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Air quality — Environmental meteorology — Part 3: Ground-based remote sensing of wind by heterodyne continuous-wave Doppler lidar

Qualité de l'air — Météorologie de l'environnement — Partie 3: Télédétection du vent par lidar Doppler à ondes entretenues basée sur le sol

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*, and by the World Meteorological Organization (WMO) as a common ISO/WMO Standard under the Agreement on Working Arrangements signed between the WMO and ISO in 2008.

A list of all parts in the ISO 28902 series can be found on the ISO website.

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

Lidars ("light detection and ranging"), used in this document to designate atmospheric lidars, have proven to be valuable systems for the remote sensing of atmospheric pollutants in various meteorological parameters, such as wind, clouds, aerosols and gases. Extensive optical and physical properties of the probed targets, such as size distribution, chemical composition, shape of the particles and gas concentration, and optical properties of the atmosphere, such as visibility, extinction and backscatter, can be retrieved using lidars. Atmospheric targets such as these can be spatially resolved along their line of sight by, for example, focusing the continuous-wave beam at the chosen specific range. The measurements can be carried out without direct contact and in any direction as electromagnetic radiation is used for sensing the targets. Lidar systems, therefore, supplement the conventional *in situ* measurement technology. They are suited for a large number of applications that cannot be adequately performed by using *in situ* or point measurement methods.

There are several methods by which lidar can be used to measure atmospheric wind. The four most commonly used methods are heterodyne pulsed Doppler wind lidar (see ISO 28902-2:2017[1]), heterodyne continuous-wave Doppler wind lidar, direct-detection Doppler wind lidar and resonance Doppler wind lidar (commonly used for mesospheric sodium layer measurements). For further reading, refer to References [2] and [3].

This document describes the use of (monostatic) heterodyne continuous-wave Doppler lidar.

Air quality — Environmental meteorology — Part 3: Ground-based remote sensing of wind by heterodyne continuous-wave Doppler lidar

1 Scope

This document specifies the requirements and performance test procedures for monostatic heterodyne continuous-wave (CW) Doppler lidar techniques and presents their advantages and limitations. The term “Doppler lidar” used in this document applies solely to monostatic heterodyne CW lidar systems retrieving wind measurements from the scattering of laser light by aerosols in the atmosphere. Performances and limits are described based on standard atmospheric conditions. This document describes the determination of the line-of-sight wind velocity (radial wind velocity).

NOTE Derivation of wind vector from individual line-of-sight measurements is not described in this document since it is highly specific to a particular wind lidar configuration. One example of the retrieval of the wind vector can be found in ISO 28902-2:2017, Annex B.

This document does not address the retrieval of the wind vector.

This document can be used for the following application areas:

— meteorological briefing for e.g. aviation, airport safety, marine applications, oil platforms;

— wind power production, e.g. site assessment, power curve determination;

— routine measurements of wind profiles at meteorological stations;

— air pollution dispersion monitoring;

— industrial risk management (direct data monitoring or by assimilation into micro-scale flow models);

— exchange processes (greenhouse gas emissions).

This document can be used by manufacturers of monostatic CW Doppler wind lidars as well as bodies testing and certifying their conformity. This document also provides recommendations for users to make adequate use of these instruments.

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.

IEC 61400-12-1:2017, *Wind energy generation systems — Part 12-1: Power performance measurements of electricity producing wind turbines*

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 http://www.electropedia.org/

3.1
data availability
ratio between the number of actual considered measurement data with a predefined data quality and the number of expected measurement data for a given measurement period

Note 1 to entry: In the wind industry, this term commonly applies to measurements averaged over a standard period of 10 min.

3.2
displayed range resolution
spatial interval between the centres of two successive range measurements

3.3
effective range resolution
application-related variable describing an integrated range interval for which the target variable is delivered with a defined uncertainty

[SOURCE: ISO 28902-1:2012, 3.14, modified — The example has been deleted.]

3.4
effective temporal resolution
application-related variable describing an integrated time interval for which the target variable is delivered with a defined uncertainty

[SOURCE: ISO 28902-1:2012, 3.12, modified — The symbol and the example has been deleted.]

3.5
extinction coefficient
α
measure of the atmospheric opacity, expressed by the natural logarithm of the ratio of incident light intensity to transmitted light intensity, per unit light path length

[SOURCE: ISO 28902-1:2012, 3.10]

3.6
integration time
time spent in order to derive an independent value of the line-of-sight velocity

3.7
maximum acquisition range
R_{MaxA}
maximum distance at which a lidar signal can be recorded and processed

Note 1 to entry: It depends primarily on the laser wavelength and transmitter aperture size; also, to some extent, it depends on the number of acquisition points and the sampling frequency.

3.8
minimum acquisition range
R_{MinA}
minimum distance from which a lidar signal can be recorded and processed

Note 1 to entry: If the minimum acquisition range is not given, it is assumed to be zero. It can be different from zero, when the reception is blind by focusing limitations.

3.9
maximum operational range
R_{MaxO}
maximum distance to which a wind speed can be derived with confidence from the lidar signal

Note 1 to entry: The maximum operational range is less than or equal to the maximum acquisition range.

Note 2 to entry: The maximum operational range is defined along an axis corresponding to the application. It is measured vertically for vertical wind profiler. It is measured horizontally for scanning lidars able to measure in the full hemisphere.

Note 3 to entry: The maximum operational range depends on lidar parameters but also on atmospheric conditions, particularly the extinction coefficient.

3.10
measurement period
interval of time between the first and last measurements

[SOURCE: ISO 28902-2:2017, 3.10]

3.11
minimum operational range
R_{MinO}
minimum distance where wind speed can be derived with confidence from the lidar signal

Note 1 to entry: The minimum operational range is also called blind range.

Note 2 to entry: In continuous-wave lidars, the minimum operational range is determined by the closest position of the focus achievable by the transceiver optical system.

3.12
physical range resolution
width [full width at half maximum (FWHM)] of the range weighting function

[SOURCE: ISO 28902-2:2017, 3.12]

3.13
probe length
width [full width at half maximum (FWHM)] of the spatial weighting function selecting the region in space that contributes to the wind speed computation

Note 1 to entry: The probe length is centred on the measurement distance.

3.14
range resolution
equipment-related variable describing the shortest range interval from which independent signal information can be obtained

[SOURCE: ISO 28902-1:2012, 3.13]

3.15

range weighting function
weighting function of the radial wind speed along the line of sight

[SOURCE: ISO 28902-2:2017, 3.15]

3.16
temporal resolution
equipment-related variable describing the shortest time interval from which independent signal information can be obtained

[SOURCE: ISO 28902-1:2012, 3.11]

3.17
velocity bias
maximum instrumental offset on the velocity measurement

Note 1 to entry: The velocity bias has to be minimized with adequate calibration, for example, on a fixed target.

[SOURCE: ISO 28902-2:2017, 3.17]

3.18
velocity range
range determined by the minimum measurable wind speed, the maximum measurable wind speed and the ability to measure the velocity sign, without ambiguity

Note 1 to entry: Depending on the lidar application, the velocity range can be defined as the radial wind velocity (scanning lidar) or as horizontal wind velocity (wind profiler).

[SOURCE: ISO 28902-2:2017, 3.18]

3.19
velocity resolution
instrumental velocity standard deviation

Note 1 to entry: The velocity resolution is determined by the signal processing bin width.

3.20
wind shear
variation of wind speed across a plane perpendicular to the wind direction

[SOURCE: ISO 28902-2:2017, 3.20]

4 Fundamentals of heterodyne Doppler lidar

4.1 Overview

A CW Doppler lidar emits a narrow laser beam (see Figure 1). As it propagates in the atmosphere, the laser radiation is scattered in all directions by aerosols, molecules and other scattering material. Part of the scattered radiation propagates back to the lidar, it is captured by a telescope, detected and analysed. Since the aerosols and molecules move with the atmosphere, a Doppler shift results, changing the frequency of the scattered laser light.

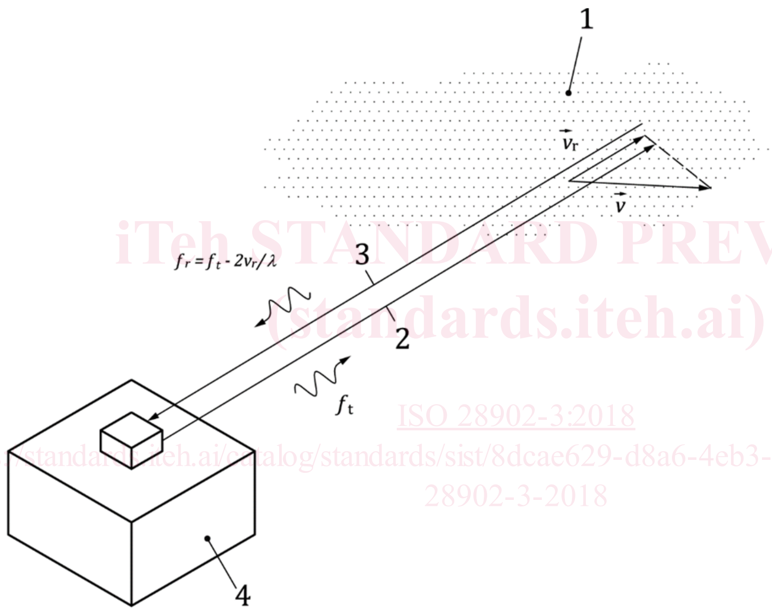
At the wavelengths (and thus frequencies) relevant to heterodyne (coherent) Doppler lidar it is the aerosols that provide the principal target for measurement of the back-scattered signal.

The analysis aims at measuring the difference Δf between the frequencies f_t of the emitted laser pulse and f_r of the backscattered light. According to the Doppler equation, this difference is proportional to the line-of-sight wind component, as shown by Formula (1):

$$\Delta f = f_r - f_t = -2 v_r / \lambda \qquad (1)$$

where

- λ is the laser wavelength;
- v_r is the line-of-sight wind component (component of the wind vector $\vec{v}$ along the axis of the laser beam, counted positive when the wind is blowing away from the lidar).



Key

1 scattering particles moving with the wind

2 optical path of the emitted laser beam

3 optical axis of the receiver

4 lidar instrument

Figure 1 — Measurement principle of a heterodyne Doppler lidar

For a CW Doppler lidar system, the measurement range is usually determined by focusing the beam to create a waist at the chosen distance. Light backscattered from those regions in close proximity to the waist is efficiently re-imaged back into the receiver; light from a significantly closer or greater distance from the waist or focus is inefficiently gathered.

