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**Meteorology — Ground-based remote  
sensing of wind — Radar wind profiler**

*Météorologie — Télédétection du vent basée au sol — Profileur de  
vent radar*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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](http://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](http://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](http://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.

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](http://www.iso.org/members.html).

## Introduction

Radar wind profiler, also referred to as wind profiler radar, wind profiling radar, atmospheric radar, or clear-air Doppler radar (hereafter abbreviated to WPR) is an instrument that measures height profiles of wind velocity in clear air. WPR detects echoes produced by perturbations of the radio refractive index with a scale half of the radar wavelength (i.e. Bragg scale). The mechanism of radio wave scattering in clear air was theoretically and experimentally understood in the 1960s. Since the 1970s, large-sized Doppler radars for observing wind and turbulence in the mesosphere, stratosphere, and the troposphere (MST radars) have been developed. Owing to their capability of measuring wind and turbulence with excellent time and height resolution, they have made great contributions to describing and clarifying the dynamical processes in the atmosphere.

Based on the MST radars, WPRs have been developed mainly since the 1980s. WPRs are designed for measuring wind velocity predominantly in the troposphere, including the atmospheric boundary layer. The measurement principle of WPRs are the same used in MST radars but a WPR is frequently smaller in size than a typical MST radar. WPR can measure wind profiles in both a clear and cloudy atmosphere.

In order to monitor and forecast meteorological phenomena, nationwide operational WPR networks have been constructed by meteorological agencies. Operational WPRs contribute to improving weather forecast accuracy through assimilation of their wind products into numerical weather prediction models used by meteorological agencies. Wind products obtained by operational WPRs are distributed globally. Further applications of WPRs include the measurement of wind profiles in the vicinity of airports to enable or improve wind shear warnings. The use of WPRs can improve an airport's ability to safely depart and land aircraft. WPRs are also used to analyse or predict the diffusion of pollutants. In addition, WPRs are widely used by government agencies and various industries, including chemical plants, mines, and power plants, to control emission levels or for computation of nowcast trajectories during emergency situations. The high-quality wind products of WPRs are also widely used in atmospheric research. Therefore, WPRs are an indispensable means for observing wind profiles continuously in time and height. By additionally using radio acoustic sounding system, WPRs can measure height profiles of virtual temperature.

In order to attain and retain high quality wind products, WPRs need to be designed, manufactured, and maintained with state-of-the-art knowledge and ensured measurement capability. Aiming at ensuring measurement capability of WPRs, this document provides guidelines in design, manufacture, installation, and maintenance of WPRs.

# Meteorology — Ground-based remote sensing of wind — Radar wind profiler

## 1 Scope

This document provides guidelines for the design, manufacture, installation, and maintenance of a WPR. It describes the following:

- Measurement principle (Clause 5). Scatterers that produce echoes and methods of wind velocity measurement are described. The description of the measurement principle mainly aims at providing the information necessary for describing the guidelines in Clauses 6 to 11.
- Guidelines for WPR system (Clause 6). Frequency, hardware, software, and signal processing are described. They are mainly applied in designing and manufacturing the hardware and software of WPR.
- Guidelines for system performance (Clause 7). Measurement resolution, range sampling, radar sensitivity evaluation, and measurement accuracy are described. They can be used for estimating the measurement performance of a WPR's system design and operation.
- Guidelines for quality control (QC) in digital signal processing (Clause 8).
- Guidelines for measurement products and data format (Clause 9). Measurement products obtained by a WPR and their data levels are defined. Guidelines for data file formats are also described.
- Guidelines for installation (Clause 10) and maintenance (Clause 11).

This document does not aim at providing a thorough description of the measurement principle, WPR systems, and WPR applications. For further details of these items, users are referred to technical books (e.g. References [1],[2],[3]).

WPRs are referred to by various names (e.g. radar wind profiler, wind profiler radar, wind profiling radar, atmospheric radar, or clear-air Doppler radar). Conventional naming for WPRs should be allowed.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology 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/>

## 4 Symbols and abbreviated terms

### 4.1 Symbols

$c$	speed of light ( $\approx 3,0 \times 10^8 \text{ m s}^{-1}$ )
$C_n^2$	refractive index structure constant
$f_{\text{Nyq}}$	Nyquist frequency
$f_r$	mean Doppler frequency shift of the echo
$G_{\text{ant}}$	antenna gain in decibels
$L_p$	loss factor caused by the pulse shaping
$n$	radio refractive index
$N_{\text{beam}}$	number of antenna beam directions
$N_{\text{coh}}$	number of coherent integrations. In this document, $N_{\text{coh}}$ is defined as the number excluding $N_{\text{pseq}}$
$N_{\text{data}}$	number of elements in I and Q (I/Q) time series after coherent integrations. $N_{\text{data}}$ is also the number of elements in the Doppler spectrum
$N_{\text{freq}}$	number of transmitted frequencies
$N_{\text{incoh}}$	number of incoherent integrations
$N_{\text{pseq}}$	number of pulse sequences
$N_{\text{subp}}$	number of sub-pulses used in phase-modulated pulse compression
$T_{\text{IPP}}$	inter pulse period
$P_{\text{echo}}$	echo power
$P_N$	noise power of the receiver
$P_n$	noise power of the Doppler spectrum
$p_n$	noise power of the Doppler spectrum per Doppler velocity bin
$P_p$	peak output power of the transmitter
$P_t$	peak output power at the antenna
$u$	zonal wind velocity
$v$	meridional wind velocity
$V_{\text{pp}}$	peak-to-peak voltage
$V_r$	radial Doppler velocity
$V_s$	sample volume
$V_{\text{wind}}$	wind vector
$w$	vertical wind velocity
$\Delta r$	range resolution
$\eta$	volume reflectivity
$\lambda$	radar wavelength
$\sigma_{3\text{dB}}$	spectral width defined as the half-power full width
$\sigma_{\text{std}}$	spectral width defined as the standard deviation



$\tau_{3dB}$	time width between the two 3-dB drop-off points from the peak point
$\tau_d$	duration during which the transmission signal is generated
$\tau_p$	transmitted pulse width
H	Hermitian operator (complex transposition)
T	superscript which indicates matrix transposition
*	complex conjugation

## 4.2 Abbreviated terms

ACS	adaptive clutter suppression
A/D	analog-to-digital
ADC	A/D converter
BUFR	binary universal form for the representation of meteorological data
COHO	coherent oscillator
CRI	coherent radar imaging
D/A	digital-to-analog
DBS	Doppler beam swinging
DCMP	directionally constrained minimization of power
DSP	digital signal processor
FCA	full correlation analysis
FDI	frequency domain interferometry
FMCW	frequency modulated continuous wave
I/O	input/output
I/Q	in-phase (I)/quadrature-phase (Q)
IF	intermediate frequency
FPGA	field programmable gate array
IPP	inter pulse period
ITU	International Telecommunication Union
JMA	Japan Meteorological Agency
LNA	low noise amplifier
MTBF	mean time between failures
MTTF	mean time to failure
NC-DCMP	norm-constrained DCMP
NF	noise figure
QC	quality control
RF	radio frequency
RIM	range imaging
RL	antenna return loss
SA	spaced antenna
SNR	signal to noise ratio
STALO	stable (stabilized) local oscillator
UHF	ultra high frequency
UPS	uninterruptible power supply

VHF	very high frequency
VAD	velocity azimuth display
VSWR	voltage standing wave ratio
WMO	World Meteorological Organization
WPR	radar wind profiler, wind profiler radar, wind profiling radar, atmospheric radar, or clear-air Doppler radar

## 5 Measurement principle

### 5.1 Spectral parameters of the echo

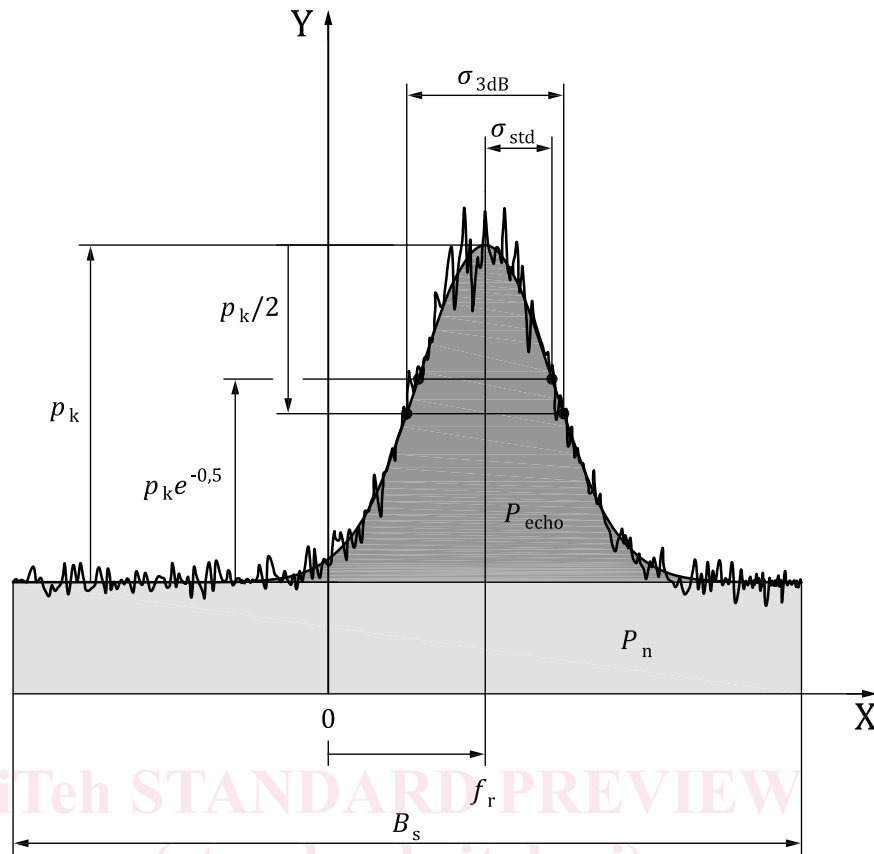
The properties of all WPR echoes are generally estimated from the properties of the Doppler spectrum. Spectral analysis is typically applied to estimate a finite set of parameters such as signal to noise ratio (SNR), Doppler shift and spectral (spectrum) width. Of particular importance for a WPR is the echo generated by clear air scattering (clear-air echo). For details of the clear-air echo, see [5.2.1](#).

NOTE 1 For real-time signal processing to obtain the Doppler spectrum, see [6.2.2](#) and [6.2.6](#).

NOTE 2 Interchangeable with spectral width, spectrum width, is also frequently used. The two terms have the same meaning.

The frequency distribution of the echo contains information on the radial Doppler velocity ( $V_r$ ) and on the wind variance caused by turbulence. [Figure 1](#) shows an example of the Doppler spectrum. The Doppler spectrum of the echo ( $S_{\text{echo}}$ ) and the noise shown in [Figure 1](#) were produced by a numerical simulation. In the numerical simulation, Doppler spectra composed of  $S_{\text{echo}}$  and white noise were produced. The noise power of the Doppler spectrum is expressed by  $P_n$ . It is assumed that  $S_{\text{echo}}$  follows a Gaussian distribution and that each spectrum point of  $S_{\text{echo}}$  follows the  $\chi^2$  distribution with 2 degrees of freedom. The frequency bandwidth of the Doppler spectrum is expressed by  $B_s$ . Produced Doppler spectra were integrated, and the Doppler spectrum after the integration (i.e. incoherent integration) is plotted. Therefore, the noise variance over  $B_s$  is smaller than the square of the noise power per Doppler velocity bin ( $p_n^2$ ). The noise variance is one of the principal factors that determine the sensitivity of a WPR receiver. See [6.2.2](#) and [7.3](#) for details of incoherent integration and radar sensitivity, respectively.

In general, it is assumed that  $S_{\text{echo}}$  follows a Gaussian distribution. This assumption is generally applied for the clear-air echo. In this assumption, only the zeroth, first, and second order moments of the echo are taken into account when determining the spectral parameters. This assumption shall be carefully discriminated from the assumption that the received signal is the realization of one or more Gaussian stochastic processes, which include those in both radio wave scattering and of course, uncorrelated (white) noise. In the event of deviations from this assumption, higher order moments may be considered. The noise produced in the receiver (receiver noise) can generally be regarded as white noise. For details of the receiver noise, see [6.2.5.4](#).



**Key**

- X Doppler velocity
- Y intensity

**NOTE**

- For the definition of the symbols which are not listed in the keys, see text.
- The thin solid curve is an example of a Doppler spectrum which contains the Doppler spectrum of  $S_{\text{echo}}$  and the white noise. The thick solid curve is the sum of  $P_n$  and the idealized  $S_{\text{echo}}$  which follows a Gaussian distribution and does not have perturbation. The idealized  $S_{\text{echo}}$  and  $P_n$  are darkly and lightly shaded, respectively. The power of the idealized  $S_{\text{echo}}$  is denoted by  $P_{\text{echo}}$ .  $f_r$ ,  $\sigma_{\text{std}}$ ,  $\sigma_{3\text{dB}}$ , and the peak intensity of the idealized  $S_{\text{echo}}$  ( $p_k$ ) is indicated by arrows.

**Figure 1 — Example of Doppler spectrum and spectral parameters**

Echo power ( $P_{\text{echo}}$ ),  $V_r$ , and the spectral width are the principal parameters that characterizes the echo. They are referred to as the spectral parameters.  $V_r$  is computed from the mean Doppler frequency shift of the echo ( $f_r$ ).  $P_{\text{echo}}$  and  $f_r$  are also the zeroth and first order moment of  $S_{\text{echo}}$ , respectively. The spectral width defined as the standard deviation ( $\sigma_{\text{std}}$ ) is the square root of the second order moment of  $S_{\text{echo}}$  (see [Figure 1](#)).  $P_{\text{echo}}$ ,  $f_r$ , and  $\sigma_{\text{std}}$  are expressed by [Formula \(1\)](#), [\(2\)](#) and [\(3\)](#):

$$P_{\text{echo}} = \int S_{\text{echo}}(f) df \tag{1}$$

$$f_r = \frac{\int f S_{\text{echo}}(f) df}{\int S_{\text{echo}}(f) df} \tag{2}$$

$$\sigma_{\text{std}} = \sqrt{\frac{\int (f - f_r)^2 S_{\text{echo}}(f) df}{\int S_{\text{echo}}(f) df}} \quad (3)$$

where  $f$  is the Doppler frequency.

The relation between  $f_r$  and  $V_r$  is expressed by [Formula \(4\)](#):

$$V_r \approx -\frac{\lambda}{2} f_r \quad (4)$$

In [Formula \(4\)](#),  $V_r$  is defined to be positive when its direction is away from the antenna. However, when one prefers to use the sign definition of  $V_r$  as that of  $f_r$ ,  $V_r$  can be defined to be positive when its direction is toward the antenna. In any case, the direction of  $V_r$  shall be defined clearly in the design and manufacture of the WPR in order to prevent possible mistakes in the design, manufacture, operation, and maintenance of the WPR. In this document,  $V_r$  is defined to be positive when its direction is away from the antenna.

The spectral width can be also defined as the half-power full width ( $\sigma_{3\text{dB}}$ ) or half-power half width of the echo (i.e.  $\frac{\sigma_{3\text{dB}}}{2}$ ). When  $S_{\text{echo}}$  is assumed to follow a Gaussian distribution,  $\sigma_{3\text{dB}}$  can be calculated by the relation of [Formula \(5\)](#):

$$\sigma_{3\text{dB}} = 2\sqrt{2\ln 2} \sigma_{\text{std}} \quad (5)$$

Because the spectral width can be expressed under the above-mentioned definitions, the definition of the spectral width shall be given explicitly. It shall be noted that the spectral width is not only determined by wind perturbation caused by turbulence, but also contains broadening effects due to the angular and vertical extension of the sample volume<sup>[4]</sup>. Details of the sample volume are described in [7.1.2](#).

In the estimation of the spectral parameters,  $P_n$  is also estimated. SNR is expressed by [Formula \(6\)](#):

$$SNR = \frac{P_{\text{echo}}}{P_n} \quad (6)$$

In the digital signal processing for estimating the spectral parameters and  $P_n$ , the noise power per Doppler velocity bin ( $p_n$ ) is generally used.  $p_n$  is expressed by [Formula \(7\)](#):

$$p_n = P_n \frac{\Delta f}{B_s} \quad (7)$$

where  $\Delta f$  is the frequency resolution of the Doppler spectrum (i.e. interval of the Doppler frequency bins). It is noted that interference from other radio sources that contaminates the received signal has frequency dependency in general. Therefore, contamination due to the radio interference can produce a frequency dependency of the noise. Details of the interference from radio sources are described in [5.2.4](#) and [10.6](#).

When it is assumed that  $S_{\text{echo}}$  follows a Gaussian distribution and SNR is infinite, the estimation error of Doppler velocity or the spectral width,  $\varepsilon_v$ , can be estimated by [Formula \(8\)](#):

$$\varepsilon_v = K_v \left( \frac{\sigma_v}{T_c} \right)^{\frac{1}{2}} \quad (8)$$

where

$K_v$  is the coefficient;

$\sigma_v$  is the spectral width defined as the standard deviation in  $\text{m s}^{-1}$ ;

$T_c$  is the measurement period in s.

When the antenna beam direction is changed after collecting a Doppler spectrum (i.e. after  $N_{\text{pseq}}N_{\text{coh}}N_{\text{data}}$  times transmissions and receptions) or after collecting all of the Doppler spectra used in incoherent integration (i.e. after  $N_{\text{pseq}}N_{\text{coh}}N_{\text{data}}N_{\text{incoh}}$  times transmissions and receptions),  $T_c = T_{\text{IPP}}N_{\text{pseq}}N_{\text{coh}}N_{\text{data}}N_{\text{incoh}}$ . When the antenna beam direction is changed on a pulse-to-pulse basis,  $T_c = T_{\text{IPP}}N_{\text{beam}}N_{\text{pseq}}N_{\text{coh}}N_{\text{data}}N_{\text{incoh}}$ . See 6.2.3.2.5 for details about the timing change of the antenna beam direction.

$K_v$  is defined by Formula (9):

$$K_v = k_{\text{err}} \left( \frac{\lambda}{2} \right)^2 \quad (9)$$

where

$k_{\text{err}}$  is the coefficient;

$\lambda$  is the radar wavelength;

Formulae (8) and (9) are derived from Formulae (13) and (14) in Reference [5], respectively. The value of  $k_{\text{err}}$  (see Reference [5]) is listed in Table 1.

Table 1 — Value of  $k_{\text{err}}$

Parameter	Least square method	Moment method
Doppler velocity	0,63	0,38
Spectral width	0,60	0,24

Error estimations of the spectral parameters when considering SNR is described in 6.3, 6.4, and 6.5 of Reference [2].

## 5.2 Sources of received signals

### 5.2.1 Turbulent scattering and partial reflection

The ability to detect the clear-air echo is the most important characteristic of a WPR. It makes a WPR capable of determining vertically resolved profiles of the wind vector from the measured Doppler shift of the clear-air echo. There are two major mechanisms that produce echoes in clear air: turbulent scattering from atmospheric turbulence and partial reflection from the horizontally stratified atmosphere. Partial reflection is also referred to as Fresnel scattering. Atmospheric turbulence produces perturbation of  $n$ , and perturbations of  $n$  with the scale of half of  $\lambda$  (i.e. Bragg scale) is a source of radio wave scattering in clear air.

**NOTE** The clear-air echo is a return from a radio wave scattering caused by variations of the radio refractive index  $n$ , and does not include scatterings from hard targets in the air (e.g. hydrometeors, insects, birds, and aircrafts).

$n$  in the neutral (i.e. unionized) atmosphere is given by [Formula \(10\)](#):

$$n = 1 + 7,76 \times 10^{-5} \frac{p}{T} + 3,73 \times 10^{-1} \frac{e}{T^2} \quad (10)$$

where

- $p$  is the atmosphere pressure in hPa;
- $T$  is the atmospheric temperature in K;
- $e$  is the partial pressure of water vapour in hPa.

When perturbations of  $n$  is isotropic, turbulent scattering is also isotropic.

The refractive index structure constant  $C_n^2$  is defined as in [Formula \(11\)](#):

$$\overline{[n(r+\delta r) - n(r)]^2} = C_n^2 |\delta r|^{2/3} \quad (11)$$

where  $r$  is an arbitrary position and  $\delta r$  is a small distance between two spaced locations, respectively. Because  $T$  and  $e$  are perturbed by turbulence and  $n$  depends on them,  $C_n^2$  significantly varies due to the atmospheric conditions that determine  $T$  and  $e$  [see [Formula \(10\)](#)].

The frequency of a WPR is generally selected so that turbulent scattering occurs in the inertial sub-range of turbulence. Frequencies between 50 MHz and 3 GHz have generally been used for WPRs.

In the inertial sub-range, the energy cascades from the largest eddies to the smallest ones through an inertial (and inviscid) mechanism. The inertial sub-range exists between the inner scale of turbulence ( $l_0$ ) and the buoyancy length scale ( $L_B$ ).  $l_0$  is the scale for determining the transition region between the viscous and inertial sub-ranges, and  $L_B$  is the scale for determining the transition region between the inertial and buoyancy sub-ranges. In the buoyancy sub-range, the turbulent eddies become flattened and anisotropic. In the viscous sub-range, the smallest eddy is strongly affected by viscosity, and kinetic energy is converted into heat. The transition from the inertial range to the viscous range explains the reason why the maximum attainable height coverage for WPRs decreases towards smaller wavelengths. Viscous subrange is also referred to as dissipative subrange. Long wavelengths (i.e. low frequencies) whose Bragg scale lie in buoyance sub-range and short wavelengths (i.e. high frequencies) whose Bragg scale lie in the viscous sub-range are not preferable from the viewpoint of radar sensitivity. See 3.4.2 and 7.3.3 of Reference [1] for more details of the inertial sub-range.

Horizontally stratified layers having sharp vertical gradients of  $n$  are known to produce partial reflection. The echo intensity from partial reflection shows a strong dependency on the zenith angle. Near zenith it reaches a maximum and decreases rapidly as the zenith angle increases.

The partial reflection coefficient  $\rho$  is given by [Formula \(12\)](#):

$$|\rho|^2 = \frac{1}{4} \left| \int_{-l/2}^{+l/2} \frac{1}{n} \frac{dn}{dz} e^{-j\kappa z} dz \right|^2 \quad (12)$$

where

- $l$  is the thickness of the stratified layer;
- $z$  is the altitude;
- $\kappa$  is the wave number given as  $\kappa = 4\pi/\lambda$ .

See 3.4.3 of Reference [1] for more details of partial reflection. Partial reflection is not observed at the UHF and microwave bands[1].

The intensity of the clear-air echo is determined by the strength of  $n$  perturbation caused by turbulence or by the strength of vertical gradient of  $n$  caused by horizontally stratified layers.

### 5.2.2 Echo in precipitation

Raindrops, hail, snow crystals, ice crystals, and mixed-phase particles in precipitation (precipitation echo) are also sources of echoes. The intensity of the precipitation echo is frequently comparable to that of the clear-air echo for the VHF band and is generally greater than that of the clear-air echo for the UHF band.

If both the precipitation echo and the clear-air echo exist in the Doppler spectrum, the measured Doppler velocity can be a combination of wind (velocity of clear air) and terminal velocity of hydrometeors relative to the ground. In this case, the vertical wind cannot be estimated correctly when both scattering contributions cannot be separated. Nevertheless, the horizontal wind can usually be derived accurately since the horizontal displacement velocity of the rather small hydrometeors is a good proxy for the horizontal wind. WPRs using the UHF band generally measure the horizontal wind velocity at a greater height in precipitation than in clear air.

### 5.2.3 Clutter

Undesired echoes are referred to as clutter. Because clutter contaminates the Doppler spectrum, it can significantly decrease the quality of measurement products obtained by the WPR.

The sources of clutter are as follows:

- Clutter from sources fixed on the ground, referred to as ground clutter: Land, grass, trees on hills and mountains, and high metallic structures (e.g. towers, buildings, and power lines) are the major sources of ground clutter. Ground clutter can be distributed over a wide area. Though the mean Doppler frequency of ground clutter is zero, the oscillation of clutter source can broaden the Doppler spectrum of the ground clutter. Especially when the source of ground clutter is oscillatory (e.g. grass, trees or power lines), the ground clutter peak in the Doppler spectrum can be significantly broadened by a strong surface wind.
- Clutter from rotating objects: Wind turbines and rotating antennas are the major sources. Clutter from them significantly spreads over a wide frequency range of the received Doppler spectrum.
- Clutter from the sea surface, referred to as sea clutter: Because sea clutter is distributed over a wide area, it generally spreads over the received Doppler spectrum both in range and in frequency. The intensity and Doppler spreading of sea clutter is a function of the surface wind.
- Clutter from moving sources on the ground or sea: Vehicles, trains, and ships are the major sources. Clutter from vehicles frequently spreads over a wide frequency range of the Doppler spectrum because road traffic flows in two opposite directions. The location and Doppler velocity of clutter from trains can rapidly vary with time. Clutter from ships overlaps with sea clutter.
- Clutter from flying objects: Aircraft (e.g. airplanes and helicopters), birds, bats, and insects are the major sources, and their flying velocity varies with time. Clutter from an aircraft can significantly spread over the received Doppler spectrum due to its large Doppler velocity and intensity. Clutter from helicopters can also spread over a wide frequency of the received Doppler spectrum because of the high speed of their rotating blades. Birds are also a significant clutter source. Migratory birds can fly at altitudes up to several thousand meters, and they typically fly at night. Intense bird migration episodes can be a significant problem for WPR measurements if this type of clutter is not properly addressed in signal processing. Even then, it can lead to gaps in the wind data. Insects in the air can also be a source of clutter.

Clutter should be carefully taken into account in the design, installation, and digital signal processing. The clutter environment should be examined in the survey of the installation site (see [10.5](#)). A fence designed to attenuate radio waves within the frequency band of the WPR (hereafter referred to as the clutter fence) is a means for mitigating clutter and interference. For details of the clutter fence, see [6.2.3.4](#) and [10.5](#).