CHAPTER 15

OBSERVATION OF CLOUDS

15.1 GENERAL

The observation of clouds and the estimation or measurement of the height of their bases above the Earth's surface are important for many purposes, especially for aviation and other operational applications of meteorology. This chapter describes the methods in widespread use. Important further information is to be found in WMO (1975; 1987), which contain scientific descriptions of clouds and illustrations to aid in the identification of cloud types. Information on the practices specific to aeronautical meteorology is given in WMO (1990).

15.1.1 Definitions

Cloud: An aggregate of very small water droplets, ice crystals, or a mixture of both, with its base above the Earth's surface, which is perceivable from the observation location. The limiting liquid particle diameter is of the order of 200 μm; drops larger than this comprise drizzle or rain.

With the exception of certain rare types (for example, nacreous and noctilucent) and the occasional occurrence of cirrus in the lower stratosphere, clouds are confined to the troposphere. They are formed mainly as the result of the vertical motion of air, in convection, in forced ascent over high ground, or in the large-scale vertical motion associated with depressions and fronts. Clouds may result, in suitable lapse-rate and moisture conditions, from low-level turbulence and from other minor causes.

At temperatures below 0°C, cloud particles frequently consist entirely of water droplets supercooled down to about –10°C in the case of layer clouds and to about –25°C in the case of convective clouds. At temperatures below these very approximate limits and above about –40°C, many clouds are "mixed", with ice crystals predominating in the lower part of the temperature range.

Cloud amount: The amount of sky estimated to be covered by a specified cloud type (partial cloud amount), or by all cloud types (total cloud amount). In either case, the estimate is made to the nearest okta (eighth) and is reported on a scale which is essentially one of the nearest eighth, except that figures 0 and 8 on the scale signify a completely clear and cloudy sky, respectively, with consequent adjustment to other figures near either end of the scale.

Cloud base: The lowest zone in which the obscuration corresponding to a change from clear air or haze to water droplets or ice crystals causes a significant change in the profile of the backscatter extinction coefficient. In the air below the cloud, the particles causing obscuration show some spectral selectivity, while in the cloud itself, there is virtually no selectivity; the difference is due to the different droplet sizes involved. The height of the cloud base is defined as the height above ground level. For an aviation station, the ground (surface) level is defined as the official aerodrome elevation.

Cloud type (classification)*:* Various methods of cloud classification are used, as follows:

(a) In WMO (1975), division is made into cloud genera with 10 basic characteristic forms, with further subdivision, as required, into:
   (i) Cloud species (cloud shape and structure);
   (ii) Cloud varieties (cloud arrangement and transparency);
   (iii) Supplementary features and accessory clouds (for example, incus, mamma, virga, praecipitatio, arcus, tuba, pileus, velum and pannus);
   (iv) Growth of a new cloud genus from a mother-cloud, indicated by the addition of "genitus" to the new cloud and mother-cloud genera – in that order, if a minor part of the mother-cloud is affected – and of "mutatus" if much or all of the mother-cloud is affected, for example, stratocumulus cumulogenitus, or stratus stratocumulomutatus;

(b) A classification is made in terms of the level – high, middle or low – at which the various cloud genera are usually encountered. In temperate regions, the approximate limits are: high, 6–12 km (20 000–40 000 ft); middle, surface–6 km (0–20 000 ft); and low, surface–1.5 km (0–5 000 ft). The high clouds are cirrus, cirrocumulus and cirrostratus; the middle clouds are altocumulus and altostratus (the latter often extending higher) and nimbostratus (usually extending both higher and lower); and the low clouds are stratocumulus, stratus, cumulus and cumulonimbus (the last two often also reaching middle and high levels).

For synoptic purposes, a nine-fold cloud classification is made in each of these three latter divisions of cloud genera, the corresponding codes being designated C_H, C_M and C_L, respectively. The purpose is to report characteristic states of the sky rather than individual cloud types;

(c) Less formal classifications are made as follows:
  (i) In terms of the physical processes of cloud formation, notably into heap clouds and layer clouds (or "sheet clouds");
  (ii) In terms of cloud composition, namely ice-crystal clouds, water-droplet clouds and mixed clouds.

Most of these forms of cloud are illustrated with photographs in WMO (1987).

Vertical visibility: The maximum distance at which an observer can see and identify an object on the same vertical as him/herself, above or below. Vertical visibility can be calculated from the measured extinction profile, $\sigma(h)$, as stated by WMO (2003). The relationship, however, is less simple than for horizontal visibility, because σ may not be regarded as a constant value. Nevertheless, the $I(h=VV)/I_{I0}=5$ per cent rule can be applied. Taking into account this assumption, the vertical visibility can be expressed in a relation with $\sigma(h)$, in which VV is represented intrinsically, i.e.

$$\mathop{\equiv}\limits_{h=0}^{h=VV} \sigma(h)dh = -\ln(5\%) \oplus 3 \qquad (15.1)$$

15.1.2 Units and scales

The unit of measurement of cloud height is the metre or, for some aeronautical applications, the foot. The unit of cloud amount is the okta, which is an eighth of the sky dome covered by cloud, as seen by the observer.

15.1.3 Meteorological requirements

For meteorological purposes, observations are required for cloud amount, cloud type and height of cloud base. For synoptic observations, specific coding requirements are stated in WMO (1995), which is designed to give an optimum description of the cloud conditions from the surface to high levels. From space, observations are made of cloud amount and temperature (from which the height of the cloud top is inferred). Measurements from space can also be used to follow cloud and weather development.

Accuracy requirements have been stated for synoptic, climatological and aeronautical purposes. These requirements are summarized in Part I, Chapter 1, Annex 1.B and with respect to cloud height, are most stringent for aeronautical purposes.

15.1.4 Observation and measurement methods

15.1.4.1 Cloud amount

Most measurements of cloud amount are made by visual observation. Instrumental methods are under development and are used operationally in some applications for estimation of low cloud amount. Estimates of cloud amount in each identified layer and total cloud amount in view of the observation point are made.

The total cloud amount, or total cloud cover, is the fraction of the celestial dome covered by all clouds visible. The assessment of the total amount of cloud, therefore, consists in estimating how much of the total apparent area of the sky is covered with clouds.

The partial cloud amount is the amount of sky covered by each type or layer of clouds as if it were the only cloud type in the sky. The sum of the partial cloud amounts may exceed both the total cloud amount and eight oktas.

The scale for recording the amount of cloud is that given in Code table 2700 in WMO (1995), which is reproduced below:

Code figure		
0	0	0
1	1 okta or less, but not zero	1/10 or less, but not zero
2	2 oktas	2/10–3/10
3	3 oktas	4/10
4	4 oktas	5/10
5	5 oktas	6/10
6	6 oktas	7/10–8/10
7	7 oktas or more, but not 8 oktas	9/10 or more, but not 10/10
8	8 oktas	10/10
9	Sky obscured by fog and/or other meteorological phenomena	
/	Cloud cover is indiscernible for reasons other than fog or other meteorological phenomena, or observation is not made.	

15.1.4.2 Cloud base (height)

The height of the cloud base lends itself to instrumental measurement, which is now widely used at places where cloud height is operationally important. However, the estimation of cloud height by observer is still widespread.

Several types of instruments are in routine operational use, as described in this chapter. An international comparison of several types of instruments was conducted by WMO in 1986, and is reported in WMO (1988). The report contains a useful account of the accuracy of the measurements and the performance of the instruments.

Instrumental measurement of cloud height is widespread and important for aeronautical meteorological services. This is discussed further in Part II, Chapter 2.

15.1.4.3 Cloud type

At present, the only method for observing cloud type is visual. Pictorial guides and coding information are available from many sources, such as WMO (1975; 1987), as well as from publications of National Meteorological Services.

15.2 ESTIMATION AND OBSERVATION OF CLOUD AMOUNT, HEIGHT AND TYPE

15.2.1 Making effective estimations

The site used when estimating cloud variables should be one which commands the widest possible view of the sky, and it should not be affected by fixed lighting which would interfere with observations at night. In making observations at night, it is very important that the observer should allow sufficient time for the eyes to adjust to the darkness.

There are, of course, occasions when it is very difficult to estimate cloud amount, especially at night. The previous observation of cloud development and general knowledge of cloud structure will help the observer to achieve the best possible result. Access to reports from aircraft, if available, can also be of assistance.

15.2.2 Estimation of cloud amount

The observer should give equal emphasis to the areas overhead and those at the lower angular elevations. On occasions when the clouds are very irregularly distributed, it is useful to consider the sky in separate quadrants divided by diameters at right angles to each other. The sum of the estimates for each quadrant is then taken as the total for the whole sky.

Code figure 9 is reported when the sky is invisible owing to fog, falling snow, etc. or when the observer cannot estimate cloud amount owing to darkness or extraneous lighting. During moonless nights, it should usually be possible to estimate the total amount by reference to the proportion of the sky in which the stars are dimmed or completely hidden by clouds, although haze alone may blot out stars near the horizon.

The observer must also estimate the partial cloud amount. There are times, for example, when a higher layer of cloud is partially obscured by lower clouds. In these cases, an estimate of the extent of the upper cloud can be made with comparative assurance in daylight by watching the sky for a short time. Movement of the lower cloud relative to the higher cloud should reveal whether the higher layer is completely covering the sky or has breaks in it.

It should be noted that the estimation of the amount of each different type of cloud is made independently of the estimate of total cloud amount. The sum of separate estimates of partial cloud amounts often exceeds both the total cloud amount, as well as eight eighths.

15.2.3 Estimation of cloud height

At stations not provided with measuring equipment, the values of cloud height can only be estimated. In mountainous areas, the height of any cloud base which is lower than the tops of the hills of the mountains around the station can be estimated by comparison with the heights of well-marked topographical features as given in a contour map of the district. It is useful to have, for permanent display, a diagram detailing the heights and bearings of hills and the landmarks which might be useful in estimating cloud height. Owing to perspective, the cloud may appear to be resting on distant hills, and the observer must not necessarily assume that this reflects the height of the cloud over the observation site. In all circumstances, the observer must use good judgment, taking into consideration the form and general appearance of the cloud.

The range of cloud-base heights above ground level which are applicable to various genera of clouds in temperate regions is given in the table below and refers to a station level of not more than 150 m (500 ft) above mean sea level. For observing sites at substantially greater heights, or for stations on mountains, the height of the base of the low cloud above the stations will often be less than indicated in the tables below.

In other climatic zones, and especially under dry tropical conditions, cloud heights may depart substantially from the given ranges. The differences may introduce problems of cloud classification and increase the difficulty of estimating the height. For instance, when reports on tropical cumulus clouds of an obviously convective origin, with a base well above 2 400 m (8 000 ft) or even as high as 3 600 m (12 000 ft), have been confirmed by aircraft observations. It is noteworthy that, in such cases, surface observers frequently underestimate cloud heights to a very serious degree. These low estimates may be due to two factors, namely either the observer expects the cumulus cloud to be a "low cloud" with its base below 2 000 m (6 500 ft) and usually below 1 500 m (5 000 ft), or the atmospheric conditions and the form of the cloud combine to produce an optical illusion.

When a direct estimate of cloud height is made at night, success depends greatly on the correct identification of the form of the cloud. General meteorological knowledge and close observation of the weather are very important in judging whether a cloud base has remained substantially unchanged or has risen or fallen. A most difficult case, calling for great care and skill, occurs when a sheet of altostratus covers the sky during the evening. Any gradual lowering of such a cloud sheet may be very difficult to detect, but, as it descends, the base is rarely quite uniform and small contrasts can often be discerned on all but the darkest nights.

Cloud-base height genera above ground level in temperate regions

Cloud genera	*Usual range of height of base*[a]		*Wider range of height of base sometimes observed, and other remarks*	
	(m)	*(ft)*	*(m)*	*(ft)*
Low				
Stratus	Surface–600	Surface–2 000	Surface–1 200	Surface–4 000
Stratocumulus	300–1 350	1 000–4 500	300–2 000	1 000–6 500
Cumulus	300–1 500	1 000–5 000	300–2 000	1 000–6 500
Cumulonimbus	600–1 500	2 000–5 000	300–2 000	1 000–6 500
Middle	(km)			
Nimbostratus	Surface–3	Surface–10 000	Nimbostratus is considered a middle cloud for synoptic purposes, although it can extend to other levels	
Altostratus				
Altocumulus	2–6	6 500–20 000	Altostratus may thicken with progressive lowering of the base to become nimbostratus	
High				
Cirrus			Cirrus from dissipating cumulonimbus may occur well below 6 km (20 000 ft) in winter	
Cirrostratus	6–12	20 000–40 000	Cirrostratus may develop into altostratus	
Cirrocumulus				

[a] For stations over 150 m above sea level, the base of low-level clouds will often be less than indicated.

15.3 INSTRUMENTAL MEASUREMENTS OF CLOUD AMOUNT

No completely satisfactory ground-based operational sensors are available to measure total cloud amount. Measurements from space-borne radiometers in the visible band, supplemented by infrared images, can be used to estimate cloud amounts over wide areas, even though difficulties are often experienced, for example, the inability to distinguish between low stratus and fog. Amounts of low cloud within the range of a ceilometer can be estimated by measuring the proportion of elapsed time occupied by well-identified layers and assuming that these time-averaged results are representative of the spatial conditions around the observing site. For synoptic meteorology, this technique is satisfactory in many cases but for airfield observations it can lead to significant errors in the estimation of cloud amount over the airfield. For automatic weather stations in the United States, a "clustering" technique has been developed using data from ceilometers. Other countries, like Sweden (Larsson and Esbjörn, 1995) and the Netherlands (Wauben, 2002), have introduced similar techniques in their operational observations.

15.3.1 The ASOS sky condition algorithm

In the United States National Weather Service's Automated Surface Observing System (ASOS), the cloud height indicator (laser ceilometer — see section 15.7) compiles samples of backscatter return signals every 30 s and determines the height of valid cloud "hits". Every minute, the last 30 min of 30 s data are processed to give double weighting to the last 10 min in order to be more responsive to recent changes in sky condition. The data are then sorted into height "bins".

Each minute, if more than five height bin values have been recorded (during the last 30 min), the cloud heights are clustered into layers using a least-square statistical procedure until there are only five bins remaining (each bin may have many hits in it). These bins, or clusters, are then ordered from lowest to highest height. Following this clustering, the ASOS determines whether clusters can be combined and rounded, depending on height, into meteorologically significant height groups. The resulting bins now are called "layers" and the algorithm selects up to three of these layers to be reported in the METAR/SPECI in accordance with the national cloud layer reporting priority.

The amount of sky cover is determined by adding the total number of hits in each layer and computing the ratio of those hits to the total possible. If there is more than one layer, the hits in the first layer are added to the second (and third) to obtain overall coverage. For reporting purposes, the ASOS-measured cloud amount for each layer is then converted to a statistical function equivalent to a human observation.

The algorithm also tests for total sky obscuration based on criteria of low surface visibility and a high percentage of "unknown hits" at low levels.

A sky condition algorithm has also been developed for use where cloud formation (or advection) typically occurs in (or from) a known location and results in significant concurrent differences in sky conditions over an airport. This meteorological discontinuity algorithm uses input from two cloud-height indicator sensors. The primary sensor is sited near the touchdown zone of the primary instrument runway. The second sensor is typically sited 3 to 6 km (2 to 4 miles) from the primary sensor, upwind in the most likely direction of the advection, or closer to the fixed source of the unique sky condition. The second cloud-height indicator serves to detect operationally significant differences in sky conditions.

Further details on the sky condition algorithm and its verification are provided by NOAA (1988) and the United States Government (1999).

15.4 MEASUREMENT OF CLOUD HEIGHT USING A SEARCHLIGHT

15.4.1 Measurement method

Using this method, illustrated in Figure 15.1, the angle of elevation, E, of a patch of light formed on the base of the cloud by a vertically-directed searchlight beam is measured by an alidade from a distant point. If L is the known horizontal distance in metres (feet) between the searchlight and the place of observation, the height, h, in metres (feet) of the cloud base above the point of observation is given as the following:

$$h = L \tan E \tag{15.2}$$

The optimum distance of separation between the searchlight and the place of observation is about 300 m (1 000 ft). If the distance is much greater than this, then the spot of light may be difficult to see; if it is much less, the accuracy of measuring a height above about 600 m (2 000 ft) suffers. A distance of 250–550 m (800–1 800 ft) is usually acceptable.

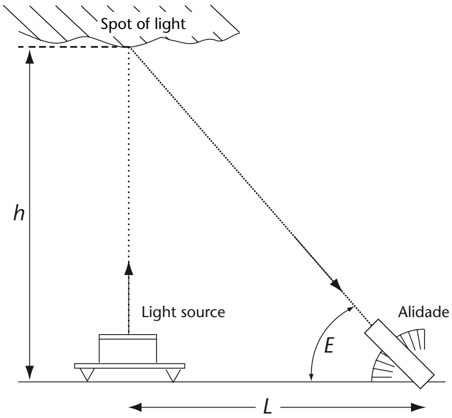

Figure 15.1. Principle of the cloud searchlight method

15.4.2 Exposure and installation

It is desirable to have a clear line of sight between the searchlight and the alidade, both of which should be mounted on firm, stable stands. Where there is a difference in the height above the ground between the searchlight and the alidade, a correction must be incorporated in the calculated heights. If a clear line of sight is not possible, any obstruction between the searchlight beam and the alidade should not be higher than 100 feet.

15.4.3 Sources of error

The largest source of error is due to uncertainty in the measured angle of elevation. Height errors due to small errors of verticality are insignificant.

The absolute error≡Δh in the derived cloud height due to an error ΔE in the measured elevation is given by the following (L is assumed to be an accurately measured constant):

$$\Delta h = L \cdot (1/\cos^2 E) \cdot \Delta E = L \sec^2 E \cdot \Delta E \quad (15.3)$$

with E in radians (1° = π/180 rad). Note that Δh tends to infinity when $E \rightarrow 90°$. If L = 1 000 ft (300 m) and ΔE = 1°, the value of Δh is 17 ft (6 m) when h = 1 000 ft (300 m), and Δh is about 450 ft (140 m) when h = 5 000 ft (1 500 m). The relative error in h is given by:

$$\Delta h/h = 1/(\sin E \cdot \cos E) \cdot \Delta E \quad (15.4)$$

with E in radians. $\Delta h/h$ is minimal when E = 45° (or $h = L$).

15.4.4 Calibration and maintenance

The focusing and verticality of the beam, should, if possible, be checked about once a month because the lamp filament is liable to undergo slight changes in shape with time. When a lamp is replaced, the adjustment for lamp position should be carried out since not all lamps are identical.

The verticality of the beam should be checked during an overcast night with the aid of a theodolite. The check should be made from two positions, one near the alidade and the other at about the same distance away from the searchlight in a direction at right angles to the line joining the searchlight and the alidade (Figure 15.2). The azimuths of the searchlight and of the spot of light on the cloud should be measured as accurately as possible, together with the elevation of the spot of light. If the difference between the azimuth readings is A and the angle of elevation is E, the deviation ϕ of the beam from the vertical is given by:

$$\phi = \arctan(\tan A/\tan E) \approx A/\tan E \quad (15.5)$$
$$(\text{for } A \approx 1° \text{ or less})$$

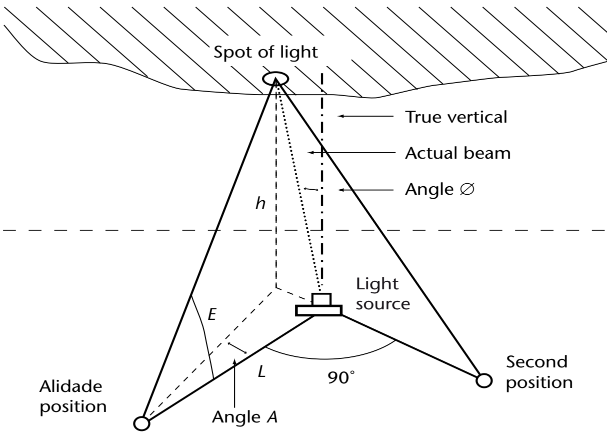

Figure 15.2. Checking the verticality of the searchlight beam

If the value of ϕ is more than 1° when viewed from the alidade, or more than 0.5° in the other position, these adjustments should be repeated until the necessary accuracy is obtained.

Focusing can be checked and adjusted on an overcast night by observing the diameter of the light spot on the highest cloud above the instrument. If necessary, the focus should be adjusted to minimize the spot diameter.

15.5 MEASUREMENT OF CLOUD HEIGHT USING A BALLOON

15.5.1 Measurement method

Cloud height may be measured in daylight by determining the time taken by a small rubber balloon, inflated with hydrogen or helium, to rise from ground level to the base of the cloud. The base of the cloud should be taken as the point at which the balloon appears to enter a misty layer before finally disappearing.

The rate of ascent of the balloon is determined mainly by the free lift of the balloon and can be adjusted by controlling the amount of hydrogen or helium in the balloon. The time of travel between the release of the balloon and its entry into the cloud is measured by means of a stop-watch. If the rate of ascent is n metres per minute and the time of travel is t minutes, the height of the cloud above ground is $n \cdot t$ metres, but this rule must not be strictly followed. Eddies near the launch site may prevent the balloon from rising until some time after it is released. Normally the stop-watch is started on the release of the balloon and, therefore, the elapsed time between when the balloon is released and the moment when it is observed to have left the eddies will need to be subtracted from the total time before determining the cloud height. Apart from eddy effects, the rate of ascent in the lowest 600 m (2 000 ft) or so is very variable.

Although the height of the base of a cloud at middle altitude is sometimes obtained as a by-product of upper wind measurements taken by pilot balloons, the balloon method is mainly applicable to low clouds. Where no optical assistance is available in the form of binoculars, telescope or theodolite, the measurement should not be attempted if the cloud base is judged to be higher than about 900 m (3 000 ft), unless the wind is very light. In strong winds, the balloon may pass beyond the range of unaided vision before it enters the cloud.

Precipitation reduces the rate of ascent of a balloon and measurements of cloud height taken by a pilot balloon should not be attempted in other than light precipitation. This method can be used at night by attaching an electric light to the balloon. For safety reasons, the use of candle lanterns is strongly discouraged.

15.5.2 Sources of error

Measurements of cloud-base taken using a height balloon must be used with caution, since the mean rate of ascent of a balloon, especially in the first few hundred metres, may differ appreciably from the assumed rate of ascent (owing to the effects of vertical currents, the shape of the balloon, precipitation and turbulence).

15.6 ROTATING-BEAM CEILOMETER

15.6.1 Measurement method

The rotating-beam ceilometer (RBC) involves the measurement of the angle of elevation of a light beam scanning in the vertical plane, at the instant at which a proportion of the light scattered by the base of the cloud is received by a photoelectric cell directed vertically upwards at a known distance from the light source (see Figure 15.3). The equipment comprises a transmitter, a receiver and a recording unit.

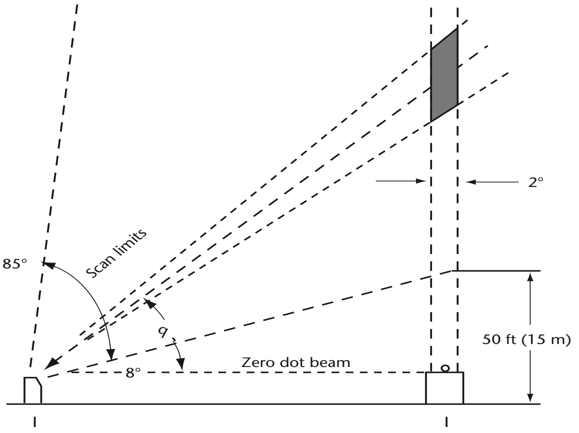

Figure 15.3. A typical rotating-beam ceilometer

The transmitter emits a narrow light beam of a 2° divergence, with most of the emitted radiation on the near infrared wavelengths, i.e. from 1 to 3 μm. Thus, the wavelength used is small in comparison with the size of the water droplets in clouds. The light beam is swept in a vertical arc extending typically from 8 to 85° and is modulated at approximately 1 kHz so that, through the use of phase-sensitive detection methods, the signal-to-noise ratio in the receiver is improved.

The receiving unit comprises a photoelectric cell and an angle-of-view restrictor; the restrictor ensures that only light vertically downwards can reach the photoelectric cell. A pen in the recording unit, moving simultaneously with the transmitter beam, records when a cloud signal is received.

15.6.2 Exposure and installation

The transmitter and receiver should be sited on open, level ground separated by some 100 to 300 m and mounted on firm and stable plinths. It is extremely important that the transmitter scans in the same plane as the receiver. This is achieved by the accurate alignment of the optics and by checking the plane of the transmitter beam in suitable conditions at night.

15.6.3 Sources of error

Errors in the measurement of cloud-base height using an RBC may be due to the following:

(a) Beamwidth;
(b) Optical misalignment;
(c) Mechanical tolerances in moving parts;
(d) Receiver response.

Since in most designs the volume of intersection of the transmitter and receiver cone is very significant with a cloud height above 500 m, beamwidth-induced errors are generally the most serious. The definition of cloud base given in section 15.1.1 is not an adequate basis for the objective design of ceilometers, thus the algorithms in current use are based on experimental results and comparisons with other methods of estimation. Some RBCs use a "threshold" technique to determine the presence of cloud, while others use a "peak" signal detection scheme. In either case, receiver sensitivity will affect reported cloud heights, giving rise to large errors in excess of stated operational requirements in some circumstances (Douglas and Offiler, 1978). These errors generally increase with indicated height.

RBCs are very sensitive to the presence of precipitation. In moderate or heavy precipitation, the instrument can either indicate low cloud erroneously or fail to detect clouds at all. In foggy conditions, the light beam may be dissipated at a low level and the ceilometer can fail to give any useful indication of clouds, even when a low cloud sheet is present.

Comparisons of RBCs and laser ceilometers have been carried out and widely reported (WMO, 1988). These have shown good agreement between the two types of ceilometers at indicated heights up to some 500 m, but the detection efficiency of the RBC in precipitation is markedly inferior.

15.6.4 Calibration and maintenance

The only maintenance normally undertaken by the user is that of cleaning the transmitter and receiver windows and changing the chart. The outside of the plastic windows of the transmitter and receiver should be cleaned at weekly intervals. A soft, dry cloth should be used and care should be taken not to scratch the window. If the transmitter lamp is replaced, the optical alignment must be checked. The transmitter and receiver levelling should be checked and adjusted, as necessary, at intervals of about one year.

15.7 LASER CEILOMETER

15.7.1 Measurement method

With the laser ceilometer, the height of the cloud base is determined by measuring the time taken for a pulse of coherent light to travel from a transmitter to the cloud base and to return to a receiver (principle: light detection and ranging, LIDAR). The output from a laser is directed vertically upwards to where, if there is cloud above the transmitter, the radiation is scattered by the hydrometeors forming the cloud. The major portion of the radiation is scattered upward but some is scattered downward and is focused in the receiver onto a photoelectric detector. The radiant flux backscattered to the receiver decreases with range according to an inverse-square law. The ceilometer (Figure 15.4)

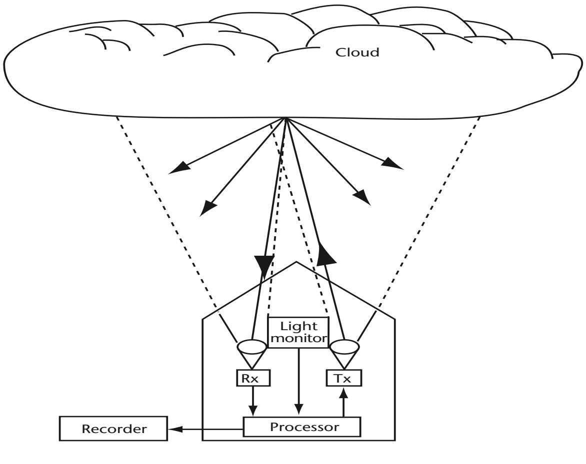

Figure 15.4. Typical laser ceilometer

comprises two units, a transmitter-receiver assembly and a recording unit.

The transmitter and receiver are mounted side by side in a single housing, together with signal detection and processing electronics. The light source is a gallium arsenide semiconductor laser that produces typically 75 W pulses of light of 110 ns duration at a rate of about 1 kHz. The wavelength of the laser radiation is 900 nm. The optics of the transmitter are arranged to place the laser source and receiver detector at the focus of a conventional or Newtonian telescope system. The surfaces of the lens are given a suitable quarter-wavelength coating to reduce reflection and to provide high transmission of light with a 900-nm wavelength. The transmitter aperture is sealed by a glass window, which is anti-reflection, coated on its inner surface and angled at approximately 20° to the horizontal so that rain will run off it.

The receiver is of similar construction to the transmitter except that the light source is replaced by a photodiode and a narrow-band optical filter is incorporated. The filter excludes most of the background diffuse solar radiation, thus improving the detection of the scattered laser radiation by day.

The transmitter beam has a divergence of typically 8 min of arc and the receiver has a field of view of typically 13 min of arc. The transmitter and receiver are mounted side by side so that the transmitter beam and the receiver field of view begin to overlap at about 5 m above the assembly and are fully overlapped at some 300 m.

The housing is provided with thermostatically controlled heaters to prevent condensation from forming on the optical surfaces, and the humidity within the housing is reduced by the use of a desiccator. The top of the housing is fitted with a cover hood incorporating optical baffles that exclude direct sunlight.

The output from the detector is separated by an electronic processing unit into sequential "range gates", each range gate representing the minimum detectable height increment. Each laser firing provides either a "cloud" or a "no-cloud" decision in each range gate; during one scan, the laser is fired many times. A threshold is incorporated so that the probability of the instrument not "seeing" cloud, or "seeing" non-existent cloud, is remote.

Some laser ceilometers provide an estimate of vertical visibility based on the integrated reflected energy within range. Comparisons carried out during the WMO International Ceilometer Intercomparison (WMO, 1988) showed that, on many occasions, values reported were unreliable and that further development of this capability would be necessary before estimates could be used with confidence.

15.7.2 **Exposure and installation**

The unit should be mounted on a firm, level base with a clear view overhead within a cone of approximately 30° about the vertical. If necessary, a rooftop site can be used with suitable adjustment of reported heights to ground level. Although laser ceilometers in operational use are designed to be "eye-safe", care should be taken to prevent the casual observer from looking directly into the transmitted beam.

15.7.3 **Sources of error**

There are three main sources of error as follows:

(a) Ranging errors: These can occur if the main timing oscillator circuits develop faults, but, in normal operation, error due to this source can be neglected;

(b) Verticality of the transmitted/received beams: Provided that the instrument is aligned with the beam at better than 5° from the vertical, errors from this source can be neglected;

(c) Errors due to the signal-processing system: Because a cloud base is generally diffuse and varies greatly in time and distance, complex algorithms have been developed to estimate a representative cloud base from the returned cloud signal. In conditions of fog (with or without cloud above) and during precipitation, serious errors can be generated. Thus, it is important to have knowledge of visibility and precipitation conditions to assess the value of ceilometer information. In conditions of well-defined stratiform cloud (for example, low stratocumulus), measurement errors are controlled solely by the cloud threshold algorithms and can be assumed to be consistent for a particular make of ceilometer.

In operational use and conditions of uniform cloud base, laser ceilometer measurements can be compared routinely with pilot balloon ascents, aircraft measurements and, at night, with cloud searchlight measurements. Intercomparisons of laser ceilometers of different manufacturers have been carried out extensively. During the WMO International Ceilometer Intercomparison (WMO, 1988), for example, several designs of ceilometer were intercompared and comparisons made with RBCs and pilot-balloon observations. Although some early comparisons between RBC and newly developed laser ceilometers indicated that the RBC had a superior performance during moderate rain, the international intercomparison revealed that, using current technology, laser ceilometers provided the most accurate, reliable and efficient means of measuring cloud base from the ground when compared with alternative equipment.

15.7.4 Calibration and maintenance

Most laser ceilometers are provided with built-in capability to monitor transmitted output power and guard against serious timing errors. Calibration checks are normally confined to checking both the master oscillator frequency and stability using external high-quality frequency standards, and the output power of the transmitter. Calibration may also be performed by intercomparison (WMO, 1988). Routine maintenance consists typically of cleaning the exposed optics and external covers, and of replacing air filters when cooling blowers are provided.

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