# CHAPTER 6

# CLIMATOLOGY AND WORLD WEATHER

One of the major tasks of the Aerographer's Mate and the Naval Meteorology and Oceanography Command is providing long-range weather information and predictions based on recognized meteorological occurrences in a particular area or region of the world. Naval exercises both at sea and ashore is planned months and sometimes years in advance. To carry out these exercises successfully, we must have an idea of the normal weather conditions for the operational area (OPAREA) at that time of year. It is both dangerous and unwise to conduct costly training exercises if the weather conditions for the OPAREA are known to be adverse at that time of year.

During wartime, an extensive knowledge of weather conditions can be a decisive advantage. Naval and land forces can use their knowledge of weather to surprise the enemy and predict when the enemy will strike. Historically, man wages war when the weather permits. When Napoleon invaded Russia, his defeat was not due to the wisdom of his opponents, but rather to his lack of knowledge of the severe Russian winters. He was beaten by the weather.

As you gain more experience, your job will include the preparation of long-range weather forecasts based on climatological studies. You must prepare charts, tables and/or graphs that include sky cover, temperatures, winds, sea conditions, etc. This climatological information is needed for long-range naval exercises, ship deployments overseas, and actual combat operations.

## CLIMATE AND CLIMATOLOGY

**LEARNING OBJECTIVE**: Define climate, climatology, and related terminology.

Before starting any discussion about climate and climatology, we must become familiar with these and other related terms. In this lesson, we define climate, various types of climatology, and climatology as it relates to other sciences such as ecology.

## CLIMATE

Climate is the average or collective state of Earth's atmosphere at any given location or area over a long period of time. While weather is the sum total of the atmosphere's variables for a relatively short period of time, the climate of an area is determined over periods of many years and represents the general weather characteristics of an area or locality. The term *climate* applies to specific regions and is therefore highly geographical.

## CLIMATOLOGY

Climatology is the scientific study of climate and is a major branch of meteorology. Climatology is the tool that is used to develop long-range forecasts. There are three principal approaches to the study of climatology: physical, descriptive, and dynamic.

### Physical Climatology

The physical climatology approach seeks to explain the differences in climate in light of the physical processes influencing climate and the processes producing the various kinds of physical climates, such as marine, desert, and mountain. Physical climatology deals with explanations of climate rather than with presentations.

### Descriptive Climatology

Descriptive climatology typically orients itself in terms of geographic regions; it is often referred to as regional climatology. A description of the various types of climates is made on the basis of analyzed statistics from a particular area. A further attempt is made to describe the interaction of weather and climatic elements upon the people and the areas under consideration. Descriptive climatology is presented by verbal and graphic description without going into causes and theory.

### Dynamic Climatology

Dynamic climatology attempts to relate characteristics of the general circulation of the entire atmosphere to the climate. Dynamic climatology is used by the theoretical meteorologist and addresses dynamic and thermodynamic effects.

## Climatology as Related to Other Sciences

Three prefixes can be added to the word *climatology* to denote scale or magnitude. They are micro, meso, and macro and indicate small, medium, and large scales, respectively. These terms (micro, meso, and macro) are also applied to meteorology.

**MICROCLIMATOLOGY**.—Microclimatological studies often measure small-scale contrasts, such as between hilltop and valley or between city and surrounding country. They may be of an extremely small scale, such as one side of a hedge contrasted with the other, a plowed furrow versus level soil, or opposite leaf surfaces. Climate in the microscale may be effectively modified by relatively simple human efforts.

**MESOCLIMATOLOGY**.—Mesoclimatology embraces a rather indistinct middle ground between macroclimatology and microclimatology. The areas are smaller than those of macroclimatology are and larger than those of microclimatology, and they may or may not be climatically representative of a general region.

**MACROCLIMATOLOGY**.—Macroclimatology is the study of the large-scale climate of a large area or country. Climate of this type is not easily modified by human efforts. However, continued pollution of the Earth, its streams, rivers, and atmosphere, can eventually make these modifications.

Climate has become increasingly important in other scientific fields. Geographers, hydrologists, and oceanographers use quantitative measures of climate to describe or analyze the influence of our atmospheric environment. Climate classification has developed primarily in the field of geography. The basic role of the atmosphere in the *hydrologic cycle* is an essential part of the study of hydrology. Both air and water measurements are required to understand the energy exchange between air and ocean (heat budget) as examined in the study of oceanography.

## ECOLOGY

Ecology is the study of the mutual relationship between organisms and their environment. Ecology is briefly mentioned here because the environment of living organisms is directly affected by weather and climate, including those changes in climate that are gradually being made by man.

During our growing years as a nation, our interference with nature by diverting and damming rivers, clearing its lands, stripping its soils, and scarring its landscape has produced changes in climate. These changes have been on the micro and meso scale and possibly even on the macro scale.

## REVIEW QUESTIONS

*Q6-1. What is the definition of climate?*

*Q6-2. What type of climatology is typically oriented to a geographic region?*

*Q6-3. What type of climatology applies to a small area such as a golf course or a plowed field?*

## CLIMATIC ELEMENTS

**LEARNING OBJECTIVE**: Describe the climatic elements of temperature, precipitation, and wind.

The weather elements that are used to describe climate are also the elements that determine the type of climate for a region. This lesson presents a brief explanation of the importance of these elements. The climatic elements of temperature, precipitation, and wind are not the only parameters included in a climatology package; however, they are the most significant elements used to express the climate of a region.

## TEMPERATURE

Temperature is undoubtedly the most important climatic element. The temperature of an area is dependent upon latitude or the distribution of incoming and outgoing radiation; the nature of the surface (land or water); the altitude; and the prevailing winds. The air temperature normally used in climatology is that recorded at the surface.

Moisture, or the lack of moisture, modifies temperature. The more moisture in a region, the smaller the temperature range, and the drier the region, the greater the temperature range. Moisture is also influenced by temperature. Warmer air can hold more moisture than can cooler air, resulting in increased evaporation and a higher probability of clouds and precipitation.

Moisture, when coupled with condensation and evaporation, is an extremely important climatic element. It ultimately determines the type of climate for a specific region.

## PRECIPITATION

Precipitation is the second most important climatic element. In most studies, precipitation is defined as water reaching Earth's surface by falling either in a liquid or a solid state. The most significant forms are rain and snow. Precipitation has a wide range of variability over the Earth's surface. Because of this variability, a longer series of observations is generally required to establish a mean or an average. Two stations may have the same amount of annual precipitation, but it could occur in different months or on different days during these months, or the intensity could vary. Therefore, it often becomes necessary to include such factors as average number of days with precipitation and average amount per day. Precipitation is expressed in most studies in the United States in inches, but throughout the rest of the world, millimeters are normally used.

Since precipitation amounts are directly associated with amount and type of clouds, cloud cover must also be considered with precipitation. Cloud climatology also includes such phenomena as fog and thunderstorms.

## WIND

Wind is the climatic element that transports heat and moisture into a region. The climate of an area is often determined by the properties of temperature and moisture that are found upstream of that region.

Climatologists are mostly interested in wind with regard to its direction, speed, and gustiness. Wind is therefore usually discussed in terms of *prevailing* direction, average speeds, and maximum gusts. Some climatological studies use *resultant* wind, which is the vectorial average of all wind directions and speeds for a given level, at a specific place, and for a given period.

### REVIEW QUESTIONS

*Q6-4. What is the most important climatic element?*

*Q6-5. Which climatic element transports heat and moisture into a region?*

# EXPRESSION OF CLIMATIC ELEMENTS

**LEARNING OBJECTIVE**: Define the terms used to express climatic elements and the methods used to derive these terms.

Climatic elements are observed over long periods of time; therefore, specific terms must be used to express these elements so they have definite meaning. This lesson defines the most commonly used terms and discusses how they are used to express climatic elements.

## MEAN (AVERAGE)

The mean is the most commonly used climatological parameter. The term *mean* normally refers to a mathematical averaging obtained by adding the values of all factors or cases and then dividing by the number of items. For example, the average daily temperature would be the sum of the hourly temperatures divided by 24.

Other methods are used for computing various meteorological elements. For example, the mean temperature for 1 day has been devised by simply adding the maximum and minimum values for that day and dividing by 2. Assume the maximum temperature for a certain day is 75°F and the minimum temperature is 57°F. The mean temperature for the day is 66°F.

Unfortunately, the term *mean* has been used in many climatological records without clarification as to how it was computed. In most cases, the difference in results obtained is slight. In analyzing weather data, the terms *average* and *mean* are often used interchangeably.

## NORMAL

In climatology, the term *normal* is applied to the average value over a period of time, which serves as a standard with which values (occurring on a date or during a specified time) may be compared. These periods of time may be a particular month or other portion of the year. They may refer to a season or to a year as a whole. The normal is usually determined over a 20- or 30-year period.

For example, if the average temperature for your station on 10 June has been 80°F over a specified period of time, the *normal* temperature for your station on 10 June is 80°F. If the temperature on 10 June this year was only 76°F, then the temperature for that day is 4°F below normal.

## ABSOLUTE

In climatology, the term *absolute* is usually applied to the *extreme* highest and lowest values for any given meteorological element recorded at the place of observation and are most frequently applied to temperature. Assume, for example, that the extreme highest temperature ever recorded at a particular station was 106°F and the lowest recorded was -15°F. These values are called the absolute maximum and absolute minimum, respectively.

## EXTREME

The term *extreme* is applied to the highest and lowest values for a particular meteorological element occurring over a period of time. This period of time is usually a matter of months, seasons, or years. The term may be used for a calendar day only, for which it is particularly applicable to temperature. For example, the highest and lowest temperature readings for a particular day are considered the temperature extremes for that day. At times the term is applied to the average of the highest and lowest temperatures as mean monthly or mean annual extremes.

## RANGE

Range is the *difference* between the highest and lowest values and reflects the extreme variations of these values. This statistic is not recommended for precise work, since it has a high variability. Range is related to the extreme values of record and can be useful in determining the extreme range for the records available. For example, if the highest temperature recorded yesterday was 76°F and the lowest was 41°F, then the range for the day was 35°F.

## FREQUENCY

Frequency is defined as the number of times a certain value occurs within a specified period of time. When a large number of various values need to be presented, a condensed presentation of data may be obtained by means of a frequency distribution.

## MODE

Mode is defined as the value occurring with the greatest frequency or the value about which the most cases occur.

## MEDIAN

The median is the value at the midpoint in an array. In determining the median, all values are arranged in order of size. Rough estimates of the median may be obtained by taking the middle value of an ordered series; or, if there are two middle values, they may be averaged to obtain the median. The position of the median may be found by the following formula:

$$\text{Median} = \frac{n+1}{2}$$

where n is the number of items.

The median is not widely used in climatological computations. However, some sources recommend the use of the median instead of the mean or average for some climatic elements to present more representative pictures of distribution and probability. A longer period of record might be required to formulate an accurate median.

## DEGREE-DAY

A degree-day is the number of degrees the mean daily temperature is above or below a standard temperature base. The base temperature is usually 65°F; however, any temperature, Celsius or Fahrenheit, can be used as a base. There is one degree-day for each degree (°C or °F) of departure above or below the standard.

Degree-days are accumulated over a *season.* At any point in the season, the total can be used as an index of past temperature effect upon some quantity, such as plant growth, fuel consumption, power output, etc. This concept was first used in connection with plant growth, which showed a relationship to cumulative temperature above a standard of 41°F. Degree-days are frequently applied to fuel and power consumption in the form of heating degree-days and cooling degree-days.

## AVERAGE AND STANDARD DEVIATIONS

In the analysis of climatological data, it may be desirable to compute the deviation of all items from a central point. This can be obtained from a computation of either the mean (or average) deviation or the standard deviation. These are termed measures of dispersion and are used to determine whether the average is truly representative or to determine the extent to which data vary from the average.

### Average Deviation

Average deviation is obtained by computing the arithmetic average of the deviations from an average of the data. First we obtain an average of the data, then the deviations of the individual items from this average are determined, and finally the arithmetic average of these deviations is computed. The plus and minus signs are disregarded. The formula for computation of the average deviation is as follows:

$$\text{Average deviation} = \frac{\Sigma d}{n}$$

where the Greek letter Σ (sigma) means the sum of d (the deviations) and n is the number of items.

## Standard Deviation

The standard deviation, like the average deviation, is the measure of the scatter or spread of all values in a series of observations. To obtain the standard deviation, square each deviation from the arithmetic average of the data. Then, determine the arithmetic average of the squared deviations. Finally, derive the square root of this average. This is also called the root-mean-square deviation, since it is the square root of the mean of the deviations squared.

The formula for computing standard deviation is given as follows:

$$\text{Standard deviation} = \sqrt{\frac{\Sigma d^2}{n}}$$

where $d^2$ is the sum of the squared deviations from the arithmetic average, and n is the number of items in the group of data.

An example of the computations of average deviation and standard deviation is given in table 6-1 and in the following paragraphs.

**Table 6-1.—Computation of Average and Standard Deviation**

| January year | Mean temperature | Deviations from mean | Deviations squared |
|---|---|---|---|
| 1978 | 47 | – 4 | 16 |
| 1979 | 51 | + 0 | 0 |
| 1980 | 53 | + 2 | 4 |
| 1981 | 50 | – 1 | 1 |
| 1982 | 49 | – 2 | 4 |
| 1983 | 55 | + 4 | 16 |
| 1984 | 46 | – 5 | 25 |
| 1985 | 52 | + 1 | 1 |
| 1986 | 57 | + 6 | 36 |
| 1987 | 50 | – 1 | 1 |
| **Totals** | 510 | 26 | 104 |
| **Mean** | 51 | 2.6 | 3.2 |

Suppose, on the basis of 10 years of data (1978-1987), you want to compute the average deviation of mean temperature and the standard deviation for the month of January. First, arrange the data in tabular form (as in table 6-1). Given the year in the first column, the mean monthly temperature in the second column, the deviations from an arithmetic average of the mean temperature in the third column, and the deviations from the mean squared in the fourth column.

To compute the average deviation:

1. Add all the temperatures in column 2 and divide by the number of years (10 in this case) to get the arithmetic average of temperature.

2. In column 3, compute the deviation from the mean or average determined in step 1. (The mean temperature for the 10-year period was 51°F.)

3. Total column 3, disregarding the negative and positive signs. (Total is 26.)

4. Apply the formula for average deviation:

$$\frac{\Sigma d}{n} = \frac{26}{10} = 2.6°F$$

The average deviation of temperature during the month of January for the period of record, 10 years, is 2.6°F.

To compute the standard deviation:

1. Square the deviations from the mean (column 3).

2. Total these squared deviations. In this case, the total is 104.

3. Apply the formula for standard deviation:

$$\text{Standard deviation} = \sqrt{\frac{\Sigma d^2}{n}} = \sqrt{\frac{104}{10}}$$

$$\sqrt{10.4} = 3.225 \text{ or } 3.2°F$$

The standard deviation of temperature for the month and period in question is 3.2°F (rounded off to the nearest one-tenth of a degree).

From the standard deviation just determined, it is apparent that there is a small range of mean temperature during January. If we had a frequency distribution of temperature available for this station for each day of the month, we could readily determine the percentage of readings which would fall in the 6.4-degree spread (3.2 either side of the mean). From these data we could then formulate a probability forecast or the number of days within this range on which we could expect the normal or mean temperature to occur. This study could be broken down further into hours of the day, etc., as required.

### REVIEW QUESTIONS

*Q6-6. If one adds all the daily high temperatures for the week and divides by 7, what climatological parameter would be determined by this calculation?*

*Q6-7. A temperature of 124 degrees Fahrenheit was the highest temperature ever recorded at a particular station. What type of climatological parameter was determined?*

*Q6-8. What is a degree-day?*

## CLASSIFICATION OF CLIMATE

**LEARNING OBJECTIVE**: Recognize climatic zones and climatic types as they relate to the classification of climate.

The climate of a given region or locality is determined by a combination of several meteorological elements and not by just one element. For example, two regions may have similar temperature climates but very different precipitation climates. Their climatic difference, therefore, becomes apparent only if more than one climatic factor is considered.

Since the climate of a region is composed of all of the various climatic elements, such as dew, ice, rain, temperature, wind force, and wind direction, it is obvious that no two locations can have exactly the same climate. However, it is possible to group similar areas into what is known as a climatic zone.

### CLIMATIC ZONES

The basic grouping of areas into climatic zones consists of classifying climates into five broad belts based on astronomical or mathematical factors. Actually they are zones of sunshine or solar climate and include the torrid or tropical zone, the two temperate zones, and the two polar zones. The tropical zone is limited on the north by the Tropic of Cancer and on the south by the Tropic of Capricorn, which are located at 23 1/2° north and south latitude, respectively. The Temperate Zone of the Northern Hemisphere is limited on the south by the Tropic of Cancer and on the north by the Arctic Circle located at 66 1/2° north latitude. The Temperate Zone of the Southern Hemisphere is bounded on the north by the Tropic of Capricorn and on the south by the Antarctic Circle located at 66 1/2° south latitude. The two polar zones are the areas in the Polar Regions which have the Arctic and Antarctic Circles as their boundaries.

Technically, climatic zones are limited by isotherms rather than by parallels of latitude (fig. 6-1). A glance at any chart depicting the isotherms over the surface of the earth shows that the isotherms do not coincide with latitude lines. In fact, at some places the isotherms parallel the longitude lines more closely than they parallel the latitude lines. The astronomical or light zones therefore differ from the zones of heat.

### CLIMATIC TYPES

Any classification of climate depends to a large extent on the purpose of the classification. For instance, a classification for the purpose of establishing air stations where favorable flying conditions are important would differ considerably from one for establishing the limits of areas that are favorable for the growing of crops. There are three classifications that merit particular attention. They are the classifications of C. W. Thornthwaite, W. Köppen, and G. T. Trewartha.

Thornthwaite's classification of climates places a great deal of emphasis on the effectiveness of precipitation. Effectiveness of precipitation refers to the relationship between precipitation and evaporation at a certain locality. Thornthwaite classified climates into eight main climatic groups; five groups give primary emphasis to precipitation and the other three groups are based on temperature.

Köppen's classification includes five main climatic types. They are *tropical rain, dry, warm temperate rainy, cool snow forest (boreal*), and *polar* climates. These main types are further divided into climatic provinces. The Köppen classification is based mainly on temperature, precipitation amount, and season of maximum precipitation. Numerical values for these elements constitute the boundaries of the above types, which were selected primarily according to their effect on plant growth. Figure 6-2, shows Köppen's climatic types.

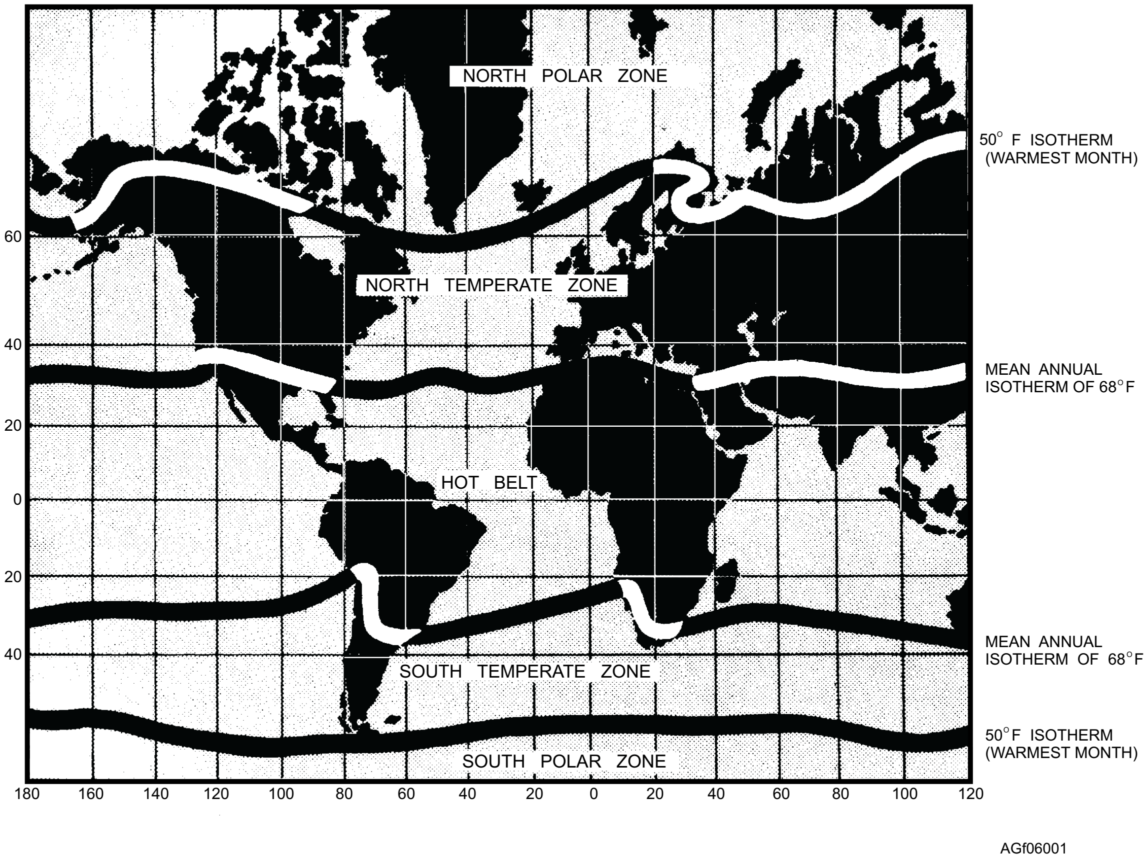



**Figure 6-1.—Temperature zones.**

Köppen's climatic types are still considered valid today. His climatic zones, like others, are by no means static. Climatic zones shift with long-range weather patterns. The most noticeable shifts in these climatic zones have been observed over the northern portions of North America and Asia and over Africa. Russia and Canada, for example, have been able to conduct farming at higher latitudes over the past 200 years due to milder temperatures. Recent studies, however, indicate a general return of cooler temperatures at high latitudes, and now the growing region is gradually moving southward again where temperatures are more moderate. In Africa, desert regions have made notable shifts southward due to decreasing precipitation.

Trewartha is the most recent classifier of climate. Initially, his climatic classifications were based on Köppen's; however, over the years, he has made significant changes and is now recognized for developing his own six climatic groups. These six groups are *tropical, dry, subtropical, temperate, boreal, and polar.* Five of these groups are based on temperature and one is based on precipitation (see Table 6-2). Trewartha's climatic groups, like Köppen's, are also further broken down into climatic types and subtypes.

## REVIEW QUESTIONS

*Q6-9. List the five climatic belts and their boundaries.*

*Q6-10. Name the three classifications of climatic types.*

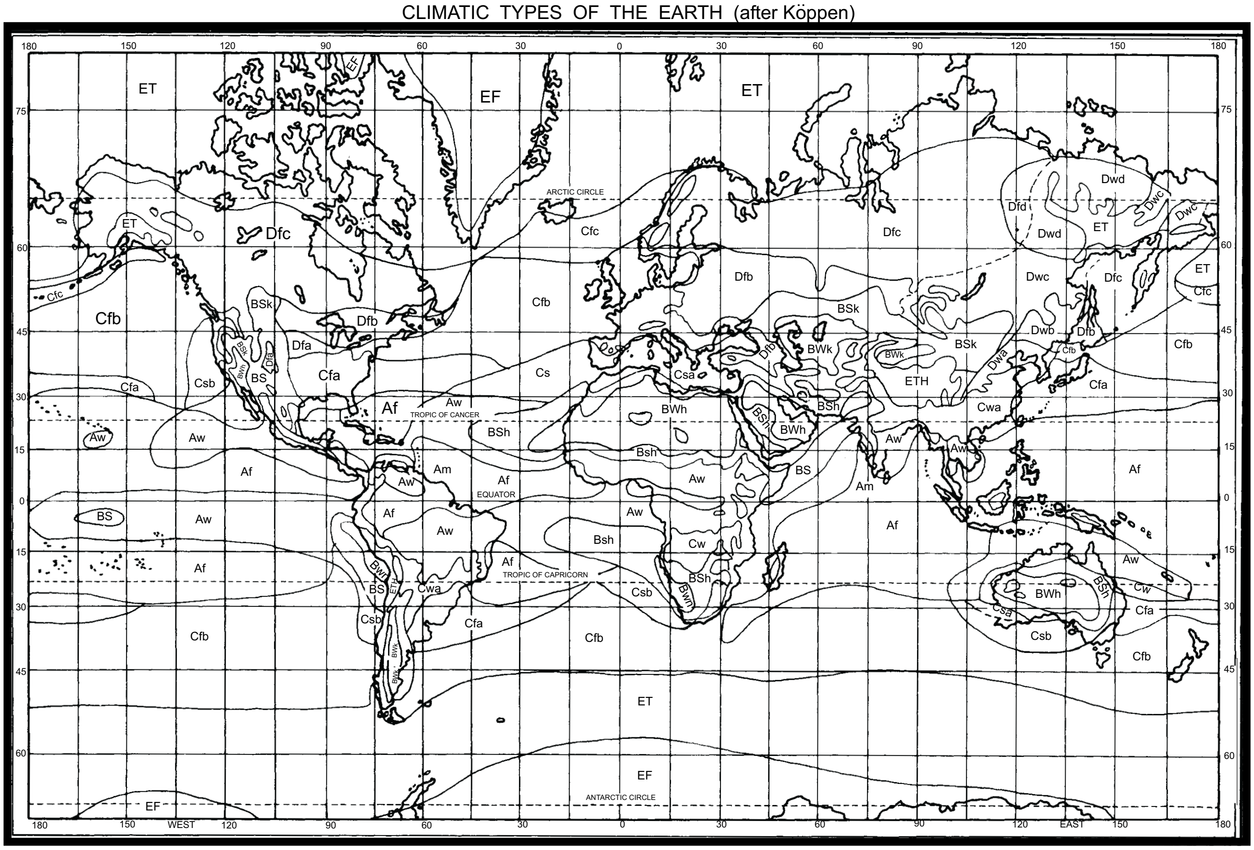
*Q6-11. What are the five climatic types according to Köppen?*

## CLIMATIC CONTROLS

**LEARNING OBJECTIVE**: Identify the controlling factors that affect climate.

The variation of climatic elements from place to place and from season to season is due to several factors called climatic controls. The same basic factors that cause weather in the atmosphere also determine the

CLIMATIC TYPES OF THE EARTH (after Köppen)




## LEGEND TO CLIMATIC TYPES

A. TROPICAL RAINY CLIMATES
- Af TROPICAL RAIN FOREST CLIMATE
- Am TROPICAL MONSOON CLIMATE
- Aw TROPICAL SAVANNA CLIMATE

B. DRY CLIMATES
- BW DESERT CLIMATE
- BS STEPPE CLIMATE
- h Denotes a Hot B Climate
- k Denotes a Cool B Climate
- k' Denotes a Cold B Climate
- n Denotes a B Climate with Frequent Fog

C. WARM TEMPERATE RAINY CLIMATES
- Cs SUMMER-DRY
- Cw WINTER-DRY
- Cfa WITHOUT DRY SEASON, HOT SUMMERS
- Cfb WITHOUT DRY SEASON, WARM SUMMERS
- Cfc WITHOUT DRY SEASON, COOL SUMMERS

D. COOL SNOW-FOREST CLIMATES (BOREAL)
- Dfa, Dwa HOT SUMMERS
- Dfb, Dwb WARM SUMMERS
- Dfc, Dwc COOL SUMMERS
- Dfd, Dwd VERY COLD WINTERS
- w Denotes a Dry Season in Winter
- f Indicates the Absence of a Dry Season

E. POLAR CLIMATES
- ET TUNDRA CLIMATE
- EF FROST CLIMATE
- H Denotes Polar Climates E due to High Altitude

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**Figure 6-2.—Köppen's climatic types.**

**Table 6-2.—Trewartha's Climatic Groups and their Poleward Boundaries**

| Basis for Classification | Climate Group | Poleward Boundary |
|---|---|---|
| Temperature | A. Tropical | Frost line over continents and 65°F (18°C) over oceans (coolest months) |
| Precipitation | B. Dry | Bounded by the outer limits where potential evaporation is equal to precipitation |
| Temperature | C. Subtropical | 50°F (10°C) or above for 8 months of the year |
| Temperature | D. Temperature | 50°F (10°C) or above for 4 months of the year |
| Temperature | E. Boreal | 50°F (10°C) or above for 1 month (warmest month) |
| Temperature | F. Polar | Below 50°F (10°C) entire year |

climate of an area. These controls, acting in different combinations and with varying intensities, act upon temperature, precipitation, humidity, air pressure, and wind to produce many types of weather and therefore climate.

Four climatic controls largely determine the climate of every ocean and continental region. These controls are latitude, land and water distribution, topography, and ocean currents. Another factor, which is now significant in determining a region's climate, is man. Man's influence on climate through pollution, deforestation, and irrigation, is now considered a climatic factor.

## LATITUDE

Perhaps no other climatic control has such a marked effect on climatic elements as does the latitude, or the position of Earth relative to the Sun. The angle at which rays of sunlight reach Earth and the number of *Sun* hours each day depends upon the distance of the Sun from the equator. (See fig. 6-3.) Therefore, the latitude directly influences the extent to which an air mass is heated. Latitude influences the sources and direction of air masses and the weather they bring with them into a region.

Comparing an equatorial area to a polar area can show the importance of latitude as a climatic control. In the former, the Sun is close to being directly overhead during the day throughout the year. Therefore, there is little difference between mean temperatures for the coldest and warmest months. In the polar area, however, the Sun never rises far above the horizon; that is, the angle of the Sun to Earth's surface is always acute. The radiant energy received per unit area is therefore slight, and the warming effects of the Sun are relatively weak.

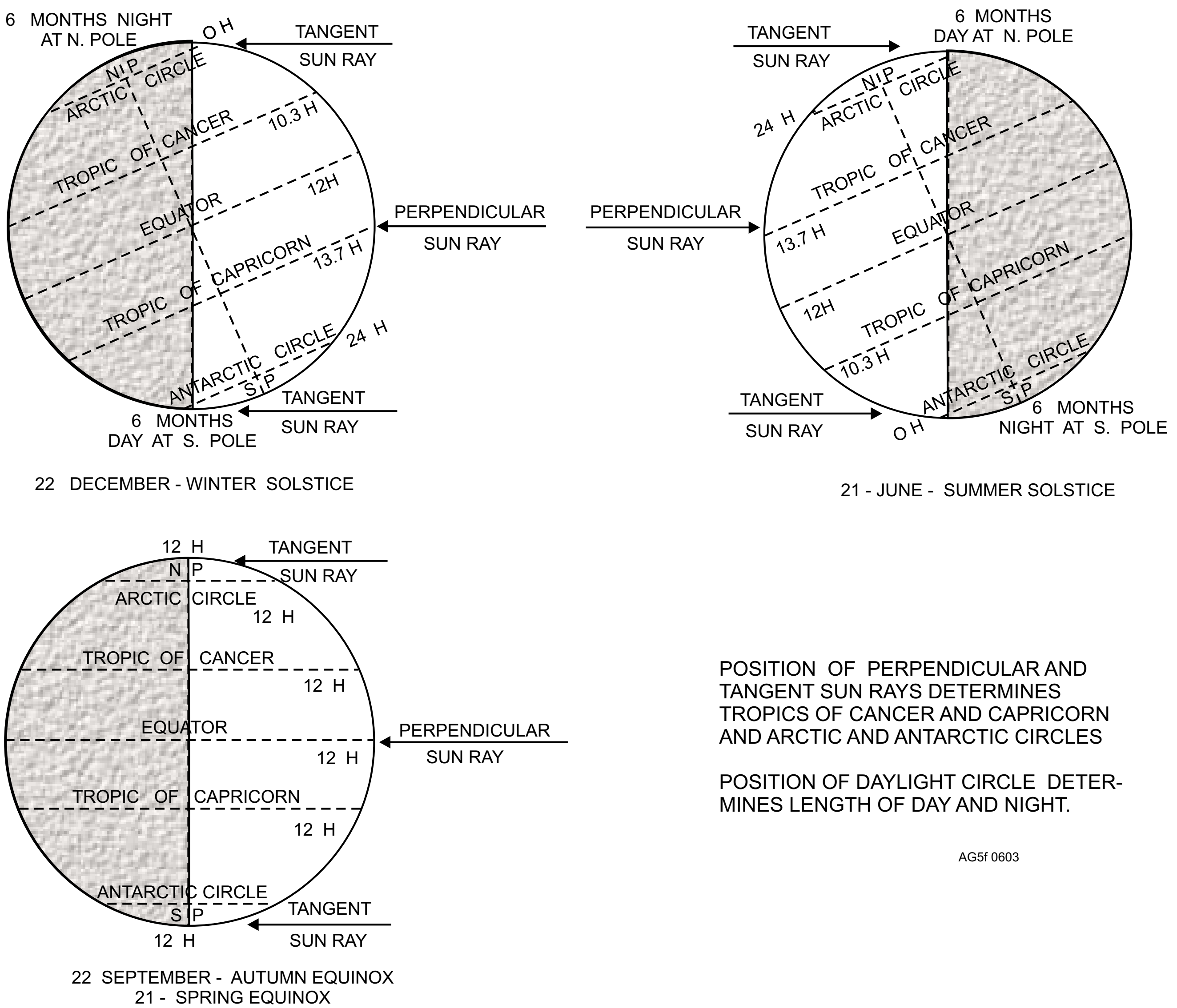


**Figure 6-3.—Latitude differences in amount of insolation.**

In chapter 3, the average world surface temperatures are represented on two world charts for January and July in figures 3-2A and 3-2B. These are mean charts and are not meant to be an accurate portrayal of the temperatures on any one particular day. Note that in general the temperatures decrease from low to high latitudes.

## LAND AND WATER DISTRIBUTION

Land heats and cools about four times faster than water. Therefore, the location of continents and oceans greatly influences Earth's pattern of air temperature as well as the sources and direction of movement of air masses.

### Influence on Air Temperature

Coastal areas assume the temperature characteristics of the land or water that is on their windward side. In latitudes of prevailing westerly winds, for example, west coasts of continents have oceanic temperatures and east coasts have continental temperatures. These temperatures are determined by the wind flow.

Since the upper layer of the ocean is nearly always in a state of mixing, heat losses or heat gains occurring at the surface are distributed throughout a large volume of water. This mixing process sharply reduces air temperature contrasts between day and night and between winter and summer over oceanic areas.

Over land, there is almost no redistribution of heat by turbulence; also, the effect of conduction is negligible. Thus strong seasonal and diurnal contrasts exist in the interiors of continents. During the winter, a large part of the incident solar radiation is reflected back toward space by the snow cover that extends over large portions of the northern continents. For this reason, the northern continents serve as source regions for dry polar air.

The large temperature difference between the land and water surfaces, which reverses between the two seasons, determines the seasonal weather patterns to a great extent.

In chapter 3, figures 3-2A and 3-2B, the isotherms over the Northern Hemisphere are more closely spaced and parallel in winter than in summer. In the Southern Hemisphere, the temperature gradient does not have as great a seasonal change as it does in the Northern Hemisphere. These conditions are due to the unequal distribution of land and water on the two hemispheres. Since the Southern Hemisphere has less land and more water surface than the Northern Hemisphere, the change due to the greater water surface is less with consequently more nearly uniform isotherms. Also, the continents of the Southern Hemisphere taper toward the poles and do not extend as far poleward as do those in the Northern Hemisphere.

The nature of the surface affects local heat distribution. Color, texture, and vegetation influence the rate of heating and cooling. Generally, a dry surface will heat and cool faster than a moist surface. For instance, plowed fields, sandy beaches, and paved roads become hotter than surrounding meadows and wooded areas during the day. During the night, however, the situation is reversed.

The distribution of water vapor and clouds is another important factor influencing air temperature. Although areas with a high percentage of cloud cover have a high degree of reflectivity, the energy, which is not reflected, is easily trapped in the lower layers due to the greenhouse effect. Thus, areas of high moisture content have relatively high temperature.

### Influence on Air Circulation

The higher mean temperature of the Northern Hemisphere is an effect not only of its higher percentage of land, but also of the fact that its oceans are also warmer than those in the Southern Hemisphere are. This is partly due to the movement of warm equatorial waters from the Southern Hemisphere into the Northern Hemisphere caused by the southeast trades crossing the equator. Another factor conducive to higher mean temperatures in the Northern Hemisphere is the partial protection of its oceans from cold polar waters and arctic ice by land barriers. There is no such barrier between the Antarctic region and the southern oceans.

## TOPOGRAPHY

Climates over land may vary radically within very short distances because of the elevation and variations in landforms. Therefore, topography plays an extremely important role in determining the climate of a region.

The height of an area above sea level exerts a considerable influence on its climate. For instance, the climate at the equator in the high Andes of South America is quite different from that found a few feet above sea level at the same latitude. All climatic values are affected by surface elevation.

An important influence on climate is mountainous terrain, especially the long, high chains of mountains that act as climatic divides. These obstacles deflect the tracks of cyclones and block the passage of air masses at the lower levels. If the pressure gradients are strong enough to force the air masses over the mountains, the forced ascent and descent modifies the air masses to a great extent, thus modifying the climate on both the windward and leeward sides of the range.

The orientation of the mountain range may block certain air masses and prevent them from reaching the lee side of the mountains. For example, the Himalayas and the Alps, which have east-west orientations, prevent polar air masses from advancing southward. Therefore, the climates of India and Italy are warmer in winter than are other locations of the same latitude. The coastal ranges in North America, running in a north-south line, prevent the passage of unmodified maritime air masses to the lee side.

The most noted effect of mountains is the distribution of precipitation. The precipitation values, level for level, are much higher on the windward side than on the leeward side.

In regions where the prevailing circulation flows against a mountain barrier, the amount of precipitation increases more or less uniformly with elevation on the windward side of the range. This steady increase normally occurs up to elevations of about 10,000 feet. However, in the trade wind zone (such as at the Hawaiian Islands), precipitation increases only to about 3,000 feet and then decreases gradually. Even with this decrease in amount, more rain is received at 6,000 feet than at sea level.

Another important topographical feature is the presence of lakes. The lake effect can be notable for large unfrozen bodies of water. The lee sides of lakes show considerable diurnal and annual modification in the form of more moderate temperatures; increased moisture, clouds, and precipitation; and increased winds (due to less friction) and land and sea breeze effects.

## OCEAN CURRENTS

Ocean currents play a significant role in controlling the climate of certain regions. Ocean currents transport heat moving cold polar water equatorward into warmer waters and moving warm equatorial water poleward into cooler waters.

Currents are driven by the major wind systems; therefore, cold southward-moving currents flow along the west coasts of continents, and warm northward moving currents flow along the east coasts of continents. This is true in both hemispheres. Basically, this results in cooler climates along the west coasts and warmer climates along the east coasts.

A brief explanation of the effects of ocean currents is presented here.

### Effects on the West Coasts

The northern portions of the west coasts of continents generally have cool summers and warm winters. The summers are cool because of the presence of cold northern waters along their shores. However, the winters are generally mild because of the transport of warm ocean waters to these latitudes. For example, the south and southeast coasts of Alaska and the west coasts of Canada, Washington, and Oregon have relatively warm currents flowing along their shores. These currents are the Aleutian and North Pacific currents, which are branches of the warm northward-flowing Kuroshio Current. The currents flow along the West Side of the Pacific high and bring warm water into southern Alaska and the Pacific Northwest.

As these currents merge and flow southward along the British Columbia coast, they move into warmer waters and become the cold California Current.

The southern portions of the west coasts of continents generally have cooler climates than do the east coasts of the same latitude. For example, during summer, the cold California Current flows southward along the shores of California. Due to the Pacific high, the winds normally flow either across the cold current toward shore (onshore) or parallel to the coastline. This results in cool air being advected inland allowing cities such as San Francisco and Seattle to enjoy relatively cool summers. Unfortunately, when the warm, moist air from the Pacific high does move over the underlying cold current, extensive fog and stratus develop which also move inland. This situation is typical along the southern portions of the west coasts in both hemispheres.

Another factor affecting west coasts is upwelling. Upwelling is the process by which cold subsurface waters are brought to the surface by wind. It occurs in areas where the wind causes the surface water to be transported away from the coast. The colder subsurface water then replaces the surface water. In the Northern

Hemisphere, upwelling is common where the wind blows parallel to the coast and the surface water is transported away from the coast. In the process of upwelling, the exchange of water takes place only in the upper layers.

Generally, the following statements are true regarding the effects of ocean currents along the west coasts of continents:

- The west coasts of continents in middle and higher latitudes are bordered by warm waters, which cause a distinct maritime climate characterized by cool summers and relatively mild winters with small annual range of temperatures (upper west coasts of the United States and Europe).

- The west coasts of continents in tropical and subtropical latitudes (except close to the equator) are bordered by cool waters and their average temperatures are relatively low with small diurnal and annual ranges. There are fogs, but generally the areas (southern California, Morocco, etc.) are arid (dry).

**Effects on the East Coasts**

The effects of currents along the eastern coasts of continents are less dramatic than those of the west coasts because of the west-to-east flow of weather. The effects, however, are just as significant.

In the tropical and subtropical regions, warm ocean currents introduce warm, rainy climates, especially on the windward sides of mountainous landmasses. As the warm currents progress northward into middle latitudes, warm, moist air produces a hot, humid climate with frequent rain showers during the summer. Winters are relatively moderate (but still cold) along the coast due to the transport of warm water. The higher latitudes along eastern shores normally have cold waters flowing southward from the polar region; warm ocean currents rarely extend very far north. The regions where the two currents meet have cool summers and cold winters with extensive fogs. This is especially true along the Grand Banks of Newfoundland and the Kamchatka Peninsula of eastern Asia.

The following general statements are true regarding the effects of ocean currents along the eastern coasts of continents:

- The east coasts in the tropics and subtropical latitudes are paralleled by warm currents and have resultant warm and rainy climates. These areas lie in the western margins of the subtropical anticyclone regions (Florida, Philippines, and Southeast Asia).

- The east coasts in the lower middle latitudes (leeward sides of landmasses) have adjacent warm waters with a modified continental-type climate. The winters are fairly cold, and the summers are warm and humid.

- The east coasts in the higher middle latitudes typically experience cool summers with cool ocean currents paralleling the coasts.

**Other Effects**

Ocean currents also affect the location of primary frontal zones and the tracks of cyclonic storms. Off the eastern coast of the United States in the winter, two of the major frontal zones are located in areas where the temperature gradient is strong and where a large amount of warm water is being transported into the middle latitudes. The fact that these frontal zones are located near large amounts of energy suggests that cyclones developing in these regions along the primary front may be of thermodynamic origin. The main hurricane tracks in the Atlantic and Pacific also appear to follow warm waters. Extratropical cyclones also tend to occur in warm waters in fall and early winter.

## CLIMATIC FACTORS

Human activity and vegetation can have marked effects on the climates of local areas. Eventually man's activities could affect larger areas and ultimately whole continents.

It has been known for years now that urban areas and industrial complexes have an influence on climate. Atmospheric pollution is increased, for example, and the radiation balance is thereby altered. This change affects the daily maximum and minimum temperatures in cities, where they tend to be generally higher than in nearby suburbs. A higher concentration of hygroscopic condensation nuclei in cities results in an increased number of fogs. Also, with the greater heat source found in cities, increased convection gives rise to greater amounts of cloudiness and precipitation. An apparent benefit of this increased heat is a slight decrease in severe weather occurring in large cities (Chicago, for example) as compared to adjacent areas.

Areas of heavy vegetation generally have distinct climates, which may differ considerably from climates of nearly open areas. Falling precipitation caught in trees before reaching the ground may be evaporated, but precipitation, which reaches the ground, does not evaporate or run off readily. Heavily forested areas can absorb and store considerable quantities of water. Snow in forests can be protected from direct insolation by the trees and may stay on the ground for much longer periods than snow on open, exposed surfaces. In forests, temperature maximums and minimums are higher than over open land at the same latitude. Relative humidity is also higher and wind speeds are considerably lower.

### REVIEW QUESTIONS

*Q6-12. Which climatic control has the biggest effect on climatic elements?*

*Q6-13. A weather station on the western coast of the United States will receive the characteristics of what type air as compared to a weather station on the eastern coast?*

*Q6-14. Generally, how do ocean currents effect climate?*

## CLIMATOLOGICAL DATA

**LEARNING OBJECTIVE**: Describe the use of climatological data in meteorology and what references and services are available.

Climatological records are based on the meteorological observations that are taken at a particular locality. This information may be presented in a number of ways.

Temperature records generally include the following temperature values: daily maximums and minimums by months; the extremes; the average temperature by year and month; the mean monthly and annual temperature; the mean monthly maximum and minimum temperature; and (sometimes) the monthly and seasonal degree-days. Of great climatic significance is the range between the mean temperature of the warmest month and the coldest month. Other temperature data are sometimes given. These may include the number of days with the following temperatures: maximum of 90°F and above; maximum of 32°F and below; minimum of 32°F and below; and minimum of 0°F and below.

Precipitation records include the mean annual and monthly totals. The range between the highest and the lowest annual rainfall for a locality is the best indication of the dependability of the precipitation. The records often show the absolute maximum rainfall and snowfall for a 24-hour period by months, as well as the maximum and minimum precipitation for each month.

Climatic records usually show data on winds. Such information indicates the mean hourly speed and the prevailing direction by month. Also shown are the speed and direction of the strongest wind for the 12 months and the year in which it occurred.

Data on cloudiness, humidity, thunderstorms, and heavy fog are often included. Other helpful data would be the frequency and distribution of cyclones and anticyclones; passage of fronts; proportion of rainfall and snowfall received from cyclonic storms and local, air mass thunderstorms; and climatological data on upper air conditions.

### METHODS OF PRESENTATION

Climatological information is presented in many different ways. Tables are frequently used. Maps are particularly useful in presenting climatic information in cases where geography is an important factor. Wind data can be given by means of a device called a wind rose, which presents information on the prevailing wind directions. (See fig. 6-4.)

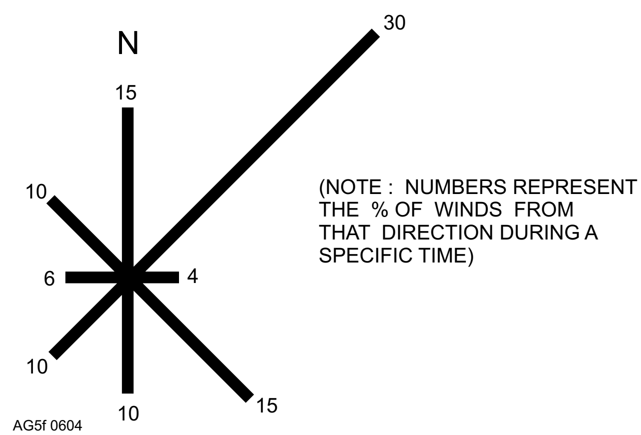


**Figure 6-4.—A wind rose.**

Graphs are usually divided into bar and line graphs, or the graph may be a combination of the two. Figure 6-5 is an example of a bar graph and a line graph showing the same information. Figure 6-6 shows a combination of a bar and line graph used to depict cloud cover. This type of depiction is used in the most recent *U.S. Navy Marine Climatic Atlas of the World.*

## AVAILABILITY OF DATA

Every Naval Meteorology Oceanography Command activity should have climatological records available for their area and for such other areas as may be necessary to provide climatological support at the local command level. Various climatological records are available from Fleet Numerical Meteorology and Oceanography Detachment (FNMOD), Asheville, NC 28801-2696, or by contacting their website. These records include the *Summary of Meteorological Observations, Surface* (SMOS); *Local Climatological Data* (LCD); *Summary of Synoptic Meteorological Observations* (SSMO); and *Summary of Meteorological Observations, Radiosonde* (SMOR).

### Frequency SMOS

Frequency SMOS summaries are prepared for all naval observing stations from navy monthly meteorological records (MMRs). Each SMOS is for a specific station. Frequency distributions for various parameters are presented by time of day, month, and year. SMOS are revised every 5 years.

### Local Climatological Data Summary

The LCD summary is prepared only for selected civilian stations in the continental U.S.A. (CONUS). It consists of means and extremes (temperature, precipitation, wind, etc.) by month, mean temperature and total precipitation by month for specific years of record, and monthly and seasonal degree-days. The LCD is revised annually.

### Cross-Wind Summary

The Cross Wind Summary presents the percentage of occurrence of cross winds for a given location. It is produced only on request.

### Summary of Synoptic Meteorological Observations (SSMO)

The SSMO presents useful monthly and annual tabulations of surface climatological data and various combinations of the included parameters. SSMOs were last updated in the mid-seventies and are supplemented by the Near Coastal Zone Studies.

### Near Coastal Zone Studies

Near Coastal Zone Studies are currently being developed by FNMOD, Asheville, to supplement the SMOS by providing detailed climatological data for areas of higher interest. Near Coastal Zone Studies present data in both graphic and tabular formats.

### Summary of Meteorological Observations, Radiosonde (SMOR)

The SMOR is used to prepare monthly winds aloft summaries, which generally include various constant height and constant pressure levels. The summaries contain winds aloft data, giving speeds and directions over the period covered.

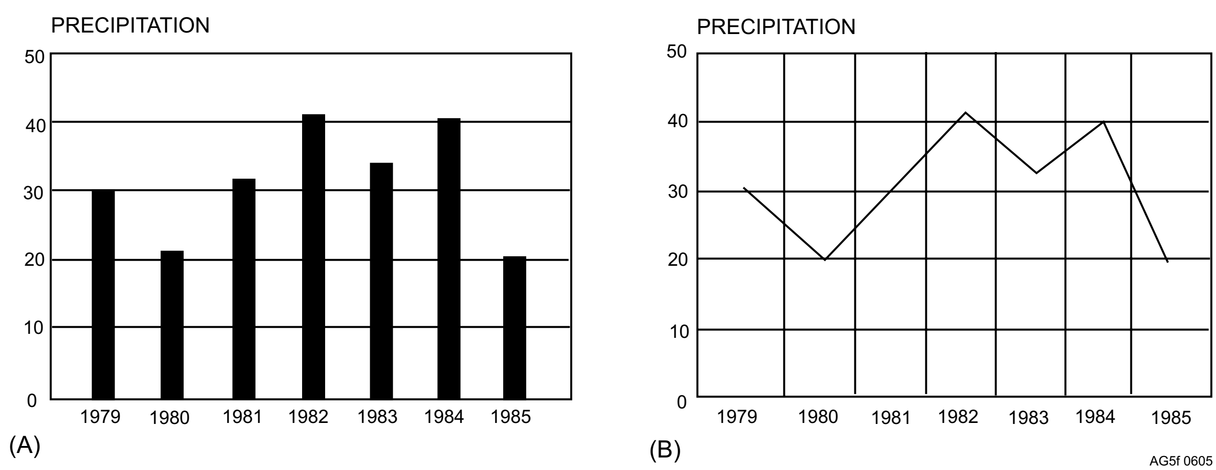


**Figure 6-5.—A comparison of the bar and line graph method of showing the variable annual precipitation in a time series. (A) Bar graph; (B) Line graphs.**

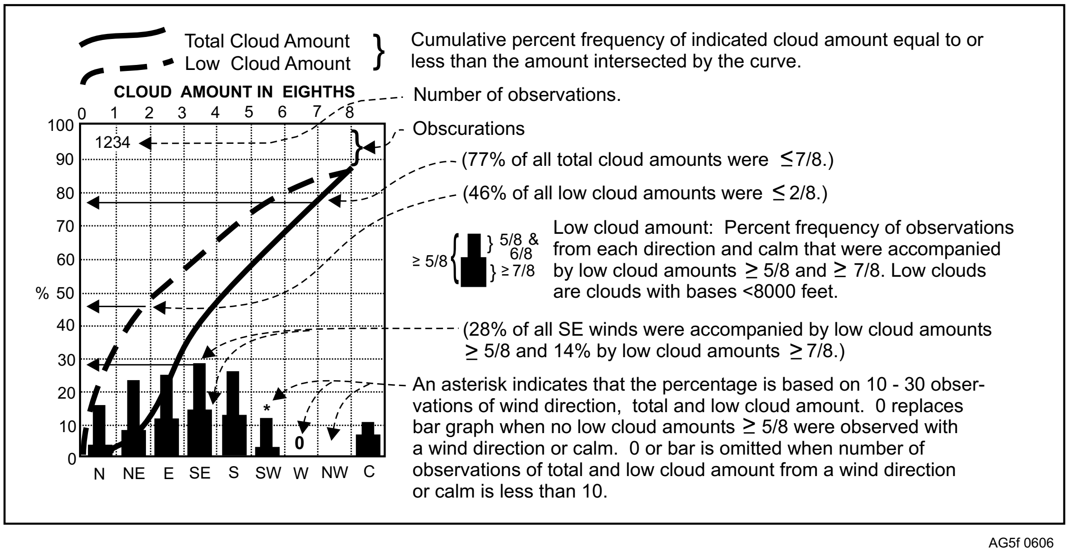


**Figure 6-6.—Combination bar and line graph (with legend and instructions for use).**

### Worldwide Airfield Summary

The *Worldwide Airfield Summary* provides climatological data for airfields and geographical areas throughout the world. There are 10 volumes, some published in two or more parts.

## CLIMATOLOGICAL REFERENCES

There are many references, which can be used in climatological work, so many in fact that they would be too numerous to list here. They are tabulized in the following publications:

- *Guide to Standard Weather Summaries* (NAVAIR 50-1C-534) contains an index of all the standard machine-tabulated summaries available through FNMOD, Asheville.

In addition, many navy climatic references are listed in the *Navy Stock List of Forms and Publications*, NAVSUP publication 2002, section 2B. Navy climatology publications are found under the NA-SO-1C-series.

The following publications can also be used to prepare climatological briefings and packets:

- *U.S. Navy Marine Climatic Atlas of the World,* volumes 1 through 7 and 9 (NAVAIR 50-1C-528 through 533, 550, 554, s and 565). These publications contain climatic data for all the principal ocean areas of the world. They have both land and ocean sections. The surface section contains data presented by graphs, tables, and isopleths on such elements as surface winds, visibility, precipitation, storm tracks, etc. The oceanographic section includes charts of tidal data, currents, and ice.

- *U.S. Navy Hindcast Spectral Ocean Wave Model Atlases*, volume 1, North Atlantic (NAVAIR 50-1C-538), volume 2, Pacific (NAVAIR 50-1C-539). These atlases represent ocean wave data by tables, bar graphs, and isopleths. Data is based on numerically derived historical data in the form of wind and wave climatology. These publications are designed to provide a more accurate representation of overall ocean wave climatic data for some applications. They are designed to supplement but not supersede the conventional Marine climatic atlases.

### Local Area Forecaster's Handbooks

The *Local Area Forecaster's Handbooks*, as required by NAVMETOCCOM Instruction 3140.2( ), contain valuable information on local and area weather as follows: A description of the local topography, terrain and general synoptic characteristics of weather occurrences in the area. Mean storm tracks for the region, a limited amount of climatological data, and local forecasting rules and techniques are also available. A handbook can serve as a composite summary of expected weather events and the effects of certain parameters on local weather.

### Naval Intelligence Survey (NIS) Publications

The Naval Intelligence Survey (NIS) publications have been discontinued, and distribution is limited. However, when available, these classified publications are a valuable source of information about general climatic influences and topographic/oceanic effects on regions from which unclassified data may no longer be available.

### Miscellaneous Publications

The following publications contain generally the same type of climatological information or specific data. They have proven to be extremely useful.

1. *Climatic Summaries for Major Seventh Fleet Ports and Waters,* NAVAIR 50-1C-62.

2. *Climatic Summaries of Indian Ocean Ports and Waters,* NAVAIR 50-IC-63.

3. *A Climatic Resume of the Mediterranean Sea,* NAVAIR 50-1C-64.

4. *Upper Wind Statistics of the Northern Hemisphere,* volumes 1, 2, and 3, NAVAIR 50-1C-535.

5. *Marine Climatic Guide to Tropical Storms at Sea,* NAVAIR 50-IC-61.

6. *Sea Ice Climatic Atlases,* volume 1, *Antarctic,* NAVAIR 50-1C-540. Volume 2, *Arctic East,* NAVAIR 50-IC-541. Volume 3, *Arctic West,* NAVAIR 50-1C-542.

## CLIMATOLOGICAL SERVICES

Requests for climatic support should be made to the Meteorology Oceanography Facility or Center in your chain of command. Requests that cannot be fulfilled are forwarded to:

Fleet Numerical Meteorology and
Oceanography Facility
Asheville, NC 28801-5014

### Additional Climatic Sources

In addition to navy climatic publications, there are other sources for air/ocean climatology data, which are available to the Aerographer's Mate for preparing climatic studies. They are as follows:

- The Warfighting Support Center (WSC), Stennis Space Center Mississippi, provides oceanographic support. Available data includes tides, currents, and water structure, etc.

- The Air Weather Service Environmental Technical Application Center (ETAC) provides climatic information for Air Force operations. However, data produced by ETAC can be used for naval applications. A listing of climatology studies available from the Air Weather Service can be found in *Index of Air Weather Service Technical Publications* (AWS/TI-84/00 1). Requests for Air Weather Service publications must be made to Commander, Naval Meteorology Oceanography Command, Stennis Space Center, Mississippi.

## INTERPRETATION

Climatological records must be interpreted correctly to gain the needed information. Proper interpretation requires that all of the meteorological elements be studied so they present a composite picture. One meteorological element alone may mean very little. For instance, it is possible to conclude that Cairo, Egypt, and Galveston, Texas, has about the same kind of weather based solely on the temperature, since the yearly and monthly means and annual range are approximately the same. However, Galveston has about 40 times as much precipitation. Thus, their weather conditions over the year differ greatly.

To interpret just one meteorological element requires a study of several factors. For example, the temperature of a particular locality must be studied from the standpoint not only of the mean but also of the extremes and the diurnal and annual ranges. The effectiveness of precipitation also depends on several factors, such as amount, distribution, and evaporation. The mean precipitation for a particular month for a locality may be several inches, but the interpreter may find from a study of the locality's records that in some years the precipitation for that month is less than an inch, possibly not even a trace.

## APPLICATION TO WEATHER PREDICTION

Climatology is introduced where operational planning is required for a length of time beyond the range covered by weather-forecasting techniques. A study of the climate of an area or region may well foretell the general weather pattern to be expected.

Both the experienced and the inexperienced forecaster and assistant forecaster can make a more direct application of climatology. Those personnel having personal experience at a particular station can use climatology as a refresher for the overall weather patterns that can be expected for the ensuing season. This knowledge can help them to be more perceptive in their everyday analyses, to be alert for changing patterns with the seasons, and to produce a higher quality forecast.

The personnel who have had no experience at a particular station must rely on climatology as a substitute for their experience. Forecasters and assistant forecasters cannot be expected to become familiar overnight with the weather peculiarities of their new area of responsibility. The station certification period can be greatly reduced if the new people are furnished with "packaged experience" in a form that can place them more nearly on a par with those forecasters already experienced at that station. *The Local Area Forecaster's Handbooks* are good examples of this type of packaged information.

The Naval Meteorology Oceanography Command makes many uses of climatological data. In using the data, however, it must be clear that climatology has its limitations in the field of meteorology. It may be put this way. *Climatology is an essential supplement to meteorology, but it must never be considered a substitute for the meteorological situation that constitutes current weather conditions.*

### REVIEW QUESTIONS

*Q6-15. What is the correct method to obtain climatology information?*

*Q6-16. What publication is also useful for obtaining climatology information for a particular weather station?*

## WORLD WEATHER

**LEARNING OBJECTIVE**: Identify the various types of weather and climate of the oceans and continents.

Aerographer's Mates are stationed, and may travel, around the world. Ships and aircraft are constantly in global transit. Therefore, the Aerographer's Mate must have a general knowledge of types of weather encountered during various seasons in regions all around the world. This knowledge also increases insight into atmospheric circulation, weather development and movement, weather effects on the environment, and credibility as a knowledgeable analyst, interpreter, and briefer.

**NOTE**: You will find that a world atlas can be extremely useful and informative if used in conjunction with the information that follows.

## OCEANIC WEATHER

Naval vessels of the United States operate in virtually all the oceanic areas of the world; therefore, the Aerographer's Mates must be acquainted with oceanic weather. Some general considerations of the weather encountered over ocean areas are discussed in this lesson.

Because land and water heat and cool at different rates, the location of continents and oceans greatly affects the Earth's pattern of air temperature and therefore influences the weather. The upper layers of the ocean are almost always in a state of motion. Heat loss or gain occurs at the sea surface and is distributed throughout large volumes of water. This mixing process sharply reduces the temperature contrasts between day and night and between winter and summer.

### Oceanic Weather Control

It has long been recognized that the ocean plays an important part in climate and weather, particularly in the realms of temperature, humidity, and precipitation. This is only natural, since three-fourths of Earth's surface is covered by water.

The two climatic extremes that relate to water and land distribution over Earth are *maritime* and *continental*. A wide range in annual and diurnal temperatures, little cloudiness, and little precipitation generally evidences Continental climate. Continental climate is a product of a minimal influence from the oceans. Maritime climate prevails over the oceans and is characterized by a small temperature range, both annual and diurnal, and considerable precipitation and cloudiness.

Water vapor is considered one of the most important variables in meteorology. The state of the weather is largely expressed in terms of the amount of water vapor present and what is happening to the water vapor. Two principal elements of climate, precipitation and humidity are dependent upon water vapor. Since the oceans are the main source of water vapor, it follows that the oceans largely control weather.

### Effects of Air-Sea Interchange

The atmosphere and the oceans have tremendous effects on each other. These effects are principally in the realms of temperature and water vapor. The processes of radiation, the exchange of sensible heat, and the evaporation and condensation of water vapor on the sea surface maintain the heat balance of the oceans.

The amount of radiant energy absorbed by the sea depends upon the amount of energy reaching the surface and the amount of reflection by the surface. When the Sun is directly overhead, the amount of its energy reflected amounts to only about 3 percent. Even when the Sun is 30° above the horizon, the amount of reflection is just 6 percent. However, there is a reflection of about 25 percent of the energy when the Sun is 10° above the horizon. (See fig. 6-7.) Reflection loss is especially great in the presence of waves when the Sun is low.

Much of the insolation is absorbed in the first meter of seawater. This is true of the clearest water as well as of quite turbid (opaque) water. In water that is extremely turbid, the absorption is in the very uppermost layers. Foam and air bubbles are two major causes of a proportionately greater amount of absorption in the uppermost meter of the sea. However, due to vertical mixing, the heat absorbed in the upper layer is carried to great depths of the ocean, which acts as a great heat storage reservoir.

There is an exchange of energy between the oceans and the atmosphere. The surface of the oceans emits long-wave heat radiation. The sea surface at the same time receives long-wave radiation from the atmosphere. Although some of this incoming radiation from the atmosphere is reflected from the surface of the oceans, most of it is absorbed in a very thin layer of the water surface. The difference between the incoming long-wave atmospheric radiation and the outgoing long-wave radiation from the sea surface is known as the *effective back radiation*. The effective back radiation depends primarily on the temperature of the sea surface and on the water vapor content of the atmosphere. The time of day and the season have little effect on effective back radiation, since the diurnal and annual variation of the sea-surface temperature and of the relative humidity of the air above the oceans is slight.

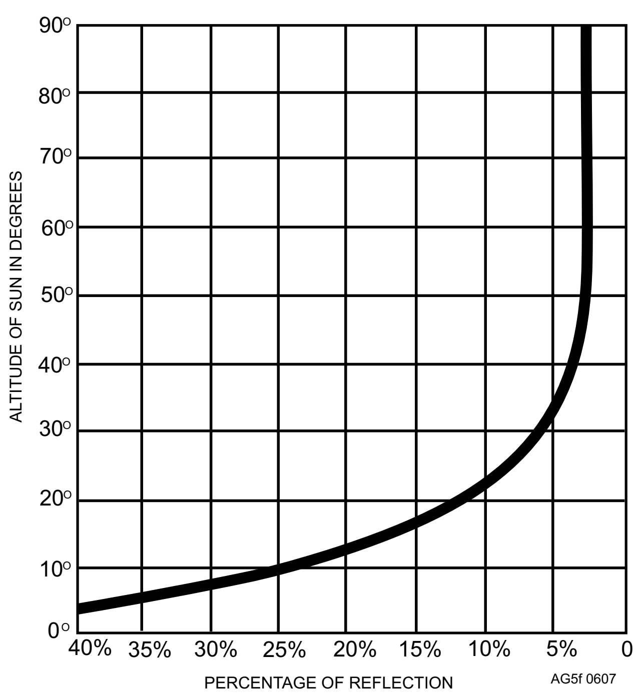

**Figure 6-7.—Percentage of reflected radiation.**

For conduction to take place between the oceans and the atmosphere there must be a temperature difference between the ocean surface and the air immediately overlying it. On the average, the temperature of the surface of the oceans is higher than that of the overlaying air. It might be expected that all of the ocean's surplus of heat is either radiated or conducted to the atmosphere. This is not the case. Only a small percentage of the ocean's surplus heat is actually conducted to the atmosphere. About 90 percent of the surplus are used for evaporation of ocean water.

Due to the processes of radiation and mixing, the oceans act as a thermostat relative to the atmosphere. The energy stored at one place during one season may be given off at another locality and during a later season. Hence, there seems to be a constant effort by the atmosphere and the oceans to keep their temperatures in balance by an interchange of heat.

**STABILITY**.—The deciding factor of most weather phenomena is the stability of the atmosphere. Air masses may become more stable or less stable as they move over ocean surfaces. The temperature contrast between the ocean surface and the lowest layers of the overlying air determines whether the ocean will promote stability or instability.

When the air moving over the ocean has a higher temperature than that of the ocean surface, the lower layers of the air become stable in time. On the other hand, when the air mass is colder than the ocean surface over which it is moving, instability results. As the colder air is warmed by the ocean, convective activity eventually develops. If the warming is sufficiently intense, thunderstorms develop.

**MOISTURE CONTENT**.—The interchange of moisture between the atmosphere and the oceans is one of the most important features of the whole meteorological picture. Without this interchange, weather, as we know it, could not exist; there would be no clouds and no precipitation. The oceans are by far the greatest source of moisture for the atmosphere. Other moisture sources are negligible in comparison.

Whether the atmosphere gives up some of its moisture to the ocean or vice versa depends greatly upon vapor pressure. Vapor pressure is the pressure exerted by the molecules of water vapor in the atmosphere or over the surface of liquid water. When the vapor pressure of a liquid is equal to that of the atmosphere above the liquid, there is little or no apparent interchange of moisture. In other words, at equal vapor pressure, just as many molecules escape from the liquid to the atmosphere and vice versa. This is the case when air becomes saturated. The saturation vapor pressure increases with increasing temperature.

If the temperature of the surface water is warmer than that of the air, the vapor pressure of the water at its surface is greater than that of the air. When this condition exists, there can be abundant evaporation from the ocean surface. This evaporation is aided by the turbulence of the air brought on by the unstable condition of the lower layers. It follows, then, that the greatest evaporation takes place when cold air flows over warm ocean waters.

Let us consider the opposite condition—warm air flowing over a relatively cold body of water. When this happens, there is stable stratification in the lower layers of the atmosphere. The vapor pressure of the air soon reaches a state of equilibrium with that of the water surface. Evaporation stops. However, if the warm air is quite moist, it is possible for the moisture in the air to condense on the water surface. Contact of the warm air with the cold water may result in the formation of fog by lowering the air temperature to the dew point.

The direct interchange of moisture from the atmosphere to the oceans occurs through precipitation and, to a lesser extent, condensation. The direct interchange, however, is not as important meteorologically as the indirect interchange. The indirect interchange is a sequence of events beginning with the evaporation of water from the ocean surfaces and ending with the subsequent condensation and precipitation over land areas.

Generally, precipitation occurs more frequently over land than over the oceans. Though the oceans are a source of abundant moisture, they normally lack the required precipitation mechanisms, such as vertical mixing, strong temperature contrasts, and orographic lifting.

**Equatorial and Tropical Weather**

In the Temperate Zone, where westerly winds predominate, pressure patterns move in an easterly direction. In the tropics, however, weather usually moves in the opposite direction. Normally, a moist layer, 5,000 to 8,000 feet deep exists in this region. During unfavorable weather, this layer deepens to more than 12,000 feet. Convergence occurs in opposing trade wind streams, northward flowing air, and areas of cyclonic curvature. The presence of a deep, moist layer and convergent winds account for the weather in equatorial and tropical regions.

**North Atlantic and North Pacific Oceans**

In the winter, the most favorable conditions for vigorous frontal activity are concentrated along the east coasts of North America and Asia. These conditions are associated with polar front activity. Cold air masses from continental sources meet warm, moist air from over the oceans. The warm ocean currents along these coasts greatly accentuate the frontal activity. The great temperature difference of the air masses, caused by the contrasting characteristics and proximity of their sources and the moisture that feeds into the air from the warm ocean currents, accounts for the intensity and persistence of these frontal zones off the east coasts in the winter. Modification of the air masses as they sweep eastward across the ocean leads to modified frontal activity on the west coasts. Refer back to chapter 4, to figures 4-25 and 4-26 for the location of the following frontal zones:

1. Polar fronts in the Atlantic. In the Atlantic, in winter, polar fronts are found situated in various locations between the West Indies and the Great Lakes area. Intensity is at a maximum when the fronts coincide with the coastline. Waves, with cold and warm fronts, form along the polar front and move northeastward along the front. Like all cyclonic waves, they develop low-pressure centers along the frontal trough. They may grow into severe disturbances and go through the usual stages of development: formation, growth, occlusion, and dissipation.

These cyclonic waves occur in families. Each family of waves is associated with a southward surge, or outbreak, of cold polar air. The polar front commonly extends approximately through the Great Lakes area. As the polar air advances, it pushes the front southward. The outbreak occurs, and polar air, joining the trade winds, spills equatorward.

There is no regular time interval for these large outbreaks of polar air, but the average period is about 5 1/2 days between them. Under average conditions, there are from three to six cyclonic waves on the polar front between each outbreak of polar air. The first of these usually travels along the front that lies farthest to the north. As the polar air accumulates north of the front, the front is pushed southward, and the last wave therefore follows a path that starts farther south than the path followed by the first wave. These families of polar front cyclones appear most frequently over the North Atlantic and North Pacific in the winter.

During the summer months, the polar fronts of the Atlantic recede to a location near the Great Lakes region, with the average summer storm track extending from the St. Lawrence Valley, across Newfoundland, and on toward Iceland. Polar outbreaks, with their accompanying family groupings of cyclones, are very irregular in summer and often do not exist at all. Frontal activity is more vigorous in the winter than in the summer because the polar and tropical air masses have greater temperature contrasts in the winter, and polar highs reach maximum development in the winter. Both of these factors increase the speed of winds flowing into fronts. Over oceans of middle latitudes, a third factor helps to make winter fronts more vigorous than summer fronts. In the winter, continental air becomes very unstable when it moves over the comparatively warm ocean surface; in the summer, it remains relatively stable over the comparatively cool ocean. Summer frontal activity (in middle latitudes) is therefore weak over oceans as well as over land. The high moisture content of maritime air causes much cloudiness, but this moisture adds little energy to frontal activity in the relatively stable summer air.

2. The polar fronts in the Pacific. These fronts are similar to those of the Atlantic, except that in the winter there are usually two fronts at once. When one high dominates the subtropical Pacific in the winter season, the pacific polar front forms near the Asiatic coast. This front gets its energy from the temperature contrast between cold northerly monsoon winds and the tropical maritime air masses, and from the warm, moist Kuroshio Current. In moving along this polar front of the Asiatic North Pacific in winter, storms occlude before reaching the Aleutian Islands or the Gulf of Alaska. Because of its steady cyclonic circulation, the Aleutian low becomes a focal center, or a gathering point, for cyclones. The occluded fronts move around its southern side like wheel spokes. This frontal movement is limited to the southern side of the Aleutian low because mountains and the North American winter high-pressure center prevent fronts from passing northward through Alaska without considerable modification.

In the winter the cyclones reach the Aleutians and the Gulf of Alaska. Here, Arctic air from the north meets the relatively warmer maritime air from the south. The Pacific arctic front of winter is found in this region. Although many occluded storms dissipate in the Gulf of Alaska, others strongly regenerate with waves developing on what were once occluded fronts.

When the Pacific subtropical high divides into two cells or segments (as it does 50 percent of the time in the winter and 25 percent of the time in the summer), a front forms in the vicinity of Hawaii. Along this front, storms develop and move northeastward. These storms called Kona storms, have strong southwest winds and bring heavy rains to the islands. Those storms that succeed in moving beyond the realm of the northeast trade winds, which stunt them, may develop quite vigorously and advance to the North American coast, generally occluding against the mountains. When this second polar front exists, two systems of cyclonic disturbances move across the Pacific. Because of their greater sources of energy, however, storms that originate over the Kuroshio Current and move toward the Aleutians are almost always more severe. In the Atlantic, a second polar front, similar in nature and source to the second polar front of the Pacific, sometimes—though rarely—develops.

During the summer months, the Pacific polar front lies to the north of Kamchatka and the Aleutians and shows no rhythmic polar outbreaks.

**Air-Mass Weather**

Flying weather is usually best in tropical maritime air, at its source, within the subtropical highs. Scattered cumulus and patches of stratocumulus clouds may develop, but the sky is almost never overcast. Scant precipitation falls in scattered showers and variable, mild winds prevail.

The excellent flying weather in these mT source regions commonly extends through the moving air masses some distance from the sources. Cloudiness in the mT air increases with an increase in distance from the source.

On flights from Hawaii or from the Azores northward, through northward-moving mT air, stratiform clouds increase. On flights from Hawaii or the Azores southward, through southward-moving mT air (or the northeast trades), cumuliform clouds increase. Here we are considering only Northern Hemisphere situations; however, a comparable pattern exists in the Southern Hemisphere.

A typical breakdown of the weather conditions you may encounter in air masses around the subtropical highs (fig. 6-8) is as follows:

1. North of a subtropical high. Any mT air that moves northward becomes cooled over the cool ocean surface. A stratus overcast may form, and drizzle may fall. Farther north, low ceilings (usually below 1,000 feet) may reach the surface, producing fog. The mT air surges farthest north in summer because subtropical highs are best developed and polar fronts lie farthest north. This mT air brings most of the summer fogginess to northern seas and coasts. It brings the greatest fogginess in the Atlantic where it blows from the warm Gulf Stream over the cold Labrador Current (near Newfoundland), and in the Pacific where it blows from the warm Kuroshio Current over the cold Oyashio current (near the Kamchatka peninsula).

2. East of a subtropical high. Along the California coast, and along the Atlantic coast of North Africa, the mT air blows from the west and the northwest. This air tends to remain stable for the following reasons:

a. It is coming from the northern, cooler portion of the source region.

b. Its surface layers remain cool because it moves over cold ocean currents.

c. Its upper portions warm adiabatically because of subsidence.

Throughout the year, airways are smooth. The skies are clear to partly cloudy. Clouds are generally patches of stratocumulus, and rain is rare. The chief flight hazard in this air is coastal fog, which often hides the California or European coastal land. Stratus and stratocumulus clouds may cause the sky to be overcast, develop low ceilings, and produce drizzle that reduces visibility.

3. South of a subtropical high. Where the mT air moves southward or southwestward (as trade winds), its lower layers are warmed by the tropical ocean surface. This produces scattered cumulus. Near the equator, after absorbing much moisture and being heated, this air may develop cumulonimbus.

4. West of a subtropical high. This mT air blows from the east and the southeast. Since it flows over warm water all of the way, the air neither cools nor warms. Over the ocean near the Philippines (and near Florida and the West Indies), this trade wind brings good flying weather—clear or scattered cumulus clouds. When it is moving over land, this warm, moist air becomes unstable and turbulent and is a source of thunderstorms. When it moves over cold land (for example, southeastern United States in the winter), it becomes stable and produces stratus clouds or fog. Over cold ocean surfaces, such as the Sea of Japan and the Kamchatka and Labrador currents, it develops the persistent low stratus and fogs characteristic of these areas.

## ARCTIC AND ANTARCTIC WEATHER

Geographically, the arctic zone is north of the Arctic Circle (66.5°N) and the Antarctic zone is south of Antarctic Circle (66.5°S) The Arctic is extremely important to the military defense of Canada and the United States and is the subject of ever-increasing military operations. Therefore, Aerographer's Mates must familiarize themselves with the prevailing weather and peculiarities of these regions.

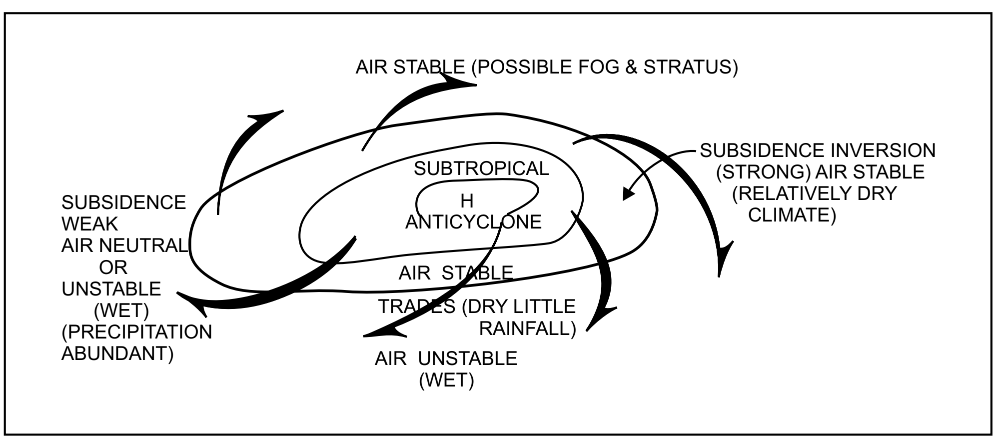


**Figure 6-8.—Weather, winds, and stability conditions around the subtropical high.**

## Arctic Weather

The Arctic is the aerial crossroads of the world. This is not only due to the shorter arctic routes between some of the major cities of the world, but also because flying weather over the Arctic is generally better than that encountered over the familiar ocean routes. To understand some of the important weather and problems of the Arctic, you must understand the broad underlying causes of the arctic climate.

**SEASONAL TEMPERATURE VARIATIONS**.—From our previous discussion of climatic controls, we have seen that the most important factor that determines the climate of an area is the amount of energy it receives from the Sun. During the winter much of the Arctic receives little or no direct heat from the Sun. The cold winter temperatures common in the Arctic result from a lack of the Sun's energy.

The Sun is not the only factor responsible for the arctic climate. Two other factors, the land-sea-ice distribution and mountain barriers, contribute to the tremendous variation in climate at different points of similar latitude.

1. Land-sea-ice features. In the Northern Hemisphere, the water features include the Arctic, North Atlantic, and North Pacific oceans. These bodies of water act as temperature moderators since they do not have large temperature variations. A major exception occurs when large areas are covered by ice in winter. The land features are the northern continents of Eurasia, North America, the island of Greenland, and the Canadian Archipelago. As opposed to the water areas, the land areas tend to show the direct results of the extremes of seasonal heating and cooling by their seasonal temperature variations.

2. Mountains. The arctic mountain ranges of Siberia and North America are factors, which contribute to the climate and air mass characteristics of the regions. These mountain barriers, as in mid-latitudes, restrict the movement of air from west to east. During periods of weak circulation, the air is blocked by the ranges and remains more or less stagnant over the area. It is during these periods that the air acquires the temperature and moisture characteristics of the underlying surface. Thus, these areas are air-mass source regions, and they are particularly effective as source regions during the winter when the surface is covered with snow and ice.

The Greenland ice cap is essentially a mountain range more than 10,000 feet above mean sea level. It restricts the movement of weather systems, often causing low-pressure centers to move northward along the West Coast of Greenland. Some of the largest rates of falling pressure in the world (other than hurricanes and tornadoes) are recorded here. The deep, low centers that move along the west coast of Greenland are primarily responsible for the high winds that are recorded occasionally in that area.

At times, winter temperatures in the Arctic are unusually high. This situation is brought about by deep, low centers moving into the Arctic, coupled with compression of air (the Foehn effect) as it often blows down off the sloping edges of the ice caps, primarily the Greenland ice cap.

**ARCTIC AIR MASSES**.—The moisture content of air masses that originate over land is low at all altitudes in the winter. The distinction between air masses almost disappears during the summer because of the nearly uniform surface conditions over the arctic and subpolar regions. The frozen surface thaws under the influence of lengthened or continual daylight, the snow melts from the glaciers and pack ice, the ice melts in the lake areas in the Arctic, and the water areas of the polar basin increase markedly. Thus, the polar area becomes mild, humid, and semimaritime in character. Temperatures are usually between freezing and 50°F. Occasionally, strong disturbances from the south increase the temperature for short periods. Daily extremes, horizontal differences, and day-to-day variability are slight.

During the winter months, air masses are formed over areas that are completely covered by ice and snow. The air masses are characterized by very cold surface air and a large temperature inversion in the lowest few thousand feet. Since the amount of moisture the air can hold depends on the air temperature, the cold arctic air is very dry (low absolute humidity). The air mass that originates over oceans does not have a surface temperature inversion in the winter, the surface air temperature is warmer, and there is a corresponding increase in the moisture content of the air. It is during movement inland of moist air from the warmer waters that most of the rather infrequent arctic cloudiness and precipitation occurs during this season.

During the summer months, the large expanse of open water and warmer temperatures in the Arctic result in increased moisture. Consequently, the largest amount of cloudiness and precipitation occurs during these summer months.

**ARCTIC FRONTS**.—The weather associated with fronts in the Arctic has much the same cloud structure as with polar fronts, except that the middle and high cloud types are generally much lower, and the precipitation is usually in the form of snow.

Periods of maximum surface wind usually occur during and just after a frontal passage. This strong wind flow often creates hazards, such as blowing snow and turbulence, which make operational flying difficult.

The best flying weather in the Arctic over land usually occurs in midsummer and midwinter; the worst (low ceilings and visibility) is during the transitional periods between the two seasons. Winter is characterized by frequent storms and well-defined frontal passages, but because of the dryness of the air, cloudiness and precipitation are at a minimum. In the summer, there are fewer storm passages and fronts are weaker; however, the increased moisture in the air results in more widespread clouds and precipitation. Over the sea areas the summer weather is very foggy, but winds are of lower speeds than in the winter.

During the transitional periods of spring and fall, operational flying conditions are usually the worst. Frontal systems are usually well defined, active, and turbulent. Icing may extend to high levels.

**TEMPERATURES IN THE ARCTIC**.—Temperatures in the Arctic, as one might expect, are very cold most of the year. But contrary to common belief, the interior areas of Siberia, northern Canada, and Alaska have pleasantly warm summers with many hours of sunshine each day. There are large differences in temperature between the interior and coastal areas.

In the interior during the summer days, temperatures climb to the mid 60s or low 70s and frequently rise to the high 70s or low 80s, occasionally even into the 90s. Fort Yukon, Alaska, which is just north of the Arctic Circle, has recorded an extreme high temperature of 100°F, while Verkhoyansk in north central Siberia has recorded 94°F.

During the winter, the interior areas of Siberia, northern Canada, and Alaska act as a source region for the cold arctic air that frequently moves southward into the middle latitudes. The coldest temperatures on record over the Northern Hemisphere have been established in Siberia.

In the northern areas of the interior regions, temperatures are usually well below zero during the winter months. In fact, during these long periods of darkness and near darkness, the temperature normally falls to –20°F or –30°F, and in some isolated areas the normal daily minimum temperature may drop to –40°F. In north central Siberia the normal minimum daily temperature in the winter is between –45°F and –55°F.

The arctic coastal regions, which include the Canadian Archipelago, are characterized by relatively cool, short summers. During the summer months the temperatures normally climb to the 40s or low 50s and occasionally reach the 60s. There is almost no growing season along the coasts, and the temperatures may fall below freezing during all months of the year. At Point Barrow, Alaska, the minimum temperature rises above freezing on no more than about 42 days a year.

Over the Arctic Ocean, the temperatures are very similar to those experienced along the coast; however, the summer temperatures are somewhat lower. Winter temperatures along the Arctic coast are very low but not nearly as low as those observed in certain interior areas. Only on rare occasions does the temperature climb to above freezing during the winter months. The coldest readings for these coastal areas range between –60° and –70°F.

These figures may seem surprising. At first one might think that the temperatures near the North Pole would be lower than those over the northern continental interiors. Actually the flow of heat from the water under the ice has a moderating effect upon the air temperature along the coast.

**CLOUDINESS**.—Cloudiness over the Arctic is at a minimum during the winter and spring and at a maximum during the summer and fall, again due to the low-moisture capacity of cold air. The average number of cloudy days for the two 6-month periods on climatic charts shows a general decrease in cloudiness in the entire arctic area during the winter months. The greatest seasonal variation is found in the interior, and the least is found along the coasts.

During the warm summer afternoons in the interior regions, scattered cumulus form and occasionally develop into thunderstorms. The thunderstorms are normally widely scattered and seldom form continuous lines. Along the arctic coast and over the Arctic Ocean, thunderstorms occur infrequently. Although tornadoes have been observed near the Arctic Circle, their occurrence is extremely rare. In these areas, summers are quite cloudy, with stratiform clouds predominating.

Seasonal changes in cloudiness take place quite rapidly. Winters are characterized by extensive cloudiness in the coastal regions. These clouds are associated with migratory lows and generally disperse inland as the systems lose their moisture.

**WINDS**.—Wind speeds are generally light in the continental arctic interior throughout the year. The strongest winds in the interior normally occur during the summer and fall. During the winter, the interior continental regions are areas of strong anticyclonic activity that produce only light surface winds.

Strong winds occur more frequently along the arctic coast than in the continental interiors. The frequency with which these high winds occur in coastal areas is greater in the fall and winter than in the summer. These winds frequently cause blowing snow.

Very strong wind speeds have been observed at many arctic coastal stations. Strong winds are infrequent over the ice pack, but the wind blows almost continuously because there are no natural barriers (such as hills and mountains) to retard the wind flow. As a result, the combination of wind speed and low temperatures produces equivalent wind chill temperatures that are extreme and severely limit outdoor human activity.

**PRECIPITATION**.—Precipitation amounts are small, varying from 5 to 15 inches annually in the continental interior and 3 to 7 inches along the arctic coastal area and over the ice pack. The climate over the Arctic Ocean and adjoining coastal areas is as dry as some of the desert regions of the mid-latitudes. Most of the annual precipitation falls as snow on the Arctic Ocean and adjacent coastal areas and ice caps. On the other hand, most of the annual precipitation falls as rain over the interior.

**RESTRICTION TO VISIBILITY**.—Two factors make the visibility in the Polar Regions a very complex matter. Arctic air, being cold and dry, is exceptionally transparent, and extreme ranges of visibility are possible. On the other hand, there is a lack of contrast between objects, particularly when a layer of new snow covers all distinguishable objects. Limitations to visibility in the Arctic are primarily blowing snow, fog, and local smoke. Local smoke is serious only in the vicinity of larger towns and often occurs simultaneously with shallow radiation fogs of winter.

1. Blowing snow. Blowing snow constitutes a more serious hazard to flying operations in the Arctic than in mid-latitudes because the snow is dry and fine and is easily picked up by moderate winds. Winds in excess of 8 knots may raise the snow several feet off the ground, and the blowing snow may obscure surface objects such as runway markers.

2. Fog. Of all the elements that restrict flying in the Arctic regions, fog is perhaps most important. The two types of fog most common to the Polar Regions are advection fog and radiation fog.

Fog is found most frequently along the coastal areas and usually lies in a belt parallel to the shore. In the winter, the sea is warmer than the land, and relatively warm, moist air is advected over the cool land causing fog. This fog may be quite persistent. In the summer, warm, moist air is advected over sea ice, which is now melting, creating the same situation, which is found over land in winter.

3. Ice fog. A fog condition peculiar to Arctic climates is ice fog. Ice fog is composed of minute ice crystals rather than water droplets of ordinary fog and is most likely to occur when the temperature is about –45°C (–50°F) or colder but can occur when temperatures are as warm as -30°C (–20°F).

4. Sea smoke or steam fog. The cold temperatures in the Arctic can have effects, which seem peculiar to people unfamiliar with the area. During the winter months, the inability of the air to hold moisture results in an unusual phenomenon called sea smoke. Open bodies of comparatively warm water existing simultaneously with low air temperature cause this. Actually, this phenomenon is similar to that of steam forming over hot water.

In the case of sea smoke, the temperatures of both the air and the water are quite low, but the air temperature is still by far the lower of the two, causing steam to rise from the open water to form a fog layer. This fog occurs over open water, particularly over leads (navigable passages) in the ice pack and is composed entirely of water droplets.

5. Arctic haze. This is a condition of reduced horizontal and slant visibility (but good vertical visibility) encountered by aircraft in flight over arctic regions. Color effects suggest this phenomenon to be caused by very small ice particles. Near the ground, it is called arctic mist or frost smoke; when the sun shines on the ice particles, they are called diamond dust.

**ARCTIC WEATHER PECULIARITIES**.—The strong temperature inversions present over the Arctic during much of the winter causes several interesting phenomena. Sound tends to carry great distances under these inversions. On some days, when the inversion is very strong, human voices can be heard over extremely long distances as compared to the normal range of the voice. Light rays are bent as they pass through the inversion at low angles. This may cause the appearance above the horizon of objects that are normally below the horizon. This effect, known as *looming,* is a form of mirage. Mirages of the type that distort the apparent shape of the Sun, Moon, or other objects near the horizon are common under inversion conditions.

One of the most interesting phenomena in the Arctic is aurora borealis (northern lights). These lights are by no means confined to the Arctic but are brightest at the arctic locations. Their intensity varies from a faint glow on certain nights to a glow, which illuminates the surface of the Earth with light almost equal to that of the light from a full moon. The reactions resulting in the auroral glow have been observed to reach a maximum at an altitude of approximately 300,000 feet.

The amount of light reflected from a snow-covered surface is much greater than the amount reflected from the darker surfaces of the middle latitudes. As a result, useful illumination from equal sources is greater in the Arctic than in lower latitudes. When the sun is shining, sufficient light is often reflected from the snow surface to nearly obliterate shadows. This causes a lack of contrast, which, in turn, results in an inability to distinguish outlines of terrain or objects even at short distances. The landscape may merge into a featureless grayish-white field. Dark mountains in the distance may be easily recognized, but a crevasse immediately ahead may be obscured by the lack of contrast. The situation is even worse when the unbroken snow cover is combined with a uniformly overcast sky and the light from the sky is about equal to that reflected from the snow cover. In this situation, all sense of depth and orientation is lost in what appears to be a uniformly white glow; the term for this optical phenomenon is *whiteout.*

Pilots have reported that the light from a half-moon over a snow-covered field is sufficient for landing aircraft at night. It is possible to read a newspaper on occasions by the illumination from a full moon in the Arctic. Even the illumination from the stars creates visibility far beyond what one would expect elsewhere. It is only during periods of heavy cloud cover that the night darkness begins to approach the degree of darkness in lower latitudes. In lower latitudes, south of 65° north latitude, there are long periods of moonlight, since the Moon may stay above the horizon for several days at a time.

### Antarctic Weather

Many of the same peculiarities prevalent over the arctic regions are also present in the Antarctic. For instance, the aurora borealis has its counterpart in the Southern Hemisphere, called aurora australis. The same restrictions to visibility exist over the Antarctic regions as over the Arctic. Some other characteristics of the Antarctic regions are as follows:

Precipitation occurs in all seasons, with the maximum occurring in summer. The amount of precipitation decreases poleward from the coast. Temperatures are extremely low. The lowest temperature in the world, –127°F, was recorded at Vostok, Antarctica. In the winter, temperatures decrease from the coast to the pole, but there is some doubt that this is true in the summer. The annual variation of temperature as indicated by Macmurdo station shows the maximum in January and the minimum in early September. A peculiar, and to date unexplained, feature of Antarctic temperature variations during the Antarctic night is the occurrence of maximum temperatures on cloudless days in the early hours after midnight. On cloudy days, however, the day is warmer than the night.

## UNITED STATES WEATHER

The weather in the United States, with minor exceptions, is typical of all weather types within the temperate regions of the North American, European, and Asiatic continents. The general air circulation in the United States, as in the entire Temperate Zone of the Northern Hemisphere, is from west to east. All closed surface weather systems (highs and lows) tend to move with this west-to-east circulation. However, since this is only the average circulation and weather systems move with the general flow, the fronts associated with the migratory lows also tend to move southward if they are cold fronts and northward if they are warm fronts. Surface low-pressure centers, with their associated weather and frontal systems, are referred to as cyclones. Knowledge of the mean circulation in the temperate region makes it possible to observe and plot average storm tracks and to forecast future movement with a reasonable degree of accuracy.

Certain geographical and climatic conditions tend to make specific areas in the United States favorable for the development of low-pressure systems such as west Texas, Cape Hatteras, central Idaho, and the northern portions of the Gulf of Mexico. Once a low has formed, it generally follows the same mean track as the last low that formed in that area. The averages, or mean paths, are referred to as storm tracks.

These storms (lows) are outbreaks on the polar front or the generation or regeneration of a storm along the trailing edge of an old front. The low pressure along these fronts intensifies in certain areas as the front surges southward ahead of a moving mass of cold polar air. Much of the weather, especially the winter weather, in the Temperate Zone is a direct result of these storms.

Air-mass weather also affects temperate climates. Air-mass weather is the name given to all weather other than the frontal weather in the temperate region. Air-mass weather is the net effect of local surface circulation, terrain, and the modifying effect of significant water bodies.

There are many subdivisions of weather regions in the United States. For the purpose of this discussion, we have divided the continental United States into seven regions as indicated in figure 6-9.

**Northwest Pacific Coast Area**

The northwest pacific coast area has more precipitation than any other region in North America. Its weather is primarily the result of frontal phenomena, consisting mainly of occlusions, which move in over the coast from the area of the Aleutian low and orographic lifting of moist, stable maritime air. Predominant cloud forms are stratus and fog, which are common in all seasons. Rainfall is most frequent in the winter and least frequent in the summer.

**Southwest Pacific Coast Area**

The southwest pacific coast area experiences a Mediterranean-type climate and is distinctively different from any other North American climate. This climate occurs exclusively in the Mediterranean and southern California in the Northern Hemisphere. In the Southern Hemisphere, it occurs over small areas of Chile, South Africa, and southern Australia.

This climate is characterized by warm to hot summers, tempered by sea breezes, and by mild winters during which the temperatures seldom go below freezing. Little or no rainfall occurs in the summer and only light to moderate rain in the winter.

Cold fronts rarely penetrate the southwest pacific coast region. The weather over this region is due to the circulation of moist pacific air from the west being forced up the slope of the coastal range. In the summer, air is stable, and stratus and fog result. In the winter, unstable air, which is forced over the mountain ranges causes showers or snow, showers in the mountains.

**Intermountain West Central Area**

The intermountain west central area includes the Great Plains region. This region is located east of the Cascade and coastal ranges, west of the Mississippi Valley, and north of the southwest desert area. The climate is generally cold and dry in the winter, and warm and dry in the summer. Most of the region is

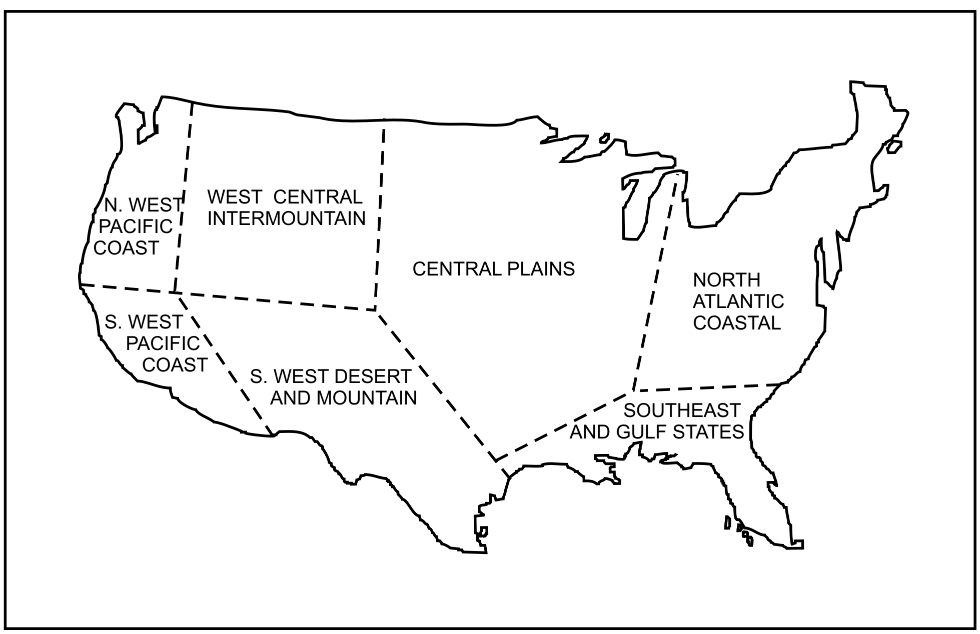


**Figure 6-9.—United States weather regions.**

semiarid. The western mountain range, which acts as a climatic barrier, has an extreme drying effect on the air in the westerly circulation.

Maximum rainfall occurs in the spring and is due mainly to the predominance of cyclonic storm passages during this season. In midwinter a cold high is generally centered in this region which prevents the possibility of storm passages. Annual precipitation is normally light.

### Southwest Desert and Mountain Area

The southwest desert and mountain area includes Lower California and some of southeast California as well as the southern portions of Arizona, New Mexico, and Texas. It is an area almost completely surrounded by high mountains and is either very arid or actual desert. Annual rainfall seldom exceeds 5 inches. The more northerly sections have cold winters, and all parts have extremely hot summers. The chief flying hazard results from a predominance of summer and spring thunderstorms caused mainly by maritime tropical air being forced aloft at the mountains. For this reason nearly all significant peaks and ranges have thundershowers building over them in the spring and summer. The thunderstorms are generally scattered and are almost always severe; however, pilots can usually avoid them by circumnavigating them.

### Central Plains Area

The Central Plains area includes the continental climate regions of the Great Plains, Mississippi Valley, and Appalachian Plateau between the Rocky Mountains to the west, the Appalachians to the east, and the Gulf States to the south. The western section is generally drier than the eastern section. Wintertime outbreaks and associated wave phenomena along polar fronts cause the main weather hazards. Convective air-mass thunderstorms, which are prevalent over this area in summer, also pose a threat to flying.

Frontal passages, both cold and warm, and associated weather is common in this area. Thunderstorms are usually of convective origin and are most violent if they have developed in maritime tropical air. This occurs often in the spring, and tornado activity becomes a climatic feature due to its frequency.

### Southeast and Gulf States Area

The southeast and Gulf States area includes all the states bordering on the Gulf of Mexico as well as South Carolina and Georgia. Stagnating southbound cold fronts, rapidly moving squall lines, air-mass thunderstorms, and stratus clouds occur in various combinations to make this area an especially complex one for the forecaster.

Frontal passages can be expected only in the late fall, winter, and early spring. A circulation phenomenon known as gulf stratus affects this area. In the winter, when the circulation near the surface is southerly, the warm, moist gulf air is cooled from below to saturation. When this occurs, fog and the gulf stratus may form and may persist over the area for several days. The southerly circulation in summer causes warm, moist air to be heated from below, and convective thunderstorms are common. Since the air is generally quite moist and unstable, these storms are generally severe.

### North Atlantic Coastal Area

The North Atlantic coastal area is an area of storm track convergence, and cyclonic storm activity is frequent in winter. Moreover, the heating and addition of moisture to the air intensify these storms over the Great Lakes. The lake effect is directly accountable for the large amounts of snowfall often found over this area in the winter. Generally good weather prevails in summer due to the predominant influence of the Bermuda high.

## EUROPEAN WEATHER

Most of Europe has a relatively mild climate, which is largely due to its oceanic exposure to the north, west, and south. The east-west orientation of the mountains in Europe normally prevents extremely cold arctic air from penetrating southward to the Mediterranean. As a result, very cold weather is limited to the northern limits. The southern coast and Mediterranean countries enjoy moderate temperatures year round because relatively warm maritime air masses move inland from the Atlantic and because of the moderating influence of the Mediterranean Sea. However, this inflow of maritime air also brings frequent cloudiness, considerable precipitation, and high humidity.

When continental air masses dominate, Europe is subjected to low-temperature extremes, low humidity, and clear skies much the same as North America. This is especially true north of the Alpine Mountains. South of this region, somewhat normal migratory patterns do exist. The end result is relatively dry summers and wet winters characteristic of the western coastal region of North America and Canada.

Temperatures are highest in Europe during the summer; Athens, Greece averages 80°F; Granada, Spain 77°F; Greenwich, England 63°F; and Paris, France 65°F. Farther north, summer temperatures average as much as 20 to 25 degrees less. During the winter, the Mediterranean temperatures average in the upper 40°F to low 50°F range while the extreme northern sections average 10°F or less. The Atlantic coastal countries with their predominantly maritime climates maintain far less temperature extremes between summer and winter.

Precipitation in the form of rain and drizzle is common along the European Atlantic coast and near the Mediterranean Sea. Snow does occur at times in areas east of Spain and north of the Mediterranean Sea. At higher elevations inland, snow is common and frequently abundant. Central Spain and southern Russia, by contrast, experience semiarid and arid climates.

## ASIATIC WEATHER

Asia's climate is predominantly continental. The only exceptions are the heavily populated coastal areas that have tropical and maritime climates during the summer. This primarily continental climate results in limited precipitation and large temperature ranges both daily and seasonally.

Asia is a huge continent with large expanses of land extending far northward. The Himalaya Mountains stretch across the southern portion in an east-west direction; mountains also parallel the eastern coast. These geographical features often contain continental arctic and polar air inland, resulting in the most extreme temperature ranges found in the Northern Hemisphere. Northeastern Siberia's temperatures often range from –60°F in the winter to above 60°F in the summer. Extremes range as high as 98°F and as low as –90°F. The large interior of Asia also results in extreme pressure difference. In the winter, a cold high-pressure area dominates the continent. In the summer, a warm low-pressure area dominates the continent. This accounts for the northeast winter monsoons and southwest summer monsoons.

In the winter the interior is dry, receiving less than 1 inch of precipitation. Coastal areas under maritime influence receive normal amounts (about 8 inches) of precipitation. In the summer, precipitation is plentiful except well inland. Rain is so abundant in some regions, such as India, that the yearly rainfall average (425 inches or more) is among the highest in the world.

The extreme south and southeast regions of Asia differ sharply from its northern neighbors. These southern regions enjoy the tropical and maritime climates that feature only minor seasonal temperature variations. Eastern Asia enjoys a climate very similar to that found along the eastern coast of North America from the Florida Keys to eastern Canada. East and Southeast Asia, like the eastern and southeastern United States, is also subject to an occasional tropical cyclone (typhoon) in the summer and in the fall.

## SOUTH AMERICAN WEATHER

South America has a variety of climates but lacks the severe weather of North America. Continental polar air does not exist here because the continent tapers sharply from north to south. The larger northern area is close to the equator and does not experience the influx of cold maritime polar air from the south. Tropical climates prevail over much of the continent. Yet, due to the high Andes Mountains along the western coast, there are areas that are extremely dry and others that are extremely wet.

### Northeastern Climate

The South American northeast's climate consists mainly of high temperature and humidity and copious rainfall throughout the year. September is the warmest month with average temperatures of around 82°F. January is the coolest month with average temperatures of around 79°F. Nighttime temperatures rarely fall below 65°F. Rainfall averages 87 inches annually with 12 inches falling in June and just over 2 inches falling in October. The higher elevations of northeastern South America have greater ranges of temperature, humidity, and precipitation; however, these ranges are not extreme.

### Southern Climate

In the southern region, below 200 south latitude, South America has distinct seasons very similar to those in the southeastern United States. These seasons, however, are reversed. The warmest month is January, which averages 74°F; July, which averages 49°F is the coolest month. Precipitation occurs fairly evenly throughout the year and averages 38 inches. There is no distinct rainy season.

Below 40° south latitude, the climate is progressively drier and cooler. However, the extreme southern tip of South America is characterized by year round cold and damp climate due to a strong maritime influence.

**West Coast Climate**

The West Coast, from northern Peru to the middle of Chile, is a desert. North and south of this desert midsection, the climate is quite humid. The northwest coast has a typical tropical climate with wet and dry seasons.

Below central Chile, the climate again shows a typical Southern Hemisphere seasonal reversal of that found in North America. The weather in this region is similar to that found along the northwest coast of North America. The climate is generally rainy and cool. Summer does not seem to exist as we know it. Yet, winter temperatures average above freezing.

## AFRICAN WEATHER

Africa's climate is unlike that of any other continent for several reasons. The most important is the fact that the entire continent is within the tropical zone. The equator bisects the continent; therefore, in the area north and south of the equator, the climates are similar, yet they differ because the region north of the equator is much larger than the southern region. Since the northern area is so broad in the east-west direction, maritime effects inland are minimal. Also, an extensive low-pressure area develops inland due to extreme land mass heating. A belt of high pressure, however, with its maritime influences dominates the southern section, during winter and by low pressure during summer.

Another factor is the cold currents, which exist along its western shores. These currents allow an influx of cool winds and associated weather to the West Coast. The final factor involves the lack of high mountain ranges common to other continents. Since there are no prominent mountain ranges, the various climate types in Africa blend together, showing no sharp distinctions.

The most important climatic element in Africa is precipitation. Precipitation is greatest near the equator (60 to 80 inches to over 120 inches in places). It decreases sharply to the north (less than 10 inches), and decreases gradually south of the equator (average of 20 to 40 inches). Because Africa is in the tropical zone, the precipitation belt of the intertropical convergence zone (ITCZ) moves with the seasons. This belt of precipitation moves northward in the summer and southward in the winter. Africa does have distinct climatic regions. Air-mass movement and influences allow for a division of eight climatic regions.

**Northern Region**

The northern region includes the great Sahara desert. The desert is a source region for dry continental-type air masses. While maritime air may transit the area, the air masses are highly modified and often exhibit continental properties after moving inland. This desert region is extremely hot during the day throughout the year but is very cool at night due to a lack of moisture; hence, strong radiational cooling.

**Southwestern Region**

The southwest region is an arid to semiarid area, which is known as the Kalahari Desert. The temperatures are not as extreme as in the Sahara because the land area involved is much smaller.

**North Central Region**

The north central region is a semiarid area located along the edge of the Sahara. While the temperatures are similar to those of the neighboring desert (50°F in winter to well above 80°F in summer), this area occasionally gets precipitation in the winter. The source of this precipitation for the northern area is maritime air from the Mediterranean; in the south, it is the spotty rainfall provided by the meandering ITCZ.

**Sub-Equatorial Region**

The sub-equatorial region extends toward the equator from the semiarid region in the north. The region is marked by seasonal rainfall associated with the position of the ITCZ. The region is wet for about 5 months (Nov-Mar), and dry during the rest of the year. Temperatures show little seasonal variation (68°F to 86°F) because of the close proximity to the equator. The only exception to this temperature stability occurs in the western portion which, during the winter, is occasionally influenced by cool weather from the north.

**Equatorial Region**

The equatorial region includes the southwest tip of northern Africa and the region between 5° north and south latitudes, extending from the western coast to Lake Victoria. It is the wettest climate in all Africa.

These areas have two distinct rainy seasons associated with the northward and southward movement of the ITCZ. Rainfall averages over 120 inches annually in some areas. Throughout the rest of the year, precipitation remains plentiful because of the influx of maritime air from the west. There are no significant mountains in the region to prevent this maritime air from migrating inland. Temperatures are moderate year round.

### Southeast Coastal Region

The southeast coastal region has a humid subtropical climate. This region has rainfall all year (45 inches on the average) and temperatures remain generally moderate all year, ranging from an average maximum of 72°F in winter (July) to 89°F in summer (January).

### Southeastern Interior Region

This region has a wet-and-dry type of maritime climate; however, it is considered temperate because of the lower temperatures common to the higher elevation.

## AUSTRALIA AND NEW ZEALAND WEATHER

Australia has a generally mild climate with cool winters in the south and warm winters in the north. Summers are warm along the coasts and generally hot in the interior. Freezing temperatures are infrequent. Australia's climatic zones are relatively uncomplicated due to the lack of high mountain ranges.

The northern third of Australia is located within the tropical zone. The region has a rainy season that runs from January to April. Annual precipitation is greatest (nearly 100 inches) in the extreme north and tapers off to the south and inland toward the semiarid interior. The interior, along the Tropic of Capricorn, is very hot and dry in the summer with average maximum temperatures at or above 90°F. In the winter, average maximum temperatures in some areas drop to 68°F.

The southern two-thirds of Australia is under the influence of the high-pressure belts of the Southern Hemisphere as well as of the migratory lows found farther southward. The southwest and southern portions of this region have rainy winters and near-drought conditions in the summer similar to the Mediterranean climate. Temperatures average 80°F in January and 55°F in July. The climate of the southeast corner is very similar to the southwest region except it experiences a shorter winter and less annual precipitation.

New Zealand is located southeast of Australia. It is a very narrow country with a southwest to northeast orientation and is exposed to the prevailing westerlies. Therefore, the climate is moderate and predominantly maritime with moderate precipitation occurring throughout the year. The northern part of New Zealand has a subtropical climate; however, winter frost and occasional snow can occur at locations farther south in highland areas. Fog is often widespread and very persistent over much of the country in advance of approaching frontal systems. Precipitation averages 49 inches in the northern half of the country and up to 170 inches in the southern half. Temperatures range from an annual average of 59°F in the north and 55°F in the central region to 50°F in the south.

## REVIEW QUESTIONS

*Q6-17. What are the two climatic extremes that relate to water and land distribution over the earth?*

*Q6-18. What region in the United States experiences Mediterranean type climate?*

*Q6-19. What is the major cause of the winter and summer monsoons near Asia?*

*Q6-20. Why does South America lack the severe weather that is common in North America?*