3.2 Wind direction / wind velocity

The direction from which air moves to is called the wind direction, and the distance air moves per unit time is the wind velocity. Wind has to be measured not only as a scalar quantity but also as a vector quantity by taking both the magnitude and direction into account. Surface wind is generally measured as a horizontal flow of atmosphere, as the vertical component is insignificant compared with the horizontal component.

Types of instruments

(1) Wind vanes

The most commonly used instrument for measuring wind direction is the weathercock vane. Two- or three-axis ultrasonic anemometers are now used in some cases.

(2) Anemometers

There are various types of anemometers. These differ by measuring method. The main types are shown below.

Cup anemometer

The cup anemometer, invented by Robinson in 1850, is called the Robinson anemometer. It consists of hemispherical or conical cups and a vertical shaft. Originally it was designed with four cups and a long radius of rotation to gain as much torque as possible. Because of its poor performance, however, the four-cup anemometer was redesigned. For greater efficiency, it was made smaller and more lightweight by reducing the number of cups to three and by shortening the arms. As the cup anemometer has the advantage of being turned regardless of the horizontal direction in which air flows past the cups, it is widely used for determining the average wind velocity. With regard to the wind velocity at which the cups start rotating, the lower it is, the better.   Attention should be paid to excessive rotation due to the inertia of the cups in motion.

Windmill anemometers

Unlike the cup anemometer, which has a vertical axis of rotation, this propeller anemometer has a horizontal axis of rotation that makes the propeller anemometer capable of measuring the wind velocity in the direction parallel to the axis of rotation. Most are integrated with a wind vane so that the instrument always faces windward.

Ultrasonic anemometers

Ultrasonic anemometers measure wind velocity based on the time of flight of sonic pulses between pairs of transducers which face each other. Sound waves that are emitted in the same direction as the wind are faster than those emitted against the wind; therefore, there is difference in the travel time of sound waves between receivers. The difference in travel time is proportional to wind velocity, so the wind velocity can be determined by measuring the time difference electrically. Unlike cup anemometers or windmill anemometers, this type does not suffer from the inertia of wind catchers and it is well suited to the observation of wind velocity fluctuations in a short time span. (See Section 2.1 "Ultrasonic anemometer thermometers (SATs)" for details.) Those with a higher resolution of wind velocity (approx. 0.01 ms^{-1}) have come to be available at reasonable prices.

Hot-wire anemometers

In this instrument, a wire is electrically heated while exposed to the ambient atmosphere. Based on the temperature equilibrium between wire heating and wind cooling, the wind velocity is calculated. Although the instrument has high sensitivity at low wind velocities, it cannot be used where rain and snow strike the heating wire and it cannot afford continuous long-time measurement. Therefore, it is mostly used in indoor wind tunnel tests.

Measuring method

Below an altitude of approximately 50 m, which is within the surface boundary layer, the profile of horizontal wind velocity tends to be logarithmic and vertical transport is approximately constant with height. In the surface boundary layer or the canopy layer, where substances and energy are directly exchanged, the wind velocity distribution is complex. For this reason, representative values of wind velocity for a given observation point need to be measured above the canopy layer.

Weather stations carry out regular observations in flat, open spaces that are unobstructed by obstacles such as buildings and trees. The measuring height specified by the World Meteorological Organization is 10m above ground. Japan's Automated Meteorological Data Acquisition System (AMeDAS) conducts observations at 6m above ground.

If research measurement is carried out from a tower, it is desirable to install the instrument as far away from the tower as possible, with the help of devices such as arms in order to avoid having the tower affect the measurements. The tower's effects can be minimized by projecting the instrument in the prevailing wind direction (Photo 3.2-1). When a measurement box is installed in the tower, it should be placed at a different elevation from that of the
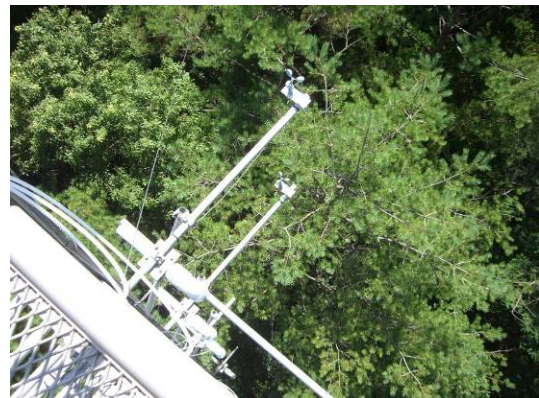

Photo 3.2-1 Installed anemometer. (Fujiyoshida forest meteorology research site)

anemometer, to minimize its influence.

By observing the wind velocity in a vertical profile with anemometers placed at four or five elevation points above the forest canopy, the friction speed can be calculated. In this case, as the profile of wind velocity above the canopy tends to be logarithmic, anemometers should be placed more densely as one moves toward the lower heights, to obtain a logarithmic profile of wind velocity with height.

Anemometers of cup type and windmill type contain moving parts. Such anemometers need to be cleaned and lubricated to maintain smooth rotation for long use. Electromechanical components must be replaced and recalibrated regularly. In cold, snowy regions, attention has to be paid to snow and ice accretion.

In installing a wind vane, it should be noted that true north and magnetic north differ.

💡 Tips!

The difference between geographic (true) north and magnetic north is called magnetic declination, D [°]. The declination differs from place to place and changes over time. The value as of 0:00 on Jan. 1, 2000, is approximated by the following equation (National Astronomical Observatory of Japan, 2005).

$$D_{2000.0} = 7°37.142' + 21.622'\Delta\varphi - 7.672'\Delta\gamma + 0.442'\Delta\varphi^2 - 0.320\Delta\varphi\Delta\gamma + 0.675\Delta\gamma^2$$

$$\Delta\varphi = \varphi - 37°\,\mathrm{N}, \quad \Delta\gamma = \gamma - 138°\,\mathrm{E}$$

where φ: latitude [°], and γ: longitude [°].

Tips 3.2-1

Record of wind velocity / wind direction data

Wind velocity sensors come in two types in terms of the readout, one with pulse counts and the other with voltage. For wind direction measurement, potentiometers that operate on the basis of resistance are commonly used. Most ultrasonic anemometers are capable of producing voltage output of wind velocity measurements for the x and y axes, as well as digital output of wind direction measurements.

Calibration

Anemometers must be checked frequently. To three-cup anemometers, which contain moving parts, pre- and post-observation tests should be given. Ultrasonic anemometers, which have no moving parts, require little maintenance. However, the voltage signal released from ultrasonic anemometers with analog output is likely to include some residual deviation (about 20 ~ 30 mV at a wind velocity of 0 ms^{-1}). As the amount of residual deviation differs between instruments, zero-point output should be confirmed during installation to give a zero-point adjustment to the output voltage values that are acquired.

Where a wind tunnel is available, tests can be undertaken with real wind velocities that are obtained with the help of a Pitot tube, which measures the wind velocity based on the pressure differential inside

and outside the tube (Photo 3.2-2 and Fig. 3.2-1). By the side of the anemometer that is to be calibrated, the Pitot tube is placed such as not to hinder the air flow. While the wind velocity in the tunnel is being varied, comparison and calibration are carried out based on measurements checked at ten or so points. The dynamic pressure (the difference between total pressure and static pressure) measured by the Pitot tube (which is measured beforehand with a differential pressure gauge) and the air density (which changes in response to temperature and therefore should be measured simultaneously with temperature) are input into Bernoulli's equation in order to calculate the wind velocity.

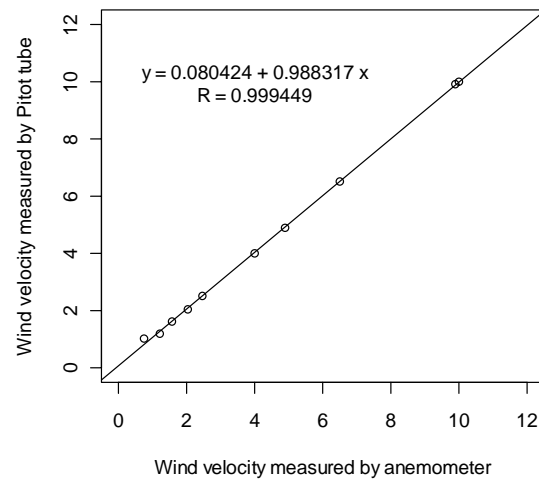Photo 3.2-2 Inspection of an ultrasonic anemometer in a wind tunnel.

Fig. 3.2-1 Wind velocity (real) calculated through the dynamic pressure of the Pitot tube vs. wind velocity given by the tested anemometer.

💡 **Tips!**

Equation to obtain the wind velocity (u [ms^{-1}]) using a Pitot tube (Bernoulli's law):

$$dP = 1/2\ \rho u^2$$

where dP: the difference between total pressure of wind vertical to a Pitot tube hole and static pressure of wind parallel to a Pitot tube hole [Pa] and ρ: air density [kgm^{-3}].

Tips 3.2-2

💡 **Tips!**

With the aim of establishing national standards of low wind velocity, the National Metrology Institute of Japan has constructed an underground tunnel that is unaffected by surrounding conditions, where the accuracy of anemometers at low wind velocities can be tested by mounting them on a car and running the car at low speeds.

Tips 3.2-3

Data processing

(1) Wind direction

Wind direction is the direction from which wind blows. The direction is indicated by cardinal points (e.g., N, NNE), in azimuth degrees from 0° to 360° clockwise from north, or in 16 or 36 points of the compass for which the circumference is divided into 16 or 36 sections (Fig. 3.2-2).
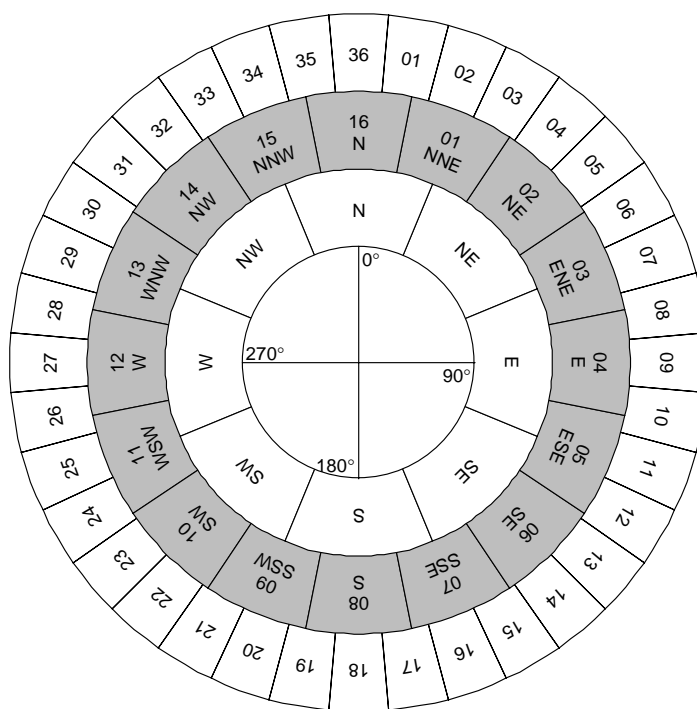

Fig. 3.2-2 Notation of wind direction.

It is desirable to use the average vector as the representative wind direction index. In this case, data of wind direction and wind velocity need to be collected simultaneously. In some cases, the scalar average and the prevailing wind direction within a given time period can be used as the average wind direction. In the case of no wind blowing, the calm value is expressed by "-" or "00".

(2) Wind velocity

Wind velocity can be an instantaneous reading or an average. Unless otherwise specified, the wind velocity is the average of wind velocity measurements for a given period. Regarding instantaneous wind velocity, there is no clear definition of "instantaneous" in terms of seconds, and the observed value differs depending on responsiveness and recording procedure of each anemometer.