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DOPPLER SOUNDING ACOUSTIC RADAR

by

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DOPPLER SOUNDING ACOUSTIC RADAR

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Submitted 27 December 1980

Sounding of the wind speed of the boundary layer atmosphere is very important for studies on problems of atmospheric eddies, atmospheric diffusion and contamination. The tangential shift of wind speed at low altitudes has a direct effect on safe flight of aircraft. Since the 1970s, Doppler sounding acoustic radar has been rapidly developed and extensively applied. On the foundation of acoustic radar sounding of temperature [1], the authors attained preliminary results in developing the Dopper sounding acoustic radar; the sounding altitude of vertical wind speed may attain 500 to 600 meters. Besides, dual point Doppler sounding acoustic radar has also been used to conduct measurements of horizontal wind speed and wind direction.

I. Fundamental Principle

By using an acoustic radar vertically transmitting through the atmosphere an acoustic pulse of fixed frequency, a Doppler effect causes wind function in the atmosphere. A frequency deviation is produced between the echo frequency (received by the radar) and transmission frequency; the magnitude of the frequency deviation is related to the wind speed. Beran et al. [2] used for the first time the single point radar for sounding the vertical wind velocity. Later, quite a few researchers applied the Doppler acoustic method to conduct measurement of vectors of overall wind speed.

The fundamental principle of acoustic radar is shown in Fig. 1a. An acoustic pulse of frequency f_o is transmitted from point A. At point O, the pulse meets a scattering body moving with wind speed V; due to the Doppler effect, the frequency is f_s received at point B with frequency difference $\Delta f = f_s - f_o$. In Fig. 1, K_o is the wave vector of the transmitted acoustic wave; and K_s is the wave vector of the scattering acoustic wave. The Doppler frequency deviation can be expressed as

$$\Delta f = \frac{1}{2\pi}(K_s - K_o) \cdot V, \qquad (1)$$

V is the vector of the wind speed. We can deduce from Eq. (1)

$$\Delta f \simeq \frac{2V}{\lambda_0}\sin\left(\frac{\alpha}{2}\right)\cos\beta, \qquad (2)$$

α is the angle of scattering; β is the included angle between V and $K_s - K_o$; $\lambda_o = (c)/f_o$ is the wavelength of the transmitting acoustic wave; and c is the sound velocity. Then

$$V\cos\beta = \frac{c}{2\sin\left(\frac{\alpha}{2}\right)}\left(\frac{\Delta f}{f_0}\right), \qquad (3)$$

In Eq. (3), $V\cos\beta$ is the wind speed component at direction $K_s - K_o$.

Figure 1b is a diagram showing the principle of measuring the vertical wind-speed vector. Point A is an antenna for vertical transmission and reception; B and C are transmission antennas with dip angles, respectively, at θ_B and θ_C (also called the reception antenna); point O shows a scattering body moving with wind speed ($\angle CAB = 90°$); α is the scattering angle; similar to Eq. (3), V_{qC} and V_{qB} are the respective components of the Doppler wind speed at directions q_C and q_B. We assume that the antenna dip angle $\theta_B = \theta_C = \theta$, and also that the vertical wind speed can be neglected compared with the horizontal wind speed. Therefore, we can obtain

$$\begin{cases} V_x = \dfrac{c}{\cos\theta}\dfrac{\Delta f_C}{f_{0C}}, \\ V_y = \dfrac{c}{\cos\theta}\dfrac{\Delta f_B}{f_{0B}}, \\ V_z = -\dfrac{c}{2}\dfrac{\Delta f_A}{f_{0A}}, \end{cases} \qquad (4)$$

In the equations, V_x, V_y and V_z are, respectively, components of the wind speed vector V at x, y and z coordinate axes. The horizontal wind speed V_h can be written as

$$V_h^2 = V_x^2 + V_y^2, \qquad (5)$$

The wind direction can be determined from the ratio between V_x and V_y, and the positive or negative sign of the Doppler frequency deviation.

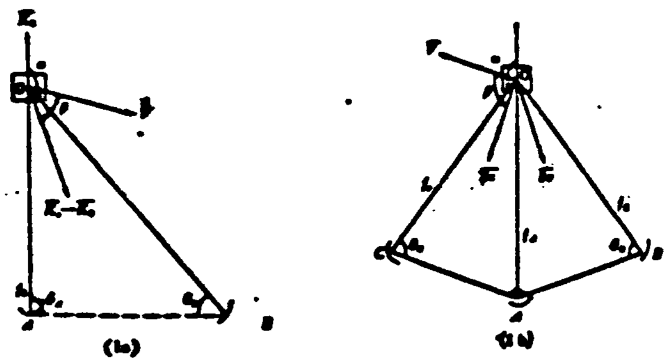

Fig. 1. Diagram showing principle of Doppler acoustic radar sounding of wind speed.

II. General Description of Doppler Acoustic Radar Wing Sounding System

The Doppler wind sounding acoustic radar is composed of four parts: an antenna, a transmitter, a receiver, and data processing. Table 1 lists the major technical parameters of Doppler wind sounding acoustic radar.

Table 1. Major parameters of wind sounding acoutic radar.

(a) [illegible]	2000 [illegible] (f)	(k) [illegible]	4 [illegible] (o)
(b) [illegible]	100 [illegible] ([illegible]) (g)	(l) [illegible]	±100 [illegible] (f)
(c) [illegible]	3.0 [illegible] (h)	(m) [illegible]	15 [illegible] (f)
(d) [illegible]	7° ([illegible]) (i)	(n) [illegible]	80 [illegible] (j)
(e) [illegible]	100 [illegible] (j)		

Key: (a) Transmission frequency; (b) Transmission power; (c) Diameter of antenna; (d) Orientation of transmission beam of antenna; (e) Pulse width; (f) Hertz; (g) Watts (electric power); (h) Meters; (i) Half power point; (j) Milliseconds; (k) Repetition frequency of pulse; (l) Tracking range of locked phase ring; (m) Width of noise band of locked phase ring; (n) Capture time of locked phase ring; (o) Seconds.

The diameter of the parabolic antenna (for vertical transmission and reception) is 3.0 meters and its focal length is 60 centimeters. When horizontal wind speed is measured, antennas of lateral-direction transmission are placed at points B and C.

The transmitter is composed of a quartz crystal oscillator, a frequency divider, a carrier frequency producer, a transmitter gate-controlled producer, a power amplifier, and an antenna switch. The hour-and-minute system is used to measure the horizontal wind speed. According to the predetermined work program, the antenna switch controls transmission in rotation of three points (A, B and C) with frequency at 2000 Hertz.

The receiver is composed of a preamplifier, a selective amplifier, a selective frequency amplifier, an automatic increment controller and a locked phase ring. The authors used the locked phase frequency measurement method to accurately measure the value of the frequency deviation.

The value of the Doppler frequency deviation is obtained by measuring the beat frequencies of two crystal oscillations. Before data processing, there is a pre-processing gate. Only after the locked-phase ring locks, is the beat signal output then transmitted.

In the data processing part, there is input into a recorder by a certain logic program for sampling command, altitude marking, antenna sequence number, and standard time. The sampling command controls a frequency meter for sampling at definite time and definite point to send output and obtain a printout on the value of frequency deviation. The time interval of the printout is 0.5 second.

III. Preliminary Analysis of Observation Results

The observation experiments using the Doppler wind sounding acoustic radar were conducted near a 320-meter meteorological observation tower in Beijing's north suburb. During sunny days with convection conditions from July to November of 1980, several measurements of vertical and horizontal wind speeds were conducted by using the Doppler wind sounding acoustic radar; a comparison was made with the data obtained by direct observation instruments installed on the tower.

Figure 2 is a time-altitude profile diagram of vertical wind speed from 1216 to 1235 hours on 28 October 1980. The ascending and descending air-flow zones can be clearly seen from Fig. 2 This is consistent with the general development rule of heat convection.

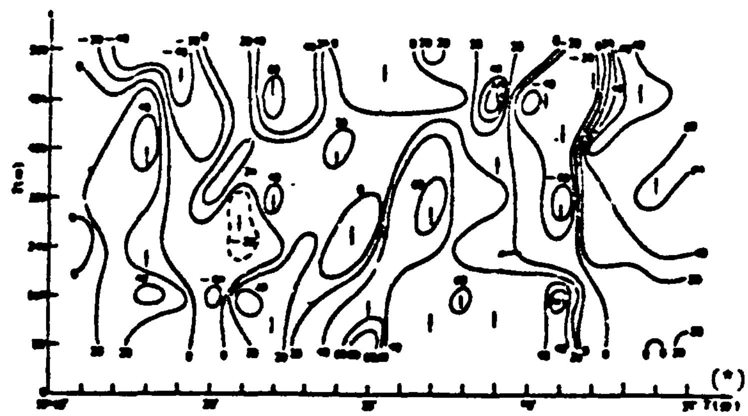

Fig. 2. Time-altitude profile diagram of vertical wind speed (from 1216 to 1235 hours on 28 October 1980): Unit of vertical wind speed: cm/sec.
Key: (*) Minutes.

The authors obtained continuous observation data of vertical wind speed by using the Doppler wind sounding acoustic radar; the vertical wind speed spectrum was calculated and the distribution of the vertical wind speed spectrum with altitude (diagram not included) was plotted. In distribution of the vertical wind speed spectrum, there is a peak value frequency of the energy spectrum, which mainly reflects the convection motion in the boundary layer atmosphere. In the convection boundary layer, this peak value frequency moves toward the direction of low frequency with increase of altitude; this is consistent with the authors' analysis results [3] in the past. Some researchers like Neff et al. [4] and Asimakopoulos [5] also analyzed the vertical wind speed measured with acoustic radar; some of their results are similar to results obtained by the authors; however, the non-Chinese researchers did not present the variation of energy spectrum with altitude.

In addition, like the arrangement in Fig. 1b, a lateral-direction transmission antenna was installed at 175 meters to the east and north of the vertical transmission and reception antennas. Through an antenna switch, transmission was done every four seconds in rotation toward three points (vertical, eastward and northward). The antenna for vertical transmission is 250 meters from the iron tower. Sometime transmissions were done in rotation with two eastward transmissions and two northward but without transmission at the vertical direction with time interval of sampling at 0.5 second. According to the horizontal distance and sampling time between the vertical and inclined antennas, wind speeds and wind directions can be obtained at two altitudes, 125 and 225 meters. Figure 3 shows the time variation curves of wind speed and wind direction measured by acoustic radar from 1027 to 1057 hours on 24 November 1980, and directly measured with a cup anemometer and a wind vane installed on the tower. Table 2 presents the comparison data of wind speed and wind direction of acoustic radar sounding and direct measurement. It is apparent from the aforementioned comparison results that the average wind speeds and wind directions are quite close using these two methods.

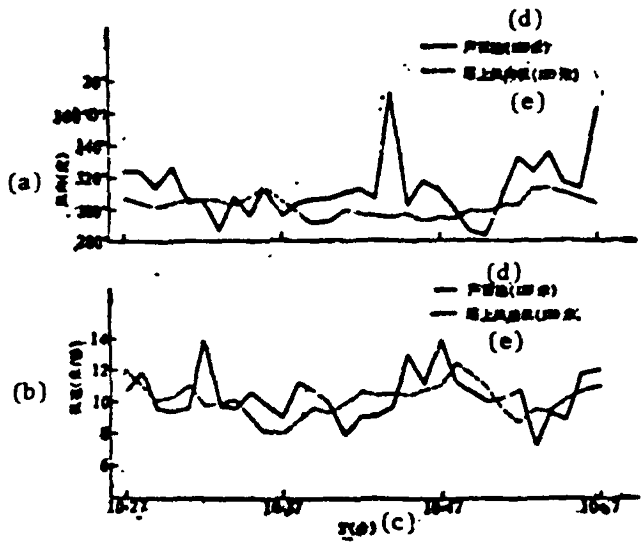

Fig. 3. Time variation diagrams of horizontal wind speed and wind direction (24 November 1980).
Key: (a) Wind direction (degree); (b) Wind speed (meters per second); (c) Minutes; (d) Acoustic radar (125-meter altitude); (e) Anemometer installed on the tower (125-meter altitude).

Table 2. Comparison of wind speed and wind direction using acoustic radar and direct measurement.

(a) [illegible]	(b) [illegible]	(c) [illegible]	(d) [illegible]	(e) [illegible]	(f) [illegible]
(g) [illegible]	125	10.2	2.36	315°	22.3°
[illegible] (h)	120	10.1	1.00	303°	5.7°
(g) [illegible]	125	12.6	2.91	344°	20.3°
[illegible] (h)	120	11.6	0.79	303°	4.1°

Key: (a) Measurement instrument; (b) Altitude (meters); (c) Average wind speed (meters per second); (d) Square difference of wind speed (meters per second); (e) Wind direction; (f) Square difference of wind direction; (g) Acoustic radar; (h) Wind vane and anemometer.

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