Weather

FOR AIRCREWS

DEPARTMENT OF THE AIR FORCE

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1Lt TONY BORRA

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Weather

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DEPARTMENT OF THE AIR FORCE

AIR FORCE MANUAL
NO. 105-5

DEPARTMENT OF THE AIR FORCE
WASHINGTON 25, D.C.
1 September 1962

Weather

WEATHER FOR AIRCREWS

The purpose of this manual is to emphasize that it is highly desirable for aircrew members to possess a basic knowledge of weather in order to receive and use weather briefing information intelligently. A wealth of current and forecast weather data is available to flight personnel. You will become a well informed, professional aircrew member if you realize this fact and get the very most from all available weather data. Since weather is such an important factor in the accomplishment of any flying mission, it is mandatory that aircrew personnel be thoroughly familiar with this factor upon which the mission so vitally depends.

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Comments or recommendations for the improvement of this manual should be sent to Headquarters Air Training Command, Randolph Air Force Base, Texas.

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WEATHER FOR AIRCREWS

AFM 105-5, 1 September 1962, is changed as follows:

1. Staple, paste, or scotch-tape the attached pages to the superseded pages in the manual:

Fasten Page	*To Page*
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2. After necessary action, fasten this change page inside the back cover of the manual.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

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CHAPTER 1

The Sea of Air

A study of the basic mission of the Air Force reveals that weather still is a very significant factor with respect to the dependability and superiority of the Air Force. If there should be one instance during military flight operations when the Air Force is grounded en masse, then the ground forces may become vulnerable and susceptible to defeat. No matter what the bomb load, the range, the fire power, or the speed of modern aircraft may be; no matter how skilled the flight and maintenance crews may be, certain weather may prevent or materially hinder the accomplishment of any flying mission. Because weather is such an important factor in the accomplishment of any flying mission, it is mandatory that aircrew personnel be thoroughly familiar with this factor upon which the mission so greatly depends.

It is not the purpose of this manual to teach the principles of weather forecasting to aircrew members. Good weather analysis and weather forecasting require a highly technical knowledge of all phases of meteorology. Forecasting weather for the Air Force is the job of the Air Weather Service. However, it is highly desirable that aircrew members possess a basic knowledge of weather in order to receive and utilize weather briefing information intelligently. There is a wealth of current and forecast weather data available to flight personnel. You will become a well informed, professional aircrew member if you realize this fact and get the very most out of all available weather data.

Meteorology is the science of the atmosphere, its activities, and phenomena. There are several subdivisions of meteorology, some of which are: dynamic meteorology, physical meteorology, synoptic meteorology, and aeronautical meteorology. Aeronautical meteorology is concerned with weather as it affects aviation.

Weather scientists have worked to enlarge their knowledge of the atmosphere using kites, balloons, aircraft, rockets, and satellites. New instruments usually increase man's knowledge of the atmosphere, and the knowledge gained sometimes opens our minds to new questions; questions that require a fuller understanding of the complex atmosphere.

The mass of air surrounding the earth, covering land and sea alike, shares many of the characteristics of the oceans. Although we cannot see it, it is as real as the water that covers some three-quarters of the earth's surface. Like the oceans, the air rotates with the earth as the earth orbits about the sun. However, the air has its own circulation relative to the earth's surface.

COMPOSITION AND PROPERTIES OF THE ATMOSPHERE

This colorless sea of air enveloping the earth is called the atmosphere. It is characterized by general motion (currents), and variations from the general motion. Some winds flow with the regularity of the great ocean currents, while others are as changeable as the flight of a bumblebee. The atmosphere has depth, and man's desire to explore the unknown and probe

Figure 1–1. Diagram Showing Relative Heights Attained and Dates

the physical world about him has been a basic motivation for upper atmospheric investigation since the invention of the balloon.

Man, at his home on the bottom of this air-ocean, has attempted for centuries to explore the atmosphere to determine its height, composition, and characteristics. Even today, with high altitude rockets, balloons, and aircraft, he has been able to do little more than to rise momentarily off the floor of this great ocean of air to gather fragments of information and experience in the upper atmosphere.

Ingredients of the Atmosphere

Air, the material of the atmosphere, is a mechanical mixture of several gases. At sea level dry air contains about 21% oxygen, 78% nitrogen, and about 1% argon. Other gases such as carbon dioxide, helium, krypton, and neon are found in very small and varying amounts. It is believed by many scientists that the earth may be unique among the planets in having free oxygen in its atmosphere.

There is another component of air, although found in variable and relatively small quantities, that is of major importance in meteorology—*water vapor*. A molecule of water vapor weighs about ⅝ as much as a molecule of dry air. Without water vapor in the air we would have few of the phenomena which comprise what we call "weather". There would be no cloud cover to protect us from the sun, no rain to water the plant life upon which animals and man depend for food. Life in its present form could not exist upon the earth.

The water vapor content of the atmosphere varies with latitude and altitude; it is lowest at high latitude and high altitude. Although practically all water vapor content is concentrated below the 25,000-foot level, no air with a water vapor content of zero has been found in the atmosphere up to at least 250,000 feet.

Solid particles such as dust, smoke, and salt from sea spray are found in the lower layers of the atmosphere. They range greatly in size, from submicroscopic to those large enough to be seen with the naked eye. These particles reduce visibility and some act as nuclei for condensation of water vapor.

No definite upper limit can be given to the atmosphere. Some idea of the vertical extent of the atmosphere can be gained by measuring the height at which certain phenomena occur which we know to be within its boundaries. For example, meteors glow at altitudes of 200 miles because of friction with the atmosphere. One-half of the mass of all the atmosphere is found between the ground and 18,000 feet (500 millibars), while three-quarters of it is found between the ground and about 36,000 feet (250 millibars). The remaining one-fourth is spread out through approximately 500 miles.

The evaluation of some elements or activities of the atmosphere such as turbulence, clouds, fog, haze, rain, and snow can be made by seeing or feeling. Others such as pressure, temperature, wind direction and speed, and relative humidity can be evaluated better by instruments.

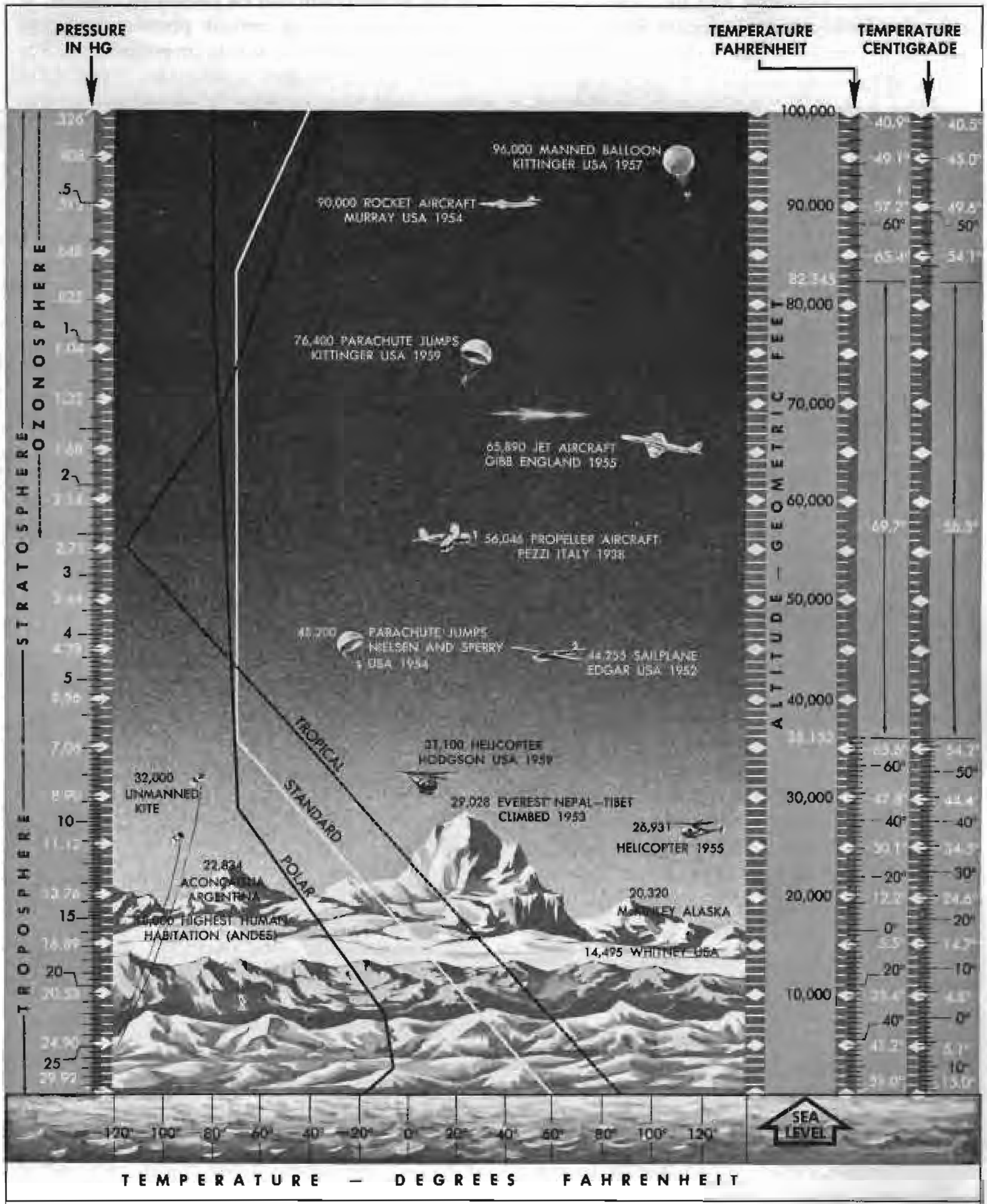
Although air is light, the weight of the atmosphere is enormous. However, man is not aware of this because the pressure of the air and fluids within his body counter-balances the pressure exerted on the outside of his body. The pressure exerted on the entire earth is 2116 pounds per square foot, or 14.7 pounds per square inch.

The main properties of the atmosphere are its mobility, its capacity to expand and contract (compressibility), and its ability to hold varying amounts of water vapor. So, the sea of air is similar to a sea of water, although there is somewhat more freedom of movement in the sea of air, and the water is not compressible.

Layers of the Atmosphere

In meteorology the earth's atmosphere is generally divided into two major regions—the lower atmosphere and the upper atmosphere. The atmospheric layers are discussed in the following paragraphs.

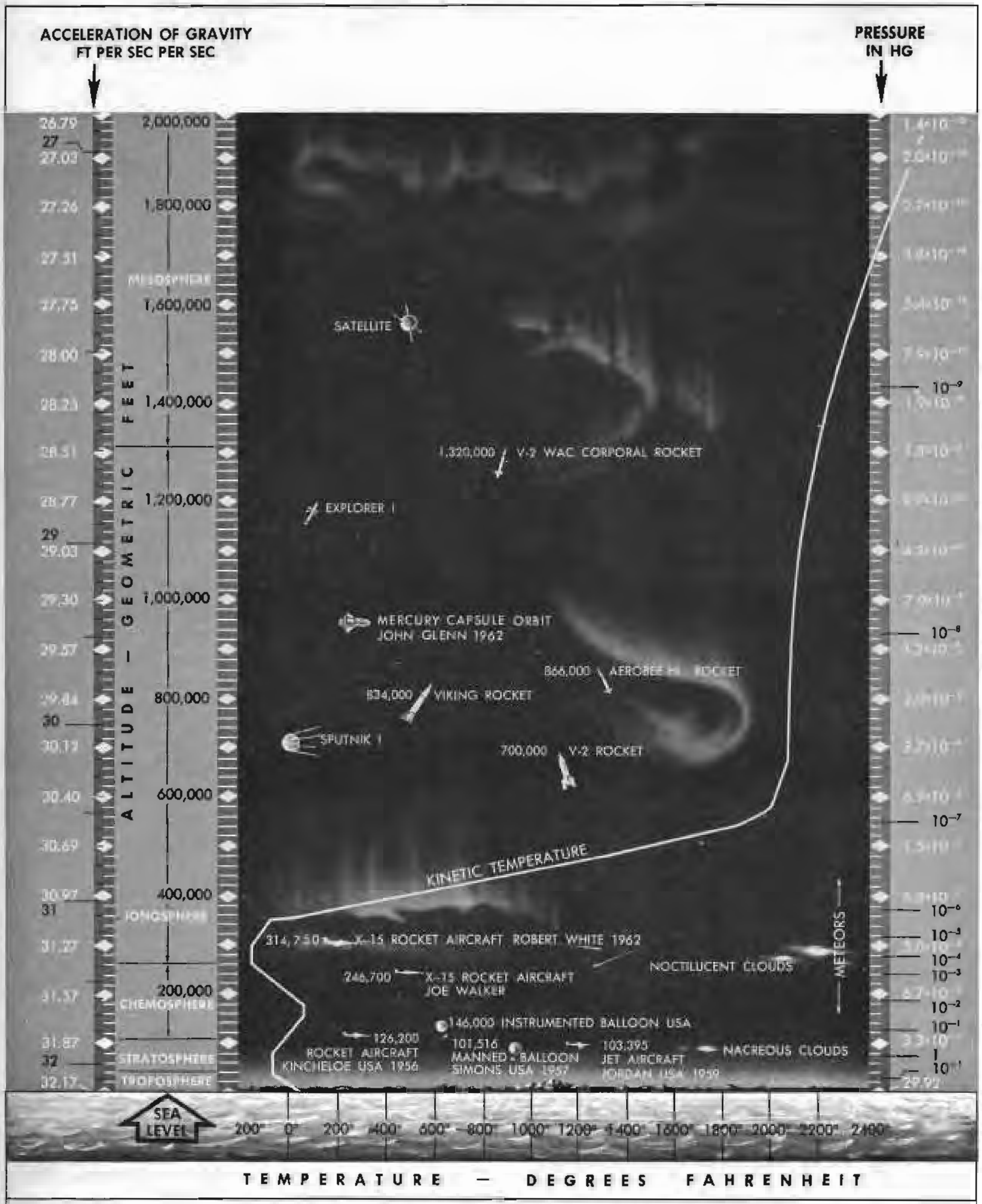
The lower atmosphere is called the troposphere. The thickness of the troposphere fluctuates with time and latitude, but averages about 54,000 feet over the equator and about 28,000 feet over the poles. In the temperate zones seasonal changes greatly affect the thickness of the troposphere, being thicker in summer than in winter. The thickness of the troposphere is constantly changing because of the temperature changes of the earth and the at-



This chart presents the latest recognized standard values for the temperature, pressure and density of the air at altitudes up to 100,000 geometric feet. The pictorial inserts represent various steps in man's achievement in learning to reach and to exist at high altitudes. The data in the columns on the sides, and the central profile, all refer to the ARDC Model Atmosphere, 1959.

Courtesy The Garrett Corporation

Figure 1–2. *Atmosphere Chart*



This chart presents standard values for the temperature, pressure and density of the air, based on the ARDC Model Atmosphere, 1959. The altitude column on the left presents geometric altitude. The energy required to lift an object 2,000,000 geometric feet is only 1,824,929 times that required to lift it one foot above sea level, because of the decrease in the acceleration of gravity with altitude. Kinetic temperature is a measure of the kinetic energy of the molecules and atoms constituting the atmosphere.

Courtesy The Garrett Corporation

Figure 1–3. High Altitude Chart

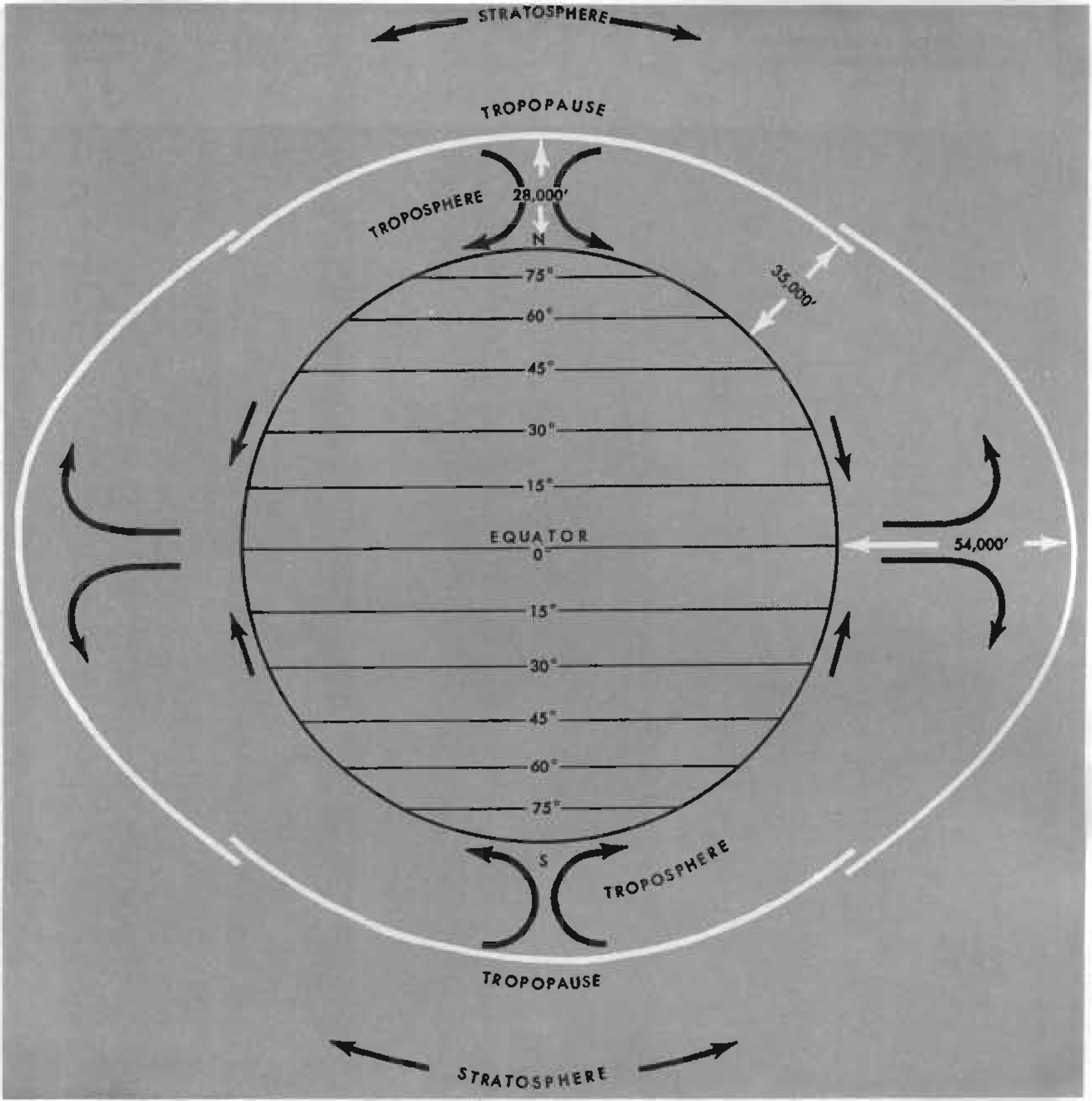


Figure 1–4. General Structure of the Atmosphere

mosphere—from day to night, and season to season. Even with these seasonal and daily changes the thickness of the troposphere in the temperate zone is rarely as deep as it is in the equatorial areas or as shallow as it is in the polar areas. At 45° latitude the average height of the troposphere is approximately 35,000 feet.

The troposphere is probably the most unsettled layer of the earth's atmosphere. It is the region of most cloud activity and most visible weather. Here are spawned nearly all the air masses, fronts, and storms that give the earth its weather.

Most of the weather is confined to the troposphere for several reasons, namely:

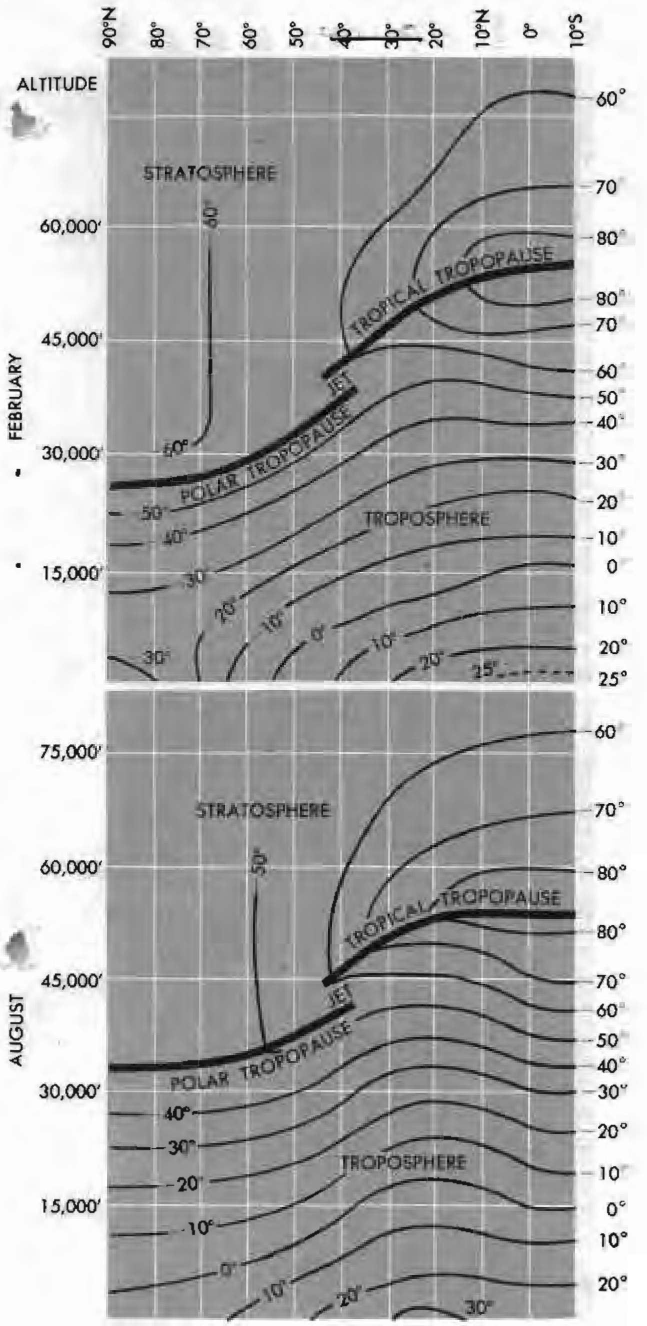
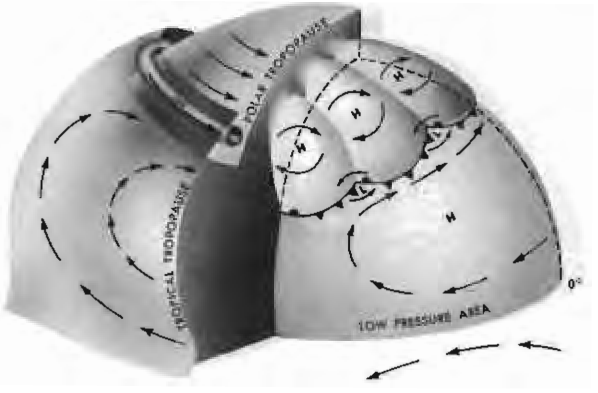


Figure 1–5. A Cross Section of the Atmosphere During February and August Showing Mean Temperatures Along a Meridian and the Position of the Tropopause

- A high percentage of the water vapor is in the lower atmosphere.
- Condensation nuclei are concentrated in the troposphere.
- Heating and cooling by radiation are at maximum at the surface.

The troposphere is the area in which the temperature drops at an average rate of approximately 2°C/1000 feet of altitude. This average temperature decrease is called the Standard Lapse Rate. The altitude at which this temperature decrease changes significantly (and there above remains essentially unchanged through a relatively thick layer) is the zone or boundary separating the lower atmosphere from the upper atmosphere. This imaginary zone is known as the tropopause and it is often considered as a sharp, narrow zone of transition.

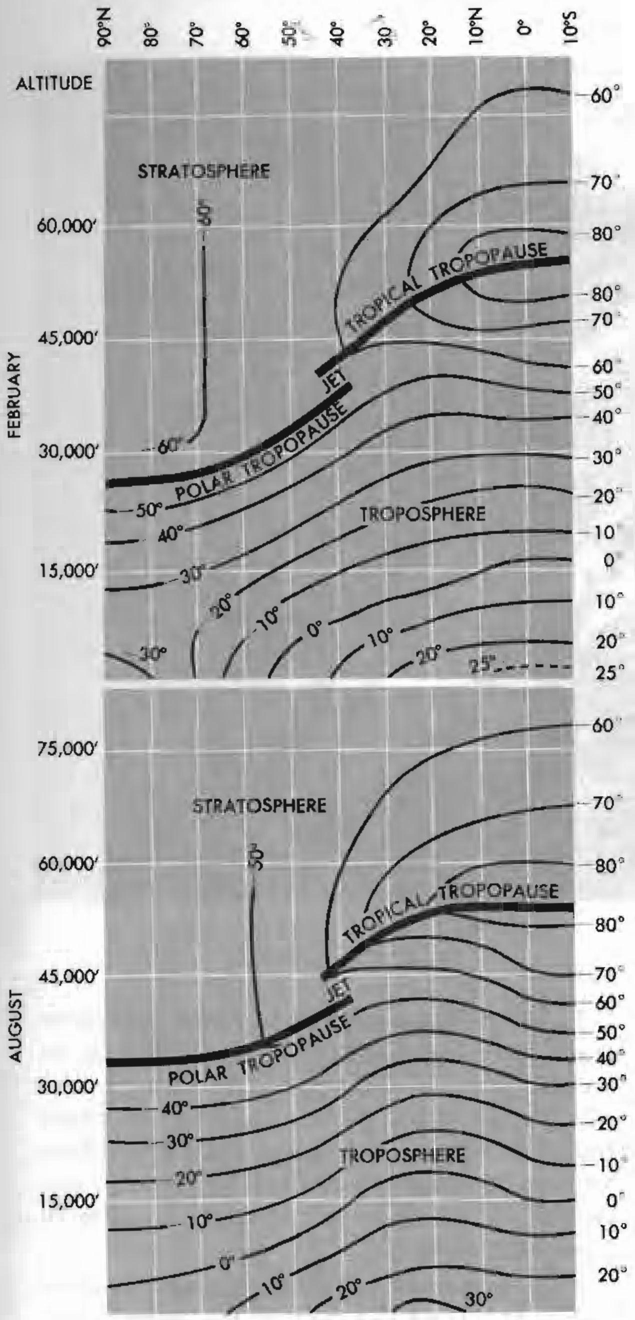
The average altitude at which the tropopause is found varies systematically with latitude, being higher at the equator and lower at the poles. The tropopause temperature at 45° latitude is an average −55° C; at the poles the tropopause temperature is warmer than at the equator (due primarily to the fact that the troposphere is so much more shallow in the arctic regions). The cross-sectional chart of the atmosphere indicating the average height of the tropopause during February and August, shows there is also a seasonal variation, especially in middle latitudes.



Remember, that the tropopause is just the dividing zone between the lower and upper atmosphere; its height will shift constantly with changes in the thickness of the troposphere.

The region of the atmosphere above the troposphere is commonly divided into layers or shells, according to several sets of criteria.

Temperature distribution is the most common criterion. The next layer above the troposphere, according to this criterion, is the stratosphere. The term *stratosphere* has been used to denote the shell or layer extending from the tropopause to the maximum temperature level at about 160,000 feet altitude. This layer sometimes includes an isothermal layer



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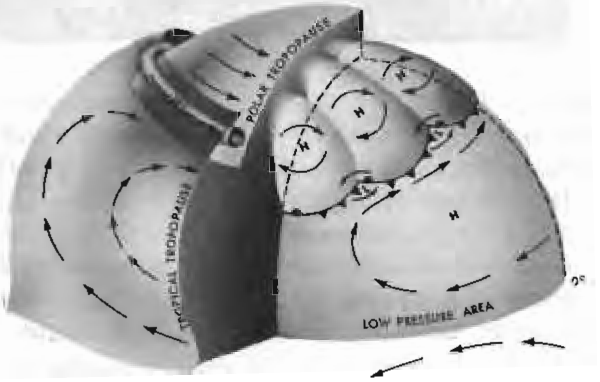

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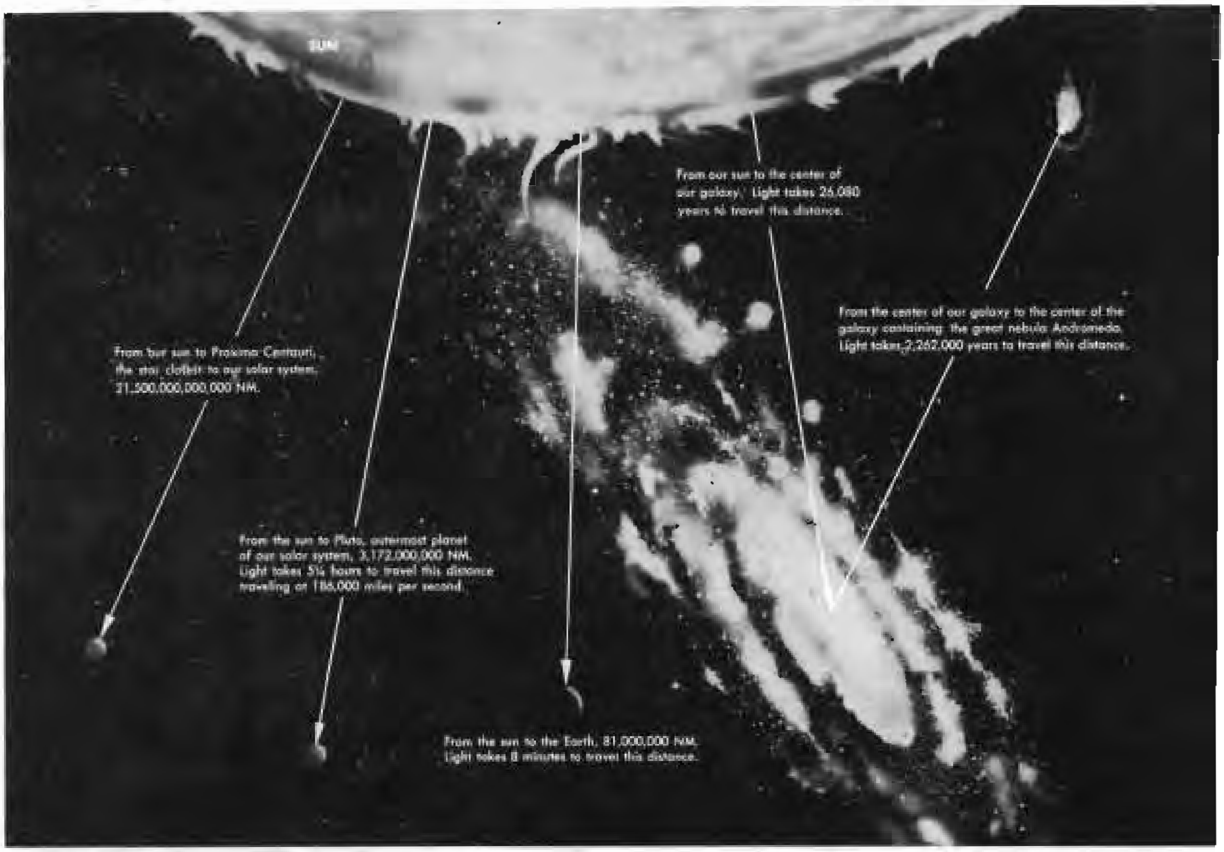


in the lower portion of the layer. The term *mesosphere* is now used to denote the shell which has a broad maximum temperature at ahout 160,000 feet altitude extending from the top of the stratosphere to about 270,000 feet. The term *thermosphere* is used to denote the shell above the mesosphere with a more or less steadily increasing temperature with height.

Another criterion is the distribution of various physico-chemical processes. The *ozonosphere* is the term used to denote the first layer according to this criterion, lying between approximately 32,000 feet and 165,000 feet, and is the general region of the upper atmosphere in which there is an appreciable concentration of ozone. The *ionosphere* is the term used to denote the next layer under the physico-chemical process concept which starts at an altitude of about 190,000 feet.

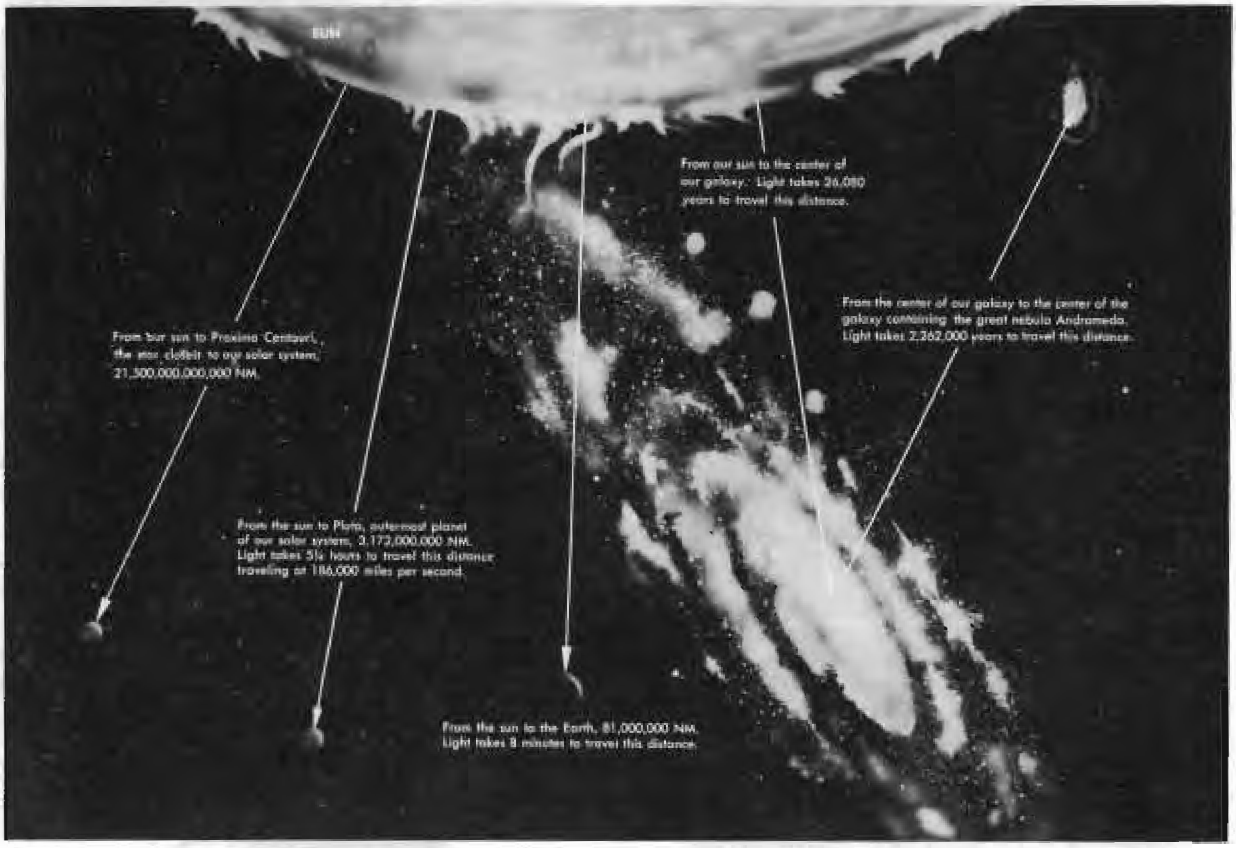
Several other terms are used to distinguish still higher layers, the definition of which is beyond the scope of this manual. Some of these are: (1) chemosphere, (2) neutrosphere, (3) exosphere, (4) homosphere, and (5) heterosphere.

SOLAR SYSTEM

In the future, we might be flying into outer space. The diagram of the *Solar System* is an indication of the vast areas to be explored. The relative size of the planets and their distances from the sun are shown on the chart. Miles are a cumbersome measure of distance in discussion of space, so better units of measure have been devised.

One such unit is called the *astronomical unit,* (AU), and is based on the average distance from the earth to the sun. Another unit of measurement is called the *parsec.* This is a contraction of *parallax second,* and indicates the distance at which the mean radius of the earth's orbit would subtend an angle of one second of arc. Each parsec is equal to 19,150,000,000,000 (or 19.15 trillion) miles.

The most familiar unit of space measurement is the *light year.* This is the distance light would travel in one year. Each light year contains 5,880,000,000,000 (or 5.88 trillion) miles. There are 3.26 light years in every parsec.



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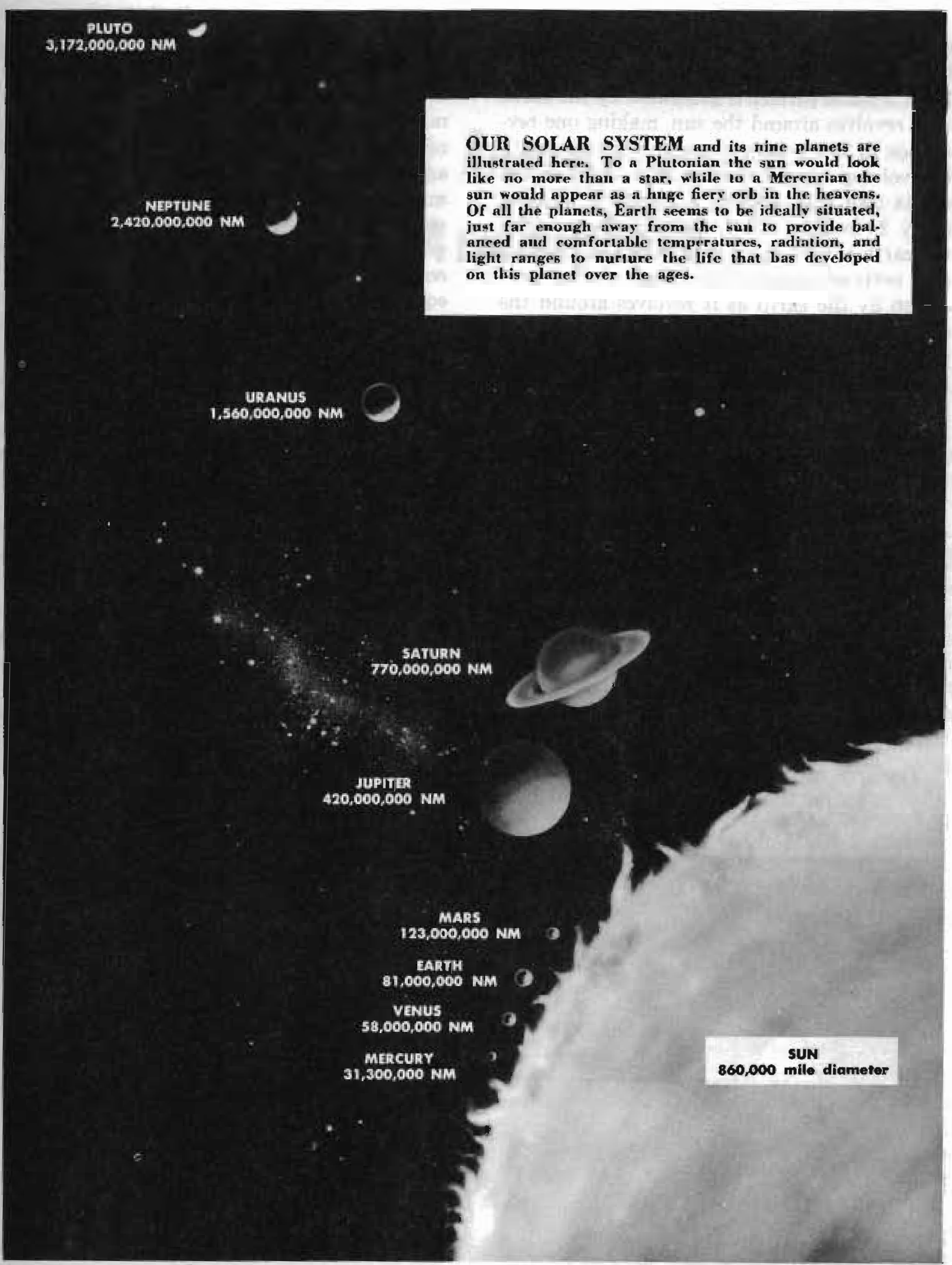

OUR SOLAR SYSTEM and its nine planets are illustrated here. To a Plutonian the sun would look like no more than a star, while to a Mercurian the sun would appear as a huge fiery orb in the heavens. Of all the planets, Earth seems to be ideally situated, just far enough away from the sun to provide balanced and comfortable temperatures, radiation, and light ranges to nurture the life that has developed on this planet over the ages.

Figure 1–6. The Solar System

Other features of the solar system are of major concern and importance especially to us here on earth (see also Radiation, Chapter 2). First, a plane surface is generated by the earth as it revolves around the sun, making one revolution in 365¼ days. Second, while the earth is revolving around the sun it is also rotating on its own axis, making a complete rotation every 24 hours. Third, the axis about which the earth is rotating is inclined 23½° from an axis perpendicular to the plane surface generated by the earth as it revolves around the sun. Any given position of the earth's axis is parallel to its axis in any other position. Therefore, the earth's axis remains essentially parallel to itself in consecutive positions. This allows us to have a *North Star* or a star lying along the extended axis of rotation of the earth.

The fact that the earth's axis of rotation is inclined 23½° to the line perpendicular to the plane of the earth's orbit is responsible for other important facts. Notice in the accompanying diagram of the 21 June and 21 December positions of the earth in its orbit, that the maximum sunlight (the point on the earth's surface lying in the plane of the earth's orbit) is not at the earth's equator, but rather is north of the equator in June, and south of the equator in December.

The area of the earth that at some time or another during the year lies in the orbital plane varies from 23½° north latitude to 23½° south latitude. This spreads the area of maximum incoming energy from the sun over a large area of the earth. This also means that the polar regions receive considerably less insolation (incoming energy from the sun) on a yearly average than the equatorial regions and the reader might be led to believe that the equatorial regions would continue to get warmer, the polar regions colder. The atmosphere and the oceans combine efforts to take heat from the warmer equatorial regions and carry it poleward. This moderates conditions in both equatorial and polar regions.

Notice also in the diagram that in the 21 June position there is an area at the South Pole that remains in the dark half of the earth throughout the period of rotation, and an area at the North Pole which remains in the sunlit half of the earth throughout the period of rotation (24 hours). The 21 December position reverses the 21 June situation. This shows also that while the Northern Hemisphere is having summer the Southern Hemisphere is having winter. Thus the 21st of December is the first day of summer in Buenos Aires, Argentina.

The darkness periods allow heat to escape to space from the polar atmosphere, which balances most of the heat gain from the overheating of the equatorial regions.

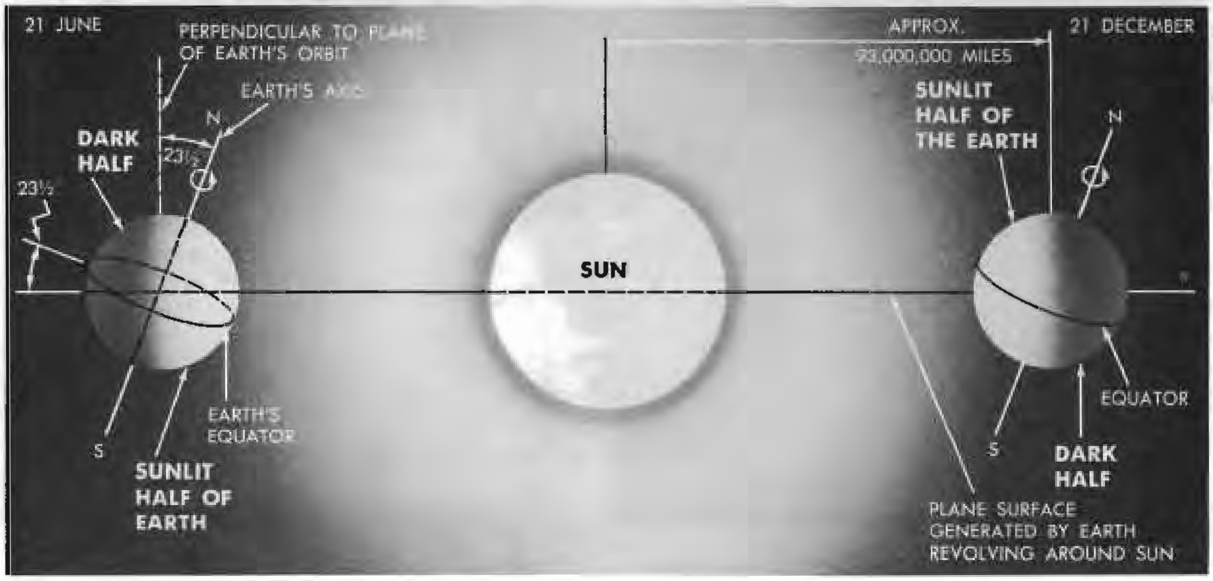

Figure 1–7. Diagram Showing Two Positions of Earth in Its Orbit. Note That the Axes are Parallel.

CHAPTER 2

Heat Energy in the Atmosphere

For millions of years the sun has been radiating its light and energy to the earth from what seems to be a never-ending supply. The sun plays a tremendous part in our everyday living. We take for granted the effect the sun has on our lives and environment. We accept the daybreak as the sun presents itself over the horizon from the east and slowly pushes the darkness toward the west. We accept the warm rays from the sun on cold wintry days and its life-sustaining energy.

CHARACTERISTICS OF THE SUN

The sun rotates about an axis which is inclined about 83° toward the orbit of the earth. It is not a solid, but a mass of gas, and does not spin at a uniform rate. The sun's equator makes a circuit, or rotation, in a period of time equal to about twenty-five and a half of our days; its polar regions take nine days longer to revolve. This enormous mass of matter, which we call the sun, measures more than 2,700,000 miles around its equator.

The gravitational attraction of the sun (whose volume is over a million times the volume of the earth) holds the earth in its orbit, 93 million miles away. As the earth spins around its tilted axis and makes one annual revolution around the sun in an elliptical orbit, we experience day and night and the four seasons of the year.

Visible light that is emitted from the sun travels at a speed of 186,000 miles per second. Heat waves (infrared) also travel with the speed of light, but are invisible to the human eye.

According to careful studies, the solar output that reaches the earth is equal of 1.94 gram-calories per square centimeter per minute. This is called the "solar constant" and is the average energy falling in one minute on one square centimeter of surface at the outer edge of the earth's atmosphere placed at right angles to the sun's rays. A calorie is the amount of heat necessary to raise the temperature of one gram of water one degree Celsius (centigrade) from 14.5°C to 15.5°C. An appreciation of these figures can be obtained by the following comparison: If all the energy radiated by the sun could be used to heat the oceans, the temperature of the oceans would rise from the freezing point to the boiling point in less than two seconds.

RADIATION

Radiation is the process by which energy is propagated through space by virtue of changes in the electric and magnetic fields in space. In many ways, however, radiant energy acts as if it were transmitted in the form of waves. The wave point of view is often satisfactory to explain problems in weather.

Radiation occurs over a considerable range of wave lengths, depending on the temperature of the radiating body. The light we see and the heat we feel from the sun's surface is emitted as short wave radiation. Cooler objects, such as the earth, emit energy as long wave radiation. Consequently, two different types of radiational transfer must be considered. Incoming solar radiation, or insolation, from the sun, and terrestrial radiation from the earth.

The energy radiated by the sun is the major impulse for weather phenomena on the earth. The sun might be said to inaugurate the circulation of the atmosphere which, in turn, causes changes in atmospheric pressure and thereby produces wind. It is important to know the effect of the sun's energy on our planet.

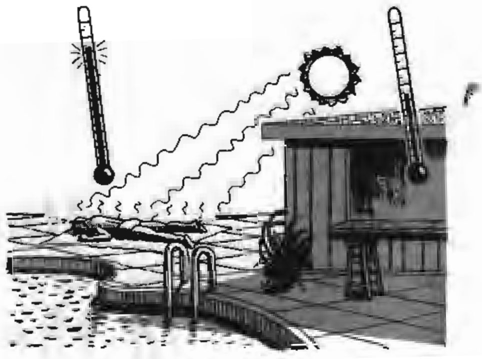

Figure 2–1. Radiational Heating From the Sun

First, this energy must pass through the atmosphere which surrounds the earth. Different substances will absorb or reflect energy in different ways and varying amounts. Of the total of short wave radiation emitted from the sun that reaches the earth, the earth absorbs only about 47%. The accompanying diagram (Figure 2–2), shows that the remaining 53% is either reflected to outer space or is absorbed by the atmosphere (34% reflected to outer space plus 19% absorbed by the atmosphere). The clear air within the troposphere is nearly transparent to short wave radiation. In general, the short wave radiation from the sun passes on through the atmosphere and does not affect the temperature of the air to any great extent. In the early part

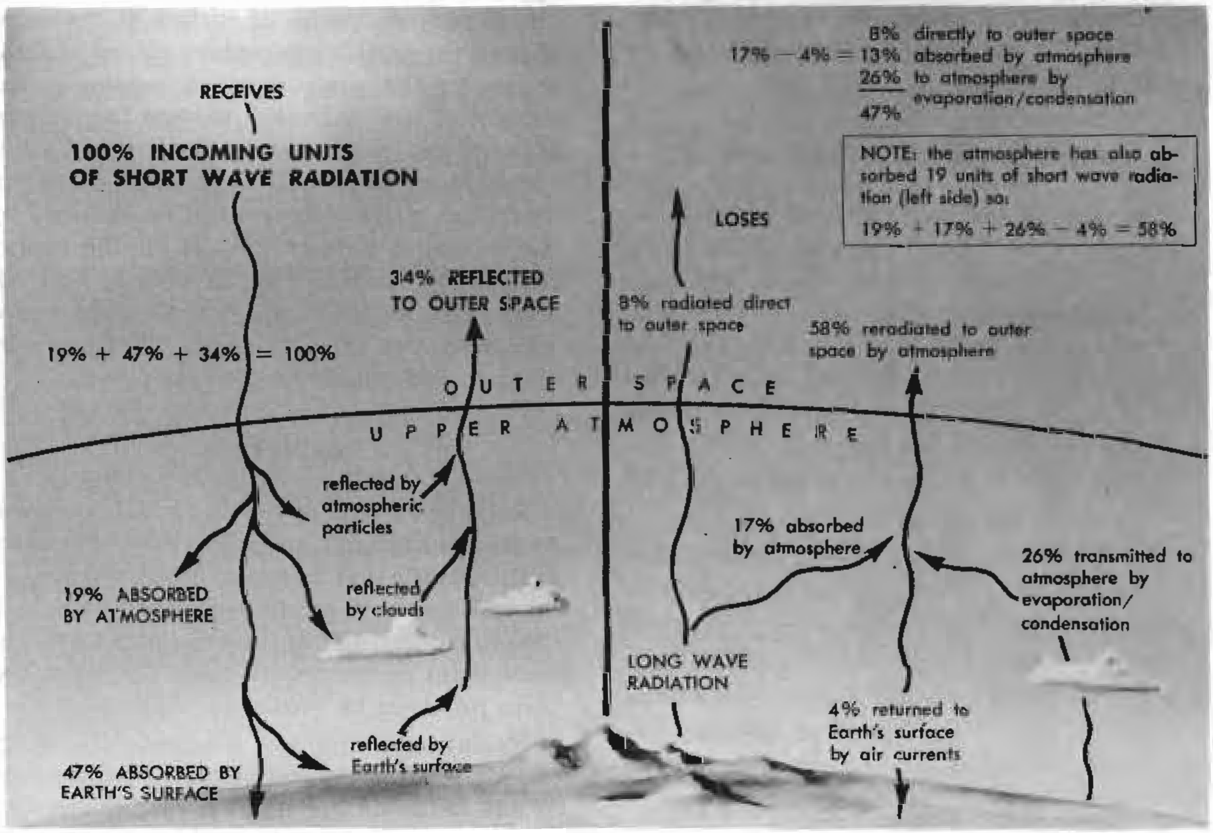

Figure 2–2. Annual Budget of Heat Loss and Gain by Radiation for the Earth and Atmosphere

of the morning when the earth starts to receive radiation from the sun, the temperature of the earth increases before there is an appreciable increase in the temperature of the air.

Four factors responsible for seasonal and geographical variations in general weather conditions on the earth are:

1. The earth's daily rotation about its axis.
2. Its yearly motion about the sun (revolution).
3. Nonuniform heating of the earth's surface.
4. Spheroidal shape of earth.

The heating of the earth during the day and cooling at night is primarily a result of the earth's rotation about its axis. As the earth turns from west to east, the side facing the sun is heated; when night comes, the same side is opposite the sun and will begin to cool. The ground and air in immediate contact with it will generally reach their lowest temperature shortly before sunrise.

The effects due to the yearly revolution around the sun are modified by the tilt of the axis of the earth. In Figure 2–3, *Variations in Solar Energy Received by the Earth,* notice that the areas under the direct or perpendicular rays of the sun receive more heat than those under the slanting rays (comparing equal areas). The slanting rays also pass through more of the atmosphere which absorbs, reflects, and scatters the sun's energy. This accounts for the difference in the warmth of sunlight at 0800 local time when the rays are slanting, and at midday when they are more overhead. Also, there is less radiation per unit time received on a given area near the poles than near the equator because the earth is a spheroid.

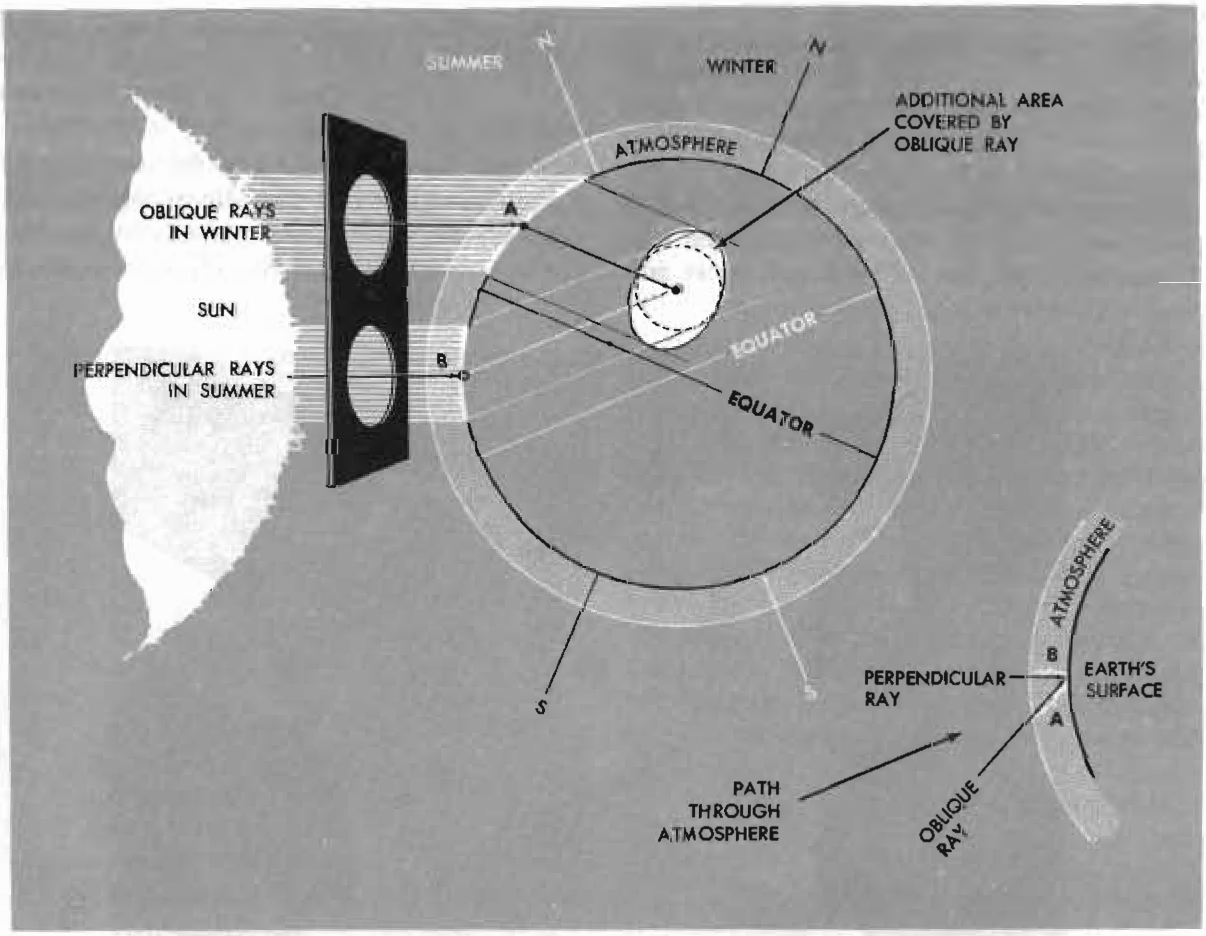

Figure 2–3. Seasonal Variations in Solar Energy Received at the Surface of the Earth Due to Angle of the Sun's Rays

Each year the perpendicular rays of the sun migrate from 23½° North Latitude (21 June) to 23½° South Latitude (22 December), causing the seasons of the Northern and Southern Hemisphere. The diagram, *Effect of Inclination of the Earth on Seasons*, Figure 2–4, indicates why the rays are perpendicular at 23½° North Latitude on June 21, at the Equator on September 22, at 23½° South Latitude on December 22, and at the Equator again on March 21.

Unequal duration of daylight contributes to the uneven distribution of heat. The diagram also shows that each pole has 6 months of daylight and 6 months of darkness. On June 21, all territory within the Arctic Circle has 24 hours of daylight; on December 22, all territory within the Arctic Circle has darkness or twilight.

The nonuniform heating of the earth's surface is another factor that produces weather within the troposphere. This is caused by the different reactions to heat by the land masses and water masses. Different types of land surfaces and water surfaces absorb heat energy at different rates.

Absorption of heat energy from the sun is confined to a shallow layer of the land surface. As a result, the land will heat faster during the day and cool faster during the night than will the water surface. Water surfaces heat more slowly than land surfaces because:

- The sun's rays can penetrate water better.
- The movement of water distributes the heat over larger areas.
- The specific heat of water is about three times that of land; that is, about three times as much heat is required to raise the temperature of a given mass of water as is required to effect the same rise in temperature of an equal mass of land.
- Evaporation, which is a cooling process, occurs over water.
- Vertical mixing within the water.

Color, texture, and vegetation influence the rate of heating and cooling of the ground. Generally, dry surfaces heat and cool faster than moist surfaces. Plowed fields, sandy beaches, paved roads, and runways become hotter than surrounding meadows and wooded areas. During the day the air over a plowed field is warmer than over a forest or swamp; during the night, the situation is reversed.

Heat energy absorbed by the earth must be reradiated out into the atmosphere so that a heat balance will be maintained over the years. This is accomplished by terrestrial radiation.

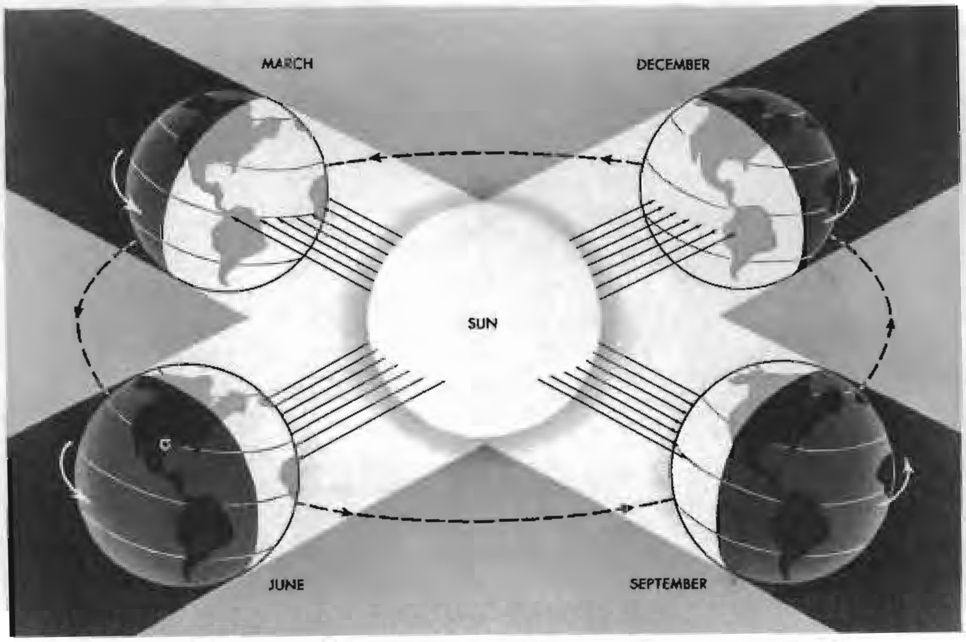

Figure 2–4. The Earth's Seosons are Caused by the Inclination of its Axes

The earth, being a relatively cool object, radiates its energy in the form of long waves which are invisible to the human eye. This goes on night and day, but the earth can transmit energy at only a fraction of the rate that it is received from the sun during the day, so it is only at night that the effect of the terrestrial radiation shows up as a net cooling of the ground.

The atmosphere acts as a shield over the earth by transmitting most of the solar radiation and absorbing or re-emitting the long-wave terrestrial radiation. This restriction of cooling is called the greenhouse effect, and results in a heating effect on the atmosphere. As we have already seen, the atmosphere is nearly transparent to the incoming solar radiation, but in general the moisture in the air is capable of absorbing long wave or terrestrial radiation. The ability of the atmosphere to absorb terrestrial radiation is dependent upon the moisture content. This accounts for the large day to night temperature range over desert areas, and the small range over humid areas.

This absorption of terrestrial radiation by the atmosphere traps, for a time, some of the energy which would otherwise be more quickly lost to space, thus preventing the atmosphere from cooling as rapidly as it would if it were drier. The water in the atmosphere has the same effect upon maintaining a warmer atmosphere as the glass in a greenhouse. If the atmosphere were as transparent to terrestrial radiation as it is to insolation, the average temperature of the earth would be much colder than it is. Figure 2–2 shows how the earth and its atmosphere is able to maintain a heat balance because of the earth's ability to reradiate the energy it receives from the sun.

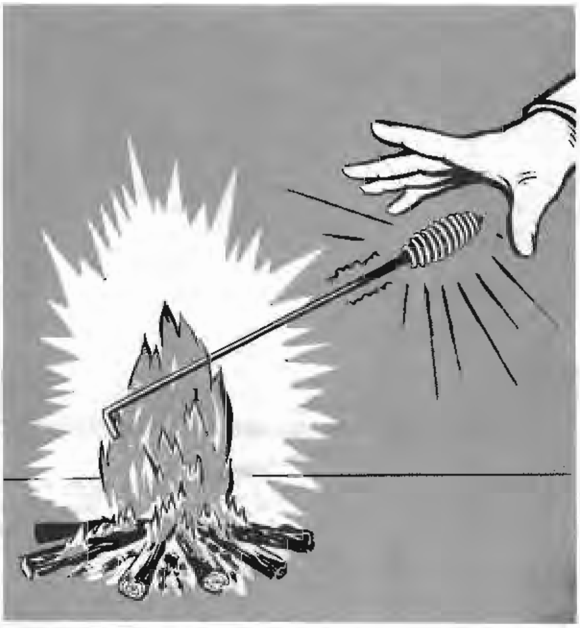

Figure 2–5. Transfer of Heat by Conduction

To summarize then, the earth is heated during the day by solar radiation or insolation, and is cooled by terrestrial radiation (day and night). How does this affect the temperature of the atmosphere near the surface of the earth?

CONDUCTION

Conduction is the process by which heat is transferred through matter, without the transfer of matter itself. Some solid substances are good conductors of heat while others are not. When a silver spoon is heated at one end, the other end soon becomes hot by conduction. When one end of a piece of wood is heated, the other end remains cool. Silver is a good conductor, wood a poor one. Like the piece of wood, still air is a very poor conductor of heat.

Heat transfer by conduction is defined as going from the warmer to the colder object. On a sunny day the earth's surface is heated by absorbing insolation. After the earth's temperature becomes higher than that of the surface air, the air in contact with the earth is warmed by conduction. At night, the process is reversed. The earth is cooled rapidly by terrestrial radiation and then the air in immediate contact with the ground is cooled as it gives some of its heat by conduction to the cooler earth. This process continues throughout the night so that the ground surface and air are cooled and both remain about the same temperature. Remember that air is a poor conductor of heat, and this change in the temperature of the air would be effective only for a few inches above the surface of the earth, were it not for wind and turbulence, which distribute the cooling to greater heights (a few feet or a few thousand feet, depending on the wind strength).

For this reason the temperature of the air lags behind that of the earth and changes less. The air is not as warm as the land in the sunshine, nor as cool at night. The poor conductivity of the air and its slow loss of heat explains why ground frost can occur when the ambient air temperature at standard 3 feet observation height is considerably above freezing. At night the grass, automobiles, aircraft, and other surfaces where frost forms, are often colder than the air a few feet above.

CONVECTION

As previously pointed out, various types of surfaces will absorb heat energy at different rates. For instance, air lying over a land surface will warm up (or cool off) faster than air lying over a water surface; air lying over a paved runway will heat faster than the air over the surrounding grassy areas. This unequal local distribution of heat will bring about another method of heat transfer, *convection.* In meteorology the term "convection" is used to indicate the transfer of atmospheric properties primarily by vertical motion. As the air is heated near the earth's surface, it becomes lighter or less dense than the surrounding air. The lighter air will rise, thus producing convection which is usually accompanied by turbulence. As a parcel of air rises the atmospheric pressure on the parcel will decrease, producing expansion and cooling. Convection is often very noticeable along a coastline, especially during the summer, where the rising moist air will produce a line of cumulus clouds. The accompanying illustration, Figure 2–6, *Vertical Currents (Convection) Produced by Unequal Surface Heating,* shows how this process takes place.

ADVECTION

When air rises in convection currents, another method of transfer of an atmospheric property takes place, namely, *advection.* Advection is the transfer of some atmospheric property by horizontal motion of air (wind). When warm air rises in a vertical motion, the cooler surrounding air will move in and replace the air that has been lifted.

WORLD SURFACE TEMPERATURES

The average world surface temperatures are represented on the two world charts for July and January shown in Figure 2–7. The large temperature difference between the land and water surface which reverses between the two

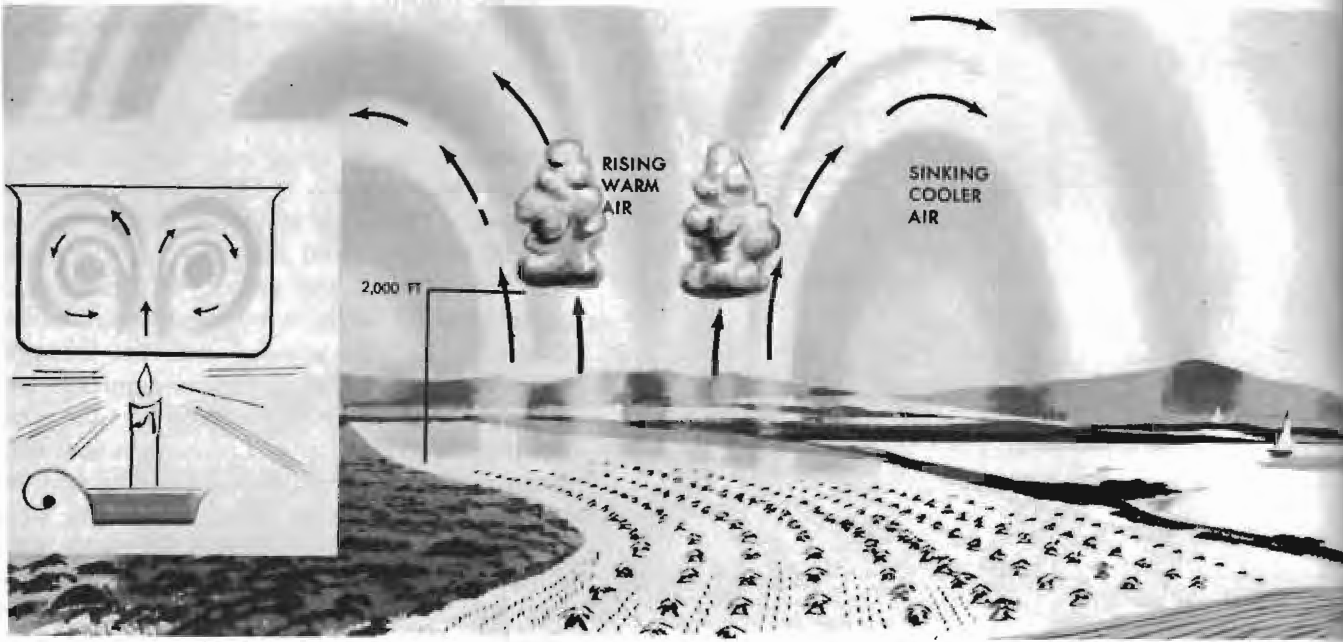

Figure 2–6. Vertical Currents (Convection) Produced by Unequal Surface Heating

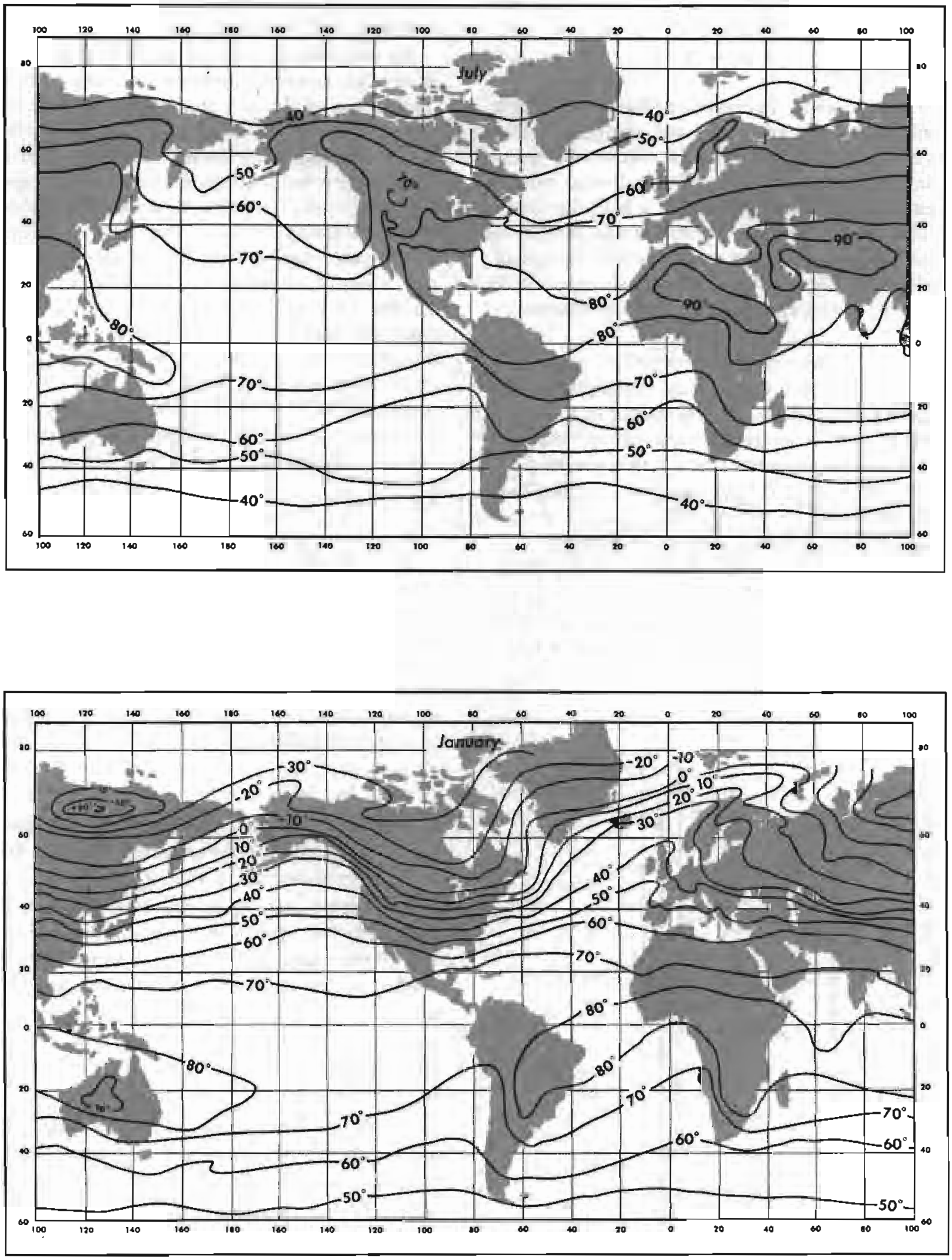

Figure 2–7. Distribution of Mean Temperatures (Degrees Fahrenheit)

seasons determines, to a great extent, the seasonal weather patterns.

Temperature

According to the molecular theory of matter, all substances are composed of minute molecules which are in rapid motion among themselves. As the velocity of its molecular motion increases, the temperature of a body increases. The energy due to its molecular motion is called heat. Heat is a measureable quantity, although not a substance. Air temperature is usually measured with a mercury thermometer.

Two scales commonly used for measuring temperature are the Celsius (Centigrade) and Fahrenheit scales. Pilots sometimes find it necessary to convert temperature readings from one scale to another for two reasons:

1. Surface temperatures are given in the Fahrenheit scale while upper air temperatures are given in the Celsius (Centigrade) scale.
2. Aircraft are equipped with Celsius (Centigrade) thermometers.

The accompanying diagram (Figure 2–8) includes the conversion formulas and a quick conversion scale. From the scale you will notice that 59°F is equal to 15°C.

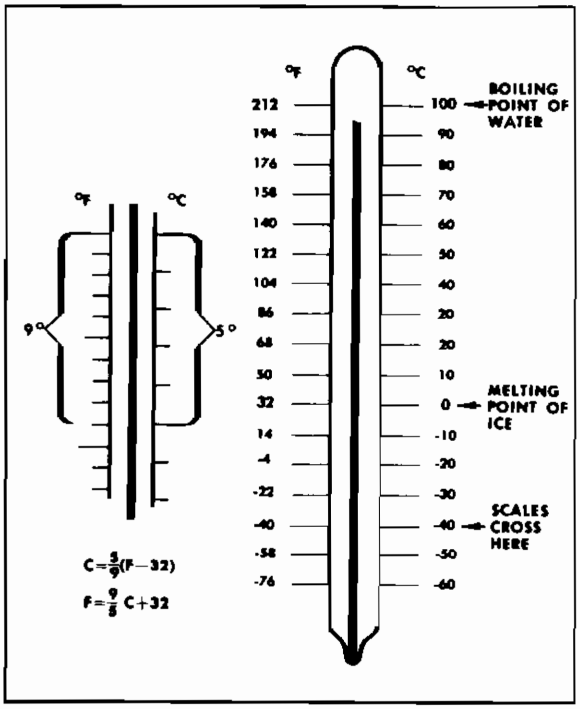

Figure 2–8. Temperature Conversion Diagram

As you gain altitude in an aircraft you will notice an over-all decrease in temperature. This is due to the fact that the air nearest the earth is heated the most — it is closer to the insolation absorbing earth. The variation in temperature with altitude is called the lapse rate, and is expressed by meteorologists in degrees per thousand feet. This rate of cooling (lapse rate) varies from day to day and from one area to another. It depends upon the amount of heat energy reaching and escaping the earth, and upon vertical and horizontal atmospheric motions aloft. In the troposphere the average temperature decrease with altitude is about 2°C/1000 feet. Remember, this is an average and can vary greatly from one day to the next, as well as with place and height.

Inversions

Almost every day a layer of the atmosphere will be found over a place that shows an increase of temperature with altitude, rather than a decrease. This situation occurs frequently, but is generally confined to a relatively shallow layer. This is called an inversion. Inversions are formed as follows:

- Advection of warm air (a warm wind) brings in air aloft warmer than the air near the surface, and the associated inversion is often called a frontal inversion.
- The most frequent type of inversion over land is that produced immediately above the surface by nocturnal cooling of the earth's surface. The air near the ground is cooled by contact with the ground and is accompanied by low winds and little vertical mixing, so the cooling does not extend very high, while at an altitude of a few hundred feet, the air temperature may often remain constant from 1800L the previous evening to 0600L the next morning. Refer to Figure 2–9.
- Inversions are also caused by descending air aloft (which compresses and is heated) while the air below does not descend nor warm.
- Inversions are also formed by cold air moving under warmer air (a cold front), and the associated inversion is often called a frontal inversion.

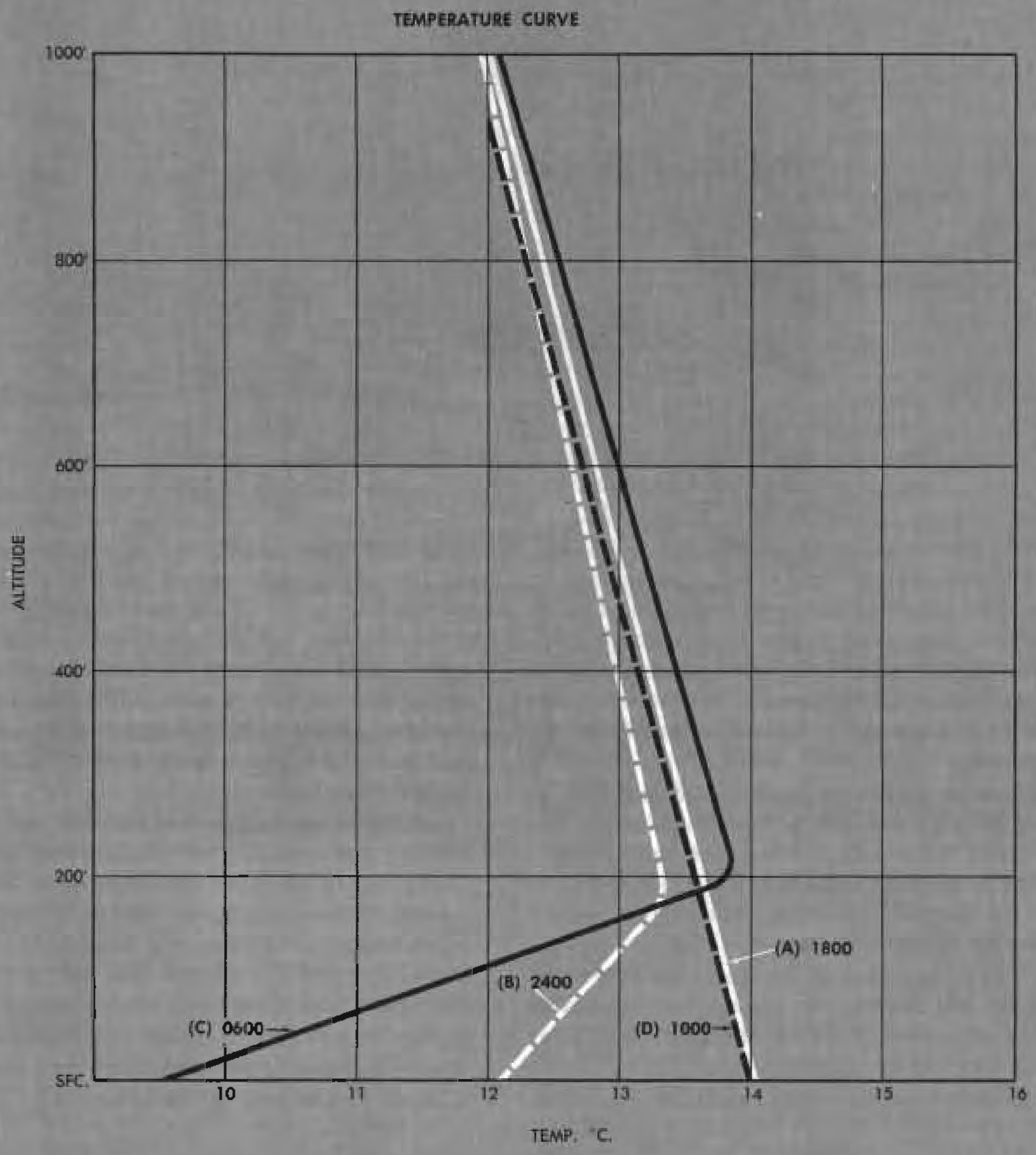

Figure 2–9. A Surface Inversion Due to Nocturnal Radiation Cooling

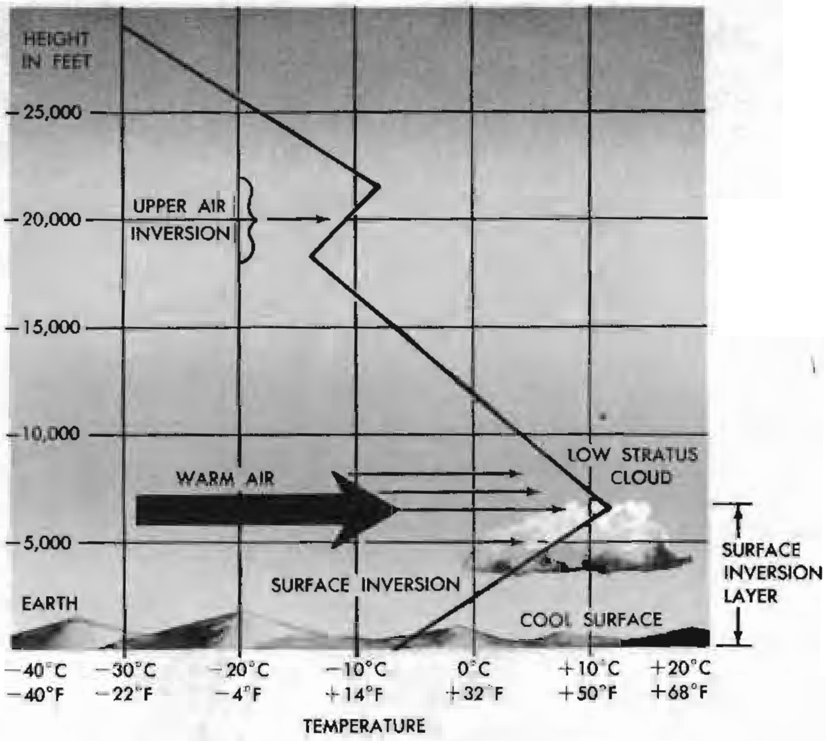

Figure 2–10. Surface and Upper Air Inversions

- A warm wind blowing over colder ground or water forms an inversion a few hundred feet above the ground — called a turbulence inversion.

Another variation from the general rule of temperature decrease with altitude is the isothermal lapse rate. If the temperature does not change with a change in altitude, we have an isothermal (constant temperature) lapse rate (0°C/1,000 feet).

The accompanying illustration, *Surface and Upper Air Inversions*, Figure 2–10, indicates how advection of air in one particular layer may develop an inversion.

Restrictions to vision, such as fog, haze, smoke, and low clouds are often found in or below low inversions and isothermal layers. Another characteristic feature of inversions and isothermal layers is the absence of turbulence within them.

Inversions at higher levels within the troposphere are normally produced by the advection of warm air over cold air or of colder air under warm air, or by air that is warmed by subsidence. Inversions are important to a pilot since many land and sea fogs occur in their presence. Even without a thermometer, a pilot may easily determine the height of an inversion since rising smoke and dust will be stopped by the base of the inversion.