MODULE 2

UNIT 1 NATURE AND COMPONENTS OF ATMOSPHERE

CONTENT

1.0 INTRODUCTION

The atmosphere is a deep blanket of gaseous envelope that surrounds the solid and liquid surface of the earth. It extends upward for hundreds of kilometres, and eventually meets the rarefied inter-planetary medium of the solar system. The gas which constitutes the atmosphere is called air. It is a mixture of several gases. The most abundant of the elements in the air are nitrogen, oxygen and argon.

The atmosphere is essential for life, and without it, life would not exist and there would be no clouds, winds and storms, indeed, there would be no weather. Besides being an essential for life and a medium for weather processes, the atmosphere acts as a great canopy that protects the earth from the full force of the sun by day. It also prevents loss of too much heat at night.

If there were no atmosphere, the temperatures of the earth would rise to over 93^0C in the daytime, and drop to around -344^0C at night.

The atmosphere is also refers to a layer of gases which surrounds the entire Earth. It consists mainly of Nitrogen, Oxygen, as well as a few other gaseous elements. The purpose of this "layer" around the Earth is to prevent excessive amounts of radiation from reaching the Earth, thereby allowing us, as animals/planets, to survive. A planet such as Mars has very little, if any, atmosphere and hence has little or no life on it (at least as we see it now). Several million years ago Mars may have supported life. Has your class ever seen pictures of the huge "ancient rivers" or Canyons on Mars? Many scientists these formations could have been made by water, rivers, etc many millions of years ago.

The entire mass of air and other gases surrounding the earth is called atmosphere. With increasing height above earth's surface, the atmosphere becomes rarer and rarer.

The earth's atmosphere is a covering of various gasses that surrounds the plant to a depth of 1000km, or about 600 miles. Without these gases to create an atmosphere, no life would exist and there would be no weather. We would just be another lifeless planet in existence. Scientist has divided the atmosphere into five separate layers – the exosphere, the thermosphere, the mesosphere, the stratosphere and the troposphere. The troposphere is the nearest layer to the surface of the earth and is the only part of the atmosphere where weather happens.

If you look at a photo of the earth taken from a satellite in space you can see the weather systems clearly moving around the atmosphere. The height of the troposphere varies between different areas of the earth. At the equator for example, it stretches to about 20KM above the surface. At the poles, the layer reaches a height of about 10KM or about six miles.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- explain the structure of the atmosphere;
- describe the composition of the atmosphere;
- explain how solar energy influence the atmosphere; and
- state the importance of the atmosphere.

2.1 HOW TO STUDY THIS UNIT

1. You are expected to read carefully through this unit at least twice before attempting to answer the self-assessment questions or tutor- marked assignment.
2. Do not look at the solution given at the end of the unit until you are satisfied that you have done your best to get all answers.
3. Share your difficulties with your course mates, facilitators and by consulting other related material, particularly the internet.
4. Note that if you follow the instructions you will feel self fulfilled that you have achieved the aim of studying this unit. This should stimulate you to do more.

3.0 WORD STUDY

Aurorae – an atmospheric events created by charged particles from the sun striking the upper atmosphere creating a colour light in the sky
Greenhouse effect- the process by which a planet is warmed by its atmosphere

4.0 MAIN CONTENT

4.1 STRUCTURE OF THE ATMOSPHERE

The atmosphere has a distinct vertical structure comprising four broad layers, each with its own characteristics. Each layer is warmed by different portions of the Sun's radiation, so the temperature of the atmosphere varies between layers. The atmosphere is divided vertically into four layers based on temperature: the troposphere, stratosphere, mesosphere, and thermosphere. Throughout the cycle’s unit, we will focus primarily on the layer in which we live the troposphere.

The lowest layer, the troposphere, is the layer in which we live. It gets its warmth from the ground, which is heated by the Sun. Temperatures in the troposphere decrease steadily with distance from the ground. The rate of cooling, known as the environmental lapse rate, is remarkably even at around 6°C (42.8^{0}F) per 1,000 metres (3,280 feet). The troposphere contains 75 per cent of the atmosphere's gas. It also holds huge amounts of dust and water vapour, and is often dense with clouds and mist. Air pressure is greatest in the troposphere, because gravity pulls the atmosphere towards the Earth, squeezing most of its weight into this lowest layer.

The boundary that separates the troposphere from the stratosphere is called the tropopause. The height of this boundary varies between about 15 kilometres (nine miles) at the Equator and eight kilometres (five miles) at the North and South Poles. In the stratosphere, temperatures begin to rise. This is due to the presence of the ozone layer, which absorbs the Sun's ultraviolet (UV) light and, at the same time, protects the Earth from the dangerous effects of UV rays. The ozone actually soaks up so much UV light that the stratosphere gets quite warm towards the top. Since the air gets warmer beyond the tropopause, moisture evaporated from the sea can never rise into the stratosphere, because it is carried by colder, denser air in the troposphere. Because the air in the stratosphere contains little moisture, and is heated from above as ozone absorbs UV light, the stratosphere is still and calm, which is why jet airliners climb up to this level for long distance flights. The only clouds are faint noctilucent (nightshining) clouds and mother-of-pearl clouds. The stratosphere contains 19 per cent of the atmosphere's gas.

Higher still, the mesosphere is heated as oxygen and nitrogen are warmed by extreme ultraviolet light, but temperatures begin to drop with height as the gases get thinner and thinner. The air in the mesosphere is very thin, but thick enough to slow down meteorites, which burn up as they hurtle into it, leaving fiery trails in the night sky.

The mesopause is the boundary that separates the mesosphere from the fourth layer of the atmosphere, the thermosphere. Gases in the thermosphere are even thinner than those in the mesosphere, but because they are exposed to the full glare of the Sun, temperatures soar to 2,000°C (3,632C). However, because there is so little gas, there is very little real heat.

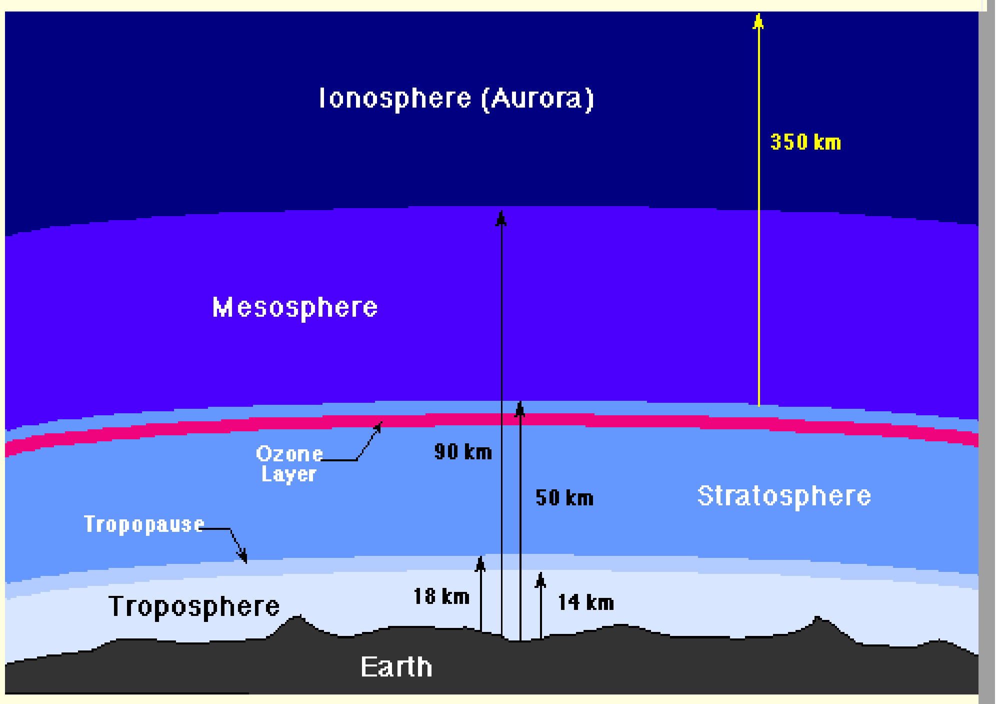
The upper part of the mesosphere and the lower part of the thermosphere are together referred to as the ionosphere, since this layer contains many electrically charged particles called ions. Ions are atoms or molecules that have lost or gained one or more negatively charged electron. Ions in the atmosphere are formed when gas molecules, such as nitrogen and oxygen, are energised by ultraviolet rays from the Sun to such an extent that they lose one or more of their electrons. Because ions are electrically charged, they are capable of reflecting radio signals. During the day, the Sun's ultraviolet rays turn more and more atoms into ions, and so the ionosphere is most highly charged just after sunset. By dawn, the ionosphere is much weaker because the electrons slowly recombine with ions during the night.

The electrical nature of the Earth's atmosphere is responsible for the coloured lights known as aurorae. Aurorae are permanent features of the Earth's upper atmosphere, although they vary in vividness. There are two aurorae—the aurora borealis at the North Pole, and the aurora australis at the South Pole. Aurorae are gigantic, stretching far up through the atmosphere. The lowest fringes hang about 64 kilometres (40 miles) above the ground, while the upper rays extend more than 965 kilometres (600 miles) into space—three times as high as the space shuttle's orbit. The coloured lights we see in the sky are the atoms and molecules of the atmosphere glowing as they are bombarded by charged particles streaming from the Sun. These atoms and molecules are then deflected towards Earth's magnetic poles.

The outer layer of the atmosphere, the exosphere, lies more than 483 kilometres (300 miles) above the ground. At this height, gases become so rarefied that they drift off into space. Even further out are indistinct regions called the heliosphere and protonosphere. In the heliosphere, the atmosphere has thinned out to a near vacuum, but slight frictional drag on spacecraft indicates that gas is present - mostly helium, which is why it is called the heliosphere. The protonosphere, which stretches out more than 60,000 kilometres (37,200 miles) above the Earth, is even more rarefied, and probably consists of a sparse scattering of charged hydrogen particles, known as protons, hence the name.

Layers of the Atmosphere

The atmosphere of the Earth may be divided into several distinct layers, as the following figure indicates.



Layers of the Earth's Atmosphere

Fig 1.1: Layers of the Earth's Atmosphere

4.2 Composition of the Atmosphere

The Earth's atmosphere consists mainly of the harmless inert gas nitrogen (78 per cent), and the vital oxygen we need to breathe (21 per cent). It also contains tiny traces of argon, ozone, carbon dioxide, neon, krypton, xenon, helium, methane, and hydrogen. Water vapour and solid particles, such as dust, pollen, and salt spray from the oceans are also present in the lowest level of the atmosphere, the troposphere.

No other atmosphere in the solar system is remotely like that of the Earth. The atmosphere of Venus, for instance, is 96 per cent carbon dioxide, while that of Mars is 95 per cent carbon dioxide. Earth's atmosphere contains practically no carbon dioxide, because most of this gas was absorbed by the oceans early in the planet's history, where it combined with calcium to form the mineral calcium carbonate, or limestone. Mars and Venus have no oceans, so their carbon dioxide is still present in their atmospheres.

The air is almost always moist, even when it is not raining, because it contains water vapour. This water vapour is normally invisible, but if the air is cooled enough, it condenses into drops of liquid water or solid ice and forms clouds, fog, mist, dew, rain, or snow.

Water is continually being recycled between the atmosphere and the oceans in a process known as the water cycle.

The air is filled with a wide range of minute airborne particles, known as aerosols. Most of these aerosols are natural, such as volcanic ash, ash from forest fires, pollen, and fungal spores. The biggest sources of aerosols are salt from the sea and dust from soil. More than a billion tons of sea salt joins the air from sea spray every year, and almost a quarter of a billion tons of soil dust is whipped up by the wind. Without these aerosols, there would be nothing for water in the atmosphere to condense on, and there would be no mists, clouds, or rain.

The oxygen so characteristic of our atmosphere was almost all produced by plants (cyanobacteria or, more colloquially, blue-green algae). Thus, the present composition of the atmosphere is 79 per cent nitrogen, 20 per cent oxygen, and one per cent, other gases.

Composition of the Atmosphere

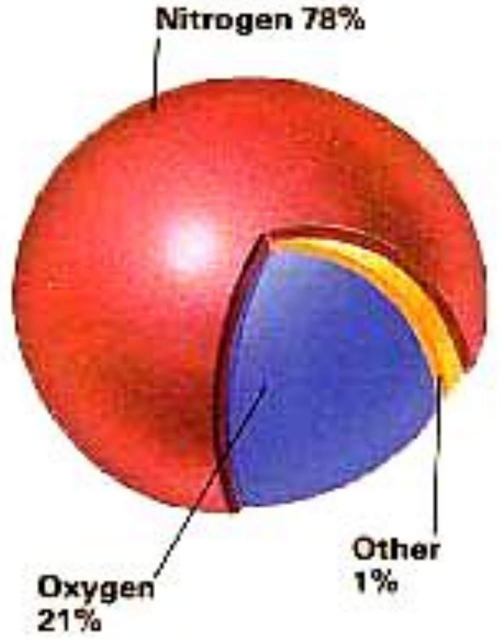


Fig 1.2: Composition of the Atmosphere

4.3 How Does Solar Energy Influence the Atmosphere?

The heat source for our planet is the sun. Energy from the sun is transferred through space and through the earth's atmosphere to the earth's surface. Since this energy warms the earth's surface and atmosphere, some of it is or becomes heat energy. There are three ways heat is transferred, into the atmosphere: radiation, conduction and convection.

If you have stood in front of a fireplace or near a campfire, you have felt the heat transfer known as radiation. The side of your nearest the fire warms, while your other side remains unaffected by the heat. Although you are surrounded by air, the air has nothing to do with this transfer of heat. Heat lamps, that keep food warm, work in the same way. Radiation is the transfer of heat energy by electromagnetic radiation.

Most of the electromagnetic radiation that comes to the earth from the sun is in the form of visible light. Light is made of waves of different frequencies. The frequency is the number of instances that a repeated event occurs, over a set time. In electromagnetic radiation, the frequency is the number of times an electromagnetic wave moves past a point each second.

Our brains interpret these different frequencies into colours, including red, orange, yellow, green, blue, indigo, and violet. When the eye views all these different colours at the same time, it is interpreted as white. Waves from the sun which we cannot see are infrared, which have lower frequencies than red, and ultraviolet, which have higher frequencies than violet light.

Most of the solar radiation is absorbed by the atmosphere and much of what reaches the earth's surface is radiated back into the atmosphere to become heat energy. Dark coloured objects such as asphalt absorb more of the radiant energy and warm faster than light coloured objects. Dark objects also radiate their energy faster than lighter coloured objects.

Learning Lesson: Melts in your bag, not in your hand.

Conduction

Conduction is the transfer of heat energy from one substance to another or within a substance. Have you ever left a metal spoon in a pot of soup being heated on a stove? After a short time the handle of the spoon will become hot. This is due to transfer of heat energy from molecule to molecule or from atom to atom. Also, when objects are welded together, the metal becomes hot (the orange-red glow) by the transfer of heat from an arc. This is called conduction and is a very effective method of heat transfer in metals. However, air conducts heat poorly.

Convection

Convection is the transfer of heat energy in a fluid. This type of heating is most commonly seen in the kitchen when you see liquid boiling. The air in the atmosphere acts as a fluid. The sun's radiation strikes the ground, thus warming the rocks. As the rock's temperature rises due to conduction, heat energy is released into the atmosphere, forming a bubble of air which is warmer than the surrounding air. This bubble of air rises into the atmosphere. As it rises, the bubble cools with the heat contained in the bubble moving into the atmosphere.

As the hot air mass rises, the air is replaced by the surrounding cooler, denser air, what we feel as wind. These movements of air masses can be small in a certain region, such as local cumulus clouds, or large cycles in the troposphere, covering large sections of the earth. Convection currents are responsible for many weather patterns in the troposphere.

4.4 Importance of the Atmosphere

- The atmosphere is earth's protective armour. The atmosphere separates the earth from the space and thus, hot asteroids do not hit the ground all the time. Another very important significance of the atmosphere is that it regulates temperature on earth. Although now the increasing greenhouse effect has become such a big crisis as it is causing global warming, the earth does need the greenhouse effect to some extent. This is because the atmosphere traps some of the heat that comes from sun during the day so that the nights are tolerable too. Do you know that Mercury, the planet closest to the sun and therefore the hottest has a night time temperature of -173°C while during daytime, it is almost 350°C? That is because it has no atmosphere. Imagine how impossible it would have been to inhabit earth if its temperatures fluctuated between such extremes every day!
- The atmosphere also offers protection against the harmful rays of the sun. That is the issue of concern about the ozone holes. As the layer of atmosphere disintegrates from an area, it is in direct contact with sunlight without the atmosphere between it to remove the harmful radiation. This increases the risk of sunburns and skin cancer to a great degree.
- The atmosphere is the source of every living thing in the world, it plays a very important role in serving the world's need and it supports the earth and it's consisting elements.....it provides ventilation to the earth because the atmosphere filters the ultraviolet rays coming from the sun which causes the living things in the world to die....it also gives the air we breathe, the food we eat and the water we drink and above all it supports life.
- It protects us from ultra violet rays of the sun. It also protects us from the meteors. Without the atmosphere, the earth's surface will look like the surface of the moon (full of craters).

Summary of the Importance of Atmosphere.

- Atmosphere serve as an umbrella which protects us from harmful UV rays that results to melanoma, a skin disease. Anonymous.
- The layers of atmosphere is very important for living beings because it reflects some of the heat of the sun and some is also absorbed by it.
- The Atmosphere is very important part of the biosphere.
- It controls the heat.
- Protects us from the ultra contains ray of the sun.
- Separates the earth from the space.
- Helps us to breathe as atmosphere contains air...
- Regulates the temperature on the Earth.
- Traps some of the heat that comes from the sun during the day, so that the nights are tolerable too.

5.0 CONCLUSION

The atmosphere is the envelope of gases that surrounds the earth. Earth's atmosphere makes conditions on earth suitable for living things. The atmosphere contains oxygen and other gases that living things need to survive. It protects living things from radiation of sun. Atmosphere also prevents earth's surface from being hit by meteoroids or rocks from outer space. So imagine the world without the atmosphere, it will be better to live on any other planet rather to live on the earth! Living things would probably die from living on earth. Scientists divide earth's atmosphere into four main layers classified according to changes in the temperature.

6.0 ACTIVITY

1. Explain the term atmosphere
2. What do think will happen to the Earth if the atmosphere suddenly disappears
3. Suggest reasons why the day time temperature of Mars differs considerable from its night time.

7.0 SUMMARY

In summary the atmosphere consists of the following layers:

- Troposphere: it extends to about seven miles.
- Stratosphere: it extends to 20 miles.
- Mesosphere: it extends to about 80 miles. Here ozone gas is generated by the action of the sun.
- Ionosphere: it is the region of upper atmosphere with layers of electric particles formed by loss or gain of electrons.
- Exosphere: it extends beyond 400 miles, and is the last distinct feature of atmosphere.

The Troposphere

The troposphere is where all weather takes place; it is the region of rising and falling packets of air. The air pressure at the top of the troposphere is only 10 per cent of that at sea level (0.1 atmospheres). There is a thin buffer zone between the troposphere and the next layer called the tropopause.

The Stratosphere and Ozone Layer

Above the troposphere is the stratosphere, where air flow is mostly horizontal. The thin ozone layer in the upper stratosphere has a high concentration of ozone, a particularly reactive form of oxygen. This layer is primarily responsible for absorbing the ultraviolet radiation from the Sun. The formation of this layer is a delicate matter, since only when oxygen is produced in the atmosphere can an ozone layer form and prevents an intense flux of ultraviolet radiation from reaching the surface, where it is quite hazardous to the evolution of life. There is considerable recent concern that man-made fluorocarbon compounds may be depleting the ozone layer, with dire future consequences for life on the Earth.

The Mesosphere and Ionosphere

Above the stratosphere is the mesosphere and above that is the ionosphere (or thermosphere), where many atoms are ionised (have gained or lost electrons so they have a net electrical charge). The ionosphere is very thin, but it is where aurora takes place, and is also responsible for absorbing the most energetic photons from the Sun, and for reflecting radio waves, thereby making long-distance radio communication possible.

The structure of the ionosphere is strongly influenced by the charged particle wind from the Sun (solar wind), which is in turn governed by the level of solar activity. One measure of the structure of the ionosphere is the free electron density, which is an indicator of the degree of ionisation. Here are electron density contour maps of the ionosphere for months in 1957 to the present. Compare these simulations of the variation by month of the ionosphere for the year 1990 (a period of high solar activity with many sunspots) and 1996 (a period of low solar activity with few sunspots).

8.0 ASSIGNMENT

1. With the aid of a diagram where necessary, write short notes on the following:
    a. Layers of the atmosphere
    b. Composition of the atmosphere
    c. Conduction
    d. Convention.
2. What is the importance of the atmosphere?

9.0 REFERENCES/FURTHER READING

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UNIT 2 ELEMENTS OF WEATHER AND CLIMATE

CONTENT

1.0 INTRODUCTION

Weather is the current atmospheric conditions, including temperature, rainfall, wind, and humidity at a given place. If you stand outside, you can see that it's raining or windy, or sunny or cloudy. You can tell how hot it is by taking a temperature reading. Weather is what's happening right now or is likely to happen tomorrow or in the very near future.

Climate, on the other hand, is the general weather conditions over a long period of time. For example, on any given day in January, we expect it to be rainy in Portland, Oregon and sunny and mild in Phoenix, Arizona. And in Buffalo, New York, we're not surprised to see January newscasts about sub-zero temperatures and huge snow drifts.

Some meteorologists say that "climate is what you expect and weather is what you get." According to one middle school student, "climate tells you what clothes to buy, but weather tells you what clothes to wear."

Climate is sometimes referred to as "average" weather for a given area. The National Weather Service uses data such as temperature highs and lows and precipitation rates for the past thirty years to compile an area's "average" weather.

The earth's climate is generally defined as the average weather over a long period of time. A place or region's climate is determined by both natural and anthropogenic (human-made) factors. The natural elements include the atmosphere, geosphere, hydrosphere, and biosphere, while the human factors can include land and resource uses.

Changes in any of these factors can cause local, regional, or even global changes in the climate.

The weather is made up of different elements, which are measured either by special instruments or are observed by a meteorologist. These measurements are then recorded and used in the making of climate graphs and weather forecasts.

Although an area's climate is always changing, the changes do not usually occur on a time scale that's immediately obvious to us. While we know how the weather changes from day to day, subtle climate changes are not as readily detectable. Weather patterns and climate types take similar elements into account.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- List and explain the elements of weather and climate;
- State the factors influencing weather and climate ;
- List and explain the equipment of standard meteorological station; and
- Describe how to measure wind speed direction.

2.1 HOW TO STUDY THIS UNIT

1. You are expected to read carefully through this unit at least twice before attempting to answer the self-assessment questions or tutor- marked assignment.
2. Do not look at the solution given at the end of the unit until you are satisfied that you have done your best to get all answers.
3. Share your difficulties with your course mates, facilitators and by consulting other related material, particularly the internet.
4. Note that if you follow the instructions you will feel self fulfilled that you have achieved the aim of studying this unit. This should stimulate you to do more.

3.0 WORD STUDY

Anthropogenic- having its origin in the influence of human activity on nature
Azimuth- bearing of a line surveying

4.0 MAIN CONTENT

4.1 Elements of Weather and Climate and Importance of measuring them

When studying weather or climate, the elements of each seem to be interchangeable. Though the difference between terms like "precipitation" and "average precipitation" may seem negligible, their differences are important factors in what separates climate from weather. Weather is the combination of daily factors that result in rain or sunshine, while climate is the long-term total of those daily factors over periods of decades. To truly distinguish the differences in how these elements concern weather and climate, you first have to understand what the elements are.

Precipitation

Precipitation is simply any water form that falls to the Earth from overhead cloud formations. As an element of weather, precipitation determines whether outdoor activities are suitable or if the water levels of creeks and rivers will rise. As an element of climate, precipitation is a long-term, predictable factor of a region's makeup. For instance, a desert may experience a storm (weather) though it remains a typically dry area (climate).

Humidity

Humidity is the measurable amount of moisture in the air of the lower atmosphere. The humidity element of weather makes the day feels hotter and can be used to predict coming storms. However, the humidity element of climate is the prolonged moisture level of an area that can affect entire ecosystems. For instance, tropical jungles can sustain different forms of life than dry, arid climates because of the overall humidity from rainfall and other factors.

This is an aspect of climate rather than weather, in that the typically high humidity levels of these regions is predictable over periods of decades.

Temperature

Temperature is simply the measurement of how hot or cold a region is on a day-to-day basis. The weather aspect of temperature can change throughout the day; however, it generally falls within a certain range of predictable highs and lows (as climate). Cold snaps and heat waves are weather that affects the temperatures of particular climates. For example, a heat wave in northern Siberia is an aspect of weather affecting a climate that is typically considered to be cold. The weather in this case (the heat wave) is simply happening inside of a climate (the normal cold range of Siberian temperatures).

Atmospheric Pressure

Atmospheric pressure is basically the "weight" of the air. It is used primarily by meteorologists to monitor developing storms that can seem to come out of nowhere. While typically considered an aspect of weather, certain regions of the world exist in zones where changing atmospheric pressures form part of the predictable climate. This is because of their proximity to large bodies of water (a major factor in atmospheric pressure changes), places like coastal regions and islands experience severe storms on a regular basis.

Meteorological Phenomena

Tornadoes, hail storms and fog are all examples of meteorological phenomena that are hard to predict. As an element of weather, these occurrences can seem random and are a result of a set of unique circumstances. However, some regions of the world can factor meteorological phenomena into their climate. For instance, the American Midwest's "Tornado Alley" (tornadoes), the Great Lakes region (lake effect snow), and places like London (fog) and Bangladesh (drastic and rapid climate changes) have these occurrences so often that they are an almost predictable part of the region's climate.

Importance of Measuring and Recording Weather and Climatic Element

- Helps in describing the climate of a place; weather it is equatorial climate or tropical climate among other climatic types.
- Helps farmers to plan when to plant their crops and when to harvest them.
- Important in the aviation industry, in that it helps pilots to know when to take off and when to land.
- Helps sailors at sea to timetable their journeys.
- Helps farmers to plan when to plant and when to harvest their crops.
- Helps people to plan what to put on or dress for the day for example they will know whether or not to put on a sweater or jacket and weather or no to carry an umbrella.
- Helps the government to prepare for disasters like floods, drought, and very strong winds among others.

4.2 Factors Influencing Weather and Climate

Relief: Highlands or mountains lead to the formation of relief rainfall on the windward side and dry conditions on the lee ward side.

Altitude: Highlands experience lower temperatures than low lands. The higher one goes the cooler it becomes.

Latitude: The tropical areas i.e. areas of low latitude experience higher temperatures and rainfall. Areas of higher latitude e.g. the temperate and Polar Regions, experience lower temperatures.

Water Bodies: Nearness to a large water body influences the climate of the area. Water bodies are sources of atmospheric moisture through evaporation and areas near them experience higher rainfall.

Natural Vegetation: Forested and wetland areas contribute to the atmospheric vapour though transpiration leading to the formation of rainfall. Areas without vegetation or limited vegetation experience less rainfall.

Prevailing Winds: Moist prevailing winds bring in rainfall unlike dry winds. Winds also help in the distribution of temperatures i.e. warm winds bring in warm conditions while cold winds bring in cool conditions.

Ocean Currents: These are moving ocean waters. They may be cold or warm i.e. cold and warm ocean currents. Warm ocean currents lead to the formation of high rainfall on the adjacent coastal areas. Cold ocean currents lead to low rainfall and formation of marine deserts in the adjacent coastal areas e.g. the Namib Desert.

Man's Activities: Activities like deforestation, swamp reclamation; industrialisation, etc. lead to semi arid and arid conditions through the process of desertification. In addition environmentally unfriendly human activities lead to global warming.

Also, weather and climate are different, they are very much interrelated. A change in one weather element often produces changes in the others element and in the region's climate. For example, if the average temperature over a region increases significantly, it can affect the amount of cloudiness as well as the type and amount of precipitation that occur. If these changes occur over long periods of time, the average climate values for these elements will also be affected.

4.3 Equipment of Standard Metrological Station

A Metrological station is a place where weather instruments are kept and used for measuring and recording the elements of weather. A similar facility which is bigger and more advanced is known referred to as a Meteorological station. A weather station is normally established in an open area free from any form of obstruction, to ensure accurate and reliable data collection. A major structure in a weather station is a Stevenson screen. The other instruments in a weather station include a rain gauge, wind vane, anemometer, evaporimeter, windsock, sunshine recorder etc. They are fenced off so that animals cannot get in and damage the equipment.

Rain Gauges

Rain gauges are used to determine the precipitation at a certain point which is representative for a certain area. It is essential that the day-figures have an accuracy of 0.2 mm.

Important characteristics of rain gauges are:

- They have adequate measuring area.
- It also has a collecting bucket with a sharp edge, a smooth inside and such a shape that splashing out of precipitation is avoided.

Rain Gauge, Type Rain-O-Matic

Combined electronic rain- and temperature meter with 10 m cable and digital read-out unit with memory and an accuracy of 1.0 mm is especially used at home. The digital LCD is placed indoors. The meter has a memory function for precipitation, and highest and lowest registered temperatures during the measuring period.

Rain Gauge with Large (External) Collecting Jar

Rain gauge consisting of a collecting funnel with collecting jar and measuring vessel placed in an open area. The rain gauge is connected to an external collecting jar (contents 20 litre) by a syphon tube. The rain gauge is specially designed for intensive precipitation (tropics). The collecting area measures 200 cm^2.

Standard Rain Gauge

Rain gauge (in accordance with DIN 58666C) consisting of a collecting funnel with a one litre collecting jar and measuring vessel of 0-10 mm with a 0.1 mm division with collecting area 200 cm2.

Mechanical Precipitation Recorder

It is a mechanical self-recording rain gauge with sheet metal funnels with limit ring and siphon with automatic drain after 10 mm height of precipitation. The precipitation recorder has a collecting area of 200 cm^2, and registration over a seven day period. Scale division 0.1 mm. Complete with recording sheets and accessories. The mechanical self-recording rain gauge is suitable for measuring the precipitation intensity (determination of precipitation peaks).

Thermometer

Temperature and Humidity

Temperature and humidity are two important meteorological parameters. They have a great influence on numerous processes in nature, such as the evaporation rate of water, germination of seeds and the spread of (plant) diseases. Especially the daily temperature cycle is important here. Measuring the air temperature usually takes place at a standard height. The thermometer must be protected against direct sunlight. This can be done by using a temperature screen.

Digital Thermometer

The K-thermocouple thermometer has a standard probe with a length of 12 cm packed in a case. There are also three specially designed compost temperature probes available with a length of 50, 100 and 150 cm.

The thermometer is waterproof (IP67), has a large display and membrane key-pad.

The thermometer can be used to measure temperature in degrees Celsius and Fahrenheit and has a measuring range of -50 to +150°C. Accuracy is 0.5°C. The display can be read to 0.1°C. The thermometer has options to display the measurement and to reset the maximum- and minimum temperature and hold facility. Power supply four 1.5 V AAA batteries. The stainless steel compost temperature probes have a handle and a rod with a diameter of 10 mm. The point of the rod contains a temperature sensor, thermical insulated from the rod by an insulation collar. Influence of heat exchange between rod and material to be measured is minimal. The instrument can also be used to measure temperature in ensilage, hay, peat or other soft materials or liquids.

Assmann Psychrometer

Model in chromed design, the model is equipped with two thermometers and a psychrometer with a measuring range of -10 to +60°C. The psychrometer is fitted with a mechanical ventilator. The accuracy of both thermometers is+/- 0.2°C, with division 0.2°C. The psychrometer is supplied inclusive accessories and psychrometer.

Portable Relative Humidity and Temperature Meter

The portable digital relative humidity and temperature meter displays directly relative humidity or temperature. The meter is equipped with a separate probe with 1.5 m cable and has a high contrast LCD display.

- Measuring range relative humidity 0 to 100 per cent
- Resolution 0.1 per cent,accuracy +/- 2 per cent
- Measuring range temperature -20 to +60°C
- Resolution 0.1°C accuracy +/- 0.2°C

Thermo-Hygrograph

The hydro-thermograph independently measures and records the relative humidity and temperature of the surroundings. This self-recording thermo hygrograph has a bimetal as temperature element and a hair-wire measuring element for humidity. The instrument is supplied with quartz clockwork (switchable 1, 7 or 31 days). Measuring range is 0-100 per cent relative humidity. The accuracy is +/- 2.5 per cent of the measuring range. Temperature range -10 to +50°C, and accuracy +/- 1%. Inclusive registration charts with recording period of seven days.

Piche Evaporation Meter

They are simple and cheap instrument for measuring the evaporation. A humid filter paper disk is used here under a glass measuring tube closed at one end and filled with water. The paper surface is constantly wetted with a division of 0 - 30 mm. Inclusive evaporation discs and disc holder. The instrument only indicates the evaporation rate; it is suitable for educational purposes.

Stevenson Screen

This is a specially designed box – like structure on stands in which some instruments for recording weather is kept. A Stevenson screen has a number of characteristics or features.

Important Features of a Stevenson Screen:

- It is made up of wood: i.e. to prevent absorption and conduction of heat.
- Panted white or silver grey; In order to reflect sunshine.
- Stands are one metre high: to avoid the influence of ground conditions.
- The sides and floor are made of louvers or slats to allow free circulation of air and to keep off direct sun rays.
- It has an insulated roof to create a bad conductor of heat. This is done by creating an air space between the layers of the roof.
- The roof is slanting to avoid the accumulation and stagnation of rain water.
- It stands on grass covered ground.
- It is fixed or placed far from buildings or obstacles to avoid any interference.

Campbell-Stokes Sunshine Recorders

Principles and Structure

A Campbell-Stokes sunshine recorder concentrates sunlight through a glass sphere onto a recording card placed at its focal point. The length of the burn trace left on the card represents the sunshine duration.

The focus shifts as the sun moves, and a burn trace is left on the recording card at the focal point. A burn trace at a particular point indicates the presence of sunshine at that time, and the recording card is scaled with hour marks so that the exact time of sunshine occurrence can be ascertained. Measuring the overall length of burn traces reveals the sunshine duration for that day. For exact measurement, the sunshine recorder must be accurately adjusted for planar levelling, meridional direction and latitude. Campbell-Stokes and Jordan sunshine recorders mark the occurrence of sunshine on recording paper at a position corresponding to the azimuth of the sun at the site, and the time of sunshine occurrence is expressed in local apparent time.

Reading of Recording Paper

To obtain uniform results for observation of sunshine duration with a Campbell-Stokes sunshine recorder, the following points should be noted when reading records:

- If the burn trace is distinct and rounded at the ends, subtract half of the curvature radius of the trace’s ends from the trace length at both ends. Usually, this is equivalent to subtracting 0.1 hours from the length of each burn trace.
- If the burn trace has a circular form, take the radius as its length. If there are multiple circular burns, count two or three as a sunshine duration of 0.1 hours, and four, five or six as 0.2 hours. Count sunshine duration this way in increments of 0.1 hours.
- If the burn trace is narrow, or if the recording card is only slightly discoloured, measure its entire length.
- If a distinct burn trace diminishes in width by a third or more, subtract 0.1 hours from the entire length for each place of diminishing width. However, the subtraction should not exceed half the total length of the burn trace.

Jordan Sunshine Recorders

A Jordan sunshine recorder lets in sunlight through a small hole in a cylinder or a semi- cylinder onto photosensitised paper set inside the cylinder on which traces are recorded. One common type has two hollow semicylinders arranged back to back with their flat surfaces facing east and west.

(a). Each flat surface has a small hole in it. The Jordan sunshine recorder used by JMA is the same in principle, but consists of a hollow cylinder with two holes.

(b). The instrument has its cylinders inclined to the relevant latitude and their axes set in the meridional direction. Photosensitised paper with a time scale printed on it is set in the cylinders in close contact with the inner surface. When direct solar radiation enters through the hole, the paper records the movement of the sun as a line. Sunshine duration is ascertained by measuring the length of time the paper was exposed to sunlight.

Radiometers (Solar Radiation Measuring Instruments)

A radiometer absorbs solar radiation at its sensor, transforms it into heat and measures the resulting amount of heat to ascertain the level of solar radiation. Methods of measuring heat include taking out heat flux as a temperature change (using a water flow pyrheliometer, a silver-disk pyrheliometer or a bimetallic pyranograph) or as a thermoelectromotive force (using a thermoelectric pyrheliometer or a thermoelectric pyranometer). In current operation, types using a thermopile are generally used.

The radiometers used for ordinary observation are pyrheliometers and pyranometers that measure direct solar radiation and global solar radiation, respectively, and these instruments are described in this section.

For details of other radiometers such as measuring instruments for diffuse sky radiation and net radiation, refer to ”Guide to Meteorological Instruments and Observation Methods” and “Compendium of Lecture Notes on Meteorological Instruments for Training Class III and Class IV Meteorological Personnel” published by WMO.

Evaporation Pan

The class-A evaporation pan is used to determine the evaporation rate of open water. The pan has a 1206 mm diameter and an inside height of 254 mm, an evaporation area of 1.15 m and is made of high grade stainless steel. The evaporation pan is supplied complete with highly qualified evaporation micrometer and stilling well (wave dampening cylinder), water level and wooden support for evaporation pan. Measuring range of the evaporation micrometer spans 100mm with accuracy 0.02mm. For a more exact use of the evaporation pan it is recommended to use an additional wind path meter.

For automatic measurement of the evaporation use can be made of a level sensor. The level sensor consists of a sensitive pressure transducer built in stainless steel housing. The sensor has a pressure range of 0-20 mbar, accuracy 0, 25 per cent. With output signal 0-20 mA, power supply voltage 8-28 V. The sensor is supplied with five m cable. The sensor is read-out with a data logger. To configure and read-out the data logger and to process the measuring data, use is made of the evaporation pan software.

Wind or Weather Vanes

Weather vanes are one of the oldest of all weather instruments, working by swinging around in the wind to show which direction it is blowing from. Traditionally, weather vanes had a religious importance and appeared in the form of weathercocks on church roofs as early as the ninth century AD. The head of the cockerel would point into the wind, indicating the direction the wind was blowing from. Weather vanes now appear in a wide variety of forms and it is even possible to make your own. Keep an eye out for weather vanes and see how many different types you see.

Wind Stocks

Another device used to measure the wind is a wind sock. This instrument is found mainly at airports, seaports and other open areas such as mountain roads where a very visual indication of the wind is needed. Wind socks actually show both the direction and speed of the wind. The direction is shown when the wind blows into the open end and the sock points the way the wind is blowing. An indication of wind strength is given by the shape and movement of the wind sock. If it is flapping about gently the wind is only light, whereas if it sticks out in a straight line the wind is much stronger. This information is very useful to people on both ships and planes, and sometimes to car drivers too. If you want to discover more about wind socks, why not make one for yourself.

Anemometer

The cup anemometer is at present the standard instrument used for mean wind speed measurement in wind energy. It is being applied in high numbers around the world for wind energy assessments. It is also applied exclusively for accredited power performance measurements for certification and verification purposes, and for purposes of optimisation in research and development. The little cups on this device catch the wind and spin round at different speeds according to the strength of the wind. A recording device is used to count how many times they spin round in a given time. If you have ever seen an anemometer, you will have noticed that the cups spin round very fast in a strong breeze.

4.4 Measurement of Wind Speed and Direction

Wind speed is the average velocity at which the air travels over a one-minute period and is measured in nautical miles per hour (NM/H or knots). The display is in miles per hour (mph), with the knots in parentheses.

Wind speed has always meant the movement of air in an outside environment, but the speed of air movement inside is important in many areas, including weather forecasting, aircraft and maritime operations, building and civil engineering. High wind speeds can cause unpleasant side effects, and strong winds often have special names, including gales, hurricanes, and typhoons.

Wind speed is typically judged as the velocity of wind. Most measurements of air movement are taken of outside air, and there are several factors that can affect it. Average wind speed is often determined by an anemometer and is usually categorised in a standardised measurement scale, called the Beaufort scale.

Factors Affecting Wind Speed

Wind speed is affected by a number of factors and situations, operating on varying scales (from micro to macro scales). These include the pressure gradient, Rossby waves and jet streams, and local weather conditions. There are also links to be found between wind speed and wind direction, notably with the pressure gradient and surfaces over which the air is found.

Pressure gradient is a term to describe the difference in air pressure between two points in the atmosphere or on the surface of the Earth. It is vital to wind speed, because the greater the difference in pressure, the faster the wind flows (from the high to low pressure) to balance out the variation. The pressure gradient, when combined with the Coriolis Effect and friction, also influences wind direction.

Rossby waves are strong winds in the upper troposphere. These operate on a global scale and move from West to East (hence being known as Westerlies). The Rossby waves are themselves a different wind speed from what we experience in the lower troposphere.

Local weather conditions play a key role in influencing wind speed, as the formation of hurricanes, monsoons and cyclones as freak weather conditions can drastically affect the velocity of the wind.

The major factors that influence wind speed, the most important is called the pressure gradient, created by a graduated disparity in atmospheric pressure that occurs in different places. Some areas have low pressure, while others have higher pressure. For example, a valley may have a higher atmospheric pressure than the peak of a mountain that is only a few miles away. Usually, the pressure increases gradually between both points.

An anemometer measures the force or speed of the wind. A common anemometer uses cups mounted on four horizontal arms at equal distance from each other on a vertical shaft. The air flow past the cups turns the cups in proportion to the speed of the wind.

Many anemometers convert the revolutions per minute into wind speed measured in several different ways:

MPH (miles per hour) – unit of speed measuring the number of miles covered in a period of one hour.

Knots – units of speed measuring one nautical mile per hour.

M/S (meters per second) – unit of speed measuring the number of meters covered in one second.
F/S (feet per second) – unit of speed that tells the number of feet covered in one second.

KM/H (kilometres per hour) – unit of speed that tells the number of kilometres covered in one hour.

Information about wind speed, collected from anemometers world-wide, is used by weather forecasters, pilots, sailors, scientists and builders for planning and management purpose.

A crane operator, for example, needs to know wind speed and direction when there are plans to operate a tall crane. A landfill must know the behaviour of the wind in order to maintain odour control. The speed at which the wind is moving the clouds is especially important in forecasting (predicting) the weather.

Wind Direction

Wind direction is reported by the direction from which it originates. For example, a northerly wind blows from the north to the south. Wind direction is usually reported in cardinal directions or in azimuth degrees. So, for example, a wind coming from the south is given as 180 degrees; one from the east is 90 degrees.

Winds are caused by many different climactic conditions. The ocean currents, temperature and air pressure have a large impact of wind direction. When two areas have different levels of air pressure, air tends to flow from the high-pressure area into the low-pressure area to balance the system, creating winds. Often, pressure differences are accompanied by rainstorms, or even tornadoes or hurricanes.

Wind direction is the direction from which a wind originates. It is usually reported in cardinal directions or in azimuth degrees.

There are a variety of instruments used to measure wind direction, such as the wind stocks and wind vane. Both of these instruments work by moving to minimise air resistance. The way a weather vane is pointed by prevailing winds indicates the direction from which the wind is blowing. The larger opening of a windsock faces the direction that the wind is blowing from; its tail with the smaller opening points in the direction the wind is blowing.

True Wind Direction Indicators

1. Flags and Windsocks: Flags and windsocks are an excellent way to determine where the true wind is coming from. This does not include a flags or windsock on the boat or other boats that may be moving. It has to be a stationary object to give an accurate true direction; otherwise you'll get the apparent direction instead.
2. Smoke Stacks: Smoke coming from a smoke stack will help to give an indication of the true direction. Smoke will fly away from the true direction. Steam can also give an indication of the direction, but tends to dissipate quickly making it hard to follow.
3. Water Surface: The surface of the water can indicate the true direction of the wind. Water will create wavelets that are horizontal to the true direction.
4. Boats Anchored or Moored: When a boat is anchored or moored, it will sway away from the wind and its bow will eventually face into it. It's important to keep in mind that the current may affect how the boat is positioned in the water, so this method may only provide an approximation of the true direction.
5. Trees and Plants: If the wind is strong enough to move a tree then it can be used to determine the direction of the true wind. In the fall, leaves falling to the ground or pollen moving through the air can also be used to understand the changing patterns in the area.

Apparent Wind Direction Indicators

1. Masthead Wind Indicator: One of the best ways to determine the apparent wind direction on your boat is to use a masthead indicator. The masthead indicator is impacted by the direction of the boat as it moves through the water as well as the true wind. It will give you an accurate account of how the wind is acting on your boat at any point in time. You can also check out the masthead indicators of other boats to determine how the wind is affecting them and what may be coming your way.
2. Club Burgee: Another method to determine the apparent wind is to look at club burgees. Like the masthead indicator, it will provide an accurate assessment of the current apparent direction.
3. Face: The feeling of the wind on your face while you're on the boat will provide a rough estimate of the apparent direction. Trust your instincts and they will help you guide the boat.
4. Testing the Wind: If a masthead indicator isn't available, you can always test the wind by turning the boat into the wind until the sails begin to luff. This will give you a rough indication of the apparent direction based on the edge of the 'no go' zone.
5. String: Another method of determining the apparent direction is attaching a string to a shroud. The string will fly away from the apparent wind and can be used as a continual visual indicator while you are sailing. This method is a favourite among many sailors since you don't have to strain to look up at the masthead indicator. In addition, many strings can be tied to several places on the shrouds to see how the wind is impacting different parts of the boat.

Methods of Determining Wind Speed and Direction

Wind-sock Method

- Suspend a wind-sock on a tall pole that is unobstructed from the wind by buildings, trees, etc. Note the direction of wind using a compass. Note that direction is measured in degrees so a wind from the east (easterly) is recorded as $90\ ^{o}$ and from the south-east as 135^{o}.Take readings in the morning and afternoon.

Wind vane Method

- A more accurate way is to use a wind vane, on a 6–10 ft (1.8–3.0 m) pole, connected to a meter or data logger. Recordings can be averaged daily and plotted as a radial diagram. **Anemometer Method**
- Measure wind speed in an unobstructed area. Hold the anemometer or pitot gauge tube at arm’s length and read off the wind speed in kilometres per hour.
- Some gauges will give a number against the pith ball path that is converted on a table to kilometres per hour.
- Daily statistics can be more easily obtained from an electronic anemometer wired to a meter/data logger.
- Repeat at the same time each day.

5.0 CONCLUSION

You learnt that weather is the current atmospheric conditions, including temperature, rainfall, wind, and humidity at a given place. If you stand outside, you can see that it's raining or windy, or sunny or cloudy. You can tell how hot it is by taking a temperature reading. Weather is what's happening right now or is likely to happen tomorrow or in the very near future.

Climate, on the other hand, is the general weather conditions over a long period of time. For example, on any given day in January, we expect it to be rainy in Portland, Oregon and sunny and mild in Phoenix, Arizona. And in Buffalo, New York, we are not surprised to see January newscasts about sub-zero temperatures and huge snow drifts.

6.0 ACTIVITY

1. Explain the statement “It is a rainy, windy, sunny or cloudy day in Kaduna”.
2. Explain the statement “on any given day in September it is expected to rainy Lagos, sunny in Sokoto and mild in Jos”.
3. How many days will it take for a heat wave, moving at 50km/h to reach a town 6000km along its path?

7.0 SUMMARY

In this unit the following topics were explained:

- Elements of weather & climate and importance of measuring
- Factors influencing weather and climate
- Equipment of standard metrological station
- Measurement of wind speed and direction.

8.0 ASSIGNMENT

1. What are the factors influencing weather and climate.
2. Write short note on all element of weather and climate.
3. Write short notes on any five of standard meteorological equipment.
4. List and explain the true and apparent wind direction indicators.

9.0 REFERENCES/FURTHER READING

Dahlberg, J.Å., et al. (2001). “Development of a Standardised Cup Anemometer Suited to Wind Energy Applications.” *Contract JOR3*-CT98-0263.

Dahlberg, J.Å., Pedersen, T.F. & Westermann, D. (2000). “Development of a Standardised Cup Anemometer Suited to Wind Energy Applications.” *CLASSCUP EWEC*, 2000

UNIT 3 RADIATION AND MEASUREMENT

CONTENT

1.0 INTRODUCTION

Radiation quantities may be classified into two groups according to their origin, namely solar and terrestrial radiation.

Solar energy is the electromagnetic energy emitted by the sun. The solar radiation incident on the top of the terrestrial atmosphere is called extraterrestrial solar radiation; 97 per cent of which is confined to the spectral range 290 to 3000 nm are called solar (or sometimes short-wave) radiation. Part of the extra-terrestrial solar radiation penetrates through the atmosphere to the Earth's surface, while part of it is scattered and/or absorbed by the gas molecules, aerosol particles, cloud droplets and cloud crystals in the atmosphere.

Terrestrial radiation is the long-wave electromagnetic energy emitted by the Earth's surface and by the gases, aerosols and clouds of the atmosphere; it is also partly absorbed within the atmosphere. For a temperature of 300 K, 99.99 per cent of the power of the terrestrial radiation has a wavelength longer than 3 000 nm and about 99 per cent longer than 5_000 nm. For lower temperatures, the spectrum is shifted to longer wavelengths.

The various fluxes of radiation to and from the Earth's surface are among the most important variables in the heat economy of the Earth as a whole and at any individual place at the Earth's surface or in the atmosphere. Radiation measurements are used for the following purposes:

- to study the transformation of energy within the Earth-atmosphere system and its variation in time and space
- to analyse the properties and distribution of the atmosphere with regard to its constituents, such as aerosols, water vapour, ozone, and so on
- to study the distribution and variations of incoming, outgoing and net radiation
- to satisfy the needs of biological, medical, agricultural, architectural and industrial activities with respect to radiation
- to verify satellite radiation measurements and algorithms.

Measurement Methods

Meteorological radiation instruments are classified using various criteria, namely the type of variable to be measured, the field of view, the spectral response, the main use etc.

Absolute radiometers are self-calibrating, meaning that the irradiance falling on the sensor is replaced by electrical power, which can be accurately measured. The substitution, however, cannot be perfect; the deviation from the ideal case determines the uncertainty of the radiation measurement.

Most radiation sensors, however, are not absolute and must be calibrated against an absolute instrument. The uncertainty of the measured value, therefore, depends on the following factors, all of which should be known for a well characterised instrument:

(a) Resolution, namely, the smallest change in the radiation quantity which can be detected by the instrument;
(b) Drifts of sensitivity (the ratio of electrical output signal to the irradiance applied) over time;
(c) Changes in sensitivity owing to changes of environmental variables, such as temperature, humidity, pressure and wind;
(d) Non-linearity of response, namely, changes in sensitivity associated with variations in irradiance;
(e) Deviation of the spectral response from that postulated, namely the blackness of the receiving surface, the effect of the aperture window, and so on;
(f) Deviation of the directional response from that postulated, namely cosine response and azimuth response;
(g) Time-constant of the instrument or the measuring system;
(h) Uncertainties in the auxiliary equipment.

Instruments should be selected according to their end-use and the required uncertainty of the derived quantity. Certain instruments perform better for particular climates, irradiances and solar positions.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- explain the measurement and calibration of radiation
- discuss the measurement and instrument of solar radiation

- discuss the measurement and instrument of total and long-wave radiation
- describe the measurement and instrument for UV radiation
- explain the measurement and instrument of sunshine duration.

2.1 HOW TO STUDY THIS UNIT

1. You are expected to read carefully through this unit at least twice before attempting to answer the self-assessment questions or tutor- marked assignment.
2. Do not look at the solution given at the end of the unit until you are satisfied that you have done your best to get all answers.
3. Share your difficulties with your course mates, facilitators and by consulting other related material, particularly the internet.
4. Note that if you follow the instructions you will feel self fulfilled that you have achieved the aim of studying this unit. This should stimulate you to do more.

3.0 WORD STUDY

Terrestrial- relating to land
Spectrum- a range possibly bounded by extremes

4.0 MAIN CONTENT

4.1 Measurement of Solar Radiation

Everything in nature emits electromagnetic energy, and solar radiation is energy emitted by the sun. The energy of extraterrestrial solar radiation is distributed over a wide continuous spectrum ranging from ultraviolet to infrared rays. In this spectrum, solar radiation in short wavelengths (0.29 to 3.0 m) accounts for about 97 per cent of the total energy.

Solar radiation is partly absorbed, scattered and reflected by molecules, aerosols, water vapour and clouds as it passes through the atmosphere. The direct solar beam arriving directly at the earth’s surface is called direct solar radiation. The total amount of solar radiation falling on a horizontal surface (i.e. the direct solar beam plus diffuse solar radiation on a horizontal surface) is referred as global solar radiation.

Direct solar radiation is observed from sunrise to sunset, while global solar radiation is observed in the twilight before sunrise and after sunset, despite its diminished intensity at these times.

The solar irradiance is expressed in watts per square meter (W/m^2) and the total amount in joules per square meter (J/m^2). Conversion between the currently used unit (SI) and the former unit (calories) can be performed using the following formulae: Solar irradiance: 1 $kW/m^2 = 1.433$ $cal/cm^2/min$. Total amount of solar radiation: 1 $MJ/m^2 = 23.89$ cal/cm^2

Measurement Methods

The principles used for measuring sunshine duration and the pertinent types of instruments are briefly listed in the following methods:

(a) **Pyrheliometric method**: Pyrheliometric detection of the transition of direct solar irradiance through the 120 W m^{-2} thresholds (according to recommendation 10 (CIMO-VIII)). Duration values are readable from time counters triggered by the appropriate upward and downward transitions.

Type of instrument: pyrheliometer combined with an electronic or computerised threshold discriminator and a time-counting device.

(b) Pyranometric method:

(i) Pyranometric measurement of global (G) and diffuse (D) solar irradiance to derive the direct solar irradiance as the WMO threshold discriminator value and further as in (a) above.

Type of instrument: Radiometer systems of two fitted pyranometers and one sunshade device combined with an electronic or computerised threshold discriminator and a time-counting device.

(ii) Pyranometric measurement of global (G) solar irradiance to roughly estimate sunshine duration.
Type of instrument: a pyranometer combined with an electronic or computerised device which is able to deliver 10 min means as well as minimum and maximum global (G) solar irradiance within those 10 min.

(b) **Burn method**: Threshold effect of burning paper caused by focused direct solar radiation
(This is heat effect of absorbed solar energy). The duration is read from the total burn length.
Type of instrument: Campbell-Stokes sunshine recorders, especially the recommended version, namely the IRSR.

(c) **Contrast method**: Discrimination of the insolation contrasts between some sensors in different positions to the sun with the aid of a specific difference of the sensor output signals which corresponds to an equivalent of the WMO recommended threshold (determined by comparisons with reference SD values) and further as in (b) above.
Type of instrument: Specially designed multisensory detectors (mostly equipped with photovoltaic cells) combined with an electronic discriminator and a time counter.

(d) **Scanning method**: Discrimination of the irradiance received from continuously scanned, small sky sectors with regard to an equivalent of the WMO recommended irradiance threshold (determined by comparisons with reference SD values).

4.1.1 Measurement of Direct Solar Radiation

Direct solar radiation is measured by means of pyrheliometers, the receiving surfaces of which are arranged to be normal to the solar direction. By means of apertures, only the radiation from the sun and a narrow annulus of sky is measured, the latter radiation component is sometimes referred to as circumsolar radiation or aureole radiation. In modern instruments, this extends out to a half-angle of about 2.5° on some models, and to about 5° from the sun's centre (corresponding, respectively, to 6 · 10–3 and 2.4 · 10–2 sr). The pyrheliometer mount must allow for the rapid and smooth adjustment of the azimuth and elevation angles. A sighting device is usually included in which a small spot of light or solar image falls upon a mark in the centre of the target when the receiving surface is exactly normal to the direct solar beam. For continuous recording, it is advisable to use automatic sun following equipment (sun tracker).

Primary Standard Pyrheliometers
An absolute pyrheliometer can define the scale of total irradiance without resorting to reference sources or radiators. The limits of uncertainty of the definition must be known; the quality of this knowledge determines the reliability of an absolute pyrheliometer. Only specialised laboratories should operate and maintain primary standards. Details of their construction and operation are given in WMO (1986a). However, for the sake of completeness, a brief account is given here.

All absolute pyrheliometers of modern design use cavities as receivers and electrically calibrated, differential heatflux meters as sensors. At present, this combination has proved to yield the lowest uncertainty possible for the radiation levels encountered in solar radiation measurements (namely, up to 1.5 kW m^{-2}).

Normally, the electrical calibration is performed by replacing the radiative power by electrical power, which is dissipated in a heater winding as close as possible to where the absorption of solar radiation takes place.

The uncertainties of such an instrument's measurements are determined by a close examination of the physical properties of the instrument and by performing laboratory measurements and/or model calculations to determine the deviations from ideal behaviour, that is, how perfectly the electrical substitution can be achieved.

4.2 Measurement of Total and Long-Wave Radiation

The measurement of total radiation includes both short wavelengths of solar origin (300 to 3_000 nm) and longer wavelengths of terrestrial and atmospheric origin (3_000 to 100_000 nm). The instruments used for this purpose are pyrradiometers. They may be used for measuring either upward or downward radiation flux components, and a pair of them may be used to measure the differences between the two, which is the net radiation. Single-sensor.

pyrradiometers with an active surface on both sides, are also used for measuring net radiation. Pyrradiometer sensors must have a constant sensitivity across the whole wavelength range from 300 to 100_000 nm.

Instruments for the Measurement of Total Radiation

One problem with instruments for measuring total radiation is that there are no absorbers which have a completely constant sensitivity over the extended range of wavelengths concerned. Similarly it is difficult to find suitable filters that have constant transmission between 300 and 100000 nm.

The use of thermally sensitive sensors requires a good knowledge of the heat budget of the sensor. Otherwise, it is necessary to reduce sensor convective heat losses to near zero by protecting the sensor from the direct influence of the wind. The technical difficulties linked with such heat losses are largely responsible for the fact that net radiative fluxes are determined less precisely than global radiation fluxes. In fact, different laboratories have developed their own pyrradiometers on technical bases which they consider to be the most effective for reducing the convective heat transfer in the sensor. During the last few decades, pyrradiometers have been built which, although not perfect, embody good measurement principles. Thus, there is a great variety of pyrradiometers employing different methods for eliminating, or allowing for, wind effects, as follows:

- no protection, in which case empirical formulae are used to correct for wind effects
- determination of wind effects by the use of electrical heating
- stabilisation of wind effects through artificial ventilation
- elimination of wind effects by protecting the sensor from the wind.

4.3 Measurement of UV Radiation

Measurements of solar UV radiation are in demand because of its effects on the environment and human health, and because of the enhancement of radiation at the Earth’s surface as a result of ozone depletion (Kerr and McElroy, 1993). The UV spectrum is conventionally divided into three parts, as follows:

(a) UV-A is the band with wavelengths of 315 to 400 nm, namely, just outside the visible spectrum. It is less biologically active and its intensity at the Earth’s surface does not vary with atmospheric ozone content.

(b) UV-B is defined as radiation in the 280 to 315 nm band. It is biologically active and its intensity at the Earth’s surface depends on the atmospheric ozone column, to an extent depending on wavelength. A frequently used expression of its biological activity is its perythemal effect, which is the extent to which it causes the reddening of white human skin.

(c) UV-C, in wavelengths of 100 to 280 nm, is completely absorbed in the atmosphere and does not occur naturally at the Earth’s surface.

UV-B is the band on which most interest is centred for measurements of UV radiation. An alternative, but now nonstandard, definition of the boundary between UV-A and UV-B is 320 nm rather than 315 nm.

Measuring UV radiation is difficult because of the small amount of energy reaching the Earth's surface, the variability due to changes in stratospheric ozone levels, and the rapid increase in the magnitude of the flux with increasing wavelength.

Instruments

Three general types of instruments are available commercially for the measurement of UV radiation. The first class of instruments use broadband filters. These instruments integrate over either the UV-B or UV-A spectrum or the entire broadband UV region responsible for affecting human health. The second class of instruments use one or more interference filters to integrate over discrete portions of the UV-A and/or UV-B spectrum. The third class of instruments are spectro radiometers that measure across a pre-defined portion of the spectrum sequentially using a fixed pass band.

4.4 Measurement of Sunshine Duration

Sunshine duration is the length of time that the ground surface is irradiated by direct solar radiation (i.e., sunlight reaching the earth's surface directly from the sun). In 2003, WMO defined sunshine duration as the period during which direct solar irradiance exceeds a threshold value of 120 watts per square meter (W/m^2). This value is equivalent to the level of solar irradiance shortly after sunrise or shortly before sunset in cloud-free conditions. It was determined by comparing the sunshine duration recorded using a Campbell-Stokes sunshine recorder with the actual direct solar irradiance.

Sunshine Duration Measuring Instruments

Campbell-Stokes sunshine recorders and Jordan sunshine recorders have long been used as instruments to measure sunshine duration, and are advantageous in that they have no moving parts and require no electric power. Their disadvantages are that the characteristics of the recording paper or photosensitised paper used in them affect measurement accuracy, differences between observers may arise in determining the occurrence of sunshine, and the recording paper must be replaced after sunset. As sunshine is defined quantitatively at present, a variety of photoelectric sunshine recorders has been developed and is used in place of these instruments. As the threshold value for the occurrence of sunshine is defined in terms of direct solar irradiance, it is also possible to observe sunshine duration with a pyrheliometer.

5.0 CONCLUSION

Sunshine recorders and radiometers should be installed in a location where solar radiation is not shaded by trees or buildings in any season from sunrise to sunset and where there are no smoke emission sources. Pyranometers in particular should be installed at a site where the instrument is not influenced by intense reflected light from the wall surfaces of buildings. Usually, such instruments are installed on rooftops or towers, but the convenience of routine maintenance and checking tasks such as cleaning of the sensor part should be taken into consideration.

When installing a sunshine duration or solar radiation instrument, it must be set properly using a spirit level. It must also be oriented in the prescribed direction using the meridional plane as reference with its elevation angle set to the latitude of the site. It should be checked that the pyranometer's output does not fluctuate when the sensor rotates in clear weather.

6.0 ACTIVITY

1. What will happen to the Earth;
i) with clear skies
ii) with cloud cover
on a sunny day?
2. What will happen to the Earth;
i) with clear skies
ii) with cloud cover
on a moonlight day?
3. What will happen to the Earth if the sun dies?

7.0 SUMMARY

In this unit, you have learnt measurement of sunshine duration, measurement of UV radiation, measurement of total and long-wave radiation, and measurement of direct solar radiation

8.0 TUTOR-MARKED ASSIGNMENT

1. Write short notes on the following:
   a. Sunshine duration
   b. UV radiation
   c. Long-wave radiation
2. Give a detail description of measurement and instrument of solar radiation.
3 Give a detail account of the measurement and instrument of total and long-wave radiation.

9.0 REFERENCES/FURTHER READING

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UNIT 4 TEMPERATURE AND MEASUREMENT

CONTENT

1.0 INTRODUCTION

Temperature is a measure of the sensation of warmth or coldness of an object, felt from contact with it. This sensation of touch gives an approximate or relative measure of the temperature. Temperature is measured in different scales, including Fahrenheit (F) and Celsius (or centigrade, C). The units of the Fahrenheit and Celsius scales are called degrees and are denoted by. Swedish astronomer Anders Celsius devised the Celsius scale in 1742. He fixed the of the scale at the freezing of water, and the at the boiling of water.

In simple terms, temperature is the ‘degree of hotness’ of an object or, more specifically in science and technology, the ‘potential for heat transfer’.

A proper understanding of what it is, and how it relates to heat, was only developed in the mid-to-late 19th century, when it was realised that it is a measure of the average energy of an ensemble of particles at equilibrium. The particles may be the atoms or molecules of a gas, a liquid or a solid, but they may also be the ‘photons’ of electromagnetic radiation inside a closed blackbody cavity.

If two objects are placed in contact, heat will flow from the hotter to the colder. Eventually, when no more heat flows, we can say that they are at equilibrium with each other and that their temperatures are the same. We use this property in measuring temperature when we place a thermometer in contact with an object: the reading of the thermometer after they have reached equilibrium tells us what the temperature of the object is.

It is easy to demonstrate that when two objects of the same material are placed together (physicists say when they are put in thermal contact), the object with the higher temperature cools while the cooler object becomes warmer until a point is reached after which no more change occurs, and to our senses, they feel the same. When the thermal changes have stopped, we say that the two objects (physicists define them more rigorously as systems) are in thermal equilibrium. We can then define the temperature of the system by saying that the temperature is that quantity which is the same for both systems when they are in thermal equilibrium.

If we experiment further with more than two systems, we find that many systems can be brought into thermal equilibrium with each other; thermal equilibrium does not depend on the kind of object used. Put more precisely, if two systems are separately in thermal equilibrium with a third, then they must also be in thermal equilibrium with each other, and they all have the same temperature regardless of the kind of systems they are.

Strictly this is the ideal case – to come to equilibrium they must be isolated from any other objects and their surrounding environment. We would also like the thermometer to be small enough that it does not upset the temperature of the object under measurement. Many of the difficulties of measuring temperature come from achieving these conditions.

Further ideas about temperature and its significance in physics and engineering came through the development of the second law of thermodynamics, which considers the fundamental limits to the conversion of heat into work. They are discussed in textbooks of thermodynamics.

The important point to note here is that the second law shows how a ‘thermodynamic’ (absolute) temperature can be derived as a fundamental parameter of physics and chemistry, independent of any particular material property (like the expansion of a liquid or the resistance of a wire). Thus experiments to measure thermodynamic temperature, using the fundamental laws governing the properties of gases or thermal radiation, should all give the same results. Such experiments are very difficult and time-consuming, but they nevertheless form the basis of the temperature scale used in science, technology and everyday life.

To put the measurement of temperature on a quantitative and objective basis, with sufficient accuracy, we need an agreed unit and temperature scale, and reliable thermometers to work with the accurate measurement of temperature is vital across a broad spectrum of human activities, including industrial processes (e.g. making steel), manufacturing; monitoring (in food transport and storage), and in health and safety. In fact, in almost every sector, temperature is one of the key parameters to be measured.

The two temperature scales commonly in use today date from the 18th century and are named after Gabriel Daniel Fahrenheit and the Swedish astronomy professor Anders Celsius. Fahrenheit designed his scale to have two reference points that could be set up in his workshop. He originally chose the melting point of pure ice and the temperature of a normal human body, which he took as being 32° and 96° respectively. These conveniently gave positive values for all the temperatures he encountered. Later he changed to using the boiling point of water (212°) as the upper fixed point of the scale.

Celsius also used the ice and steam points, but took them to be 0°C and 100°C respectively. Although the Celsius scale has taken precedence over the Fahrenheit scale, the latter is still familiar in weather reports in the United Kingdom: a summer’s day temperature of 75°F seems much more pleasant than one of 23°C!

A third, fundamental, temperature scale was proposed in 1854 by the Scottish physicist William Thomson, Lord Kelvin. It is based on the idea of the absolute zero, the point of no discernible energy, which is independent of any particular material substance. The Kelvin scale is widely used by physicists and engineers to determine and apply fundamental laws of thermodynamics.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- examine the evolution and growth of the use of thermometer;
- discuss the types and classification of thermometer ;
- examine the development of thermometers and temperature scales; and
- explain kinetic theory.

2.1 HOW TO STUDY THIS UNIT

1. You are expected to read carefully through this unit at least twice before attempting to answer the self-assessment questions or tutor- marked assignment.
2. Do not look at the solution given at the end of the unit until you are satisfied that you have done your best to get all answers.
3. Share your difficulties with your course mates, facilitators and by consulting other related material, particularly the internet.
4. Note that if you follow the instructions you will feel self fulfilled that you have achieved the aim of studying this unit. This should stimulate you to do more.

3.0 WORD STUDY

Kink- a tight curl, twist, or bend in a length of thin material
Kinetic- relating to motion

4.0 MAIN CONTENT

4.1 History of Thermometry

A thermometer is used to measure the temperature of an object – it is used to find how cold or hot the object is. Galileo invented a rudimentary water thermometer in 1593. He called this device a "thermoscope". However, this form was ineffective as water freezes at low temperatures. In 1714, Gabriel Fahrenheit invented the mercury thermometer, the modern thermometer. The long narrow uniform glass tube is called the stem of a thermometer. The small tube called the bulb, which contains mercury. Mercury is toxic, and it is very difficult to dispose it when the thermometer breaks. So, nowadays digital thermometers are used to measure the temperature, as they do not contain mercury

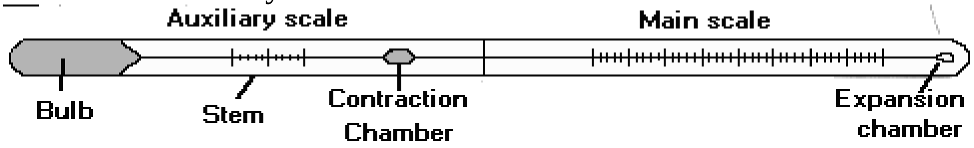

Fig.4.1: Mercury-in-Glass Thermometer

The mercury-in-glass thermometer illustrated in Figure 4.1 contains a bulb filled with mercury that is allowed to expand into a capillary. Its rate of expansion is calibrated on the glass scale.

The most significant 17th century contribution to the study of heat was the appearance of the thermometer a term apparently first used by Leurchon in 1626. The first thermometers, introduced early in the century, were air thermometers, of which there were two types: the open (Italian) and the differential (Dutch). The discovery of the former has been popularly associated with Galileo, but the evidence is inconclusive, being based on assertions by his friends and pupils. Independent discovery has also been attributed to Santorio Santorii and Robert Fludd. The first known description of an open air thermometer is that of Santorio Santorii in 1611, and the first diagram is that in the Telioux manuscript (Rome, 1611). The discovery of the differential air thermometer is usually attributed to Cornelius Drebbel. Air thermometers were quite common in the second quarter of the 17th century, but, with the awareness (from the 1640s) of the variability of atmospheric pressure, the main defect of the open variety (i.e. its response to pressure as well as temperature changes) became apparent.

For liquid—in—glass thermometers, the question of discovery is less ambiguous. The open variety was invented by Jean Rey, a French doctor living in the Dordogne, before 1632. Two sealed varieties (Florentine thermometers), the familiar liquid-in-glass model and another based on changes in liquid density with temperature, were invented by the Grand Duke Ferdinand II of Tuscany, a member of the Medici family, around the mid-l7th century. Such thermometers, particularly the usual liquid-in—glass type, were widely used. Various liquids, including mercury, were tried, but initially spirit of wine was preferred because of its greater coefficient of thermal expansion. In 1713 Daniel Gabriel Fahrenheit (1686-1736) experimented with the use of mercury, and four years later he began to make mercury—in-glass thermometers commercially. These and imitations thereof soon became the most widely used model.

In the second half of the 17th century, the need for a satisfactory temperature scale was recognised; in the 1660s, for example, the Royal Society of London, Huygens, and Boyle independently referred to the importance of making thermometers comparable. An early attempt to do so was that of Robert Hooke in his Micrographia (1665); this scale was based on a single fixed point (the freezing point of water), and the degree corresponded to a particular fractional change (1/1000) in the volume of a liquid (spirit of wine). There followed a proliferation of temperature scales; the mid-l8th century saw thermometers with more than a dozen scales attached. Only three survived into the 19th century: the Raumur, Celsius and Fahrenheit scales. These were based on two fixed points, although the first started off as a one fixed point scale. Eventually, the melting and boiling points of water became the accepted fixed points, but doubts about the constancy of these lingered well into the 18th century. In the 1690s, Halley and Amontons independently reported the constancy of the boiling point of water, but some doubted this. It was fairly widely believed that the freezing point of water was lower in cold climates.

Early Thermometric Studies

Thermometric measurements from the mid-l7th to the mid-l8th century yielded many, now familiar results: thermal equilibrium, thermal expansion, the constancy of melting and boiling points at constant pressure, their variations with pressure, the temperature changes accompanying many chemical reactions, the depression of the freezing point when salts are added to water, and so on. It is sometimes difficult to appreciate that such results were often controversial.

The means of accurately measuring temperatures has long fascinated people. One of the differences between temperature and other physical concepts, such as mass or length, is that it is subjective: different people will have different perceptions of what is hot and what is cold. To make objective measurements, we must use a thermometer in which some physical property of a substance changes with temperature in a reliable and reproducible way.

Thermoscopes, the ancestors of modern thermometers, have been around since about 200 BC. The first recognisable, modern thermometers were made in the 16th century by both the Italian Galileo Galilei and Santorio Santorio, a physician to the King of Poland. The latter produced a thermometer incorporating a scale, and his writings show that he understood the importance of the temperature measurement in the diagnosis of disease. The first sealed thermometer was made by the Grand Duke Ferdinand of Tuscany in 1641. This thermometer was more accurate than its predecessors since it wasn’t dependent on atmospheric pressure. Later, the scientists Fahrenheit and Celsius both made glass thermometers containing mercury, and used reference points (the melting point of pure ice and the boiling point of water) to improve the accuracy.

4.2 Types and Classification of Thermometer

Liquid-in-Glass Thermometer

Liquid-in-glass, in particular mercury, thermometers have been used for almost 300 years in science, medicine and metrology and in industry. They rely on the expansion of a fluid with temperature. The fluid is contained in a sealed glass bulb and the temperature is read using a scale etched along the stem of the thermometer.

Platinum Resistance

In the modern world, mercury and spirit-filled thermometers have largely given way to electrical devices, which can be digitised and automated. Platinum resistance thermometers are electrical thermometers which make use of the variation of resistance of high-purity platinum wire with temperature. This variation is predictable, enabling accurate measurements to be performed. They are sensitive and, with sophisticated equipment, measurements can routinely be made to better than a thousandth part of 1°C.

Thermocouples

Thermocouples are the most common sensors in industrial use. They have a long history, the original paper on thermoelectricity by Seebeck being published in 1822. They consist of two dissimilar metallic conductors joined at the point of measurement. When the conductors are heated a voltage is generated in the circuit, and this can be used to determine the temperature.

Radiation Thermometer (or Pyrometers)

Radiation thermometers, or pyrometers, make use of the fact that all objects emit thermal radiation, as seen when looking at the bars of an electric fire or a light bulb. The amount of radiation emitted can be measured and related to temperature using the Planck law of radiation. Temperatures can be measured remotely using this technique, with the sensor situated some distance away from the object. Hence it is useful for objects that are very hot, moving or in hazardous environments.

Classification of Thermometers

There are different types of thermometers that measure the temperatures of different things like air, our bodies, food and many other things. There are clinical thermometers, laboratory thermometers, Galileo thermometers and digital remote thermometers. Among these, the commonly used thermometers are clinical thermometers and laboratory thermometers

Clinical Thermometer

These thermometers are used to measure the temperature of the human body, at home, clinics and hospitals. All clinical thermometers have a kink that prevents the mercury from falling down rapidly so that the temperature can be noted conveniently. There are temperature scales on either side of the mercury thread, one in Celsius scale and the other in Fahrenheit scale

A clinical thermometer indicates temperatures from 35^0C to 42^0C or 940F to 1080F note a reading, place the thermometer in the person's mouth. Since the Fahrenheit scale is more sensitive than the Celsius scale, body temperature is measured in degrees Fahrenheit only. A healthy person's average body temperature is between 98.60F and 98.80F

Precautions
Wash the thermometer before and after use with an antiseptic solution, and handle it with care.

See that the mercury levels are below the kink and don't hold the thermometer near its bulb.

While noting down the reading in the thermometer, place the mercury level along the eye sight.

Do not place the thermometer in a hot flame or in the hot sun

Laboratory Thermometers
These thermometers are used to measure the temperature in school and other laboratories for scientific research. They are also used in the industry as they can measure temperatures higher than what clinical thermometers can record. The stem and the bulb are longer when compared to that of a clinical thermometer. A laboratory thermometer has only the Celsius scale ranging from -10^oC to 110^o C.

Precautions:
- A laboratory thermometer doesn't have a kink.
- Do not tilt the thermometer. Place it upright.
- Note the reading only when the bulb has been surrounded by the substance from all sides.

4.3 The Development of Thermometers and Temperature Scales

The historical highlights in the development of thermometers and their scales given here are based on "Temperature" by Quinn, T. J. and "Heat" by James M. Cork.

One of the first attempts to make a standard temperature scale occurred about AD 170, when Galen, in his medical writings, proposed a standard "neutral" temperature made up of equal quantities of boiling water and ice; on either side of this temperature were four degrees of heat and four degrees of cold, respectively.

The earliest devices used to measure the temperature were called thermoscopes. They consisted of a glass bulb having a long tube extending downward into a container of coloured water, although Galileo in 1610 is supposed to have used wine. Some of the air in the bulb was expelled before placing it in the liquid, causing the liquid to rise into the tube. As the remaining air in the bulb was heated or cooled, the level of the liquid in the tube would vary reflecting the change in the air temperature. An engraved scale on the tube allowed for a quantitative measure of the fluctuations.

The air in the bulb is referred to as the thermometric medium, i.e. the medium whose property changes with temperature.

In 1641, the first sealed thermometer that used liquid rather than air as the thermometric medium was developed for Ferdinand II, Grand Duke of Tuscany. His thermometer used a sealed alcohol-in-glass device, with 50 "degree" marks on its stem but no "fixed point" was used to zero the scale. These were referred to as "spirit" thermometers.

Robert Hook, Curator of the Royal Society, in 1664 used a red dye in the alcohol. His scale, for which every degree represented an equal increment of volume equivalent to about 1/500 part of the volume of the thermometer liquid, needed only one fixed point. He selected the freezing point of water. By scaling it in this way, Hook showed that a standard scale could be established for thermometers of a variety of sizes. Hook's original thermometer became known as the standard of Gresham College and was used by the Royal Society until 1709. (The first intelligible meteorological records used this scale).

In 1702, the astronomer Ole Roemer of Copenhagen based his scale upon two fixed points: snow (or crushed ice) and the boiling point of water, and he recorded the daily temperatures at Copenhagen in 1708- 1709 with this thermometer.

It was in 1724 that Gabriel Fahrenheit, an instrument maker of Däanzig and Amsterdam, used mercury as the thermometric liquid. Mercury's thermal expansion is large and fairly uniform, it does not adhere to the glass, and it remains a liquid over a wide range of temperatures. Its silvery appearance makes it easy to read.

Fahrenheit described how he calibrated the scale of his mercury thermometer: "placing the thermometer in a mixture of sal ammoniac or sea salt, ice, and water a point on the scale will be found which is denoted as zero. A second point is obtained if the same mixture is used without salt. Denote this position as 30. A third point, designated as 96, is obtained if the thermometer is placed in the mouth so as to acquire the heat of a healthy man." (D. G. Fahrenheit, Phil. Trans. (London) 33, 78, 1724)

On this scale, Fahrenheit measured the boiling point of water to be 212. Later he adjusted the freezing point of water to 32 so that the interval between the boiling and freezing points of water could be represented by the more rational number 180. Temperatures measured on this scale are designated as degrees Fahrenheit (° F).

In 1745, Carolus Linnaeus of Upsula, Sweden, described a scale in which the freezing point of water was zero, and the boiling point 100, making it a centigrade (one hundred steps) scale. Anders Celsius (1701-1744) used the reverse scale in which 100 represented the freezing point and zero the boiling point of water, still, of course, with 100 degrees between the two defining points.

In 1948 use of the Centigrade scale was dropped in favour of a new scale using degrees Celsius (° C). The Celsius scale is defined by the following two items that will be discussed later in this essay:

(i) The triple point of water is defined to be 0.01° C.
(ii) A degree Celsius equals the same temperature change as a degree on the ideal-gas scale.

On the Celsius scale the boiling point of water at standard atmospheric pressure is 99.975 C in contrast to the 100 degrees defined by the Centigrade scale.
To convert from Celsius to Fahrenheit: multiply by 1.8 and add 32.

$$°F = 1.8°C + 32$$
$$°K = °C + 273.$$

In 1780, J. A. C. Charles, a French physician, showed that for the same increase in temperature, all gases exhibited the same increase in volume. Because the expansion coefficient of gases is so very nearly the same, it is possible to establish a temperature scale based on a single fixed point rather than the two fixed- point scales, such as the Fahrenheit and Celsius scales. This brings us back to a thermometer that uses a gas as the thermometric medium.

In a constant volume gas thermometer a large bulb B of gas, hydrogen for example, under a set pressure connects with a mercury-filled "manometer" by means of a tube of very small volume. (The Bulb B is the temperature-sensing portion and should contain almost all of the hydrogen). The level of mercury at C may be adjusted by raising or lowering the mercury reservoir R. The pressure of the hydrogen gas, which is the "x" variable in the linear relation with temperature, is the difference between the levels D and C plus the pressure above D.

P. Chappuis in 1887 conducted extensive studies of gas thermometers with constant pressure or with constant volume using hydrogen, nitrogen, and carbon dioxide as the thermometric medium. Based on his results, the Comité International des Poids et Mesures adopted the constant-volume hydrogen scale based on fixed points at the ice point (0°C) and the steam point (100°C) as the practical scale for international meteorology.

Experiments with gas thermometers have shown that there is very little difference in the temperature scale for different gases. Thus, it is possible to set up a temperature scale that is independent of the thermometric medium if it is a gas at low pressure. In this case, all gases behave like an "Ideal Gas" and have a very simple relation between their pressure, volume, and temperature:

$$pV = (\text{constant})T.$$

This temperature is called the thermodynamic temperature and is now accepted as the fundamental measure of temperature. Note that there is a naturally-defined zero on this scale - it is the point at which the pressure of an ideal gas is zero, making the temperature also zero. We will continue a discussion of "absolute zero" in a later section. With this as one point on the scale, only one other fixed point need be defined. In 1933, the International Committee of Weights and Measures adopted this fixed point as the triple point of water , the temperature at which water, ice, and water vapor coexist in equilibrium); its value is set as 273.16. The unit of temperature on this scale is called the kelvin, after Lord Kelvin (William Thompson), 1824-1907, and its symbol is K (no degree symbol used).

To convert from Celsius to Kelvin, add 273.

$$K = {}^\circ C + 273.$$

Thermodynamic temperature is the fundamental temperature; its unit is the kelvin which is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

Sir William Siemens, in 1871, proposed a thermometer whose thermometric medium is a metallic conductor whose resistance changes with temperature. The element platinum does not oxidize at high temperatures and has a relatively uniform change in resistance with temperature over a large range.

The Platinum Resistance Thermometer is now widely used as a thermoelectric thermometer and covers the temperature range from about -260° C to 1235° C.

Several temperatures were adopted as Primary reference points so as to define the International Practical Temperature Scale of 1968. The International Temperature Scale of 1990 was adopted by the International Committee of Weights and Measures at its meeting in 1989. Between 0.65K and 5.0K, the temperature is defined in terms of the vapour pressure - temperature relations of the isotopes of helium. Between 3.0K and the triple point of neon (24.5561K) the temperature is defined by means of a helium gas thermometer. Between the triple point of hydrogen (13.8033K) and the freezing point of silver (961.78°K) the temperature is defined by means of platinum resistance thermometers. Above the freezing point of silver the temperature is defined in terms of the Planck radiation law.

T. J. Seebeck, in 1826, discovered that when wires of different metals are fused at one end and heated, a current flows from one to the other. The electromotive force generated can be quantitatively related to the temperature and hence, the system can be used as a thermometer - known as a thermocouple. The thermocouple is used in industry and many different metals are used - platinum and platinum/rhodium, nickel-chromium and nickel-aluminum, for example. The National Institute of Standards and Technology (NIST) maintain databases for standardising thermometers.

For the measurement of very low temperatures, the magnetic susceptibility of a paramagnetic substance is used as the thermometric physical quantity. For some substances, the magnetic susceptibility varies inversely as the temperature. Crystals such as cerrous magnesium nitrate and chromic potassium alum have been used to measure temperatures down to 0.05 K; these crystals are calibrated in the liquid helium range. For these very low, and even lower, temperatures, the thermometer is also the mechanism for cooling. Several low-temperature laboratories conduct interesting applied and theoretical research on how to reach the lowest possible temperatures and how work at these temperatures may find application.

Heat and Thermodynamics

Prior to the 19th century, it was believed that the sense of how hot or cold an object felt was determined by how much "heat" it contained. Heat was envisioned as a liquid that flowed from a hotter to a colder object; this weightless fluid was called "caloric", and until the writings of Joseph Black (1728-1799), no distinction was made between heat and temperature. Black distinguished between the quantity (caloric) and the intensity (temperature) of heat.

Benjamin Thomson, Count Rumford, published a paper in 1798 entitled "an Inquiry Concerning the Source of Heat which is excited by Friction". Rumford had noticed the large amount of heat generated when a cannon was drilled. He doubted that a material substance was flowing into the cannon and concluded "it appears to me to be extremely difficult if not impossible to form any distinct idea of anything capable of being excited and communicated in the manner the heat was excited and communicated in these experiments except motion."

But it was not until J. P. Joule published a definitive paper in 1847 that the caloric idea was abandoned. Joule conclusively showed that heat was a form of energy. As a result of the experiments of Rumford, Joule, and others, it was demonstrated (explicitly stated by Helmholtz in 1847), that the various forms of energy can be transformed one into another.

When heat is transformed into any other form of energy, or when other forms of energy are transformed into heat, the total amount of energy (heat plus other forms) in the system is constant.

This is the first law of thermodynamics, the conservation of energy. To express it another way: it is in no way possible either by mechanical, thermal, chemical, or other means, to obtain a perpetual motion machine; i.e., one that creates its own energy (except in the fantasy world of Maurits Escher's "Waterfall"!)

A second statement may also be made about how machines operate. A steam engine uses a source of heat to produce work. Is it possible to completely convert the heat energy into work, making it a 100 per cent efficient machine? The answer is to be found in the second law of thermodynamics:

No cyclic machine can convert heat energy wholly into other forms of energy. It is not possible to construct a cyclic machine that does nothing but withdraw heat energy and convert it into mechanical energy.

The second law of thermodynamics implies the irreversibility of certain processes - that of converting all heat into mechanical energy, although it is possible to have a cyclic machine that does nothing but convert mechanical energy into heat!

Sadi Carnot (1796-1832) conducted theoretical studies of the efficiencies of heat engines (a machine which converts some of its heat into useful work). He was trying to model the most efficient heat engine possible. His theoretical work provided the basis for practical improvements in the steam engine and also laid the foundations of thermodynamics. He described an ideal engine, called the Carnot engine that is the most efficient way an engine can be constructed. He showed that the efficiency of such an engine is given by

$$\text{Efficiency} = 1 - T''/T',$$

Where the temperatures, T' and T'' , are the hot and cold "reservoirs" , respectively, between which the machine operates. On this temperature scale, a heat engine whose coldest reservoir is zero degrees would operate with 100 per cent efficiency. This is one definition of absolute zero, and it can be shown to be identical to the absolute zero we discussed previously. The temperature scale is called the absolute, the thermodynamic, or the Kelvin scale.

The way that the gas temperature scale and the thermodynamic temperature scale are shown to be identical is based on the microscopic interpretation of temperature, which postulates that the macroscopic measurable quantity called temperature is a result of the random motions of the microscopic particles that make up a system.

The International Temperature Scale of 1990 (ITS-90)

Since 1954 the unit of (thermodynamic) temperature has been defined as the kelvin, and is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. This is the unique temperature and pressure at which the three phases of water (solid, liquid and vapour) co-exist in equilibrium. It is fractionally higher than the melting point, being 0.01°C or 273.16 K. From this single point it is possible to generate a thermodynamic temperature scale using gas thermometers and radiation thermometers which accurately obey known laws.

Such experiments are not easy and are rarely done, but good values have been established for a series of fixed points: freezing points of pure metals at high temperatures and triple points of gases at low temperatures. These are incorporated into the International Temperature Scale so that standard platinum resistance thermometers and radiation thermometers can be calibrated with excellent reproducibility. The National Physical Laboratory maintains the temperature scale (currently the International Temperature Scale of 1990, the ITS-90) in the UK, and compares this with the ITS-90 maintained in other national laboratories. In this way temperature standards around the world can be accurately equivalent, and all manner of thermometers can be reliably calibrated for everyday use.

Future of Thermometry
The international temperature community is working towards a redefinition of the kelvin. This would be based on a fundamental constant of nature known as the Boltzmann constant. The advantages of this are that the new definition would be freed from any physical artefact (i.e. the triple point of water) and allow the use of any appropriate thermodynamic method for temperature measurement

4.4 The Kinetic Theory

This brief summary is abridged from a more detailed discussion to be found in Quinn's "Temperature"

About the same time that thermodynamics was evolving, James Clerk Maxwell (1831-1879) and Ludwig Boltzmann (1844-1906) developed a theory describing the way molecules moved - molecular dynamics. The molecules that make up a perfect gas moves about, colliding with each other like billiard balls and bouncing off the surface of the container holding the gas. The energy associated with motion is called Kinetic Energy and this kinetic approach to the behaviour of ideal gases led to an interpretation of the concept of temperature on a microscopic scale.

The amount of kinetic energy each molecule has is a function of its velocity; for the large number of molecules in a gas (even at low pressure), there should be a range of velocities at any instant of time. The magnitude of the velocities of the various particles should vary greatly - no two particles should be expected to have the exact same velocity. Some may be moving very fast; others, quite slowly. Maxwell found that he could represent the distribution of velocities statistically by a function known as the Maxwellian distribution. The collisions of the molecules with their container give rise to the pressure of the gas. By considering the average force exerted by the molecular collisions on the wall, Boltzmann was able to show that the average kinetic energy of the molecules was directly comparable to the measured pressure, and the greater the average kinetic energy, the greater the pressure. From Boyles' Law, we know that the pressure is directly proportional to the temperature; therefore, it was shown that the kinetic energy of the molecules related directly to the temperature of the gas. A simple relation holds for this: average kinetic energy of molecules = $3kT/2$, where k is the Boltzmann constant. Temperature is a measure of the energy of thermal motion and, at a temperature of zero, the energy reaches a minimum (quantum mechanically, the zero-point motion remains at 0 K).

In July, 1995, physicists in Boulder, Colo.achieved a temperature far lower than has ever been produced before and created an entirely new state of matter predicted decades ago by Albert Einstein and Satyendra Nath Bose. The press release describes the nature of this experiment and a full description of this phenomenon is described by the University of Colorado's BEC Homepage.

Dealing with a system which contained huge numbers of molecules requires a statistical approach to the problem. About 1902, J. W. Gibbs (1839-1903) introduced statistical mechanics with which he demonstrated how average values of the properties of a system could be predicted from an analysis of the most probable values of these properties found from a large number of identical systems (called an ensemble). Again, in the statistical mechanical interpretation of thermodynamics, the key parameter is identified with a temperature which can be directly linked to the thermodynamic temperature, with the temperature of Maxwell's distribution, and with the perfect gas law.

Temperature becomes a quantity definable either in terms of macroscopic thermodynamic quantities such as heat and work, or, with equal validity and identical results, in terms of a quantity which characterised the energy distribution among the particles in a system. (Quinn, "Temperature")

A second mechanism of heat transport is illustrated by a pot of water set to boil on a stove - hotter water closest to the flame will rise to mix with cooler water near the top of the pot. Convection involves the bodily movement of the more energetic molecules in a liquid or gas.

The third way that heat energy can be transferred from one body to another is by radiation; this is the way that the sun warms the earth. The radiation flows from the sun to the earth, where some of it is absorbed, heating the surface.

A major dilemma in physics since the time of Newton was how to explain the nature of this radiation.

5.0 CONCLUSION

With this understanding of the concept of temperature, it is possible to explain how heat (thermal energy) flows from one body to another. Thermal energy is carried by the molecules in the form of their motions and some of it, through molecular collisions, is transferred to molecules of a second object when put in contact with it. This mechanism for transferring thermal energy by contact is called conduction.

6.0 ACTIVITY

1. Convert the following to Fahrenheit scale;
   i) 0^0 C ii) 100^0 C. iii) 35^0 C iv) 42^0 C
2. Convert the following to Celsius scale;
   i) 32^0 F ii) 212^0 F. iii) 78^0 F iv) 108^0 F
3. i). Convert your results in question (ii) above to the Kelvin scale.

7.0 SUMMARY

A thermometer is an instrument that measures the temperature of a system in a quantitative way. The easiest way to do this is to find a substance having a property that change in a regular way with its temperature. The most direct 'regular' way is a linear one:

$$t(x) = ax + b,$$

where t is the temperature of the substance and changes as the property x of the substance changes. The constants a and b depend on the substance used and may be evaluated by specifying two temperature points on the scale, such as 32°C for the freezing point of water and 212°C for its boiling point.

For example, the element mercury is liquid in the temperature range of -38.9°C to 356.7° C (we'll discuss the Celsius °C scale later). As a liquid, mercury expands as it gets warmer; its expansion rate is linear and can be accurately calibrated.

8.0 TUTOR-MARKED ASSIGNMENT

1. With the aid of annotated diagram, describe a thermometer.
2. List and explain types and classifications of thermometer.
3. What did you understand by kinetic theory?

9.0 REFERENCES/FURTHER READING

Forgan, B.W. (1996). “A New Method for Calibrating Reference and Field Pyranometers.” *Journal of Atmospheric and Oceanic Technology,* 13, pp. 638–645.

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UNIT 5 PRECIPITATION AND MEASUREMENT

CONTENT

1.0 INTRODUCTION

Water evaporates into the air from every water surface on Earth and from living things. This water eventually returns to the surface as precipitation. Precipitation is any form of water that falls from clouds and reaches Earth’s surface.

Precipitation always comes from clouds. But not all clouds produce precipitation. For precipitation to occur, cloud droplets or ice crystals must grow heavy enough to fall through the air. One way that cloud droplets grow is by colliding and combining with other cloud droplets. As the droplets grow larger, they fall faster and collect more and more small droplets. Finally, the droplets become heavy enough to fall out of the cloud as raindrops.

Precipitation varies across a range of space–time scales. Larger space-scale variations generally occur at longer time scales, and are associated with correspondingly larger scale phenomena in the atmosphere or ocean–atmosphere system. For example, scales of variability within an individual convective storm may vary from metres and seconds to kilometres and hours, while the El Nin˜o–Southern Oscillation (ENSO) related scales of variability are regional to hemispheric in extent and multi-year in length (Daly, 1991).

However, these different scales are not unrelated: precipitation within individual storms is likely to be more intense and of longer duration when ENSO is causing a general enhancement in precipitation across a region. At all these time and space scales, precipitation is inherently more variable than other commonly reported climate variables, such as temperature and pressure, with the result that precipitation measurement and analysis are more demanding. Overlying this variability of precipitation within the climate system is the potential for secular changes in the intensity and distribution characteristics of precipitation.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- examine the various forms of precipitation;
- explain measurement and calibration of precipitation; and
- list and discuss the factors that modify as precipitation mounts.

2.1 HOW TO STUDY THIS UNIT

1. You are expected to read carefully through this unit at least twice before attempting to answer the self-assessment questions or tutor- marked assignment.
2. Do not look at the solution given at the end of the unit until you are satisfied that you have done your best to get all answers.
3. Share your difficulties with your course mates, facilitators and by consulting other related material, particularly the internet.
4. Note that if you follow the instructions you will feel self fulfilled that you have achieved the aim of studying this unit. This should stimulate you to do more.

3.0 WORD STUDY

Homogeneous- of the same kind or alike
Yardstick- a measuring rod 36inches long
Spatial- of or pertaining to space

4.0 MAIN CONTENT

4.1 Types of Precipitation

In warm parts of the world, precipitation is almost always rain or drizzle. In colder regions, precipitation may fall as snow or ice. Common types of precipitation include rain, sleet, freezing rain, hail, and snow.

Rain is the most common kind of precipitation. Drops of water are called rain if they are at least 0.5 millimetres in diameter. Precipitation made up of smaller drops of water is called mist or drizzle. Mist and, drizzle usually fall from stratus clouds.
Sleet Sometimes raindrops fall through a layer of air below 0°C, the freezing point of water. As they fall, the raindrops freeze into solid particles of ice, ice particles smaller than five millimetres in diameter are called sleet.

Freezing rain at other times raindrops falling through cold air near the ground do not freeze in the air. Instead, the raindrops freeze when they touch a cold surface. This is called freezing rain. In an ice storm, a smooth, thick layer of ice builds up on every surface. The weight of the ice may break tree branches onto power lines, causing power failures. Freezing rain and sleet can make sidewalks and roads slippery and dangerous.

Hail round pellets of ice larger than five millimetres in diameter are called hailstones. Hail forms only inside cumulonimbus clouds during thunderstorms. A hailstone starts as an ice pellet inside a cold region of a cloud. Strong updrafts in the cloud carry the hailstone up and down through the cold region many times. Each time the hailstone goes through the cold region, a new layer of ice forms around the hailstone. Eventually the hailstone becomes heavy enough to fall to the ground. If you cut a hailstone in half, you can often see shells of ice, like the layers of an onion. Because hailstones can grow quite large before finally falling to the ground, hail can cause tremendous damage to crops, buildings, and vehicles.

Snow often form water vapour in a cloud is converted directly into ice crystals called snowflakes. Snowflakes have an endless number of different shapes and patterns, all with six sides or branches. Snowflakes often join together into larger clumps of snow in which the six-sided crystals are hard to see.

4.2 Identification of Measurement and Calibration of Precipitation

Gauges that measure precipitation at a point remain the most common approach to ground-based measurement. Although radar observations have tended to supplant gauges by providing a real estimate directly, the gauge remains the ultimate reference and is the only measurement method available in many regions of the world. Other forms of surface observation include standard present-weather classifications and more qualitative historic documentary records, such as wet day counts (Ohara and Metcalfe, 1995; Rodrigo et al., 1995, 1999; Kastellet et al., 1998; Pfister et al., 1999). The first rain gauge in Europe was developed by Richard Townley in Burnley, Lancashire, in 1677. Even earlier gauge measurements are believed to have occurred in Korea, where the Japanese used a type of gauge to determine the annual rice tax each region should pay. However, analyses of these data are considered unreliable as many Koreans probably understood the tax system and modified the amounts in the ‘gauges’ accordingly.

Gauge design (often called ombrometers in earlier times) varied considerably across Europe until some form of standardisation came in the late 19th century (Middleton, 1953, 1965). Developments were largely dependent on climate regime, with Russian, Scandinavian and Canadian scientists emphasising designs that maximised snow catch, particularly during strong winds. Other countries realised that catch was higher if the gauge was located at ground level rather than one to two m above the ground. The main result of these developments has been that nearly all long-term records of precipitation are not homogeneous, exhibiting trends and/or discontinuities attributable to design changes. It has been estimated that at least 250,000 different precipitation gauges have been established globally by various meteorological and hydrological agencies over the last few decades (Groisman and Legates, 1995).

Precipitation is ‘any liquid or solid aqueous deposit from the atmosphere’. This includes rain, drizzle, snow, ice, hail, diamond dust, snow grains, snow pellets, ice pellets, rime, glaze, frost and dew, and any deposit from fog. The term ‘rain’ instead of ‘precipitation’ will be used here for simplicity.

There are generally two types of rain gauge — the automatic, which makes a record of the time a known sized container is filled and emptied — and the storage, which collects and stores the rain for later measurement. The copper splayed-base and Snowdon are examples of storage gauges, though increasing use is also being made of stainless steel. The notes below concern mainly storage gauges.

Make sure the amount of rain collected is not increased by condensation, splash-in, or flooding, and is not decreased by evaporation, leaks or splash-out.

Occasionally test the funnel for leaks by placing thumb over the tube end and pouring water into the funnel. Or trap air in the funnel with your thumb while lowering it upside down into a bucket of water — air will escape through.

Measurements from storage gauges Manually-read gauges All measurements should be made as close as possible to 10 a.m. during British Summer Time or 9 a.m. for the rest of the year, unless you have an alternative arrangement, or you are unable to make the measurement for some reason.

Make sure you always note the date and time of your reading. If your reading is not at your usual time, make a note of why not.

If you provide values weekly instead of daily, make sure you do them on the same day each week and on daily read the 1st of each month. Monthly gauge readings should be done on the first of each month.

Make sure you use the measure that is appropriate for your size of rain gauge — commonly a tapered 10 mm measure for daily-read gauges, or flat-base 50 mm measure for Octapents or large Bradfords

Methodology of Measuring Liquid Precipitation

- Carefully lift the funnel out of the base of the rain gauge.
- Lift out the collection bottle.
- Carefully pour the water into the rain measure. If there is too much for the measure, pour in less than a full measure each time, write down each value, and then add them all up to get the total.
- Then empty each amount into a spare container to repeat the process to check the total.

- Carefully replace the empty bottle and put the funnel back into it.
- For accuracy, read the measure with the water surface at your eye level and the measure vertical, held between thumb and first finger.
- You can check the measure is vertical by making sure that the scales on both sides of the measure are lined up as you look through the glass.

Measuring a trace

There is a continuous ring below the 0.1 mm mark on the rain measure. This shows the limit of a trace.

If the rain amount is exactly on or above that mark, your reading should be 0.1 mm.

Record a trace when the amount is below that mark (and you are sure this is from precipitation since your last measurement).

Also, record a trace if there have been a few spots of rain, drizzle, etc. since your last reading but the bottle is dry.

If you know the weather has been dry since your last reading, do not record droplets left over from your previous measurement as a trace.

Take care to consider if there has been dew or frost, and make a note if there was.

Method of Measuring Heavy rain

- To get more information about heavy rain in short periods, you can measure the rainfall as soon as it stops.
- Put the rain back into the bottle so that the next reading is not affected.
- Note the start/stop times of the rain. If it is raining heavily through the day, check that the gauge won't overflow by taking a reading and discarding the water.
- Remember to add the amount to the next routine measurement.
- Measuring liquid equivalent of solid precipitation.
- Always try to note the type of precipitation — whether it is snow, ice pellets, hail, etc.

Slight Falls

- If precipitation is not falling, take the funnel and collecting bottle indoors to melt the snow.
- Keep the funnel covered while the snow is melting to prevent evaporation.

How to Measure Snow

If snow is falling, you can either:

- Pour in a measured amount of warm water (but not hot, as it may crack the bottle) to melt the snow. Measure the total then subtract the amount of warm water you poured in.

- Or wrap a cloth dipped in hot water around the bottle and funnel to melt the snow and then measure it in the usual way. Make sure water from the cloth does not get into the bottle or freeze the cloth to the funnel.

Moderate or Heavy Falls

Measurement can be complicated because wind eddies may carry snow over or blow it out of the gauge, or even lift lying snow and blow it into the gauge. Sometimes the gauge may be completely buried in snow. However, your readings are very important, particularly for assessing the risk of flooding if the snow thaws quickly.

If there was no snow lying when you made your previous reading, take a sample of the (level, undrafted) snow by pressing the inverted funnel of the gauge downwards through the snow.

Take this sample indoors to melt it and measure the water.

It is a good idea to make three readings like this, as it is often difficult to find a representative sample of snow. Take each sample about a metre apart and report the average of these three samples.

(b) If snow was lying when you made your previous reading, you need to be able to measure the fresh snow that has fallen since. You can do this by placing a board onto and flush with the old snow. Sweep the board clean after measuring the snow on it, by taking a funnel sample as in (a), and then replace the board, ready for later measurements. You may wish to mark the place of the board with a thin cane so you can find it under new snow.

If the gauge becomes covered with snow, make a measurement as soon as you can and clear the gauge to continue collecting. Add this measurement to your next routine reading and solid and liquid precipitation between readings.

Extra care is needed if a mixture of rain and snow has fallen. If it is a slight fall of snow, follow the guidelines for slight falls.

If the fall is moderate or heavy, then follow the guidelines for moderate or heavy falls. Don’t forget any liquid precipitation in the bottle and make a note of the amount from melting, if possible.

Do not throw away snow or hail in the funnel when you make a measurement — melt it and add it to the bottle to be measured in the usual way.

If measurement is not possible, leave the snow in the funnel to melt in its own time, but please note this on the relevant form (Rainfall data or 3208b) along with the reason, such as the examples below.

- Snow filling funnel — no more snow can enter.
- Snow being blown out of funnel, even if not full.
- Drifting or blowing snow being deposited in funnel.

- Gauge covered by snow due to heavy falls or drifting.

Measuring the Depth of Frozen Precipitation
This includes snow, hail and ice pellets.

If, at the time of your observation, the ground representative of the station is covered by snow or other solid precipitation, then the depth should be measured and reported.

Measure the depth in centimetres using a ruler held vertically in a location free from drifting or scouring by wind.

Choose a location as near as possible to the rain gauge. Ideally, take three measurements at different places and report the average of these.

You must ensure that the ruler is either adapted to read zero at ground level or you take account of the length of the short gap between the end of the ruler and the zero mark, when you make your measurement.
Make sure your ruler does not pierce the grass or other ground surface beneath the frozen precipitation, as this will give a false reading.

Average annual precipitation is a vital piece of climatic data - one that is recorded through a variety of methods. Precipitation (which is most commonly rainfall but also includes snow, hail, sleet, and other forms of water falling to the ground) is measured in units over a given time period. In the United States, precipitation is commonly represented in inches per 24-hour period. This means that if one inch of rain fell in a 24-hour period and water wasn't absorbed by the ground nor did it flow downhill, after the storm there would be a layer of one inch of water covering the ground.

The low-tech method of measuring rainfall is to use a container with a flat bottom and straight sides (such as a cylinder coffee can). While a coffee can help you determine whether a storm dropped one or two inches of rain, it's difficult to measure small amounts of precipitation.

A tipping bucket electronically records precipitation on a rotating drum or electronically. It has a funnel, like a simple rain gauge, but the funnel leads to two tiny "buckets." The two buckets are balanced (somewhat like a see-saw) and each holds .01 inch of water. When one bucket fills, it tips down and is emptied while the other bucket fills with rain water. Each tip of the buckets causes the device to record an increase of .01 inch of rain.

Snowfall is measured in two ways. The first is a simple measurement of the snow on the ground with a stick marked with units of measurement (like a yardstick). The second measurement determines the equivalent amount of water in a unit of snow. To obtain this ratio, the snow must be collected and melted into water. Generally, 10 inches of snow produces one inch of water. However, it can take up to 30 inches of loose, fluffy snow though as little as two to four inches of wet, compact snow can produce an inch of water.

Wind, buildings, trees, topography, and other factors can modify the amount of precipitation that falls so rainfall and snowfall tend to be measured away from obstructions. A thirty-year average of annual precipitation is used to determine the average annual precipitation for a specific place.

Determining and recording the average annual precipitation is very important and for a meteorologist it is a vital piece of climatic data. There are several methods used by meteorologists to measure precipitation. Precipitation is generally rainfall, but is also includes snow, sleet, hail, and other types of water that falls to the ground. It is measured over a given period of time in units.

Precipitation measurement is typically represented per 24-hour period in inches. This means that if an inch of rain fell within a 24-hour period of time and the ground didn't absorb the water, or the water didn't flow down a hill, after a storm has occurred there would be a one-inch layer of water covering the ground.

Low-Tech Measuring Method

To measure precipitation using a low-tech method, one would use a flat-bottom container that has straight sides, such as a coffee cans that is cylindrical in shape. With this method small amounts of precipitation are difficult to measure, but it can help to determine if a storm lead to one to two inches of precipitation being dropped. This method to measure precipitation is typically only used to measure rainfall.

Rain Gauges

Rain gauges are an instrument used to measure precipitation that has wide openings at the top. The rain that falls will be funneled into a narrow tube that is one-tenth the diameter of the gauges top. Since the funnel is less narrow than the tube, the measurement units are further apart than on a ruler making it possible for exact measuring to the one-hundredth of an inch. It is known as a trace of rain, when less than .01 inch of rain drops to the ground.

Tipping Bucket

This instrument used to measure precipitation records precipitation electronically or on a rotating drum. Like a simple rain gauge, it has a funnel, but on a tipping bucket, two tiny buckets are what the funnel leads to. The two tiny buckets each hold .01 inch of water and they are balanced, similar to how a see-saw balances when there is a person on each end. A tipping bucket tips down, when one bucket fills, and then it is emptied while the other bucket fills up with rain water. Every time the buckets tip, this precipitation measurement tool records a .01 inch increase in rain.

Measuring Snow

There are two different precipitation measurement methods used to measure snow. The first instrument is similar to a yardstick and it is marked with the measurement units. It is used to measure snow that has already fallen to the ground. The second tool to measure snow is used to measure how much water a unit of snow contains. The snow has to be collected and then melted into water in order to obtain this ratio. In most cases, one inch of water will be produced by ten inches of snow. However, if the snow is fluffy and lose it can take approximately thirty inches of snow to produce the same amount of water as two to four inches of snow that is compact and wet.

3.3 Factors that Modify Precipitation Amounts

Certain factors can modify precipitation amounts, such as buildings, topography, wind, and trees. Because of this, precipitation, such as snowfall and rainfall, are measured in areas that are free of obstructions. To determine the annual precipitation for a specific area, a thirty-year annual precipitation average is used.

Precipitation is all liquid and solid products of water that are deposited from the atmosphere on the ground, and is generally caught by precipitation gauges at a point. If a spatial scale looking for is expanded, it is effective that many precipitation gauges are installed in the area or precipitation of the area is estimated using radar. Further, in the case that precipitation is expanded to a grid scale, the estimation using satellites is effective. Since the amount of precipitation using radar and satellites is necessary to compare with that of precipitation gauges, the precipitation measured by the precipitation gauges is fundamental and important values.

However, it has been recognised widely so far that gauge-measured precipitation has systematic errors mainly caused by wind-induced under catch, wetting and evaporation losses and that the error of snowfall observation in high wind speeds is very large. Since many types of precipitation gauges are used in the world at present [Sevruk and Klemm, 1989], the different types are measuring different precipitation amounts, respectively [e.g., Goodison et. al., 1981. From a viewpoint of accurate precipitation data set for better understanding of the water cycle and providing them to the modelling activities, we should not neglect this scientific issue. In order to test the performance of precipitation gauges and to adjust the precipitation measurements, the World Meteorological Organisation (WMO) initiated international precipitation measurement comparisons.

5.0 CONCLUSION

Precipitation is ‘any liquid or solid aqueous deposit from the atmosphere’. This includes rain, drizzle, snow, ice, hail, diamond dust, snow grains, snow pellets, ice pellets, rime, glaze, frost and dew, and any deposit from fog. The term ‘rain’ instead of ‘precipitation’ will be used here for simplicity.

6.0 ACTIVITY

1. State at least 5 points to keep in mind when measuring precipitation.
2. List some effects of too much or too little precipitation
3. Suggest how to overcome or reduce the above effects.

7.0 SUMMARY

Weather observers use more sophisticated instruments, known as rain gauges and tipping buckets to more precisely measure precipitation. Rain gauges have wide openings at the top for rainfall. The rain falls and is funnelled into a narrow tube, one-tenth the diameter of the top of the gauge. Since the tube is thinner than the top of the funnel, the units of measurement are further apart than they would be on a ruler and precise measuring to the one-hundredth (1/100 or .01) of an inch is possible. When less than .01 inch of rain falls, that amount is known as a "trace" of rain.

8.0 TUTOR-MARKED ASSIGNMENT

1. Compare and contrast the basic method of measuring liquid and solid precipitation.
2. List and explain the various types of precipitation.
3. List and explain 4 observations errors in measuring precipitation.

9.0 REFERENCES/FURTHER READING

Forgan, B. W. (1996). “A New Method for Calibrating Reference and Field Pyranometers.” *Journal of Atmospheric and Oceanic Technology,* 13, pp. 638–645.

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