Climatology

The impact of weather and climate on human communities is so varied and all pervading that naturally (innately) becomes the most important components of our physical environment. The welfare, safety and quality of human society are subject to the profound effects of the vagaries of weather and climate. In developing countries, the effects may be calamities. It highly tends to be neutralized by complex socio-economic systems, but even in these countries, extreme climatic conditions may produce major impacts. There are certain climatic phenomena such as draughts, floods, violent tropical storms of hurricane, intensity, heat and cold waves which may endanger lives and property and disrupt even the most sophisticated systems.

Nature and Scope of Climatology

Climatology is compounded of two Greek words, klima + logos; klima means slope of the earth, and logos means a discourse of study. Here slope of the earth refers to our conception of latitude. At present climatology is a broad and diverse field; it seeks to describe and explain the nature of climate. In brief, climatology may be defined as the scientific study of climate. It is the study of the varieties of climates found on the earth and their distribution over its surface.

Critchfield, H.J. – Climatology is the science that seeks to describe and explain the nature of climate, how it differs from place to place, and how it is related to man's activities. In his opinion, "Climatology broadens the findings of meteorology in space and in time to cover the whole earth and periods of time as long as observations and indirect evidence will permit'.

Relay. D, and Spolton. L – Define the science of climatology as the study of the weather conditions over a longer period. Miller. A.A. views climatology as that branch of science which discusses the average conditions of the weather. Court Arnold considers the science of climatology to be compounded of parts of three other modern disciplines: meteorology, statistics and geography. Each discipline, in his opinion, to a certain extent, is a child of climatology. Climatology must select from each of these disciplines the principles, observations, methods, and outlook that it needs.

Thornthwaite C.W. broadens the scope of climatology when he suggests that the study of the atmosphere as well as that of the earth's surface from the core of this discipline. This is so because each and every characteristics of climate is determined by the exchange of heat, moisture and momentum between the earth's surface and the atmosphere. The term climatology is correctly applied to the study of the following five growing fields: (i) climatological record, (ii) theory of climate, (iii) energy and moisture balances of the earth, (iv) study of climate as the environment of living organisms and (v) study of climate as the direct environment of man.

Geography and Climatology

Since geography studies the earth as habitat of human societies, it is naturally concerned with the study of climate as the dominant element in the natural environment. Riley and Spolton put it, the distribution of atmospheric phenomena over the earth is differentiated by latitude, topography, altitude, distribution of land, sea and ice-caps, and also, to some extent, by forests and great cities. All these influences are geographical. The geographers, among other social scientists, are engaged in long-term acquisition and application of environmental knowledge.

Climatology, according to F. Kenneth Hare is an integral part of physical geography, perhaps closer to the center than any other. At the same time, it has also been described as a major aspect of meteorology from which it must draw its fundamental principles. The geographer is interested in the study of climate simply because there are climatic regions found on the earth's surface, and each climatic region, despite the different geographical setting, is characterized by certain degree of uniformity. The boundaries of these climatic regions are so well-marked that they can be easily recognized on the basis of soil-groups, different types of land forms, and various plant communities. They can be easily defined on the basis of climatic numerical data. Since climate is said to be the key to regional variations, the geographer is, therefore, naturally interested in the science of climatology. Similarities of differences found in different landscapes are the resultant effects of diversities in climate. A particular type of climatic condition gives rise to a specific landscape.

Sub-Divisions of Climatology

There are three basic sub-divisions of the science of climatology.

- Physical Climatology
- Regional (or Descriptive) Climatology
- Applied Climatology

Physical Climatology – This branch of climatology seeks to explain the factors responsible for bringing about the temporal and spatial variations in heat exchange, moisture exchange and air movement. Observations of such climatic elements as insolation, duration of sunshine, temperature, air pressure, precipitation, winds, cloudiness and fog, and visibility, etc. help solve these problems. Various combinations of the aforesaid weather or climatic elements are caused by the complex processes of the transfer of heat, moisture and momentum between the earth's surface and atmosphere and within the atmosphere itself. There are certain climatic factors such as latitude, height above sea level, nature of surface, local relief, and prevailing winds, etc. which in turn control these processes. In fact, physical climatology is directly concerned with the discussion of all those factors and all those weather processes that cause regional differentiation of climate.

Thus, physical climatology is closely related to meteorology which includes not only the physics, chemistry and dynamics of the atmosphere, but also many of its direct effects upon the earth's surface, the oceans and life in usual. Physical climatology is a major aspect of meteorology from which most of its basic principles are drawn.

Regional Climatology – This branch of climatology seeks to determine and describe the various types of climates. It is also labeled as descriptive climatology, for it is concerned with the identification of important climatic characteristics and analyses the interaction of the weather and climatic elements upon the life, health and economics of peoples and areas.

It may be pointed out that the very basis of the classification of climatic types is the statistical analysis of the climatic data. Moreover, while discussing the spatial distribution of climatic elements, regional climatology encompasses the concept of scale as well. On the basis of size and extent of the climatic regions, the world is divided into three regions:

(a) macro-climatic regions

(b) meso-climatic regions

(c) micro-climatic regions

While making a study of macro-climates, basic factors of climate such as distribution of continents and oceans, the earth's albedo, and the intensity of the solar radiation incident of the outer margin of our atmosphere are taken into consideration. On the contrary, the meso- and micro-climates are largely controlled by local factors.

Applied Climatology – This branch of climatology is concerned with the application of the climatological knowledge to specific practical problems. It analyses the relationship of climatology to other sciences. In applied climatology, the main purpose is to find out ways and means to make use of our knowledge of climatic elements for the betterment of human life on the earth. The practical application of the discoveries and techniques to various types of human activities is growing day by day. Knowledge of weather and climate is being applied to the solution of such problems as plant and animal production, transportation, communication and industry, structural designs and construction activities, atmospheric pollution and many other activities of man. Besides, there are various economic activities of man which have highly specialized climatic requirements. For examples, while building airports, the runways are made, as far as possible, in alignment with the direction of prevailing winds in order to ensure safe landing as well as take-off of the aeroplanes. Similarly, the planting of crops requires an intelligent use of climatological information regarding the length and characteristics of the growing season. For frost-sensitive vegetable, the possibility of the occurrence of sub-freezing temperature must be taken into account. Thus, available climatological data have a great many applications.

Because of the rapidly growing literature of climatology and the experience of persons working in the field, there have emerged, in recent decades, many specialized branches of the science of climatology. They are labeled as agricultural or agro climatology, medical climatology, urban climatology, bio-climatology, architectural climatology, etc.

Relation with Meteorology

There exists a close relationship between meteorology and climatology. Meteorology, the physics of the lower atmosphere, studies the individual phenomenon of the atmosphere. In other

words, it is concerned with the study of the characteristics and behaviour of the atmosphere. Climatology, on the other hand, is concerned with the discussion of the component elements of climate as well as the factors which determine and control its distribution. The function of climatology is two-fold. First, the meteorological aspect of this discipline examines the process of gain and loss of heat energy by the air layer near the ground, keeping in view the fact that the basic principles apply at any place on the globe. Second, climatological aspect of the discipline examines the global pattern of thermal environment as it is expressed by characteristic values of air temperatures. The same is true in case of other climatic elements. Thus, climatology recognizes global climatic types and regions in terms of various combinations of the basic environmental ingredients such as air, temperature, and availability of water to plants in terms of precipitation and evaporation.

Critchfield has clearly stated that climatology broadens the findings of meteorology in space and time. Meteorology is the atmosphere and the phenomena that occur within it, whereas climatology is the study of the weather conditions over a longer period.

Meteorology is mainly concerned with the physical analysis of the individual weather element. It explains and analyses the changes of air pressure, temperatures and humidity that are brought about due to the effect of insolation on the earth's surface.

Meteorology combines physics and geography. It draws its fundamental principles from physics and applies them to the behaviour of the atmosphere which is a mixture of different kinds of gases. It also studies the whole atmosphere and its movements as they are largely controlled by the geographic factors such as topography, distribution of continents and oceans, altitude, and latitude. As a branch of physics, meteorology is primarily concerned with the physical processes operating in the atmosphere. At the same time, it is descriptive and explanatory of the physical environment of man. Because of this, meteorology may become a branch of geography. Even though meteorology combines physics and geography, it is rather different from both.

Although climatology aims at a systematic study of climate and its distribution on the earth's surface, a knowledge of the individual weather or climatic element is equally essential. It is in this respect that climatology comes closer to meteorology. However, it should be remembered that climatology is primarily interested in the climates of the earth in themselves and as elements in the natural environment of life. It may be pointed out that in climatology, the investigation of the physical processes underlying various climatic phenomena, even though valuable and interesting, occupies only a secondary place.

Introduction to the Atmosphere

Earth is different from all other known planets in a variety of ways. One of the most notable differences is the presence around our planet of an atmosphere distinctive from other planetary atmospheres. It is our atmosphere that makes life possible on Earth. The atmosphere supplies most of the oxygen that animals must have to survive, as well as the carbon dioxide needed by plants. It helps maintain a water supply, which is essential to all living things. It insulates Earth's

surface against temperature extremes and thus provides a livable environment over most of the planet. It also shields Earth from much of the Sun's ultraviolet radiation, which otherwise would be fatal to most life forms.

Air, generally used as a synonym for atmosphere is not a specific gas but rather a mixture of gases, mainly nitrogen and oxygen. In addition, most air also contains minor but varying quantities of solid and liquid particles that can be thought of as impurities. The individual particles are mostly submicroscopic and therefore held in suspension in the air. Most air also contains some gaseous impurities.

Pure air is invisible because the gases in it are colour less, odour less, and tasteless. Gaseous impurities, on the other hand, can often be smelled, and the air may even become visible if enough submicroscopic solid and liquid impurities coalesce (stick together) to form particles large enough to either reflect or scatter sunlight. Clouds, by far the most conspicuous visible features of the atmosphere, represent such a coalescing of impurities, primarily water vapour.

The atmosphere completely surrounds Earth and can be thought of as a vast ocean of air with Earth at its bottom. It is held to Earth by gravitational attraction and therefore accompanies our planet in all its celestial motions. The attachment of Earth and atmosphere is a loose one, however, and the latter can therefore move on its own, doing things that the solid Earth cannot do.

Although the atmosphere extends outward at least 10,000 km, most of its mass is concentrated at very low altitudes. More than half of the mass of the atmosphere lies below the elevation of North America's highest peak, Mount Mckinley in Alaska, elevation 6.2 km, and more than 98 percent of it lies within 26 km of sea level. Therefore, relative to Earth, the diameter of which is about 13,000 km, the 'ocean of air' we live in is a very shallow one.

In addition to reaching upward above Earth's surface, the atmosphere also extends slightly downward. Because air expands to fill empty spaces, it penetrates into caves and into crevices in rocks and soil. Moreover, it is dissolved in the waters of Earth and in the bloodstreams of organisms.

The atmosphere interacts with other components of the earthly environment, and it is instrumental in providing a hospitable milieu for life. Whereas we often speak of human beings as creatures of Earth, it is perhaps more accurate to consider ourselves creatures of the atmosphere. As surely as a crab crawling on the sea bottom is a resident of the ocean, a person living at the bottom of the ocean of air is a resident of the atmosphere.
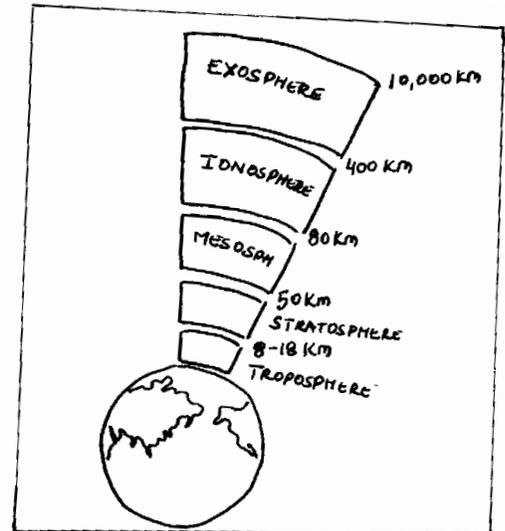
Composition of the Atmosphere

The chemical composition of pure, dry air at lower elevations (by which we mean lower than about 80 km) is simple and uniform and the concentrations of the major components are basically unvarying over time. Certain minor gases and nongaseous particles vary markedly from place to place and from time to time, however, as does the amount of moisture in the air.

The Gases

Nitrogen and oxygen are the two most abundant gases in the atmosphere. Nitrogen makes up more than 78 percent of the total, and oxygen makes up nearly 21 percent. Nitrogen is added to the air by the decay and burning of organic matter, by volcanic eruptions, and by the chemical breakdown of certain rocks, and it is removed by certain biological processes and by being washed away in rain or snow. Overall, the addition and removal of nitrogen gas are balanced, and consequently the quantity present in the air remains constant over time. Oxygen is produced by vegetation and is removed by a variety of organic and inorganic processes; its total quantity also apparently remains stable. The remaining 1 percent of the atmosphere's volume consists mostly of the inert gas argon. These three principal atmospheric gases – nitrogen, oxygen, argon – have a minimal effect on the weather and climate and therefore need no further consideration here. The trace gases neon, helium, methane, krypton, and hydrogen also have little effect on weather and climate.

Several other gases occur in sparse but highly variable quantities in the atmosphere, and their influence on weather and climate is significant. The amount of *water vapour* present determines the humidity of the atmosphere. It is most abundant in air overlying warm, moist surface areas, such as tropical oceans, where water vapour may amount to as much as 4 percent of total volume. Over deserts and in Polar Regions, the amount of water vapour is but a tiny fraction of 1 percent. (For the atmosphere as a whole, the total amount of water vapour remains virtually constant. Thus, the listing of it as a variable gas means variable in location, not variable in time). Water vapour has a significant effect on weather and climate in that it is the source of all clouds and precipitation and is intimately involved in the storage, movement, and release of heat energy. Atmospheric *carbon dioxide* also has a significant influence on climate, primarily because of its potent ability to absorb infrared radiation, which is the type of radiation that keeps the lower atmosphere warm. Carbon dioxide is distributed fairly uniformly in the lower layers of the atmosphere, but its concentration has been increasing for the last century or so, and the rate of accumulation has been accelerating, presumably because of the increasing burning of fossil fuels. The long-range effect of increasing amounts of carbon dioxide in the atmosphere is debatable, but many scientists believe that the higher levels will cause the lower atmosphere to warm up enough to produce major, and still unpredictable, global climatic changes. The proportion of carbon dioxide in the atmosphere has been increasing at rate of about 0.0002 percent (2 parts per million) per year, and at present is about 370 parts per million.

Another minor but vital gas in the atmosphere is **ozone**, which is a molecule made up of three oxygen atoms joined together (O_3). For the most part, ozone is concentrated in a layer of the

atmosphere called the **ozone layer**, which lied between 15 and 48 km above Earth's surface. Ozone is an excellent absorber of ultraviolet solar radiation; it filters out enough of these rays to protect life forms from potentially deadly effects.

The other variable gases – carbon monoxide, sulfur dioxide, nitrogen oxides, and various hydrocarbons – are increasingly being introduced into the atmosphere by emission from factories and automobiles. All of them are hazardous to life and may possibly have some effect on climate.

The Particles

The larger nongaseous particles in the atmosphere are mainly water and ice, which form clouds, rain, snow, sleet and hail. There are also dust particles large enough to be visible, which are sometimes kept aloft in the turbulent atmosphere in sufficient quantity to cloud the sky, but they are too heavy to remain long in the air. Smaller particles, invisible to the naked eye, may remain suspended in the atmosphere for months or even years.

The solid and liquid particles found in the atmosphere are collectively called **particulates**. They have innumerable sources, some natural and some the result of human activities. Volcanic ash, wind-blown soil and pollen grains, meteor debris, smoke from wildfires, and salt spray from breaking waves are examples of particulates from natural sources. Particulates coming from human sources mostly consist of industrial and automotive emissions and smoke and soot from fires of human origin.

These tiny particles are most numerous near their places of origin – above cities, seacoasts, and active volcanoes. They may be carried great distances, however, both horizontally and vertically, by the restless atmosphere. They affect weather and climate in two major ways:

- Many are *hygroscopic* (which means they absorb water), and water vapour condenses around them as they float about. This accumulation of water vapour molecules is a critical step in cloud formation.
- Some either absorb or reflect sunlight, thus decreasing the amount of solar energy that reaches Earth's surface.

Vertical Structure of The Atmosphere

Lower portion of the atmosphere is the zone in which most weather phenomena occur. Even though the upper layers of the atmosphere affect the environment of Earth's surface only minimally, it is still useful to have some understanding of the total atmosphere. Therefore, we now note some general characteristics of the atmosphere in its total vertical extent, emphasizing vertical patterns of temperature, pressure and composition.

Temperature

Most of us have had some personal experience with temperature variables associated with altitude. As climb a mountain, for instance, we sense a decrease in temperature. Until about a

century ago, it is was generally assumed that temperature decreased with increasing altitude throughout the whole atmosphere, but now we know that such is not the case.

The vertical pattern of temperature is complex, consisting of a series of layers in which temperature alternately decreases and increases. From the bottom up, these *thermal layers* are called the **troposphere**, **stratosphere**, **mesosphere**, **thermosphere**, and **exosphere**. In addition to these five principal names, we also have a special name for the top of the first three layers: **tropopause**, **stratopause**, and **mesopause**. We use the *-sphere* name when talking about an entire layer and the *–pause* name when our interest is either in the upper portion of a layer or in the boundary between two layers.

The names 'troposphere' and 'tropopause' are derived from the Greek word *tropos* (turn) and imply an overturning of the air in this zone as a result of vertical mixing and turbulence. The depth of the troposphere varies in both time and place. It is deepest over tropical regions and shallowest over the poles, deeper in summer than in winter, and varies with the passage of warm and cold air masses. On the average, the top of the troposphere (including the tropopause) is about 18 km above sea level at the equator and about 8 km above sea level over the poles.

The names 'stratosphere' and 'stratopause' come from the Latin *stratum* ('a cover'), implying a layered, or stratified, condition without vertical mixing. The stratosphere extends from an altitude of 20 km above sea level to about 48 km. The names 'mesosphere' and 'mesopause' are from the Greek *meso* ('middle'). The mesosphere begins at 48 km to about 80 km above sea level. Above the mesopause is the thermosphere (from the Greek *therm*, meaning 'heat'), which begins at an altitude of 80 km above sea level and has no definite top. Instead, it merges gradually into the region called the exosphere, which in turn blends into interplanetar space. Traces of atmosphere extend for literally thousands of km higher. Therefore, 'top of the atmosphere' is a theoretical concept rather than a reality, with no true boundary between atmosphere and outer space.

Air temperature beginning at sea level, first decreases steadily with increasing altitude through the troposphere. It then remains constant through the tropopause and for some distance into the stratosphere. At an altitude of about 20 km, air temperature begins increasing with increasing altitude, reaching a maximum at 48 km, at the bottom of the mesosphere. Then the temperature decreases with increasing altitude all through the mesosphere, reaching a minimum at the top of that layer at an altitude of 80 km. Temperature remains constant for several miles into the thermosphere and then begins to increase until, at an altitude of 200 km, it is higher than the maximum temperature in the troposphere. In the exosphere, the normal concept of temperature no longer applies.

Each warm zone in this temperature gradient has a specific source of heat. At ground level, the heat source is the visible portion of sunlight, the energy of which is absorbed by the lowest layer of the troposphere as well as by Earth's surface. The heat absorbed by the ground is conducted upward into the troposphere. The warm zone at the stratopause is near the top of the ozone layer, where ozone is absorbing the ultraviolet portion of sunlight and thereby warming the atmosphere. In the thermosphere, various atoms and molecules also absorb ultraviolet rays

and are thus split and heated. The cold areas that separate these warm zones are cold because they lack sources of heat.

Although there are many interesting physical relationships in the stratosphere, mesosphere, thermosphere, and exosphere, storms and essentially all the other phenomena we call 'weather' occur in the troposphere. Only occasionally do we consider atmospheric conditions above the troposphere.

Pressure

Atmospheric pressure can be thought of, for simplicity's sake, as the weight of the overlying air. The taller the column of air above an object, the greater the air pressure exerted on that object. Because air is highly compressible, the lower layers of the atmosphere are compressed by the air above, and this compression increases both the pressure exerted by the lower layers and the density of these layers. Air in the upper layers is subjected to less compression and therefore exerts a lower pressure and has a lower density.

Air pressure is normally highest at sea level and decreases rapidly with increasing altitude. The change of pressure with altitude is not constant, however. As a generalization, pressure decreases upward at a decreasing rate. At 16 km, the atmospheric pressure is only 10 percent of its sea-level value; this is just another way of saying that most of the mass of the atmosphere is found relatively close to the ground.

One-half of all the gas molecules making up the atmosphere lie below 3.5 miles (5.6 kilometers), and 90 percent of them are concentrated in the first 16 km above sea level. Pressure becomes so light in the upper layers that, above about 80 km, there is not enough to register on an ordinary barometer, the instrument used to measure air pressure. Above this level, atmospheric molecules are so scarce that air pressure is less than that in the most perfect laboratory vacuum at sea level.

Composition

The principal gases of the atmosphere have a remarkably uniform vertical distribution throughout the lowest 80 km or so of the atmosphere. This zone of homogenous composition is referred to as the **homosphere**. The sparser atmosphere above this zone does not display such uniformity; rather, the gases tend to be layered in accordance with their molecular masses – nitrogen below, with oxygen, helium, and hydrogen successively above. This higher zone is called the **heterosphere**.

Water vapour also varies in its vertical distribution. Most is found near Earth's surface, with a general diminishment increasing altitude. Above 16 km above sea level, the temperature is so low that any moisture formerly present in the air has already frozen into ice. At these altitudes, therefore, there is rarely enough moisture to provide the raw material to make even a wisp of a cloud. If you have done any flying, you may recall the remarkable sight of a cloudless sky overhead once the plane breaks through the top of a solid cloud layer below.

Two other vertical compositional patterns are worthy of mention here:

1. The ozone layer, which, as stated above, lies between 15 and 48 km up, is sometimes called the ozonosphere. Despite its name, the ozone layer is not composed primarily of ozone. It getsits name because that is where the concentration of ozone relative to other gases is at its maximum. Even in the section of the ozonosphere where the ozone attains its greatest concentration, at about 25 km above sea level, this gas accounts for about 12 parts per million of the atmosphere.

2. The ionosphere is a deep layer of electrically charged molecules and atoms (which are called 'ions') in the middle and upper mesosphere and the lower thermosphere, between about 60 and 400 km. the ionosphere is significant because it aids long-distance communication by reflecting radio waves back to Earth. It is also known for its auroral displays, such as the northern lights.

Weather and Climate

Our vast and invisible atmospheric envelope is energized by solar radiation, stimulated by earthly motions, and affected by contact with Earth's surface. The atmosphere reacts by producing an infinite variety of conditions and phenomena known collectively as **weather**. The term 'weather' refers to short-run atmospheric conditions that exist for a given time in a specific area. It is the sum of temperature, humidity, cloudiness, precipitation, pressure, winds, storms, and other atmospheric variables for a short period of time. Thus, we speak of the weather of the moment or the week or the season, or perhaps even of the year or the decade.

Weather is in an almost constant state of change, sometimes in seemingly erratic fashion. Yet in the long view, it is possible to generalize the variations into a composite patter, which is termed **climate**. Climate is the aggregate of day-to-day weather conditions over a long period of time. It encompasses not only the average characteristics but also the variations and extremes. To describe the climate of an area requires weather information over an extended period, normally several decades at least.

Weather and climate, then, are related but not synonymous terms. The distinction between them is the difference between immediate specifics and protracted generalities. As the country philosopher said, 'Climate is what you expect; weather is what you get'. Or, stated more sarcastically, 'It is the climate that attracts people, and the weather that makes them leave'.

Weather and climate have direct and obvious influences on agriculture, transportation and human life in general. Moreover, climate is a significant factor in the development of all major aspects of the physical landscape – soils, vegetation, animal life, hydrography, and topography.

Because climate and weather are generated in the atmosphere, our ultimate goal in studying the atmosphere is to understand the distribution and characteristics of climatic types over Earth. To achieve this understanding, we must consider in detail many of the processes that take place in the atmosphere. Our concern is primarily with long-run atmospheric conditions (climate), but we must also have appreciation for the dynamics involved in the momentary state of the atmosphere (weather).

The Elements of Weather and Climate

The atmosphere is a complex medium, and its mechanisms and processes are sometimes very complicated. Its nature, however, is generally expressed in terms of only a few variables, which are measurable. The data thus recorded provide the raw materials for understanding both temporary (weather) and long-term (climate) atmospheric conditions.

These variables can be thought of as the elements of weather and climate. The most important are

- **temperature,**
- **moisture content,**
- **pressure, and**
- **wind.**

These are the basic ingredients of weather and climate, the ones you hear about on the nightly weather report. Measuring how they vary in time and space makes it possible to decipher at least partly the complexities of weather dynamics and climatic patterns.

The Controls of Weather and Climate

Variations in the climatic elements are frequent, if not continuous, over Earth. Such variations are caused by, or at least strongly influenced by, certain semi-permanent attributes of our planet, which are often referred to as **controls**. It should be emphasized that there often is much overlap and interaction among controls with widely varying effects.

Latitude – The continuously changing positional relationship between the Sun and Earth brings continuously changing amounts of sunlight, and therefore of radiant energy, to different parts of Earth's surface. Thus, the basic distribution of heat over Earth is first and foremost a function of latitude. In terms of elements and controls, we say that the control latitude influences the element temperature.

Distribution of Land and Water – Probably the most fundamental distinction concerning the geography of climate is that between continental climates and maritime (oceanic) climates. Oceans head and cool more slowly and to a lesser degree than do landmasses, which means that maritime areas experience milder temperatures than do continental areas in both summer and winter. For example, Seattle, Washington, and Fargo, North Dakota, are at approximately the same latitude (47° N), with Seattle on the western coast of the United States and Fargo deep in the interior. Seattle has an average January temperature of 5° C, while the January average in Fargo is -13° C. In the opposite season, Seattle has a July average temperature of 19° C, whereas in Fargo, the July average is 22° C.

Also, oceans are a much more prolific source of atmospheric moisture; thus, maritime climates are normally more humid than continental climates. The uneven distribution of

continents and oceans over the world, then, is a prominent control of the elements moisture content and temperature.

General Circulation of the Atmosphere – The atmosphere is in constant motion, with flows that range from transitory local breezes to vast regional wind regimes. At the planetary scale, a semi-permanent pattern of major wind and pressure systems dominates the troposphere and greatly influences most elements of weather and climate. As a simple example, most surface winds in the tropics come from the east, whereas the middle latitudes are characterized by flows that are mostly from the west.

General Circulation of the Oceans – Somewhat analogous to atmospheric movements are the motions of the oceans. Like the atmosphere, the oceans have many minor motions but also a broad general pattern of currents. These currents assist in heat transfer by moving warm water pole ward and cool water equatorward. Although the influence of currents on climate is much less than that of atmospheric circulation, the former is not inconsequential. For example, warm currents are found off the eastern coasts of continents, and cool currents occur off western coasts, a distinction that has a profound effect as coastal climates.

Elevation – WE have already noted that three of the four weather elements – temperature, pressure, and moisture content – generally decrease upward in the troposphere and are therefore under the influence of the control altitude. This simple relationship between the three elements and the control has significant ramifications for many climatic characteristics, particularly in mountainous regions.

Topographic Barriers – Mountains and large hills sometimes have prominent effects on one or more elements of climate by blocking or diverting wind flow. The side of mountain ranges facing the wind (the 'windward' side) for example is likely to have a climate vastly different from that of the sheltered ('leeward') side.

Storms – Various kinds of storms occur over the world; some have very widespread distribution, whereas others are localized. Although they often result from interactions among other climate controls, all storms create specialized weather circumstances and so are themselves considered to be a control Indeed, some storms are prominent and frequent enough to affect not only weather but climate as well.

Insolation and Temperature

The temperature of the air at any time and at any place in the atmosphere is the result of the interaction between a variety of complex factors. Attention is to be focused on the energetics of the atmosphere – the important processes involved in bringing insolation (incoming solar radiation) to the atmosphere, in determining the extent of heating (and cooling) that takes place,

and in transferring heat from one place to another. Understanding these processes will help us understand the distribution of temperature over Earth.

The Impact of Temperature on the Landscape

All organisms have certain temperature tolerances, and most are harmed by wide fluctuations in temperature. Thus, when the weather becomes particularly hot or cold, mobile organisms are likely to search for shelter, and their apparent presence in the landscape is diminished. Human beings also seek haven from temperature extremes, although they have other option (such as specialized clothing) that allow them to brave the elements. In a broader view, immoderate temperatures have a more profound effect on the landscape because both animals and plants often evolve in response to hot or cold climates. For this reason, the inventory of flora and fauna in any area of temperature extremes is likely to be determined by the capability of the various species to withstand the long-term temperature conditions.

Most inorganic components of the landscape also are affected by long-run temperature and conditions. For example, temperature is a basic factor in soil development, and repeated fluctuations of temperature are a prominent cause of the breakdown of exposed bedrock. The human-built landscape also is influenced by temperature considerations, as demonstrated by architectural styles and building materials.

Solar Energy

The Sun is the only important source of energy for Earth's atmosphere. Millions of other stars radiate energy, but they are too far away to affect Earth. Energy is also released from inside Earth, primarily as radioactive minerals decay, but only in insignificant quantities. Tidal energy is also of minor importance. Thus the Sun supplies essentially all the energy that supports life on Earth and energizes most of the atmospheric processes.

The Sun is a star of average size and average temperature, but its proximity to Earth gives it a far greater influence on our planet than that exerted by all other celestial bodies combined. The Sun is a prodigious generator of energy. In a single second, it produces more energy than the amount used by humankind since civilization began. The Sun functions as an enormous thermonuclear reactor, producing energy by fusion, a process that burns only a very small portion of the Sun's mass but provides an immense and continuous flow of radiant energy that is dispersed in all directions.

The radiant energy from the Sun is in the form of electromagnetic waves. These are waves that can transport energy without requiring a medium (the presence of matter) to pass through. They traverse the great voids of space in unchanging form. The waves travel outward from the sun in straight lines at the speed of light – 300,000 km per second.

Electromagnetic waves are classified on the baits of wavelength, which can be thought of as the distance from the crest of one wave to the crest of the next. Only a tiny fraction of the Sun's radiant output is intercepted by Earth. The waves travel through space without loss of energy, but since they are diverging from a spherical body, their intensity continuously diminishes with increased distance from the Sun. As a result of this intensity drop and the distance separating

Earth from the Sun, less than one two-billionth of total solar output reaches the outer limit of Earth's atmosphere, having travelled 150,000,000 km in just over 8 minutes. Although it consists of only a minuscule portion of total solar output, in absolute terms the amount of solar energy Earth receives is enormous: the amount received in 1 second is approximately equivalent to all the electric energy generated on Earth in a week.

Insolation

Electromagnetic waves of various lengths make up what is called the electromagnetic spectrum. For the physical geographer, only three areas of the spectrum are of importance:

Wavelengths that measure from about 0.01 to 0.4 micrometers are the **ultraviolet waves**, which are too short to be seen by the human eye. The Sun is a prominent natural source of ultraviolet rays, and solar insolation reaching the top of our atmosphere contains a considerable amount. However, much of it is absorbed by the atmosphere, and the shortest ultraviolet rays do not reach Earth's surface, where they could cause considerable damage to most living organisms.

- **Visible light** is concentrated entirely in the narrow band between about 0.4 and 0.7 micrometers. Only about 3 percent of all electromagnetic waves are in the visible-light spectrum.

- Between about 0.7 and 1000 micrometers are **infrared waves**, which are too long to be seen by the human eye. They are generally emitted by hot objects and are sometimes referred to as 'heat rays'. They have a variety of uses that depend in part on their ability to pass through materials that block ordinary light rays but still produce heat inside the blocking material, as with infrared heat lamps. Earth radiation is entirely infrared, but only a small fraction of solar radiation is.

Solar radiation is mainly visible light along with some shorter infrared and longer ultraviolet wavelengths. Terrestrial radiation is entirely in the infrared spectrum. A wavelength of about 4 micrometers is considered the boundary on the spectrum separating long waves from short ones; thus, all terrestrial radiation is long-wave radiation, and almost all-solar radiation is shortwave radiation. The longest terrestrial radiation waves are approximately 20 times longer than that the longest solar radiation waves.

As a basic generalization, hot bodies radiate mostly short waves, and cool bodies radiate mostly long waves. The Sun is the ultimate hot body of our solar system, and so most of its radiation is in the shortwave part of the electromagnetic spectrum. For this reason, solar radiation is often referred to as **shortwave radiation**.

The total insolation received at the top of the atmosphere is believed to be constant when averaged over a year, although it may vary slightly with fluctuations in the Sun's temperature. This constant amount of incoming energy – referred to as the **solar constant** – is slightly less than 2 calories per square centimeter per minute. (A calorie is the amount of heat required to raise the temperature of 1 gram of water by 1° C). The solar constant is more properly given as slightly less than 2 langleys per minute because the unit of radiation intensity is the **langley**, which is equal to 1 calorie per square centimeter.

The entrance of insolation into the atmosphere is just the beginning of a complex series of events in the atmosphere and at Earth's surface. Some of the insolation is reflected off the atmosphere and bounces back into space, and the part that is not reflected is transformed in one way or another. Some passes through the atmosphere to Earth's surface, some does not. The mixed reception of solar energy waves and the energy cascade that results are discussed after a brief digression to define our terms.

Basic Processes in heating and cooling the Atmosphere

Before looking at the events that occur as energy travels from the Sun to Earth, let us examine the physical processes involved in the movement of heat energy. There are three ways in which heat energy can move from one place to another – by radiation, by conduction, and by convection. Once that energy gets to a destination, it can be absorbed, reflected, scattered or transmitted.

Radiation

Radiation is the process by which heat energy is emitted from a body. It involves the flow of radiant energy out of the body and through the air. All bodies radiate, but hotter bodies are more potent radiators than cooler ones. The hotter the object, the more intense its radiation and the shorter the wavelength of that radiation.

Temperature, however, is not the only control of radiation effectiveness. Objects at the same temperature may vary considerably in their radiating capability because the nature of the surface of the objects is in important determining factor. A body that emits the maximum amount of radiation possible – at every wavelength – is called a **blackbody**.

Both the Sun and Earth function essentially as blackbodies, that is, as perfect radiators. They radiate with almost 100 percent efficiency for their respective temperatures. Because it is exceedingly hotter than Earth, however, the Sun emits 2 billion times more energy than Earth.

Absorption

Heat energy striking an object can be absorbed by the object like water into a sponge; this process is called **absorption**. When insolation strikes an object and is absorbed, the temperature of the object increases, as exemplified by the uncomfortably warm skier.

Different materials vary in their absorptive capabilities, with the variations depending in part on the temperature and wavelength of the radiation being absorbed. The basic generalization is that a good radiator is also a good absorber, and a poor radiator is a poor absorber. Both the Sun and Earth, then, are efficient absorbers as well as radiators.

Mineral materials (rock, soil) are generally excellent absorbers; snow and ice are poor absorbers; water surfaces vary in their absorbing efficiency. One important distinction concerns colour. Dark-coloured surfaces are much more efficient absorbers in the visible portion of the spectrum than are light-coloured surfaces (which is why the dark-clothed skier is sweating).

Reflection

For our purposes, **reflection** is the ability of an object to repel waves without altering either the object or the waves. Thus in some cases insolation striking a surface in the atmosphere or on

Earth is bounced away, unchanged, in the general direction from which it came, much like a mirror reflection, where nothing is changed.

In this context, reflection is the opposite of absorption. If the wave is reflected, it cannot be absorbed. Hence, an object that is a good absorber is a poor reflector, and vice versa. A simple example of this principle is the existence of un melted snow on a warm, sunny day. If it is to melt, the snow must absorb heat energy from the Sun. Although the air temperature may be well above freezing, the snow does not melt rapidly because its white surface reflects away a large share of the solar energy that strikes it.

Scattering

Particulate matter and gas molecules in the air sometimes deflect light waves and redirect them in a process known as scattering. This deflection involves a change in the direction of the light wave but no change in wavelength. Some of the waves are backscattered into space and thus are lost to Earth, but most of them continue through the atmosphere in altered directions.

The amount of scattering that takes place depends on the wavelength of the wave as well as on the size, shape and composition of the molecule or particulate. Shorter waves are more readily scattered than longer ones. This means that the violets and blues in the visible part of the spectrum are more likely to be redirected than are the oranges and reds.

Transmission

Transmission in the process whereby a wave passes completely through a medium, as when light waves are transmitted through a pane of clear, colour less gas. There is obviously considerable variability among mediums in their capacity to transmit rays. Earth materials, for example, are very poor transmitters of insolation; sunlight is absorbed at the surface of rock or soil and does not penetrate at all. Water, on the other hand, transmits sunlight well: even in murky water, light penetrates some distance below the surface, and in clear water, sunlight may illuminate to considerable depths.

In some cases, transmission depends on the wavelength of the rays. For example, glass has high transmit capacity for shortwave radiation but not for long waves. Thus, heat builds up in a closed automobile left parked in the Sun because shortwave insolation is transmitted through the window glass, but the long waves that are reradiated from the interior of the car cannot escape in similar fashion.

The atmosphere transmits a considerable amount of shortwave solar radiation, but it is not nearly as effective a transmitter of long-wave terrestrial radiation. This characteristic is enhanced when the air contains clouds, water vapour, or dust. In simplest terms, solar energy readily penetrates to Earth's surface, but reradiated terrestrial energy is mostly 'trapped' in the lower troposphere and much of it is reflected back toward the ground. This entrapment keeps Earth's surface and lower troposphere at a higher average temperature than would be the case if there were no atmosphere.

The circumstances just described are referred to as the greenhouse effect because it was long thought that greenhouses maintained heat in the same manner – the glass roof transmitting shortwave solar energy in but inhibiting the passage of long-wave radiation out. Recently it has

been shown that this is not the full story; for example, greenhouses having windows made of rock salt, which permits equal transmission of long waves and short waves, experienced a heat buildup approximately as great as that of ordinary glass greenhouses.

Further investigation showed that glass greenhouses maintain high temperatures largely because the warm air in the building is trapped and does not dissipate through mixing with the cooler air outside. Thus the term *greenhouse effect* is based on a misconception, and the trapping of heat in the lower troposphere because of differential transmissivity for short waves and long waves should probably be called something else; atmospheric effect has been suggest, but greenhouse effect continues to be the customary term.

Conduction

The movement of heat energy from one molecule to another without changes in their relative positions is called **conduction**. This process enables heat to be transferred from one part of a stationary body to another or from one object to a second object when the two are in contact.

Conduction comes about through molecular collision. A hot molecule becomes increasingly agitated as heat is added to it and collides against a cooler, calmer molecule, transferring energy to it. In this manner, the heat is passed from one place to another. The principle is that when two molecules of unequal temperature are in contact with one another, heat passes from the warmer to the cooler until they attain the same temperature.

The ability of different substances to conduct heat is quite variable. For example, most metals are excellent conductors, as can be demonstrated by pouring hot coffee into a metal cup and then touching your lips to the edge of the cup. The heat of the coffee is quickly conducted throughout the metal and burns the lips of the incautious drinker. On the other hand, hot coffee poured into a ceramic cup only very slowly heats the cup because such earthy material is a poor conductor.

Earth's land surface warms up rapidly during the day because it is a good heat absorber, and some of that warmth is transferred away from the surface by conduction. A small part is conducted deeper underground, but not much because earth materials are not good conductors. Most of this absorbed heat is transferred to the lowest portion of the atmosphere by conduction from the ground surface. Air, however, is a poor conductor, and so, only the air layer touching the ground is heated very much. Physical movement of the air is required to spread the heat around.

Moist air is a slightly more efficient conductor than dry air. If you are outdoors on a winter day, you will stay warmer if there is little moisture in the air.

Convection

In **convection**, heat is transferred from one point to another by a moving substance. This method of heat transfer involves movement of the heated molecules from one place to another. Do not confuse this movement from one place to another with the back-and-forth vibratory movement of conduction. In convection, the molecules physically move away from the heat source. In conduction, they do not.

A similar convective pattern frequently develops in the atmosphere. As far as our study of insolation is concerned, the important point to remember about convection is that it causes warm

air to rise. Unequal heating (for a variety of reasons) may cause a parcel of surface air to become warmer than the surrounding air. The heated air expands and moves upward, in the direction of lowest pressure. The cooler surrounding air then moves in toward the heat source and air from above sinks down to replace that which has moved in, thus establishing a convective system. The prominent elements of the system are an updraft of warm air and a downdraft of cool air. Convection is common in each hemisphere during its summer and throughout the year in the tropics.

Adiabatic Cooling and warming

Whenever air ascends or descends its temperature changes. This invariable result of vertical movement is due to the variation in pressure. When air rises, it expands because there is less air above it, and so less pressure is exerted on it. When air descends, it is compressed because there is more air above it, and so more pressure is exerted on it.

The expansion that occurs in rising air is a cooling process even though no heat is taken away. Spreading the molecules over a greater volume of space requires energy, and this energy comes from the molecules. The loss of energy slows them down and decreases their frequency of collision. The result is a drop in temperature. This is **adiabatic cooling** – cooling by expansion in rising air.

Conversely, when air descends, it must become warmer. The descent causes compression as the air comes under increasing pressure. The molecules draw closer together and collide more frequently. Then result is a rise in temperature even though no heat is added from external sources. This is **adiabatic warming** – warming by compression in descending air.

Latent Heat

The physical state of moisture in the atmosphere frequently changes – ice changes to liquid water, liquid water changes to water vapour, and so forth. The changes involve either the storage or the release of energy, depending on the process. The two most common state changes are **evaporation**, in which liquid water is converted to gaseous water vapour, and **condensation**, in which gaseous water vapour condenses to liquid water. In evaporation, energy is stored as **latent heat** (*latent* is from the Latin, 'lying hidden'), in condensation, the latent heat is released.

The Heating of the Atmosphere

In the long run, there apparently is a perfect balance between the total amount of insolation received by Earth and its atmosphere on one hand, and the total amount of terrestrial radiation returned to space on the other. Otherwise Earth would be getting progressively warmer or cooler. The annual balance between incoming and outgoing radiation is the global *heat budget*, which can be illustrated by using 100 units to represent total insolation received at the outer edge of the atmosphere and tracing its dispersal.

Most of the insolation that enters the atmosphere does not heat it directly. About 30 units of total insolation are reflected (or scattered) back into space; this radiation that is bounced back into space is called Earth's **albedo**. ('Albedo' is the technical term for the reflectivity of an object. The higher the albedo value, the more radiation the object reflects). About 48 units of the

insolation pass on through the atmosphere to Earth's surface, leaving only 22 units to heat the atmosphere directly, 3 of them heating the ozone layer and 19 heating the rest of the atmosphere.

Terrestrial (mostly long-wave) radiation from Earth's surface to the atmosphere amounts to about 110 units. This is possible because the atmosphere's 'greenhouse' effect traps large amounts of energy and reradiates it back to Earth. The sequence of radiation between Earth and atmosphere continues indefinitely. In terms of annual balance, about 96 units of long-wave radiation are returned to Earth for every 110 units that go to the atmosphere from Earth. Thus, the atmosphere receives a net gain of 14 units.

Another important source of outgoing energy is the transport of latent heat during the process of evaporation. More than three-fourths of all sunshine falls on a water surface when it reaches Earth. Much of this energy is utilized in evaporating moisture from oceans, lakes, and other bodies of water. Thus, the energy is passed into the atmosphere as latent heat stored in the resulting water vapour; it will be released subsequently when condensation takes place. This amounts to about 22 units in the heat budget equation.

Another 6 units of energy is conducted from Earth's surface back into the atmosphere, where it is dispersed by convection. Another 6 units of terrestrial energy is transmitted directly through the atmosphere to space.

For the most part, then, the atmosphere is heated by Earth, although the Sun is the original source of the energy. Thus, there is an intimate link between troposphere temperatures and Earth surface conditions. The air temperature at any given time represents the balance between insolation and terrestrial radiation.

This complicated sequence of atmospheric heating has many ramifications. One of the most striking is that the atmosphere is heated mostly from below rather than from above. The result is a troposphere in which cold air overlies warm air. This unstable situation creates an environment of almost constant convective activity and vertical mixing. If the atmosphere were heated directly from the Sun, producing warm air at the top and cold air near Earth's surface, the situation would be stable, essentially without vertical air movements. The result would be a troposphere that is largely motionless, apart from the effects of Earth's rotation.

SPATIAL AND SEASONAL VARIATIONS IN HEATING

The radiation budget is broadly generalized. There are, however, many latitudinal and vertical imbalances in this budget, and these are among the most fundamental causes of weather and climate variations. In essence, we can trace a causal continuum wherein radiation differences lead to temperature differences that lead to air-density differences that lead to pressure differences that lead to wind differences that often lead to moisture differences.

It has already been noted that world weather and climate differences are fundamentally caused by the unequal heating of Earth and its atmosphere. This unequal heating is the result of latitudinal and seasonal variations in how much energy is received by Earth.

Latitudinal Differences

There are only a few basic reasons for the unequal heating of different latitudinal zones:

Angle of incidence – The angle at which rays from the Sun Strike Earth's surface is called the **angle of incidence**. This angle is measured from a line drawn tangent to the surface. By this definition, a ray striking Earth's surface directly, when the Sun is directly overhead, has an angle of incidence of 90, a ray striking the surface at a slant has an angle of incidence smaller than 90°, and for a ray striking Earth at either pole, the angle of incidence is zero.

Because Earth's surface is curved and because the positional relationship between Earth and the Sun is always changing, the angle of incidence is also always changing. This changing angle is the primary determinant of the intensity of solar radiation received at any spot on Earth. If a ray strikes Earth's surface directly, the energy is concentrated in a small area; if the ray strikes Earth not directly but obliquely, the energy is spread out over a larger portion of the surface. The more nearly perpendicular the ray (in other words, the closer to 90° the incidence angle), the smaller the surface area heated by a given amount of insolation and the more effective the heating. It is clear that, considering the year as a whole, the insolation received by high-latitude regions is much less intense than that received by tropical areas.

Day Length – The duration of sunlight is another important factor in explaining latitudinal inequalities in heating. Longer days allow more insolation to be received and thus more heat to be absorbed. In tropical regions, this factor is relatively unimportant because the number of hours between sunrise and sunset does not vary significantly from one month to another; at the equator, of course, daylight and darkness are equal in length (12 hours each) every day of the year. In middle and high latitudes, however, there are pronounced seasonal variations in day length. The conspicuous buildup of heat in summer in these regions is largely a consequence of the long hours of daylight, and the winter cold is a manifestation of limited insolation being received because of short days.

Atmospheric Obstruction – We have already noted that clouds, particulate matter, and gas molecules in the atmosphere absorb, reflect, or scatter insolation. The result is a reduction in the intensity of the energy received at Earth's surface. On the average, sunlight received at Earth's surface is only about half as strong as it is outside Earth's atmosphere.

This weakening effect varies from time to time and from place to place, depending on two factors: the amount of atmosphere the radiation has to pass through and the transparency of that atmosphere. The distance a ray of sunlight travels through the atmosphere (commonly referred to as 'path length') is determined by the angle of incidence. A large-angle ray (in other words, a nearly perpendicular ray) traverses a shorter course through the atmosphere than a small-angle one. A tangent ray (one having an incidence angle of zero) must pass through nearly 20 times as much atmosphere as a direct ray (one striking Earth at a 90° angle).

The effect of atmospheric obstruction on the distribution of solar energy at Earth's surface is to reinforce the pattern established by the varying angle of incidence. Solar radiation is more depleted of energy in the high latitudes than in the low latitudes; thus, there are smaller losses of energy in the tropical atmosphere than in the polar atmosphere.

Latitudinal Radiation Balance – As the direct rays of the Sun shift northward and southward across the equator during the course of the year, the belt of maximum solar energy swings back and forth through the tropics. Thus in the low latitudes, to about 28° N and 33° S, there is an energy surplus, with more incoming than outgoing radiation. In the latitudes north and south of these two parallels, there is an energy deficit, with more radiant loss than gain. The surplus of energy in low latitudes is directly related to the consistently large angle of incidence, and the energy deficit in high latitudes is associated with small angles.

The distribution of radiation around the world is the same as in Untied States and parts of Canada and Mexico. The variations are largely latitudinal, as is to be expected. The principal interruptions to the simple latitudinal pattern are based on the presence or absence of frequent cloud cover, where insolation is reflected, diffused, and scattered. The radiation is greatest in the southwestern United States, where clouds are consistently sparse, and is least in the northwestern and northeastern corners of the country, where cloud cover is frequent.

Despite the variable pattern, there is a balance between incoming and outgoing radiation for the Earth – atmosphere complex as a whole; in other words, the net radiation balance for Earth is zero. The mechanisms for exchanging heat between the surplus and deficit regions involve the general circulation patterns of the atmosphere and oceans.

Land and Water Contrasts

The atmosphere is heated mainly by heat reradiated from Earth rather than by heat from the Sun; thus the heating of Earth's surface is primary control of the heating of the air above it. To comprehend variations in air temperatures, it is useful to understand how different kinds of surfaces react to solar energy. There is considerable variation in the absorbing and reflecting capabilities of the almost limitless kinds of surfaces found on Earth – soil, water, grass, trees, cement, rooftops, and so forth. Their varying receptivity to insolation in turn causes differences in the temperature of the overlying air.

By far the most significant contrasts are those between land and water surfaces. The generalization is that land heats and cools faster and to a greater degree than water.

Heating – A land surface heats up more rapidly and reaches a higher temperature than a comparable water surface subject to the same insolation. In essence, a thin layer of land is heated to relatively high temperatures, whereas a thick layer of water is heated more slowly to moderate temperatures. There are several significant reasons for this difference:

- Water has a higher **specific heat** than land. Specific heat is the amount of energy required to raise the temperature of 1 gram of a substance by 1° C. The specific heat of water is about five times as great as that of land, which means that water can absorb much more solar energy without its temperature increasing.
- As mentioned above, Sunrays penetrate water more deeply than they do land; that is, water is a better transmitter than land. Thus in water the heat is diffused over a much greater volume

of matter, and maximum temperatures remain considerably lower than they do land, where the heat is concentrated and maximum temperatures can be much higher.

- Water is highly mobile and so turbulent mixing and ocean currents disperse the heat both broadly and deeply. Land, of course, is essentially immobile, and so heat is dispersed only by conduction (and land is a very poor conductor).
- The unlimited availability of moisture on a water surface means that evaporation is much more prevalent than on a land surface. The latent heat needed for this evaporation is drawn from the water and its immediate surroundings, causing a drop in temperature. Thus, the cooling effect of evaporation slows down any heat buildup on a water surface.

Cooling – When both are overlain by air at the same temperature, land surface cools more rapidly and to a lower temperature than a water surface. During winter, the shallow heated layer of land radiates its heat away quickly. Water loses its heat more gradually because the heat has been stored deeply and is brought only slowly to the surface for radiation. As the surface water cools, it sinks and is replaced by warmer upwellings from below. The entire water body must be cooled before the surface temperatures decrease significantly.

Implications – The significance of these contrasts between land and water heating and cooling rates is that both the hottest and coldest areas of Earth are found in the interiors of continents, distant from the influence of oceans. In the study of the atmosphere, probably no single geographic relationship is more important than the distinction between continental and maritime climates. A continental climate experiences greater seasonal extremes of temperature – hotter in summer, colder in winter – than a maritime climate.

These differences portray average monthly temperatures for San Diego and Dallas. These two cities are at approximately the same latitude and experience almost identical lengths of day and angles of incidence. Although their annual average temperatures are almost the same, the monthly averages vary significantly. Dallas, in the interior of the continent, experiences notably warmer summers and cooler winters than San Diego, which enjoys the moderating influence of an adjacent ocean.

The oceans, in a sense, act as great reservoirs of heat. In summer, they absorb hat and store it. In winter, they give off heat and warm up the air. Thus, they function as a sort of global thermostatically controlled heat source, moderating temperature extremes.

The ameliorating influence of the oceans can also be demonstrated, on a totally different scale, by comparing latitudinal temperature variations in the Northern Hemisphere with those in the Southern Hemisphere. The former is often thought of as a 'land hemisphere', because 3 percent of its area is land surface; the latter is a 'water hemisphere', with only 19 percent of its area as land.

Temperature: A Measure Of Heat

Energy is the capacity to do work and can take various forms. **Heat** is one form of energy; it is associated with how fast the atoms in any solid, liquid, or gas are vibrating. The more heat

energy any atom contains, the faster it vibrates. **Temperature** is an expression of the degree of hotness or coldness of a substance.

Most people have a ready sensitivity to temperature. The nerves in our skin readily respond to variations in heat and cold and make us conscious of temperature changes. The sensitivity of our skin is not a reliable temperature indicator, however. Our nerves may be 'misled' by other factors, such as the presence of moisture or air movement, factors that are quite separate from temperature but affect our perception of temperature. For example, on a cool day when a strong wind is blowing, we may perceive that the weather is colder than the temperature would indicate, simply because our body heat is dissipated so rapidly by the air movement. The term sensible temperature is applied to this phenomenon. It is the 'sensation' of temperature that we feel in response to the total condition of the air around us; it may or may not be representative of the actual air temperature.

Mechanisms Of Heat Transfer

If there were not mechanisms for moving heat pole ward in both hemispheres, the tropics would become progressively warmer until the amount of heat energy absorbed equaled the amount radiated from Earth's surface and the high latitudes would become progressively colder. Such temperature trends do not occur because there is a persistent shifting of warmth toward the high latitudes and the consequent cooling of the low latitudes. This shifting is accomplished by circulation patterns in the atmosphere and in the oceans. The broad-scale, or planetary, circulation of these two mediums moderates the buildup of heat in equatorial regions and the loss of heat in polar regions, thereby making both those latitudinal zones more habitable than they would otherwise be. Both the atmosphere and the oceans act as enormous thermal engines, with their latitudinal imbalance of heat driving the currents of air and water, in turn, transfer heat and somewhat modify the balance.

Atmospheric Circulation

Of the two mechanisms of global heat transfer, by far the more important is the general circulation of the atmosphere. Air moves in an almost infinite number of ways, but there is a broad planetary circulation pattern that serves as a general framework for moving warm air pole ward and cool air equator ward. Some 75 o 80 percent of all horizontal heat transfer is accomplished by atmospheric circulation.

Oceanic Circulation

There is a close relationship between the general circulation patterns of the atmosphere and oceans. Various kinds of oceanic water movements are categorized
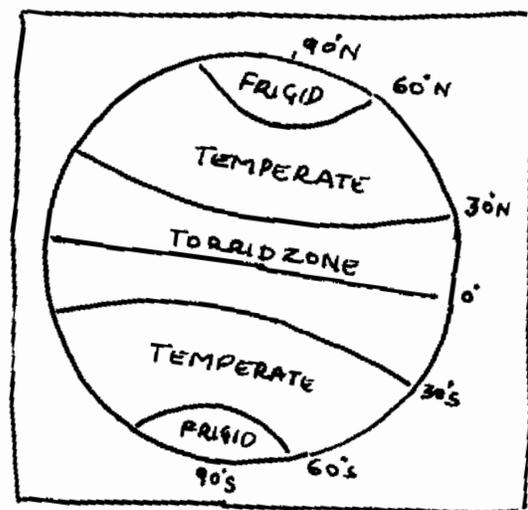
as **currents**, and it is air blowing over the surface of the water that is the principal force driving the major surface ocean currents. In the other direction, the heat energy stored in the oceans has important effects on atmospheric circulation.

For our purposes in understanding heat transfer by the oceans, we are concerned primarily with the broad scale surface current that make up the general circulation of the ocean. These major currents respond to changes in wind direction, but they are so broad and ponderous that the response time normally amounts to any months. In essence, ocean currents reflect average wind conditions over a period of several years, with the result that the major components of oceanic circulation are closely related to major components of atmospheric circulation.

The Basic Pattern – All the oceans of the world are interconnected. Because of the location of landmasses and the pattern of atmospheric circulation, however, it is convenient to visualize five relatively separate ocean basins – North Pacific, South Pacific, North Atlantic, South Atlantic, and South Indian. Within each of these basins, there is a similar pattern of surface current flow, based on a general similarity of prevailing wind patterns.

Despite variations based on the size and shape of the various ocean basins and on the season of the year, a single simple pattern of surface currents is characteristic of all the basins. It consists of series of enormous elliptical loops elongated east west and centered approximately at 30° of latitudes (except in the Indian Ocean, where it is centered on the equator). These loops, called **gyres**, flow clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

On the equator ward side of each subtropical (this word means 'bordering on the tropics') gyre is the *Equatorial Current*, which moves steadily toward the west. The two equatorial currents have an average position 5° to 10° north or south of the equator and are separated by the *Equatorial Countercurrent*, which is an east-moving flow approximately along the equator in each ocean. The equatorial currents feed the Equatorial Countercurrent near its western margin in each basin. Water from the Equatorial Countercurrent in turn drifts poleward to feed the Equatorial Current near the eastern end of its path.

Near the western margin of each ocean basin, the general current curves pole ward. As these currents approach the pole ward margins of the ocean basins they curve east, and as they reach the eastern edges of the basins, they curve back toward the equator, producing an incompletely closed loop in each basin.

The movement of these currents, although impelled partially by the wind, is caused mainly by the deflective force of Earth's rotation, which is called the **Coriolis Effect**. This force dictates that the ocean currents are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. A glance at the basic pattern shows that the current movement around the gyres responds precisely to the Coriolis Effect.

Northern and Southern Variations – In the two Northern Hemisphere basins – North Pacific and North Atlantic – the bordering continents lie so close together at the poleward basin margin that the bulk of the current flow is prevented from entering the Arctic Ocean. This effect is more

pronounced in the Pacific than in the Atlantic. The North Pacific has only very limited flow northward between Asia and North America, whereas in the North Atlantic a larger proportion of the flow escapes northward between Greenland and Europe.

In the Southern Hemisphere, the continents are far apart. Thus the poleward parts of the gyres in the South Pacific, South Atlantic, and South Indian Oceans are connected ad one continuous flow in the uninterrupted belt of ocean that extends around the world in the vicinity of latitude 60° S. This circumpolar flow is called the West Wind Drift.

Current Temperatures – Of utmost importance to our understanding of latitudinal heat transfer are the temperatures of the various currents. Each major current can be characterized as warm or cool relative to the surrounding water at that latitude. The generalized temperature characteristics are as follows:

- Low-latitude currents (Equatorial Current, Equatorial Countercurrent) have warm water.
- Pole ward-moving currents on the western sides of ocean basins carry warm water toward higher latitudes.
- Northern components of the Northern Hemisphere gyres carry warm water toward the north and east.
- Southern components of the Southern Hemisphere gyres (generally combined into the West Wind Drift) are strongly influenced by Antarctic waters and are essentially cool.
- Equator ward-moving currents on the eastern sides of ocean basins carry cool water toward the equator.

In summary, the general circulation of the oceans is a pole ward flow of warm tropical water along the western edge of each ocean basin and an equator ward movement of cool high-latitude water along the eastern margin of each basin.

Rounding out the Pattern – Two other relatively minor aspects of oceanic circulation are influential in heat transfer:

- The northwestern portions of Northern Hemisphere ocean basins receive an influx of cool water from the Arctic Ocean. A prominent cool current from the vicinity of Greenland comes southward along the Canadian coast, and a smaller flow of cold water issues from the Bering Sea southward along the coast of Siberia to Japan.
- Wherever an equatorward-flowing cool current pulls away from a subtropical western coast, a pronounced and persistent upwelling of cold water occurs. This is most striking off South America but is also notable off North America, northwestern Africa, and southwestern Africa. It is much less developed off the coast of Western Australia.

Vertical Temperature Patterns

Temperature in the troposphere is relatively predictable. Throughout the troposphere, under normal conditions, there is a general decrease in temperature with increasing altitude. However, there are many exceptions to this general statement. Indeed, the rate of vertical temperature decline can vary according to season, time of day, amount of cloud cover, and a host of other

factors. In some cases, there is even an opposite trend, with the temperatures increasing upward for a limited distance.

Lapse Rate

The rate at which temperature decreases with height is variable, particularly in the lowest few hundred feet of the troposphere, but the normal rate is about 3.6° F per 1000 feet (6.5° C per km). This is the average **lapse rate**, or normal vertical temperature gradient. The lapse rate tells us that, if a thermometer measures a temperature 1000 feet above a previous measurement, the reading will be, on the average, 3.6° F cooler; if the second measurement is 1000 feet below the first, the thermometer will register about 3.6 °F warmer.

Determining the lapse rate of a column of air involves measuring air temperature at various elevations. Then a graph of temperature as a function of height is drawn to get a temperature profile of the air column.

When measuring a lapse-rate temperature change, only the thermometer is moved; the air is at rest. If the air is moving vertically, expansion or contraction will cause an adiabatic temperature change, which is totally different from a lapse-rate temperature change.

Temperature Inversions

The most prominent exception to a normal lapse-rate condition is a **temperature inversion**, a situation in which temperature in the troposphere increases rather decreases, with increasing altitude. Inversions are relatively common in the troposphere but are usually of brief duration and restricted depth. They can occur near Earth's surface or at higher levels. These are also called Negative Lapse Rate

Inversions influence weather and climate. An inversion inhibits vertical air movements and greatly diminishes the possibility of precipitation. Inversions also contribute significantly to increased air pollution because they create stagnant air conditions that greatly limit the natural upward dispersal of urban-industrial pollutants.

Surface Inversions – The most readily recognizable inversions are those found at ground level. These are usually classified as **radiation inversions** because they result from rapid radiation cooling. They occur typically on a long, cold winter night when a land surface (an efficient radiator) rapidly emits long-wave radiation into a clear, calm sky. The ground is soon colder than the air above it and so now cools the air by conduction. In a relatively short, time, the lowest few hundred feet of the troposphere become colder than the air above and a temperature inversion is in effect. Radiation inversions are primarily winter phenomena because there is only a short daylight period for incoming solar heating and long night for radiation cooling. They are therefore much more prevalent in high latitudes than elsewhere.

An inverted surface temperature gradient can also be the result of an **advection inversion**, in which there is a horizontal inflow of cold air into an area. This condition commonly is produced by cool maritime air blowing in a coastal locale. Advection inversions are usually short-lived

(typically overnight) and shallow. They may occur at any time of year, depending on the location of the relatively cold surface and on wind movement.

Another type of surface inversion results when colder air slides down a slope into a valley, thereby displacing slightly warmer air. This fairly common occurrence during winter in some mid latitude region sis called a **cold-air-drainage inversion**.

Effects of Temperature Inversion

Inversion forms a division between the atmospheric layers. Movement of air is the cause of heat transfer that takes place in the troposphere. So, a diversion or break from the normal pattern of convection impacts many atmospheric processes like cloud formation, presence of fog, the pattern of precipitation, etc.

Prevents Convection: Inversion stops the exchange of air within the layers at the base of troposphere. Thus, air currents do not rise upwards.

Clouds and Fog: Water vapor and moisture contained by the air also gets confined, resulting into cloud formation and fog over the surface.

Valley Inversion: Cold air is denser and heavier. Thus, it sinks down at the bottom of the valleys. Mountains with leeward slopes experience thermal inversions in valleys every now and then.

Troposphere Ducting: On a foggy night, the sound of a radio can be heard from long distances. This happens when the radio signal gets bent and reverted from the inversion boundary, where it finds a warm layer of air (instead of cooler air present normally).

Freezing Rain: When snowflakes pass through an inversion layer, they melt due to the warm air and cool off as rapidly due to the cold air. However, the water drops are super cooled and not frozen until they hit the ground.

Rising Pollution Levels: This is one of the harmful effects of inversion. Warm layers of inversion do not allow any air to enter their sphere. Thus, industrial pollutants and vehicle exhausts are circulated within the layer nearing the ground. Concentration of these gases shoot up the toxin levels we breathe and form a brown-colored haze on the skyline as well.

Upper Air Inversions – Temperature inversions well above the ground surface nearly always are the result of air sinking from above. These **subsidence inversions** are usually associated with high-pressure conditions, which are particularly characteristic of subtropical latitudes throughout the year and of Northern Hemisphere continents in winter. A subsidence inversion can be fairly deep (sometimes several thousand feet), and its base is usually a few thousand feet above the ground, as low-level turbulence prevents it from sinking lower.

Vertical temperature profile of the atmosphere

There are several ways of classifying the different layers of the atmosphere. The most common classification is based on the vertical distribution and variations of temperature in the atmosphere. In this classification, from the lowest layer to the highest layer are respectively the troposphere, the stratosphere, the mesosphere, and finally the thermosphere. The thickness and the boundary of each layer are not identical throughout the globe but vary in different time and places .

The troposphere is about 12 kilometers thick on average; it is thicker in summer than in winter. The troposphere over low latitude regions is usually thicker than over high latitude regions. The troposphere over the equator is about 18 kilometers thick, while its thickness in the regions nearest the two poles is only about eight to nine kilometers. The temperature in the troposphere usually decreases with height at the average lapse rate of 6.5 °C per kilometer. The air in the troposphere is more unstable and with strong convection. Almost all the water vapor in the atmosphere exists within this layer; therefore, common weather phenomena such as clouds, fog, rain, and snow, occur only in this layer and more often than not in its lower part.

The stratosphere extends from 10 kilometers to 50 - 55 kilometers above ground. Within the lower part which extends from the top of the troposphere to about 30-35 kilometers the temperature is almost constant, or increases slightly with height. Above 35 kilometers the temperature actually increases with height at the average rate of 5 °C per kilometer. Since almost no dust or water vapor from the land surface will reach the stratosphere, the air flow in this layer is steady. The upper part of the stratosphere experiences an increase of temperature due to the fact that the sun's ultraviolet radiation is absorbed by the ozone layer.

The region of the **mesosphere** is about 50 to 80 kilometers in altitude. The temperature in this layer usually decreases as the height increases up to the top of the mesosphere where the temperature can be as low as - 95 °C or even lower. The composition of gases in the atmosphere from the ground to the top of the mesosphere, are almost identical except for water vapor and ozone. Therefore the region is also called the homosphere.
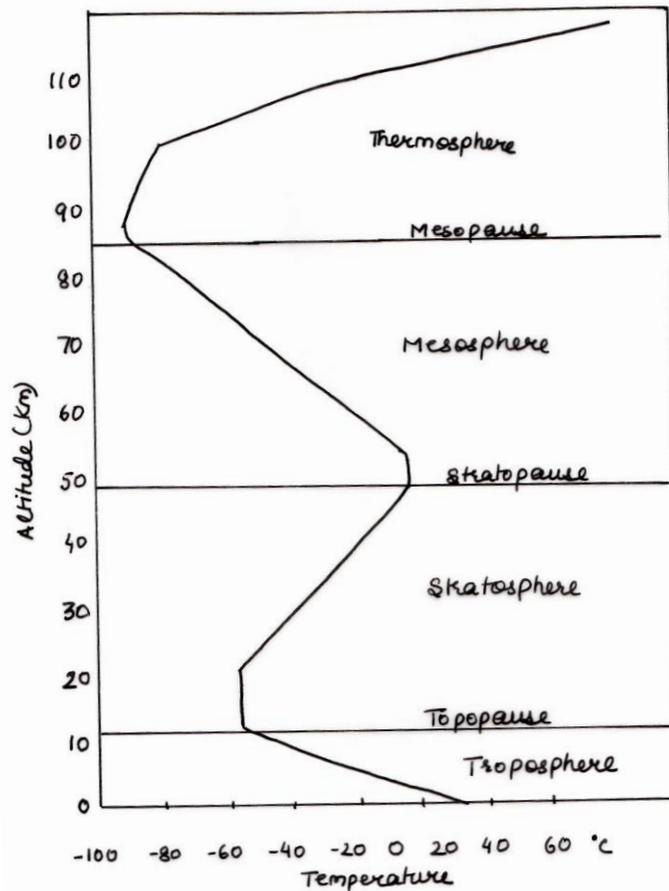
The **thermosphere** is the region above the top of mesosphere where the temperature begins to rise again. When sun activity is low, this layer can extend to 400 kilometers in altitude. During high sun activity periods the layer can reach around 500 kilometers in altitude. The air in the

lower region of the thermosphere is extremely thin; therefore the particles in the air can easily be ionized, resulting in profuse free electrons in the air. Therefore this layer is also called the ionosphere; it is very effective in reflecting radio waves.

Global Temperature Patterns

Maps of global temperature patterns display season's extremes rather than annual averages. January and July are the months of lowest and highest temperatures in most places on Earth, and so maps portraying the average temperatures of these two months provide a simple but meaningful expression of thermal conditions in winter and summer. Temperature distribution is shown by means of **isotherms**, lines joining points of equal temperature. Temperature maps are based on monthly average, which are based on daily averages; the maps do not show the maximum daytime heating or the maximum nighttime cooling. Although the maps are on a very small scale, they permit a broad understanding of temperature patterns for the world.

Prominent controls of Temperature

Gross patterns of temperature are controlled largely by four factors – altitude, latitude, land-water contrasts, and ocean currents.

Altitude – Because temperature responds sharply to altitudinal changes, it would be misleading to plot actual temperatures on a temperature map, as high-altitude stations would almost always be colder than low-altitude stations. The complexity introduced by hills and mountains would make the map more complicated and difficult to comprehend. Consequently, the data for most maps displaying world temperature patterns are modified by reducing the temperature to what it would be if the station were at sea level. This is done most simply by using the average lapse rate, a method that produces artificial temperature values but eliminate the complication of terrain differences. Maps plotted in this way are useful in showing world patterns, but they are not satisfactory for indicating actual temperatures for locations that are not close to sea level.

Latitude – Clearly the most conspicuous feature of any world temperature map is the general east-west trend of the isotherms, roughly following the parallels of latitude. If Earth had a uniform surface and did not rotate, the isotherms probably would coincide exactly with parallels, showing a progressive decrease of temperature pole ward from the equator. However, Earth does rotate, and it has ocean waters that circulate and land that varies in elevation. Consequently, there is precise temperature correlation with latitude. Nevertheless, the fundamental cause of temperature variation the world over is insolation, which is governed primarily by latitude, and the general temperature patterns reflect latitudinal control.

Land-Water Contrasts – The different heating and cooling characteristics of land and water are also reflected conspicuously on a temperature map. Summer temperatures are higher over the continents than over the oceans, as shown by the pole ward curvature of the isotherms over continents in the respective hemispheres (July in the Northern Hemisphere, January in the Southern). Winter temperatures are lower over the continents than over the oceans; the isotherms bend equator ward over continents in this season (January in the Northern Hemisphere, July in the Southern). Thus at both seasons, isotherms make greater north-south shifts over land than over water.

PLANETARY HEAT BUDGET

Ocean Currents – Some of the most obvious bends in the isotherms occur in near-coastal areas of the oceans, where prominent warm or cool currents reinforce the isothermal curves caused by land-water contrasts. Cool currents deflect isotherms equator ward, whereas warm currents deflect them pole ward. Cool currents produce the greatest isothermal bends in the warm season: Note the January situation off the western coast of South America and the southwestern coast of Africa or the July conditions off the western coast of North America. Warm currents have their most prominent effects in the cool season: witness the isothermal pattern in the North Atlantic Ocean in January.

Seasonal Patterns

Apart from the general east-west trend of the isotherms, probably the most conspicuous feature is the latitudinal shift of the isotherms from one map to the other. The isotherms follow the changing balance of insolation during the course of the year, moving northward from January to July and returning southward from July to January. Note, for example, the 50° F isotherm in southernmost South America: in January (midsummer), it is positioned at the southern tip of the continent, where in July (midwinter), it is shifted considerably to the north. This isotherm shift is
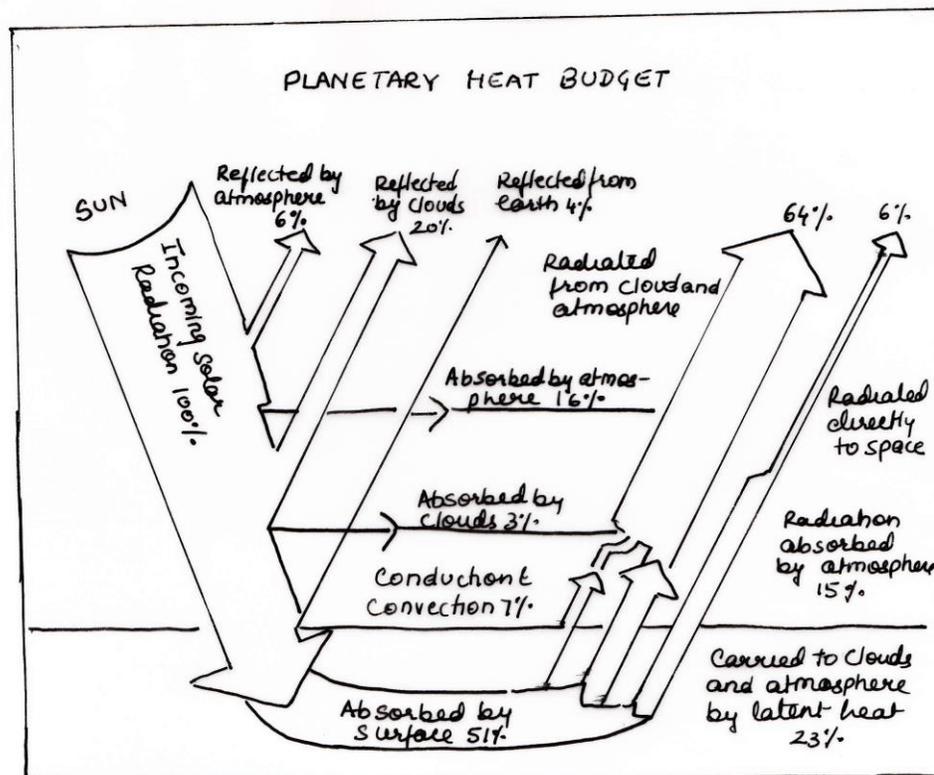
much more pronounced in high latitudes than in low and also much more pronounced in high latitudes than in low and also much more pronounced over the continents than over the oceans. Thus tropical areas, particularly tropical oceans, show relatively small displacement of the isotherms from January to July, whereas over middle- and high-latitude landmasses, an isotherm may migrate northward or southward more than 4000 km – some 14° of latitude.

Isotherms are also more tightly packed in winter. This close line spacing indicates that the temperature gradient (rate of temperature change with horizontal distance) is steeper in winter than in summer, which, in turn, reflects the greater contrast in radiation balance in winter. The temperature gradient is also steeper over continents than over oceans.

The coldest places on Earth are over landmasses in the higher latitudes. During July, the polar region of Antarctica is the dominant area of coldness. In January, the coldest temperatures occur many hundreds of miles south of the North Pole, in subarctic portions of Siberia, Canada, and Greenland. The principle of greater cooling of land than water is clearly demonstrated.

The highest temperatures are also found over the continents. The locations of the warmest areas in summer, however, are not equatorial. Rather, they are in sub-tropical latitudes, where descending air maintains clear skies most of the time, allowing for almost uninterrupted insolation. Frequent cloudiness precludes such a condition in the equatorial zone. Thus the highest July temperatures occur in northern Africa and in the southwestern portions of Asia and North America, whereas the principal areas of January heat are in subtropical parts of Australia, southern Africa, and South America.

Average annual temperatures are highest in equatorial regions, however, because these regions experience so little winter cooling. Subtropical locations cool substantially on winter nights, and so their annual average temperatures are lower.

The ice-covered portions of the Earth – Antarctica and Greenland – remain quite cold throughout the year.

Annual Temperature Range

Another map useful in understanding, the global pattern of air temperature is one that portrays the average annual range of temperatures. Annual temperature range is the difference between the average temperatures of the warmest and coldest months (normally July and January). The data are portrayed on the map by isolines that resemble isotherms.

Enormous seasonal variations in temperature occur in the interiors of high-latitude continents, and continental areas in general experience much greater ranges than do equivalent oceanic latitudes. At the other extreme, the average temperature fluctuates only slightly from season to season in the tropics, particularly over tropical oceans.