors

Qualité de l'air — Méthodes d'essai des capteurs de hauteur de neige

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 5, *Meteorology*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Solid precipitation is one of the more complex parameters to be observed and measured by automatic sensors. The measurement of precipitation has been the subject of a multitude of studies, but there has been limited information regarding the procedures and performance criteria describing the ability and reliability of automatic sensors to accurately measure solid precipitation[13].

Recently, an increasing percentage of precipitation data used in a variety of applications have been obtained using automatic instruments and stations including the measurement of snow depth, and many new applications have emerged[13].Also, the modern data processing capabilities, data management, and data assimilation techniques provide the means for better assessment and error analysis.

For the past years, various automatic snow depth measurement systems or snow depth sensors have been deployed and tested at different places to take advantages of their efficiency and get more objective measurement results[6].

An ultrasonic snow depth sensor measures the time interval between transmission and reception of ultrasonic pulses reflected from a target surface. This measurement is used to determine the distance between the sensor and the surface. The performance of the acoustic snow depth measurement technique depends on air temperature. Therefore, the ultrasonic sensor requires correction for variations in the speed of sound in air due to temperature. The measurement uncertainty of sonic rangers (distance meters) is 0,5 % to 1 % of the distance, which leads under typical conditions to a measurement uncertainty for snow depth in the order of 1 cm[2].

Laser sensors for snow depth measurement were introduced a few years ago and have already been under test and in operational use in various places[11][14][18]. A laser snow depth sensor uses an optoelectronic distance measurement principle to measure the distance between the sensor and the surface of the snow. Most of the laser snow sensors today employ a single laser distance meter, and, this results in an important drawback of this type of snow sensors, the lack of spatial representativeness. To resolve this issue, there have been a few trials and products with multipoint measurements, including a fixed 3 points sensor and scanning laser snow depth sensors which scan multiple points along a circular path or a segment of line. Apart from the laser distance sensors, there are other optical techniques capable of measurement of the state of ground and snow depth[2].

In spite of some of the drawbacks and difficulties, automated snow depth measurement techniques are evolving to offer more objective results which can be made available continuously and in near real-time.

The procedures presented in this document define methods for performance test of snow depth sensors to be used for snow depth measurements. Minimum requirements for conformance with this document include successful completion of the basic functional test (see Clause 7), the temperature chamber test (see Clause 8), and the field test (see Clause 10).

Air quality — Test methods for snow depth sensors

1 Scope

This document provides requirements for the evaluation and use of test method for snow depth sensors. This document is applicable to the following types of automatic snow depth sensors which employ different ranging technologies by which the sensors measure the distance from the snow surface to the sensor:

a) Ultrasonic type, also known as sonic ranging depth sensors;

b) Optical laser snow depth sensors including single point and multipoint snow depth sensors;

c) Other snow depth sensors.

This document mainly covers two major tests: a laboratory(indoor) test and a field (outdoor) test. The laboratory test includes the basic performance test and other tests under various environmental changes. The field test is proposed to ensure the performance of the snow depth sensors in field measurement conditions. For the field test, both the natural ground and artificial target surface such as snow plates are considered for the procedures defined in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5725 (all parts), *Accuracy (trueness and precision) of measurement methods and results*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
mean
mean value over the (selected) averaging interval of the sonic

3.2
dead zone
area that cannot be measured near the sensor

3.3
half-power beam width
beam angle width that the transmitted acoustic power decreases by half

3.4
beam angle clearance
angular range where obstacles should be excluded to prevent interference due to acoustic reflection

4 Fundamentals of snow depth sensors

4.1 Overview

The term “snow” should also include ice pellets, glaze, hail, and sheet ice formed directly or indirectly from precipitation. Snow depth usually means the total depth of snow on the ground at the time of observation. Depth measurements of snow cover on the ground had been taken mainly with snow rulers until a couple of decades ago. The development of practical ultrasonic and laser ranging devices to provide reliable snow depth measurements at automatic stations has provided feasible alternatives to the standard observation. Most of these sensors are capable of an uncertainty within ±1,0 cm (Reference [17]). In addition, these sensors can be utilized to control the quality of automatic recording gauge measurements by providing additional details on the type, amount and timing of precipitation.

4.2 Observation methods

The ultrasonic snow depth sensor has an ultrasonic wave transmitter/receiver installed downward on the upper part of the observation pole, emits an ultrasonic pulse, and measures the time it takes for the ultrasonic pulse to be reflected and returned. The depth of snow is calculated by converting the propagation time and the speed of sound into distance.

The laser snow depth sensor uses laser light instead of the ultrasonic waves. Laser light is emitted obliquely downward from the upper part of the observation pole. The laser light has a spot shape on the irradiated snow surface, and there are single-point laser sensors and multi-point laser sensors that measure a single point and multiple points on the snow surface respectively.

4.3 Points to note

There are a few points to note. Firstly, measurements should be taken at the representative observing point without slope and with no obstructions around measurement points, since the snow drifts and is redistributed under the effects of the wind.

Secondly, since the ultrasonic snow depth sensor has a wide beam, it requires a wide irradiation surface.

Thirdly, a single-point laser sensor requires attention to be paid to the snow surface representativeness of the measurement point.

5 Test criteria and summary of methods

5.1 Test criteria and considerations

5.1.1 Measurement performance

1) Resolution: the minimum measurement unit in 0,1 cm. (typical e.g. 0,1 cm)

2) Measurement accuracy: deviation of the measurement from the real depth in 0,1 cm. (typical e.g. 0,5 cm)

3) Dead zone: area that cannot be measured near the sensor. (typical e. g. 50 cm from the centre of the target area)

4) Measurement height range: maximum measurable snow height considering dead zone in cm. (typical e.g. 300 cm).

5) Maximum measurable distance from the ground and/or "dead-zone" in cm. (typical e.g. 500 cm)

6) Measurement area (in cm^2): the size of the target area (typical e.g. 100 cm in radius (approx. 7 850 cm^2). For ultrasonic sensors, the measurement area is limited by the “half-power beam

width" not the "beam angle clearance. The former is usually within 10 deg., on the other hand the latter is about 30 deg.

7) Measurement pattern: the shape of the scanning measurement (e.g. a single point, a triangle, a rectangle, a circle, a line etc.).

8) Measurement speed: minimum measurement period or data output interval. (typical e.g. 1 min)

5.1.2 Installation-related

1) Allowed installation angle: the maximum angle between the vertical pole or wall and the pointing direction of the snow depth sensor.

2) Influence of shadows: the influence of shadows generated by obstacles such as cables, tree branches, poles, and other snow depth meters.

3) Max height: the maximum height where the snow sensor should perform measurement with the proclaimed accuracy and resolution; it is to determine if the maximum measurable height is bigger than the maximum possible snow depth at the site.

4) Target surface: determine if the target surface, either natural ground or a snow plate is structured for optimal measurement of snow depth.

5) Calibration procedure: determine if there is a straight forward procedure to calibrate the sensor.

5.1.3 Environmental/operational

1) Snow measuring temperature: temperature range where the snow sensor should perform measurement with the proclaimed accuracy and resolution. (e.g. -40 ~ 30 °C).

2) Operating temperature and humidity where the snow sensor can be operated without being damaged or malfunctions. (e.g. -40 ~ 50 °C, 0 ~ 99 %).

3) Wind (ultra-sonic sensors only): (e.g. 0 ~ 20 m/s speed, apply the manufacturer's specification).

4) Visibility (laser sensor only): effect of snowstorm, fog and dirt on the snow surface. (apply the manufacturer's specification).

5) Conditions of testing and calibration: conditions that have impacts on the performance of the sensor. Although testing in extreme environments should be encouraged, one should not infer results from these tests to the performance that can be expected in less extreme conditions.

5.2 Summary of test methods

1) Manufacturer design specifications check: the sensor should be examined for damage and conformance with manufacturer design specifications prior to testing. The accuracy of all measurements and results shall be ascertained and reported in accordance with ISO 5725 (all parts).

2) Basic functional test: the instrument's basic performance in terms of resolution, accuracy, and measurement range are tested and determined.

3) Temperature chamber test: The deviation of the measured is determined over the operational temperature range.

4) Calibration (ground level adjustment) or manual configuration test: the offset of the measured distance is determined over the operational temperature range.

5) Field test: addresses the response to potentially adverse environmental conditions, which are difficult to simulate in the laboratory.

6 Manufacturer design specifications check

6.1 Purpose

Check if the measurement performance and specifications proclaimed by the manufacturer meets the intended use.

6.2 Requirements to list

The list includes the sensor's measurement performance, installation related issues including zero adjustment and calibration procedures, and environmental/operational conditions.

7 Basic functional test

7.1 Purpose

The purpose of the basic functional test is to verify the basic performance of the test subject. This clause defines procedures of calibration of the sensors, test setup, and running tests.

7.2 Calibration of the sensor prior to testing

Before any use or test of the sensors, they need to be properly calibrated.

There are different ways to calibrate the snow sensors depending on the measurement types of the sensors. Below is a list of proposed calibration methods:

1) Calibration using a reference object;

2) Calibration using a moving target surface (or changing the installation height);

3) Plumb procedure.

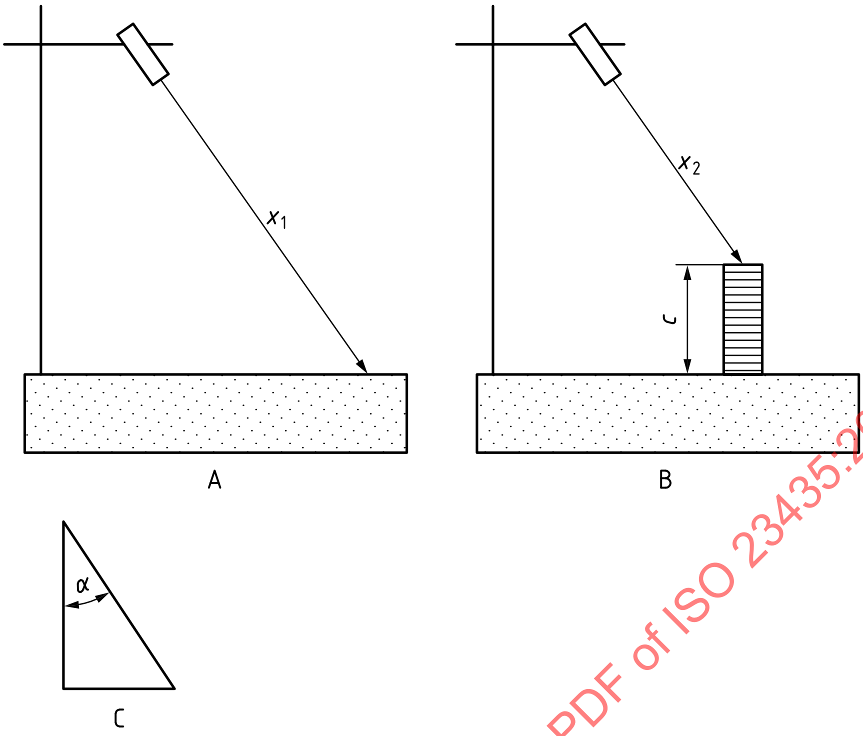
7.2.1 Calibration using a reference object

1) In this calibration setup, measurements are done with and without a reference object. The measurement without the reference object is supposed to be same as the measurement for the ground level.

2) The installation angle (α) can be derived easily by the formula as shown in Figure 1.

3) Adjust the scale, the offset, and other factors so that the resulting output matches the height of the reference object, c.

4) In this scheme, if the height of the reference object c is not well determined, the corresponding error in the installation angle, α leads to 1:1 error in the measured distance between the sensor and the surface.



Key

A calibration setup and Measurement without the reference object

B measurement with reference object

C calculation of the installation angle

α installation angle

c reference object

x_1 distance from the ground level

x_2 distance from the top of the reference object c

Figure 1 — Calibration using a reference object

7.2.2 Calibration by moving the target surface

1) In this scheme, the direction of the laser beam doesn't have to perpendicular to the target surface.

2) This scheme shown in Figure 2 is virtually equivalent to the one using a reference object in 7.2.1, but, the distance between the sensor and the target surface is changed by moving either the sensor or the target surface instead of inserting a reference object in 7.2.1.

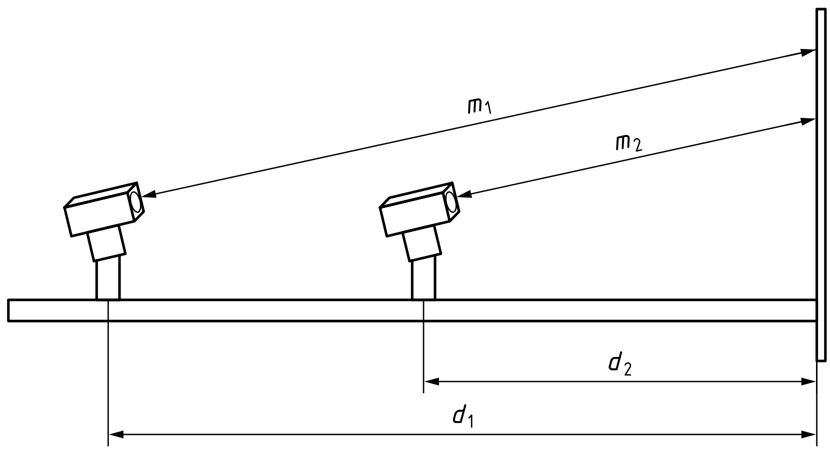
3) First measure the distance m_1(equivalent to x_1 in Figure 1 of 7.2.1) as the ground level.

4) Second measure the distance m_2(equivalent to x_2 in Figure 1 of 7.2.1) as a reference height.

5) Compare $(m_1 - m_2)$ and $(d_1 - d_2)$.

Adjust the scale, the offset, and other factors that the calculated output from $(m_1 - m_2)$ matches the distanced moved, $(d_1 - d_2)$. When the sensor's beam is perpendicular to the target surface or the ground (as with ultrasonic snow depth sensors) as shown in Figure 3, the process becomes much simpler. In this scheme $(m_1 - m_2)$ is equal to $(d_1 - d_2)$.

Rail distance d_1 or d_2 corresponds to the height from the ground. Calibration is carried out according to 7.3.2 Running test



Key

m_1 laser distance reading at the distance d_1

m_2 laser distance reading at the distance d_2

d_1, d_2 rail distance

Figure 2 — Calibration by moving the target surface (laser)

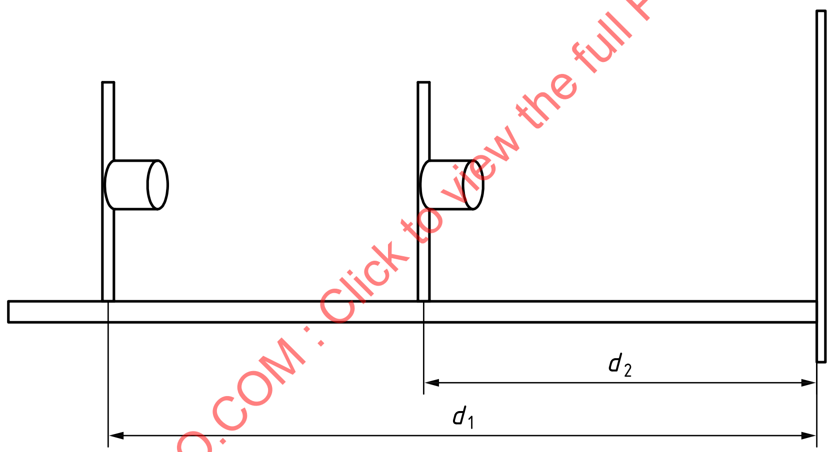


Figure 3 — Calibration by moving the target surface (ultrasonic)

Key

d_1, d_2 rail distance

7.2.3 Plumb procedure (only applicable to sensors using visible laser signals)

1) Establish a setup as shown in Figure 4.

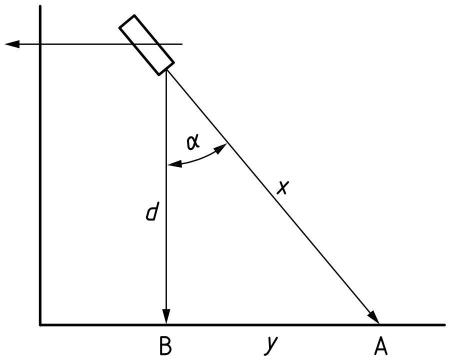
2) Measure and record the distance *x* from the sensor to the laser spot (*A*) at an angle *α*.

3) Measure the distance (y) from A to the shortest point on the ground (*A*).

4) Use y to calculate the actual height d using $\alpha = arcsin\ (y/x)$ and $d = y/tan(\alpha)$ or $d = x\ cos(\alpha)$.

5) Adjust the scale, the offset, and other factors so that the resulting output from the sensor matches the calculated height *d.*

6) In this scheme, it requires attention to precisely locate point B where the vertical line from the sensor to the ground perfectly perpendicular to the target surface. A pendant hung vertically from the sensor can be used to find the point (B).



Key

A the point on the target surface pointed by the sensor

B the point on the target surface where the line from the sensor is perfectly perpendicular to the target surface

d *installation height*

x *measured distance*

α *angle (d, x_1)*

Figure 4 — Plumb procedure

7.3 Basic functional test procedure

7.3.1 Test setup

1) As shown in Figures 1 through 4, firmly mount the subject sensor on a rail or a pole with a target surface.

2) The system setup in a horizontal way in Figure 2 and Figure 3 can be converted into a vertical scheme with a pole.

3) There shall be a means to vary the distance between the subject sensor and the target surface. For the horizontal system, it would be appropriate to put the subject sensor on a rail-like mechanism, fix the target surface, and move the sensor back and forth to change the distance from the target surface. For a vertical system, one can raise or lower the target surface as needed. Because of the weight of the sensor and the target surface, it will be more practical to use a horizontal mechanism for precise movement of the sensor.

7.3.2 Running test

1) Position the sensor at the farthest distance and configure the sensor at the ground level. (0 cm level).

2) Move the sensor or the target surface to the minimum test height and run a round of measurement(s) and record the result.

3) Move the sensor or target surface to the next level and repeat step 2.

4) Repeat step 3 for all the levels listed below:

   Min. height: 0,5 cm

   1,0 cm/5,0 cm/10,0 cm/50,0 cm/100,0 cm (the intervals and heights can be selected as required for the intended use)

   Max. height: 200,0 cm (this number can be changed according to the manufacturers' specification of the equipment)

7.3.3 Evaluation of the results

1) Compare the measurement readings with the scale of the measure (ruler or digital ruler).

2) Determine if the variation or offset goes over the specified accuracy range.

3) Determine if the sensor was able to measure at the maximum distance.

4) Determine if the sensor is capable of the specified resolution of the measurement.

7.3.4 Consideration

1) It is very important that the reference is precise and reliable because all the test procedures rely on the reference readings.

2) Make sure to have a very flat target surface perfectly perpendicular to the rail or pole.

3) Make sure to perform proper calibration before the test.

8 Temperature chamber test (optional)

8.1 Purpose

The purpose of the temperature chamber test is to determine if the subject snow depth sensor properly operates with the change of the ambient temperature.

8.2 Test chamber

It is important to consider and apply the potential variation due to expansion of the mechanical structure due to the temperature change in the test chamber. The temperature coefficients of the materials used to construct the structure should be known beforehand and applied to the final measurement results.

8.3 Procedure

1) Set the system of the subject snow depth sensor at a fixed distance and run the measurement every 1 min.

2) While the snow depth sensor keeps running, decrease the temperature at 5 ~ 10°/10 min until it reaches the minimum operational temperature.

3) Keep the subject snow depth sensor running at the minimum operational temperature for additional 60 min.

4) While the snow depth sensor keeps measuring, increase the temperature at 5 ~ 10°/10 min until it reaches the maximum operational temperature.

5) Determine if the sensor's measurement performance meets the manufacturer's specification and/or the user's requirements at the temperatures below:

   a. 0 °C

   b. The minimum operational temperature claimed by the manufacturer or specified by the user such as the government of the country (e.g. -40 °C, -55 °C, etc.)

   c. The maximum operational temperature claimed by the manufacturer (e.g. 20 °C, 40 °C, 50 °C, etc.)

   d. Nominal room temperature (e.g. 25 °C)

8.4 Evaluation

1) After running the sensor for a reasonable amount of time, collect the measurement data for different temperatures applied.

2) Determine if the snow depth sensor under test has been operating normally without missing measurements, delay or any errors in the temperature range from the minimum operational temperature claimed by the manufacturer or specified by the user to 25 °C.

3) For other temperature ranges, determine if the snow depth sensor are still operational and start measuring when the temperature returns to the range between the minimum temperature and 25 °C.

4) If there have been any errors, analyse the errors and categorize the errors that may have occurred.

5) Determine if the errors are acceptable and fit in the specification of the sensor.

9 Calibration (ground level adjust) test

9.1 Purpose

The purpose of this test is to make sure the sensor is equipped with a calibration or configuration feature either manual or automatic:

All types of snow depth sensors should have a calibration or automatic adjustment feature to keep track of changes of the target surface's height by different causes. Some of the examples of the factors that would affect the current calibration are: change in the height of the sensor due to moving to a different location, reinstalling the whole setup, natural change of the ground level, etc.

9.2 Procedures

As the calibration (or configuration) procedures heavily depend on the snow depth sensor types, detailed procedures go beyond the scope of this document. Any procedures similar to the calibration procedures specified in 7.2 would meet the requirements.

10 Field tests

10.1 Purpose

Not all tests can be conducted under laboratory conditions. For example, the full variation of atmospheric conditions cannot be simulated in a laboratory environment. Moreover, it is necessary to verify the snow depth sensors' performance with different kinds of precipitation, including freezing rain.

Field tests have the big disadvantage that the conditions cannot be controlled, and that a complete set of relevant statistics is sometimes difficult to obtain. Therefore, only some of the important conditions to be met in a field test are described here. Full guidance on how to perform and to evaluate field tests is beyond the scope of this document.

10.2 Duration

For an instrument designed to operate unattended for long periods, general field tests should be conducted in conditions representative of a full snowing season.

10.3 Siting

Choosing a proper field test site is not a simple job, and it's subject to the requirements of the proposed use. But it's recommended that 3 to 4 different sites with different aspects of atmospheric conditions such as the wind, sun exposure, temperature, type of soil, the direction of installation, etc.[12].

The site shall satisfy the general siting conditions for snow depth measurements, as set out in WMO No.8 the CIMO Guide 6.7 (2014 edition), Annex 6.B (2018 edition) to ensure satisfying the environmental conditions at the test locations.

The following siting criteria may be considered prior to installation:

1) Ideal location for snow measurement is level and grassy area naturally shielded from the wind in all directions.

2) Where obstructions cannot be avoided, snow measurements should be taken a minimum of twice the distance from the obstacle as that obstacle is high.

3) Avoid drainage areas or areas prone to flooding during heavy rain or snowmelt.

4) Avoid slopes greater than 5°.

5) Avoid south-facing slopes because of faster melt-out.

6) Avoid, to the greatest extent possible, areas prone to drifting snow and wind scour.

10.4 Climate

Relevant climate elements are:

1) Wind distribution (wind rose).

2) Temperature distribution.

3) Rainfall distribution.

4) Snowfall (snow depth) distribution.

5) Occurrence of other types of precipitation.

6) Occurrence and strength of icing conditions.

7) Exposure to the sun and other obstacles.

10.5 Installation

10.5.1 Mounting and installation of ultrasonic snow depth sensors

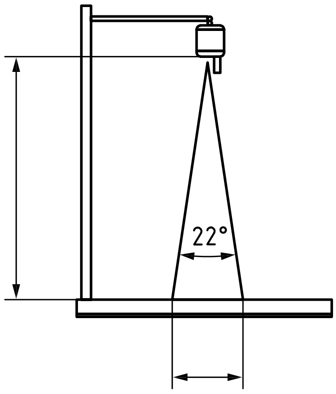


Figure 5 — Beam angle clearance

For ultrasonic snow depth sensors, it is always the best to mount the sensor vertically, perpendicular to the intended target surface. An ultrasonic sensor has a beam angle clearance (e.g. 30°) as shown in Figure 5. The objects outside the beam angle will not be detected nor interfere with the intended target. Therefore, any unwanted target must be outside the beam angle or further.

The following formula is used to get the clearance radius from the height. For example, the required clearance angle is 30 deg (Reference [1]).

Clearance radius formula:

$CONE\text{radius} = \tan(\psi/2)(CONE\text{height})$

ψ beam angle clearance (typical e.g. 30°)

Any target to the sensor should be apart from the face of the transducer (e.g. 20 in/50 cm). An attempt should also be made not to mount the sensor too far from the target surface. The further the sensor is from the target the more the absolute error increases. The maximum range proclaimed by the manufacturer should be referred so as not to increase the error.

10.5.2 Mounting and installation of laser-based sensors

Unlike ultrasonic snow depth sensors, it is not necessary to install the sensor perpendicular to the target surface. However, depending on the manufacturer, there is a certain limit in terms of the installation angle (inclination angle between the installation pole and the laser beam direction), and it's required the sensor to be installed at an angle less than the maximum installation angle specified the manufacturer. Figure 6 shows a typical setup of a laser snow depth sensor installed at the height *h*.