Chapter 25
Meteorological Measurements and Observations

Why are atmospheric observations necessary? Geophysical and associated meteorological observations, and monitoring of the natural environment, are carried out for various reasons. They are used for the preparation of weather analysis in real time, the forecasts and warnings of natural disasters related to weather, water, and climate. Meteorological measurements and observations are used for the local operational activities that depend on time, such as flight-route operations at airports, construction works, transportation, agricultural activities, health, and others. Meteorological and climate data are important for research on climate and climate change. Meteorology has made significant progress in the quality and diversity of weather forecast services since the launch of the first meteorological satellites in 1957/1958 gave rise to the World Weather Watch (WWW) in 1963. Growing global temperature will cause a rise in sea level and is expected to increase the intensity of extreme weather events and to change the amount and mode of precipitation. But current societal challenges – due to the unfolding impacts of climate change – demand further evolution of the Earth observation network: an upgrading of the global space- and surface-based observing systems (Fig. 25.1) and the adoption of a new and integrated approach that incorporates recent scientific and technical advances.

25.1 Meteorological Observing Systems

The requirements for observational data may be met using:

- In situ measurements
- Remote sensing (including space-borne) systems

The Global Observing System, designed to meet these requirements, is composed of the surface-based subsystem and the space-based subsystem. The surface-based subsystem comprises a wide variety of types of stations according to the

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Fig. 25.1 Liquid-in-glass thermometers

application (e.g. surface synoptic station, upper air station, climatological station, etc.). The space-based subsystem comprises a number of spacecraft's with on-board sounding missions and the associated ground segment for command, control, and data reception.

The representativeness of an observation is the degree to which it accurately describes the value of the variable needed for a specific purpose. For instance, synoptic observations should typically be representative of an area up to 100 km around the station, but for small-scale or local applications, the considered area may have dimensions of 10 km or less. According to Orlanski (1975), horizontal meteorological scales may be classified as follows, with a factor two uncertainty:

(a) **Microscale** (less than 100 m) for agricultural meteorology, for example, evaporation
(b) **Local scale** (100–3 km), for example, air pollution, tornadoes
(c) **Mesoscale** (3–100 km), for example, thunderstorms, sea and mountain breezes
(d) **Large scale** (100–3000 km), for example, fronts, various cyclones, cloud clusters
(e) **Planetary scale** (larger than 3000 km), for example, long upper tropospheric waves

25.2 Basic Meteorological Elements

The present state and the further behaviour of the atmosphere are defined using the basic meteorological elements such as the temperature, pressure, and humidity of the air, wind speed and direction, cloud cover, precipitation, and visibility (the transparency of the atmosphere), as well as soil and surface water temperatures, solar radiation, and longwave terrestrial and atmospheric radiation. They also include weather phenomena such as thunderstorms and snowstorms. The variations in the meteorological elements are the result of atmospheric processes, and they determine the weather and the climate. The meteorological elements are observed at aerological and meteorological (weather) stations and at meteorological observatories by means of aerological and meteorological instruments. The following elements are observed at a station making surface observations:

- Present weather
- Past weather
- Wind direction and speed
- Cloud amount
- Cloud type
- Cloud-base height
- Visibility
- Temperature
- Relative humidity
- Atmospheric pressure
- Precipitation
- Snow cover
- Sunshine and/or solar radiation
- Soil temperature
- Evaporation

When we know these items, others such as dew point, freezing point, and other elements can be defined as "secondary elements". There are instruments for measuring these elements, except for the type of clouds.

25.3 Standardization of Measurements

Many of the elements necessary for synoptic, climatologic, or aeronautical targets can be measured automatically. Observations and measurements of meteorological elements are made in the meteorological and weather stations on certain standardized procedures and methods in order to be consistent, representative, and uniformed (e.g. Brock and Richardson 2001; Emeis, 2010; Harrison, 2015). Each state, through its National Weather Service, establishes and maintains its own national network of stations. Data from these measurements, according to the standards and procedures of the World Meteorological Organization (WMO), are sent on international exchange as a part of the global telecommunications surveillance system. The term "standard" and other similar expressions denote different instruments, methods, and steps used to avoid uncertainties in the measurements. To effectively control the standardization of meteorological instruments of national and international scale, the WMO has adopted a system of national and regional standards. WMO has adopted a system of national and regional standards. Most of the elements required for synoptic, climatological, or aeronautical purposes can be measured by automatic instrumentation. All the instruments should also be carefully calibrated and regularly maintained. Trained observers are required and/or certified by an authorized meteorological service to establish their *competence to make observations* to the required standards. They should have the ability to interpret instructions for the use of instrumental and manual techniques that apply to their own observing systems. Meteorological observing stations are designed so that representative measurements (or observations) can be taken according to the type of station involved.

Siting and exposure. The following considerations apply to the selection of site and instrument exposure requirements for a typical synoptic or climatological station in a regional or national network:

(a) Outdoor instruments should be installed on a level piece of ground, preferably no smaller than 25 m x 25 m where there are many installations.
(b) The ground should be covered with short grass or a surface representative of the locality and surrounded by open fencing or palings to exclude unauthorized persons.
(c) Within the enclosure, a bare patch of ground of about 2 m x 2 m is reserved for observations of the state of the ground and of soil temperature at depths of equal to or less than 20 cm.
(d) There should be no steeply sloping ground in the vicinity, and the site should not be in a hollow.
(e) The site should be well away from trees, buildings, walls, or other obstructions.
(f) Very open sites which are satisfactory for most instruments are unsuitable for rain gauges.
(g) If in the instrument enclosure surroundings, maybe at some distance, objects like trees or buildings obstruct the horizon significantly, alternative viewpoints should be selected for observations of sunshine or radiation.
(h) The position used for observing cloud and visibility should be as open as possible and command the widest possible view of the sky and the surrounding country.
(i) At coastal stations, it is desirable that the station commands a view of the open sea. However, the station should not be too near the edge of a cliff because the wind eddies created by the cliff will affect the wind and precipitation measurements.
(j) Night observations of cloud and visibility are best made from a site unaffected by extraneous lighting.

Symbols, units, and constants. Instrumental measurements produce numerical values. The purpose of these measurements is to obtain physical or meteorological variables representing the state of the local atmosphere. For meteorological practices, instrumental readings are variables, such as "atmospheric pressure", "air temperature", or "wind speed". For meteorological observations, the following units are used:

(a) Atmospheric pressure (p), expressed in hectopascals (hPa)
(b) Temperature (T), expressed in degrees Celsius (°C) or (T) in Kelvin (K)
(c) Wind speed, at the surface and upper level observations, in metre per second (m $s^{-1)}$
(d) Wind direction expressed in degrees clockwise from the north or in the scale (0–36), where 36 is the wind from the north and 09 the east wind (°)
(e) Relative humidity (U), expressed in percent (%)
(f) Precipitation (total amount) expressed in millimetres (mm) or (kg $m^{-2)}$

25.4 Measurement of Air Temperature

The traditional instruments used for measurement of air temperature are called thermometers. Meteorological thermometers commonly in use can be widely classified into following categories based on the physical processes made use of in their design.

Basic standards in measurement. In meteorological practices, the surface air temperature refers to the temperature near Earth's surface at a height of between 1.25 m and 2 m above the ground level. In order for the air temperature to be representative and reliable, it is necessary for the area around the meteorological station to be in free external conditions and a large enough (spacious) area, and it should not be disturbed by some external influences or by the surrounding objects. For agro-meteorological practices, the surface air temperature measurements are generally required to be made at different level near the ground.

Liquid-in-glass thermometers. These are thermometers (see Fig. 25.1) that are based on the principle of the expansion of liquid in a fine bore glass tune to measure temperature. The most broadly used among these are commonly known as "ordinary" thermometers which are employed to measure prevailing atmospheric temperature. Others suitably modified in their design, which are used to indicate extreme temperatures attained during the period they are exposed to the atmosphere, are called as "maximum" or "minimum" thermometers (Fig. 25.2).

Two types of liquid-in-glass thermometers commonly in use are:

(i) Mercury-in-glass thermometers
(ii) Spirit-in-glass thermometers

Liquid-in-glass thermometers. Such thermometers make use of the expansion/contraction of liquid in a scaled metal container to measure air temperature. The variations in pressure in the metal container caused due to the changes in the liquid volume gives a measure of air temperature to which the container is exposed.

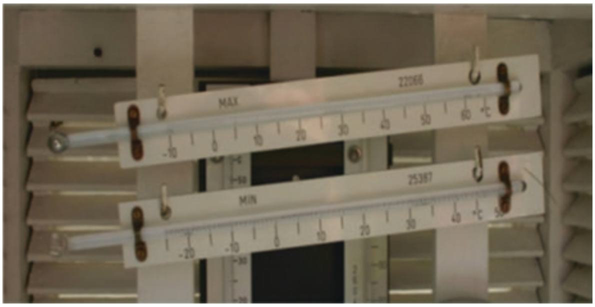

Fig. 25.2 Maximum and minimum thermometers

Mercury in steel and Bourdon tube thermometers fall under this category. These thermometers are essentially a pressure gauge calibrated in terms of temperatures.

Ordinary (station) thermometers. Ordinary (station) thermometers are the most precise instruments of all meteorological thermometers. Usually, such an instrument is a type of glass thermometer filled with mercury.

Maximum thermometers. A maximum thermometer mainly used for measuring air temperature is a mercury-in-glass thermometer having a constriction near the bulb end. It has a small area where the glass tube is narrower on one end. This is known as a “constriction”. As the air temperature rises, the mercury in the thermometer expands and moves freely up the tube (past the constriction) until the maximum temperature occurs. When the air temperature begins to drop, the constriction prevents the mercury from flowing back down the tube. The mercury will not move back down the tube until the thermometer is shaken.

Minimum thermometers. When it comes to minimum thermometers, the most acceptable instrument is the alcohol thermometer. It contains an index of dark glass, submerged in alcohol, with a length of about 2 cm. As part of the air remains in the tube of alcohol thermometer, it should provide a protective chamber in the upper end, which should be long enough to allow the instrument to withstand a temperature of about −50 °C without being destroyed.

Ground thermometers. For measuring the temperature of the ground, at depths of 20 cm or less, mercury thermometers with glass are used. The body of this kind of thermometer is curved, with dust, or other suitable angle, below the lowest scale. The tube of the thermometer is placed in the ground at the desired depth, but the scale is read directly from the thermometer (Fig. 25.3).

Mechanical thermograph. Mechanical thermograph which is used daily works on sensors or bimetal Burdon’s tube because they are relatively cheap, reliable, and flexible. However, mechanical thermometers are not suitable for remote or electronic recording of air temperature.

Bimetallic thermometers. These thermometers use a bimetallic strip/coil as a temperature-sensing element. The change in the curvature of the strip/coil, with changes in temperature, gives a measure of air temperature. At the bimetal thermograph, movement of registered pen (marker) is controlled by the change in the curve of bimetal spring or bar, which is firmly fixed on the shoulder which is set on the

Fig. 25.3 Ground thermometers

frame. To be able to change the zero of the instruments, it is a tool for fine-tuning of the shoulder.

Thermograph with Burdon's tube. The basic composition of the thermographs with a Burdon's tube is like bimetal thermograph, except that its temperature-sensitive element is in the form of a curved metal tube with a flat, elliptical section filled with alcohol. Burdon tube is less sensitive than bimetal element and usually requires a mechanism of multiplication to obtain enough scale value. The typical time constant is about 6 m, the air speed of (5 cm s^{-1}).

Electrical thermometers. This type of thermometer (Fig. 25.4) makes use of the electrical characteristics of the sensing device that generates an output signal which varies with changes in temperature. Electrical instruments for measuring air temperature are widely used in meteorology. Their principle of operation is essentially based on their ability to provide an external signal that is suitable for use in remote indication, labelling, preservation, or transmission of temperature data. Commonly used sensors are electrical resistance elements, semi-conductive thermometers (thermostats) and thermopares.

The two main types of thermometers under this category are the platinum resistance thermometer and thermistor thermometer.

Electrical resistance thermometers. This type of thermometers shown in Fig. 25.5 uses the principle of measuring the electrical resistance of the material. The manner in which the electrical resistance of a particular material changes is known in physics. Here, the representation of the temperature can be used to change the resistance. Here, the representation of the temperature can be used to change the resistance. For small temperature changes, the increase in the resistance of pure metal is proportional to the change of temperature, as given by (Eq. 25.1):

$$R_T = R_0\left[1+\alpha\left(T-T_0\right)\right] \tag{25.1}$$

Fig. 25.4 Electrical thermometer. Credit: Harke/ CC BY-SA (https://creativecommons.org/licenses/by-sa/3.0)

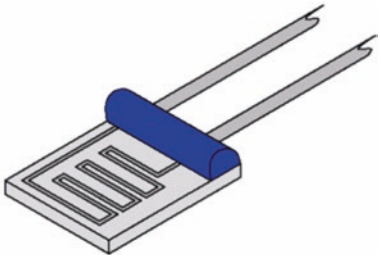

Fig. 25.5 Electrical resistance temperature

where $(T - T_0)$ is the temperature difference, R_T – resistance of a fixed amount of metal at temperature T, R_0 –resistance at reference temperature T_0 and is the temperature coefficient of resistance near $T_{0.}$

*Semi-conductive thermometers. These are a*nother type of resistive element that is widely used in thermostats. As it is shown in Fig. 25.6a, it has a semiconductor with a relatively large temperature coefficient of resistance, which can be either positive or negative depending on this material. Stalactites mixtures of metal oxides are suitable for making practical thermostats which usually have the form of small discs or spheres and are often glassy. Typical thermostats have a resistance which changes by a factor of 100 or 200 in the temperature range - 40 to 40 °C.

Thermocouples. These thermometers (Fig. 25.6b) use the principle of establishing the contact of electromotor force is used, on the place where two different metals touch. If you make a simple circle with two metals and by merging the same temperature, then there will be resultant electromotor force in the circle, because of the contact between the two metals, and the electromotor force will be reversed and the connection interrupts. If the temperature of one junction is changing, both electromotor forces will be more in balance, then we will have a total electromotor force

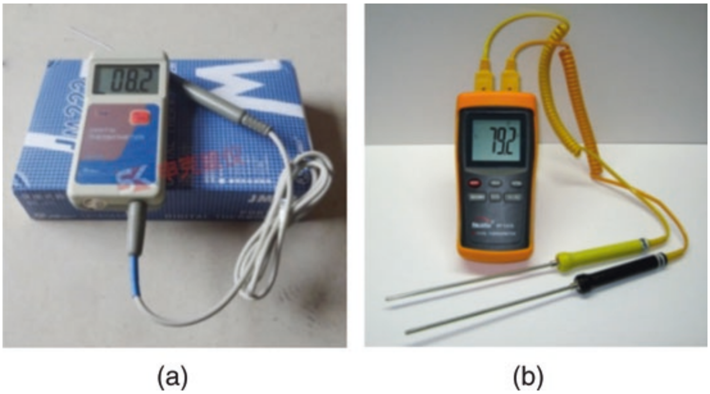

Fig. 25.6 (**a**) Semi-conductive thermometer; (**b**) thermocouple

set up in the circle, and then the electricity will flow. The physical principle used for the construction of thermometers is known as thermocouples.

25.5 Measurement of Atmospheric Pressure

For meteorological purposes, atmospheric pressure is generally measured with electronic barometers, mercury barometers, aneroid barometers, or hypsometers. The latter class of instruments, which depends on the relationship between the boiling point of a liquid and the atmospheric pressure, has so far seen only limited application and will not be discussed in depth in this publication. In standard use for measuring, atmospheric pressure instruments called barometers are common. There are several standard types of barometers: mercury, electrical, and metal.

Mercury barometers. There is a growing trend of gradual disposal of the use of mercury barometers (Fig. 25.7), because it is highly toxic; free mercury is corrosive to the aluminium alloys used in air frames (for these reasons there are specific regulations in some countries that proscribe handling or carriage of mercury barometers). The barometer is very delicate and difficult to transport.

The instrument must be read and corrections to be applied manually. Also available are other types of sensors for pressure, with equivalent accuracy and stability with the electronic reader.

Electronic barometers. Most of the recently designed barometers use electronic assemblies that transform into electric sensor response magnitude associated with the pressure in the form of analogy or digital signals. Analogy signals can be shown in different electronic metres. Monitors and systems for collecting data, such as those used in automatic weather stations, are often used to display digital outputs or analogy to digital outputs. The barometer with current digital technology uses

Fig. 25.7 A mercury barometer

different modules in order to improve long-term stability and accuracy of measurements.

Bourdon tube barometers. Bourdon tube barometers usually consist of a sensor element that, as for an aneroid capsule, changes its shape under the influence of pressure changes (pressure transducers) and a transducer that transforms the changes into a form directly usable by the observer. The display may be remote from the sensor. Precise and stable digital instruments with quartz Bourdon tubes are used as working reference barometers in calibration laboratories.

Aneroid barometers. The advantages of conventional barometers regarding mercury barometers are their compactness and portability, which makes them especially suitable for use at sea and in the field. The main components of the metal barometer shown in (Fig. 25.8a) are closed metal chamber, completely or partially vacant, and strong elastic system which protects the chamber from destruction under the influence of external atmospheric pressure. At any given pressure, there is a balance between the force caused by spring and that by external pressure. Steel chamber can be made of materials (steel or beryllium copper) that have elastic properties as a result of which the chamber can act as a spring itself.

Tools are needed to detect and display changes in the deviation that occurs. This can be a system of levers which are intensified deviations and moving the cursor over the scale graduated to indicate pressure. Alternatively, the light beam can be removed over the scale. Instead of these mechanical analogue techniques, certain barometers are equipped with a manual operating micrometre counter which indicates the pressure directly in the tens of hectopascals. The reading takes place when

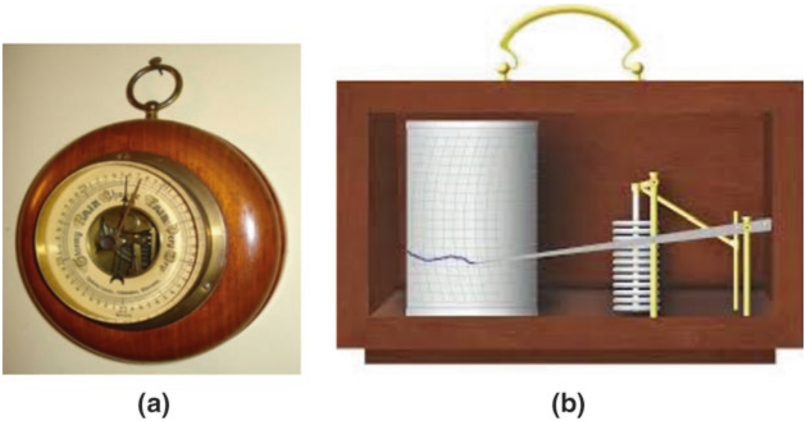

Fig. 25.8 (**a**) Aneroid barometer; (**b**) barograph

the luminescent indicator signals that micrometre only contacted metal. This type of metal is movable and robust.

Barographs. Barographs represent an aneroid barometer used for continuous recording of the changes in atmospheric pressure over time (Fig. 25.8b). It is a recording aneroid barometer. The reading of the barometric pressure over time is produced on a paper or a foil chart, which is known as barograms. The working of the barograph is very scientific, and it indicates the atmospheric pressure. The output is presented through a continuous graph on paper or foils. The barograph has a metal cylinder, which is linked with a pen arm. The pen arm is directly proportional to the changing atmospheric pressure that enables the meteorologists to study the forthcoming climate. Pressure versus weather is traced by the pen and is recorded on the chart, which is rotated by clockwork. The barograph is used both on the ships as well as on the land. Today they come in various shapes and sizes from small ones to very large ones. To give it a fancy look, the barographs even come in glass boxes. The drawer below collects the barograms. The barograph generally provides a reading for a week. For synoptic purposes they have the following characteristics:

(a) Graduation in (hPa)
(b) Readability up to (0.1 hPa)
(c) Measurement factor (10 hPa) in (1.5 cm) of the bar

25.6 Measurement of Air Humidity

The measurement of atmospheric humidity, and often its continuous recording, is an important requirement in most areas of meteorological activity. This chapter deals with the measurement of humidity at or near the Earth's surface. There are different methods for measuring the humidity of the air. Humidity of air can be expressed in several ways:

- Relative humidity
- Absolute humidity
- Water mixing ratio
- Water vapour

All these definitions of humidity can be set with the same instruments; only the procedure for obtaining a value from another course is different. Relative humidity is a relation between the current amount of water vapour in the air and the maximum amount which that same air may receive, not reaching saturation. Relative humidity is expressed in (%).

Hygrometer. Any instrument for measuring humidity is known as a hygrometer. The physical principles most widely employed for hygrometry are:

(i) The gravimetric method
(ii) Condensation method
(iii) The psychrometric method
(iv) Sorption method

The gravimetric method. This method uses the absorption of water vapour by a desiccant from a known volume of air (gravimetric hygrometer. The gravimetric method yields an absolute measure of the water vapour content of an air sample in terms of its humidity mixing ratio. This is obtained by first removing the water vapour from the sample. The mass of the water vapour is determined by weighing the drying agent before and after absorbing the vapour. The mass of the dry sample is determined either by weighing or by measuring its volume.

Condensation method. The first type is chilled mirror method (dew point or frost-point hygrometer). The basic principle is when moist air at temperature T, pressure p, and mixing ratio r_w (or r_i) is cooled, it eventually reaches its saturation point with respect to water (or to ice at lower temperatures) and a deposit of dew (or frost) can be detected on a solid non-hygroscopic surface.

Other type is heated salt solution method (vapour equilibrium hygrometer, known as the dew cell). The equilibrium vapour pressure at the surface of a saturated salt solution is less than that for a similar surface of pure water at the same temperature. The temperature of the solution at which the ambient vapour pressure is reached provides a measure of the ambient vapour pressure. For this purpose, a thermometer is placed in good thermal contact with the solution.

The psychrometric method. The psychrometer consists essentially of two thermometers exposed side by side, with the surface of the sensing element of one being covered by a thin film of water or ice and termed the wet or ice bulb, as appropriate. The sensing element of the second thermometer is simply exposed to the air and is termed the dry bulb. This is the most widely used method and is described in detail.

Sorption methods. Certain materials interact with water vapour and undergo a change in a chemical or physical property that is sufficiently reversible for use as a sensor of ambient humidity.

The psychrometer. In order to determine air temperature and humidity, a psychomotor is used (Fig. 25.10a). It consists of two thermometers, one of which (the dry

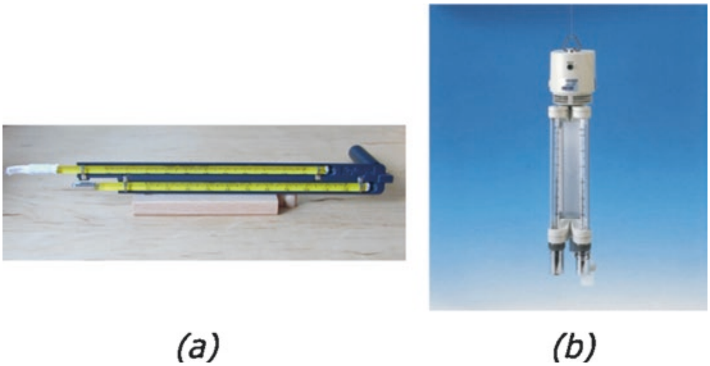

Fig. 25.9 (**a**) The psychrometer; (**b**) the Assmann aspirated psychrometer

bulb) is an ordinary glass thermometer, while the other (wet bulb) has its bulb covered with a jacket of clean muslin which is saturated with distilled water prior to an observation. The less moisture in the air, the stronger the evaporation, so the difference between damp and dry thermometer is greater. From these two readings of the thermometers from the table or by calculating the formulas, all the above forms of humidity and dew point are given.

The Assmann aspirated psychrometer. The Assmann aspirated psychrometer is composed of two glass mercury thermometers mounted vertically (Fig. 25.9b). The aspirator may be driven by a spring or an electric motor. One thermometer bulb has a well-fitted muslin wick which, before use, is moistened with distilled water. Each thermometer is located inside a pair of coaxial metal tubes, highly polished inside and out, which screen the bulbs from external thermal radiation. The tubes are all thermally insulated from each other.

Screen psychrometer. Two mercury-in-glass thermometers are mounted vertically in a thermometer screen. The diameter of the sensing bulbs should be about 10 mm. One of the bulbs is fitted with a wet-bulb sleeve, which should fit closely to the bulb and extend at least 20 mm up the stem beyond it. If a wick and water reservoir are used to keep the wet-bulb sleeve in a moist condition, the reservoir should preferably be placed to the side of the thermometer and with the mouth at the same level as, or slightly lower than, the top of the thermometer bulb. The wick should be kept as straight as possible, and its length should be such that water reaches the bulb with sensibly the wet-bulb temperature and in enough (but not excessive) quantity.

The hair hygrometers. Any absorbing material tends to equilibrium with its environment in terms of both temperature and humidity. The water vapour pressure at the surface of the material is determined by the temperature and the amount of water bound by the material.

Any difference between this pressure and the water vapour pressure of the surrounding air will be equalized by the exchange of water molecules. The hair hygrometers (Fig. 25.10) utilize the absorption properties of hair. These instruments are used to measure relative humidity, and they operate on the principle of

Fig. 25.10 Hygrometer

absorption of moisture from organic substances (e.g. human or horsehair, etc.) that are changing the humidity of the air. Hygrograph is an instrument that records the relative humidity at the time and records it on paper or it memorizes it.

Heated psychrometer. The principle of the heated psychrometer is that the water vapour content of an air mass does not change if it is heated. This property may be exploited to the advantage of the psychrometer by avoiding the need to maintain an ice bulb under freezing conditions. Heat psychrometers use the principle of sustainability of the water vapour content of the mass air unit when it is heated. This feature can be used as an advantage in making psychrometer in order to avoid holding the ice tank in freezing conditions. The air is removed in the tube where it passes through an electric heat element and then comes the measurement chamber, which consists of dry and wet thermometer from the tank with water. The heat element controls circulation and provides air temperature not to be declined below a certain level, which is typically 10 °C. There are also hygrometers which are using absorption of electromagnetic radiation. Water molecules absorb electromagnetic radiation in the range of wavelengths. This feature can be used to obtain a measure of molecular concentration of water vapour or gas. The most useful belts of the electromagnetic spectrum for this purpose are the ultraviolet and the infrared belt. The method applies measurements of attenuation of radiation in the wave zone, which is typical for absorption of water vapour, along the path between the radiation source and the receiving device.

25.7 Measurement of Surface Wind

Direction and speed of wind are very important meteorological elements. Surface wind is usually measured by a wind vane and cup or propeller anemometer. When the wind blows constantly from one direction, it is called dominant or prevailing wind. Wind speed is often measured by an instrument known as anemometer. Wind is a vector quantity, which is fully determined when knowing both its components: direction and speed. The direction of the wind is part of the horizon where the wind blows, and the speed is the elapsed time of air particle pass in unit time. Direction shall be indicated by the parties of the world or the azimuth in degrees from 0 to 360, while the speed is measured in metres per second (m/s) or kilometres per hour (km/h). Because of the lack of devices for measuring speed, it is estimated by Bofor scale. The wind direction is determined by wind vane (Fig. 25.11). It is an easy indicator in the form of a shaft, mounted on a vertical axis that rotates freely around its axis. The direction of the arrow to the wind, the back has a vertical plate which serves as a "rudder". The speed of wind is measured with an anemometer (wind gauge). It is a vertical axis with 3 or 4 hollow semi-spherical (Robinson Cross) that rotates under the influence of wind.

The wind is stronger, faster spheres spin, and rotation is easily transformed into mechanical or electrical equivalent graduate units for wind speed. Instead of semi-spherical, sometimes a small propeller is used. Anemometer is used for measurement of the mean velocity in a period (usually 2 or 10 minutes) or current speed. Measurement is performed on standard height of 10 metres above the surface

Fig. 25.11 Wind vane

(ground). Anemograph measures the speed of wind at the time and the measured data recorded on paper or stored electronically.

25.8 Measurement of Precipitation

Precipitation is the most important meteorological element that quantifies the amount of fallen rainfall at the ground. Precipitation is defined as liquid or solid products of condensation of water vapour, which falls on the Earth's surface from the clouds. Precipitation includes several forms of hydrometeors: rain, hail, snow, dew, frost, freezing rain, and tiny droplets of mist. The total amount of rainfall that falls at the ground in a period of time is expressed in the form of vertical thickness, water depth or snow water equivalent, in case of solid forms. Snow cover is also expressed through the thickness of the fresh, fallen snow covering a horizontal surface. Unit rainfall is linear thickness, usually expressed in millimetres (volume/area) or (kg/m$^{2)}$ (mass/area) of liquid precipitation. That means, for example, 1 mm = 1litre/cm^2. The daily measurements of precipitation should be taken at fixed times common to all network or networks of interest. Rainfall of less than 0.1 mm is generally known as a trace. The amount of rainfall (intensity) is similarly expressed in linear measure per unit time, usually in millimetres per hour. Measurements of snow precipitation are taken in units and tens of centimetres to the nearest 0.2 cm. Lower value of 0.2 cm is generally called a trace. The thickness of snow on the Earth's surface is usually measured daily and expressed in centimetres.

Instruments for measurement of precipitation. Generally, an open receptacle with vertical sides is used, usually in the form of a right cylinder, with a funnel if its main purpose is to measure rain. The instrument for measurement of precipitation is called rain gauge (Fig. 25.12a). This instrument is a container in the shape of the

Fig. 25.12 (**a**) Rain gauge, (**b**) totalizer, (**c**) pluviograph

cylinder, placed vertically with a hole on top and with an area of 200 cm². Rain comes through the hole, which is mixed in a vessel at the bottom. Around the vessel there is a closed space for thermal insulation to prevent evaporation of accumulated precipitation. During the reading, accumulated water in the vessel is discharged in a tube with scale in millimetres and quotes its quantity. Rain gauge usually sets the column, the height of one (1) metre above the Earth's surface. For measurement of precipitation in inaccessible areas where observations are not continuous, the most common instruments are totalizers (Fig. 25.12b). Besides rainfall, its intensity can also be measured. The intensity of rain is expressed in millimetres per minute (mm/min). The intensity of rainfall is measured with an instrument called *pluviography* (Fig. 25.12c).

Measurement of precipitation of snow and snow cover. Snowy precipitation is the thickness of the freshly fallen snow, deposited at the Earth's surface in a specified period (usually 24 h). In this way, snowfall does not include deposition of moved or blown snow. For purposes of measurement of thickness, the word "snow" should also include ice pallets, graupel or hail, and plate ice, which appear to be formed by precipitation directly or indirectly.

Average depth of snow is the total thickness of snow on the Earth's surface, at the time of observation. Water equivalent of snow cover is the vertical thickness of the water that would be obtained by melting of the snow cover. Direct measurements of the thickness of snow cover in the open country are made with engraved stick or scale (Fig. 25.13). In order for representative thickness measurements to be obtained, numerous vertical measurements in places covered by snow need to be

Fig. 25.13 Measurement of snow thickness

made. The stick should be placed on a flat surface that is not leeward, nor covered with some of the surrounding objects (tree, building facilities, etc.). The total amount of snow cover is measured, but only the snow that fell in the last 24 hours.

25.9 Measurement of Solar Radiation

The Sun and other elements emit a spectrum of electromagnetic radiation, which depends on its temperature. The temperature is higher, so the spectrum is strongly shifted to the side of higher frequencies. But for the meteorological purposes, two variables are measured from solar radiation: the duration of radiation on any point on the Earth's surface in a certain period (day, month, year) and energy that comes from the Sun, a certain area at some time.

Heliograph is an *instrument* for recording the duration and intensity of sunshine (Fig. 25.14). This type of recorder is made up of a glass ball which concentrates sunshine on to a thick piece of card. The sunshine then burns a mark on the card which shows the number of hours of sunshine in the day.

Pyranograph. The energy that a surface receives from the Sun is usually measured by pyranograph or pyradiograph (Fig. 25.15a) and is expressed in Julies per metre square per hour (J/cm^{2} h$^{-1),}$ or some other proportional units. It should be noted that these instruments must be in an open space, which is not covered with object such as trees, buildings and the like. In these objects, of course, mountain barriers are not included.

Pyrheliometer. The direct solar radiation is measured using pyrheliometer (Fig. 25.15b). This means the instrument is always aimed directly at the Sun, via a tracking mechanism that continuously follows the Sun. It is sensitive to wavelengths in the band from 280 to 3000 nm. This device is composed of metal surfaces that receive radiation and are placed perpendicular to the solar radiation.

Angstrom's compensation pyrheliometer works on the principle of two manganese plates: one is heated by the Sun, Moon, and other electrical paths, until they

Fig. 25.14 Heliograph

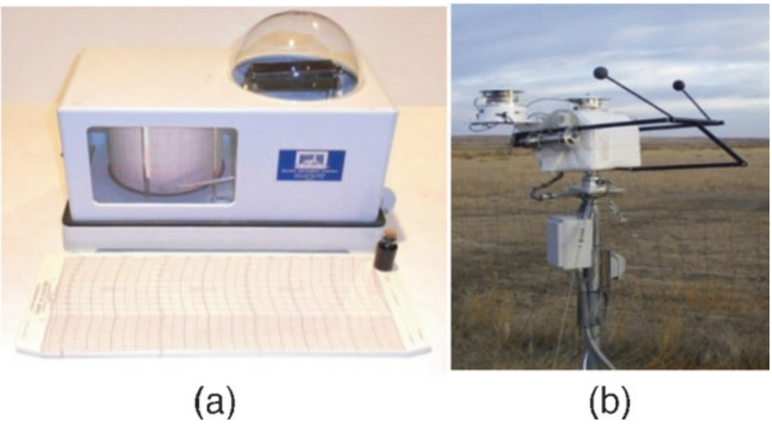

Fig. 25.15 (a) Pyranograph; (b) Pyrheliometer

Fig. 25.16 Pyranometer

reach an identical temperature. Electricity required for heating the plate is proportional to incoming shortwave radiation.

Pyranometer. Pyranometer is an instrument used for measurement of the solar radiation at full angle, the flat surface, and the diapason of the spectrum of radiation from (300 to 3000 3000 nm). This instrument is sometimes used to measure solar radiation on inclined surfaces in a horizontal position and turned to reflected measured global radiation (Fig. 25.16). When the diffusive component of solar radiation is measured, a component of direct solar radiation is protected from the pyranometer with a device for darkening. Pyranometers are normally used as thermal power sensors, photoelectrical, pyroelectrical, or bimetal elements. Since pyranometers are constantly exposed to all weather conditions, they must be solid in design and resistant to external influences and effects of moist air, especially near the sea.

Measurement of longwave radiation from the Earth can be achieved either indirectly, by subtracting the measured global radiation, measured by the total radiation, or directly, using pyrgeometres. Frequently pyrgeometres eliminate short wavelengths using filters that have constant visibility for long wavelengths, while they are almost non-transparent for short wavelengths (300 to 3000 nm). Longwave radiation, shortwave radiation, and total radiation are measured radiometers representing two instruments or a hybrid instrument ventilation polyethylene dome and a carefully balanced detector response.

25.10 Measurement of UV Radiation

Measurement of solar UV radiation is necessary, primarily because of the negative effects that this has caused to the environment and human health. These measurements are of interest for monitoring the growth of radiation on the Earth's surface, due to ozone depletion. UV spectrum is conventionally divided into three parts:

(a) (UV-A) radiation with a range of wavelengths in the interval from 315 to 400 nm), just outside the visible spectrum. It is less biologically active, and its intensity on the Earth's surface does not change the content of atmospheric ozone.
(b) (UV-B) radiation in the belt of wavelengths from 280 to 315 nm. This radiation is biologically active. Its intensity depends on the atmospheric ozone column. A frequently used expression for its biological activity is its negative skin effect, which means the extent to which radiation causes redness of the human skin.
(c) (UV-C) radiation at wavelengths from 100 to 280 nm is completely absorbed in the atmosphere and does not occur naturally on the Earth's surface.

The most sophisticated commercial instruments for measuring UV are called "radiometers" (Fig. 25.17). They use holographic traps to disperse incoming energy spectrum. Low-energy UV radiation compared to that of the visible spectrum requires a strong blocking from outside the belt. This is achieved by using double monochromatic or blocking filters, which transmit only UV radiation. The measurement of output from monochromatic commonly uses fotoamplifier.

The most sophisticated commercial instruments for measuring UV are called "radiometers" (Fig. 25.18). They use holographic traps to disperse incoming energy spectrum. Low-energy UV radiation compared to that of the visible spectrum requires a strong blocking from outside the belt. This is achieved by using double monochromatic or blocking filters, which transmit only UV radiation. The measurement of output from monochromatic commonly uses fotoamplifier.

Fig. 25.17 Instrument for measurement radiation (radiometer)

Fig. 25.18 Transmissometer

25.11 Measurement of Visibility

Meteorological visibility is an element that is very important in the measurements. Its size can be estimated by the observer. Assessment of visibility depends on many subjective and physical factors. Meteorological size, which is transparent to the atmosphere, can be measured objectively, and it represents the meteorological optical range. Visibility can be measured with telephotometric instruments, which are referred to us as transmissometers (see Fig. 25.18) that are designed for daily measurement of the ratio of attenuation, by comparing the visible light a separate facility to the facility of the sky. But they are usually not used for routine measurements because of the preferred use of direct visual observations.

Transmissometers represent instruments that are commonly used for measuring the average coefficient of attenuation. This instrument consists of a transmitter that provides modulated flux light from a source with constant average power, and receiver, i.e. accompanied photodetector. Frequently used sources of light are halogen lamps. Modulation of the light source prevents disturbance of sunlight. The transmission factor is determined by the output of photodetector, which allows calculating the ratio of attenuation and meteorological optical distance.

25.12 Measurement of Evaporation

Evaporation represents the quantity of evaporated water from open water surface or from the ground. Transpiration is the process through which water from the plants is transferred to the atmosphere in the form of water vapour. Hence, evapotranspiration (or effective evapotranspiration), means an amount of water vapour that evaporated from the Earth's surface and plants, in terms of natural moisture content. Potential evaporation is the quantity of water vapour, which can be broadcasted from the surface of pure water from unit surface area and unit time, of the existing atmospheric conditions. Potential evapotranspiration is a maximum amount of water that can evaporate in each climatic region, the continuous expanse of vegetation. Speed of evaporation is defined as the amount of water evaporated from unit area in unit time. It can be expressed as mass or volume of liquid water, evaporated per unit area in unit time, usually as an equivalent depth of liquid water, evaporated in unit time from the whole area. Direct measurements of evaporation or evapotranspiration, the widespread natural water or land surfaces, are not practically feasible at the present time. However, several indirect methods are developed that are performed by point measurements or other calculations that provide reasonable result. The water lost by default saturated surface is measured with evaporimeters (Fig. 25.19), which can be classified as atmometers, and evaporimeters the container or tank. Atmometer is an instrument which measures the loss of water from the wet porous surface. Moist surfaces are porous ceramic spheres, cylinders, containers, or exposed filter paper discs saturated with water. The evaporating element of atmometer is consisting of a ceramic sphere (~5 cm) in diameter, associated with reservoir of bottle with water through glass or metal tube. Subsequent measurements of the volume of water that remains in the engraved tube will give the amount lost by evaporation at any given time.

25.13 Upper Air Measurements

For the measurement of meteorological elements, pressure, temperature, and humidity at a certain height, a device called radiosonde is used (Fig. 25.20). Radiosondes consist of a balloon into the atmosphere, equipped with devices for measuring one or

Fig. 25.19 Evaporimeter

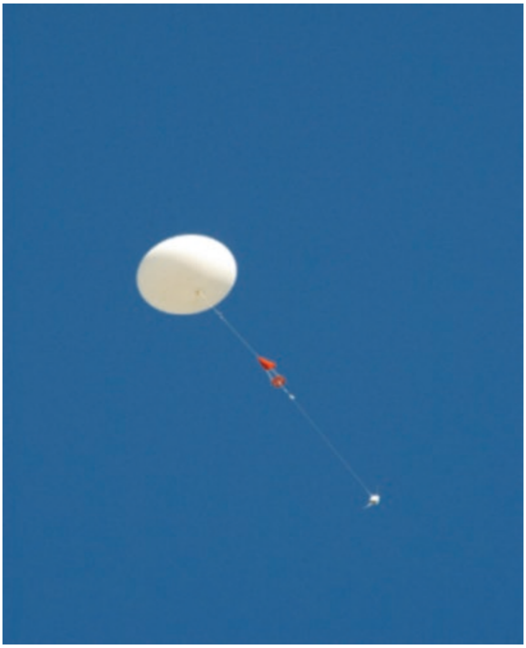

Fig. 25.20 Radiosonde

more meteorological parameters. It is provided with a radio transmitter, which is used for sending information to the observation station. Radiosondes can attach to the balloon or may be dropped from an airplane or rocket. The stations, at which measurements are conducted, are made from electronic tools. Upper measurements of temperature and relative humidity are used to initialize the analysis of numerical forecast models for operational weather forecasting. Radiosondes provide most of the measurements of temperature and relative humidity directly above the land, while radiosondes launched from separate islands or vessels have limited coverage over the oceans. Temperatures, with vertical scale like radiosondes, can be measured by air at different levels of cruises. Aircraft measurements are used as an addition to upper air sounding measurements, especially overseas. Satellite measurements of temperature and distribution of water vapour have lower vertical resolution than radiosondes or aircraft measurements. Satellite measurements have the greatest impact on the analysis of numerical forecast over oceans and other areas of the globe where upper air sounding and aircraft measurements are rare or not available. Precise measurements of the vertical structure of the field and temperature profile of water vapour in the troposphere are extremely important for all types of forecast, especially for the regional and local forecasting. The vertical structure of the field of temperature and water vapour determines the stability of the atmosphere. Radio sounding measurements are vital for studies referred to the pollution of the environment and climate change with height.

25.13.1 Measurement of Upper Wind

Upper winds data are mainly obtained by using radio sounding techniques, although when additional data are needed for elevation winds without cost to launch the radiosonde can use pilot balloons (Fig. 25.21), which use the principle of determining upper level winds with optical recording of the free balloon and radio wind measurements (determination of upper winds with recording the free balloon by electronic tools). Measurements of upper stations in the Global Observer System over land are supplemented with measurements from aircrafts, wind profilers, and Doppler weather radar. The system for measuring the wind profile, known as LIDAR, provides a measurement of the direction and speed of wind above ground level to about 5 km altitude.

25.14 Advanced Remote Sensing Measurements

The requirements for observational data may be met using in situ measurements or remote sensing (including space-borne) systems, according to the ability of the various sensing systems to measure the elements needed. Thus, a different type of measurements and observations is continuously carried out to monitor the weather, climate, and water of our planet. Some of the measurements have a special research

Fig. 25.21 Pilot balloon

nature in frame of some research programme, field campaign, experiment, or other activities:

- Measurements and observations at aeronautical meteorological stations
- Aircraft observations
- Marine observations
- Special profiling techniques for the boundary layer and the troposphere
- Rocket measurements in the stratosphere and mesosphere
- Locating the sources of atmospherics
- Satellite observations
- Radar measurements
- Balloon techniques
- Urban observations
- Road meteorological measurements

25.14.1 The Global Observing System

The Global Observing System is designed to meet these requirements and is composed of the surface-based subsystem and the space-based subsystem. The surface-based subsystem comprises a wide variety of types of stations according to the application (e.g. surface synoptic station, upper air station, climatological station, and so on). The space-based subsystem comprises several spacecrafts with on-board sounding missions and the associated ground segment for command, control, and data reception.

25.14.2 LIght Detection And Ranging (LIDAR)

LIDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses combined with other data recorded by the airborne system generate precise three-dimensional information about the shape of the Earth and its surface characteristics. A LIDAR instrument (see Fig. 25.22) principally consists of a laser, a scanner, and a specialized GPS receiver. Airplanes and helicopters are the most commonly used platforms for acquiring LIDAR data over broad areas. There are two types of LIDARs: topographic and bathymetric. Topographic LIDAR typically uses a near-infrared laser to map the land, while bathymetric LIDAR uses water-penetrating green light to also measure seafloor and riverbed elevations. LIDAR systems allow scientists and mapping professionals to examine both natural and manmade environments with accuracy, precision, and flexibility. Over sea, the winds at altitude are mainly obtained by civilian aircraft at different flight levels. In future, LIDAR data from satellites and radars is expected to be used in order to obtain wind measurements and improve global coverage of current monitoring systems.

25.14.3 SOund Detecting And Ranging (SODAR)

SODAR is an instrument used for remote measurement of dispersion of sound waves caused by disturbances in the atmosphere. It is adjusted to measure the speed of wind at different heights and layers just above the ground (Fig. 25.23). These types of remote sensing systems have several advantages. SODAR operate a single, simple process and include coverage of greater height. The main advantage of the system is that it can be installed in a very short time.

Fig. 25.22 LIDAR

Fig. 25.23 SODAR

The standard height limit of the meteorological towers is (~150 m), where measurements with SODAR exceed this limit and provide a precise reading. Radio sounding methods for measuring the speed and direction of wind at altitude essentially depends on the monitoring of movement or free balloon, which rises to a uniformed rate or by placing the object under the influence of gravity. If you need to measure a given horizontal movement of air, there should not be a significant horizontal motion in terms of air that is monitored. The core information needed by systems directly includes the targeted amount and measurements of its flat position or, alternatively, its horizontal speed at certain intervals. Remote measurement systems are used to measure the movement of the atmosphere with the rejection of electromagnetic radiation or sound, of one or more of the following purposes: hydrometeors, sand, aerosols, etc. the index breaches caused by atmospheric turbulence at small scales or in the air molecules themselves.

25.15 Measurements at Automatic Weather Stations (AWS)

Automated weather station (AWS) is defined as a meteorological station where measurements are made of meteorological elements and are transferred automatically (Fig. 25.24). Instrumental measurements are read from the outside by means of sensors. The measured data is then disseminated to the central unit for acquisition of data. Data collected by measuring devices can be processed locally at the present

Fig. 25.24 Automated weather station – AWS

automatic station or elsewhere, for example, the central processor in the network. Automatic weather stations can be designed as an integrated concept of different devices in combination with measurement units for reception and processing of data. They are used to meet several needs, ranking from the simple assistance to the observer to complete replacement of the observations in completely automatic stations.

25.16 Satellite Observations

Application of techniques of remote control in the measurement and monitoring of meteorological variables and supporting the Earth's surface, troposphere, and stratosphere using satellite are called satellite measurements (Webber 2009; Tan, 2016). Satellite systems continue to evolve, and for several years, new systems are expected to be operational. Typical meteorological satellites orbit the Earth at heights of about (36,000 km) or approximately (850 km), and they are used for obtaining images and quantitative information about the properties of the surface and lowest (20 km) from the atmosphere (Fig. 25.25). The use of sensors with satellite platforms has its advantages and flaws in terms of measurements, compared to the use of surveillance systems from the Earth surface. Ability to obtain images from meteorological satellites is part of the justification for the use of satellites. Cloudiness images provide valuable diagnostic information in the support analysis

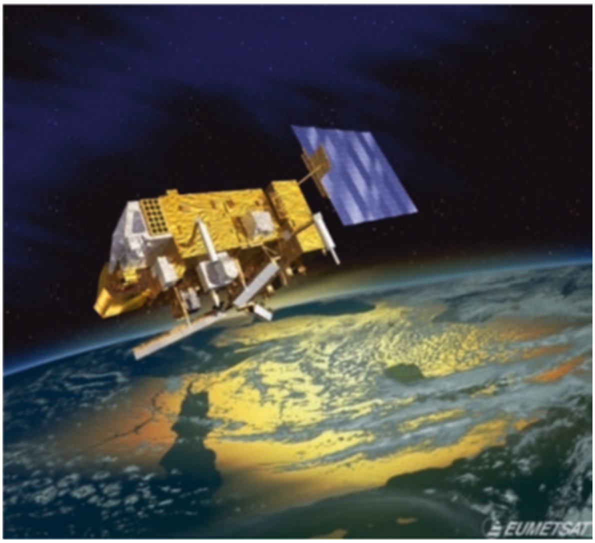

Fig. 25.25 Meteorological satellite

of meteorological characteristics. Meteorological variables are measured operationally in the present time, with variable resolution and accuracy, including:

- Profile of temperature and temperature at the top of the cloud at the surface of the sea and land
- Profile of moisture
- Wind at the cloud and the ocean surface
- Liquid and total water intensity of rainfall
- Total radiation and albedo
- Cloud type and height of cloud tops
- Total ozone
- Coverage and height of the ice and snow

With the help of satellites, non-meteorological variables such as vegetation, volcanic dust, etc., which are operationally important, are also measured.

Meteorological satellites of the second generation are designed to monitor the advantage of new technologies and improve the already successful and proven design of the original "Weather-Sat" satellites. SEVIRI radiometer (MSG-2) satellite represents a total of 12 channels that generate images through scanning the Earth every 15 minutes. Visible channel provides the highest resolution data at 1 km resolution; other channels provide data at 3 km. This generation of satellites is a powerful tool for obtaining precise information about the state of the atmosphere in real time.

Besides obtaining data on cloudy systems in different parts of the globe, many applications for measuring and monitoring atmospheric phenomena and processes with the help of satellite are developed.

Today they have successfully detected the development of cyclones and other atmospheric disturbances of smaller scale. Satellites are successfully used for prediction and monitoring of development and evolution of tropical cyclones, hurricanes, typhoons, and tornadoes. Numerous applications for prediction of fires, air pollution, the emergence of low stratus clouds or fog, solar eclipse, and related atmospheric phenomena are also developed. Meteorological Satellite Third Generation (MTG) is a six-satellite system of four imaging satellites carrying imaging and lightning detection mission as well as two sounder satellites providing infrared and ultraviolet capabilities, for both climate and meteorological applications. It will provide the atmospheric chemistry and air quality information.

Radar observations and measurements. The word radar comes from the English term "Radio Detection and Ranging". It operates on the principle of radio waves that are emitted in sequences and refuse to back the cloudy particles. The time between emission and detection can compute the distance of the object. The intensity of the signal depends on the concentration of facilities, size of particles, and their type (snow, city, or rain). Radar data is usually shown as reflexivity in decibels. The Doppler radar (Fig. 25.26), using speed mode, is based on the Doppler effect (see Doviak and Zrnic 2006), which can determine the direction and speed of the object (precipitation). The most prominent meteorological radar today is Doppler dual-polarization radar. They improve the accuracy of precipitation estimates, leading to better flash flood detection, ability to discern between heavy rain, hail, snow, and sleet, and improve detection of non-meteorological echoes (e.g. ground clutter, chaff, anomalous propagation, birds, and tornado debris) and identification of the melting layer (e.g. bright band).

Radar measurements are very important in operational meteorology and forecast the weather, especially in the very short-term forecast and the announcement of

Fig. 25.26 Radar measurements (Doppler radar)

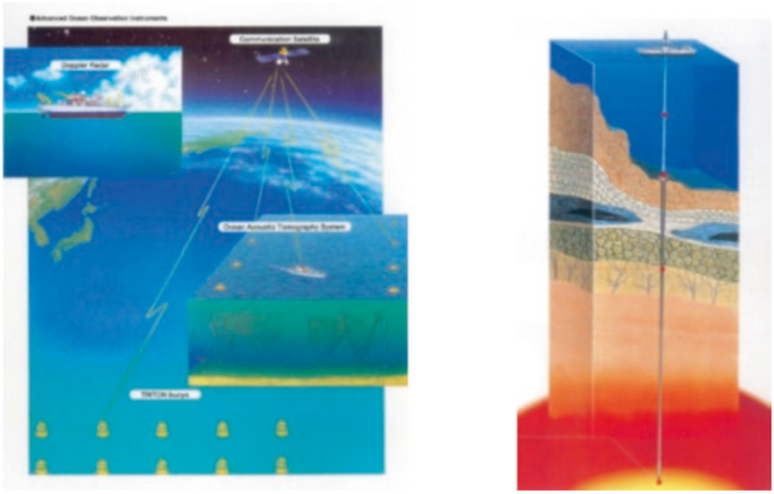

Fig. 25.27 Advanced Observation Instruments on "CHikyu"

weather disasters (nowcasting), related storms, strong winds, electrical discharges, heavy rainfall, and the hail occurrence.

25.17 Special Measurements

Ocean drilling in the twenty-first century. For meteorological, and much general, for geophysical needs, the Chikyu platform was developed with a programme of special measurements in the atmosphere, in deep oceans, and deep into the land beneath the ocean. "Chikyu" will enable to drill 7 km under the sea floor at maximum water depth more than 4 km (see Fig. 25.27). This extremely complex ship is specially built to serve as a mobile platform for special measurements that should provide answers to many unknown geophysical issues, such as why the occasional quasi periodically occurs the worming of ocean water in a tropical deck of the Pacific. This has a significant influence on the weather and climate of not only these areas but also much wider.

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