Indira Gandhi National Open University
School of Sciences

MGG 005
CLIMATOLOGY

BLOCK
2

ATMOSPHERIC PROCESSES

BLOCK 2: ATMOSPHERIC PROCESSES

In Block 2 students will embark on a comprehensive exploration of atmospheric processes, unravelling the intricate dynamics that govern earth's atmosphere. Learners will delve into the fundamental principles underlying the behaviour of the atmosphere, from the mechanisms of insolation and heat balance to the complexities of temperature variations and pressure systems.

In Unit 4 on Insolation and Heat Balance learners will study the significance of the sun as earth's primary energy source, examining various factors influencing insolation. Through detailed study, learners gain insights into the latitudinal distribution of solar radiation and its implications for the planet's heat balance.

Unit 5 on Temperature explores into the intricate processes governing the heating and cooling of the atmosphere. Students analyse the horizontal and vertical distribution of temperature, exploring phenomena such as adiabatic lapse rates and temperature inversions.

In Unit 6 on Pressure Systems learners will study the measurement and distribution of atmospheric pressure, scrutinising horizontal and vertical pressure patterns. Through comprehensive study, learners gain insights into the shifting nature of pressure belts and their impact on global wind patterns and climate dynamics.

Unit 7 on General Atmospheric Circulations enquires into the complex dynamics of winds, encompassing planetary, seasonal, local, jet streams, and the tri-cellular meridional circulation systems. Through this unit, students gain a comprehensive understanding of the mechanisms driving atmospheric circulation on various scales, from global to local phenomena.

After studying this Block, you should be able to:

- identify and analyse various factors influencing insolation and comprehend the mechanisms governing the heating and cooling of the atmosphere;
- explain the concept of adiabatic lapse rates and temperature inversions and their significance in atmospheric stability and weather patterns;
- Interpret horizontal and vertical pressure distribution and analyze the shifting nature of pressure belts and their influence on global wind patterns and climate dynamics; and
- describe the different types of atmospheric circulations, including planetary, seasonal, and local winds, as well as jet streams and the tri-cellular meridional circulation system.

Our best wishes are with you in this endeavour.

We suggest for any assistance regarding this course, you can contact satyaraj@ignou.ac.in.

MGG 005 CLIMATOLOGY

UNIT 4

INSOLATION AND HEAT BALANCE

Structure

4.1 INTRODUCTION

In the previous block, you have studied about the basic concepts of climatology, its scope, development, and relationship with meteorology. You can now distinguish between weather and climate, detailing the elements of each and the factors that control their patterns and variations. You have also learnt about earth's atmosphere, covering its origin, evolution, composition, and structural layers. So now you can also describe different layers of atmosphere on the basis of thermal properties and on the basis of chemical composition.

This is the first unit of this block. You all know that Sun serves as the primary energy provider for earth. The Sun warms both earth's atmosphere and the surface through a process known as insolation which is elaborated in Sec. 4.2. In Sec. 4.3, various factors contributing to the heating of the atmosphere and earth will be examined. Sec. 4.4 deals with the distribution of solar radiation across the globe, offering insight into how this energy is dispersed. Following this exploration, Sec. 4.5 focuses on discussing the heat budget of both the atmosphere and earth, providing a comprehensive understanding of the intricate mechanisms involved in maintaining earth's thermal equilibrium. By studying these sections, one can gain a deeper appreciation for the intricate relationship between the Sun, earth's atmosphere, and the processes that govern the planet's energy balance.

In the next unit, you will study about temperature and its horizontal and vertical distribution in the planet and the factors responsible for it.

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Expected Learning Outcomes

After completing the study of this unit, you should be able to:

- explain the role of insolation and its impact on the atmosphere and planetary surface;
- comprehend how solar energy heats the earth's atmosphere and surface;
- discuss how solar energy is dispersed across different regions of the earth and correlate its implications for climate and weather patterns;
- evaluate various factors contributing to the heating of earth's atmosphere and surface; and
- discuss the complex mechanisms involved in temperature regulation of earth.

4.2 SUN AS A SOURCE OF ENERGY

The Sun, which appears as a massive celestial body at the centre of our solar system, is not just a dazzling spectacle in the sky; it is the ultimate source of energy that sustains life on earth and holds an immense potential for human endeavors. From the dawn of civilisation to the modern era of renewable energy, the Sun has been revered, studied, and harnessed for its boundless power.

You might know about the fusion process that takes place at the core of the Sun. This generates enormous amount of energy. Through the fusion of hydrogen atoms, helium is produced, releasing vast quantities of energy in the form of light and heat. This process is known as nuclear fusion which powers the Sun and emits radiation across the electromagnetic spectrum, including visible light, infrared radiation, and ultraviolet rays.

The journey of solar energy begins with photons which are the tiny packets of energy emitted by the Sun. These photons travel through the vacuum of space, reaching earth's atmosphere and penetrating its protective layers. Most of the Sun's energy reaches the earth's surface, where it plays a pivotal role in driving the planet's climate, weather patterns, and ecosystems.

One of the most remarkable manifestations of solar energy is photosynthesis, the process by which green plants, algae, and some bacteria convert sunlight into chemical energy. Through this absorption of light, chlorophyll molecules within plant cells initiate a series of biochemical reactions, synthesizing glucose and oxygen from carbon dioxide and water. This process not only fuels plant growth but also forms the basis of the food chain, providing sustenance for all living organisms.

Beyond sustaining life through photosynthesis, the Sun also serves as a prolific source of renewable energy for human civilisation. Millennia ago, ancient cultures recognised the Sun's power and worshipped it as a deity. So Sun is revered not only for its celestial grandeur but also for its life-giving properties.

As human knowledge expanded, so did our ability to harness solar energy for practical purposes. The development of solar architecture in ancient civilisations, such as the design of south-facing windows to capture sunlight for warmth, exemplifies early efforts to utilise solar energy for heating and lighting.

In the modern era, technological advancements have unlocked the potential of solar energy on an unprecedented scale. Solar photovoltaic (PV) systems, pioneered in the mid-20th century, directly convert sunlight into electricity using semiconductor materials like silicon. PV cells, arranged in solar panels, absorb photons and generate an electric current, providing clean and sustainable power for homes, businesses, and communities. Let us learn about them.

Concentrated solar power (CSP) systems represent another innovative approach to harnessing solar energy. By employing mirrors or lenses to focus sunlight onto a small area, CSP systems generate intense heat that can produce steam to drive turbines and generate electricity. Molten salt storage enables CSP plants to store excess heat for use during cloudy periods or at night, enhancing their reliability as a renewable energy source.

Thus solar thermal technologies, ranging from solar water heaters to solar cookers, leverage the Sun's heat for various applications. Solar water heating systems also utilise rooftop collectors to absorb sunlight and heat water for domestic or industrial use, reducing reliance on fossil fuels and lowering energy costs. Similarly, solar cookers harness solar radiation to cook food, offering a sustainable alternative to traditional cooking methods in off-grid communities.

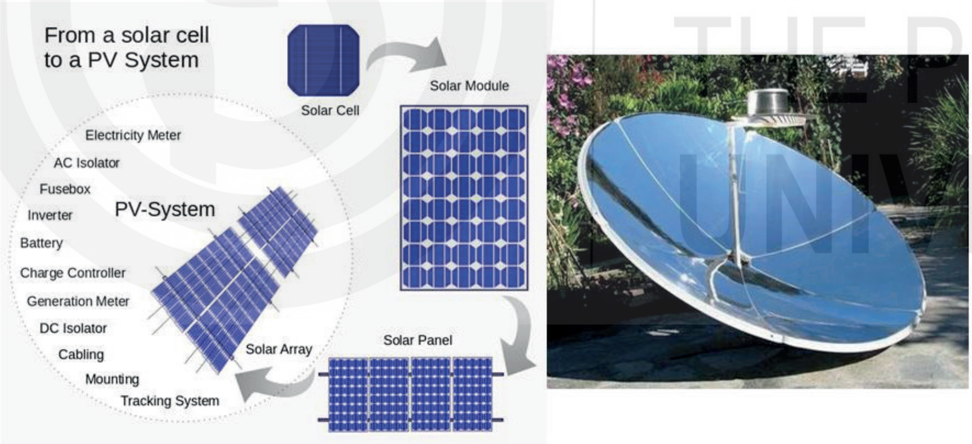

Fig. 4.1: A PV System (Left) and A Parabolic Solar Cooker (Right).
(Source: Rfassbind, CC: Public domain)

The integration of solar energy into mainstream energy systems has accelerated in recent years, driven by concerns about climate change, energy security, and economic sustainability. Governments, businessmen, and individuals worldwide are increasingly investing in solar power infrastructure, incentivised by declining costs and supportive policies.

In addition to its role in electricity generation, solar energy contributes to decentralised energy access, empowering communities in remote areas to meet their energy needs independently. Off-grid solar systems, comprising solar panels, batteries, and inverters, provide reliable electricity to households, schools, and healthcare facilities in underserved regions, catalysing socio-economic development and improving quality of life.

The transition to a solar-powered future holds immense promise for combating climate change and fostering sustainable development. By displacing fossil fuels and reducing greenhouse gas emissions, solar energy mitigates the environmental impacts of energy production and consumption, safeguarding ecosystems and biodiversity.

However, challenges remain on the path to widespread solar adoption, including intermittency, grid integration, and energy storage. Innovations in solar technology, coupled with supportive policies and investment frameworks, are essential for overcoming these hurdles and realising the full potential of solar energy as a cornerstone of the global energy transition.

Thus, Sun stands as a beacon of hope and opportunity, illuminating the path towards a cleaner, brighter future for humanity. From its ancient origins as a divine symbol to its modern incarnation as a powerhouse of renewable energy, the Sun continues to inspire awe and admiration. By harnessing its radiant energy responsibly and innovatively, we can foresee a sustainable tomorrow for generations to come.

SAQ I

What are some modern technologies that harness solar energy, and how do they contribute to sustainable development?

4.2.1 What is Insolation

The term "insolation" literally translates to "incoming solar radiation." Did you know that earth intercepts only a minuscule fraction of solar radiation? This fraction amounts to approximately 1/2,000,000,000th (one in two billion) of the Sun's total energy output, and it takes a mere 8 minutes and 20 seconds for this radiation to travel from the Sun to the earth's surface. The distance of between the Sun and earth is about 149 million kilometers. Despite its small quantity, this solar radiation holds immense significance as it governs numerous physical and biological phenomena on earth. The solar radiation intercepted by the earth's surface averages about 2 calories per square centimeter per minute, a value commonly referred to as the solar constant, often expressed in Langley units which is equivalent to 1 calorie per square centimeter per minute.

The Sun emits energy in the form of electromagnetic radiation. It consists of a spectrum of rays with varying wavelengths as illustrated in Fig. 4.2. These rays span from shorter wavelengths such as x-rays and gamma rays to longer wavelengths like radio waves. The incoming solar radiation, termed shortwave radiation, encompasses ultraviolet, visible, and short infrared radiation. In contrast, the radiation emitted by earth, known as longwave terrestrial radiation, falls in the thermal-infrared portion of the electromagnetic spectrum. A wavelength of 4 micrometers serves as the boundary between longer and shorter wavelengths.

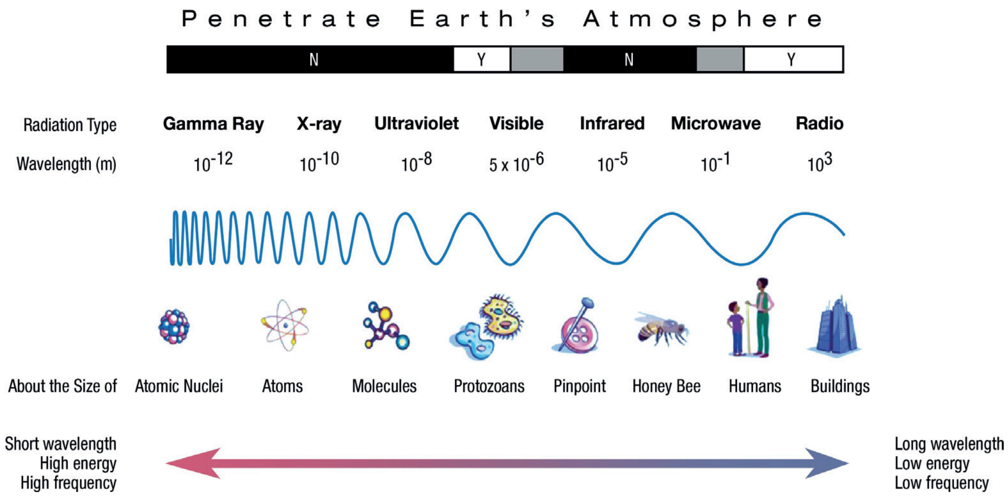

Fig. 4.2: The Electromagnetic Spectrum. (Image Credit: NASA)
(Source: https://mynasadata.larc.nasa.gov/basic-page/electromagnetic-spectrum-diagram)

Sunlight, upon reaching the earth's surface, undergoes a transformation upon absorption, converting from shortwave to longwave radiant energy. This is commonly referred to as heat. This conversion initiates various processes responsible for the movement of heat energy and the heating and cooling of the atmosphere. Let us study these processes to gain a deeper understanding.

Conduction

Conduction involves the transfer of energy between the adjacent molecules without altering their relative positions. This mechanism facilitates heat transfer between surfaces. During the day, earth's surface, being an efficient absorber of heat, heats up and conducts heat to the lower atmosphere. However, since air is a poor conductor, only a small portion of the air that is in direct contact with the surface, is heated.

Convection

Convection denotes the transfer of heat through the movement of air. Warm air near the earth's surface expands, becomes less dense, and rises. This creates a convective circulation as cooler air replaces it. This movement contributes significantly to the distribution of heat in the atmosphere.

Radiation

Radiation involves the emission of electromagnetic energy from a hot body. Hot bodies emit shorter wavelengths of energy compared to cooler bodies. Consequently, the Sun, being a hot body, radiates short wavelengths of electromagnetic energy, while earth, a cooler body, emits longer wavelengths of radiant energy, particularly thermal infrared.

Transmission

Transmission represents the proportion of solar radiation that successfully passes through the atmosphere. The transmissivity of radiation primarily depends on the distance travelled by the solar beam through the atmosphere, with inclined rays traversing longer distances compared to vertical ones.

Advection

Advection involves the horizontal transfer of warm or cool air by winds from one location to another. This process facilitates the redistribution of heat across different regions.

Absorption

Absorption refers to the retention of incident radiation by a surface, converting it into other forms of energy. This absorbed energy typically manifests as sensible heat, causing an increase in temperature. For instance, sunlight striking a surface, like the side of a building, is absorbed, leading to the heating of that surface.

Reflection

Earth and its atmosphere reflect a portion of solar radiation back into space. This reflective property is quantified as reflectivity, expressed as a percentage of incident radiation reflected, also known as albedo or reflection coefficient. Earth's albedo, representing the mean reflectivity from its oceans, landmasses, and atmosphere, is approximately 30%.

Table 4.1: Albedos of Various Surfaces to Solar Radiation

Type of Surface	Albedo (%)
Fresh snow	75-95
Clouds	45-90
Old snow and sea ice	30-40
Dry sand	35-45
Desert	25-30
Dry savannah	25-30
Wet savannah	15-20
Grass covered meadow	10-20
Asphalt road	5-17
Deciduous forest	10-20
Coniferous forest	5-15
Water	10
Angles of Inclination of the Sun	**Albedo (%)**
0°	99+
10°	35
30°	6
50°	2.5
90°	2

(Source: Climatology-An Atmospheric Science, John E. Oliver, John J. Hidore)

Scattering

Scattering involves the diffusion of radiation in different directions by dust particles and gaseous molecules. One prominent effect of scattering in the atmosphere is the coloration of the sky. The scattering phenomenon can be observed in the atmosphere through Reyliegh scattering and Mie scattering. When diameters of the particles are smaller than the incident solar radiation, the sky appears in brilliant blue. Reyleigh scattering is best seen when the atmosphere is free of suspended particles. On the other hand, when diameters of particles are larger than the wavelengths of incident radiation, Mie scattering occurs.

The processes that are mentioned above intricately govern the heating and cooling of both the atmosphere and earth's surface, influencing the movement and distribution of heat energy within the earth-atmosphere system. Understanding these mechanisms is crucial for comprehending the dynamics of earth's climate and weather patterns.

Insolation varies globally due to a number of factors. These factors influence the intensity and distribution of solar radiation across different regions. Now let us study the factors that affect insolation in the next section.

4.3 FACTORS AFFECTING INSOLATION

The amount of insolation, or incoming solar radiation, fluctuates due to numerous factors. Geographic location plays a crucial role, with regions closer to the equator receiving more direct sunlight throughout the year. Seasonal variations, caused by the tilt of the earth's axis, lead to changes in solar intensity. Additionally, weather patterns, such as cloud cover and atmospheric pollution, can lessen sunlight reaching the earth's surface. Surface characteristics like albedo, which determines the reflectivity of surfaces, also influence insolation levels. Let us study them in detail.

A. Angle of Incidence

The angle at which the Sun's rays intersect the earth's surface is defined as the angle of incidence. This angle varies with the Sun's position relative to the earth and is measured from a line tangent to the earth's surface. The amount of insolation received by the earth's surface fluctuates with changes in the angle of incidence. When the Sun is directly overhead, the angle of incidence is steeper, and its rays are perpendicular to the earth's surface, resulting in a higher concentration of solar energy. Conversely, when the angle of incidence is lower, the rays are more oblique, leading to a dispersion of solar energy. Additionally, oblique rays traverse a greater distance through the atmosphere before reaching the earth's surface, increasing the likelihood of energy loss through processes like reflection, absorption, and scattering. Consequently, insolation is most intense at midday and diminishes during morning and evening hours. Moreover, regions at higher latitudes receive less insolation compared to lower latitudes or the tropics due to the inclination of the Sun's rays. The latitude of a location, time of day, and season collectively determine the angle of incidence of the Sun. Refer to Fig. 4.3 to understand better.

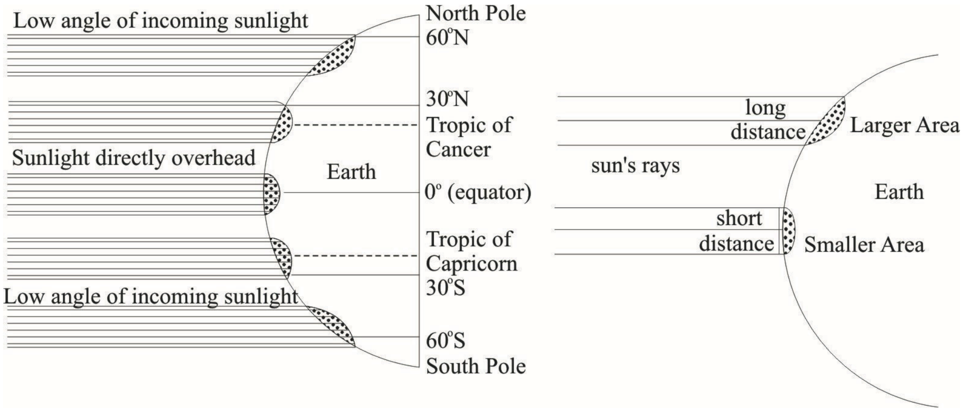

Fig. 4.3: Sun's Angle of Incidence and Its Concentration on the Earth's Surface.

B. Duration of Sunshine

The duration of daylight varies with seasons and latitude, directly influencing the amount of solar radiation received at a particular location. Extended periods of sunshine yield a greater influx of solar radiation, while shorter durations result in reduced solar radiation. The variation in duration of daylight across different latitudes can be observed by examining Table 4.2, which demonstrates the differing lengths of day from the equator to the poles. A detailed examination of day and night lengths offers further insight into this phenomenon.

Table 4.2: Length of the Day in Different Latitudes

Latitude	Max. Length of day
0°	12 hours
17°	13 hours
31°	14 hours
41°	15 hours
49°	16 hours
58°30'	18 hours
63° 24'	20 hours
66°30'	24 hours
67°24'	1 month
69°48'	2 months
78°12'	4 months
90°	6 months

(Source: Climatology and Oceanography, D. S. Lal)

C. Distance from the Sun

As earth orbits the Sun in an elliptical orbit, the distance between the two celestial bodies fluctuates throughout the year. On July 4th, earth is farthest from the Sun. This position is aphelion, with a distance of approximately 152,000,000 kilometers. This results in decreased insolation. Conversely, on January 3rd, earth is closest to the Sun, the position being perihelion, with a distance of around 147,000,000 kilometers. During this position, the earth receives high solar radiation. These variations in distance contribute to the fluctuations in the amount of solar radiation received by earth.

D. Transparency of the Atmosphere

The transparency of the atmosphere plays a significant role in determining the amount of insolation reaching earth's surface. The presence of water droplets, dust particles, and certain gases in the atmosphere can lead to reflection, scattering, and absorption of solar radiation, thereby reducing the amount of solar radiation reaching the earth's surface. Transparency varies spatially and temporally, closely correlating with latitude. The regions in higher latitudes, where the Sun's rays are more oblique, they must traverse through thicker atmospheric layers compared to the lower latitudes. Additionally, heavy cloud cover and a turbid atmosphere further diminish the amount of radiant energy reaching the earth's surface. Overall, the reflection, absorption, and transmission of solar radiation are dependent upon the transparency of the atmosphere, thereby influencing the quantity of insolation received.

SAQ 2

How does the angle of incidence of the Sun's rays affect the concentration of solar energy on earth's surface?

Having discussed these factors, let us now examine the average annual distribution of solar radiation across the globe.

4.4 DISTRIBUTION OF SOLAR RADIATION

Figure 4.4 depicts the average annual distribution of solar radiation at ground level, offering valuable insights into the variations in solar energy across different regions. The data generated from this illustration provides the foundation for the subsequent explanations.

In examining the figure, it becomes apparent that solar radiation exhibits a wide range of values, with lower levels, approximately 70 kg calories per square centimeter, observed primarily in high latitudes. Conversely, notably higher levels exceeding 220 kg calories per square centimeter are noted in regions like the eastern Sahara of North Africa. Generally, solar radiation intensity tends to be higher in equatorial regions, gradually decreasing towards the poles. A discernible zonal pattern emerges in middle and higher latitudes, emphasising the latitudinal influence on solar radiation distribution.

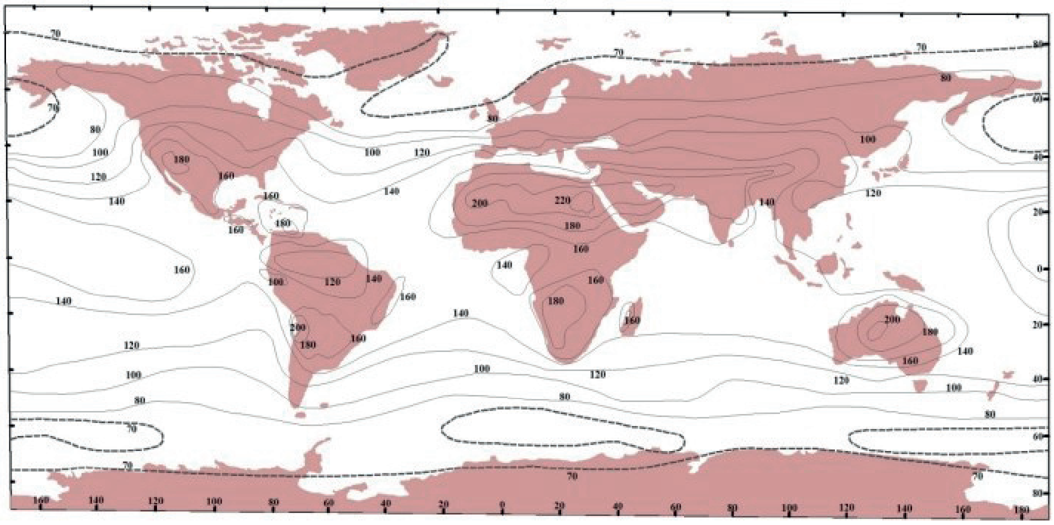

Fig. 4.4: Average Annual Distribution of Solar Radiation at Surface Level.

Furthermore, it is crucial to recognise that solar radiation patterns in higher latitudes are markedly seasonal, with these regions experiencing minimal radiation during winter months, while the majority is received between the spring and autumn equinoxes (March 23rd and September 22nd, respectively). The lowest annual radiation values recorded in the oceans of high latitudes are attributed to the prevalence of abundant clouds associated with semi-permanent oceanic low-pressure cells which significantly reduces the solar radiation exposure. Similarly, tropical regions exhibit relatively low solar radiation due to the prevalence of dense cloud cover and strong convection currents, particularly in comparison to subtropical regions.

Conversely, the sub-tropics receive the maximum solar radiation, owing to the presence of high-pressure cells, extensive deserts, and comparatively fewer clouds, particularly over landmasses. This concentration of solar radiation underscores the significance of geographical and meteorological factors in influencing solar energy distribution.

So far, we have studied the concept of insolation and the multifaceted factors governing its distribution. Additionally, we have explored the intricacies of solar radiation distribution across various regions. With this foundational understanding established, let us now turn our attention to examine the heat budget of both the atmosphere and the earth.

SAQ 3

Briefly discuss the distribution of solar radiation across different latitudinal regions.

4.5 HEAT BALANCE

The heat balance between the earth and its atmosphere involves the exchange of energy through various processes. Incoming solar radiation warms the earth's surface, which then emits infrared radiation back into the atmosphere. Greenhouse gases, namely carbon dioxide and water vapour, absorb some of this outgoing radiation, trapping heat and warming the atmosphere. Atmospheric circulation redistributes heat globally, with warm air rising at the equator and sinking of cool air at the poles. This equilibrium regulates global temperatures, sustaining life and climate systems. However in recent times, human activities, like burning fossil fuels, disrupt this balance by increasing greenhouse gas concentrations, leading to global warming. Understanding and managing this delicate heat balance is crucial for mitigating climate change and preserving the stability of earth's ecosystems

During daytime, earth continually receives solar energy. Without the outgoing radiation, the earth's surface would progressively heat up. It is interesting to note that there exists a delicate equilibrium between the incoming solar radiation and the outgoing terrestrial radiation. This equilibrium, balancing the amount of insolation and outgoing terrestrial radiation, is referred to as the earth's heat budget.

Figure 4.5 elucidates the intricacies of the heat budget of both the atmosphere and the earth. Out of the total 100 units of solar radiation reaching the outer atmosphere, 34 units are promptly returned to space without contributing to atmospheric heating. Among these, 25 units are reflected back by clouds, 2 units are reflected by the earth's albedo, and 7 units are lost due to scattering by air molecules and dust particles in the atmosphere. Subsequently, of the remaining 66 units, 19 units are absorbed within the atmosphere, 16 units are absorbed by gases and 3 units by clouds. The remaining 47 units reach the earth's surface, where they are converted into heat energy. Of this, 19 units are received as direct radiation, 23 units as diffused radiation through clouds, and 5 units as scattered radiation. Thus, a total of 66 units of effective solar radiation is absorbed by the atmosphere and the earth's land-sea surface, contributing to the heating of the earth's atmosphere.

To maintain terrestrial heat balance, the 66 units of solar radiation absorbed must be counterbalanced by an equal amount of energy radiated back to space in the form of longwave terrestrial radiation. The operation of the terrestrial heat balance, as depicted in Figure 4.5, reveals that the earth radiates 120 units of energy upwards, with 6 units directly radiated to space. The atmosphere absorbs the remaining 114 units of longwave terrestrial radiation. Additionally, 10 units of heat are transported upward by convection currents, further contributing to the atmosphere's energy gain. The atmosphere also gains 23 units as latent heat carried within the hydrologic cycle due to processes such as evaporation, condensation, and precipitation. Considering the 19 units of solar energy absorbed directly by the atmosphere, the total units absorbed amount to 166. Out of these, 106 units are reradiated back to the earth's surface, while only 60 units are radiated to space. When combined with the 6 units directly radiated by the earth's surface, this sums up to 66 units of energy radiated back into space, thus balancing the incoming solar radiation with an equal amount of outgoing radiation.

This intricate interplay between solar radiation absorption, atmospheric processes, and terrestrial radiation emission underscores the dynamic equilibrium governing earth's heat budget, crucial for maintaining the planet's overall thermal balance.

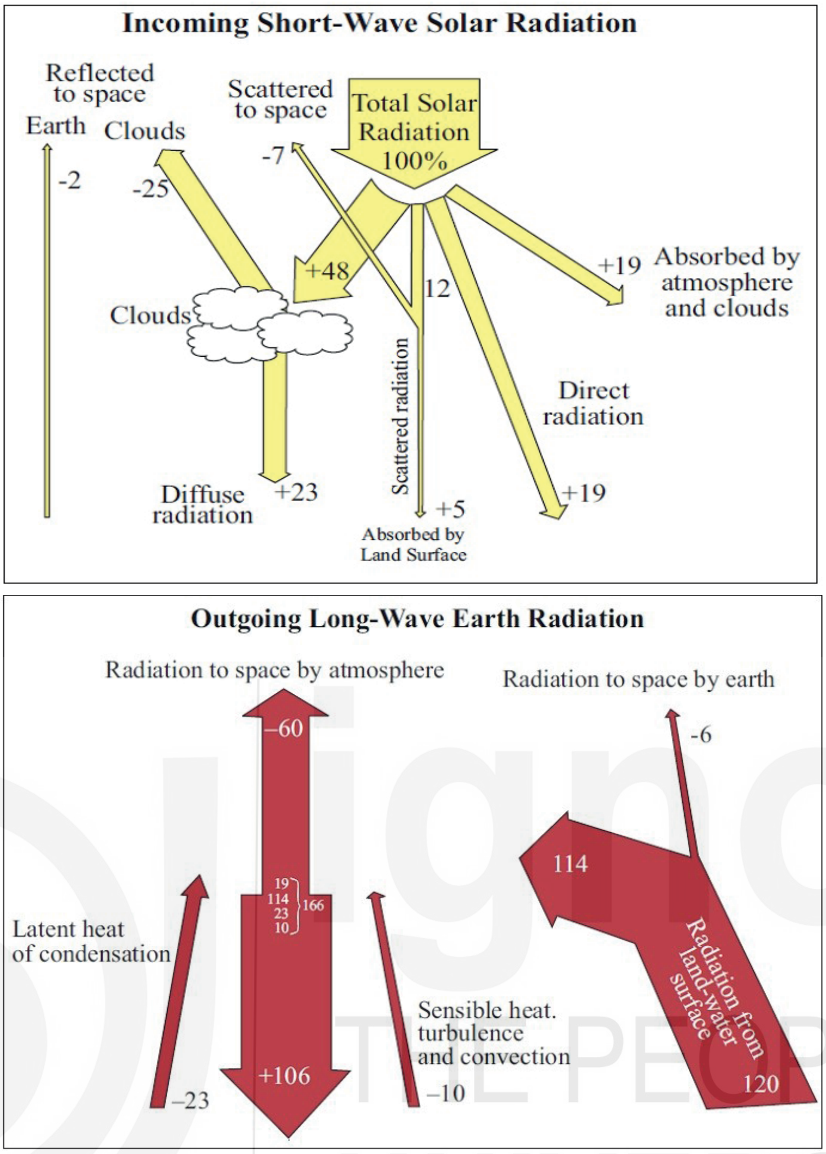

Fig. 4.5: Heat Budget of the Earth and Atmosphere.

4.6 SUMMARY

Let us recapitulate what we have learnt in this unit:

- We focused on solar radiation and its effects on earth's surface.
- We discussed the concept of insolation, which refers to incoming solar radiation.
- We explored factors influencing its distribution. These factors include the angle of incidence, duration of Sunshine, distance between the earth and the Sun, and transparency of the atmosphere.
- Additionally, we examined the average annual distribution of solar radiation across different regions, noting variations in intensity and seasonal patterns.
- Furthermore, we studied the earth's heat budget, which maintains a delicate balance between incoming solar radiation and outgoing terrestrial radiation. Understanding these concepts is crucial for comprehending earth's climate and energy dynamics.

4.7 TERMINAL QUESTIONS

1. What is insolation? Explain the factors controlling insolation.
2. What is heat budget of the atmosphere and earth?

4.8 ANSWERS

Self-Assessment Questions (SAQ)

1. Modern solar technologies like photovoltaic (PV) systems and concentrated solar power (CSP) harness sunlight to generate electricity. PV systems use semiconductor materials to directly convert sunlight into electricity, while CSP systems focus sunlight onto a small area to produce heat for driving turbines. These technologies contribute to sustainable development by reducing reliance on fossil fuels, mitigating climate change, and enhancing energy access, particularly in remote and underserved areas.
2. The angle of incidence, where the Sun's rays meet the Earth's surface, affects the amount of solar energy received. A steeper angle occurs when the Sun is overhead, concentrating energy. A lower angle disperses energy, as the rays become more oblique and travel farther through the atmosphere, increasing energy loss. Insolation is strongest at midday and weaker in the morning and evening. Higher latitudes receive less insolation than the tropics due to the angle of the Sun's rays. The angle of incidence is influenced by latitude, time of day, and season.
3. There are disparities in solar radiation intensity, with lower levels observed primarily in high latitudes and notably higher levels noted in regions such as the eastern Sahara of North Africa. The latitudes have a great influence on solar radiation distribution. There are also seasonal variations in solar radiation patterns, particularly in higher latitudes, where minimal radiation is experienced during winter months, contrasting with increased radiation between the spring and autumn equinoxes. The depiction of lower annual radiation rates in oceans of high latitudes and tropical regions is attributed to cloud cover and convection currents respectively.

Terminal Questions

1. After defining and explaining insolation, list all the factors controlling insolation and describe them too. Refer to Sections 4.2.1 and 4.3 of this unit.
2. First give the definition of heat budget and then describe how incoming solar radiation is equal to outgoing terrestrial radiation in terms of units. Support your answer with a figure as given in Sec. 4.5 of this unit.

4.9 REFERENCES AND SUGGESTED FURTHER READINGS

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Web Links

- Insolation and Atmospheric Temperature: https://www.youtube.com/watch?v=ZT2MxX-R4rw&list=PLDCsGRRaAZqf0UAvuVbte3ZssrUXVHBcb&index=2&t=42s

UNIT 5

TEMPERATURE

Structure

5.1 INTRODUCTION

In this course, so far you have studied about the meaning and scope of climatology, basic difference between weather and climate and various elements of weather and climate. You have also studied about the various layers of atmosphere, that is, the vertical structure of atmosphere and how the temperature varies in different layers. In Block 2, you have been introduced to the process of insolation which heats up the earth and its atmosphere. You have also learnt about the energy balance or heat budget of earth and atmosphere.

Now since you have already learnt about insolation, you will study in detail about temperature and its variation both horizontally and vertically in this unit. Sec. 5.2 will just give you a general overview of heating and cooling of the atmosphere based on the concepts you have learnt in the preceding unit on insolation. Sec. 5.3 will introduce you to surface air temperature and various terms associated with it. In Sec. 5.4, you will study about horizontal distribution of temperature on earth and the factors affecting it. Sec. 5.5 will acquaint you with adiabatic lapse rate. The subsequent Sec. 5.6 will discuss the vertical distribution of temperature, which you have already studied in unit 3 of this course, when you studied the different layers of atmosphere. Lastly Sec. 5.7 will describe inversion of temperature.

Expected Learning Outcomes

After studying this unit, you will be able to:

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- define temperature;
- explain the process of heating and cooling of atmosphere;
- discuss the factors affecting horizontal distribution of temperature on earth;
- illustrate the variations in distribution of temperature over the earth's surface in the months of January and July; and
- describe inversion of temperature.

5.2 HEATING AND COOLING OF ATMOSPHERE

The earth's atmosphere is a dynamic system where heating and cooling processes play pivotal role in shaping weather patterns, climate dynamics, and the overall equilibrium of our planet's environment. You have already studied in detail about insolation and heating and cooling of earth and atmosphere and their heat budget in the previous unit. Understanding the mechanisms behind heating and cooling in the atmosphere is fundamental to comprehending meteorological phenomena and climate change. Let us just recall the processes involved in heating and cooling, exploring their mechanisms, impacts, and its significance in earth's atmospheric dynamics.

Solar Radiation and Atmospheric Heating

Sun serves as the primary source of energy for earth. Solar radiation penetrates the atmosphere, interacting with its various components. Upon reaching the earth's surface, sunlight is absorbed, causing the land, oceans, and vegetation to warm up. This process is known as insolation and it drives the surface temperatures and influences atmospheric dynamics.

However, not all solar radiation is absorbed at the surface. A significant portion is reflected back into space by clouds, aerosols, and reflective surfaces like ice and snow. This phenomenon, termed albedo, plays a crucial role in modulating the earth's energy balance. Albedo affects the amount of solar radiation absorbed by the planet and contributes to regional and global temperature variations.

Atmospheric Structure and Vertical Heating

The atmosphere is stratified into layers based on temperature gradients, with distinct heating and cooling patterns characterising each layer. The troposphere, the lowest layer, experiences a decrease in temperature with elevation due to the adiabatic cooling associated with decreasing air pressure. This vertical temperature gradient is fundamental to atmospheric stability and the formation of weather systems.

In contrast, the stratosphere exhibits a temperature inversion, where temperatures increase with altitude due to the absorption of solar radiation by ozone molecules. This unique heating mechanism in the stratosphere plays a critical role in shielding the earth from harmful ultraviolet (UV) radiation. Vertical Distribution of Temperature is discussed in detail in Sec. 5.5.3 of this unit.

Heat Transfer Mechanisms

The transfer of heat within the atmosphere occurs through various mechanisms, including conduction, convection, and radiation. You have already studied about these processes in Unit 4 of this course. Conduction involves the direct transfer of heat between adjacent molecules through collisions. While conduction is more prevalent in solids and liquids, it also occurs to a lesser extent in the lower atmosphere.

Convection, on the other hand, involves the transfer of heat through the movement of fluids, such as air and water. Warm air rises while cool air sinks, creating vertical circulation patterns that drive weather phenomena like thunderstorms, hurricanes, and fronts. Convection is a primary mechanism for redistributing heat within the atmosphere and plays a crucial role in regulating temperature gradients.

Radiation is another significant mechanism for heat transfer in the atmosphere. Unlike conduction and convection, radiation does not require a medium and can propagate through the vacuum of space. The earth emits longwave radiation, primarily in the infrared spectrum, back into the atmosphere. Greenhouse gases such as water vapor, carbon dioxide, methane, and ozone absorb and re-radiate this outgoing heat, trapping it in the atmosphere and contributing to the greenhouse effect.

Seasonal and Diurnal Variations

Heating and cooling processes exhibit pronounced seasonal and diurnal variations driven by the tilt of earth's axis and its orbit around the Sun. During the summer solstice, the Northern Hemisphere receives maximum direct sunlight, leading to warmer temperatures and longer daylight hours. Contrary to this, the winter solstice results in shorter days and cooler temperatures, as sunlight strikes the earth at a more oblique angle.

Diurnal variations refer to the daily cycle of heating and cooling experienced by the atmosphere. As the Sun rises, solar radiation increases, warming the surface and initiating convective processes. Daytime heating peaks in the afternoon, leading to the formation of convective clouds and thunderstorms. As the Sun sets, radiative cooling takes over, causing temperatures to decrease rapidly, especially under clear skies and calm conditions.

Impacts on Weather and Climate

Heating and cooling processes profoundly influence weather patterns, atmospheric circulation, and climate variability. Differential heating of land and ocean surfaces generates temperature gradients that drive the global circulation patterns, such as the Hadley, Ferrel, and Polar cells. These atmospheric circulation systems play a crucial role in distributing heat and moisture around the planet, shaping regional climates and weather phenomena.

Moreover, variations in atmospheric heating and cooling contribute to the formation of extreme weather events, including heat waves, cold waves, droughts, and hurricanes. The interaction between oceanic and atmospheric processes, such as El Nino and La Nina events, can disrupt normal weather patterns and trigger anomalous temperature and precipitation patterns across different regions.

Climate change exacerbates the impacts of heating and cooling processes on earth's atmosphere. Rising concentrations of greenhouse gases intensify the greenhouse effect, leading to global warming and alterations in precipitation patterns. Melting polar ice caps, shifting weather patterns and more frequent extreme weather events are among the observable consequences of anthropogenic climate change.

Heating and cooling processes are fundamental drivers of atmospheric dynamics, influencing weather patterns, climate variability, and earth's overall energy balance. Understanding the intricate mechanisms behind these processes is essential for predicting weather phenomena, assessing climate change impacts, and implementing effective mitigation strategies. As we continue to study earth's atmosphere, unraveling the complexities of heating and cooling remains a cornerstone of meteorological and climatological research, guiding our efforts to safeguard the planet's environmental stability for future generations.

5.3 SURFACE AIR TEMPERATURE

The heating and cooling of the earth's atmosphere are fundamental processes that govern weather patterns, climate dynamics, and the overall equilibrium of the planet's systems. At the heart of atmospheric dynamics lies the concept of temperature. Temperature is a fundamental physical quantity that represents the degree of hotness or coldness of a substance. It is a measure of the average kinetic energy of the particles within that substance. In simpler terms, temperature reflects how fast the particles in a substance are moving. The faster the particles move, the higher the temperature; conversely, the slower the particles move, the lower the temperature.

Are you confused between the terms temperature and heat? Let us understand it clearly. Heat is a form of energy transfer that occurs between two substances or systems due to temperature differences. Heat flows from regions of higher temperature to regions of lower temperature until thermal equilibrium is reached, where the temperatures of the systems become equal.

So the key distinction between heat and temperature lies in their definitions and physical properties:

1. Temperature:

- Temperature is a measure of the average kinetic energy of particles within a substance.
- It is an intrinsic property of the substance and does not depend on the amount of substance present.
- Temperature is a scalar quantity and is measured in units such as degrees Celsius (°C), Fahrenheit (°F), or Kelvin (K).

- Temperature determines the direction of heat transfer and influences the physical properties of materials, such as volume, density, and conductivity.

2. Heat:

- Heat is a form of energy transfer that occurs due to temperature difference between two substances or systems.
- It flows spontaneously from regions of higher temperature to regions of lower temperature.
- Heat is a vector quantity, as it has both magnitude and direction, and it is measured in units of joules (J) or calories (cal).
- Heat transfer can occur through various mechanisms, including conduction, convection, and radiation, depending on the nature of the substances involved and the physical conditions.

Overall, temperature represents the thermal state of a substance, while heat represents the energy transferred between substances as a result of temperature differences. Understanding the distinction between temperature and heat is crucial for analysing thermal processes, designing efficient heating and cooling systems, and comprehending the behaviour of matter under different environmental conditions.

Surface air temperature, often referred to simply as air temperature, is the measure of the temperature of the air at a specific location and time. It is typically measured using instruments such as thermometers placed at weather stations, which record the ambient temperature of the surrounding air. Surface air temperature serves as a critical parameter for understanding regional climates, forecasting weather events, and assessing long-term climate trends.

5.3.1 Measurement of Temperature

The formula provided for converting temperatures between Celsius (°C) and Fahrenheit (°F) is indeed a fundamental equation used in temperature conversions. For better understanding of the conversion process, let's break down the formula:

Given:

C represents the temperature in degrees Celsius.

F represents the temperature in degrees Fahrenheit.

The conversion formula from Celsius to Fahrenheit is:

$C/5 = (F-32)/9$

To convert from Celsius to Fahrenheit, we rearrange the formula as follows:
$°F = \{(9/5)*C\} + 32$

Conversely, to convert from Fahrenheit to Celsius, we rearrange the formula as follows:

$°C = (°F-32)*5/9$

This conversion formula is useful for various purposes, including international communication of temperature data, scientific research, and practical applications in everyday life. Understanding temperature conversions allows individuals to interpret temperature measurements regardless of the unit used, facilitating communication and analysis across different regions and disciplines.

Now let us learn how temperature is measured.
A ***thermometer*** is an instrument used to measure temperature. It works on the principle that the physical properties of materials change in a predictable way with temperature variations. There are various types of thermometers, each utilising different mechanisms for temperature measurement.

The most common type of thermometer is the ***liquid-in-glass thermometer***, which consists of a glass bulb connected to a narrow tube containing a liquid, typically mercury or alcohol. As the temperature changes, the liquid expands or contracts, causing it to rise or fall within the calibrated scale marked on the thermometer tube. The temperature is then read from the scale at the level of the liquid.

Another type of thermometer is the ***bimetallic strip thermometer***, which consists of two different metals bonded together. These metals have different coefficients of thermal expansion, causing the strip to bend when exposed to temperature changes. The amount of bending is proportional to the temperature, allowing for temperature measurement.

Resistance thermometers, such as the *platinum resistance thermometer*, use the principle of electrical resistance to measure temperature. The electrical resistance of the sensor material changes with temperature and this change is calibrated to provide an accurate temperature measurement.

Thermocouples are another common type of thermometer, which consists of two different metal wires connected at one end. When there is a temperature difference between the two ends, it generates a voltage that is proportional to the temperature difference. This voltage can be measured and used to determine the temperature.

Six's thermometer

Six's thermometer, also known as a maximum and minimum thermometer, is a specialised type of thermometer used to measure the maximum and minimum temperatures over a period of time. It comprises a U-shaped tube (see Figure 5.1) with a narrow, consistent bore, and both ends of the tube taper into bulbs. As the temperature changes, the liquid expands and contracts, causing it to rise and fall in the U-shaped tube. The left bulb is entirely filled with alcohol, while the right bulb contains partially filled alcohol with a vacuum at the top. Between them lies the U-shaped portion of the tube filled with mercury. With rising temperature, the alcohol in the left bulb expands, causing the mercury to rise in the right portion of the tube, marking the maximum temperature. Two steel indices above the mercury columns move autonomously, recording the maximum and minimum temperatures unless prompted by the rising mercury. Minimum temperature is noted when alcohol contracts, causing the mercury to fall in the right portion and rise in the left portion of the tube. Steel springs are affixed to the indices, ensuring they stay against the tube wall.

The thermometer is supplied with a small horseshoe magnet for returning the steel indices to contact with the mercury. By placing the magnet on a steel index and moving it towards the mercury, the index reconnects with the mercury.

Six's thermometer is commonly used in meteorology, agriculture, and environmental monitoring to track temperature fluctuations over time and assess temperature extremes. It provides valuable data for understanding weather patterns, plant growth cycles, and environmental conditions in various settings.

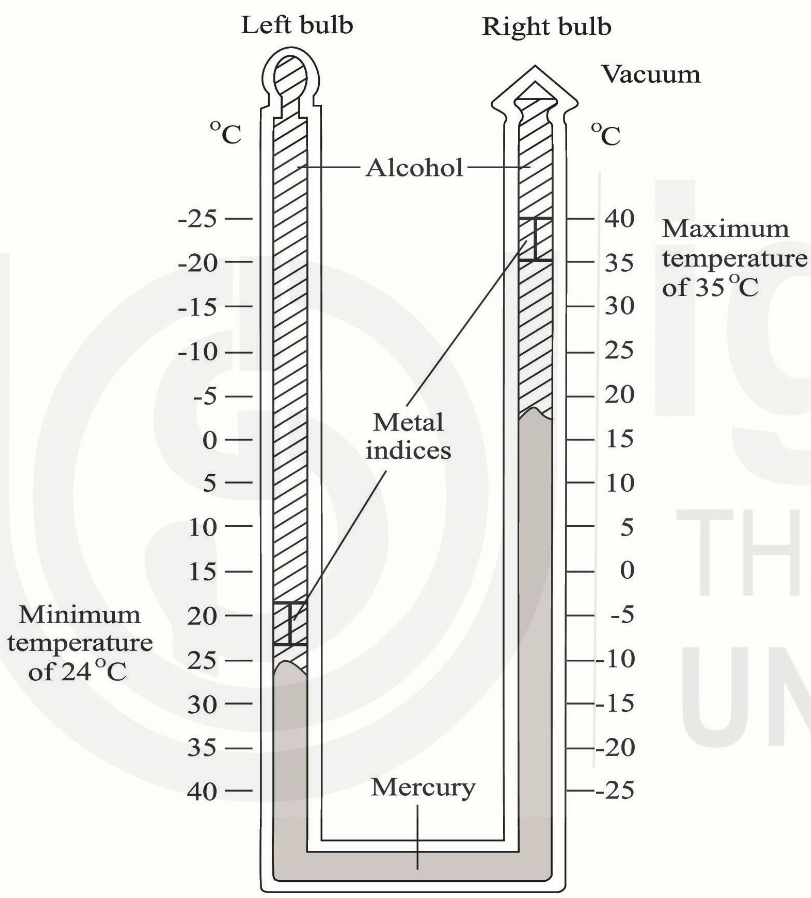

Fig. 5.1: Six's Maximum and Minimum Thermometer.

Now that we have grasped temperature measurement, let's delve into the horizontal distribution of temperature on earth.

5.4 HORIZONTAL DISTRIBUTION OF TEMPERATURE

The horizontal distribution of temperature on earth refers to the variation in temperatures across different regions and latitudes of the planet's surface. This distribution is influenced by various factors such as latitude, altitude, proximity to large bodies of water, ocean currents, prevailing winds, and physiographic features like mountains and valleys. The horizontal distribution of temperature on earth can be represented and analysed through temperature maps. Before studying the horizontal distribution of temperature on the surface of earth, let us first study about isotherms and factors affecting the horizontal distribution of temperature on earth.

5.4.1 Isotherms

Isotherms are commonly used to represent the horizontal distribution of temperature on earth. The term 'isotherm' is derived from two Greek words, 'iso' meaning equal, and, 'therm' meaning temperature. Isotherms are lines that connect points of equal temperature, reduced to the mean sea level (that is, supposing the places to be at mean sea level on a weather map). By plotting isotherms on a map, scientists can visualise temperature patterns and gradients across different regions and latitudes.

Isotherm maps provide valuable insights into temperature distribution, seasonal variations, and climatic patterns. They help identify temperature gradients, climate zones, and areas of temperature anomalies. Isotherms are often used in conjunction with other meteorological data, such as precipitation, wind patterns, and atmospheric pressure, to analyse weather and climate phenomena comprehensively.

Meteorological organisations, research institutions, and climatologists frequently use isotherm maps to study climate change, monitor temperature trends, and assess the impacts of global warming on ecosystems and human societies. These maps play a crucial role in understanding the earth's climate systems and informing climate-related policies and decision-making processes.

5.4.2 Factors Affecting Horizontal Distribution of Temperature on the Earth

Temperature of a place on earth's surface is determined by a multitude of factors. Understanding these factors unveils the complex interplay that shapes the horizontal distribution of temperature across diverse regions. The factors that influence the temperature distribution are latitude, altitude, distribution of land and water, ocean currents, winds, clouds, and relief features. Let us study each of them.

Latitude

You may recall that latitude is the angular distance north or south of the equator. It plays a pivotal role in dictating the temperature regimes. Equatorial regions come under the sun's direct rays and experiences higher temperatures, while the Polar Regions, where sunlight strikes at an oblique angle, remain cooler. The tropics, nestled between the Tropic of Cancer and the Tropic of Capricorn, witness the zenith of solar heating, with temperatures soaring under the relentless gaze of the equatorial sun.

Altitude

Altitude, the vertical distance above sea level, represents a symphony of temperature variations. As one ascends up to the higher altitudes, the air thins and temperatures drop, heralding the onset of cooler climes. The atmosphere is heated primarily through conduction from earth's surface and undergoes a steady decline in temperature with increasing elevation, known as the lapse rate. This phenomenon is accentuated by the lower density of air and diminished water vapour content at higher altitudes, sets the stage for the emergence of alpine environments and snow-capped peaks.

The Distribution of Land and Water

The distribution of land and water, characterised by its irregularity, amplifies the heterogeneity of earth's temperature landscape. Landmasses are associated with low specific heat capacities and rapid heat exchange dynamics. It manifests extreme temperature fluctuations. Conversely the vast water bodies endowed with higher specific heat capacities and slower heating and cooling rates, exhibit milder temperature oscillations. Coastal areas, influenced by the adjacent oceans, enjoy climatic moderation, while inland regions endure the experiences of temperature extremes.

Ocean Currents

Ocean currents influence coastal temperatures by transporting warm or cold water from one region to another region. Warm currents raise temperatures of the coastal areas, while cold currents lower them. For example, the North Atlantic Drift warms the coasts of Western Europe, while the California and Benguela currents cool their respective coastal regions.

Winds

Prevailing winds can transport temperature characteristics from one region to another. Winds from land areas lower temperatures in temperate regions during winter and raise them during summer, while winds from oceans have the opposite effect. Local winds, such as Chinook or the winds from Rajasthan, also impact local temperatures significantly.

Cloud

Cloud cover affects incoming solar radiation and outgoing terrestrial radiation, which in turn influence the temperature patterns. Cloudy regions have lower temperature ranges compared to clear skies, and cloud cover can moderate extreme temperatures. Cloud cover, acting as a thermal veil, modulates incoming solar radiation and outgoing terrestrial radiation. Regions covered with clouds experience subdued temperature ranges, while regions with clear skies experiences diurnal extremes. The equatorial belt, covered in perpetual cloud cover, witnesses the subtle interplay between evaporation, condensation, and temperature moderation.

Relief Features

Elevation and slope orientation play a crucial role in temperature distribution. Southward-facing slopes receive more sunlight and become warmer than northward-facing slopes in northern hemisphere. Additionally, the orientation of mountain ranges affects the temperature patterns, with north-south trending ranges having different effects from east-west trending ranges.

These factors collectively contribute to the complex and dynamic horizontal distribution of temperature on earth's surface, influencing regional climates and weather patterns. From the hot equatorial tropics to the frost-laden polar realms, the ebb and flow of temperature is responsible for the ever-changing rhythms of our planet's dynamic biosphere.

5.4.3 January and July Isotherms

You may recall that temperatures decrease from the equator to the poles, reflecting the impact of latitude on temperature distribution. Isotherms, which represent lines of equal temperature, help visualise this distribution. Isotherms generally trend east-west and closely mirror lines of latitude. The tropics and subtropics experience the highest temperatures due to varying levels of sunlight, with temperatures gradually decreasing towards the poles. Differential heating of land and water causes temperature variations between oceans and landmasses along the same latitude. Consequently, isotherms bend and distort as they transition from ocean to land and vice versa, particularly noticeable in the northern hemisphere where there is more landmass. Isotherms exhibiting wider spacing, indicates slower temperature changes, while they appear more regular in the southern hemisphere, where water in the form of oceans predominates.

Mean monthly isotherms, especially for January and July, are crucial for understanding temperature extremes. January marks the coldest month in the northern hemisphere and the hottest in the southern hemisphere, while July experiences the opposite. Analysis of isothermal maps for these months reveals shifting of global temperature patterns influenced by the sun's apparent position, land-water distribution, ocean currents, and prevailing winds.

January Isotherms

In January, the southern hemisphere experiences summer while the northern hemisphere experiences winter. Isotherms exhibit irregular patterns in the northern hemisphere, bending towards the equator over continents whereas these bend towards the poles over oceans as oceans are warmer. Conversely, the southern hemisphere displays more regular isotherm patterns during January, as depicted in Fig. 5.2.

July Isotherms

In July, with the sun overhead along the Tropic of Cancer, the northern hemisphere experiences summer while the southern hemisphere experiences winter. High temperature belts span from North Africa through South-West Asia to the North-Western part of the Indian Subcontinent, as well as in the South-Western United States. July isotherms bend towards the equator over oceans and towards the poles over continents, reflecting the rapid heating of land compared to the ocean at similar latitudes. Isotherms appear more regular in the southern hemisphere due to its ocean predominance, while irregularities characterise the northern hemisphere.

All isotherms shift slightly northward in July with the sun's apparent movement, while the thermal equator shifts northward too. This trend is reversed in January.

Understanding these gradations in temperature distribution enhances our comprehension of earth's climatic dynamics, shedding light on the intricate interplay of geographical and atmospheric factors shaping our planet's temperature landscape.

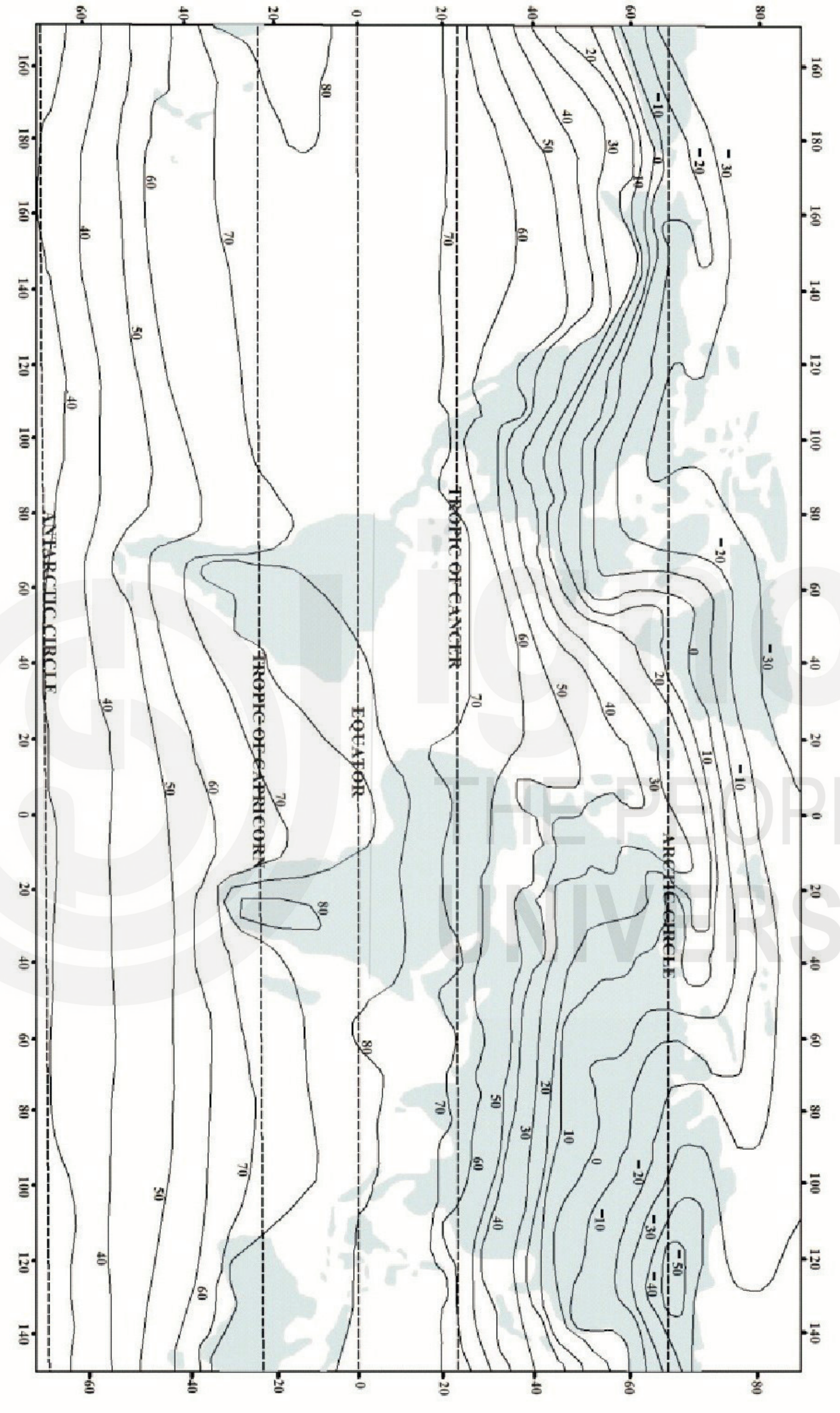

Fig. 5.2: January Isotherms (°F).

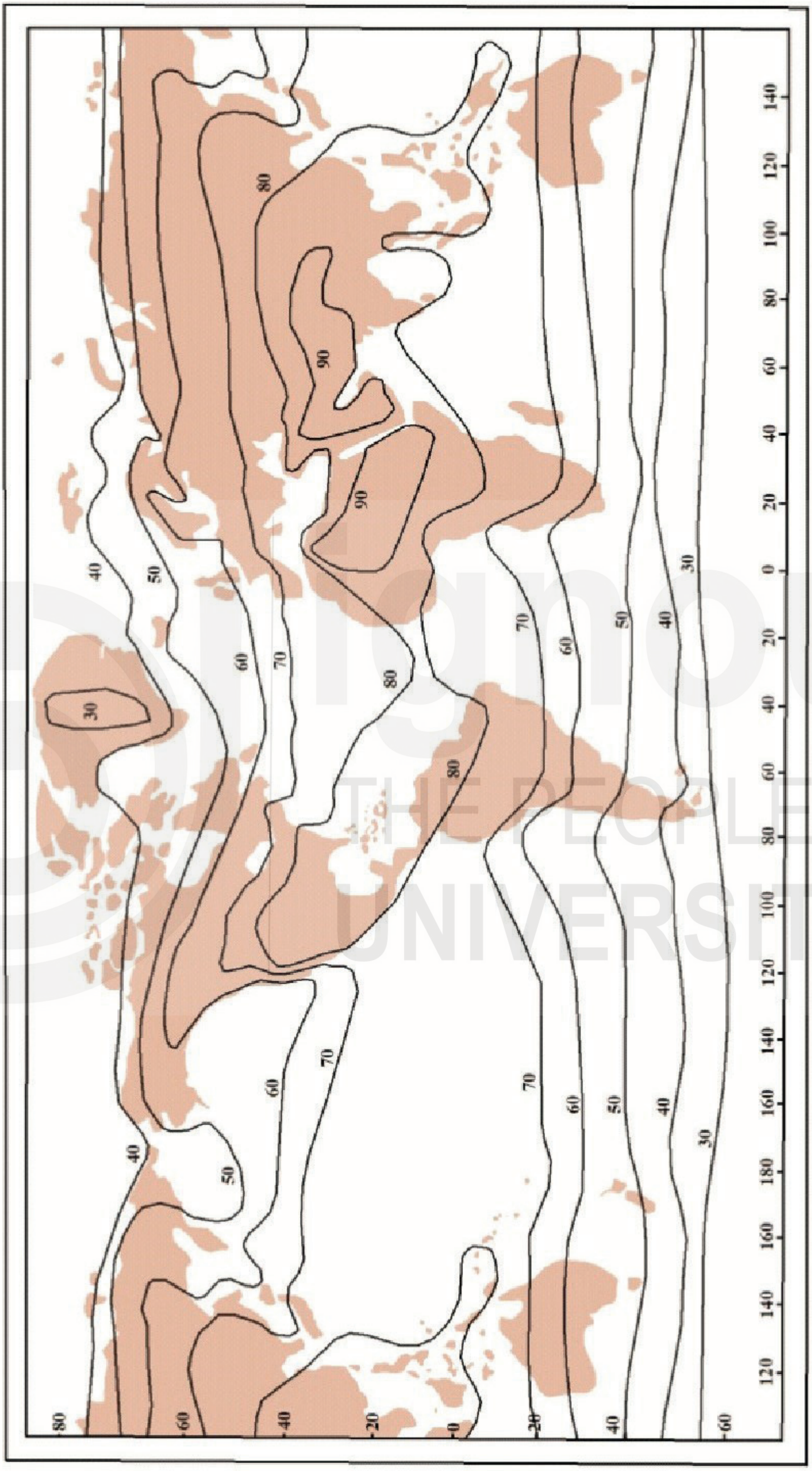

Fig. 5.3: July Isotherms (°F).

SAQ I

What are isotherms, and how do they represent the horizontal distribution of temperature?

5.5 VERTICAL DISTRIBUTION OF TEMPERATURE

Before studying, the vertical distribution of temperature on earth let us first understand adiabatic lapse rate and normal lapse rates.

5.5.1 Adiabatic Lapse Rate

The adiabatic lapse rate refers to the rate at which the temperature of a parcel of air changes as it ascends or descends in the atmosphere without exchanging heat with its surroundings. There are two types of adiabatic lapse rates: the dry adiabatic lapse rate and the moist adiabatic lapse rate.

1. **Dry Adiabatic Lapse Rate (DALR):** DALR describes the rate at which the temperature of dry air changes as it ascends or descends through the atmosphere without undergoing condensation or evaporation. The standard value for the dry adiabatic lapse rate is approximately 9.8°C per 1000 meters (5.5°F per 1000 feet) of altitude. As air parcels rise, the pressure decreases, causing the air to expand and cool adiabatically. Conversely, as air descends, the pressure increases, causing compression and adiabatic warming.
2. **Moist Adiabatic Lapse Rate (MALR):** The moist adiabatic lapse rate refers to the rate at which the temperature of moist air changes as it rises or descends and undergoes condensation or evaporation. Unlike dry air, moist air experiences changes in its latent heat content due to the process of condensation or evaporation of water vapour. The moist adiabatic lapse rate varies depending on the moisture content and temperature of the air parcel but generally ranges between 5°C and 9°C per 1000 meters.

The actual lapse rate experienced in the atmosphere can vary based on environmental conditions, such as humidity levels, solar radiation, and atmospheric stability. In stable atmospheric conditions, where the environmental/normal lapse rate (the actual rate at which temperature changes with altitude) is less than the dry adiabatic lapse rate, air parcels tend to resist vertical movement, resulting in stable weather conditions. Conversely, when the environmental lapse rate exceeds the dry adiabatic lapse rate, the atmosphere becomes unstable, promoting vertical motion and the development of clouds and precipitation.

Understanding adiabatic lapse rates is crucial for meteorologists and atmospheric scientists in analysing atmospheric stability, predicting weather patterns, and understanding processes like cloud formation, precipitation, and atmospheric convection.

5.5.2 Normal Lapse Rate

The term "normal lapse rate" typically refers to the rate at which the temperature of the atmosphere decreases with increasing altitude under standard atmospheric conditions. The standard lapse rate is approximately 6.5°C per 1000 meters (3.5°F per 1000 feet) of altitude gained.

This lapse rate is a general approximation and may vary based on local weather conditions, relief and time of the year. The normal lapse rate accounts for the adiabatic cooling of dry air as it rises through the atmosphere. As air ascends, it expands due to decreasing atmospheric pressure, causing it to cool at a predictable rate.

It is important to note that the actual lapse rate experienced in the atmosphere can deviate from the standard lapse rate due to various factors such as humidity levels, atmospheric stability, and the presence of weather systems. In some cases, the lapse rate may be steeper or shallower than the standard rate.

Meteorologists and atmospheric scientists use lapse rates to understand atmospheric stability, predict weather patterns, and analyse conditions that may lead to cloud formation, precipitation, and other atmospheric phenomena. Understanding the normal lapse rate helps in interpreting temperature profiles and atmospheric behavior across different altitudes.

Thus, while both adiabatic and normal lapse rates describe temperature changes with altitude in the atmosphere, adiabatic lapse rates are specific to adiabatic processes affecting air parcels, whereas the normal lapse rate provides a general representation of temperature variations in the atmosphere under standard conditions.

SAQ 2

What is the difference between adiabatic lapse rate and normal lapse rate in meteorology?

By now, you should be aware that as elevation increases the temperature generally decreases. You are also acquainted with the concept of the normal lapse rate, which describes this phenomenon. Another term used to describe this phenomenon, is the vertical temperature gradient.

5.5.3 Vertical Temperature Gradient

The vertical temperature gradient is influenced by both energy transfer and vertical air motion. Energy transfer occurs through latent heat release during condensation and sensible heat transfer from the ground. Descending air currents associated with high-pressure systems warm extensive air masses, while ascending air currents associated with low-pressure systems cool as they expand. This leads to changes in the vertical temperature gradient.

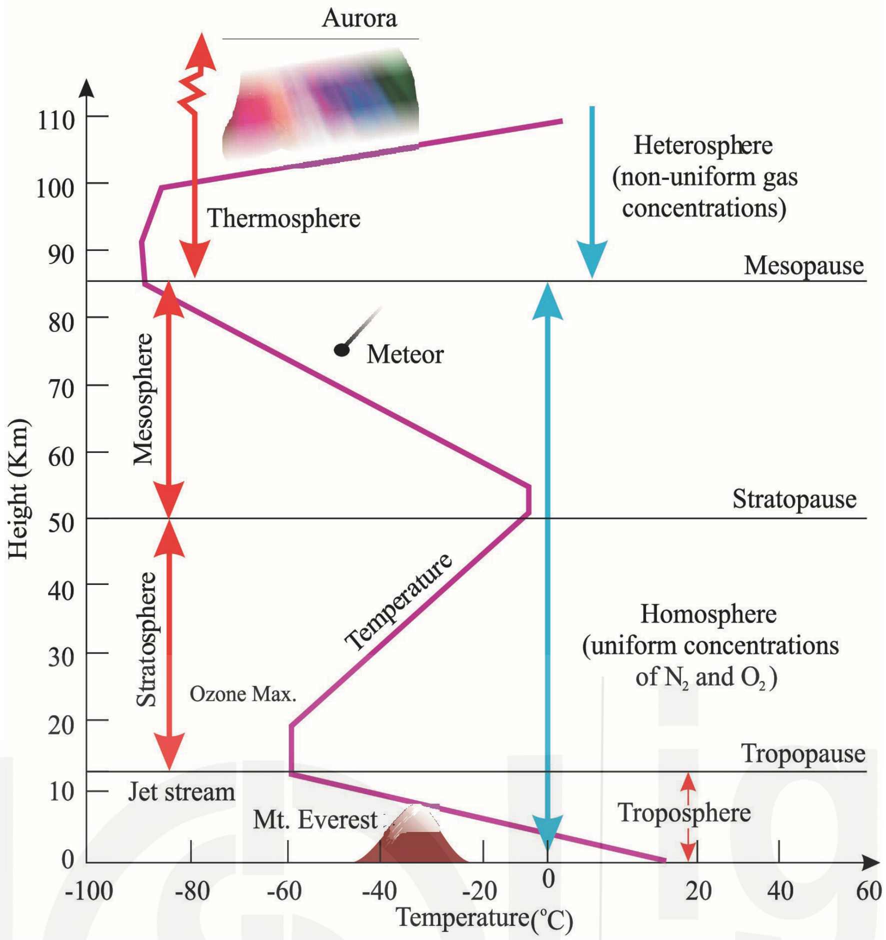

Fig. 5.4: Vertical Distribution of Temperature on Earth.

In unit 3, you learned about the vertical layers of the atmosphere. In the *troposphere*, temperature typically decreases with altitude at an average rate of 6.5°C per kilometer of ascent, known as the normal lapse rate. However, variations in the normal lapse rate can occur due to altitude, location, or season as discussed. In certain latitudes, temperature inversion may occur, where temperature increases with altitude instead of decreasing. Temperature inversions are common during winter seasons, characterised by clear skies and rapid radiative cooling. We will discuss this in next section. Near the tropopause, the temperature variation with height is minimal.

In the *stratosphere*, temperature increases with height. In the mesosphere, beyond the stratosphere, temperature decreases again, reaching a minimum of -100°C at 80 kilometers above earth's surface. Above this altitude, temperature increases due to the absorption of shortwave solar radiation by oxygen and nitrogen atoms in the rarified air of the lower part of the thermosphere, known as the ionosphere. In the thermosphere, temperatures rise significantly, exceeding 1000°C.

Fig. 5.4 provides a visual representation of the vertical distribution of temperature in the atmosphere.

So far, this unit has provided insights into the complex dynamics of temperature distribution in the atmosphere, highlighting the role of altitude, energy transfer, and vertical air motion. Now let us study about inversion of temperature.

5.6 INVERSION OF TEMPERATURE

Temperature inversion refers to a meteorological phenomenon where the normal atmospheric temperature profile is inverted, meaning that air temperature increases with altitude instead of decreasing as it typically does in the troposphere. This reversal of the normal temperature gradient can have significant effects on weather patterns, air quality, and the dispersion of pollutants.

During a temperature inversion, a stable layer of warm air overlies cooler air near the surface. This often occurs under specific atmospheric conditions, such as clear skies, calm winds, and long nights, which allow for rapid radiative cooling of the earth's surface. As the surface cools, the air in contact with it also cools, resulting in a shallow layer of cooler air near the ground.

Above this cool layer, warmer air is trapped beneath a layer of cooler air, forming an inversion layer. The inversion layer acts as a lid, preventing vertical mixing of air and trapping pollutants, moisture, and other atmospheric particles beneath it. This can lead to the formation of haze, fog, or smog in urban areas, as pollutants are unable to disperse vertically and become concentrated near the surface.

Let us now study the conditions under which temperature inversion occurs. Temperature inversions typically occur under specific atmospheric conditions that promote the trapping of warm air beneath cooler air near the surface. Some of the key conditions that can lead to the formation of temperature inversions include the following:

1. **Clear Skies**: Clear skies allow for efficient radiative cooling of the earth's surface during the night. As the surface cools, the air in contact with it also cools, creating a stable layer of cool air near the ground, above which warmer air is trapped forming an inversion layer.
2. **Light Winds**: Calm or light winds prevent the mixing of air near the surface with the air at higher altitudes. In the absence of strong winds, warm air aloft remains undisturbed and can act as a lid, trapping cooler air below.
3. **Long Nights**: Longer nights provide more time for the earth's surface to cool through radiative cooling. This prolonged cooling period enhances the development of a stable layer of cool air near the surface.
4. **High Pressure Systems**: High pressure systems are associated with sinking air motions and stable atmospheric conditions. Under high pressure, air near the surface sinks and warms, creating a temperature inversion layer that traps cooler air below.
5. **Geographical Features**: Certain geographical features, such as valleys, basins, and coastal areas, can enhance the likelihood of temperature inversions. These features can act as natural traps for cool air, especially during calm and clear nights.
6. **Seasonal Factors**: Temperature inversions are more common during the cooler months of the year, particularly in late autumn and winter when nights are longer and radiative cooling is more pronounced.

7. **Urbanisation**: Urban areas with extensive infrastructure, buildings, and pavement can absorb and retain heat during the day, leading to warmer surface temperatures. This urban heat island effect can contribute to the development of localised temperature inversions, especially during calm, clear nights.

Understanding these atmospheric conditions and their interactions is crucial for predicting and identifying instances of temperature inversions. Monitoring weather patterns, surface conditions, and atmospheric stability can help forecasters and researchers anticipate the formation of temperature inversions and assess their potential impacts on air quality, weather, and environmental conditions.

SAQ 3

What are the conditions leading to temperature inversion, and what are its effects?

5.7 SUMMARY

Let us now recapitulate what we have learnt in this unit:

1. **Surface Air Temperature:**
   - Refers to the temperature of the air near the earth's surface.
   - Influenced by various factors including solar radiation, land and water distribution, and atmospheric dynamics.
2. **Horizontal Distribution of Temperature:**
   - Represented by isotherms, the lines connecting points of equal temperature.
   - Influenced by latitude, altitude, land-water distribution, ocean currents, winds, clouds, and relief features.
3. **Factors Affecting Horizontal Distribution of Temperature:**
   - Latitude: Temperature decreases from equator to poles.
   - Altitude: Temperature decreases with increasing altitude.
   - Land-Water Distribution: Landmasses heat and cool faster than water bodies.
   - Ocean Currents: Warm and cold currents influence coastal temperatures.
   - Winds: Transport temperature characteristics from source regions.
   - Clouds: Impact incoming solar radiation and outgoing terrestrial radiation.
   - Relief Features: Elevation and slope orientation affect regional temperatures.
4. **Vertical Distribution of Temperature:**
   - Describes temperature changes with altitude in the atmosphere.

- Controlled by adiabatic and normal lapse rates.

5. **Adiabatic Lapse Rate:**
   - Dry and moist adiabatic rates describe temperature changes in rising or descending air parcels without heat exchange.

6. **Normal Lapse Rate:**
   - Standard rate of temperature decrease with altitude under normal atmospheric conditions.
   - Approximately 6.5°C per 1000 meters.

7. **Inversion of Temperature:**
   - Occurs when temperature increases with altitude, contrary to the normal atmospheric profile.
   - Caused by stable atmospheric conditions, including clear skies, light winds, and high-pressure systems.
   - Traps pollutants and moisture near the surface, impacting air quality and weather patterns.

5.8 TERMINAL QUESTIONS

1. What are isotherms? Describe January and July distribution patterns of isotherms.
2. Discuss the factors affecting horizontal distribution of temperature on earth.
3. Explain the working of a six's maximum and minimum thermometer?
4. Under what conditions inversion of temperature occurs?

5.9 ANSWERS

Self-Assessment Questions (SAQs)

1. Isotherms are lines connecting points of equal temperature on a map.
   - They visually represent how temperature varies across different geographical regions.
   - Isotherms aid in understanding temperature patterns influenced by factors like latitude, altitude, and land-water distribution.

2. The adiabatic lapse rate describes the rate at which the temperature of an air parcel changes as it ascends or descends without exchanging heat with its surroundings. There are two types: dry adiabatic lapse rate (DALR) for dry air and moist adiabatic lapse rate (MALR) for moist air. In contrast, the normal lapse rate refers to the average rate of temperature decrease with altitude in the earth's atmosphere under standard conditions, which is approximately decrease of 6.5°C per 1000 meters (3.5°F per 1000 feet). While adiabatic lapse rates are specific to air parcel behaviour, the normal lapse rate is a general approximation of atmospheric temperature change.

3. Temperature inversion occurs when warm air traps cooler air near the earth's surface.
   - It is caused by stable atmospheric conditions, as clear skies, calm winds, and long nights etc.
   - They disrupt normal atmospheric processes and can lead to weather anomalies and poor air quality.

Terminal Questions

1. Give a brief introduction to isotherms as in Sec. 5.4.1, and then explain the January and July isotherms as given in Sec. 5.4.3.
2. First explain what horizontal distribution of temperature is and then explain all factors one by one. Refer to Sec. 5.4.2.
3. First define temperature and explain how it is measured. Then explain in detail about Six's thermometer as given in Sec. 5.3.1. Can give a rough sketch.
4. First explain what inversion of temperature is. Then discuss all factors causing temperature inversion. Refer to Sec. 5.6

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UNIT 6

PRESSURE SYSTEMS

Structure

6.1 INTRODUCTION

In this block so far you have been acquainted with the concept of insolation, which is responsible for warming the earth and its atmosphere. Additionally, you have gained knowledge regarding the energy equilibrium, or heat distribution within the earth and its surrounding atmosphere. You have also explored surface air temperature, as well as the horizontal and vertical distribution of temperature, along with the phenomenon of temperature inversion. In this unit you will study about pressure systems.

You already know that air pressure is an integral element of weather dynamics. It is introduced in Sec. 6.2 and you will also learn here how to measure air pressure. Globally, various pressure systems operate, each playing a crucial role in shaping diverse climatic patterns across the earth. This is elaborated upon in Sec. 6.3. Minor fluctuations in atmospheric pressure lead to noticeable shifts in daily weather conditions which is discussed as shifting of pressure belts in Sec. 6.4. You will also study about the vertical distribution of air pressure in Sec. 6.5.

In the next unit, you will study about general atmospheric circulations in the form of winds.

Expected Learning Outcomes

After studying this unit, you will be able to:

- describe atmospheric pressure, its measurement, and its significance in weather patterns and climate systems;

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- explain the role of pressure gradient in driving air movements, including wind patterns, and how variations in pressure influence weather phenomena;
- describe the distribution of surface pressure systems globally, including high and low-pressure areas; and
- analyse the factors leading to the shifting of pressure systems.

6.2 MEASUREMENT OF ATMOSPHERIC PRESSURE

6.2.1 What is Air Pressure?

The earth's atmosphere exerts pressure due to the weight of the air above it. This pressure is known as atmospheric pressure. It varies depending on the amount of air present above a given point. For instance, the pressure on a one-square-centimeter area of the earth's surface equals the weight of the column of air directly above that area, extending all the way to the outer reaches of the atmosphere. Therefore, atmospheric pressure can be understood as the force per unit area exerted by the weight of the air above a particular point.

Since air is compressible, the air near the earth's surface is heavily compressed and consequently denser. As one ascend in altitude, both the density and pressure of the air decrease.

Furthermore, it is important to note that the pressure exerted by air at a specific location is influenced by its temperature and density. Any alteration in either temperature or density will result in a corresponding adjustment in air pressure.

6.2.2 How to Measure Atmospheric Pressure?

At sea level, the air pressure is 1013.2 millibars. As one ascends from sea level to higher altitudes, the air pressure diminishes. Can you reason out why travelling to high-altitude regions may result in mountain sickness, characterised by symptoms such as nosebleeds, ear bleeding, and nausea. Mountaineers often encounter these challenges due to the progressive thinning of the atmosphere at higher elevations, leading to lower air pressure and consequently reduced oxygen levels. Nose bleeds and similar ailments can be attributed to the higher internal pressure compared to the lower external pressure, causing the delicate nasal capillaries to bleed. For instance, at the summit of Mount Everest (8848 meters above mean sea level); the air pressure is approximately two-thirds of that at sea level.

The device used to measure atmospheric pressure is called a *barometer*. The *Mercurial Barometer*, devised by Evangelista Torricelli in 1643, is a notable type of barometer that measures atmospheric pressure. It consists of a glass tube, typically one meter in length, filled entirely with mercury. The tube is then inverted and immersed into a dish of mercury, with the open end temporarily sealed. Upon uncovering the opening, the mercury within the tube falls a few centimeters but stabilises at a height of about 76 centimeters above the surface of the mercury in the dish. This height indicates that the atmospheric pressure balances the weight of the mercury column. Any increase or decrease in air pressure causes the mercury level to rise or fall, respectively. Through various refinements since its inception, the Mercurial Barometer has become a standard instrument for measuring atmospheric pressure at specific locations. Refer to Figure 6.1 for a visual representation of this process.

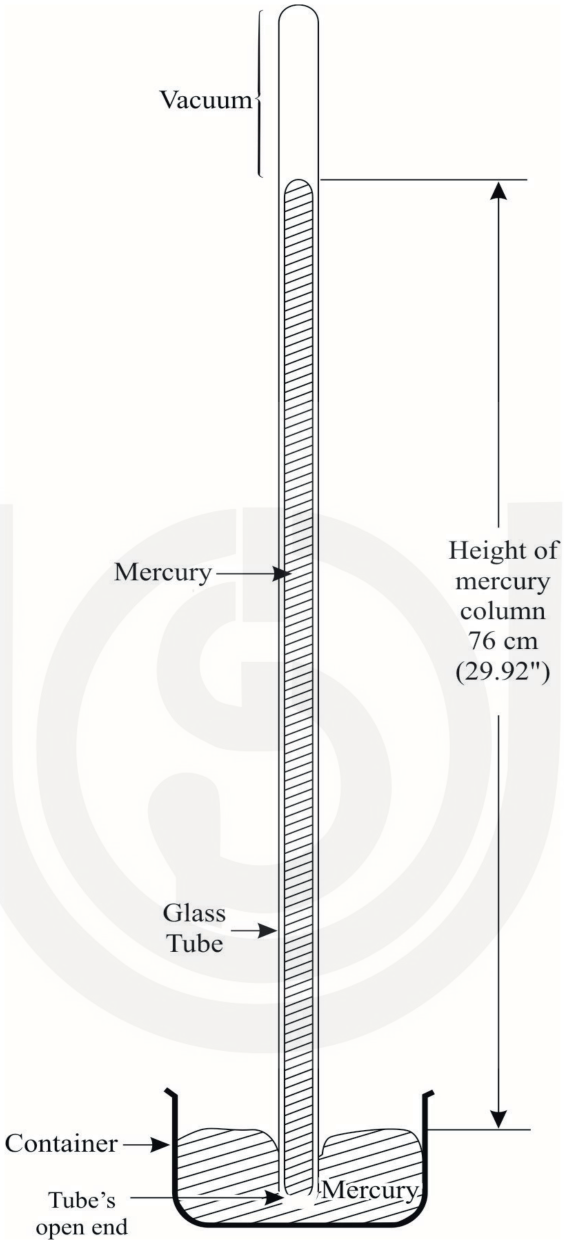


Fig. 6.1: A Mercurial Barometer.

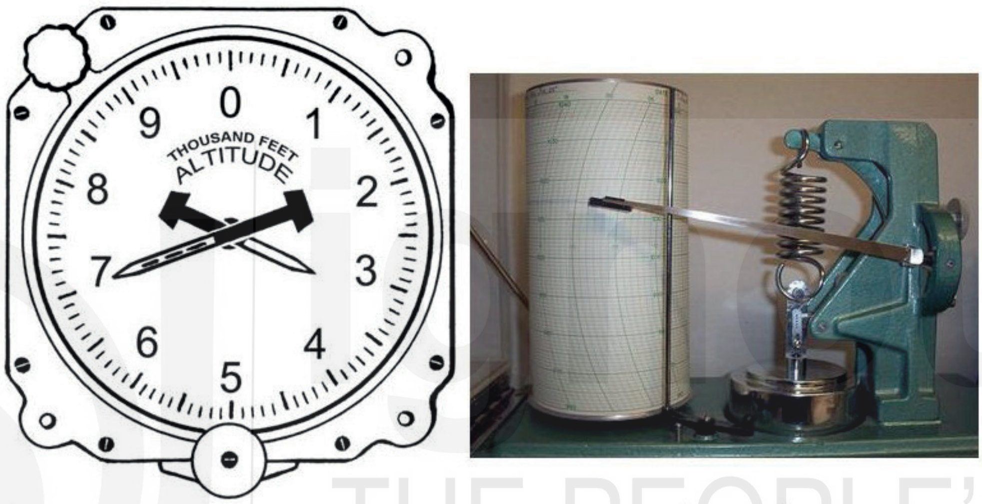
Measurement of pressure traditionally employs centimeters or inches of mercury, quantifying the height of the mercury column. At standard sea level conditions, this pressure registers at 76 centimeters (equivalent to 29.92 inches). Since 1910, millibars have gained prominence as a convenient unit of atmospheric pressure. A millibar corresponds to a force of 1000 dynes acting on one square centimeter. In the International System of Units (SI), pressure is denoted in Pascals, equivalent to one Newton of force per square meter. At sea level, under specified conditions of temperature (15°C) and latitude (45°), atmospheric pressure measures 1013.25 millibars. This equates to a mercury column height of 76 centimeters or 1.013×10^5 Pascals.

Beyond the mercurial barometer, various instruments fulfill the task of measuring atmospheric pressure.

Aneroid barometer: It features a flexible diaphragm that responds to fluctuations in external air pressure and records the variations on a calibrated circular dial.

Altimeter: When *Aneroid barometer* is calibrated to indicate altitude rather than pressure, it transforms into Altimeter, an essential device used in aircrafts (refer to fig. 6.2 left).

Barograph: These instruments automate the pressure recordings. *Microbarographs*: It utilises precision siphon cells and detects even minute pressure alterations (refer to fig. 6.2 right).



Altimeter Barograph

Fig. 6.2: An Altimeter (Left) and A Barograph (Right).
(Altimeter Source: https://commons.wikimedia.org/wiki/File:Altimeter_%28PSF%29.png, Author: Pearson Scott Foresman, CC: Public Domain)
(Barograph Source https://en.m.wikipedia.org/wiki/File:Barograph.JPG, author: CambridgeBayWeather, CC: Public Domain)

Considering the representation of atmospheric pressure on maps, a distinct methodology emerges. This will be explored in subsequent section.

6.3 HORIZONTAL DISTRIBUTION OF ATMOSPHERIC PRESSURE

The horizontal distribution of atmospheric pressure across earth's surface is a fundamental aspect of meteorology, influencing weather patterns, climate dynamics, and global atmospheric circulation. This intricate interplay of pressure systems creates a mosaic of high and low-pressure regions, shaping the world's climates and weather phenomena. Before we study the horizontal distribution of atmospheric pressure, let us first get acquainted with few terms.

<u>Isobars</u>

Isobars serve as abstract lines on weather maps, linking areas with the same atmospheric pressure. These lines are derived from mean sea level pressure data and typically measured in millibars. They offer a visual representation of pressure distribution across a geographical area. Fig. 6.3 shows a map of isobars associated with the 1915 Galveston hurricane on the evening of August 16, 1915, roughly six hours before landfall.

The arrangement of isobars is instrumental in identifying regions characterised by steep pressure gradients, denoted by closely spaced lines. Such tight packing of isobars signifies rapid changes in pressure over a relatively short distance.

In summary, isobars are valuable tools for visualising pressure patterns on weather maps. By viewing the arrangement of isobars, meteorologists can pinpoint regions with significant pressure gradients, which in turn influence wind speeds and weather phenomena. This understanding of pressure gradients is fundamental in deciphering atmospheric processes and forecasting weather conditions. Let us know about them.

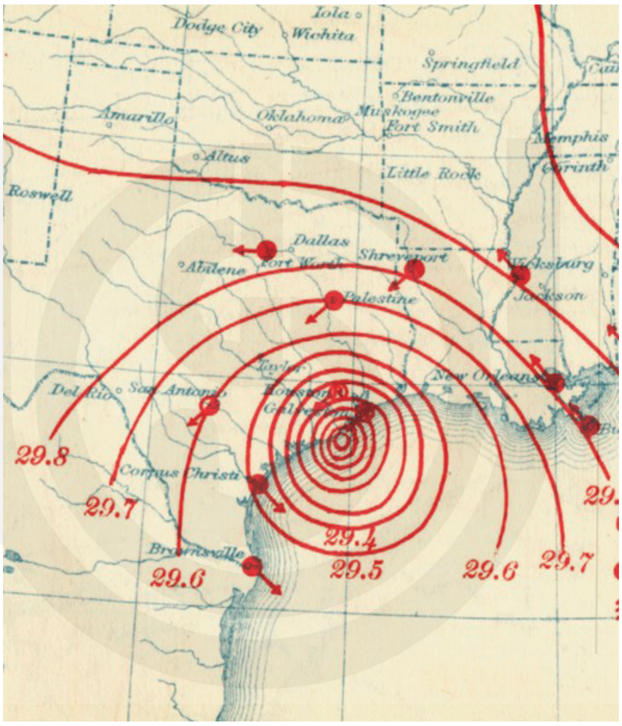


Fig. 6.3: Isobars.
(Source: https://en.m.wikipedia.org/wiki/File:1915_Galveston_hurricane_isobars_Aug_16_1915 _ 8_p.m._CT.png, United States Weather Bureau, CC: Public Domain)

<u>Pressure Gradient</u>

The variation in pressure over a given distance is termed as the "pressure gradient." This gradient is discerned by examining the difference in atmospheric pressure between two points, typically delineated by isobars on weather maps. Isobars, depicted as lines connecting locations with identical pressure levels, furnish a visual representation of pressure distribution across a geographic area. As depicted in Fig. 6.3, closely spaced isobars signify a robust pressure gradient and correspondingly elevated wind speeds. This correlation between pressure gradient and wind speed is pivotal in forecasting weather phenomena and understanding atmospheric dynamics.

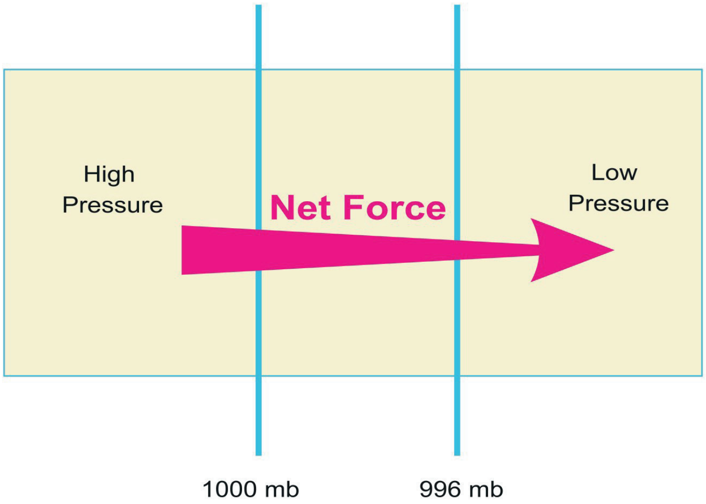


Fig. 6.4: Pressure Gradient.

Coriolis Force

The Coriolis force is a crucial component of earth's atmospheric dynamics and oceanic circulation patterns. It arises due to the rotation of the earth on its axis, causing a deflection in the path of moving objects, including air masses and ocean currents.

When an object or fluid, such as air or water, moves across the earth's surface, it appears to deviate from its intended path due to the Coriolis force. This apparent deflection is to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The magnitude of this deflection depends on the object's speed and the latitude at which it is moving. The magnitude of Coriolis deflection varies with latitude due to discrepancies in rotational speed.

Ferrel's law succinctly describes this phenomenon, stating that any object or fluid in motion on the earth's surface will tend to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This deflection is a consequence of the varying rotational speeds of different latitudes. At the equator, where the rotational speed is greatest, the Coriolis force is negligible, while it increases progressively towards the poles where the rotational speed is minimal.

In practical terms, the Coriolis force influences the direction of large-scale wind patterns, such as the trade winds and prevailing westerlies, as well as ocean currents like the Gulf Stream and the Kuroshio Current. It plays a significant role in shaping global climate patterns and weather systems by influencing the movement of air masses and the distribution of heat across the earth's surface.

Understanding the Coriolis force is essential for meteorologists, oceanographers, and climatologists, as it provides insights into the complex interactions between the atmosphere, oceans, and the earth's rotation. By accounting for the Coriolis force, scientists can better predict weather patterns, ocean circulation, and climate variability on regional and global scales.

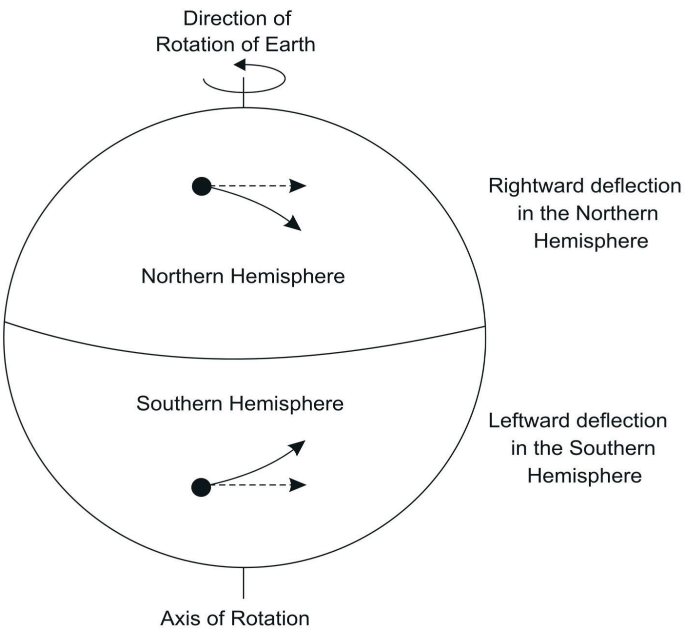


Fig. 6.5: Deflection due to Coriolis Force.

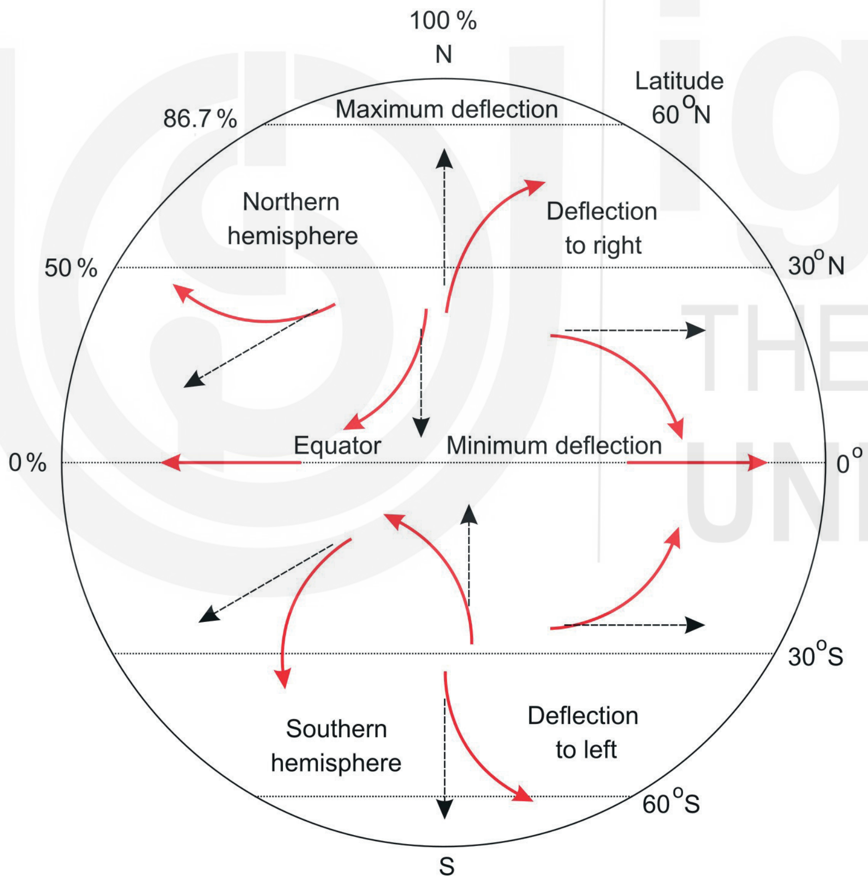


Fig. 6.6: Coriolis Effect on Different Latitudes.

SAQ I

a) How does an aneroid barometer differ from a traditional mercurial barometer in measuring atmospheric pressure?

b) How does the Coriolis force influence the movement of air masses and ocean currents on earth's surface?

Now since we have understood the terms like isobars, pressure gradient and Coriolis force, let us now study the factors affecting the horizontal distribution of pressure on earth.

6.3.1 Factors Influencing Horizontal Pressure Distribution

Several factors contribute to the horizontal distribution of atmospheric pressure on earth's surface. These include solar radiation, earth's rotation, topographical features, oceanic currents, and the redistribution of heat energy through atmospheric circulation patterns. Understanding the interactions among these factors is essential for comprehending the complexities of pressure distribution.

1. Solar Radiation

Solar radiation plays a pivotal role in driving atmospheric circulation and pressure distribution. Differential heating of the earth's surface due to variations in solar insolation leads to temperature gradients, which, in turn, influence air density and pressure. Regions receiving direct sunlight, experience warming, causing air to expand and ascend, creating areas of low pressure. Conversely, cooler regions exhibit higher atmospheric pressure due to denser, descending air masses.

2. Earth's Rotation (Coriolis Effect)

The Coriolis Effect, as already studied is a consequence of earth's rotation. It deflects moving air masses, giving rise to global wind patterns and pressure belts. In the Northern Hemisphere, this causes winds to deflect to the right, while in the Southern Hemisphere, they deflect to the left. This deflection effect significantly impacts the formation and movement of pressure systems, contributing to the establishment of distinct pressure belts and circulation cells.

3. Topographical Features

Geographical features such as mountains, valleys, and coastlines influence local pressure patterns through their effects on air circulation and temperature gradients. Mountain ranges can act as barriers, causing air to rise and cool, leading to the formation of localised areas of low pressure on the windward side and high pressure on the leeward side. Coastal areas may experience sea breezes and land breezes, altering pressure distributions near shorelines.

4. Oceanic Currents

Oceanic currents, driven by temperature gradients, wind patterns, and earth's rotation, influence atmospheric pressure distribution by modulating surface temperatures and moisture content. Warm ocean currents contribute to the formation of low-pressure systems, while cold currents induce high-pressure zones. The interaction between oceanic and atmospheric circulation play a crucial role in shaping regional climates and weather patterns.

6.3.2 Horizontal Pressure Distribution Patterns

The horizontal distribution of atmospheric pressure exhibits distinct patterns characterised by alternating zones of high and low pressure belts across different latitudes. These pressure belts are influenced by a combination of thermal and dynamic factors, resulting in complex circulation patterns and weather phenomena.

The latitudinal arrangement of atmospheric pressure, also known as its horizontal distribution, is delineated by alternating low and high-pressure zones. Seven principal pressure belts exist on earth, each influenced primarily by two factors: the Thermal factor and the Rotational factor. The Thermal factor arises from differential heating of the earth's surface and atmosphere, giving rise to pressure belts like the equatorial low-pressure belt and polar high-pressure belts. Conversely, the rotational factor, influenced by the earth's rotation, induces dynamic pressure belts such as the sub-tropical high-pressure belts and sub-polar low-pressure belts. A comprehensive understanding of these pressure belts necessitates detailed exploration.

1. Equatorial Low-Pressure Belt

This pressure zone lies near the equator, spanning between latitudes 5° N and 5° S. The average pressure within this zone remains below 1013 millibars consistently. Due to receiving direct sunlight year-round, temperatures soar, heating the ground and lower layers of air, causing them to expand and rise. Consequently, a low-pressure area forms at ground level, earning this zone a name as "Doldrums." The equatorial trough of low pressure serves as the convergence zone for trade winds from the sub-tropical high pressure belts in both hemispheres, resulting in the formation of the Inter-Tropical Convergence Zone (ITCZ). This pressure belt is intricately linked with the Sun's position, thus shifting northward and southward with the Sun's apparent movement across the equator northwards and southwards respectively.

2. Sub-Tropical High-Pressure Belt

The sub-tropical high-pressure belts spans between 25° to 35° latitudes in both hemispheres, characterised by the presence of multiple high-pressure centres or cells. Unlike being thermally induced, these belts result from the descent of winds originating in the equatorial region, deflected towards the poles by earth's rotation. A notable feature is the presence of convergence zones at higher altitudes, and finally the subsiding air leads to air accumulation and volume reduction, resulting in high pressure. Consequently, anticyclonic conditions prevail, fostering calm and arid weather patterns. Historically, traversing vessels encountered challenges navigating through these calm conditions which prompted sailors to lighten their loads by discarding horses into the sea. Hence, these subtropical high-pressure zones were also named as ***"horse latitudes".*** Additionally, winds originating from these belts diverge towards equatorial and sub-polar low-pressure regions, marking them as areas of wind divergence at ground level. This dynamic interplay of atmospheric dynamics shapes regional climates and weather patterns, influencing maritime navigation and agricultural practices.

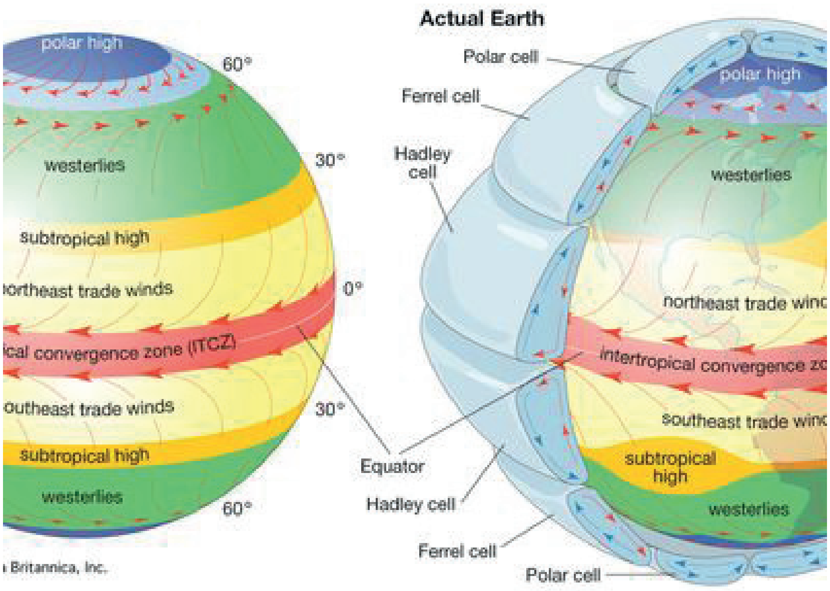


Fig. 6.7: Latitudinal Distribution of Pressure Belts.
(Source: https://www.britannica.com/science/atmospheric-circulation#/media/1/41463/107938Encyclopædia Britannica)

3. Sub-Polar Low-Pressure Belts

The sub-polar low-pressure belts extend between latitudes 60° to 70° in both hemispheres. Despite experiencing persistently low temperatures and the prevailing cold conditions, these pressure belts are dynamically induced due to the Coriolis effect resulting from earth's rotation. This effect causes air in these regions to disperse outwardly, leading to the formation of low-pressure zones. Winds originating from these belts are redirected towards sub-tropical high-pressure and polar high-pressure zones, further contributing to the development of low pressure. In the Southern Hemisphere, a continuous belt of low pressure exists between latitudes 60° and 70° due to the expansive ocean coverage. However, in the Northern Hemisphere, the presence of extensive landmasses interrupts this belt. Nevertheless, distinct low-pressure cells emerge over northern oceans, particularly near the Aleutian Islands in the Pacific Ocean and between Greenland and Iceland in the Atlantic Ocean. These localised features play a significant role in shaping regional weather patterns and atmospheric circulation dynamics.

4. Polar High-Pressure Belts

The Polar High-Pressure belts envelop the polar regions of both hemispheres, characterised by exceedingly low temperatures year-round. Despite the formidable Coriolis effect, these regions sustain high-pressure systems. Winds emanating from these belts flow towards sub-polar low-pressure zones in both hemispheres.

In summary, the latitudinal distribution of atmospheric pressure manifests through a series of alternating low and high-pressure belts across the earth's surface. While some belts are primarily influenced by thermal differentials, others result from the dynamic interplay of rotational forces. Understanding these pressure belts elucidates the intricate mechanisms governing global atmospheric circulation and weather patterns.

As the seasons change, the positioning of pressure belts undergoes a corresponding shift towards the north or south. Let us know about this shifting of pressure belts in the next section.

SAQ 2

How do pressure belts influence global wind patterns?

6.4 SHIFTING OF PRESSURE BELTS

On March 21 and September 23, the Sun's rays align vertically over the equator, resulting in the expansion of equatorial low-pressure belts up to approximately 5° on either side of the equator. Concurrently, sub-tropical high-pressure belts are situated around 30° latitudes in both the hemispheres.

Following March 21, the Sun's apparent trajectory shifts towards the northern hemisphere. By June 21, known as the summer solstice, the Sun's rays vertically illuminate the Tropic of Cancer. During this period, all pressure belts undergo a northward displacement of approximately 5° to 10° from their original positions.

Subsequently, after September 23, the Sun's trajectory shifts apparently towards the southern hemisphere, culminating in the December 22 winter solstice, where the Sun's rays align vertically over the Tropic of Capricorn. Throughout this phase, all pressure belts migrate southwards by approximately 5° to 10° from their initial positions. Refer to Fig. 6.8 which provides a visual representation of these seasonal shifts in pressure belt positioning.

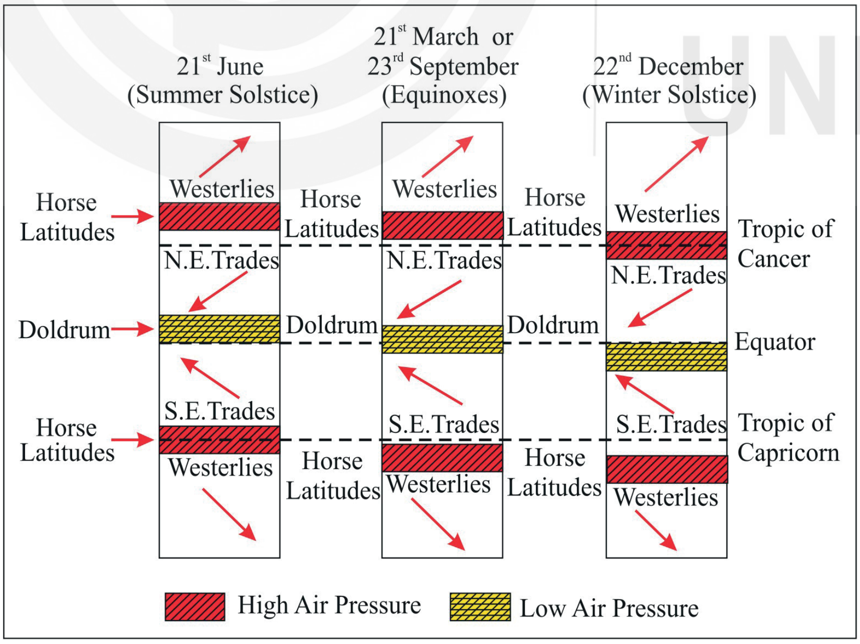


Fig. 6.8: Shifting of Pressure Belts.

6.4.1 July and January Isobars

Let us now examine the horizontal distribution of air pressure across the globe during the peak of summer and winter seasons. This distribution is depicted through isobars for the months of January and July, as illustrated in Fig. 6.9 and Fig. 6.10, respectively. Notably, these figures reveal minimal seasonal variations in lower latitudes due to lesser temperature disparities compared to higher latitudes.

In the Northern Hemisphere during January, high-pressure cells form over landmasses, while low-pressure cells develop over warmer oceanic regions, notably the Aleutian and Icelandic Lows. The presence of relatively warmer temperatures contributes to the establishment of these low-pressure systems. Additionally, the development of strong polar high-pressure systems in the Northern Hemisphere during this period is attributed to the southern shift of the Sun towards the Tropic of Capricorn. Conversely, in the Southern Hemisphere, January's isobars exhibit a fragmentation into three cells over oceans, reflective of the warmer landmasses where low-pressure cells predominate (refer to Fig. 6.9).

In contrast, July's isobars illustrate the influence of the Sun's apparent movement towards the Tropic of Cancer. In the Northern Hemisphere, sub-tropical high-pressure systems become more prominent along oceanic regions, notably the Pacific high and Bermuda high. Conversely, the polar high-pressure systems in the Northern Hemisphere weaken during July due to the intensified heating of this hemisphere. For a clearer understanding, Fig. 6.10 provides visual insights into these seasonal pressure distribution dynamics.

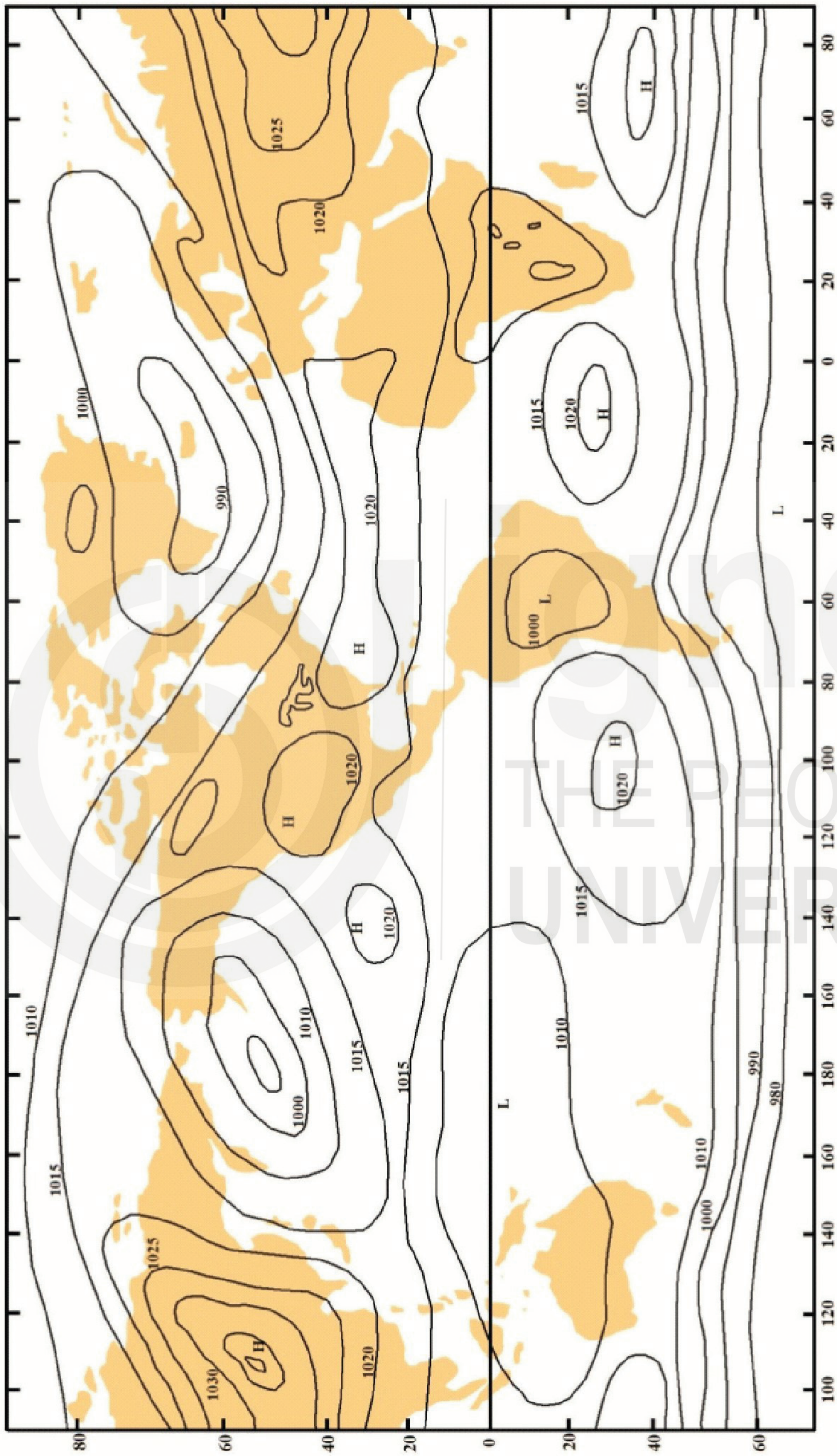


Fig. 6.9: Isobars for the Month of January in Millibars.

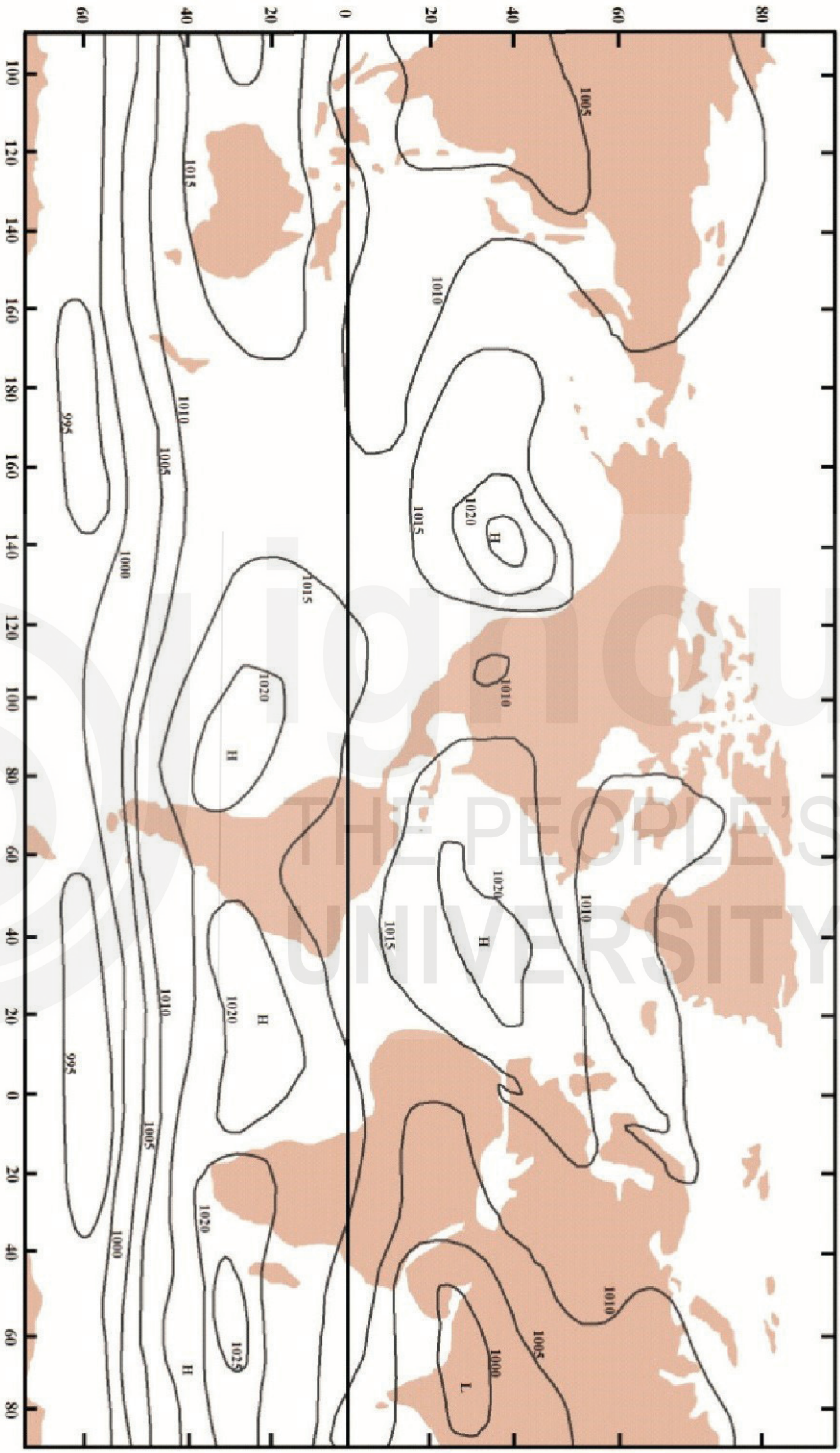


Fig. 6.10: Isobars for the Month of July in Millibars.

6.5 VERTICAL DISTRIBUTION OF ATMOSPHERIC PRESSURE

The vertical distribution of atmospheric pressure refers to the variation in air pressure with altitude above earth's surface. We have already studied in the previous sections that atmospheric pressure decreases with increasing altitude due to the decreasing density of air molecules as one move away from the earth's surface. This relationship is described by the barometric formula, which states that pressure decreases exponentially with height.

Several factors influence the vertical distribution of atmospheric pressure:

1. **Gravity:** Gravity pulls air molecules towards the earth's surface. This creates greater pressure at lower altitudes. As the altitude increases, the gravitational force weakens, resulting in lower pressure values.

2. **Temperature:** Temperature also plays a significant role in shaping vertical pressure distribution. Warmer air is less dense and exerts lower pressure compared to cooler air. Thus, regions with higher temperatures typically exhibit lower atmospheric pressure at the same altitude.

3. **Moisture Content**: The presence of water vapour in the atmosphere affects its density and pressure distribution. Moist air is less dense than dry air at the same temperature and pressure, leading to variations in atmospheric pressure with humidity levels.

4. **Weather Systems:** Dynamic weather systems such as high-pressure systems, low-pressure systems, fronts, and storms can cause localised fluctuations in atmospheric pressure at different altitudes. These systems result from the horizontal movement and vertical motion of air masses, contributing to changes in pressure gradients vertically.

The vertical structure of high-pressure systems, characterised by descending air, creates stable atmospheric conditions and clear skies. As air descends within a high-pressure system, it warms adiabatically, preventing the formation of clouds and promoting fair weather conditions. High-pressure systems often bring dry and calm weather, making them favourable for outdoor activities and agricultural practices.

Conversely, low-pressure systems exhibit a vertical structure marked by ascending air. As air rises within a low-pressure system, it cools adiabatically, leading to condensation and cloud formation. The rising air parcels reach their dew point, resulting in the formation of clouds and often precipitation. Low-pressure systems are associated with unsettled weather conditions, including rain, thunderstorms, and sometimes severe weather events such as hurricanes and tornadoes.

The vertical motion within low-pressure systems is integral to atmospheric circulation patterns. As warm, moist air rises, it creates a region of lower pressure at the surface, which encourages convergence and the further ascent of air. This upward motion fuels the development and intensification of weather systems, contributing to the redistribution of heat and moisture in the atmosphere.

In addition to influencing weather, the vertical distribution of atmospheric pressure also affects aircraft performance, mountain weather, and the formation of clouds and precipitation. Meteorologists use data from radiosondes, satellites, and weather balloons to study vertical pressure profiles and improve weather forecasting models.

Overall, the vertical distribution of atmospheric pressure is a complex and dynamic aspect of earth's atmosphere, with far-reaching implications for weather, climate, and human activities.

SAQ 3

What factors contribute to the vertical distribution of atmospheric pressure?

6.6 SUMMARY

Let us now recapitulate what we have learnt in this unit:

Measurement of Atmospheric Pressure:

- Various units used to measure atmospheric pressure, such as millibars and inches of mercury.
- Instruments like barometers and altimeters etc. employed for measuring pressure.

Horizontal Distribution of Atmospheric Pressure:

- Description of pressure belts across earth's surface, including equatorial low-pressure belts and subtropical high-pressure belts.
- Factors influencing the formation of pressure belts, such as solar radiation and earth's rotation.

Shifting of Pressure Belts:

- Explanation of how pressure belts shift with changing seasons due to the tilt of earth's axis.
- Effects of the Sun's apparent movement on the positioning of pressure belts during solstices.
- Illustration of the seasonal variations in pressure belt positions through isobar maps.

Vertical Distribution of Atmospheric Pressure:

- Discussion of how atmospheric pressure varies with altitude above earth's surface.
- Factors influencing vertical pressure distribution, including gravity, temperature, and moisture content etc.
- Significance of vertical pressure variations in weather phenomena, such as high-pressure systems promoting stable weather and low-pressure systems leading to cloud formation and precipitation.

6.7 TERMINAL QUESTIONS

1. Write short notes on:
   a) Isobars
   b) Pressure Gradient and
   c) Coriolis Force

2. Give an account of horizontal distribution of pressure belts on the globe. Explain with the help of a neat sketch.

3. What is the reason behind the shifting of pressure belts? Explain with the help of a neat sketch. What are the significant differences in isobars for the month of January and July?

6.8 ANSWERS

Self-Assessment Questions (SAQ)

1. a) An aneroid barometer differs from a traditional mercurial barometer in its mechanism and operation. While a mercurial barometer uses a column of mercury to measure pressure, an aneroid barometer features a flexible diaphragm that responds to changes in atmospheric pressure. The diaphragm's movement is then translated into pressure readings displayed on a calibrated circular dial. Unlike a mercurial barometer, which requires periodic adjustments and maintenance, aneroid barometers are often more compact, portable, and suitable for various applications. Additionally, aneroid barometers can be calibrated to indicate altitude, making them essential devices known as altimeters, particularly in aircraft navigation.

   b) The Coriolis force, a consequence of earth's rotation, causes moving objects such as air masses and ocean currents to deflect from their intended paths. In the Northern Hemisphere, this deflection is to the right, while in the Southern Hemisphere, it is to the left. The magnitude of deflection varies with an object's speed and latitude, with the greatest deflection occurring at higher latitudes where rotational speeds are lower. This phenomenon, succinctly described by Ferrel's law, plays a crucial role in shaping large-scale wind patterns like the trade winds and prevailing westerlies, as well as ocean currents such as the Gulf Stream and the Kuroshio Current. By understanding the Coriolis force, scientists can better predict global climate patterns, weather systems, and ocean circulation dynamics, aiding in the development of more accurate forecasts and climate models.

2. Pressure belts, such as the equatorial low-pressure belt and sub-tropical high-pressure belts, create pressure gradients that drive global wind circulation. Winds flow from areas of high pressure to low pressure, establishing prevailing wind patterns like the trade winds and westerlies, which in turn affect weather and climate across the globe.

3. The vertical distribution of atmospheric pressure is influenced by gravity, temperature, and moisture content. As altitude increases, the density of air decreases due to reduced gravitational force, while temperature and humidity variations affect air density and pressure.

Terminal Questions

1. Write short notes based on the content given in the beginning of Sec. 6.3.
2. Describe all the pressure belts, that are equatorial low-pressure belt, sub-tropical high pressure belt, sub-polar low pressure belts, polar high-pressure belts as given in Sec 6.3.2 Ref Fig 6.7.
3. Explain shifting of pressure belts as given in Sec. 6.4. Ref Fig. 6.8. Regarding difference in January and July isobars refer to Fig. 6.9 and Fig. 6.10 and Sec. 6.4.1.

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UNIT 7

GENERAL ATMOSPHERIC CIRCULATION

Structure

7.1 INTRODUCTION

In the previous unit you have learnt about atmospheric system over the earth surface. In this unit you will learn about general atmospheric circulations. We all know that sun is the prime source of heat and energy. Earth receives energy from incoming solar radiation which called as ***Insolation***. It is unequally distributed over the earth surface from equator to pole. This variations cause pressure differences in the atmosphere. As a result, winds tend to transfer from high pressure to low pressure regions. The pattern of the horizontal as well as vertical movement of winds over the globe is called as general circulation of the atmosphere. It is largely depends on-(1) Latitudinal variation of atmospheric heating, (2) Pressure belt patterns (high and low), (3) Shifting of winds following apparent path of the Sun, (4) Rotation of the earth, and (5) Distribution of the continents and the oceans.

The variations in the amount of insolation over the earth surface are responsible for the formation of Thermal induced low pressure in equatorial region and Thermal induced high pressure over the Polar Regions. The air pressure measured with the help of mercurial barometer, altimeter (altitude barometer) and recorded on barograph. The lines joining the places of equal pressure at sea level are called *Isobars*. The standard air pressure at sea level is 1013.25mb (millibar). The heated air expands and moving upwards and cooled air gets compressed in high pressure thermal induced belts. These cold and warm air movements over the earth surface formed two Dynamic

Kailash Nath Singh

induced air pressure belts i.e., tropical high and sub polar low pressure belts. As a result the air moves from high pressure to low pressure. The horizontal movement of air over the earth surface is called wind.

Expected Learning Outcomes

After reading this unit, you will be able to:

- explain the circulation of winds over the earth surface;
- outline the various processes involved in circulation of planetary, seasonal and local wind systems;
- describe the upper atmospheric circulation namely jet streams; and
- analyse the circulation of winds from surface to upper atmosphere and formation of tricellular meridional circulation in the both hemispheres.

7.2 WINDS

What is wind? It cannot be seen, but we just feel the wind. The bulk movement of air horizontally on the surface of the earth is known as wind. The winds are explained based on their strength and direction from which they are blowing. Winds are generated based on the pressure differences which are in turn due to differential heating of the earth. Wind moves from high pressure region to the low pressure regions. The instrument which measures direction and speed of wind is wind vane.

7.2.1 Changes in Wind Direction

If the earth is non-rotating, winds would blow from high pressure areas to low areas without any deviation. But on the rotating earth, winds deviates while blowing. The direction of wind flows is basically determined by three forces namely pressure gradient, Coriolis force and friction velocity of wind is based on pressure gradient.

I) Pressure Gradient: The differences in atmospheric pressure between two places is called pressure gradient. Wind generates due to these differences of pressure. If the pressure gradient is steep, velocity of wind is high and if the pressure gradient is gentle, the wind velocity is low. Steep pressure gradient is represented on a weather map by closely spaced isobars while weak pressure gradient represents widely spaced isobars. The pressure gradient force acts at right angles to the direction of isobars in the direction of low pressure.

II) Frictional Force: The rough topography of the earth surface exerts greatest frictional force up to an elevation of 1 to 3 km. Over the sea surface, the frictional force is minimum. It directly lows down wind and moderates the direction of wind.

III) Coriolis Force: Due to the rotation earth, the winds get deflected and follow coriolis paths or curved trajectories instead of straight path. This type of deflection was initially observed by the French physicist G.G. Coriolis. Hence the deflection force is named as Coriolis force. According to this force the winds deflects to the right in the Northern Hemisphere and towards left in the Southern Hemisphere. The deflection of wind depends on its velocity. Higher the velocity, more is the deflection and vice-versa. The Coriolis force is maximum at the poles while absent at the equator. This is also known as Ferrel's law.

7.2.2 Geostrophic Wind

When pressure gradient and Coriolis force are at balance the resultant winds are geostrophic winds. In the weather maps their flows are indicated parallel to isobars (Fig. 7.1). The wind begin to move above the surface are free from frictional forces deflected by the Coriolis force to the right direction in the northern hemisphere and to the left direction in the southern hemisphere.

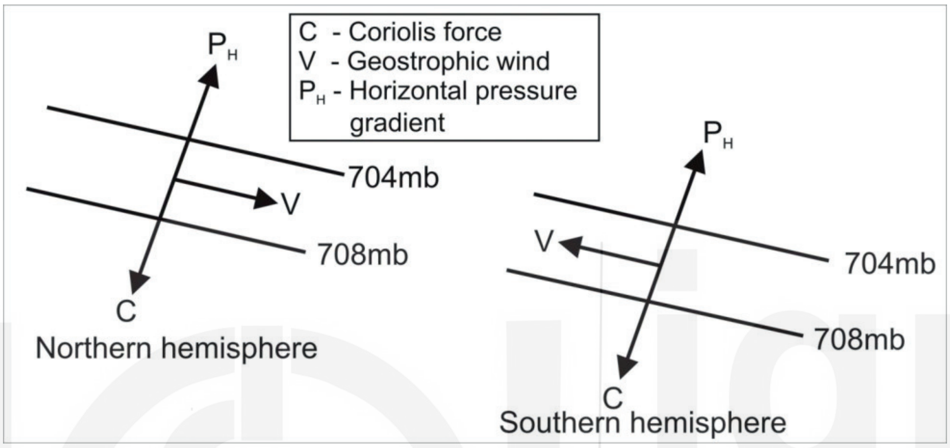

Fig. 7.1: Geostrophic Wind.

SAQ I

a) Define atmospheric circulation.
b) Explain Ferrell's law and explain why winds deflect from their original path.

7.3 PLANETARY WINDS

The winds blow throughout the year from one place to another because of differences in the atmospheric pressure. Planetary winds patterns are based on high and low pressure pattern of the world. These winds blow in a single direction over a specific area over the earth from high pressure to low pressure. Due to the rotation of the earth winds are deflected to the right (anticlockwise) in northern hemisphere and left (clockwise) in the southern hemisphere. Three sets of planetary winds are existing on either side of the equator namely - Trade Winds, Westerlies and Polar winds. This can be easily understood by the Fig. 7.2 given below.

7.3.1 Trade Winds

The winds that blow from subtropical high pressure (30°-35° N and S) areas towards equatorial low pressure areas in between 5° to 30° latitude in both hemispheres are called as trade or easterly winds. The word trade has been derived from German word which means 'track' and these winds helped the sea merchants in sailing their ships steadily and constantly in the same direction. The 30° latitude in both hemispheres is called Horse latitude because winds are descending and stable in subtropical high pressure belt. As a result, ships became stagnant and in order to reduce the weight of the ship and to gain speed, the merchants used to throw the horses in the ocean. Hence, those latitudes are called as Horse latitudes. These trade winds originate from these high pressure areas move towards equator and deflect their path due to Coriolis force/Ferrell's law and blow as North-East Trade Winds in northern hemisphere and South-East Trade Winds in the southern hemisphere. These trade winds converged at equatorial low pressure belt (5° north to 5° south). The converged air rises between 5° north and 5° south latitude due to high insolation and form low pressure zone. In between 5° N to 5° S latitude North-east and South-east Trade Winds converge at Inter Tropical Convergence Zone (ITCZ). It is also known as ***Doldrum*** or the ***Zone of Calm*** because of its windless weather. The Trade Winds have a tendency to migrate north and south along Doldrum following the Sun. The ITCZ plays very important role in mechanism of monsoon.

7.3.2 Westerlies

The westerlies blow from the sub-tropical high pressure belt (30°- 35° N/S latitude) to sub polar low pressure belt (60°-65° latitude) in both hemispheres. Like trade winds, these winds deflects from their original path due to Coriolis force and blow from south west to north east direction in northern hemisphere and north-west to south-east in southern hemisphere. Hence these winds are called as Westerlies. Westerlies are not as steady as trade winds in direction as well as speed in the Northern hemisphere due to disruption caused by land-masses. While, in the southern hemisphere between 40°- 60°S latitude, westerlies are strong and persistent due to present of vast ocean which does not disrupt the flow. Based on the nature of westerlies in different latitudes, marines of older times named them “Roaring Forties”, Furious Fifties of “Screaming Sixties”. The path of westerlies is uncertain due to the formation of cyclones in the temperate regions.

7.3.3 Polar Winds

The winds blowing from polar high pressure belts to sub-polar low pressure belts are called polar winds. These cold winds originate in the polar region and blow north-east to south-west direction in northern hemisphere and south-east to north-west direction in southern hemisphere due to the Coriolis force. Polar front forms where cold Polar easterlies meet warm westerlies at 60° N and S. Middle latitude cyclones forms along with this front. Polar circulation is confined between 60°-90° latitudes in both the hemispheres and is characterised by surface polar easterly winds. Since temperature remains below freezing point during most part of the year, the high pressure systems and resultant divergent air flow from the polar areas are more persistent and become annual feature. The influence zone of cold poles expand during winter season and shrinks during summer season. The pressure gradient between polar high pressure and sub-polar low pressure generates easterly air circulation known as polar circulation. The zone of polar winds shrinks due to northward shifting of pressure belts at the time of northern summer (summer solstice) in the northern hemisphere but it is extended upto 60°N latitude during northern winter(winter solstice). The polar easterly wind system is complicated in the southern hemisphere, by the presence of ice capped continent of Antarctica where anticyclonic circulation is predominant feature mainly in the eastern part of the continent.

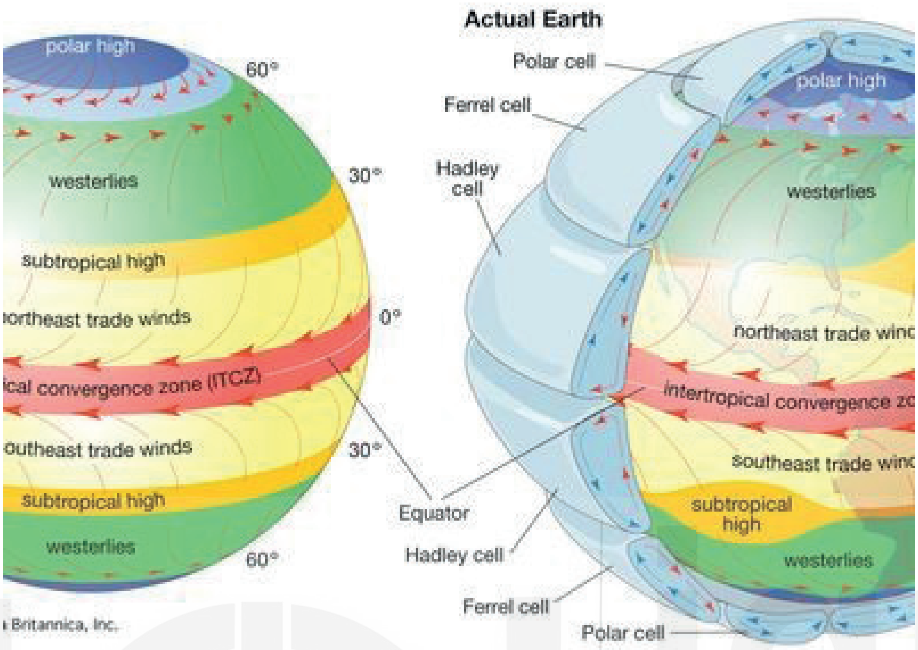

Fig. 7.2: Atmospheric Circulation and Winds.
(Source: https://www.britannica.com/science/atmospheric-circulation#/media/1/41463/107938Encyclopædia Britannica)

SAQ 2

What are Prevailing winds?

7.4 SEASONAL WINDS AND PERIODIC WINDS

The winds that change their direction with change in season are called seasonal winds. Monsoons are the best example of large scale seasonal reversal of wind direction.

Periodic Winds: Certain winds reverse their directions periodically with season are known as periodic winds. It blows at regular interval with localised differences in pressure and temperature e.g. land and sea breeze, mountain and valley breeze. Land and sea breeze are regular phenomena in the coastal region. During day hours land get more heated and develop low pressure while sea being comparatively cools, develops high pressure, sea breeze move from sea towards land and reduce the temperature of land. During the night rapid outgoing radiation makes the land cooler than the adjoining sea. High pressure develops over the land and low pressure over the sea, responsible for blowing the land breeze from land surface to sea.

In mountain region, during day hours the slope of the mountain heated more than valley floor and air flows from valley to top ridges called valley breeze. During night mountain breeze blow from ridges to valley is called mountain breeze.

7.5 LOCAL WINDS

The movement of winds between high and low pressure systems within smaller areas is called local winds. These winds also divided on the basis of temperature e.g. warm and cold winds.

Warm Winds

Blackroller: A hot and dry gusty wind in the Great Plains of the U.S.A.

Brick fielder: warm and dry gusty and dust laden wind in southern Australia.

Chinook: Hot dry winds descending the eastern slopes of Rocky Mountains in North America. Due to this wind the snow present at the surface melts away because of sudden rise in temperature, thus it is also called ***snow eater***.

Foehn: Hot dry wind on the lee ward slope of Alps in France classified as katabatic wind like Chinook. These winds help in early sowing of spring wheat, ripening of grapes and check autumn frost.

Gibli: A hot, dry and dust laden wind in Libya.

Haboob: Hot and dry sandstorm wind in northern and central Sudan.

Harmattan: Hot dry dusty wind blow from Sahara desert over West Africa into the gulf of guinea where it is called ***'Guinea Doctor'*** because it reduces the high humidity of western cost of Africa (Guinea).

Karaburun: A violent north east wind of central Asia.

Khamsin: Hot dry and dusty winds in Egypt and North Africa to the eastern Mediterranean region.

Loo: Hot and dry wind blows from west to east over plains of India and Pakistan.

Lest: A warm, dry and dusty wind in North Africa and Arabia.

Nor'easter: Warm strong storm winds blow north east coast of North America.

Norwester: Warm and dry winds blow to the east coast of New Zealand.

Santa Ana: Hot and dry winds blows in south California USA. It is considered as ***'climatic hazard'*** because the soil and vegetation moisture is desiccated and widespread forest fires results due to extreme dryness and high temperatures.

Shamal: Warm dry over Iraq and the Persian Gulf states.

Simoom: Warm dry and dusty winds of Arabian Desert and eastern Sahara

Siroco: Hot dry wind blow from Sahara desert towards Italy. Particles of red sand in the sky pictured like ***'Red blood rains'***. It is apparent that sirocco is very much injurious to agricultural and fruit crops.

Yamo: A warm dry wind in Japan.

Zonda: It is also called *Sondo, winter Foehn*. It is warm dry wind blowing east Andes in Argentina. It becomes more vigorous during winter season.

Cold Winds

Bise: An extremely cold wind in France.

Blizzard: It is a violently stormy cold and powderly polar wind laden with dry snow and is prevalent in north and south Polar regions, Siberia, Canada and the USA. They are called ***'northers'*** in the southern USA and ***'buran'*** in Siberia.

Bora: cold and dry wind blows from Hungary to north Italy where it descends through the southern slopes of the Alps and blow in southerly direction. Bora is extremely cold before descending the Alpine slopes but its temperature is a bit increased due to dry adiabatic warming.

Friagem: A cold wind blowing in Amazon valley.

Levanter: A strong easterly cold wind in southern Spain and Straits of Gibraltar. This is a moist and damp wind and causes foggy weather. This is more frequent in early winter to late winter.

Mistral: Strong cold north westerly wind blowing from north west coast of Mediterranean sea particularly in the Alps and France. These winds are more common and effective during winter season because of development of high pressure over Europe and low pressure over Mediterranean Sea. The Arrival of mistral causes sudden drop in air temperature to below freezing point.

Pampero: A north-westerly cold wind in the ***'pampas'*** of South America. Pampero is similar to '***northers***' of North America and Siberia and its more active during winter season.

Papagayo: A very strong, sometimes violent, northeast wind blowing during the colder months in the Gulf of Papagayo on the northwest coast of Costa Rica, as well as in adjacent Pacific coastal waters.

Punas: It is a cold and dry wind that blows in the western side of Andes mountain.

Purga: It is a cold wind that blows in Russia.

Tehuantepecer: A violent northerly local wind in southern Mexico and north Central America. It brings an inflow of cold air to central America and especially to regions around the Gulf of Tehuantepec.

Uvanter: Cold wind blown in Spain.

SAQ 3

a) Differentiate between land and sea breeze.

b) Do you consider loo as a local wind?

7.6 JET STREAMS

The jet stream is a ribbon of air some thousands of kilometers wide and a few kilometres deep with a minimum wind speed of about 120 km per hour. Two main types of jet streams are recognised namely the subtropical and polar front jet streams which are located just below troposphere. There are two permanent jet streams in both hemispheres. Polar jet streams and Subtropical jet streams are shown in the Fig. 7.3.

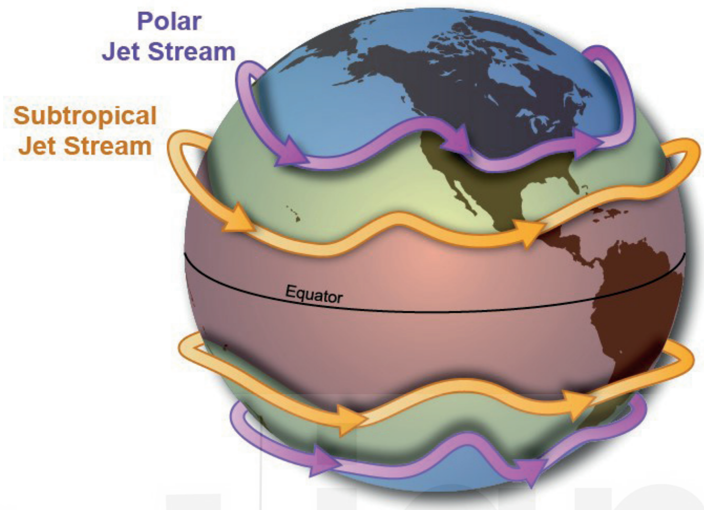

Fig. 7.3: Polar and Subtropical Jet Streams.
(Source: https://www.noaa.gov/jetstream/global/jet-stream)

Subtropical Jet Stream

The subtropical jet stream is of dynamic origin and formed due to rotation of the earth. The subtropical Westerly Jet stream in upper troposphere concentrated around at 30° to 35° North and South. It dominates in winter season and merged with polar jet particularly in northern hemisphere. During the winter season it flows west to east direction at the height of 7 to 10 km. Himalayan mountain system splits the jet stream into two parts. The southern branch of jet stream flows over Gangetic plain (south of Himalaya) resulting in atmospheric stability during the winter and in summer (March to May). It is closely connected to the Indian monsoon.

Polar Front Jet Stream

Polar front jet streams are highly variable in position over a wide range of temperature latitudes. It is provided due to temperature differences and closely related to polar front. Polar front jet streams are the strongest wind flows at the height of 7 to 10 km above the sea level. In northern hemisphere polar Jet stream flow over North America, Europe and Asia, while Polar jet mostly an over the Antarctica in southern hemisphere. The formation of polar jet is due to the undercutting of subtropical air masses by the more dense polar air masses. It greatly influences climates of temperate regions.

Jet streams are of great importance in aviation. A plane that moves with jet streams gains speed and conserve fuel. In contrast the plane that moves against jet stream will be slowed down and consume more fuel. This realisation led to the discovery during World war II bombing missions in the Far East.

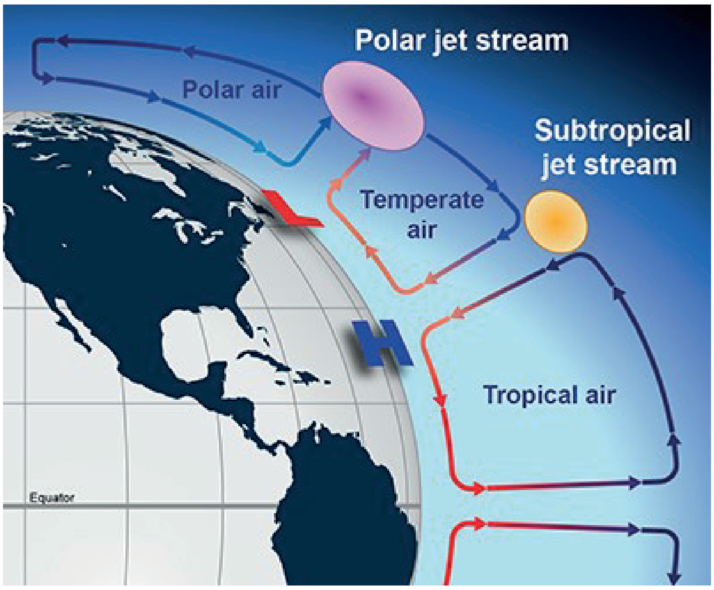

Fig. 7.4: Polar Jet Streams.
(Source: https://www.noaa.gov/jetstream/global/jet-stream)

Rossby waves, also known as planetary waves, are a type of inertial wave naturally occurring in rotating fluids. The Sweden-born American meteorologist Carl-Gustaf Arvid Rossby was first to identify it. Atmospheric Rossby waves on earth are giant meanders in high-attitude winds that have a major influence on weather. These waves are associated with pressure systems and the jet streams. Oceanic Rossby waves move along the thermocline: the boundary between the warm upper layer and the cold deeper part of the ocean.

Types of Rossby Wave

Atmospheric Waves: Atmospheric Rossby waves are a result of conservation of potential vorticity and influenced by Coriolis force and pressure gradient. As it moves towards the northern hemisphere the rotational fluids turn to the right and to the left while to the southern hemisphere. An atmospheric Rossby Wave can be identified by its phase velocity and wave crest which has a westward component has been proposed that a number of regional weather extremes in the Northern Hemisphere associated with blocked atmospheric circulation patterns may have been caused by amplification of Rossby waves

Poleward-propagating Atmospheric Waves: When heat is transferred to the lower layer of the atmosphere (known as the troposphere) is strengthened over very warm sea surface, it generates a form of atmospheric Rossby waves which have a polewards and eastwards direction. This is seen during ***El-Nino*** events. Poleward-propagation of atmospheric waves help in establishing statistical connection between low and high-latitude climates.

Oceanic Waves: Oceanic Rossby waves are waves with an ocean basin. Compared to the atmospheric Rossby waves, the oceanic variant has low amplitude. The ocean Rossby Waves gain pace through wind strength at the ocean surface layer and thus shows the effects of climate change due to factors like wind and buoyancy.

The tricellular model explains the meridional circulation of the atmosphere.

7.7 TRICELLULAR MERIDIONAL CIRCULATION

The mechanism of general circulation of the atmospheric air movement is based on temperature. The tropical areas receive maximum amount of solar energy which substantially decreases pole ward. Thus, there is latitudinal imbalance of solar radiation from lower latitude to higher latitude. Consequently there is transfer of heat through horizontal air circulation from areas of the high temperature to low temperature area in order to balance the heat energy. The surface winds blow from high pressure areas to low pressure areas and air rises when gets heated. The warm air rises from low pressure belt and after cooling (cold) it settles down in high pressure belt. The meridional circulation of the atmosphere is explained by the tricellular model. The global air circulation can be divided into three cells namely Hadley cell, Ferrell cell, and polar cell (Fig. 7.7).

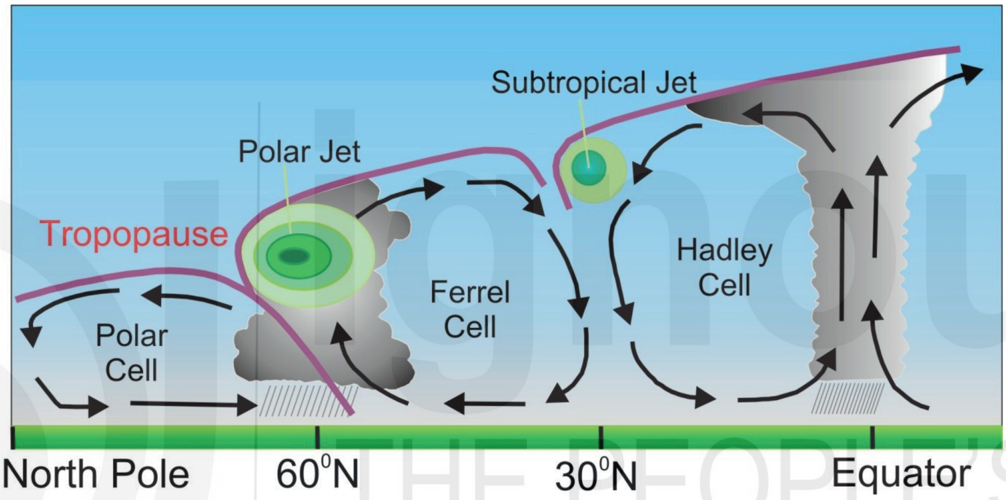

Fig. 7.5: Tricellular Meridional Circulation.

1) **Hadley Cell:** This cell is a tropical cell which is first identified by G.Hadely in 1735 occurs between equator and the tropics (10°-30° N & S). The trade wind blow from subtropical high pressure belt to equatorial low pressure belt and move upward from equator. The winds after being heated due to very high temperature at the equator ascend upward. These ascending warm and moist winds release latent heat after condensation which causes further ascent of the winds which after reaching the height of 8 to 12 km in the troposphere over the equator diverge northward and southward. The surface trade winds blow from subtropical high pressure belt to equatorial low pressure belt in order to replace the ascending air at the equator. The upper air is moving in opposite direction to trade winds in upper atmosphere. These winds descend near 30°-35° latitude in both hemispheres. Thus one complete meridional cell of air circulation is formed in between equator to 30° latitude in both hemispheres. It is one of the most stable cells and linked to a tropical monsoon and a desert climate.

2) **Ferrel Cell:** It is also called polar front cell or mid-latitude cell. The westerlies blow from subtropical high pressure belt to sub-polar low pressure belt (60°-65° North and South) in both hemispheres. The warm winds ascend near 60°-65° latitudes and after reaching the upper troposphere diverge in opposite direction (pole ward and equator ward).

Thus the circulation of winds from surface to upper troposphere in between 30° latitude to 65° latitude in both the hemispheres is called the Ferrell cell.

3) **Polar Cell (65°-90° North and South):** Polar cell involves the atmospheric circulation prevailing between 60° to poles from surface to upper troposphere in both the hemispheres is called polar cell. Polar cold winds blow from polar high pressure belt to sub-polar low pressure belt. These polar cold winds converge with warm westerlies near 60°-65° latitude and form fronts. The warm wind ascends upward due to rotation of the earth and these winds descend at pole.

7.8 SUMMARY

Let us now recapitulate what we have learnt in this unit.

The general atmospheric circulation means the movement of winds over the entire globe. Due to the pressure gradient these wind patterns are in form of planetary winds, seasonal winds, and local wind patterns over the earth surface. The circulation of wind transfers heat energy horizontally as well as vertically. It also helps in maintaining the balance of moisture through the process of evaporation and precipitation.

The upper atmospheric circulation in form of strong and rapidly moving polar and sub-tropical westerly jet streams is in the upper limit of troposphere. These upper atmospheric westerly winds govern the vertical circulations of winds. The tricellular model explains the meridional circulation of the atmosphere. The formation of three cells in each hemisphere has been divided on the basis of thermal and dynamic factors associated with global air circulation. These cells are the Hadley cell, Ferrell cell and Polar cell which influence the weather and climate of the earth surface.

7.9 TERMINAL QUESTIONS

1. Explain the planetary wind system and discuss how winds are influenced by pressure belts?
2. Describe the concept of jet streams. How do they influence atmospheric circulation?
3. Give a detailed description of tricellular meridional circulation.

7.10 ANSWERS

Self-Assessment Questions (SAQs)

1. a) Atmospheric circulation is the large-scale movement of air and together with ocean circulation is the means by which thermal energy is redistributed on the surface of the earth. Earth and its atmosphere are both controlled primarily by the sun and they make up an interconnected global system. Different climatic areas are the result of atmospheric movements within this global system.

b) The rotation of the earth on its axis deflects the direction of winds from its path and this is called deflection force or Coriolis force. The **Ferrell's** law explains the deflecting winds towards the right in the northern hemisphere and to the left in southern hemisphere.

2. The winds blowing in the same direction throughout the year are called as prevailing winds. These winds do not change their direction with the changing of seasons.

3. a) Blowing of land and sea breezes is a regular phenomena in the coastal areas. During the day land gets more heated than the adjoining sea and develops low air pressure. The sea being comparatively cool develops high pressure. The warm air of land being lighter ascends and its place is taken by the cooler air coming from the sea, which is called sea breeze. At night, rapid radiation makes the land cooler than the adjoining sea. As a result high pressure develops over the land and low pressure over the sea. Air starts blowing from land to sea and is known as land breeze.

   b) The loo is a strong dusty hot and dry summer wind and blows from west to east over the Indo-Gangetic plain of north India and Pakistan. Hence it is a local wind. It blows strongly in the months of April, May and June. Due to its very high temperature and dryness, it causes fatal heat strokes.

Terminal Questions

1. Start your answer with definition of planetary winds then about the distribution pattern of winds and pressure belt system over the globe as given in Sec. 7.3 of this unit.

2. Discuss the detail concept of jet streams with pictorial presentation which is given in Sec. 7.6 of this unit.

3. Explain the concept of Tricellular Meridional circulation as given in Sec. 7.7 of this unit.

7.11 REFERENCES AND FURTHER SUGGESTED READING

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2. Lal, D.S. (1985). *Climatology,* Chaitanya Publishing House, Allahabad.
3. Singh, S. (2009). *Climatology,* PrayagPustak Bhawan, Allahabad.
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GLOSSARY

Advection : Transfer of heat from a locality to another by winds.

Albedo : Reflecting power of a surface.

Anemometer : An instrument used to measure the speed of the wind.

Atmospheric Pressure : The weight of the atmosphere pushing down on a unit area on the earth's surface is called atmospheric pressure. It is measured by Barometer.

Blood Rain : The fallout of red sands with falling rains associated with *'sirocco'* local wind in south Italy is called blood rain.

Chinook/Foehn : Warm and local dry winds blowing on the leeward slopes of the mountains are called 'Chinook' in the USA and Foehn in the Switzerland.

Coriolis Force : It is the force which deflects the direction of surface winds. Coriolis force or effect is not a force in itself in real sense rather it is an effect of the rotational movement of the earth (named after G.G. Coriolis).

Cyclone : These are centers of low pressure surrounded by closed isobars having increasing pressure outward and closed air circulation (convergent air circulation) from outside towards the central low pressure in such a way that winds blow in anticlockwise and clockwise directions in the northern and the southern hemispheres respectively.

Diurnal Range of Temperature : Difference between maximum and minimum temperature of a day.

Doctor Wind : Warm, dry and sandy winds are called '***harmattan'*** or '*doctor wind'* in the western Sahara of Africa.

Doldrums : A belt of low pressure, popularly known as equatorial trough of low pressure extending discontinuously within a zone of 5°N and 5°S latitude is called the ***belt of calm*** or doldrums.

Equatorial Westerlies : The westerly surface air circulation in the doldrums or in the Inter-Tropical Convergence Zone (named by Flohn).

Ferrel Cell : An intermediate mid-latitude thermally indirect cell or air circulation between tropical Hadley cell and polar cell is called Ferrel cell or polar front cell.

Ferrel's Law : It is related to deflection of winds. The law states that if one stands with one's back towards the direction from where winds are coming they (winds) are deflected to the right in the northern hemisphere and to the left in the southern hemisphere.

Frictional Force : The force generated by the resistance of the surface of an object against a moving object is called frictional force.

Geostrophic Wind : The wind blowing parallel to the isobars and at the right angle to the pressure gradient is called geostrophic wind.

Gradient Wind : It is a variant of geostrophic wind, blows along a curved path parallel to the curved circular Isobars.

Hadley Cell : The tropical convective cell, one each in the northern and the southern hemispheres is called Hadley cell (named after George Hadley).

Heat Budget : The gain and loses in heat by way of incoming and outgoing radiation.

Horse Latitudes : Horse latitudes are sub-tropical highs or the zone of calms falling between 30°and 35° north and south of Equator. Cargoes carrying horses during olden times found it difficult to sail through this zone. Hence they used to throw their horses into the ocean to make the vessel lighter and able to sail.

Insolation : The radiant energy received by the earth and its atmosphere from the sun is called insolation.

Isobars : The lines joining the places of equal pressures reduced to sea level on the maps are called isobars.

Isotherm : A line on a map joining places having equal temperature, reduced to mean sea-level.

Jet Stream : The strong and rapidly moving circumpolar upper air westerly air circulation in a narrow belt of a few hundred kilometers width in the upper limit of the troposphere is called jet stream.

Land Breeze : At night, the land cools down much faster than the sea. The air over the sea is warmer and lighter. The warm air over the sea rises. Pressure over the sea is lower than the pressure over the land. Air from land therefore blows out towards the sea. This is known as *Land breeze*.

Local Winds : Winds that arise due to local or regional changes in temperature or pressure are known as local winds.

Mean Daily Temperature : An average of highest and lowest temperatures recorded during 24 hours.

Normal Lapse Rate : It is related to the decrease in temperature in troposphere at a uniform rate of 1°C for an ascent of 165 m or 6.5°C for every 1 km of ascent.

Permanent Wind : The winds that blow from the permanent high-pressure belts towards the permanent low- pressure belts maintain their directions of flow throughout the year. They are called *Permanent prevailing or Planetary winds*.

Pressure Gradient : It is defined as decrease in air pressure between two isobars of different values from high pressure to low pressure. This is also called ***Barometric slope***.

Rossby Waves : Rossby Waves are a form of inertial wave that occurs in rotating fluids. Also known as planetary waves, they were discovered by Carl-Gustaf Arvid Rossby. These waves are associated with jet streams and the earth's pressure systems.

Sea Breeze : During the day the land becomes hotter than the sea. The air above the land becomes hot and rises, leading to low pressure over the land. The cooler air from the sea moves towards the land during the day. This breeze is called *Sea breeze*.

Snow Eater : Warm Chinook wind is called snow eater because snow melts as if by magic on its arrival.

Summer Solstice : It is also called the '***Estival Solstice'*** or mid-summer, occurs when one of earth's poles has its maximum tilt towards the Sun. It happens twice yearly, once in each hemisphere (Northern and Southern). This is the June Solstice (usually 20 or 21 June) in the Northern hemisphere and the December solstice (usually 21 or 22 December) in the Southern.

The Inter Tropical Convergence Zone (ITCZ) : The Inter Tropical Convergence Zone (ITCZ) is also called doldrums, a low pressure area extending around the Equator. Here North East trade winds and South East trade winds coming from subtropical high pressure belts converge. This convergence causes lifting up of air due to convective impact. However the entire volume is not uplifted. Some winds converge to form equatorial westerlies which blow from west to east along ITCZ.

Thermal Equator : Imaginary line drawn on a map by connecting places that have the highest mean temperature for any particular period.

Wind : The horizontal movement of air is called wind

Winter Solstice : It is also called the '***Hibernal Solstice'***, occurs when either of earth's poles reaches its maximum tilt away from the Sun. This happens twice yearly, once in each hemisphere (Northern and southern). In the Northern hemisphere, this is the December solstice (usually 21st or 22nd December) and in the Southern hemisphere, this is the June solstice (usually 20th or 21st of June).